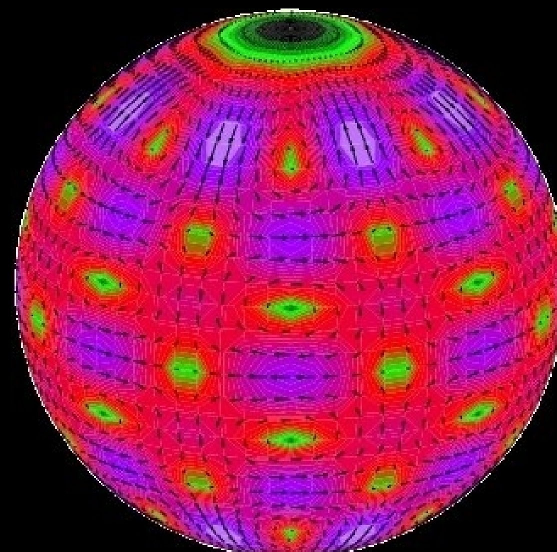
HIGH FREQUENCY OSCILLATIONS DURING MAGNETAR FLARES



EVIDENCE FOR NEUTRON STAR VIBRATIONS

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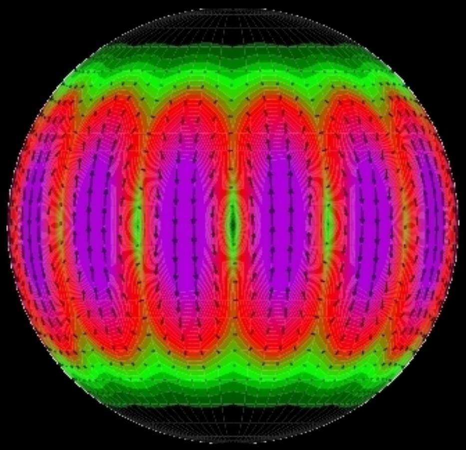
Hyperflares and starquakes

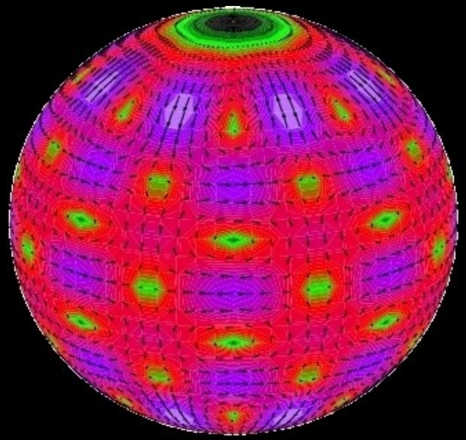
Chilean earthquake, 1960
Image by Pierre St. Amand

- Hyperflares occur when the decaying magnetic field reaches a point of catastrophic instability, leading to a global reconfiguration
- Light curves show a short hard flash, and a softer decaying tail due to a 'trapped fireball' modulated by the star's rotation
- Likely to be associated with large-scale fracturing of the stellar crust
- On Earth, major crust fractures trigger global seismic oscillations

