First Stars V

Heidelberg, July 31 – August 5, 2016

Program and Abstract Booklet

(page intentionally left blank)

Contents

Organization and practical information

Scientific Organizing Committee (SOC)

- Martin Asplund (Australian National University, Australia)
- Beatriz Barbuy (Universidade de São Paulo, Brazil)
- Piercarlo Bonifacio (Observatoire Paris-Meudon, France)
- Volker Bromm (University of Texas at Austin, USA)
- Cristina Chiappini (Leibnitz-Institut für Astrophysik, Potsdam, Germany)
- Norbert Christlieb (ZAH/LSW, Germany; **co-chair**)
- Andrea Ferrara (Scuola Normale Superiore di Pisa, Italy)
- Anna Frebel (Massachussetts Institute of Technology, USA)
- Alexander Heger (Monash University, Australia)
- Sadegh Khochfar (Royal Observatory of Edinburgh, UK)
- Ralf Klessen (ZAH/ITA, Germany; **co-chair**)
- Chiaki Kobayashi (University of Hertfordshire, UK)
- Karin Lind (Max-Planck Institut für Astronomie, Heidelberg, Germany)
- Abraham Loeb (Center for Astrophysics, Harvard University, USA)
- Ken'ichi Nomoto (University of Tokyo, Japan)
- Michal Norman (University of California, San Diego, USA)
- Kazuyuki Omukai (Tohoku University Astronomical Institute, Japan)
- Raffaela Schneider (Osservatorio Astronomico di Roma, Italy)
- Massimo Stiavelli (Space Telescope Science Institute, Baltimore, USA)
- Marta Volonteri (Institut d'Astrophysique de Paris, France)
- Naoki Yoshida (University of Tokyo, Japan)
- Gang Zhao (National Astronomical Observatories of China, China)

Local Organizing Committee (LOC)

- Norbert Christlieb (ZAH/LSW; **co-chair**)
- Simon Glover (ZAH/ITA)
- Melanie Hampel (ZAH/LSW)
- Ralf Klessen (ZAH/ITA; **co-chair**)
- Hans-Günter Ludwig (ZAH/LSW)
- Guido Thimm (ZAH/ARI)

How to read the booklet

In the booklet, abstracts of talks and posters are ordered according to session. Within each session, talks are ordered according to their appearance in the program, posters alphabetically according to first author. Posters are identified by **P⟨session number⟩.⟨count⟩**. If you want to check out your abstract(s) it is perhaps easiest to start from the author index at the end of the booklet.

Links in the booklet are shown in blue, and (hopefully) work as expected. On the inner margin close to the title of all abstracts you find two links. ToC takes you to the top of the table of contents, Prg to the top of the session in the conference program which the abstract is associated with. This should enable an easy back-and-forth between program and abstracts.

Venue

The venue of First Stars V is the Heidelberg conference center called "Stadthalle Heidelberg", address:

Kongresshaus Stadthalle Heidelberg
Neckarstaden 24
69117 Heidelberg

You can find its location marked in the map on the back-cover of the abstract booklet. The main entrance is on the western side of the building.

Conference office

The conference office is located in the basement, below the lecture hall. The opening hours are: Sunday 16:00-20:00; Monday to Friday 8:30-18:00.

Questions and help

In case of questions contact Mrs. Barbara Wright and/or Mrs. Lydia Finster at the conference office:

- Barbara Wright: bwright@lsw.uni-heidelberg.de
- Lydia Finster: lydia.finster@zuv.uni-heidelberg.de

In urgent cases you may contact Norbert Christlieb via the mobile phone numbers +49 - (0)176 - 67 67 14 08, or Ralf Klessen via +49 - (0)152 - 09 34 08 47.

Name badge

We kindly request all participants to wear their name badges for getting access to the Stadthalle during the conference.

WLAN access at the Stadthalle

The WLAN at Stadthalle is provided free of charge! However, you have to perform the following steps to obtain a "ticket code" that you need to access the WLAN of Stadthalle:

1. Turn on the WLAN receiver of your device.
2. Connect to the network "Stadthalle".
3. Open an internet browser. An input screen will open.
   (If this fails, enter the following address: http://172.16.200.1:8080).
4. You can now switch to English navigation by clicking the UK flag icon in the upper right corner.
5. Please enter your mobile phone number and click "**Send**".
6. Click "**here**" in the lower part of the confirmation page. You will receive a text message with your personal ticket code. If your mobile phone does not work in Germany, the conference office can provide you with a ticket code.
7. Enter your ticket code and confirm by pressing "**Activate**"
8. You will now see a page with the period during which your ticket will be valid. During this period you will not have to enter your ticket number again.

Please note: Each ticket number is valid only for one device. If you would like to use more than one device, please retrieve more ticket codes, using the procedure described above. You can also get ticket codes at the conference office.

Mobile phones

All participants should keep their mobile phones on mute in the auditorium during the sessions.

Information for speakers

We would like to ask all speakers to upload their presentation to one of the laptops on the stage in the auditorium in time — however, latest during the break before the session of their presentation. We will provide — besides the standard PDF viewers — OpenOffice under Linux, Keynote as well as PowerPoint under MacOS, and PowerPoint Windows. If really necessary speakers can use their own laptop.

Information for poster presenters

Poster walls will be provided on the 2nd floor of the Stadthalle. Their size is approximately 0.95 m × 2.5 m (width × height); i.e. a poster printed in A0 format (0.841 m × 1.189 m) will easily fit. We will provide you with material for mounting your poster. The three best posters will be awarded a prize.

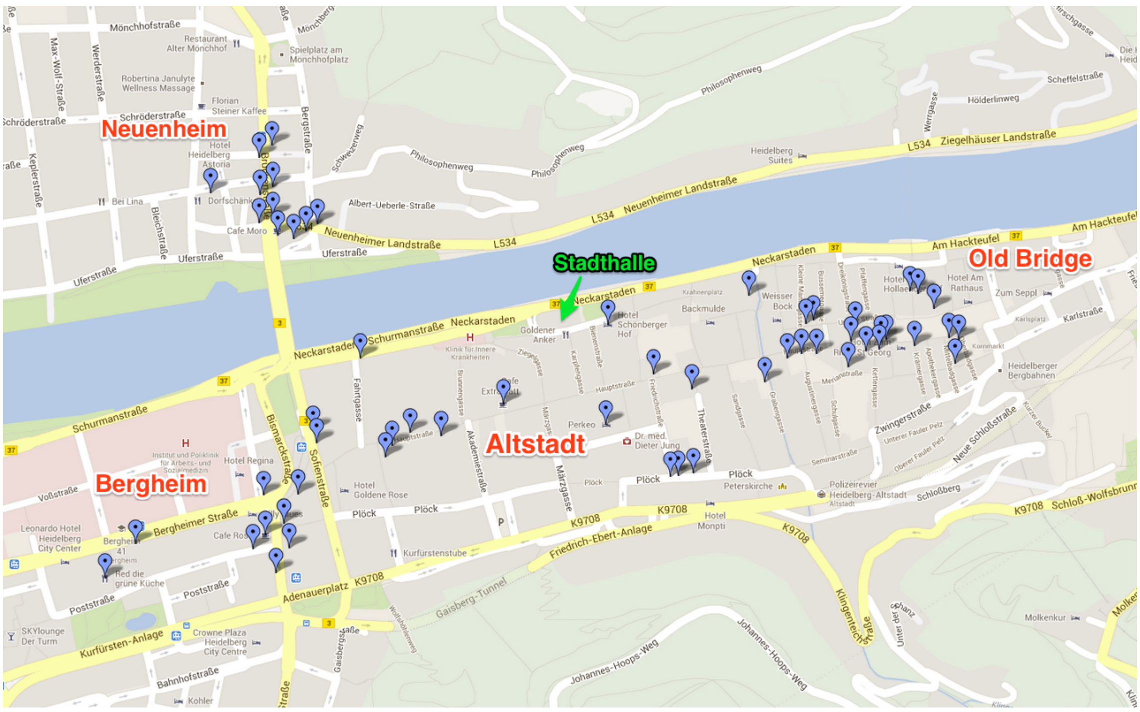
You will have the opportunity to present a summary of your poster in a one-slide, one-minute presentation at the end of the session to which your poster has been assigned to (see the program for details). Please upload your slide to one of the laptops on the stage as early as possible, and during the break before the relevant session at the latest.

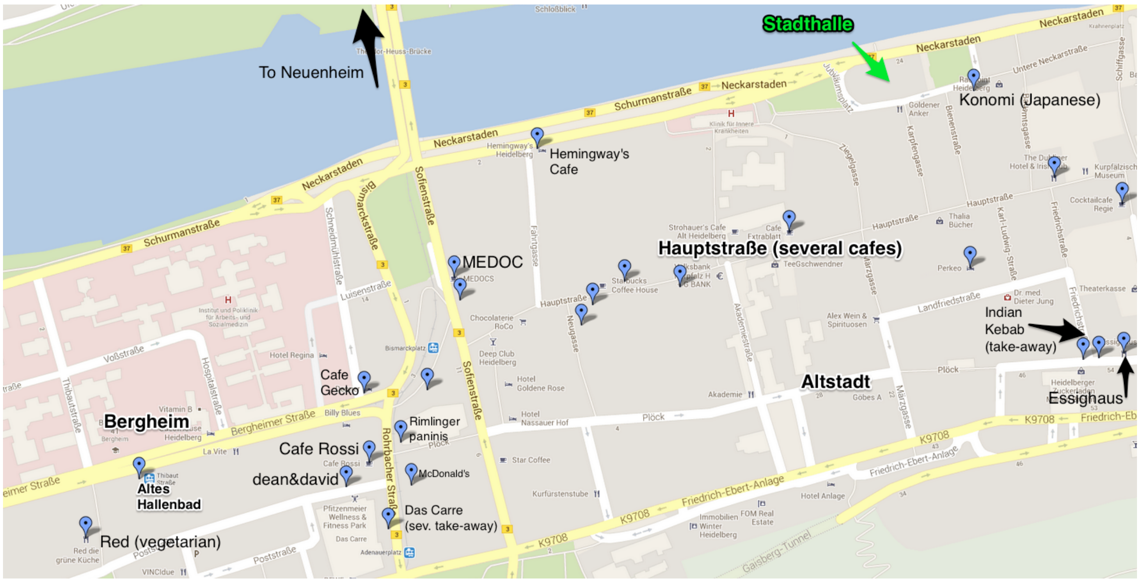
Sponsors

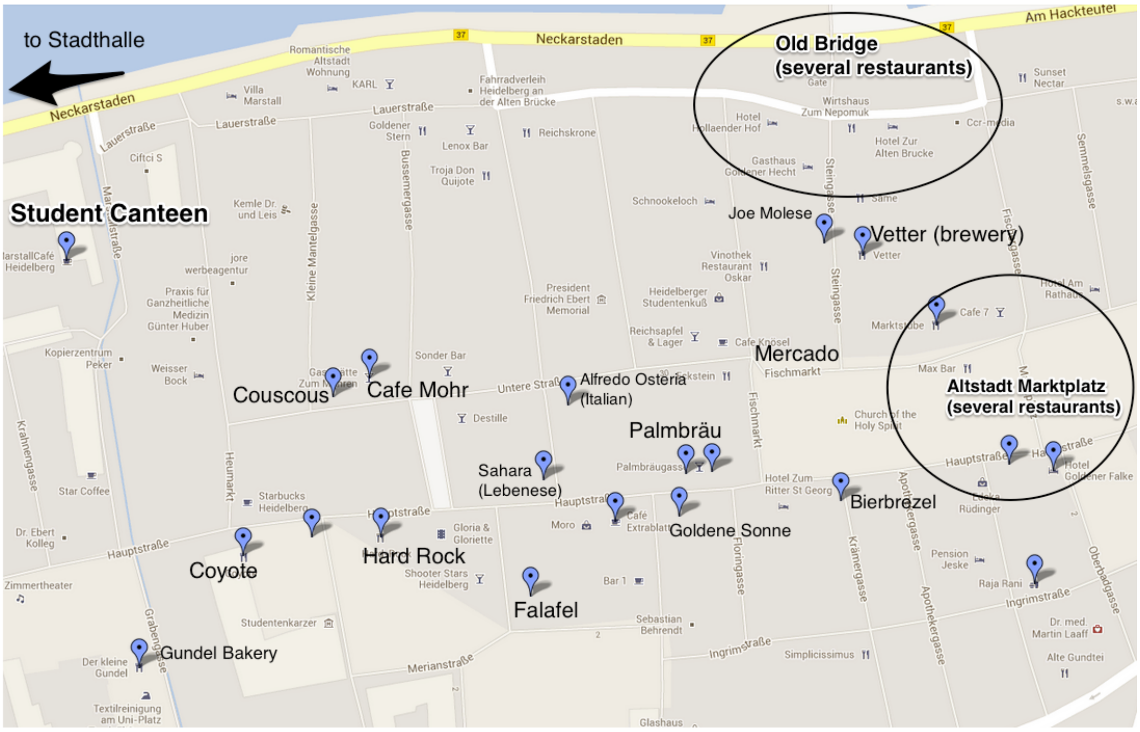
The organizers would like acknowledge financial support by the ERC Advanced Grant "STARLIGHT", and by the Sonderforschungsbereich 881 (Collaborative Research Center) "The Milky Way System" of the Deutsche Forschungsgemeinschaft (DFG).

Restaurants in the vicinity of the Stadthalle

There are many options for eating and drinking in Heidelberg. Below you find maps (courtesy LOC of Protostars and Planets VI) where some restaurants are marked. You may also use the following link or the QR code on the back cover referring to a Heidelberg Restaurant Guide compiled by UniKT, the conference department of the University of Heidelberg. Map scale: the distance between the Stadthalle and the suburb of Neuenheim on the other side of the river Neckar is about 1.5 km, it takes about 20 min to walk.




Stadthalle
To Neuenheim
Konomi (Japanese)
Hemingway's
Cafe
MEDOC
Hauptstraße (several cafes)
Indian
Kebab
(take-away)
Cafe
Gecko
Altstadt
Essighaus
Bergheim
Rimlinger
paninis
Cafe Rossi
dean&david
Altes
Hallenbad
Das Carre
(sev. take-away)
Red (vegetarian)
Neckarstaden
Schurmanstraße
Sofienstraße
Bergheimer Straße
Friedrich-Ebert-Anlage
Plöck


to Stadthalle
Neckarstaden
Old Bridge
(several restaurants)
Student Canteen
Joe Molese
Vetter (brewery)
Mercado
Couscous
Cafe Mohr
Alfredo Osteria
(Italian)
Palmbräu
Altstadt Marktplatz
(several restaurants)
Sahara
(Lebenese)
Bierbrezel
Goldene Sonne
Hard Rock
Coyote
Falafel
Gundel Bakery

Program

Sunday, July 31

16:00-20:00	Registration (Foyer, Stadthalle)
18:00-22:00	Welcome reception (Foyer, Stadthalle)

Monday, August 1

09:00-10:00	Registration
10:00-10:15	**Conference organizers: Welcome address**
	Session 1: Population III stars: formation, IMF, stellar multiplicity, and rotation
10:15-10:30	Daniele Galli: Honoring the contributions of Francesco Palla (1954-2016)
10:30-11:10	Takashi Hosokawa: Population III stars (invited review)
11:10-11:30	Michael Norman: Late Pop. III star formation during the epoch of reionization
11:30-11:50	Jennifer Schober: Generation of strong magnetic fields during formation of the first stars
11:50-12:00	Poster presentations P1.01, P1.02, P1.03, P1.04, P1.05, P1.06, P1.07, P1.08, P1.09, P1.10, P1.11
12:00-14:00	Lunch break
14:00-14:20	Tomoaki Ishiyama: Where are the low-mass Pop. III stars?
14:20-14:40	Piercarlo Bonifacio: A local perspective of Pop. III star formation from the TOPoS project
	Session 2: Stellar evolution and nucleosynthesis in metal-free and metal-poor stars
14:40-15:20	Sylvia Ekström: Stellar evolution of metal-poor and metal-free stars (invited review)
15:20-15:50	Coffee break
15:50-16:30	Alexander Heger: Nucleosynthesis of the first stars (invited review)
16:30-16:55	Alexander Ji: The r-process dwarf galaxy Reticulum II (highlight talk)
16:55-17:15	Timothy Beers: Constraints on the r-process from halo r-II stars
17:15-17:40	Ian Roederer: Observations of neutron-capture element abundances (highlight talk)
17:40-18:00	Poster presentations P2.01, P2.02, P2.03, P2.04, P2.05, P2.06, P2.07, P2.08, P2.09, P2.10, P2.11, P2.12, P2.13, P2.14, P2.15, P2.16, P2.17, P2.18
18:00-22:00	Poster viewing

Tuesday, August 2

	Session 3: The transition to second-generation star formation
09:00-09:40	Raffaela Schneider: The transition to second-generation star formation (invited review)
09:40-10:00	Britton Smith: Ab initio simulations of the first metal-enriched stars
10:00-10:20	Dominik Schleicher: Formation of the metal-poor stars SDSS J1029 and SMSS J0313
10:20-10:50	Coffee break
10:50-11:10	Luca Graziani: The role of feedback in regulating star formation through cosmic times
11:10-11:15	Poster presentations P3.01, P3.02, P3.03, P3.04
	Session 4: Formation of primordial galaxies and observations of the high-z Universe
11:15-12:00	Volker Bromm: Theory of formation of the first galaxies (invited review)
12:00-14:00	Lunch break
14:00-14:40	Nick Gnedin: Cosmic reionization and background radiation (invited review)
14:40-15:20	Ross McLure: Observations of the first galaxies (invited review)
15:20-15:45	Jarrett Johnson: Pop. III galaxies and accreting BHs (highlight talk)
15:45-16:05	Anna Schauer: Lyman-Werner UV escape fractions from primordial halos and galaxies
16:05-16:35	Coffee break
16:35-16:55	Andrea Pallottini: Cosmic metal-enrichment by the first galaxies
16:55-17:15	Claes-Erik Rydberg: A search for Population III galaxies in CLASH
17:15-17:35	John Wise: Physical and observable predictions for the first galaxies
17:35-17:45	Poster presentations P4.01, P4.02, P4.03, P4.04, P4.05, P4.06, P4.07, P4.08, P4.09, P4.10
19:00-20:30	Public talk by Volker Bromm (Alte Aula der Universität Heidelberg)

Wednesday, August 3

	Session 5: The first supernovae, and gamma-ray bursts
09:00-09:40	Carla Fröhlich: The first supernovae, and gamma-ray bursts (invited review)
09:40-10:05	Ken'ichi Nomoto: Superluminous SNe: their models and first-star connection (highlight talk)
10:05-10:25	Thomas Nordlander: Implications for Pop. III SNe from 3D-NLTE analysis of Keller's star
10:25:10:45	Daniel Whalen: Finding the first cosmic explosions
10:45-10:50	Poster presentations P5.01, P5.02
10:50-11:00	Conference photo in front of the Stadthalle
11:00-18:00	Lunch break/excursions
19:00-23:00	Conference dinner at Restaurant Molkenkur

Thursday, August 4

	Session 6: Formation, growth and feedback of supermassive black holes at high z
09:00-09:40	Priya Natarajan: Formation, growth and feedback of SMBHs (invited review)
09:40-10:00	Rosa Valiante: From the first stars to the first black holes
10:00-10:20	Mark Dijkstra: Observational signatures of direct collapse black holes
10:20-10:50	Coffee break
10:50-11:10	Simon Glover: Forming black holes by direct collapse: what determines the critical UV flux?
11:10-11:30	Kohei Inayoshi: Hyper-Eddington accretion flows onto massive black holes
11:30-11:50	Edwige Pezzulli: Super-Eddington growth of the first black holes
11:50-12:00	Poster presentations P6.01, P6.02, P6.03, P6.04, P6.05, P6.06, P6.07, P6.08, P6.09, P6.10, P6.11
12:00-14:00	Lunch break
	Session 7: Galactic archaeology and metal-poor stars in the local Universe
14:00-14:40	Stefania Salvadori: The local fossils of the first stars and galaxies (invited review)
14:40-15:20	Anna Frebel: Dwarf galaxies (invited review)
15:20-15:45	Lyudmila Mashonkina: NLTE abundance analysis of Milky Way satellites (highlight talk)
15:45-16:15	Coffee break
16:15-16:55	David Yong: Galactic metal-poor stars (invited review)
16:55-17:15	David S. Aguado: Follow-up observations of EMP stars identified in SDSS and LAMOST
17:15-17:35	Benjamin Wehmeyer: Galactic chemical evolution of the r-process elements
17:35-17:45	Poster presentations P7.01, P7.02, P7.03, P7.04, P7.05, P7.06, P7.07, P7.08, P7.09
17:45-22:00	Poster viewing

Friday, August 5

09:00-09:25	Louise Howes: Metal-poor stars in the Galactic bulge (highlight talk)
09:25-09:45	Sarah Martell: Globular clusters and galaxy assembly: results from APOGEE
09:45-10:10	Ryan Cooke: Metal-poor damped Lyman alpha systems (highlight talk)
10:10-10:30	**Poster award ceremony and talk of the poster prize winner**
10:30-11:00	Coffee break
	Session 8: Future surveys and observational facilities
11:00-11:30	Sofia Feltzing: Wide-angle spectroscopic surveys (invited talk)
11:30-12:00	Andreas Korn: Gaia (invited talk)
12:00-14:00	Lunch break
14:00-14:30	Jean-Gabriel Cuby: Euclid (invited talk)
14:30-15:00	Asantha Cooray: Future infrared missions (invited talk)
15:00-15:30	Massimo Stiavelli: JWST (invited talk)
15:30-16:00	Coffee break
16:00-16:30	Jeff Wagg: SKA (invited talk)
16:30-17:00	Michele Cirasuolo: E-ELT (invited talk)
17:00-17:30	Rebecca Bernstein: GMT (invited talk)
17:30-17:45	**Conference organizers: Farewell address**

Talks at First Stars V

ToC Prg

Francesco Palla: an appreciation

D. Galli

INAF Osservatorio Astrofisico di Arcetri, Firenze, Italy

Francesco Palla (1954-2016)

Francesco Palla was a leading expert in the field of star formation, co-author of one of the most authoritative textbooks on the subject, and a man of great intellect and humanity. This talk will focus on some aspects of Francesco's scientific legacy, from the chemistry of the early Universe to to the processes involved in the formation of the first stars.

