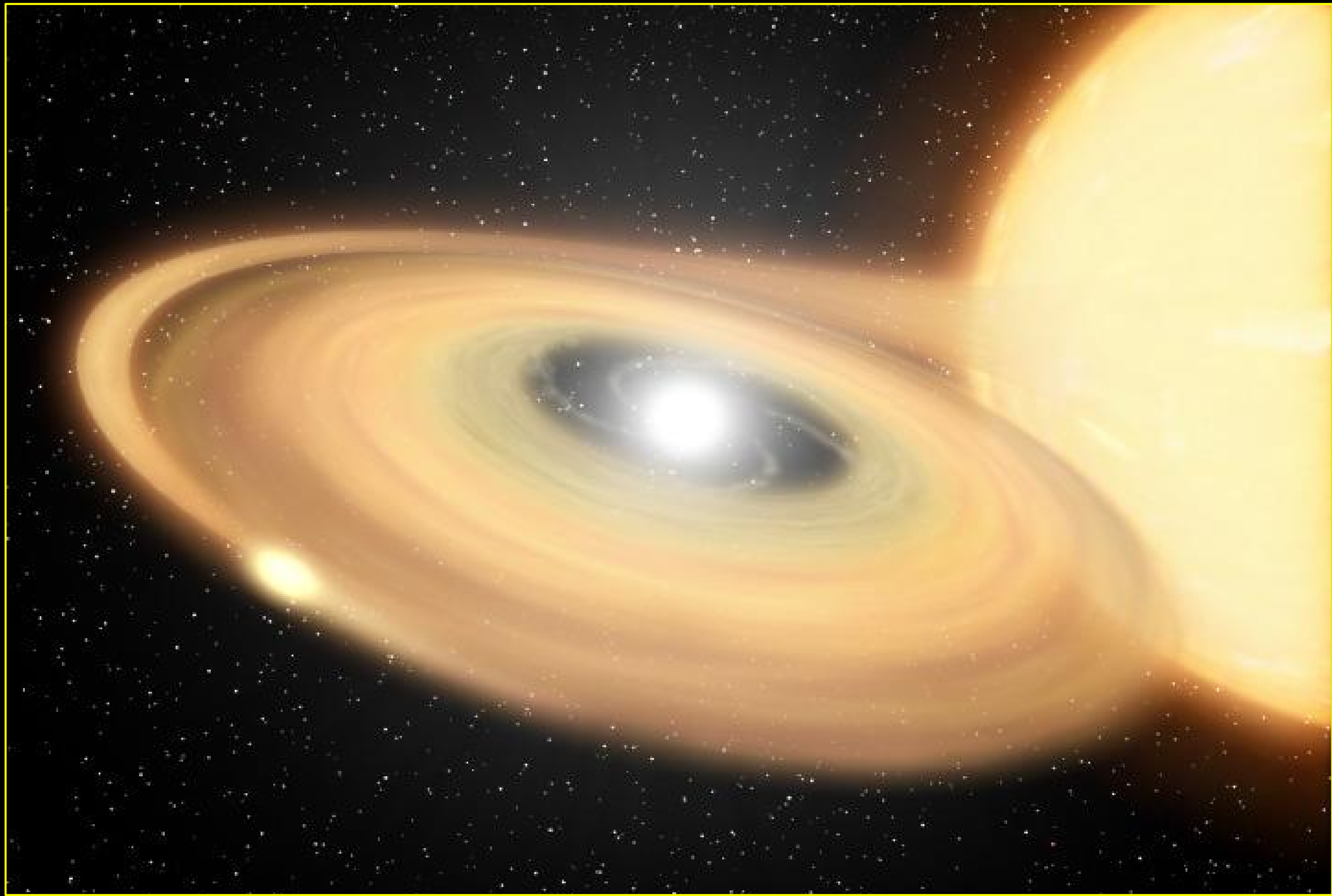

Classical Novae – Theory and Observations

Jordi José

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& Institut d'Estudis Espacials de Catalunya (IEEC), Barcelona

Nova (*stella nova*): sudden appearance of a luminous object in the sky (at a spot where nothing was clearly visible before), that fades away in a matter of ~ weeks

Discovered more than 2.000 years ago... → Many existing compilations of *stellae novae*: the earliest by Ma Dualin (XIII AD), listing events from 206BC...

↓

Stellae novae = supernovae, novae, comets...

→ Novae vs. Supernovae

↓

S Andromedae 1885 in M31

(Too) Early Explanations of the Nova Phenomenon

* G. B. Riccioli, *Almagestum Novum* (1651), lib. 2, pp. 177-179

14 (im)possible explanations!


AD
MAGNANIMVM PRINCIPEM
HONORATVM II.
MONOECI PRINCIPEM
DVCEM VALENTINVM
PAREM FRANCIÆ
MARCHIONEM BAVCII, COMITEM CARLADESII
BARONEM BVISSII, ET CALVINETI
DOMINVM S. REMIGII &c.
ALMAGESTI NOVI
PARS POSTERIOR
TOMI PRIMI.

* I. Newton, *Principia Mathematica* (1726), 3rd ed., lib. 3, prop. 42

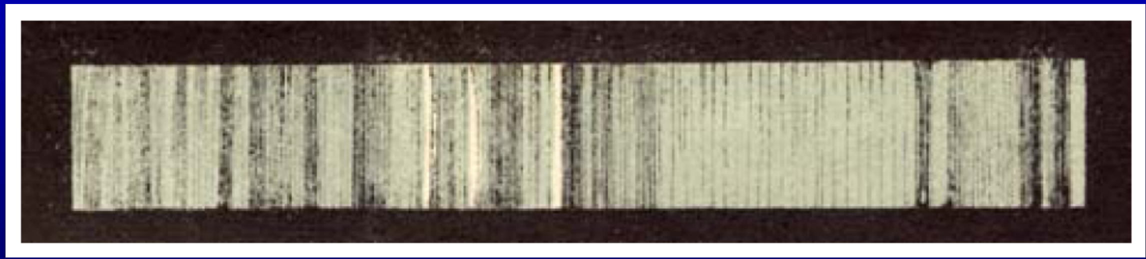
So fixed stars, that … emitted from them
for a long time, ma… this fresh supply
of new fuel those old stars, acquiring new splendor, may pass for new stars

Old stars accreting (fuel) material!

Observational & Theoretical Breakthroughs

Observations

* Huggins & Miller perform the first (optical) spectroscopic study of a nova [T CrB 1866]



* Sidgreaves (1901) finds [Ne III] 3869, 3968 Å in GK Per, revealing different nova types (chemically) → Ne-novae!
* Pickering (1894), Pike (1929) and others explain the spectral features by ejection of a shell from a star
* Stratton & Manning (1939) propose that the minimum in DQ Her light curve is due to dust formation
* Walker (1954) unveils the binary nature of DQ Her
* Kraft (1963, 1964) demonstrates that binarity is a common property of CVs (novae, in particular)

Hartmann (1925): shortest paper ever?

RR Pic (1925): *"Nova problem solved: star expands, and bursts"*

Theory

* Schatzmann (1951): outburst triggered by nuclear reactions [^{3}He]

REMARQUES SUR LE PHÉNOMÈNE DE NOVA (IV)

L'onde de détonation due à l'isotope ^{3}He

par Evry Schatzman

Sommaire. — *L'isotope ^{3}He peut s'accumuler en faible quantité dans les étoiles. Une faible concentration de ^{3}He est suffisante pour que puisse se former une onde de détonation, à condition que l'amorçage convenable existe.*

On en conclut que l'isotope ^{3}He est vraisemblablement à l'origine du phénomène de Nova.

Ann. d'Astroph. (1951) **14**, 294

* Sparks (1969): first hydrodynamic simulation of a nova outburst

DYNAMICAL MODELS OF NOVAE*

Warren M. Sparks

Department of Astronomy, Indiana University, and Goddard Space Flight Center
National Aeronautics and Space Administration, Greenbelt, Maryland

Received June 26, 1968; revised September 27, 1968

ABSTRACT

The dynamics of a nova outburst are studied by means of a time-dependent hydrodynamics computer program which includes transport of energy by radiation and convection. Two distinct types of ejections which could give rise to novae are identified. The "flash" nova (e g., T CrB) has a very rapidly rising and falling light curve and a rapidly decreasing velocity curve. A strong shock wave which imparts a velocity greater than the escape velocity to the outer layers of the star will produce this behavior. A less rapidly rising and falling light curve and a nearly constant velocity are characteristic of the "ordinary" nova (e.g., GK Per). These features will result when the stellar material is forced outward by a pressure front which is not a shock wave. The pre-maximum halt, which is characteristic of the latter type of nova, results from the temperature dependence of the opacity of neutral hydrogen.

