

Chandra ToO Observations of Anomalous X-ray Pulsars

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*8 Yr of Science
With Chandra
October 24, 2007*



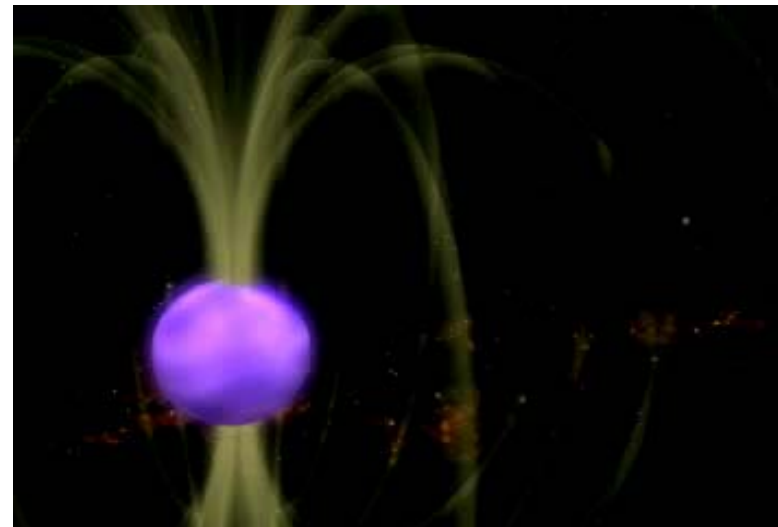
Collaborators: **Cindy Tam** **Fotis Gavriil**
Pete Woods **Weiwei Zhu** **Rim Dib**

Magnetars

- Young, isolated, ultrahighly magnetized neutron stars
- Soft Gamma Repeaters and Anomalous X-ray Pulsars
- X-ray pulsars with periods 2-12 s, large spin-down rates, moderate L_x , soft X-ray spectra typically fit by blackbody+power law
- Inferred $B \sim 10^{14} - 10^{15} \text{ G} > B_{\text{QED}}$
- L_x powered by internal heating due to B field
- Thermal X-rays scattered by currents in twisted magnetosphere (Thompson, Lyutikov & Kulkarni 2002)

Variability in Magnetars

- SGRs (5): giant flares, short bursts, spectral changes, pulse profile changes, timing anomalies...
- AXPs (9): short bursts, outbursts, slow flux changes, long-lived flares, glitches...
 - Most recognized only since 2002
- Transient AXPs (2):
 - Fluxes increase by factor of >100
 - Extreme form of AXP variability?



Major Magnetar Mysteries

- Population:
 - How many magnetars in the Milky Way?
 - What fraction of NSs born as magnetars?
- Evolution:
 - How are SGRs and AXPs related? One evolves to the other?
 - How are both related to high-B radio pulsars and other neutron stars?
 - Distinguishing property: Age? Mass?
- Physics:
 - How does matter behave in ultrahigh B fields?
 - How do magnetars produce such spectacular shows?

