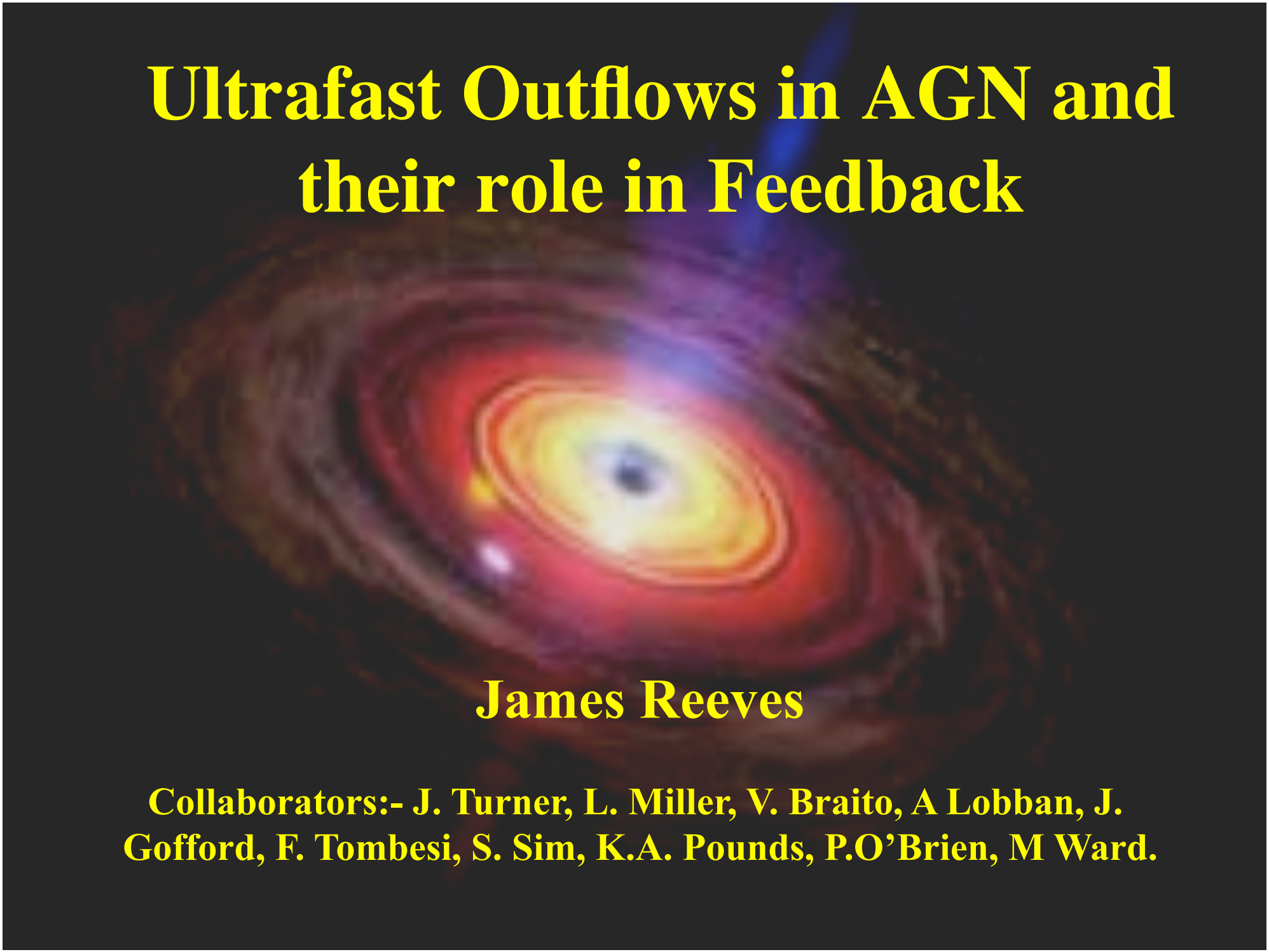
Ultrafast Outflows in AGN and their role in Feedback



James Reeves

Collaborators:- J. Turner, L. Miller, V. Braito, A Lobban, J. Gofford, F. Tombesi, S. Sim, K.A. Pounds, P.O'Brien, M Ward.

Ultrafast Outflows in AGN

• How much mass is carried out of the AGN by the outflow - need to know *covering fraction* and location of the outflow.

