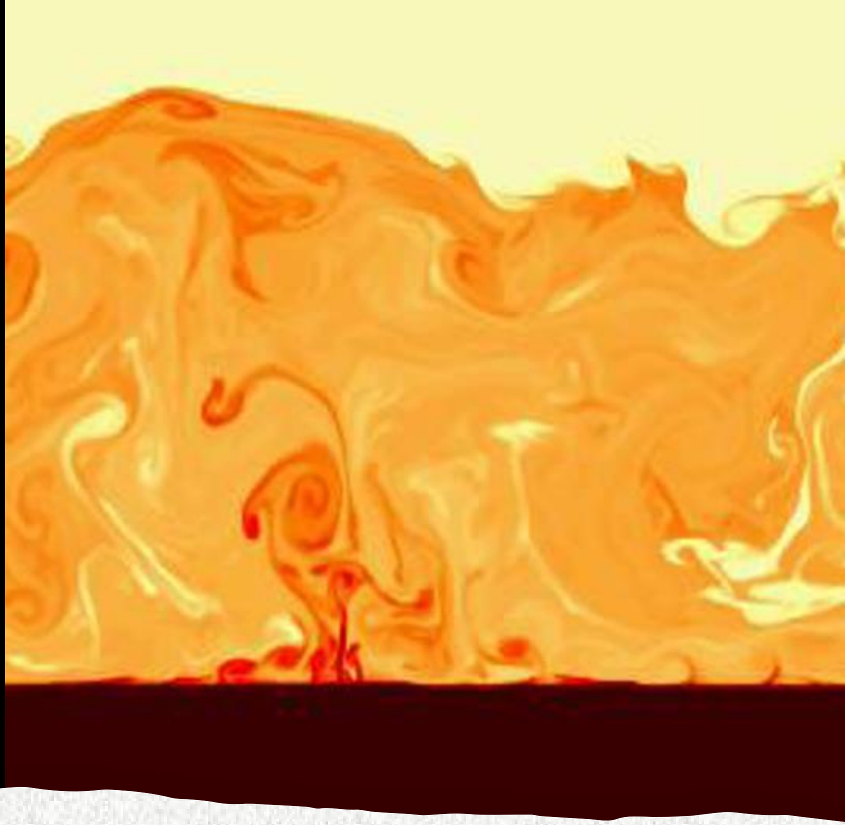
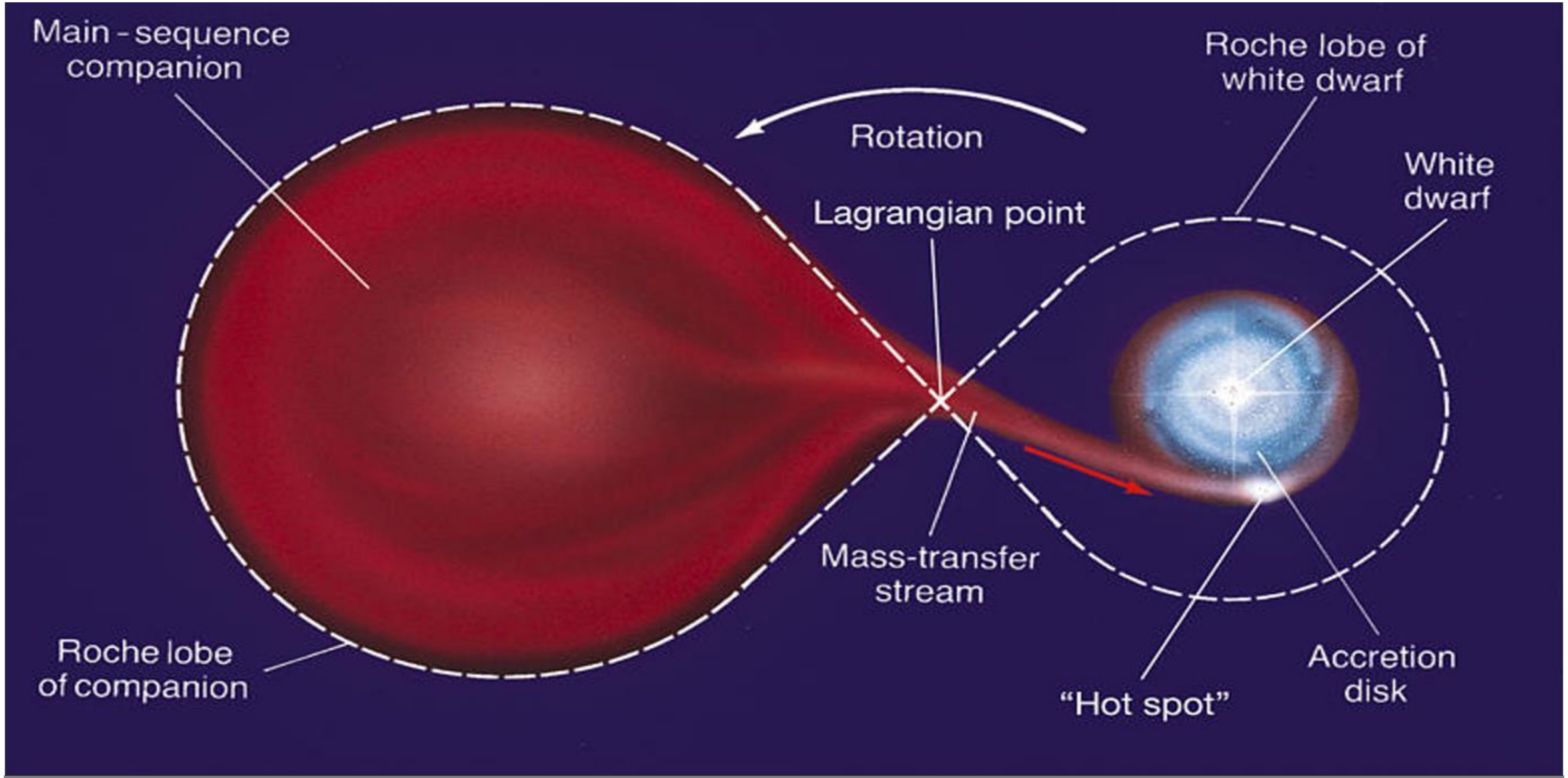


Multi-Dimensional Simulations of Classical Novae

Jordi Casanova
Regis University


Main - sequence companion
Rotation
Roche lobe of white dwarf
White dwarf
Lagrangian point
Mass-transfer stream
Roche lobe of companion
"Hot spot"
Accretion disk

Thermonuclear Runaway Model

- Hydrogen-rich matter (**metallicity Z ~ 0.02)** from companion on top of the white dwarf becomes **partially degenerate.**
- Temperature ~ 10^7K → **Thermonuclear reactions** take place (Starrfield et al. 1972; Prialnik et al. 1986; José & Hernanz 2008).

