(Anomalous) X-Ray Pulsars

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Summary

- **Introduction to AXPs**
- **Evidence that AXPs are magnetars**
- **Open Issues and Recent Results:**
  - **IR emission**
  - **Transient AXPs and Magnetar birthrate**
  - **Connection with radio pulsars**

Goal:

Understand Physics of Neutron Stars

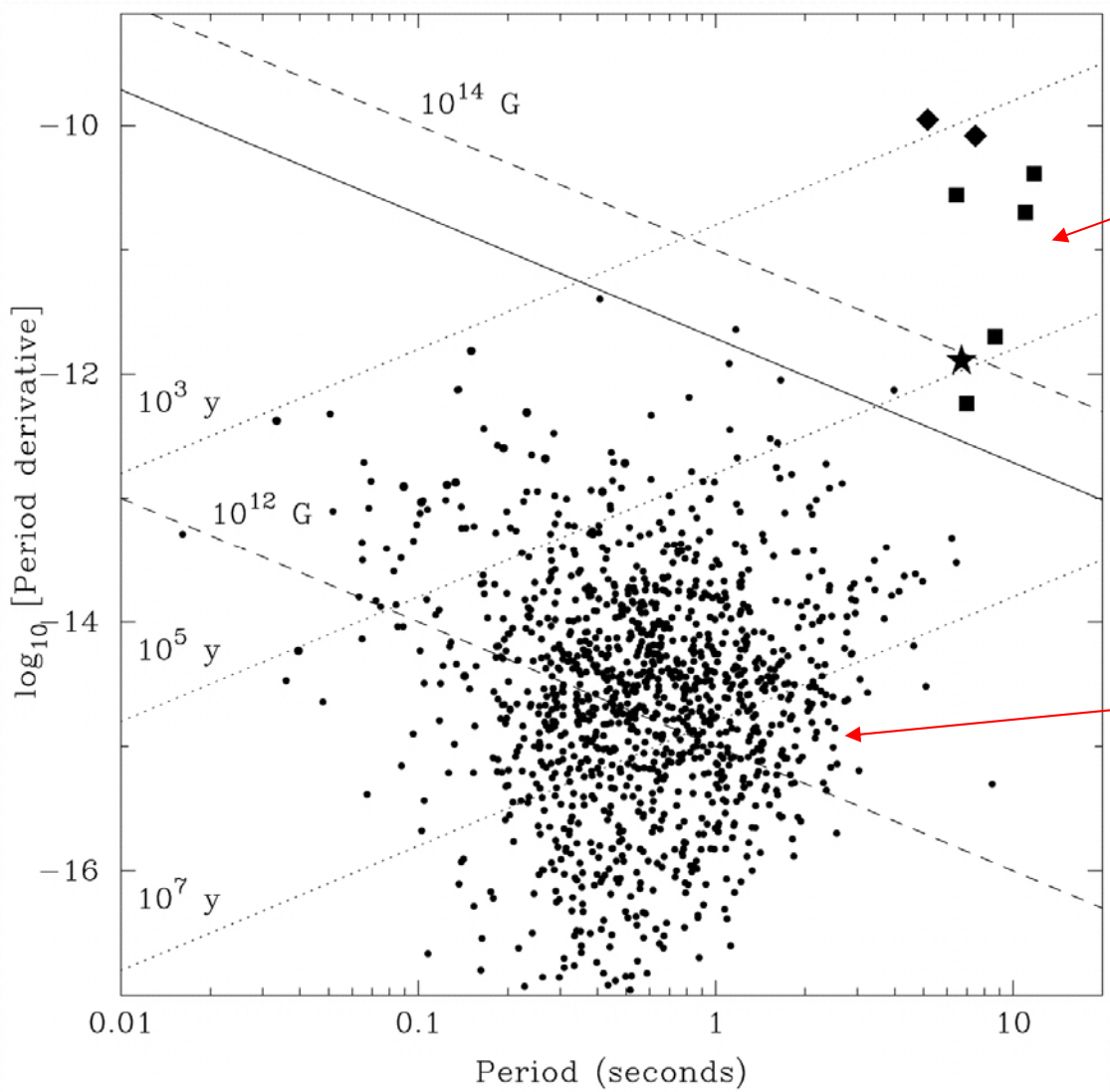
(Anomalous) X-ray Pulsars

- 5(8) known
- All but 1 in Galactic Plane (|b| < 1 deg), exception in SMC; some in SNRs→ **young sources**
- periods from 6-12 s, all **spinning down**
- X-ray luminosities 10^33 – 10^36 erg/s
- Soft X-ray spectra: thermal and non-thermal components
  - kT ~ 0.3-0.4 keV, Gamma ~ 2-4
  - But recently hard X-ray emission detected (Kuiper et al. 2004)
- **“anomalous” as energy source unclear: X-ray luminosity much too high to be rotation-powered**

Evidence for AXP being Magnetars

- AXP X-ray luminosity requires energy source
- B-field implied by P, dP/dt is magnetar-strength

P-Pdot Diagram



SGRs,
AXPs

$$B = 3.2 \times 10^{19} \sqrt{\dot{P} P G}$$

main
radio pulsar
population

McLaughlin et al. 2003

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- Similar X-ray spectra to SGRs
- Can exhibit X-ray bursts
  - Seen in 2 sources
  - Quantitatively similar to SGR bursts (Gavriil et al. 2004)

