ON THE PROPERTIES OF CONVECTION IN THE SILICON/OXYGEN LAYER OF A MASSIVE STAR PRIOR TO CORE-COLLAPSE.

THE LAST 7 MINUTES

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UNDERSTANDING THE MECHANISM OF CORE-COLLAPSE SUPERNOVAE?

Mechanism of core-collapse supernova is not well understood.

(neutrino-driven explosions)

- Dimensionality, (Janka et al. 2016)
- Rotation (Summa et al. 2017) , magnetic fields (Obergaulinger et al. 2018),
- Neutrino flavour oscillations (Tamborra 2017),
- Muon creation (Bollig et al. 2017).

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- Progenitors asymmetries (Couch et al. 2013)

etc..

- Shock revival by asphericity (Couch et al. 2013, 15, Müller et al. 2015.)
  - 1D progenitor mapped to 3D + impose perturbations
    - Large scale modes ($\ell \sim 1-2$) are important

3D PROGENITOR MODELS "A NECESSITY"

Progenitors asymmetries (Couch et al. 2013)

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Self-consistent 3D progenitor models

- Simulation of an ($18\,M_{\odot}$) progenitor (Muller et al 2016) [5 minutes long]

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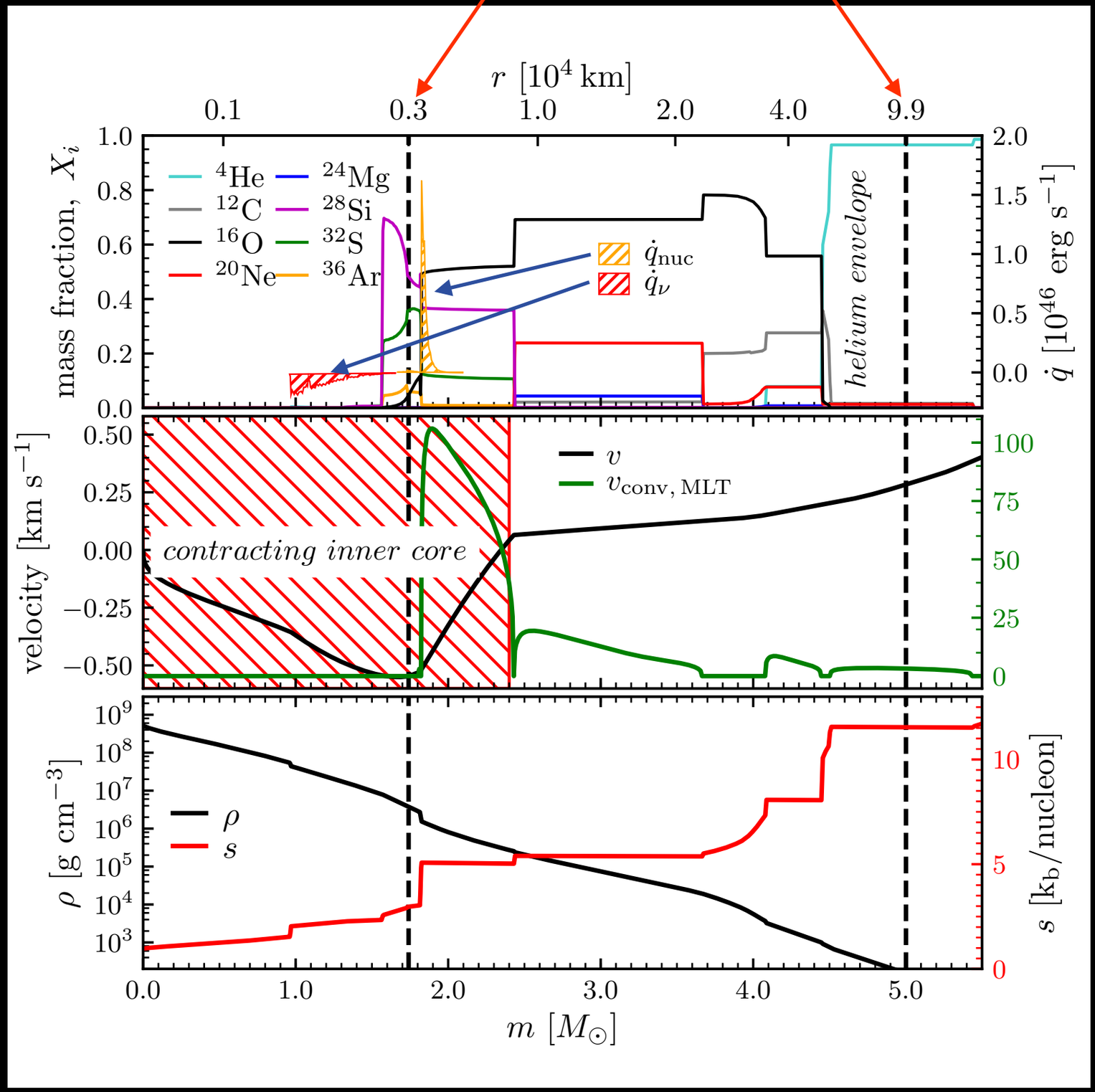
Core-collapse simulation (Muller et al 2017)

