Neutron Stars and Dense Matter

- Fundamental Objectives:
  - Determination of the EoS of dense matter.
  - What is composition of dense matter, and its thermodynamic and transport properties?
  - What is the maximum density and the maximum pressure?

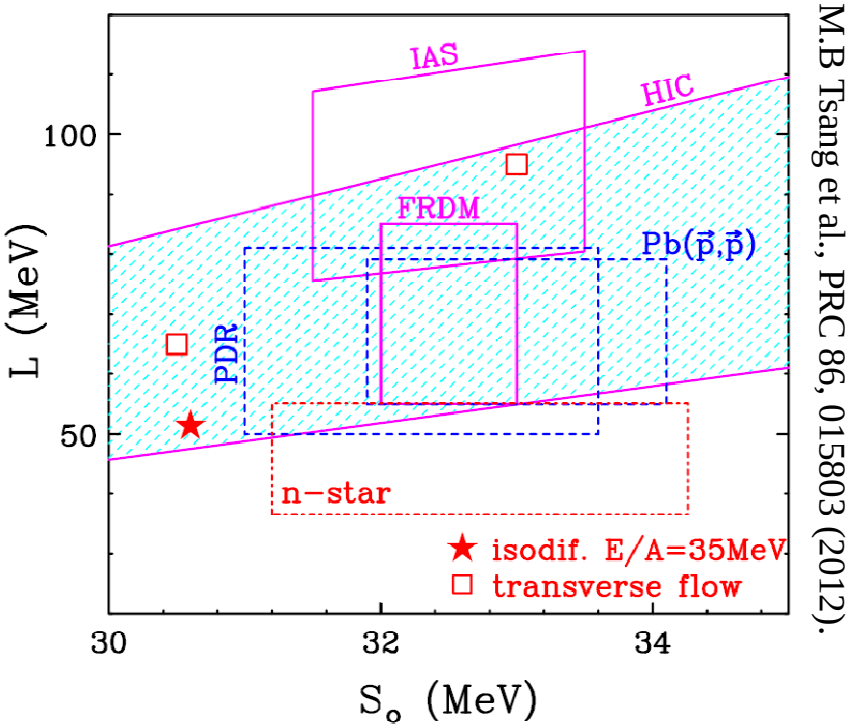
Key achievements

- 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.

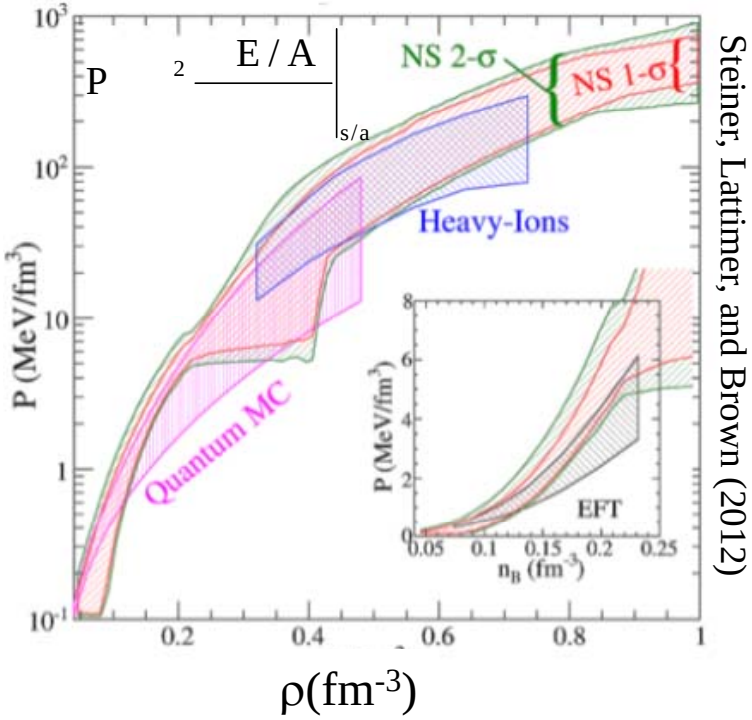
Towards the EoS: illustrative examples:

$$S \quad S_o \quad \frac{L}{3} \quad \frac{\quad_0}{\quad_0} \quad \frac{K_{sym}}{18} \quad \frac{\quad_0}{\quad_0}^2 \quad \ldots$$

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



M.B Tsang et al., PRC 86, 015803 (2012).



Steiner, Lattimer, and Brown (2012)

- 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 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 $\rho\approx 2\rho$.
- 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.