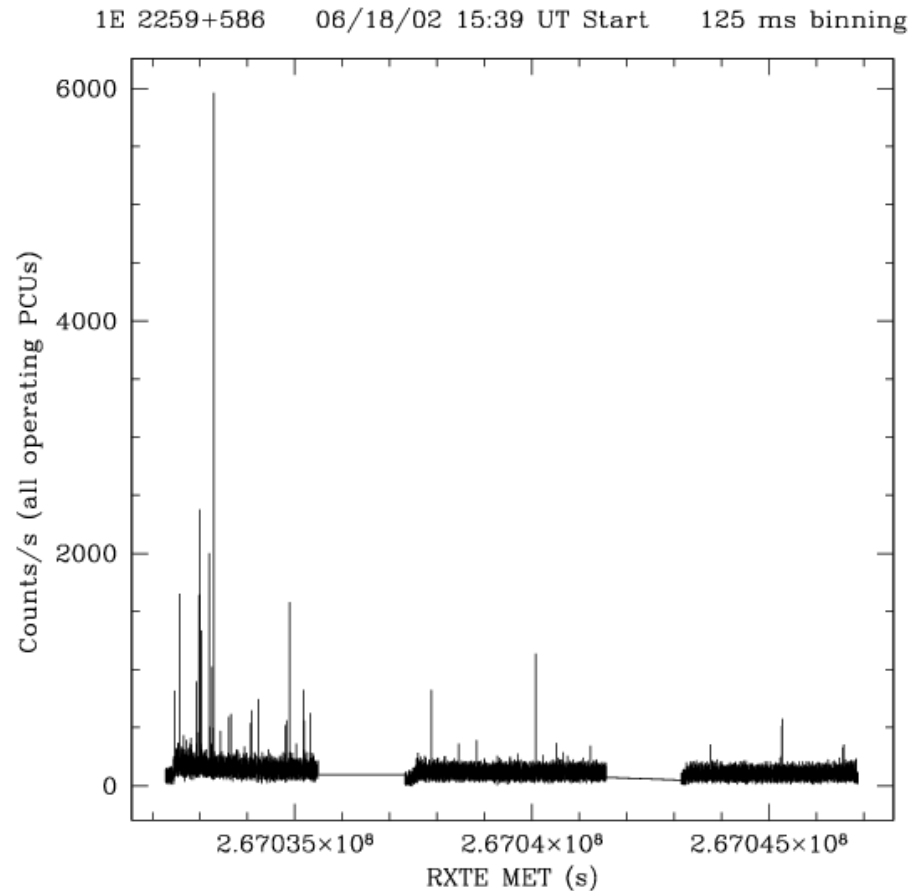
RXTE Monitoring of AXPs



- Large, long-term project, since 1996
- Bi-weekly snapshot monitoring of 5 AXPs
- Original goal: phase-coherent timing
 - predict pulse phase using few-parameter ephemeris
 - account for *every* rotation over years
 - very precise rotational parameters
- Monitor pulsed flux, pulse profile, search for bursts using the Proportional Counter Array
- PCA non-imaging, large background
 - Pulsed fluxes only, little/no useful spectral information
- Discoveries: AXP rotational stability, first AXP glitch, AXP bursts, AXP outbursts, AXP flares...

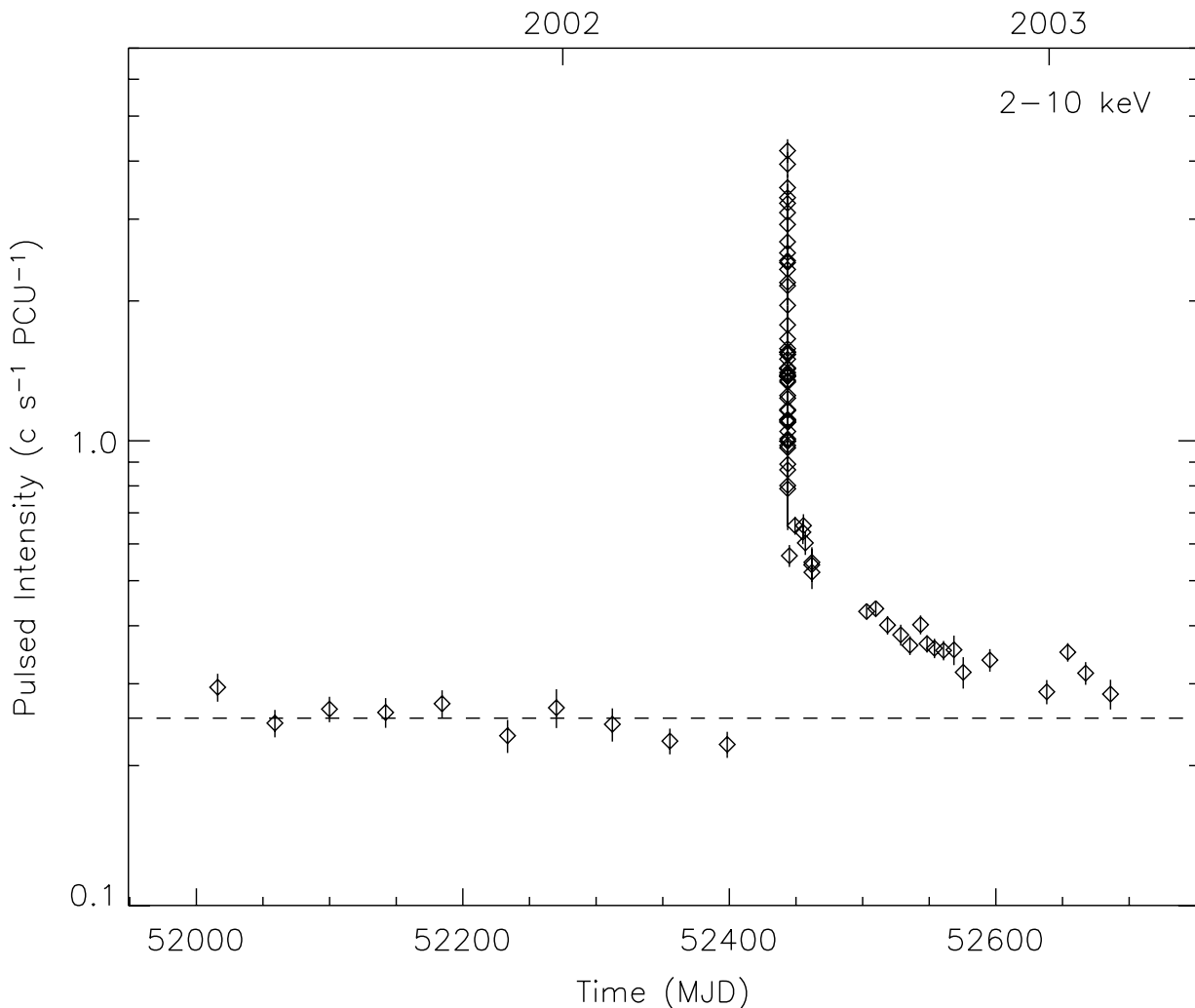
AXP 1E 2259+586: 2002 Outburst

- on June 18, 2002, luckily during *RXTE* obs.
- 80 SGR-like bursts in 15 ks; large glitch; pulse profile & spectral changes; >20x flux jump
- XMM ToOs, follow-up; mostly recovered by mid-2005, power-law index ~ -0.7 like SGRs (Lyubarsky et al. 2002; Zhu et al., submitted)



