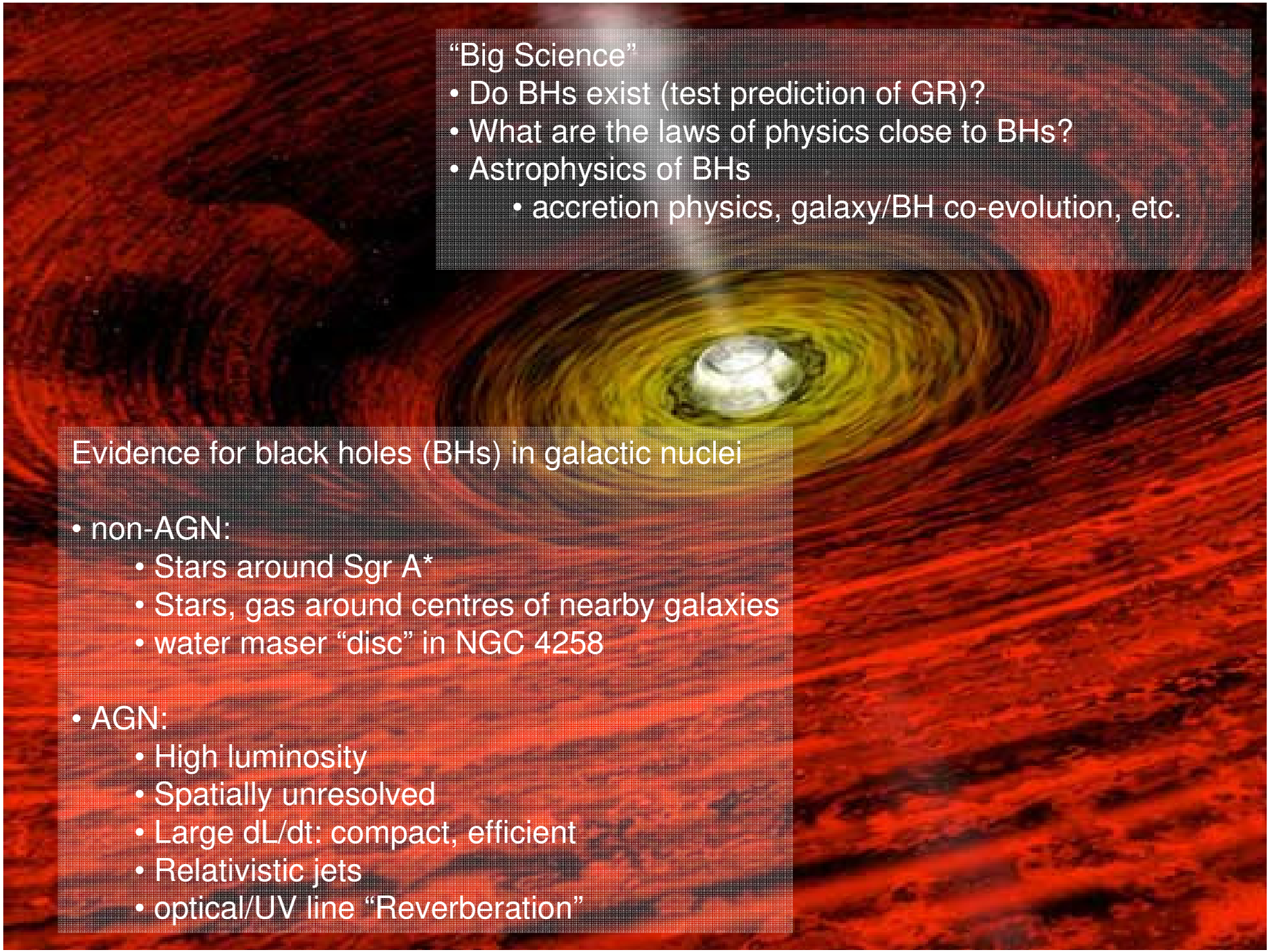
Relativistic gravity, AGN

and the next generation X-ray Observatory

Simon Vaughan

(University of Leicester)

Image credit: bosch.com



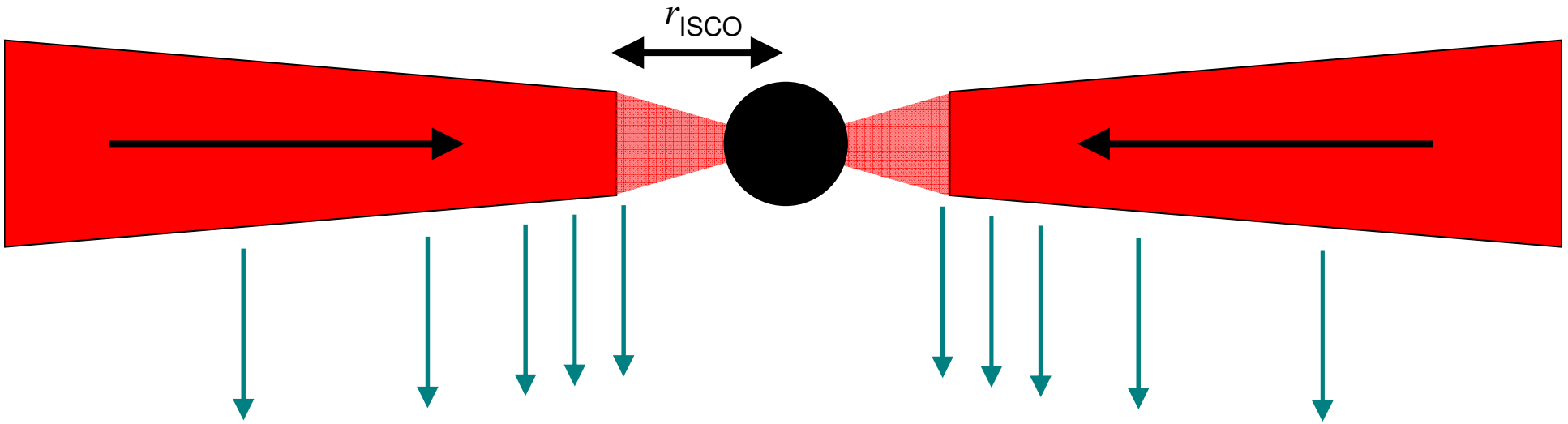
"Big Science"

- Do BHs exist (test prediction of GR)?
- What are the laws of physics close to BHs?
- Astrophysics of BHs
    - accretion physics, galaxy/BH co-evolution, etc.

Evidence for black holes (BHs) in galactic nuclei

- non-AGN:
    - Stars around Sgr A*
    - Stars, gas around centres of nearby galaxies
    - water maser "disc" in NGC 4258
- AGN:
    - High luminosity
    - Spatially unresolved
    - Large dL/dt: compact, efficient
    - Relativistic jets
    - optical/UV line "Reverberation"

Observations from the BH region



Photons (mainly EUV + X-rays)

- Spatial (x,y) – unresolved (until interferometry)
- Time (t) – this talk
- Energy (E) – this talk
- Polarization (PA) – possible with IXO

