

# **Neutron Star Crusts: Nuclear Physics Input and Consequences for Neutron Star Seismology**

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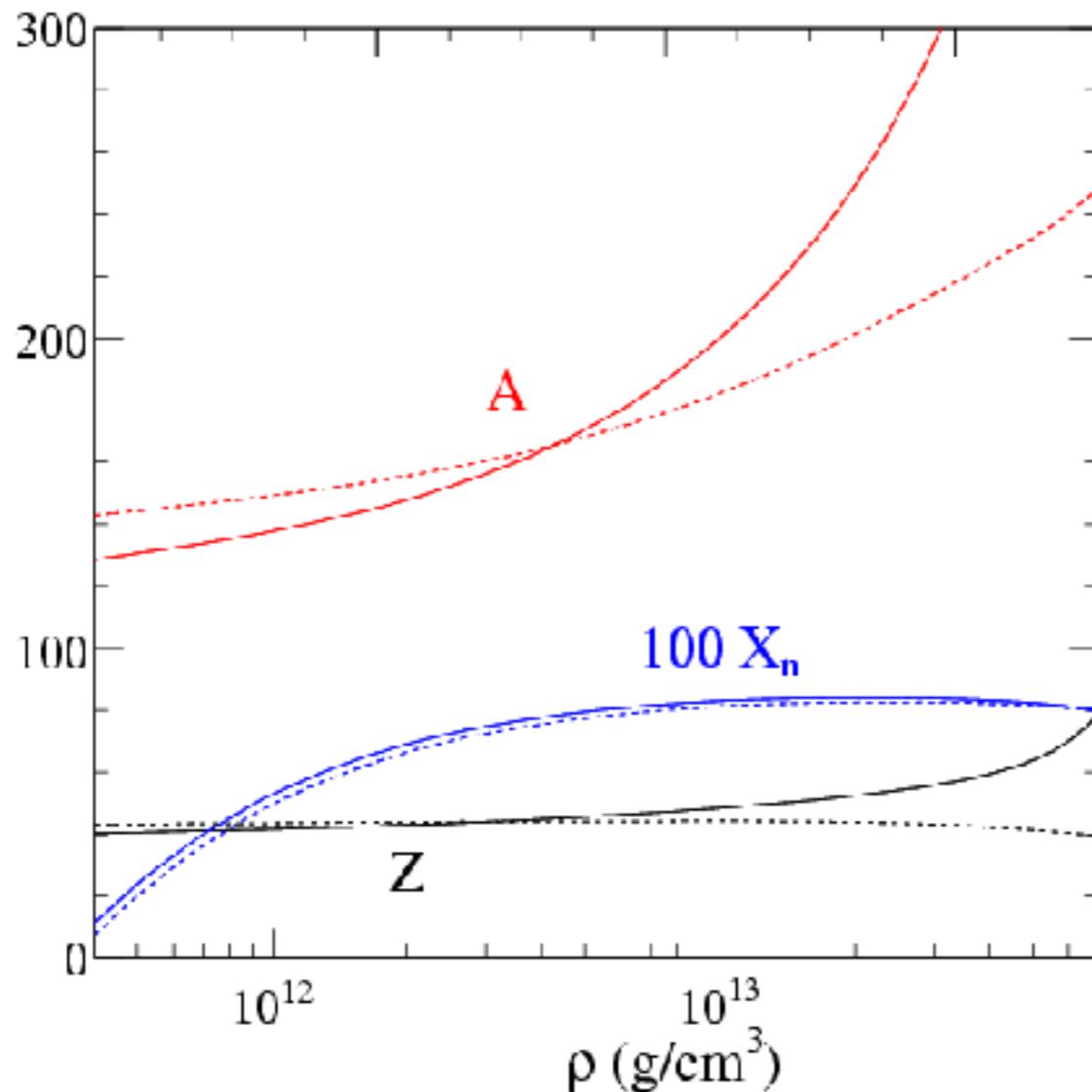