Credit: NASA / JPL-Caltech

Thermonuclear Runaway Model

- **Convection** sets in.
- Unstable chemical species **^{13}N, ^{14}O, ^{15}O, ^{17}F** disintegrate via β^+ (Starrfield et al. 1972).
- **Degeneracy is lifted** (Starrfield et al. 1972).
- **Ejecta: $10^{-7} - 10^{-3}$ $M_\odot$, v ~ 10^3 km/s, T ~ (1-4) x 10^8 K**

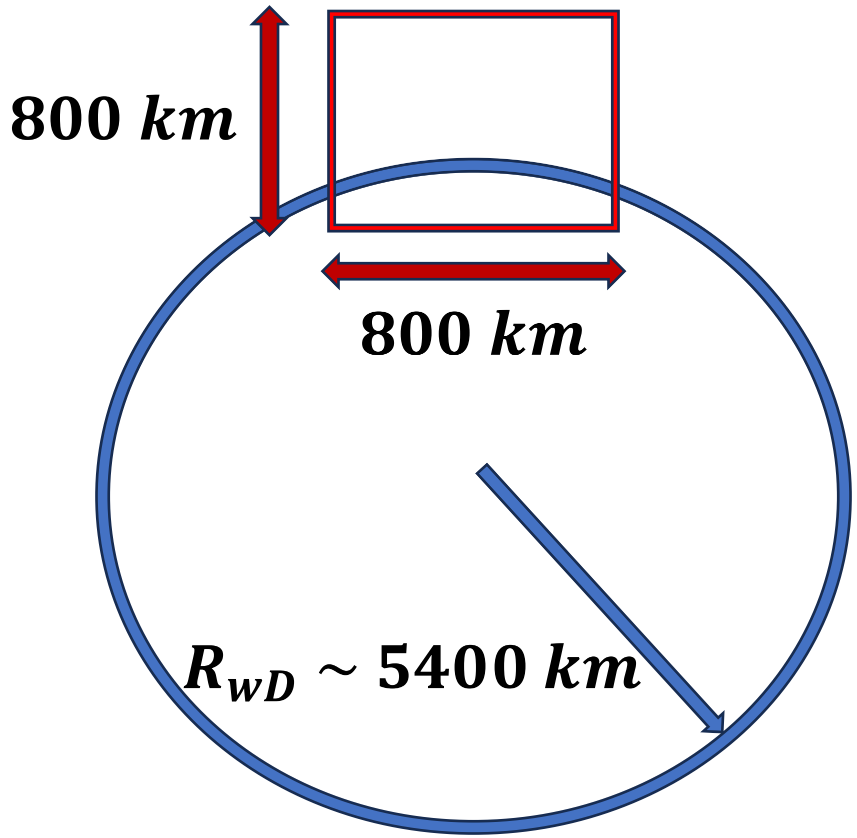
IMPORTANT! Non-solar isotopic abundances in the ejecta! Z ~ 0.25 - 0.50

(Gehrz et al. 1998)

Metals from the core of the white dwarf are transported to the accreted envelope by a mixing process, increasing the metallicity of the ejecta

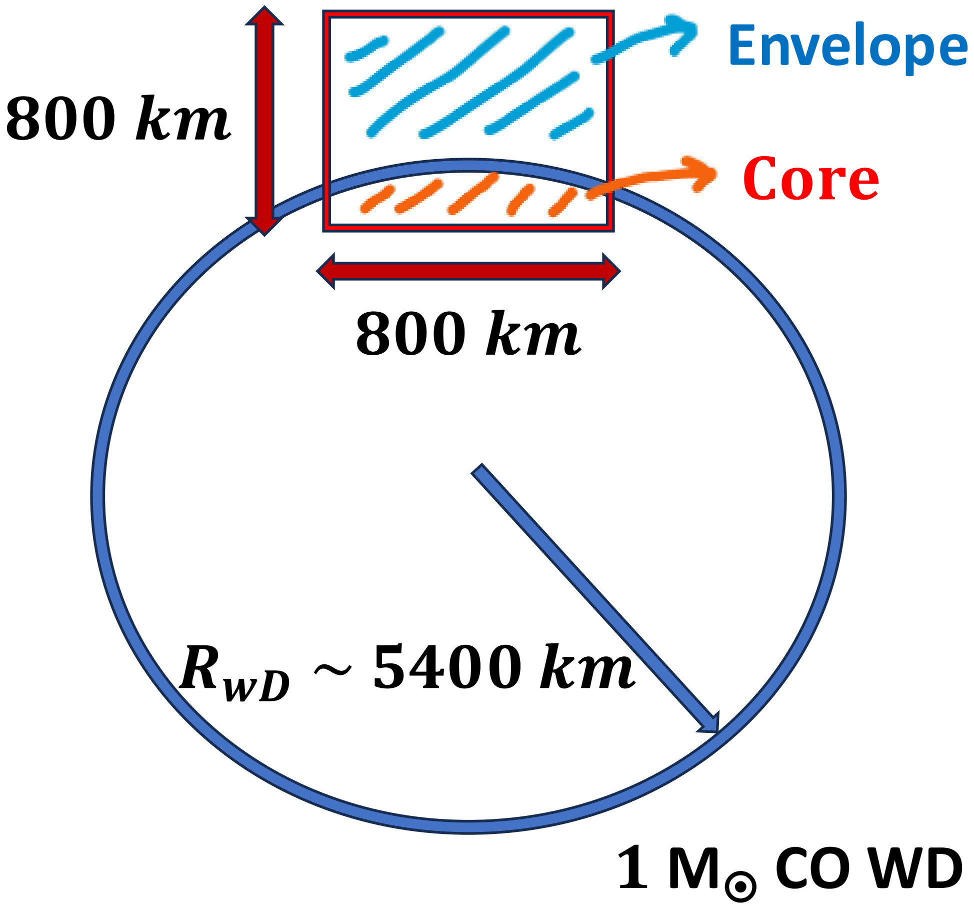
(Sparks, W. M. 1969; Starrfield et al. 1972)

