High Magnetic Field Pulsars

Fotis Gavriil

(CRESST: NASA Goddard Space Flight Center
& University of Maryland Baltimore County)

High Magnetic Field Pulsars

- 1. Magnetars: Young, isolated neutron stars powered by their enormous magnetic fields (Thompson & Duncan 1995, 1996). Rotational kinetic energy cannot account for their emission.
  - Soft Gamma Repeaters (SGRs)
    - Part of the core program (monitoring + ToO)
  - Anomalous X-ray Pulsars (AXPs)
    - Part of the core program (monitoring + ToO)
- 2. Highly Magnetized Rotation-Powered Pulsars (RPPs):
  - PSR J1846-0258 is the only known “magnetically active” RPPs
    - Part of the core program
  - Other Magnetically active RPPs??
    - A Cycle 13 monitoring campaign

Part 1. *RXTE* Monitoring of AXPs

As part of the core program RXTE regularly monitors AXPs in order to:

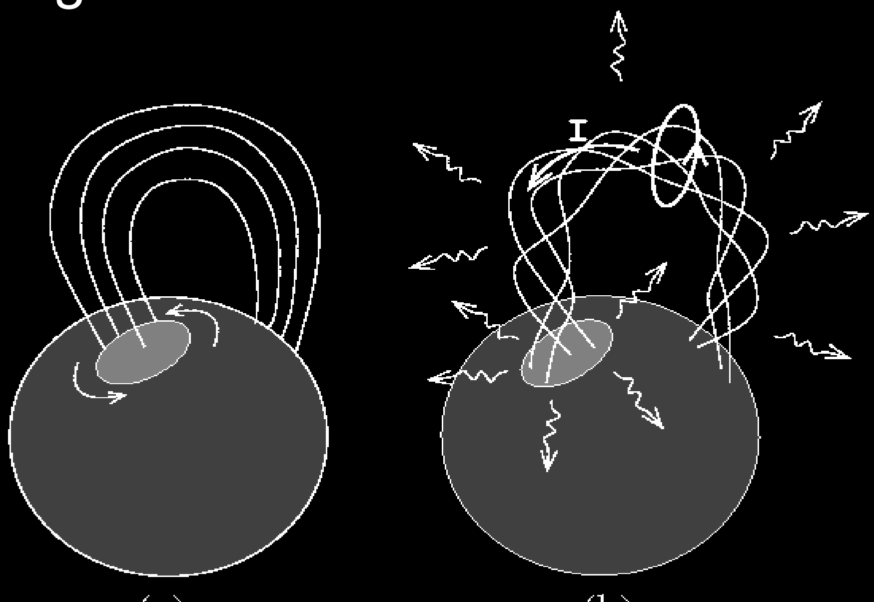
- Phase coherently time them. Phase coherent timing enables the detection and characterization of rotational glitches.
- Detect variations in their pulse profiles.
- Detect long (~weeks to month) enhancements in their pulsed flux.
    - Correlate any flux variations with spectral variations
- Detect short (~ms) SGR-like bursts.
    - Search for spectral features in these bursts

This program has been very successful for RXTE.

- RXTE detected the first glitch from an AXP (Kaspi et al. 2000, ApJ, 537, L31). Since then glitches have been observed from five other AXPs. All but one glitch was seen exclusively by RXTE.
- RXTE was the first instrument to detect SGR-like bursts from an AXP (Gavriil et al. 2002, Nature, 419, 142). Since then six AXPs have been observed to burst, and all but two burst episodes were detected exclusively by RXTE.
- Pulse profile variations have been observed by RXTE in connection with large radiative changes.
- RXTE has detected large flux variations in AXPs. Although not the only instrument to observe large flux variations in an AXP, RXTE was the first instrument to detect a "transient AXP". Transient AXPs are sources that show flux enhancements that are much larger (factor of ~100) and longer lived.