Population III stars

ToC Prg

T. Hosokawa

University of Tokyo, Japan

I review the current status of our understanding of the formation of Pop III stars, mostly from the theoretical point of view. One of our ultimate goals is deriving the typical mass and mass spectrum of Pop III stars, which should have played vital roles in the early Universe. Toward such a direction, previous studies have shown various aspects of dynamical evolution through their formation process, such as the cloud collapse, protostellar accretion, disk fragmentation, radiative feedback and so on. The current picture predicts that Pop III stars are typically high-mass stars with a few times 10-100 $M_{\odot}$, and that their mass spectrum is top-heavy. However, there are still uncertainties on properties of Pop III stars: the exact shape of the mass spectrum, minimum and maximum stellar masses, multiplicity, and internal rotation etc. Difficulties to determine such properties come from the fact that the evolution occurs over very a broad dynamic range, from the cosmological large-scale structure to the stellar interior. I will summarize what kind of future studies are awaited to resolve the difficulties and extend our knowledge.

ToC Prg

Late Pop III star formation during the epoch of reionization: results from the Renaissance simulations

M. Norman[1], H. Xu[1], B. O'Shea[2], J. Wise[3]

(1) U. California San Diego, USA
(2) Michigan State U., USA
(3) Georgia Institute of Technology, USA

We present results on the formation of Pop III stars at redshift 7.6 from the Renaissance Simulations, a suite of extremely high-resolution and physics-rich radiation transport hydrodynamics cosmological adaptive-mesh refinement simulations of high redshift galaxy formation performed on the Blue Waters supercomputer. In a survey volume of about 220 comoving Mpc^3, we found 14 Pop III galaxies with recent star formation. The surprisingly late formation of Pop III stars is possible due to two factors: (i) the metal enrichment process is local and slow, leaving plenty of pristine gas to exist in the vast volume; and (ii) strong Lyman-Werner radiation from vigorous metal-enriched star formation in early galaxies suppresses Pop III formation in ("not so") small primordial halos with mass less than 3×10^7 $\mathrm{M}_\odot$. We quantify the properties of these Pop III galaxies and their Pop III star formation environments. We look for analogues to the recently discovered luminous Ly emitter CR7 (Sobral et al. 2015), which has been interpreted as a Pop III star cluster within or near a metal-enriched star forming galaxy. We find and discuss a system similar to this in some respects, however the Pop III star cluster is far less massive and luminous than CR7 is inferred to be.

On the generation of strong magnetic fields during the formation of the first stars and galaxies

ToC Prg

J. Schober

Nordita, Sweden

The first stars form in an environment that is considered to be very simple in comparison to the present-day ISM. Recent studies suggest, however, that magnetic fields could have significant influence already in the early Universe. Their origin is likely to be a turbulent small-scale dynamo which converts turbulent kinetic energy into magnetic energy by randomly stretching, twisting, and folding the field lines. In my talk I will discuss how this mechanism can amplify very weak magnetic seed fields by many orders of magnitude. In particular, I will present our recent analytical model for the saturation of the turbulent dynamo. Our model covers the shift of magnetic energy from the dissipative scales up to the forcing scale of turbulence by including a scale-dependent effective magnetic resistivity. Depending on the physical conditions, e.g. the compressibility of the gas and the Reynolds number, we predict that the magnetic energy at saturation is roughly 0.1-40 % of the turbulent kinetic energy. This corresponds to field strengths of the order of 10^{-6} Gauss that are produced within a few Myrs. The resulting turbulent magnetic fields can be included in future theoretical models and might change our understanding of the formation of the first stars and galaxies.

ToC Prg

Where are the low mass Pop III stars?

T. Ishiyama[1], K. Sudo[2], S. Yokoi[2], K. Hasegawa[3], N. Tominaga[2], H. Susa[2]

(1) Chiba University, Japan
(2) Konan University, Japan
(3) Nagoya University, Japan

We study the number and the distribution of low mass Pop III stars in the Milky Way. In our numerical model, hierarchical formation of dark matter minihalos and Milky Way sized halos are followed by a high resolution cosmological simulation, which can predict the spatial distribution of Pop III survivors in the Milky Way. We model the Pop III formation in H_2 cooling minihalos without metals under UV radiation of the Lyman-Werner bands. Assuming a Kroupa IMF from 0.15 to 1.0 $M_\odot$ for low mass Pop III stars as a working hypothesis, we try to constrain the theoretical models in reverse by current and future observations. We find that the number of survivors is proportional to the halo mass and the number of Pop III per minihalo. Thus, the distribution of survivors reflects that of dark matter, and the survivors tend to concentrate on the center of halo and subhalos. We also evaluate the observability of Pop III survivors in the Milky Way and dwarf galaxies, and constraints on the number of Pop III survivors per minihalo. The higher latitude fields require lower sample sizes because of the high number density of stars in the galactic disk, the required sample sizes are comparable in the high and middle latitude fields by photometrically selecting low metallicity stars with optimized narrow band filters, and the required number of dwarf galaxies to find one Pop III survivor is less than ten at <100 kpc for the tip of redgiant branch stars. Provided that available observations have not detected any survivors, the formation models of low mass Pop III stars with more than ten stars per minihalos are already excluded.

The dawn of star formation: a local perspective from the TOPoS project ToC Prg

P. Bonifacio

Observatoire de Paris, France

At the end of the Dark Ages, gravity began to make matter collapse around over-densities, resulting in the formation of the first stars, the Pop III. These stars are very important in the cosmological context, since the most massive ones contributed ionizing photons that played a role in the reionization of the Universe and synthetised the first metals. We know that the formation mode of these first stars was different than the one operating today. The lack of metals implies that it is difficult to cool a contracting cloud, which would argue for a preferential formation of massive or very massive stars. However from the theoretical point of view it is not yet possible to determine the initial mass function of the first stars. Simulations show that, even in the absence of metals, a collapsing cloud may fragment into smaller clouds giving rise to stars that span a range of masses, even sub-solar. Once the first metals begin to be shed in the clouds cooling becomes possible, either through atomic lines or through dust. It is likely that there is a transition from Pop III to "normal" Pop II star formation at some critical metallicity, however the precise value of this critical metallicity cannot be presently determined theoretically. In this talk I will describe the observational efforts that our group is conducting in the local Universe, in order to derive as many constraints as possible on the nature of the Pop III stars. These include searches of the most metal-poor stars, and their chemical characterization. Both the metallicity distribution function and the chemical pattern of the most metal-poor stars contain precious information on the first stars.

ToC Prg

Stellar evolution of metal-free and metal-poor stars

S. Ekström[1], G. Meynet[1], R. Hirschi[2], A. Choplin[1], C. Georgy[1]

(1) Geneva University, Switzerland
(2) Keele University, UK

I will recall the basics of stellar evolution and show the role the metallicity plays in the equilibrium and evolution of stars. I will present the peculiarities of metal-free or metal-poor stars during their life, and the way they contribute to the enrichment of the Universe.

Nucleosynthesis of the first stars

ToC Prg

A. Heger

Monash Centre for Astrophysics, Monash University, Australia

One of the key questions in modern cosmology is to learn about the properties of the first generation of stars. Given the wealth of observational data of ultra-metal poor stars that preserve the nucleosynthetic signatures of these first and other early stellar generations to the present day, understanding the nuclesynthetic signature of the first stars is one, if not the best, avenue toward that understanding. The first stars are quite unique due to their pristine primordial initial composition. This dramatically alters both their evolution and the way they die, e.g., as supernovae. The possible outcomes of stellar evolution may well be very different from modern stars, e.g., due to reduced mass loss or different internal structure and transport processes. Different kinds of supernova and supernovae from stars more massive at the end of their lives may produce unique nucleosynthesis signatures. An example could be, e.g., pair instability supernovae. The nucleosynthesis is also much affected by the lack of initial CNO elements that in modern massive stars are one of the key sources of neutrons for the weak s-process and help to reduce the odd-even effect in the nucleosynthesis pattern. At the same time, the seed for the s-process, iron is also missing in primordial stars. Small amounts of iron, as may be present in massive second-generation UMP stars, on the other hand, can become the seeds for very strong neutron exposure in case of primordial production of neutron sources. In this review I will discusss the different scenarios and outcomes. An important question is also how to use the predieced abundances to compare to observational data. How can we best interpret, and combine, the predicted yields to learn more about the nature and fates of these early stars that produced the observed abundance patterns?

ToC Prg

Dwarf galaxy archaeology with the r-process galaxy Reticulum II

A. Ji[1], A. Frebel[1], A. Chiti[1], J. Simon[2]

(1) Massachusetts Institute of Technology, USA
(2) Observatories of the Carnegie Institution of Washington, USA

Ultra-faint dwarf galaxies are old, metal-poor relics from the era of first galaxies. Their simple formation histories preserve a fossil record of early chemical enrichment. I present high-resolution chemical abundances of nine stars in the recently discovered ultra-faint dwarf Reticulum II, seven of which display extremely enhanced r-process abundances 2-3 orders of magnitude higher than in the other ultra-faint dwarfs. Stars with such extreme r-process enhancements are only rarely found in the Milky Way halo. The r-process abundances imply that the neutron-capture material in Reticulum II was synthesized in a single prolific event, either a neutron star binary merger or a magnetically driven supernova. This event occurred before the galaxy was enriched to [Fe/H] $= -3$, raising the question of whether the r-process elements were synthesized by Population III stars. Furthermore, the single event breaks chemical abundance degeneracies associated with inhomogeneous metal mixing, providing the opportunity to construct uniquely detailed chemical evolution models for this relic galaxy.

Constraints on the r-process from halo r-II stars

ToC Prg

T. C. Beers, V. M. Placco, E. M. Holmbeck, R. A. Surman

University of Notre Dame, USA

There are presently some 20 highly r-process-element-enhanced metal-poor (r-II) stars known in the Galactic halo, roughly twenty years after their first recognition. These stars exhibit enhancements of their r-process-element to iron ratios, relative to Solar ratios, by a factor of 10 to more than 100 ([r-element/Fe] $> +1.0$). Despite their very low metallicities ([Fe/H] < -2.0), these stars exhibit an apparently universal [r-element/Fe] pattern that is very well-matched to the Solar r-process pattern. As such, they have long been thought to provide fundamental information on the likely astrophysical site of the r-process. We report on a comparison of the observed properties of field r-II stars with the remarkable recent detection of a large sample of r-II stars identified in the Ultra Faint Dwarf (UFD) galaxy Reticulum-II [1,2], and suggest that the UFD environment is the natural birthplace of essentially all r-II stars – due to their relative rarity, the clear overlap in metallicity of the field r-II stars with that of UFDs, and the observed range in the absolute abundances of r-process elements in such stars. Other recent observational constraints, including the demonstration that the formation of r-II stars does not rely on the presence of a binary companion [3], will be reported. A new, much-expanded effort to dramatically increase the numbers of known r-II stars in the halo is now underway, and will also be described.

[1] A.P. Ji et al., Nature 531, 610 (2016).
[2] I.U. Roederer et al., Astronomical Journal, in press, arXiv:1601.04070 (2016).
[3] T.T. Hansen, et al., Astronomy & Astrophysics 583, 49 (2015).

ToC Prg

Neutron-capture elements from the first stars

I. Roederer

University of Michigan, USA

Observational studies of heavy elements produced by neutron-capture reactions have revealed a variety of abundance patterns in metal-poor stars. My work focuses on abundances derived from ultraviolet and optical high-resolution spectroscopic data of dwarf galaxies, globular clusters, and field stars in the stellar halo. I will present recent observations of these elements that change our understanding of when and how they were first produced in the early Universe. I will also present the case for future facilities that could revolutionize the field.

The transition to second-generation star formation

ToC Prg

R. Schneider

INAF/Osservatorio Astronomico di Roma, Italy

Predominantly massive Population III stars are predicted to form in the first dark matter mini-halos. During their brief evolution, they largely modify their surroudings, through the emission of radiation, their energetic explosions, and the injection in the interstellar and intergalactic medium of the first metals and dust. The nature and properties of second-generation stars are deeply connected to their formation environment. I will review the emerging theoretical picture, and how observations of the most metal-poor stars in our local neighbourhood provide fundamental constraints on this early transition phase in cosmic history.

ToC Prg

Ab initio simulations of the first metal-enriched stars

B. Smith[1], S. Khochfar[1], J. Wise[2], B. O'Shea[3], M. Norman[4]

(1) Institute for Astronomy, University of Edinburgh
(2) Georgia Institute of Technology
(3) Michigan State University
(4) University of California, San Diego

I will present the first simulations to directly form the first metal-enriched stars from cosmological initial conditions. We simulate the formation of a 10^7 $M_\odot$ halo forming at z = 10 with a dark matter particle mass of 1.5 $M_\odot$, small enough to fully resolve all progenitor mini-halos in which Pop III stars form and the first metals are created. We find that, in most situations, the formation of metal-enriched stars occurs first in mini-halos that have been externally enriched by Pop III supernovae from neighboring halos. The timescale for this process is signifcantly shorter than the time it takes for metals to fall back onto the mini-halo in which they originated. We also study how the era and physical conditions of second-generation star formation is affected by variations in the simulation parameters, such as the energy of the Pop III supernovae and the absence of dust grains. I will conclude by discussing what these simulations can tell us about the requisite conditions for the transition to low-mass star formation.

The formation of the metal-poor stars SDSS J102915+172927 and SMSS J03130036-6708393

ToC Prg

D. Schleicher[1], S. Bovino[2], R. Banerjee[2], T. Grassi[3]

(1) Universidad de Concepción, Chile
(2) Hamburg Observatory, Germany
(3) STARPLAN, Copenhagen, Denmark

Due to the efforts of stellar archeology, the abundances of a number of extremely metal-poor stars have now been measured, allowing us to test their formation via detailed numerical simulations, including the physics of chemistry and cooling. I will focus here on two particularly interesting cases, the oldest-known metal poor star SMSS J031300.36-670839.3, and the most metal poor star SDSS J102915+172927. In the first case, the metal abundances are so high to still allow efficient metal line cooling down to the CMB temperature, while in the second case dust cooling is the only mechanism that provides relevant cooling beyond the primordial regime. Using 3D simulations, I will show that the dust fragmentation threshold is an order of magnitude higher than anticipated from one-zone studies. I will further address the impact of these cooling mechanisms in the presence of strong radiation backgrounds.

ToC Prg

The role of feedback in regulating star formation through cosmic times

L. Graziani

INAF - Istituto nazionale di astrofisica, Italy

The increasing number of galaxies recently discovered in the high redshift Universe and the formidable amount of details provided now by observational facilities such as ALMA or MUSE, open the possibility of constraining models of star formation through cosmic times, in the context of galaxy evolution. A deep theoretical knowledge of the various feedback processes closely linking the evolution of stars, their interstellar medium (ISM) and the intergalactic medium (IGM), is essentcial to unveil the intricate interplay between enrichment by atomic metals and dust, cosmic reionisation and hydro-dynamical processes. Hydro-dynamical, semi-analytic, and radiative transfer simulations are then required, because of their combined capability of exploring feedback on different astrophysical scales, to interpret the spectral properties of observed galaxies at various redshifts. In this talk I will first review dustyGadget, CRASH (Graziani et al. 2013, MNRAS; 2016 in prep) and GAMESH (Graziani et al 2015, MNRAS), three tools jointly developed by the ERC-First group in Rome, and the Max Planck Institute for Astrophysics (MPA), to investigate the many feedback processes described above, in the context of galaxy formation and evolution. While dustyGadget is a novel extension of Gadget-3 (Springel 2005, Tornatore 2007, Maio 2010, Graziani et al., in prep.) accounting for the formation and evolution of atomic metals and dust, self-consistently with the evolution of stellar populations, the cosmological radiative transfer code CRASH is now able to perform multi-frequency bands radiative transfer simulations through cosmic gas polluted by metals and dust. GAMESH is finally a new hybrid approach implementing self-consistent chemical and RT feedback in a semi-analytic model of galaxy formation powered by a NBody simulation. Finally, the results of high-resolution simulations will be shown, to discuss the interplay between feedback, cosmic star formation and Pop III to Pop II population transition in a cosmological scenario, including inhomogeneous chemical enrichment, dust evolution and IGM reionisation. Many key quantities, both theoretical and observed, will be commented on, as the cosmic star formation rate, the evolution of dust mass in collapsed structures and the temperature evolution of the IGM, to finally enlight the effects of the cosmic environment in regulating the process of star formation in galaxies.

Theory of formation of the first galaxies

ToC Prg

V. Bromm

University of Texas, USA

I will review our current state-of-the-art theoretical framework for the formation of the first galaxies, based on ab initio cosmological simulations. The key goal is to make robust predictions for the upcoming deep field observations with the JWST, and the next generation of extremely large, ground based telescopes. A second key goal is to connect the in-situ formation theory of the first galaxies with near-field cosmological probes of dwarf galaxies in the Local Group.

ToC Prg

Cosmic reionization

N. Gnedin

Fermilab, USA

I will review recent (amazing) progress in observational and theoretical studies of cosmic reionization, and will dwell on the forthcoming revolution in that the field. Many fundamental questions that plagued us for decades will finally be answered, and many long-established models will finally be confirmed – or definitely dethroned.

Observations of the first galaxies

ToC Prg

R. McLure

University of Edinburgh, UK

Studying the nature of the first generation of galaxies to form in the Universe is central to efforts to understand the earliest phases of galaxy evolution and the physical processes driving cosmic reionization. Over the last decade, significant progress has been made towards these goals, and independent studies of the basic demographics of the high-redshift galaxy population are now beginning to converge. Consequently, the challenge now is to exploit the combination of new optical/near-IR instrumentation and sub-mm/mm interferometry provided by ALMA to study the physics of star-formation at high redshift. As a result, large observational efforts are currently being invested to try and understand the star formation, metal enrichment and dust production processess in high-redshift galaxies. This talk will attempt provide a review of the latest observational results, highlighting both recent progress and the questions still to be addressed within the forthcoming JWST and ELT era.

ToC Prg

The brightest primordial sources: Population III galaxies and accreting black holes

J. Johnson, J. Smidt, B. Wiggins

Los Alamos National Laboratory, USA

While future observatories such as the James Webb Space Telescope are likely to reveal many candidate primordial objects in the high-redshift universe, there has already been detected at least one very bright source at $z > 6$, in CR7, which may in fact be powered by emission from primordial gas. This source may be powered by either a large cluster of Population III stars or by accretion onto a black hole formed from the direct collapse of the primordial gas. I will present new large-scale cosmological radiation hydrodynamics simulations of the growth of such a black hole, which demonstrate that the nebular emission that it powers can explain the extremely high luminosity of CR7 in key emission lines. I will also present a scenario in which massive Population III galaxies form from the rapid collapse of photo-heated gas in the early universe, a scenario which could also potentially explain the emission from CR7 and which is important to consider in evaluating future searches for the first metal-free galaxies.

Lyman-Werner UV escape fractions from primordial haloes and early galaxies

ToC Prg

A. Schauer[1], S. Glover[1], R. Klessen[1], D. Whalen[2], M. Latif[3]

(1) ITA/ZAH, University of Heidelberg, Germany
(2) ICG, Portsmouth, UK
(3) IAP, Paris, France

Population III (Pop III) stars can regulate star formation in the primordial Universe in several ways. They can ionise nearby halos, and even if their ionising photons are trapped by their own halos, their Lyman-Werner (LW) photons can still escape and destroy H_2 in other halos, preventing them from cooling and forming stars. LW escape fractions are thus a key parameter in cosmological simulations of early reionisation, star formation and black hole seed formation, but have not yet been parametrised for realistic halos by halo or stellar mass. To do so, we present results from radiation hydrodynamical simulations of LW UV escape from 9-120 $M_\odot$ Pop III stars in 10^5-10^7 $M_\odot$ halos with ZEUS-MP. In addition, we present preliminary results of LW escape fractions from early galaxies at z=10, varying the stellar initial mass function and star formation efficiency. We find them to reach from 0 per cent up to more than 90 per cent, strongly depending on the parameters. Shielding of H_2 by neutral hydrogen, which has been neglected in most studies to date, produces escape fractions that are up to a factor of 3 smaller than those predicted by H_2 self-shielding alone.

ToC Prg

Cosmic metal enrichment by the first galaxies

A. Pallottini

University of Cambridge, UK

Galaxy formation is regulated by the competition between gas accretion from the intergalalactic medium and supernova/AGN outflows. The circumgalactic medium is the interface that bears the signatures of both phenomena. Using state-of-the-art simulations, we have modelled metal enrichment by the first galaxies. In this talk I will discuss the main outcome of our study, clarifying the interplay between galaxies and their surrounding environment. These predictions are compared to current observational data using synthetic quasar spectra, allowing to draw key conclusions on the physics of galaxy formation and cosmic enrichment.