INITIAL MODEL

$18.88\,M_\odot$

Non-rotating

Solar metallicity



DYNAMICS-I

Fractional density fluctuations

$$\frac{\rho'}{\bar{\rho}} = \frac{\rho - \bar{\rho}}{\bar{\rho}}$$

where $\bar{\rho}$ is the conventional average of density

$$\bar{\rho} = \int_{\Omega} \rho \, d\Omega$$

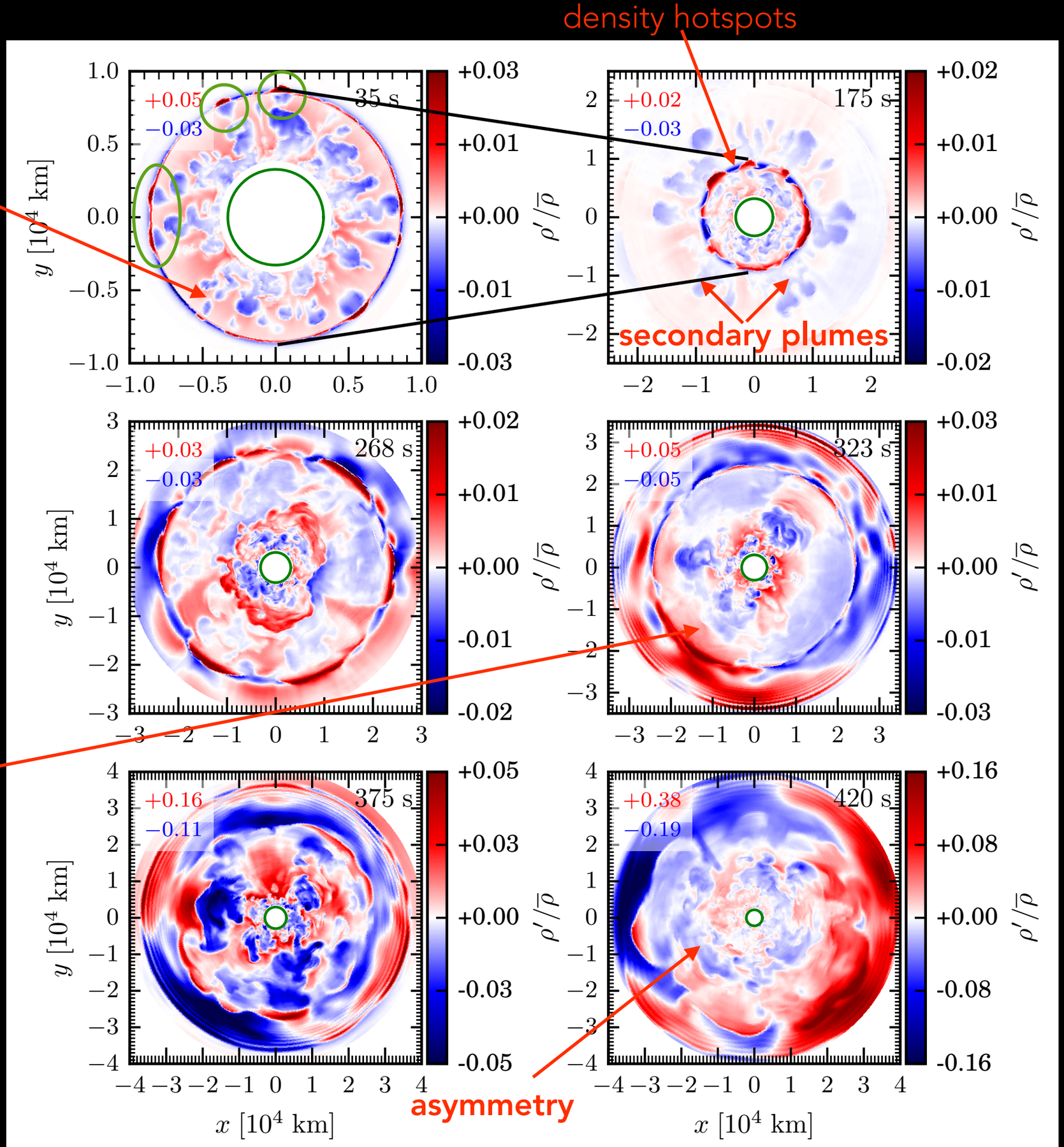
primary plumes

density hotspots

secondary plumes

outflow

asymmetry



DYNAMICS-II

Scale ~ 10,000 km

primary plumes

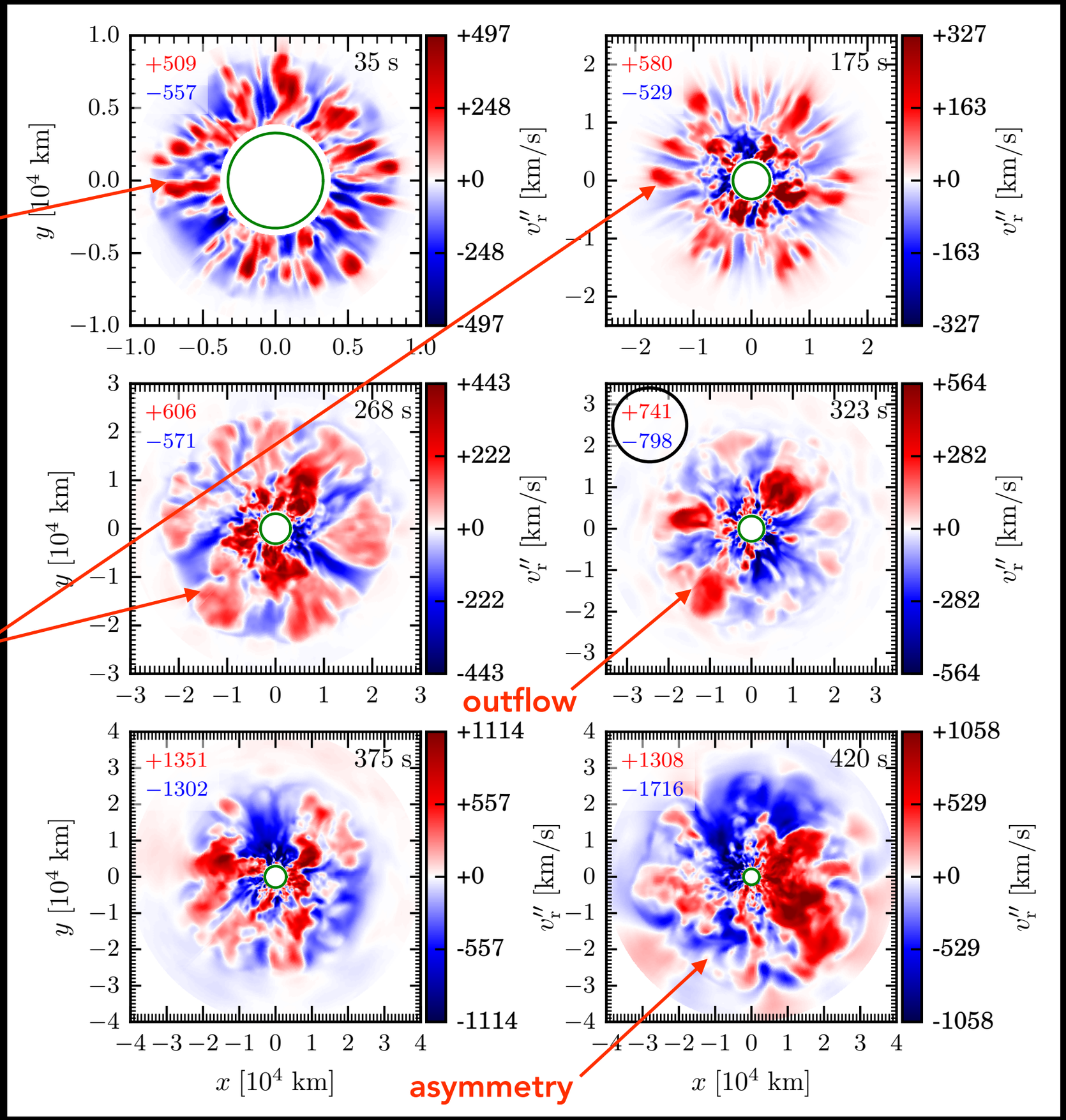