Crustal shear modes

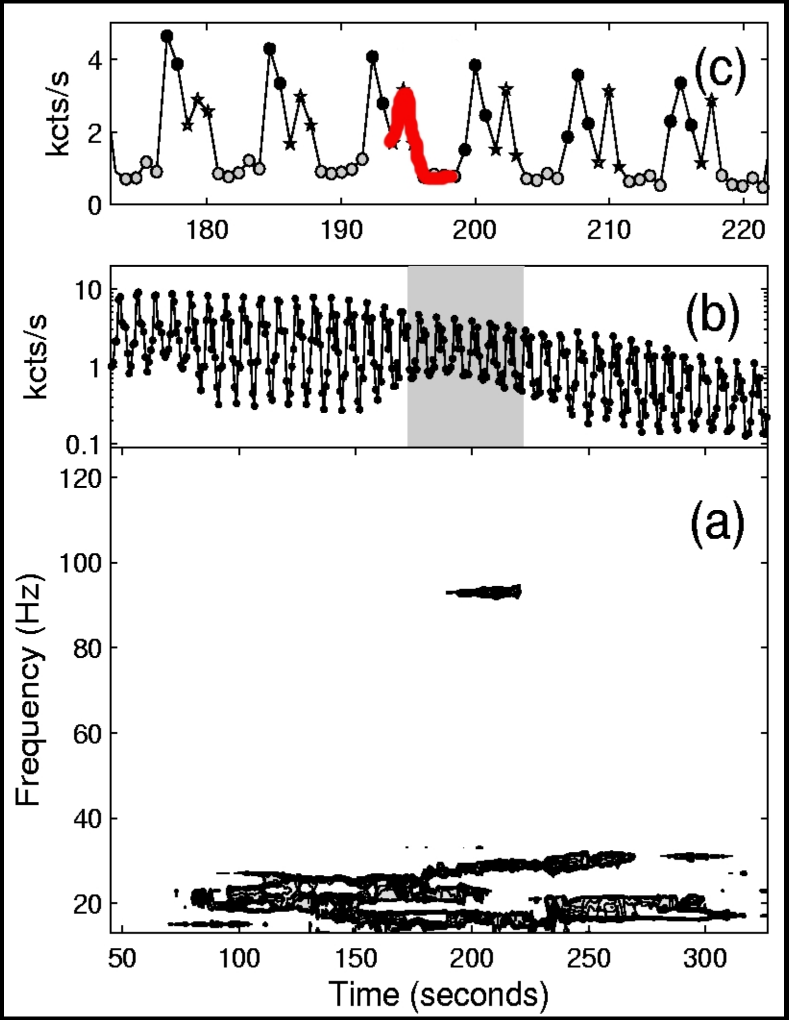
- Various different types of mode possible
- Neutron star crust models suggest that the easiest to excite should be the toroidal (shear) modes
- Mode frequency depends on neutron star mass, radius, crustal composition and magnetic field
- Harmonics excited would depend on nature of fracture
- Crust is coupled to the field, so modes should modulate the X-ray lightcurve





SGR 1806-20: QPOs revealed

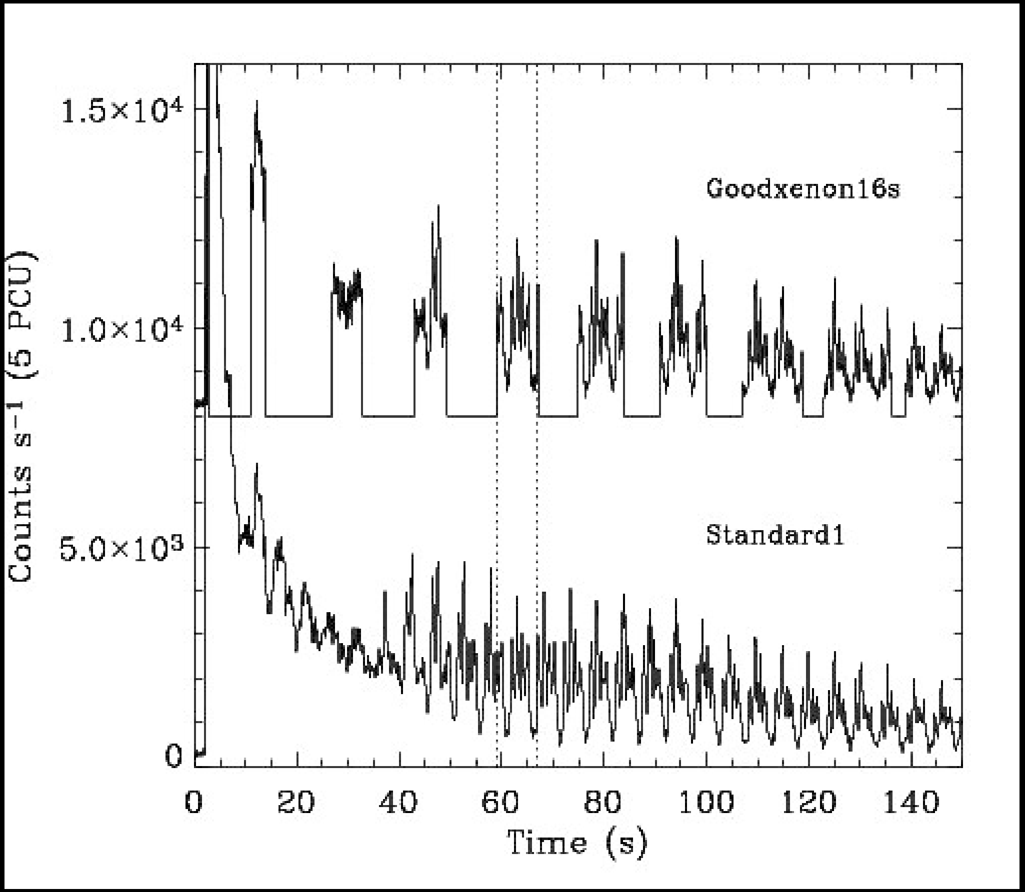
- December 27th 2004 - SGR 1806-20 emits the brightest flare ever recorded. Detected by RXTE and a host of other satellites.
- Israel et al. (2005) find a strong 92.5 Hz QPO appearing ~170s after peak.
- QPO is transient, associated with a particular rotational phase and a boost in unpulsed emission
- Weaker evidence at late times for 18 and 30 Hz signals
- The 30 Hz and 92.5 Hz QPOs could be l=2, l=7 toroidal modes



