Continuous gravitational waves and neutron star microphysics

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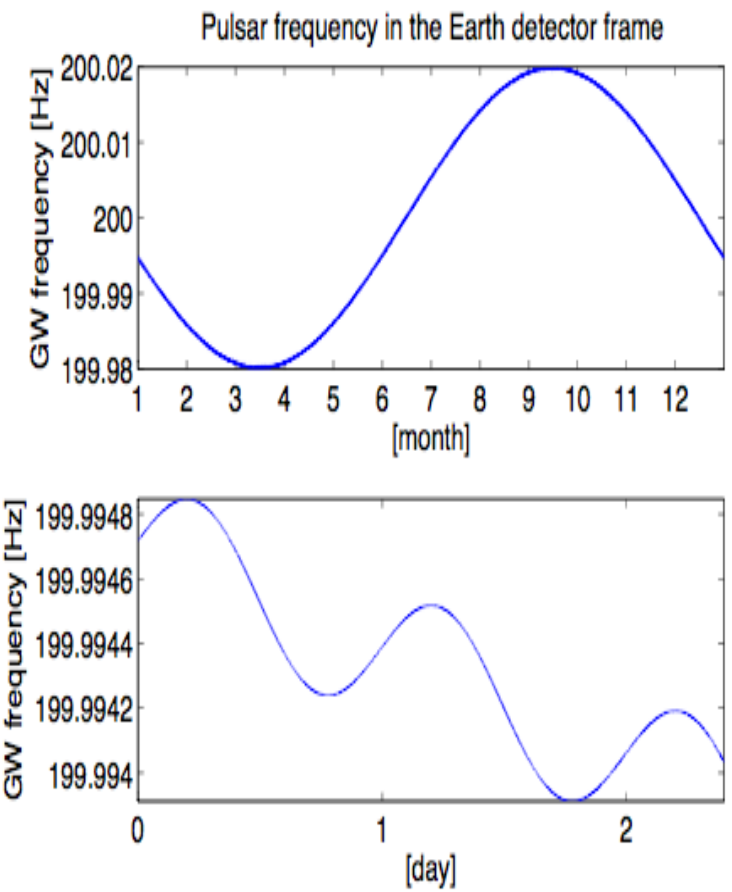
NS2014 @ Florence

2014-03-28

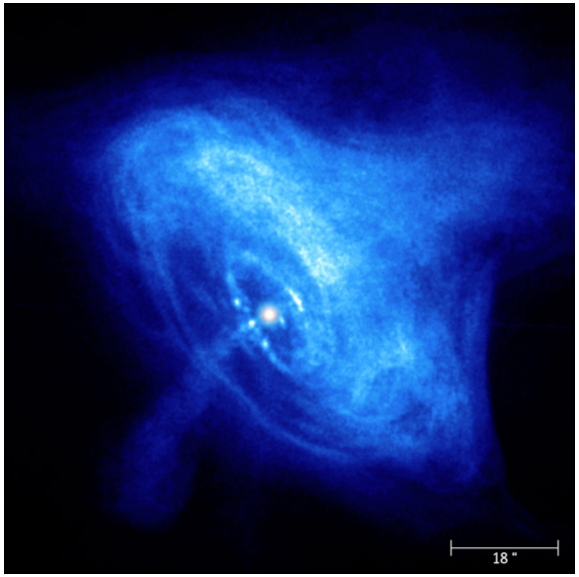
Continuous gravitational waves

- Talks at this meeting by Keitel, Shaltev, Palomba
- Signals long compared to observations (1–2 yr)
- Implies slowly evolving frequency (+ Doppler)
- Sources must be rotating "neutron" stars
- Hard to detect, but…
- Many cycles = much info