Radial velocity fluctuations

$$v_r'' = v_r - \tilde{v}_r$$

where $\tilde{v}_r$ is the Favre average of radial velocity.

secondary plumes

$$\tilde{v}_r = \frac{\int_\Omega \rho v_r \, d\Omega}{\int_\Omega \rho \, d\Omega}$$

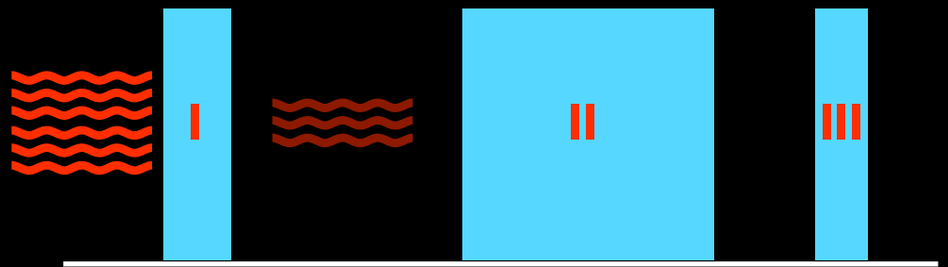


CONVECTIVE STABILITY

$\omega_{\rm BV} \leq 0$ Stable,

$\omega_{\rm BV} > 0$ Unstable .

Stable zones act as barriers



convectively stable zones

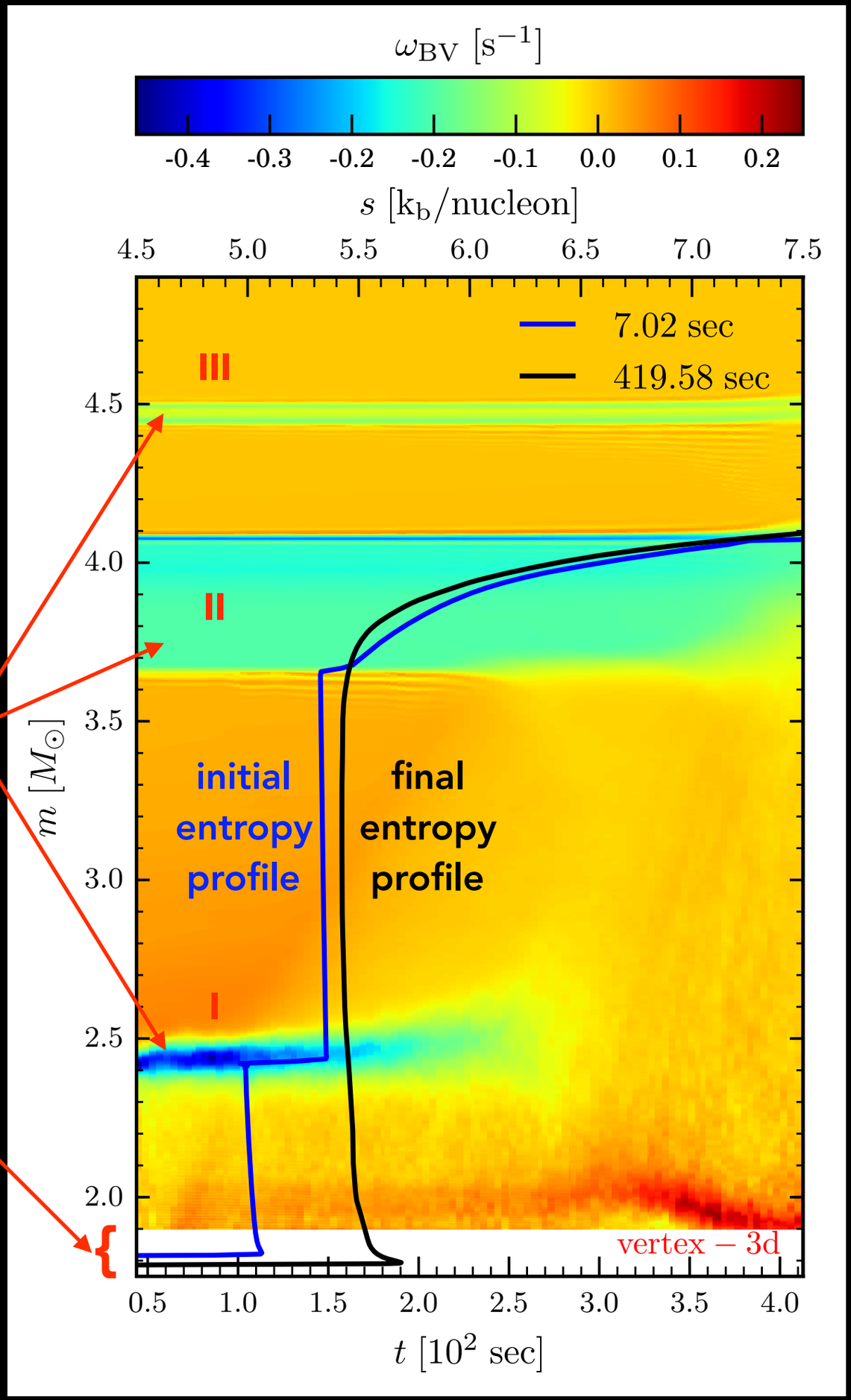
A. Three convectively stable zones.

