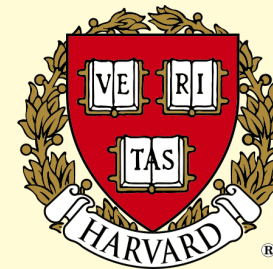
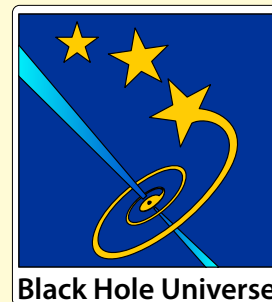
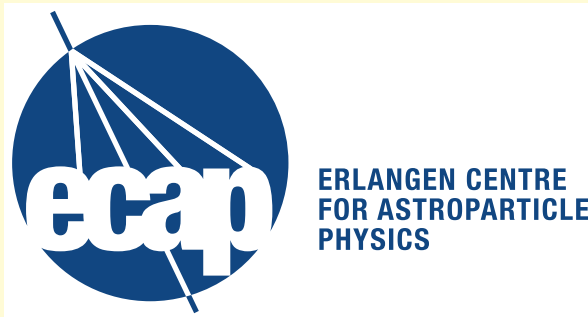


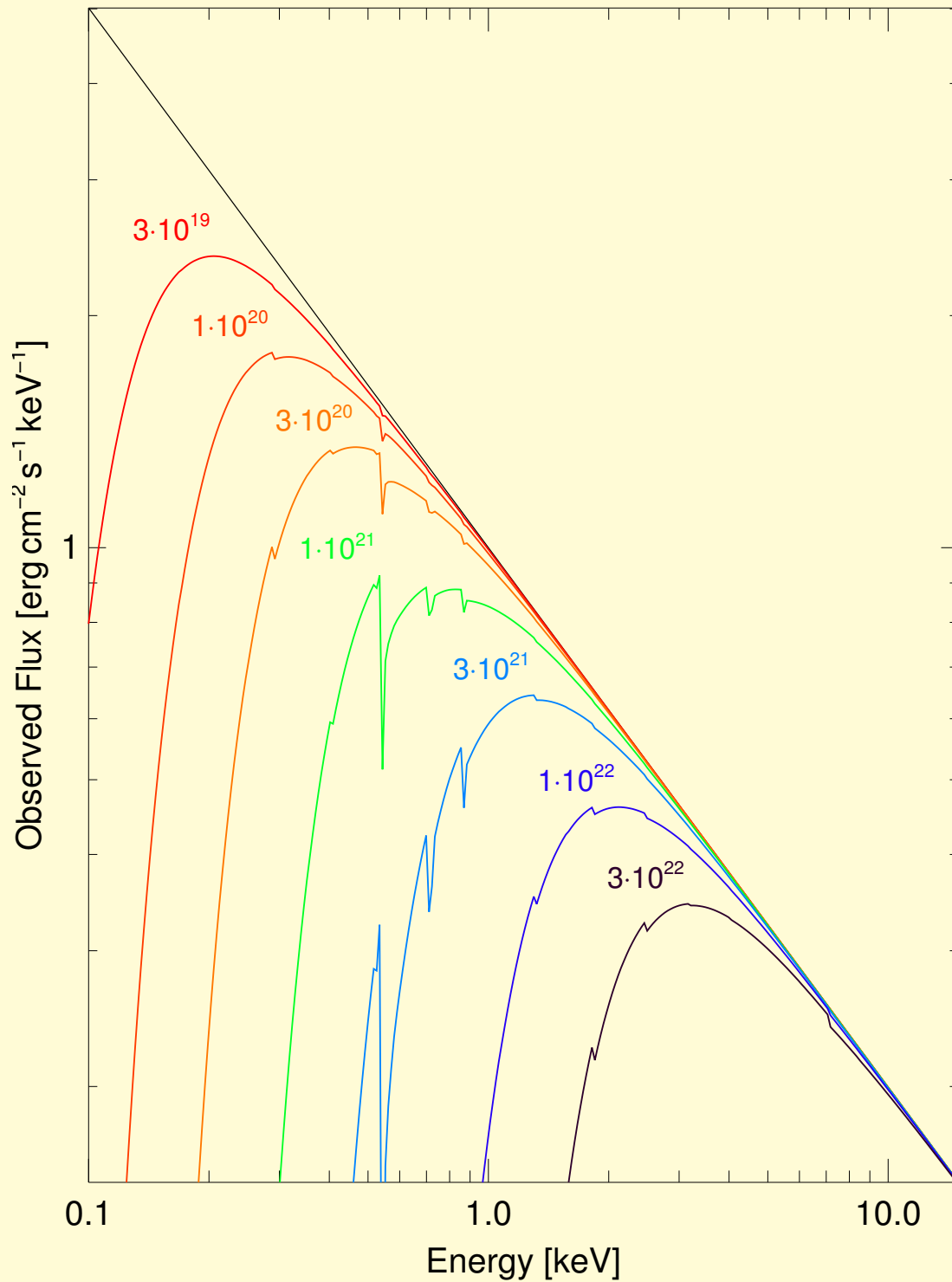
# Improved Absorption Models for the ISM

Jörn Wilms  
Dr. Remeis-Sternwarte &  
ECAP

*in collaboration with:*

J.C. Lee (Harvard), M.A. Nowak (MIT), N.S. Schulz (MIT), A. Juett (Ex-GSFC)





**Photoabsorption in ISM: strong modification of observed spectrum**

⇒ To understand source physics, we need to understand this modification and correct for it as precisely as possible

⇒ X-ray astronomers should really care about the subject of this talk.

⇒ How many of us care about absorption in the ISM?

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ADS: Total number of papers from 2000–2010 using *XMM-Newton*, *Chandra*, or *Suzaku*:

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Of this:

Morrison & McCammon (1983): 767 (58%)

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Wilms et al. (2000): 316 (24%)

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Wilms et al. (2000): 316 (24%)

Only 43% of all citations, and ~10% of all X-ray papers cite a modern absorption paper!

Typical life of an X-ray astronomer:

```
solaris:~/data> make proposal
```

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linux:~/data> make observation
```

Typical life of an X-ray astronomer:

solaris:~/data> make proposal

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macos:~/data> make datareduction

Typical life of an X-ray astronomer:

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```
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```
macos:~/data> xspec
```

```
Xspec 15.3.1xy 21:14:59 05-Mar-2020
```

For documentation, notes, and fixes see

<http://xspec.gsfc.nasa.gov/>

Plot device not set, use "cpd" to set it

Type "help" or "?" for further information

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XSPEC>data coolobs.pha
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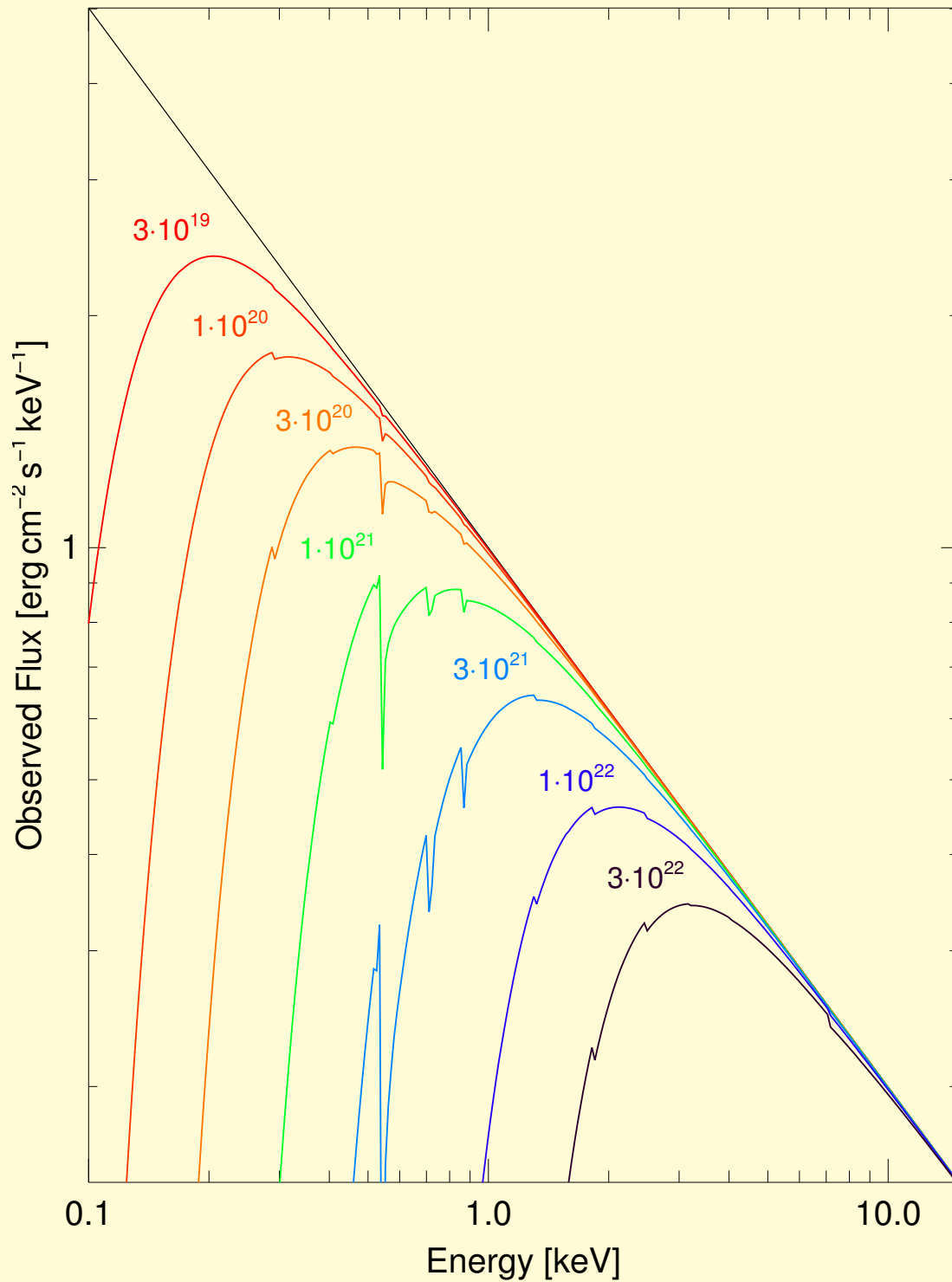
```
Type "help" or "?" for further information
```

```
XSPEC>data coolobs.pha
```

```
XSPEC>model wabs*power
```

⇒ and *this* is where a mistake is made!

also promoted until recently in xspec manual – thanks for changing this!



