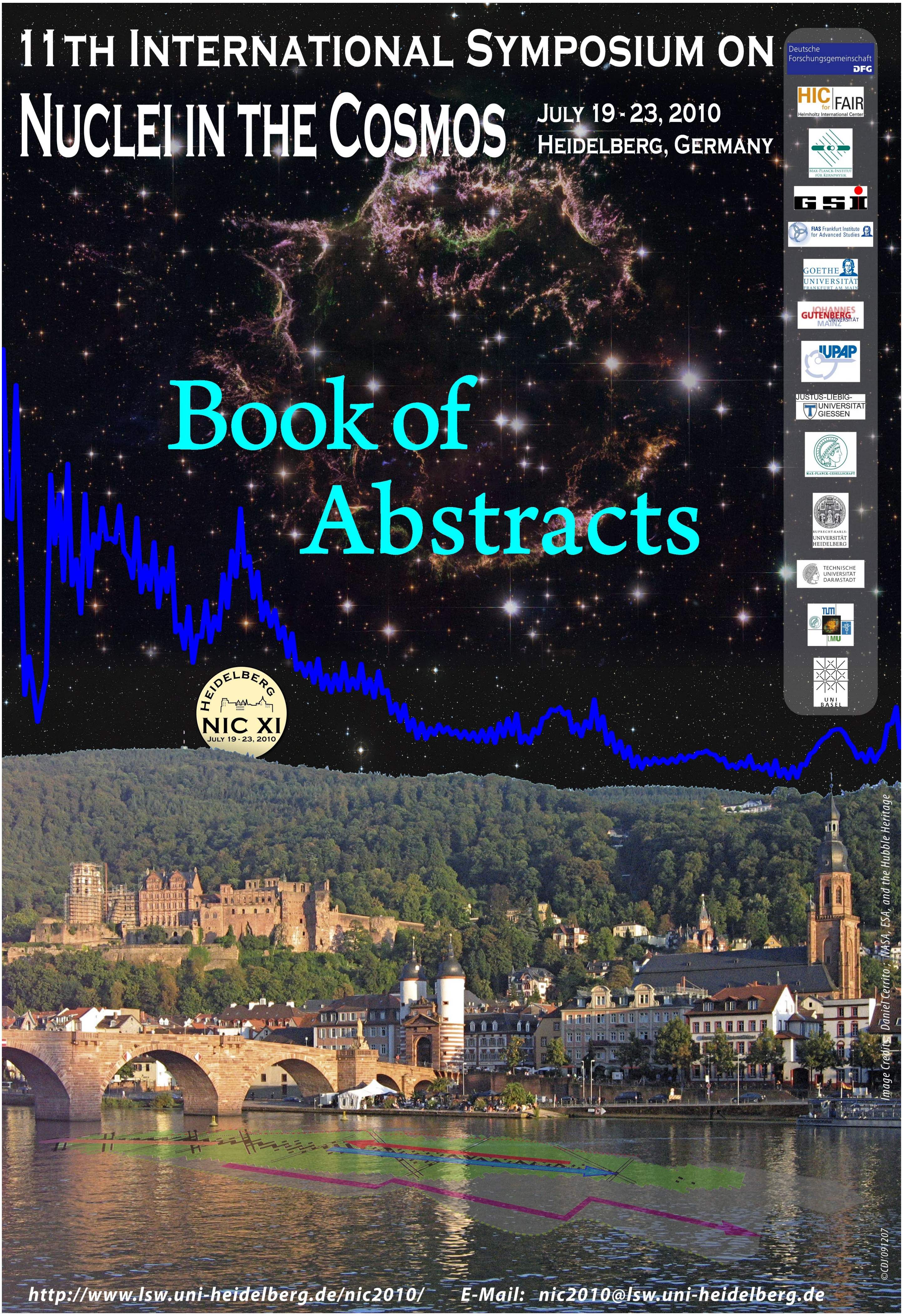

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Nuclei in the Cosmos
July 19 - 23, 2010
Heidelberg, Germany
Book of Abstracts
Heidelberg
NIC XI
July 19 - 23, 2010
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11th International Symposium on Nuclei in the Cosmos

Heidelberg, Germany
July 19-23, 2010

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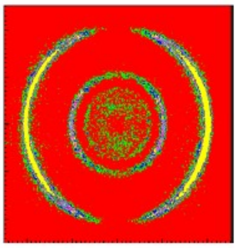

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11th International Symposium on Nuclei in the Cosmos
Heidelberg, Germany, July 19-23, 2010

Program

Sunday, July 18

15:00 -20:00	Registration (Foyer, Stadthalle)
18:00 -22:00	Welcome reception (Foyer, Stadthalle)

Monday, July 19

09:00 Welcome address

10:15 -10:45	Coffee break (sponsored by Pfeiffer Vacuum GmbH)

12:15 -14:00	Lunch break

16:35 -17:00	Coffee break (sponsored by Pfeiffer Vacuum GmbH)

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17:45	12 m	Oliver Kirsebom, *Aarhus University* The ^{8}B neutrino spectrum	16
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10:15 -10:45	Coffee break (sponsored by Pfeiffer Vacuum GmbH)

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18:15 -18:30	Farewell address

Poster Program

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The Big Bang (Kammermusiksaal)

Chemical evolution (Kammermusiksaal)

Stars (Left gallery)

Grains and gamma-ray observations (Right gallery)

Core-collapse supernovae (Left gallery)

Hypernovae and mergers (Left gallery)

Compact objects (Left gallery)

The s-process (Kammermusiksaal)

Novae (Right gallery)

X-ray bursts (Right gallery)

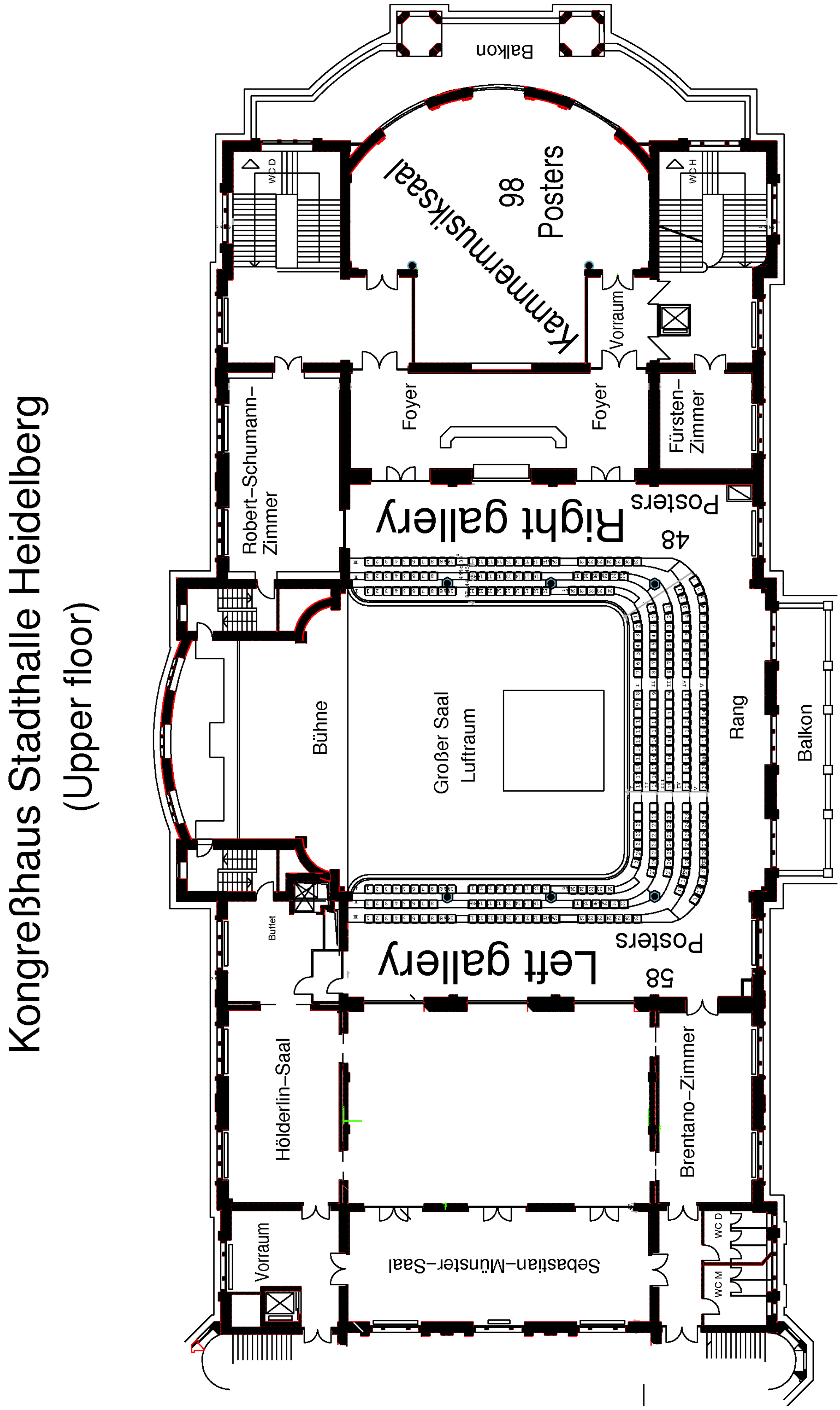
Explosive nucleosynthesis (Kammermusiksaal)

Type Ia supernovae (Right gallery)

The r-process (Kammermusiksaal)

Observations of metal-poor stars (Kammermusiksaal)

Poster distribution plan



NIC XI excursions on 21 July 2010

Boat trip on Neckar river (group A)

15:00	Departure of the boat (pier is at 5 minutes walking distance from Stadthalle)
16:30	Return of the boat
16:45	Start of guided tour of Old Town at Universitätsplatz
18:15	End of guided tour
18:30	Busses leave from Stadthalle for Restaurant Molkenkur
19:00	Start of conference dinner

Guided tour of the castle (group B)

15:00	Departure from Stadthalle; walk to funicular station
16:00	Beginning of guided tour
17:30	End of guided tour; walk to funicular station. Alternatively, you may directly walk to Restaurant Molkenkur, which is open for us from 18:00.
18:15	(Latest) arrival at Stadthalle
18:30	Busses leave from Stadthalle for Restaurant Molkenkur
19:00	Start of conference dinner

Guided tour of Landessternwarte (group C)

15:00	Departure of busses from Stadthalle
15:20	Arrival of busses at Landessternwarte
15:30	Beginning of guided tour (alternatives: hiking in the forrest on Königstuhl mountain; sitting in the beer garden at funicular station on Königstuhl mountain)
16:50	End of guided tour
17:00	Departure of busses from Landessternwarte. Alternatively, you can take a short walk in the forrest on Königstuhl mountain and after that proceed to Restaurant Molkenkur, which is open for us from 18:00.
17:20	Arrival of busses at Stadthalle
18:30	Busses leave from Stadthalle for Restaurant Molkenkur
19:00	Start of conference dinner

PRIMORDIAL NUCLEOSYNTHESIS: PREDICTED AND OBSERVED ABUNDANCES

Steigman G.[1]

(1) Physics Department, The Ohio State University, Columbus

For a brief time in its early evolution the Universe was a cosmic nuclear reactor. The expansion and cooling of the Universe limited this epoch to the first few minutes, allowing time for the synthesis in astrophysically interesting abundances of only the lightest nuclides (D, 3He, 4He, 7Li. For big bang nucleosynthesis (BBN) in the standard models of cosmology and particle physics, the BBN-predicted abundances depend only on the baryon density parameter, the ratio of baryons (nucleons) to photons. The predicted and observed abundances of the relic light elements are reviewed, testing the internal consistency of primordial nucleosynthesis. The consistency of BBN is also explored by comparing the values of the cosmological parameters inferred from primordial nucleosynthesis for standard and non-standard models with those determined from studies of the cosmic background radiation which provide a snapshot of the Universe some 400 thousand years after BBN.

Big Bang Nucleosynthesis constraints on Supersymmetry

Cyburt R.[1]

(1) NSCL, MSU, East Lansing

The decays of exotic particles during or after big bang nucleosynthesis (BBN) may alter the primordial light element abundances. Given the main success of the theory in predicting the He4 and D abundances, strong constraints can be placed on these extensions of the standard model of particle physics. In some cases, the discrepancy between Li7 observations and predictions can be alleviated. I will review the constraints one can place on super-symmetric (SUSY) extensions of particle physics and comment on what may be seen at the Large Hadron Collider (LHC).

Study of the BBN reaction D(α,γ)6Li deep underground with LUNA

Erhard M.[1], Bemmerer D.[2], Broggini C.[1], Caciolli A.[1], Corvisiero P.[3], Costantini H.[3], Elekes Z.[4], Formicola A.[5], Fülöp Z.[4], Gervino G.[6], Guglielmetti A.[7], Gustavino C.[5], Gyürky G.[4], Imbriani G.[8], Junker M.[5], Laubenstein M.[5], Lemut A.[3], Marta M.[2], Mazzocchi C.[7], Menegazzo R.[9], Prati P.[3], Rocca V.[8], Rolfs C.[10], Rossi Alvarez C.[9], Somorjai E.[4], Straniero O.[11], Strieder F.[10], Terrasi F.[8], Trautvetter H.[10]

(1) Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, Padova, (2) Forschungszentrum Dresden-Rossendorf (FZD), Institut für Strahlenphysik, Dresden, (3) INFN, Sez. di Genova, Genova, (4) Institute of Nuclear Research (ATOMKI), Debrecen, (5) INFN, Laboratori Nazionali del Gran Sasso (LNGS), Assergi, (6) INFN, Sez. di Torino, Torino, (7) INFN, Sez. di Milano, Milano, (8) INFN, Sez. di Napoli, Napoli, (9) INFN, Sez. di Padova, INFN, Laboratori Nazionali di Legnaro (LNL), Padova, (10) Ruhr-Universität Bochum, Institut für Experimentalphysik III, Bochum, (11) Osservatorio Astronomico di Collurania, Teramo, INFN, Sez. di Napoli, Teramo

The amount of 6Li detected in metal poor stars is unexpectedly large compared to Big-Bang Nucleosynthesis predictions [1]. The radiative capture reaction D(α,γ)6Li with a *Q*-value of 1.474 MeV is the main reaction for the 6Li production at temperatures of 0.3×109 K. The Gamow window reaches from E_{Gamow} = 30 keV up to 300 keV with the max. at 96 keV, but direct measurements do not exist below a center-of-mass energy of 650 keV. Theoretical calculations for the S-factor differ by more than one order of magnitude.
The LUNA setup (Laboratory for Underground Nuclear Astrophysics) below the Gran Sasso mountain offers measurement conditions with a reduction of the cosmic ray induced μ- and n-flux by six and three orders of magnitude, respectively. Prediction have shown that the cross section of σ(*E* = 96 keV) ≈ 2×10-11 b can be measured with an improved setup like it was used for the study of the 3He(α,γ)7Be reaction [2]. Especially the beam-induced background was studied and reduced.

[1] P. D. Serpico *et al.*, J. Cosmol. Astropart. Phys. **12** (2004) 010
[2] A. Caciolli *et al.*, Eur. Phys. J. A **39** (2009) 179

Formation of the First Stars

Bromm V.[1]

(1) University of Texas, Department of Astronomy, Austin

How and when did the cosmic dark ages end? I present simulations of the formation of the first stars and galaxies, and discuss their feedback on the intergalactic medium. The impact of the first supernova explosions is key in transforming the early universe into a state of increasing complexity. I describe ways to probe the signature of the first stars with missions such as the Wilkinson Microwave Anisotropy Probe and the James Webb Space Telescope. The properties of the first stars are determined by the interplay between cold dark matter and the atomic and molecular physics of hydrogen. I will identify the key processes and outline the major remaining uncertainties.

Observations of the most metal-poor stars and what they tell us about early Universe

Frebel A.[1]

(1) Harvard-Smithsonian Center for Astrophysics, Cambridge

The chemical evolution of the Galaxy and the early Universe is a key topic in modern astrophysics. Since the most metal-poor Galactic stars are the survivors of the high-redshift Universe, they offer the means to reconstruct the nature and chemical yields of the first stars, the origin and evolution of the elements, and associated nucleosynthesis processes, and chemical evolution more generally. Through their abundances, they also provide constraints on early star formation and the assemly history of the Milky Way Galaxy. I will discuss that, among others, the two most iron-poor halo stars as well as the new discoveries of extremely metal-poor stars in small dwarf galaxies are prime candidates to study the elusive first stars and the nucleosynthetic yields of early supernovae with different mass ranges.

A systematic study of extremely metal-poor stars with SDSS/Subaru

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Chemical abundance studies for extremely metal-poor (EMP) stars ([Fe/H] < -3) in the Galactic halo systems provide unique constraints on the nucleosynthesis of first generations of stars. Although abundance patterns of the lowest metallicity stars, in particular the three carbon-enhanced stars with [Fe/H] <-4 discovered to date, have been extensively studied, systematic studies of much larger samples of EMP stars are required to obtain better insight on the formation of first generations of stars and early enrichment in the Galaxy.

Large-scale surveys such as the Sloan Digital Sky Survey (SDSS), in particular the sub-survey SEGUE, have provided homogeneous samples of over a thousand candidate EMP stars. We have conducted follow-up high resolution spectroscopy with the Subaru Telescope High Dispersion Spectrograph (HDS) for some 150 EMP candidates discovered by this survey, in order to determine accurate metallicities and elemental abundance ratios. Here we report first results for 113 objects, most of which are unevolved stars, i.e. main-sequence or subgiant stars, not often studied in previous samples of EMP.

We find:(1) 70 stars among our sample have [Fe/H] < -3, doubling the known samples of such stars. We clearly confirm the rapid decrease of the number of stars below [Fe/H] = -3.5. Our results also provide a new calibration for metallicity estimates from low-resolution SDSS spectra, and will enable to establish the metallicity distribution function based on larger samples. (2) The alpha-element Mg exhibits over-abundances through the metallicity range covered by our sample (-4 < [Fe/H] < -2.5) with no clear changes as a function of metallicity. However, a small fraction of stars exhibit particularly high ([Mg/Fe] > +1) or low ([Mg/Fe] < 0) values. (3) We determined the chemical abundances for two cool (~5000 K) main-sequence stars with [Fe/H] < -3, the first measurement for this class of stars based on high-resolution spectra. One of them exhibits an extremely large enhancement of r-process elements (e.g., [Eu/Fe] > +1.5). The metallicity of this object ([Fe/H] ~ -3.4) is the lowest yet found such r-process-enhanced stars.

David vs Goliath: pitfalls and prospects in abundance analyses of dwarf vs giant stars

Korn A.[1]

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I will review the pros and cons of analyses of dwarf and giants stars in Galactic chemical evolution studies. While giants have obvious observational advantages over dwarfs, a number of key elements must be studied in unevolved stars to avoid evolutionary effects that can not yet be corrected for on a single-star basis using stellar-evolution models. Beyond classical modelling of stars, there are numerous effects which bias our abundance view: hydrodynamics, non-LTE, atomic diffusion, mass loss, self-enrichment etc. All of these have a more or less complicated luminosity dependence. Its impact on abundance studies shall be discussed.

Galactic chemical evolution – the observational side

McWilliam A.[1]

(1) Carnegie Observatories, Pasadena, USA

I will present a limited review of observational stellar abundance results for a few elements studied in the Galaxy and nearby dwarf systems.

Various element families offer the opportunity to improve our understanding of chemical evolution, including the stellar element yields, evolution timescales of galactic systems, star formation rates (SFR) and the stellar initial mass function (IMF).

Possible explanations (exciting or prosaic) for a few anomalous element abundance ratios will also be discussed.

Topics in galactic chemical evolution

Prantzos N.[1]

(1) Institut d'Astrophysique de Paris, Paris

I will present an overview of recent advances - both from the observational and theoretical sides - in studies of galactic chemical evolution, focusing mainly on the Milky Way galaxy.

Evolution of Massive Stars

Langer N.[1]

(1) Argelander-Institut, Universität Bonn, Germany

Evolution of low and intermediate-mass stars

Herwig F.[1]

(1) University of Victoria, Victoria

I will review the evolution of RGB and AGB stars as relevant for nuclear production, with particular emphasis on mixing and nucleosynthesis. Progress is being made on developing a more realistic picture of mixing, both through hydrodynamic simulations, as well as through semi-empirical investigations based on observations. Predictive simulations of AGB mass loss have advanced significantly, and the results are now, together with chemistry dependent low-T opacities, incorporated in the latest generation of models. Providing detailed, comprehensive and internally consistent yields (including all species between H and Pb) of large sets of tracks is now carried out by several groups. The evolution at very low metallicity remains of particular interest because problems regarding mixing and the interaction with nuclear burning are being amplified. I will describe those challenges.

3D Stellar Models

Meakin C.[1]

(1) University of Arizona, Steward Observatory, Tucson, AZ

In this talk I will summarize the current state of 3D stellar modeling with an emphasis on interior evolution.

Nucleosynthesis and chemical evolution of intermediate mass stars: results from planetary nebulae

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Planetary nebulae (PN) are an excellent laboratory to investigate the nucleosynthesis and chemical evolution of intermediate mass stars. Accurate abundances can be obtained for several chemical elements, including (i) those elements that are manufactured by the PN intermediate-mass progenitor stars (He, N, C), and (ii) heavier elements that were originally produced by more massive stars of previous generations (O, Ne, Ar, S). The former can be used in order to investigate the nucleosynthesis of the intermediate mass stars, while the latter reveal the interstellar abundances at the time and place the progenitor stars were formed. Therefore, the determination of chemical abundances of PN produces important observational constraints to the nucleosynthesis and chemical evolution models for the galaxies hosting these objects. Moreover, PN present bright emission lines which lead to very accurate abundances of several elements, so that they provide a useful comparison with the results derived from stars.

In the past few years, we have obtained a large sample of PN with accurately derived abundances. Our sample includes objects that are representative of different galactic populations, especially the solar neighbourhood, the galactic disk and anticentre, the galactic bulge and the Magellanic Clouds. In this work, we present the results of our recent analysis of the chemical abundances of He, O, N, S, Ar and Ne in galactic and Magellanic Cloud planetary nebulae. Our results are compared with recent determinations in the literature, and a comprehensive sample can thus be obtained. Average abundances and abundance distributions of all elements are determined, as well as distance-independent correlations involving these elements. These correlations are extremely important, as they are not affected by the often uncertain distances of the nebulae, so that they can be directly compared with the predictions of recent theoretical evolutionary models for intermediate mass stars. This is particularly true for the correlations involving helium and nitrogen, or those involving helium and the heavier elements, since these correlations are specifically predicted by the evolutionary models. As a consequence, the observational results can be used to constrain properties such as the stellar masses and metallicities. (FAPESP/CNPq)

Reaction rate measurements in underground labs

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The reaction cross sections at temperatures typical of quiescent hydrogen and helium burning are extremely small and experimental measurements at Earth's surface laboratories are hampered by cosmic ray induced background. Thanks to the high background reduction of LNGS underground laboratory, the LUNA collaboration has demonstrated the advantage of performing low energy cross section measurements in an underground environment. This talk will give an overview of the experimental techniques adopted in underground nuclear astrophysics and will present a summary of the main results and achievements. The plans for future nuclear astrophysics measurements in underground laboratories will also be discussed.

The 3He(α,γ)7Be cross section at astrophysical relevant energies

Di Leva A.[1], Gialanella L.[2], Strieder F.[3], Terrasi F.[1], Kunz R.[3], Rogalla D.[3], Schürmann D.[2], De Cesare M.[1], De Cesare N.[4], D'Onofrio A.[1], Fülöp Z.[5], Gyürky G.[5], Imbriani G.[6], Mangano G.[6], Rolfs C.[3], Romano M.[6], Somorjai E.[5]

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The rate of 3He(α,γ)7Be reaction plays a key role in the production of 7Li during the Big Bang Nucleosynthesis as well as in stellar hydrogen burning, where it has a strong influence on the high energy component of the solar neutrino spectrum. In the last decades several experiments exploited either the detection of the prompt γ-rays or the off-line determination of the number of 7Be atoms collected in the target, in few cases both. Recently the total cross section has been measured, in the energy region E_{cm}= 0.7 to 3.2 MeV, using the recoil mass separator ERNA (European Recoil separator for Nuclear Astrophysics) for direct detection of the produced 7Be recoils. This novel approach is completely independent from previous techniques leading to substantially different systematic dependencies and, thus, independent information. The combined analysis of the existing data sets, which includes the selection of theoretical models, shows substantial discrepancies among them. Although analyses based on single experiments achieve a precision of 3% a significantly larger uncertainty still affects the determination of the 3He(α,γ)7Be cross section at the energies relevant for astrophysics.

The 8B neutrino spectrum

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Knowledge of the energy spectrum of the neutrinos emitted in the β decay of 8B in the interior of the Sun is needed in order to interpret the neutrino spectrum measured on Earth. Experimentally, the 8B neutrino spectrum may be extracted from the measurements of the β-delayed α spectrum. Two recent measurements [1,2] give consistent results, but disagree with a third recent measurement [3]. In order to clarify the situation we have performed two new measurements of the β-delayed α spectrum using two different experimental techniques. Special care was paid to the energy calibration. Both approaches give an improved handle on systematics compared to [1,2,3] and cross checks give improved confidence in the results. In this contribution our two experimental approaches will be discussed, the measured α spectrum will be compared to the existing ones and the implications for the neutrino spectrum will be clarified.

[1] W.T. Winter et al., Phys. Rev. C73, (2006) 25503.
[2] M. Bhattacharya et al., Phys. Rev. C73 (2006) 55802.
[3] C.E. Ortiz et al., Phys. Rev. Lett. 85 (2000) 2909.

Microscopic nuclear structure and reaction calculations in the FMD approach

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Low-energy nuclear reactions play an important role in astrophysical scenarios. In many cases experimental data are not available at the energies relevant for the astrophysical processes. Typically such reactions are described in potential models that describe the reaction partners as point-like nuclei interacting via nucleus-nucleus potentials fitted to experimental data on bound and scattering states. In a microscopic picture the system is described as a many-body system of interacting nucleons. The wave functions are fully antisymmetrized and realistic nucleon-nucleon interactions are used.

In the Fermionic Molecular Dynamics (FMD) approach we aim at a consistent description of bound states, resonances and scattering states using realistic low-momentum nucleon-nucleon interactions. Intrinsic many-body basis states are Slater determinants employing Gaussian wave packets as single-particle states. The basis contains harmonic oscillator shell model and Brink-type cluster wave functions as special cases. The symmetries of the system are restored by projection on parity, angular momentum and total linear momentum. The full wave function is obtained in multiconfiguration mixing calculations. FMD has been successfully used to describe the structure of exotic nuclei in the *p*- and *sd*-shell.

We will present results for the structure of the Hoyle state in 12C that is of critical importance for the triple-alpha reaction and which is found to be essentially a loosely bound system of three alpha-particles with a small admixture of shell model configurations. We will also present results for a fully microscopic calculation of the 3He(α,γ)7Be cross section. At large distances the wave functions are described by cluster configurations, in the interaction region additional many-body configurations are included to account for the polarization of the clusters.

Direct Measurement of 4He(12C,16O) γ cross section near stellar energy

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A cross section of the nuclear fusion reaction 12C + 4He → 16O + γ is very important to know the evolution of the heavy stars after helium burning process. The cross section is, however, still unknown in spite of more than 40 years experimental efforts around the world because of its quite low value and existence of the resonance state of 16O at sub-threshold region. We are, then, planning to measure the cross section with the direct detection of the produced 16O by using an inverse kinematics for the energy range of E_{cm}= 2.4 downto 0.7 MeV. A direct measurement is most possible method to measure the cross section near stellar energy of 0.7MeV, since the detection efficiency of the 16O is very high.
The experiments of cross section measurement of 4He(12C,16O) γ reaction were performed at Kyushu University Tandem Laboratory in 2009 and 2010. We used a pulsed 12C beam to obtain the timing information of the particles which is very effective tool for the background reduction. A blow-in type windowless gas target was developed to achieve high confinement capability for the 4He gas. The produced 16O was transported to the Recoil Mass Separator(RMS) to separate from the un-reacted 12C beam, and finally detected by a Silicon SSD placed at the end of RMS. The TOF and total energy of the particles were obtained by the detector.
We have successfully developed a new windowless 4He gas target, and achieved the thickness of 24 Torr × 4 cm. Furthermore, many movable slits were installed in the RMS newly, and the background ratio of 12C(BG)/12C(beam)<10-16 was achieved. Finally, the cross section and the astrophysical S-factor at E_{cm} = 2.4 and 1.5 MeV could be obtained thanks to these instruments. We will describe these results and the future experimental plan at the energy of E_{cm} = 1.15 MeV.

Carbon fusion reactions in stars.

Gialanella L[1]

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Knowledge of carbon fusion reaction rates at stellar temperatures is necessary for a complete picture of stellar evolution. The minimum stellar mass necessary for quiescent carbon burning as well as the conditions necessary for type Ia supernovae hinge on it. The astrophysically relevant region of reaction rates is contained within a narrow energy band (the Gamow window), which lies on the far low energy end. Thus current rates in this regime rely heavily on extrapolated values from higher energies and ignore the effects of possible resonances in or near the Gamow window. Previous measurements of the total fusion cross section at lower energies were halted by beam induced and cosmic background, depending on the detection techniques. In a recent experiment at the CIRCE (Center for Isotopic Research on Cultural and Environmental heritage) advances in target preparation and measurement techniques allowed to extend the data near the region of stellar interest. The experimental setup and procedures will be discussed along with recent data and implications.

Density and temperature dependence of production rates of 6He, 9Be, 12C

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We assume an environment of neutrons and α-particles of given density and temperature where nuclear syntheses into 6He, 9Be, 12C are possible. The necessary three-body processes are usually treated as two-step processes where the unstable isotopes 5He and 8Be first are created and second, before decaying, react with another neutron or α-particle. This approximation of two independent sequential processes does not provide an accurate description since the lifetimes of the intermediate configurations are comparable to, or shorter than, the reaction time of the last step of the process [1]. This implies that the processes proceed through genuine three-body reactions where resonance structure and the decay mechanism is crucial [2,3].

The correct three-body calculations are technically difficult because they involve the continuum dynamics of three particles interacting via a mixture of short and long-range forces. Only recently it has become feasible to perform general three-body computations with the correct boundary conditions at both small and large distances, and where no assumption is made about the capture mechanism. These computations provide reactions rates as functions of temperature for processes leading from continuum states of different angular momenta and parities to ground states of the three nuclei. We combine these elaborate three-body computations to obtain the relative abundance of the three nuclei as a function of density and temperature.

For small Y_α production of 6He is largest except at small temperatures where 9Be production dominates as also found for intermediate to larger Y_α values. In a narrow region around $Y_\alpha \approx 1$, 12C is most abundantly produced. The full implications of the present results require detailed numerical investigations of the sequences of processes leading to formation of heavier nuclei. The initial conditions in these related chains of reactions should be our relative production rates. Whether the outcome is consistent with observations of nuclear abundances remains to be seen.

[1] H.O.U. Fynbo et al., Phys. Rev. C79 (2009) 054009.
[2] R. Alvarez-Rodrìguez et al., Phys.Rev. C77 (2008) 064305.
[3] E. Garrido, D.V. Fedorov, A.S. Jensen, Phys.Lett. B684 (2010) 132-136.

Measurements of Presolar Grains

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Primitive meteorites and interplanetary dust particles contain small quantities (up to several 100 ppm) of nanometer- to micrometer-sized dust grains that formed in the winds of evolved stars or in the ejecta of stellar explosions. These pristine samples are named presolar grains which can be studied in the laboratory for their isotopic compositions and mineralogy. Studies of individual presolar grains have provided a wealth of astrophysical information, such as on stellar nucleosynthesis and evolution, mixing in stars, Galactic chemical evolution, grain formation in stellar environments, chemical and physical processes in the ISM, and on the types of stars that contributed dust to the Solar System. Among the identified presolar minerals are silicon carbide (SiC), graphite, silicon nitride, refractory oxides, and silicates. Recent advances were pushed ahead by the availability of new analytical intrumentation (NanoSIMS, RIMS) and by co-ordinated multi-analytical approaches (SIMS, RIMS, noble gas mass spectrometry, FIB, TEM, Auger spectroscopy) in the study of single grains. This has changed our knowledge on the inventory of presolar grains considerably (e.g., discovery of presolar silicates) and allowed to get much more detailed insights into all stages of the life cycle of presolar grains, from their formation around evolved stars over the journey through the ISM to the incorporation into Solar System bodies. The isotopic compositions of the major and minor elements in presolar grains range over many orders of magnitude, indicative of contributions from different stellar sources. Most presolar SiC (>90 %) and oxide/silicate (ca. 90 %) grains apparently formed in the winds of low-mass AGB stars, as inferred mainly from heavy element isotopic compositions (SiC) and, respectively, O-isotopic ratios (oxides/silicates). A small fraction of presolar grains appear to come from binary systems, including novae. Although less abundant than grains from AGB stars, grains from SNeII are of particular importance. These grains incorporated matter from the outer H-rich zone down to the innermost Ni-rich zone in variable proportions, as indicated by specific isotopic fingerprints. A couple of recent findings have advanced our understanding of SN grains: For SiC new Si isotope data support the idea that the 29Si production in the C- and Ne-burning zones of SNeII is about 2x higher than predicted, 54Fe/56Fe and 34S/32S isotope ratios can not be reconciled with simple SN mixing model predictions, and the grains do not only show excesses in 28Si but sometimes also large excesses in the heavy Si isotopes, in particular for very small grains. The proposed SN origin for 18O-rich oxide/silicate grains is substantiated by multi-element isotope data, an extremely 16O-rich oxide grain shows clear evidence for the incorporation of now extinct 44Ti, and the carrier of a 54Cr-rich component in meteorites are possibly Cr-bearing oxide grains from Sne.

Extreme 54Cr-rich oxide grains in meteorites: Evidence for a single late supernova injection into the Solar System

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Systematic variations in 54Cr/52Cr ratios between different classes of meteorites point to large scale spatial and/or temporal isotopic heterogeneity in the solar protoplanetary disk. These variations have been attributed to nucleosynthetic effects, possibly carried by as-yet-unidentified presolar grains. We have recently identified extremely 54Cr-rich <200 nm oxide grains in the Orgueil meteorite, with estimated 54Cr/52Cr ratios (after correcting for dilution by neighboring material on the sample mount) reaching more than 50 times the solar system value. The most likely source of these grains is the 16O-rich O/Ne and/or O/C zones of Type II supernovae. When combined with the unusual distribution of O isotopic compositions of other supernova-derived oxide grains, the variability in bulk 54Cr/52Cr ratios between meteorite classes argues for a heterogeneous distribution of supernova grains, including the 54Cr carrier, injected directly into the solar protoplanetary disk from a single supernova.

Chromium Isotopic Compositions in Presolar SiC Grains

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Most presolar SiC grains derive from Asymptotic Giant Branch (AGB) stars, which are the main source of s-process nuclides in the galaxy. However, s-process nucleosynthesis is not a major contributor to iron peak nuclides. Models of AGB nucleosynthesis predict ~100 per mil enhancement in the 54Cr/52Cr ratio, while the 50Cr/52Cr and 53Cr/52Cr ratios are predicted to change less than 20 per mil. We measured chromium isotopic compositions in 20 presolar SiC grains from the Murchison meteorite, 19 of which are likely to be from AGB stars, and observed resolvable Cr anomalies in several of them.

SiC grains were isolated from the Murchison meteorite. Grains from the 2-4 micron size fraction were pressed into a high purity gold foil. Chromium isotopic compositions were measured by Resonance Ionization Mass Spectrometry (RIMS) using techniques specifically developed for Cr.

The Cr isotopic compositions of 19 of the grains formed a distinct group, but one had a strong positive 50Cr anomaly (+246 ± 49 per mil) and was clearly different from the others. We conclude that the group of 19 grains is mainstream (i.e. AGB-derived), while the outlier is probably an X-grain (i.e. Type II supernova-derived). Several of the mainstream grains had resolvable (>2 sigma) 50Cr and 53Cr deficits ranging as low as -178 per mil. The 54Cr/ 52Cr ratios were all within 2 sigma of the Solar System value, though most were slightly positive. The average delta-values for the mainstream grains were -45±31 per mil (1 sigma) for 50Cr, -37±21 per mil for 53Cr, and +25±26 per mil for 54Cr.

Given that AGB stars change Cr isotope ratios very little, and that these grains' progenitor stars formed from a few hundred million to about three billion years before the Solar System (assuming their initial masses were 1.5 - 3 solar masses), and that grain interstellar residence times are generally less than ~100 - 200 million years, the Cr isotopes in mainstream grains reflect the composition of the interstellar medium from about 5 to 7.5 billion years ago. Comparing our data to predictions for Cr synthesis in Type II and Type Ia supernovae (the main producers of Cr) shows deviations from simple mixing lines. The mixing model predicts greater deficits in 50Cr than is seen in the grains and/or an enhancement in 53Cr, whereas the grains show deficits. In the case of 54Cr, a 100 per mil enhancement due to AGB nucleosynthesis nearly accounts for the deviation from the mixing line.

Our work is supported by the NASA Cosmochemistry program, through grants to Argonne National Laboratory and the University of Chicago, and by the US Dept. of Energy, BES-Materials Sciences, under contract DEAC02-06CH11357.

INTEGRAL observations of gamma-ray lines from radioactive decays

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Gamma-ray line observations with INTEGRAL measure decay of unstable isotopes which are ejected from sites of nucleosynthesis. Massive stars are believed to be producers of gamma-ray emitting isotopes 44Ti, 26Al, and 60Fe. Measurements with the Ge spectrometer have shown that (1) inner core-collapse supernova ejecta from the Cas A supernova remnant appear to still travel at velocities beyond a few hundred km/sec; (2) 26Al synthesis occurs throughout the Galaxy as confirmed bz Doppler shifts from Galactic rotationö the intensity corresponds to a supernova rate from core collapses of about one every 50 years; (3) 60Fe synthesis expected from massive stars is above the constraints from gamma-ray observations; (4) 26Al synthesis in the Cygnus region appears on the high side of predictions from models; (5) the nearby Sco-Cen region is identified as a 26Al source.
We will discuss these findings, and also discuss the implications of these nucleosynthesis constraints in the context of INTEGRAL's observed positron annihilation gamma-rays.

The final stages of stellar evolution

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I will review the neutrino dominated phases of the evolution of a massive star, i.e. the C, Ne, O and Si burnings and their dependence on the initial mass and chemical composition. In particular I'll focus on the main uncertainties that affect the final mass-radius relation as well as the chemical structure of a massive star just before the passage of the shock wave.

Models and direct observables of core-collapse supernovae

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Knowledge in astrophysics originates from a synthesis of astronomical observation, knowledge of terrestrial physics and theoretical models of astrophysical scenarios. The extraction of information about the laws of physics in the universe is most efficient, if the degree of detail and quality in the observation can be matched by corresponding astrophysical models that link the observation to uncertainties in the input physics. We focus on stellar core-collapse supernova explosions, which still pose open proof of-principle questions regarding their explosion mechanism, for which detailed observations are available in almost all astronomical windows (optical, electromagnetic, neutrinos, cosmic rays, in future hopefully gravitational waves), which probe matter under interesting conditions that are not always accessible in terrestrial experiments, and whose nucleosynthetic yields provide a key to the understanding of Galactic evolution. We review the current status of supernova theory and demonstrate that the neutrino signature of a galactic supernova will reveal detailed information about the explosion mechanism. We try to visualise the dynamics and fluid instabilities in the explosion mechanism by discussing the results of first three-dimensional models with spectral neutrino transport approximations that will serve as foundation for efficient parameter studies in 3D, for example to explore the dependence of the gravitational wave signal on the microscopic input physics.

Core-collapse supernova simulations with CHIMERA

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Unraveling the core-collapse supernovae mechanism is an outstanding computational challenge and the problem remains essentially unsolved despite more than four decades of effort. However, much progress in realistic modeling has occurred recently through the availability of petascale platforms and the increasing sophistication of supernova codes. I will briefly describe CHIMERA, a code we have developed to simulate core-collapse supernovae in 1, 2, and 3 spatial dimensions. I will describe the results of an ongoing suite of 2D simulations for several massive progenitors, and provide a glimpse of ongoing 3D simulations.

Gamow-Teller strength distributions at finite temperatures and electron capture in stellar environments.

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We propose a new method to calculate stellar weak-interaction rates in nuclei. It is based on the Thermo Field Dynamics formalism and allows the
calculation of the weak-interaction response of nuclei at finite temperatures in a thermodynamically consistent way. The thermal evolution of the Gamow-Teller (GT_+) distributions is presented for the sample nuclei 54,56Fe and 76,78,80Ge. In the present application, correlations described by the thermal (proton-neutron) quasiparticle random phase approximation are taken into account. For Ge we also calculate the strength distribution of first-forbidden transitions. We show that thermal effects shift the GT_+ centroid to lower excitation energies and make possible negative- and low-energy transitions. In our model we demonstrate that the unblocking effect for GT_+ transitions in neutron-rich
nuclei is sensitive to increasing temperature. The obtained strength distributions are used to calculate electron capture rates and are compared to those obtained from the shell-model and the hybrid model.

Delivery of Supernova Material to the ISM Through Ejecta Knots

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Detailed and spatially resolved observations of supernova remnants (SNR) suggest that early in the evolution of the remnant the SN ejecta fragments and forms over-dense knots (Spyromilio et al. 1993). These knots are also observed in the SNRs many years after the explosion (e.g. Moon et al. 2009, Ghavamian et al. 2005, Hammell & Fesen 2008) showing that they are long-lived features of SNRs.

We are currently doing numerical simulations of supernova explosions in three dimensions to study the fragmentation of supernova ejecta from the onset of the explosion. We are specifically interested in the formation and development of ejecta knots, their physical properties (size, mass, composition, temperature evolution), and the factors that influence those. For the simulations we are using a parallel, 3D Smooth Particle Hydrodynamics code (Fryer et al. 2006) with 1 million SPH particles. We have performed one control run of a 15 M_{sol} star without cooling or nuclear burning, one run of the same star with a small (20 isotope) nuclear reaction network, and are adding a radiative cooling routine to our code to do a run with cooling also. We do not expect cooling to be important until the ejecta becomes optically thin, though once this happens we expect the cooling to contribute to the formation of over-dense knots and the formation of substructure in these knots. Since we are also interested in the detailed yield of the explosion, all runs are post-processed with a more extensive network as well.

The control run so far shows promising results which we will present at this conference; Rayleigh-Taylor instabilities readily develop when the shock reaches the oxygen-rich layer and persist to the end of the simulation (about 1.5 yrs in the remnant's time). After about 55 hrs in the remnant's evolution, a large fraction of the ejecta resides in these over-dense filaments and on the order of a few hundred knots have formed out of these. While nuclear burning and cooling were not included in the control run, we expect these processes to aid the formation of knots. Specifically we expect the run with radiative cooling to show further fragmentation of the already formed knots into smaller structures, increasing the total number of knots. We will present a comparison between the control run, the run with included cooling, and the run with nuclear burning, to gauge the influence individual processes have on the formation and evolution of knots.

The final stage of the simulations is to include an interstellar medium (ISM) into which the supernovae expand, as in the current calculations the ejecta expands into vacuum. With this last step we are able to study the interaction of the knots with the ISM, and compare our simulations to observations of SNRs.

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Hypernovae and Gamma-Ray Bursts

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Supernovae (SNe) associated with Gamma-Ray Bursts (GRBs) are characterized by the large explosion energy exceeding 1E52 erg, thus being called Hypernovae. The hypernova explosions are also suggested to be highly aspherical. We summarise characteristic nucleosynthesis in such hypernova explosions and the comparison with the peculiar abundance patterns observed in extremely metal-poor stars. We also discuss how core-collapse hypernovae are related to the recently discovered extremely luminous supernovae and extremely faint supernovae.

Nucleosynthesis from Black Hole Accretion Disks

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Rapidly accreting disks surrounding black holes can form in compact object mergers or long duration gamma ray bursts. Several types of nucleosynthesis occur in hot outflows from these objects, including an r-process, p-process and significant production of Nickel-56. Neutrinos play a pivotal role in all of these processes. We outline these with comments on general relativistic corrections for the neutrinos, and "collective" flavor transformations of neutrinos from hot dense environments.

Black hole and neutron star mergers

Rosswog S.[1]

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Compact binary mergers are exitng for a slew of reasons. They are the prime candidates for the first direct gravitational wave detection by the ground-based detector facilities that have taken up operation recently. Moreover, they are still the "best buy model" for the central engine of short gamma-ray bursts. Last but not least, they are possibly an important source of r-process elements. In my talk I will discuss recent developments in this very active field of research.

Radioactively Powered Electromagnetic Counterparts of Neutron Star Mergers

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The most promising astrophysical sources of gravitational waves (GWs) with ground-based interferometers such as LIGO and Virgo are the inspiral and merger of binary neutron star (NS) and black hole systems. However, maximizing the scientific benefits of a GW detection will require identifying a coincident electromagnetic counterpart. One of the most likely sources of isotropic emission from NS mergers is a supernova-like transient powered by the radioactive decay of r-process elements synthesized in the merger ejecta. I will present the first calculations of the optical transients from NS mergers that self consistently determine the radioactive heating using a nuclear reaction network and which determine the resulting light curve with a Monte Carlo radiation transfer calculation. Due to the rapid evolution and low luminosity of NS merger transients, optical counterpart searches triggered by a GW detection will require close collaboration between the GW and astronomical communities. NS merger transients may also be detectable following a short duration Gamma-Ray Burst or blindly with present or upcoming optical transient surveys. Because the emission produced by the merger ejecta is powered by the formation of rare r-process elements, I will show how current and future optical transient surveys can be used to directly constrain the unknown astrophysical origin of the heaviest elements in the Universe.