Israel et al. 2005

SGR 1900+14: a mode sequence?

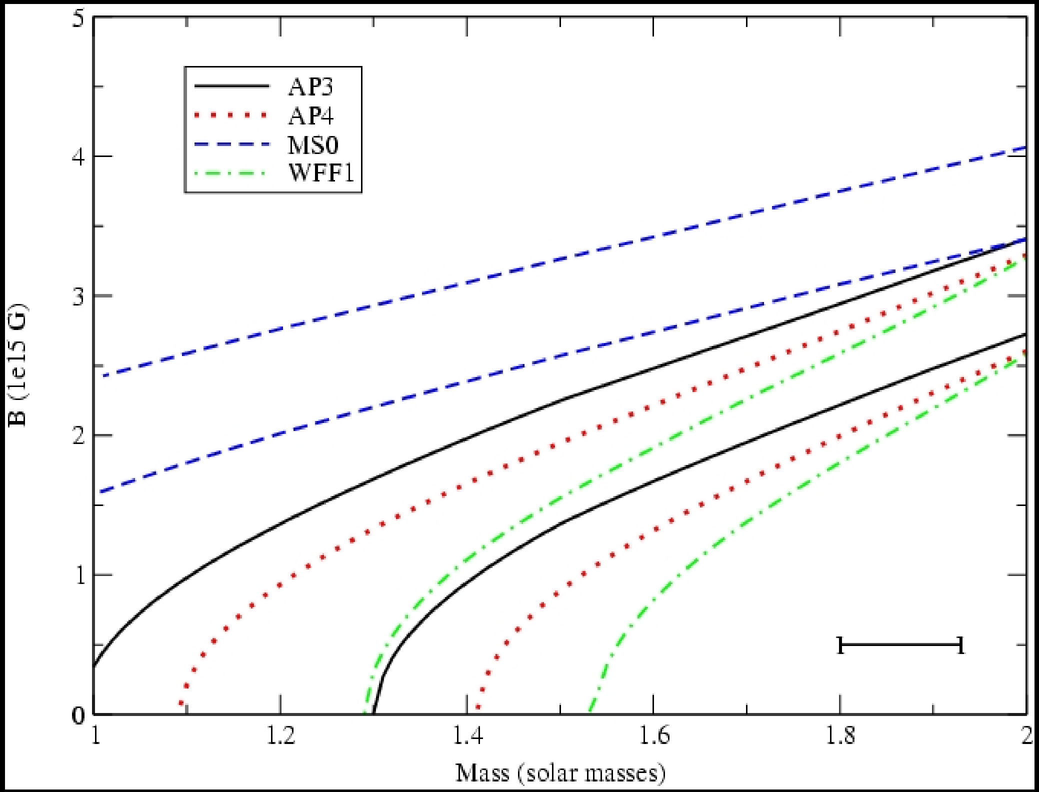
- August 27th 1998: Giant flare from SGR 1900+14 detected by RXTE, albeit with data gaps.
- Strong transient 84 Hz QPO
- Folding up data from the same rotational phase we find additional QPOs at 28, 53 and 155 Hz
- Fits a sequence of l=2, 4, 7 and 13 toroidal modes