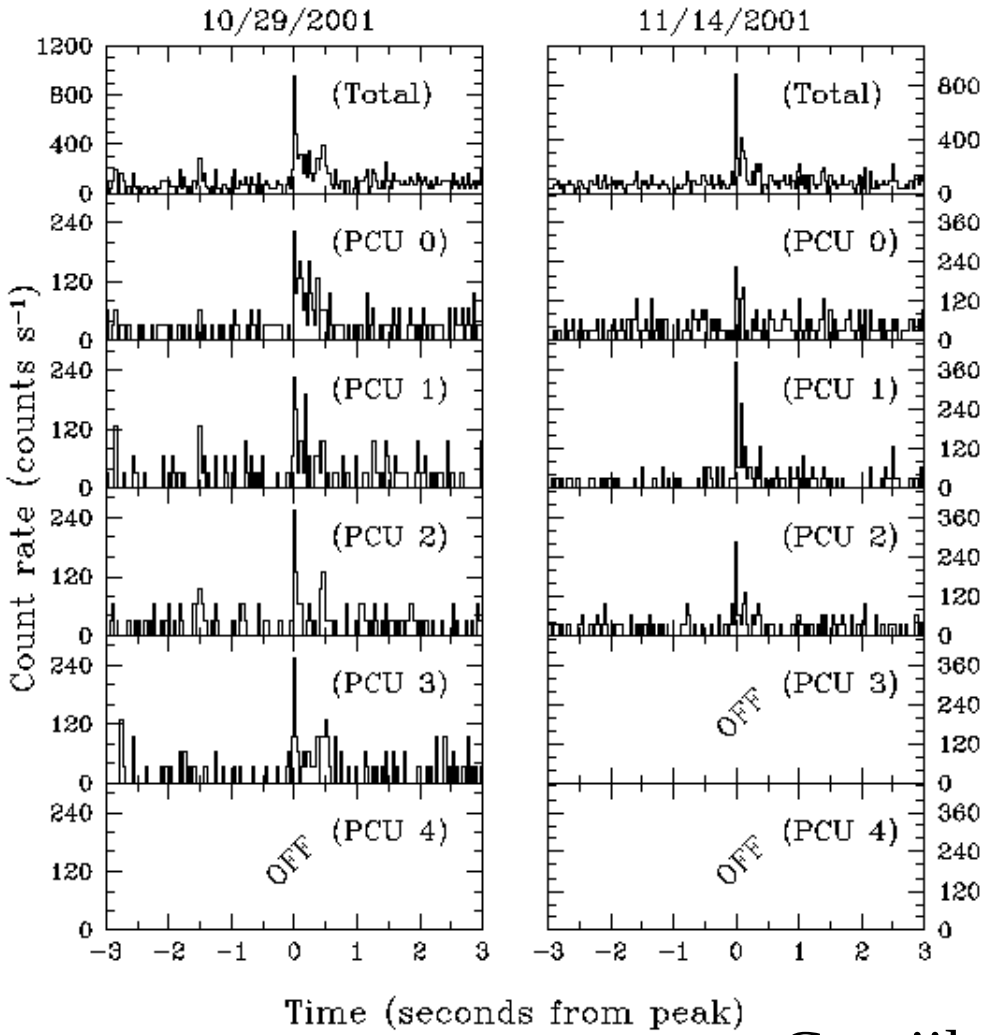
AXP Bursts

RXTE/PCA

1E 1048-5937

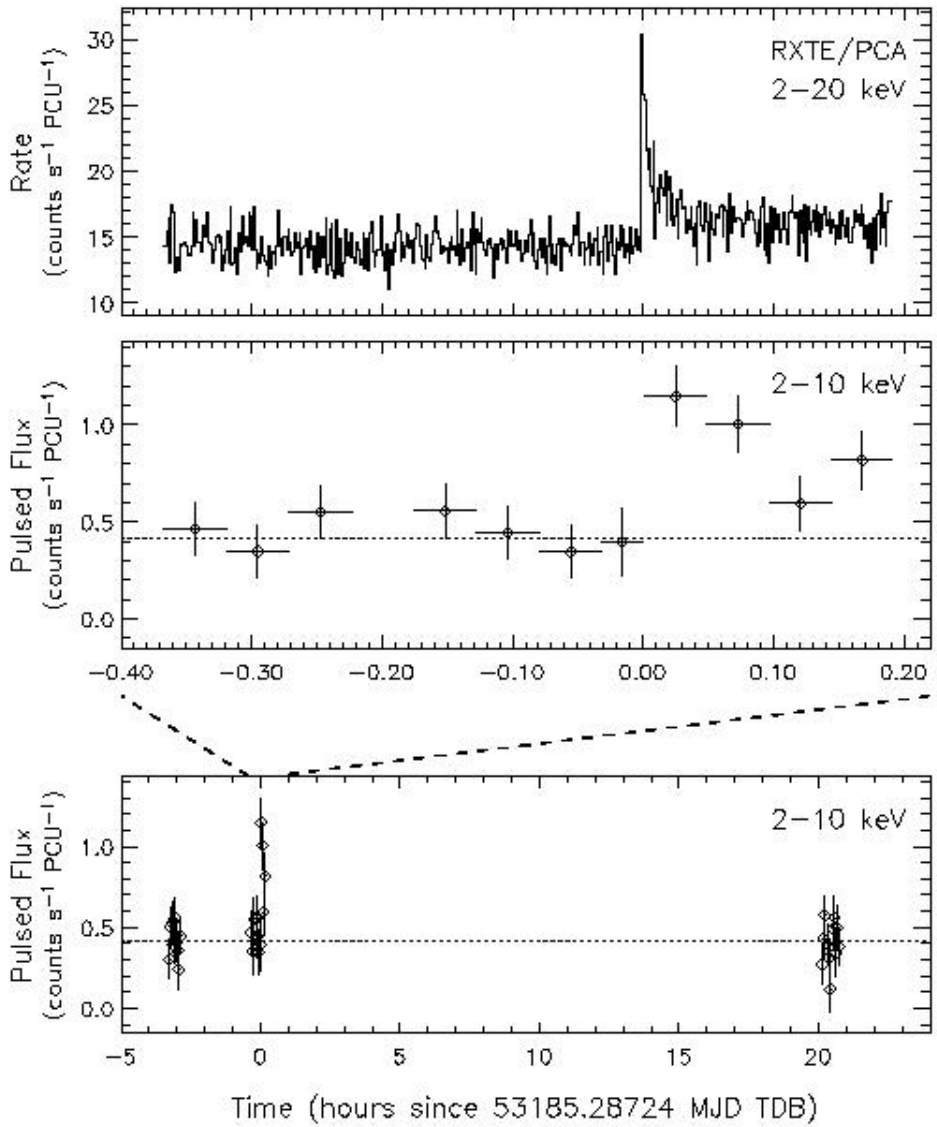
2 bursts detected in ~500 ks, over ~5 yr

