Anomalous X-ray Pulsars

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Isolated Neutron Stars
London, UK
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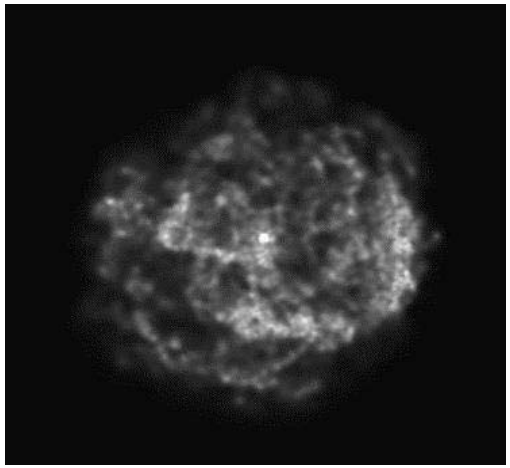
Summary

- **Review of AXP properties:**
  - **TIMING**
  - **VARIABILITY**
  - **SPECTRA**
  - **POPULATION**

Anomalous X-ray Pulsars

- **7(+2) known:**
  - 5 “classical” Galactic AXPs: 4U 0142+61, 1E 1048-5937, RXS J1708-4009, 1E 1841-045, 1E 2259+586
  - 1 SMC AXP CXOU J010043.1-721134
  - 1(+1) transient AXPs: XTE J1810-197, (AX J1845-0258)
  - (1 candidate AXP: Wes 1 CXO J164710.2-455216)
- **P=6-12 s**
- **all spinning down**
- **Lx >> Edot; no binary companions**
  → ``**anomalous**’’
  Mereghetti & Stella (1995)
  van Paradijs et al. (1995)

1E 1841-045 in Kes 73



AXPs Generally Accepted to be Magnetars

- Thompson & Duncan (1995, 1996)
- AXP X-ray luminosity requires energy source
- Like SGRs, B-field implied by P, dP/dt is magnetar-strength
- Similar X-ray spectra to SGRs
- AXPs exhibit SGR-like bursts
  - Now seen in **4** sources

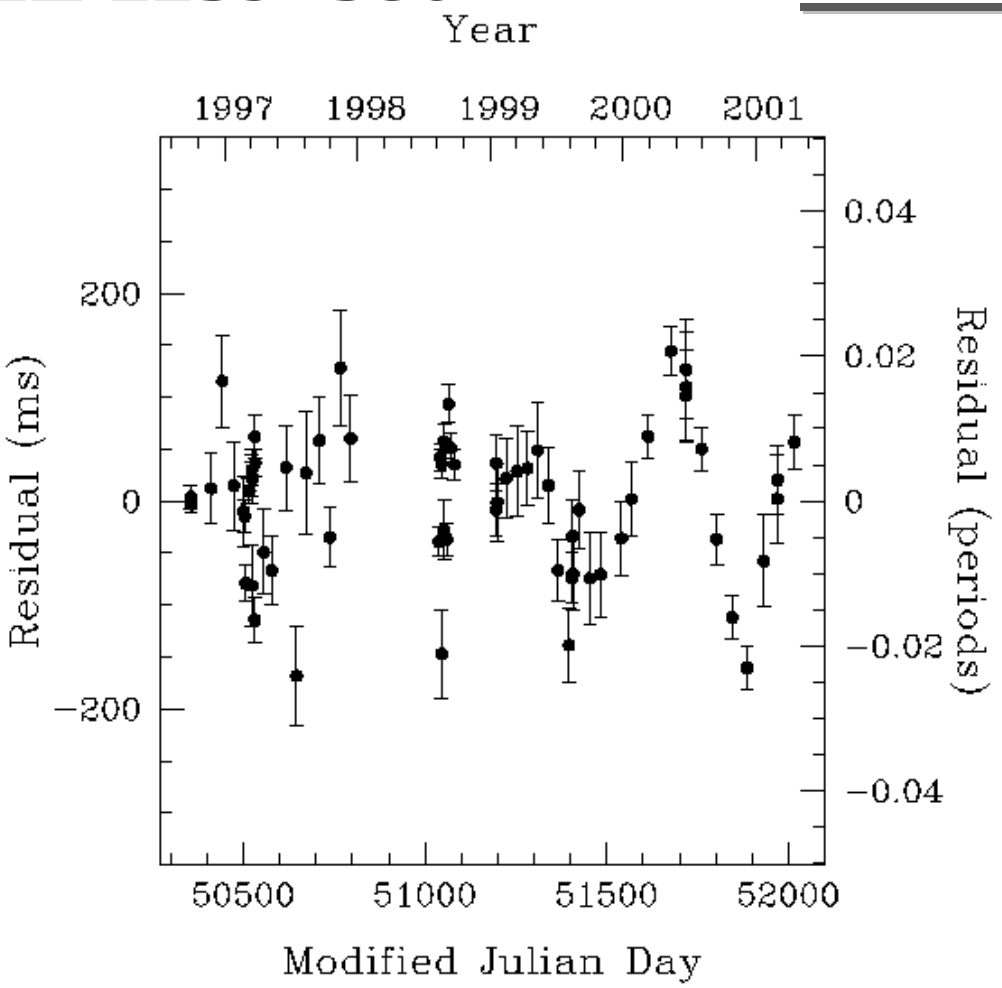
Important puzzles remain!

AXP TIMING

- General rotational stability
- Occasional glitches
  - 4 glitches detected in 3 sources
  - Sometimes associated with radiative events
- Some anomalies