## Outline

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- The model
- Relevance for SGR flares
- Input nuclear physics: Low-density neutron matter
- Input nuclear physics: The symmetry energy

# Model of the Neutron Star Crust



- Model of the inner crust: from neutron drip to the transition to nuclear matter
- Dependence on nuclear physics input - relevance for X-ray bursts, pulsar glitches, SGR flares
- Simplified model or FRDM from Moller, et al.

$$I = 1 - 2Z/A, n = n_0 - n_1 I^2, \delta \sim I$$

$$n_n = n(1 + \delta)/2$$

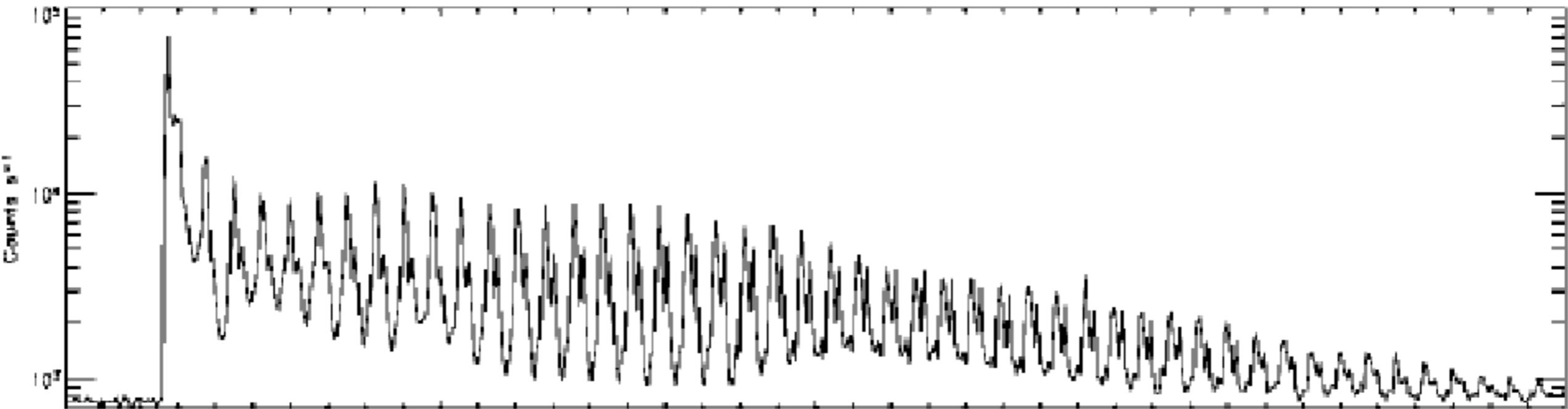
$$n_p = n(1 - \delta)/2$$

$$B(Z, A) = B_{\text{bulk}}(n_n, n_p) + \sigma \mathcal{B}(n_n, n_p) \frac{(36\pi n)^{1/3}}{nA} + \mathcal{C} \frac{4\pi}{5} \left(\frac{3}{4\pi}\right)^{2/3} \frac{Z^2 e^2}{n^{1/3} A^{1/3}}$$

$$E(Z, A, n_{n,\text{drip}}, n_{p,\text{drip}}) = M(Z, A) + (1 - \chi) E_{\text{bulk}}(n_{n,\text{drip}}, n_{p,\text{drip}}) + E_{\text{el}}$$