PCA FOV 1 deg: Can't prove bursts from AXP…But burst properties unlike any other known phenomenon…



Gavriil, VK & Woods 2002

June 2004 Burst from 1E 1048-5937

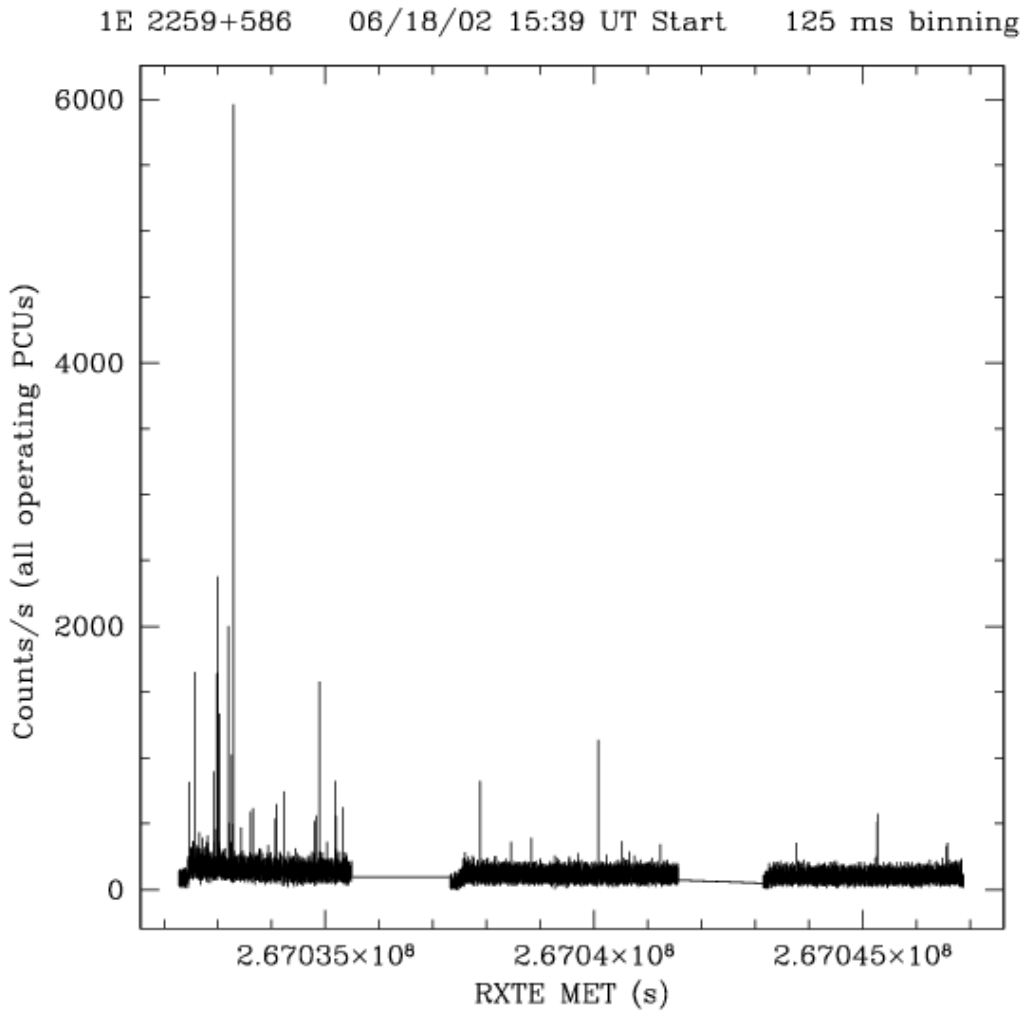


Simultaneous pulsed flux enhancement proves AXP is the burster.

Gavriil, VK & Woods, in preparation

Major Outburst from 1E 2259+586

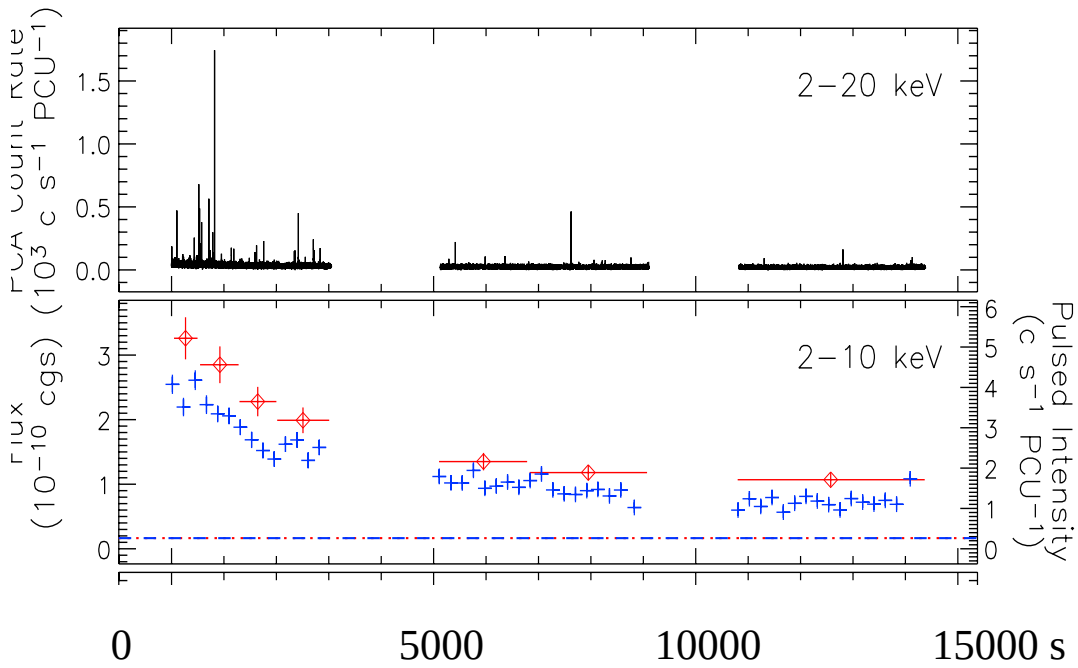
- on June 18, 2002, during *RXTE* observations, major bursting detected from 1E 2259+586
- 80 bursts detected in 15 ks observations; wide range of burst peak fluxes, fluences, rise times, durations, morphologies.



