Mixing in core-collapse supernovae:3D simulations with CASTRO

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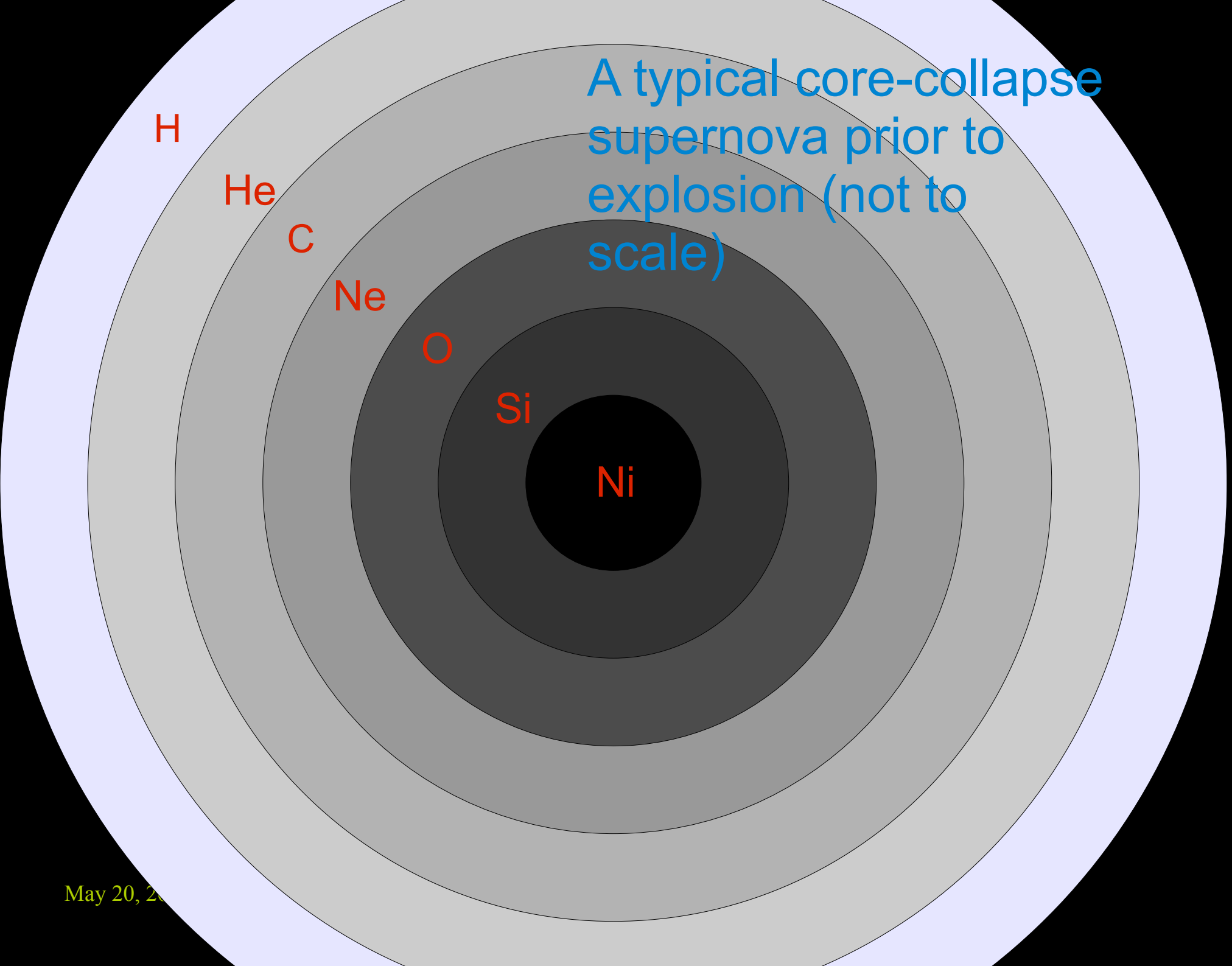
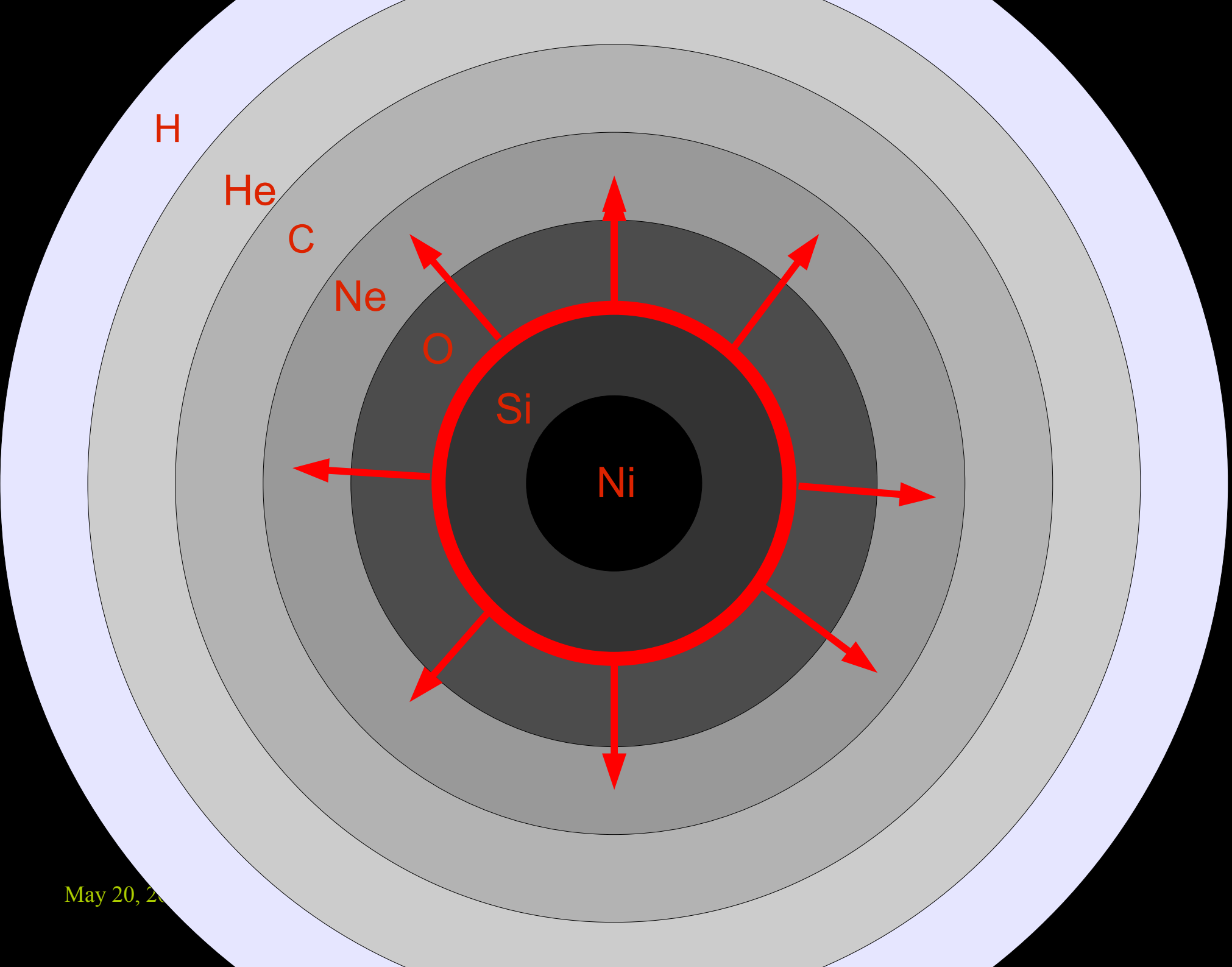

