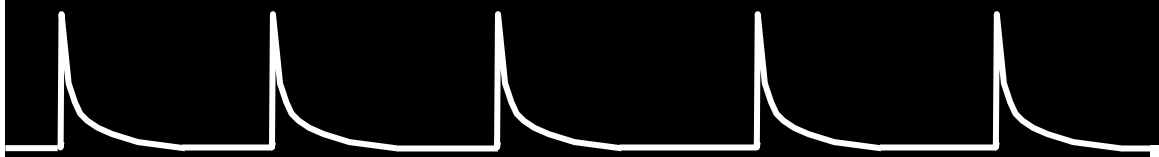
A 552 Hz Burst Oscillation in EXO 0748-676



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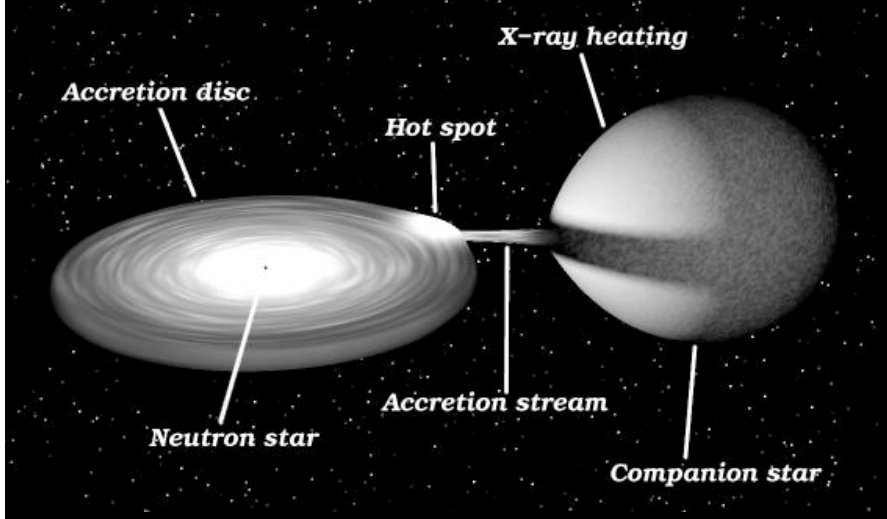
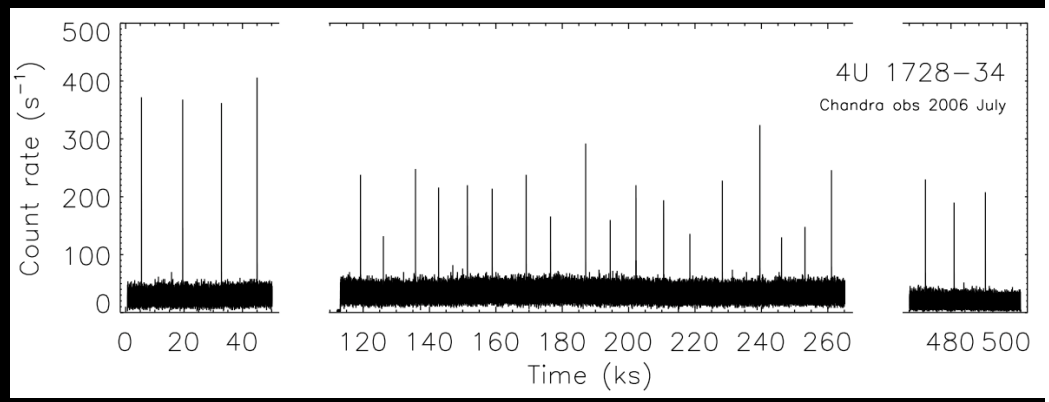
Thermonuclear (type-I) X-ray bursts

- Thermonuclear (type-I) X-ray bursts occur in neutron stars accreting from low-mass binary companions; ~90 bursters known