• How does it compare to the amount of matter being accreted?

• Does the ionized outflow carry a significant fraction of the energy output of the AGN? - $\propto$ (***outflow velocity)***^{3}

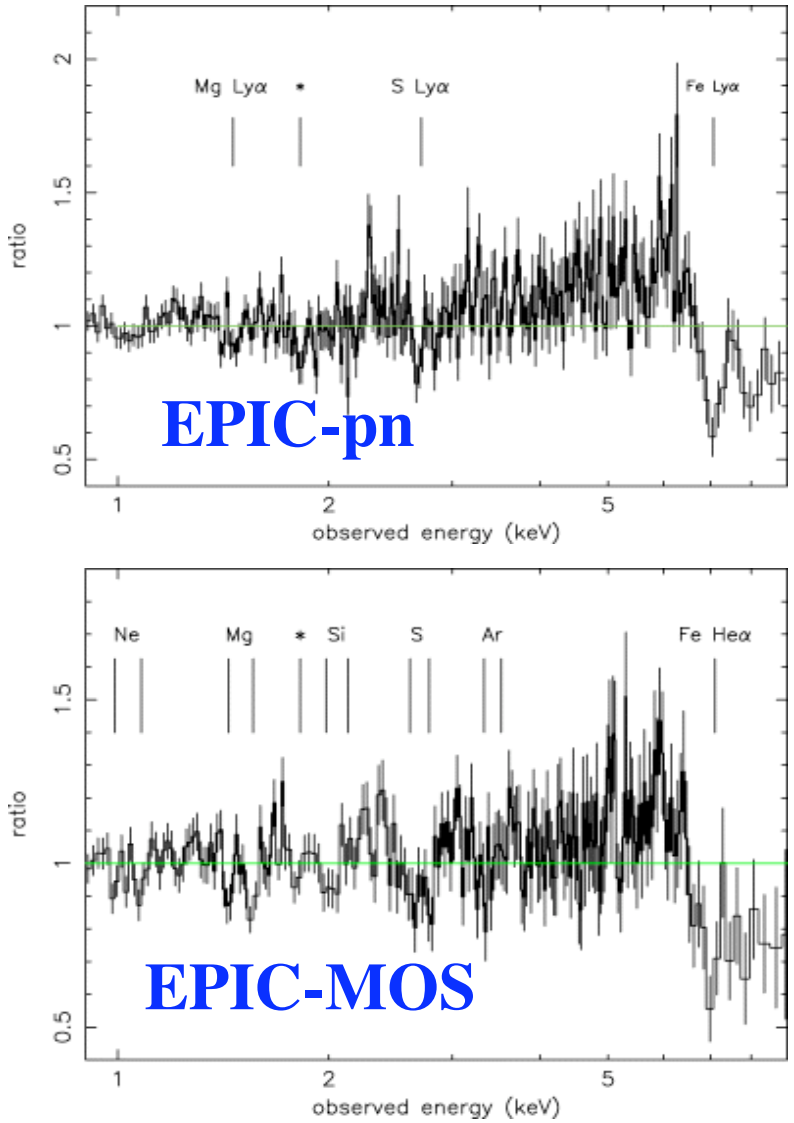
[c.f. E=10^{59} erg binding energy of a bulge with 10^{11} M_{solar} and σ=300 km/s.]

•Can the outflow regulate the growth of the black hole and the galaxy (bulge) through feedback, i.e. a physical explanation of the M-sigma relation (e.g. King & Pounds 2003; King 2003, 2010)?