1. Disklines

The “diskline” model

“thick” accretion flow at ~few r_g

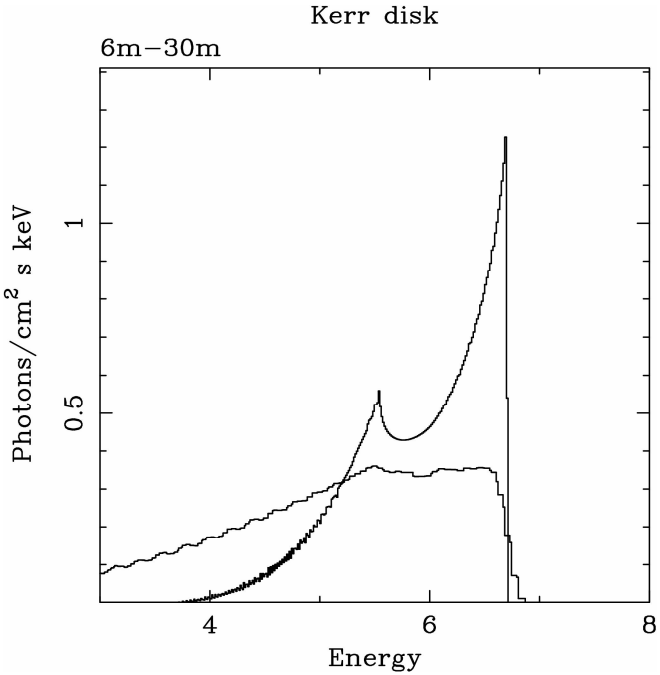
+

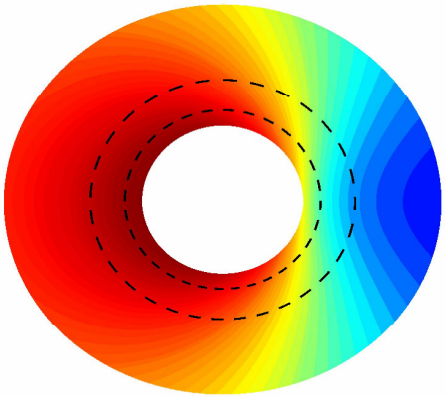
X-rays ~few r_g

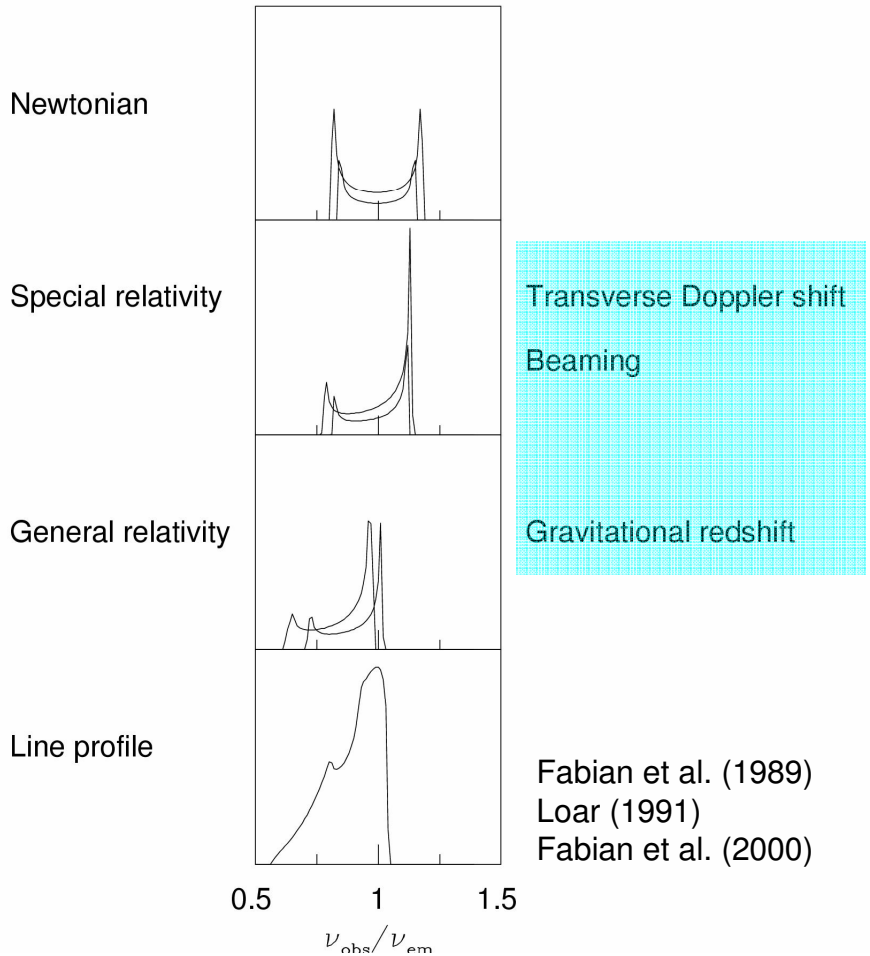
=

“diskline”

Fe is our “probe” near BH







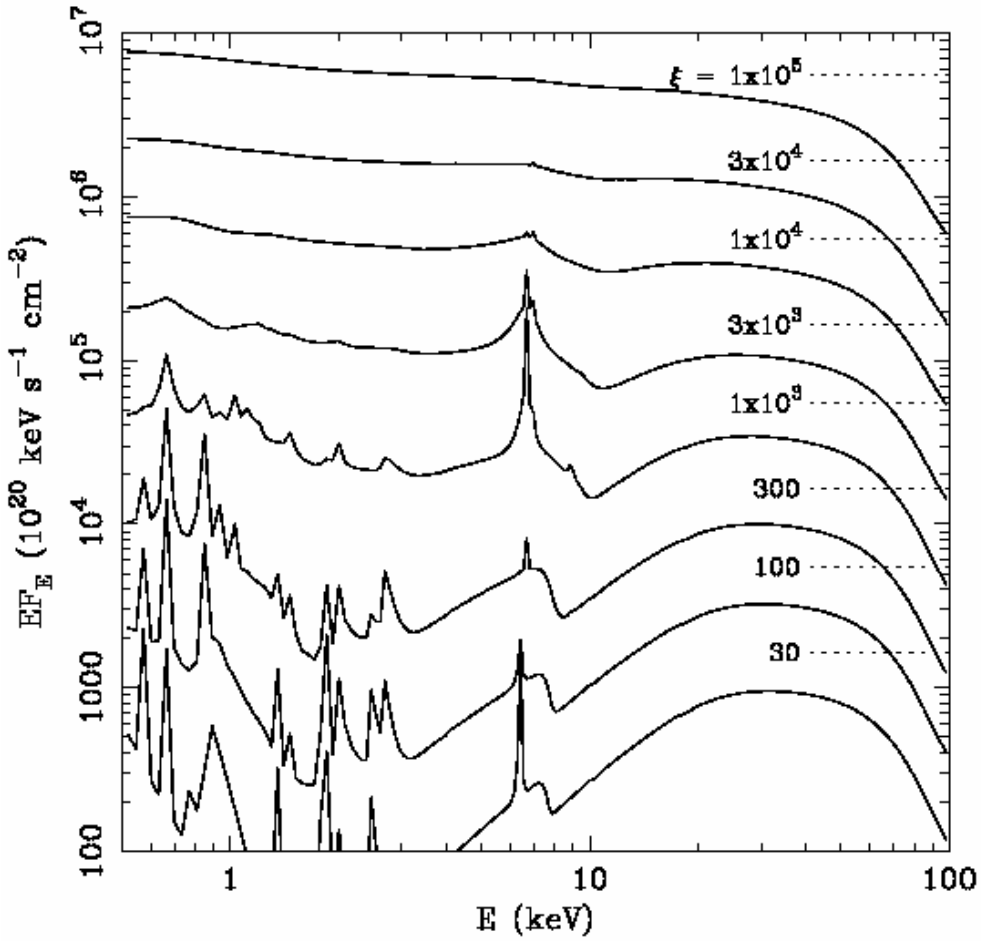
Fabian et al. (1989)
Loar (1991)
Fabian et al. (2000)

What could destroy the diskline(s)?

