Ultra-Fast Outflows (High-Velocity Outflows): A 15 years perspective

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AGN Driven winds - Technion – 24 May 2017

Mass outflow seen in the X-ray

- How much mass is carried out from the AGN by the outflow?
- How does it compared to the amount of matter being accreted?
- Does the ionized outflow carry a significant fraction of the energy output of the AGN?

UFOs are potentially high mass outflow contributors , but:

- Are UFOs really exist, or can other interpretations explain the data?
- What is the fraction of AGNs with UFOs?
- Are UFOs a variable phenomenon and thus what is its real influence on the AGN environment?
- What studies need to be done to shed more light on the UFOs phenomenon?

Answers are currently model dependent

Identification of low-velocity outflows

• Several to hundreds absorption lines of different ion of several elements at the same outflow velocity.

• Identified at high resolution spectra.

• Many of the troughs are detected at 10σ or higher confidence.

• All/Most lines are consistent with a self-consistent photionized model.

High S/N & high resolution spectrum

Continuum power low model with slope $\Gamma = 1.65$.

Three-ionization component model for the absorption and emission lines:

$U_{oxygen} = 0.004, 0.06, 0.25$ $N_H = 10^{21.9}, 10^{22.0}, 10^{22.3}$ cm^{-2}

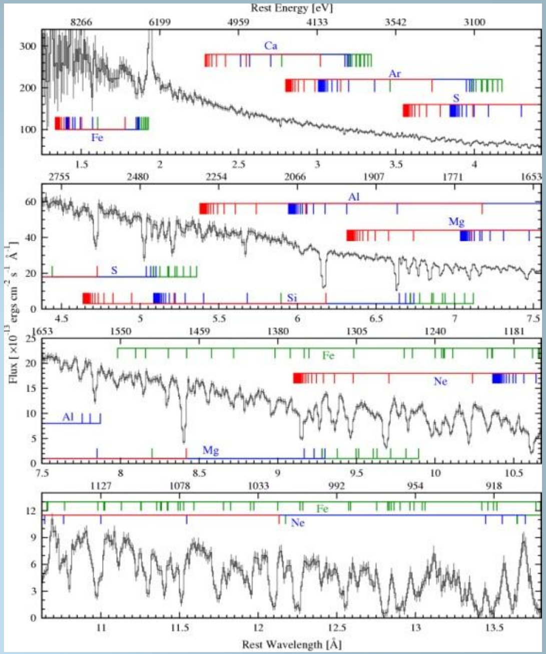
• Wide rage of ionization

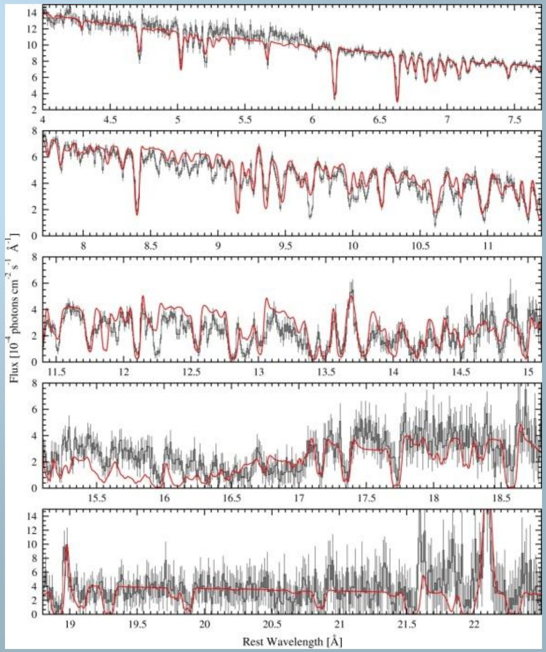
• Turbulence velocity is 250 km/s

• X-ray absorption does not change in time

• Outflow of 590 km/sec

(Kaspi et al. 2002 ; Netzer et al. 2003)





Mass outflow in low-luminosity AGNs

Outflows can provide key results about AGNs' central regions, e.g.:

- Dynamics: outflows velocities of several 100 km/s in multiple components.
- Range of ionization parameters $U_{Oxygen} \sim 0.01$ to 1 (degeneracy of location and density).
- Column density ~ 10^{21-23} cm^{-2}.
- Normal outflows are not very significant in terms of energy as the outflow is of ~ 0.1-3 $M_{\odot}$ yr^{-1} .

Ultra-Fast Outflows (v/c ~ 0.1-0.4) are potentially energetically significant and would be dominant component of AGN feedback, and cosmological structure formation.

Ultra-Fast Outflows (UFOs)

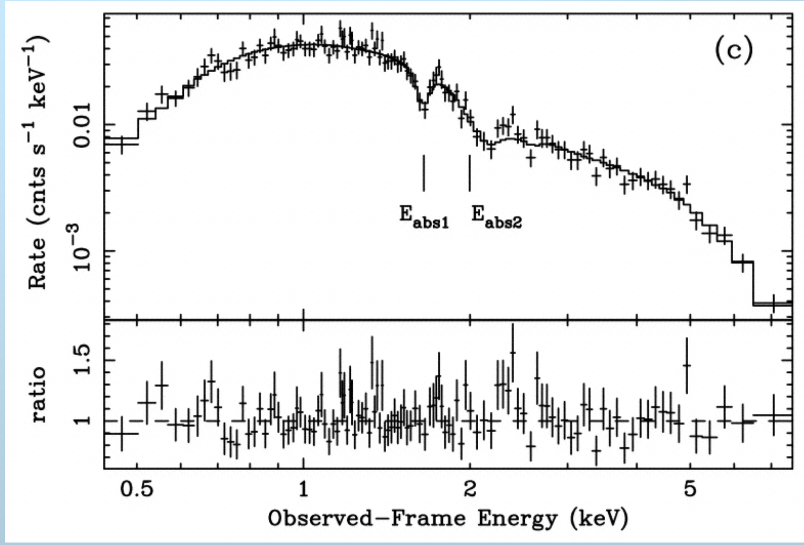
Most ultra fast outflows are claimed from absorption seen in 7-9 keV energies and are interpret to be from Fe XXVI Lyα, thus giving outflow velocities of a fraction of the speed of light. E.g.:

APM 08279+5255 ,	0.2c 0.4c,	Chartas et al. (2002),
PDS 456,	0.17c,	Reeves et al. (2003)
PG 1211+143	0.1c,	Pounds et al. (2003)
IC 4329 A ,	0.1c,	Markowitz et al. (2006)
PG 1115+080,	0.1, 0.36c,	Chartas et al. (2003, 2007)
MCG -5-23-16,	0.1c,	Braito et al. (2007)
3 Radio-loud quasars,	0.04-0.15c,	Tombsi et al. (2010)
3C 111, 3C 120, 3C 390.3		
~5 more Radio-loud quasars,	0.04-0.4c,	Tombsi et al. (2014)

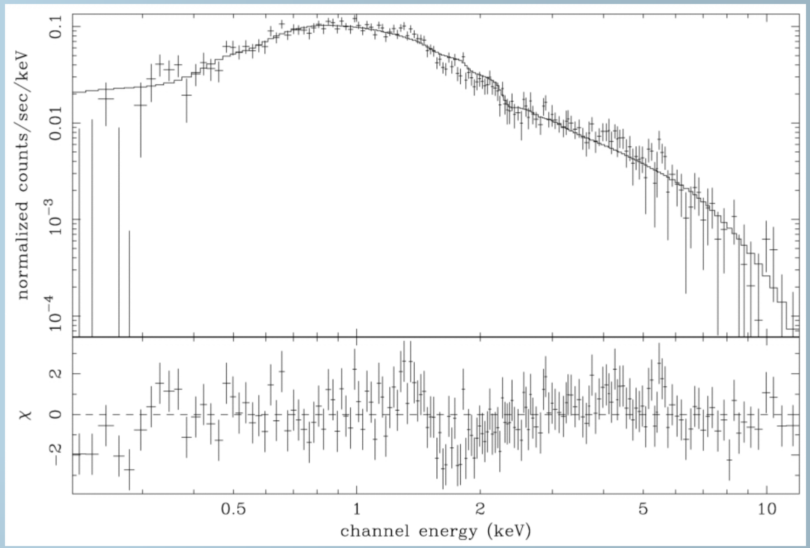
Mass outflow of few to ~ 10 $M_\odot$ yr^{-1}

APM 08279+5255

Chartas et al. (2002) - Chandra



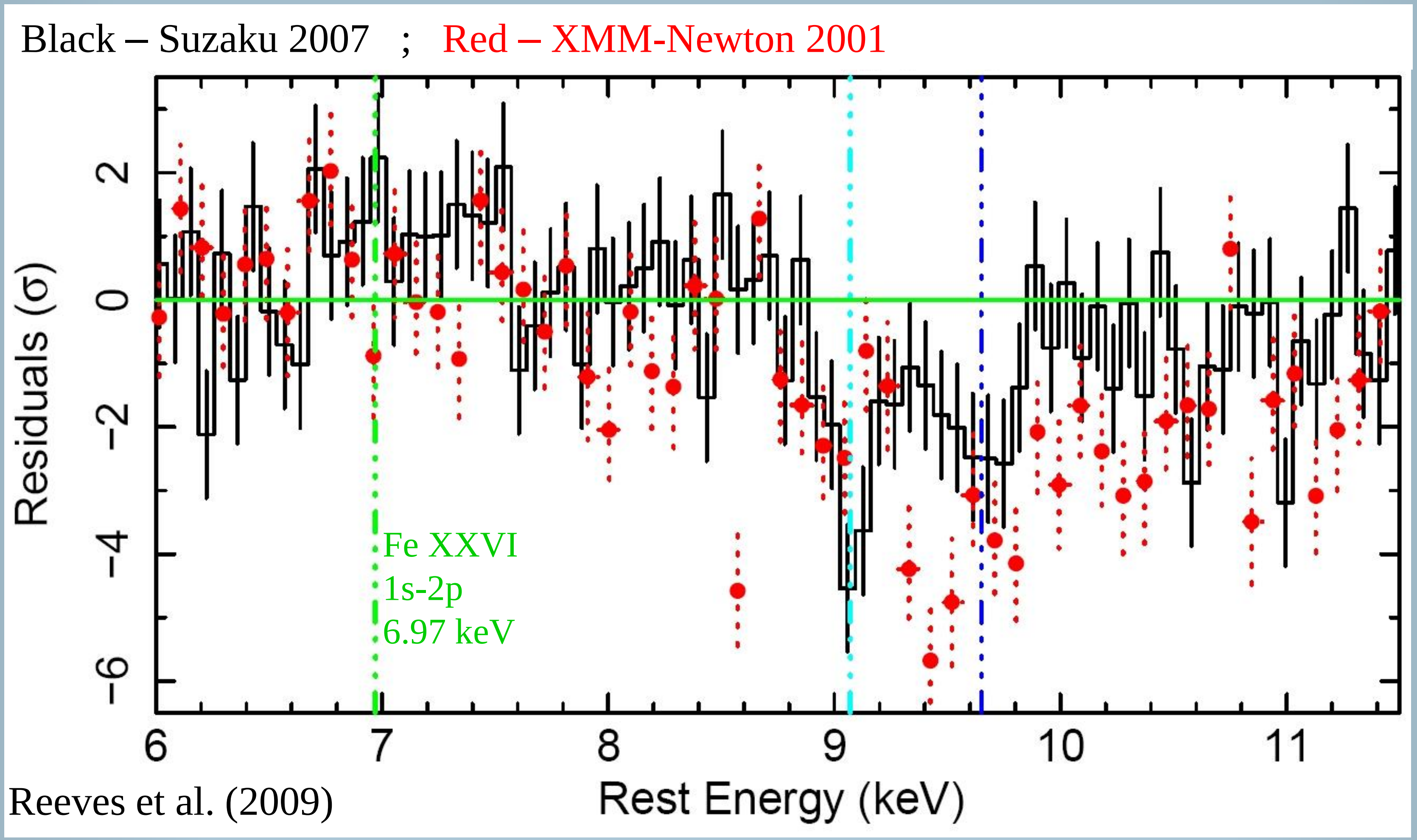
Hasinger et al. (2002) - XMM



Rest frame: 8.1 and 9.8 keV
Assuming FeXXV Heα
Velocities: ~0.2c and 0.4c
z = 3.91
Mass outflow ~ 1$M_{\odot}$ yr^{-1}

Rest frame k-shell absorption edges of FeXV-FeXVIII
Consistent with the UV BAL up to 12,000 km/sec
Moderate to no outflow

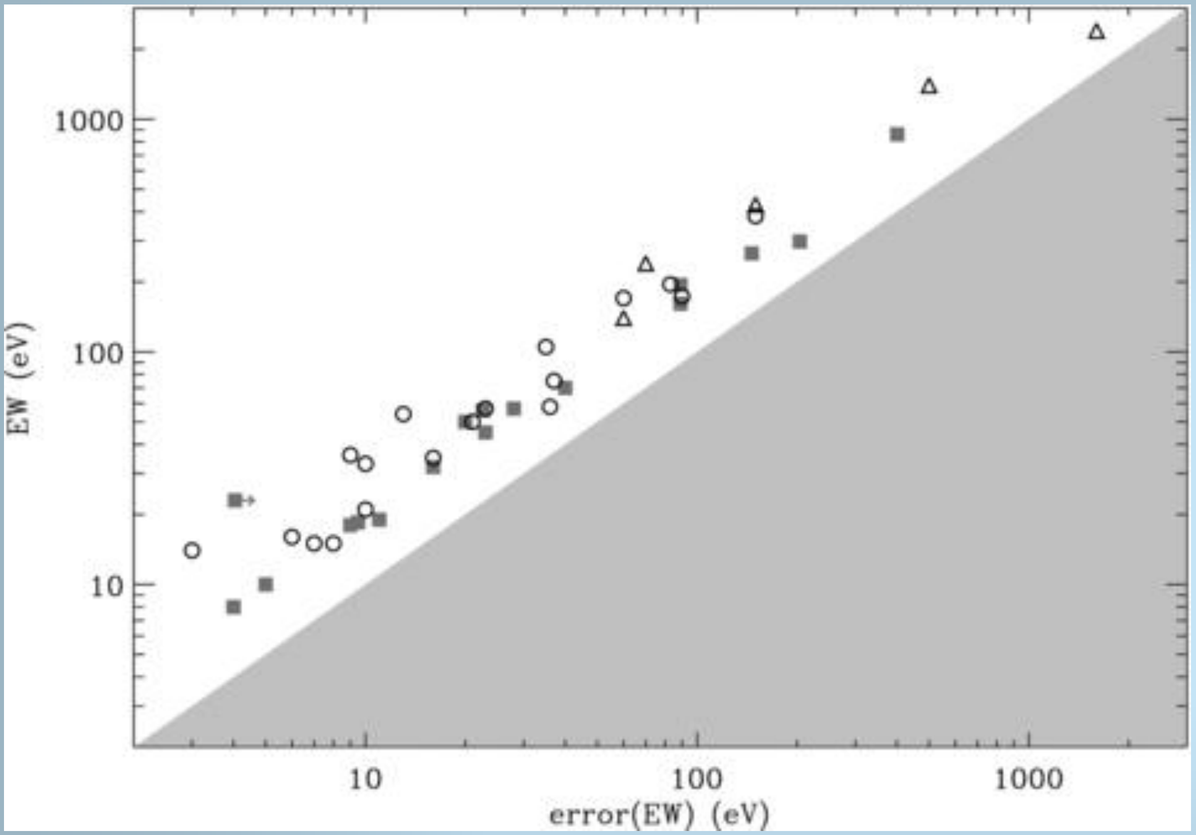
PDS 456 - Fe absorption line



If the detected absorption is the Fe XXVI line then the outflows are at 0.26c and 0.31c

Publication bias

Detection of relativistically shifted X-ray lines



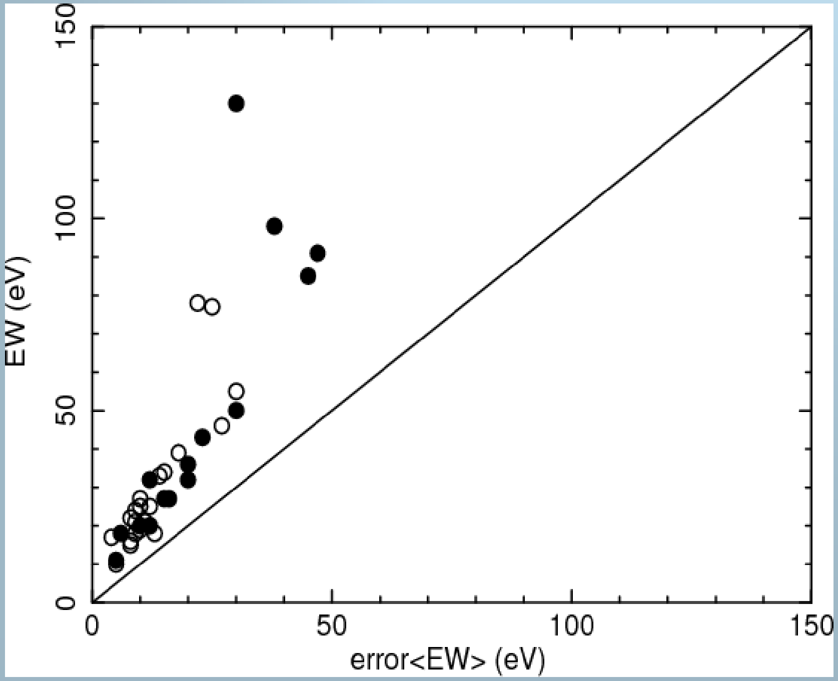
Vaughan & Uttley (2008) found linear relationship between the line strength and its uncertainty.