B. Zone-I is totally decimated by 250 s.

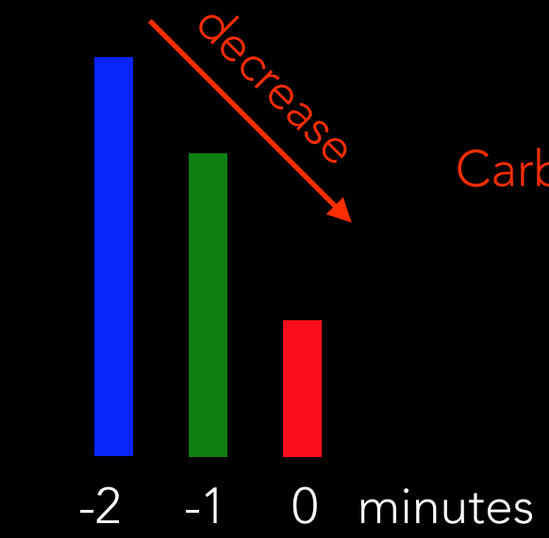
C. Zone-II also wears out over time.

burning layer

What powers the convection?

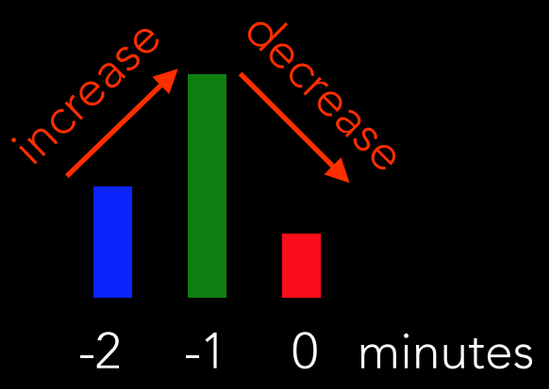


