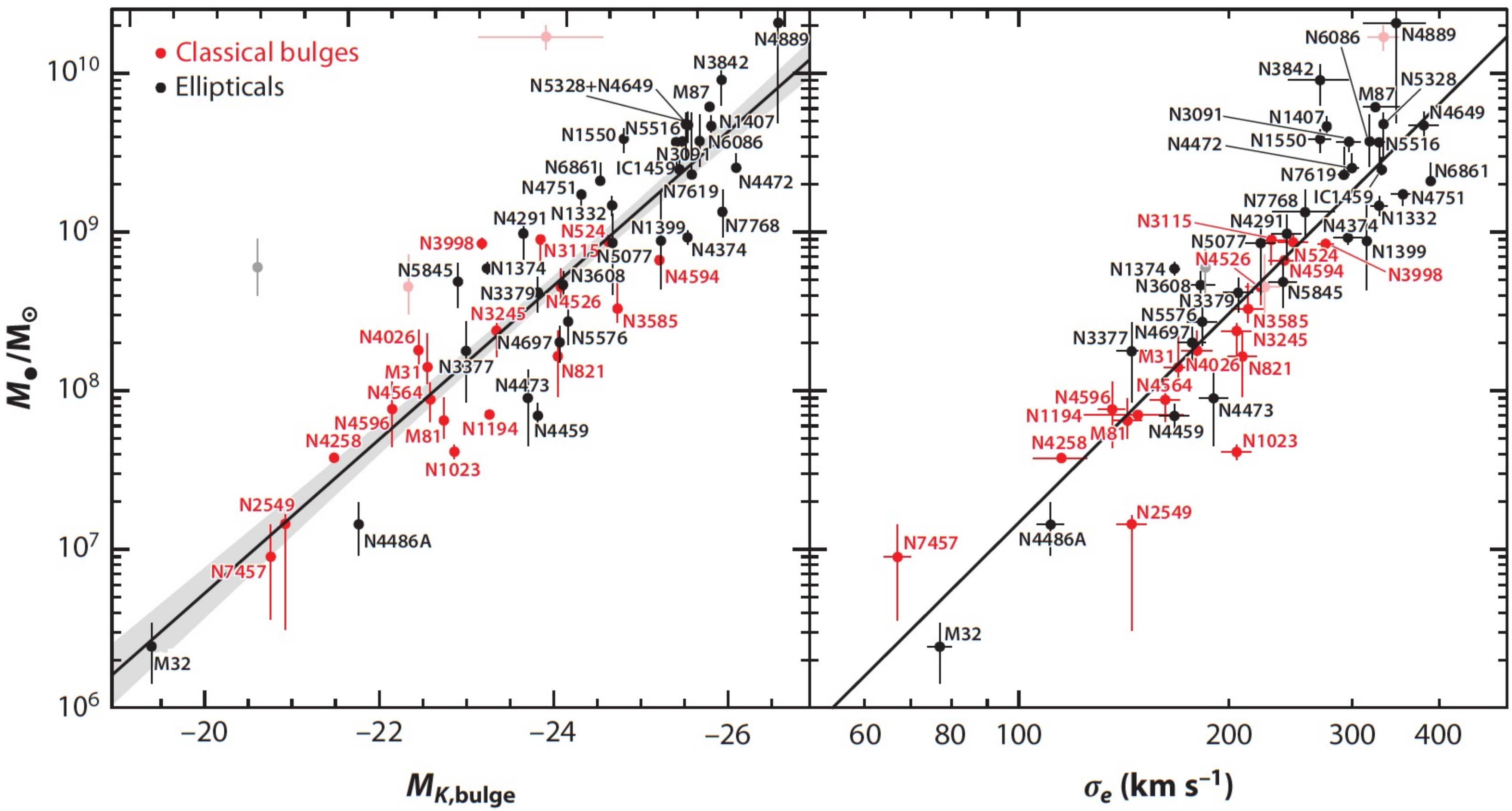
The Powerful Black Hole Wind in the Luminous Quasar PDS 456

James Reeves
Astrophysics Group, Keele University & UMBC

in collaboration with: **E. Nardini** (Keele), J. Gofford (Keele/UMBC) - **M. Costa**, **G. Matzeu** (Keele) - V. Braito (Brera/ASI) - F. Harrison, D Walton (Caltech) - G. Risaliti (Arcetri/CfA), P.T. O'Brien (Leicester), E. Behar (Technion), G. Matt (Roma) T.J. Turner (UMBC), M. Ward (Durham) and NuSTAR team.

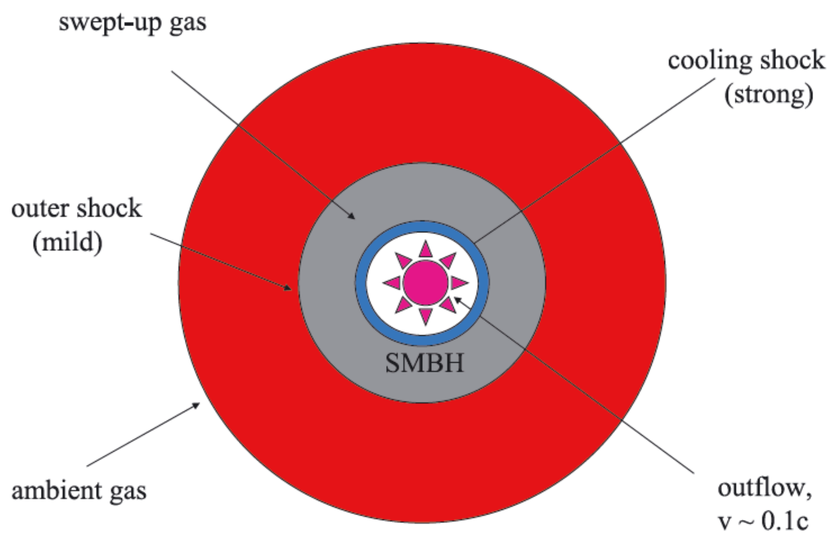
The Extremes of Black Hole Accretion, ESAC, Madrid, June 8-10, 2015

