# PULSARS

# X-ray emission properties of old

**Werner Becker**

Max-Planck Institut für extraterr. Physik

# X-ray emission properties vary with spin-down age

Crab-like pulsars

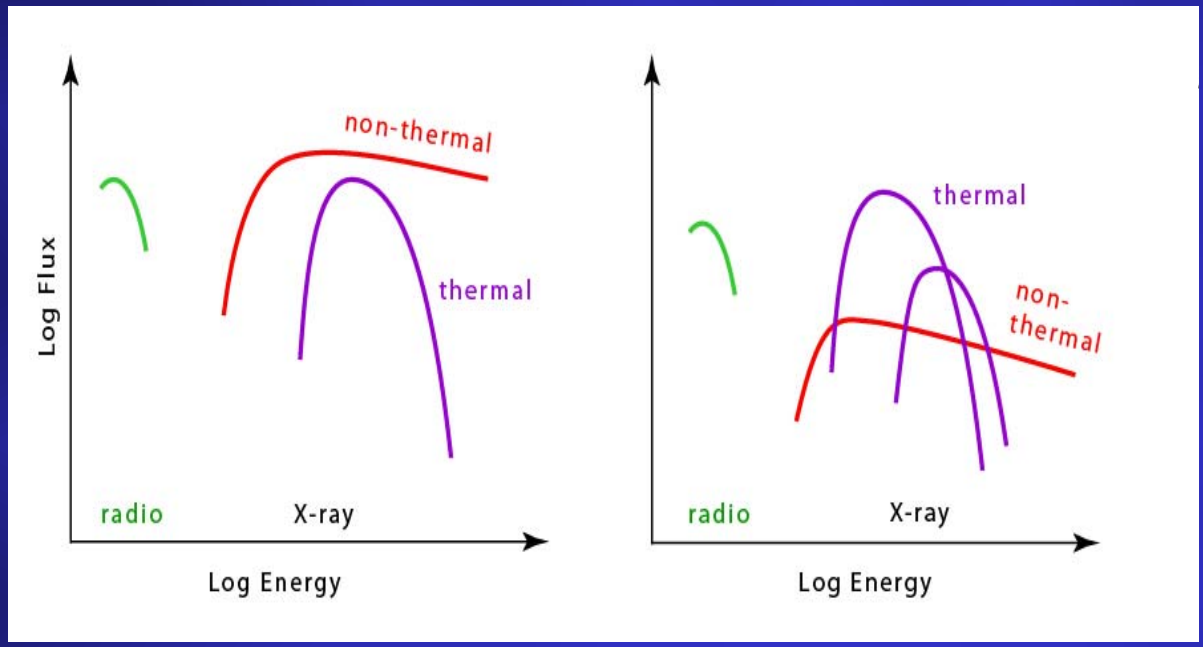
(< $10^4$ yrs)

Cooling neutron stars

( ~$10^5$ - $10^6$ yrs)

Old pulsars

(~$10^6$ - $10^8$ yrs)




?

# X-ray emission properties vary with spin-down age

Crab-like pulsars

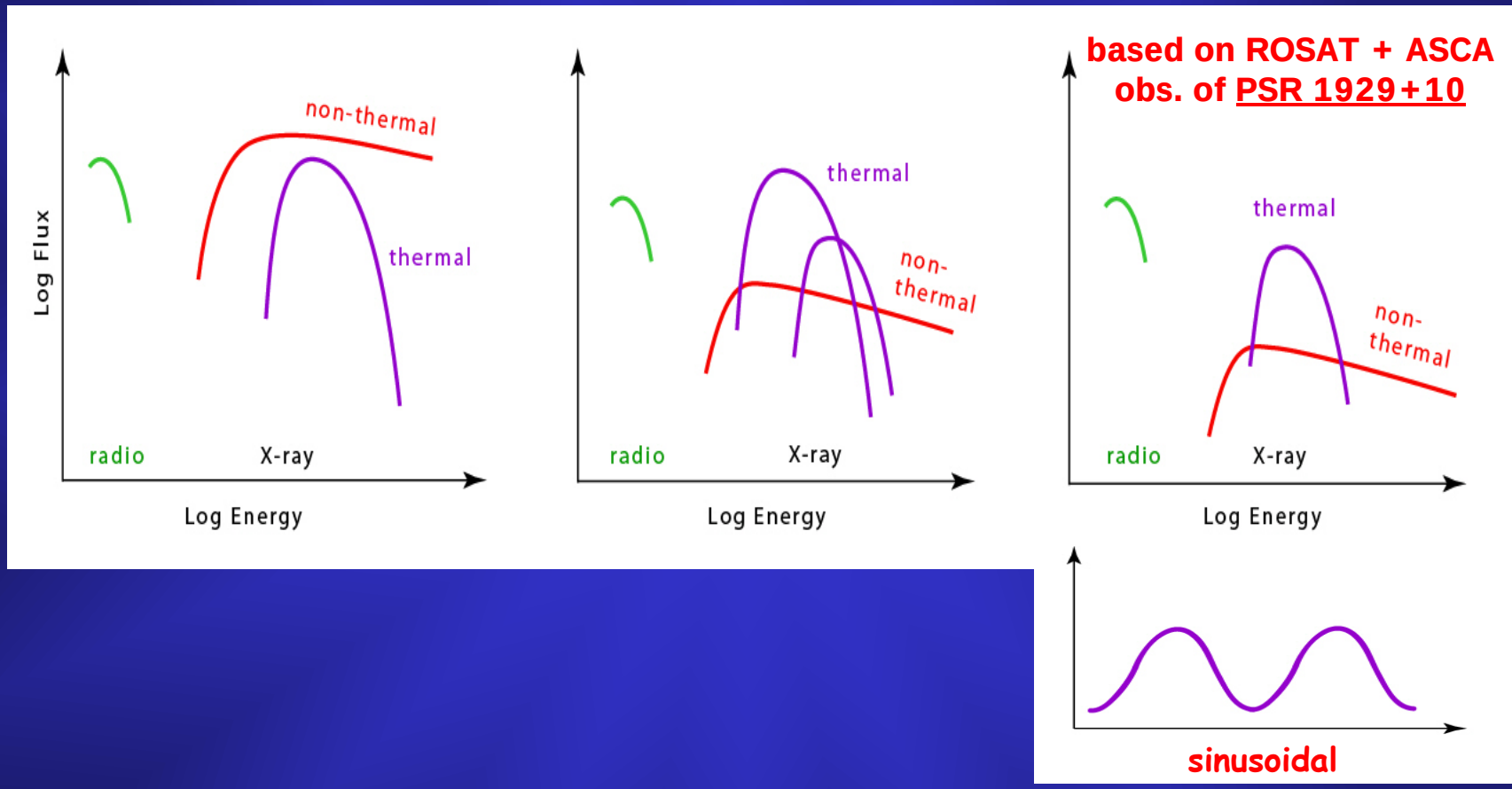
(< $10^4$ yrs)

Cooling neutron stars

( ~$10^5$ - $10^6$ yrs)

Old pulsars

(~$10^6$ - $10^8$ yrs)



# X-ray emission properties vary with spin-down age

Crab-like pulsars

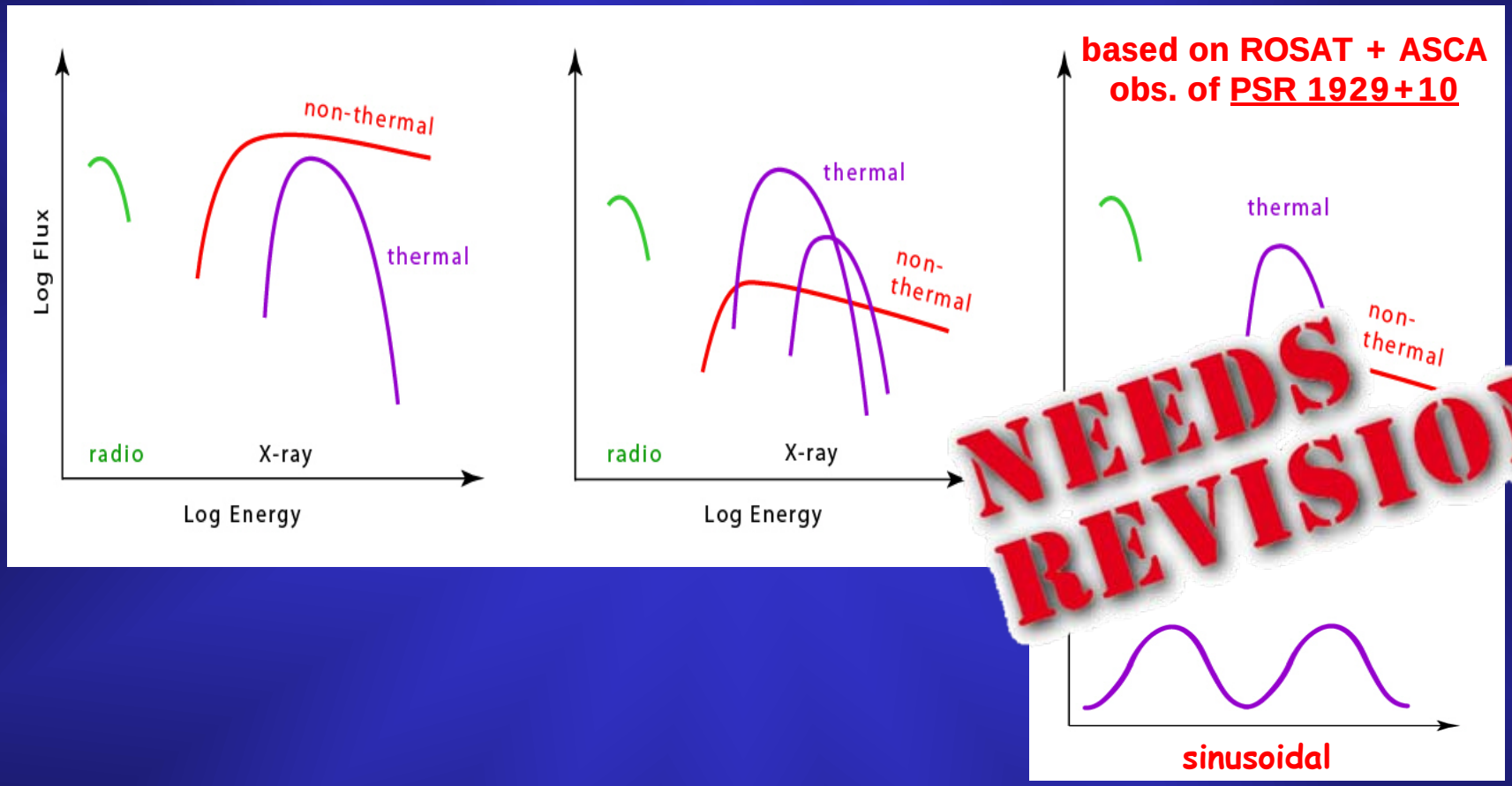
(< $10^4$ yrs)

