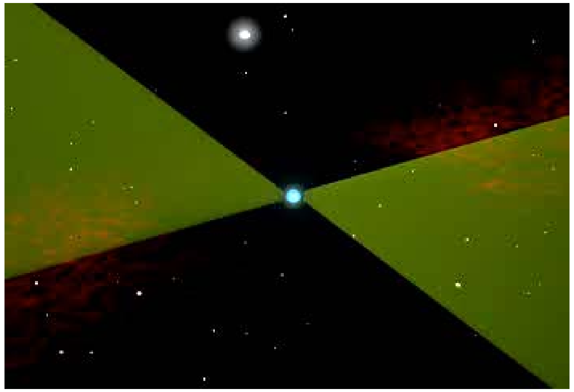
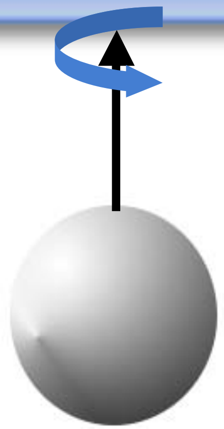
GWs from Pulsars

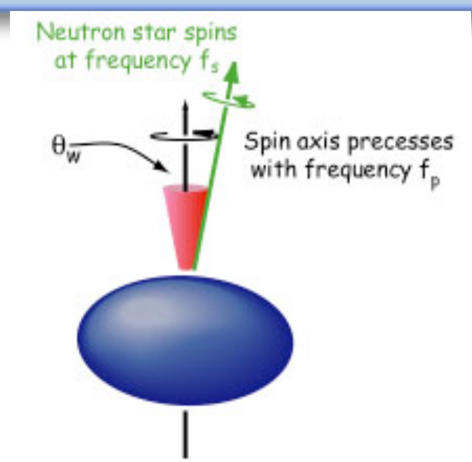
Kostas Kokkotas



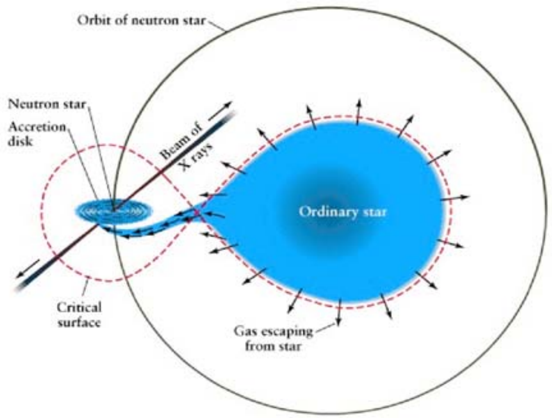
Rotating Neutron Stars



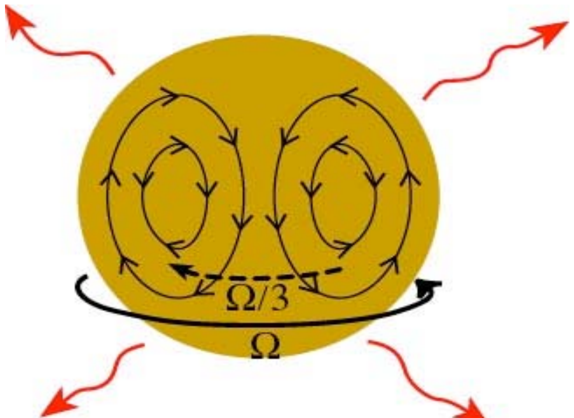
“Mountain” on neutron star



Wobbling neutron star



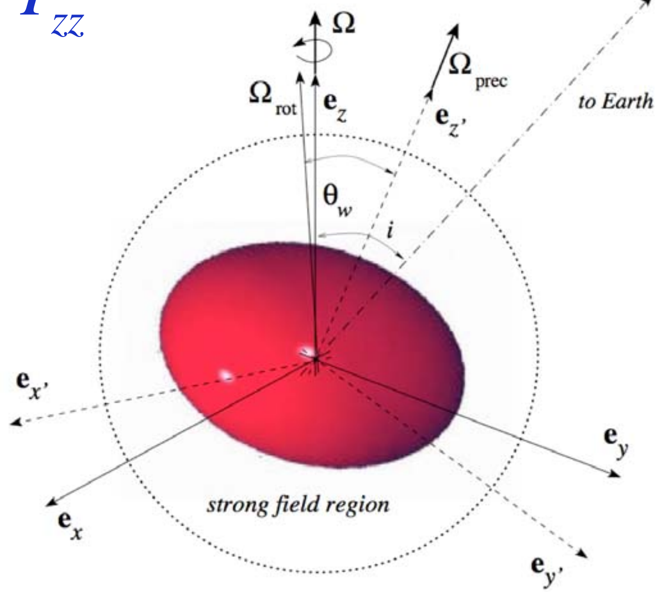
Accreting neutron star



R-modes

Triaxial Spinning Neutron Stars

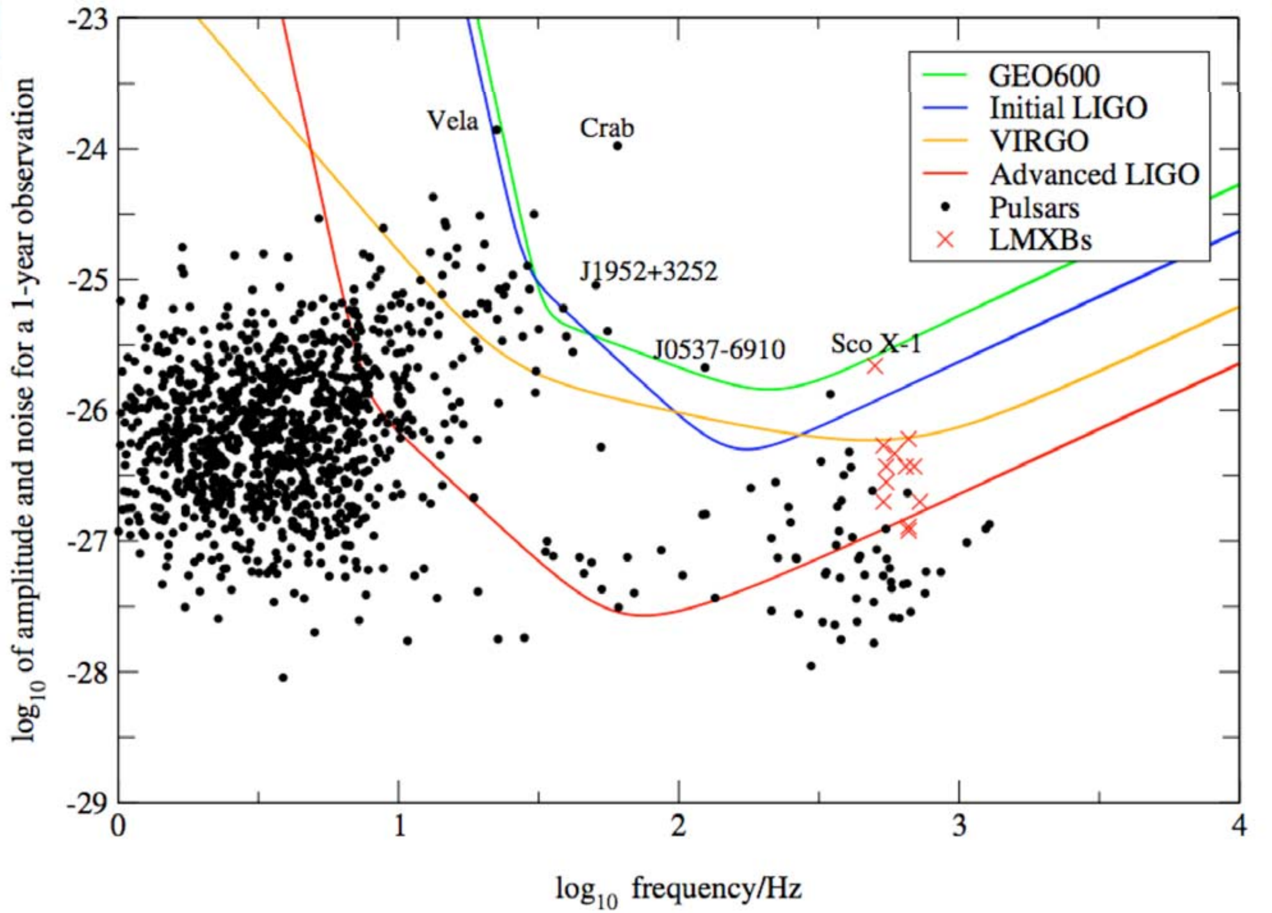
- Non-axisymmetric $\varepsilon = \frac{I_{xx} - I_{yy}}{I_{zz}}$
- Rotation rate ν
- GW frequency $f = 2\nu$
- GW strain-amplitude



$$h = \frac{16\pi^2 G}{c^4} \frac{\varepsilon I_{zz} \nu^2}{d}$$

$$= 4 \times 10^{-25} \left(\frac{\varepsilon}{10^{-6}}\right) \left(\frac{I_{zz}}{10^{45}\, gcm^2}\right) \left(\frac{\nu}{100\, Hz}\right)^2 \left(\frac{100\, pc}{d}\right)$$

Slowdown of radio pulsars



Upper limits on GW emission from triaxial NS can be used to decide which pulsars to target

Neutron Star "Mountain"