Enrichment of the r-Process Elements in the Sub-Halos as Building Blocks of the Milky Way Halo

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The role of neutron star mergers in the enrichment history of the r-process elements is investigated in the framework of the hierarchical formation of the Milky Way from a large number of sub-halos. We find that neutron star mergers can be a major source of the r-process elements if the smaller sub-halo has the lower star formation rate as indicated from the spectroscopic studies of some dwarf spheroidals. Our result naturally explains both the large star-to-star scatter of the r-process abundances and the small scatter of the alpha and iron-peak abundances as found in extremely metal-poor stars of the Galactic Halo.

The Nuclear Equation of State

Lattimer J.[1]

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Neutron stars provide a unique laboratory with which to study cold, dense matter. The observational quantities of primary astrophysics interest are the maximum mass and the typical radius of a neutron star. These quantities are related to the relative stiffness of neutron-rich matter at supernuclear densities and the density dependence of the nuclear symmetry energy near the nuclear saturation density. Laboratory measurements via nuclear systematics and structure, heavy-ion collisions, and parity-violating electron scattering from neutron-rich nuclei, help to constrain these properties. At the same time, observations of binary pulsars, thermal emissions, and X-ray bursts are providing new information on the masses and radii of neutron stars. Several recent observations, including that of a high mass pulsar in a binary and a more accurate distance determination for a nearby cooling neutron star, will be summarized. The combined astrophysical data is able to shed new light on the pressure-density relation of extremely dense matter, implying that the equation of state near nuclear saturation density is relatively soft but that the neutron star maximum mass is perhaps 2 solar masses or larger.

Pulsar Mass Measurements

Stairs I.[1]

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Radio pulsar timing is a powerful technique for determining neutron-star parameters to high precision. In some binary systems, the basic Keplerian description of the orbit is inadequate, and relativistic corrections must be included in the pulsar ephemeris. With two or more such parameters measured, the pulsar and companion masses are obtained. In other cases, geometric constraints or spectroscopic information from a non-degenerate companion may be available. Masses are measured in systems with a range of different evolutionary histories, and have the potential to set constraints on the neutron-star equation of state.

Constraints on neutron-star theories from nearby neutron star observations

Neuhaeuser R.[1]

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We try to constrain the nuclear equation-of-state (EOS) and supernova ejecta models by observations of young neutron stars in our galactic neighbourhood. There are seven thermally emitting neutron stars known from X-ray and optical observations, the so-called Magnificent Seven (M7), which are young (few Myrs), nearby (few hundred pc), and radio-quiet with blackbody-like X-ray spectra, so that we can observe their surfaces and study their origin. It is even feasible to find the neutron star which was born in the supernova, from which those 60Fe atoms were ejected, which were recently found in the Earth crust.

As bright X-ray sources, we can determine their rotational (pulse) periods and their period derivatives from X-ray timing. We observe those neutron stars in X-ray and optical regimes to also determine radius and mass: From XMM or Chandra X-ray spectra, we can determine their temperatures. With precise astrometric observations using the Hubble Space Telescope, we can determine their parallax (i.e. distance) and optical flux. From flux, distance, and temperture, one can derive the radius using just the Stefan-Boltzmann law. This has been successfull in one to two cases, e.g. RX J1856.5-3754. Then, from identifying atomic or cyclotron absorption lines in X-ray spectra and from phase-resolved spectroscopy, we can determine the compactness (mass/radius) and/or gravitational redshift. This has also just been successfull in one to two cases.

Knowing the position, proper motion, and distance of such a neutron star, we can also determine its past flight path and kinematic origin. For such calculations, we have to assume the otherwise unknown radial velocity through Monte-Carlo simulations. We can then find the stellar association, in which the neutron star may have been born by a recent supernova, by tracing back its motion. If a neutron star seems to have flown through a nearby young stellar association, where at least one supernova may have taken place, it may have formed there. We search for additional indications for such events, like run-away stars ejected in supernovae in binaries etc. Once the birth place of a neutron star in a supernova is found, we would have determined the distance towards the supernova and the age of the neutron star (as kinematic age). If all stars in such an association have formed roughly at the same time, as assumed by star formation theories, we also know the life-time and, hence, mass of the supernova progenitor star. In this way, we try to find the neutron star, which was born in the nearby recent supernova, which may have ejected 60Fe found in the Earth's crust. We can then test and calibrate supernova models.

Nuclear pasta with a touch of quantum : towards the dynamics of bulk fermion systems.

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Among the myriad of phenomena in the universe, a neutron star is one of the most interesting objects. As an "oversized nucleus", it is one of the most dense and compact objects known. The neutron star's high mass and densities lead to intriguing speculations about the composition of the interior. However, a sound description of the neutron-star crust, or nuclear matter at sub-nuclear densities in general, is needed to understand various astrophysical observations related to neutron stars.

In the crust, one believes that nuclear matter arranges itself in a variety of complex shapes often designated as nuclear pasta. This foam like neutron-rich matter has been been modelled with classical molecular dynamics [1,2]. This technique, however, lacks quantum mechanical features like the Pauli principle as well as uncertainty relations.

We present a novel method that allows one to study the dynamics of such a bulk fermion systems on a quantum mechanical level. By introducing periodic boundary conditions into fermionic molecular dynamics [3], it becomes possible to examine these systems with full antisymmetry, a long-range correlation of the infinite system. The presented technique treats the spins and the quantal nature of the nucleons explicitly and permits to investigate spatial dynamics of the system. Disregarding the introduced complexity, the formalism remains computationally feasible.

We show that the proposed technique is able to reproduce essential fermion features and present the first nuclear-matter results.

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Clusters in dense matter and the equation of state

Typel S.[1]

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The equation of state of dense matter is an important ingredient in astrophysical models for supernovae and compact stars. The thermodynamical properties and the composition of matter below nuclear saturation density is modified by the appearance of clusters and inhomogeneities. In this contribution a generalized relativistic mean-field model is presented that considers the formation and dissolution of light and heavy clusters in a microscopic approach. The model allows to describe dense matter consistently from very low densities where strong correlations are important up to and beyond nuclear saturation density where a quasi-particle description is very successfull. The parameters of the model are constrained by properties of atomic nuclei and nucleon-nucleon scattering. The aim of the work is to construct a new equation of state in a range of densities, asymmetries and temperatures that is relevant for astrophysical applications.

Experimental Applications of the Nuclear Equation-of-State to Neutron Star Dynamics

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The characterization of the density dependence of the nuclear equation-of-state (EOS) remains a longstanding problem in nuclear astrophysics. While observations of neutron star masses have placed astronomical lower limits on the asymmetry term of the EOS, experimental constraints remain open. Recent improvements in experiment, data interpretation, and theoretical predictions have greatly reduced the constraints on what is known concerning this dependence. Future work must focus on studying the nuclear EOS at higher-density ($\rho > \rho_o$). Recent heavy-ion beam experimentation will be described, and the theoretical interpretation will be presented. Of particular importance are plans to increase the density of the explored region of the nuclear EOS. The applications of experimental results from 40,48Ca+112,124Sn reactions at 140 MeV/A will also be covered. These reactions were studied to constrain the in-medium nucleon masses, which are a considerable unknown in model predictions of the nuclear EOS. Finally, applications of nuclear experimental results to neutron-star macroscopic structure will be presented.

Quark-Hadron mixed phase with hyperons in proto-neutron stars

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We study the quark-hadron (QH) phase transition w/wo neutrinos at finite temperature. For the hadron phase, we adopt a realistic equation of state (EOS) in the framework of the Brueckner-Hartree-Fock calculation including hyperons. This EOS of hyperon matter becomes then too soft to support the canonical mass of 1.4 solar mass, but QH transition may help it out of a difficulty [1].

Generally the properties of the mixed phase should strongly depend on electromagnetic interaction and surface tension, and these effects, sometimes called "the finite-size effects", lead to the nonuniform "pasta" structures. In the calculations of these structures, they require the pressure balance and the equality of the chemical potentials between two phases besides the thermal equilibrium. In the previous papers, these finite-sized effects have been properly taken into account to elucidate the properties of the pasta structure and demonstrate the importance of the charge screening at zero temperature [2]. However, finite temperature comes in many cases such as relativistic heavy-ion collisions and astrophysical phenomena. In this conference, we show the hadron-quark mixed phase with the finite-size effects at finite temperature[3].

We find that the mixed phase is limited due to thermal instability, and thereby EOS gets closer to that given by the Maxwell construction. Moreover, the number of hyperons is suppressed by the presence of quarks. In this talk, we will show the effects of neutrinos to the pasta structures as new results. We note that the pasta structures of QH mixed phase will change the structures of compact stars drastically, though the well known nucleus pasta does not change them so much. Hence, these characteristic features of the hadron-quark mixed phase should be important for many astrophysical phenomena such as mergers of binary neutron stars, or supernovae.

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The s-process in AGB stars

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About half of the solar abundance of elements heavier than iron are made by the slow neutron capture process occurring in low and intermediate-mass asymptotic giant branch (AGB) stars. Elements are "dredged" from the core to the surface and then expelled into the interstellar medium through strong stellar winds. In comparison to the rapid neutron capture process, modelling the s-process has presented fewer difficulties owing to the fact that most of the nuclei involved are near the valley of stability, and we observe stars enriched in heavy elements produced by the s process. However, many important uncertainties still remain including the mechanism leading to the formation of 13C pockets, and the efficiency of convection leading to the third dredge-up in AGB stellar models. There is an increasing wealth of observational data that is being used to constrain s-process modelling in AGB stars. These include spectroscopic abundances from AGB stars and their progeny (post-AGB stars and planetary nebulae), pre-solar meteoritic grains, globular cluster stars, and the very metal-poor Halo stars with enrichments of carbon and s-process elements. In this talk I will review the current status of AGB s-process models. I will also show results from our recent efforts to explain the s-process abundance pattern of planetary nebulae and globular cluster stars. Finally, I will discuss the contribution of intermediate-mass AGB stars, showing how recent models suggest they may be significant producers of light s-process elements (e.g., Cu, Rb) in the early Galaxy. I will also show that intermediate-mass low-metallicity AGB stars may produce elements beyond the first s-process peak, including Pb.

The experimental side of the s-process

Couture A.[1]

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The slow neutron capture process, or s-process is a neutron-capture process responsible for the production of approximately half of the elements with A>60. Because most of the isotopes in the process lie on or near stability, the experimental knowledge of the relevant cross sections is quite mature. However, there are still significant gaps, particularly for the cross sections on unstable isotopes. In addition, the modeling of the astrophysical environments has advanced rapidly, putting even more stringent requirements on the nuclear physics input on order to distinguish between competing models and better predict the synthesis in the cosmos.

I will provide on overview of the state-of-the-art in measurements for the s-process and perspective on new developments coming in the near future to extend our detailed knowledge of the nuclear physics at work.

NUCLEOSYNTHESIS IN VERY LOW METALLICITY AGB STARS: TRACES FROM PROTON INGESTION EPISODES

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We present and discuss a set of low-mass (0.85 < M/M_{SUN} < 2.0) low-metallicity (-3.2 < [Fe/H] < -2.2) theoretical AGB models. We find that there is a minimum mass (increasing with decreasing the metallicity) under which AGB stars undergo proton ingestion from the envelope down to the underlying He-rich region (Fujimoto, Ikeda & Iben 2000; Iwamoto et al. 2004). Proton ingestion occurs during the first fully developed convective Thermal Pulse. We refer to this phenomenon as PIE (Proton Ingestion Episode). The occurrence of PIE basically depends on the stellar mass and on the CNO content in the envelope. Stellar models have been calculated with a full nuclear network (700 isotopes, linked by more than 1200 reactions) directly coupled with the physical evolution of the structure. In order to properly follow the PIE, the use of a full nuclear network is an essential condition, because the energetic of neutron-capture processes drives the physical evolution of convective regions. The energy released by on-flight proton captures on the abundant 12C, splits the He-intershell convective region into a lower shell and an upper one. This splitting is delayed with respect to PIE, thus implying that a consistent amount of 13C is mixed down to the bottom of the convective shell. In the upper shell, elements belonging to the first s-process peak (ls elements: Sr-Y-Zr) are largely synthesized, while in the lower one elements belonging to the second s-process peak (hs elements: Ba-La-Nd-Sm) and lead (third s-process peak) are mainly produced. Then, the whole upper shell is eroded by a deep Third Dredge Up (d-TDU) episode, leading to a large surface enrichments of 13C, 14N and ls elements. Later on, hs elements and lead (previously synthesized in the lower shell) are carried to the surface by a second TDU. Interestingly, in the lowest mass models we find rather large 151Eu/(151Eu+153Eu) ratios: support to this result comes from two observed very metal poor stars (Aoki et al. 2003). In larger mass models, this feature disappears, as due to the occurrence of further TDU episodes. Physical conditions, similar to those found in very-low metallicity stars, may occur during the so-called Very Late Thermal Pulse in post-AGB stars. Thus, PIE could help explaining the elemental pattern observed in Sakurai´s object (Asplund et al. 1999).

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The first direct measurement of 17O(α,γ)21Ne and its impact upon s-process abundances

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The production of elements heavier than 56Fe is mainly due to the s- and r-processes. In massive stars, the so-called "main" component of the s-process, responsible for production of isotopes between Sr and Ba, is crucially dependent on the abundance of "parasitic" light isotopes which absorb neutrons otherwise available to the s-process. Since the final s-process abundances are so reliant on the neutron flux, the presence of these light isotopes, and their subsequent absorption of the few neutrons available, can cause huge uncertainties in the expected abundances.

One of the strongest neutron absorbers is 16O, being one of the end products of the helium burning stage and particularly important in stars at low metallicity. However, its efficiency as a neutron poison depends crucially on the competing α-capture reactions on 17O [1], the 17O being the result of (n,γ) reactions on 16O. A significant fraction of (α,γ) reactions would prevent those neutrons absorbed by the 16O being otherwise recycled by an (α,n) reaction and still available for the later s-process. The efficiency of 16O as a neutron poison is therefore dependent on the ratio of these competing reactions.

Existing data on 17O(α,n)20Ne extends to E_{cm} ~ 0.5 MeV; however, the strength of the competing 17O(α,γ)21Ne reaction is less well known, with little experimental information and predictions from two separate, conflicting theoretical models. A study by Descouvemont [2], using a generator coordinate method, predicts that the 17O(α,γ)21Ne reaction is some 104 times weaker than the competing (α,n) reaction. However, the earlier prediction by Caughlin and Fowler [3] suggests that the two reactions should only differ by a factor of 10 in rate, thus suggesting much lower s-process abundances between Sr and Ba than the Descouvemont predictions.

A campaign to measure the 17O(α, γ)21Ne reaction was therefore undertaken using the DRAGON facility at TRIUMF, Vancouver, spanning energies approaching the region of astrophysical interest. The experimental techniques involved and some preliminary results will be discussed.

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Sensitivity of 26Al, 44Ti, 60Fe Production in Core-Collapse Supernovae to Uncertainties in the 3- α and 12C(α , γ)16O Reaction Rates

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We have studied the sensitivity to variations in the triple alpha and 12C (α , γ) 16O reaction rates of the production of 26Al, 44Ti, and 60Fe in core collapse supernovae. The KEPLER code was used to model the evolution of 15, 20, and 25 solar mass stars to the onset of core collapse and the ensuing supernova explosion was simulated using a piston model. Calculations were performed for both the Anders and Grevesse (AG 1989) and Lodders (2003) abundances, and over a range of ±2 σ for each helium-burning rate (2 x 12% for triple alpha; 2x 25% for 12C (α , γ) 16O). This study involved more that 200 stellar evolutions; the cases studied are shown in Fig.1 of ref. [1]. Contributions from more massive Wolf-Rayet stars were not considered.

In previous work [1,2] we have shown that variations of a factor of three to five occur for many elements over the range of rates studied. The variations found in the present study [3] are still larger, and the variation with rate is far from monotonic. The observed changes for 60Fe are over a factor of 10, smaller for 26Al and smallest for 44Ca; even in the later case, however, changes greater than a factor of two occurred for certain rate combinations. Changes in the ratio 60Fe/26Al are also large, a factor of well over 10 in the reaction rate range. Production of all three isotopes and their ratios also depended on the solar abundance set used for the initial stellar composition; for example the production of 60Fe in a 25 solar mass star was about five times greater for the AG89 abundances.

It appears that the underlying reason for the rapid variations is the changing convection structure of the star and the rapid variation of the element lifetimes with temperature. For example, the life time of 60Fe drops from 2.6 Myr at low temperature to 0.5 yr at T_9 =1, so that the abundance depends strongly on whether an element formed at high T is rapidly convected to a lower T region.

The large variations observed also render uncertain some deductions from nucleosynthesis yields and astrophysical observations. For example, a comparison of the observed gamma ray flux from 26Al and the calculated production of 26Al in supernovae has been used to predict the supernova rate in the galaxy. And the ratio of the 60Fe and 26Al gamma ray fluxes has been compared to the prediction of supernova models. Conclusions based on both these comparisons are highly uncertain, given the variations of 60Fe and 26Al production outlined here.

There are presently experiments addressing the triple alpha rate, and there is hope that the 1 σ uncertainty can be reduced by a factor of two. The situation for 12C(α , γ)16O seems more difficult.

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Half-life of 60Fe

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The radioisotope 60Fe plays an eminent role in astrophysics. Until now there exists only a single measurement of the half-life by Kutschera et al., NIMB5,430(1984). The reported half-life is 1.49+/-0.27 Myr. The importance of the 60Fe half-life for the early solar system history, nucleosynthesis and gamma ray astronomy and for the accretion of life 60Fe on earth will be discussed. A report on our measurements yielding a significantly longer and much more precise half-life of 2.62+/-0.04 Myr (PRL 103, 072502 (2009)) will be given.

New measurement of the astrophysically important reaction 62Ni(n,γ) at n_TOF

Lederer C.[1], Berthoumieux E.[2], Calviani M.[2], Cano-Ott D.[3], Colonna N.[4], Dillmann I.[5], Domingo-Pardo C.[6], Giubrone G.[7], Guerrero C.[3], Gunsing F.[8], Heil M.[6], Käppeler F.[9], Leeb H.[10], Massimi C.[11], Mengoni A.[12], Tain J.[7], Vlachoudis V.[2], Wallner A.[1], the n_TOF collaboration .[2]

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Elements heavier than Fe are dominantly produced by neutron capture reactions which can be classified in two types, the r-process (rapid capture) and the s-process (slow capture). Recent observations of Ultra-Metal-Poor stars showed discrepancies to expected elemental abundances for the mass region below A=120, which indicates either an incomplete knowledge on s/r- process scenarios or systematic uncertainties in experimental cross-section data. Last year the second phase of measurements at the neutron-time-of-flight facility n_TOF at CERN has started. It comprises the measurement of the neutron capture cross-sections of all stable Fe and Ni isotopes, which are of relevance for the astrophysical s-process. At the n_TOF facility, a high instantaneous neutron flux is produced by spallation reactions of a pulsed proton beam with Δt = 7 ns and 20 GeV/c on a Pb target. Capture cross sections for neutron energies between 1 eV and 1 MeV can be analyzed by detecting the prompt gamma-deexcitaion of the compound nucleus with two liquid scintillation detectors. A flight path of 185 m ensures an excellent neutron energy resolution. Data taking for the first reactions 62Ni(n,γ) and 56Fe(n,γ) is already finished and the analysis is under way. The data are treated using the Pulse-Height-Weighting-Technique, which accounts for the different deexcitation paths of the compound state. Background studies are performed by measurement of adequate reference samples and by simulations. The capture yield is normalized relative to Au applying the saturated resonance technique. Preliminary results on 62Ni(n,γ) show that due to the unique energy resolution of n_TOF a number of resonances could be resolved up to several hundred keV. First results will be presented and compared to recent complementary measurements by Accelerator-Mass-Spectrometry in the Fe-Ni mass region.

First measurement of the 64Ni(γ ,n) cross section

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In the last 10 years new and more accurate stellar neutron capture cross section measurements have changed and improved the abundance predictions of the weak s-process. The solar abundances of 63Cu and 65Cu are to a large extent produced in this scenario. However, experimental data for the stellar 63Ni(n,γ)64Ni cross section is still missing, but strongly required for a reliable prediction of the copper abundances [1].

63Ni ($t_{1/2}$=101 y) is a branching point and also bottleneck in the weak s-process flow, and behaves different during core He and shell C burning. During core He burning the branching ratio is f_b=0.91 [2] and the reaction flow proceeds via β-decay to 63Cu, and a change of the 63Ni(n,γ)64Ni cross section would have no influence. However, this behavior changes at higher temperatures and neutron densities during the shell C burning phase with f_b=0.02. Now the reaction flow passes through 63Ni and a change in the 63Ni(n,γ)64Ni cross section would be propagated through the abundances of all heavier isotopes up to A=90 [1].

Experimental information is up to now missing for this reaction as well as for the inverse 64Ni(γ,n) channel. We have measured for the first time the 64Ni(γ,n)63Ni cross section via photoactivation and following Accelerator Mass Spectrometry (AMS). The activations were performed at the ELBE facility in Dresden-Rossendorf and followed by the 63Ni/64Ni determination with AMS at the MLL accelerator laboratory in Garching [2,3]. First results indicate that theoretical predictions have overestimated this cross section up to now. If the same is assumed for the inverse channel 63Ni(n, γ)64Ni, solar ratios of 63Cu and 65Cu could be reproduced.

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[3] I. Dillmann et al., Nucl. Instr. and Meth. B (2009), doi:10.1016/j.nimb.2009.10.153

Novae: theory and observations

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Classical nova outbursts are powered by thermonuclear runaways that take place in the H-rich accreted envelopes of white dwarfs in close binary systems. Extensive numerical simulations of such explosions have shown that the accreted envelopes attain peak temperatures ranging between 10+8 and 4×10+8 K, for about several hundred seconds, and therefore, their ejecta is expected to show signatures of a significant nuclear activity. Indeed, it has been claimed that novae can play a certain role in the enrichment of the interstellar medium through a number of intermediate-mass elements. This includes 17O, 15N, and 13C, systematically overproduced in huge amounts with respect to solar abundances, with a lower contribution to a number of other species with A < 40, such as 7Li, 19F, or 26Al.
In this review, we present new 1-D hydrodynamic models of classical nova outbursts, from the onset of accretion up to the explosion phase. A special emphasis is put on their gross observational properties (including constraints from meteoritic presolar grains and potential gamma-ray signatures) and on their associated nucleosynthesis. 2-D models of mixing at the core-envelope interface during outbursts will also be presented. The impact of nuclear uncertainties on the final nucleosynthetic yields will be also outlined.

Destruction of 22Na in Novae: Surprising Results from an Absolute Measurement of 22Na(p,γ) Resonance Strengths

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Hydrodynamic simulations of classical novae on ONe white dwarfs predict substantial production of 22Na [1]. Observation of 22Na decay should be correlated with the corresponding nova because the half life of 22Na is only 2.6 years. The 1275-keV gamma ray from the β decay of 22Na is, therefore, an excellent diagnostic for the nova phenomenon and a long-sought target of gamma-ray telescopes. Nova simulations determine the maximum 22Na-detection distance to be < 1 kpc for the INTEGRAL spectrometer SPI, consistent with its non-observation to date. However, model estimates are strongly dependent on the thermonuclear rate of the 22Na(p, γ)23Mg reaction, which destroys 22Na in novae.

The 22Na(p, γ)23Mg rate is expected to be dominated by narrow, isolated resonances with E_p < 300 keV. The currently employed rate is based on a single set of absolute resonance-strength measurements with E_p ≥ 290 keV [2], and one relative measurement of resonances with E_p ≥ 214 keV [3] that was normalized to a strength from Ref. [2]. Recently, a new level has been found in 23Mg which would correspond to a resonance at E_p ≈ 198 keV that might dominate the reaction rate at nova temperatures and reduce the production of 22Na in novae by up to a factor of 3 [4].

We have measured the 22Na(p, γ) resonance strengths directly and absolutely. Proton beams were produced at the University of Washington and delivered to a specially designed beam line that included rastering and cold vacuum protection of the 22Na-implanted targets (fabricated at TRIUMF). Two high purity germanium detectors were employed and surrounded by anti-coincidence shields to reduce cosmic backgrounds. Measurements were made on known 22Na+p resonances and on the proposed new resonance at E_p ≈ 198 keV. The proposed resonance was not observed, and the upper limit placed on its strength indicates that the resonance at E_p ≈ 214 keV still dominates the reaction rate across the temperature range important to novae. However, we measured the strengths of the known resonances to be inconsistent with previous measurements [2,3]. Due to the resulting change in the 22Na(p, γ) reaction rate, we expect the amount of 22Na produced by novae to differ significantly from current estimates, revising the prospects for its observation. Full analysis of our results will be presented at the conference.

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The 33S(p, γ)34Cl reaction in classical nova explosions

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The analysis of microscopic grains within primitive meteorites has revealed isotopic ratios largely characteristic of the conditions thought to prevail in various astrophysical environments. Recently, several grains have been identified with isotopic signatures similar to those predicted within the ejecta of nova explosions on oxygen-neon white dwarfs. A possible smoking gun for a grain of nova origin is a large 33S abundance: nucleosynthesis calculations predict as much as 150 times the solar abundance of 33S in the ejecta of oxygen-neon novae. This overproduction factor may, however, vary by factors of at least 0.01 - 3 because of uncertainties in the 33S(p, γ)34Cl reaction rate over nova temperatures. In addition, better knowledge of this rate would help with the interpretation of nova observations over the S-Ca mass region, and contribute towards the firm establishment of a nucleosynthetic endpoint in these phenomena. Finally, constraining this rate may help to confirm or rule out the decay of the metastable state of 34Cl (E_x = 146 keV, $t_{1/2}$ =32 m) as a source for observable gamma-rays from novae.

Direct examinations of the 33S(p, γ)34Cl reaction in the past have identified resonances down to only E_R = 434 keV. At nova temperatures, lower-lying resonances could certainly play a dominant role. We discuss several recent, complementary studies dedicated to improving our knowledge of the 33S(p, γ)34Cl rate, using both indirect methods (measurement of the 34S(3He,t)34Cl and 33S(3He,d)34Cl reactions with the Munich Q3D spectrograph) and direct methods (in normal kinematics at CENPA, University of Washington, and in inverse kinematics with the DRAGON recoil mass separator at TRIUMF). Our results will affect predictions of sulphur isotopic ratios in nova ejecta (e.g. 32S/33S) that may be used as diagnostic tools for the nova paternity of grains.

Unbound States of 32Cl Relevant for Novae*

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The SiP cycle [1], which is closed by the 31P(p,α)28Si reaction, can break out via the 31S(p,γ)32Cl proton-capture reaction. The duration of the cycle influences the timescale of explosive hydrogen burning and may be important for understanding the enrichment of elements near sulfur seen in nova ejecta. At novae temperatures, 0.1-0.4 GK, the 31S(p,γ)32Cl reaction rate is dominated by 31S+p resonances corresponding to unbound states in 32Cl. Discrepancies in the 32Cl excitation energies have been reported in previous measurements [1,2]. We have studied the 32S(3He,t)32Cl charge-exchange reaction at Yale University's Wright Nuclear Structure Laboratory to produce unbound states in 32Cl. The excitation energies of levels in 32Cl were determined by detecting the tritons at the focal plane of the Enge Spectrograph. One of the levels, relevant for nucleosynthesis processes and never observed before, has been discovered in the presented experiment. Proton-decay branching ratios were determined for some levels by detecting decay protons from the residual 32Cl states using a silicon array in the spectrometer's target chamber. This experiment reduces the uncertainty in the 31S(p, γ)32Cl reaction rate. Results from the experiment and implications for astrophysics will be presented.

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The rp-process in X-ray bursts

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Explosive hydrogen burning via the rapid proton capture process powers X-ray bursts frequently observed from accreting neutron stars. Nuclear physics affects the observed burst profiles and the composition of the burst ashes, which in turn affects neutron star observations. I will review the current open questions, progress in our understanding of the interplay between nuclear physics and astrophysics, and progress in obtaining the relevant nuclear data in rare isotope beam experiments.

Precision measurements of 20Na, 24Al, 28P, 32Cl, and 36K for the *rp* process

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Thermonuclear rates of radiative proton capture reactions on unstable nuclides are used to model the *rp* process, and are often dominated by contributions from narrow, isolated resonances. Energies for potential resonances in these reactions may be acquired indirectly by determining the *Q* values of the reactions via mass measurements, and measuring the excitation energies of levels that may correspond to (p,γ) resonances. These indirect resonance energies must be both precise and accurate to make reliable estimates of the thermonuclear rates in the absence of direct measurements, and to facilitate direct measurements with radioactive ion beams.

To improve the experimental information on the (p,γ) reactions leading to 20Na, 24Al, 28P, 32Cl, and 36K, we have measured the (3He,t) reactions leading to these nuclides. Thin, ion implanted carbon foil targets of 20Ne, 24Mg, 28Si, 32S, and 36Ar were prepared at the University of Washington. The targets were bombarded with 32 MeV 3He beams at the Maier-Leibnitz Laboratorium of the Ludwig-Maximilians-Universitaet and the Technische Universitaet Muenchen. The momenta of outgoing tritons were determined by measuring their positions at the focal plane of a Q3D spectrograph.

In this way, the mass excesses of 20Na, 24Al, 28P, and 32Cl have been measured to uncertainties of 1.1 or 1.2 keV: substantial improvements in precision over the 2003 Atomic Mass Evaluation (AME03). The masses of 20Na and 32Cl are found to be in good agreement with the AME03 values, but the masses of 24Al and 28P are found to be inconsistent with the AME03 values by more than 3σ . The new mass values resolve a discrepancy in the energy of the lowest-lying resonance in the 23Mg(p,γ)24Al reaction and constrain a recent direct measurement of its strength.

Excitation energies of levels above the proton thresholds in 32Cl and 36K have been measured. The results for 32Cl resolve a discrepancy between two previous sets of measurements. A new 36K level has been found in the Gamow window for the 35Ar(p,γ)36K reaction, and uncertainties in the energies of known levels have been reduced by over an order of magnitude. The new information on 36K points to a better arrangement of T=1, A=36 isobaric-analog triplets and pushes the 35Ar(p,γ)36K reaction rate far outside of the currently accepted uncertainty bounds.

Studying the (*α,p*)-process in X-ray Bursts using Radioactive Ion Beams

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In type I X-Ray Bursts (XRBs) the nuclear flow is driven towards the proton-drip line by the triple-*α* reaction, the (*α,p*)-process, and the *rp*-process. Along the nucleosynthetic path, the reaction flow can be stopped at so-called waiting-point nuclei. The low $Q_{p,\gamma}$ value of a waiting-point nucleus leads to (*p,γ*)-(*γ,p*) equilibrium causing the flow to stall and await a β decay. However, if the temperature is high enough the competing (*α,p*) reaction can bypass the waiting point. This can have significant effects on final elemental abundances, energy output, and observables such as double-peaked luminosity profiles. In the intermediate mass region 22Mg, 26Si, 30S, and 34Ar have been identified as possible candidates for waiting-point nuclei in XRBs.

A method to study the (*α,p*)-process on intermediate mass waiting-point nuclei has been developed whereby the time-inverse reaction is studied in inverse kinematics using radioactive ion beams produced by the in-flight method at the ATLAS facility at Argonne National Laboratory. The two reactions *p*(33Cl,30S)*α* and *p*(37K,34Ar)*α* have been studied for the first time to determine reaction rates for 30S(*α,p*)33Cl and 34Ar(*α,p*)37K, respectively. The results and possible implications for nucleosynthesis in XRBs will be discussed.

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Mass measurements on the rp-process path

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Spreading of ion trap techniques to nuclear spectroscopy laboratories has resulted in a rapid expansion of precise nuclear binding data all over the nuclide chart. In this presentation a recent atomic masses of neutron-deficient nuclei below A=120 will be reviewed. These data, which extends from Molybdenum to Iodine, have been obtained mainly at JYFLTRAP facility coupled to IGISOL (Ion Guide Isotope Separator On-line) separator at University of Jyväskylä, Finland. In addition to JYFLTRAP, some results from SHIPTRAP and ISOLTRAP facilities at GSI and CERN will be discussed. Main emphasis in this contribution will be on the data affecting the rp-process path above A=60. Implications on the termination of rp-process in SnSbTe-cycle will also be presented.

Mass measurements of proton-rich nuclides in the region of A=85 and their impact on the rp-process

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A longstanding problem in the field of nuclear astrophysics is the explanation of the abundance of certain light p-nuclides. It has been suggested that processes known as the vp- and rp-process could be responsible for creation of these p-nuclides. Much of the understanding of these processes is based on model calculations, for which basic nuclear properties are important input parameters.

The accelerator complex at GSI, Darmstadt, offers excellent opportunities to study nuclear properties such as the mass of nuclides far from stability. At the Penning trap system SHIPTRAP mass measurements of proton-rich and transfermium nuclides are performed. The exotic nuclides are produced in fusion-evaporation reactions, separated from the primary beam by the velocity filter SHIP and transferred to SHIPTRAP. The products are decelerated by degraders and thermalized in a helium-filled stopping cell. The ions are guided by DC and radio frequency fields to a nozzle and extracted into a radio-frequency quadrupole (RFQ) structure. In the RFQs, the ions are cooled and formed into ion bunches, which can be captured in the double Penning trap system. In a first Penning trap mass-selective buffer gas cooling is performed. In the second trap accurate mass measurements using a time-of-flight technique (TOF-ICR) are performed.

Recently, nuclides with mass numbers around A=85 produced in the reaction 36Ar + 54Fe → 90Ru* were measured with an accuracy ranging from 5×10-8 to 3×10-7. The masses of 85Mo and 87Tc were measured for the first time, and deviate from the extrapolated values of the 2003 Atomic Mass Evaluation (AME 2003) by up to 1.6 MeV. As a consequence the proton separation energy of 87Tc has been determined to be only half of the AME 2003 value. These are the heaviest N=Z+1 nuclides, whose masses have been measured directly. The masses of two other nuclides, 86,87Mo, were measured and their uncertainties were reduced. Additionally, the masses of 86Zr and 85Nb were measured and found to be in agreement with the values obtained at JYFLTRAP.

Based on the new mass data and contributions from other facilities, a local mass extrapolation has been made for the mass range A=80-95. Even though the masses generally are shifted in the same direction, significant changes in the proton and neutron separation energies are obtained as well. One observes a smoother trend in the separation energies.

Taking into account the new mass excess values, network calculations of the rp-process in x-ray bursts have been performed. Preliminary results show large changes in the final abundances for A=86-94 and in the reaction flux in this region. Due to the smaller proton separation energy of 87Tc the abundance of nuclides with A=86 increases by a factor of 20. Noticeable is also the sensitivity of the abundance of A=94 to the proton separation energy of 95Ag. Results of measurements and calculations will be presented, and the issue of a potential Zr-Nb cycle will be addressed.

Explosive nucleosynthesis and the p-process

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A number of naturally occurring, proton-rich isotopes (the p-nuclei) cannot be made in the s- and r-processes. Another hypothetical process has to be invoked, the p-process. It has been found that massive stars can produce p-nuclei through photodisintegration of pre-existing intermediate and heavy nuclei. This so-called γ-process requires sufficiently high temperatures and occurs in pre-explosive or explosive O/Ne burning, depending on the mass of the star. Although the γ-process has been successful in producing a large range of p-nuclei, two mass regions remain problematic, A<124 and 150<A<168, which are severely underproduced. The origin of the problems is yet to be identified. A large number of unstable nuclei with only theoretically predicted reaction rates are included in the reaction network and thus the nuclear input may involve large uncertainties. Deficiencies in charged-particle optical potentials at γ-process temperatures have been found for nuclei at stability. On the other hand, the γ-process conditions (temperature profiles, entropy of the O shell, seed composition) also sensitively depend on details of the stellar structure and evolution, as well as on the initial metallicity. Nevertheless, especially the deficient low-mass p-nuclei may call for an additional production process or site, such as the vp-process, rp-process or production in type Ia supernovae. In this case, the hypothetical p-process would be realized as superposition of several different processes, not necessarily in the same site. An overview of the γ-process is given, with special emphasis on the nuclear uncertainties and their impact on the prediction of p-nuclei production.

Production of light element primary process nuclei in supernova neutrino-driven winds

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Elemental abundances of metal poor stars are assumed to originate from a few primary nucleosynthesis processes and therefore require the correct identification of all important sources and their relative contributions. Although it has been shown that at least two nucleosynthesis processes were needed to explain meteoritic data, only until recently the typical patterns of the r-process and an additional light element primary process (LEPP) were obtained based on metal-poor star abundances observations [Montes et al. (2007),Qian \& Wasserburg(2008)]. Furthermore, it has been suggest that the LEPP is likely to have contributed to the solar system abundances and that it could explain deficiencies in current s-process models. Although neutrino driven wind nucleosynthesis calculations have traditionally focused on reproducing r-process nuclei, the necessary conditions to produce elements up to the third peak are difficult to obtain in state-of-the-art simulations. In this work we show that LEPP abundances can be produced under realistic conditions with current neutrino-driven wind models. Furthermore, we show that proton-rich conditions may be enough to produce abundance patterns observed in some metal-poor stars.

Montes, F. et al. 2007, ApJ, 671, 1685
Qian, Y.Z., Wasserburg, G.J. 2008, ApJ, 687, 272

The Impact of Reaction Rates (and other nuclear physics inputs): A Sensitivity Study for the v p-Process

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The v p process has been shown to be an important nucleosynthesis process, occurring in core collapse supernovae, that contributes to the synthesis of nuclei in the mass region 64<A<120. Such a nucleosynthesis process (in addition to the conventional r- and s-processes) is needed to explain the observed abundance patterns in this mass region - particularly in very low metallicity stars. The nucleosynthesis path of the neutrino-p process consists of a sequence of (p,g) and (n,p) or β + reactions, where the slowest reactions set the timescale. Nucleosynthesis studies of such events as the v p process typically involve the use of reaction networks that include several thousand nuclei and associated reaction cross sections and lifetimes, most of which are only known theoretically. A majority of the nuclei involved are unstable and hence pose a challenge for experimental nuclear physicists. With improvements in existing facilities such as NSCL at MSU and ATLAS at ANL and with a future FRIB facility, experimental investigations of reaction rates and other nuclear quantities involving unstable nuclei will become feasible. In this talk, we will demonstrate the sensitivity of the resulting nucleosynthesis on the reaction rates. In addition, we will identify important reactions and nuclei to be studied experimentally with upcoming techniques at the new facilities.

Direct determination of the 11C(α,*p*)14N reaction rate with CRIB: an alternative synthesis path to the CNO elements

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The 11C(α ,*p*)14N reaction is considered as an alternative pathway from the *pp*-chain region to the CNO region, on which its contribution is estimated as large as of the triple-α process in some cases related to high-temperature hydrogen burning processes, such as the breakout process from the hot *pp*-chains in low-metallicity stars or the ν*p*-process in type II supernovae. Recent simulations of the ν*p*-process suggest that this reaction path could considerably contribute to synthesis of CNO elements at 1.5-3 GK and finally affect the production rate of the p-nuclei around *A* = 90-100.

The 11C(α,*p*)14N reaction cross section was experimentally unknown and the Hauser-Feshbach cross section was adopted for these theoretical stellar simulations. There are some experimental data by the time-reverse reaction studies with the activation method and the Hauser-Feshbach calculations roughly explains the base-line feature of the cross section for the *p* + 14N(g.s.). However, experimental efforts were really needed since resonant contributions appear to dominate the reaction rate at temperatures of interest and the cross sections for the (α,*p*) reaction to the excited states in 14N were still not confirmed.

The first direct measurement has recently been performed by means of the thick-target inverse-kinematics method with low-energy 11C beams from the CNS Radioactive Ion Beam separator (CRIB) and a 4He gas target. The excited states of the 14N in the final channels were identified from the time-of-flight information. The experiment covered E_{CM} = 0.5-5 MeV which includes the corresponding stellar temperature range 1-3 GK.

Our present experimental results have confirmed the importance of this reaction pathway for the synthesis of the CNO elements. We will report the newly determined cross sections for each final channel as well as the reaction rate. Implication to the p-nuclei production in the vp-process will be also discussed.

The neutrino-process and light element production

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Type Ib(c) supernova is the gravitational collapse of a massive star without H (and He) layers. It propels several solar masses of material to the typical velocity of 10,000 km/s, a very small fraction of the ejecta nearly to the speed of light. We investigate SNe Ic as production sites for the light elements Li, Be, and B, via the neutrino process and spallations. As massive stars collapse, neutrinos are emitted in large numbers from the central remnants. Some of the neutrinos interact with nuclei in the exploding materials and mainly 7Li and 11B are produced. Subsequently, the ejected material with very high energy impinge on the interstellar/circumstellar matter and spallate into light elements. The contributions of SNe Ic to the Galactic chemical evolution and the observed abundances of the light elements on some halo stars are discussed.

Observational Tests of Neutrino Nucleosynthesis in Supernovae : Li and B in the IC443 SNR

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Here we present an observational test of the neutrino nucleosynthesis process in supernovae from observations of the ground-state radio-frequency hfs-transitions of B I and Li I at 732 MHz and 803 MHz. We used the 300 m Arecibo telescope to study the shocked molecular cloud associated with the IC443 in November 2009 and determined the Li/H and B/H ratios. The neutrino process predicts that a significant fraction of interstellar Li and B comes from neutrino-induced spallation reactions in He and C shells of SN and that the localized abundances are of Li and B can be enhanced by 100 to 10,000 times respectively compared to their Pop I ISM abundances to Li/H ~ 2x10(-7) and B/H ~ 10(-6) (Woosley, & Weaver, and Thomas; 1995, APJS, 101, 181; Timmes, Woosley, Weaver, & Thomas, 1995, APJS, 98, 617).

The molecular cloud associated with the IC 443 supernova remnant is an excellent target to test supernova nucleosynthesis models. The progenitor was a massive star resulting in a Type II supernova. Associated with this SNR are shocked molecular clouds indicating that the supernova shockwave and the metal-rich ejected material penetrated this cloud. MMM-Newton, Chandra, and Spitzer observations show that the SN ejecta interact with the molecular cloud indicating that the molecular cloud should have increased Li and B abundances (Bykov et.al. 2008, ApJ, 676, 1050).

The neutrino nucleosynthesis process has also been predicted to be a major source of fluorine in the Galaxy. In future radio, X-ray, and IR observations of F in SNRs we will also test the neutrino process. These observations will help determine the origin and nucleosynthesis of Li and B.

p-process nucleosynthesis coupled to multidimensional SNIa models

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Among the nuclei heavier than Fe, there is a class of about 35 neutron-deficient nuclei called p-nuclei between 74Se and 196Hg. They are bypassed by the s and r neutron capture processes, and are typically 10-1000 times less abundant than the corresponding s- and/or r-isotopes in the solar system.
The bulk of p isotopes is created in the 'gamma processes' by sequences of photodisintegrations and beta decays in explosive conditions in both core collapse supernovae (SNII) and in Type Ia SNe (SNIa). SNII contribute to the production of p-nuclei through explosive neon and oxygen burning. However, the major problem in SNII ejecta is a general underproduction of the light p-nuclei, for A < 120. We explore the SNIa as p-process sources in the framework of two-dimensional SNIa delayed detonation models calculated at MPA Munich, using enhanced s-seed distributions as directly obtained from a sequence of thermal pulse instabilities in the He shell in the precursor WD.

We apply the tracer-particle method to reconstruct the nucleosynthesis by the thermal histories of Lagrangian particles, passively advected in the hydrodynamic calculations. For each particle we follow the explosive nucleosynthesis with a detailed nuclear reaction network for all isotopes up to 209Bi.
The SNIa WD precursor is assumed to have reached the Chandrasekhar mass limit in a binary system by mass accretion from a giant/main sequence companion.

The s-enrichment occurs both during the Thermal Pulse AGB phase of the more massive companion and, much more importantly, during recurrent thermal pulses taking place during the mass accretion phase. Nevertheless the general difficulty of following with full evolutionary codes these peculiar conditions, we followed some general realistic prescriptions discussed by Iben 1981.

We select tracers within the typical temperature range for p-process production, 1.5 - 3.7 10^9K, and analyse in detail their behaviour, exploring the influence of different s-process distributions on the p-process nucleosynthesis. In addition, we discuss the sensitivity of p-process production to parameters of the explosion mechanism, taking into account the consequences on Fe and alpha elements. We find that SNIa produce a large amount of p-nuclei, both the light p-nuclei below A=120 and the heavy-p nuclei at a quite flat average production factors.

For the first time, the very abundant Ru and Mo p-isotopes are reproduced at the same level than the heavy p-nuclei. The production factor of the neutron magic Mo92, the p-isotope with the largest cosmic abundance, is short by less than a factor of five.

Finally, we investigate the metallicity effect on p-process production in our models. Starting with s-process distribution at different metallicities, running SNIa two-dimensional models with different initial composition, and applying a galactic chemical evolution model, we give estimates of SNIa contribution to the solar p-process composition.

