X-rays from Radio Millisecond Pulsars: Comptonized Thermal Radiation

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X-ray emission from MSPs (so far…)

- Non-thermal (pulsed) magnetospheric emission
  - e.g. B1937+21, B1821-24

    $\dot{E}$~10^{36} ergs s^{-1} L_X~$10^{32\text{-}33}$ ergs s^{-1}

- Shock emission
  - e.g. B1957+20, the 'black-widow'

    $\dot{E}$~10^{35} ergs s^{-1} L_X~10^{31} ergs s^{-1}

- Thermal (pulsed) emission from polar caps
  - e.g. J0437-4715, 47 Tuc MSPs…

    $\dot{E}$~$10^{33\text{-}34}$ ergs s^{-1} L_X~10^{30} ergs s^{-1}

PSR J0437-4715

- **Nearest MSP known**

  D_π=139±3 pc

  P = 5.76 ms

  $\dot{E}$ = 4×10^{33} ergs s^{-1}

  P_b = 5.7 d

  i = 42°

  a = 1.2×10^{12} cm

  m_c= 0.24 $M_\odot$ (He-WD)

  M =1.58±0.18 $M_\odot$

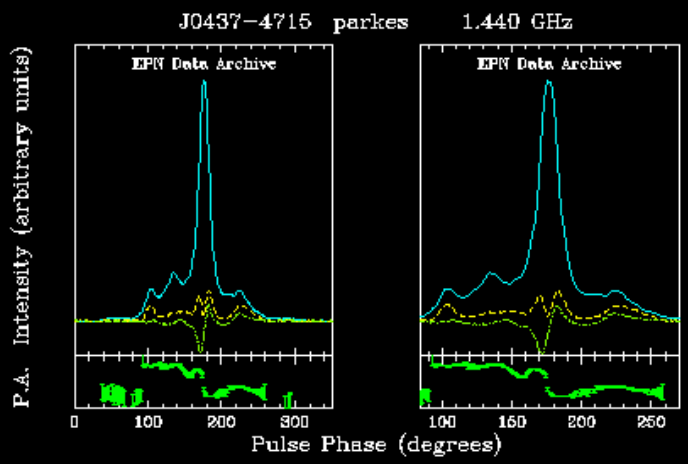


Table 1 PSR J0437–4715 physical parameters

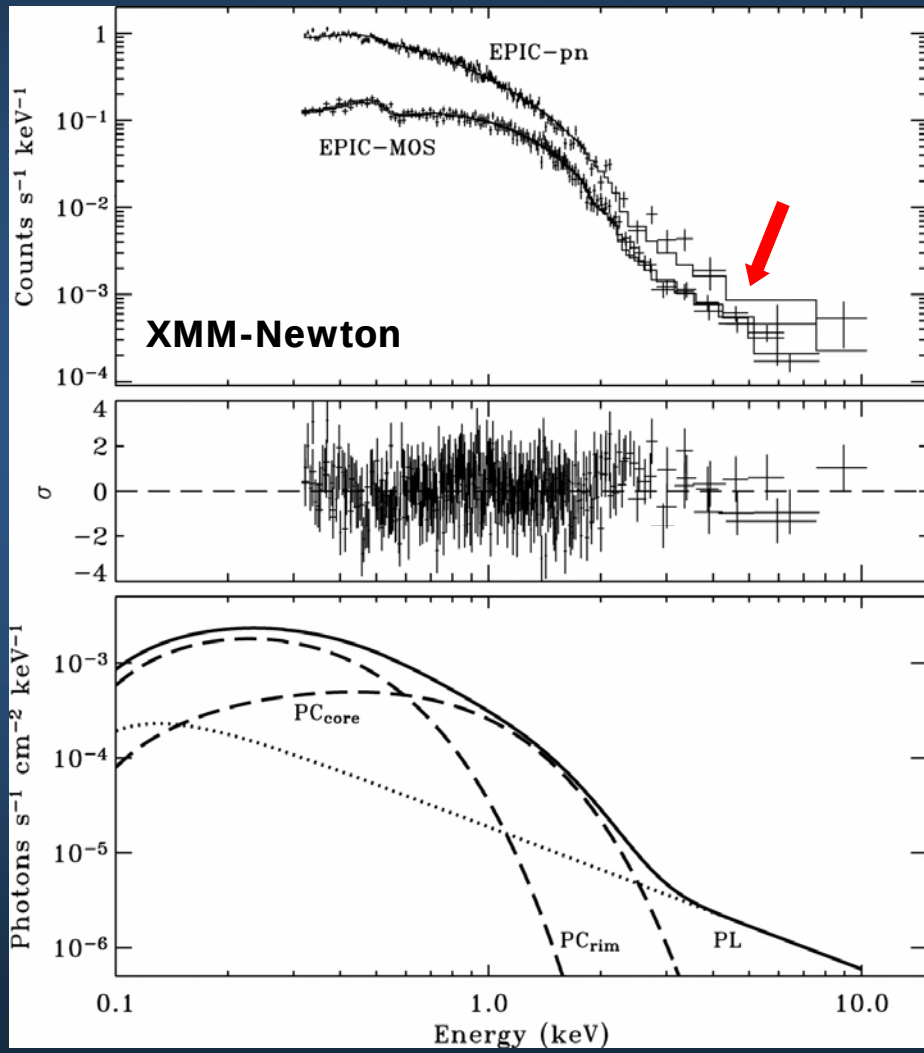
Right ascension, α (J2000) ...	$04^h37^m15^s.7865145(7)$
Declination, δ (J2000)	-47°15′08″.461584(8)
μ_α (mas yr^{-1})	121.438(6)
μ_δ (mas yr^{-1})	-71.438(7)
Annual parallax, π (mas)	7.19(14)
Pulse period, P (ms)	5.757451831072007(8)
Reference epoch (MJD)	51194.0
Period derivative, $\dot{P}$ (10^{-20}) ..	5.72906(5)
Orbital period, P_b (days)	5.741046(3)
x (s)	3.36669157(14)
Orbital eccentricity, e	0.000019186(5)
Epoch of periastron, T_0 (MJD)	51194.6239(8)
Longitude of periastron, ω (°) .	1.20(5)
Longitude of ascension, Ω (°) .	238(4)
Orbital inclination, i (°)	42.75(9)
Companion mass, m_2 ($M_\odot$) ...	0.236(17)
$\dot{P}_b(10^{-12})$	3.64(20)
$\dot{\omega}$ (°yr^{-1})	0.016(10)

