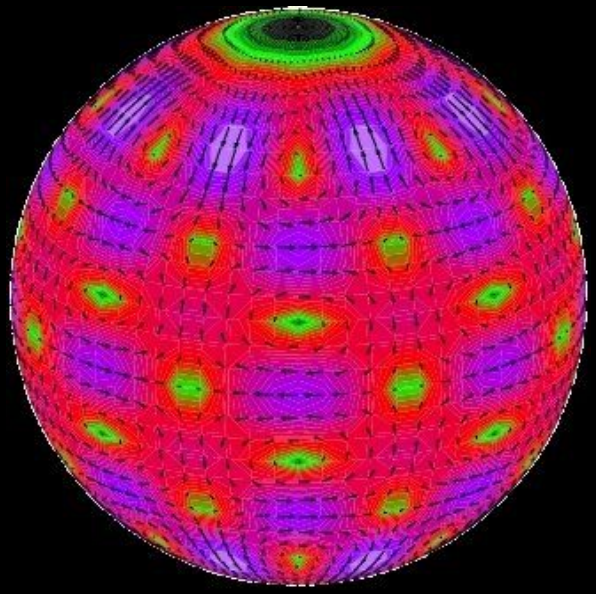
Rapid X-ray oscillations in magnetar giant flares



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Magnetar giant flares

- Three such events to date:
  - March 5th 1979: SGR 0526-66
  - August 27th 1998: SGR 1900+14
  - December 27th 2004: SGR 1806-20
- Powered by a global reconfiguration of the magnetic field
- Likely to involve large-scale crust fracturing/ reconfiguration, which may excite global toroidal oscillations in the crust (see e.g. Duncan 1998)
- Such modes observed after earthquakes (Park et al. 2005)

Crustal shear modes

- Duncan (1998) calculated the period of the fundamental toroidal mode to be:

$$P(_2t_0) = 33.6\,R_{10}\,\frac{(0.87+0.13\,M_{1.4}\,R_{10}^{-2})}{(1.71-0.71\,M_{1.4}\,R_{10}^{-1})^{1/2}}\ \text{ms}$$

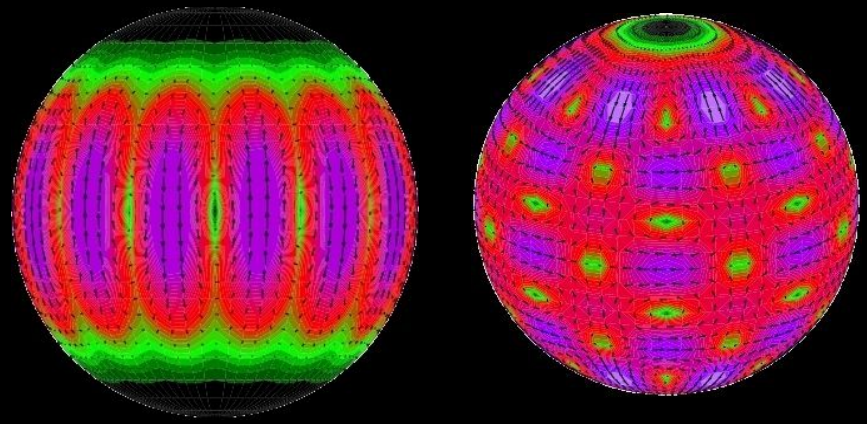
- Higher order modes (l>2, n=0):

