Constraining properties of dense matter with precision radio timing measurements

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- What spin variations have revealed about:
  - the ground state of NS matter
  - its dynamics
- Future directions (and wishes)

The central question of nuclear physics

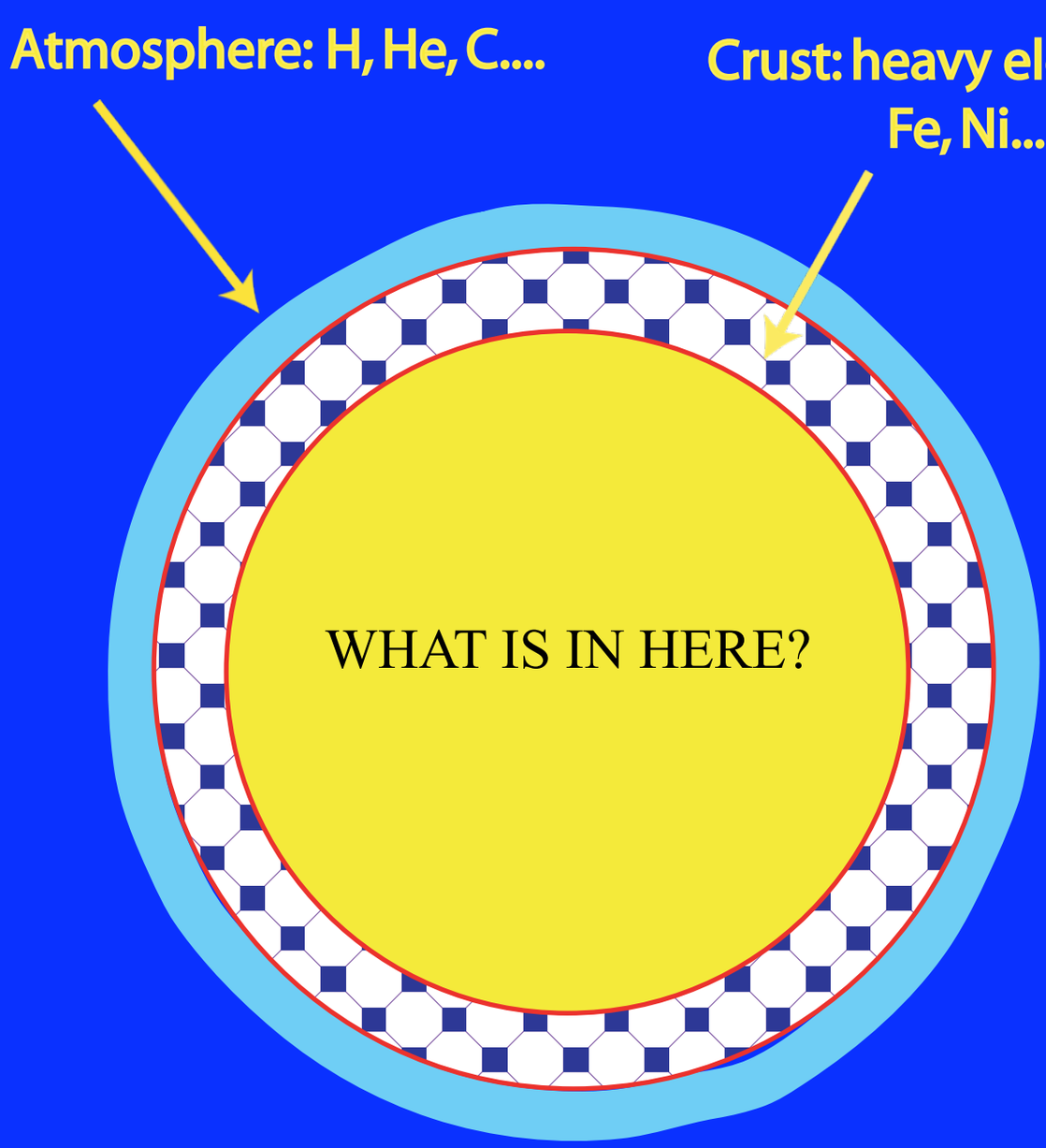
What are the properties of matter above nuclear density (~ 3×10^{14} g cm^{-3})?

