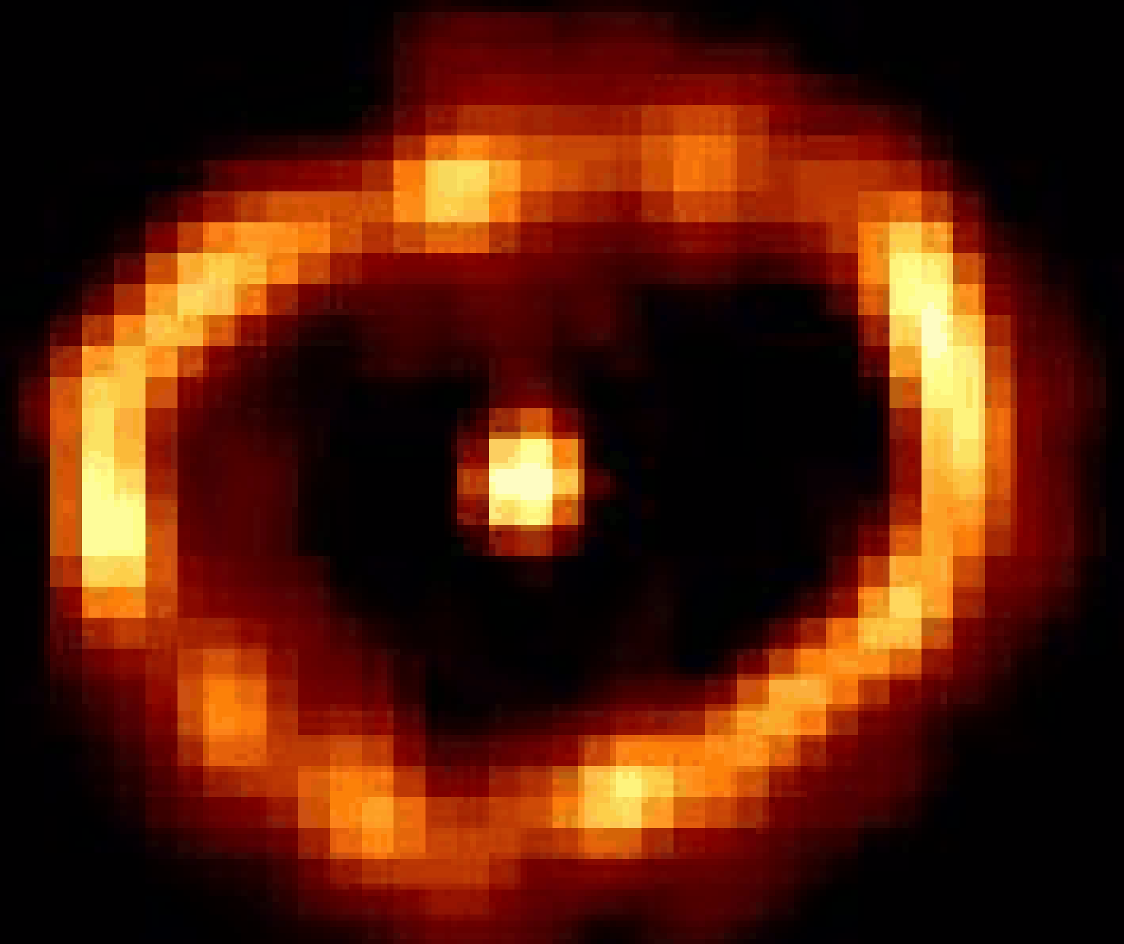
Classical Novae in the XXIst Century



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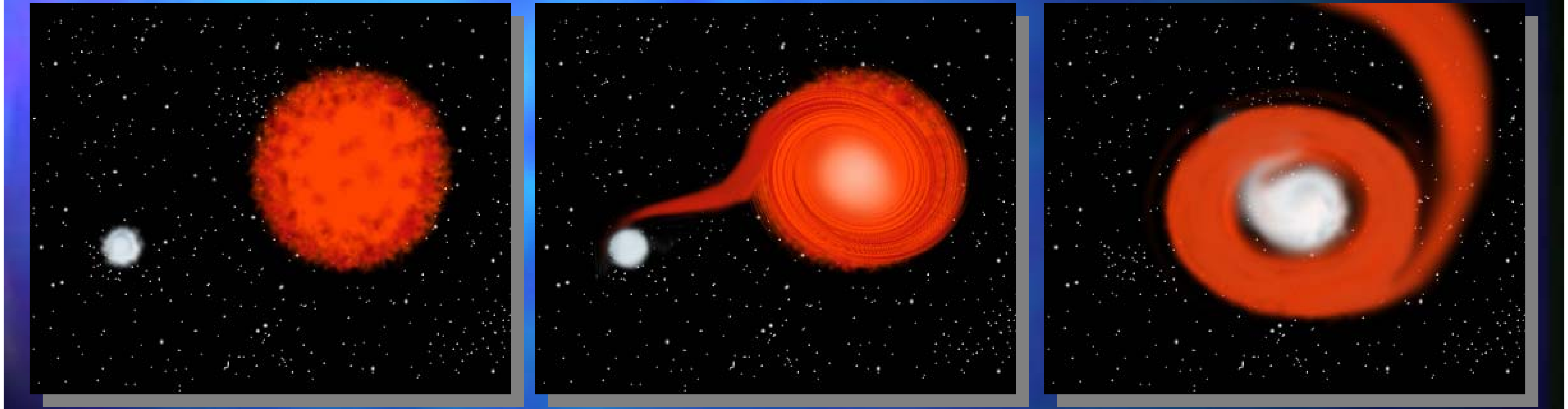
& Institut d’Estudis Espacials de Catalunya, Barcelona

Related talks:

* E. van den Heuvel: accretion rates
* A. Glasner, M. Hernanz, S. Starrfield, D. Townsley, A. Shafter...

Thermonuclear runaways in the white dwarf/neutron star component of close binary systems.

The low-mass companion transfers matter through the inner L_1 Lagrangian point by Roche lobe overflow, building up an accretion disk. A fraction of this H-rich matter ends up on top of the WD/NS, where it's compressed until conditions to drive a TNR are reached.



Type Ia (or thermonuclear) Supernovae [SN Ia]
Classical Nova Outbursts [CN]
} WD

X-Ray Bursts [XRBs]: NS

Classical Nova Outbursts

Discovered more than 2.000 years ago... Observed in all wavelengths (but never detected so far in γ-rays)

Pioneering TNR models: Starrfield et al. 1972; Prialnik, Shara, & Shaviv 1978

CNe:

Moderate rise times (<1 – 2 days)

$L_{Peak} \sim 10^4 \ L_o$

Recurrence time: $\sim 10^4 – 10^5$ yr

Frequency: $30 \pm 10 \ yr^{-1}$

$E \sim 10^{45}$ erg

Mass ejected: $10^{-4} – 10^{-5} \ M_o$

($10^2 – 10^3$ km s^{-1})

Nova Nucleosynthesis

~ 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 is/will be soon primarily based on experimental information"
(José, Hernanz & Iliadis 2006)

Type I X-Ray Bursts

First discovered in 1975 (Grindlay , Heise, et al. 1976) with the ANS (also Belian, Conner & Evans 1976: Vela satellites)

Observations with OSO-8 (Swank et al. 1978) → Identification of the central emitting source (4U 0614 +09) as a NS

First models: Woosley & Taam 1976; Maraschi & Cavalieri 1977; Joss 1977

XRBs [80 XRBs known]:

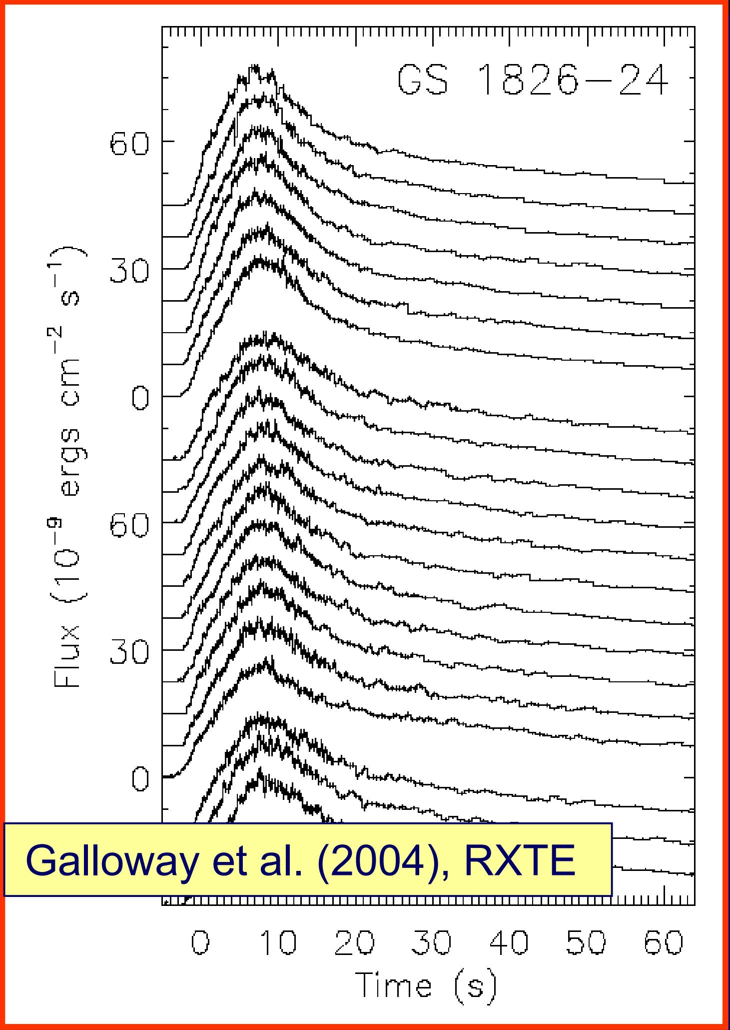
Very fast rise times (< 2 – 10 sec)

E_x: ~ 10^{39} ergs [in about 10 – 20 sec]

Recurrence time: ~ hours – days

Mass ejected? →

Weinberg, Bildsten & Schatz 2006



Galloway et al. (2004), RXTE

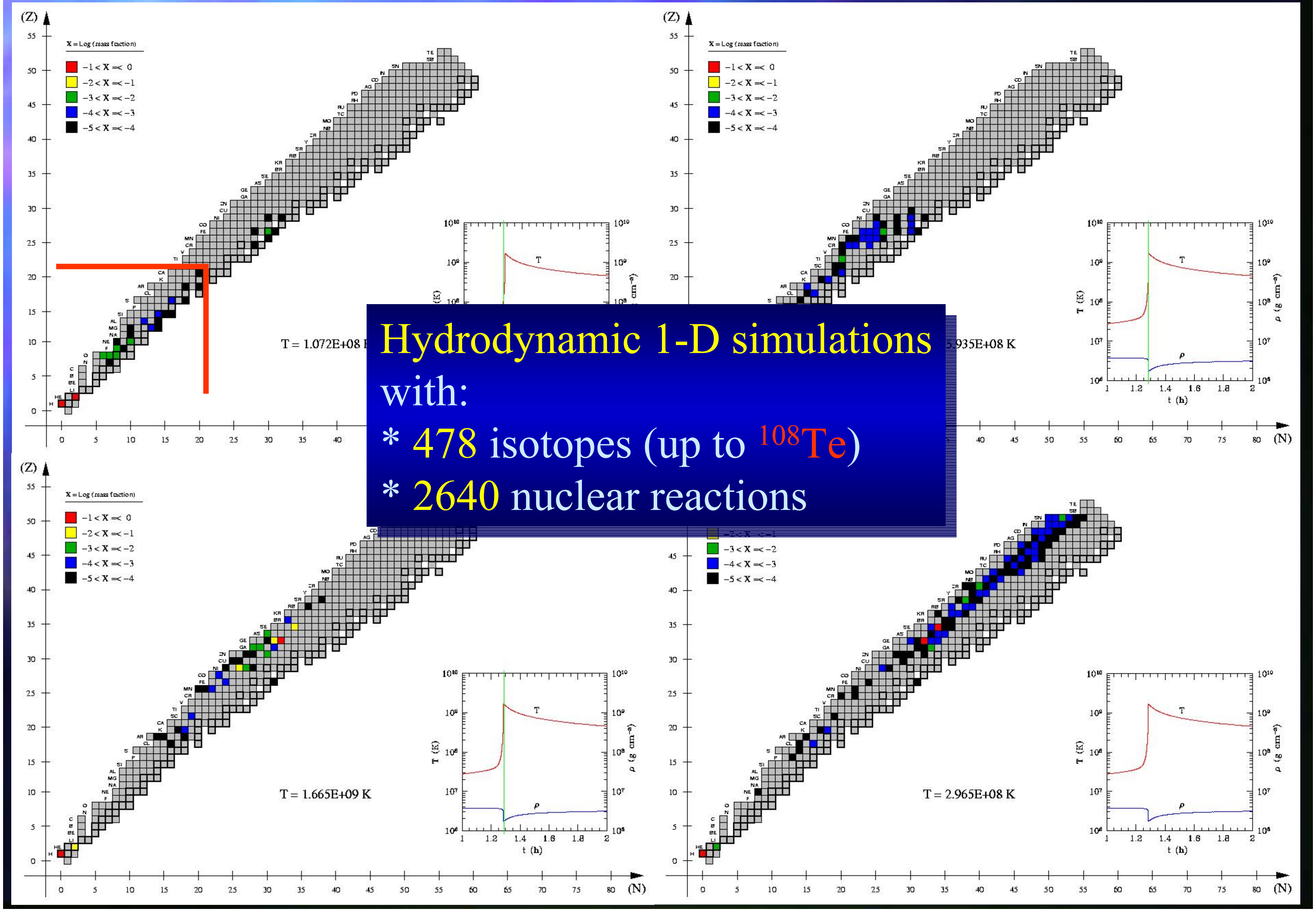
Nucleosynthesis in X-Ray Bursts

~ 300 – 500 relevant isotopes (A>100) & several thousand nuclear reactions (T_{peak} > 1GK)

↓

Nuclear physics input is primarily based on theoretical models

José & Moreno (2006)



Hydrodynamic 1-D simulations with:

* 478 isotopes (up to ^{108}Te)

* 2640 nuclear reactions

GOAL: to show how relevant nucleosynthesis theory is in our understanding of the nova phenomenon (and the role played by nuclear physics & cosmochemistry)

↕

A few examples of the "need" for dialogue between astrophysicists and nuclear physicists...

- In a review paper on explosive nucleosynthesis written by a nuclear physicist (2003):

" ...to the study of the ^{20}Na(p,γ)^{21}Mg. This latter is believed to play an important role in the energy generation and nucleosynthesis involved in nova explosions [...], via the NeNa cycle:

$$^{20}\mathrm{Ne}(p,\gamma)^{21}\mathrm{Na}(p,\gamma)^{22}\mathrm{Mg}(\beta^+)^{22}\mathrm{Na}(p,\gamma)^{23}\mathrm{Mg}\ (\beta^+)^{23}\mathrm{Na}(p,\alpha)^{20}\mathrm{Ne}$$

Clearly this reaction path can only occur if ^{20}Ne seed nuclei, produced by the beta decay of ^{20}Na, are available."