Cooling neutron stars

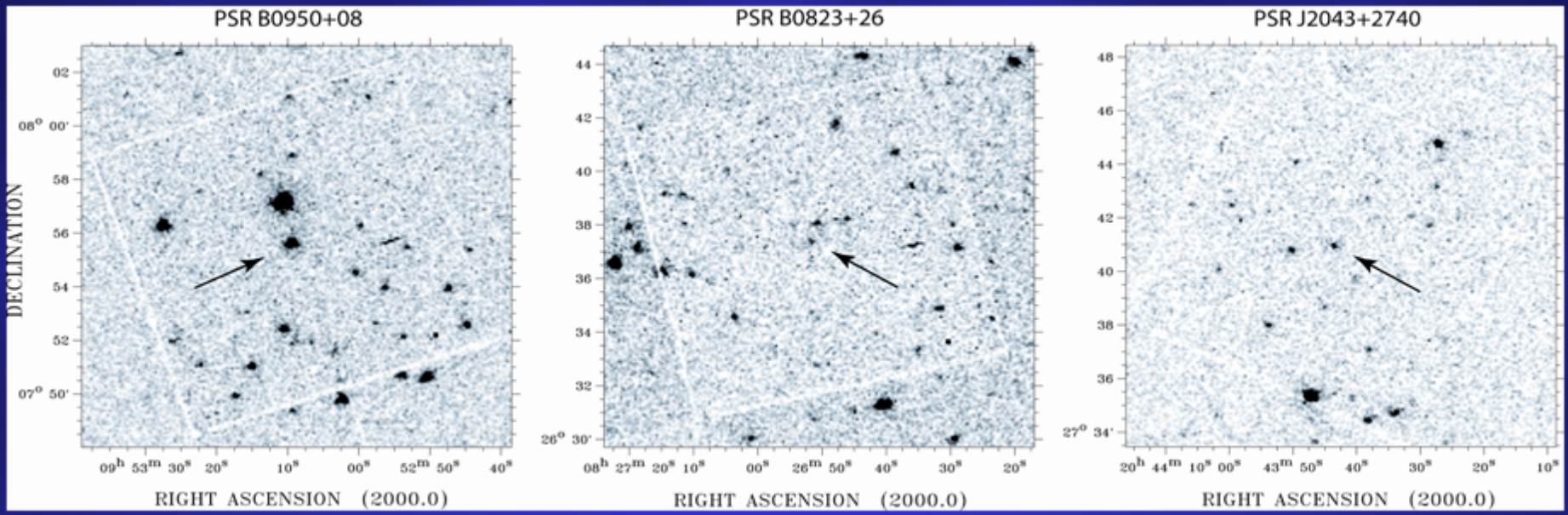
( ~$10^5$ - $10^6$ yrs)

Old pulsars

(~$10^6$ - $10^8$ yrs)



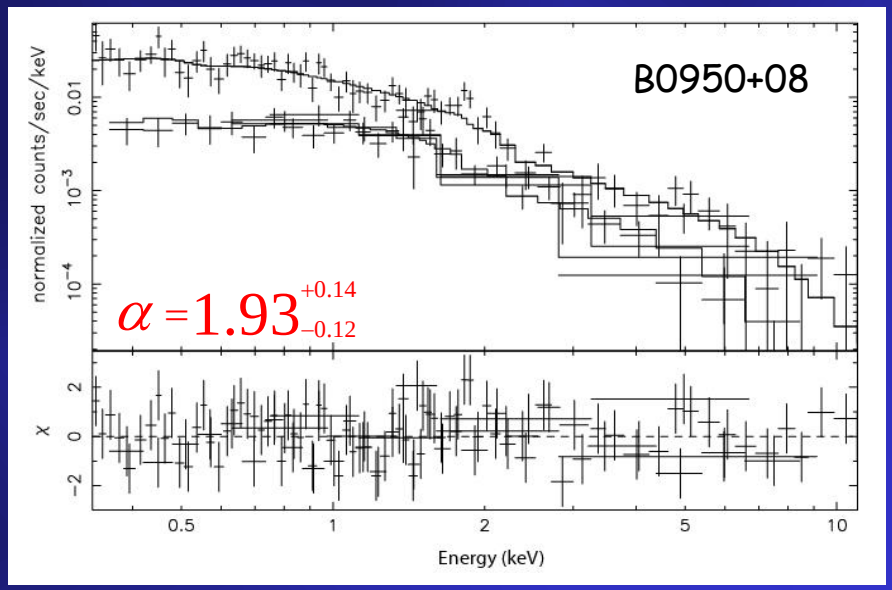
# XMM-Newton observations of old pulsars

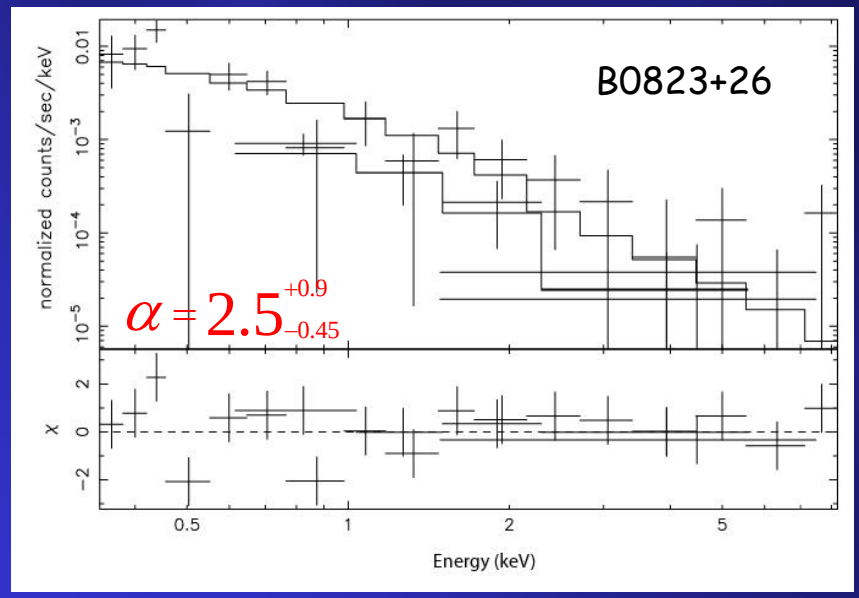



| | PSR B0950+08 | PSR B0823+26 | PSR J2043+2740 |
|---|---|---|---|
| $\tau$ | ~ 17 x $10^6$ yrs | ~ 5 x $10^6$ yrs | ~ 1.2 x $10^6$ yrs |
| P | ~ 253 ms | ~ 530 ms | ~ 96 ms |
| $\dot{E}$ | ~ 5.6 x $10^{32}$ erg/s | ~ 4.5 x $10^{32}$ erg/s | ~ 5.6 x $10^{34}$ erg/s |
| d | ~ 255 pc | ~ 340 pc | ~ 1130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