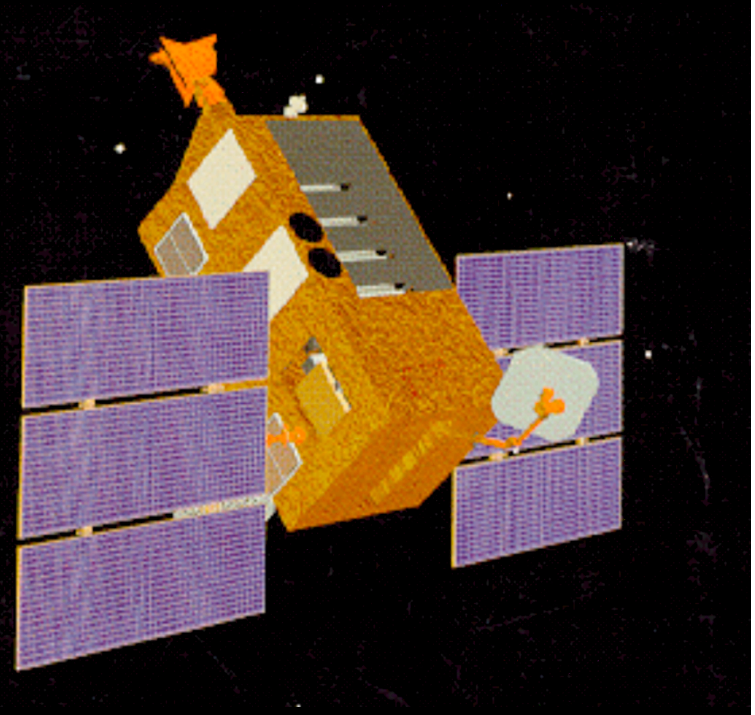


- Understood since the `80s as resulting from unstable ignition of accreted H/He on the NS surface (e.g. Fujimoto et al. 1981, ApJ 247, 267)

Neutron star spin measurements

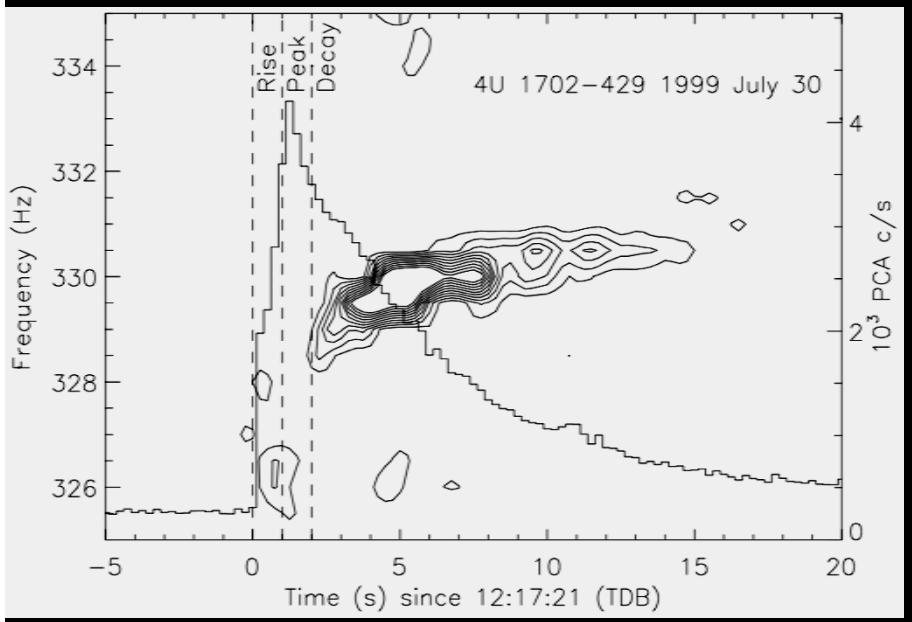
- Requires timing precision of <1ms, and high effective area
- Such capability has been available since the 1995 launch of NASA's *Rossi X-ray Timing Explorer*
- Success soon after launch with detection of 363 Hz oscillations during thermonuclear bursts from 4U 1728-34

  (Strohmayer et al. 1996, ApJL 469, L9)
- Could this be the spin frequency?



Nuclear-powered pulsations?