Strohmayer & Watts, 2005

Constraining NS properties

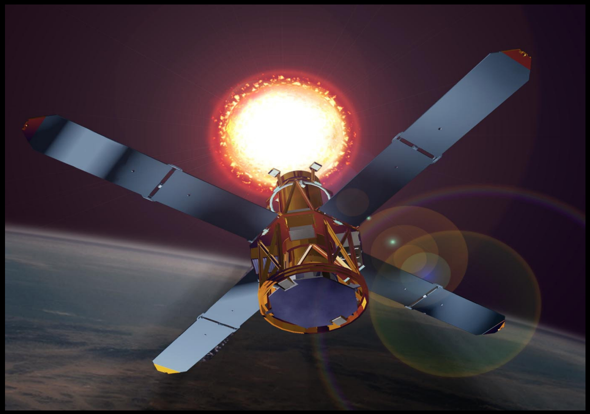
- Mode frequencies depend on M, R and crustal field B
- Mode sequence permits identification of fundamental frequency. Different values imply stellar parameters differ.
- Unless masses differ significantly, SGR 1806-20 has higher magnetic field
- Highest masses and hardest EOS require fields higher than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



Upper line: SGR 1806-20
Lower line: SGR 1900+14

RHESSI observes SGR 1806-20

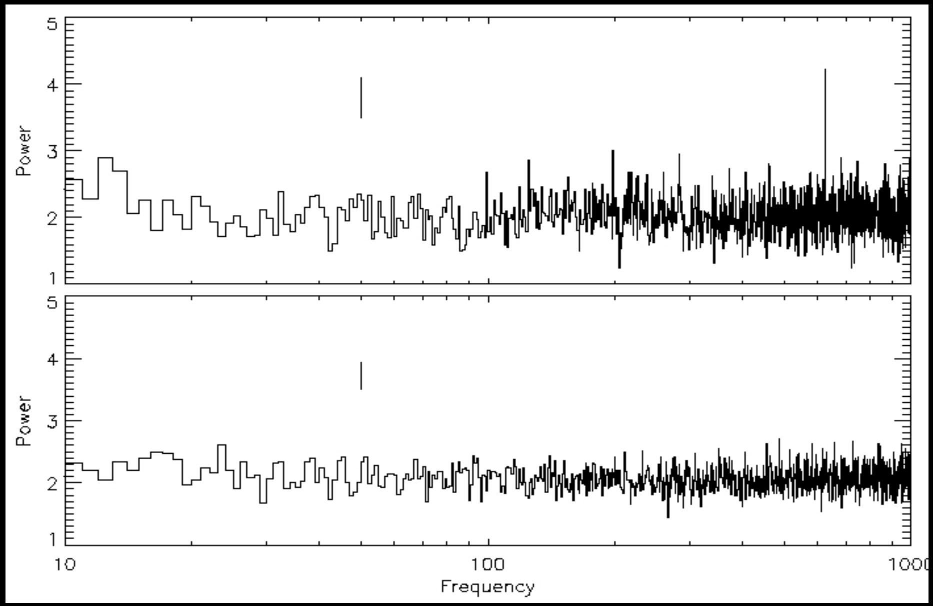
- High time resolution data, going to higher energies than RXTE
- Segmented detectors: albedo flux affects time resolution of rear segments, but when these are included countrate higher than RXTE