(van Straten et al. 2001)

PSR J0437-4715

- **First MSP detected in X-rays by *ROSAT***
  (Becker & Trümper 1993)

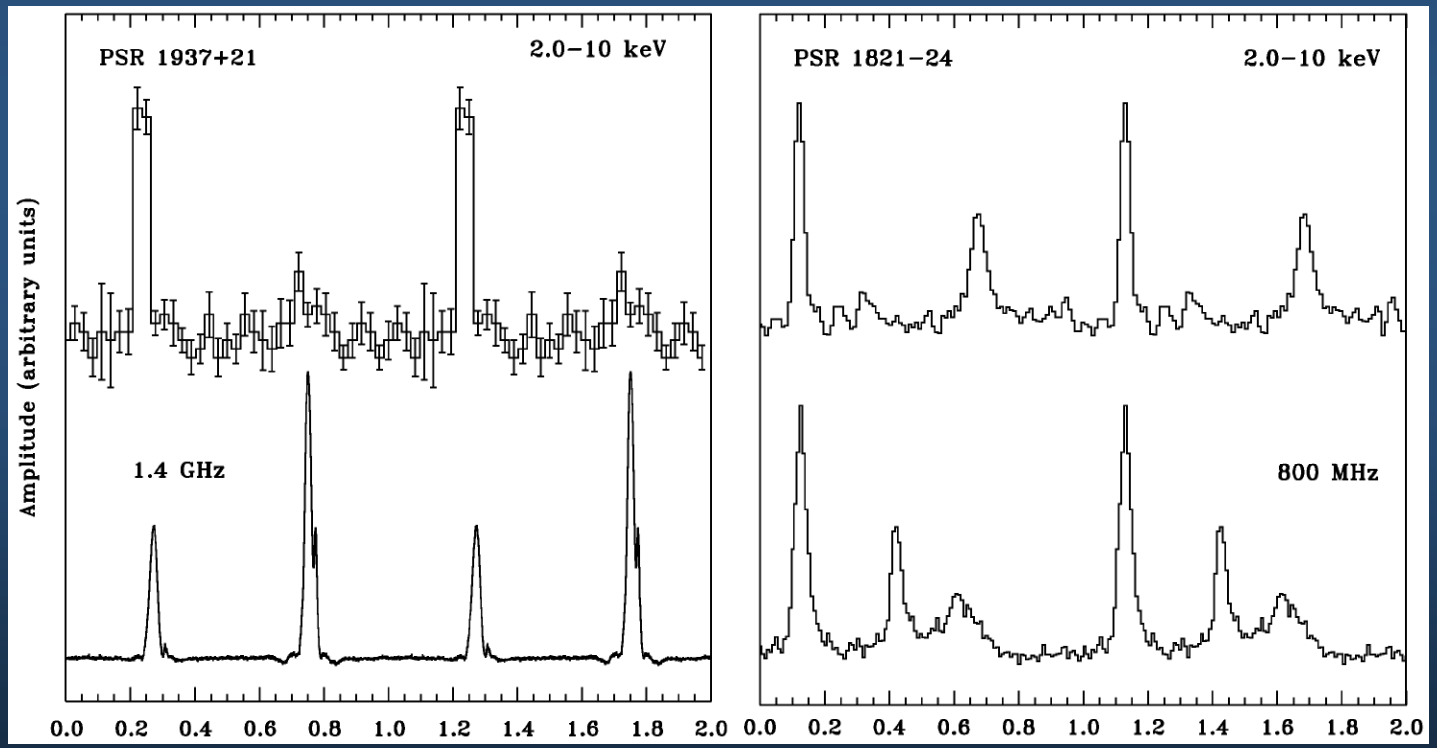
- **X-ray spectrum:**
  - 2 thermal components +
  PL tail (Γ=2.0±0.4)
  (Zavlin et al. 2002; Zavlin 2006)



Zavlin (2006)

