Multi-messenger observations of neutron rich matter

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Neutron rich matter is central to many fundamental questions in nuclear physics and astrophysics. Moreover, this material is being studied with an extraordinary variety of new tools such as the Facility for Rare Isotope Beams (FRIB) and the Laser Interferometer Gravitational Wave Observatory (LIGO). We describe the Lead Radius Experiment (PREX) that uses parity violating electron scattering to measure the neutron radius in ^{208}Pb. This has important implications for neutron stars and their crusts. We discuss X-ray observations of neutron star radii. These also have important implications for neutron rich matter. Gravitational waves (GW) open a new window on neutron rich matter. They come from sources such as neutron star mergers, rotating neutron star mountains, and collective r-mode oscillations. Using large scale molecular dynamics simulations, we find neutron star crust to be very strong. It can support mountains on rotating neutron stars large enough to generate detectable gravitational waves. Finally, neutrinos from core collapse supernovae (SN) provide another, qualitatively different probe of neutron rich matter. Neutrinos escape from the surface of last scattering known as the neutrino-sphere. This is a low density warm gas of neutron rich matter. Observations of neutrinos can probe nucleosyntheses in SN. Simulations of SN depend on the equation of state (EOS) of neutron rich matter. We discuss a new EOS based on virial and relativistic mean field calculations. We believe that combing astronomical observations using photos, GW, and neutrinos, with laboratory experiments on nuclei, heavy ion collisions, and radioactive beams will fundamentally advance our knowledge of compact objects in the heavens, the dense phases of QCD, the origin of the elements, and of neutron rich matter.

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