Multi-Dimensional Novae

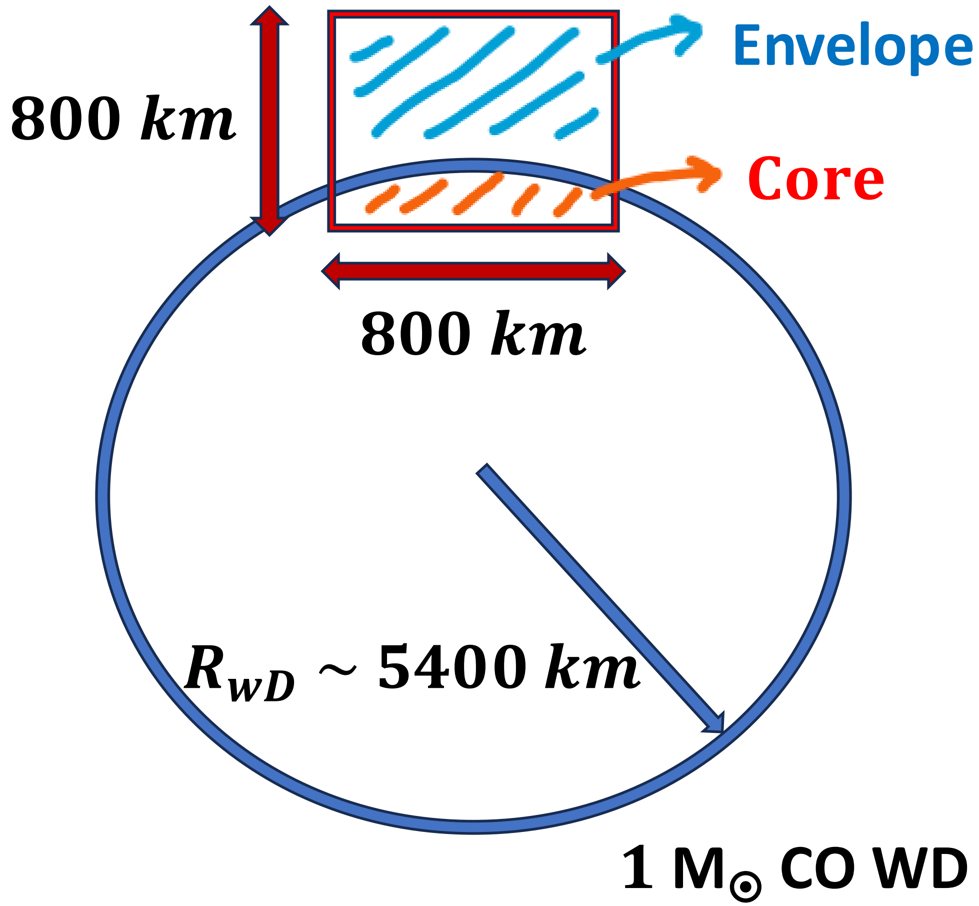


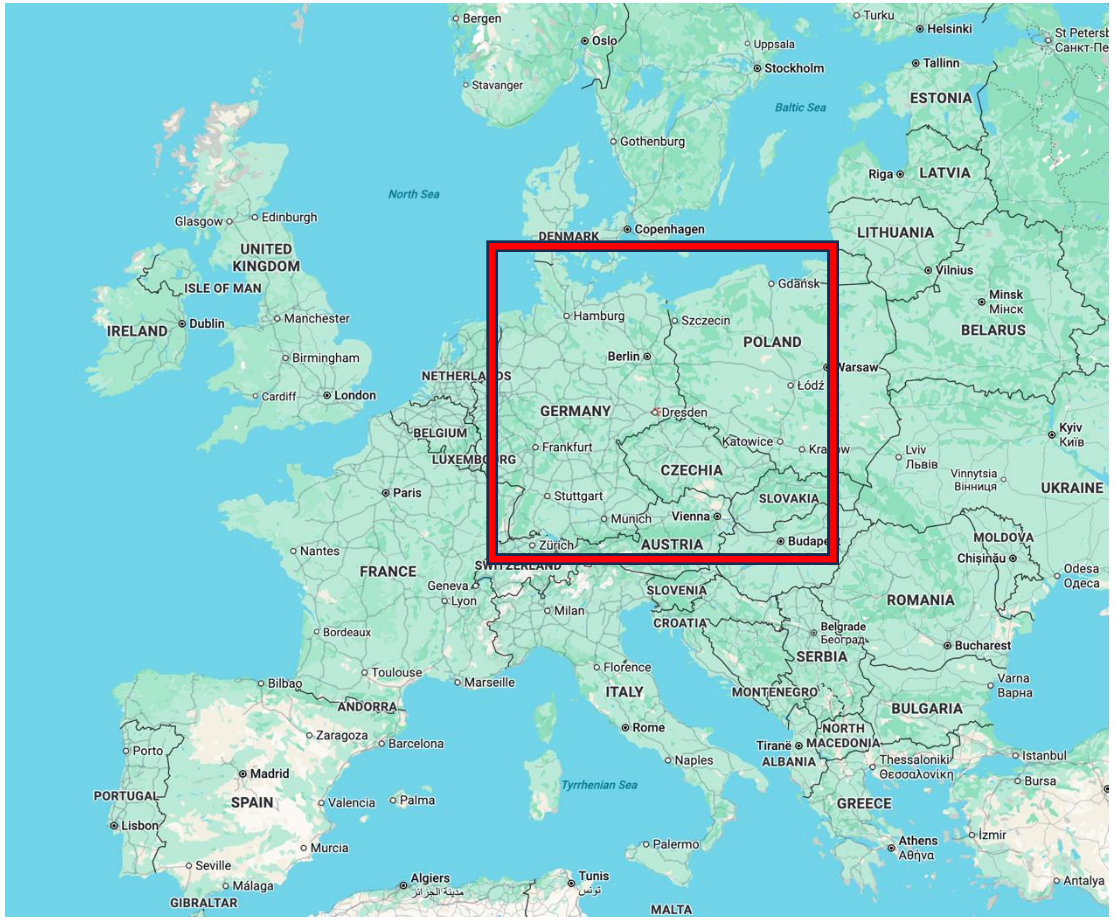
1 $M_\odot$ CO WD

Multi-Dimensional Novae



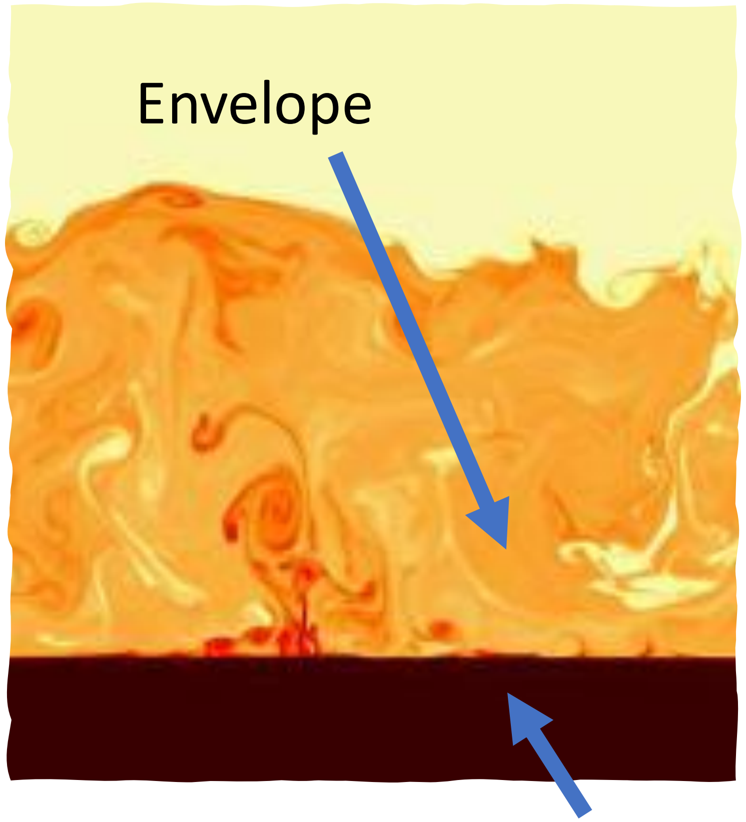
Multi-Dimensional Novae





Initial Conditions

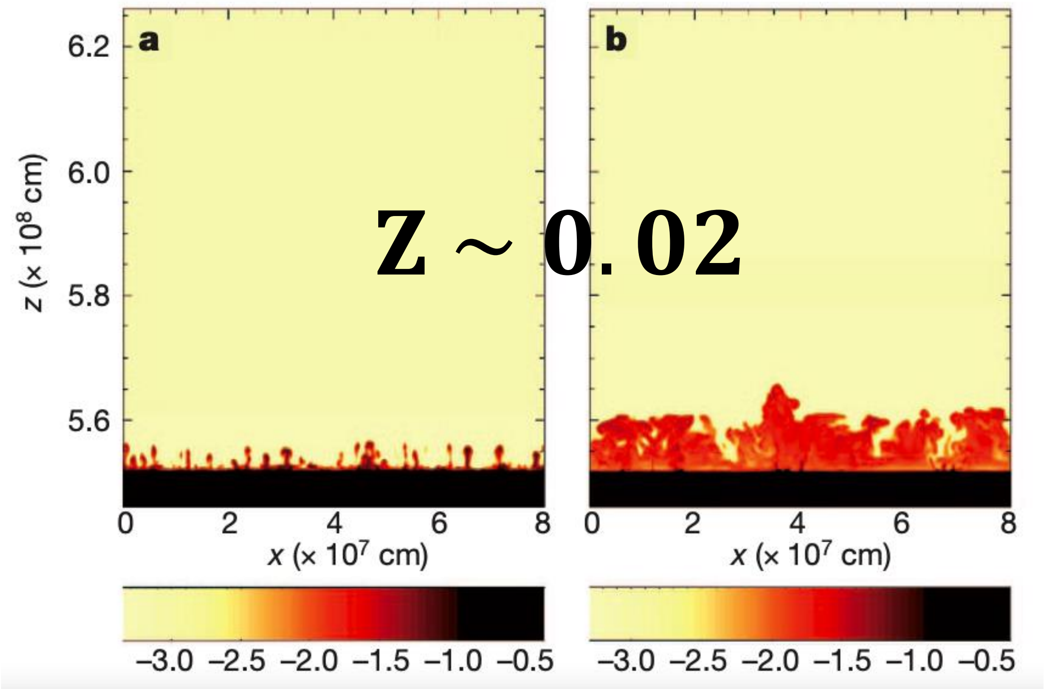
- **1D model computed by the Barcelona group.**
- Accretion of matter with solar composition **(Z = 0.02)** onto a **1 $M_\odot$ CO white dwarf** at a rate of **2×10^{-10} $M_\odot$ yr^{-1}**.