- Other detections soon followed; these “burst oscillations” were always found at the same frequency for each source, and only in bursts, but not in every one
- Highly coherent, although small (~1Hz) frequency drifts while present



- Seen to date in ~14 sources, at frequencies of ~200-600 Hz
- Possible link with kHz QPOs, also seen in burst sources

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Accretion-powered pulsations

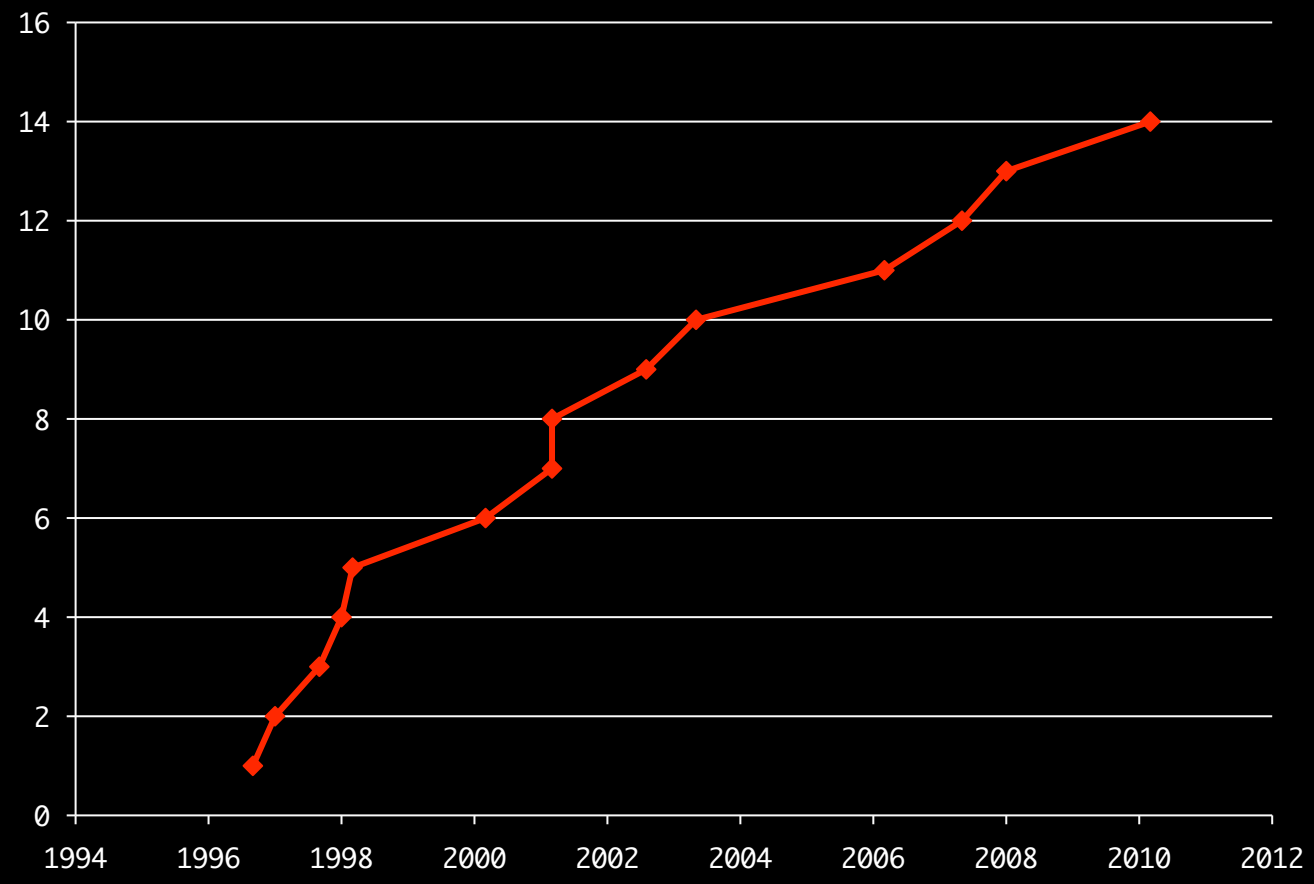
- Confirmation that the burst oscillation frequency was almost certainly the spin frequency came with the detection of burst oscillations at the spin frequency of SAX J1808.4–3658

