Can Neutron Stars Predict the Neutron Skin Thickness?

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The CREX mascot?

- Related, but smaller
- A little more closer to everyday life
- Easier to model

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- Looking in the parity violating mirror

Outline

- Neutron star mass and radius measurements are constraining properties of terrestrial nuclei and other quantities of interest for nuclear physics!
  - Correlations
  - Equations of state, masses, and radii
  - Symmetry energy
  - Three-body forces

Correlations with the Pressure

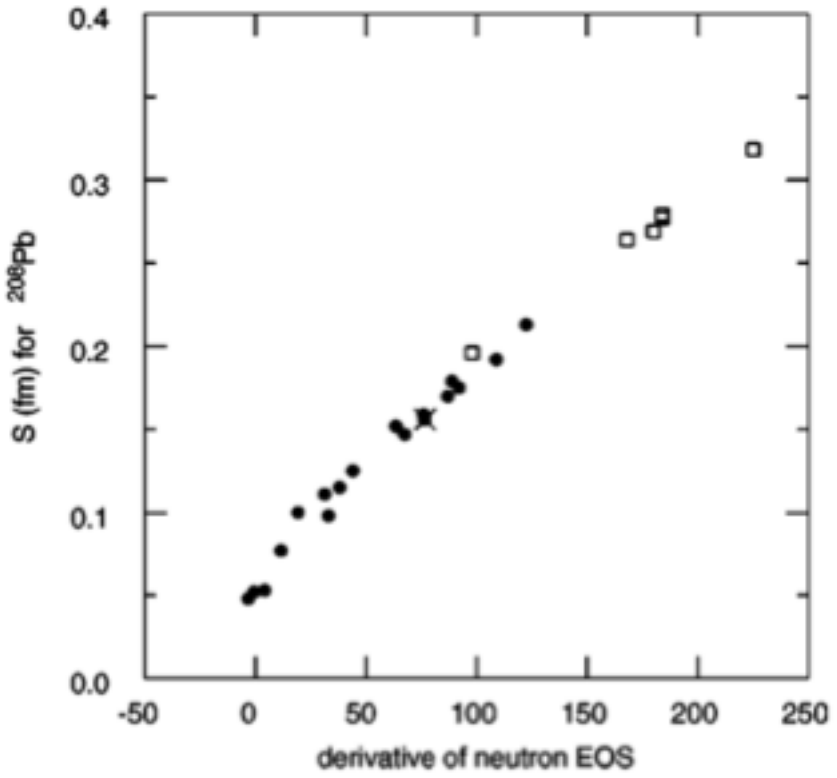
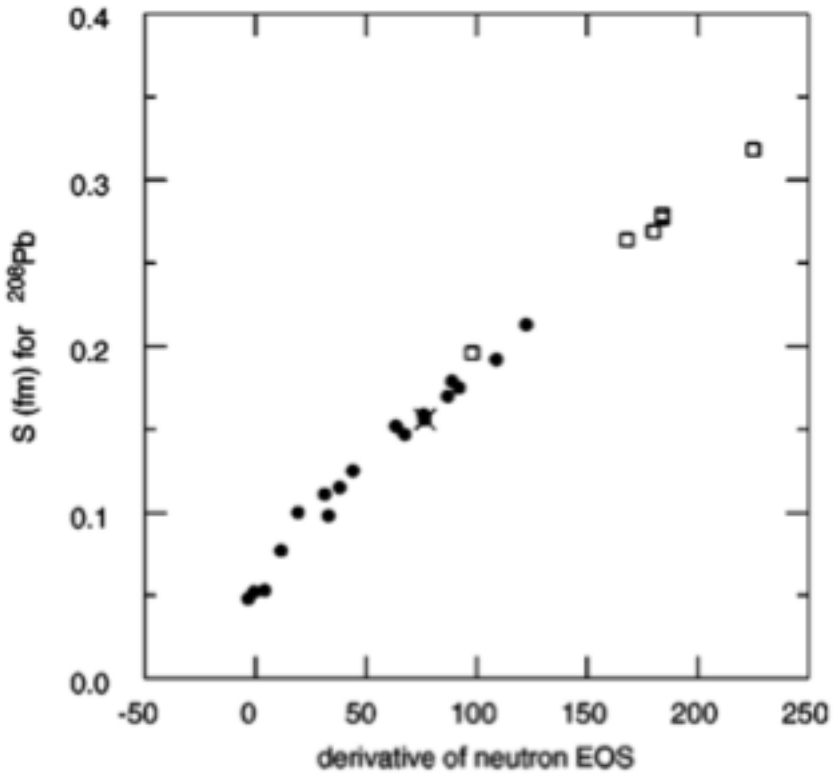


FIG. 1. The derivative of the neutron EOS at $\rho_0 = 0.10$ neutrons/fm^3 (in units of MeV fm^3/neutron) vs the S value in ^{208}Pb for 18 Skyrme parameter sets (filled circles) and for the six relativistic models (squares). The cross is the SKX Skyrme Hamiltonian [18].

Typel and Brown (2001)

- The pressure of neutron rich matter is correlated with both the neutron skin thickness and NS radii

Correlations with the Pressure



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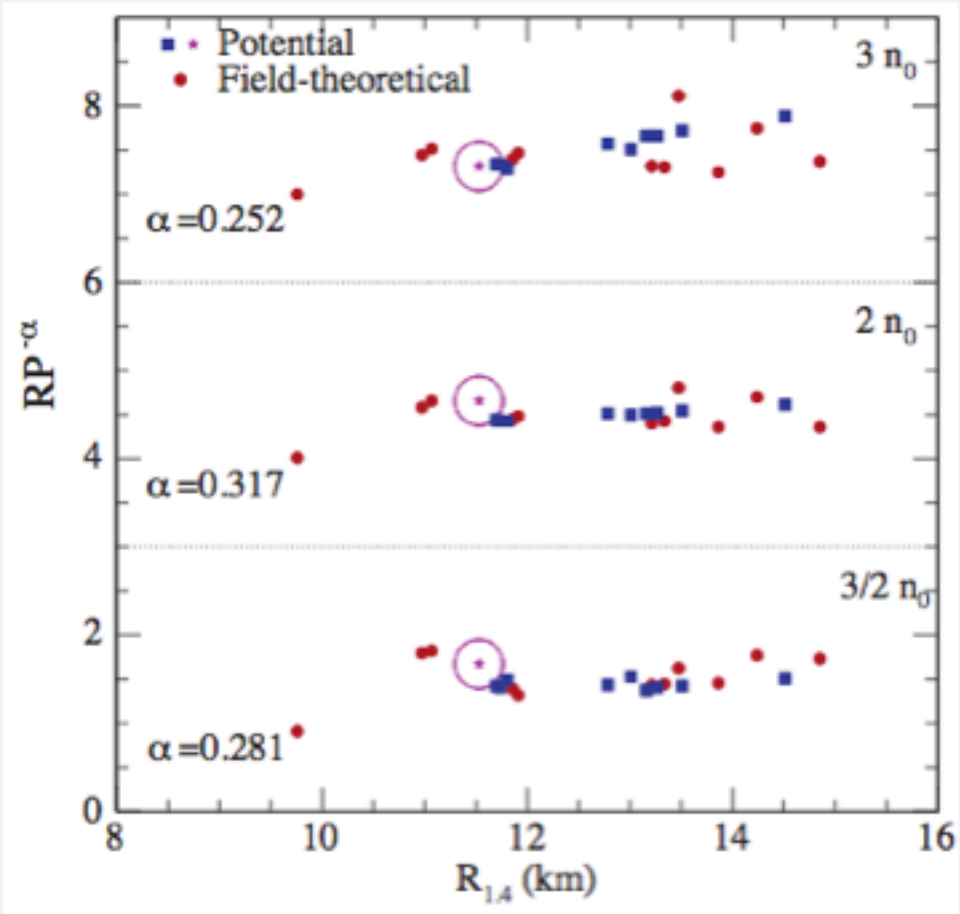

