X-ray Observations of Ultra Fast Outflows in AGN

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Outflows from Active Galactic Nuclei

Introduction – Observations of winds in Active Galactic nuclei and the discovery of ultra fast outflows.

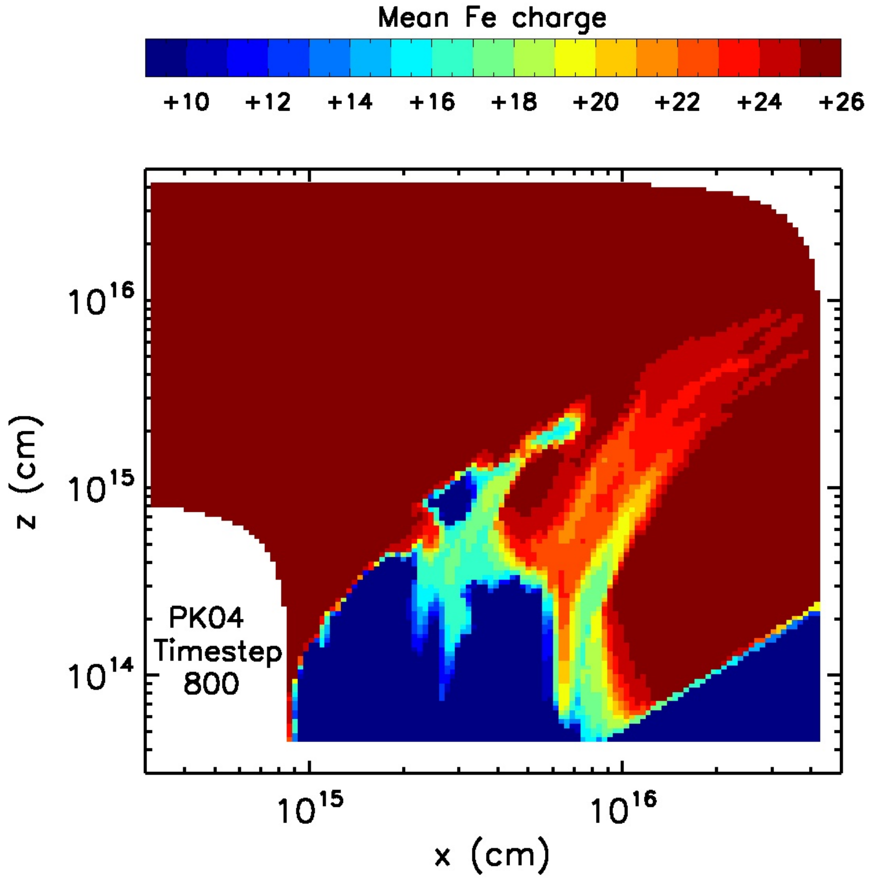
Case Study 1 – The powerful, wide angle, disk wind in the luminous quasar PDS 456. What are the outflow energetics? Revealing the outflow variability and structure. Possible driving mechanism

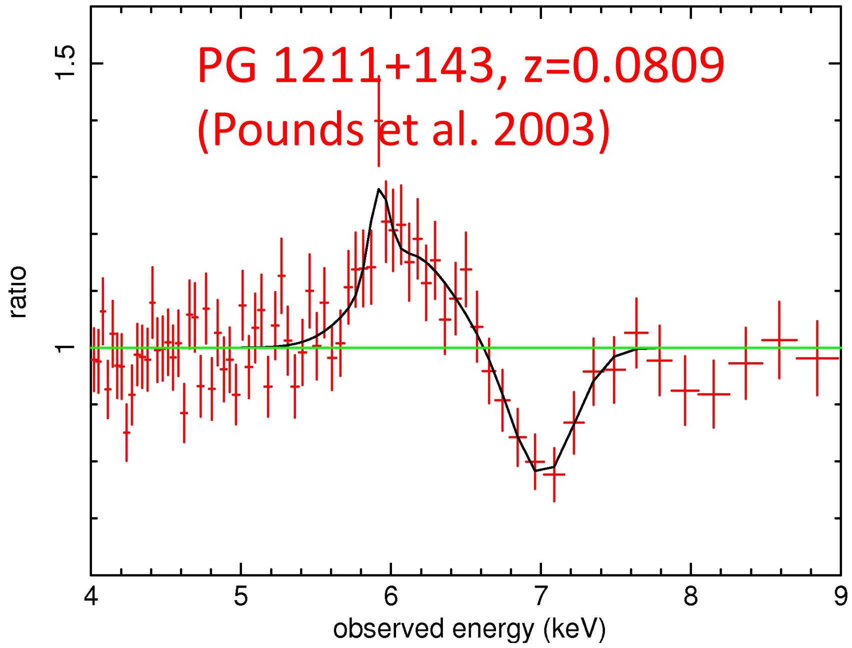
Case Study 2 – the large XMM-Newton campaign on the nearby narrow line quasar, PG 1211+143. Observations of a rapidly variable accretion disk wind. The soft X-ray signature of the fast wind.

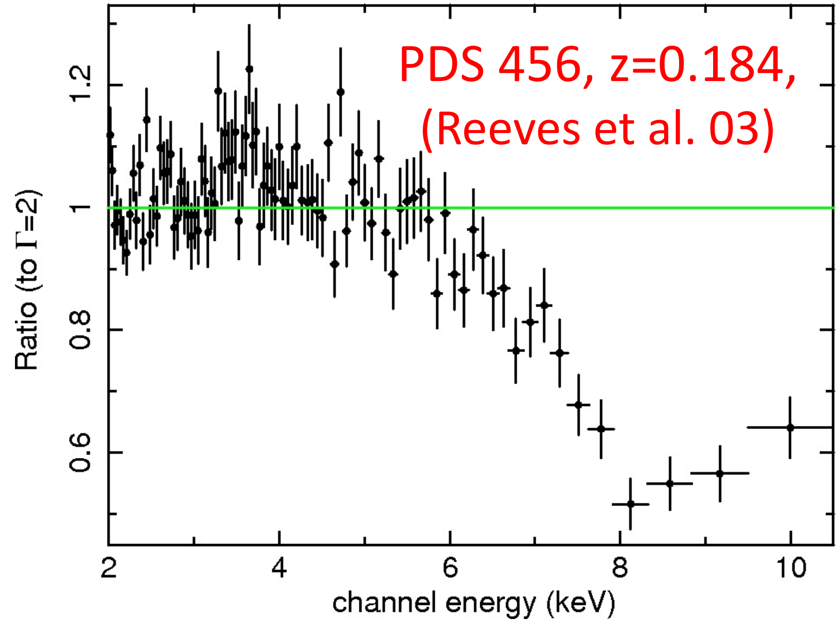
Discussion – statistics and occurrence. Energetics and role in feedback. What are the signatures of the fast outflow? Driving mechanism and acceleration.

Discovery of Accretion Disk Winds in AGN

- Initial discovery in PG 1211, PDS 456 and APM 08279 (Chartas et al. 2002).
- Disk winds simulations of Sim et al. (2010), Proga & Kallman (2004). Produces blue-shifted Fe K absorption
- Also MHD wind models (Ohsuga & Mineshige 2011, Fukumura et al. 2015).





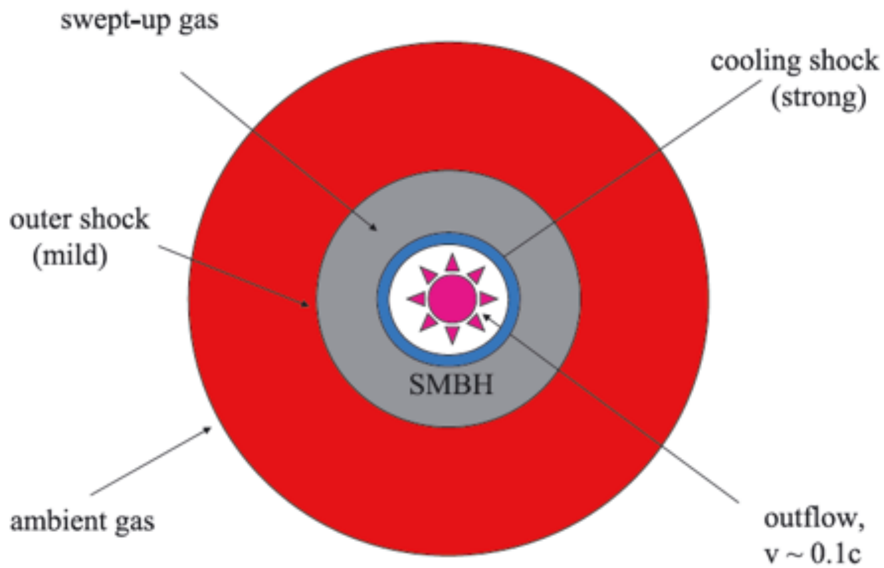


Powerful disc winds are naturally expected at high accretion rates:

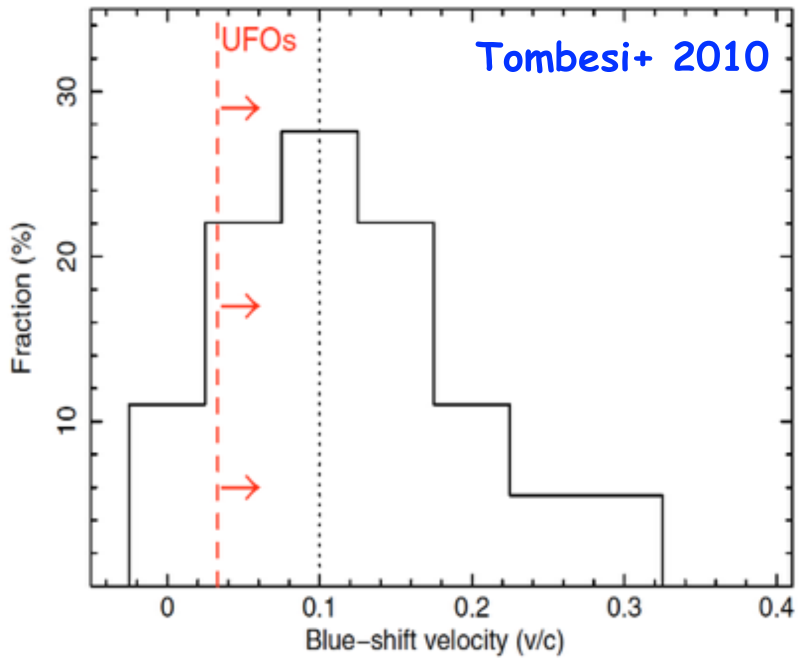
$$\dot{M}_{\rm out} v_{\rm out} \sim L_{\rm Edd}/c$$

$$v_{\rm out}/c = 0.1$$

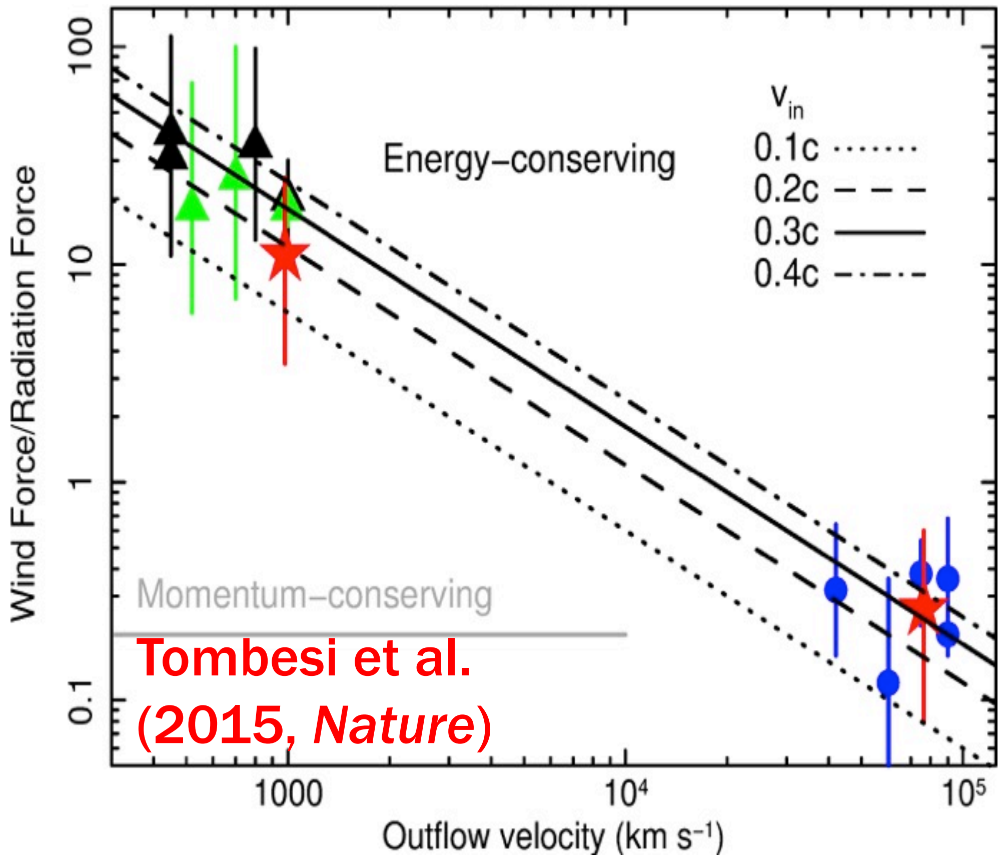
$$P_{\rm kin} \sim 0.05\, L_{\rm Edd}$$



King 2010



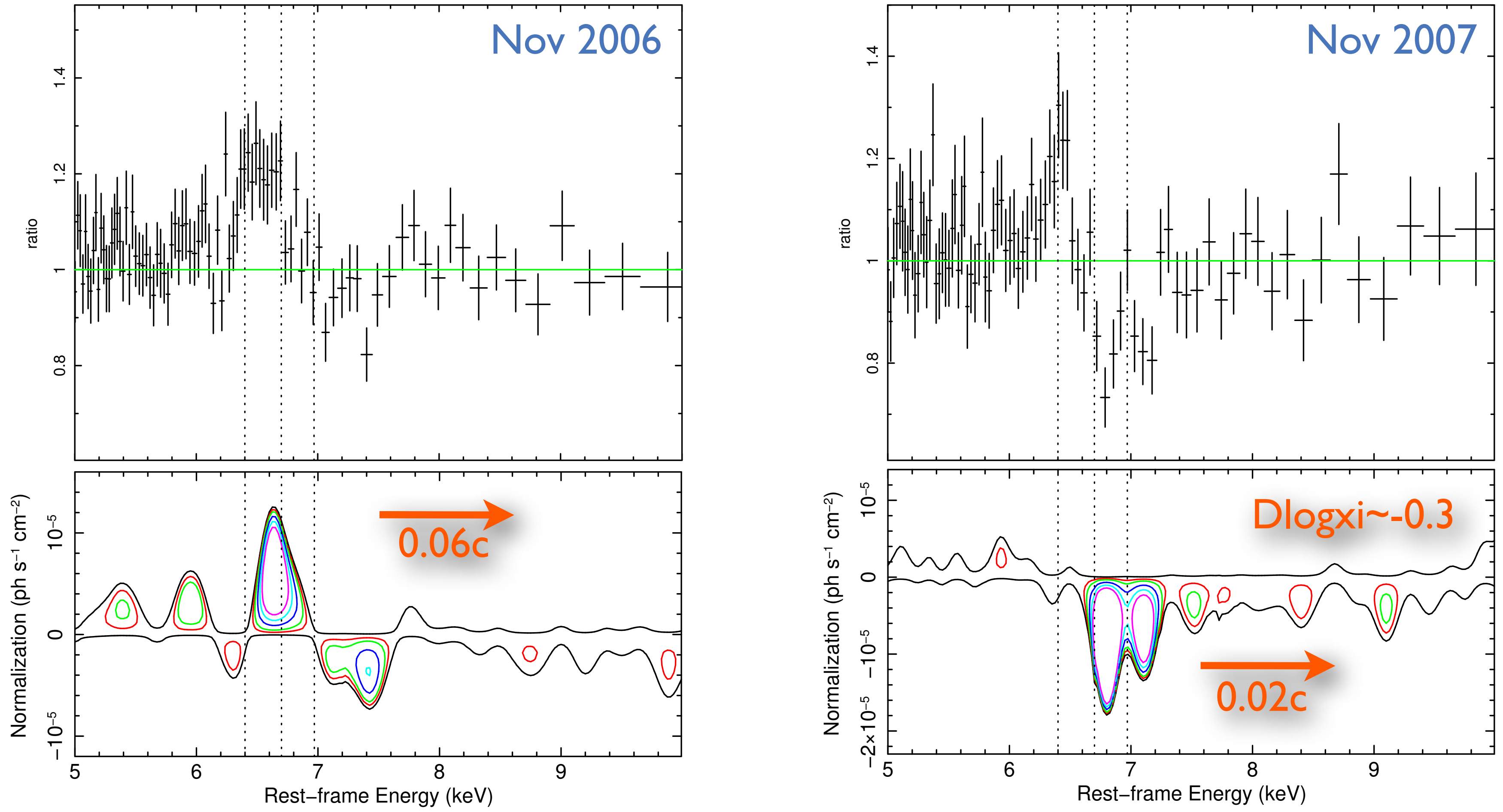
Tombesi+ 2010



Tombesi et al. (2015, *Nature*)