VK et al. 2003; Woods et al. 2005; Gavriil et al. 2005

Longer Term 1E 2259+586 Pulsed Flux History

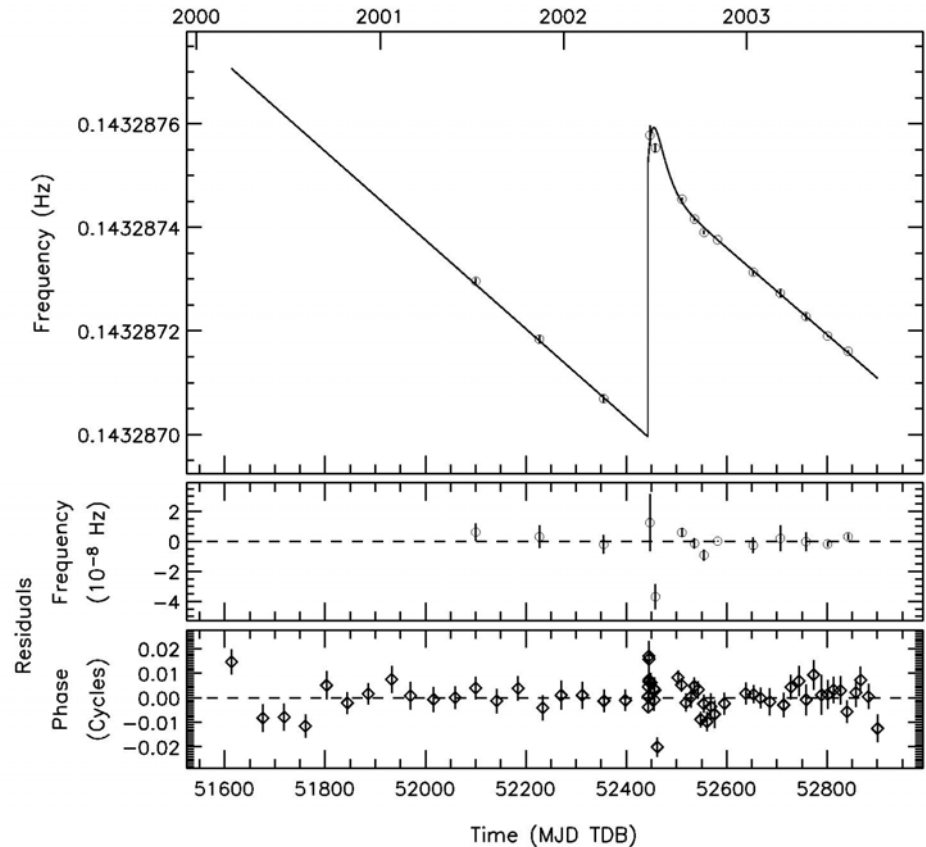


**~20x increase
in pulsed
flux at time
of outburst;
simultaneous
glitch, pulse
profile changes,
spectral changes**

Woods et al. 2004

1E 2259+586 Outburst: Glitch

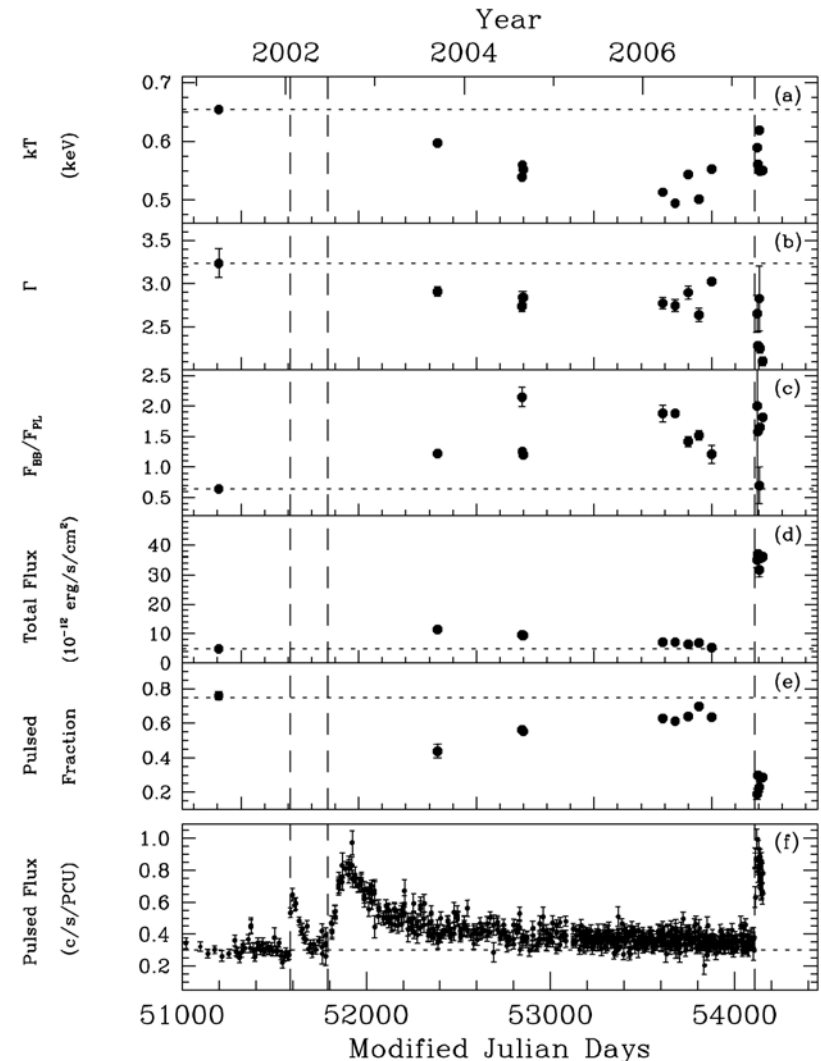
- rotation glitch occurred at outburst
- Highly unusual glitch recovery: core superfluid?
- first neutron star glitch accompanied by radiative changes: **stellar interior and exterior affected by event**