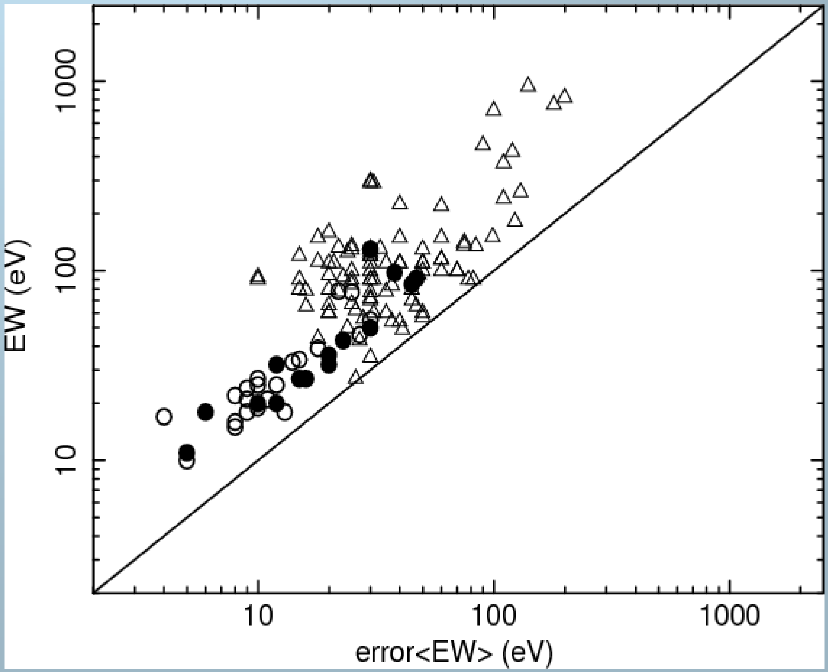
Better observations (with smaller uncertainties) always show the smallest lines.

Consistent with many of the reported lines being false detections resulting from random fluctuations.

UFO detections with XMM

Comprehensive work of Tombesi et al. (2010, 2011, 2012): 101 spectra of 42 RQ quasars and detected 36 narrow absorption lines above 6.4 keV. If assumed to be Kα lines of Fe XXV and/or Fe XXVI then 18 are UFOs consistent with outflow velocity of 0.1c to 0.4c, and 18 are low velocity outflows at < 6000 km/sec.

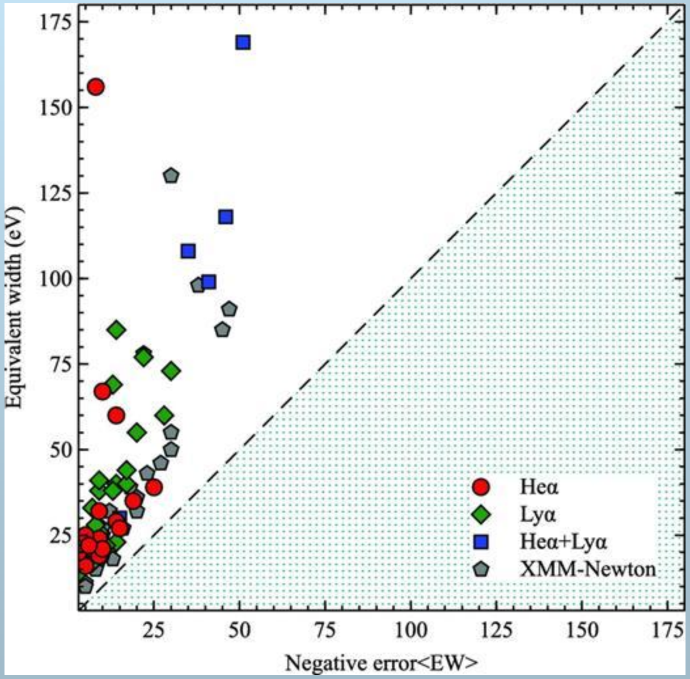




open circles v < 0.05c ; filled circles v ≥ 0.05c ; open triangles - neutral FeKα emission lines.

UFO detections with SUZAKO

- Comprehensive work of Gofford et al. (2013, 2015): Search for outflows in 51 AGNs at the 5-10 keV region. Find significant absorption in 20 objects. If assumed to be Kα lines of Fe XXV and/or Fe XXVI then the outflow velocity of 0.005c to 0.33c.



Both Tombesi et al, and Gofford et al. found the fast winds are located at about $10^{15\text{-}18}$ cm (typically ~ $10^{2\text{-}3}$ r_s) and the mass outflow rates are of order 0.01-1 $M_\odot$ yr^{-1}

High Resolution Spectra

Ultra-Fast Outflows

- To really confirm these UFOs we need high resolution spectra which will show several absorption lines in several ions.

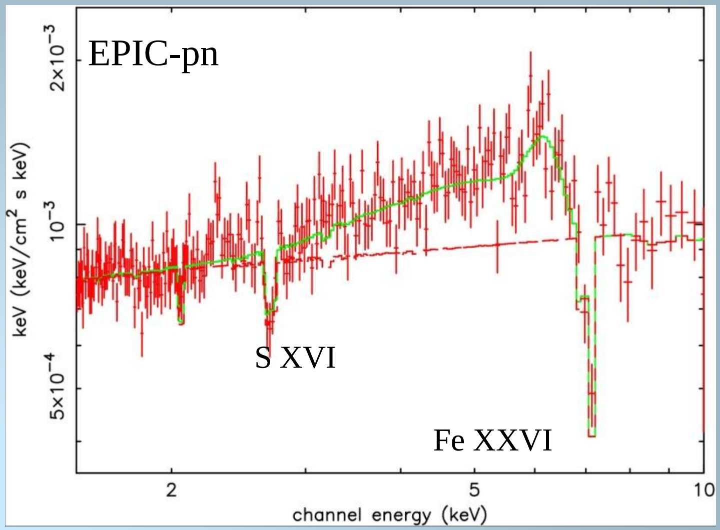
- Only few object with UFOs have claimed detections in high resolution spectra:

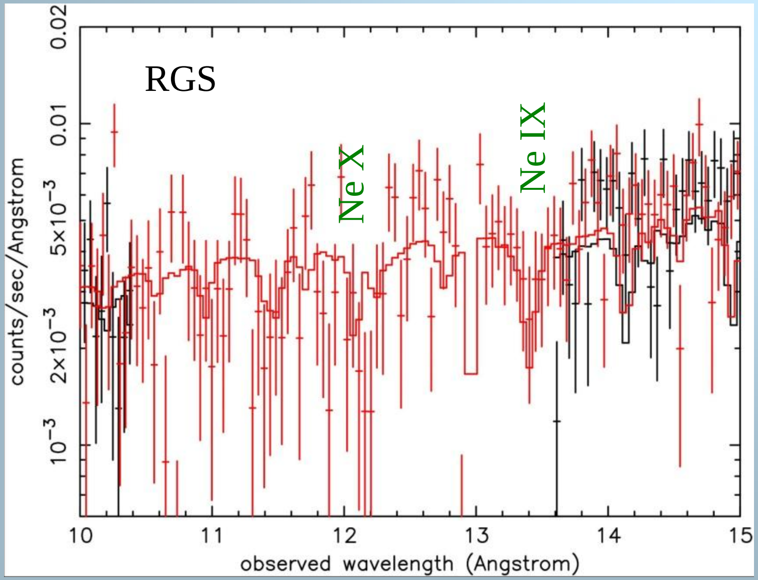
  PG 1211+123
  PDS 456
  PG 0844+349
  IRAS 17020+4544

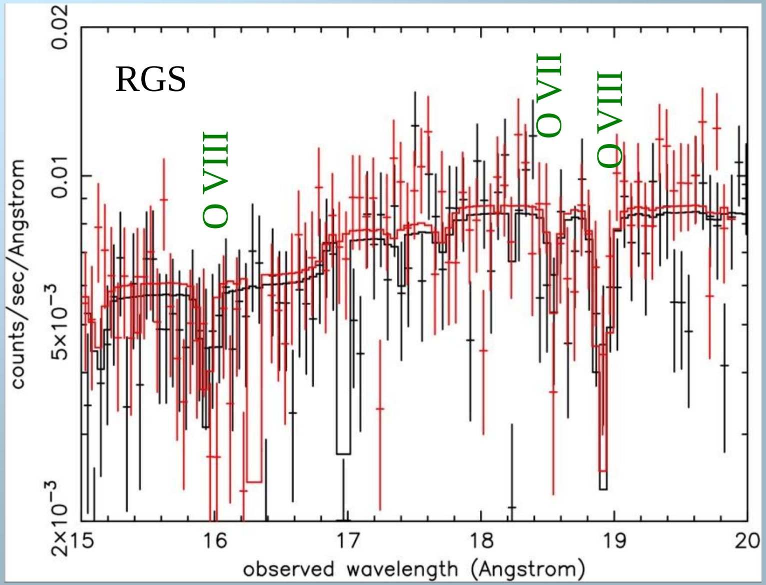
PG 1211+143

PG 1211+143

Pounds et al. (2003) analyzed
~ 60 ks XMM-Newton observation
(2001-06-15) and find an ionized
outflow velocity of ~ 24000 km/s (0.08c)
Column density of $\sim 10^{24}$ cm^{-2}.
Assuming accretion at Eddington rate
the mass outflow rate is $\sim 3 M_{\odot}$ yr^{-1}.

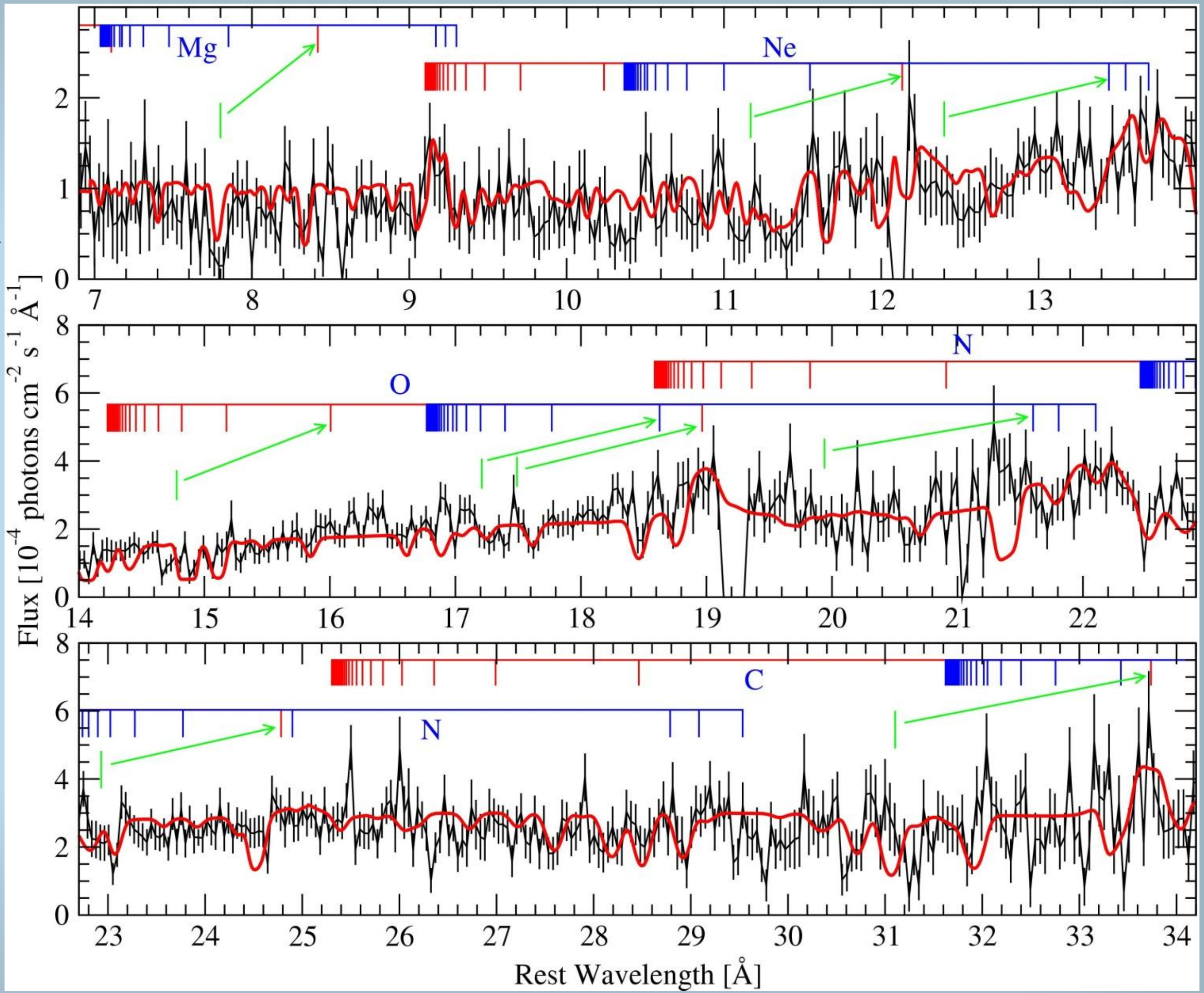






Alternative Interpretation for PG 1211+143

- RGS 1 & 2 evenly binned
- Fitting series of lines for each ion
- Absorption **and** emission lines are included
- V ~ 3,000 km/s
- Lower Column Densities $10^{21} – 10^{22}$ cm^{-2}
- One order of magnitude smaller outflow mass