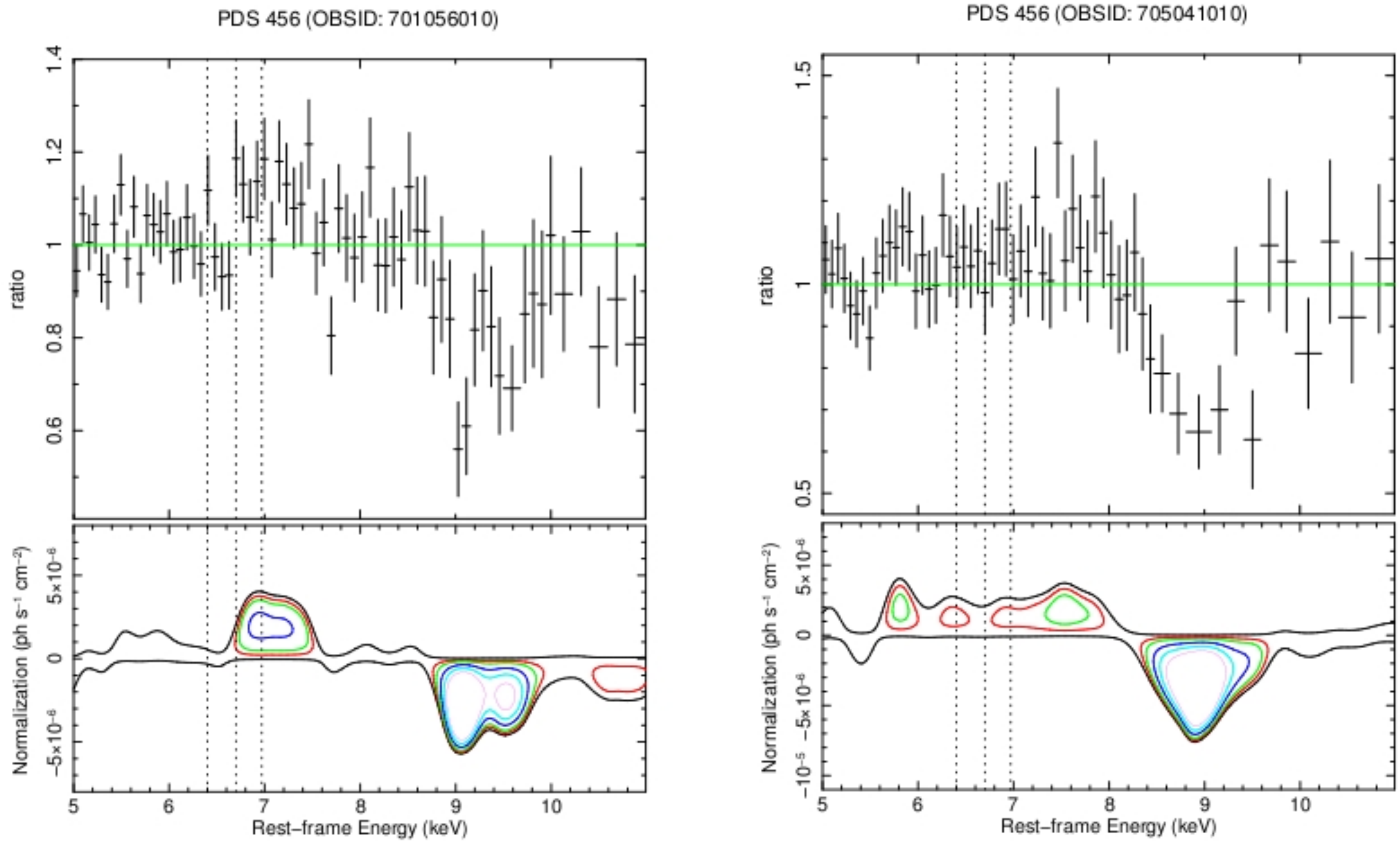
Suzaku Outflow Sample (Gofford et al. 2013)

Mrk 766 (NLS1, z=0.0129)



Note - statistical significance of absorption lines in all cases tested from Monte Carlo simulations

PDS456 (RQ QSO, z=0.184)



Outflow velocity of 0.25-0.30c, if associated with Fe XXV/XXVI resonance lines (at 6.7-6.97 keV).

Suzaku Outflow Sample (Gofford et al. 2013, 2015)

- 20/51 AGN found to have significant iron K absorption (18/51 at >99% significance from Monte Carlo).

- This corresponds to 28/73 of the fitted X-ray spectra (or 40%). The absorption line systems break down as follows:-

  9/28 systems likely associated with Fe XXVI Lyα

  4/28 with Fe XXV or lower ionization.

  12/28 associated with at least 2 lines due to Fe XXV and Fe XXVI.

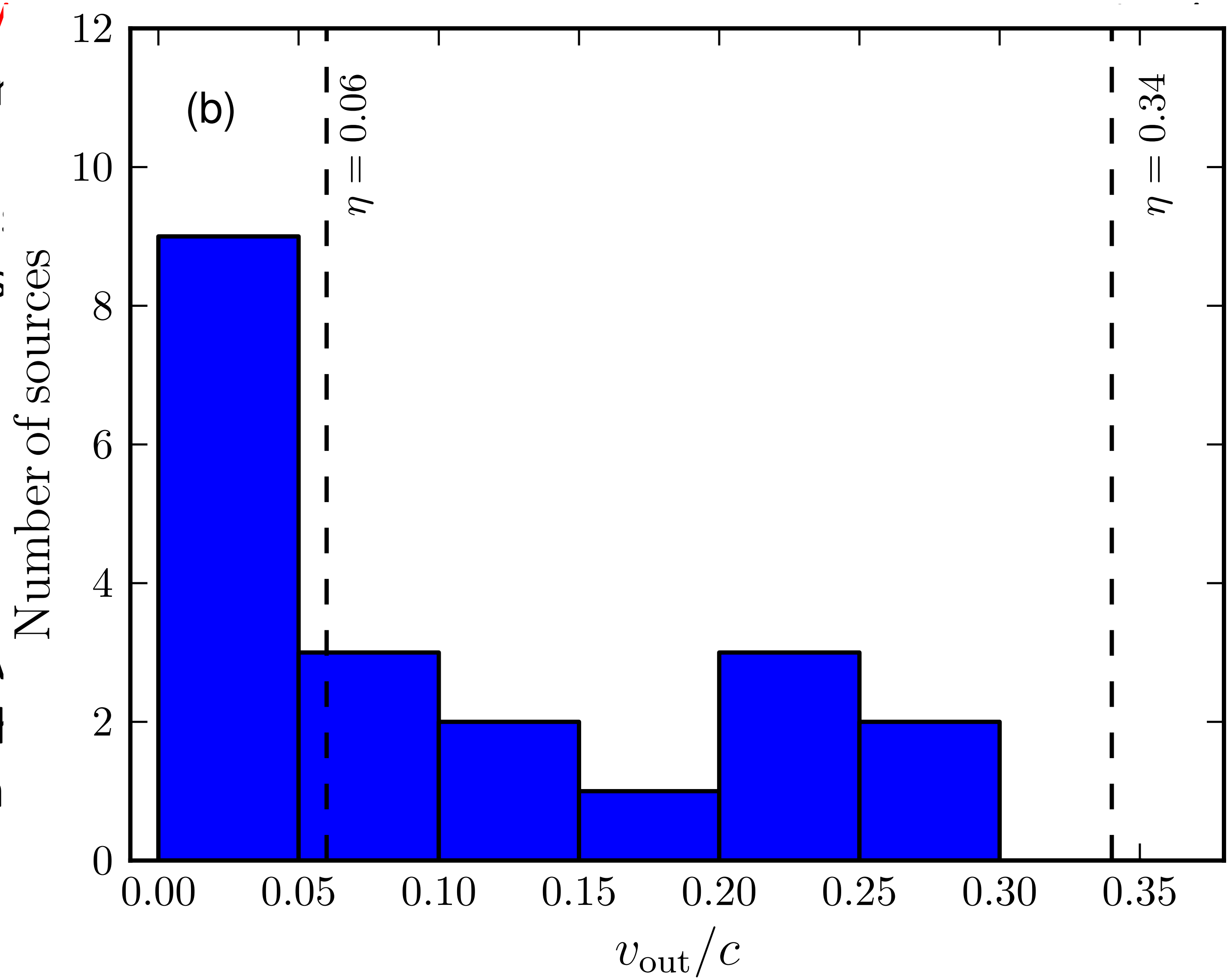
  3/26 may have multiple velocity systems.

- Overall 12/20 of the AGN have outflow velocities >10000 km/s of which 8 have v>0.1c. Only 3/19 are consistent with no-net velocity-shift.

- Mean ionization parameter, log xi=4, column log (N_H /cm^{-2})=23

Suzaku Outflow Sample (Gofford et al. 2013, 2015)

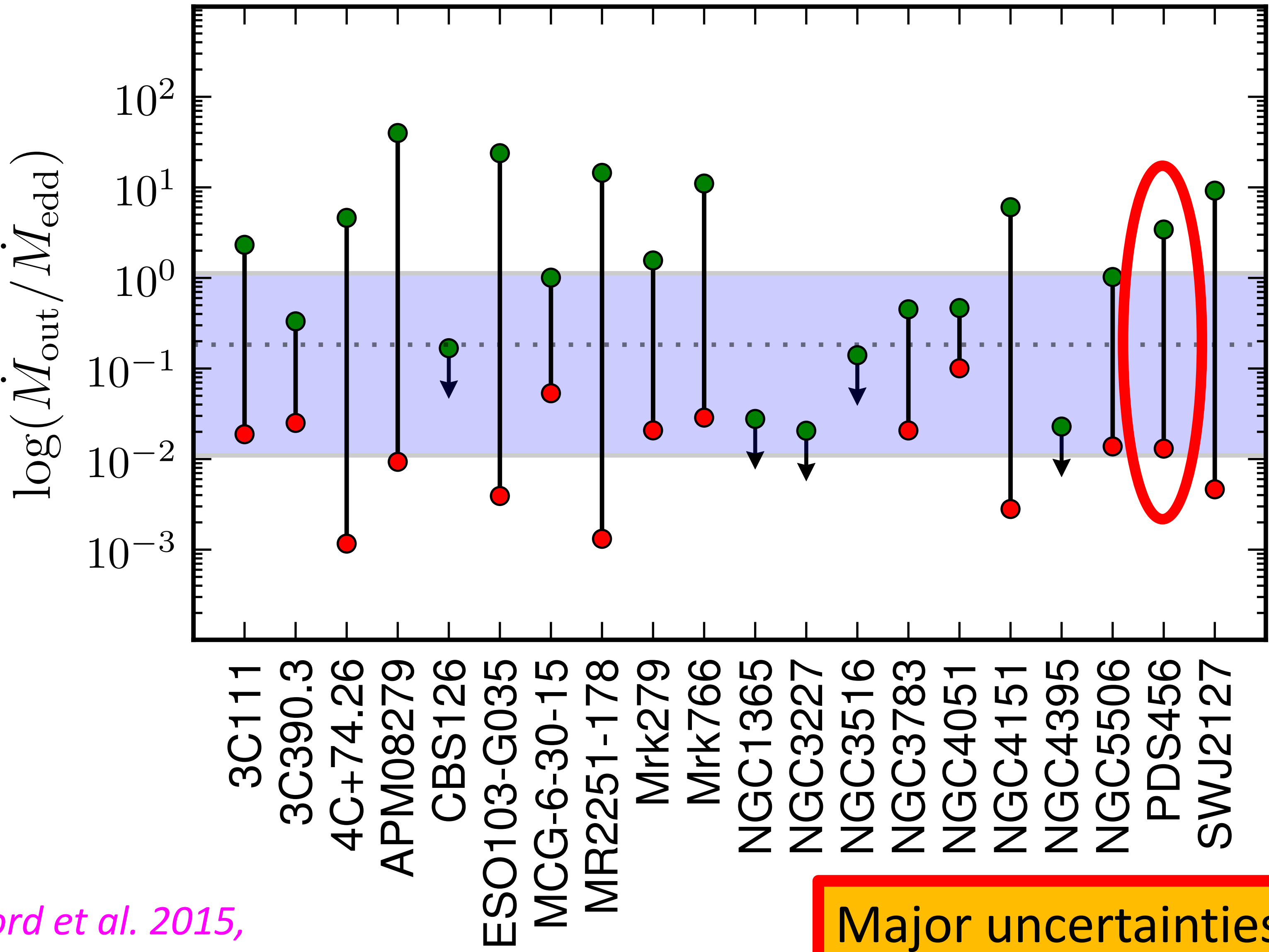
- 20/ … 1 at >99% sigr …
- Thi…). The abs…



… l Fe XXVI.

- Ov… n/s of wl… velocity- sh…
- M… :23

How powerful are disk winds?



Gofford et al. 2015, Sample of iron K outflows with Suzaku

Major uncertainties: launch radius + solid angle

How powerful are disk winds?

The detection of narrow, blueshifted X-ray absorption lines does not provide any solid constraint on the total energetics of a wind

$$\dot{M}_{\rm out} \sim \Omega \, N_{\rm H} \, m_{\rm p} \, v_{\rm out} \, R_{\rm in}$$

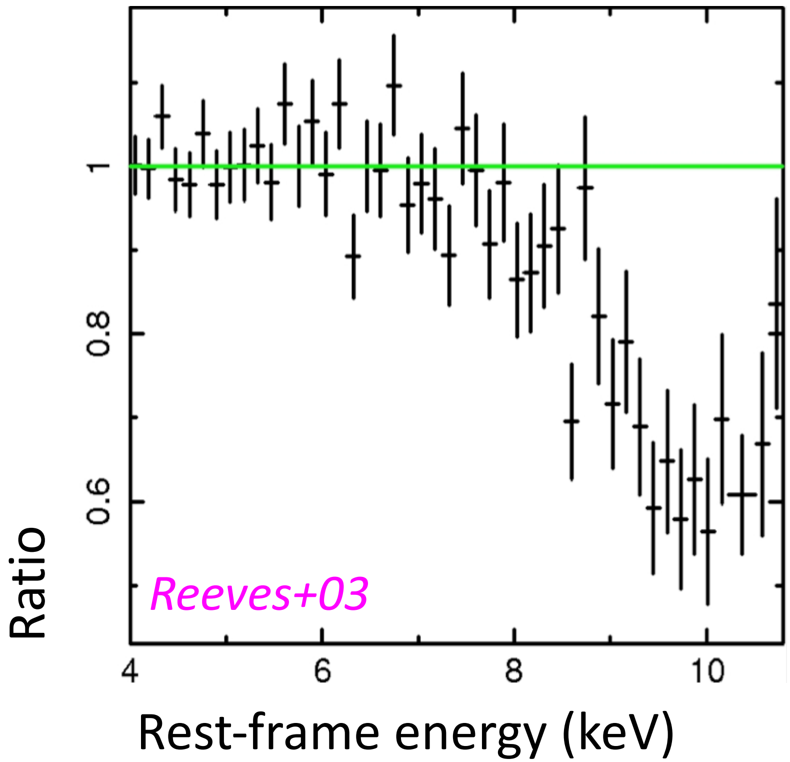
- ★ Solid angle: frequency of BH wind signatures among local AGN
- ★ Column density: modelling of absorption by photo-ionised gas
- ★ Outflow velocity: line's energy shift following identification
- ★ Launch radius: ionisation state of the gas and escape velocity

It is still unclear whether disk winds have sufficient mechanical energy to power feedback on galactic scales

PDS 456: the Rosetta Stone of AGN disk winds

Most luminous radio-quiet AGN in the local Universe

$$M_B \sim -27 \qquad L_{\rm bol} \sim 10^{47}\,{\rm erg\,s^{-1}} \qquad M_{\rm BH} \sim 10^9\,M_\odot$$

