Anomalous X-ray Pulsars

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Isolated Neutron Stars

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April 23, 2006
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
  \[ \rightarrow \text{``anomalous''} \]

Mereghetti & Stella (1995)
van Paradijs et al. (1995)
AXPs Generally Accepted to be Magnetars

- 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

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

Gavriil & VK 2002
1E 2259+586: 2002 Glitch

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

Woods et al 2004
AXP TIMING...
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.
1E 1048-5937: Anomalous AXP

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

AXP VARIABILITY

- Flares
- Outbursts
- Pulse profile changes
- Transients
- Bursts
- see talk by Nanda Rea
1E 1048-5937: Anomalous AXP

X-ray “flares”: several week rises; $10^{41}$ erg

Poor rotational stability


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

AXP VARIABILITY...

Ibrahim et al. 2004
Gotthelf et al. 2004
Woods et al. 2005
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
Simultaneous pulsed flux enhancement proves AXP is the burster.
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

**AXP 1E2259+586 - XMM Pre-burst**

**AXP 1E2259+586 - XMM Post-burst**

Woods et al. 2004
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 VARIABILITY...
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)
Hard X-ray Emission

- Spectrum turns over!
- $E > 10 \text{ keV} \gg \dot{E}$
- Generic AXP property
- Similar to Vela-like pulsar hard X-ray spectra
- See talk by Peter den Hartog

Kuiper et al., in press
Infrared Emission

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

Wang et al. 2006

AXP SPECTRA...
IR Flux Decay

- 1E 2259+586 2002 outburst: IR enhancement in K
- power-law decay, exponent $-0.21 \pm 0.02$
- X-ray flux decay exponent $-0.21 \pm 0.01$
- 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 AXP\(\text{s}\) 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?