Type Ia supernovae-Observations and Theory

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There is a wide consensus that Type Ia supernovae are the outcome of the thermonuclear explosion of a carbon-oxygen white dwarf in a binary system. Nevertheless, the nature of the binary system, the process of ignition itself and the development of the explosion continues to be a mystery despite the important improvements that both, theory and observations, have experienced the last years. Furthermore, the discovery a new events that are challenging the classical scenario forces the exploration of new issues or, at least, to reconsider scenarios that were rejected at a given moment. In this review I present the state of the art of the topic as well as the recent advances and the problems still remaining.

Multi-dimensional models of Type Ia supernovae

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Type Ia supernovae (SNe Ia) exhibit a significant diversity in their observables suggesting that a variety of progenitor channels and/or explosion mechanisms contributes to this class of objects. Understanding the origin of the diversity is essential for applying SNe Ia as distance indicators in cosmology and for studying their role in cosmic nucleosynthesis.

Multi-dimensional simulations of SN Ia explosions allow for a consistent treatment of the underlying physical mechanisms. Consequently, their predictive power enables a direct comparison with observations and, this way, the validity of different explosion scenarios can be assessed.

Based on a comprehensive sequence of modeling taking into account aspects of population synthesis, multi-dimensional hydrodynamic explosion simulations, nucleosynthetic postprocessing and radiative transfer calculations, I will discuss the capability of different explosion scenarios to reproduce SN Ia observations. Although traditional Chandrasekhar mass models are promising candidates for explaining "normal" SNe Ia, their progenitors may not be numerous enough to account for their rate. Sub-Chandrasekhar mass explosions of white dwarfs provide a potential alternative. The observables predicted for violent mergers of two white dwarfs, however, resemble a class of sub-luminous SNe Ia rather than the bulk of normal events.

An accurate modeling the nucleosynthesis in SN Ia explosions is found to be critical not only for drawing conclusions on their impact on galactic chemical evolution, but also for the predicted observables.

Multi-dimensional Models of Convection Preceding Type Ia Supernovae

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The standard model for a Type Ia supernovae is the thermonuclear explosion of a white dwarf growing toward the Chandrasekhar mass. For centuries before the ultimate explosion, carbon fusion reactions drive convection throughout most of the interior of the white dwarf. Plumes heated from the reactions buoyantly rise and cool via expansion. Eventually, as the temperature continues to increase, the reactions can no longer be quenched via expansion and a burning front is born. This subsequently burns through the white dwarf. Understanding the details of the convection is critical to determining how and where the first burning fronts form. We use the low Mach number code, Maestro, to model the final hours of convection throughout the full star. We will discuss the details of the convective field and the first hotspots to form and explore the effects of rotation.

Nucleosynthesis in surface detonation models of Type Ia supernova

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Type Ia supernovae (SNe Ia) are commonly believed to be the thermonuclear incineration of accreting carbon oxygen (C/O) white dwarfs. Observational evidence suggests that if a white dwarf explodes in a SN Ia some sort of detonation must take place. Several scenarios have been proposed as to how this detonation may actually occur, but the exact mechanism remains elusive. Using the FLASH code we have performed simulations, in two dimensions, of surface detonations in white dwarfs. Detailed yields, resulting from the explosive burning of the C/O plasma in these models, are examined using post-processing of tracer particles through a 532-nuclide reaction network. The reaction network includes strong as well as weak interactions. Results indicate that since the detonation is initiated at a point on the surface, there is a gradient in the thermal expansion timescale with polar angle. This leads to differential abundances across the explosion of, e.g., elemental Ni in the regions that did not proceed to a nuclear satistical equilibrium (NSE) composition. Observations of remnants could potentially test for such gradients.

Experiments on reaction rates for the p-process

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An overview will be given on reaction rates relevant to the astrophysical p-process responsible for the production of the heavy proton rich nuclei known as p-nuclei.

The nuclear physics input of the standard p-process scenario (gamma-process) involves the knowledge of photo induced reaction cross sections, mostly calculated within the Hauser-Feshbach statistical model [1,2].

Experimentally determined radiative capture cross section data can test the reliability of the model calculations
in the proton rich region as well as provide experimental information directly relevant
to the p-process. Recent advances involving also the study of (p,n) reactions underline the importance of the stellar enhancement factor and call for a modified optical parameter set [3,4].
In addition, complementary low energy elastic alpha scattering experiments can serve as a tool to determine alpha optical potentials, an important and relatively poorly known ingredient of statistical model calculations.

ATOMKI has a long range program, supported by the European Research Council, to study reactions relevant to p-process using
low energy accelerators. A full description of the scientific program, its advances and limitations will be provided.

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Proton capture reaction cross section measurements on 162Er for the astrophysical γ-process

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The measurements of the reaction cross sections relevant to the astrophysical γ-process is crucial to test the theoretical reaction rates with experimental data. For this study, it is also aimed to extend the experimental data on higher mass region; 162Er is the heaviest p-nuclide measured by activation method so far. The total cross sections for the 162Er(p,γ)163Tm and 162Er(p,n)162Tm reactions have been measured by the activation method in the effective center-of-mass energies 3.995 MeV ≤ E_{cm}eff ≤ 8.997 MeV and 5.996 MeV ≤ E_{cm}eff ≤ 8.997 MeV, respectively. It is important to note that the energy range for the (p,γ) reaction measurement covers a large fraction of the astrophysically relevant energy window (3.0151 MeV ≤ E_G ≤ 5.428 MeV). Moreover, the stellar enhancement factor is small at γ-process energies and therefore the astrophysical (p,γ) reaction rate can be directly inferred from the data. The targets were prepared by evaporation of 28.2 % isotopically enriched $162Er_2O_3$ powder on Carbon backing foils, and bombarded with proton beams provided by the FN Tandem Accelerator at the University of Notre Dame. The reaction yields have been determined by the observed activity of produced radioactive isotopes, which was detected off-line by a HPGe detector. The preliminary results are presented and compared with the predictions of two statistical model calculations; NON-SMOKER and TALYS.

Extended energy density functionals and ground-state correlations in nuclei

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Reliable predictions of nuclear properties in exotic nuclei, with controlled theoretical errors, are essential for modelling many stellar processes. In medium heavy and heavy nuclei, the only available approach, able to provide global information on ground-state properties, is based on the one-body degrees of freedom, which in modern formulation takes the form of the energy density functional (EDF) theory. Over the years, methods based on such ideas have proved to be extremely efficient, however, the present-day status thereof is far from being complete. Two elements of the approach are currently intensely studied, namely, construction of schemes that would allow for systematic improvements of the precision and determination of theoretical errors and variances.

In Ref. [1], it was proposed to shift attention and focus of the EDF methods from ground-state bulk properties (e.g. total nuclear masses) to single-particle (s.p.) properties, and to look for a spectroscopic-quality EDFs that would correctly describe nuclear shell structure. Proper positions of s.p. levels are instrumental for good description of deformation, pairing, particle-core coupling, and rotational effects, and many other phenomena. Up to now, methods based on using EDFs, in any of its variants like local Skyrme, non-local Gogny, or relativistic-mean-field [2] approach, were mostly using adjustments to bulk nuclear properties. As a result, shell properties were described poorly. After so many years of investigations, a further increase in precision and predictability of all methods based on the EDFs may require extensions beyond forms currently in use [3,4]. Before this can be fully achieved, it was proposed to first take care of the s.p. properties, and come back to precise adjustment of bulk properties once these extensions are implemented.

Within the standard 12-parameter form of the Skyrme functional [2], an improvement of spectroscopic properties cannot be obtained [3], and extensions of this form seem to be mandatory. One possible way could be the inclusion of density dependence into all the 12 coupling constant of the standard functional [5]. Another one, which was recently proposed in Ref. [4], aims at including gradient corrections up to next-to-next-to-next-to-leading order (N3LO -- sixth order). I this talk I describe recent progress and new ideas emerging in the EDF approaches, including the attempts of microscopic derivations from first principles.

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In collaboration with: B.G. Carlsson, M. Kortelainen, N. Michel, A. Pastore, F. Raimondi, J. Toivanen, P. Toivanen, and P. Veselý

Mass and lifetime measurements of stored exotic nuclei

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SIS-FRS-ESR at GSI and CSRm-RIBLL2-CSRe at IMP are the two facilities worldwide for experimental studies of stored, highly-charged exotic nuclei. There, the experiments focus on measurements of the ground state properties such as binding energies and beta-lifetimes which are indispensable quantities for calculations of nucleosynthesis processes. Particularly, the information on masses and half-lives of nuclei involved in the r-process is still very scarse.

Broad-band Schottky (SMS) and Isochronous (IMS) mass spectrometry are extremely powerful methods for simultaneous measurements of big numbers of nuclear masses in one experiment. The former method is applied to electron-cooled beams and can therefore address nuclides with half-lives longer than about one second. The shortest lifetimes that can be measured with the second method are in the few-ten microseconds range. Both methods are extremely efficient and are sensitive to single stored ions. Large-scale explorations of the nuclear mass-surface have been done in the last years providing a vast information on nuclear structure properties, such as the limits of nuclear existence, nucleon separation energies, nucleon-nucleon interactions, etc. Several new long-lived isomeric states and new neutron-rich isotopes have been discovered.

Radioactive decays of highly-charged ions are addressed with time-resolved Schottky mass spectrometry. In a decay, the mass of the ion changes, which is manifested by a sudden change of the revolution frequency. Stellar nucleosynthesis is the field where the beta decay of highly-charged ions has an immediate and obvious impact due to the high mean atomic charge state in stellar plasmas.

Experimental results on masses and lifetimes of exotic nuclei will be reported. Plans for future experiments including the prospects with the future project FAIR, which contains a new large-acceptance in-flight separator Super-FRS coupled to a new storage ring complex, will be outlined.

r-Process-Enhanced Metal-Poor Stars

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In this review we summarize the current state of observational studies of low metallicity stars that have been enriched with products of rapid-neutron-capture nucleosynthesis events. Attention will be drawn to the element domains where there is little star-to-star variation in relative abundances (such as the rare earths), and those with substantial variations (the lightest neutron-capture elements and the very heavy radioactive elements Th and U). We will highlight some new work on rarely-discussed elements that can be made in the r-process. Suggestions for future observational work will be given.

High-precision mass measurements at ISOLTRAP for nucleosynthesis studies

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The nuclear binding energy, derived from the atomic mass, defines the amount of energy available for nuclear reactions and decays. Therefore, it provides a valuable input into the models of the nucleosynthesis at different proposed stellar sites.

The ISOLTRAP Penning trap mass spectrometer [1] at ISOLDE/CERN has allowed to measure the masses of over 400 unstable nuclides with relative precision reaching 10-8, many of them relevant for r- and rp-processes (for a recent compilation, see [2]). In this contribution we update the results and discuss their implications for different r- and rp-nucleosynthesis scenarios.

More specifically, the r-process was addressed at ISOLTRAP with the study of Zn isotopes up to 81Zn [3]. The mass measurements confirmed the robustness of the $N = 50$ shell closure for $Z = 30$ and allowed a precise mapping of the astrophysical conditions required for 80Zn and its associated abundance signatures to occur in r-process models. The studies of 131-134Sn showed a 0.5-MeV deviation of the binding energy of the r-process waiting point nucleus, 134Sn, from the literature value [4]. This restored the neutron-shell gap at $N = 82$, previously considered to be a case of shell quenching and has considerable impact on fission recycling during the r-process. Below the Sn chain, the studies were extended to 114-124Ag and 122,124,-126,128Cd [5].

On the neutron-deficient side, relevant for the rp-process, the masses of 70-73Se, 72-75Br, 98-101,103Ag were analysed [6]. Based on a more recent run, 72Kr [7] turned out to be a strong waiting point in the rp-process. The latest measurements on 99-109Cd [8] allowed the first direct mass measurement of 99Cd which reduced the uncertainty of the abundance and overproduction created by the rp-process.

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New N-Capture Element Abundance Determinations in an r-Process Enriched Star

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We report on new abundance determinations for
the neutron-capture elements Cd I (Z=48), Lu II (Z = 71) and Os II (Z = 76) in the r-process enriched star BD + 17 3248. These abundances are derived
from an ultraviolet spectrum obtained with the Space
Telescope Imaging Spectrograph on the Hubble Space Telescope. These are the first detections of these elements in metal-poor r-process enriched
halo stars. In addition to the HST observations we have obtained new abundance measurements of the elements Mo I, Ru I and Rh I, based upon High Resolution Echelle Spectrograph observations with Keck. Combining these and previous observations, we have now detected 32 n-capture elements in BD +17 3248 - this is the most of any metal-poor halo star to date.
The lighter n-capture elements (38 <= Z <= 48) appear to show a pronounced odd-even effect.
New Hf I abundances from transitions in the UV were also derived and they were lower than previous values based upon optical transitions. The new Hf abundance agrees better with the scaled Solar system r-process distribution.
We also derive an age for this star based upon the Th II/Os II chronometer, which is in better agreement with the age derived from other chronometers than the age derived using Th II/Os I.

HST-STIS abundances in the uranium-rich metal-poor star CS31082-001

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The near-ultraviolet region presents a large number of lines of the heavy elements, and in the case of some elements such as Pt, Au, detectable lines are not available elsewhere. CS~31082-001 shows neutron-capture elements exhibiting similar enhancements to the previously known ``r-process star'' CS~22892-052, also observed with HST/STIS. Since CS~31082-001 is not carbon- and nitrogen-enriched, it allows a more reliable determination of its elemental abundances due to the reduced blending from molecular species, enabling measurement of previously undetectable weak features. The extreme ``r-process star'' CS~31082-001 ([Fe/H] $ ~-2.9$) was observed in the near-UV in order to determine its abundances of the heaviest stable elements, from absorption lines that are only reachable in the near UV, using STIS on board HST.

We will report abundance derivation of heavy r-elements
from a series of available lines, and point out the difficulties.
These abundances may provide a better undertanding
of the r-process, and the determination of several reference r-elements should allow a better determination of the star's age.

Enrichment of heavy elements in the Sextans dwarf Spheroidal Galaxy

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The r-process is the dominant source of heavy elements in the early Galaxy, which is investigated by the chemical compositions of extremely metal-poor (EMP) stars. This is interpreted as the result of short time-scale of r-process events compared to the enrichment of s-process elements by evolved intermediate-mass stars (AGB stars), although the astrophysical site of the r-process is still not well understood.
Such a scenario of heavy element enrichment is examined by the measurements of heavy elements in dwarf galaxies around the Milky Way for which individual stars can be studied based on high resolution spectroscopy.

We determined chemical abundances of extremely metal-poor stars for Sextans and Ursa Minor dwarf galaxies (Aoki et al. 2009, A&A 502, 569, Sadakane et al. in preparation). The heavy element Ba is deficient in these galaxies in general, as found in most of the Milky Way field EMP stars. Ba is significantly underabundant even at slightly higher metallicity ([Fe/H]~-2.5) in Ursa Minor, suggesting delay of contributions of r-process in this galaxy.

For Sextans, we identified two objects that show exceptionally high Ba abundances. One of them (with [Fe/H]~-3) has [Ba/Fe]~+0.5 , which is as high as the r-process enhanced stars in the Milky Way (so-called r-II stars). We recently conducted high resolution spectroscopy for this object to determine the origin of the heavy elements in this object. The result is reported in the conference. The preliminary result suggests that the Ba of this object is not fully explained by the r-process, but s-process at least partially contributed to the enrichment of heavy elements.

The r-process -- the theoretical/astrophysical side

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Astrophysical origin of the r-process nuclei is still unknown. All the existing models of the supernova r-process are now facing severe difficulties. In particular, recent hydrodynamic studies show no sign of neutron-rich matter ejection in the neutrino-driven winds of core-collapse supernovae. On the other hand, a recent study of Galactic chemical evolution suggests that the mergers of double neutron stars or of a neutron star and a black hole can be the dominant source of the r-process nuclei (Ishimaru, Wanajo, Prantzos, in prep.). We discuss the possibility of r-processing in the neutrino-driven winds from the black-hole accretion disk, based on a semi-analytic, general-relativistic wind model. This condition is assumed to be realized in a merger or a hypernova, both of which are presumed to be the origins of gamma-ray bursts.

An inconvenient truth: The low r-process fraction in the metal-poor subgiant star HD 140283

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Current theory regarding heavy element nucleosynthesis in metal-poor environments states that the r-process would be dominant. Several studies have been conducted in an effort to establish observational evidence. One star in particular, HD 140283, has been the subject of debate after it appeared to be dominated by the s-process. Since then a second spectrum of the star has been reanalysed twice. Contrary to the previous analysis, both studies found the star's heavy elements to be dominated by the r-process. All investigations to this point were conducted assuming 1D LTE. When a new 3D hydrodynamical code was used, it was found that the star had an s-process dominated isotope ratio, and the controversy arose again. We provide an independent measure of the Ba isotope mixture using an extremely high quality spectrum and an extensive χ2 analysis. We have acquired a very high resolution, very high signal-to-noise spectrum of HD 140283. We exploit hyperfine splitting of the Ba II 4554 Å and 4934 Å resonance lines in an effort to constrain the isotope ratio in 1D LTE. Using the code ATLAS in conjunction with KURUCZ06 model atmospheres we analyse 93 Fe lines to determine the star's macroturbulence. With this information we construct a grid of Ba synthetic spectra and, using a χ2 code, fit these to our observed data. We set an upper limit of the rotation of HD 140283 at v sin i ≤ 3.9 km s-1 . We find that, in the framework of a 1D LTE analysis, the isotopic ratios of Ba in HD 140283 indicate f_{odd} = 0.02±0.06, a purely s-process signature. This implies that observations and analysis do not validate currently accepted theory. We speculate that a 1D code, due to simplifying assumptions, is not adequate when dealing with observations with high levels of resolution and signal-to-noise because of the turbulent motions associated with a 3D stellar atmosphere. New approaches to analysing isotopic ratios, in particular 3D hydrodynamics, need to be considered when dealing with the levels of detail required to properly determine them. However current 3D results exacerbate the disagreement between theory and observation.

Co-Production of Light and Heavy p-, s- and r-Process Isotopes in the High-Entropy Wind of Core-Collapse Supernovae

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The nucleosynthesis origin of the stable isotopes of the light trans-Fe elements in the Solar System (SS), historically believed to be composed of different fractions of the "p-process", the "weak s-process" and the "weak r-process", has been a fascinating subject for nuclear astrophysicists since more than 50 years. Recent observations of elemental abundances in ultra-metal-poor halo stars, as well as anomalous isotopic patterns in type X SiC grains have revived and intensified this interest, and have led to various nucleosynthesis studies with increasing realism. However, even the most recent models have major shortcomings the one or other way. In particular, still none of the presently favored astrophysical scenarios seems to produce sufficiently high
abundances of the "light" p-nuclei of Sr (Z=38) to Pd (Z=46), and all models fail to reproduce the SS abundance ratio of the two most abundant p-isotopes ^{92}Mo and ^{94}Mo. \\
Therefore, we have performed large-scale dynamical network calculations within the high-entropy wind (HEW) of core-collapse type II supernovae (SN II) in order to constrain the astrophysical conditions for the nucleosynthesis of the light trans-Fe elements between Zn (Z=30) and Cd (Z=48).
We find that for electron fractions in the range 0.450 $\le$Y$_e$$\le$0.495, only minor amounts of Zn to Rb but high abundances of the classical p-,s- and r-process nuclei of Sr to Pd are co-produced at low entropies (S) after normal and neutron-rich α-freezeout. No initial abundances of p-, s- or r-process seeds need to be invoked, as in some other models. In the HEW scenario, all nucleosynthesis components are primary, rather than secondary. Taking the isotope chain of the seven stable Mo nuclides (from p-only ^{92}Mo, via s-only ^{96}Mo up to r-only ^{100}Mo) as a particularly interesting example, we show that HEW trajectories with moderate electron fractions of Y$_e$$\simeq$0.46 and low entropies of S$\le$50 are able to reproduce the SS ratio of Y(^{92}Mo)/(^{94}Mo)=1.60. Furthermore, for slightly higher Y$_e$$\simeq$0.38 and S$\le$80 trajectories, our nucleosynthesis results can explain the anomalous
abundances of ^{92}Mo to ^{100}Mo recently discovered in type X SiC grains as possible SN condensates.

Explosive nucleosynthesis: nuclear physics impact using neutrino-driven wind simulations

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The specific mechanism and astrophysical site for the production of half of the heavy elements, the so-called r-nuclei, remains to be found. We address this problem with improvements along two main fronts: the astrophysical environment and the nucleosynthesis network that includes different nuclear physics input for nuclei far from stability. Observational data indicate that there are at least two components. The heavy r-process nuclei (A>130) are produced by rapid neutron capture in a yet unknown site. The other component corresponds to the "lighter heavy nuclei" or weak r-process and is probably produced in neutrino-driven winds.

Our nucleosynthesis studies are based on trajectories of hydrodynamical simulations for core-collapse supernovae and their subsequent neutrino-driven winds. We show that weak r-process elements can be produced in neutrino-driven winds and we relate their abundances to the neutrino emission from the nascent neutron star. Although the conditions found in these simulations are not suitable for the production of r-process elements heavier than A~130, this can be solved by artificially increasing the wind entropy. In this way one can mimic the general behavior of an ejecta where the r-process occurs. In this way one can study the impact of the nuclear physics input and of the long-time dynamical evolution on the final abundances. We show that different nuclear mass models lead to significant variations in the abundances. We show how this differences can be linked to the behavior of nuclear masses far from stability. In addition, we have analyzed in detail the effect of neutron capture and beta-delayed neutron emission when matter moves back to stability. In all our studied cases, freeze out effects are larger than previously estimated and produce substantial changes in the post freeze out abundances.

The anatomy of the simplest Duflo-Zuker mass formula

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The simplest version of the Duflo-Zuker mass model (due entirely to the late Jean Duflo) is described by following step by step the published computer code. The model contains six macroscopic monopole terms leading asymptotically to a Liquid Drop form, three microscopic terms supposed to mock configuration mixing (multipole) corrections to the monopole shell effects, and one term in charge of detecting deformed nuclei and calculating their masses. A careful analysis of the model suggests a program of future developments that includes a complementary approach to masses based on an independently determined monopole Hamiltonian, a better description of deformations and specific suggestions for the treatment of three body forces.

Production and beta half-lives of heavy neutron-rich nuclei approaching the r-process path at N=126

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The astrophysical rapid-neutron capture, or r-process [1], is responsible for the synthesis of roughly half the heavy nuclei in the Universe. The structure and decay properties of the nuclei participating in this process are important because they determine the time scale at the r-process 'ladders' (N=50, 82, 126) and therefore could help to understand how, when and where this nucleosynthesis process takes places.

One of the main problems that nuclear astrophysicists have to face is the lack of information on heavy neutron-rich nuclei, most of them still unknown. During the last years promising results have been obtained investigating the properties of medium-mass neutron-rich nuclei close to the waiting point N=82 while the waiting point around N=126 remains a completely unexplored territory. Fortunately the situation is changing and recent experiments have shown the possibility to produce heavy neutron-rich nuclei by means of cold-fragmentation reactions [2].

In this work we report on several experiments performed with the FRS at GSI to produce new heavy neutron-rich nuclei and determine the beta decay half-lives of some of them close to the neutron shell N=126. These nuclei were produced by cold-fragmentation reactions induced by 238U and 208Pb projectiles at 1 A GeV impinging a Be target. The isotopic identification was achieved by determining both the atomic number and the mass-over-charge ratio of each nucleus by means of the measurements of the magnetic rigidities, time of flight and energy loss of each fragment transmitted through the FRS.

The identified nuclei were implanted on an active catcher made of four 5x5 cm2 Double-Side Silicon Strip Detectors. The position and time correlation between the implanted nuclei and the subsequent beta decay allowed us to determine their half-lives. In more recent experiments, the active catcher was surrounded by the RISING gamma-ray spectrometer.

In these experiments we were able to produce more than 70 new neutron-rich nuclei from Z=73 to Z=89 approaching the waiting point N=126 and determine their production cross sections with high accuracy. We could also determine for the first time the half-lives of several of them (204-203Pt, 202-201-200Ir, 198-199Ir, 199-200Os, 194,195,196Re). These half-lives have been compared with different model calculations, Gross Theory [3] and QRPA [4] which in general overestimate the measured half-lives. Calculations based on the fully microscopic density functional+continuum [5] provide a much better description of the data indicating that first-forbidden transitions would play a more important role in these nuclei than previously.

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Future radioactive beam facilities: RIBF, FAIR, FRIB

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The new generation of facilities for the production of radioactive ion beams in Japan (RIBF), Europe (FAIR), and the U.S. (FRIB) will enable unprecedented access to many of the short lived nuclei that play an important role in explosive nucleosynthesis. In this talk the specific features of these next generation facilities will be reviewed with an emphasis on their experimental program related to nuclear astrophysics. This includes measurements of properties for ground and resonance state as well as direct and indirect measurements of relevant reaction rates for various nucleosynthesis processes, such as the r-process, the rp-process, the p-process, as well as the neutrino-p process.

The above facilities hold the promise to provide essential nuclear physics input on short lived nuclei to constraint, together with ever more sensitive astronomical observations and more realistic astrophysical modeling, the astrophysical sites of various explosive processes responsible for the element production in the Universe.

Future Facilities for probing Stellar Reaction Processes

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The presentation will provide an overview of new projects and facilities that offer experimental opportunities for the measurement of critical nuclear reactions in stellar burning. In particular highlighted will be the development of underground facilities such as DIANA at DUSEL in South Dakota, and novel opportunities envisioned for the NIF facility at LLNL, California.

Future Surveys for Metal-Poor Stars

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I review the present status of surveys for metal-poor stars in the Galaxy. Stars with observed metallicities less than [Fe/H] = -2 are the "natural laboratory" for constraining ideas concerning the astrophysical origin of the elements, and the variety of nucleosynthesis sites associated with specific processes such as the r-process and the s-process. The progress that has
been made in the past few decades has been enormous (HK Survey, Hamburg/ESO Survey, SDSS/SEGUE, and RAVE), but it pales in comparison with what will be accomplished in the coming decade. Anticipated contributions will come from such surveys as LAMOST, the Chinese-led survey that will begin collecting spectroscopic data for
up to 5 million stars in 2011, as well as photometric metallicity surveys such as SkyMapper in Australia and LSST, and eventually Gaia, a European-led space-based mission that will provide spectroscopic/photometric information for a billion stars.

The Future of High Resolution Spectroscopy of Metal-Poor Stars

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This last decade has seen significant advancements in the high-resolution spectroscopy of metal-poor stars: higher quality data than ever before in terms of both signal-to-noise and resolution; larger numbers of stars being observed; specialized surveys to uncover the oldest, the most-metal-poor, and the stars most enhanced by name-your-favourite-nucleosynthetic-process. In the last few years alone, high resolution spectroscopy of metal-poor stars have led to insights ranging from the details of nucleosynthetic processes contributing to various isotopes to the contributions to stellar populations and galaxies from various astrophysical sites.

This talk will focus on the future prospects of high resolution spectroscopy of metal-poor stars. Useful results depend critically upon three main issues: (i) wavelength, (ii) resolution, and (iii) the amount of light detected. Not all elements can be equally well-observed in the UV, optical, and IR ranges, and there are only a handful of elements that lend themselves relatively easily to isotopic determinations. Many metal-poor stars that have been observed with the greatest scrutiny to date are "special cases". How will the next generation of telescopes, spectrographs, and surveys address these and related issues.

Screening of reaction rates in primordial nucleosynthesis

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We incorporate screening effects in standard primordial nucleosynthesis calculations. Our main finding is that screening by electrons play a negligible role for the observed abundances of the light isotopes, e.g., D, 3He, 4He and 7Li. We explore different scenarios for electron screening and the uncertainties on the abundance ratios such as the 7Li/H abundance.

Precision measurement of the photodissociation of the deuteron at energies relevant to Big Bang nucleosynthesis

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For the reaction p(n,γ)d experimental data are rare at energies relevant to Big Bang nucleosynthesis and in network calculations its reaction rate relies on theoretical models constrained by nucleon-nucleon scattering data, the capture cross section for thermal neutrons and experimental data of the inverse reaction d(γ,n)p. The latter reaction, the photodisintegration of the deuteron, is only sparsly measured at Big-Bang energies (T_{CMS} = 10 - 300 keV), too, and a comparison of the measurements with precise calculations is difficult due to large experimental uncertainties. In recent years, the reaction d(γ,n)p, especially the M1 contribution to its cross section, was studied using quasimonochromatic gamma rays from laser-compton scattering (AIST Tsukuba/Japan, HIGS Durham/USA), charge-exchange spin-flip reactions (RCNP Osaka/Japan) or electrodisintegration (S-DALINAC Darmstadt/Germany).
To address the need for precise experimental data we started to measure the differential cross section of the reaction d(γ,n)p. We used high-intensity bremsstrahlung with an endpoint energy of 4.8 MeV generated at the superconducting electron accelerator ELBE at Forschungszentrum Dresden-Rossendorf. The intensity was determined by means of nuclear resonance fluorescence where the well known transitions of 27Al at 2.2 and 3.0 MeV were detected with high-purity Germanium detectors. With a pulse length of some ps and an adjustable repetition rate, ELBE offers ideal conditions for precise time-of-flight experiments which allow to determine the neutron energy. For neutron detection we used long plastic scintillators read out on two sides by high-gain photomultipliers. With this setup we can measure neutrons between 20 keV and 1.3 MeV with an energy resolution of about 4 %. The statistical uncertainty reached so far is about 5 %, the analysis of systematic effects is ongoing.
This work is supported by DFG (JU 2705/1-1).

Evidence for a Primordial Magnetic Field in the Cosmic Microwave Background and Large Scale Structure

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Magnetic fields are everywhere in nature and they play an important role in every astronomical environment which involves the formation of plasma and currents. It is natural therefore to suppose that magnetic fields could be present in the turbulent high temperature environment of the big bang. However, to date no such field has been detected. Such a primordial magnetic field (PMF), however, could manifest itself in the cosmic microwave background (CMB) temperature and polarization anisotropies, and also in the formation of large-scale structure. In this talk we will discuss the development of a new high-precision theoretical framework in which to probe the effects of a magnetic fields on the CMB temperature and polarization anisotropies, along with the matter power spectrum. We will show preliminary evidence that the existing accumulated data on both the matter and CMB power spectra on small angular scales fixes both the upper and lower limits to the magnetic field strength and power spectral index. We find that a maximum develops in the probability distribution for a magnitude of the PMF of B = 0.85 + or - 1.25 (1 σ) nG on a comoving scale of at 1 Mpc, corresponding to upper limits of < 2.10 nG (68% CL) and < 2.98 nG (95% CL). While for the power spectral index we find $n_B = -2.37+0.88_{-0.73}$ (1σ), corresponding to upper limits of < -1.19 (68% CL) and < -0.25(95% CL). This result provides new constraints on models for magnetic field generation and the physics of the early universe. We also show that this finite magnetic field can be used to determine an independent constraint on the sum of the neutrino masses from their effect on the CMB polarization spectrum.

Studies in the Big-Bang Nucleosynthesis of Lithium

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There has been a nagging puzzle in nuclear astrophysics which is that the 6Li abundance observed in metal poor halo stars appears to exhibit a plateau as a function of metallicity similar to that for 7Li. This suggests a big bang origin for 6Li. However, because the radiative capture of a deutron by an alpha particle during the big bang is suppressed, it is difficult to explain this observed 6Li abundance. At the same time the observed 7Li abundance is below that expected from big bang nucleosynthesis (BBN). In this talk we summarize a variety of approaches which have been investigated to explain this observation. Among the possibilities are uncertainties in the astrophysics of lithium isotope detection, galactic chemical evolution, and effects from a massive charged or uncharged unstable relic supersymmetric particle present during BBN. We note that it is possible, but difficult, to obtain a simultaneous solution to both the problems of underproduction of 6Li and overproduction of 7Li in a single paradigm.

What is the chemical connection between Galactic bulge and local thick disk red giant stars?

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The formation and evolution of the Galactic bulge and its relationship
with the other Galactic populations is not very well understood.
To establish the chemical differences and similarities between
the bulge and other stellar populations, we performed an elemental abundance analysis of α- (O, Mg, Si, Ca, and Ti) and
Z-odd (Na and Al) elements of red giant stars in the bulge as well as of local thin disk, thick disk and halo giants using high-resolution spectra.

In this talk I will present our main higlights that clearly suggest that the bulge and local thick disk stars experience similar formation timescales, star formation rates and initial mass functions in contrast to other groups relying on literature values for nearby disk dwarf stars.

NLTE strontium abundances in extremely metal poor halo stars

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NLTE analysis of the SrII lines in the spectra of 35 extremely metal poor halo stars has been performed. For this we have created SrII atomic model consisting of 44 levels of SrII with n < 13 and l < 6, as well as the ground level of SrIII. The following lines of SrII have been used to derive of the strontium abundance in our program stars: resonance lines 4077 A, 4215 A, and subordinate lines 10036 A, 10327 A, 10914 A. Strontium abundance has been analyzed together with previously determined NLTE barium abundance in these stars. We show that within the interval of metallicities ([Fe/H] is from -2.2 to -4.2) the ratio [Sr/Ba] is almost independent of [Fe/H]. The mean value is around zero with scatter from about -0.5 to 0.5. One star of our sample show significant deviation from the bulk of stars. Its [Sr/Ba] ratio is 1.4. Obtained results are discussed from the evolutionary point of view.

Chromium: NLTE abundances in metal-poor stars and nucleosynthesis in the Galaxy

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Manganese Abundances as Clues to Chemical Evolution in Omega Centauri

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Omega Cen is a globular cluster which exhibits some peculiar characteristics in the nature of its chemical evolution. It is now thought to possibly be the surviving remnant of a captured galaxy. Some elements, such as copper, show a different behavior in Omega Cen when compared to Milky Way populations, with an abundance pattern that is more similar to what is observed in the Sagittarius dwarf galaxy. We present LTE Mn abundances for a sample of red giants in Omega Cen and discuss the origins of manganese from comparison with Mn/Fe abundance patterns in Milky Way globular clusters, field stars, as well as dwarf galaxies. The Mn abundances in Omega Cen suggest that low-metallicity supernovae of either Type II or Type Ia dominated the enrichment of its more metal rich populations.

On the Physical Existence of the Zeta Reticuli Moving Group: a chemical composition analysis

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Stellar Kinematic Groups (SKGs) are assemblages of stars which share approximately the same vectors of Galactic space velocity. Presumably they constitute a link between gravitationally bound systems, such as the open clusters, and the field stars, and they are supposed to share the same features of these systems, as coeval age and chemical composition. The scarcity of old kinematic groups bears witness to the processes that tear them apart, probably encounters with massive objects, such as stellar clusters, spiral arms and giant molecular clouds, in time scales of a billion years or less. Therefore, the majority of these groups must be young but some relatively old groups have already been considered as is the case of the Zeta Reticuli group. We report a detailed spectroscopic analysis of four objects of this group (with FEROS data), besides two new kinematically selected candidates (with OPD/LNA data). We derive the atmospherics parameters and chemical abundances of 12 elements of the group. The stellar effective temperatures were determined by three different methods: spectroscopy, photometry and Hα profile; with an excellent agreement between them. The spectroscopic analysis demonstrated that the sample defines a metal-poor SKG, but the observed dispersion in [Fe/H] does not seem to be entirely accommodated by errors in the analysis. According to a set of evolutionary tracks calculated for the metacility of the group, we concluded that the group may be slightly older than the Sun, with the exception of one object, HD 158614, which does not seem to belong chemically to the group. A discrepancy that remains in our analysis is the fact that the component ζ1 Ret presents a higher degree of chromospheric activity than one expects for this age. Continually, defining a kinematic and chemical core for the Group, we intend to for new kinematic candidates in the solar neighborhood.

Interstellar Constraints on the Primordial Abundance and Evolution of Lithium

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The cosmic abundance of lithium continues to represent a conundrum, as predictions from standard theories of Big Bang nucleosynthesis are inconsistent with measurements in the atmospheres of the lowest-metallicity stars. This discrepancy may be caused by astrophysical effects, such as the destruction of Li over stellar lifetimes, but no fully satisfactory astrophysical explanation has been found. Alternatively, it may also be explained by new physics in the early universe, e.g., by the early decay of particle dark matter. We are following an alternate approach to studying the cosmic Li abundance: the use of interstellar gas-phase Li in low-metallicity galaxies as a constraint on the primordial abundance and the cosmic evolution of Li. I will present our measurement of gas-phase Li in the Small Magellanic Cloud, the first such measurement beyond the Milky Way. We measure both the absolute abundance and the isotopic ratio. I will discuss the implications of our measurements and the prospects for future advances in this area.

Chemodynamical Simulation of the Milky Way Galaxy and the Galactic Archaeology

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We predict the frequency distribution of elemental abundance ratios from Carbon to Zinc as a functions of time and location, which can be directly compared with the next generation of the galactic archeology project such as the HERMES.
We simulate the chemodynamical simulations of a Milky Way-type galaxy from a CDM initial condition, using a self-consistent hydrodynamical code with supernova feedback and chemical enrichment. In the simulated galaxy, the kinematical and chemical properties of bulge, disk, and halo are consistent with the observations.

The bulge have formed from the assembly of subgalaxies at z>3, and have higher [$¥alpha$/Fe] ratios because of the lack of contribution of Type Ia Supernovae. The disk have formed with a constant star formation over 13 Gyr, and shows a decreasing trend of [$¥alpha$/Fe] and increasing trends of [(Na,Al,Cu,Mn)/Fe]. However, the thick disk stars tend to have higher [$¥alpha$/Fe] and lower [Mn/Fe] than thin disk stars. $60¥% of the thick disk stars have formed in the satellite galaxies before they accrete on the disk in this CDM-based simulation.

NLTE barium abundance in thin and thick disks of the Galaxy

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We present the determinations of the barium abundance taking into account the non-LTE (NLTE) effects in 173 dwarf stars belonging to the thin and thick disks.
The NLTE profiles of the unblended Ba II lines (4554, 5853, 6496 A) have been computed and compared to the observed profiles. The line 6141 A was also used, but taking into account an influence of iron line. We used a modified version of the MULTI code and atomic model of Ba atom with 31 levels of Ba I, 101 levels of Ba II. Atmosphere models of investigated stars have been calculated by means the ATLAS9 code (modified using the New Opacity distribution functions by Castelli & Kurucz 2003). The obtained trend in the Ba abundance vs. [Fe/H] suggests a complex process of the Ba production in the thin and thick disks.

Origin and Evolution of Structure and Nucleosynthesis for Galaxies in the Local Group

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Our Milky way galaxy did not form in isolation, but is the product of a complex evolution of generations of merges, collapse, star formation, supernova and collisional heating, radiative and collisional cooling, and ejected nucleosynthesis. Moreover, all of this occurs in the context of the cosmic expansion, the formation of cosmic filaments, dark-matter haloes, spiral density waves, and emerging dark energy. This talk will review recent attempts to reconstruct this complex evolution in a modified version of the Smoothed-Particle hydrodynamics code GADGET-2 in which a sample large-scale structure simulations have been scanned to identify local-group-like poor clusters. Detailed nucleosynthesis in supernovae and stars along with matter heating and cooling have been added to the simulations in an attempt to reconstruct the evolution of stars, gas and elements among the various components of the local group. We will summarize comparisons with stellar surveys and highlight the role which early stellar evolution and nucleosynthesis play in shaping of our local galactic cluster.

Analysis of neutron capture elements in thin and thick disks of the Galaxy

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We have performed n-capture element's abundance analysis for 174 of FGK dwarfs in range -1 < [Fe/H] < +0.3. The studied stars were observed at high resolution, high signal to noise ratio with the ELODIE echelle spectrograph at the Observatoire de Haute-Provence. Stellar parameters and selection of stars belonging to the Galactic thin - thick-disc components were presented in our previous study (Mishenina et al. 2004). Effective temperatures were estimated by the line depth ratio method and from the H_alpha line-wing fitting. Surface gravities log g were determined by two methods : parallaxes and ionization balance of iron. Spatial velocities and orbits have been computed.
Abundances of Y, Zr, La, Ce, Nd , Sm and Eu have been obtained under LTE approximations, The synthetic calculations for Eu were made taking into account the hiperfine structure. The abundances for the thick-disc stars are compared with those for the thin-disc members.
The relative contributions of s- and r-procesess were evaluated and interpreted through theoretical computations of the chemical evolution of the Galaxy

Chemical and dynamical evolution of Lyman alpha emitters and Lymman break galaxies

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Although much has been elucidated on the present-day galaxies, little has been revealed on the embryonic galaxies. For instance, elliptical galaxies or bulges in disk galaxies are found, at the present epoch, to be chemically-enriched and well-evolved systems with the age higher than 10^9 years and be characterized by several key universal properties. However, it is unresolved how such galactic systems are related to distant bright objects that are recently observed in the deepest universe. To unravel the relation, we perform high-resolution hydrodynamic simulations of a galaxy, including star formation cycles and supernova (SN) explosions. We find that
an early "sparkling" phase with multitudinous SN explosions at less than
3×10^8 years exhibits intense Lyman α emission from cooling shocks and well
resembles Lyman alpha emitters (LAEs) that have been discovered at redshifts greater than 3.
Subsequently, the galaxy shifts to a stellar continuum radiation-dominated phase within 10
9 years, which appears like Lyman break galaxies (LBGs).
LBGs are high-redshift star-forming galaxies. At the LAE phase, the
abundance of heavy elements is subsolar and shows strong spatial variance,
but it convergently reaches the level of solar abundance at the LBG phase.
Hence, it turns out that LAEs and LBGs correspond to the on-going and major
phases of chemical enrichment in galaxies. The stellar dynamics after the
LBG phase is also pursued, and it is found that the galaxy eventually
reaches the area of elliptical galaxies on the fundamental plane. The
comparisons of such simulation results with the observations of elliptical
galaxies allow us to conclude that LAEs and LBGs are infants of elliptical
galaxies or bulge systems in the nearby universe

Compositional Variation of Dwarfs in the Solar Neighborhood

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We analyze published abundances for thirteen elements derived from high-resolution spectroscopy from the AAT radial velocity planet search. The sample consists of G and near-G F and K dwarfs with ages > 3Gyr in order to produce a uniform sample that approximates as well as possible the primordial stellar abundances. We find that for C, O, Na, Al, Mg, Ca, and Ti the intrinsic variation in [X/Fe] for a given [Fe/H] is large, often on the order of a factor of two around the mean (approximating 3 σ for a normal distribution). Of the measured elements below the Fe peak, only Si shows a small intrinsic variation. The sun has mildly anomalous abundances compared to the local mean, particularly for oxygen. We will discuss scenarios for enrichment of stars with extreme abundance ratio anomalies and the effects of the spread in abundances on stellar models.

Deuterium Link: From Interstellar Medium and Chemical Evolution to Cosmology and Structure Formation

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Deuterium has a special place in cosmology, nuclear astrophysics, and galactic chemical evolution, because of its unique property that it is only created in the big bang nucleosynthesis while all other processes result in its net destruction. However, a large scatter found in the interstellar medium (ISM) deuterium abundance measurements indicates that deuterium might be preferentially depleted onto dust grains, which complicates the use of deuterium as a probe of galactic chemical evolution (GCE) models. We have applied a model-independent, statistical Bayesian method and determined the true, undepleted ISM D abundance. Having found the ISM D abundance one can identify the successful GCE models, which can then be used to learn about nucleosynthesis in the ISM, but can also be placed in cosmological context to learn about the infall rates of the primordial gas to our Galaxy, which bares implications for models of galaxy formation. Here we present our results and their implications for discriminating between different GCE models, for our understanding of the nature and physics of interstellar dust grains, as well as implications for cosmological evolution.

Galactic carbon and oxygen isotopic ratios

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Despite many advances in the fields of stellar evolution and nucleosynthesis, the stellar yields of 12C, 13C, 17O and 18O are still highly uncertain. In this contribution we adopt a widely used, well-tested model for the chemical evolution of the Galaxy and study the evolution of the 12C/13C, 16O/17O and 18O/17O isotope ratios in the Milky Way. We make use of updated stellar nucleosynthesis prescriptions, as well as of older stellar yields for these elements. We demonstrate that, while some problems are overcome by now, many others still wait for a solution.

Chemical evolution of elements from C to Zn in the Galaxy with different grids of stellar yields

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Galactic chemical evolution models are useful tools to interpret the large body of high-quality observational data on the chemical composition of stars and gas in galaxies which has become available in recent years. In this contribution, we adopt a widely used model for the chemical evolution of the Galaxy and test the effects of changing the stellar nucleosynthesis prescriptions on the predicted evolution of several chemical species. Up-to-date results from stellar evolutionary models are taken into account carefully. We find that, except for a handful of elements whose nucleosynthesis in stars is well understood by now, large uncertainties still affect the model predictions. This is especially true for the majority of the iron-peak elements, but also for much more abundant species such as carbon and nitrogen. The main causes of the mismatch we find among the outputs of different models assuming different stellar yields and among model predictions and observations are: (i) the adopted location of the mass cut in models of type II supernova explosions; (ii) the adopted strength and extent of hot bottom burning in models of asymptotic giant branch stars; (iii) the neglection of the effects of rotation, magnetic fields and thermohaline mixing on the chemical composition of the stellar surfaces; (iv) the adopted rates of mass loss and (v) nuclear reaction rates and (vi) the different treatment of convection. Our results suggest that it is mandatory to include processes such as hot bottom burning in intermediate-mass stars and thermohaline mixing in low-mass stars in accurate studies of stellar evolution and nucleosynthesis. In spite of their importance, both these processes still have to be better understood and characterized. As for massive stars, presupernova models computed with mass loss and rotation are available in the literature, but they still wait for a self-consistent coupling with the results of explosive nucleosynthesis computations.