Results of a search for Population III galaxies in CLASH

ToC Prg

C.-E. Rydberg

ZAH, Universität Heidelberg, Germany

Population III galaxies are predicted to exist at high redshifts and may be rendered sufficiently bright for detection with current telescopes when gravitationally lensed by a foreground galaxy cluster. Lyα emitters (LAE) with very high Lyα equivalent, EW(Lyα) $>$ 150 Å, potentially Population III galaxies, should furthermore be identifiable from broadband photometry because of their unusual colors. Here, I present the results of a search for such objects at z $>$ 6 in the imaging data from the Cluster Lensing and Supernova survey with Hubble (CLASH), covering 25 galaxy clusters in 16 filters. Our selection algorithm returns five singly-imaged objects with Lyα-like color signatures at z between 6.8 and 8.8, for which ground-based spectroscopy with current 8–10 m class telescopes should be able to test the predicted strength of the Lyα line. None of these five objects have been included in previous CLASH compilations of high-redshift galaxy candidates. However, only two of these objects are significantly better fitted by Population III models than by more mundane, low-metallicity stellar populations. The algorithm also identified two likely gravitationally lensed images of a single LAE candidate behind the Abell 2261 (z = 0.225) cluster. The object has substructure and could be a merger or two galaxies interacting. Model fits to the CLASH broadband photometry suggest strong intrinsic Lyα emission, rest-frame Lyα equivalent width EW(Lyα) $>$ 150 Å, at a redshift of z $\approx$ 6.2. While Population III galaxy models formally provide the best fits, Population I/II models with unusually strong Lyα emission can also reproduce the observations.

ToC Prg

Physical and observable predictions for the first galaxies

J. Wise[1], K. Barrow[1], B. O'Shea[2], N. Michael[3], H. Xu[3]

(1) Georgia Institute of Technology, USA
(2) Michigan State University, USA
(3) UC - San Diego, USA

The Hubble Ultra Deep Field and Frontier Fields have discovered over 1,500 galaxies at redshifts greater than 6. We present observational predictions for this high-redshift population, using the Renaissance Simulations, a suite of high-resolution cosmological simulations, that enables the correlation between key observables and the physical properties of the first galaxies in the Universe. Using a sample of over 3,000 resolved galaxies along with the formation of 10,000 massive Population III stars, we show that the luminosity function flattens above a UV magnitude of -14 but does not drop to zero even to our resolution limit of $M_{UV} \approx -4$. These galaxies are the dominant source for radiation during the early stages of reionization. We find that dark matter halos below the atomic cooling limit ($\approx 10^8\,M_\odot$) can form stars if they are chemically enriched, and they have similar mass-to-light ratios as local ultra-faint dwarfs. We utilize stellar population synthesis models, dust extinction using Monte Carlo methods, and photo-ionization modeling, all sourced from the simulation data, to obtain synthetic observations of the first galaxies. Using these results, we will be able to constrain the following properties of the first galaxies: (1) star formation histories and stellar populations, (2) nebular emission and dust extinction, and (3) the faint end of the luminosity function.

The first supernovae, and gamma-ray bursts

ToC Prg

C. Fröhlich

North Carolina State University, Raleigh, USA

This talk will review our understanding of supernovae from the first stars from simulations and observations. Recent progress will be highlighted, and riddles and open questions will be discussed.

ToC Prg

Superluminous supernovae: their models and first star-connection

K. Nomoto

University of Tokyo, Japan

The physical origin of type-I (hydrogen-less) superluminous supernovae (SLSNe-I), whose luminosities are 10 to 500 times higher than the luminosities of normal core-collapse supernovae, remains still unknown. Thanks to their brightness, SLSNe-I would be useful probes of the distant Universe. In particular, the host galaxies of SLSNe-I tend to have low metallicities, so that their first star-connection would be interesting. For the power source of the light curves of SLSNe-I, radioactive-decays, magnetars, and circumstellar interactions have been proposed, although no definitive conclusions have been reached yet. Since most of light curve studies have been based on simplified semi-analytic models, we have constructed detailed light curve models by means of radiation-hydrodynamical calculations for various star masses including very massive ones, and large amounts of mass loss. The rising time, peak luminosity, width, decline rate of the light curves are compared with observations of SLSNe-I, which show quite a large diversities. We discuss how to discriminate three models, relevant model parameters, their evolutionary origin, possible roles of chemical enrichment of the early Universe, and implications for the identifications of the first stars.

Implications for Population III supernovae from 3D-NLTE analyses of Keller's [Fe/H] < -6 star (SMSS 0313-6708)

ToC Prg

T. Nordlander[1], K. Lind[2]

(1) Uppsala Universitet, Sweden
(2) Max-Planck-Institut für Astronomie, Heidelberg, Germany

Metal-poor stars offer direct clues to the properties of population III stars, which enriched the early Universe. Population III stars themselves have never been observed, and their IMF is debated due to the sensitivity to the physics of accretion and fragmentation. Ejecta from population III supernovae are however imprinted on the chemical composition of the most metal-poor stars, which we can still observe today. We have performed full 3D-NLTE abundance analyses of Li, Na, Mg, Al, Ca and Fe for Keller's star, which is essentially devoid of heavy elements with the lowest [Fe/H] (< -6) and [Ca/H] (-7) of any star. These are the first ever 3D-NLTE analyses of Mg, Al and Fe, and our results indicate higher abundances than classical 1D LTE analyses by 1 dex for Fe, and 0.5 dex for Mg, Al and Ca. The abundance results match predicted population III supernova yields well in a range of progenitor masses. We shall discuss the new 3D-NLTE spectroscopic abundance analysis, as well as implications for the progenitor scenario.

ToC Prg

Finding the first cosmic explosions

D. Whalen[1], C.-E. Rydberg[2], R. Klessen[2]

(1) Institute of Cosmology and Gravitation, University of Portsmouth, UK
(2) Institute for Theoretical Astrophysics, University of Heidelberg

Primordial stars formed about 200 Myr after the Big Bang, ending the cosmic dark ages. They were the first great nucleosynthetic engines of the universe and may be the origins of the supermassive black holes found in most massive galaxies today. In spite of their importance to the evolution of the early Universe not much is known for certain about the properties of Pop III stars. But with the advent of JWST, WFIRST and the 30 m telescopes it may soon be possible to directly observe their supernovae in the NIR and thus unambiguously constrain the properties of the first stars. I will present radiation hydrodynamical calculations of the light curves of the first SNe in the Universe and discuss strategies for their detection. I will also describe how some may already have been captured in surveys of galaxy cluster lenses such as CLASH, Frontier Fields and GLASS.

Formation, growth and feedback of SMBHs

ToC Prg

P. Natarajan

Yale University, USA

— no abstract available —

ToC Prg

From the first stars to the first black holes

R. Valiante[1], R. Schneider[1], M. Volonteri[2], K. Omukai[3]

(1) INAF, - Osservatorio Astronomico di Roma, via di Frascati 33, 00040, Monteporzio Catone, Italy
(2) CNRS, UMR 7095, Institut dAstrophysique de Paris, F-75014, Paris, France
(3) Astronomical Institute, Tohoku University, Aoba, Sendai 980-8578, Japan

The growth of the first super massive black holes (SMBHs) at $z > 6$ is still a major challenge for theoretical models. If it starts from black hole (BH) remnants of the first, Population III, stars (light seeds with mass $\approx$100 $M_\odot$), it requires super-Eddington accretion. An alternative route is to start from heavy seeds formed by the direct collapse of gas onto a $\approx 10^5$ $M_\odot$ BH. I will present a detailed analysis of the role of light and heavy seeds as progenitors of the first SMBHs. We use a cosmological, data constrained, semi-analytic model, based on physically motivated prescriptions to form light and heavy seeds, to consistently model the evolution of the environment out of which seed BHs form and of the chemical properties (metals and dust) of their host galaxies.

Observational signatures of Direct Collapse Black Holes

ToC Prg

M. Dijkstra

University of Oslo, Norway

The direct collapse black hole (DCBH) scenario describes the isothermal collapse of a pristine gas cloud directly into a massive, $M_{BH} = 10^4 - 10^6 M_\odot$ black hole. I will argue that the physical conditions that enable direct collapse are very interesting from a radiative transfer point of view, as they simplify the Lyman alpha (Lyα) radiative transfer problem enormously. I will first focus on the Lyα signatures from DCBHs (luminosities/spectra), and compare these two some high-redshift Lyα emitting sources, including CR7, a candidate DCBH. Also, I will show that the conditions inside the clouds that undergo direct collapse are optimal for pumping of the 3-cm fine structure transition of atomic hydrogen by trapped Lyα radiation. I will briefly discuss the prospects for detecting this 3-cm maser emission, which would truly be a 'smoking gun' for direct collapse.

ToC Prg

Forming black-holes by direct collapse: what determines the critical UV flux?

S. Glover

Heidelberg University, Germany

Observations of high-redshift quasars show that supermassive black holes (SMBH) with masses of order a billion Solar masses have already formed by the time that the Universe is a billion years old. It is generally assumed that these SMBHs form through the growth of lower mass seed black holes by accretion. However, if these seed black holes have masses typical of those produced as the end points of the evolution of normal massive stars, there does not appear to be sufficient time available in the early Universe for them to grow into the observed SMBHs. For this reason, an alternative model for seed black hole formation - the "direct collapse" model - has recently attracted considerable attention. In this model, the suppression of H_2 cooling in high-redshift metal-free protogalaxies leads to the formation of seed black holes with masses of 10,000 solar masses or more, either directly or via a short-lived supermassive star. Crucial for the viability of this model is the strength of the UV radiation background required to suppress H_2 cooling in these protogalaxies. If the required flux (J_{crit}) is too large, then too few massive seed black holes will be formed to explain the observed number density of SMBHs. Many different simulations have attempted to determine J_{crit}, but the results span several orders of magnitude, and there is still no consensus on its value. In this talk, I will summarize what we have learnt about the different physical processes that influence J_{crit}. I will also discuss the significant uncertainties that can be introduced into our estimates of J_{crit} by over-simplifications and approximations in our modelling of the microphysics of the gas, and will show how these uncertainties can be dramatically reduced.

Hyper-Eddington accretion flows onto massive black holes

ToC Prg

K. Inayoshi[1], Z. Haiman[1], J. Ostriker[1,2], Y. Sakurai[3]

(1) Columbia University, USA
(2) Princeton University, USA
(3) University of Tokyo, Japan

How fast can black holes (BHs) grow? The existence of bright quasars at high-redshift provides a challenging puzzle about the origin of supermassive BHs. To form such massive objects within a billion years, rapid growth of seed BHs is required. We study very-high rate, spherically symmetric accretion flows onto massive BHs embedded in dense metal-poor clouds. We find solutions from outside the Bondi radius at hyper-Eddington rates, unimpeded by radiation feedback, when $(\mathrm{n}/10^5\,\mathrm{cm}^{-3}) > (\mathrm{M_{BH}}/10^4\,\mathrm{M_\odot})^{-1}\ (\mathrm{T}/10^4\,K)^{3/2}$, where n and T are the density and temperature of ambient gas outside of the Bondi radius. The resulting accretion rates in this regime are steady, and larger than $5000\,\mathrm{L_{Edd}}/\mathrm{c}^2$ (≈ 500 times the Eddington rate for 10% of the radiative efficiency). At lower rates, the accretion is episodic due to radiative feedback, and the average rate is below the Eddington rate. The hyper-Eddington accretion solution is maintained as long as the emergent luminosity is limited to $<$ (10-30) $\mathrm{L_{Edd}}$ because of photon trapping due to electron scattering. We apply our result to the rapid formation of massive BHs in protogalaxies with a virial temperature of $\mathrm{T_{vir}} \gtrsim 10^4\,\mathrm{K}$. Once a seed BH forms at the center of the galaxy, it can grow to a maximum $\approx 10^5\,\mathrm{M_\odot}\,(\mathrm{T_{vir}}/10^4\,\mathrm{K})$ via gas accretion, independent of the initial BH mass. Finally, we discuss possible observational signatures of rapidly accreting BHs with/without allowance for dust. We suggest that these systems could explain Ly-alpha emitters without X-rays and nearby luminous infrared sources with hot dust emission, respectively.

ToC Prg

Super-Eddington growth of the first black holes

E. Pezzulli

Universitá di Roma La Sapienza / INAF-Osservatorio Astronomico di Roma, Italy

The formation and growth of the first super massive black holes (SMBHs) at $z \approx 6$ is a subject of intense debate. If black holes grow at their Eddington rates, they must start from high-mass seeds, ($M_{seed} \approx 10^4 - 10^5\,M_\odot$), formed by direct collapse of gas. Here I will consider an alternative scenario, where remnants of population III stars, ($M \approx 100\,M_\odot$), can grow at super-Eddington rates via radiatively inefficient slim accretion disks. In Pezzulli et al., (MNRAS 2016), we use an improved version of the cosmological, data-constrained semi-analytic model GAMETE/QSODUST. We follow, for each progenitor present in the simulation, the evolution of a nuclear BH, gas cooling, disk and bulge formation of their host galaxies together with the star formation, SNe/AGN feedback and chemical and dust enrichment. By adopting SDSS J1148+5251 at z=6.4 as a prototype of luminous z=6 quasars, we find that $\approx$80% of the SMBH mass of J1148 is provided by super-Eddington gas accretion, which can be sustained down to $z \approx 10$ in dense, gas-rich environments, and the BH progenitors of the final SMBH evolve in symbiosis with their host galaxies. We reproduce all the observed quantities of J1148, also predicting an AGN-driven mass outflow rate at z=6.4 broadly consistent with the radial profile inferred from CII observation by Cicone et al. (2015). Interestingly, we find that $\approx$20% of the J1148 progenitors at z=7.1 have BH luminosities and masses comparable to ULAS J1120, suggesting that the most distant quasar ever observed may be one of the progenitors of J1148.

The living fossils of the first stars and galaxies

ToC Prg

S. Salvadori

GEPI, Paris Observatory, France

The Local Group holds the living fossils of the first stars and galaxies. Still, these precious relics are extremely rare, and hence difficult to catch. In this talk, I will review the most recent observational findings and theoretical predictions for present-day metal-poor stars and galaxies, underlying the links with the properties of the first star-forming systems. I will present new ideas to identify the direct descendants of massive first stars and to constrain the primordial initial mass function. By discussing the observed properties of different dwarf galaxy types in a full cosmological context, I will argue that ultra-faint dwarfs are the living fossils of star-forming mini-halos and the building-blocks of more massive galaxies.

ToC Prg

Dwarf galaxies

A. Frebel

MIT, USA

Dwarf galaxies play an integral part in the formation and evolution of large galaxies like the Milky Way. By now, nearly 30 dwarf galaxies are known to orbit the Galaxy, altogether covering a wide range of properties such as luminosity and metallicity. The most attention has recently been given to the ultra-faint dwarfs given that new ones are still being discovered, e.g. in DES. Studies of the stellar chemical abundances have revealed that these systems are very metal-poor although with large spreads in [Fe/H], and devoid of solar-type stars. The abundance signatures of the dwarf galaxy stars closely resemble those of equivalent halo stars, suggesting that the metal-poor tail of the Galactic halo was assembled from early analogs of the ultra-faint dwarfs. Especially the most metal-poor halo stars may all originate from such systems. This is supported by the ancient 13 Gyr old age of these galaxies and their lack of any extended star formation. Some of them could plausibly be surviving first galaxies. The ultra-faint dwarfs also present the unique opportunity to study metal-poor star formation and individual nucleosynthesis events from supernovae and other sources. This takes the stellar archaeology approach to dwarf galaxy archaeology in which environmental information on the early gas clouds can be added to the chemical abundance data.

Early chemical enrichment of the Milky Way satellites from NLTE analysis of their very metal-poor stars

ToC Prg

L. Mashonkina[1], P. Jablonka[2], P. North[2], Y. Pakhomov[1], T. Sitnova[1]

(1) Institute of Astronomy of Russian Academy of Sciences, Russian Federation
(2) Laboratoire d'Astrophysique, École Polytechnique Fédérale de Lausanne (EPFL), Observatoire de Sauverny, CH-1290 Versoix, Switzerland

Based on high-resolution spectral observations, NLTE line formation, and precise stellar atmospheric parameters, we present the first complete sample of dSphs with accurate chemical abundances in the VMP regime, -4 < [Fe/H] < -2. The VMP stars in the Sculptor, Sextans, Fornax classical dSphs and the Bootes I UFD reveal enhancement of Mg, Ca, and Ti, with similar [alpha/Fe] of about 0.25 dex in different dSphs. In contrast to LTE, NLTE finds that in each dSph abundances of the alpha-process elements follow each other. The Mg/Fe and Ca/Fe ratios observed in these dSphs favour the early chemical enrichment by ejecta of intermediate-mass SNeII, as predicted by Heger & Woosley (2008). Different case is in the only [Fe/H] = -2.5 star in Leo IV UFD, which does not reveal a notable alpha-enhancement. In NLTE, Na/Mg in all the dSphs, including Leo IV, form a plateau at [Na/Mg] of about -0.6 over -3.8 < [Fe/H] < -2 that is well reproduced by the yields of a single supernova of 14.4 solar mass. The same methods were applied to determine atmospheric parameters and chemical abundances of the MW halo comparison sample. We find 0.1 dex higher Mg/Fe and Ca/Fe ratios in the MW halo compared with the dSphs and very similar Ti/Fe ratios. NLTE is a major step forward for studies of the dSphs and the MW halo in the VMP regime.

ToC Prg

Galactic metal-poor stars

D. Yong

Australian National University, Australia

I will present an overview and highlights of the discovery and analysis of metal-poor stars in the Galactic halo.

Follow-up observations of new extremely iron-poor stars identified from SDSS and LAMOST

ToC Prg

D. Sánchez Aguado, C. Allende Prieto, J. González Hernández

Instituto Astrofísico de Canarias, Spain

The most metal-poor stars in Milky Way witnessed the early phases of formation of the Galaxy, and have chemical compositions that are close to the pristine mixture from Big Bang nucleosynthesis, polluted by one or very few supernovae. Here we present a program we are carrying out to search for, and characterize, new ultra metal-poor stars formed in the early Milky Way. Unfortunately, these stars are extremely rare, with only a few known with less than 1/100,000 of the Solar iron abundance. We have selected iron-poor candidates from SDSS and LAMOST. Dozens of them have been observed with ISIS on the 4.2 m William Herschel Telescope. The most interesting objects have been confirmed with OSIRIS on the 10.4 m-GTC and HRS on the 9.2 m HET. We present the results of our analysis with FERRE as an analysis tool. In addition, we report the discovery of J0815, a carbon rich ultra metal-poor (CRUMP) dwarf star in the [Fe/H] ≈ -5.0 regime. We will discuss the implications of this discovery on our knowledge of the early Galaxy, and the formation of the first stars and supernovae.

ToC Prg

Inhomogeneous Galactic chemical evolution of r-process elements

B. Wehmeyer[1], M. Pignatari[2], F.-K. Thielemann[1]

(1) Dept. Phys., University of Basel, Switzerland
(2) E.A. Milne Centre for Astrophysics, University of Hull

The cosmic life cycle has many features and can be described by many parameters, e.g. stellar production sites, their variations as a function of metallicity, and their occurrence frequency during Galactic evolution. Gas clouds form and eventually collapse to stars, which experience different burning stages according to their individual properties. They end their life either in planetary nebulae, or in violent events like supernovae or hypernovae / gamma-ray bursts (re-ejecting matter to the interstellar medium), leaving behind either a neutron star or a black hole. Eventually, such compact objects might merge, leading to neutron star mergers, neutron star – black hole mergers or black hole mergers. Although the production sites and the ejected yields, determining the evolution of the nuclear abundances of many lighter elements are known, the origin of the heaviest elements still remains a puzzle. The respective and relative contributions of the proposed sources (e.g., supernovae, neutron star mergers) are still debated. We use our chemical evolution tool "ICE" [1, 2] to examine the impact of some of the main factors (e.g., yields and occurrence rates of nucleosynthesis events) of the cosmic life cycle. With ICE's higher resolution runs, we are able to resolve the impact of abundances in supernova remnants on newly born stars. This approach allows to study the chemical inhomogeneities in the early Galaxy, and test different scenarios to explain the scatter of r-process elements in low-metallicity stars [3].

[1] B. Wehmeyer, M. Pignatari, F.-K. Thielemann, 2015 MNRAS 452, 1970–1981
[2] B. Wehmeyer, M. Pignatari, F.-K. Thielemann: Inhomogeneous Chemical Evolution of r-process Elements, submitted to AIPC (2016)
[3] I. Roederer et al., 2010 ApJ 724:975–993

Metal-poor stars in the Galactic bulge

ToC Prg

L. Howes

Lund University, Sweden

Over the past five years, the assumption that metal-poor stars exist only in the Galactic halo has been shown to be false. Several observational campaigns have succeeded in finding very metal-poor giant stars within the confines of the Galactic bulge, and following the principle that the Milky Way formed "inside-out", there is significant theoretical weight behind the idea that these stars are the oldest in the Galaxy. By studying the chemistry of these stars, we can gain insight into the earliest stages of the Milky Way's formation, including what the very first stars of the Galaxy would have looked like. In this talk I will present the latest findings from the EMBLA survey, which has successfully identified more than 500 RGB stars in the bulge with [Fe/H] < -2. The survey has observed 50 stars qwith high-resolution spectrographs, and has found some peculiar chemical differences in them compared to the younger metal-poor stars found in the halo. This includes a lack of carbon-enhanced metal-poor stars; one of the notable characteristics of the population of metal-poor stars in the halo. We have also been able to confirm – for a small subsample of our stars – that the majority are indeed on tightly-bound orbits, rather than passing through the bulge region on typical eccentric halo star orbits. This discovery confirms that these stars live permanently in the bulge, and that the bulge we see today has grown around them. We are following up some 200 of these stars with Kepler K2 Campaign 9, from which we will get highly accurate stellar parameters, and be able to derive ages. We hope the statistical age of all 200 stars will then confirm that we have truly found the remnants of the first stars of the Milky Way.