Black hole/host galaxy correlations



Kormendy & Ho 13

AGN feedback is widely accepted as the underlying mechanism …



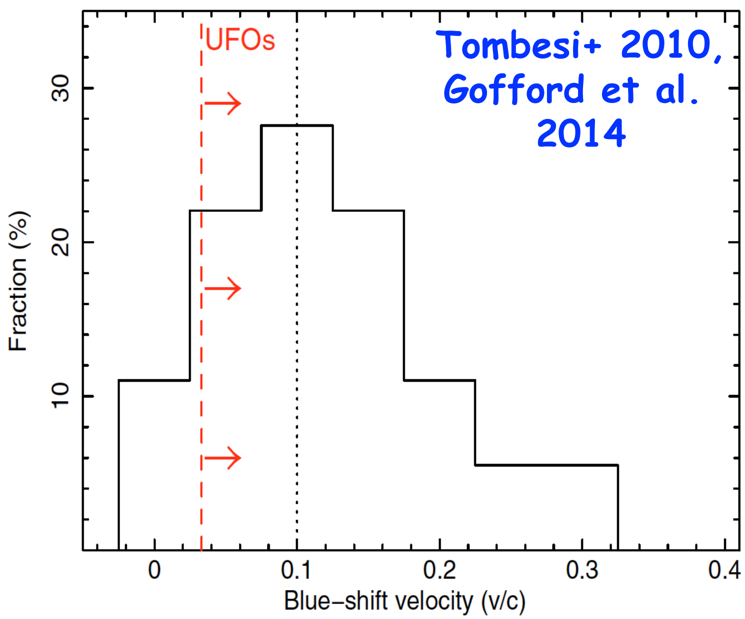
King 2010

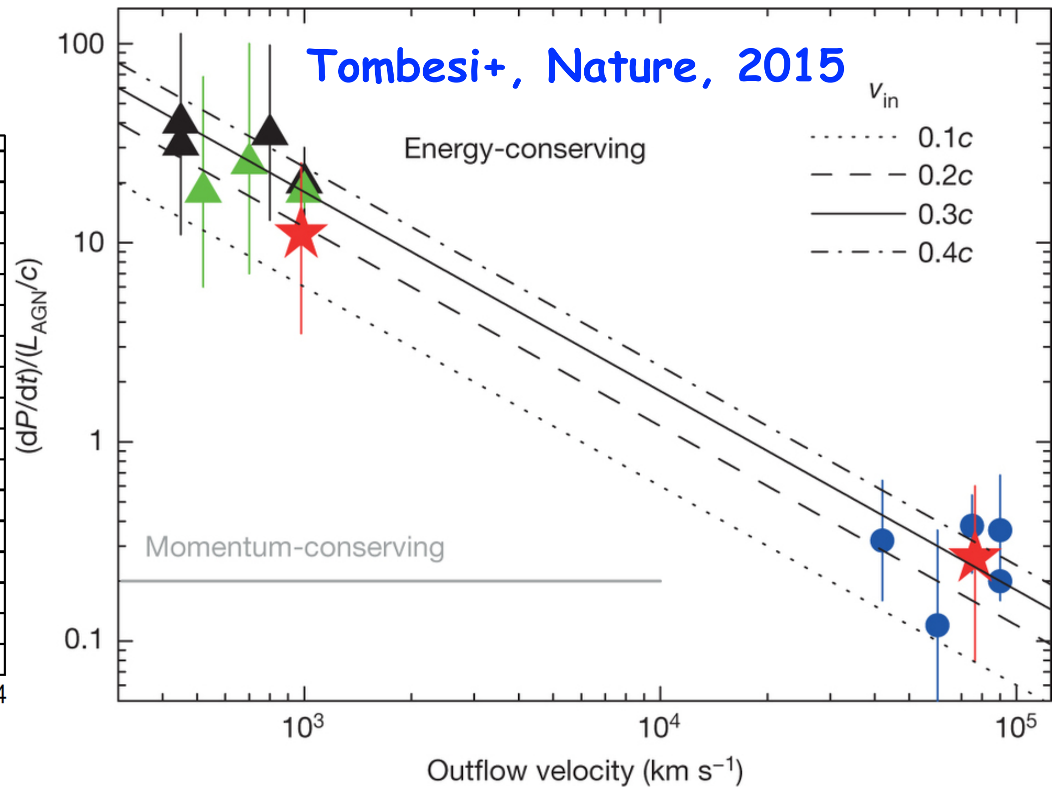
Powerful disc winds are naturally expected at high accretion rates:

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

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

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





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

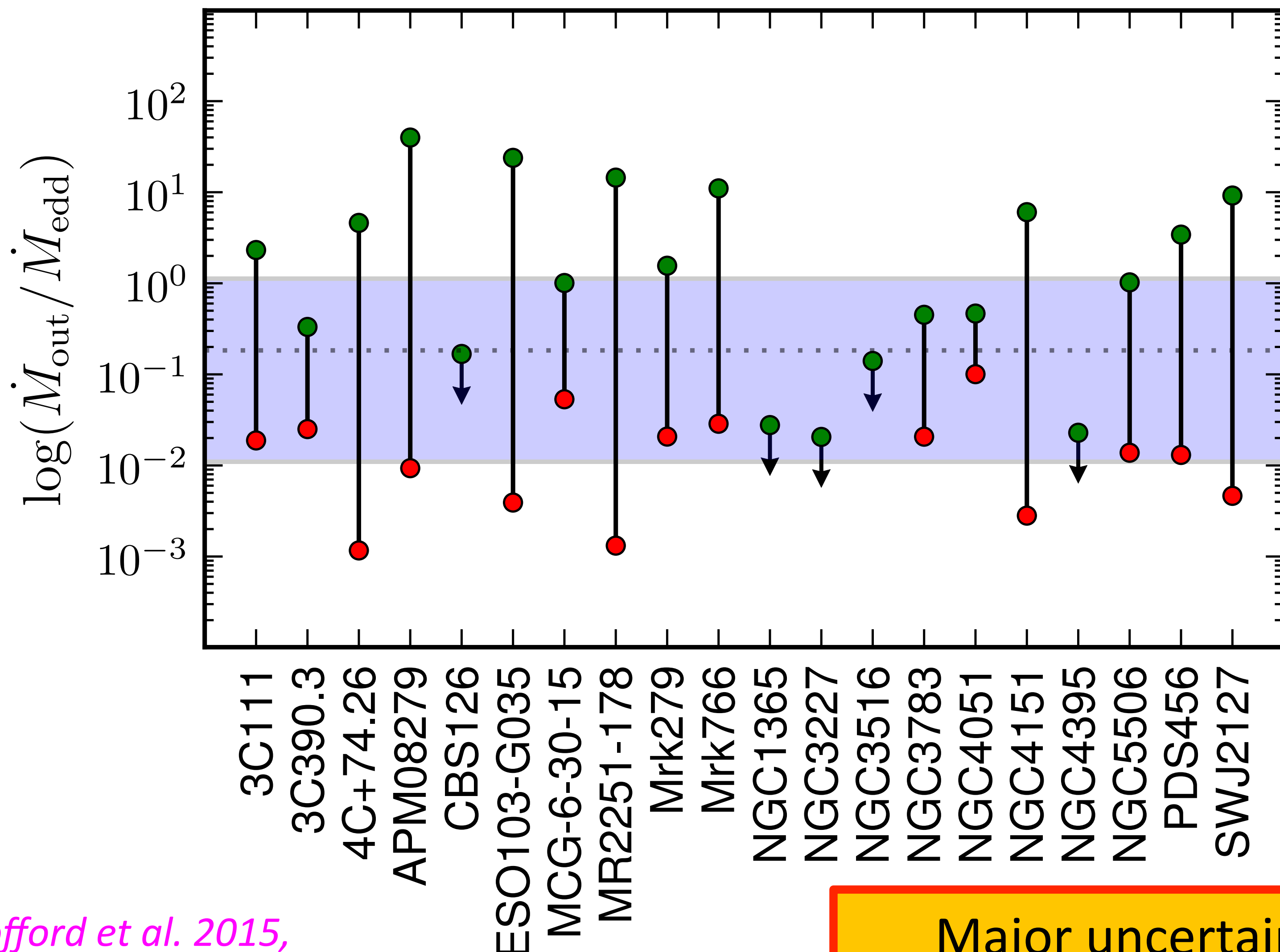
★ Column density: modelling of absorption by photo-ionised gas

