# PULSARS

# X-ray emission properties of old

**Werner Becker**

Max-Planck Institut für extraterr. Physik

# Progress in Pulsar detection

- With EINSTEIN & EXOSAT:

  7 radio pulsars detected in X-rays

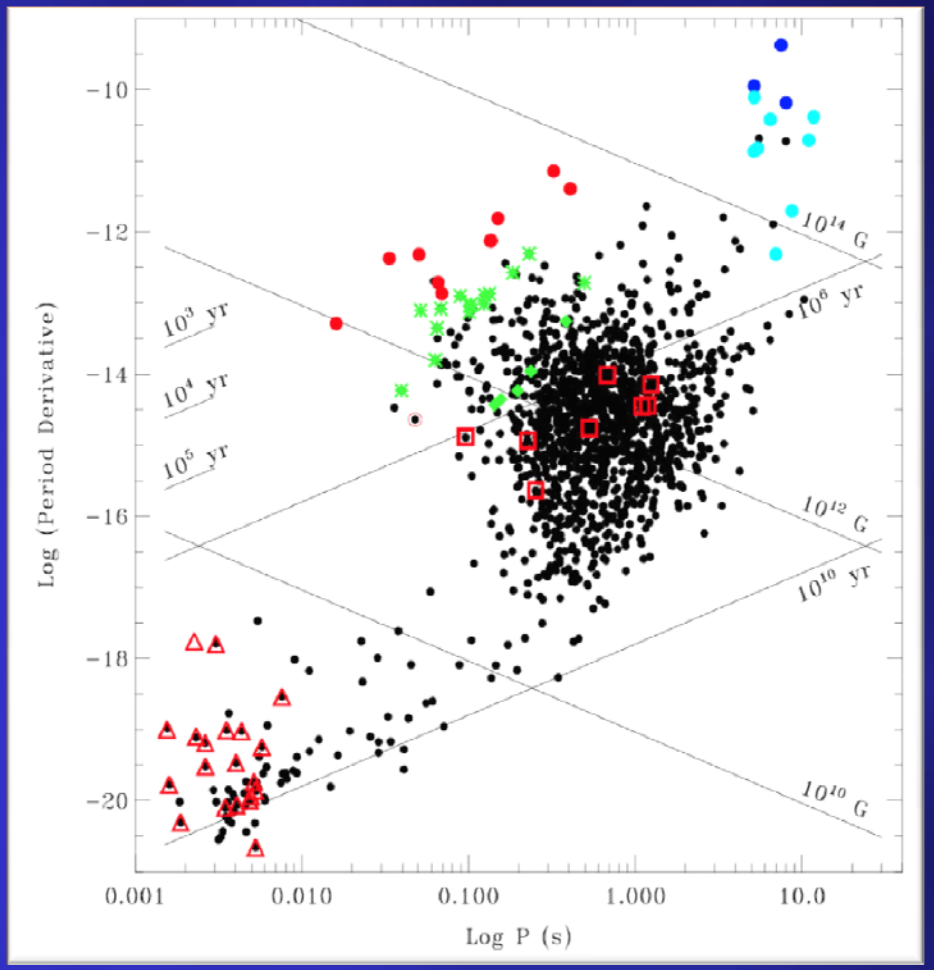
- With ROSAT, ASCA & BSAX:

  33 radio pulsars detected in X-rays

- After ~8 yrs with XMM & Chandra:

  81 radio pulsars detected in X-rays

- 8 pulsars fall into the category of old and nearby neutron stars




Becker, Haberl & Trümper 2007

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

Crab-like pulsars

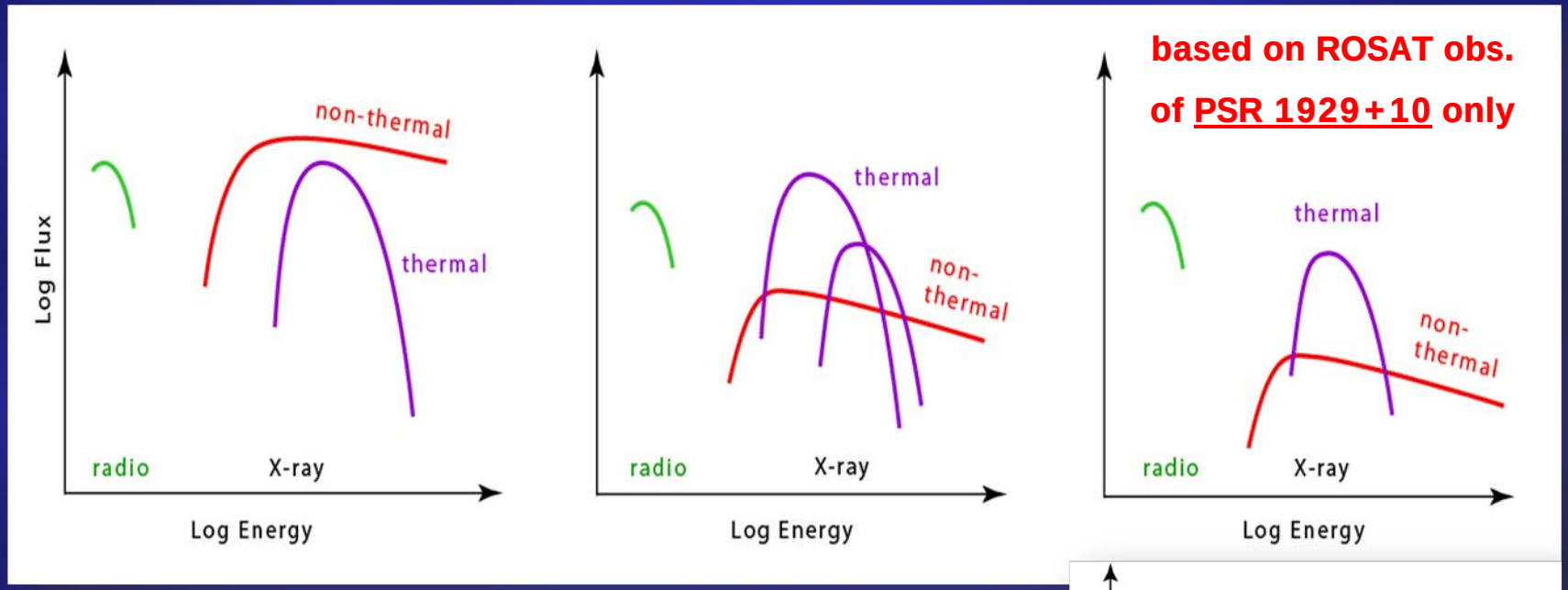
(< $10^4$ yrs)

Cooling neutron stars

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

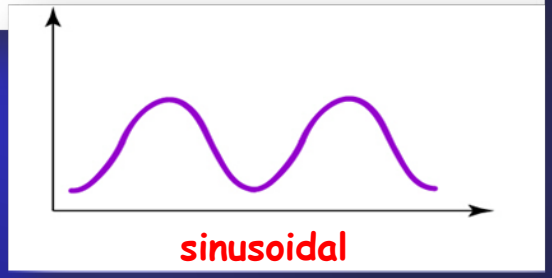
Old pulsars

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




Fraction of pulsed photons ~100%

Fraction of pulsed photons ~20-30%



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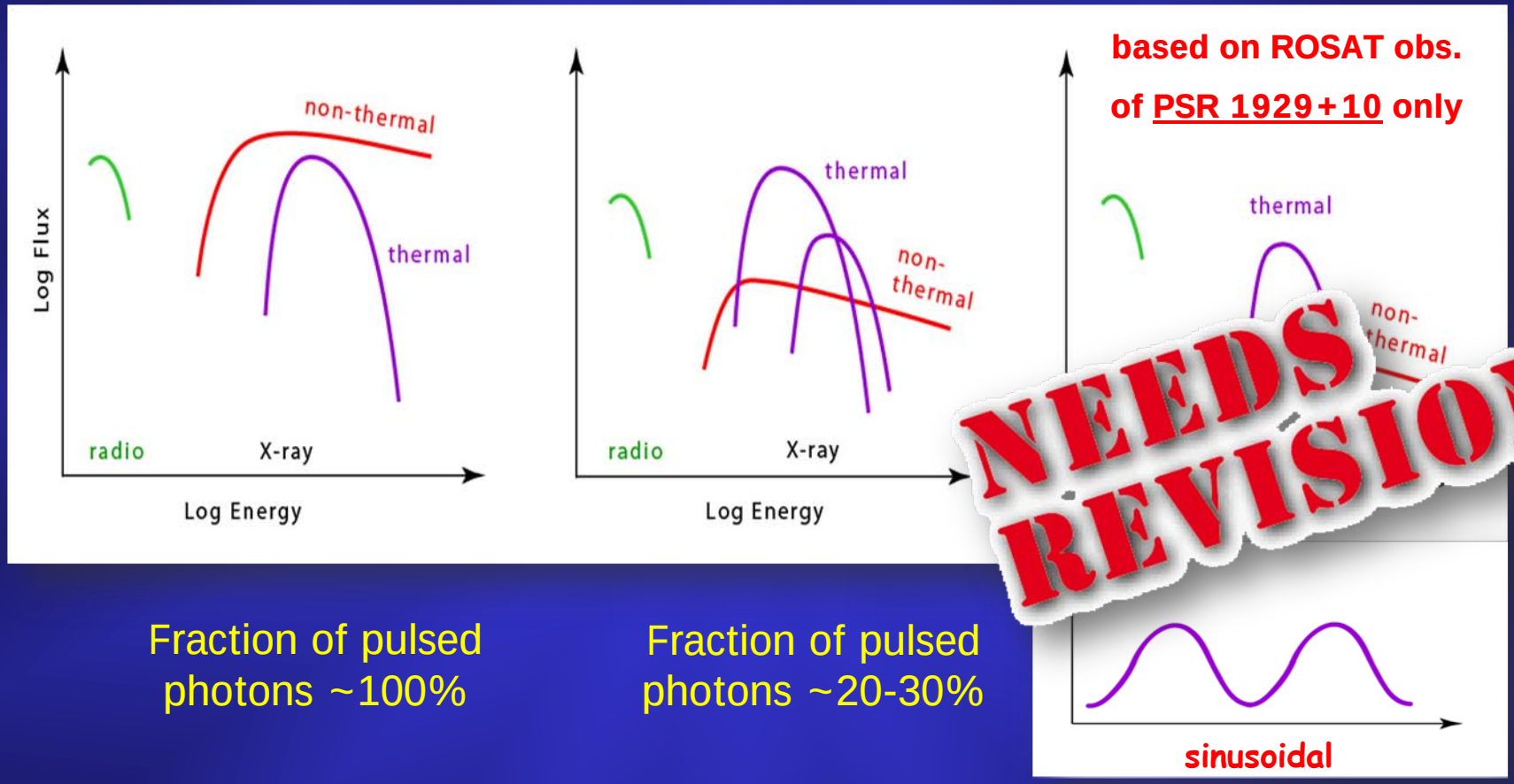
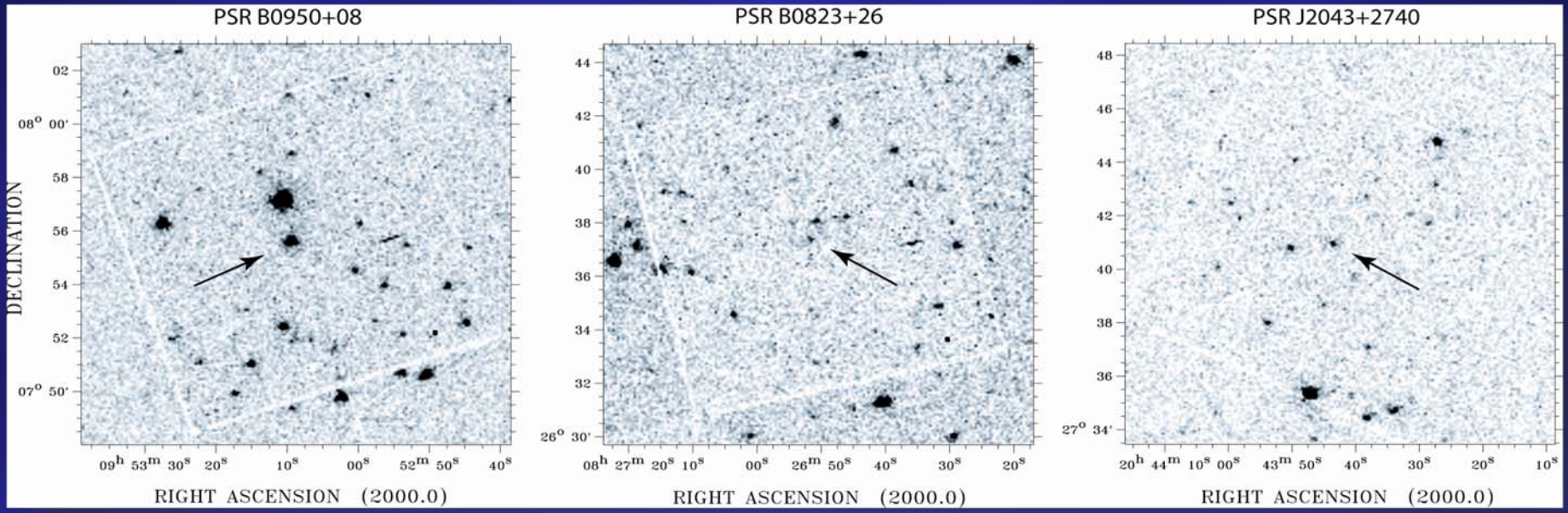