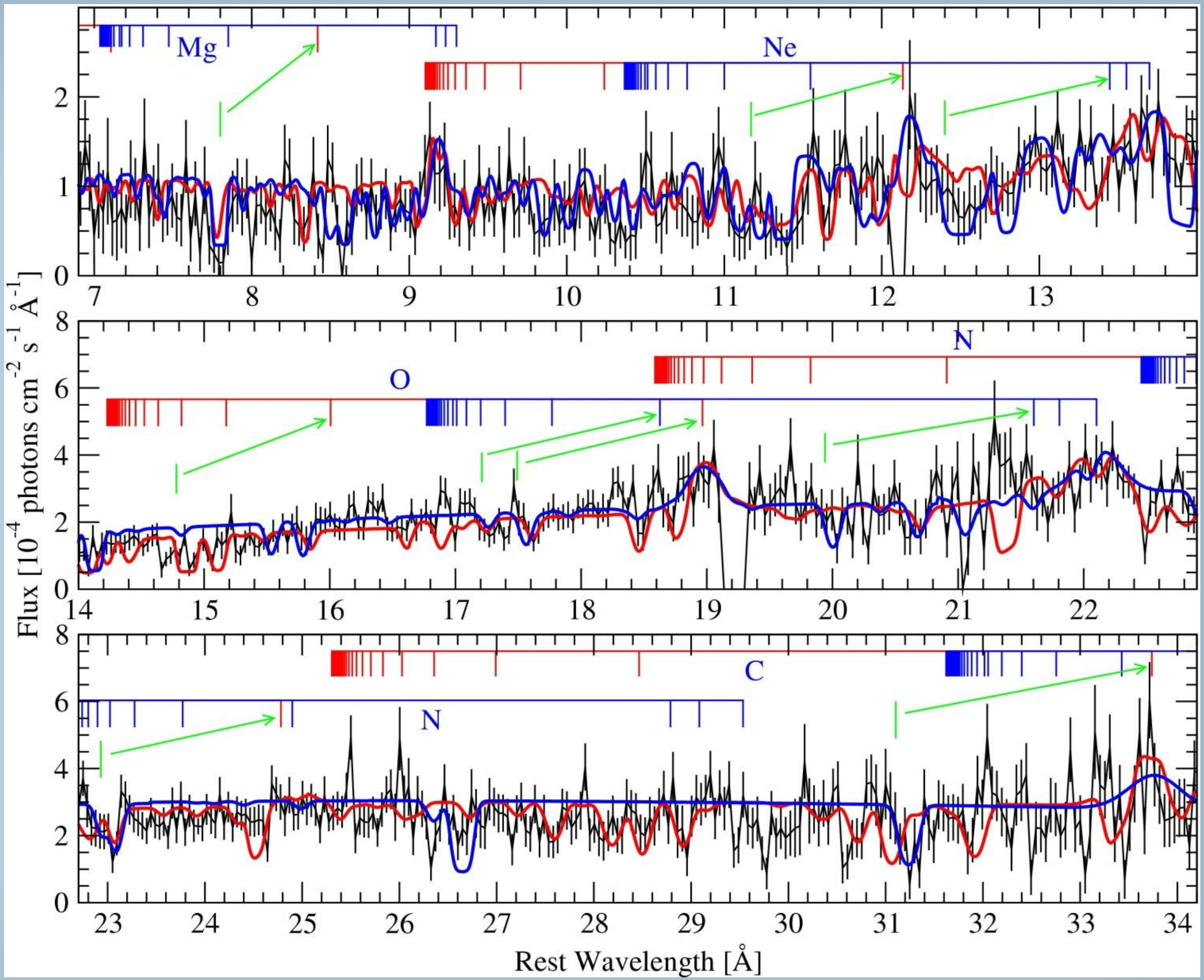


Kaspi & Behar (2006)

Comparison with 24,000 km/s

3000 km/s

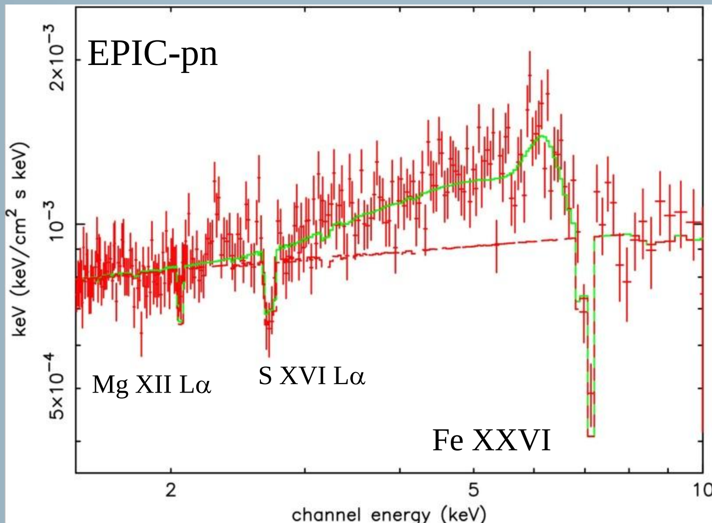
24000 km/s

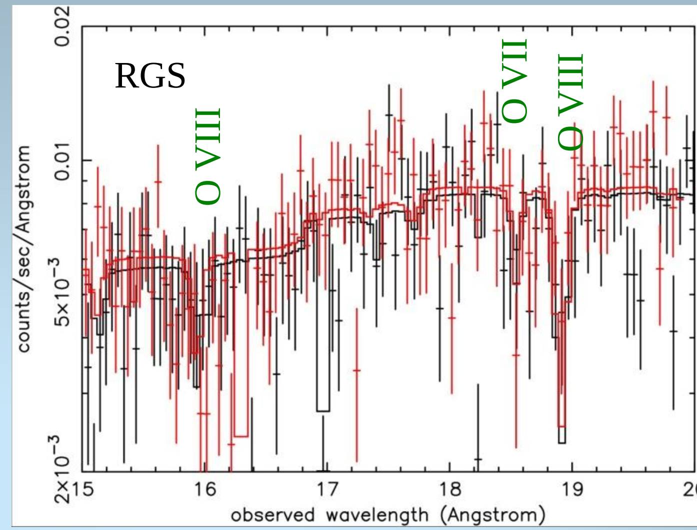


Both velocities are consistent with the data.

Though, 3000 km/s has more line identifications.

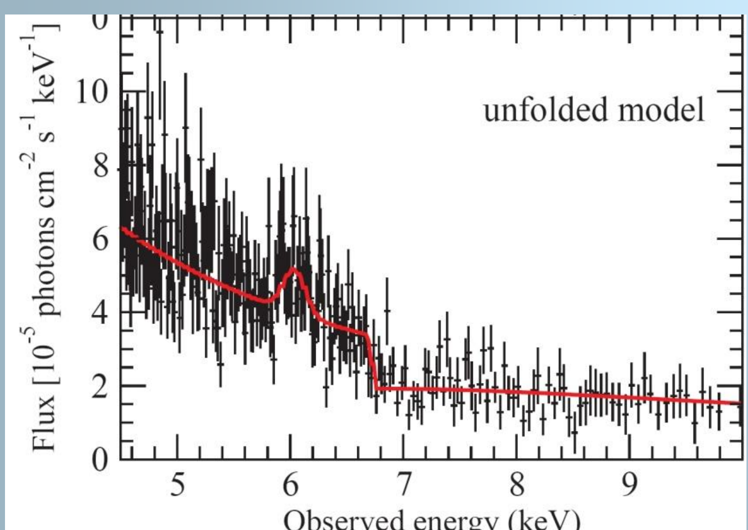
PG1211+143 - XMM 2001

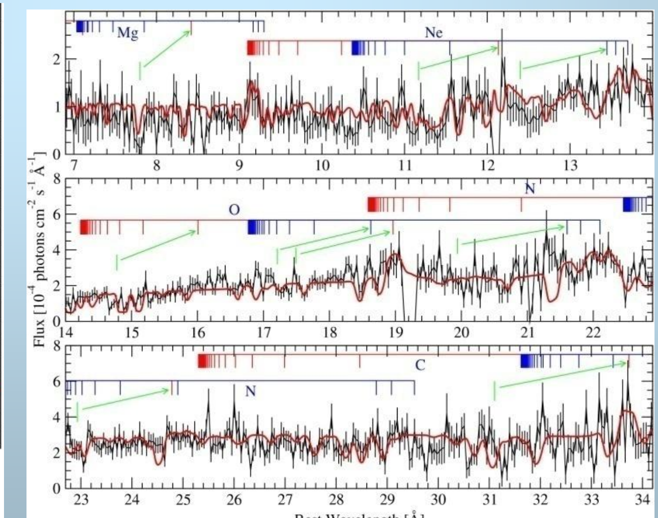




Pounds, Reeves et al. (2003) claim to detect an outflow of at ~ 0.1c.
$N_H \sim 10^{24}$ cm^{-2}

Mg XI Heβ S XV Heβ





Kaspi & Behar (2006) gave alternative interpretation of an outflow at 3000 km/sec.
$N_H \sim 10^{21.5}$ cm^{-2}

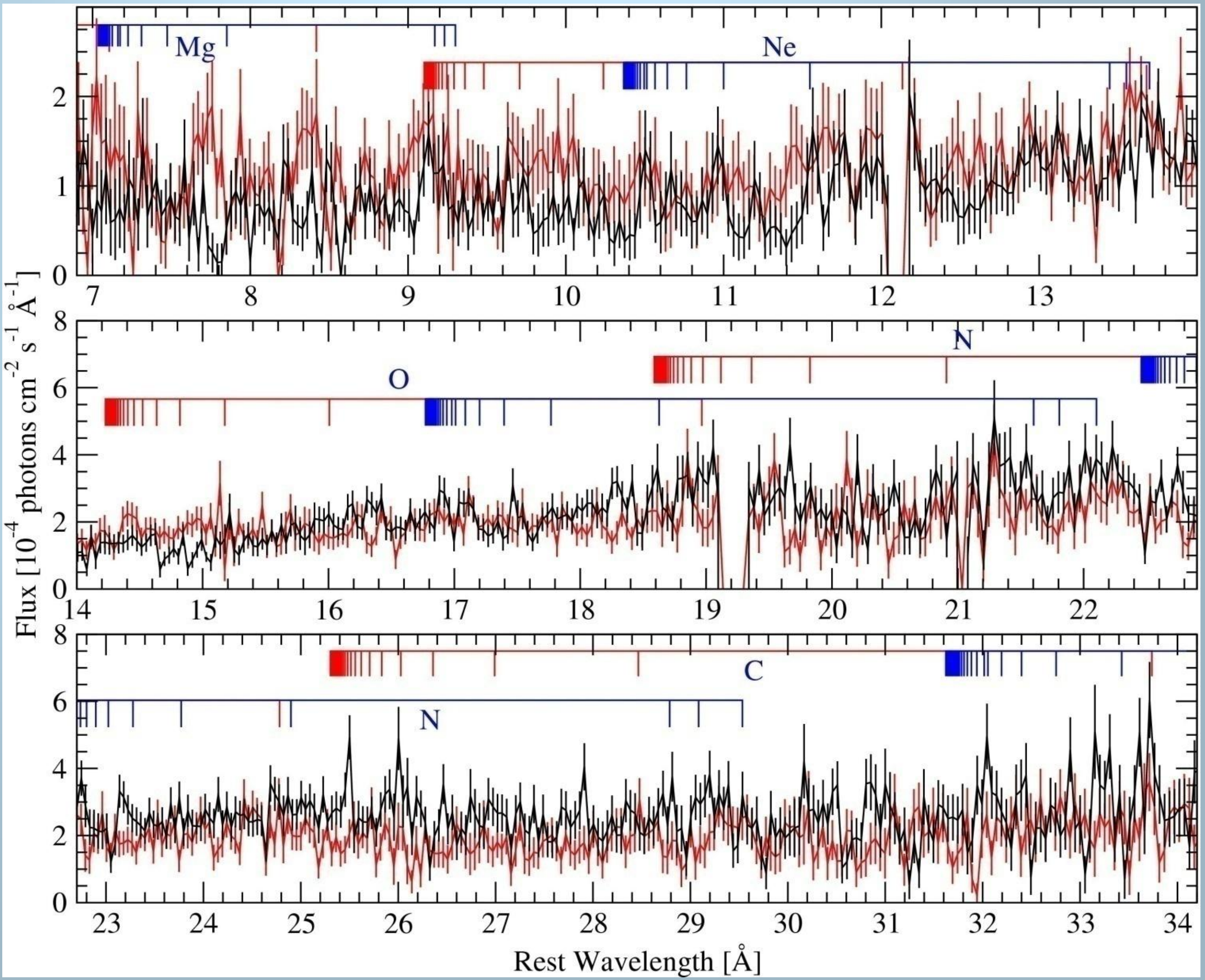
Two interpretations – differ by one order of magnitude in the outflowing mass

PG1211+143 Two RGS observations

2001-06-15

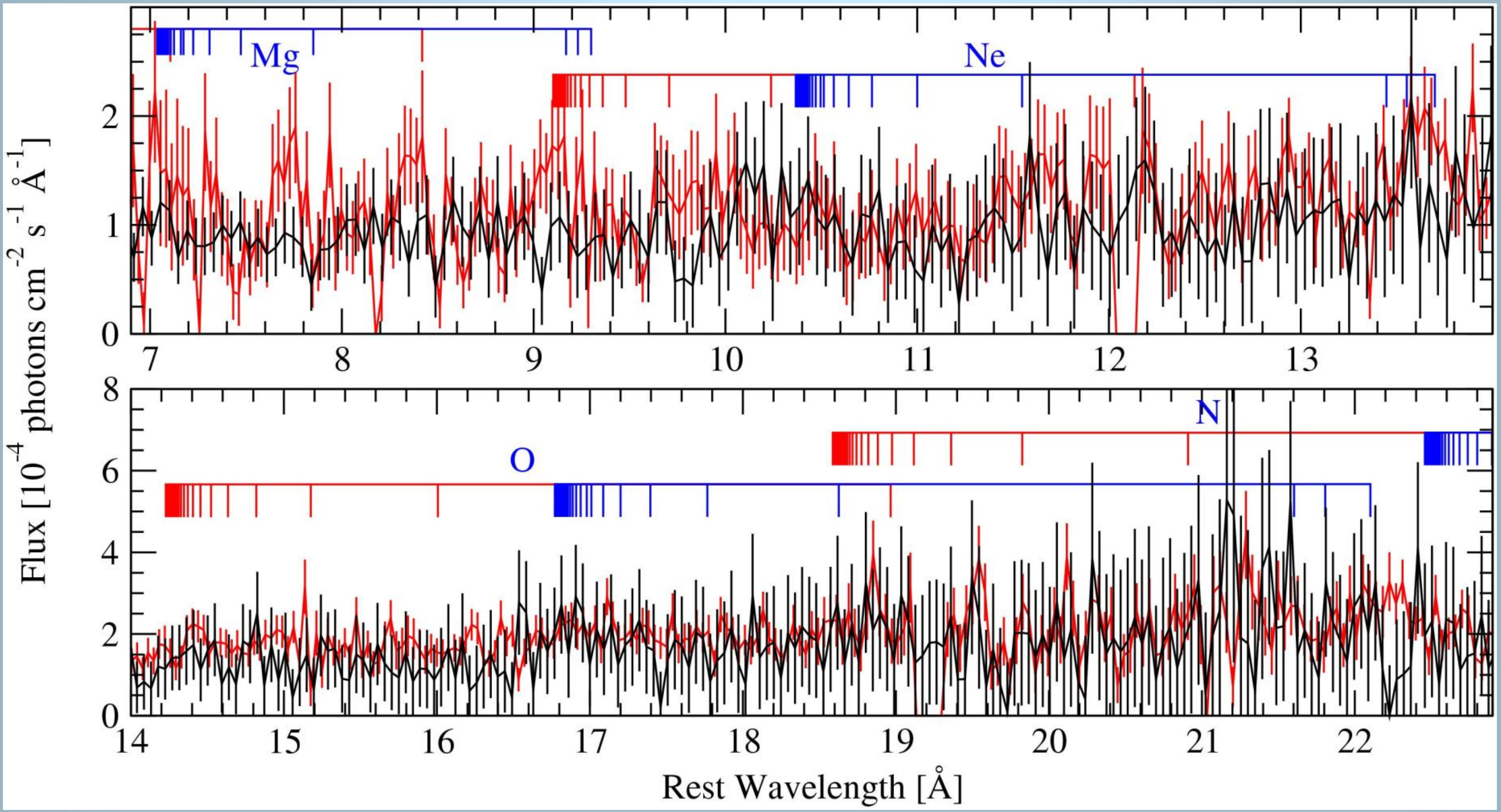
2004-06-21

Spectra are generally consistent, but a bit different slope and very different details.



