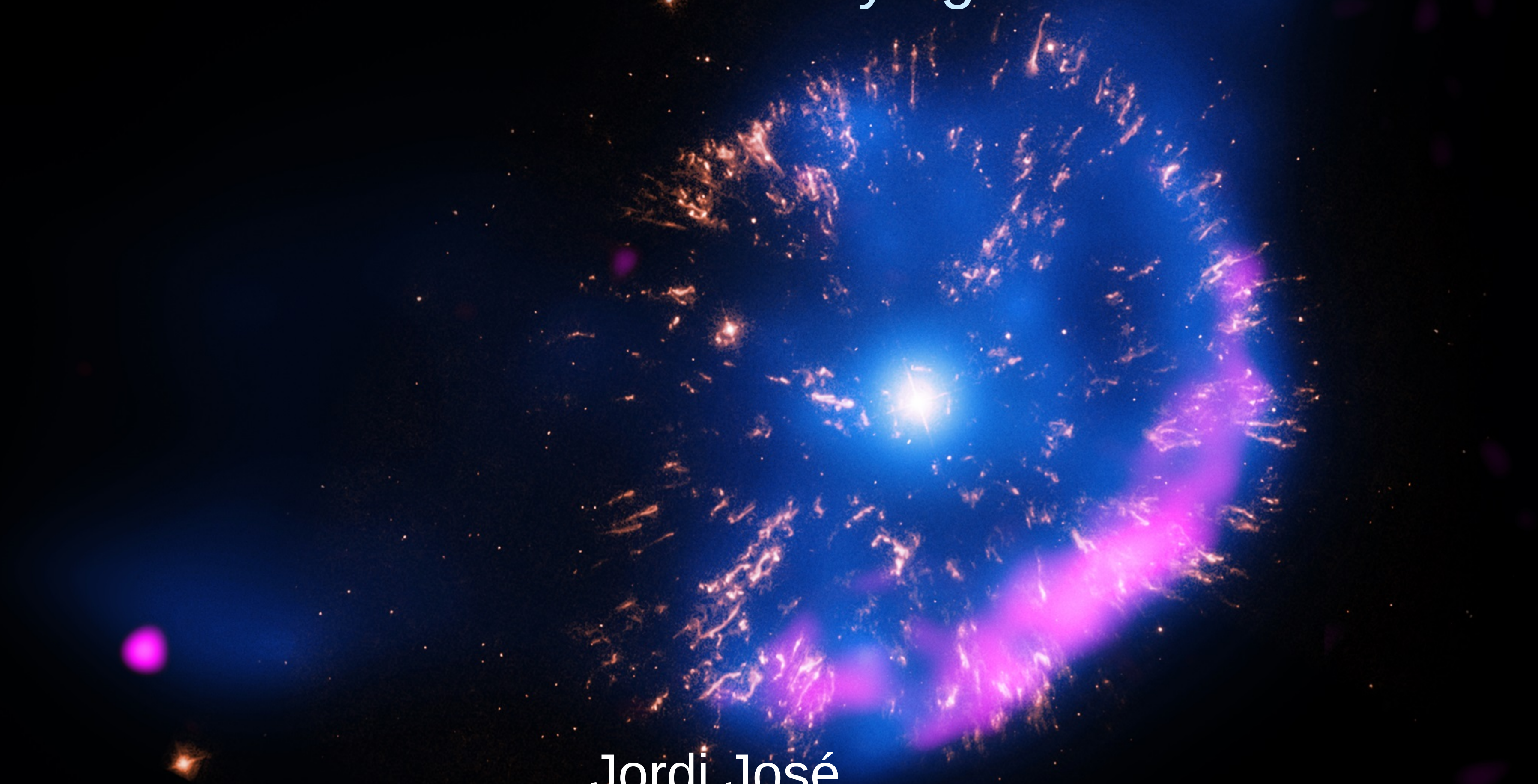
Classical (and Recurrent) Novae and the Mass of the Underlying White Dwarf



Jordi José

Dept. Física, Univ. Politècnica de Catalunya (UPC), & Institut d'Estudis Espacials de Catalunya (IEEC), Barcelona
Catalonia

A Roadmap for Today's Talk:

What are classical novae

What do/don't we know about novae?

What is the connection (if any) between novae and (type Ia) supernovae?

I. Introduction – Classical Novae in a Nutshell

A **nova** is a thermonuclear explosion driven by mass transfer onto a WD in a close binary system (P_{orb} ~ 1 – 10 hr). They have been observed in all λ's (but detected in γ-rays only at E > 100 MeV)

Moderate rise times (<1 – 2 days),

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

$E_{output} \sim 10^{45}$ ergs = **1 μFOE**

WD + MS (often, K-M dwarfs), WD + RG

Mass ejected: $10^{-7} - 10^{-4} M_\odot$

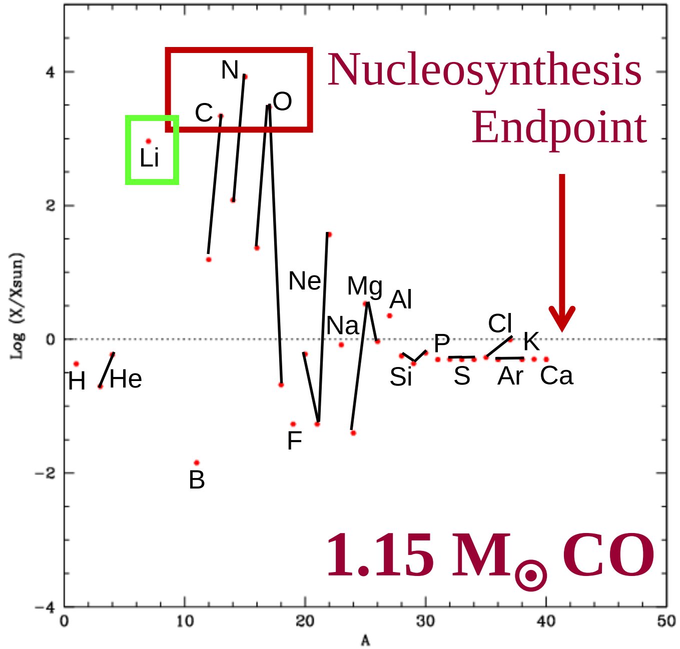
($\sim 10^3$ km s^{-1})

Recurrence: ~ 1 - 100 yr (RNe) –

10^5 yr (CNe)

Frequency: 30 ± 10 yr^{-1}

[Obs. ~ 10 yr^{-1}]


Nucleosynthesis
Endpoint
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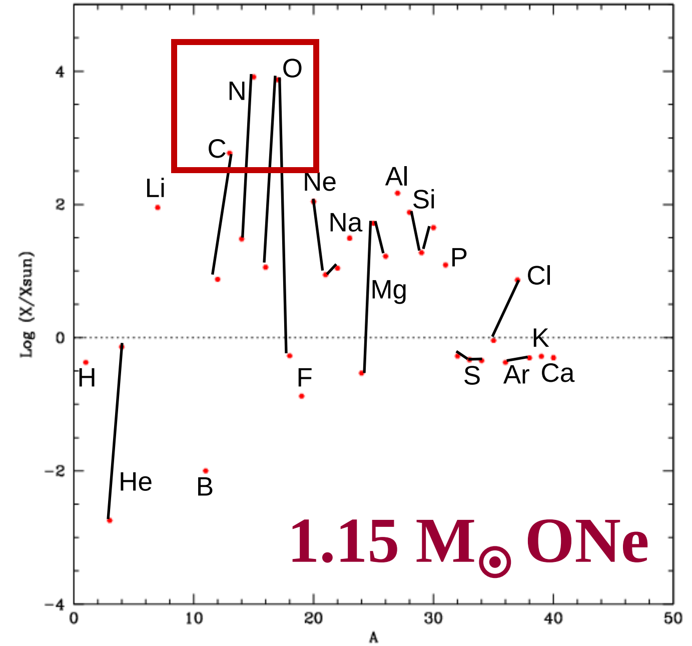
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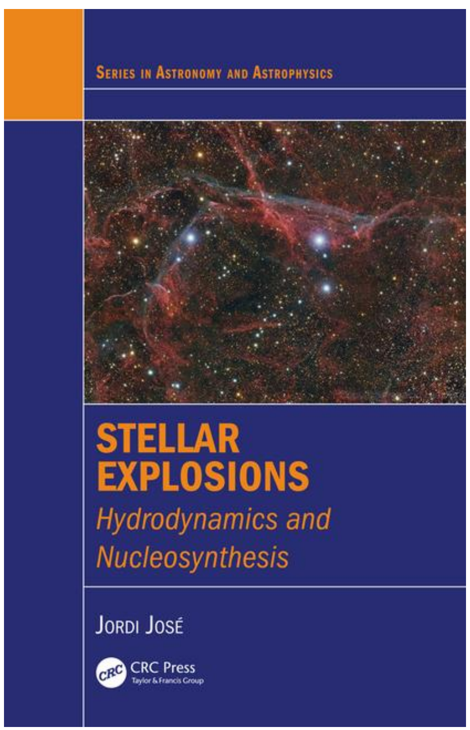
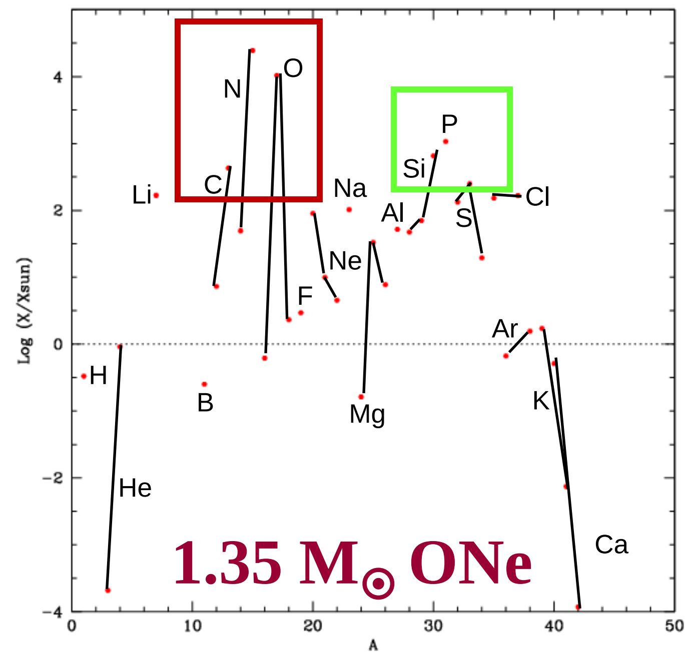