Lattimer and Prakash (2001)

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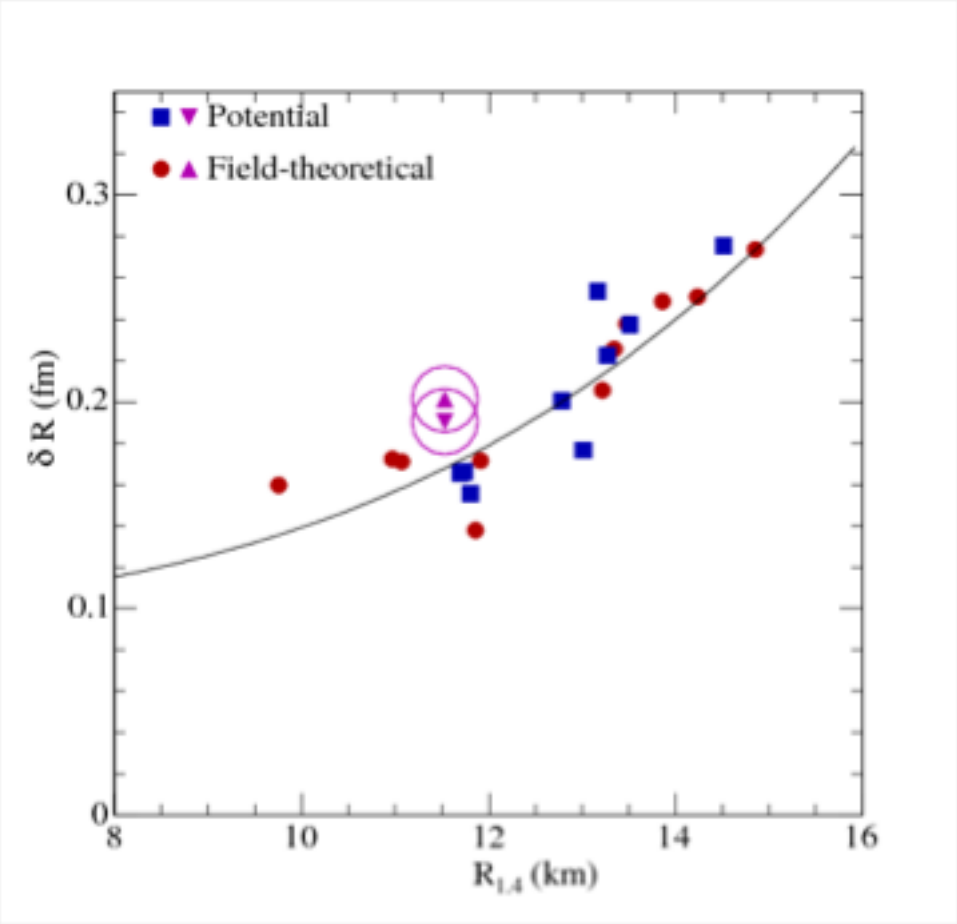
Data-to-data Correlations



Steiner et al. (2005) based on
Horowitz and Piekarewicz (2001)

- Neutron star radius ⇔ Neutron skin thickness ⇔ Isospin diffusion in HIC

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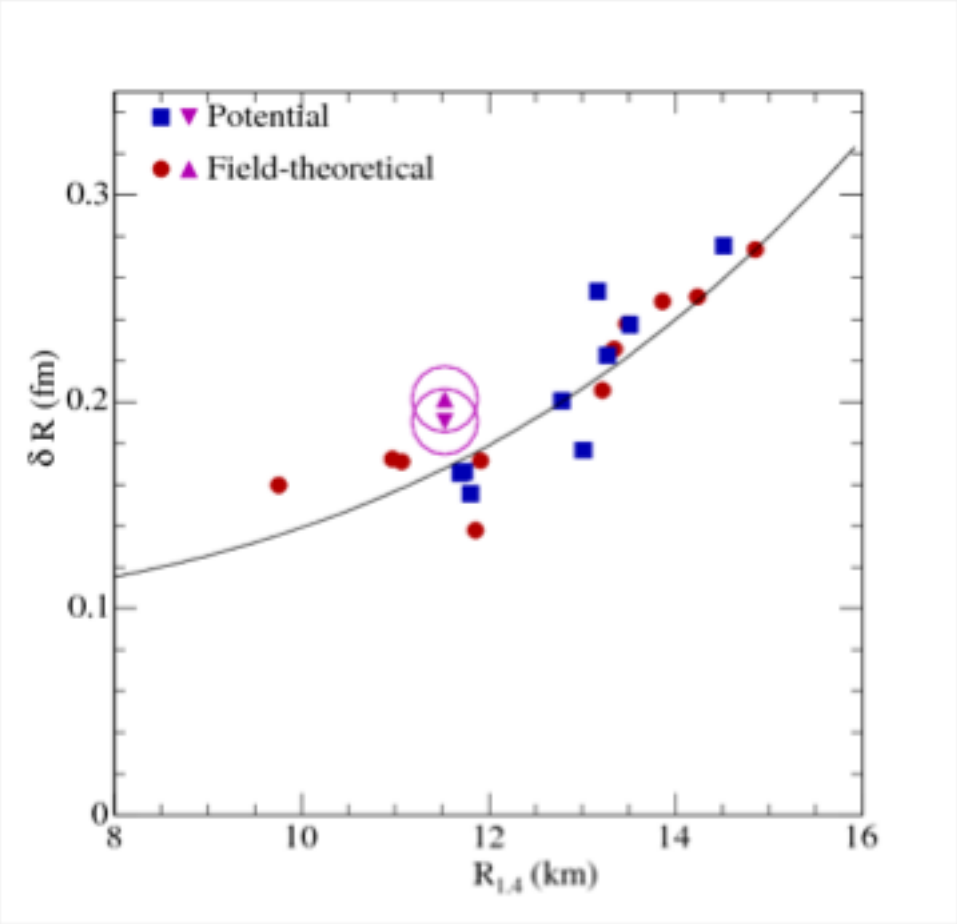