ToC Prg

Globular clusters and Galaxy assembly: new chemical tagging results from APOGEE

S. Martell

University of New South Wales, Australia

Hierarchical accretion models for galaxy formation predict that the majority of stars in the halo of a spiral galaxy are accreted from dwarf galaxies. In 2010, we used a rough chemical tagging approach to identify stars in the Milky Way halo that were likely to have formed in globular clusters, using the light-element abundance anomalies that are well-studied in Galactic globular clusters. This was the first identification of this population of halo stars that formed in situ, and subsequent studies have confirmed our initial result. This chemically taggable halo field population contains as many stars with "second generation"-like light element abundances as the present-day Galactic globular cluster system. Ideally, one would use this population to explore the importance of in situ star formation in halo assembly. However, the interpretation is strongly dependent on models for globular cluster formation, mass loss, and dissolution. I will present successful new searches for globular cluster migrants in the Galactic bulge and halo in SDSS-III APOGEE survey data. I will also discuss the interpretation of this chemically taggable population in the light of recent theoretical work on globular cluster formation that is upending many previous assumptions.

Metal-poor damped Lyman-alpha systems

ToC Prg

R. Cooke

Durham University, UK

The first metals in our Universe were created and distributed by stars that we still know very little about. Before these metals were incorporated into the second generation of stars, they were (presumably) stored within a large reservoir of neutral gas. In this talk, I summarise recent surveys aimed at finding these reservoirs of gas among the most metal-poor damped Lyman-alpha systems (DLAs) at $z \approx 3$. I also report the discovery of the lowest metallicity DLA, which exhibits a metallicity as low as some of the most metal-poor stars in the Galactic halo. For the full sample of very metal-poor DLAs, I show a comparison of their chemical abundances to Galactic metal-poor stars, and comment on the new insight this has afforded for several highly-debated trends seen in stars when [Fe/H] < -2.0. The talk will conclude with a discussion of the future prospects for finding near-pristine environments at high redshift, and I offer some insight into what these systems might become at $z = 0$.

ToC Prg

Wide-angle spectroscopic surveys

S. Feltzing

Lund Observatory, Sweden

Not so long ago we thought that the Milky Way was a reasonable simple stellar system, with a few major stellar components. In the last decades this view has changed enormously; the Sagittarius dSph galaxy was found in a spectroscopic survey and the proper motions from Hipparcos helped reveal the very rich structures in velocity space in the direct solar neighbourhood. The realisation of the astrometric Gaia satellite further invigorated the interest in ground based wide-angle spectroscopic surveys. In this talk I will summarise some of the major results from past and on-going surveys and look the future with a review of the prospects of the upcoming very large surveys of millions of stars. Special attention will be paid to results with bearing on the first stars.

Gaia: DR1 and beyond

ToC Prg

A. Korn

Uppsala University, Sweden

I will review central aspects of ESA's ongoing astrometric Galaxy survey mission Gaia, from the imminent Gaia Data Release 1 to a possible mission extension. The different data sets (astrometry, spectrophotometry, CaT spectroscopy) will be discussed. In particular, I will try to give an overview of what to expect from Gaia in the coming years for studies of the old populations of the Milky Way.

ToC Prg

Mapping the geometry of the dark Universe with the ESA mission Euclid

J.-G. Cuby

Laboratoire d'Astrophysique de Marseille - LAM Technopôle de Marseille-Etoile

Euclid will be equipped with a 1.2 m diameter telescope feeding two instruments: a high-quality panoramic visible imager (VIS), and a near infrared 3-filter (Y, J and H) photometer and slitless spectrograph (NISP). With these instruments, Euclid will probe the expansion history of the Universe and the evolution of cosmic structures by measuring the modification of shapes of galaxies induced by gravitational lensing effects of dark matter and the 3-dimensional distribution of structures from spectroscopic redshifts of galaxies and clusters of galaxies. Euclid will also probe the high-redshift Universe by detecting $z > 8$ quasars from the 14,000 deg^2 wide survey, and hundreds of $z > 7$ Lyman Break Galaxies from the 40 deg^2 deep survey. It will also measure Baryon Acoustic Oscillations at $z \approx 10$, and may be able to detect supernovae out to very high redshifts.

Future infrared studies of first stars and galaxies

ToC Prg

A. Cooray

University of California, Irvine, USA

I will overview the scientific capabilities of the NASA Small Explorer SPHEREx, WFIRST, and the 2020 NASA Decadal Flasgship Far-Infrared Surveyor, to study the epoch of reionization and first galaxies. I will describe multiwavelength information from near-IR, mid-IR, and far-IR, and both imaging and spectral line surveys. In addition to a detection of stellar emission, the Far-Infrared Surveyor will extend studies during reionization to the cosmic dark ages, and will detect primoridal molecular hydrogen cooling through rotational lines at 17 and 28 microns. Other on-going studies, such as IR background fluctuations to study PopIII stars, will be discussed and the latest results presented.

ToC Prg

Observing the first stars with the James Webb Space Telescope

M. Stiavelli

Space Telescope Science Institute, USA

I will review the capabilities of the James Webb Space Telescope to study the era of the first stars, particularly focussing on the study of lensed or unlensed primordial star clusters or dwarf galaxies. I will discuss possible avenues of discovery of pair-instability supernovae using JWST or other telescopes, and how JWST could follow them up. Finally, I will provide a brief status on the mission and on the upcoming opportunities to learn more about JWST and propose for time.

The Square Kilometre Array

ToC Prg

J. Wagg, R. Braun, T. Bourke, E. Keane, A. Bonaldi

SKAO, UK

Building on the major scientific achievements of the current generation of centimetre and metre-wavelength telescopes, phase 1 of the Square Kilometre Array (SKA1) will be the next global radio astronomy observatory. It is currently being designed by engineers and scientists from around the world, with the aim of beginning construction in 2018, and early science operations in 2020. SKA1 will conduct key tests of general relativity through surveys and timing of pulsars in our Galaxy. It will help answer fundamental questions related to the evolution of atomic hydrogen in the Universe, from the present day back to the cosmic dawn. I will give an overview of some of the science objectives that have been identified for SKA1, with an emphasis on studies of the early Universe using the 21cm hydrogen line.

ToC Prg

The European Extremely Large Telescope

M. Cirasuolo

European Southern Observatory, Germany

I will present an overview of the E-ELT Programme, including the key science drivers and an update on the current status of telescope and its instrumentation.

Giant Magellan Telescope

ToC Prg

R. Bernstein

GMT Project Office, Pasadena, USA

— no abstract available —

(page intentionally left blank)

Posters at First Stars V

ToC Prg

P1.01 - Tracing the evolutionary pathways of the first stars and galaxies within the hierarchical assembly history of the Milky Way

B. Griffen, A. Frebel, G. Dooley, A. Ji

MIT, USA

I will present a statistical investigation into first star and galaxy formation of the Milky Way via cosmological simulations. The Caterpillar project consists of the largest sample of Milky Way sized dark matter halos simulated at one of the highest mass and temporal resolution done to date, more than quadrupling what is currently in the literature (www.caterpillarproject.org). I will discuss our initial results probing the first stellar systems of the Milky Way over a wide variety of assembly histories. Using a semi-analytic approach to model of Pop. III/II star formation, Lyman-Werner feedback and simple chemical enrichment, I will describe how the clustering properties of the Milky Way progenitors at high redshift have a dramatic impact on present day low-mass survivor distributions and their chemical abundances. By tracing the descendants of the high-z star forming regions to the present day we illustrate that one can indeed probe the high-z Universe, without the need for expensive high-z observations. [arXiv:1509.01255].

P1.02 - Detecting the remnants of the first stars with gravitational waves ToC Prg

T. Hartwig[1], M. Volonteri[1], V. Bromm[2], R. Klessen[3], E. Barausse[1], M. Magg[3], A. Stacy[4]

(1) Institute d'Astrophysique de Paris, France
(2) Department of Astronomy, Austin, USA
(3) Institut fuer Theoretische Astrophysik, ZAH Heidelberg, Germany
(4) Department of Astronomy, Berkeley, USA

Gravitational waves (GWs) provide a revolutionary tool to investigate yet unobserved astrophysical objects. Especially the first stars, which are believed to be more massive than present-day stars, might be indirectly observable via the merger of their compact remnants. We develop a self-consistent, cosmologically representative, semi-analytical model to simulate the formation of the first stars and track the binary stellar evolution of the individual systems until the coalescence of the compact remnants. We estimate the contribution of primordial stars to the merger rate density and to the detection rate of the Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO). Owing to their higher masses, the remnants of primordial stars produce strong GW signals, even if their contribution in number is relatively small. We find a probability of $\approx 1\%$ that the current detection GW150914 is of primordial origin. We estimate that aLIGO will detect roughly 1 primordial BH-BH merger per year for the final design sensitivity, although this rate depends sensitively on the primordial initial mass function. Turning this around, the detection of black hole mergers with a total binary mass of $\approx 300 M_\odot$ would enable us to constrain the primordial initial mass function.

ToC Prg

P1.03 - Supersonic streams drive the formation of massive blackholes in the early Universe

S. Hirano[1], T. Hosokawa[2], N. Yoshida[2,3]

(1) The University of Texas, USA
(2) University of Tokyo, Japan
(3) Kavli Institute for the Physics and Mathematics of the Universe, Japan

The existence of super-massive black holes in the early universe poses a serious challenge to the theory of blackhole formation and evolution. A plausible physical model posits that an early black hole forms through direct gravitational collapse of a massive primordial gas cloud, but the model resorts to invoking a number of conditions such as the existence of a young galaxy in the vicinity. Here we report an ab initio simulation of the formation of a super-massive star that gravitationally collapses to yield a massive blackhole. The key process is the relative bulk velocity between dark matter and ordinary baryonic matter in the early universe (Tseliakhovich & Hirata 2010). The supersonic streaming motions suppress early star formation until a large clump of dark matter is assembled. The massive gas cloud in our simulation cools and condenses first by atomic hydrogen cooling, and then by H_2-cooling. During the temperature drop via H_2-cooling, the collected cloud becomes gravitationally unstable when its mass exceeds the Jeans mass of 20,000 $M_\odot$. Then a previous assumption of direct blackhole formation that the gas evolves nearly iso-thermally at a high temperature of ≈ 8000 K has turned out not to be a necessary condition. We stop our cosmological simulation when a tiny protostar with mass of $\approx 0.01\,M_\odot$ is formed at the center of the gas cloud. We then turn to a three-dimensional radiative-hydrodynamic simulation coupled with a self-consistent stellar evolution calculation in order to follow directly the complex interplay between the gas mass accretion. A protostar formed at the center of the hot gas cloud grows quickly without halting the gas accretion. Finally, an extremely massive star having more than ten thousand solar-masses is formed. It ends the life with catastrophic collapse to seed the formation of a super-massive blackhole. Unlike the previous studies of direct collapse blackhole formation, our simulations do not assume additional conditions such as the existence of strong radiation sources and/or high-speed collisions of gas clouds. We estimate the number density of the intermediate mass blackholes formed in the above described manner and the resulting abundance is remarkably close to the abundance of the observed super-massive blackholes. Therefore, our ab initio cosmological simulations provide a viable formation path of massive blackholes.

P1.04 - Binary black holes of first stars for the gravitational wave source

ToC Prg

T. Kinugawa

ICRR, University of Tokyo, Japan

Using our population synthesis code, we found that the typical chirp mass of binary black holes (BH-BHs) whose origin is the first star (Pop III) is $\approx 30\,\mathrm{M}_\odot$ with the total mass of $\approx 60\,\mathrm{M}_\odot$ so that the inspiral chirp signal as well as quasi normal mode (QNM) of the merging black hole are interesting targets of LIGO, VIRGO and KAGRA (Kinugawa et al.2014 and 2016). The detection rate of the coalescing Pop III BH-BHs is $\approx 180\,\mathrm{events/yr}$ $(\mathrm{SFRp}/10^{-2.5}\,\mathrm{M}_\odot/\mathrm{yr/Mpc3}) \times ([\mathrm{fb}/(1+\mathrm{fb})]/0.33) \times \mathrm{Errsys}$ in our standard model where SFRp, fb and Errsys are the peak value of the Pop III star formation rate, the binary fraction and the systematic error with Errsys=1 for our standard model, respectively. Furthermore, we found that the chirp mass has a peak at $\approx 30\,\mathrm{M}_\odot$ in most of parameters and initial distribution functions (Kinugawa et al. 2016). This result predicted the gravitational wave events like GW150914, and a LIGO paper (Abbott et al. ApJL 818, 22, 2016) said that "recently predicted BBH total masses agree astonishingly well with GW150914 and can have sufficiently long merger times to occur in the nearby Universe (Kinugawa et al. 2014)". Thus, there is a good chance to check indirectly the existence of Pop III massive stars by gravitational waves.

ToC Prg

P1.05 - The effect of rotation in the evolution of Pop III protostars

H. Lee, S.-C. Yoon

Seoul National University, Republic of Korea (South Korea)

The modified Eddingtion limit with rapid rotation (the Omega-Gamma limit) may bring about significant effect on the formation process of Population III stars. We performed one-dimensional stellar evolution calculation using the MESA code, where stellar rotation is considered with a post-process. The protostar reaches the Keplerian limit soon after it begins mass accretion, but the mass accretion can proceed by losing angular momentum to the accretion disk via viscous stress. When the protostar reaches $5 \ldots 7\,\mathrm{M}_\odot$, the envelope abruptly expands and the Eddingtion factor drastically increases. Due to the high Eddington factor the protostar would rotate critically with a sub-Keplerian angular velocity (the Omega-Gamma limit). In this limit the angular velocity gradient in the boundary region between the protostar and the disk becomes positive. This makes it difficult for the angular momentum of the protostar to be transferred to the accretion disk, effectively reducing the mass accretion rate. As a result the protostar cannot grow beyond $20 \ldots 40\,\mathrm{M}_\odot$. The Omega-Gamma limit also prevents the fluffy protostellar structure ($R > 500\,\mathrm{R}_\odot$) that is often found in protostellar models with a high mass accretion rate, and restricts prtostellar radius to be compact ($R < 50\,\mathrm{R}_\odot$). This would make binary interations during the protostar phase less probable. While our calculation is based on the Population III protostar models, this effect of rotation would be important for any metallicity.

P1.06 - Pop III signatures in the spectra of Pop II/I GRBs

ToC Prg

Q. Ma[1], U. Maio[2,3], B. Ciardi[1], R. Salvaterra[4]

(1) Max-Planck Institute for Astrophysics, Germany
(2) INAF - Osservatorio Astronomico di Trieste
(3) Leibniz-Institute for Astrophysics
(4) INAF, IASF Milano

We investigate signatures of Population III (PopIII) stars in the metal-enriched environment of GRBs originating from Population II-I (PopII/I) stars by using abundance ratios derived from numerical simulations that follow stellar evolution and chemical enrichment. We find that at $z > 10$ more than 10% of PopII/I GRBs explode in a medium previously enriched by PopIII stars (we refer to them as GRBII→III). Although the formation of GRBII→III is more frequent than that of pristine PopIII GRBs (GRBIIIs), we find that the expected GRBII→III observed rate is comparable to that of GRBIIIs, due to the usually larger luminosities of these latter. GRBII→III events take place preferentially in small proto-galaxies with stellar masses $\mathrm{M}_* \approx 10^{4.5} - 10^7\,\mathrm{M}_\odot$, star formation rates $\mathrm{SFR} \approx 10^{-3} - 0.1\,\mathrm{M}_\odot/\mathrm{yr}$ and metallicities $\mathrm{Z} \approx 10^{-4} - 10^{-2}\,\mathrm{Z}_\odot$. On the other hand, galaxies with $\mathrm{Z} > 10^{-2.8}\mathrm{Z}_\odot$ are dominated by metal enrichment from PopIII stars and should preferentially host GRBII→III. Hence, measured GRB metal content below this limit could represent a strong evidence of enrichment by pristine stellar populations. We discuss how to discriminate PopIII metal enrichment on the basis of various abundance ratios observable in the spectra of GRBs' afterglows. By employing such analysis, we conclude that the currently known candidates at redshift $z \simeq 6$ – i.e. GRB 050904 (Kawai et al. 2006) and GRB 130606A (Castro-Tirado et al. 2013) – are likely not originated in environments pre-enriched by PopIII stars. Abundance measurements for GRBs at $z \simeq 5$ — such as GRB 100219A (Thöne et al. 2013) and GRB 111008A (Sparre et al. 2014) — are still too poor to draw definitive conclusions, although their hosts seem to be dominated by PopII/I pollution and do not show evident signatures of massive PopIII pre-enrichment.

ToC Prg

P1.07 - A new statistical model for Pop III supernova rates

M. Magg[1], T. Hartwig[2], S. Glover[1], R. Klessen[1], D. Whalen[3]

(1) Institut für Theoretische Astrophysik, ZAH Heidelberg, Germany
(2) Institute d'Astrophysique de Paris, France
(3) Institute of Cosmology and Gravitation, University of Portsmouth, UK

With new observational facilities becoming available soon, discovering and characterizing supernovae from the first stars will open up alternative observational windows to the end of the cosmic dark ages. Based on a semi-analytical merger tree model of early star formation we constrain Population III supernova rates. We find that our method reproduces the Population III supernova rates of large-scale cosmological simulations very well. Our computationally efficient model allows us to survey a large parameter space and to explore a wide range of different scenarios for Pop III star formation. Our calculations show that observations of the first supernovae can be used to differentiate between warm and cold dark matter models and to constrain warm dark matter particle masses. Our predictions can also be used to optimize survey strategies with the goal to maximize supernova detection rates.

P1.08 - X-ray twinkles and Pop III stars

ToC Prg

M. Ricotti

University of Maryland, USA

We estimate the optimal level of X-ray emission in the early universe for promoting the formation of the first stars (Pop III). This is important in determining the number of dwarf galaxies formed before reionization and their fossils in present day universe. X-ray emissivity above the optimal level reduces the number of Pop III stars because it increases the Jeans mass of the intergalactic medium (IGM), while a lower emissivity suppresses the formation rate of H_2 preventing or delaying star formation in minihalos above the Jeans mass. The build up of the H_2 dissociating background is slower than the X-ray background due to the shielding effect of resonant Lyman lines. Hence, the nearly unavoidable X-ray emission from SN remnants of the first stars is sufficient to boost their number to few tens per comoving Mpc^3 at redshift $z \approx 15$. High-mass X-ray binaries instead have a negligible effect with respect to SNe. Moreover, if a non-negligible fraction of Pop III stars end their lives as hypernovae, their soft X-ray emission is sufficient promote the formation of Pop III stars to about 400 per comoving Mpc^3, that is near the theoretically-allowed maximum number of Pop III stars with typical masses $10 - 40\ \mathrm{M}_\odot$. A higher X-ray flux, for instance produced by accretion onto intermediate mass black holes and miniquasars, would suppress the number of first stars because of the excessive heating of the IGM. In these models the increased ionization fraction of the IGM from X-rays contributes negligibly to the optical depth to Thompson scattering.

ToC Prg

P1.09 - Understanding the upper mass limit of Population III stars

K. Wollenberg[1], V. Bromm[2], R. Klessen[1]

(1) Institute of Theoretical Astrophysics, Zentrum für Astronomie, Universität Heidelberg, Germany
(2) Department of Astronomy and Texas Cosmology Center, University of Texas, Austin, USA

What is the upper mass limit for Population III stars? This is a key open question in astrophysics, bearing on the strength and character of the feedback from the first stars on early cosmic history. We present analytical constraints on important stages in the Pop III star formation process. Specifically, we derive conservative upper limits for the accretion rate and accretion timescale, within the context of realistic cosmological initial conditions, and take into account key physical effects. Among them, we critically discuss radiative feedback mechanisms, protostellar disk fragmentation, and the role of magnetic fields. Given such constraints, we provide a conservative estimate for the upper mass limit of Pop III stars. Our underlying goal is to chart a heuristic map for where future simulations should focus on to sharpen our understanding of the high-mass end of the primordial initial mass function.

P1.10 - The influence of magnetic fields on Population III protostellar accretion disks

ToC Prg

K. Wollenberg[1], T. Peters[2], S. Glover[1], R. Klessen[1]

(1) Institute of Theoretical Astrophysics, Zentrum für Astronomie, Universität Heidelberg, Germany
(2) Max Planck Institute For Astrophysics, Garching, Germany

Population III protostellar accretion disks are prone to gravitational fragmentation due to the fact that gas accretes onto the disk more rapidly than it can flow through the disk and onto the central object. However, if strong and ordered magnetic fields are present on the scale of the disk, they may help to stabilize it, reducing or completely supressing the amount of fragmentation that occurs. Magnetic fields are known to play an important role in the dynamics of present-day accretion disks and it is reasonable to assume that the same may be true in the case of Population III star formation. To investigate this, we perform 3D magnetohydrodynamical simulations of magnetized collapsing cores in the context of primordial star formation using the FLASH AMR code. We consider magnetic seed fields which have been amplified until saturation by small-scale dynamo action during the turbulent gas cloud collapse phase. We follow the further evolution of this magnetic field during the protostellar accretion phase and examine its effects on Pop. III protostar formation. In particular, we examine whether it is able to stabilize the accretion disk against fragmentation and consider what this implies for the Population III IMF.