AXPs Generally Rotationally Stable

1E 2259+586 **RXTE**



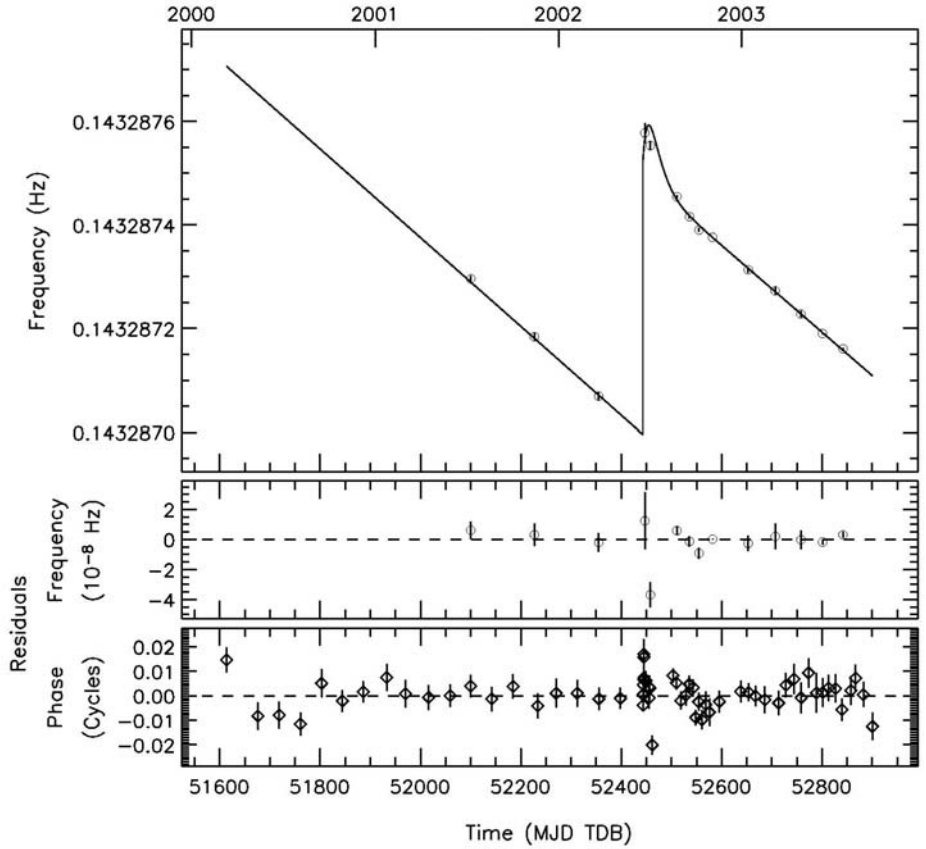
- Phase-coherent timing generally possible over years with few free parameters
- Enables glitch detection

Gavriil & VK 2002

AXP TIMING…

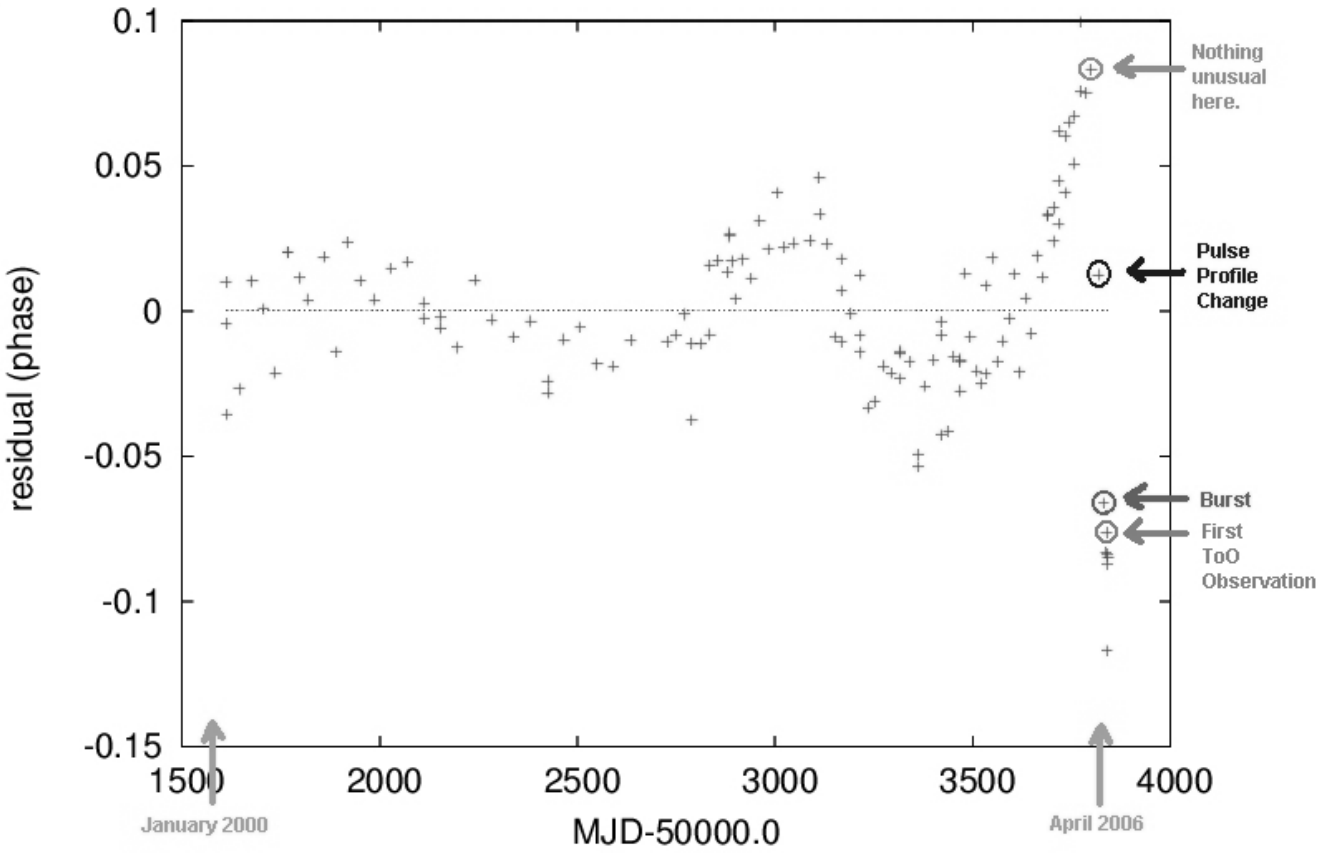
1E 2259+586: 2002 Glitch

- rotation glitch occurred at major radiative outburst
- fractional frequency increase 4×10^{-6}
- first neutron star glitch accompanied by radiative changes: **stellar interior and exterior affected by event**



Woods et al 2004

New: 4U 0142+61 Glitch?



