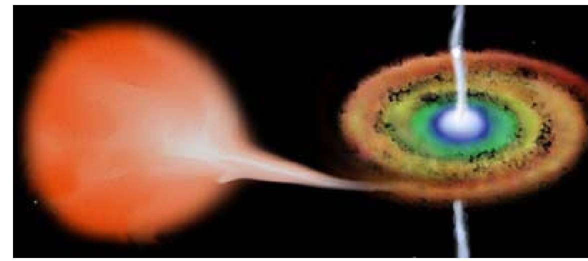
I. OVERVIEW: ACCRETING NS

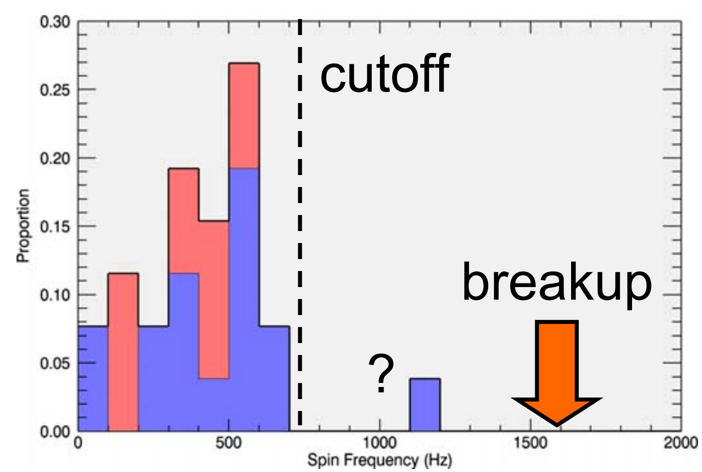
- X-ray binary **spins** below $0.7\ \text{kHz}$ (Chakrabarty et al. 03)
- "Stalling" when $N_{gw} = N_{acc}$ if $\varepsilon \approx 10^{-8}$ (Bildsten 98)
- Promising targets!