Such dense matter exists in neutron stars

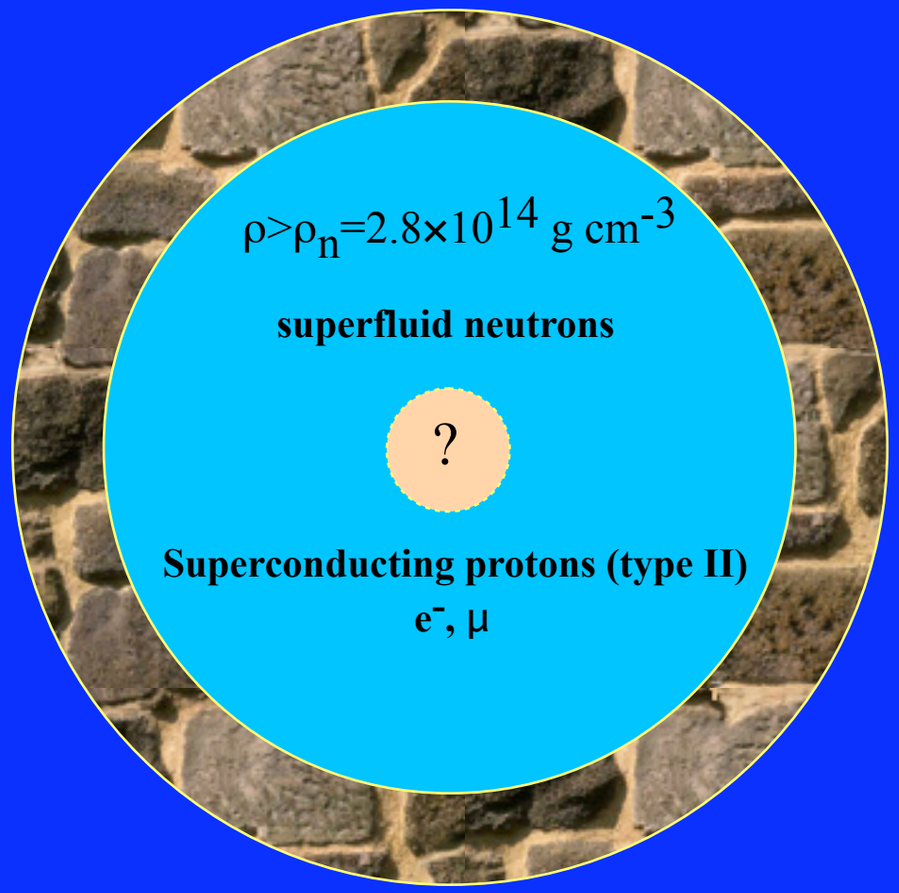
- M ≅ 1.4 M_{sun}
- R ≅ 10 km

$$\Rightarrow \rho = M/(4\pi R^3/3) = 5\text{x}10^{14}\ \text{g/cm}^3 \approx 2\ \rho_{\text{nucleus}}.$$

The central question in neutron star physics



The NS ground state (according to theory)

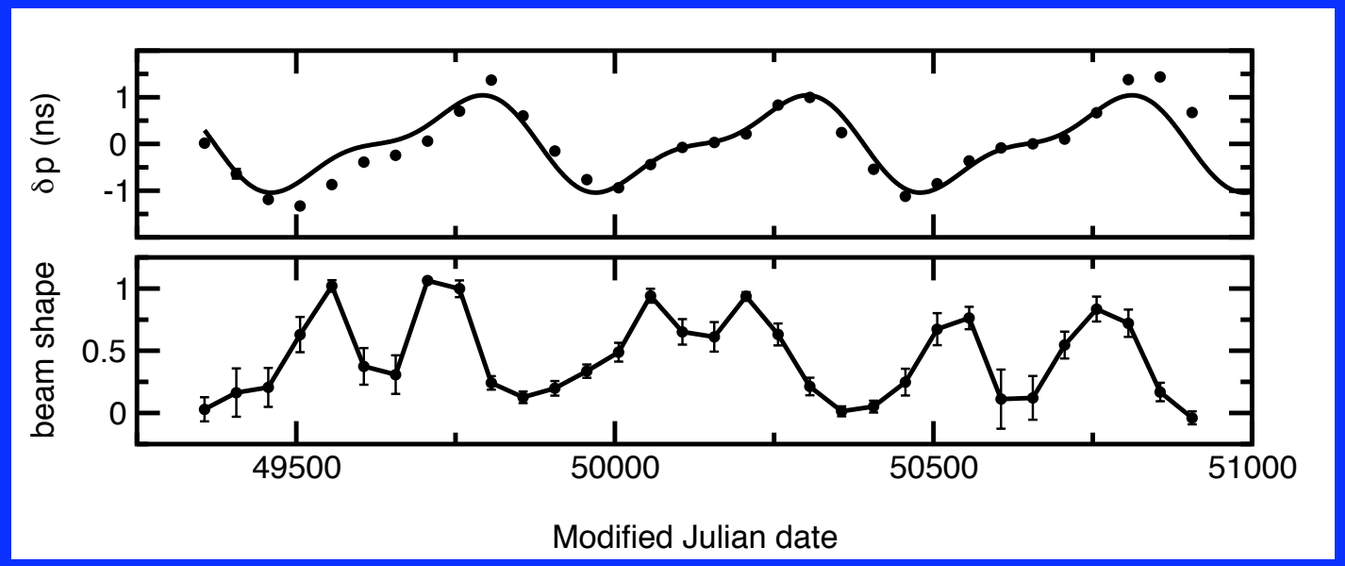


- Predictions:
  - Most of the interior is liquid, with
  - SF neutrons + SC protons (type II)
- Questions:
  - Is this right?
  - What are the implications?

