Proton cyclotron absorption features in X-ray spectra of isolated neutron stars ?

Frank Haberl

MPE, Garching

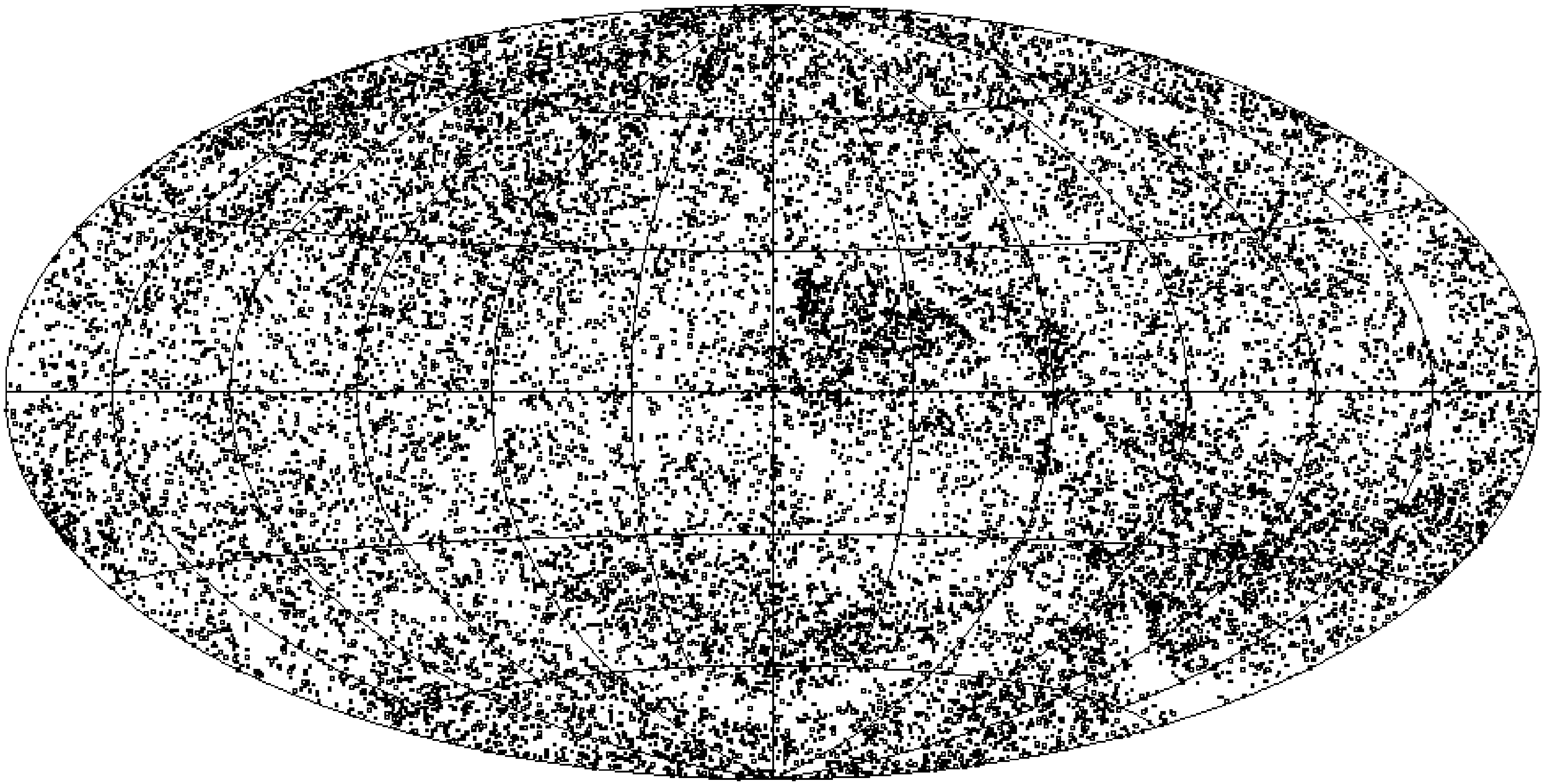
Topics in X-ray Astronomy

Workshop on the occasion of Rüdiger Staubert‘s 65th birthday

23-25 February 2004, Tübingen

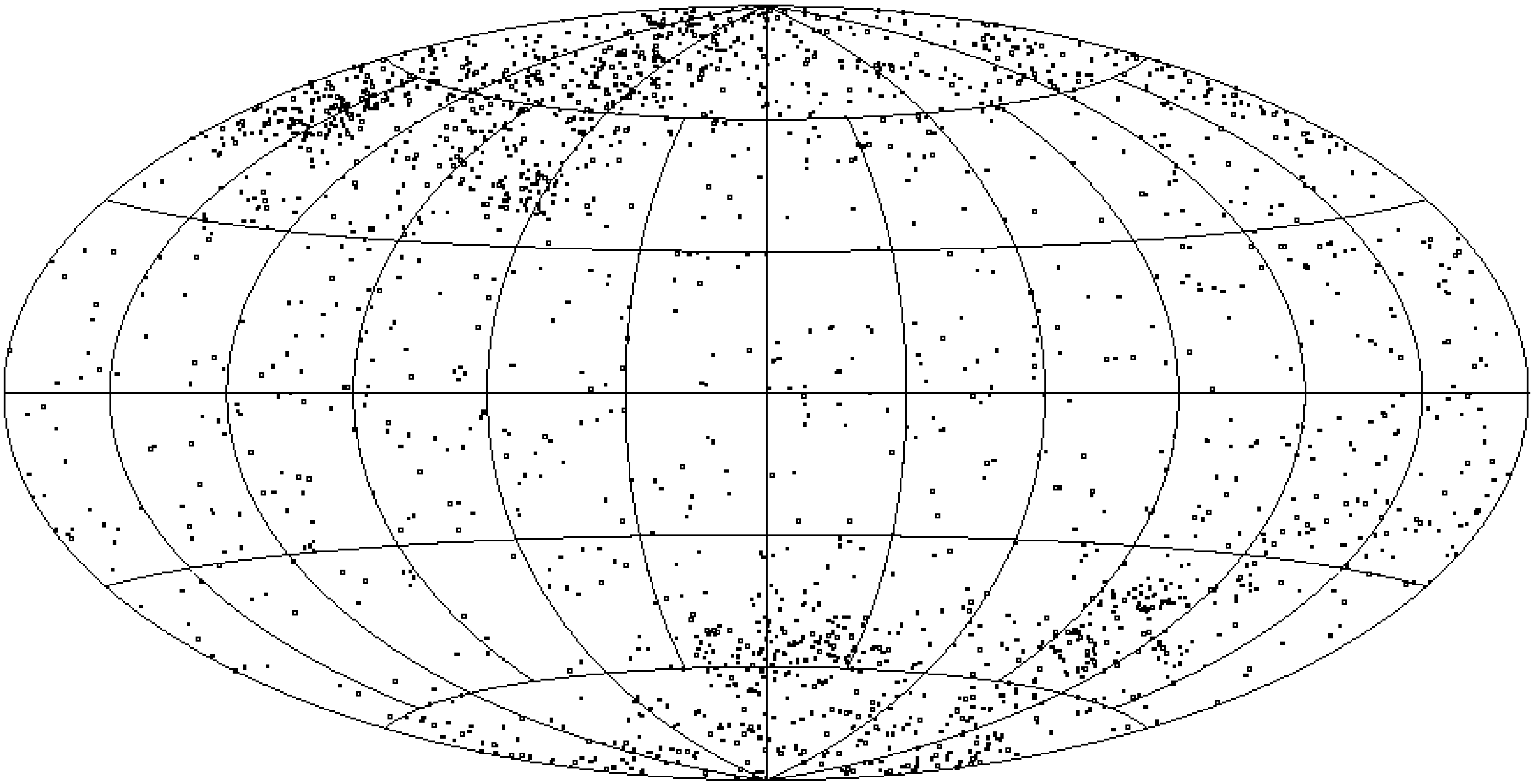
Isolated Neutron Stars in the ROSAT All-Sky Survey

Bright Source Catalogue



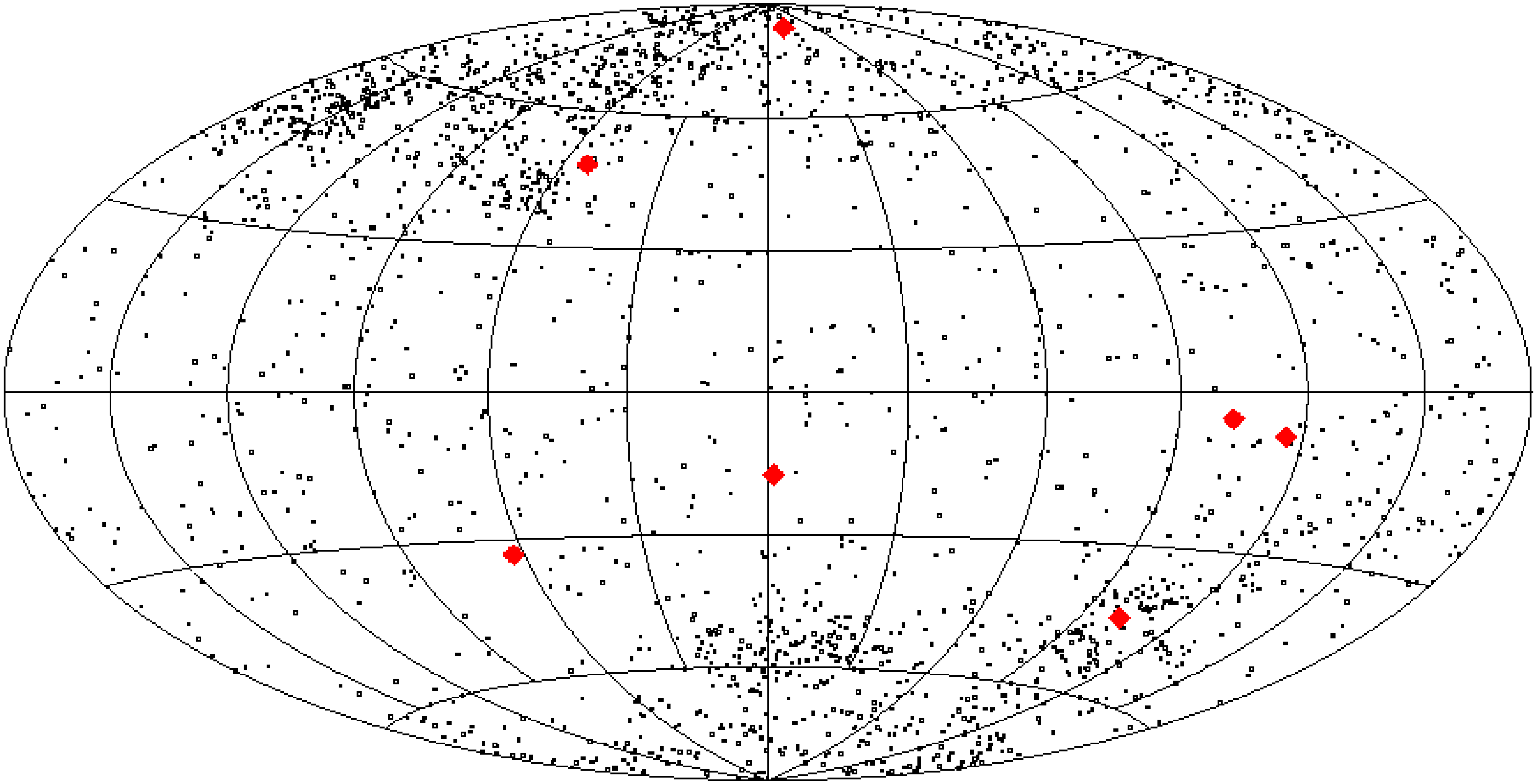
How to find them ?

Soft X-ray spectrum



How to find them ?