- **Mountains**
- ***r*-modes**

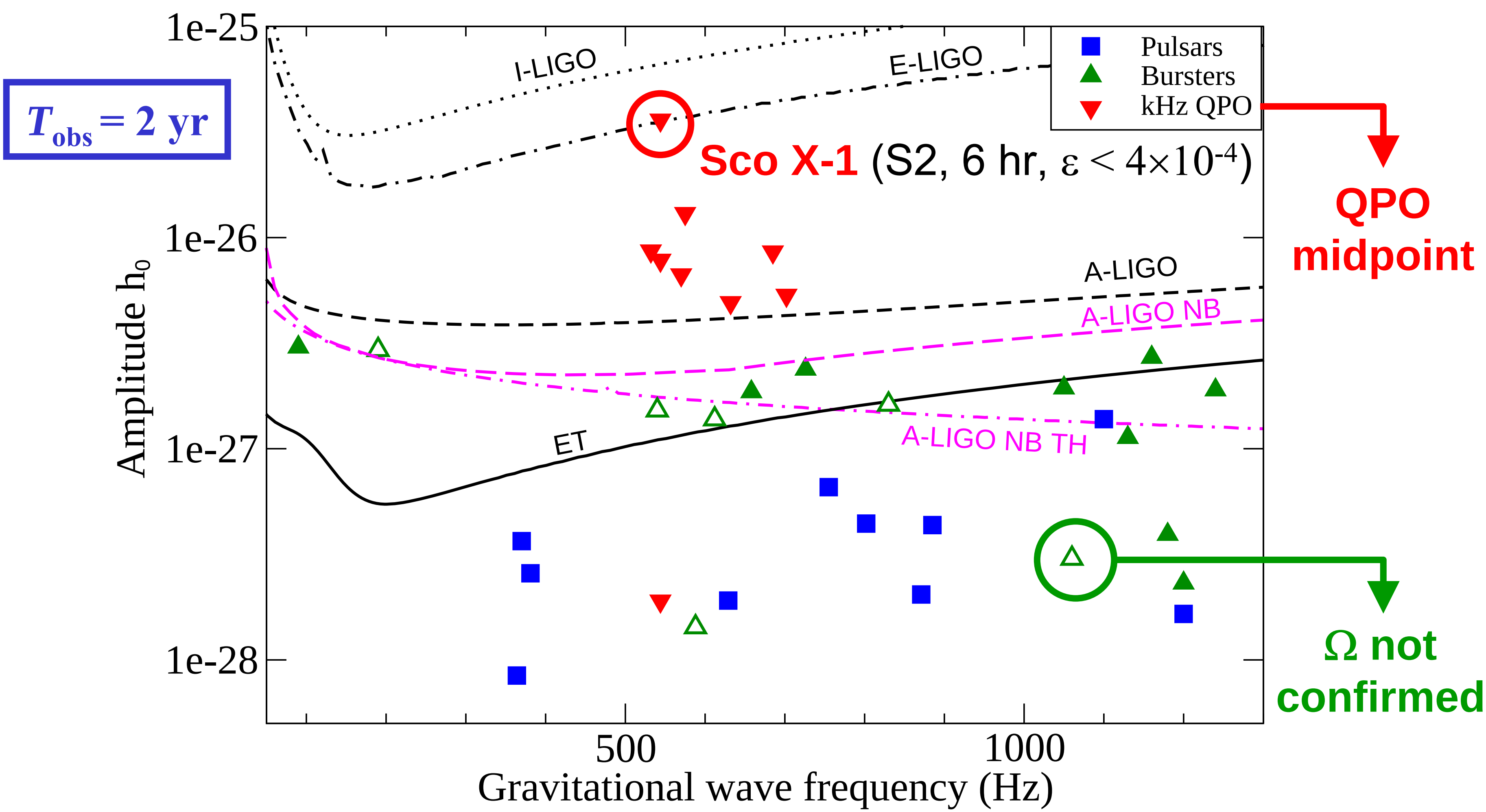


$< 1M_{Sun}$ **red giant**

NS

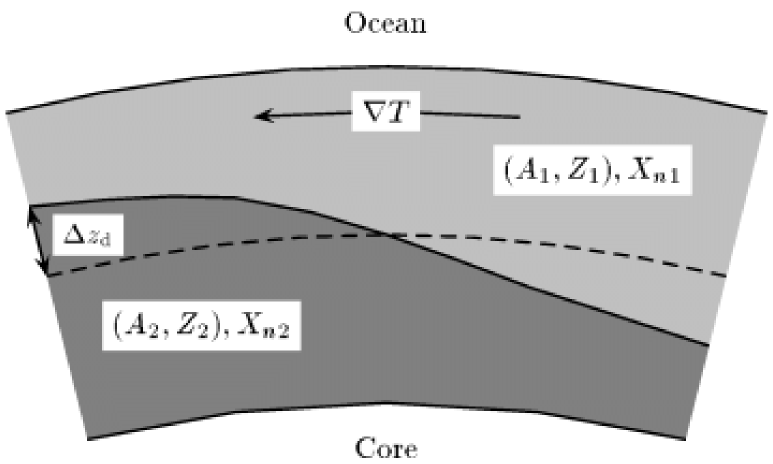


pulses & **burst oscillations**



- Coherent (single template) search difficult
- Raise h_0 with outburst or magnetic lever arm