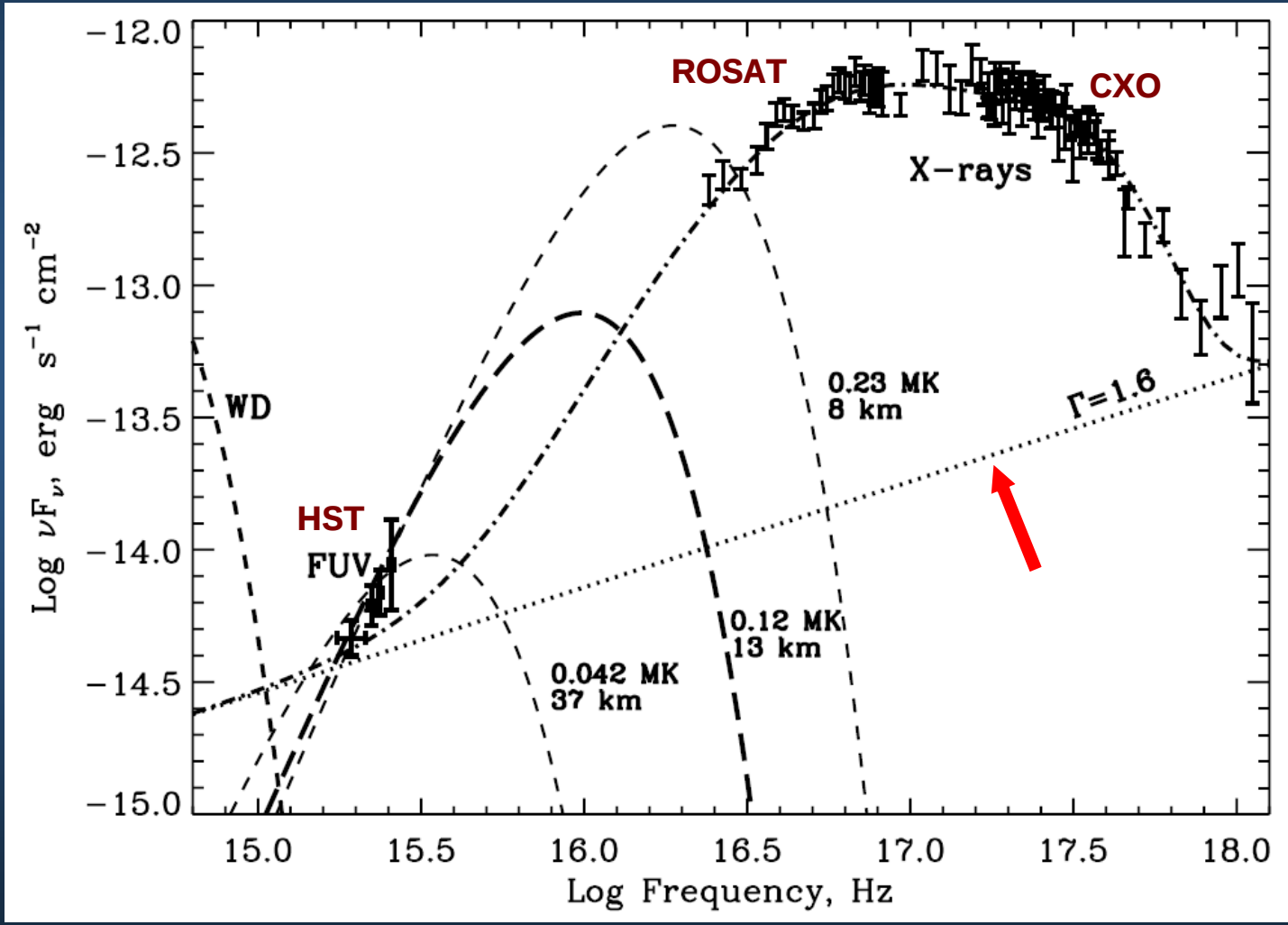
X-ray emission from J0437-4715

- Non-thermal magnetospheric emission



Becker & Aschenbach (2002)