Soft X-ray spectrum + faint in optical

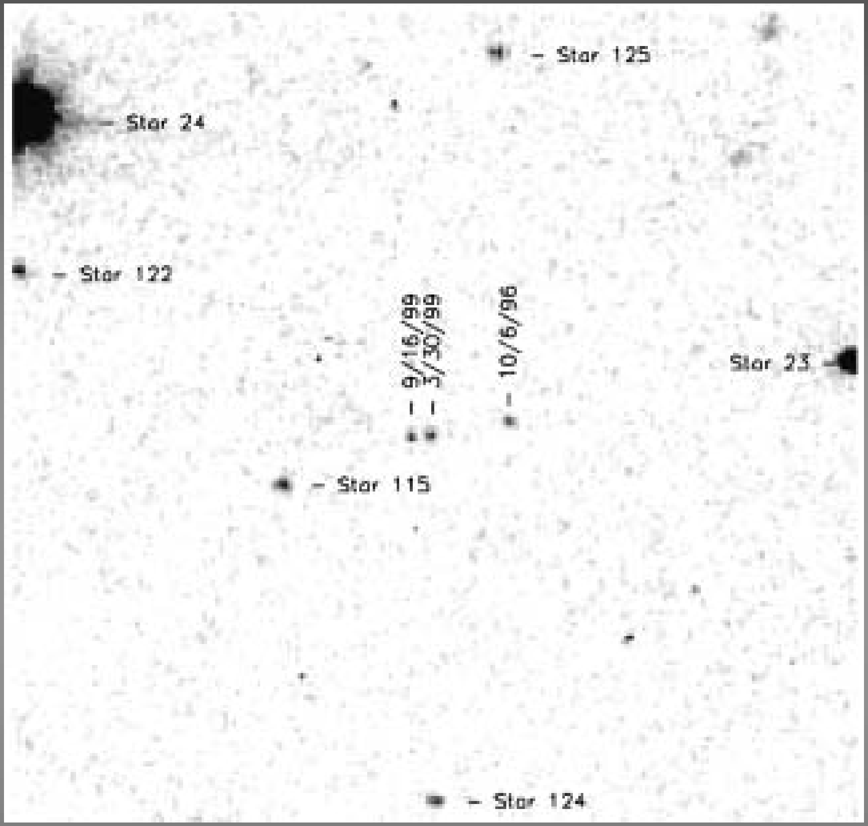


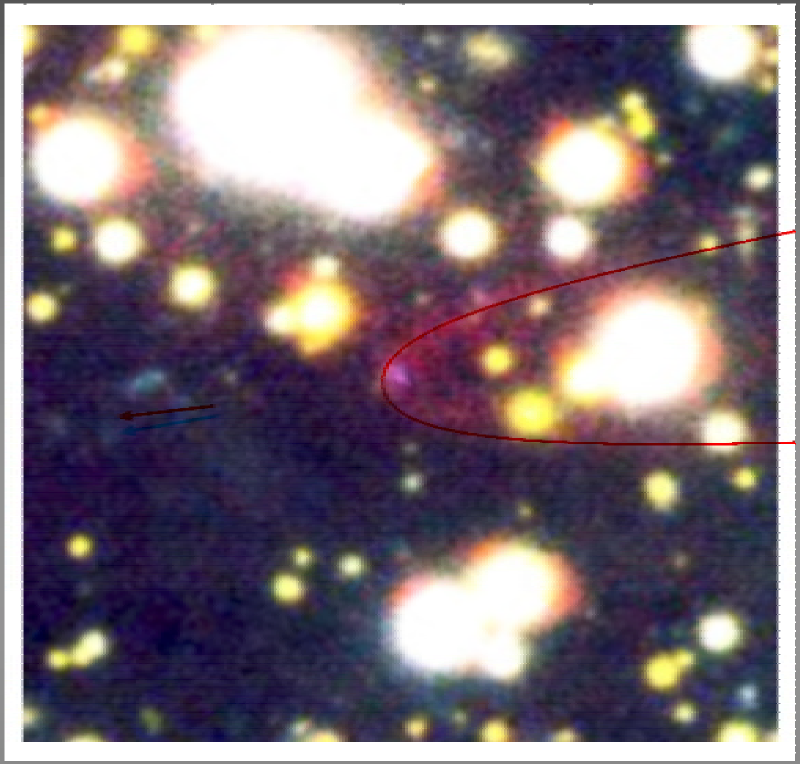
X-ray dim (thermal) Isolated Neutron Stars

- **Soft X-ray sources in ROSAT survey**
- **optically faint**
- **Blackbody-like X-ray spectra, NO non-thermal hard emission**
- **Low absorption, nearby**
- **Constant X-ray flux on time scales of years ?**
- **Some are X-ray pulsars (3.45 – 11.37 s)**
- **No radio emission ?**
- **No obvious association with SNR**

Object	kT/eV	L_x/erg s^{-1}	d/pc	Opt.	Comment
RX J0420.0–5022	44	$2.7x10^{30}$	100	B = 26.6	
RX J0720.4–3125	85	$2.6x10^{31}$	100	B = 26.6	PM
RX J0806.4–4123	96	$5.7x10^{30}$	100	B > 24	
1RXS J130848.6+212708	86	$5.1x10^{30}$	100	m_{50ccd} = 28.6	
RX J1605.3+3249	96	$1.1x10^{31}$	100	m_{50ccd} = 26.8	PM
RX J1856.5–3754	60	$1.5x10^{31}$	117	V = 25.7	PM, parallax
1RXS J214303.7+065419	(90)	$1.1x10^{31}$	100	R > 23	

Optical identifications RX J1856.5 - 3754





Bowshock Nebula VLT

Distance 117 ± 12 pc HST

Kerkwijk & Kulkarni (2001)

Proper motion 332 mas y^{-1}

Tangential space velocity 185 km s^{-1}

Walter (2001); Walter & Lattimer (2002)

High proper motion:
Not heated by accretion of ISM !!

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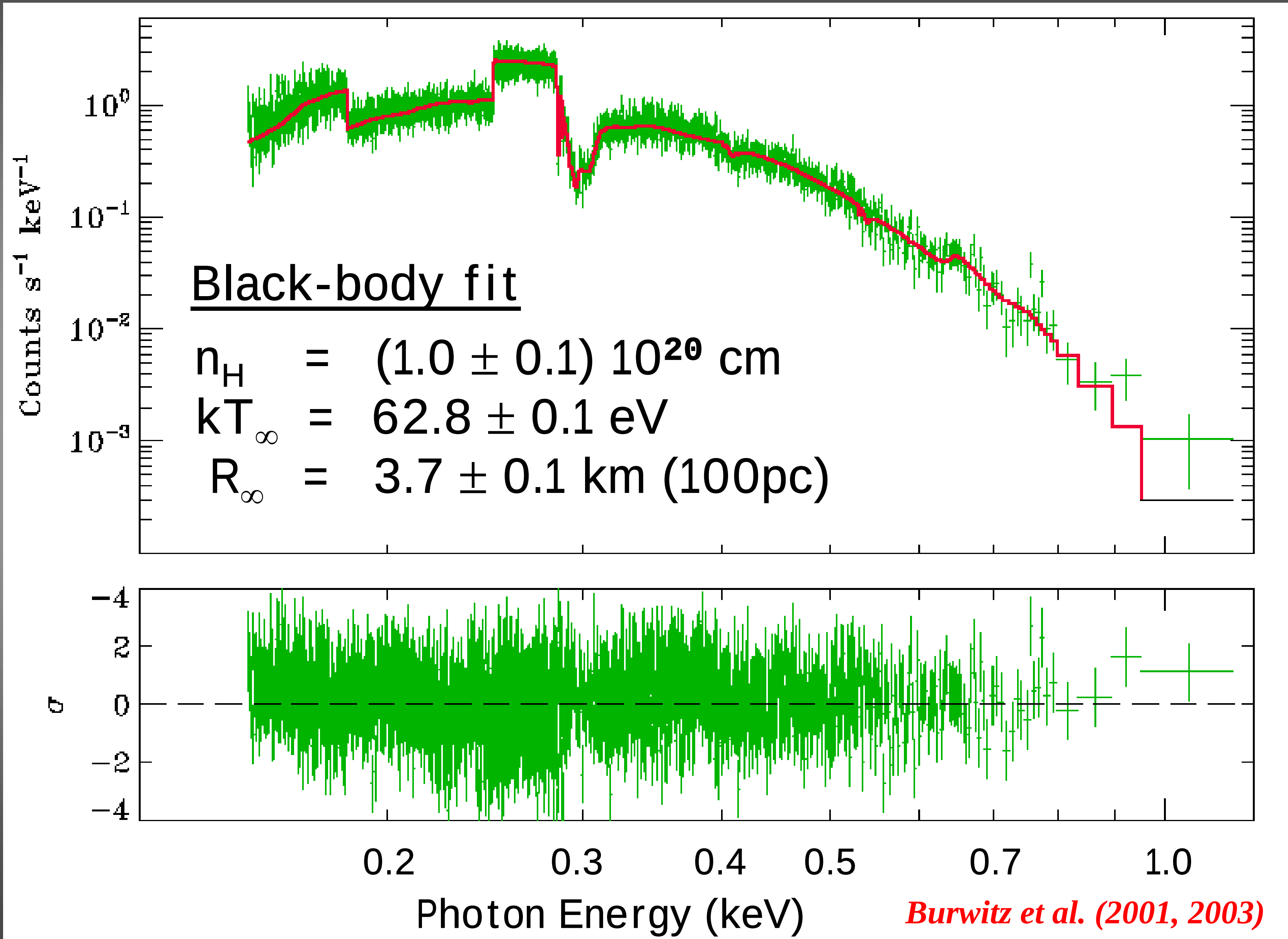
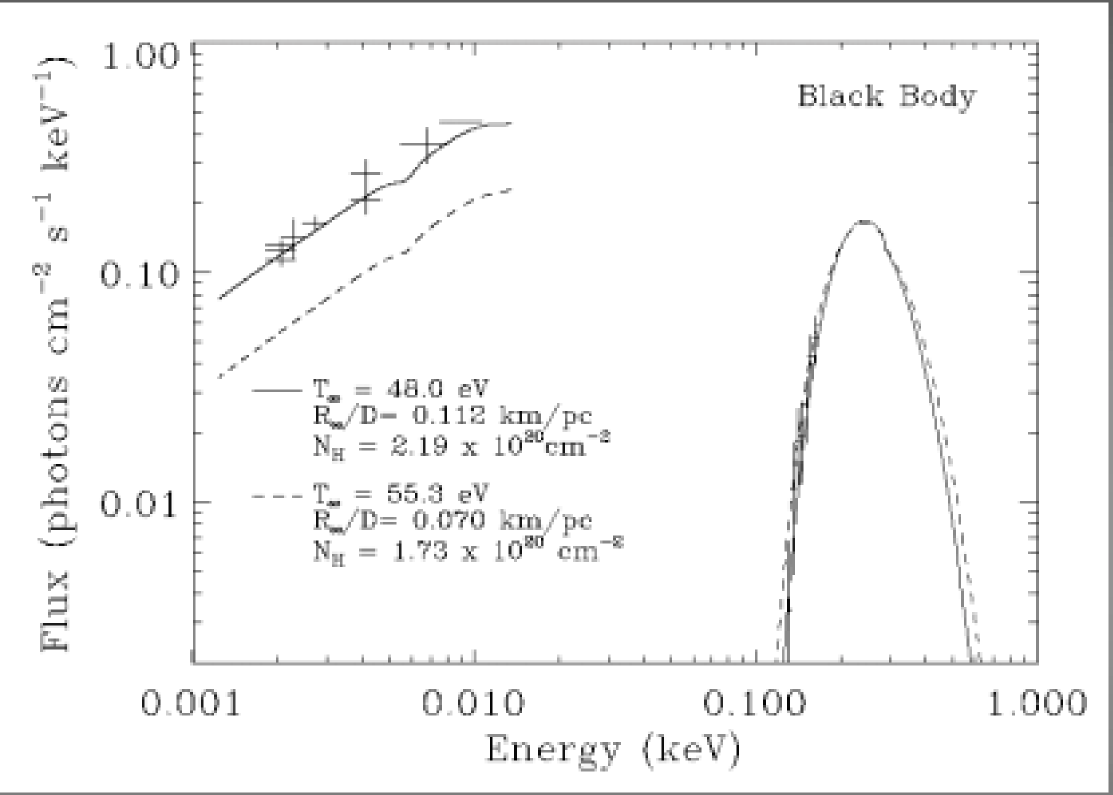
X-ray spectra: RX J1856.4-3754 (Chandra LETG)