- **Nuclear network (13 isotopes, 18 reactions):** Angulo et al. (1999), José et al. (2006), José & Shore (2008).
- Plane-parallel geometry $\mathbf{800 \times 800 \times 800\ km^3}$
- **FLASH code.**



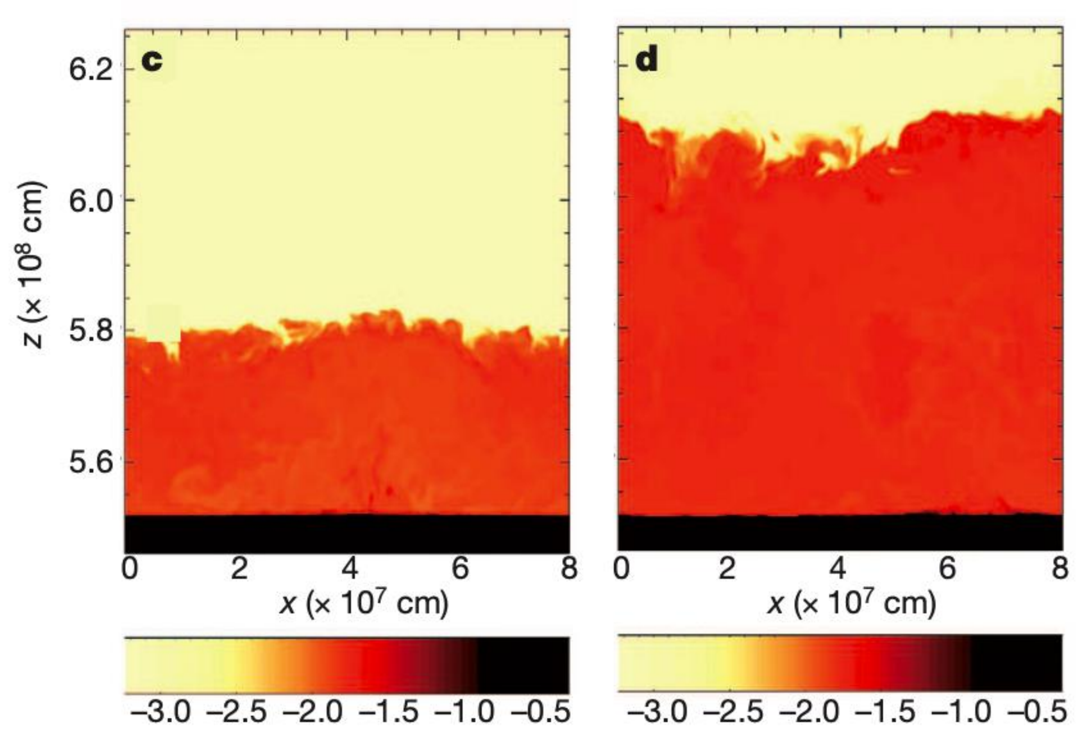
Core: X(^{12}C)=X(^{16}O)=0.5

Three-Dimensional Simulations

Casanova, J., José, J., García-Berro, E., Shore, S. N., & Calder, A. C. 2011b, Nature, 478, 490.