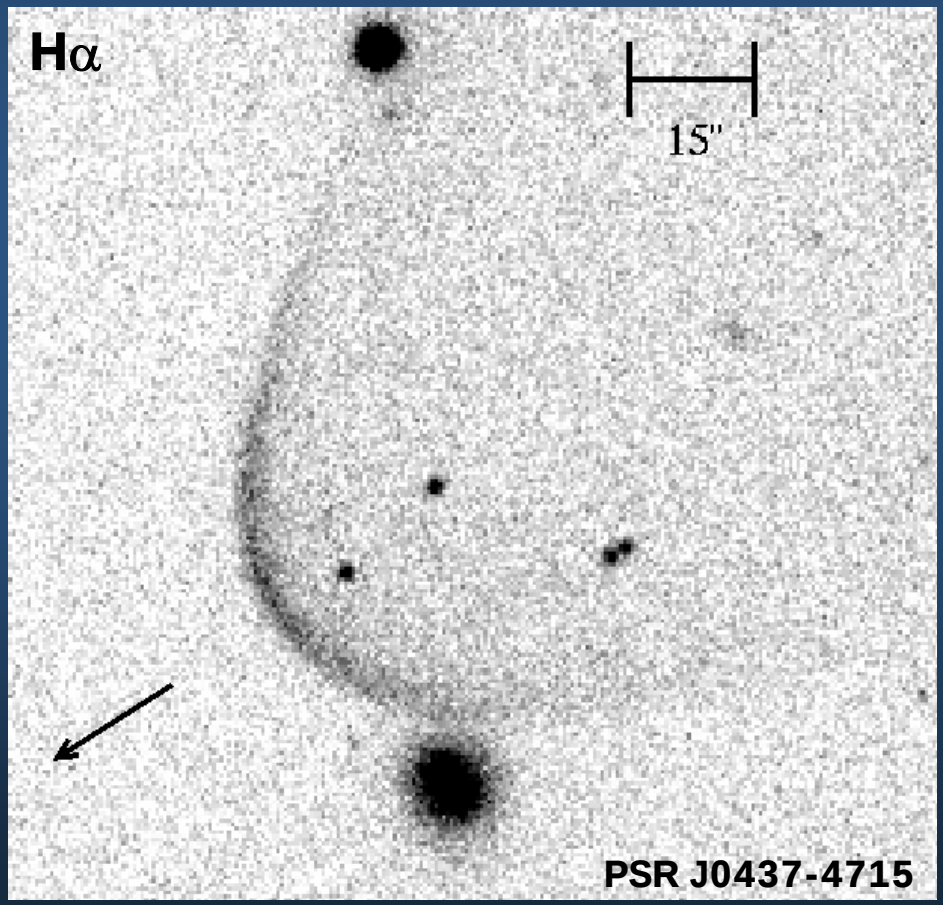
X-ray emission from J0437-4715



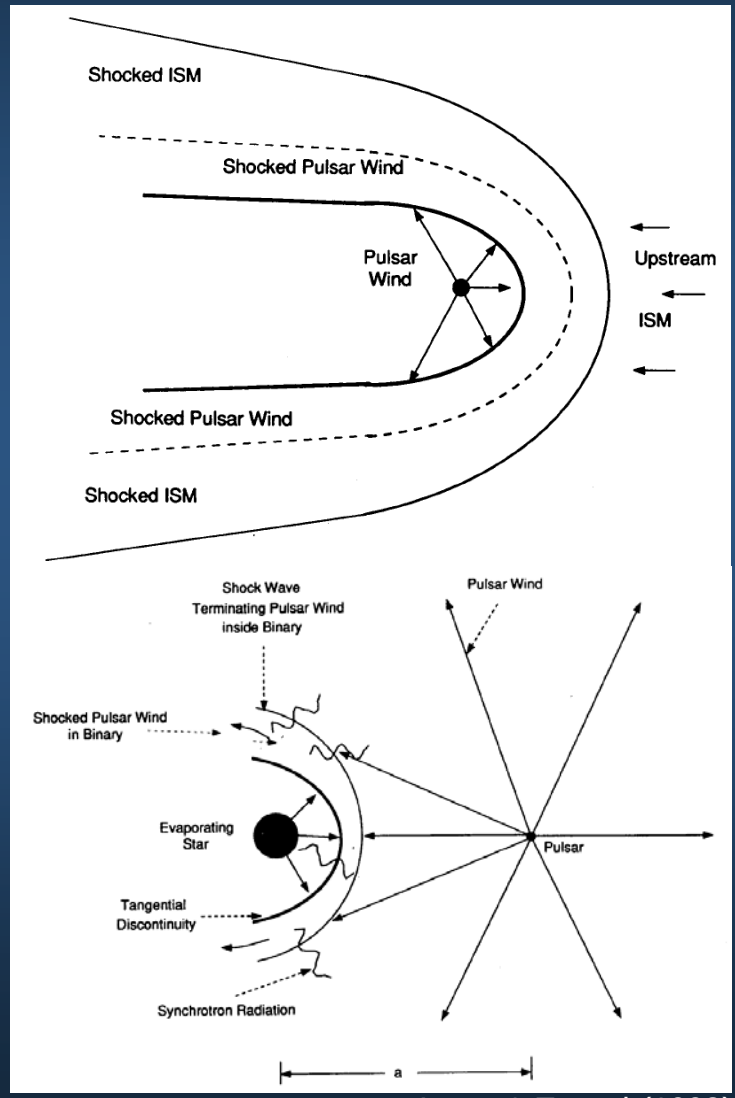
Kargaltsev, Pavlov, & Romani (2004)

X-ray emission from J0437-4715

- **Interaction of MSP wind with ISM or binary companion**



Fruchter (1995)



Arons & Tavani (1993)