Optical to X-rays



RX J1856.5-3754

In optical a factor ~3 brighter than extrapolation from X-rays (from ROSAT PSPC)

Pons et al. (2002)

(Factor 5-7 if LETG spectrum is used)

RX J0720.4-3125

Factor ~5

Motch & Haberl (1998)

RBS1223

Factor <5

Kaplan et al. (2001)

RX J1605.3+3249

Factor ~14

Motch et al. (2004)

RX J0420.0–5022

Factor <12

Haberl et al. (2004)

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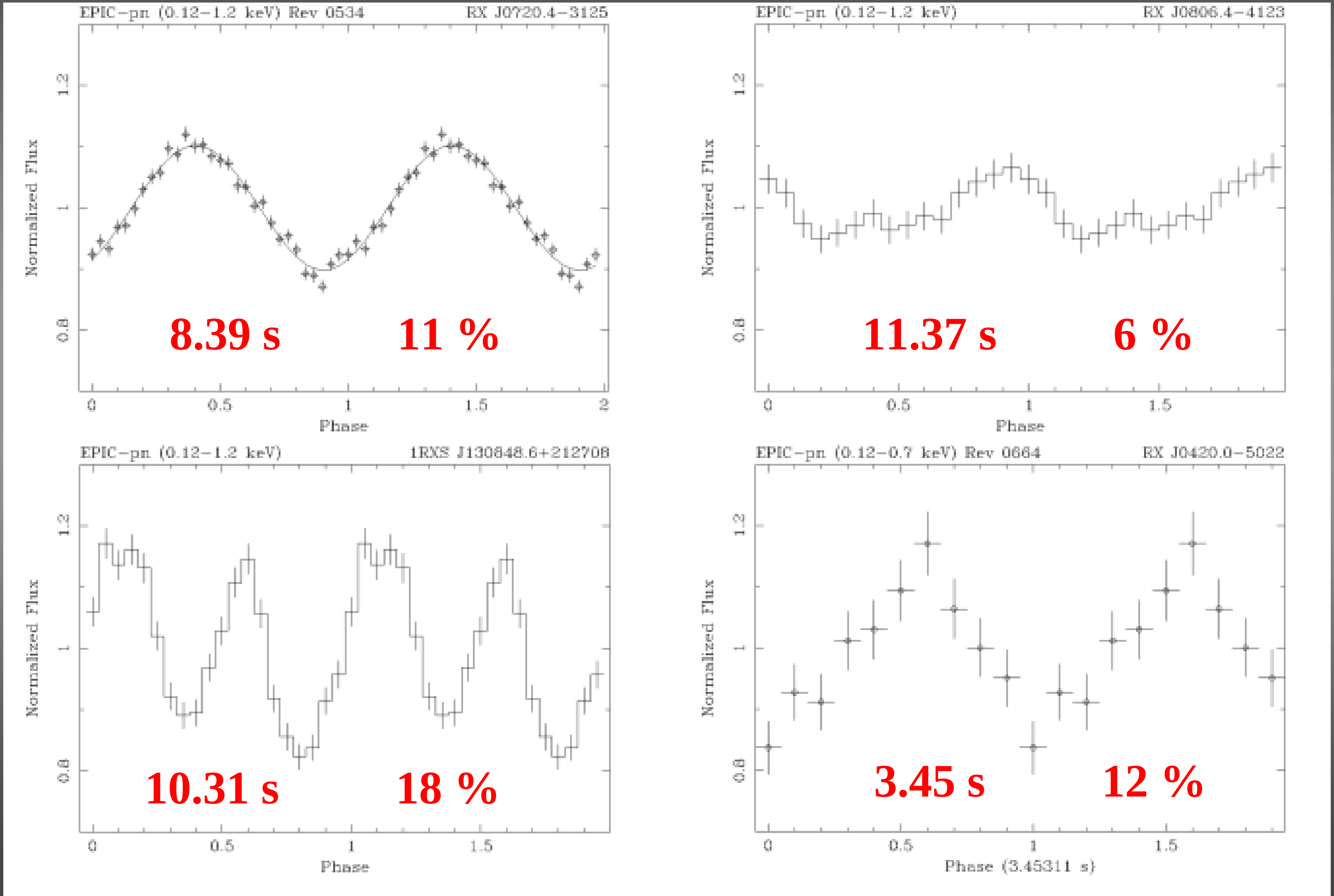
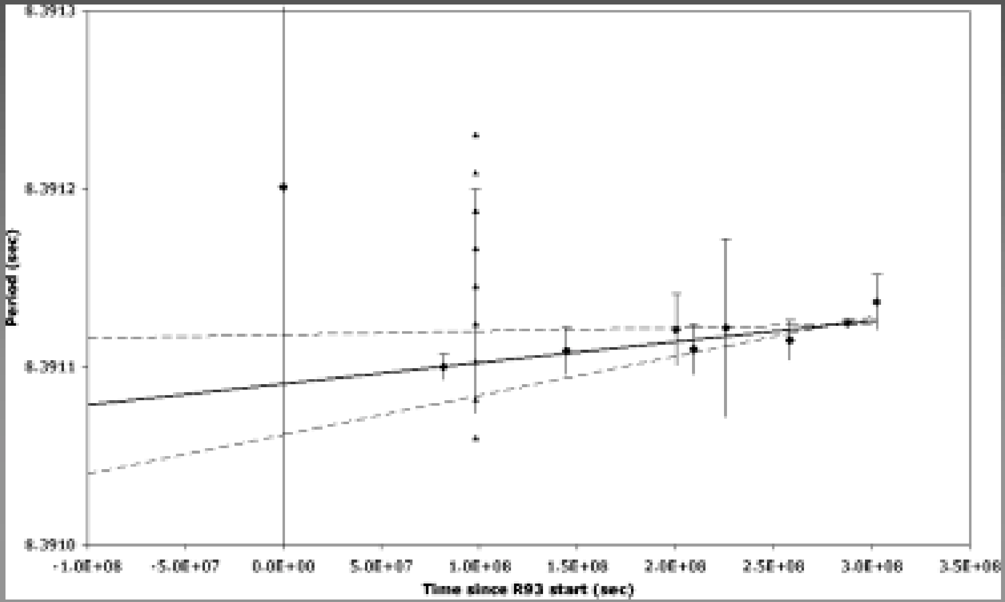
X-ray pulsations



Period changes



RX J0720.4–3125

P=8.39 s

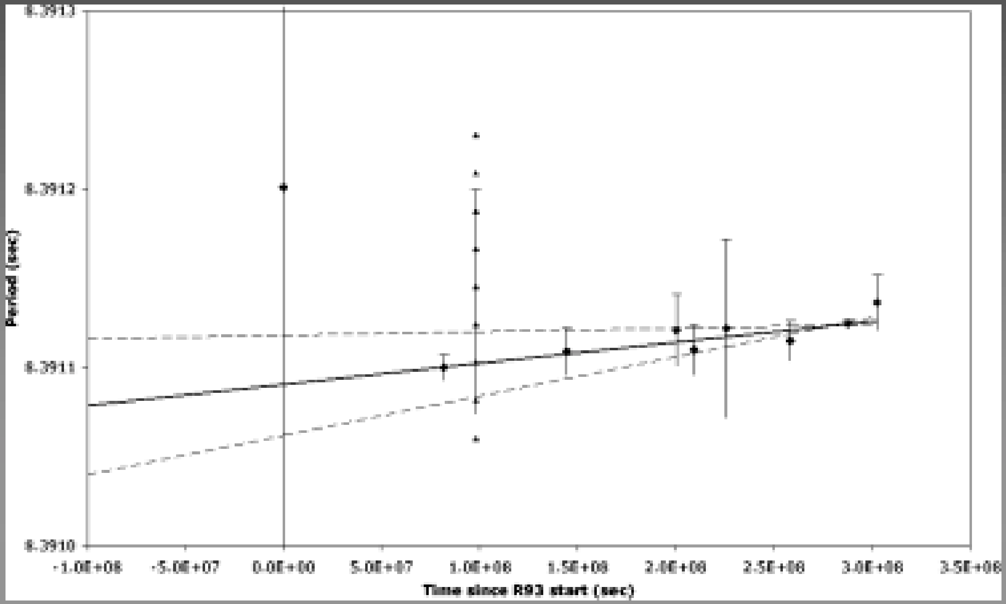
dP/dt = $(1.4 \pm 0.6) \times 10^{-13}$ s s^{-1}(99%)

τ = P/2(dP/dt) = (0.6-1.5) x 10^6 y

B = (2.8-4.2) x 10^{13} G

Cropper et al. (2004) submitted

Period changes



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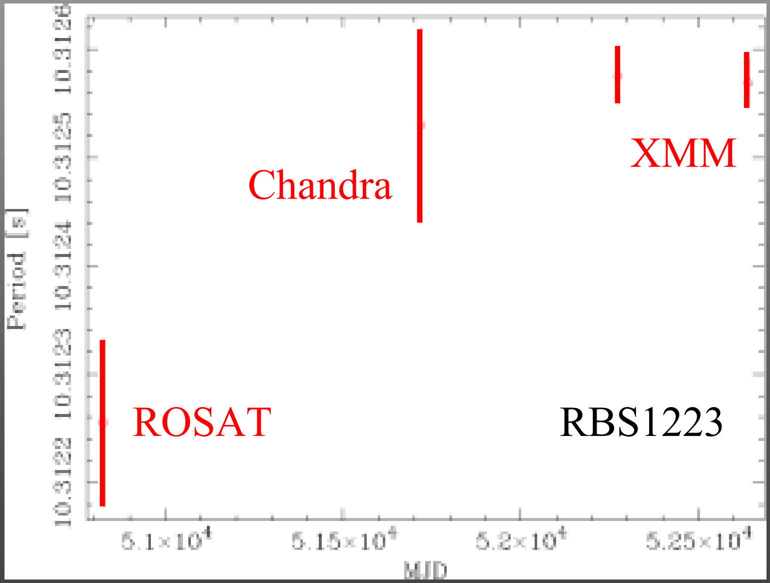
Upper limits for dP/dt

RX J0806.4–4123: < 1.8 x 10^{-12} s s^{-1}

RX J0420.0–5022: < 9.2 x 10^{-12} s s^{-1}

RBS1223: < 6 x 10^{-12} s s^{-1} (non-monotonous?)