Woods et al 2004

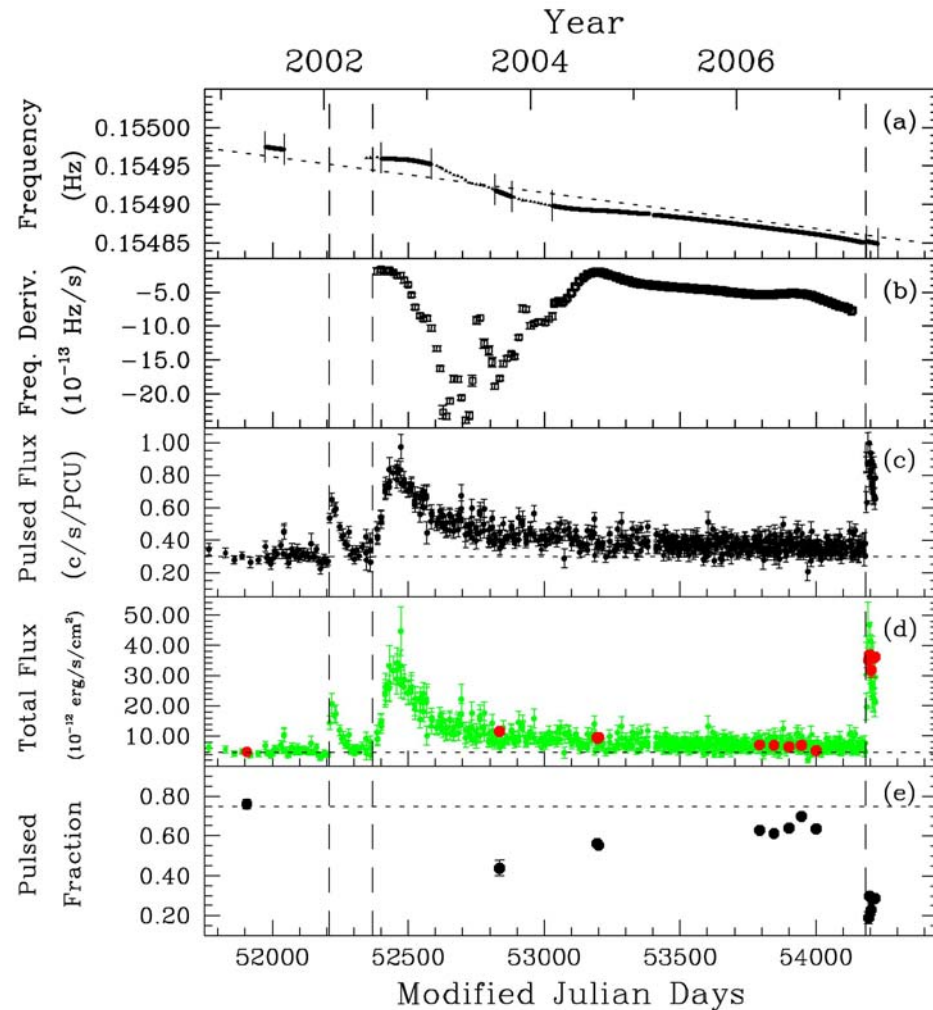
AXP 1E 1048-5937: 2007 Outburst

- 2001-2004 activity
 - Radiative and timing
- 2004-2007 quiescence
 - Radiative and timing
- 2007 outburst: glitch, pulse profile changes, spectral changes, unusual recovery
- CXO ToO trigger...



1E 1048-5937: Pulsed Fraction

- Pulsed fraction/flux anti-correlated: puzzling
- Energy release in flares greatly underestimated from *RXTE* pulsed fluxes (see also Tiengo 2005, Gavriil & VK 2005)
- Origin unclear – large growing hot spot?
 - Can be modeled in twisted magnetosphere model (e.g. Fernandez & Thompson 2006)
 - Highly constraining on models of purely thermal enhancement (e.g. Ozel & Guver 2007)