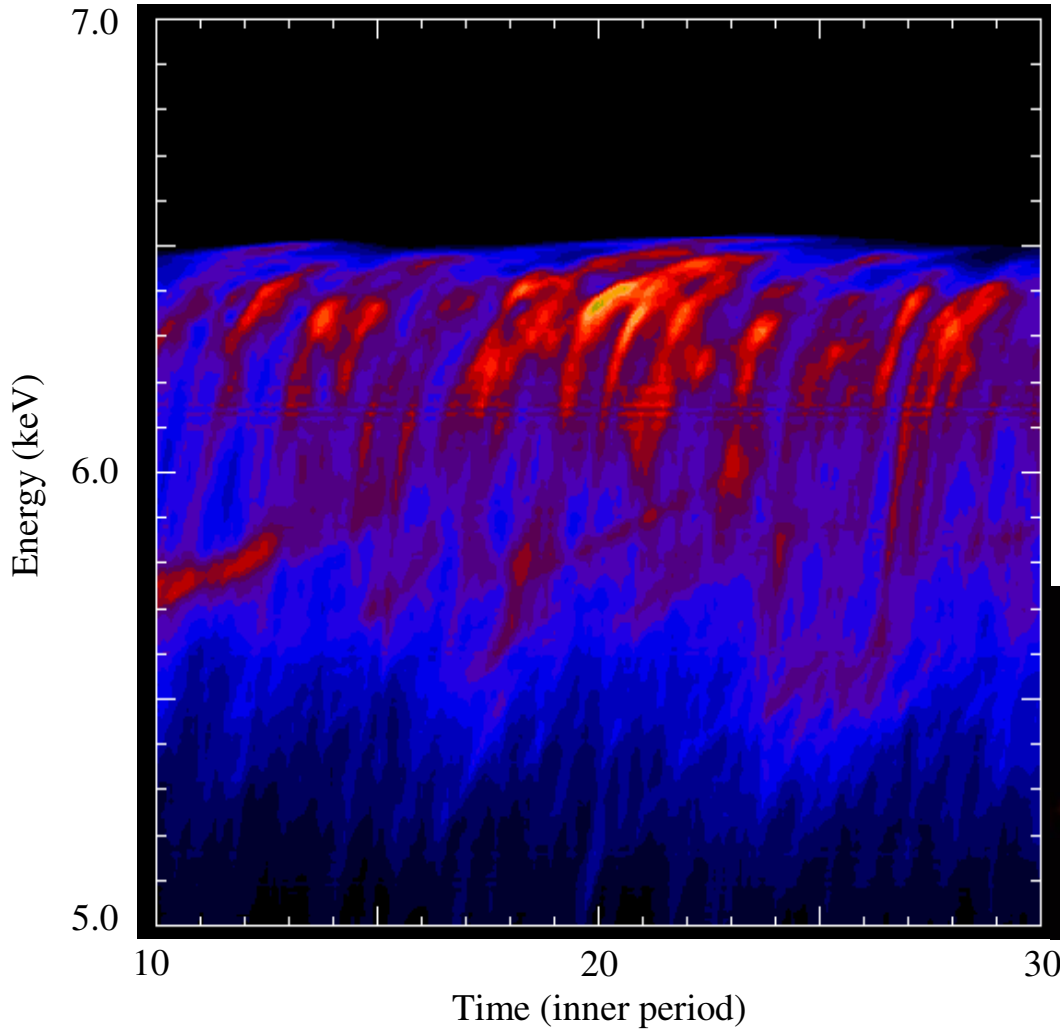
- No Fe^{+0}-Fe^{+25}
  - low abundance
  - complete ionisation
- viewing angle/covering
- electron scattering
- Thick disc truncated
  at r_{in} >> ~few r_g
- No BH/GR ?

[Not just a line!]

See Ross & Fabian et al.; Nayaskshin et al.

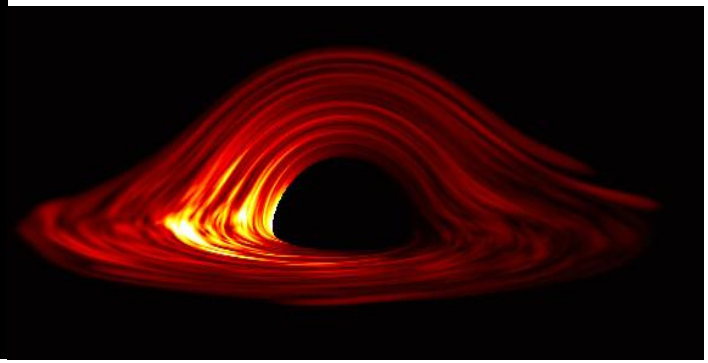


Reverberation

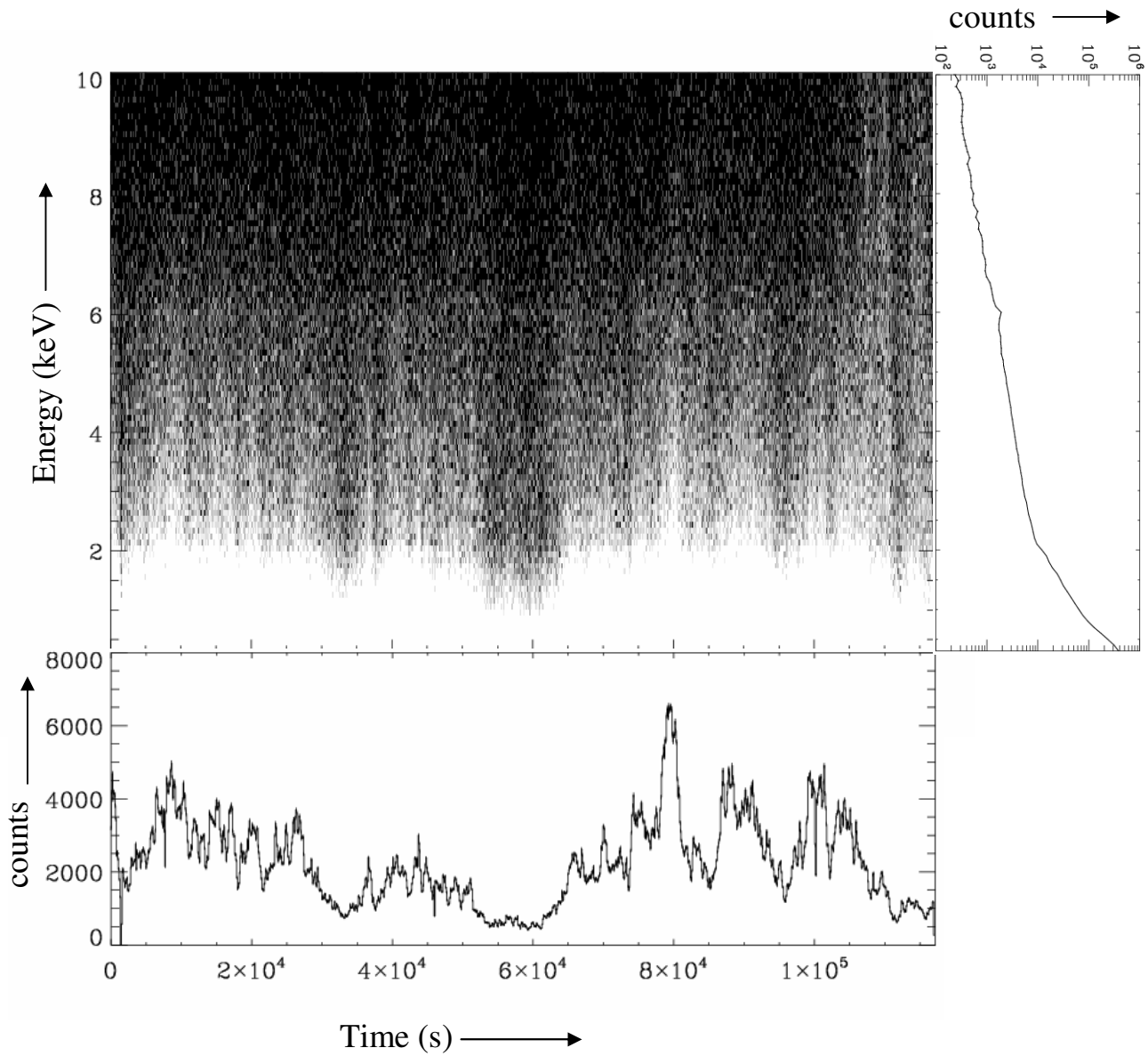


Armitage & Reynolds (2003)

"reverberation" - the X-ray light echo that propagates across the accretion disk due to the finite speed of light.
These reverberation signatures encode detailed information about the spacetime geometry, and might allow for a quantitative test of General Relativity in the very strong field limit.
(Reynolds & Nowak (2003)

