PULSARS

X-ray emission properties of old

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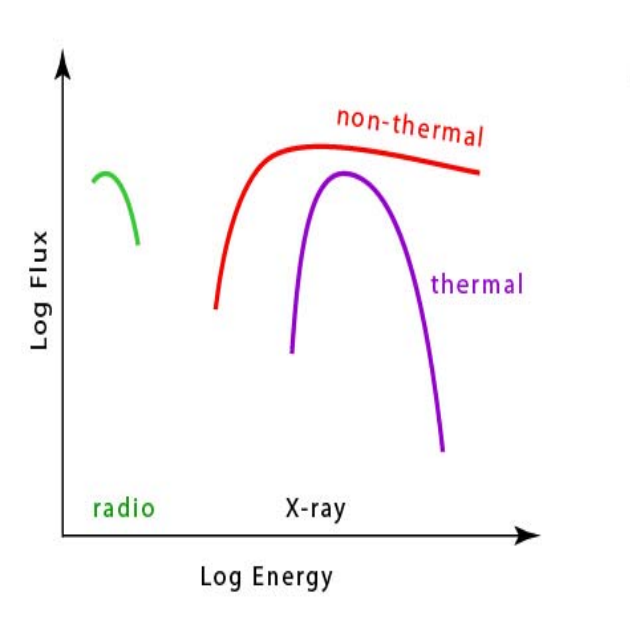
X-ray emission properties vary with spin-down age

Crab-like pulsars

(< 10^4 yrs)



X-ray emission properties vary with spin-down age

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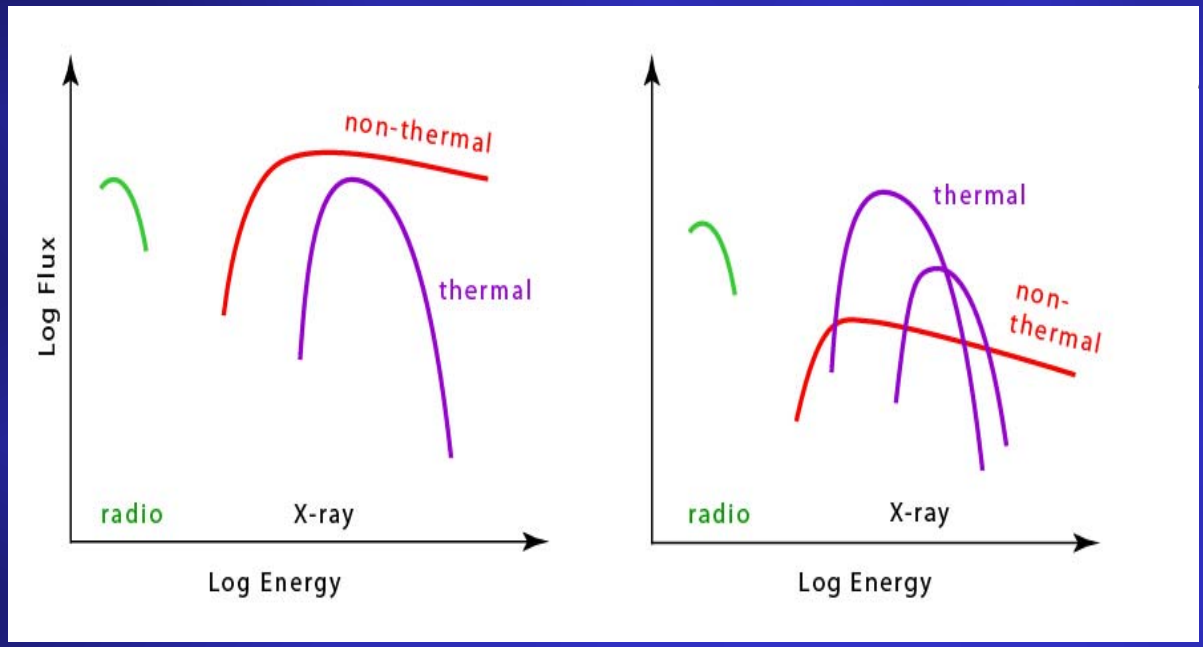
Cooling neutron stars

(~10^5 - 10^6 yrs)



X-ray emission properties vary with spin-down age

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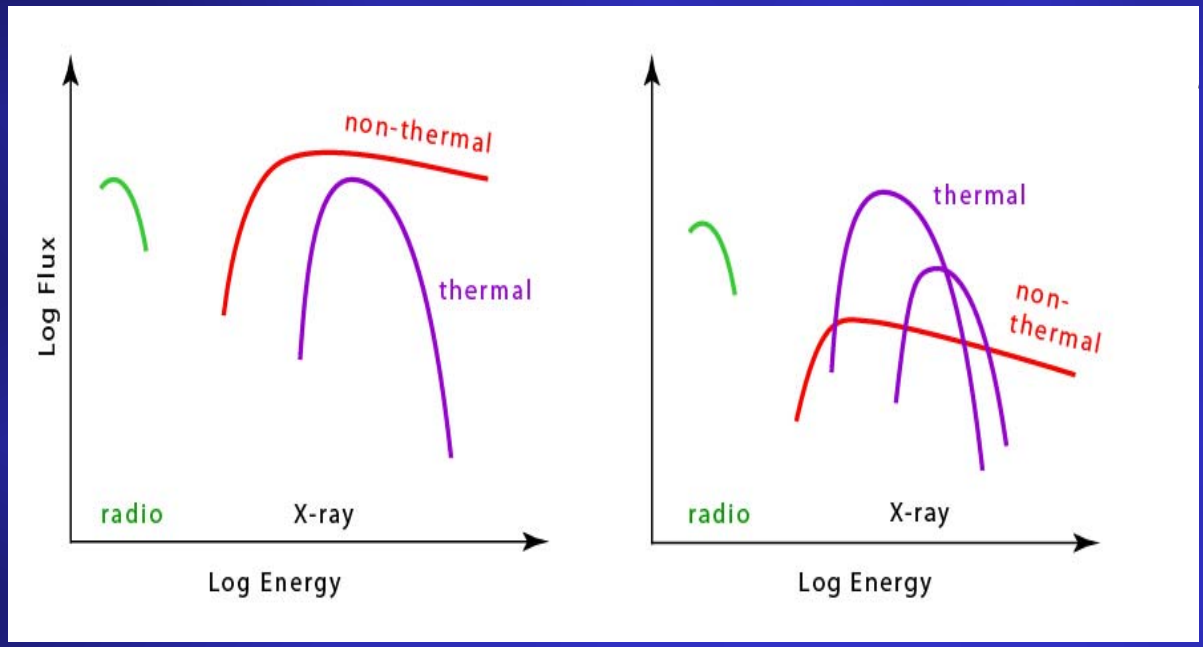
Old pulsars

(~10^6 - 10^8 yrs)



?

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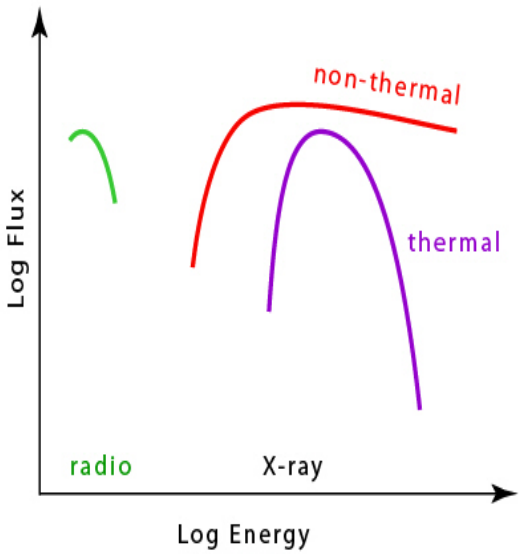
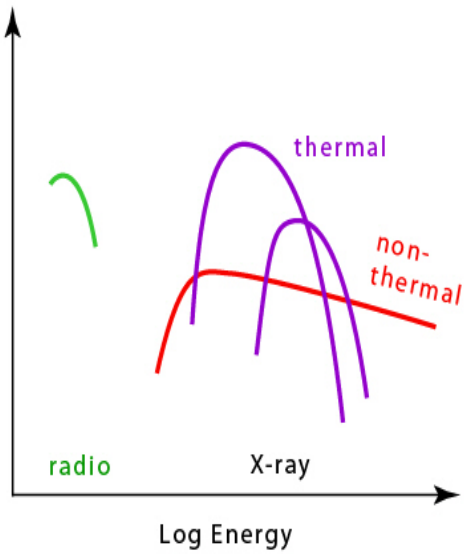
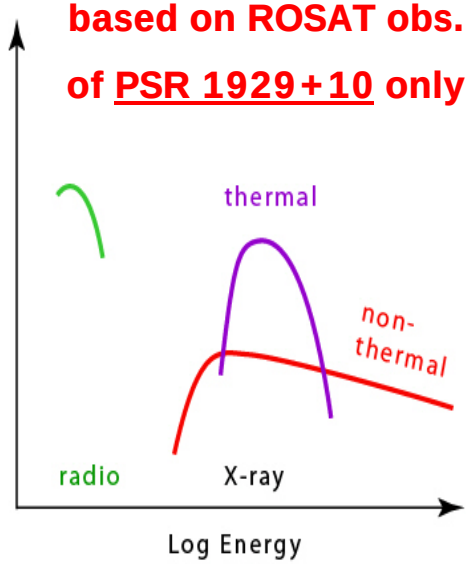
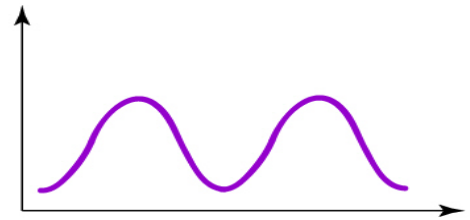




