

Connecting Neutron Star Properties to the Nuclear Symmetry Energy

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The knowledge of the density dependence of the nuclear symmetry energy is crucial in both nuclear physics and neutron-star astrophysics.

The nuclear symmetry energy is an essential ingredient (yet not very well known part) of the equation of state of *nucleonic matter* and:

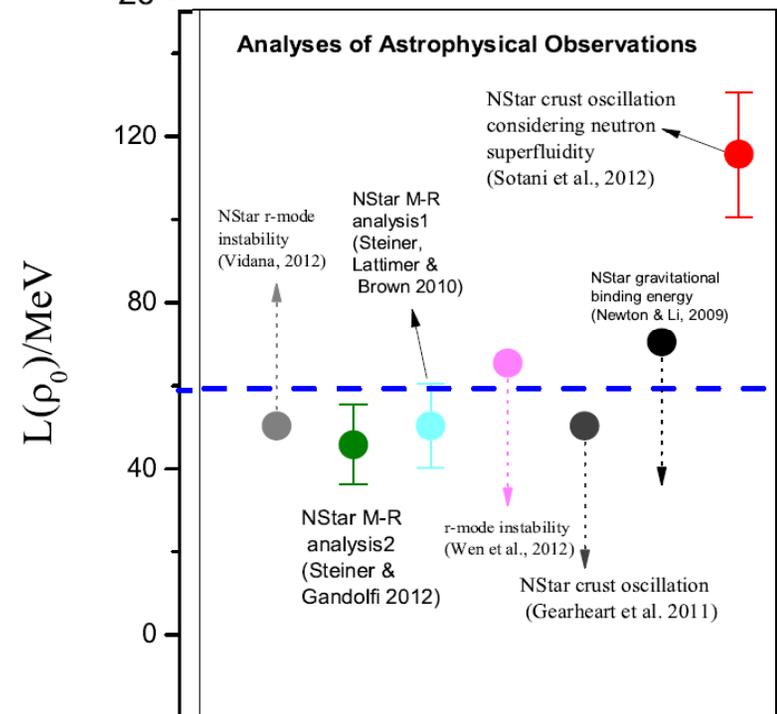
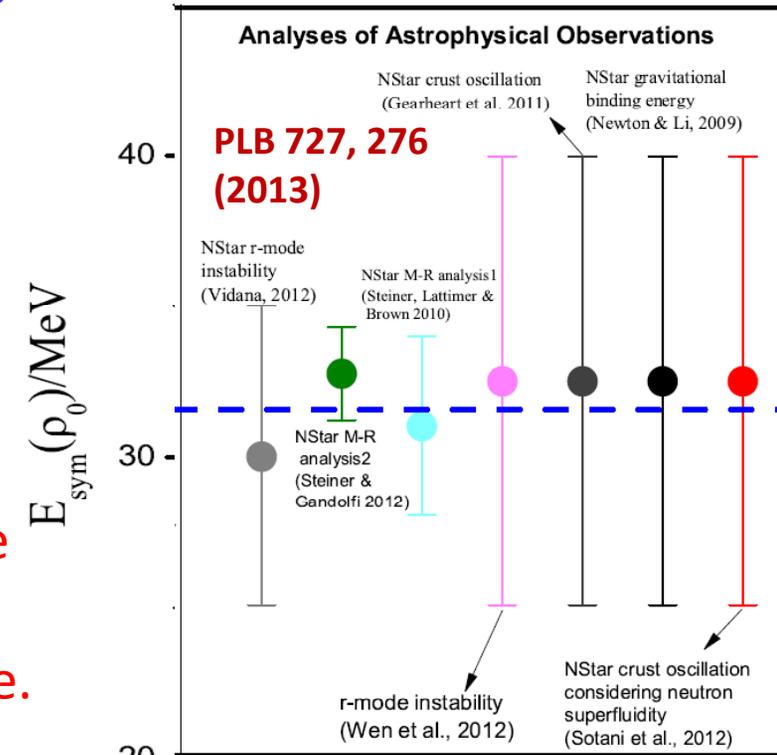
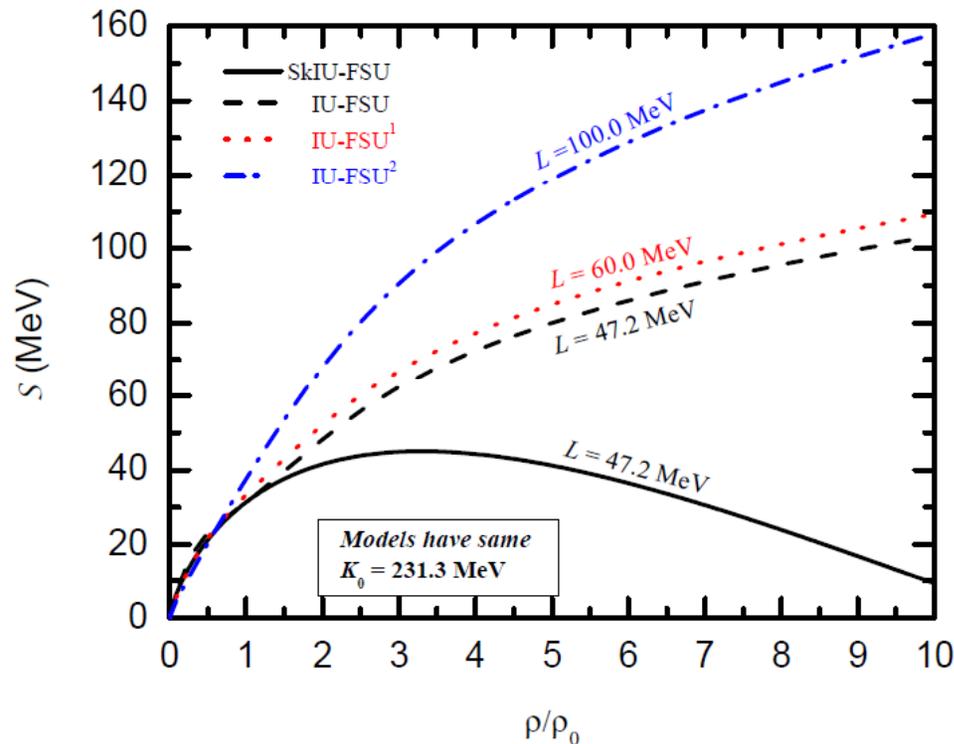
- plays vital role in describing the structure of medium to heavy nuclei, the structure of rare isotopes and their reaction mechanisms, etc.;
- determines uniquely the proton fraction essential for the understanding of cooling mechanisms in neutron stars and appearance of exotic species in neutron stars;
- affects significantly the structure of neutron stars, such as radii, moments of inertia, tidal deformabilities, crust-core transition properties, frequencies and damping times of various oscillation modes in neutron stars.

Present Status

Limited data are available from neutron-star observations to constrain the density dependence of the nuclear symmetry energy.

The extracted knowledge still remains largely uncertain *even around nuclear saturation density*.

There is very little or no information that connects the nuclear symmetry energy at supra-saturation to neutron-star properties. Model predictions are diverse.



Future Challenges

Basic questions that are still unanswered, yet are strongly connected to the symmetry energy:

- Do exotic species (hyperons, quark matters, etc.) exist at the core of neutron stars?
- How fast do neutron stars cool?
- What is the true mechanism behind the pulsar glitches?
- What is the origin of quasi periodic oscillations in giant magnetar flares?
- What neutron-star observations *unambiguously* probe the symmetry energy at supra-saturation? (tidal deformability, neutrino flux from proto-neutron stars)
- **What is the impact of the strong-field gravity in analyzing observations? (going beyond TOV)**
- **How to properly break the degeneracy between the equation of state and different models of gravity?**

TO FURTHER ADVANCE:

Statistical covariance method and/or Bayesian inference should be carried out **to quantify theoretical uncertainties and to find correlations** between various pairs of both neutron-star and laboratory observables sensitive to the symmetry energy.

Requirement: Large-scale computing facilities

