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HIGH-B RADIO PULSARS

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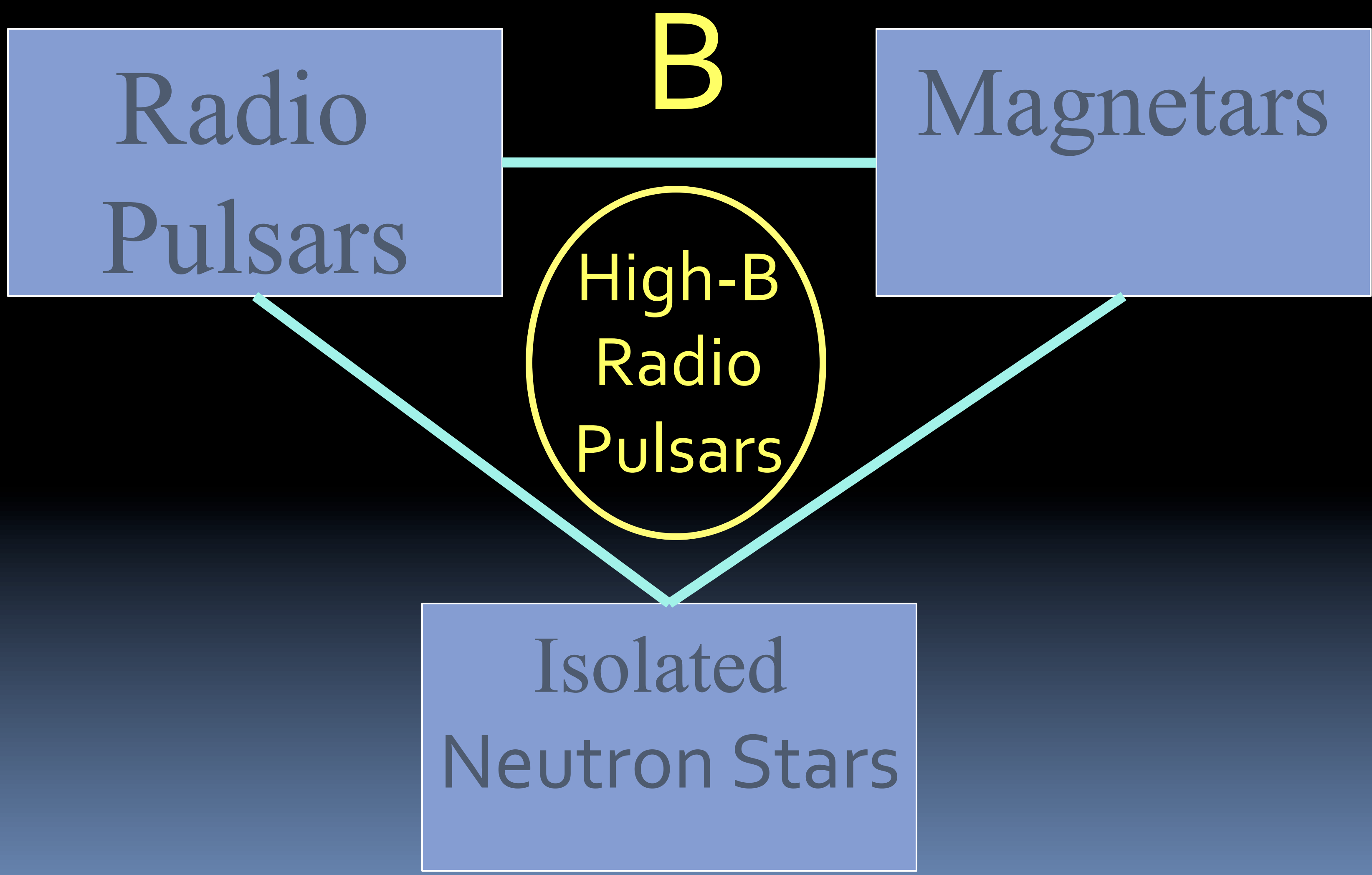
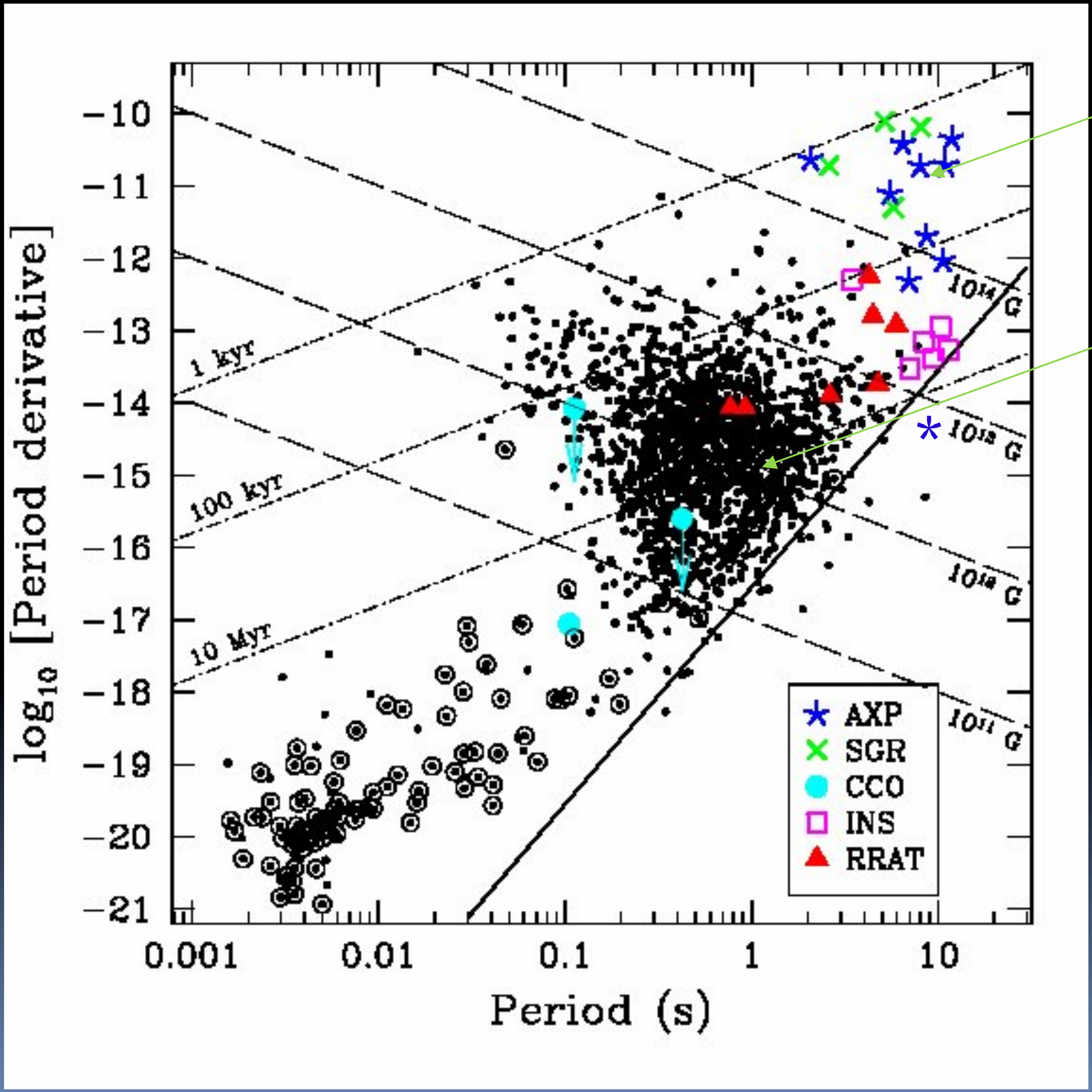
HIGH-B RADIO PULSARS

Why High-B Radio Pulsars?



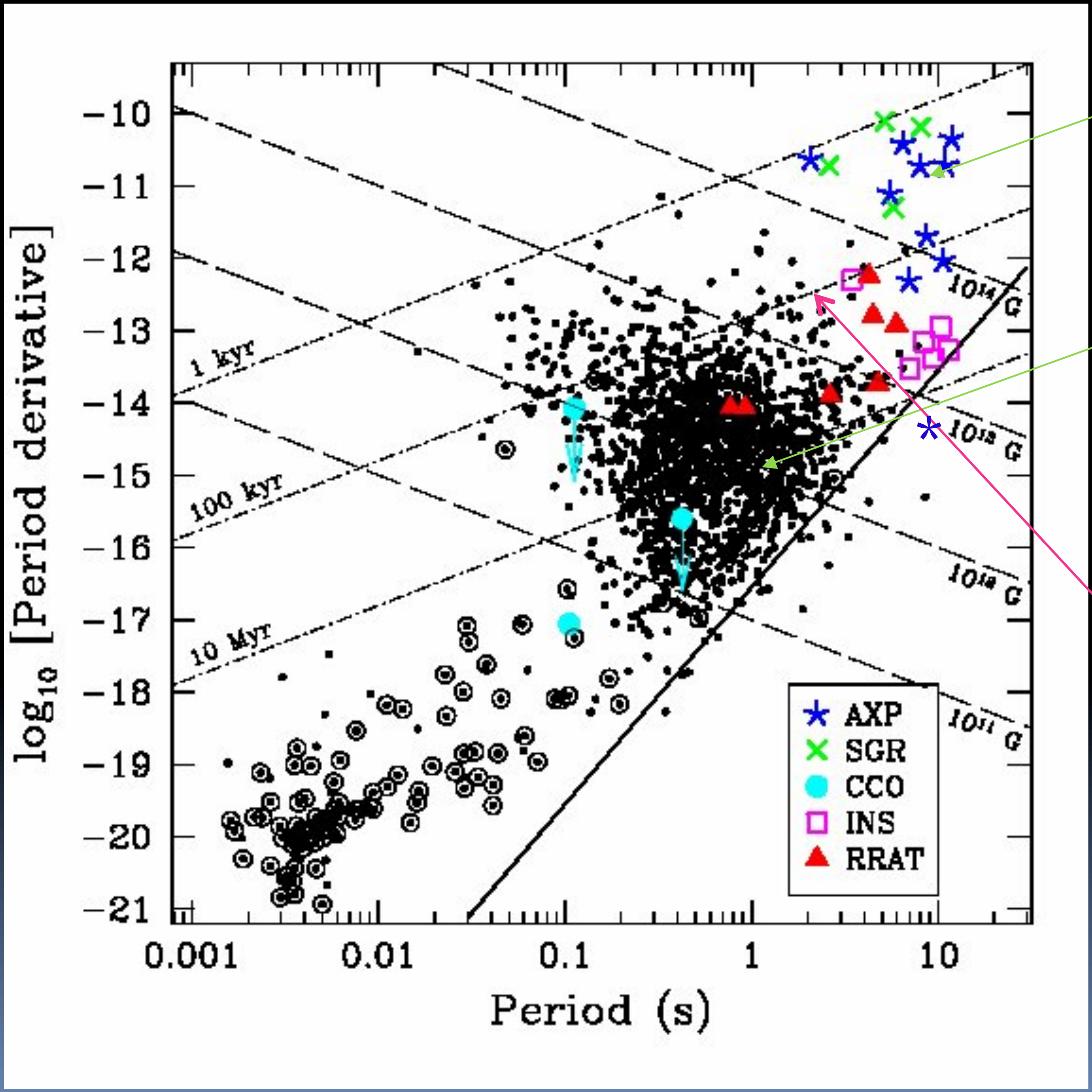
P-Pdot Diagram



SGRs, AXPs

Radio Pulsars

P-Pdot Diagram



SGRs, AXPs

Radio Pulsars

High-B Radio Pulsars

High-B Radio Pulsars

- My language:
  "radio pulsar" = "rotation-powered pulsar"
  "high B" = B > 4e13 G (Bqed=4.4e13G)
- B estimated from P, Pdot: uncertain!
  - Spitkovsky (2006) suggests at worst factor of ~2 (at least for stable sources)
  - Thompson, Lyutikov & Kulkarni (2002) suggest could be overestimated due to global field twist

This talk will be highly EMPIRICAL.