- In a preprint by a top astrophysicist in the field...(1998):

"the $^{26}\mathrm{Al}^{m}$ present in the ejected nova shells decays into $^{26}\mathrm{Al}^{g}$"

The Explosion: CO versus ONe White Dwarfs

Ignition is triggered by
$^{12}C(p,\gamma)$

↓

^{12}C

* Amount of accreted mass (ΔM_{env}) → P_{base}
  Strength of the outburst (MacDonald 1983)
  → T_{peak}, K_{ejecta} ($\Delta M_{ejected}$)

* Characteristic timescales (t_{acc}, t_{rise}…)

Two (main) types of explosions: CO vs. ONe White Dwarfs

- Core composition (outermost shells):
  - CO WDs (Salaris et al. 1996): $X(^{12}C)=X(^{16}O) \sim 0.5$
  - ONe WDs (Ritossa, García-Berro & Iben 1996):
    $X(^{16}O):X(^{20}Ne):X(^{24}Mg) = 10:6:1$ (1.5:2.5:1
    Arnett & Truran 1969)

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)
$^{14}N(p,\gamma)^{15}O$
$^{16}O(p,\gamma)^{17}F$

Sudden release of energy from the short-lived, β^+-unstable nuclei $^{14,\,15}O$, ^{17}F (^{13}N) powers the expansion and ejection stages [Starrfield et al.1972]: → $^{14,\,15}N$, ^{17}O (^{13}C)

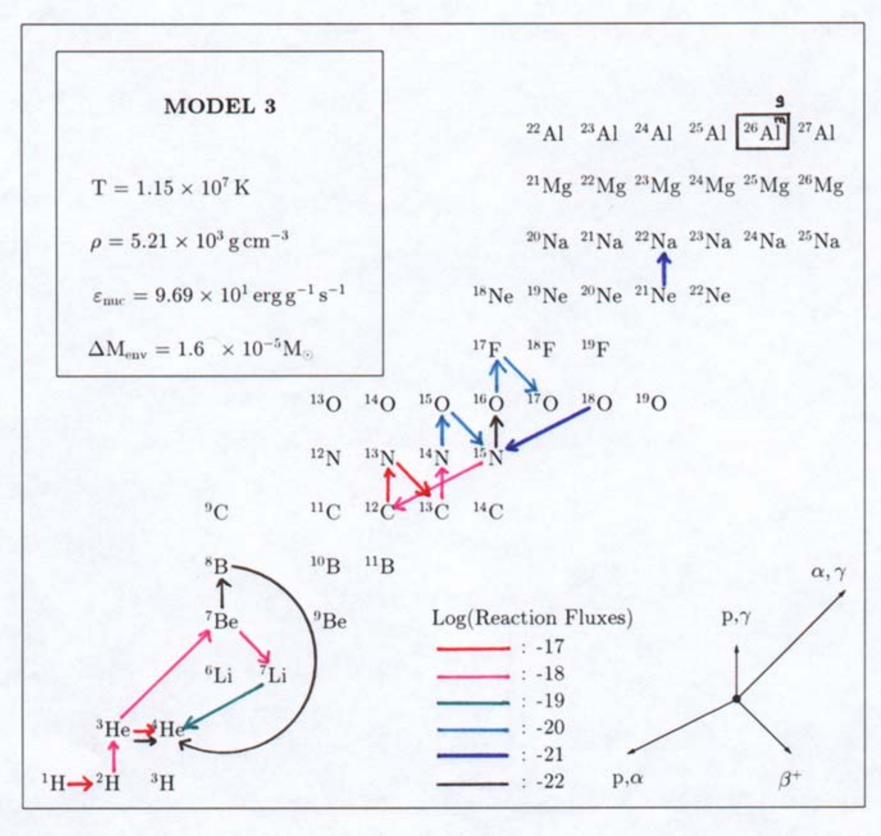
Mechanisms of mixing:

- * 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 & Truran 1997; Glasner & Livne 2002; Rosner et al. 2002; Alexakis et al. 2003]

Usual assumption, → 50% solar-like material (accreted)
50% core material (outermost shells)

But! Degree of mixing: another free parameter (to account for the wide spread in metallicity)

1.15 M_o ONe



MODEL 3

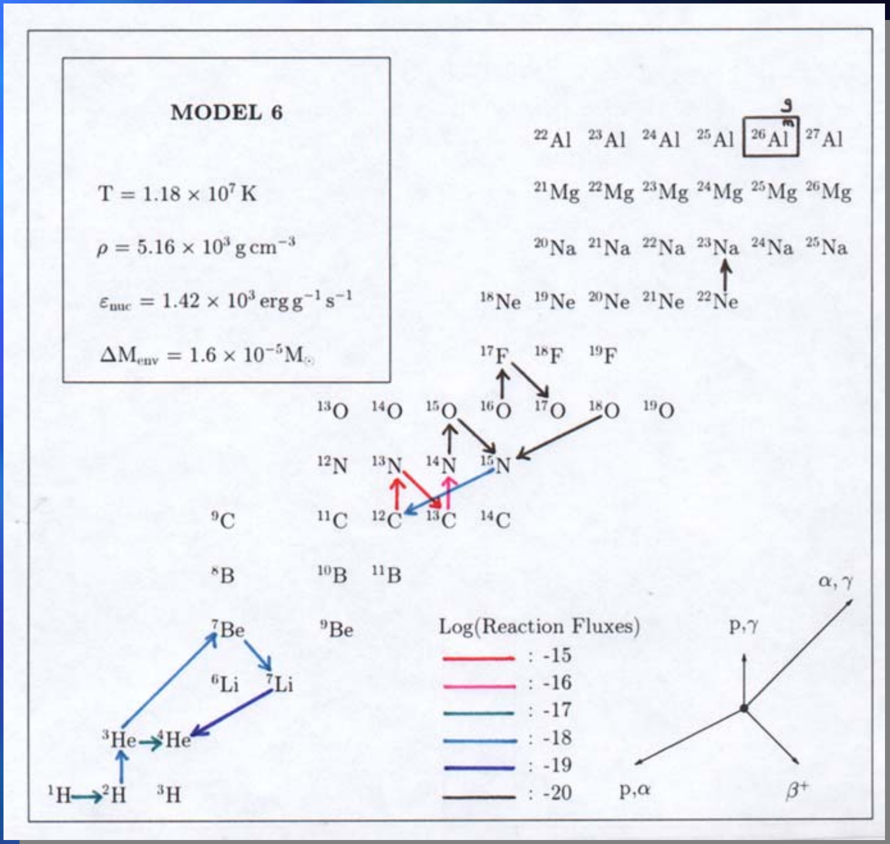
$T = 1.15 \times 10^7$ K

$\rho = 5.21 \times 10^3$ g cm^{-3}

$\varepsilon_{nuc} = 9.69 \times 10^1$ erg g^{-1} s^{-1}

$\Delta M_{env} = 1.6 \times 10^{-5} M_\odot$

1.15 M_o CO



MODEL 6

$T = 1.18 \times 10^7$ K

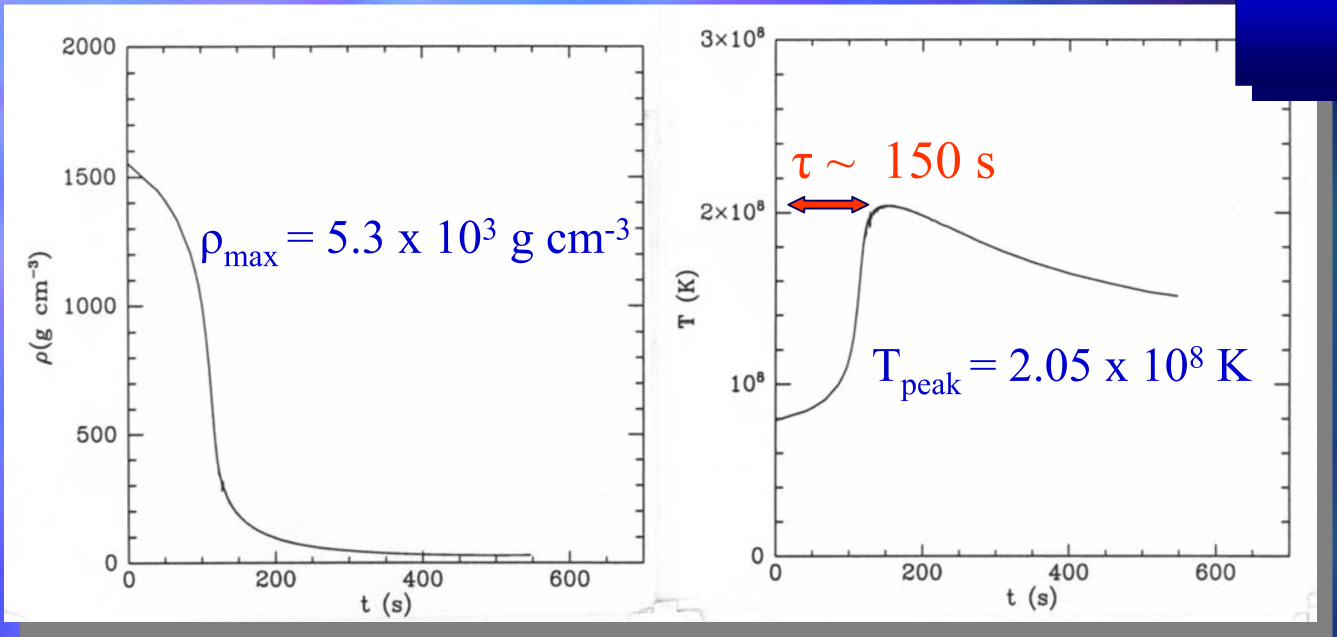
$\rho = 5.16 \times 10^3$ g cm^{-3}

$\varepsilon_{nuc} = 1.42 \times 10^3$ erg g^{-1} s^{-1}

$\Delta M_{env} = 1.6 \times 10^{-5} M_\odot$

ONe vs. CO Novae: Reaction fluxes [# reactions sec^{-1} cm^{-3}] at the beginning of the accretion phase