★ 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

How powerful are disk winds?



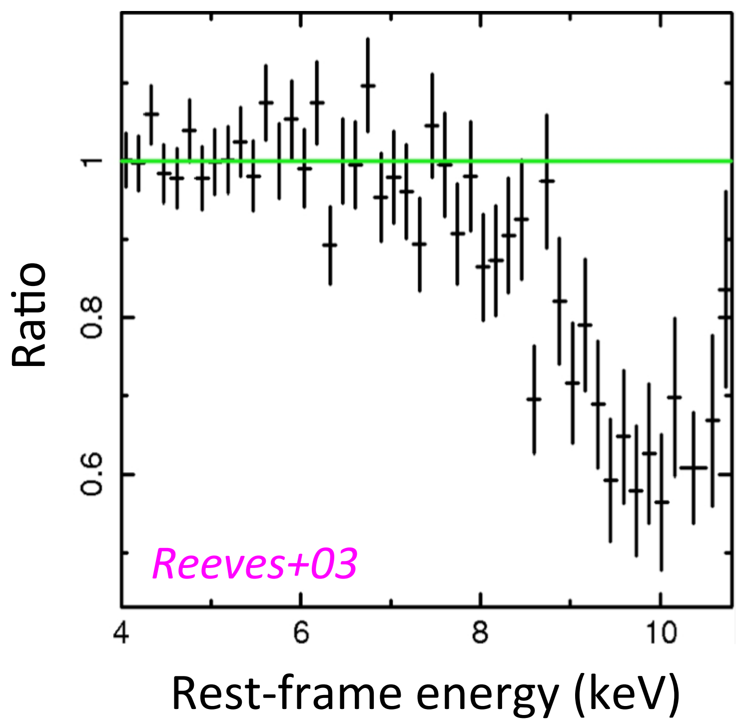
Gofford et al. 2015, MNRAS, in press

Major uncertainties:
launch radius + solid angle

PDS 456: the Rosetta Stone of AGN disk winds

Most luminous radio-quiet AGN in the local Universe

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

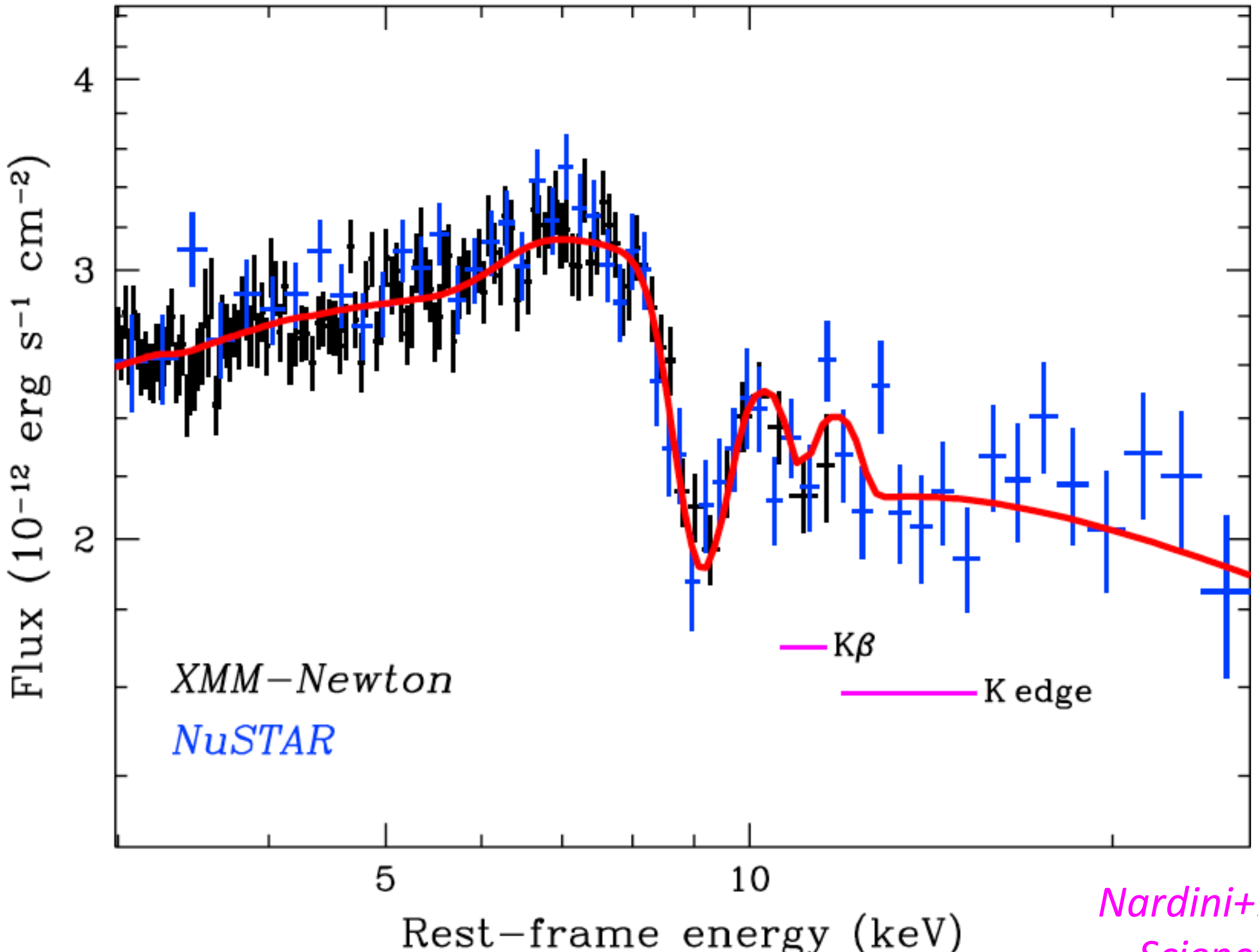


Systematic detection of a deep trough above 7 keV rest-frame: evidence for a large column of highly ionised matter outflowing at about one third of the speed of light