SERIES IN ASTRONOMY AND ASTROPHYSICS
STELLAR EXPLOSIONS
Hydrodynamics and Nucleosynthesis
JORDI JOSÉ
CRC Press
Taylor & Francis Group

JJ (2016)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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

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

PRESOLAR GRAINS FROM NOVAE

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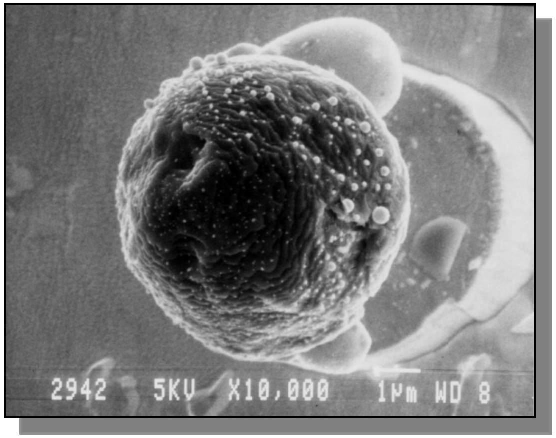
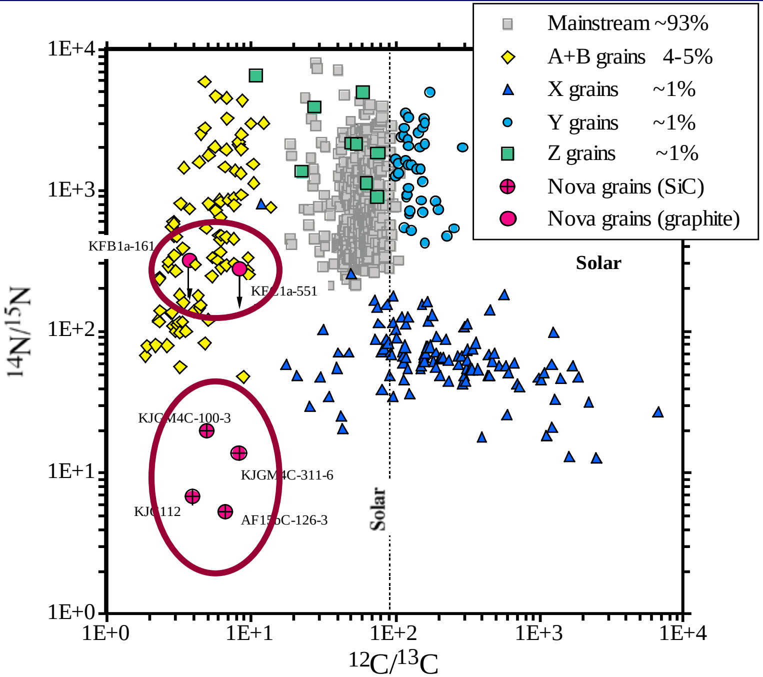
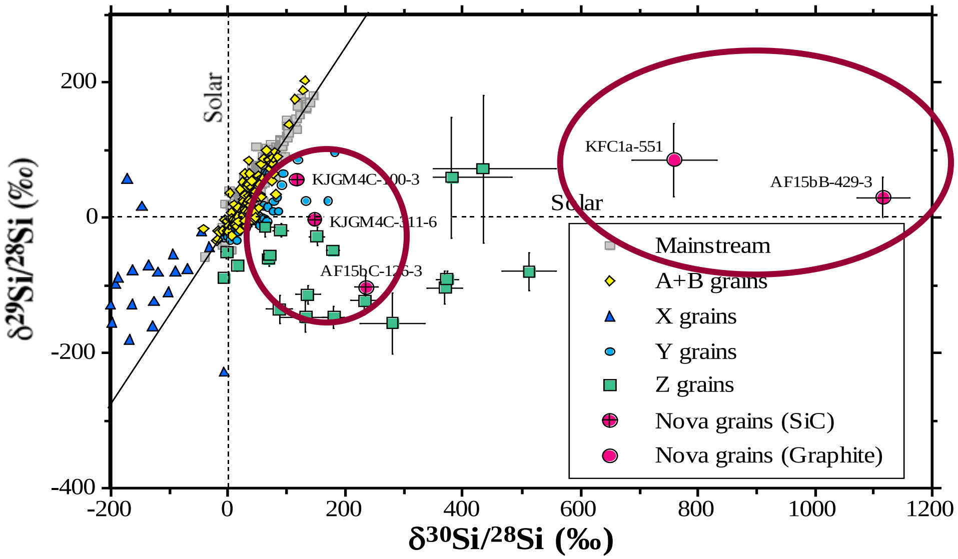
Received 2000 September 15; accepted 2000 December 18

Presolar Grains







Novae may have contributed to the invetory of **presolar grains**

*** identification of 18 presolar nova candidates**

The Astrophysical Journal, 855:76 (14pp), 2018 March 10
https://doi.org/10.3847/1538-4357/aaabb6

CrossMark

On Presolar Stardust Grains from CO Classical Novae

Christian Iliadis[1,2], Lori N. Downen[1,2], Jordi José[3,4], Larry R. Nittler[5], and Sumner Starrfield[6]
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Received 2017 December 15; revised 2018 January 26; accepted 2018 January 28; published 2018 March 9

nature astronomy

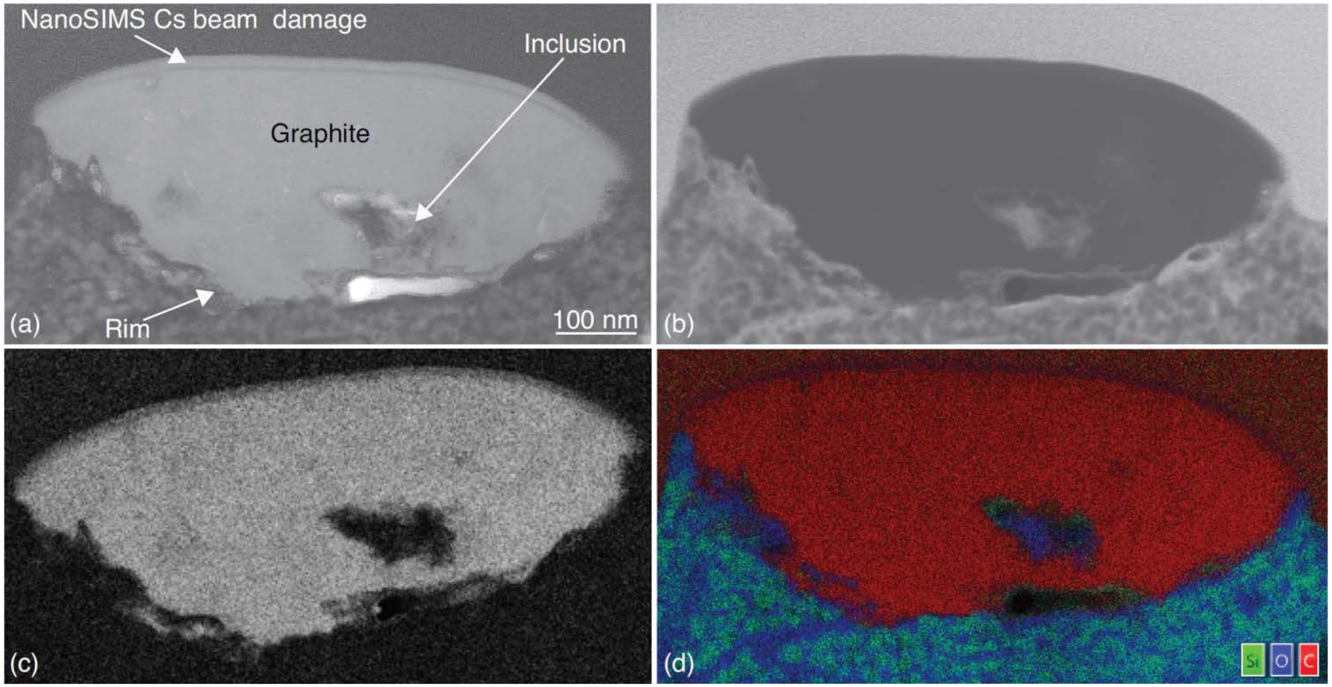
LETTERS

https://doi.org/10.1038/s41550-019-0757-4

Laboratory evidence for co-condensed oxygen- and carbon-rich meteoritic stardust from nova outbursts