ApJ (1969) **156**, 569

The Classical Nova ID Card:

Moderate rise times (<1 – 2 days):

8 – 18 magnitude increase in brigthness

$L_{Peak} \sim 10^4 - 10^5 L_\odot$

Stellar binary systems: WD + MS (K-M dwarfs)

Recurrence time: $\sim 10^4 - 10^5$ yr (CN)
10 – 100 yr (RN)

Frequency: 30 ± 10 yr^{-1}
[Observed frequency: ~ 5 yr^{-1}]

$E \sim 10^{45}$ ergs

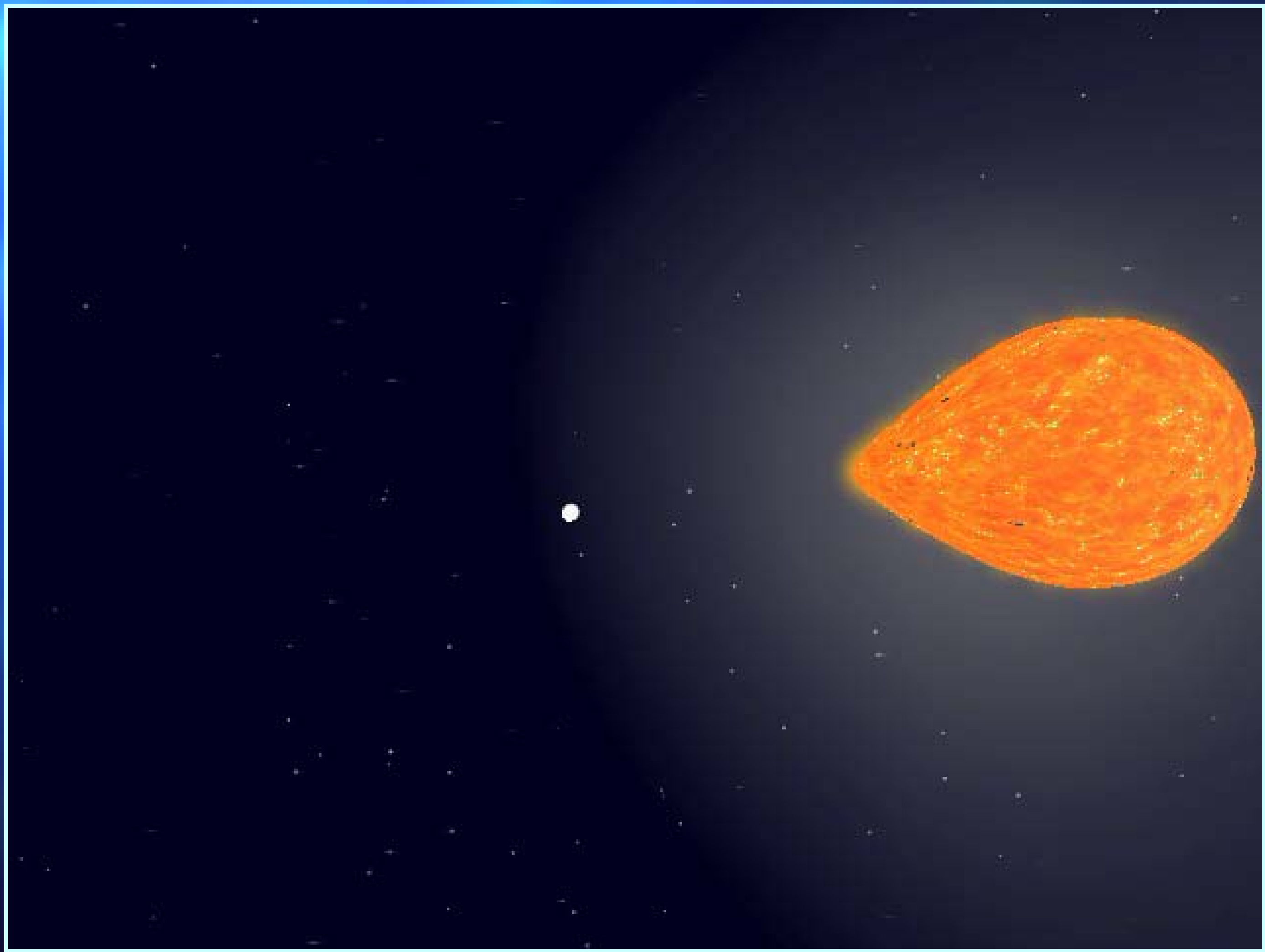
Mass ejected: $10^{-4} - 10^{-5} M_\odot$
($\sim 10^3$ km s^{-1})

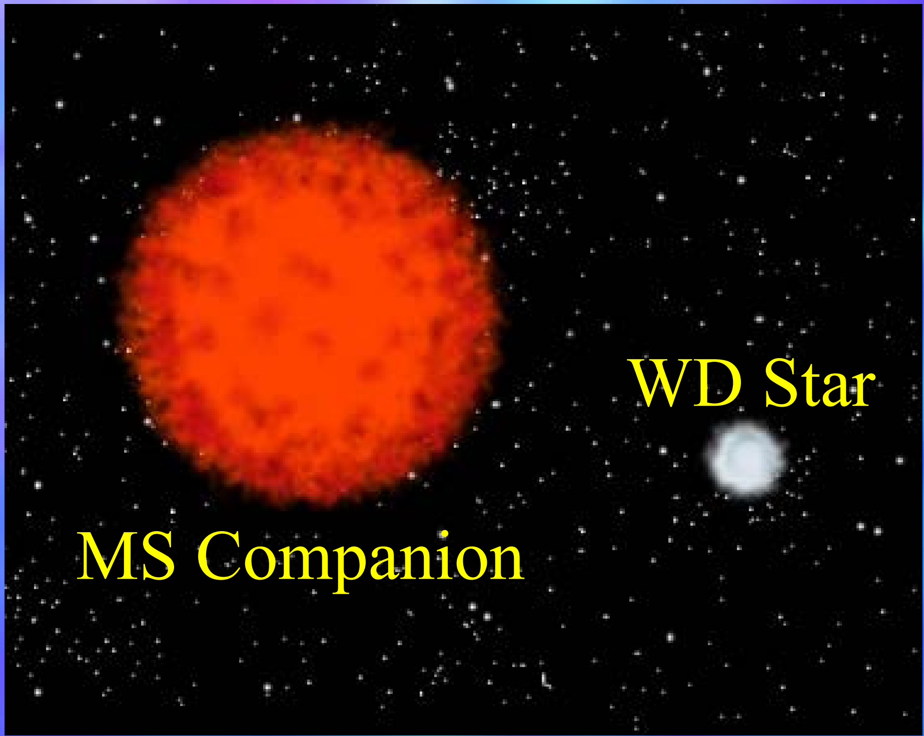
Novae have been observed in all wavelengths (but never detected so far in γ-rays)

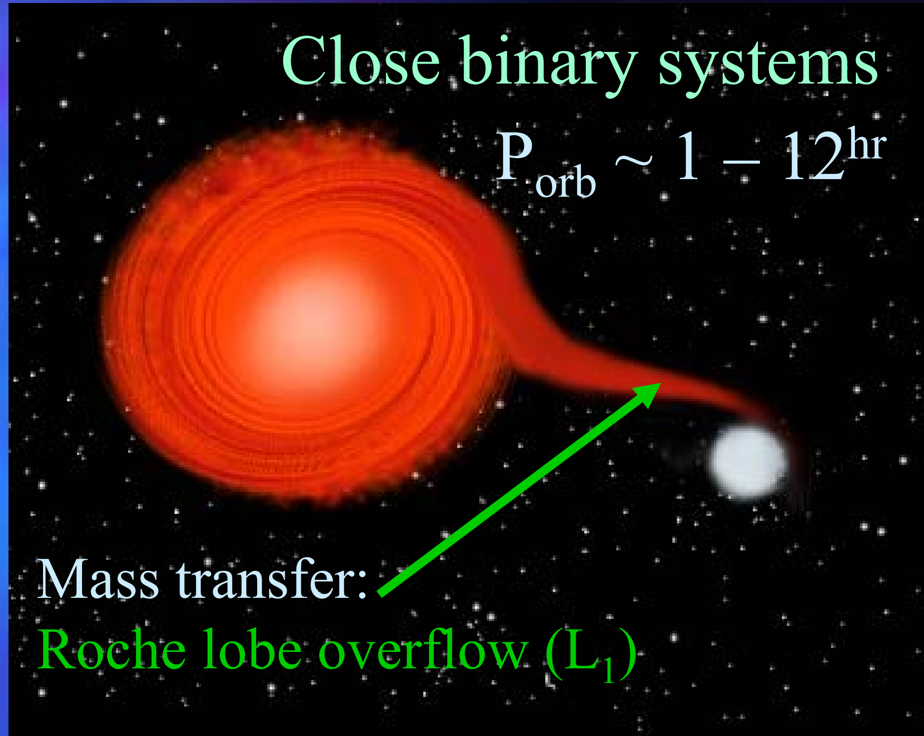
Spectroscopy (abundances)
Photometry (lightcurves)
Hydrodynamics

