Pushing the limit on neutron star spin rates

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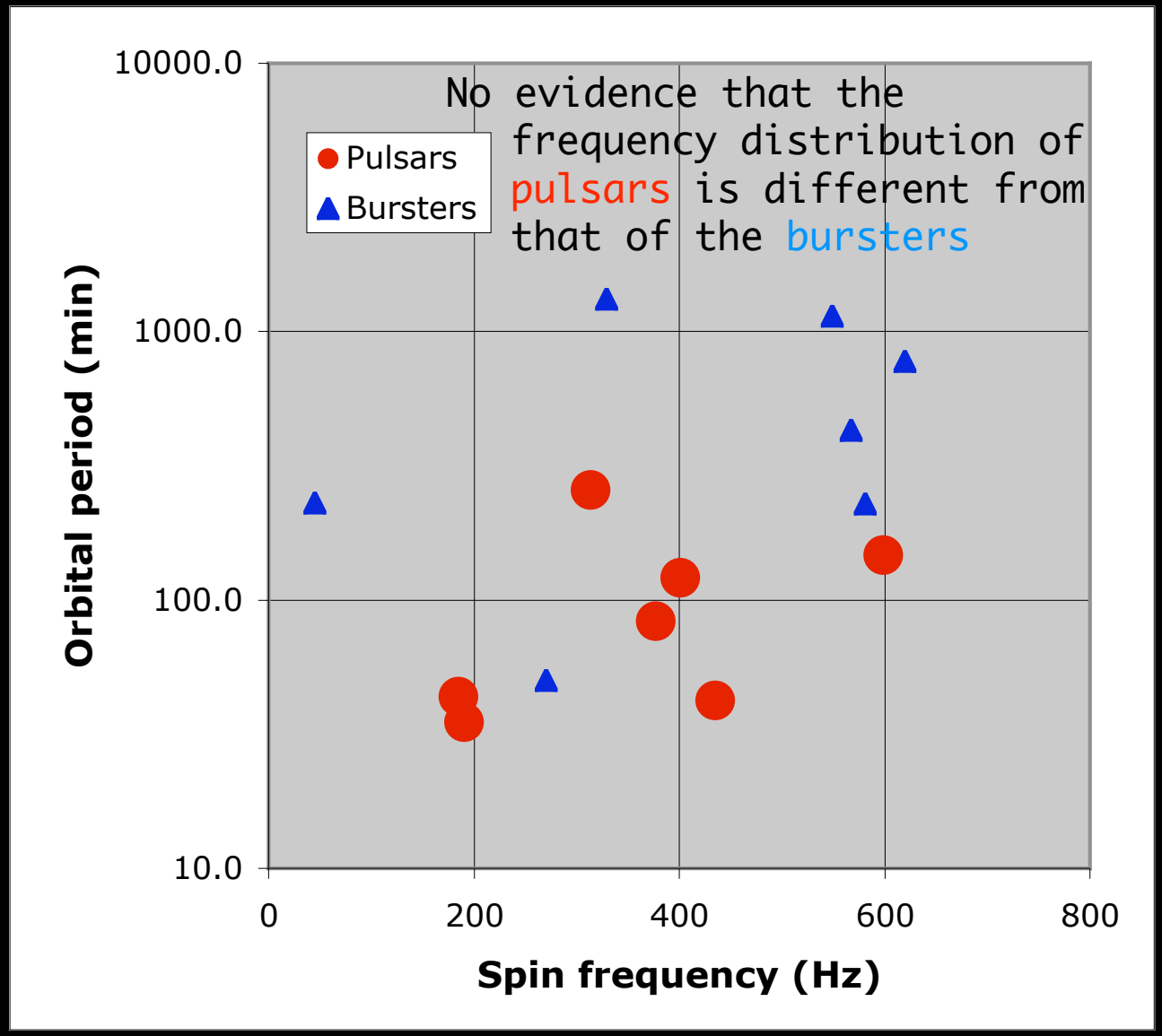
Low-mass X-ray binaries

- Neutron stars with low-mass binary companions have orbital periods of a few hours, and characteristically exhibit bursts from thermonuclear ignition of accreted material on the surface
- Precursors to the millisecond radio pulsars, which are thought to have been spun-up by an extended period of accretion
- ~100 LMXBs known; most do not pulse persistently, although since 1996 some have been found to exhibit burst oscillations in the range 40-620 Hz
- Since 1998, a growing subset of *accretion-powered millisecond pulsars* do exhibit pulsations, although we don't know *why*
- Two sources show pulsations at the same frequency as burst oscillations, confirming that the latter trace the NS spin