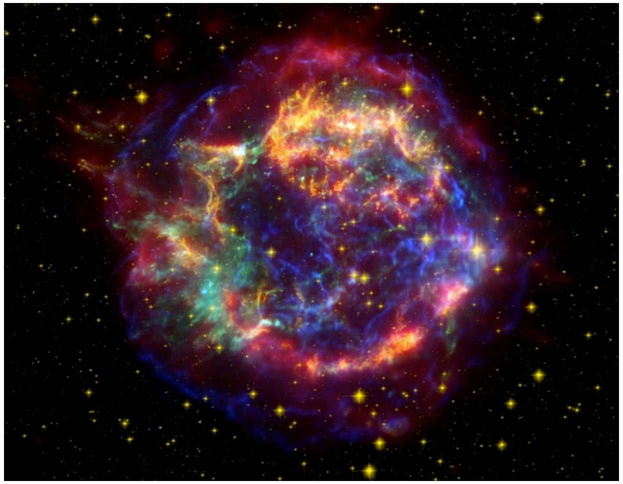


Credit: Einstein@Home

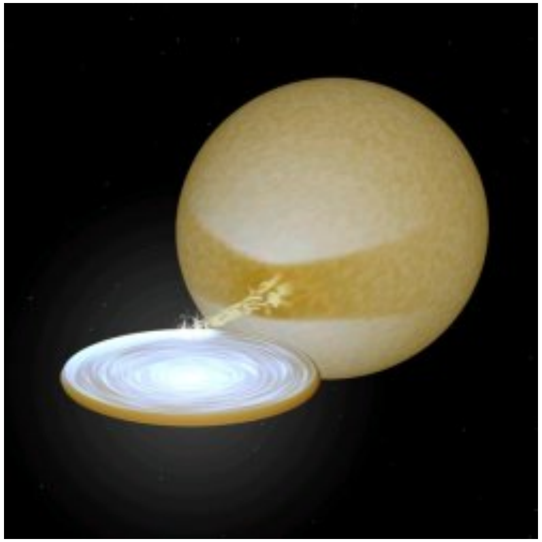
Four types of continuous GW searches



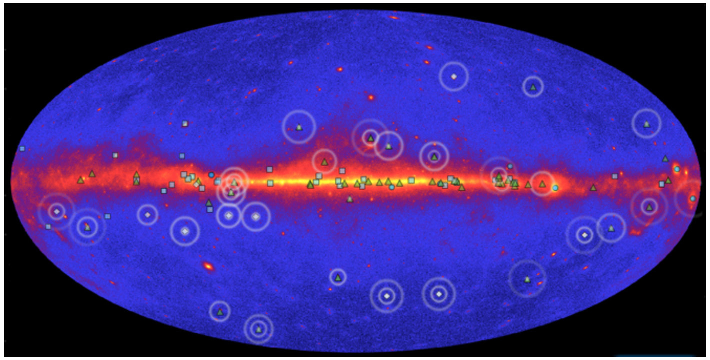
Credit: NASA/Chandra



Credit: NASA/Chandra/STScI/Spitzer



Credit: M. van der Sluys



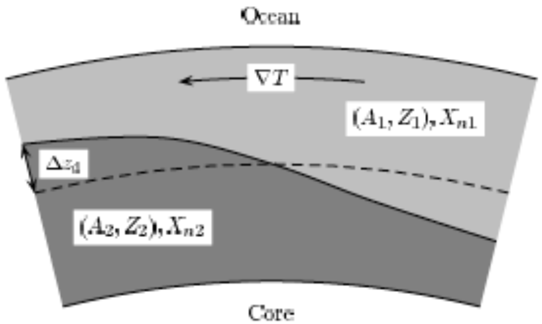
Credit: NASA/GSFC

- Knowledge = sensitivity
- Different constraints from EM
- Different physics at work

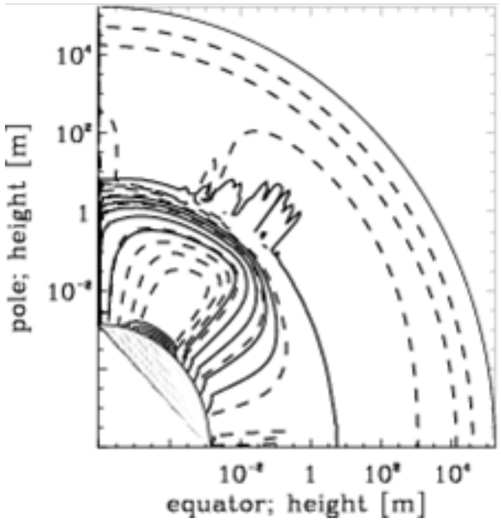
How to get a rotating quadrupole?