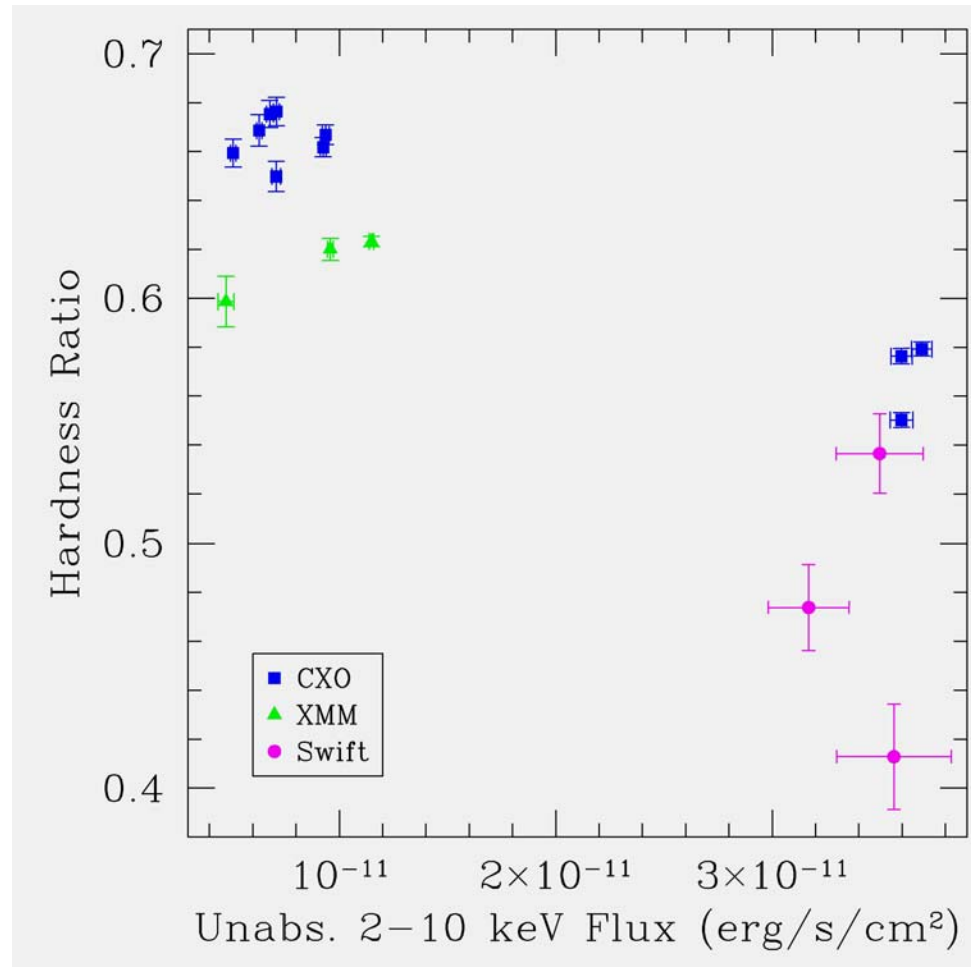


Tam et al., submitted

BATSE work?

1E 1048-5937: Hardness/Flux

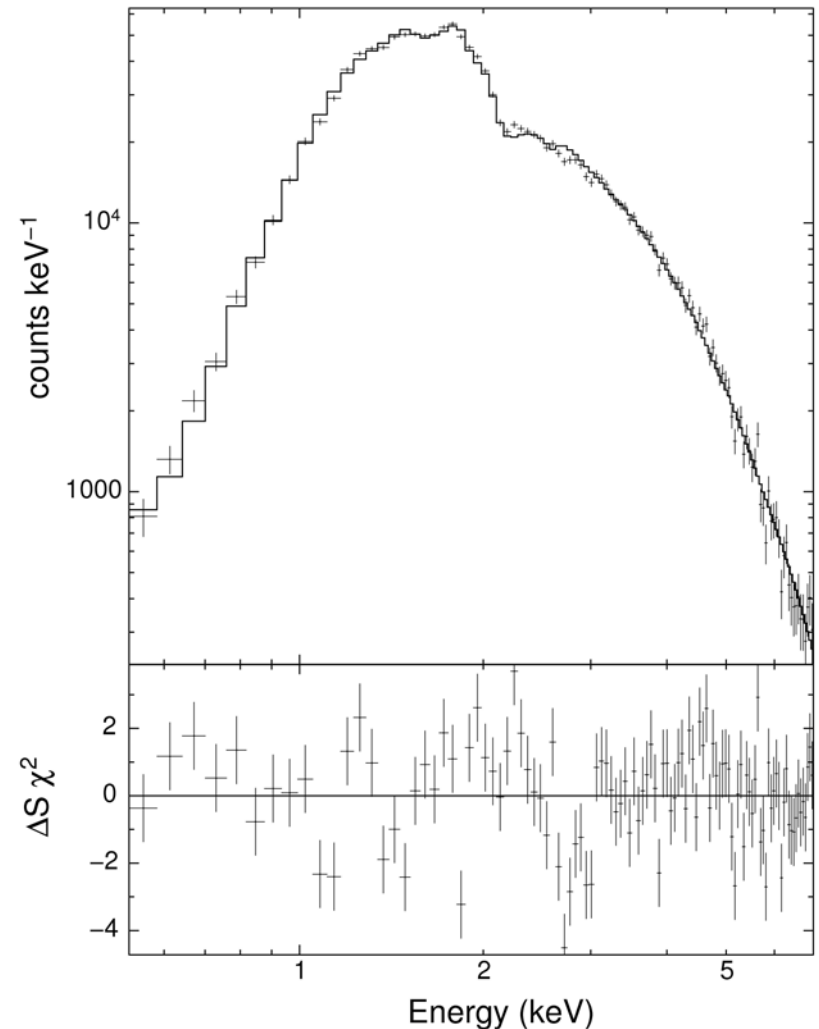
- CXO ToOs reveal hardness/flux correlation
- Seen in other AXPs too
- Predicted in twisted magnetosphere model (Thompson et al. 2002)
- Expected in purely thermal model (Ozel & Guver 2007)



Tam et al., submitted

1E 1048-5937: Spectral Feature?