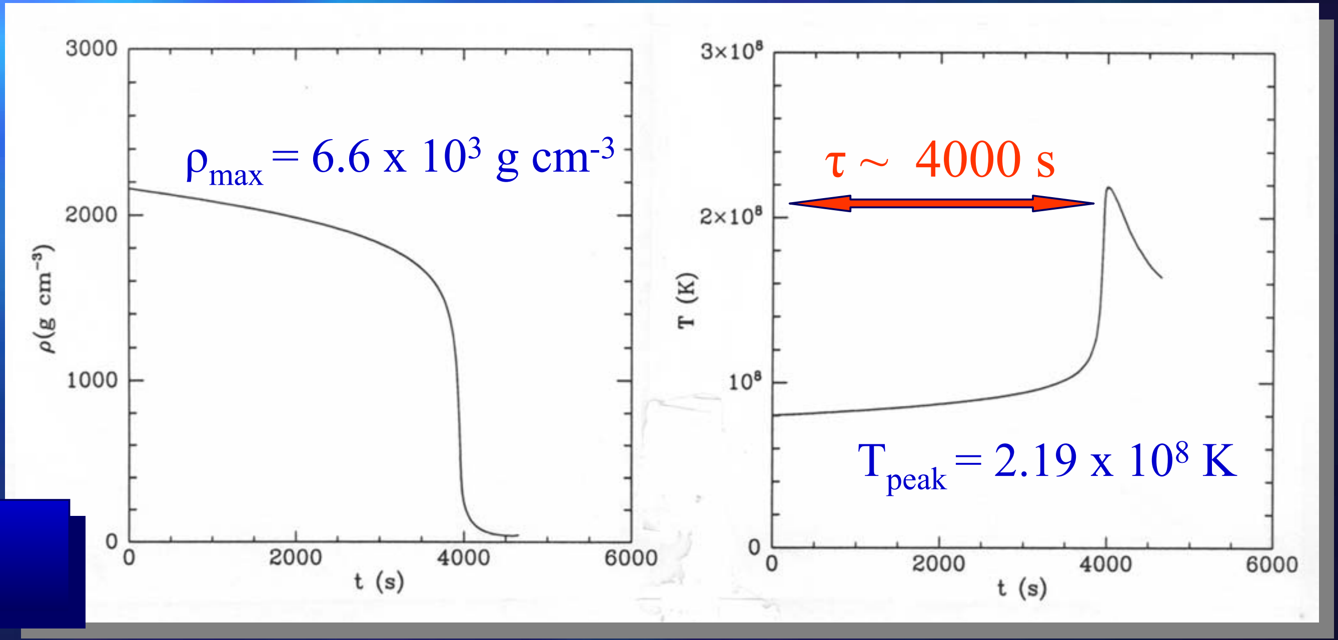
1.15 M_o CO



$\rho_{max} = 5.3 \text{ x } 10^3$ g cm^{-3}

$\tau \sim$ 150 s

$T_{peak} = 2.05 \text{ x } 10^8$ K



$\rho_{max} = 6.6 \text{ x } 10^3$ g cm^{-3}

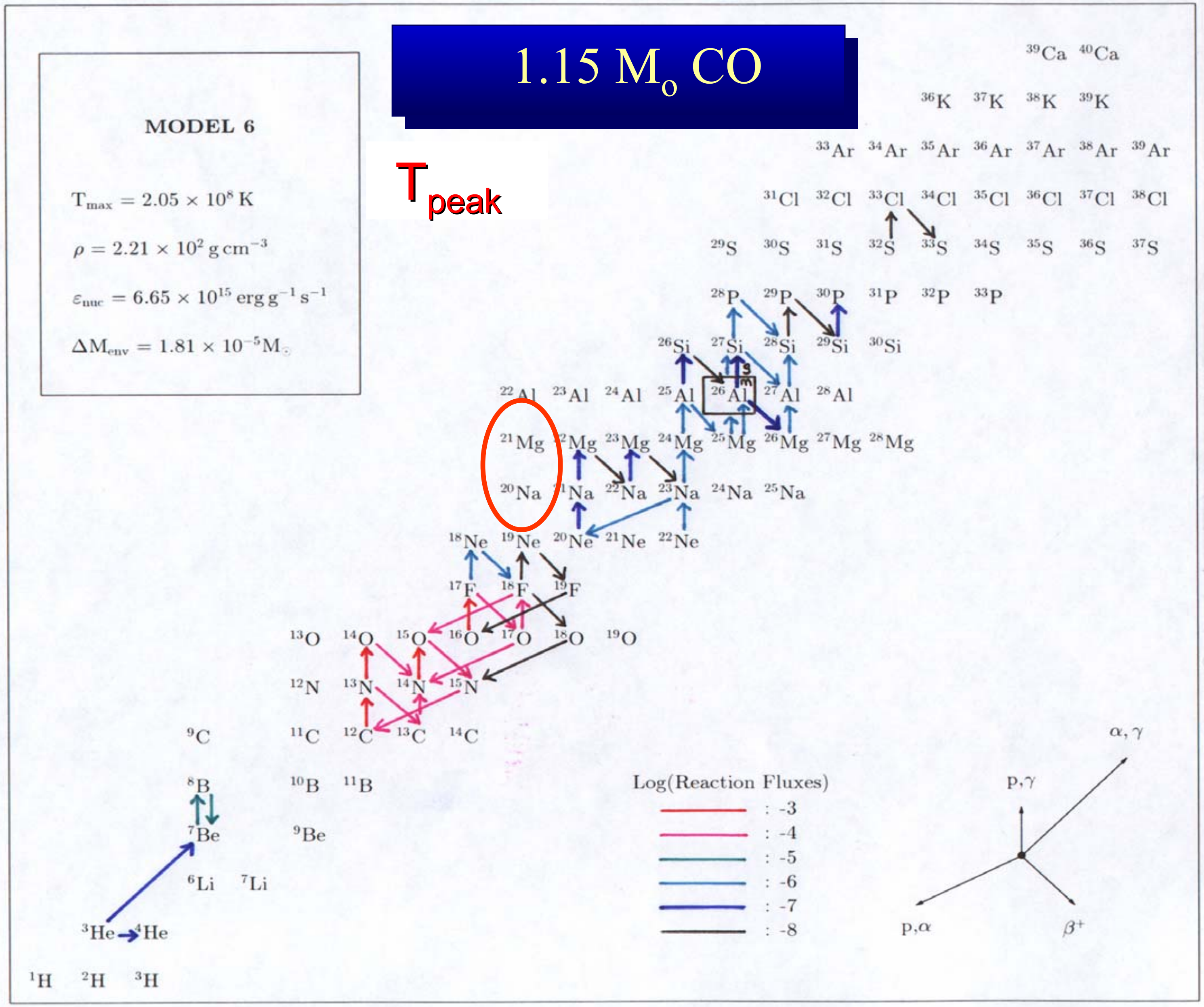
$\tau \sim$ 4000 s

$T_{peak} = 2.19 \text{ x } 10^8$ K

1.15 M_o ONe

1.15 M_o CO

T_{peak}



MODEL 6

$T_{max} = 2.05 \times 10^8$ K

$\rho = 2.21 \times 10^2$ g cm^{-3}

$\varepsilon_{nuc} = 6.65 \times 10^{15}$ erg g^{-1} s^{-1}

$\Delta M_{env} = 1.81 \times 10^{-5} M_\odot$

1.15 M_o ONe

T_{peak}

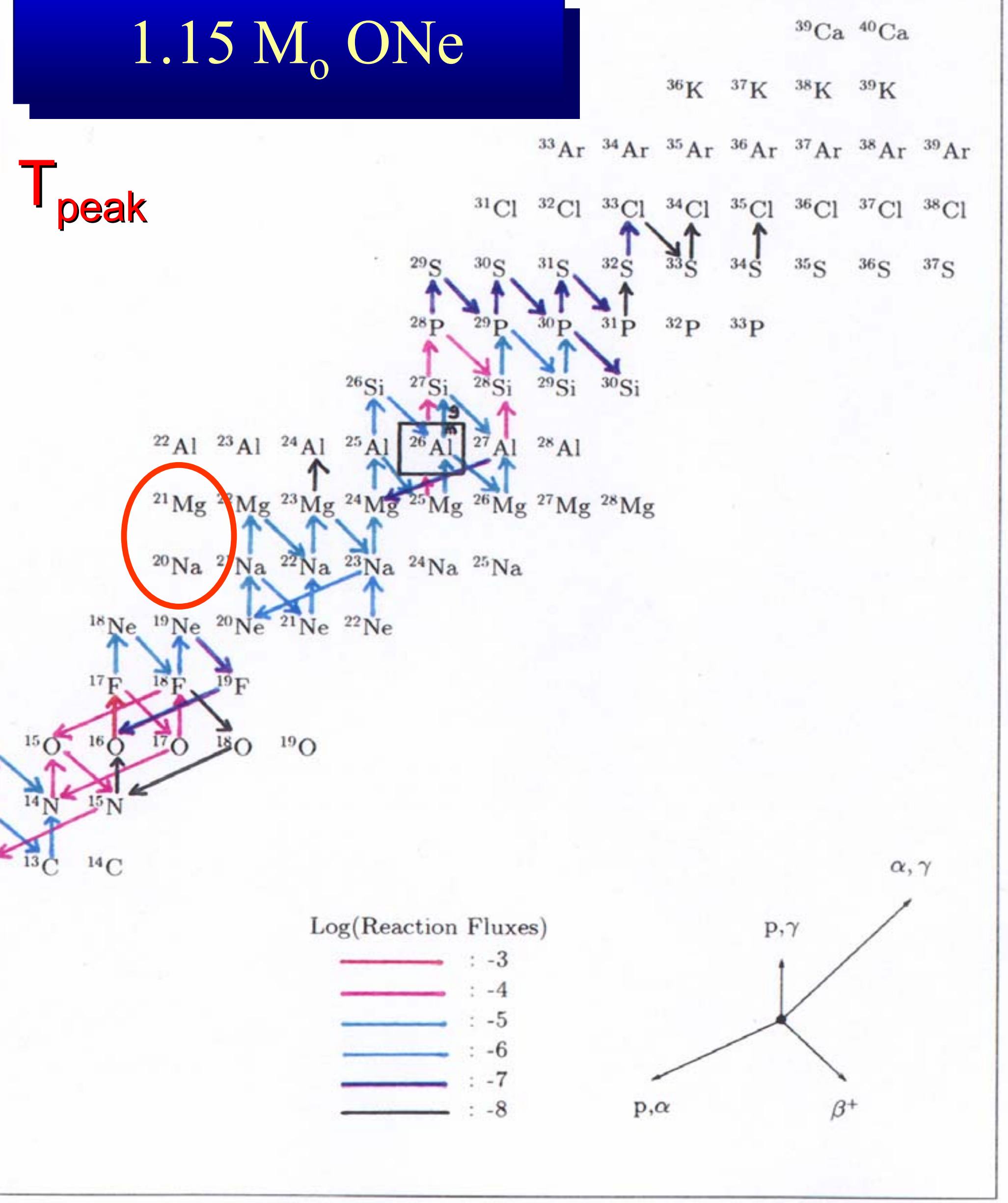
MODEL 3

$T_{max} = 2.19 \times 10^8$ K

$\rho = 2.28 \times 10^2$ g cm^{-3}

$\varepsilon_{nuc} = 2.74 \times 10^{15}$ erg g^{-1} s^{-1}

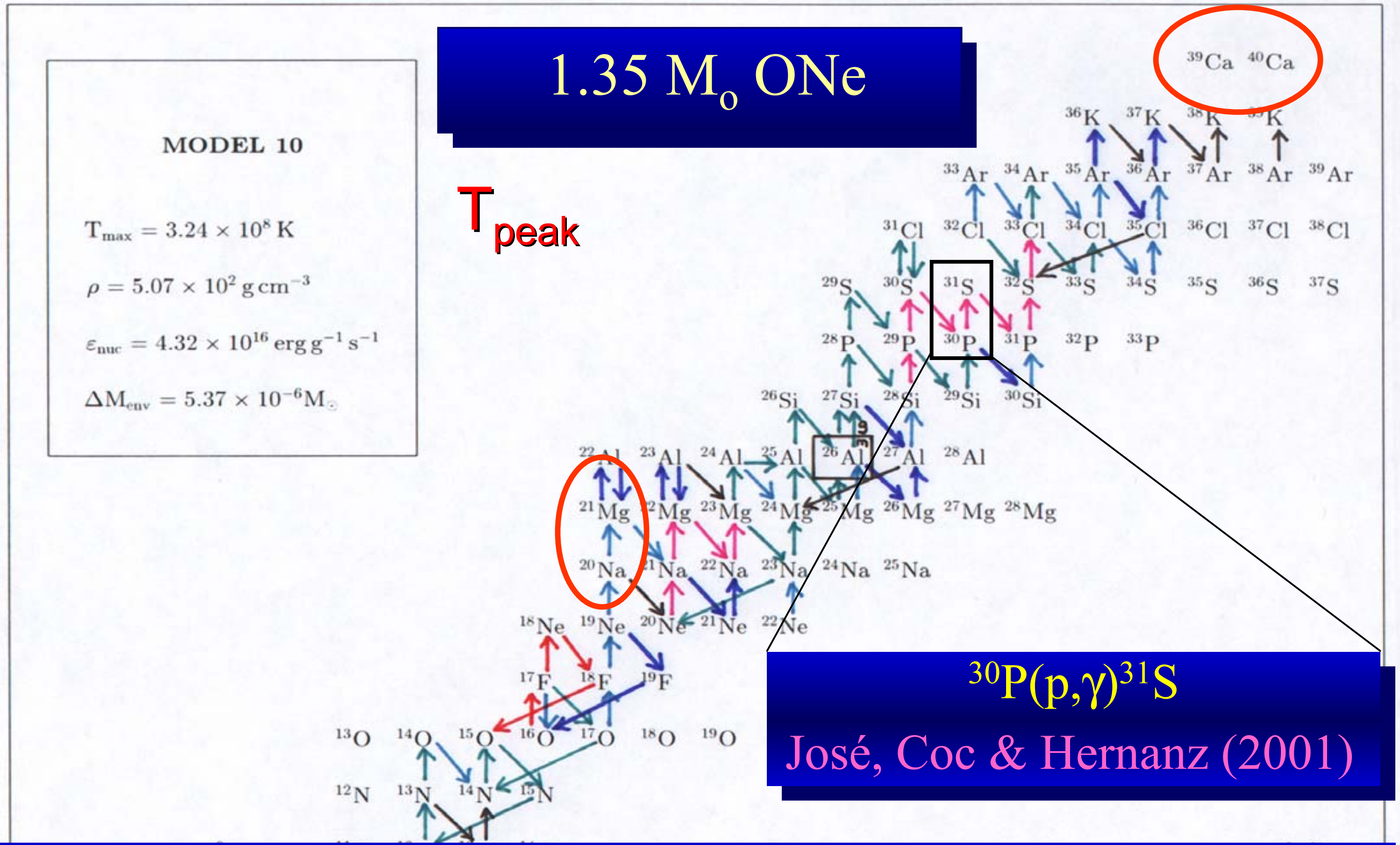
$\Delta M_{env} = 3.18 \times 10^{-5} M_\odot$



Endpoint of nova nucleosynthesis

1.35 M_o ONe

T_{peak}



MODEL 10

$T_{max} = 3.24 \times 10^8$ K

$\rho = 5.07 \times 10^2$ g cm^{-3}

$\varepsilon_{nuc} = 4.32 \times 10^{16}$ erg g^{-1} s^{-1}

$\Delta M_{env} = 5.37 \times 10^{-6} M_\odot$

$^{30}P(p,\gamma)^{31}S$

José, Coc & Hernanz (2001)

Main nuclear path close to the valley of stability, and driven by (p,γ), (p,α) and β^+ reactions

Negligible contribution from any (n,γ) or (α,γ) reaction: No $^{15}O(\alpha,\gamma)$, please!

Endpoint of (classical) nova nucleosynthesis ~ Ca

Nucleosynthesis vs. Galactic Abundances

Hydrodynamic nova models → Mass ejection (~ 2 x 10^{-5} M_o)

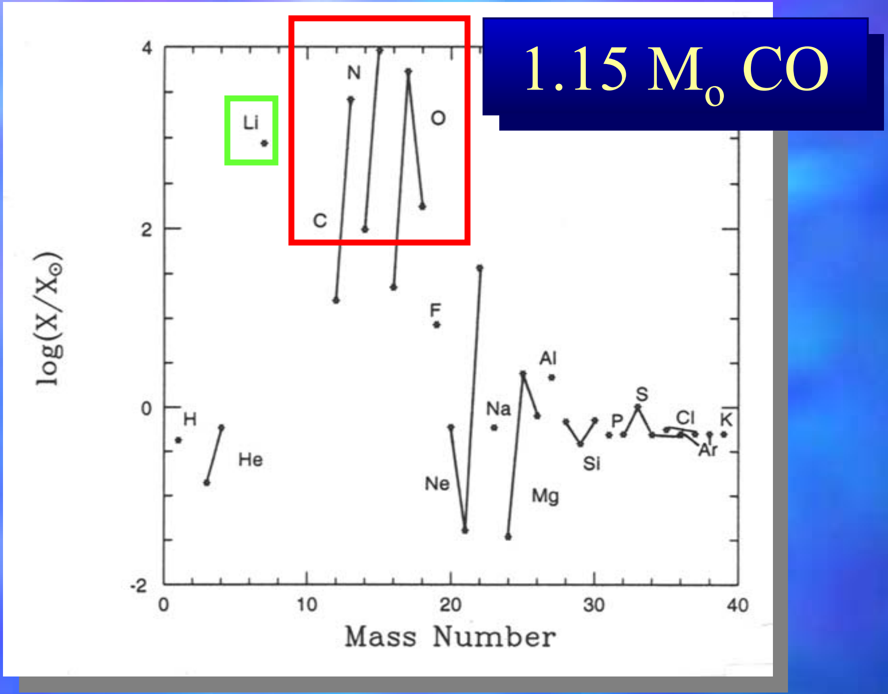
Since T_{peak} ~ (2 - 3) x 10^8 K → Nuclear processed material

Which is the role of nova outbursts in the Galactic chemical puzzle?

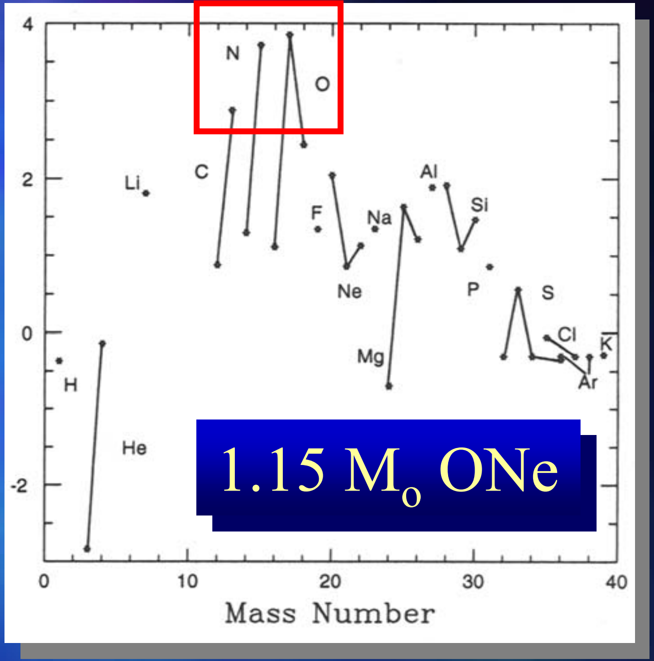
Galactic nova rate: ~ 30 events.yr^{-1}
Galaxy's lifetime: ~ 10^{10} yr
Mean ejected mass per outburst: ~ 2 x 10^{-5} M_o

~ 6 x 10^6 M_o (~ 1/3000 of the Galactic disk's gas & dust component)

→ Novae scarcely contribute to the Galactic abundances, but they can be likely sites for the synthesis of individual nuclei with production factors, $f = X_i / X_{i,\ solar} > 1000$

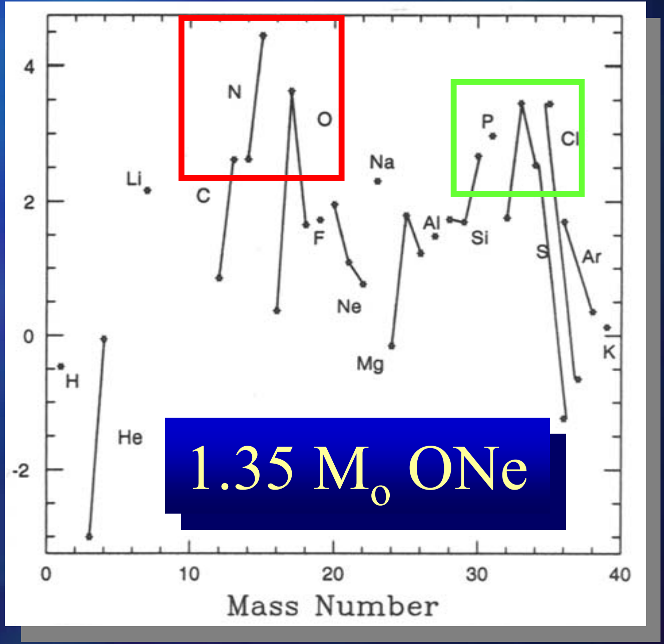


1.15 M_o CO



1.15 M_o ONe

José & Hernanz (1998), ApJ



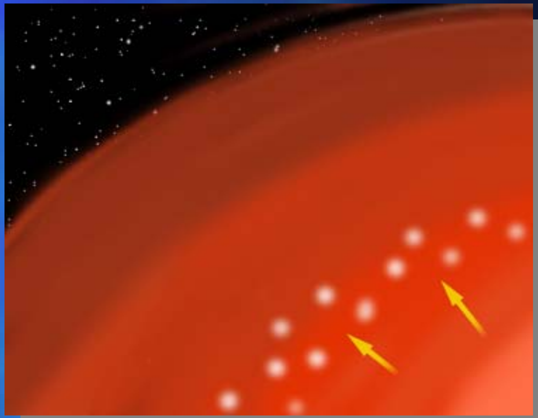
1.35 M_o ONe

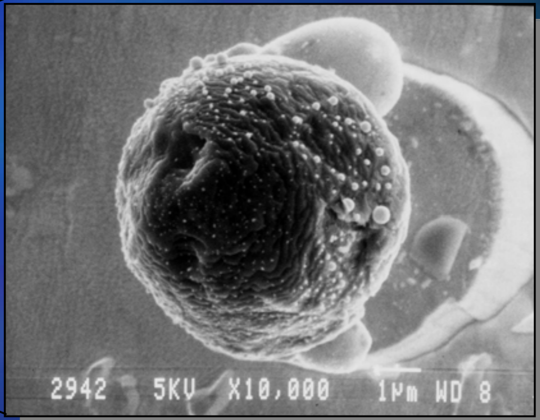
Models vs. Observations for Some Classical Nova Systems

	H	He	C	N	O	Ne	Na-Fe	Z
V693 CrA 1981								
Vanlandingham et al. (1997)	0.25	0.43	0.025	0.055	0.068	0.17	0.058	0.32
ONe3 (JH98)	0.30	0.20	0.051	0.045	0.15	0.18	0.065	0.50
Andreä et al. (1994)	0.16	0.18	0.0078	0.14	0.21	0.26	0.030	0.66
ONe4 (JH98)	0.12	0.13	0.049	0.051	0.28	0.26	0.10	0.75
Williams et al. (1985)	0.29	0.32	0.0046	0.080	0.12	0.17	0.016	0.39
ONe5 (JH98)	0.28	0.22	0.060	0.074	0.11	0.18	0.071	0.50
V1370 Aql 1982								
Andreä et al. (1994)	0.044	0.10	0.050	0.19	0.037	0.56	0.017	0.86
ONe7 (JH98)	0.073	0.17	0.051	0.18	0.14	0.24	0.14	0.76
Snijders et al. (1987)	0.053	0.088	0.035	0.14	0.051	0.52	0.11	0.86
ONe7 (JH98)	0.073	0.17	0.051	0.18	0.14	0.24	0.14	0.76
PW Vul 1984								
Andreä et al. (1994)	0.47	0.23	0.073	0.14	0.083	0.0040	0.0048	0.30
CO4 (JH98)	0.47	0.25	0.073	0.094	0.10	0.0036	0.0017	0.28
QU Vul 1984								
Austin et al. (1996)	0.36	0.19	......	0.071	0.19	0.18	0.0014	0.44
ONe1 (JH98)	0.32	0.18	0.030	0.034	0.20	0.18	0.062	0.50

Presolar Grains: Gifts from Heaven

Sample of the *Murchison* meteorite,
Murchison (Australia, 1969)



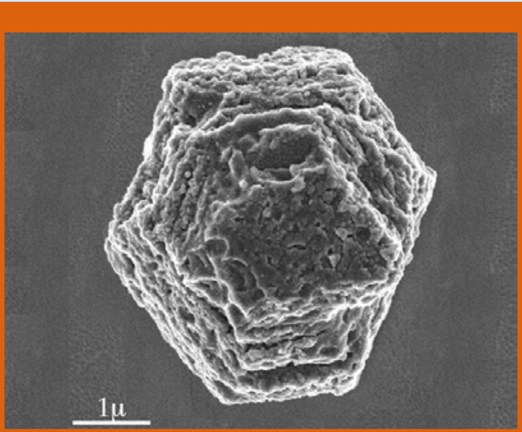


Secondary electron image of graphite grain
KFC1a-551 after SIMS analysis.