A typical core-collapse supernova prior to explosion (not to scale)
H
He
C
Ne
O
Si
Ni


H
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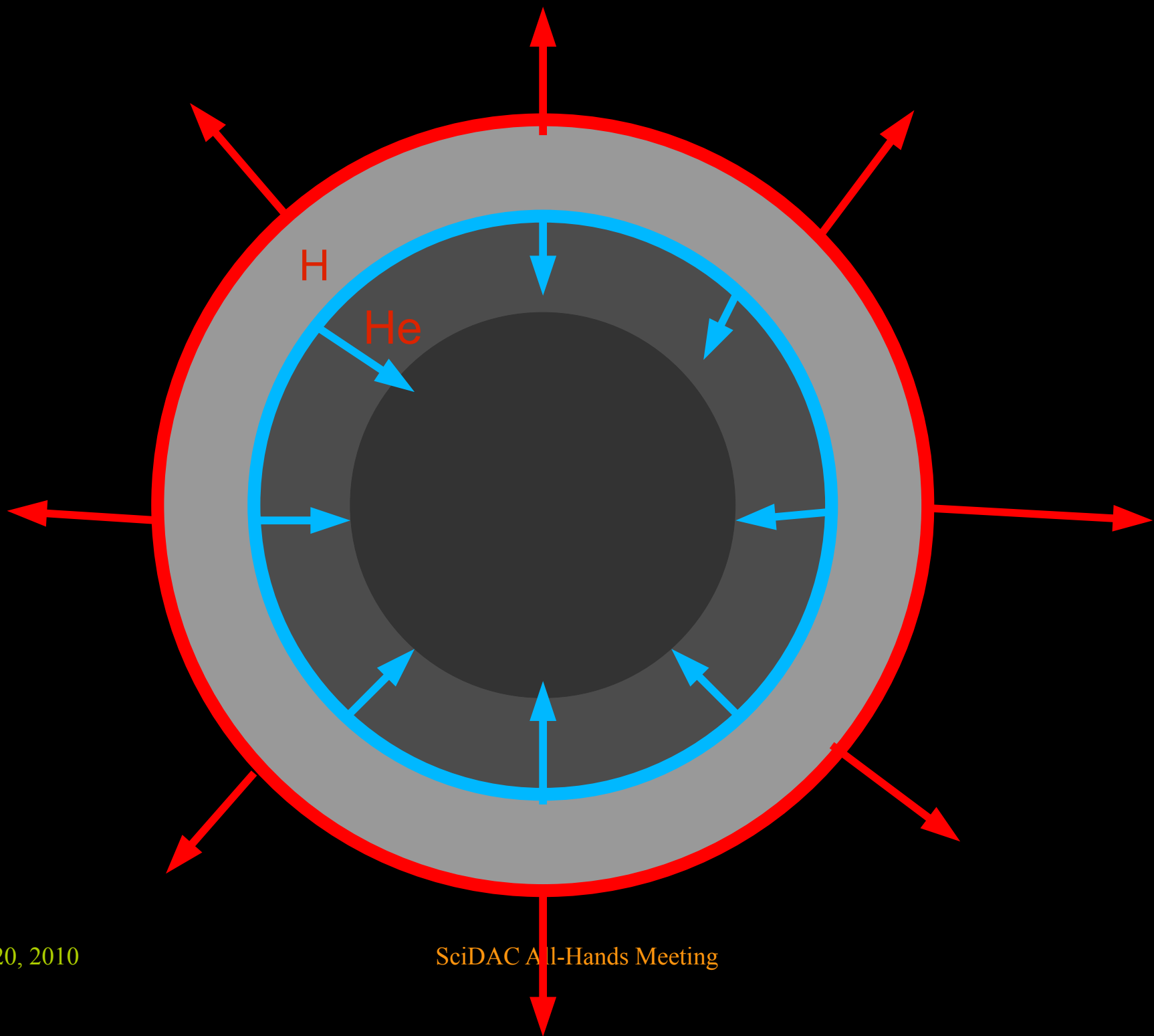
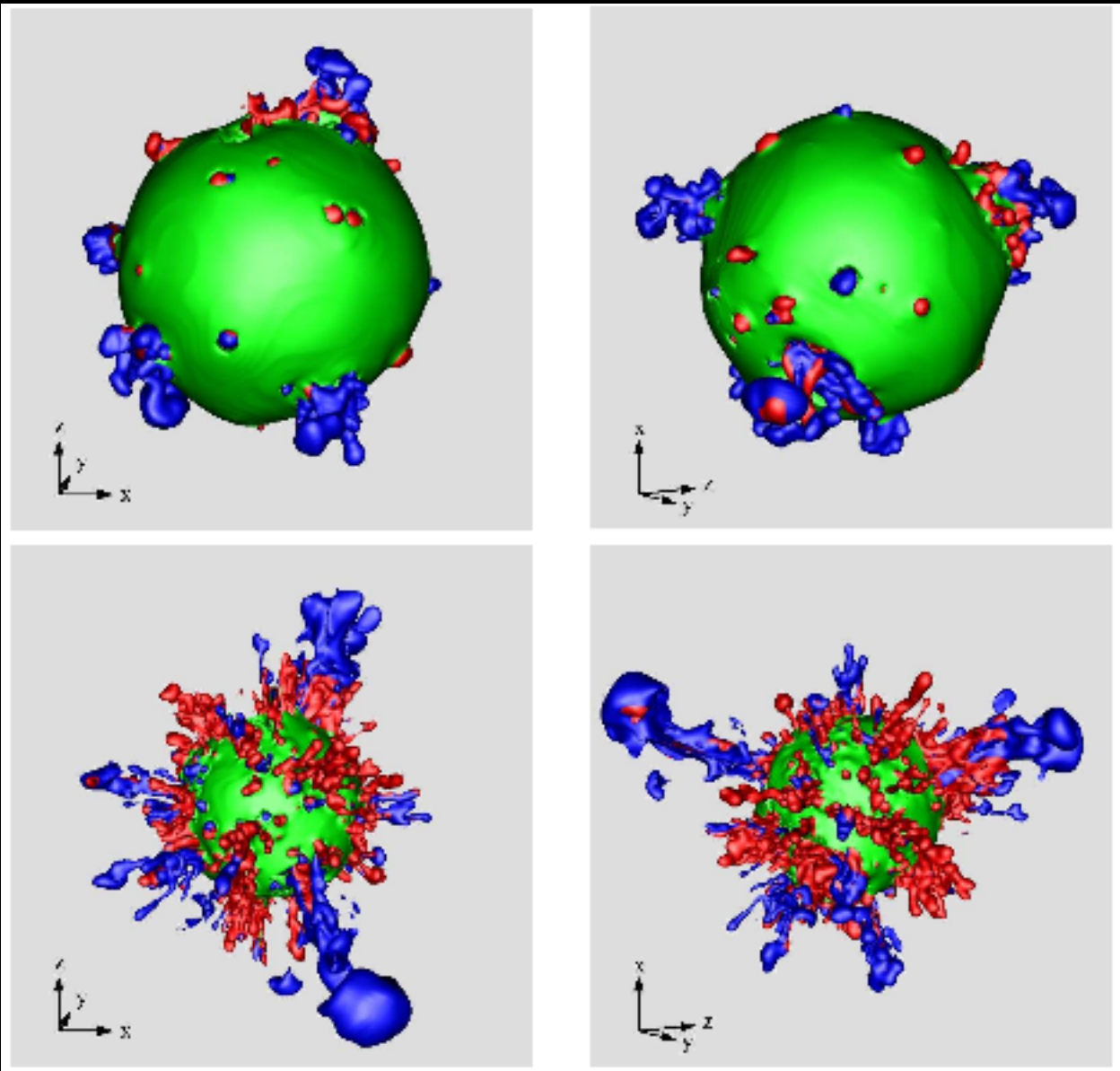
Ni