THERMAL MOUNTAIN



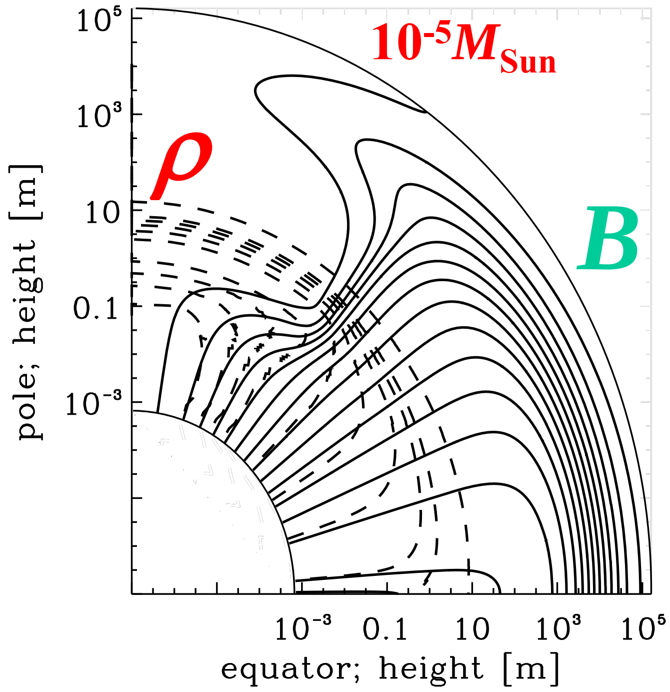
$$(A,Z) \rightarrow (A,Z-1)$$

"Wavy" layers
(Ushomirsky et al. 00)

- Lateral $\nabla T \rightarrow$ asymmetric **e^- capture**
- **Elastic** crust adjusts to reduce ε (Haskell et al. 06)
- **Thermal conductivity** (impurities)
- **Breaking strain**

MAGNETIC MOUNTAIN

- Polar accretion funnel
- Electrical resistivity (mountain subsides)
- Oscillations excited by X-ray burst → B geometry



(Payne & Melatos 04)

Predicts $\varepsilon > 10^{-5}$ and $h_{GW} \propto \mu^{-1}$

II. OVERVIEW: ISOLATED NS

- Coherent searches (e.g. Crab S5, $\varepsilon < 2\times10^{-4}$)

- Zoo of **internal waves** (e.g. after SGR storm)
- **Superfluid vortex** motion (e.g. pulsar glitches)

- 1^{st} proof of superfluidity in bulk nuclear matter
- Transport: viscosity, mutual friction
- EOS: compressibility

Network → localization → radio follow-up
1^{st} detection: NS "next door" (99.99% unseen!)

GLITCHES: BURST SIGNAL

$$h \propto \frac{\partial^2}{\partial t^2} \int d^3x Y_{lm}^*(\hat{\mathbf{x}}) r^l \mathbf{x} \cdot \mathrm{curl}(\psi \nabla \psi^* - \psi^* \nabla \psi)$$

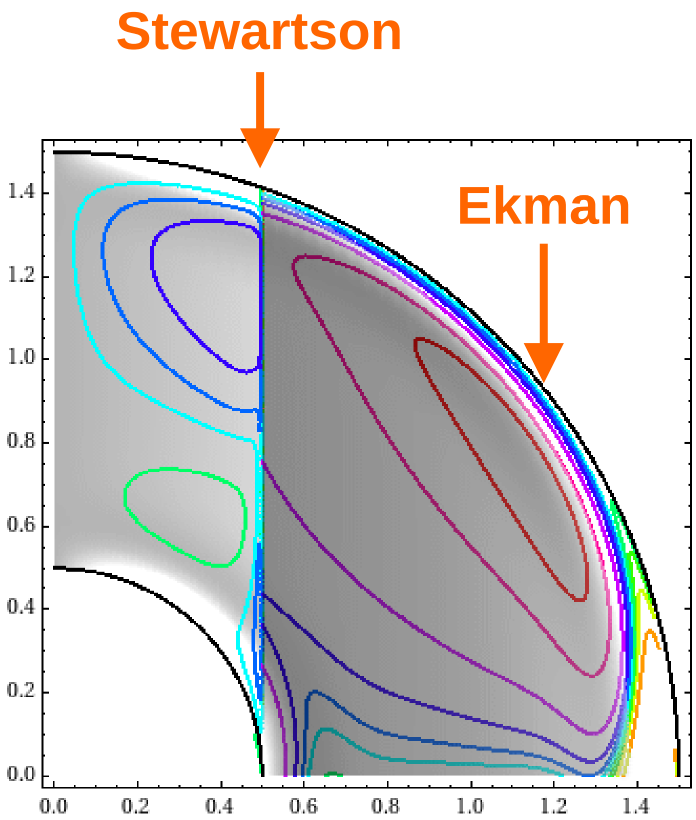
integral over source

QM mass current

- Asymmetric, jerky vortex motion
- **Current** quadrupole $(l,m) = (2,1)$ dominates
- QM $\rightarrow \psi \rightarrow$ mass current $\rightarrow$ radial vorticity