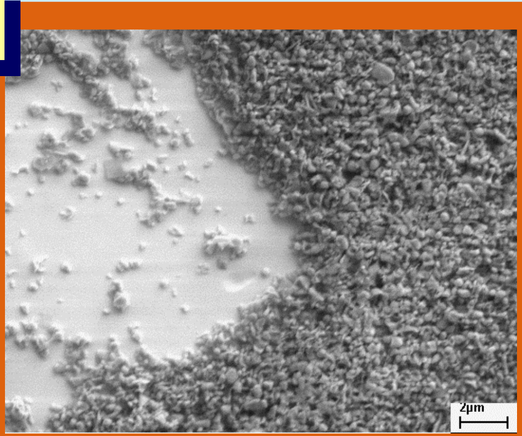
“Burning the haystack to find the needle”

So far, silicon carbide (SiC), graphite (C), diamond (C), silicon nitride (Si_3N_4), silicates, and oxides such as corundum (Al_2O_3) or spinel ($MgAl_2O_4$), have been identified as presolar grains

From E. Zinner

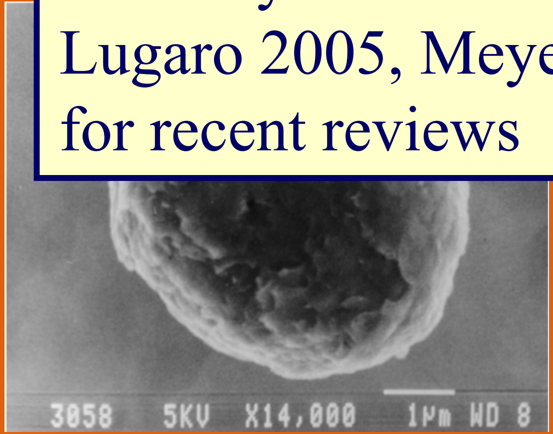


Silicon carbide grains: all are of presolar origin

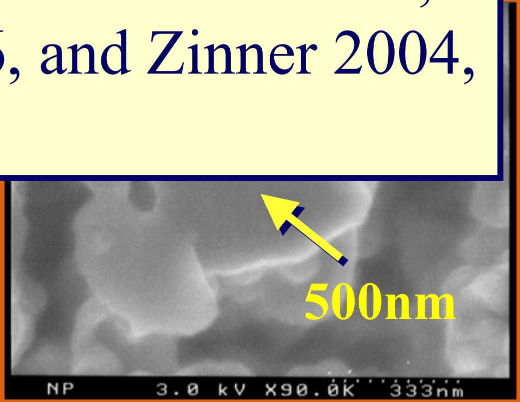


Spinel grains: only ~2% are of presolar origin

See Clayton & Nittler 2004, Lodders & Amari 2005, Lugaro 2005, Meyer & Zinner 2006, and Zinner 2004, for recent reviews



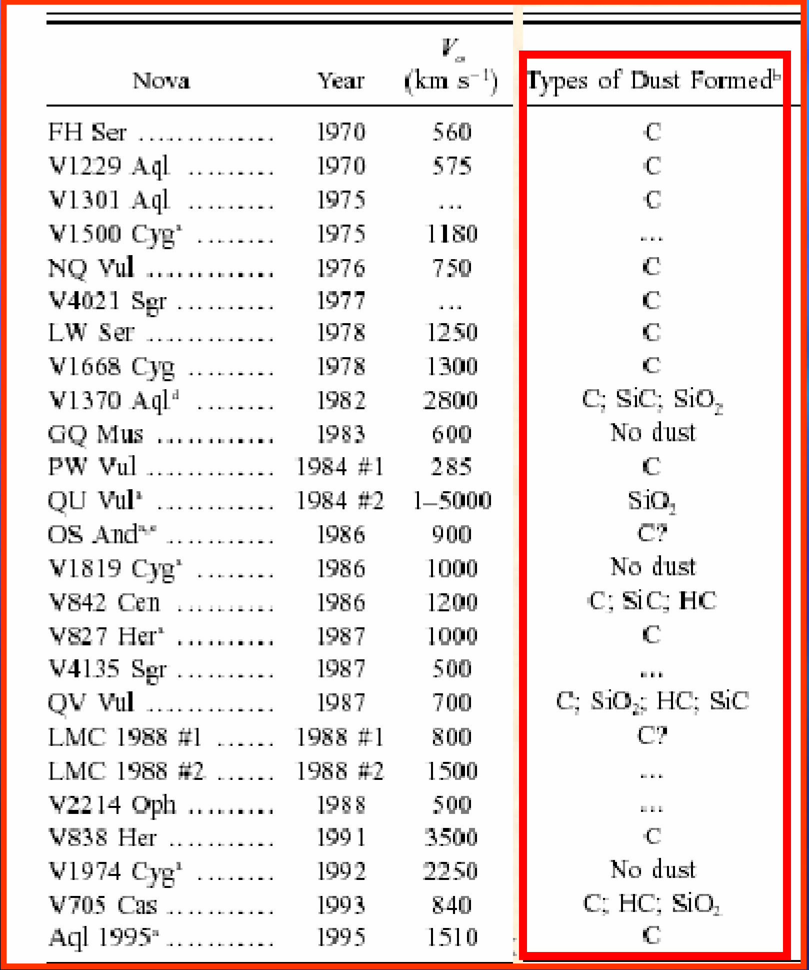
Graphite grains: approximately half of them are of presolar origin



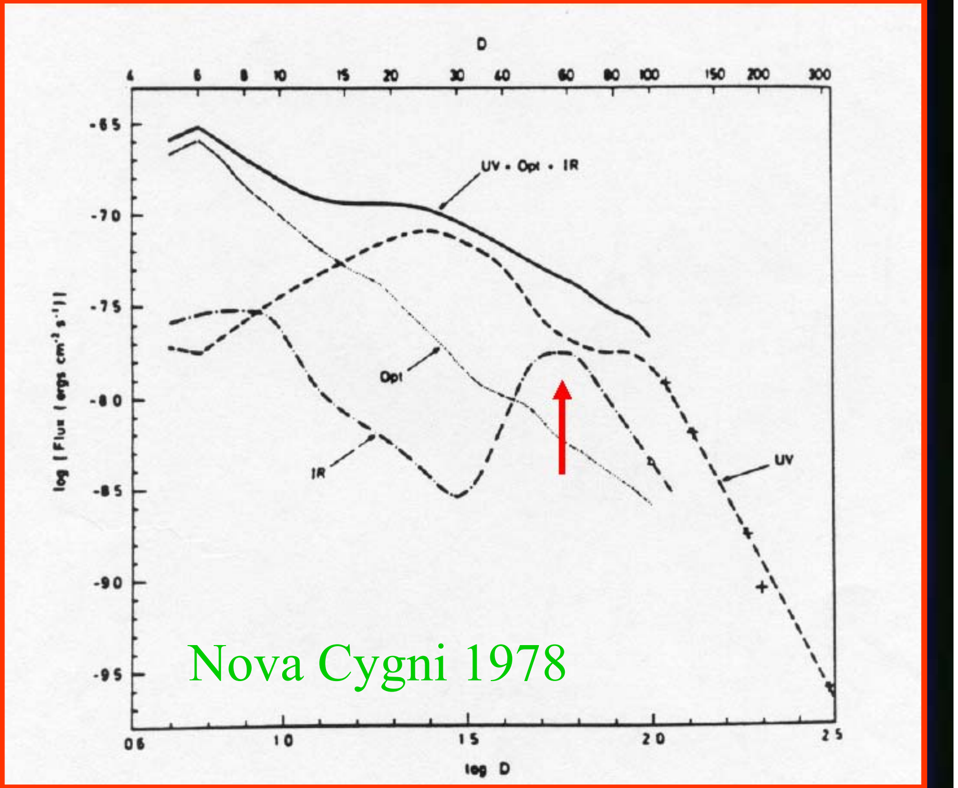
Silicate grains: only 0.001-0.02% are of presolar origin

Ashes to ashes, dust to dust: dust in classical novae

Evidence for dust formation (IR) accompanying nova outbursts

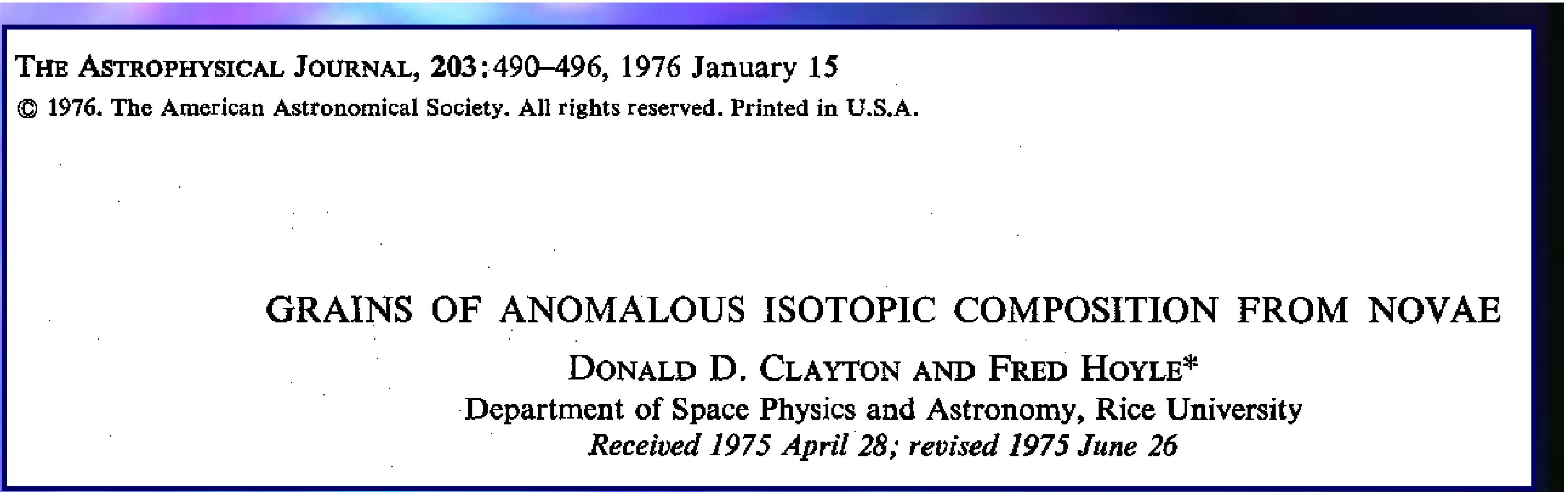


Nova	Year	V_o (km s^{-1})	Types of Dust Formed[b]
FH Ser	1970	560	C
V1229 Aql	1970	575	C
V1301 Aql	1975	...	C
V1500 Cyg[a]	1975	1180	...
NQ Vul	1976	750	C
V4021 Sgr	1977	...	C
LW Ser	1978	1250	C
V1668 Cyg	1978	1300	C
V1370 Aql[d]	1982	2800	C; SiC; SiO_2
GQ Mus	1983	600	No dust
PW Vul	1984 #1	285	C
QU 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



Nova Cygni 1978

From R. Gehrz



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GRAINS OF ANOMALOUS ISOTOPIC COMPOSITION FROM NOVAE

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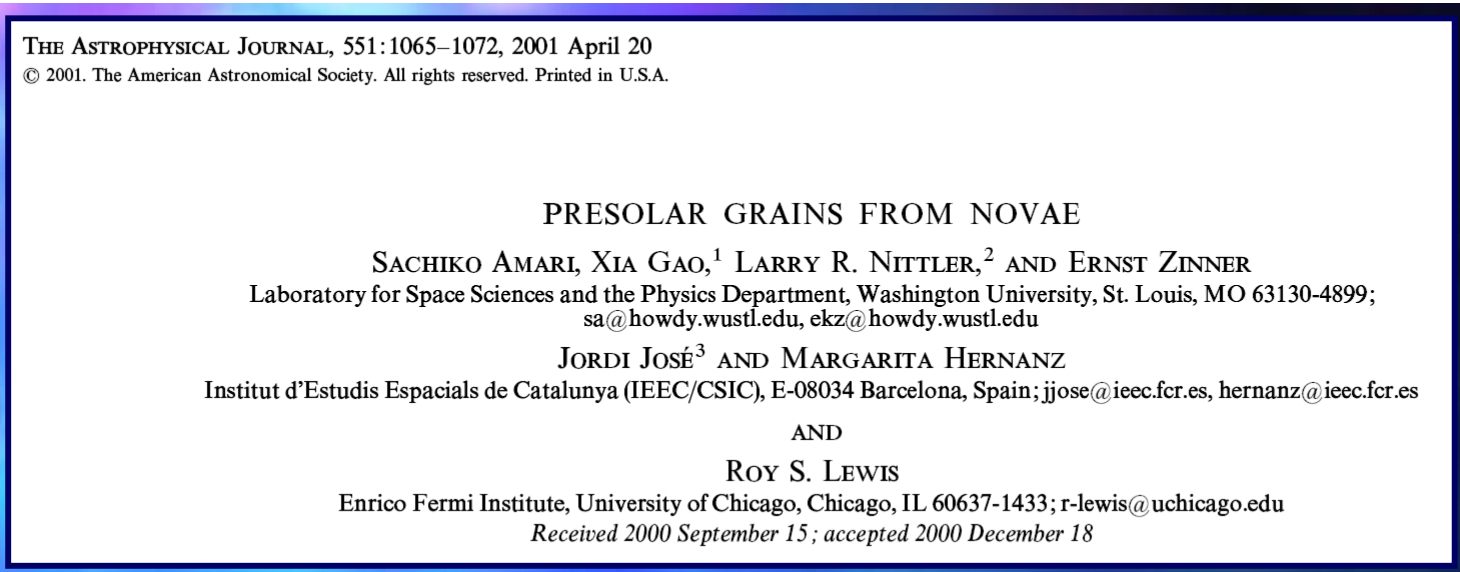
Received 1975 April 28; revised 1975 June 26