Constraining the ground state of NS matter

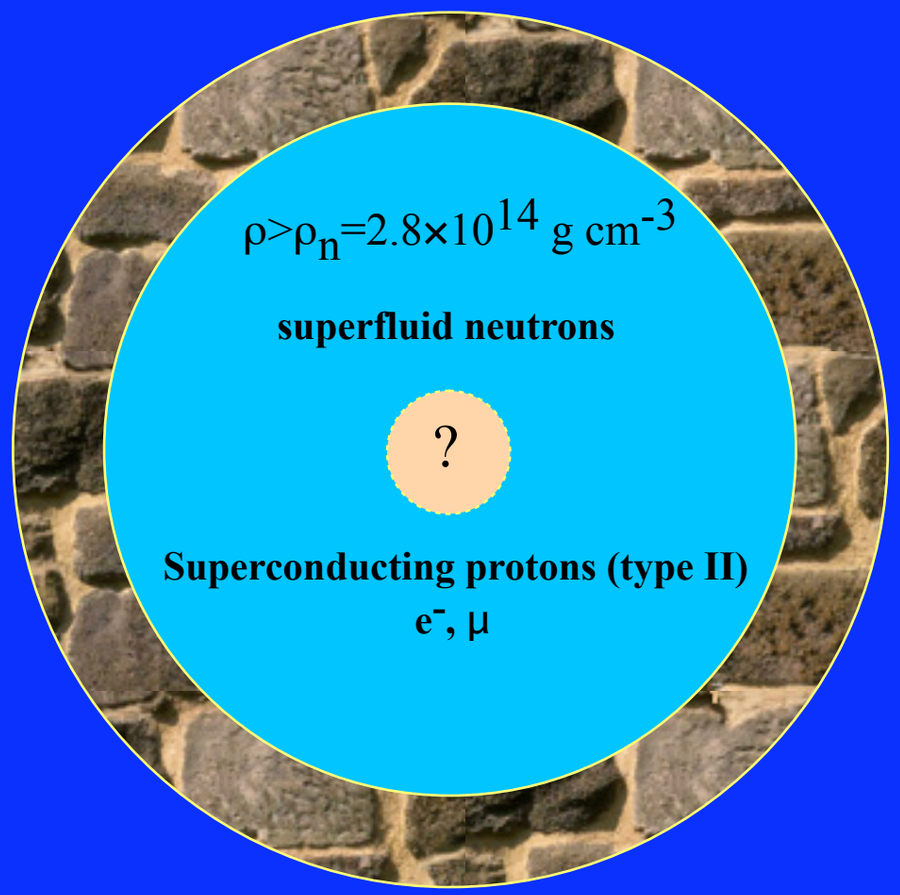
Some NSs precess (nutate) with periods of years