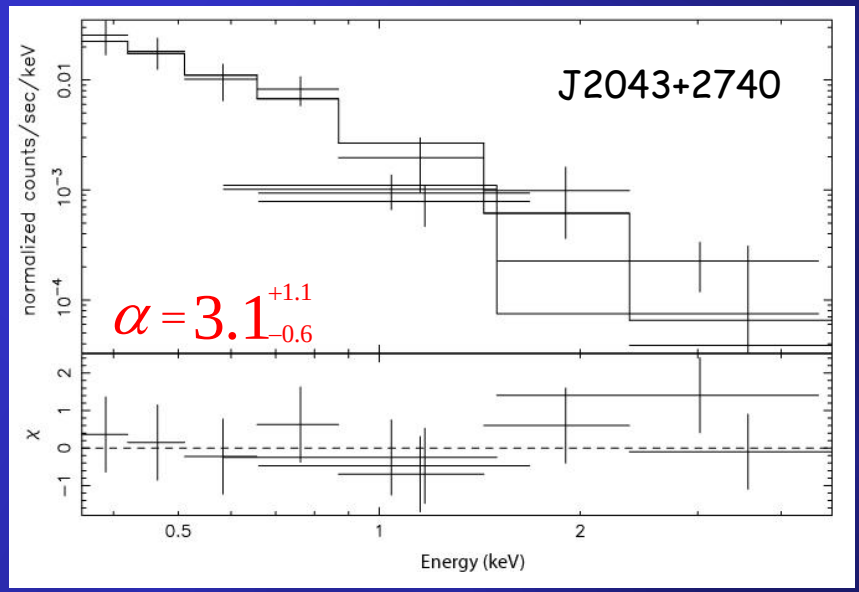
Becker, Weisskopf, Tennant et al.(2004)

# X-ray emission properties of old pulsars



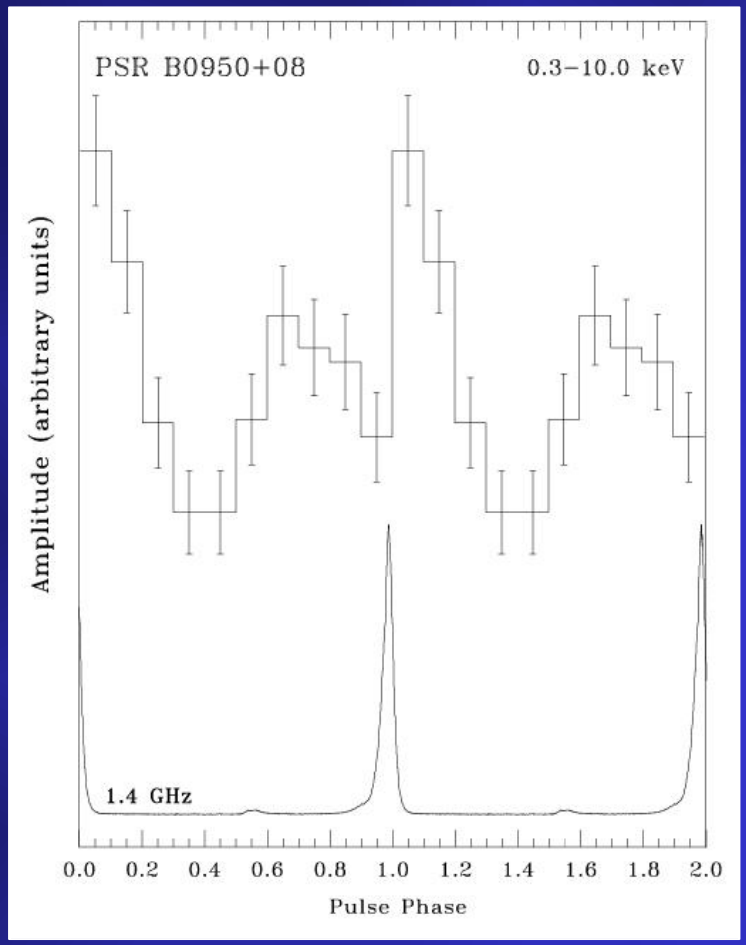




- A single BB spectrum can safely be excluded
- The simplest model which fits best is a PL → non-thermal emission dominates
- PL fit so good that in composite models the BB intrinsically appears to be an upper limit
- in J2043+1740 some thermal contr. possible




Becker, Weisskopf, Tennant et al.(2004)