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



The Astrophysical Journal, 551:1065–1072, 2001 April 20

PRESOLAR GRAINS FROM NOVAE

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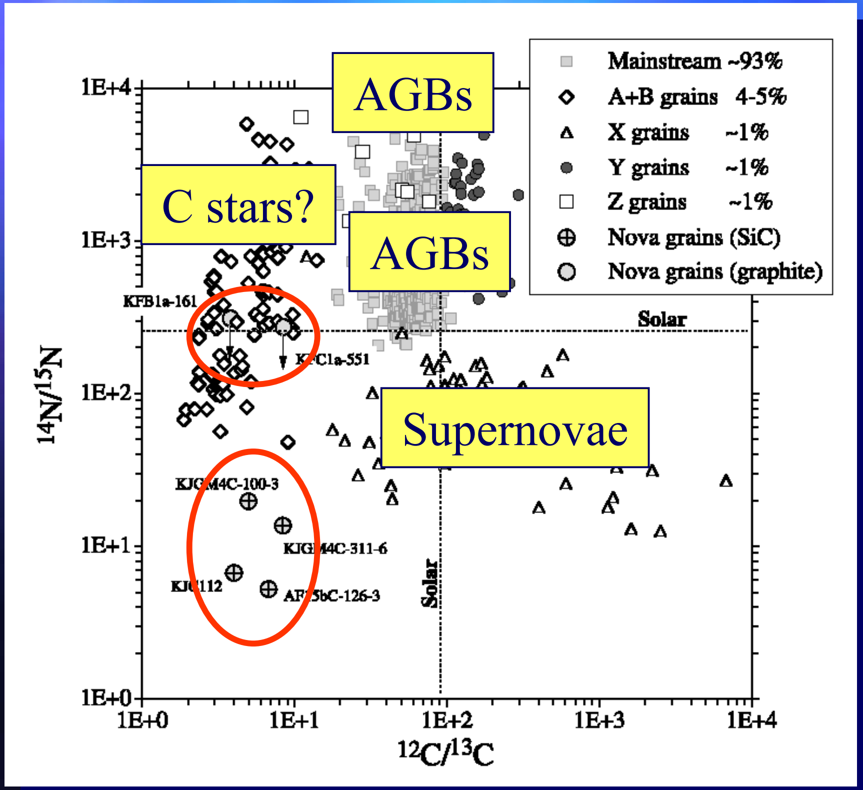
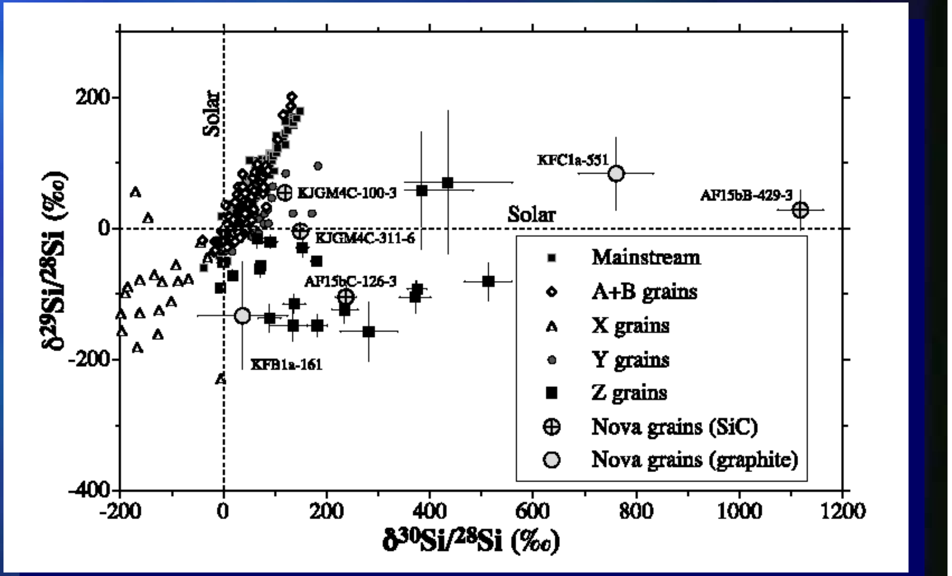




Presolar Nova Grains: *The Magnificent Seven*

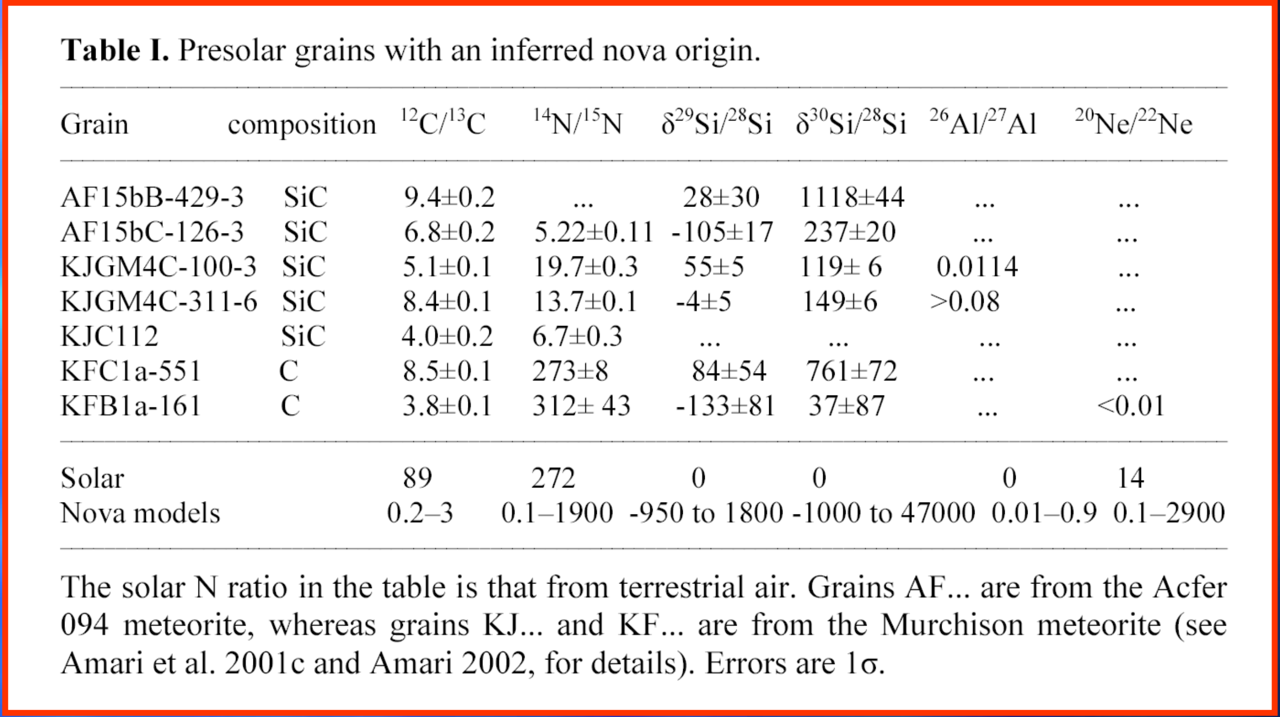


Table I. Presolar grains with an inferred nova origin.

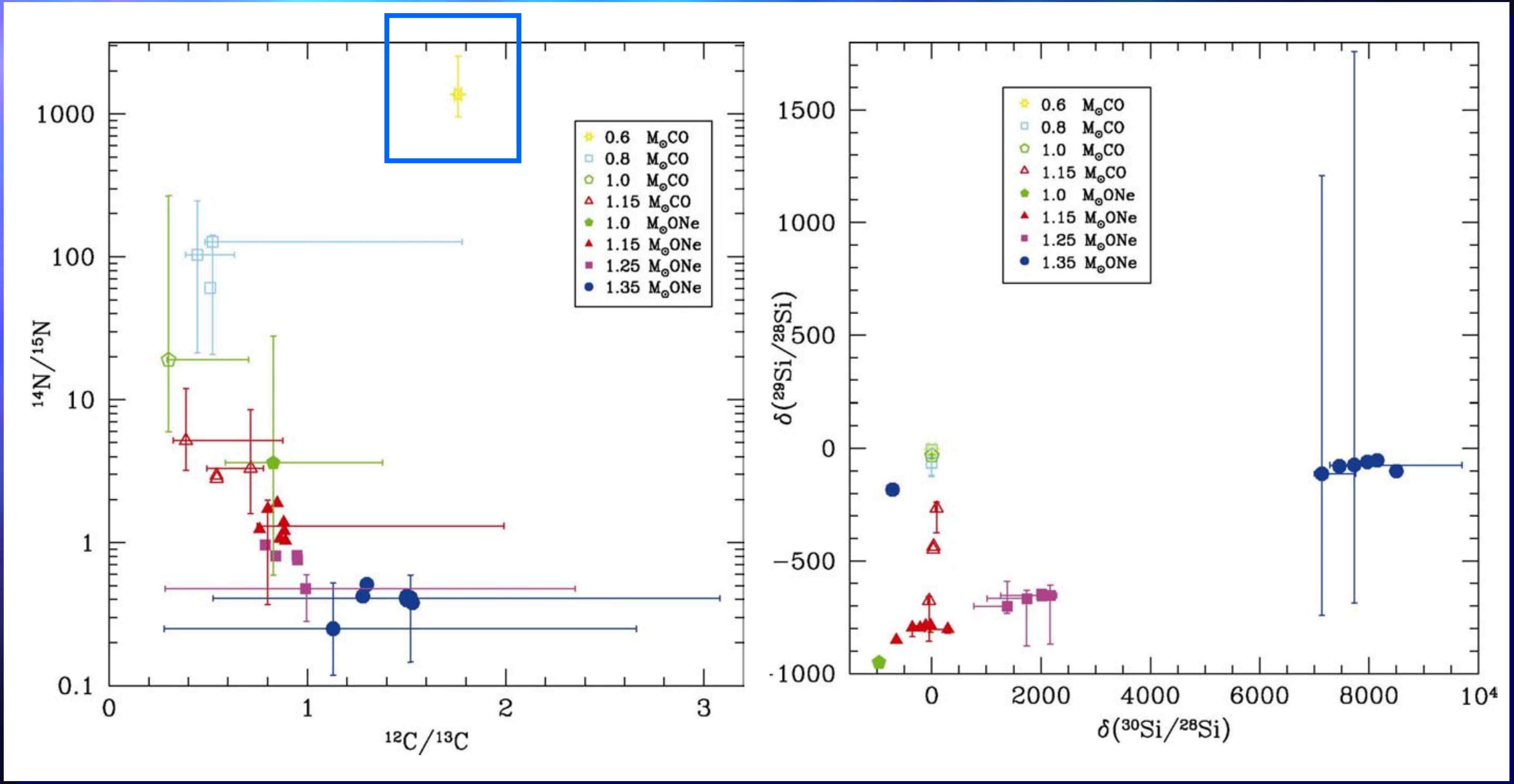
Grain	composition	$^{12}C/^{13}C$	$^{14}N/^{15}N$	$\delta^{29}Si/^{28}Si$	$\delta^{30}Si/^{28}Si$	$^{26}Al/^{27}Al$	$^{20}Ne/^{22}Ne$
AF15bB-429-3	SiC	9.4±0.2	...	28±30	1118±44	...	...
AF15bC-126-3	SiC	6.8±0.2	5.22±0.11	-105±17	237±20	...	...
KJGM4C-100-3	SiC	5.1±0.1	19.7±0.3	55±5	119± 6	0.0114	...
KJGM4C-311-6	SiC	8.4±0.1	13.7±0.1	-4±5	149±6	>0.08	...
KJC112	SiC	4.0±0.2	6.7±0.3	...	...	...	...
KFC1a-551	C	8.5±0.1	273±8	84±54	761±72	...	...
KFB1a-161	C	3.8±0.1	312± 43	-133±81	37±87	...	<0.01
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.

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.

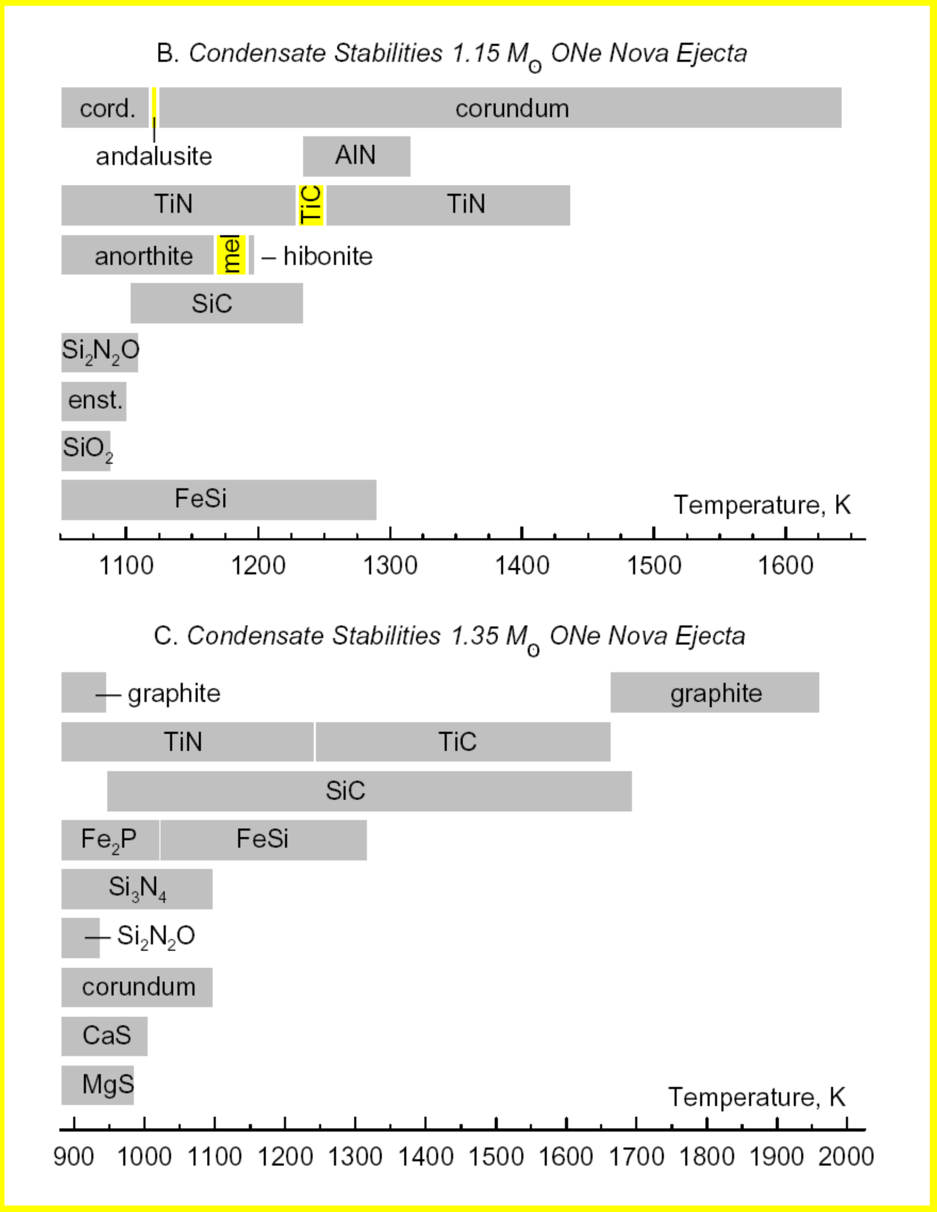
Theoretical isotopic ratios for nova outbursts

José, Hernanz, Amari, Lodders, & Zinner, ApJ (2004)



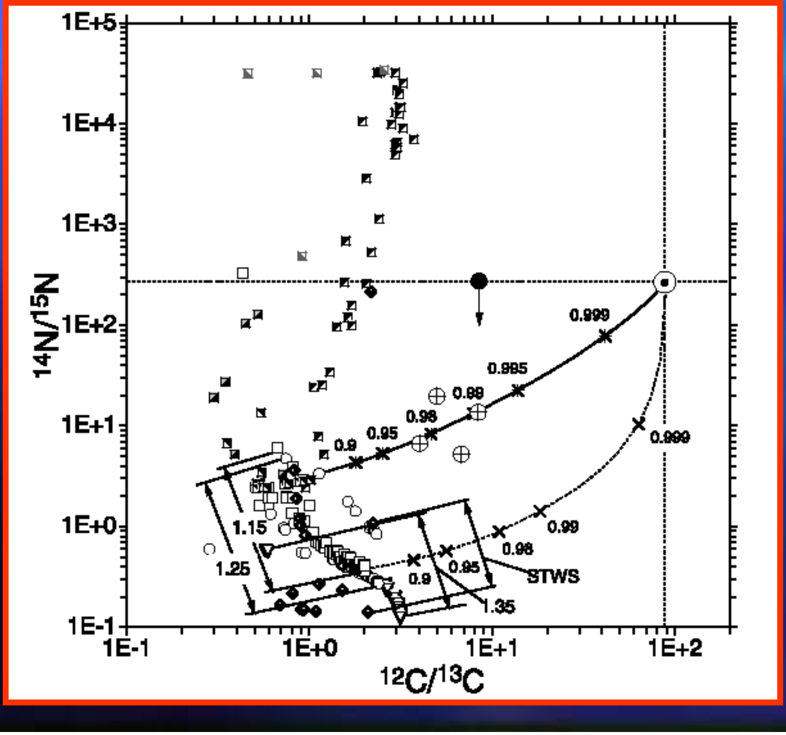
CO emission in V2274 Cygni 2001 (Rudy et al. 2003): $^{12}C/^{13}C \sim 1.2$

Also, equilibrium condensation sequences to predict the expected mineralogy in the dust condensed in nova explosions



The grains reported by Amari et al. (2001) likely formed in ONe nova explosions hosting white dwarfs of at least 1.25 $M_\odot$. But in order to quantitatively explain the grain data, one has to assume that material newly synthesized in the nova outburst was somewhat mixed with more than ten times as much unprocessed, isotopically close-to-solar, material before grain formation.

