Compact Stars as Laboratories for Matter at Extremes and Fundamental Physics

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The term compact stars is used in astronomy to refer collectively to white dwarfs, neutron stars, and other exotic dense stars. These are the collapsed cores of stars which, near the ends of their luminous lives, have shed most of their mass in supernova explosions or other, less spectacular, instabilities. Here gravity crushes matter to realms that lie far beyond present empirical knowledge.

Compact stars are unique laboratories that allow us to probe the building blocks of matter and their interactions at regimes that terrestrial laboratories cannot explore. As an example, in a neutron star one can encounter all of the 4 forces of matter, the strong force, the weak force, the electromagnetic force and gravity. Compact stars are, after black holes, the densest objects in the universe. They are as heavy as the sun, but their radius is only about 10 km. They also rotate very fast and can also have enormously large magnetic fields. Their extreme density, fast rotation, and large magnetic fields make compact stars a perfect "laboratory" for fundamental physics, and for studying matter under extreme conditions.

Compact stars have already led to breakthrough discoveries in nuclear and subnuclear physics, quantum chromodynamics (QCD), general relativity and high-energy astrophysics. The advent of a new generation of observatories and gravitational wave detectors will assist us in innovative and fundamental discoveries that will complement those achieved through nuclear and subnuclear experimental facilities. Multi-messenger (electromagnetic, neutrino, gravitational wave and cosmic ray) observations are expected to reveal the underlying physical processes of extreme astrophysical phenomena involving neutron stars such as neutron-star merger and core-collapse supernovae. These observations could provide new insights into particle and nuclear physics under extreme conditions and physics beyond the standard model.

This Quarks to Cosmos (Q2C) internship topic brings together knowledge from nuclear physics, particle physics, astrophysics, gravitational physics and cosmology to address this fascinating but challenging research area through an interdisciplinary approach.

In this topic, interns will investigate:

(i) nuclear-physics properties of compact stars, their impact on the astrophysical evolution and observability of compact stars and vice versa,

(ii) properties of QCD in compact stars and phase transitions that could take
place in their interiors,

(iii) gravitational-wave emission from single and binary compact stars; probing nuclear astrophysics using gravitational waves from neutron stars,

(iv) the equation of state (EoS) of hot and dense matter - a fundamental input to describe static and dynamical properties of neutron stars core-collapse supernovae and binary compact-star mergers,

(v) effects of a strong phase transition on compact stars, their mergers and supernova explosions,

(vi) the distribution of masses of neutron stars,

(vii) fast-spinning and magnetized white dwarfs,

(viii) pulsar glitches as probes for the structure of neutron stars and

(ix) physics and astrophysics of super-dense matter.