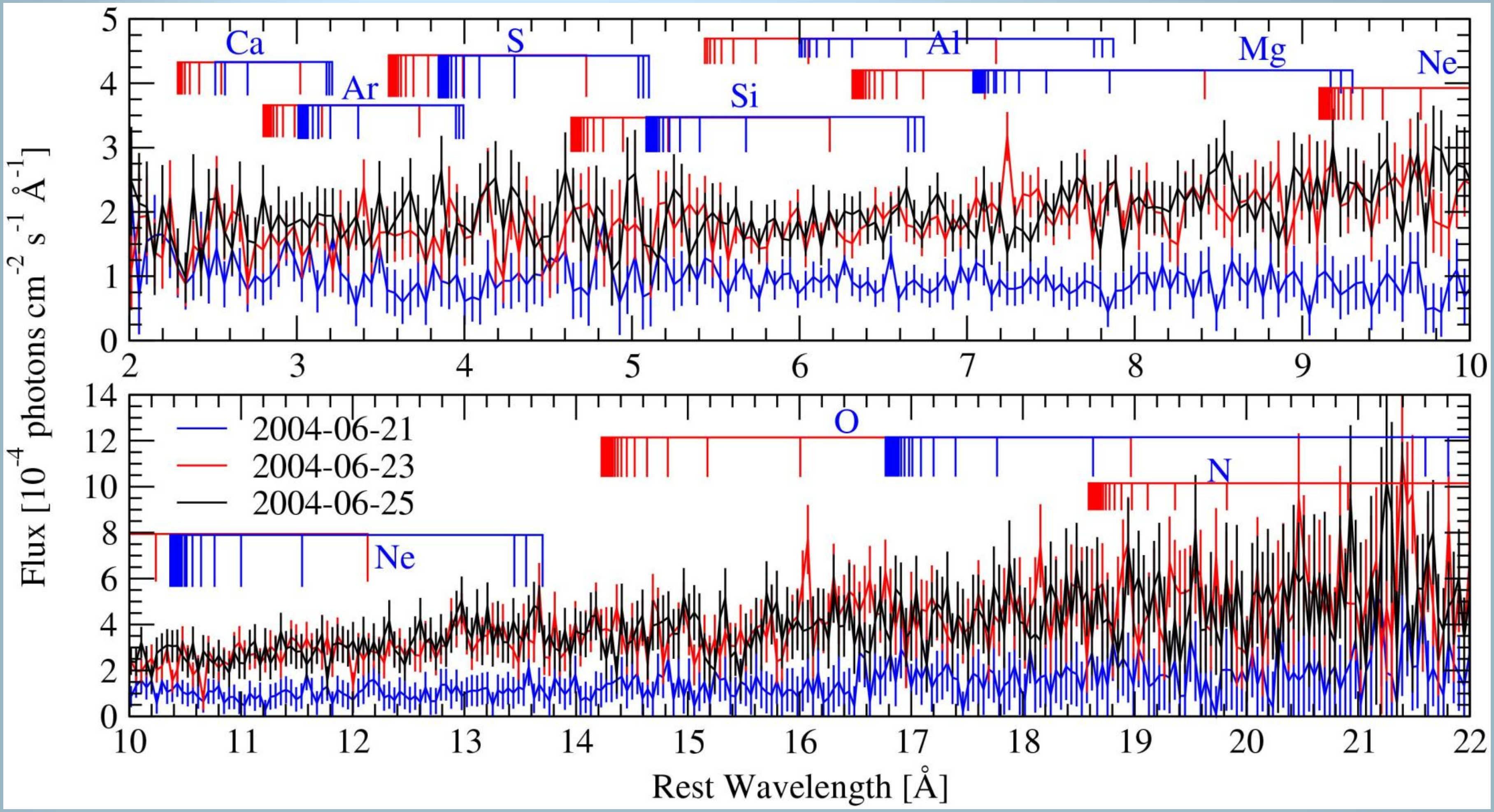
⇒**Object varied in time or a result of the poor S/N**

Simultaneous XMM-Newton and Chandra



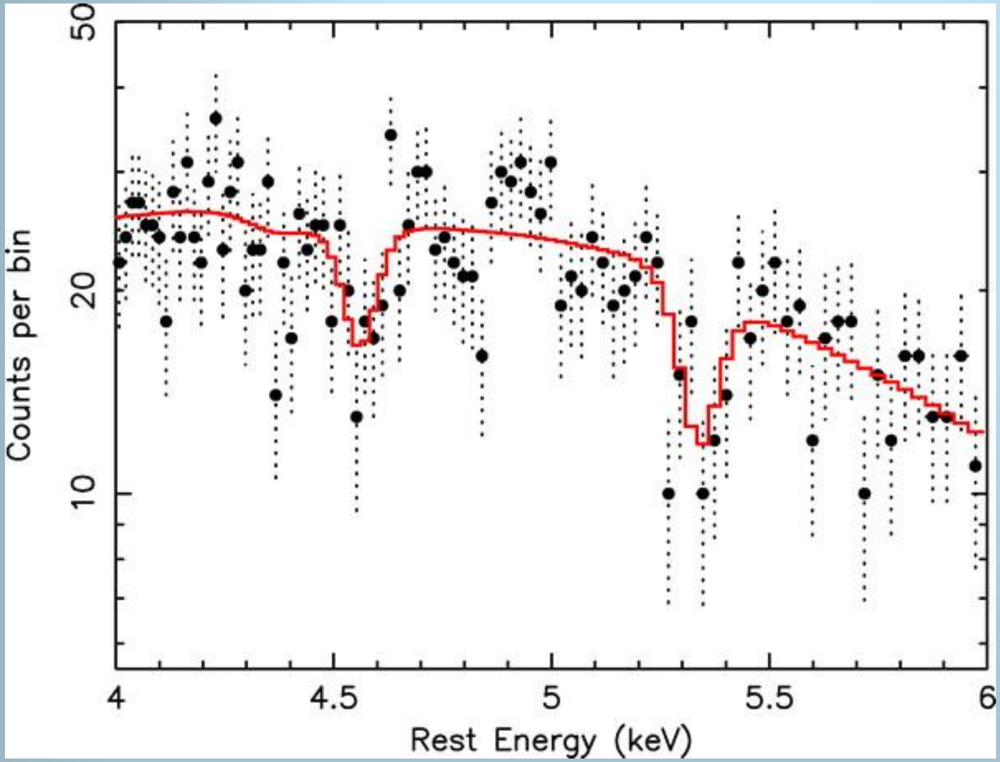
Xmm-Newton/RGS and Chandra/LETGS spectra are consistent overall, **but** differ in many details – probably a consequence of the poor S/N.

Three Chandra/LETGS observations



PG 1211+143 doubled its luminosity in two days. Narrow line features does not reproduce in the different spectra.

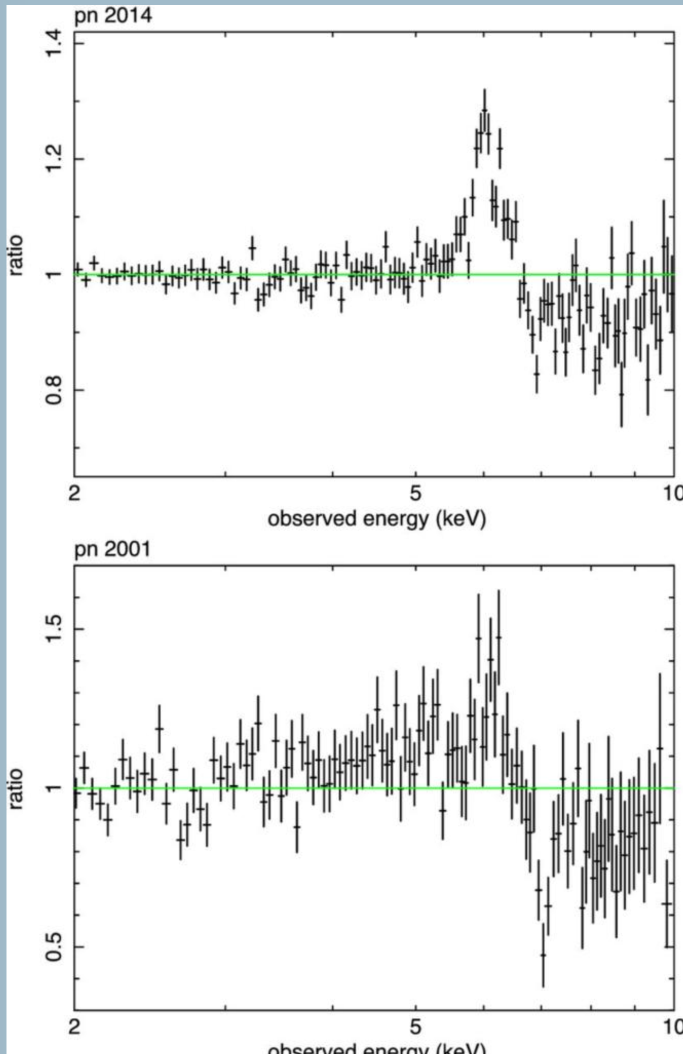
Three Chandra/LETGS observations

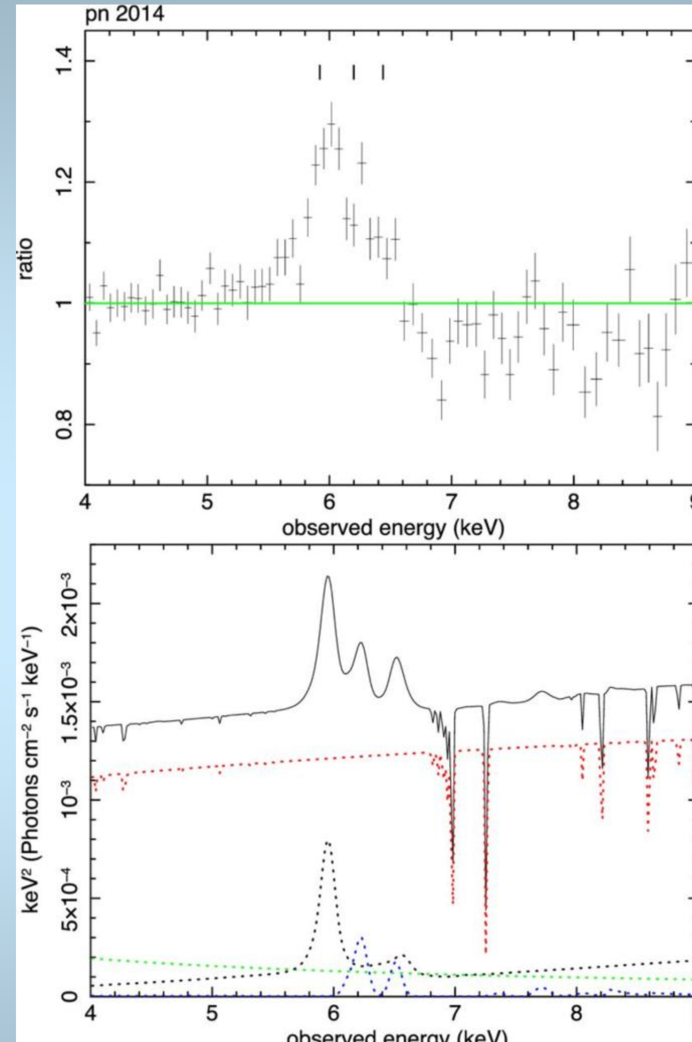


Only in the middle observation Reeves et al. (2005) identified two absorption line, which If identified with Fe XXVI Kα, then the redshift of each line would correspond to velocities of 0.26c and 0.40c, i.e., an infalling mass at relativistic velocities

Source is highly variable on time scales of days

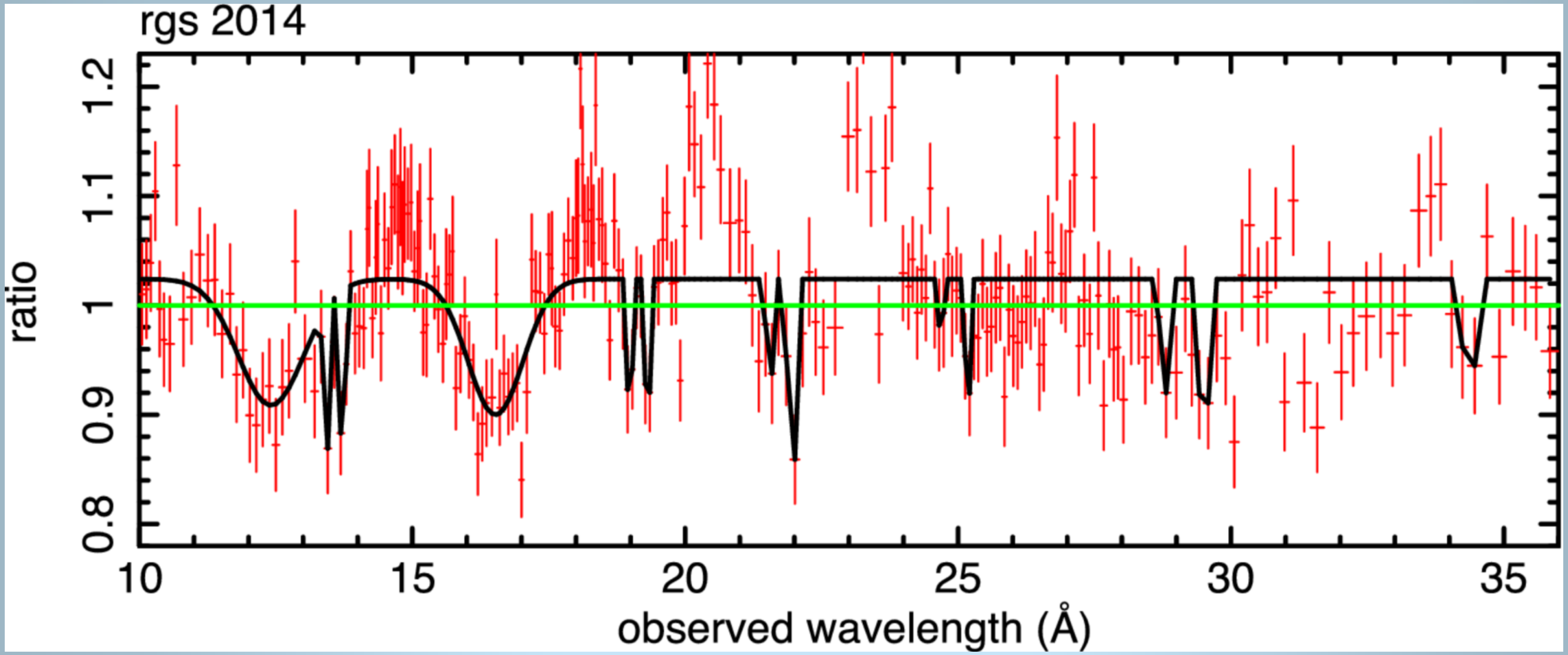
PG1211+143 - 2014 640ks in XMM





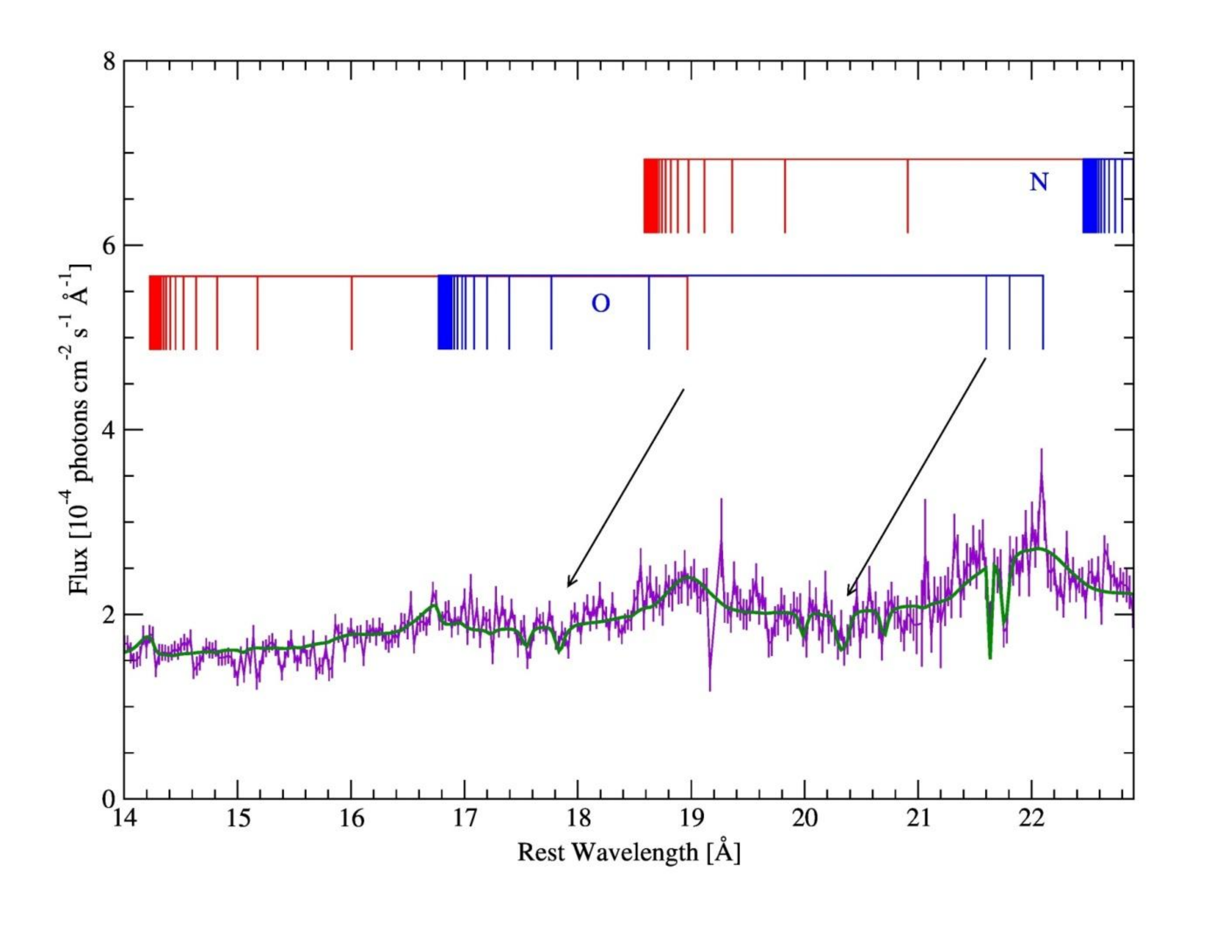
Pounds et al. (2016): Much better S/N data. Absorption at 7 keV is weaker. Structure in the Fe Ka line. Two outflow absorption systems, 0.066c and 0.129c.