Pierre Haenecour[1*], Jane Y. Howe[2,9], Thomas J. Zega[1,3], Sachiko Amari[4,5], Katharina Lodders[5,6], Jordi José[7], Kazutoshi Kaji[8], Takeshi Sunaoshi[2] and Atsushi Muto[2]

2019



The Recurrent Nova ID Card

- long period binaries: very homogeneous class (WD + RG)
  ex: **RS Oph**
- short period binaries: heterogeneous class (WD + MS)
  → Subclasses: **U Sco, CI Aql, T Pyx** [Anupama 2007]

Recurrence time: 1 – 100 yr

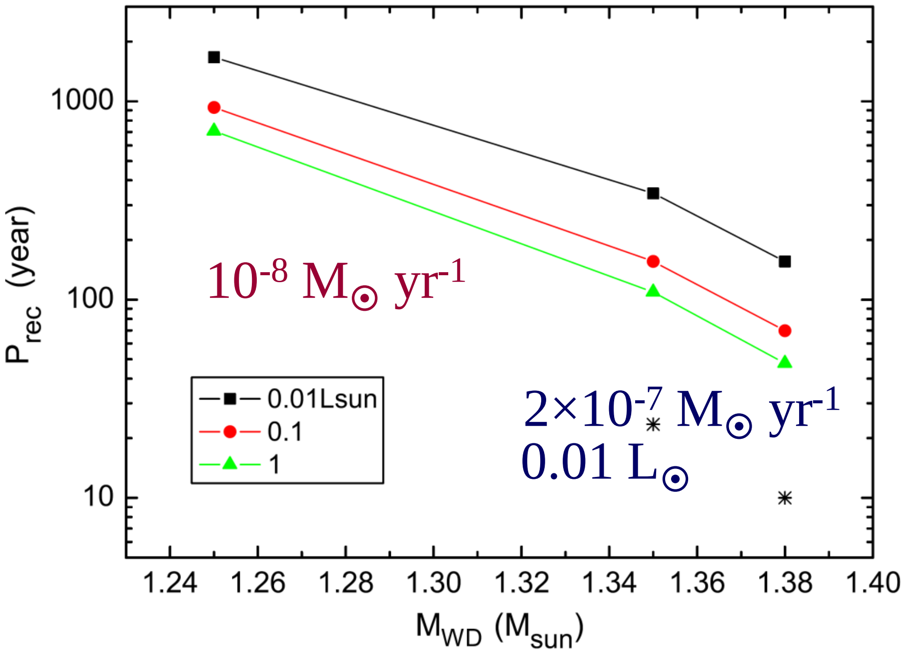
$M_{acc} \sim 10^{-7} - 10^{-8}\ M_{\odot}\ yr^{-1}$

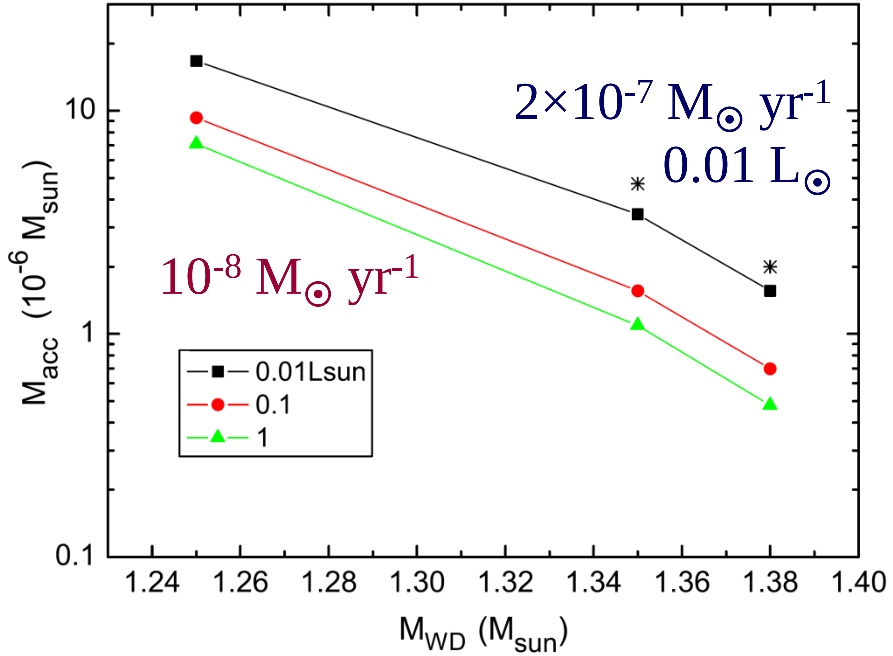
M_{WD} close to Chandrasekhar limit (RS Oph, U Sco)

NOT all the accreted material is ejected → **SN Ia progenitors**

M_{WD}	T_{peak}	M_{acc}	M_{ej}	t_{acc}	t_{rec}	ΔM_{wd}	$\Delta t_{Chandra}$
$L_{ini} = 10^{-2}$ L$_\odot$; $\dot{M} = 2 \times 10^{-7} M_\odot$/year							
1.35	2.8	4.7E−6	3.0E−6	23.3	24	1.7E−6	6.9E5
1.38	3.1	2.0E−6	1.3E−6	10.0	10.4	0.7E−6	2.9E5
$L_{ini} = 10^{-2}$ L$_\odot$; $\dot{M} = 10^{-8}$ M$_\odot$/year							
1.38	3.0	1.6E−6	1.1E−6	156	157	4.1E−7	7.6E6
$L_{ini} = 1$ L$_\odot$; $\dot{M} = 10^{-8}$ M$_\odot$/year							
1.38	2.5	4.8E−7	4.0E−7	47.8	57.6	7.7E−8	1.2E7

Hernanz & JJ (2008), New Astr. Rev.