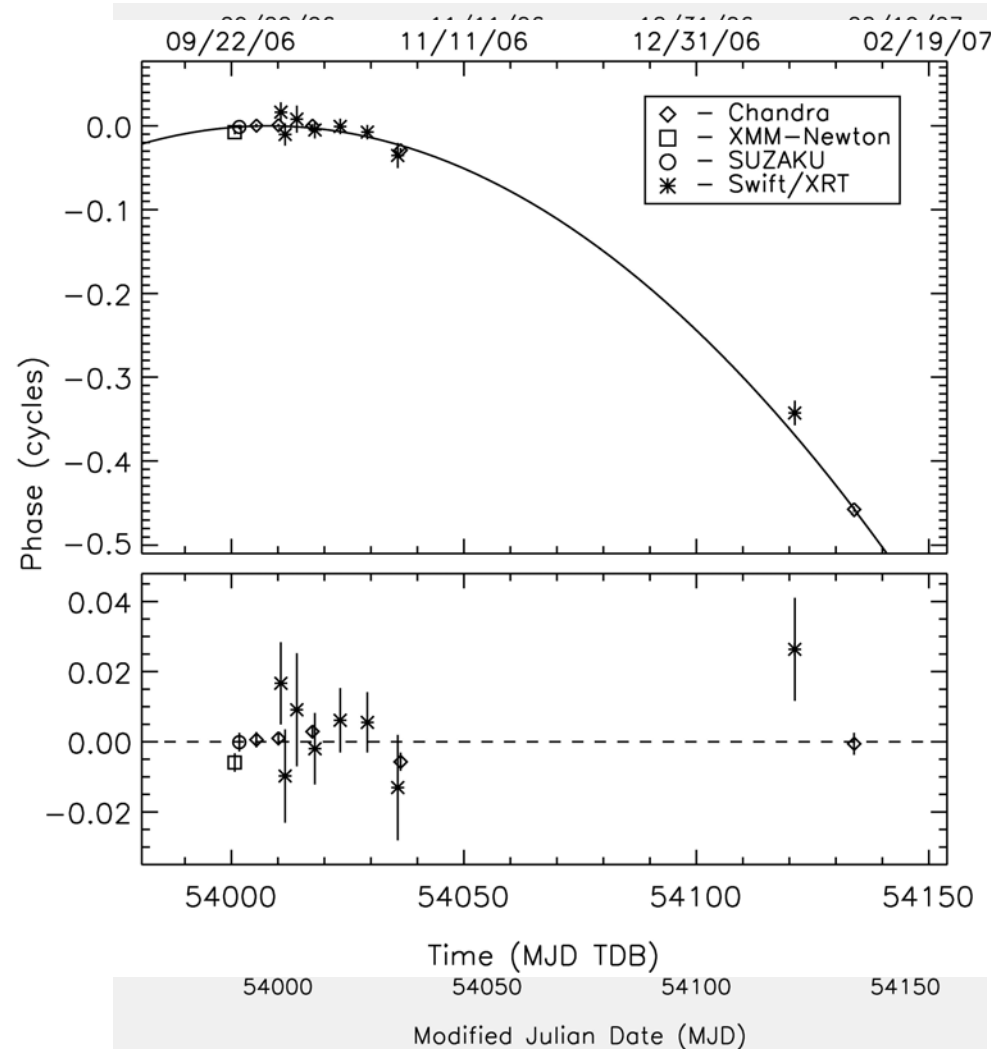
- Spectral feature detected in CXO ToO obs immediately following first burst
- $<0.13\%$ chance of being due to noise
- Not seen in any other CXO obs, incl. 10 days later
- Origin unclear...similar to those seen in INSs