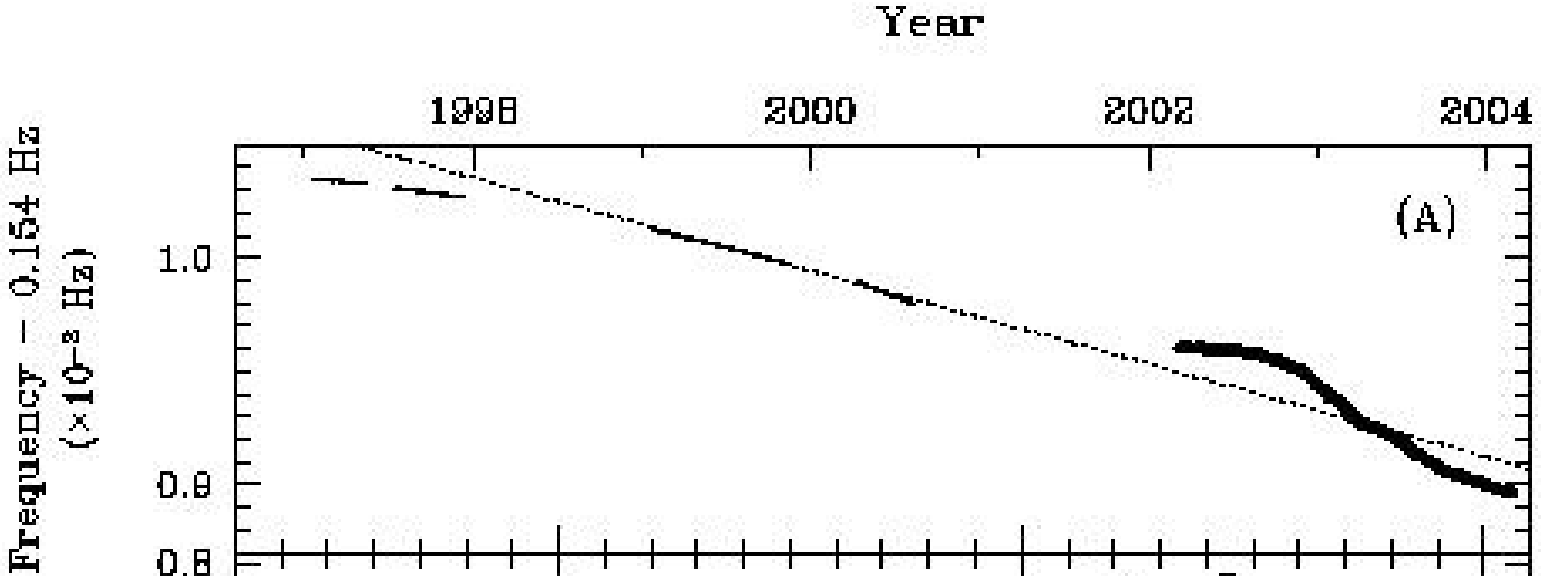
- April 2006
- df/f~10^-7
- Associated burst, pulse profile change seen *after* glitch
- Main event went unseen?

Dib, VK & Gavriil, in prep.

AXP TIMING…

1E 1048-5937: Anomalous AXP

Poor rotational stability: cannot be phase-connected beyond a few months at a time; like SGRs.



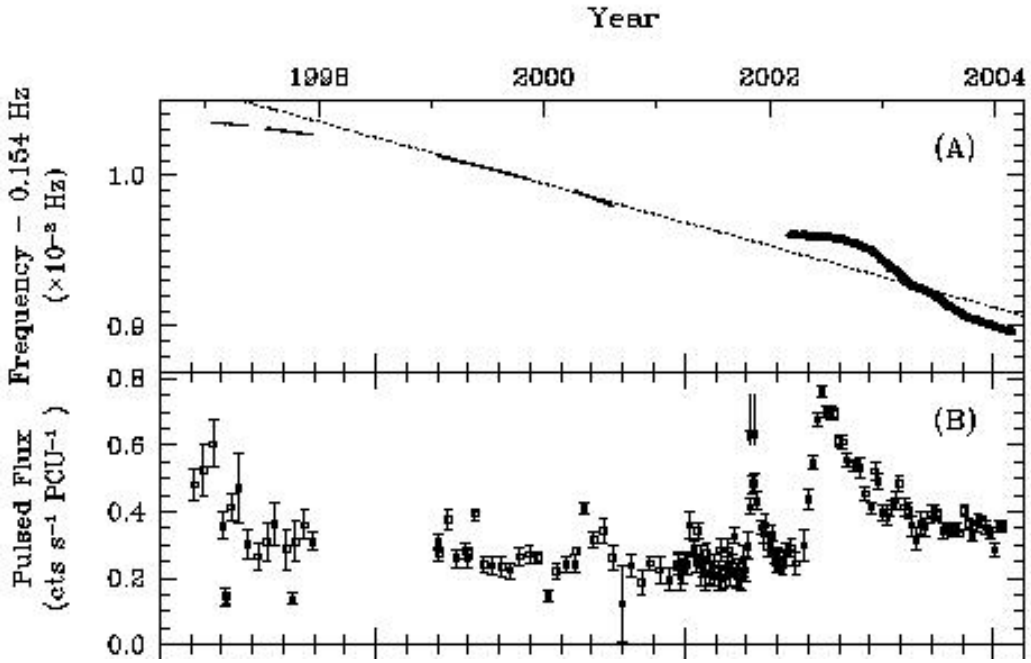
Gavriil & VK 2004.

AXP TIMING…

AXP VARIABILITY

- Flares
- Outbursts
- Pulse profile changes
- Transients
- Bursts
- see talk by **Nanda Rea**

1E 1048-5937: Anomalous AXP



Gavriil & VK 2004.