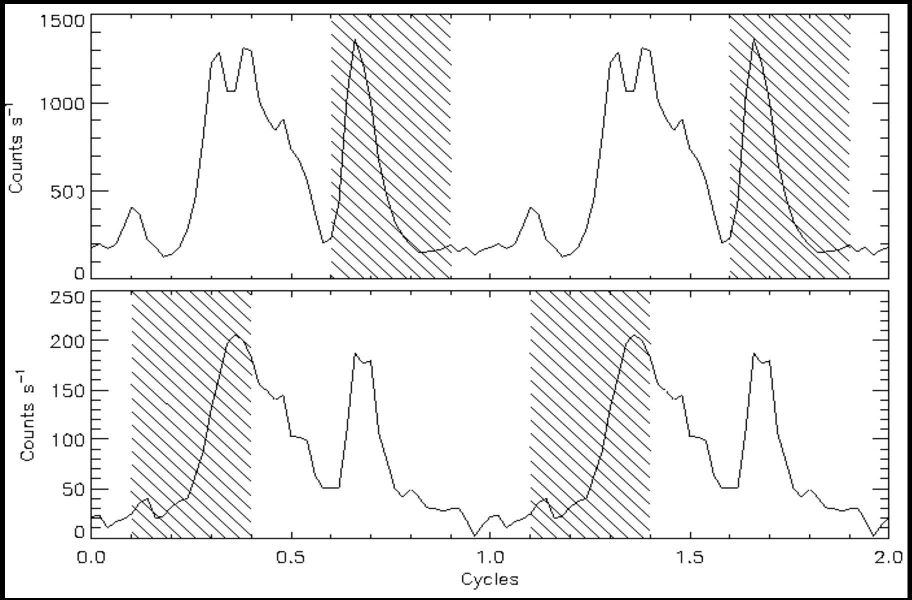


- 92.5 Hz QPO: RXTE detection confirmed, at same time and phase
- Low frequency QPOs
  - Broad QPOs at 18 Hz and 26 Hz from 50-200s after the main flare, at the same rotational phase as the 92.5 Hz QPO
  - There is also a weaker feature at 30 Hz, but it is not at the 3 sigma level after accounting for number of trials

Discovery of a 626 Hz QPO

- Compared to the 92.5 Hz QPO
  - Higher energy band
  - Emerges earlier
  - Rotational phase differs



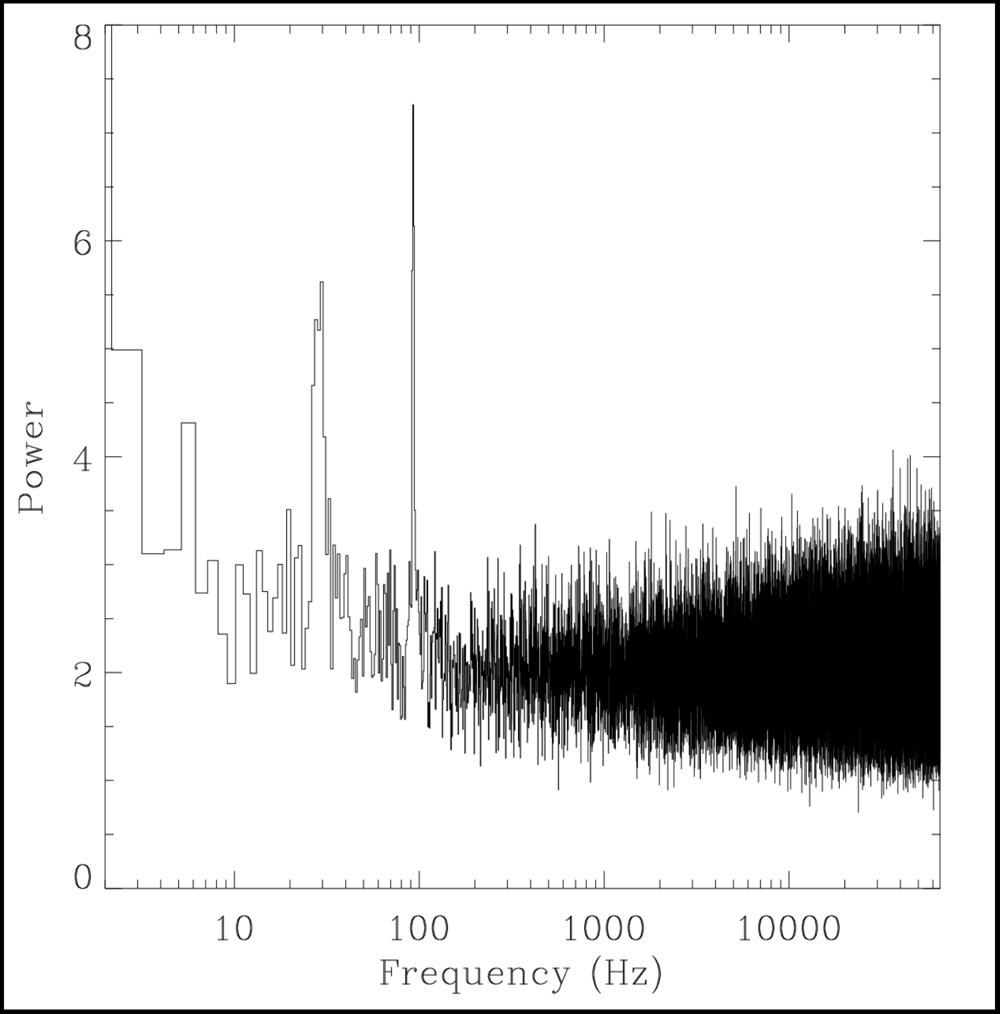


Watts & Strohmayer, 2006

- Could this be a higher radial overtone toroidal mode?
- If so, it should reveal fracture depth and crust thickness!