Theory: "Magneto-thermal Evolution"

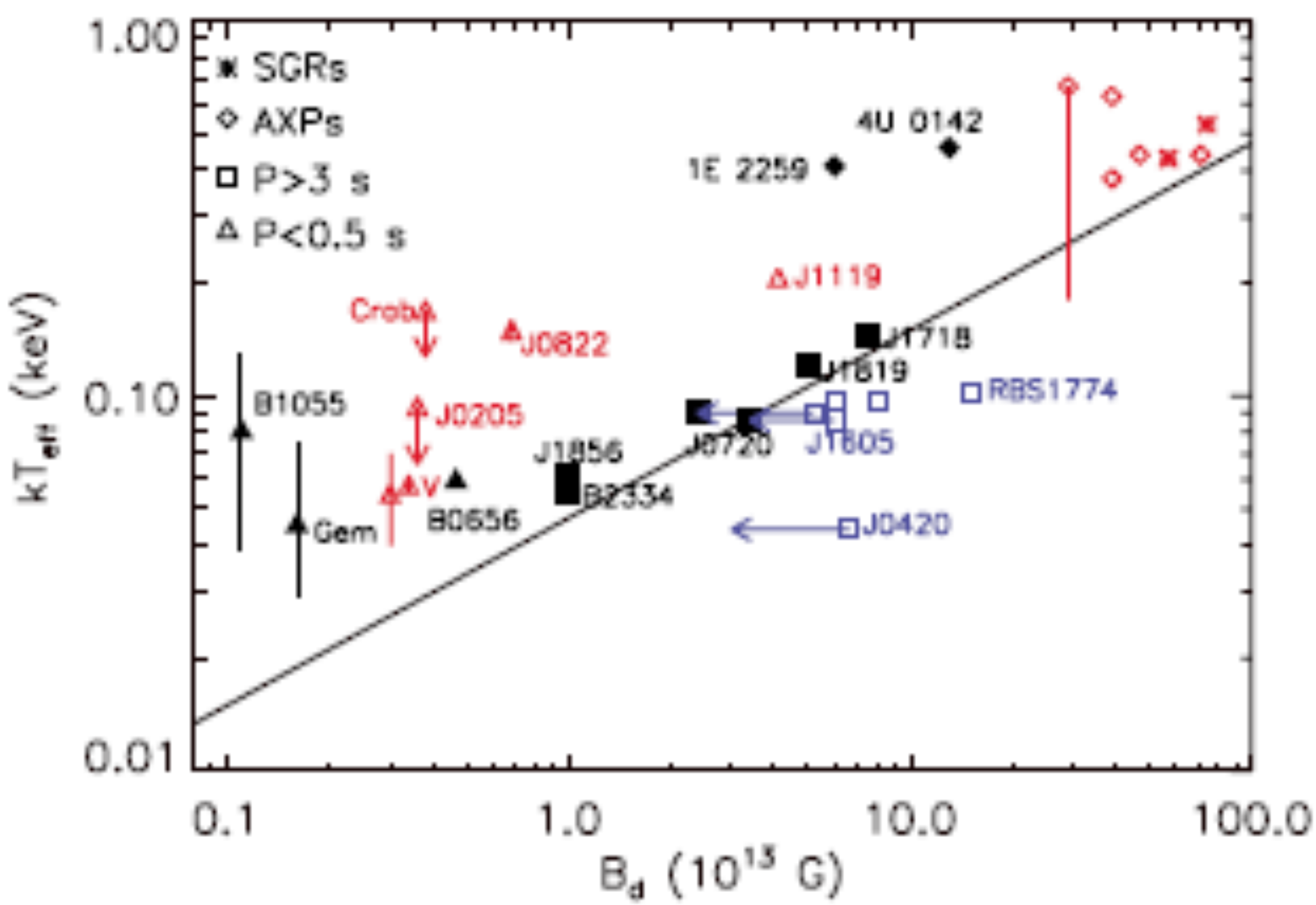
- Initially hot NSs cool depending on EOS, mass
- B decay, for large B, delays cooling
- highest B NSs stay hotter longer: ``magneto-thermal evolution."
- Explains why INSs high-B
- Pons et al. 2007,
  Aguilera et al. 2008,
  Pons et al. 2009

$$-A_{eff}\Delta R\frac{dE_m}{dt} = A_{eff}\sigma T_{eff}^4,$$

$$E_m = B^2/8\pi,$$

$$\frac{dB}{dt} = -\frac{B}{\tau_D},$$

$$\longrightarrow T_{eff} \propto B^{1/2}$$

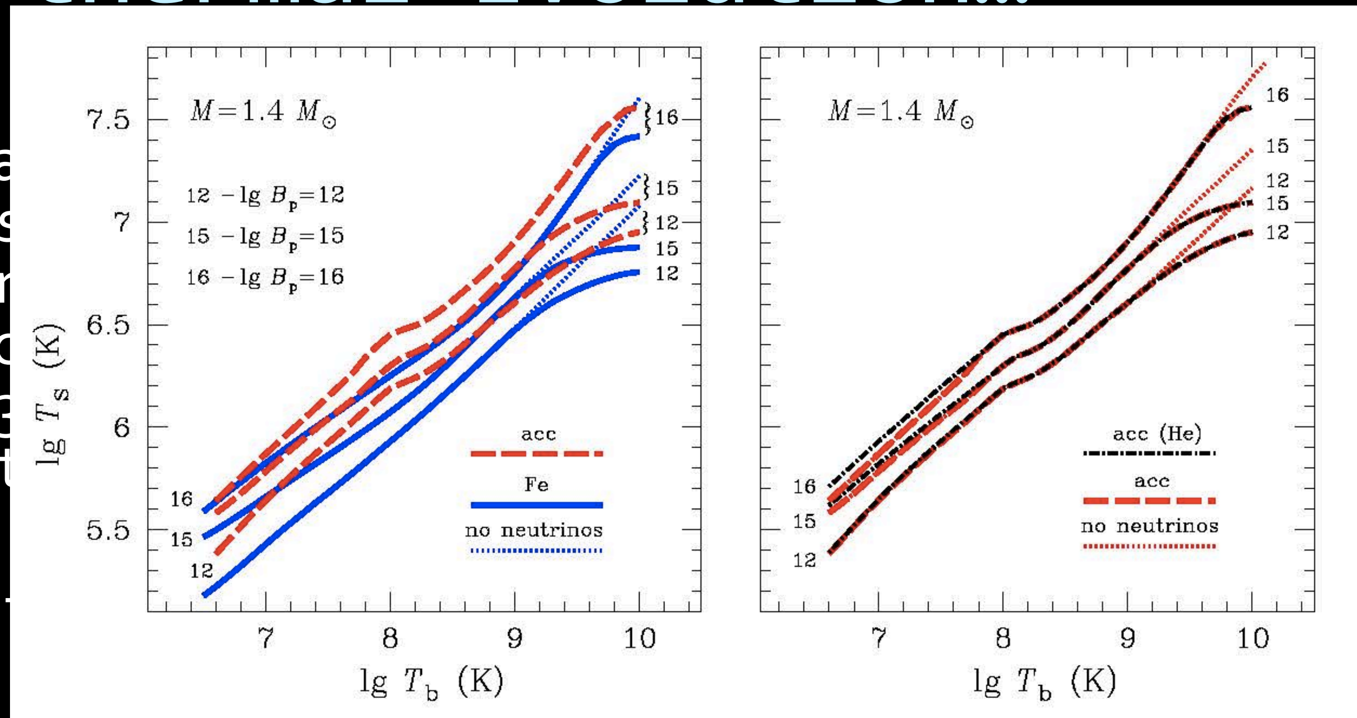


$$T_{eff} \propto B^{1/2}$$

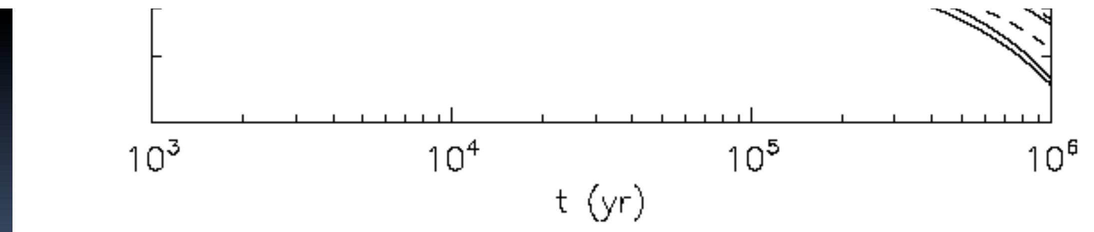
Pons et al. 2007

Magneto-thermal Evolution…

Kaminker et al. 2009



- Magneto-therma evolution models predict for pulsar same age Teff inc with B for B>1e13 (especially with t field)
- Should play role t high-B RPPs too
- Note envelope composition matters (Kaminker et al. 2009)



Pons, Miralles, Geppert 2009

Observational Progress: Past Decade

- Parkes MB survey discovers PSR J1814-1744 (B = 5.5e13 G), J1119-6127 (B=4.1e13G) by Camilo et al. 1999
- Pivovaroff, Kaspi & Camilo (2000): PSR J1814-1744: no X-ray emission, >10x fainter than other known AXPs
  - Paper originally rejected from ApJ!