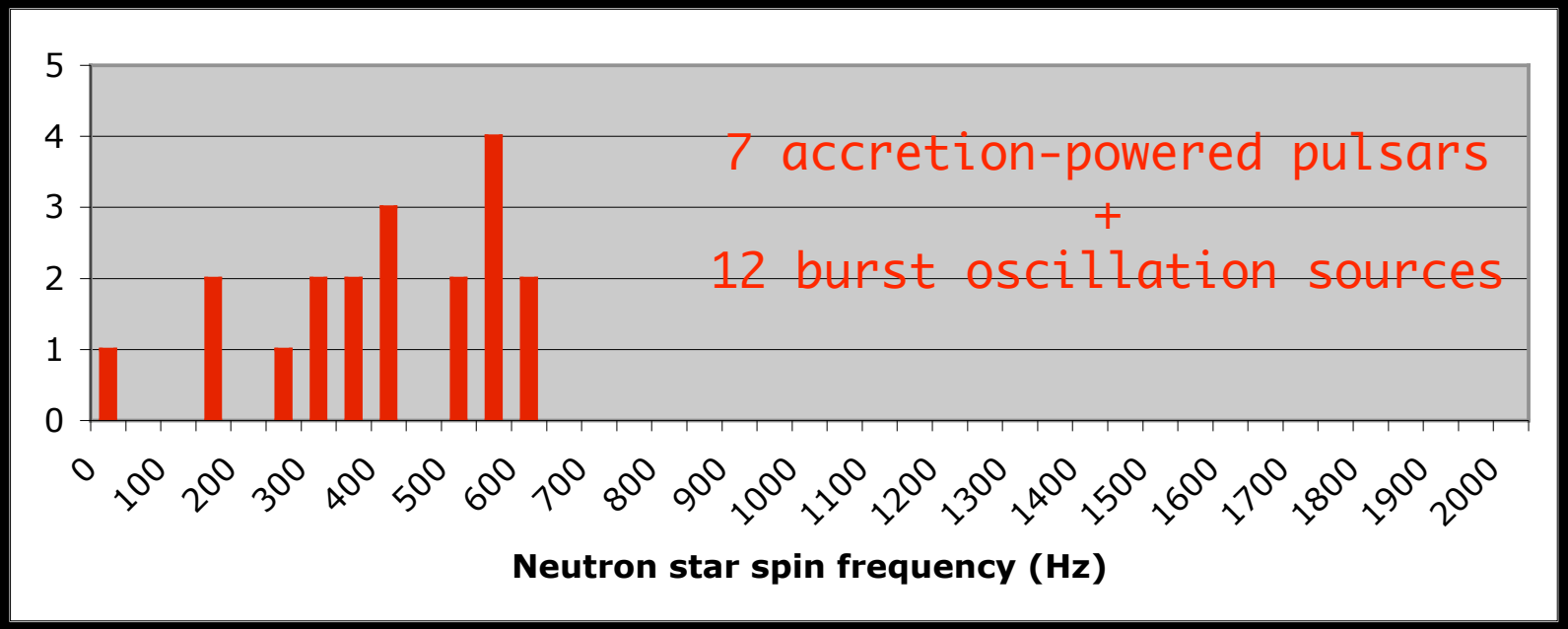
Classes of LMXBs

Type	Pulsations	Orbital period?	F_X
Accretion-powered millisecond pulsar (7)	Always (except for HETE J1900.1-2455)	Yes, Doppler modulation	Transient $<10^{-9}$ ergs cm^{-2} s^{-1}
Burst oscillation "atoll" source (12)	Only during bursts; also kHz QPOs	Optical photometry/spectro-scopy	Moderate Few 10^{-9} ergs cm^{-2} s^{-1}
Twin kHz QPOs (e.g. Sco X-1) "Z-source"	No; but kHz QPOs may be present	Optical photometry/spectro-scopy	High $\sim 10^{-8}$ ergs cm^{-2} s^{-1}