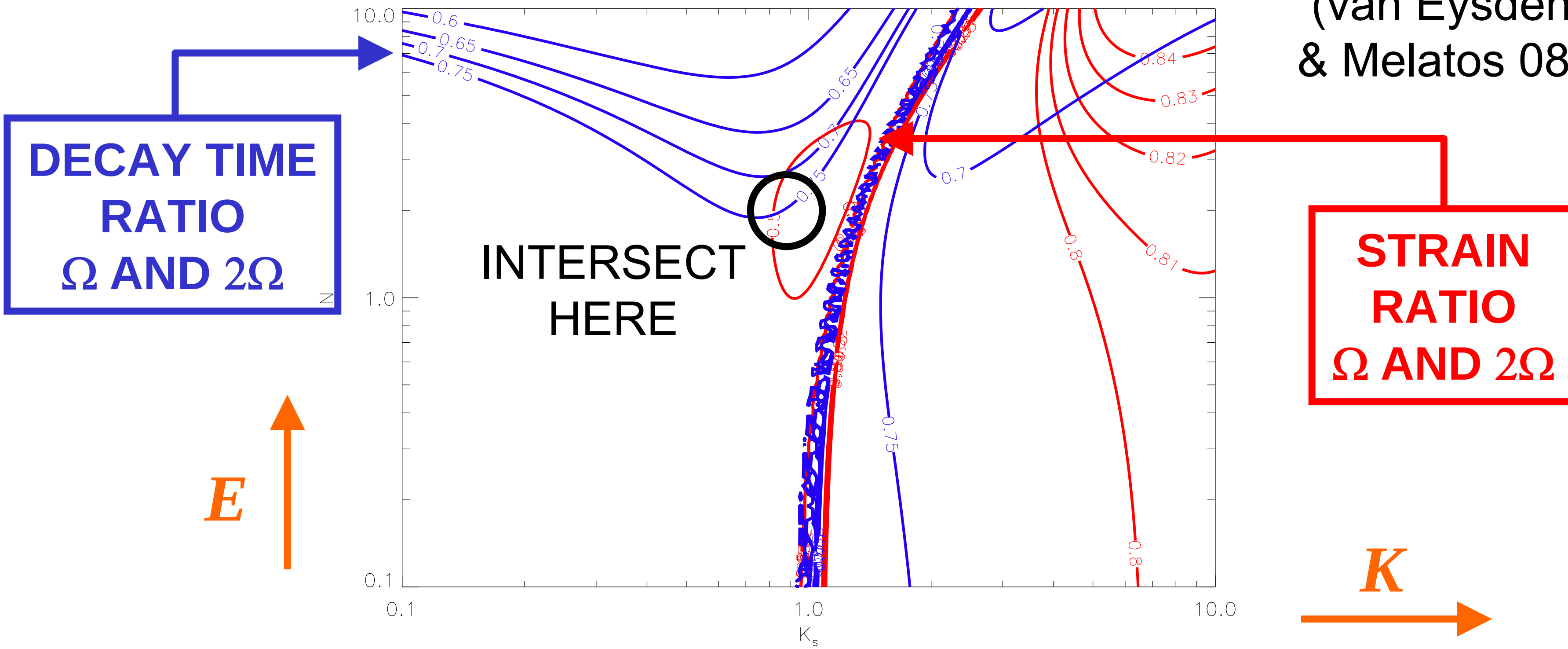
$$h \approx 10^{-23} (\Delta t / 1 \text{ ms})^{-2} (N_{\text{vortices}} / 10^{19})^{1/2}$$