VK et al. 2003.

1E 2259+586 Outburst: Persistent Emission

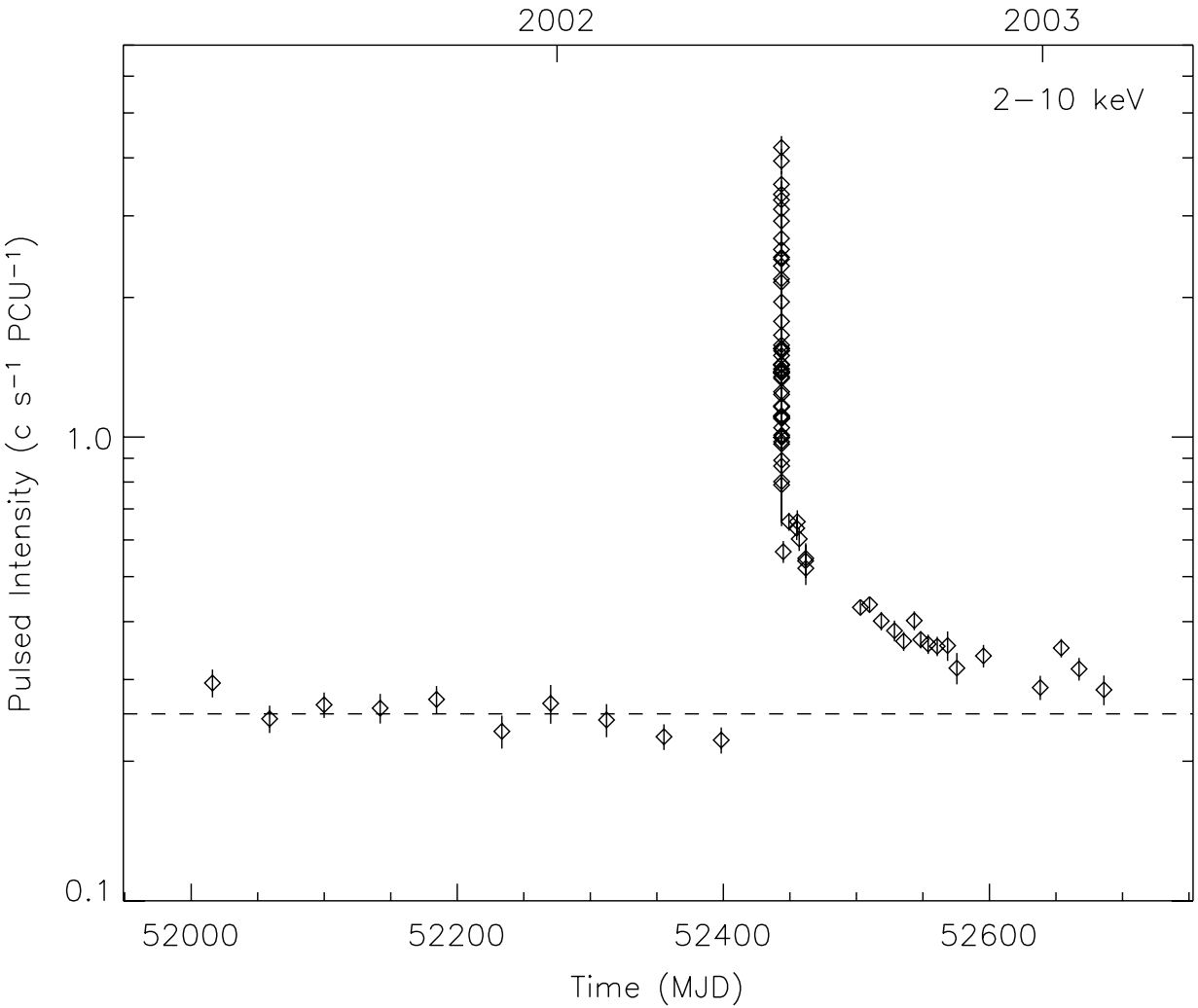
- pulsed, persistent flux increased by factor of >20 during outburst; decreased during observation, in concert with burst rate