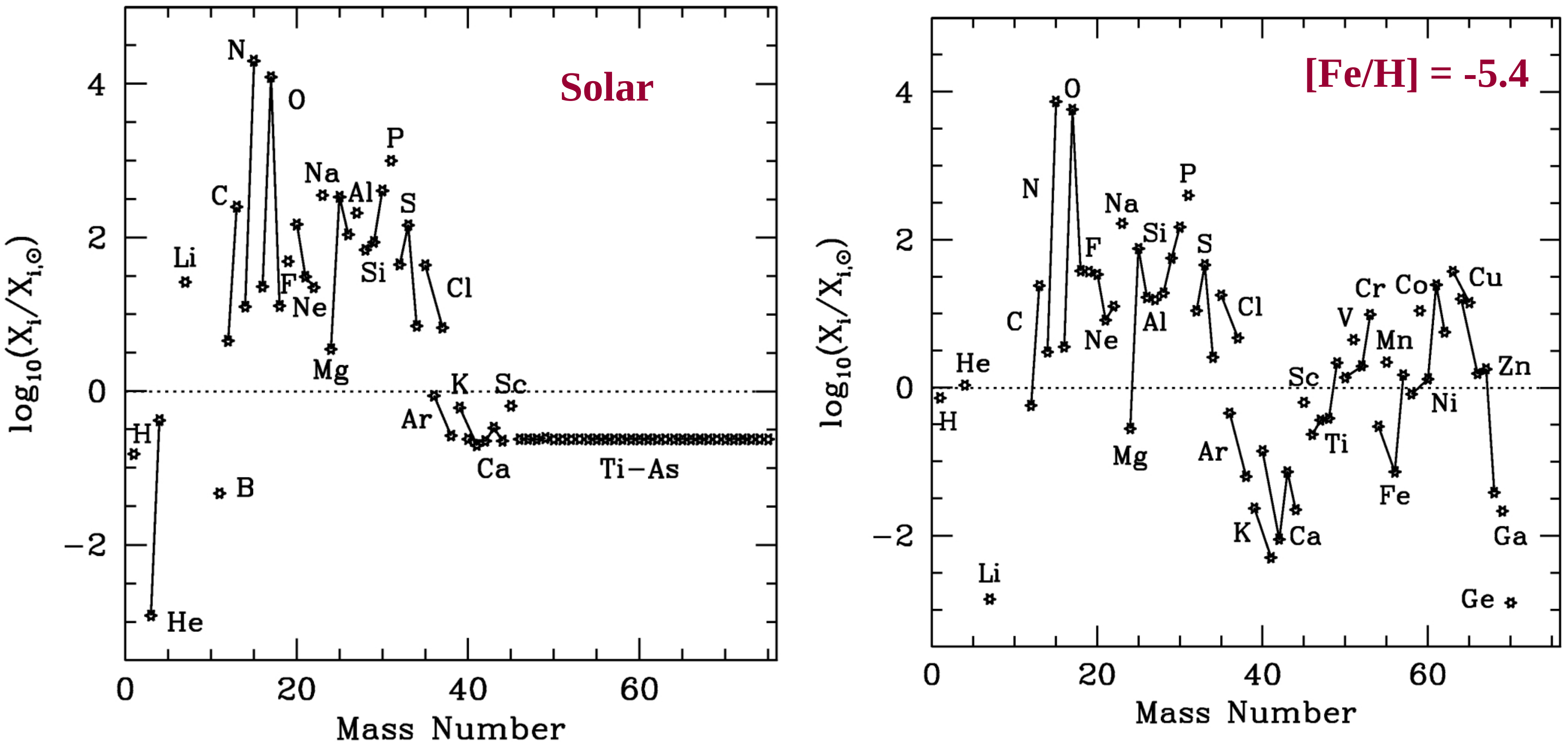




II. Current Challenges in Nova Modeling

1D (Spherically Symmetric) Models have been successful in reproducing the *gross* observational features that characterize Classical Nova outbursts (e.g., light curves, nucleosynthesis...)

***** Have **nova explosions** been **similar** during the overall Galaxy's history?



JJ, García-Berro, Hernanz, & Gil-Pons, ApJL (2007)

The assumption of spherical symmetry (1D) has excluded an entire sequence of events:

***** The way the **explosion/TNR initiates** (point-like ignition) and **propagates**

* **Composition of the ejecta:** $Z_{\odot}$ → **Z ~ 0.2 - 0.5** (up to **0.86**, for V1370 Aql 1982)? Limited T_{peak} CNO-breakout **unlikely**! → **Mixing at the core-envelope interface**

↓ Some 1D attempts

Diffusion Induced Convection [Prialnik & Kovetz 1984; Kovetz & Prialnik 1985; Iben, Fujimoto & MacDonald 1991, 1992; Fujimoto & Iben 1992]
Shear mixing [Durisen 1977; Kippenhahn & Thomas 1978; MacDonald 1983; Livio & Truran 1987; Kutter & Sparks 1987; Sparks & Kutter 1987]
Convective Overshoot Induced Flame Propagation [Woosley 1986]
Convection Induced Shear Mixing [Kutter & Sparks 1989]

* The amount of **mass ejected** predicted by 1D models is smaller than values *inferred* observationally [not unanimously agreed!]

* The long-term evolution of a classical nova requires to address the **interaction** between the nova ejecta, the disk and the stellar companion

A&A 613, A8 (2018)
https://doi.org/10.1051/0004-6361/201731545

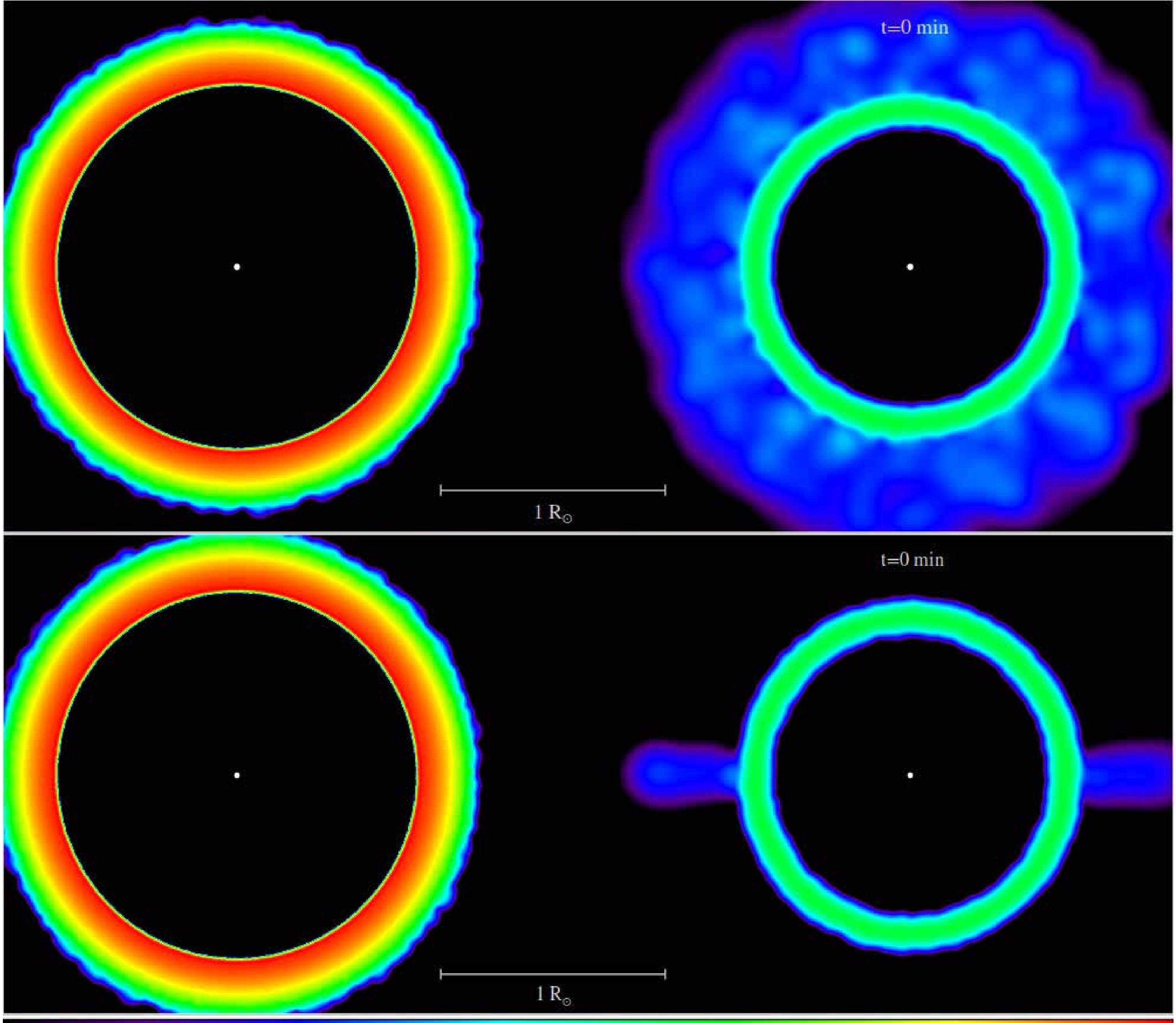
Astronomy & Astrophysics

Three-dimensional simulations of the interaction between the nova ejecta, accretion disk, and companion star★

Joana Figueira[1,2], Jordi José[1,2], Enrique García-Berro[2,3], Simon W. Campbell[4,5,6], Domingo García-Senz[1,2], and Shazrene Mohamed[7,8,9]