$$P(_lt_0) = P(_2t_0)\left[\frac{6}{l(l+1)}\right]^{1/2}$$

- Correction associated with magnetic field

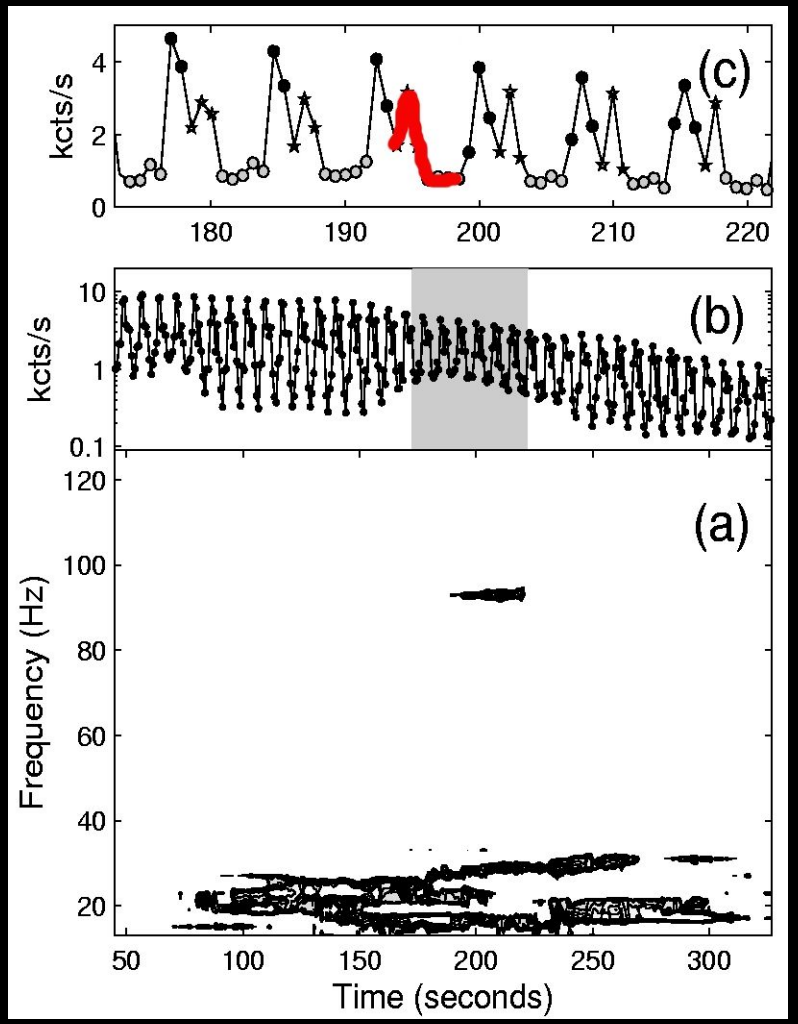
$$P_l^B \approx P(_lt_0)\left[1+\left(\frac{B}{4\times10^{15}\,G}\right)^2\right]^{-1/2}$$

- Splitting associated with m, B small
- Could modulate X-ray emission....