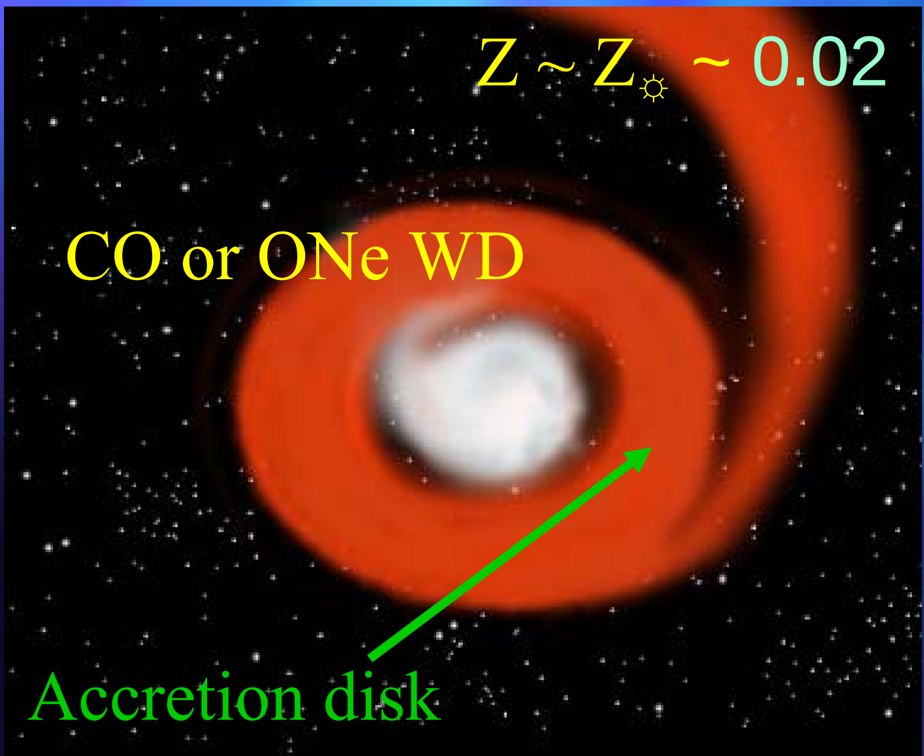
} Thermonuclear runaway model of classical nova explosions

Classical Nova: term first coined (likely) by Gerasimovic (1934)









Build-up of an envelope in semi-degenerate conditions:
Thermonuclear runaway (TNR)

Strength of the explosion:
$P_{base}(\Delta M_{env}, \text{gravity})$ ⟶
More violent outbursts for:
a) massive M_{wd}
b) larger ΔM_{env}

Triggering reaction: $^{12}C(p,\gamma)^{13}N$ → $^{13}N(\beta^+)^{13}C(p,\gamma)^{14}N$ (*cold* CNO)

As T increases: $\tau_{(p,\gamma)}[^{13}N] < \tau_{(\beta+)}[^{13}N]$ → $^{13}N(p,\gamma)^{14}O$ (*hot* CNO)

$^{14}N(p,\gamma)^{15}O$

$^{16}O(p,\gamma)^{17}F$

The presence of intermediate-mass (CNO) elements in the envelope has remarkable consequences for the energy transport:

* low Z regime → p-p chains → radiation
* high Z regime → CNO-cycle → radiation + convection

Critical role of convection: carrying the short-lived, β^+-unstable nuclei $^{14,15}O$, ^{17}F (^{13}N) to the outer, cooler layers of the envelope (escaping *deadly* p-capture reactions)

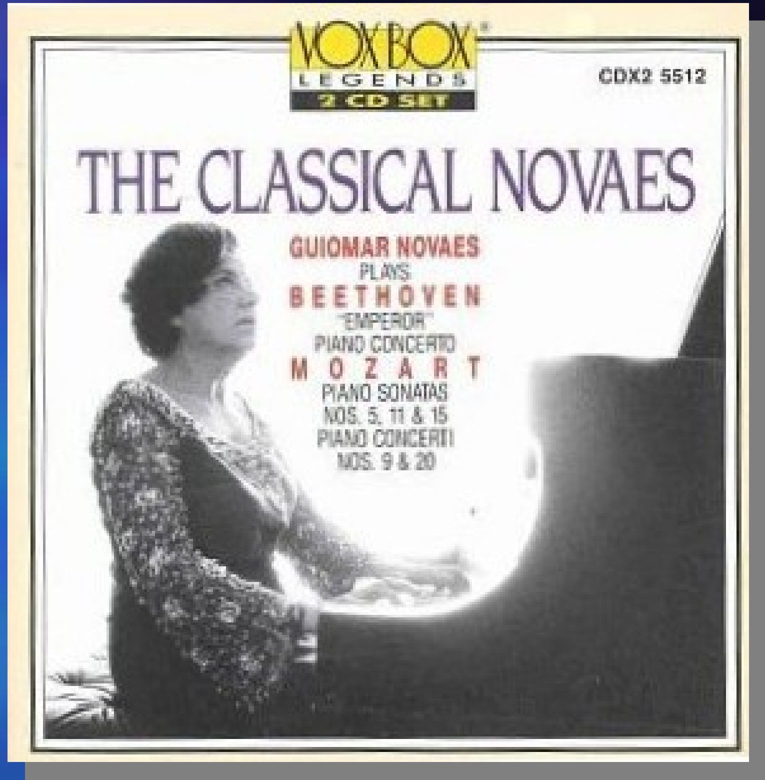
Sudden release of energy from these short-lived species powers the expansion and ejection stages [Starrfield et al.1972]:

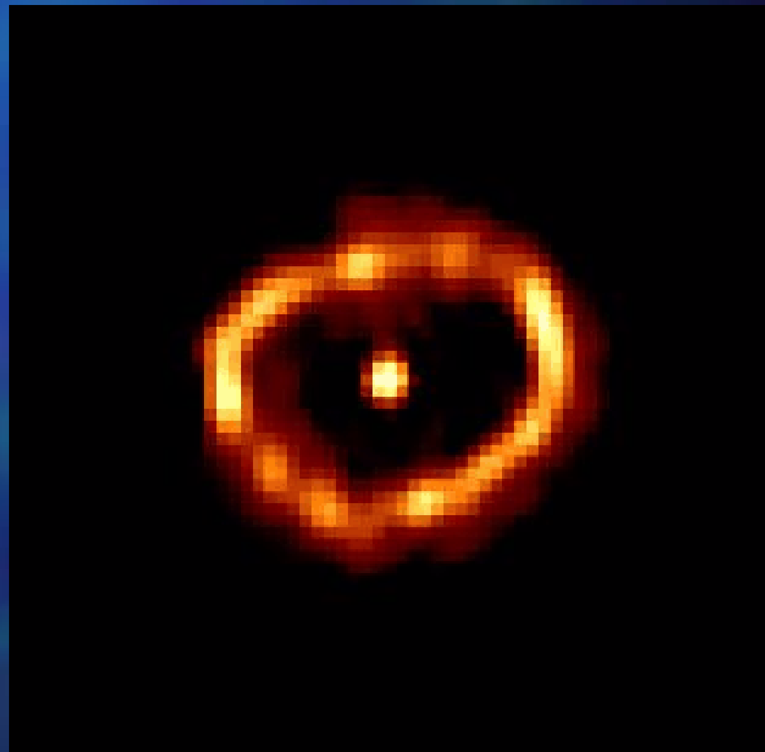
^{15}N, ^{17}O (^{13}C)

The Nova Nuclear Symphony

* Classical Novae: ~ 100 relevant isotopes (A<40) & a (few) hundred nuclear reactions (T_{peak} ~ 100 – 400 MK)

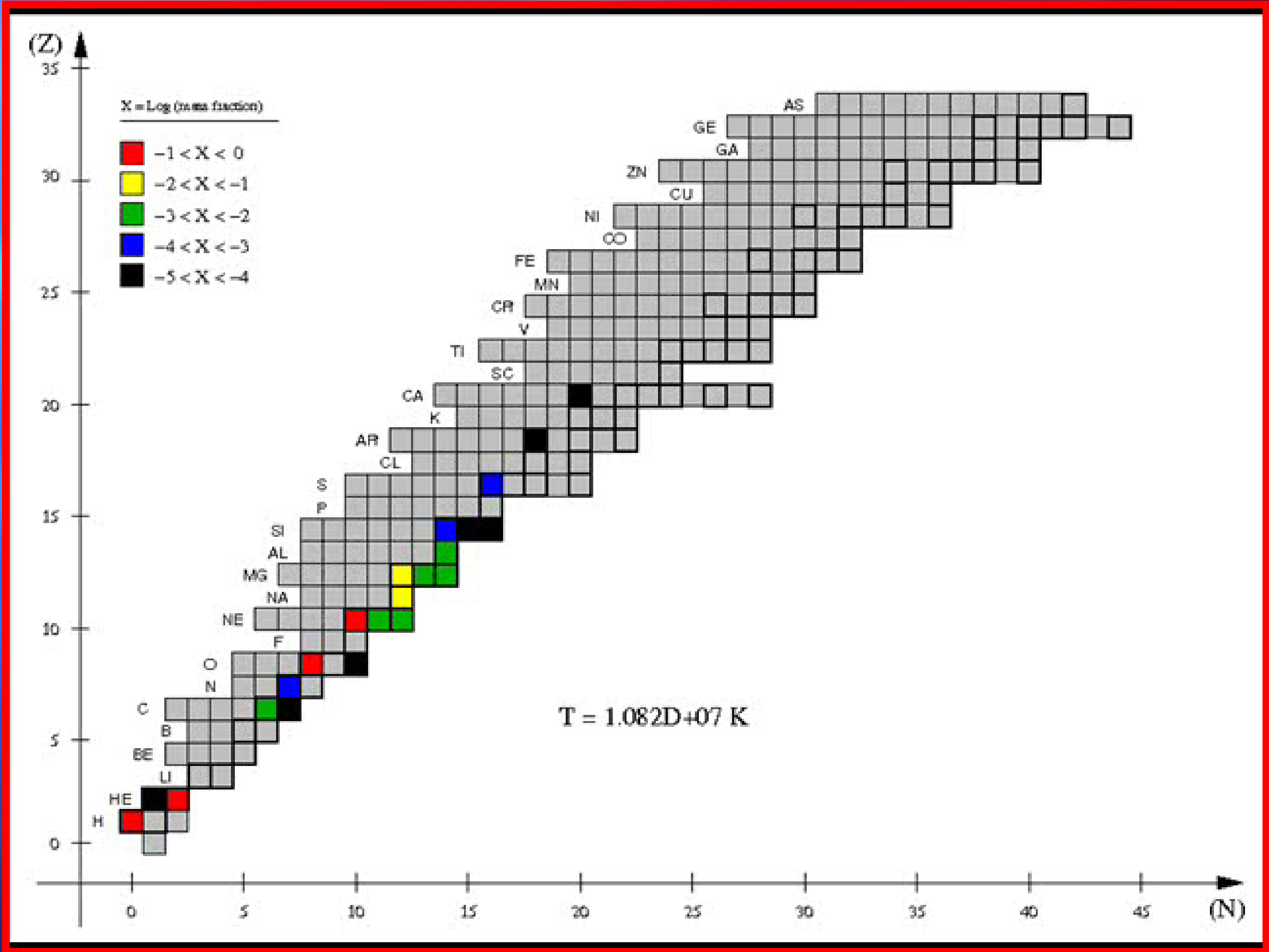
Novae as unique stellar explosions for which the nuclear physics input will be soon (?) primarily based on experimental information (JJ, Hernanz & Iliadis, Nucl. Phys. A 2006)