It is not clear if the interaction between the ejected shells and the surrounding disk can account for this mixing process.



⊕	SiC grains	◆	ONe.JH98
●	Graphite KFC1a-551	◆	ONe.STWS98
◪	CO.SGT97	□	1.15ONe.J00
◪	CO.KP97	○	1.25ONe.J00
◪	CO.JH98	▽	1.35ONe.J00
◪	CO.J00		

Radioactivities from novae

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

Main radioactive species synthesized during nova outbursts

* $^{14,\,15}$O, ^{17}F (^{13}N): Expansion and ejection stages

* ^{13}N, ^{18}F: Early gamma-ray emission (511 keV plus continuum)

* ^{7}Be, ^{22}Na, ^{26}Al: Gamma-ray lines

^{7}Li

* Pioneering calculations: Arnould & Nørgaard (1975)

Starrfield et al. (1978) → confirms the *Beryllium transport* mechanism (Cameron 1955)

^{1}H(p,e$^{+}\nu_{e}$)^{2}H(p,γ)^{3}He(α,γ)^{7}Be (also initial ^{3}He)

Hernanz et al. (1996): ^{7}Be(p,γ)^{8}B versus ^{8}B(γ,p)^{7}Be

[Boffin et al. (1993): ~~important~~ role of ^{8}B(p,γ)^{9}C?]

* Nuclear uncertainties: not relevant (at nova Ts)

→ Synthesis of ^{7}Li favored in CO novae

* Contribution to Galactic ^{7}Li abundances:

Assuming: a Galactic nova rate ~ 30 yr^{-1},
a Galaxy's age of ~ 10^{10} yr

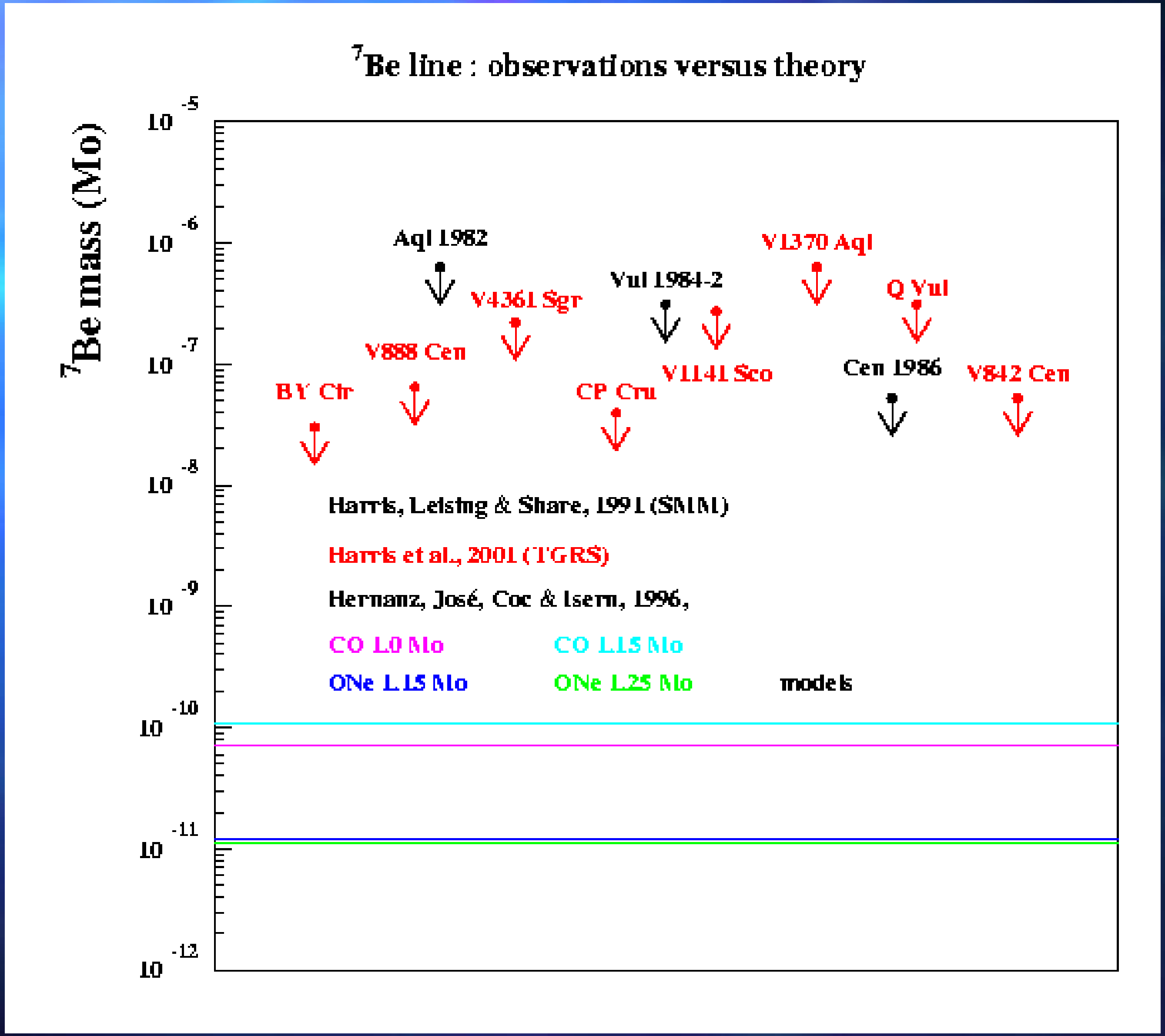
→ Novae ≤ 30 M_o of ^{7}Li (< 150 M_o of Galactic ^{7}Li)

Romano et al. (1999); Romano & Matteucci (2002): contribution of novae to match the ^{7}Li content in models of Galactic chemical evolution

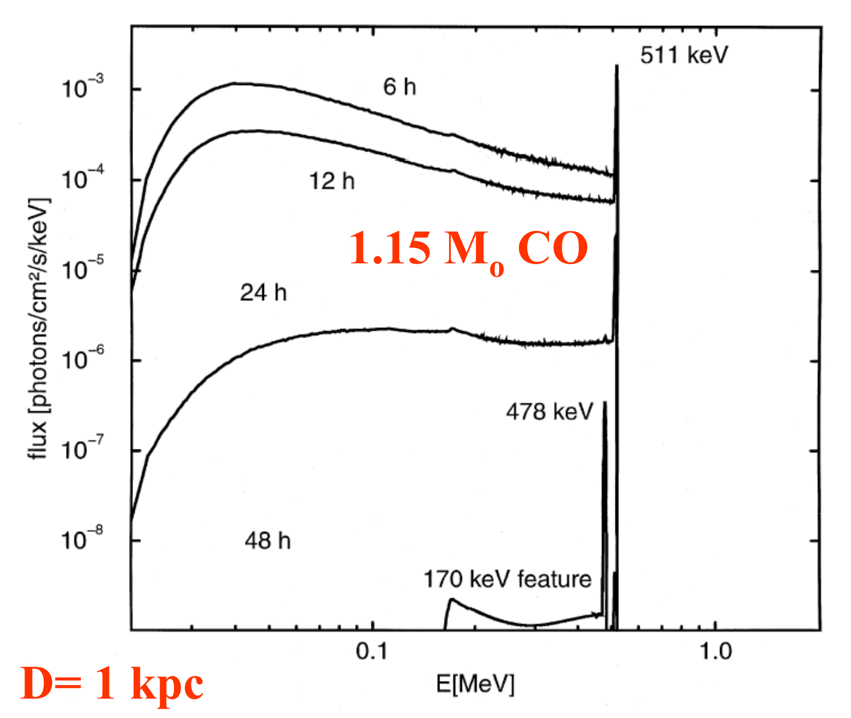
* Optical observations of ^{7}Li: a challenging issue

Della Valle (2002): a possible detection of ^{7}Li in Nova Vel 1999 (Li I doublet at 6708 ? Å) → N I? (Shore et al., 2003)

Observational attempts to detect the 478 keV ^{7}Be line



* γ-ray signature: Peak fluxes for the 478 keV γ-ray line (transition: ^{7}Be to ^{7}Li) might be detectable by gamma-ray satellites (i.e. INTEGRAL) at very short distances (i.e., <0.2 kpc)



1.15 M_o CO

D= 1 kpc

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

^{22}Na

* Clayton & Hoyle (1974): potential role of ^{22}Na for diagnosis of nova outbursts

$$^{22}\mathrm{Na} \xrightarrow[1.275\ \mathrm{MeV}]{\tau \sim 3.75\ \mathrm{yr}} {}^{22}\mathrm{Ne}$$

* Iyudin et al. (1995): upper limit of $3.7 \text{ x } 10^{-8}\ M_o$ of ^{22}Na ejected by any novae in the Galactic disk

→ Constraints on pre-existing theoretical models!

* Main reaction paths: ^{20}Ne(p,γ)^{21}Na → ^{21}Na(p,γ)^{22}Mg(β^+)^{22}Na

→ ^{21}Na(β^+)^{21}Ne(p,γ)^{22}Na

* Destruction channel: ^{22}Na(p,γ)^{23}Mg and ^{22}Na(β^+)^{22}Ne

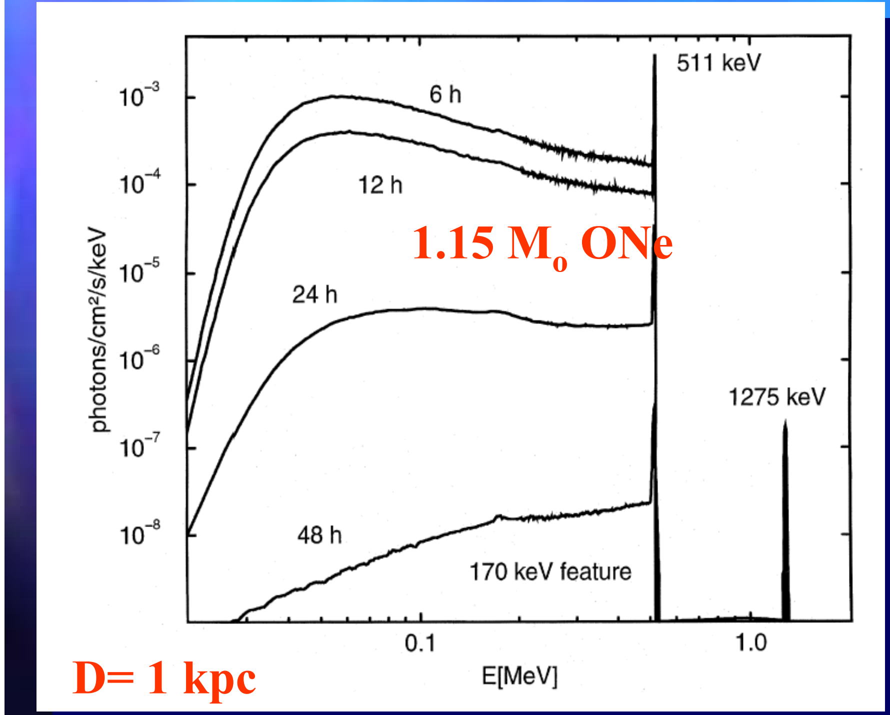
* Nuclear uncertainties: ^{21}Na(p,γ)^{22}Mg
^{22}Na(p,γ)^{23}Mg (José, Coc & Hernanz 1999)

→ uncertainties in the rates translated into a factor ~ 3 uncertainty in the ^{22}Na yields

Recent improvements:

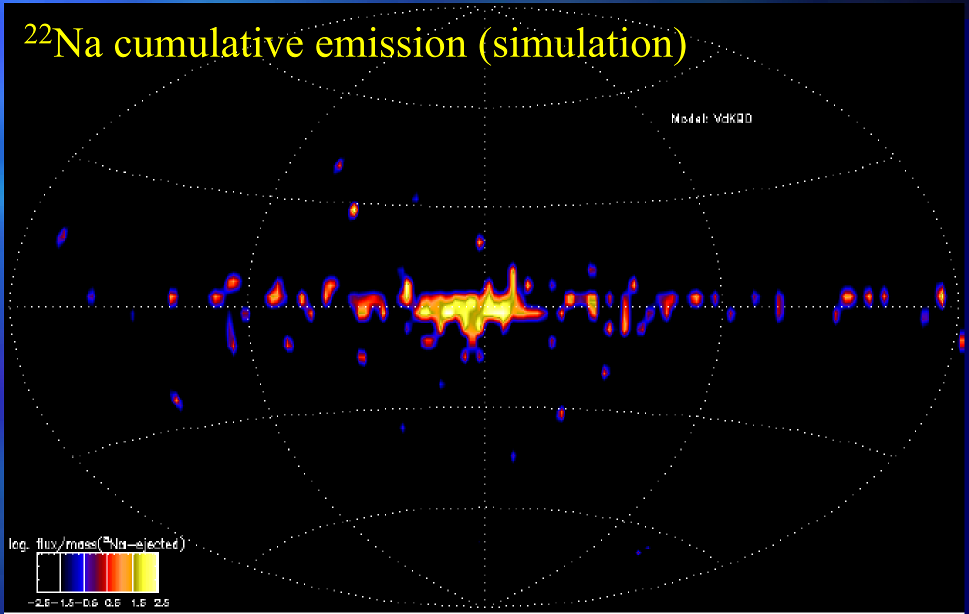
^{21}Na(p,γ)^{22}Mg: S. Bishop, et al. (PRL, 2003), J.M. D'Auria, et al. (PRC, 2004): direct measurement; ^{22}Na(p,γ)^{23}Mg: D.G. Jenkins, et al. (PRL, 2004): ^{12}C(^{12}C,n)^{23}Mg , Gammasphere

Peak fluxes for the 1275 keV γ-ray line (^{22}Na decay) might be detectable by near future gamma-ray satellites (i.e. INTEGRAL: d<0.5 kpc)



1.15 M_o ONe

D= 1 kpc



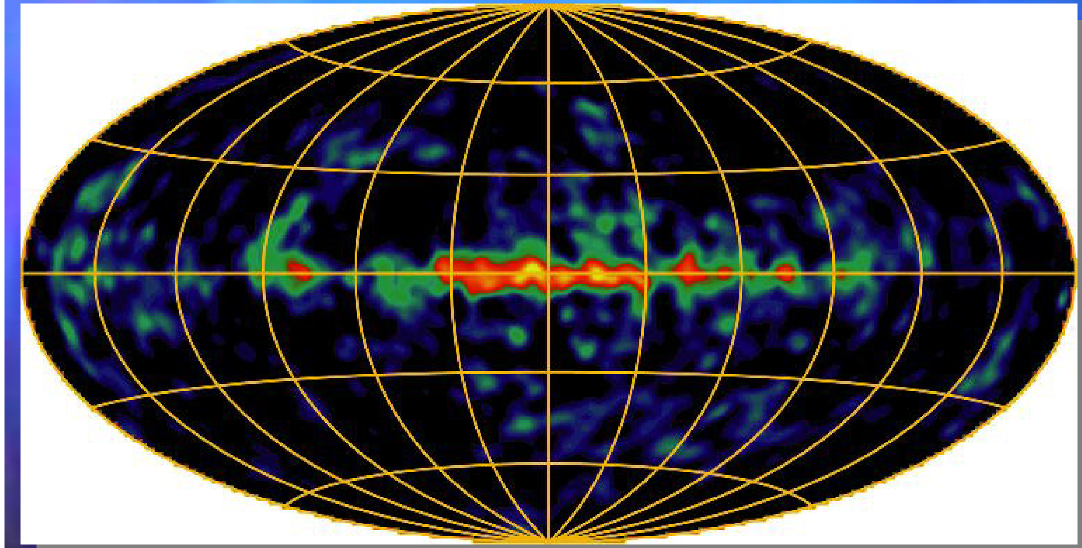
^{22}Na cumulative emission (simulation)

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

Jean, Hernanz, Gómez-Gomar, & José (2000), MNRAS

^{26}Al

$$^{26}\mathrm{Al} \xrightarrow{\tau \sim 1.04\ \mathrm{Myr}} {}^{26}\mathrm{Mg}^{*} \xrightarrow[1.809\ \mathrm{MeV}]{} {}^{26}\mathrm{Mg}$$



COMPTEL measurements: map of the 1.809 MeV emission in the Galaxy (Diehl et al., A&A, 1995; Prantzos & Diehl, Ph. Rep. 1996)

Galactic ^{26}Al related to young progenitors

SN II vs. WR stars: → Diehl (2004), Diehl et al. (2006)

But ^{60}Fe?