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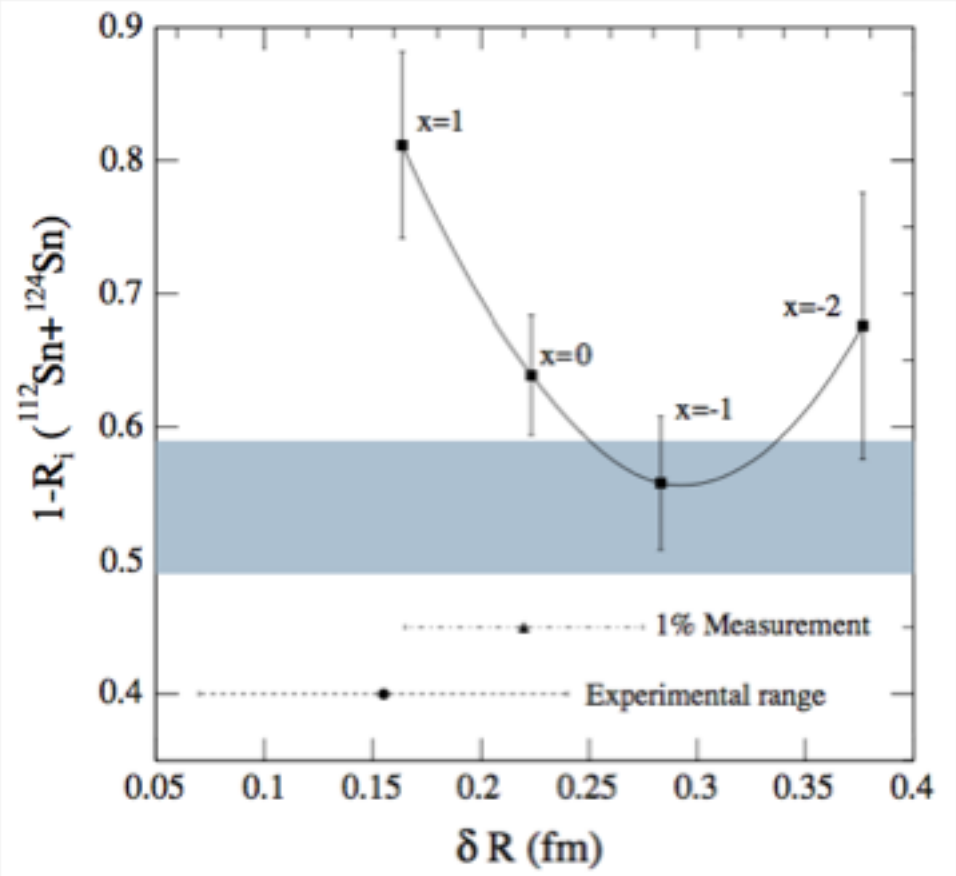
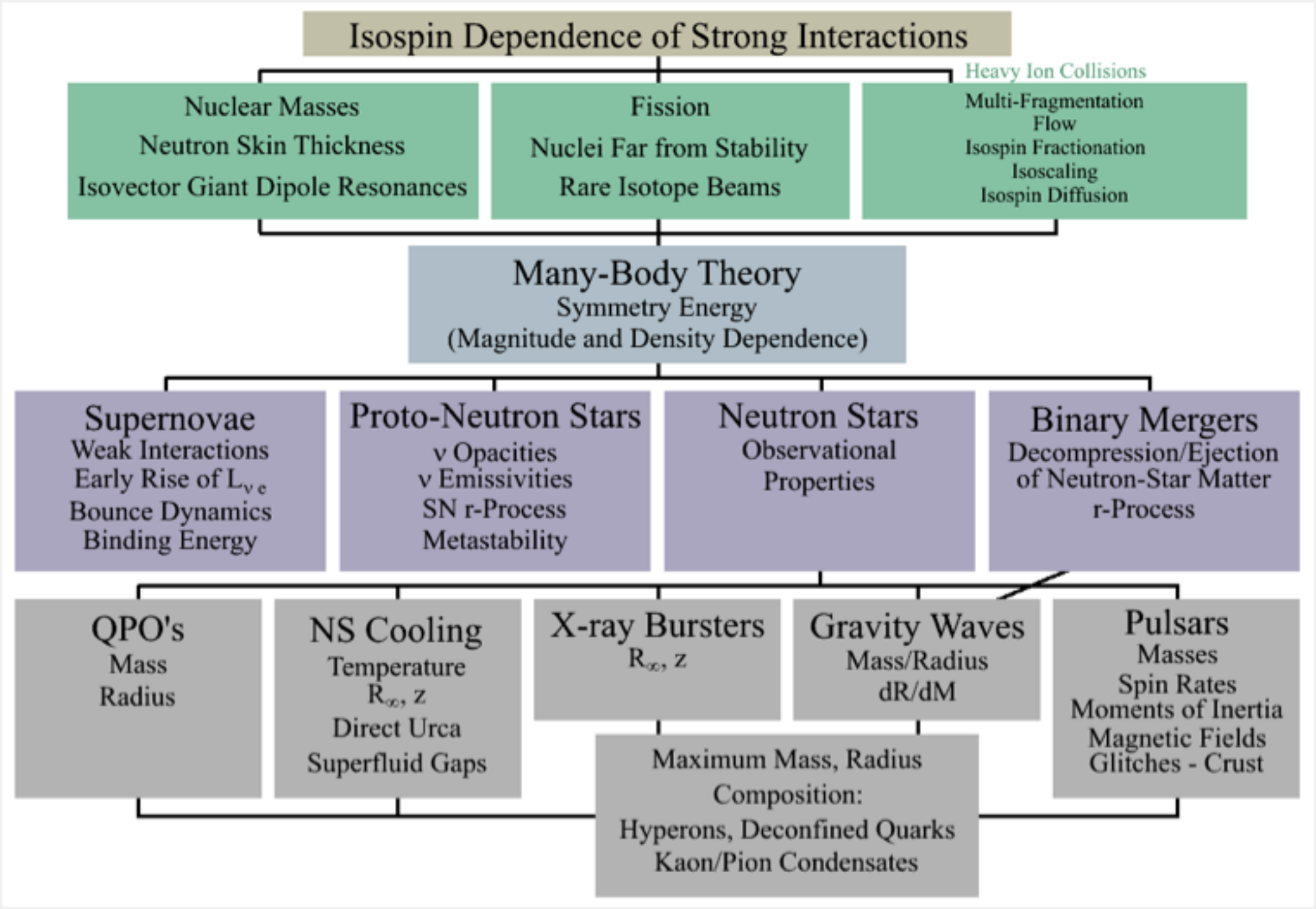