based on ROSAT obs. of PSR 1929+10 only





sinusoidal

X-ray emission properties vary with spin-down age

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Old pulsars

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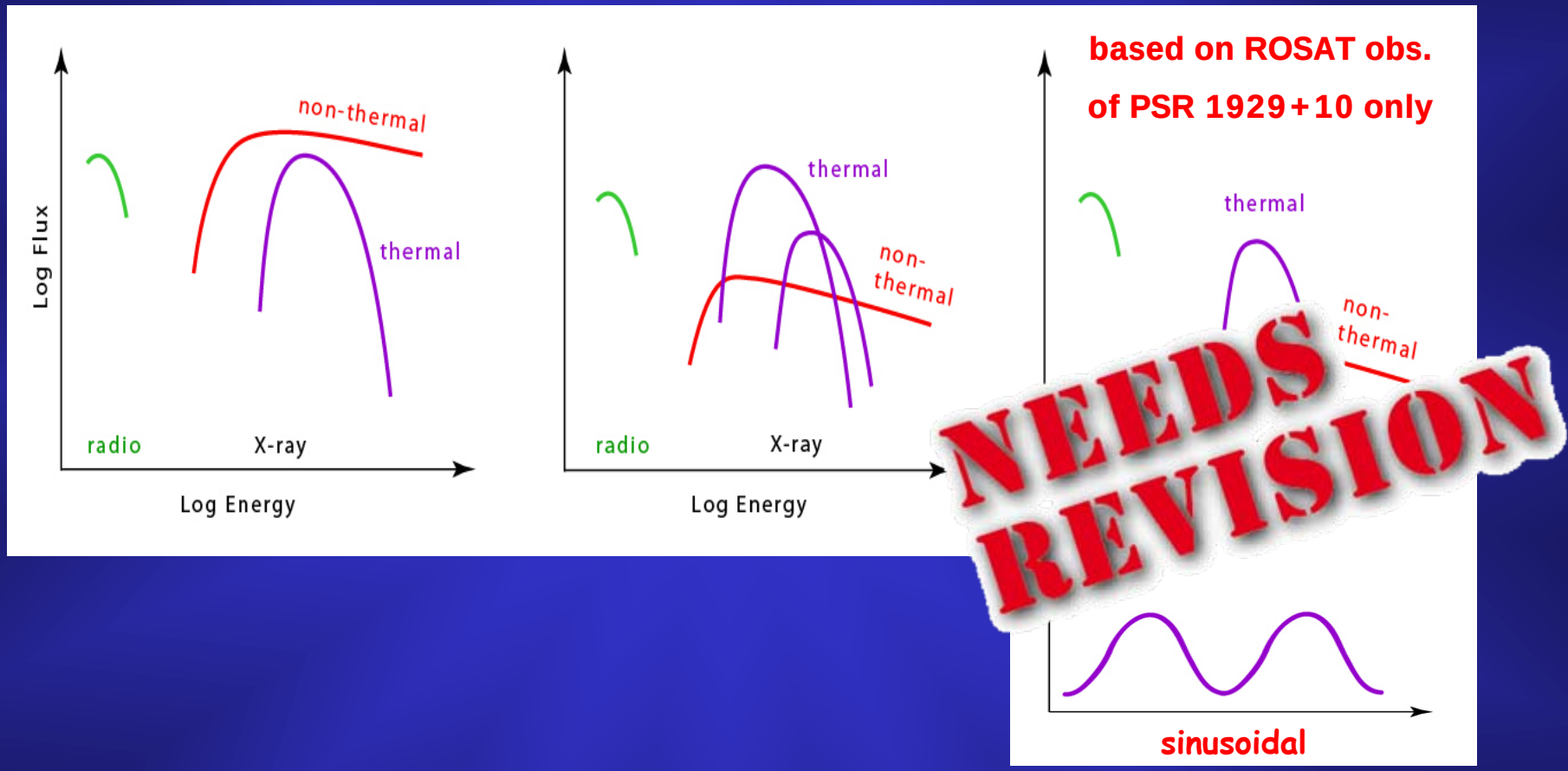
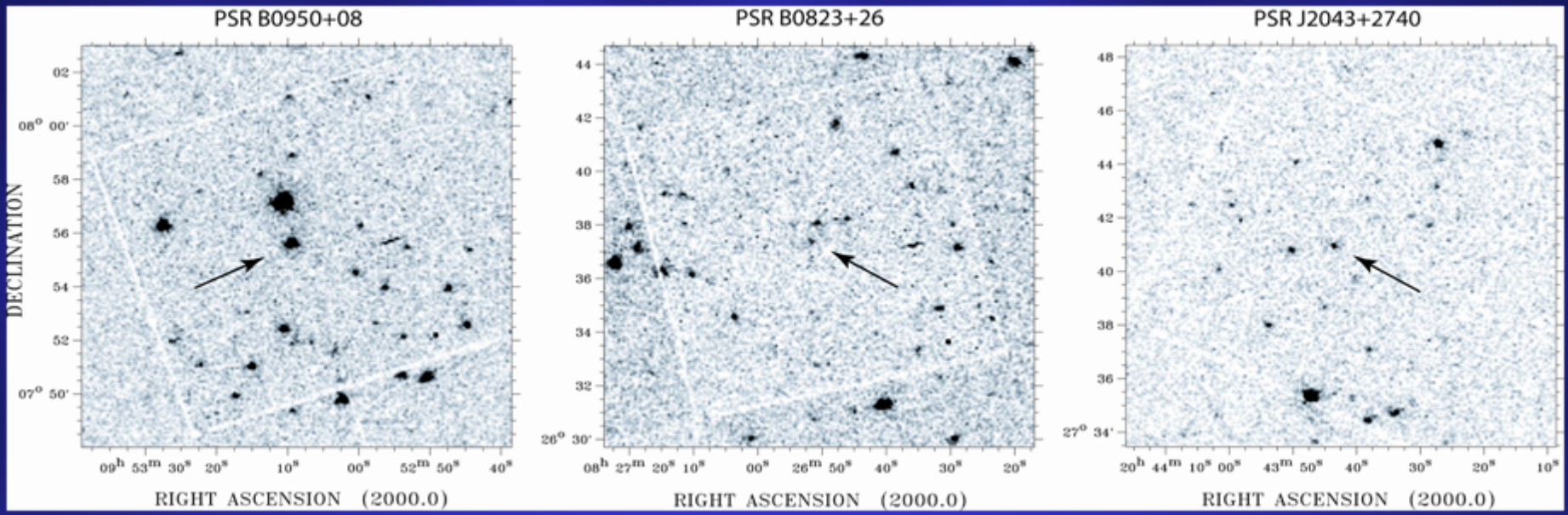


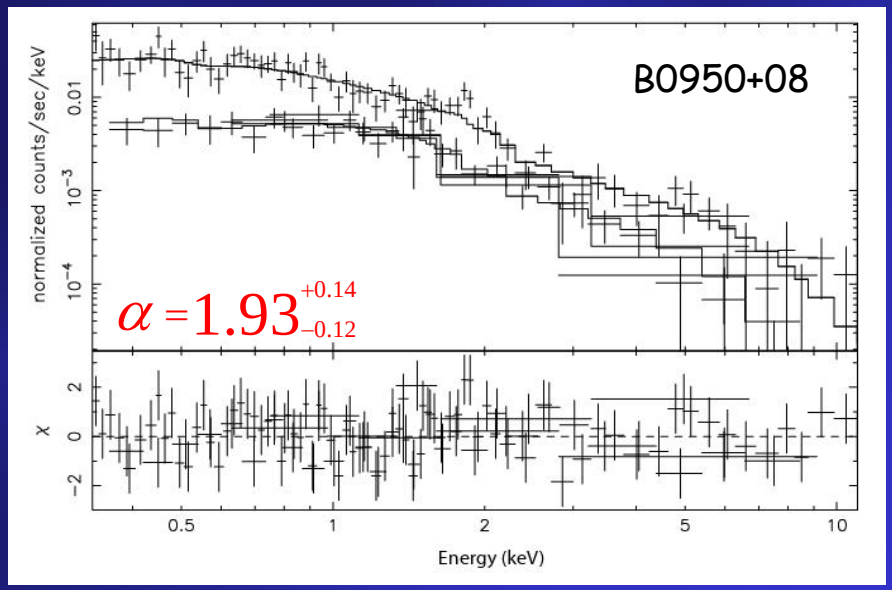
XMM-Newton observations of old pulsars

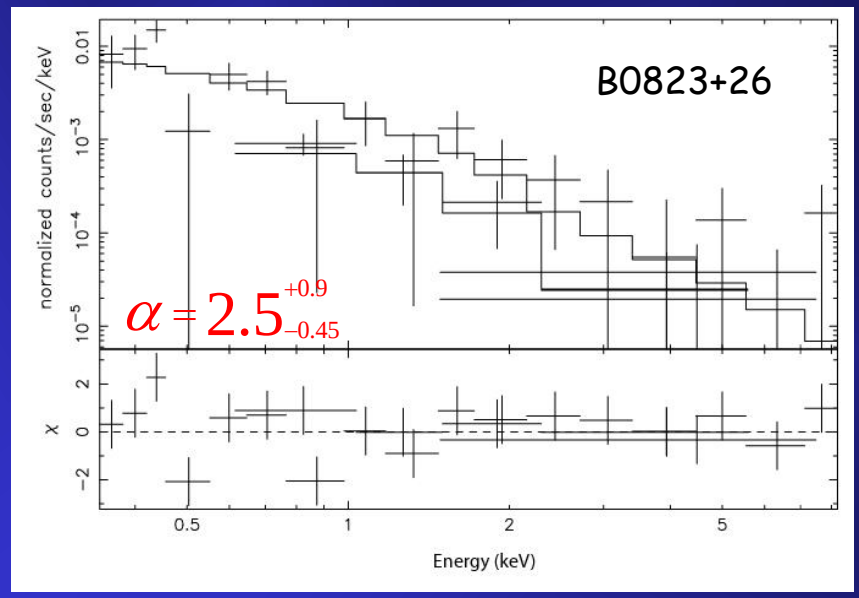


	PSR B0950+08	PSR B0823+26	PSR J2043+2740
τ	~ 17 x 10^6 yrs	~ 5 x 10^6 yrs	~ 1.2 x 10^6 yrs
P	~ 253 ms	~ 530 ms	~ 96 ms
$\dot{E}$	~ 5.6 x 10^{32} erg/s	~ 4.5 x 10^{32} erg/s	~ 5.6 x 10^{34} erg/s
d	~ 255 pc	~ 340 pc	~ 1130 pc
N_H	~ 9.6 x 10^{19} cm^{-2}	~ 60 x 10^{19} cm^{-2}	~ 65 x 10^{19} cm^{-2}

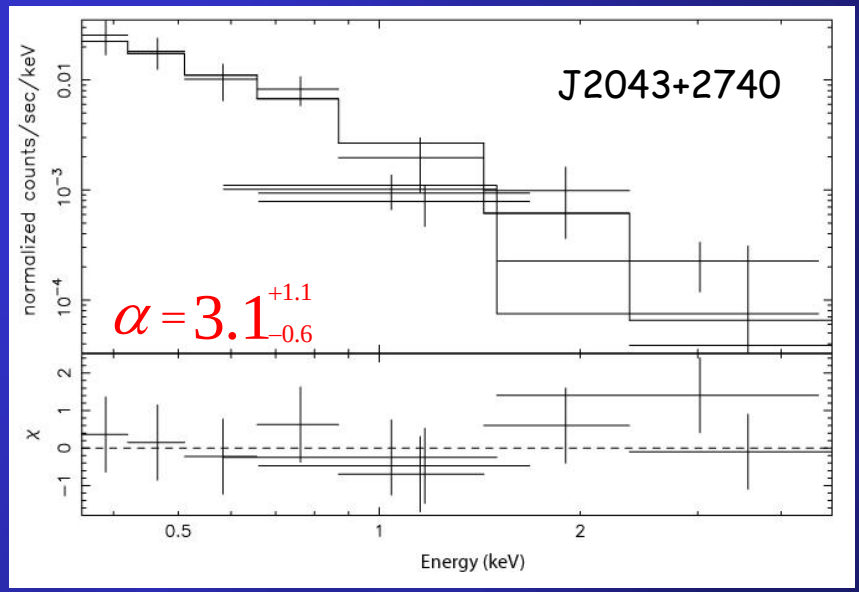
Becker, Weisskopf, Tennant et al.(2004)