Nucleosynthesis in the Hyades Open Cluster: Evidence for the Enhanced Depletion of 12C

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The CNO bi-cycle is the dominant set of H burning reactions powering the cores of stars more massive than the Sun. The cycle results in no net loss of the CNO nuclei, but due to different lifetimes to proton capture, the relative numbers of each do change: 12C is depleted, 14N is enhanced, and 16O, if the ON cycle is active, is depleted. At the end of core H burning, stars experience the first dredge-up, and material processed by the CN and possibly ON cycles are mixed to the surface layers where the products of these core nuclear processes can be observed. Here I present the results of our observational program designed to test standard stellar evolution models and our understanding of core nuclear processes on the main sequence (MS). We have derived CNO abundances of three giants and three solar-type MS dwarfs in the Hyades open cluster and used the abundances of the dwarfs as a proxy for the initial composition of the giants. The observed N and O abundances are found to match well a stellar evolution model tailored to the Hyades giants, but the observed C abundance is a factor of 1.5 lower than the model prediction. Empirically, the observed C+N+O abundance of the giants does not equal the C+N+O abundance of the dwarfs, as is expected from the CNO bi-cycle. I describe our efforts to account for the missing 12C, including the possibility that a heretofore unknown nucleosynthetic process may be active in the cores of near-solar metallicity 2.5 M_solar stars.

APOGEE: A high resolution SDSS-III H-band survey of the Milky Way

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Standing Apart: Galactic Chemical Evolution of the Transition Elements Copper and Zinc

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We have employed the nucleosynthetic yield calculations of Chieffi & Limongi (2004) in conjunction with a selection of initial mass functions to examine the evolution of copper, zinc and the iron-peak elements as a function of metallicity. Concomitantly, we have performed an exact derivation of Cu and Zn abundances in extremely metal deficient stars. We will ascertain the relative agreement between the theoretical yield calculations and observational results. In addition, we will evaluate the yield dependence on metallicity and compare the calculations to those from Timmes et al. (1995), Kobayashi et al. (2006), and other recent investigations. As the main focus of the study is the region below [Fe/H] = -1.9, we will analyze the chemical signatures of Type II Supernova and explore the possible contributions from additional nucleosynthetic processes.

The Role of Mixing and Nucleosynthesis in Extremely Metal-Poor Stars and Implications for Chemical Enrichment of the Galaxy Using the SAGA Database

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We discuss the characteristics of known extremely metal-poor (EMP) stars in the Galaxy using the Stellar Abundances for Galactic Archaeology (SAGA) database (Suda et al. 2008, PASJ, 60, 1159). We focus on the characteristics of carbon-enhanced EMP (CEMP) stars, abundance trends of alpha, iron group, and neutron capture elements, and the evolution and nucleosynthesis in EMP stars. The following summary and conclusions are deduced from the statistics of stars in the database and the comparisons of models with observations.

(1) The analyses of carbon-enhanced stars in our sample suggest that the nucleosynthesis in AGB stars can contribute to the carbon enrichment in a different way depending on whether the metallicity is above or below [Fe/H] ~ -2.5, which is consistent with the current models of stellar evolution at low metallicity.

(2) Observed small scatters of abundances for alpha-elements and iron-group elements suggest that the chemical enrichment of our Galaxy takes place in a well-mixed interstellar medium. We find that the abundance trends of alpha-elements are highly correlated with each other, while the abundances of iron-group elements are subject to different slopes relative to the iron abundance. This implies that the supernova yields of alpha-elements are almost independent of metallicity, while those of iron-group elements have a metallicity dependence.

(3) The occurrence of the hot bottom burning in the mass range of 5 < M/Msun < 6 is consistent with the initial mass function of the Galaxy peaked at ~10Msun that is derived by our previous work, based on the statistics of CEMP stars with and without s-process element enhancement, and of nitrogen enhanced stars.

(4) For s-process elements, we discover not only the positive correlation between carbon and s-process element abundances, but the increasing slopes of the abundance ratio between s-process element and carbon with increasing mass number. This suggests that the dominant site of the s-process is unlikely by 22Ne(a, n)25Mg in the helium flash convective zones of thermally pulsating AGB stars that finally pollute the low-mass binary component with the mass transfers. However, it is difficult to explain the increasing slopes by considering radiative 13C pockets or convective neutron-capture nucleosynthesis driven by hydrogen ingestion into the helium flash convective zones.

(5) In spite of the evidence of AGB evolution in observed abundances of EMP stars, we cannot find any evidence of binary mass transfer through the effect of dilution in the convective envelope.

(6) We report the discovery of the dependence of sulphur and vanadium abundances on the effective temperatures in addition to the previously reported trends for silicon, scandium, titanium, chromium, and cobalt.

An Improved Charged-Particle Induced Thermonuclear Reaction Rate

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The reaction rate formula utilized in compilations such as NACRE uses low energy approximation. An improved formulation for calculating the nuclear reaction rate is discussed in this paper. The exact tunneling probability that is applicable for all energies is obtained by solving the Schrodinger equation. This yields an enhanced expression for the astrophysical S-factor for calculating the thermonuclear reaction rate at high temperature. The thermonuclear reaction rate from this work is applied to the 2H(p, γ)3He, 7Li(p, α)4He and 12C(p, γ)13N reactions and compare with the NACRE compilation. An additional data from LUNA has been included in the 2H(p, γ)3He reaction. This improved reaction rate can be included in the nuclear reaction network in a stellar evolution code.

` δ μ mixing' on the Red Giant Branch

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We provide a brief review of thermohaline mixing (also called` δ μ mixing') and discuss why it is a candidate extra mixing mechanism during the red giant branch (RGB). Its operation on the RGB was first discovered by Eggleton, et al, (2006) using a 3D hydrodynamical code in *Djehuty* and since then it has successfully been implemented in many stellar evolution codes. Within the literature several 1D parameterisations are suggested (Eggleton, et al 2008, Charbonnel and Zahn, 2007) and for each parameterisation so too a range of diffusion coefficients. This range in diffusion coefficients can result in the mixing velocities varying by up to two orders of magnitude. It is our aim to constrain thermohaline mixing and understand the underlying physics. We have undertaken the following studies in order to do so:

1. We use observations of carbon depletion in globular clusters to help constrain the formalism and the mixing velocity. Here we vary our diffusion coefficient and determine whether we can match the carbon depletion as a function of visual magnitude for various clusters.

2. We then turn to 3 dimensional hydrodynamical modelling of thermohaline mixing. As the mixing is a double diffusive process we expect to see the formation of 'salt fingers' we discuss whether this is the case. We also compare the predicted mixing velocity from the simulation with that found in our first study.

Possible Tsallis nonextensive corrections to Gamow peak

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The potential barrier penetration approach to stellar nuclear reactions rate is rediscussed in the framework of Tsallis nonextensive statistics. It is found that, within the extended formulation, the nonextensive q-parameter is constrained to a maximum value. Accordingly, the q-energy is shown to exhibit a minimum. An analytical expression for the q-Gamow peak is derived and, in connection with the usual Gaussian approximation, the corresponding half q-width is also estimated. Plots of the q-energy, q-Gamow peak and half q-width for some reactions with stellar physics interest are also shown.

A possible accelerator laboratory in the Dresden Felsenkeller

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The field of underground accelerator physics to study rare nuclear reaction events has greatly expanded over the last decade. Consequently, there is an increasing need to put ion accelerators in underground laboratories, making use of overlying rock to suppress cosmic-ray induced background. Recently the option has emerged to put such an accelerator in the shallow-underground facility Felsenkeller (Dresden/Germany). Owing to the relative ease of installation, such a facility could be part of a staged approach before more sophisticated deep-underground sites become available. Here we show data from a feasibility study performed with an actively shielded high-purity germanium detector. We compare spectra taken with one and the same detector at Gran Sasso, at Felsenkeller, and at the Earth's surface. The conclusion is that while the background is higher at Felsenkeller than at Gran Sasso, the difference is small enough to still allow some interesting nuclear-astrophysics studies at a possible Felsenkeller accelerator.

14N+p Elastic Scattering and the S-factor for 14N(p, γ)15O at Stellar Energies

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The 14N(p,γ)15O reaction regulates the rate of energy generation for the CN-cycle, most importantly at temperatures characteristic of stars on the main sequence and red-giant branch. Inadequate knowledge of the ground state transition at low energies remains the largest contribution to the uncertainty in the total S-factor for this reaction. Until now, 14N+p radiative capture data were analyzed using a single-channel phenomenological R-matrix formalism. These analyses have always indicated that the radiative width of the 3/2+ bound state in 15O has a dominant role in setting the zero-energy S-factor for the ground state transition, $S(0)_{gs}$. We have conducted a new 14N(p,p) cross section measurement and subsequently performed the first multichannel global R-matrix analysis of the ground state transition by incorporating the new scattering data. The result further constrains the extrapolated value for $S(0)_{gs}$ and implies, contrary to long-held understanding derived from simpler reaction models, that the 3/2+ bound state plays a much more limited role in the 14N(p, γ)15O reaction mechanism at stellar energies than previously thought. The upturn seen in the low-energy ground state transition S-factor is produced more by the combined effects of very broad resonances at higher excitation energy than by the radiative width of the 3/2+ state.

LUNA: The 15N(p, γ)16O reaction study at low energies with a BGO detector

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The 15N(p, γ)16O reaction links the first CNO cycle to the second one. It determines the abundances of the oxygen isotopes 16O, 17O and 18O. This reaction is important in nova explosions where it is related to the production of 16O.
Previous experiments were performed by Hebbard in 1960 and by Rolfs and Rodney in 1974 to study this reaction. The two extrapolated S-factors are in disagreement by more than a factor two.
In the Gran Sasso LUNA facility, the 15N(p, γ)16O has been measured down to the energies of the Gamow peak in nova and AGB stars using two different setups characterized by a solid and a gas target, respectively.
In both the two setups a 4 π -BGO detector was used.
The results cover a range of energy in the center of mass from 380 keV down to 70 keV covering the resonance at 312 keV and reaching energies lower than in the previous direct experiments.
In this contribution the results of the two LUNA experiments will be reviewed and the obtained data will be discussed.

Angular Distributions of Alpha Particles in Breakup Reactions

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The breakup reaction channel is one of the most important mechanisms of the radioactive weakly bound nuclei. In the field of nuclear astrophysics, light radioactive ions, such as 6He, 7Be and 8Li, may constitute an alternative path to the triple-alpha process for the formation of 12C. In the last years a great interest on these nuclei have arisen due to the development of experimental facilities capable of producing them. However, the extremely low beam currents achievable make the systematic study of their properties very difficult. Alternatively, these properties might be studied using weakly bound but stable nuclei, like 6Li, 7Li and 9Be, which can be produced with normal rates in conventional accelerators.

In this work, we performed measurements of angular distributions of alpha particles in the 7Li + 27Al system to determine the contribution of each type of reaction. Particularly, with the weakly-bound nucleus 7Li there are at least three exit channels involving alpha particles, namely: transference, fusion-evaporation and breakup. To discriminate each process it is necessary to determine energy, scattering angle, and atomic number of the reaction products. For this purpose, we designed, constructed and characterized a detector-system that consists in an ionization chamber with two anodes plus three position sensitive silicon-detectors (PSD). The ionization chamber gives two partial energy-loss signals; meanwhile the three PSDs (covering a 30º range) provide remnant-energy and angle information. This experiment was carried out at the TANDAR Laboratory using a 20 UD tandem accelerator. We obtained angular distributions between 25 and 175 degrees with energies in the 5 - 12 MeV range.

Data analysis is still ongoing, but we mean to join together existing data of the same nuclear system to formulate an integral theoretical description of the reaction channels involving weakly bound 7Li nucleus. We are also planning to do identical measurements in the 6Li + 27Al and 6,7Li + 144Sm systems.

AGB and RGB nucleosynthesis: the influence of new, high-accuracy measurements of the 18O(p,alpha)15N and 17O(p,alpha)14N low-energy resonances

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The 18O(p,alpha)15N and 17O(p,alpha)14N reactions are of primary importance in the nucleosynthesis inside Asymptotic Giant Branch and Red Giant Branch stars [1]. They are key processes to understand oxygen and nitrogen isotopic ratios in meteorite grains [2], to model exotic systems such as R-Coronae Borealis stars [3] and novae [4], respectively. Thus, the measurement of their cross sections in the low energy region is crucial to reduce the nuclear uncertainty on theoretical predictions, because the resonance parameters are poorly determined [5]. The Trojan Horse Method [6,7,8,9], in its newly developed form particularly suited to investigate low energy resonances [8], has been applied to the 2H(18O,alpha 15N)n and the 2H(17O,alpha 14N)n reactions to deduce the 18O(p,alpha)15N and 17O(p,alpha)14N cross sections at low energies. In particular, the 20 keV resonance in the 18O(p,alpha)15N and the 65 keV resonance in the 17O(p,alpha)14N reactions have been investigated [8,9,10]. At such energies, either a direct measurement is impossible, as in the case of the 20 keV resonance in 18O(p,alpha)15N; or electron screening prevents access to the bare nucleus cross section, as in the case of the 65 keV resonance in 17O(p,alpha)14N). From the deduced high-precision bare-nucleus resonance strengths (up to a factor 8.5 more accurate) the rates for the 18O(p,alpha)15N and the 17O(p,alpha)14N reactions have been calculated. Possible consequences for astrophysics are discussed [11].

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The St. George recoil separator at the university of Notre Dame, a status update

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The St. George recoil separator is designed specifically to study Helium radiative capture of astrophysical interest with stable beams. Its design characteristics are an angular acceptance of ±40 mrad, ±7.5% in energy and a mass resolving power M/ΔM=100. The manufacturing is in its final stage. The difficult higher order correction embedded in the pole edges of the dipole magnets delayed significantly the delivery of the system. It is expected that at the time of the symposium, the magnet will be delivered and in their installation phase. The status of the project will be presented as well as the experimental program.

Study of the β -delayed particle emission of 17Ne

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The 12C/16O abundance ratio at the end of the helium burning phase of stellar evolution is determined by the competition of the triple-α and the 12C(α, γ)16O reactions. The ratio of 12C and 16O is a key ingredient in the determination of the abundance pattern of heavier elements created in the subsequent evolution of massive stars [1]. While the triple-α reaction is reasonably known the direct measurement of the 12C(α,γ)16O cross section at the relevant center of mass energy (300 keV) remains challenging due to its very low cross section. The rate of this alpha capture reaction is basically dominated by a E2 component to the Jπ = 2+ 7.117 MeV state in 16O lying under the 12C+α threshold, and by a E1 component to the Jπ = 1- resonance at 9.585 MeV and the subthreshold Jπ = 1- 6.917 MeV state. Therefore, the properties of these subthreshold states, and the width in particular, affect the strength of the E1 and E2 rates. In order to constraint the extrapolation of the measurements performed at CM energies above 900 keV [2] the β-delayed α particle spectrum of 16N has been also used [3].

We have performed and experiment at ISOLDE to investigate the β-delayed proton and alpha emitter 17Ne with the aim of studying the β-delayed proton decay branches, and in particular those unstable to α decay. We have studied the β-delayed charged-particle channels using the ISOLDE Si-Ball along with a DSSSD-PAD Si telescope. Time-of-Flight and energy loss event selection were used to separate the proton and alpha channels in order to obtain branching ratios and β feeding to levels of interest. A R-Matrix fit to the data has been performed in order to reproduce the shape of the spectrum, including the interference. We have been able to determine the spin-parity and widths of most of the levels relevant to the particle emission processes from the excited states of 17F. We have estimated the β-delayed pα decay probabilities to 12C through the tails of the 7.117 and 6.917 MeV states in 16O and explored the possibility of obtaining information on the rates of the E1 and E2 components of the 12C(α,γ)16O reaction.

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A nuclear astrophysics underground accelerator facility at Canfranc

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The measurement of reaction cross-sections of stellar nuclear reactions is hindered by experimental difficulties, particularly the very small cross-section values at the Gamow peak and the comparatively high background arising from the cosmic ray interactions. At the Earth's surface the low signal to background ratio can be overcome up to a certain limit by active and passive shielding and by a suitable choice of the experimental technique. But achieving the required sensitivity at low energies for key measurements requires a further reduction of the background. Thus, measurements are being performed at underground laboratories.

The Canfranc Underground Laboratory provides an excellent site for a unique accelerator-based nuclear astrophysics facility. With a depth of 2400 meters water equivalent it offers a reduction of the neutron flux down to the level of 2 x 10-2 m-2s-1 and a reduction of the muon flux to about 3 x 10-2 m-2s-1 . Under these conditions, the CUNA collaboration is proposing to develop an experimental nuclear physics programme, with the main purpose of studying the 13C(α,n)16O and 22Ne(α,n)25Mg reactions. These reactions have been identified as the dominant stellar neutron sources for the s-process and are therefore essential for the production of half of the elements above iron by slow neutron capture in stellar environments. The presentation will give the present status in the planning of an underground accelerator facility at Canfranc.

Nucleosynthesis analysis of the Sakurai's object

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Sakurai's object (V4334 Sagittarii) is a post-AGB star that evolved through a very-late thermal pulse event (VLTP). In particular, H-rich material is ingested in the convectively unstable He burning shell on top of electron-degenerate core.
In this event, nuclear burning time scale of 12C+p is comparable with the hydrodynamic time scale of convection.
Abundances of Sukurai's Object has been observed in detail, providing a powerful tool to improve our understanding of the physics of H ingestion in He-shell flashes, and in general of convective-reactive episodes in stars.
In this work, we present detailed and highly resolved nucleosynthesis simulations for the VLTP in the Sakurai's object. In particular, we show that the observed abundances are not compatible with the mixing evolution indicated by one-dimensional stellar evolution models.
On the other hand, by using preliminary indications from hydrodynamic simulations, we are able to better reproduce most of the abundance observations.

Ab initio many-body calculations of reactions important for astrophysics

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We build a new *ab initio* many-body approach [1] capable of describing simultaneously both bound and scattering states in light nuclei, by combining the resonating-group method (RGM) [2] with the *ab initio* no-core shell model (NCSM) [3]. In this way, we complement a microscopic-cluster technique with the use of realistic interactions, and a microscopic and consistent description of the nucleon clusters, while preserving Pauli principle and translational symmetry. We will present results for neutron and proton scattering on light nuclei, including n-7Li and p-7Be. Our calculations predict low-lying resonances in 8Li and 8B that have not been experimentally observed so far. We will also discuss our progress towards the *ab initio* calculation of capture reactions important for astrophysics, in particular 7Be(p,γ)8B and 3He(α,γ)7Be. Finally, we will highlight the first results of the d-3H fusion calculation obtained within our *ab initio* NCSM/RGM approach.

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Determining the ratios of partial widths of the states in O18 using the (d,p) reaction

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For the rates of the capture reactions, the information on partial widths of states near threshold is crucial to characterize the thermonuclear reactions. Due to the small cross sections, direct measurements are often difficult. We have studied the (d,p) reaction in inverse kinematics with a O17 beam to populate the excited states above the n- and α- thresholds in O18 using ATLAS at the Argonne National Laboratory. HELIOS (HELical Orbital Spectrometer) was particularly essential for this method to obtain the good Q-value resolution necessary to separate the individual excited states, as well as to provide high coincidence efficiency for determining the specific decay modes. Experimental results for the ratios ($\Gamma_\alpha / \Gamma_\gamma$ and Γ_n / Γ_γ) will be presented and compared to the direct measurements. In addition, the new estimates of the partial widths on the 7.1 MeV resonance will be discussed in the interest of C14(α, γ) reaction.

The DIANA Underground Accelerator Facility at DUSEL Laboratory

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Non-resonant nuclear reactions induced by charged particles take place inside a star in a narrow energy window, the Gamow peak,
which lies far below the Coulomb barrier.
At such low energies, the non resonant reaction cross-section σ(E) drops down almost exponentially with decreasing energy E, because of the tunnelling probability through the Coulomb barrier.
Experimental studies of nuclear reaction of astrophysical interest are
hampered by the exponential drop of the cross-section.
The extremely low values of σ(E) within the Gamow peak prevents its measurement in a laboratory at the earth surface.
The signal to noise ratio would be too small, even with the highest beam intensities presently available from industrial accelerators, because of the cosmic ray interactions with the detectors.
An excellent solution has been proved to install an accelerator facility deep underground where the cosmic rays background into detectors is strongly suppressed.

To address several pressing problems in cosmology, astrophysics, and non-Standard-Model neutrino physics,new high precision measurements of direct-capture nuclear fusion reaction cross sections will be essential.
To address this need, a new underground accelerator facility is being designed and will allow for the measurement of essential cross sections at low, near-solar, energies.
The DIANA project (Dakota Ion Accelerators for Nuclear Astrophysics) is a collaboration between the University of Notre Dame, Colorado School of Mines, Regis University, Univerisity of North Carolina, Western Michigan University, and Lawrence Berkeley National Laboratory, to build a nuclear astrophysics accelerator facility 1.4~km below ground.
DIANA is a part of the US proposal DUSEL (Deep Underground Science and Engineering Laboratory) to establish a inter-disciplinary undeground laboratory in the former gold mine of Homestake in South Dakota, USA.
The DIANA accelerator facility is being designed to achieve large
laboratory rection rates by delivering high ion beams currents
to a high density, super-sonic jet-gas target.
The DIANA accelerator facility design will be presented, together with its science plans and goals.

The 14N(p,γ)15O reaction studied at 0.6 - 2 MeV.

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The 14N(p,γ)15O is the bottleneck reaction of the hydrogen burning CNO cycle. Although it contributes only 0.8% to energy production in our Sun, the CNO cycle is responsible for neutrino fluxes from the decay of 13N and 15O, which can be detected by underground laboratories as Borexino and SNO+. The interpretation of these data requires more precise nuclear reaction cross section data.
Recent experiments on 14N(p,γ)15O focused mainly in the region 70 < *E* < 500 keV. Only one set of data extends up to 2 MeV. However, also high energy data are important for the S-factor extrapolation towards lower energies.
The present experiment re-studied the reaction cross section in the energy region from *E* = 0.6 to 2 MeV, including the resonance at *E* = 0.987 MeV. New resonance strength and off-resonance S-factors will be presented.

Hydrostatic carbon-burning: Reaction cross section inside the Gamow window

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In the Gamow window's energy range of hydrostatic carbon burning, recently progress in both experimental data on and theoretical description of the reaction cross section has been made. Evidence for resonant structures of the carbon induced fusion reaction on carbon in this energy range has been found. Elastic scattering angular distributions measured at centre-of-mass energies from 1.6MeV to 2.5MeV in 0.1MeV energy steps will be presented, that offer the possibility to determine the total reaction cross section model-independently using the generalised optical theorem for charged identical particles. In addition, the generalised optical theorem allows for the determination of the nuclear forward scattering amplitude in both modulus and phase yielding boundary conditions on potentials describing this reaction. Comparison with the aforementioned experimental findings is made. The evidence for resonant structures in the reaction cross section and implications on carbon-burning in evolved stars is discussed.

Study of 12C(α, γ)16O reaction via the transfer reaction 12C(7Li,t)16O

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The 12C(α, γ)16O reaction plays an important role in helium burning in massive stars and their evolution. However, despite many experimental studies, the low-energy cross section of 12C(α , γ)16O still highly uncertain. The extrapolation of the measured cross sections to stellar energies (E~ 300 keV) is made particularly difficult by the presence of the two sub-threshold states at 6.92 and 7.12 MeV of 16O. In order to further investigate the contribution of these two-subthreshold resonances to the 12C(α, γ)16O cross section, we performed a new determination of the α -reduced widths via a measurement of the transfer reaction 12C(7Li,t)16O at two incident energies, 34 and 28 MeV.
The measured and calculated differential cross sections will be presented as well as the obtained spectroscopic factors and the α -reduced widths and their effect on the R-matrix calculations of 12C(α,γ)16O.

Effects of new reaction rates on p-capture nucleosynthesis in Low Mass Stars

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Evolved low and intermediate mass stars are important sites for the production of heavy nuclei (through slow n-captures) and of light and intermediate-mass isotopes (through p-captures). This was revealed by spectroscopy of evolved stars as well as by the chemical analysis of presolar grains of circumstellar origins. The observational basis for these issues has grown considerably over the years, confirming peculiar abundances of 3He, 7Li, CNO isotopes, 19F and 26Al. Many studies have been presented in the last thirty years suggesting that the above evidence can be accounted for by non-convective transport mechanisms (sometimes called deep mixing) that link the stellar envelope with the region where proton captures take place, during the red giant phases. Nucleosynthesis in deep mixing episodes is made uncertain by two series of problems. On one side one has to identify the physical mechanism for the transport (thermohaline diffusion, rotational shear, gravitational waves, magnetic buoyancy). On the other, several reaction rates adopted in the calculations are still uncertain, mainly because hydrogen burning takes place in red giants at typical Gamov-Peak energies of a few tens of keV, where experimental measurements are extremely difficult. Most results present in the literature were obtained using reaction rates from either the [1] or the [2] compilations. Here we want to discuss the effects of upgrades in the nuclear physics inputs occurred recently on p-capture nucleosynthesis during extended mixing. We show how the use of more accurate reaction rates from new experiments induces considerable differences in the results as compared to previous studies. Among the most remarkable novelties we mention a possible higher production of 26Al, changes in the 14N/15N ratio in stellar envelopes and an extremely precise account of the oxygen isotopic ratios in oxide grains, from which even the mass of the parent AGB stars can be unambiguously derived. Finally, we present an analysis of the 7Li enrichment/destruction problem in low mass red giants and we argue that in this case the nuclear physics improvements are not sufficient to explain the complex phenomenology, which is instead accounted for by different velocity profiles in the mixing, because of the competition between the fast 7Be-decay and the speed of the mass transport. As a consequence, the 7Li abundance becomes a strong constraint on the physical details of the mixing mechanisms. We also show that deep mixing as implemented by the buoyancy of magnetic instabilities is the most promising model both for producing and for destroying 7Li, as it allows for both fast and slow transport during red giant phases.

Angular Distribution Anisotropy of the $E_{c.m.}$=2.68-MeV Resonance in the 12C(α,γ)16O Reaction and Its Astrophysical Impact

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The 12C(α,γ)16O reaction, in combination with the triple-α process, determines the 12C/16O fraction at the end of hydrostatic helium burning in red giant stars. This fraction affects the subsequent evolution and nucleosynthesis in those stars and, due to imprecise knowledge of the 12C(α,γ)16O reaction rate, is a large uncertainty in stellar models. Much of the uncertainty lies in the ground state *E2* cross section, which is estimated at 30−60% of the total capture cross section at astrophysical energies $E_0 \approx 0.3$ MeV. A prominent feature in the measured *E2* cross section is the narrow resonance at $E_{c.m}$=2.68 MeV. The resonance affects the *E2* cross section over much of the energy domain accessed by previous experiments $2< E_{c.m.}<3$ MeV. How the resonance affects the *E2* cross section depends in part on the relative sign of its amplitude with the other *E2* amplitudes. The relative sign is not well determined by existing capture data and has a non-negligible effect upon the extrapolation of the *E2* cross section. To determine the interference sign we have measured the γ-ray yield, integrated over the 2.68-MeV resonance, at several angles. Details of the experimental measurement and how the anisotropy was utilized in a new R-matrix extrapolation of global 12C(α,γ)16O data will be reported.

Test of extrapolating models for heavy ion fusion reactions at extreme sub-barrier energies

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The heavy-ion fusion reactions between 12C and 16O isotopes, such as 12C+12C, 12C+16O and 16O+16O, are crucially important in a wide variety of stellar burning scenarios. Limited by the experimental technology, these reactions have only been measured down to energies that are much higher than those of astrophysical interest. Traditionally, optical model or equivalent square-well optical model are used to fit the average cross section and predict the reaction cross sections at the energies of astrophysical interest. Recently, a new model, the hindrance model, was proposed to provide systematic fits to fusion reaction data at extreme sub-barrier energies. To test these extrapolating models, we have measured the cross sections for the 12C(13C,p)24Na reaction in the energy range Ec.m.= 2.6-4.8 MeV, which is lower than all previous experiments. Preliminary results will be presented.

Enhanced electron screening in nuclear reactions: a plasma or solid-state effect?

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Electron screening of the Coulomb barrier between reacting nuclei can increase nuclear reaction rates in dense astrophysical plasmas even by many orders of magnitude. Study of the d+d reactions at very low energies in metallic environments, being a very good model for the strongly coupled plasma, enables us to determine the strength of this effect in the terrestrial laboratories. First experiments performed under high vacuum (HV) conditions showed that the experimentally determined screening energies corresponding to the reduction of the Coulomb barrier height were larger than the theoretical values calculated in terms of the dielectric function theory by at least a factor of two.

Since contamination of the target surface plays a crucial role in the screening experiments we performed a series of new experiments dealing with atomically clean targets under ultra-high vacuum (UHV) conditions. The resulting screening energies turned to be significantly larger than the previous experimental values, stepping up the discrepancy to the theoretical data. As the origin of the so-called enhanced screening effect observed in nuclear reactions taking place in metals still remains unexplained we discuss here two alternative scenarios. First, we analyse a strong long-range correlation between conduction electrons as a solid-state effect. On the other hand, we examine the interplay between a strong plasma screening and a narrow resonance placed close to reaction threshold, which leads to the target material dependence of the reaction cross section.

Measuring the 12C(α,γ)16O reaction rate with a bubble chamber.

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We have devised a technique for measuring the ^{12}C(α,γ)^{16}O reaction with a considerable improvement in sensitivity from previous experiments. Adopting ideas from dark matter search experiments with bubble chamber detectors, we have found that a vessel containing superheated water would be sensitive to α-particle and ^{12}C recoils produced from a γ-ray beam impinging on ^{16}O nuclei. The main advantage of the new target-detector system is a density as high as a factor of 10,000 over conventional oxygen-gas targets. Also, the detector is insensitive to the γ-ray beam while being an excellent tunable background rejection device.
We will discuss the latest results and the prospects of this novel technique in the context of future experimental nuclear astrophysics.

Screening correction to nuclear reaction rates in brown dwarfs and low-mass stars

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Reaction rates for deuterium burning and proton-proton fusion in brown dwarfs and low-mass stars are revisited. The screening correction is calculated using a perturbative approach to thedensity-density response function. With the help of thermo-dynamic Green's functions, many-body and quantum effects are systematically taken into account. For the pair correlation function, we perform a detailed study of the transition from the quantum to the classical regime. Also, the relevance of dynamical screening effects is discussed. Comparison is made with the traditional integral equation theories as well as path integral Monte Carlo calculations.

Impact of Mass Loss and Rotation on the Evolution of Very Massive Stars

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Very massive stars (>100 M_o) are thought to end their lives as pair creation supernovae (PCSN). Observations of supernova 2007bi in the local universe give the latest proof of the PCSN. We investigate the effects of the mass loss and rotation in these very massive stars. We will discuss how the mass loss and rotation affects the evolution and fate of these very massive stars. We will present the results of a series of evolution models of very massive stars for both solar and Magellanic Clouds metallicities.

TUNGSTEN ISOTOPIC COMPOSITIONS IN STARDUST SiC GRAINS FROM AGB STARS: AN EVALUATION OF REACTION RATES AT THE Hf-Ta-W-Re-Os REGION

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Recent s-process analyses of the Hf-Ta-W-Re-Os region have identified two major problems. First, it appears that model predictions underestimate the slow neutron capture (*s*-process) contribution to 182W and, consequently, the 182W rapid neutron capture (*r*-process) residual shows a significant positive deviation from the otherwise smooth *r*-process solar abundance pattern. Second, analysis of the *s*-process flow at the 185W branching point shows that the 186Os *s*-process abundance is also somewhat problematic, indicating a significant overproduction with respect to its solar abundance. These problematic *s*-process abundances and, consequently, the inferred 182W *r*-residual, may reflect remaining uncertainties related to neutron-capture reaction and beta decay rates. We present new data on the W and Hf isotopic compositions in meteoritic stardust silicon carbide (SiC) grains believed to have condensed in the outflows of low mass (~ 1.5 to 3 solar masses) carbon-rich asymptotic giant branch (AGB) stars of metallicity close to solar. These measured compositions show the clear signature of the *s*-process and can be used to infer new information on the *s*-process contribution in the Hf-Ta-W-Re-Os region and on the 182W and 186Os problems. We will present a detailed comparison of the SiC data to *s*-process models with the aim of providing predictions for the neutron-capture reaction rates of the W isotopes.

Stardust Material in the Meteorite SAH 97096

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Introduction: True stardust material can be found in the form of micrometer- to sub-micrometer-sized grains in various types of solar system materials, such as meteorites, interplanetary dust particles, and comets. Carbonaceous and oxide stardust grains have been studied in the laboratory for more than 20 years [Zinner 2004, In Treatise on Geochemistry Vol. 1 (ed. A. M. Davis) pp. 17-39]. Silicate stardust is not scarce in the solar system materials but its identification was hindered because silicate stardust is embedded within an overwhelming background of isotopically normal and chemically similar silicate phases that make up the bulk of the meteoritic materials. Silicate stardust grains were discovered in the laboratory only recently when new analytical techniques for isotope imaging searches at 100nm spatial resolution became feasible [e.g., Messenger et al. 2003, Science 300, 105; Nguyen & Zinner 2004, Science 303, 1496]. Most searches for silicate stardust grains have been carried out in carbonaceous chondrites. Much less information is available about silicate stardust in enstatite chondrites; however, these meteorites are of interest because they formed under highly reducing conditions, which may allow the preferential survival of different types of silicate stardust. In addition, surviving stardust grains can provide information about conditions in the early solar nebula when these meteorites formed. Here we report searches for stardust grains in an enstatitic meteorite SAH 97096 using the Washington University NanoSIMS.
Methods: Stardust grains were identified in the NanoSIMS by rastering a Cs+ primary beam over areas of size-separated grains of SAH 97096, and simultaneously imaging 12,13C- and 16,17,18O- ions. The elemental compositions of the isotopically anomalous grains were subsequently acquired in the Auger Nanoprobe.
Results: This study led to the identification of eight oxygen-anomalous grains. Five grains have enrichments in 17O and are largely normal in their 18O/16O indicating an origin from a low-mass red giant or asymptotic giant branch star with close-to-solar or slightly lower-than-solar metallicity and about 1.1-2.5 M_{Sun} [Nittler et al. 1997, ApJ. 483, 475]. One grain has a 17O/16O ratio of (1.33±0.01)×10-2 and an 18O/16O ratio of (1.43±0.04)×10-3; for such a composition Nittler et al. [2008, ApJ. 682, 1450] suggested a possible origin in binary star systems, in which material was transferred from an evolved star or a nova explosion to a main sequence star. Two grains show enrichments in 18O and have oxygen isotopic compositions consistent with formation in supernova ejecta. Elemental compositions of the stardust grains will be presented at the symposium. We also identified four grains with carbon anomalies; their 12C/13C ratios range from 19 to 78, similar to the compositions of mainstream SiC grains. The conditions under which these stardust grains formed and/or were subsequently modified will also be evaluated.

Wind composition beyond the tip of the AGB and its relevance to stardust grains

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After its H-rich envelope is reduced to small values, less than 10-3MΘ , an asymptotic giant branch (AGB) star evolves to become a post-AGB star and then may become the central star of a planetary nebula. The star evolves at a constant luminosity to hotter temperatures while the mass of the thin H-rich region decreases because of winds. We investigate the isotopic composition of this wind which shows the signature of hydrogen burning. We compare our predictions to the compositions measured in Group II stardust oxide and silicate grains to assess the hypothesis that some of this dust formed from material ejected by post-AGB stars and central stars of planetary nebula. We find that the composition of this H-rich region is very close to that of Group II grains, especially if some mixing of the different layers within the region is performed. The problem is that the total mass involved appears to be too small to reproduce the frequency of Group II grains. However, we cannot exclude this origin for Group II grains because their frequency would also be determined by the uncertain mechanism of grain formation.For example, grain formation may occur in the post-shocked regions
produced by fast post-AGB winds colliding with the cooler circumstellar material ejected during the previous AGB phase.

Making CHILI: a progress report

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Each increase in lateral resolution of micro- or nanoanalytical instruments has revealed new worlds. The Stardust mission returned two types of samples, cometary dust and contemporary interstellar dust, that clearly point to a need for improvements in lateral resolution and sensitivity beyond what is available with current state-of-the-art secondary ion mass spectrometry (SIMS) instruments. SIMS lateral resolution has reached ~50 nm and useful yields (atoms counted per atom removed from the sample) are at most a few percent for easily ionized atoms but can be much lower. We are in the midst of construction of CHILI (the CHicago Instrument for Laser Ionization), a resonant ionization mass spectrometry (RIMS) instrument designed for isotopic and chemical analysis at the few-nm scale with a useful yield of 40-50% [1]. CHILI will combine a high-resolution liquid metal ion gun (LMIG) that can be focused to <5 nm, tunable solid-state lasers for laser resonant ionization, and a time-of-flight mass spectrometer. It will be equipped with an electron gun for secondary electron imaging, as optical imaging is diffraction-limited to ~0.5 µm. The physical layout will also be different from previous instruments [2,3], with the flight tube of CHILI mounted vertically above the sample chamber; this assembly is mounted in the center of an H-shaped laser table equipped with active vibration cancellation devices. Isotopic precision in RIMS can be limited by the temperature stability of photoionization lasers [4], so a thermally stabilized, low-vibration, draft-free room to house CHILI was recently completed. The laser table, sample chamber, a nanomotion stage, and a low-vibration vacuum system are now in place. Existing ion optical components are now being modified for high voltage operation, construction of the time-of-flight mass spectrometer and tunable lasers for photoionization of at least two elements simultaneously are now underway.

CHILI reflects many recent developments in instrument design. It will be applied to a broad range of cosmochemical problems including: (1) isotopic analyses of contemporary interstellar grains returned by the Stardust mission; (2) 26Al/26Mg dating of chondrules and refractory inclusions in cometary dust to compare with the chronology record of inner solar system materials; (3) isotopic study of subgrains within presolar graphite grains; (4) U-Pb dating of presolar grains; (5) isotopic characterization of the carriers of nucleosynthetic anomalies in meteorites. In addition, each prior increase in lateral resolution has led to recognition of new kinds of presolar grains: we hope that this trend will continue.

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Oxygen Rich Stardust Grains from Novae

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Stardust grains which have condensed from nova ejecta are exceedingly rare in meteorites. Principally through proton captures, novae are efficient producers of the stable isotopes 13C, 15N, and 17O, as well as radioactive isotopes such as 22Na and 26Al [1-3]. To date, primarily carbonaceous phases of stardust grains (e.g., SiC and graphite), with combinations of low 12C/13C and 14N/15N ratios, high 30Si/28Si, and high inferred 26Al/27Al and 22Ne/20Ne ratios (when measured), have been purported to have formed in novae [4-6]. A few purported nova grains may have actually condensed in supernova ejecta [7]; however, some are undoubtedly nova condensates [8, 9]. Conversely, as material ejected in nova explosions is O-rich, it remains a puzzle why to date mostly carbonaceous nova grain candidates, with only a few possible exceptions [10, 11], have been discovered. O-rich stardust grains with 17O/16O ratios significantly greater than 0.004, the predicted maximum value that can be reached in low- and intermediate-mass AGB and RGB stars [12], have been proposed to be of nova origin. In most cases, the O isotopic compositions of many of these grains can be fairly well matched by CO nova model predictions. However, for the two grains which have had their Mg-Al compositions determined, the models greatly overproduce the heavy Mg isotopes, missing the grain data by up to several orders of magnitude [11, 13]. Hopefully, new nova models computed with recently updated reaction rates and multi-element isotopic data for two new nova candidate grains can provide further insight into the composition of dust from these sources.

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A promising method to obtain accurate Mg and Fe isotope compositional data on presolar silicate particles found in the primitive carbonaceous chondrite Acfer 094

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Besides SiC and diamond, silicate minerals are the most abundant presolar particles found in primitive meteorites [1]. Presolar silicate grains are rarely larger than 200-300 nm in diameter and are either amorphous or crystalline (e.g., olivine, pyroxene). Due to their small grain size and chemical similarity to the host meteorite matrix, the isotope analysis of presolar silicates must be performed using in situ techniques, such as the NanoSIMS, a mass spectrometer separating and detecting ions from a target material ejected due to irradiation by a primary ion beam on a spot as small as 50-400 nm. The achievable resolution depends on the element of interest.

In the last few years, an increasing amount of O and Si isotope data, obtained using the NanoSIMS technique, has provided new information about the formation of presolar silicate grains and their relation to stellar evolution and nucleosynthesis [2, 3]. However, isotope analysis of elements such as Mg and Fe in individual presolar silicate grains, which cannot be analyzed with the highest spatial resolution, are strongly affected by dilution with the isotope signal of neighbouring matrix material, leading to inaccurate results. Here we present a new method to prepare 200-300 nm presolar silicate grains for in situ isotope analysis with the NanoSIMS in order to eliminate dilution effects imposed by the matrix. This method will be applied to silicates in meteoritic thin sections and follows the procedure developed by [4] for dense grain separates. First, presolar silicate grains are identified by their O isotope compositions, which can be analyzed at high spatial resolution (ca. 100 nm). After relocating the grains using SEM images, a focussed Ga ion beam will be used to remove material around the grains in a 3 μm diameter circle to a depth of 0.5-1.0 μm. As the material in the neighbourhood of the presolar silicate grains will not exist anymore, dilution effects are minimized. The major focus of our efforts will be on the accurate analysis of e.g., alkaline earth elements and transition metals provided they are present in sufficient quantity. Magnesium and Fe are good candidates for this kind of analysis as they are major elements of presolar silicates [5]. Besides the potential of giving insight into nucleosynthetic processes in stars, the Mg and Fe isotope compositions of presolar silicate grains will also provide information on the Galactic chemical evolution of these elements. For a subset of grains prepared with the present method we also plan to measure the O and/or Si isotopes, in order to check whether dilution effects might have also compromised previous results on presolar silicates to some extent [2].

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Massive stars and the inner Galaxy's ISM: tracing the gamma-ray line from 26Al.

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Observation of the gamma-ray line emission from the decay of the radioisotope 26Al is a tool for the study of the interstellar medium around the sites of recent star formation. The spatial distribution of this radiation points to massive stars as the dominant sources of 26Al in the inner Galaxy. High-resolution spectroscopy of this emission line measures local velocity dispersion as well as large scale motions. The width of the measured line shows that the bulk of the 26Al nuclei in the ISM moves with radial velocities of less than 200 km/s, i.e. comparable to those of Galactic rotation. New spatially resolved spectroscopy using observations of the inner Galaxy with ESA's INTEGRAL/SPI spectrometer now measures the radial velocity along the Galactic plane. The resulting l-v diagram in the 1.8 MeV line from 26Al offers a new view on the distribution of the hot phase of the ISM.

The Inventory of Presolar Grains in Primitive Meteorites: A NanoSIMS Study of C-, N-, and O-isotopes in NWA 852

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Primitive solar system materials contain varying amounts of presolar dust grains that formed in the winds of evolved stars or in the ejecta of stellar explosions. Silicates and oxides are among the most abundant types of these grains. Although they belong to the most primitive chondrite groups, first studies of CR chondrites indicated only small amounts of presolar material. Recent investigations, however, revealed much higher abundances of presolar dust in individual meteorites of this group. Investigating the content of presolar matter in CR chondrites can shed light on the distribution of presolar grains and molecular cloud material in the solar nebula.

We performed ion imaging of 5×5 μm²- to 10×10 μm²-sized matrix areas in a thin section of the CR2 chondrite NWA 852 with a NanoSIMS 50 ion probe to search for C- and O-bearing presolar grains and to characterize the N-isotopic composition. All analyses were performed with a 100 nm-sized Cs+ ion beam at high mass resolution. 16O-, 17O-, 18O-, 28Si-, and 27Al16O- were measured in multi-collection to identify presolar silicate and oxide grains in situ by their O-isotopic composition. Detection of 28Si and 27Al16O allows distinguishing between silicates and Al-rich oxides. 12C-, 13C-, 12C14N-, 12C15N-, and 28Si- were measured on a sub-set of matrix material to search for C- and N-isotopic anomalous phases. About 20,000 μm² of fine-grained matrix material have been analyzed. 22 presolar silicate and 9 oxide grains were identified, representing abundances of 71 ppm for silicates and 43 ppm for oxides, respectively. 26 of the grains belong to O isotope group 1, most likely originating from low-mass AGB-stars, while 4 grains fall into group 4, probably condensates from Type II supernovae. One grain is depleted in 17O and is a candidate for group 3. A large group 1 presolar Al-rich oxide grain was subsequently prepared by the focused ion beam technique (FIB) for transmission electron microscopy (TEM). TEM investigations revealed that it consists of a single crystal of hibonite with distinct Ti enrichment in the central part. 1800 μm² of C- and N-rich material have been analyzed so far. A 15N-rich phase is present (average δ15N of +100 o/oo), with δ15N > 1000 o/oo in individual spots. Eight C-anomalous SiC grains have been found, representing a matrix-normalized abundance of ~160 ppm.