H
He

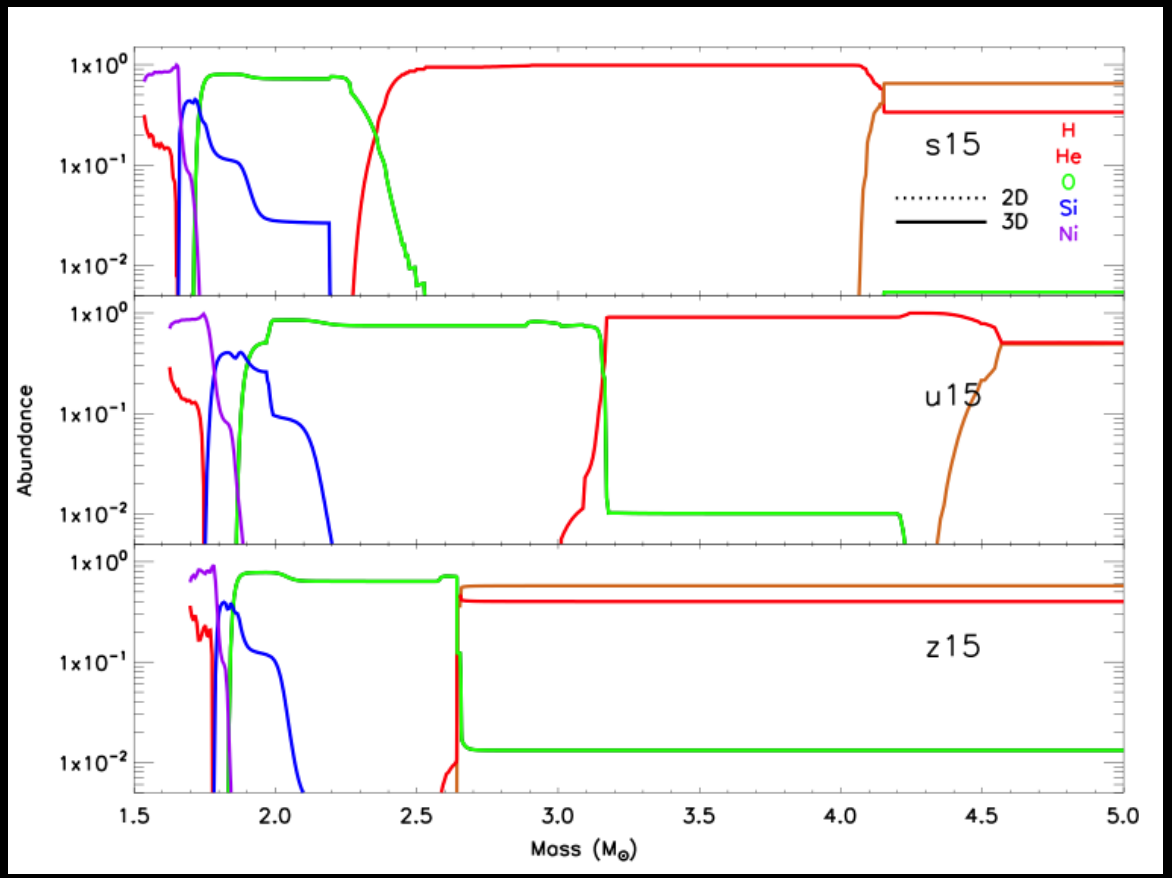
Mixing in an 87A progenitor

- Instabilities grew ~30% faster in 3D than in 2D
- This allowed bubbles of ^{56}Ni to penetrate the He layer
- Little interaction between instabilities



Hammer et al. 2010

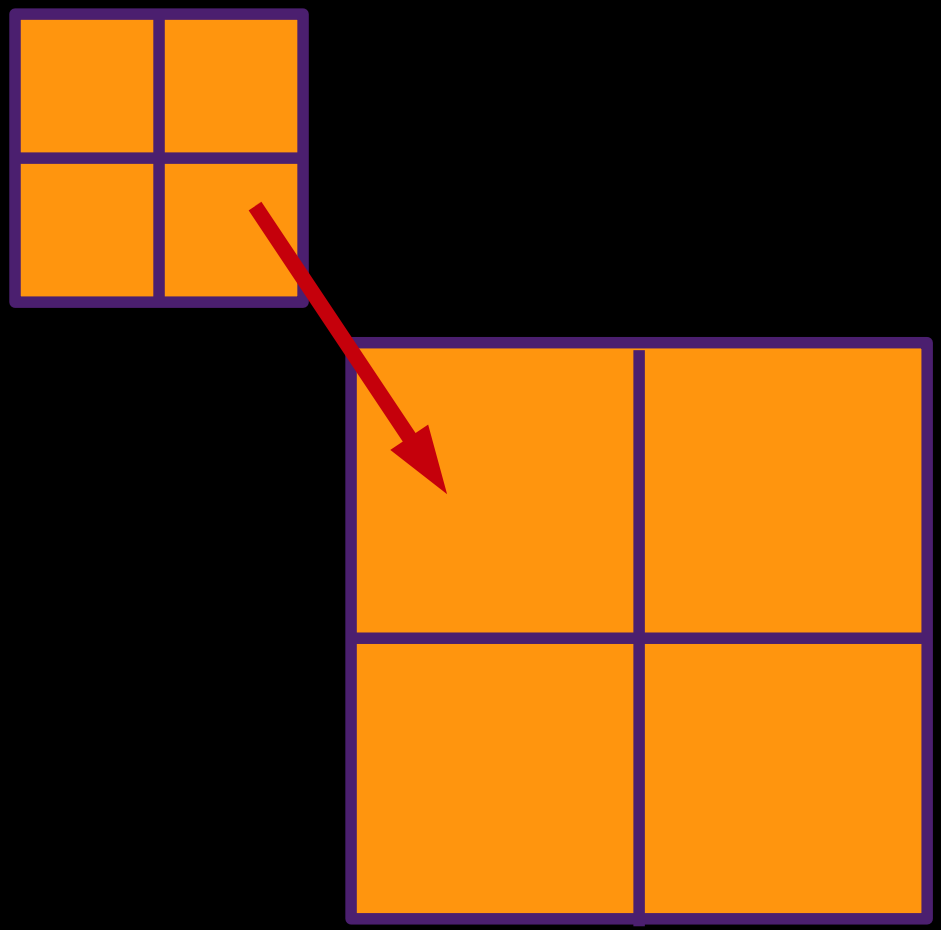
Three models used for 3D simulations with CASTRO



Joggerst et al. 2010 (submitted)

- S15 and z15 die as red giants
- U15 dies as a blue giant
- Z15 lacks a helium shell because of convection