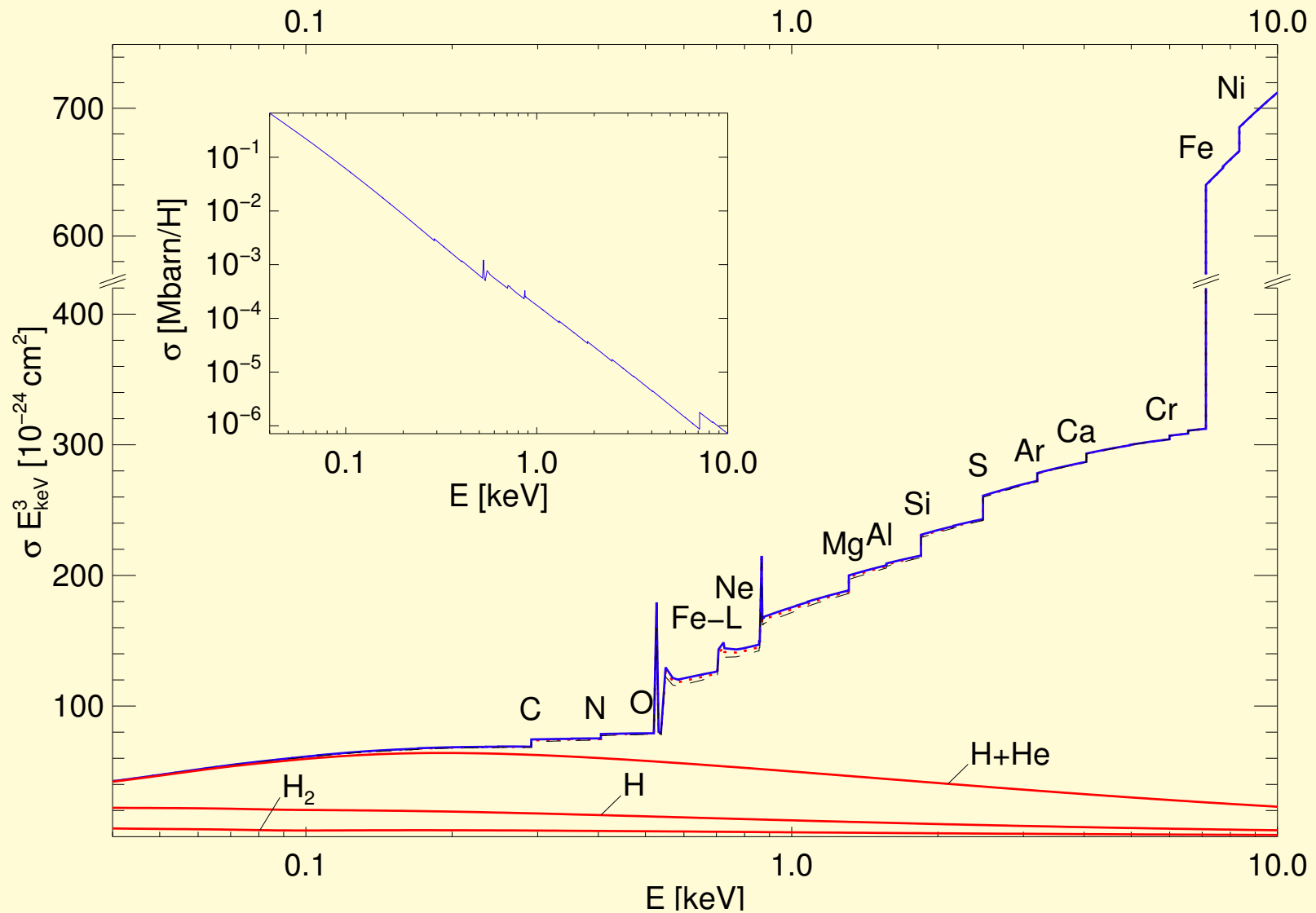
## Photoabsorption in ISM: modification of observed spectrum

⇒ To understand source physics, we need to understand this modification and correct for it

Here, I will discuss three subjects in more detail:

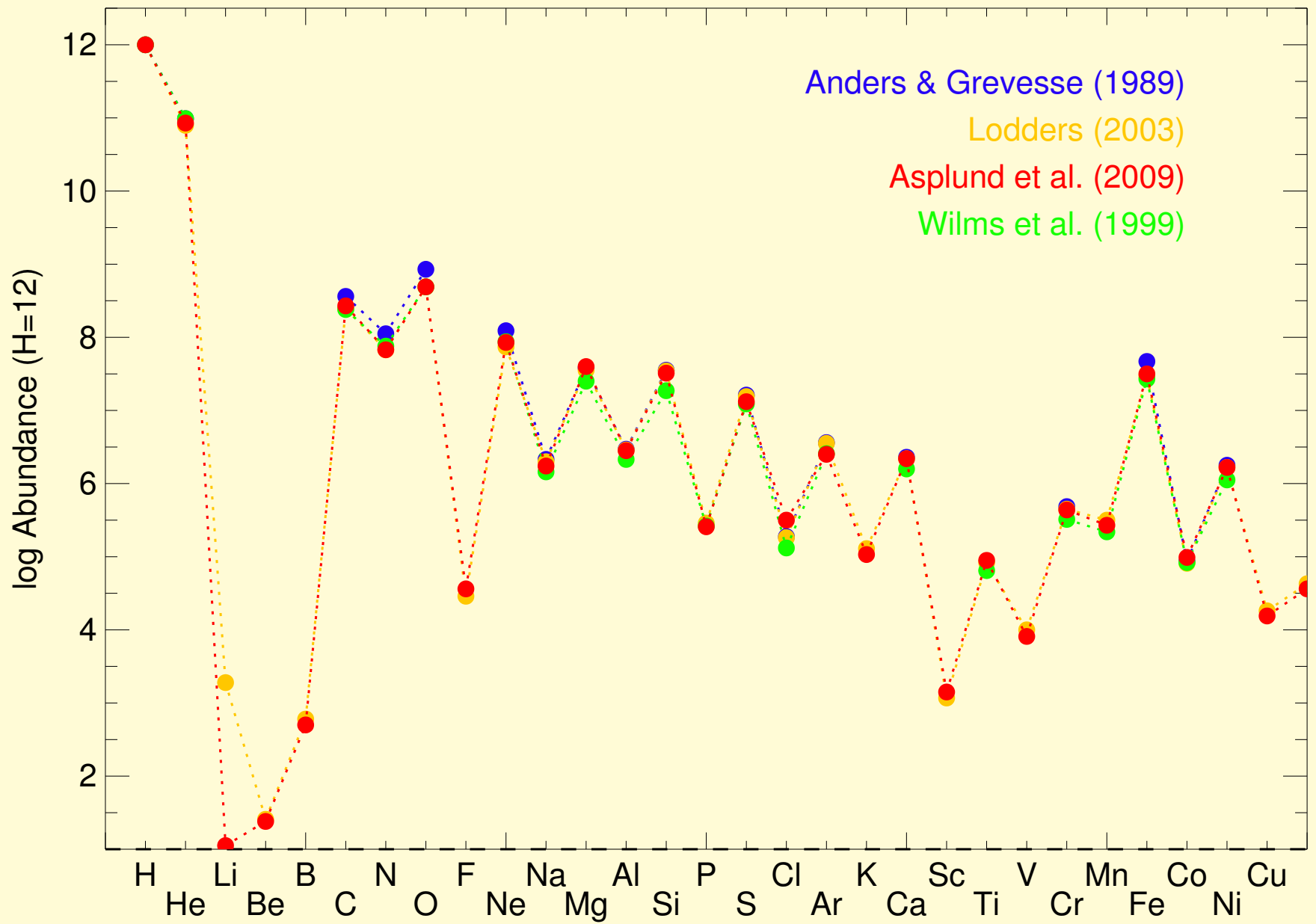
1. **Elemental abundances**
2. **Photoabsorption cross section**
3. **Influence of dust**

Any errors in the above will distort the inferred source spectrum!

