From Convection to Ignition and Beyond:
A Computational Story of M_{Ch} SNIa

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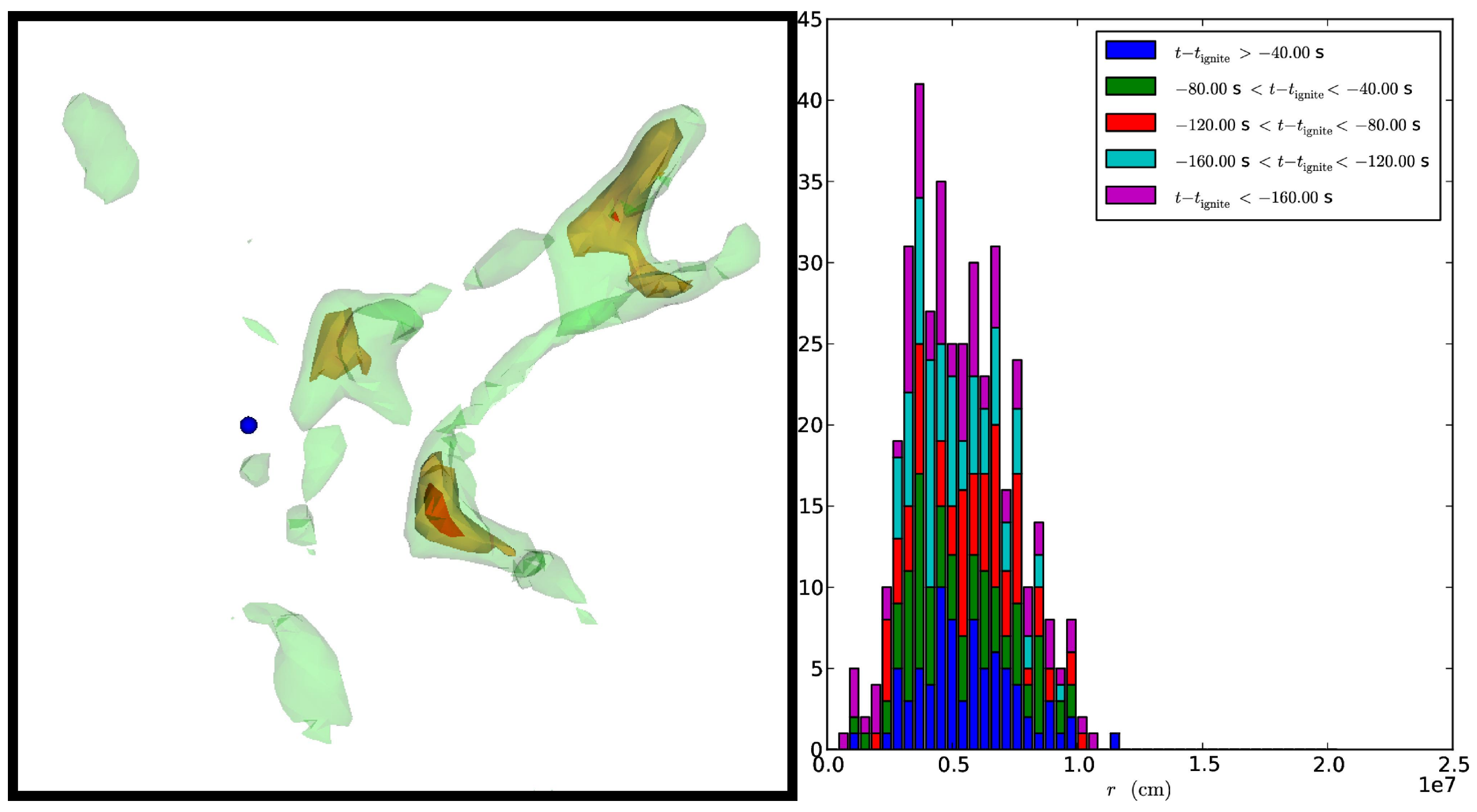
LOW MACH NUMBER SIMMERING

Accretion increases the WD's central temperature and density until carbon fusion occurs. The energy release from nuclear burning drives core convection that extends to $r \simeq 1000$ km. The flow becomes very dipolar, with the axis of the dipole stochastically changing direction. Our results from low Mach number simulations of this slow convection reveal that runaway ignition of the carbon burning, which occurs at $T \simeq 8 \times 10^8$ K, likely occurs ~ 50 km off-center [1, 2].