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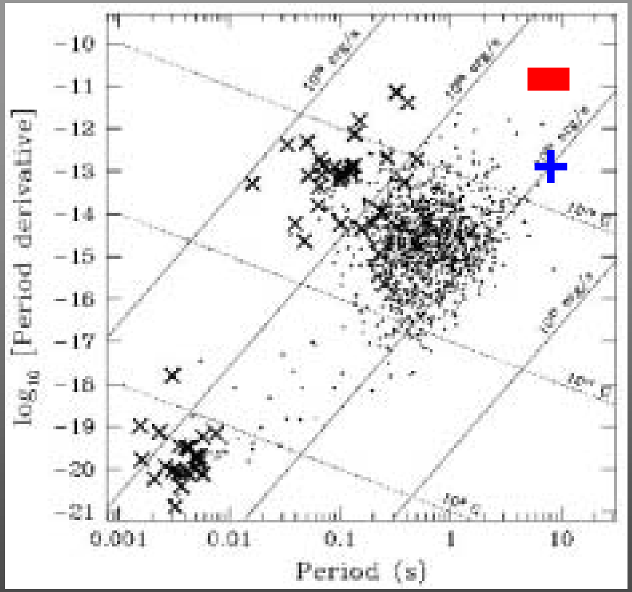
Isolated Neutron Stars

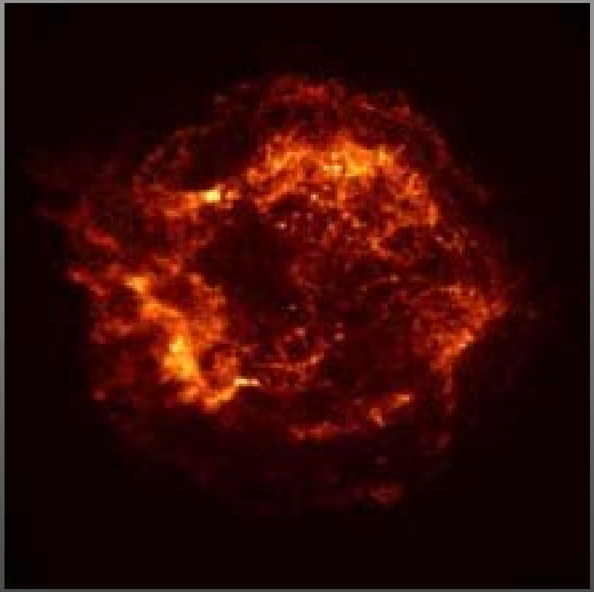
1400 Radio Pulsars

14 Soft Gamma Repeaters and Anomalous X-ray Pulsars

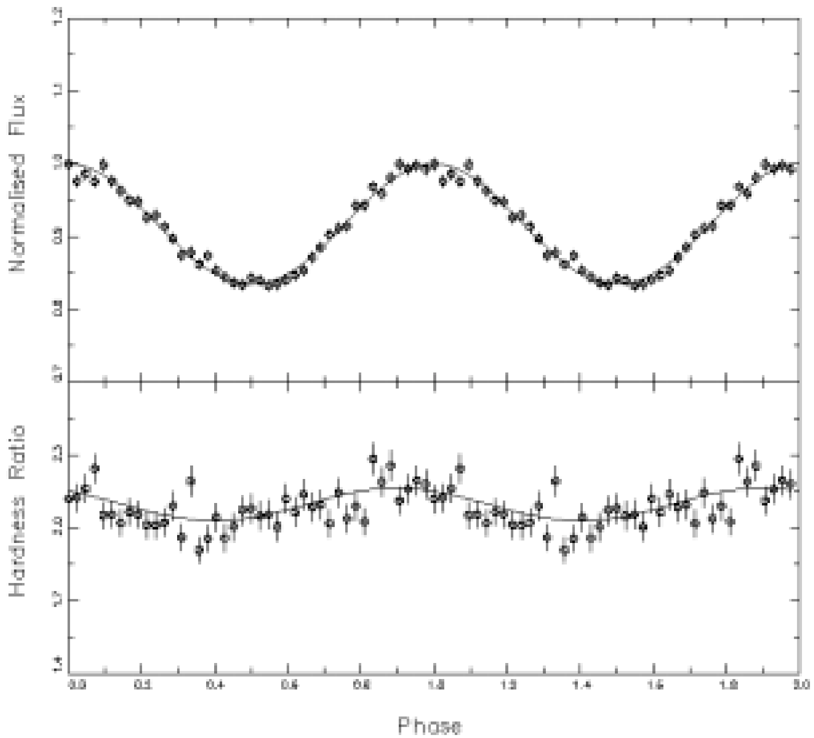
5 Central Compact Objects in SNRs

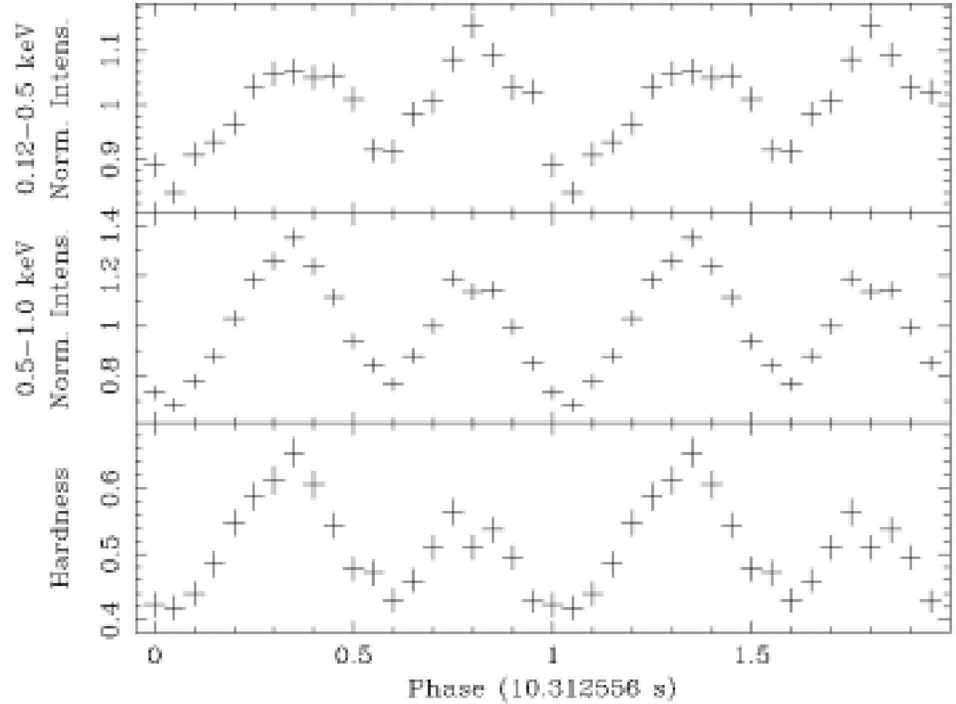
+ 7 X-ray dim thermal neutron stars





Spectral variations with pulse phase





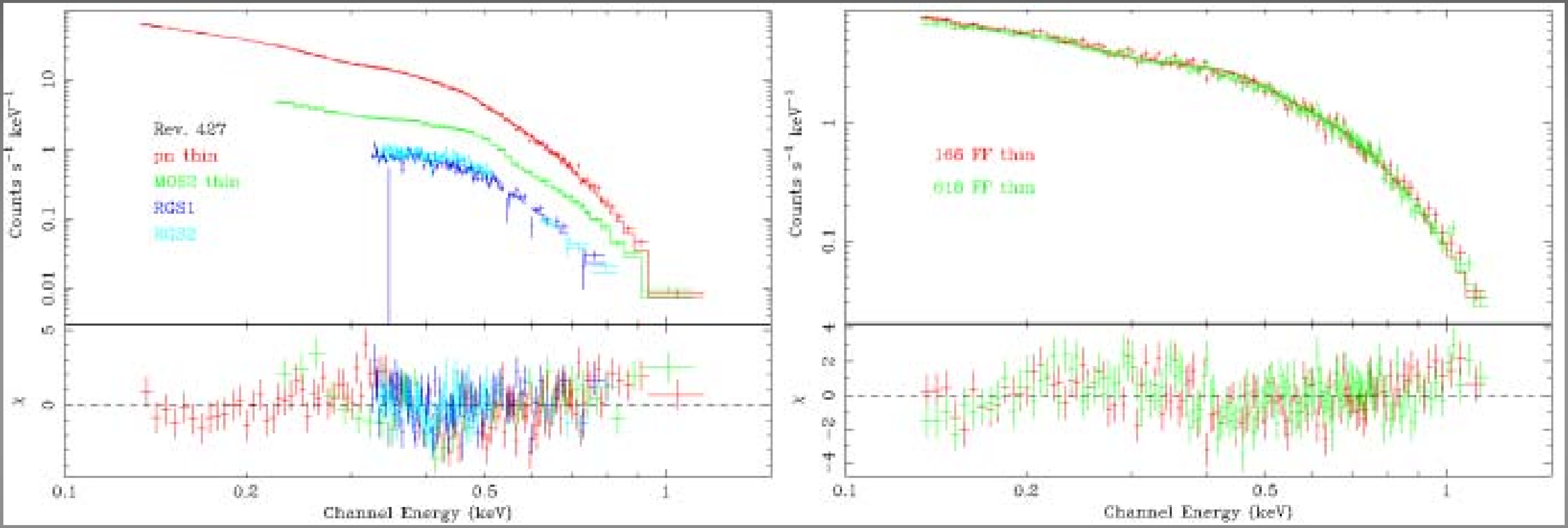
RX J0720.4-3125 (8.39 s)

Cropper et al. (2001)

RBS 1223 (10.31s)

Haberl et al. (2003)