- Elastic mountains
- Magnetic mountains (2 kinds)
- Modes

Credit: Eric Priest



Credit: Ushomirsky et al. (MNRAS 2000)



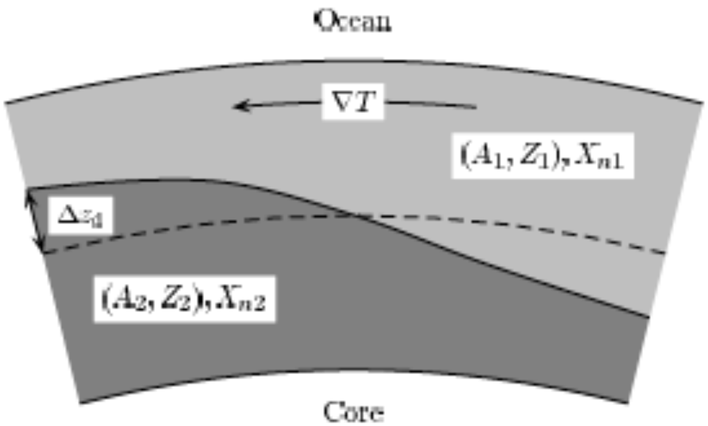
Credit: Melatos & Payne (ApJ 2005)

Elastic mountains

- Require a solid part (NS crust, hybrid star core, …)
- How big could they be?
- Quadrupole ~ (structure) × (shear modulus) × (strain)
  - **Shear modulus**: composition (huge), charge separation, thermo
  - **Breaking strain**: pressure crushes away voids & defects
  - Structure: **equation of state**, bulk properties, general relativity
- Latest answers (Johnson-McDaniel & Owen 2013)
  - Normal neutron stars up to 10^{40} g cm^2
  - Hybrid stars up to 10^{42} g cm^2
  - Solid quark stars up to 10^{44} g cm^2

Elastic mountains

- What could drive them? Accretion
  - **E-capture** has small T dependence
  - Onion layers move up under hot spot
  - Enough w/10% lateral ΔT/T
  - (Torque balance model)

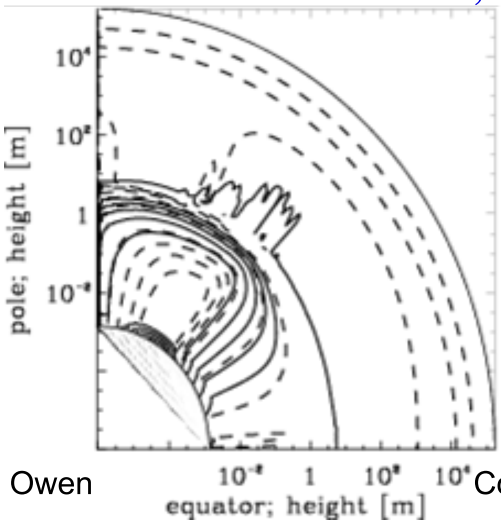


Credit: Ushomirsky et al. (MNRAS 2000)

- What could drive them in young neutron stars? ???
- How long could they last? Viscoelastic creep? ???

Magnetic mountains

- Can happen, must happen in all stars (Jones 1970s)
- How big could they be?
  - Buried: $Q \sim 10^{39}$ g cm^2 $(B_{int}/10^{15}\ G)^2$
  - Accreting: also $Q \sim 10^{39}$ g cm^2 at Eddington
- How long could they last?
  - **Ohmic diffusion**, other issues from earlier in week

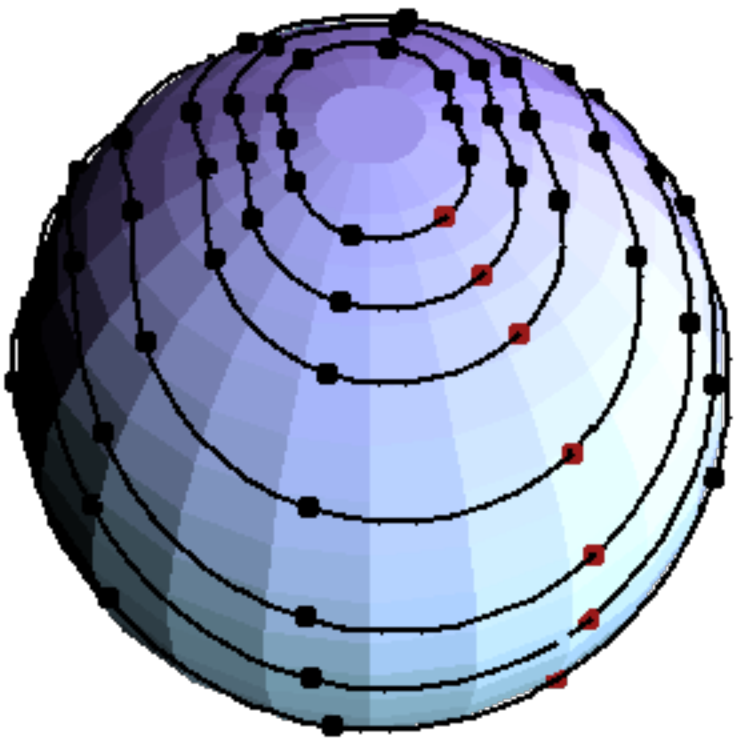


Credit: Melatos & Payne (ApJ 2005)