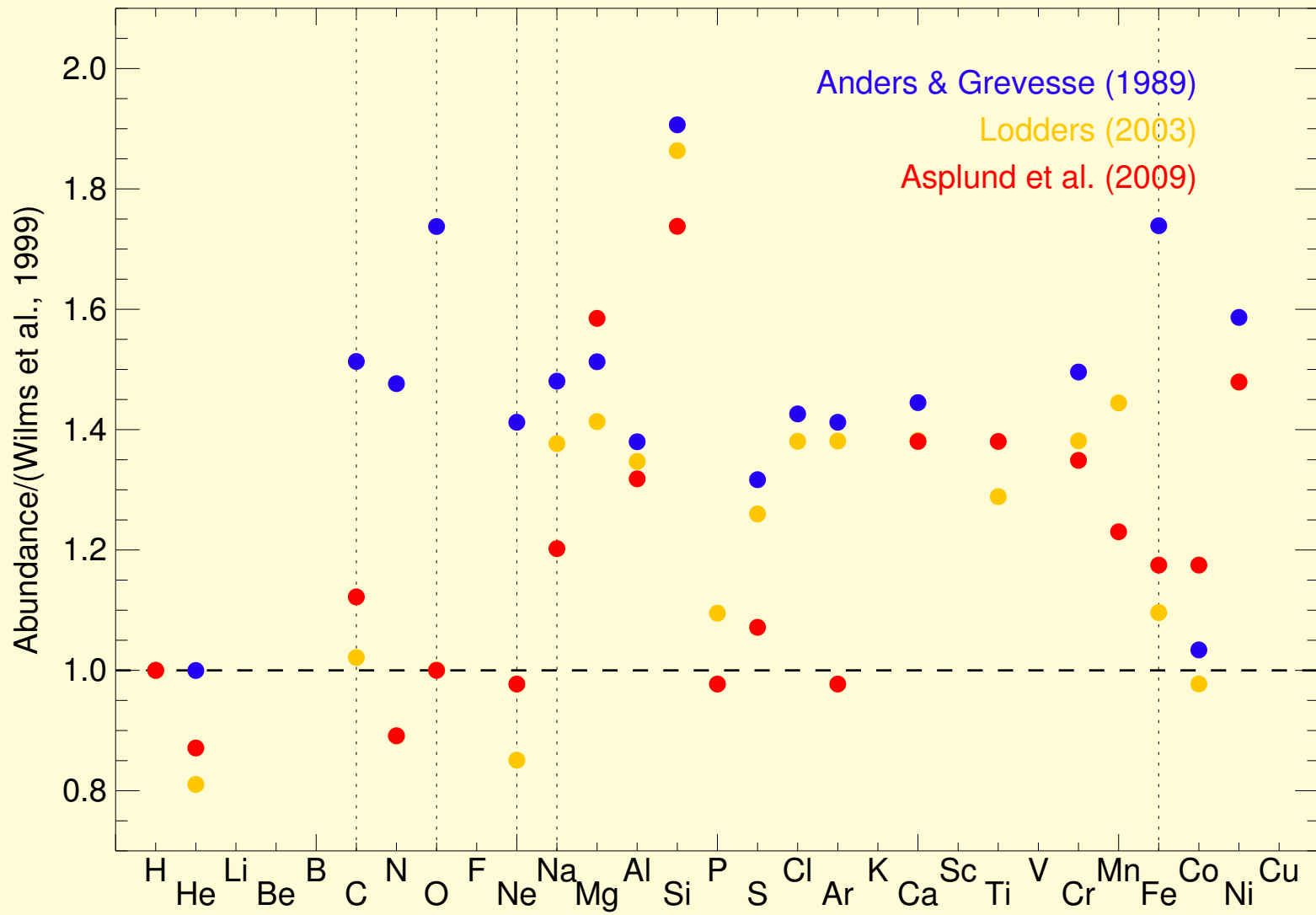


Although you use  $N_{\text{H}}$  to describe the column, what you measure in X-rays is the column of metals.

$\Rightarrow$  Knowing abundances is important to be able to compare  $N_{\text{H}}$  measurements from multiwavelength observations.

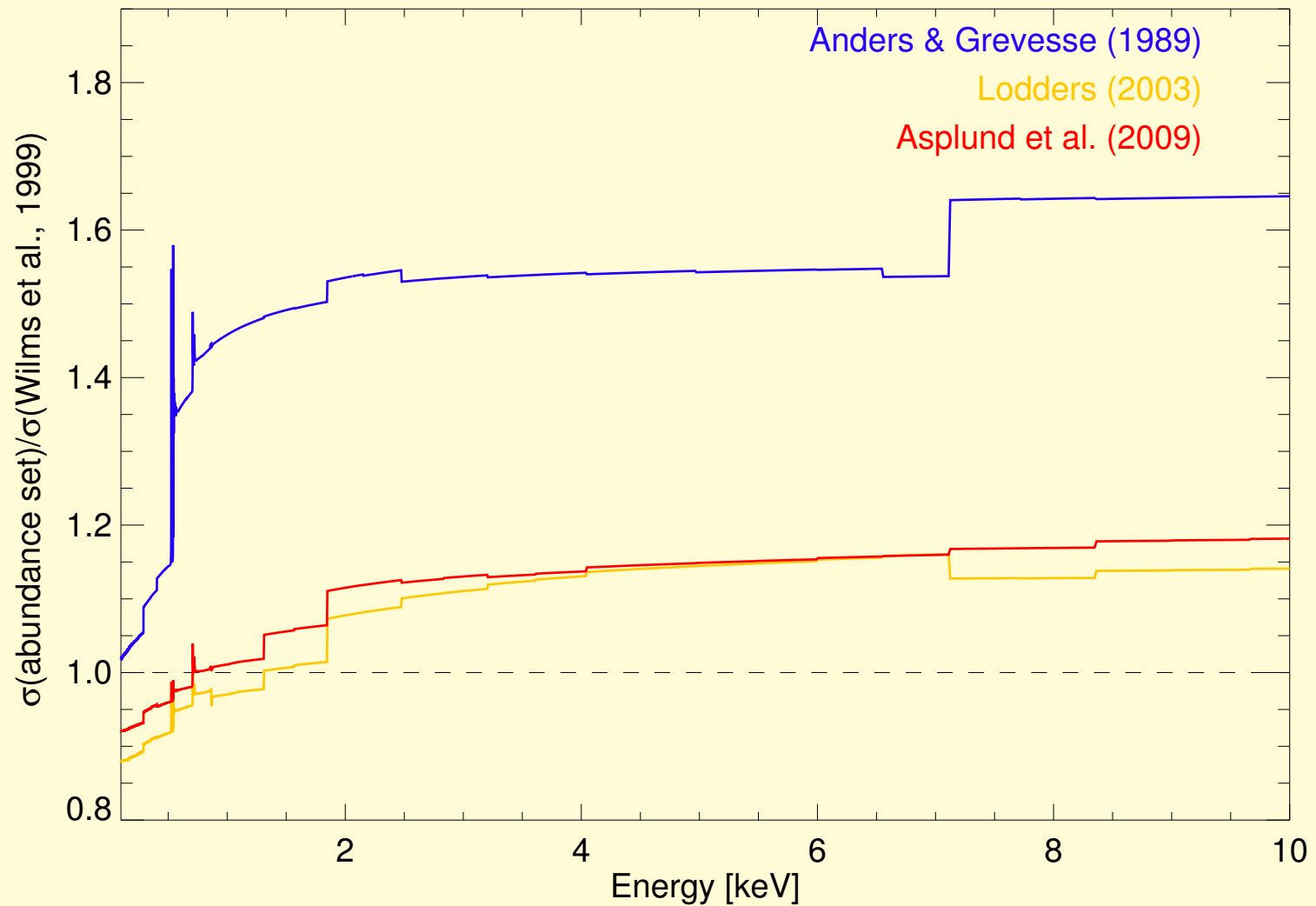


XSPEC-Default: Solar abundance of Anders & Grevesse (1989), which is outdated.  
 Best current values for Sun: Asplund et al. (2009).



“Solar abundances” of Anders & Grevesse (1989):  $\sim 40\%$  higher than ISM and  $\sim 20\%$  higher than modern solar abundance.

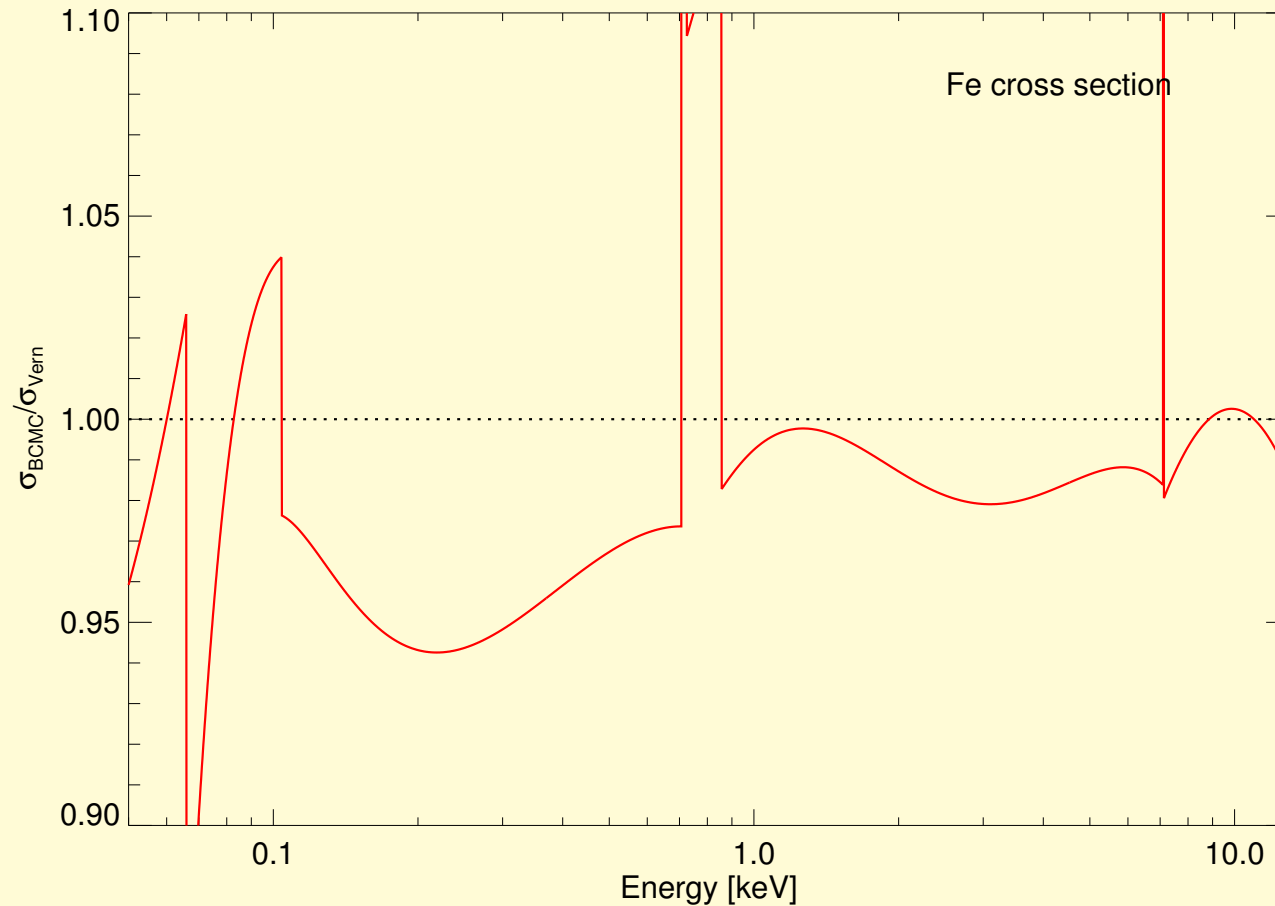
Therefore use Wilms et al. (2000) abundances. Note that Sun is still overabundant wrt. ISM!



