

*X-ray dim isolated neutron stars:  
What do we know?*

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MPE Garching*

*Multiwavelength Approach of Neutron Stars and Supernova Remnants*

*MPIfR / MPE Pulsar Meeting – 24-25 April 2003 – MPIfR Bonn*

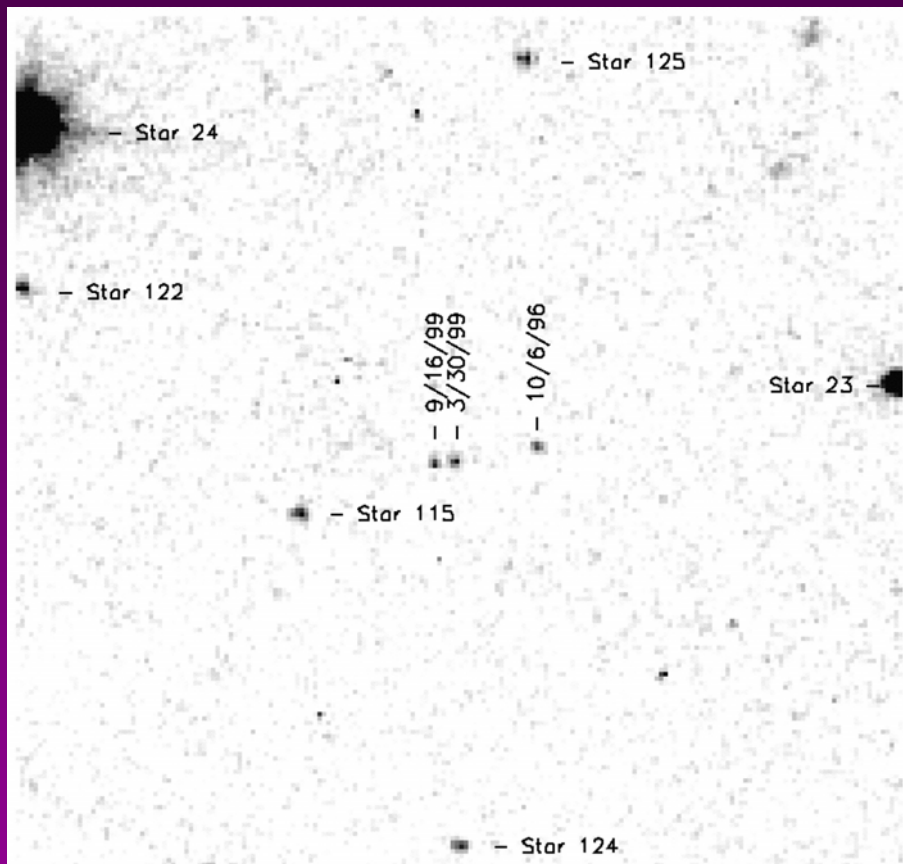
## *X-ray Dim Isolated Neutron Stars (XDINS)*

- **Bright, soft X-ray sources in ROSAT survey**
- **Blackbody-like spectra, no non-thermal hard emission**
- **Low absorption, nearby**
- **Constant X-ray flux**
- **No radio emission ?**
- **No obvious association with SNR**
- **Some are X-ray pulsars (8.39 – 11.37 s)**

Object	kT/eV	$L_x/\text{erg s}^{-1}$	d/pc	Opt.	Comment
RX J0420.0–5022	46	$2.7 \times 10^{30}$	100	B > 25.5	
RX J0720.4–3125	85	$2.6 \times 10^{31}$	100	B = 26.6	
RX J0806.4–4123	96	$5.7 \times 10^{30}$	100	B > 24	
1RXS J13048.6+212708	86	$5.1 \times 10^{30}$	100	$m_{50\text{ccd}} = 28.6$	RBS1223
RX J1605.3+3249	96	$1.1 \times 10^{31}$	100	B > 27	RBS1556
RX J1856.5–3754	60	$1.5 \times 10^{31}$	117	V = 25.7	
1RXS J214303.7+065419	(90)	$1.1 \times 10^{31}$	100	R > 23	RBS1774
RX J1836.2+5925 ?	(43)	$5.4 \times 10^{30}$	400	V > 25.2	variable ?