BURNING: 3D MODEL

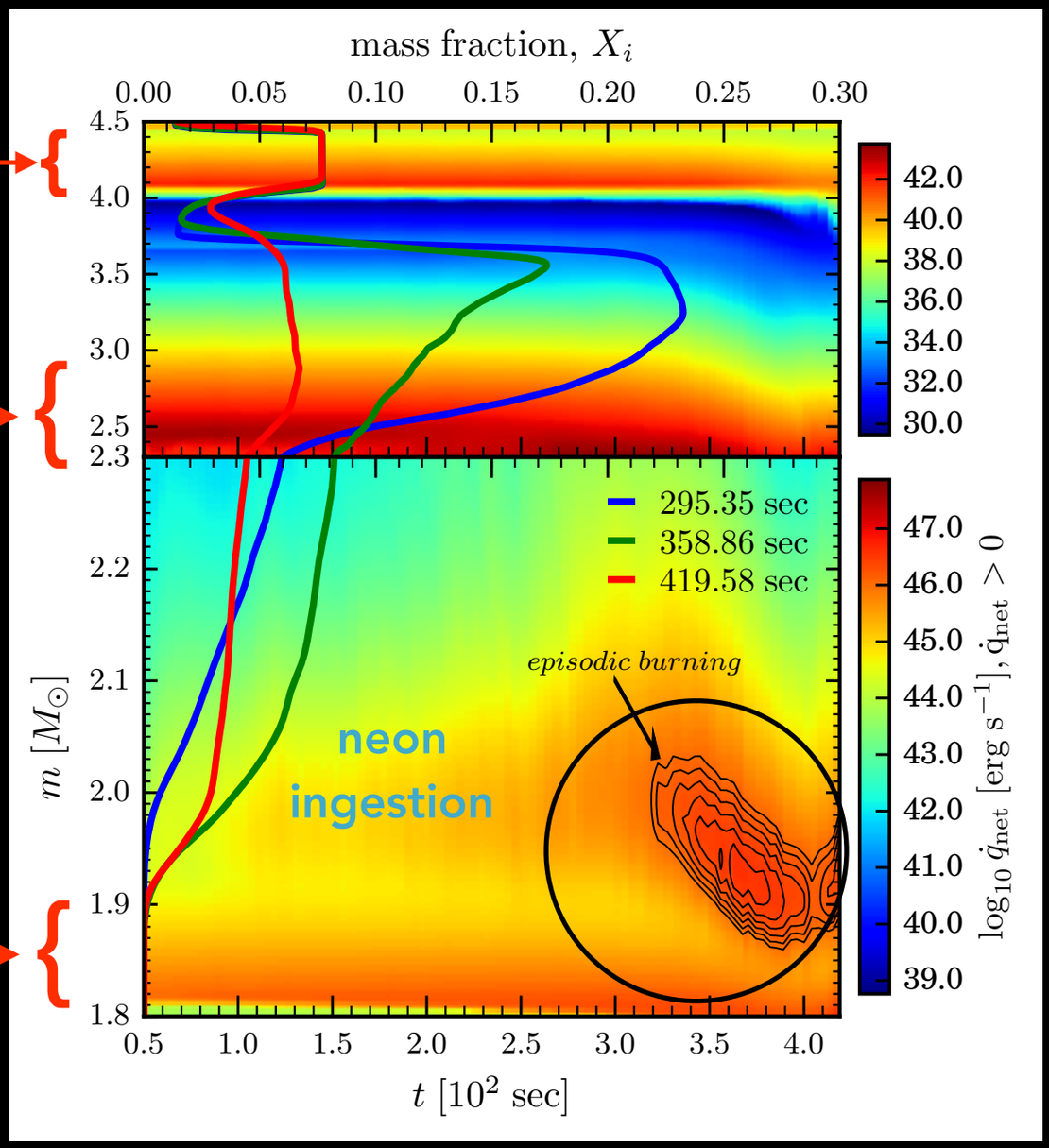


Carbon shell burning

Neon shell burning



Oxygen burning

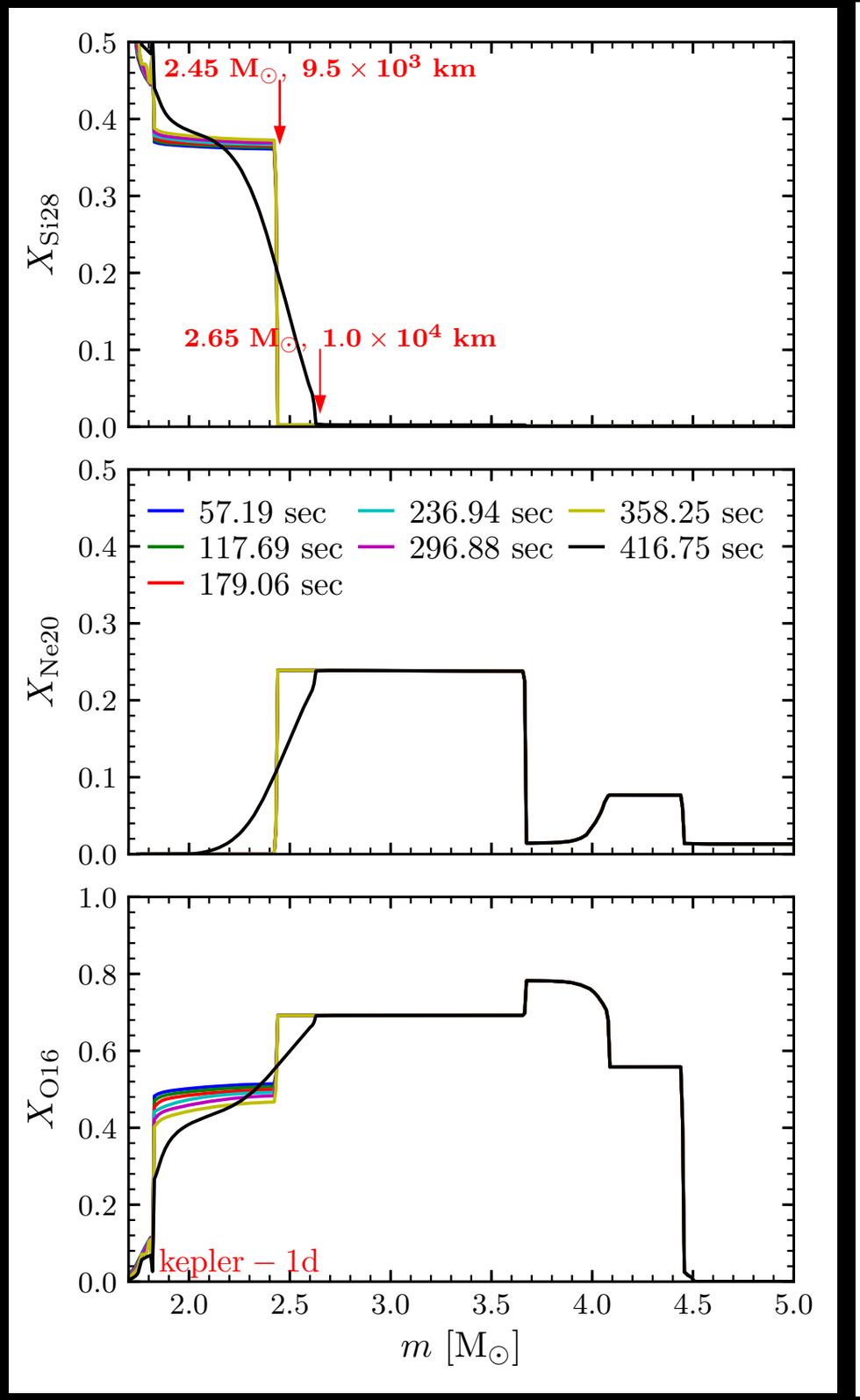