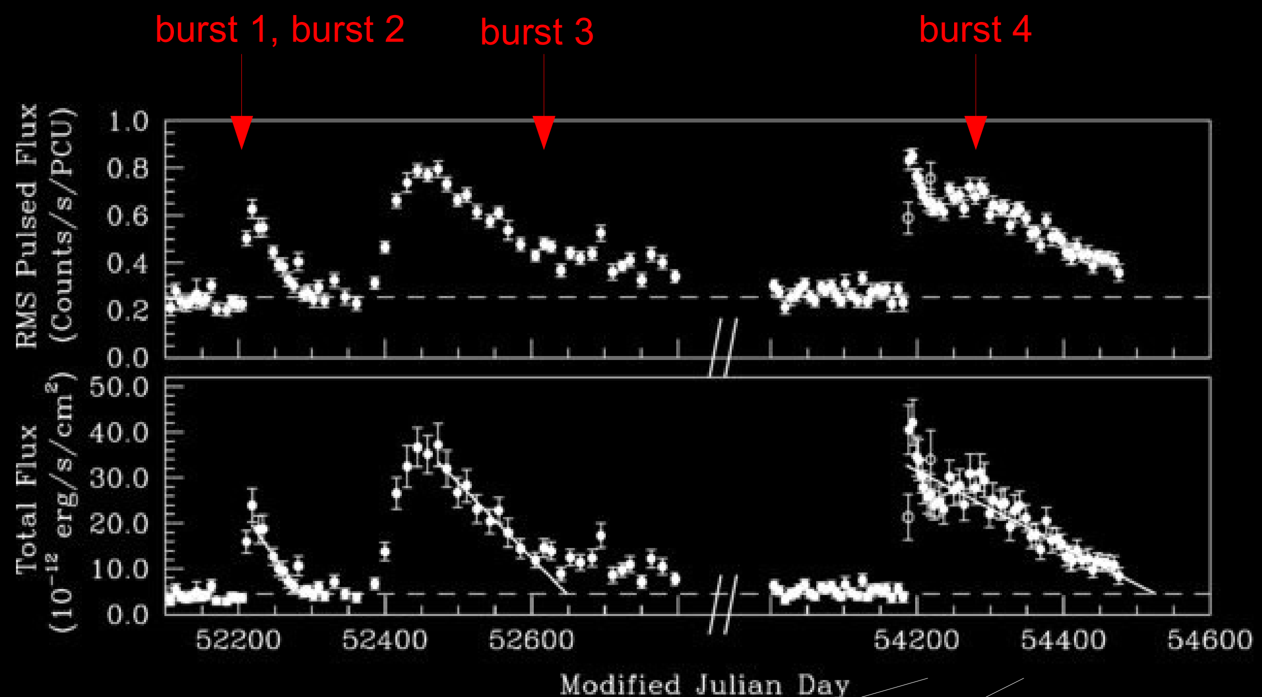
New Results for AXPs

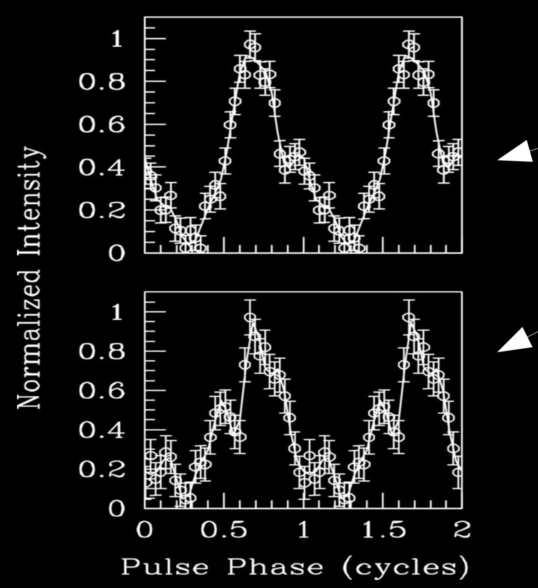
- Anomalous X-ray Pulsars
- In the last year we have submitted two papers on comprehensive studies of two major outbursts from two very different AXPs
  - 1E 1048.1-5947 (Dib, Kaspi, Gavriil, 2009)
  - 4U 0142+61 (Gavriil, Dib, Kaspi, 2009, in press)
- Both outbursts included: flares, bursts, spectral changes, rotational glitches, and pulse morphology changes. In both of these outbursts every aspect of the pulsar's emission changed.