Credit: Eric Priest

R-modes

(Stergioulas Living Review 2003)

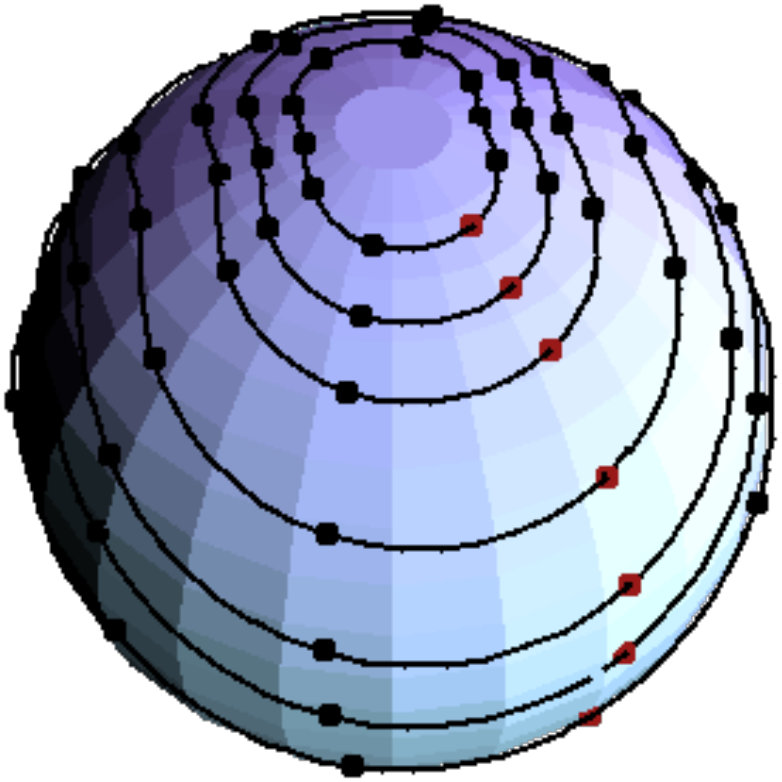


Credit: C. Hanna / B. Owen

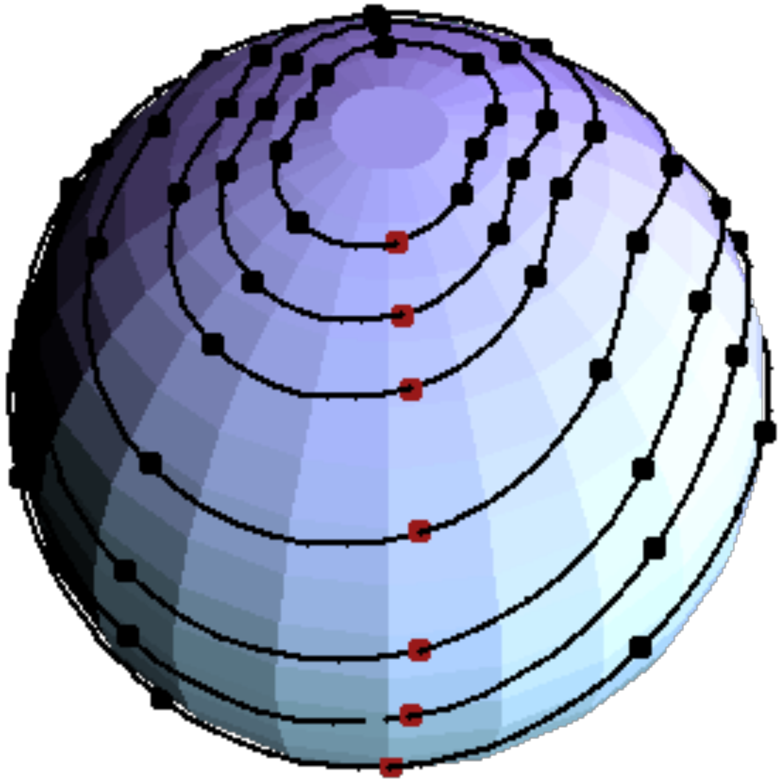
- Coriolis restoring force
- Mode freq. ~ 4/3 spin
- Mostly δ-velocity
- Little δ-density
- Prograde / retrograde
- CFS instability driving
- Can beat damping!
- Can last few kyr
- Or throughout accretion