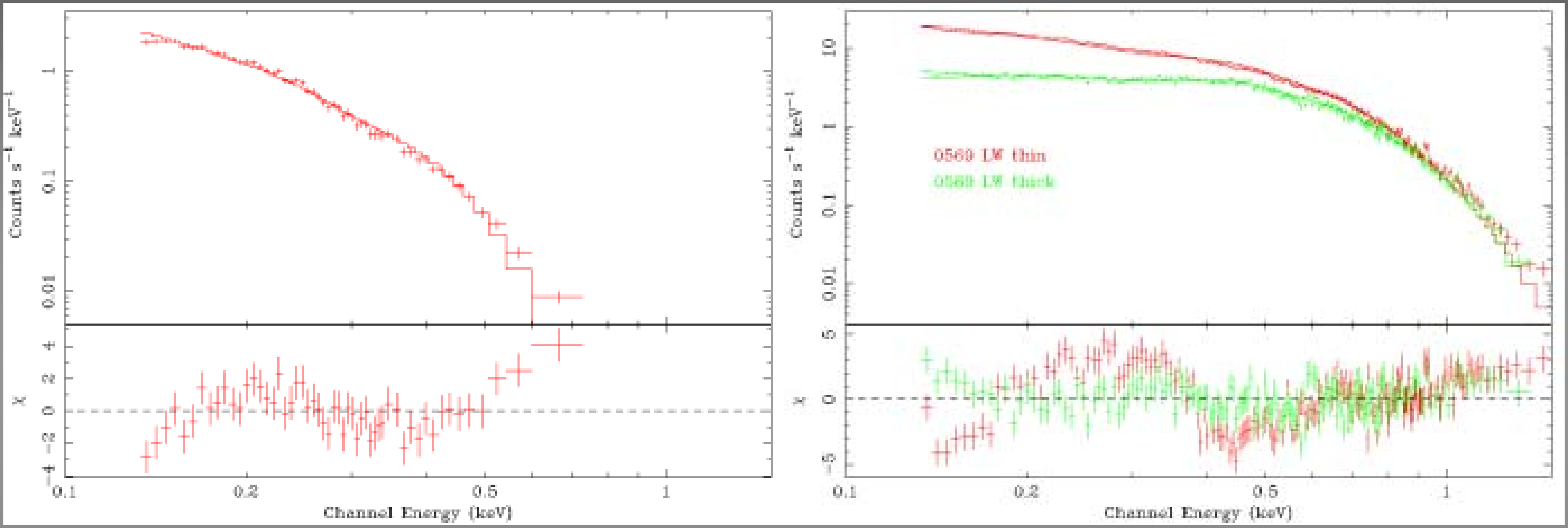
XMM-Newton: X-ray spectra



RX J1856.5-3754
kT = 60 eV
N_H = 8.7 x 10^{19} cm^{-2}

RX J0806.4-4123
kT = 96 eV
N_H = 2.8 x 10^{19} cm^{-2}

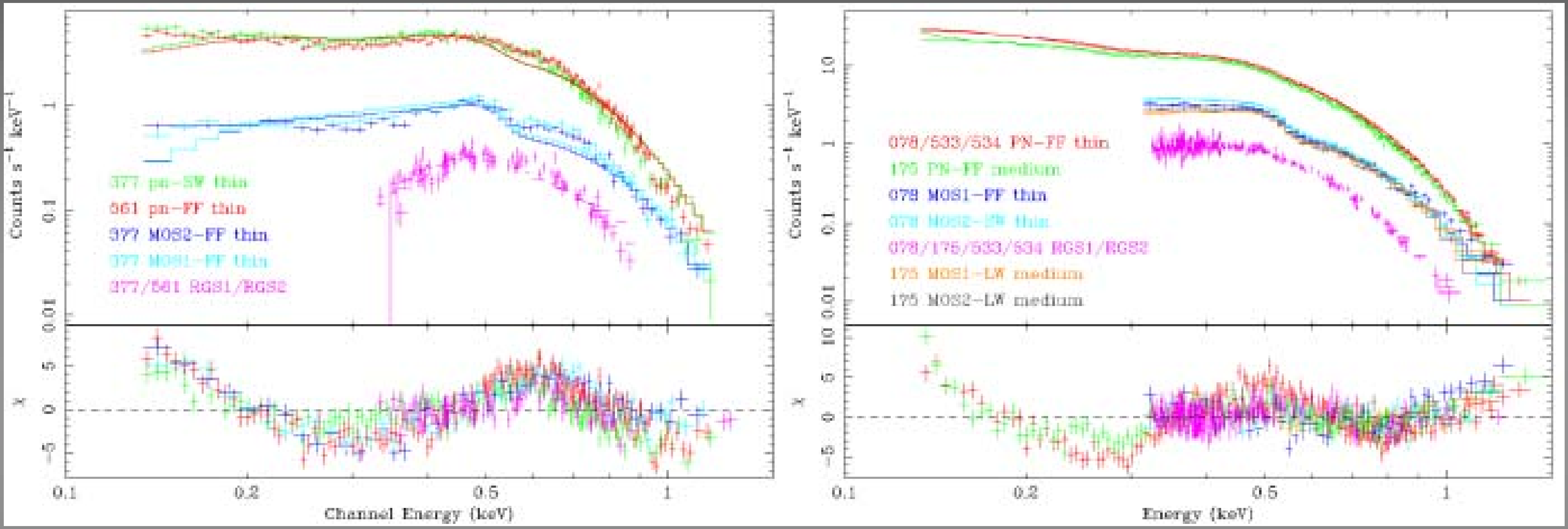
XMM-Newton: X-ray spectra



RX J0420.0-5022
kT = 45 eV
N_H = 1.0 x 10^{20} cm^{-2}

RX J1605.3+3249
kT = 96 eV
N_H = 2.7 x 10^{19} cm^{-2}

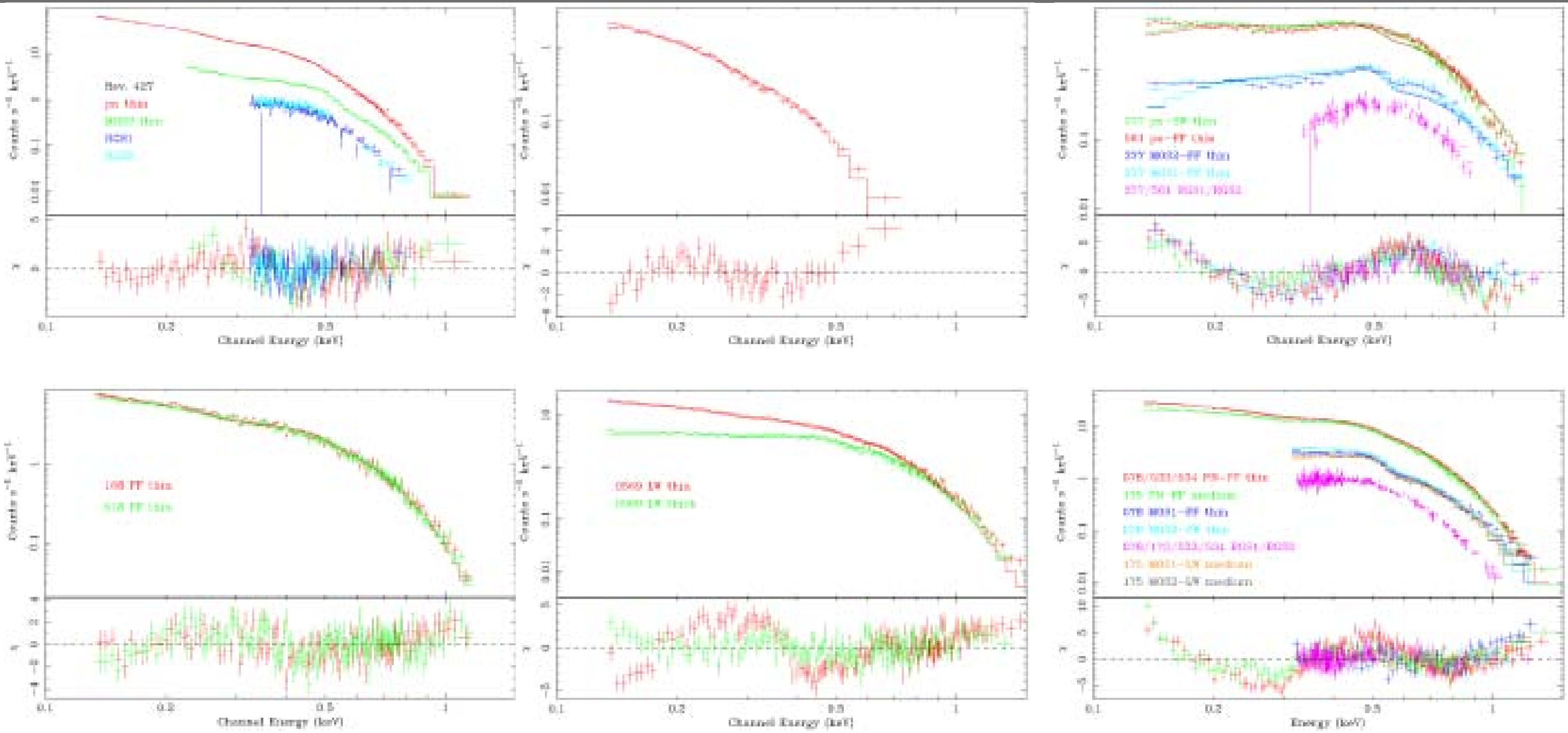
XMM-Newton: X-ray spectra



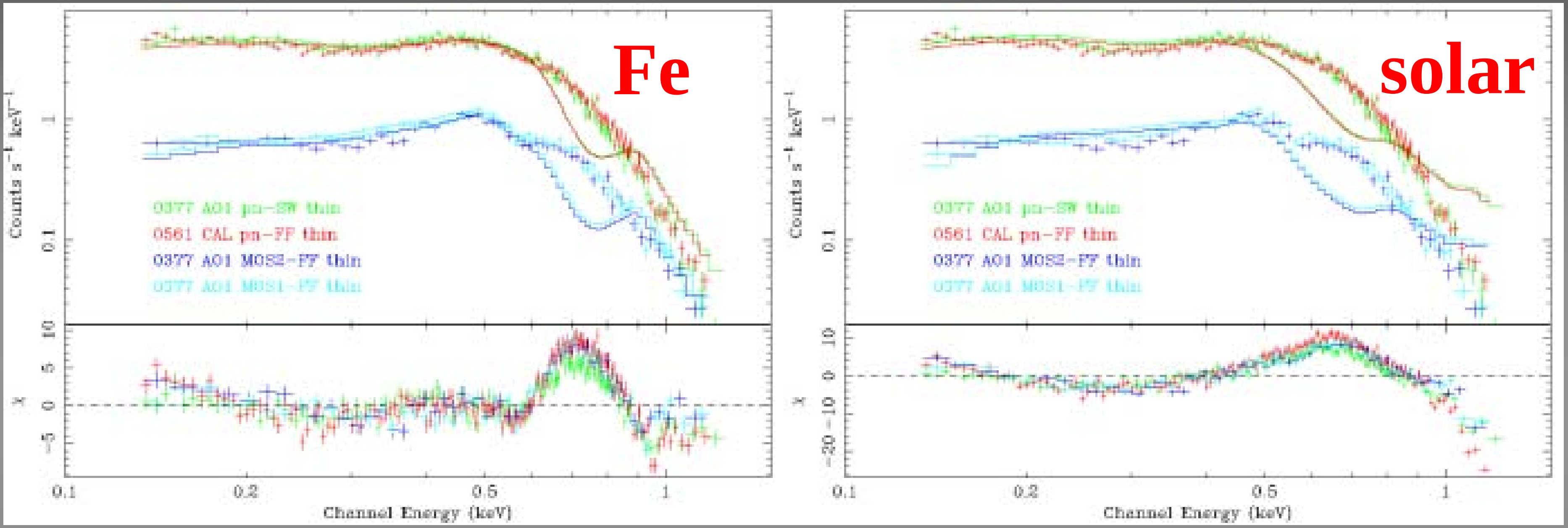
RBS1223
kT = 95 eV
$N_H = 7.1 \times 10^{20}$ cm^{-2}