RXTE: Low frequency QPOs

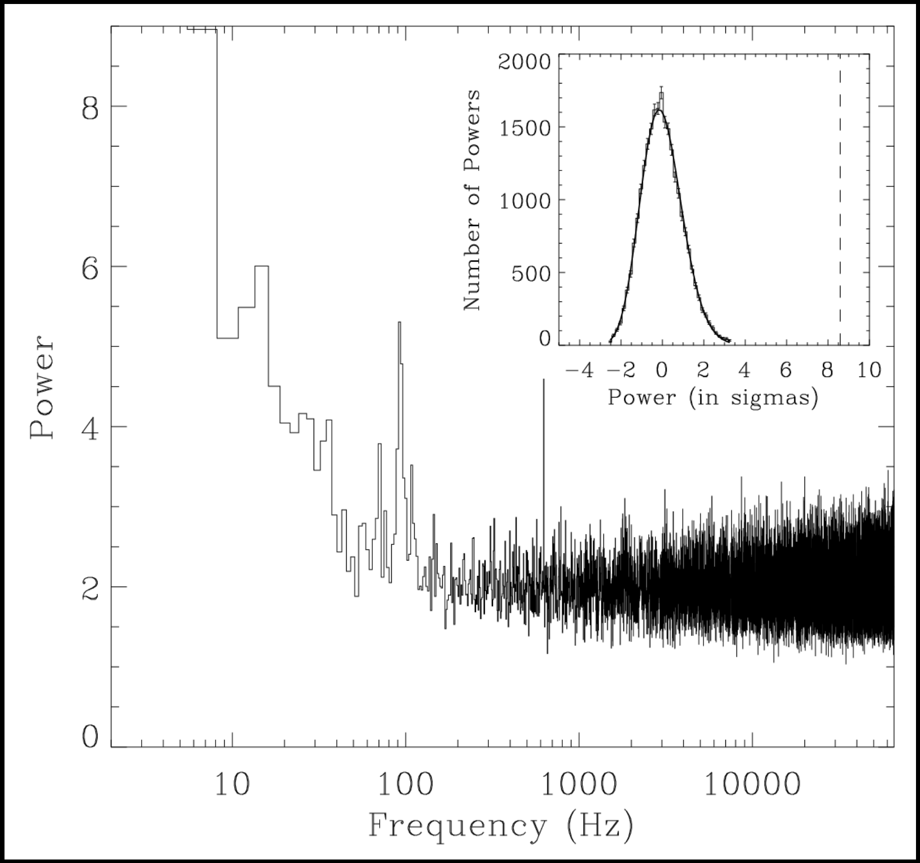
- At times when the 18 and 26 Hz QPOs are particularly strong in the RHESSI dataset they are also detected in the RXTE data – confirming the frequencies and the rotational phase dependence
- Further analysis of 30 Hz QPO
  - Confirmed detection reported by Israel et al.
  - QPO is strongly rotational phase dependent
  - Closer analysis reveals why RHESSI feature is weaker