persistent flux
pulsed flux

VK et al 2003

Longer Term 1E 2259+586 Pulsed Flux History



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

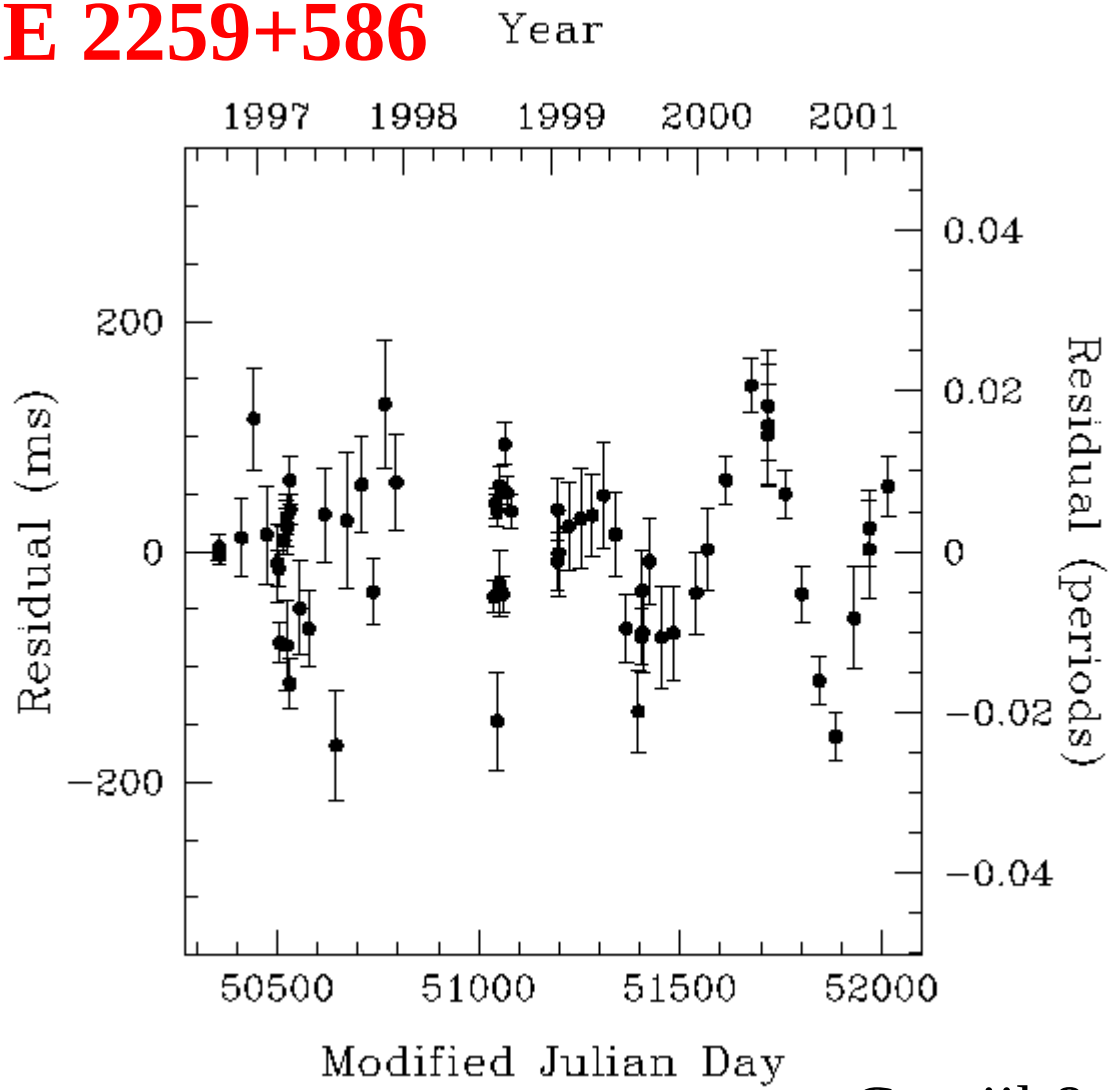
Woods et al. 2004

AXPs Accretion-Powered?

- Accretion from a supernova **fall-back disk**? (Van Paradijs et al. 1995; Chatterjee et al 1999; Alpar 1999)
  - **no mechanism or energy for bursts**
  - AXPs generally rotationally very stable

AXPs Generally Rotationally Stable

1E 2259+586



Also
4U 0142+61,
RXS J1708-4009,
1E 1841-045

Renders accretion models unlikely; makes glitch detection easy.

Gavriil & VK 2002

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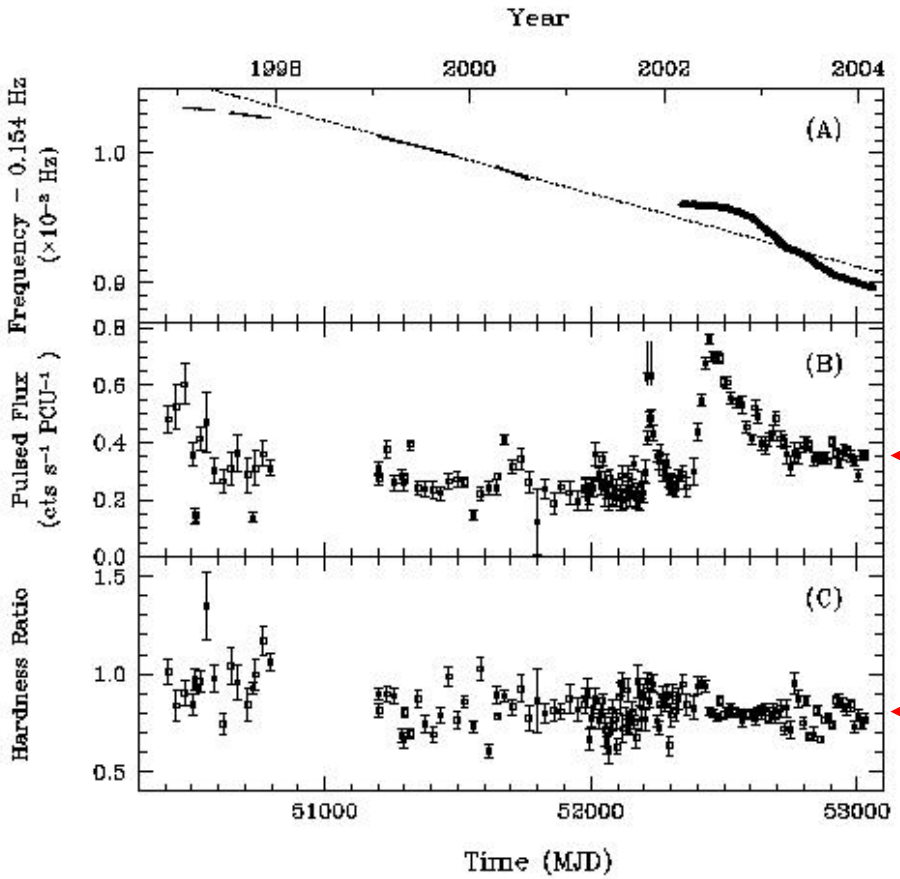
1E 1048-5937 Monitored with RXTE: an Anomalous AXP