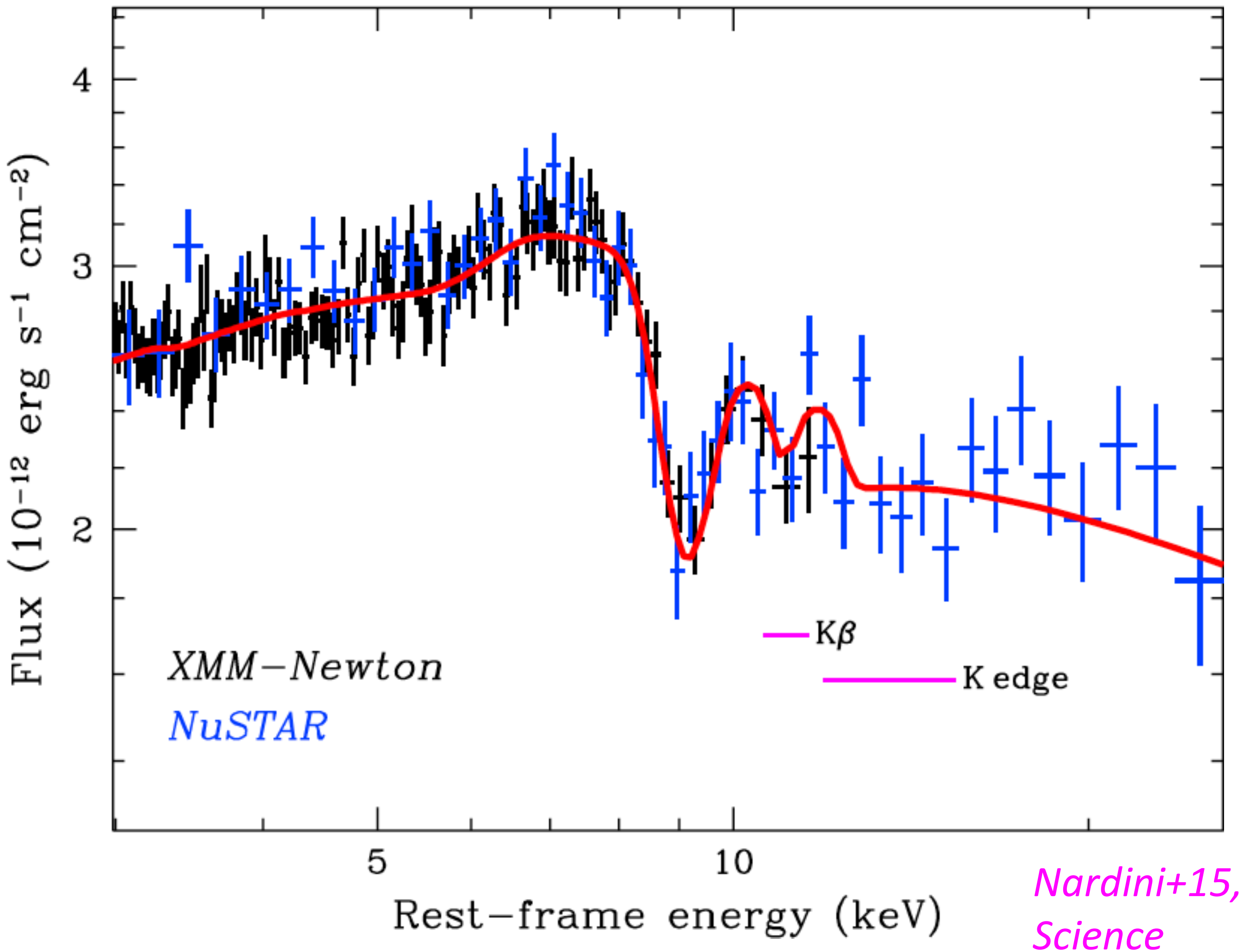


Systematic detection of a deep trough above 7 keV rest-frame: evidence for a large column of highly ionised matter outflowing at about one third of the speed of light

Ideal target for studying BH winds in the Eddington-limited regime

2013/14 campaign: 5 simultaneous *XMM + NuSTAR* observations

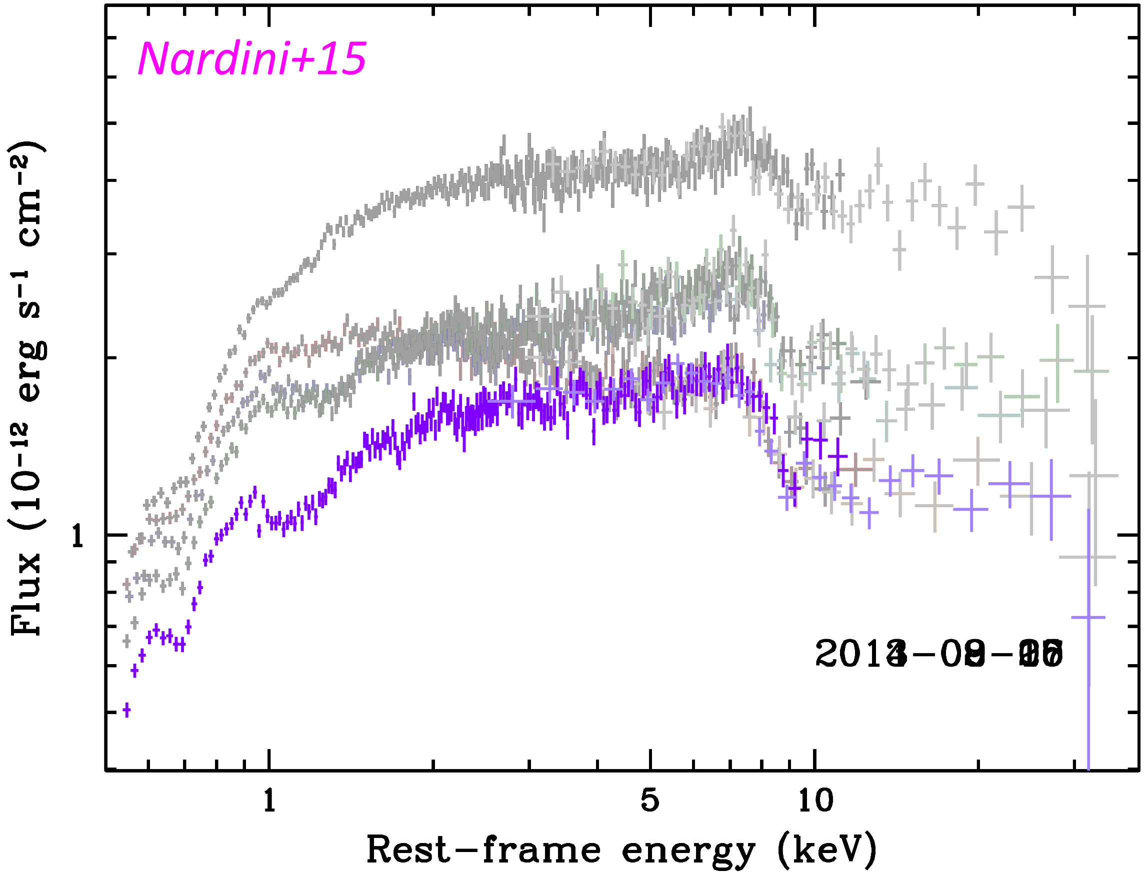
The Wide Angle UFO is the Quasar PDS 456

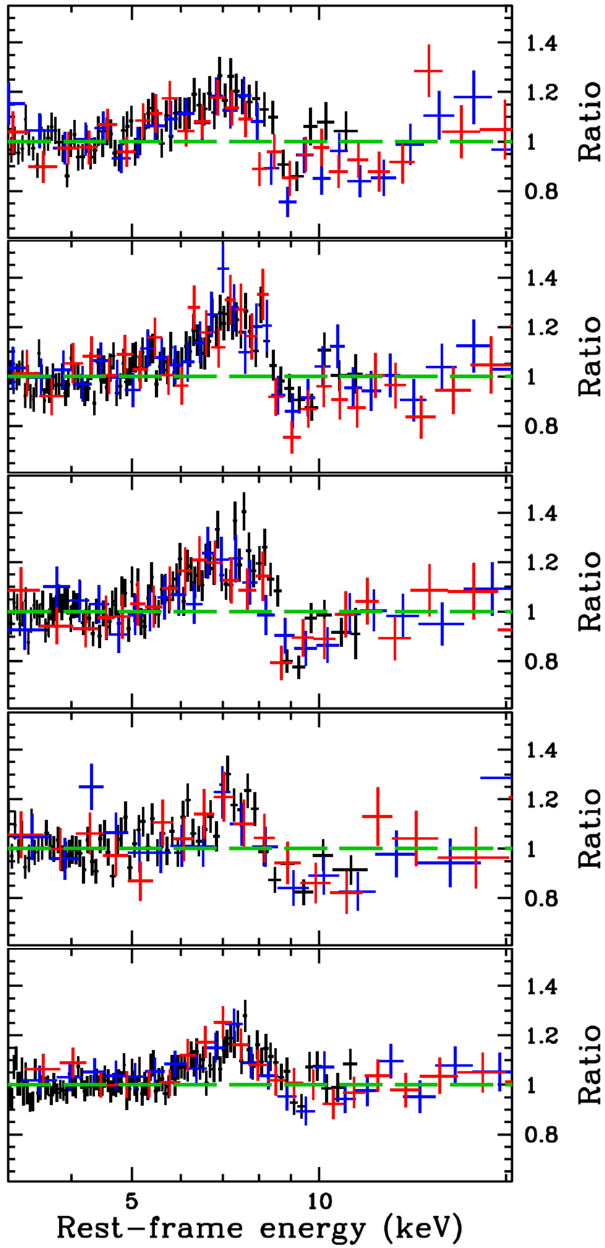


Nardini+15, Science

A persistent, wide-angle wind

P-Cygni-like profile resolved at any epoch (aperture > 50° from FWHM)





Apparent response to continuum changes over 7-10 days

Some relevant numbers

$$\dot{M}_{\rm out} \sim \frac{\Omega}{4\pi} \times \frac{N_{\rm H}}{10^{23}\,{\rm cm}^{-2}} \times \frac{v_{\rm out}}{c} \times \frac{R_{\rm in}}{10^{15}\,{\rm cm}}\ M_{\odot}\,{\rm yr}^{-1}$$

All the information can now be determined from the data

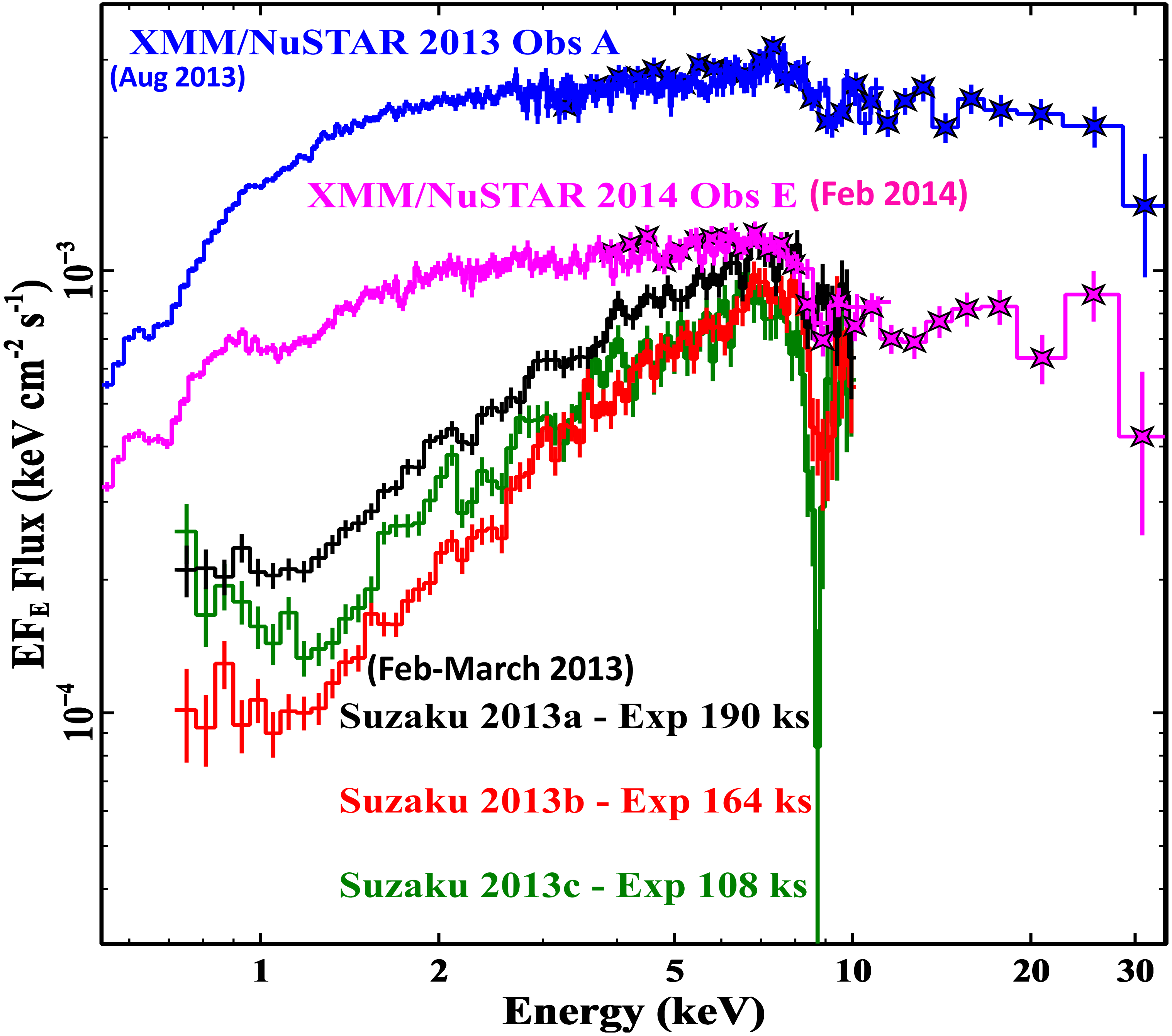
The solid angle is obtained from the emitted/absorbed luminosity ratio, and the launch radius from the variability timescale

$$\dot{M}_{\rm out} \sim 10\ M_{\odot}\,{\rm yr}^{-1} \Rightarrow P_{\rm kin} \sim 2 \times 10^{46}\,{\rm erg\,s}^{-1} \sim 0.2\,L_{\rm bol}$$

The deposition of a few % of the total radiated energy is enough to prompt significant feedback on the host galaxy *(Hopkins & Elvis 10)*. Over a lifetime of 10^7 yr the energy released through the accretion disk wind likely exceeds the binding energy of the bulge

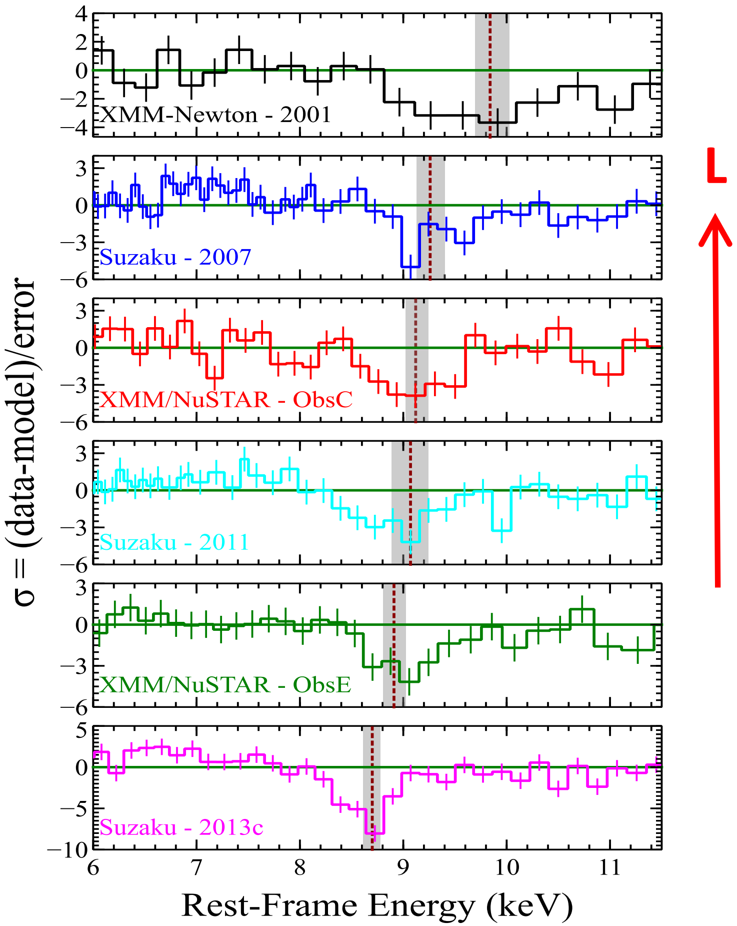
$$E_{\rm wind} \sim 10^{61}\,{\rm erg} \sim 3 \times M_{\rm bulge}\,\sigma^2$$

One Year in the Life of PDS 456...(Matzeu et al. 2016)