To obtain proper  $N_{\text{H}}$ , use Wilms et al. (2000), if not, your column will be  $\sim 10\%–20\%$  too small.

abund wilm in XSPEC...,  
generally gives consistent results with other measurements, cf. Weisskopf et al. (2004).

## 2nd and 3rd subject: Cross sections and solid state effects.



Three sets of cross sections available in fitting programs:

- **wabs**: Total cross section only (no free abundances)
- **xsect bcmc**: Fits to Henke et al. (1993) by Bałucińska-Church & McCammon (1992)
- **xsect vern**: Fits to ab initio QM calculations by Verner et al. (1996) (most trustworthy)

In addition: **solid state effects**:

- Self-shielding: dust reduces absorptivity by shielding  $\implies$  Wilms et al. (2000)
- Modification to cross sections around edges (XAFS)  
see Lee & Ravel (2005) and Lee et al. (2009) for introductions for astrophysicists

Over the past years we have updated the code of Wilms et al. (2000): **tbnew**

<http://pulsar.sternwarte.uni-erlangen.de/wilms/research/tbnew>

*Main advantages:*

- **significantly faster** than phabs, tbabs, comparable to wabs

Due to internal caching algorithms

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- can be used to fit **relative abundances** or **absolute columns**

```
isis> list_free;
```

idx	param	tie-to	freeze	value	min	max	
1	tbnew(1).nH	0	0	<b>1.2</b>	0	10	$10^{22}$
6	tbnew(1).Ne	0	0	<b>0.591</b>	0	5	

vs.

```
isis> list_free;
```

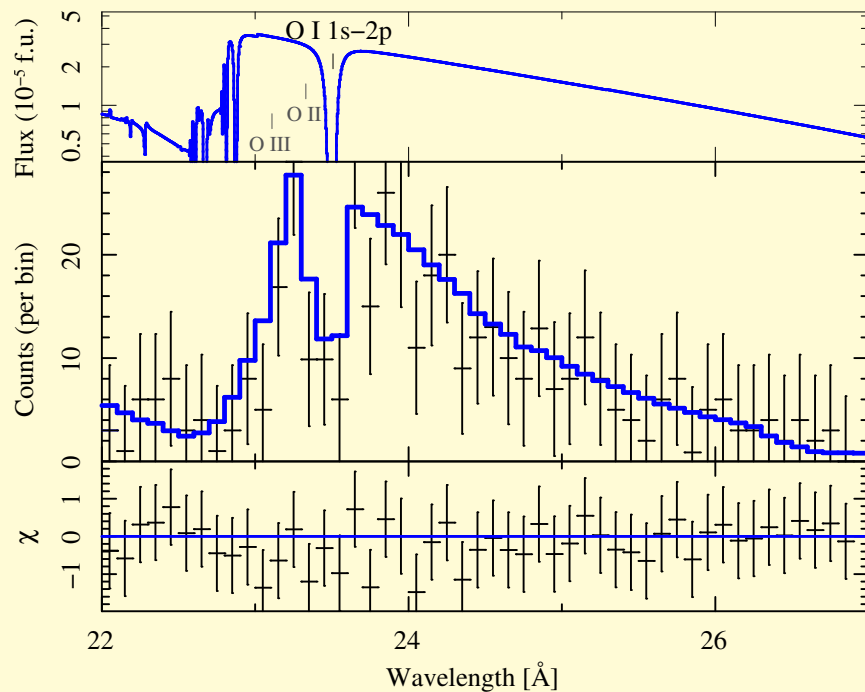
idx	param	tie-to	freeze	value	min	max	
6	tbnew(1).Ne	0	0	<b>-8.7e17</b>	-1e19	0	

Over the past years we have updated the code of Wilms et al. (2000): **tbnew**

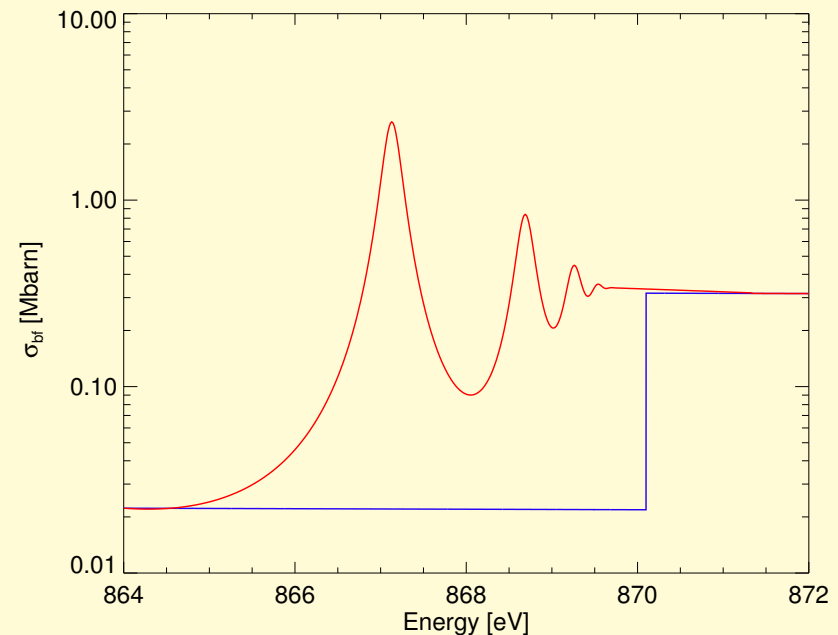
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### Main advantages:

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Due to internal caching algorithms
- can be used to fit **relative abundances** or **absolute columns**
- includes the **detailed structure** of important edges (Fe-L, O-K, Ne-K, [Mg-K])



**O-edge** theory: Gorczyca & McLaughlin (2000)  
Observation: Cygnus X-1 (Hanke et al., 2009)



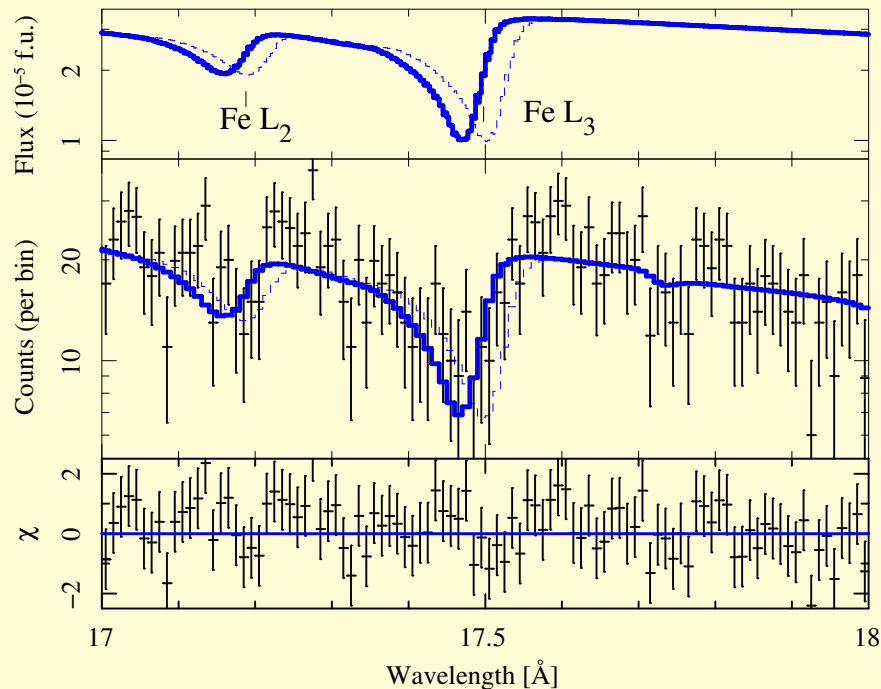
**Ne-edge**: Verner et al. (1996) vs. Gorczyca (2000)  
not trivial: need smooth transition to Verner et al. (1996)!