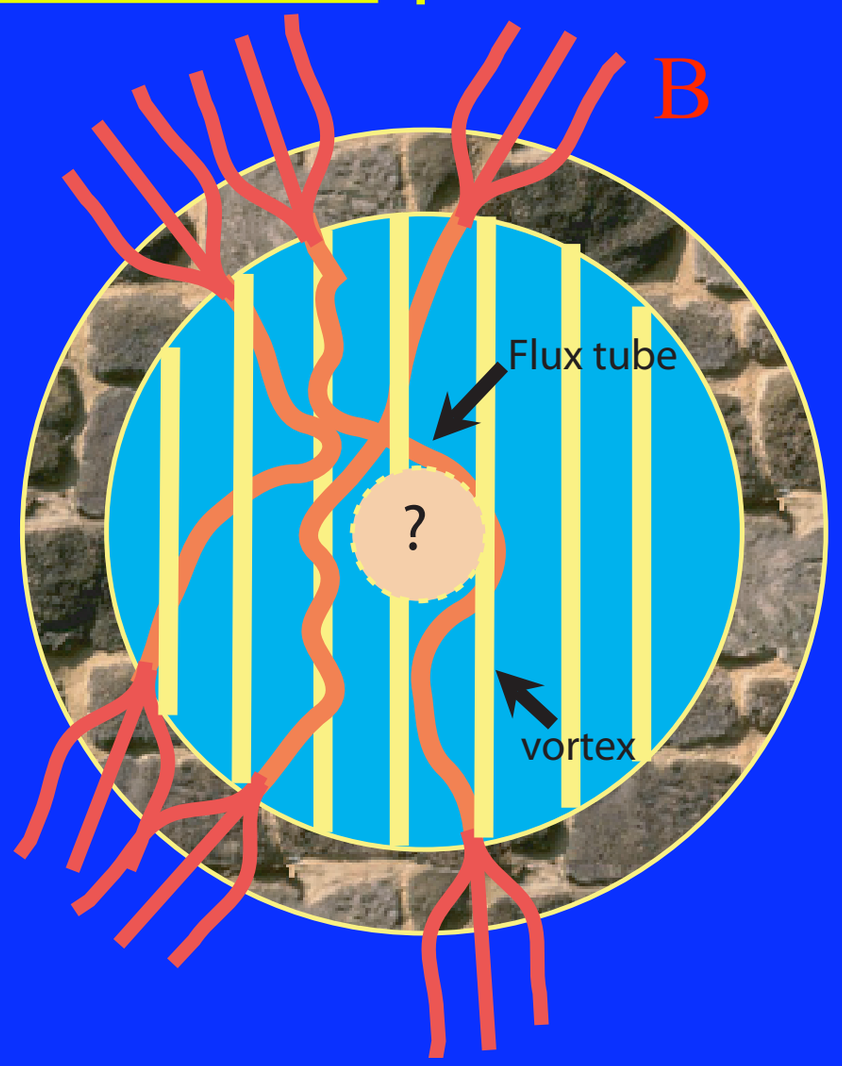
PSR 1828-11



(Stairs et al. 00)

