Fairall 51:

X-ray variable absorber within the Broad Line Region

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Outline

- Polar-scattered Seyfert 1 galaxies
  - why are they interesting?
  - reasons for their large X-ray spectral variability
- Fairall 51: archival X-ray observations
- Fairall 51: new observations with Suzaku
  - results of the spectral analysis
  - constraints on the location of the X-ray absorber
- Conclusions & discussion

Polar-scattered Seyfert 1s

- who are they?

Fairall 51 ESO 323-G077

Mrk 766 NGC 3227

Mrk 704 Mrk 231

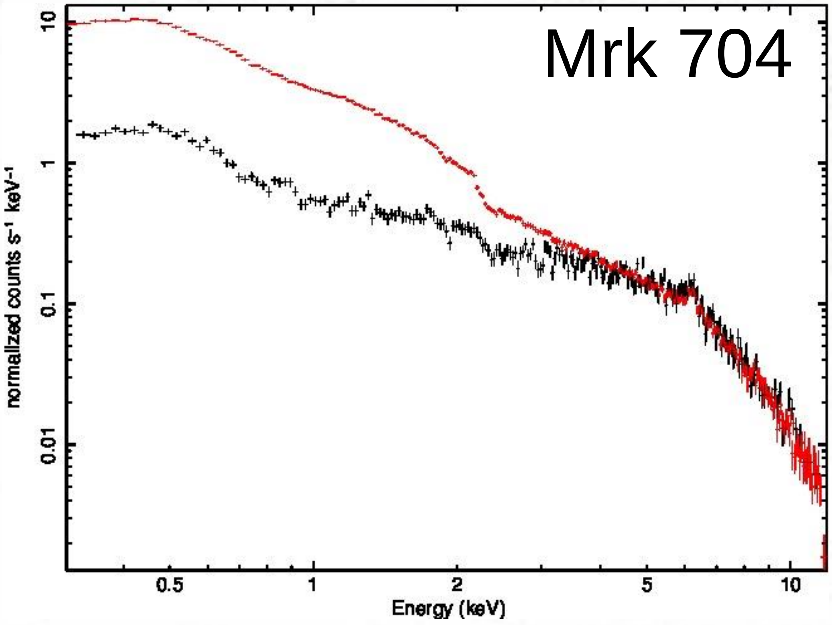
NGC 4593 IRAS 15091-2107

- - -

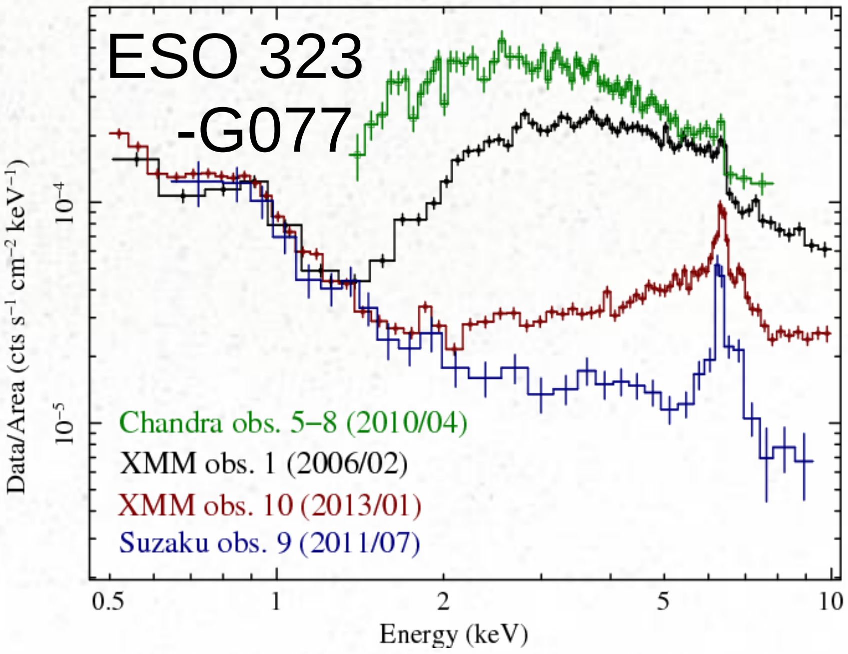
- **Seyfert 1 galaxies with high optical polarisation** (like Seyfert 2 polarisation spectra)

Polar-scattered Seyfert 1s

- represent a bridge between type 1 and type 2 galaxies
- highly X-ray variable at soft X-rays:



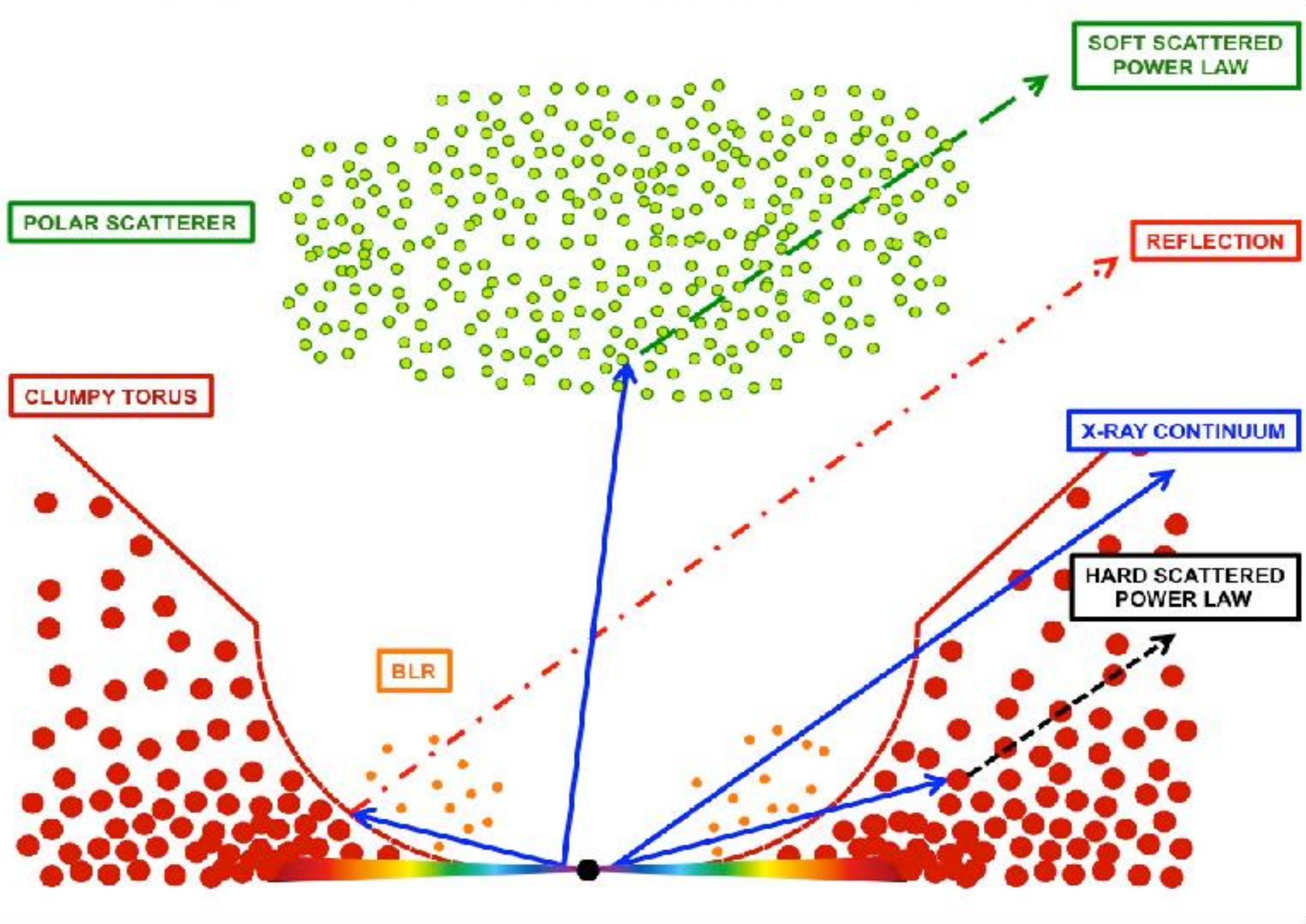
Matt+,11



Miniutti+,14

Polar-scattered Seyfert 1s

- illustration of the geometry:

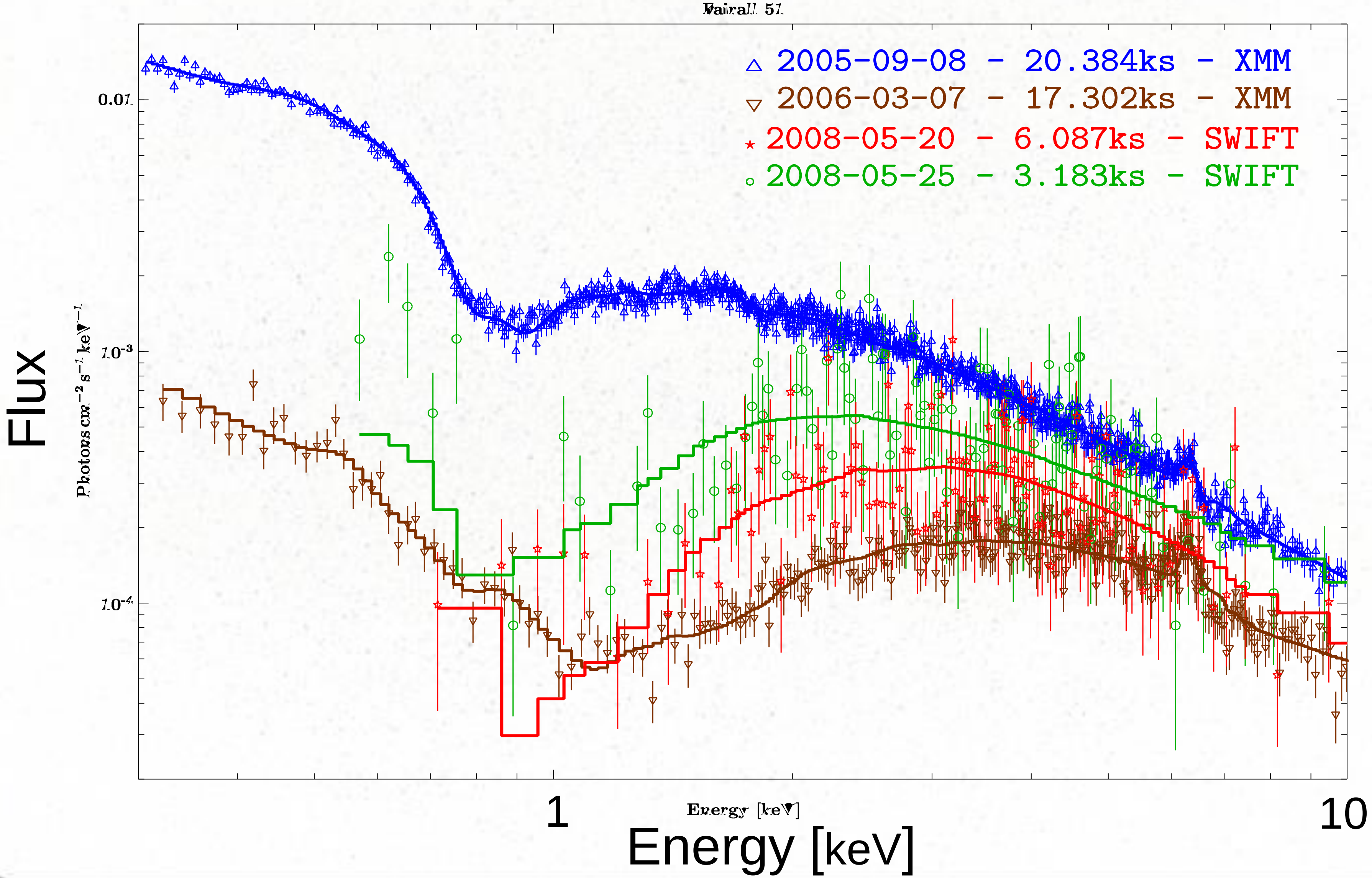


Miniutti+, 14

Fairall 51 (ESO 140-43)