X-ray emission properties of old pulsars



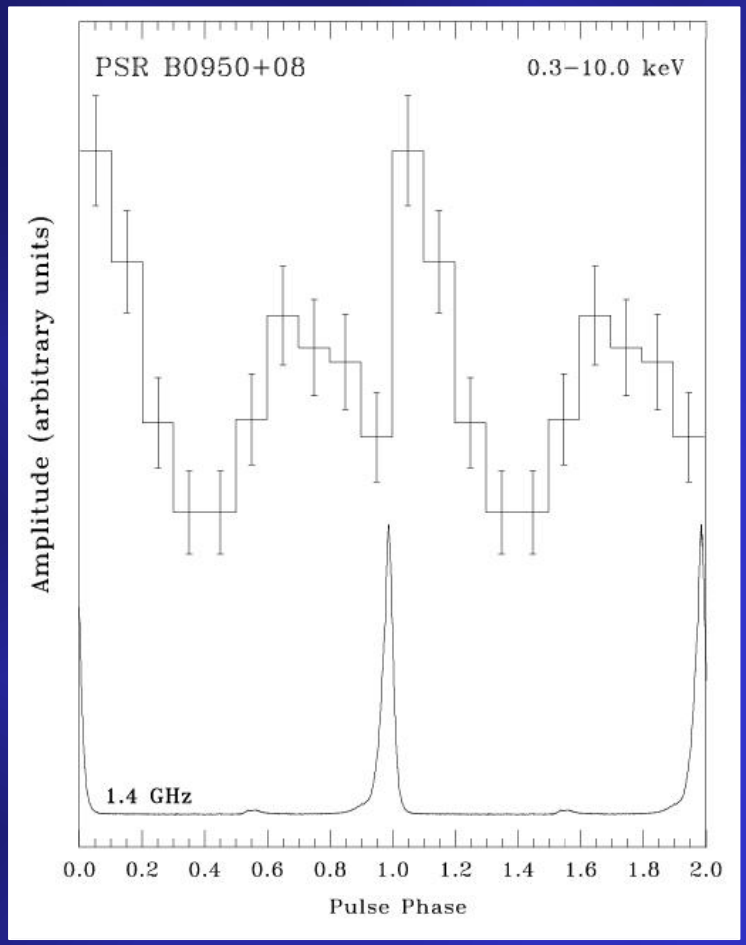


- BB spectra are clearly excluded
- BB+BB doesn't fit as well
- single PL spectrum fits best → non-thermal emission dominates
- in J2043+1740 some thermal contr. possible



Becker, Weisskopf, Tennant et al.(2004)

X-ray emission properties of old pulsars: B0950+08

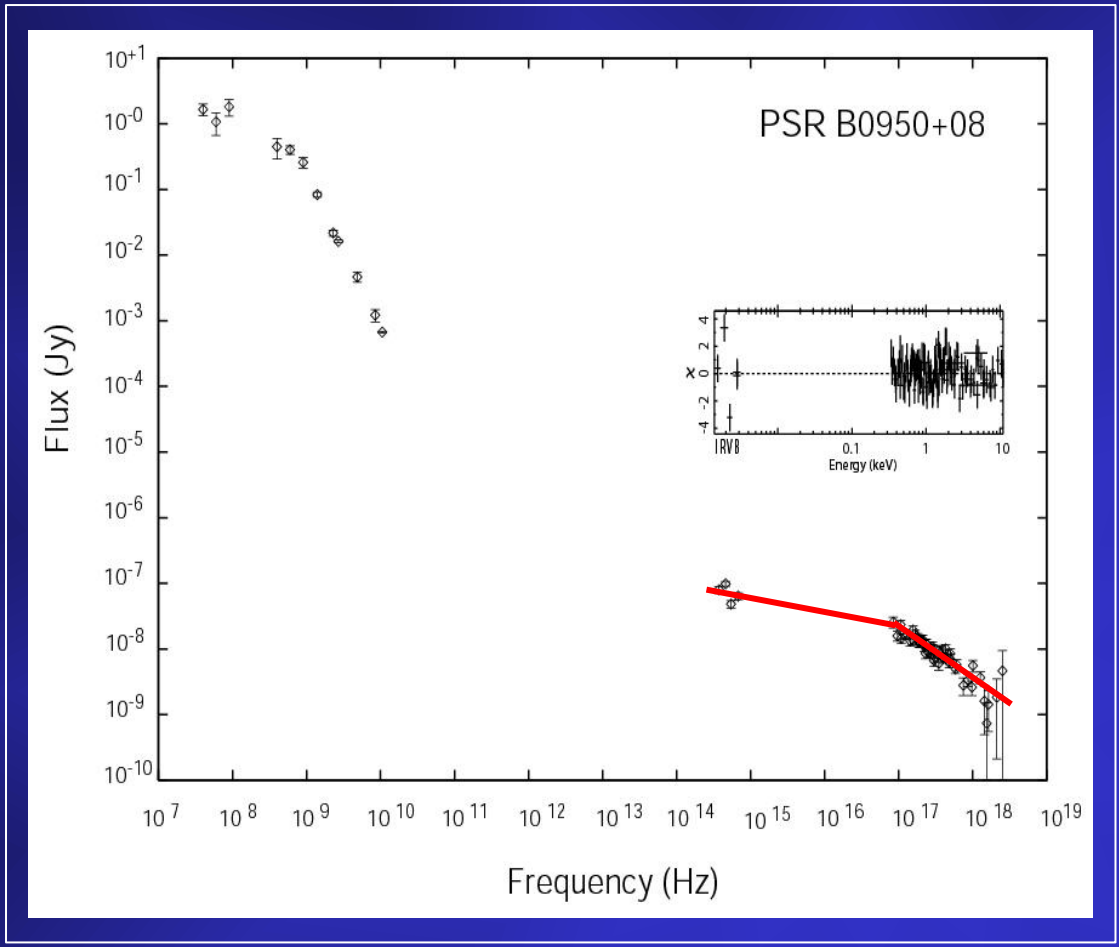


PF = 28 +- 6%, phase separation ~ 144^0

- pulse profile **NOT** sinusoidal
- double peaked pulse profile
- phase separation between X-ray peaks ~ 144^0 the same as for radio pulse and interpulse

Becker, Weisskopf, Tennant et al.(2004)

Multi-wavelength emission spectrum: B0950+08



- Optical to X-ray data:

  → broken power law

$$\alpha_1 = 1.27^{+0.02}_{-0.01}$$

$$\alpha_2 = 1.88^{+0.14}_{-0.11}$$

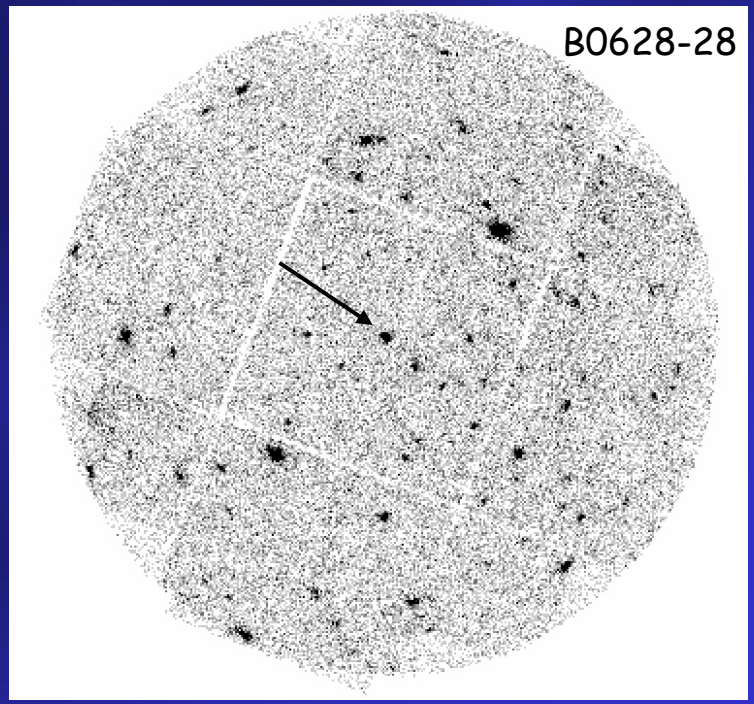
$$E_{break} = 0.67^{+0.18}_{-0.41}$$

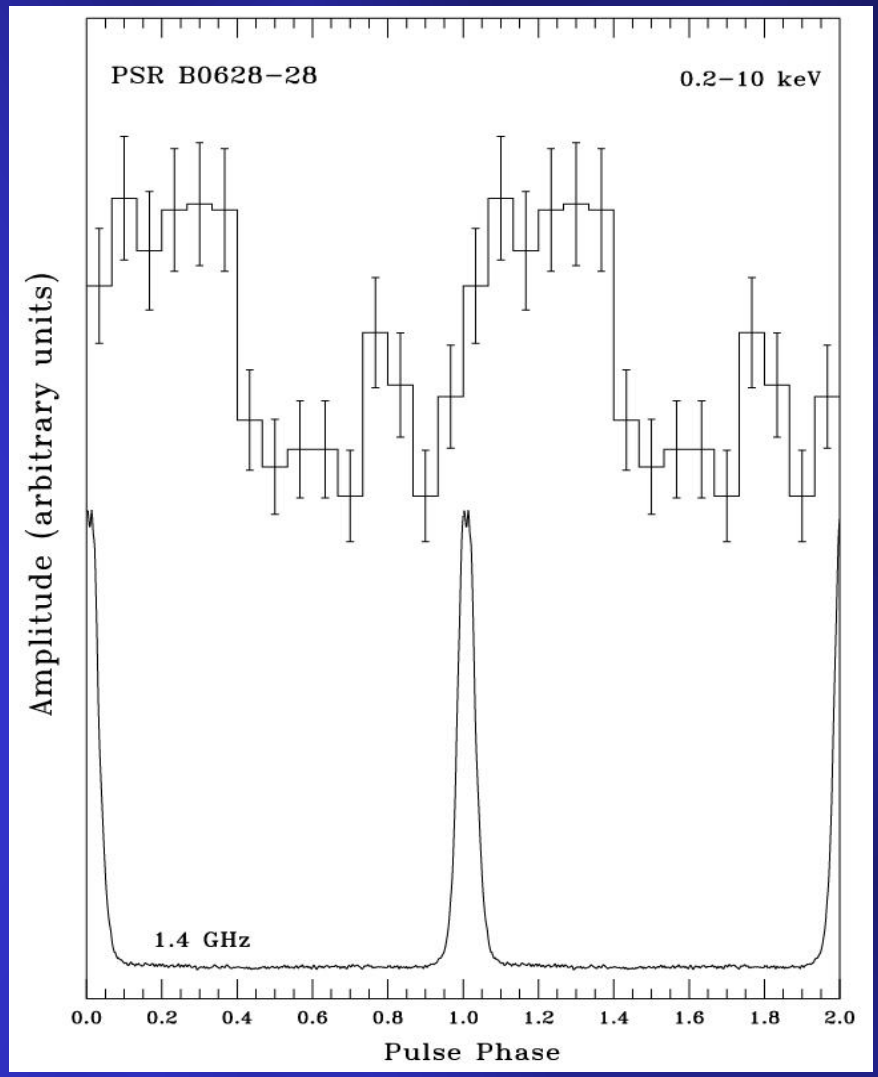
Optical data taken with the VLT FORS1 (Zharikov et al. 2003)

Radio data from Malofeev et al.(1994)

Becker, Weisskopf, Tennant et al.(2004)