Accreting NS with known P_{spin}, P_{orb}



Evidence for gravitational radiation

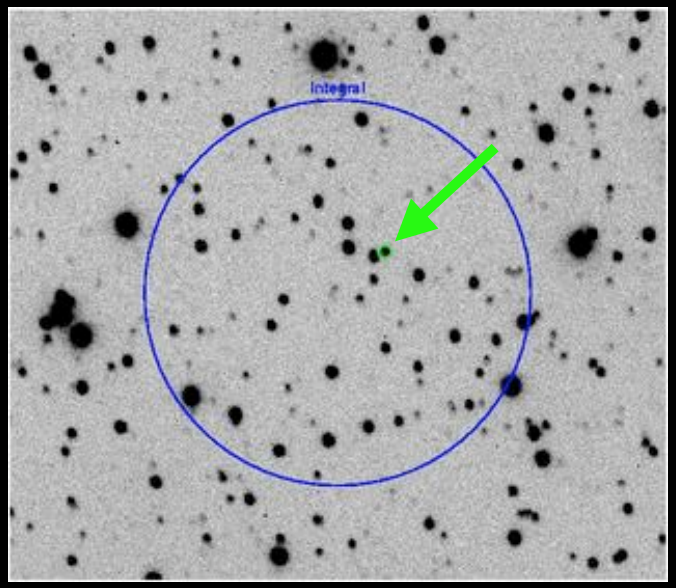


- A Bayesian analysis suggests that the spin frequency is limited to 760 Hz (95% confidence; Chakrabarty et al. 2003)
- Several have suggested that gravitational radiation from a non-spherical neutron star might limit the maximum frequency (amplitude $\propto f^6$; e.g. Bildsten et al. 1998)

-> detection by Advanced LIGO?

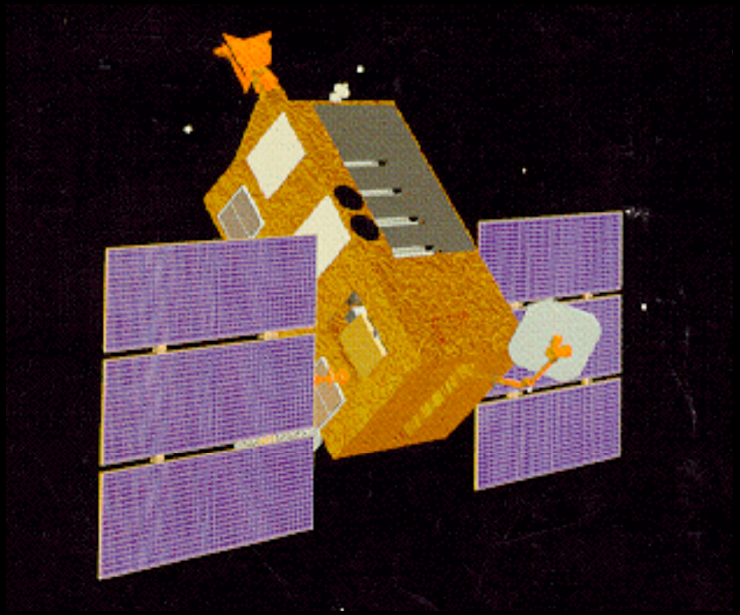
Case study: IGR J00291+5934

- Discovered 2004 December 2 with IBIS/ISGRI and JEM-X aboard *INTEGRAL* (Eckert et al., ATel #352; see also Shaw et al. '05)
- *R*~17.4 optical counterpart (Fox et al., ATel #354). Rapidly fading with e-folding time 5.7 d (Bikmaev et al., ATel #395)
- IR magnitudes J=16.8, H=16.8, K=16.1 (Steeghs et al., ATel #363); IR excess compared to disk model?
- Spectroscopic observations show weak He & Hα lines (Roelofs et al., ATel #356)
- Fading radio counterpart <1mJy @ 5, 15 GHz (ATels #355, 361, 364)