- Main reaction paths: $^{24}Mg(p,\gamma)^{25}Al(\beta^{+})^{25}Mg(p,\gamma)^{26}Al^{g}$
  (Also some potential contribution from initial ^{20}Ne or ^{23}Na)

- Destruction channel: $^{26}Al^{g}(p,\gamma)^{27}Si$

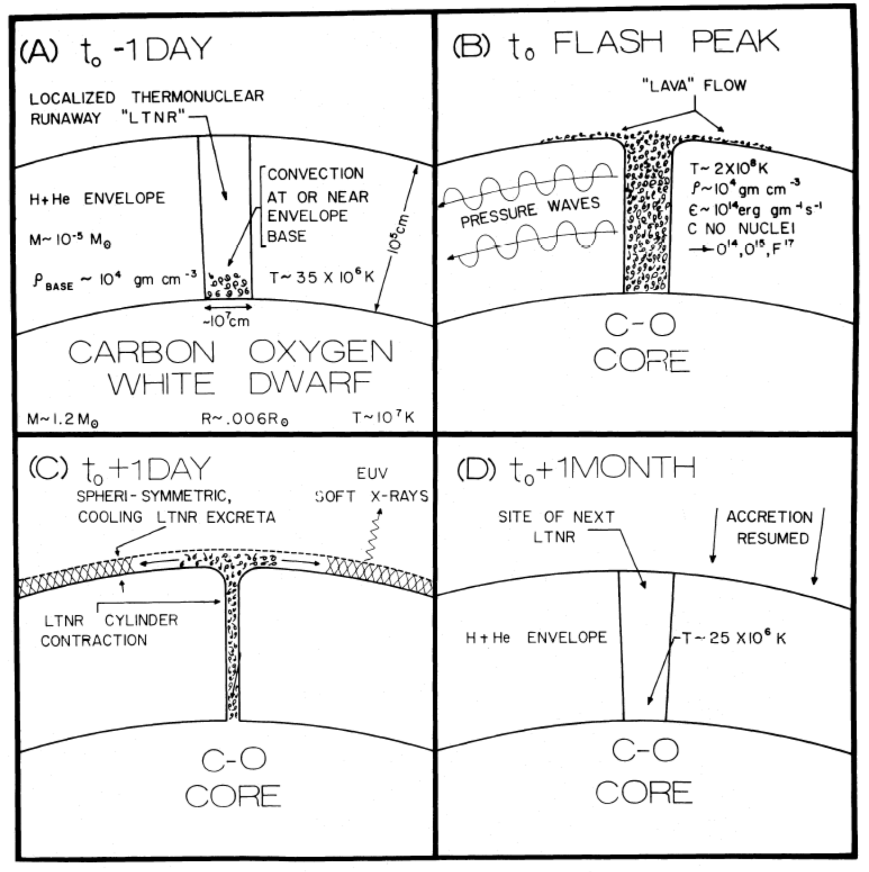
- Nuclear uncertainties: $^{25}Al(p,\gamma)^{26}Si$, $^{26}Al^{g}(p,\gamma)^{27}Si$ (José, Coc & Hernanz 1999)

$^{26}Al^{g}(p,\gamma)^{27}Si$: C. Ruiz, et al. (PRL, 2006): direct measurement

$$M(^{26}Al) = 0.4 \, \frac{X(^{26}Al)}{2\mathrm{x}10^{-3}} \, \frac{N(ONe)}{0.25} \, \frac{M_{ej}(M_{o})}{2\mathrm{x}10^{-5}} \, \frac{R_{nova}(yr^{-1})}{40} \sim 0.2 \, M_{o}$$

- José, Hernanz, et al.: Novae account for < 20% of the Galactic ^{26}Al

Multidimensional Nova Models



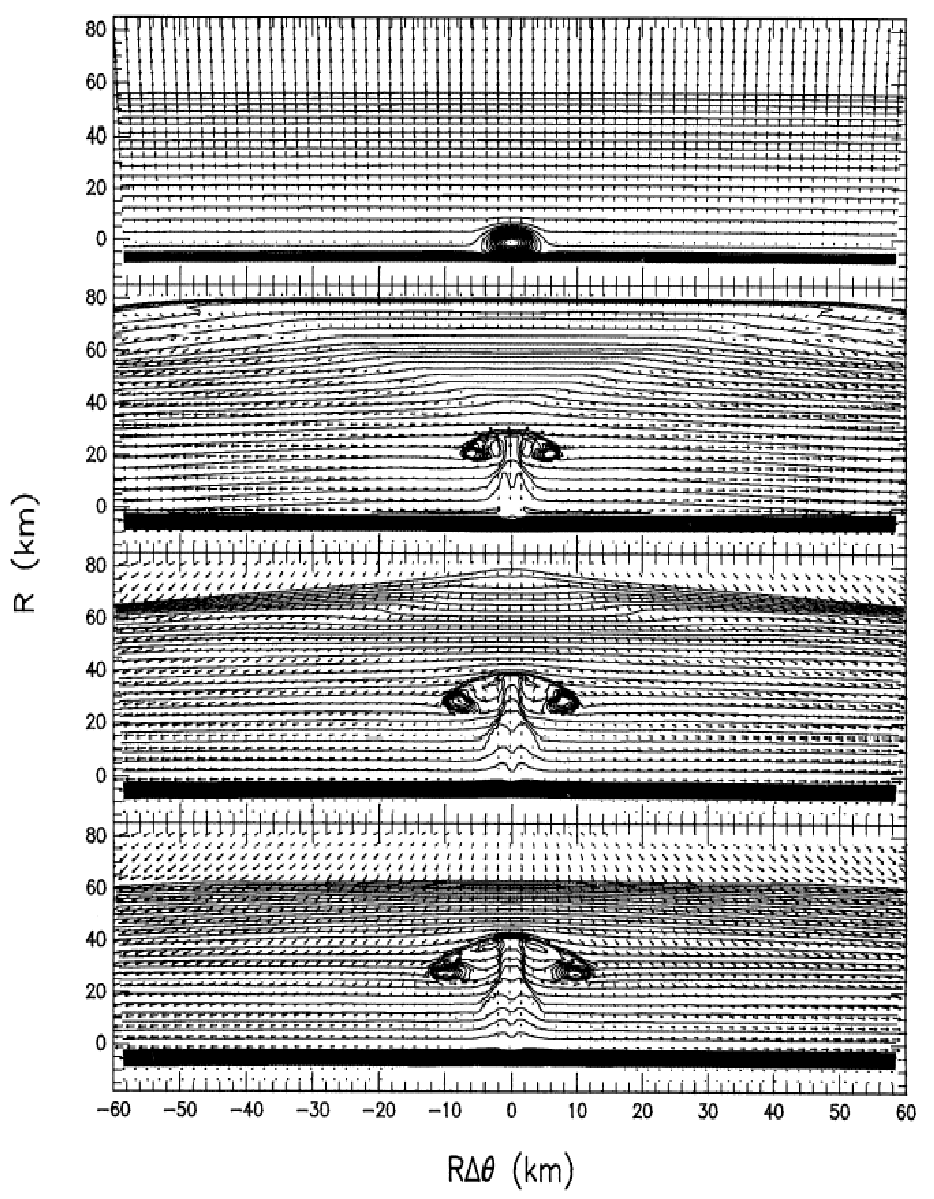
Shara 1982

Semianalytic model of localized, *volcanic-like* TNRs

Heat transport is too inefficient for a flame to spread a localized TNR to the rest of the WD surface

But! The study ignored the major role played by convection

Shankar, Fryxell & Arnett 1992; Shankar & Arnett 1994



-An accreting 1.25 M_o WD (1-D) → mapped into a 2-D domain (polar grid, 25x60 km)

-2-D simulation performed with PROMETHEUS (Eulerian code)

-12 isotope network

-Computed time: 1 sec!

-T perturbations cause Rayleigh-Taylor instabilities → Rapid rise and expansion (τ_{dyn}) halts the lateral spread of TNR → favors localized TNRs

But!, very extreme (unphysical?) conditions

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

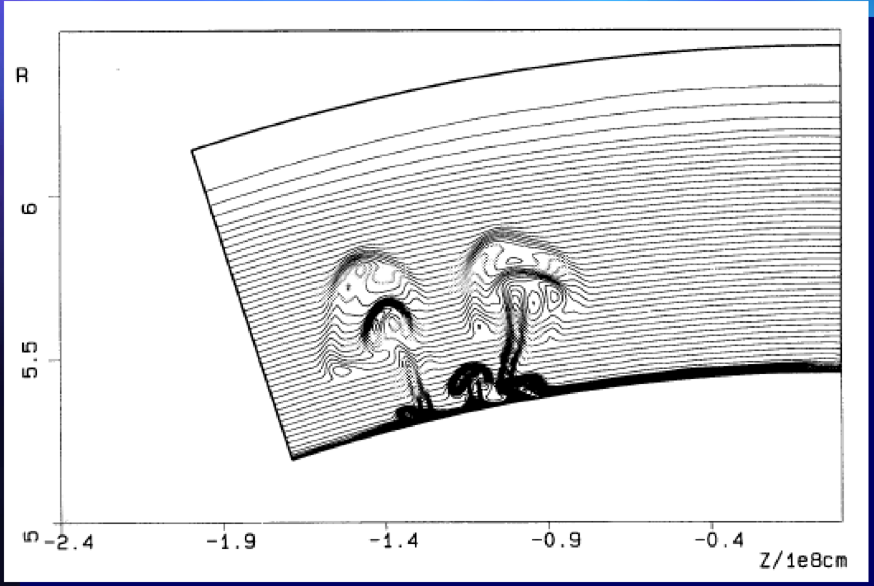
-An accreting 1.0 M_o CO WD (1-D) → mapped into a 2-D domain at $T=10^8$ K

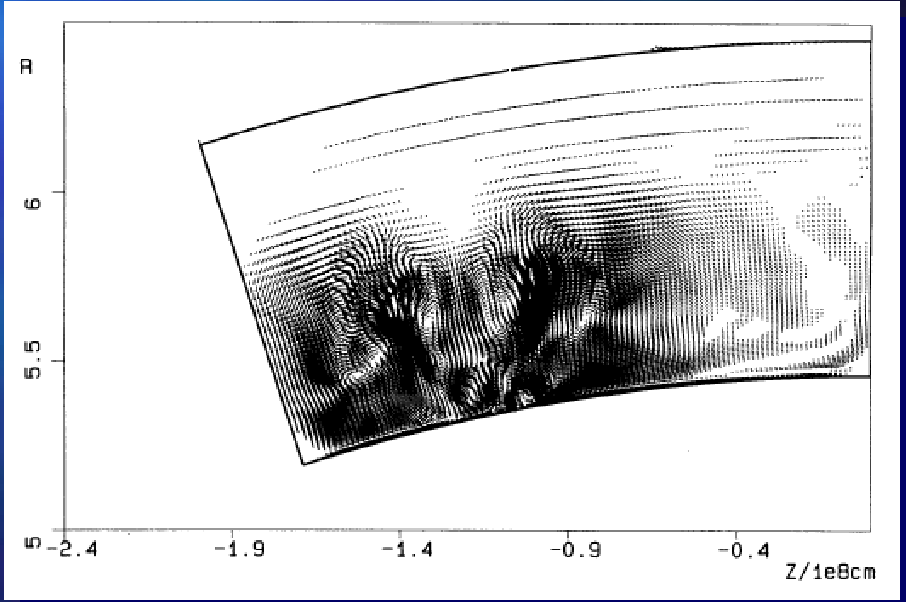
-2-D simulation performed with VULCAN (ALE code)

-Spherical/polar coordinates, with reflecting boundary conditions

-Slice of 0.1 π rad, resolution 5 x 5 km

-12 isotope network



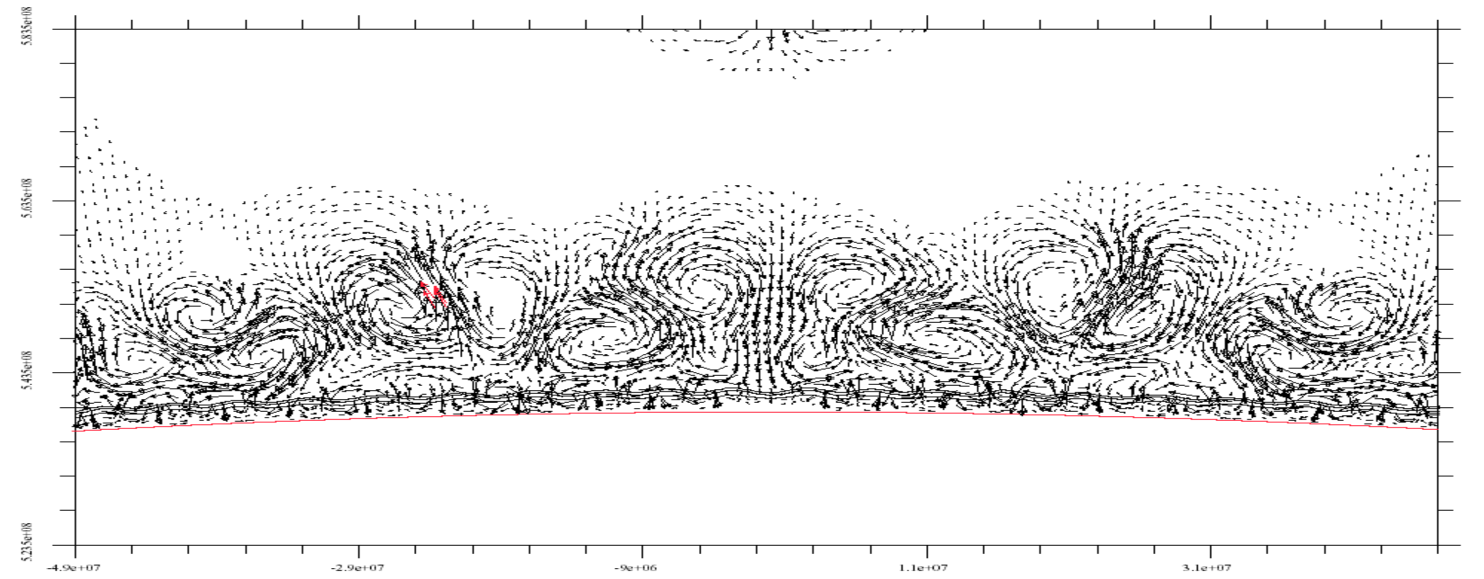


Good agreement with 1-D simulations!

