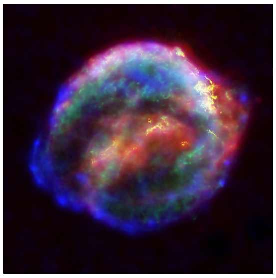
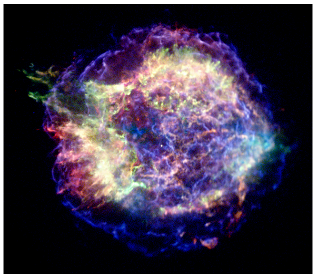
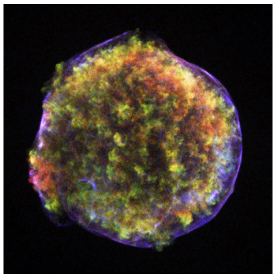
Ignition of Detonations for Type Ia Supernova Simulations



Kepler's SNR[1]



Cas A SNR[2]



Tycho's SNR[3]

A new mechanism for Type Ia supernovae explosions in massive white dwarfs has been developed at the Flash Center based on work made by possible by the multi-dimensional modeling capabilities of the Flash Code, a modular reactive, adaptive mesh, Eulerian hydrodynamics code. This new picture of how a Type Ia supernova explodes has been called the gravitationally confined detonation (GCD) model. A central aspect of the model is a centrally offset buoyant hot bubble that rises to the surface of the star whilst burning nuclear fuel as a subsonic deflagration under the influence of various hydrodynamic instabilities. Once the bubble arrives near the surface of the white dwarf gravity confines the material, which leads to a sweeping flow around the star towards the opposite pole (Fig. 1a), where the colliding flows are seen to produce a hot jet of material (Fig. 1b) which penetrates into the core of the expanded white dwarf (Fig. 1c). This hot and dense material is thought to reach conditions under which a detonation will initiate.

To develop a criterion for whether or not a detonation can successfully initiate in the jet, we have performed a series of 1D reactive (13-nuclide network) hydrodynamics calculations. We imposed a central hot spot in the form of a linear temperature profile falling from a peak temperature T_m at the origin to the background temperature T_0 at radius R on a constant density background. By systematically varying the radius we determined the smallest possible radius R_{crit} that leads to a self sustaining detonation to within better than 10% for a range of densities, peak and background temperatures. An interesting result is that at low densities an increase in the ambient background temperature T_0 from 10^7 to 10^9 K decreases R_{crit} by almost and order of magnitude, whereas changing the peak temperature T_m from 3.2 to $2.4 \cdot 10^9$ K has a much smaller effect on R_{crit} (Fig. 2.). At high densities the opposite is true, and R_{crit} has a stronger dependence on the peak temperature T_m. While the initial conditions that employ a linear temperature profile used for the determination of critical radii are not entirely physical, the combined information of Fig. 1c. and Fig. 2. suggests that a detonation is likely. In the future we would like to extend the work to develop a more consistent criterion for the ignition of a detonation that considers the coupling of the nuclear energy generation to the hydrodynamical flows.

Image credit:
[1]NASA/ESA/JHU/R.Sankrit & W.Blair
[2]NASA/CXC/SAO
[3]NASA/CXC/Rutgers/J.Warren & J.Hughes et al.

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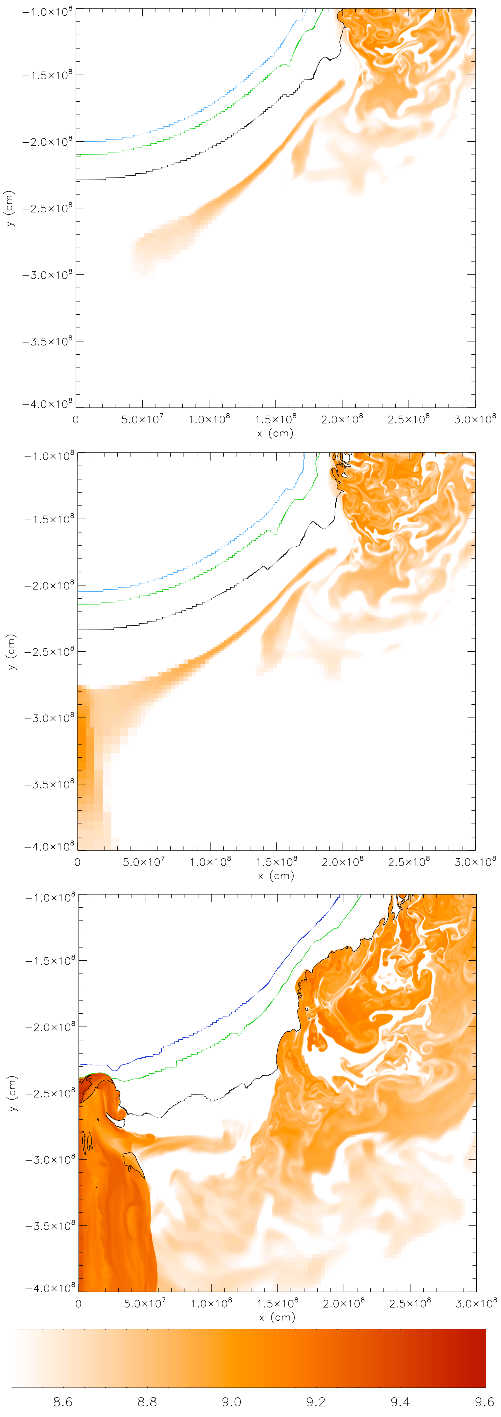

Figs. 1a-c. Log(Temperature [K]) near south pole at 1.87s, 1.92s, and 2.30s after ignition. Density isocontours for $3, 7, 10 \cdot 10^6$ $\mathrm{g\,cm^{-3}}$ are black, green, blue. (2D simulations with 8km resolution).

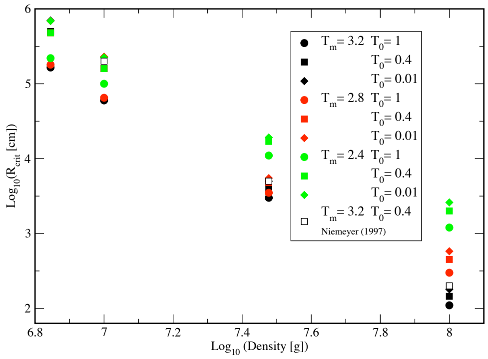

Fig. 2. R_{crit} for selected densities, peak- (T_m) and background- (T_0) temperatures (in units of 10^9K). Niemeyer & Woosley (1997) for comparison.