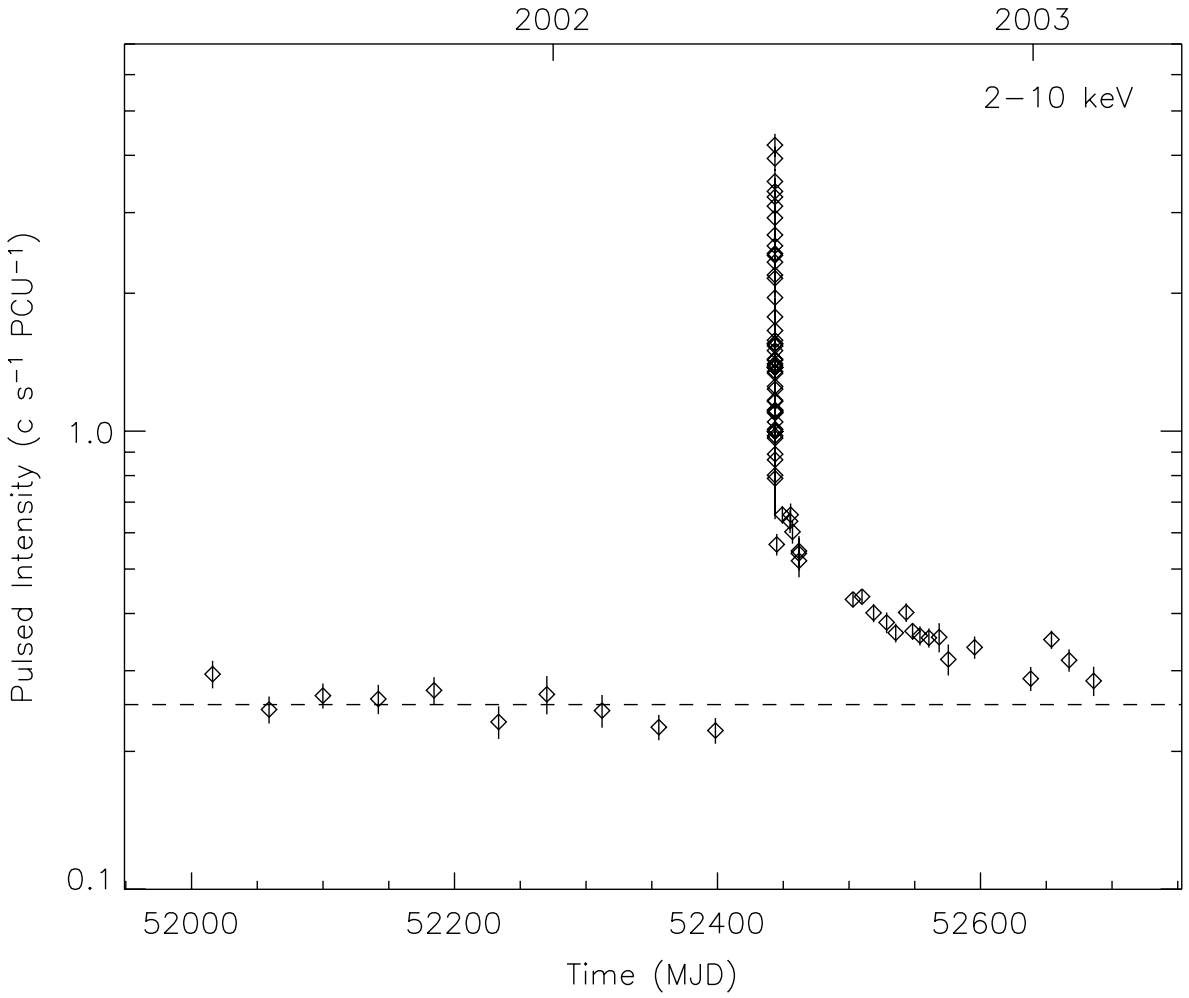
Poor rotational stability

X-ray "flares": several week rises; 10^41 erg

Tiego et al. 2005: Pulsed fraction/flux anti-correlation

AXP VARIABILITY…

Outburst: 1E 2259+586 Pulsed Flux History



~20x increase in pulsed flux at time of 2002 glitch; **simultaneous bursting**, pulse profile changes, spectral changes

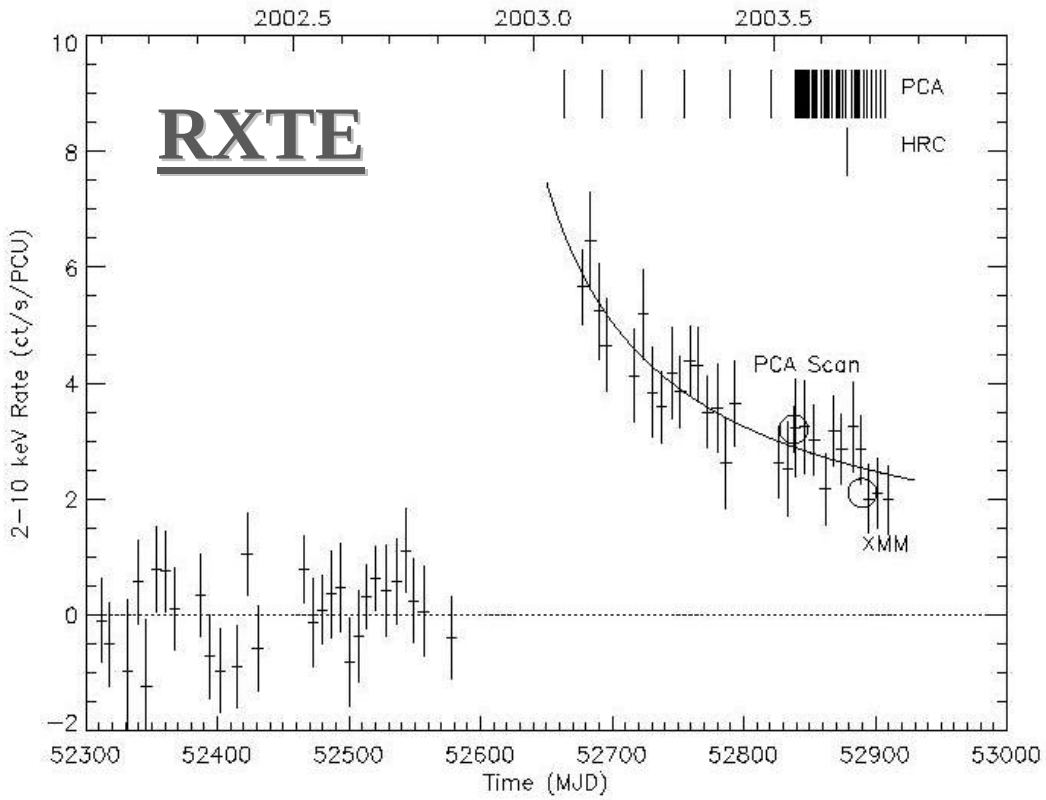
Woods et al. 2004

AXP VARIABILITY…

Transient AXP

- 5.5 s X-ray pulsar appeared in Jan 2003
- Outburst like that in 1E 2259+586?
- Larger dynamic range: 2 orders of mag.
- Why so faint in quiescence?
- **How many more out there?**
- See **Tam et al.** poster for another candidate

XTE J1810-197



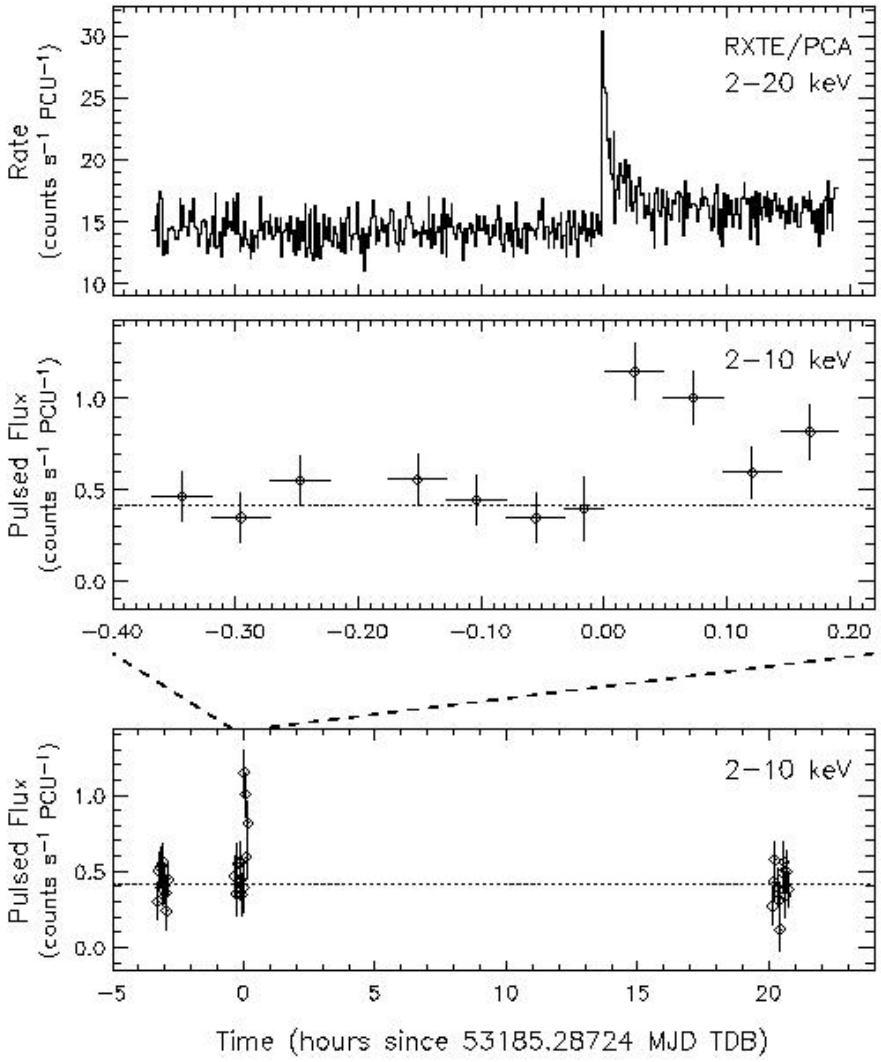
Ibrahim et al. 2004
Gotthelf et al. 2004
Woods et al. 2005