XY Plane

YZ Plane



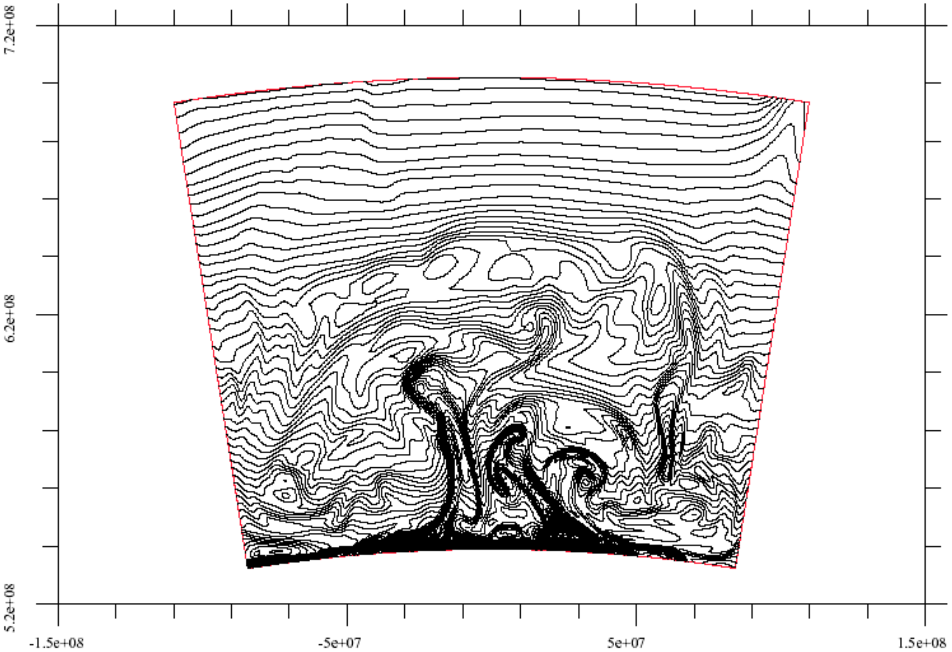
III. Multidimensional Models

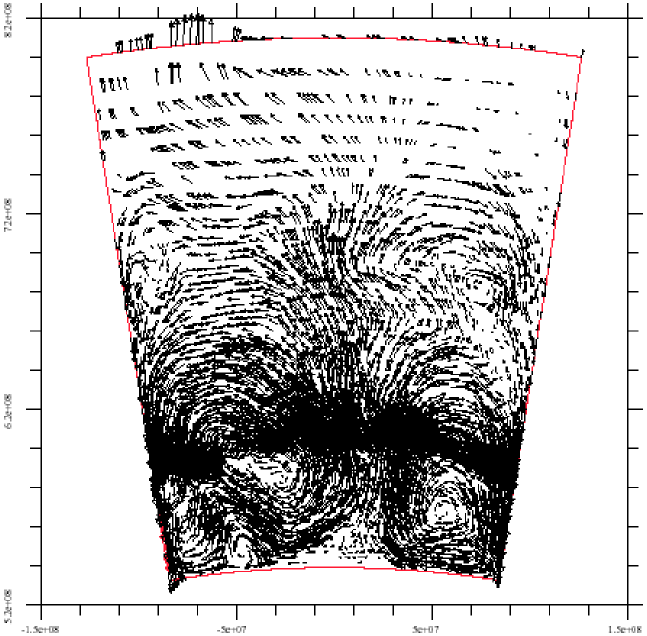
Glasner & Livne (1995), ApJ; Glasner, Livne & Truran (1997), ApJ

A 1.0 M_o CO WD accreting solar composition material (1D) → mapped into a 2D domain at **$T_{base}=10^8$ K.** 2D simulations performed with *VULCAN* (ALE code). Slice of $0.1\pi^{rad}$, **resolution** 5×5 km^2, 12 isotope network

Differences with 1-D simulations:

* TNR initiates as a myriad of irregular, **localized eruptions**
* **Core/envelope interface is now convectively unstable** → mechanism for mixing? (~ convective overshoot, Woosley 1986)
* **Large** convective eddies ($h \sim 2/3\ \Delta z_{env}$)





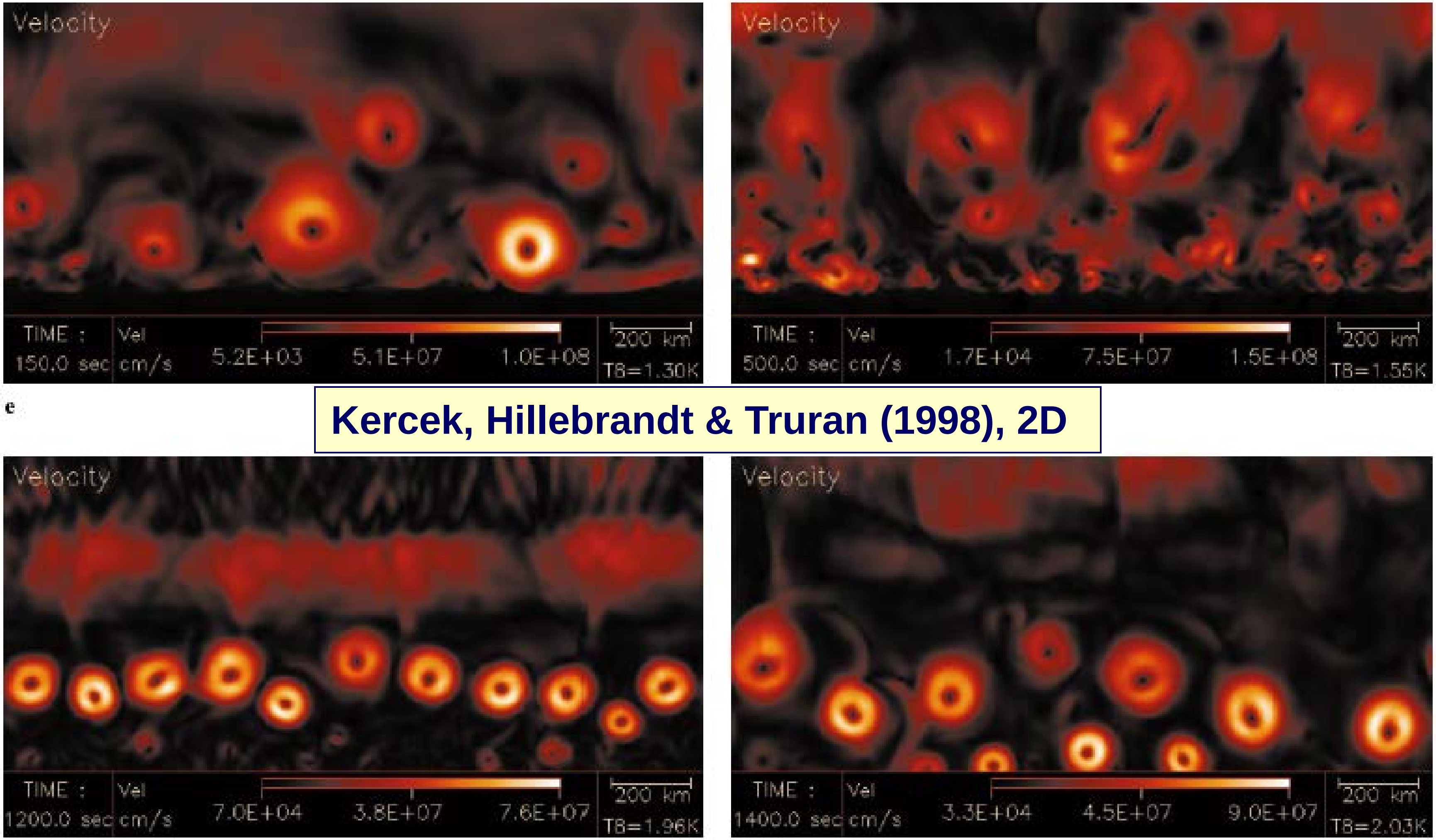
But, overall, good agreement with 1-D simulations!

* 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

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

➡ **Kelvin-Helmholtz** instabilites identified as responsible for **mixing**


Kelvin-Helmholtz instabilities

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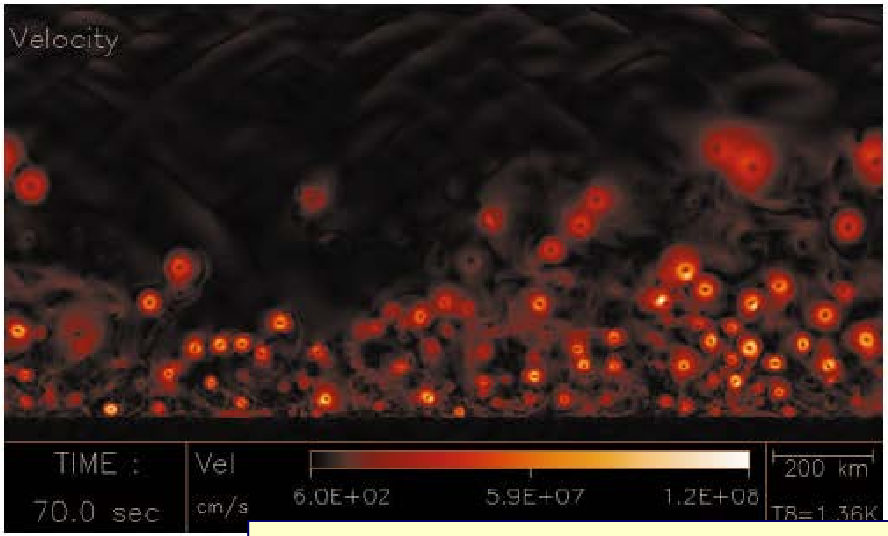
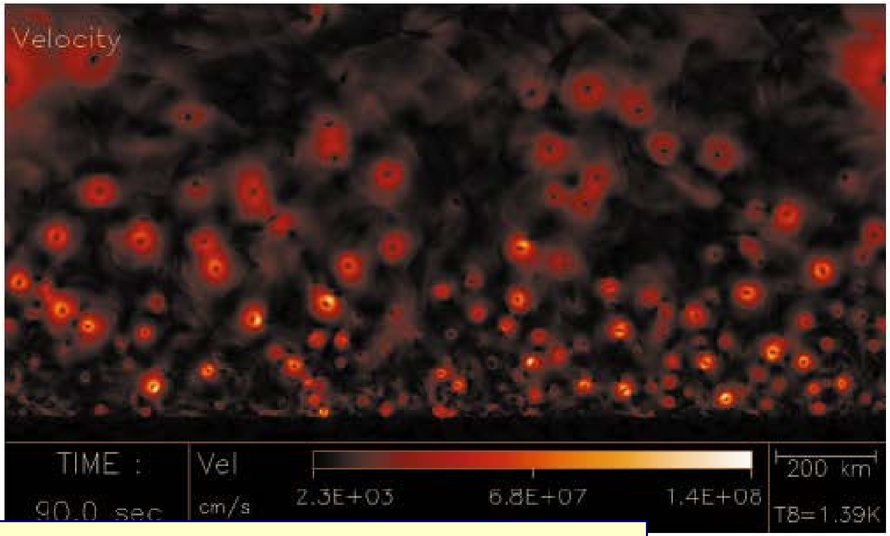
Kercek, Hillebrandt & Truran (1998), 2D

