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Unified Theory of Detonation Initiation in Type Ia Supernovae and Terrestrial Chemical Systems

The nature of stellar progenitors and the associated explosion mechanism of type Ia supernovae (SNIa) remains one of the major open questions in astrophysics. Virtually all existing theoretical models require formation of a supersonic
detonation wave capable of providing nearly complete incineration of the stellar material of a WD after it becomes gravitationally unbound. The mechanism of detonation initiation in unconfined systems, such as the interior of a WD, remains poorly understood. Modern large-scale numerical models of SNIa are unable to capture detonation formation from first principles due to the extreme range of dynamical scales involved, and instead they are forced to trigger detonations artificially. As a result, the time and location of the detonation initiation are free parameters present in all existing SNIa models. This limits predictive power of SNIa models and does not allow them to be conclusively and rigorously confirmed or disproved using observations.

We discuss recent advances in our understanding of the physics of detonation initiation in unconfined turbulent reacting flows, both terrestrial and astrophysical. In particular, we present the general theory of turbulence-induced deflagration-to-detonation transition (tDDT). We use direct numerical simulations (DNS) of unconfined turbulent thermonuclear flames in a degenerate 12C stellar plasma to show for the first time that under conditions representative of those in a SNIa explosion this tDDT mechanism can result in the spontaneous formation of strong shocks and subsequently detonation ignition. We also describe results of experimental and numerical studies in terrestrial chemical systems corroborating this theory. Finally, we discuss the implications of this DDT theory for the classical single-degenerate Chandrasekhar-mass model. These results open path for the new generation of the first-principles predictive SNIa models, in which detonation initiation conditions can be determined accurately and self-consistently.

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