*Frank Haberl*

# Optical identifications *RX J1856.5-3754*



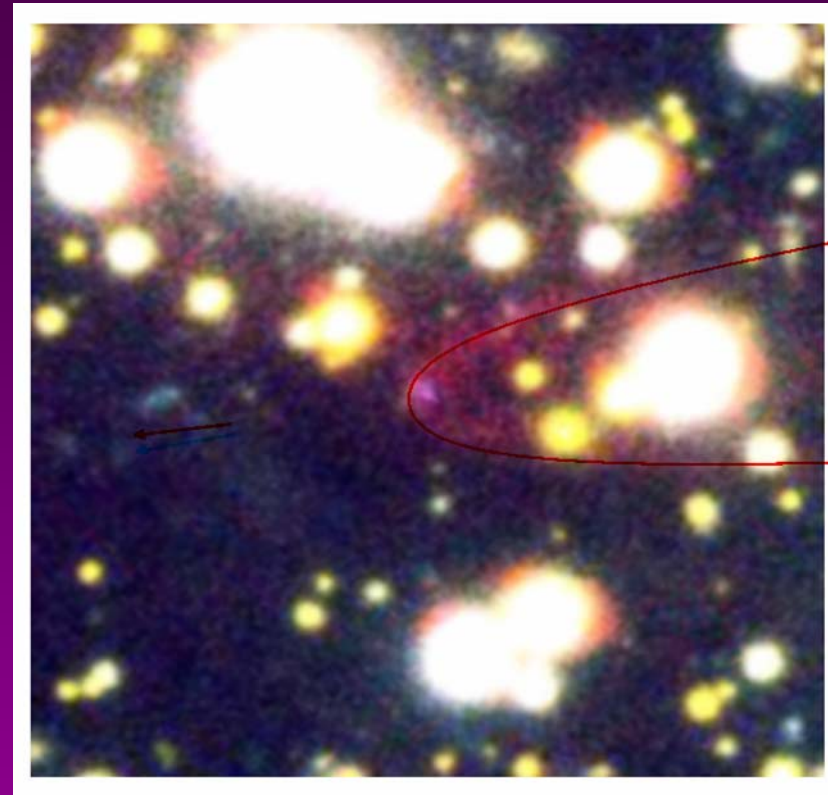
Distance  $117 \pm 12$  pc

HST

Proper motion  $332 \text{ mas y}^{-1}$

Tangential space velocity  $185 \text{ km s}^{-1}$

*Walter (2001); Walter & Lattimer (2002)*

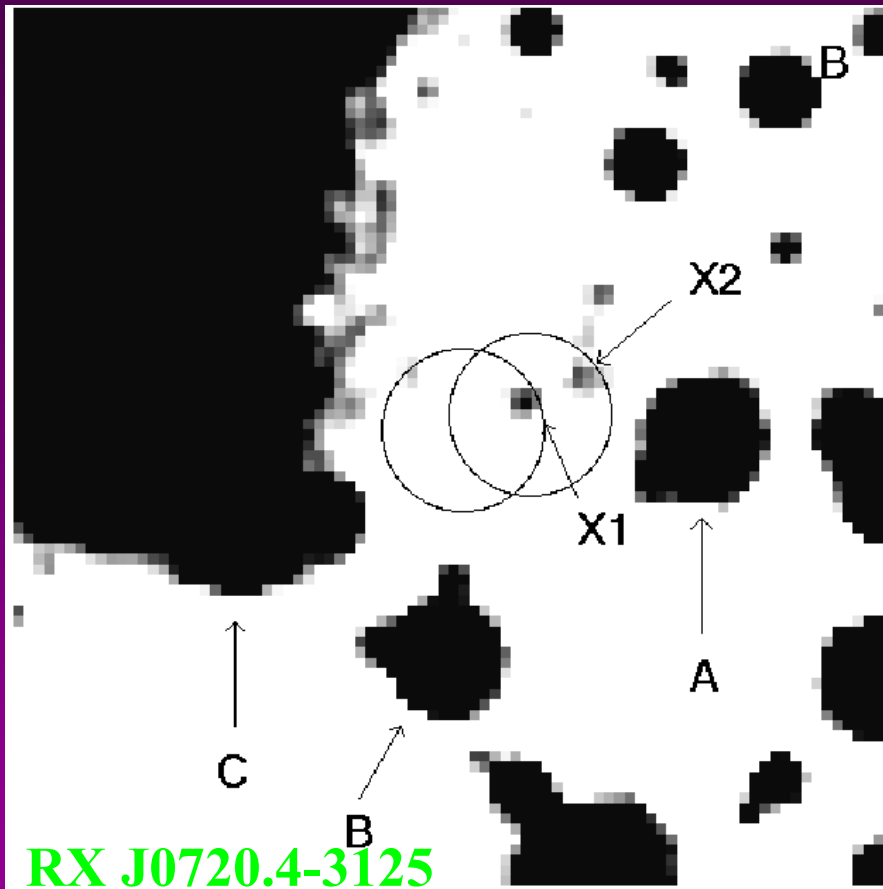


Bowshock Nebula

VLT

*Kerkwijk & Kulkarni (2001)*

# Optical identifications

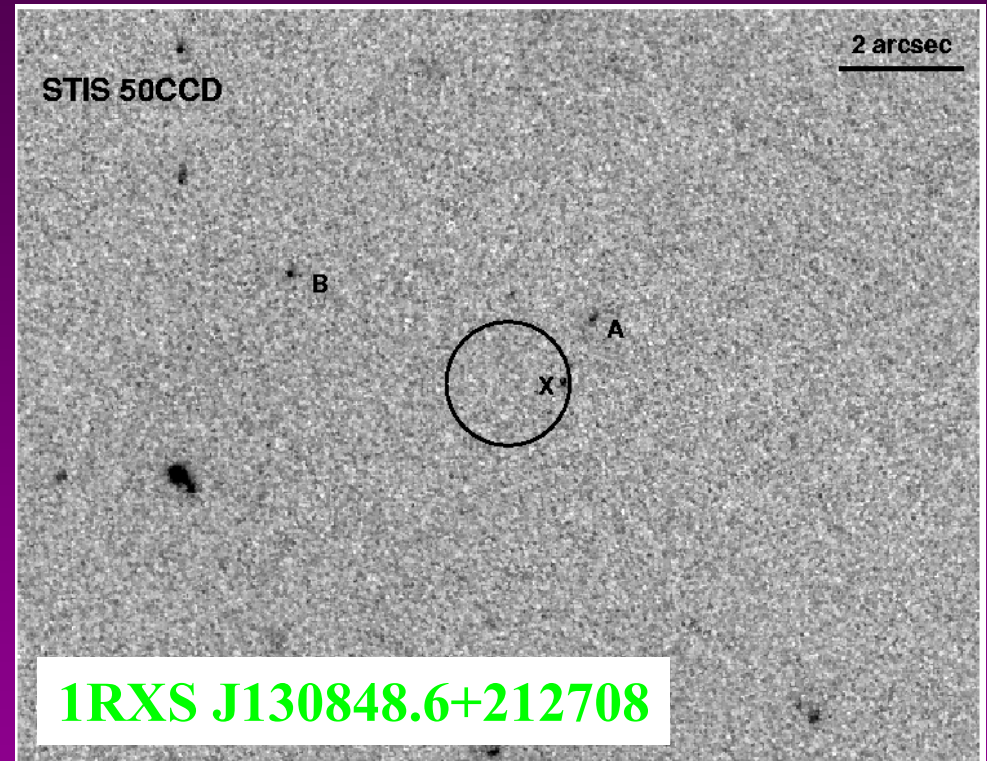


*Motch & Haberl (1998)*

*Kulkarni & van Kerkwijk (1998)*

Proper motion  $100 \text{ mas y}^{-1}$

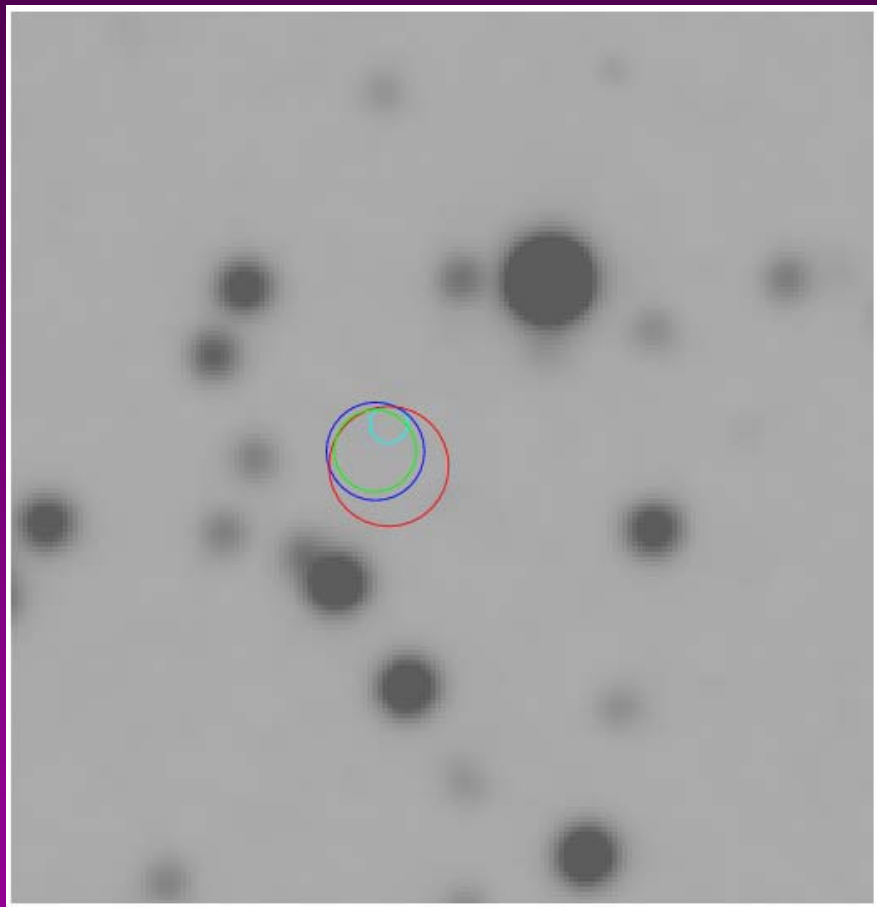
*Motch, Zavlin & Haberl (2003)*



Chandra / HST

*Kaplan, Kulkarni & van Kerkwijk (2002)*

## *Precise X-ray positions*



RX J0420.0-5022

1RXS J130848.6+212708

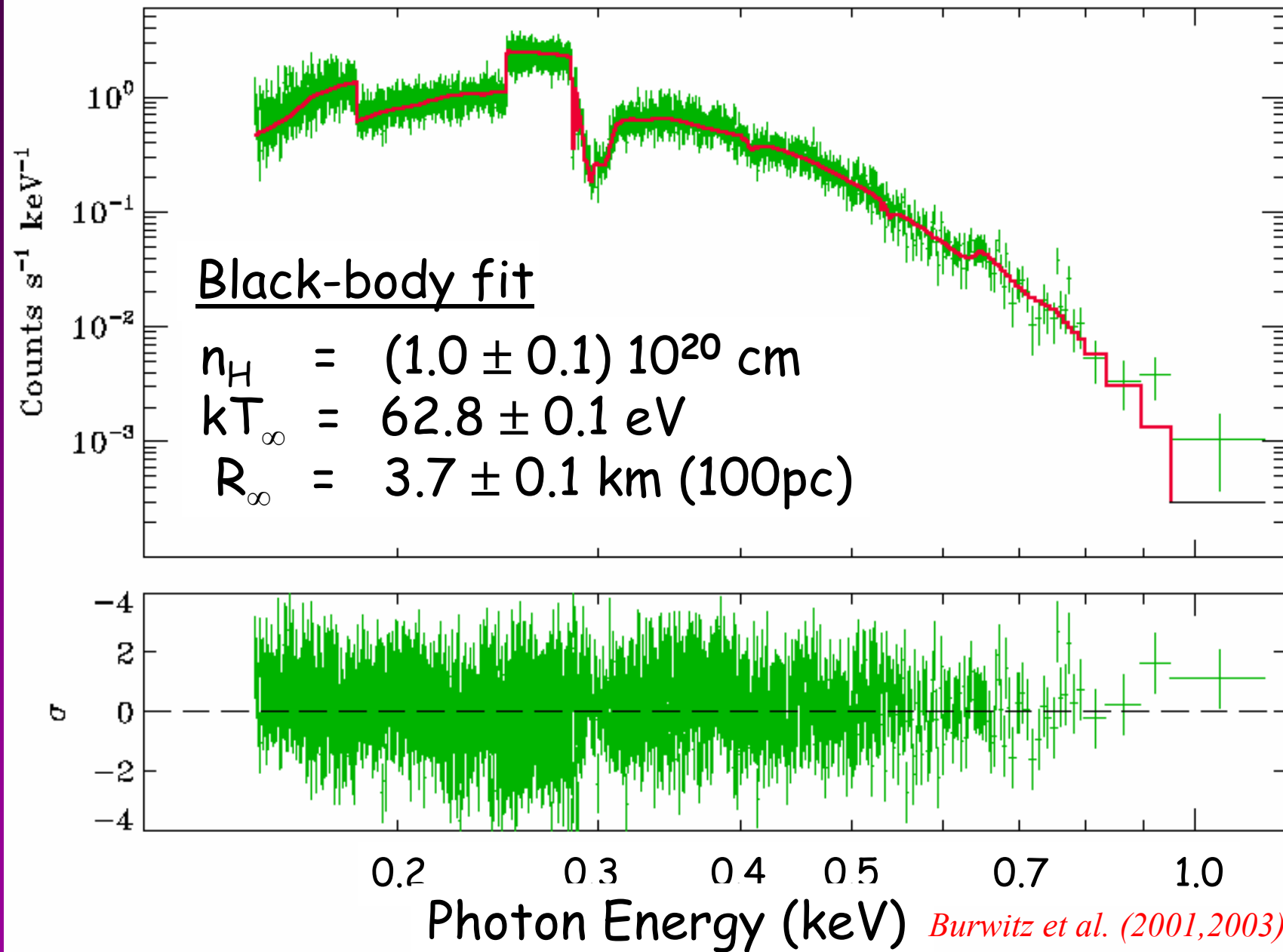
RX J1605.3+3249

*Chandra observations, PI: Motch*

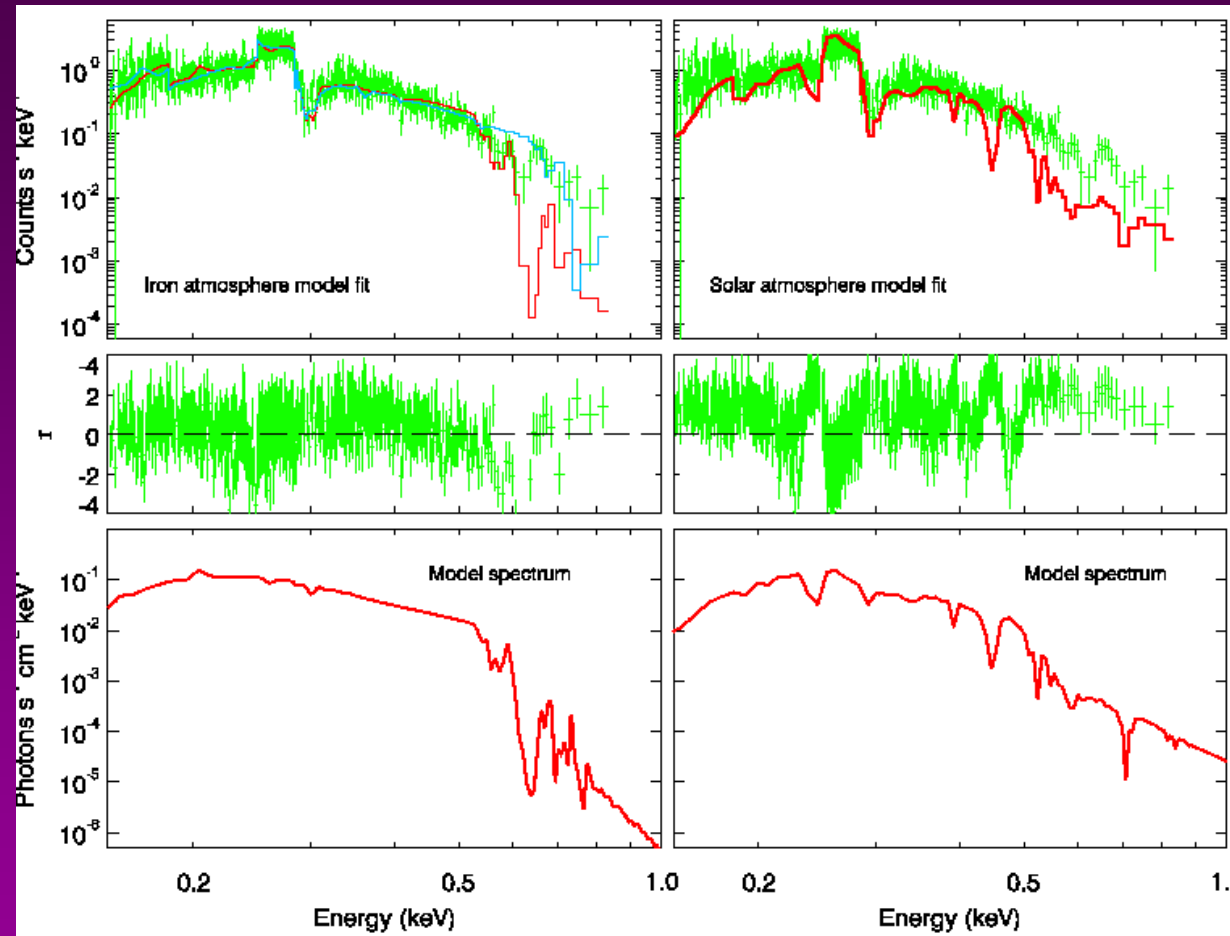
RX J0806.4-4123

*Haberl, Zavlin & Motch (2002)*

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

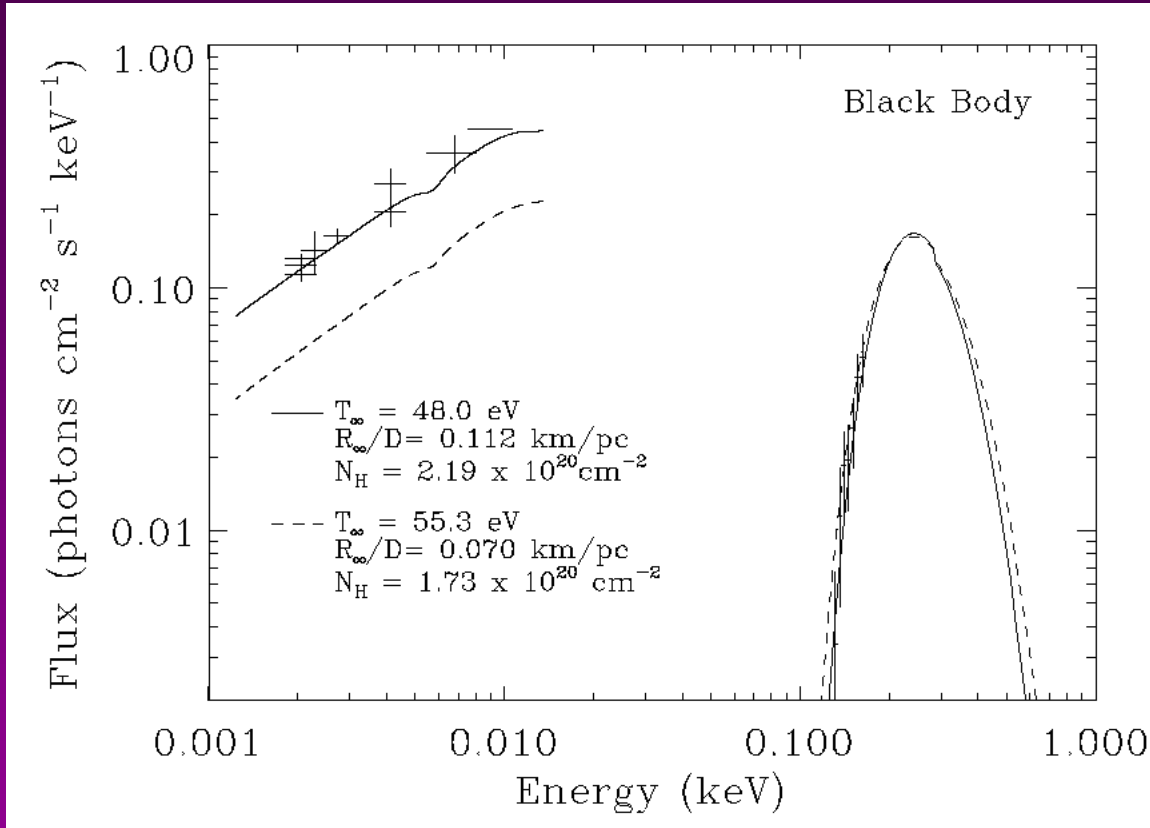


# X-ray spectra: *RX J1856.4-3754*



*Burwitz et al. (2001)*

# *XDINS: Optical to X-rays*



**RX J1856.5-3754**

In optical a factor  $\sim 3$  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  $\sim 5$