RELAXATION SIGNAL

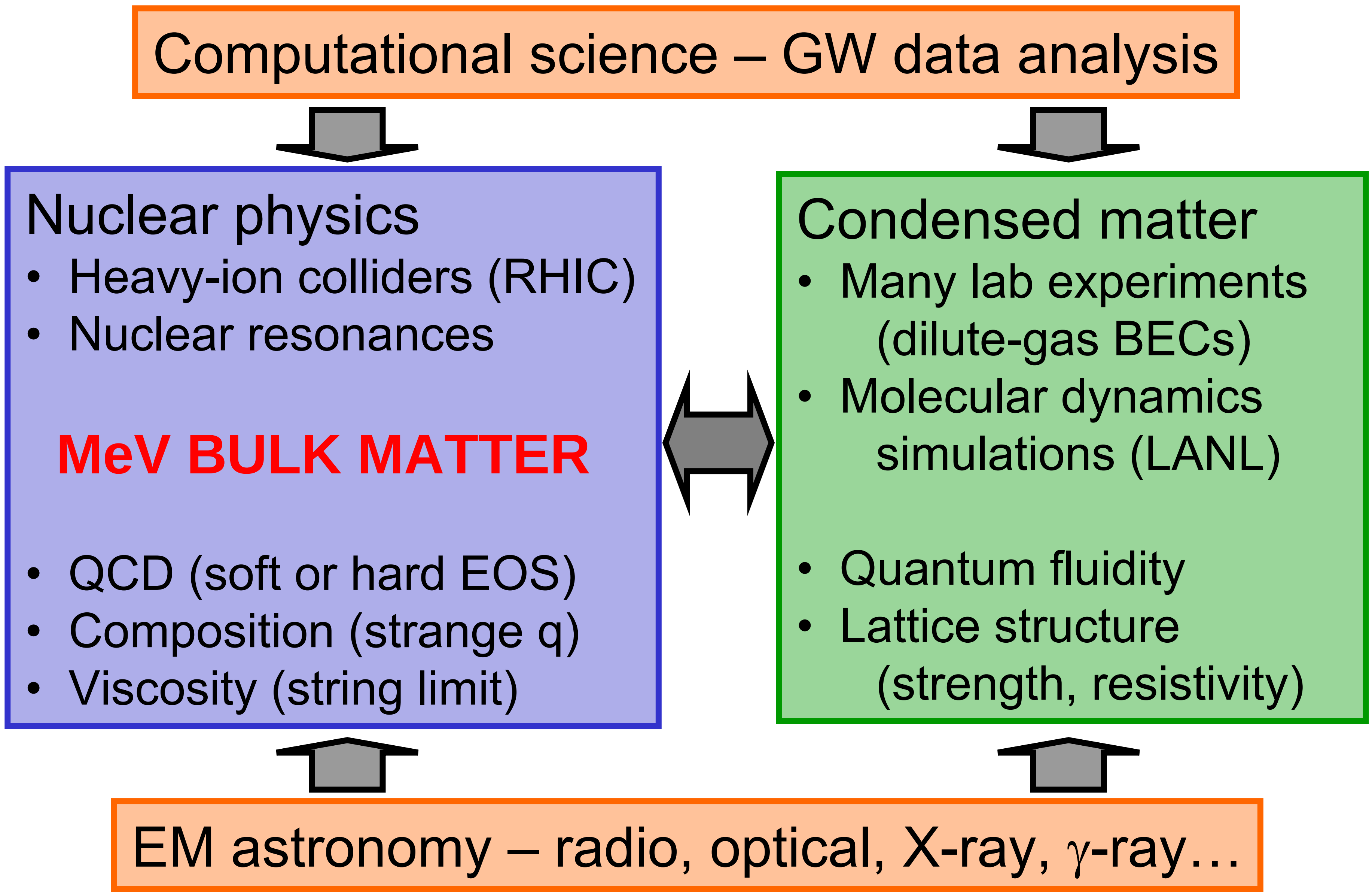


- Differentially rotating "cup of tea"
- **Viscous** boundary layers fill cup in time $\sim Re^{1/2}\,\Omega^{-1}$
- Erases $\cos(m\varphi)$ modes
- **Sinusoidal GW decaying over days to weeks**

(van Eysden & Melatos 08)