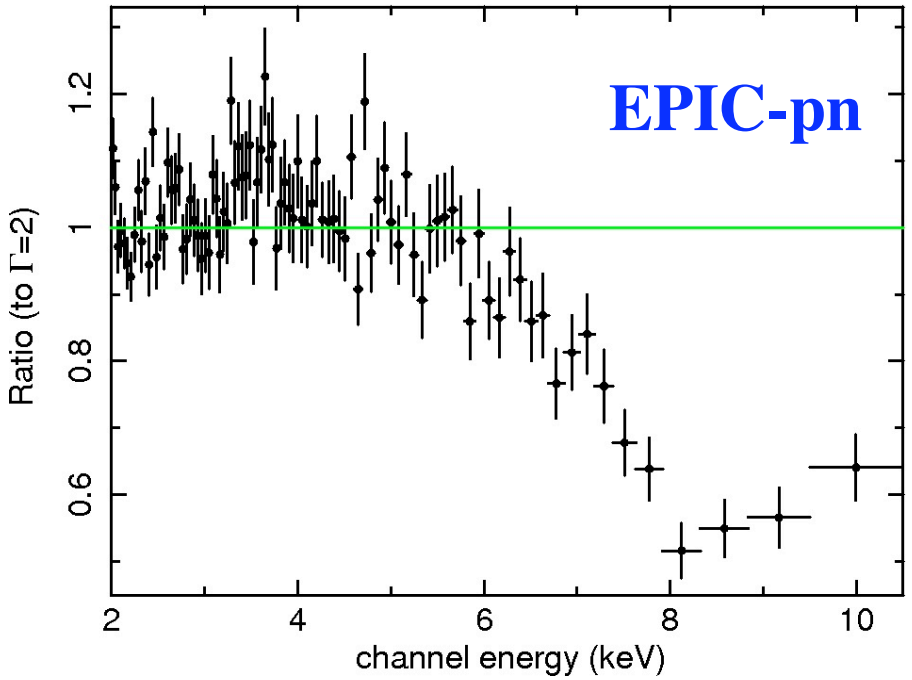
High-velocity outflows, with v~0.1c in high accretion rate AGN, are potentially energetically significant.

Discovery of Fast Outflows with XMM-Newton

PG 1211+143, z=0.081 (Pounds et al. 03)



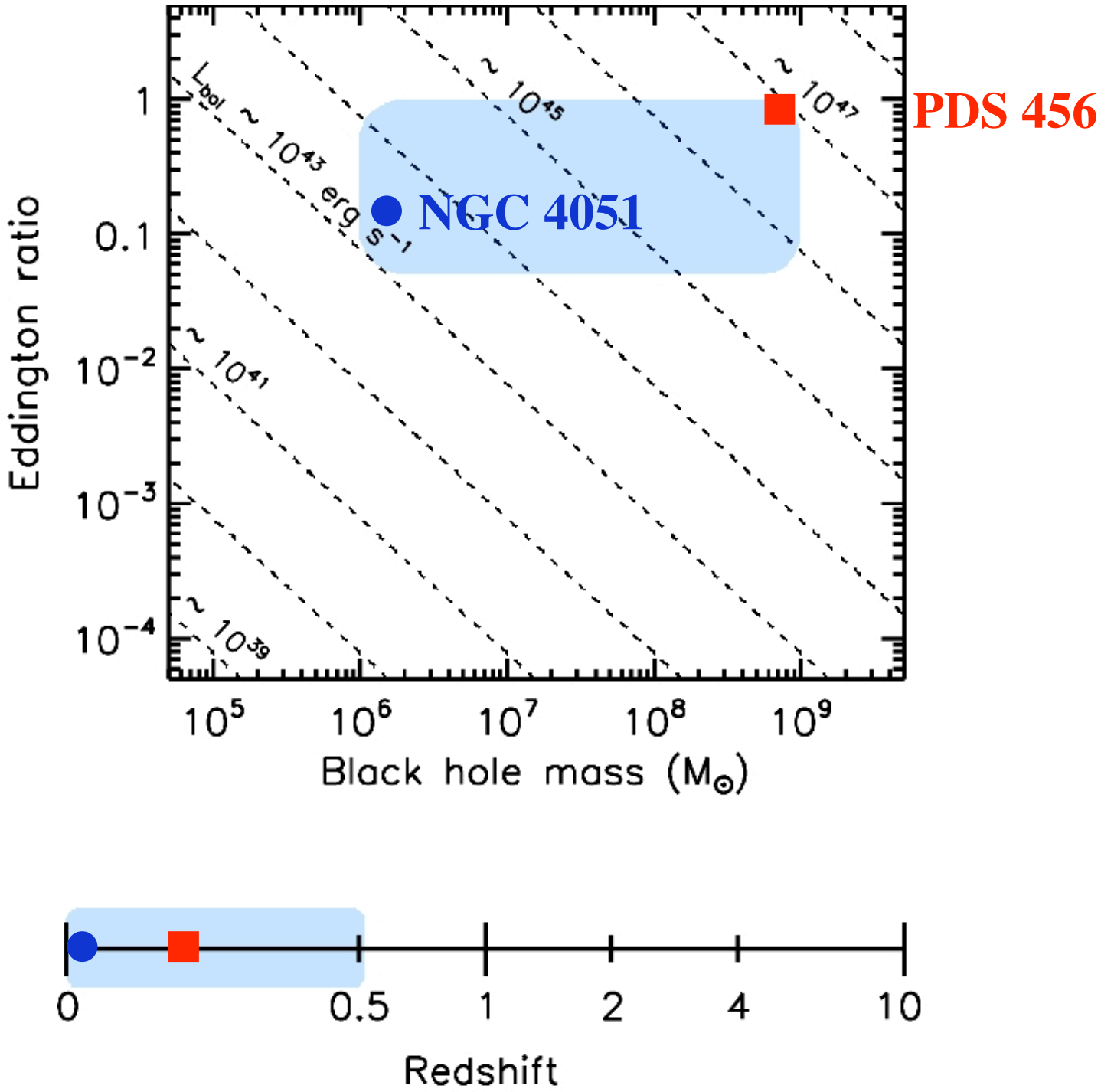
PDS 456, z=0.184, (Reeves et al. 03)