g

h

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





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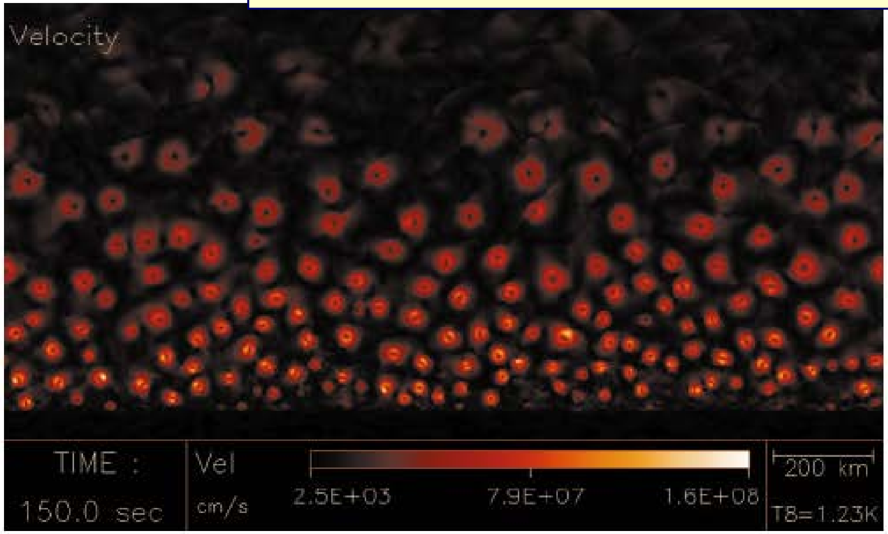
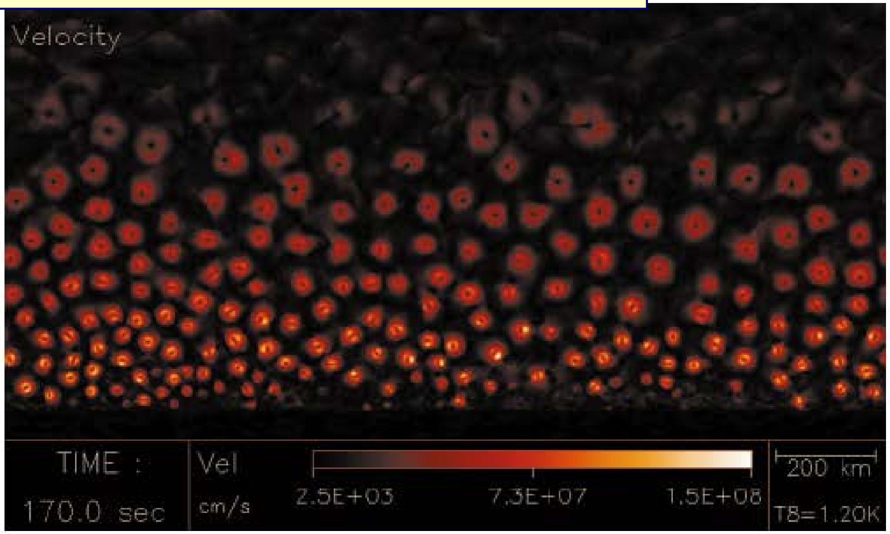
Kercek, Hillebrandt & Truran (1999), High-resolution 2D





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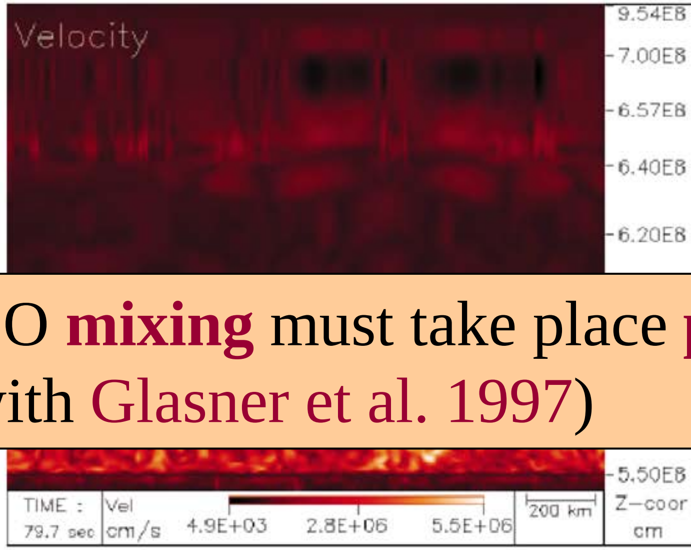
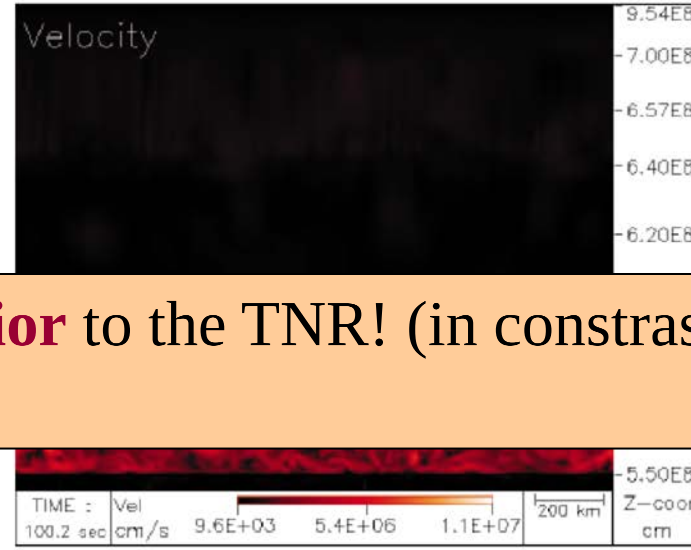
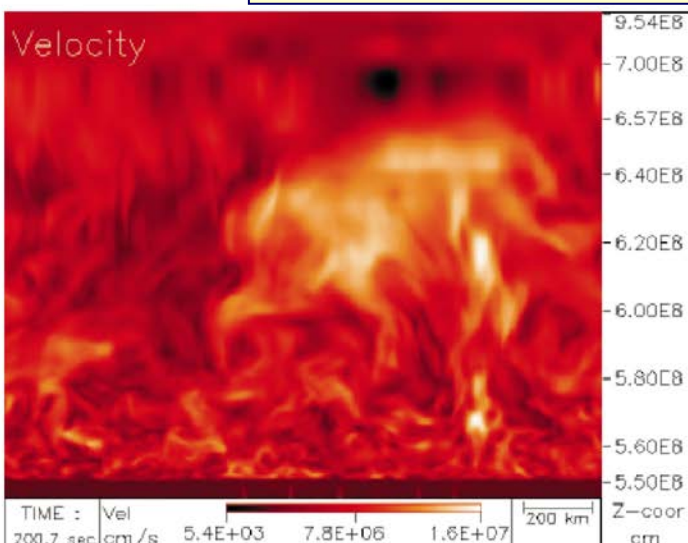




CO **mixing** must take place **prior** to the TNR! (in constrast with Glasner et al. 1997)

c

Kercek, Hillebrandt & Truran (1999), 3D



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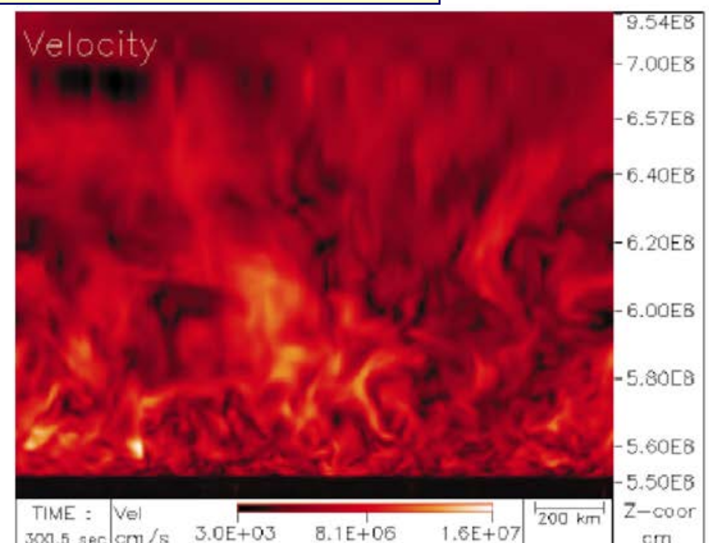