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

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

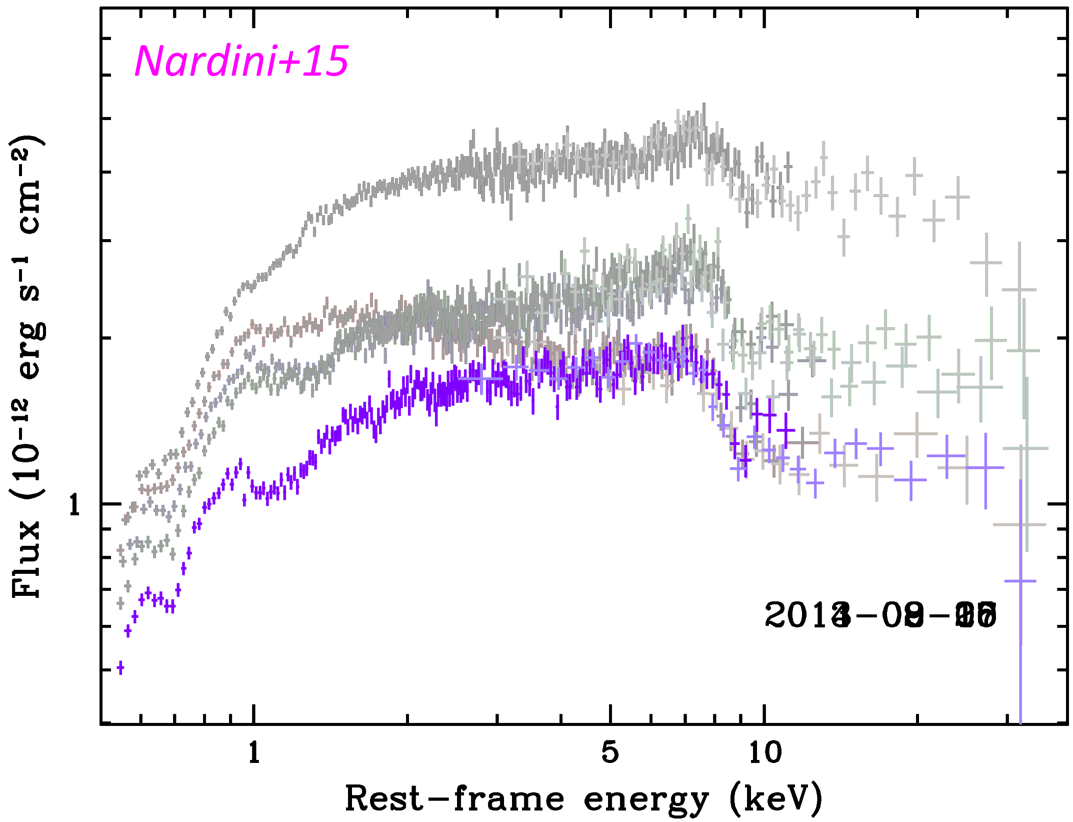
The revolutionary broadband view

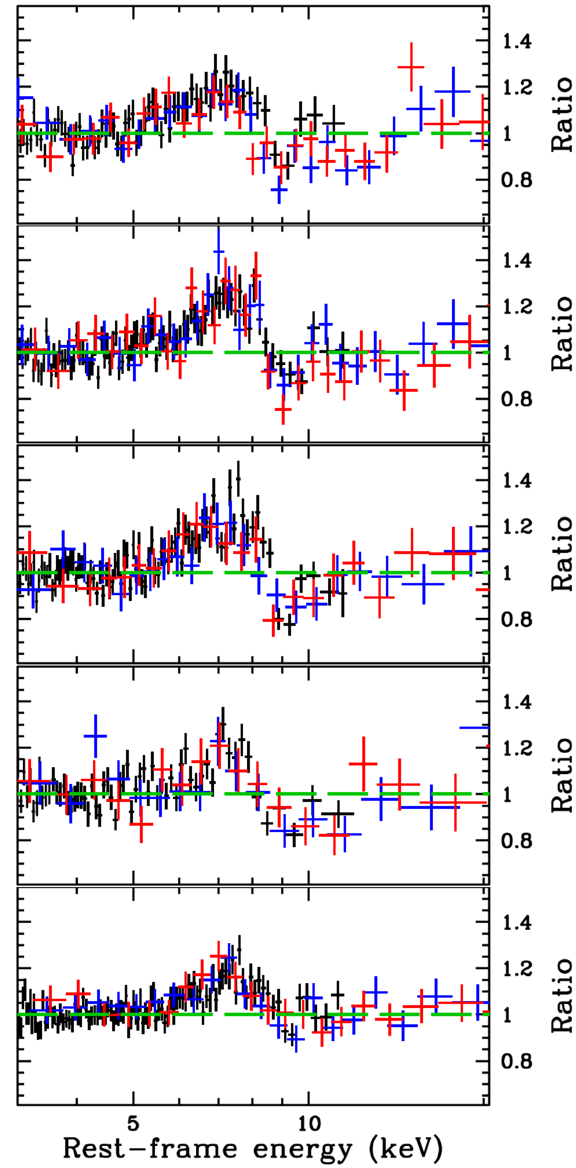


Nardini+15, Science

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

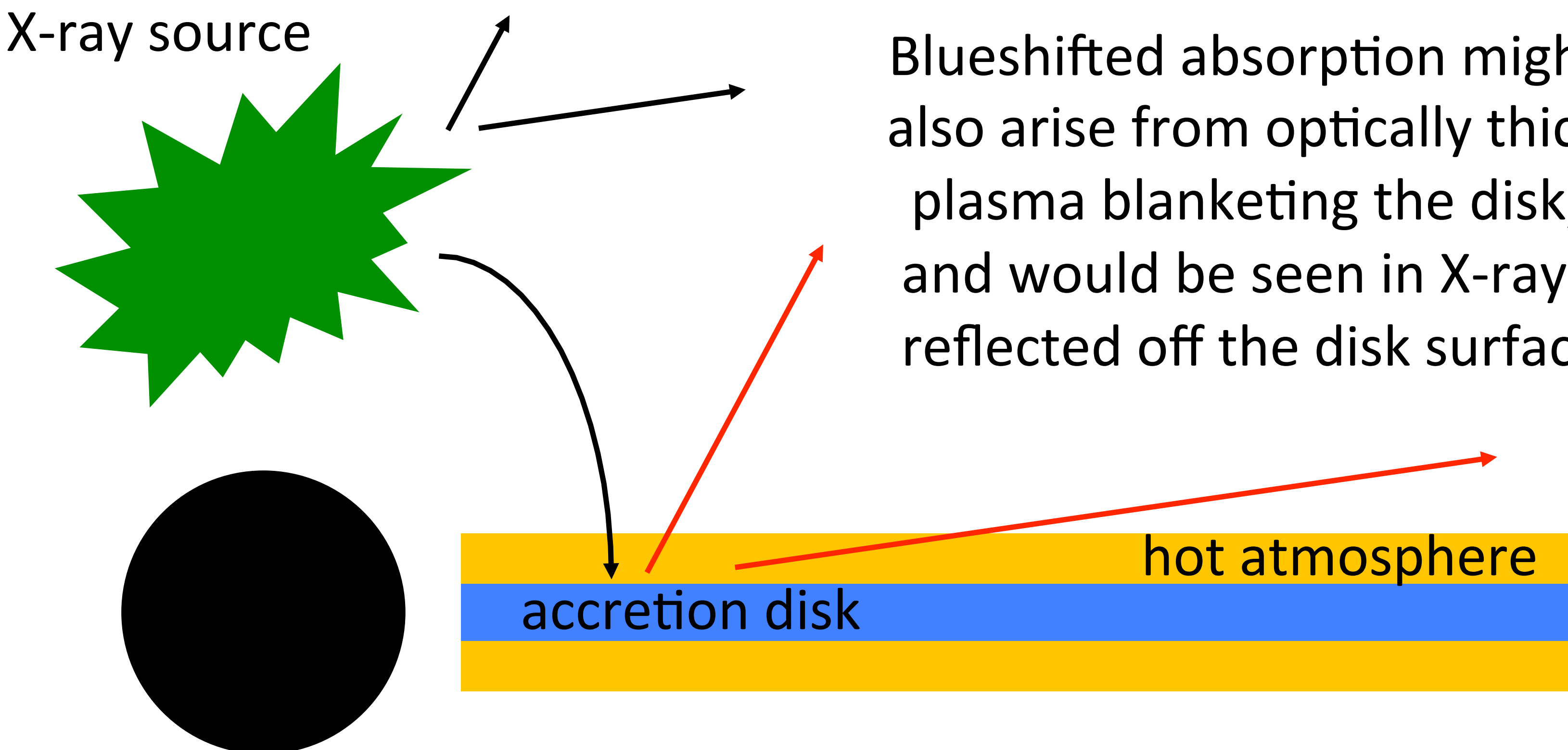
The solid angle is obtained from the emitted/absorbed luminosity ratio, and the launch radius from the variability timescale

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