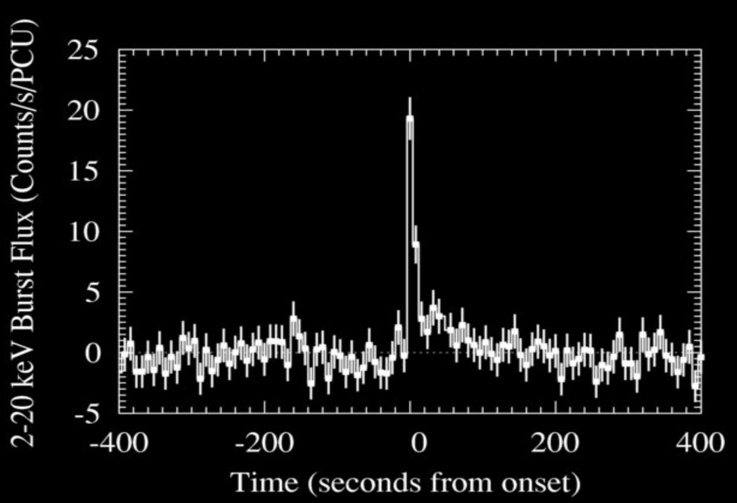


(a) (b)

1E 1048.1-5937

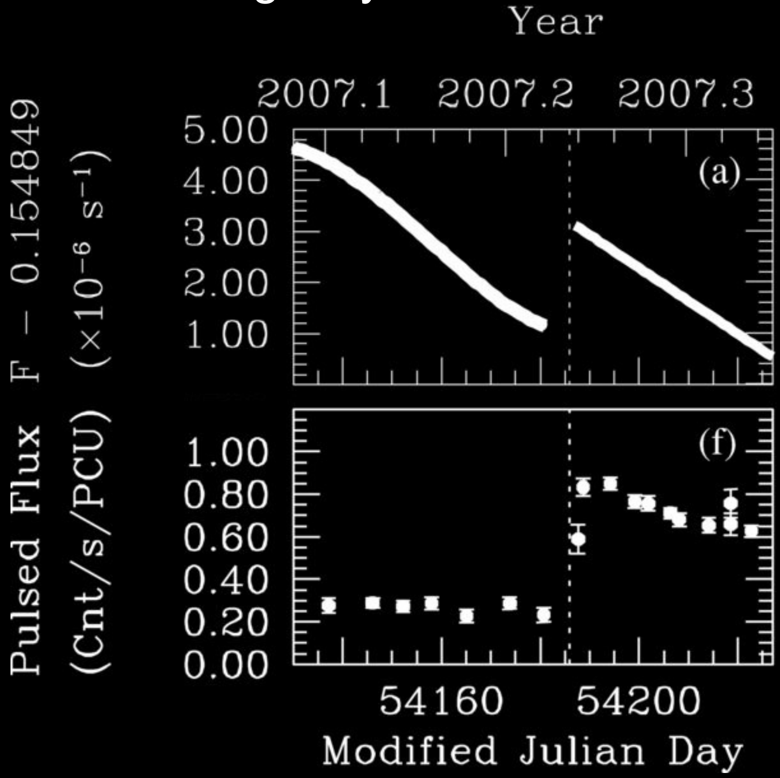






Dib, Kaspi, Gavriil, 2009, ApJ, 702, 614

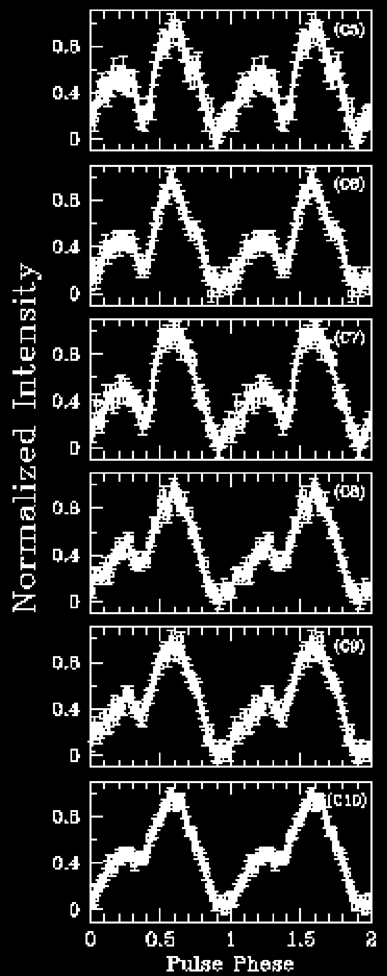
- As well as bursts and pulse profile changes the flares were accompanied by rotational variations:
  - A Timing anomaly of uncertain nature was seen near the onset of the first pulsed flare
  - A rotational glitch near the onset of the second flare, $\Delta\nu/\nu=2.91(9)\times10^{-6}$
  - A rotational glitch near the onset of the third flare, $\Delta\nu/\nu=1.63(2)\times10^{-5}$