*Motch & Haberl (1998)*

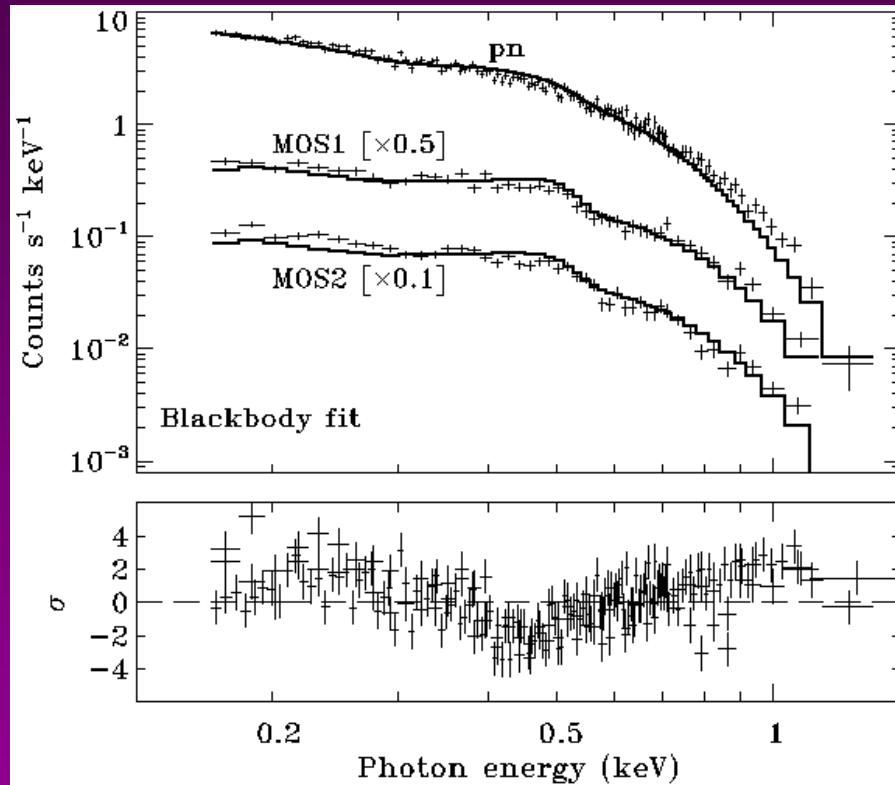
**1RXS J130848.6+212708**

Factor  $\sim 5$

*Kaplan et al. (2001)*

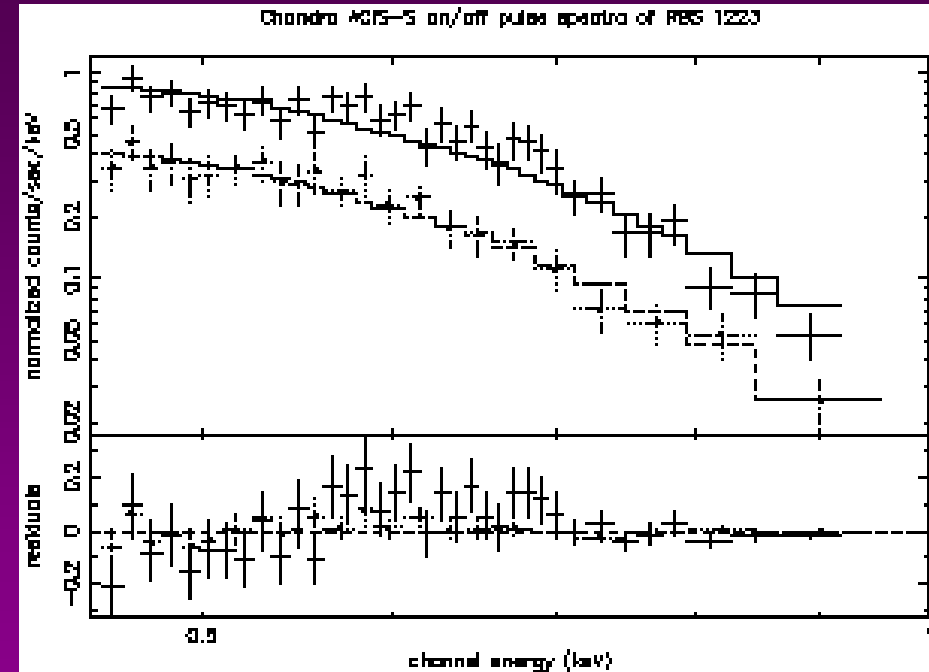


# *X-ray Spectra: deviation from black body or calibration problem*



RX J0806.4-4123 (XMM-Newton EPIC)

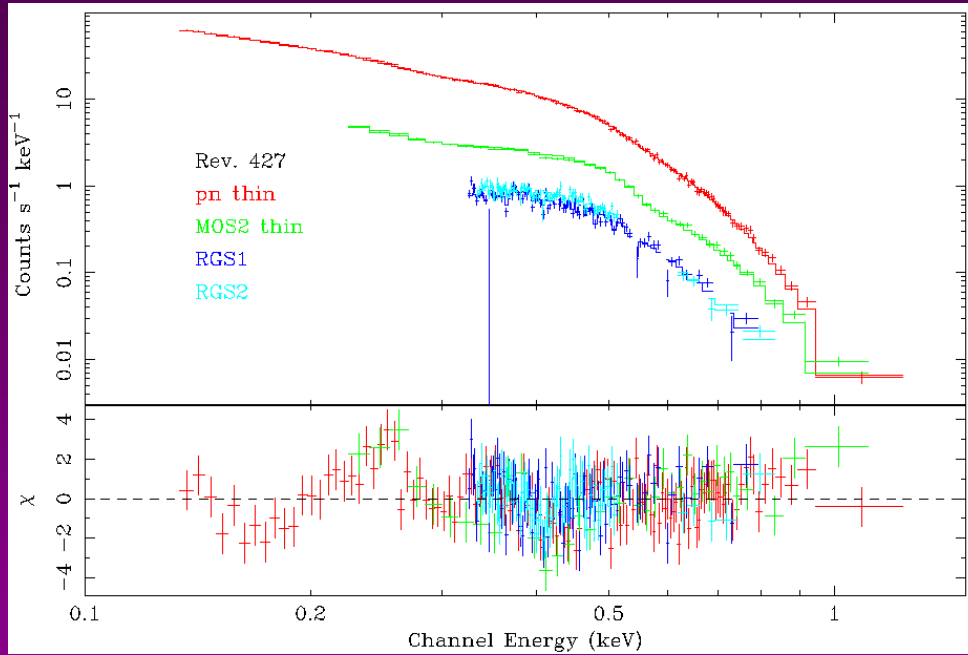
*Haberl & Zavlin (2002)*



1RXS J130848.6+212708 (Chandra ACIS)