QPOs in the SGR 1806-20 flare

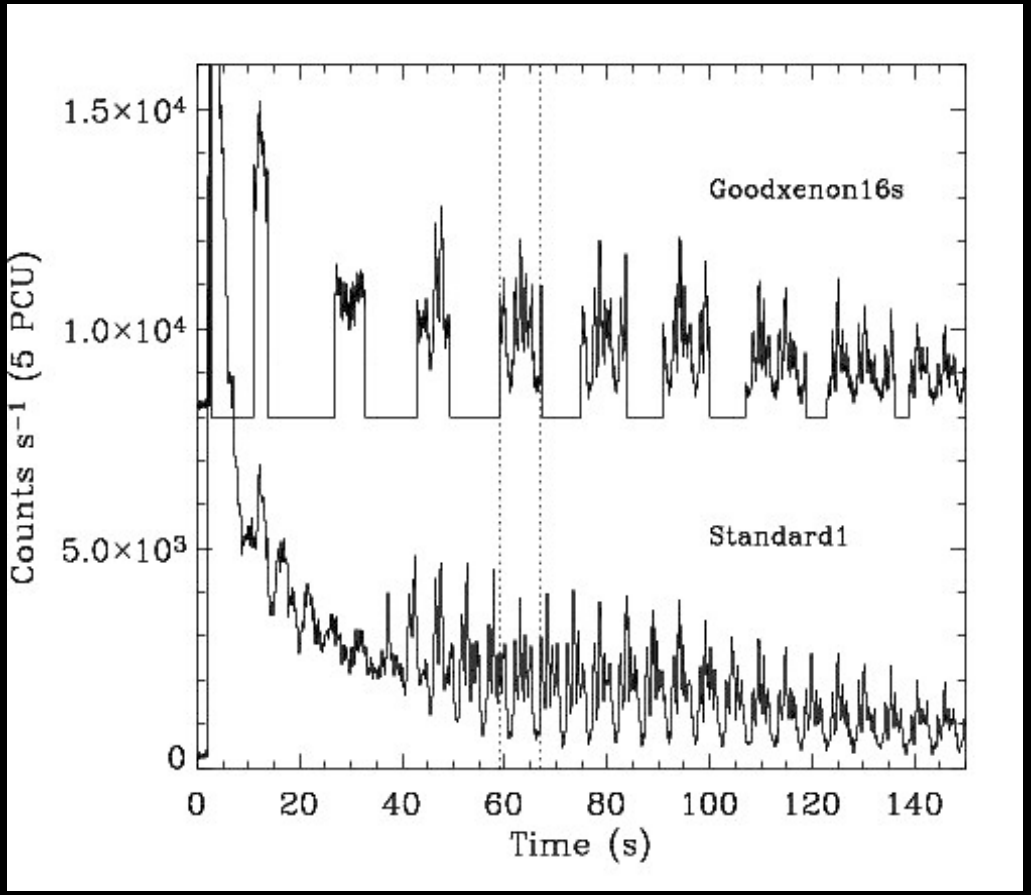
- Detected by RXTE despite being ~30º off-axis
- Israel et al. (2005) reported 92.5 Hz QPO appearing ~170s after peak, with significance better than 10^{-4}
- QPO is transient, associated with a particular rotational phase and a boost in unpulsed emission
- Weaker evidence at late times for a longer duration 30 Hz signal
- Are we seeing l=2, l=7 modes?



Israel et al. 2005

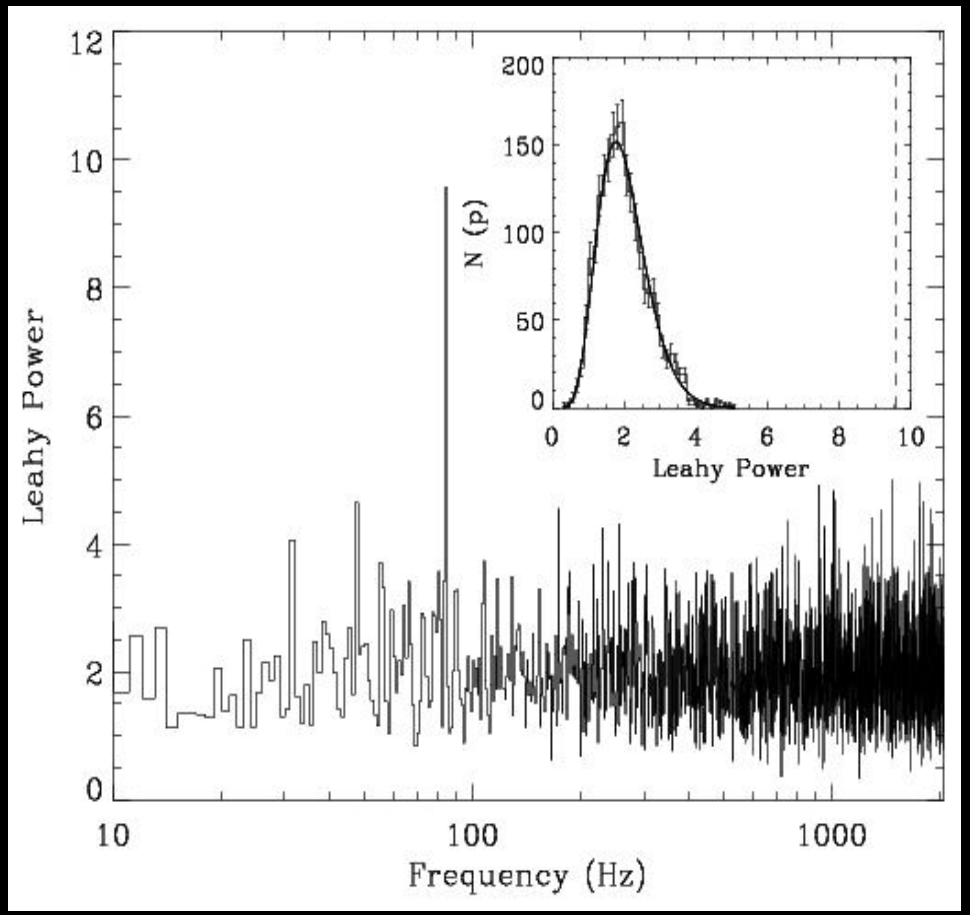
What about SGR 1900+14?