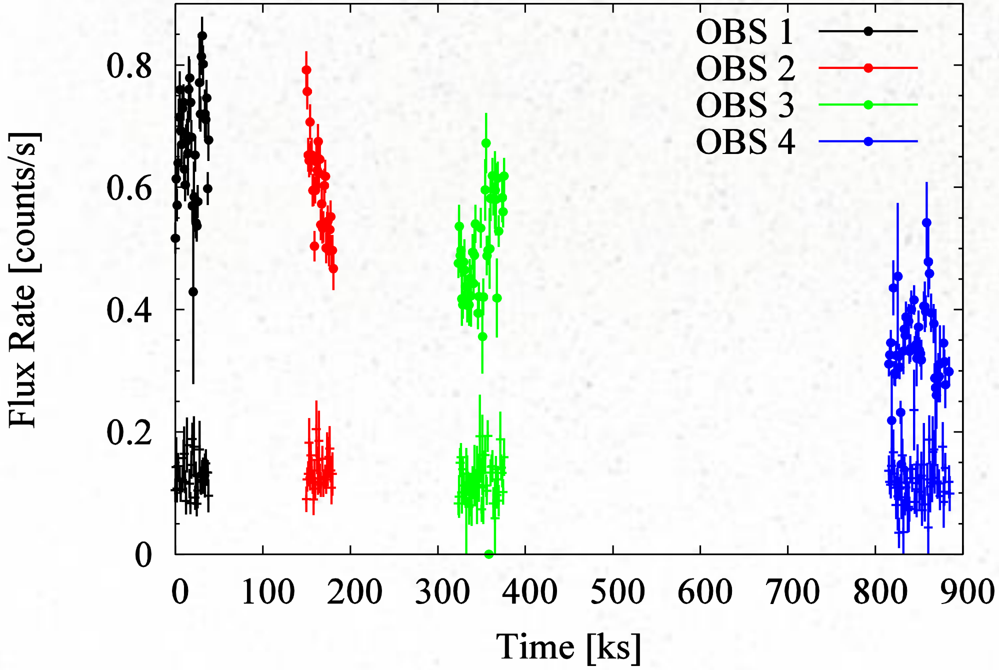
- broad lines in the optical spectrum → **Seyfert 1**
- high degree of polarisation: 5 – 13% (red – UV)
  - the highest polarization measured for a type-1 object
- X-ray bright (about 1 milicrab)
  - observed twice by XMM-Newton (2005, 2006), Ricci+,10
- short-term variability suggested from two Swift observations separated by 5 days (Ricci+,10, Beuchert+,13)

XMM and Swift observations



Suzaku observations

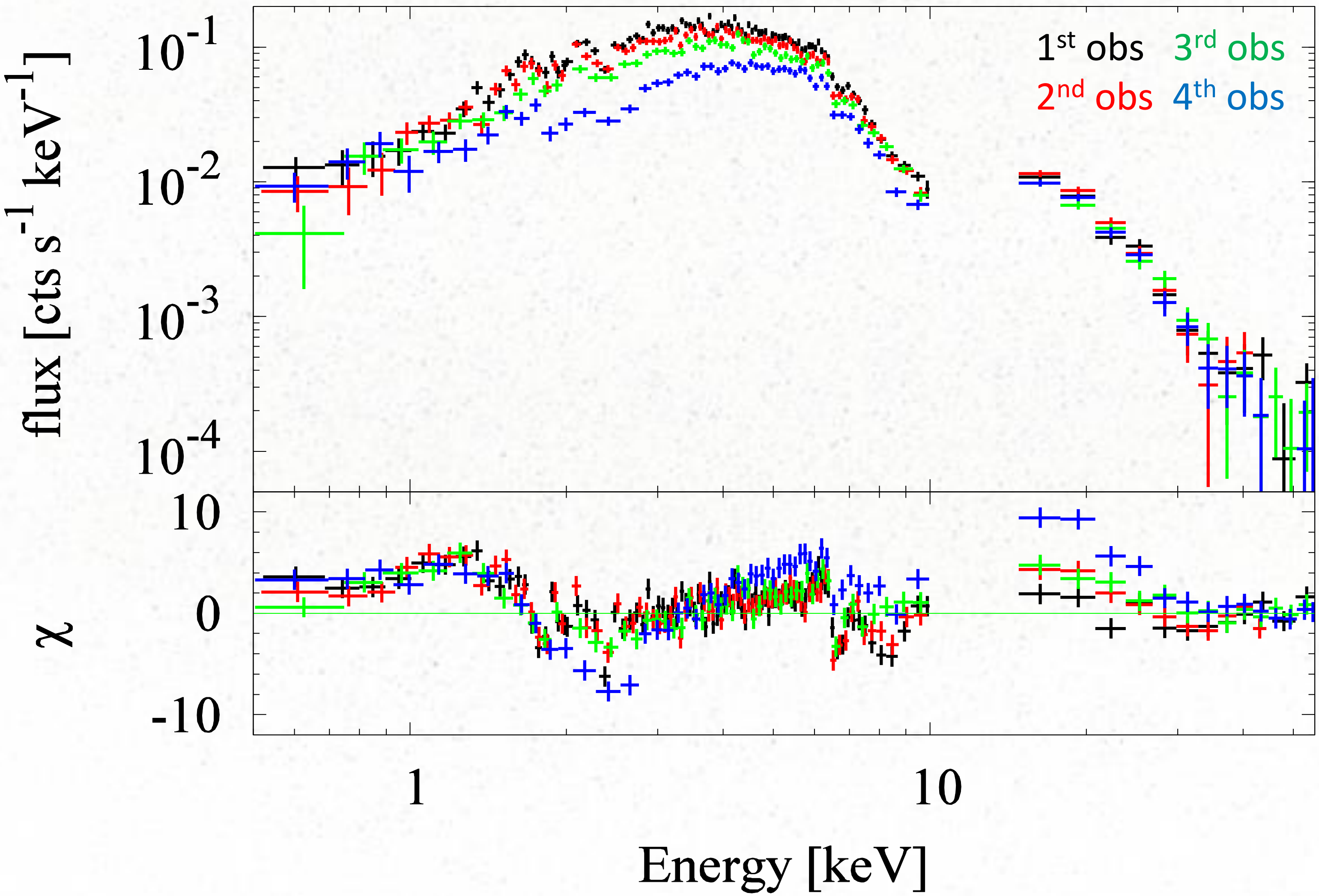
- four observations performed in Sep 2013 separated by 1.5, 2 and 5 days (exposure 30 ks each)
- flux variability:



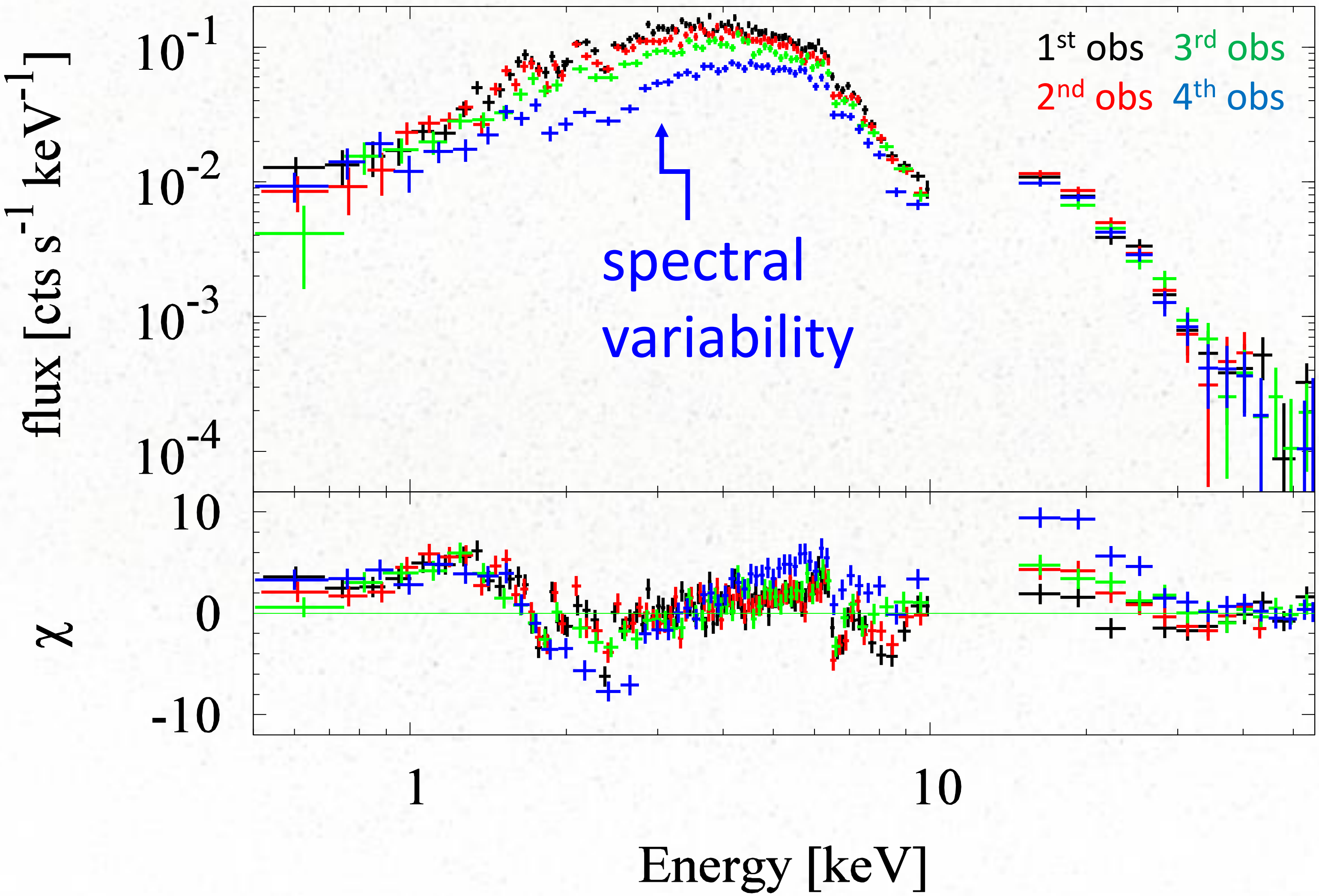
0.5-10 keV
VARIABLE

15-55 keV
CONSTANT

Spectral comparison



Spectral comparison



X-ray continuum

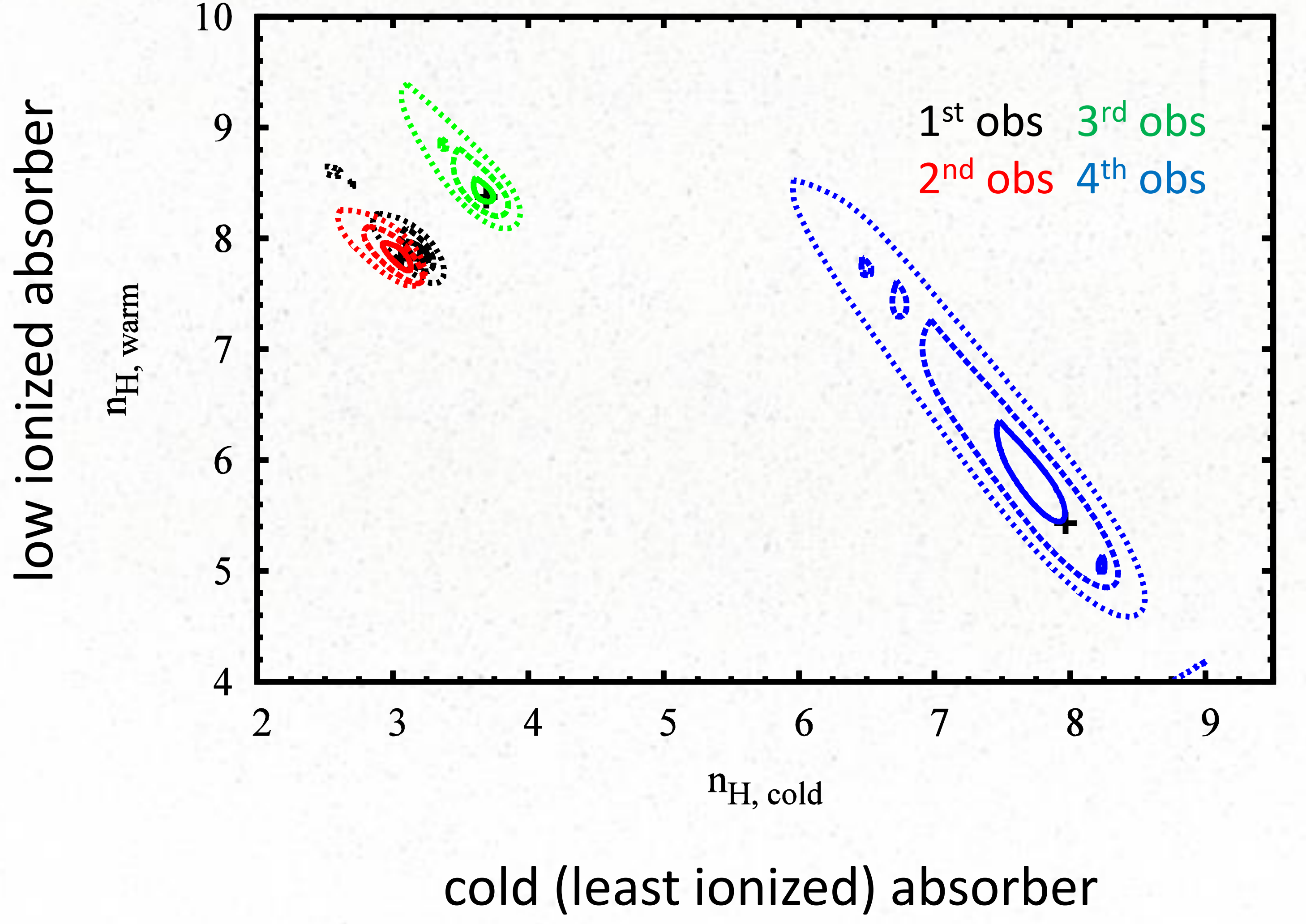
- dominated by a power-law emission with $\Gamma \approx 2$
- two components:
  1) direct (primary) – affected by a warm absorber
  2) scattered (soft)
     - unaffected by warm absorber
     - dominates in soft X-rays around 1 keV where is almost no spectral variability detected
- reflection continuum
  - Compton hump at ≈ 15keV (lower energy than usually)
    - redshifted by the relativistic effects?