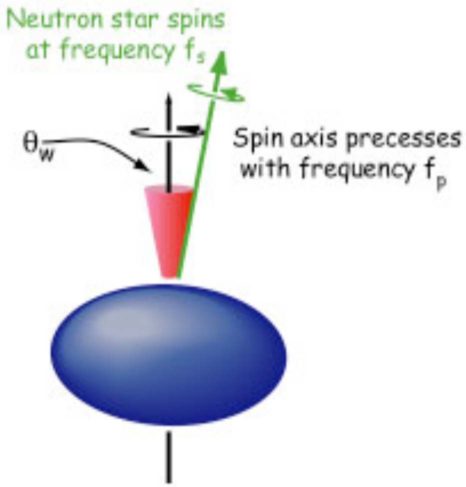
- Conventional NS crustal shear mountains : $\varepsilon \leq 10^{-7}$–10^{-6}
- Supefluid vortices : Magnus-strain deforming crust : $\varepsilon \leq 5 \times 10^{-7}$
- Exotic EoS : strange-quark solid cores
  - Solid quark matter $\varepsilon \leq 10^{-4}$
  - Quark-baryon mixture of meson condensate matter (half of the core will be solid) $\varepsilon \leq 10^{-5}$
- Magnetic mountains:
  - Large toroidal field $\sim 10^{15}$ G $\perp$ to rotation : $\varepsilon \sim 10^{-6}$
  - Accretion along B-lines ➔ "bottled" mountains : $\varepsilon \leq 10^{-6}$–10^{-5}

CONCLUDING:

- Normal nuclear crusts can only produce ellipticity $\varepsilon <$ few $\times 10^{-7}$
- High ellipticity measurement means exotic state of matter
- Low ellipticity is **inconclusive**: strain, buried B-field…

Free Precession

- Most general motion of a rigid body
- NS are **not** rigid : coupled crust – core
  - Likely to be damped rapidly
  - No obvious instability or pumping mechanism

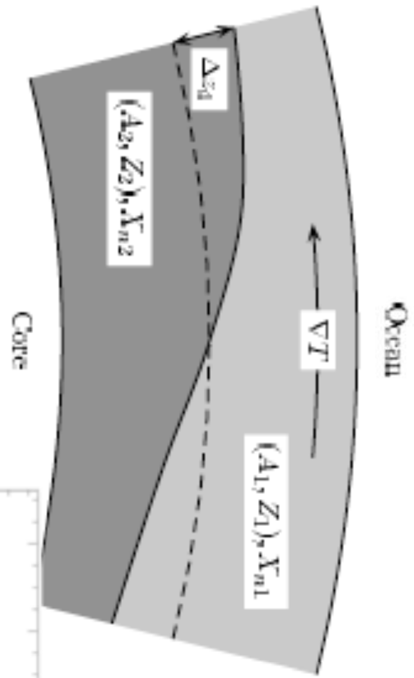


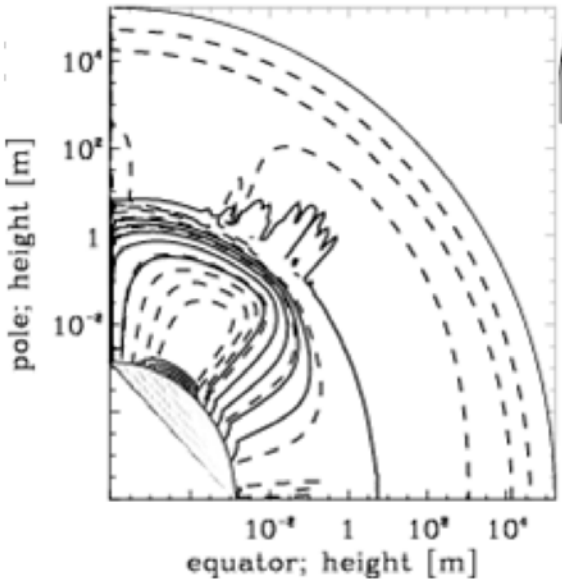
Wobbling neutron star

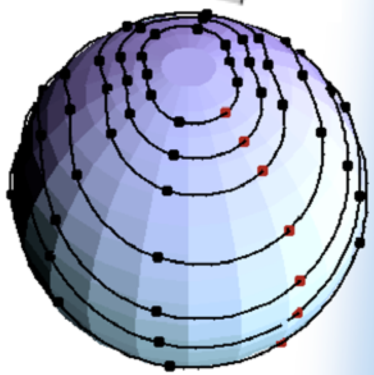
$$h \sim 10^{-26}\left(\frac{\theta}{0.1}\right)\left(\frac{100\,pc}{d}\right)\left(\frac{\nu}{500\,Hz}\right)^2$$

Periodic signals: Accreting binaries

- Low-mass x-ray binaries are best bet
  - Rapidly accreting (up to Eddington limit)
  - Rapidly spinning (up to 600Hz) … but why not faster?
  - Spin mystery could be nicely solved by GW
- Emission mechanisms
  - Elastic mountains
  - Magnetic mountains
  - r & f-mode oscillations







Conclusion

- Isolated NS are plausible sources for GW detection
- Whether or not they are detectable depends on many poorly-understood aspects of NS physics
  - Any GW-detection from rotation NS will be extremely valuable for NS physics
  - Even the absence of detection can yield astrophysically interesting information (crust deformation, B-field, instabilities)

S2 analysis : 28 pulsars (all the ones above 50 Hz for which search parameters are "exactly" known) $\varepsilon<2.9\times10^{-4}$
S5 analysis : 78 pulsars $\varepsilon<4.0\times10^{-7}$