Hard X-ray Emission from J0437-4715

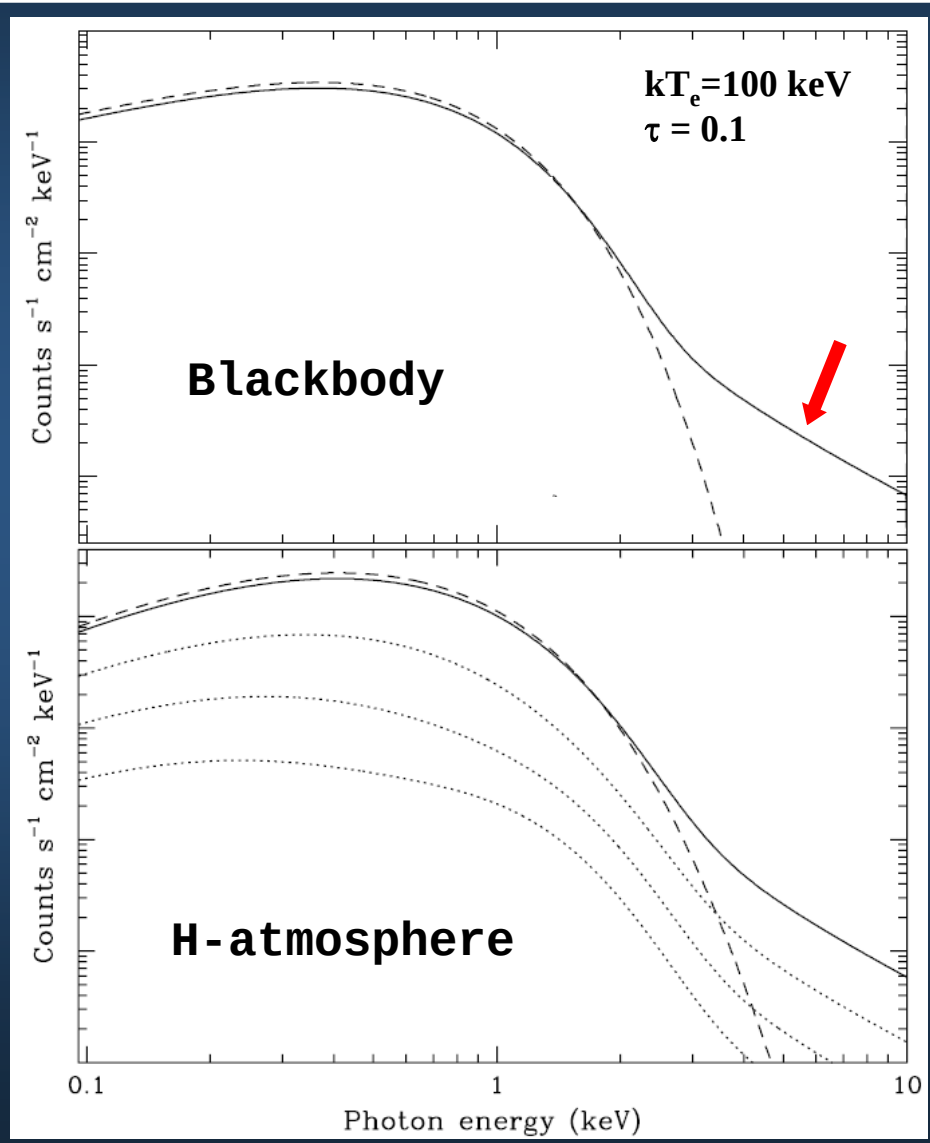
- Non-thermal magnetospheric emission ✗
  - inconsistent with FUV data
- Intrabinary shock emission ✗
  - pulsar wind too weak
- Thermal emission from polar caps ✗
  - too small + too hot

Inverse Compton Scattering

- **Repeated ICS by hot $e^{\pm}$ of low optical depth ($\tau<1$)**
  $\rightarrow$ PL
  §7.5 Rybicki & Lightman (1979)

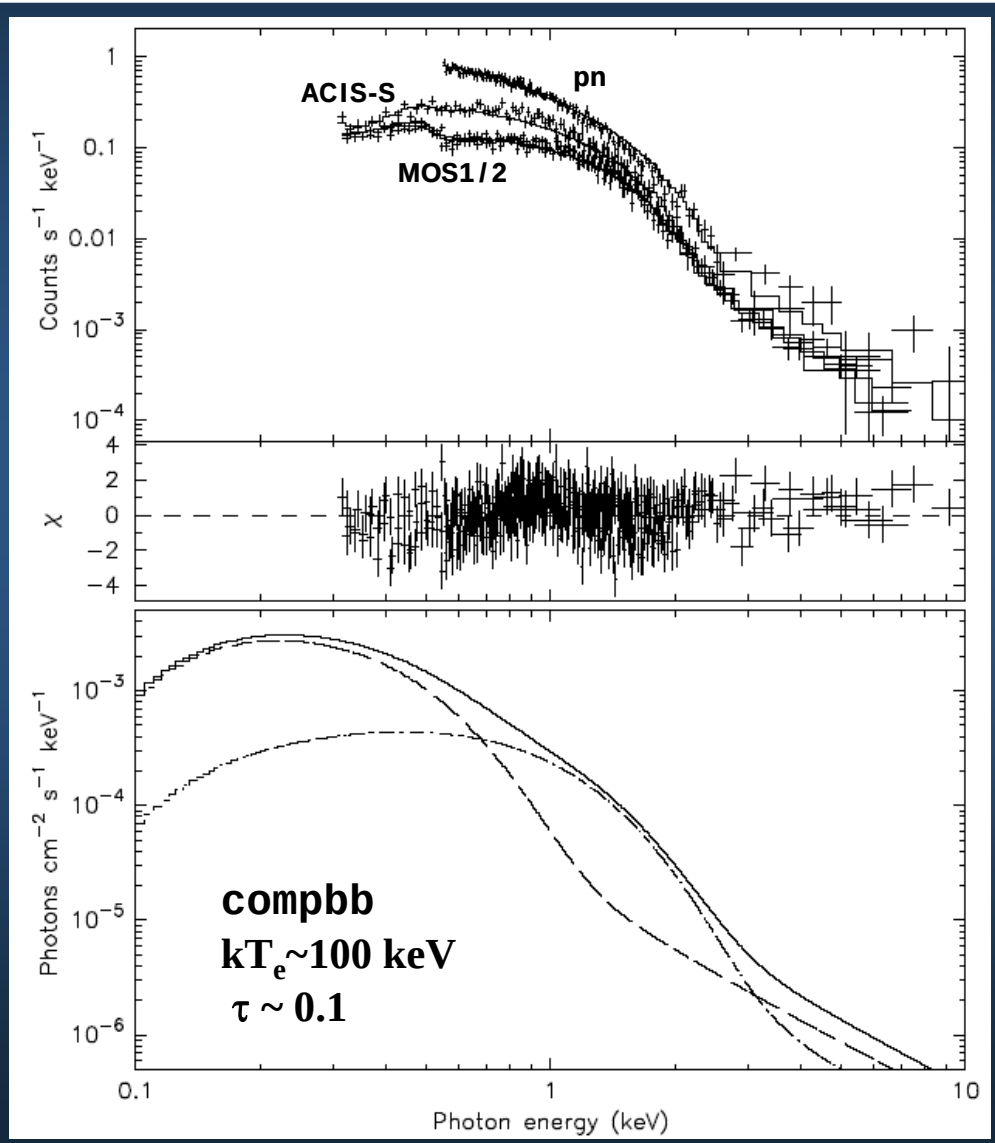
- **Comptonized blackbody**
  Nishimura, Mitsuda, & Itoh (1986)
  $E_0 << kT_e < m_e c^2$