Anonymous ApJ Review: Aug 12, 1999

"I believe this paper contains neither substantive new observational nor theoretical results for publication in the Astrophysical Journal… It is not clear if the analogy between PSR J1814-1744 and 1E 2259+586 is valid. Because, first of all, PSR J1814-1744 is a radio pulsar, while 1E 2259+586 is radio-quiet pulsar, without considering their X-ray properties. … There is no solid evidence that this object is similar to that of AXP…"

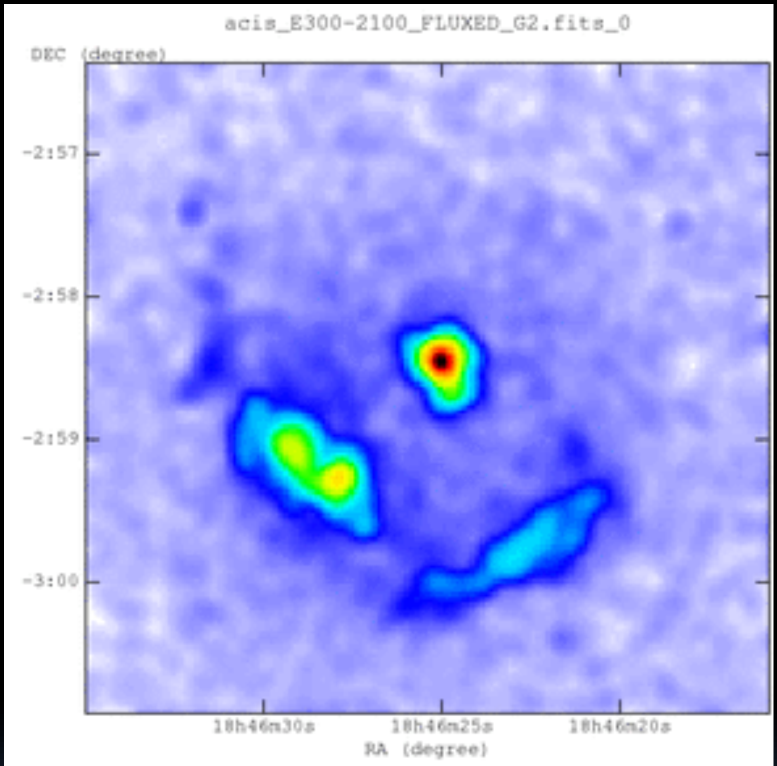
We have come very far.

Referee lacked vision:

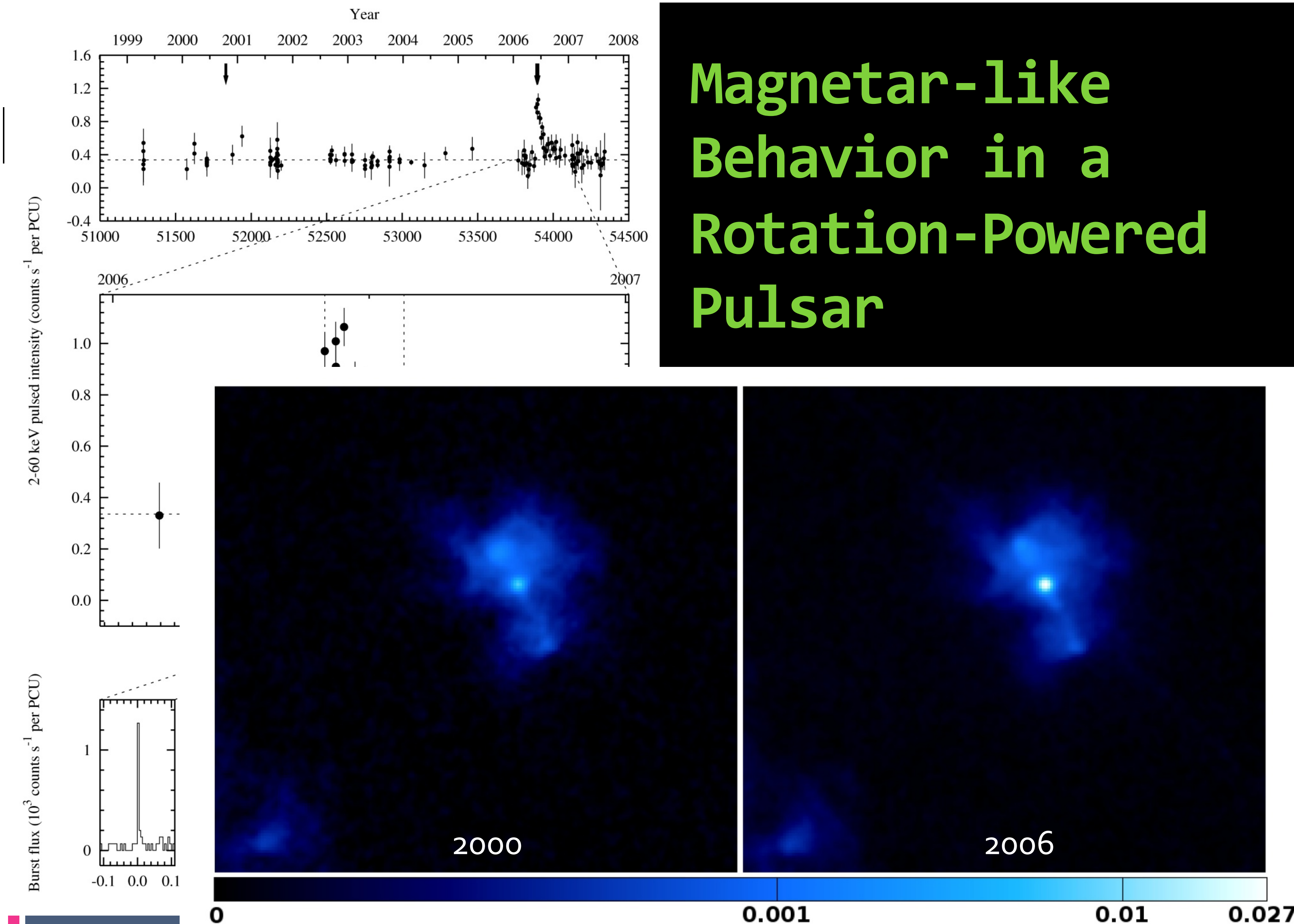
- PSR J1846-0258 in Kes 75

PSR J1846-0258

- 0.3 s pulsar in SNR Kes 75
- B = 5e13 G
- Youngest known: 884 yr
- *Bona fide* **rotation-powered**:
  - Lx << Edot
  - Power-law X-ray spectrum
  - Pulsar wind nebula
  - Normal timing properties, including n=2.65+/-0.01 (Livingstone et al. 2006)
- No radio emission (Archibald et al. 2008)



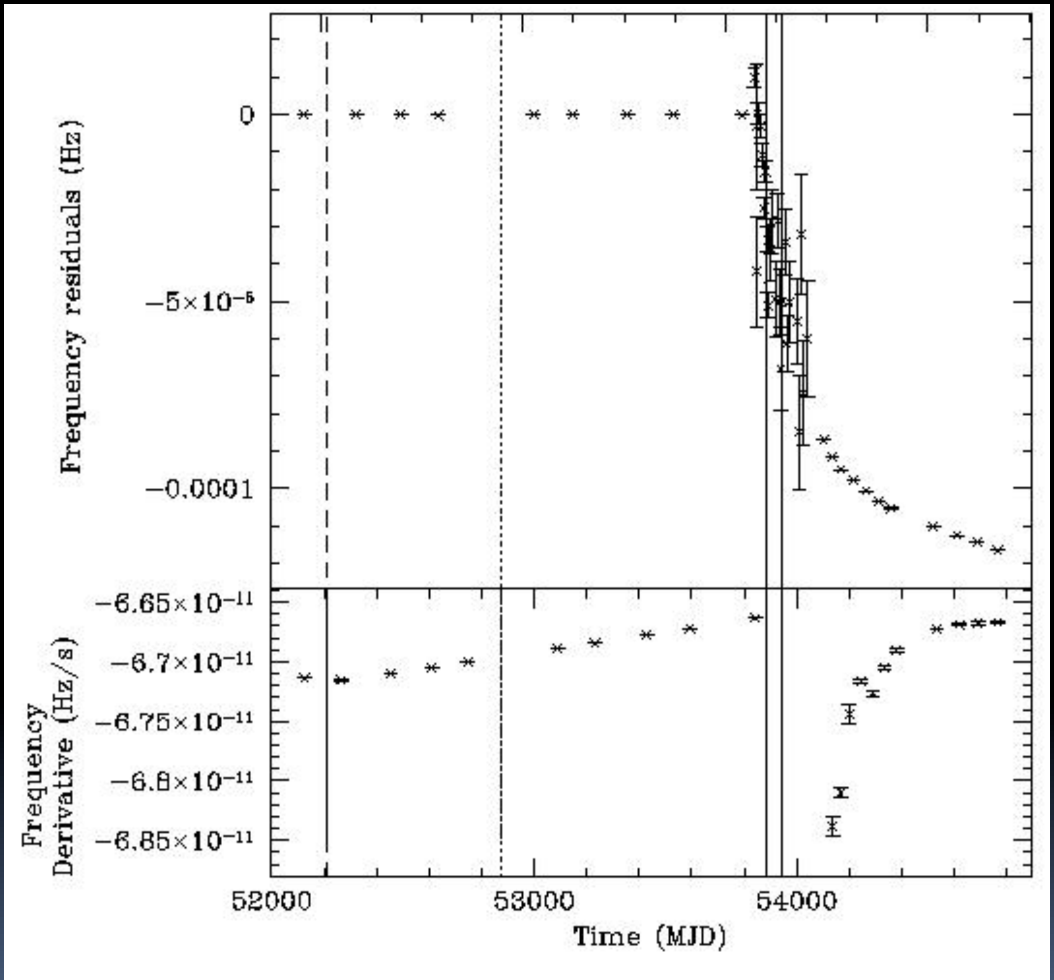
Magnetar-like Behavior in a Rotation-Powered Pulsar



Gavriil et al., Science, 2008

Timing Anomaly in PSR J1846-0258

- Pulsar had spin-up glitch (df/f~4e-6; Kuiper & Hermsen 2009) followed by strong spin-down (Livingstone et al. 2010)
- Net effect: large spin-down df/f = 5e-5
- Similar to that in SGR 1900+14 (Thompson et al. 2000); also AXP 4U 0142+61 (Gavriil et al., 2011)
- Interesting glitch behavior in magnetars!