FIG. 4. (Color online) Skin thickness in lead, δR, versus the isospin diffusion parameter $1 - R_i$ for the four equations of state in this work. A sample measurement with an uncertainty corresponding to a 1% measurement of the neutron radius is included, as well as the present acceptable experimental range.

Steiner and Li (2005)

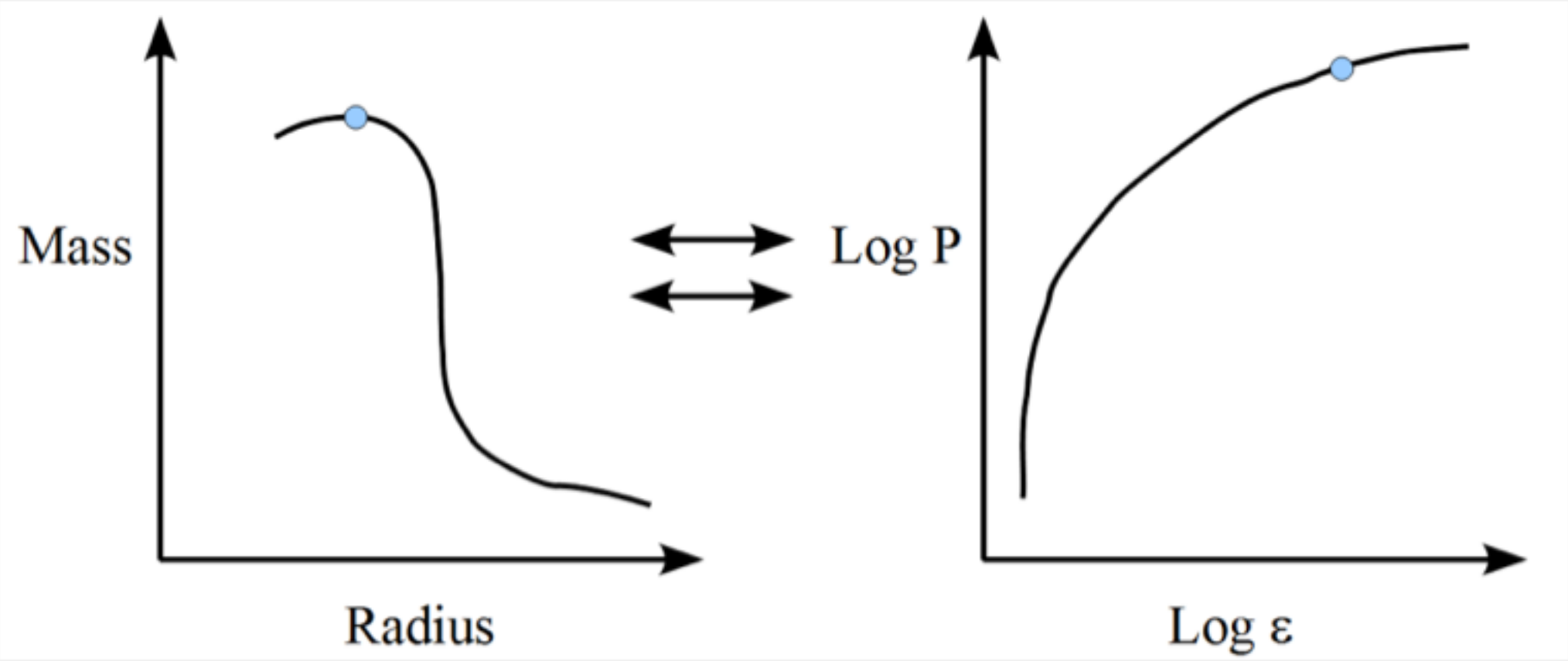
- Neutron star radius ⇔ Neutron skin thickness ⇔ Isospin diffusion in HIC

There are many correlations...