- Detected by RXTE despite being 42º off-axis
- Same high time resolution as for SGR 1806-20 (1 μs) but less frequent readout so more data gaps
- *Strohmayer & Watts, ApJ Letters in press, astro-ph/0508206*
- Started by searching each good interval separately



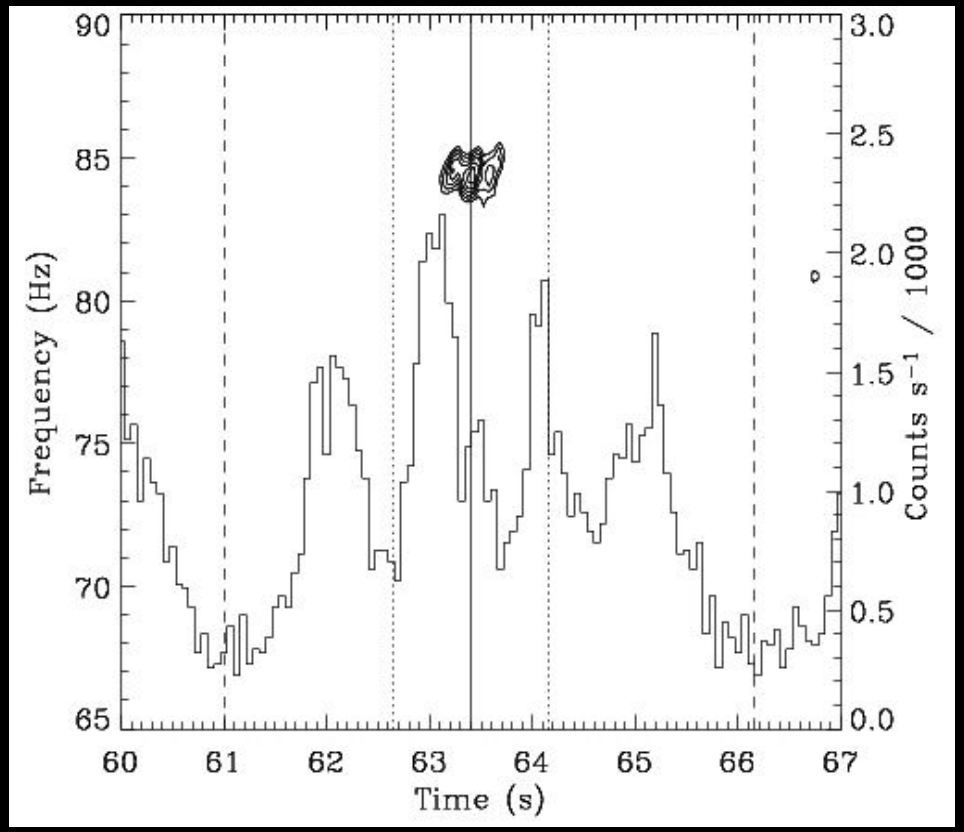
A QPO at 84 Hz (1)

- 84 Hz QPO found in the first interval after the main pulse profile emerges
- Significance of 5.6e-6 after taking into account the number of frequency bins and time intervals searched
- Transient, like the 92.5 Hz signal in SGR 1806-20
- Could it be caused by the l=6 or 7 torsional mode?