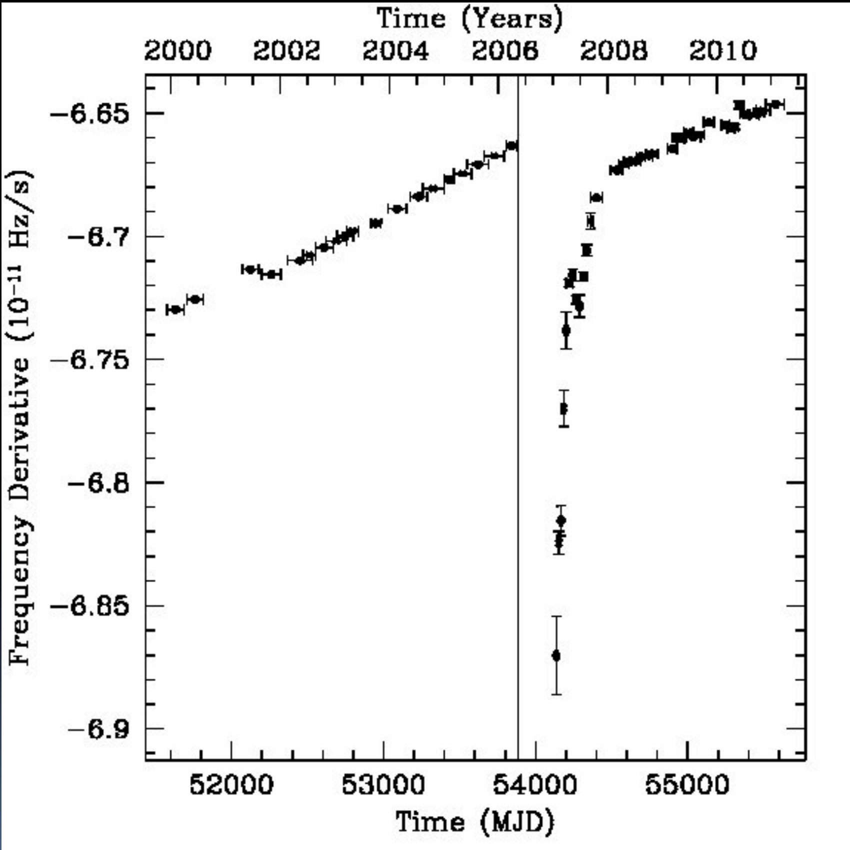


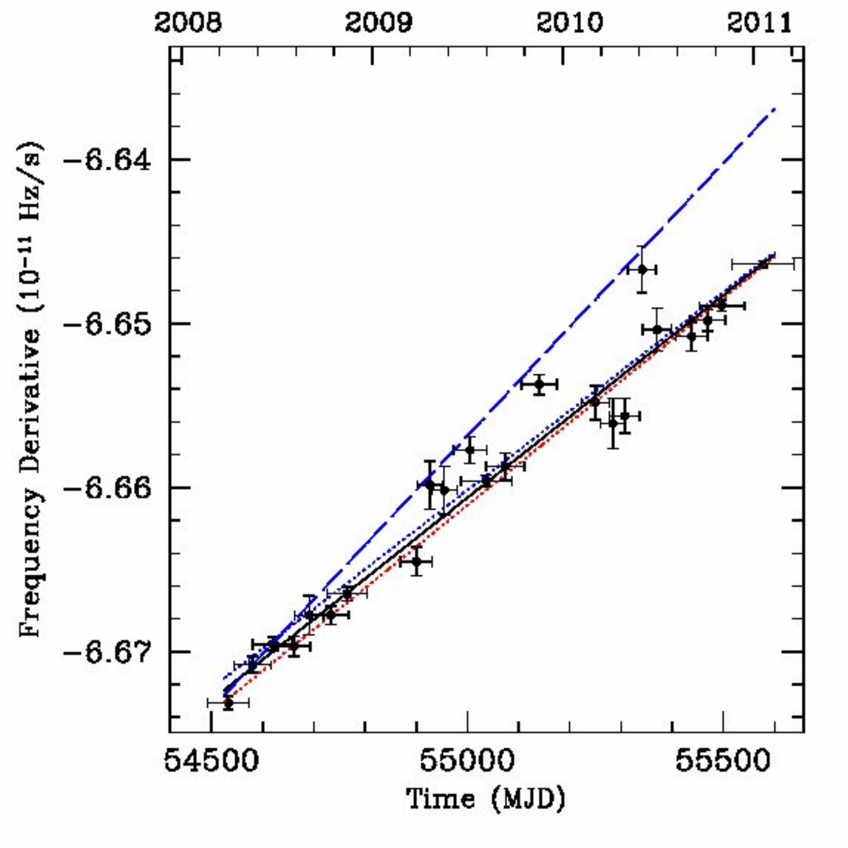
Livingstone, VK, Gavriil 2010

Chandra ToO Program: Look at High-B radio pulsars at glitch epochs

Change of Braking Index!

n before: 2.65 +/- 0.01; n now: 1.97 +/- 0.04





Livingstone, Ng, VK et al. 2011, updated

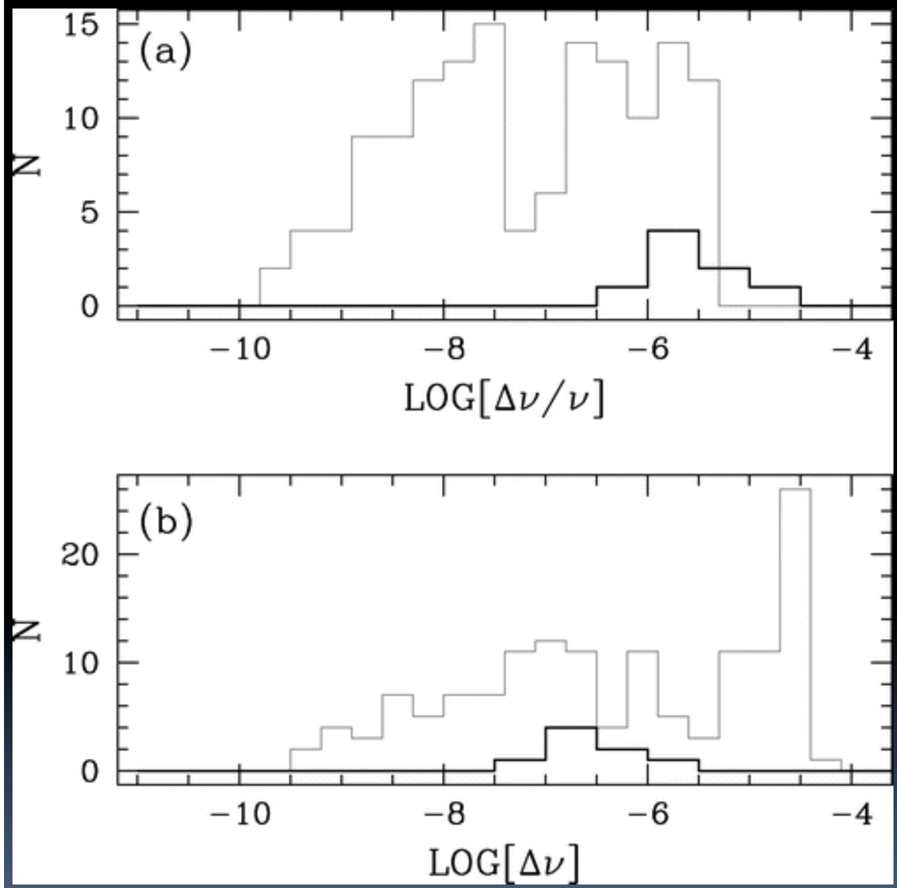
What about other High-B Pulsars?

High-B Psrs vs Magnetars

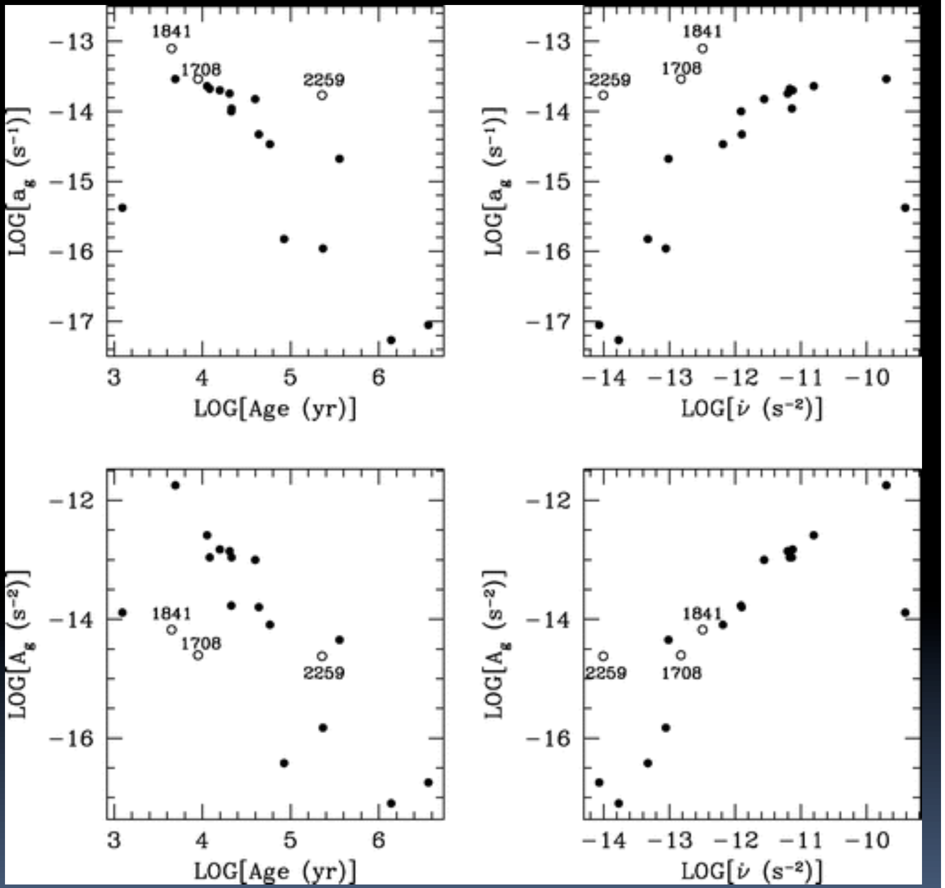
- Overlap in spin properties?
  - YES! Overlap in P, Pdot, glitches, timing noise

Glitches: AXP vs Radio Pulsars

Glitch amplitude



Glitch activity



Dib, VK, Gavriil 2008

High-B Psrs vs Magnetars

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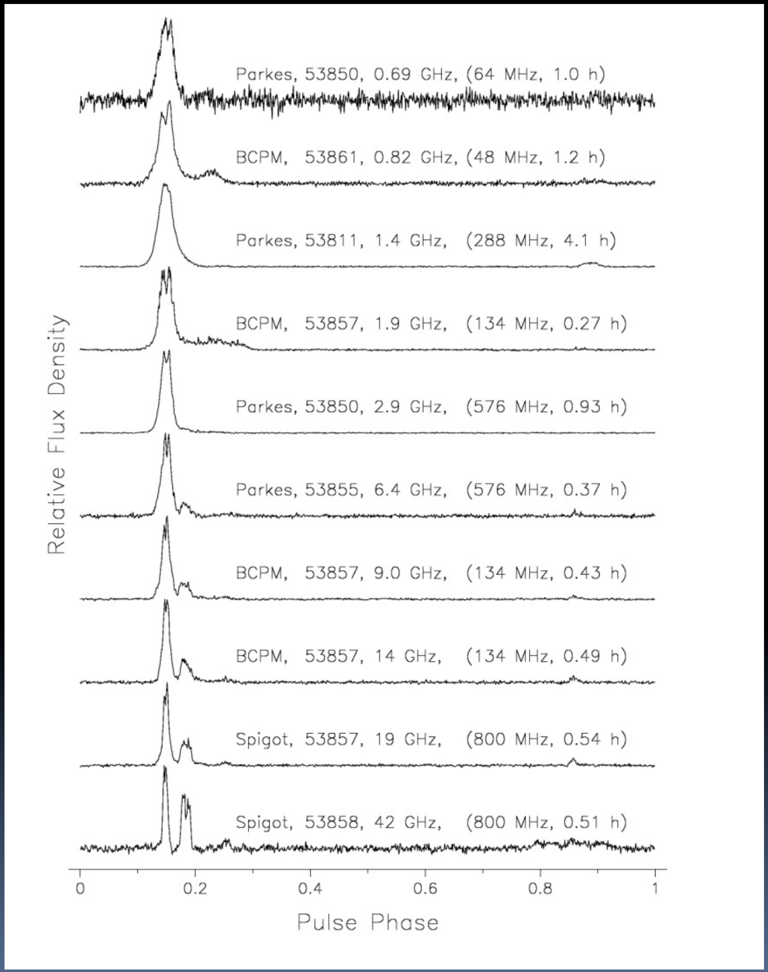
High-B Psrs vs Magnetars