Blue-shifted absorption due to highly ionized iron (e.g. Fe XXV) as well as Mg/Si/S.

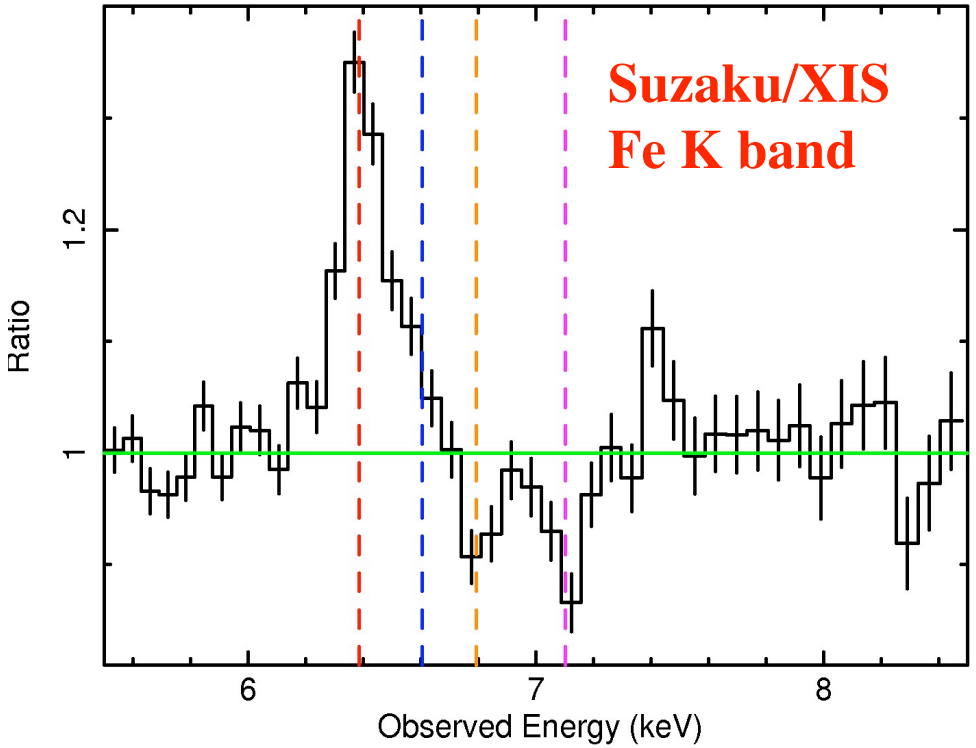
Velocities implied are 0.1-0.2c, launched from < 100Rg, with columns $>10^{23}$ cm^{-2}. Suggests kinetic power can approach L_{bol}.