Over the past years we have updated the code of Wilms et al. (2000): **tbnew**

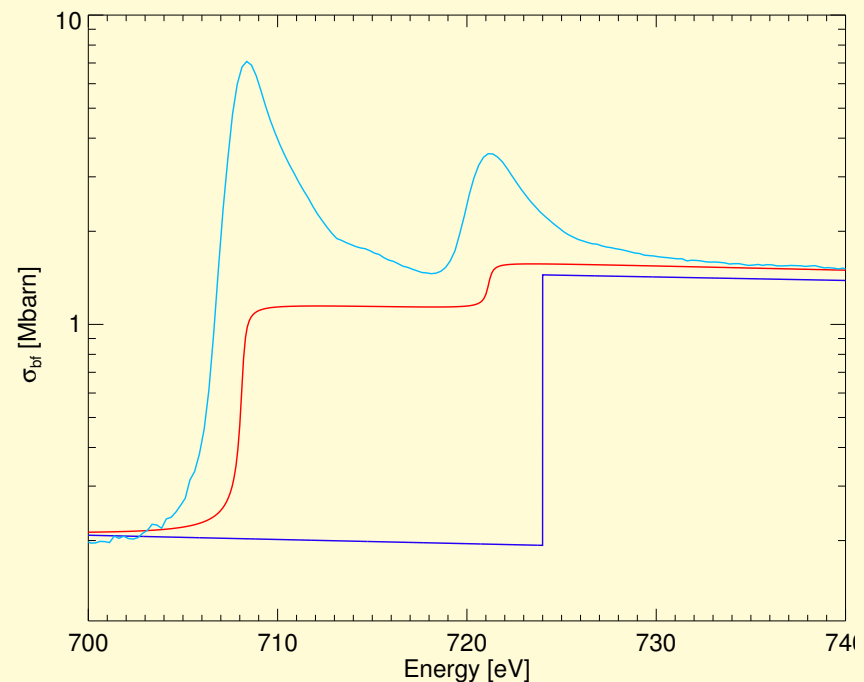
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*Main advantages:*

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Due to internal caching algorithms
- can be used to fit **relative abundances** or **absolute columns**
- includes the **detailed structure** of important edges (Fe-L, O-K, Ne-K, [Mg-K])
- started to include **solid-state effects** (cf. Lee & Ravel, 2005; Lee et al., 2009)



Fe L-edge in Cygnus X-1 (Hanke et al., 2009)



Fe L-edge: Verner et al. (1996), Brennan & Cowan (1992), Kortright & Kim (2000)

Further extension to `tbnew`: `bcdust` (or similar name)

## Step 1: Interface to external cross section data

- FITS-files listing energy and cross section
- Specification of elemental composition to allow depletion calculation

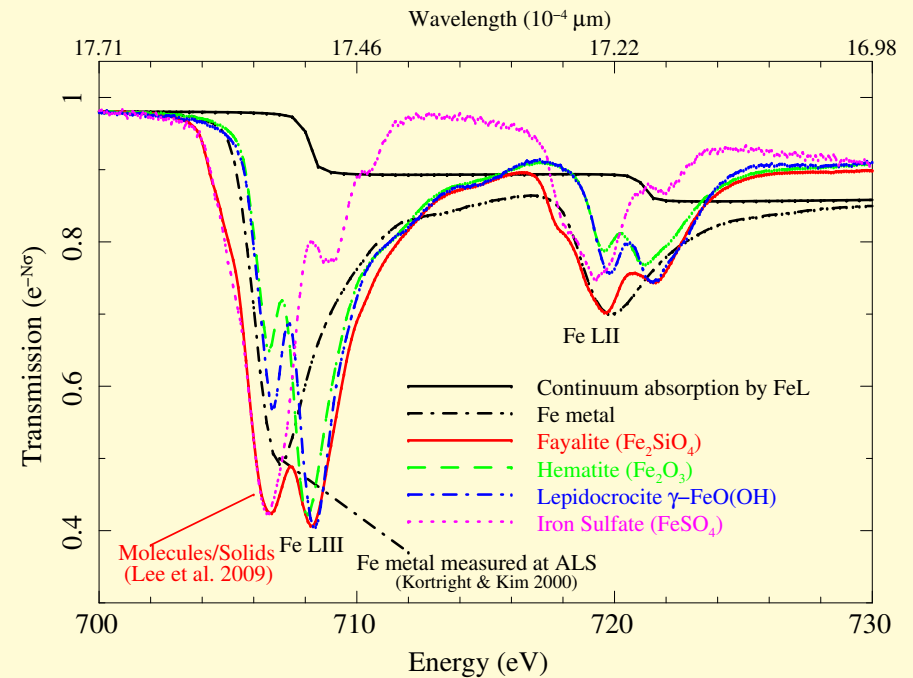
- Optional extrapolation (MBACK/splines) to get smooth transition to vacuum cross section

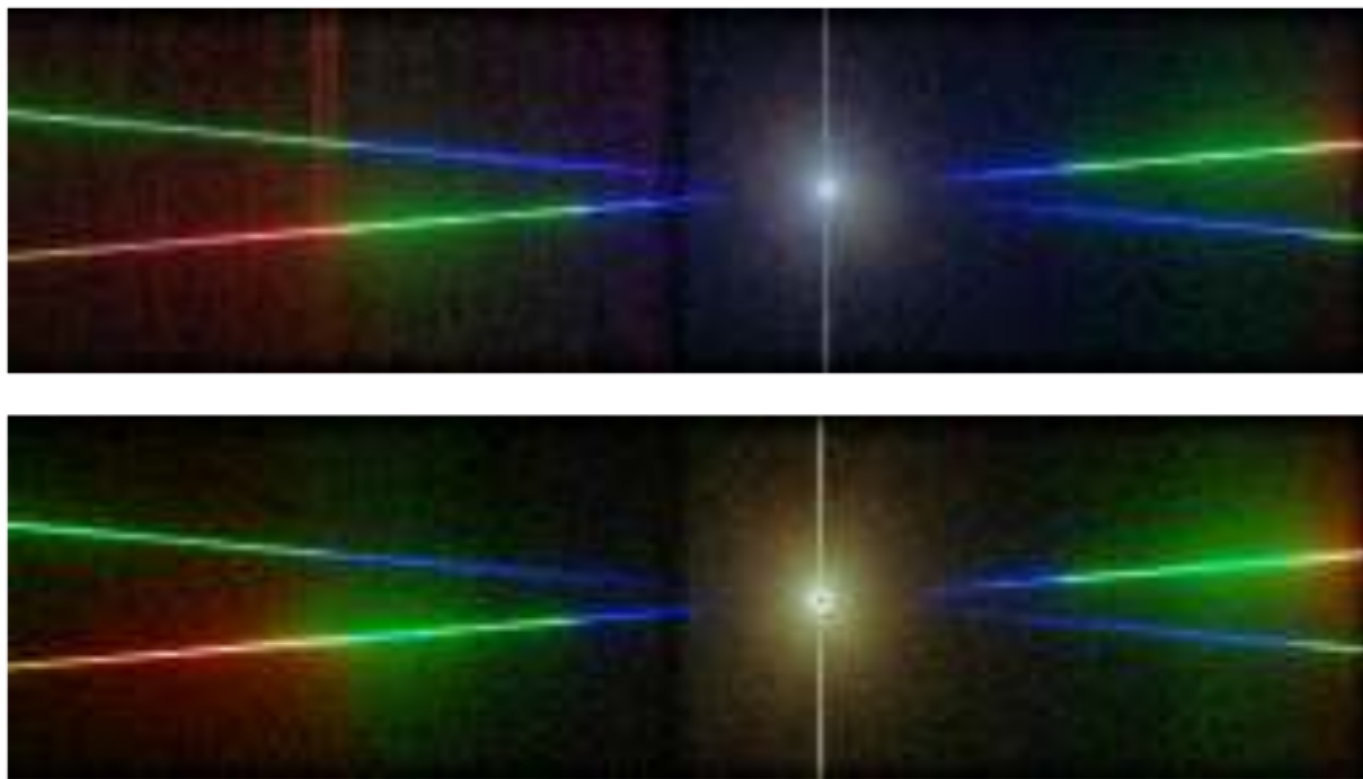
... code done in IDL; rewrite in C almost done, after this: testing phase; release 2012 Oct./Nov.

If this works:

- build library of compound cross sections

see <http://xafs.org/JuliaLee/Standards> and Lee et al. (2009)





Hanke (2010, PhD Thesis)

## Step 2: halo modeling?

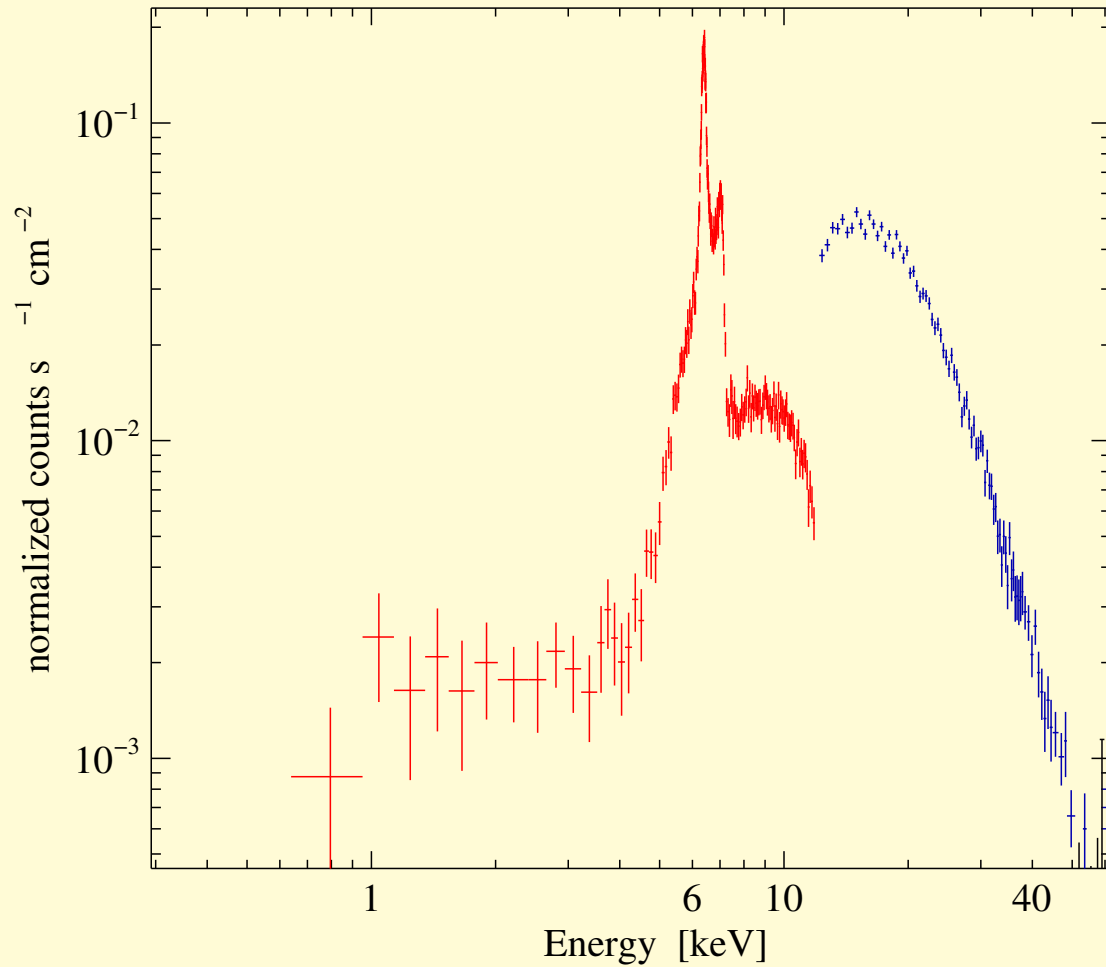
Plans so far...