  (Chakrabarty et al. 2003, Nature, 424, 42)
- These *accretion-powered pulsars*, of which there are now 10, are transients discovered during bright outbursts
- Since then, we have also detected 3 systems with *intermittent* pulsations in their persistent flux; with burst oscillations at the same frequency (where detected)

  (e.g. Galloway et al. 2007, ApJ 654, 73)

Increasingly scarce oscillations

- Discovery rate has slowed somewhat in recent years



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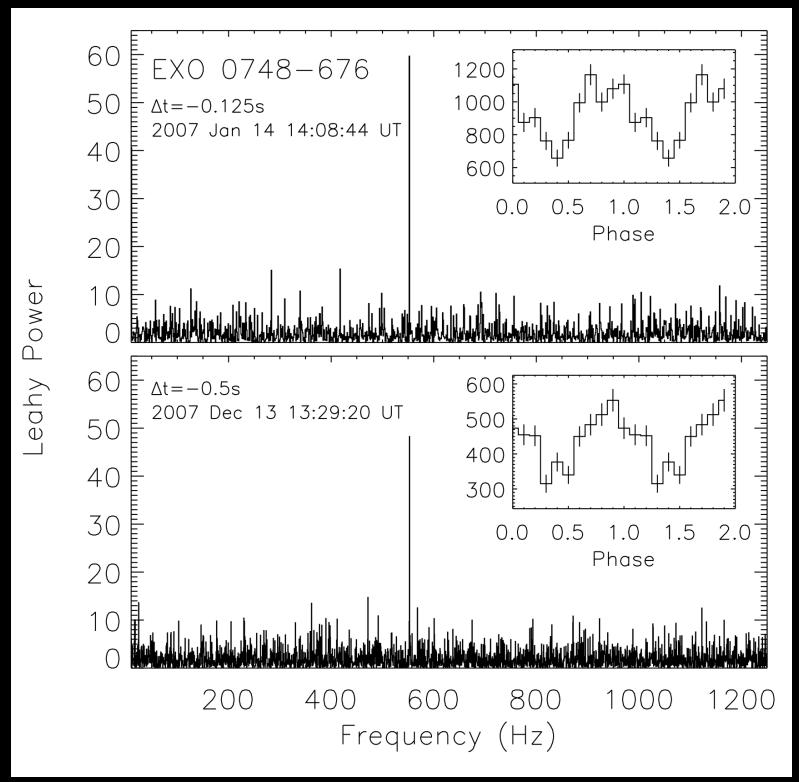
The latest detection: EXO 0748–676

- A blind search for burst oscillations in bursts from this system revealed two detections at 552 Hz, in bursts separated by ~11 months (Galloway et al., 2010, ApJ 711, 148)



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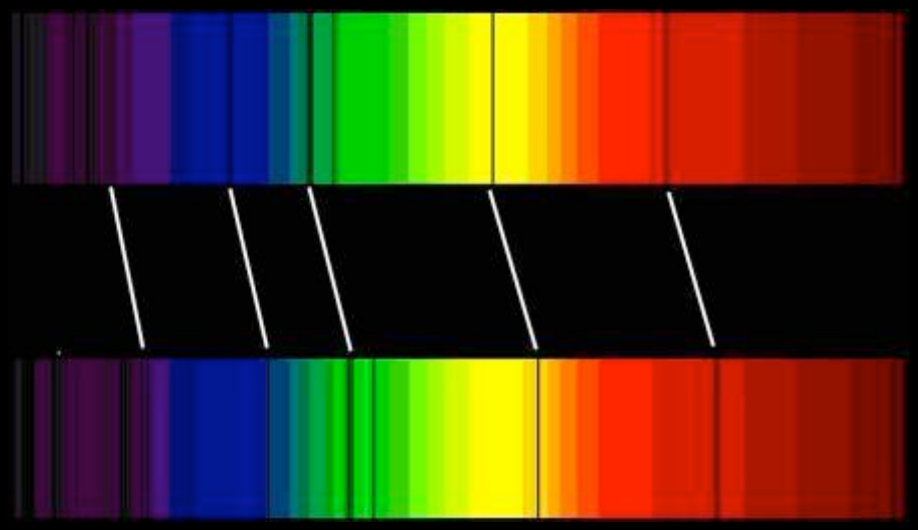
- Probability for two noise peaks this strong, at virtually the same frequency, is $\sim 10^{-10}$
- This is the *second* detection in this system; previously at 45 Hz!