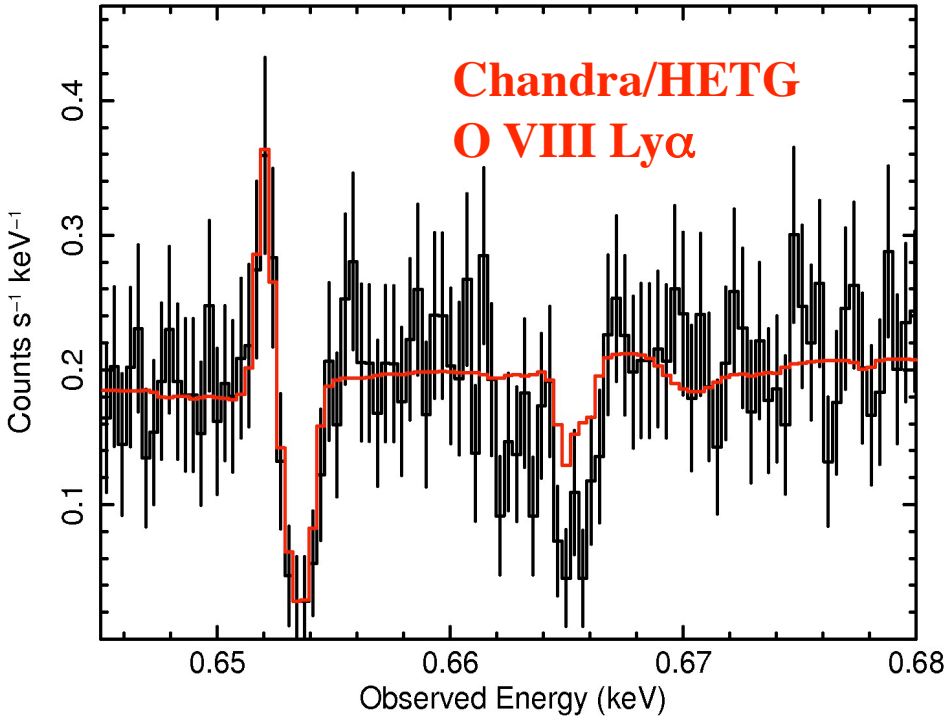
Also X-ray BAL QSOs (Chartas et al. 2003)


PDS 456
NGC 4051
Eddington ratio
1
0.1
10^{-2}
10^{-3}
10^{-4}
$L_{bol} \sim 10^{43}$ erg s^{-1}
$\sim 10^{45}$
$\sim 10^{47}$
$\sim 10^{41}$
$\sim 10^{39}$
10^5
10^6
10^7
10^8
10^9
Black hole mass ($M_\odot$)
0
0.5
1
2
4
10
Redshift

High Ionization Outflow in NGC 4051 (Lobban et al. 2010)