- Using assumed dust composition and cross sections, build halo model
- Interface with point spread function to allow proper fitting of point sources with halo contribution

Difficult to do in XSPEC data model, but can do this in ISIS and (perhaps) Sherpa

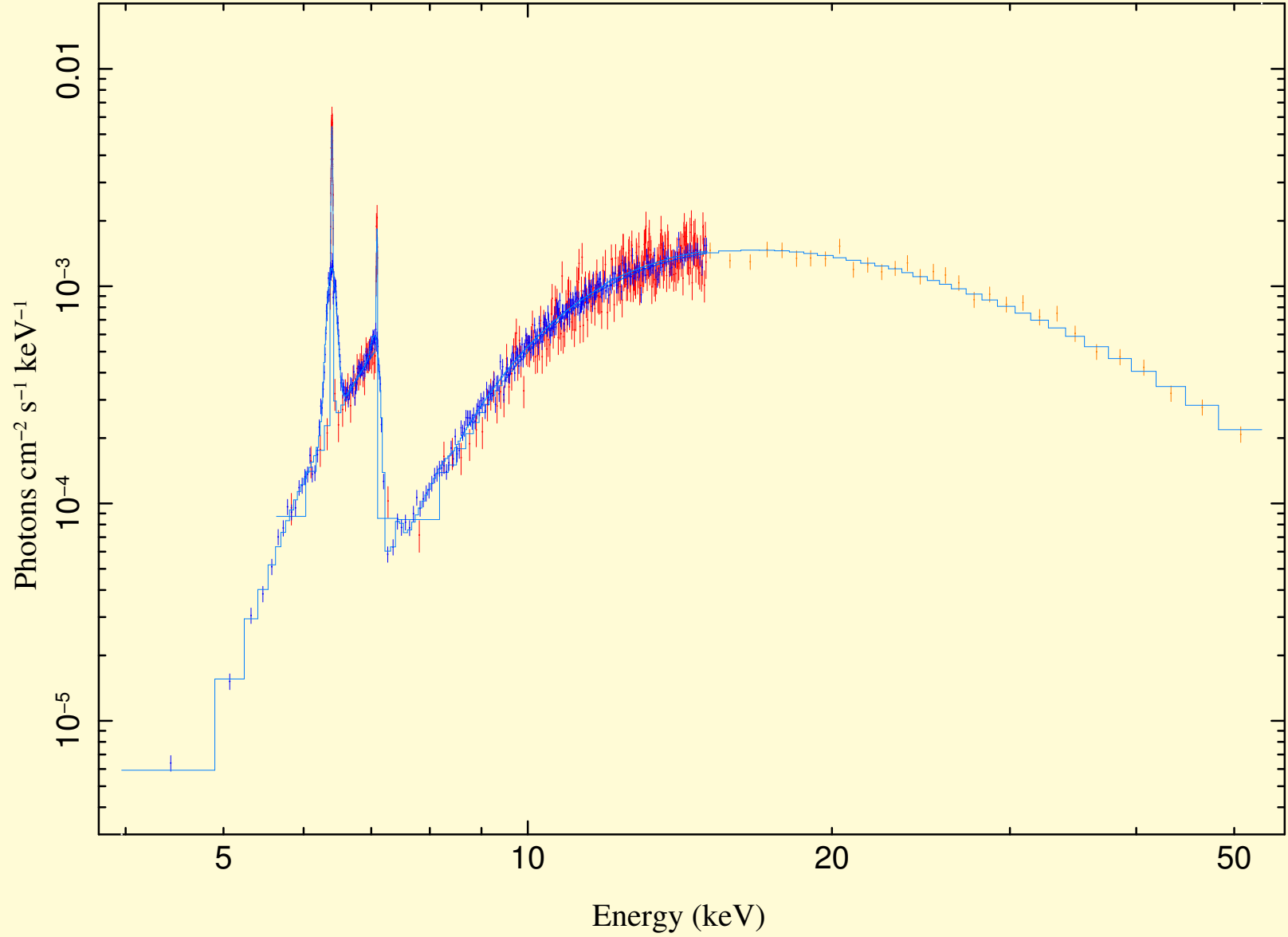
One of the most important discoveries by *INTEGRAL*: “IGR sources”, i.e., population of accreting neutron stars with  $N_{\text{H}} \gg 10^{22} \text{ cm}^{-2}$ .

(Walter et al., 2004; Filliatre & Chaty, 2004)

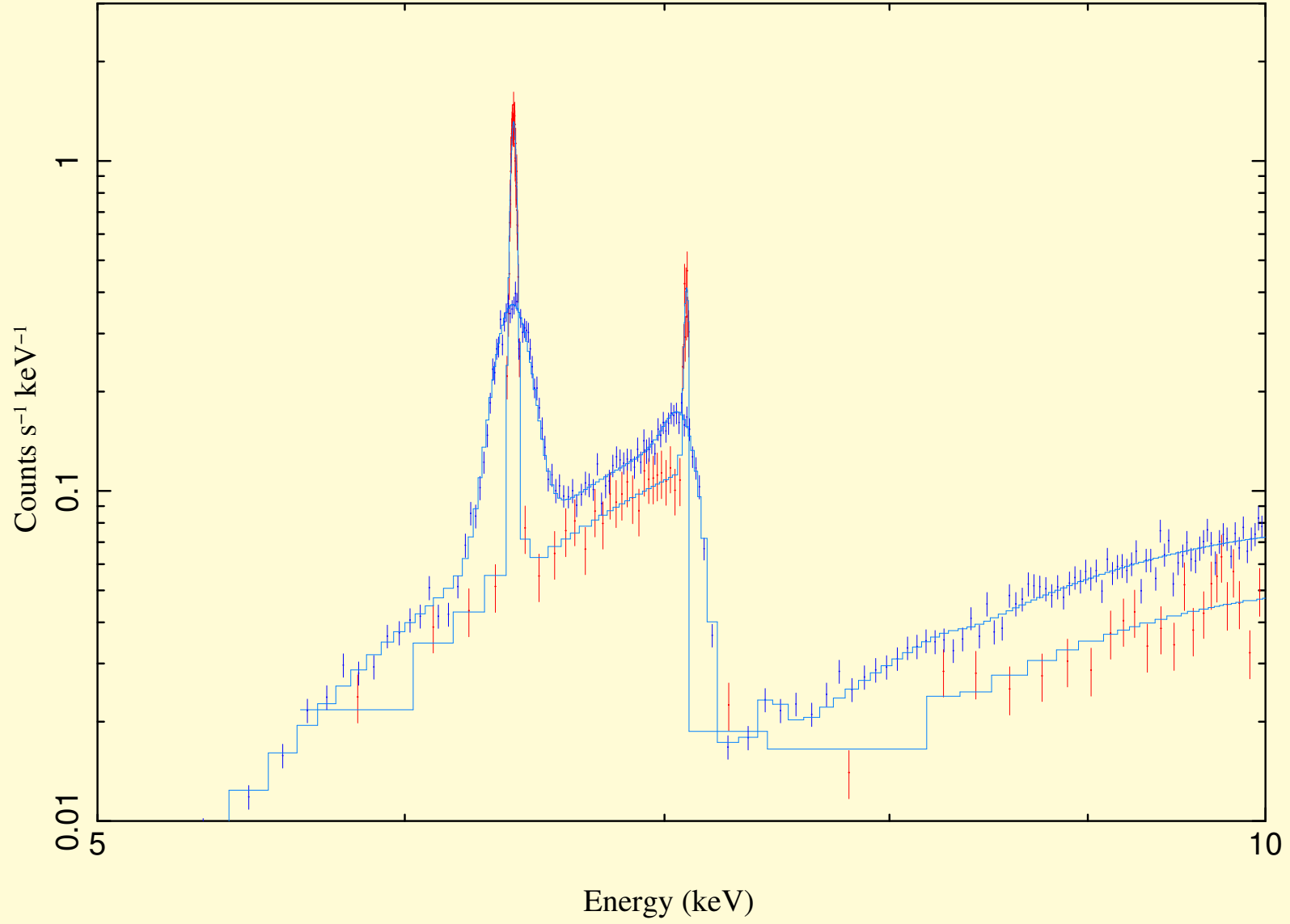


- up to 50% of all neutron stars in Galaxy
- Fluorescent Fe K $\alpha$  line can contribute >50% of flux <10 keV
- Fe line: ionization state of wind (ratio Fe K $\alpha$ /Fe K $\beta$  – not well known!)
- Absorber geometry from Compton shoulder (e.g., Matt & Guainazzi, 2003; Watanabe et al., 2003)