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

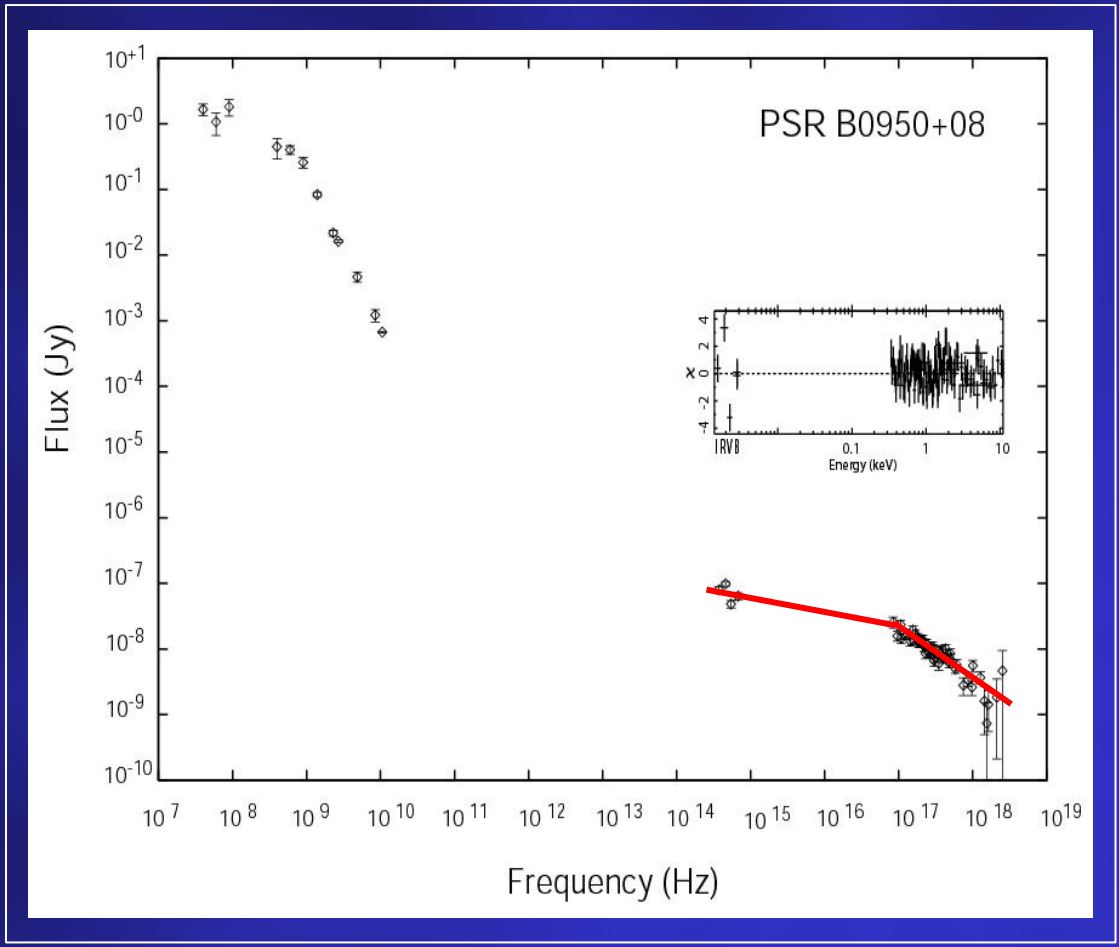



PF = 28 +- 6%, phase separation ~ $144^0$

- 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

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

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

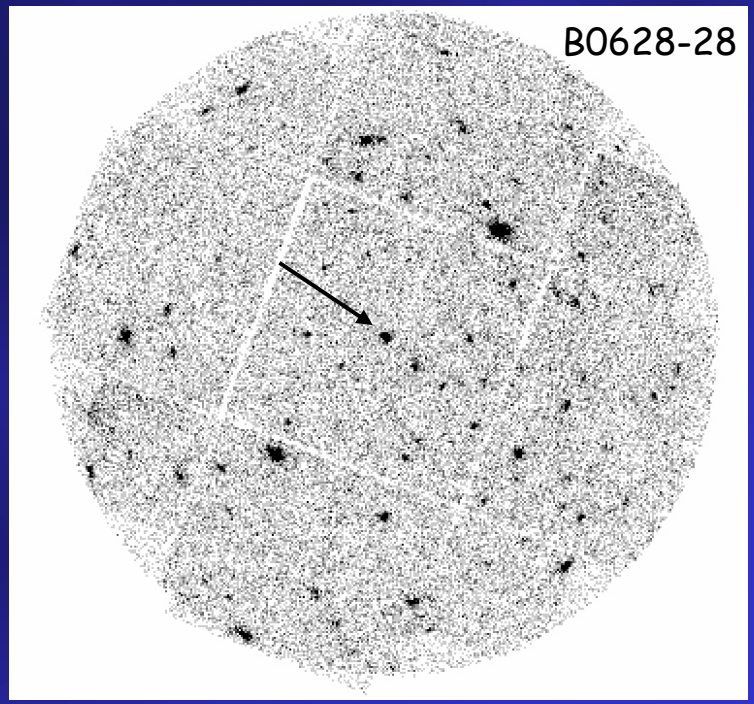
$$E_{break} = 0.67^{+0.18}_{-0.41}$$

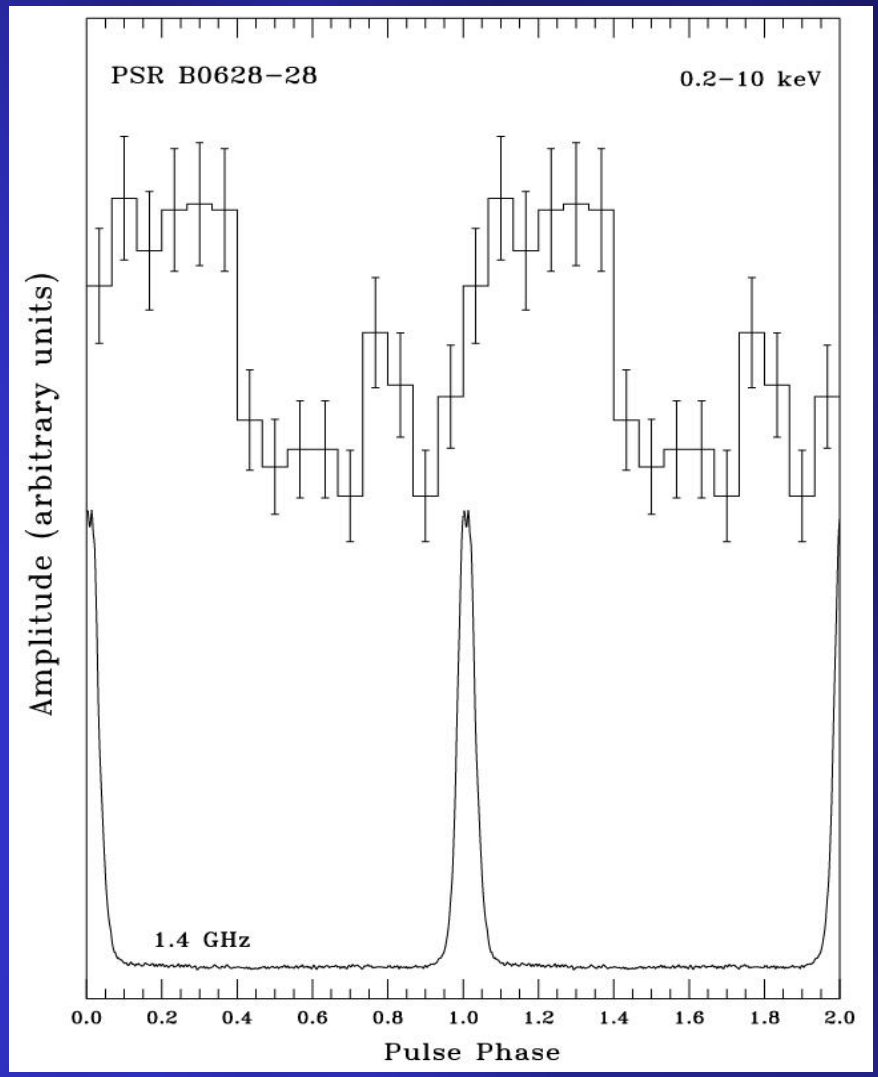
Optical data taken with the VLT FORS1 (Zharikov et al. 2003)

Radio data from Malofeev et al.(1994)

Becker, Weisskopf, Tennant et al.(2004)

# XMM-Newton observations of old pulsars: B0628-28




$\tau$ ~ 2.75 x $10^6$ yrs

P ~ 1.24 s

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

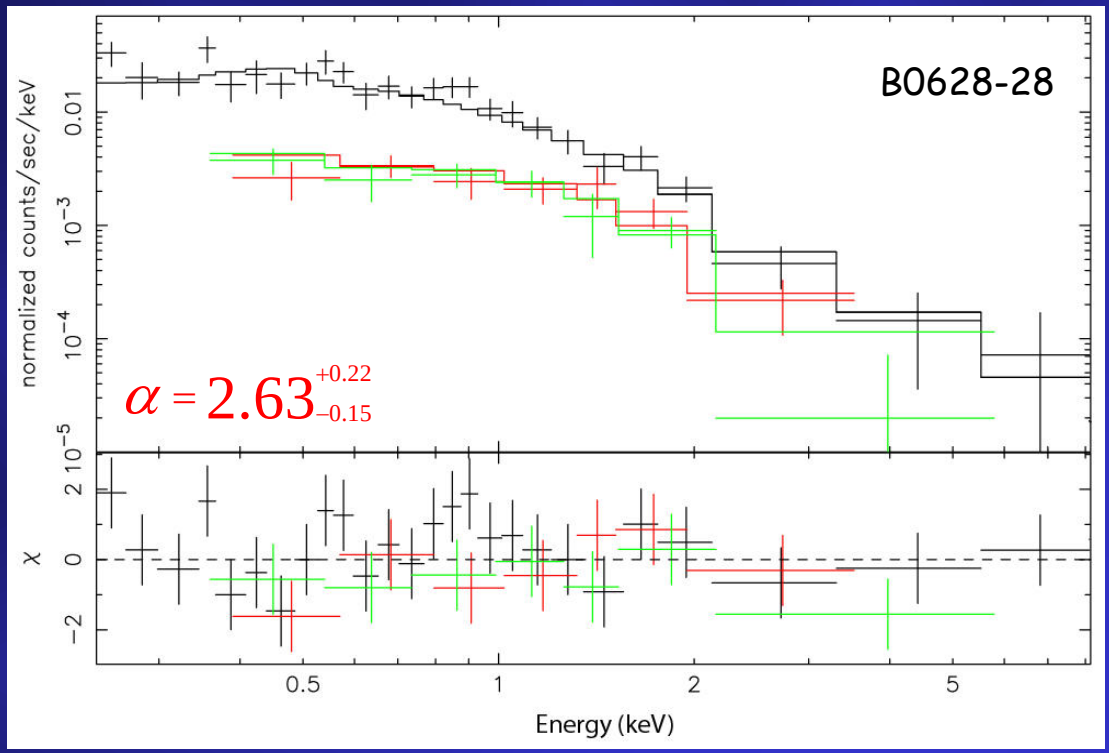
d ~ 1.45 kpc

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

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

Becker, Jessner, Kramer et al.(2005)

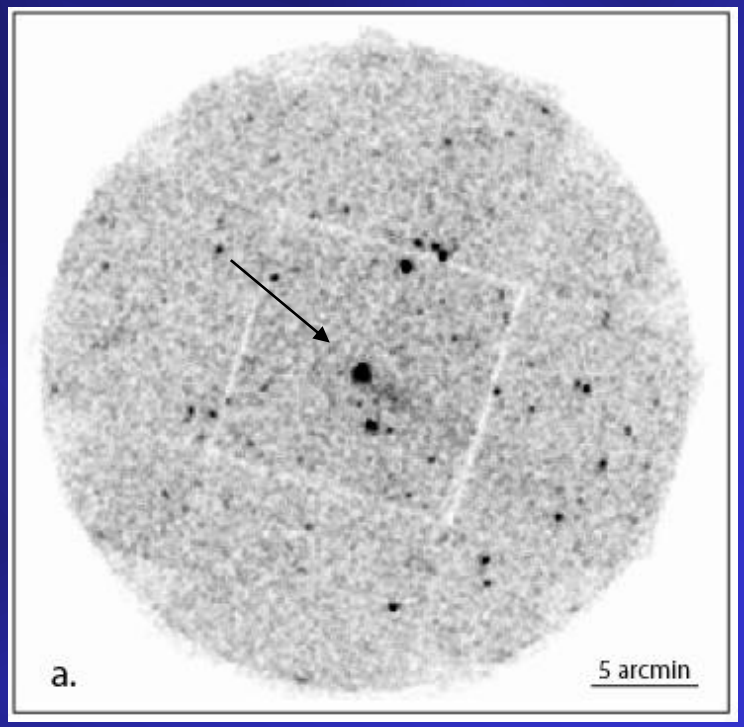
# XMM-Newton observations of old pulsars: B0628-28




- single PL spectrum fits best
  → non-thermal emission dominates
- some thermal contrib. possible

Becker, Jessner, Kramer et al.(2005)