XMM-Newton observations of old pulsars: B0628-28





τ ~ 2.75 x 10^6 yrs

P ~ 1.24 s

$\dot{E}$ ~ 1.45 x 10^{32} erg/s

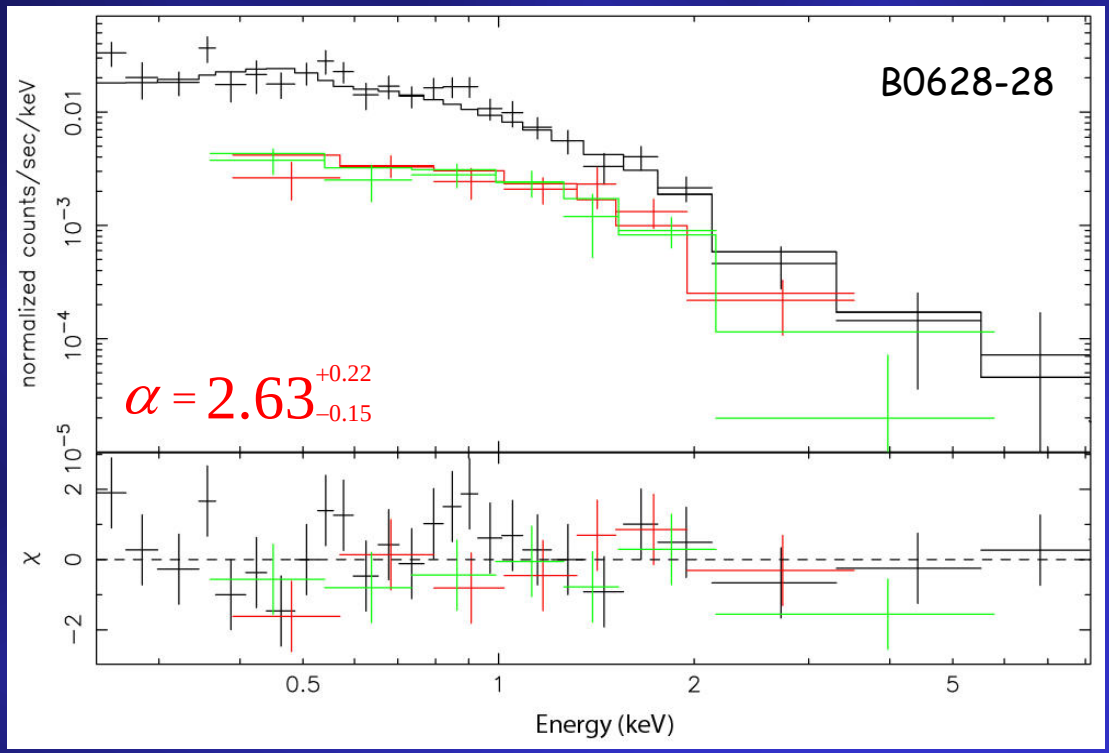
d ~ 1.45 kpc

N_H ~ 6 x 10^{20} cm^{-2}

PF = 39 +- 6% (0.2 - 10 keV)

Becker, Jessner, Kramer et al.(2005)

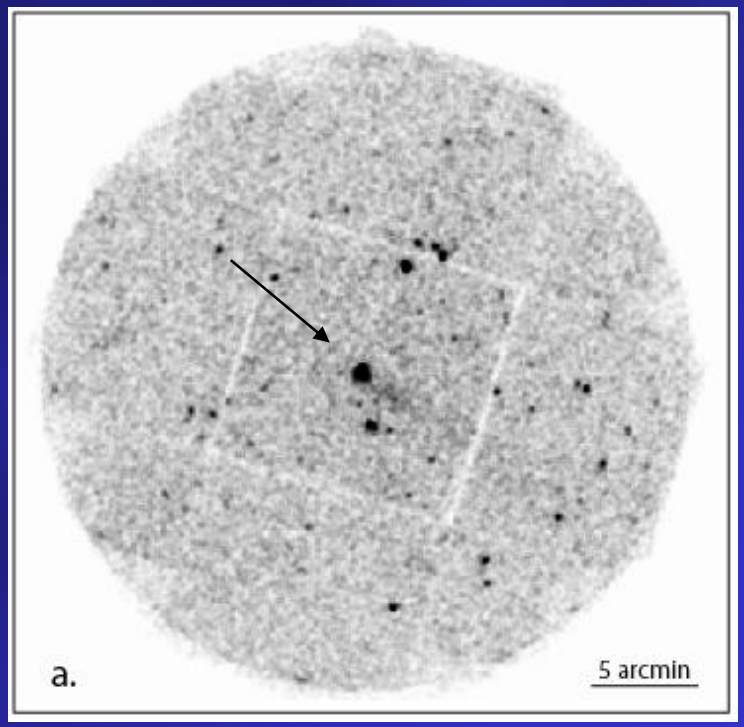
XMM-Newton observations of old pulsars: B0628-28



- BB spectra are clearly excluded
- single PL spectrum fits best
  → non-thermal emission dominates
- ~ 20% thermal contrib. possible

Becker, Jessner, Kramer et al.(2005)

X-ray emission properties of old pulsars: B1929-10



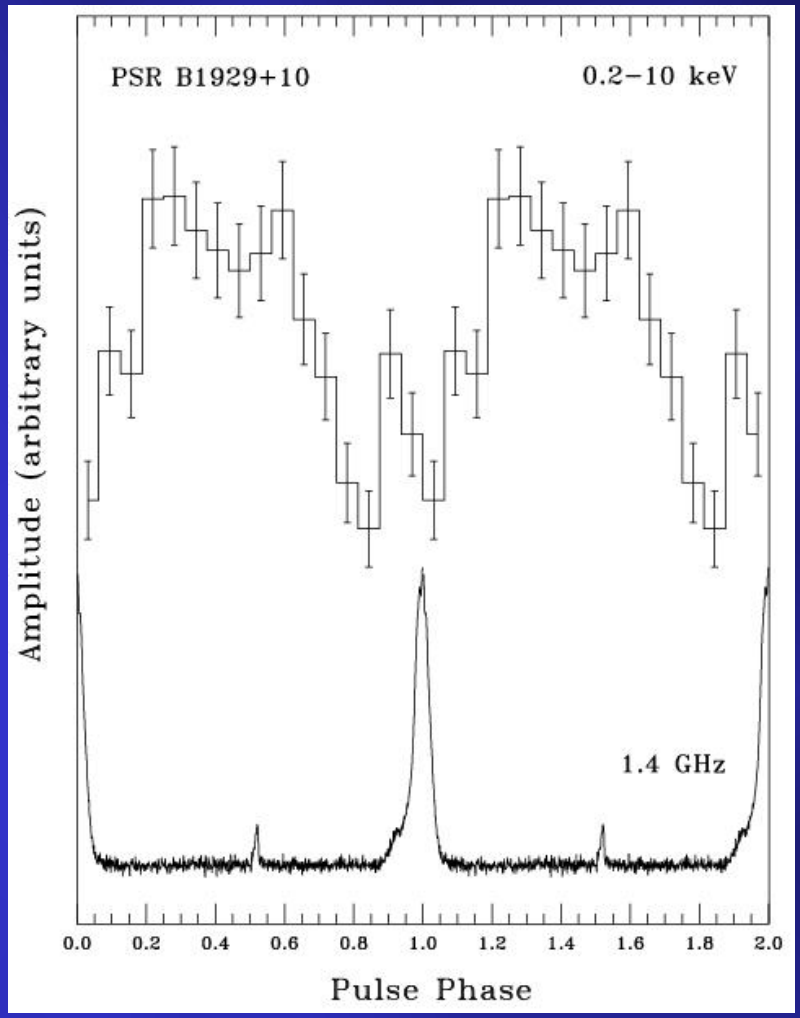
τ ~ 3.1 x 10^6 yrs

P ~ 226 ms

$\dot{E}$ ~ 3.9 x 10^{33} erg/s

d ~ 3.178 pc

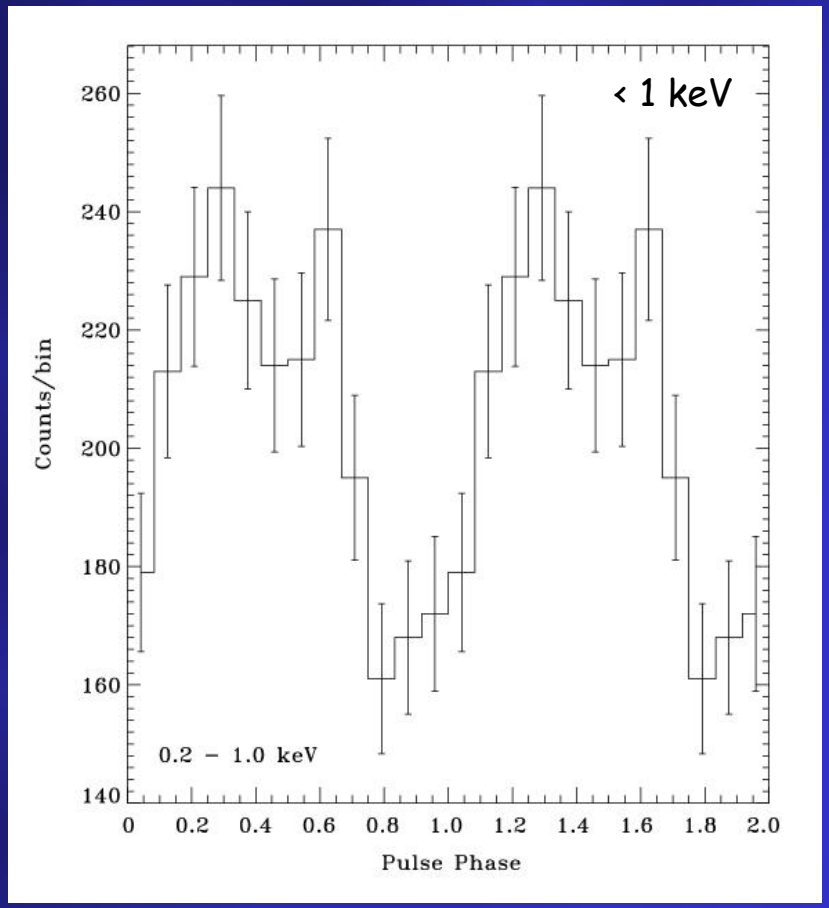
N_H ~ 6 x 10^{20} cm^{-2}



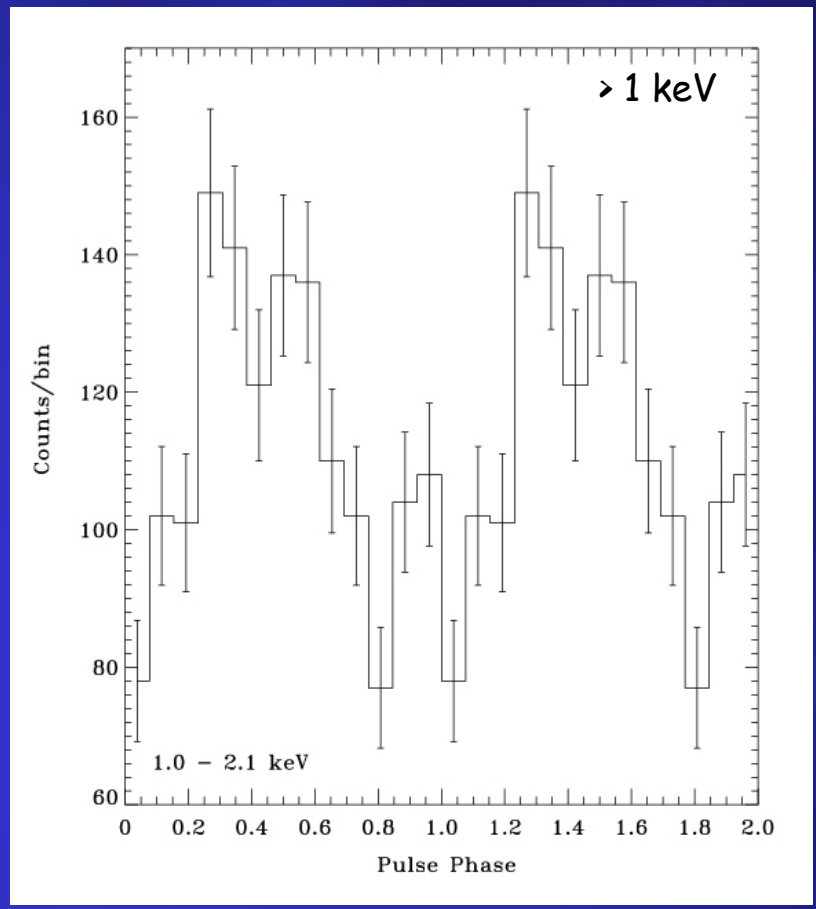
PF = 32 +- 4% (0.2 - 10 keV)