Properties of the absorbers

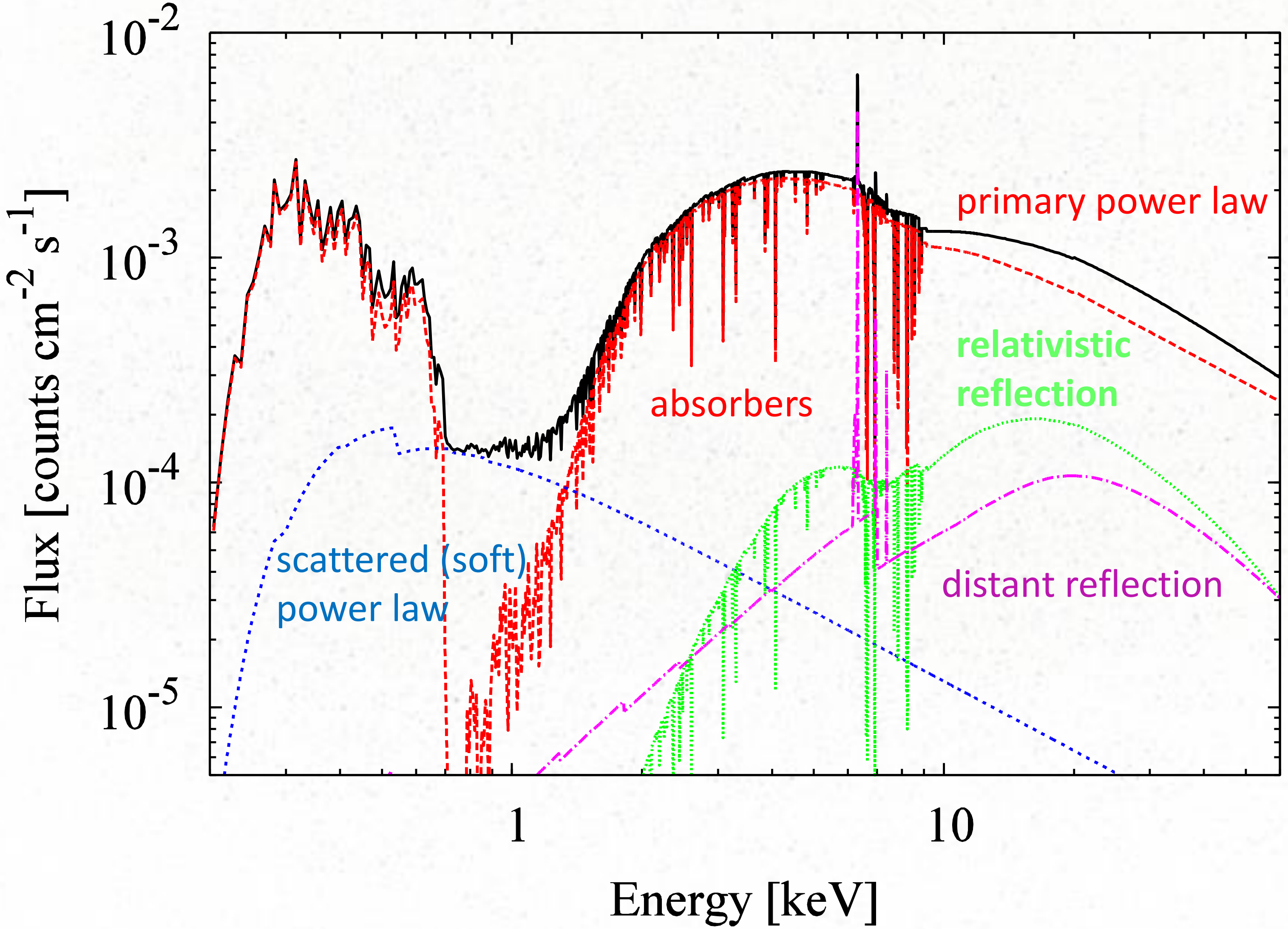
- primary power law affected by at least 3 absorbers
  - consistent with Ricci+,10 based on XMM-Newton data
  - $\log \xi \approx 1 - 4$ erg cm^{-2} s^{-1}
  - cold/least ionized absorber is the most variable one

absorber	ionization $\log \xi$ [erg cm^{-2} s^{-1}]	column density [10^{22} cm^{-2}]	outflow velocity [km s^{-1}]
1 (least ionized)	1.2 ± 0.1	variable, **2.5 – 8**	-
2 (low ionized)	1.6 ± 0.1	variable (?), 5 - 9	-
3 (warm)	3.6 ± 0.1	30 ± 10	1300 ± 600