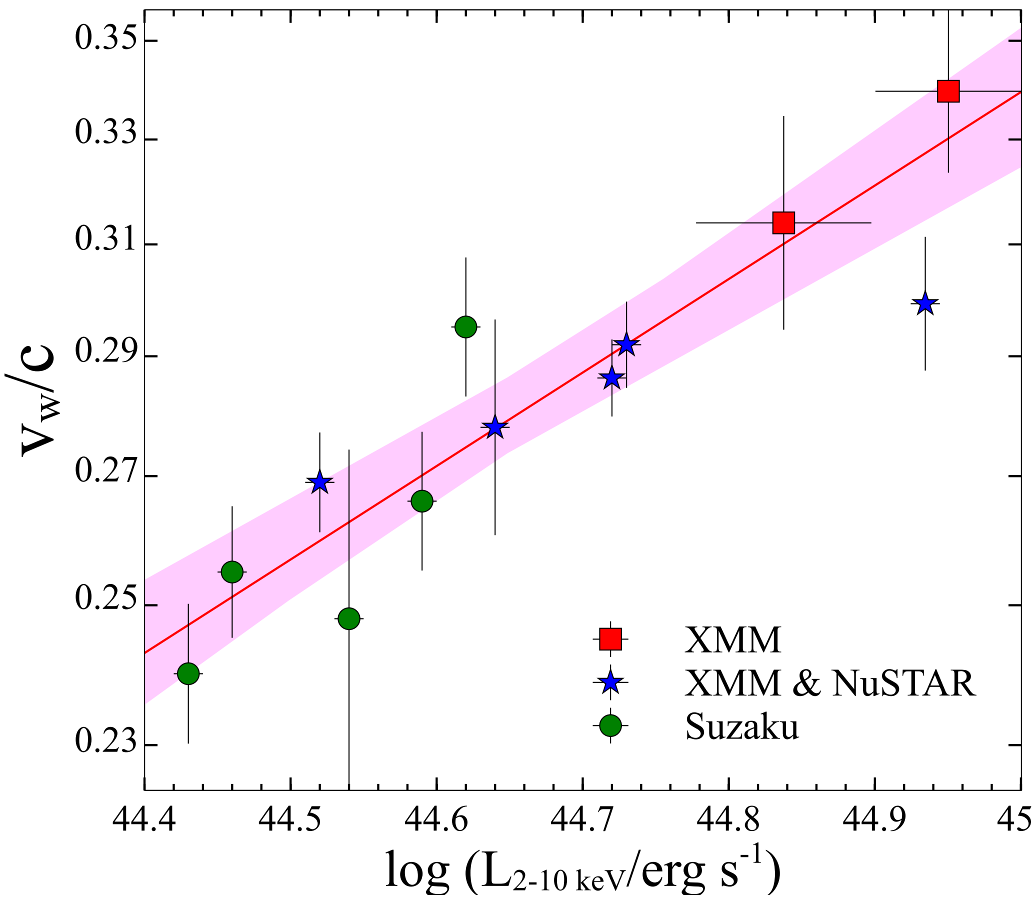


Variability of Wind velocity in PDS 456 (Matzeu et al. 2017)

Centroids of Fe K absorption



Wind velocity vs luminosity



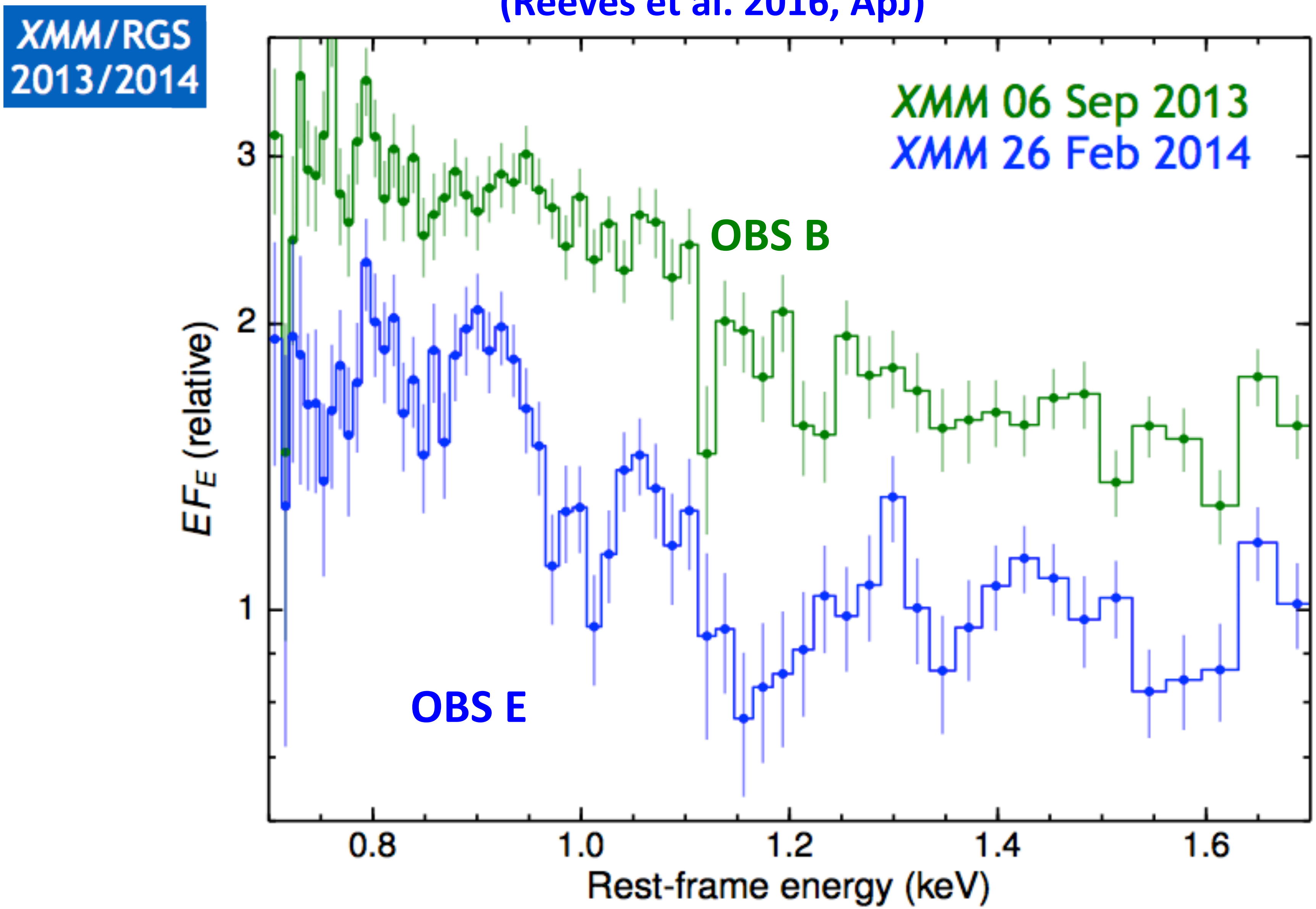
Centroid energy of iron K absorption appears to increase with increasing luminosity over 12 XMM/NuSTAR/Suzaku observations from 2001-2014.

Wind velocity increases with ionizing luminosity (as $L_X^{1/4}$)

May be explained in terms of radiative driving in the Eddington limited regime.

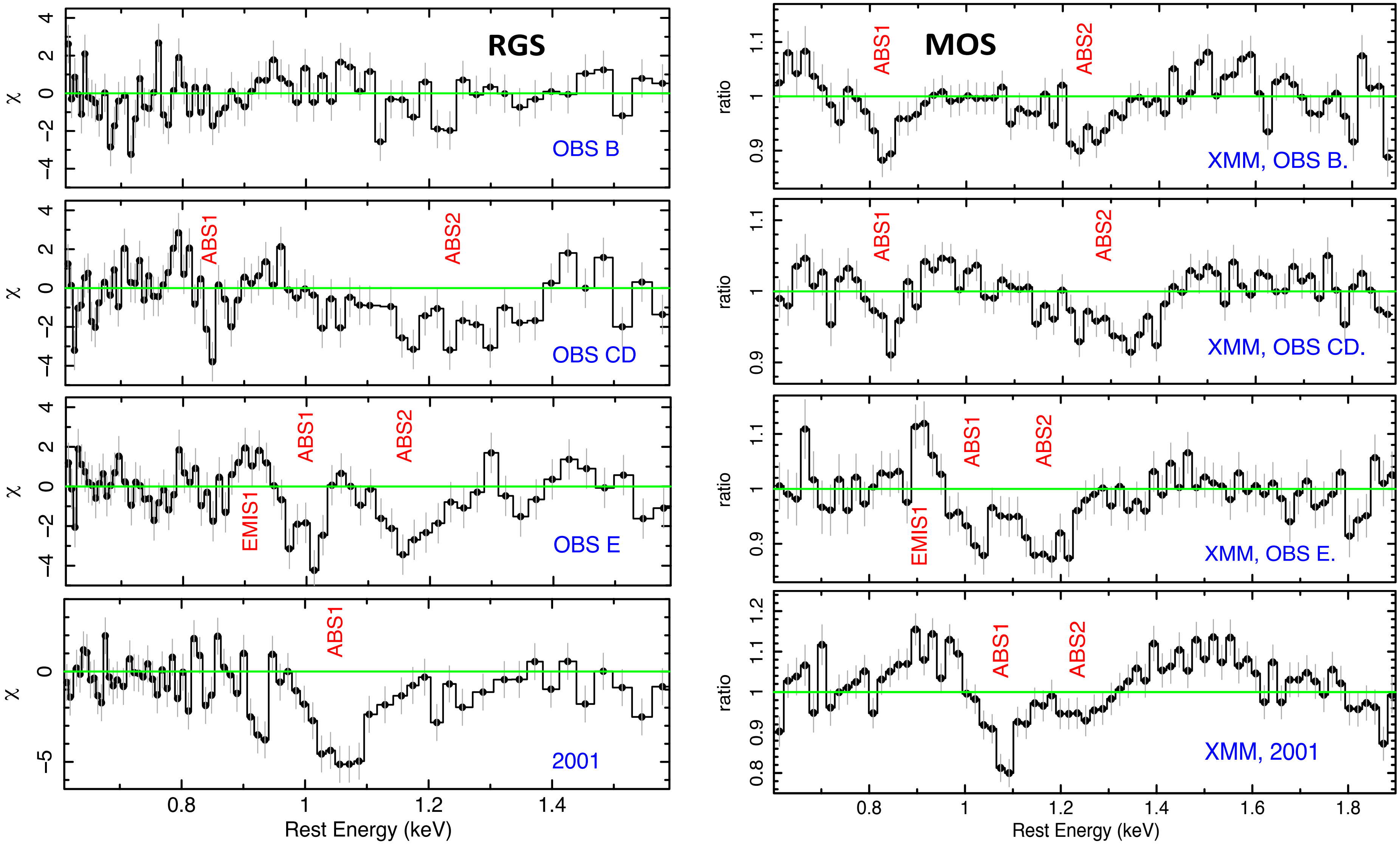
Broad Soft X-ray Absorption Profiles in PDS 456

(Reeves et al. 2016, ApJ)



Signatures of fast (0.15c) “BAL” like profiles in soft X-rays with XMM-Newton/RGS. Velocity widths σ≈10000 km/s.

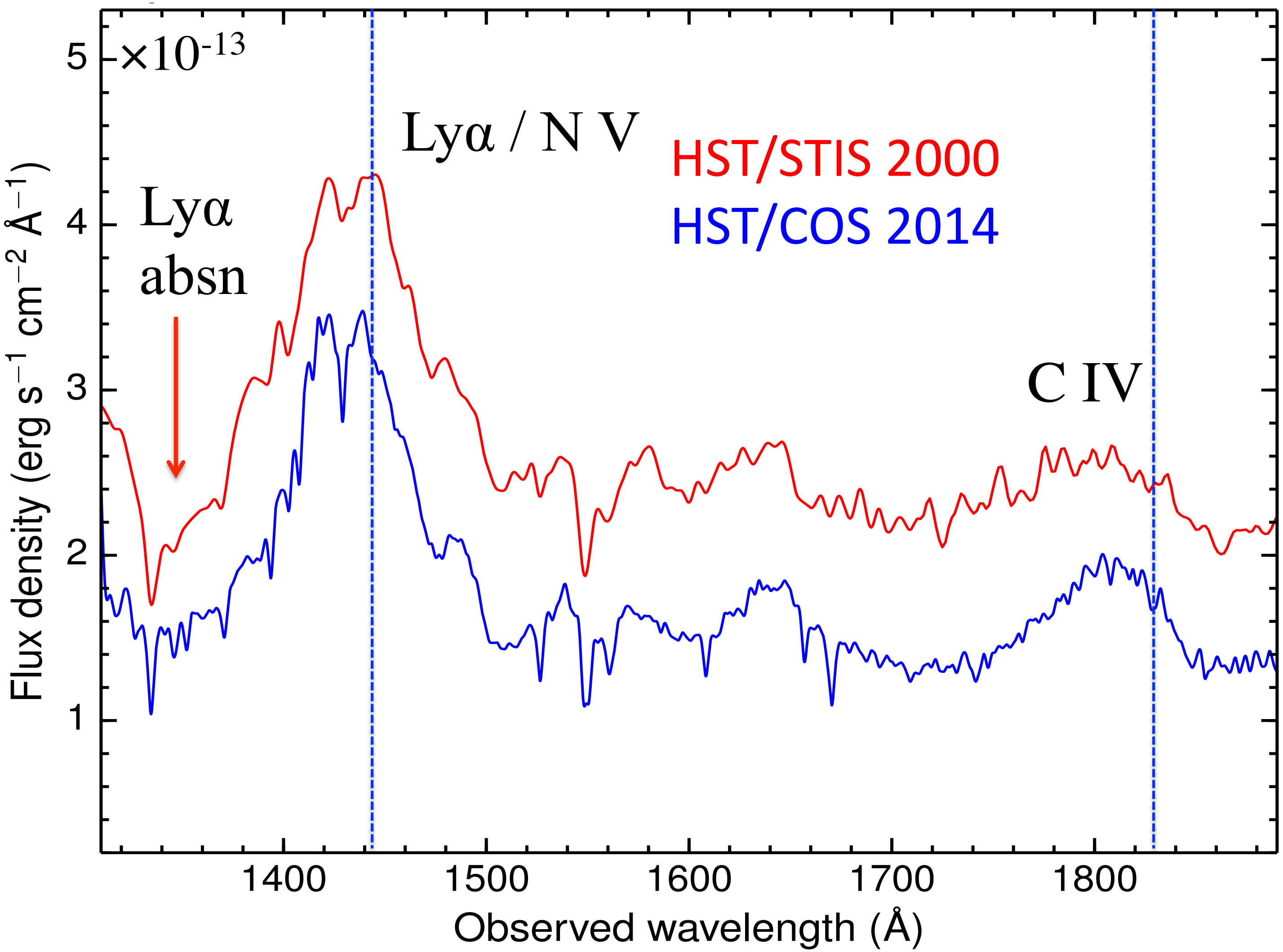
Broad Soft X-ray Absorption Lines



Soft X-ray absorbing gas the likely signature of an inhomogeneous wind, partially obscuring the AGN. Velocities of up to 0.2c.

Absorption primarily due to highly ionized Fe (Fe XX-XXIV) as well as NeIX/X

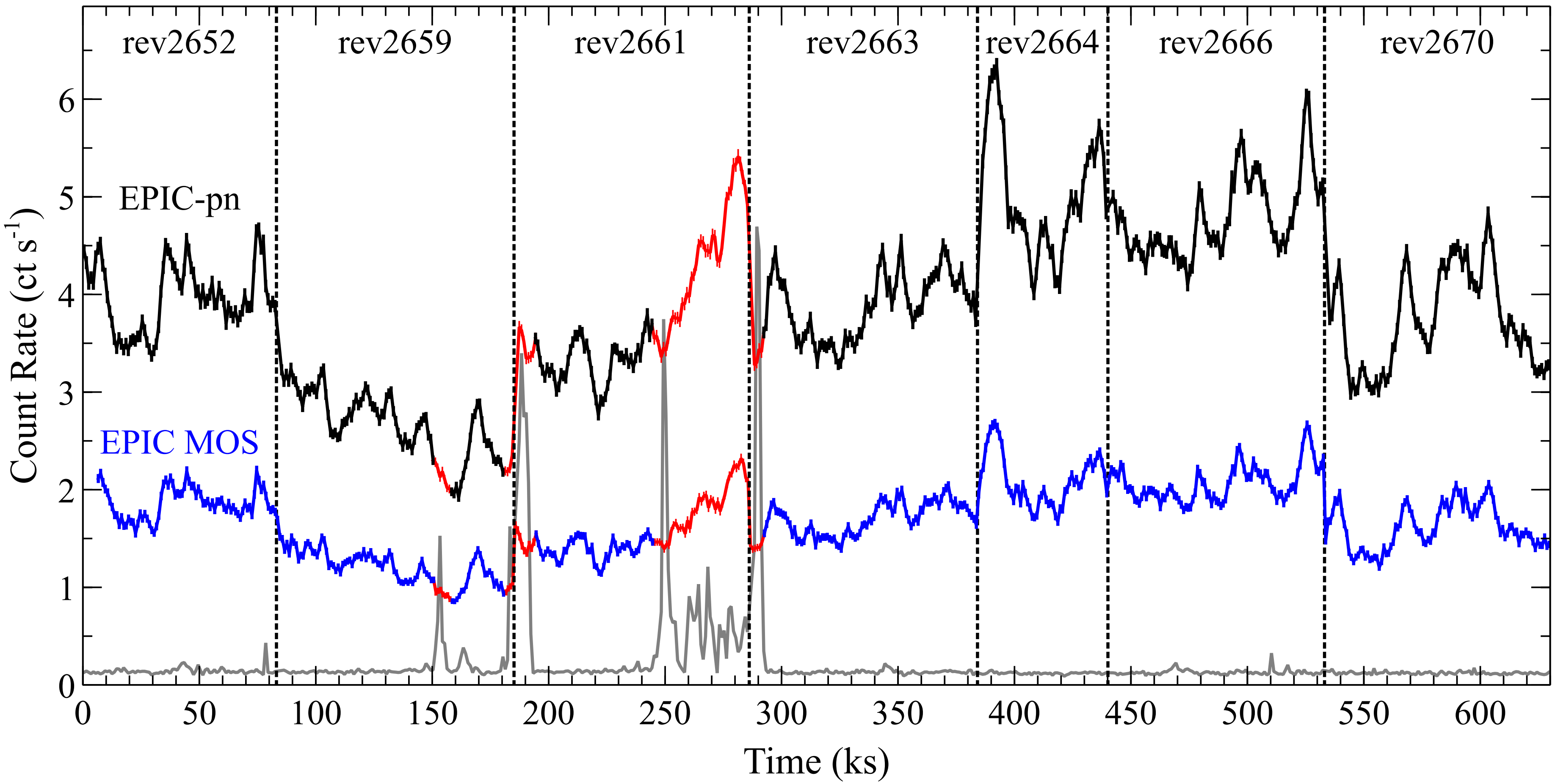
The UV connection – is PDS 456 a BAL QSO?