PG1211+143 - 2014 640ks in XMM



RGS data also consistent with the two outflow systems 0.066c and 0.129c, showing 11 absorption lines of H-like and He-like ions of Ne, O, and N as well as L-Shell and M-Shell Fe trough.

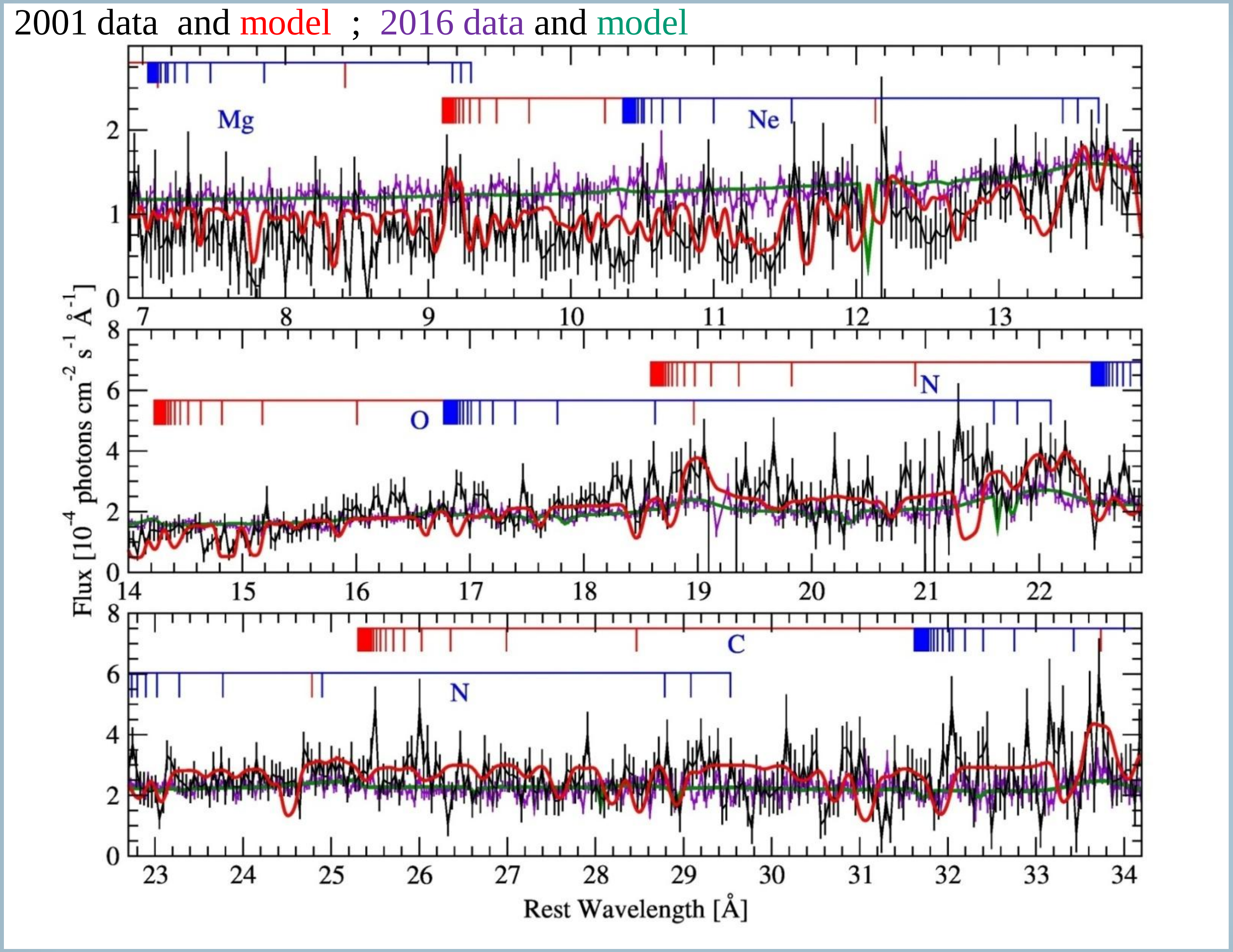
PG1211+143 2014 RGS observations



Preliminary Fit of the data with local Galactic absorption and ionized outflow system at velocity of 18,000 km/s.

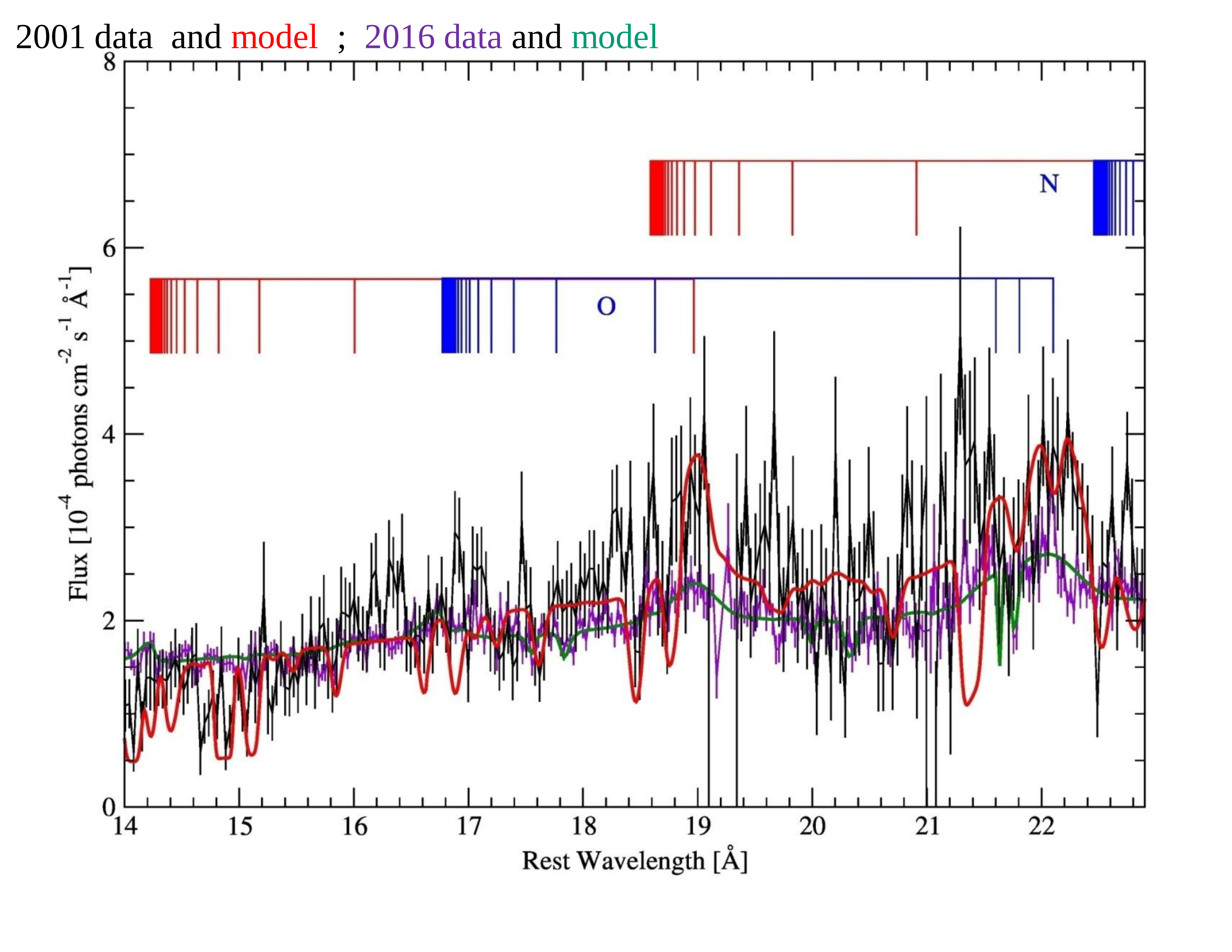
Few lines are fitted.

PG1211+143   2001 and 2014 RGS



Absorption features are much weaker. A result of the better S/N or the absorption has changed over the years?

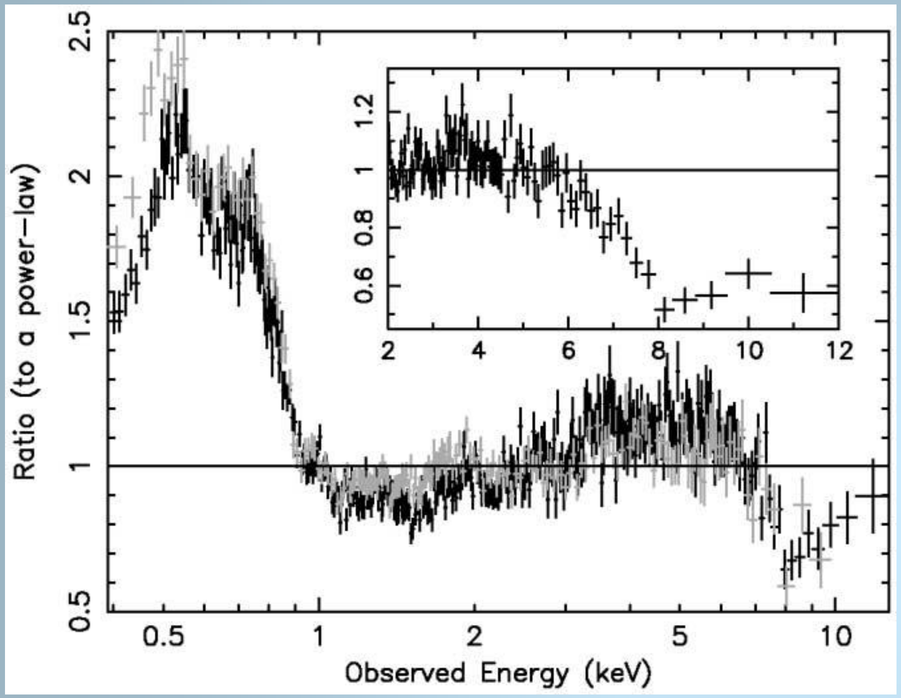
PG1211+143 2001 and 2014 RGS



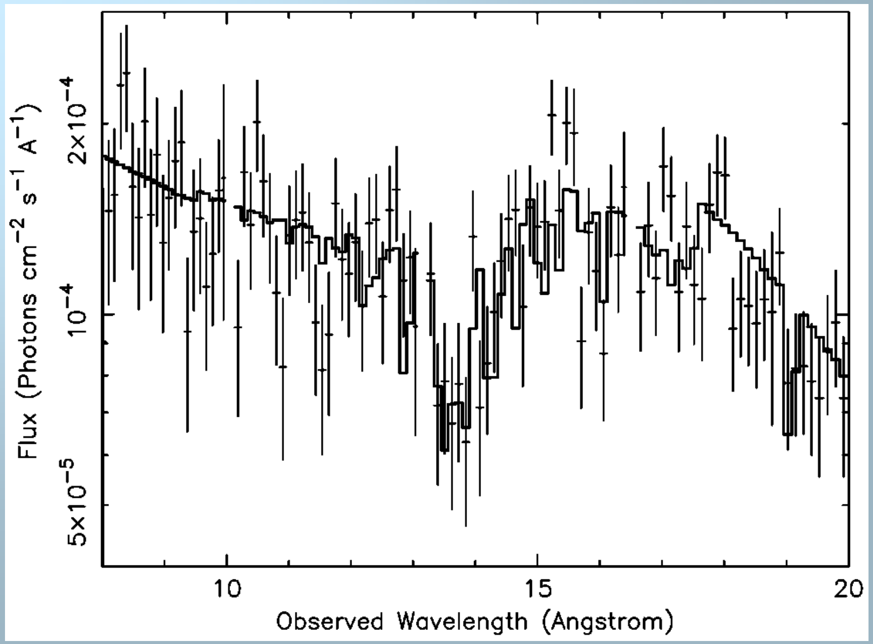
PDS 456

PDS456 - XMM observation 2001 Feb - 40Ks

Reeves, O'Brien, Ward (2003)

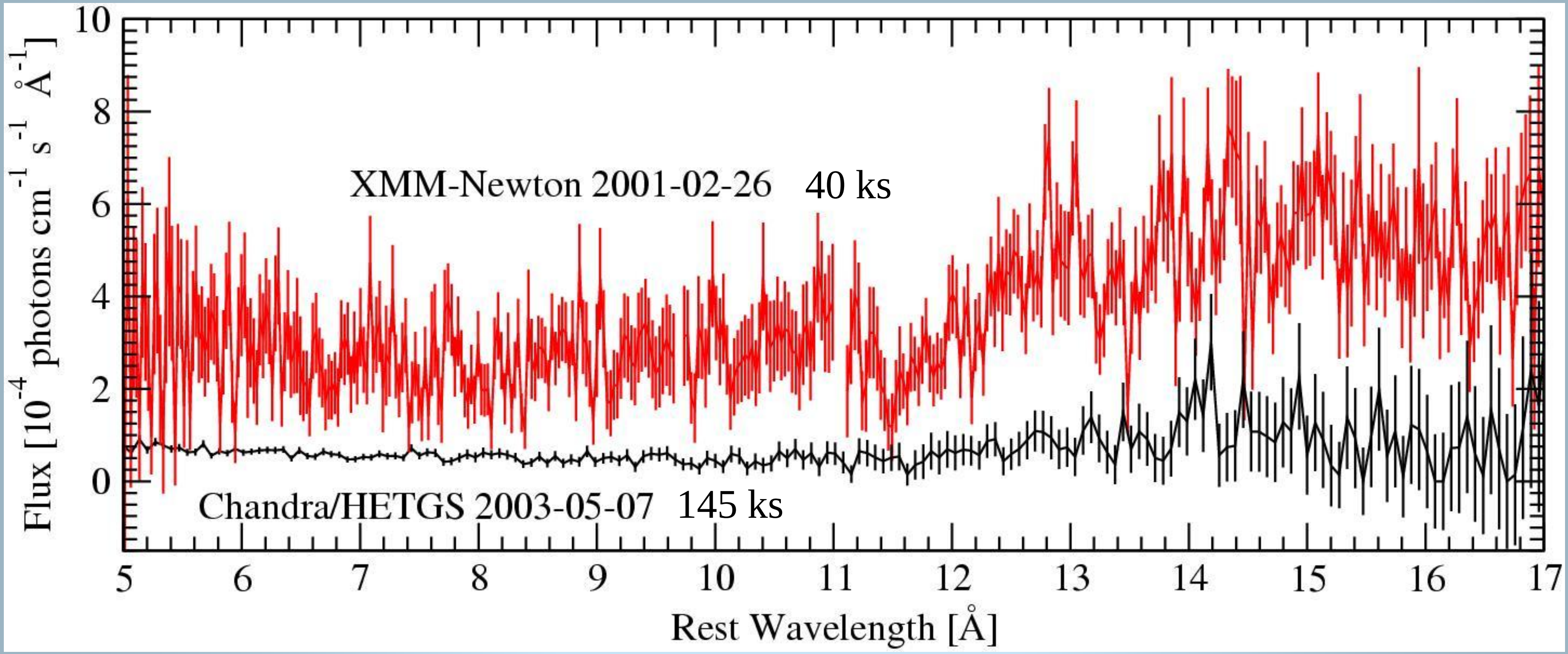


EPIC spectra show soft excess and a deep absorption trough around 7 keV which if interpreted as Fe K-Shell absorption edges it is an outflow at ~50000 km/sec.