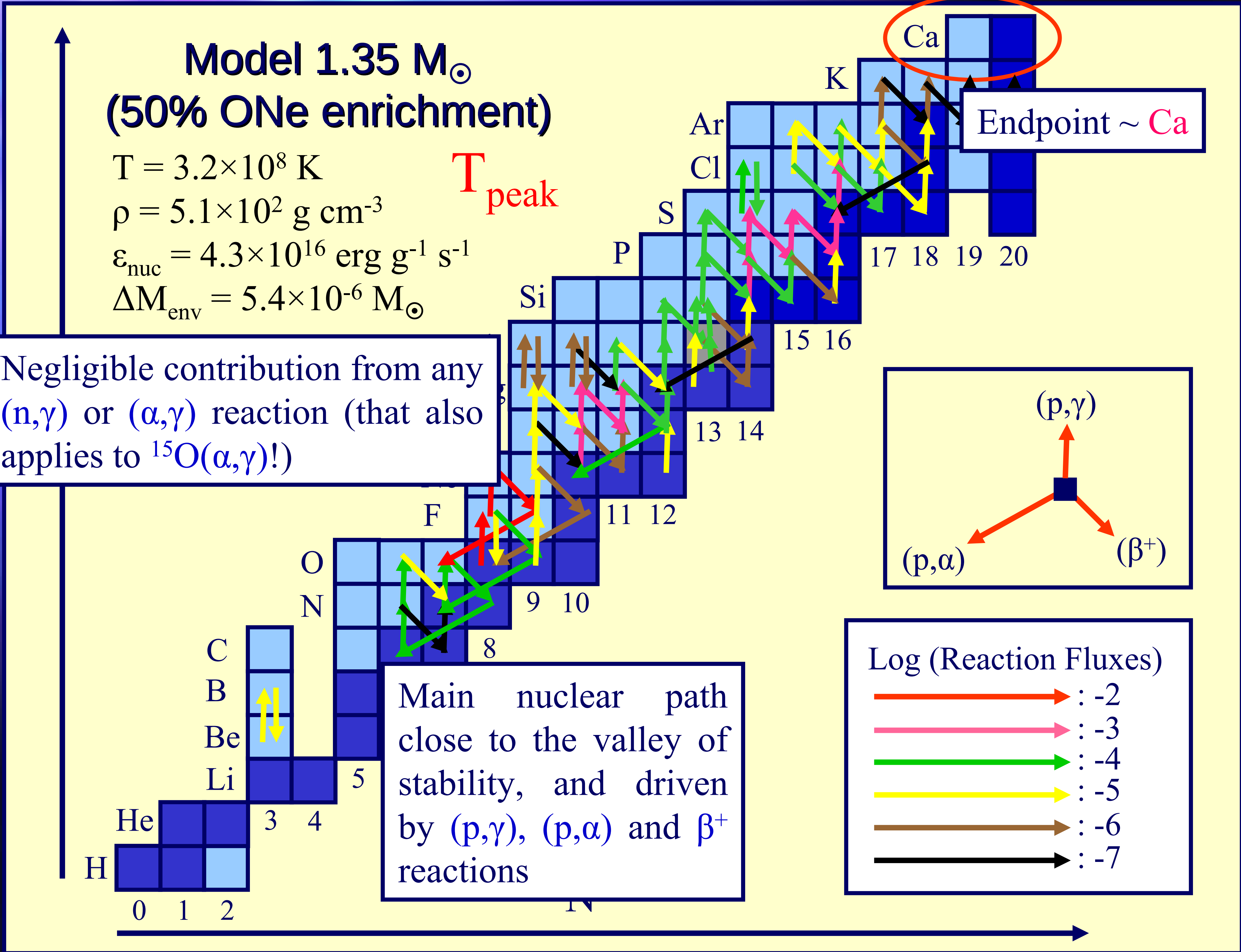


Nova Cygni 1992

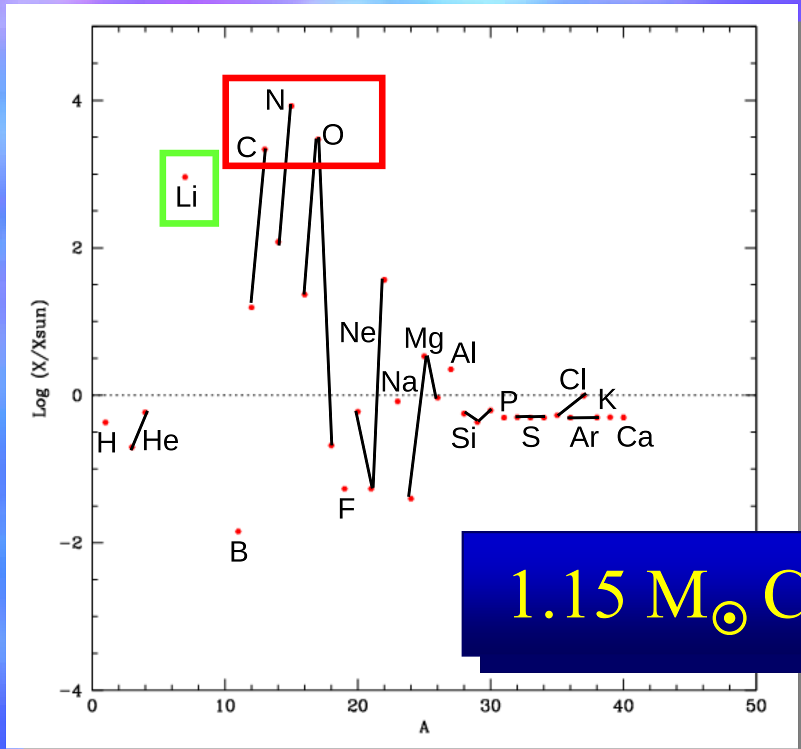
1.35 $M_\odot$ ONe

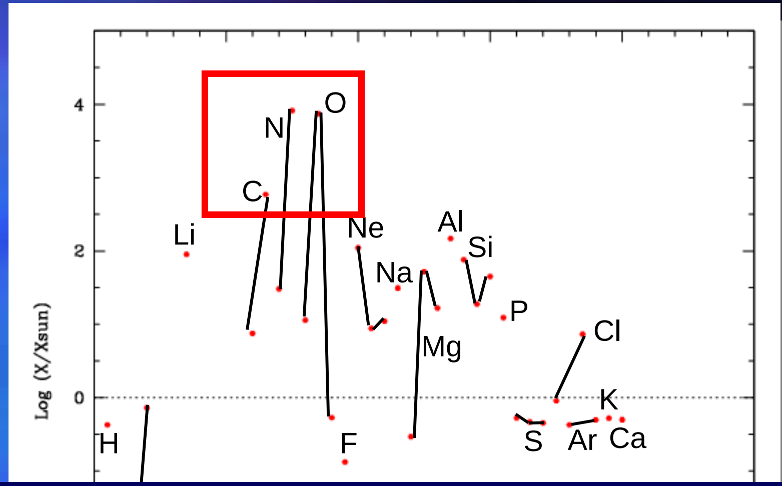


JJ, Hernanz, Coc & Iliadis (2010), in preparation



Model 1.35 M☉
(50% ONe enrichment)
T = 3.2×10^8 K
ρ = 5.1×10^2 g cm^-3
ε_nuc = 4.3×10^16 erg g^-1 s^-1
ΔM_env = 5.4×10^-6 M☉
T_peak
Negligible contribution from any (n,γ) or (α,γ) reaction (that also applies to 15O(α,γ)!)
Main nuclear path close to the valley of stability, and driven by (p,γ), (p,α) and β+ reactions
Endpoint ~ Ca
Ca
K
Ar
Cl
S
P
Si
F
O
N
C
B
Be
Li
He
H
0
1
2
3
4
5
8
9
10
11
12
13
14
15
16
17
18
19
20
N
(p,γ)
(p,α)
(β+)
Log (Reaction Fluxes)
: -2
: -3
: -4
: -5
: -6
: -7