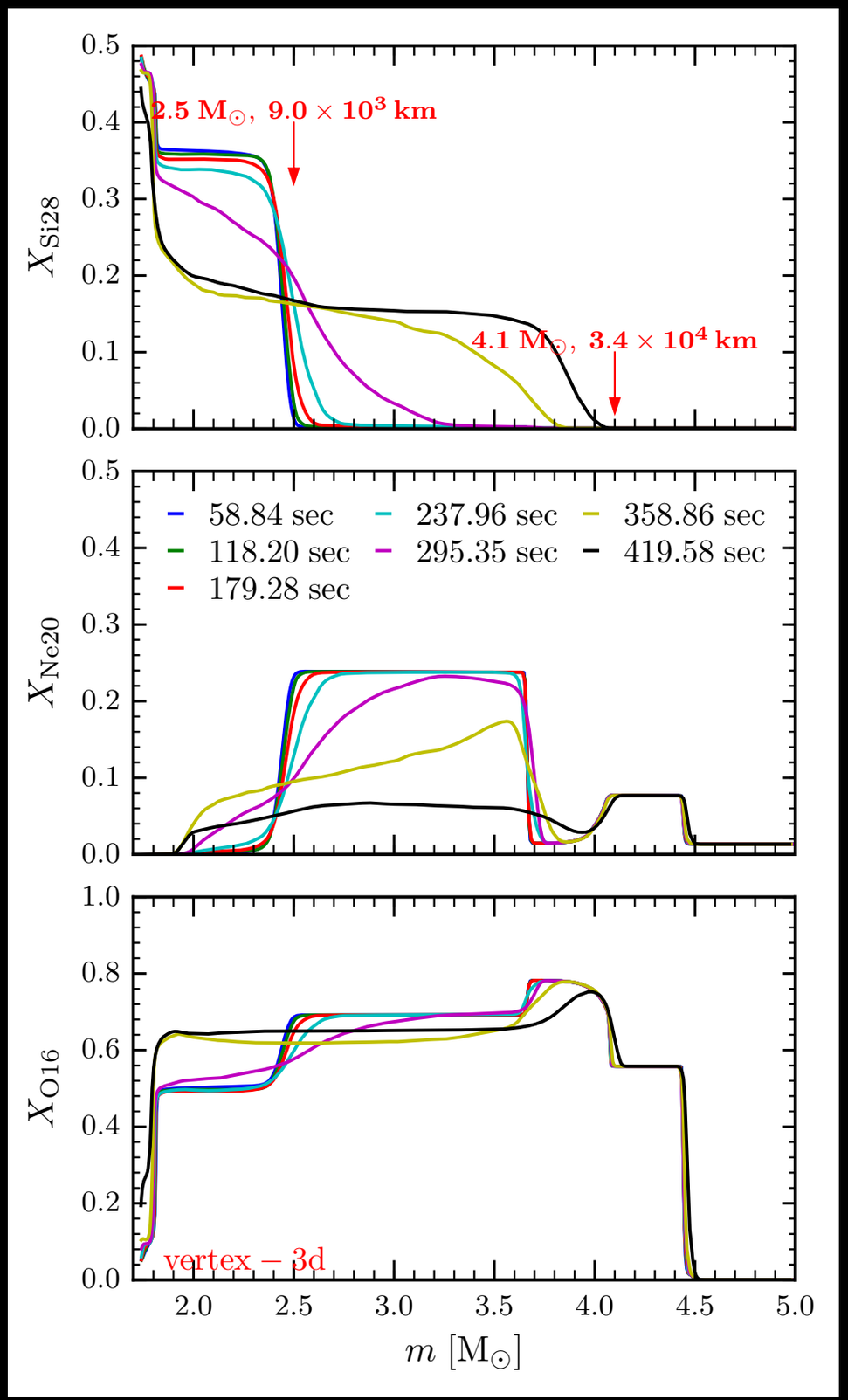
CHEMICAL EVOLUTION: 1D VS 3D MODEL

silicon

neon

oxygen

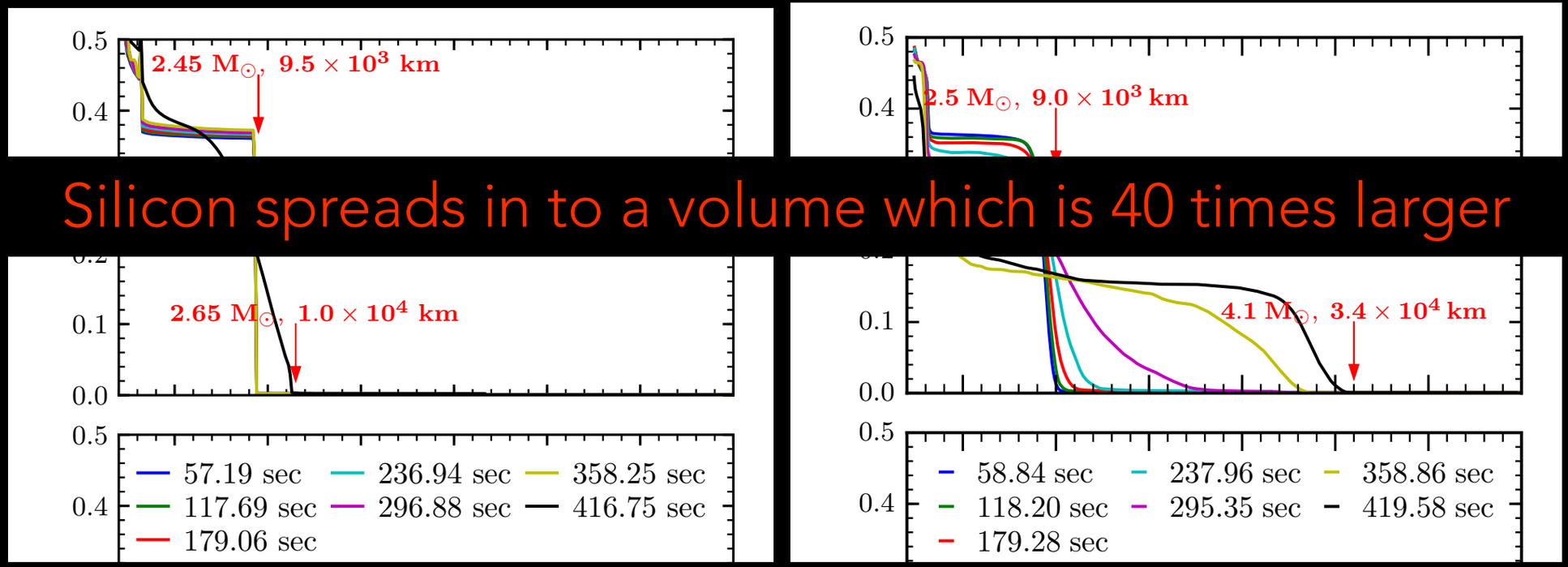




CHEMICAL EVOLUTION: 1D VS 3D MODEL

silicon