NLS1 z=0.00236, M_{BH} = 1.7x10^6 $M_\odot$, L_{bol} = 2 x 10^{43} erg s^{-1}

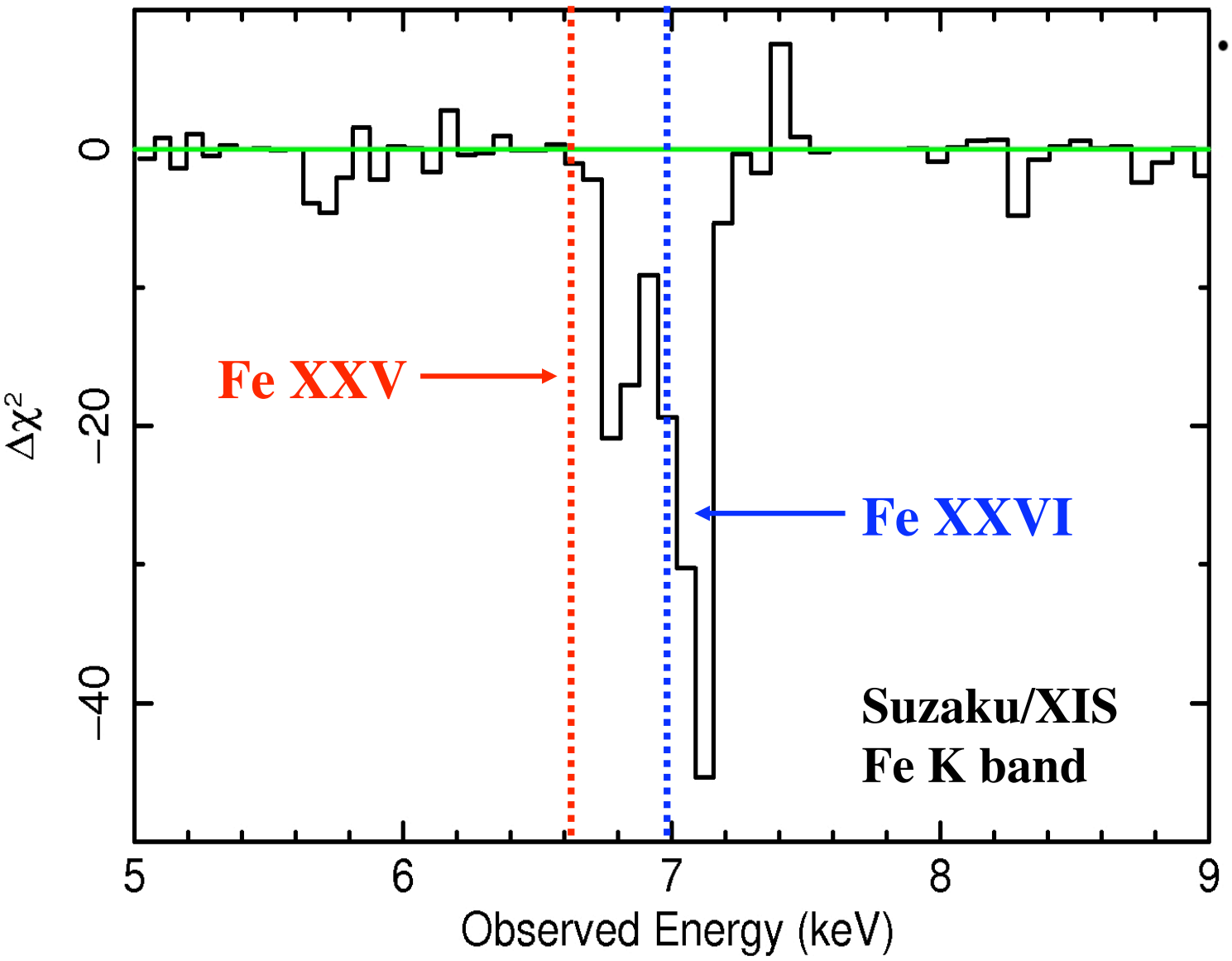




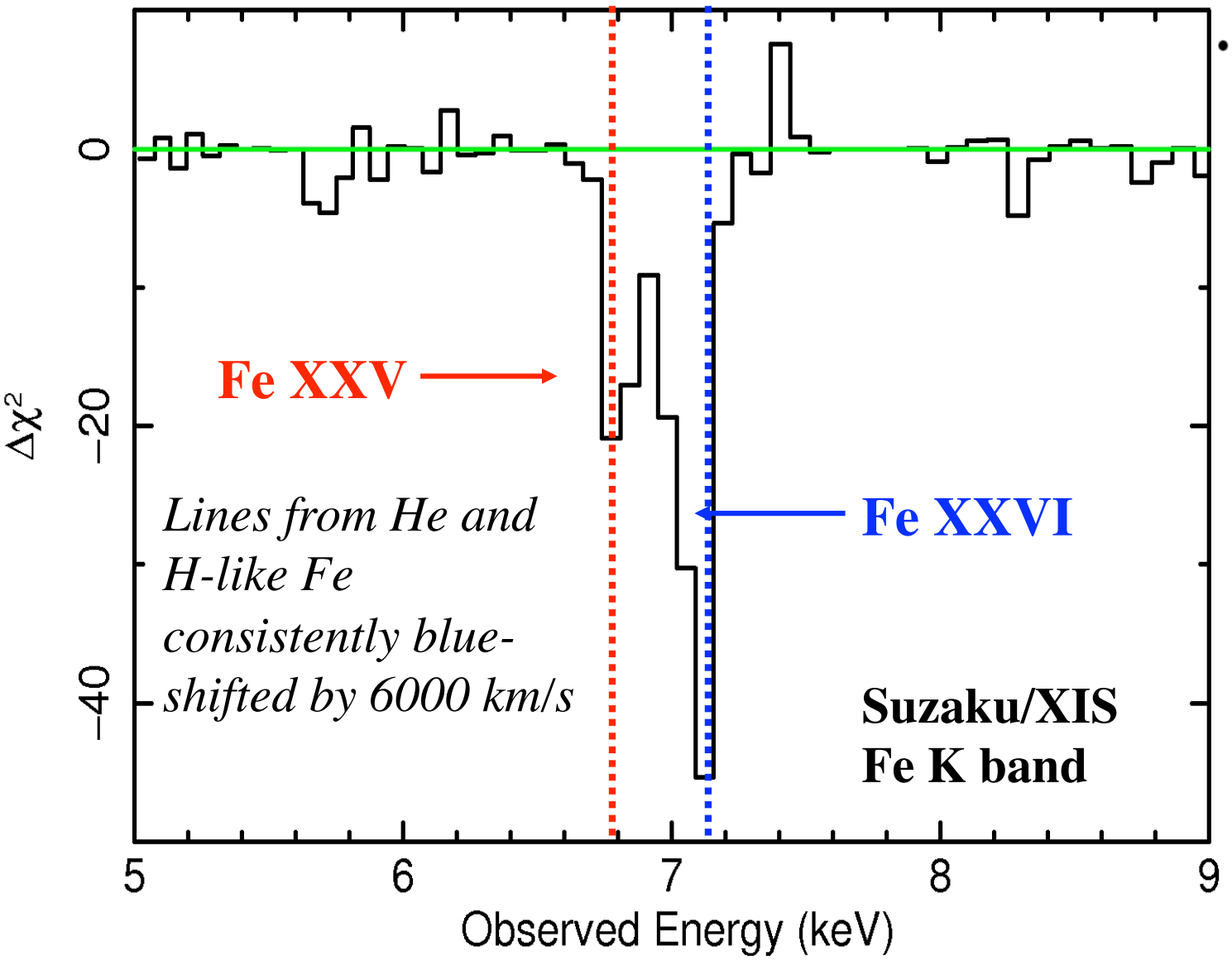
High Ionization absorption lines present at Fe K (6.81 keV, 7.11 keV). Outflow velocity of **5000-6000 km s^{-1}** c.f. He and H-like Fe.