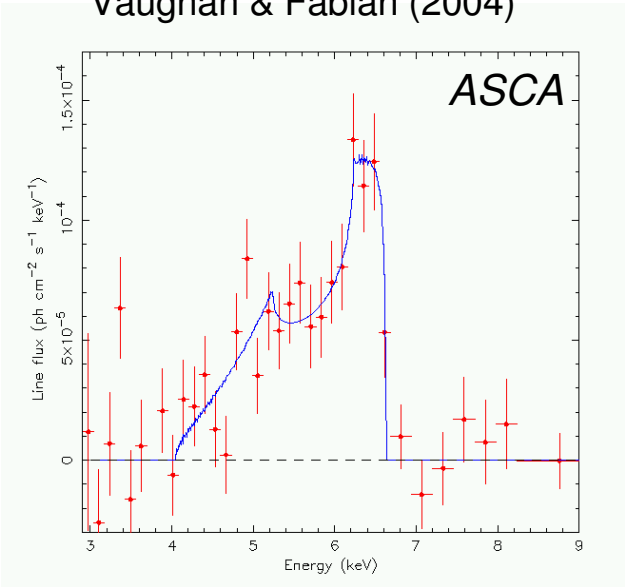


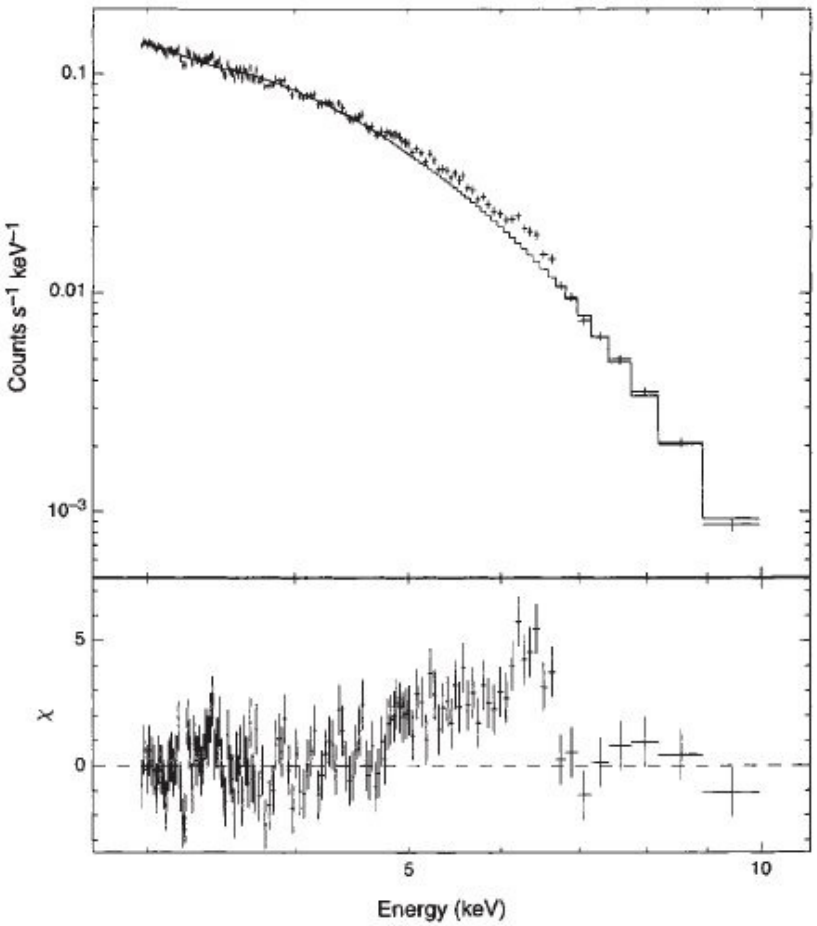
Real data (energy + time)



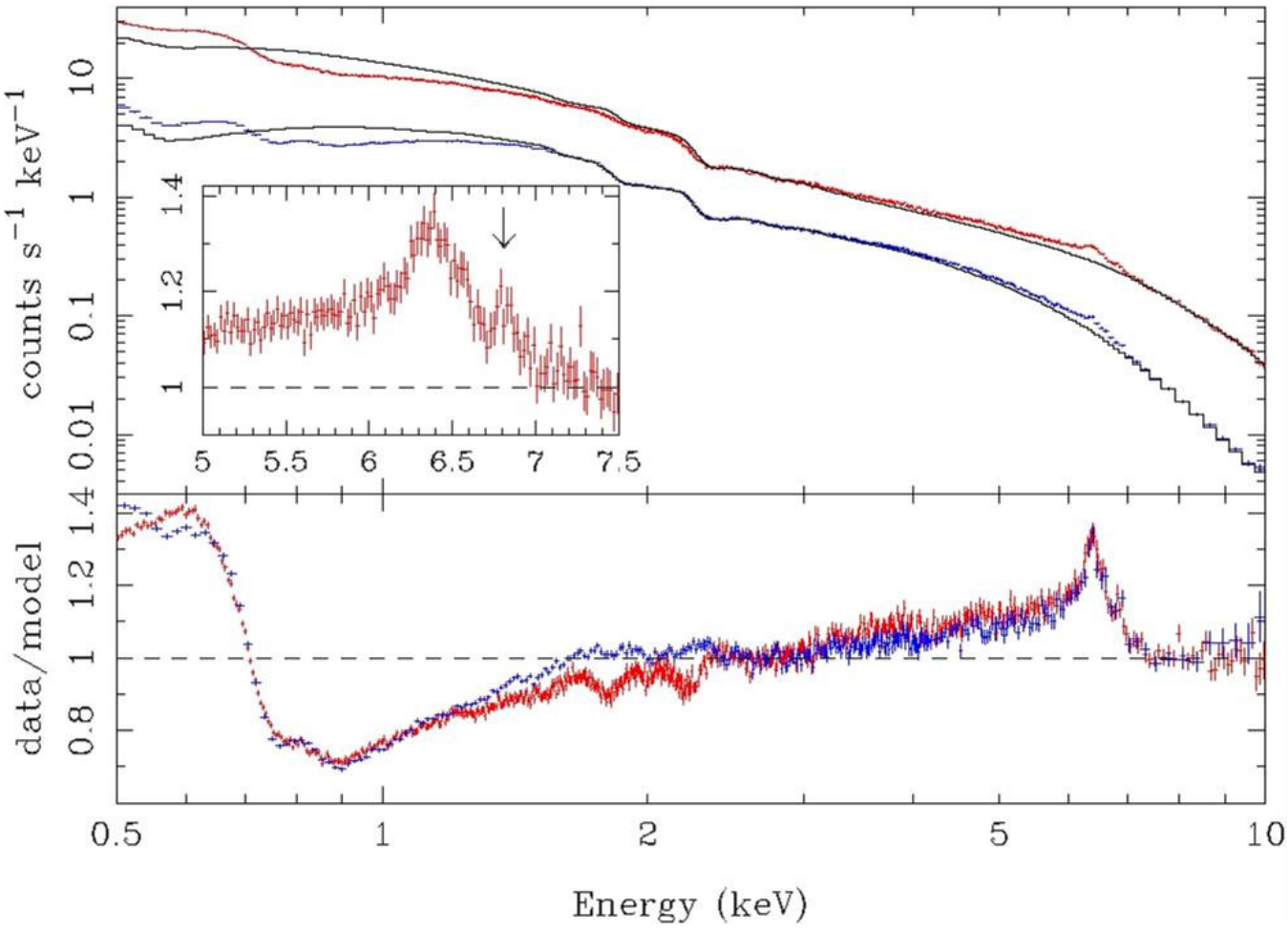
MCG-6-30-15: the “poster child” of broad lines

Tanaka et al. (1995)
Fabian et al. (1995)
Iwasawa et al. (1996)
Nandra et al. (1997)
Inoue & Matsumoto (2001)
Wilms et al. (2001)
Fabian et al. (2002)
Vaughan & Fabian (2004)



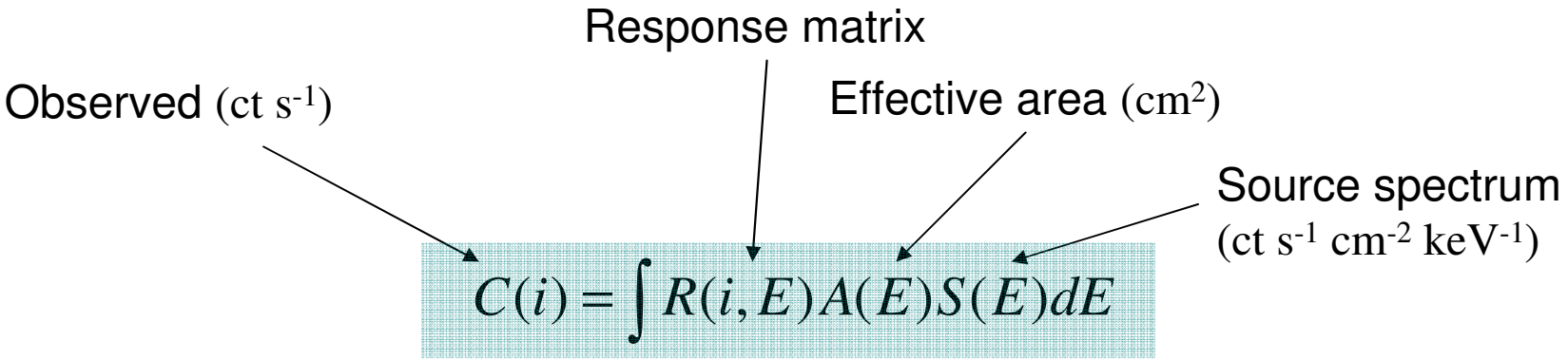


MCG-6-30-15 with *XMM-Newton*: enough photons



Fabian et al. (2002)