AXP VARIABILITY…

AXP Bursts

- **4 AXPs have now exhibited bursts:**
  - 1E 1048-5937: 3 bursts in 8 yr
  - 1E 2259+586: >80 bursts in few hr period, nothing else seen in 8 yr period
  - XTE J1810-197: 4 bursts in 3 yr
  - 4U 0142+61: 1 burst in 8 yr
- **Bursts are a generic behavior of AXPs**

June 2004 Burst from 1E 1048-5937



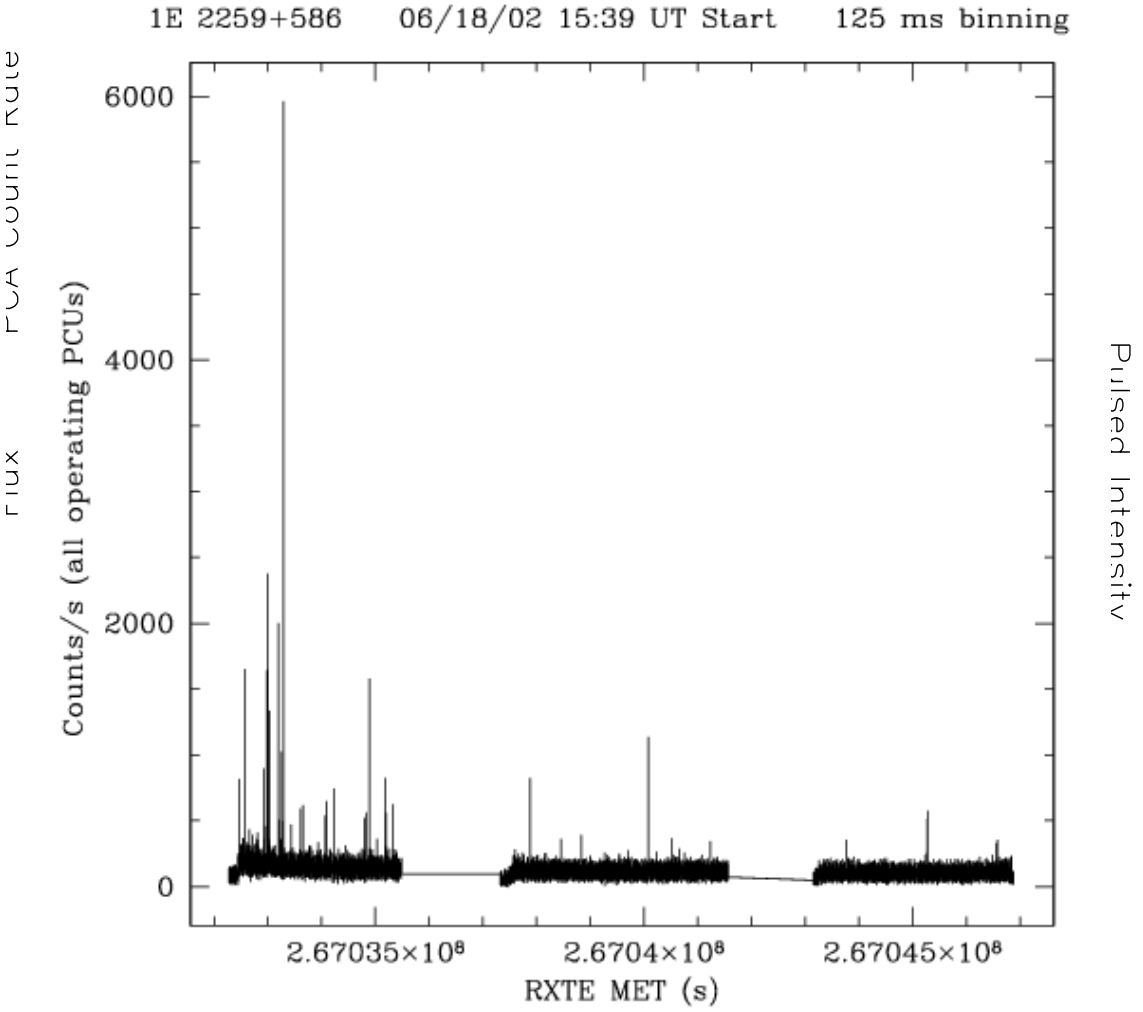
Simultaneous pulsed flux enhancement proves AXP is the burster.

Gavriil, VK & Woods (2005)

AXP VARIABILITY…

Major Outburst from 1E 2259+586

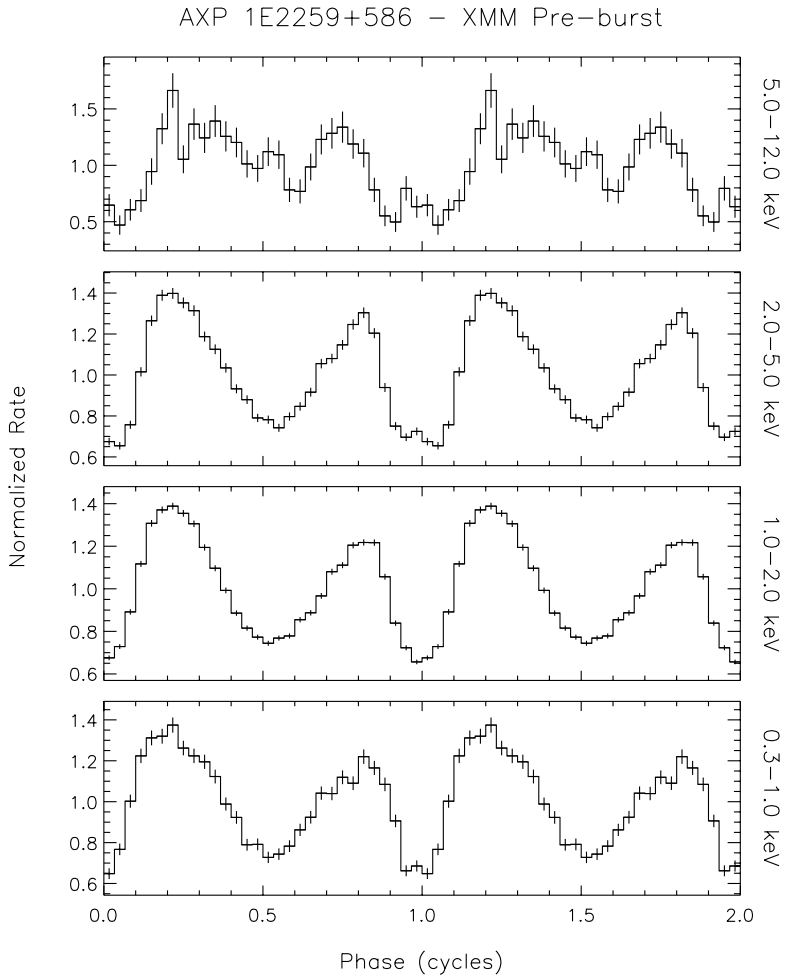
- on June 18, 2002, during *RXTE* observations, major bursting detected from 1E 2259+586
- 80 bursts detected in 15 ks observations; wide range of burst peak fluxes, fluences, rise times, durations, morphologies.