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

X-ray emission properties of old pulsars: B1929-10



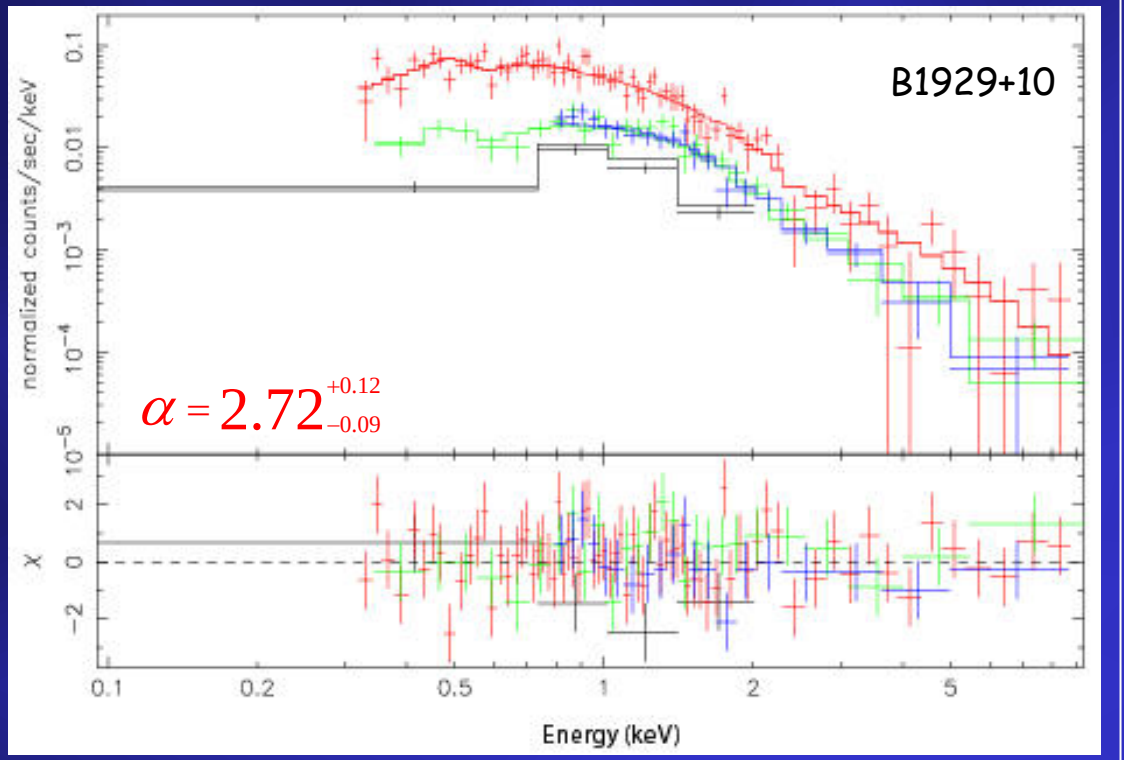
PF = 24 +- 5%



PF = 44 +- 6%

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

X-ray emission properties of old pulsars: B1929-10

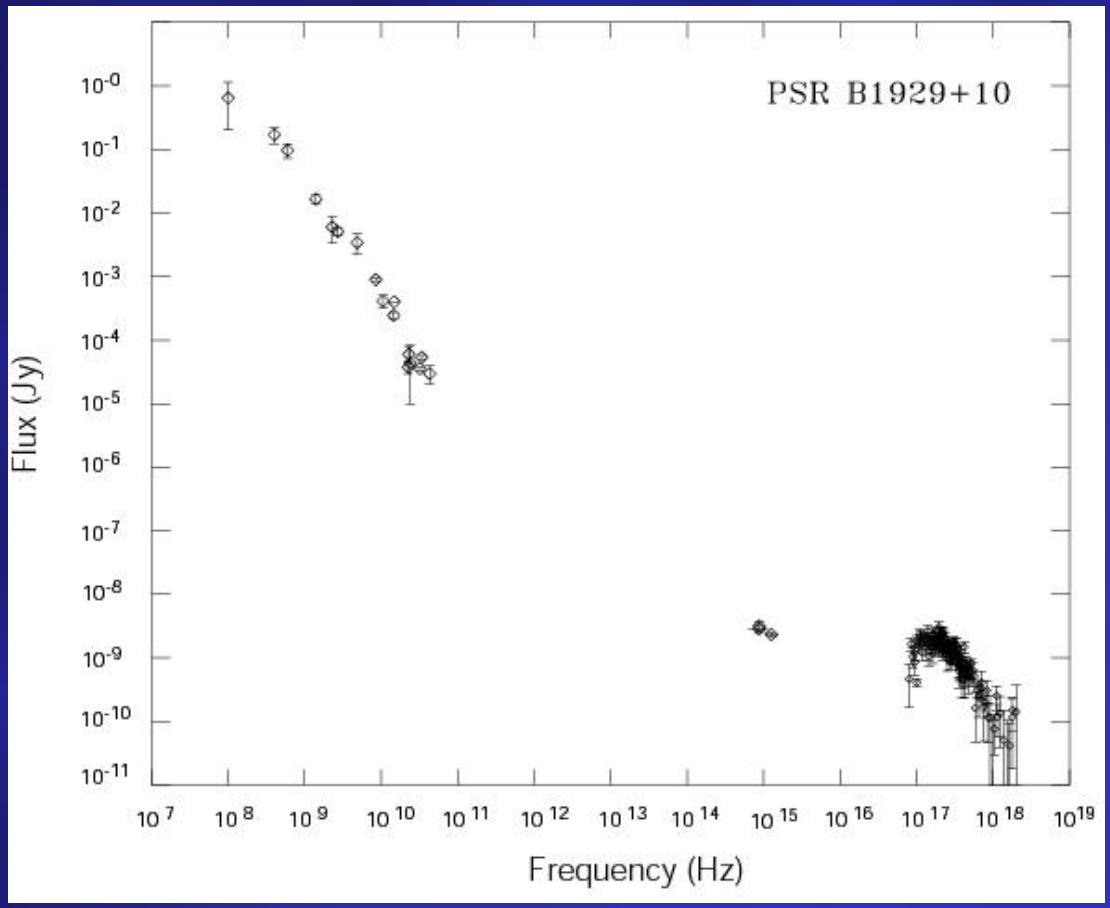


ROSAT + XMM-Newton (MOS1/2 & PN)

- BB spectra are clearly excluded
- single PL spectrum fits best
  → non-thermal emission dominates
- only 7% thermal contrib. possible

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

Multi-wavelength emission spectrum: B1929+10



- Optical to X-ray data:

  → broken power law

$$\alpha_1 = 1.12^{+0.02}_{-0.03}$$

$$\alpha_2 = 2.48^{+0.06}_{-0.07}$$

$$E_{break} = 0.83^{+0.05}_{-0.03}$$

Optical data from Mignani et al.(2002) & Pavlov et al.(1996)

Radio data by Maron et al.(2000)

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

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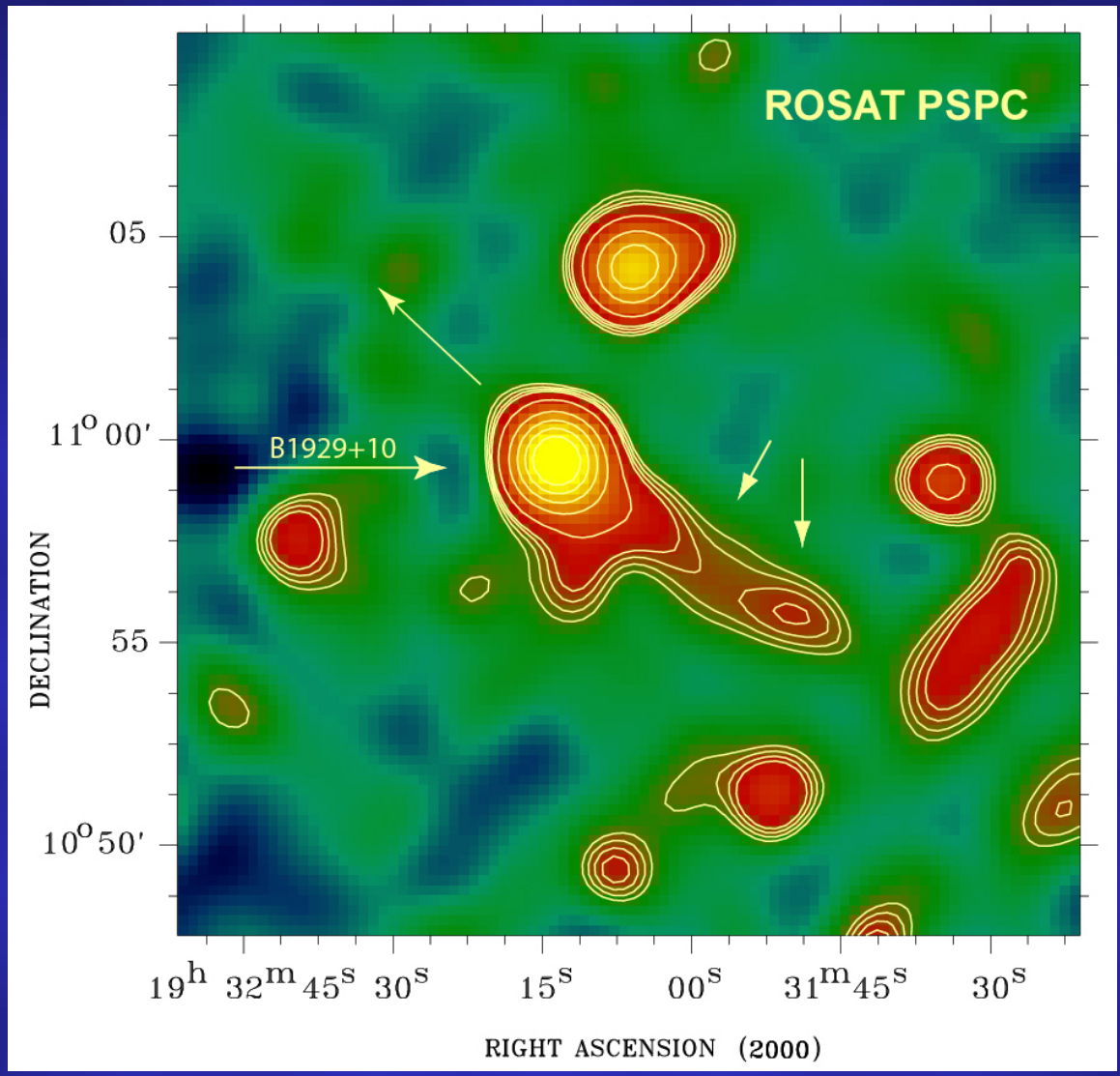