Very broad UV emission profiles, e.g. Lyα / C IV 12000-15000 km/s.
Highly blueshifted, CIV=5000 km/s.
Broad absorption trough bluewards of Lyalpha or highly blueshifted CIV?

The XMM-Newton Large Programme on PG1211+143

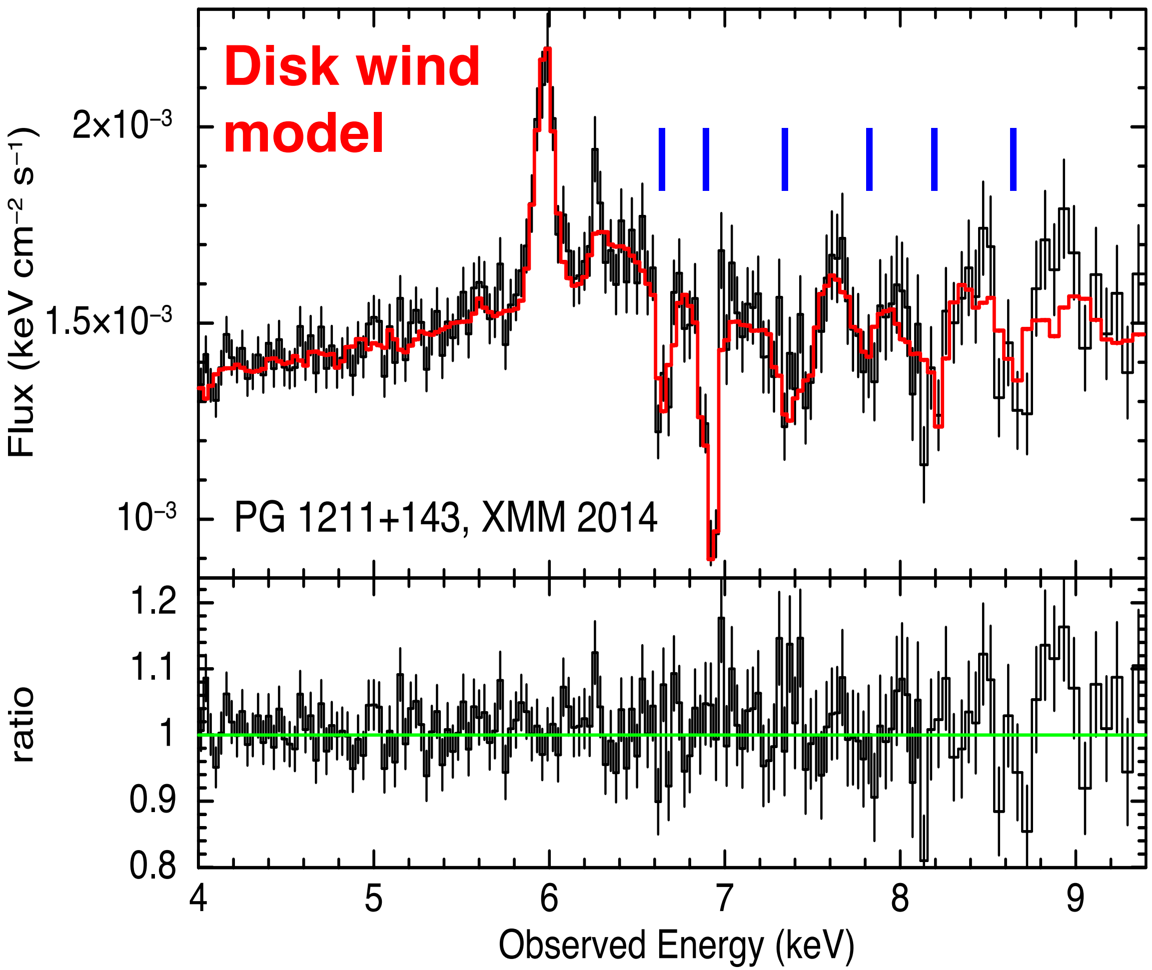
(Lobban et al. 2015, 2016; Pounds et al. 2016a, b)



PG 1211+143, luminous (L_{bol}~10^{46} erg/s), nearby, narrow-lined type I quasar (z=0.0809), the initial proto-type example of an ultra fast outflow (Pounds et al. 2003).

7 Sequences with XMM-Newton in June/July 2014. Total exposure ~630ks.
Note lowest flux during rev 2659 with XMM-Newton.

Ultra Fast Fe K Outflow in The Quasar PG 1211+143



Overall wind parameters in 2014:-
Mass outflow rate M_{out}/M_{Edd} = 0.72±0.13
Ionization L_X/L_{Edd} = 3%, inclination = 57°.

<u>600ks observation of PG 1211 from XMM/2014 campaign.</u>

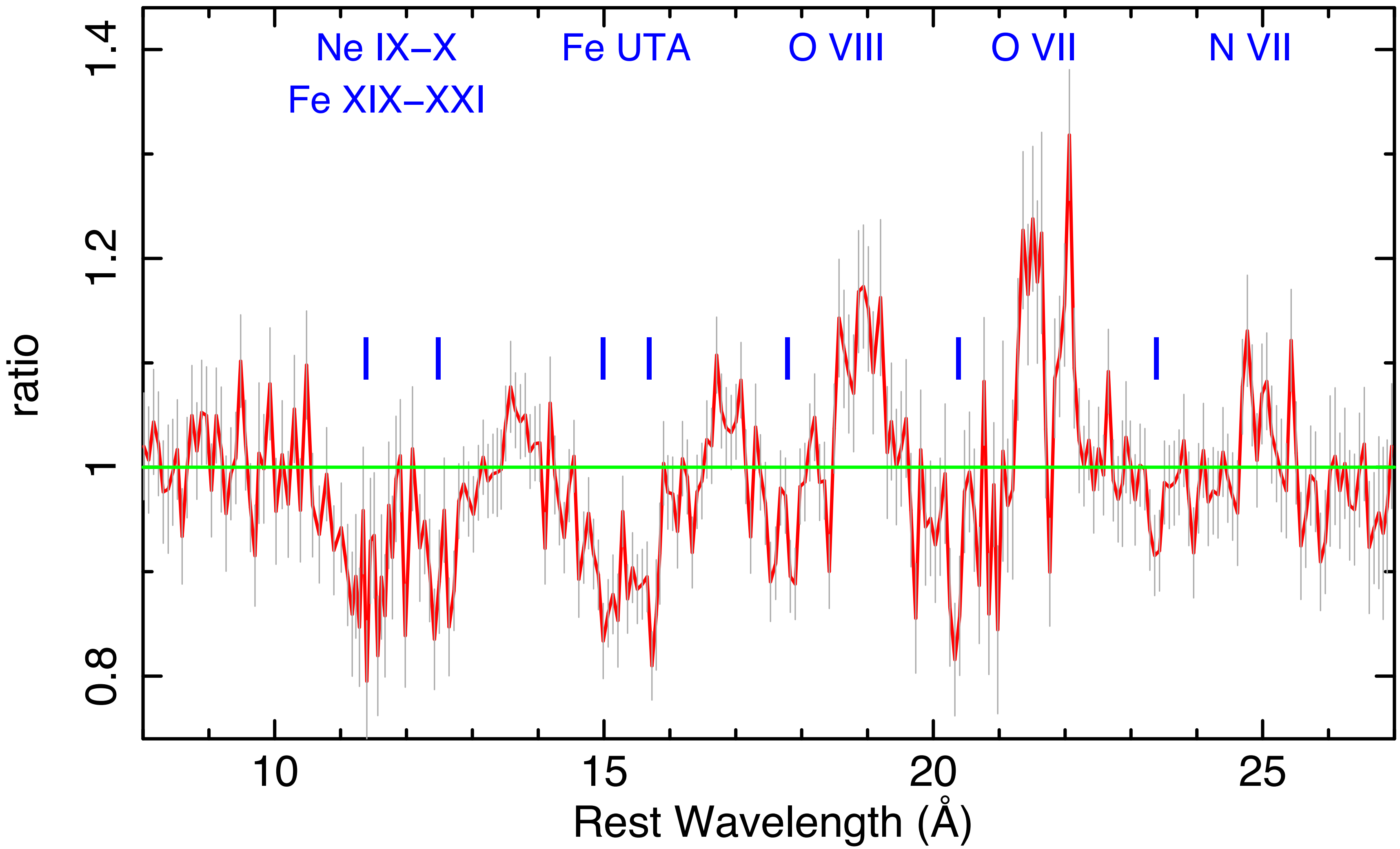
Spectrum shows a wealth of high ionization absorption lines from Fe XXV and Fe XXVI.

The line profiles are fitted with a disk wind model (Sim et al. 2008, 2010), with two streamlines at different radii/velocities

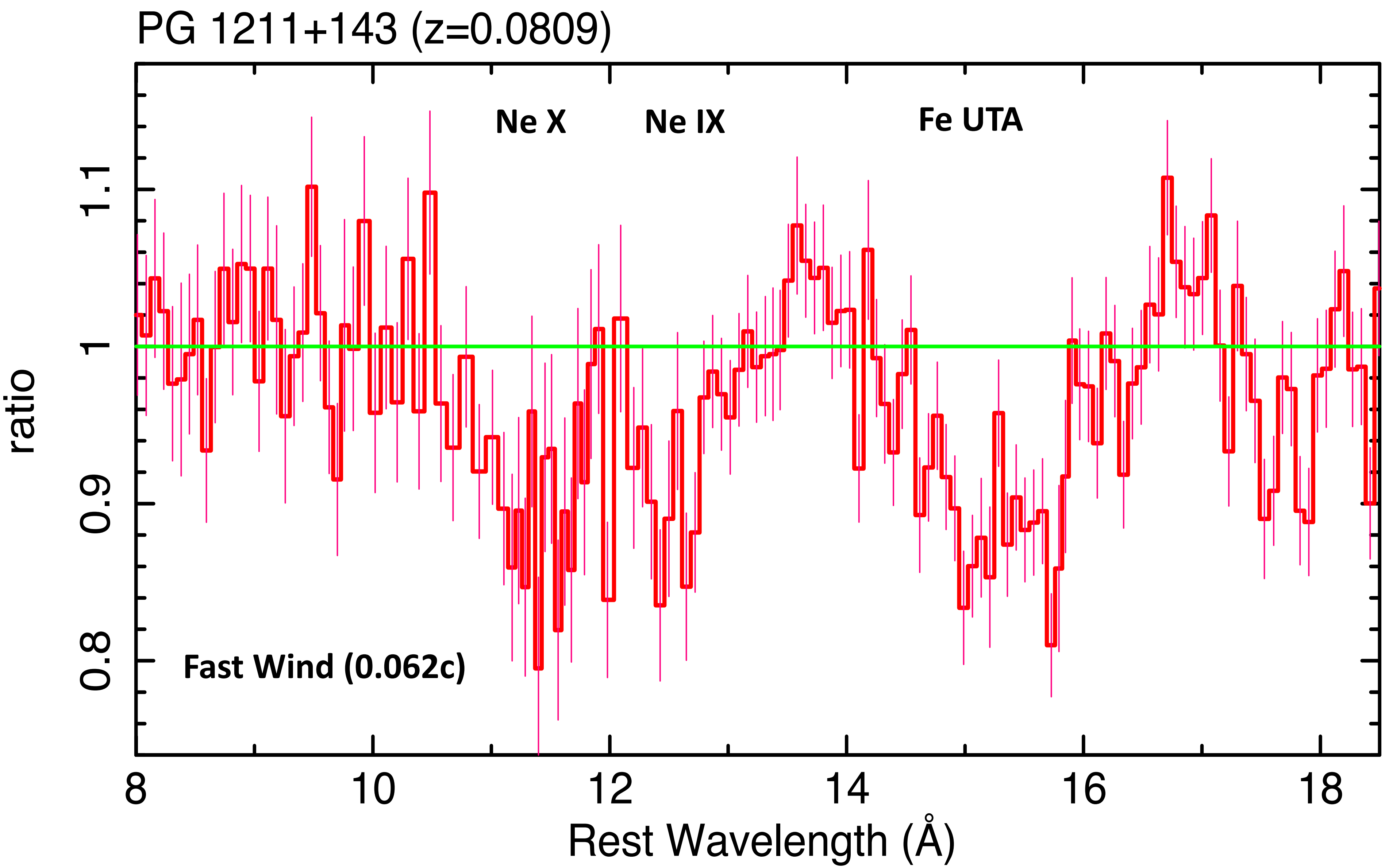
Wind launch radius of R_{min}=64R_G and 250R_G

Resultant wind terminal velocities of v=0.07c and 0.14c (consistent with analysis in Pounds et al. 2016).

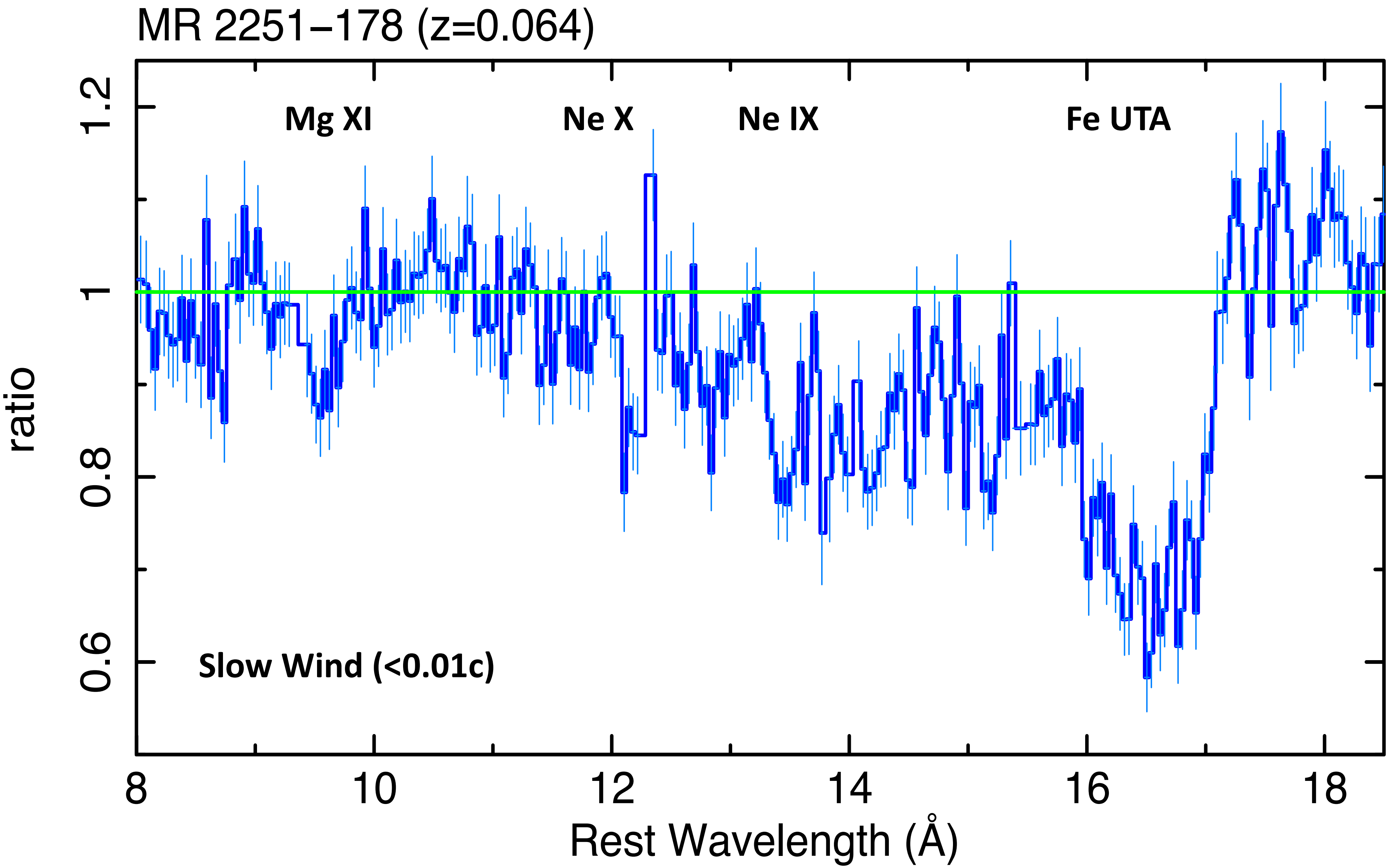
Is there evidence for the fast outflow in the soft X-ray spectrum of PG 1211? Mean RGS spectrum (June 2014, 600ks exposure)