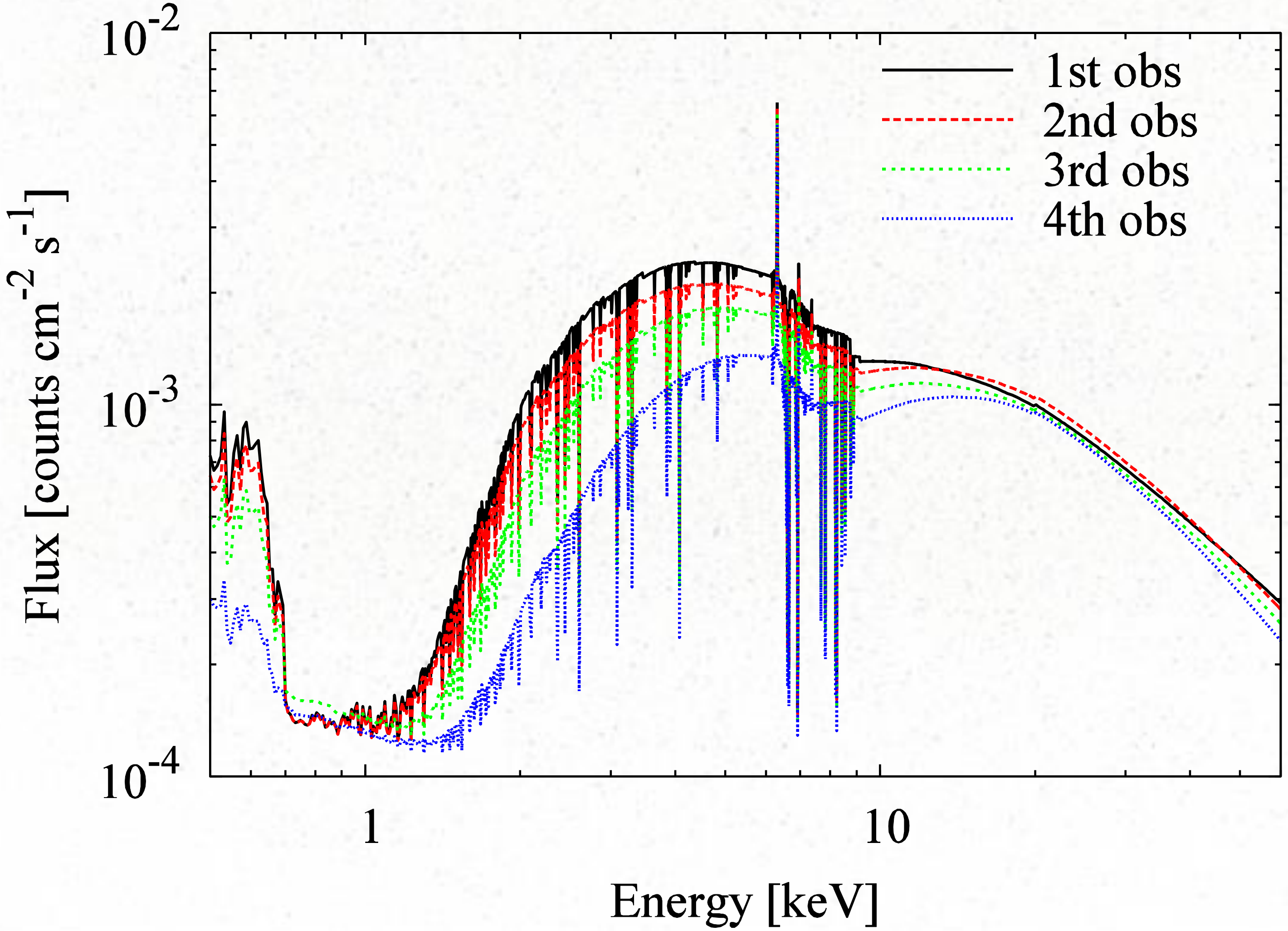
Variability of the absorber



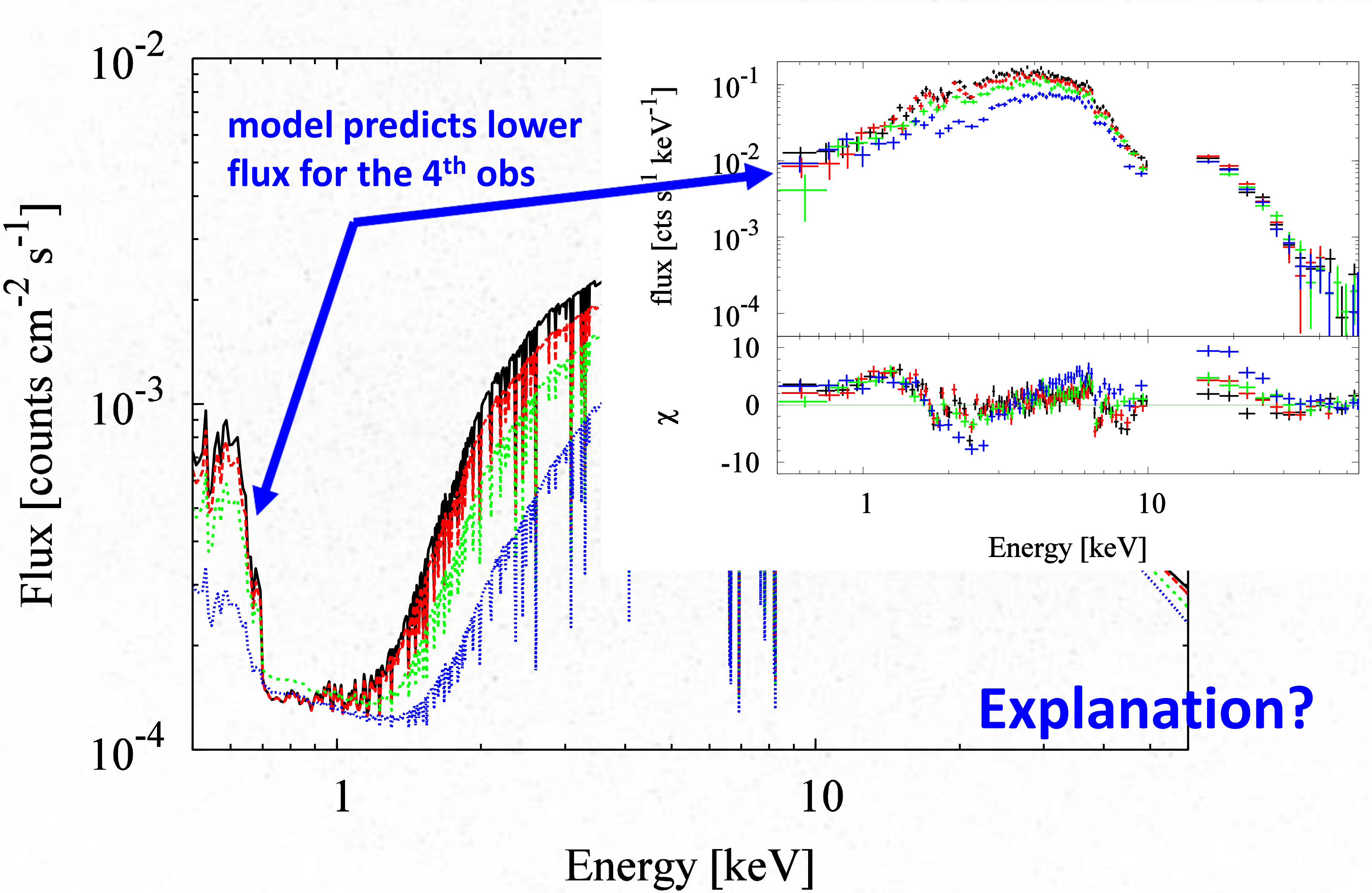
Spectral model



Model comparison between the observations



A problem at E < 0.7 keV?