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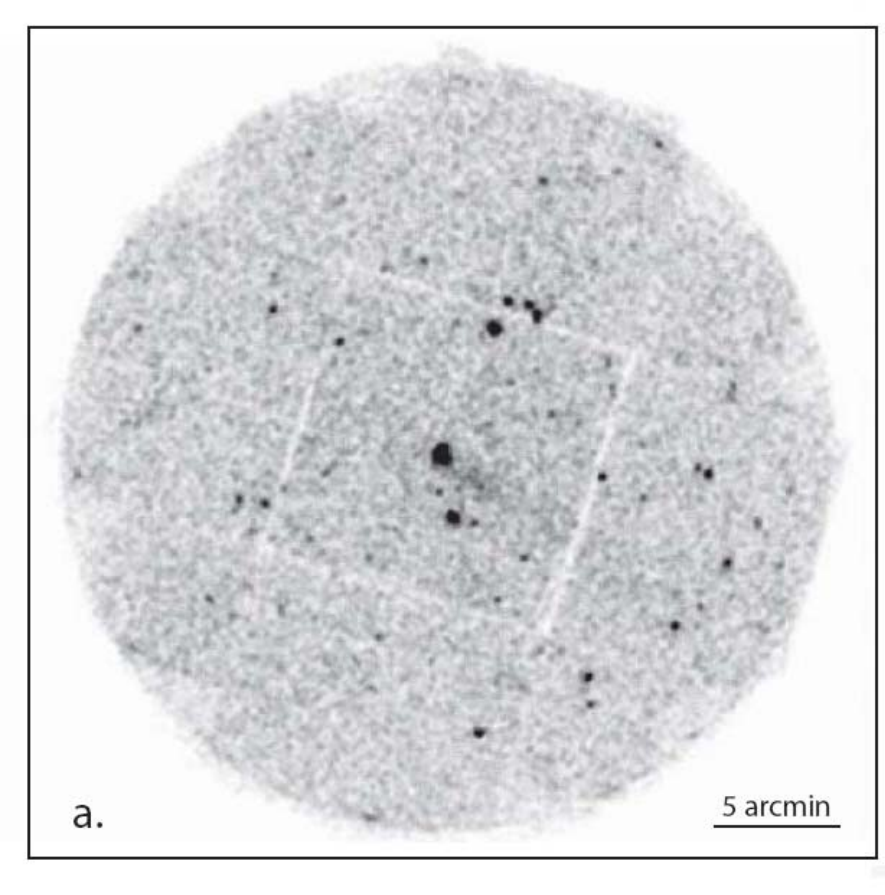

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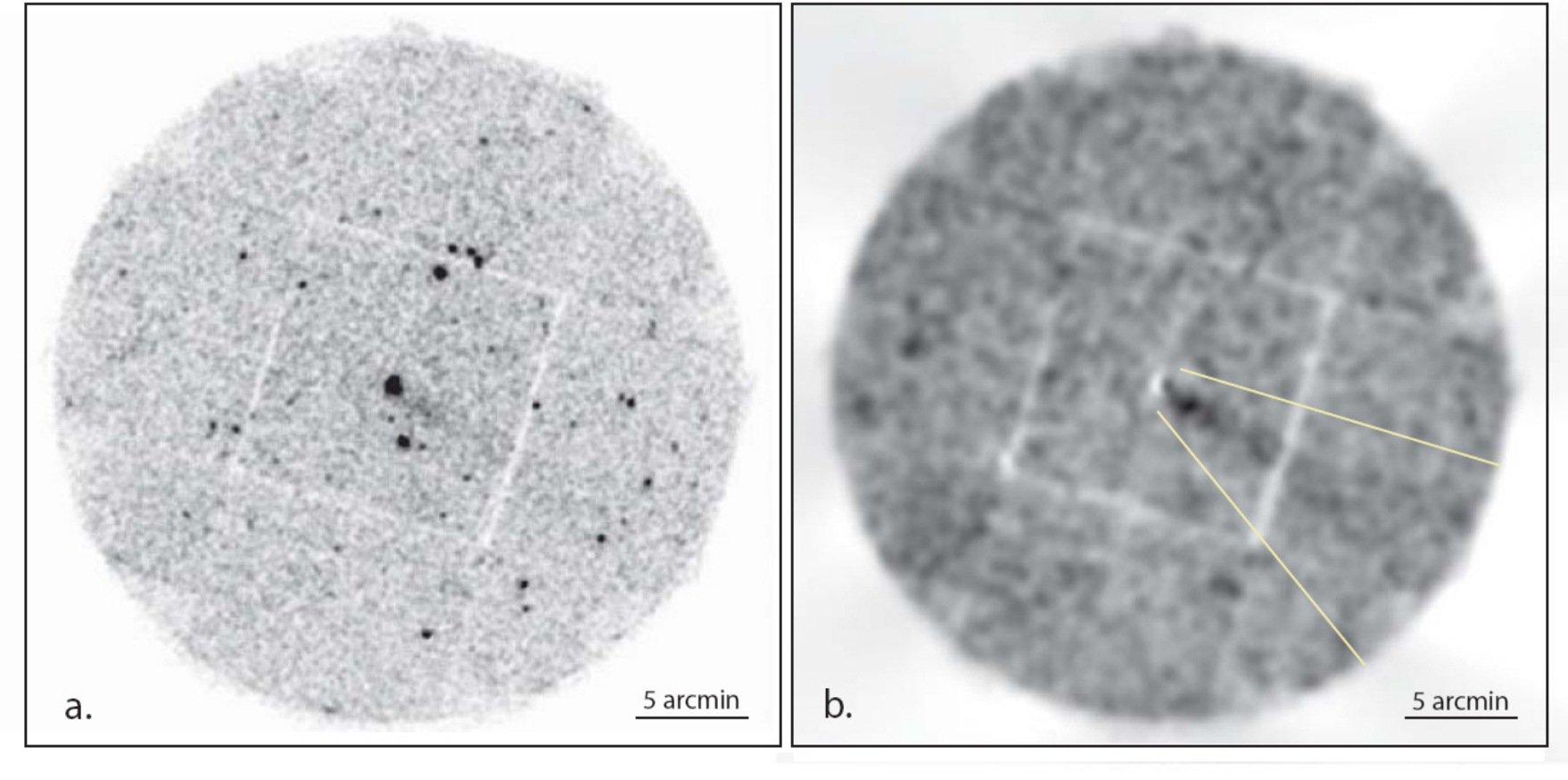
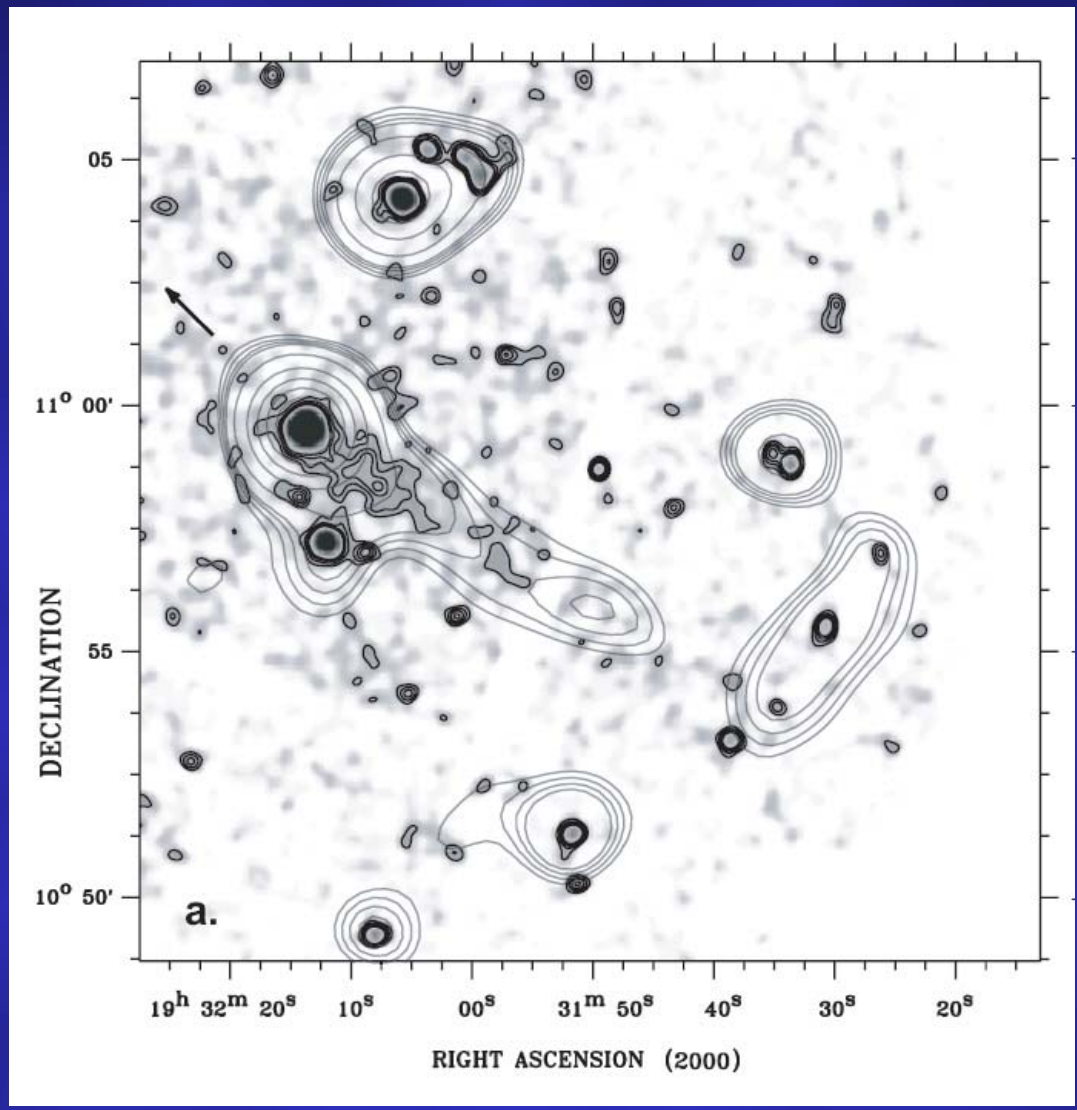


- length of the trail not very well constraint → requires deeper observations !!