How we should all be plotting our spectra



Discrete version
(channel i energy j)

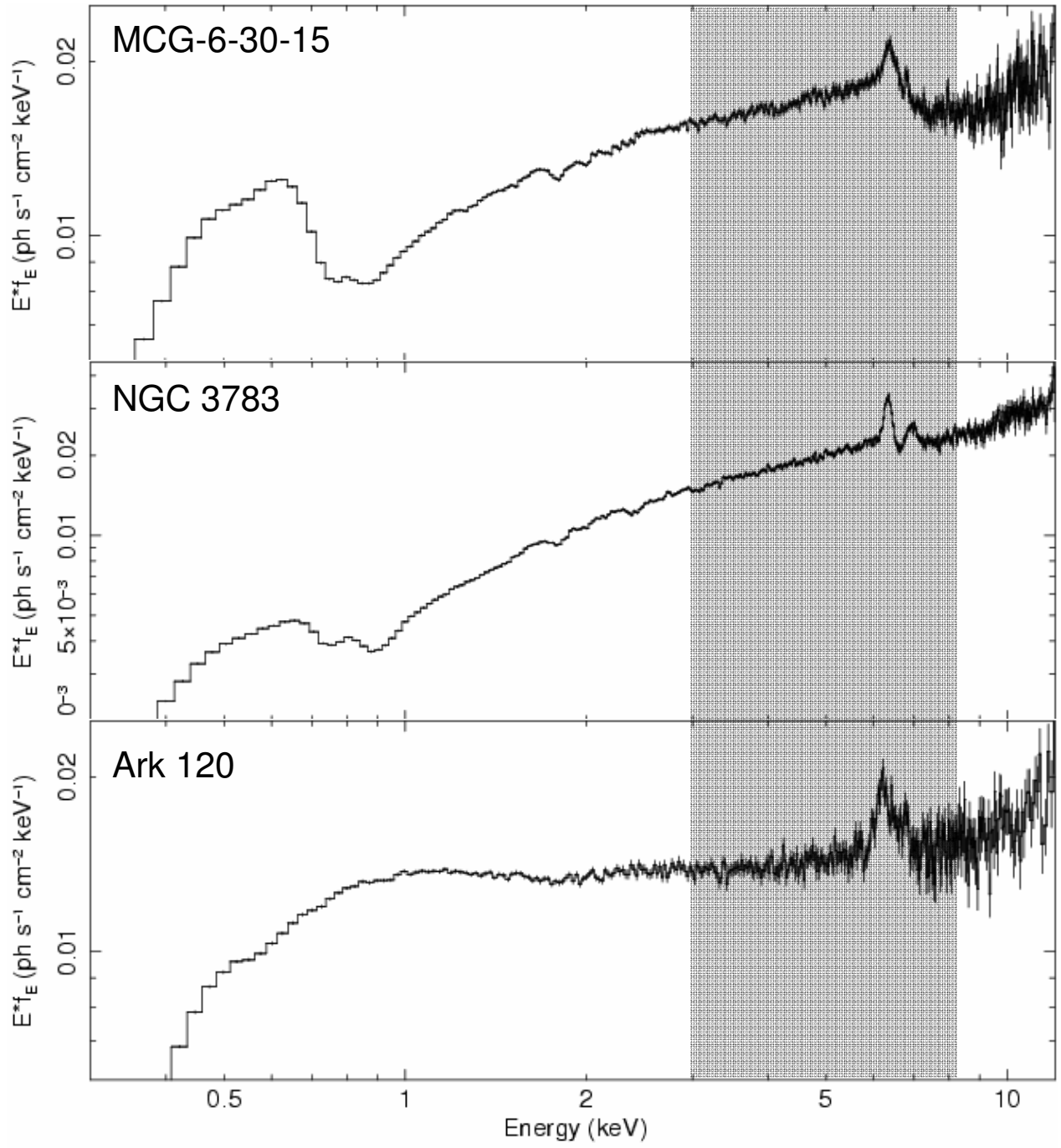
$$C_i = \sum_{j=1}^{N} R_{ij} A_j S_j$$

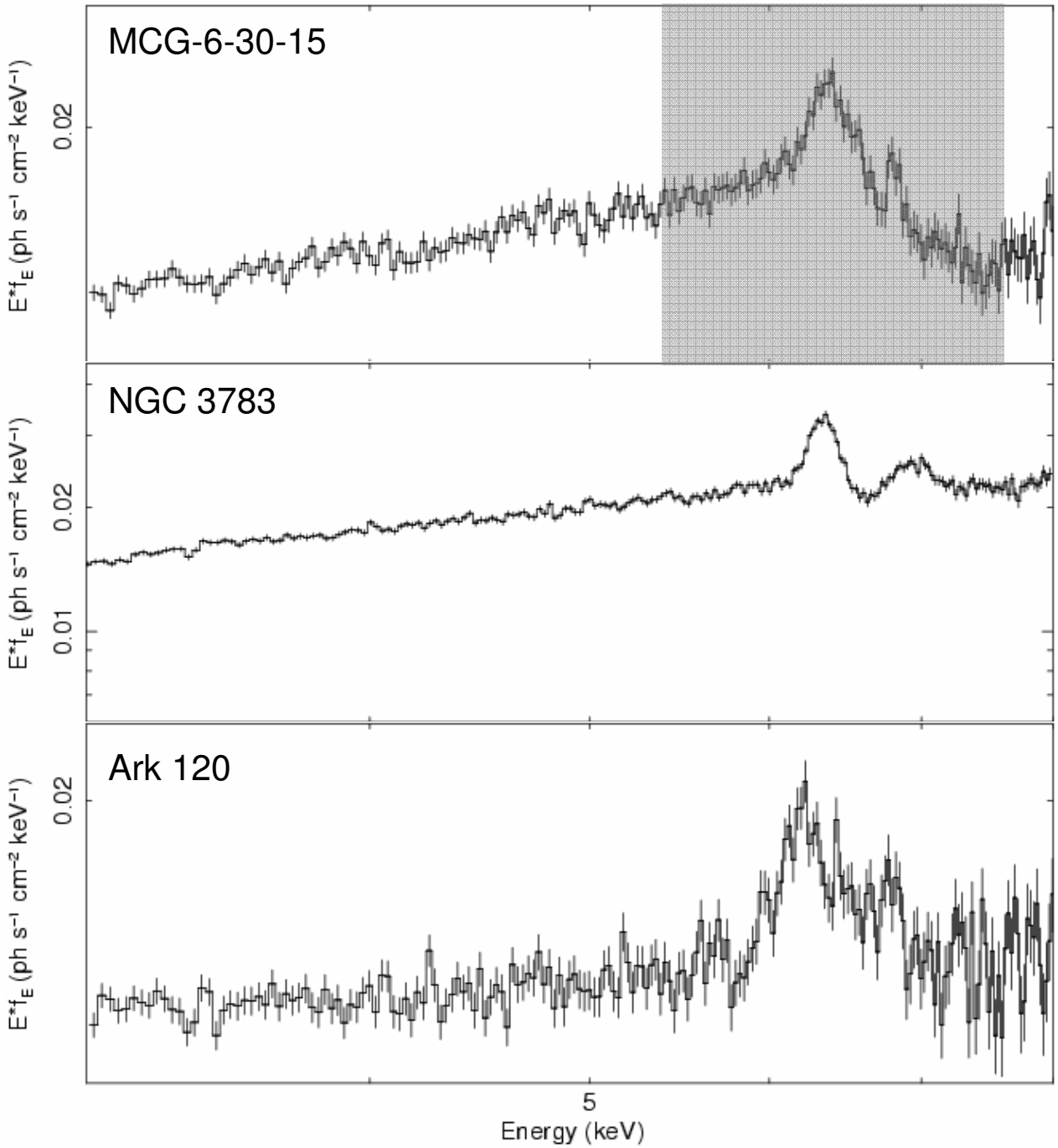
$$\hat{S} = C_i / \sum_{j=1}^{N} R_{ij} A_j$$