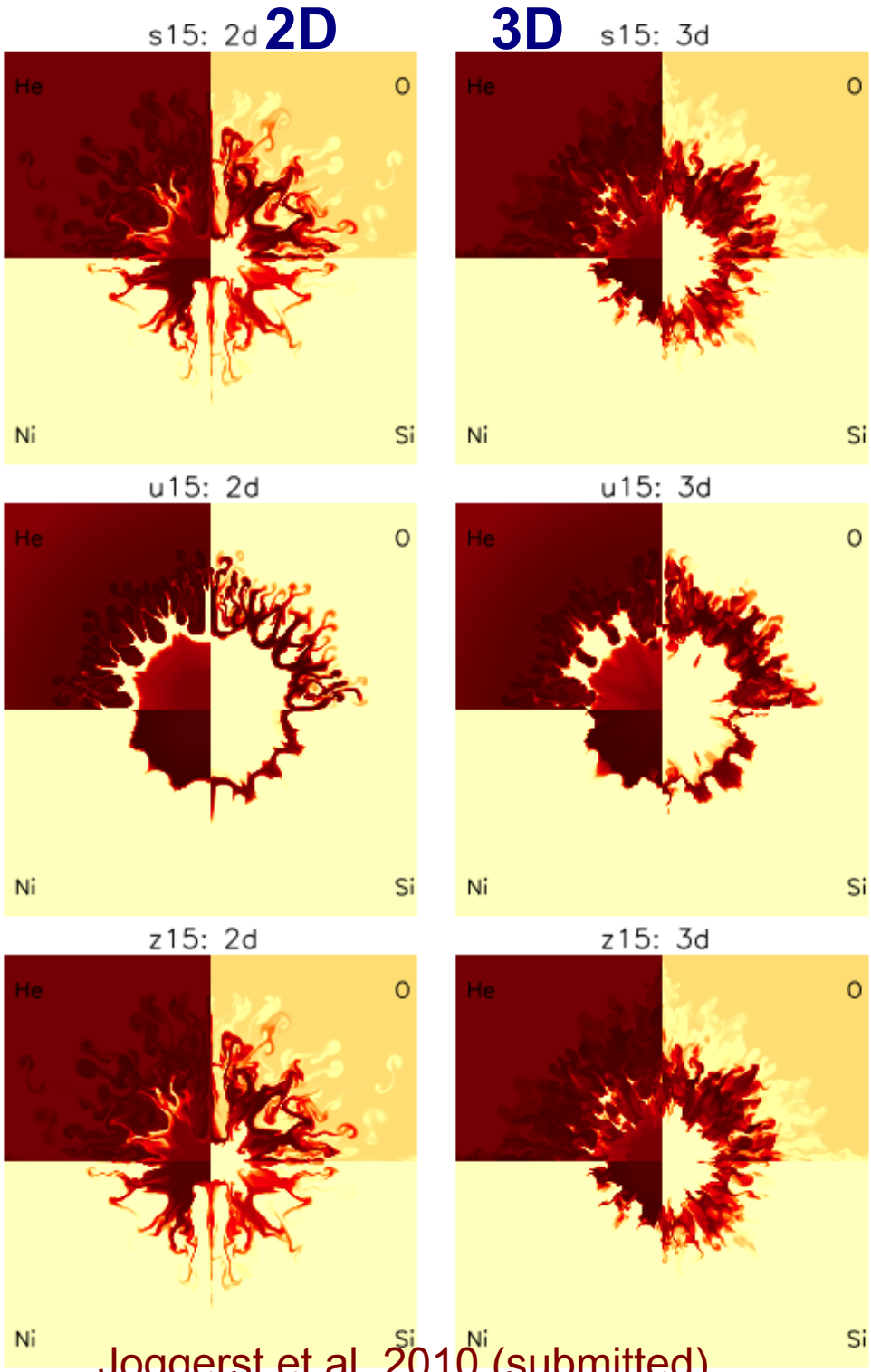
Simulation setup



- KEPLER models mapped to 2D and 3D 20 or 100 S after bounce
- Spherically symmetric explosions
- Original grid 128^n, with 2 levels of refinement
- Simulations enlarged when shock neared outer edge of grid
- 1 octant modeled