- Finite temperature, deformation, distributions of nuclei

# Oscillations in Giant Flares from Soft Gamma-Ray Repeaters

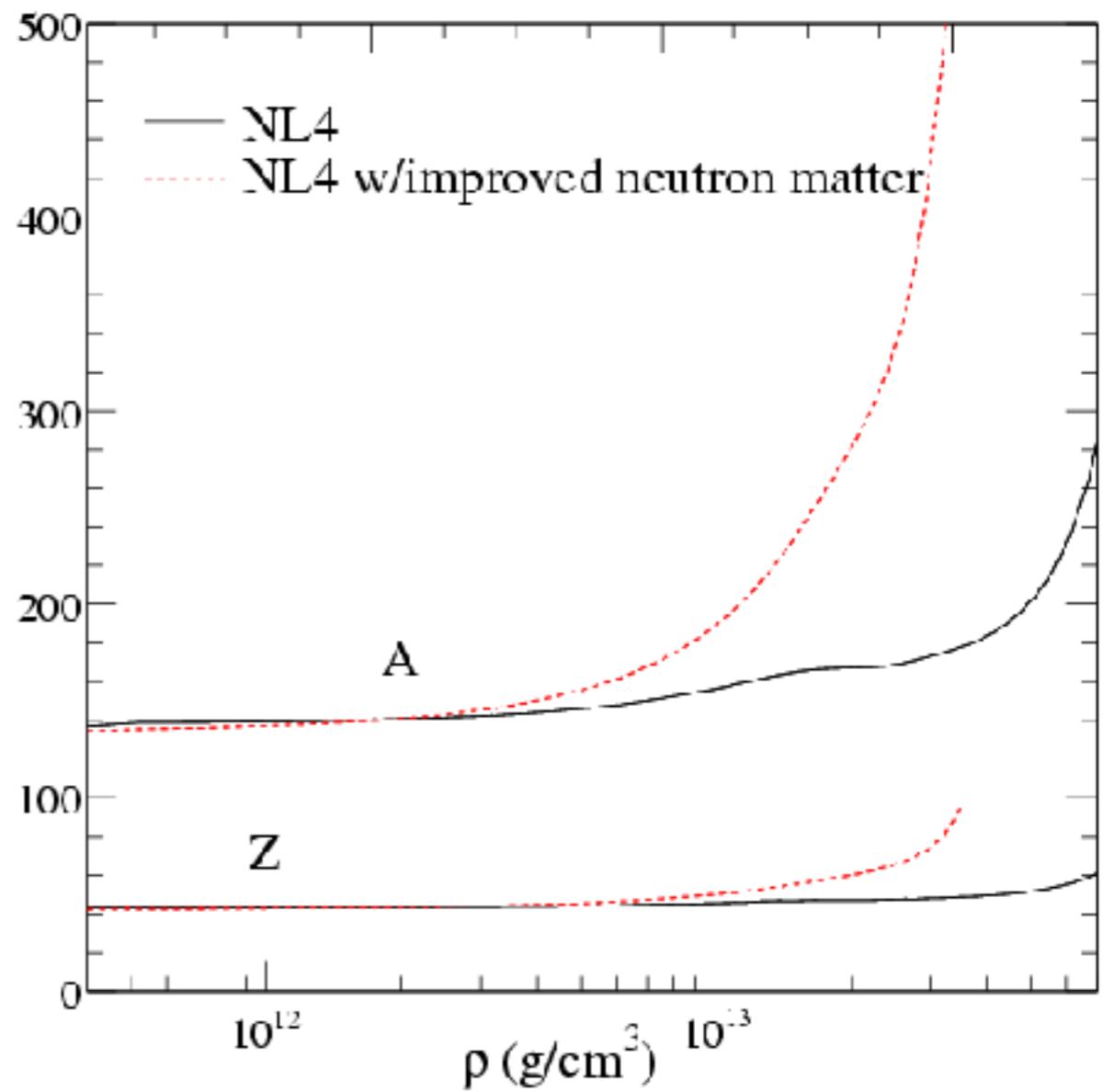
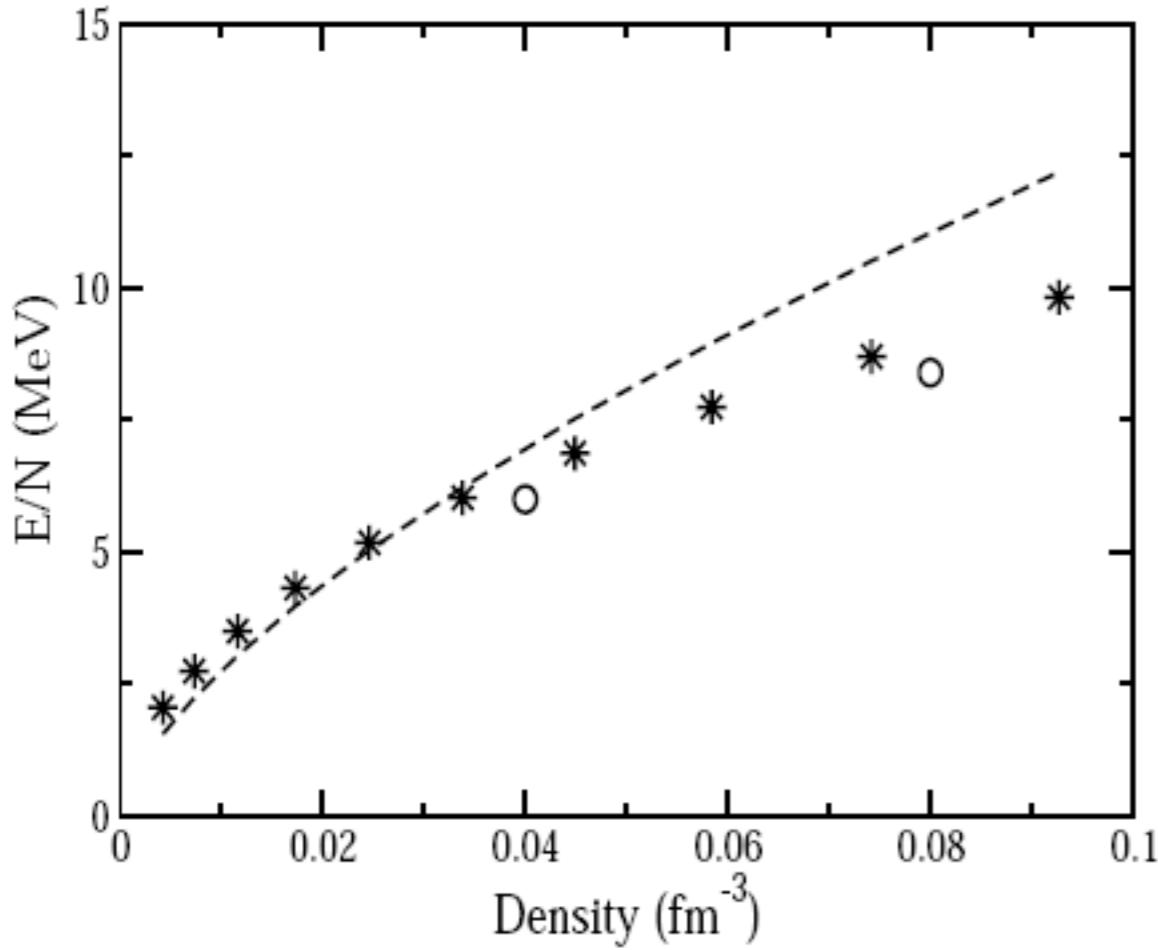