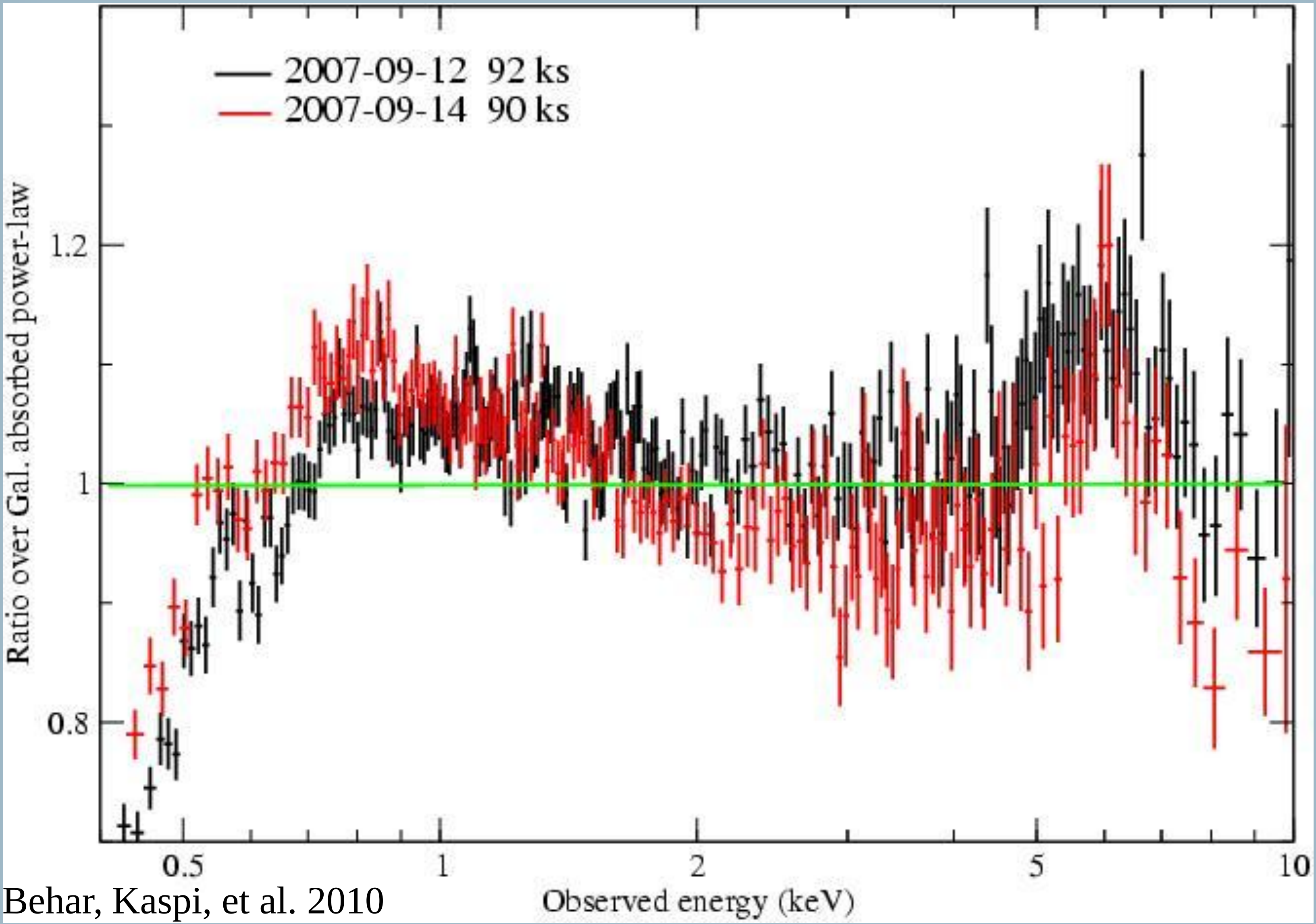
RGS spectra show deep absorption around 1 keV which if interpreted as a blend Fe L-shell absorption it is an outflow at ~50000 km/sec.

Chandra Observation 2003 May 7 – 145 ks



Chandra/HETGS observation two years after the XMM one.
PDS456 is in a low state and hardly any features can be detected.

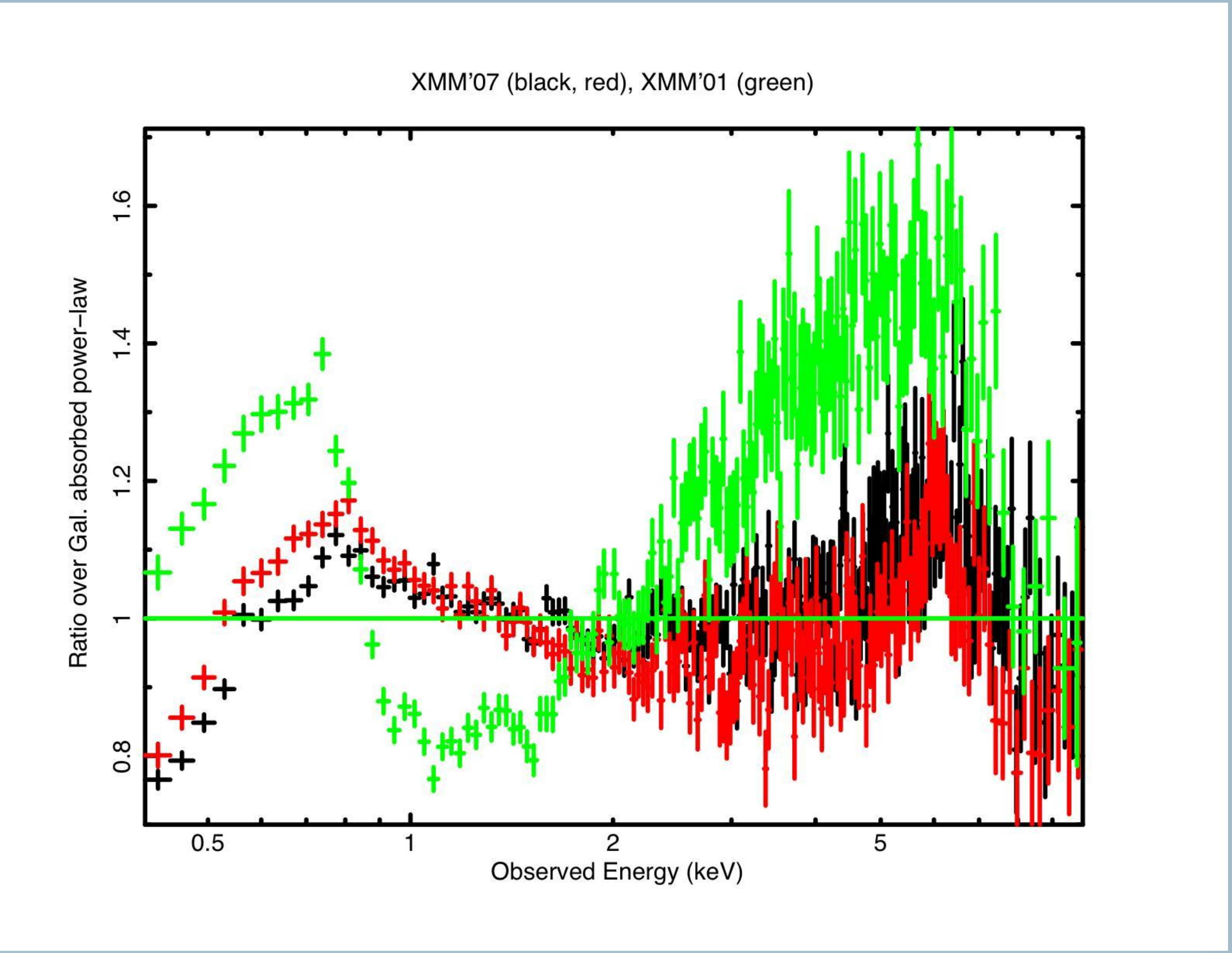
Two more XMM Observations



Behar, Kaspi, et al. 2010

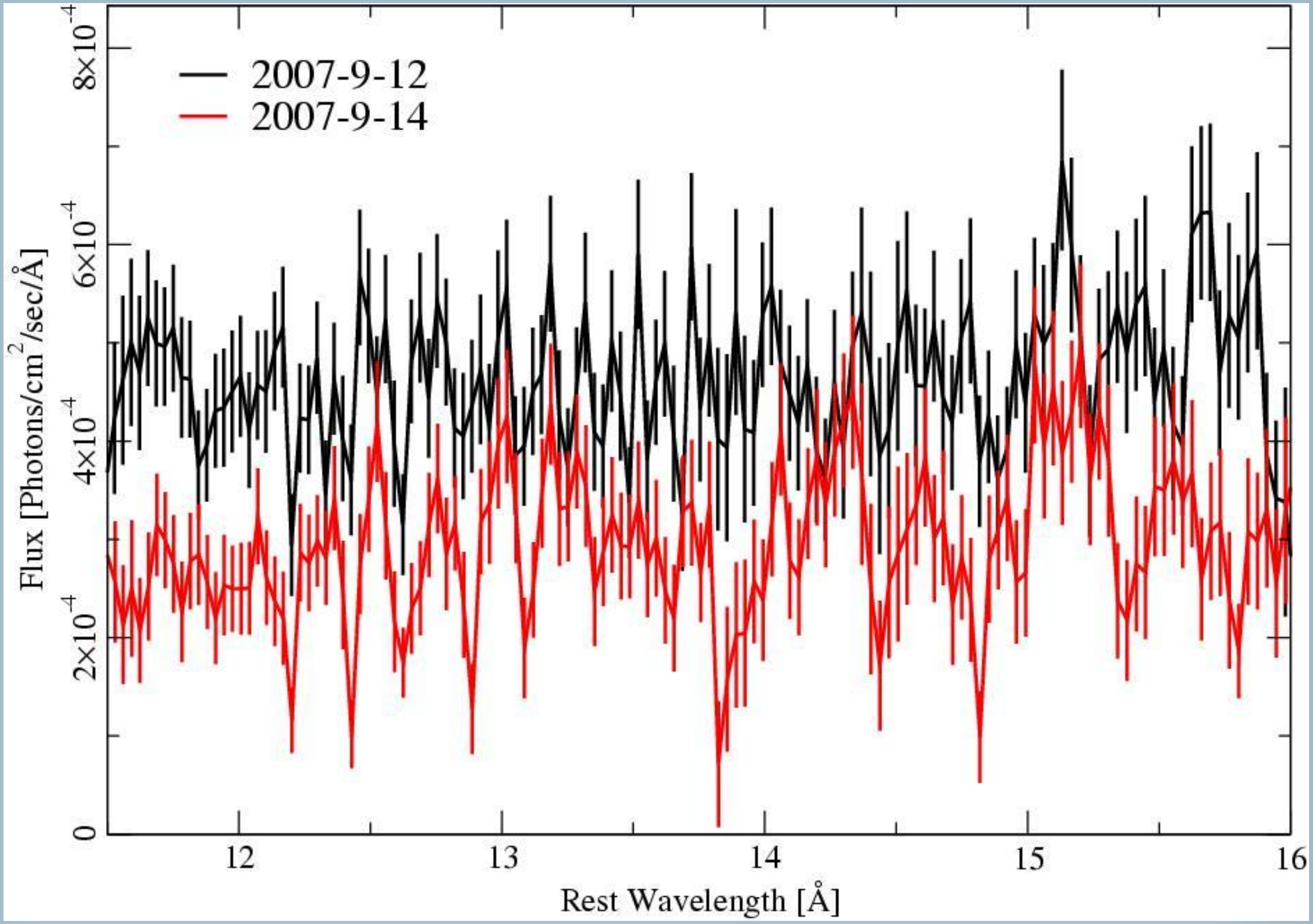
Spectral variability over 1-2 days

XMM 2001 and 2007 comparison



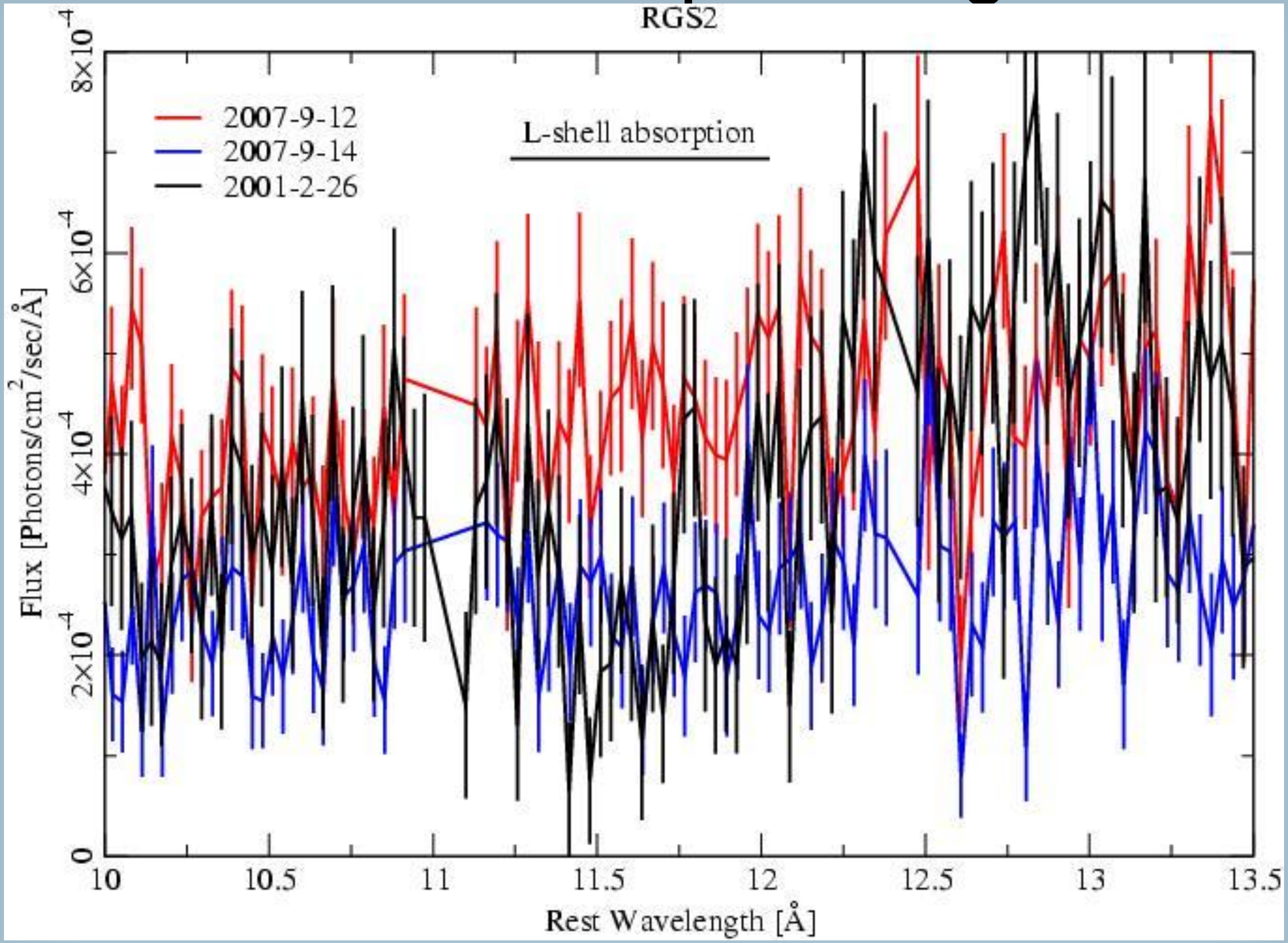
Strong variability over 6 years. Also spectral variability over 2 days.