- Overlap in spin properties?
  - YES! Overlap in P, Pdot, glitches, timing noise
- Can magnetars produce radio emission?
  - YES! but intermittent, variable, broad pulses, very flat radio spectrum

Radio Pulsations from an AXP

XTE J1810-197

- Note source is "transient AXP"
- Radio emission has very flat spectrum
- Brightest "radio pulsar" at 22 GHz… why?
- Detected up to 44 GHz
- Very variable radio emission, fading… why?
- Related to transient X-ray nature?



Camilo et al Nature, 2006

High-B Psrs vs Magnetars

- Overlap in spin properties?
  - YES! Overlap in P, Pdot, glitches, timing noise
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High-B Psrs vs Magnetars

- Overlap in spin properties?
  - YES! Overlap in P, Pdot, glitches, timing noise
- Can magnetars produce radio emission?
  - YES! but intermittent, variable, broad pulses, very flat radio spectrum
  - Search for radio pulsations/bursts from persistent magnetars (Burgay et al. 07; Crawford et al. 07; Lazarus et al., submitted; but see talk by Malofeev)

High-B Psrs vs Magnetars

- Can high-B radio pulsars produce "anomalous" X-rays?
  - YES! One unambiguous event from Kes 75 pulsar
  - Other hints?

Moderate-High B Radio Pulsars

- 1e13 G < B < 9e13 G
- Experiment: for long-P, low Edot, nearby sources, look at thermal X-ray emission
- PSR B0154+61 (Gonzalez, VK et al. 2004):
  - P=2 s, B=2.1e13 G, D=2.2 kpc; no XMM detection (31ks)
- PSR B1916+14 (Zhu, VK et al. 2009):
  - P=1.2 s, B=1.6e13 G, D=1.9 kpc; kT~0.13 keV in XMM ~10 ks; more data requested

High-B Radio Pulsars: "Anomalous" X-rays?

Name	P (s)	Pdot	B (G)	D (kpc)
J1119-6127	0.4	4.1e-12	4.1e13	8.4
J1718-3718	3.4	1.6e-12	7.4e13	4.9
J1734-3333	1.2	2.3e-12	5.2e13	7.4
J1814-1744	4.0	7.4e-13	5.5e13	9.8
J1819-1458 (RRAT)	4.3	5.7e-13	5.0e13	3.6
J1846-0258	0.3	7.1e-12	4.8e13	6
J1847-0130	6.7	1.3e-12	9.3e13	8.4

High-B Radio Pulsars: "Anomalous" X-rays?

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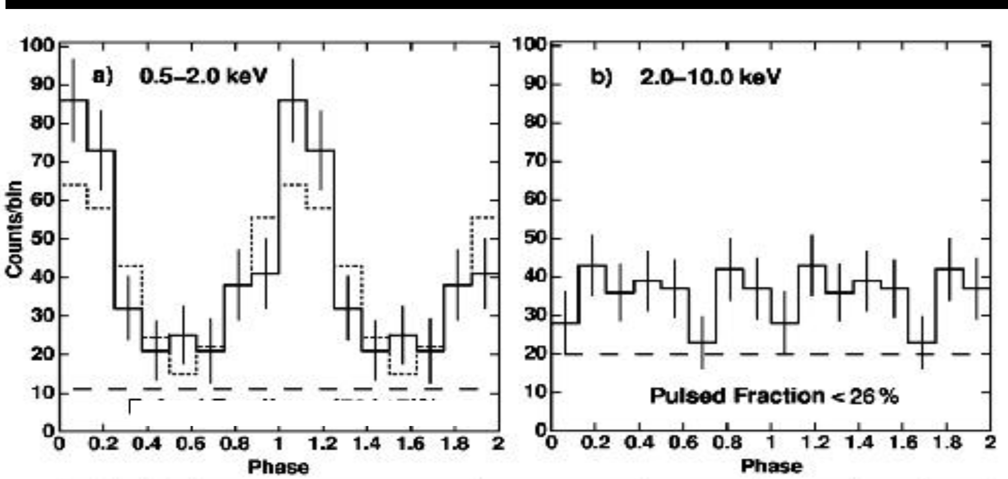
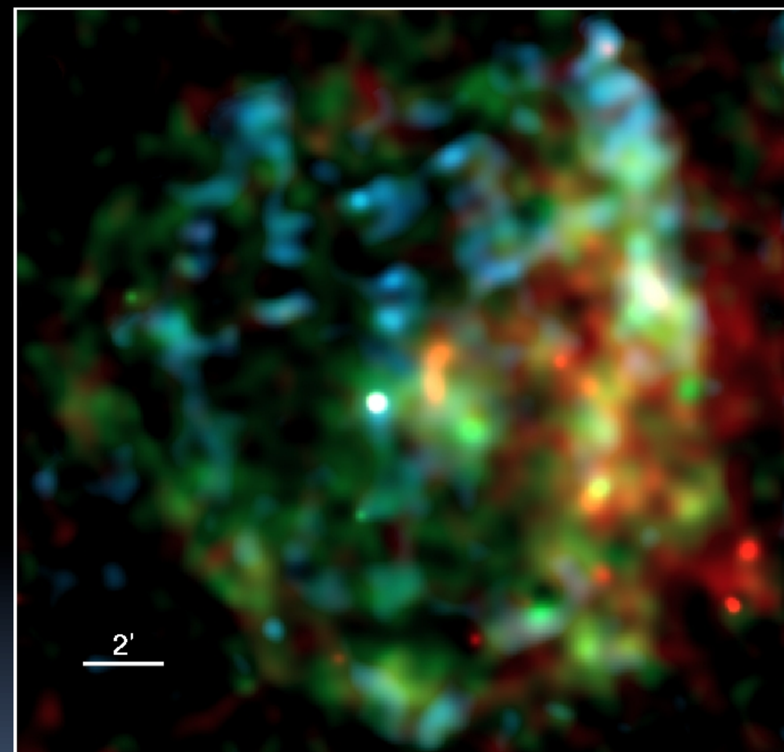
J1846-0258	0.3	7.1e-12	4.8e13	6
J1847-0130	6.7	1.3e-12	9.3e13	8.4

PSR J1119-6127

- P=0.4 s, B=4.1e13 G, D=8.4 kpc
- Age $=P/2\dot{P}$=1.7 kyr
- At center of SNR G292.2-0.5
- XMM: pulsations detected E< 2 keV
- PF 74 +/- 14 %

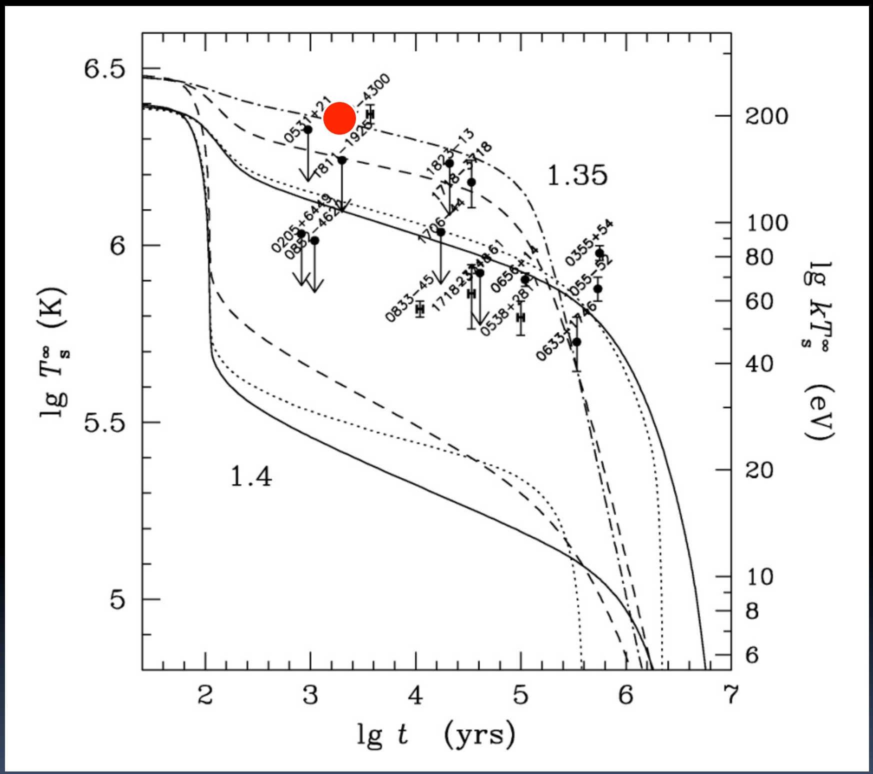




Gonzalez, VK et al. 2005

PSR J1119-6127

- Blackbody temperature high:



kT = 0.21 +/- 0.01 keV

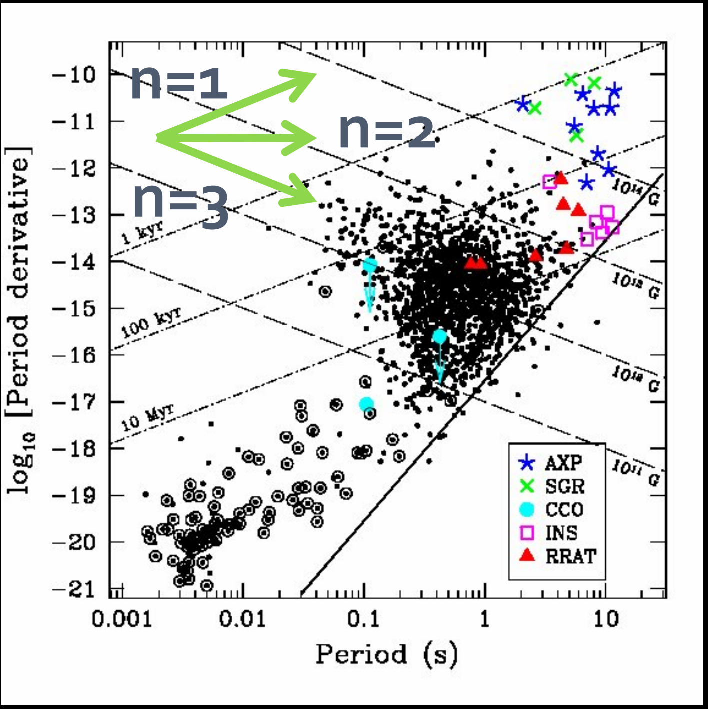
Of known young (<2 kyr) rotation-powered pulsars, this is among the hottest