f

Multidimensional Models @ UPC Barcelona

2D Simulations

A&A 513, L5 (2010)
DOI: 10.1051/0004-6361/201014178

Astronomy & Astrophysics

LETTER TO THE EDITOR

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

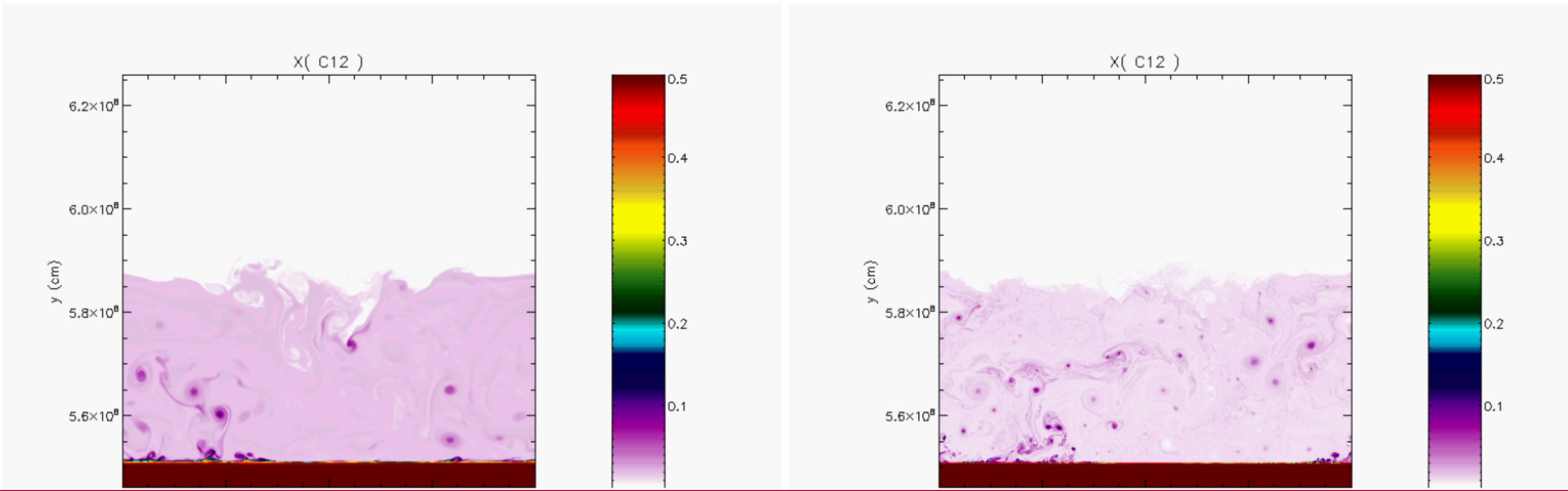
J. Casanova[1], J. José[1], E. García-Berro[2], A. Calder[3], and S. N. Shore[4]

A&A 527, A5 (2011)
DOI: 10.1051/0004-6361/201015895

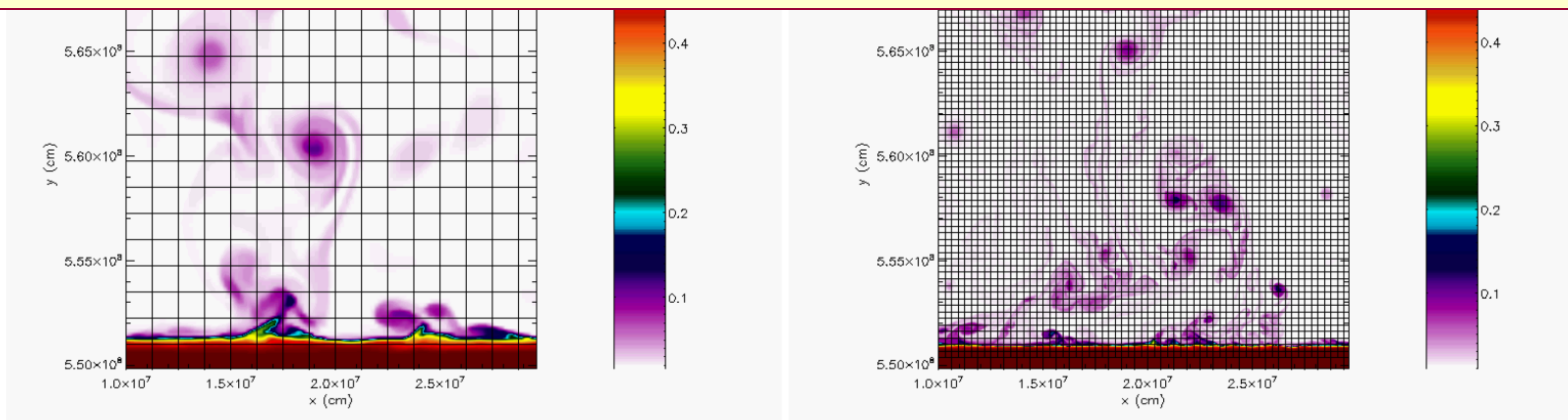
Astronomy & Astrophysics

Mixing in classical novae: a 2-D sensitivity study★

J. Casanova[1,2], J. José[1,2], E. García-Berro[3,2], A. Calder[4], and S. N. Shore[5]



Results are **independent** of the specific choice of the **initial perturbation** (duration, strength, location, and size), **the resolution adopted**, or the **size of the computational domain**

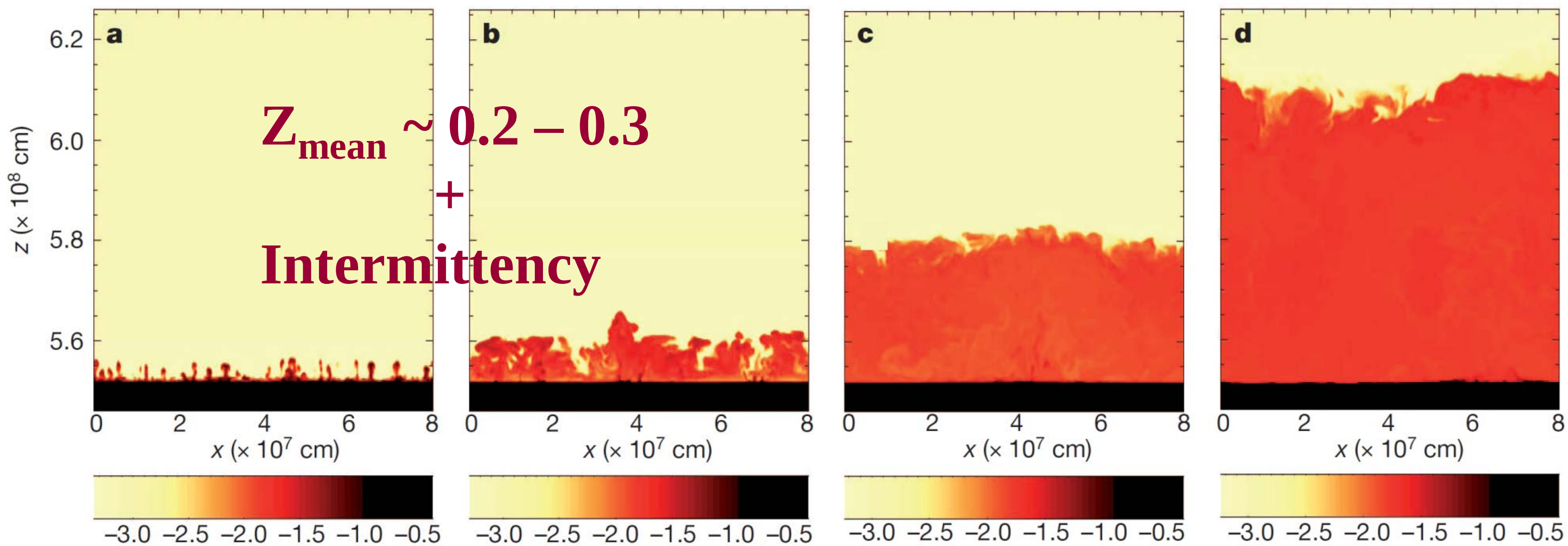


LETTER
doi:10.1038/nature10520

3D Models of Mixing

Kelvin–Helmholtz instabilities as the source of inhomogeneous mixing in nova explosions

Jordi Casanova[1,2], Jordi José[1,2], Enrique García-Berro[3,2], Steven N. Shore[4] & Alan C. Calder[5]



$Z_{mean} \sim 0.2 - 0.3$

+

Intermittency

MareNostrum II (BSC, 2006), 94.21 Tflops/s, 10,240 cores

MareNostrum III (BSC, Jan. 2013), >1 Petaflop/s, 48,000 cores

MareNostrum IV (BSC, Jun. 2017), >11 Petaflop/s, 165,888 cores

A&A 595, A28 (2016)
DOI: 10.1051/0004-6361/201628707

Astronomy & Astrophysics

Three-dimensional simulations of turbulent convective mixing in ONe and CO classical nova explosions★

Jordi Casanova[1], Jordi José[2,3], Enrique García-Berro[4,3], and Steven N. Shore[5]