- The third glitch was very large by any glitch standards. A large glitch, $\Delta\nu/\nu\sim10^{-4}$ was claimed by Israel et al. 2006 (ATEL #986) for AXP CXO J164710.2-455216. However this glitch is contested by our group (Woods et al. 2009, in press). Reanalyzing the Swift data, we find no evidence for such a glitch. CXO J164710.2-455216 exhibited huge pulse profile variations such that the relative amplitudes of the peaks would swap, making pulse numbering very difficult.

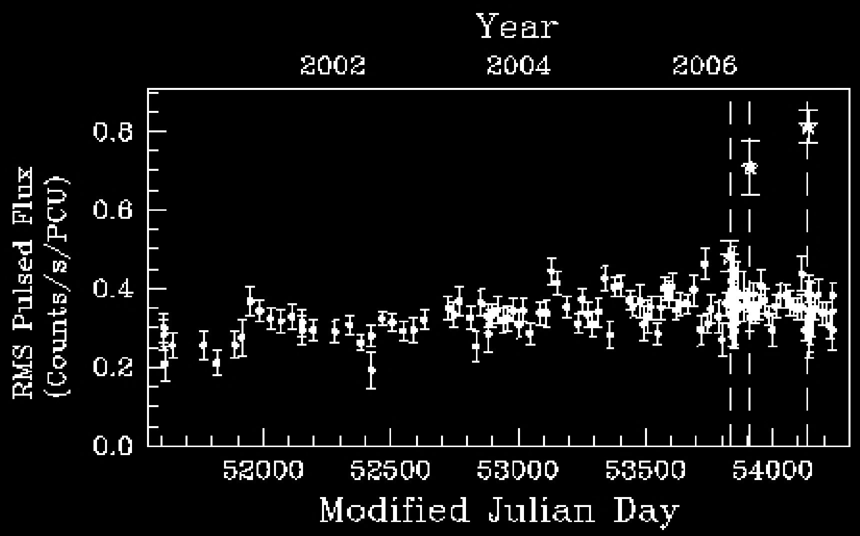


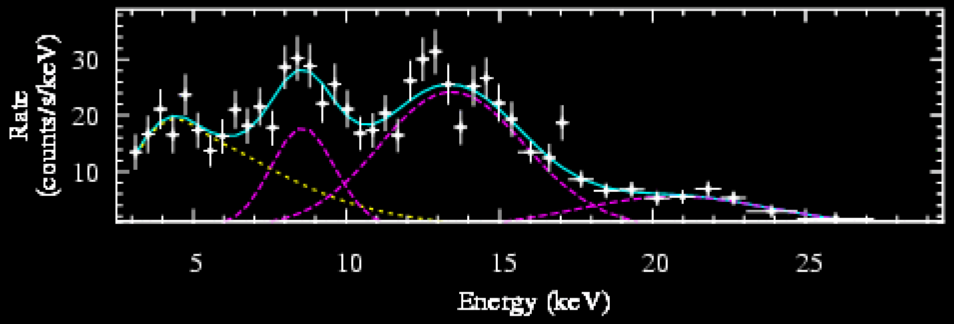
$$\nu(t) = \nu_0(t) + \Delta\nu + \Delta\nu_d \exp[-(t-t_g)/t_d] + \Delta\dot{\nu}(t-t_g)$$