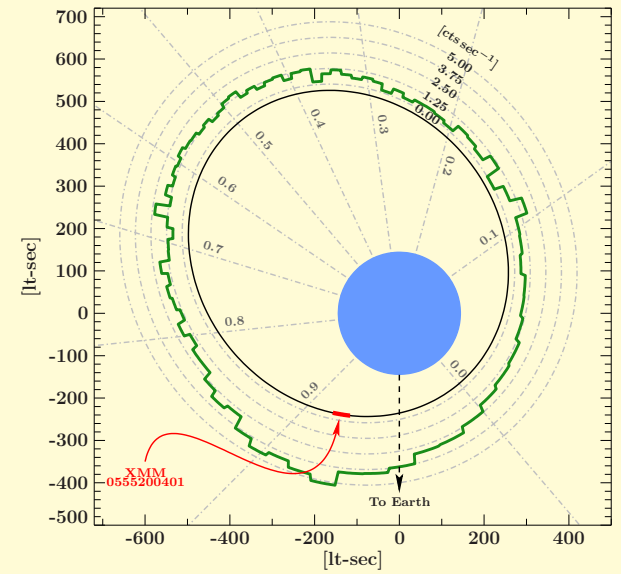
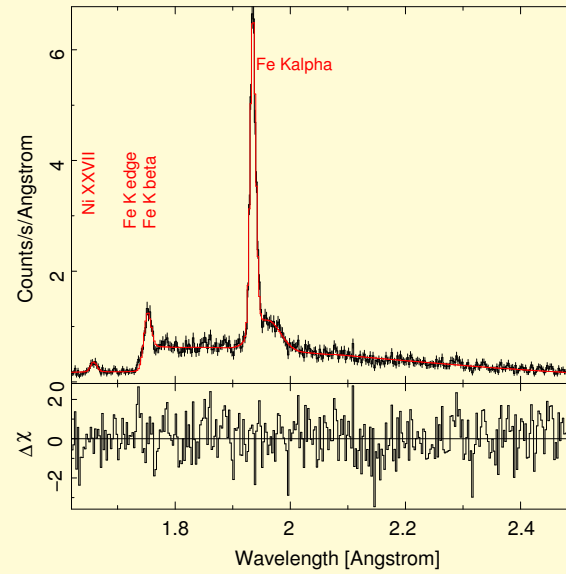
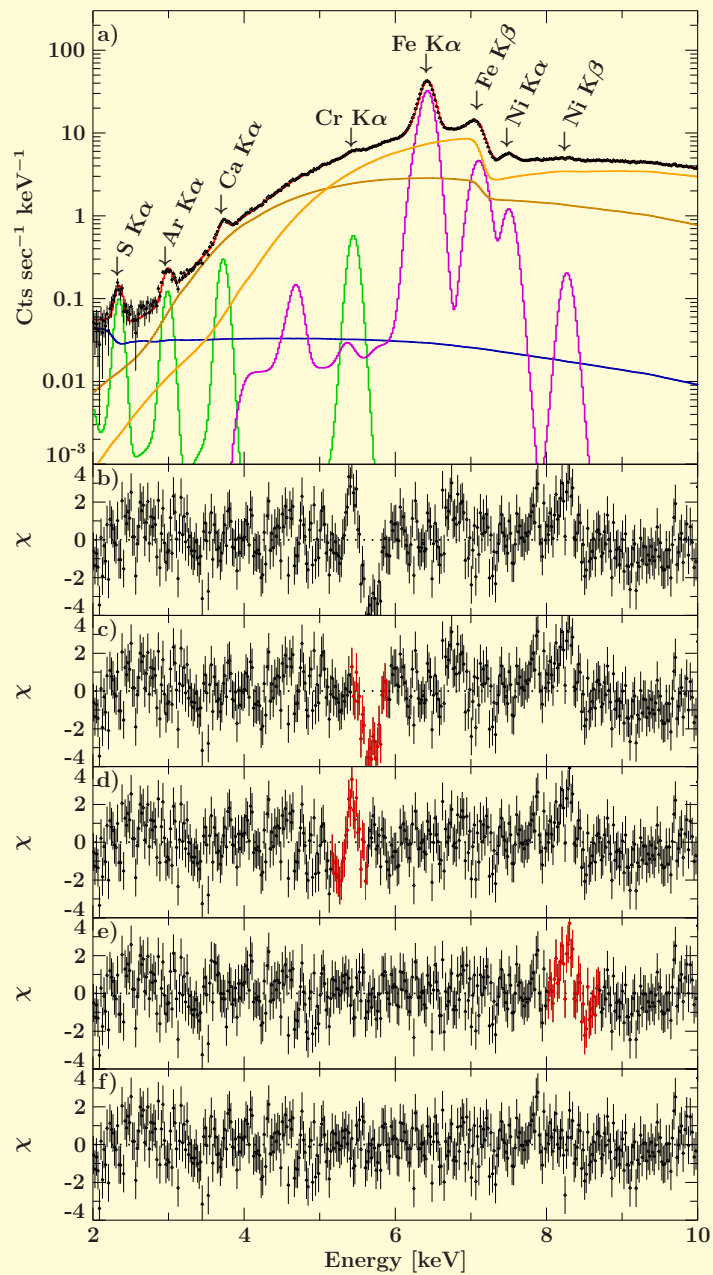
(Barragán et al., 2009; Barragán et al., 2011)



IGR J16318-4848: Model (100 ksec)



IGR J16318—4848: Fe-Band (100 ksec)

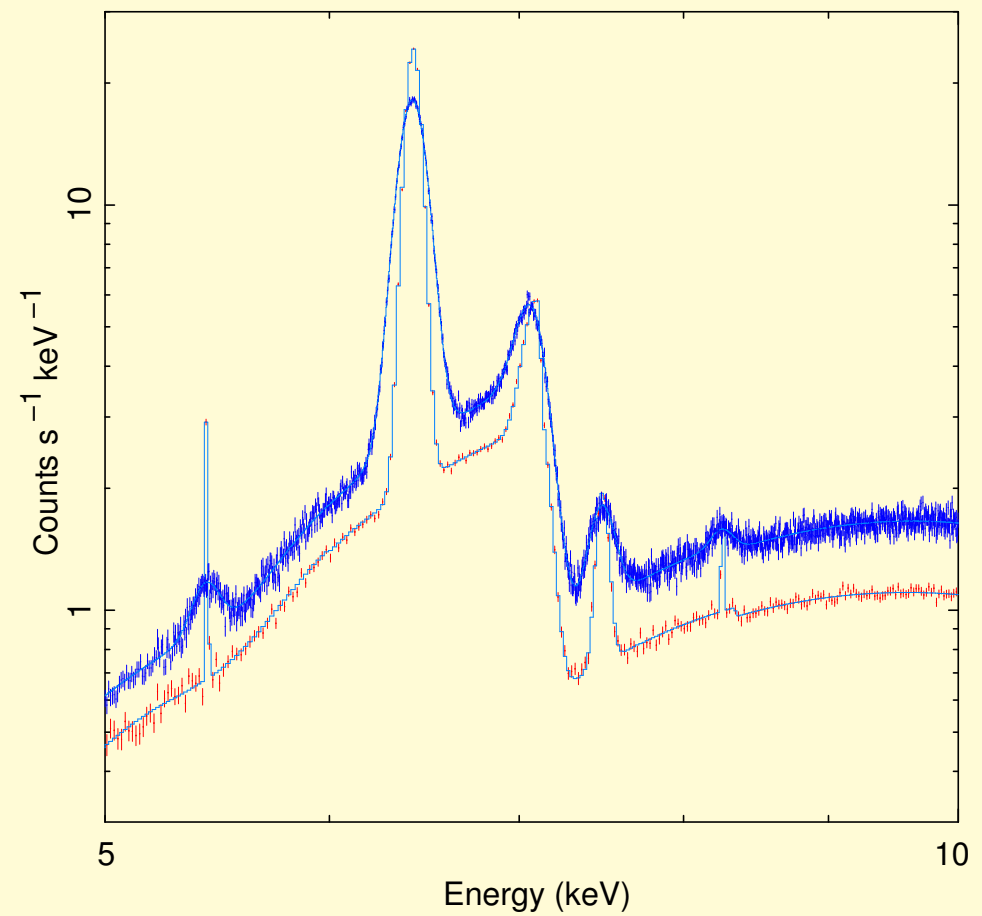
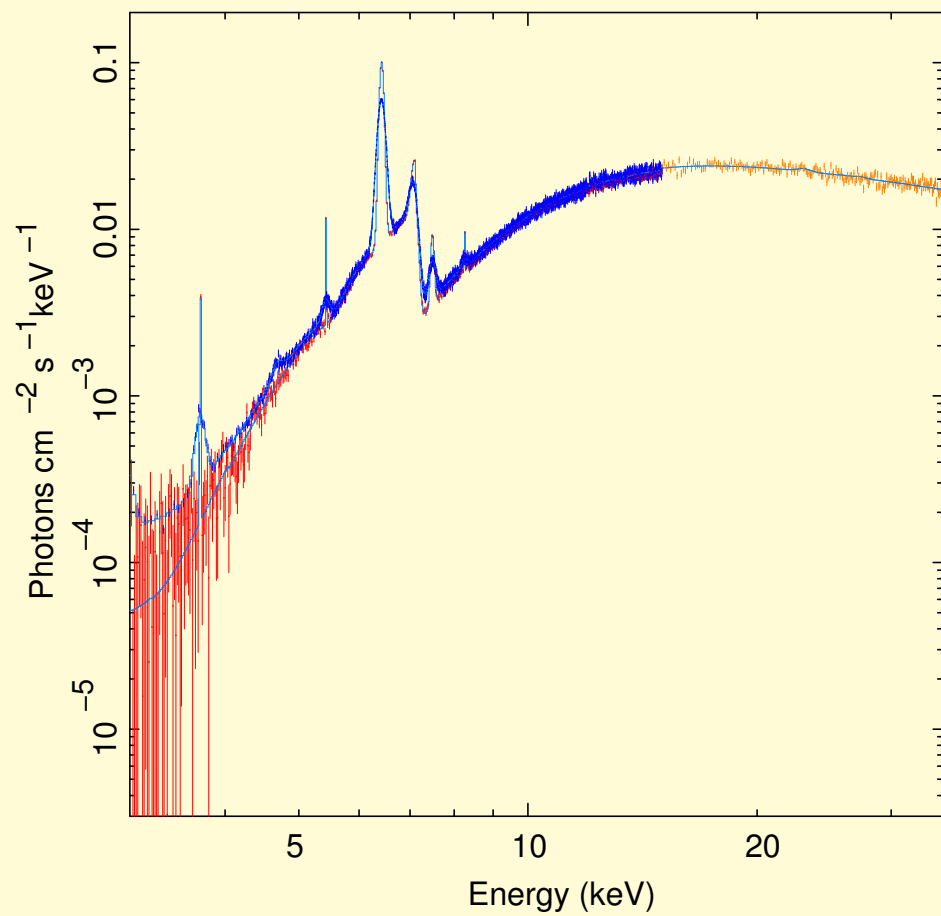