RGS spectra



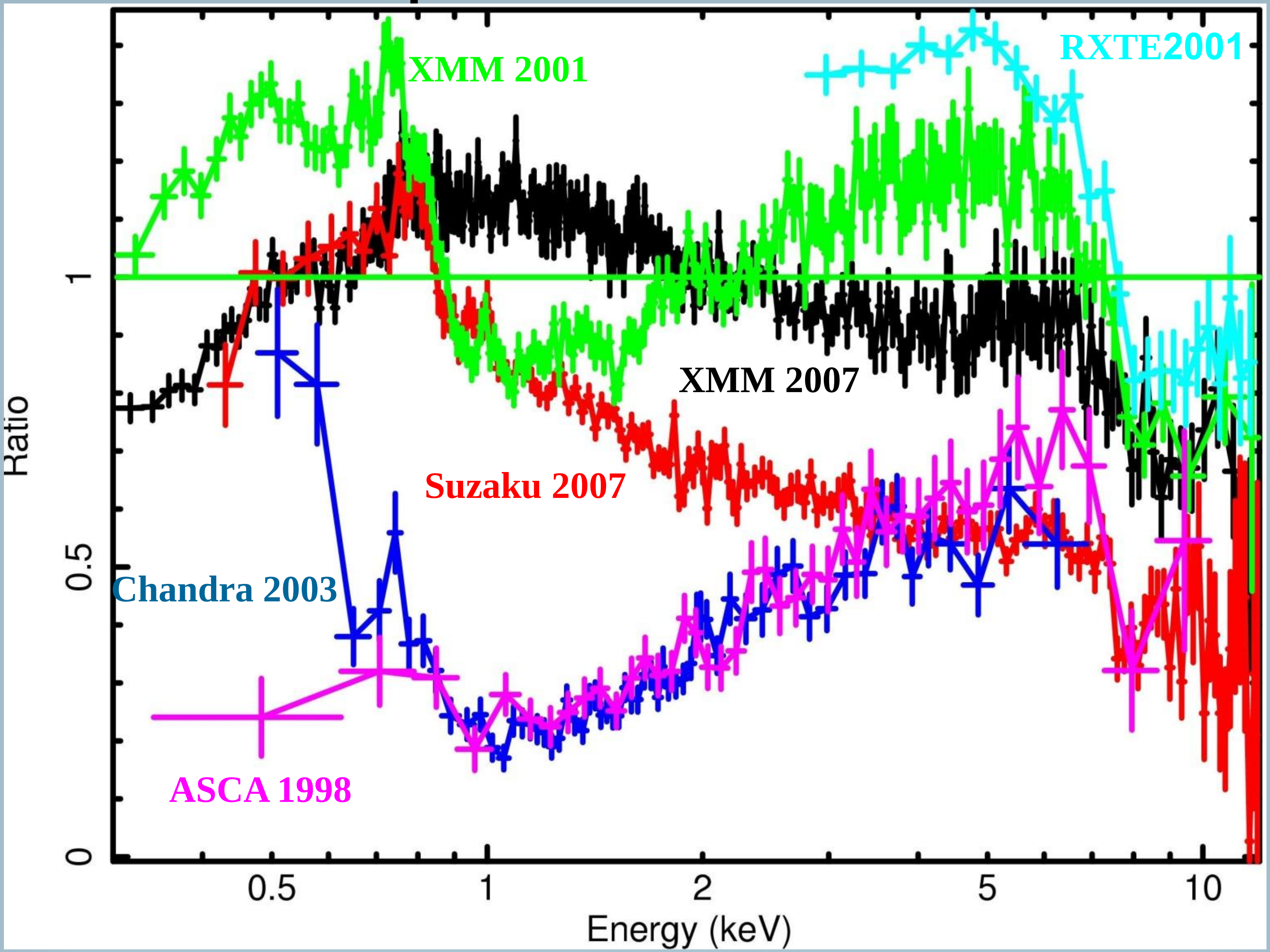
Variability over 1-2 days – however features are not identified

L-shell absorption region



2007 observations do not show same absorption feature from 2001

PDS456 - Spectra from 1998 to 2007



Ratio of spectra to a Γ=2 power law
illustrating the drastic long term spectral variability

PDS456 Spectral Variability

- The varying broad-band curvature can be explained by a partially covering absorber, with covering factor changing between 0 to 1.

- Narrow features in the source vary on timescale from days to years, but are elusive and difficult to track.

- A reflection component can explain some of the emission and appear to be outflowing at ~10000 km/sec.

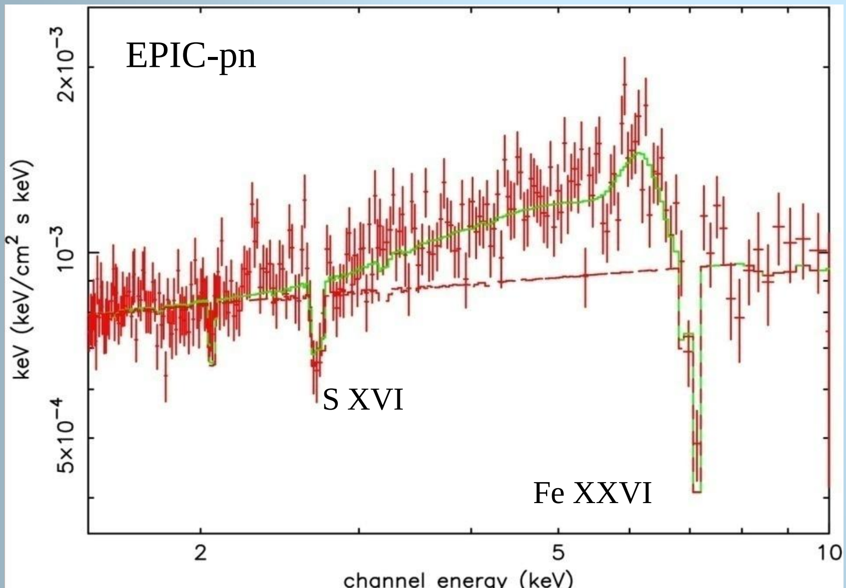
- No outflow is detected in the 2007 XMM observation.

- **The fact that the spectrum and the outflow are different at every observation makes the confirmation of specific features by recurrence impossible and makes the study of these outflows very challenging.**

Alternative

Identified lines may have different identification

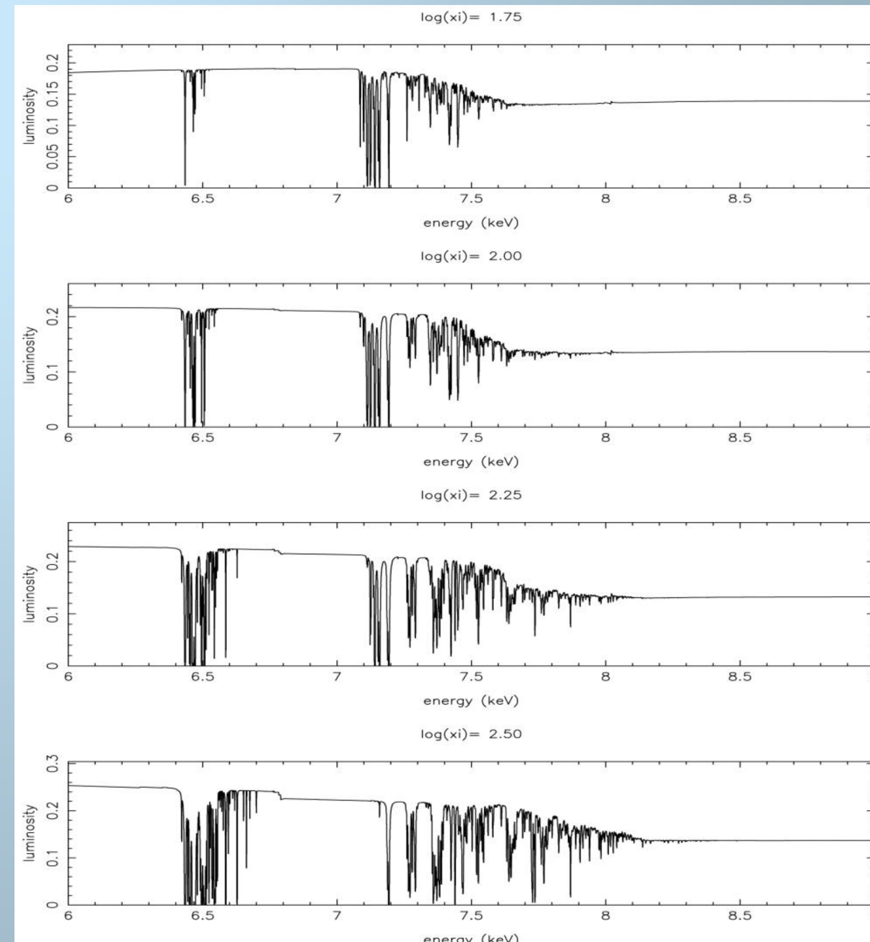
Absorption at > 6.4 keV – An alternative



Pounds et al. (2003) - PG1211

Feature at 7 keV (rest frame 7.6 keV) traditionally identified as Fe XXVI Lyα

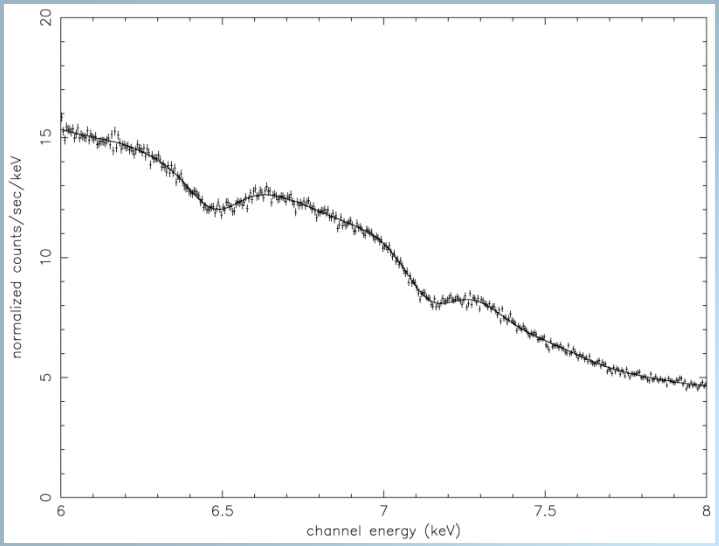
Could be an absorption from a different lines!



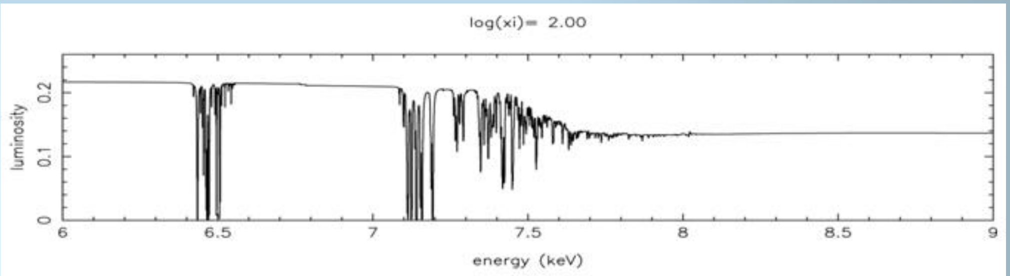
Kallman et al. (2004)

Complex absorption of Fe XVII to Fe XXIII

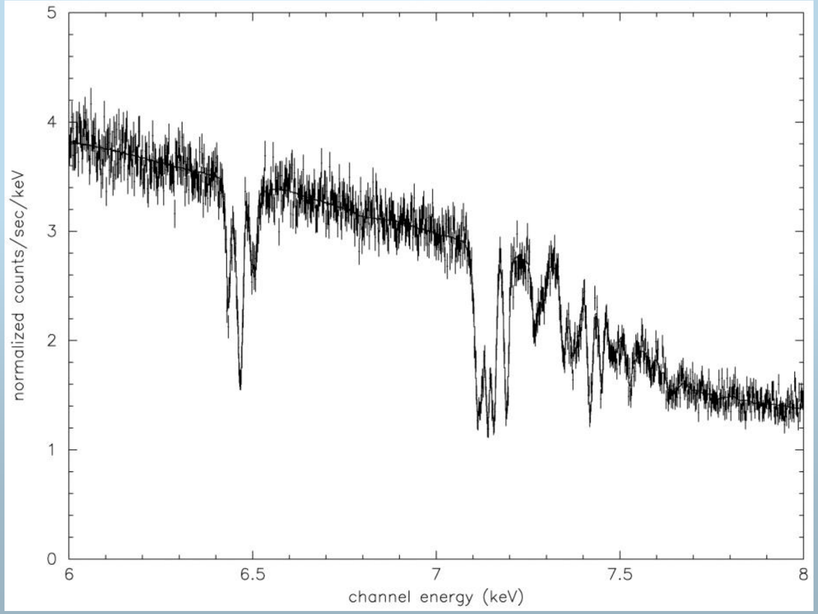
Need for better X-ray spectral resolution



Kallman et al. (2004)
model



PN camera on
XMM-Newton

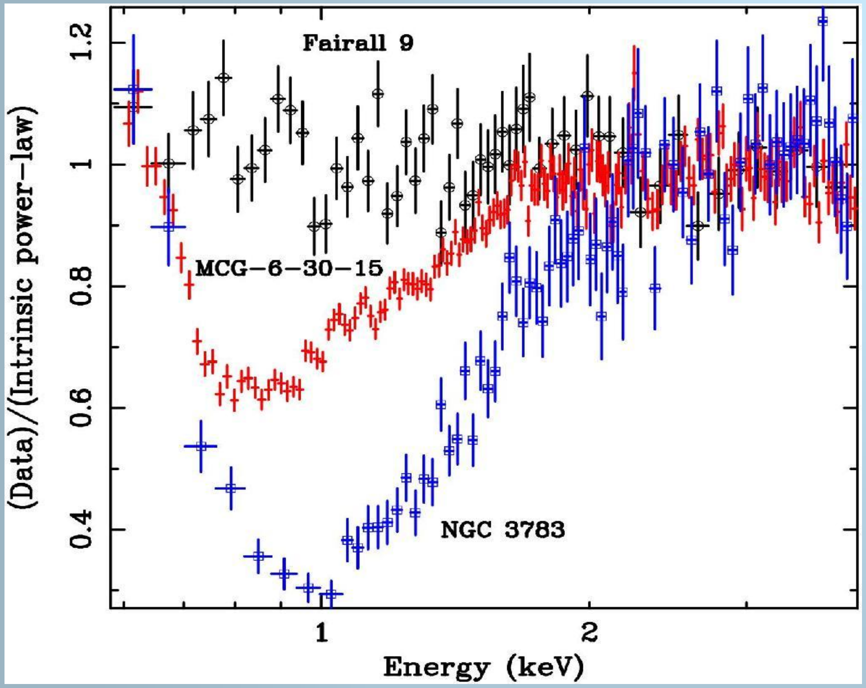


X-ray Spectrometer
(XRS) instrument

(Astro-E, Astro-E2,
Astro-H, …)