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

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

Alternative interpretations



Blueshifted absorption might also arise from optically thick plasma blanketing the disk, and would be seen in X-rays reflected off the disk surface

Gallo & Fabian 11

This model requires a strong reflection component, and has been successfully applied to PG 1211+143, for which claims of no wind also come from recent *NuSTAR* observations

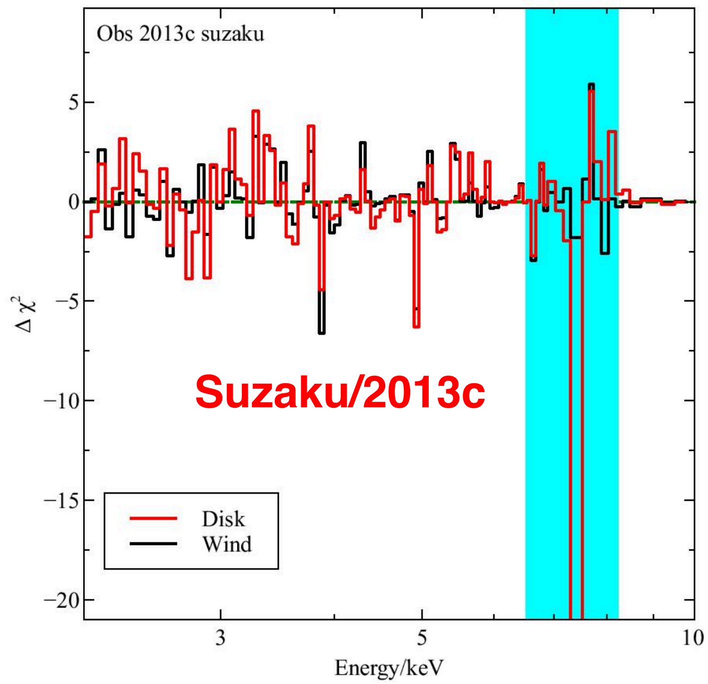
(Zoghbi+15, but see Pounds et al. talk!)