Not just your average LMXB

- EXO 0748-676 is also the only system which has shown (in an *XMM-Newton* spectrum) evidence for *redshifted absorption lines* arising from the neutron star surface (Cottam et al. 2002, Nature 420, 51)
- This allows us to measure the *gravitational redshift*, and constrain the neutron star EOS; a long-sought result for LMXBs!



$$\begin{aligned} z &= \Delta\lambda/\lambda \\ &= \left(1 - \frac{2GM}{Rc^2}\right)^{-1/2} - 1 \end{aligned}$$

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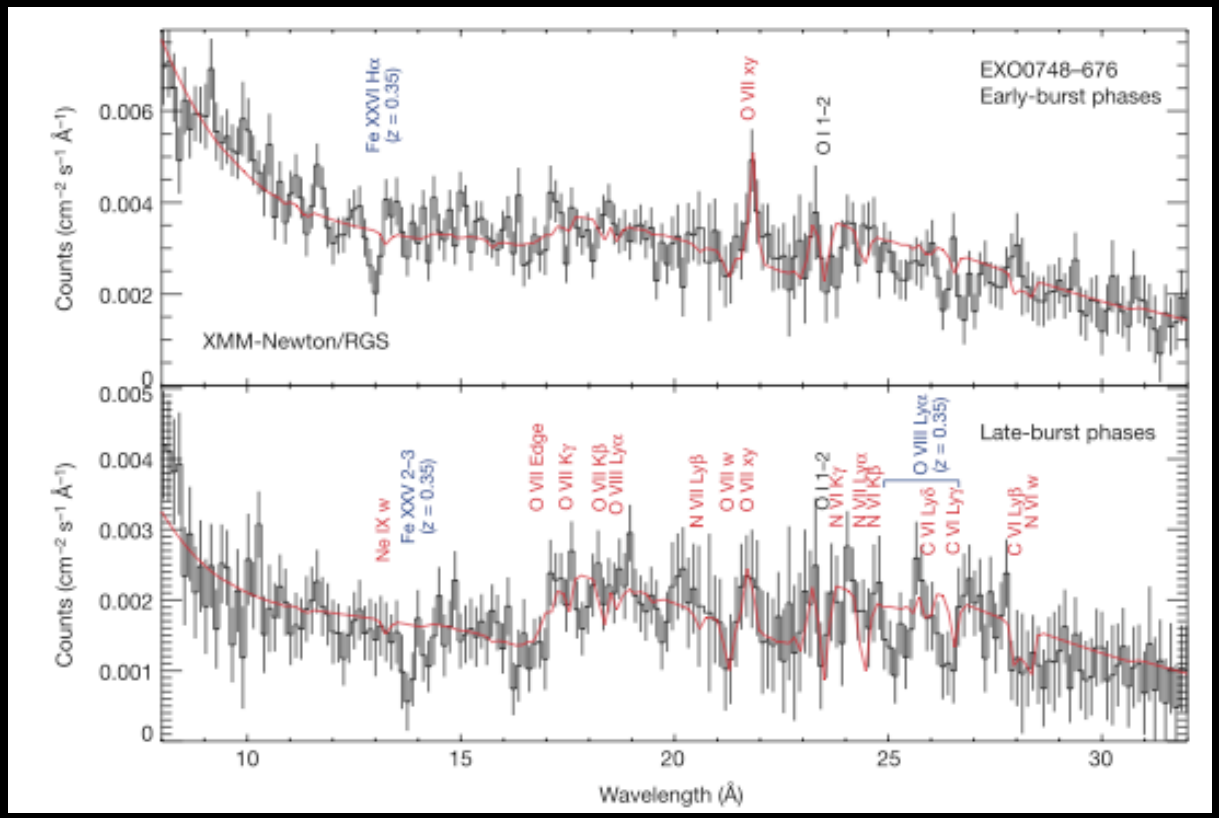
The *XMM-Newton* spectral lines