Fraction of pulsed photons ~100%

Fraction of pulsed photons ~20-30%

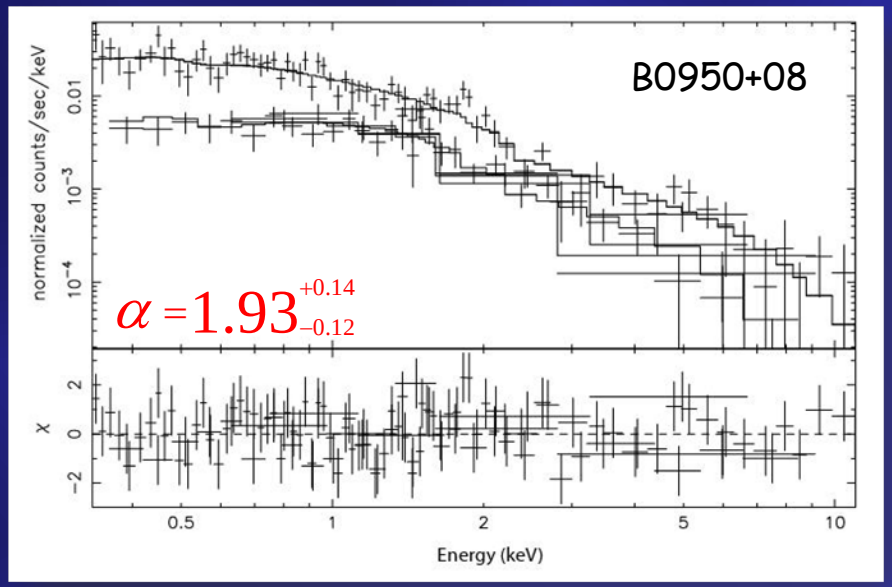
# XMM-Newton observations of old pulsars

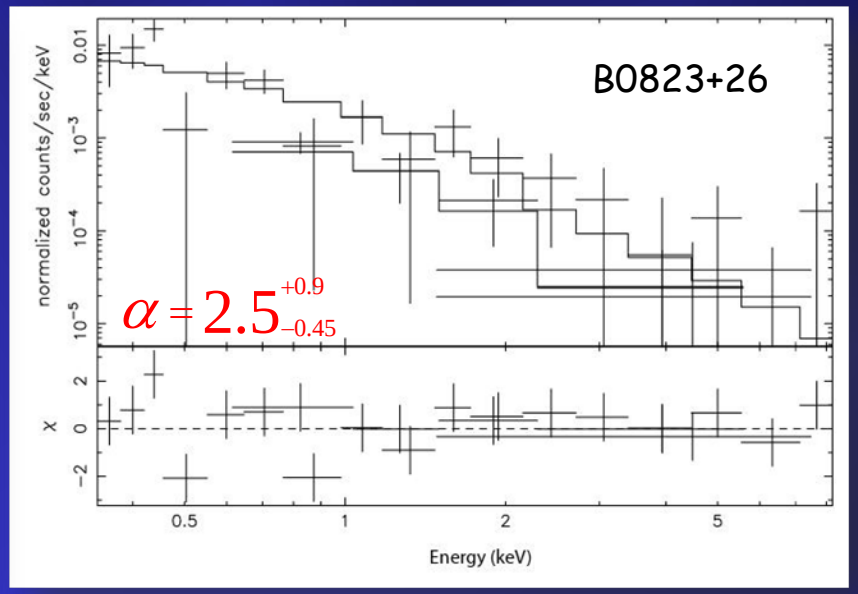
Becker, Weisskopf, Tennant et al. (2004)



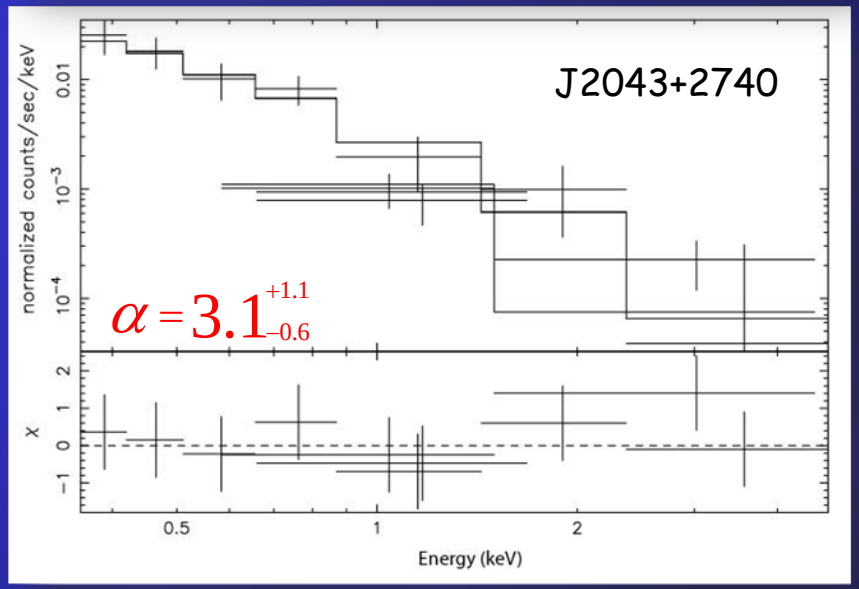

| | | | |
|---|---|---|---|
| $\tau$ | **~ 17 $10^6$ yrs** | **~ 5 $10^6$ yrs** | **~ 1.2 $10^6$ yrs** |
| d | ~ 255 pc | ~ 340 pc | ~ 1130 pc |
| $N_H$ | ~ 9.6 $10^{19}$ $cm^{-2}$ | ~ 60 $10^{19}$ $cm^{-2}$ | ~ 65 $10^{19}$ $cm^{-2}$ |
| $\dot{E}$ | ~ 5.6 $10^{32}$ erg/s | ~ 4.5 $10^{32}$ erg/s | ~ 5.6 $10^{34}$ erg/s |

# X-ray emission properties of old pulsars



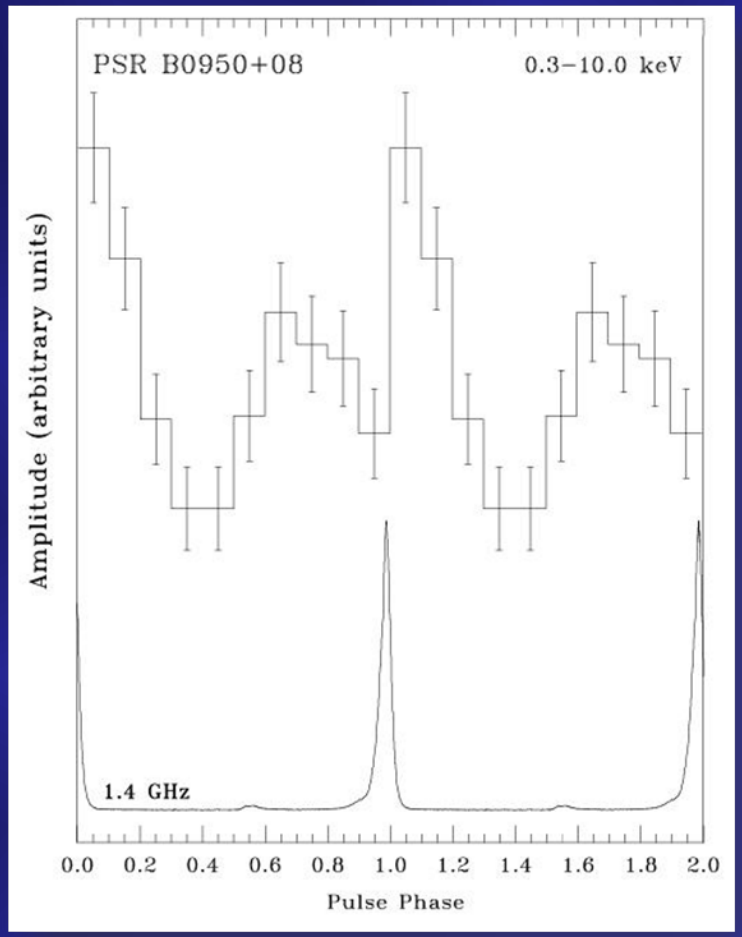




- BB spectra are clearly excluded
- BB+BB model resulted in an emitting area for possible polar caps of ~cm size
- **Simplest model:** single PL spectrum fits best




Becker, Weisskopf, Tennant et al. (2004)