Poor rotational stability

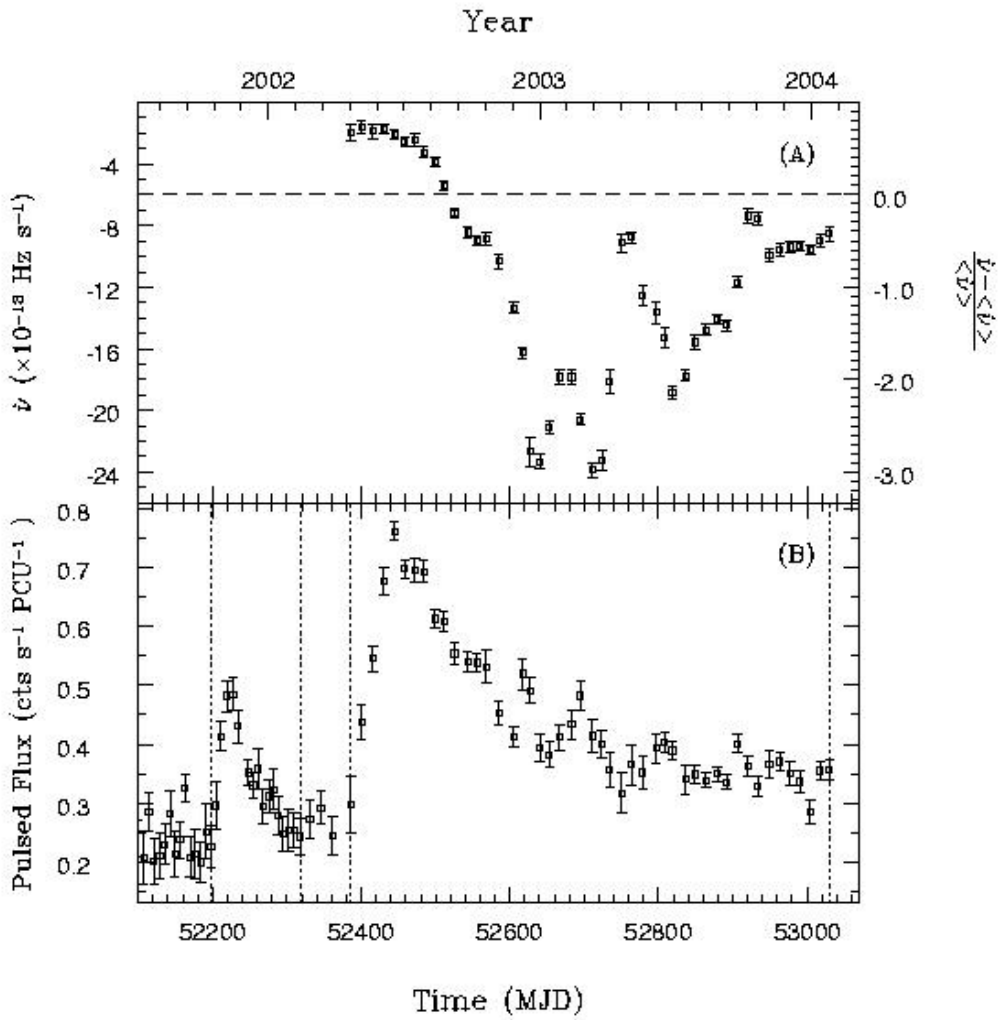
X-ray “flares”: several week rises

no large spectral changes

Gavriil & VK 2004.

Torque/Flux Correlation in 1E 1048-5937?

- no significant torque-flux correlation
- hard to explain in fossil disk model
- can possibly be explained in magnetar model (Thompson, Lyutikov & Kulkarni 2002)



Gavriil & VK 2004

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  - **27% optical pulsed fraction too high for reprocessing (Kern & Martin 2002)**

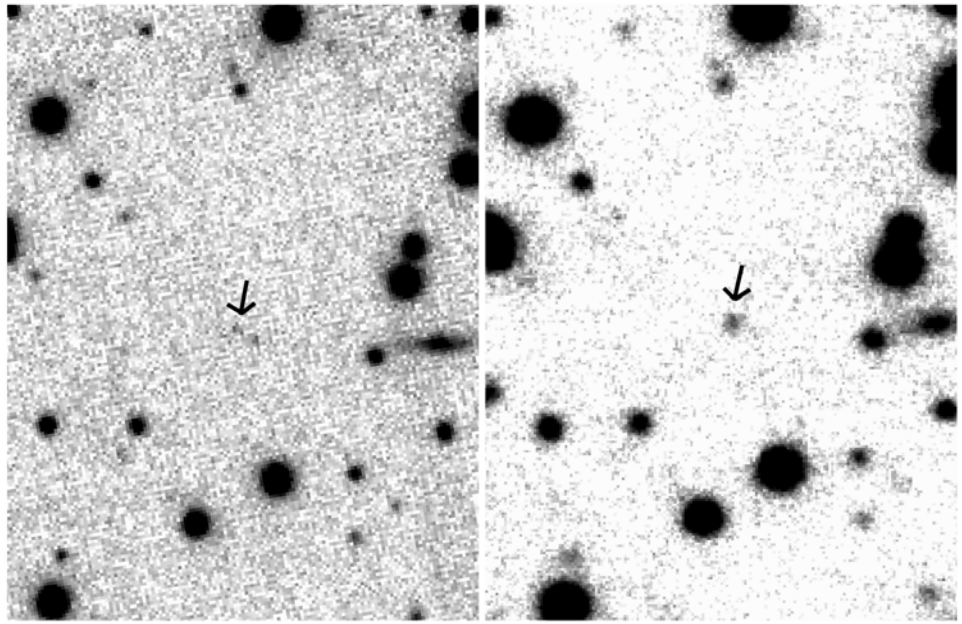
Very Probably NO.