NWA 852 has the lowest presolar silicate/oxide-ratio observed so far for presolar-grain-rich material, an indicator for extensive aqueous alteration. Nevertheless, a significant amount of O-anomalous grains remained intact, and N-isotopic compositions are comparable to observations from more pristine CR chondrites, while the abundance of SiC grains in the matrix is comparably high. Thus, NWA 852 may be linking presolar-silicate-rich, nearly unaltered CR chondrites and CRs with lower presolar grain abundances. This can be due to varying degrees of parent body alteration, or initial heterogeneities in the solar nebula.

Lithium-beryllium-boron isotopes in the meteorites: implications for irradiation in the early solar system

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We performed Li-Be-B isotopic measurements of individual hibonite grains extracted from the Murchison meteorite, with a goal of understanding the distribution of 7Be and 10Be, as well as the irradiation history in the solar nebula. It is found that 10B excesses correlate with the 9Be/11B ratios in 26Al-free PLAty-hibonite Crystals (PLACs), from which an initial 10Be/9Be = (5.5 ± 1.6) × 10-4 (2σ) and 10B/11B = 0.2508 ± 0.0015 can be inferred. On the other hand, the boron isotopic compositions in 26Al-bearing Spinel-HIBonite spherules (SHIBs) appear to be chondritic, most likely due to contamination with normal boron. Consideration of the combined dataset from this study and [1] yields the best defined 10Be/9Be = (5.3 ± 1.0) × 10-4 (2σ) and 10B/11B = 0.2513 ± 0.0012 for PLACs. These observations support a heterogeneous distribution of 10Be and its proto-Solar irradiation origin. This study failed to find resolvable 7Li excesses due to 7Be decay. We also consider two possible irradiation scenarios that could potentially lead to the observed Li-Be-B isotopic compositions in PLACs. Although in-situ irradiation of solids with hibonite chemistry seems to provide the simplest explanation, more high quality data will be needed for quantitatively constraining the irradiation history.

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26Al emission from the Scorpius-Centaurus association

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Massive stars dominate the structure of the interstellar medium. Among the numerous isotopes synthesized there, there is 26Al. It is predominantly emitted by stars in their Wolf-Rayet phases or undergoing supernovae and therefore is a tracer of massive stars. In OB associations, such stars cluster in a confined region. Being young, these associations unite stars of all masses and in several evolutionary stages, making them a favoured target for observations.

The OB association closest to our Sun is Scorpius-Centaurus in the southern sky. It consists of three subgroups and may have originated in a sequential event, in which the massive stars of the older groups triggered further star formation. We evaluated observations with the gamma-ray telescope SPI onboard the INTEGRAL satellite in the 1809 keV 26Al decay line and achieved age assessments independent of all prior studies, constraining the possibility of triggered star formation in the region.

Possible r-process origin for Xenon-H

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Introduction: Xenon hosted by presolar nanodiamonds found in primitive meteorites is characterized by excesses in the heavy Xe isotopes (Xe-H) made by the r-process and in the light isotopes (Xe-L) made by the p-process, but in detail the abundance patterns differ from r-process and p-process Xe as observed in the Solar System abundances [1]. While a neutron burst has been suggested as a possible source for Xe-H [2], here we will explore whether the r-process is a possible alternative after all.

Neutron burst: Acting on an s-process seed, the neutron burst [2,3] shifts abundances to the neutron-rich side of elements such as Xe. It has been very successful in explaining the Mo isotope pattern in silicon carbide X grains [3] of supernova origin, but less so in explaining their Ba isotopic compositions [4] and in the case of Xe-H in diamonds [5].

High entropy wind (HEW) r process: As noted above, Xe-H differs from classical r-process Xe. A similar situation is encountered in the relative abundances of 129I and 182Hf in the early Solar System [6]. Also along the same lines, astrophysical observation of metal-poor stars indicate a "robust" r-process abundance pattern from Ba upwards, but variable patterns in the lower mass range below A~110 [7]. We have shown that the HEW model for the r-process can produce 135Ba and the Hf isotopes in the "correct" r-process ratio, while at the same time producing only little 129I, if material synthesized only above a certain entropy value is considered [8]. Such an "entropy cut" will have a significant impact on the Xe isotopic composition, which we are going to explore, along with the sensitivity to other parameters characterizing r-process conditions. First results indicate that - under appropriate conditions - it is possible to produce Xe that is unlike Solar-System r-process Xe and more akin to Xe-H, but the fit is far from perfect. We note, however, the possibility of further modification of the observed composition by a "rapid" separation of stable Xe isotopes from radioactive precursors produced in the r-process [5, 9].

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Silicon Carbide Grains of Type X and Supernova Nucleosynthesis

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Silicon carbide grains of type X, constitute ~1% of all presolar SiC grains found in primitive meteorites. These grains have 15N and 28Si excesses, mostly light C, high inferred 26Al/27Al ratios, and evidence (from 44Ca and 49Ti excesses) for the initial presence of the short-lived radioisotopes 44Ti and 49V [e.g. 1].
These main isotopic signature clearly indicate an origin in the ejecta of Type II supernovae and material from different SN zones [2] had to contribute to the mix from which the grains formed: He/N (26Al), He/C (12C and 15N), and the Si/S zone (28Si, 44Ti, 49V). However, in detail there are many discrepancies between grain data and theoretical predictions from SN models [3]. One major discrepancy concerns the distribution of the Si isotopic ratios. In a Si 3-isotope plot, most grains plot along a line, which points to a primary isotopic composition with 29Si/28Si = ~1/3×solar and almost no 30Si. However, such a composition is not produced by any of the SN models. Another set of discrepancies involve the correlation between C, N and Al isotopic ratios: 12C/13C and 15N/14N ratios are high in the He/C and low in the He/N zone, whereas the 26Al/27Al ratios shows the opposite behavior. As a consequence, mixing between these zones results in negative correlations between these ratios, in contrast to the grain data [4]. Another example is the lack of large 54Fe excesses in X grains [5]. While mixing with material from the Si/S zone, rich in 28Si, is necessary to explain the 28Si excesses in these grains, the 54Fe, abundant in this zone, must have been separated from the 28Si before grain condensation by a process still not understood. We will discuss these discrepancies and solicit suggestions for solutions.

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Abundances of ejecta from neutrino- and magnetically-driven core collapse supernovae

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Explosion mechanism of core collapse supernovae (SNe) is still not clearly understood. Multi-dimensional effects are recognized to be important for supernova explosion, in particular for a progenitor heavier than about 11 Msun in its main sequence phase. Standing accretion shock instability (SASI) is a reliable candidate to initiate bipolar oscillations of a stalled shock. Recent two-dimensional simulations of stellar core collapse showed that delayed neutrino-driven mechanism aided by SASI is likely to cause an aspherical explosion of non- or slowly- rotating massive stars. While if a progenitor is rapidly rotating and has appropriate magnetic fields, magnetically-driven mechanism is important for the explosion and bipolar, jet-like explosion can be realized.

In the present study, we have investigated explosive nucleosynthesis in ejecta from a SASI-aided, neutrino-driven SN and a magnetically-driven SN, based on two dimensional hydrodynamic and magnetohydrodynamic simulations of the explosion. We compare the composition of the SN ejecta due to the two mechanism with those observed in young SN remnants. Then we discuss explosion mechnism about the remnants.

We find that composition of the ejecta due to the two mechanism are largely different from each other. Abundance pattern of the neutrino-driven SN ejecta is similar to that of the solar system for models with high neutrino luminosities. While the magnetically-driven SN ejecta is Fe-rich and the composition is largely different from the solar composition.

Electro-weak responses of ^{4}He using realistic nuclear interactions

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A study of neutrino-nucleus reaction is important to the scenario of a supernova explosion. In the final stage of a core collapse supernova, ^{4}He is exposed to intense flux of neutrino. The ν-^{4}He reaction is expected to play a significant role, and the reaction rate is proportional to the weak responses, for example, due to Gamow-Teller, dipole, spin-dipole, etc. operators. Reliable theoretical study is desired for precise evalulation of the reaction rate. ^{4}He is the lightest closed shell nucleus which has several excited states above the excitation energy of 20 MeV. We have recently reported that all the observed levels below 26 MeV are well reproduced in a full four-body calculation using realistic nuclear interactions [1]. It is interesting to extend this approach in order to study some excitations in ^{4}He.

The dipole response of ^{4}He is also very interesting. In the energy region around 26 MeV, photoabsorption reaction occurs mainly through the electric dipole transition. The current experimental situation is controversial. Two groups have shown quite different cross sections [2,3]. Because there are only few theoretical studies on the reaction starting from a realistic interaction, further study may help clarify the situation.

In this contribution, we will discuss strength functions of ^{4}He related to the above mentioned electro-weak reactions mainly focusing on the dipole strength. The wave function of the ground state is obtained accurately using an explicitly correlated basis and four-body final states are also expressed in a superposition of many basis functions which contain important configurations for the low-lying strength functions. We find that the configurations dividing ^{4}He into 3+1 or 2+2 are important for describing the low-lying dipole strength functions. Also, we will discuss the strength functions induced by the weak interaction and mention the ν-^{4}He reaction cross section.

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HIP 60350: A supernova ejected hyper-runaway star?

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Halo runaway stars, i.e., young, massive, high-velocity stars in the halo of our Galaxy, are widely supposed to be the result of an ejection event from the Galactic disk. The two most likely ejection scenarios are a supernova explosion disrupting a binary system or dynamical interactions in star clusters, e.g., binary-binary encounters. Here, we present a detailed spectroscopic and kinematic analysis of the runaway B star HIP 60350 to discuss the two competing mechanisms. Using spectrum synthesis techniques that allow for deviations from local thermal equilibrium, we derived chemical elemental abundances from high resolution spectra. The pattern shows hints of α-element enhancement being characteristic of supernova debris but still needs confirmation. The supersolar metallicity would be consistent with the kinematically predicted birthplace ~6kpc away from the Galactic center. HIP 60350's outstanding high Galactic rest-frame velocity of 530 ± 35 km/s slightly exceeds the local Galactic escape velocity and qualifies the star as a hyper-runaway candidate.

Evaluating nuclear physics inputs in core-collapse supernova models

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Core-collapse supernova models depend on the details of the nuclear physical inputs just as they depend on the details of the numerical methods and progenitors. The dynamics of core-collapse, bounce, and shock progression are dependent on the thermodynamic properties of the nuclear equation of state (EoS). The state of the infalling material and the neutrino driven shock revival are also regulated by neutrino transport and the neutrino opacities. We present the results of our recent comparison studies of nuclear inputs to core-collapse supernovae using the spherically symmetric, general relativistic, neutrino radiation hydrodynamics code Agile-Boltztran. We focus on comparisons of the nuclear EoS and the effects of opacities, particularly nuclear electron capture and neutrino-nucleon scattering. We also demonstrate the interaction of the EoS and opacities with each other and with variations in the pre-supernova progenitors.

A general relativistic neutrino-hydrodynamics code for core-collapse supernovae

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We present a new general relativistic (GR) code for hydrodynamic supernova simulations with neutrino transport in spherical and azimuthal symmetry (1D/2D). The code is a combination of the CoCoNuT hydro module, which is a Riemann-solver based, high-resolution shock-capturing method, and the three-flavor, energy-dependent neutrino transport scheme VERTEX. VERTEX integrates the neutrino moment equations with a variable Eddington factor closure computed from a model Boltzmann equation and uses the so-called ray-by-ray plus approximation in 2D. Our space-time treatment employs the ADM 3+1 formalism with the conformal flatness condition for the spatial three-metric. This approach is exact in 1D and has been shown to yield very accurate results also for rotational stellar collapse. We present the results of of a number of simulations in 1D and 2D that demonstrate the accuracy and robustness of our code. In particular, we discuss simulations of proto-neutron star cooling over several seconds and 2D simulations of different progenitors. Our new relativistic models strongly support the results hitherto obtained with the Newtonian PROMETHEUS-VERTEX code, in which the effects of general relativity are approximated by means of a modified gravitational potential.

Black Hole Formation in Massive Star Collapse

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We present results on black hole (BH) formation in computational simulations of massive star collapse. The electron-degenerate iron cores of massive stars undergo core collapse to nuclear densities as the final stage of stellar evolution and form a protoneutron star. Many of these core collapse events will result in a supernova explosion with a neutron star remnant; for a subset of massive stars the protoneutron star may surpass the maximum neutron star mass before explosion sets in and undergo further collapse to a BH, shutting down the supernova engine. In spherical symmetry, we use our open-source 1.5D general-relativistic (GR) stellar collapse code, GR1D, to perform a parameter study and place limits on black hole formation in collapsing stars. Using a parametrized neutrino leakage/heating scheme to approximate the effect of neutrinos, we investigate the effect of both observational and theoretical unknowns: progenitor model, mass, metallicity, equation of state and rotation. We also show results from the first 3D GR simulations of BH formation in failing rotating and non-rotating core-collapse supernovae with simplified microphysics and present data on the initial BH spin and early accretion history.

Self-consistent theory of stellar electron capture rates

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A fully self-consistent microscopic framework is introduced for evaluation of nuclear weak-interaction rates at finite temperature, based on Skyrme energy density functionals[1]. The single-nucleon basis and the corresponding thermal occupation factors of the initial nuclear state are determined in the finite-temperature Skyrme
Hartree-Fock model, and charge-exchange transitions to excited states are obtained using the finite-temperature random phase approximation (RPA). Effective interactions are implemented self-consistently: both the finite-temperature single-nucleon
Hartree-Fock equations and the matrix equations of RPA are based on the same Skyrme functional. On the other side, self-consistent framework for weak interaction rates at finite temperatures is also developed within relativistic mean field theory starting from
the effective Lagrangians with density dependent meson-nucleon vertex functions. Nuclear excitations are described using the finite temperature relativistic random phase approximation[2] in the range of temperatures relevant for the stage of supernova precollapse, as well as in nuclei far from stability, including multipole excitations
and charge-exchange modes (e.g. Gamow-Teller resonances and forbidden transitions). It is shown that finite temperature effects include novel low-energy multipole excitations and modifications of the Gamow-Teller transition spectra[1-3]. Using a representative set of Skyrme functionals, as well as covariant energy density functional with DD-ME2 parameterization, both theory frameworks have been applied in the calculation of stellar electron-capture cross sections, in particular for the iron mass group and for neutron-rich Ge isotopes[1]. Finally, recent self-consistent studies of weak interaction rates also include description of neutrino-nucleus cross sections[4] and muon capture rates[5]. Current developments are focused toward systematic calculations of stellar electron
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Light Clusters in Core-Collapse Supernovae

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Light clusters (up to A=4) in nuclear matter at subsaturation densities are treated in a quantum statistical approach. Self-energy, Pauli-blocking, and effects of continuum correlations are taken into account to calculate the quasiparticle properties and abundances of light elements [1]. Results are compared with experiments from Heavy Ion Collisions [2].

Consequences for the Equation of State [3] and nuclear structure are given [4]. The appearence of light clusters in core-collapse supernovae at post-bounce stage may modify the neutrino emission and absorption processes and, thereby, influence the supernova mechanism [5].

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Neutrino bursts from failed supernovae as a promising target of neutrino astronomy

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We reveal the unique characteristics of neutrino bursts from the black-hole-forming collapse of non-rotational massive stars, which is a definite branch among other core-collapse supernovae. We clarify that the neutrino signals from the failed supernovae are short and energetic, being different from the ordinary supernova neutrinos, by performing the numerical simulations of the general relativistic neutrino-radiation hydrodynamics with the neutrino reactions rates.

We predict that the number of neutrino detection at Super-Kamiokande for a Galactic event amounts to ~104, which is comparable with the case of supernova explosions, by taking into account the neutrino oscillations. We demonstrate with the statistical analysis that we can discriminate the detailed differences of the neutrino signals using the sets of equation of state including nucleons, hyperons and quarks. We discuss that the dependence of neutrino characteristics on the density profiles of the progenitors.

We stress that the massive stellar collapse with the short neutrino burst is an important astronomical target as a probe of the equation of state of the hot and dense matter. Having the systematic studies of the numerical simulations adopting the models of massive stars of 40-50Msun with our development of the data tables of equation of state with hyperons, pions and quarks based on the Shen EOS, the future observation by the monitoring survey of the massive stars and the detection of the neutrino observatories is awaited for.

Thermal Nucleation of Quark Matter in a Lepton-Rich Environment

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During the collapse of a massive star, very high densities and temperatures can be achieved. In particular, such conditions may allow a phase transition from nuclear matter to quark matter. Assuming this phase transition to be of first order, the simplest mechanism for phase conversion is the nucleation of bubbles of the quark phase inside the uniform nuclear matter phase. In this work, we compare the nucleation time scales with the typical time scale of the early post-bounce phase in a supernova explosion. We find that nucleation is a feasible mechanism for phase conversion in this scenario only if the surface tension between the nuclear and the quark phase has a relatively small value.

Excluded volume approximation for supernova matter

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Starting from simple modification of ordinary Fermi-gas description we develop general approach to excluded volume approximation (EVA). This approach takes into account the arbitrary degree of particle degeneracy and permits the inclusion of other interactions. We introduce the effective excluded volume function, whose form can be chosen in different ways to obtain various models. In particular it is easy to obtain well-known EVA which was used in the heavy ion reactions study.
By implementing our general approach to the case of Boltzmann limit we can reproduce the results of well-designed theory of hard-sphere particles and describe the behavior of many-component different sized mixtures.
By adding to the EVA additional long-ranged attractive potential we have obtained quasi Van der Waals equation of state and use it to explore thermodynamic properties and chemical composition of matter in collapsed supernova cores. The ability of above approach to describe a phase transition to uniform nuclear matter is also considered.

Simulations of strange star mergers and observational consequences

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Hydrodynamical simulations of strange star mergers are presented. These studies allow to estimate the amount of strange matter that becomes gravitationally unbound and thus contributes to the cosmic ray flux of strangelets. Implications for the Madsen-Caldwell-Friedman argument are discussed. Furthermore, gravitational wave features of this kind of mergers are compared to the signals of ordinary neutron stars to explore the possibilities to distinguish merging strange stars from colliding neutron stars.

Probing Baryons in Gas and Dust to the Highest Redshifts with GRBs

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Long duration Gamma Ray Bursts (GRBs) trace massive stars, possibly to the first generations of stars. Their bright afterglow emission offers unique opportunities to probe element abundances and dust properties in their host galaxies with rapid follow-up spectroscopy (X-ray and optical/NIR). We present abundance/dust evolution models for GRB host galaxies, and discuss instrumental developments of Xenia and EXIST, which will utilize the rapidly decaying GRB afterglow for spectroscopic study of GRB hosts, to establish cosmic chemical evolution and to probe the reionization epoch. We also discuss the era when dust was of pure supernova origin, and we describe how Xenia can probe the thermodynamic conditions of the WHIM, containing the bulk of the missing baryons, and study galaxy clusters well beyond their virial radii. The focus of this talk it the use of GRBs as probes of cosmic chemical evolution, but chemo-dynamical aspects will be addressed as well.

Unique feature of expected event number of neutrinos from collapsar

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Long-duration gamma-ray bursts (GRBs) are one of the energetic phenomena in the universe, while central engine of the GRB has not been clarified yet.The theoretical models for GRBs are studied in these years. The duration of the long bursts may correspond to the accretion to the central black holes (BHs), which suggests the observational consequence of the BH formation. Pushed by those observations, the collapsar model has received quite some interest for the central engines of the long GRBs In the collapsar model, the outflow is formed with the BH and the accretion disc, which is consequent of gravitational collapse of massive star. This accretion disc is thought to emit neutrinos. In collapsars, the neutrino luminosity from the accretion disc is high, and the duration time is long. Thus the neutrinos of GRB are different from that of the supernova, and might have a special feature. By foreseeing the large volume detector, it is important for clarifying the dynamics of the engine of GRB to expect the neutrino signal from GRB.

We calculate how the neutrino radiation from three collapsar models at several Mpc scale is observed on the earth taking into account the effect of the neutrino self-interaction and MSW matter effect. We assume inverted mass hierarchy, and sin2 2 θ_{13} = 10 -4.
As a result, we find that the neutrinos from GRB at Mpc scale may be directly detectable with next generation Mton-class detectors, depending on the duration of the collapsar disk. We also point out that the duration time of neutrino detection reflects that of collapsar disk. These observational profiles of neutrinos might clarify the dynamics of long GRBs. Moreover, we found that the event number of the neutrinos from the collapsar with the self-interaction is larger than that without self-interaction. Therefore, the neutrino self-interaction is important for the neutrino from GRBs to be observed, which might provide us a new astrophysical tool to investigate the neutrino physics. If the central engine is powered by the neutrinos, neutrino-induced gravitational waves (GWs) are detectable for 1 Mpc events by LISA and 100 Mpc by DECIGO/BBO. The GW and the neutrinos are helpful for probing the explosion mechanism. Therefore, it might be clarified the dynamics of long GRB by the direct detection of the neutrinos from GRB.

Nucleosynthesis in jet-induced supernovae

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The first metal enrichment in the universe was made by supernova (SN) explosions of population III stars and the results are recorded in abundance patterns of extremely metal-poor (EMP) stars. Meanwhile, it has been found that gamma-ray bursts with relativistic jets are associated with highly-energetic SNe (hypernovae) and observations of SNe in recent days also smoke out that SNe are universally aspherical. Thus, we present hydrodynamical and nucleosynthetic properties of the jet-induced explosion of a population III star with a two-dimensional special relativistic hydrodynamical code. In the jet-induced SNe, Fe-peak products are ejected along the jet axis, while unprocessed materials fall onto a central remnant along the equatorial plane. This coexistence accounts for the abundance patterns of the EMP stars. Also, the jet-induced explosion realizes the high-entropy environment that enhances [(Sc, Ti, V, Cr, Co, Zn)/Fe]. The enhancements of [Sc/Fe] and [Ti/Fe] improve agreements with the abundance patterns of the EMP stars. Furthermore, we point out that the evidence of jet-induced SN is found in a Si-deficient metal-poor star HE 1424-0241 with high [Mg/Si] (=1.4) and normal [Mg/Fe] (=0.4). While the peculiar abundance pattern is difficult to be reproduced by previous SN models, it is reproduced by the angle-delimited yield of the jet-induced SN if the interaction between the SN ejecta and interstellar medium induces a weak mixing of the abundances.

Strongly Magnetized Neutron Star Crust

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We discuss the outer and inner crusts of neutron stars in strong magnetic fields. In particular, we demonstrate the effects of Landau quantization of electrons on the structure and stability of nuclei in neutron star crust. In
the presence of a magnetic field, the electron motion is quantized in the plane perpendicular to the field. For strong magnetic fields, this leads to the enhancement of the electron number density with respect to the zero field
case. We obtain the sequence of nuclei and the equation of state of the outer crust in the presence of strong magnetic fields adopting the Baym, Pethick and Sutherland (BPS) model and most recent versions of the theoretical and
experimental nuclear mass tables. It is noted that some new nuclei appear and some nuclei disappear from the sequence compared with the zero field case. Further the neutron drip point is shifted to higher density in a strong magnetic field.

We also investigate the stability of nuclei in the inner crust in the presence of strong magnetic fields using the Thomas-Fermi model. In the inner crust nuclei are immersed in a nucleonic gas as well as a uniform background of electrons. Nuclei are also arranged in a lattice.
The Wigner-Seitz approximation is adopted in this calculation. Each lattice volume is replaced by a spherical cell. The coexistence of two phases of nuclear matter - liquid and gas, is considered in this case. The proton number density in the cell is affected in strong
magnetic fields through the charge neutrality. We obtain a nucleus corresponding to a baryon density just by minimizing the free energy of the cell. The cell size at every density point is appreciably reduced in the presence of magnetic fields compared with the corresponding zero field case. Further we find nuclei with smaller mass number in the presence of strong magnetic fields than those of the zero field. These results might have

Shear viscosity and the nucleation of antikaon condensed matter in hot neutron stars

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The shear viscosity plays an important role in damping gravitational wave driven instabilities in old and accreting neutron stars. We discuss the shear viscosity in the presence of an antikaon condensate in neutron stars, using Boltzmann kinetic equation in the relaxation time approximation. The calculation of shear viscosity involves the equation of state (EoS) as an input, that we construct for antikaon condensed matter at finite temperature within the framework of relativistic field theoretical model. We consider a first order phase transition from charge neutral and beta-equilibrated nuclear matter to K- condensed phase in a hot neutron star after the emission of trapped neutrinos.

Antikaons, which form a s-wave (p = 0) condensation, do not take part in momentum transfer during collisions with other particles. However, with the onset of K- condensation, electrons and muons are rapidly replaced by them. This influences the proton fraction and EoS which, in turn, have important consequences for the electron, muon and proton shear viscosity. We find that the electron and muon shear viscosities drop steeply after the formation of the K- condensate in neutron stars. Hence, the total shear viscosity decreases in the K- condensed matter due to the sharp drop in the lepton shear viscosities. However, the proton shear viscosity whose contribution to the total shear viscosity was negligible compared to the leptonic contribution in nucleons only matter, now becomes significant in the presence of the K- condensate. The proton shear viscosity may even exceed the neutron as well lepton shear viscosities at higher densities.

Further the shear viscosity might control the nucleation rate of bubbles in first order phase transitions. The thermal nucleation time is inversely proportional to the shear viscosity. In this connection we discuss the effect
of shear viscosity on the nucleation process of bubbles of K- condensed phase in neutron stars.

The medium effect of magnetic moments of baryons on the neutron

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We investigate the medium effect due to the density-dependent magnetic moments of baryons on the neutron star under strong magnetic fields. If we allow the variation of the anomalous magnetic moments of baryons in a dense matter under strong magnetic fields, it naturally affects the chemical potentials of the baryons to be large and leads to the increase of proton fraction because the enhancement of the anomalous magnetic moments of nucleons is larger than that of hyperons. Consequently, it causes the suppression of hyperons, resulting in the stiffness of the equation of state. Under the presumed strong magnetic fields, we evaluate the relevant particles' population, the equation of state and the maximum masses of neutron stars by including the anomalous magnetic moment depending on density, and then compare them with those obtained from the anomalous magnetic moment in free space. The magnetic fiedls can cause the maximum mass of neutron star with hyperons to be about 2-3M_{sun} and the effect of density dependent magnetic moment is about 0.1 M_{sun}.

Excitation and destruction of nuclei in hot astrophysical plasmas around black holes

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The importance of nuclear reactions in low-density astrophysical plasmas with ion temperature $T_i \geq 10^{10}$K has been recognized some thirty years ago.
However, the lack of adequate data banks of relevant nuclear reactions and the limited computational power did not allow detailed theoretical studies. Recent developments in these areas make it timely to conduct comprehensive studies of the radiation properties of
such plasmas, formed, in particular, around black holes. Such studies are of great interest in the context of scientific programs of future low-energy gamma-ray telescopes
In this work we study, using the public available code TALYS, the evolution of the hot accretion plasmas with ion temperature exceeding 10^{10} K due to destruction of nuclei in collisions with protons.
We calculate the resulting gamma-ray spectra due to superposition of the excitation lines, as well as the abundances of light nuclei such as d, t, ^{3}He, and discuss the astrophysical implications of these results.

Nuclear reactions in the crust of accreting neutron star

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Recently there has been a wide range of discoveries from the observations of accreting neutron stars in x-ray binaries, and a lot of the observational phenomena are affected by the thermal properties and the composition of the crust. We run a self-consistent reaction network from the atmosphere down to the inner crust of the accreting neutron star to model the nuclear reactions and compositions in the crust. We take into account reaction rates including electron capture, neutron capture, beta decay and pycnonuclear reactions. We present new results for the composition and heat depositions at different depths in the crust.

Liquid-gas mixed phase in nuclear matter at finite temperature

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Liquid-gas (LG) phase transition and the relevant equation of state (EOS) is one of the most important subjects in nuclear physics and astrophysics.
In the crust region of compact stars or supernovae we can expect non-uniform matter with exotic shapes called pasta as a mixed phase
during the liquid-gas phase transition.
It is not only interesting theoretically but may affect the mechanical and thermodynamical properties of compact stars.

We explore the geometrical structure of LG mixed phase by using relativistic mean-field model.
To get the EOS of the system, the Maxwell construction is found to be applicable to symmetric nuclear matter,
where protons and neutrons behave simultaneously.
For asymmetric nuclear matter, on the other hand, the phase equilibrium is obtained by fully solving the Gibbs conditions since the components in the L and G phases are completely different.
We also discuss the effects of surface and the Coulomb interaction on the mixed phase.

Ultra High-Energy Neutrinos via Heavy-Meson Synchrotron Emission in Strong Magnetic Fields

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We propose that the acceleration of ultra-relativistic protons and nuclei in the presence of strong magnetic fields (H ~1015 G) in such environments as AGNs, Magnetars, or GRB central engines could be a viable site for strong meson synchrotron emission. We show that charged scalar mesons like π ± (along with π0's), vector mesons like ρ, and even heavier mesons like $D_{\_S}$, J/ Ψ and ϒ, could be emitted with high intensity (~ 103 times the photon intensity) through strong couplings to ultra-relativistic nucleons. We estimate the flux of energetic neutrinos originating from the decay of ultra-high-energy neutrons produced in a SGR magnetar environment by proton synchrotron emission of p → π+ + n. We deduce the event rate in energetic neutrino detectors and show that a nearby strong SGR burst might be detectable. We also analyze the possibility that the synchrotron emission of massive mesons like the ϒ might produce a burst of three flavors of ultra high-energy cosmic neutrinos with E_ν ≥1012 eV and evaluate the spectra of ν_e, ν_μ and ν_τ from this process.

Nuclear Equation of State in the Presence of a Strong Magnetic Field

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Magnetars have been suggested as the most promising site for the origin of observed soft gamma-ray repeaters (SGRs) and anomalous X-ray pulsars (AXPs). In this work we investigate the possibility that SGRs and AXPs might be observational evidence for a magnetic phase separation in magnetars. Strong magnetic fields (~1017 G) can exist in the interiors of magnetars. Such fields can modify the nuclear equation of state through effects of the magnetic pressure and the population of Landay levels by the electrons and nucleons. We study magnetic domain formation as a new mechanism for SGRs and AXPs in which magnetar-matter separates into two phases containing different flux densities. We identify the parameter space in matter density and magnetic field strength at which there is an instability for magnetic domain formation. We conclude that such instabilities will likely occur in the deep outer crust for the magnetic BPS model and in the inner crust and core for magnetars described in relativistic Hartree theory. Moreover, we estimate that the energy released by the onset of this instability is comparable with the energy emitted by SGRs and AXPs.

Pasta Phase with Gyroid Morphology at Subnuclear Densities

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About a quarter of a century ago, it was shown that nuclei deform at subnuclear densities from spheres to cylinders, slabs, cylindrical holes and spherical holes as the density increases to ~ 10^14 g/cm^3, the density of the uniform nuclear matter. Although these five shapes have been long thought to be the only major constituents of so-called nuclear pasta at subnuclear densities, we discuss other possible structures, that is, gyroid and double-diamond morphologies, which are periodic bicontinuous structures discovered in a block copolymer. In this study, we employ the compressible liquid drop model, which is a phenomenological model also used in earlier studies, for the investigation. We then find that the gyroid morphology may appear near the transition point from a cylinder to a slab as well as that from a slab to a cylindrical hole. Our results are also interesting because recent studies on the dynamics of pasta phases by quantum molecular dynamics show that intermediate phases, which are different from any of the known pasta phases, may emerge between the cylinder and slab phases as well as between the slab and cylindrical holes phases.

Astrophysical constraints on the nuclear symmetry energy

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Recently, much progress has been made in constraining the value of the nuclear symmetry energy E_{sym} and its derivative L at saturation density from analysis of nuclear structure and heavy ion collisions. In this talk, I compare the experimental constraints with those currently available from observations of neutron stars. I focus on a new constraint on L derived from one possible formation scenario of pulsar J0737-3039B, which involves a progenitor helium star ending its life in an electron-capture (*e*-capture) supernova. Conversely, I will discuss the implications of experimental constraints on L on the *e*-capture SN formation scenario.

Symmetry Energy in Isoscaling for Nuclear Reactions

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Isotopic effects in nuclear multifragmentation are important not only for the context of nuclear physics but also for astrophysical processes such as supernova simulations and neutron star models. It is shown that the N/Z dependence of nuclear fragmentation at relativistic energies predicts modifications in symmetry energy. Possibilities of modifications for symmetry and surface energy coefficients of nuclear matter at freze-out density are investigated theoretically by means of isoscaling (isotopic scaling) on the basis of statistical multifragmentation model. It is seen that while the isoscaling parameters as predicted by Markov-chain calculations for the single sources 124Sn and 112Sn are very sensitive to the symmetry term, the surface energy variation slightly affects the isoscaling parameters in multifragmentation region. In order to compare our results with MSU experimental data we consider a possible simulation by taking the single sources formed in the central collisions as A0=186, Z0=75 and A0= 168, Z0 =75 with the same N/Z ratios of the single sources 124Sn and 112Sn, respectively. In this way it may also be justified that isoscaling parameters depend mainly on N/Z ratio of sources and excitation energies, but not on their sizes. The influence of these changes on the mean neutron to proton ratios of light fragments for is also shown. Comparing our results with MSU experimental data, it is confirmed that a significant reduction of the symmetry term coefficient is found necessary to reproduce the isoscaling parameters of fragments [1,2].

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Nuclear matter for compact stars and its properties at finite temperature

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Nuclear Equation of state (EoS) is of great interest as its features control the stability of neutron star (NS), the evolution of the universe, supernova explosion, nucleosynthesis as well as central collisions of heavy nuclei. Extensive studies in the past two decades of nuclear matter created at subnormal or supernormal density in heavy ion collisions have resulted in experimental constraints on the nuclear EoS of symmetric matter. Recent astrophysical observations of massive neutron stars and heavy-ion data are confronted with our present understanding of the EoS of dense hadronic matter. The data from massive neutron stars (NSs) and pulsars may provide an important cross-check between high-density astrophysics and heavy-ion physics. The density dependence of nuclear symmetry energy (NSE) obtained by using nuclear EoS plays an important role for modelling the structure of the NSs and the dynamics of supernova explosions since a series of observables (e.g. slope L of NSE, the value of NSE at nuclear density etc.) can be determined from the knowledge of symmetry energy. The stiffness of the high-density matter controls the maximum mass of NSs. New measurements of the properties of pulsars point towards large masses and correspondingly to a rather stiff EoS characterized by symmetric nuclear matter (SNM) incompressibility 250-270 MeV or more. We investigate the impacts of the compression modulus and NSE on the maximum mass of NSs in view of the recent constraints. In the present work, the density dependent M3Y effective interaction (DDM3Y) which provides a unified description of the elastic and the inelastic scattering, various radioactivites and nuclear matter properties, is employed to obtain EoS of the beta equilibrated NS matter. A systematic study of the properties of static as well as rotating NSs is presented in view of the recent observations of the massive compact stars. The variation of pressure with density for the present EoS is consistent with the experimental flow data confirming its high density behaviour. We find that the large values of gravitational masses for the NSs are possible with the present EoS with the SNM incompressibility =274.7+/-7.4 MeV, which is rather `stiff' enough at high densities to allow compact stars with large values of gravitational masses ~2.0 Mʘ while the corresponding symmetry energy is `super-soft' as preferred by FOPI/GSI experimental data. This formalism is also extended to finite temperatures that requires the neutron and proton chemical potentials and Fermi distributions to be determined self consistently. The finite temperature EoS allows studying the liquid gas phase transition in nuclear matter and various properties of the hot asymmetric nuclear matter such as the pressure, the isothermal and adiabatic incompressibilities and the velocity of sound. The present formalism unifies radioactivity, nuclear matter, nuclear scattering and compact stars.

Physics on huge X-ray luminosity of Magnetars

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The x-ray Luminosity of Magnetars (AXPs and SGRs) with ultra-strong magnetic field more than 10**14-10**15 gauss is high as 10**34-10**36 ergs/sec. The superstrong magnetic field of the magnetars originates really from the induced magnetic field due to the induced paramagnetic moment of the 3P2 neutron superfluid with significant mass more than 0.1m(Sun) at temperature lower than 2×10**7K in the neutron star interior, and the upper limit for the magnetic field of the magnetars is about 3×10**15 gauss. These ideas have been presented by me in last conference < Nuclei in the Cosmos X> (NIC X).
I am going to present physics on huge X-ray luminosity of Magnetars in this meeting. My idea is as follows.
The magnetars are instable due to the ultra high Fermi energy of electrons:
The overwhelming majority of electrons congregate in the lowest levels n=0 or n=1, when B >> Bcr = 4.414*10**13 gauss.
The Landau column is a very long cylinder along the magnetic filed, but it is very narrow. The Fermi energy EF(e) of the electrons increases significantly under the ultra strong magnetic field.
It is found that EF(e)~60*[B/Bcr]**(1/4) MeV or EF(e)= ~131MeV when B= 10**15 gauss, in which the electron capture process on protons will be happen rapidly.
Energy of the resulting neutrons will be rather high (greater than Fermi Energy of neutrons) and they will react with the neutrons in the 3P2 Cooper pairs and will destroy these 3P2 Cooper pairs. It will cause the magnetic field induced by the 3P2 Cooper pairs being weaken at the same time. The residual kinetic energy of the outgoing neutron (produced by the previous process) will be transferred into thermal energy. It is just the origin of the x-ray luminosity of the magnetars. The x-ray luminosity of magnetars is calculated theoretically through the previous electron capture process in the work. Our calculation shows that stronger magnetic field, the higher x-ray luminosity. This result is just in consistent with observation.

The Equation of State from Observed Masses and Radii of Neutron Stars

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Recent observational data on neutron star masses and radii from observations of Type I X-ray bursts, thermal emission from cooling neutron stars, and the emission of quiescent low-mass X-ray binaries are analyzed. A Bayesian statistical analysis of these results yields probability contours for the mass versus radius curve and the pressure-energy density relation for dense matter, i.e., the equation of state. With simultaneous mass and radii information, accurate to order 20%, of only six neutron stars, we obtain significant constraints on the equation of state of dense matter. Nuclear parameters such as the incompressibility, symmetry energy, and the density dependence of the symmetry energy all are found to be compatible with laboratory experimental values. In addition, we find that the equation of state at densities just above the nuclear saturation density is moderately soft, resulting in relatively small neutron star radii around 11 to 12 km, but the equation of state stiffens at higher densities to support neutron stars of larger mass.

Magnetic orderings in compact stars

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Magnetic properties of matter should be very important for observation of compact stars. We discuss two magnetic aspects of QCD on the temperature-density plane: one is the spontaneous magnetization of quark matter [1], and the other is the spin-density wave (SDW) [2]. The former is ferromagnetic ordering with uniform order parameter, while the latter is an anti-ferromagnetic ordering characterized by the spatially modulated order parameter.

A possibility of ferromagnetism has been suggested by the use of OGE interaction. The Fock exchange interaction is totally repulsive, like the Coulomb interaction in the electron gas, and then spin triplet state is favored due to the Pauli principle. A rough estimate has given *O*(1015G) for the surface magnetic field of compact stars [1], which may be relevant for magnetars. This subject has been further studied within the Fermi-liquid theory [3]. The magnetic susceptibility has been evaluated and the phase boundary has been presented in the density-temperature plane [3]. Theoretically, we find that quark matter behaves like a *marginal* Fermi-liquid [4]. Actually an anomalous *T*2ln*T* term appears in the susceptibility.

On the other hand the possibility of SDW has been discussed within the context of the restoration path of chiral symmetry [2]. Different from the usual ansatz, the pseudoscalar condensate is allowed, as well as the scalar condensate, to take a finite value at finite density. Since there is chiral symmetry, both condensates must have spatial modulation. It has been demonstrated that SDW is favored near the critical density of the restoration of chiral symmetry. Interestingly we can see that it is driven by the *nesting* effect of the Fermi surface, while the vacuum polarization gives the kinetic energy term for SDW to act against the SDW formation.

Since these two orderings exhibit completely different magneic properties, it should be intersting to see their interplay as density or temperature changes. Note that this is one of the pararells between magnet and superconductor, which are recently appreciated in condensed matter physics [5]; the spatially inhomegenous LOFF phase should appear, following the uniform BCS state in superconductor. Anyhow both phases are characterized by the magnetization w/wo the spatial dependence, and can be studied in a unified way. Here we discuss them by using the NJL model: we examine their emergence at moderate densities and figure out their thermodynamical properties. We also discuss their relation to the restoration of chiral symmtry.

These magnetic aspects of QCD may affect the thermal as well as magnetic evolutions of compact stars.

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The Equation of State of Asymmetric Nuclear Matter at Zero and Finite Temperatures with the Variational Method

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The equation of state (EOS) of nuclear matter is one of the important ingredients in the studies of astrophysical objects such as neutron stars and supernovae(SNe). In this study, we report the EOS of asymmetric nuclear matter at zero and finite temperatures with the cluster variational method[1, 2].
At zero temperature, the nuclear Hamiltonian is decomposed into the two-body part with the AV18 two-body potential and the three-body part with the UIX three-body force. The expectation value of the two-body Hamiltonian is calculated with the Jastrow wave function in the two-body cluster approximation. In this calculation, two constraints are imposed on the variational functions so that the obtained two-body energy reproduces the result calculated with a more sophisticated variational method[3]. The three-body energy is composed of the expectation value of the three-body Hamiltonian with the degenerate Fermi-gas wave function. Parameters included in the three-body energy are determined so that the total energy reproduces the empirical data.
At finite temperatures, the free energies of asymmetric nuclear matter are calculated with an extension of the variational method proposed by Schmidt and Pandharipande[4]. In this method, the free energy is expressed with the approximate internal energy and approximate entropy. The approximate internal energy is calculated in a way similar to that at zero temperature; the Jastrow wave function at finite temperature is employed. This Jastrow wave function is specified by the averaged occupation probabilities of the single particle states for protons and neutrons, respectively. The single particle energies are parameterized by the effective masses of nucleons. The approximate entropy is also expressed with the averaged occupation probabilities. The free energy is minimized with respect to the effective masses.
The free energies and related thermodynamic quantities such as pressures and chemical potentials are calculated for various densities, temperatures and proton fractions. It is confirmed that the entropies derived from the free energies are very close to the approximate ones implying that this variational calculation is self-consistent. It is also found that the free energy is not a quadratic function of the proton fraction, contrary to the case at zero temperature.
The goal of our project is to construct a nuclear EOS appropriate for SN simulations with use of the variational calculations reported above. At present, there are few nuclear EOSs for SN simulations, and they are based on phenomenological frameworks. Therefore, the SN-EOS based of the many-body calculations is desirable. We will also report possible new results of our project.

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Nuclear equation of state in the relativistic mean field model with density dependent coupling constants

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Description of neutron star matter requires the knowledge of the equation of state in the wide range of densities. In this work we are trying to construct the phenomenological description of nuclear matter within relativistic mean field model with density dependent coupling constants. The couplings are well defined only near the saturation density of nuclear matter and are extrapolated to smaller and higher densities. A comparison of the RMF equation of state for nuclear matter with the virial expansion leads to the new constraints of the couplings at small densities. The new parametrization function is built based on this constraints and applied in the calculation of the finite nuclei and neutron star properties.

Compact stars: Laboratory for extremely dense and cold matter

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In this presentation I will discuss pulsar's structure from an astrophysical point of view. Radiation from both magnetosphere and surface is considered to constrain the interior structure of pulsar-like stars, which depends on the physics of cold matter at supra-nuclear density. Although one still cannot answer what the interior structure really is, we conclude that pulsar-like stars could be composed by solid quark matter according to their different manifestations observed.

The effect of 12C + 12C rate uncertainties on the weak s-process component

Bennett M.[1], Hirschi R.[1], Pignatari M.[2], Diehl S.[3], Fryer C.[3], Herwig F.[2], Hungerford A.[3], Magkotsios G.[4], Rockefeller G.[3], Timmes F.[5], Wiescher M.[4], Young P.[5]

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Massive stars (M ≥ 10-12 solar-masses) are responsible for most of the s-process abundances in the solar system between iron and the strontium peak (the weak s-process component). The 22Ne(α,n)25Mg reaction is the main neutron source, which is activated near the end of core helium burning. The residual 22Ne left over from core helium burning is then reignited during convective shell carbon burning, affecting the previous s-process isotopic distribution. The nucleosynthesis picture described above, and in general the weak s-process efficiency, is sensitive to the stellar structure and to the uncertainties of different nuclear reaction rates. In this work, the impact on the weak s-process component of the 12C + 12C reaction rate uncertainty is discussed. In particular, we present the stellar structure and nucleosynthesis yields for 15, 20, 25 and 32 solar-mass stellar models at solar metallicity calculated using different carbon burning rates, where stellar models are calculated using the Geneva Stellar Evolution Code and the nucleosynthesis yields are provided by the MPPNP post-processing code.

Determination of the Stellar Reaction Rates of 17-O(alpha, n)20-Ne and 17-O(alpha, gamma)21-Ne

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The reaction 16-O(n, gamma)17-O acts as a neutron poison in the weak s-process by reducing the number of available neutrons in the stellar burning environment. The captured neutrons can be re-emitted into the stellar environment by the reaction 17-O(alpha, n)20-Ne, weakening the poisoning effect of 16-O. This branch competes with the reaction 17-O(alpha, gamma)21-Ne. Therefore in order to determine the strength of 16-O as a neutron poison one needs to know the ratio of the two stellar reaction rates 17-O(alpha, gamma)21-Ne / 17-O(alpha, n)20-Ne.