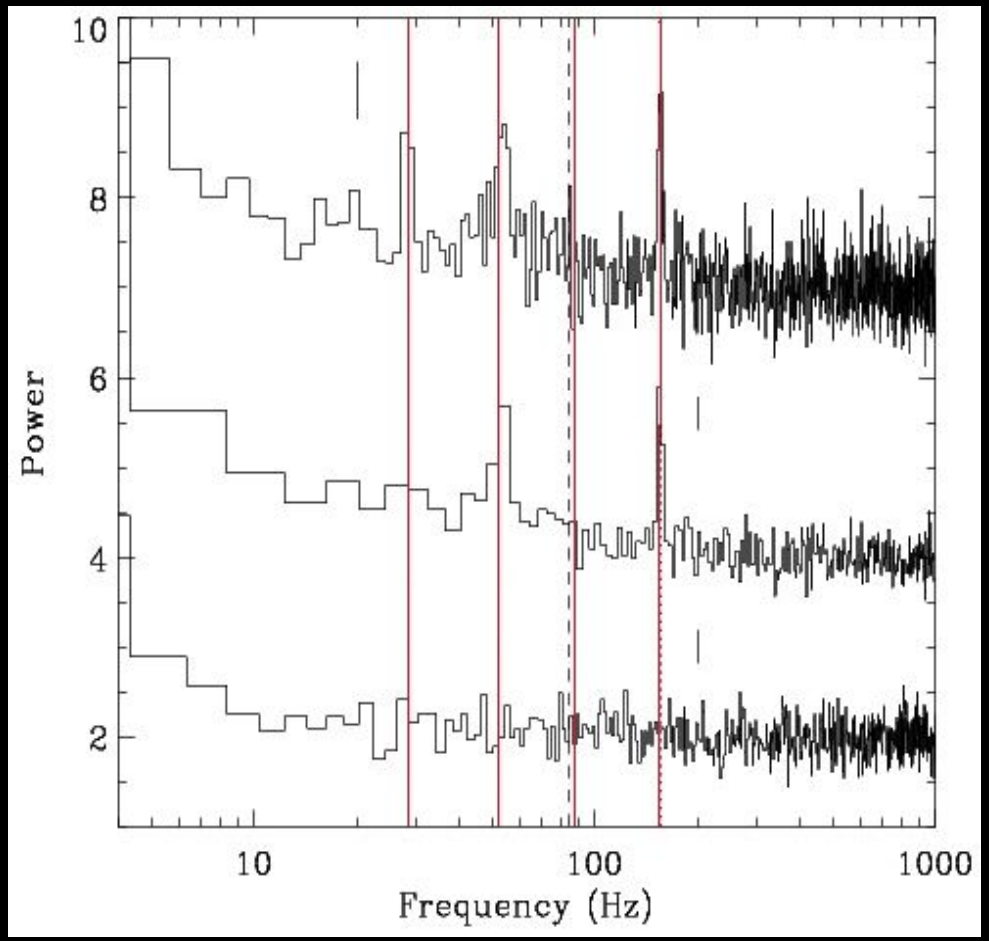
A QPO at 84 Hz (2)

- Not centered on main peak
- RMS amplitude 20 ± 3%
- No apparent boost in unpulsed emission
- No other strong transient signals in other intervals – but what about weaker longer duration signals?
- Compute average power spectra using ALL intervals, centered on rotational phase where 84 Hz signal is seen