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

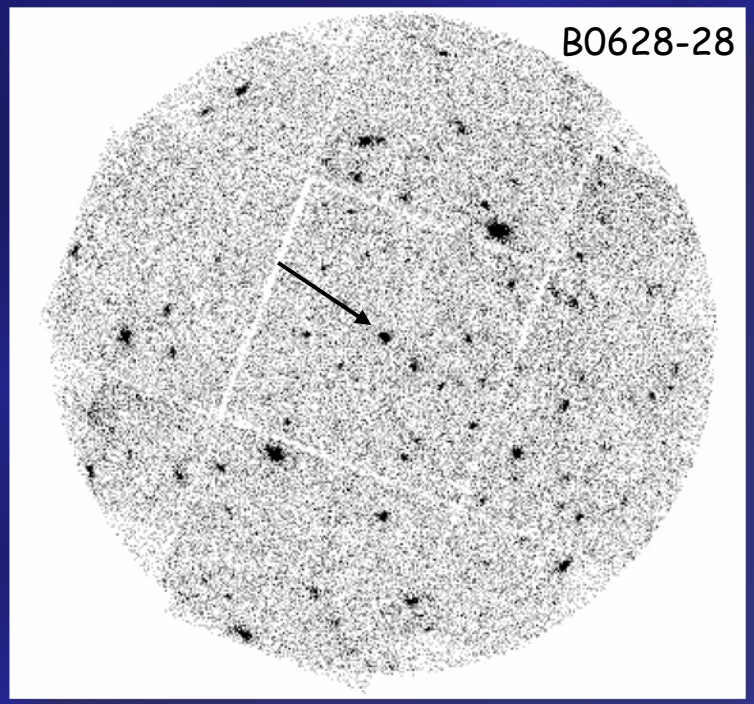


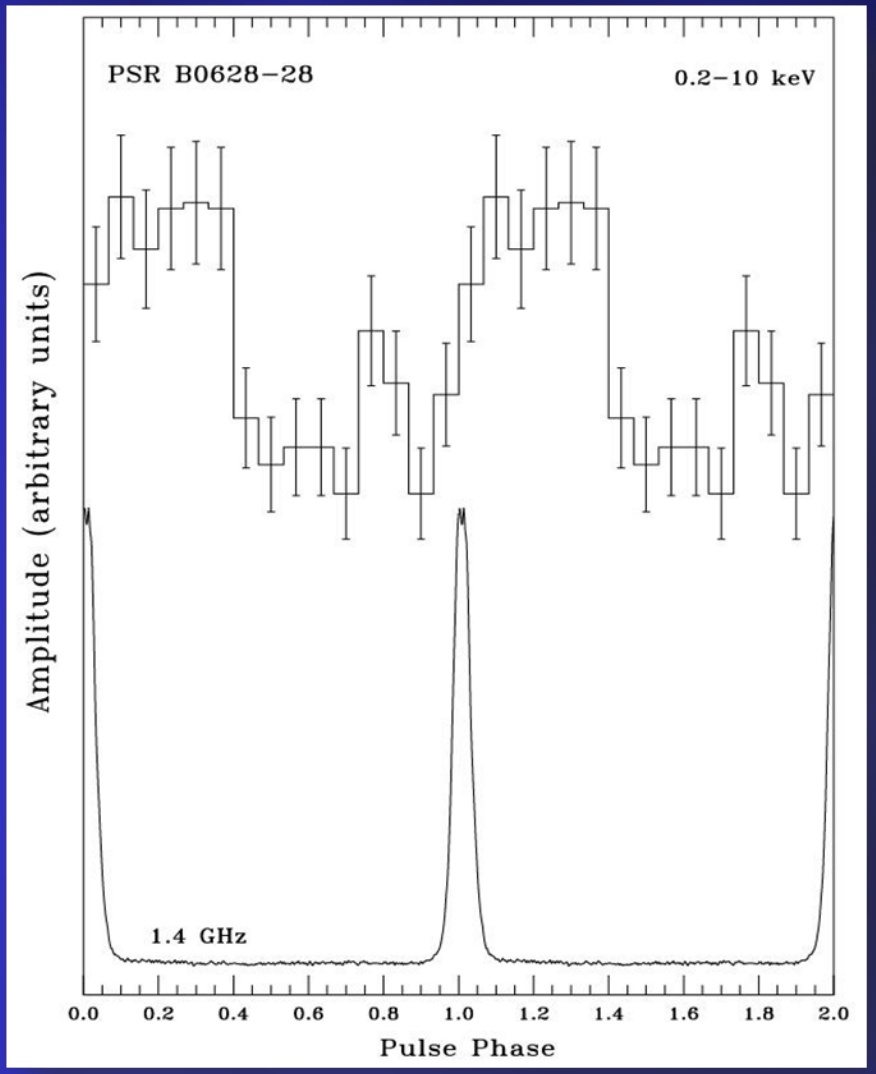

- pulse profile is **NOT sinusoidal**
- double peaked pulse profile
- phase separation between X-ray peaks of ~ $144^0$, the same as for radio pulse and interpulse

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

Becker, Weisskopf, Tennant et al. (2004)

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




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

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

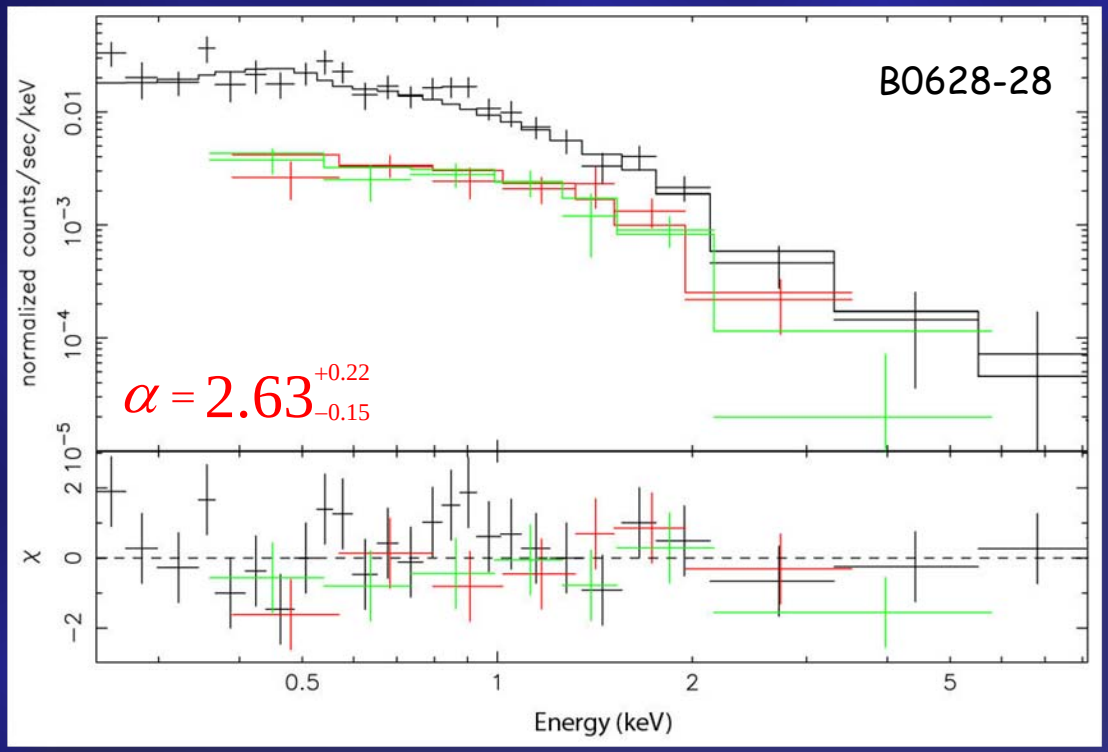
d ~ 1.45 kpc

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

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

Becker, Jessner, Kramer et al.(2005)

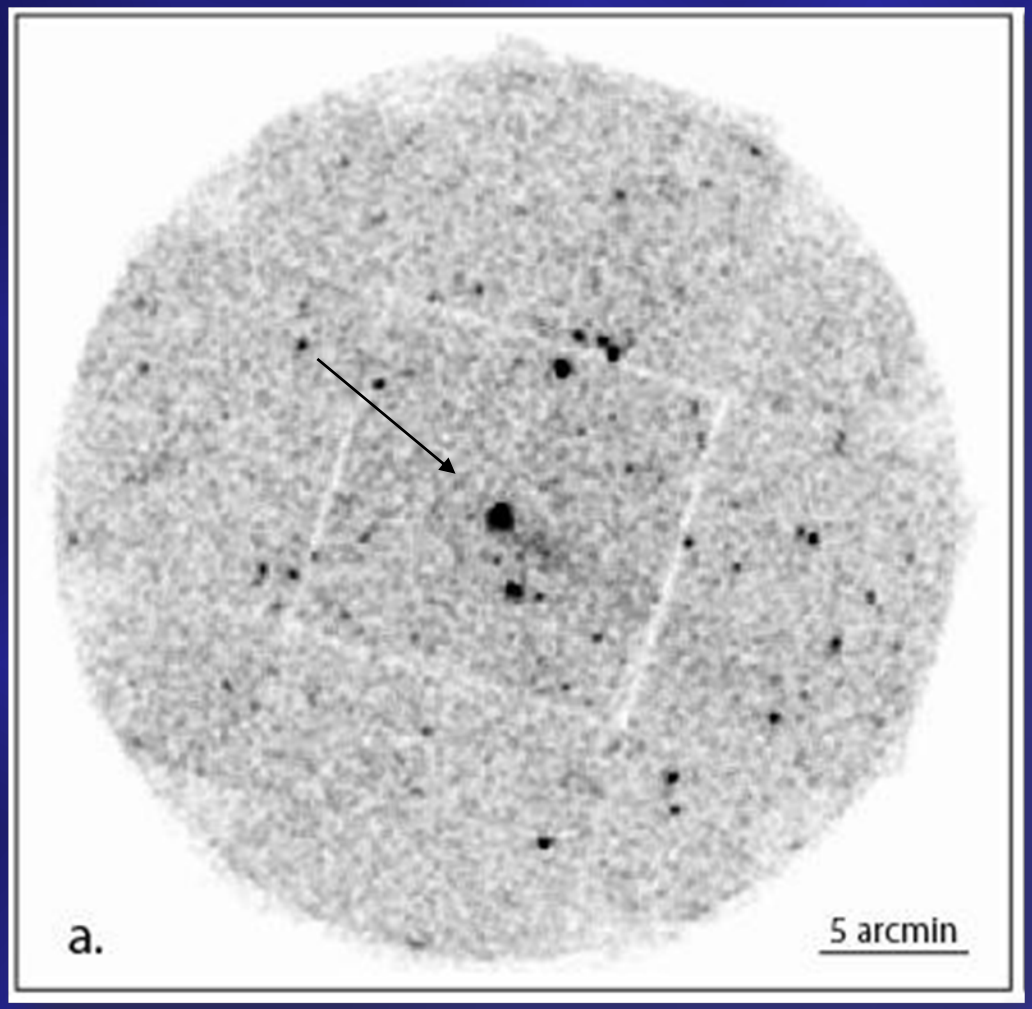
# XMM-Newton observations of old pulsars: B0628-28




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

Becker, Jessner, Kramer et al.(2005)

# The prototype of an old pulsar: PSR B1929-10




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

P ~ 226 ms

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

d ~ 317.8 pc

Becker, Kramer, Jessner et al. (2006)