- **NS H-atmosphere (B=0)**
  McClintock, Narayan, & Rybicki (2004)



Bogdanov, Grindlay, & Rybicki (2006)

Comptonization in MSPs



Bogdanov, Grindlay, & Rybicki (2006)

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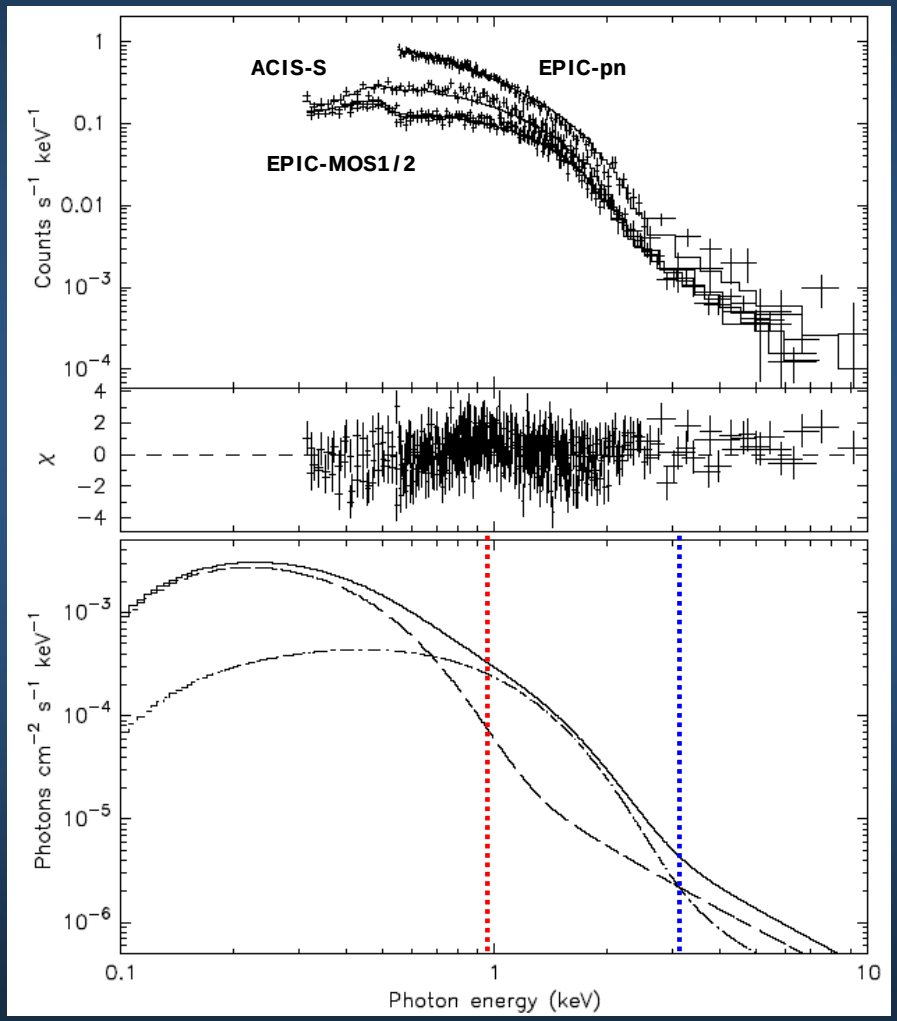
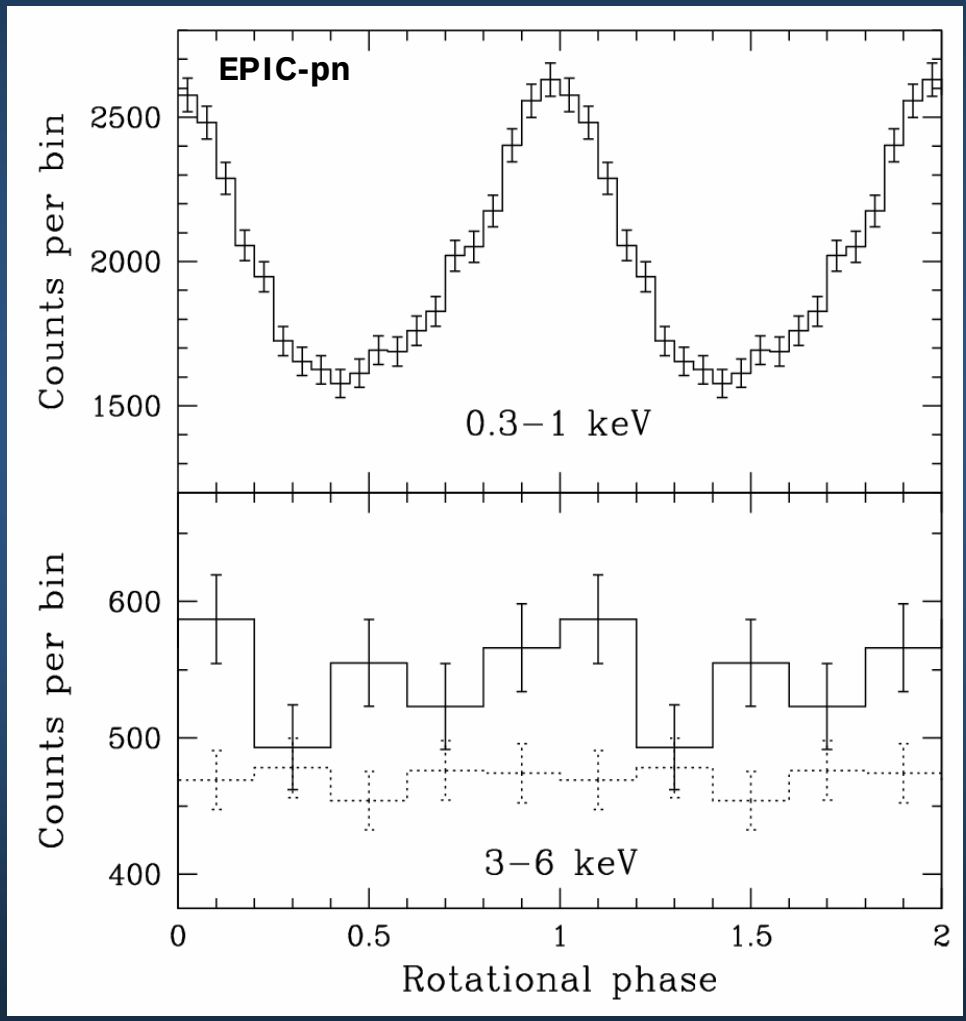
  - too small & too hot
- **Comptonization** ✓