A "best efforts" unfolded spectrum

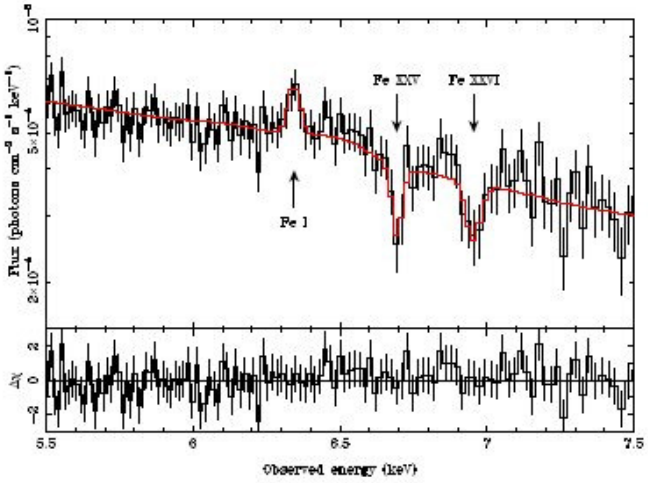
```
xspec> model powerlaw
       Index: 0
       Norm:  1
xspec> plot eeuf
```

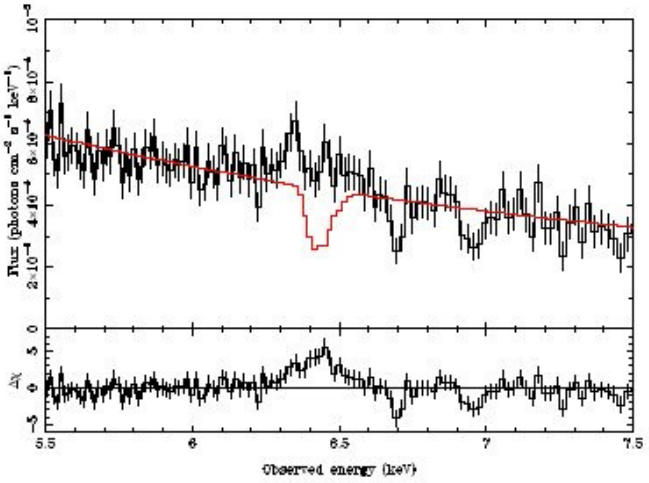
for a νF_ν style plot


MCG-6-30-15
NGC 3783
Ark 120
E*f_E (ph s⁻¹ cm⁻² keV⁻¹)
0.02
0.01
5×10⁻³
0⁻³
0.5
1
2
5
10
Energy (keV)


MCG-6-30-15
NGC 3783
Ark 120
E*f_E (ph s⁻¹ cm⁻² keV⁻¹)
0.02
0.01
5
Energy (keV)

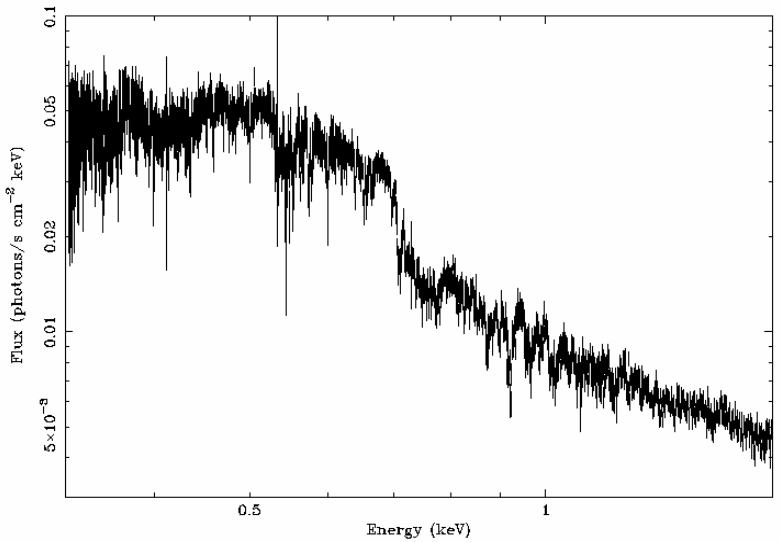
The “poster child” at grating resolution

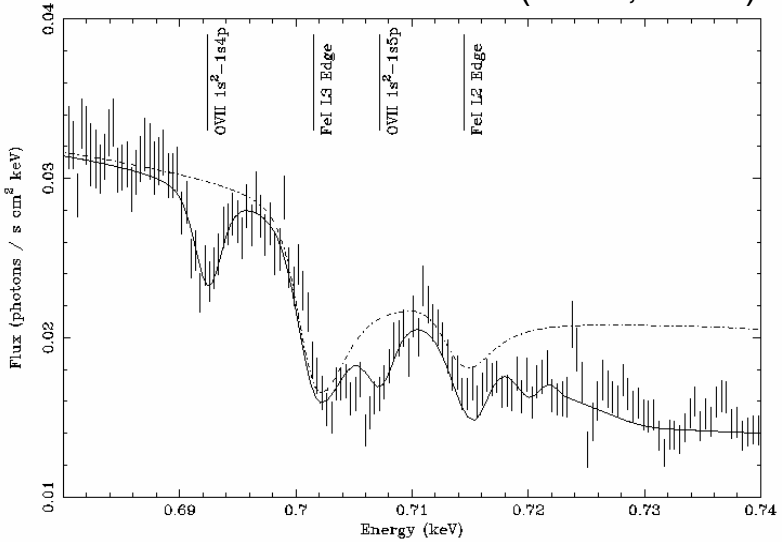




Young et al. (2005)

Turner et al. (2003, 2004)