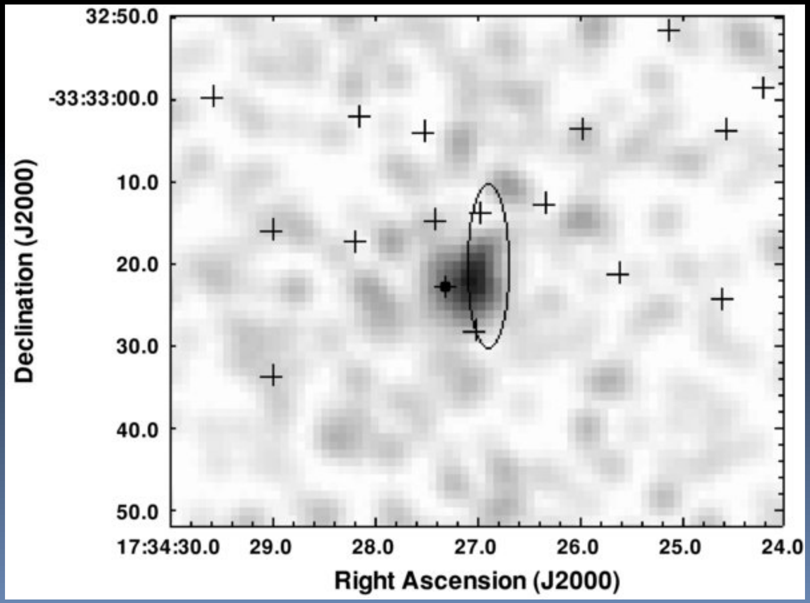
Gonzalez, VK et al. 2005
Safi-Harb & Kumar 2008

New 100 ks XMM data
Just obtained…
Ng, VK et al. in prep

PSR J1734-3333

- P=1.2 s, B=5.2e13G, D=6 kpc
- Age = 8 kyr
- n=0.9 +/- 0.2 (Espinoza et al., ApJ, submitted)
- 10 ks XMM obs faint probable detection
- Lx < 0.1 Edot
- New 100 ks XMM obs just obtained

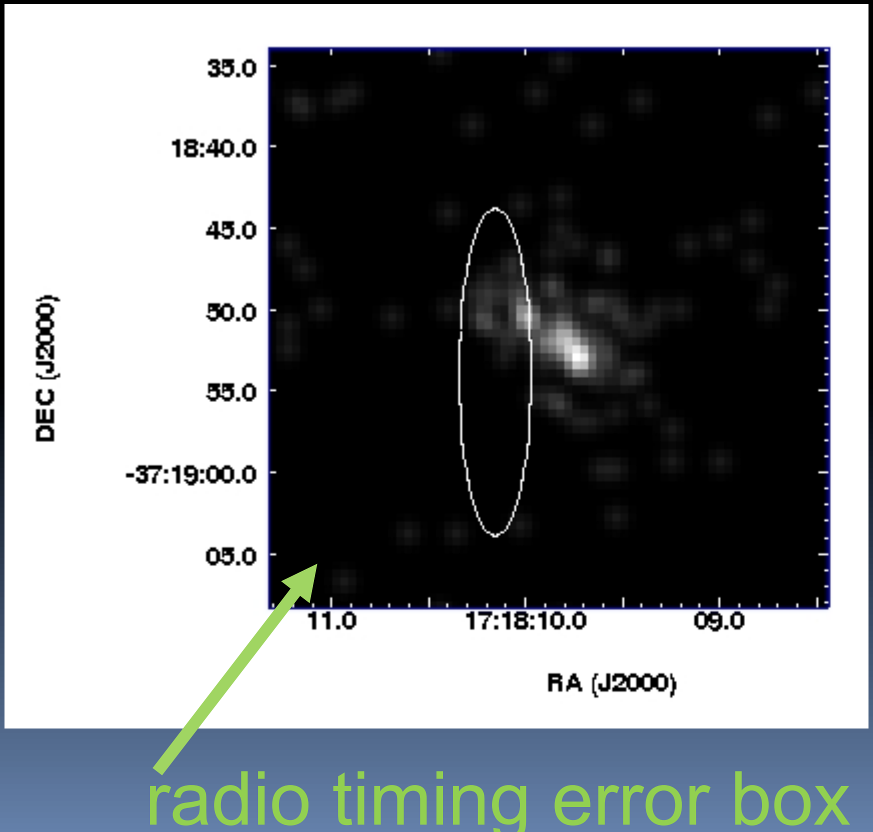




Olausen, VK, Lyne, Kramer 2010

PSR J1718-3718

- P=3.4 s, B=7.4e13G, D=4.9 kpc
- Age = 34 kyr
- 50 ks archival Chandra/ACIS obs 7′ off axis



- formal positional offset: 0.2σ in DEC, 1.6σ in RA
- probability of chance < 1%
- Need more time!

VK & McLaughlin 2005

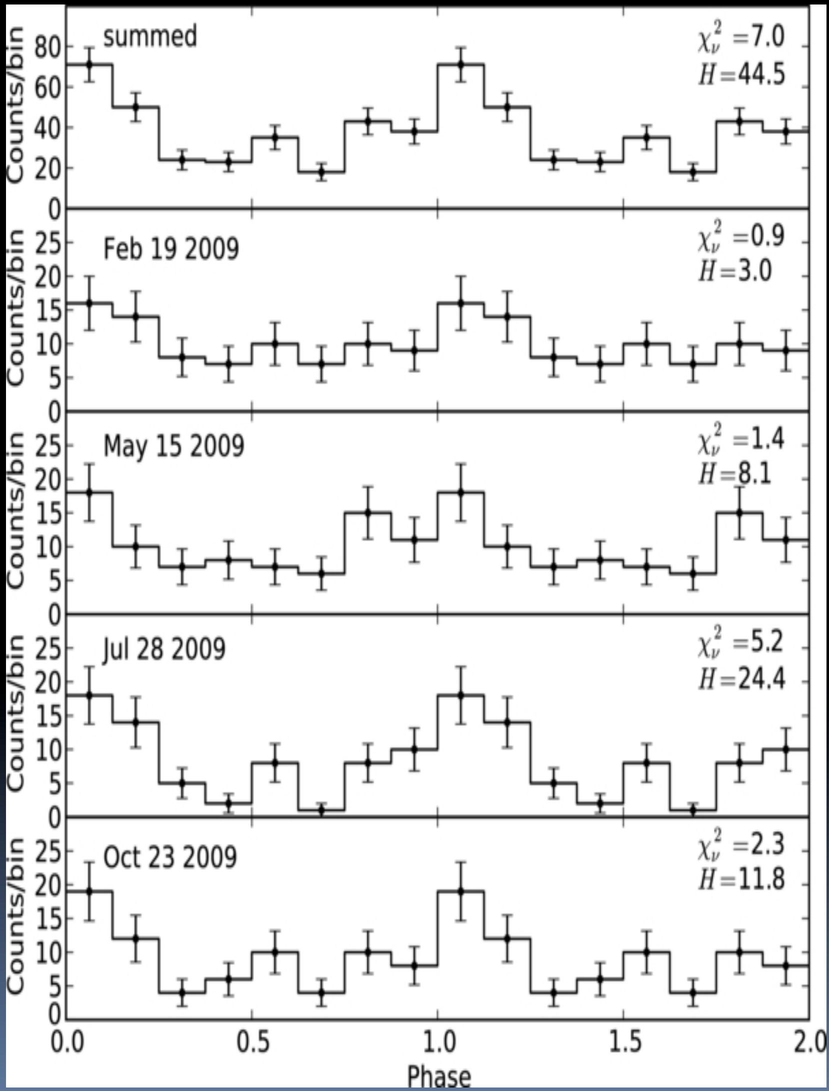
PSR J1718-3718

- Spectrum, flux:
  - kT possibly high but poorly determined
  - Lx > 3 orders of magnitude fainter than for any known persistent AXP
  - …**but** consistent with transient AXP in quiescence…

"This raises the interesting possibility that PSR J1718-3718, and other high-B radio pulsars, may one day emit transient magnetar-like emission, and conversely that the transient AXPs might be more likely to exhibit radio pulsations." (VK & McLaughlin 05)

PSR J1718-3718: New Data

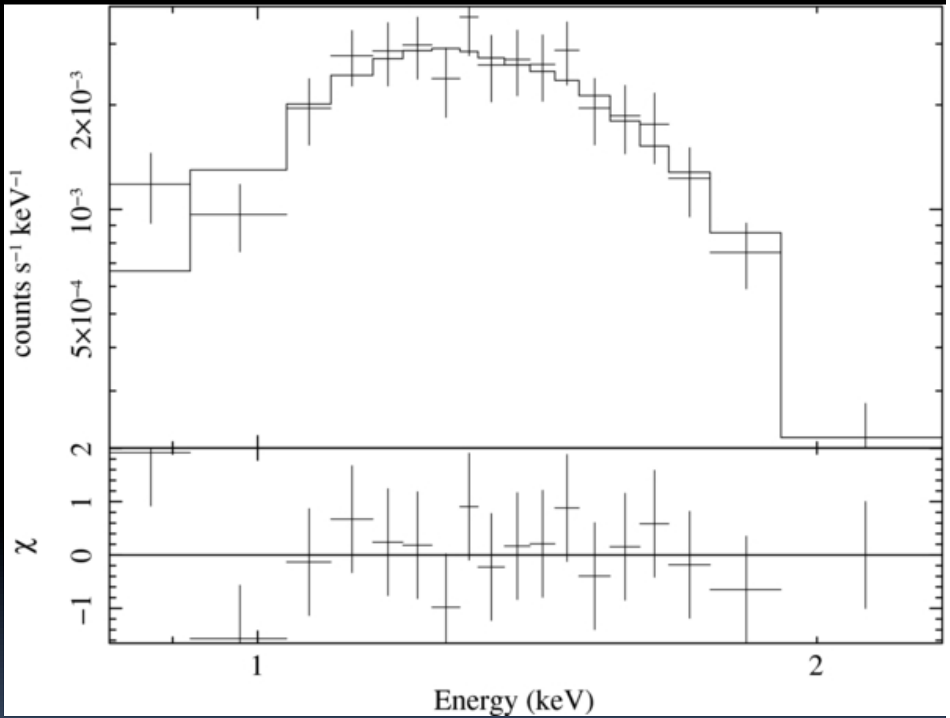
- 130 ks new Chandra observations, split in 4
- Pulsations detected with high significance: confirms ID
- Pulsed fraction 52 +/- 13 % (0.8-2keV)