$$\mathbf{Z \sim 0.02}$$



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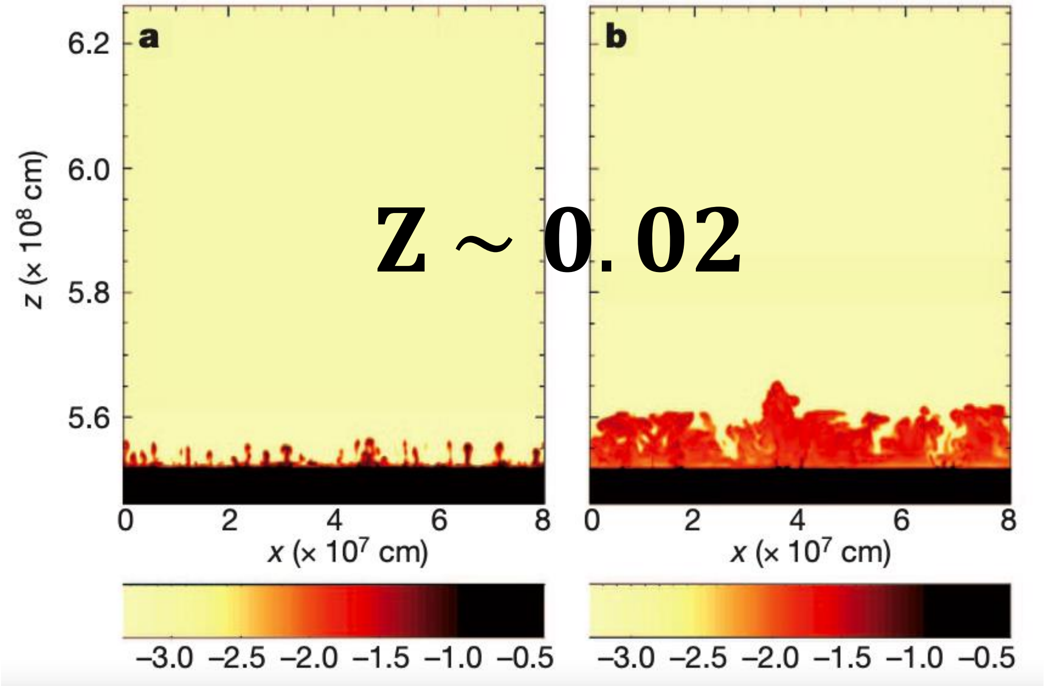
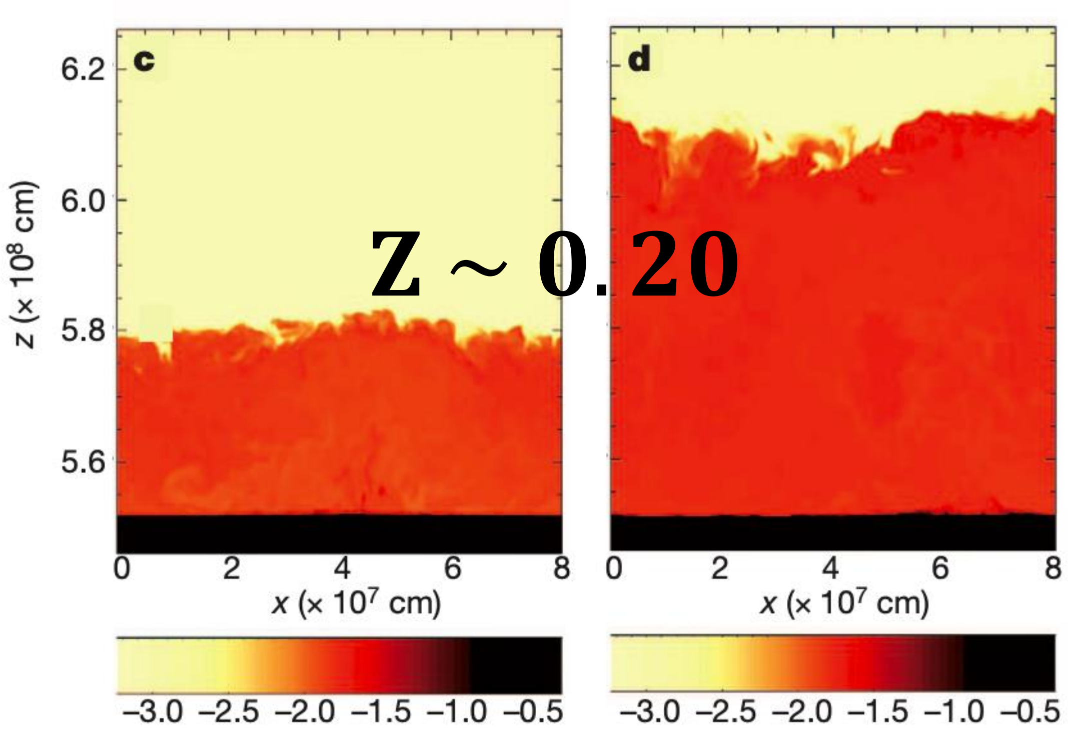


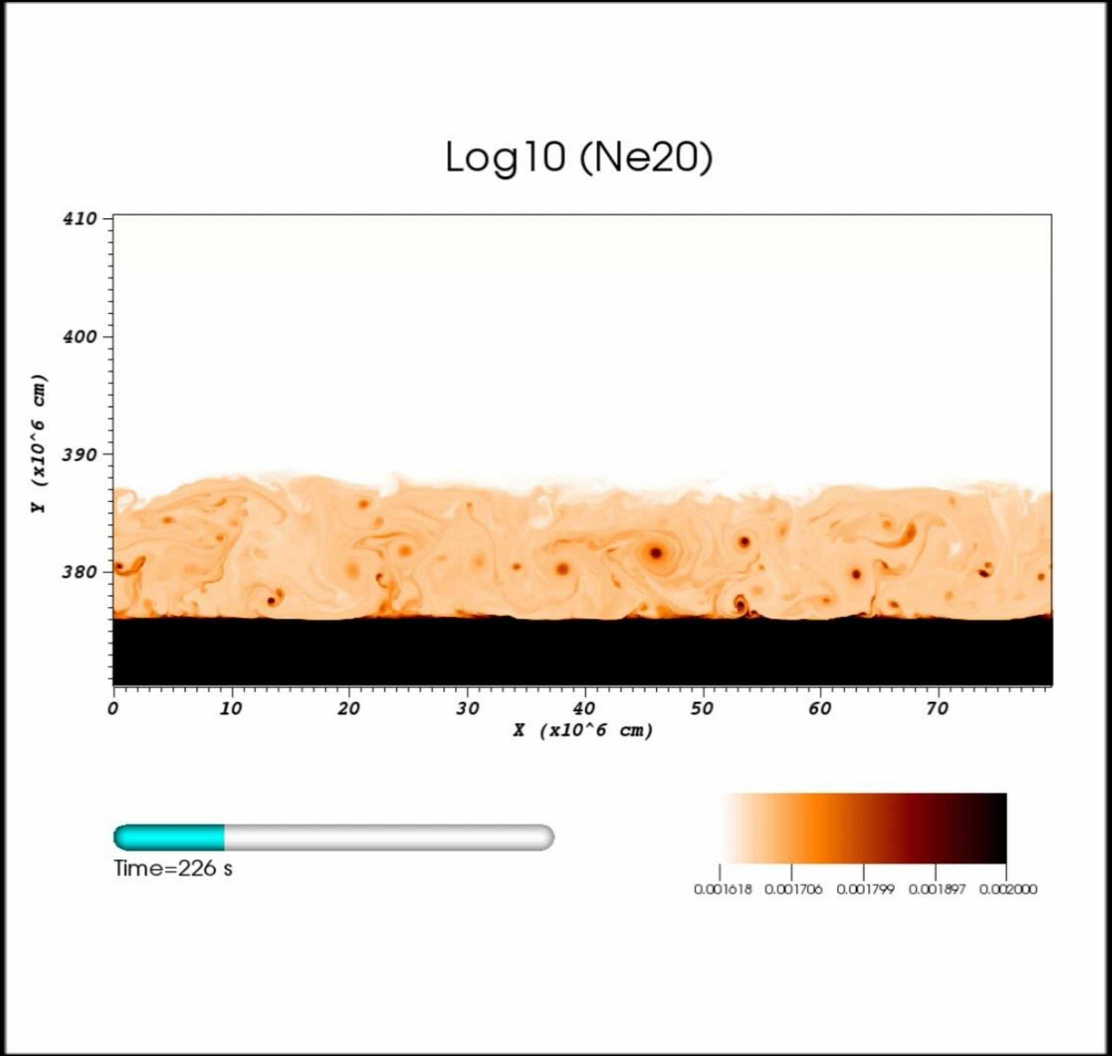


3D Nova Simulations

Mixing at the Core-Envelope Interface

Extended Work

- **3D simulations of mixing in neon novae** (Casanova, J., José, J., García-Berro, E., & Shore, S. N. 2016, A&A, 595, A28).
- **Effect of white dwarf composition and mass: 2D study** (Casanova, J., José, J., & Shore, S. N. 2018, A&A, 619, A121).