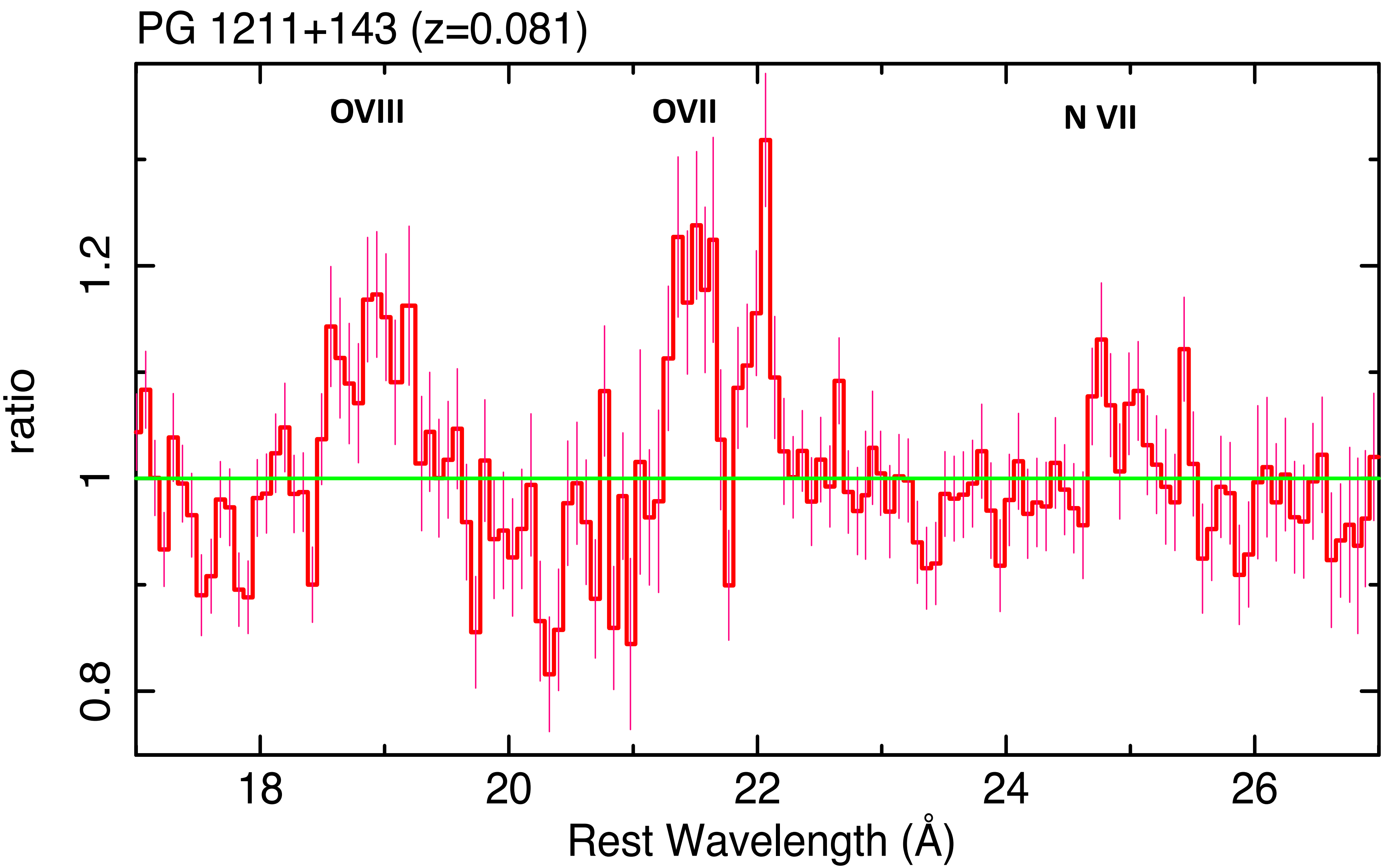


Blue-shifted absorption profiles revealed in deep RGS exposure of PG 1211+143, e.g. from N, O, Ne, Fe. Systematic velocity shift of 0.06-0.07c.
Note position of low ionization UTA component and strong emission (OVII/OVIII).

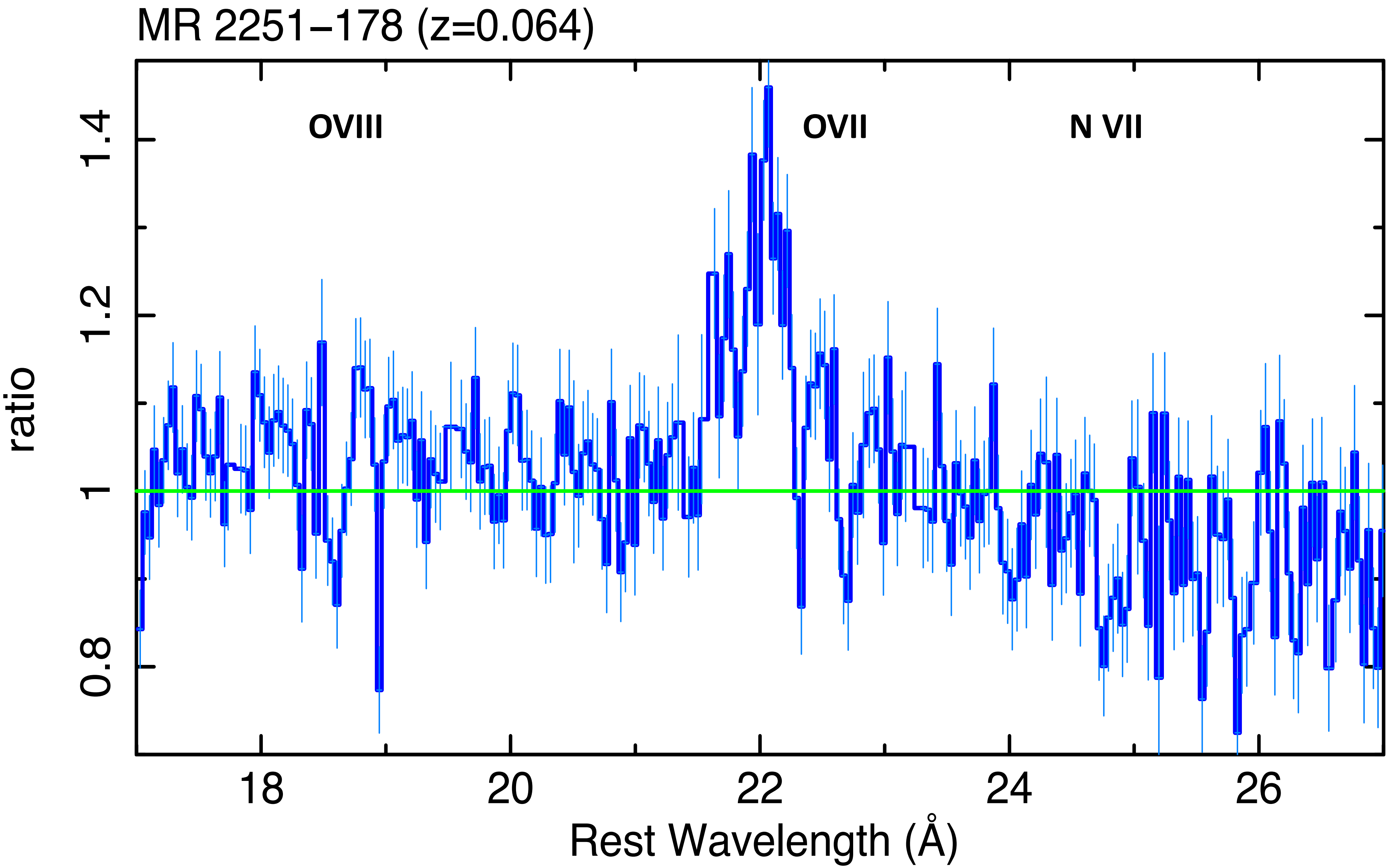


Comparison between XMM-Newton (RGS) spectra of the QSOs PG 1211+143 (z=0.0809) vs MR 2251-178 (z=0.064)


MR 2251−178 (z=0.064)
Mg XI
Ne X
Ne IX
Fe UTA
Slow Wind (<0.01c)
ratio
1.2
1
0.8
0.6
8
10
12
14
16
18
Rest Wavelength (Å)

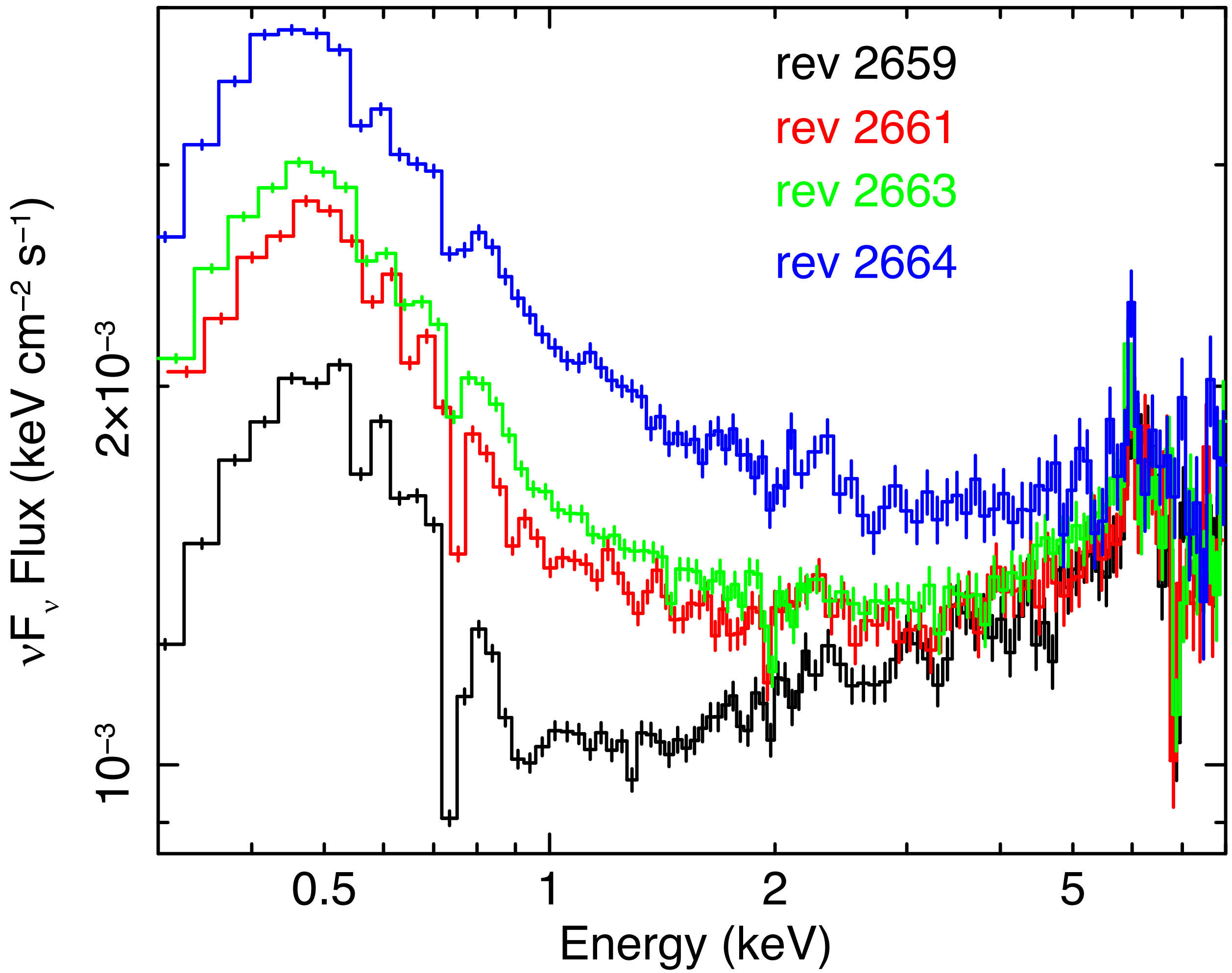


Soft band comparison – note also the presence of broad soft X-ray emission lines (e.g. OVII and OVIII) in addition to the blueshifted absorption.



MR 2251−178 (z=0.064)
OVIII
OVII
N VII
ratio
1.4
1.2
1
0.8
18
20
22
24
26
Rest Wavelength (Å)

Rapid Variability of Ultra Fast Outflow in PG 1211+143



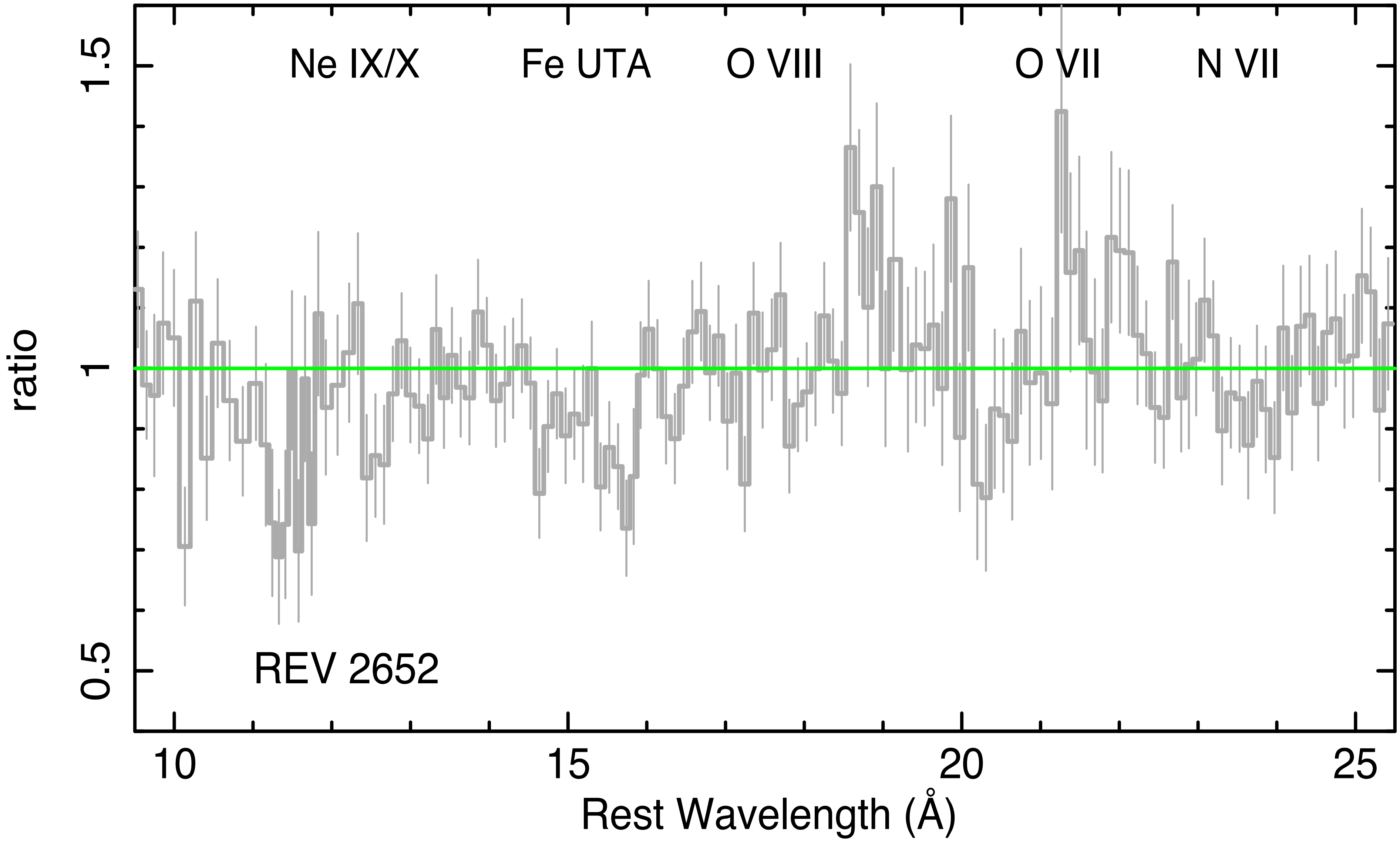
Low flux spectrum in rev 2659. Source then progressively brightens.

Soft X-ray absorption is rapidly variable (within 2 orbits), decreasing with increasing flux.

PG 1211 undergoes absorption event during rev 2659, increasing in lower ionization absorption.

Soft X-ray absorber not a conventional warm absorber. Fast (0.07c) and rapidly variable on timescales of < 1 week. Implies absorber is compact, on scales of 10s Rs, likely part of clumpy disk wind.