Dib, Kaspi, Gavriil, 2009, ApJ, 702, 614

4U 0142+61

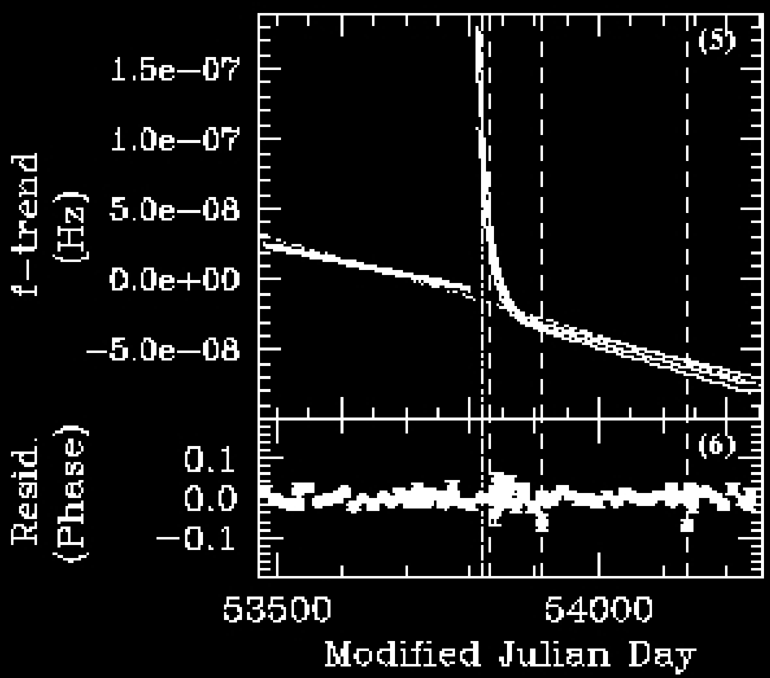






Gavriil, Dib, Kaspi, 2009, in press.

- The persistent change in frequency after the glitch was negative
  - The pulsar was actually spun down, sort of an “anti-glitch”
  - The net fractional change was $\Delta\nu/\nu=-1.1(1)\times10^{-7}$
  - This has only seen before during the giant flare of SGR 1900+14 (this event had a fractional change of $\sim10^{-4}$)