ToC Prg

P1.11 - Radiative feedback on mini-halos and very metal-poor stars

M. de Bennassuti

INAF-OAR, Italy

The first stars form in the Universe out of metal-free gas. In the absence of metals, gas cooling proceeds only through the roto-vibrational lines of H_2 leading to the formation of metal-free massive stars, classified as Pop III stars. These stars form in the first structures with virialized temperature $< 10^4$ K (the so called "mini-halos"), where the UV radiation in the Lyman-Werner band can photo-dissociate the H_2 molecule, quenching the star formation in mini-halos. Using the most metal-poor stars observed in the halo of the Milky Way, stellar archaeology represents a promising way to test star formation and metal enrichment of the Galaxy at cosmic epochs which are otherwise not accessible to observations. In the poster, I will present how the observed properties of the most metal-poor stars can place constraints on the Pop III initial mass function, on the nature of the first supernovae, and on the physical processes which govern star formation and metal enrichment in the pre-reionization epoch. These results have been first achieved using a data-calibrated semi-analytical model for the chemical evolution of the Galaxy in a cosmological context. Then, the model has been interfaced with a high-resolution N-body simulation of the Local Group and with a radiative transfer code. In this way, we have been able to explore the effects of inhomogenous radiative feedback on the properties of metal-poor stars of the Galaxy and its dwarf satellites.

P2.01 - The transition between Population III and II stars in the cosmic chemical evolution

ToC Prg

L. Camargo Corazza, O. D. Miranda, C. A. Wuensche

INPE - Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research), Brazil

We present the chemical evolution for 17 elements in the cosmological context from redshift $z = 20$ to 0. We use a code that calculates the formation of structures taking into account the hierarchical structure formation scenario and a Press-Schechter formalism (Pereira & Miranda 2010). The code then effectively calculates the cosmic star formation rate and we are able to implement a chemical evolution model to study the elements O, Fe, Zn, Ni, Cr, Mn, Co, Ti, V, Si, Mg, Al, Ca, C, N, P and S and the total metalicity of the universe. The chemical yields used are from stars with masses from 0.85 to 260 $M_\odot$. We also take into account a Salpeter IMF. Preliminary results show a good agreement of the model with data from Damped Lyman-α Systems (DLAs). Iron shows a supermetalicity in the Population III model and Zinc shows a submetalicity. The behaviour of all elements change between Population III and II, but some, specially Iron, provide a window to explore the possibility that chemical elements are capable of tracing the transition metalicity and redshift range between stellar populations.

ToC Prg

P2.02 - The r-process events in the early Universe: the role of ultra-faint galaxies

G. Cescutti[1], C. Kobayashi[1], C. Chiappini[2]

(1) University of Hertfordshire, UK
(2) Leibniz-Institut für Astrophysik Potsdam (AIP)

We have an indirect but powerful tool to study stellar evolution and nucleosynthesis: Galactic Archeology. In this contribution, I focus on chemical anomalies of neutron-capture elements in the Galactic halo and in the galactic ultra faint dwarfs. Adopting a stochastic chemical evolution model, I will present new constraints in the rate and time scale of the r-process events, based on the recent discovery of the r-process rich ultra faint galaxy Reticulum 2 (Roederer et al. 2016). Moreover, I will show that the existence of spinstars can offer a new twist in the interpretation of the abundance patterns not only in the Galactic halo (Cescutti et al. 2013), but also in ultra-faint galaxies.

P2.03 - Understanding the fossil records of the first stars using genetic algorithms

ToC Prg

C. Chan, A. Heger

Monash Centre for Astrophysics, Australia

Numerical simulations of the formation of the first stars have long predicted that these stars formed in multiples. It follows that the chemical yields of multiple supernova explosions may have contributed to the formation of a next generation star. To infer the characteristics of the first stars, we attempt to match the theoretical chemical signatures of these first explosions to stars that we can observe today. We have designed a Genetic Algorithm to efficiently find the best matching combination of stars.

ToC Prg

P2.04 - Possible discovery of the r-process characteristics in the abundances of metal-rich barium stars

W. Cui

Hebei Normal University, People's Republic of China

We found that six barium stars have a significant r-process characteristic, and we divided the barium stars into two groups: r-rich barium stars (Cr > 5.0, [La/Nd] < 0) and normal barium stars. The behavior of the r-rich barium stars seems more like that of the metal-poor r-rich and CEMP-r/s stars. We suggest that the most possible formation mechanism for these stars is the s-process pollution, although their abundance patterns can be fitted very well when the pre-enrichment hypothesis is included. That we cannot explain them well using the s-process nucleosynthesis alone may be due to our incomplete knowledge on the production of Nd, Eu, and other relevant elements by the s-process in metal-rich and super metal-rich environments (see details in Pereira et al. 2011).

P2.05 - Carbon enhanced stars in the SDSS/BOSS survey

ToC Prg

J. González Hernández, C. Allende Prieto, D. Sánchez Aguado

Instituto de Astrofísica de Canarias, Spain

The stellar population of the galactic halo is composed of metal-deficient stars, with a metallicity distribution centered at about [Fe/H] ≈ -1.6 dex. A significant fraction of metal-poor stars are C-enhanced, and its frequency increases towards lower metallicities from 10–30% at [Fe/H] ≈ -2.5 to about 75% for [Fe/H] < -4. We have analyzed the whole SDSS/BOSS spectra using the FERRE code to derive in a consistent way the stellar parameters, metallicity, alpha-enhancement, and carbon abundance. We select a subsample of about ten thousand stars with S/N > 10 in the effective temperature range 4750–6900 K at metallicity below -2 dex. We will discuss the frequency of C enhanced stars at different metallicity ranges and different distances Z from the Galactic plane, and will compare it with the SDSS/SEGUE sample.

ToC Prg

P2.06 - The intermediate neutron-capture process and carbon-enhanced metal-poor stars

M. Hampel[1,2], R. J. Stancliffe[2], M. Lugaro[3,4], B. S. Meyer[5]

(1) Zentrum für Astronomie der Universität Heidelberg, Landessternwarte, Heidelberg, Germany
(2) Argelander-Institut für Astronomie, Universität Bonn, Bonn, Germany
(3) Konkoly Observatory, Budapest, Hungary
(4) Monash Centre for Astrophysics, Monash University, Melbourne, Australia
(5) Department of Physics and Astronomy, Clemson University, Clemson, USA

Carbon-enhanced metal-poor stars are often classified into four sub-groups based on their presence or absence of barium and europium (e.g. [1]). The origin of the so-called CEMP-r/s stars, which display high abundances of barium and europium, is currently unclear. Most of the proposed formation scenarios simply cannot work [2]. In this contribution, we examine whether the abundance patterns of CEMP-r/s can arise from neutron capture nucleosynthesis. While low neutron densities give rise to the s-process, and extremely high densities characterise the r-process, intermediate neutron densities of around $10^{15}\,\mathrm{cm}^{-3}$ give rise to their own signatures — the so-called i-process [3]. Such high neutron densities may occur in the thermal pulses of asymptotic giant branch (AGB) stars due to proton ingestion episodes. Using a one-zone nucleosynthesis code, we show that an i process can explain the abundance patterns in a sample of 20 CEMP-r/s stars that [4] showed could not be explained by s process nucleosynthesis.

[1] T. C. Beers, N. Christlieb, Ann. Rev. Astron. & Astro., 43, 531, (2005)
[2] C. Abate, R. J. Stancliffe, Z.-W. Liu, A&A, 587, 50, (2016)
[3] J. J. Cowan, W. K. Rose, ApJ, 212, 149, (1977) [4] C. Abate, O. R. Pols, R. G. Izzard, A. I. Karakas, A&A, 581, 22, (2015)

P2.07 - Population II black holes

ToC Prg

S. Heap[1], N. Cappelluti[2]

(1) NASA/Goddard, Astrophysics Division, USA
(2) Astronomy Department, Yale University, USA

Observations of I Zw 18 and SBS 0335-052, two very low-metallicity, star-forming galaxies, make clear that massive stellar black holes form not only from Pop III stars but also from Pop II stars ($\log Z/Z_\odot \approx -1.7$). These two galaxies demonstrate the variety of environments in which massive stellar black holes can form: I Zw 18-NW has the structure and density of an open cluster, while SBS 0335-052 is a collection of > 6 superstar clusters (SSC's); I Zw 18 has the lowest Dust/Gas ratio of any star-forming galaxy, while SBS 0335 is quite dusty. There are of course similarities between the two galaxies beside very low metallicity. In both galaxies: Their black holes are very luminous X-ray sources with $L_x = 10^{39} \ldots 10^{40}$erg/s (Thuan et al.2004) suggesting high black-hole masses. In the one case studied, the black hole in I Zw 18 has a mass, $M_{BH} > 85\,M_\odot$ (Kaaret & Feng 2013). The black holes are not concentrated toward the galactic center. The BH progenitors – young massive O-type stars– show no evidence of a stellar wind, so it is unlikely that their stellar masses were reduced substantially through evolution. Star formation has barely started (Mstar/Mbaryon is only a few percent). There is no evidence of a galaxy outflow, perhaps because of the high mass-loading factor (Lebouteiller, Heap et al. 2013); There is evidence of cold gas streaming toward the star clusters. The observed properties of Pop II black holes and their stellar progenitors provide constraints on the formation of AGN's and possibly SMBH's in the early universe and shed light on the origin of the co-evolution of galaxies and black holes.

ToC Prg

P2.08 - Evolution of low mass Population III stars from the pre-main sequence through the white dwarf cooling track: how are they different?

T. Lawlor

Pennsylvania State University - Brandywine, USA

Although it is not clear if low mass, Population III stars would have formed during the early universe, there are arguments for their existence such a number of observed very low metal, low mass stars and it has been suggested that feedback from massive Population III stars could give rise to low mass star formation from primordial or nearly primordial gas. In this paper we present calculations for the evolution of $0.6 \ldots 6.0\,\mathrm{M}_{\odot}$ stars with initial metallicity $\mathrm{Z} = 10^{-14}$ from pre-main sequence through the white dwarf cooling track. We make comparisons between the characteristics of these initially metal free models with existing models over a range of metallicities from $\mathrm{Z} = 10^{-6}$ to 0.02. One goal of this comparison is to identify potential observable markers for local universe white dwarfs whose progenitors are first or nearly first stars. We also present an initial-final mass relationship, a mass-radius relationship, and identify the minimum white dwarf mass that can exist given the approximate time of formation for stars with a Population III progenitor.

P2.09 - The importance of convection criterion in Population III stellar evolution models

ToC Prg

T. Lawlor[1], J. MacDonald[2], T. Young[3], J. Teffs[4]

(1) Pennsylvania State University - Brandywine, Media, PA USA
(2) University of Delaware, Newark, DE USA
(3) University of North Dakota, Grand Forks, ND USA
(4) University of North Dakota, Grand Forks, ND USA

We present stellar evolution calculations from pre-main sequence to near core collapse for stars with primordial initial composition (Pop III stars) in the mass range 15 $M_\odot$ to 100 $M_\odot$. We find that the choice of convection criterion has a significant effect on the evolution, especially during the giant branches. Model calculations that use the Schwarzschild criterion for convective onset result in a cooler giant with a much larger radius in most cases. The opposite is true when using the Ledoux criterion for convective onset. This difference is primarily due to the presence of a molecular weight gradient outside the helium burning core which suppresses convection in models that use the Ledoux criterion. The significance of this is many-fold. For example, it may govern the total galactic energy output in the first galaxies during certain epochs, and it plays a critical role in determining the energy output for Population III type II supernovae. This will in turn have an effect on the yields and detectability of early universe type II supernovae. We compare our models to those of Heger & Woosley (2010) and we present our model surface abundances just before core collapse.

ToC Prg

P2.10 - Dust formation in the first supernovae

S. Marassi

INAF-OAR, Italy

The first supernovae to explode in the Universe start the process of metal enrichment and have a major impact on early structure formation in the Universe. The metals and dust grains released and dispersed by the first supernovae change the cooling properties of the interstellar medium out of which second generation stars form, allowing the first low-mass and long-lived stars to form. Stellar archaeology of the most metal-poor stars observed in the halo of our Galaxy is providing strong constraints on these early chemical enrichment phases. Yet, theoretical predictions have to rely on poorly constrained physical parameters, such as the mass of Population III stars and their physical properties. We present a systematic investigation of the metal and dust yields released by the first supernovae with the aim to reproduce the properties of the environment out of which the most metal-poor stars have formed. We also investigate dust formation in the ejecta of faint Pop III SN, where the ejecta experience a strong fallback. We discuss the mass and composition of dust yields and the role of dust-induced cooling and fragmentation in the formation of the most metal-poor stars. In particular we search a combination of mixing and fallback that provides the best-fit to the observed abundance pattern of all currently known C-enhanced hyper- iron-poor stars.

P2.11 - Differential abundance analysis in extremely metal-poor stars

ToC Prg

H. Marques Reggiani, J. Meléndez

Universidade de São Paulo-USP, Brazil

Through the study of metal-poor stars we can uncover important details on the formation of our Galaxy. Nissen & Schuster (2010) have shown the existence of two distinct populations in the Galactic halo, using stars with metallicities [Fe/H] > -1.5. These populations have distinct α-elements (Mg, Si and Ti) abundances. The distinction can also be seen in oxygen, as shown by Ramírez, Meléndez & Chananné (2012). To study this distinction in more metal-poor stars it is necessary to achieve a precision better than 0.05 dex. In Reggiani et al. (2016) we demonstrated that it is possible to study chemical abundances in EMP stars ([Fe/H] < -3.0) with a precision as low as 0.02 dex using high resolution spectra (R=95 000) with high S/N (700 at 5000 Å) and a line-by-line differential analysis. Such a precision might allow us to determine if there is real scatter due to different populations, as found by Nissen & Schuster (2010) for more metal-rich stars. We also present preliminary results of our UVES sample of 11 metal-poor ($-2.2 <$ [Fe/H] < -2.7) stars. We employed the differential analysis in this study, but with spectra of lower S/N (S/N = 200 at 5000 Å) and lower resolution (R = 52000). This difference in data quality has translated itself into a lower precision. This sample show an star-to-star deviation of 0.065 dex in [Mg/Fe], which is about the same as our precision (≈ 0.062 dex). This work shows that a 0.06 dex precision is not enough to distinguish between observational uncertainties and intrinsic scatter in our sample.

ToC Prg

P2.12 - Radiation driven wind from an accreting supermassive star?

D. Nakauchi[1], T. Hosokawa[2], K. Omukai[1], H. Saio[1], K. Nomoto[3]

(1) Tohoku University
(2) University of Tokyo
(3) Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo

Supermassive stars (SMS; $\approx 10^5$ $\mathrm{M}_\odot$) formed in the early universe are plausible progenitors of supermassive black holes found at $z > 6$. They are supposed to be formed from primordial protostars with rapid mass accretion ($\approx 0.1 - 1\mathrm{M}_\odot/\mathrm{yr}$). Recent studies have revealed that rapidly accreting protostars have very bloated envelopes and have luminosities comparable to the Eddington luminosity when they grow $> 100\,\mathrm{M}_\odot$. Such a structure resembles those of Wolf-Rayet stars in the local universe, which show vigorous mass ejection via radiation pressure force. Here, we consider the possibility of a radiation driven wind from a rapidly accreting protostar, by constructing steady and spherical supersonic solutions which are smoothly connected to the stellar envelope at the wind base. We find that a steady wind cannot be expected from an accreting SMS, since the wind temperature becomes lower than the recombination temperature of hydrogen, and wind acceleration ceases owing to the drop of the opacity in the supersonic region. This indicates that the growth to an SMS would not be interrupted by the radiation driven mass loss.

P2.13 - Supermassive star formation by episodic accretion: a highly unstable protostellar disk and UV feedback

ToC Prg

Y. Sakurai[1], E. Vorobyov[2], T. Hosokawa[1], N. Yoshida[1], K. Omukai[3], H. Yorke[4]

(1) University of Tokyo, Japan
(2) University of Vienna, Austria
(3) Tohoku University, Japan
(4) Jet Propulsion Laboratory, USA

Supermassive black holes (SMBHs) have been observed at $z \gtrsim 6$, leading to much speculation on how to form such objects within less than a billion years. A promising pathway is the formation and subsequent direct collapse of supermassive stars (SMSs), which act as seeds for SMBHs, followed by accretion of gas onto these seeds. A primary concern for forming SMSs is UV feedback from the accreting protostar, which can potentially suppress its growth by stopping the accretion flow. In this study we investigate the impact of UV feedback on the evolution of SMSs. First, we conduct a 2D thin-disk hydrodynamical simulation of an accretion disk around an SMS until the stellar mass reaches 10^4 $M_\odot$. The disk is highly unstable and fragments to form many clumps, most of which fall onto the central star. The resulting accretion rate is highly variable: short episodic accretion bursts are followed by longer quiescent phases. Using the obtained accretion rate we perform stellar evolution calculations to estimate the UV emissivity of the accreting (proto-)star. The results show that the stellar radius increases monotonically though the accretion rate is highly variable. The effective temperature remains fixed at about 5000 K. Due to the star's low effective temperature, its UV emissivity is insufficient to cause significant UV feedback. The insensitivity of stellar evolution to this type of variable accretion is attributed to the short variability of the accretion rate $\lesssim 10^3$ yr, which is too short to affect the stellar structure. We conclude that with a sufficiently large mass reservoir, an accreting SMS can grow to 10^5 $M_\odot$, followed by the direct collapse to a BH due to the relativistic instability.

ToC Prg

P2.14 - Photometric identification of Population III core-collapse supernovae: multicolor light curve simulations

A. Tolstov[1], K. Nomoto[1], N. Tominaga[2,1], M. Ishigaki[1], S. Blinnikov[3,1], T. Suzuki[4]

(1) Kavli IPMU, The University of Tokyo, Japan
(2) Konan University, Japan
(3) ITEP, Russia
(4) Chubu University, Japan

The properties of the first generation of stars and their supernova (SN) explosions remain unknown due to the lack of their actual observations. Recently, many transient surveys have been conducted and the feasibility of detecting supernovae (SNe) of Pop III stars is growing. We study the multicolor light curves for a number of metal-free core-collapse SN models (25-100 solar mass range) to determine the indicators for the detection and identification of first generation SNe. We use mixing-fallback supernova explosion models which explain the observed abundance patterns of metal poor stars. Numerical calculations of the multicolor light curves are performed using the multigroup radiation hydrodynamic code STELLA. The calculated light curves of metal-free SNe are compared with non-zero-metallicity models and several observed SNe. We have found that the shock breakout characteristics, the evolution of the photosphere's velocity, the luminosity, the duration, and color evolution of the plateau, that is, all of the SN phases from shock breakout to ^{56}Co decay, are helpful for estimating the parameters of the SN progenitor: the mass, the radius, the explosion energy, and the metallicity. The metallicity is calculated using color evolution curves of the plateau phase. We conclude that the multicolor light curves could potentially be used to identify first-generation SNe in the current (Subaru/HSC) and future transient surveys (LSST, James Webb Space Telescope). They are also suitable for identifying of the low-metallicity SNe in the nearby Universe (PTF, Pan-STARRS, Gaia).

P2.15 - Nucleosynthetic constraints on gamma-ray bursts and supernovae

ToC Prg

N. Tominaga

Konan University, Japan

Although the explosion mechanisms of Gamma-ray bursts (GRBs) and supernovae (SNe) have been investigated theoretically for a long while, they have not been clarified yet and thus it is required to obtain information from the other point of view. In this presentation, I focus on constraints of the extremely metal-poor (EMP) stars. Since the first metal enrichment in the universe was made by GRBs and/or SNe, the EMP stars, formed in the early universe, preserve the nucleosynthetic features of GRBs and/or SNe in their abundance patterns and thus the abundance patterns of the EMP stars can reveal their explosion properties. I present nucleosynthesis in explosions with relativistic jets and/or non-relativistic mildly aspherical components, assuming GRBs, SNe, and GRB-SNe, and compare their abundance ratios with those of the EMP stars. The explosion with non-relativistic energy deposition can explain [Mg/Fe] and [Ca/Fe] but not [Ti/Fe], while the explosion with relativistic jets can explain [Ti/Fe] but not [Mg/Fe] and [Ca/Fe]. It is shown that the overall abundance patterns of EMP stars, including [Mg/Fe], [Ca/Fe], and [Ti/Fe], are reproduced by the explosion with relativistic jets and non-relativistic component as in GRB-SNe. Furthermore, I demonstrate that the relation between GRBs and SNe, e.g., the temporal difference between the injections of the relativistic jets and non-relativistic mildly aspherical components, can be constrained from a nucleosynthetic point of view.