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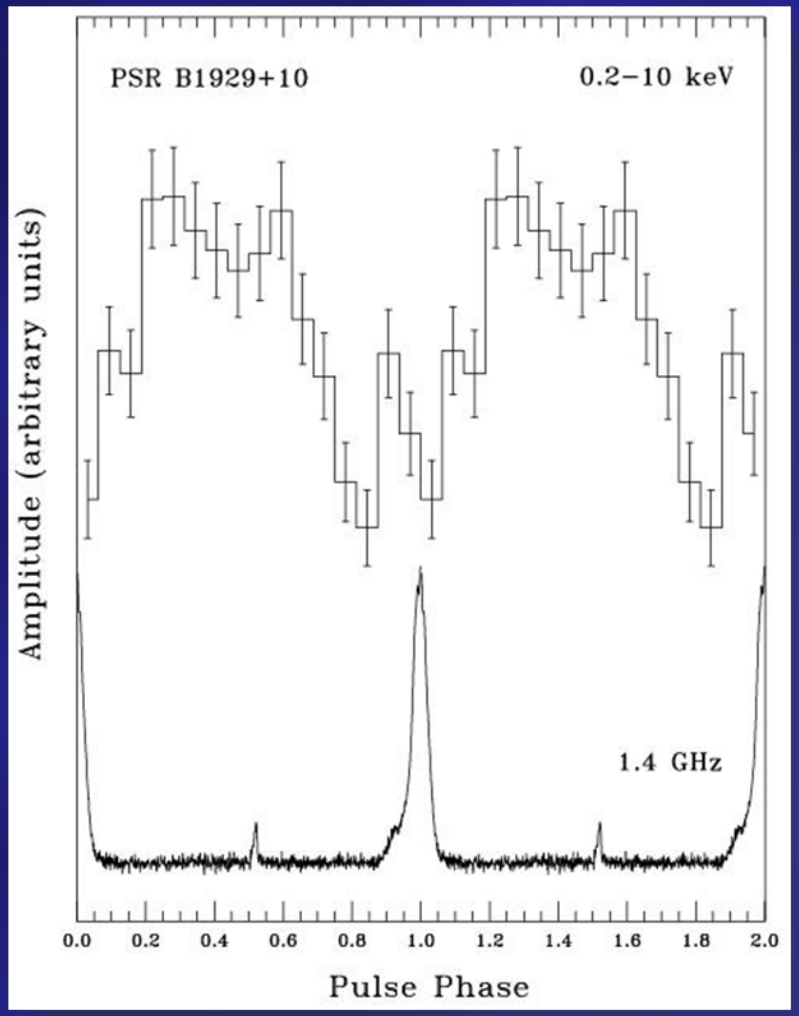


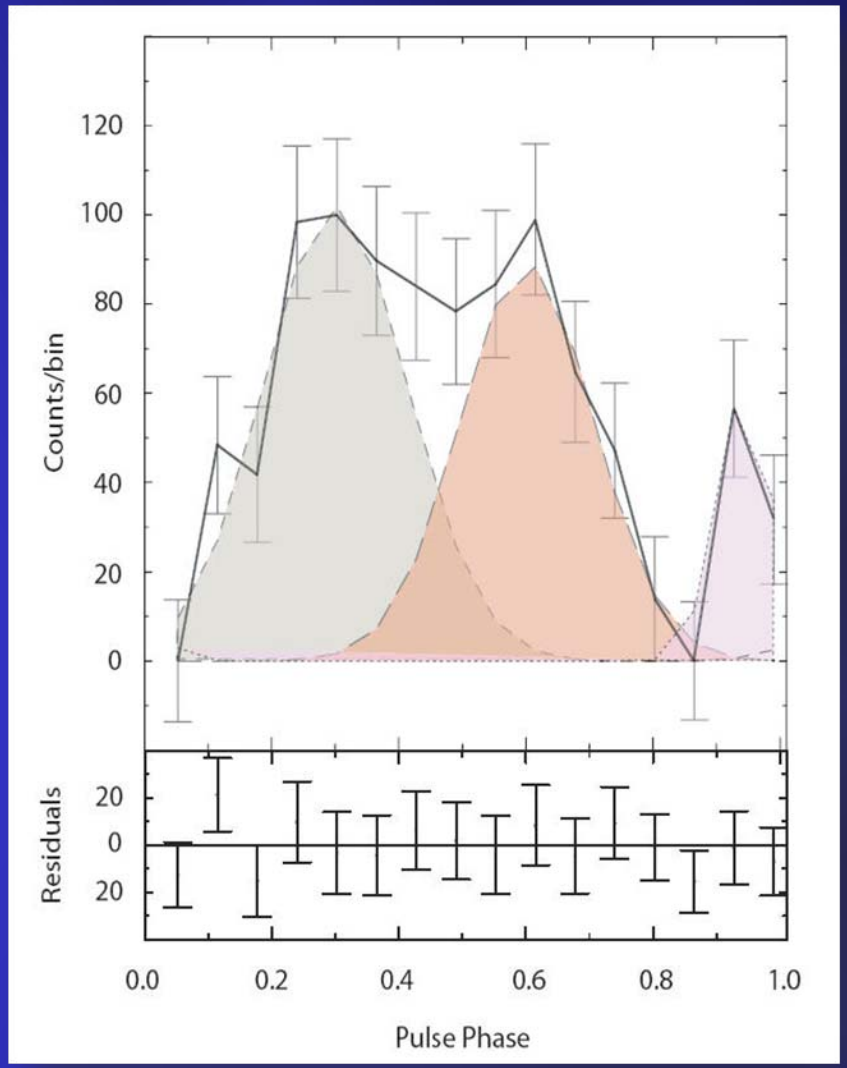


PF = 32 +- 4% (0.2 - 10 keV)

Becker, Kramer, Jessner et al. (2006)

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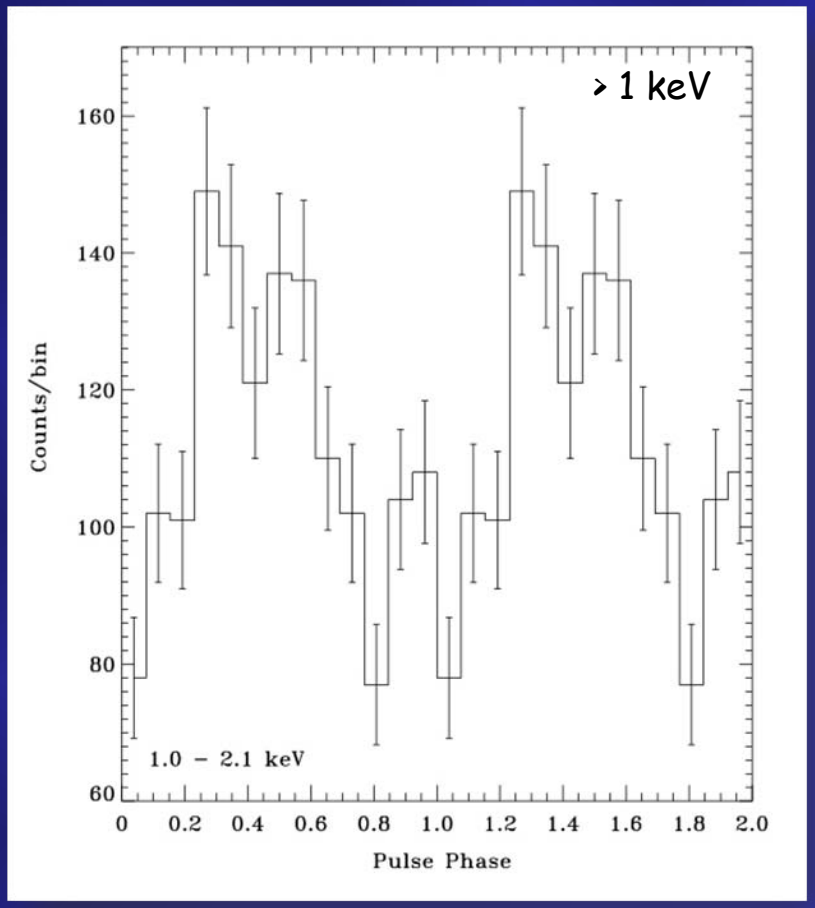
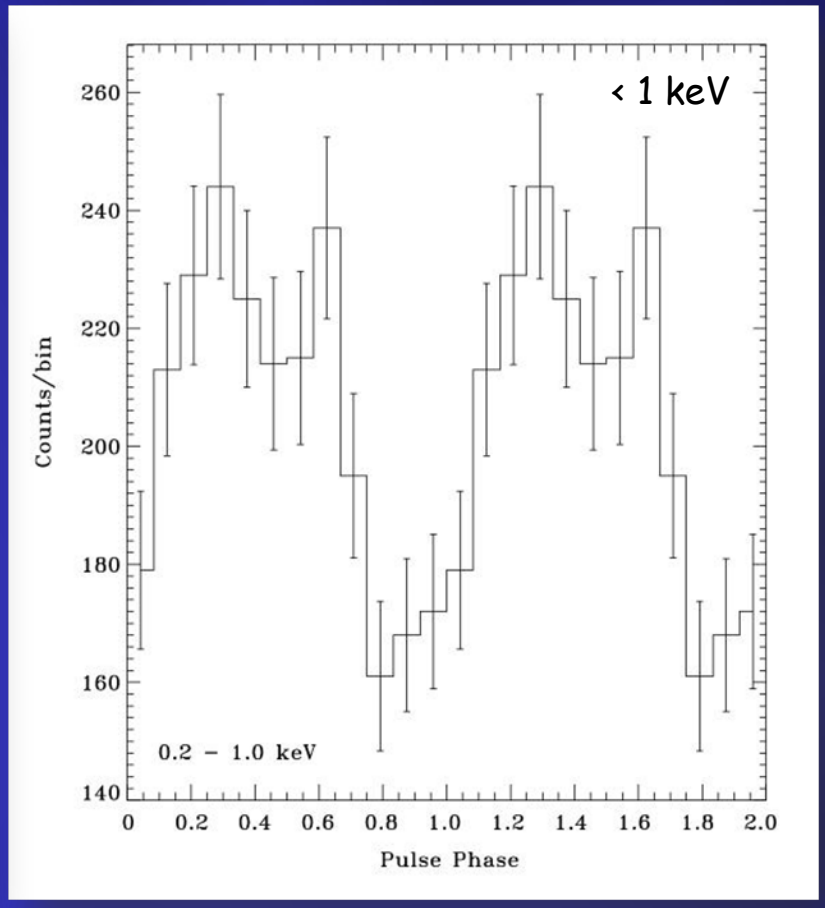