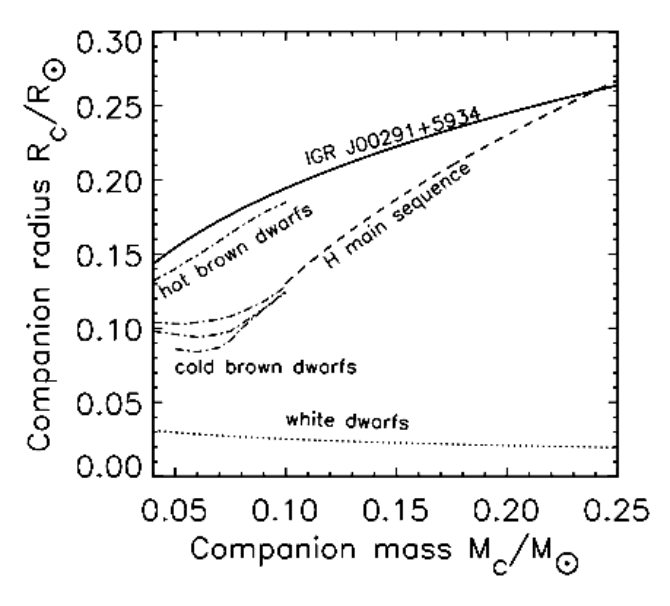
Pulse timing with *RXTE*: f_0 = 598.89 Hz

Fastest accretion-powered pulsar … but not the fastest spinning NS (641 Hz) or even the fastest NS in an LMXB (620 Hz)

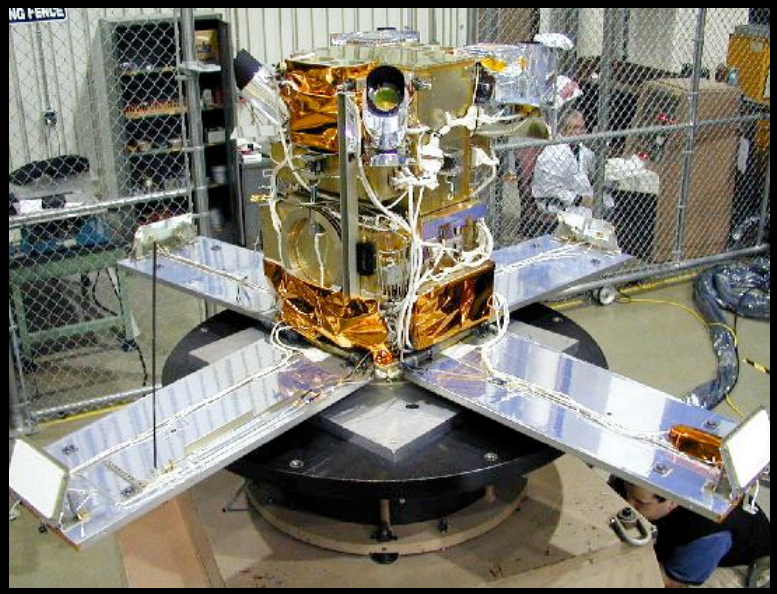


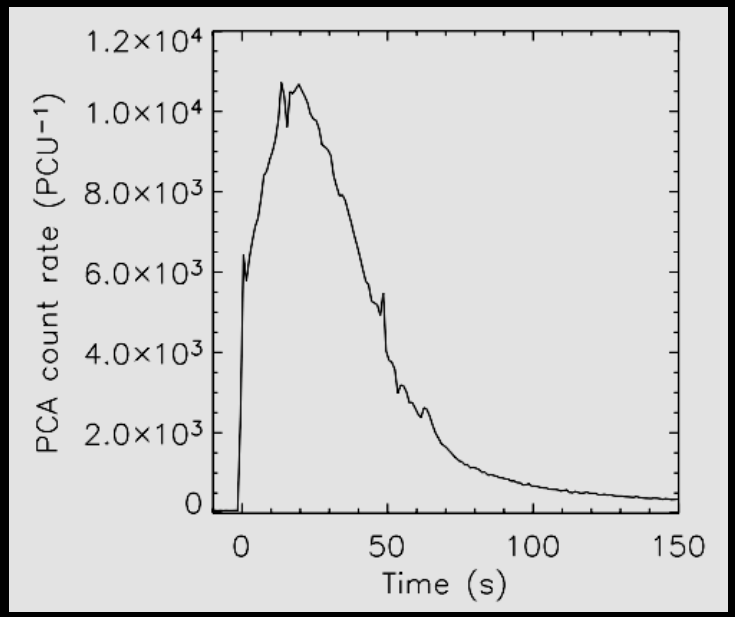
- Two previous outbursts detected retro-actively by *RXTE*/ASM; recurrence time 3 yr
- P_{orb}=2.46 hr
- Mass fn. $f_X = 2.8\times10^{-5}\ M_\odot$
- Mass donor is likely a brown dwarf ($M>0.039\ M_\odot$) heated by low-level X-ray emission during quiescence