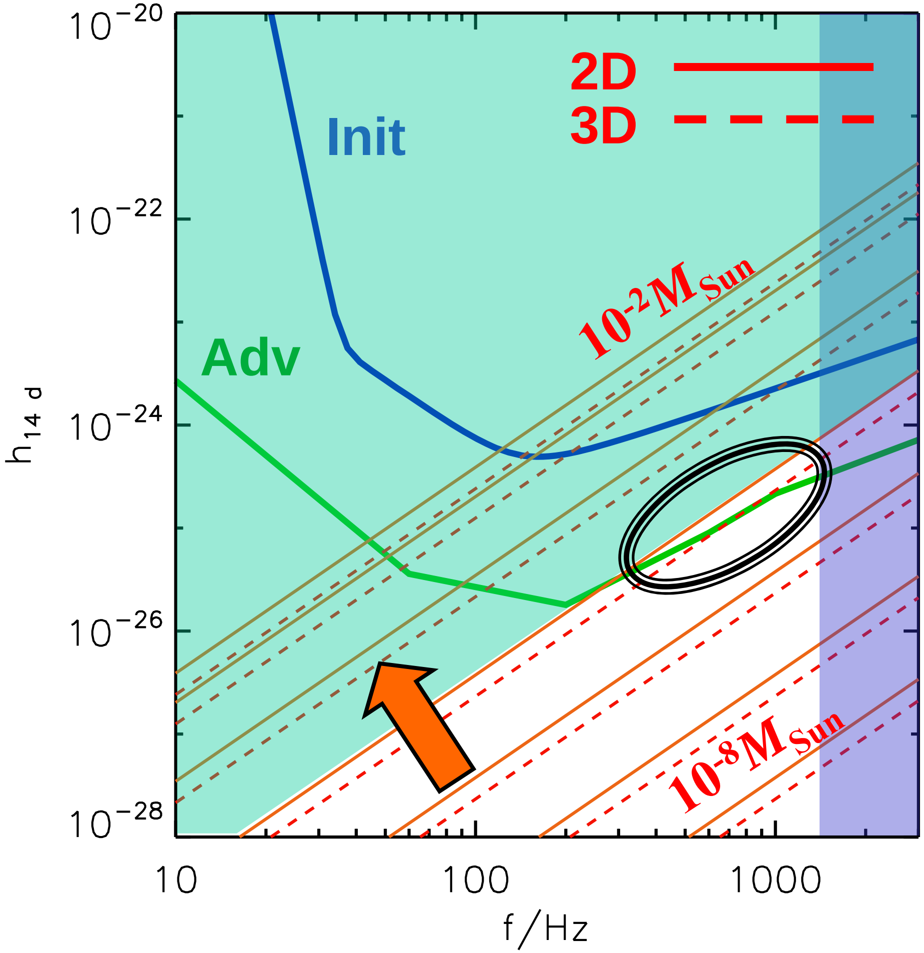


- Compressibility ***K***, viscosity ***E*** set Ekman layer thickness → wave strain & decay time
- **Nuclear equation of state!**
- Polarization mix → source **inclination**
- Wave strain ~ 10^{-25}



Owen 09 (LIGO-T0900053-v1)

DETECTABILITY BY LIGO



- 14 days @ 10 kpc
- Known f_* and orbit
- $S/N = 11.4\ [T_{data}/S_h(f)]^{1/2}$
- False alarm (1%), dismissal (10%)

- **De-phasing**
- Spin wandering
- Precession: $h(f_*)$, $h(2f_*)$
- Alfven oscill'ns

(Payne & Melatos 06; Vigelius & Melatos 08)

STALLING PHYSICS

- Torque balance

$$N_{\mathrm{gw}} = \frac{32GQ^2\Omega^5}{5c^5} = \dot{M}(GM_*R_a)^{1/2} = N_{\mathrm{acc}}$$