Comptonization in MSPs





Bogdanov, Grindlay, & Rybicki (2006)

Other Nearby MSPs

- **PSR J0030+0451**

  D ≈ 300 pc

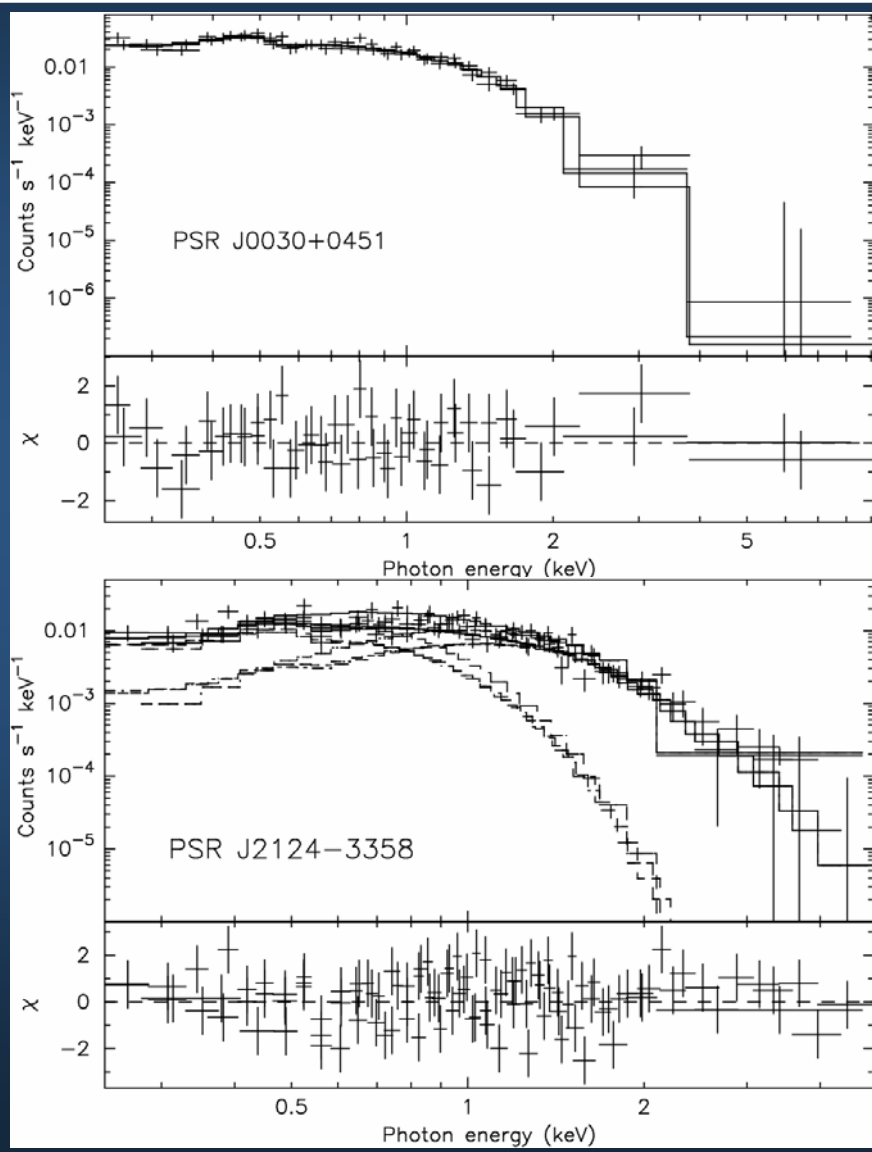
- **PSR J2124+3358**

  D ≈ 250 pc

- **Solitary**

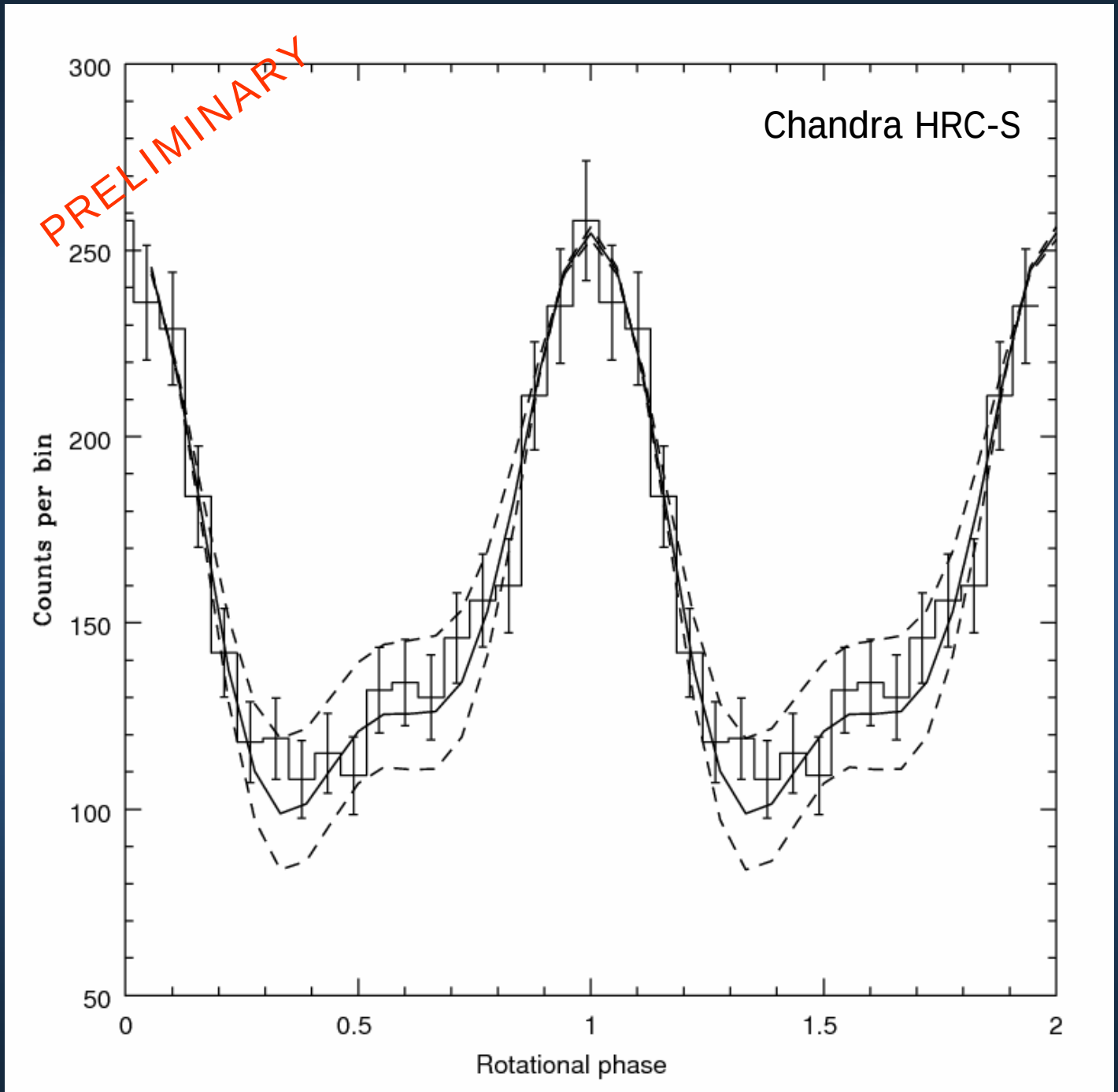
- **Spectra similar to PSR J0437-4715**

- **Need deeper X-ray and Optical/UV observations**



Conclusion

- **Comptonization model works**
- **⇒ *All* emission <1 keV is purely thermal**
- **⇒ Allows constraints on fundamental NS parameters** (Pavlov & Zavlin 1998)
  - **M/R**
  - **Global B-field configuration**
  - **Surface properties**


PRELIMINARY
Chandra HRC-S
300
250
200
150
100
50
Counts per bin
0
0.5
1
1.5
2
Rotational phase

See Bogdanov, Grindlay, & Rybicki (2006) for more details

astro-ph/0605237

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