ToC Prg

P2.16 - Identification of carbon-enhanced metal-poor stars from S-PLUS photometry using artificial neural networks

D. Whitten[1], V. Placco[1], T. Beers[1], C. Mendes[2]

(1) University of Notre Dame, USA
(2) Universidade de São Paulo, Brazil

Very ([Fe/H] < -2; VMP), Extremely ([Fe/H] < -3; EMP), and Ultra ([Fe/H] < -4; UMP) metal-poor stars are believed to have formed shortly after the Big Bang, and thus are some of the oldest objects in the Universe today. A subset of these stars exhibit a characteristic enhancement in carbon (and other light elements) that indicate they formed from gas clouds polluted by the very first stars. These Carbon-Enhanced Metal-Poor (CEMP) stars therefore provide key information regarding the chemistry of the early Universe. Using the Southern Photometric Local Universe Survey (S-PLUS), we aim to develop a new method of identifying VMP, EMP, and UMP stars for subsequent high-resolution spectroscopic follow-up. We will employ an artificial neural network for analysis of the photometric data to predict stellar parameters such as the effective temperature, Teff, surface gravity, log g, metallicity, [Fe/H], and carbon abundance ratio, [C/Fe]. With the stars identified by S-PLUS, we expect to increase the number of known UMP stars by at least a factor of three, and discover numerous bright CEMP stars suitable for detailed analysis of the nucleosynthesis processes that were in operation in the first-generation of stars.

P2.17 - The final fates of accreting supermassive stars

ToC Prg

T. Woods[1], A. Heger[1], L. Haemmerle[2], R. Klessen[2], D. Whalen[3]

(1) Monash University, Monash Centre for Astrophysics, Australia
(2) University of Heidelberg, Institute for Theoretical Astrophysics, Germany
(3) University of Portsmouth, Institute of Cosmology and Gravitation, UK

The discovery of enormous (billion Solar mass) high-redshift quasars challenges our understanding of the early Universe: how did such massive objects form in the first billion years? A popular model is the "direct collapse" scenario: An atomically-cooled gas cloud of primordial composition accretes rapidly onto a single stellar core, ultimately collapsing through the general relativistic instability after reaching $\approx 100,000$ Solar masses and forming an initial supermassive seed black hole. To date, the full evolution of such supermassive stars, from protostar up to and including relativistic collapse, has not been followed in detail. We present the results of such calculations using the stellar evolution code KEPLER, incorporating implicit hydrodynamics, GR corrections, and a detailed treatment of nuclear burning processes. We find that the final mass converges on the hydrostatic limit of $\approx 150,000$ Solar masses only at the highest accretion rates. We discuss the response of the supermassive star to accretion, and the evolutionary state at the time of collapse for a wide range of accretion rates. Finally, we close by discussing observational prospects.

ToC Prg

P2.18 - Constraining the progenitors of CEMP stars using their absolute carbon distribution

J. Yoon[1], T. C. Beers[1], V. M. Placco[1], D. Carollo[1], S. He[2]

(1) University of Notre Dame, USA
(2) Xi'an Jiao Tong University, Xi'an, China

We report on a compilation of available high-resolution spectroscopic data for Carbon-Enhanced Metal-Poor (CEMP) stars, and use these data to investigate the existence of the claimed carbon abundance plateaus. As previously shown, the absolute carbon abundances, A(C), of the CEMP stars is bi-modal, with (newly-determined) peaks at A(C) = 6.2 and A(C) = 7.9, respectively. A large fraction of the CEMP-s stars belong to the high-C peak, and most CEMP-no stars reside on the low-C peak. There also exists a substantial fraction of CEMP stars in the transition region between the two carbon peaks. We discuss how the morphology of these behaviors can be used to constrain the nature of the progenitors of the CEMP-s and CEMP-no stars.

P3.01 - Chemo-thermal evolution of collapsing gas cloud and the formation of metal-poor stars

ToC Prg

G. Chiaki[1], N. Yoshida[2], S. Hirano[3]

(1) Konan University, Japan
(2) University of Tokyo, Japan
(3) University of Texas, USA

We present the results of the simulations of star formation in the low-metallicity gas clouds. The metal-poor stars in the Galactic halo have recently been observed, while metal-free stars have not yet. It is considered that the typical mass scale of the stellar mass is reduced in the course of the metal and dust pollution in the early Universe. In order to define the critical conditions under which the first low-mass stars are formed, we employ the three-dimensional simulations of collapsing clouds with various metallicities. We set the realistic components of metal and dust and size distribution of grains, which are taken from self-consistent calculations of a Pop III supernova. We also consider accretion of the gas-phase metal onto grains (grain growth) during collapse. We consider a uniform cloud and three cosmological minihalos taken from Hirano et al. (2014) as initial conditions, enhancing metallicity up to $10^{-6} \ldots 10^{-3}$ $Z_\odot$, and follow their evolutions. As a result, the cloud fragmentation occurs in one out of four clouds with each metallicity. With 10^{-6} $Z_\odot$, where dust cooling does not work, the circumstellar disk fragments. With $> 10^{-5}$ $Z_\odot$, cloud elongation proceeds by dust cooling and the thin filaments fragment. We find that there two 'modes' of fragmentation. We also find that the clouds do not fragment in most cases even with metallicities $10^{-3} \ldots 10^{-4}$ $Z_\odot$ because the rapid gas heating owing to the formation of hydrogen molecules halts the gas elongation. In some cases, cloud elongation is enhanced by OH and H_2O molecular cooling. The different cooling/heating processes become important for different clouds because the collapse timescale, which has an effect on the thermal evolution of clouds, is different from cloud to cloud.

ToC Prg

P3.02 - Analysis of molecular bands synthesised using 3D model atmospheres

A. Gallagher[1], E. Caffau[1], P. Bonifacio[1], H.-G. Ludwig[2], M. Steffen[3], M. Spite[1]

(1) Observatoire de Paris, France
(2) LSW, ZAH, Heidelberg, Germany
(3) AIP, Potstam, Germany

A considerable collective effort has been invested in the acquisition and analysis of the most metal-poor stars known as they allow us to examine the chemical processes that occurred in the early Universe. Roughly one in five metal-poor stars exhibit chemically peculiar abundance patterns that show enhancements in carbon. These stars are known as carbon-enhanced metal-poor (CEMP) stars. One of the most widely used techniques to measure a star's CNO abundance pattern is to analyse molecular bands such as the G-band, CN-band, NH-band, etc. Typically, this is performed using classical one-dimensional (1D) model atmospheres and spectrum synthesis codes under the assumption of local thermodynamic equilibrium (LTE). Our recent work has focused on the computation of molecular band spectra using the three-dimensional (3D) spectrum synthesis code Linfor3D, which utilises 3D hydrodynamic model atmospheres computed with CO5BOLD. The aims of this work are to produce a set of 3D abundance corrections for CEMP stars by exploiting several molecular bands, to better understand the origins of these stars. We began by examining the G-band and computed a large grid of 3D spectra for many metal-poor CO5BOLD models. We are currently investigating other molecular bands, such as the CN-band and NH-band.

P3.03 - Thermal instability and multi-phase interstellar medium in the first galaxies

ToC Prg

T. Inoue[1], K. Omukai[2]

(1) National Astronomical Observatory of Japan
(2) Astronomical Institute, Tohoku University, Japan

We examine the linear stability and nonlinear growth of the thermal instability in isobarically contracting background gas with various metallicities and far-UV (FUV) field strengths. Such a background medium can be expected for protogalactic clouds and shocked gas with metallicity $Z/Z_{\odot} > 10{-}4$. When the H_2 cooling is suppressed by FUV fields ($G_0 > 10^{-3}$) or the metallicity is high enough ($Z/Z_{\odot} > 10{-}3$), the interstellar medium (ISM) is thermally unstable in the temperature range 100-7000 K owing to the cooling by C II and O I fine-structure lines. In this case, a bi-phasic medium with a bimodal density probability distribution is formed as a consequence of the thermal instability. The characteristic scales of the thermal instability become smaller with increasing metallicity. Comparisons of the nonlinear simulations with different resolution indicates that the maximum scale of the thermal instability should be resolved with more than 60 cells to follow runaway cooling driven by the thermal instability. Under sufficiently weak FUV fields and with low metallicity, the density range of the thermal instability shrinks owing to the dominance of H2 cooling. As the FUV intensity is reduced, the bi-phasic structure becomes less remarkable and eventually disappears. Our basic results suggest that, in early galaxies, (i) fragmentation by the nonlinear growth of thermal instability could determine the mass spectrum of star clusters for $Z/Z_{\odot} \lesssim 0.04$), and (ii) a thermally bistable turbulent ISM like our galaxy becomes ubiquitous for $Z/Z_{\odot} \gtrsim 0.04$, although the threshold metallicity depends on conditions such as thermal pressure, FUV strength, and redshift.

ToC Prg

P3.04 - Dissipation of magnetic fields in star-forming clouds with different metallicities

H. Susa[1], K. Omukai[2]

(1) Konan University, Japan
(2) Tohoku University, Japan

We study the dissipation process of magnetic fields in the metallicity range $0 \ldots 1\,\mathrm{Z}_\odot$ for contracting prestellar cloud cores. By solving non-equilibrium chemistry for important charged species, including charged grains, we evaluate the drift velocity of the magnetic-field lines with respect to the gas. We find that the magnetic flux dissipates in the density range $10^{12}\,\mathrm{cm}^{-3} \lesssim n_\mathrm{H} \lesssim 10^{17}\,\mathrm{cm}^{-3}$ for the solar-metallicity case at the scale of the core, which is assumed to be the Jeans scale. The dissipation density range becomes narrower for lower metallicity. The magnetic field is always frozen to the gas below metallicity $\lesssim 10^{-7} \ldots 10^{-6}\,\mathrm{Z}_\odot$, depending on the ionization rate by cosmic rays and/or radioactivity. With the same metallicity, the dissipation density range becomes wider for lower ionization rates. The presence of such a dissipative regime is expected to cause various dynamical phenomena in protostellar evolution such as the suppression of jet/outflow launching and the fragmentation of circumstellar disks depending on the metallicity.

P4.01 - Hunting Direct Collapse Black Holes in theory and observations

ToC Prg

B. Agarwal

Yale University, USA

Direct Collapse Black Holes (DCBH) offer an interesting pathway to seed the supermassive black holes of the $z > 6$ quasars. Under the influence of a critical Lyman-Werner (LW) radiation field, pristine gas in atomic cooling halos can collapse to form direct collapse black hole seeds of $10^4 - 10^5\,\mathrm{M}_\odot$. I will discuss my work that has revised the LW flux requirement by assigning realistic SEDs to external radiation sources instead of black body type spectra. This resulted in a paradigm shift in the critical threshold of LW radiation that leads to DCBH formation. We conclude that it is the actual reaction rates related to the photo-destruction of molecular hydrogen that govern the isothermal collapse as the LW flux that allows for DCBH formation spans 3 orders of magnitude, whereas the reaction rates can be understood as a critical curve in reaction rate parameter space. I will also discuss where favourable sites for DCBH may occur in the Universe on the basis of our simulations and analytical work, i.e. the typical time window where a pristine atomic cooling halo remains unpolluted in the presence of an external LW radiation field. The physical motivation for the recently observed object CR7 to be a DCBH host will also be presented. Our recent work using: dark matter halo histories; SED modeling; constructing a blueprint of the system's LW radiation history; and accounting for external metal pollution, has led to strong indications for CR7 to be a likely DCBH host, instead of a Pop III source. Based on this, I will outline a new strategy for uncovering these DCBHs in the existing Hubble data.

ToC Prg

P4.02 - The 21 cm signature of primeval quasars

C. Bernhardt[1], K. Ahn[2], D. Whalen[1,3], J. Smidt[4]

(1) Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany
(2) Department of Earth Science Education, Chosun University, Gwangju 501-759, Korea
(3) Institute of Cosmology and Gravitation, Portsmouth University, Portsmouth, UK
(4) T-2, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Recent observations of supermassive black holes (SMBHs) with billions of solar masses near redshift 7 pose problems for current paradigms of cosmological structure formation, as it is difficult to form such massive objects at such early times in the universe. Seeds of SMBHs are believed to come from 10^5 $M_\odot$ direct-collapse black holes (DCBHs) formed in metal-free atomic cooling halos around $z = 18 - 20$. However, DCBHs can only form SMBHs when placed at the intersection of strong, cold accretion flows. We use Enzo AMR simulations with full X-ray transport to study the growth of a DCBH within a large, cosmological volume. We study whether radiative feedback from the growing black hole is able to disrupt these cold flows, preventing its mass from reaching values comparable to the most massive high-redshift SMBHs. Using the same simulation, we also calculate the 21 cm signature of the SMBH through cosmic time in order to evaluate its prospects for detection by future facilities such as the SKA.

P4.03 - The earliest galaxies with JWST — searching for Population III stellar populations with NIRSpec

ToC Prg

A. Bunker

University of Oxford, UK

I will describe future searches for galaxies in the early Universe with the James Webb Space Telescope (JWST). The NIRSpec near-infrared spectrograph on JWST is sensitive out to 5microns, probing the rest-frame optical emission of galaxies out to $z = 7$, and potentially lines such as Lyman-alpha, He II and [O II] at $z \gg 10$. With my colleagues on the ESA NIRSpec Instrument Science Team, we are planning a large GTO survey of galaxies in the high redshift universe, taking advantage of the multiplex available with the microshutter array of NIRSpec to target hundreds of Lyman break galaxies at $z > 5$. By studying line ratios, we can chart the evolution of metallicity, dust extinction and AGN contribution, and coupling with SED fits to the continuum we can determine stellar masses and potentially look for signatures of a different initial mass function (IMF). In particular, the He II 1640 Å line might be the signature of a hard ionizing spectrum expected from a top-heavy IMF expected from Population III stars. We will also address the build-up of stellar mass in galaxies at high redshift, and will estimate for the first time the escape fraction of ionizing photons for galaxies at $z > 6$ through comparison of the Balmer lines with the rest-UV continuum. The escape fraction is a critical and unknown quantity in the quest for which sources reionized the Universe at $z \approx 6 \ldots 9$. JWST will push to even earlier epochs, using the Lyman break to potentially detect the first massive galaxies to form at $z > 10$, and I will present our expected parameter space and sensitivities for our survey.

ToC Prg

P4.04 - FirstLight: simulations of the first galaxies in the early Universe

D. Ceverino, R. Klessen, S. Glover

Universität Heidelberg, Germany

I will present first results of the FirstLight project. This project aims to follow the formation of the first galaxies in the early Universe, by using the N-body+gas-dynamics code, ART with novel models of feedback and a resolution below 10 parsecs. Upon completion, the FirstLight dataset will consist of an order of 1000 different galaxies, covering a grid of different halo properties. This will generate a mock survey of galaxies between redshifts 4 and 12. This survey will make predictions about the properties of the primeval galaxies that would be observed by future deep surveys with the James Webb Space Telescope and Extremely Large Telescopes. In the pilot study, we follow the formation of a dwarf galaxy with an UV absolute magnitude of $\mathrm{M}_{1500} = -13$ at redshift 8, a candidate for driving the reionization of the Universe.

P4.05 - Cosmological simulations of early blackhole formation: halo mergers, tidal disruption, and the conditions for direct collapse

ToC Prg

S. Chon, S. Hirano, T. Hosokawa, N. Yoshida

University of Tokyo, Japan

Gravitational collapse of a massive primordial gas cloud is thought to be a promising path for the formation of supermassive blackholes in the early universe. We study conditions for the so-called direct collapse (DC) blackhole formation in a fully cosmological context. We combine a semi-analytic model of early galaxy formation with halo merger trees constructed from dark matter N-body simulations. We locate a total of 68 possible DC sites in a volume of 20 Mpc/h on a side. We then perform hydrodynamics simulations for 42 selected halos to study in detail the evolution of the massive clouds within them. We find only two successful cases where the gas clouds rapidly collapse to form stars. In the other cases, gravitational collapse is prevented by the tidal force exerted by a nearby massive halo, which otherwise should serve as a radiation source necessary for DC. Ram pressure stripping disturbs the cloud approaching the source. In many cases, a DC halo and its nearby light source halo merge before the onset of cloud collapse. Only when the DC halo is assembled through major mergers, the gas density increases rapidly to trigger gravitational instability. Based on our cosmological simulations, we conclude that the event rate of DC is an order of magnitude smaller than reported in previous studies, although the absolute rate is still poorly constrained. It is necessary to follow the dynamical evolution of a DC cloud and its nearby halo(s) in order to determine the critical radiation flux for DC.

ToC Prg

P4.06 - Exploring the nature of the Lyman-alpha emitter CR7

T. Hartwig[1], M. Latif[1], M. Magg[2], V. Bromm[3], R. Klessen[2], S. Glover[2], D. Whalen[4], E. Pellegrini[2], M. Volonteri[1]

(1) Institute d'Astrophysique de Paris, France
(2) Institut fuer Theoretische Astrophysik, ZAH Heidelberg, Germany
(3) Department of Astronomy, Austin, USA
(4) Institute of Cosmology and Gravitation, Portsmouth, UK

CR7 is the brightest Lyman-α emitter observed at $z > 6$, which shows very strong Lyman-α and HeII 1640Å line luminosities, but no metal line emission. Previous studies suggest that CR7 hosts either young primordial stars with a total stellar mass of 10^7 $M_\odot$ or a black hole of $\approx 10^6\,M_\odot$. Here, we explore different formation scenarios for CR7 with a semianalytical model, based on the random sampling of dark matter merger trees. We find that primordial stars cannot account for the observed line luminosities because of their short lifetimes and because of early metal enrichment. Black holes that are the remnants of the first stars are either not massive enough, or reside in metal-polluted halos, ruling out this possible explanation of CR7. Our models instead suggest that direct collapse black holes, which form in metal-free halos exposed to large Lyman-Werner fluxes, are more likely the origin of CR7.

P4.07 - The colors of high redshift galaxies

ToC Prg

M. Mancini

INAF, Italy

UV observations of high redshift ($z > 5$) galaxies have the potential to probe both the presence of very metal-poor stellar populations and the level of dust enrichment of their interstellar medium (ISM). Indeed, at lower redshift well established relations correlate the UV properties with the amount of dust in star forming galaxies (e.g., Meurer et al. 1999). Although multiple verifications of these relations exist at $z < 4$, it is not clear if these hold at higher redshift. Moreover, theoretical predictions from numerical simulations seem to overestimate the number of bright galaxies with $\mathrm{M_{UV}} < -20$ at $z \approx 6 - 7$ with respect to observations and do not reproduce the relation between the slope of the UV continuum and the UV magnitude observed (Bouwens et al. 2015). Using a semi-numerical approach that combines a cosmological hydrodynamical simulation with dust enrichment (Mancini et al. 2015), we make detailed predictions on the evolution of UV colors and luminosities of galaxies in the redshift range $5 < z < 8$, which provide a good agreement with observations. We then interpret the observed color evolution in terms of the properties of stellar populations and ISM conditions and infer the dust attenuation — UV slope relation that applies to galaxies up to $z = 8$. The results of our study have important implications for the process of cosmic reionization.

ToC Prg

P4.08 - A common origin for globular clusters and ultra-faint dwarfs in simulations of the first galaxies

M. Ricotti[1], O. Parry[1], N. Gnedin[2]

(1) University of Maryland
(2) Fermilab, University of Chicago

This constribution focuses on understanding what determines the size and morphology of stellar objects in the first low mass galaxies, using parsec-scale cosmological simulations performed with an adaptive mesh hydrodynamics code. Although the dense gas in which stars are formed tends to have a disk structure, stars are found in spheroids with little rotation. Halos with masses between 10^6 and 5×10^8 $M_\odot$ form stars stochastically, with stellar masses in the range 10^4 to $2{\times}10^6$ $M_\odot$. Nearly independent of stellar mass, we observe a large range of half-light radii for the stars, from a few parsecs to a few hundred parsecs and surface brightnesses and mass-to-light ratios ranging from those typical of globular clusters to ultra-faint dwarfs. In our simulations, stars form in dense stellar clusters with high gas-to-star conversion efficiencies and rather uniform metallicities. A fraction of these clusters remain bound after the gas is removed by feedback, but others are destroyed, and their stars, which typically have velocity dispersions of 20 to 40 km/s, expand until they become bound by the dark matter halo. We thus speculate that the stars in ultra-faint dwarf galaxies may show kinematic and chemical signatures consistent with their origin in a few distinct stellar clusters. On the other hand, some globular clusters may form at the center of primordial dwarf galaxies and may contain dark matter, perhaps detectable in the outer parts.

P4.09 - The 21 cm line bispectrum as method to probe cosmic dawn and EoR

ToC Prg

H. Shimabukuro

Observatoire de Paris, France

The redshifted 21cm signal is a promising tool to investigate the state of intergalactic medium (IGM) in the Cosmic Dawn (CD) and Epoch of Reionization(EoR). In our previous work, we studied the variance and skewness of the 21cm fluctuations to give a clear interpretation of the 21cm power spectrum and found that skewness is a good indicator of the epoch when X-ray heating becomes effective. Thus, the non-Gaussian feature of the spatial distribution of the 21cm signal is expected to be useful to investigate the astrophysical effects in the CD and EoR. In this talk, in order to investigate such a non-Gaussian feature in more detail, we focus on the bispectrum of the 21cm signal. It is expected that the 21cm brightness temperature bispectrum is produced by non-gaussianity due to the various astrophysical effects such as the Wouthysen-Field (WF) effect, X-ray heating and reionization. We study the various properties of 21cm bispectrum such as scale dependence, shape dependence and redshift evolution. And also we study the contribution from each component of 21cm bispectrum. We find that the contribution from each component has characteristic scale-dependent feature. In particular, we find that the bulk of the 21cm bispectrum at z =20 comes from the matter fluctuations, while in other epochs it is mainly determined by the spin and/or neutral fraction fluctuations and it is expected that we could obtain more detailed information on the IGM in the CD and EoR by using the 21cm bispectrum in the future experiments, combined with the power spectrum and skewness. In addition, we perform Fisher analysis for the EoR model parameters with 21cm bispectrum and show the results.