*Hambaryan et al. (2002)*

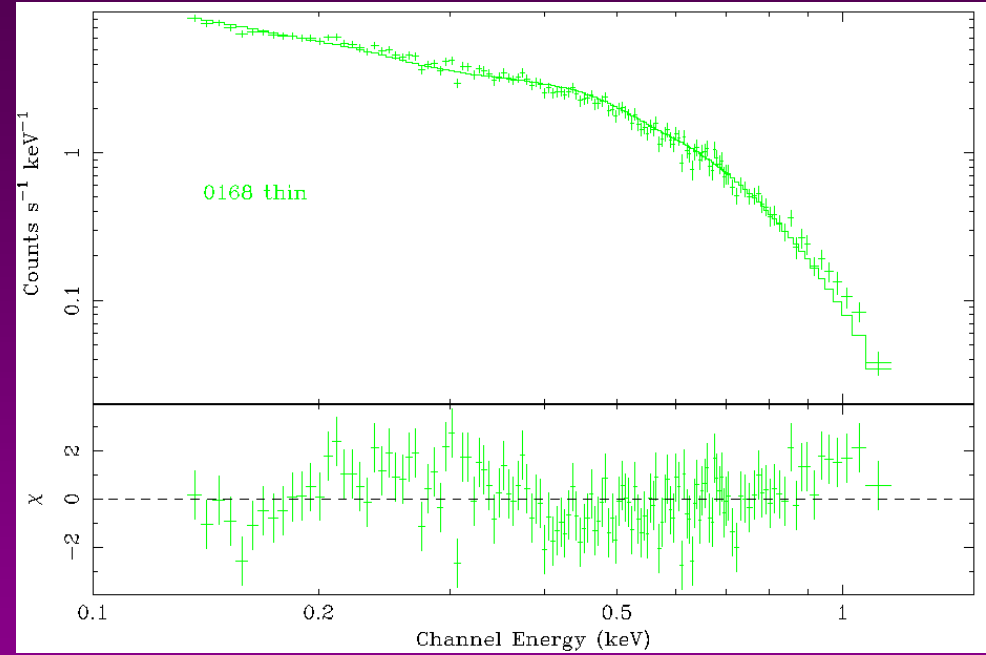
# *XMM-Newton: X-ray spectral survey*



**RX J1856.5-3754**

**kT = 60.4 eV**

**$N_{\text{H}} = 9.5 \times 10^{19} \text{ cm}^{-2}$**

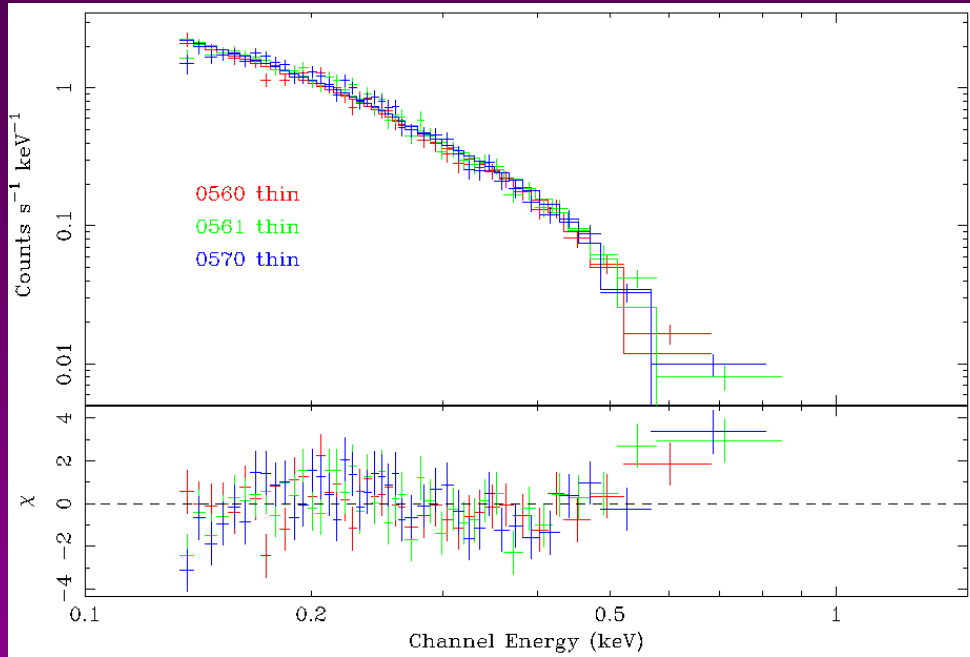


**RX J0806.4-4123**

**kT = 96 eV**

**$N_{\text{H}} = 1.5 \times 10^{19} \text{ cm}^{-2}$**

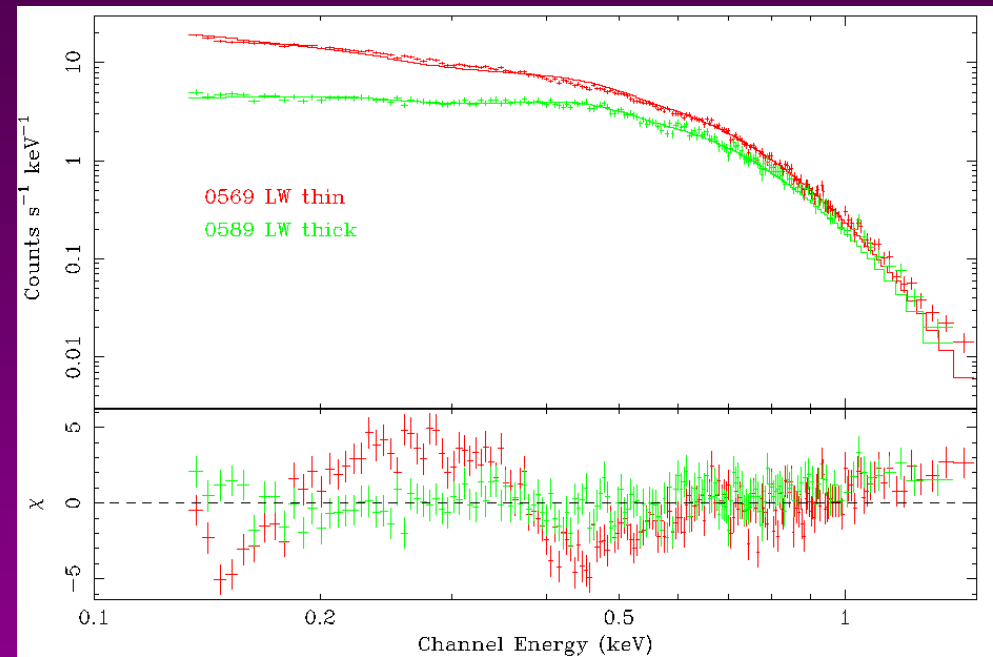
# *X-ray spectral survey*



**RX J0420.0-5022**

**kT = 45 eV**

**N<sub>H</sub> = 1.1 x 10<sup>20</sup> cm<sup>-2</sup>**

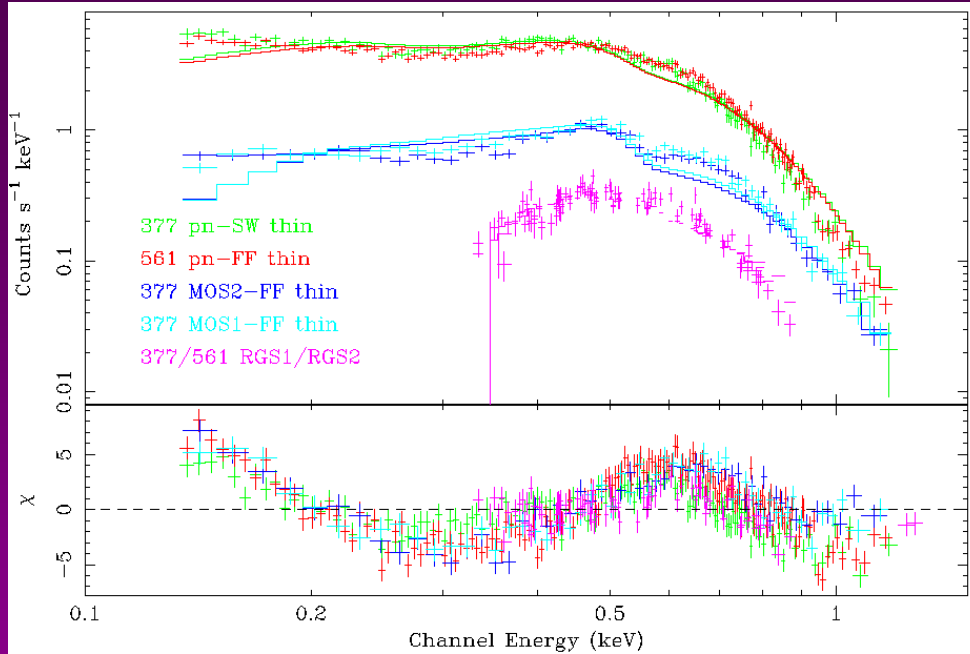


**RX J1605.3+3249**

**kT = 97 eV**

**N<sub>H</sub> = 2.8 x 10<sup>19</sup> cm<sup>-2</sup>**

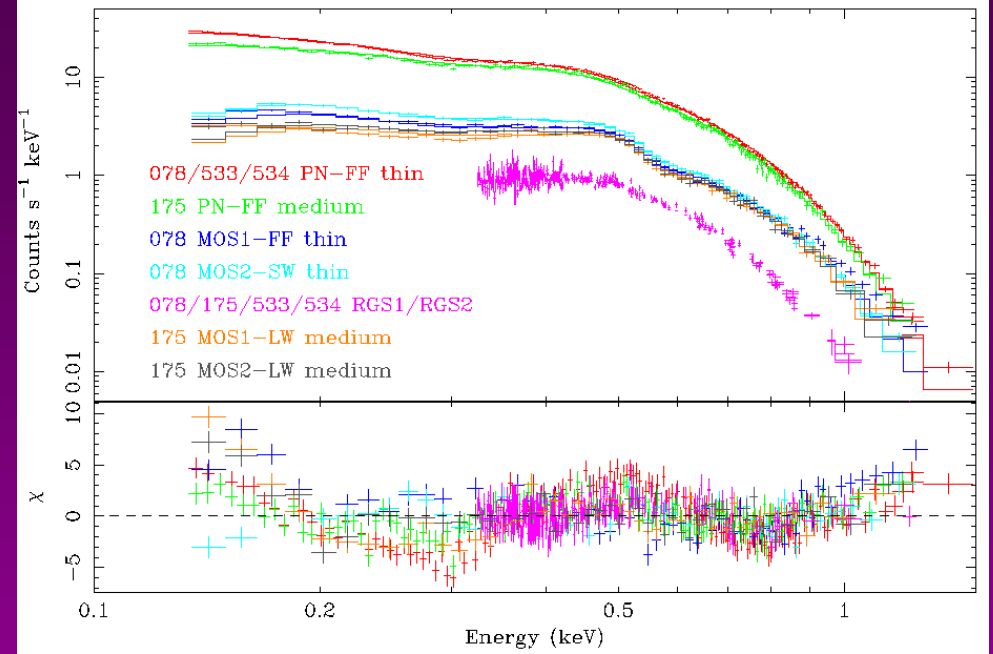
# X-ray spectral survey



**RBS1223**

**kT = 95 eV**

**N<sub>H</sub> = 7.1 x 10<sup>20</sup> cm<sup>-2</sup>**

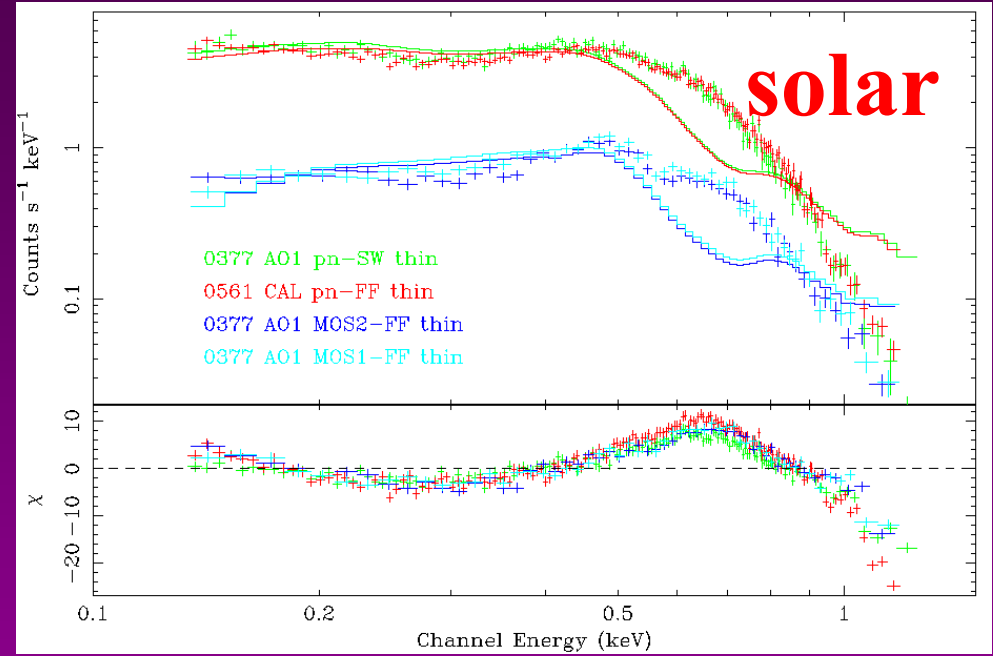
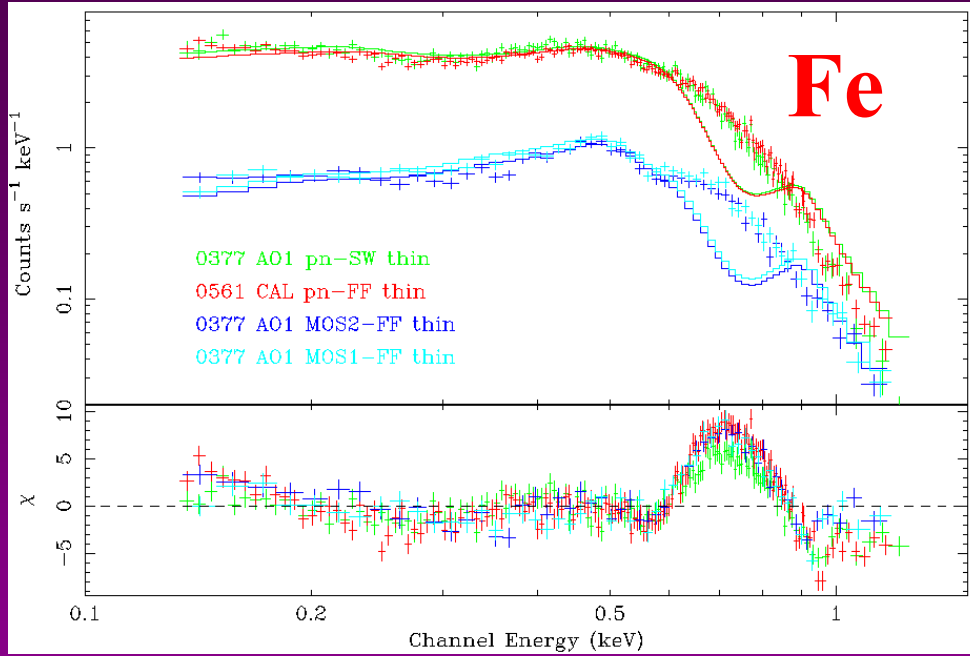