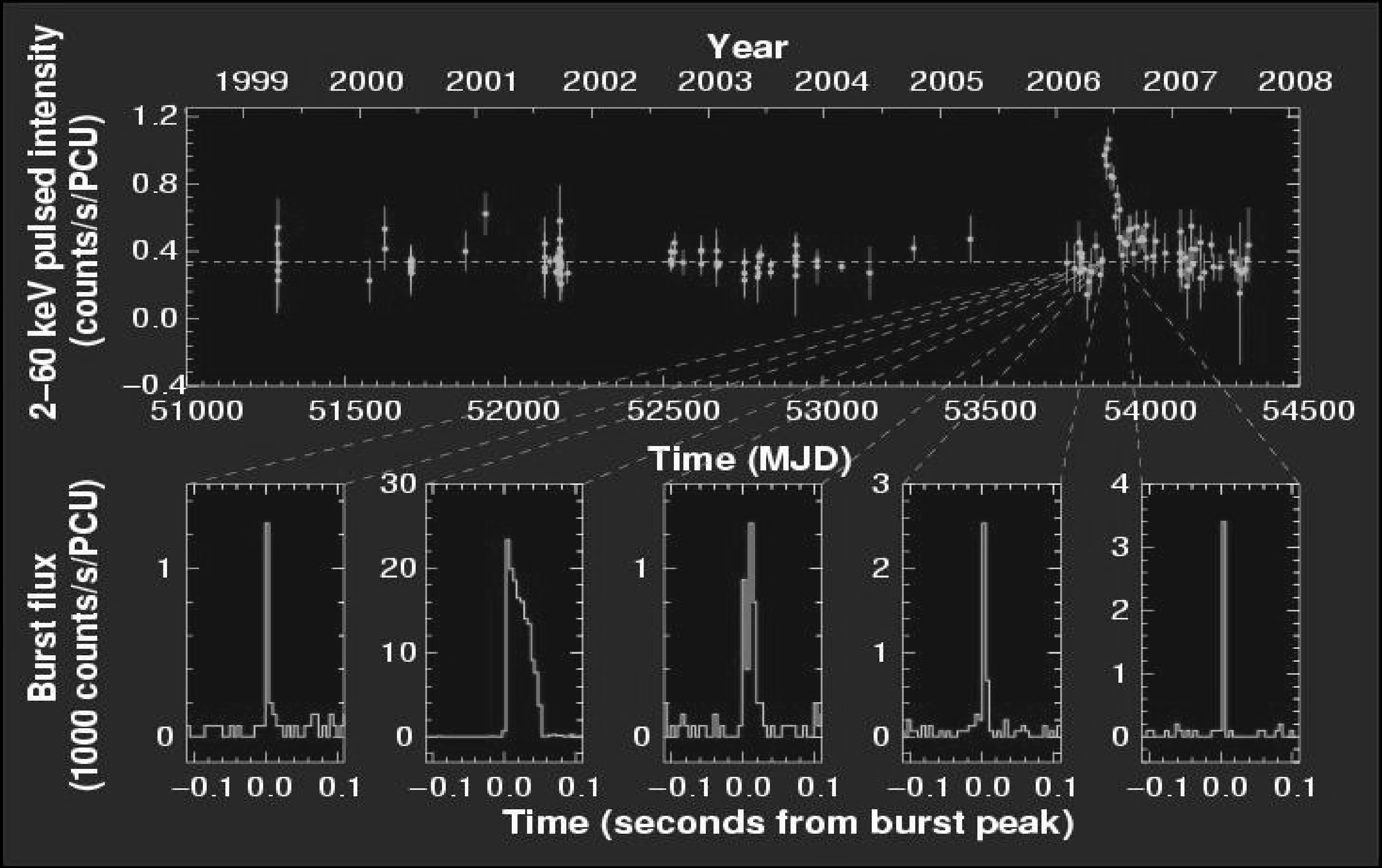
$$\nu(t) = \nu_0(t) + \Delta\nu + \Delta\nu_d \exp[-(t-t_g)/t_d] + \Delta\dot{\nu}(t-t_g)$$

Gavriil, Dib, Kaspi, 2009, in press.

Part 2. High-B Rotation-Powered Pulsars

- PSR J1846-0258 is an example of a High-B Rotation Powered Pulsar:
  - PSR J1846-0258 is the young pulsar in Kes 75
  - P = 326 ms
  - Rotation power can account for observed X-ray Luminosity
  - High Magnetic field $B \equiv 3.2\times10^{19}\mathrm{G}(P dP/dt)^{1/2}$
- What's the connection between High-B Rotation-Powered Pulsars and Magnetars ??