RX J0720.4-3125
kT = 86 eV
$N_H = 1.3 \times 10^{20}$ cm^{-2}

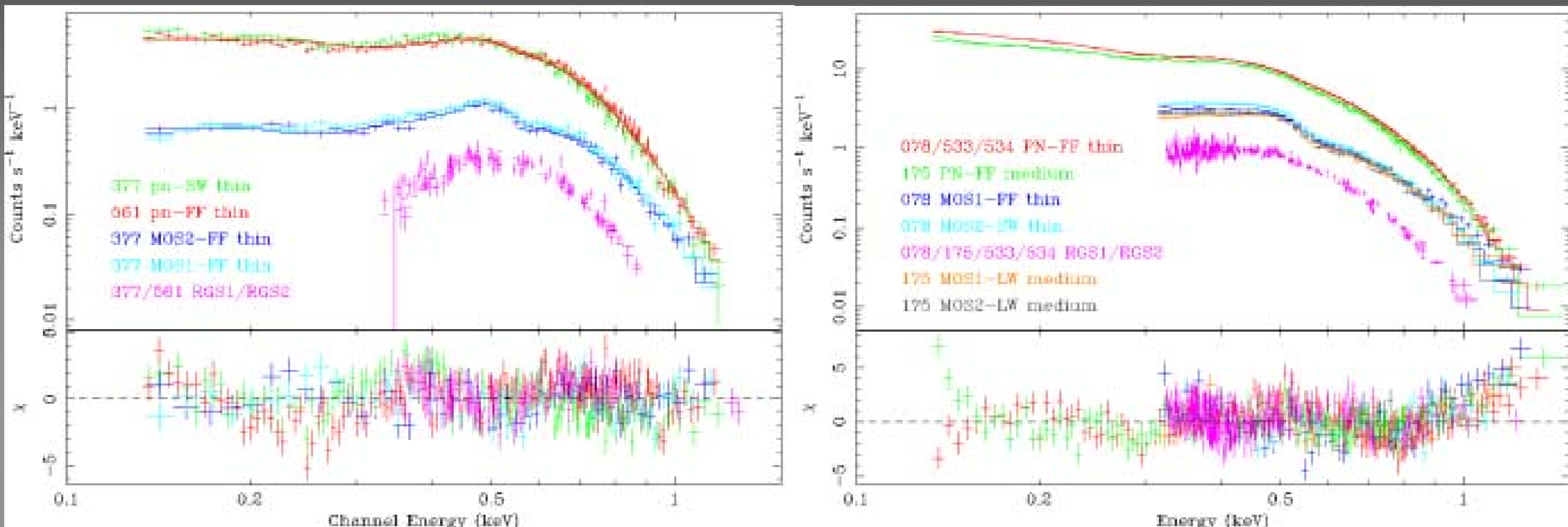
X-ray spectral survey: black-body fits



RBS1223: non-magnetic atmosphere models



X-ray spectral survey: absorption feature



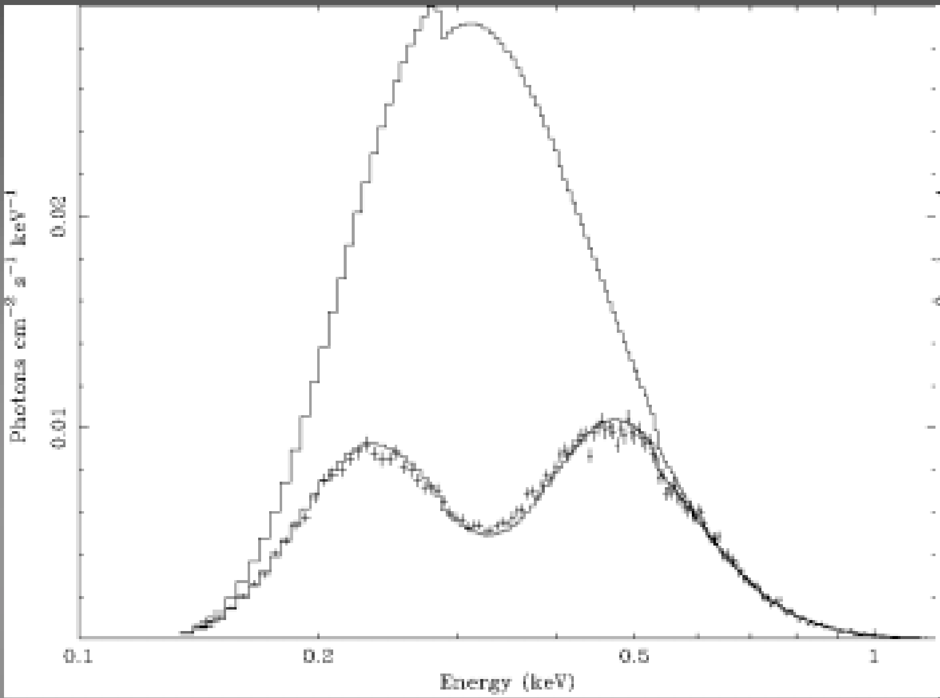
RBS1223
kT = 95 eV
N_H = 7.1 x 10^{20} cm^{-2}
E_{line} ~ 300 eV
σ ~ 100 eV
EW = 150 eV

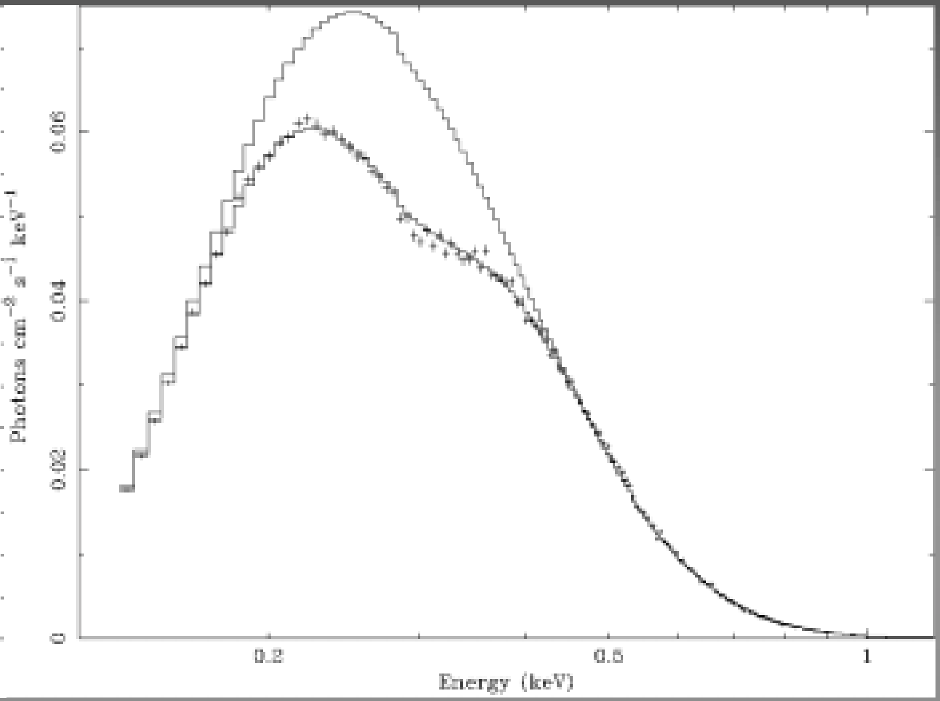
Haberl et al. (2003)

RX J0720.4-3125
kT = 85 eV
N_H = 9 x 10^{19} cm^{-2}
E_{line} = 271 $\pm$ 14 eV
σ = 66 $\pm$ 7 eV
EW = 40 eV