Zhu, VK, McLaughlin, Pavlov, Ng et al. 2011

PSR J1718-3718: New Data…

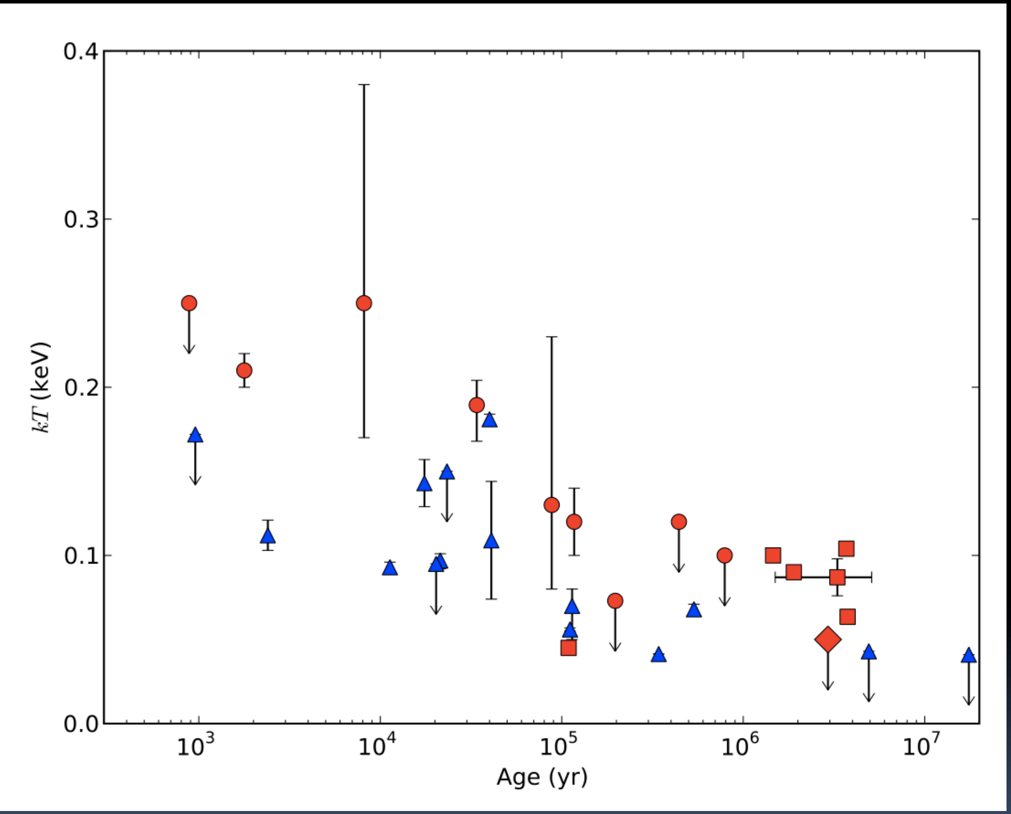
- Soft X-ray spectrum
- Blackbody:
  kT = 0.186+/-0.019 keV
- H atmosphere:
  kT = 0.057+/-0.012 keV



Zhu, VK et al. 2011

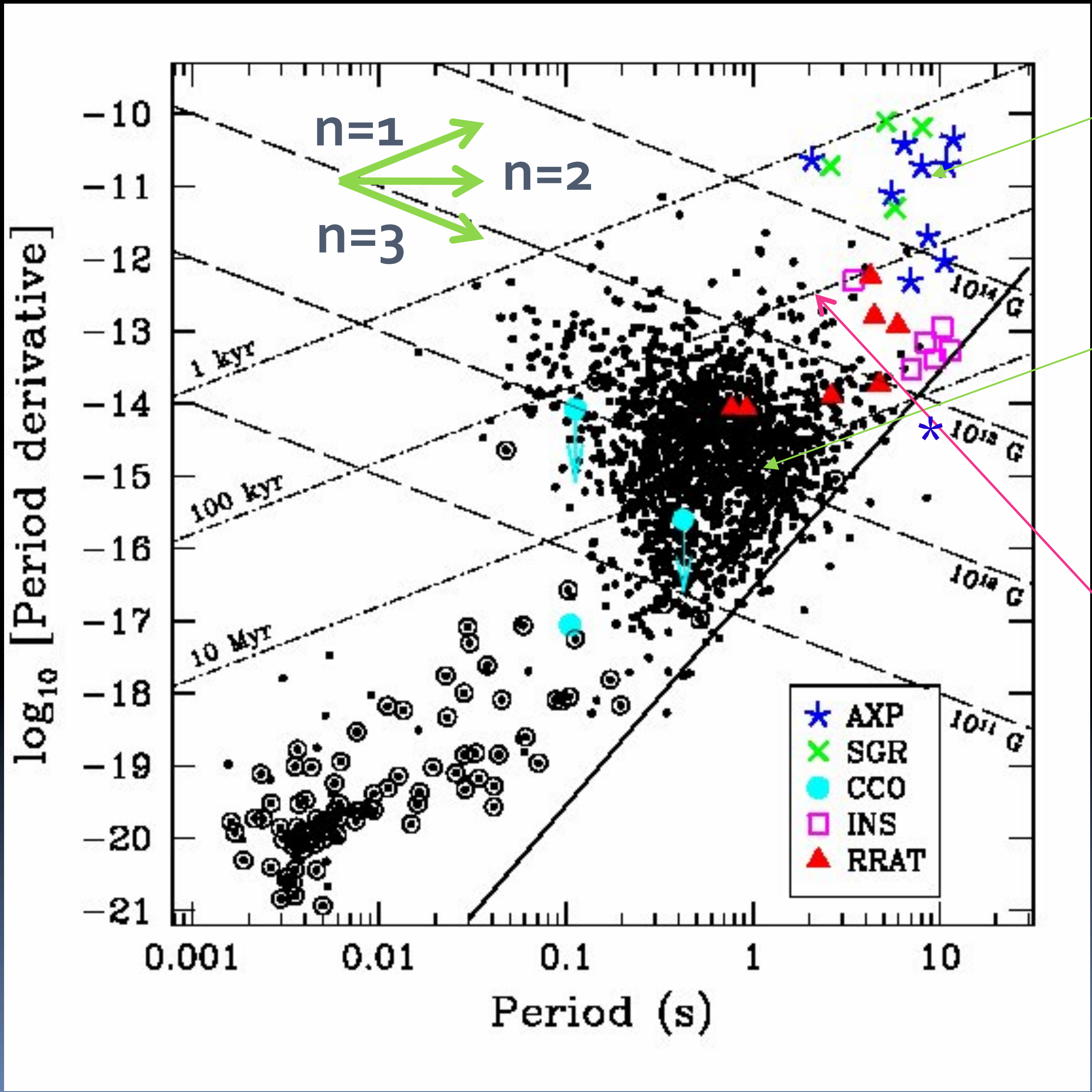
kT vs Age: "High"-B vs "Low"-B

- Compare bbody kT's
  B > 1e13G (filled)
  B < 1e13G (empty)
- Omit sources with polar-cap reheating
  (Rbb < 1 km)
- Hint that "high"-B pulsars may appear hotter than "low"-B pulsars of same age
- Squares are INSs