Issues: IR "Excess"

- Most AXPs IR-detected; K~19-23 mag
- Energetically tiny compared to X-rays
- IR emission much brighter than expected from extrapolation of thermal spectrum
- Fainter than extrapolation of power law
- **IR variability** common; time scale unknown
  - In 1E 1048-5937, 4U 0142+61 IR and X-ray variability uncorrelated (Israel et al. 2002; Hulleman et al. 2004)
- Origin?
  - Magnetar + disk ? (Israel et al. 2003; Eksi & Alpar 2003)
  - Magnetospheric synchrotron emission as in radio pulsars? (Eichler et al. 2002; Ozel 2004)

1E 2259+586 Outburst: IR Brightening

- detected a brightening of IR counterpart by factor of 3.4, two days after 2002 burst, using NIRI and Gemini-North



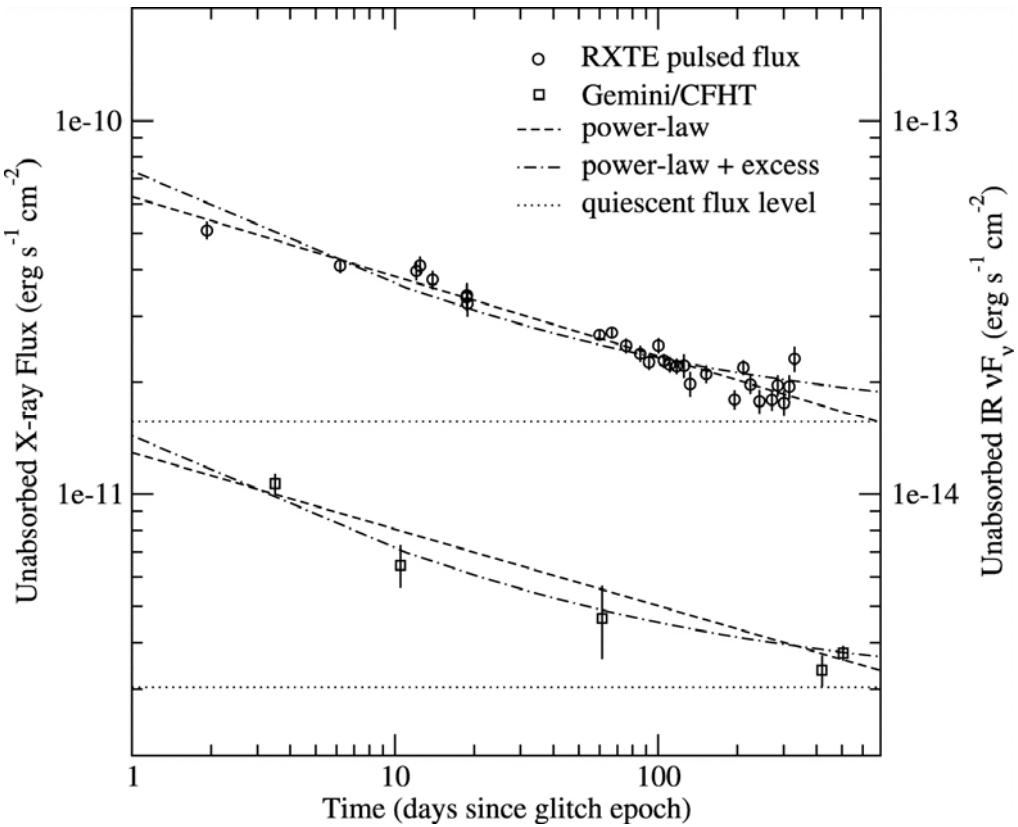
Keck, 2000
Ks = 21.6 mag
courtesy F. Hulleman

Gemini, 2002
Ks = 20.4 mag

VK et al 2003

IR Flux Decay

- Ks-band near-IR flux monitored with Gemini NIRI
- power-law decay
- exponent -0.21 +/- 0.02
- X-ray flux decay exponent -0.21+/-0.01
- **implies IR, X-rays correlated during <u>outbursts</u>**



Tam, VK, van Kerkwijk, Durant (2004)

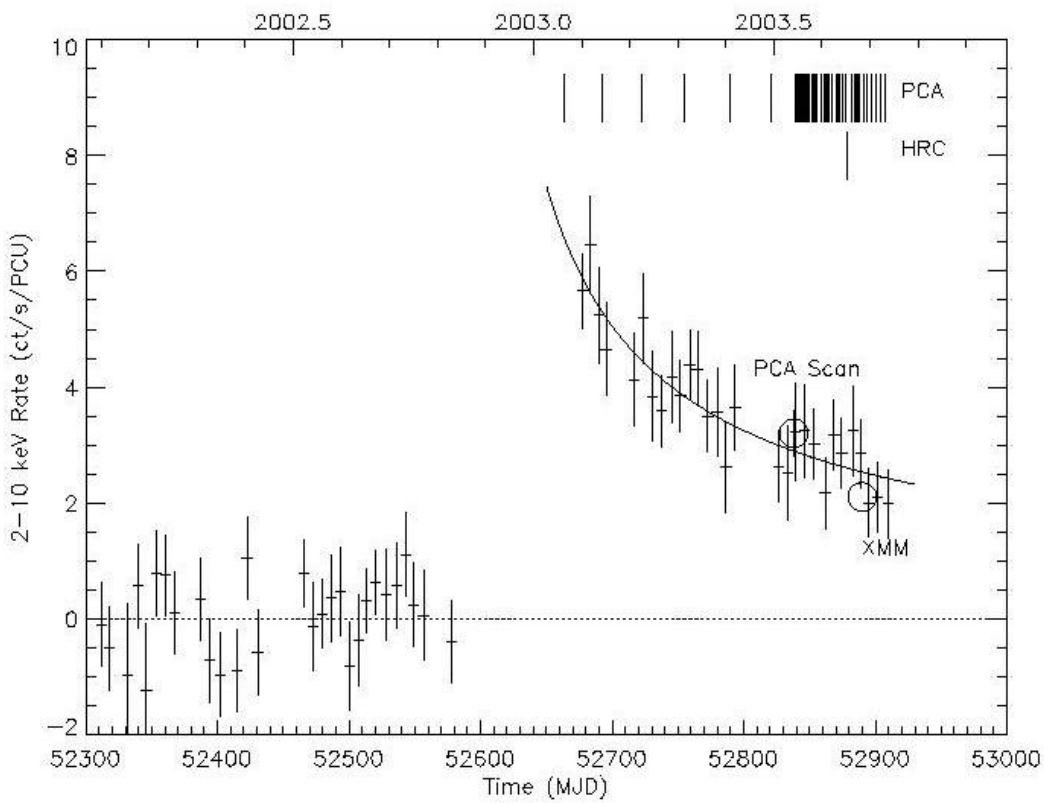
Issues: Transient AXPs

- 2 AXPs discovered in “outburst”: AX J1845-0258, XTE J1810-197
- Quiescent luminosities > 10-100x lower than in outburst
- No accompanying bursts detected (but easily could have been missed)
- Possibly correlated X-ray/IR decay (Rea et al. 2004)
- **How many more out there??**

Transient AXP

- Ibrahim et al. 2004 discovered new 5.54 s X-ray pulsar with RXTE in Jan 2003.
- pulsar spinning down regularly but noisily
- magnetar strength field inferred
- Quiescent spectrum thermal, kT~0.18 keV (Gotthelf et al. 2004)

XTE J1810-197



Ibrahim et al. 2004

How many more out there??