Tam et al., submitted

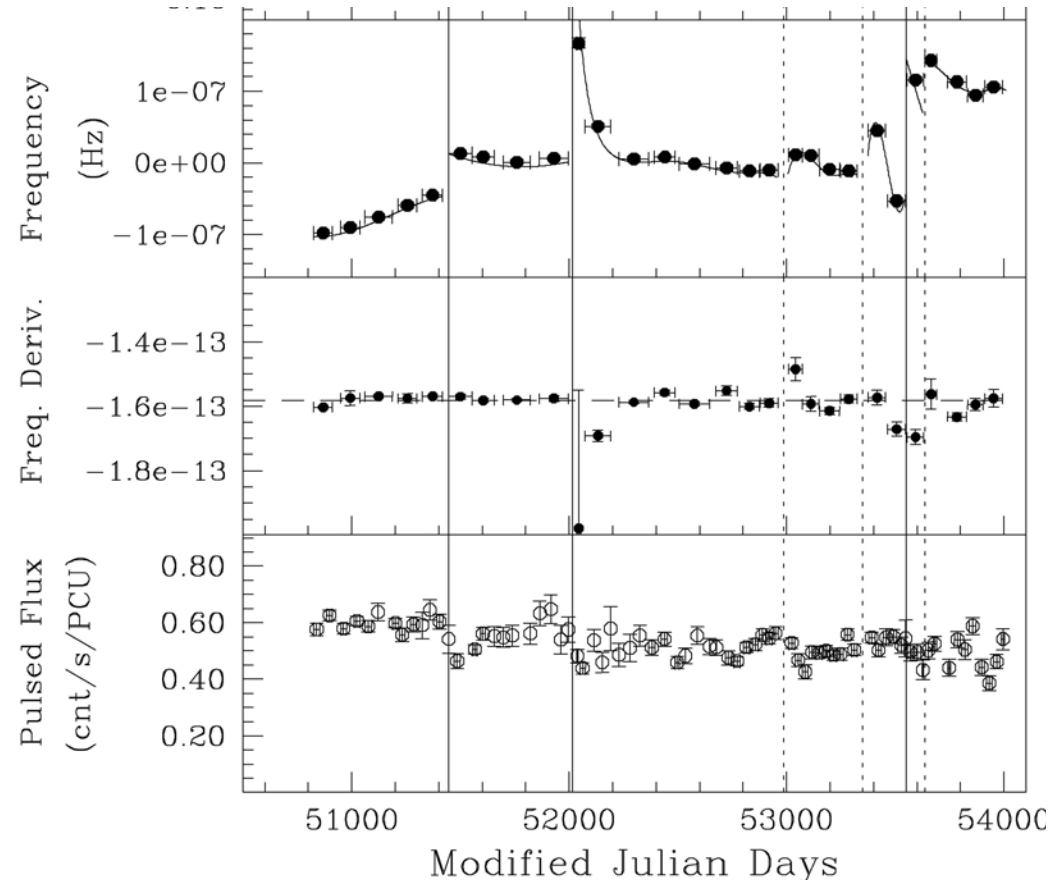
CXOU J164710.2-455216

- Recently discovered AXP in Wes 1 (Muno et al. 2005)
- Swift detected 2006 outburst
- Unobservable to *RXTE*
- CXO ToO measured P_{dot} , implied magnetar-strength B , power-law decay index -0.33
- Israel et al. 07 claim largest glitch ever
- We find no evidence for any glitch...



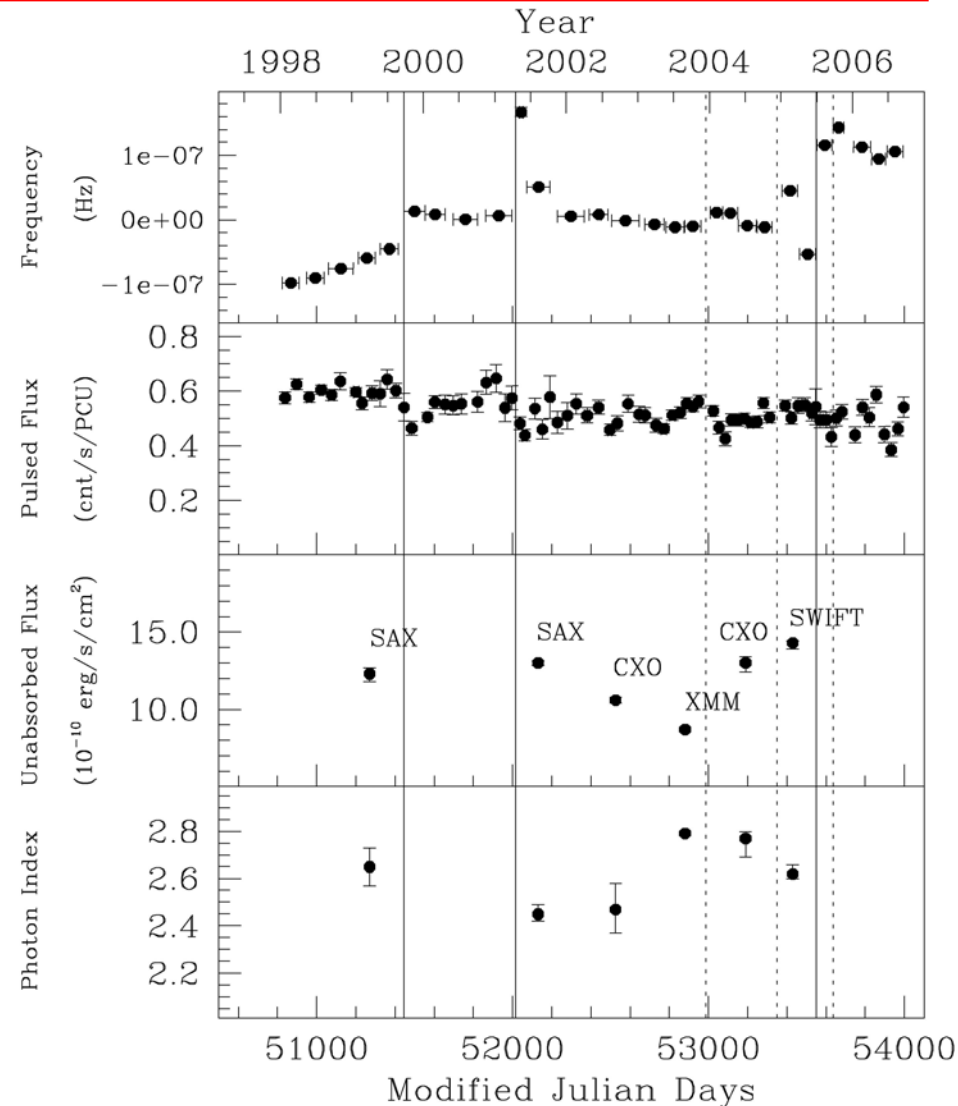
AXP Glitches and Outbursts?