Inconsistent with this <u>theoretical</u> prediction

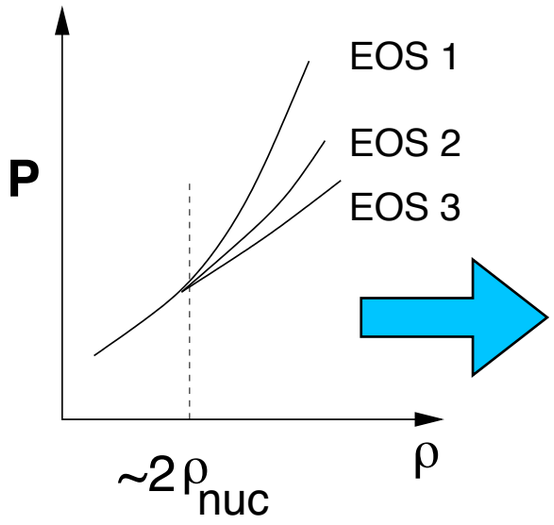


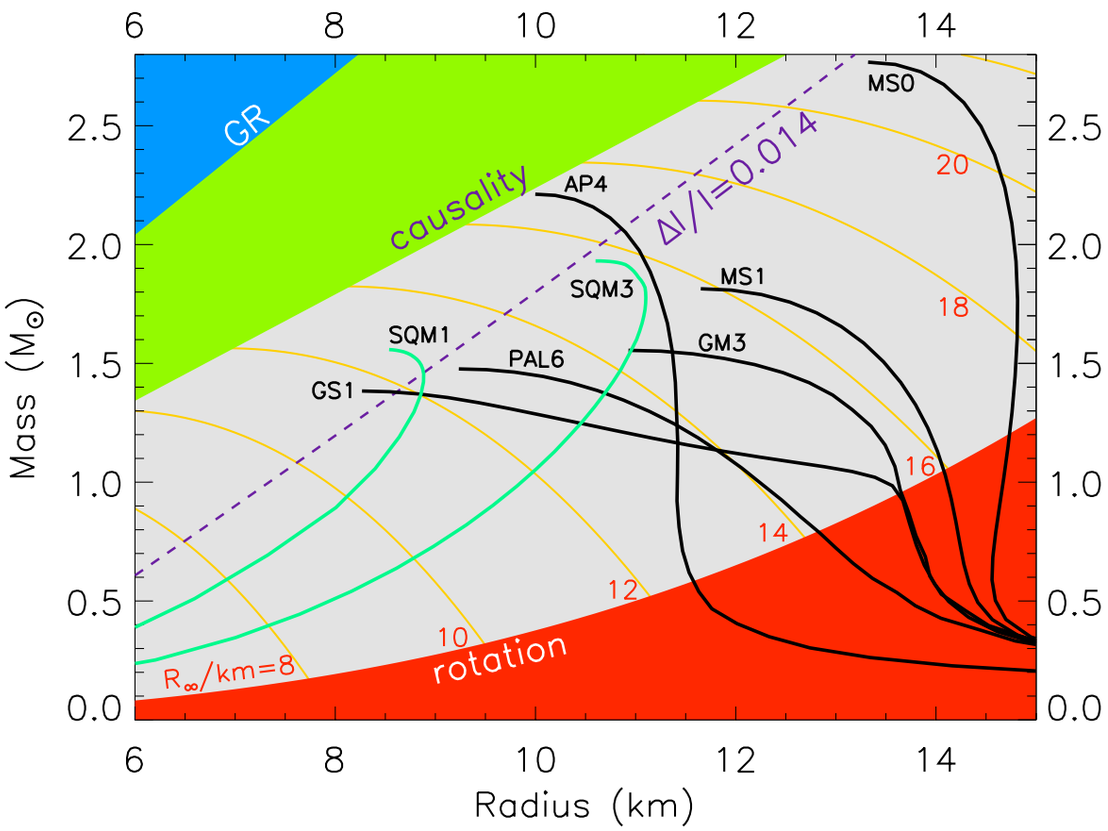


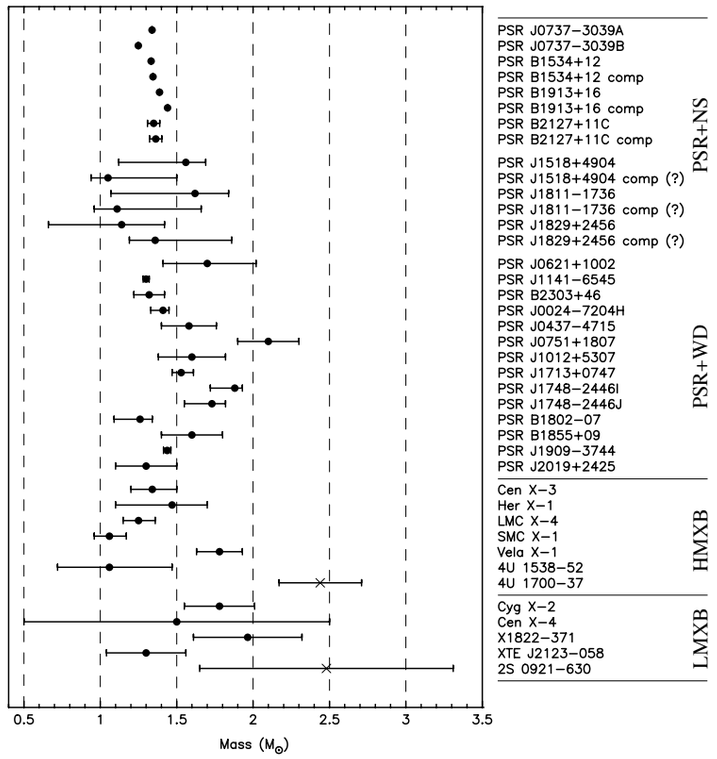
which would precess with a period of <u>at most seconds</u>, rather than years. (Link 03).

⇒ the current picture of ground state of the interior is seriously challenged

Constraining composition (equation of state)