- The lines are narrow, which requires *slow rotation*; subsequent detection of 45 Hz oscillations appeared to support the detection (Villarreal & Strohmayer 2004, ApJL 614, L121)



- Much excitement and theoretical work on what we can learn from lines in LMXBs followed…

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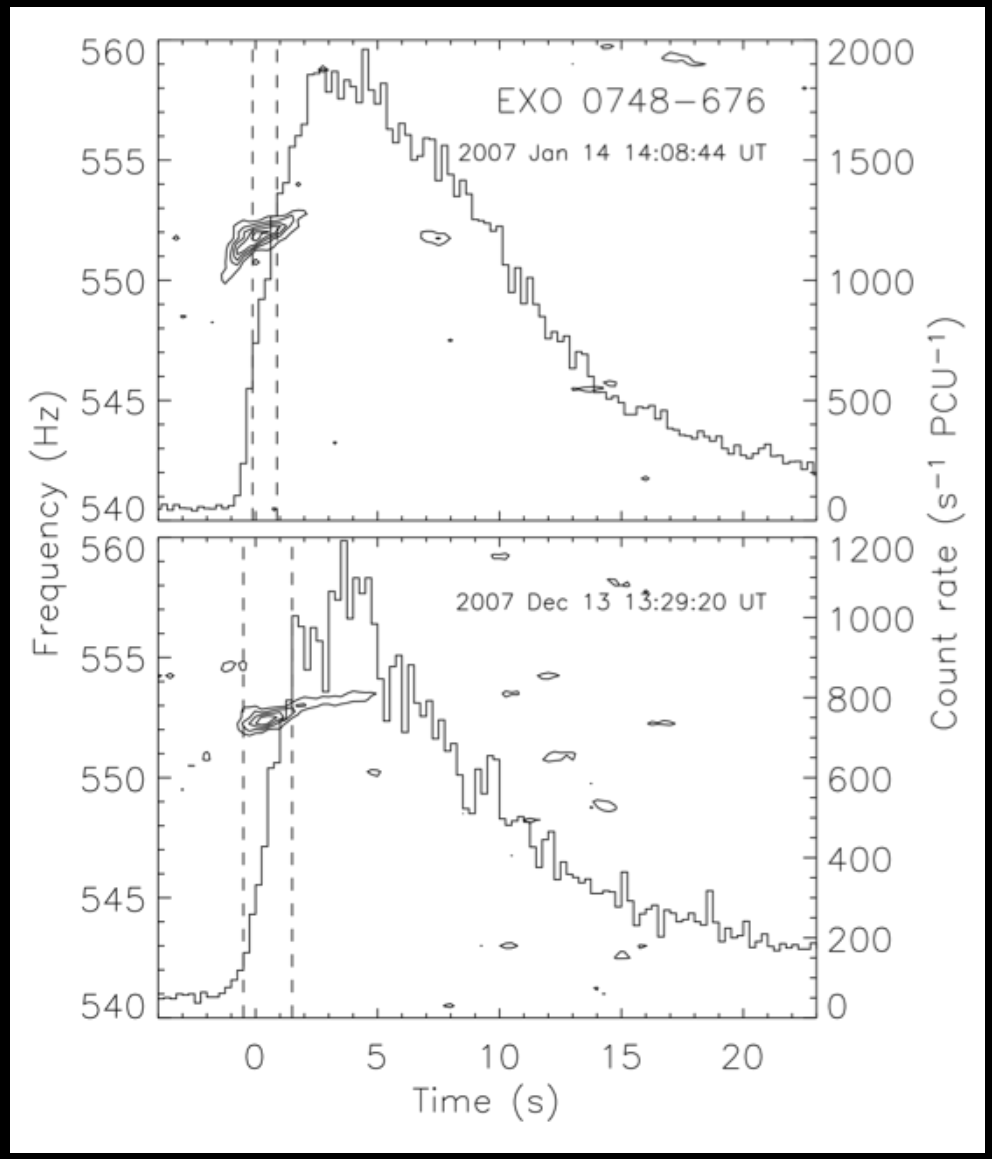
So which is the spin frequency?