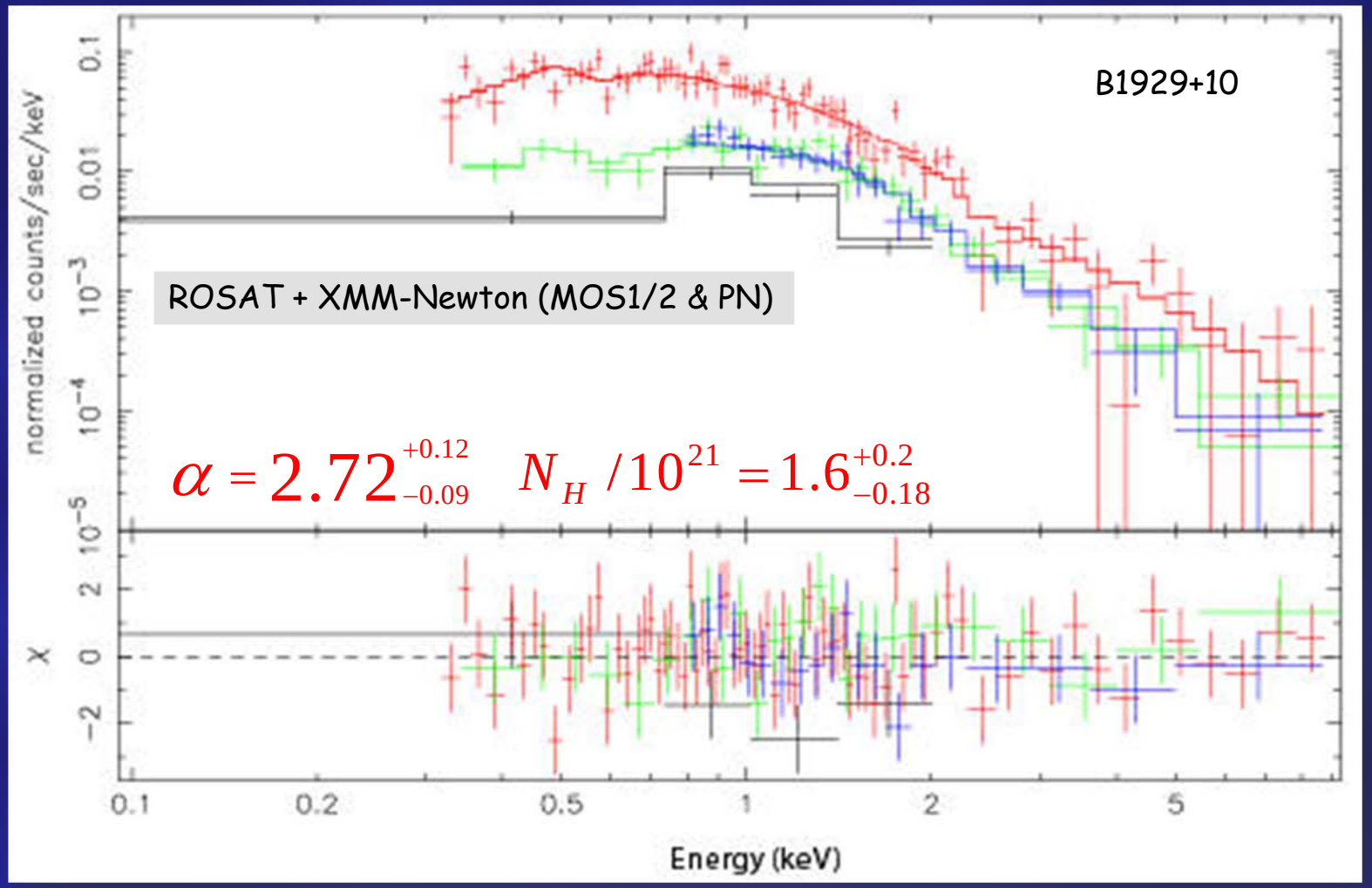

PF = 44 +- 6%




PF = 24 +- 5%

Becker, Kramer, Jessner et al. (2006)

# The prototype of an old pulsar: PSR B1929-10




- single PL spectrum fits best → non-thermal emission dominates

# The prototype of an old pulsar: PSR B1929-10

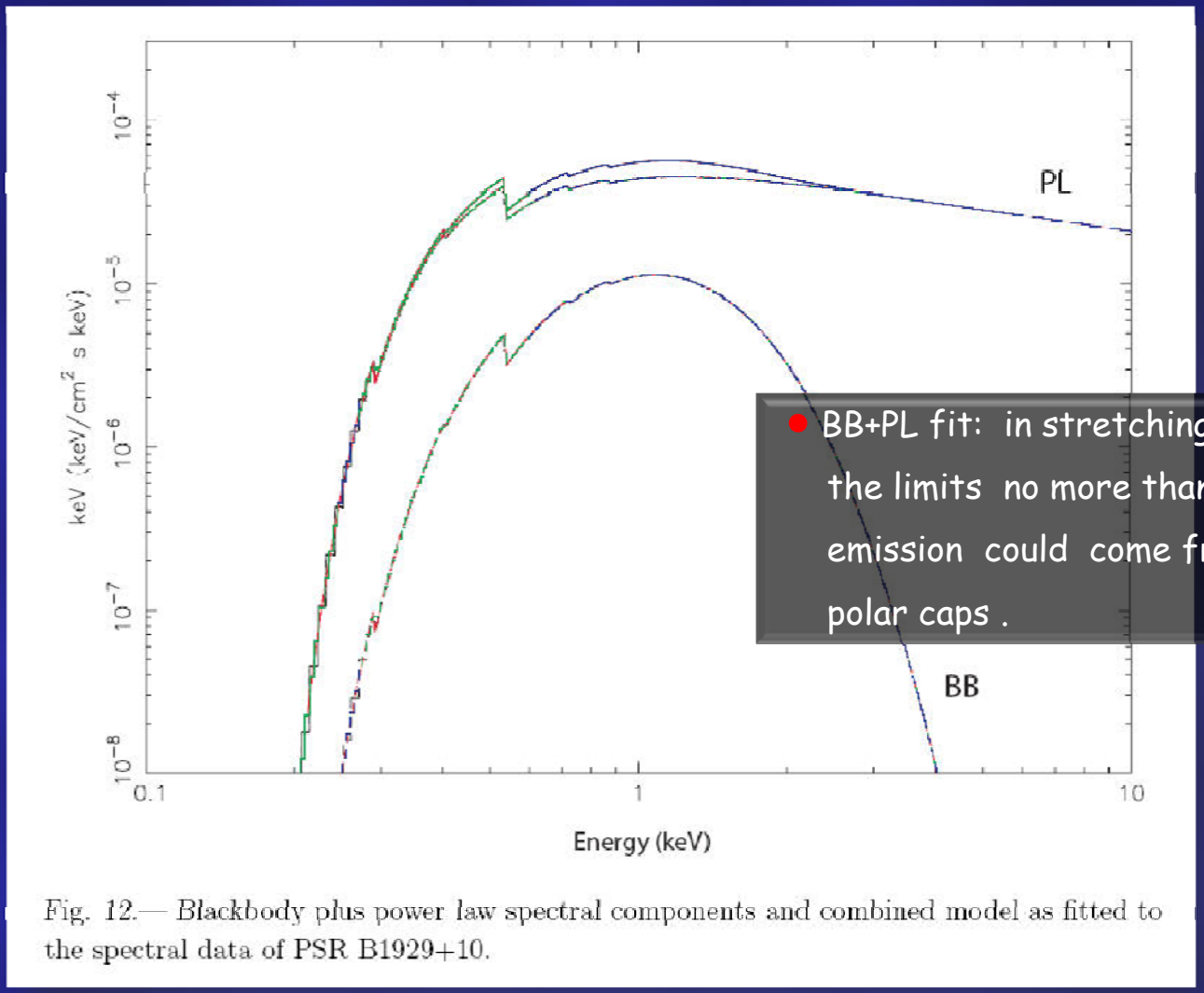


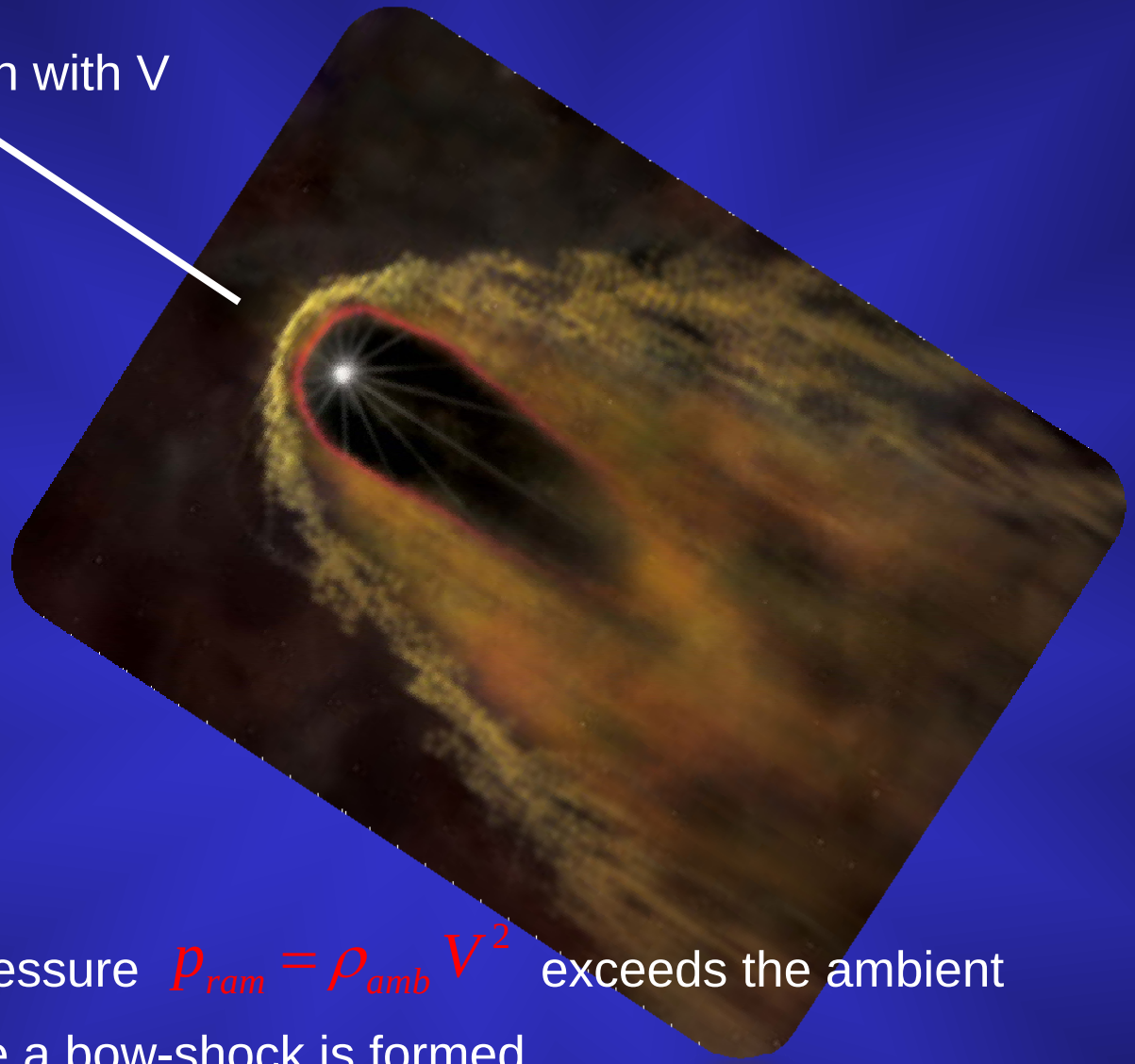

Fig. 12.— Blackbody plus power law spectral components and combined model as fitted to the spectral data of PSR B1929+10.