Success & Limitations of Current Nova Models

- Multi-dimensional calculations performed with the FLASH code show that **Kelvin-Helmholtz instabilities** at the core-envelope interface **enrich the envelope with core material** at levels in agreement with observations for a wide range of scenarios.
- Is that all we need to understand nova explosions? **NO!**
- **Reduced computational domain is a major limitation.**

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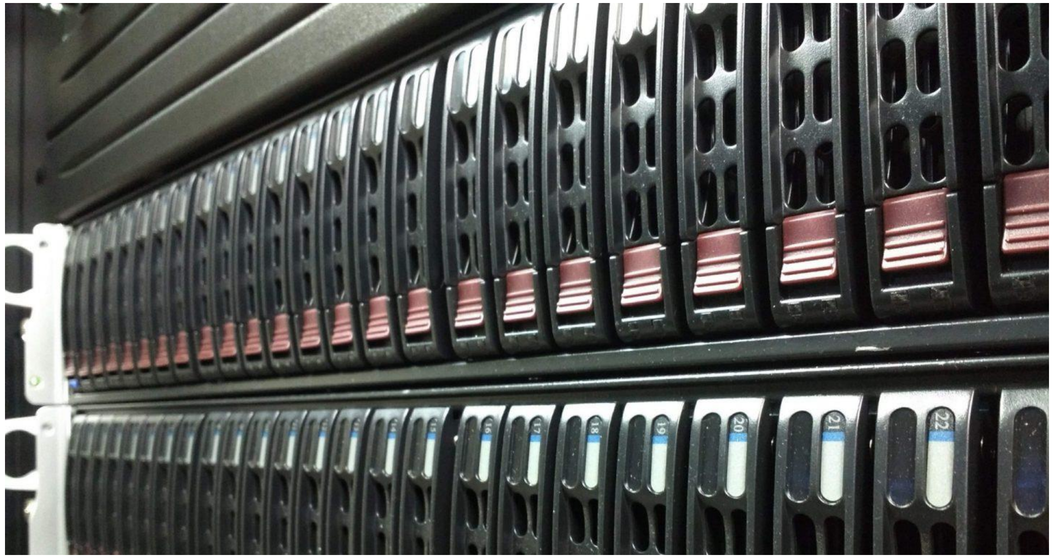
PROGRESS OF THE NOVA OUTBURST FROM MIXING THROUGH EXPANSION AND UP TO DETACHMENT!

VIPER – High Performance Computing Cluster (University of Hull, UK)

- 180x2x14-core processors (3.3 GHz, 128 GB RAM)
- 4x4x10-core processors (2GHz, 1TB RAM)
- **524,160 CPU hours**
- **Collaboration: Regis University & Polythecnic University of Catalonia.**



High memory nodes at Viper. Credit: VIPER, Chris Collins

CHETEC INFRA

Chemical Elements as Tracers of the Evolution of the Cosmos – Infrastructures for Nuclear Astrophysics

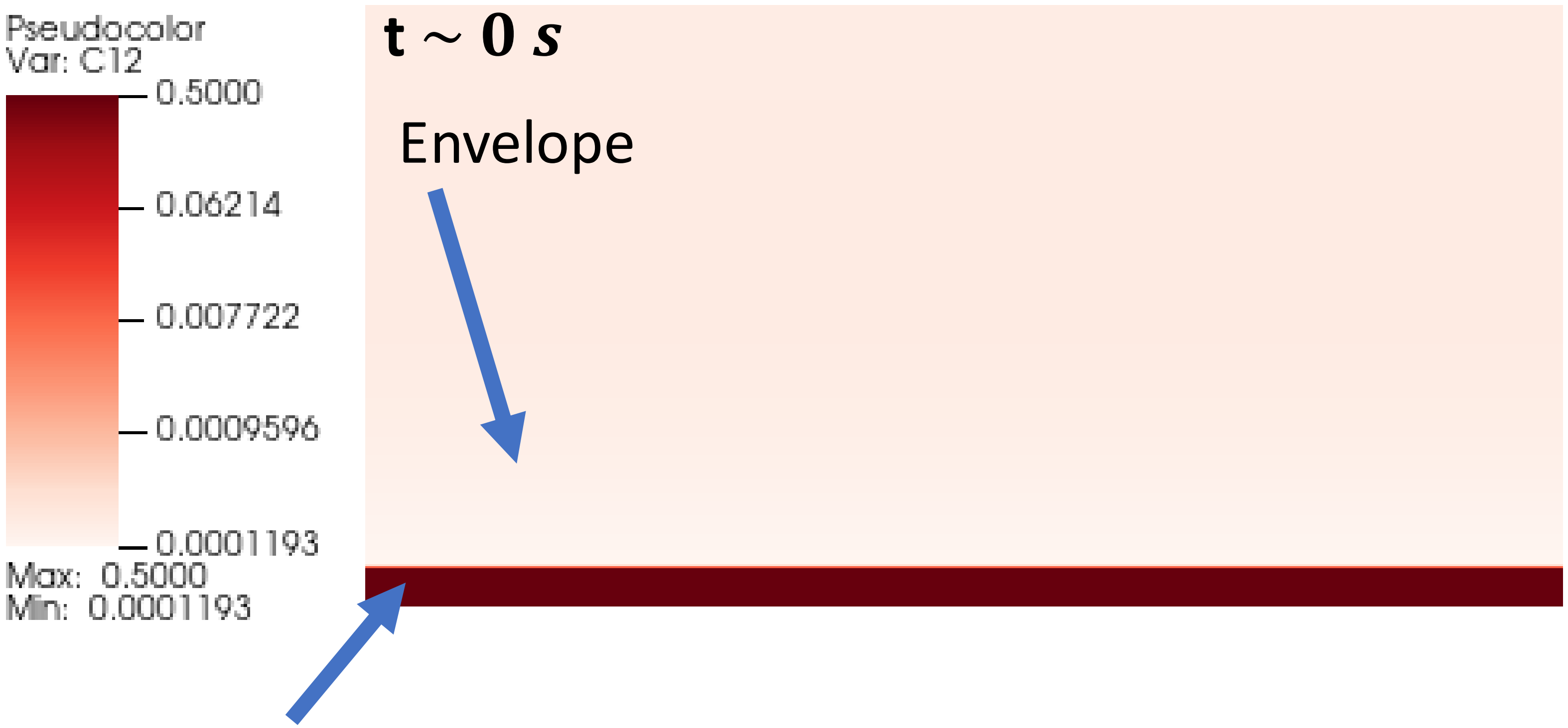
Next Generation of Nova Models

1. **Horizontal stretch!**

- $1600 \times 1600 \times 800\ \mathrm{km}^3$

2. **Realistic gravity profile!**

- Gravity allowed to vary throughout the envelope.