Variability of PG 1211 wind seen in RGS spectrum



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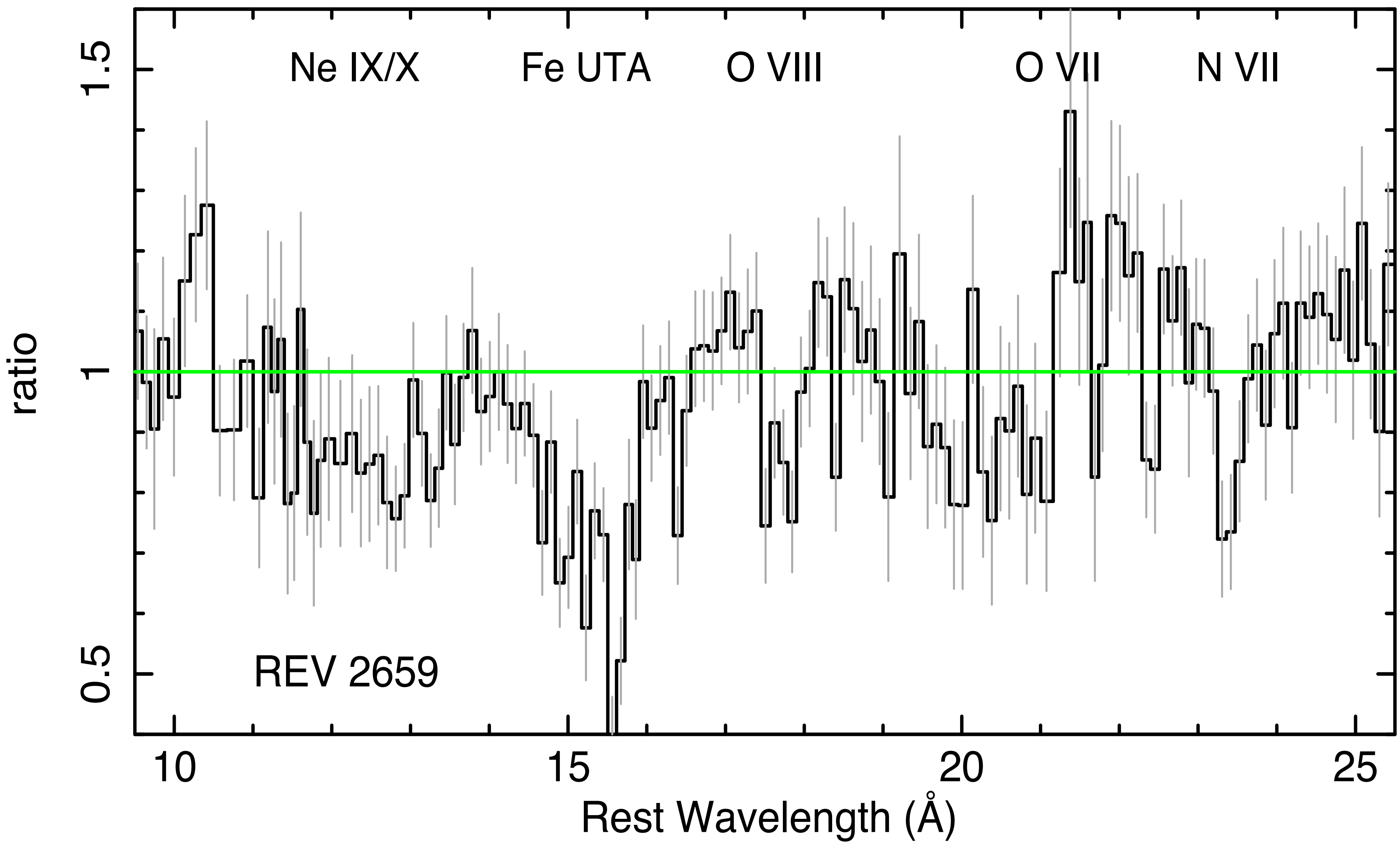

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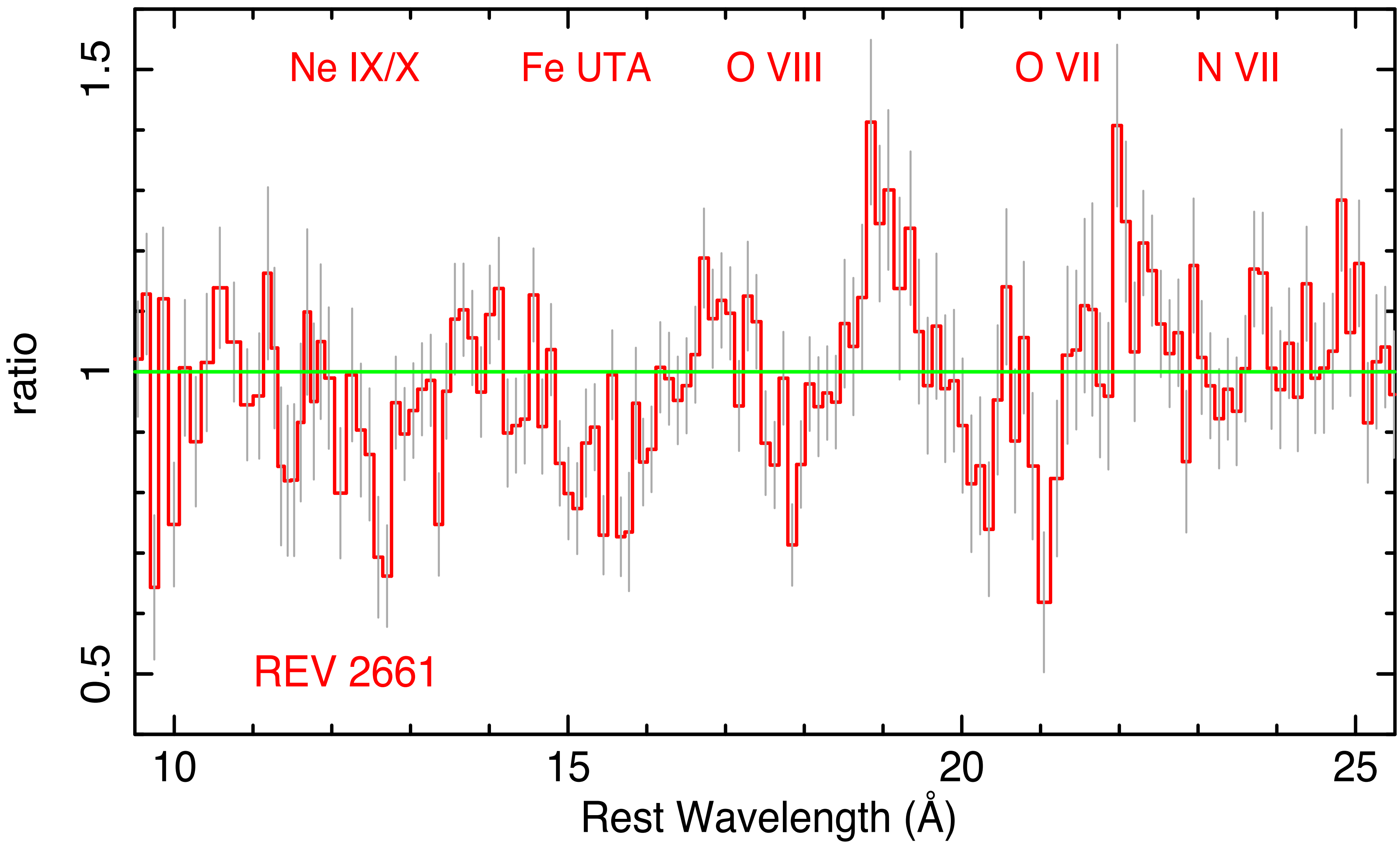

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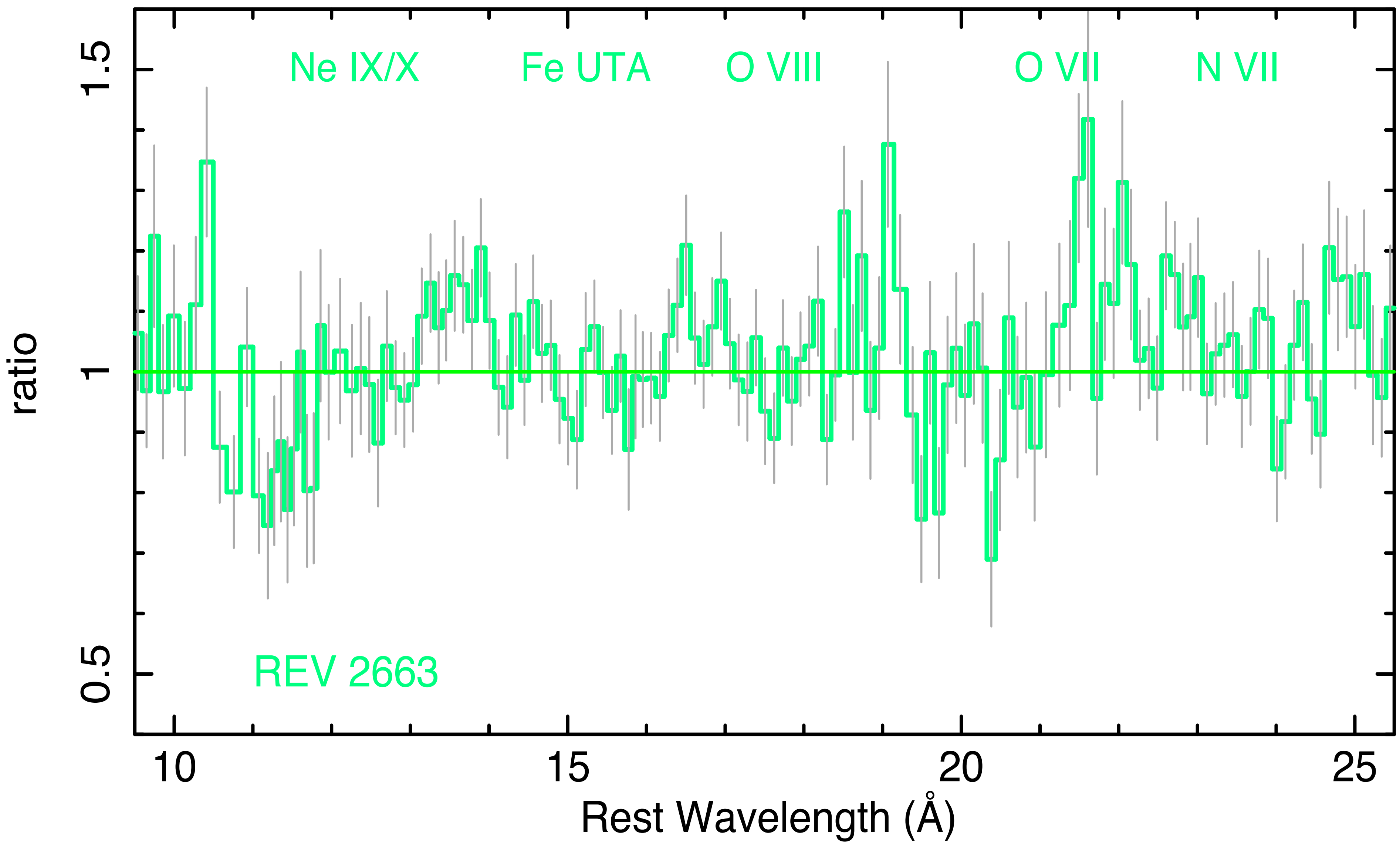

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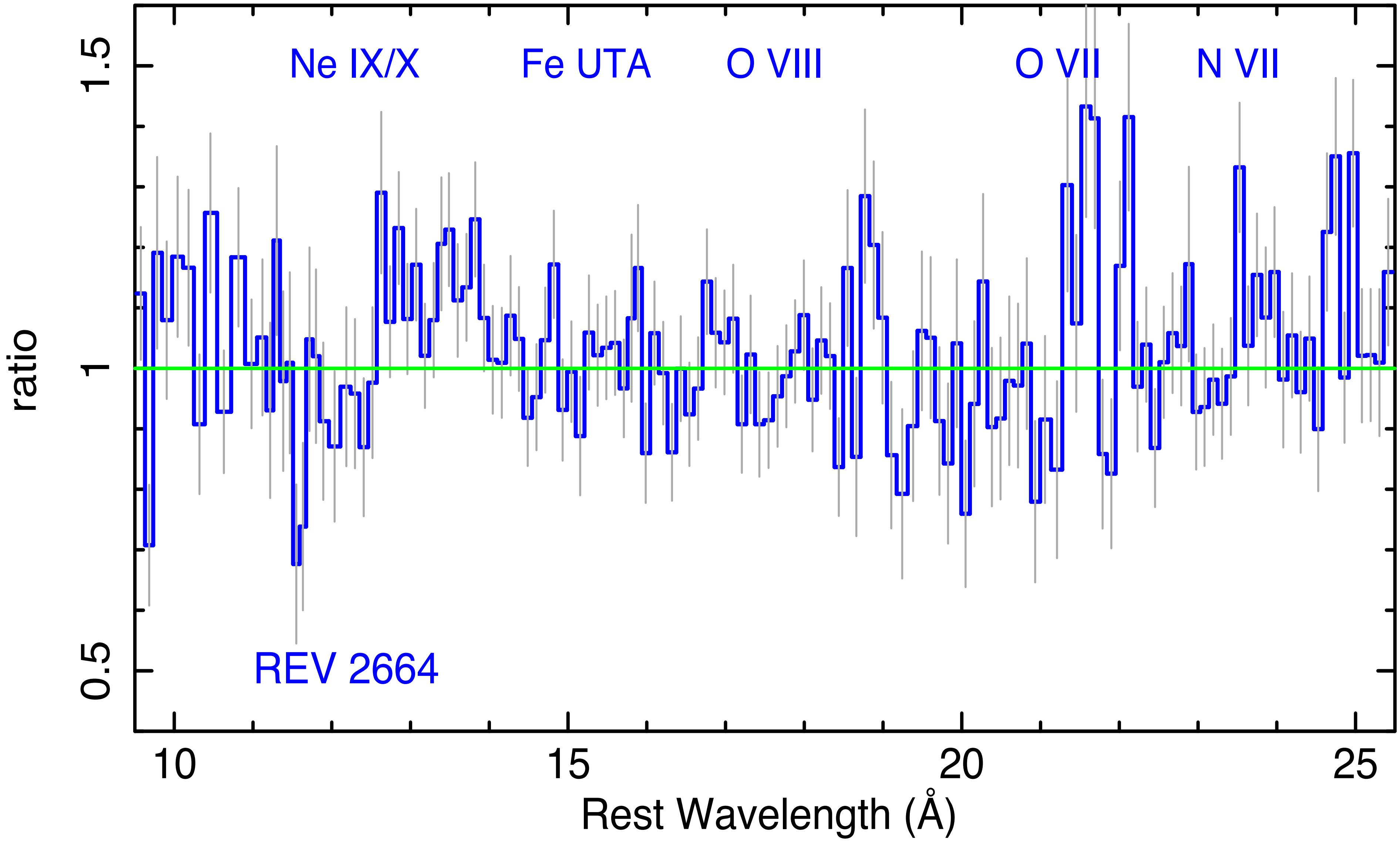
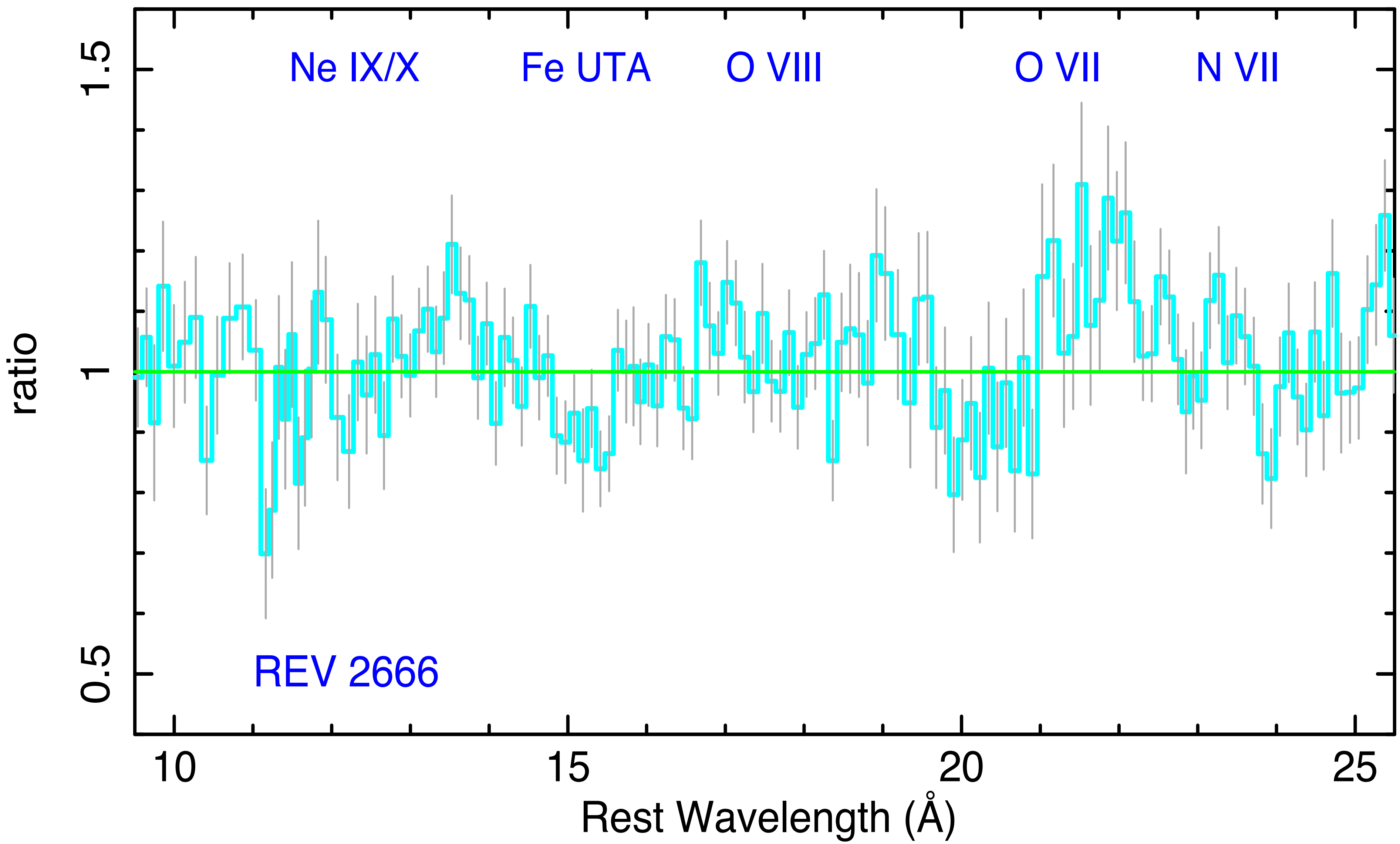
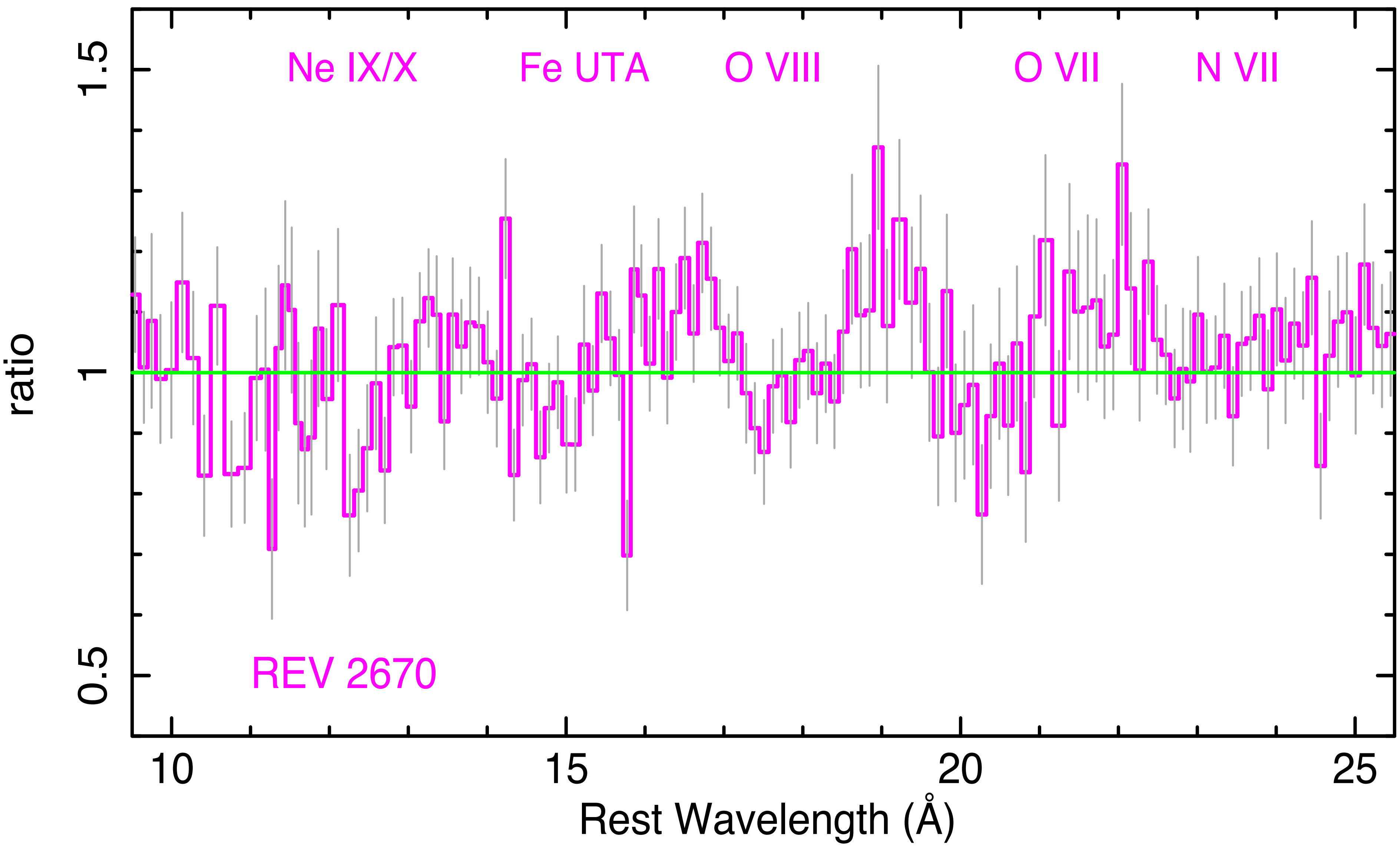