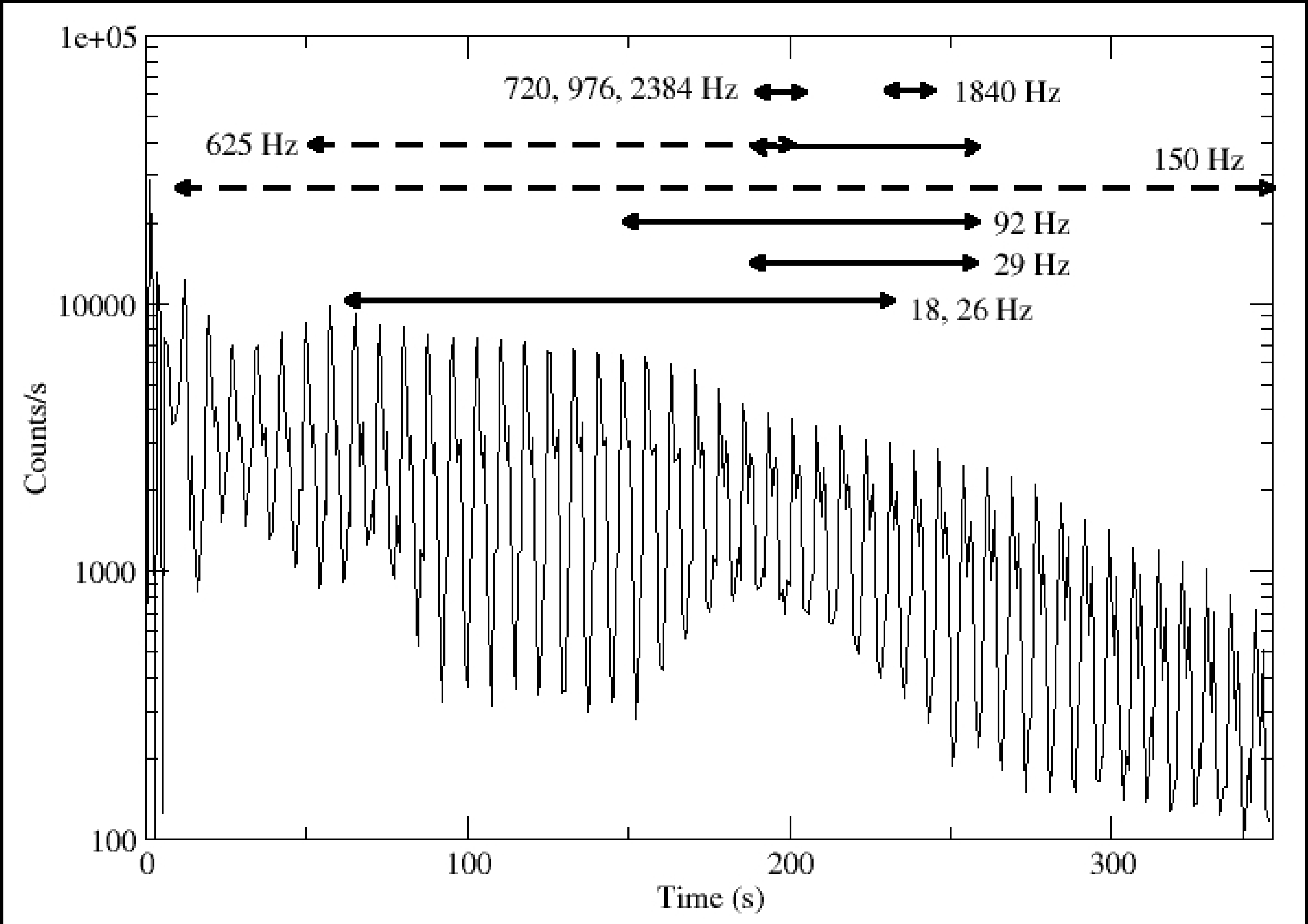
Strohmayer & Watts, in preparation

RXTE: High frequency QPOs

- Rotational phase dependent analysis reveals additional QPOs at 150 Hz, 1840 Hz, and - most excitingly - at 625 Hz!
- Compared to the RHESSI 626 Hz QPO: lower fractional amplitude, lower coherence, later, lower energy and different phase
- Evolution of the RHESSI QPO? Or perhaps two different n=1 toroidal modes (Piro 2005)?
- Either way we can estimate crust thickness: ~0.1 times NS radius



Evolution over the flare



Conclusions

- RHESSI observations have confirmed the early RXTE results, revealed new lower frequency signals, and provided the first evidence for higher radial overtones
- Phase-dependent analysis of the RXTE data confirms the lower frequencies and provides new evidence for higher frequencies
- Detection of 30, 90, and 150 Hz signals in hyperflares from SGRs 1806-20 and 1900+14 suggests same process operating
- Rotational phase dependence of ALL signals implies surface process
- Detection of 625 Hz signal in both data sets allows direct estimate of crust thickness
- Outstanding issues: lightcurve modulation; interpretation of frequencies that do not 'fit'; excitation and damping; frequency/amplitude variation.....