- Role of β^+-unstable nuclei $^{14,\,15}$O, ^{17}F (^{13}N) in the ejection process
- Significant presence of $^{14,\,15}$N, ^{17}O (^{13}C) expected in the ejecta

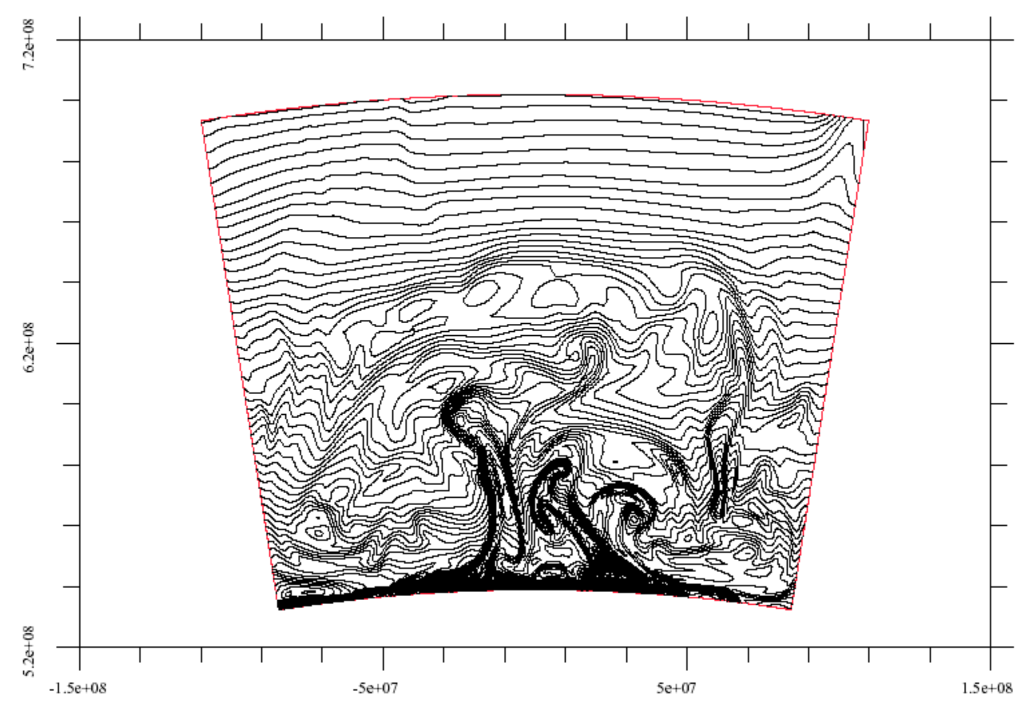
But!, differences with 1-D simulations:

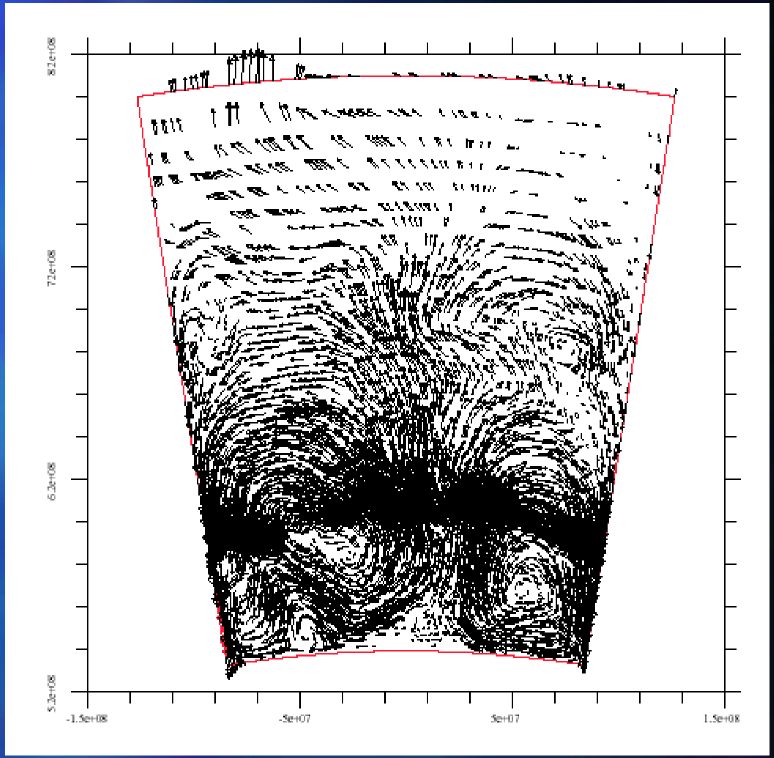
- TNR initiates as a myriad of irregular, localized eruptions
  → although the TNR spreads through the entire envelope



- Core/envelope interface is now convectively unstable →
  mechanism for mixing? (~ convective overshoot, Woosley 1986)

* Large convective eddies ($h \sim 2/3\ \Delta z_{env}$)





Expansion and progress of the TNR is almost spherically symmetric (although the initial burning process is not!)

Kercek, Hillebrandt, & Truran 1998, 1999

-Same initial model than GLT97 → mapped into a 2-D domain at $T=10^8$ K

-2-D/3-D simulations performed with PROMETHEUS

-Cartesian, plane-parallel geometry, with periodic boundary conditions

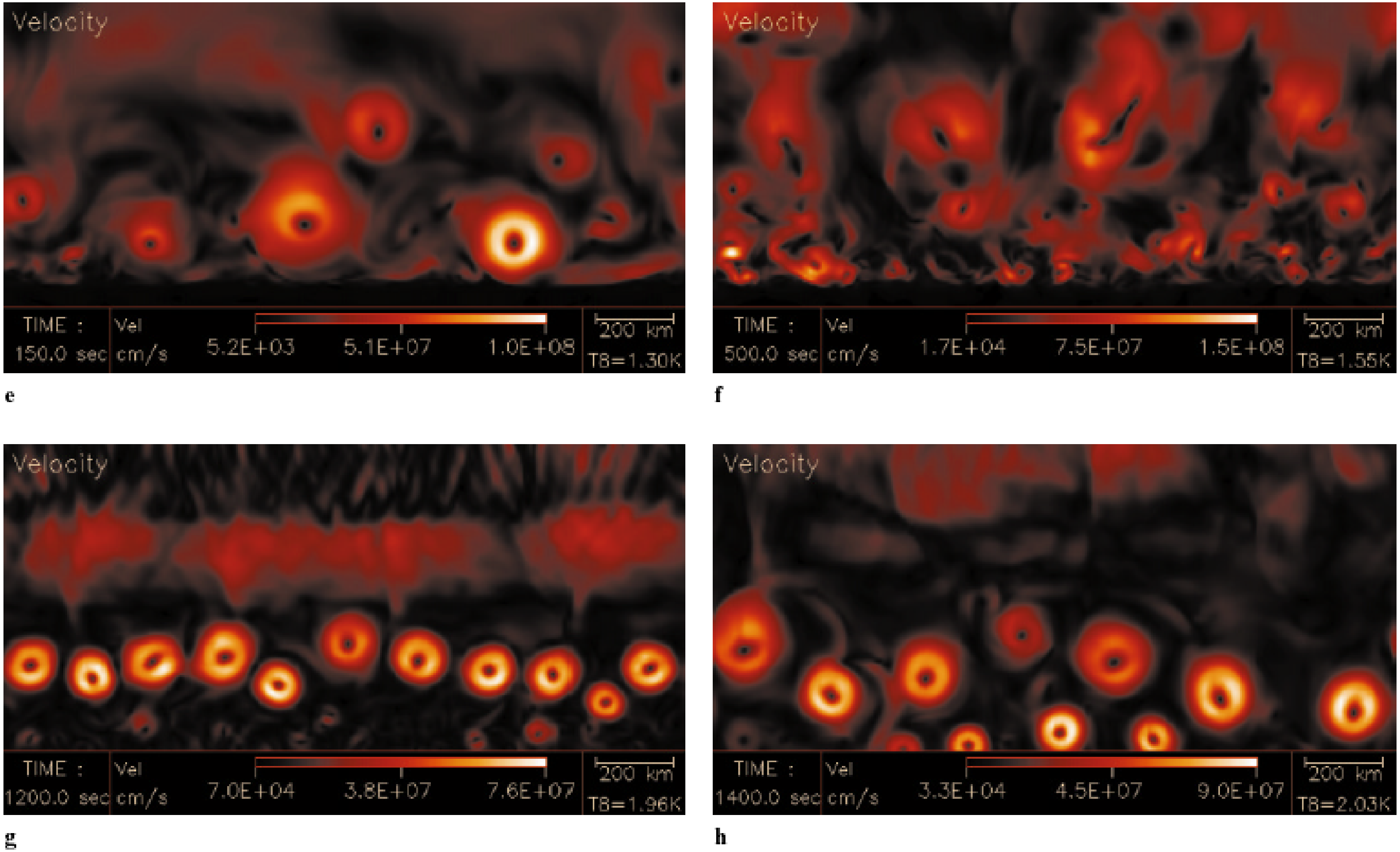
-Computational domains: 1800x1000 km (2-D);
1800x1800x1000 km (3-D)

-Resolution: 5 x 5 km, 1 x 1 km (2-D); 8 x 8 x 8 km (3-D)

-12 isotope network

* 2-D: Qualitatively, similar results than in Glasner, Livne, & Truran (1997), but somewhat less violent outbursts (longer τ_{TNR}, lower T_{peak} & v_{ejec}) caused by major differences in the convective flow patterns:

few, large convective eddies ↔ small, very stable eddies
(Glasner et al. 1997) (Kercek et al. 1998)

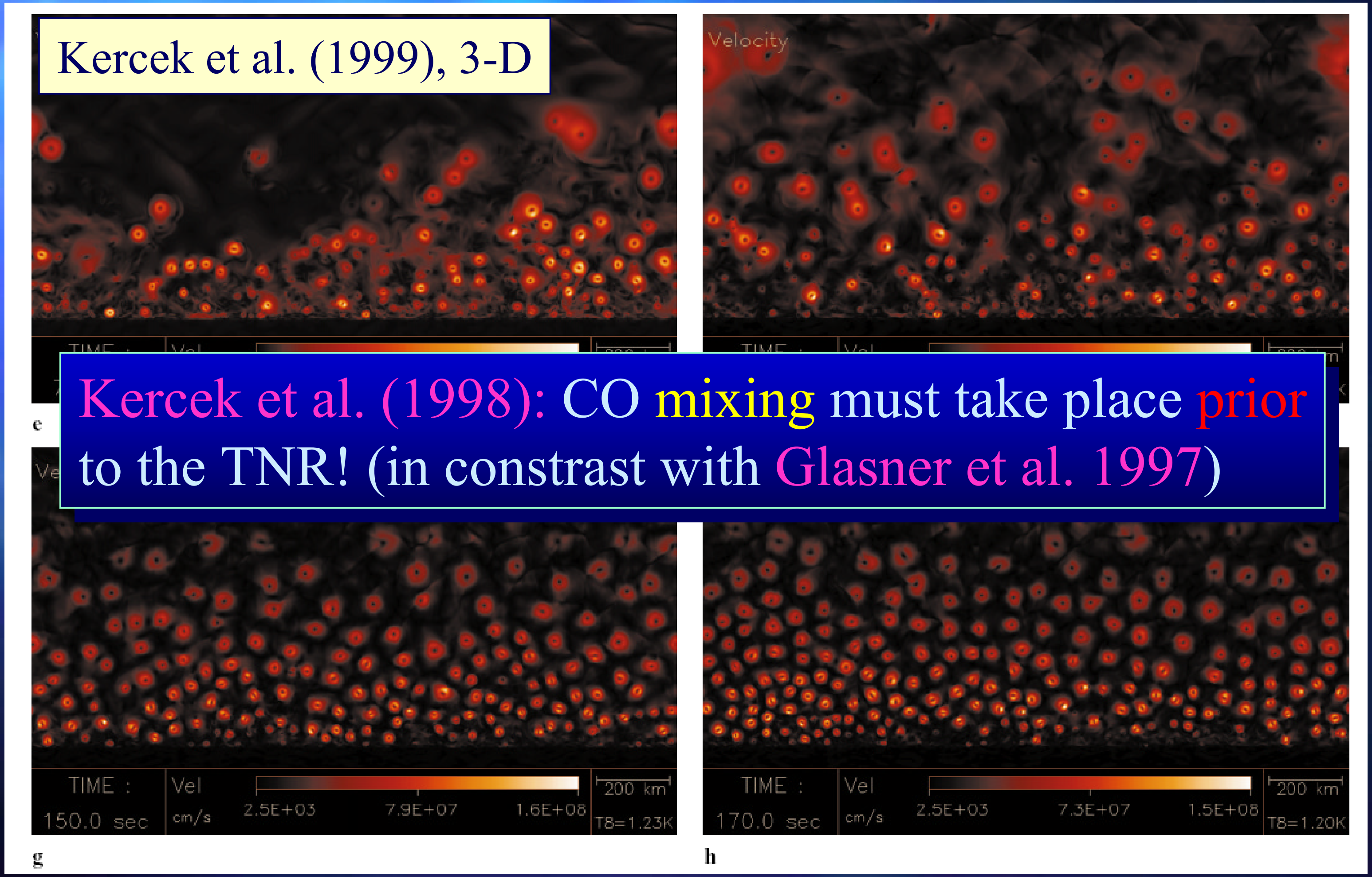


Kercek et al. (1998), 2-D

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

* 3-D: Flow patterns are dramatically different from those in 2-D

Mixing by turbulent motions on very small scales: no nova (i.e., no mass-ejection phase expected) is found!, as a result of a very limited dredge-up and mixing episodes.

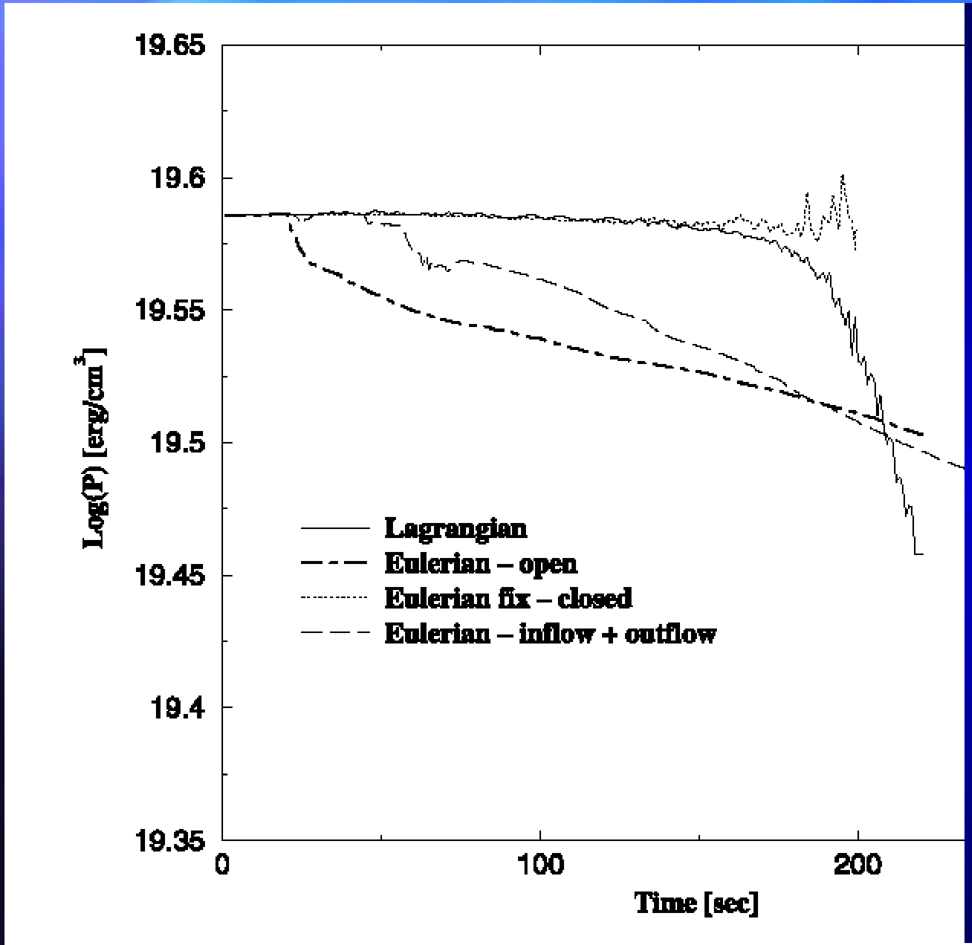


Kercek et al. (1999), 3-D

Kercek et al. (1998): CO mixing must take place prior to the TNR! (in constrast with Glasner et al. 1997)

Glasner, Livne, & Truran 2005

Sensitivity of multidimensional nova calculations to the outer boundary conditions



Solutions obtained from Lagrangian simulations, where the envelope is allowed to expand and mass is being conserved, are consistent with spherically symmetric solutions

In Eulerian schemes, which utilize an outer boundary condition of free outflow, the outburst can be artificially quenched

Jordi José

Classical Novae in the XXIst Century

Accretion and Explosion: the Astrophysics of Degenerate Stars

KITP, Santa Barbara, CA, February 6, 2007