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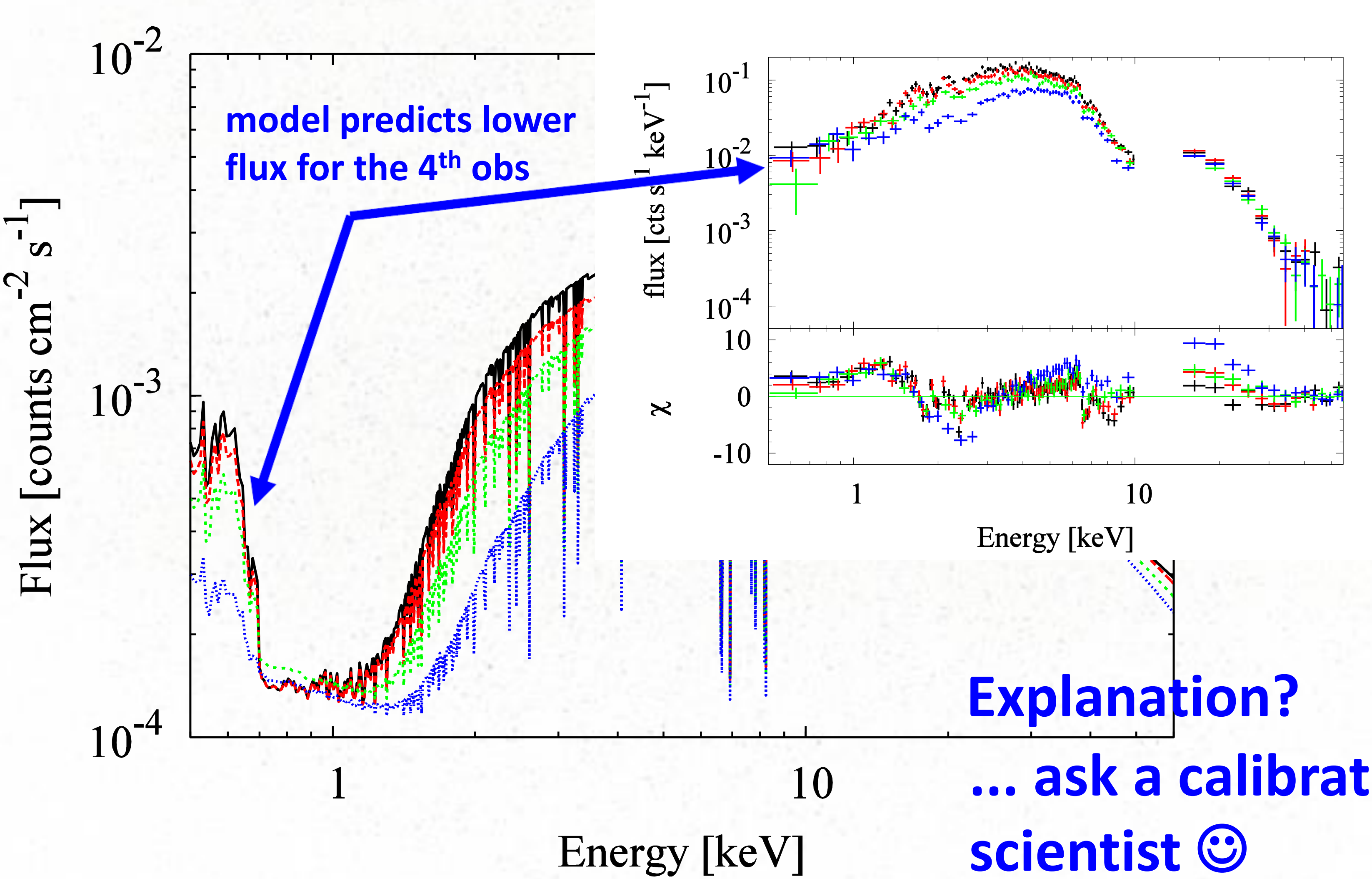
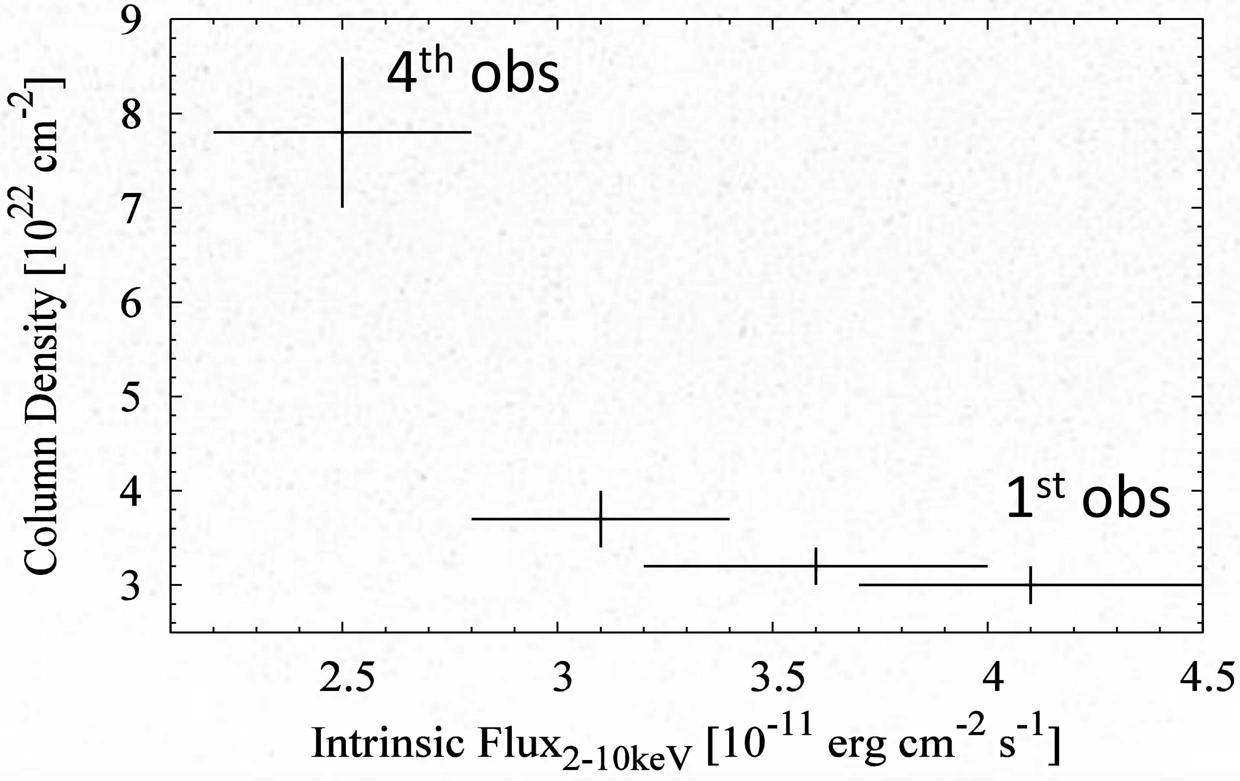


Explanation?