Haberl et al. (2003) submitted

X-ray spectral survey: absorption feature



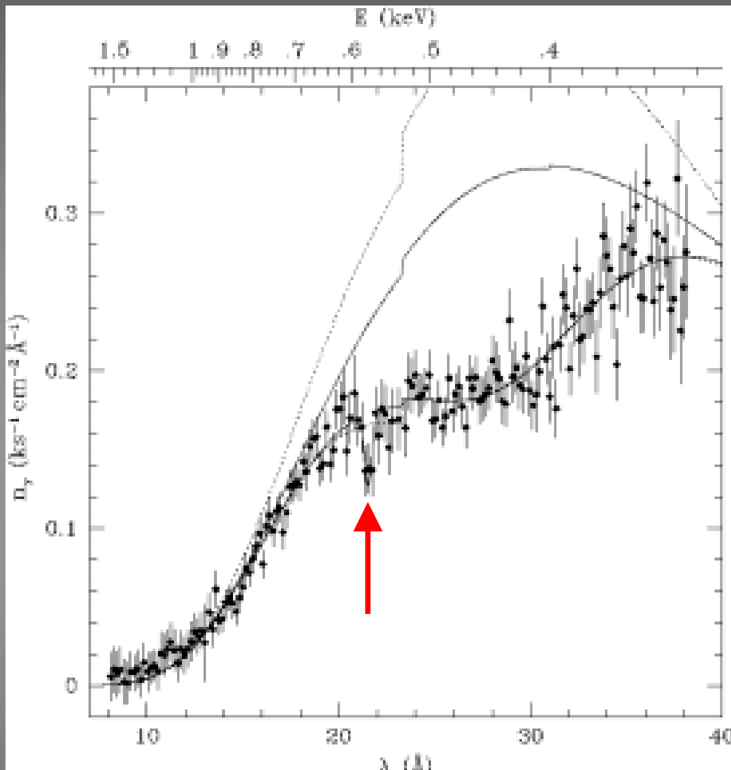


RBS1223
EW = 150 eV

RX J0720.4-3125
EW = 40 eV

X-ray spectral survey: absorption feature

RX J1605.3+3249



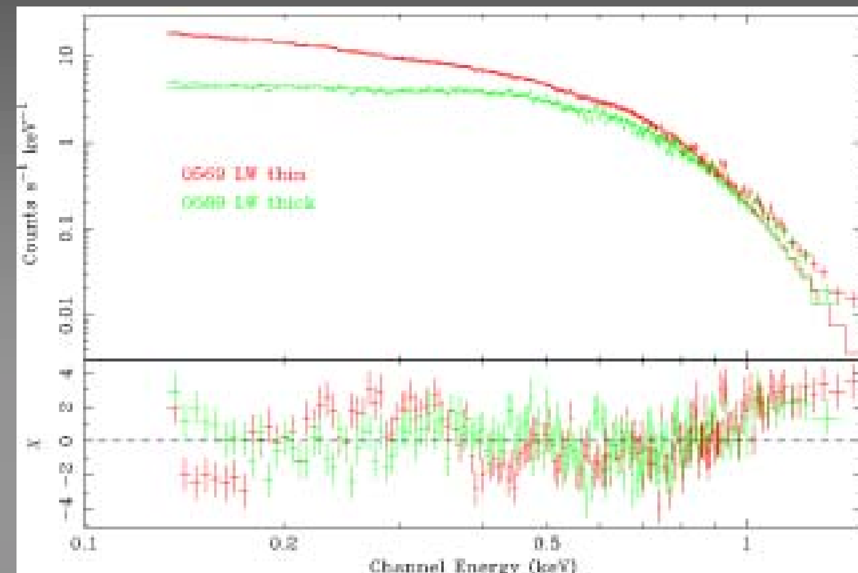
RGS

kT = 95 eV

N_H = 0.8 x 10^{20} cm^{-2}

E_{line} = 450 – 480 eV

Van Kerkwijk et al. (2003) submitted



EPIC

kT = 92 eV

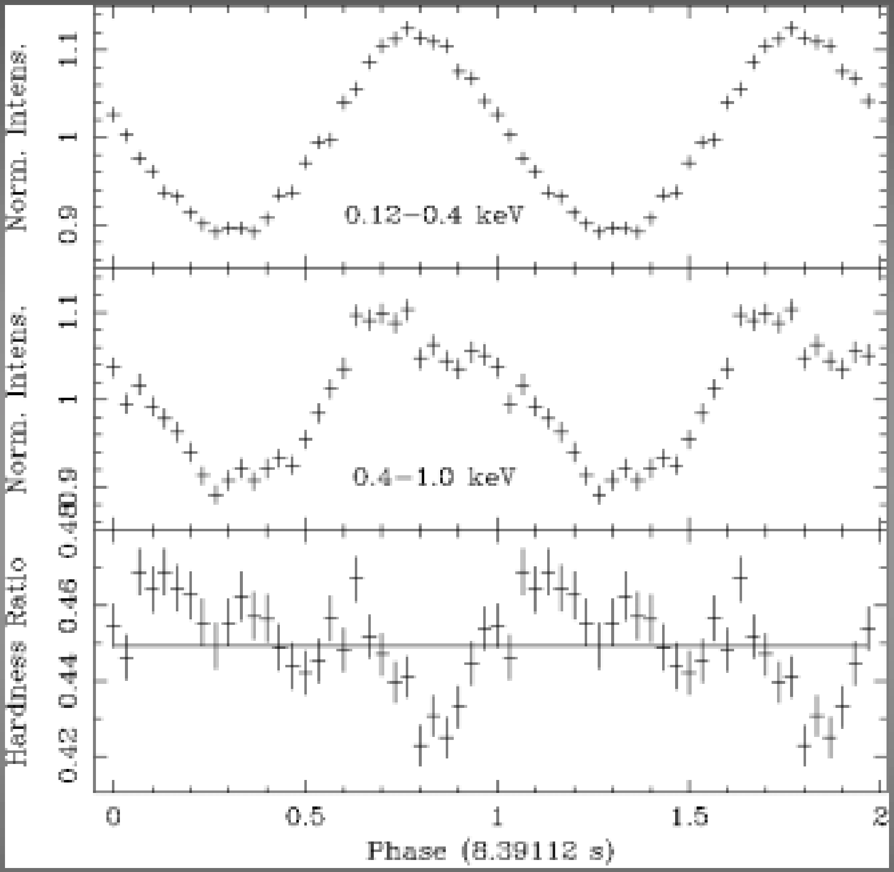
N_H = 1.0 x 10^{20} cm^{-2}

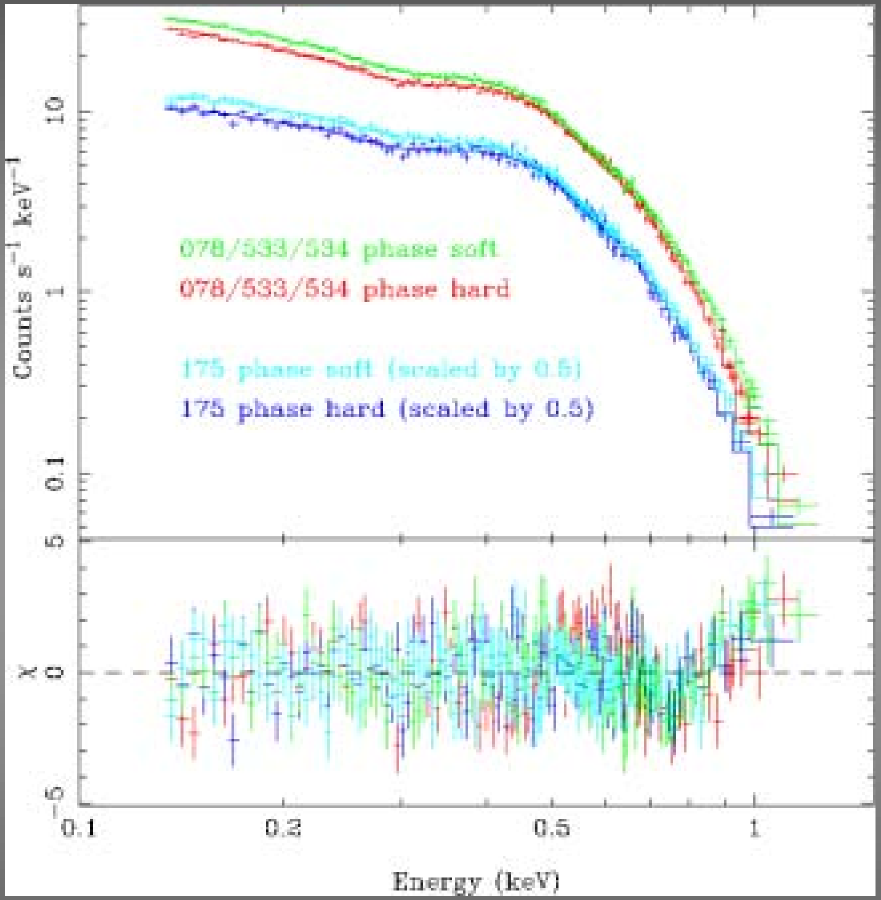
E_{line} ~ 450 eV

σ ~ 70 eV

EW = 37 eV

RX J0720.4-3125: Variation of absorption line with pulse phase



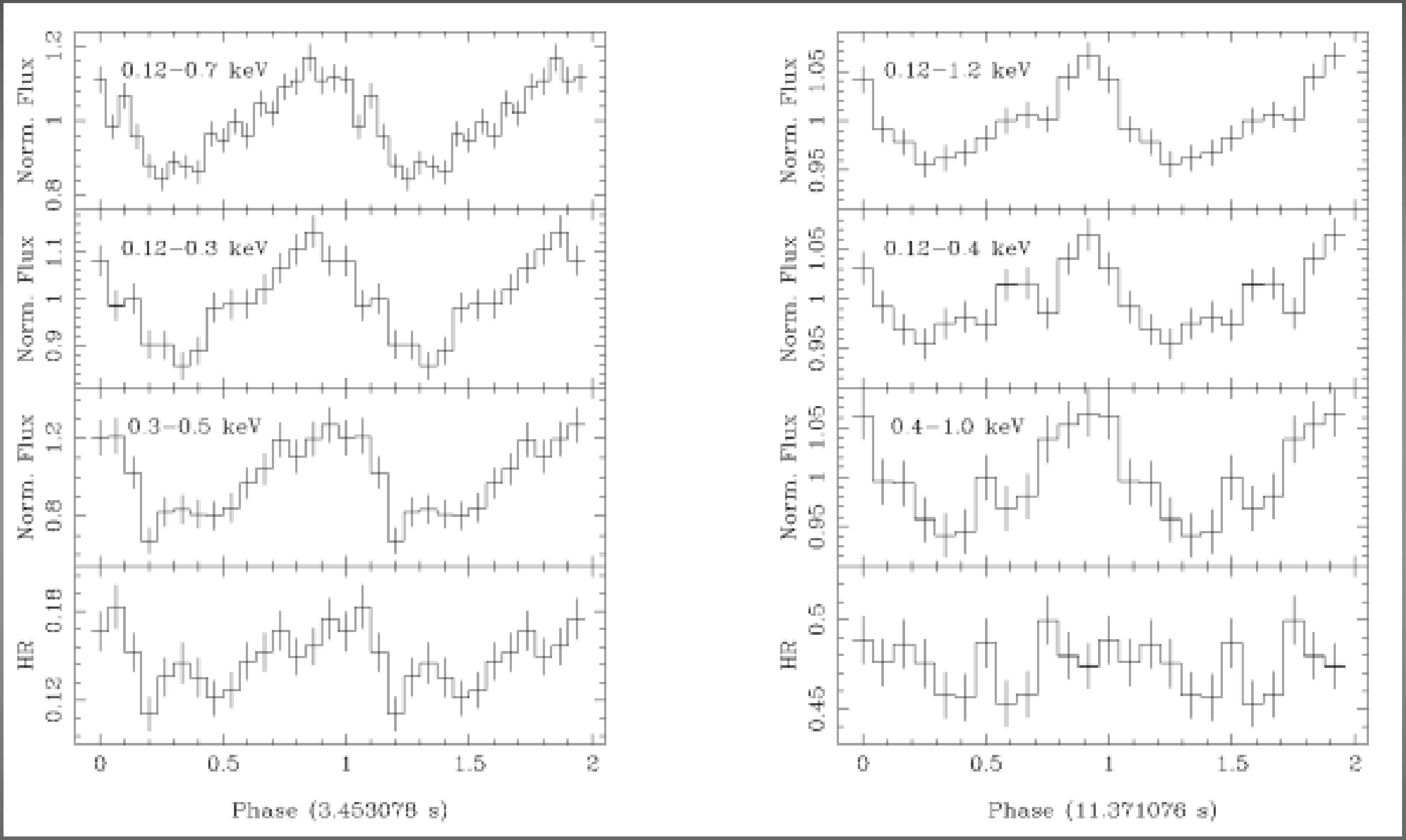


Absorption line equivalent width varies between 30 eV to 60 eV.

Small temperature variations by 2-3 eV.

Haberl et al. (2003) submitted

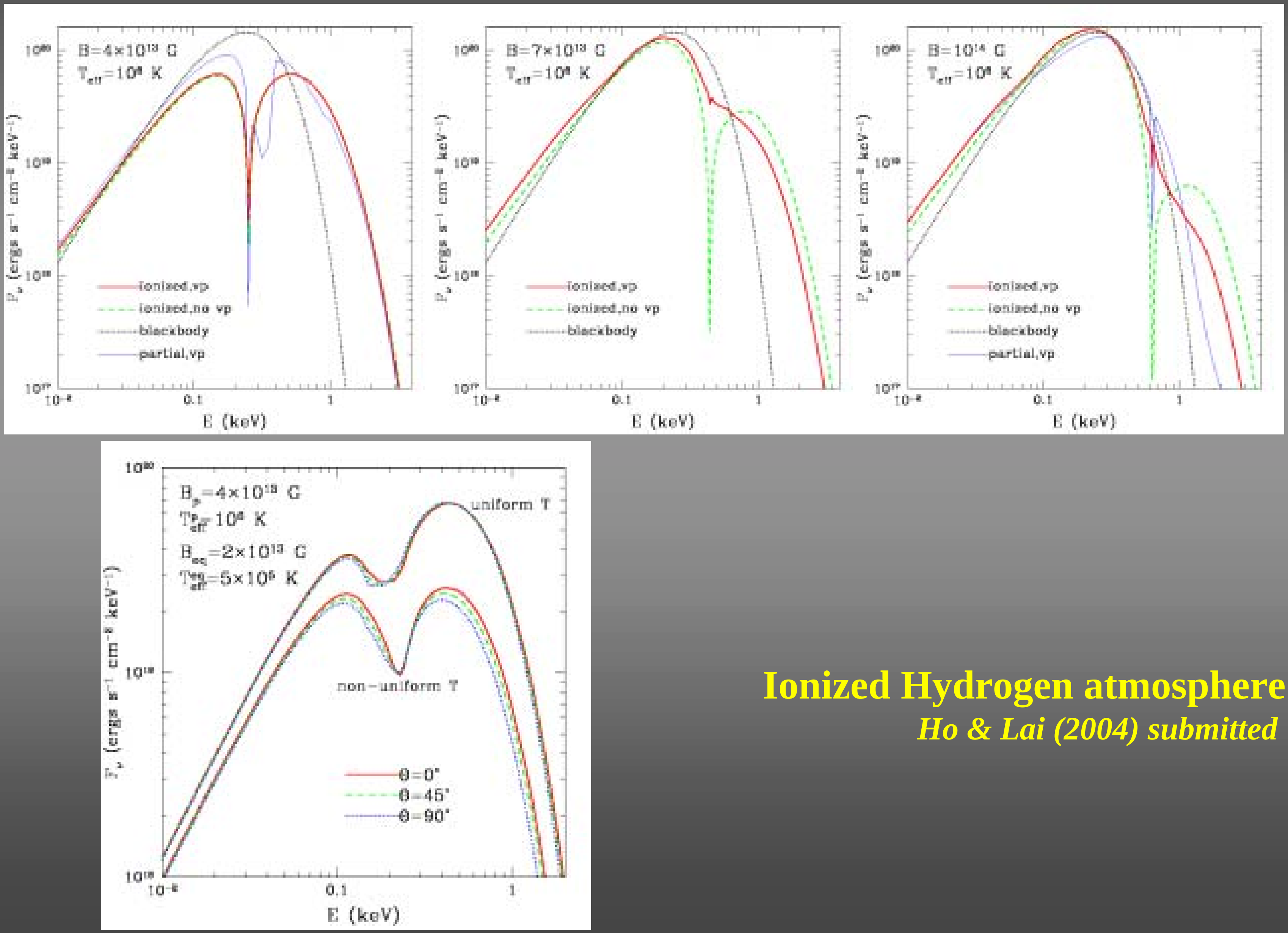
Hardness ratio variations with pulse phase



RX J0420.0-5022 RX J0806.4-4123

Haberl et al. (2004) in preparation

Proton cyclotron absorption ?