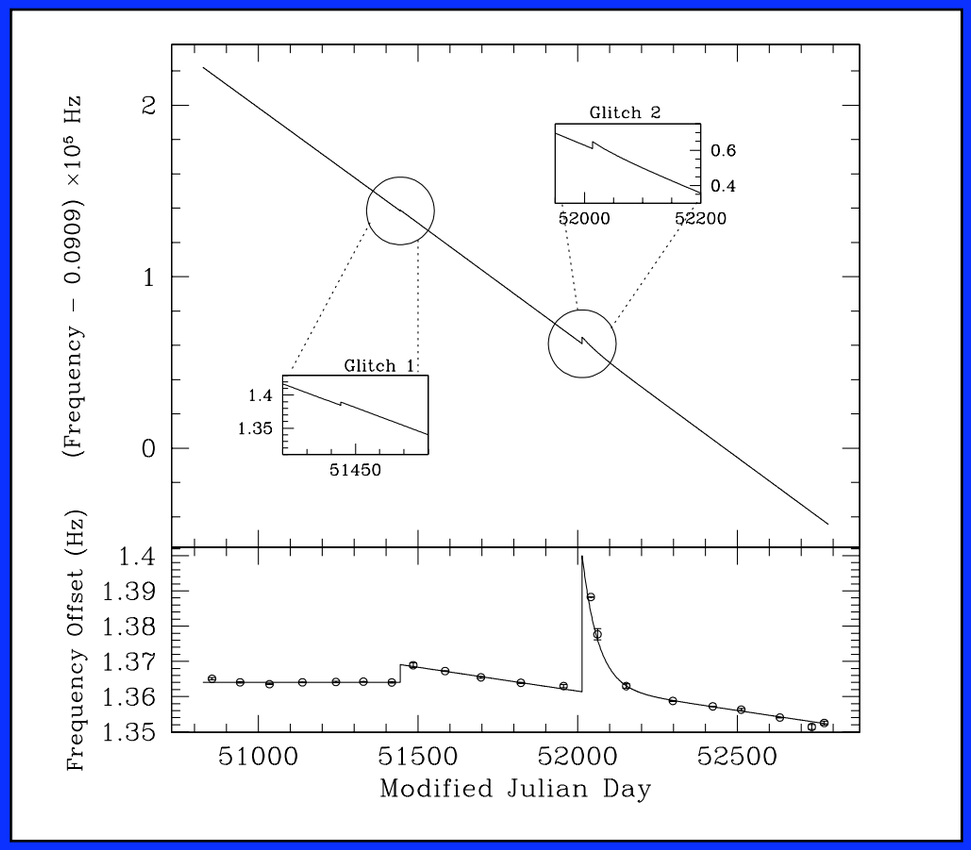




- Want M and R for the same object.
- Rapid rotators: fastest observed is 716 Hz. Discovery of a kHz pulsar would be very constraining.

Constraining internal dynamics with spin variations

- Glitches

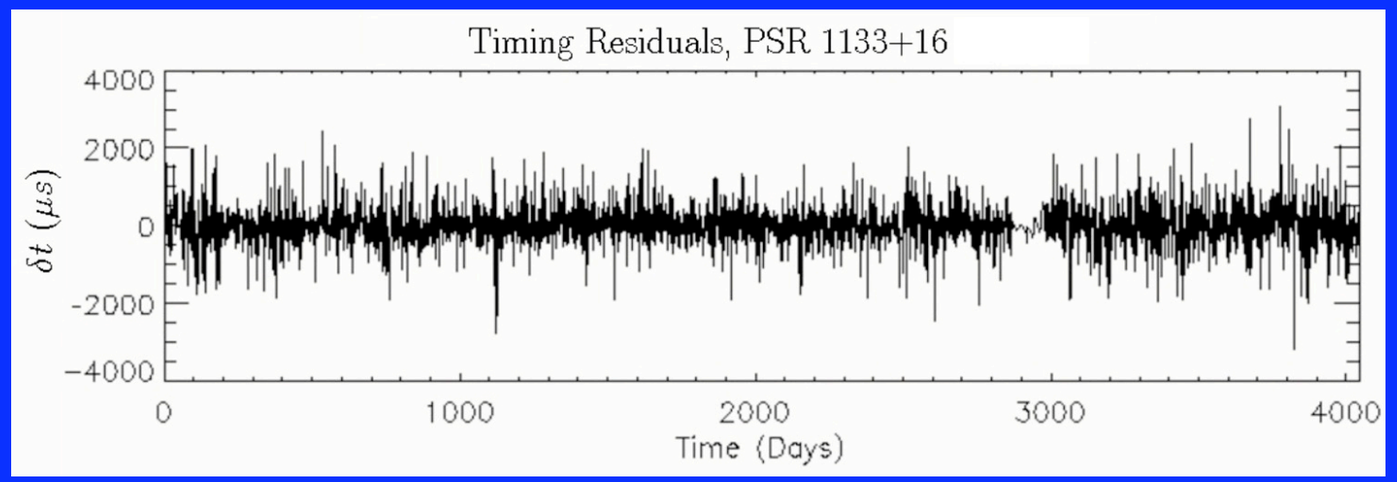


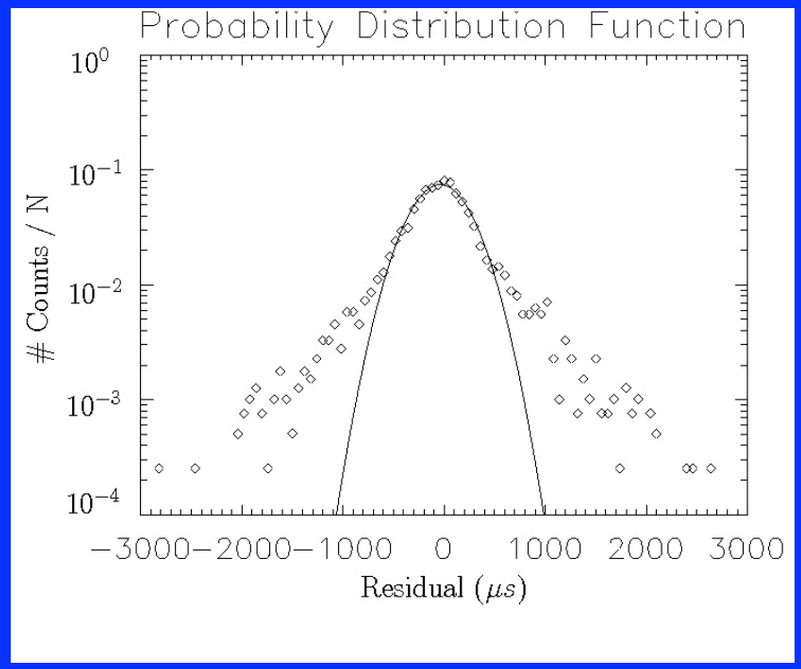
⇒ loose (liquid) component

- Statistically, $\frac{I_{loose}}{I} \simeq 1\,\%$ suggestive of inner-crust origin