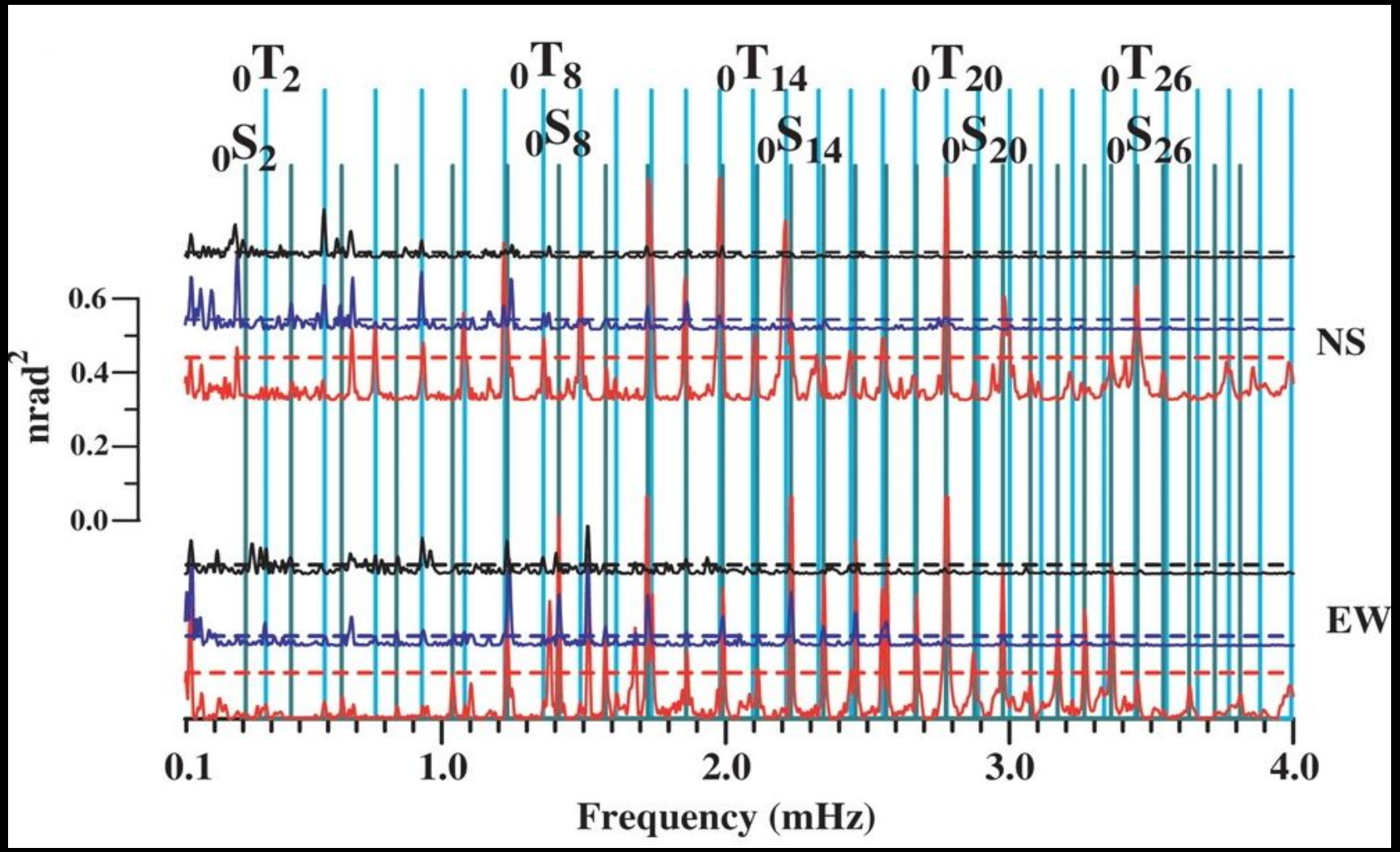


A mode sequence?

- Find additional significant QPOs at 53 and 155 Hz
- Possibly also at 28 Hz, but this is tentative
- No evidence for QPOs at other rotational phases
- Implies phenomena are associated with a particular area of the surface or magnetic field bundle
- Fits a mode sequence with l=2, 4, 7 and 13!



