Initiation of CO Detonations from a Temperature Gradient

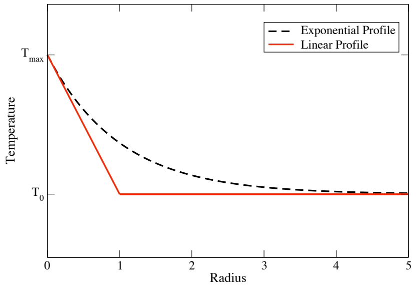

Fig. 1: Initial temperature profiles considered in this work. The exponential profile (dashed line) has the functional form $T(r) = (T_{max} - T_0)\exp(-r) + T_0$.

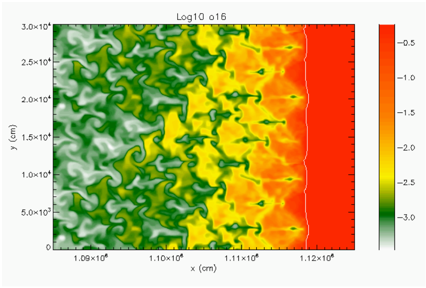

Fig. 2: Resolved cellular structure of ^{16}O burning in 2d simulations. Detonation was initiated from a linear temperature gradient without any transverse perturbations. White line is isocontour of X(^{12}C) = 0.1.

Type Ia supernovae (SNe Ia) are believed to be thermonuclear explosions of accreting C/O white dwarfs near the Chandrasekhar limit, powered by the energy liberated by the fusion of the initial composition to nuclear statistical equilibrium (NSE). The explosion mechanism of SNe Ia is still unknown, and the large variation of their peak luminosity and spectral properties allows for a range of explosion mechanisms. In many of the explosion models, detonations are a necessary ingredient, because the observed layered structure of many supernova ejecta is a strong signature of a detonation. The location and details of the formation of the detonation are unknown, but initiation via some form of the Z'eldovich gradient mechanism is a likely scenario.

We determine the critical (smallest) size of hot spots that marginally result in a detonation in white dwarf matter by integrating the reactive Euler equations with the hydrodynamics code FLASH. We investigate the dependencies of the critical sizes of such hot spots on density, composition, background temperature T_0, peak temperature T_{max}, geometry (planar or spherical), resolution, functional form of the temperature disturbance (Fig. 1) and dimensionality (Fig. 2). A detonation fails when the ^{12}C burning fails to stay coupled to the shock that was set up near the boundary layer (Fig. 3). A detonation successfully ensues only if the ^{12}C burning layer remains coupled to the shock until ^{16}O burning is fully operational (Fig. 4). The critical sizes are strongly dependent on density, composition and T_0, whereas geometry, choice of linear or exponential profile and dimensionality have a much smaller effect. The peak temperature T_{max} has no effect on the critical sizes as long as it is chosen to be larger than some critical value, which depends weakly on density and T_0 but is typically around 2.4×10^9 K.

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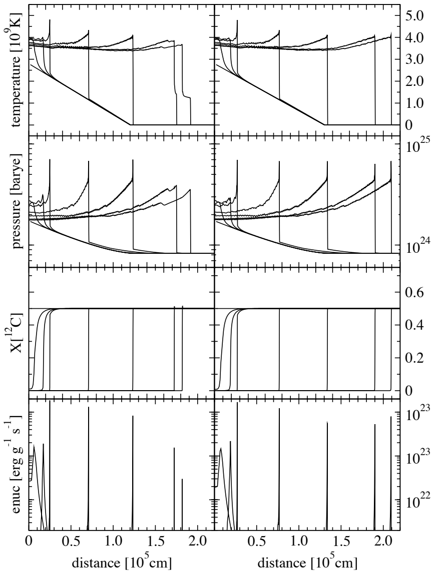

Fig. 3: Snapshots of temperature, pressure, ^{12}C mass fraction, and energy generation rate at a density of 10^7 g cm^{-3} in planar geometry for initial conditions that fail (R = 1.2km, left) and that successfully initiate a detonation ($R = 1.3$km, right).

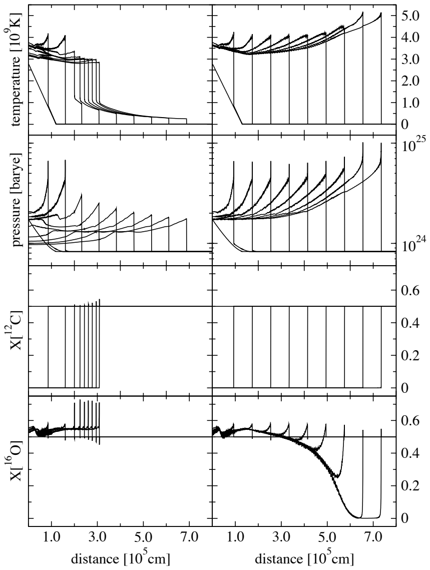

Fig. 4: Snapshots of temperature, pressure, ^{12}C and ^{16}O mass fractions at a density of 10^7 g cm^{-3} in planar geometry for initial conditions that fail ($R = 1.2$km, left) and that successfully initiate a detonation ($R = 1.3$km, right).

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