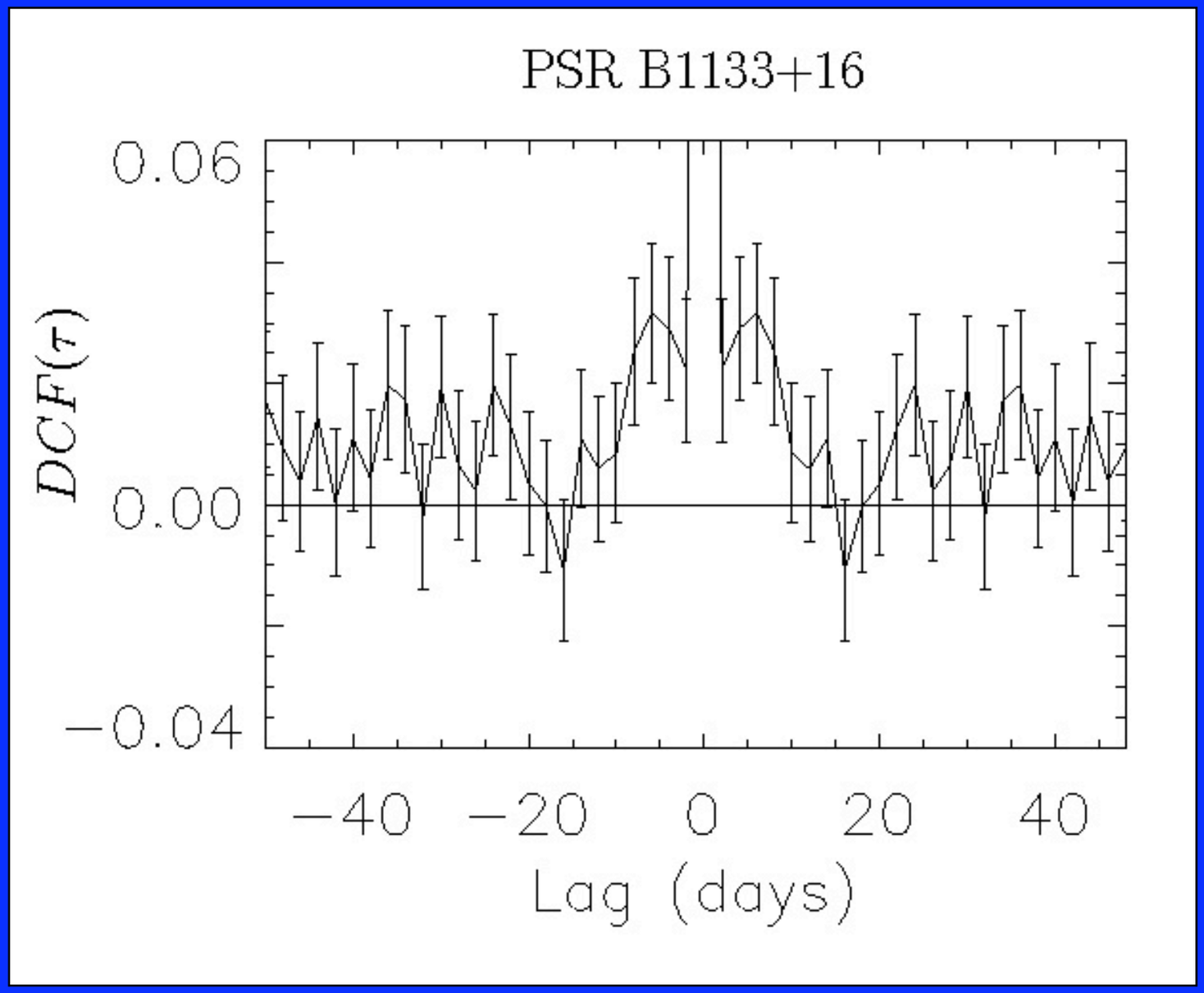
(Link, Epstein & Lattimer 99)