Warm absorber – The revolution

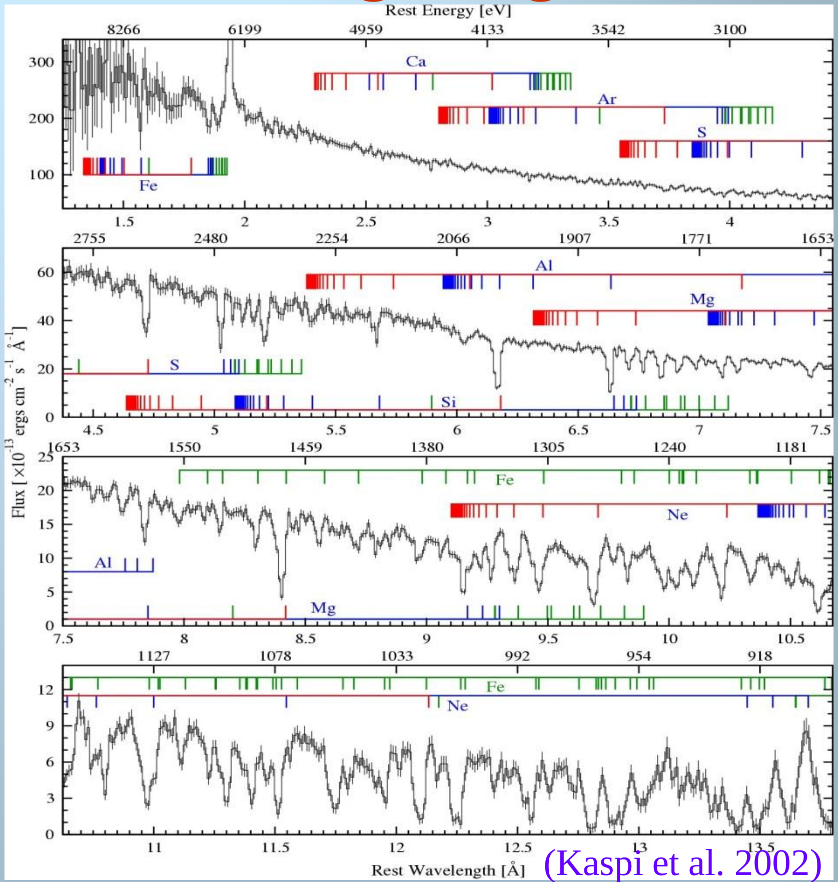
Pre-grating



3 Seyfert-type active galaxies observed with the ASCA CCD detectors

Velocity resolution ~ 25000 km/s

Post-grating



(Kaspi et al. 2002)

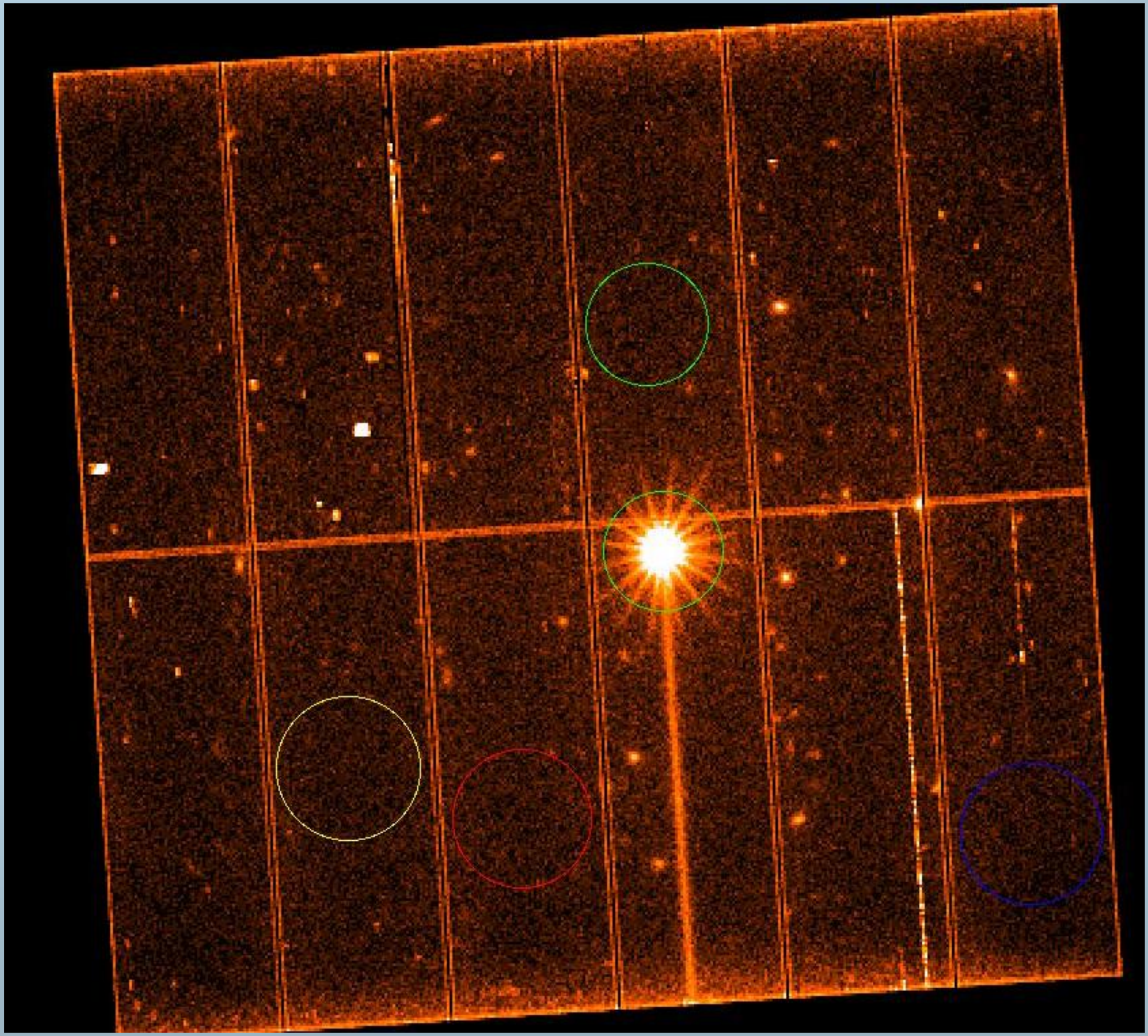
NGC3783 observed with the Chandra High-Energy Transmission Grating

Velocity resolution ~ 400 km/s

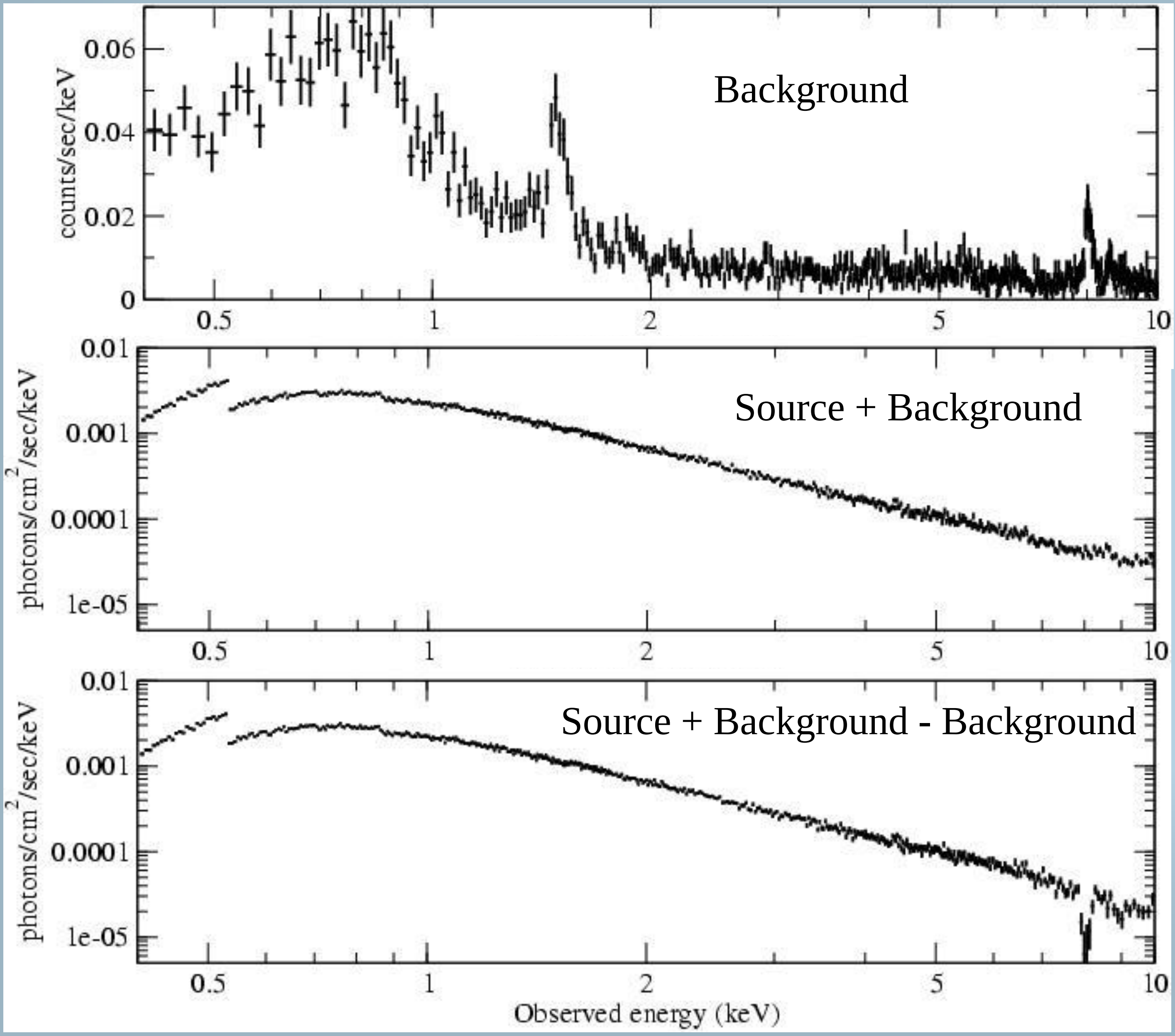
Revolution at the 6.4 keV region will come with the high resolution of the XRS

Word of caution:

PDS456 - EPIC-pn image - 2007



Problem with background in 2007

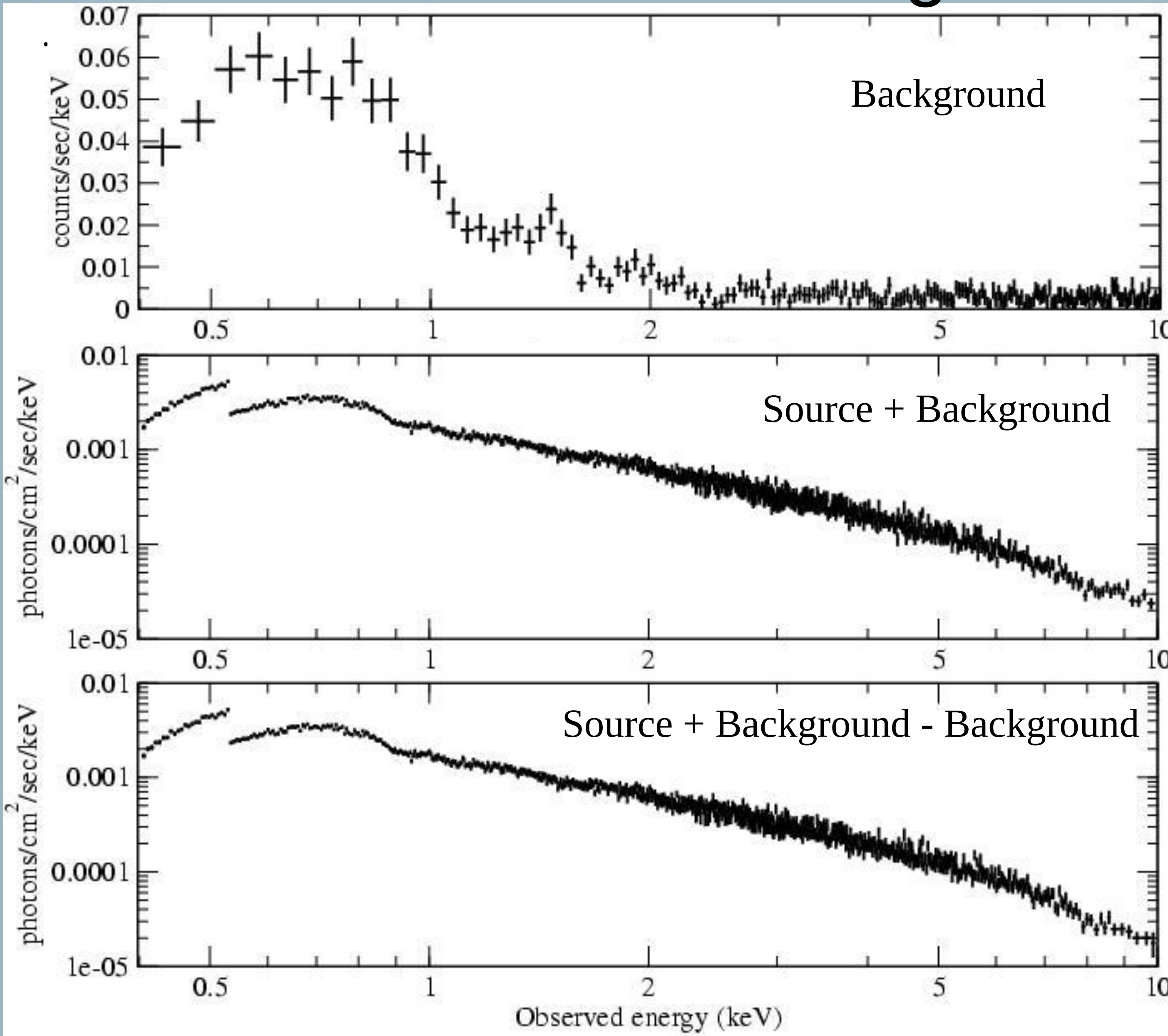


Background is showing strong narrow fluorescence emission lines due to Kα of Al, Ni, Cu, and Zn from the CCD structure.

Source+Background does not show these lines as the center of the CCD is free of these lines.

Subtracting the Background will indicate a false absorption line at ~8 keV.

No Problem with background of 2001



The background of the 2001 observation does not show the narrow emission lines.

The deficit in flux around 8 keV is not caused by the background lines

Ultra-Fast Outflows identification

For most of the claimed UFOs:

- Identification is mostly done based on the significant detection of only one absorption trough bluer of the Fe Kα line.
- Based on the significant detection of only one trough, which could possibly be associated with other spectral line.
- In most cases the claimed UFO trough is only seen in one epoch.
- If seen again in the same source it does not have the same velocity.
- Sometimes appear and disappear on short time scales as short as 2 days.
- Troughs are usually shallow (optical depth of 0.05 to 0.2).
- **Such a behavior of a claimed phenomenon is bringing it very close to being unfalsifiable.**

Ultra-Fast Outflows in X-rays: True or False?

• Extraordinary claims require extraordinary evidence

(Carl Sagan)

• UFOs are not found in low-luminosity AGNs.

• Some High-luminosity AGNs show increasing evidences of having UFOs, indicating mass outflow that can affect the surrounding host galaxy.

• UFOs are potentially energetically significant but their variations and model dependent parameters cannot yet give a coherent picture.

• UFOs are varying on time scales of days to years and this needs to be taken into account when calculating the effect of the mass outflow on the surrounding.

• Some/Most detections may simply be due to photon noise plus modest systematic effects that were not taken into account.

Thank you