Only limited information is available for the 17-O(alpha, gamma)21-Ne and O-17(alpha, n)20-Ne reactions, which leads to a large uncertainty in the isotopic abundances predicted by weak s process calculations.

The (alpha, n) reaction was measured using a high efficiency 4 pi neutron detector in the energy range from 900 keV to 2300 keV. In order to improve the efficiency determination of the detector the (alpha, n1) channel has been measured over the same energy range by detecting the gamma-rays from that reaction with a HPGe detector. Further a GEANT simulation of the detector has been developed.

An initial measurement of the (alpha, gamma) channel has been successfully completed and a second experiment using the newly desigend 5 HPGe detector array GEORGINA is in planning.

Preliminary results of the measurements and the future experiment will be discussed.

The effect of r-process enhancement in binary CEMP-s+r stars

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About half of carbon- and s-process-rich, extremely metal-poor stars (CEMP-s) show high r-process Eu enhancement (CEMP-s+r). Comparable enhancements of other r-process elements, like Dy, Ho, Er, Tm, Os, Ir, are also observed in CEMP-s+r showing [Eu/Fe] ~ 2.
CEMP-s stars belong to binary systems, with C and s-process enrichment resulting from mass transfer from the winds of the primary AGB companion (now a white dwarf). Likely, the high r-process enrichment was present in the molecular cloud from which the binary system formed.
The initial r-enrichment does not affect the synthesis of the three s-process peaks during the AGB phase. However, one should consider that the hs s-process index is usually defined as the average of (La, Nd, Sm), where 70% of solar La, 60% of solar Nd, and 30% of solar Sm are made by the s-process (Bisterzo et al 2009). Consequently, in presence of a very high r-process enrichment, the actual value of [hs/Fe] has also to account of a remaining contribution by the r-process (30% of solar La, 40% of solar Nd, and 70% of solar Sm). The same r-process by SNII that contributes to the heavy abundance beyond Ba does not seem to contribute to Y and Zr, which define the light s-peak index ls (Travaglio et al. 2004).
In substance, for an r-process enrichment characterised by [Eu/Fe] = 2 dex, the s-process index [hs/ls] increases of 0.3 dex. This is in agreement with observations of CEMP-s+r stars that show an observed [hs/ls] in average higher than that observed in CEMP-s.

A Study of 12C(12C,n)23Mg

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The 12C(12C,n)23Mg reaction may be a significant neutron source for the weak s-process. It was recently studied with the FN Tandem Van de Graaff accelerator at the University of Notre Dame using beta and gamma spectroscopy. Measurements were made at low center-of-mass energies down to 3.54 MeV. Since only one other data set exists at these low energies (Dayras et al. 1977), it is important to check these results and attempt to push the measurements towards lower energies, in order to more accurately predict the reaction rate in astrophysical environments. Preliminary results of the new cross-section measurements, along with a comparison to previous measurements, will be presented at the conference.

Re-measuring the half-life of 60Fe

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A recent experiment both at PSI and at Munich on the 60Fe lifetime points to a T1/2 for 60Fe that is possibly 70% higher (i.e. ~ 2.6e+6 years) than the presently accepted value (1.5e+6 years). 60Fe is mainly produced in core collapse supernovae explosions and these new results open up a number of questions as many factors scale with this number; from the 60Fe abundance determination with gamma ray telescope measurements to recent 60Fe(n,gamma) cross section studies.

We are presently working on a double-pronged attempt at re-measuring this half-life using the "old" AMS technique used by the Kutschera group in 1984 as well as a low-background activity measurement on the growth of 60Co from the decay of 60Fe. Both rely however on a clean production of a 60Fe sample as measurements rely on measuring the 60Co decay gamma-line from 60Co produced by the decay of 60Fe. Beam time was made available at the NSCL to produce a number of well characterized 60Fe sample at the focal plane of the A1900 fragment separator. The 60Fe ions were implanted in a high purity Al target. We will report the results from this run as well as from the chemical separation of the 60Fe and first measurements of the sample.

Impact of the reactions 25Mg(α,n)28Si, 26Mg(α,n)29Si and 18O(α,n)21Ne on nucleosynthesis

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Recent network calculations of stellar nucleosynthesis emphasize a need for improved experimental results for the reactions 18O(α ,n)21Ne and 25,26 Mg(α,n)28,29Si. At the University of Notre Dame (Nuclear Science Laboratory) a series of experiments was performed to improve the experimental data. The results, techniques and the impact on stellar nucleosynthesis will be presented.

A liquid-lithium target project for production of high-intensity quasi-stellar neutrons

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A windowless Liquid-Lithium Target (LiLiT) is under construction and development at Soreq NRC (Israel). The target is designed to be bombarded by a 2-4 mA proton beam (E_p= 2.5 MeV) from the high-intensity Soreq Applied Research Accelerator Facility (SARAF), a superconducting linear accelerator for light ions. The liquid-lithium forced flow at a velocity of ~ 20 m/s and a thickness of ~ 1.8 mm serves both as a power dump (10 kW) for the proton beam and as a neutron-producing target via the 7Li(*p,n*)7Be reaction. As known from the work of the Forschungszentrum Karlsruhe group [1], the energy distribution of neutrons emitted for a proton energy E_p= 1.912 MeV, ~ 30 keV above the reaction threshold, and a thick Li target is very similar to that of a Maxwell-Boltzmann flux at a thermal energy of ~ 25 keV, well suited for activation measurements relevant to *s*-process nucleosynthesis. The neutron intensity expected under these conditions from the combination of the SARAF proton beam and the LiLiT thermal properties is of 2-4 × 1010 s-1 mA-1, larger by more than one order of magnitude than currently available. The LiLiT setup is built as a loop circulating liquid lithium at a temperature of ~200 oC and producing a jet (acting as the target) onto a thin concave supporting wall, driven by a rotating magnet inductive electromagnetic pump. The liquid lithium is collected in a reservoir housing a heat exchanger with a mineral-oil closed loop. Circulation and thermal tests of the loop are presently in progress in an offline dedicated electron-gun laboratory and online installation at the SARAF accelerator is planned for end 2010. Characterization of the SARAF proton beam (beam energy, energy width and transverse profile) and of the neutron spectrum obtained under these conditions will be studied in parallel using a solid-lithium (lithium fluoride) target at low beam intensities. The SARAF-LiLiT system will be used to measure stellar neutron capture cross sections for stable or radioactive targets demanding high neutron fluxes. Present status and plans will be discussed.

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Effects of rotation on the weak s process

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The weak s process takes place in massive stars and it produces the majority of s-only isotopes in the atomic mass range from 60 to 90. This process is qualitatively well understood, however there are still large uncertainties remaining on the quantitative side. Rotation has a strong effect on the stellar structure and mixing, but its impact on the s process has not been studied yet. We implemented an extended and flexible reaction network inside the Geneva stellar evolution code (GENEC) to be able to study the influence of rotation on the s process. For a star with a particular initial mass and composition rotation increases the He core size and the central temperature enhancing the s-process efficiency during core helium burning. In turn the C-shell contribution is reduced since more 22Ne has already been burnt during He-burning. Rotation also affects the contribution of the He-burning shell.

Indirect study of 60Fe(n, γ)61Fe via the transfer reaction 60Fe(d,p γ)61Fe

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Observations of 60Fe γ -ray lines by RHESSI and INTEGRAL as well 60Fe observations in deep ocean crust and pre-solar grains have underlined the need for precise nuclear inputs concerning the nucleosynthesis of this radioactive nuclei. Indeed, the cross sections of the reactions 59Fe(n,γ)60Fe and 60Fe(n,γ)61Fe, respectively responsible of its production and destruction, suffer large uncertainties. Hence, we decided to study 60Fe(n,γ)61Fe reaction via the transfer reaction 60Fe(d,pγ)61Fe. This study will allow to determine the location of the bound states of 61Fe as well as their corresponding angular momenta and spectroscopic factors needed to calculate the direct component of 60Fe(n,γ)61Fe cross section.
The experiment was performed at GANIL, using an 60Fe beam, the MUST2 telescopes for particle detection and 4 EXOGAM clovers for gamma-ray detection. A description of the experimental setup will be given as well as the preliminary results concerning the 61Fe excitation energy spectrum.

Stellar enhancement factors in a parity dependent approach

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Due to the finite temperature of stellar environments, nuclear reactions can proceed differently than in the laboratory. The reason for this is that the relative energy of the interacting particles depends on the temperature of the environment. Furthermore the target nuclei can become thermally excited if the corresponding temperature is high enough. This thermal excitation is difficult to reproduce in a laboratory. Thus to account for this thermal excitation of the target nuclei, the so called stellar enhancement factors (SEF) are introduced. The SEF are given by the ratio of the stellar reaction rate $\langle \sigma v \rangle$, which describes the theoretical reaction rate in a stellar plasma, divided by the laboratory reaction rate $\langle \sigma v \rangle_{lab}$, that describes the reaction at a certain temperature, but with the target nucleus being in its groundstate. In our work we calculated the SEF for (n,γ)-reactions of all s-process nuclei in a parity dependent statistical model. In this model the nuclear reaction is described in two steps, first the target nucleus and the projectile form a so called compound nucleus. In a second step the decay from the compound nucleus to the desired daughter nucleus is described. The most imortant input parameter for the calculation of SEF are the excited states of the target nuclei. Due to the fact that the excited states for s-process nuclei are well known, the new included parity dependence is mainly important in the compound nucleus and for the description of the γ-decay in the desired final state.

Nucleosynthesis yields from SAGB stars

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Super asymptotic giant branch (SAGB) stars, in a mass range somewhere between 5 and 11 solar mass have a similar evolution to high mass AGB stars but are hot enough to ignite carbon in their cores non-degenerately during the early AGB phase. However, they do have a different nucleosynthesis signature because of the higher temperature of the base of the envelope, and hence very efficient hot bottom burning. For example, it could be responsible for lithium production in globular clusters (Ventura & D'Antona 2010).

We have used the new Monash nucleosynthesis code (MONTAGE) to compute yields of 86 different isotopes, including s-process elements, from SAGB stars. We will highlight how the nucleosynthesis pattern of SAGB stars is different from AGB stars because the star is much hotter and Ne22 is the major source of neutron. We will also talk about under what circumstances lithium is produced. If time permitted, we will discuss how SAGB yields depend on metallicity and how it fit on the chemical evolution history and observed carbon enhanced metal-poor star pattern.

Definition of a standard neutron field with the 7Li(p,n)7Be reaction

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Neutrons in the keV region produced by the reaction 7Li(p,n)7Be have been used in various cross-section measurements related to astrophysical and technological applications. This reaction is particularly suited for s-process studies. By choosing an incident proton energy of E_p =1912 keV the resulting neutron spectrum resembles a Maxwell-Boltzmann distribution around kT = 25 keV, which corresponds to stellar s-process environments. Furthermore, the neutron capture cross-section on 197Au was previously measured via this technique with an uncertainty of only 1.4% [Ratynski and Käppeler, Phys. Rev. C37 (1988), 595] and used as a reference in a number of other experiments. Since these results require an accurate knowledge of the neutron spectrum itself, a new measurement of the neutron spectrum of the 7Li(p,n)7Be reaction at E_p=1912 keV was performed to check and verify existing information. The experimental setup at the Ion-Accelerator-Facility PIAF of Physikalisch-Technische-Bundesanstalt (PTB) in Braunschweig was perfectly suited for this purpose. Protons were accelerated via the 3.75 MV Van de Graaf accelerator to 1912 keV energy onto a metallic Li-target with a repetition rate of 625 kHz and a pulse-width of 1.5 ns. The neutron spectrum was measured by a movable 6Li-glass detector using the time-of-flight technique in steps of 5 deg. at angles from 0 deg. to 65 deg. with respect to the proton beam and at two different flight-path lengths of 36.9 cm and 71.9 cm, respectively. The neutron fluence was monitored using a long counter mounted at an angle of 16° and a distance of about 6 m. Preliminary results will be presented and compared to previous measurements.

New experimental measurement of the 25Mg neutron capture cross section at n_TOF.

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The slow neutron capture process (s process) in stars is responsible for the production of about half of the elemental abundances beyond iron that we observe today. Most of the s-process isotopes between iron and strontium (60 < A < 90) are produced in massive stars ($M > 10\text{-}12\ M_{sun}$) where the 22Ne(α ,n)25Mg reaction is the main neutron source. Beyond strontium, the s-process abundances are mostly produced in low mass Asymptotic Giant Branch stars (AGB stars, $1.2\ M_{sun} < M < 3\ M_{sun}$), where the neutrons are provided by the 13C(α, n)16O reaction and by the partial activation of the 22Ne(α ,n)25Mg reaction. In stars with an initial metal content similar to solar, 25Mg is the most important neutron poison via neutron capture on 25Mg in competition with neutron capture on 56Fe that is the basic s-process seed for the production of the heavier isotopes. For this reason, a precise knowledge of the 25Mg(n, γ)26Mg is required to properly simulate s-process nucleosynthesis in stars.

We will show the results from a combination of neutron total and capture cross section measurement on 25Mg in order to determine the resonance parameters and the Maxwellian averaged cross section. Capture data come from a recent (n, γ) measurement at the neutron time-of-flight facility n_TOF at CERN. On the other hand transmission data come from an experiment performed at the electron linear accelerator in Oak Ridge. These results constitute the only available neutron resonance data on Mg isotopes.

Neutron capture processes in stars between the s process and the r process

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Most of the isotopes heavier than iron that we observe today are made by neutron capture processes in stars. The standard astrophysical picture is that about half of the heavy element abundances are made by the slow neutron capture process (s process) at low neutron densities, and half by the rapid neutron capture process (r process) with neutron densities beyond 1020 cm-3.
However, the neutron density regime between the s process and the r process is experienced in both low mass stars (e.g., during the H ingestion in post AGB stars) and in massive stars (e.g., during the more advanced burning phases and in the explosive shell He burning).
In these intermediate (between s and r) n-capture events the network flux proceeds further away from stability compared to the s-process, producing unique observable elemental and isotopic signatures. The accurate simulation of this regime requires nuclear data of unstable isotopes that is currently often not available from experiments.
In this work we present the main features of these fast neutron capture processes in stars, the observational constraints available today to study their nature, and the main sources of uncertainty in our simulations.
For our analysis we use the NuGrid stellar evolution and explosion (SEE) library and the NuGrid PPN codes for nucleosynthesis simulations of all stellar environments.

Nucleosynthesis in the He-burning shell in massive stars

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In massive stars He first burns in a convective core, building up fresh carbon and oxygen as main products. Initial CNO nuclei are converted in 22Ne before the He exhaustion, which is the main neutron source for s process via the 22Ne(α,n)25Mg reaction.
When He in the center is exhausted, He burning continues in a convective shell, until the supernova explosion. The He shell pre-explosive abundances are characterized by an incomplete He burning, with carbon more abundant than oxygen, and a mild s-process enrichment due to a partial activation of the 22Ne(α,n)25Mg.
After the explosion, the supernova shock wave boosts the temperature at the bottom of the He shell, causing a burst of neutrons due to the abundant 22Ne with neutron densities ≤ 1018 cm-3.
In this work we discuss the main features of the He shell nucleosynthesis in massive stars, taking into account the relevant uncertainties in the stellar models and in the nuclear physics. We also compare our results with measurements in a sample of single presolar carbon-rich grains, which condensed in the ejecta of old supernovae, mostly from He shell carbon-rich material.

Complete calculation of evaluated Maxwellian-averaged cross sections and their errors for s-process nucleosynthesis

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Present contribution represents a significant improvement of our previous calculation of Maxwellian-averaged cross sections and astrophysical reaction rates [1]. Addition of newly-evaluated neutron reaction libraries, such as ROSFOND and Low-Fidelity Covariance Project [2,3], and improvements in data processing techniques allowed us to extend it for entire range of s-process nuclei, calculate Maxwellian-averaged cross section errors for the first time, and provide additional insights on all currently available neutron-induced reaction data. Nuclear reaction calculations using ENDF libraries and current Java technologies will be discussed and new results will be presented. This work was sponsored by the Office of Nuclear Physics, Office of Science of the U.S. Department of Energy, under Contract No. DE-AC02-98CH10886 with Brookhaven Science Associates, LLC.

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Investigation of s-process branching nuclei with real photons

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The ratio of the neutron-capture rate and the β-decay rate of the so-called branching nuclei determines the isotopic abundance distribution in *s*-process nucleosynthesis. Direct measurements of the neutron-capture rate are limited to particular cases due to the instability of the branching nuclei. We have measured the inverse photo-neutron reaction to constrain the prediction of the neutron-capture rate in the framework of the Hauser-Feshbach model. We compare the results for measurements performed recently with quasi-monochromatic photons at the High Intensity γγ-ray Source (HI γγS) at DFELL, TUNL, USA [1], with an earlier approach using bremsstrahlung of the High Intensity Photon Setup (HIPS) at S-DALINAC, Darmstadt, Germany [2]. Possible influences on the corresponding neutron-capture rates and their effect on isotopic abundance ratios produced in *s*-process nucleosynthesis are discussed.

[1] K. Sonnabend *et al.*, AIP Conf. Proc. **1090** (2009) 481.
[2] K. Sonnabend *et al.*, AIP Conf. Proc. **704** (2004) 463.

The 41Ca(n, α)38Ar reaction cross section up to 100 keV neutron energy

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The 41Ca(n, α)38Ar reaction cross section has been studied with resonance neutrons at the GELINA neutron facility of the Institute for Reference Materials and Measurements in Geel (Belgium) in the neutron energy region from 10 eV up to 100 keV . A Frisch-gridded ionization chamber with methane as detector gas was installed at a 30 meter long flight path. More than 20 resonances have been identified. From the cross section data obtained, the Maxwellian averaged cross section (MACS) has been calculated by numerical integration.

AMS and Nuclear Astrophysics

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Key ingredients to our understanding of nucleosynthesis are accurate cross-section data. Accelerator mass spectrometry (AMS) allows measuring precisely neutron-capture cross sections, thus elucidating current open questions within the s-process path. Recently, the measurement of neutron-induced cross sections relevant to nuclear astrophysics has become one main research topic at the VERA (Vienna Environmental Research Accelerator) facility. Nuclear cross section measurements were performed through ultra-low isotope ratio measurements with excellent sensitivity for the detection of radionuclides: We irradiated a series of samples, consisting of 9Be, 13C, 14N, 35Cl, 40Ca, 54Fe and 209Bi for studying neutron capture reactions. Besides thermal neutron energies from reactors, quasi-stellar neutron energy distributions were produced with suitable nuclear reactions at Forschungszentrum Karlsruhe, corresponding to energies in the range from kT = 25 to 500 keV. After activation, the long-lived product radionuclides 10Be, 14C, 36Cl, 41Ca, 55Fe and 210Bi were analyzed using the technique of AMS.
An overview on recent activities of the AMS technique in nuclear astrophysics will be given including applications relevant for Big-Bang nucleosynthesis, s-process nucleosynthesis, recent space-born observations of ongoing stellar nucleosynthesis, and r-process nuclides like 244Pu.

Neutron-capture element abundances in the globular clusters: 47 Tuc, NGC 6388 and NGC 362

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A spectroscopic study of neutron-capture element abundances has been carried out in three globular clusters: 47 Tuc, NGC 6388 and NGC 362, using both high and medium resolution data.

The stars analysed at high resolution, using data acquired with UVES on the VLT, were luminous giant stars located near the asymptotic giant branch for each cluster. The medium resolution studies have analysed stars that reached below the level of the horizontal branch in at least one cluster, 47 Tuc. We are also exploring the possibility of undertaking large scale studies using the Fabry-Pérot Interferometer (FPI) on the Robert Stobie Spectrograph on the Southern African Large Telescope.

With the high resolution UVES data, two stars were analysed in NGC 6388, six stars in 47 Tuc and eleven stars in NGC 362. The NGC 6388 and 47 Tuc stars showed enhancements in the light (ls: Y, Sr, Zr) and heavy (hs: La, Nd) s-process elements of [ls/Fe] = 0.58 ± 0.13 dex, [hs/Fe] = 0.39 ± 0.07 dex , [hs/ls] = -0.18 ± 0.06 dex and [ls/Fe] = 0.53 ± 0.02 dex, [hs/Fe] = 0.40 ± 0.06 dex, [hs/ls] = -0.13 ± 0.05 dex, respectively. In NGC 362 the stars showed heavy s-process element abundances that were more enhanced than the light s-process ([ls/Fe] = 0.32 ± 0.10 dex, [hs/Fe] = 0.46 ± 0.09 dex , [hs/ls] = +0.14 ± 0.03 dex). A comparison between the s-process element abundances of each clusters show a general trend of increasing [hs/ls] with decreasing [Fe/H]. The small spread in the abundances of these s-process elements indicates a homogeneous distribution within each cluster, confirming that the stars analysed here are not producing s-process elements internally. Hence the s-process element abundance distribution represents a pre-existing chemical signature for each cluster. The previous (Worley et al. 2008) medium resolution study had been less conclusive.

We also present our initial exploration of the use of the FPI technique to determine heavy element abundances and other stellar parameters for a large sample of stars in a range of globular clusters. This will enable us to make assessments of s-process element abundances throughout the HR diagram.

Direct Measurements of (p, γ) cross sections at astrophysical energies using radioactive beams and the Daresbury Recoil Separator*

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There are a number of astrophysical environments in which hydrogen is burned as fuel for (p,γ) fusion reactions. These include both hydrostatic stellar burning and non-hydrostatic explosive events such as novae and X-ray bursts. In many cases, the path of nucleosynthesis leads through proton-rich nuclei which have traditionally not been available as beams, and thus proton-capture reactions on these nuclei could only be studied indirectly. Now with the availability of intense proton-rich beams, some of the first direct measurements of (p,γ) cross sections can be made on these radioactive nuclei important in stellar and explosive burning.

The Daresbury Recoil Separator (DRS) has been installed at the Holifield Radioactive Ion Beam Facility to make direct measurements of proton-capture reactions of astrophysical interest. Proton-rich radioactive beams bombard a windowless hydrogen gas target, and the produced recoil nuclei are transported and separated from the unreacted primary beam with the DRS. They are then detected at the focal plane of the DRS in an isobutane-filled ionization counter. We have recently completed the first measurement of the 17F(p,γ)18Ne cross section at the energy of the most important resonance [1] and have also made the first statistically-significant measurement of the 7Be(p,γ)8B cross section with a radioactive 7Be beam [2]. The method and data will be presented.

[1] K. A. Chipps et al., Phys. Rev. Lett. 102, 152502 (2009).
[2] R. Fitzgerald et al., Nucl. Phys. A 748, 351 (2005).

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Fluid Dynamics Simulations of Ejecta from Novae Explosions

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Classical novae are binary star systems in which matter from an unevolved star is slowly accreted by a white dwarf companion. When the amount of matter accreted on the surface of the white dwarf is massive enough to make the temperature and density at the base of its envelope high enough for ignition of hydrogen, a thermonuclear runaway occurs. Apart from releasing a large amount of energy in various parts of the spectrum, the nova explosion also results in the ejection of matter, forming an expanding shell around the system. In this study we simulate this ejecta in order to follow its morphology during and after its interaction with the gas disc around the white dwarf and also its interaction with the companion star. We aim to compare the simulated ejecta morphology with observations of novae shells and also to quantify the amount of matter that is accreted by the companion star. We use the Lagrangian method of Smoothed Particle Hydrodynamics (SPH) for the simulations. Here we present some preliminary results.

On mixing at the core-envelope interface during classical nova outbursts

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Classical novae are powered by thermonuclear runaways that occur on the white dwarf component of close binary systems. During such violent stellar events, whose energy release is only exceeded by gamma-ray bursts and supernova explosions, about 10-4 − 10-5 M_{sol} are ejected into the interstellar medium. Because of the high peak temperatures attained during the explosion, Tpeak ≈ (1 − 4) × 108 K, the ejecta are enriched in nuclear-processed material relative to solar abundances, containing significant amounts of 13C, 15N, and 17O and traces of other isotopes. The origin of these metal enhancements observed in the ejecta is not well-known and has puzzled theoreticians for about 40 years. We present new 2-D simulations of mixing at the core-envelope interface. We show that Kelvin-Helmholtz instabilities can naturally lead to self-enrichment of the solar-like accreted envelopes with material from the outermost layers of the underlying white dwarf core, at levels in agreement with observations.

Proton decay of 26Si via the 28Si(p,t)26Si Reaction and Implications for 25Al(p, γ)26Si

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The rate of the 25Al(p, γ)26Si reaction in novae is important to the production of galactic 26Al, an important astronomical observable for its 1.809 MeV gamma ray. 26Al has been catalogued near massive stars and found in presolar grains. The 25Al proton capture reaction serves to bypass 26Al production by preferentially populating instead the isomeric state through the beta decay of 26Si. Several recent studies [1,2] have aimed to locate and characterize the first *l* = 0 resonances in 26Si above the 25Al+p threshold, which would dominate the reaction rate at nova temperatures.

We have studied several resonances in 25Al(p, γ)26Si via the 28Si(p,t)26Si reaction at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory. Several higher-energy states in 26Si are given spin and parity assignments for the first time, and one new state was found. In addition to measuring the angular distributions of the tritons, a partial implementation of the Oak Ridge Rutgers University Barrel Array (ORRUBA) [3] was used to measure the coincident protons emitted from the decay of states in 26Si above the proton threshold. We confirm experimentally that the 3+ 5914 keV resonance, the first *l* = 0 state above the proton threshold, does in fact decay essentially 100% of the time via proton emission, resulting in a proton branching ratio consistent with one.

This work is funded by the US DOE and NSF.

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[2] P.N. Peplowski et al., Phys. Rev. C 79, 032801(R) (2009)
[3] S.D. Pain et al., Nucl. Instrum. Meth. Phys. Res. B261, 938 (2007)

Direct measurements of radiative capture reactions with radioactive beams at DRAGON

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Three radioactive beam experiments: 21Na(p,γ)22Mg, 26gAl(p,γ)27Si, and 23Mg(p,γ)24Al, have been performed using the DRAGON recoil mass spectrometer at TRIUMF. Each of these experiments has successfully overcome increasing technical challenges, through the addition of various detectors and more rigorous particle identification. In addition to providing the first direct measurements of the rates of resonant reactions, all three of these experiments brought to light differences in resonance energies from those determined indirectly. Plans for future experiments, such as 18F(p,γ)19Ne (scheduled for fall 2010), will also be discussed.

Lifetime measurements of excited nuclear states of astrophysical interest via the Doppler Shift Attenuation Method

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Resonant (p,γ) reaction rates determine the production of heavy elements in nova explosions and other events. Because there is always a competition of efficient and inefficient reactions, these rates are of high interest to predict final elemental abundances with nuclear network calculations. Therefore, experimental data from rate measurements are required to improve models. Resonant reaction rates can be identified with the knowledge of spins, branching ratios, energy levels and lifetimes of excited states of involved product nuclei. Since the resonant rate is inversely dependent on the lifetime of the excited state, the experimental measurement of lifetimes is important to determine these rates.
The Doppler Shift Attenuation Method (DSAM) is a known technique to measure lifetimes of excited states in the range of fs up to ps. The energy of a Doppler shifted γ-ray, which is emitted by a decelerating de-exciting nucleus, is measured with a HPGe detector. The lifetime of the excited state can then be extracted from the Doppler shifted γ-ray energy spectrum.
A DSAM facility to measure lifetimes of astrophysical interest has been built by the nuclear astrophysics group at TU Munich. First tests and experiments are planned for this year at the Maier-Leibnitz-Laboratorium in Munich.
A study of 34Cl via 35Cl(p,d) will be used to understand the detector system. Known lifetimes of several 34Cl states will serve as calibration references, and new data of unknown states will be measured.

Hydrodynamic Models of Type I X-Ray Bursts: Metallicity Effects

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Type I X-ray bursts are thermonuclear stellar explosions driven by charged-particle reactions. In the regime for combined H/He-ignition, the main nuclear flow is dominated by the rp-process (rapid proton-captures and β+ decays), the 3 α-reaction, and the αp-process (a suite of (α ,p) and (p,γ) reactions). The main flow is expected to proceed away from the valley of stability, eventually reaching the proton drip-line beyond A = 38. Detailed analysis of the relevant reactions along the main path has only been scarcely addressed, mainly in the context of parameterized one-zone models. In this poster, we present a detailed study of the nucleosynthesis and nuclear processes powering type I X-ray bursts. The reported 11 bursts have been computed by means of a spherically symmetric (1D), Lagrangian, hydrodynamic code, linked to a nuclear reaction network that contains 325 isotopes (from 1H to 107Te), and 1392 nuclear processes. These evolutionary sequences, followed from the onset of accretion up to the explosion and expansion stages, have been performed for 2 different metallicities to explore the dependence between the extension of the main nuclear flow and the initial metal content. We carefully analyze the dominant reactions and the products of nucleosynthesis, together with the the physical parameters that determine the light curve (including recurrence times, ratios between persistent and burst luminosities, or the extent of the envelope expansion). Results are in qualitative agreement with the observed properties of some well-studied bursting sources. Evidence of leakage from the predicted SbSnTe-cycle is found in some of our models. Production of 12C (and implications for the mechanism that powers superbursts), light p-nuclei, and the amount of H left over after the bursting episodes will also be discussed.

The 28Si (α,p) and 30S(α,p) reactions with CRIB to study X-ray Bursts

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The 28Si(α,p) and 30S(α,p) reactions significantly affect the total energy output in X-ray burst models, but the reaction rates are not known with enough certainty. The 30S(α,p) reaction is also believed to alter isotopic abundances on the surface of the neutron star, as well as influence the burst profile resulting in double-peaked bolometric luminosities in X-ray bursters. The 30S(α,p) reaction has never been experimentally measured, and there is limited information available from indirect techniques. As the cross-section of many α-capture reactions are known to be dominated by natural-parity alpha resonances in their respective compound nuclei, leading to large discrepancies with the predictions of statistical models, it is important to experimentally constrain these reaction cross sections whenever possible. Using the low-energy Center for Nuclear Study radioactive ion beam separator facility (CRIB) we have developed a 30S RI beam suitable for studying the 30S(α,p) reaction and also measured the 4He(28Si,p) reaction over a wide energy range. Using the developed 30S RI beam, we will measure the 4He(30S,p) reaction using the thick-target inverse-kinematics technique in September 2010 using an active 4He gas target. The results of our 30S RI beam development experiments, the 4He(28Si,p) cross-section measurement, and our future plans for the 4He(30S,p) reaction cross-section measurement are discussed.

Direct measurement of the 18F(p,a)15O reaction at novae temperatures

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Novae may well be the only class of explosive environment where all the important nuclear reactions can be measured at the relevant energies. Indeed, at the present time, there remain only a few reaction rates that have significant experimental uncertainties. One of these is the 18F(p,α)15O reaction thought to be the main destruction mechanism of 18F during the outburst. Annihilation radiation from the decay of 18F after the explosion dominates the gamma-ray emission and thus observational data of its abundance will provide unique information on the conditions during the outburst, assuming the nuclear reaction rates are sufficiently constrained.

A direct measurement of this important reaction has been performed at novae temperatures. Using the ISAC radioactive beam facility at the TRIUMF laboratory, Canada, a 18F beam was incident on a CH2 target. Reaction products were detected, in coincidence, in highly segmented silicon strip arrays in the TUDA chamber. Data were taken at 250, 330, 430 and 665 keV, in the centre of mass, to study the contributions from key resonances and the interference between them. Results will be presented.

β-delayed proton decay of 23Al and nova nucleosynthesis

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Classical novae are relatively common events in our galaxy with a rate of a few per year detected. Present understanding is that novae occur in interacting binary systems where hydrogen-rich material accretes on a white dwarf from its low-mass main-sequence companion. At some point in the accretion the hydrogen-rich matter compresses leading to a thermonuclear runaway [1]. Understanding the dynamics of the nova outbursts and the nucleosynthesis fueling it are crucial in understanding the chemical evolution of the galaxy. The key parameters in understanding the astrophysical reaction rates are the energies and decay widths of the associated nuclear states. One of the key reactions for which the reaction rates are known with large uncertainties is the radiative proton capture 22Na(p, γ)23Mg. This reaction rate is dominated by the capture through low-energy proton resonances which correspond to the excited states in 23Mg nucleus. These can be studied via beta-decay of 23Al which populates excited states of 23Mg that further decay by both proton and gamma-emission.

We have studied the β-delayed proton decay of 23Al with a novel detector setup at the focal plane of the MARS separator at the Texas A&M University to complete the decay spectroscopy study of this nucleus. We also resolve existing controversies about the proton branching of the IAS in 23Mg [2,3] and determine the absolute proton branchings by combining our results to the latest gamma-decay data [4]. Using implantation in very thin Si strip detectors we succeed to measure proton lines as low as 200 keV. These lines identify resonances important in the 22Na(p,γ)23Mg reactions in novae. In particular, we experimentally identify a unique case of a state at E*(23Mg)=7787 keV that decays by both γ-ray and proton emission and we could measure both its branchings. In this contribution, a description of the used techniques along with results of the experiment are given and their relevance for astrophysics discussed.

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[2] K. Perajarvi et al., Phys. Lett. B 492, 1 (2000).
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Spectroscopic study of 26Si for application to nova gamma-ray emission.

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26Al was the first cosmic radioactivity ever detected in the galaxy through its caracteristic gamma-ray emission at 1.809 MeV. Stellar sources for 26Al nucleosynthesis include Wolf-Rayet stars, type II supernovae, Asymptotic Giant Branch stars and classical novae. In case of novae outbursts the 26Al nucleosynthesis is still uncertain mainly due to the lack of nuclear information concerning the 25Al(p,g)26Si reaction. One major source of uncertainty is the absence of clear identification of a 3+ level corresponding to a l = 0 resonance which could greatly enhance the 25Al(p,g)26Si reaction rate.

We report here on a neutron-gamma coincidence measurement of the 24Mg(3Ne,ng)26Si reaction performed at the Orsay TANDEM facility aiming at the spectroscopy study of 26Si. The produced 26Si nuclei were tagged with the detection of neutrons with an array of liquid organic scintillator while the gamma-ray deexcitation of the populated levels was followed using coaxial and clover Germanium detectors. New gamma-ray transitions associated with levels both below and above the proton threshold in 26Si have been identified and will be reported.

Study of Astrophysically Important Excited States of 30S via the 28Si(3He,nγ)30S

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The dominant nova nucleosynthetic path followed by the
thermonuclear runaway on the surface of the white dwarf is very sensitive to the chemical composition of the white dwarf, the extent to which the convective mixing occurs, and the thermal history of the envelope.
Such details can be partially obtained via the laboratory analysis of the Si isotopic abundance ratios (29Si/28Si and 30Si/28Si) in presolar grains of nova origin. Such ratios are of particular interest because the abundance of 28Si provides us with information on the nature of a nova's white-dwarf core (CO vs. ONe). In contrast, both 29Si and 30Si abundances increase monotonically with the white dwarf's mass. Thus, the measured 29Si and 30Si abundances allows one to infer the peak temperatures achieved during the nova outbursts and consequently the overall composition of the nova ejecta.
To calculate the Si isotopic abundances in presolar
grains with high precision, it is critical to know the rates of the thermonuclear reactions which affect the Si production and destruction in novae.
One such reaction is the 29P(p,γ)30S reaction. Variation of the 29P(p,γ)30S rate within its current uncertainty limits has the effect of changing 29Si and 30Si abundances by a factor of 3. At nova temperature range, the 29P(p,γ)30S reaction rate is uncertain and is thought to be dominated by two low energy proton-unbound 3+ and 2+ resonances, whose properties remain unknown.
We investigated the level structure of 30S by in-beam gamma-ray spectroscopy at University of Tskuba Tandem Accelerator Complex in Japan by using two Ge-detectors as well as a liquid scintillator to detect the neutrons. The excited states were populated by the 28Si(3He,n γ)30S nuclear reaction. The present status of the data analysis will be discussed.

Alpha-induced astrophysical reactions studied at CRIB

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CRIB (CNS Radio-Isotope Beam separator) is a low-energy RI beam separator of Center for Nuclear Study (CNS), University of Tokyo. Studies on nuclear astrophysics
and other topics have been performed using RI beams at CRIB, forming international collaborations. Recent improvements on the beam production at CRIB and
experimental studies are discussed, including some results and plans for studies on alpha-induced astrophysical reactions.

A main study currently going on is measurements of alpha resonance scattering using 7Li and 7Be beams. This study is related to astrophysical 7Li/7Be(alpha,gamma) reactions, important at hot p-p chain and neutrino-process in supernovae. It is also interesting to study exotic cluster structure of 11B/11C nuclei, similar to the one seen at Hoyle state in 12C.

Another interest is on (alpha, p) reactions, which may play important roles in hot p-p chains, gamma-ray bursts, novae,and other astrophysical phenomena. In particular, we are interested in
11C(alpha,p),14O(alpha,p),
21Na(alpha,p), 18Ne(alpha,p),and 30S(alpha,p) reactions.
Some results and plans for the measurements of these reactions at CRIB are also presented.

The level structure of 18Ne

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We have measured levels in 18Ne by the 16O(3He,n)reaction at the FN tandem accelerator of University of Notre Dame as a way to explore one of the breakout paths from the hot CNO cycle. In some explosive environments like Novae and X-ray bursts, the temperatures are high enough to bypass the beta decay of the waiting points breaking out of the hot CNO cycle by a thermonuclear runaway. One of the two paths to break from the hot CNO cycle is the reaction chain 14O(α,p)17F(p,γ)18Ne(α,p). The starting (α,p) reaction on the waiting point nucleus 14O proceeds through resonant states above α-decay threshold in 18Ne. The rate of this reaction is therefore very sensitive to the partial and total widths, excitation energies and spins of the resonances in 18Ne. We studied the relevant states in 18Ne using an array of liquid scintillators with time-of-flight and pulse-shape-discrimination techniques to measure the neutrons while decaying charged particles were detected by a silicon detector array. Coincidences of n-p/α were used to measure α and proton decay branching ratios via ground state and exited states in 17F. DWBA calculations were carried out to determine the possible spins of the states. We will include this new information in reaction network calculations to determine the impact of this breakout path on the nuclear energy generation and nucleosynthesis that occur in these explosive hydrogen burning environments.
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Forbidden EC-capture and crust heating in accreting neutron stars

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We have studied a possible impact of the first-forbidden electron capture on the superburst ignition in accreting neutron star. The main nuclear sources of heating the crust which usually have been considered are compression induced one- and two-step electron capture (EC) [1], (ϒ ,n) , (n, ϒ) reactions and less explored picno-nuclear reactions [2]. Studying the detailed balance of the crust heating and constraining relevant ignition depth presents a unique probe for the neutron star interior.

Previously, to estimate the EC-induced heating, only the ground-state to ground-state transitions were included [1], thus a heat deposition from radiative de-excitation was negligible. In the recent papers [3], the electron capture to the excited Gamow-Teller (GT) states has been included. That typically involve transitions to the excited states below the GT-resonance and consequently result in larger heating contributions. However, the QRPA model with no particle-particle channel used in [3] is known to overestimate the energies and strengths of the pairing de-blocked states in the region below the GT-resonance.

We calculated the EC-rates along the possible crust heating process paths involving very neutron-rich s-d shell nuclei within the framework of [4] using self-consistent DF+CQRPA beta-strength functions [5] for excited GT and First-Forbidden (FF) states in the daughter nuclei. Also the continuum EC-delayed neutron emission rates are of interest, as those has not been reliably calculated so far.

The DF+CQRPA calculations show the need for a fully microscopic analysis including both GT and FF decays. As the experimental data on the GT and FF decay for very neutron-rich s-d shell nuclei are absent, we have compared our predictions with a high precision data obtained in the (t,3He), (n,p) and (d,2He) reactions near 48Ca and agreement is found to be convincing.

To exemplify the results for s-d shell nuclei we consider the chain of 55Ti-55K. Interestingly enough, for the EC on the 55Ca our prediction gives no discrete GT-states in the daughter 55K nucleus. However, the EC-captures can undergo to the FF state at Ex=150KeV and strong FF state at Ex=4.45 MeV. An amplification of the EC-capture rate for 55Ca - 55K chain due to the FF decays is found to be significant (at $T=0.7T_9$ by the factor of 10 to 100 depending on the electron chemical potential.) Thus, in individual neutron-rich s-d shell nuclei inclusion of the FF transitions may significantly reduce the crust heating as compared with the predictions of [3].

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A new technique for measuring astrophysically important (α,p) reactions

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The αp-process, which consists of series of (α,p) and (p,γ) reactions, plays a crucial role in understanding the synthesis of heavy elements in explosive x-ray bursts. Most of the important (α,p) reactions, however, have never been experimentally determined in the laboratory. These measurements are challenging requiring the use of radioactive beams bombarding He targets in inverse kinematics.

We have developed a new approach for the measurement of (α,p) reactions using heavy ion beams and have measured the 4He(19F,1H)22Ne reaction as a demonstration. 19F beams were used at the Holifield Radioactive Ion Beam Facility (HRIBF) tandem accelerator in Oak Ridge National Laboratory (ORNL) to bombard a large scattering chamber filled with helium gas. Using a newly built gas recirculator system, the windowless gas target [1] was maintained at a constant pressure of 9 Torr of He. Recoiling protons from the reactions were detected by a large area annular silicon strip detector array (SIDAR) which was configured in ΔE-E telescope mode. We measured the 19F(α,p) and 19F(α,p') excitation functions over the energy range of $E_{c.m.}$~1-2.1 MeV. Details of the experimental setup and a status report on the analysis will be presented. We will also discuss plans to apply this technique for measurements of (α,p) reactions using radioactive ion beams.

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Design of SECAR, a new recoil separator for astrophysics at the NSCL and FRIB

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Radiative capture of hydrogen and helium plays a crucial role in the energy generation and element synthesis in many stellar environments. In explosive events such as novae and X-ray bursts, those reactions involve unstable ions. To study them, radioactive beams are directed at hydrogen and helium targets. The detection of the reaction products requires very high rejection of the primary beam which can only be obtained with a recoil mass separator. Large angular and energy acceptance, high transmission efficiency of a given charge state, good mass resolving power and a rejection factor that reduces the count rate at the focal plane detector to less than a few per minute are the main requirements of such a device.

SECAR, a recoil mass separator, is under development for the NSCL reaccelerated beam facility ReA3, which will later be upgraded to the high intensity of FRIB (Facility for Radioactive Ion Beams). The radioactive beams available at the NSCL and later FRIB are well suited to study explosive nucleosynthesis processes. Preliminary design ideas will be presented along with the experimental plans.

The development of SECAR is funded by the US DOE Office of Science.

A modern 15O(a,g)19Ne reaction rate for X-ray burst models

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The reaction 15O(a,g)19Ne is a key reaction for breaking out of the hot CNO cycle in explosive hydrogen and helium burning environments and may play a vital role in the triggering of x-ray bursts on accreting neutron stars. Recent experimental efforts have provided enough new information to warrant a new evaluation of this reaction rate. We evaluate these data using a Monte Carlo technique, including published lifetime and alpha decay branching ratio measurements.

Study of the 18Ne(α,p)21Na Hot-CNO breakout reaction using SHARC, a new, versatile, silicon array

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Nuclear processes driving nuclear synthesis in stars often cannot be studied directly in the laboratory. This is because the reactions in many cases involve short-lived nuclei, and are furthermore hindered by the Coulomb repulsion of the nuclei, making direct observation of the reactions difficult or even impossible. Reactions related to the breakout from the Hot-CNO cycle, where the rp-process in X-ray bursts is initiated, are in this category. Instead of direct measurements, the reactions must in many cases be studied indirectly in reaction studies which probe the nuclear structure that determine the astrophysical processes.

The Silicon Highly-segmented Array for Reactions and Coulex (SHARC) is a new multi-purpose array for charged-particle detection designed to address these questions. The array is used in conjunction with the TIGRESS gamma-ray spectrometer [Svensson C E, et al., J. Phys. G, 31:S1663 (2005)] at TRIUMF/ISAC, Canada [Laxdal R E, et al., proceedings of LINAC08, p. 97 (2008)]. The first study of an astrophysical reaction utilising the array, an indirect study of the 18Ne(α,p)21Na reaction, is presently under way. This reaction may be a key contributor to the breakout from the Hot-CNO cycle in X-ray bursts. The rate of the reaction is controlled by the structure of 22Mg in the energy region 0-2 MeV above the α threshold [Matic A, et al., Phys. Rev. C, 80:055804 (2009)], states that are populated experimentally using a radioactive ion beam in inverse kinematics via the 20Na(6Li,α)22Mg reaction. The subsequent proton and proton-γ decays of the states are measured in coincidence with the residual α particle from the reaction and properties of the relevant 22Mg states deduced.

Data from this first investigation of an astrophysical reaction utilising the combined TIGRESS/SHARC setup will be presented along with a presentation of the versatility of the array with particular focus on other present and future applications of the array to the study of astrophysical reactions in radioactive-ion-beam experiments. The presented research is supported by the UK-STFC through the STFC-EP/D060575/1 grant and is submitted on behalf of the TIGRESS/SHARC collaboration.

