"GW170817 and neutron rich matter in the laboratory and in the heavens"

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Compress almost anything to very high densities and electrons react with protons to make neutron rich matter. This material is at the heart of many fundamental questions in nuclear physics and astrophysics. What are the high-density phases of QCD? Where did the chemical elements come from? What is the structure of many compact and energetic objects in the heavens, and what determines their electromagnetic, neutrino, and gravitational-wave radiations? Recently, extensive gravitational wave and electromagnetic observations of the neutron star merger GW170817 have constrained the equation of state of neutron rich matter and strongly suggest that neutron star mergers are an important site of rapid neutron capture ($r$-process) nucleosynthesis of heavy elements such as gold and uranium. We discuss these historic developments and try and place them in a broad context. We describe how the thickness of the neutron skins of the 48Ca and 208Pb nuclei are being measured with parity violating electron scattering at Jefferson Laboratory. These skins depend on the pressure of neutron rich matter and have important implications for the structure of neutron stars. We expect many thousand neutrino events from the next galactic core collapse supernova (SN). Simple neutrino interactions suggest that the neutrino driven wind is not very neutron rich and thus, despite what is said in many textbooks, SN may not be the site of the $r$-process for heavy elements. Finally, GW170817, by suggesting the astrophysical conditions, has set the stage for the Facility for Rare Isotope Beams (FRIB) to perform a detailed study $r$-process nucleosynthesis. FRIB, a powerful radioactive beam accelerator under construction in Michigan, will produce, for the first time, many of the very neutron rich heavy nuclei that are involved in the $r$-process.