- X-ray flux $\rightarrow dM/dt$
- Average or outburst

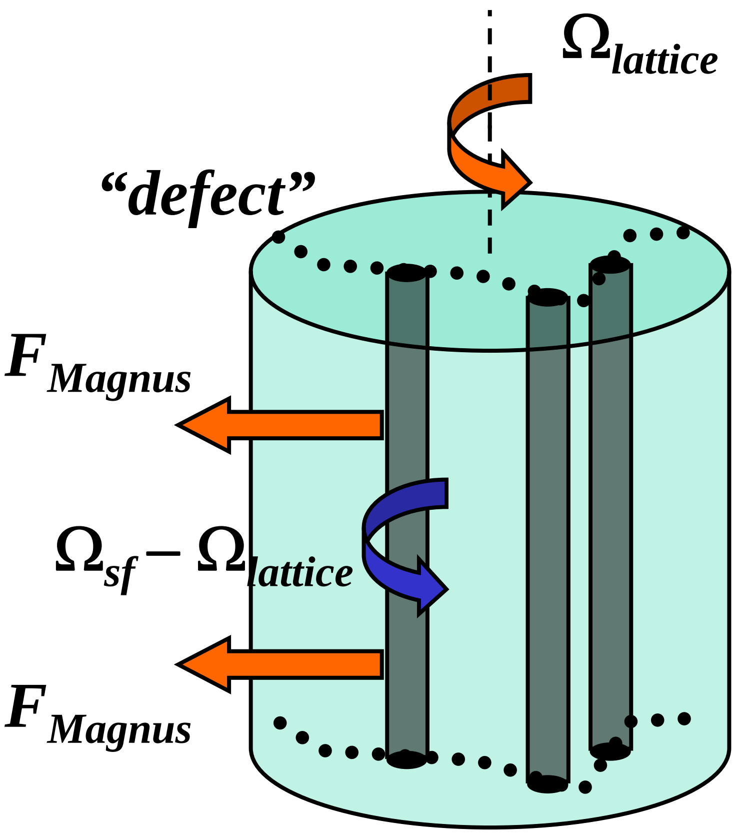
$$4\pi d^2 F_X \approx GM\dot{M}/R$$

- Einstein quadrupole

$$h_c^2 = \frac{10GN_{\mathrm{gw}}}{c^3 d^2 \Omega}$$

$h_c \propto (M_* R_a)^{1/4}$ doubles if $R_a = 3R_*$ and hyperons

VORTEX (UN)PINNING



- Defects or cracks
- Lattice spins down electromagnetically

$$\Omega_{sf} - \Omega_{lattice} > 0$$

- Magnus ("lift") force

- Expect periodic events, cf. **Poisson**
- Expect similar sizes, cf. **power law** (4 dex!)

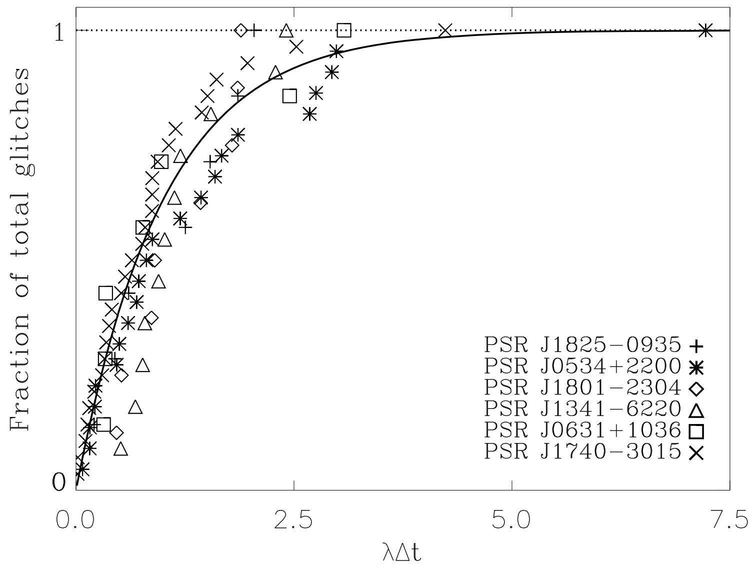
LATEST STATISTICS

- PKS Multibeam Survey & better ephemerides (Manchester et al. 05; Janssen & Stappers 06; Middleditch et al. 06)