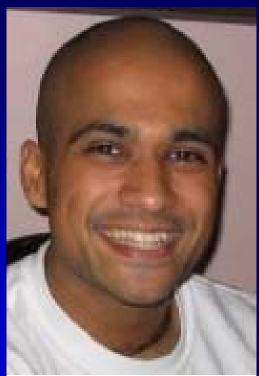




1.15 $M_\odot$ CO

...le

JJ, Hernanz, Coc & Iliadis (2010), in preparation

See  's talk, later today…

$^{33}S(p,\gamma)$

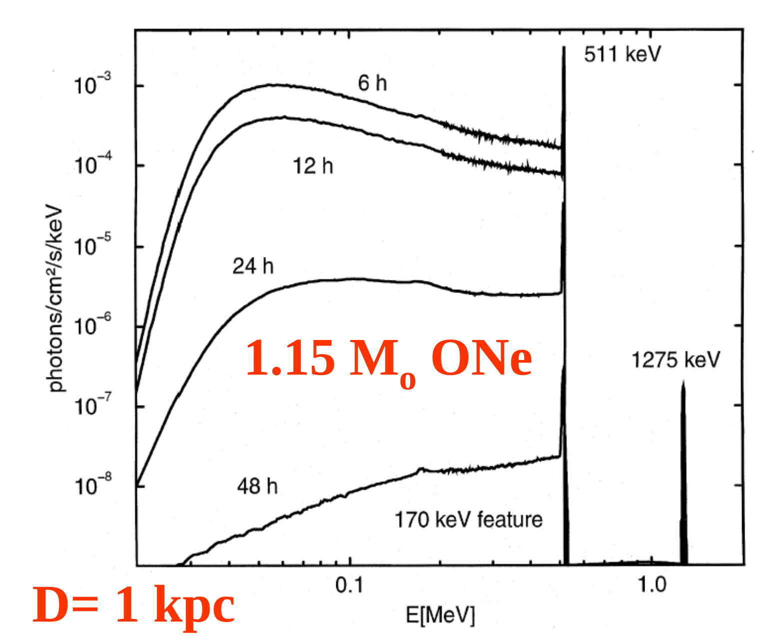
...talks (this morning) by:

* A. Sallaska: $^{22}Na(p,\gamma)$
* M. Matos: $^{31}S(p,\gamma)$

...and posters by:

* D. Bardayan: $^{7}Be(p,\gamma)$, $^{17}F(p,\gamma)$
* K. Chipps: $^{25}Al(p,\gamma)$
* C. Herlitzius: $^{33}Cl(p,\gamma)$
* A. Laird: $^{18}F(p,\alpha)$
* A. Saastamoinen: $^{22}Na(p,\gamma)$
* N. de Séréville: $^{25}Al(p,\gamma)$
* K. Setoodehnia: $^{29}P(p,\gamma)$

Radioactivities from novae



Gómez-Gomar, Hernanz, JJ & Isern (1998), MNRAS

Isotope	Lifetime	Disintegration	Nova type
^{17}F	93 sec	β^+-decay	CO & ONe
^{14}O	102 sec	β^+-decay	CO & ONe
^{15}O	176 sec	β^+-decay	CO & ONe
^{13}N	862 sec	β^+-decay	CO & ONe
^{18}F	158 min	β^+-decay	CO & ONe
^{7}Be	77 day	e^-capture	CO
^{22}Na	3.75 yr	β^+-decay	ONe
^{26}Al	1.0 Myr	β^+-decay	ONe

- $^{14, 15}O$, ^{17}F (^{13}N): Expansion and ejection stages (No γ-rays)
- ^{13}N, ^{18}F: Early γ-ray emission (511 keV + continuum); D < 2 kpc
- ^{7}Be, ^{22}Na, ^{26}Al: γ-ray lines; D < 0.2 kpc, 0.5 kpc, -

No ^{34}Cl γ-ray emission anymore...

Nuclear Uncertainties

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 142:105–137, 2002 September
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THE EFFECTS OF THERMONUCLEAR REACTION-RATE VARIATIONS ON NOVA NUCLEOSYNTHESIS: A SENSITIVITY STUDY

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Received 2002 January 19; accepted 2002 April 25

$\approx$7350 nuclear reaction network calculations

Main nuclear uncertainties: [^{18}F(p,α)^{15}O, ^{25}Al(p,γ)^{26}Si, ^{30}P(p,γ)^{31}S]

Composition of the ejecta:

a) $Z_{\odot}$ → Z ~ 0.50 (up to 0.86, for V1370 Aql 1982)? Limited T_{peak} → CNO-breakout unlikely! → Mixing at the core-envelope interface

b) Depends on the nature of the WD (cf., CO vs. ONe): M_{WD} & X_i

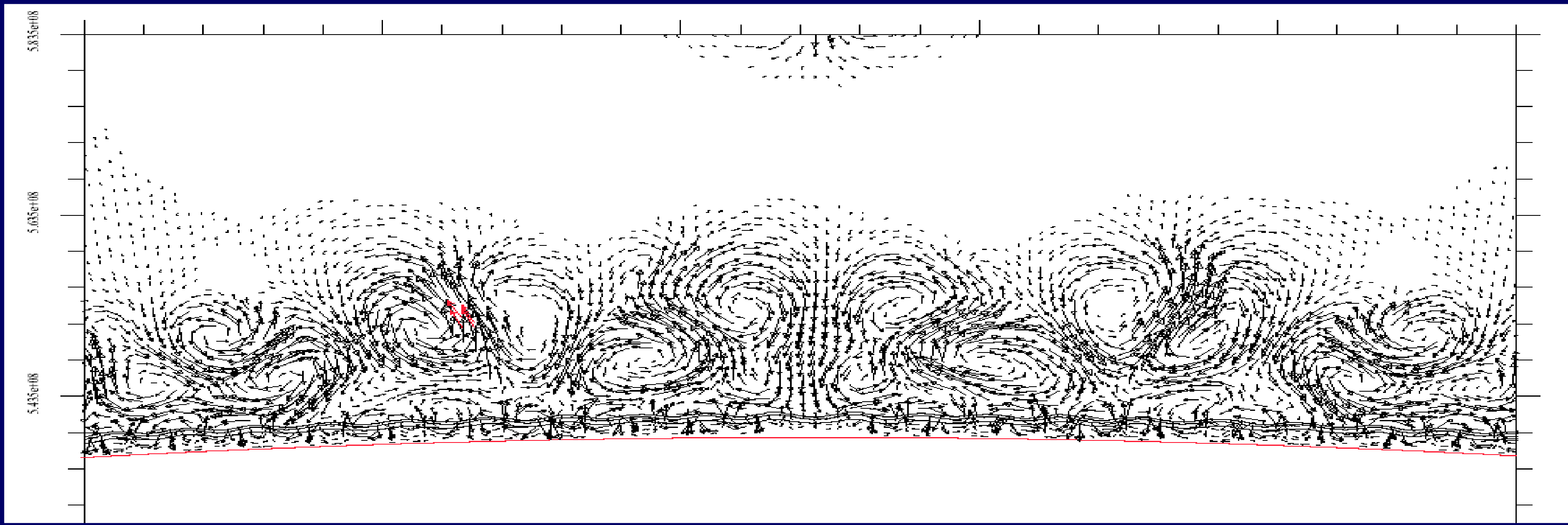
The mixing mechanism: the *Holy Grail* of nova modeling

* Diffusion Induced Convection [Prialnik & Kovetz 1984; Kovetz & Prialnik 1985; Iben, Fujimoto & MacDonald 1991, 1992; Fujimoto & Iben 1992]
* Shear mixing [MacDonald 1983; Livio & Truran 1987]
* Convective Oveshoot Induced Flame Propagation [Woosley 1986]
* Convection Induced Shear Mixing [Kutter & Sparks 1989]

* Multidimensional process [Glasner, Livne 1995; Glasner, Livne & Truran 1997, 2005, 2007; Rosner et al. 2002; Alexakis et al. 2004]