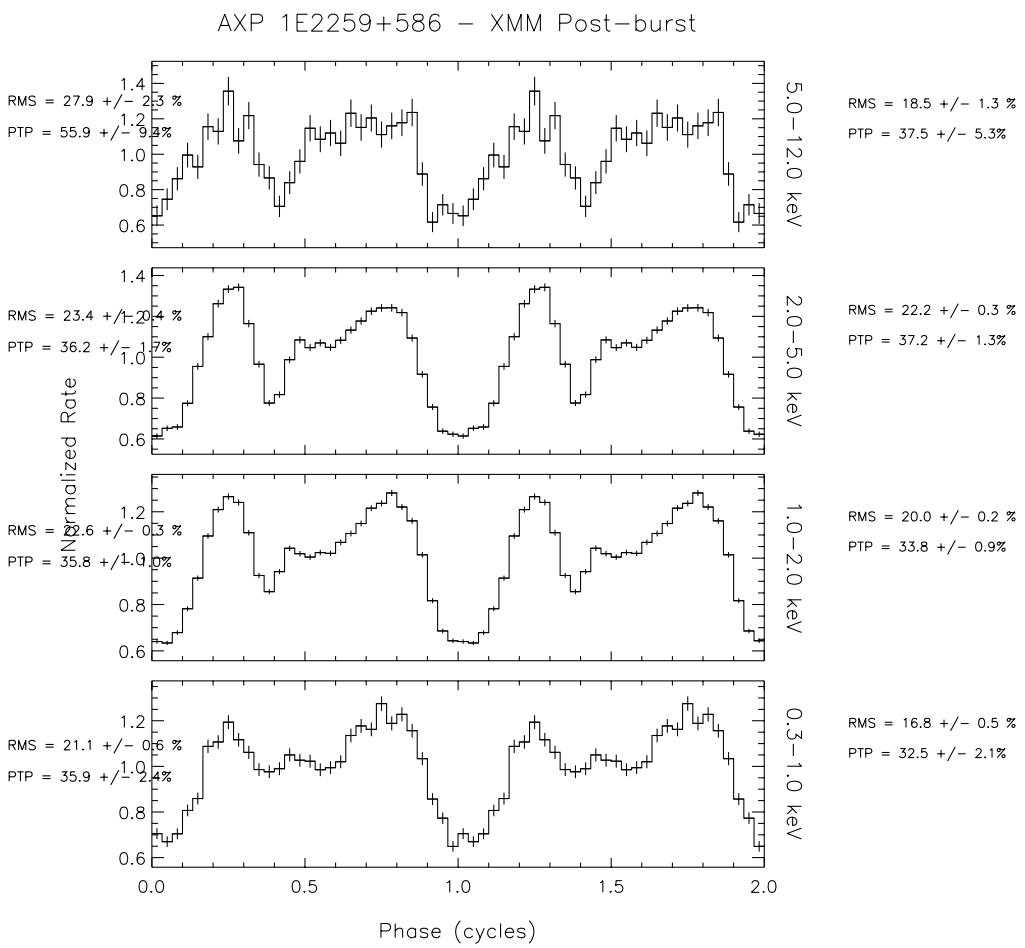
VK et al. 2003

Pulse Profile Changes in 1E 2259+586 Post 2002 Outburst

XMM: 1 week Pre-Outburst



XMM: 1 week Post-Outburst



Woods et al. 2004

AXP VARIABILITY…

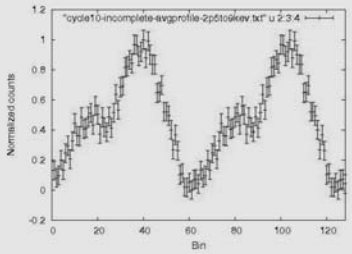


Figure 1: Average pulse profile in the last year before the burst.

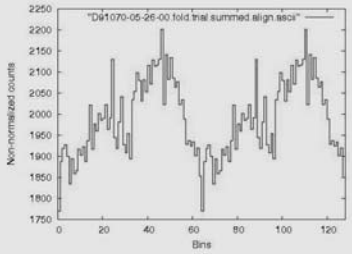


Figure 2: Pulse profile 6 weeks bofore the burst (everything normal).

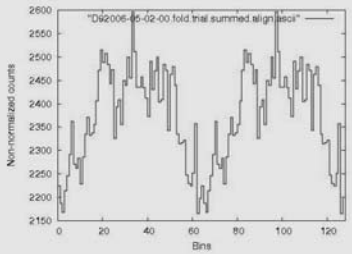


Figure 3: Pulse profile 2 weeks bofore the burst (something happened)

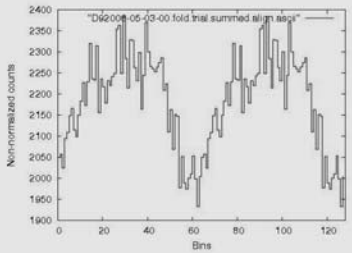
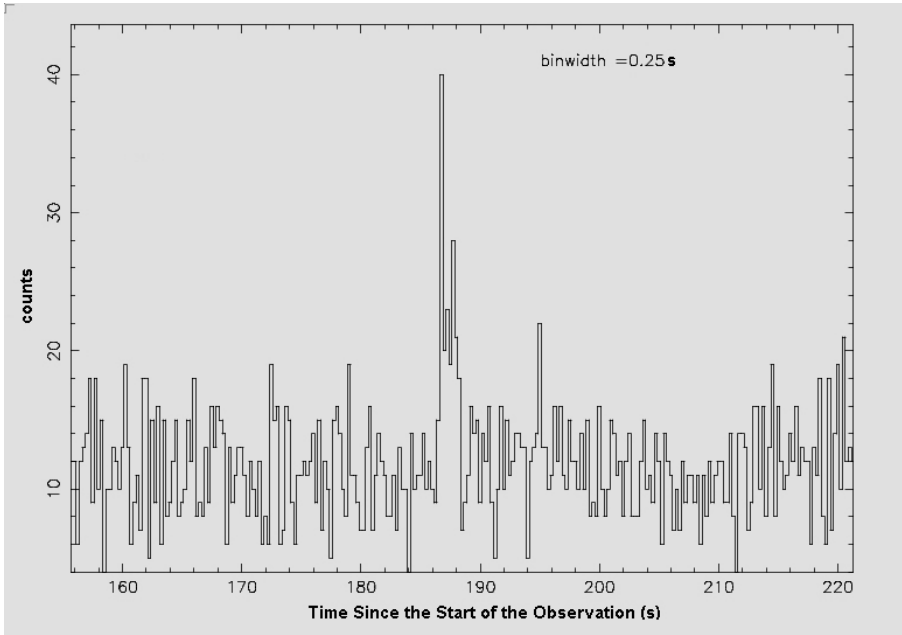