- AXP RXS J1708-4009:
3 (+3?) glitches in 10 yr
- 1 large, with recovery
- Pulsed flux relatively stable
- Why glitches “silent” here??

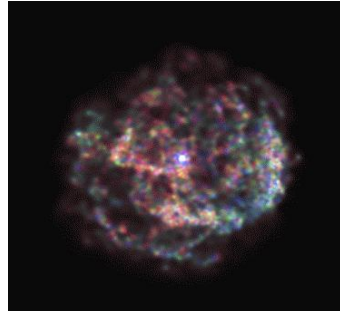


Glitch-correlated Variability?

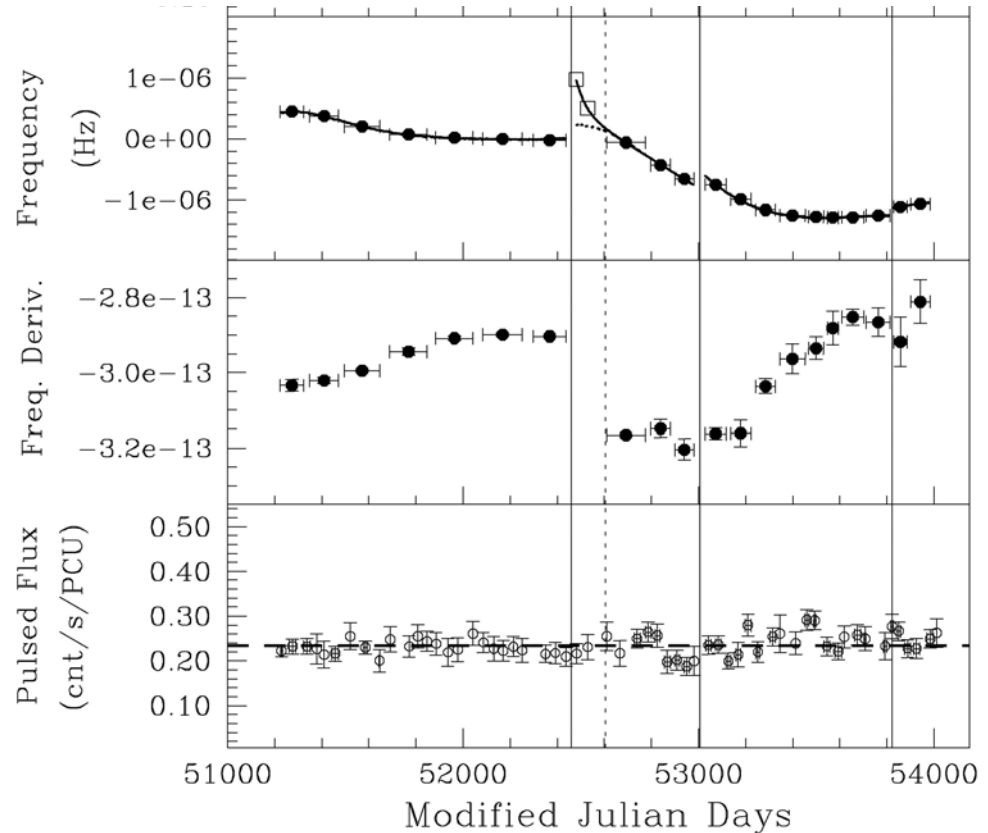
- But focusing instruments show $>60\%$ variability (Rea et al 2005; Campana et al. 2007; Gotz et al. 2007)
- Pulsed fraction anti-correlated with flux again!
- Claimed correlation with glitch epochs (Rea et al. 2005, Campana et al. 2007, Israel et al., submitted)
- Need closer monitoring obs, ToO obs near glitches



Another “quiet” glitch??



- AXP 1841-045 in SNR Kes 73
- Active glitcher; 1 large glitch with recovery
- Pulsed flux stable
- Hint from archival *XMM* data that unpulsed flux varies (W. Zhu, in prep.)
- ToO needed next large glitch, even if no pulsed flux change



Dib, VK, Gavriil, ApJ, in press

Summary: AXPs and ToOs

- Huge range of AXP variability only discovered in 2002: these are active sources!
- Outburst/glitch events provide first simultaneous window on exterior and interior of neutron star
- Also important for population issues
- Rare, unexpected, sudden events demand relentless vigilance and ... ToOs
 - Haven't mentioned optical/IR...
- CXO ToOs have played a major role in revealing behavior that is highly model constraining:
 - Pulsed fraction/flux anti-correlation, Flux/hardness correlation
 - Spectral feature?