- BB+PL fit: in stretching the errors to the limits no more than ~40% of the emission could come from heated polar caps .

Becker, Kramer, Jessner et al. (2006)

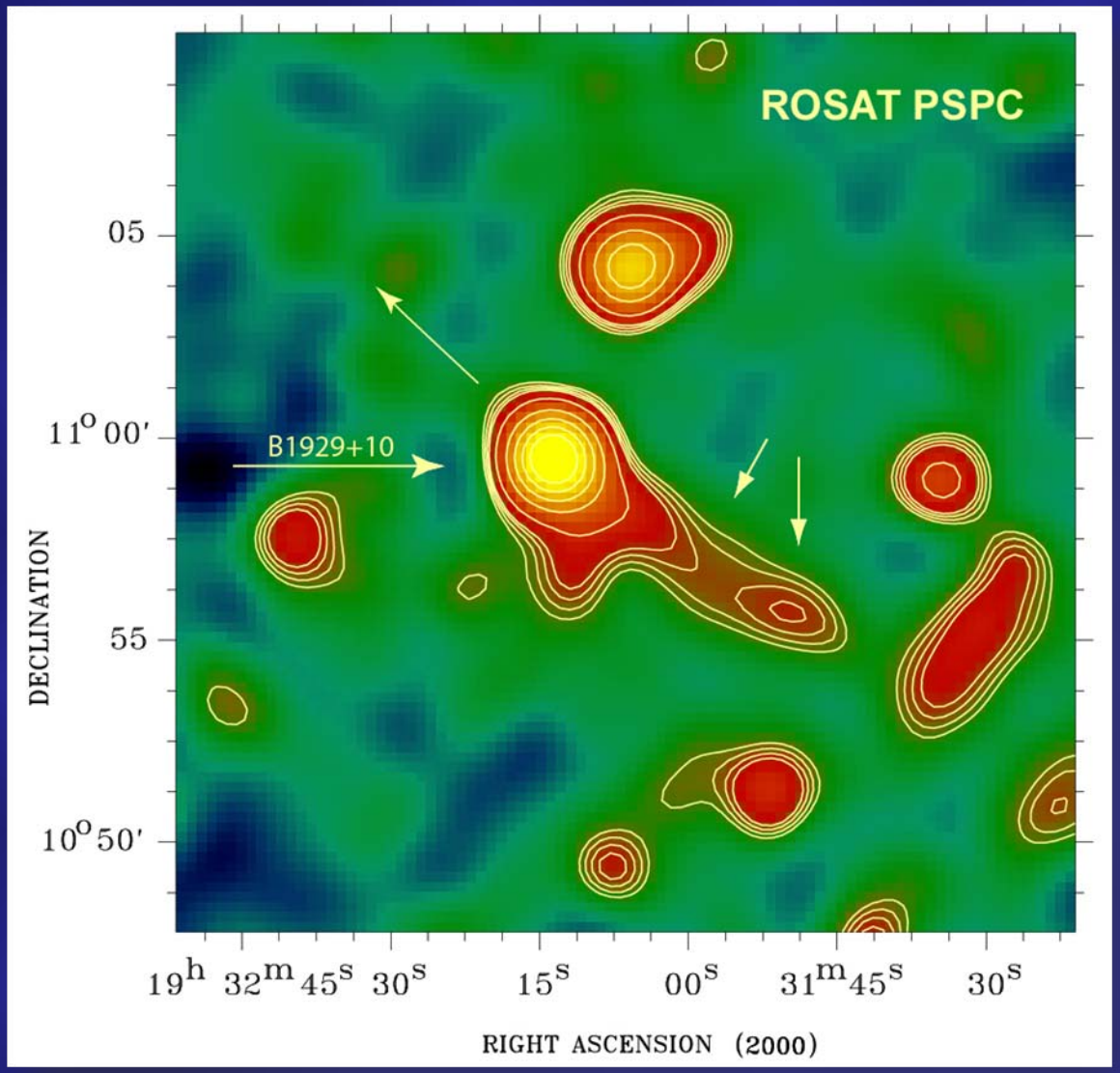
# Pulsar Bow-Shocks……

# Pulsar bow-shock nebulae




If the ram pressure $p_{ram} = \rho_{amb} V^2$ exceeds the ambient gas pressure a bow-shock is formed

# Pulsar bow-shock nebulae: PSR 1929+10

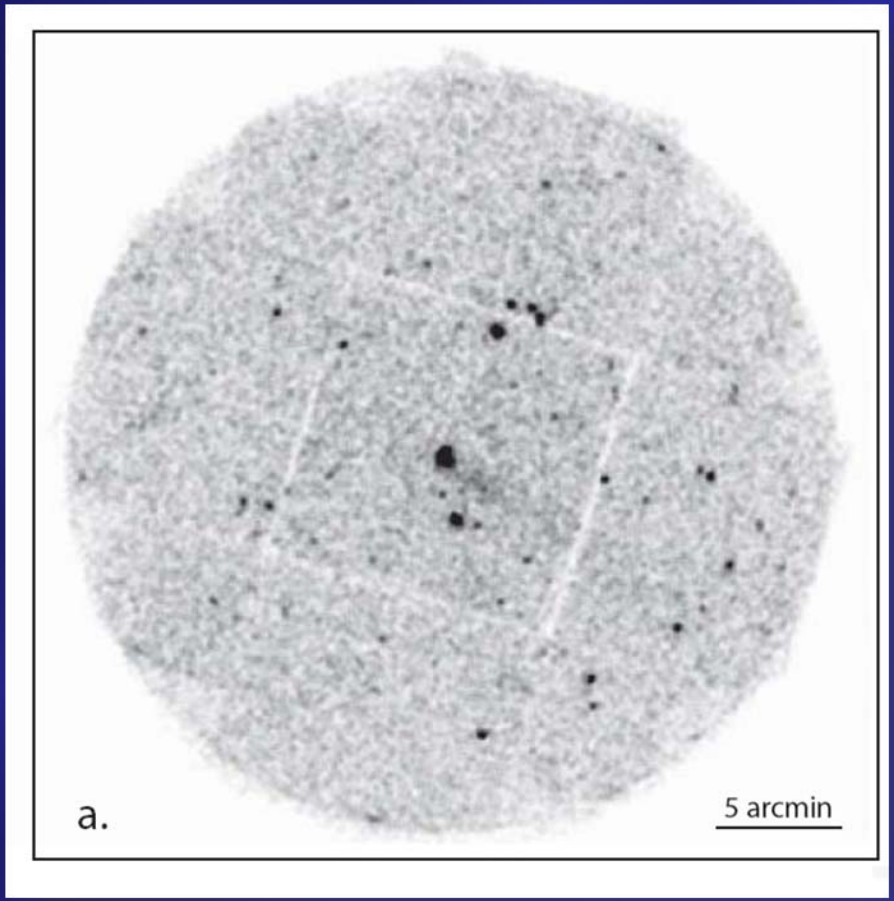



**The pulsar is moving at a transverse velocity of 177 km/s**

The trail emission is non-thermal and is likely produced from the synchrotron process of highly relativistic electrons in the shocked region between the pulsar wind and the surrounding ISM

Becker, Kramer, Jessner et al.(2006)

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




Becker, Kramer, Jessner et al.(2006)

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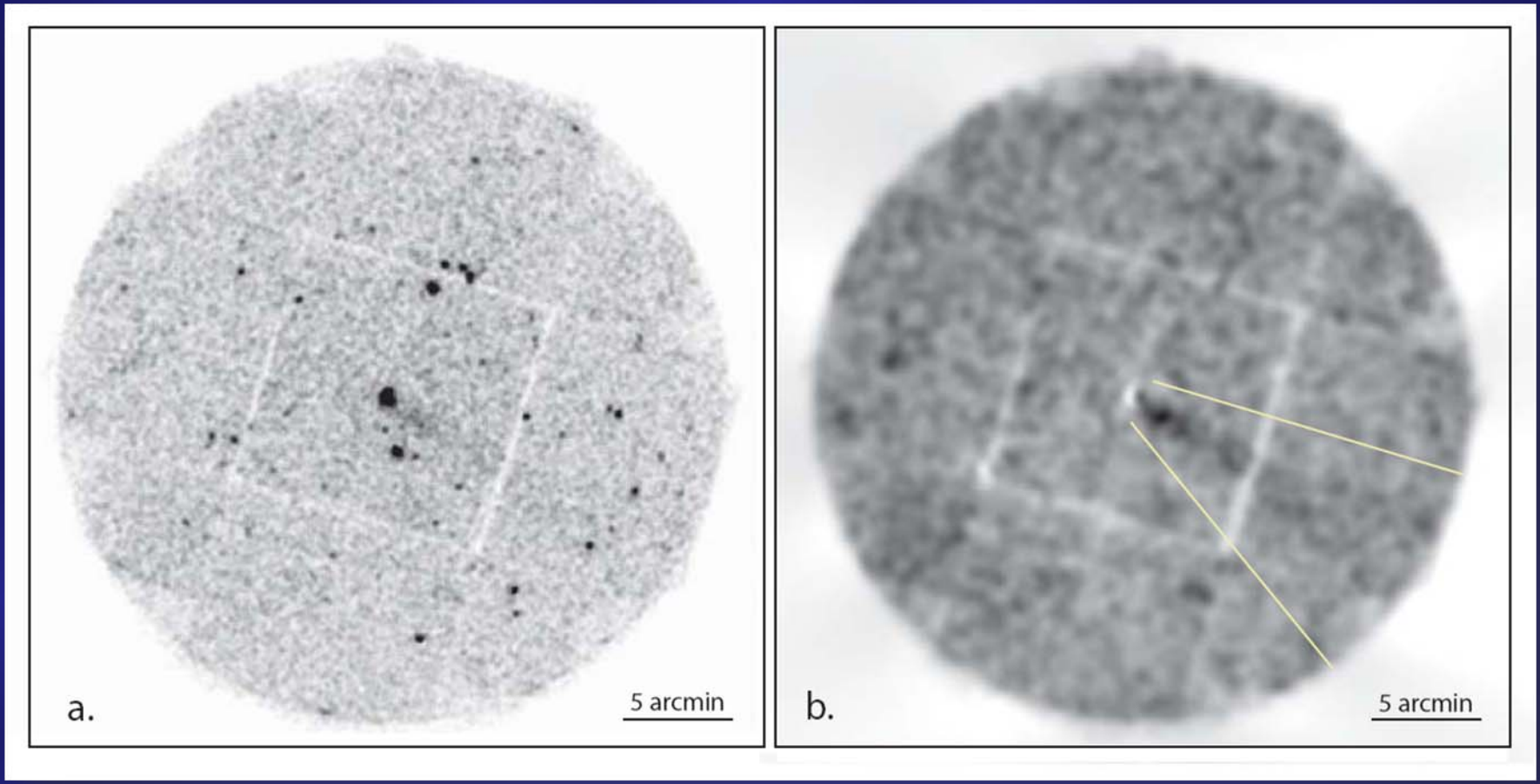
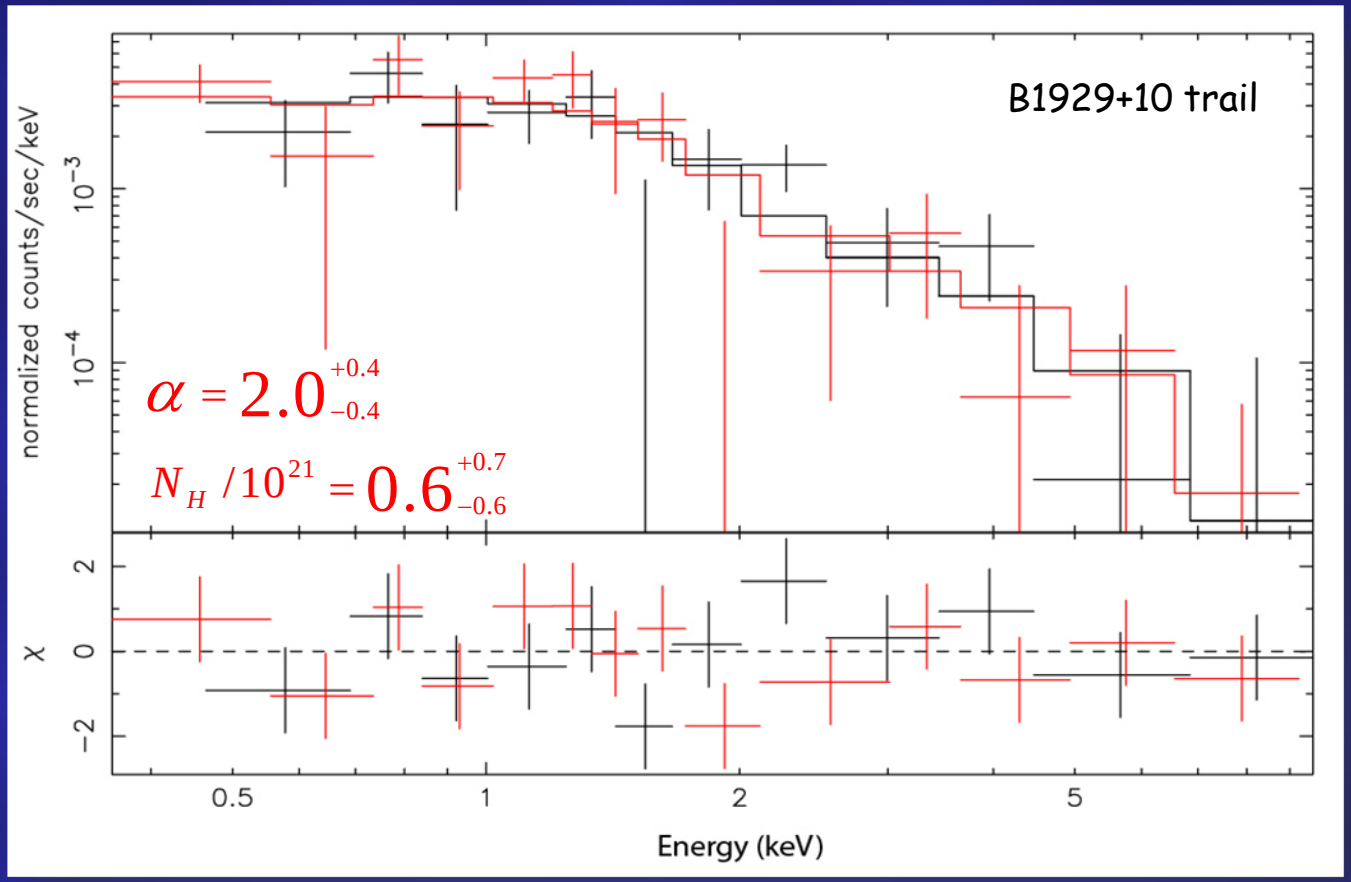