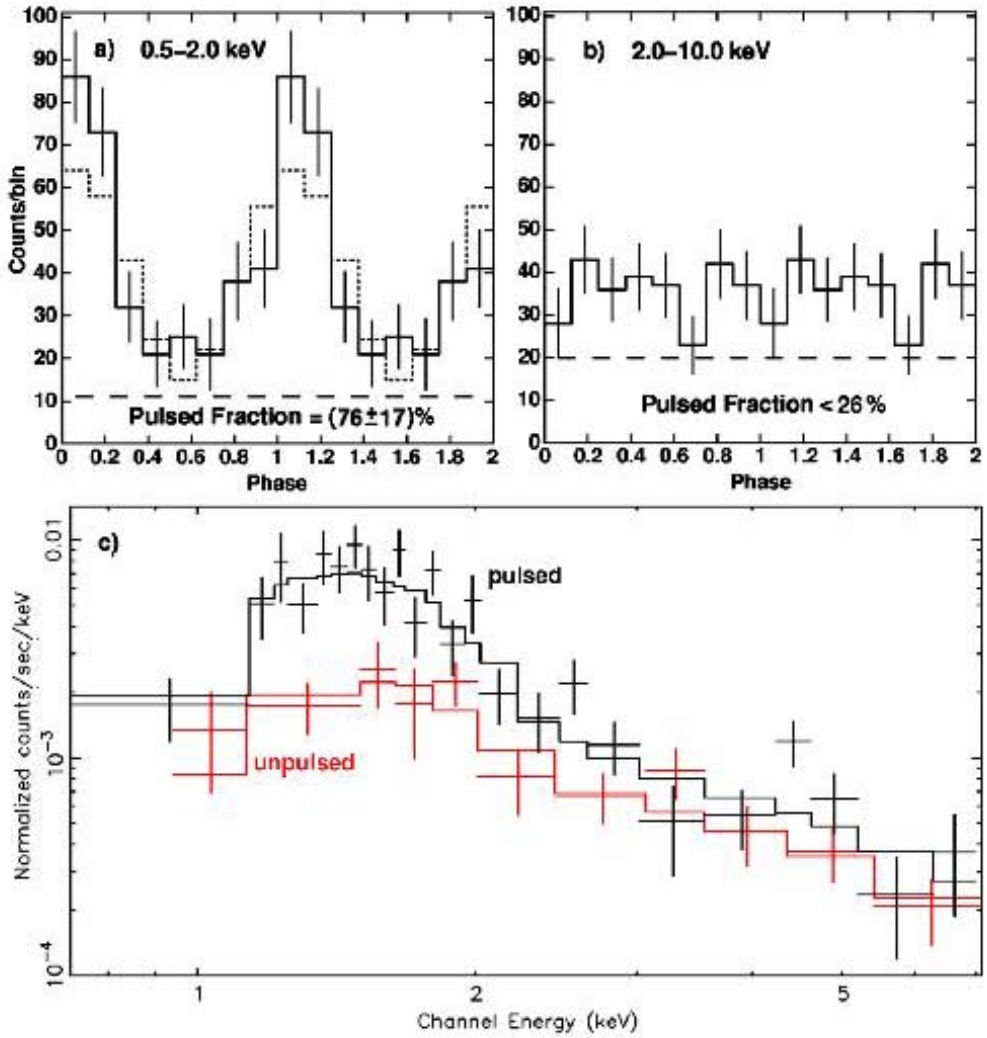
Issues: Connection to Radio Pulsars

- Some radio pulsars have B in magnetar range
- P, dP/dt, **glitches** seem to connect populations
- There should be **transition objects**
  - No AXP has shown radio emission: could be beaming
  - **Can a radio pulsar show AXP-like emission?**
- **PSR J1718-3718: B (7e13 G) higher than one AXP**
  - Chandra observations:
    - X-ray faint: flux ~ 6x10^-15 erg/s/cm2 (VK & McLaughlin 2004) though comparable to dE/dt
    - Soft spectrum (kT=0.145 keV)
  - could be initial cooling or **quiescent magnetar???**

PSR J1119-6127: A Young, High-B Radio Pulsar

- B = 4.1e13 G, age = 1.7 kyr
- XMM observation:
  - Lx ~ 0.0007 dE/dt
  - Thermal spectrum
    - T =2.3e6 K (bbody)
  - BUT: very high pulsed fraction: ~76%
  - Narrow pulse profile
- **Not explained by any conventional model for rotation-powered pulsars→ transition object??**

Gonzalez et al., submitted



Summary

- AXPs united with SGRs via P, dP/dt, spectra, X-ray luminosities, bursting, as predicted by **magnetar** model
- **Major Open issues**:
  - **What (if anything) differentiates AXPs from SGRs? Age? B?**
  - **What fraction of NSs are magnetars? Magnetar birthrate?**
  - **What (if anything) differentiates AXPs from high-B radio pulsars?**
  - **Is conventional P, dP/dt estimator for B reliable?**
- Other Open issues:
  - What is origin of IR emission?
  - What is origin of X-ray and IR variability?
  - What is origin of torque noise in AXPs (and radio pulsars!) ?

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 in Galaxy**
- need sensitive all-sky X-ray monitor to look for outbursts
- *SWIFT* may help…