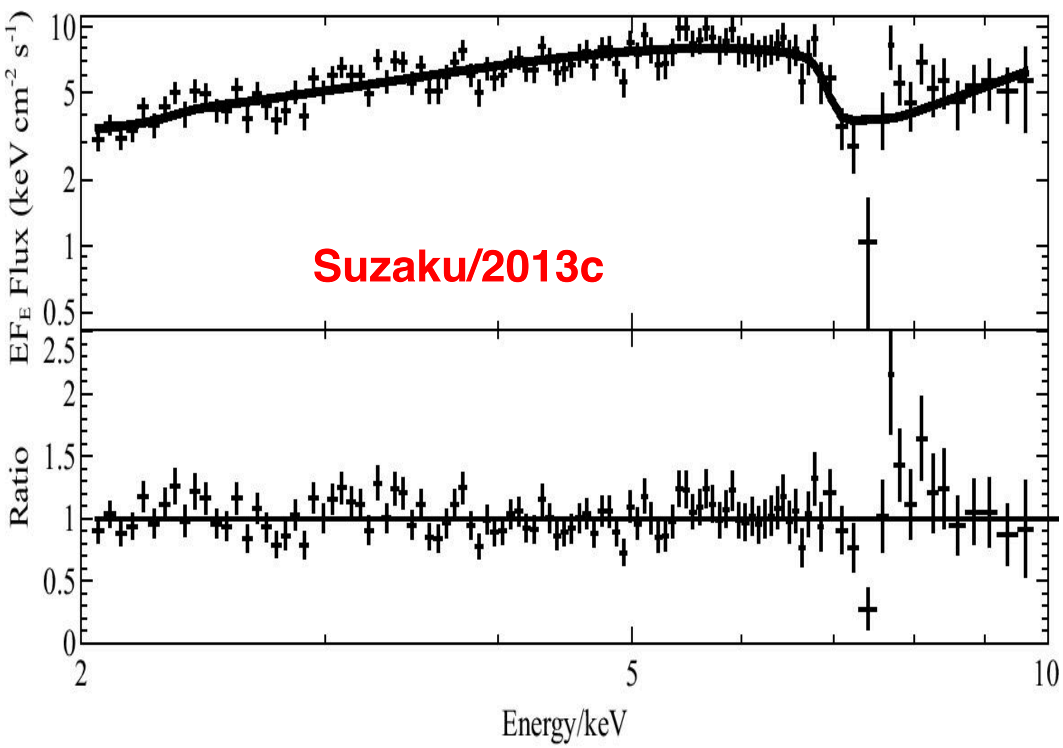
Can we account for the iron K profile in PDS 456 without a Disk Wind?

(Costa et al. 2015)

In this scenario, the disk reflection spectrum itself is **absorbed by ionized outer surface layers** of rotating disk - both reflection and absorption (transmitted) spectra are relativistically blurred.

Blue-shifted absorption through transverse Doppler shift inherent in inner disk without need for fast outflow.





Requires:-

Disk absorber:- $N_H = 1.5 \times 10^{24}$ cm^{-2} but 10x Solar Fe (unlike wind). Ionization log ξ = 4.7 (cgs).

Reflector (relconv_lp*xillver):- Inc=70°, a=0.998, Fe x10 Solar, r_h ~1.25Rg, log ξ= 0.3, R>10.

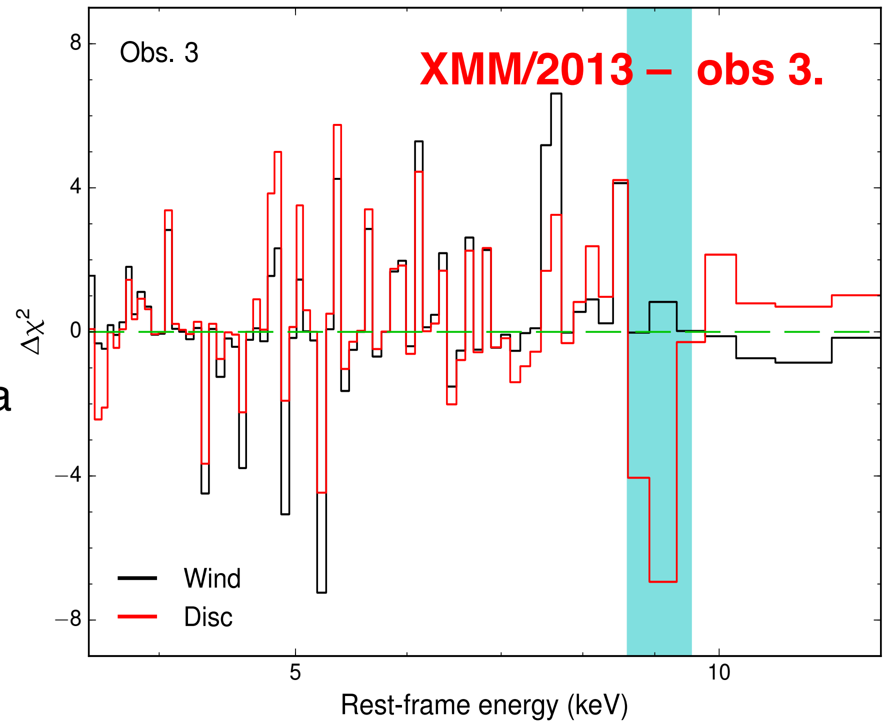
Extreme parameters. Reflection produces poor fit ($\Delta\chi^2$ = 40) at Fe K.

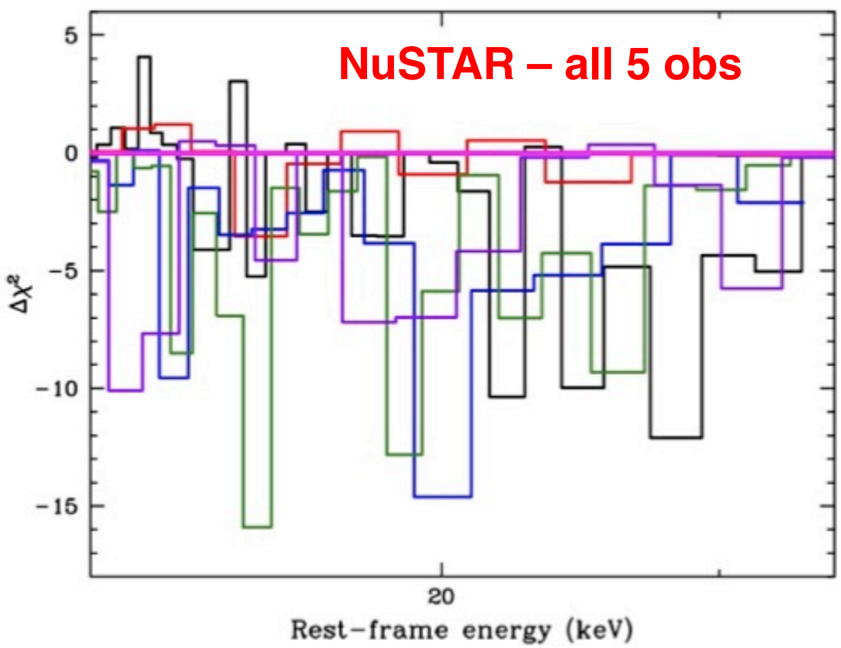
Blurred Reflection cannot account for PDS 456…