**RX J0720.4-3125**

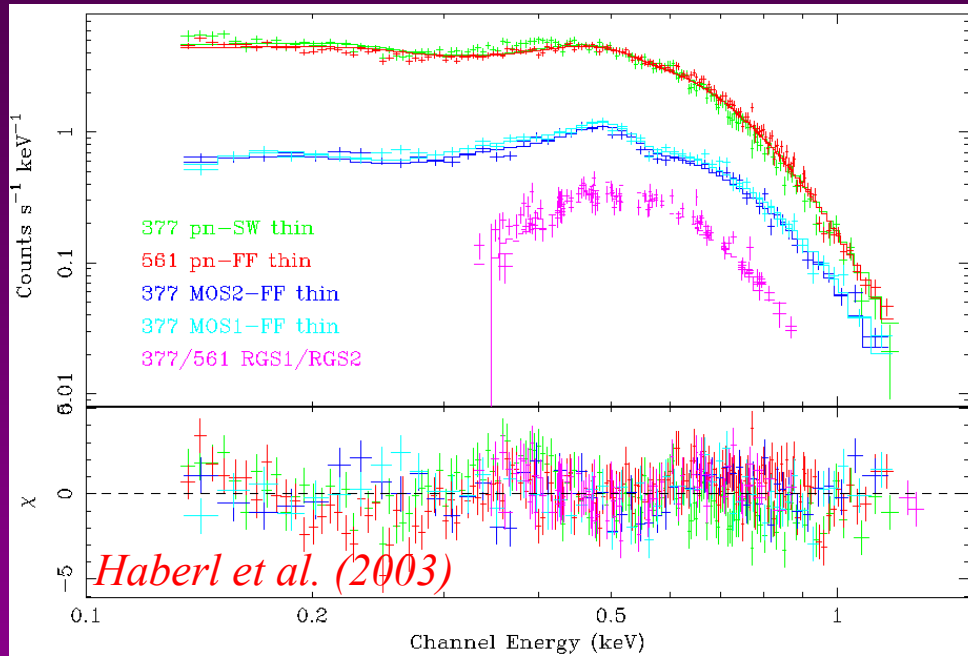
**kT = 83 eV**

**N<sub>H</sub> = 1.4 x 10<sup>20</sup> cm<sup>-2</sup>**

# *RBS1223: atmosphere models*



# Absorption features



**RBS1223**

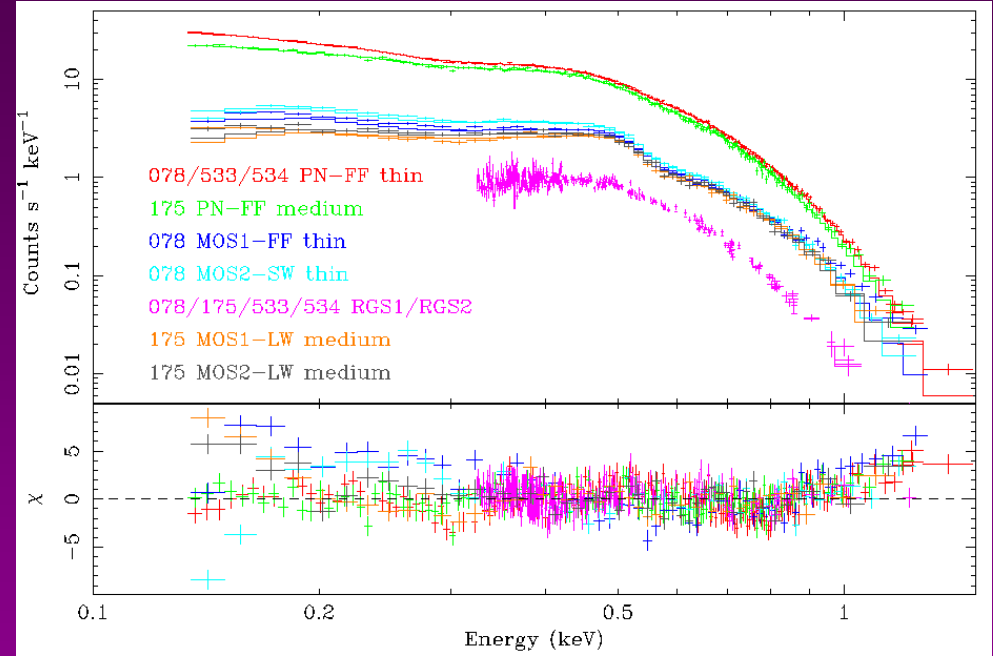
**kT = 85.8 eV**

**N<sub>H</sub> = 4.1 x 10<sup>20</sup> cm<sup>-2</sup>**

**E<sub>line</sub> = 290 eV**

**σ<sub>line</sub> = 100 eV fix**

**eqw = -150 eV**



**RX J0720.4-3125**

**kT = 83 eV**

**N<sub>H</sub> = 1.4 x 10<sup>20</sup> cm<sup>-2</sup>**

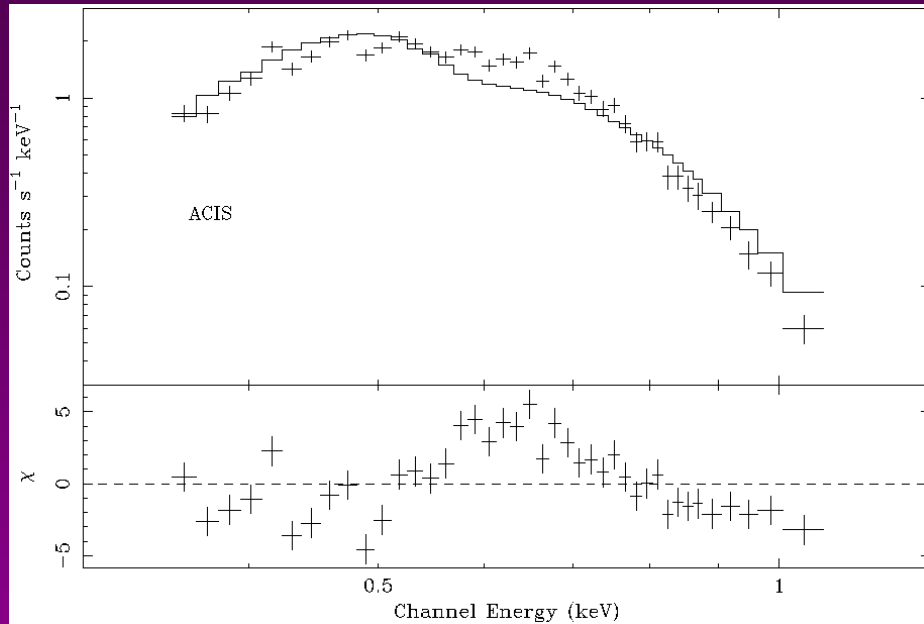
**E<sub>line</sub> = 270 eV**

**σ<sub>line</sub> = 64 eV**

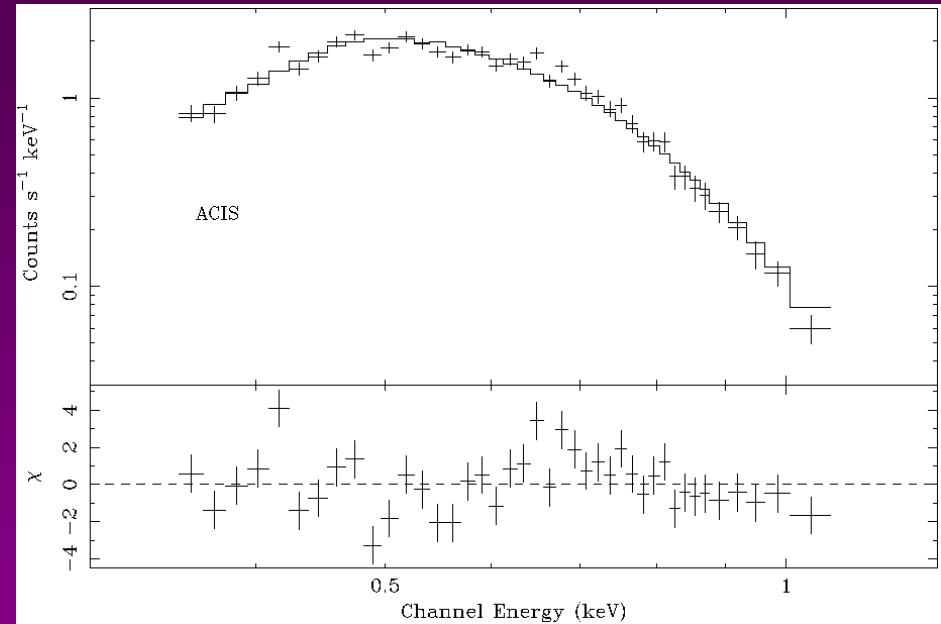
**eqw = -40 eV**

# *RBS1223: Blackbody model with absorption line*

## *Chandra ACIS-S*



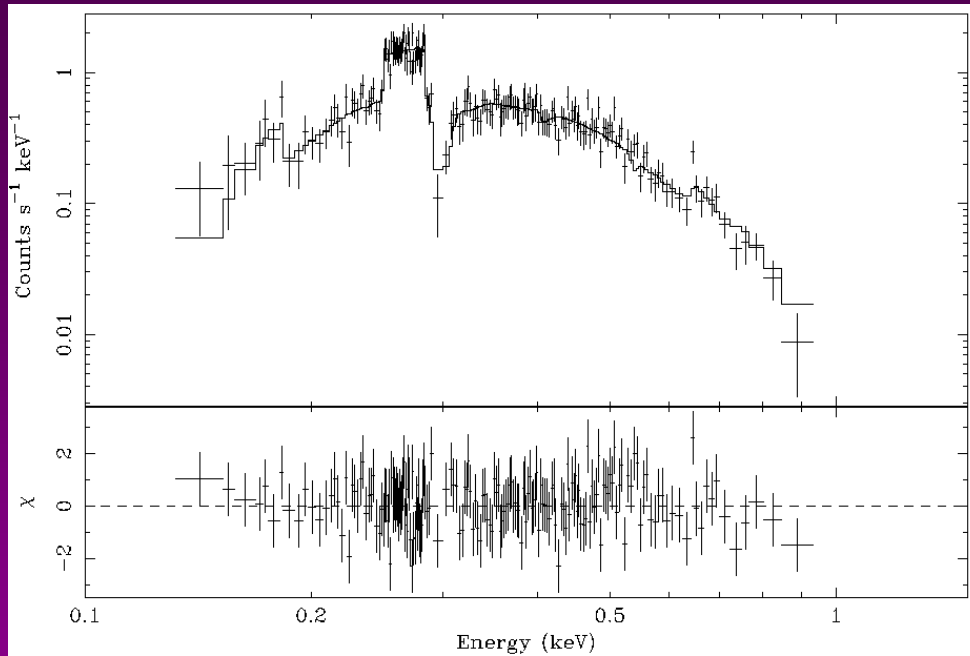
**Pure blackbody**



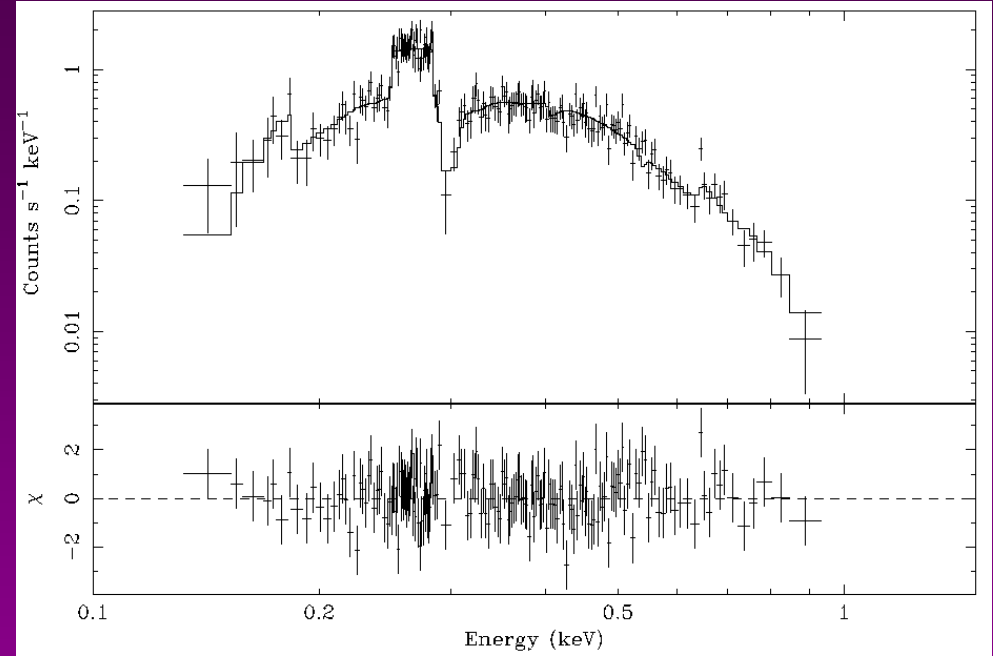
**Blackbody + absorption line**

# *RX J0720.4-3125: Blackbody model with absorption line*

## *Chandra LETGS*



**Pure blackbody**



**Blackbody + absorption line**



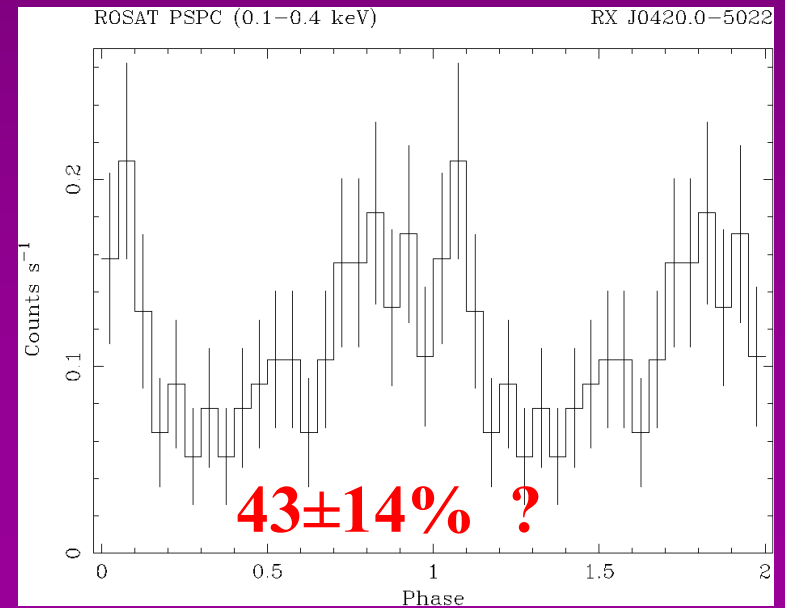
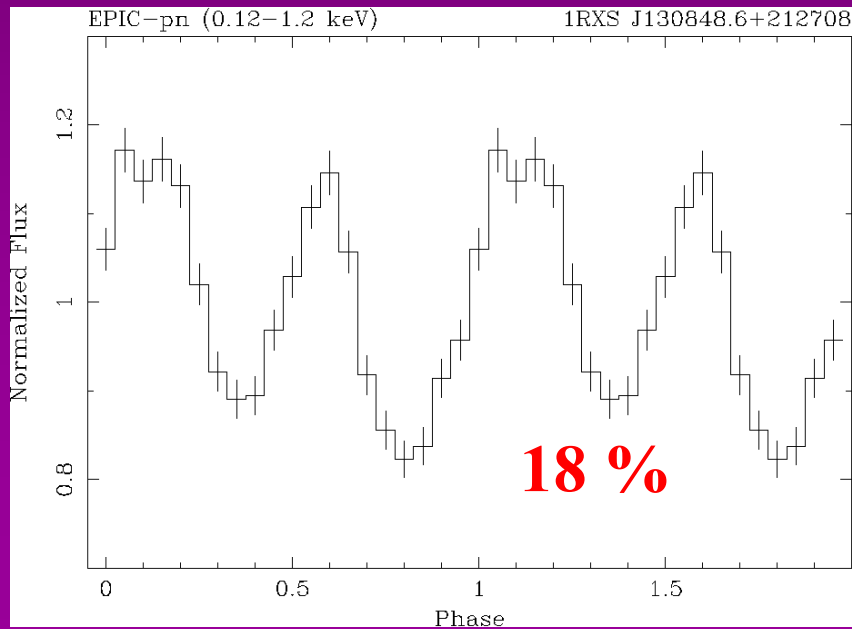
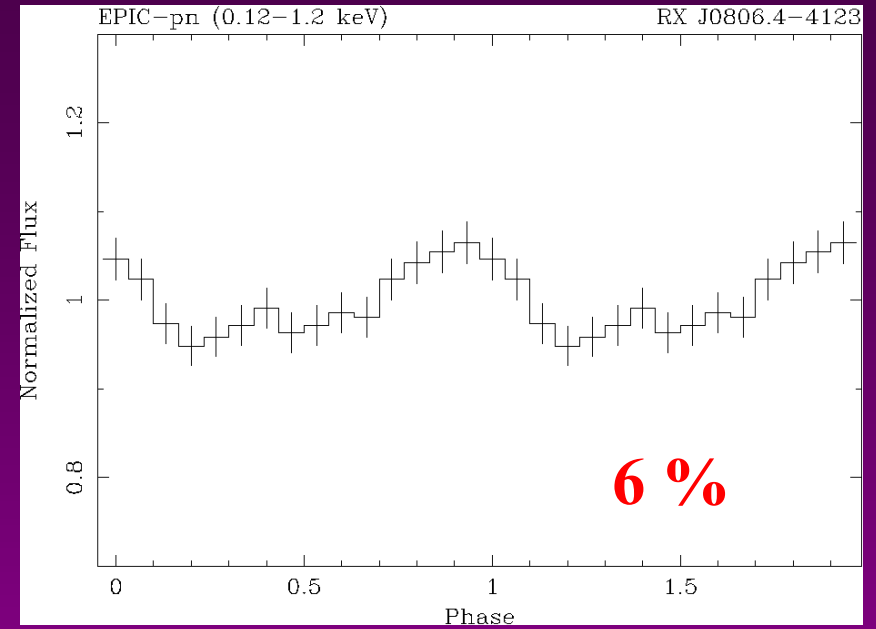
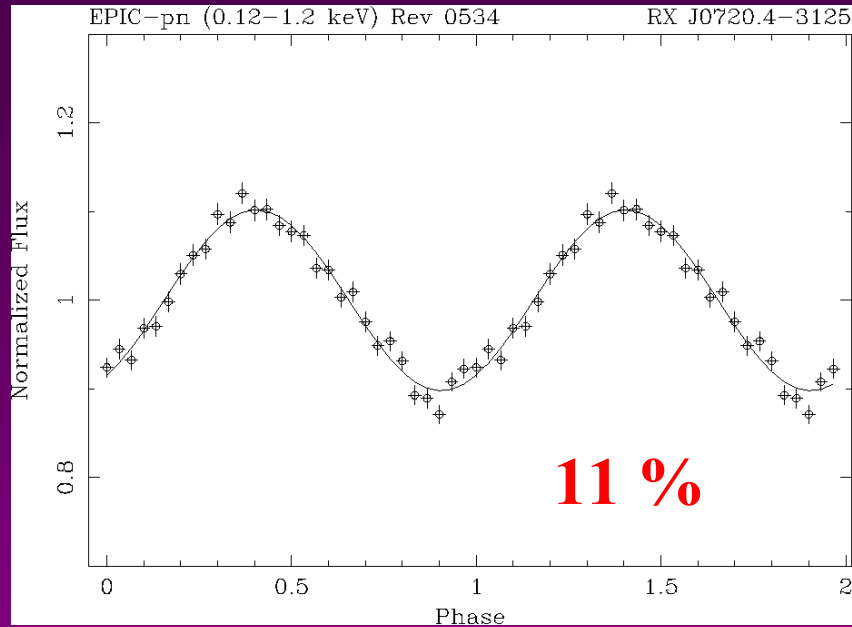
## *RBS1223: Blackbody model with absorption line*

<b>Rev-Inst</b>	<b>kT eV</b>	<b><math>N_{\text{H}}</math> <math>10^{20} \text{ cm}^{-2}</math></b>	<b><math>E_{\text{line}}</math> eV</b>	<b>EQW eV</b>	<b><math>\chi^2/\text{dof}</math></b>	<b>Flux/<math>10^{-11} \text{ erg s}^{-1}</math> (0.1-2.4 keV)</b>
