A new mechanism for Type Ia supernovae explosions in massive white dwarfs has been developed at the Flash Center based on work made 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 an 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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