Watts and Strohmayer, Ap. J. Lett. 637 (2006) 117.

- Giant flares in magnetars powered by reconfigurations of the magnetic fields
- This triggers "starquakes" - exciting normal modes in the crust
- The normal mode frequencies are dependent on properties of the inner crust: the shear velocity in particular

$$\mu \sim n_{\text{nuclei}} Z^2 / a$$

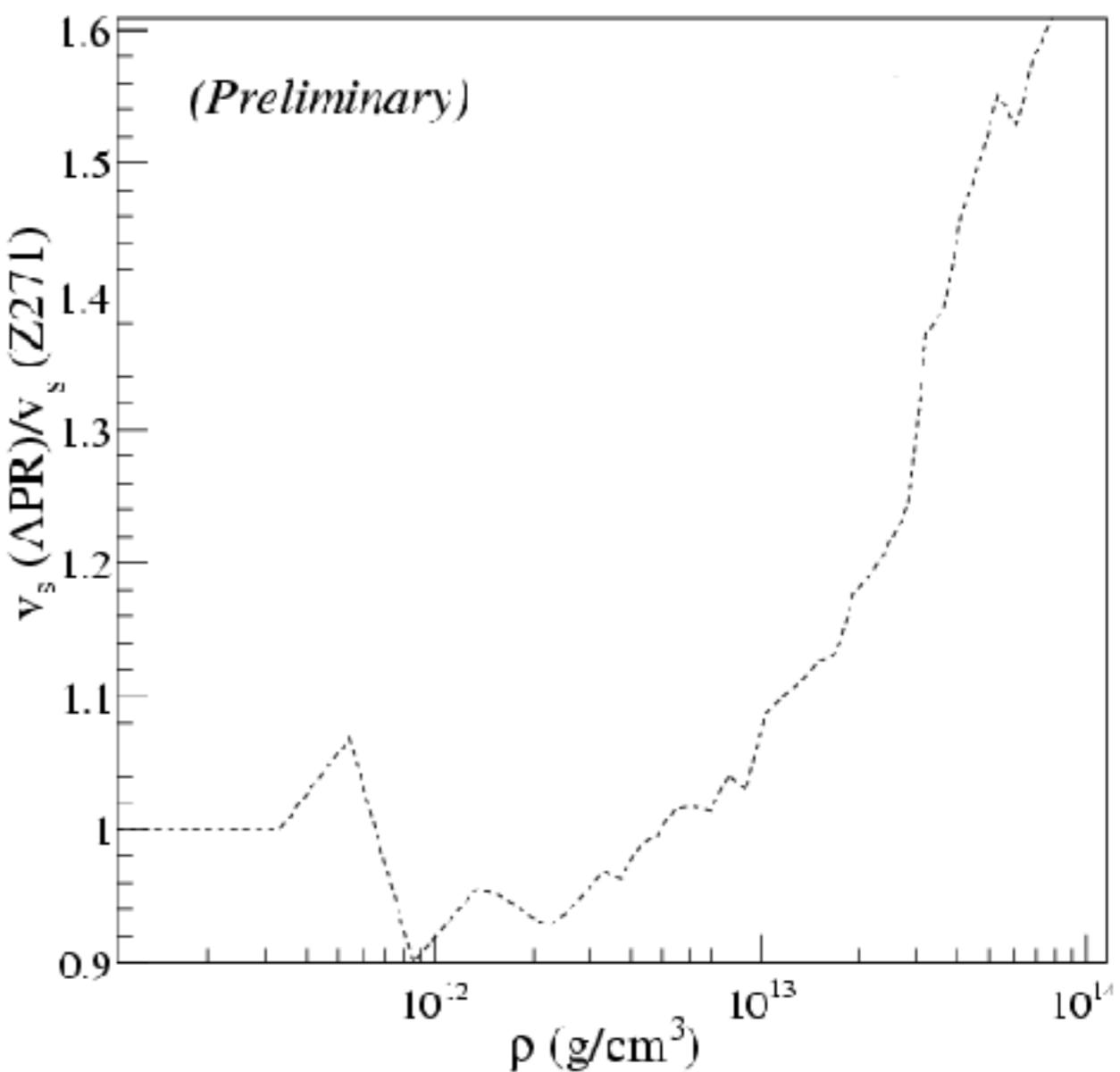
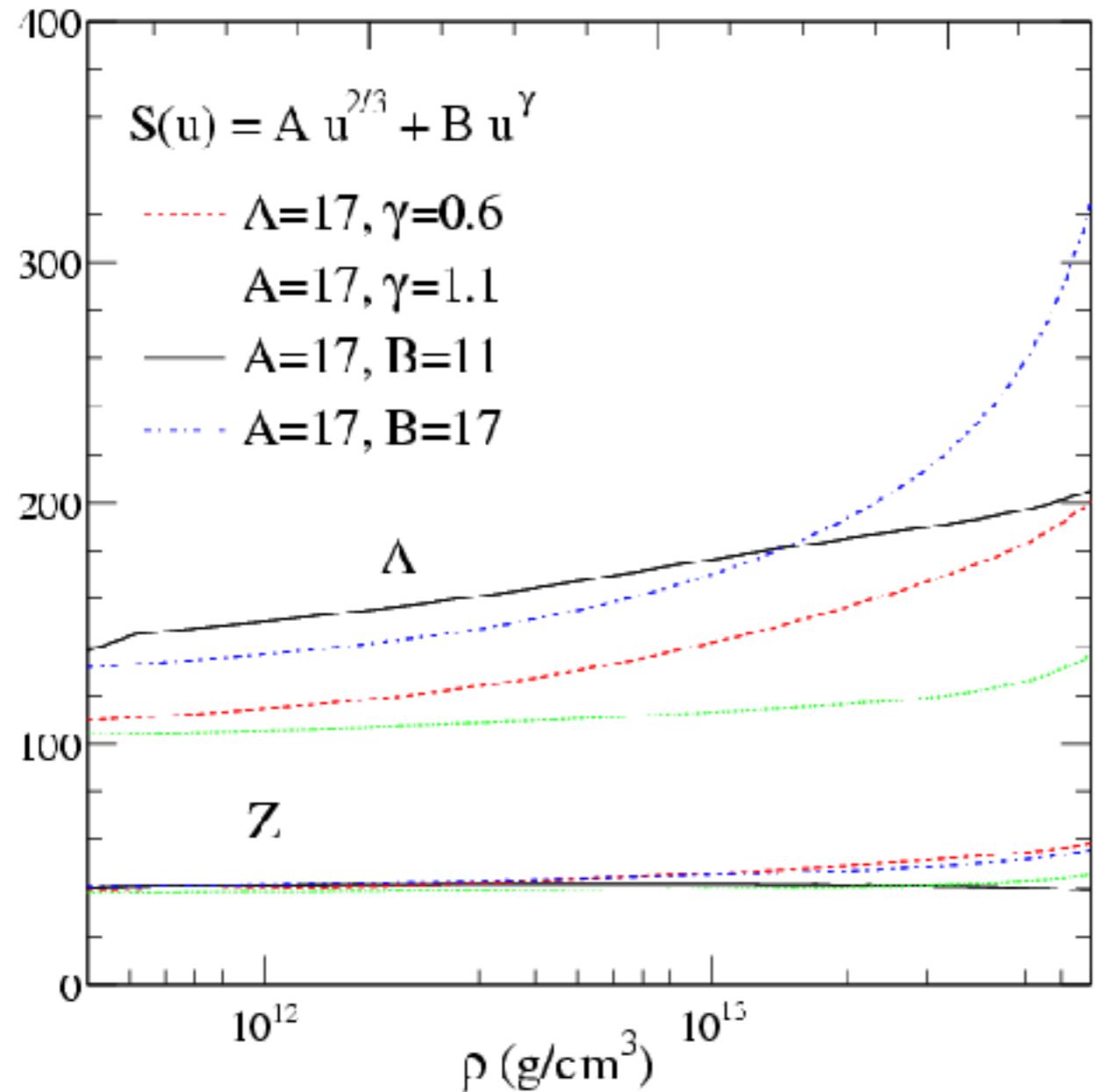
# Low-density Neutron Matter