Zhu, VK, Mclaughlin, Pavlov, Ng et al. 2011

P-Pdot Diagram

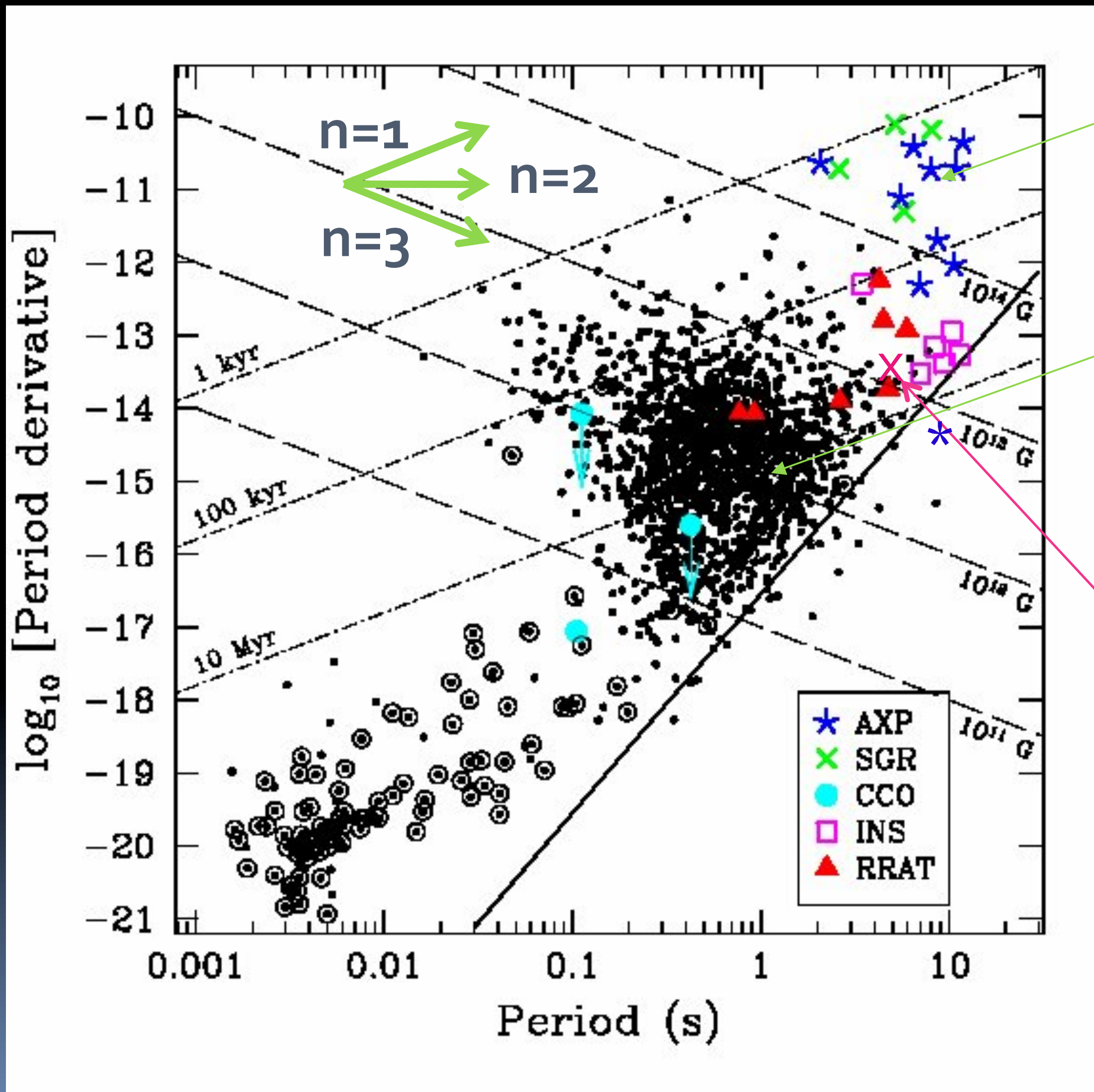


SGRs, AXPs

Radio Pulsars

High-B Radio Pulsars

P-Pdot Diagram



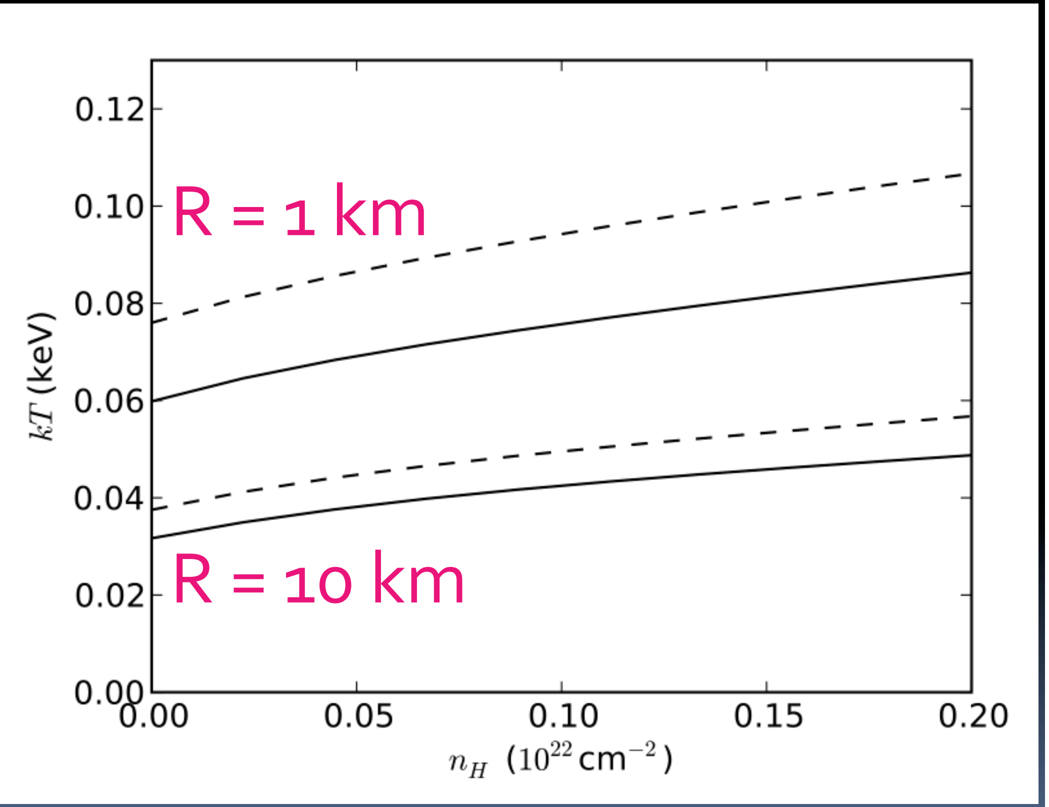
SGRs, AXPs

Radio Pulsars

PSR B1845-19

PSR B1845-19: INS Lookalike

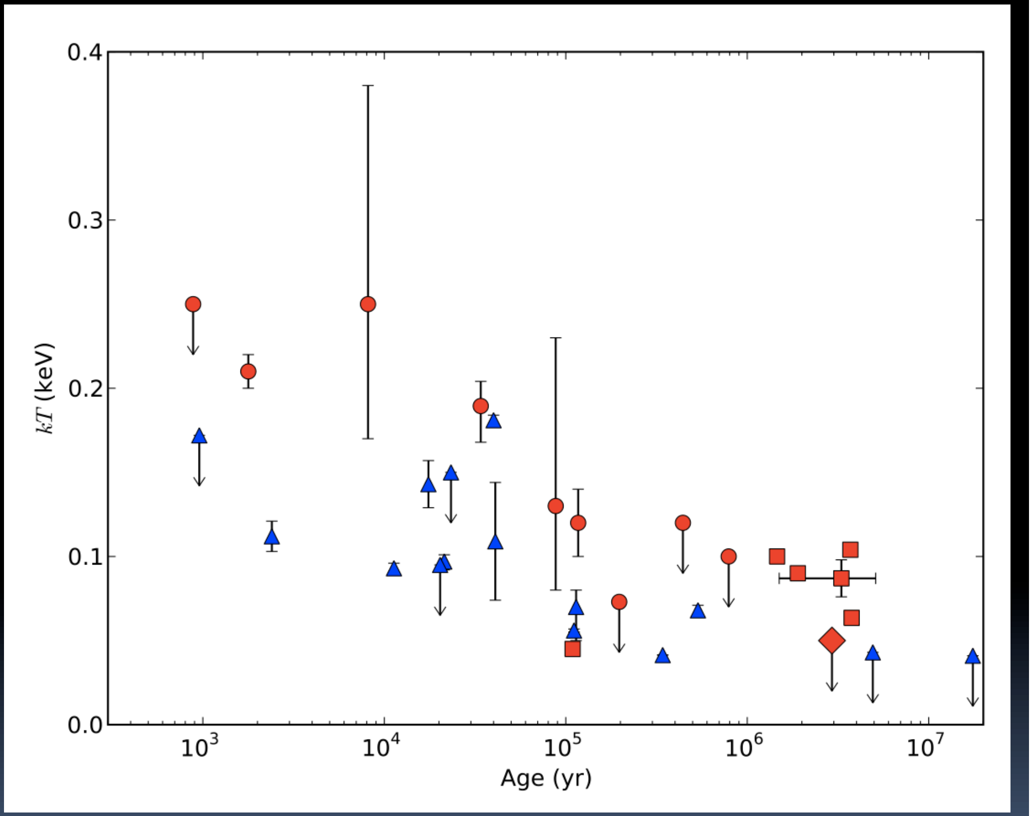
- P=4.3 s, B=1e13 G
- Near INS in P-Pdot
- DM=18 pc/cm3
- D=750 pc
- 35 ks XMM Obs
- Non-detection



Zhu, VK et al. in prep.

PSR B1845-19: INS Lookalike

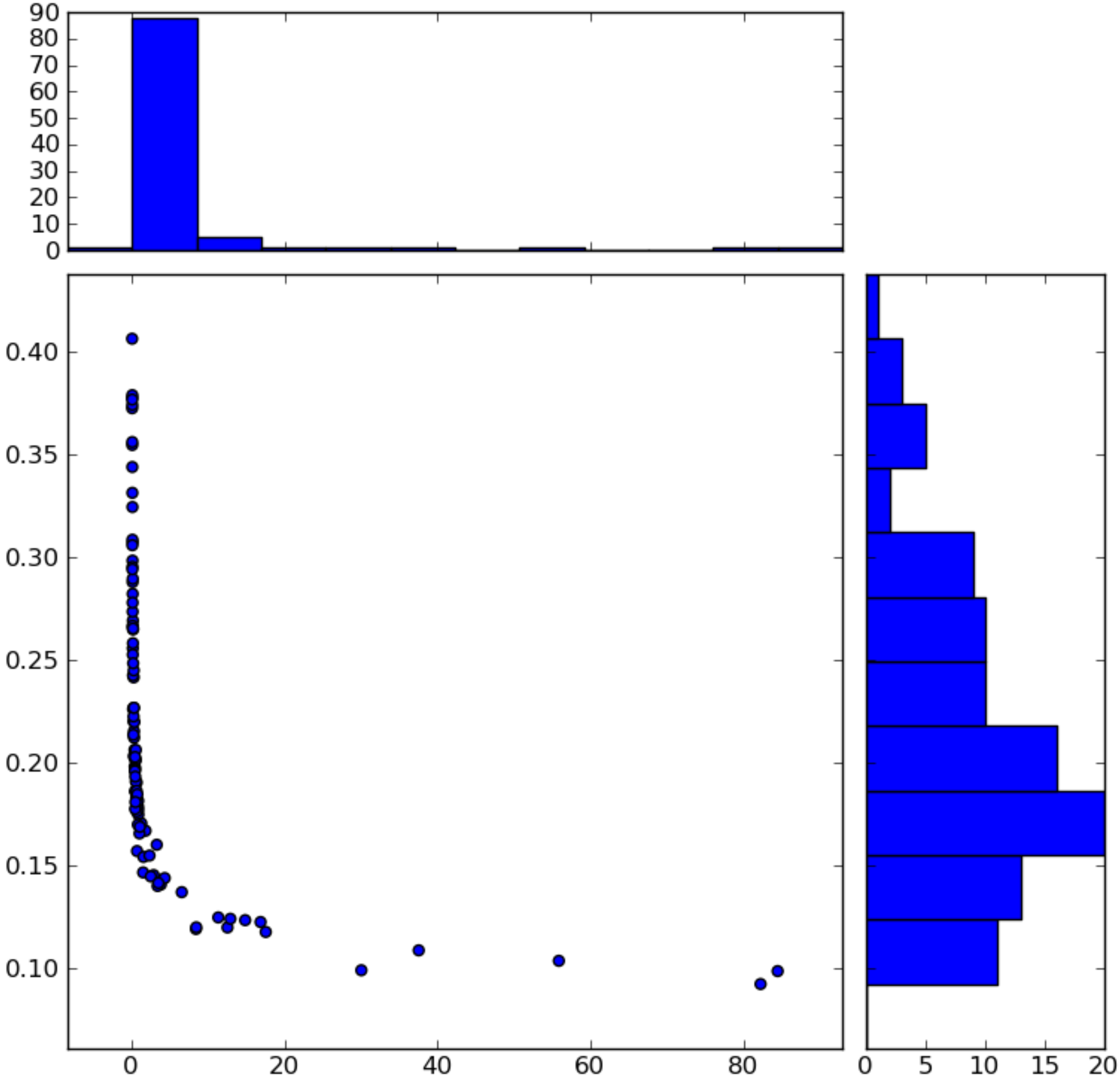
- Non-detection surprising?
- Maybe high-B radio pulsars and INSs are "different"?
  - INSs magnetar descendents
  - High-B RPPs born with 'moderate' B
  - See Pons et al. (2009)
- Need X-ray obs of more sources! 2 More in Chandra pipeline…



Zhu, VK et al. in prep.

Summary

- Natural magnetar model predictions have been verified:
  - Periodicities, spin-down in SGRs
  - Bursts in AXPs
  - Radio emission from some magnetars
  - Magnetar-like emission from one high-B radio pulsar
- Important open questions:
  - Do all high-B radio pulsars show occasional magnetar activity?
  - Do high-B radio pulsars show higher kT than low-B pulsars of same age?
  - Are there evolutionary relationships?
    - Do high-B radio pulsars evolve into magnetars?
    - Are INSs magnetar descendants?



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