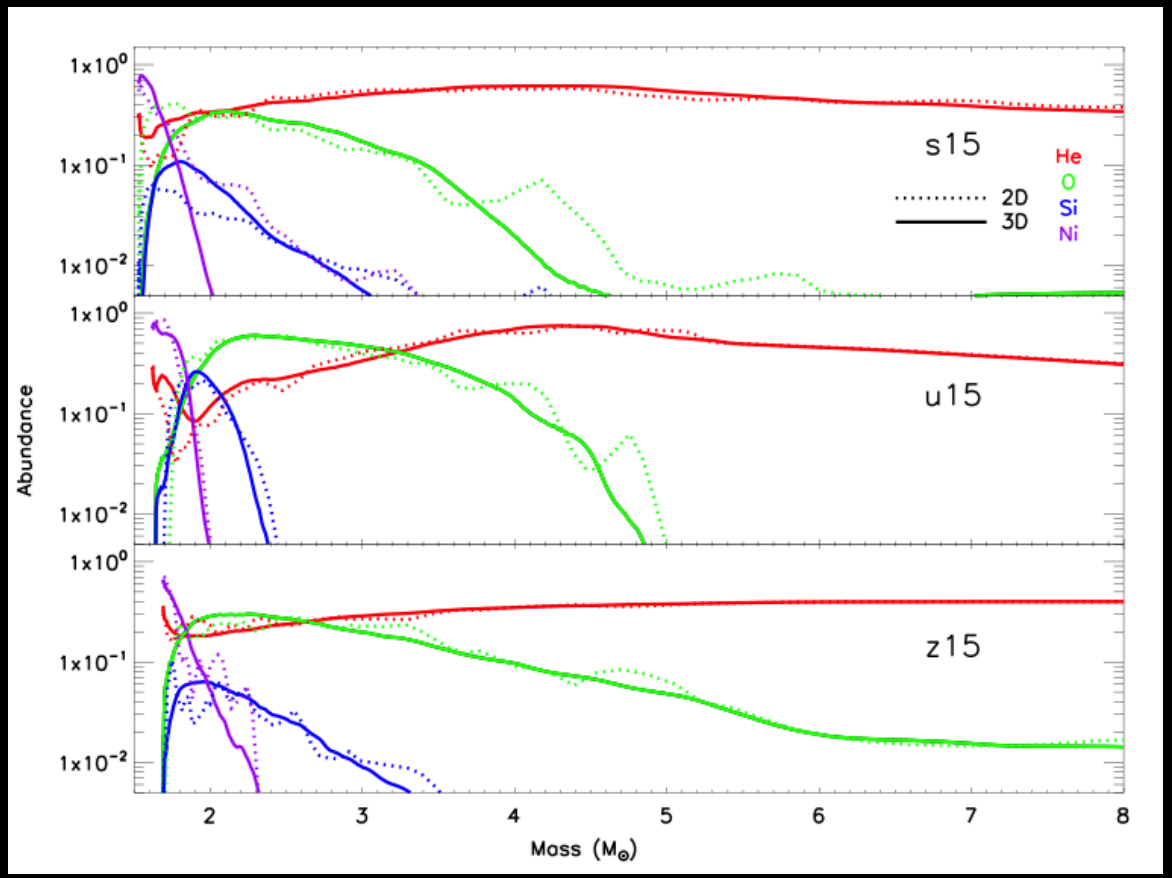
2D vs. 3D

- Shape of instabilities slightly different in 2D vs 3D
- 3D more mixed, but the width of the mixed region is essentially the same
- RT fingers have interacted with one another



Joggerst et al. 2010 (submitted)

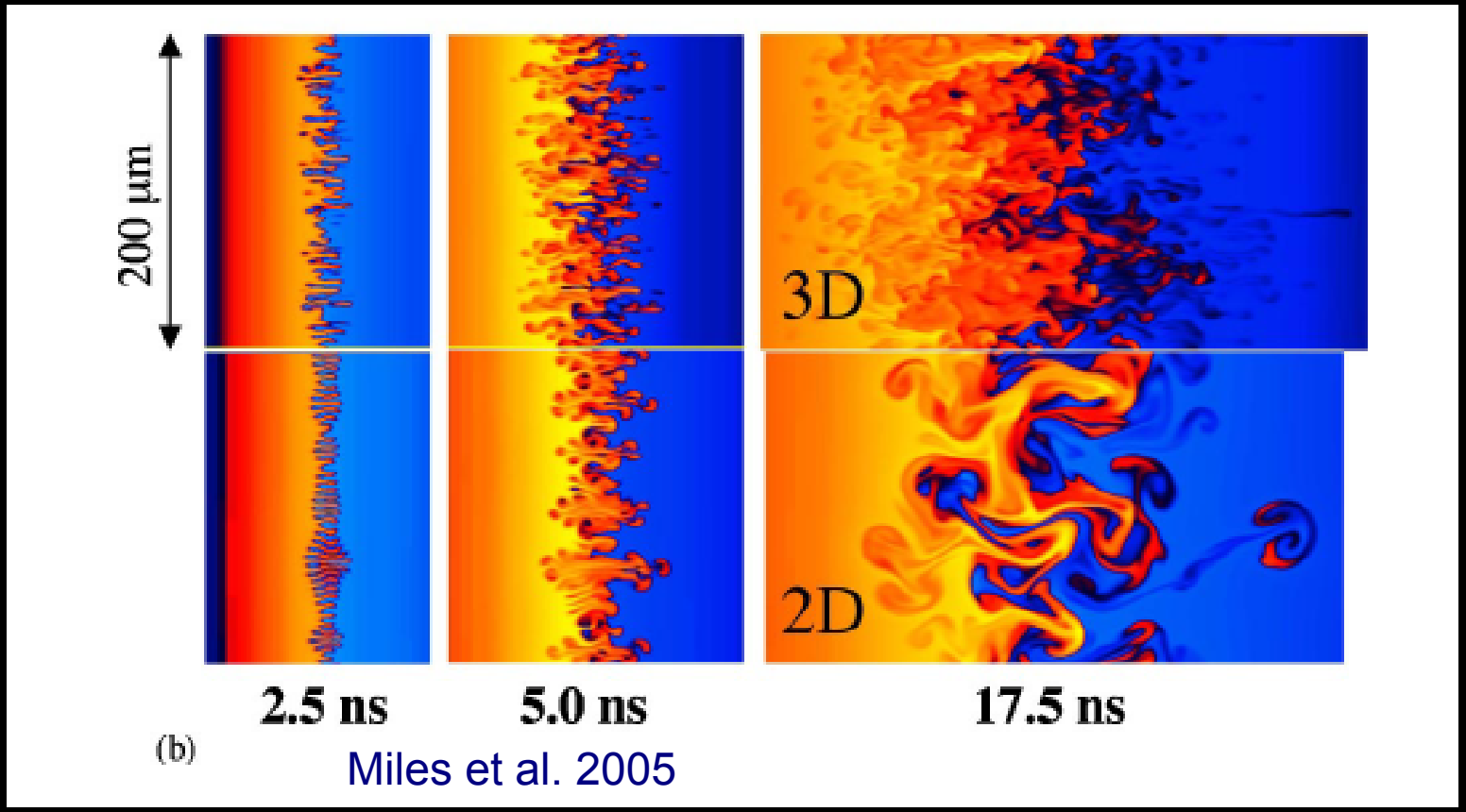
Abundance Vs Mass



Joggerst et al. 2010 (submitted)