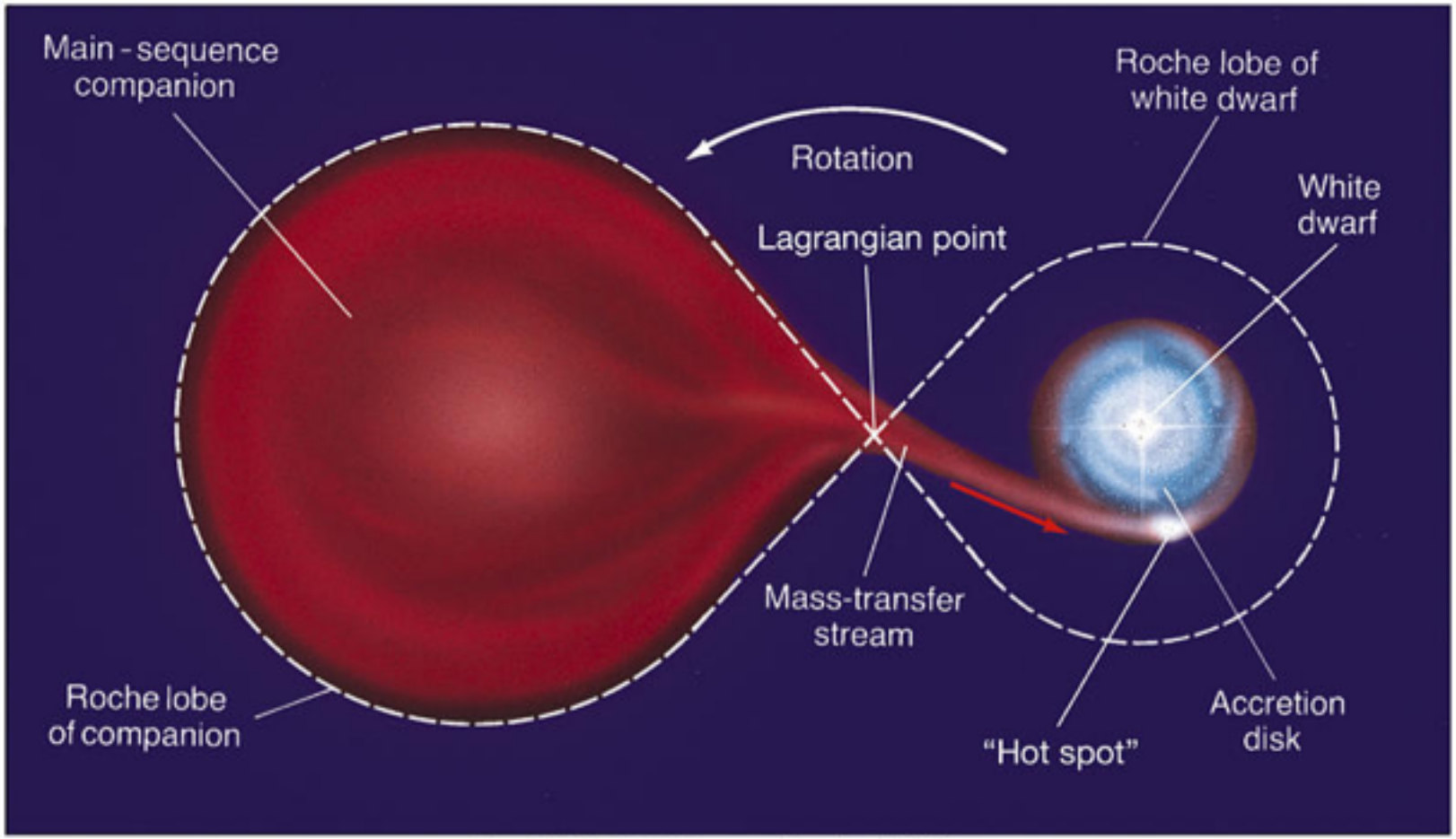
Steiner, Prakash, Lattimer, and Ellis (2005)

Neutron Star Masses and Radii and the EOS



- One-to-one correspondence: $\frac{dP}{dr} = -\frac{Gm\varepsilon}{r^2} + \ldots$
- What do recent neutron star radius measurements tell us about the EOS and the neutron skin thickness?

Accreting Neutron Stars



- Most stars have companions: neutron stars can have main-sequence ("normal star") companions
- Stellar matter accretes onto the neutron star surface and heats the crust
- Accretion is episodic

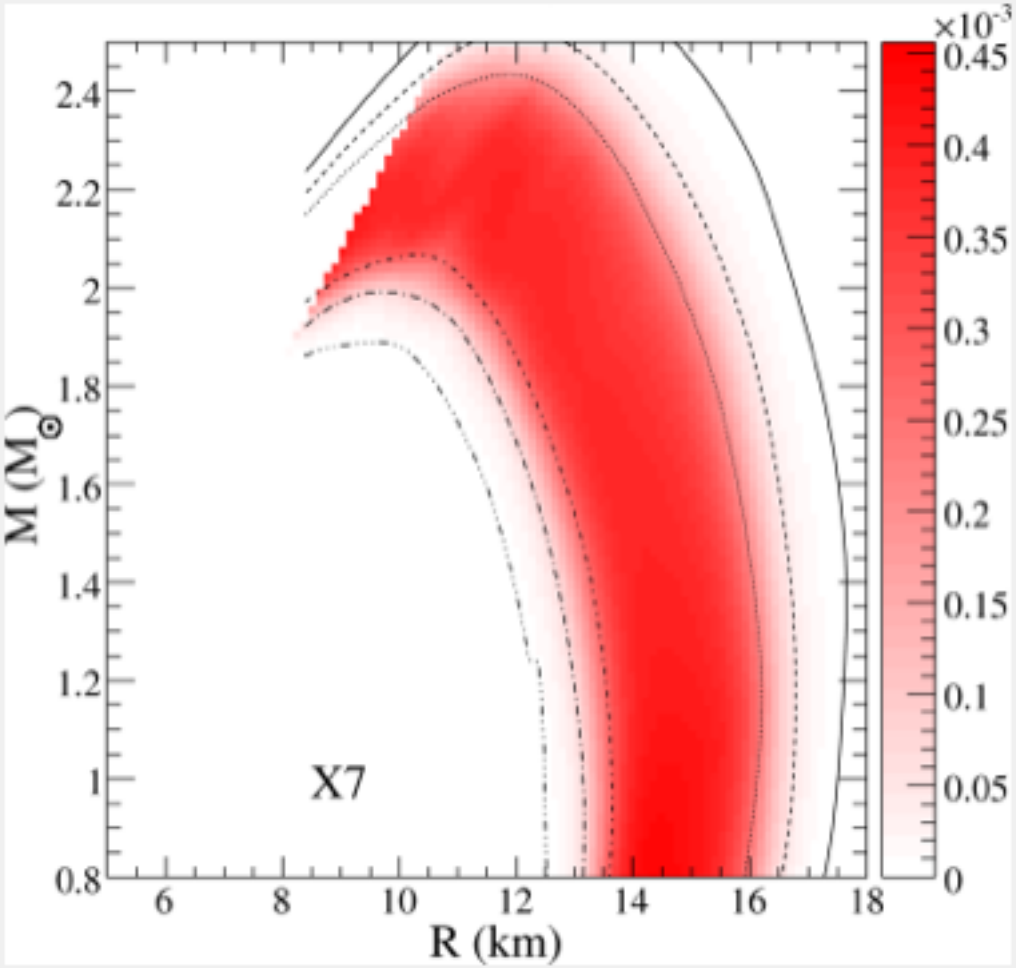
Neutron Star Radius Measurements

- Measure flux of photons and their energy distribution
- Know distance if in a globular cluster
- Implies radius measurement