(Galloway et al. 2005, ApJ 622, 45L)



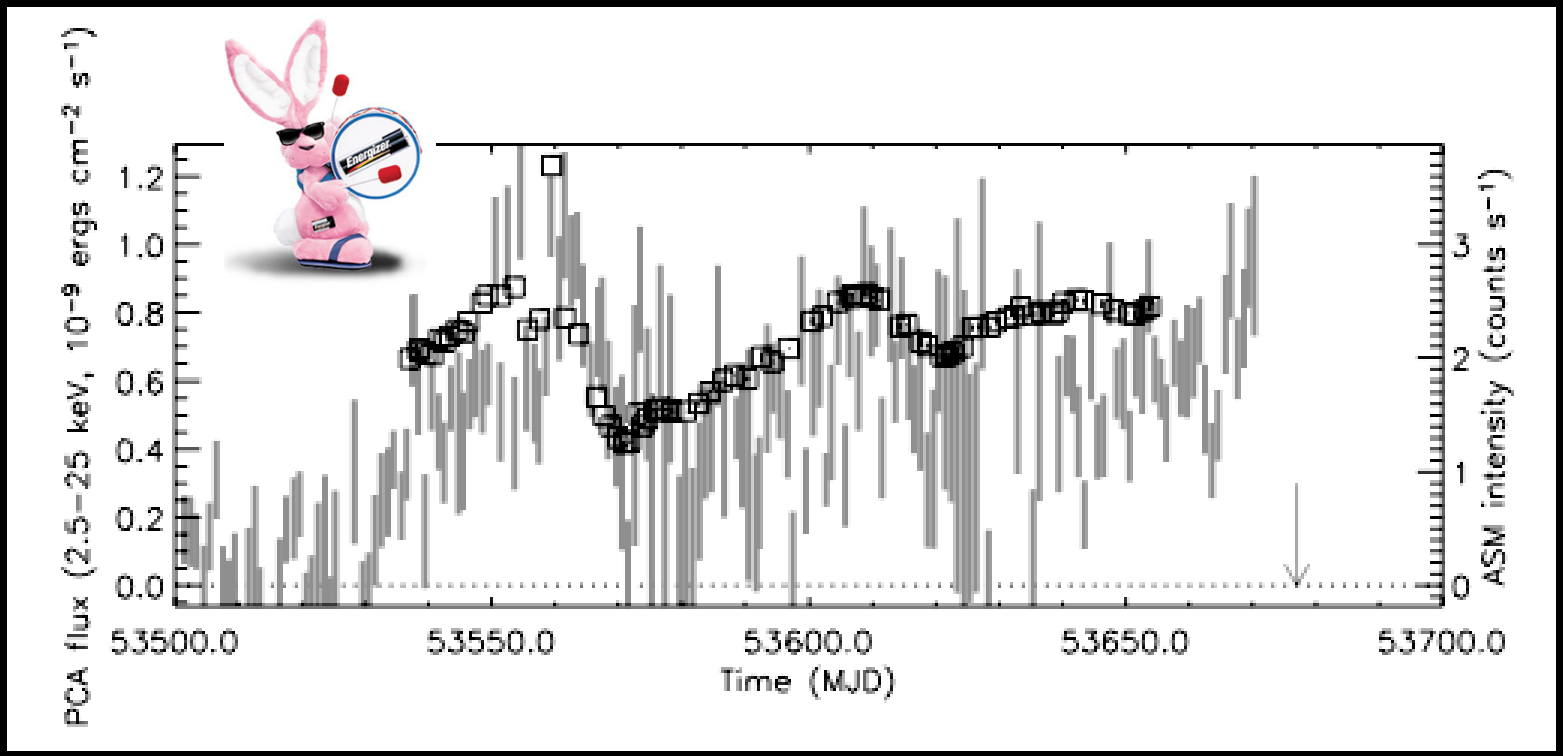
Breaking news: HETE J1900.1-2455





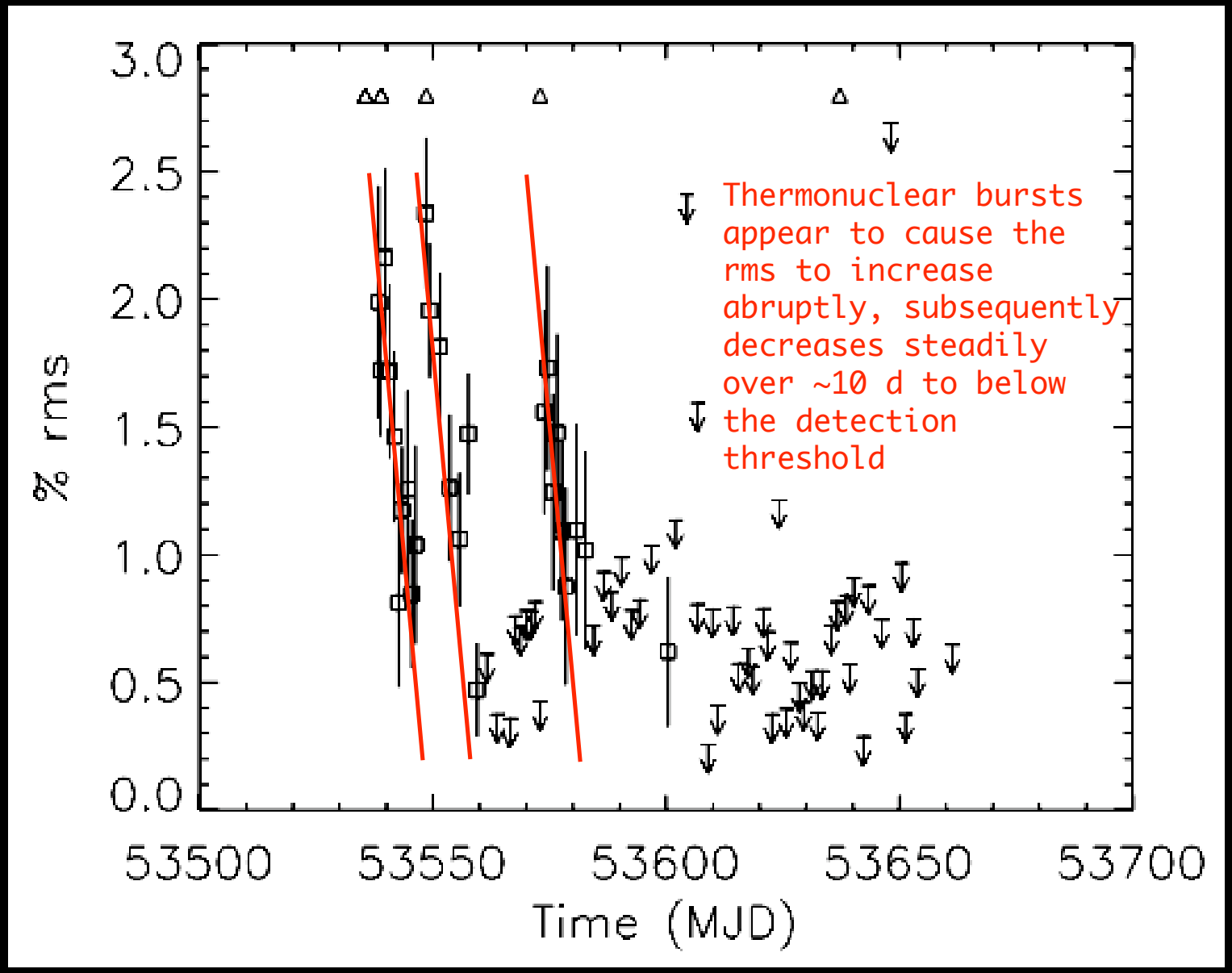
- A thermonuclear burst from this source detected by MIT's *HETE-2* satellite on 14 June 2005 (ATel #516).
- Subsequent PCA observations revealed 377.3 Hz pulsations and Doppler variations from an 83.3 min orbit (ATel #523, 538; Kaaret et al., submitted)
- *R* ~ 18.4 optical counterpart detected with the Robotic Palomar 60" telescope (Fox, ATel #526)
- Estimated distance from the peak flux of the burst is 5 kpc