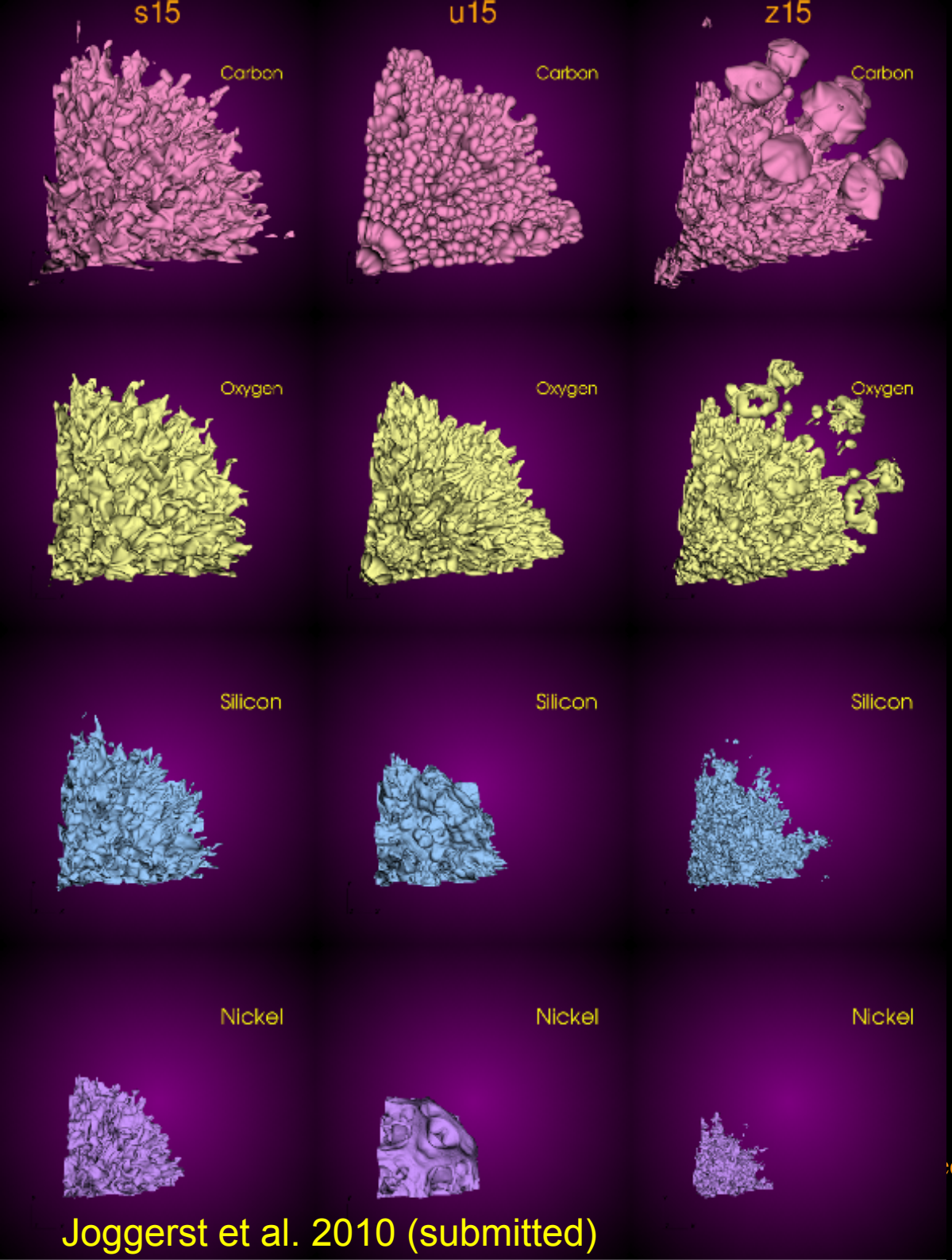
- Width of mixed region the same between 2D and 3D
- 2D is bumpier than 3D—reflects transition to turbulence; better sampling

Transition to turbulence



Miles et al. 2005

Other groups have found that interactions between RT fingers reduces the Atwood number, leading to a reduction in the growth rate and a final mixed region width that is the same in 2D and 3D