- length of the trail not very well constraint → requires deeper observations !!

Becker, Kramer, Jessner et al.(2006)

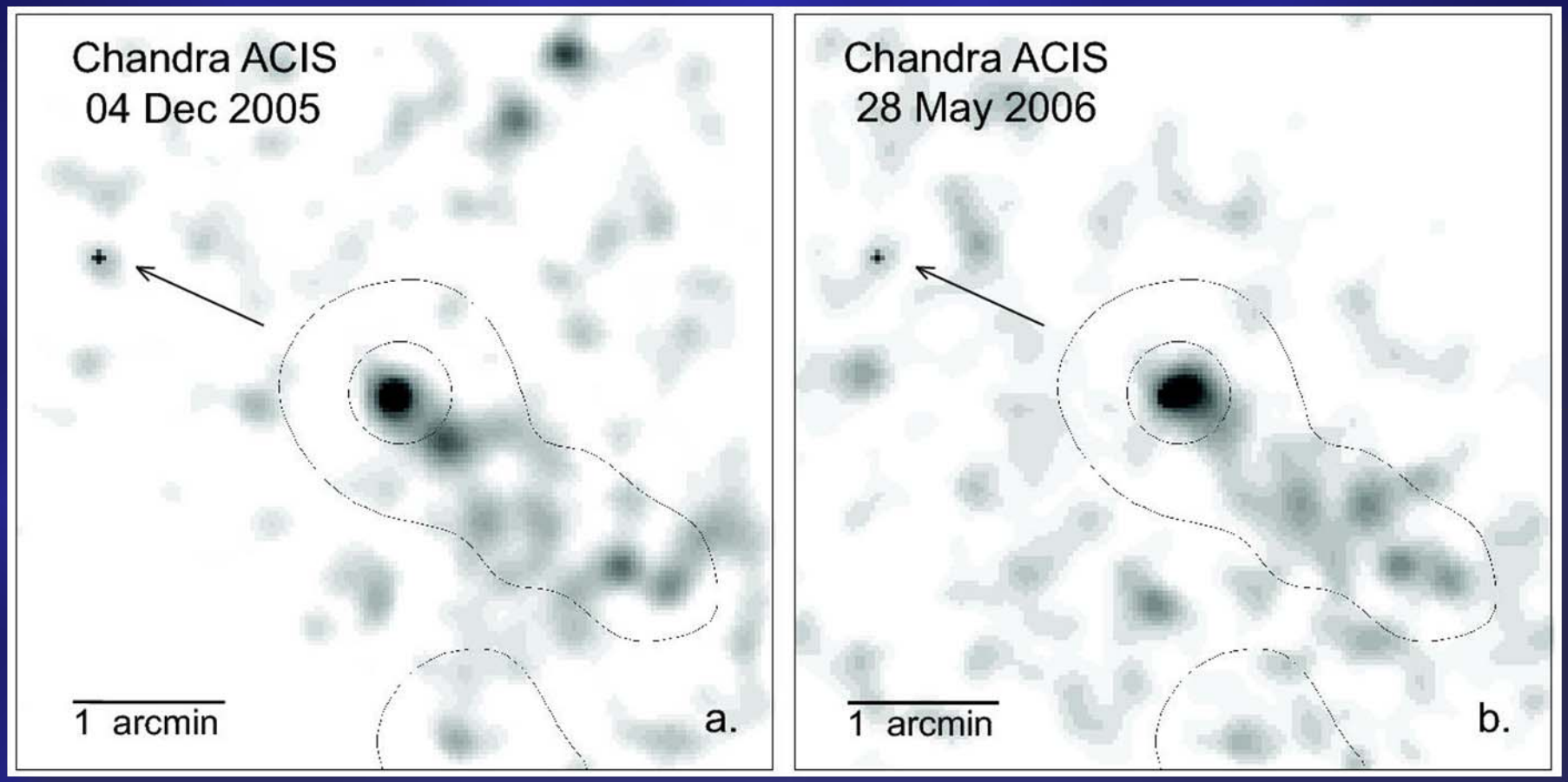
# X-ray emission properties of old pulsars: B1929-10