Constraining internal dynamics with timing noise





Evidence for a damped rotational mode



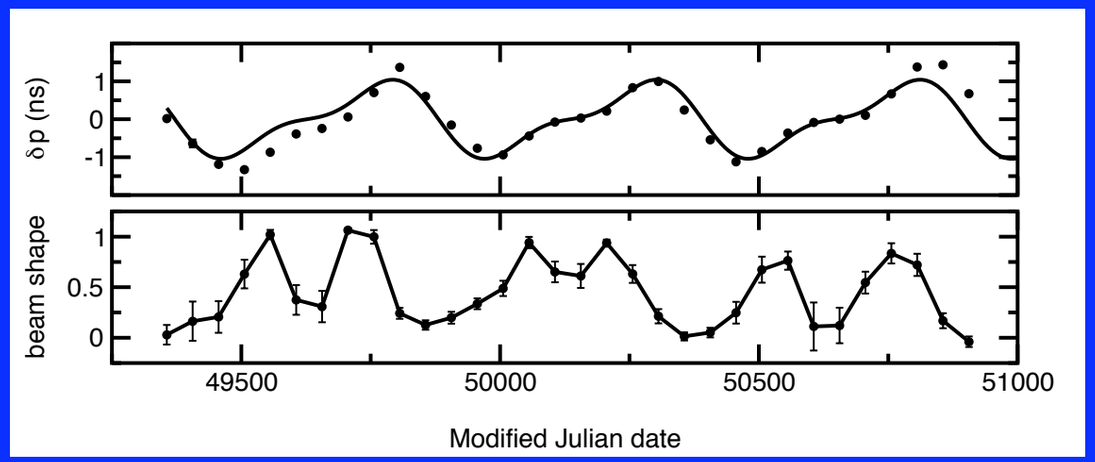
⇒ damped mode

with $\tau \sim 10$ d.

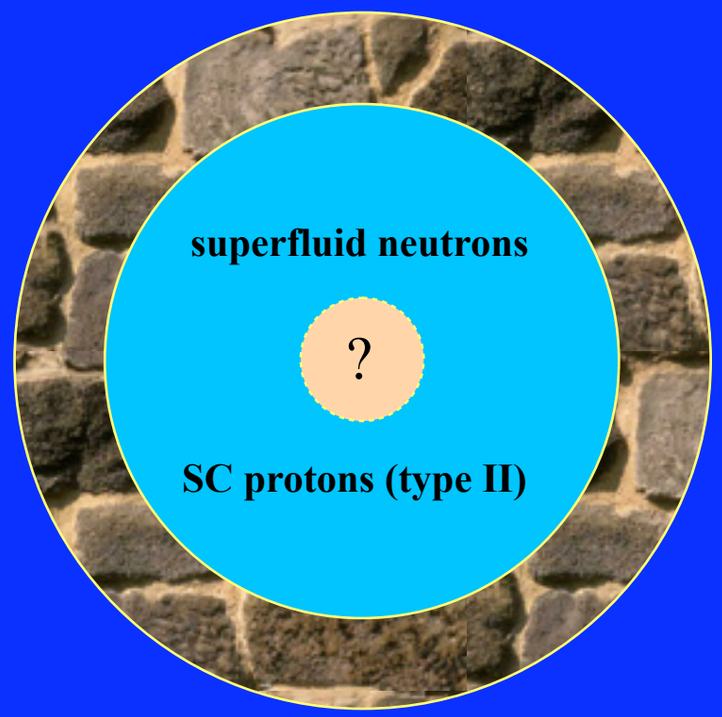
(Price, Link, Shore, Kramer & Lyne, in preparation)

Two pay-offs of precision pulsar timing

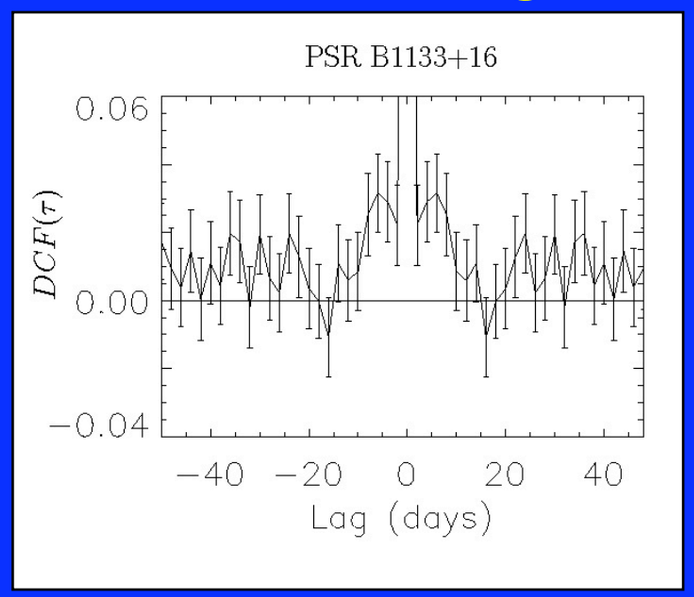
Discovery of precession



challenges



Discovery of correlated structure in timing noise



detection of crust-liquid dynamics?

Key ingredients for further progress

- EOS: Need more masses ⇒ SURVEYS!
- Internal dynamics: Need frequent (daily) timing of choice pulsars to identify modes.