- The 45 Hz signal was detected in summed FFTs of 38 bursts, and is not detected in a larger sample of ~160 bursts accumulated since
- In contrast, the 552 Hz signal was detected in individual bursts (although only 2 of them)

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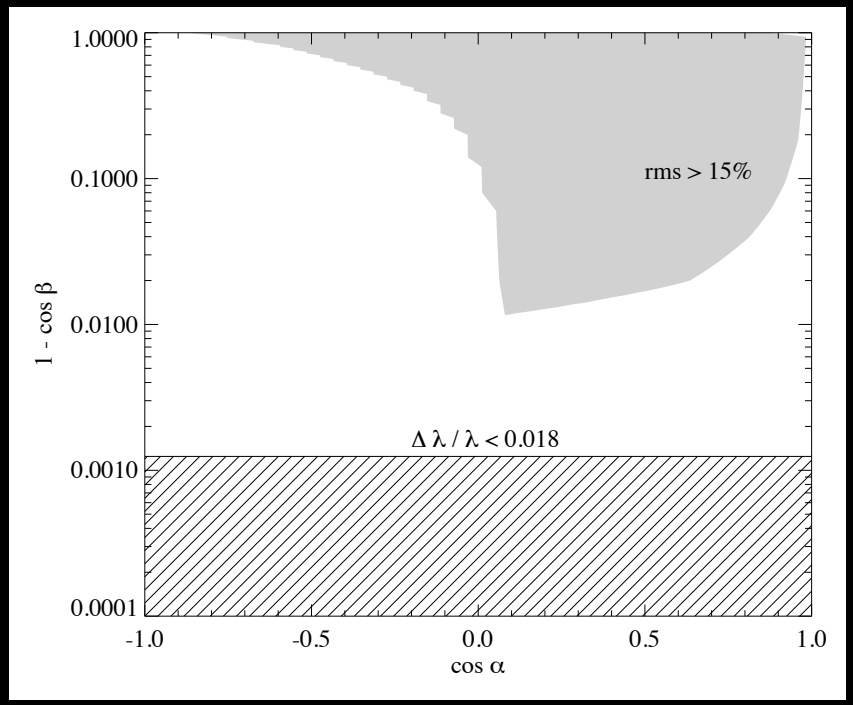
Revisiting the sum FFT search

- Villarreal et al. 2004 detected the 45 Hz signal in summed, rebinned FFTs over 38 bursts
- There are now ~160 bursts in the *RXTE* sample, so we carried out equivalent analysis on the larger sample…
- … without success
- Perhaps the 45 Hz signal only appears from bursts in a particular (low) flux state? A second search for a subset of the bursts matching this cut…
- … was also unsuccessful
- However we could confirm the original result

A disappointing conclusion

- The 552 Hz signal more closely resembles other burst oscillations
- Thus we conclude that the spin in EXO 0748-676 is likely 552 Hz, meaning that the narrow spectral lines *could not have arisen at the neutron star surface*
- Confirmed by Lin et al. (arXiv:1007.1451)
- No self-consistent solutions for ν_{spin}=552 Hz that can produce narrow lines and ~15% burst oscillation amplitude



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Summary

- EXO 0748-676 spin frequency is almost certainly ~552 Hz
- The origin of the lines remains a mystery; further observations of the source failed to detect them (Cottam et al. 2008, ApJ 672, 504)
- The origin of the 45 Hz signal also unexplained; could it be a boundary layer oscillation? (ATel #2097)
- Scarcity of the oscillations in the bursts suggests perhaps that all systems exhibit burst oscillations, most just extremely rarely?