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

# Resolving the bow-shock nebula around the old pulsar PSR B1929+10

Hui & Becker (2007) / astro-ph:07070800



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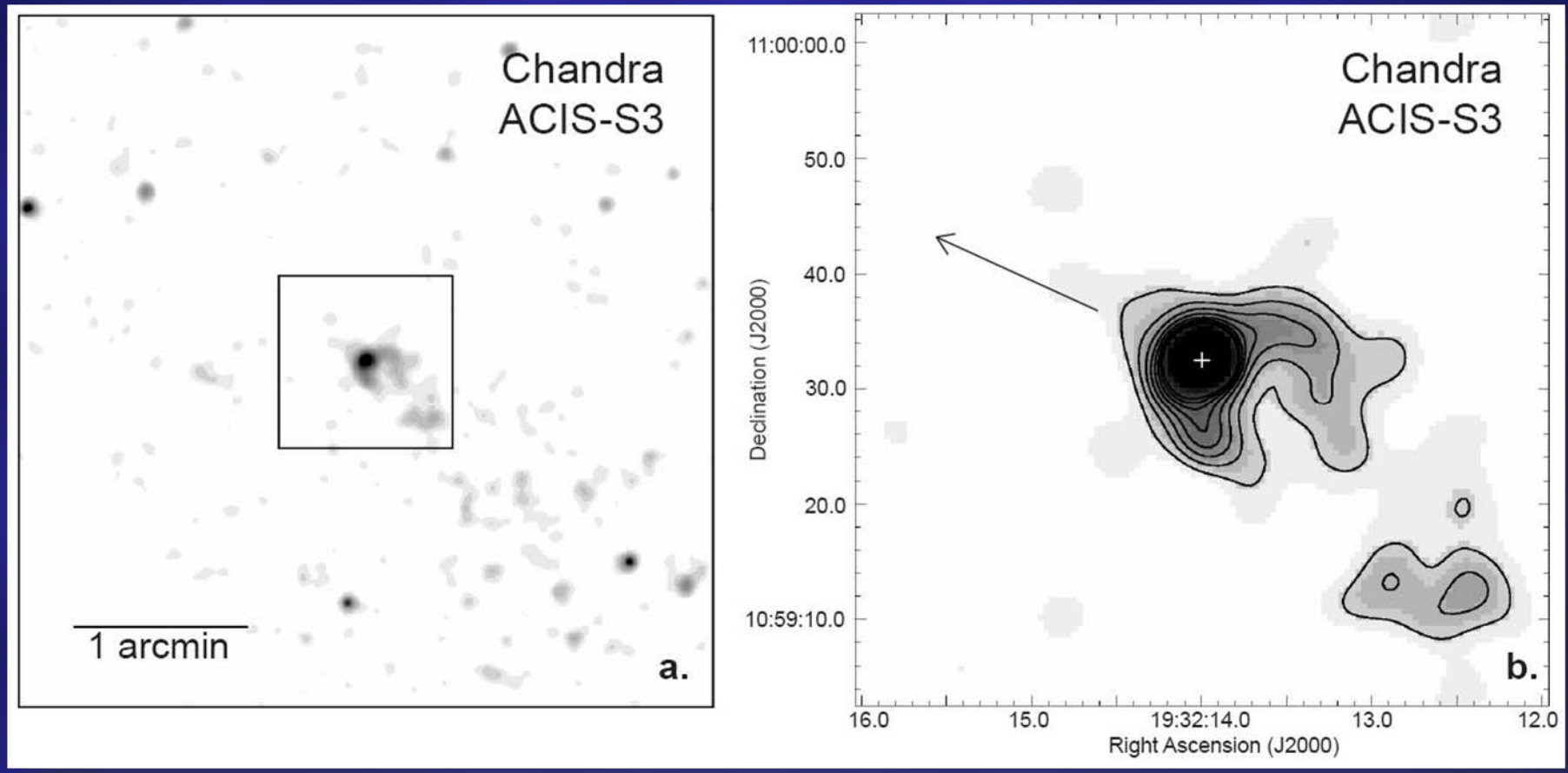
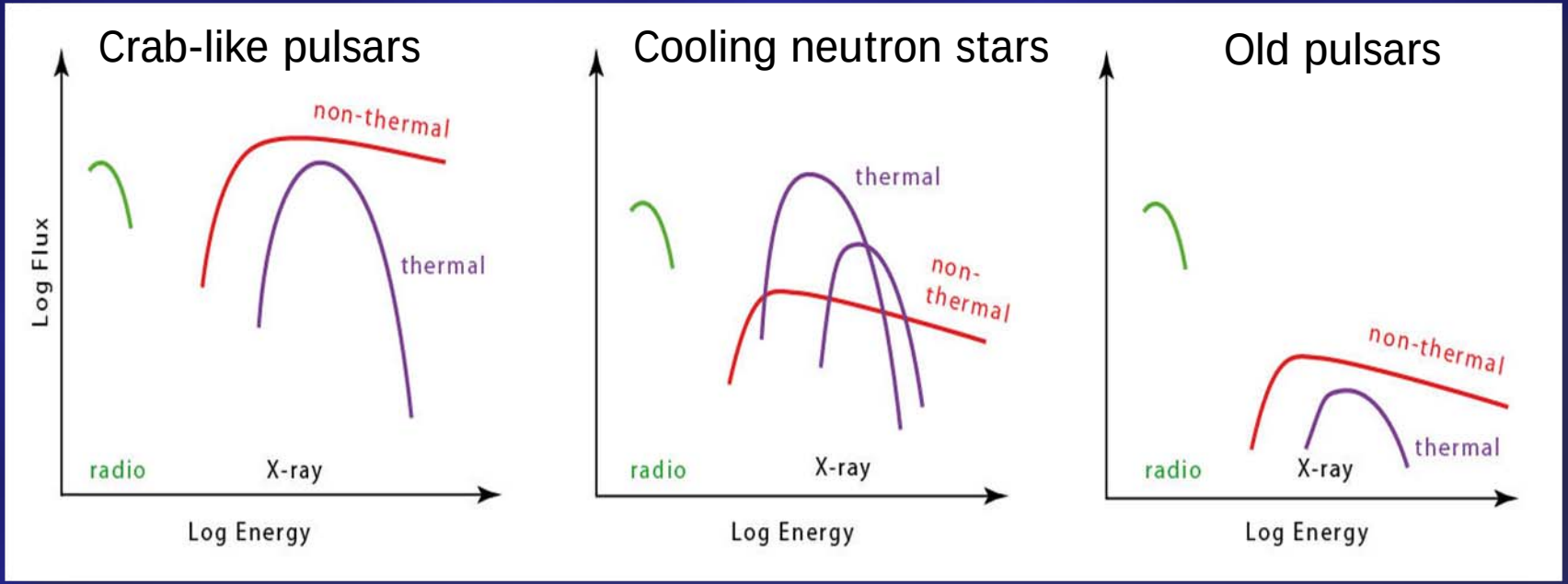
Hui & Becker (2007) / astro-ph:07070800



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

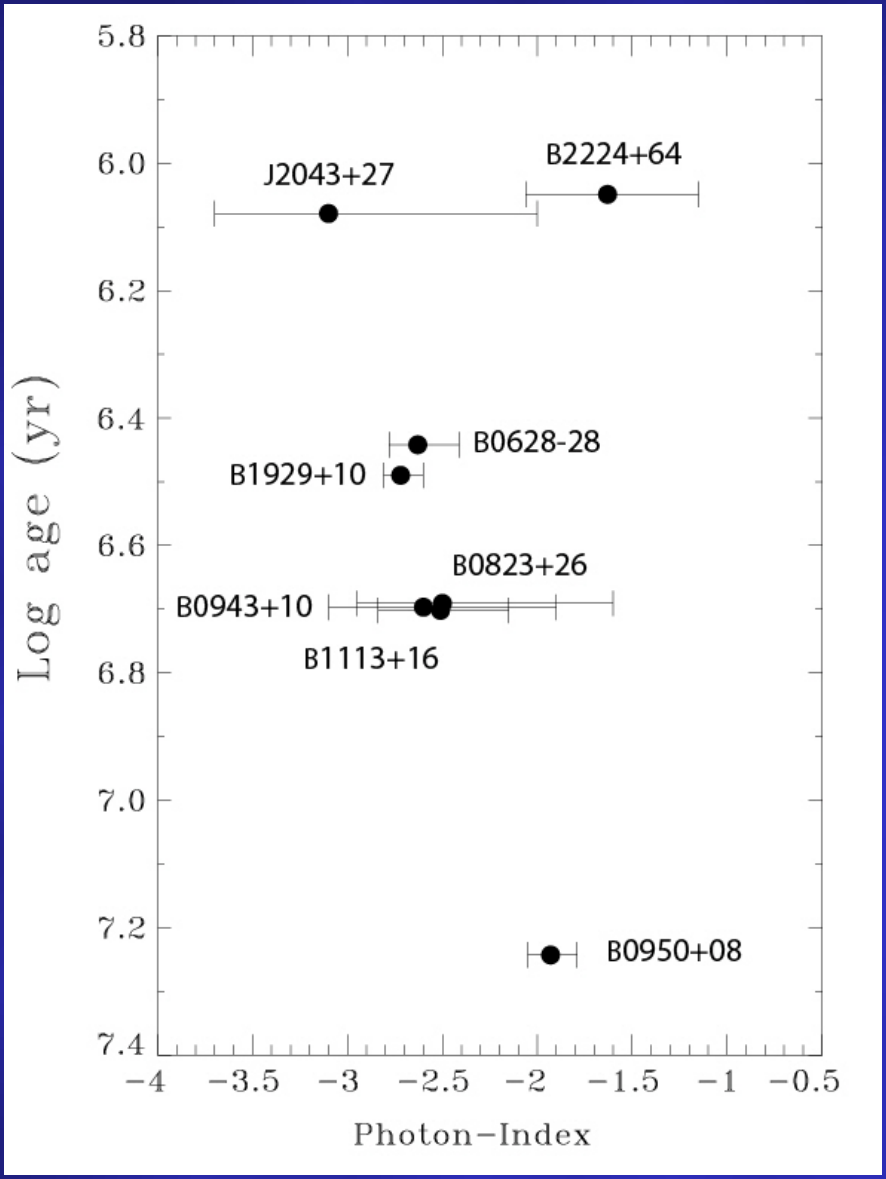



- non-thermal emission dominates in old pulsars / pulse profiles are **NOT sinusoidal**
- Diffuse bow-shock emission of these low Edot pulsars has the potential to challenge pulsar-wind models

# X-ray emission properties of old pulsars

younger

older

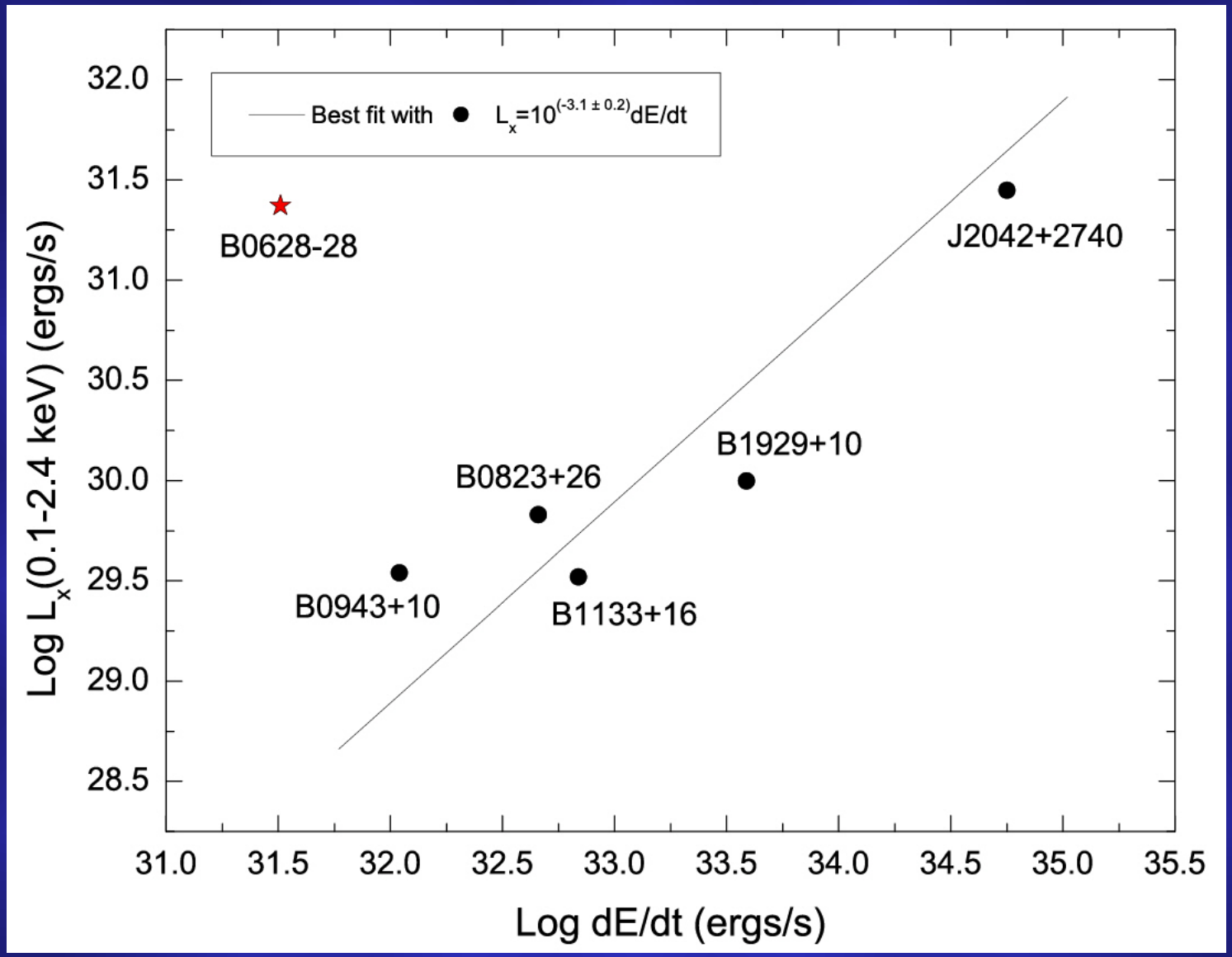



No evidence for a spectral softening with increasing spin-down age for old pulsars

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

| Pulsar | Spin down age | $T_S^{\infty}$ 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 |

# X-ray emission properties of old pulsars



# Neutron star temperature measurements