- **Disaggregate!**
- 9 PSR with 5+ glitches

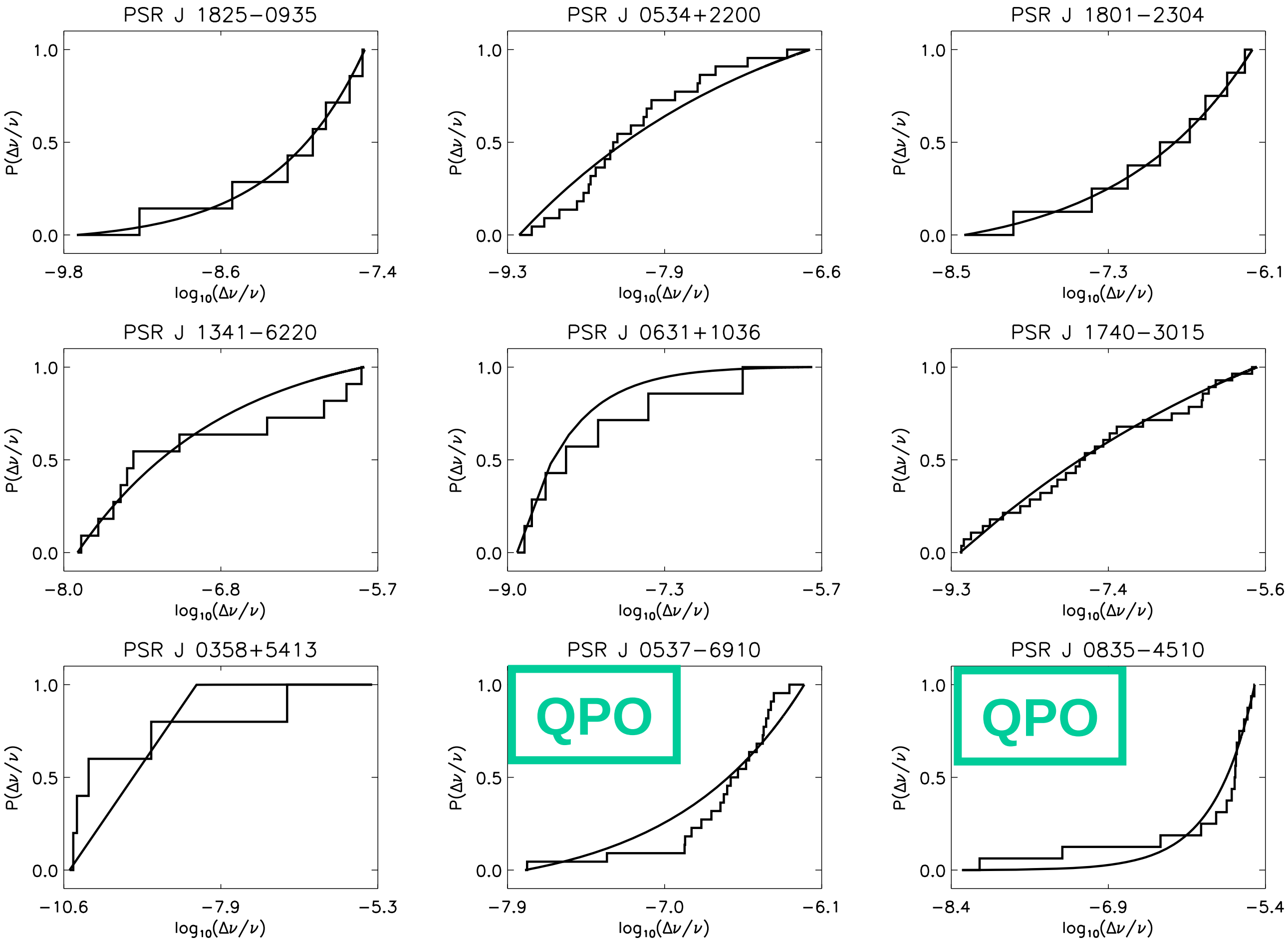
- Seven **Poisson**
  rate = $\lambda = 0.4 - 2.6\ \text{yr}^{-1}$
- Two **quasiperiodic**
  period = $0.3\ \&\ 2.8\ \text{yr}$

WAITING TIMES



$$p(\Delta t) \propto \exp(-\lambda \Delta t)$$

(Melatos et al. 08)



(Melatos et al. 08)

SIZES

$$p(\Delta\nu) \propto (\Delta\nu)^a$$

- Universal exponent ruled out **($-2.4 < a < -0.4$)**
- Average $\langle \Delta\nu \rangle$ dominated by big glitches → **dangerous to bin** objects together (Lyne et al. 00)

POLARISED LIGO SPECTRUM
(van Eysden & Melatos 08)