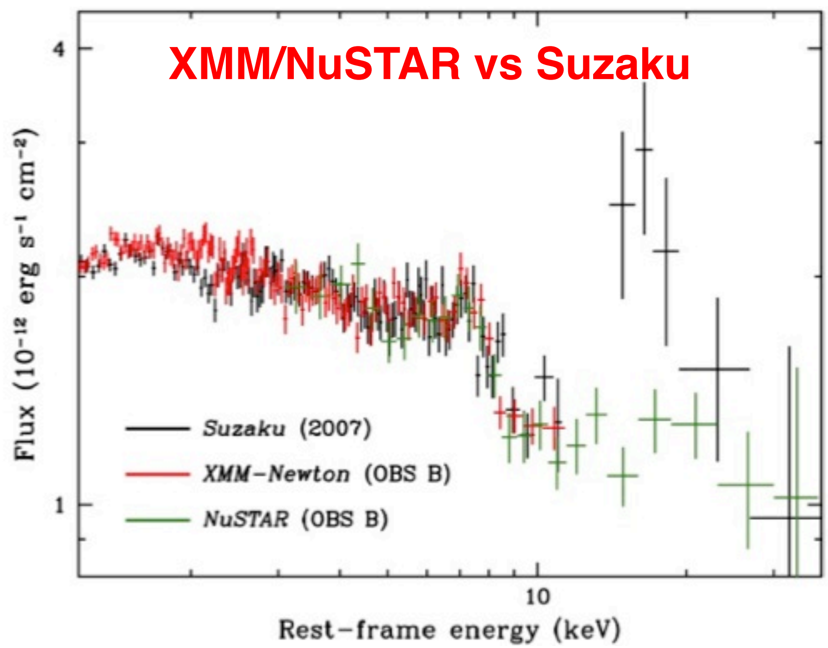
Thus reflection alone *cannot* account for iron K absorption profile – needs wind profile.

No hard excess in the 2013/14 NuSTAR data *rules out strong reflection* (steep continuum, Γ~2.4, out to 40 keV)

Reflection models over-predict the hard X-ray flux observed in all 5 NuSTAR observations.

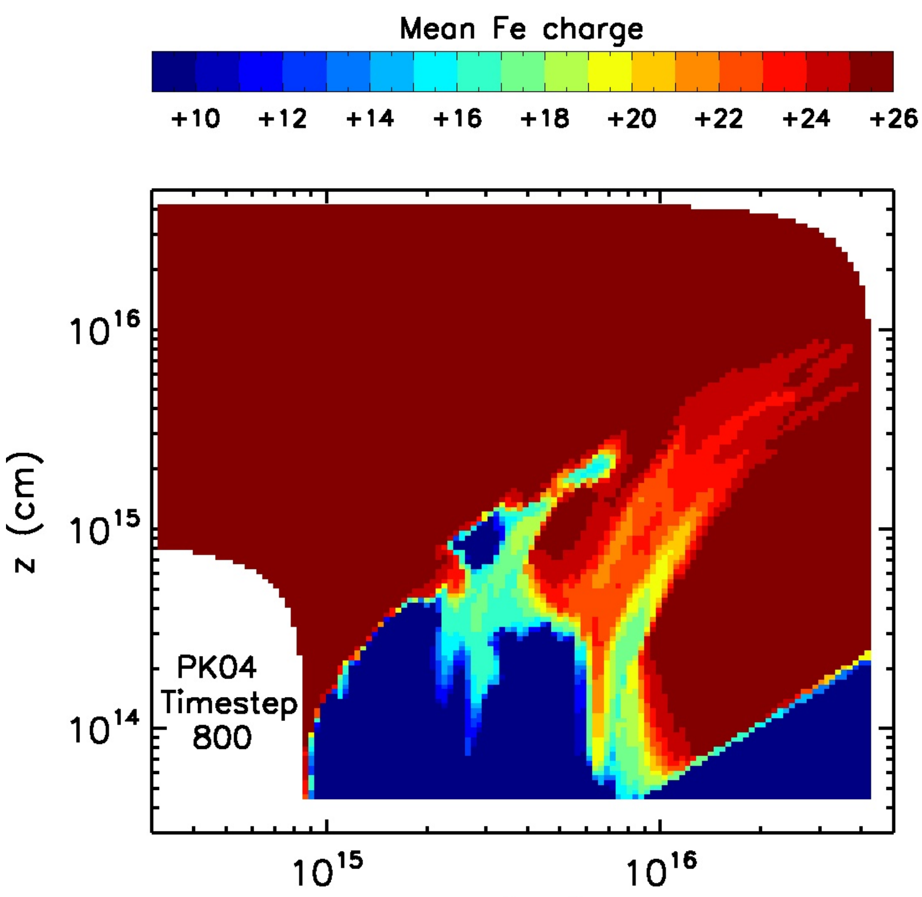


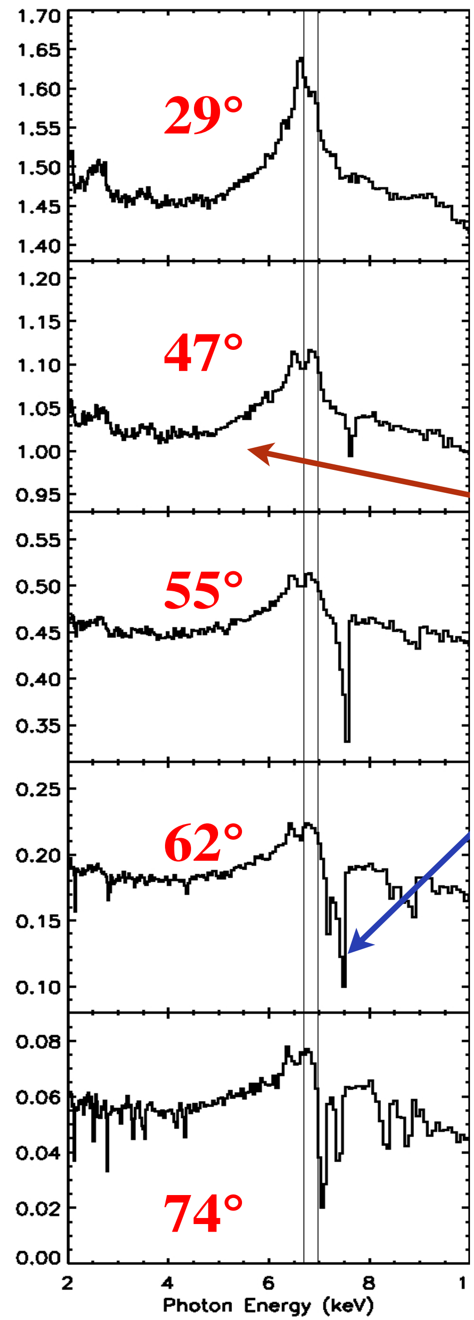




Radiatively Driven Disk Winds

- Disk winds simulations of Sim et al. (2010), Proga & Kallman (2004)
- Produces blue-shifted Fe K absorption