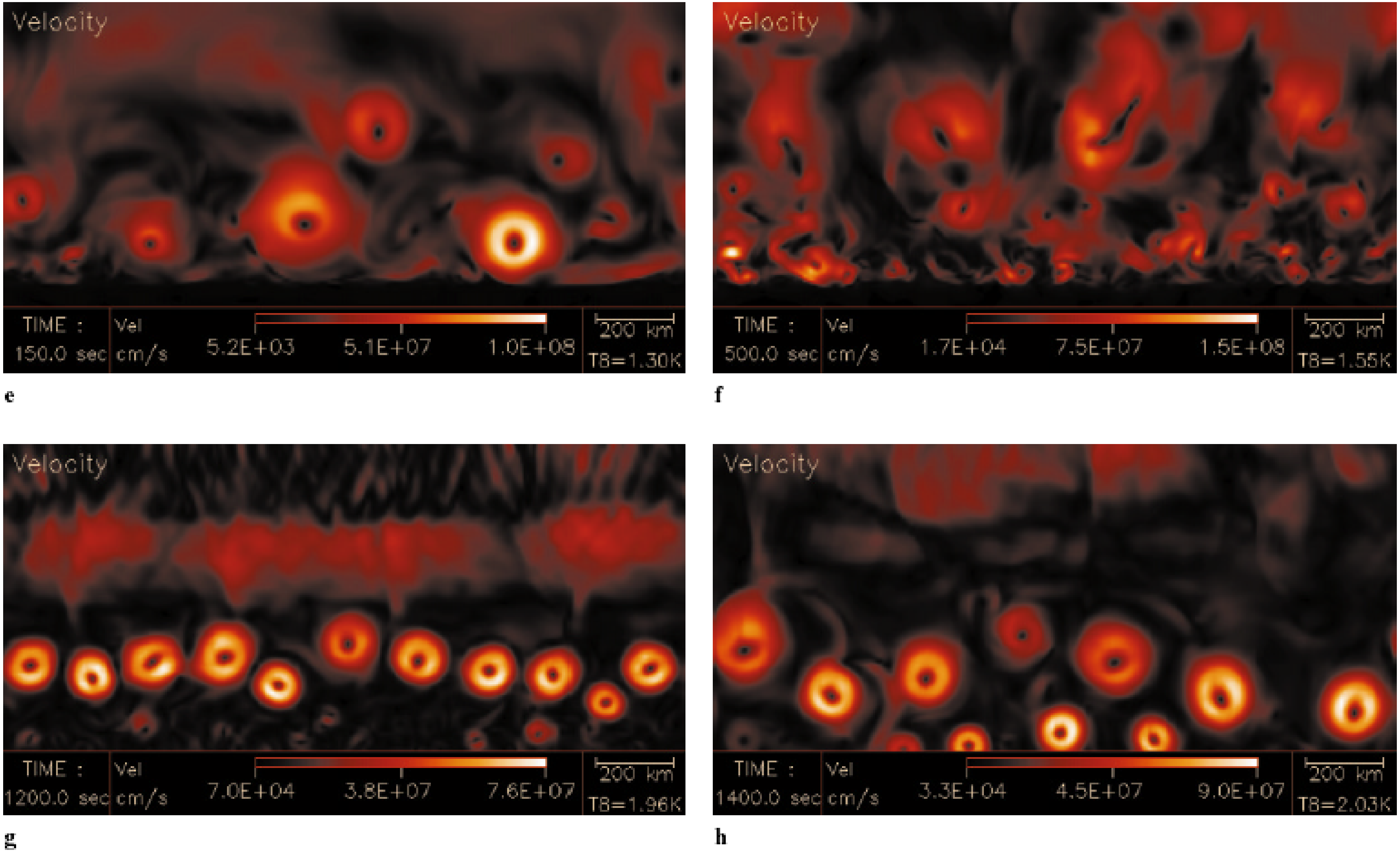
Multidimensional simulations

→ Multi-dimensional simulations agree with 1-D's , but!:



Glasner & Livne 1995; Glasner, Livne, & Truran 1997, 2005, 2007

The build-up of convective eddies at the envelope's base causes shear flow at the core/envelope interface [Kelvin-Helmholtz instability]: pure "solar-like" accreted material can be enriched at the late stages of the TNR by some sort of *convective overshoot* (Woosley 1986), leading to a powerful nova event!



Kercek et al. (1998), 2-D

Very limited dredge-up and mixing episodes → fainter events!

A&A 513, L5 (2010)

Astronomy & Astrophysics

LETTER TO THE EDITOR

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

J. Casanova[1], J. José[1], E. García-Berro[2], A. Calder[3], and S. N. Shore[4]

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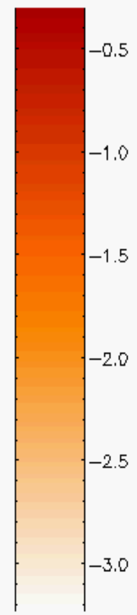
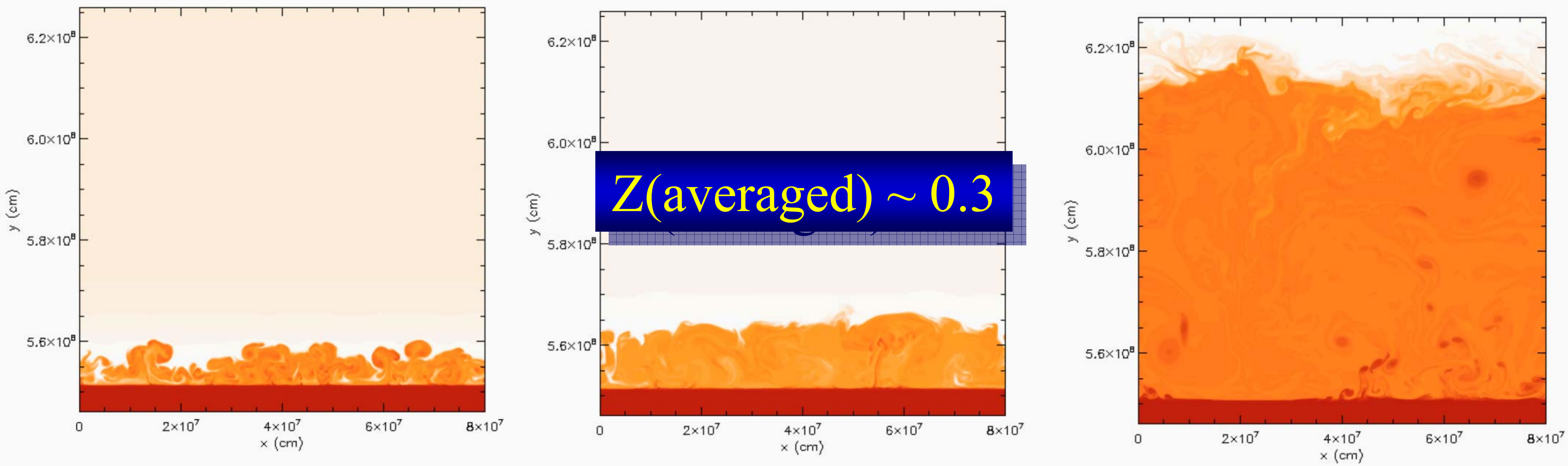