Left: contours of temperature showing the hotspot; Right: histogram of hotspot location leading up to runaway. [1, 2]

CASTRO SIMULATIONS

We have performed several 3D calculations using CASTRO for both central [3] and off-center [4] ignition. We have also taken the results from the MAESTRO simmering simulation [2] and ported them to CASTRO. We then evolved the system with very high resolution to understand the role the background turbulence generated from convection plays in propagation of the hotspot.

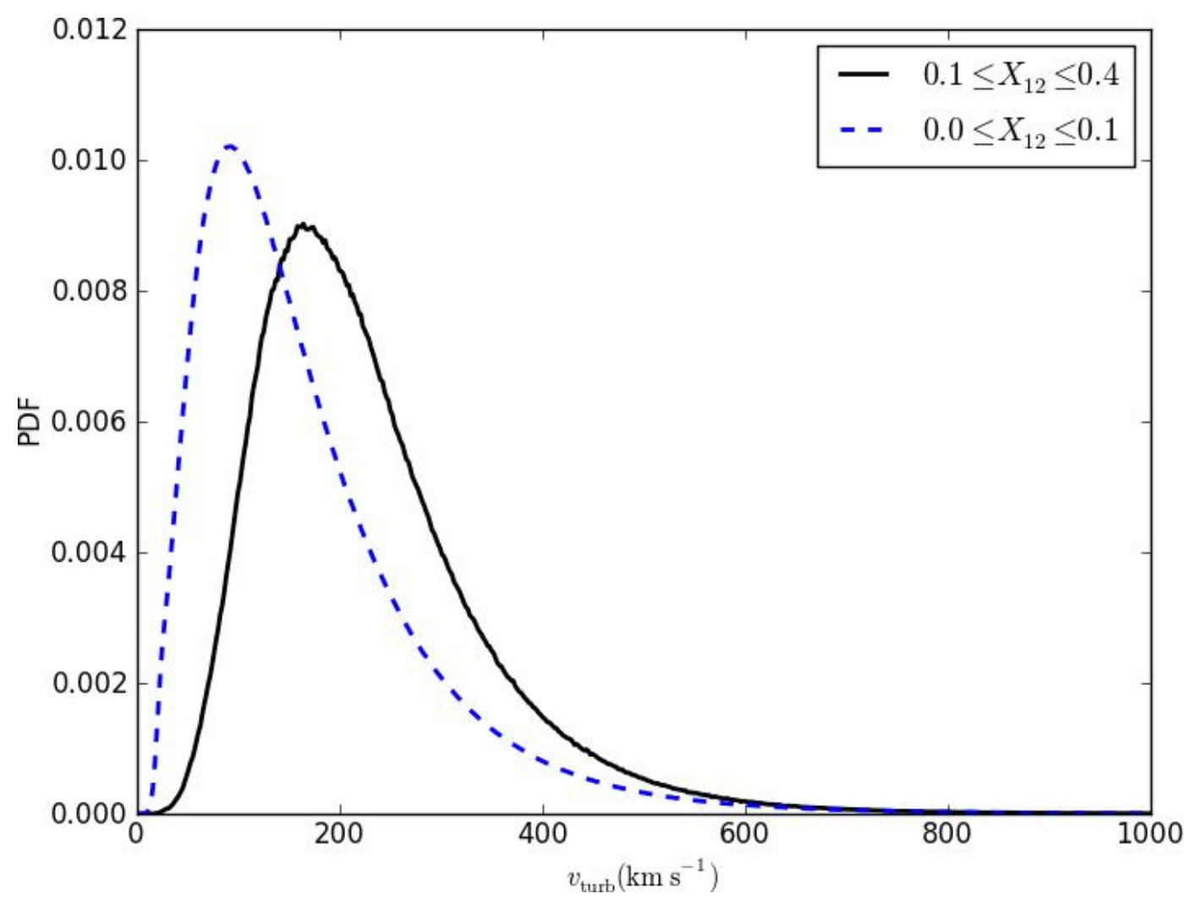
NUCLEAR NETWORK

Nuclear burning is incorporated via the use of tables generated offline with networks containing ~ 200 isotopes. We use one table for the isobaric burning conditions inside the flame that possibly lead up to NSE, and another table that determines the energy budget after the flame has passed and the ashes undergo recombination, β-decay, and/or e-capture reactions.