3D renderings

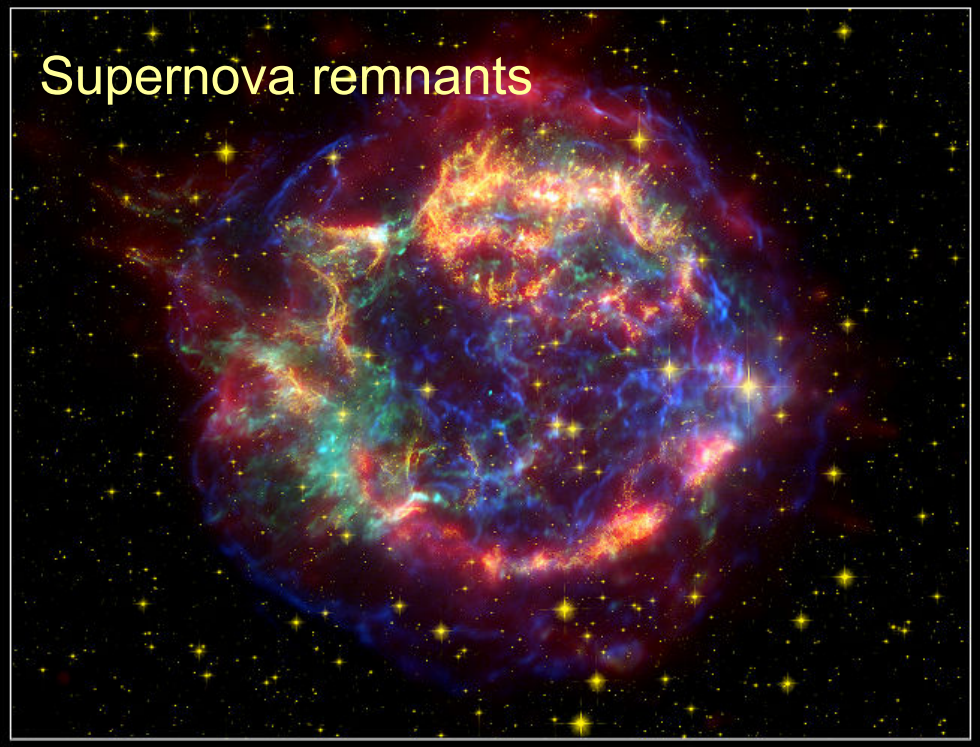
- Z15 shows broken off clumps
- U15 is least mixed
- Heavy elements don't penetrate lighter layers

Joggerst et al. 2010 (submitted)

Conclusions

- Width of mixed region the same in 2D and 3D simulations provided RT fingers interact with one another
- 2D simulations may adequately model width of mixed region in stars, provided there's no large-scale asymmetry
- Low-mode order asymmetry in red giants still to be explored

Observations of mixing in CC SNe



Cassiopeia A Supernova Remnant
NASA / JPL-Caltech / O. Krause (Steward Observatory)
ssc2005-14c

Spitzer Space Telescope • MIPS
Hubble Space Telescope • ACS
Chandra X-Ray Observatory

Abundances in metal-poor stars

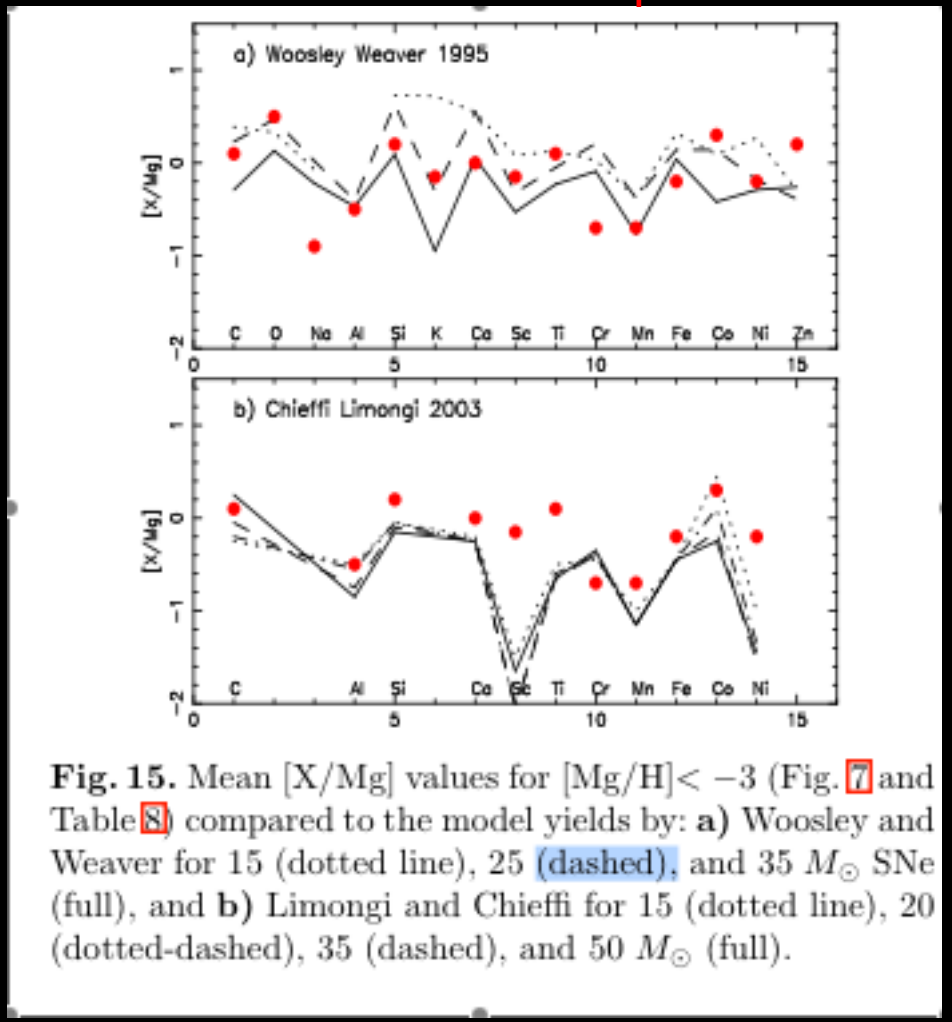


Fig. 15. Mean [X/Mg] values for [Mg/H]< -3 (Fig. 7 and Table 8) compared to the model yields by: **a)** Woosley and Weaver for 15 (dotted line), 25 (dashed), and 35 $M_\odot$ SNe (full), and **b)** Limongi and Chieffi for 15 (dotted line), 20 (dotted-dashed), 35 (dashed), and 50 $M_\odot$ (full).

Cayrel et al. 2004

Also light curves, spectra, and spectropolarimetry