Silicon spreads in to a volume which is 40 times larger

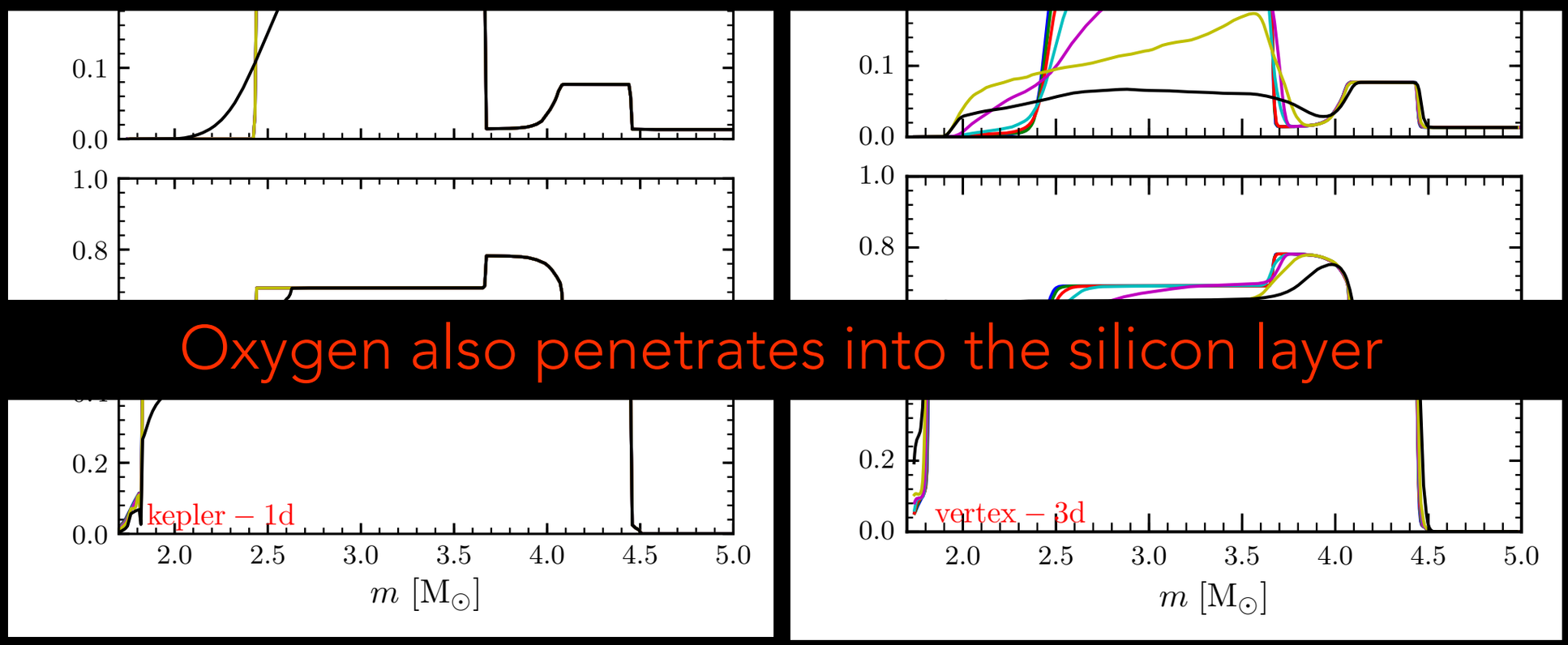


neon

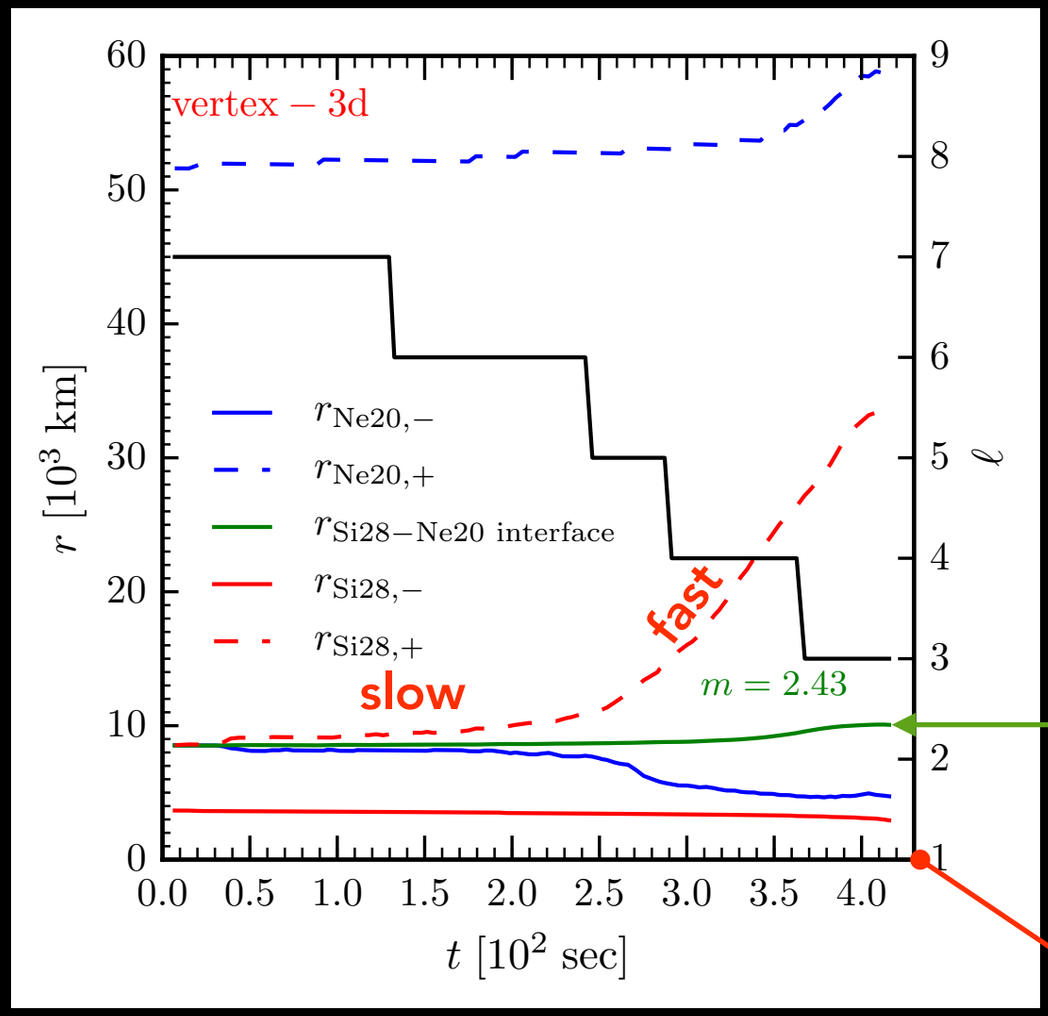
Neon penetrates in to the silicon layer and is consumed