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



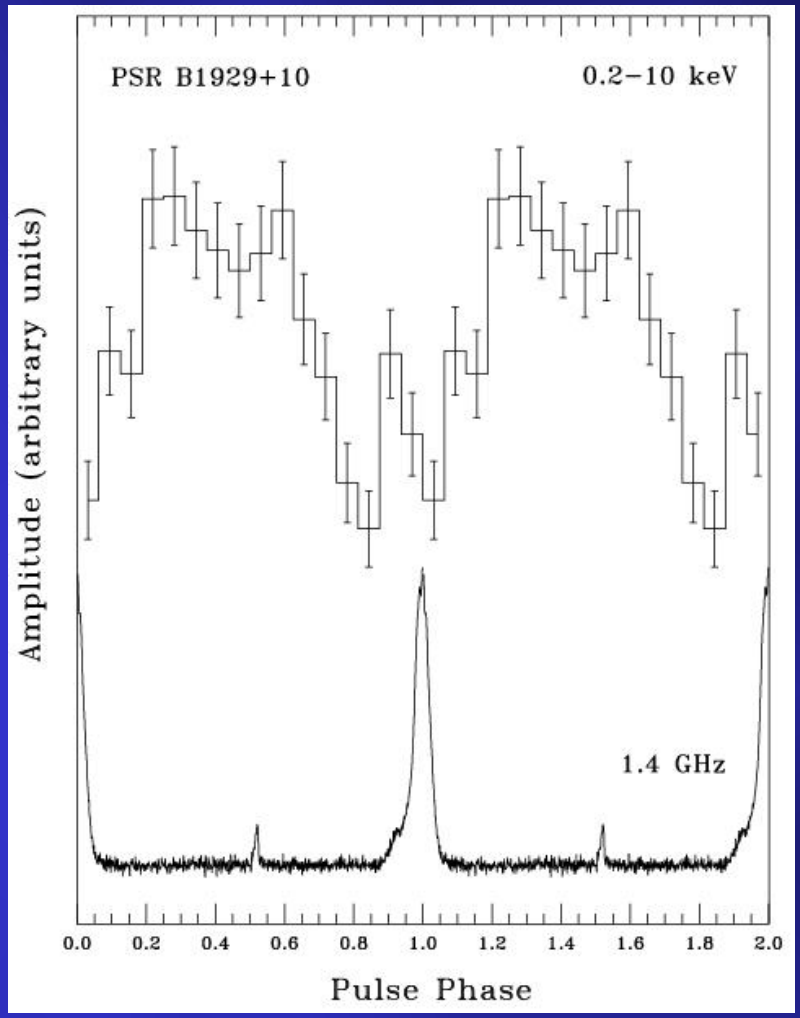

$\tau$ ~ 3.1 x $10^6$ yrs

P ~ 226 ms

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

d ~ 3.178 pc

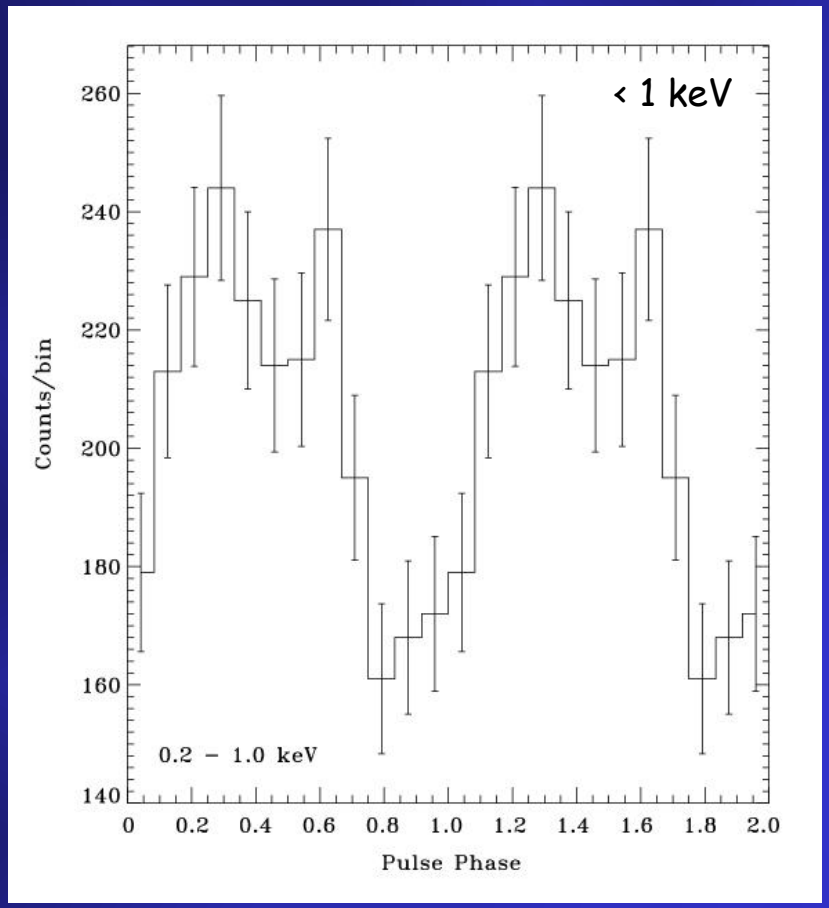
$N_H$ ~ 6 x $10^{20}$ $cm^{-2}$



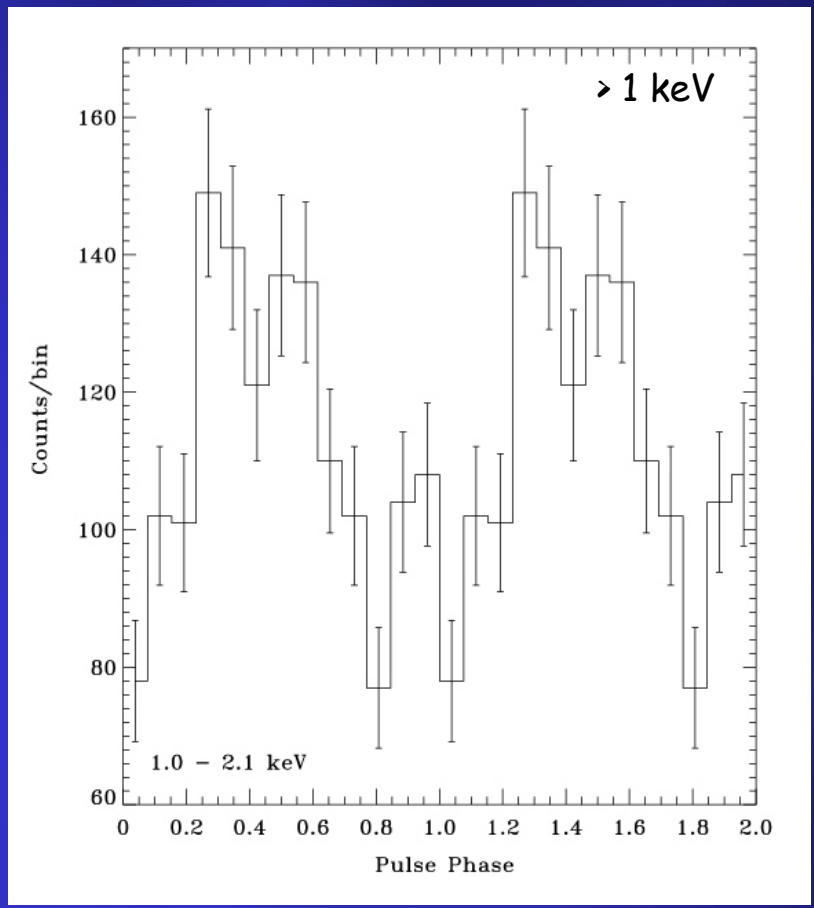

PF = 32 +- 4% (0.2 - 10 keV)