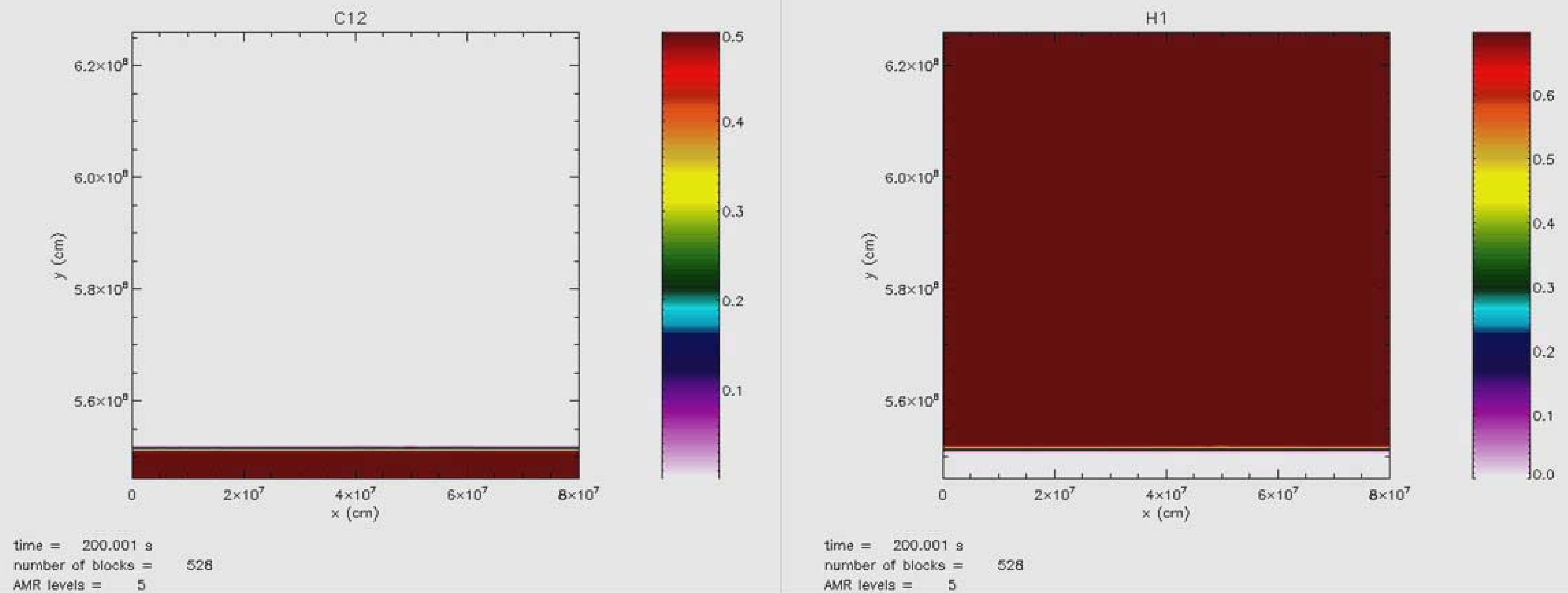


Z(averaged) ~ 0.3

MareNostrum (Barcelona Supercomputing Center), 94.21 Tflops, 10,240 processors

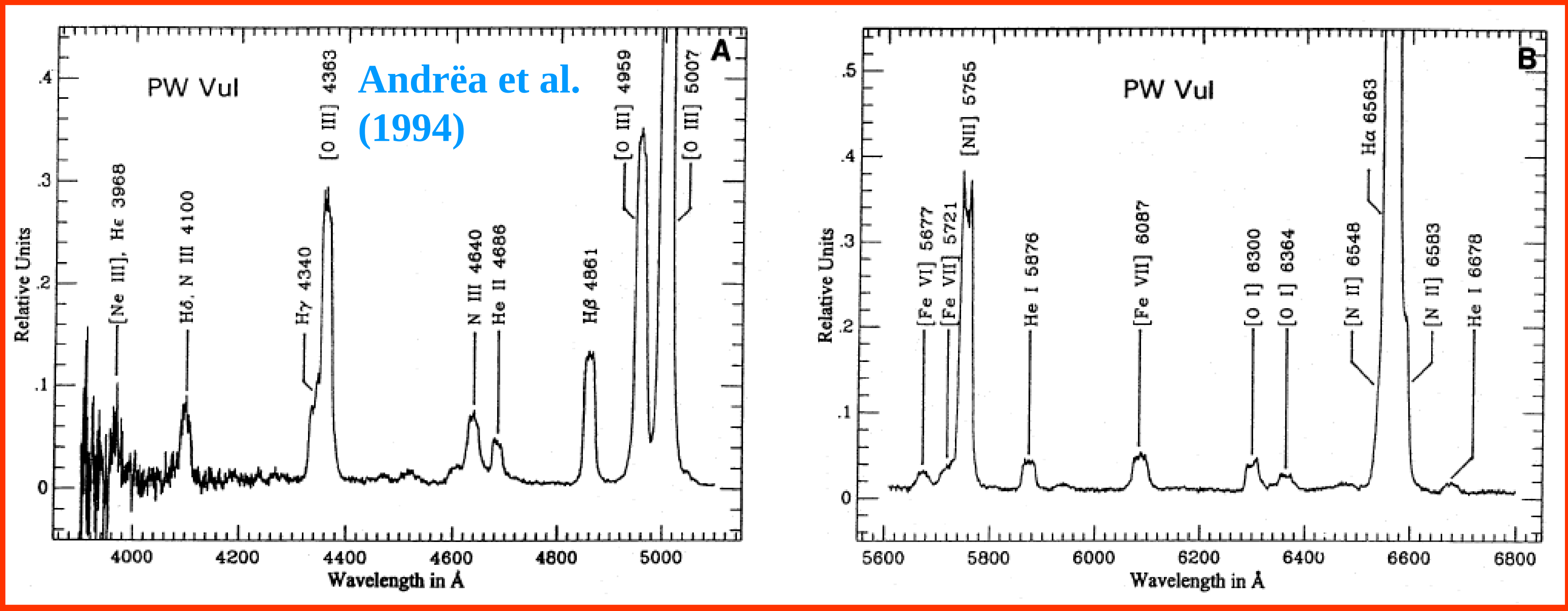
See  ’s Poster #262...

2-D Hydro Simulations with the FLASH Code



Casanova, JJ, García-Berro, Calder & Shore, A&A (2010)

Observational constraints



PW Vul 1984

	H	He	C	N	O	Ne	Na-Fe	**Z**
Observation	0.47	0.23	0.073	0.14	0.083	0.0040	0.0048	0.30
Theory	0.47	0.25	0.073	0.094	0.10	0.0036	0.0017	0.28

(JJ & Hernanz 1998)

Presolar grains and dust

Evidence for dust formation (IR) accompanying nova outbursts

Gehrz et al. (1998)

Nova	Year	V_o (km s^{-1})	Types of Dust Formed[b]
FH Ser	1970	560	C
V1229 Aql	1970	575	C
V1301 Aql	1975	...	C
V1500 Cyg[a]	1975	1180	...
NQ Vul	1976	750	C
V4021 Sgr	1977	...	C
LW Ser	1978	1250	C
V1668 Cyg	1978	1300	C
V1370 Aql[d]	1982	2800	C; SiC; SiO_2
GQ Mus	1983	600	No dust
PW Vul	1984 #1	285	C
QU Vul[a]	1984 #2	1–5000	SiO_2
OS And[a,e]	1986	900	C?
V1819 Cyg[a]	1986	1000	No dust
V842 Cen	1986	1200	C; SiC; HC
V827 Her[a]	1987	1000	C
V4135 Sgr	1987	500	...
QV Vul	1987	700	C; SiO_2; HC; SiC
LMC 1988 #1	1988 #1	800	C?
LMC 1988 #2	1988 #2	1500	...
V2214 Oph	1988	500	...
V838 Her	1991	3500	C
V1974 Cyg[a]	1992	2250	No dust
V705 Cas	1993	840	C; HC; SiO_2
Aql 1995[a]	1995	1510	C

The Astrophysical Journal, 203:490–496, 1976 January 15
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GRAINS OF ANOMALOUS ISOTOPIC COMPOSITION FROM NOVAE

Donald D. Clayton and Fred Hoyle*
Department of Space Physics and Astronomy, Rice University
Received 1975 April 28; revised 1975 June 26

Isotopic peculiarities: ^{13}C, ^{14}C, ^{18}O, ^{22}Na, ^{26}Al, ^{30}Si

The Astrophysical Journal, 551:1065–1072, 2001 April 20
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PRESOLAR GRAINS FROM NOVAE

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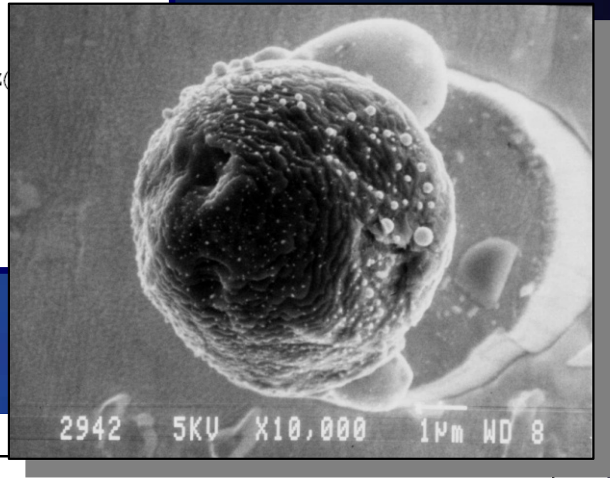
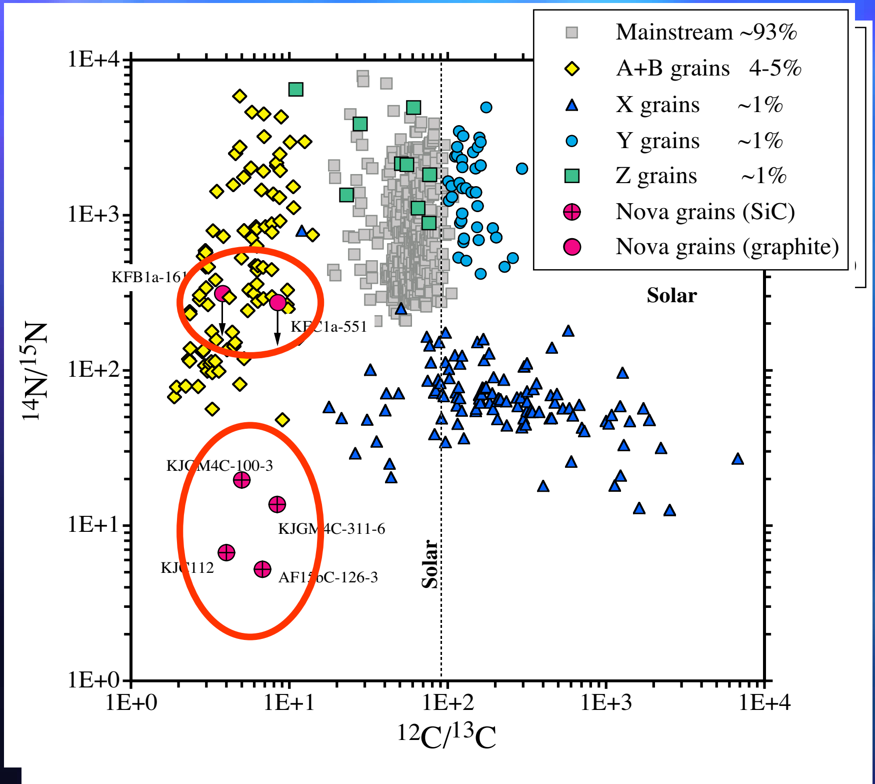
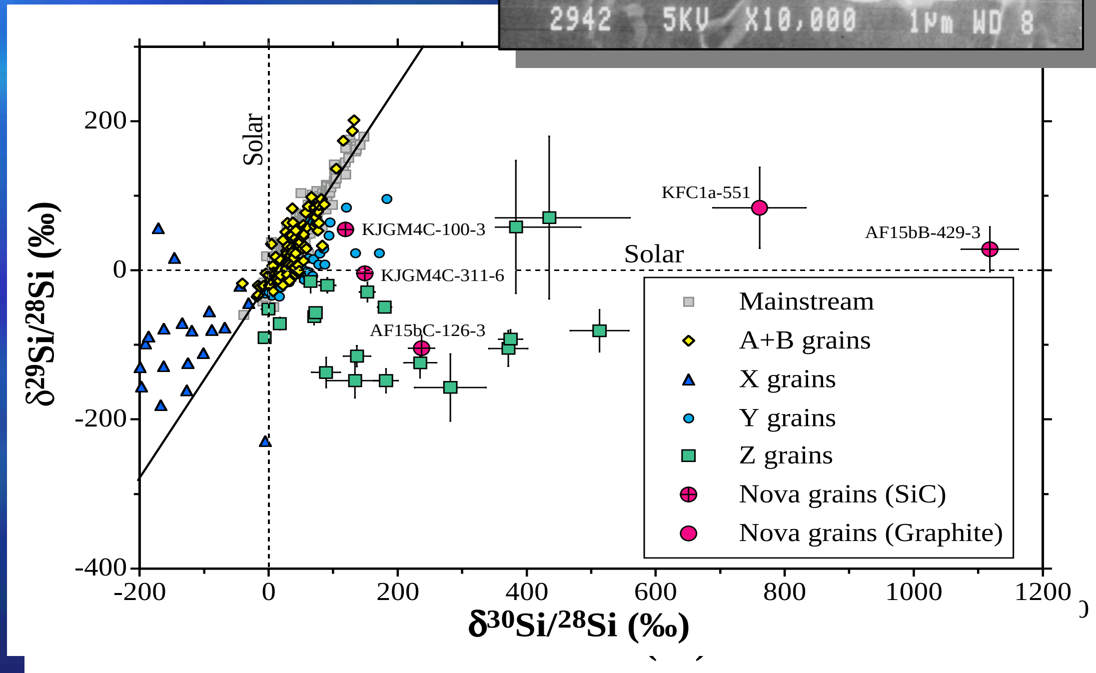