ToC Prg

P4.10 - Lyman-alpha radiation pressure in the first galaxies

A. Smith[1], V. Bromm[1], A. Loeb[2]

(1) University of Texas at Austin, USA
(2) Harvard-Smithsonian Center for Astrophysics, USA

Radiation from the first stars and galaxies initiated the dramatic phase transition marking an end to the cosmic dark ages. The emission and absorption signatures from the Lyman-alpha (Lyα) transition of neutral hydrogen have been indispensable in extending the observational frontier for high-redshift galaxies into the epoch of reionization. Lyman-alpha radiative transfer provides clues about the processes leading to Lyα escape from individual galaxies and the subsequent transmission through the intergalactic medium. Cosmological simulations incorporating Lyα radiative transfer enhance our understanding of fundamental physics by supplying the inferred spectra and feedback on the gas. We discuss the dynamic impact of Lyα radiation pressure on galaxy formation throughout cosmic reionization with the first fully coupled Lyα radiation-hydrodynamics simulations. We self-consistently follow the chemistry, cooling, self-gravity, and ionizing radiation in protogalaxies and find that Lyα radiation pressure turns out to be dynamically important in several spherically symmetric simulations. As a case in point we apply our model to the CR7 galaxy at $z = 6.6$, which exhibits a +160 km/s velocity offset between the Lyα and He II line peaks. We find that a massive black hole with a nonthermal Compton-thick spectrum is able to reproduce the observed Lyα signatures as a result of higher photon trapping and longer potential lifetime. We conclude with a general discussion of the role of Lyα radiation pressure in the first galaxies by considering simulations that cover the expected range of halo and source properties.

P5.01 - Exotic supernovae at cosmic dawn

ToC Prg

K.-J. Chen[1], S. Woosley[3], W. Zhang[2], A. Heger[4]

(1) EACOA/National Observatory of Japan, Japan
(2) UC Santa Cruz
(3) Lawrence Berkeley National Laboratory
(4) Monash U.

Recent all-sky transient searches have discovered new and unexpected explosion types that fall outside traditional SN classification schemes. These exotic outliers in many cases are due to the deaths of massive stars and therefore may have been prevalent in the primordial universe because the Pop III IMF is thought to be top-heavy. Depending on the mass of the progenitor, these outliers may be faint, magnetar-powered, pair-instability, or general relativistic instability SNe, all of which have unique observational signatures. Some of these events are superluminous, 10–100 times brighter than normal SNe, and may produce energetic UV, X-ray, or gamma-ray bursts. Their extreme luminosities enable their detection at $z > 10$ and they are ideal probes of the primordial universe at cosmic dawn, prior to the advent of the first galaxies. Here, we examine these exotic explosions with state of the art 3D radiation-hydro simulations that bridge all spatial scales from the central engine to breakout into the ISM, where observational signatures can be computed. We discuss the coevolution of radiation and turbulent mixing in SN ejecta and present realistic light curves for these explosions for JWST and the coming generation of extremely large telescopes (ELTs). Detection rates for Pop III SNe can place useful constraints on the primordial IMF, and their nucleosynthetic yields can be used to study the chemical compositions of extreme metal poor stars.

ToC Prg

P5.02 - Amplification of magnetic fields in a primordial H II region and supernova

D. Koh, J. Wise

Georgia Institute of Technology, USA

Magnetic fields permeate the Universe on all scales and play a key role during star formation. We study the evolution of magnetic fields around a massive metal-free (Population III) star at $z \approx 15$ during the growth of its H II region and subsequent supernova explosion by conducting three cosmological magnetohydrodynamics simulations with radiation transport. Given the theoretical uncertainty and weak observational constraints of magnetic fields in the early universe, we initialize the simulations with identical initial conditions only varying the seed magnetic field strength. We find that magnetic fields grow as $\rho^{(2/3)}$ during the gravitational collapse preceding star formation, as expected from ideal spherical collapse models. Massive Population III stars can expel a majority of the gas from the host halo through radiative feedback, and we find that the magnetic fields are not amplified above the spherical collapse scaling relation during this phase. However, afterwards when its supernova remnant can radiatively cool and fragment, the turbulent velocity field in and around the shell causes the magnetic field to be significantly amplified on average by ≈ 100 in the shell and up to 6 orders of magnitude behind the reverse shock. Within the shell, magnetic field strengths are on the order of a few nG at a number density of $1\,\mathrm{cm}^{-3}$. We show that this growth is primarily caused by small- scale dynamo action initiated by Rayleigh-Taylor instabilities that form in the remnant. These strengthened fields will propagate into the first generation of galaxies, possibly affecting the nature of their star formation.

P6.01 - Preliminary test results: a new metallicity calibration using ugr-CaK photometry for EMP stars

ToC Prg

S. Caliskan[1], T. Kilicoglu[1], D. Ozuyar[1], P. Bonifacio[2], E. Caffau[2]

(1) Ankara University, Turkey
(2) Observatoire Paris-Meudon, France

The Extremely Metal-Poor (EMP) stars contain the fossil record of the chemical composition of the interstellar medium at the time they were formed. These rare stars still are observable today. Our aim is to develop a new metallicity calibration for deriving accurate metallicities of EMP stars ([Fe/H] < -2.5) from the photometry. We have used the broad band u, g, r, and a narrow band centered on 3933 Å Ca II K filters for our new calibration. The observations are performed for a small number of the sample using the T100 telescope at TÜBİTAK National Observatory (TUG) during four nights in April and May, 2016. The first test results are presented in this study.

ToC Prg

P6.02 - The best and brightest metal-poor stars

A. Casey[1], K. Schlaufman[2,3,4]

(1) University of Cambridge, UK
(2) Carnegie Observatories, USA
(3) Princeton University, USA
(4) Johns Hopkins University, USA

The chemical abundances of large samples of metal-poor stars can be used to investigate metal-free stellar populations, supernovae, nucleosynthesis, as well as the formation and galactic chemical evolution of the Milky Way and its progenitor halos. However, current progress on the study of metal-poor stars is being limited by their faint apparent magnitudes and the lack of available ancillary information beyond stellar parameters and detailed abundances. We have developed a new selection that uses only public, all-sky infrared photometry to identify metal-poor star candidates through their lack of molecular absorption near 4.6 microns. Our selection is as efficient as previous techniques, yet is capable of finding bright metal-poor stars everywhere in the sky. Over the last two years, we have carried out a new survey using this technique to find the "Best and Brightest" undiscovered metal-poor stars with [Fe/H] < -2.0 and V < 12. We have discovered more than 200 such stars, most of which are in the Tycho-2 catalog and will therefore soon have precise Gaia parallaxes and proper motions. Those data will permit an unprecedented exploration of the kinematics of the most metal-poor stars in the Milky Way and help determine whether the most metal-poor stars are the metal-poor tail of the smooth halo population or were formed in dwarf galaxies that were subsequently accreted by the Milky Way. We will present highlights from our ongoing program of high-resolution spectroscopy, including the discovery of the most neutron-capture-poor extremely metal-poor star – a class of star previously thought to exist only in dwarf galaxies – as well as the brightest known carbon-normal star with [Fe/H] < -3.5. In the future, our selection will allow NIRCam on the James Webb Space Telescope to identify the most metal-poor stars in the halos of galaxies out to distances of 20 Mpc.

P6.03 - Detection of a population of carbon-enhanced metal-poor stars in the Sculptor dwarf spheroidal galaxy

ToC Prg

A. Chiti[1], J. Simon[2], A. Frebel[1], M. Mateo[3], J. Bailey III[4], I. Thompson[2], S. Shectman[2], J. Crane[2], E. Olszewski[5], M. Walker[6]

(1) Massachusetts Institute of Technology, USA
(2) Observatories of the Carnegie Institution of Washington, USA
(3) University of Michigan, Ann Arbor, USA
(4) Leiden University, Netherlands
(5) University of Arizona, USA
(6) Carnegie Mellon University, USA

The study of the chemical abundances of metal-poor stars in the Sculptor dwarf spheroidal galaxy provides a venue to constrain paradigms of chemical enrichment and galaxy formation, as dwarf galaxies are thought to be the building blocks of larger systems in current hierarchical galaxy formation scenarios. We present metallicity and carbon abundance measurements of 112 stars in Sculptor from medium-resolution (R $\approx$ 2000) Magellan/M2FS spectra. We find 41 newly identified carbon-enhanced metal-poor (CEMP) stars with [Fe/H] < -2.0, and 20 extremely metal-poor stars ([Fe/H] < -3.0) of which 18 appear carbon-enhanced ([C/Fe] > 0.7) due to our selection process favoring carbon-enhancement. We derive a CEMP fraction for Sculptor of 41% for stars with [Fe/H] < -2.0, indicating that Sculptor may have a larger CEMP fraction than that of the halo for stars below [Fe/H] $= -2.0$ and suggesting that the early chemical evolution of Sculptor may have been partially driven by either fallback supernovae with large [C/Fe] abundance ratios or massive rotating stars with large CNO yields. Within the paradigm of hierarchical structure formation, it appears possible that various halo CEMP stars have their origin in early dwarf galaxy analogs of Sculptor.

ToC Prg

P6.04 - Non-LTE iron abundances in ultra metal-poor stars

R. Ezzeddine[1,2], A. Frebel[1,2]

(1) Massachusetts Institute of Technology
(2) JINA-CEE

Iron abundance plays a vital role in all stellar spectroscopic studies. It is often used to determine the fundamental atmospheric parameters of the star. Hence accurate modelling of iron spectral lines is required to ensure an accurate characterization of the star as well as accurate chemical abundance measurements of other elements as well. Iron lines, however, can be prone to large departures from LTE, especially in metal-poor stars. We present non-LTE iron abundance determination and corrections for a sample of the ultra metal-poor stars, using the most up-to-date atomic data and a new approach to estimate hydrogen collisional rates. Our results show a better agreement between Fe I and Fe II abundances for a chosen set of stellar parameters and a much less scatter than LTE values. This re-confirms the need for including non-LTE spectral line synthesis in all spectroscopic studies.

P6.05 - Understanding the anomalous Fe-rich metal-poor stars

ToC Prg

J. Farr[1], A. R. Casey[1], K. Schlaufman[2,3,4], G. Gilmore[1]

(1) University of Cambridge, UK
(2) Carnegie Observatories, USA
(3) Princeton University, USA
(4) Johns Hopkins University, USA

The detailed chemical abundances of extremely metal-poor (EMP) stars can provide insight into nucleosynthetic pathways and star formation in the early Universe. Here we examine a rare and unusual subset of EMP stars, the so-called 'Fe-rich' stars: metal-poor stars with an unusual signature in their detailed chemical abundances, primarily characterized by a widespread suppression of abundances relative to Fe (i.e., a majority of elements with [X/Fe] < 0). Currently, only 12 such stars are known, each found individually in separate EMP star surveys. However, due to differences in analysis methodologies, valid direct comparisons cannot currently be made, and so it is difficult to establish whether these stars form a coherent group. We perform a first homogeneous analysis of all Milky Way giant stars of this kind in order to determine whether the peculiar abundance pattern is, in fact, real and if so, to better understand the stars as a group. We then consider a number of mechanisms which might have led to their formation, and assess whether a common origin can be established. We find that these stars do exhibit a common signature in their detailed chemical abundances. While most elements show [X/Fe] < 0, some are notable exceptions: Si, Ca, Cr, and Mn. Comparing to up-to-date models, the detailed abundances show strong resemblance to the patterns seen in the yields of Type Ia supernovae, suggesting that accretion of matter from nearby Type Ia supernova has occurred at some point in the past. We believe that this could occur either through pollution of the star's natal gas cloud, or by accretion of matter from a companion star which underwent a Type Ia explosion. In either case, this link means that the Fe-rich stars may represent a unique opportunity to shed light on a previously unstudied early Universe phenomenon.

ToC Prg

P6.06 - High-resolution chemo-dynamical simulation of dwarf galaxies as a solution to the substructure problems and missing building blocks of the Milky Way

K. Hayashi[1], C. Kobayashi[1,2], T. Ishiyama[3], K. Nomoto[1], M. Ishigaki[1]

(1) Kavli Institute for the Physics and Mathematics of the Universe, The University of Tokyo, Japan
(2) Centre for Astrophysics Research, University of Hertfordshire, UK
(3) Institute of Management and Information Technologies, Chiba University, Chiba

The Lambda-cold dark matter model has several controversial issues on sub-galactic scales (such as missing satellite, core-cusp and too-big-to-fail problem), even though this concordance theory has well-reproduced observational phenomena on spatial scales larger than 1 Mpc. Feedback from stars and supernovae in small galaxies are supposed to be the solution, but how this works is not yet understood because of the complexity of subgalactic-scale physics. In particular, it is so far difficult to resolve missing building blocks of the Milky Way; the elemental abundances of present-day dwarf spheroidal galaxies are too different to that of the Milky Way Halo at a given metallicity. However, we find a solution that naturally solves these problems simultaneously from galaxy formation to stellar astrophysics, which appears only in high-resolution chemo-dynamical simulations that includes relevant baryon physics such as star formation, supernova feedback, and chemical enrichment. Therefore, our chemo-dynamical simulations show that 1) feedback from stars and supernovae are indeed the solution of the substructure problems, 2) nucleosynthesis is universal, and 3) dwarf galaxies can be the building blocks of the Milky Way halo.

P6.07 - The impact of feedback models on metal ejection

ToC Prg

C. Haynes, C. Kobayashi

University of Hertfordshire, UK

The ejection of metals from galaxies by supernova feedback is important to understand the chemical enrichment of the universe. We present chemodynamical simulations to compare three supernova feedback models; the standard thermal feedback model, a kinetic feedback model and a stochastic treatment of thermal feedback. We find that thermal feedback results in a relatively high SFR and weak mass ejection from the galaxy whilst both the kinetic and stochastic method have lower SFRs and eject significantly more mass. Thermal feedback has previously been criticized for weak feedback not sufficiently suppressing star formation or ejecting gas from the galaxy, however we find that the gas ejected by thermal feedback is more chemically enriched than that of the kinetic or stochastic models. We conclude that because the processes of feedback and enrichment are simultaneous in thermal feedback it is a better method for modelling the outflow of enriched gas and we use it to predict elemental abundances in the Milky Way.

ToC Prg

P6.08 - Atmosphere models for Galactic stellar populations — synthetic photometry and spectra for the oldest stars

D. Homeier

Ruprecht-Karls-Universität Heidelberg, Germany

Model atmospheres are a fundamental tool for studying the spectral energy distribution of stars to determine their basic properties - effective temperature, mass/luminosity and overall chemical composition as well as detailed abundance analyses. Models of the bulk characteristics of entire stellar populations, but also many spectral synthesis studies, still rely largely on extensive grids of 1D atmosphere models, but improvements in accuracy require modelling of the full 3D, temporally variable photospheric structure using radiative hydrodynamic (RHD) models, especially so for the lowest metallicities. We have combined both methods using the PHOENIX code and the CO5BOLD RHD code to calibrate the average structures of the former 1D models and generate a new set of models to reproduce SEDs and evolution in colour-magnitude diagrams of stars down to the hydrogen-burning limit and into the brown dwarf regime. I will present an extension of this project into the low metallicity regime. Concurrently, the development of full RHD models is continued to construct and improve a base grid of reference 3D models, calculated with consistent abundances and opacities, to support the calibration of further 1D atmospheres and provide synthetic photometry for older Galactic populations. Finally these efforts are extended to include stars with large deviations from standard abundance relations, such as the carbon-enhanced metal poor stars. These classes may even harbour the atmospherically polluted survivors of the first generation of stars.

P6.09 - High-resolution abundances of 30 CEMP stars

ToC Prg

C. Kennedy[1], V. Placco[2], T. Beers[2]

(1) University of Tampa, USA
(2) University of Notre Dame

We report on an abundance analysis of ≈ 30 CEMP stars based on Magellan/MIKE observations. The sample of stars spans three of the four of the CEMP subclasses: stars with s-process enhancement, r/s-process enhancement, and no neutron-capture element enhancement. Two of our stars are newly recognized CEMP stars with [Fe/H] < -3.5 that exhibit no neutron-capture-element enhancements. These CEMP-no stars exhibit the characteristic signature of high [Sr/Ba] abundances and lower A(C) than their CEMP-s/rs counterparts. We compare the abundances of the CEMP stars in this sample to the predicted abundance yields of metal-poor AGB stars, faint (mixing and fallback) supernovae, and massive, rapidly-rotating, mega metal-poor stars, the so-called spinstars.

ToC Prg

P6.10 - Investigating the origin of CEMP-no stars through light element analysis with the new database RoCStars (Repository of CEMP Stars)

K. Rasmussen, J. Yoon, T. Beers, V. Placco

University of Notre Dame, USA

We are compiling an online, SQL-searchable database of carbon-enhanced metal-poor (CEMP) stellar abundances from the literature that is standardized to a set of uniform Solar photospheric abundances (Asplund 2009). As the database is constructed, we will be investigating the relationship between light element (up to Mg) abundances and absolute carbon abundances ($A(C) = \log \epsilon_C$) in CEMP-no stars. We seek to understand why a trend emerges among CEMP-no stars where the absolute carbon abundance of one population is dependent on metallicity, [Fe/H], while the other population appears to be metallicity independent. We will also be investigating further division of the CEMP-no stars into two groups: those which are Na and Mg enhanced, and those which are not. With this information, we seek to distinguish between the suggested progenitors of the CEMP-no stars in the early Universe — "faint" (mixing and fallback) supernovae or the winds from spinstars.

P6.11 - Searching for substructure in the Milky Way halo using the metal-poor stars of Pristine

ToC Prg

K. Youakim

Leibniz Institute for Astrophysics Potsdam, Germany

The Pristine survey uses narrow-band photometry in the wavelength region around the Ca H&K lines to photometrically derive metallicities and search for metal poor stars. Broad-band photometric surveys have been used to very successfully find and quantify substructures, dwarf galaxies and streams in the Milky Way. However, many substructures might lie obscured in higher stellar density regions and are thus rendered undetectable to overdensity sensitive algorithms. The Pristine survey has added an extra dimension to the SDSS broad-band information, therefore providing another parameter to resolve halo substructures from other stellar populations. The Pristine metallicities are particularly accurate for metal-poor stars and thus allow for the halo to be analyzed in narrow metallicity ranges, eliminating foreground stars and leaving only the metal-poor galactic substructures. Here we present a metallicity mapping of the Pristine footprint in the Milky Way halo with the goal to quantify in more detail the substructure at different metallicities.

ToC Prg

P7.01 - Formation of supermassive black hole seeds in the first galaxies

F. Becerra[1], V. Bromm[2], L. Hernquist[1]

(1) Harvard-Smithsonian Center for Astrophysics, USA
(2) Department of Astronomy, The University of Texas at Austin, USA

We explore the formation of supermassive black hole seeds in the direct collapse scenario. Carrying out high-resolution simulations of the collapse of an atomic cooling halo in the early Universe, we evolve the gas under a strong Lyman-Werner background and follow its collapse over more than 20 orders of magnitude in density. We show that the central gas cloud settles into a Keplerian disc around the primary protostar, which rapidly grows in mass. The high accretion rate and efficient cooling of the gas catalyse the fragmentation of the disc into a small protostellar system, although our results show that fragmentation is not a significant barrier for forming at least one massive black hole seed. Achieving such high resolution only allowed us to track the evolution of the main protostar for a short period. We therefore develop an analytical model to understand the evolution of the central object towards later times. In particular, we explore the relevant physics once densities have reached the regime where H^- emission becomes optically thick. We derive expressions for the properties of the protostar, such as radius and luminosity, as a function of its mass. To this extent, we consider the limiting cases of spherical and disc accretion for a set of high accretion rates and then compare how these choices affect the evolution of the protostar. This ultimately leads to a better understanding of how the properties of the central protostar evolve during the crucial transition to becoming a supermassive black hole seed.

P7.02 - The elemental abundance problems in dwarf and massive galaxies

ToC Prg

C. Kobayashi

University of Hertfordshire, UK

Dwarf galaxies should experience strong supernova feedback, which results in stochastic star formation and inhomogeneous chemical enrichment, as observed for nearby dwarf spheroidal galaxies. In such conditions, the mass dependence on [α/Fe] ratios of core-collapse supernovae causes a decreasing trend of [α/Fe] toward higher [Fe/H] (without Type Ia Supernovae), while [Mn/Fe] stays low, being consistent with observations. In massive galaxies, feedback from super-massive blackholes plays an essential role. Provided that blackholes originate from the first stars, the mass-metallicity relation of galaxies is reproduced (both for stars and gas), with a steeper slope at higher redshifts (for gas). [α/Fe] ratios tend to be high for massive galaxies as observed. Within galaxies, metallicity is higher in the centre (both for stars and gas), giving a flatter gradient with active galactic nuclei (for gas). These effects of feedback on elemental abundances can be predicted only with high-resolution chemodynamical simulations. I also discuss the effect of first supernovae, i.e., faint supernovae/hypernovae, with our abundance fitting analysis of extremely metal-poor stars.