THICKENED FLAME MODEL

The CASTRO simulations all use a very simplistic thickened flame model, first described in Ma et al. [3]. In this model we specify a *constant* flame speed, v_f, and thickness in units of grid spacing, n, and we use the local nuclear burning timescale to determine a diffusion coefficient for transporting heat into the cold fuel ahead of the flame:

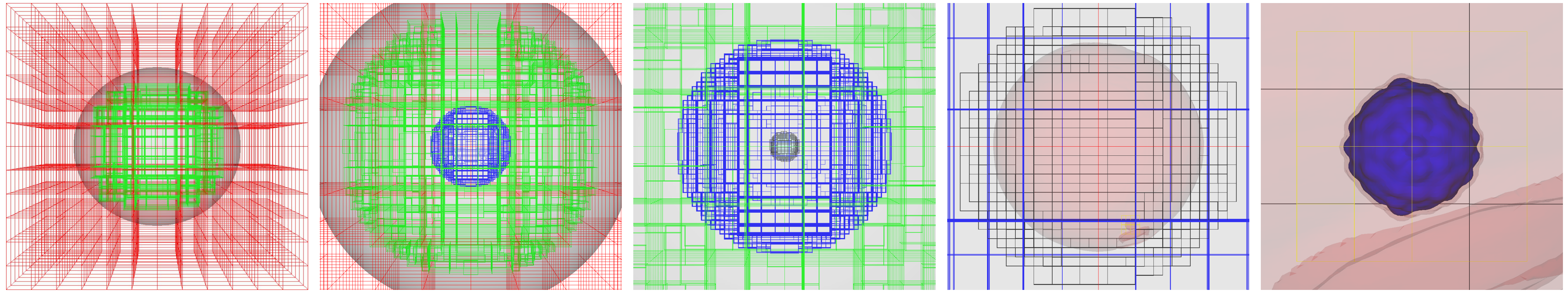
$$\kappa \simeq \frac{n^2}{\tau_{\mathrm{nuc}} v_f^2}$$



The flame speed has been varied from 50 to 200 km s^{-1} — within the range of the turbulent speeds we see on the grid scale — and this resulted in a $\sim 6\%$ and 13% variation in the total mass of intermediate mass and iron-group elements, respectively[3]. We are currently investigating a model whose flame speed is based upon the local turbulent fluctuations. Our preliminary studies with this improved flame model yield slightly less burned material.