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

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



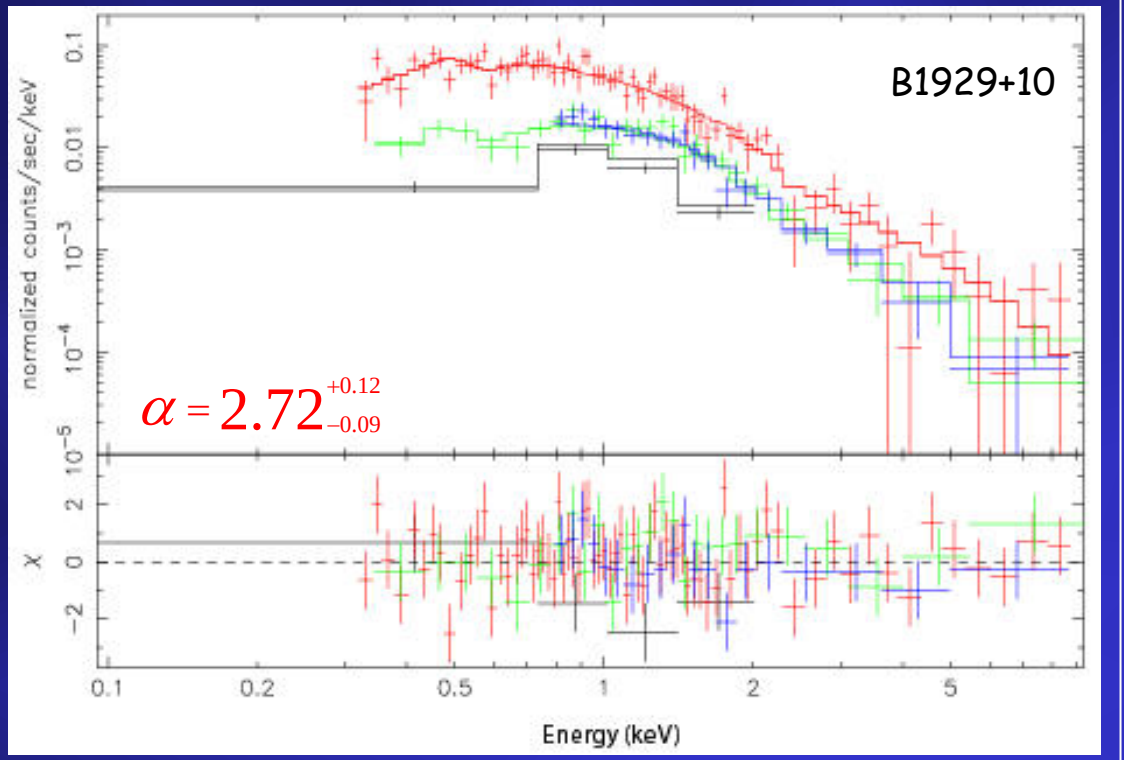

PF = 24 +- 5%




PF = 44 +- 6%

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

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

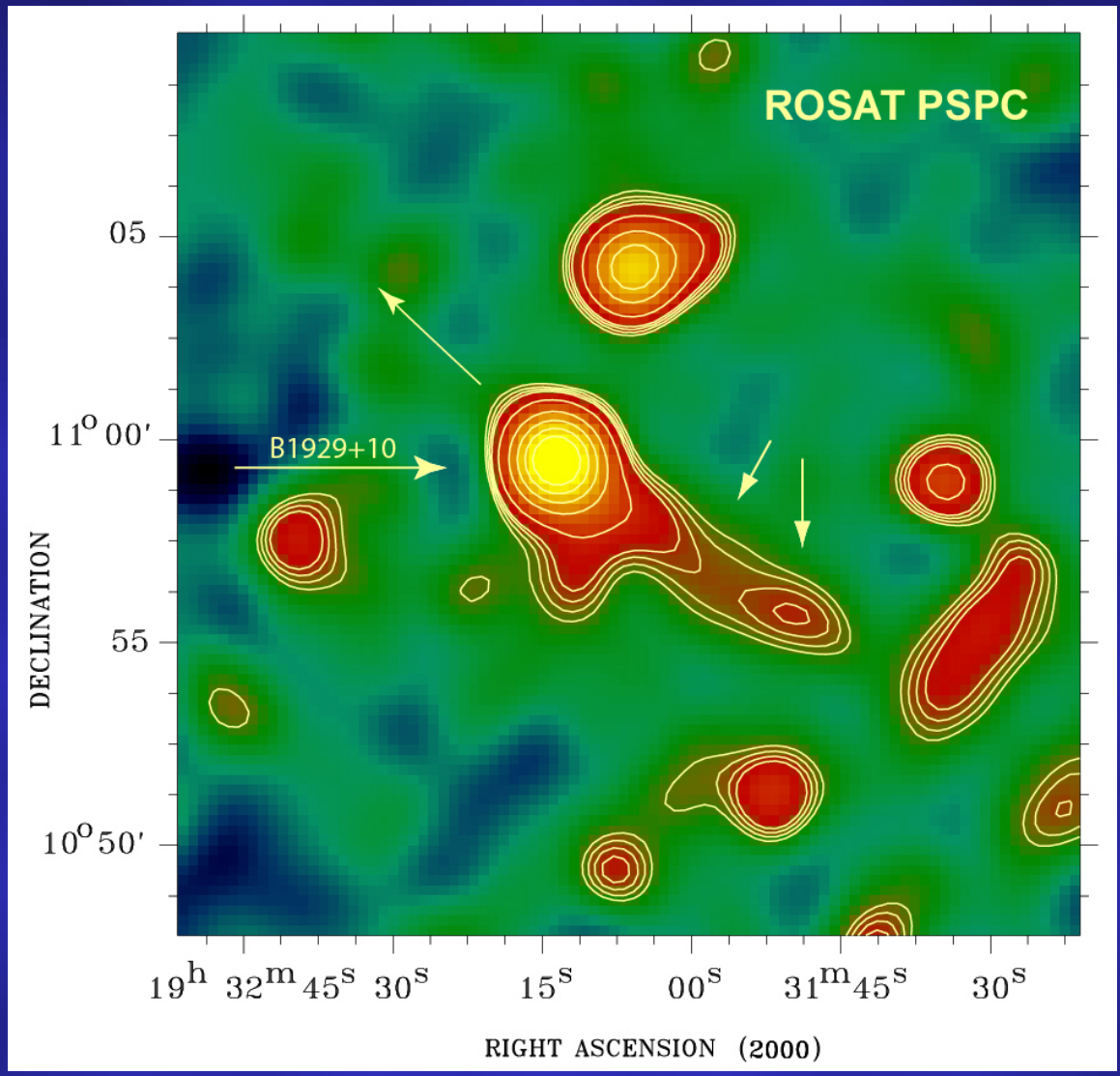



ROSAT + XMM-Newton (MOS1/2 & PN)

- Single BB spectrum excluded
- single PL spectrum fits best
  → non-thermal emission dominates
- best fitting PL allows for a 7% thermal contribution from PC

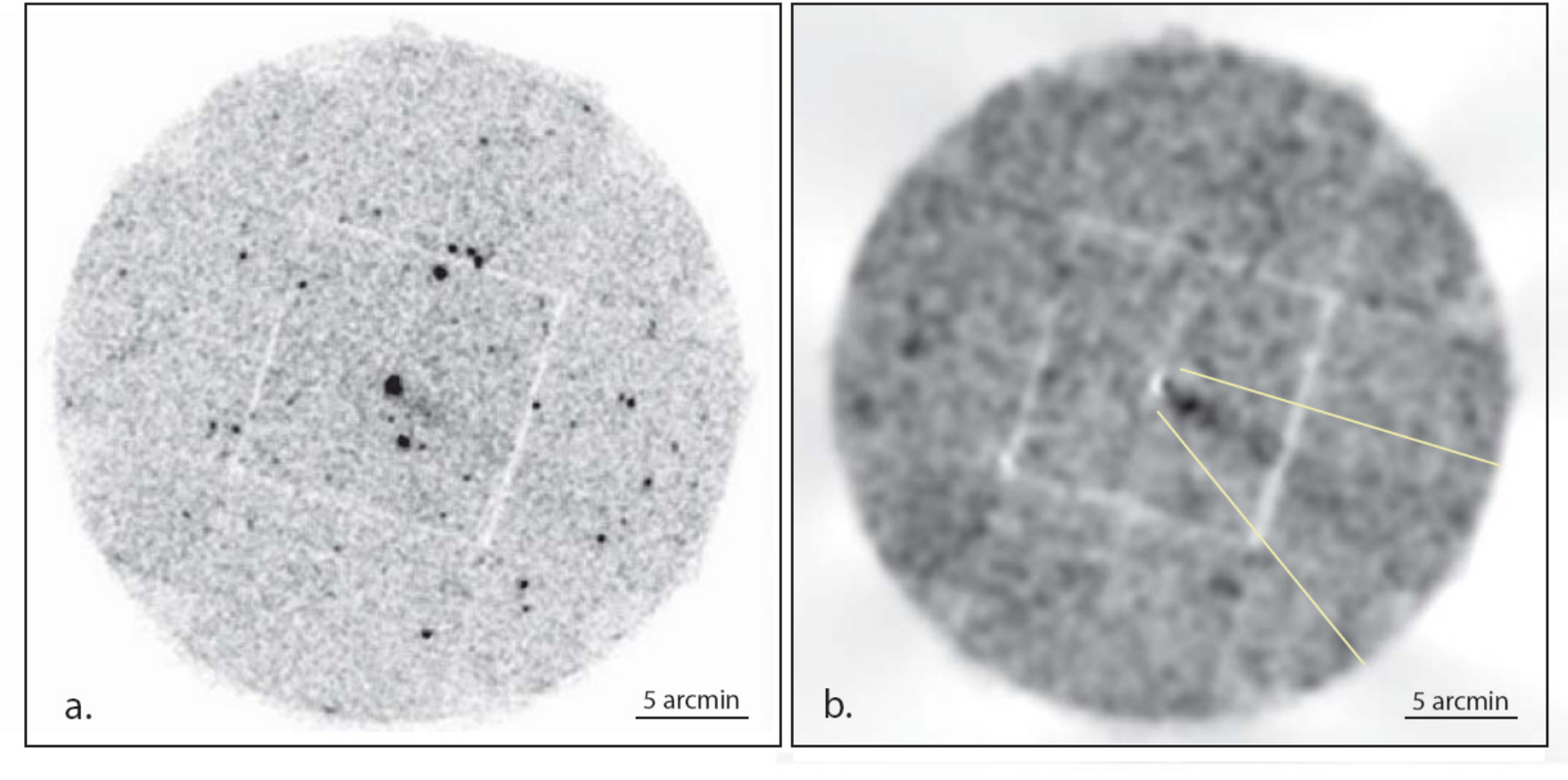
Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

