Verification and Validation of Current Models of Thermonuclear-Powered Supernovae Using Large-Scale Simulations

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Observations using Type Ia (thermonuclear-powered) supernovae led to the discovery of dark energy and are one of the most promising methods for determining its properties. Most scientists believe using these explosions to accomplish the latter will require a much better understanding of them. Two major challenges face numerical astrophysicists in the Type Ia supernova field: (1) several key physical processes in these explosions are not fully understood, including buoyancy-driven turbulent nuclear combustion; and (2) very few simulations of the current models of Type Ia supernovae have been done, making it difficult to determine which of these models is favored by observations, and even more, what values of the many parameters specifying these models are consistent with observations. We report the results of extensive verification simulations of buoyancy-driven turbulent nuclear combustion for both planar flames in a channel and flame bubbles in an open domain, using FLASH on Intrepid at the Argonne Leadership Computing Facility (ALCF). These simulations have confirmed the existence of "self-regulation," in which changes in the area of the flame exactly compensate for changes in the laminar flame speed, causing the nuclear burning rate to be independent of the laminar flame speed. They have also revealed much about the physical properties of buoyancy-driven turbulent nuclear combustion, providing important information for the verification of a subgrid model of such burning. We have also begun a comprehensive, systematic validation of the current models of Type Ia supernovae, using FLASH on Intrepid at ALCF and high-quality light curves and spectra obtained by the SDSS-II Supernova Survey team and its collaborators. We report the initial results of this validation effort.