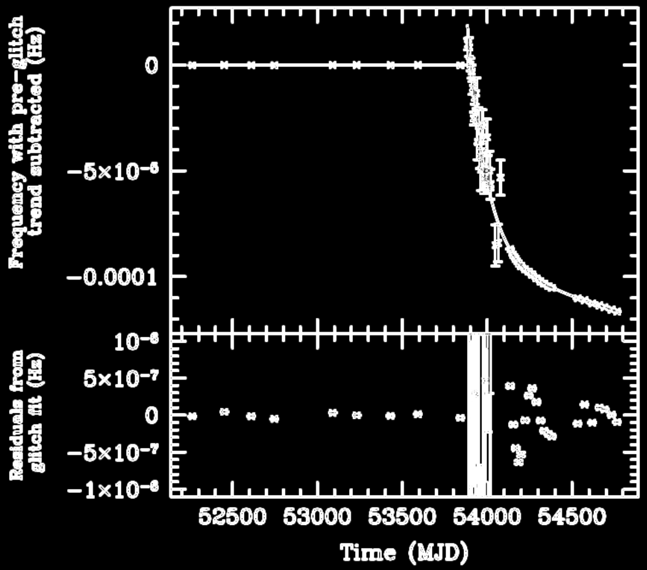
PSR J1846-0258

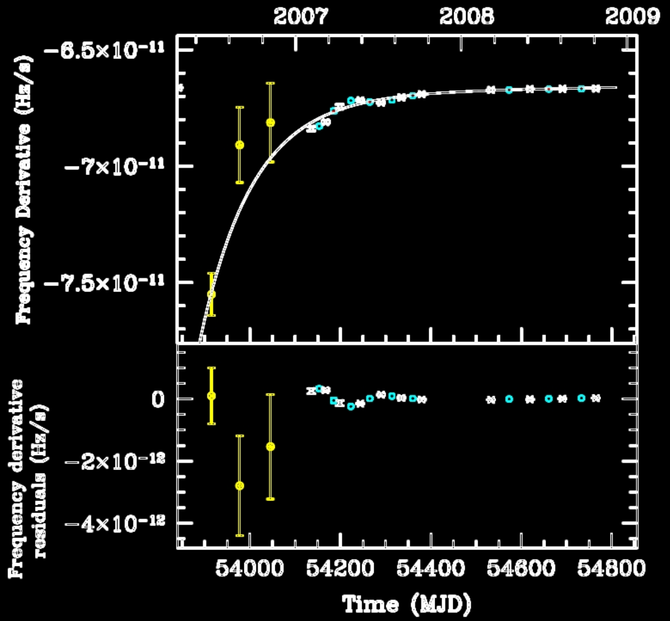


Gavriil, et al. 2008, Science, 319, 1802

New Results for High-B RPPs

- When the outburst was first discovered we announced a dramatic change in timing noise.
- Recent analysis with RXTE has shown large glitch at the time of the outburst (Kuiper & Hermsen 2009, A&AS, 501,1031, Livingstone et al. 2009, in press).
- The fractional frequency increase was large for such a young pulsar $\Delta\nu/\nu=4(1)\times10^{-6}$, and the glitch displayed a similar over-recovery that thus far has only been seen in AXP 4U 0142+61, and SGR 1900+14, and never in a young rotation-powered pulsar (Livingstone et al. 2009).





$$\nu(t) = \nu_0(t) + \Delta\nu + \Delta\nu_d \exp[-(t-t_g)/t_d] + \Delta\dot{\nu}(t-t_g)$$