... ask a calibration scientist ☺

Flux and spectral variability

- flux changed by a factor of two
- spectral variability is due to the change of the column density of the variable (least ionized) absorber



Location of the variable absorber

- assuming a cloud orbiting with the Keplerian velocity $v_K = \sqrt{\frac{GM}{R}}$, we get the distance: $R = GM\frac{\Delta t^2}{s^2} \approx GM\frac{\rho^2 \Delta t^2}{\Delta {N_H}^2}$
- the density can be constrained from the ionization:

$$\rho = \frac{L}{\xi R^2}$$

- we get relation for the distance:

$$R = \left[GM\frac{L^2 \Delta t^2}{\xi^2 \Delta {N_H}^2}\right]^{\frac{1}{5}}$$

Location of the variable absorber

- normalized to typically measured values we get: $\boldsymbol{R \approx 2.66 \times 10^{17}}$

$$\left[\frac{M}{10^7 M_\odot}\left(\frac{L}{10^{43}\ \mathrm{erg}\ s^{-1}}\right)^2\left(\frac{\xi}{\mathrm{erg\ cm}^{-2} s^{-1}}\right)^{-2}\left(\frac{\Delta t}{1\mathrm{Ms}}\right)^2\left(\frac{\Delta N_H}{10^{22}\ cm^{-2}}\right)^{-2}\right]^{\frac{1}{5}} \mathbf{cm}$$

- mass: M ~ $3 \times 10^7 M_\odot$ (Padovani & Rafanelli, 1988)
- we measured: L ~ 4×10^{43} erg s^{-1}, ξ ~ 15 erg $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, Δt ~ 0.45 Ms, and ΔN_H ~ 5×10^{22} cm^{-2}
- we get for the distance: $\boldsymbol{R \approx 7 \times 10^{16}\ \mathrm{cm} \approx 0.02\ \mathrm{pc}}$
  - typical distance of the **Broad Line Region** (Peterson+, 04)
  - the density: $\rho \approx 5 \times 10^8$ cm^{-3} also typical for BLR

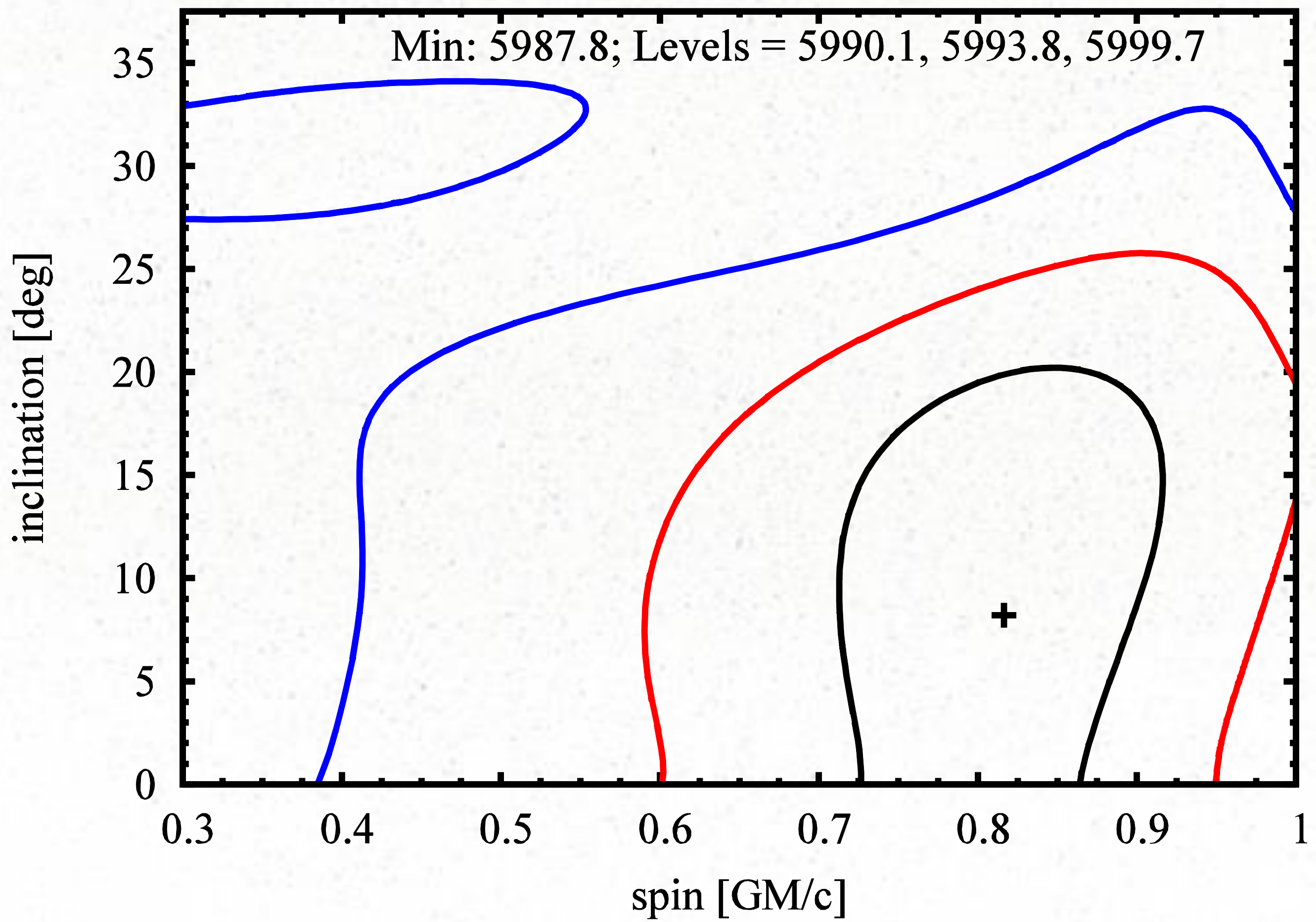
Note on the origin of BLR clouds

- dusty winds by Czerny & Hryniewicz (2011)
  - BLR regions are located where the accretion disc temperature is close to the dust sublimation temperature
  - dusty winds arise up but once they get in the strong radiation field they are destroyed
- lower flux → winds can get further, the clouds cover more radiation from the centre
- ionized absorber might serve as a protection against the illumination from the centre

Relativity...

- FERO = Finding Extreme Relativistic Objects
- is Fairall 51 extremely relativistic?
  - its spectrum is rather complicated to measure exact profile of the iron line red wing
  - Compton hump at $\approx$ 15 keV is redshifted
  - relativistic reflection improved significantly the fit

Black hole spin and inclination



Conclusions

- Fairall 51 revealed a complex structure of the absorbing gas
  - at least 3 zones with different ionization $\log \xi \approx 1 - 4$ erg cm^{-2} s^{-1}
- spectral variability is due to the least ionized absorber
  - characteristic time scale of the variability ~ **week**
  - this implies location within the **Broad Line Region**
- relativistic reflection
  - needed to model the Compton hump at ~ 15 keV
  - black hole spin measured as: $a \approx 0.8 \frac{GM}{c}$
  - inclination: $i \approx 20$ degrees – not consistent with the expectations from the intermediate galaxy type (45 degrees), also scattered part?