CONSTRAINING THE PHYSICS OF ULTRA-DENSE MATTER WITH X-RAY OBSERVATIONS OF NEUTRON STARS

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The equation of state (EoS) of cold, stable matter at densities exceeding those of atomic nuclei remains one of the principal outstanding problems in subatomic physics. Neutron stars provide the only astrophysical setting where this density-temperature regime can be explored. These compact objects can be thought of as giant atomic nuclei, and understanding how their radii change with the mass is of fundamental importance for nuclear physics and complements what is being learned from collisions of heavy ions. The conditions resulting from the enormous pressure at the center of a neutron star may include i) a dense superconducting superfluid composed primarily of neutrons; ii) dissolution of individual neutrons into an undifferentiated soup of quarks and gluons; iii) a phase transition to a "Bose condensate" of pions or kaons; or iv) a phase transition to yet-more-exotic matter made up of hyperons. Which, if any, of these theoretically well-motivated predictions actually occurs in reality is unknown – the interior composition of neutron stars has remained elusive since the first theoretical description of these objects by Oppenheimer and Volkoff in 1939.

The mass-radius relation of neutron stars is strongly sensitive to the EoS. By measuring this relation of several neutron stars with $\leq 5\%$ errors, it is possible to place stringent constraints on allowable EoS at supra-nuclear densities. Provided telescopes with adequate capabilities, this can be accomplished via X-ray observations of four particular varieties of thermally-radiating neutron stars: (i) quiescent low-mass X-ray binaries in globular clusters; (ii) thermally-emitting rotation-powered "recycled" pulsars; (iii) accreting millisecond X-ray pulsars; (iv) bursting neutron stars that show photospheric radius expansion. Enabling the required X-ray studies of these invaluable astrophysical laboratories should be of high priority in NASA's long-range science vision as they can offer unique insight into the fundamental physical laws that govern the behavior of matter. This important science goal should thus be a major consideration in the design of future space-borne X-ray observatories in terms of throughput, fast timing capabilities, and angular resolving power.