Core: X(^{12}C)=X(^{16}O)=0.5

$1600 \times 1600 \times 800\ \mathrm{km}^3$
+ realistic gravity profile

$1600 \times 1600 \times 800\ \mathrm{km}^3$

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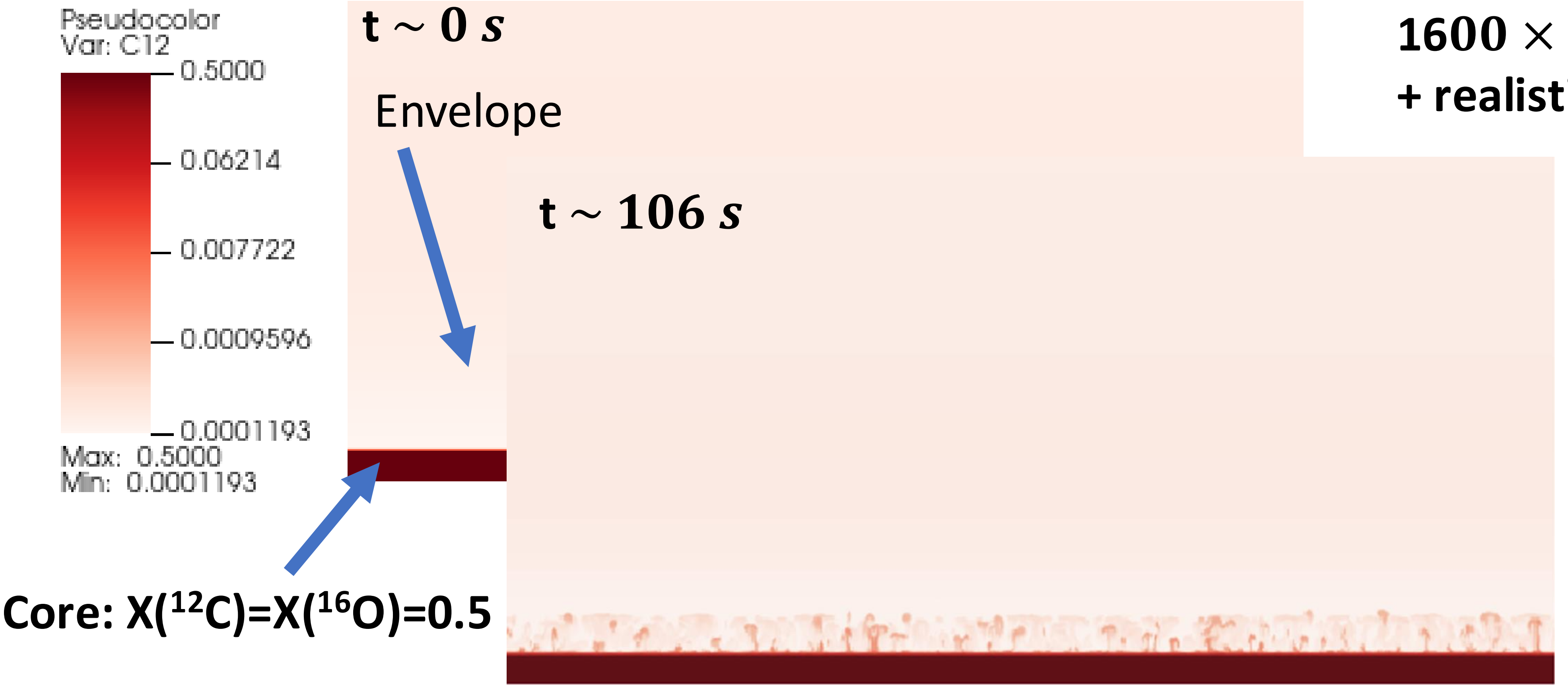
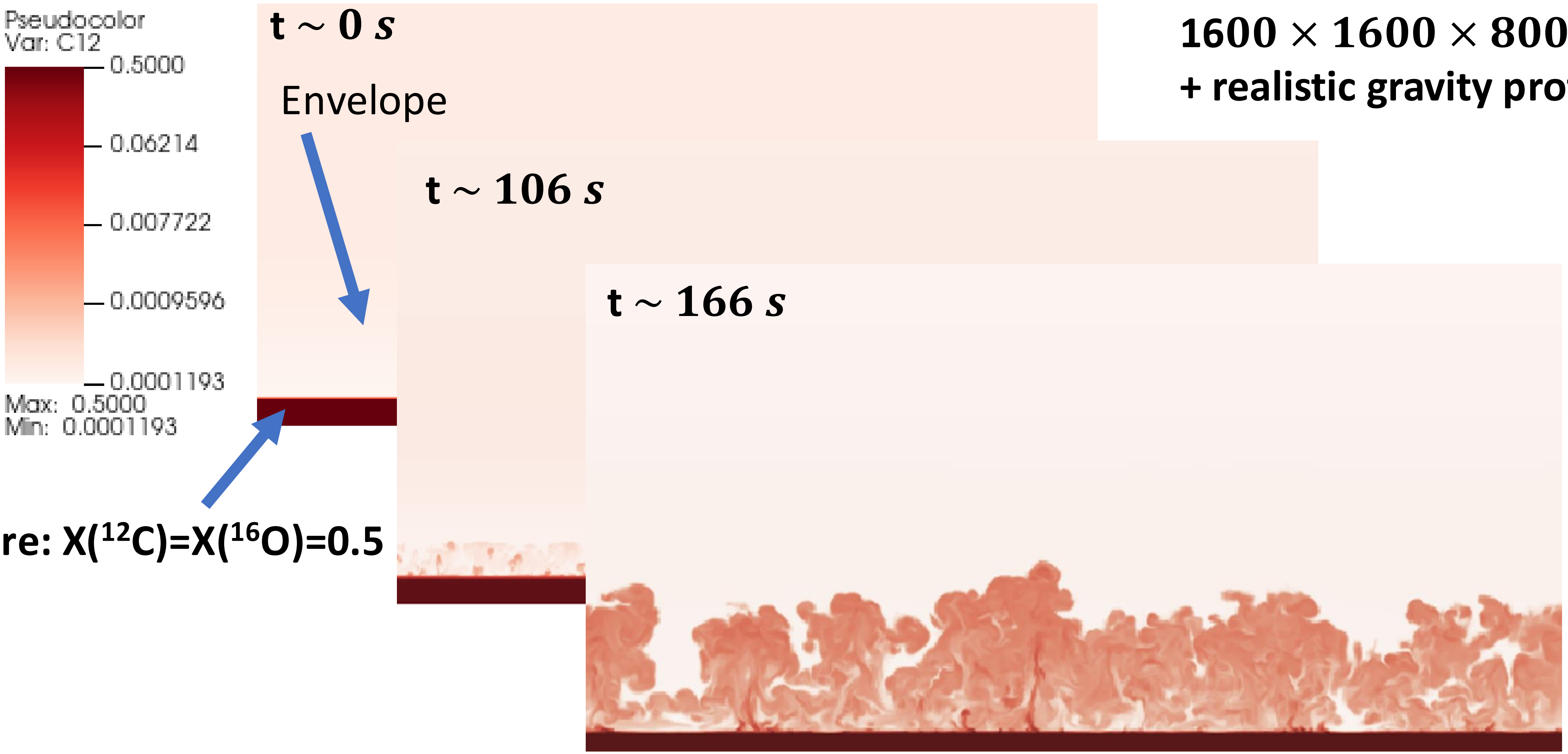
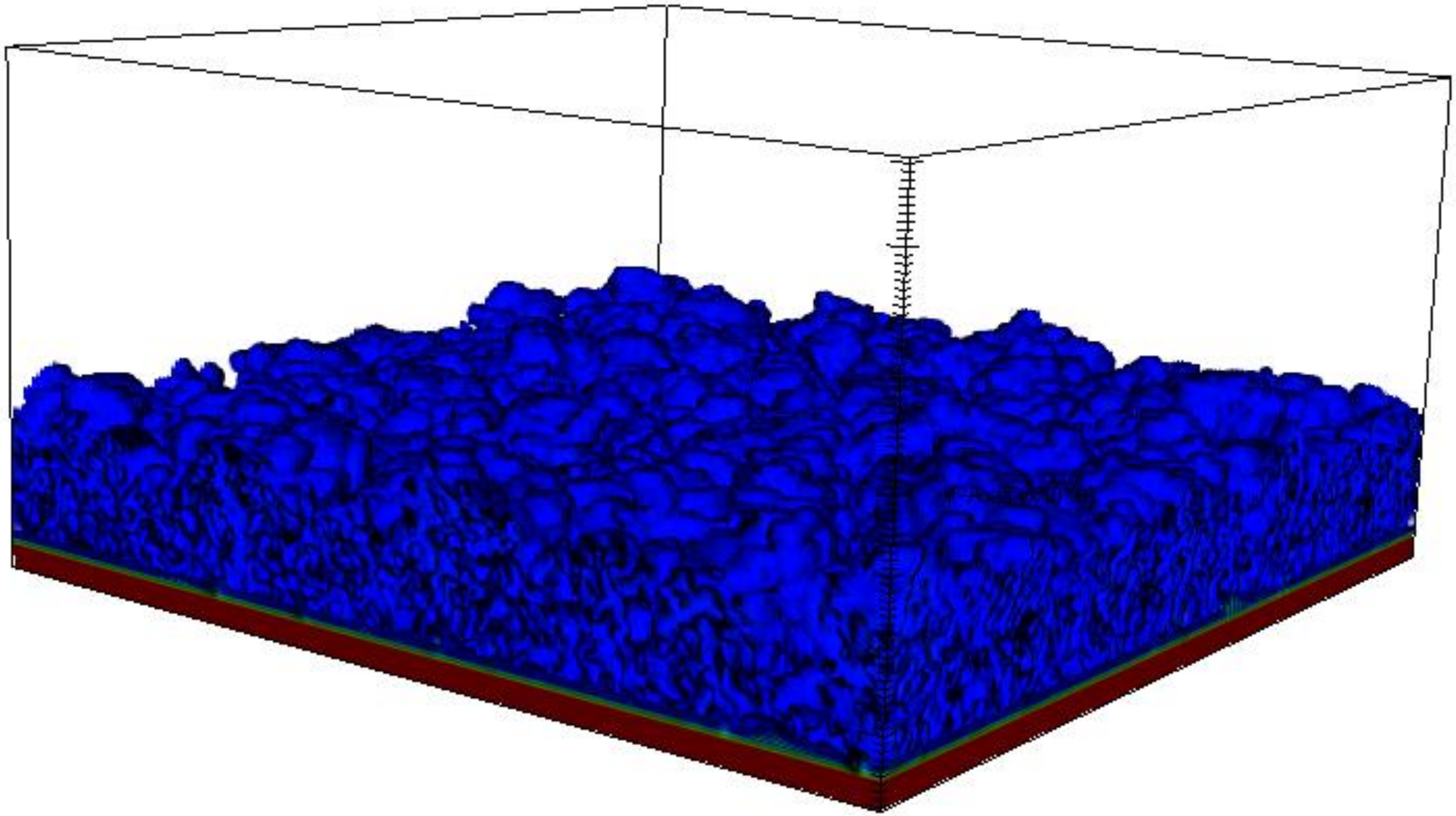