Livingstone, Kaspi, Gavriil 2009, ApJ, in press

High-B Rotation-Powered Pulsars

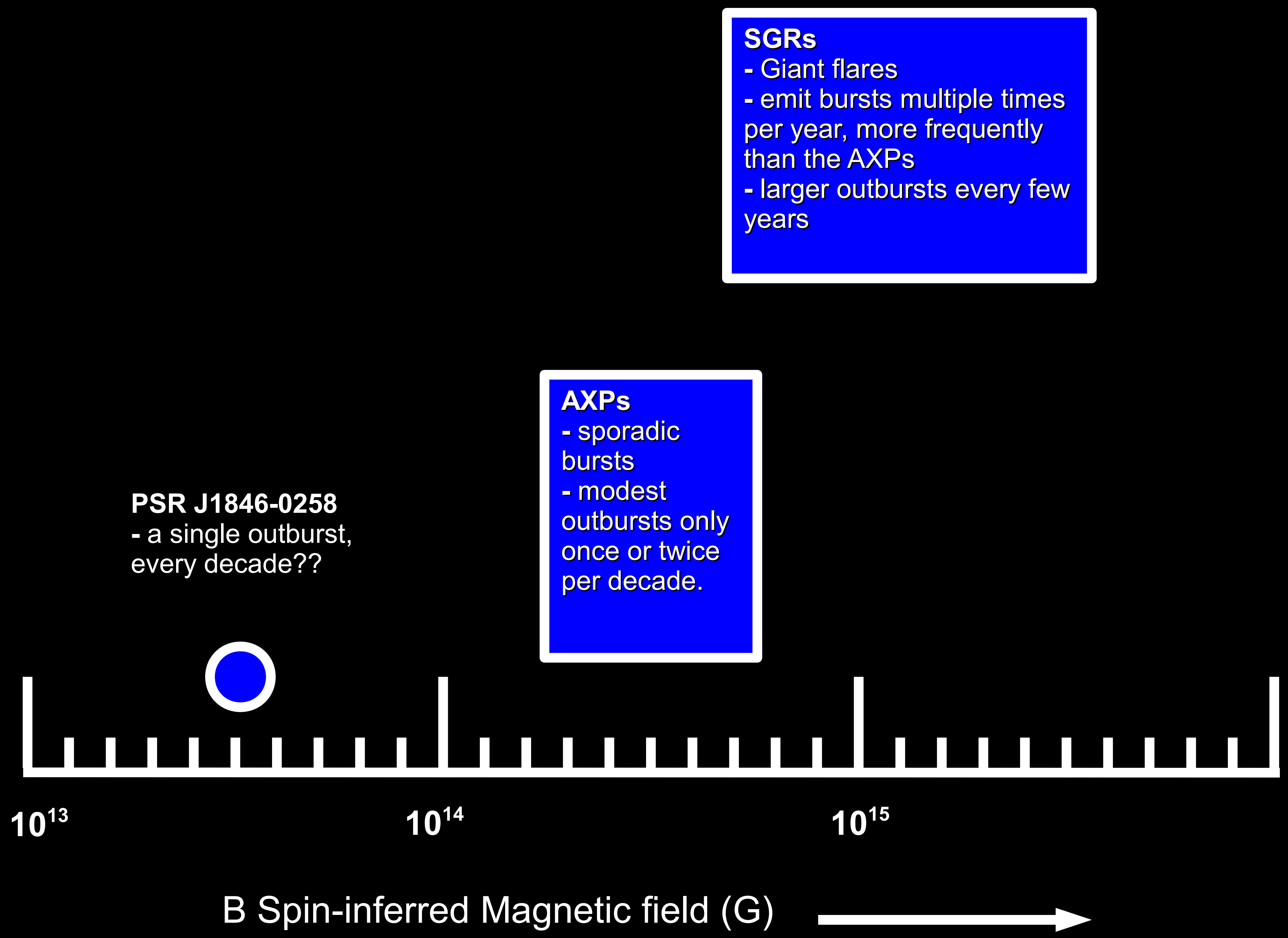
Highly magnetized RPPs

Source	B (10^{13} G)	Exposure (ks)
PSR J847-0130	9.36	0.3
PSR J1718-3718	7.44	4.5
PSR J1814-1744	5.51	1.1
PSR J1734-3333	5.22	16.9
PSR J1819-1458	5.01	96
PSR J1846-0258	**4.86**	**1686**
PSR J1119-6127	4.1	0
PSR J1821-1419	3.89	83

In Cycle 13 the exposure time of six of these RPPs has been increased by 72 ks.

Conclusions

- *RXTE* will continue to monitor AXPs in order to understand their behavior (rotational glitches, bursts, pulsed flux flares, etc.) and place constraints on the magnetar model.
- The AXP monitoring program also serves as an important trigger for other observatories. In the event of a timing, radiative or spectral variation observed by RXTE we have an approved Chandra ToO program. Chandra can provided total flux and pulsed fraction measurements, important parameters that we cannot measure with RXTE.
- Continued timing of PSR J1846-0248 in order to eventually measure its braking index, and possible variations in this parameter. The timing ephemeris provided by RXTE will be invaluable for future missions that wish to continue timing this source (e.g. this year we proposed for timing observations with *Swift*).
- In the quest to determine if PSR J1846-0258 is unique, we monitor high-B field neutron stars with RXTE. These observations can potentially detect bursts and flares from these sources. These observations also serve as an important trigger for other observatories. We also put in for Swift monitoring of these sources and an RXTE ToO program.


SGRs
- Giant flares
- emit bursts multiple times per year, more frequently than the AXPs
- larger outbursts every few years
AXPs
- sporadic bursts
- modest outbursts only once or twice per decade.
PSR J1846-0258
- a single outburst, every decade??
10^13
10^14
10^15
B Spin-inferred Magnetic field (G)