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Editorial

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# Nuclear Structure and Astrophysics

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## Editorial

The nuclear structure in regions of the Segré chart which are of astrophysical importance is reviewed. The main emphasis is put on those nuclei that are relevant for stellar nucleosynthesis in fusion processes, and in slow neutron capture, both located close to stability, rapid neutron capture close to the neutron dripline and rapid proton capture near the proton dripline. The basic features of modern nuclear structure, their importance and future potential for astrophysics and their level of predictibility are critically discussed. Recent experimental and theoretical results for shell evolution far off the stability line and consequences for weak interaction processes, proton and neutron capture are reviewed.

The Nuclear Structure and Astrophysics Group perform pioneering measurements with beams of unstable nuclei to determine the mechanism of how stars explode and the accompanying cosmic creation and dispersion of the elements of our world, including those necessary for life. We carry out our measurements at accelerator laboratories throughout the U.S. and internationally, with a scientific focus on understanding nova explosions, supernova explosions, X-ray bursts, and neutron-star mergers. We develop advanced detector and targetry systems that we use in our experiments. Our Group also performs synergistic data evaluations and cosmic element synthesis simulations to fully explore these fascinating astrophysical systems. Our focus on measurements with unstable nuclei is fully aligned with the latest Long Range Plan for U.S. Nuclear Science, and has applications in a variety of areas including homeland security, nuclear non-proliferation, and medical isotopes.

Our Group members make direct measurements of thermonuclear capture reactions on proton-rich unstable nuclei that drive some stars to undergo violent nova explosions or X-ray bursts. A significant result in this work was our utilization of the Daresbury Recoil Separator at ORNL to measure proton capture on radioactive $^{17}F$. Our measurement dramatically improved predictions of the cosmic production of the long-lived radionuclide $^{18}F$ that is used as a diagnostic of the nova explosion mechanism. Our next measurements of this type will involve the Separator for Capture Reactions SECAR that we are helping to construct at the Facility for Rare Isotope Beams (FRIB) at Michigan State University. We also use beams of neutron-rich unstable nuclei to determine the rates of reactions that produce the heaviest nuclei in neutron-star mergers and core-collapse supernovae. Our recent accomplishment in this effort is the experimental determination of the neutron capture rates on neutron-rich exotic tin isotopes, the first such systematic data set on unstable nuclei.

To carry out this work, we develop advanced detector, targetry, and data acquisition systems. A prime example is our development of the Jet Experiments for Nuclear Structure and Astrophysics (JENSA) gas jet target system that produces the highest-density helium jet for accelerator experiments in the world. JENSA was recently used with a radioactive $^{34}Ar$ beam for a measurement of the $^{34}Ar$ + alpha —> $^{37}K$ + p reaction that is important in understanding the synthesis of elements in X-ray bursts. Other systems we have developed include the SuperO RRUBA array of silicon strip detectors, the VANDLE array of neutron detectors, and the SABRE and ODeSA neutron detector arrays. Convection is not perfectly efficient so that the actual mixing time would still be definite. Given that such a limit exists, we must examine rapid evolutionary stages to see if microscopic mixing is a valid approximation. For presupernovae, the approximation is almost certainly not correct so that these stars are not layered in uniform spherical shells as conventionally assumed but are heterogeneous in angle as well as radius. In a discussion of stellar evolution, one encounters the topics of rotation, convection, pulsation, mass loss, micro-turbulence, sound waves, shocks, and instabilities (to name a few), which are all just hydrodynamics. However, the direct simulation of stellar hydrodynamics is limited by causality.

Ultimately, simulations must be well resolved in three spatial dimensions. One of the great assets of computers is their ability to represent complex geometries. An essential step toward that goal is the testing of computer simulations against reality in the form of experiment (Remington et al. 1995). This is a venue in which we can alter conditions (unlike astronomical phenomena) and thereby understand the reasons for particular results. Experiments are intrinsically three dimensional, with two-dimensional symmetry available with some effort, so that they provide a convenient way to assess the effects of dimensionality. For Rayleigh-Taylor instabilities, the Nova experiments not only sample temperatures similar to those in the helium layer of a supernova, but they hydrodynamically scale to the supernova as well (Kane et al. 1997; Ryutov et al. 1999).

In the same sense that aerodynamic wind tunnels have been used in aircraft design, these high-energy density laser experiments allow us to reproduce precisely a scaled version of part of a supernova. The Nova laser is physically imposing. The building is larger in area than an American football field ; the lasers concentrate their beams on a target about the size of a small ball bearing. This enormous change in scale brings home just how high these energy densities are. Preliminary results show that the astrophysics code (PROMETHEUS) and the standard inertial confinement fusion code (CALE) both give qualitative agreement with the experiment.

For example, the velocities of the spikes and bubbles are in agreement with both experiment and analytic theory, which is applicable in this experimental configuration (Kane et al. 1997). The two codes give similar but not identical results. These differences will require new, more precise experiments to determine which is most nearly correct. Great At least for explosive events (such as supernovae, novae, and gamma-ray bursts), there is much overlap in interests between the astrophysics community and those interested in the physics that now can be realized in high-energy density laser facilities. Collaborative efforts are already fruitful and promise to be even more productive.