Carlson, et al. PRC 68 (2003) 025802.

- Low-density neutron matter is well understood - the two-body interaction is well-described by the effective-range expansion
- Low-density neutron matter is accessible in the laboratory
- The correct description of low-density neutron matter makes a significant difference

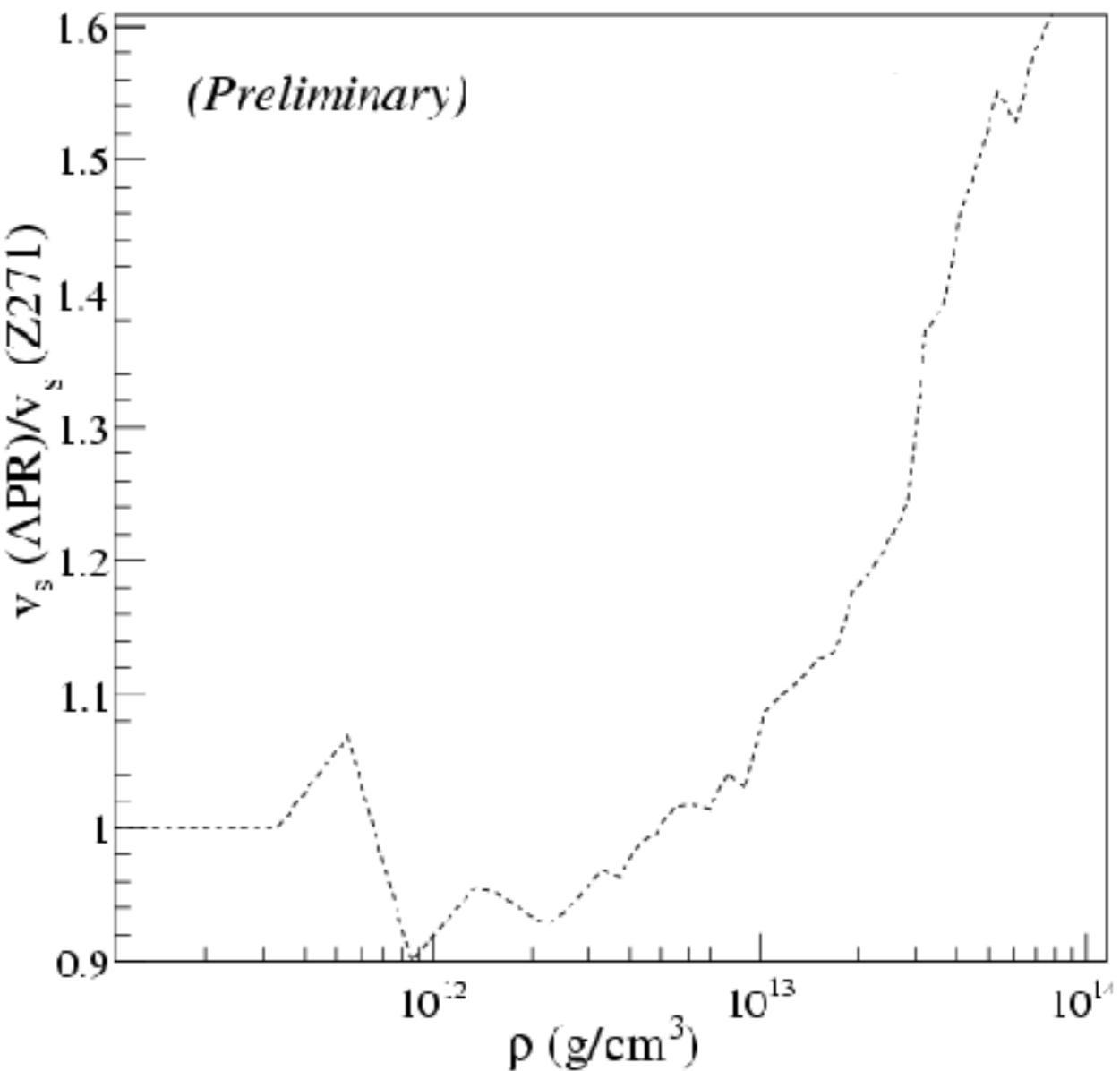
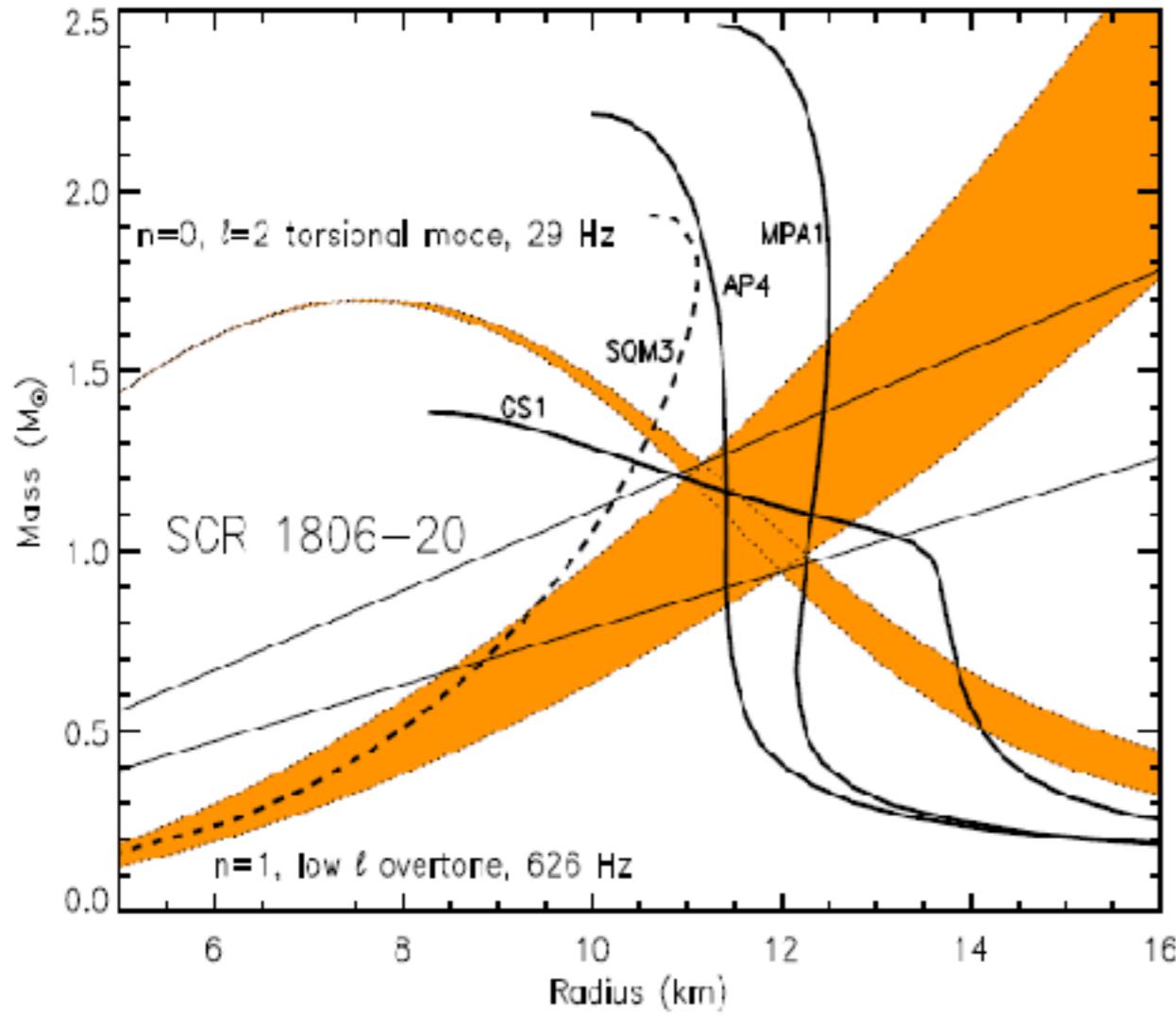
# Symmetry Energy



- Symmetry energy has a strong effect on the shear velocity  $v_s = (\mu/\rho)^{1/2}$

T. Stromayer et al., Ap J 375 (1991) 679, T. Piro Ap. J Lett. 634 (2005) 153, L. Samuelsson and N. Andersson, MNRAS 374 (2007) 256, J.M. Lattimer and M. Prakash, astro-ph/0612440 (2006)

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- Impacts mass and radius determinations

## Summary

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- Inner crust model - paying particular connection to constraints and uncertainties
- Application to SGR flare oscillations
- Low-density neutron matter as an important experimental constraint
- Symmetry energy as an important uncertainties
- Implications for determining mass and radii from SGR flares