Mass measurements of neutron rich isotopes in the Fe region and electron capture processes in neutron star crusts

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Electron capture processes in the crust of accreting neutron stars have been proposed as a heat source that can affect the thermal structure of the star. Such heating will have implications for the ignition depth of carbon superbursts, and the observed quiescent luminosity of transiently accreting neutron stars. Nuclear masses of very neutron rich nuclides are necessary inputs to model the electron capture process, as they directly influence the energy threshold of each reaction as well as the energy released. We present results of a time-of-flight mass measurement experiment at the National Superconducting Cyclotron Laboratory (NSCL). The measurement was performed for neutron rich isotopes in the region of the N=32 and N=40 subshells, which coincides with the mass range of carbon superburst ashes. We also discuss reaction network calculations performed to investigate the impact of our new measurements, and to compare the effect of using different global mass models in the calculations. The simulations show the profile of the energy deposited in the outer crust is sensitive to the measured masses. In addition, it is observed that the process is sensitive to the differences in the odd-even staggering of the nuclear masses predicted by the mass models.

Role of Shell Model Nuclear Level Densities for Nuclear Astrophysics

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Precise estimation of the reaction rates necessary for an accurate prediction of stellar evolution heavily depends on the nuclear level density model (NLD) used in the calculation. In the last decade the most used reaction rates were those reported in Ref. [1], which use a refined version of the Fermi gas model to estimate the NLD. In recent years open codes, such as talys [2], become available, which can be used to compare the reaction rates calculated with different NLD models. The results provided by talys for the potentially rp-process waiting point nuclei 64Ge and 68Se show large variation (>10) of
their reaction rates when different NLD models are used at the
temperatures relevant for the rp-process. In addition, these reaction rates are significant different from those of Ref. [1] that are still heavily used in recent analyses [3]. Recently, we developed a methodology [4-7] of calculating the the spin and parity dependent shell model NLD, which is a very important ingredient in the Huaser-Feshbach theory for calculating reaction rates for nuclear astrophysics [1]. We developed new techniques based on nuclear statistical spectroscopy to calculate the spin and parity projected moments of the nuclear shell model Hamiltonian, that can be further used to obtain an accurate description of the nuclear level density up to about 15 MeV excitation energy. In the last year we make some breakthroughs in our computational methodology, by using the proton-neutron formalism and by porting our codes to massively parallel computers, which allowed us to increase the speed of our calculations by many order of magnitude, and provides us with the opportunity to calculate shell model NLDs for a large class of nuclei. The reaction rates for the waiting point nuclei ^{64}Ge and ^{68}Se calculated with our shell model NLDs will be present in comparison with other NLD models available in talys.

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Mass measurements at JYFLTRAP for explosive hydrogen burning below A=60

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Atomic masses are one of the key input parameters in the modeling of astrophysical processes such as nucleosynthesis in novae or the rapid proton capture (rp) process taking place in hydrogen-rich environments. JYFLTRAP, a double Penning trap mass spectrometer at IGISOL (Ion-Guide Isotope Separator On-Line), is an ideal tool for measuring masses of astrophysically interesting nuclides with high precision. The neutron-deficient radioactive ions of interest are produced via fusion-evaporation reactions at IGISOL. After acceleration and mass-separation, the ions are sent to a radiofrequency cooler and buncher (RFQ) which delivers the ions as short bunches to JYFLTRAP. The first trap (purification trap) is used for isobaric purification of the beam and the mass is determined via the time-of-flight ion-cyclotron-resonance method in the second trap (precision trap).

The ion-guide method is fast and chemically insensitive and thus, mass measurements between various nuclides produced in the same target and beam combination can be performed sequentally. A network of mass measurements consisting of 13 nuclides and 17 measured frequency ratios close to the rp-process waiting-point nucleus 56Ni has led to substantially smaller mass uncertainties in this region. At 56Ni, the rp-process must proceed via the proton-capture reaction 56Ni(p,gamma)57Cu for which a Q-value has been measured directly at JYFLTRAP. In the lower mass regions, the proton-capture Q-values of 22Mg(p,gamma)23Al and 25Al(p,gamma)26Si, important for modeling the NeNa and MgAl cycles in ONe novae, have been determined with sub-keV precision. The new Qp values have a direct effect on the calculated reaction rates and decrease the uncertainties remarkably. In this contribution, an overview of the mass measurements at JYFLTRAP for explosive hydrogen burning below A=60 will be given.

Coulomb dissociation reactions on proton-rich Ar isotopes

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The rapid proton capture process (rp-process) is an important part of explosive hydrogen burning scenarios. In such explosive stellar events the β-decay rates are much slower than the proton capture rates.
The rp-process involves nuclei along the proton dripline up to its model-dependent endpoint and hence, radioactive beam experiments are necessary to measure the reactions and decay processes on radioactive nuclei [1]. Far from stability, the proton capture rates are dominantly governed by only a few resonances, hence, statistical models are not applicable any more.
The reaction flow in x-ray bursts has an important bottleneck in the 30S-34Ar region [2]. The 32Cl(p,γ)33Ar reaction is part of this bottleneck and therefore a detailed analysis of this reaction is needed.
We performed a radioactive beam experiment in inverse and complete kinematics at GSI, applying the coulomb dissociation method on proton-rich Ar isotopes. This allows the determination of the 33Ar(γ,p)32Cl reaction, which is the time-reverse reaction of the desired 32Cl(p,γ) reaction. The 33Ar was produced via fragmentation of a primary 36Ar beam at 825 AMeV on a Be target. Isotopes with similar A/Z ratios were then selected using the Bρ - ΔE - Bρ fragment seperator FRS and subsequently directed onto a 208Pb target, situated at the LAND/R3B setup in cave C.
All incoming and outgoing particles were measured with several different detector types and a particle identification is used to gate on a certain incoming nucleus. To specify the (γ,p)-reaction channel a cut on the outgoing (Z-1,N) - nucleus in coincidence with a proton is applied.
The incoming and outgoing identification will be shown and preliminary results will be discussed.

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Study of the ^{15}O($2p,\gamma$)^{17}Ne reaction by the Coulomb Dissociation method.

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At high temperature and density conditions, the CNO cycle and the \textit{rp} process are linked by the α capture reaction on ^{15}O, which allows to process the initial CNO material towards heavier nuclei. However, the main obstacle for a continuous reaction flow between the CNO cycle and the FeNi-mass region are the waiting point nuclei. One of these waiting points is ^{15}O. The ^{15}O($2p,\gamma$)^{17}Ne reaction could serve as a bypass of this point.

The three-body radiative capture can proceed sequentially (J. G\"orres \emph{et al.}, \emph{Phys. Rev. C} 51, 392, 1995) or directly from the three-body continuum (L.V Grigorenko, M.V. Zhukov, \emph{Phys. Rev. C} 72, 015803, 2005). It has been suggested that the reaction rate can be enhanced by a few orders of magnitude by taking the three-body continuum into account. In order to verify these calculations, we have deduced the ^{15}O($2p,\gamma$)^{17}Ne cross section by studying the time-reversed process, the Coulomb dissociation of ^{17}Ne, at the LAND/R^{3}B setup at GSI.

The Array for Nuclear Astrophysics Studies with Exotic Nuclei (ANASEN)*

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Reactions involving radioactive nuclei play an important role in stellar explosions, but experimental information about most reactions involving short-lived nuclei is limited. New facilities aim to provide wider access to unstable isotopes, but the limited intensities that are available require more efficient and selective techniques and devices to study the reactions important for astrophysics. The Array for Nuclear Astrophysics Studies with Exotic Nuclei (ANASEN) is a charged-particle detector array designed primarily for studies of reactions important in the αp- and rp- processes with proton-rich exotic nuclei. The array consists of 40 silicon-strip detectors backed with CsI scintillators. The detectors cover an area of about 1300 cm2 providing essentially complete solid angle coverage for the reactions of interest with good energy and position resolution. ANASEN also includes a position-sensitive annular gas proportional counter that allows it to be used as an active gas target/detector. One of the primary goals of ANASEN is the direct measurement of (α,p) reactions in inverse kinematics. ANASEN is also well-suited for studies of proton elastic and inelastic scattering, (p,α) reactions and transfer reactions, which will also be studied to indirectly determine reaction rates important for astrophysics. The array is being developed by Louisiana State University and Florida State University, and will be used primarily at the RESOLUT radioacitve ion beam facility at FSU and the ReA3 facility at the National Superconducting Cyclotron Laboratory.
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Coulomb dissociation of 27P: a reaction of astrophysical interest

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Some nucleosynthesis models developed in the 1940's assumed that nuclide were produced in a primordial process so called fireball, at the beginning of the Universe; those models failed however to explain the experimental observation that stars do not have the same surface composition. Later on, with the help of satellites, the measurement of γ-ray coming from the Galaxy confirmed the idea of an ongoing nucleosynthesis scenario still active in stars. The first evidence was the measurement of the γ -ray line from the de-excitation of 26Mg produced by the β -decay of 26Al. This nucleus has a life time of 1.05x106 years, much shorter than the age of the Universe, hence the importance of the knowledge of this nucleus and its neighbourhood.

γ -ray measurements at the Galactic plane showed that 26Al is mainly produced in massive stars (novae and supernovae). One possible production way is the rp-process.

26Al has a metastable and a ground state, the first one decays predominantly to the ground state of 26Mg, nevertheless the ground state decays to the first excited of 26Mg giving a γ -ray of 1.809MeV (the one detected in galactic measurements). The β -decay of 26Si mainly populates the 26Al(g.s.), and the production of the 26Si comes from the competition of the β -decay 25Al and the reaction 25Al(p,gamma)26Si that is destructed in the 26Si(p,gamma)27P. Within this scenario the 26Si(p,gamma)27P reaction appears as important, first because it is in the rp-path and secondly because it influences the generation of 26Al.

The direct study of the reaction 26Si(p, γ)27P at astrophysical energies is extremely challenging due to the low intensity associated to low energy radioactive beams and low cross sections involved. Coulomb dissociation studies of the inverse kinematics reaction 27P(γ ,p)26Si have instead been proposed. A 27P beam impinges on thick Pb target. The 27P is then excited via the absorption of a virtual photon to a particle unbound state which decays into p+26Si. This inverse reaction profits of a much larger cross section

The experiment was performed using the ALADIN-LAND setup at GSI with a 36Ar primary beam at 500MeV. A secondary beam of 27P was produced by projectile nuclear fragmentation at the FRS. The ALADIN-LAND setup allows to measure in full kinematics. After the Coulomb dissociation of 27P under the effect of the thick Pb target, both outgoing fragments, protons and 26Si enter in the large acceptance magnet (ALADIN) and are deflected differently according to their associated rigidities. A set of detectors located after the magnet allow to track and identify protons and fragments in an event by event basis. Preliminary results of the associated invariant mass spectrum will be presented.

Astrophysical reaction rate of 30S(*p*, γ)31Cl studied by Coulomb dissociation

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The stellar reaction 30S(*p*, γ)31Cl was studied via Coulomb dissociation. The nucleus 30S is a candidate for the waiting point, where the reaction flow to higher masses is interrupted by long β decay, in the rapid proton capture (*rp*) process. The 30S(*p*, γ)31Cl reaction decreases the amount of 30S, and thus speeds the reaction flow of the *rp* process up. Therefore the strength of this reaction affects the resultant abundance and energy generation in the *rp* process. No direct measurement of the 30S(*p*, γ)31Cl reaction was made so far due to the short lifetime of 30S and the small cross section. We overcome this difficulty by applying the Coulomb dissociation method. With this method, one can extract the cross section of the relevant stellar reaction using relatively low intensity beam. The aim of the present work is to determine the resonant capture reaction rate of 30S(*p*, γ)31Cl using the Coulomb dissociation of 31Cl.

The experiment was performed in RIKEN Nishina Center. The secondary beam of 31Cl at 58 MeV/nucleon was produced and separated using RIKEN Projectile Fragmentation Separator (RIPS), and bombarded a 208Pb target. The momentum vectors of the breakup products, the isotopes 30S and protons, were determined using the detectors located at downstream of the target. The relative energy spectrum of 30S + *p* was obtained using a invariant-mass method. Unbound excited states in 31Cl, which are relevant to the stellar reaction, were identified.

In this talk, the reaction rate of the 30S(*p*, γ)31Cl and astrophysical implications obtained from the present study will be discussed.

A study of resonant states involved in breakout from the hot-CNO cycle using inelastic proton scattering of 21Na in inverse kinematics

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The 18Ne(α,p)21Na reaction is currently considered a crucial process governing breakout conditions from the Hot-CNO cycle at temperatures of the order of 1GK, leading to energy generation and further nucleosynthesis from the rp-process in X-ray bursters (XRBs). Attempts at directly measuring reaction rates similar to this in energy regions of interest have been met with difficulty, including the requirement for high beam currents. By utilising a radioactive 21Na beam and scattering protons from a hydrogen-rich target, it is possible to study the properties of the states of the compound nucleus 22Mg above the alpha-particle reaction threshold of 18Ne. We discuss preliminary analysis of the data taken using the TIGRESS and BAMBINO detector arrays at TRIUMF, Vancouver.

νp -process nucleosynthesis as a thermometer for matter ejected in neutrino-driven winds

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The neutrino-driven wind that follows core-collapse supernova explosions is an exciting site for different nucleosynthesis processes. Hydrodynamical simulations of core-collapse supernovae and of the subsequent neutrino-driven wind show that the ejecta are proton rich. Due to the large (anti-)neutrino fluxes elements heavier than A ∼ 64 can be produced by (n,p) reactions followed by proton capture reactions which constitute the basics of the νp -process.

We have performed a detailed study of the impact of the reverse shock on the nucleosynthesis in neutrino-driven winds. In this study, we have explored the sensitivity of νp-process nucleosynthesis to the long term evolution of the ejected matter and in particular to the interaction of the wind with the slow moving supernova ejecta which results in a wind termination shock or reverse shock. In this shock, kinetic energy is transformed into thermal energy resulting in an increase in temperature. This temperature jump is crucial for the nucleosynthesis in proton-rich conditions due to the strong sensitivity of proton capture reactions to temperature. We have found that a substantial amount of light p-nuclei is produced by the νp-process if the reverse shock occurs when the ejecta reaches a temperature ($T_{rs} \approx 2$GK). When the temperature is lower $T_{rs} \approx 1$GK), the proton energy is not large enough to overcome the Coulomb barrier. Reciprocally, at high temperatures ($T_{rs} \approx 3$ GK) photodissociation reactions dominate, preventing significant formation of heavy nuclei. This puts strong constrains on the dynamics of the ejected matter and allows to use the νp-process to characterize the properties of matter ejected during the neutrino wind phase.

Study of transfer reaction channel produced in the system 12C+27Al at 73 MeV

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In recent years, there has been a lot of interest in studying transfer reactions and heavy ion induced reactions provide a wide opportunity for studying various transfer channels. Recently, we have studied one nucleon transfer (proton transfer) in the reaction 12C+27Al which ends up with 11B+28Si as exit channel. The experiment was carried out at BARC-TIFR 14UD Pelletron Accelerator Laboratory, Mumbai, using 73 MeV 12C ion beam on 27Al target. Emitted fragments have been detected in Si-Si telescope in a wide angular range. The distance of the telescope from the target was 20.9 cm. The well separated ridges corresponding to different fragments are clearly seen in deltaE-E scatter plot. Here, in this paper, the different states of 11B populated in the reactions 12C+27Al will be presented.

The experimental data have been analyzed with the software LAMPS. The theoretical zero range distorted wave Born-approximation calculations have been done using the code DWUCK4. The required optical model potential parameters were extracted by fitting the elastic angular distribution data for the systems 12C+27Al (entrance channel) [1] and 11B+28Si (exit channel) [2] respectively using the code ECIS94. Though the theoretical DWBA calculation reproduces the shape of the experimental angular distributions for the ground and first excited state very well still they vary in magnitude. DWBA calculation underpredicts the differential scattering cross sections. The analysis is in progress.

Acknowledgement: The authors gratefully acknowledge Prof. Subinit Roy of SINP to pursue this work.

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Coulomb dissociation reactions on Mo isotopes for astrophysics applications

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Photo-dissociation reactions are important for explaining abundances of the nuclei produced via the so-called p-process, which takes place in Type II supernova explosions. Theoretical calculations of the isotopic p-nuclei abundances require a huge reaction network linking thousands of isotopes, where most of the reaction rates have to be derived from theoretical estimates [1].

However, it's important that as many rates as possible are determined experimentally to provide pivot points for the calculations. In all present models, a significant underproduction of p-nuclides 92Mo and 96Ru is observed. At the same time, 92Mo has one of the highest cosmic abundances of all p-nuclei.

At the SIS/FRS/LAND facility at GSI Coulomb excitation of the stable 92, 94, 100Mo and the unstable 93Mo isotopes was studied in inverse kinematics. A 208Pb target was bombarded with primary beam of 94Mo and 100Mo. Accelerated to the energy of 500 MeV/u, the Mo nucleus was interacting with a virtual photon from the Coulomb field of the heavy target. The neutron-deficient isotopes 92, 93Mo were produced by fragmentation of 94Mo on a Be target. The Fragment Separator (FRS) allowed the selection of the incoming ion species, which was then interacting with the 208Pb target.

The experimental setup provides the possibility to identify the outgoing nucleus with respect to A and Z. Together with a neutron hit in the neutron detector LAND, it allows to tag the proper reaction channel. An important aspect of this project was to test the ability of extracting (γ,n) cross section from Coulomb dissociation and to verify the method by comparing the data with direct (γ,n) experiments performed with real photons at S-DALINAC (TU Darmastadt) and Elbe (FZD) [2].

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Half-life determination of 133mCe for activation cross section measurements

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The scarcity of experimental data relevant for the astrophysical p-process nucleosynthesis necessitates nuclear reaction cross section measurements in the mass range of the p-isotopes. As a next step in a systematic study of reactions relevant for the p-process, alpha induced reactions on 130Ba are investigated.
In order to obtain the cross section of the
130Ba(α,n)133mCe reaction with the activation technique, one needs to use the half-life of the 133mCe reaction product.
Our preliminary analysis of the cross sections showed that the literature value of this half-life (4.9 ± 0.4 h) is clearly underestimated. Moreover, the associated relative error of the literature value is unusually high, increasing the error of the final cross section value.
To solve this problem, thorough half-life measurements based on γ-spectroscopy have been made at ATOMKI, Debrecen. As a result of the experiments, a new value for the half-life of 133mCe is suggested. The poster shows the details and results of this measurement.

Investigation of neutron-nucleus optical potentials

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The p process reaction network involves about 1000 nuclei and more than 10,000 reactions. Photo-induced as well as particle-induced reactions play an important role in this network. For elements heavier than Calcium reaction rates have to be calculated within the Hauser-Feschbach model. Therefore, it is mandatory to verify and improve the predictive power of these calculations studying the influence of the underlying nuclear physics.
An investigation of optical neutron-nucleus potential is carried out via activation measurements of the three reactions 166Er(α,n), 169Tm(p,n) and 170Yb(γ,n). All reactions form the compound nucleus 170Yb and consequently occupy the same exit channel. Experimentally detemined cross sections are compared to theoretical preditions by variation of the optical neutron-nucleus potential while all further input parameters are constant. The preliminary results of the investigation will be presented.
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The IRIS facility: A new tool for nuclear astrophysics

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Reactions induced by photons play a significant role in several explosive scenarios and are the main players of the astrophysical p-process [1], which is responsible for the synthesis of about 35 stable nuclei heavier than iron. These cannot be produced via neutron capture processes such as the *s* or *r*-process.

The electron linear accelerator of the ionizing radiation facility (IRIS) at the ITN laboratory in Lisbon, Portugal, provides pulsed beams with energies up to 14 MeV. The monoenergetic beam can be converted into a continous bremsstrahlung spectrum of photons, which can be used to study photodisintegration reactions via the activation technique.

In this contribution we present the LINAC of the IRIS facility with the purpose of investigating photondisintegration reactions relevant for nuclear astrophysics, with a special focus on *p*-process relevant reactions. Furthermore, we present the results from our first test study of the reaction 197Au, and compare to previous measurements [2].

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152Gd(p, γ)153Tb reaction cross section measurement for the astrophysical p-process

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The elements heavier than iron are mainly synthesized by two mechanisms: the slow neutron capture process (s-process) and the rapid neutron capture process (r-process). The p-process is an additional mechanism that is responsible for the production of 35 proton rich stable isotopes, which are so-called p-nuclei shielded by stable nuclei from the production via the s- and r-processes. Since experimental works related to p-nuclei, between Se and Hg, are relatively few, 152Gd(p, γ)153Tb reaction cross sections have been measured with the activation method in the beam energy range between 3.5 and 8 MeV in order to extend the experimental database for the astrophysical p-process and to test the reliability of statistical model predictions in the heavier mass region. The targets were prepared by evaporating Gd_2O_3 powder enriched to 30.6 % in 152Gd on Aluminum backing foils, and irradiated with proton beams provided by the cyclotron accelerator of ATOMKI. Preliminary results are presented and compared with the predictions of statistical model calculations.

Measuring α-induced cross sections in the region of the heavy p-nuclei: the case of 169Tm+α

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The stable proton-rich nuclei with charge number Z ≥ 34 are the so-called p-nuclei. It is generally accepted that the main stellar mechanism synthesizing these nuclei - the p-process or, more specifically, the γ-process - is initiated by (γ,n) photodisintegration reactions on preexisting more neutron-rich seed nuclei [1,2]. Recent p-process models employing theoretical reaction rates in large reaction networks [3,4] have proven that in the region of heavy p-nuclei (140 ≤ A ≤ 200) the γ-process reaction flow is strongly sensitive to the (γ,α) photodisintegration rates. In order to understand the path of the γ-process in this mass range and to determine precisely the p-isotope abundances, experimental data is clearly needed.

The rate of the γ-induced reaction can be calculated through the detailed balance theorem from the cross sections of the inverse capture reactions. Recently, several (α,γ) cross sections around A ≈ 100 have been measured. However, above the A ≈ 100 mass region there are practically no experimental (α,γ) data below the Coulomb barrier due to experimental difficulties. In the present work a novel experimental approach is proposed to determine the cross sections of α-induced reaction: the detection of characteristic X-ray radiation following the electron capture decay of the reaction products. The application of this approach will be presented through the example of the cross section measurement of the 169Tm(α,γ)173Lu reaction [5].

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α-induced activation reaction cross section measurement 130Ba relevant for the astrophysical p-process

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The deeper understanding of the synthesis of elements - in stars and supernovae - is the focal point of nuclear astrophysics. The validation of nucleosynthesis theories are based mainly on experiments, i.e. on the extensive knowledge about the reaction cross sections. For this reason there is a great demand to high precision measurements in the astrophysicaly relevant energy range. Particularly, in the proton-rich region - among the so-called p-isotopes - there are elements, where the experimental results are totally missing. This contribution shows some preliminary results of the α-induced reaction cross section measurements on 130Ba, which is one of these p-isotopes.
To obtain the missing cross section data, activation technique has been used at the ATOMKI's cyclotron in the (14 - 15.5) MeV energy interval, extension of which to smaller energy range is in progress. At these energies both the (α,γ) and (α,n) channels are open, so the 130Ba(α,n)133mCe, the 130Ba(α,n)133Ce and the 130Ba(α,γ)134Ce reactions are measurable. After the activation, γ-ray spectroscopy has been used to detect the decay of the reaction products.
The preliminary experimental results and the comparison with statistical model calculations are presented.

Isomer ratio of rare p-nucleus 180mTa

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The nucleosynthesis of 180Ta has remained an unsolved problem. Most proposed nucleosynthesis models only underproduce the solar abundance of 180Ta, whereas the supernova neutrino process overproduces it by several factors. This overproduction may originate from a unique feature of 180Ta. The naturally occurring abundance of 180Ta is actually a meta-stable isomer, while the ground state is a 1+ unstable state which beta-decays with a half-life of only 8.15 hr. Both the ground state and the isomer are populated by supernova nucleosyntheses and these states are linked to each other by photon-excitations. The isomer population ratio depends on the change of the temperature and the final isomer residual ratio is crucial for understanding the production ratio of 180Ta. Here we have made a new time-dependent calculation of 180Ta meta-stable isomer residual ratio after explosive nucleosynthesis in supernovae. We model the excited-states of 180Ta as consisting of two sets of nuclear states: 1) the ground state structure, which consists of the ground state plus the excited states with strong transitions to the ground state; and 2) the isomeric structure. Each structure is independently thermalized and linked by weak interactions. We calculate the isomer ratio under temperature evolution after core-collapse supernova explosion. We include a previous experimental data [D. Belic, et al. Phys. Rev. C 65, 035801 (2002)] as the linking transitions between the two structures. We find that the final residual ratio of 0.39 +- 0.01 is insensitive to astrophysical parameters such as, temperature decay constant, peak temperature of nucleosynthesis layers, neutrino energy spectrum, and explosive energy. Note that the error is calculated from the experimental error. This ratio is robust. We calculate the neutrino process abundances of 138La and 180Ta, which are calculated previously by [A. Byelikov, et al. Phys. Rev. Lett. 98, 082501 (2007)], take into account the present isomer ratio. We find that the abundances of both the isotopes, which are normalized to 16O, are reproduced by the charged current reaction and neutrino temperature of 4 MeV. This result suggests that the astrophysical origins of both isotopes is the supernova neutrino process and constrains the neutirno temperature.

Reaction rate sensitivity of 44Ti production in massive stars and implications of a thick target yield measurement for 40Ca(α , γ)44Ti

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We evaluate two dominant nuclear reaction rates and their uncertainties that affect 44Ti production in explosive nucleosynthesis. Experimentally we develop thick-target yields for the 40Ca(α , γ)44Ti reaction at E_{α} = 4.13, 4.54, and 5.36 MeV using γ -ray spectroscopy. At the highest beam energy, we also performed an activation measurement that agrees with the thick target result. From the measured yields a stellar reaction rate is deduced that is smaller than current statistical-model calculations, which would imply lower 44Ti production in supernovae compared to recently measured reaction rates.
Special attention has been paid to assessing realistic uncertainties of stellar rates produced from a combination of experimental and theoretical cross sections, which we use to develop a new evaluation of the 44Ti(α ,p)47V reaction rate.
Using these we carry out a sensitivity survey of 44Ti synthesis in eight expansions representing peak temperature and density conditions drawn from a suite of recent supernova explosion models. Our results suggest that the current uncertainty in these two reaction rates could lead to as large an uncertainty in 44Ti synthesis as that produced by different treatments of stellar physics.

How important is the Family? Alpha nuclear potentials and p-process nucleosynthesis

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The story of nucleosynthesis beyond the iron peak is that of neutron capture reactions in the astrophysical s and r-processes. However, there are 35 stable isotopes located on the proton-rich side whose production cannot be explained in the framework of the slow and rapid neutron capture process. One of the most accepted mechanisms for the synthesis of these so-called p-nuclei is based on photodisintegration reactions on neutron-rich seed nuclei [1].

The reaction rate sensitivity to the nuclear input in a p-process network calculation has been considered in Ref.[2,3]. Whereas the low mass p-nuclei ($70 \leq A \leq 120$) show a stronger dependence on the (γ,p) reaction rates, the heavy mass stable proton-rich isotopes are very sensitive to variations on the (γ,α) reaction rates, which directly depend on the underlying α -nucleus potential.

By measuring the angular distribution of alpha particles at energies close above the Coulomb barrier it is possible to extract information on the α -nucleus potential. However, as shown for 144Sm [4] and 92Mo [5], at these energies several *families* of the potential (characterized by different depths of the real nuclear potential) provide an equally good description of the scattering data.

Here we present the results from the analysis of the potential families extracted from the angular distribution of the reaction 106Cd(α,α)106Cd measured at the ATOMKI laboratory at energies around the Coulomb barrier. The calculated (α,γ) capture cross section is compared to experimental data [6], and the sensitivity of the (α,γ) capture cross section on the chosen family of the α-nucleus potential is also shown.

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Measurements using 26Al beams for understanding the astrophysical destruction of 26Al

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The radioactive isotope 26Al has been the focus of great attention since the discovery of anomalously high ratios of 26Mg/24Mg in the Allende meteorite, in 1969. More recently, interest has been renewed following the detailed galactic mapping of the 1809-keV gamma ray associated with the beta decay of 26Al, providing an insight into the ongoing nucleosynthesis of this isotope within our galaxy. A key to the interpretation of the gamma-ray map is the rate of destruction of 26Al via the 26Al(p, γ)27Si reaction, requiring an understanding of states near the proton threshold in 27Si, to elucidate the amount of 26Al which survives to enrich the interstellar medium.

We have performed two measurements at the Holifield Radioactive Ion Beam Facility at Oak Ridge, using a batch-mode beam of 26Algs of typically 5 million particles per second, to improve our understanding of the rate of 26Al destruction. The first of these was a measurement of 26Al(p,p) in inverse kinematics, in order to constrain resonances at higher energies important for explosive nucleosynthesis. Data were taken with both thin- and thick-target techniques; in both cases, protons were measured in SIDAR silicon detectors, subtending the range 19 to 40 degrees.

The second was a measurement of the 26Al(d,p)27Al reaction in inverse kinematics, to study mirror states in 27Al to inform the 27Si structure. The mirrors to known states in the astrophysically relevant energy range have been identified previously, leaving the unknown spectroscopic strengths of these states as a significant uncertainty in the 26Al(p, γ)27Si reaction rate. Proton ejectiles were detected in SIDAR and ORRUBA silicon detectors, subtending angles from ~90-165 degrees in the laboratory frame. These data represent the first measurement performed with a complete implementation of barrel of ORRUBA detectors. Elastic scattering was monitored in ORRUBA detectors mounted at angles just forward of θ_{lab} = 90 degrees. An additional array of annular segmented silicon detectors, covering angles from ~1.5 to 10 degrees, was used to detect 27Al ions coincident with (d,p) protons.

Details of these experiments, and the current state of analysis will be presented.

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New measurements of the 40Ca(α, γ)44Ti reaction important in explosive nucleosynthesis scenarios

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The main production reaction of 44Ti observed in core collapse supernovae is the 40Ca(α , γ)44Ti reaction in the α-rich freeze-out zone. A number of different experimental studies have been performed over the years to determine the stellar reaction rate. These measurements were based on in-beam gamma spectroscopy, accelerator mass spectrometery (AMS) and most recently inverse reaction techniques with a recoil mass separator for separating and detecting the reaction products. The different experimental approaches show drasyically different results, upto a factor of ∼ 5 divergence in some cases. New experiments have been performed at the DTL, Bochum and at the NSL, Notre Dame using gamma spectroscopy and AMS techniques respectively. The results of the experiments will be presented and the impact on the reaction rate will be discussed.

Experiments on proton- and α- induced reactions of particular relevance for the *p* process

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Most nuclei heavier than iron are synthesized by the *s* and *r* processes via neutron-capture reactions [1]. 35 proton-rich nuclei are bypassed by these processes. These nuclei, referred to as *p* nuclei, are believed to be synthesized by the *p* process in the explosive scenario of supernovae type II [2]. At this astrophysical site, the *p* nuclei can be produced by a sequence of photodisintegration reactions, i.e. (γ,n), (γ,p), and (γ,α) reactions. In total, the *p* process involves an extensive reaction network consisting of about twenty thousand reactions on approximately two thousand nuclei. Due to the absence of experimental data, network calculations for the *p* process are based almost completely on theoretically predicted reaction rates stemming from Hauser-Feshbach statistical model calculations. The accuracy of these predictions depends on the adopted nuclear models for optical-model potentials, photon-strength functions and nuclear level densities. Comprehensive experimental data for astrophysically relevant reactions are mandatory to derive reliable global nuclear models for the reaction codes, but so far the experimental data base is not sufficient for this purpose.

The 10 MV ion Tandem accelerator of the University of Cologne provides unique opportunities to improve the experimental situation for proton- and α- induced reactions of relevance for the *p* process. This facility allows to perform both in-beam experiments using the highly-efficient HPGe detector array HORUS and activation experiments using a low-background counting setup which employs two large-volume HPGe Clover detectors. In addition, a new 6 MV Tandem accelerator for Accelerator Mass Spectrometry (AMS) [3] is currently being commissioned at the University of Cologne which can be used to detect smallest amounts of long-lived radionuclides being produced either by cosmic events or in the laboratory.

The combination of this variety of experimental approaches gives access to a large number of astrophysically relevant reactions and allows detailed investigations of some key reactions within the *p*-process network [4,5], which so far could not be studied in the laboratory.

In this contribution we will present first results of recent measurements and report on experiments planned in the near future.

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Proton capture reaction cross sections on 74Se, 76Se, and 77Se in p-process relevant energy range

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P-process reaction networks show that in the lower mass region of the p-isotopes mostly (γ,p) reactions compete with the main (γ,n) reaction flow. Therefore, the knowledge of (p,γ) reaction rates (the inverse of the gamma-induced reaction) is important for the better understanding of the p-process in this mass region. So far, several proton induced reactions have been measured for the Selenium isotopes close or above the Gamow window [1]. The aim of the present work is to extend the number of reactions and the studied energy range for the Selenium isotopes.
By irradiation of enriched selenium thin targets with the beams of Van de Graaff accelerators of NSC KIPT (Kharkiv) and ATOMKI (Debrecen) the cross sections of the 74Se(p,γ)75Br, 76Se(p,γ)77Br, and 77Se(p,γ)78Br reactions have been measured in the incident proton energy range up to 3.6 MeV. The cross sections have been determined measuring delayed γ-radiation following the decay of the residual Bromine radionuclides. The experimental results are compared with the earlier measurements if available and with the predictions of the Hauser-Feshbach statistical theory using the NON-SMOKERweb computer code with the standard parameter set. The experimental astrophysical S-factors derived from the cross sections are generally in good agreement with theoretical ones.

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* ERC grant holder

Is 120Te a p-process branching point: the effect on 115Sn.

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The synthesis of the group of proton-rich medium-heavy nuclei, called p-nuclei is still one of the puzzles of stellar nucleosynthesis. The most favored scenario for their production is the so called p-process which is believed to take place in explosive environments where the high gamma-fluxes can photodisintegrate the pre-existing neutron rich seed nuclei. The reaction flows start with neutron rich isotopes and move toward the proton rich ones via photoneutron reactions. At certain points (called branching points) the flow is interrupted by a (γ ,p) or (γ , α) reaction moving the reaction chain to a different element. Along the tellurium isotopes, depending on the relevant reaction rates and the temperature of the stellar environment, there are two possibilities for such a branch, 120Te or 118Te. In both cases the competition is between (γ,n) and (γ , α) reactions. In particular the (γ , α) reaction on 120Te defines whether the reaction flow will go through 115Sn or whether it will bypass it. 115Sn is one of the nuclei that are heavily underproduced in p-process nucleosynthesis due to contributions from the s-process and also from the r-process. Its origin remains to date an unsolved puzzle. In the present contribution we will report on the measurement of the reaction 116Sn(α , γ)120Te, the inverse of the p-process branch 120Te(γ , α)116Sn. We will compare our experimental results with theoretical calculations and draw some first conclusions on the effect of this reaction on the synthesis of 115Sn in the p-process.

The new p-process database of KADoNiS

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The KADoNiS (Karlsruhe Astrophysical Database of Nucleosynthesis in Stars) project is an online database for cross sections relevant to the s-process and the p-process.
The main fraction of the so-called p-nuclei is produced in the gamma-process during explosive O and Ne burning of a massive star during the core collapse. However, astrophysical network calculations cannot fully reproduce the observed abundances of all 32 p-nuclei within one scenario and call for additional processes. These reaction network calculations involve thousands of stable and unstable isotopes and ten thousands of reactions. Only the minority of these reactions are known experimentally, whereas the largest fraction has to be inferred from statistical model calculations.
The fact that self-consistent studies of the gamma-process have problems in synthesizing the p-nuclei in the mass regions $A < 124$ and $150 < A < 165$ may result from difficulties related to the astrophysical models as well as from systematic uncertainties of the nuclear physics input. Therefore, the improvement of nuclear reaction cross sections is crucial for further progress in p-process models, either by directly replacing theoretical predictions by experimental data or by testing the reliability of predictions if the relevant energy range is not accessible by experiments.
Recently, we started to collect and review all existing experimental data relevant for the p-process and to provide a user-friendly database based on the KADoNiS framework.
The p-process part of the KADoNiS database (www.kadonis.org) is currently being extended and will include all available experimental data from (p,γ), (p,n), (p,α), (α,γ), (α,n) and (α,p) reactions in or close to the respective Gamow window.

Cross section measurements of 103Rh(p, γ)104Pd with the Karlsruhe 4 π BaF_2 detector

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Most of the elements heavier than iron have been and still are synthesized in neutron-induced reactions in stars of different stages. However, some isotopes are primarily formed in the so-called p-process because they are shielded from the much more effective neutron-induced reactions. The qualitative description of the p-process requires large reaction networks. The most important components here are the proton-, alpha- and gamma-induced reactions and the associated β+-decays.

At the Karlsruhe Institute of Technology (KIT) 103Rh(p,γ) capture events in a thin metallic Rhodium target have been observed with the Karlsruhe 4π-BaF_2-detector, which consists of up to 42 spherically arranged BaF_2-crystals. The protons were accelerated with a pulsed 3.7 MV Van de Graaff accelerator to an energy of 3 MeV.

An overview of the experimental setup and first cross section results for the 103Rh(p,γ)104Pd reaction will be presented. The experiment was supported by the HGF young investigator project VH-NG-327.

An Investigation Into the Systematics of Type Ia Supernovae.

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Properties of the light curves of type Ia supernovae allow for their standardization and subsequent use as cosmological distance indicators. Despite widespread use in this capacity, details of the mechanism of a thermonuclear supernova and the effect of properties of the host galaxy remain incompletely understood. We present a study of thermonuclear supernovae assuming the deflagration-to-detonation (DDT) paradigm in which a deflagration born in the center of a near-Chandrasekhar-mass white dwarf transitions into a detonation that incinerates the star. Our simulations determine the yield of synthesized nuclear statistical equilibrium (NSE) material and its composition, a fraction of which is radioactive Ni-56 that powers the light curve. Utilizing a statistical framework, we explore the effect of properties of the progenitor white dwarf, including its composition, thermal history, and metallicity, on the yield. Our results offer an explanation for some observed trends of brightness with the environment of the host galaxy.

This work was supported by the Department of Energy through grants DE-FG02-07ER41516, DE-FG02-08ER41570, and DE-FG02-08ER41565, by NASA through grant NNX09AD19G, and utilized resources at the New York Center for Computational Sciences at Stony Brook University/Brookhaven National Laboratory, which is supported by the U.S. Department of Energy under Contract No. DE-AC02-98CH10886 and by the State of New York.

Properties of nuclear flame in presupernova white dwarf

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A work is devoted to 1D propagation of nuclear burning flame in SNIa. A model for direct numerical simulation of a flame will be considered. Calculations of kinetic properties of a matter in presupernova white dwarf will be shown. Results of a numerical simulation will be properties of a deflagration flame (its normal velocity, alteration of major thermodynamic functions across the flame).

Evaluating Systematic Dependencies of Type Ia Supernovae: The Influence of Deflagration to Detonation Density

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We explore the effects of the deflagration to detonation transition (DDT) density on the production of 56Ni in thermonuclear supernova explosions (type Ia supernovae). Within the DDT paradigm, the transition density indirectly sets the amount of expansion during the deflagration phase of the explosion and therefore the amount of nuclear statistical equilibrium (NSE) material produced, a fraction of which is radioactive 56Ni that powers the supernova light curve. We employ a theoretical framework for a well-controlled statistical study of two-dimensional simulations of thermonuclear supernovae with randomized initial conditions that produce 56Ni masses with a similar average and range to those inferred from observations with a particular choice of transition density. Within this framework, we utilize a carbon-depleted, "simmered" white dwarf progenitor model and a detailed flame model and energetics scheme to calculate the amount of 56Ni and NSE material synthesized for a suite of simulated explosions in which the transition density is varied in the range 1−3×107 g cm-3. We find a quadratic dependence of the NSE yield on the log of the transition density. The curvature of this relation is determined by the competition between plume rise and stellar expansion. By considering the dependence of the transition density on metallicity, we find the NSE yield decreases 0.055 ± 0.004 M_{Sun} for a 1 Z_{Sun} increase in metallicity evaluated for solar metallicty. For the same change in metallicity, this result translates to a 0.067 ± 0.004 M_{Sun} decrease in the 56Ni yield, slightly stronger than that due to the variation in Y_e from the initial composition. Observations testing the dependence of yield on metallicity remain somewhat ambiguous, but the dependence we find is comparable to that inferred from some studies.

This work was supported by the Department of Energy through grants DE-FG02-07ER41516, DE-FG02-08ER41570, and DE-FG02-08ER41565, by NASA through grant NNX09AD19G, and utilized resources at the New York Center for Computational Sciences at Stony Brook University/Brookhaven National Laboratory, which is supported by the U.S. Department of Energy under Contract No. DE-AC02-98CH10886 and by the State of New York.

Nucleosynthetic Signatures of Neutron Rich Isotopes from FLASH Type Ia Supernovae Simulations

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Type Ia supernovae have drawn interest both because of their contributions to galactic chemical evolution and their use as cosmological distance indicators. We detail our method of "tracer particle post processing" for calculating the nucleosynthetic yields from 3D FLASH simulations of Type Ia supernovae. Using this method, we generate nucleosynthetic yields for the Pure Deflagration, the Deflagration-to-Detonation Transition (DDT), and the Gravitationally Confined Detonation (GCD) models of Type Ia supernovae. We highlight the production of the neutron rich isotopes 48Ca, 50Ti, and 54Cr, which have been demonstrated to be produced in low entropy freeze-outs of neutron rich material at initially high temperatures and densities – the conditions created in the ash of a carbon deflagration that is believed to be the first stage of the explosion of Type Ia supernovae.

On Variations of the Brightness of Type Ia Supernovae With the Age of the Host Stellar Population

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Recent observational studies of type Ia supernovae (SNeIa) suggest correlations between the brightness of an event and properties of the host galaxy that appear to involve the age of the progenitor population. One way to influence the explosion systematically is through the central density at ignition, which is determined by the mass of the white dwarf before the onset of accretion, the white dwarf cooling time (prior to the onset of accretion), the subsequent accretion history, and neutrino losses. The dependence of the central density on cooling time connects the central density to the age of the progenitor and therefore the average stellar age of the host galaxy. We find that with increased progenitor central density, production of nuclear statistical equilibrium material does not change but production of Ni-56 decreases, which we attribute to a higher rate of neutronization occurring at higher density. These results offer an explanation for the observation of dimmer SNeIa in galaxies with an older stellar population. We also demonstrate a strong dependence of the Ni-56 yield in our results on the morphological structure of the burning front during the early deflagration, suggesting that a statistical ensemble of simulations is necessary when studying the systematics of SNeIa.

This work was supported by the Department of Energy through grants DE-FG02-07ER41516, DE-FG02-08ER41570, and DE-FG02-08ER41565, by NASA through grant NNX09AD19G, and utilized resources at the New York Center for Computational Sciences at Stony Brook University/Brookhaven National Laboratory, which is supported by the U.S. Department of Energy under Contract No. DE-AC02-98CH10886 and by the State of New York.

NuSTAR Studies of Type Ia Supernovae

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Type Ia supernovae are responsible for the nucleosynthesis of the iron peak elements and are widely used as standard candles of modern cosmology, but fundamental questions about their circumstances and nuclear processing persist. It has long been hoped that gamma-ray studies would help clarify our understanding of these explosions, but because of instrumental limitations, those measurements have not been achieved. Many theoretical studies have emphasized the bright gamma-ray lines (e.g., Milne et al. 2004), but here we focus on the lowest energy part of the Compton scattered continuum, below 80 keV. This choice is because the upcoming NuSTAR satellite will have large area mirrors that collect and focus photons up to that energy, and will have greatly improved sensitivity over previous instruments in this energy range. We calculate the hard X-ray spectra of standard models to determine at what time and to what distance NuSTAR could observe Type Ia supernovae.

Type Ia supernovae from white dwarf mergers

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The nature of progenitor system of Type Ia supernovae is still unknown. For a long time it was generally believed that mergers of white dwarfs would rather lead to accretion induced collapse than a SN Ia. Here, we show that some mergers of white dwarfs can lead to SN Ia explosions. In our scenario, the violent merger of two white dwarfs of similar mass generates a detonation during the merger itself. This detonation burns and disrupts the whole merged object.
Specifically, we model the merger of two white dwarfs of 0.9 solar masses. After the binary system merges and the detonation forms, we follow the explosion to homologous expansion. Doing detailed nucleosynthesis we are able to determine the detailed nuclear composition of the ejecta and use this information to run radiative transfer simulations of the explosion. For each of these steps we use different, appropriate numerical codes.
The synthetic lightcurves and spectra we obtain are in remarkably good agreement with observations of so-called 1991bg-like events. This class of subluminous SNe Ia has previously eluded a theoretical explanation.

Nucleosynthetic post-processing of Type Ia supernovae with variable tracer masses

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The post-processing of passively advected Lagrangian tracer particles is the most common way for obataining detailed nucleosynthetic yield predictions of Type Ia supernova (SN Ia) hydrodynamical simulations. Historically, tracer particles of constant mass are employed. However, intermediate mass elements, such as Mg, Si or Ca, are typically synthesized in the outer layers of SNe Ia, where a tracer distribution with constant mass may result in poor spatial resolution. We show how to alleviate this problem with a suitably chosen distribution of variable tracer particle masses.