Figure 4: Pulse profile of burst observation.

April 6 2006 4U 0142+61 X-ray Burst, and pulse profile change.



Dib, VK & Gavriil, in prep

AXP VARIABILITY…

Bursts from XTE J1810-197

- 4 bursts seen in 3 yr: Woods et al. (2005)
- Overall, 2 types of burst:
  - TYPE A:
    - Traditional SGR bursts
    - Not correlated with pulse phase
    - No pulsed flux enhancement
  - TYPE B:
    - Only seen in AXPs thus far
    - Correlated with pulse peak
    - Associated pulsed flux enhancement
    - Long (several min) tail with energy > than burst energy

AXP SPECTRA

- X-ray
- Hard X-ray
- Infrared

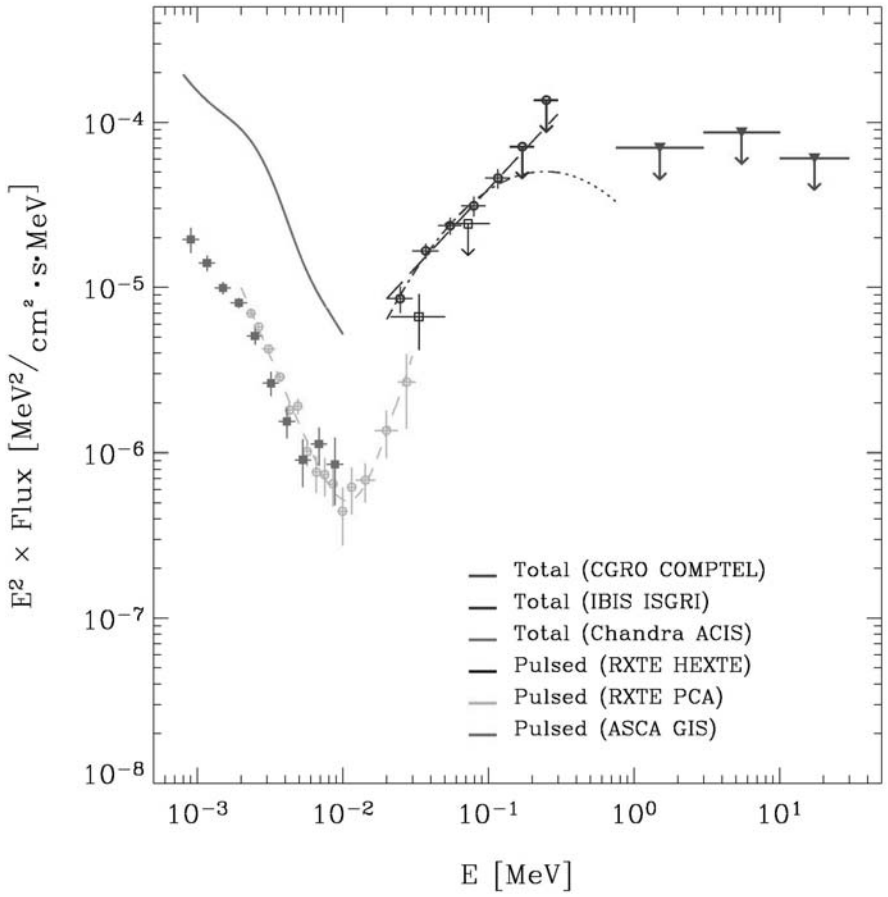
X-ray Spectra

- Typically well fit by power-law + blackbody (see talks by **Fernandez, Heyl, Belobordov, Baring**)
- Can also fit 2 blackbodies (see talk by **Gotthelf**)
- Or “Comptonized” blackbody (Lyutikov & Gavriil 2006)
- Little evidence for spectral features:
  - Rea et al. (2003): marginal line for RXS J1708-4009
    Not confirmed in XMM obs (Rea et al. 2005)
- Spectral hardness/flux correlation in RXS J1708-4009: confirms prediction of “twisted” magnetosphere model (Thompson et al. 2002)

AXP SPECTRA…

Hard X-ray Emission

AXP 4U 0142+61??