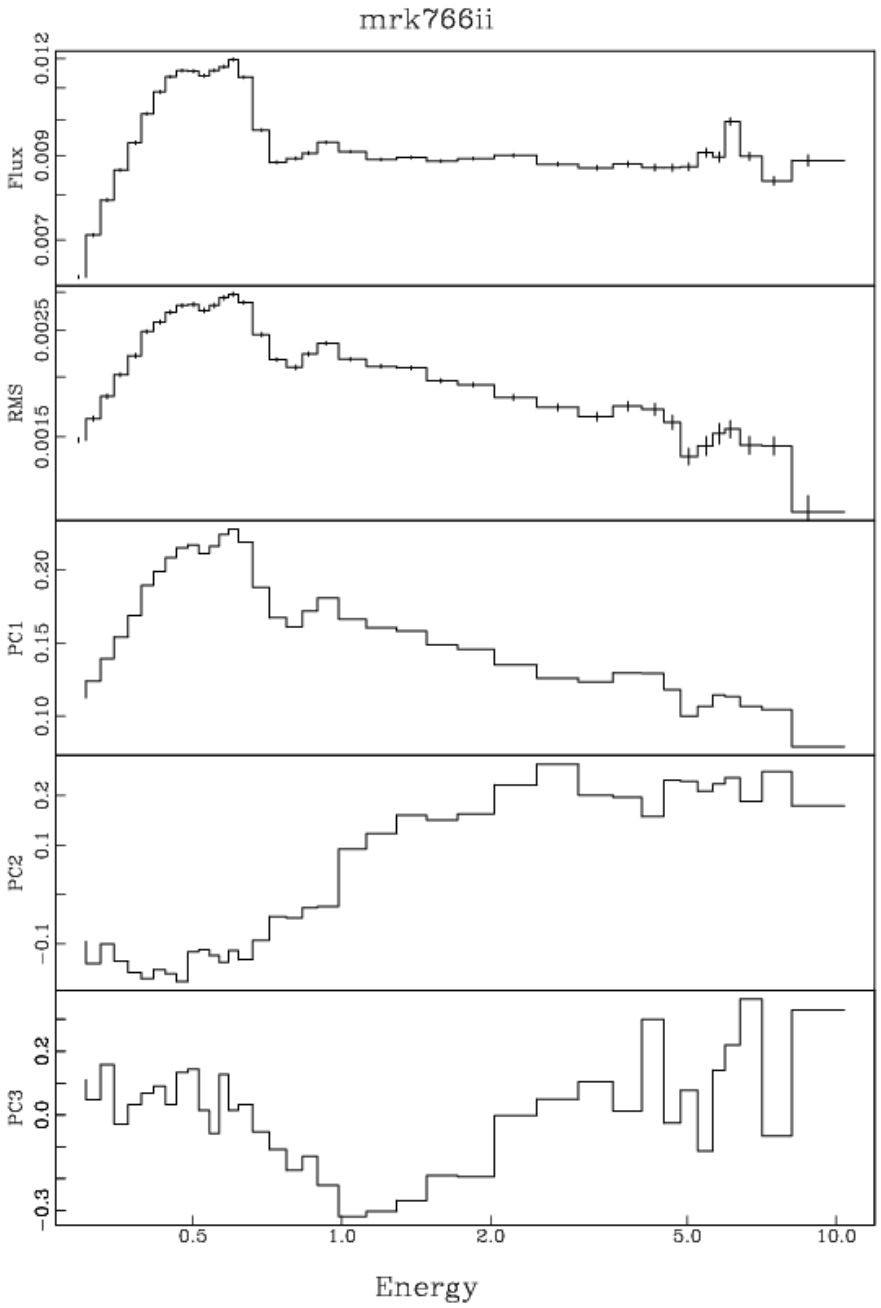




Spectral-timing methods

- RMS-spectra / Fourier resolved spectra
- flux-flux relations
- difference + ratio spectra
- Flux / time – resolved fitting
- Cross-spectrum / cross-correlation
  (time lags, coherence)
- Principal Component Analysis (PCA)

  see Vaughan & Fabian (2004)



The “consensus”

Broad lines: MCG-6-30-15 (Wilms et al. 2001; Fabian et al. 2002)
MCG-5-23-16 (Braito et al. 2007)
NGC 3516 (Turner et al. 2002)

No broad line: NGC 3783 (Reeves et al. 2004)
NGC 5548 (Pounds et al. 2003)
NGC 3516 (Turner et al. 2005) !

Nandra et al. (2007):

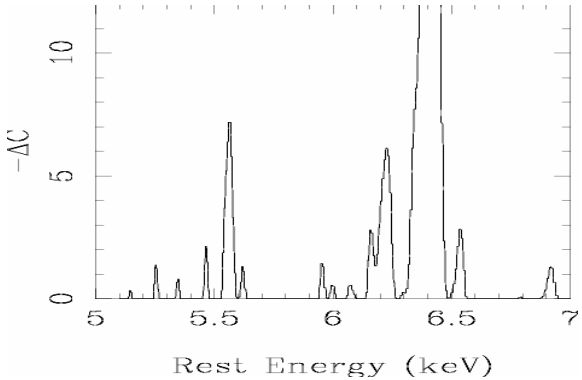
37 XMM-Newton observation of 26 Seyfert 1s
- ~11/37 narrow line only
- ~ 9/37 broad but not strong-GR
- ~17/37 broad disklines

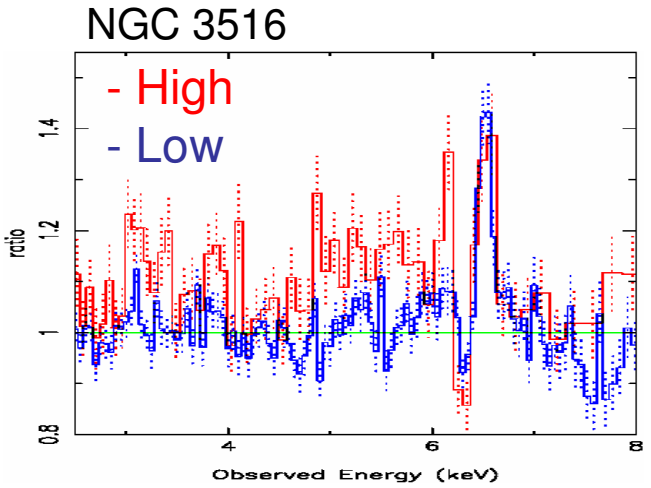
[Don’t forget GBHs – J. Miller 2007]

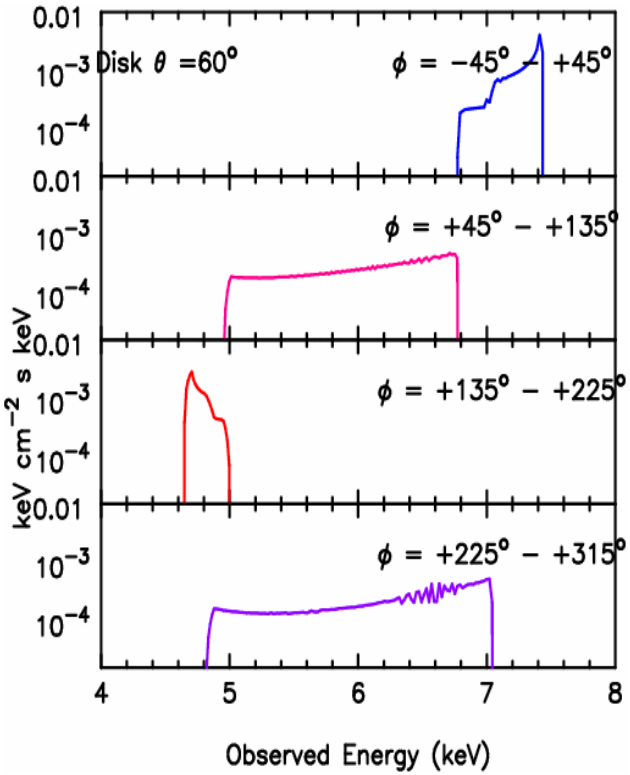
What next?
- Explain missing disklines
- Better disklines: CCD photons + grating res. + Hard X-rays
- Disklines in “simple” sources
- Consensus on line variability

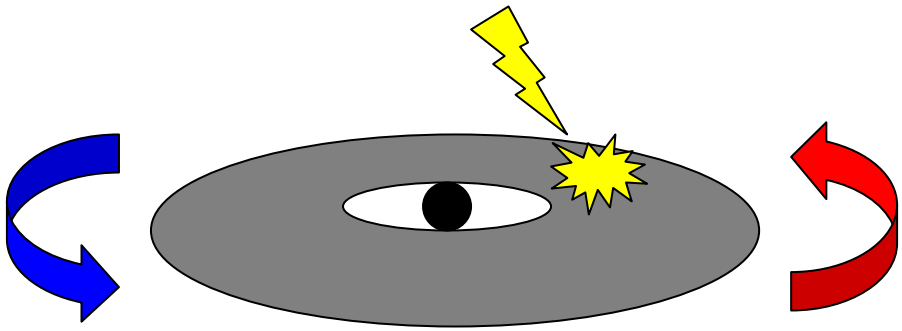
2. Narrow, relativistically shifted lines

