Pushing the limit on neutron star spin rates

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A different flavour of pulsars

- Neutron stars in binaries may accrete gas from their companions and thus emit in X-rays
- As with rotation-powered (radio) pulsars, rotation + anisotropy = pulsations
- Most accretion-powered pulsars with high-mass (>1M_☉) companions have long spin periods; conversely, most neutron stars with low-mass binary companions do not pulse persistently
- Since 1998 seven accretion-powered pulsars with low mass companions have been discovered, with spin frequencies in the range 185-599 Hz
Why are they interesting? Part I

- Long-sought evolutionary progenitors of rotation-powered millisecond pulsars
- Neutron star is spun-up ("recycled") by a long period of accretion, to reach millisecond periods
- Companion may be destroyed
The sixth accreting millisecond X-ray pulsar

- Discovered 2004 December 2 with IBIS/ISGRI and JEM-X aboard INTEGRAL (Eckert et al., ATel #352; see also Shaw et al. '05)
- $R \sim 17.4$ 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 & H$\alpha$ lines (Roelofs et al., ATel #356)
- Fading radio counterpart <1mJy @ 5, 15 GHz (ATels #355, 361, 364)
The Rossi X-ray Timing Explorer

- Launched Dec 1995
- 3 instruments: the Proportional Counter Array (PCA), High-Energy X-ray Timing Experiment (HEXTE) and the All-Sky Monitor (ASM)
- The PCA is sensitive to photons between 2-60 keV and has an area of ~6500cm²
- Spectra are typically accumulated in >64 energy channels with time resolution down to 1µs
Pulse timing with **RXTE**: $f_0 = 598.89$ Hz

*Fastest* accretion-powered pulsar (Marquardt et al. 2004, ATel #353, 360)

Pulse phase fitting results:
- $P_{\text{orb}} = 2.46$ hr
- $a_X \sin i = 65.0$ lt-ms
- Mass fn. $f_X = 2.8 \times 10^{-5} M_\odot$
- Compare with 2.01, 62.8, and $3.78 \times 10^{-5}$ for SAX J1808.4-3658 - a close relative, if not a twin!
- Mass donor in both systems 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)
Followup observations by RXTE & Chandra

- Initial X-ray flux e-folding time 8.5 d, later 1.68 d
- No thermonuclear X-ray bursts detected, in contrast to SAX J1808.4-3658...

...although we expect that bursts did occur and we missed them in data gaps
#7: HETE J1900.1-2455

- Thermonuclear bursts from this source detected by the HETE-2 satellite 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., in prep.)
- **Mass function is** $1.998 \times 10^{-6} \, M_{\odot}$ so that minimum companion mass (assuming a 1.4 $M_{\odot}$ neutron star) is $0.016 \, M_{\odot}$
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)

$\rightarrow$ detection by Advanced LIGO?
Summary and future prospects

- Detecting more of these sources with more instruments than before
- Starting to fill in the sample, although selection effects are essentially unknown
- Can precisely track pulse phase and frequency for the accretion-powered pulsars over the (typically) two-week outburst period (good for GW)

  \[ \text{BUT} \]

- Time-averaged $M$-dot is very low (bad for GW)
- Burst oscillation sources are generally higher $M$-dot, but can’t track phase as well (and some orbital periods are unknown)

Stay tuned...