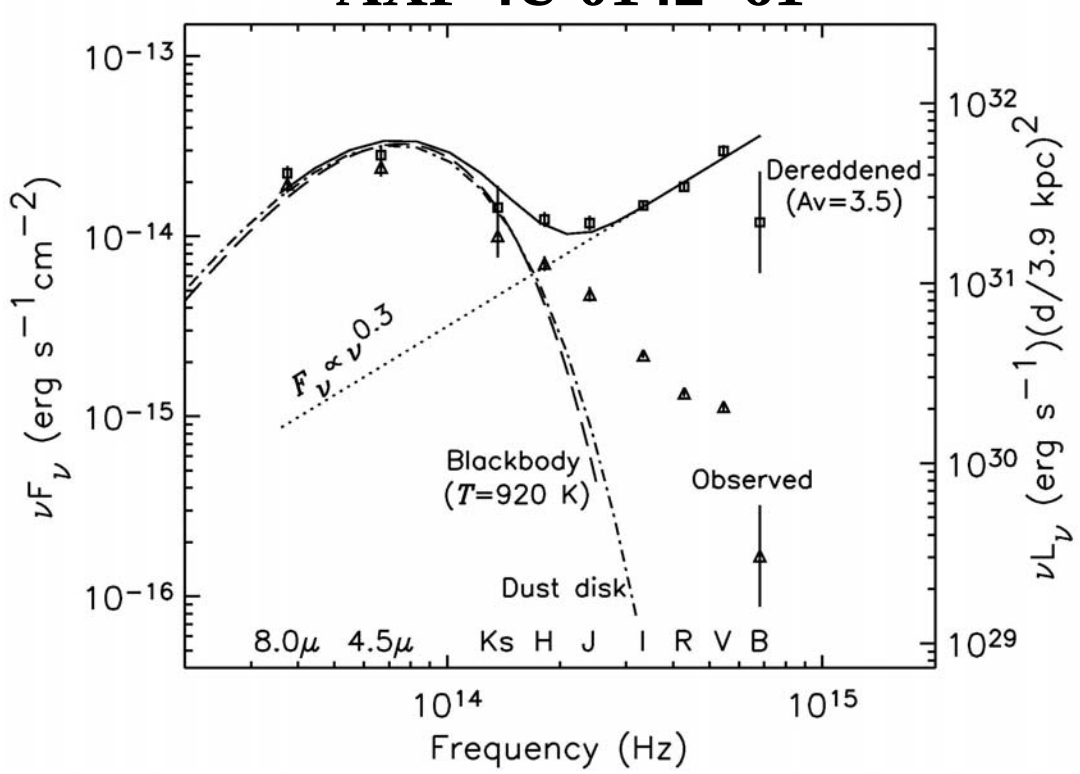
Kuiper et al., in press

- Spectrum turns over!
- E>10 keV >> Edot
- Generic AXP property
- Similar to Vela-like pulsar hard X-ray spectra
- See talk by **Peter den Hartog**

AXP SPECTRA…

Infrared Emission

AXP 4U 0142+61



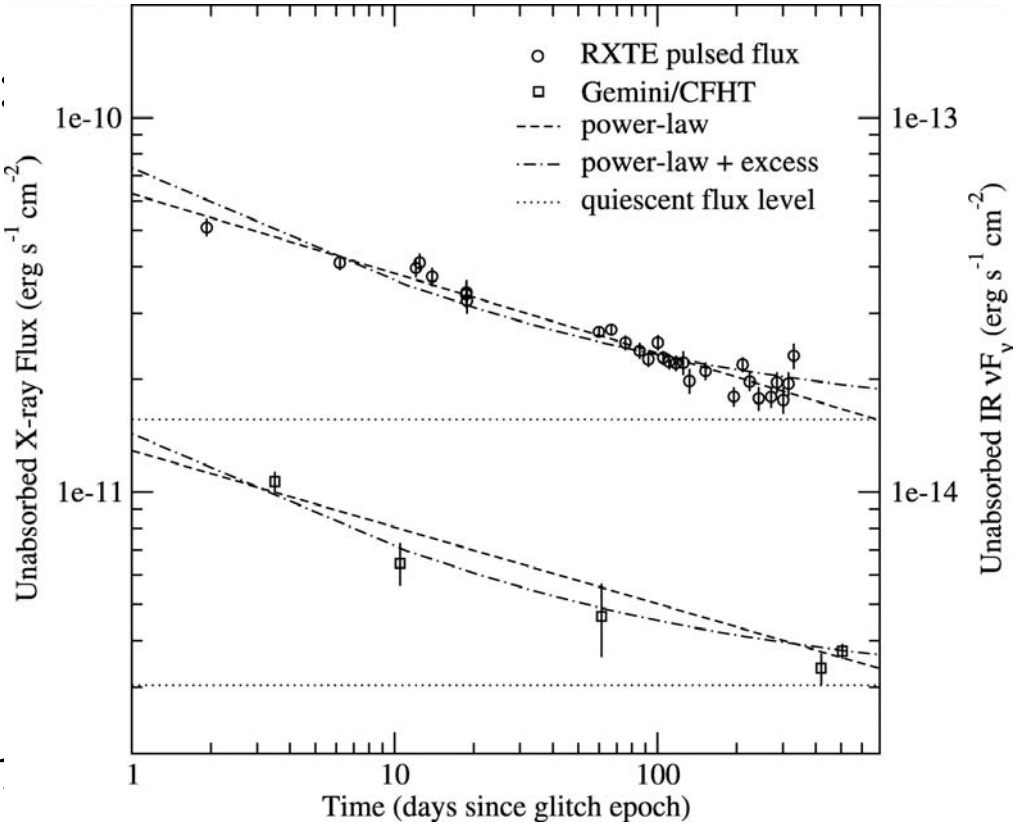
Wang et al. 2006

- Spitzer mid-IR shows spectral “hump”
- Interpreted as **passive** debris disk, supernova fallback
- HJI flux magnetospheric(?)
- K flux part of disk emission
- **Disks generic ?!**

AXP SPECTRA…

IR Flux Decay

- 1E 2259+586 2002 outburst: IR enhancement in K
- power-law decay, exponent -0.21 +/- 0.02
- X-ray flux decay exponent -0.21+/-0.01
- **implies IR, X-rays correlated during outbursts**
- Rea et al. (2004): correlation for XTE J1810-197
- IR, X-ray magnetospheric?
- Could be disk?
- See talk by **U. Ertan**



Tam et al. 2004

AXP SPECTRA…

IR/X-ray Correlations?

- In general, both X-ray and IR flux variable
- Not obviously correlated if variability time scale long (e.g. Gavriil & Kaspi 2004, Durant & van Kerkwijk 2005)
- If yet undetected short time scale variability, correlations could have been missed…need simultaneous obs!

POPULATION

- High-B radio pulsar connection?
  - See talks by **Lyne, Gonzalez, Gaensler**
- How many AXPs out there?
- Massive star progenitors?

How Many Magnetars in Milky Way?

- past studies of SGR bursts suggested 10 active magnetars (Kouveliotou et al. 1993); AXPs double this
- **AXP transients suggest many more…**
- Cappellaro et al 1997: Galactic core-collapse SNe every 50-125 yr
- Lyne et al. 1998: radio pulsar born every 60-330 yr
- **if magnetar, radio pulsar birth rates comparable, and if magnetars "live" 10 kyr, could be >150 potentially active in Galaxy**

Massive Star Progenitors of AXPs?

- 2 SGRs plausibly associated with massive star clusters (e.g. Figer et al. 2005)
- Muno et al. (2005) found likely AXP in massive star cluster Westerlund 1
- Suggests these sources formed from massive stars
- Would constrain birthrate
- Gaensler et al. (2005) argued for massive star progenitor for AXP 1E 1048-5937 via association with “bubble,” but distance problem…
  see talk by **Martin Durant**

Summary

- **Magnetar model accounts for most observables**
- **Many remaining AXP Puzzles!**
  - **What is origin of AXP timing “noise”?**
  - **What physically differentiates AXP & radio pulsar glitches?**
  - **Why are only some glitches associated with radiative events?**
  - **What is the origin of AXP “flares”?**
  - **What differentiates two types of AXP bursts?**
  - **Why are some magnetars quiescent?**
  - **What is origin of X-ray spectrum?**
  - **Why no features in X-ray spectrum?**
  - **Why near-IR variable?**
  - **Do AXPs (and other NSs) have debris disks?**
  - **What is origin of hard X-ray spectrum in AXPs (and pulsars?)**
  - **What fraction of NSs are magnetars?**
  - **What is the connection between AXPs and high-B radio pulsars?**
  - **What differentiates AXPs from SGRs? Age? B?**
  - **Do magnetars originate from massive progenitors?**