The “energizer bunny” of the AMSPs

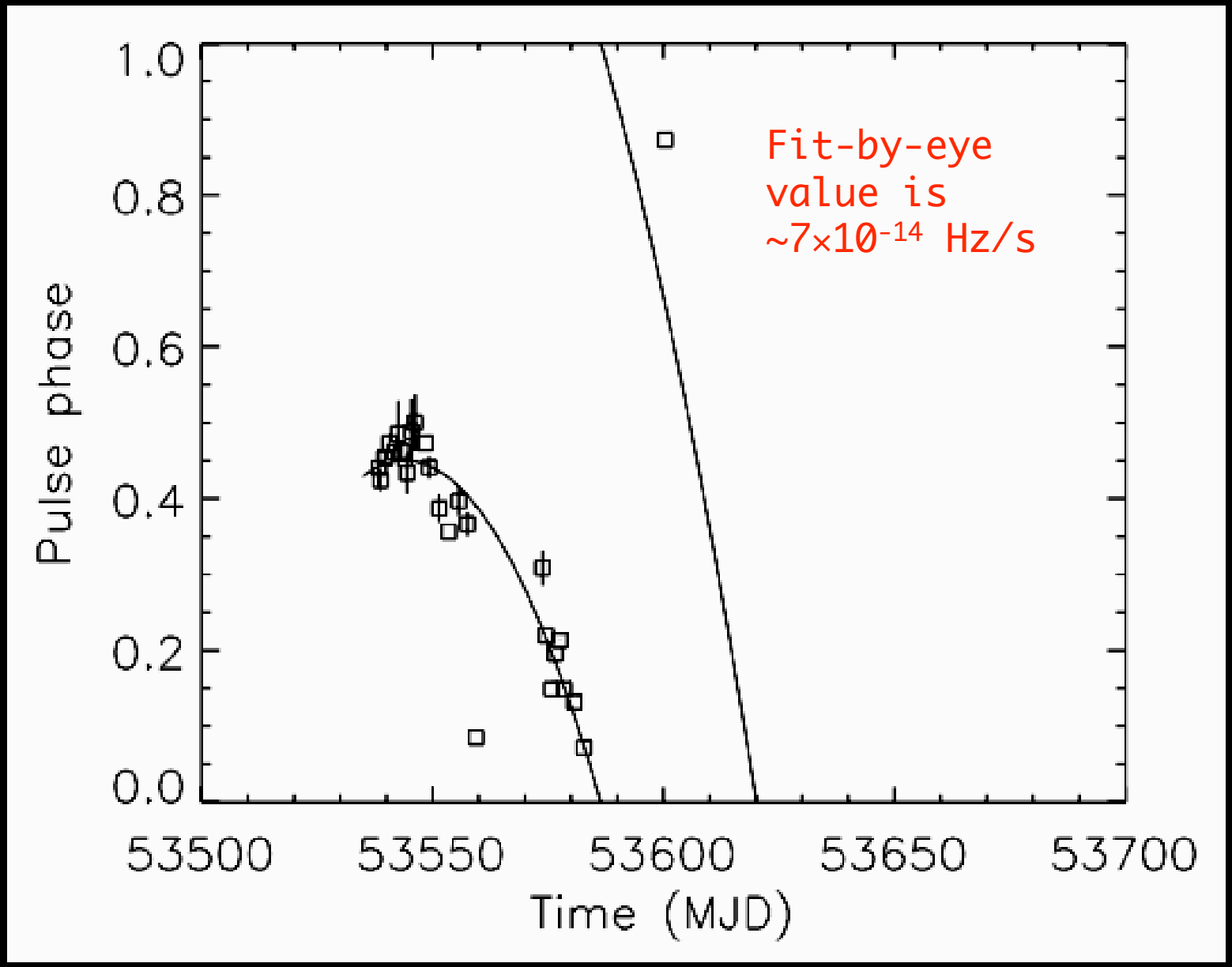


- HETE J1900.1-2455 is *still active*, >140 d after the outburst commenced. This is by far the longest active period of any of the millisecond pulsars
- While the inferred Mdot is rather low at only ~2% M_{Edd}, if it remains active it will be the highest (time-averaged) of the accretion-powered pulsars -> *best candidate for gravitational wave detection*

New & interesting behaviour



Bonus: measured spin-up



Summary and future prospects

- Accretion-powered millisecond pulsars are by far the fastest-growing subclass of LMXBs
- New examples can still reveal vital clues as to the physics of these extreme objects; conversely, searches for, and observations of, new examples should be a high priority for *RXTE* and other X-ray missions
- Results from HETE J1900.1-2455 suggest, for the first time, a connection between the bursts and the presence of pulsations. Unclear how this relates to other pulsars
- This source also gives us hope that in the future additional “quasi-persistent” sources may appear, which will be good candidates for searches for gravitational radiation