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Nucleosynthesis in Novae and X-Ray Bursts – Open Issues

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Classical novae are thermonuclear explosions that take place in the H-rich envelopes of accreting white dwarfs in stellar binary systems. The material piles up under degenerate conditions, driving a thermonuclear runaway. The energy released by the suite of nuclear processes operating at the envelope heats the material up to peak temperatures of 100 - 400 MK. During these events, about 10^{-7} – 10^{-4} solar masses, enriched in CNO and, sometimes, other intermediate-mass elements (e.g., Ne, Na, Mg, Al) are ejected into the interstellar medium. This suggests mixing between solar composition material transferred from the secondary and the outermost layers of the underlying white dwarf during the thermonuclear runaway. This paper explores a new methodology that combines 1D and 3D simulations. The early stages of the explosion (i.e., mass-accretion and initiation of the runaway) were computed with the 1D hydrodynamic code SHIVA. When convection extended throughout the entire envelope, the structures for each model were mapped into 3D Cartesian grids and were subsequently followed with the multidimensional code FLASH. Two key physical quantities were extracted from the 3D simulations and were subsequently implemented into SHIVA, which was used to complete the simulation through the late expansion and ejection stages: the time-dependent amount of mass dredged-up from the outer white dwarf layers, and the time-dependent convective velocity profile throughout the envelope. Implications for nova nucleosynthesis, with emphasis on ^{7}Li, will be discussed.

A similar type of explosion, X-Ray Bursts (XRB), occurs in the envelopes of accreting neutron stars in stellar binary systems. The overall energy output in a typical XRB, 10^{39} erg, is released in a timescale between 10 - 100 s. Maximum temperatures during the explosion reach 1 GK, with a nuclear activity reaching species with atomic masses around A = 60 (and probably beyond). A major challenge in the modeling of XRBs is associated with the lack of observational nucleosynthetic constraints. It is unclear whether XRBs contribute to Galactic abundances because of the extremely large escape velocities from a neutron star surface. Indeed, the energy required to escape from the strong gravitational field of a neutron star of mass M and radius R is G M mp/R ~ 200 MeV/nucleon, whereas the nuclear energy released from thermonuclear fusion of solar-like matter into Fe-group elements is only ~ 5 MeV/nucleon. New results based on the coupling of hydrodynamic simulations and radiation-driven winds will be presented.

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