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




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

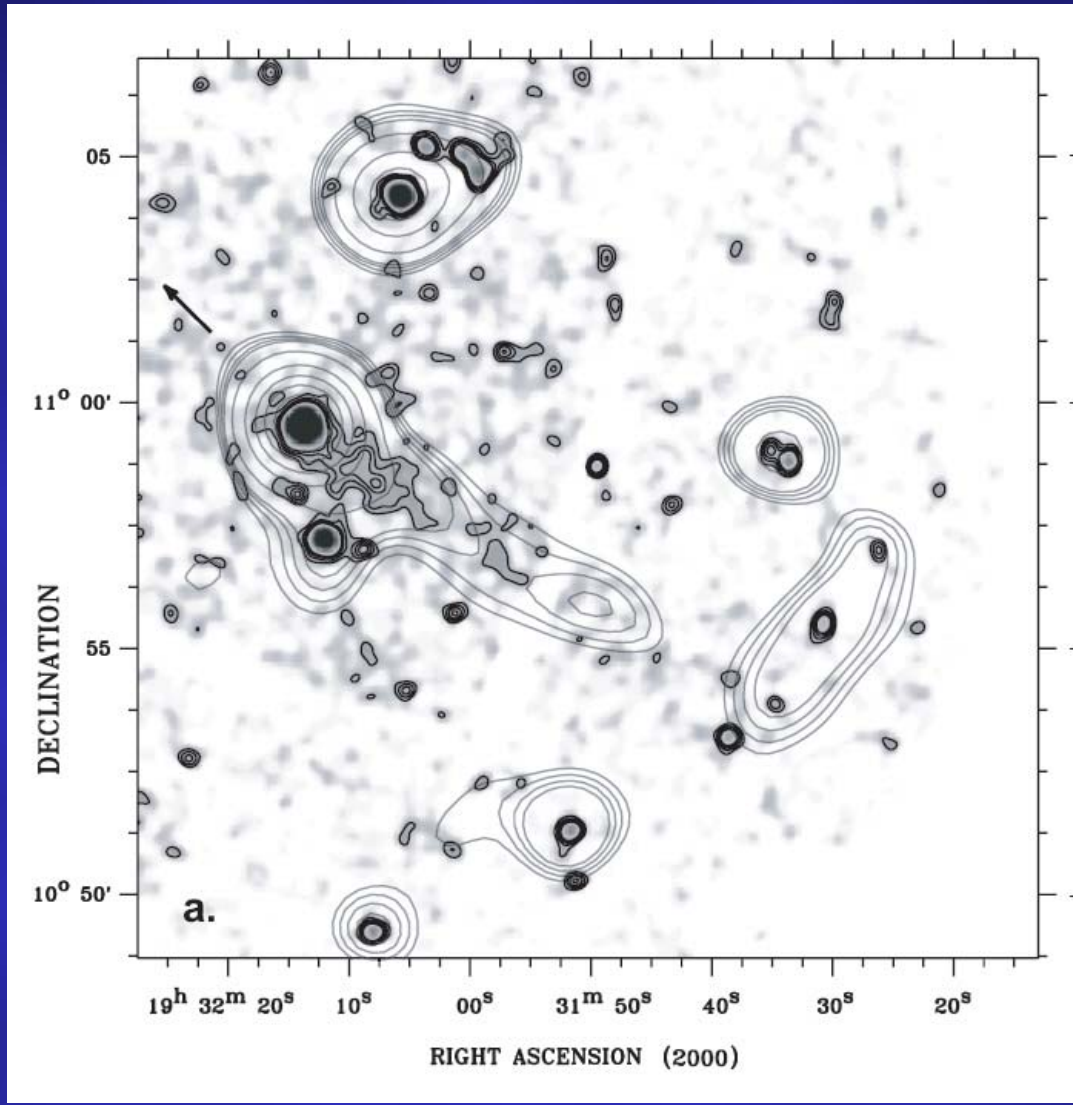
# X-ray emission properties of old pulsars: B1929-10




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

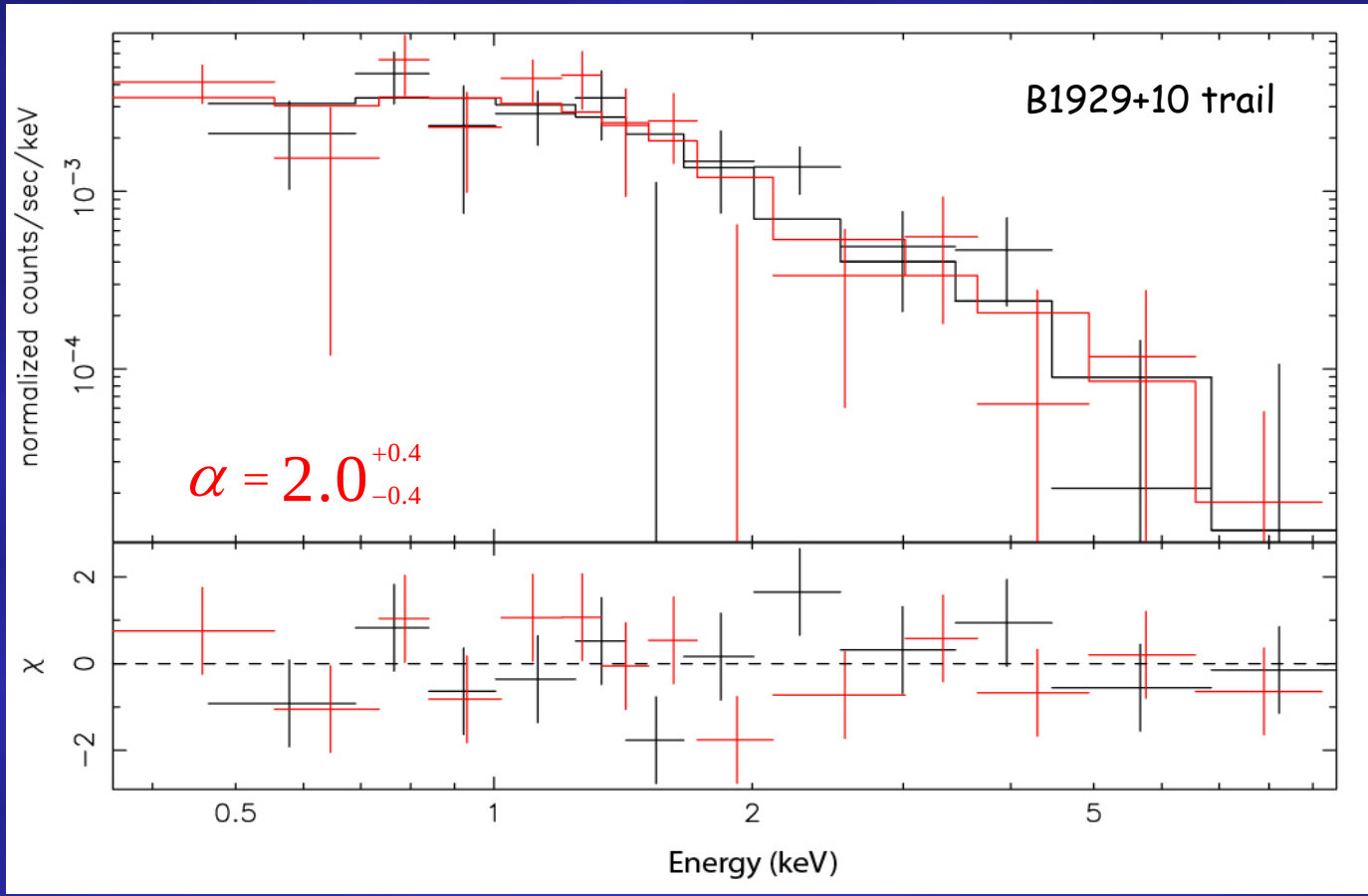
Becker, Kramer, Jessner et al.(2006) / astro-ph-0506545