### Pre-periastron flare of Be-system GX 301–2:

- GX 301–2:  $P_{\text{orb}} = 41.5 \text{ d}$ ,  $P_{\text{pulse}} \sim 685 \text{ s}$ ,  $e = 0.47$
- $N_{\text{H}} \sim 10^{24} \text{ cm}^{-2}$
- large number of fluorescent lines

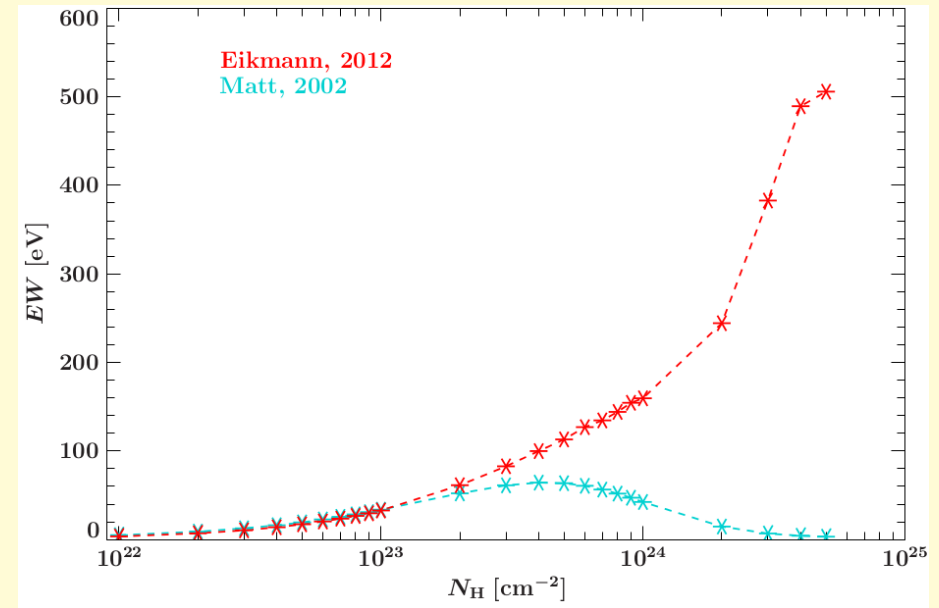
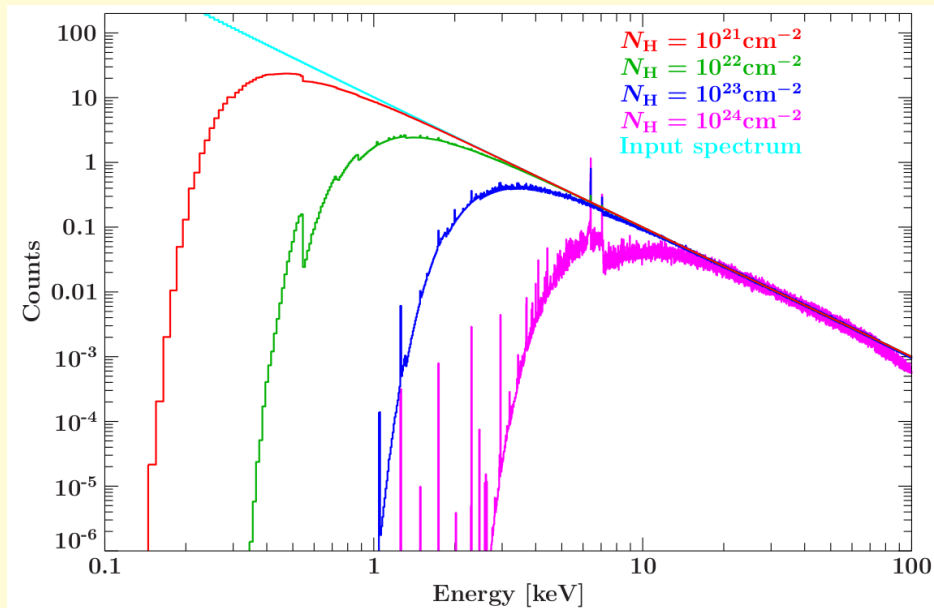
Probably low ionization stages, but difficult to measure with *XMM-Newton*.

(Fürst et al., 2011, Torrejón et al., 2011)



GX 301–2: Model and soft lines (100 ksec; assuming broadish lines)

⇒ Astro-H will resolve Compton shoulder, separate Fe  $K\beta$  and Fe edge

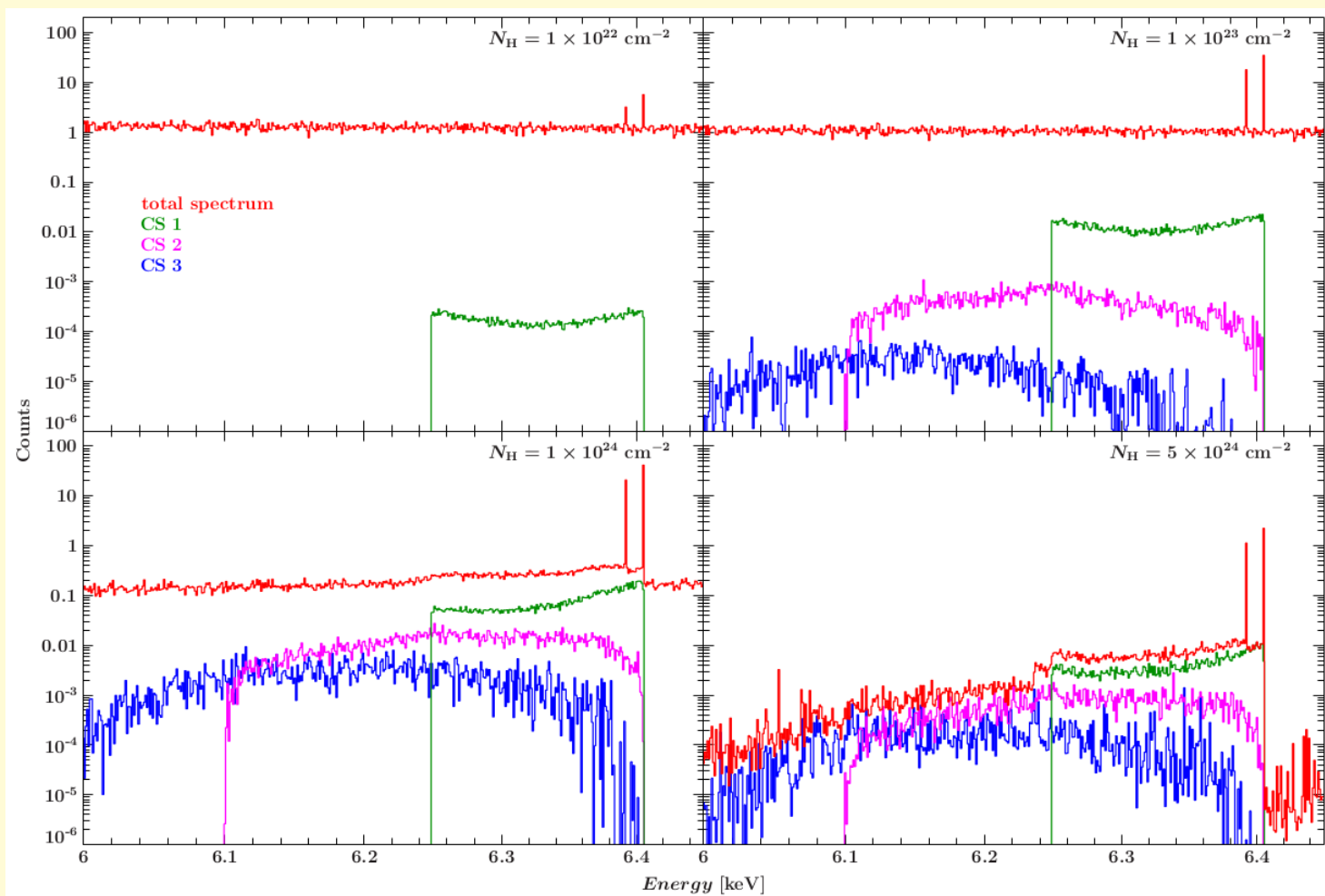


Eikmann et al. (2012, in prep)

Further improvement of absorption code: **optically thick absorption**

requires convolution model

- Fluorescence lines



Eikmann et al. (2012, in prep)

Further improvement of absorption code: **optically thick absorption**

requires convolution model

- Fluorescence lines
- Compton broadening

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Extension to large  $N_{\text{H}}$

32b

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