<b>377-pn</b>	<b><math>85.8 \pm 0.5</math></b>	<b><math>4.1 \pm 0.1</math></b>	<b><math>290 \pm 5</math></b>	<b>-148</b>	<b>589/307</b>	<b>3.65</b>
<b>561-pn</b>	<b>=1</b>	<b>=1</b>	<b>=1</b>	<b>-148</b>		<b>3.44</b>
<b>377-M1</b>	<b>=1</b>	<b><math>2.9 \pm 0.2</math></b>	<b>=1</b>	<b>-159</b>	<b>156/108</b>	<b>3.33</b>
<b>377-M2</b>	<b>=1</b>	<b><math>3.2 \pm 0.2</math></b>	<b>=1</b>	<b>-159</b>		<b>3.62</b>
<b>377-R1</b>	<b><math>82.2 \pm 2.4</math></b>	<b><math>5.0 \pm 0.6</math></b>	<b>=1</b>	<b>-</b>	<b>318/221</b>	<b>2.62</b>
<b>377-R2</b>	<b><math>85.2 \pm 2.6</math></b>	<b>=5</b>	<b>=1</b>	<b>-</b>		<b>2.50</b>
<b>561-R1</b>	<b><math>87.8 \pm 1.6</math></b>	<b>=5</b>	<b>=1</b>	<b>-</b>		<b>2.50</b>
<b>561-R2</b>	<b><math>87.6 \pm 1.5</math></b>	<b>=5</b>	<b>=1</b>	<b>-</b>		<b>2.50</b>
<b>ACIS</b>	<b><math>87.8 \pm 1.0</math></b>	<b>&lt;1.6</b>	<b>290fix</b>	<b>-</b>	<b>91/38</b>	<b>3.34</b>

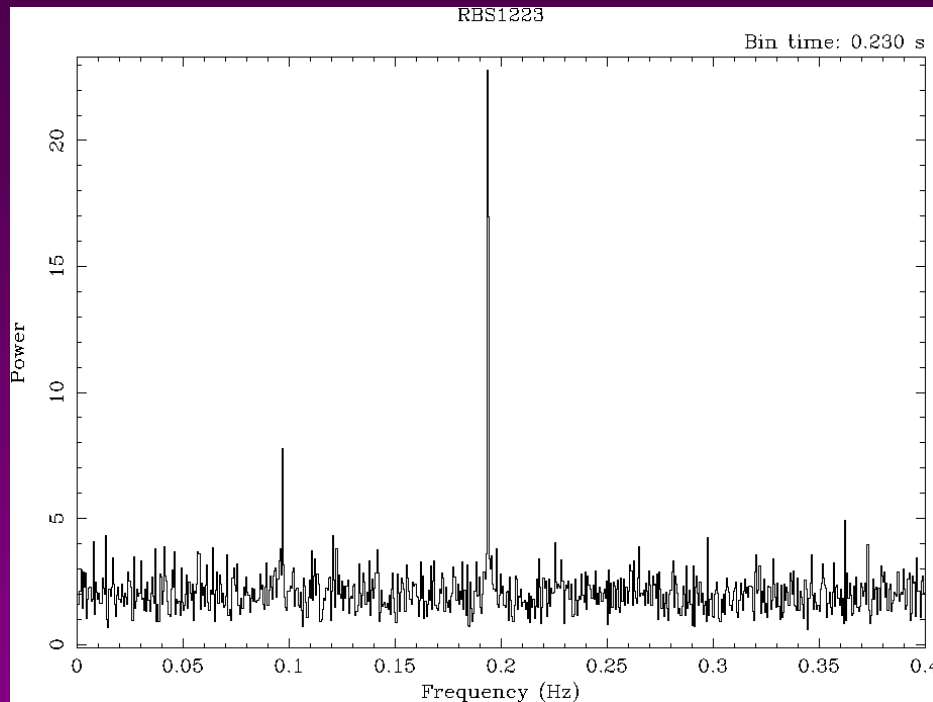
## *Magnetic fields*

Object	P [s]	dP/dt [ss <sup>-1</sup> ]	E <sub>cyc</sub> [eV]	B [10 <sup>13</sup> G]
<b>RX J0420.0–5022</b>	<b>22.69 ?</b>			
<b>RX J0806.4–4123</b>	<b>11.37</b>			
<b>RX J0720.4–3125</b>	<b>8.39</b>	<b>(3–6) x 10<sup>-14</sup></b>	<b>270</b>	<b>1.6 – 2.2 / 5.4</b>
<b>1RXS J13048.6+212708</b>	<b>10.31</b>	<b>&lt;6 x 10<sup>-12</sup></b>	<b>100 – 300</b>	<b>&lt; 25 / 2 – 6</b>