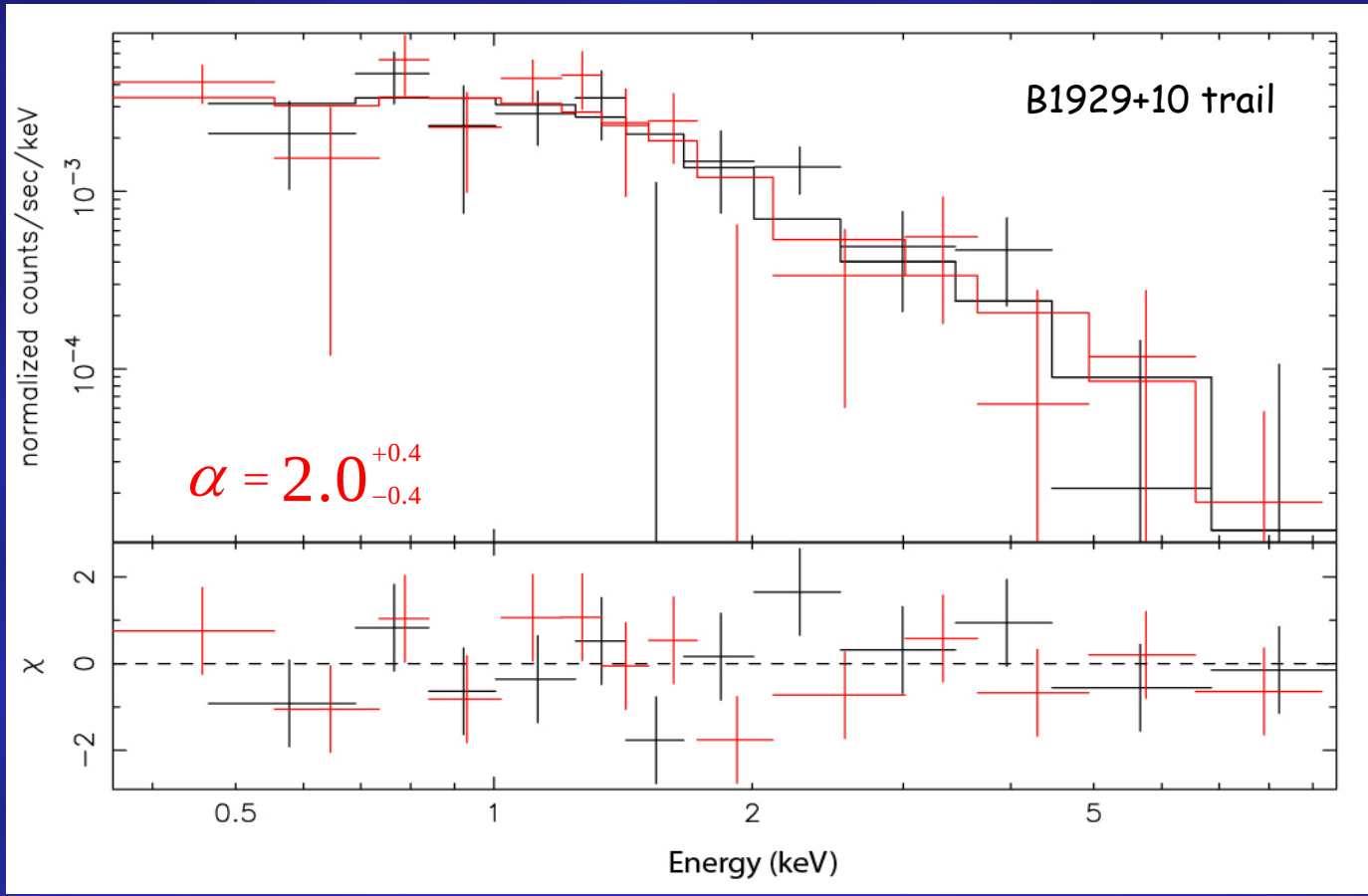
Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

X-ray emission properties of old pulsars: B1929-10



Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

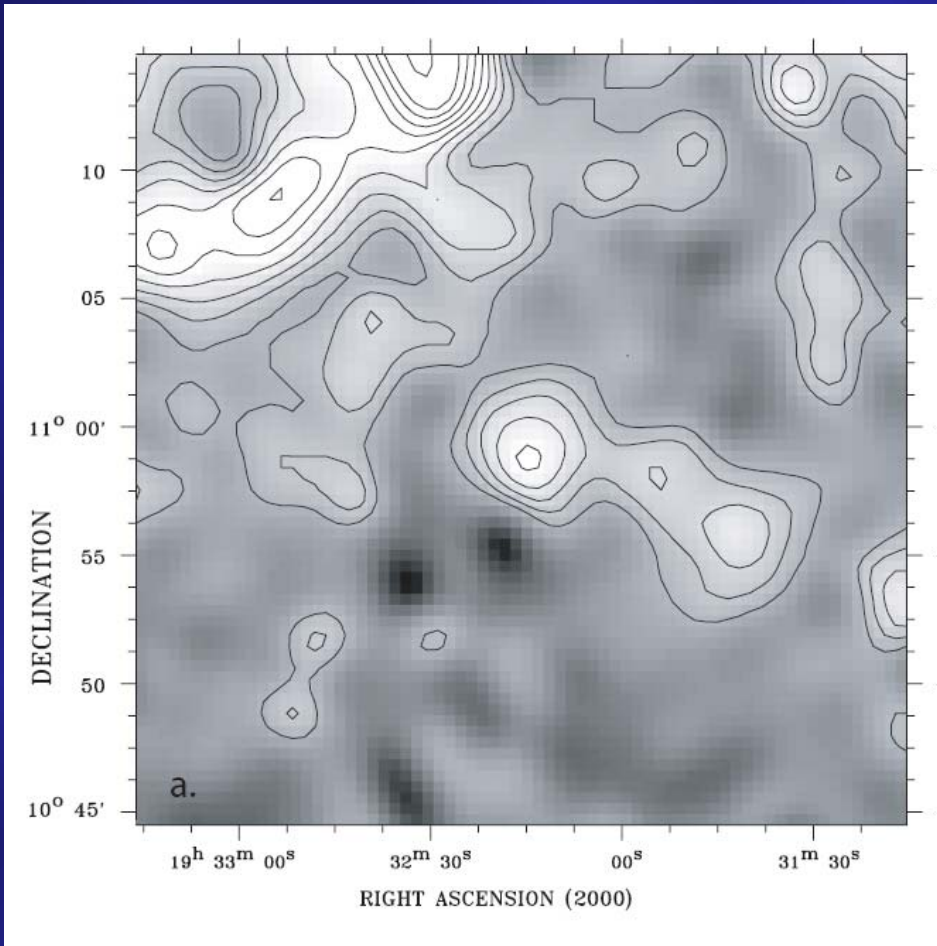
X-ray emission properties of old pulsars: B1929-10



- spectrum non-thermal
- likely from synchrotron processes in the shocked region between pulsar wind and the ISM

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

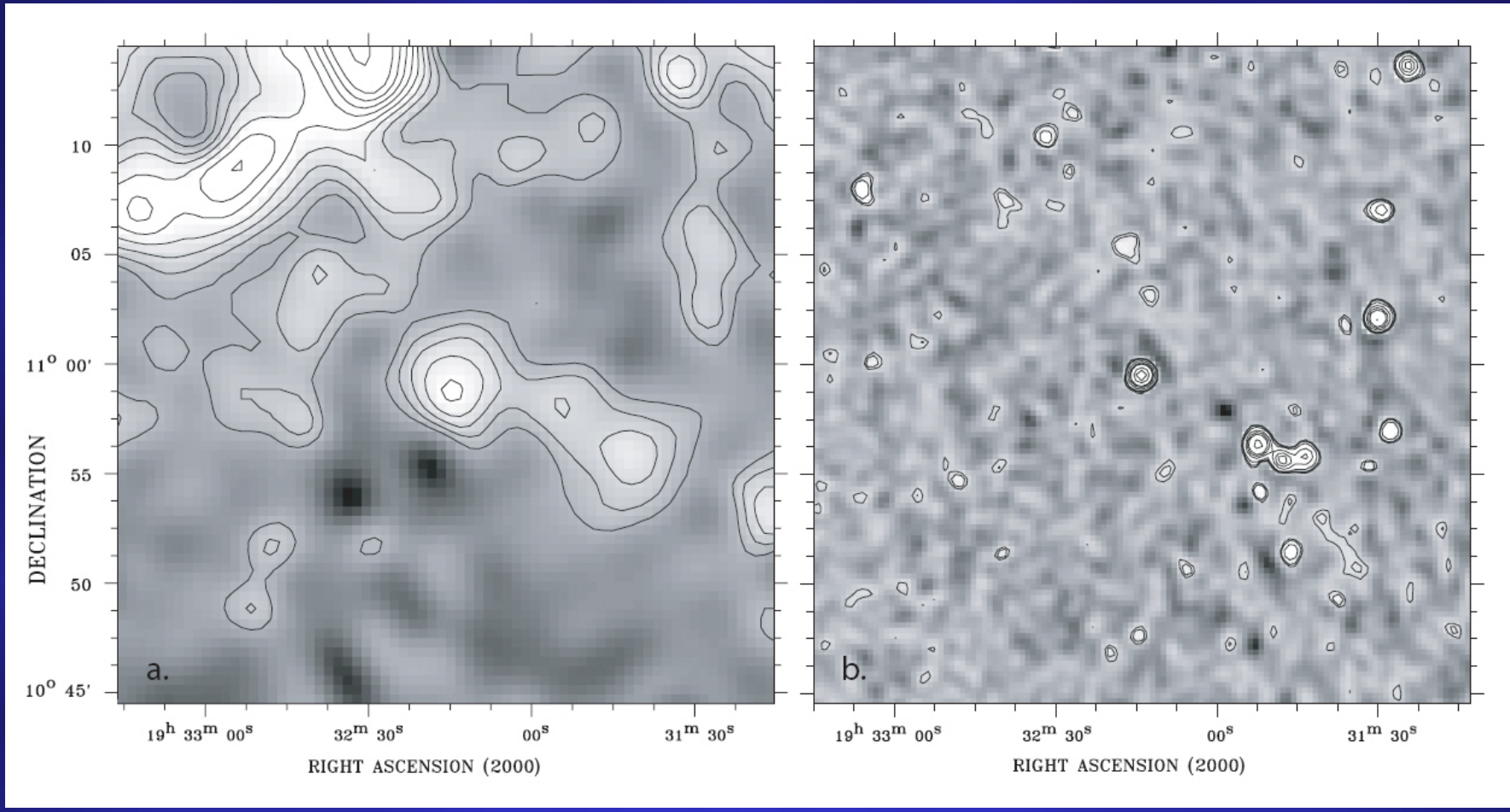
X-ray emission properties of old pulsars: B1929-10



Effelsberg 11cm (2.72 GHz) galactic plane survey

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

X-ray emission properties of old pulsars: B1929-10



Effelsberg 11cm galactic plane survey

NRAO VLA Sky survey (1.4 GHz)

Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

Summary of rot. powered pulsars detected at X

- With EINSTEIN & EXOSAT: 7 radio pulsars detected in X-rays
- With ROSAT, ASCA & BSAX: 33 radio pulsars detected in X-rays
- After ~7 yrs with XMM & Chandra: 78 radio pulsars detected in X-rays

Age τ	Pulsar category	ROSAT/ASCA	XMM/Chandra	
$< 10^4$ yrs	Crab-like	5	9	+4
$10^4 - 10^5$ yrs	Vela-like	9	15	+6
$10^5 - 10^6$ yrs	Cooling NS	5	5	
$10^6 - 10^8$ yrs	Old & nearby	3	8	+5
	other	1	2	+1
$> 10^8$ yrs	ms-Pulsars	11	39	+28
	detected #	33	78	+45