Thorium enrichment in the Milky Way Galaxy

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We have been determining abundances of the actinides element Th, as well as of other heavy neutron-capture elements, based on high resolution spectroscopy with Subaru Telescope High Dispersion Spectrograph (HDS) and Gunma Astronomical Observatory Echelle Spectrograph (GAOES). Our sample covers wide metallicity range (-2.5<[Fe/H]< +0.3). The Th abundances are determined using the Th 5989A line, which is less affected by blending of other elements than the 4019A one that is used in studies of very metal-poor stars. We obtained following results: (1) The Th/Eu abundance ratios of our metal-poor sample show no significant scatter, and the average is lower by 0.2 dex in the logarithmic scale than the solar-system value. This result indicates that the actinides production by the r-process does not show large dispersion, even though r-process models suggest high sensitivity of the actinides production to the nucleosynthesis environment, or mixing of interstellar matter before formation of these metal-poor stars is very efficient. (2) The Th/Eu ratios in relatively metal-rich ([Fe/H] >-1) stars show some scatter, and the average is higher than found in metal-poor stars. This suggest that these metal-rich stars include young objects where decay of Th is less significant. Enrichment history of heavy nuclei due to explosive r-process nucleosynthesis in the Milky Way is discussed.

Recent changes on the mass surface; moving the r-process path ?

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The Atomic Mass Tables are the fruit of the evaluation of all valid experimental data aiming at mass measurements, or in which relevant energy measurements are given. Among the various projects that stemmed in the 1950's, the concept developed by Aaldert H. Wapstra*), proved to be able to face the otherwise insolvable difficulties due to the strong interconnections among the measurements. It is referred to as the "Atomic Mass Evaluation (AME)". It was the one which survived and produced a series of Mass Tables over the years, the most recent of those, in 1983, 1993, and 2003.

This series was about to disappear due to lack of institutional support. Fortunately, in November 2008, the AME revived when the Institute of Modern Physics (IMP) at Lanzhou (China) decided to ascertain the future of this long tradition in a program called "AME-Future". The AME-Future project is defining a new working structure aiming at the production of the Ame2013 Atomic Mass Table, and the future of the AME at the IMP-Lanzhou.

I will describe the most prominent features of the AME, the reasons for its complexity, how they are faced and solved. Directly connected to the AME, is the NUBASE evaluation of the properties of ground-states and long-lived isomers of nuclei, their spins, half-lives, excitation energies and decay modes. Masses as well as nuclear and decay properties have in common to require "horizontal" collection and evaluation.

Recent measurements by several groups have explored the ridge of the valley of stability and in many places we observe that the mass surface, when approaching the drip-lines, lays significantly higher (higher masses, less binding energies) than was earlier believed. The rise can be explained by previously under-estimated Qbeta data of exotic species due to missed levels. In my talk I will draw the attention of astrophysicists on the undoubtedly impact such a rise will have on pulling the nucleo-synthesis path closer to stability. Calculations including the new mass values are needed to quantify this estimated move.

*) This talk will be dedicated to the memory of Aaldert H. Wapstra, who is also a co-author, since, after the publication of Ame2003 and during two years, he made essential contributions to the future mass evaluation project (now known as Ame2013), before passing away. And more than those two years, this work is filled with his spirit.

Number projected energy and heat capacity in the thermodynamic system.

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Recently, thermodynamic properties of hot nuclear systems have been widely investigated. Indeed, with the advent of nuclear radioactive beams, the study of these nuclei becomes an important challenge for nuclear physics.

Phase transitions are the subject of peculiar interest since they are often connected to the spontaneous symmetry breaking, leading to violation of conservation laws. The evaluation of statistical properties, such as the energy and the heat capacity, as a function of the temperature, should provide information on the structure of hot nuclei.

The purpose of the present work is to evaluate the energy and the heat capacity as a function of the temperature for the nucleus 162Dy in the framework of a microscopic model that includes the pairing effects. Since the latter play a crucial role in the description of such nuclei, they have to be taken into account rigorously. With this aim, an approach that combines the modified BCS method (MBCS) [1] and a particle-number projection method (of projection after variation (PBCS) type) [2] is proposed. The single particle energies used are those of a deformed Woods-Saxon mean field.

The obtained results show that projected energy and heat capacity have the same behavior as the MBCS predictions. Indeed, one notes a smooth variation of these physical quantities as a function of the temperature. However, an important discrepancy between the two predictions (i.e. Projected MBCS and MBCS) is observed when the temperature is close to its critical value.

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BETA-DECAY NEAR THE N=126 NEUTRON SHELL AND THE R-PROCESS

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Network calculations of the astrophysical r-process as well as the studies on radioactive radioactive beam facilities mostly rely on global models of the β-decay rates. We present fully microscopic calculations of β--decay rates and delayed neutron emission branchings P_n in a wide region near N = 126 closed shell. The self-consistent description of the ground states is based on the Fayans density functional (DF3) [1]. The Gamow-Teller (GT) and first-forbidden(FF) transitions are treated one the same footing in the continuum QRPA (CQRPA) approach [2]. The DF+CQRPA model has already been shown to give a good description of the ground state
and β--decay properties of spherical nuclei near the closed neutron shells at N=50, 82 [2].

The majority of neutron-rich nuclei close to N = 126 have remained unexplored experimentally so far. However, our calculations turn to be the closest ones to the half-lives in the N=126 region recently measured at the fragment separator FRS at the GSI Darmstadt [3]. This place a confidence into our predictions for the half-lives of the N=126 r-process waiting-point nuclei. In the DF+CQRPA model, the contributions of first-forbidden transitions to the half-lives and especially to the P_n-values near N=126 is found to be significant. This stresses a need for refined treatment of the GT and FF decays within a single fully microscopic framework [2]. In the Finite Range Droplet Model (FRDM) widely used in the r-process modeling [4] the FF decays are calculated within the statistical model.

For the nuclei with Z=60-70 near the closed neutron shell at N=126 both our and FRDM calculations typically agree quite well. However, for the most of even-even nuclei with Z=80-90 below (as well as above) N=126, the present DF3+CQRPA half-lives are shorter than the FRDM ones. A typical drop in our calculated P_n-values in the region of A=193 is a signature of a competition between the FF and GT transitions.

Together with the results of [2,5], the resulting extended set of the DF3+CQRPA weak rates is now in use for the global r-process modeling. One may expect the shorter DF3+CQRPA half-lives changing the mass flow to heavier nuclei beyond N=126 would result in enhanced abundances of rare-earth and actinide elements.

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TACTIC: A New Detector for Tracking in Low Energy Nuclear Astrophysics

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In nuclear astrophysics, detection of low energy reaction products can often prove difficult with conventional techniques such as silicon detectors. Time Projection Chambers (TPCs) and active target detectors have helped to alleviate these problems, but are often rate limited, making measurements of low reaction cross sections nearly impossible. To this end, the TRIUMF Annular Chamber for Tracking and Identification of Charged-particles (TACTIC) detector has been designed and built by an international collaboration between TRIUMF and the University of York.

TACTIC is a cylindrical, segmented-anode, active-target TPC [1]. The geometry mirrors the kinematics of the reactions studied, and utilizes a "blind" center region which serves to trap the ionization created by the beam particles and allow for much higher beam intensities than typical TPCs. High-gain, low cost per channel preamps and digital electronics are used to instrument the 480 anode pads, and a new graphical analysis tool for the data is being developed and implemented. Amplification of the small signals is accomplished using a Gas Electron Multiplier (GEM) in place of a traditional Frisch grid. The fill gas, a He-CO_2 mixture, provides both particle detection and a homogeneous, variable-thickness target for studying reactions on alphas, such as 8Li(α ,n)11B.

The 8Li(α ,n)11B reaction could be an important step in non-standard Big Bang nucleosynthesis, and is possibly a starting point for the r-process. Previous attempts to measure the reaction cross section have met with difficulty, so a direct study of the reaction using TACTIC was proposed and carried out at TRIUMF in Vancouver in June of 2009. This is the first time TACTIC has ever been used with radioactive beam; technical details and preliminary results will be discussed.

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Half-Lives for R-Process Nucleosynthesis Using the ANN Statistical Global Model

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There still remain significant uncertainties in the nuclear physics input to the modeling of astrophysical nucleosynthesis via the r-process, notably involving the beta-decay half-lives of neutron-rich nuclei. Since the vast majority of the nuclides which lie on the r-process path will not be experimentally accessible in the foreseeable future, it is important to provide accurate beta-decay half-lives predictions by reliable models. In this work we apply our recently developed multilayered feed-forward Artificial Neural Network (ANN) statistical global model [1] of the beta-decay half-life systematics to nuclei that are relevant to r-process. We present results for nuclides situated on the r-ladders N=50, 82 and 126 where abundances peak, as well as for others that affect abundances between peaks. We also give the values of half-lives of interesting neutron-rich nuclides that have been recently measured or will be measured at developing rare-isotope experimental facilities. Comparison of our results with those available from conventional models and from experiment is very promising.

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Alternative path for bridging the A=5,8 mass gap in neutron-rich nucleosynthesis scenarios

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In post-collapse supernova scenarios of astrophysical nucleosynthesis the heavy elements are formed by rapid neutron capture process in a hot neutron-rich environment. The formation of the seed nuclei for the rapid neutron process from α-particles and neutrons depends crucially on the recombination process

ααn→ 9Be,

which bridges the gap of unstable isotopes with mass numbers A=5,8. It is assumed that the recombination occurs via three-body electromagnetic reaction [1]

4He(αn, γ) 9Be,

where the three particles recombine into a (halo) nucleus giving away the excess energy by emitting a photon.

However, in neutron-rich environments the recombination can also occur via the four-body nuclear recombination reaction

4He(αnn,n) 9Be,

where the excess energy is passed to a neutron in the environment.

We investigate the nuclear four-body reaction using the participant-spectator approach [2] where the three recombining particles, the participants, are treated rigorously while the recoil neutron, the spectator, is treated within the zero-range pseudo-potential model. In this approach the number of recombinations per unit time and volume is given as

$w_{fi} = n_\alpha 2\ n_n 2\ a_{nn} 2\ v\ F_{fi}$,

where n_α and n_n are the α and neutron densities, a_{nn} is the neutron-neutron scattering length, v is the velocity of the recoil neutron and F_{fi} is the squared transition amplitude integrated over the recoil directions,

$F_{fi} = \int d\Omega_{p'}\ |\ (f|\ \exp(-i\ \mathbf{q}\ \mathbf{r}_n)\ |i)\ |2$,

where $\mathbf{q}$ is the transferred momentum, $\mathbf{r}_n$ is the coordinate of the participant neutron, |i) and |f) are the initial and final states of the participants. The reaction rate at a finite temperature is then given as Boltzmann average over the initial states |i).

We estimate the reaction rate for the four-body nuclear recombination using the ααn wave-functions calculated by means of the hyper-spherical adiabatic method and show that for very dense and hot environments the nuclear rate is comparable with and even dominating the electromagnetic rate.

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Constraints on the weak r-process: Abundance of Palladium in metal poor stars

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Silver and Palladium - tracers of the weak r-process

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Nucleosynthesis High-Entropy Hot-Bubbles of Sne and Abundance Patterns of Extremely Metal-Poor Stars

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There have been suggestions that the abundance of Extremely Metal-Poor (EMP) stars can be reproduced by Hypernovae (HNe), not by normal supernovae (Sne). However, recently it was also suggested that if the innermost neutron-rich or proton-rich matter is ejected, the abundance patterns of ejected matter is changed, and normal SNe may also reproduce the observations of EMP stars. In this letter, we calculate explosive nucleosynthesis with various $Y_{\rm e}$ and entropy, and investigate whether normal SNe with this innermost matter, which we call ``hot-bubble'' component, can reproduce the abundance of EMP stars. We find that neutron-rich ($Y_{\rm e}$ = 0.45-0.49) and proton-rich ($Y_{\rm e}$ = 0.51-0.55) matter can increase Zn/Fe and Co/Fe ratios as observed, but tend to overproduce other Fe-peak elements.

In addition to it, we find that if proton-rich matter with 0.50 $\le$ $Y_{\rm e}$ $<$ 0.501 of s/$k_{\rm b}$ $\sim$ 15-40 is ejected as much as $\sim$ 0.06 $M_\odot$, even normal SNe can reproduce the abundance of EMP stars, though it requires fine tuning of $Y_{\rm e}$. On the other hand, HNe can more easily reproduce the observations of EMP stars without fine-tuning. Our results imply that HNe are the most possible origin of the abundance pattern of EMP stars.

Precision mass measurements of neutron-rich nuclei connecting A~80 and A~130 waiting point regions

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A novel combination of an element-independent Ion Guide Isotope Separator On-Line (IGISOL) technique and ion trap technology have allowed a systematic survey of atomic masses over large set of neutron-rich nuclei from 70Ni to 140Te.
Isotopes of interest were produced in proton-induced fission of natU. Reaction products were stopped in a pure He-gas. During the thermalization process products reached the charge state 1+. He-flow transferred ions out from the gas cell and electric fields were applied to guide and accelerate ions through the mass separator into JYFLTRAP, which composes of a linear Paul trap for cooling and bunching, a purification Penning trap for isobaric cleaning and a precision trap for atomic mass measurements.
Data obtained connects two waiting point regions at A ≈ 80 and A ≈ 130. All in all, severe discrepancies compared to the recent atomic mass compilations and predictions have been observed. In addition, a variety of nuclear structure aspects have been addressed. Those include a shape change at Z ≈ 40 and N ≈ 60 and an evolution of Z=50 and N=50 shell gaps. In this contribution, a large data set of more than 170 new precision atomic masses will be presented in terms of nuclear structure and astrophysics implications.

Single particle spectroscopy of 133Sn via the (d,p) reaction in inverse kinematics

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It is important, both for nuclear structure physics and to understand the synthesis of heavy elements in the cosmos, to determine how single-particle states change as we move away from the valley of stability, especially around shell closures. One powerful method to probe single-particle structure of nuclei is to use single-nucleon transfer reactions. With short-lived exotic nuclei, these reactions need to be performed in inverse kinematics, using a radioactive ion beam and light ion targets.

A beam of 132Sn produced at ORNLs Holifield Radioactive Ion Beam Facility was used in a transfer reaction experiment to study single-particle states in 133Sn. The beam impinged on a target of CD2 with effective thickness of around 150ug/cm2. Charged ejectiles were detected in an array of position sensitive silicon detectors, mostly of the new ORRUBA type, with SIDAR detectors at very backward angles. At forward laboratory angles, telescopes of detectors were used to discriminate protons from heavier, elastically scattered particles. From the angles and energies of the protons, the energies of the states populated in the final nuclei were measured.

The present work has determined the purity of the low-spin single-neutron excitations in 133Sn. A previously unobserved state in 133Sn has also been measured here for the first time. The simplicity of the structure of 132Sn, and the single-neutron excitations in 133Sn, provides a new touchstone needed for extrapolations to nuclei further from stability, in particular those responsible for the synthesis of the heaviest elements via the r-process.

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TRIGA-TRAP: Mass measurements on neutron-rich nuclides at TRIGA Mainz

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Accurate mass measurements are required by nuclear astrophysics calculations on the neutron-capture processes responsible for the creation of heavy elements. However, most of the nuclides involved in the r-process are not available to experiments today and will not become available soon. The double-Penning trap mass spectrometer TRIGA-TRAP has been installed at the research reactor in Mainz, which is presently unique worldwide. High-precision mass measurements on neutron-rich nuclides obtained by thermal-neutron induced fission of an actinoid target will be performed. Thereby, the border of well-known masses can be extended to the neutron-rich side of the nuclear chart. Presently, a helium-gas jet for the extraction of the fission products from the reactor is being coupled to an ECR ion source, followed by a magnetic mass separator and an RFQ-ion beam cooler and buncher device.
Besides fundamental research, TRIGA-TRAP also serves as a test bench for the development of new ion detection techniques relevant for other facilities like SHIPTRAP (GSI Darmstadt) or MATS at the future FAIR facility. A non-destructive detection system based on the image currents induced in the Penning trap electrode segments by the trapped ions will finally enable mass measurements on a single stored singly charged ion. This is required to investigate very rare species with production rates in the order of only a few particles per hour, such as transactinoids.
The present status will be given with emphasis on the results of first off-line mass measurements in the rare-earth region.

Precision Mass Measurements at CARIBU

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Neutron separation energies (S_n) are essential inputs to models of *r*-process nucleosynthesis. The precision of the measured masses through which we determine S_n decreases as production of those nuclei becomes more difficult. Because the *r*-process is thought to occur in a region more neutron-rich than is accessible with current accelerator facilities, the most critical inputs to the network calculations of the *r*-process are based on extrapolations from lighter mass measurements or indirect beta-endpoint measurements. Measuring the masses of nuclides that approach the predicted *r*-process path will further constrain the systematic uncertainties in these extrapolated values. If the mass measurements can instead be made on nuclides that lie directly on the path, the systematic uncertainties can be eliminated.

The Canadian Penning Trap Mass Spectrometer (CPT) at Argonne National Laboratory (ANL) has directly measured more than 160 atomic masses. Recently, the CPT was moved to the CAlifornium Rare Isotope Breeder Upgrade (CARIBU) at ANL and given unique access to strongly produced, spontaneous fission fragments from a 1 Ci source of 252Cf. CARIBU will allow the CPT to measure the masses of approximately 100 previously unmeasured nuclides including many nuclides around the N=82 closed shell; one of the major waiting points of the r-process. Installation of the CPT at CARIBU as well as the current status of the CPT mass measurement campaign at CARIBU will be discussed.

Fission and mass properties of super-heavy elements for r-process nucleosynthesis

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The role of fission in the r-process is not completely understood yet [1,2] and the consistent modeling of fission within r-process networks has been recently done for the first time [2]. The incorporation of fission into r-process simulations is important since it allows the r-process to go through so-called fission cycles: with every fissioning nucleus neutrons are additionally set free that feed again the neutron flux and thus keep the flux alive. Moreover, the competition between fission, radiative neutron capture, beta decay and alpha decay defines the path and the end-point of the r-process in the region of heavy elements and consequently the amount of Thorium and Uranium produced in this process. In order to describe all the possible reactions and phenomena related to fissioning nuclei within the r-process, such as neutron-induced fission, beta delayed fission, neutrino-induced fission, gamma-induced fission, and spontaneous fission, one has to calculate the fission barrier as realistic as possible. This fact is even more emphasized, since experimental data regarding fission barriers is rather scarce and does not cover the whole r-process range, especially in the region of super-heavy nuclei. Hence, one has to rely on theoretical predictions to get hold of the fission properties of a nucleus.

We have determined fission barriers for super-heavy even-even nuclei ranging from the proton-dripline to the neutron-dripline by making use of the microscopic Skyrme-Hartree-Fock-BCS method and assuming axial symmetry. By comparing different forces, we show that the barrier and consequently also the spontaneous fission half-lives are - as expected - very sensitive to the used Skyrme functional but the gross behavior is similar to other approaches such as HFB14 or ETFSI. We have also performed mirror-asymmetric calculations using the Skyrme functional SLy6, in order to examine the influence of mirror-asymmetry on the potential energy surface which leads to asymmetric fission.

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Detailed abundance analysis of the very metal-poor, r-process enhanced star HE 2327-5642

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We present a detailed abundance analysis of the strongly r-process enhanced giant star newly discovered in the HERES project, HE 2327-5642 ([Fe/H] = -2.78, [r/Fe] = +0.99). Determination of stellar parameters and element abundances was based on analysis of high-quality VLT/UVES spectra. The surface gravity was calculated from the non-local thermodynamic equilibrium (NLTE) ionization balance between Fe I and Fe II, and Ca I and Ca II. Accurate abundances for a total of 40 elements and for 23 neutron-capture elements beyond Sr and up to Th were determined in HE 2327-5642. The heavy element abundance pattern of HE 2327-5642 is in excellent agreement with those previously derived for other strongly r-process enhanced stars such as CS 22892-052, CS 31082-001, and HE 1219-0312. Elements in the range from Ba to Hf match the scaled Solar r-process pattern very well. No firm conclusion can be drawn with respect to a relationship between the fisrt neutron-capture peak elements, Sr to Pd, in HE 2327-5642 and the Solar r-process, due to the uncertainty of the latter. A clear distinction in Sr/Eu abundance ratios was found between the halo stars with different europium enhancement. The strongly r-process enhanced stars reveal a low Sr/Eu abundance ratio at [Sr/Eu] = -0.92+-0.13, while the stars with 0 < [Eu/Fe] < 1 and [Eu/Fe] < 0 have 0.36 dex and 0.93 dex larger Sr/Eu values, respectively. Radioactive dating for HE 2327-5642 with the observed thorium and rare-earth element abundance pairs results in an average age of 13.3 Gyr, when based on the high-entropy wind calculations, and 5.9 Gyr, when using the Solar r-residuals. HE 2327-5642 is suspected to be radial-velocity variable based on our high-resolution spectra, covering ~4.3 years.

The Influence of Neutron Capture Rates on the Rare Earth Peak

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We study the sensitivity of the r-process abundance pattern to neutron capture rates along the rare earth peak. We determine the type of conditions which produce a rare earth peak consistent with the solar r-process data. We identify important neutron capture rates among the rare earth isotopes and show how these rates influence specific sections of the abundance pattern.

First-forbidden stellar beta decay rates for neutron-rich nickel isotopes

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The structure of neutron-rich nuclei has grown interest with the development of modern technology enabling access to the exotic regions of the nuclide chart. Reliable, quantitative estimates of beta-decay half-lives of neutron-rich nuclei are required in astrophysical problems for a better understanding of supernova explosion mechanism, and the process of nucleosynthesis, particularly the r-process. These half-lives are also needed for the experimental exploration of the nuclear landscape at existing and future radioactive ion-beam facilities.

Here I present, for the first time, the microscopic calculation of first-forbidden beta-decay rates for a number of neutron-rich nickel isotopes at high temperatures and densities using the pn-QRPA theory. Due to the increased phase space the first-forbidden beta-decay is more important for neutron rich nuclei. The first-forbidden transitions are treated microscopically in terms of the reduced multipole operators depending on the space and spin variables. The calculation is compared with measured half-lives and half-lives obtained using the CQRPA model. It is shown that the pn-QRPA calculated total beta-decay half-lives are in better agreement with the experimental data when first-forbidden transitions are taken into account along with the allowed Gamow-Teller transitions. The calculated first-forbidden beta-decay rates yield higher Ye value in comparison to allowed beta-decay rates prior to collapse. This might assist the march of post-bounce shock for a successful supernova explosion to occur. The beta-decay rates presented in this work can prove useful in determinations of the nucleosynthesis yields of the nickel isotopes, both during hydrostatic burning regimes and the subsequent collapse and explosive burning phases.

R-process Nucleosynthesis in Magnetically Dominated Core-Collapse Supernovae

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We investigate the r-process nucleosynthesis during magneto-hydrodynamic(MHD) supernova explosion driven by rapid rotations and strong magnetic fields. MHD supernovae are not only very important as the candidate for the magnetar formation sites, but also astronomical r-process sites in astrophysics. Our r-process nucleosynthesis simulations based on the astronomical supernova explosion models who followed the long-term evolution in special relativistic MHD simulations. We perform supernova simulations from the onset of core-collapse to the supernova shock propagation
with neutrino cooling process near the core and a realistic nuclear equation of state (Takiwaki 2009 [1]).
We perform r-process nucleosynthesis simulation for MHD jet supernova models based on the large nuclear reaction network including fully nuclear reactions. We have developed the nuclear reaction network which consists about 4000 isotopes and reactions related to the r-process path. Nuclear reaction networks for r-process study include a lot of unstable nuclei and undetermined reaction rates. Nuclear reaction network include many theoretical data which have a lot of uncertainties, so we construct some kinds of networks which consist of different nuclear data sets. In order to discuss the uncertainties, we also discuss the effects on r-process nucleosynthesis by nuclear physics uncertainties.

Direct capture and r-process

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The r-process is rapid neutron-capture process. This nucleosynthesis process formed about a half of elements heavier than iron in the nature via extremely neutron-rich unstable nuclei. Since current experiments cannot reach these elements, reaction rates for r-process study, such as (n,gamma), (gamma,n), and beta-decay rates are obtained by theoretical studies.

The neutron capture reaction are consist of two different process, the compound nuclear process and the direct capture process. The reaction rates for the former process can be obtained Hauser-Feshbech method. These rates have been calculated by different research group in several different nuclear physics model and archived today. The latter reaction, however, has been neglected in most r-process studies although its importance has been already pointed out. There has been a few study of the direct capture in r-process, but only canonical model was used for the discussion.

We have studied effects of the direct capture in r-process using full dynamical network code. The direct-capture reaction rates are obtained in almost-analytic way. A pattern of single-particle level are assumed from experimental data and adjusted for each nuclei. The deformation is also considered in this model.

We studied the r-process under several different physical conditions.
The direct capture furthers r-process and make freeze out earlier. In general, if freeze out become earlier, the r-process path at the freeze out become more neutron-rich. The effect changes a final abundance drastically. The impact of direct capture depend on physical condition and it is large in supersonic wind model. In this model, the direct capture effect on the position of the third peak.

We also studied the effect of short beta-decay half lives in the r-process. It works similar with the direct capture. Our results imply that the neutron capture and beta-decay rates are important in r-process studies. The validity of the waiting-point approximation will be also discussed.

17F breakup reactions: a touchstone for indirect measurements

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Dissociation has become an essential tool in several domains of nuclear physics. It provides useful information about the structure of halo nuclei [1], and Coulomb breakup can be used as an indirect method to measure radiative-capture cross sections at stellar energies [2]. Indeed, Coulomb breakup, simulated as the exchange of virtual photons between the projectile and the target, can be seen as its time-reversed reaction. The radiative-capture cross section can thus be obtained from the Coulomb-dissociation cross section via a detailed balance [2].
Though simple it may seem, this indirect technique relies on peculiar assumptions. Recent theoretical analyses of the Coulomb breakup of 8B (e.g. [3]) have shown that these assumptions are not all satisfied. This may explain the discrepancy found between direct and indirect methods of measuring the cross section of the 7Be(p, ϒ###)8B reaction.
Whereas many experimental investigations on such a phenomenon have been conducted on 8B, the case of 17F has been poorly addressed up to now. Yet the Coulomb dissociation of 17F is the ideal test case to study the validity of the indirect technique [2].
An exclusive study of 17F breakup reactions has thus been performed at the FRIBs facility of the Laboratori Nazionali del Sud, Catania (Italy). This facility produces, since a few years, Radioactive Ion Beams (RIBs) at intermediate energies, by projectile fragmentation. In order to discriminate the number of nuclei at the exit of the fragment separator, the leading idea of FRIBs is to apply the tagging technique: namely, the identification, on an event-by-event basis, of each nucleus of the secondary beam cocktail, before it impinges on the secondary target.
Primary beams of 45 AMeV 20Ne interacting with a 9Be production target has lead to the formation of a radioactive cocktail containing 18Ne and 17F of about 40AMeV. For the selected RIBs the measured rates at the tagging detector (a 16 · 16 DSSD detector) were of the order of 5 · 103 pps.
The experimental setup and the detector systems allowed the measurement, event-by- event, of the X-Y coordinates of the interaction point on the target as well as the momenta and angles of all outgoing decay particles in a solid angle of 0.34 str around zero degree with a geometrical efficiency of 72% and a resolution of approximately 300 keV.
The first results and preliminary model comparison will be presented

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Integrated Nucleosynthesis from Neutrino Driven Winds

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Although they are but a small fraction of the mass ejected in core-collapse supernovae, neutrino-driven winds (NDWs) from nascent proto-neutron stars (PNSs) have the potential to contribute significantly to supernova nucleosynthesis. In previous work, the NDW has been implicated as a possible source of r-process and light p-process isotopes. In this paper we present time-dependent spherically symmetric hydrodynamic calculations of the NDW which include accurate weak interaction physics coupled to a full nuclear reaction network. Using published models of PNS neutrino luminosities, we predict the contribution of the NDW to the integrated nucleosynthetic yield of the entire supernova. For both neutrino luminosity histories considered, we find that no true r-process occurs in the NDW in the vanilla scenario. This is true for the wind driven from a standard 1.4 M_{sun} PNS, even though it is moderately neutron rich at late times. However, the integrated wind does produce the isotopes 87Rb, 88Sr, 89Y, and 90Zr in near solar proportions to other important species such as oxygen. In the wind driven from a 1.27 M_{sun} neutron star, the wind is proton rich throughout its entire evolution. This model does not contribute significantly to the abundance of any element. It thus seems very unlikely that the simplest model of the neutrino driven wind can produce the r-process. At most, it contributes to the production of the N=50 closed shell elements and some light p-nuclei. We will also present some extensions to the standard NDW model that make the r-process feasible in the NDW.

Nuclear Astrophysics with MATS: precise Measurements on very short-lived nuclei using an Advanced Trapping System

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The importance of masses for nucleosynthesis calculations in explosions occurring in stars has been shown to be very important to model the observable nuclear abundances with those from laboratory calculations. Several methods can be used to measure short-lived nuclear masses but none of them can do it as accurately as Penning traps. From 2004 on , when first mass measurements on several waiting points showed the importance of this property in astrophysics [1,2], many other results have contributed creating a survey of masses in the nuclei chart especially in the neutron-deficient side, where the rp- and nup-process proceed (see for a very recent work e.g. [3]). However, the other side of the valley of stability, where neutron-rich nuclei are located and the r-process proceeds, is much more difficult to access and the r-process path can only be reached at existing facilities up to Z=50 [4].
MATS at FAIR is an Advanced Trapping System which will allow performing for the first time accurate measurements on the r-process path at high Z and will contribute to a better understanding of the principal mechanism explaining the synthesis of heavy elements. The facility comprises a radiofrequency cooler and buncher for beam preparation, a multi-reflection time-of-flight spectrometer for mass identification, a charge breeder, two Penning trap systems, one for preparation assembled with a trap made of detectors, and one for precision measurements of nuclear masses. The technical design report has been completed and evaluated [5]; the different elements, their performance, recent progress in construction as well as the nuclear astrophysics that will get addressed will be presented and discussed.

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Study of neutron rich Cadmium isotopes and the possible N=82 shell quenching

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The abundances of r-process nucleosynthesis in the mass A=130 region are largely affected by the nuclear structure properties around the N=82 magic number.
Some simulations show a better description of the abundances if a shell quenching of N=82 is assumed. In addition, the anomalous behavior of the experimental 2+ excitation energies in neutron rich Cd isotopes has been interpreted as an indication of a reduction of the shell gap in this region. In this work we will study the spectroscopic properties of even-even Cadmium isotopes from N=50 to N=82 shells with beyond mean field methods. Our results reproduce nicely both the 2+ energies and B(E2) transitions without adjusting any parameter of the nucleon-nucleon force (Gogny D1S). Furthermore, we do not observe N=82 shell quenching and the anomalous behavior of the 128Cd can be interpreted in terms slight deformation effects.

A Range of Neutron-Capture Abundance Ratios Produced by the r-Process

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It has been established previously that abundance ratios among the Rare Earth Elements (REE) and between the REE and the third r-process peak elements are generally constant in r-rich stars. It has also been established previously that the abundance ratios between the REE and the light elements Sr-Y-Zr are not constant in these stars. Combining new neutron-capture abundance determinations with literature data, we identify a clear correlation between the bulk r-process enrichment (e.g., [Eu/Fe]) and the ratio of light to heavy r-process material (e.g., [Y/Eu]). This correlation extends from the metal-poor stars most strongly enriched by the r-process (e.g., CS 22892-052, with [Eu/Fe] = +1.6) to metal-poor stars with significant deficiencies of heavy r-process material (e.g., HD 122563, with [Eu/Fe] = -0.5). These stars show no evidence of enrichment by the s-process, indicating that the r-process is responsible for the production of these nuclei. Furthermore, we identify a weak correlation (with dispersion of order 0.15 dex) between [Eu/Fe] and [La/Eu] in stars lacking any s-process enrichment (so characterized by their low Pb abundances), suggesting that the [La/Eu] (or [Ba/Eu]) ratio is not an ideal indicator of the relative amounts of s- and r-process enrichment in metal-poor stars.

Production and study of r-process nuclei at the CARIBU facility

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The CAlifornium Rare Ion Breeder Upgrade (CARIBU) to the ATLAS superconducting linac facility is built to provide low-energy and re-accelerated beams of neutron-rich isotopes obtained from 252Cf fission. The fission products are stopped in a large high-intensity gas catcher, thermalized and extracted through an RFQ cooler, accelerated to 50 kV and mass separated in a high-resolution separator before being sent to either an ECR charge breeder for post-acceleration through the ATLAS linac or to a low-energy experimental area. This approach gives access to beams of very neutron-rich isotopes, many of which have not been available at low-energy previously, and provides unique opportunities
for measurements along the r-process path.

Initial commissioning of the facility is proceeding with a 2.5 mCi source that will be upgraded later this spring to a 100 mCi. Full capabilities will be reached with a 1 Ci source that has been ordered from the HIFR reactor in Oak Ridge.

The radioactive beams will be available at Coulomb barrier energy to all current ATLAS instruments or at low energy as a continuous beam or as a cooled pulsed beam after an RFQ buncher. The CPT mass spectrometer has been moved to the CARIBU low-energy experimental area to take advantage of these new beams which improves the yield available for the most exotic of these isotopes by a factor of 20 with the initial commissioning source and eventually a factor of close to 10000 with the final source.

A description of the CARIBU facility will be given, with emphasis on the new technical developments of the large volume high-intensity gas catcher and cooler that provide rapid and efficient species-independent extraction and preparation, together with commissioning and first physics results on neutron-rich nuclei along the r-process path.

β-decay and neutron emission studies of r-process nuclei near 137Sb

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To improve understanding of the astrophysical r-process one needs to know β-decay half-lives and neutron emission probabilities (P_n) of nuclei along the r-process path. An experiment was performed at the focal plane of the FRS at GSI to measure relevant β-decay half-lives and P_n values in the region A=130 including the r-process waiting point nuclei 136Sn and 137Sb. A stack of four 500 μm double sided silicon strip detector were used to detect β particles, surrounded by a 4Pi neutron long counter to detect β-delayed neutrons. Preliminary results of the experiment will be discussed, along with a discussion of the β-decay background.

Neutron capture in the r-process

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Recently we have shown that neutron capture rates on nuclei near stability can significantly influence the r-process abundance pattern. We discuss the different mechanisms by which the abundance pattern is sensitive to the capture rates and identify key nuclei whose rates are of particular importance. We compare the behavior of the system in different astrophysical conditions, e.g. an equilibrium ("hot") and non-equilibrium ("cold") r-process. We consider the A=80, A=130 and the rare earth peak.

Implementation of a MR-ToF isobar separator at the on-line mass spectrometer ISOLTRAP

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A multi-reflection time-of-flight mass separator (MR-ToF-MS) was installed at the ISOLTRAP/CERN mass spectrometer for isobaric purification of rare isotope ensembles as a preparation for precision mass determinations. The MR-ToF-MS consists of two ion optical mirrors between which ions are oscillating and are separated by their mass-over-charge ratio. Flight paths of several hundreds of meters are folded to an apparatus length of less than one meter. Previous tests resulted in a mass resolving power of up to one hundred thousand and the separation was demonstrated for the isobaric ions carbon monoxide and molecular nitrogen. In combination with a Bradbury-Nielsen beamgate, the MR-ToF-MS will support the existing purification methods of the setup to gain access to nuclides produced with high isobaric contamination yields at the ISOLDE facility. The modified ISOLTRAP setup and its performance will be presented.

High resolution spectroscopy of two metal-poor red giants: HD 232078 and HD 218732

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An abundance analysis for 35 chemical elements based on a high-resolution (R = 67 000) optical spectra of two metal-poor ([Fe/H] = -1.50) halo red giants,
HD 232078 and HD 218732 is presented. Abundances of ten chemical elements were derived for the first time. Both red giants are chromospherically active and optically
variable, located close to the red giant branch tip. The physical properties and chemical composition is discussed.

Niobium in the spectra of metal-poor stars

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Abundances of Niobium are measured in several metal-poor stars, based on spectral synthesis with carefully compiled line lists. We discuss the obtained results and the possible origin of niobium in metal-poor stars.

Chemical abundances in metal-poor giants: limitations imposed by the use of classical 1D stellar atmosphere models

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Stellar abundances are generally determined using stationary 1D stellar atmosphere models which treat convection in a parametric way. Simplifications and shortcomings inherent in the convection formalism may therefore have a direct influence on the predicted strengths of spectral lines, and thus - on the derived elemental abundances.
In this work we use 3D hydrodynamical stellar atmosphere models calculated with the CO5BOLD code to study the importance of such effects in stellar abundance work related to late-type giants. The effects of convection are investigated by means of the 3D-1D abundance corrections, which are defined as differences between the stellar abundances obtained with the 3D and 1D stellar atmosphere models under the assumption of local thermodynamical equilibrium.
We find that for a number of key elements, such as Fe, Mg, Ca, Ti, Mn, Ni, Zn, Ba, Eu, the 3D-1D corrections are typically minor (< 0.1 dex) at Solar metallicity. However, the situation changes dramatically at lower metallicities ([M/H] < -2.0) where the 3D-1D abundance corrections of certain chemical elements may reach 1.5 dex. The 3D-1D abundance corrections show a complex dependence on the spectral line parameters (such as wavelength, excitation potential), with different trends for neutral atoms and ionized species.
We find that these differences are caused by horizontal temperature fluctuations and lower temperatures in the outer atmospheric layers of the 3D hydrodynamical models. This seems to be a common property of late-type giants at low metallicities.
Therefore, if the predictions of currently available 3D stellar atmosphere models are indeed correct these results may signal a warning regarding the usage of 1D stationary stellar atmosphere models in stellar abundance work at low metallicities.

Spectral analysis of CH stars: abundances of neutron-capture elements

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The chemical composition of the early-type CH stars that are characterized by enhancement of s-process elemental abundances bears signatures of the nucleosynthesis processes operating in low-metallicity companion AGB stars, provided they conserve the surface characteristics of the companion AGB stars. These stars thus form ideal targets for studying the operation of s-process at low-metallicity. However, not many studies on CH stars can be found, the few previous studies available are limited either by the resolution or by the wavelength range. In this talk we will discuss some of our recent results obtained from analysis of high resolution Subaru spectra of a selected sample of CH stars. The relative contributions of the two neutron-capture processes, r ans s, to the observed abundances, examined using a parametric model based analysis hint that the neutron-capture elements in this sample primarily originate in s-process.
A quantitative assessment of the fraction of CH stars (and other types of carbon stars), using medium resolution spectroscopy, in a sample of candidate Faint High Latitude Carbon (FHLC) stars from Hamburg/ESO survey will also be presented.

3D hydrodynamical CO5BOLD model atmospheres of late-type giants: stellar abundances from molecular lines

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We investigate the influence of convection on the formation of molecular lines in the atmospheres of late-type giants. The focus of this study is on C2, CH, CN, CO, NH, OH. These molecules are widely exploited in the abundance analysis of stars that belong to stellar populations of different age and metallicity, therefore serving as useful tools for probing chemical evolution of the local Universe. We utilize three-dimensional (3D) time-dependent radiation hydrodynamics simulations performed with the CO5BOLD stellar atmosphere code to understand the differences between the molecular abundances obtained with the 3D hydrodynamical and classical 1D stellar model atmospheres. We find that convection alters significantly the thermodynamical structure of stellar atmosphere, especially in the outer layers, and its influence grows larger with decreasing metallicity. Not surprisingly, this results in significant differences between the molecular abundances derived using the 3D and 1D model atmospheres: for example, in case of OH, CO and NH these differences may be as large as 1.0 − 1.5 dex at [M/H] = − 3.0. The extent of these effects depends also on the effective temperature of the given model atmosphere and on the parameters of individual spectral lines, such as wavelength and excitation potential. As a consequence, this may lead to serious systematic differences between the elemental abundances obtained using the 3D and 1D stellar model atmospheres and therefore should be properly addressed in stellar abundance work, especially at low metallicities.

CNO Abundances in Metal-Poor Stars

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Carbon, nitrogen, and oxygen are produced in the early universe by a variety of possible astrophysical sites. Among these are early supernovae, the winds of massive, rapidly-rotating, mega metal-poor stars, and intermediate-mass AGB stars. Large-scale surveys such as the HK Survey of Beers and colleagues and the Hamburg/ESO Survey of Christlieb and colleagues have resulted in the identification of numerous metal-poor stars in the Galactic halo; the SEGUE program within SDSS is adding many tens of thousands of additional low-metallicity stars. Follow-up spectroscopic observations of these metal-poor stars is necessary to determine the full set of their CNO abundances; techniques have been developed to determine [C/Fe], [N/Fe], and [O/Fe] with reasonable accuracy using medium-resolution spectroscopy in the near-UV, optical, and near-IR. The data for our pilot study come from several different instruments on southern-hemisphere telescopes, including the Goodman HTS and OSIRIS on SOAR, GMOS on Gemini-S, and X-SHOOTER on the VLT.

A Search for Additional Metal-Poor Candidates from HES using Carbon Abundance Estimates

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It has been noted by recent studies that there is a correlation between carbon enhancement in metal-poor stars and the presence of s-process elements overabundances (CEMP-s stars), such as Ba and Sr. This behaviour is consistent with the hypothesis that these enhancements are due to nucleosynthesis processes that took place during the AGB stage of evolution, either from the star itself or by a now-extinct binary companion that has transferred material to a surviving (observed) component. However, this correlation no longer persists (or at least is different in nature) for stars with [Fe/H]<-2.7. These so-called CEMP-no stars (indicating a lack of s-process-element overabundances), and the other categories of CEMP stars that have been noted, suggest that a variety of mechanisms for the production of carbon must have played a role in the early universe. More detailed investigations of the origin of carbon at the lowest metallicities as well as studies of s-process nucleosynthesis require significantly enlarged samples of carbon-enhanced metal-poor stars.

This work seeks to identify new carbon-enhanced metal-poor (CEMP) candidates from the Hamburg/ESO (HES) prism survey plates, based on a selection scheme that uses a new set of carbon indices for the CH G-band. We developed a criteria that also takes into account warm CEMP stars. This broadens the metallicity range in our sample and gives a better view of the trends between enrichments of carbon and neutron capture elements.

The final set of objects contains almost 15.000 unrecognized carbon-enhanced metal-poor candidates. This list will help the orientation of medium-resolution spectroscopy studies, that will gather data to calculate the abundances of neutron capture elements, and will further investigate the origin of these selected objects and its abundance patterns. This large scale analysis will also allow the quantification of the ratios of the different types of C-rich stars, and thereby constrain the possible origins and onsets of the neutron capture processes in the formation of the Galaxy.

A detailed analysis of CEMP stars

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We present a detailed study of Carbon-Enhanced Metal Poor (CEMP) stars, including our investigation of a sample of twelve stars as well as data from the literature for about 80 stars. The stellar spectra for our sample were observed at 4.2m William Herschel Telescope (WHT) on July/2003, using Utrecht Echelle Spectrograph (UES) with R $\sim$ 52000 and S/N $\sim$ 40, covering a wavelength range of λλ3700-5700. Atmospheric parameters were determined, with temperatures ranging from 4750K to 7100K, log g from 1.5 to 4.3, and $-3.02 \leq$ [Fe/H] ≤ -1.70. Abundances for C, Na, Mg, Sc, Ti, Cr, Cu, Zn, Sr, Y, Zr, Ba, La, Ce, Nd, Sm, Eu, Gd, Dy were determined. [Ba/Eu] ratios were used to classify these stars according to the classes of CEMP stars. A search for data from the literature reveals a lack of reliable r-element abundances for 70% of CEMP stars. More observing programs dedicated to investigate CEMP stars and new high resolution spectrographs in large telescopes are needed to make further progress in understanding the nucleosynthetic processes that took place in the early Galaxy.

Local stars formed at z>10: a sample extracted from the SDSS

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It is certain that the first generation(s) of stars provided a major contribution to the Universe reionisation. Current observations do not allow to study galaxies at these high redshifts, however local stars with ages above 13 Gyr were formed at redshift 10, or larger. Such stars offer us the unique opportunity of having a snapshot of the chemical composition of the ISM at these early epochs. The old, extremely metal-poor (EMP) stars, whose atmospheres provide this crucial information, are very rare and their discovery requires dedicated surveys. In this contribution I report on the use of the data from the Sloan Digital Sky Survey to detect these EMP stars and on the follow-up high resolution spectroscopy and detailed chemical composition of nearly 20 EMP candidates with UVES@VLT. I will also describe the automated codes employed for target selection, and for the subsequent parameters determination and detailed chemical analysis.

Chemical Enrichment of Metal-Poor Stars by the First Supernovae

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The first stars are key to the formation of primeval galaxies, early cosmological reionization, and the origin of supermassive black holes. Although Population III stars lie beyond the reach of direct observation, their chemical imprint on long-lived second generation stars may yield indirect measures of their masses.
While numerical models of primordial SN nucleosynthetic yields have steadily improved in recent years, they have not accounted for the chemical abundances of ancient metal-poor stars in the Galactic halo. We present new 2D models of 15 - 250 solar-mass primordial SNe that capture the effect of progenitor rotation, mass, metallicity, and explosion energy on elemental yields. Rotation dramatically alter the structure of zero-metallicity stars, expanding them to much larger radii. This promotes mixing between elemental shells by the SN shock and fallback onto the central remnant, both of which govern which elements escape the star. We find that a Salpeter IMF average of our yields for 15 - 40 solar mass Z=0 models with explosion energies of 2.4 Bethe or less is in good agreement with the abundances measured in extremely metal-poor stars. Because these stars were likely enriched by early SNe from a well-defined IMF, our models indicate that the bulk of the metals in the early universe were synthesized by low-mass primordial stars.

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