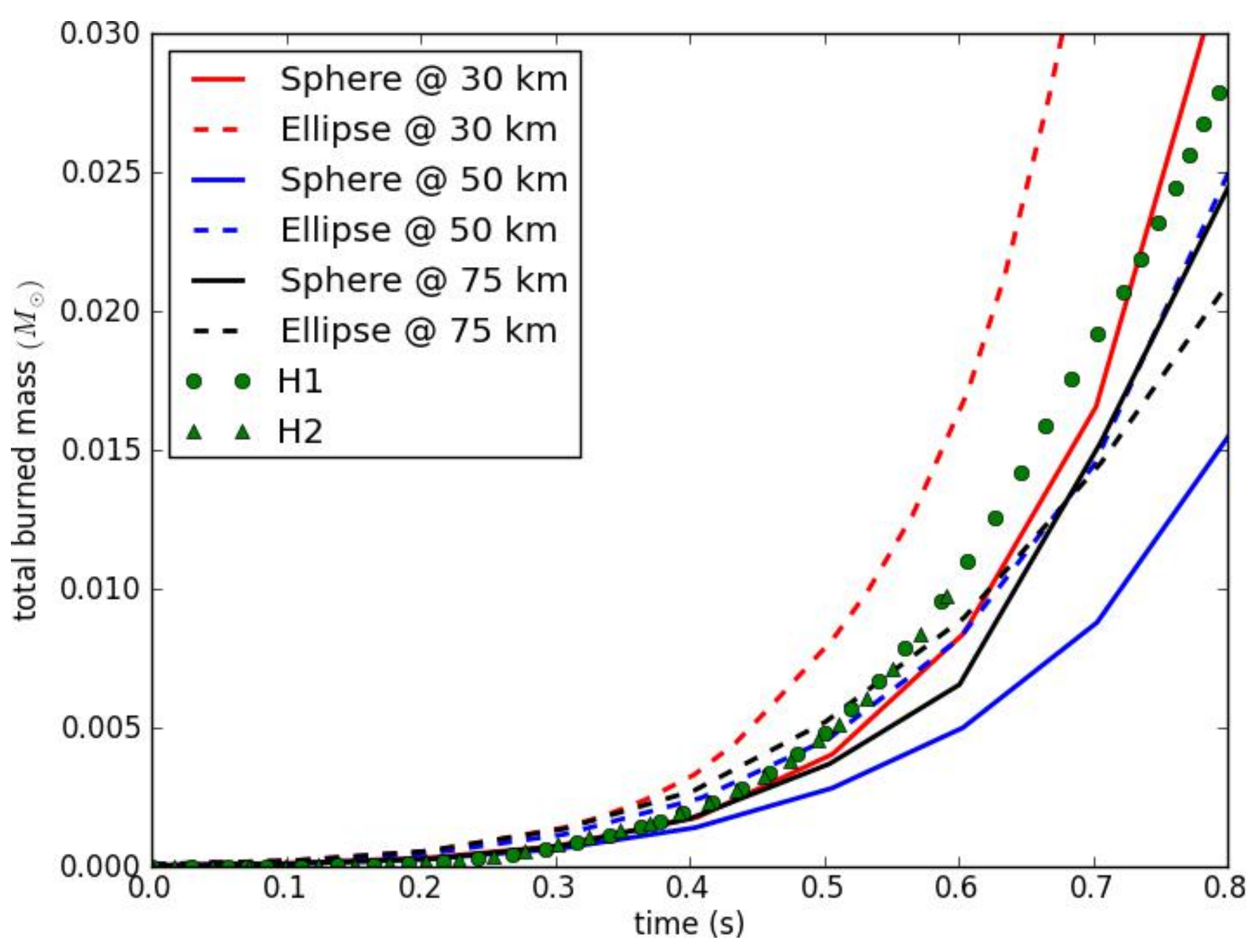
MAESTRO TO CASTRO REMAP

The low Mach number approximation in MAESTRO solves an inherently different set of equations than those in the compressible code CASTRO. For example, MAESTRO decomposes the full pressure field, p, into its *base state* (p_0)—representing the background HSE— and *dynamical* (π)components: $p(\mathbf{x}, t) = p_0(r, t) + \pi(\mathbf{x}, t)$. One consequence of this decomposition is that the base state pressure governs the *thermodynamics* of the state, whereas the dynamic pressure determines the local *dynamics* of the fluid. Care must be taken in reconstructing the fully compressible state of the star and the ignition point from the MAESTRO variable set.