R-modes

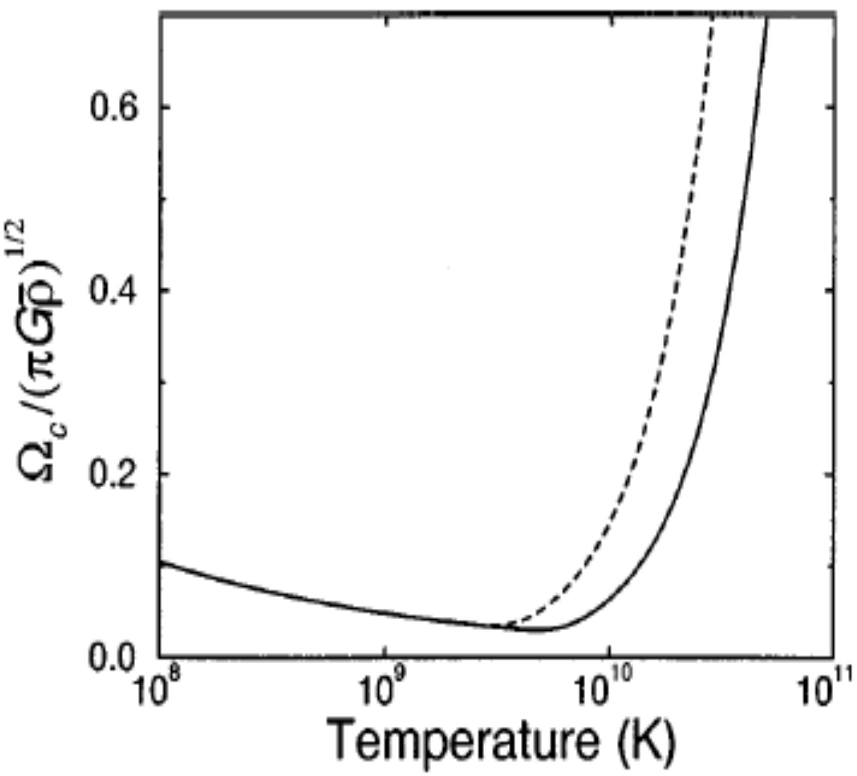
Inertial frame: prograde



Corotating frame: retrograde



R-modes

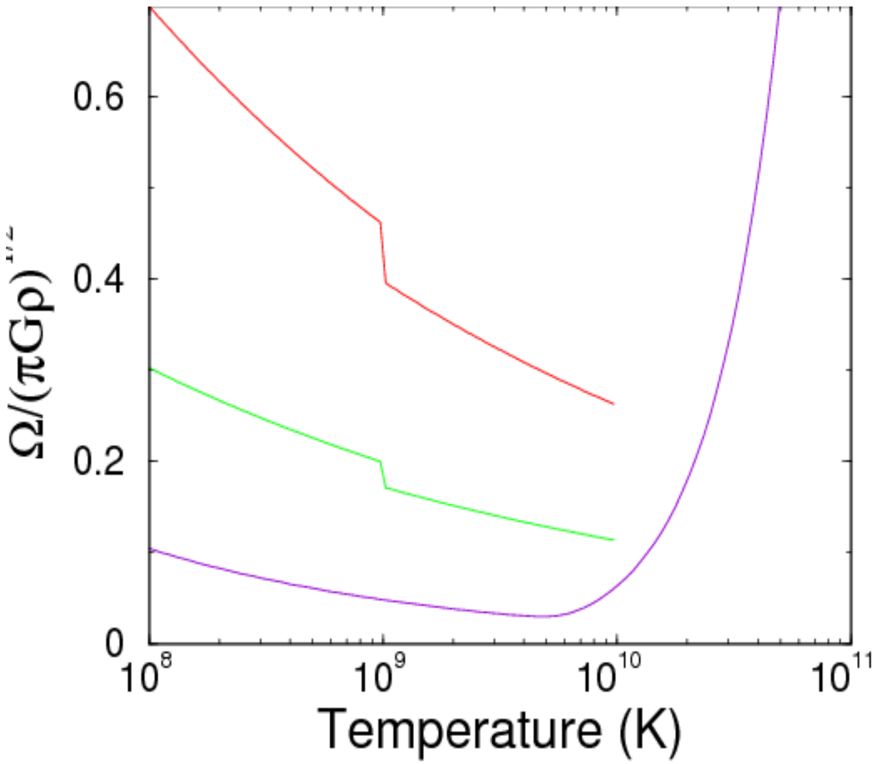


Credit: Lindblom et al. (PRD 1999)

- GW driving wins above
- Damping wins below
- **Bulk viscosity** at high T (URCA neutrinos)
- **Shear viscosity** at low T (n-n scattering)
- Bare minimum: no crust, superfluidity, etc.
- Young star & accreting star scenarios

R-modes

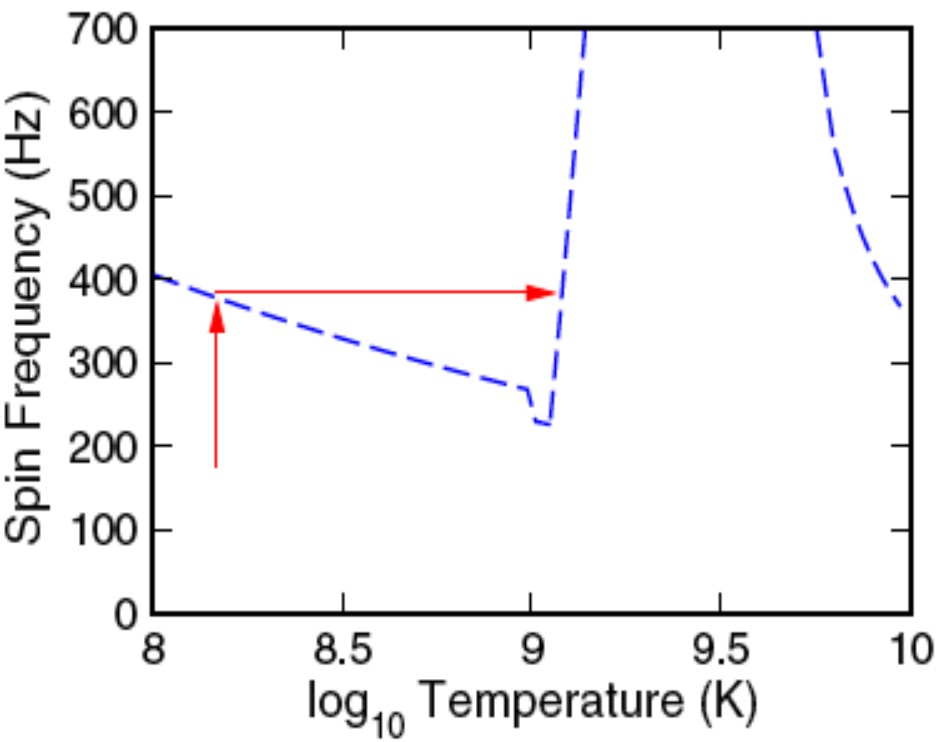
- Crust adds huge viscosity at low temperatures
- Needed for LMXBs
- **Viscous boundary layer**
- **Heat conduction**
- Hydro is different (slip condition)



Credit: Lindblom et al. (PRD 2000)

R-modes

- **Funny particles** (here hyperons) add huge viscosity at high temps
- Lack of **thermal** runaway could be taken as evidence



Credit: Nayyar & Owen (PRD 2006)

R-modes

- How big could they get?
  - Enough to be observable in principle now (Owen 2010)
  - Nonlinear hydro 3-mode coupling (Bondarescu et al. various)
  - **Nonlinear viscosity** (Alford & various)
- How long could they last?
  - During accretion & a bit after
  - See "how big could they get" (few kyr, young SNRs)
- Caveat:
  - High frequency dependence of GW driving reduces dependence on viscosity coefficients, etc (cf. Alford's talk)

Take-away

- Continuous gravitational waves are hard to detect
- But coupled to lots of microphysics when we do
- Some even with upper limits…?