$1600 \times 1600 \times 800\ \mathrm{km}^3$
+ realistic gravity profile



Core: $X(^{12}C)=X(^{16}O)=0.5$

^{12}C at $t \sim 166\ s$



Next Generation of Nova Models

3. Vertical Stretch!

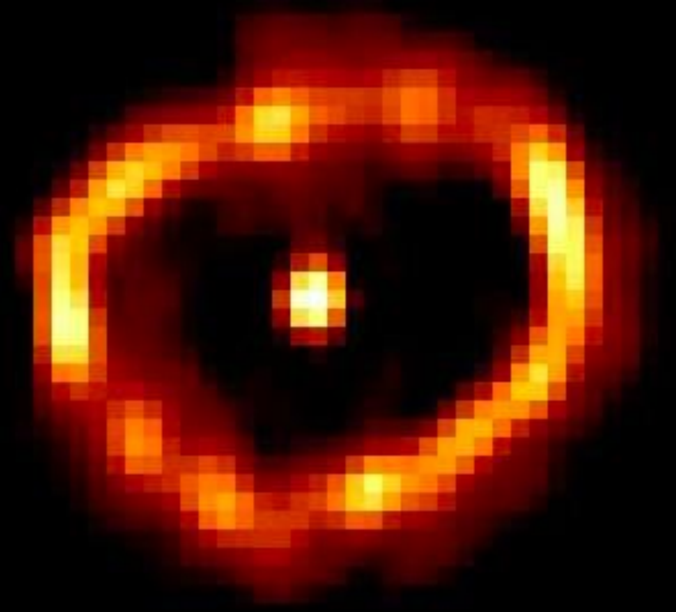
- Extended vertical domain.
- **Z=0.291 (extended box) vs Z=0.224 (non-extended box)** → Casanova, J., José, J., García-Berro, E., Shore, S. N., & Calder, A. C. 2011a, A&A, 527, A5.

Summary

- The **thermonuclear runaway model** describes the nature of nova explosions, but **mixing** is required to explain the **high metallicities** in the ejecta.
- Multi-dimensional models can investigate the mixing process **(e.g., Kelvin-Helmholtz instabilities with FLASH code).**
- **Reduced computational domain** limits the study of nova outbursts.
- **Current work on Viper (ChETEC-INFRA) → Extended domain** including **realistic gravity profile** to study the nova from mixing to detachment!
- **Future work →** Application to non-neon, neon, recurrent novae, helium novae.

THANK YOU!

- **Nova collaboration:**
- Jordi José (Polythecnic University of Catalonia).
- Steven N. Shore (University of Pisa).



Hubble Space Telescope

Credit: F. Paresce, R. Jedrzejewski (STScI), NASA and ESA