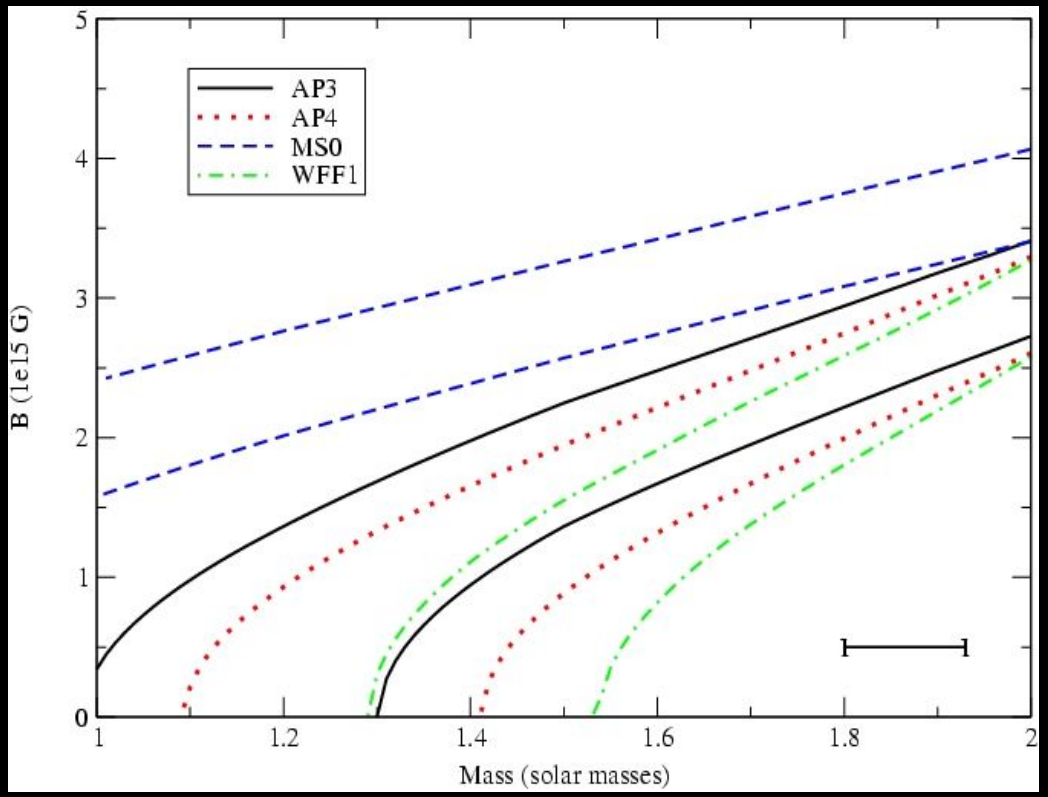
An aside on excitation



Park et al, 2005

Can we constrain NS properties?

- Mode frequencies depend on M, R and crustal field B
- Different fundamental frequencies imply stellar parameters must differ
- Unless masses differ significantly, SGR 1806-20 has higher magnetic field
- Highest masses and hardest EOS require fields higher than those inferred from timing
- Can softest EOS be ruled out?



Upper line: SGR 1806-20, 30.4 Hz
Lower line: SGR 1900+14, 28 Hz

Conclusions - and a lot of questions

- The discovery of a sequence of QPOs with the right scaling is strong evidence that we are seeing the influence of global crustal modes on X-ray emission
- This could constrain NS properties including the EOS
- Can we improve the data?
- More theoretical development also required:
  - How do the modes modulate X-ray emission?
  - How are modes excited and damped? What sets the different timescales observed?
  - Can you constrain crustal breaking strain? (IMPORTANT FOR GRAVITATIONAL WAVES AND NS PRECESSION!)
  - What is the effect of field configuration (Messios et al. 2001)?
  - Are there other modes that would fit?