X-ray emission prop. scale with spin-down age

Crab-like pulsars

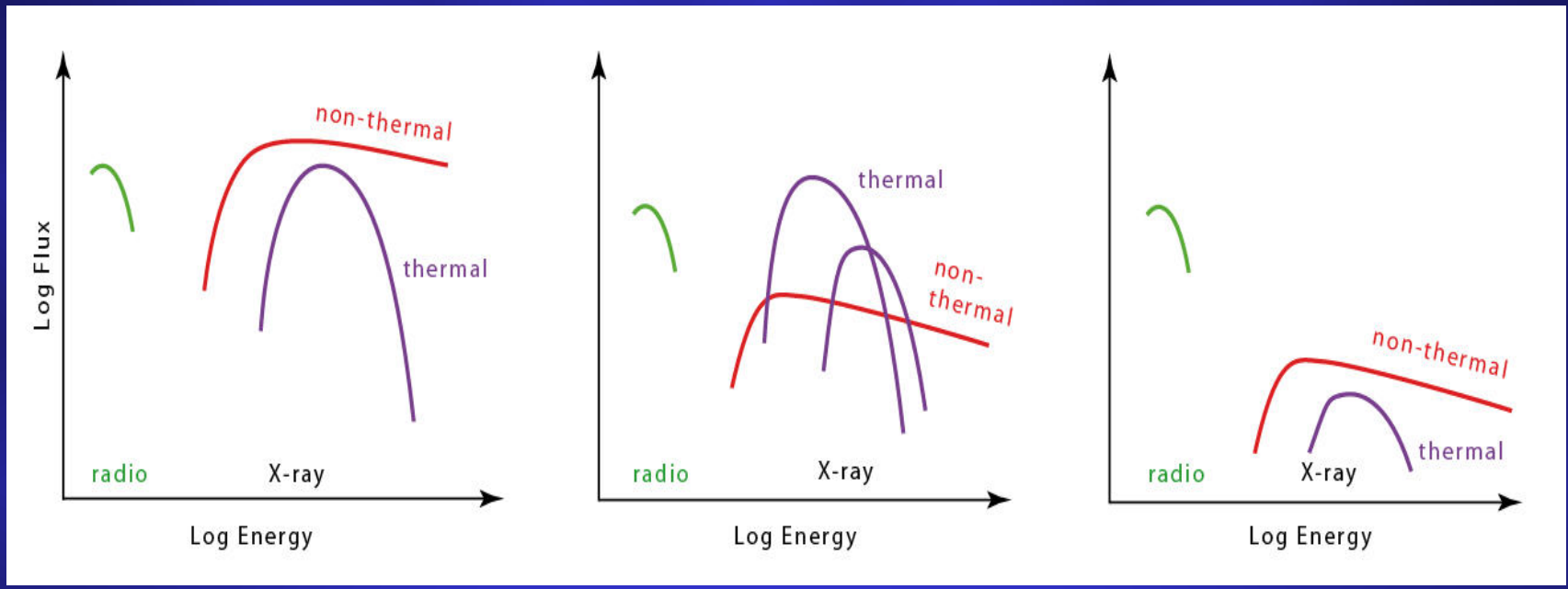
(< 10^4 yrs)

Cooling neutron stars

(10^5 - 10^6 yrs)

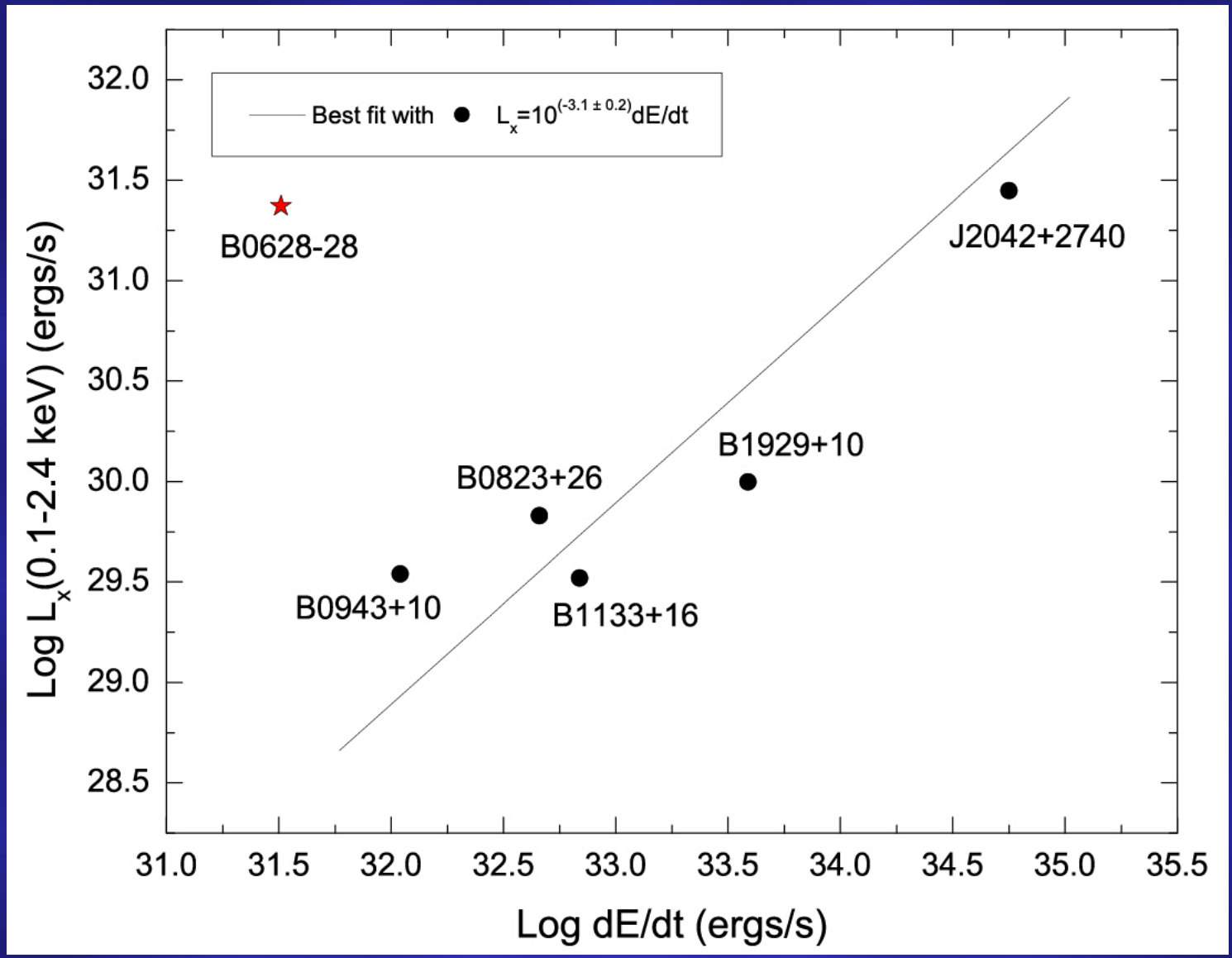
Old pulsars

(10^6 - 10^8 yrs)



- non-thermal emission dominates in old pulsars / pulse profiles **NOT sinusoidal**
- hot polar cap emission component may decreases along with the cooling surface component ?
- if so, hot polar caps in cooling neutron stars could be formed by anisotropic heat flow due to the presence of the magnetic field rather than by particle bombardment

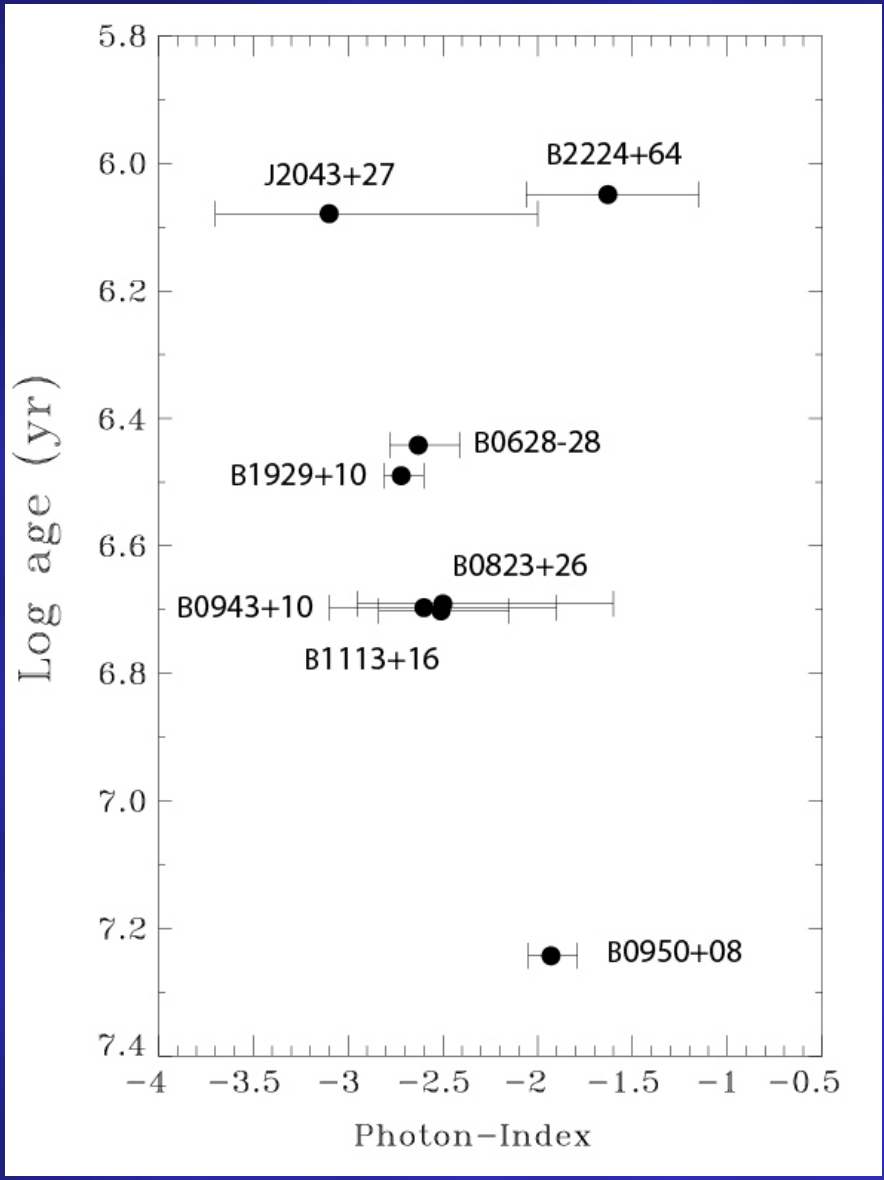
X-ray emission properties of old pulsars



X-ray emission properties of old pulsars

younger

older



No evidence for a spectral softening with increasing spin-down age for old pulsars

Surface temperature upper limits for R_{NS}=10 km

Pulsar	Spin down age	T_S^{∞} 3σ upper limt
B2224+65	1.13 x 10^6 yrs	< 0.68 10^6 k
J2043+2740	1.2 x 10^6 yrs	< 0.62 10^6 k
B0628-28	2.75 x 10^6 yrs	< 0.53 10^6 k
B1929+10	3.1 x 10^6 yrs	< 0.45 10^6 k
B0823+26	5 x 10^6 yrs	< 0.5 10^6 k
B0950-09	17 x 10^6 yrs	< 0.48 10^6 k