$$F \propto T_{\text{eff}}^4 \left(\frac{R_\infty}{D} \right)^2$$

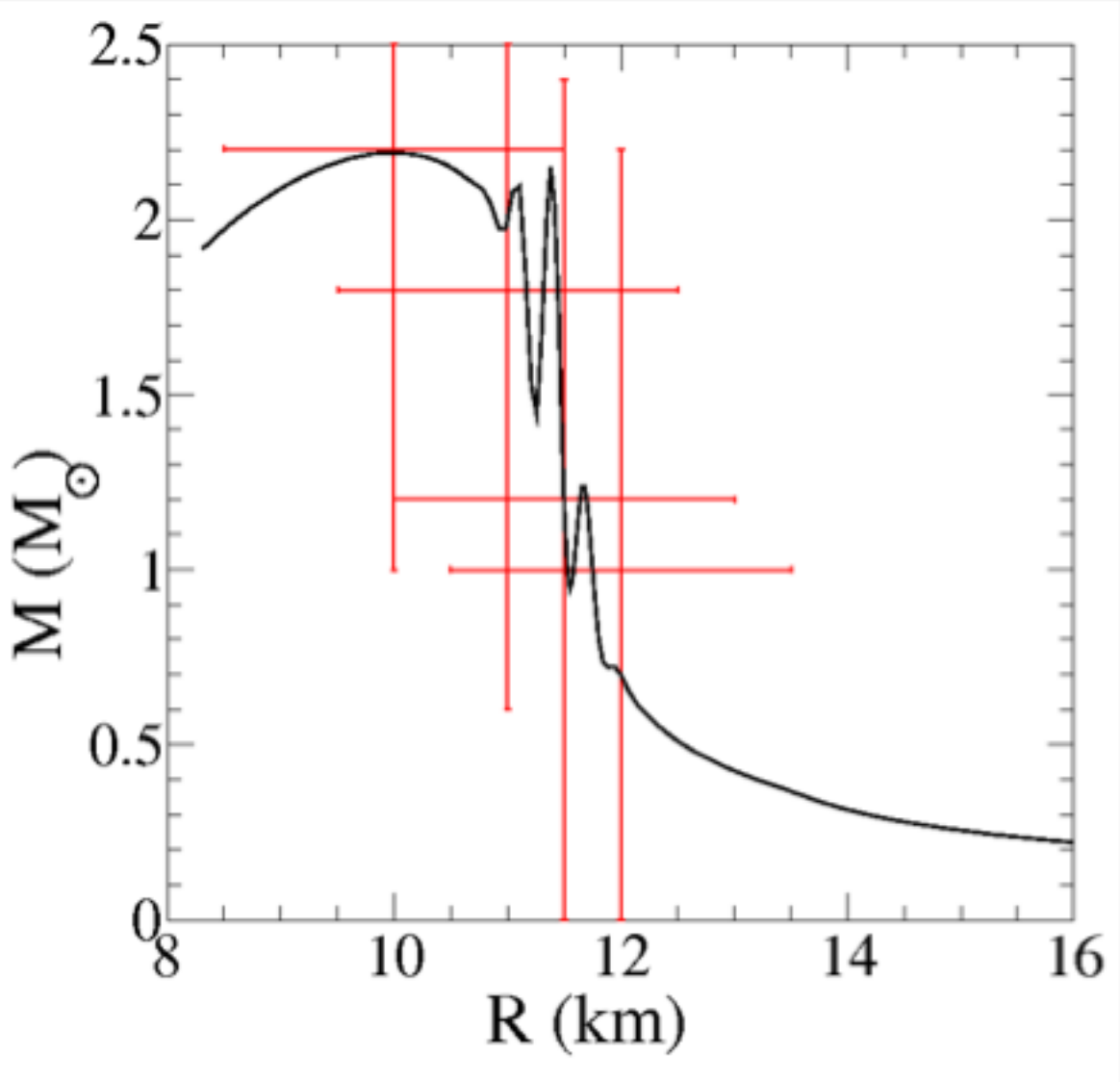
[i.e. Rutledge et al. (1999)]

- ~ 8 objects (more on the way)



Steiner, Lattimer, and Brown (2010)

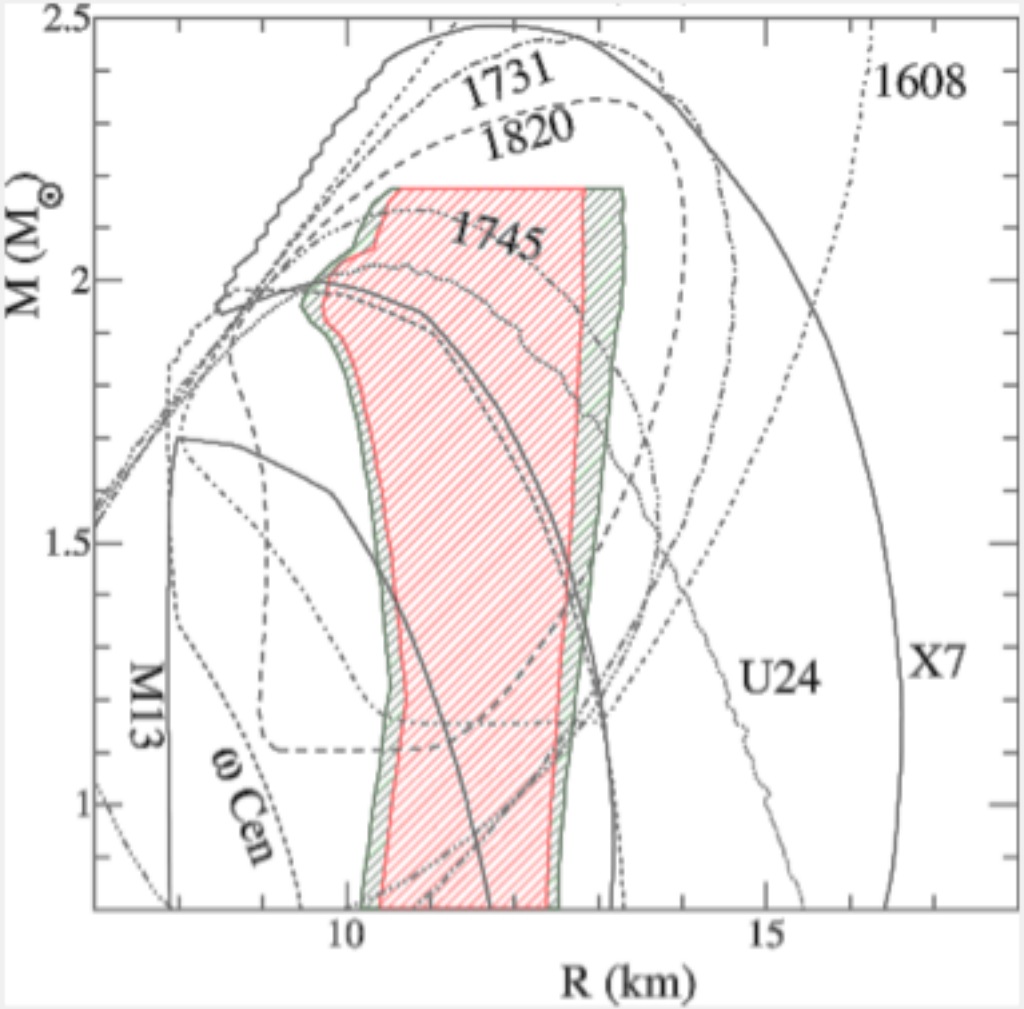
Data Analysis



- Underconstrained problem
- Natural way to include theoretical input
- Parameterizations based on known nuclear physics for low densities