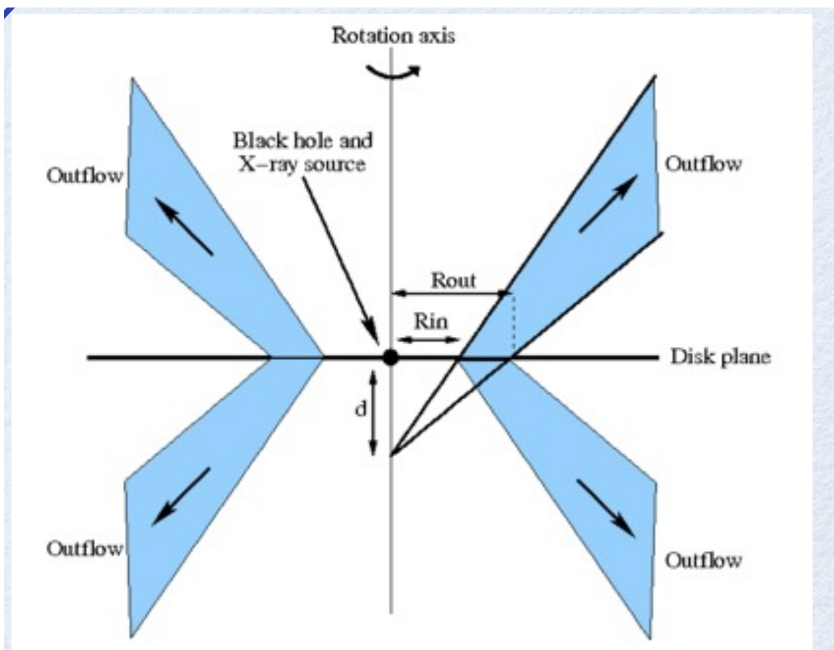
Example disk wind spectra

Fe K red-wing via emission from wind

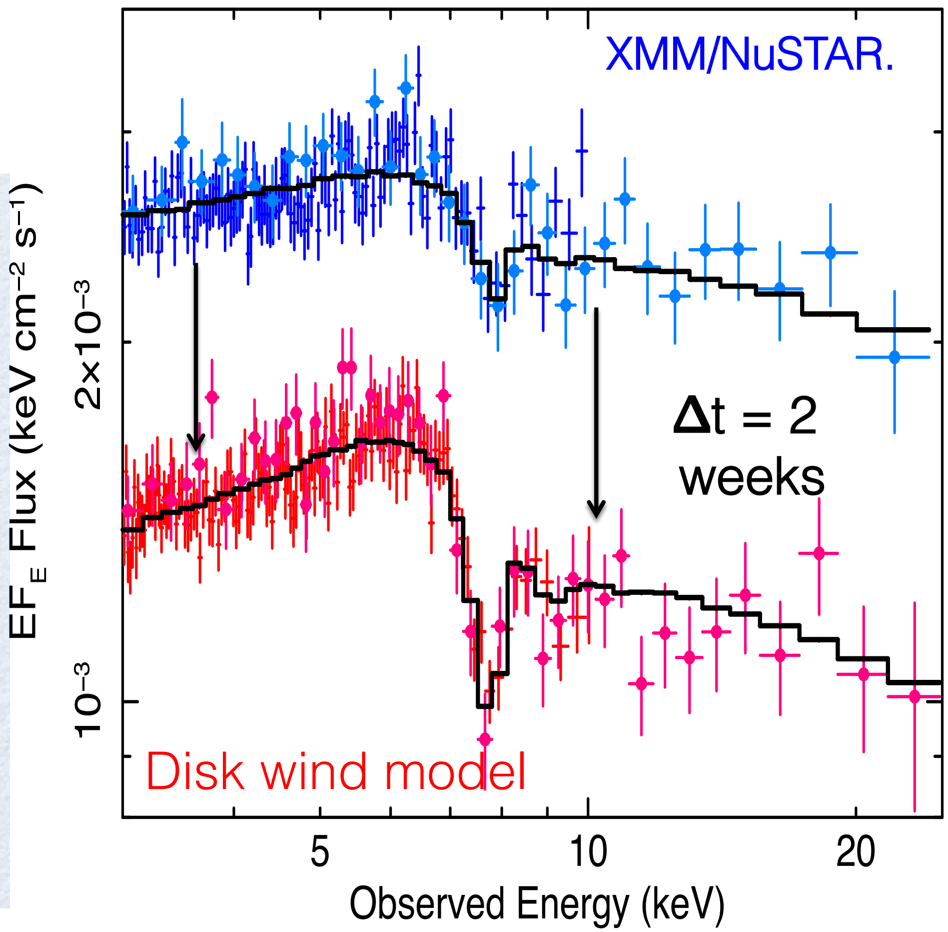
Blue-shifted absorption from l.o.s along wind

The Disk wind profile of PDS 456 (Sim et al. 2010 model)

Launch radius at **32 R_G**. Inclination = **70°**.
Mass outflow rate **M_{dot} = 0.25 M_{Edd}**. **L_K = 0.15 L_{Edd}**.
Observations 2 weeks apart. Wind in photoionization equilibrium, ionizing luminosity decreasing from **L_{2-10}/L_{Edd} = 1.4±0.2%** to **0.6±0.1%** in proportion to continuum.



Sim et al. (2008, 2010 a,b)



Summary

★PDS 456 is an exceptionally luminous AGN in the local Universe, yet representative of an accreting SMBH during its quasar phase and thus offering a unique view of the possible mechanism that links the growth of the central black holes to the evolution of their host galaxies over cosmic time.

★The new campaign XMM + NuSTAR campaign allowed the first direct measure of the mass-loss rate and total energetics of a disc outflow, whose mechanical power is largely consistent with the requirements of feedback models.

★At the peak of the quasar epoch, such powerful winds would have provided the energy and momentum to self-regulate the SMBH growth and control the star formation in stellar bulges.

★The present-day scaling relations are left as a record of this process.

Nardini et al. 2015.