Ionized Hydrogen atmosphere

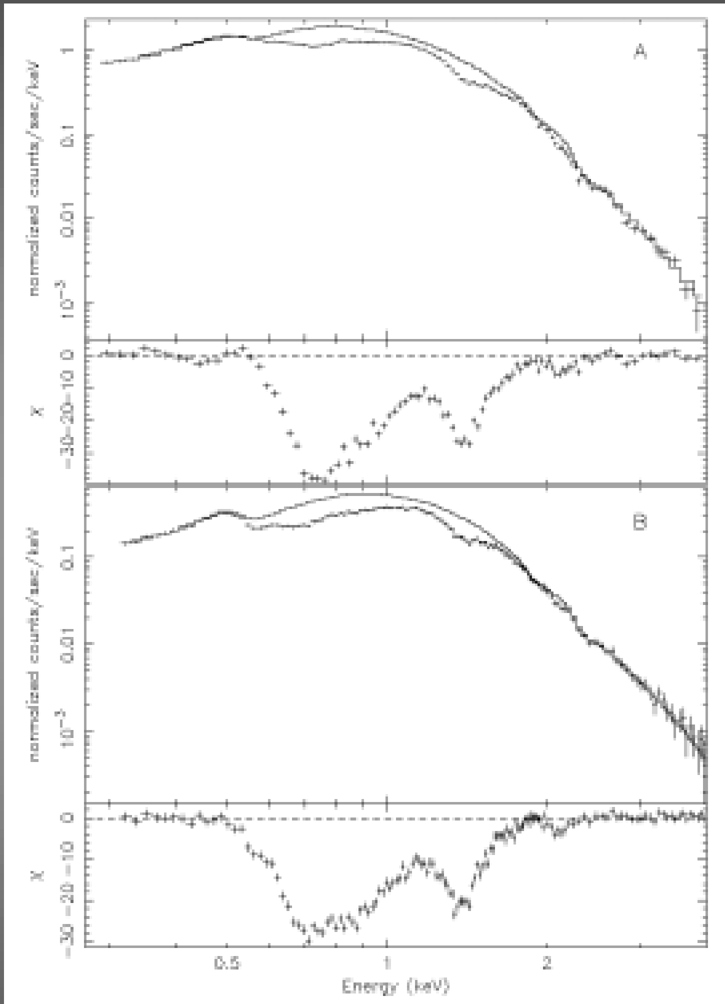
Ho & Lai (2004) submitted

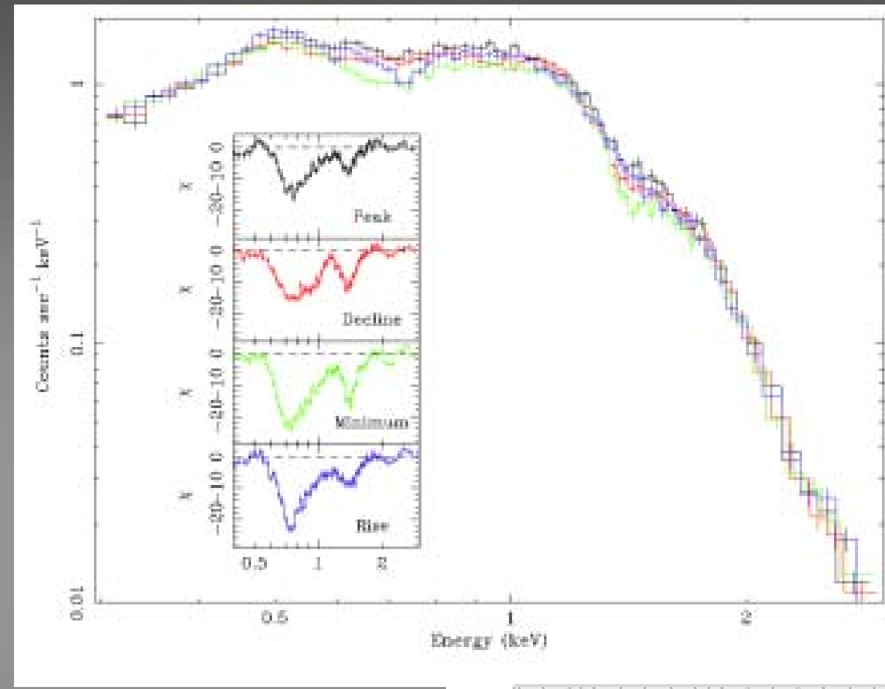
Magnetic fields

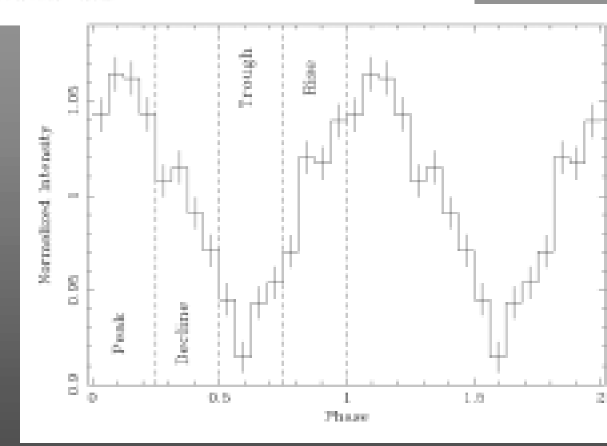
- Magnetic dipole breaking
- Proton cyclotron absorption

Object	P [s]	dP/dt [10^{-13} ss^{-1}]	E_{cyc} [eV]	B_t / B_{cyc} [10^{13} G]
RX J0420.0–5022	3.45	<92	329	< 18 / 6.6
RX J0720.4–3125	8.39	(1.4 ± 0.6)	262	2.8 – 4.2 / 5.2
RX J0806.4–4123	11.37	<18	?	< 14 /
1RXS J13048.6+212708	10.31	<60	100 – 300	< 25 / 2–6
RX J1605.3+3249	–	–	450 – 480	/ 9.1–9.7
RX J1856.5–3754	–	–	?	~ 1

The case of 1E 1207.4 - 5209



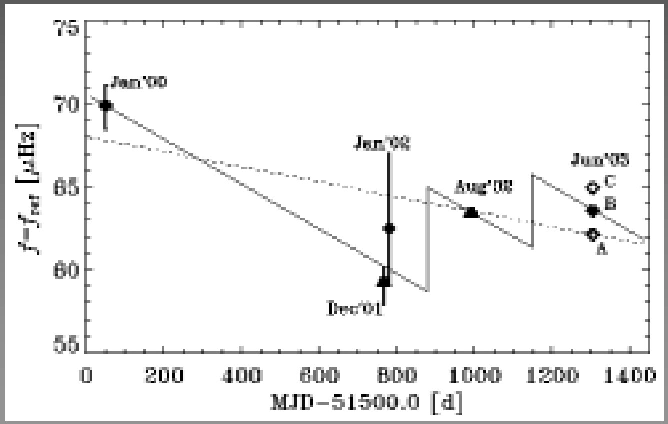


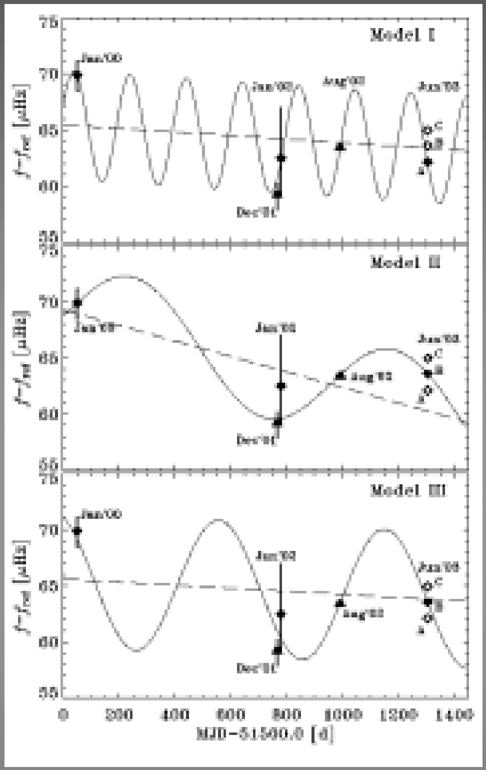


Absorption lines @
0.68 keV, 1.36 keV, 2.14 keV and 2.83 keV

Bignami et al. (2003)

The case of 1E 1207.4 - 5209

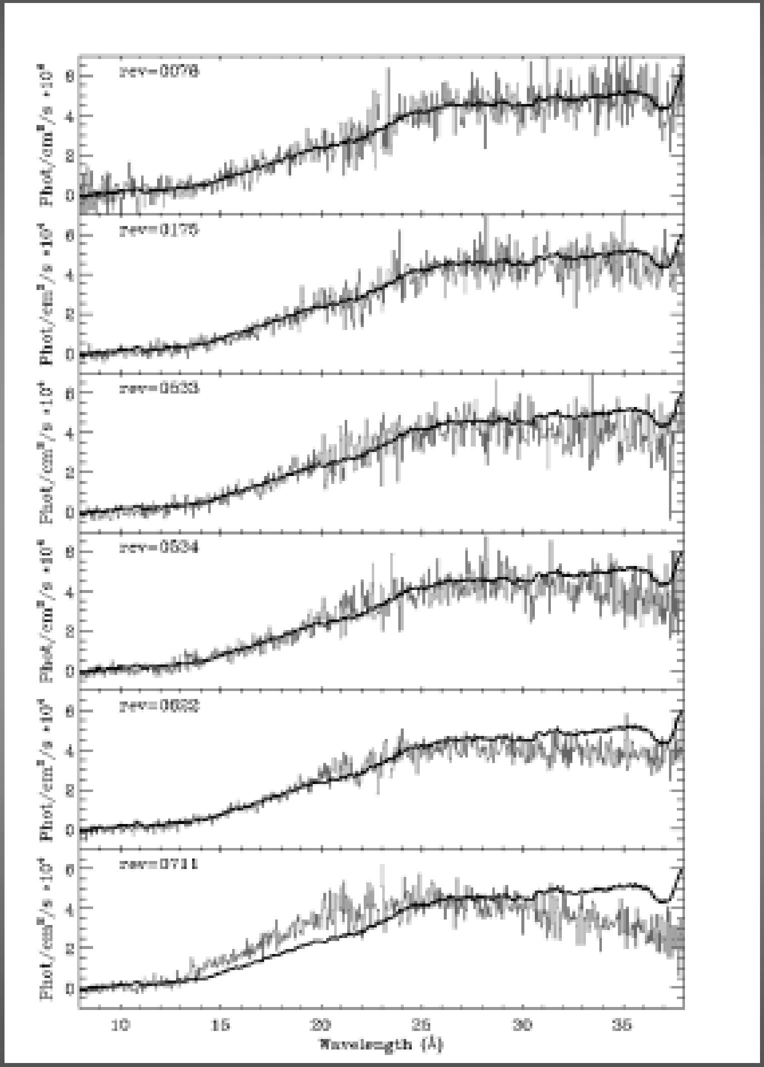


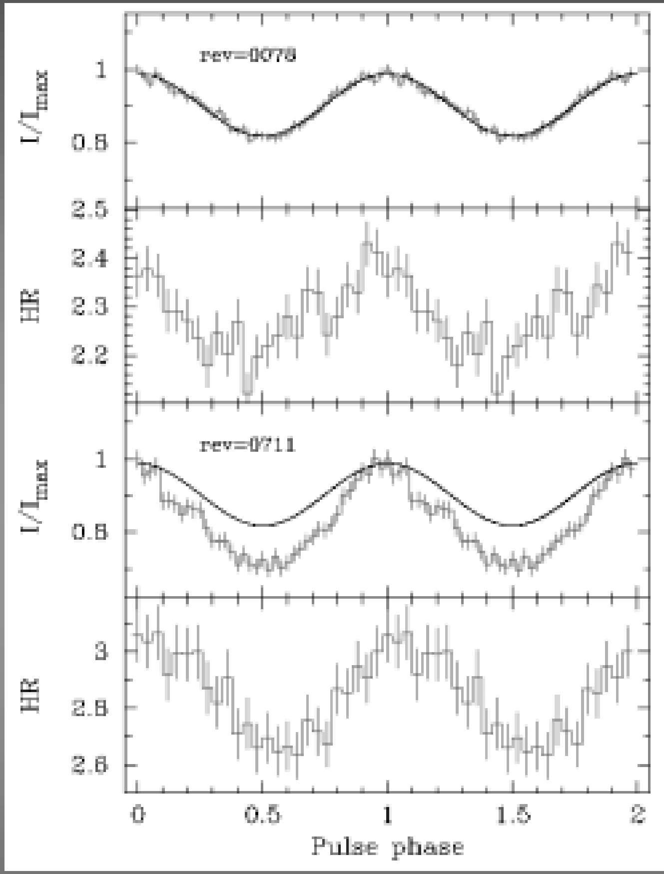


Non-monotonous period changes
Glitching pulsar?
Accretion from disk?
Wide binary system?

Zavlin et al. (2004)

Long term spectral changes from RX J0720.4-3125





Precession of the neutron star?

de Vries et al. (2004)

X-ray dim (thermal) Isolated Neutron Stars

Summary

$F_x/F_{opt} > 10^4$ → Isolated neutron stars

High proper motion → Young cooling NSs

Period changes + absorption features → Magnetic fields $10^{13\text{-}14}$ G

- **Features compatible with proton cyclotron absorption**
  - **Atomic transition lines?**
  - **Difference to 1E 1207.4-5209?**
- **Pulsations**
  - **Large pulsed fractions difficult to exlain by temperature variations**
  - **Why RX J1856.4-3754 no pulsations, no absorption feature?**
- **Spectral energy distribution**
  - **Optical excess?**