Spontaneous Deflagration-to-Detonation Transition in Thermonuclear Supernovae

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Abstract

Type Ia supernovae (SNIa) were first suggested over half a century ago to be the result of the thermonuclear incineration of a degenerate white dwarf star (WD) with a mass near the Chandrasekhar limit in a binary stellar system. Presently, the scenario best capable of explaining the observational properties of "normal" SNIa, which are of primary importance for cosmology, is the delayed-detonation model. In this model, the explosion starts as a subsonic deflagration that later transitions to a supersonic detonation (deflagration-to-detonation transition, or DDT). It remains unclear, however, whether DDT can indeed occur in the interior of a WD, and what the mechanism of this transition could be. Modern large-scale multidimensional simulations of SNIa cannot capture the DDT process and, thus, are forced to make two crucial assumptions, namely (a) that DDT does occur at some point, and (b) when and where it occurs. Furthermore, the nature of the unconfined DDT in systems without walls or boundaries remains unknown even in the context of chemical flames on Earth. Here we show, through fully resolved first principles numerical simulations, that at sufficiently high turbulent intensities, subsonic turbulent flames in such unconfined environments are inherently susceptible to the DDT. The associated mechanism is qualitatively different from the traditionally suggested gradient (spontaneous reaction wave) model. It also does not require the formation of distributed flames. The proposed mechanism predicts the DDT density in SNIa to be $\sim 10^7 g/cm^3$, in agreement with the values that were previously found to give the best match with observations. We discuss the implications of this mechanism for SNIa as well as the possibilities for its validation in terrestrial laboratory experiments.