oxygen

Oxygen also penetrates into the silicon layer



BOUNDARY OF SILICON AND NEON SHELL

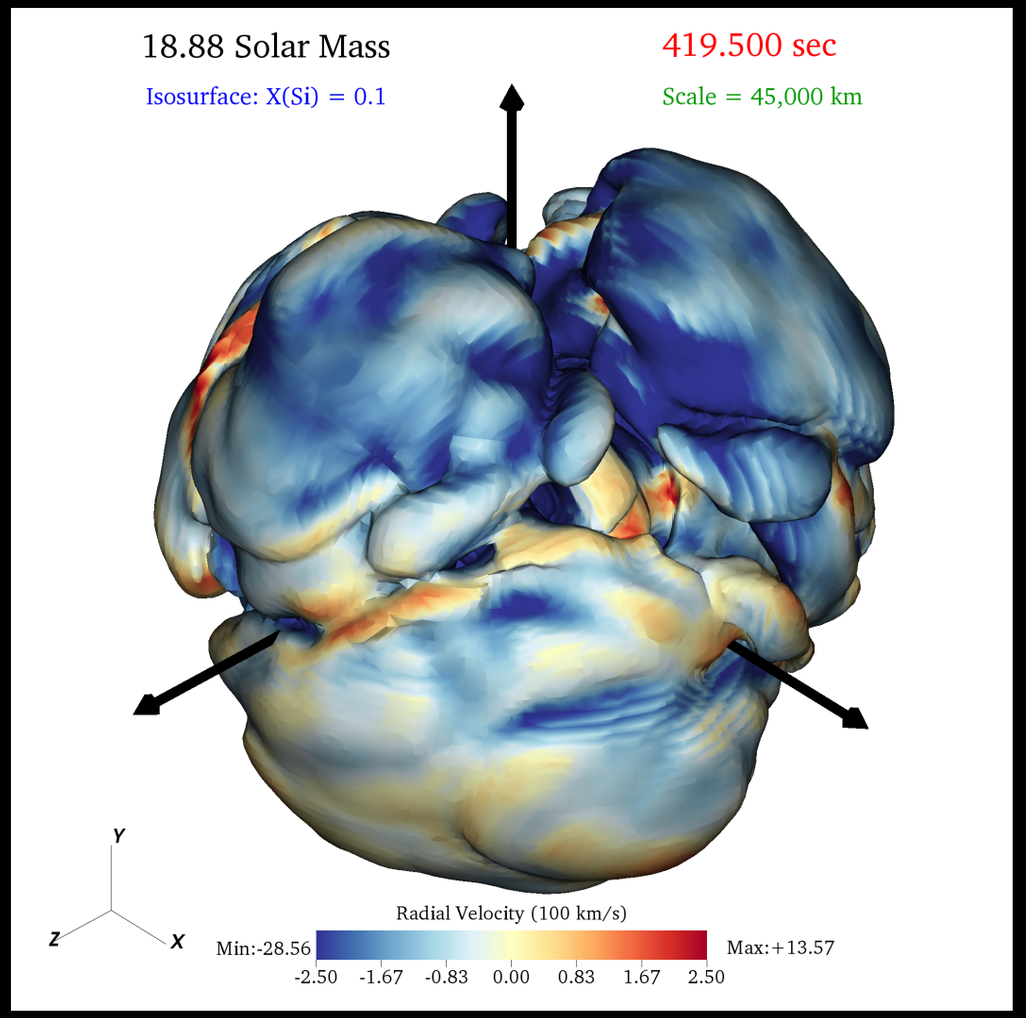


interface

inner boundary

outer boundary

silicon distribution



SUMMARY

- 3D-4π simulation of oxygen burning shell for a core-collapse progenitor.
- 3D evolution (violent) is quite different from 1D evolution (quiescent).
- Large radial Mach number in the 3D model.
- Large density fluctuations seen in the 3D model.
- Development of large scale asymmetries.
- First case of a Ne/Silicon shell merger in 3D.

Relevant for Core-Collapse Explosion

Relevant for Nucleosynthesis

Thank you.