# *XDINS: X-ray pulsations*

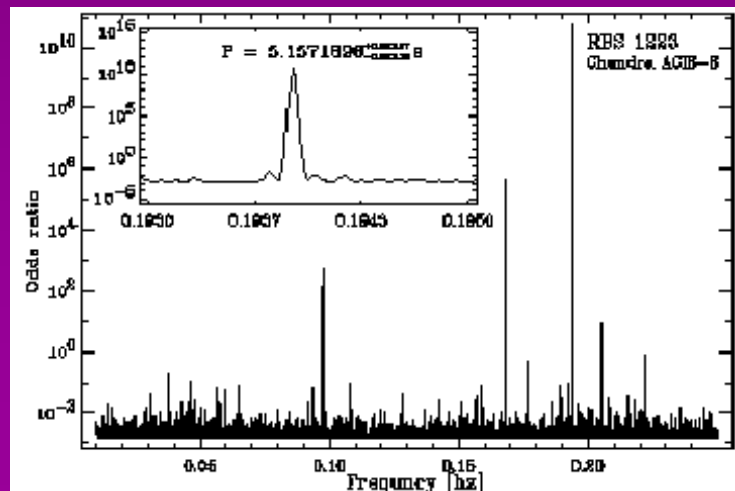
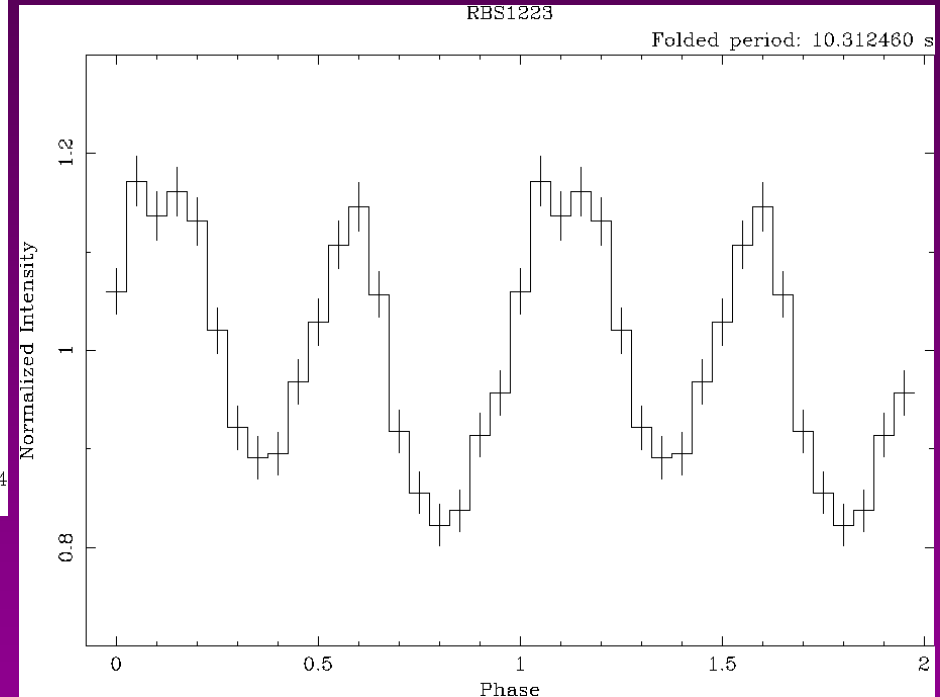


# RBS1223: X-ray pulsations



RX J1308.8+2127 (XMM-Newton EPIC-pn)

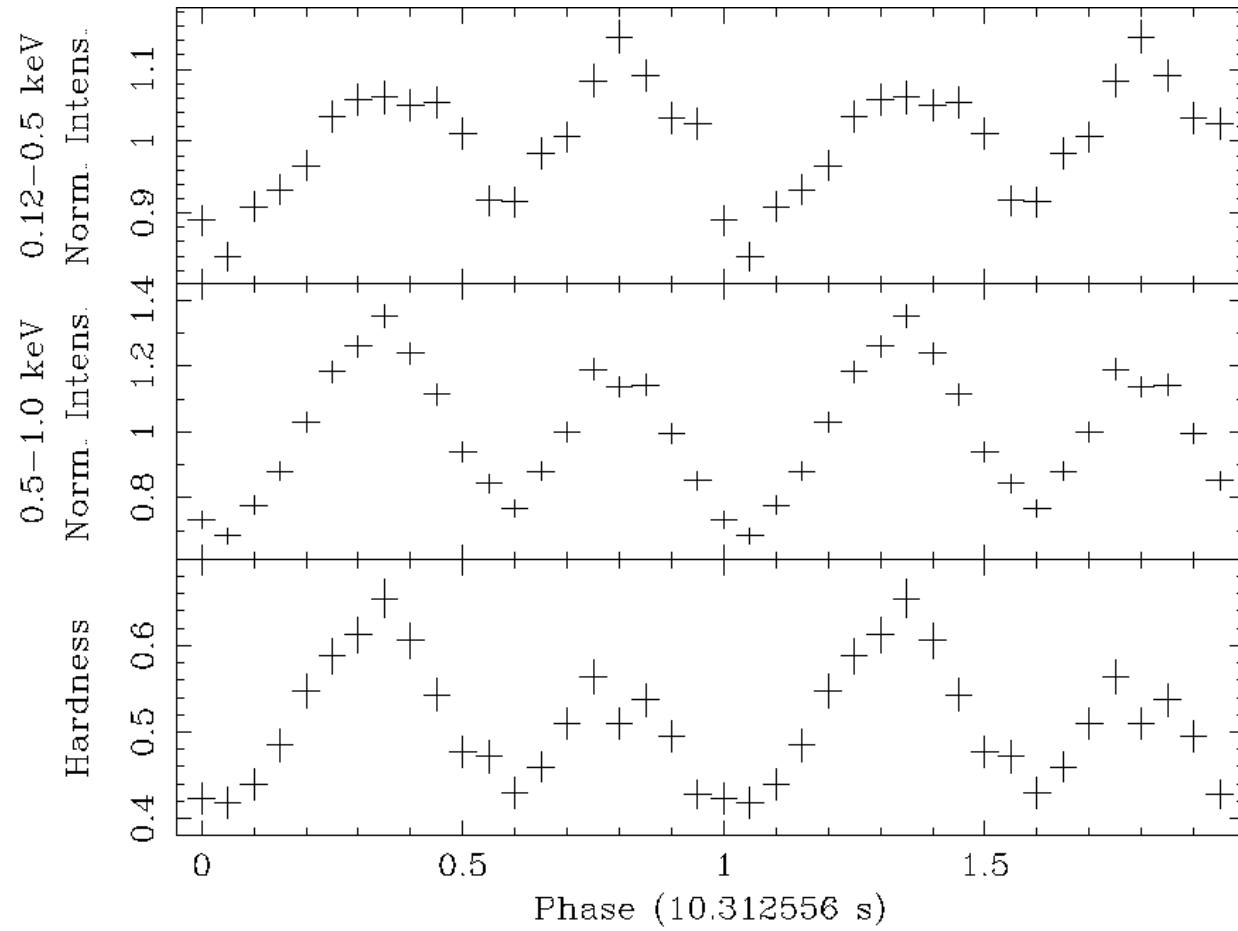
*Hambaryan, Haberl, et al. in preparation*



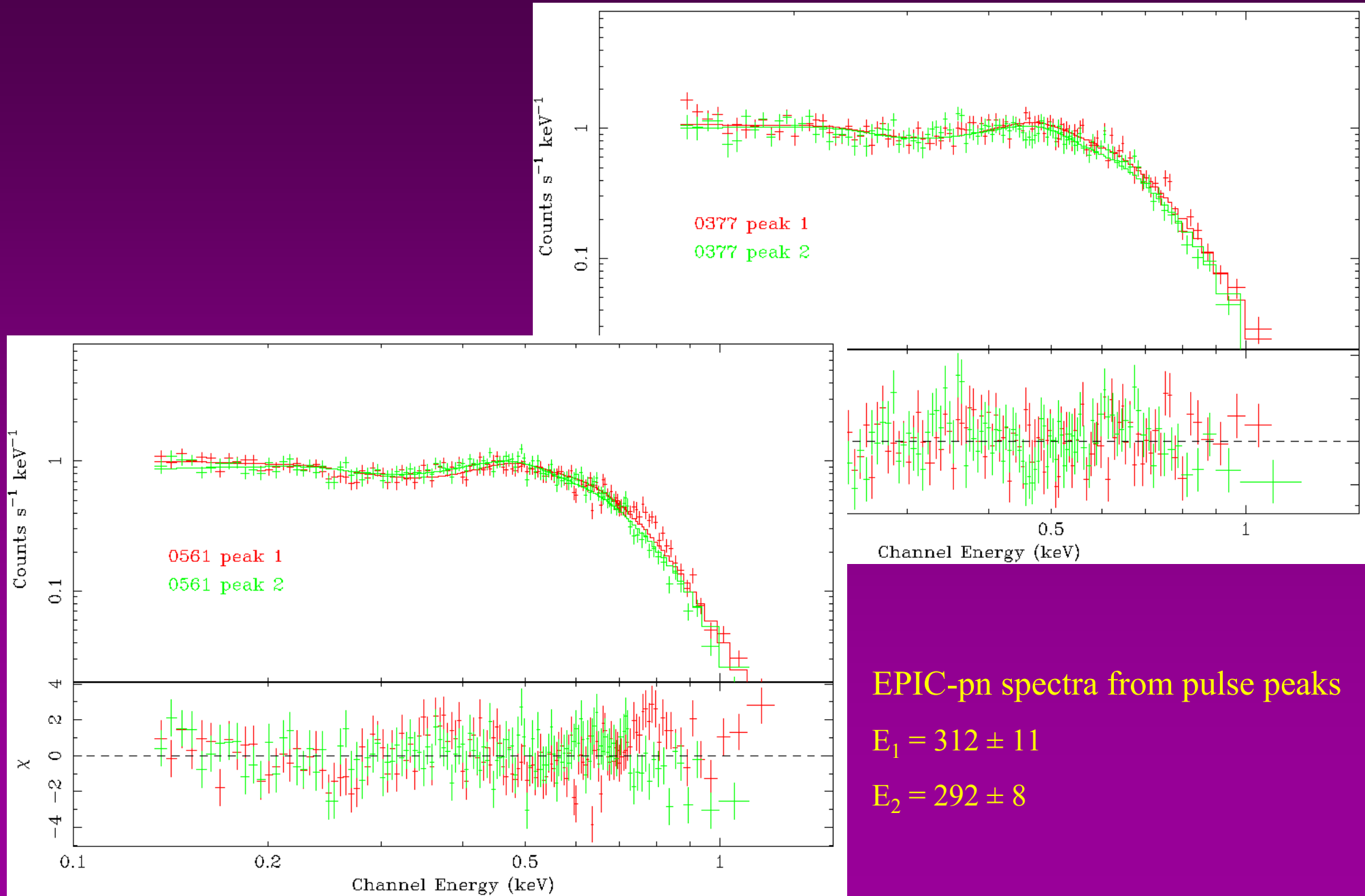
RX J1308.8+2127 (Chandra ACIS-S)