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




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

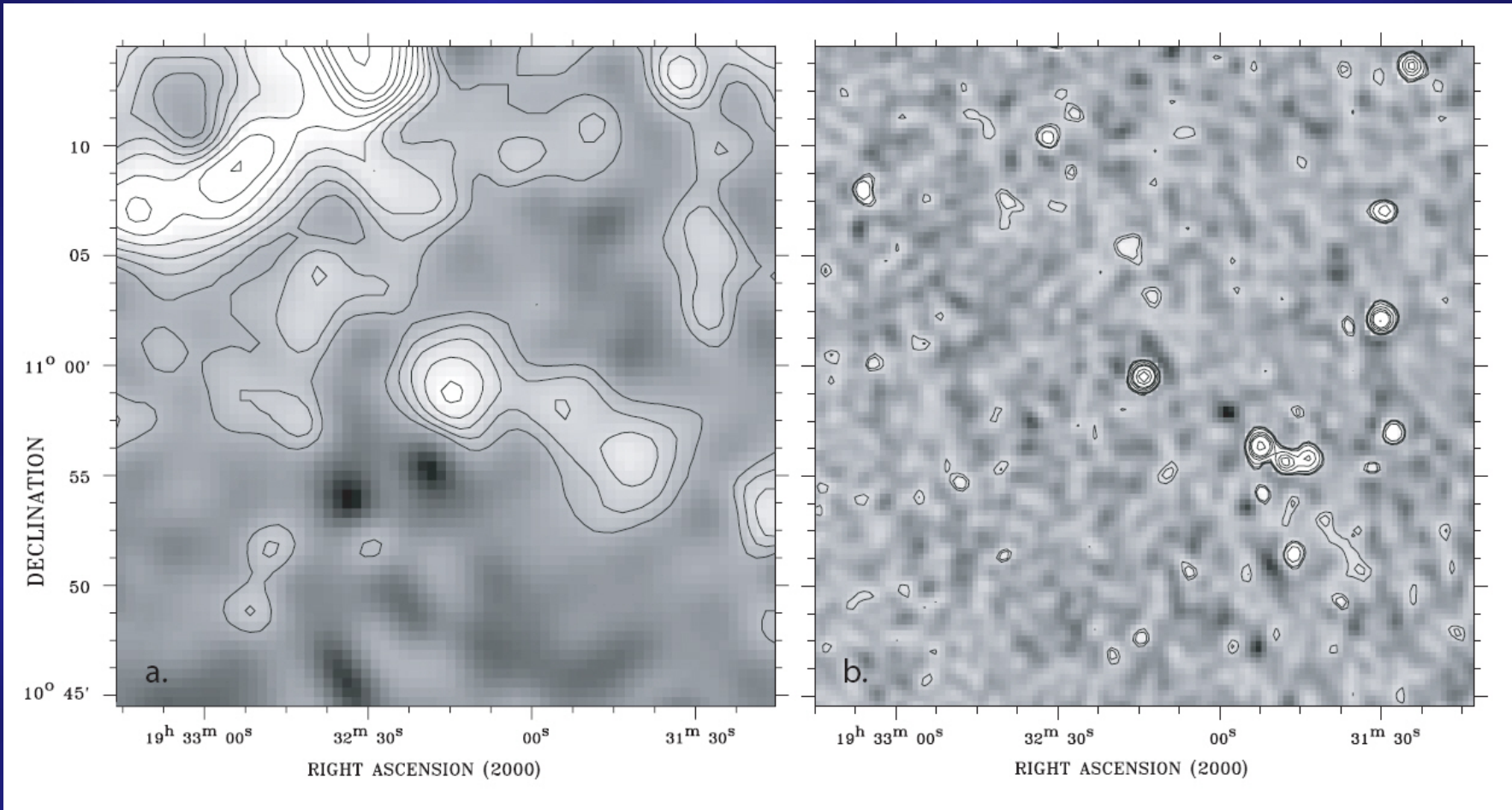
# X-ray emission properties of old pulsars: B1929-10




- 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 galactic plane survey

NRAO VLA Sky survey (1.4 GHz)

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

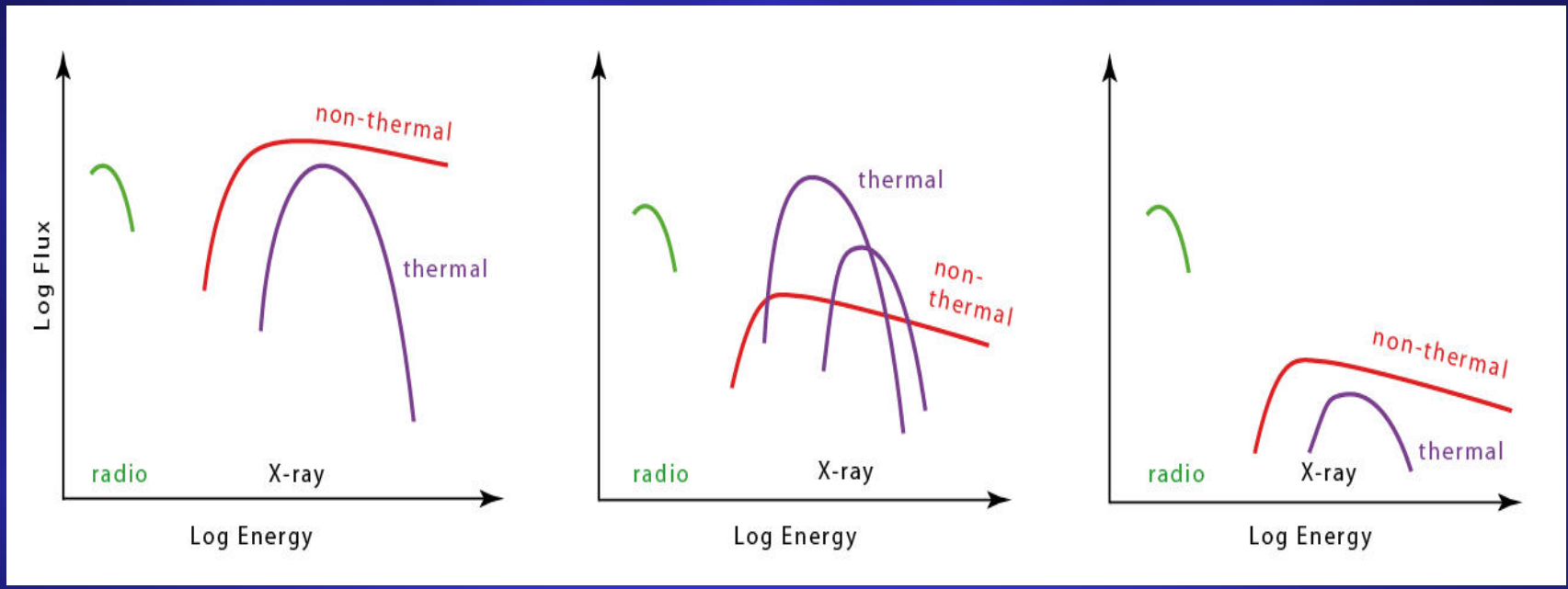
# Summary of rot. powered pulsars detected at X

- 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 $\tau$ | 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 | Cooling neutron stars | Old pulsars |
|---|---|---|
| (< $10^4$ yrs) | ($10^5$ - $10^6$ yrs) | ($10^6$ - $10^8$ yrs) |

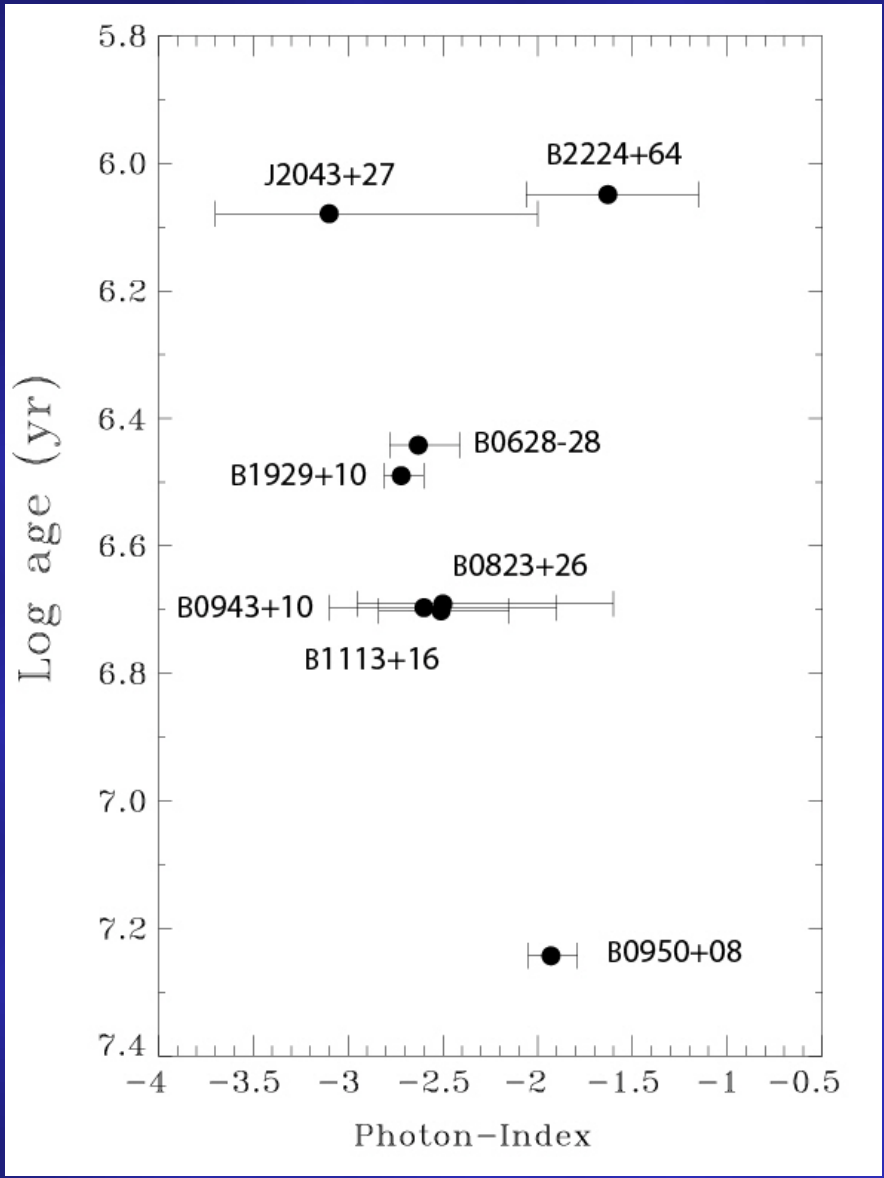



- non-thermal emission dominates in old pulsars / pulse profiles **NOT sinusoidal**
- hot polar cap emission component may decreases along with the cooling surface component ?
- if so, hot polar caps in cooling neutron stars are probably formed by anisotropic heat flow due to the presence of the magnetic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

# X-ray emission properties of old pulsars

younger

older




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