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[2] Departament de Física, EUETIB, Universitat Politècnica de Catalunya, c/Comte d'Urgell 187, 08036 Barcelona, Spain
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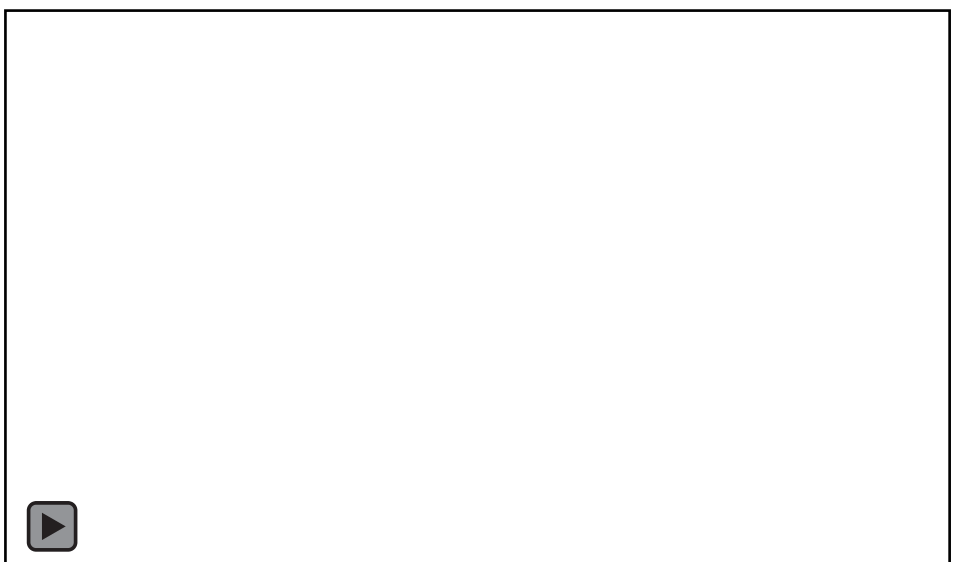

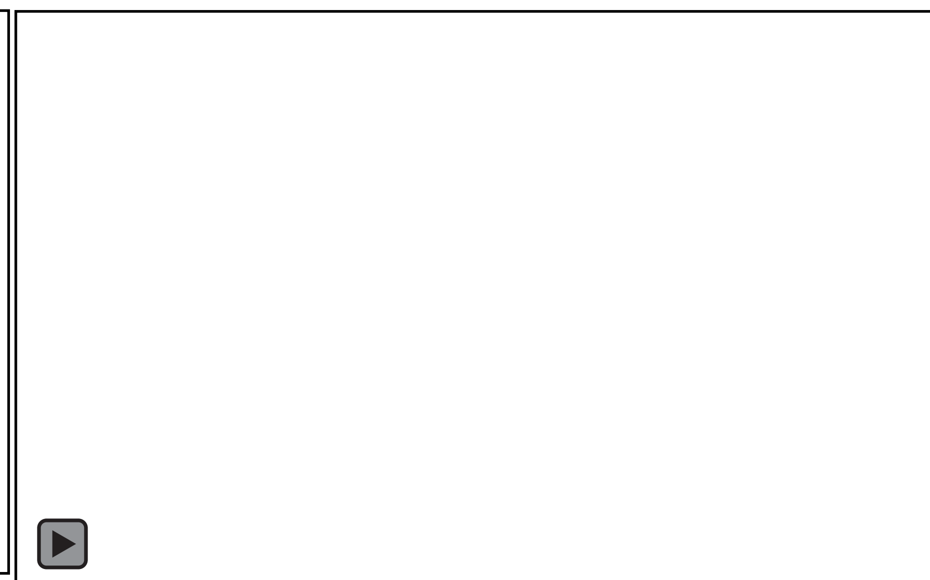

A&A 619, A121 (2018)
https://doi.org/10.1051/0004-6361/201833422

Astronomy & Astrophysics

Two-dimensional simulations of mixing in classical novae: The effect of white dwarf composition and mass★

Jordi Casanova[1], Jordi José[2,3], and Steven N. Shore[4]

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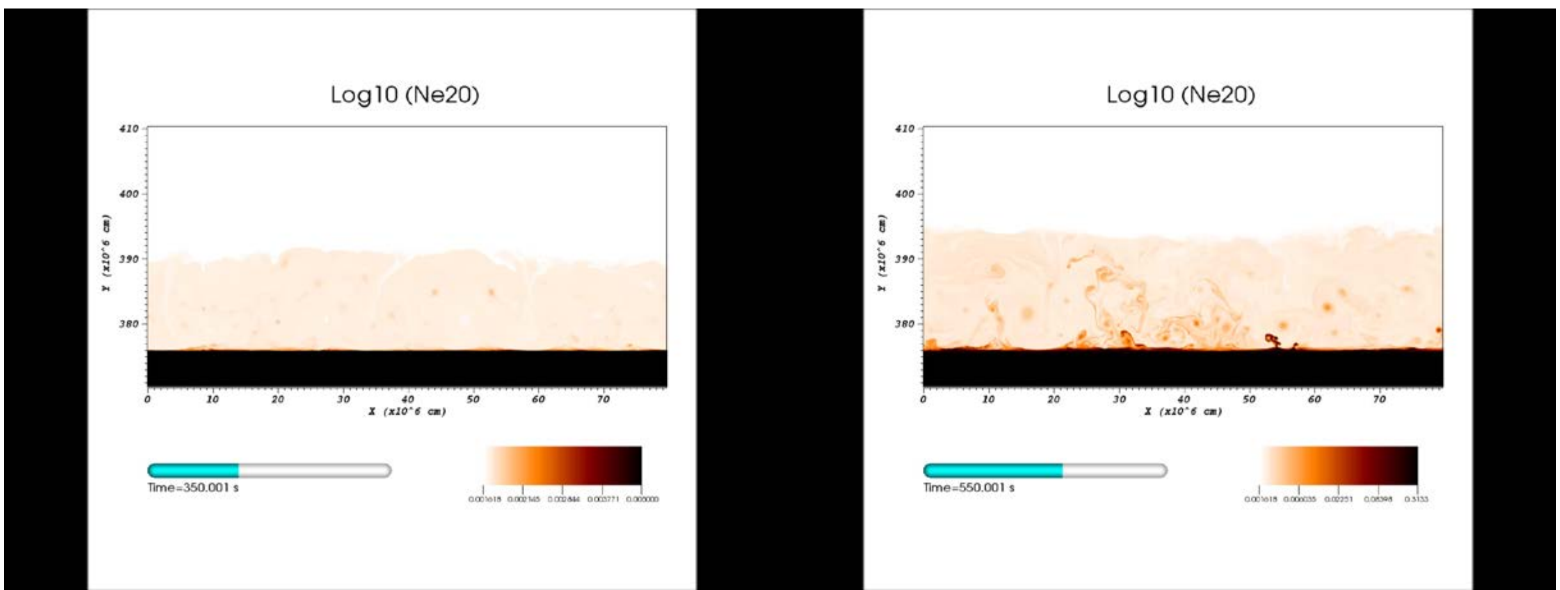

III. Does the White Dwarf Mass Grows or Decreases ?

Sumner Starrfield, *Arizona State University*

Classical nova explosions: SN Ia progenitors and lithium factories

We report on studies of Classical Nova (CN) explosions where we follow the evolution of thermonuclear runaways (TNRs) on Carbon Oxygen (CO) white dwarfs (WDs). We vary both the mass of the WD (from $0.6M_\odot$ to $1.35M_\odot$) and the composition of the accreted material. Our simulations rely on the results of multi-dimensional studies of TNRs in WDs that find sufficient mixing with WD material occurs after the TNR is well underway, reaching levels of enrichment that agree with observations of CN ejecta abundances. We use NOVA (our 1-dimensional hydrodynamic code) to accrete solar matter until the TNR is ongoing and then switch from the solar composition to a mixed composition (either 25% WD material and 75% solar or 50% WD material and 50% solar). Because the amount of accreted material is inversely proportional to the initial ^{12}C abundance, by first accreting solar matter the amount of material taking part in the outburst is larger than in those simulation where we assume a mixed composition from the beginning. We find large enrichments of ^{7}Be in the ejected gases implying that CO CNe may be responsible for a significant fraction (~ 300 $M_\odot$) of the $\sim$1000 $M_\odot$ we determined for the total amount ^{7}Li in the galaxy. Finally, these simulations eject less material than accreted. We predict, therefore, that the WD is growing in mass as a consequence of the accretion/ CN outburst/ accretion cycle. This result implies that CO CNe may be a channel of Supernova Ia progenitors and not the Super-soft X-ray sources as has been assumed previously.

Starrfield et al.

* Classical Novae **make most of the 7Li** in the Galaxy

* The WD in both CO and ONe is **growing in mass** to the Chandrasekhar limit → Novae **are SNIa Progenitors**

JJ et al.

* Classical Novae **DO NOT** make most of the 7Li in the Galaxy

* The WD in both CO and ONe is **NOT** growing in mass to the Chandrasekhar limit → Novae are **NOT** SNIa progenitors

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Thank you for your attention!

Classical (and Recurrent) Novae
and the Mass of the Underlying White Dwarf
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