ToC Prg

P7.03 - Bulge-driven growth of seed black holes

K. Park[1], J. Wise[1], T. Bogdanović[1], P. Natarajan[2], M. Ricotti[3]

(1) Georgia Institute of Technology, USA
(2) Yale University, USA
(3) University of Maryland, USA

The discovery of overly massive quasars at high redshift ($z \approx 7$) being powered by billion solar mass black holes, poses a challenge for modeling initial seed black hole formation and its subsequent growth history. To test possible scenarios, radiation-hydrodynamic simulations are crucial for estimating growth rates of seeds in the intermediate-mass black hole range of $10^2 - 10^5\,\mathrm{M}_\odot$. Radiative feedback from the black hole suppresses the cold gas accretion rate to ≈1% of the Bondi rate, making it difficult to explain the rapid growth of seed black holes. However, we find that the fueling rate of black holes embedded in bulges increases rapidly when the bulge mass $\mathrm{M}_{\mathrm{bulge}}$ is greater than the critical value of $\approx 10^6$ solar mass and is proportional to $\mathrm{M}_{\mathrm{bulge}}/\mathrm{M}_\odot$, where $\mathrm{M}_\odot$ is the black hole mass. Since the critical bulge mass is independent of the central black hole mass, the growth rate of black holes with masses $\mathrm{M}_\odot = 10^2$, 10^4, and 10^6 solar mass exhibits distinct dependencies on the bulge-to-BH mass ratio. Our results imply that heavy seed black holes ($> 10^5\,\mathrm{M}_\odot$) that may form via direct collapse can grow efficiently coupling to the host galaxies whereas light seeds ($< 10^2\,\mathrm{M}_\odot$) are not able to grow coevally with the host galaxies due to radiative feedback.

P7.04 - Probing the Direct Collapse Black Hole seed paradigm

ToC Prg

J. Regan, P. Johansson, J. Wise

Durham University, UK

Creating direct collapse black hole seeds is thought to require an environment in which the main coolant is atomic hydrogen. This then requires that molecular hydrogen is efficiently dissociated and that the halo is also metal free. We use Enzo, along with an enhanced radiation transport module and cooling module, to simulate the effect that a multi-frequency source can have on the collapse. In particular, we critically assess whether a nearby source of radiation (from infrared to X-rays) can successfully create an atomic cooling halo in which a direct collapse black hole seed could form. We conduct a wide range of realisations varying the distance to the source galaxy and also vary its intrinsic spectrum to understand the feedback from the source on the collapsing galaxy.

ToC Prg

P7.05 - How supermassive black holes form by $z \approx 7$

J. Smidt[1], D. Whalen[2], J. Johnson[2]

(1) Los Alamos National Laboratory, USA
(2) Institute of Cosmology and Gravitation, University of Portsmouth

About 50 supermassive black holes (SMBHs) have now been found at $z > 6$, including a 12 billion solar mass candidate at $z = 6.3$ and a 2 billion solar mass object at $z = 7.1$. The discovery of these high redshift quasars severely challenged current paradigms of early structure formation, but new simulations have now shown that they can be understood to be direct collapse black holes (DCBHs) at the nexus of heavy, cold accretion flows that drive their rapid growth. We have developed radiation hydrodynamical models of SMBH birth and evolution in cosmological environments that now account for the masses of the $z = 7.1$ and 6.3 quasars whose H II regions can be post processed to produce their NIR and Ly-a luminosities. I will discuss these synthetic observables and the prospects for detection of $6 < z < 15$ quasars by JWST, the E-ELT, Euclid and WFIRST.

P7.06 - Conditions for Direct Collapse Black Hole formation with detailed microphysics

ToC Prg

K. Sugimura[1], C. M. Coppola[2,3], K. Omukai[1], D. Galli[3], F. Palla[3]

(1) Tohoku University, Japan
(2) University of Bari Aldo Moro, Italy
(3) INAF-Arcetri Astrophysical Observatory, Italy

It has been proposed that supermassive black holes (SMBHs) are originated from direct-collapse black holes (DCBHs) that are formed at $z > 10$ in the primordial gas. DCBHs are thought to be formed in atomic cooling halos in which H_2 cooling is totally suppressed by strong external radiation. In this talk, we present the critical specific intensity at the Lyman-Werner (LW) bands J_{crit} (in units of $10^{-21}\,\mathrm{erg\,s^{-1}\,Hz^{-1}\,sr^{-1}\,cm^{-2}}$) required for DCBH formation, obtained with the consideration of detailed microphysics in order to have realistic value of it. Specifically, we consider non-local thermodynamic equilibrium (non-LTE) chemistry with the vibrationally resolved H_2^+ kinetics, which can affect the abundance of H_2 through the H_2^+ channel of H_2 formation. We also consider realistic radiation spectra of galaxies and reveal the effects of near infrared photons on DCBH formation. We find the effects of non-LTE H_2^+ chemistry are negligible for hard spectra of young and/or metal-poor galaxies, although J_{crit} can be underestimated by a factor of a few with LTE chemistry models for softer spectra. Thus, we use a LTE chemistry model and obtain $J_{crit} \approx 1000$ for young (the age less than 100 Myr) and/or extremely metal-poor ($Z < 5 \times 10^{-4}\,Z_\odot$) galaxies, which are thought to be typical radiation sources in the early Universe. The typical value of J_{crit} is higher than those expected in the literature, which affects the estimated DCBH number density n_{DCBH}. By extrapolating the result of Dijkstra, Ferrara & Mesinger, we obtain $n_{\mathrm{DCBH}} \approx 10^{-10}\,\mathrm{cMpc^{-3}}$ at $z = 10$, although there is still large uncertainty in this estimation. This estimated n_{DCBH} is roughly consistent with the observed number density of high-redshift SMBHs $n_{\mathrm{SMBH}} \approx 10^{-9}\,\mathrm{cMpc^{-3}}$ at $z \approx 6$, considering uncertainties.

ToC Prg

P7.07 - Rapidly accreting massive black holes: feedback of anisotropic radiation from accretion disk

K. Sugimura[1], T. Hosokawa[2], H. Yajima[1], K. Omukai[1]

(1) Tohoku University, Japan
(2) The University of Tokyo, Japan

Rapid accretion of primordial gas onto massive black holes might be essential process in forming observed high-redshift ($z > 6$) super massive black holes. In this poster presentation, we show the results of our two-dimensional radiation–hydrodynamic simulations of rapidly accreting massive black holes considering the feedback of anisotropic radiation from accretion disk. We consider several models with different direction dependence of radiation and with different radiation efficiency. We obtain the accretion rate for those models and reveal the importance of anisotropic radiation and of the radiation efficiency.

P7.08 - The near infrared signatures of the first quasars

ToC Prg

M. Surace

Institute of Cosmology and Gravitation, UK

About 50 quasars have now been discovered at $z > 6$, including a 2 billion solar mass black hole (BH) at $z = 7.1$ and a 12 billion solar mass BH at $z = 6.3$. The origins of these high redshift supermassive black holes (SMBHs) are likely direct collapse black holes forming in pristine, atomically cooled halos at $z \approx 15 - 20$. The contribution of this early population of quasars to cosmological reionization will soon be probed by observatories such as JWST, WFIRST, and ELT. We have performed cosmological simulations that follow for the first time the birth and evolution of the $z > 6$ quasars with X-ray transport that produces H II regions that can be post-processed to obtain realistic synthetic observables for $5 < z < 15$ SMBHs. We have used these simulations to model the NIR continuum emission of the first quasars and we will discuss their properties and prospects for detection by the aforementioned observatories in the coming decade.

ToC Prg

P7.09 - The growth of billion solar mass black holes in the early Universe in cosmological simulations

P. Taylor

Australian National University, Australia

Understanding how supermassive black holes formed and grew in the early Universe ($z \geqq 6$) remains an important and unsolved problem in astrophysics. It is widely believed that high mass ($\mathrm{M_{BH}} \geqq 10^5\,\mathrm{M_\odot}$) black hole seeds are necessary to enable the black holes to become supermassive in relatively short times through Eddington-limited accretion. However, the sites at which such seeds are expected to be produced require specific, rare conditions to be met: the gas must have very low angular momentum, and be unable to fragment. Cosmological simulations that include feedback from supermassive black holes typically spawn such a high mass seed in dark matter halos more massive than $10^{10}\,\mathrm{M_\odot}$. In my model, black holes form from dense, metal-free gas particles, and I find that a seed mass of only $10^{2-3}\,\mathrm{M_\odot}$ is necessary to reproduce observed galaxy scaling relations, suggesting that Population III stars can be the progenitors of today's supermassive black holes. More recently, I used my model in a much larger simulation (100/h Mpc on a side) run to $z = 6$. Even with such low mass seeds, billion solar mass black holes were produced by this redshift. In this talk, I will present my AGN feedback model and my new simulation, show how these supermassive black holes can grow quickly enough, and discuss possible observational tests of this prediction.

List of participants

Agarwal	Bhaskar	Yale, New Haven, USA, bhaskar.agarwal@yale.edu
Aguado	David	IAC, La Laguna, Spain, aguado@iac.es
Battistini	Chiara	ZAH-LSW, Heidelberg, Germany, cbattistini@lsw.uni-heidelberg.de
Becerra	Fernando	Harvard-Smithsonian Center for Astrophysics, Cambridge, USA, fbecerra@cfa.harvard.edu
Beers	Timothy	University of Notre Dame, Granger, IN, USA, tbeers@nd.edu
Bernhardt	Carla	ITA, Universität Heidelberg, Heidelberg, Germany, c.bernhardt@uni-heidelberg.de
Bernstein	Rebecca	GMT, Pasadena, USA, rbernstein@gmto.org
Bestenlehner	Joachim	Max Planck Institute for Astronomy, Heidelberg, Deutschland, bestenlehner@mpia.de
Bonifacio	Piercarlo	GEPI-Observatoire de Paris - CNRS - Univ Paris Diderot, Meudon, France, Piercarlo.Bonifacio@obspm.fr
Bromm	Volker	The University of Texas, Austin, USA, vbromm@astro.as.utexas.edu
Bunker	Andy	University of Oxford, Oxford, UK, Andy.Bunker@physics.ox.ac.uk
Caliskan Turksoy	Seyma	Ankara University, Ankara, Turkey, seyma.caliskan@science.ankara.edu.tr
Casey	Andrew	University of Cambridge, Cambridge, UK, arc@ast.cam.ac.uk
Cescutti	Gabriele	University of Hertordshire, Hatfield, UK, g.cescutti@herts.ac.uk
Ceverino	Daniel	Zentrum für Astronomie der Universität Heidelberg, Institut für Theoretische Astrophysik, Heidelberg, Germany, ceverino@uni-heidelberg.de
Chan	Conrad	Monash Centre for Astrophysics, Clayton, Australia, conrad.chan@monash.edu
Chiaki	Gen	Konan University, Kobe, Japan, chiaki@center.konan-u.ac.jp
Chiti	Anirudh	MIT, Cambridge, USA, achiti@mit.edu
Chon	Sunmyon	University of Tokyo, Tokyo, Japan, sunmyon.chon@utap.phys.s.u-tokyo.ac.jp
Christlieb	Norbert	Universität Heidelberg, Zentrum für Astronomie, Landessternwarte, Heidelberg, Germany, N.Christlieb@lsw.uni-heidelberg.de
Cirasuolo	Michele	ESO, Germany, Garching, Germany, ciras@roe.ac.uk, mciras@eso.org
Cooke	Ryan	University of California, Santa Cruz, Santa Cruz, USA, rcooke.ast@gmail.com
Cooray	Asantha	University of California, Irvine, Irvine, USA, acooray@uci.edu
Corazza	Lia	INPE - Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research), São José dos Campos, Brazil, lia.corazza@gmail.com
Cordero	Maria	Astronomisches Rechen-Institut, Heidelberg, Germany, mjcorde@ari.uni-heidelberg.de

Cuby	Jean-Gabriel	Laboratoire d'Astrophysique de Marseille, Marseille, France, jean-gabriel.cuby@lam.fr
Cui	Wenyuan	Hebei Normal University, Shijiazhuang, China, wenyuancui@126.com
de Bennassuti	Matteo	INAF/OAR, Monte Porzio Catone, Italy, matteo.debennassuti@oa-roma.inaf.it
Ekström	Sylvia	Geneva Observatory, Geneva, Switzerland, sylvia.ekstrom@unige.ch
Ezzeddine	Rana	MIT, Cambridge, MA, USA, ranae@mit.edu
Farr	James	University of Cambridge, Guildford, UK, james.a.farr@btopenworld.com
Feltzing	Sofia	Lund Observatory, Lund, Sweden, sofia@astro.lu.se
Frebel	Anna	Massachusetts Institute of Technology, Cambridge, USA, afrebel@mit.edu
Fröhlich	Carla	North Carolina State University, Raleigh, USA, cfrohli@ncsu.edu
Galli	Daniele	INAF Osservatorio Astrofisico di Arcetri, Firenze, Italy, galli@arcetri.astro.it
Geen	Sam	CEA Saclay, Gif-sur-Yvette, France, samgeen@gmail.com
Glover	Simon	Institute for Theoretical Astrophysics, Heidelberg, Germany, glover@uni-heidelberg.de
Gnedin	Nick	Fermilab, Batavia, USA, gnedin@fnal.gov
Gonzalez-Hernandez	Jonay I.	Instituto de Astrofísica de Canarias, La Laguna, Spain, jonay@iac.es
Graziani	Luca	INAF, OAR, Firenze, Italy, luca.graziani@oa-roma.inaf.it
Griffen	Brendan	Massachusetts Institute of Technology, Somerville, USA, brendan.f.griffen@gmail.com
Gronke	Max	Institute of Theoretical Astrophysics, Oslo, Oslo, Norway, maxbg@astro.uio.no
Haemmerle	Lionel	Universität Heidelberg (ITA), Heidelberg, Germany, lionel.haemmerle@unige.ch
Hampel	Melanie	Uni Heidelberg, ZAH, LSW, Heidelberg, Germany, mhampel@lsw.uni-heidelberg.de
Hartwig	Tilman	Institut d'Astrophysique de Paris, Paris, France, hartwig@iap.fr
Hayashi	Kohei	Kavli IPMU, The University of Tokyo, Kashiwa, Japan, kohei.hayashi@ipmu.jp
Haynes	Christopher	University of Hertfordshire, Hatfield, UK, cjhaynes44@gmail.com
Heger	Alexander	Monash University, Monash University, Australia, alexander.heger@monash.edu
Hirano	Shingo	The University of Texas, Austin, USA, hirano0613@gmail.com
Hosokawa	Takashi	University of Tokyo, Tokyo, Japan, takashi.hosokawa@phys.s.u-tokyo.ac.jp
Howes	Louise	Lund University, Lund, Sweden, louise@astro.lu.se
Inayoshi	Kohei	Columbia University, New York, USA, inayoshi@astro.columbia.edu
Ishiyama	Tomoaki	IMIT, Chiba University, Chiba-shi, Japan, ishiyama@chiba-u.jp

Jaura	Ondrej	ZAH ITA, Heidelberg, Germany, ondrej.jaura@uni-heidelberg.de
Ji	Alexander	Massachusetts Institute of Technology, Cambridge, USA, alexji@mit.edu
Khanna	Ramon	Springer Verlag GmbH, Heidelberg, Germany, ramon.khanna@springer.com
Kinugawa	Tomoya	ICRR, The University of Tokyo, Chiba, Japan, kinugawa@icrr.u-tokyo.ac.jp
Klessen	Ralf	Heidelberg University, Center for Astronomy, Heidelberg, Germany, klessen@uni-heidelberg.de
Kobayashi	Chiaki	University of Hertfordshire, Hatfield, UK, c.kobayashi@herts.ac.uk
Koh	Daegene	Georgia Institute of Technology, Atlanta, USA, dkoh30@gatech.edu
Korn	Andreas	Uppsala University, Uppsala, Sweden, andreas.korn@physics.uu.se
Lawlor	Timothy	Penn State University - Brandywine, Media, USA, tlawlor@psu.edu
Lee	Hunchul	Seoul National University, Seoul, South Korea, akaialee@astro.snu.ac.kr
Ludwig	Hans-Günter	ZAH - Landessternwarte, Heidelberg, Germany, H.Ludwig@lsw.uni-heidelberg.de
Ma	Qingbo	Max-Planck Institute for Astrophysics, Garching, Germany, maqb@mpa-garching.mpg.de
Magg	Mattis	Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Dossenheim, Germany, mattis.magg@stud.uni-heidelberg.de
Mancini	Mattia	INAF, Monte Porzio Catone, Italy, mattia.mancini@oa-roma.inaf.it
Marassi	Stefania	INAF-OAR, Rom, Italy, stefania.marassi@oa-roma.inaf.it
Marques	Reggiani	Henrique Universidade de São Paulo - IAG, São Paulo, Brazil, hreggiani@gmail.com
Martell	Sarah	University of New South Wales, Sydney, Australia, s.martell@unsw.edu.au
Mashonkina	Liudmila	Institute of Astronomy, RAS, Moscow, Russia, lima@inasan.ru
McLure	Ross	Insitute for Astronomy, Royal Observatory Edinburgh, Edinburgh, UK, rjm@roe.ac.uk
Nakauchi	Daisuke	Tohoku University, Sendai, Japan, nakauchi@astr.tohoku.ac.jp
Natarajan	Priya	Yale University, New Haven, USA, priyamvada.natarajan@yale.edu
Nomoto	Ken'ichi	Kavli IPMU, University of Tokyo, Kashiwa, Japan, nomoto@astron.s.u-tokyo.ac.jp
Nordlander	Thomas	Uppsala Universitet, Uppsala, Sweden, Thomas.Nordlander@physics.uu.se
Omukai	Kazu	Astronomical Institute, Tohoku University, Sendai, Japan, omukai@astr.tohoku.ac.jp

Pallottini	Andrea	University of Cambridge, Cambridge, UK, ap926@cam.ac.uk
Park	KwangHo	Georgia Institute of Technology, Atlanta, USA, kwangho.park@physics.gatech.edu
Perez-Fournon	Ismael	Instituto de Astrofísica de Canarias, La Laguna, Tenerife, Spain, ipf@iac.es
Pezzulli	Edwige	INAF/Osservatorio Astronomico di Roma, Monteporzio Catone (RM), Italy, edwige.pezzulli@oa-roma.inaf.it
Rasmussen	Kaitlin	University of Notre Dame, Mishawaka, USA, krasmus1@nd.edu
Regan	John	Durham University, ICC, Durham, UK, john.a.regan@durham.ac.uk
Rodón	Javier	Onsala Space Observatory, Onsala, Sweden, javier.rodon@chalmers.se
Roederer	Ian	University of Michigan, Ann Arbor, MI, USA, iur@umich.edu
Sakurai	Yuya	University of Tokyo, Tokyo, Japan, sakurai@utap.phys.s.u-tokyo.ac.jp
Salvadori	Stefania	GEPI, Paris Observatory, Meudon, Paris, France, stefania.salvadori@obspm.fr
Schauer	Anna	Zentrum für Astronomie Heidelberg, ITA, Heidelberg, Germany, schauer@uni-heidelberg.de
Schleicher	Dominik	Universidad de Concepción, Concepción, Chile, dschleicher@astro-udec.cl
Schneider	Raffaella	INAF/Osservatorio Astronomico di Roma, Monteporzio Catone (Roma), Italy, raffaella.schneider@oa-roma.inaf.it
Schober	Jennifer	NORDITA, Stockholm, Sweden, jschober@nordita.org
Shimabukuro	Hayato	Observatoire de Paris, Paris, France, hayato.shimabukuro@obspm.fr
Shirazi	Kaveh	Universität des Saarlandes, Saarbrücken, Germany, kaveh_shirazi@physicist.net
Smith	Britton	University of Edinburgh, Edinburgh, UK, brittonsmith@gmail.com
Smith	Aaron	University of Texas at Austin, Kyle, TX, USA, asmith@astro.as.utexas.edu
Stiavelli	Massimo	Space Telescope Science Institute, Baltimore, USA, mstiavel@stsci.edu
Sugimura	Kazuyuki	Tohoku University, Sendai, Japan, sugimura@astr.tohoku.ac.jp
Surace	Marco	Institute of Cosmology and Gravitation, Harrow, UK, marco.surace@port.ac.uk
Taylor	Philip	Australian National University, Canberra, Australia, philip.1.taylor@anu.edu.au
Tolstov	Alexey	Kavli IPMU, The University of Tokyo, Kashiwa, Japan, alexey.tolstov@ipmu.jp
Tominaga	Nozomu	Konan University, Kobe, Japan, tominaga@konan-u.ac.jp
Valiante	Rosa	INAF-OAR, Monte Porzio Catone, Italy, rosa.valiante@oa-roma.inaf.it

Wagg	Jeff	SKAO, Macclesfield, UK, j.wagg@skatelescope.org
Wehmeyer	Benjamin	Dept. Phys., University of Basel, Basel, Switzerland, benjamin.wehmeyer@unibas.ch
Whitten	Devin	University of Notre Dame, Mishiwaka, USA, dwhitten@nd.edu
Wise	John	Georgia Institute of Technology, Atlanta, USA, jwise@physics.gatech.edu
Wollenberg	Katharina	Institute of Theoretical Astrophysics, Heidelberg University, Heidelberg, Germany, k.wollenberg@stud.uni-heidelberg.de
Yong	David	Australian National University, Canberra, Australia, david.yong@anu.edu.au
Yoon	Jinmi	University of Notre Dame, South Bend, USA, jinmi.yoon@nd.edu
Youakim	Kris	Institut für Astrophysik, Potsdam, Germany, kyouakim@aip.de

Author index