- Bayes theorem: $P[\mathcal{M}_i|D] = \dfrac{P[D|\mathcal{M}_i]P[M_i]}{\sum_j P[D|\mathcal{M}_j]P[\mathcal{M}_j]}$
- Automatically handles correlations without approximation

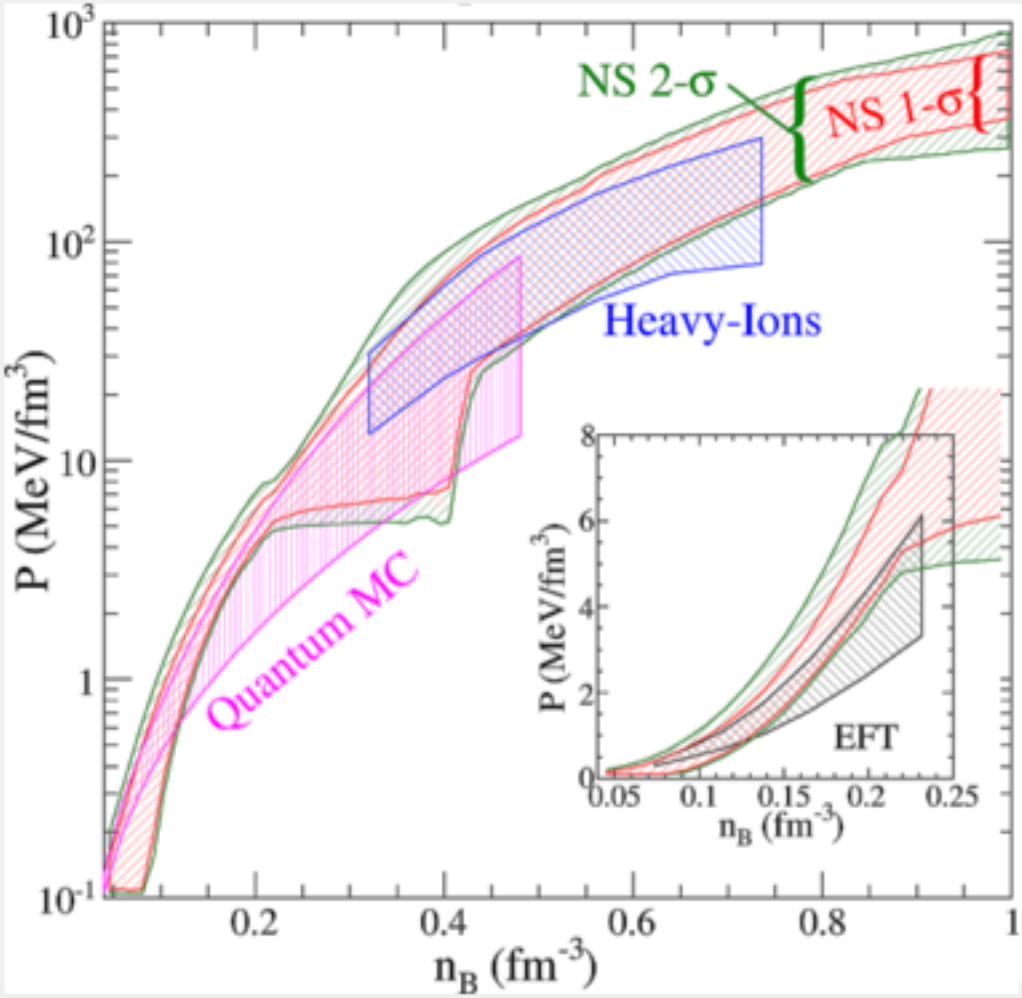
Mass and Radius Results

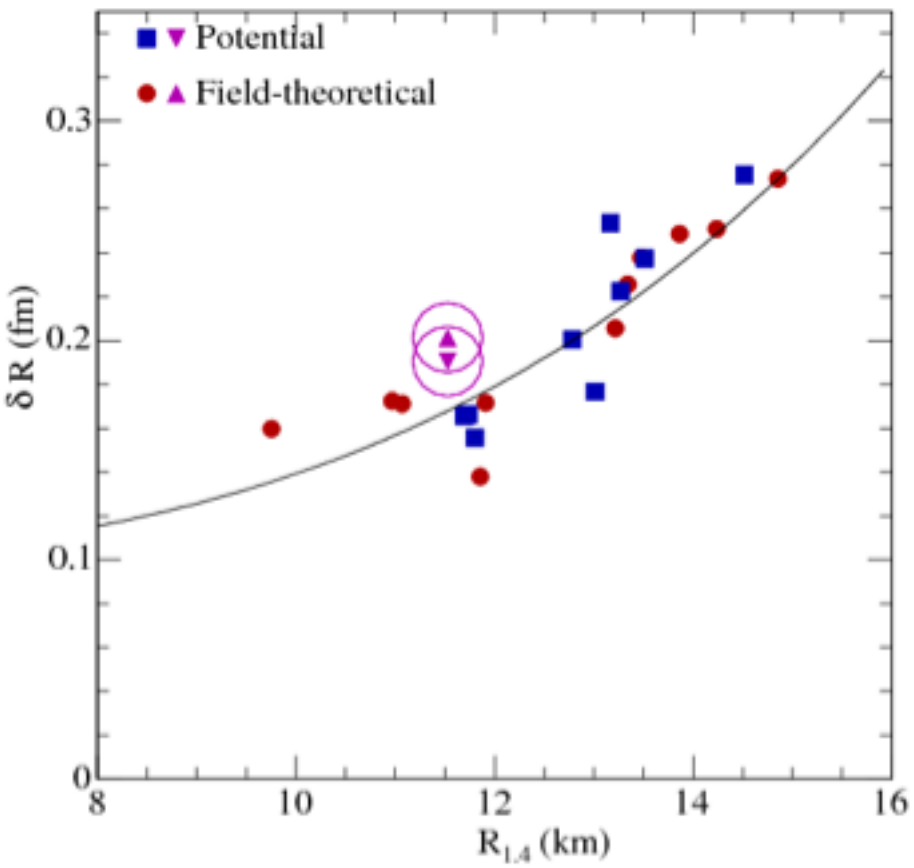


Steiner, Lattimer, and Brown (2013)