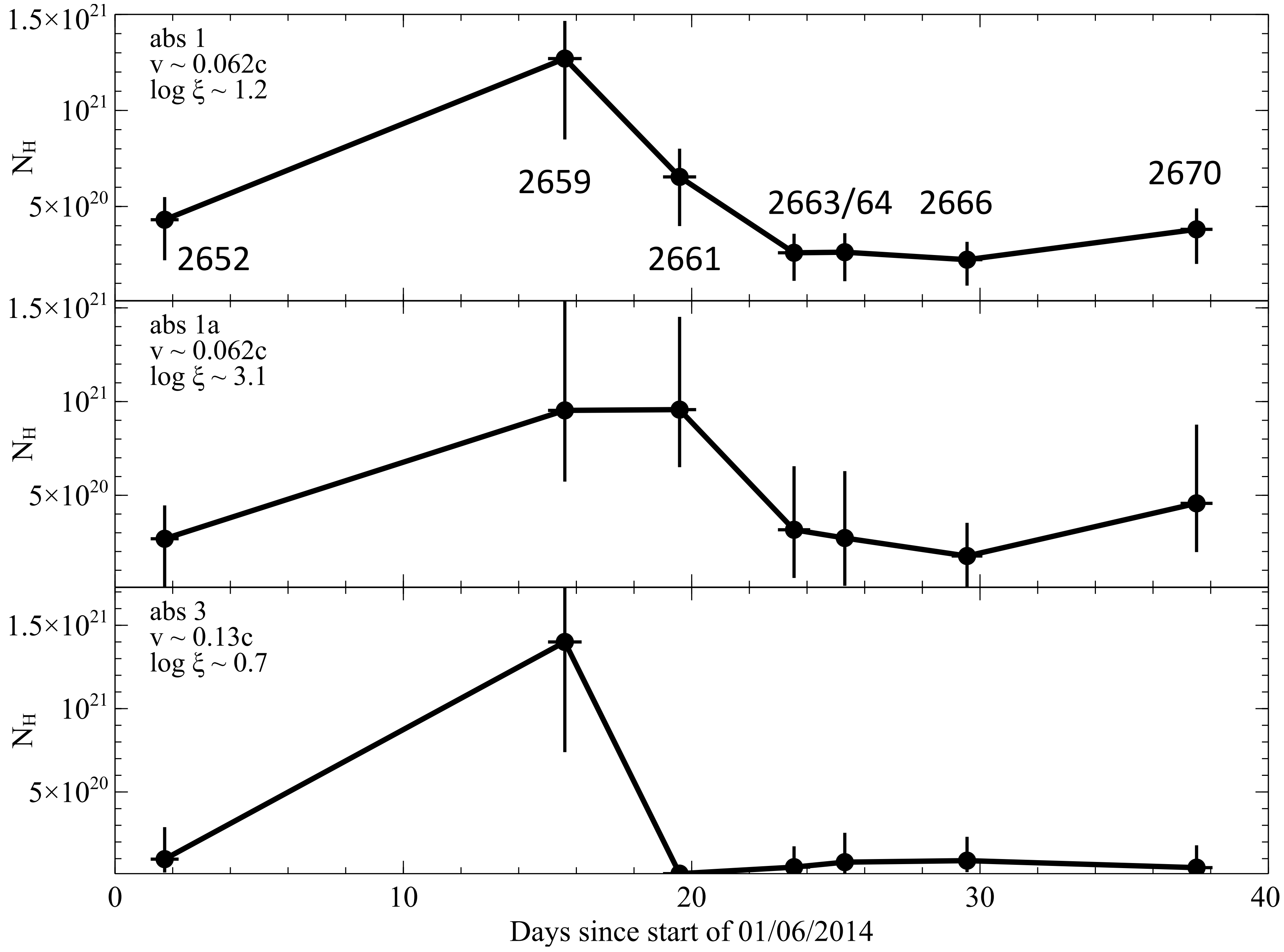
Variability of PG 1211 wind seen in RGS spectrum

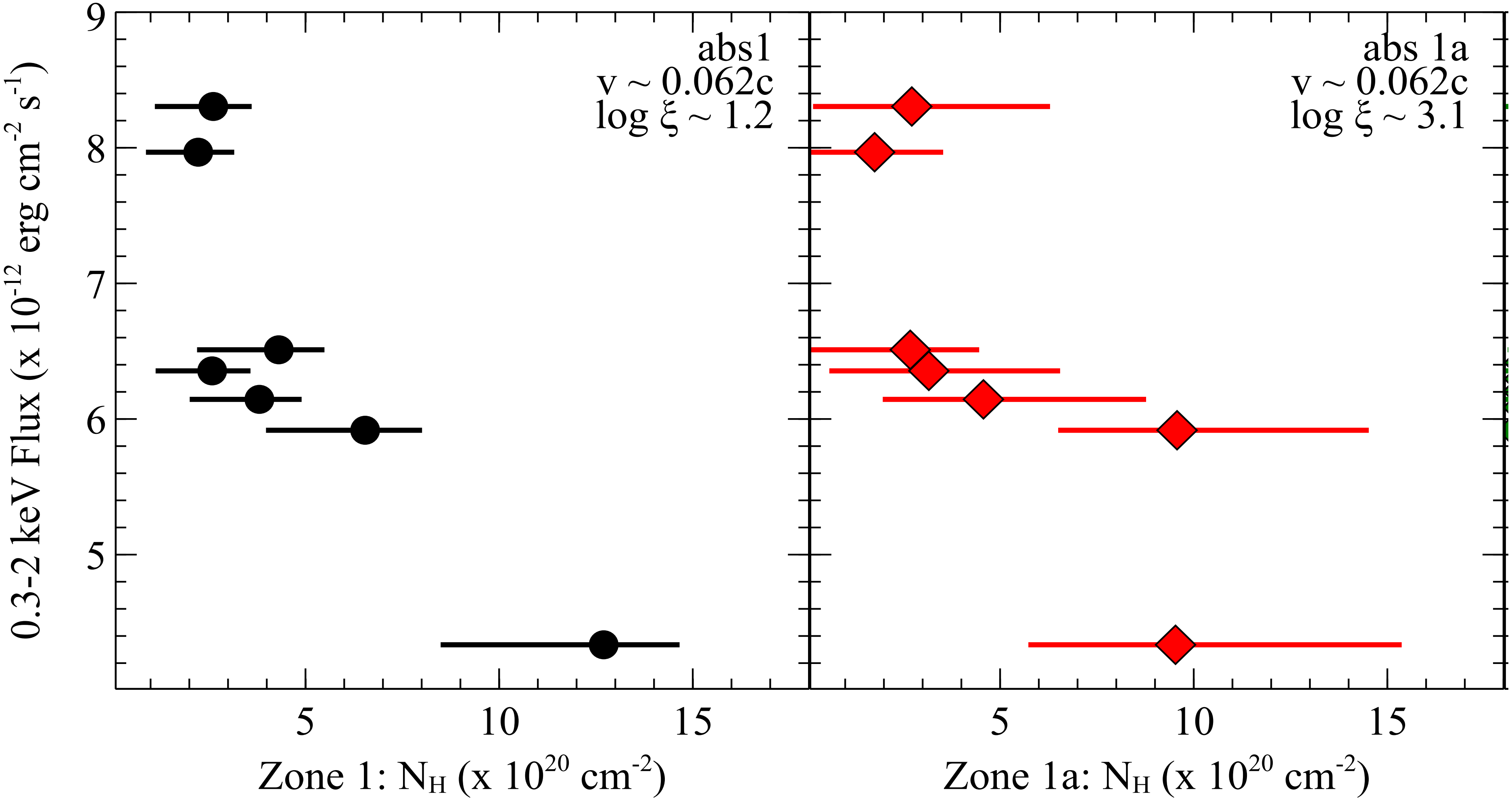


Variability of PG 1211 wind seen in RGS spectrum



Variability of Soft X-ray Wind Zones in PG 1211 vs XMM orbit.



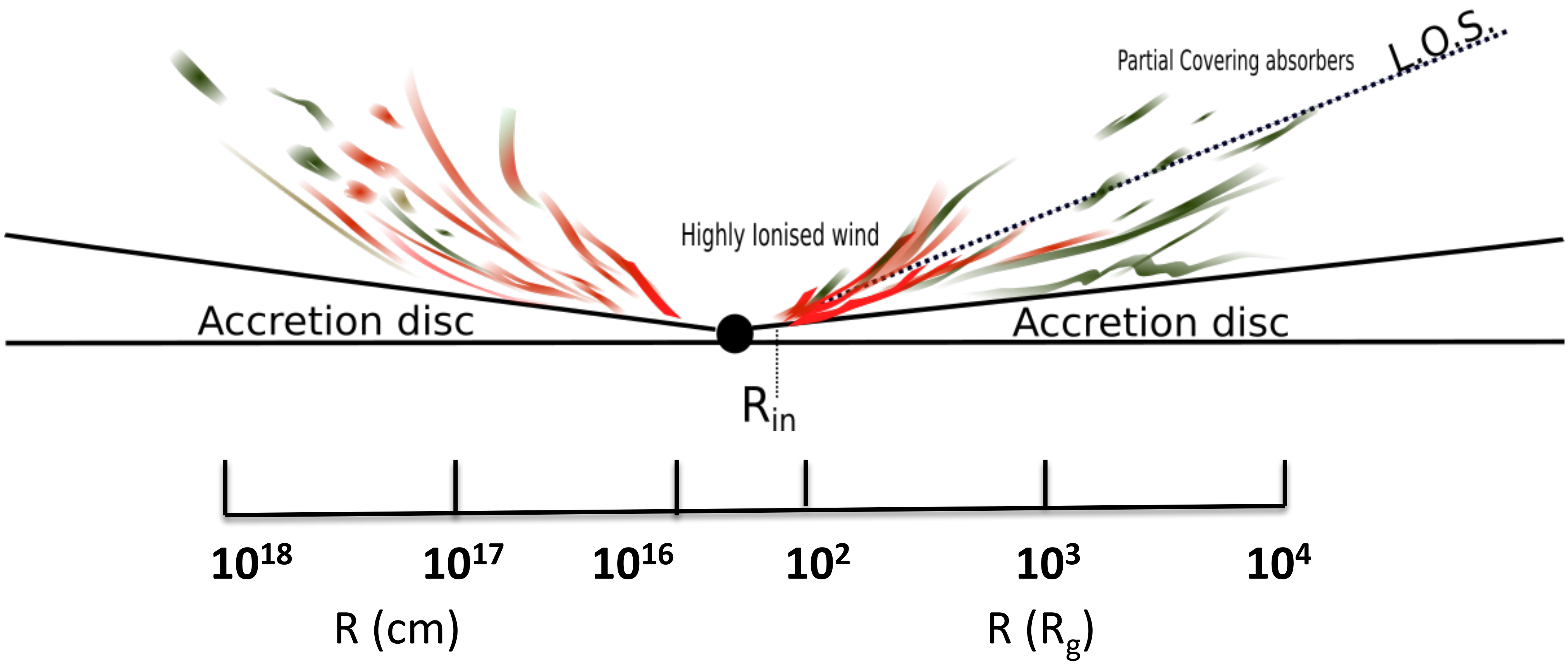


Absorber rapidly responds to the level of the soft X-ray excess below 2 keV on timescales of ~2 XMM orbits (about 300ks).

Opacity is inversely proportional to the continuum.

Wind is clumpy and multi-phase, lowest ionization phase is most compact ($\triangle R \sim 10^{14}$ cm) on scales of $R \sim 10^{17}$cm.

The Wind Structure



Innermost highly ionized wind launched from within 100 Rg (10^{16} cm) of black hole – ultra fast iron K absorption (0.3c).
Inhomogeneous soft X-ray absorber $R \approx 10^{17}$-10^{18} cm, $n_e \approx 10^7$-10^8 cm^{-3}, with thickness $\Delta R \approx 10^{15}$ cm. Filling factor $f \approx 10^{-3}$.
UV BLR emission (absorption) profiles $R \approx 10^{18}$ cm – high velocity CIV in UV.

Discussion

What is the statistical occurrence of the outflows. Is their still any doubt about their detection and origins?

How can we measure accurately the energetics of the winds and are they likely to be significant for feedback?

What is the evidence for the ultra fast outflows aside from at iron K?

What is the driving mechanism for the disk wind? Radiation, Magnetic driving or both? What is the role of the clumpy gas, is it needed to accelerate the gas?

Future - What is the occurrence of the winds amongst the higher luminosity (or higher redshift) QSOs.