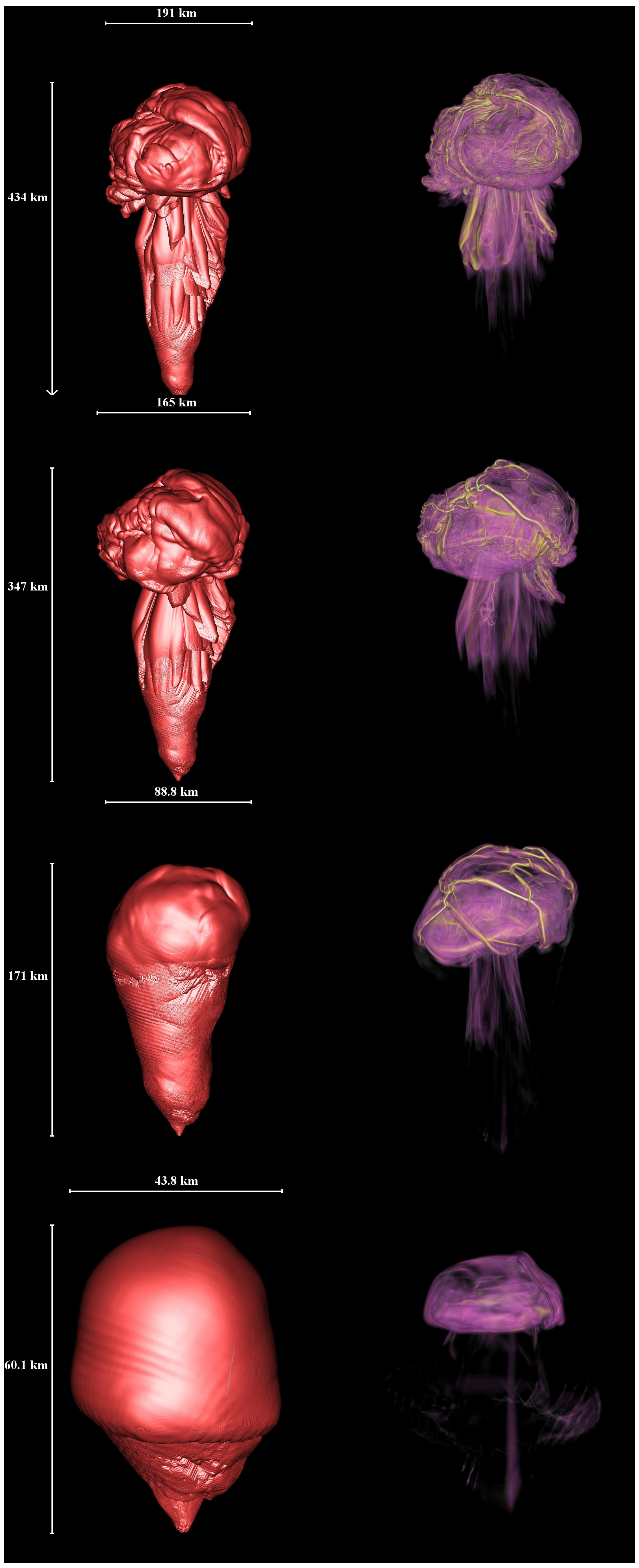


The MAESTRO data had two AMR levels, the finest being ~ 4.3 km zone^{-1}. Our high-resolution CASTRO simulations used five levels of AMR with the finest resolution being ~ 135 m zone^{-1}. Additional levels were added one at a time in CASTRO, and the system was allowed to relax for some timesteps before the next level addition.