- Range of radii for a 1.4 solar mass star: 10.4 and 12.9 km (95% conf.)
- All neutron stars have nearly the same radius

Constraining the EOS and the Skin Thickness

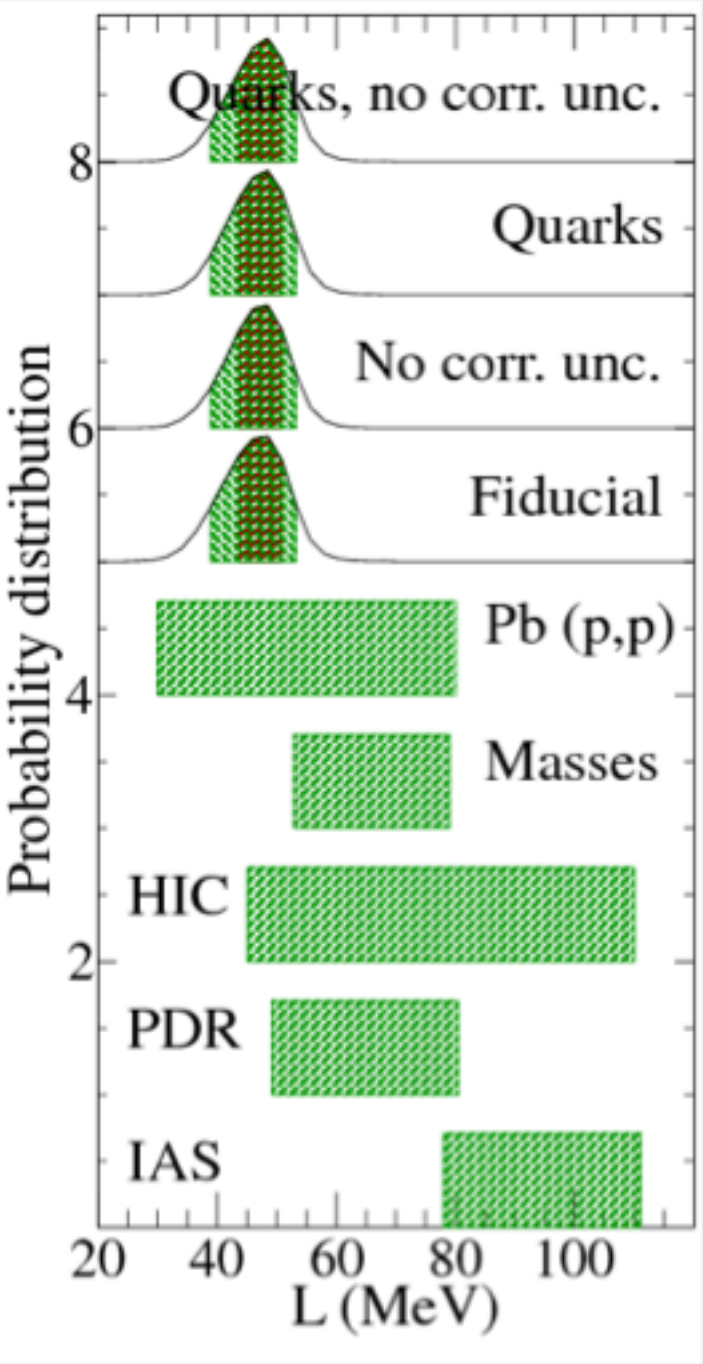


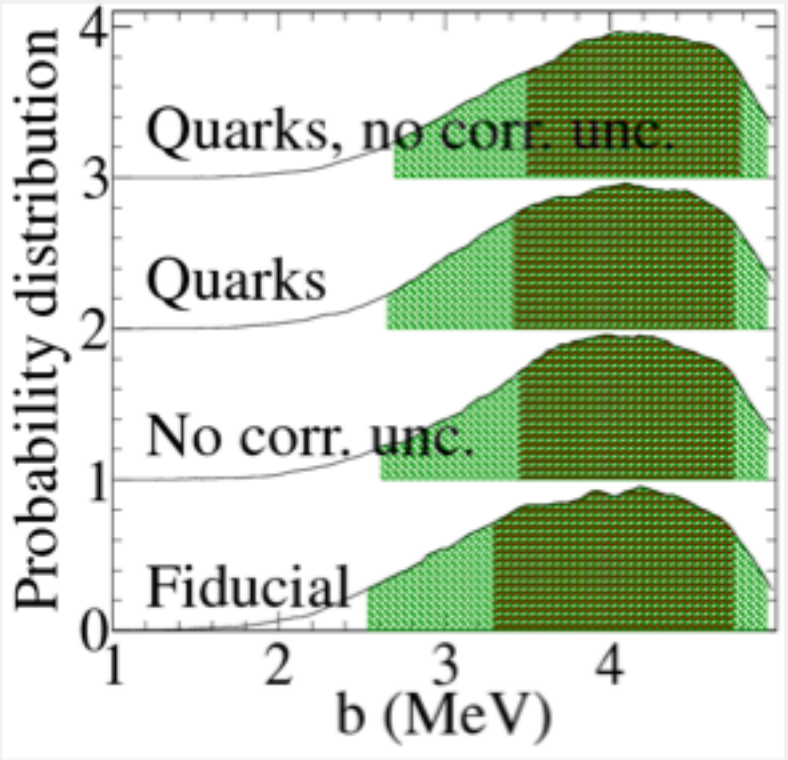


Steiner, Lattimer, and Brown (2013)

- $P(\varepsilon)$ determined to within about 60%
- Probe densities inaccessible to experiment and to perturbation theory in QCD
- Suggests $R_n - R_p < 0.2$ fm

Constraining L and Three-Body Forces





Steiner and Gandolfi (2012)

- Novel constraints on L
- Neutron star radii rule out some three-body forces

$$E_{\text{neut}} = a\left(\frac{n}{n_0}\right)^{\alpha} + b\left(\frac{n}{n_0}\right)^{\beta}$$

Summary

- Current neutron star mass and radius observations provide novel constraints for nuclear physics
- Systematic uncertainties in the astronomical measurements are problematic: distances, modeling, etc.
- Future neutron skin thickness measurements could resolve serious questions about neutron stars

From NS radius observations:

- All neutron star radii are between 10.4 and 12.9 km
- The neutron skin thickness of $^{208}\mathrm{Pb} < 0.2$ fm
- $43 < L < 67$ MeV
- Ruling out some three-nucleon forces