*Hambaryan, et al. (2002)*

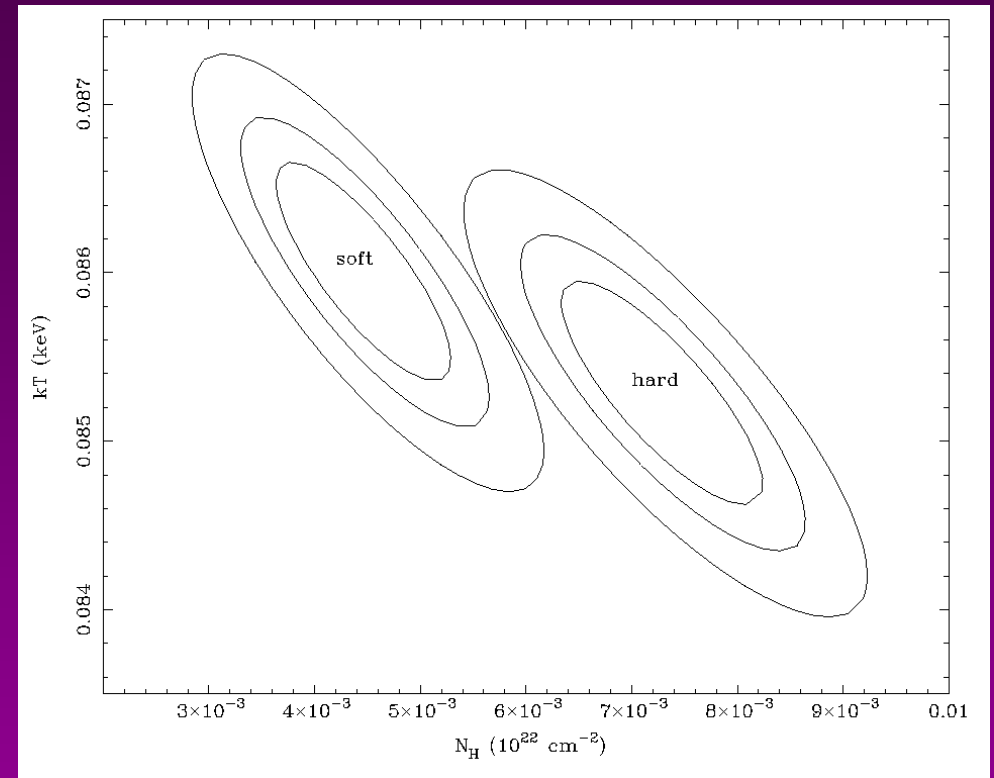
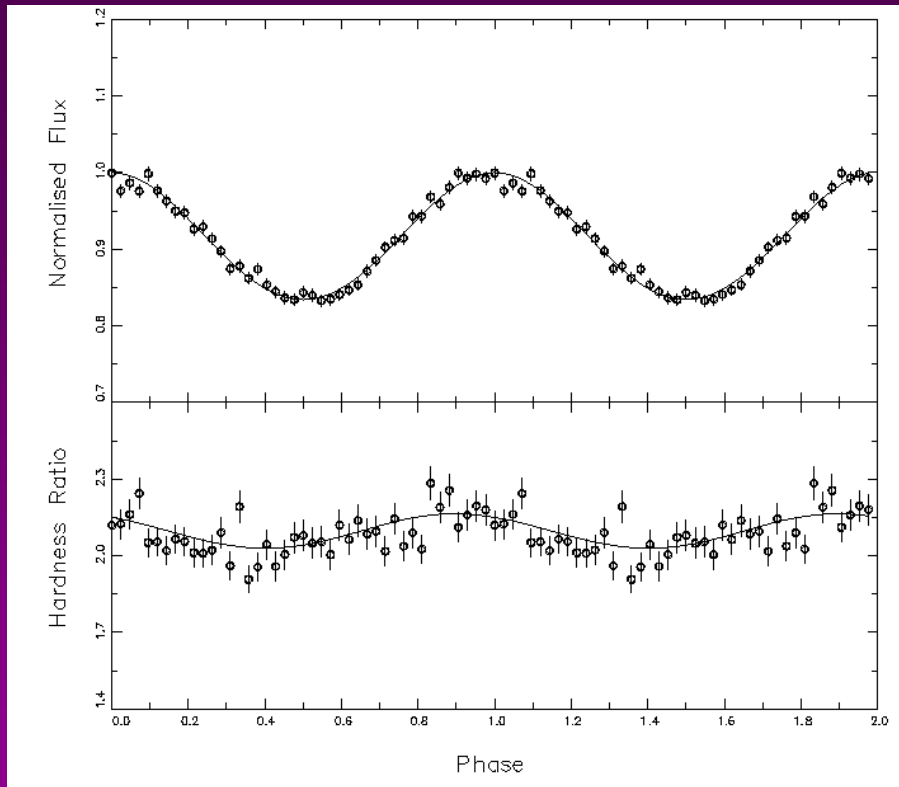
# *RBS1223: Pulse phase spectroscopy*



# RBS1223: Pulse phase spectroscopy



# *RX J0720.4-3125: X-ray spectral variations*

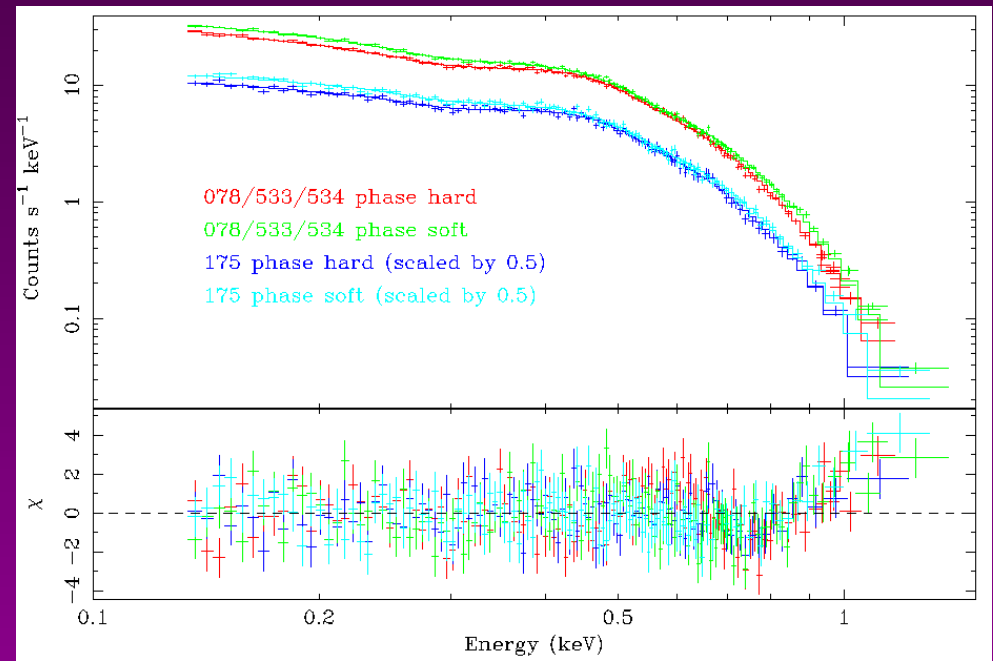
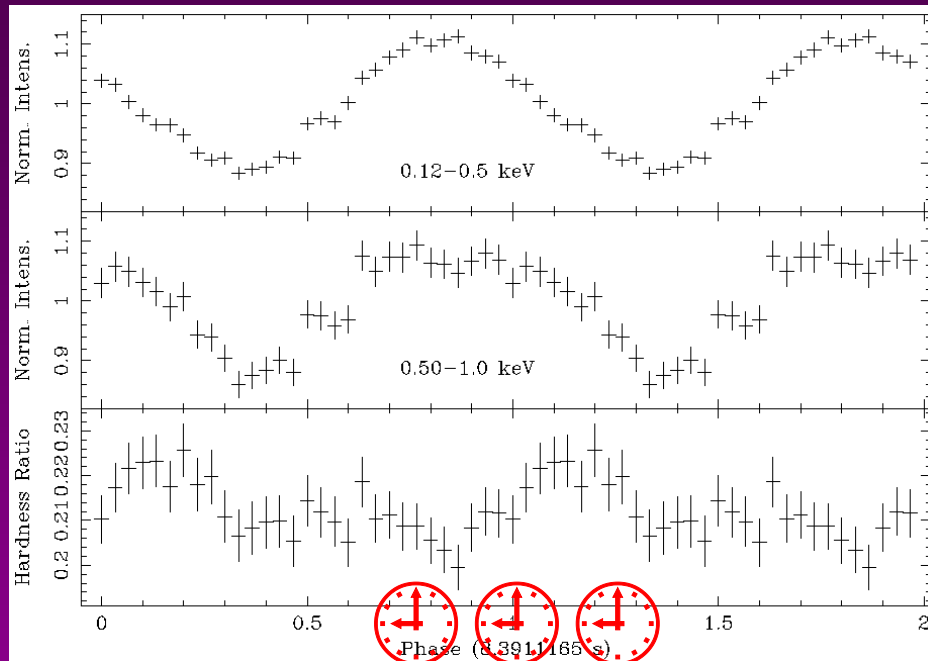


RX J0720.4-3125 (XMM-Newton)

Beaming effects?

*Cropper et al. (2001)*

# *RX J0720.4-3125: X-ray spectral variations*



RX J0720.4-3125 (XMM-Newton)

Variable cyclotron absorption ?

*Haberl et al. (in preparation)*



## *RX J0720.4-3125: Variable absorption line*

<b>Rev</b>	<b>kT</b> <b>eV</b>	<b>N<sub>H</sub></b> <b>10<sup>20</sup> cm<sup>-2</sup></b>	<b>E<sub>line</sub></b> <b>eV</b>	<b>EQW</b> <b>eV</b>
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### **``Hard'' phase**

<b>078</b>	<b>82.1 ± 0.5</b>	<b>1.0 ± 0.1</b>	<b>282 ± 6</b>	<b>-55 ± 4</b>
<b>175</b>	<b>81.3 ± 0.6</b>	<b>=1</b>	<b>=1</b>	<b>-54 ± 4</b>
<b>533</b>	<b>84.6 ± 0.6</b>	<b>=1</b>	<b>=1</b>	<b>-56 ± 4</b>
<b>534</b>	<b>84.6 ± 0.6</b>	<b>=1</b>	<b>=1</b>	<b>-56 ± 4</b>

### **``Soft'' phase (near intensity maximum)**

<b>078</b>	<b>84.3 ± 0.6</b>	<b>=1</b>	<b>278 ± 14</b>	<b>-24 ± 6</b>
<b>175</b>	<b>83.5 ± 0.7</b>	<b>=1</b>	<b>=1</b>	<b>-24 ± 6</b>
<b>533</b>	<b>87.8 ± 0.7</b>	<b>=1</b>	<b>=1</b>	<b>-25 ± 6</b>
<b>534</b>	<b>87.4 ± 0.7</b>	<b>=1</b>	<b>=1</b>	<b>-25 ± 6</b>

## *XMM-Newton spectra: summary*

<b>Source</b>	<b>kT</b> eV	<b>N<sub>H</sub></b> 10 <sup>20</sup> cm <sup>-2</sup>	<b>d</b> pc	<b>R<sub>em</sub></b> km	<b>F<sub>x</sub>(0.1-2.4 keV)</b> 10 <sup>-12</sup> erg cm <sup>-2</sup> s <sup>-1</sup>	<b>L<sub>bol</sub></b> erg s <sup>-1</sup>
<b>RX J1856.5-3754</b>	<b>60</b>	<b>1.0</b>	<b>117±12</b>	<b>5.5</b>	<b>16.4</b>	<b>5.1 · 10<sup>31</sup></b>
<b>RX J0720.4-3125*</b>	<b>83</b>	<b>0.9</b>			<b>12.0</b>	
<b>RX J1605.3+3249</b>	<b>97</b>	<b>0.28</b>			<b>7.3</b>	
<b>RBS1223*</b>	<b>86</b>	<b>4.1</b>	<b>250±60**</b>	<b>3.9</b>	<b>3.5</b>	<b>1.1 · 10<sup>32</sup></b>
<b>RX J0806.4-4123</b>	<b>96</b>	<b>0.15</b>			<b>3.1</b>	
<b>RX J0420.0-5022</b>	<b>45</b>	<b>1.1</b>			<b>0.5</b>	

\* absorption feature

\*\* DM 5±3 pc/cm<sup>3</sup> (Malofeev 2003, abstract to IAU Symp. 218)

# Summary

**Young cooling NS ↔ old accreting NS**

- |                        |  |
|------------------------|--|
| <b>RX J1856.5-3754</b> | <b>high proper motion, blackbody<br/>young cooling NS ?</b>  |
| <b>RX J0720.4-3125</b> | <b>high proper motion, blackbody + absorption line, pulsar<br/>young cooling NS ?</b>                          |
| <b>RX J1605.3+3249</b> | <b>high? proper motion, blackbody</b>  |
| <b>RBS1223</b>         | <b>blackbody + absorption line, pulsar, radio detection<br/>young cooling NS ? High B-field radio pulsar ?</b> |
| <b>RX J0806.4-4123</b> | <b>blackbody, pulsar</b>   |
| <b>RX J0420.0-5022</b> | <b>blackbody, flux variation ?<br/>the only candidate for an (old) accreting NS ?</b>                          |