Narrow and shifty lines



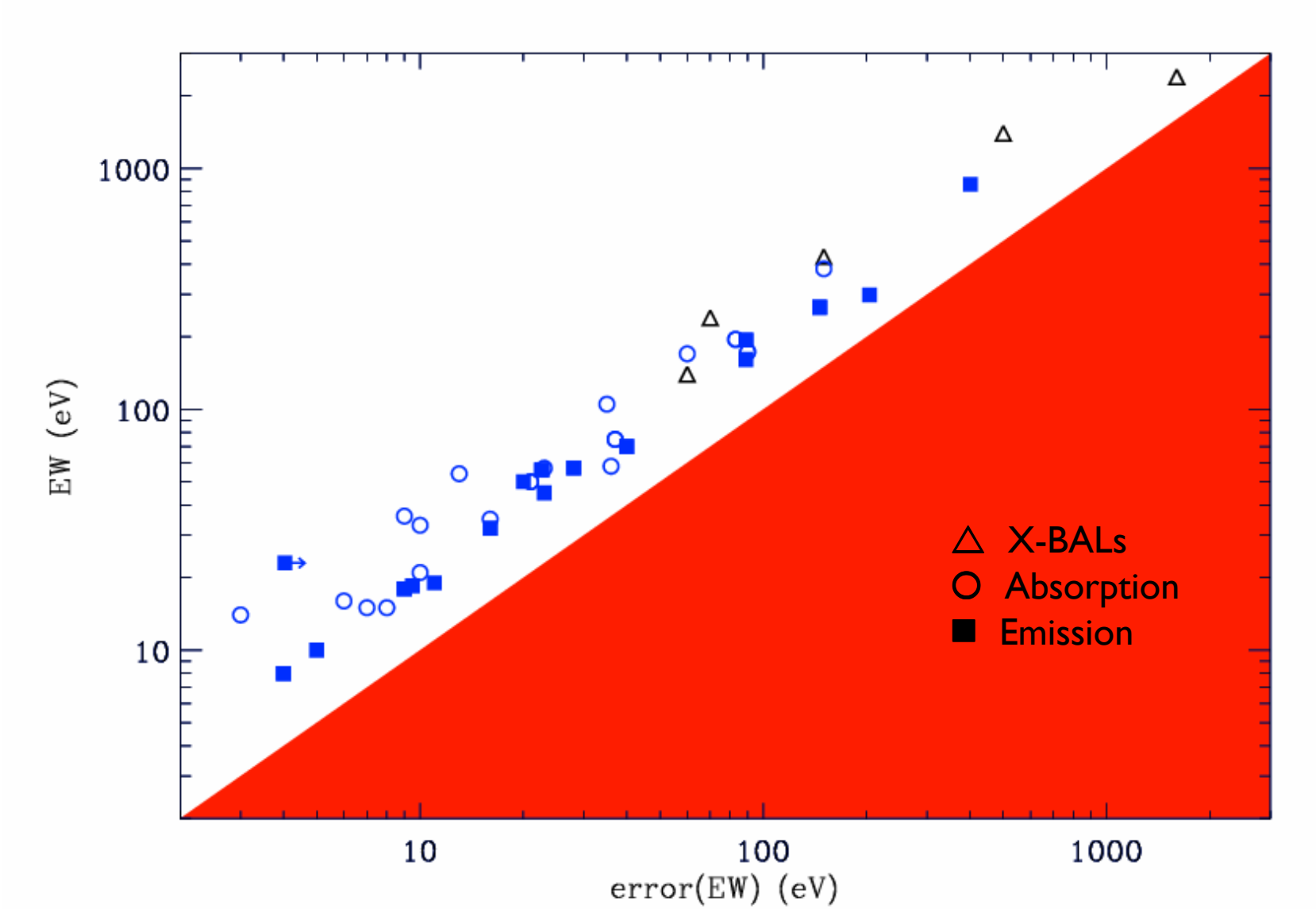






Emission from disk hotspots integrated over partial orbits at tens-hundreds of r_g ? (Turner et al 2002)

Comparing “signal” to “noise” in narrow lines



A "funnel plot" for X-ray lines

Vaughan & Uttley (2008): Meta-analysis: scan ADS for papers

"narrow *and* X-ray *and* line *and* (redshifted *or* blueshifted)"

Found 135 papers. 13 of these are new detections of shifted narrow lines (v/c > 0.05)
Added 13 more papers by following "paper trail" of the first 12.

Total of 38 lines, of which 36 have EW (or flux) and an uncertainty – "effect" and "precision".

Clearly a very strong correlation between "EW" and "error" & no lines in upper-left region of plot.

Confounding factors?

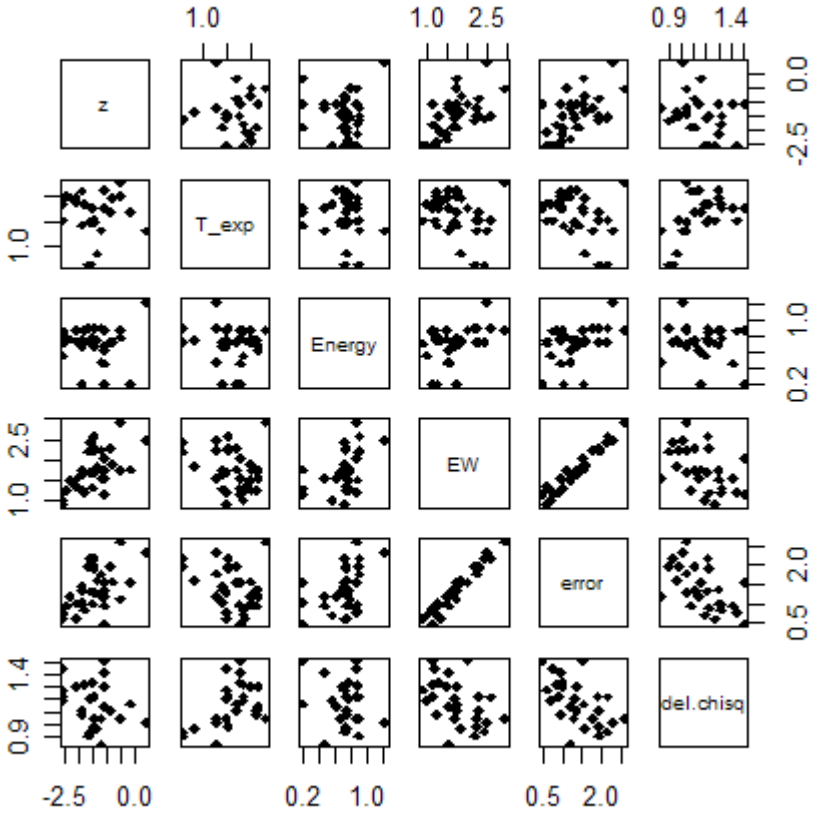
- Redshift? No.
- Line energy? No.

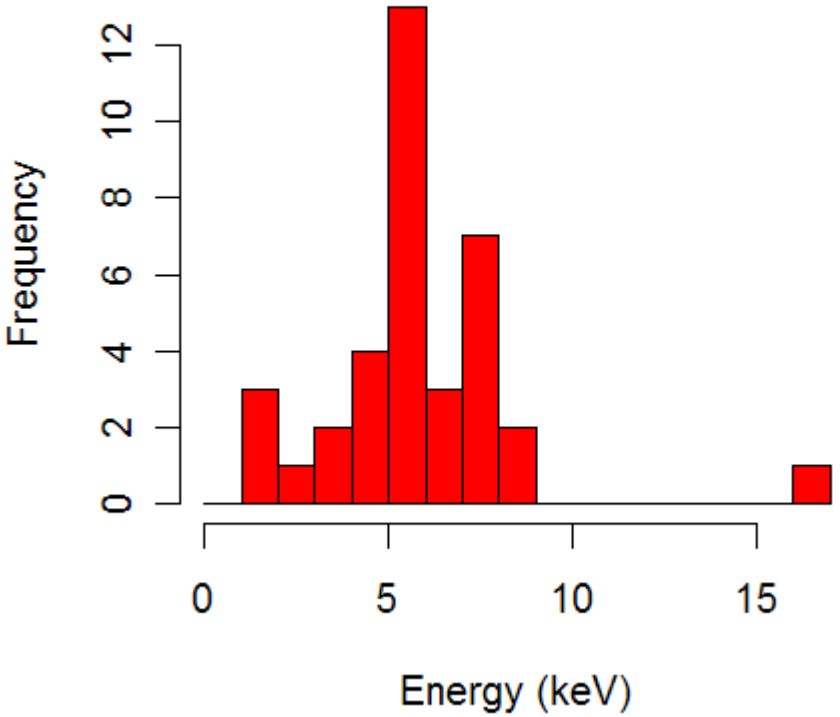
What about publication bias?

Given ~500 spectra with ~50 spectral elements expect ~67 residuals at ">3σ"

Most of these unpublished null-results lie in the lower-right half of the figure, the published ones are the "tip of the iceberg".

Confounding factors





Post hoc **reasoning**

"You know, the most amazing thing happened to me tonight. I was coming here, on the way to the lecture, and I came in through the parking lot. And you won't believe what happened. I saw a car with the license plate ***ARW 357****. Can you imagine? Of all the millions of license plates in the state, what was the chance that I would see that particular one tonight? Amazing!"*