Presolar Nova Grains: *The Magnificent Seven*

Table I. Presolar grains with an inferred nova origin.

Grain	composition	$^{12}C/^{13}C$	$^{14}N/^{15}N$	$\delta^{29}Si/^{28}Si$	$\delta^{30}Si/^{28}Si$	$^{26}Al/^{27}Al$	$^{20}Ne/^{22}Ne$
AF15bB-429-3	SiC	9.4±0.2	...	28±30	1118±44	...	...
AF15bC-126-3	SiC	6.8±0.2	5.22±0.11	-105±17	237±20	...	...
KJGM4C-100							
KJGM4C-311							
KJC112							
KFC1a-551							
KFB1a-161							
Solar		89	272	0	0	0	14
Nova models		0.2–3	0.1–1900	-950 to 1800	-1000 to 47000	0.01–0.9	0.1–2900

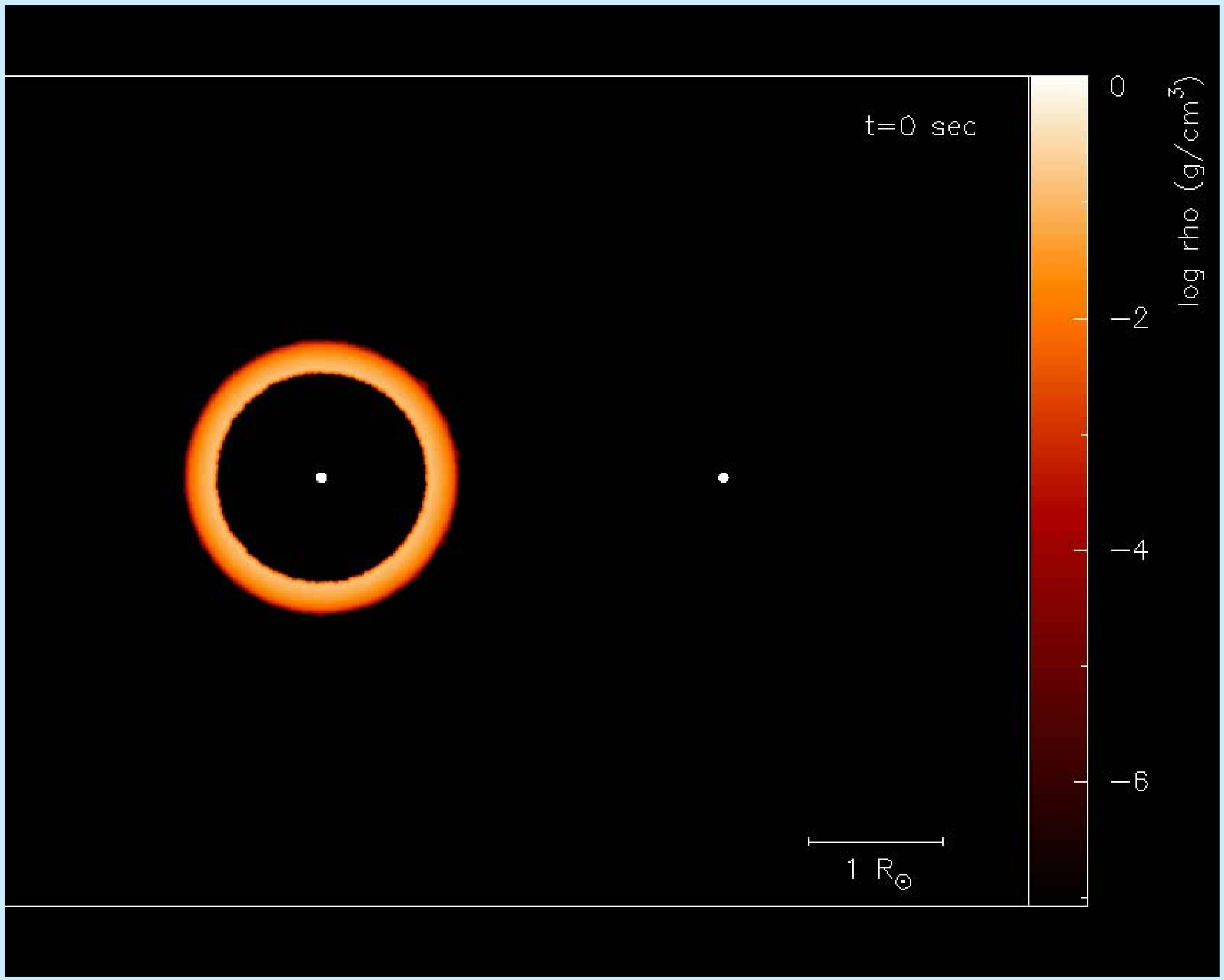
The solar N ratio in the table is that from terrestrial air. Grains AF... are from the Acfer 094 meteorite, whereas grains KJ... and KF... are from the Murchison meteorite (see Amari et al. 2001c and Amari 2002, for details). Errors are 1σ.

See F. Gyngard's Poster #239, for possible nova O-grains...

Five SiC and two graphite grains, whose isotopic ratios point toward a nova origin: low $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios, high $^{30}Si/^{28}Si$, and close-to-solar $^{29}Si/^{28}Si$. $^{26}Al/^{27}Al$ and $^{22}Ne/^{20}Ne$ ratios have been determined for some of these grains, with values compatible with nova model predictions → Dilution with $Z_\odot$ material!

A very preliminary 3-D SPH simulation of the interaction between the nova ejecta and the stellar companion

See 's Poster #245...



Homework!

-Simulations of the interaction between the nova ejecta and the accretion disk

-Contamination(?) of the MS star and effect on next CN

Classical Novae: Theory and Observations

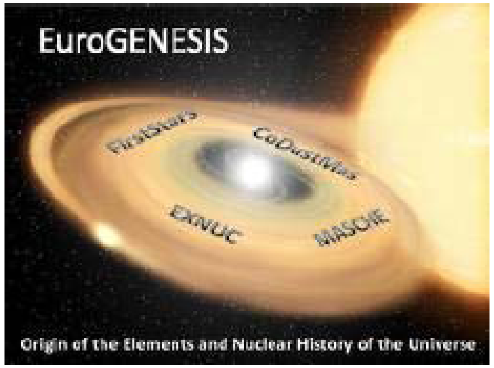
Nuclei in the Cosmos XI, Heidelberg (Germany), July 19-23, 2010

* Multi-D Simulations: J. Casanova, A. Calder, S. Shore, S.W. Campbell
* 1-D Simulations & Gamma-ray emission: M. Hernanz
* Nuclear Physics Inputs: C. Iliadis, A. Coc, A. Parikh, ... and more!
* Presolar Grains: S. Amari, E. Zinner, L. Nittler, F. Gyngard

EUROPEAN SCIENCE FOUNDATION

Origin of the Elements and Nuclear History of the Universe (EuroGENESIS)

EuroGENESIS in brief



EuroGENESIS (2010-2013) is a collaborative research programme in **nuclear astrophysics**. It involves researchers from 29 institutions from 16 countries (theoretical astrophysicists, observational astronomers, experimental and theoretical nuclear physicists, and cosmochemists).

Web page

http://www.esf.org/activities/eurocores/running-programmes/eurogenesis.html

First general workshop of **EuroGENESIS**, OPEN TO ALL INTERESTED RESEARCHERS IN THIS FIELD, will take place in **Dubrovnik, around Nov. 24, 2010** (tbc). Please, contact any of the members of the Scientific Committee for additional information

Committees of EuroGENESIS

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