Neutron Stars and Dense Matter

• Fundamental Objectives:
  – What is composition of dense matter, and its thermodynamic and transport properties?
  – What is the maximum density and the maximum pressure?
Key achievements

- **Astrophysical Observations**:
  - Two solar mass neutron star (pulsar): \( J1614-2230 \) has important implications about the EoS and the role of quark matter in the core.
  - X-ray busters: mass-radius relations - EoS, crustal conductivity
  - Magnetars: crustal vibrations – EoS, shear viscosity:

- **Laboratory Measurements**:
  - Exploitation of giant and pygmy resonances, heavy ion collisions, mass, isobaric analog resonances, skin thicknesses to constrain EoS.

- **Theory**:
  - Establishing connections: neutron star observables <=> EoS.
  - Establishing connections: laboratory observables <=> EoS.
  - Ab-initio calculations of EoS from realistic interactions.
Towards the EoS: illustrative examples:

\[ E/A (\rho, \delta) = E/A (\rho, 0) + S(\rho) \cdot (\rho_n - \rho_p)^2/\rho^2 \]

- At \( \rho < \rho_0 \), laboratory observables and neutron star observables provide some constraints on the symmetry energy.
- Precision will improve.

- At \( \rho < \rho_0 \), some initial constraints are also available.
- However, laboratory constraints on the symmetry energy at \( \rho > \rho_0 \) are not yet available.
Opportunities and needs

- **Astrophysics:**
  - Concerns: IXO cancelled. Funding for GBT (where 2 solar mass N-star was observed) is threatened. A strong statement affirming the importance of EoS work is warranted and could be important.
  - New opportunities: LOFTS (Large X-ray timing satellite:2022); Development of smaller Explorer class instruments.
  - Continued availability of Chandra and XMM-Newton.

- **Laboratory Measurements:**
  - Key issue is development of facilities (FRIB) to produce intense beams of rare isotopes for laboratory investigations of neutron–rich nuclei and nuclear matter.
  - There are excellent opportunities to improve present constraints at $\rho<\rho_0$ and extend them to higher densities $\rho\approx2\rho$.

- **Theory is essential to these efforts:**
  - Theoretical support and development is essential to refine connections between measurement and the EoS and assist in the development of new directions. This requires concerted efforts.