THE ROLE OF THE BACKGROUND TURBULENCE

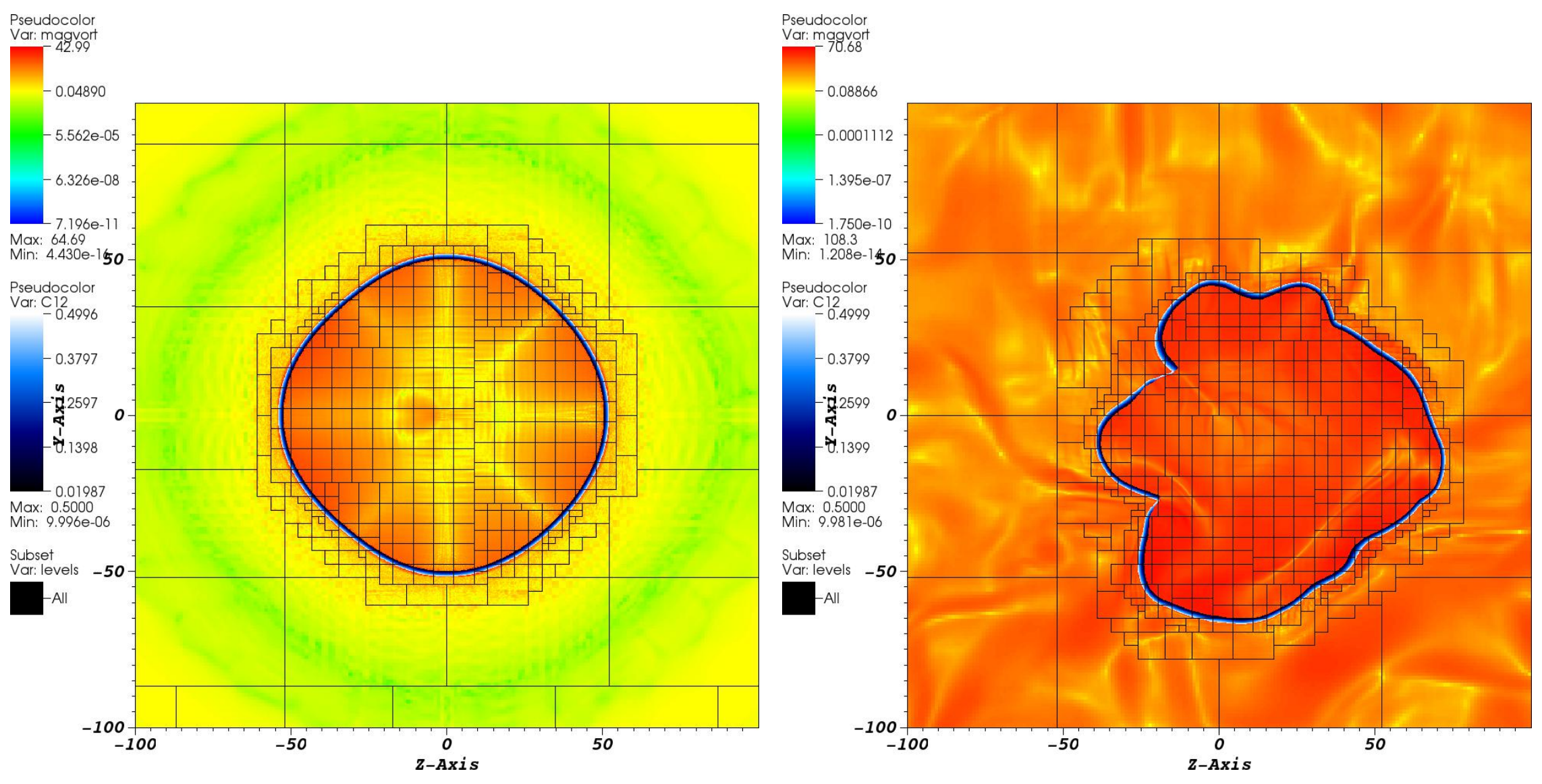


Total burned mass as a function of time for six models from Dong et. al. and two MAESTRO restart simulations, H1 and H2. The Dong models are labelled with the shape of the initial hotspot and the distance off-center; all Dong models had a hotspot radius of 20 km plus perturbations. The H1 and H2 models were ignited where the MAESTRO data underwent runaway, 41 km off-center, and had a spherical ignition point of radius 2 km plus perturbations. Model H1 included the turbulence from simmering, while model H2 did not. The H1 and H2 models track each other very well and their burned mass lies well within the range given by the various ignition conditions in the Dong models.



Evolution of the hotspot in model H1 at (from bottom to top) $t = 134, 270, 388, 431$ ms. Left: contour of $X(^{12}C) = 0.45$. Right: volume rendering of magnitude of vorticity; bright lines are vortex tubes with $\omega \gtrsim 8 \times 10^3$ s^{-1}.

CENTRAL IGNITION?



For central ignition, the background turbulence plays a stronger role in altering the hotspot's evolution. Left: central ignition without MAESTRO turbulent field; Right: same but with turbulent field. Both show in blue-scale the carbon mass fraction inside the flame and in orange $|\omega|$.

REFERENCES

[1] M. Zingale *et al.*, *ApJ*, vol. 740, 2011.

[2] A. Nonaka *et al.*, *ApJ*, vol. 745, 2012.

[3] H. Ma *et al.*, *submitted to ApJ*, 2012.

[4] S. Dong *et al.*, *in prep.*, 2012.

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