High velocity (6000 km s^{-1}) component also associated with O VIII Lyα.

Blueshifted Iron K absorption in NGC 4051

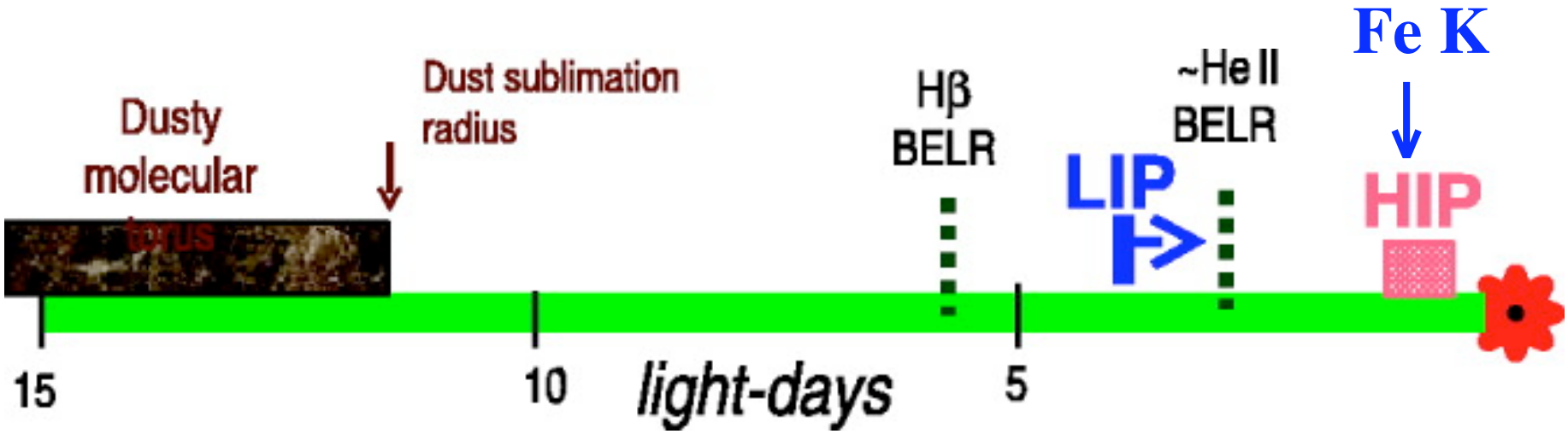


Blueshifted Iron K absorption in NGC 4051



Location of the Outflow in NGC 4051

Figure adapted from Krongold et al. (2007)

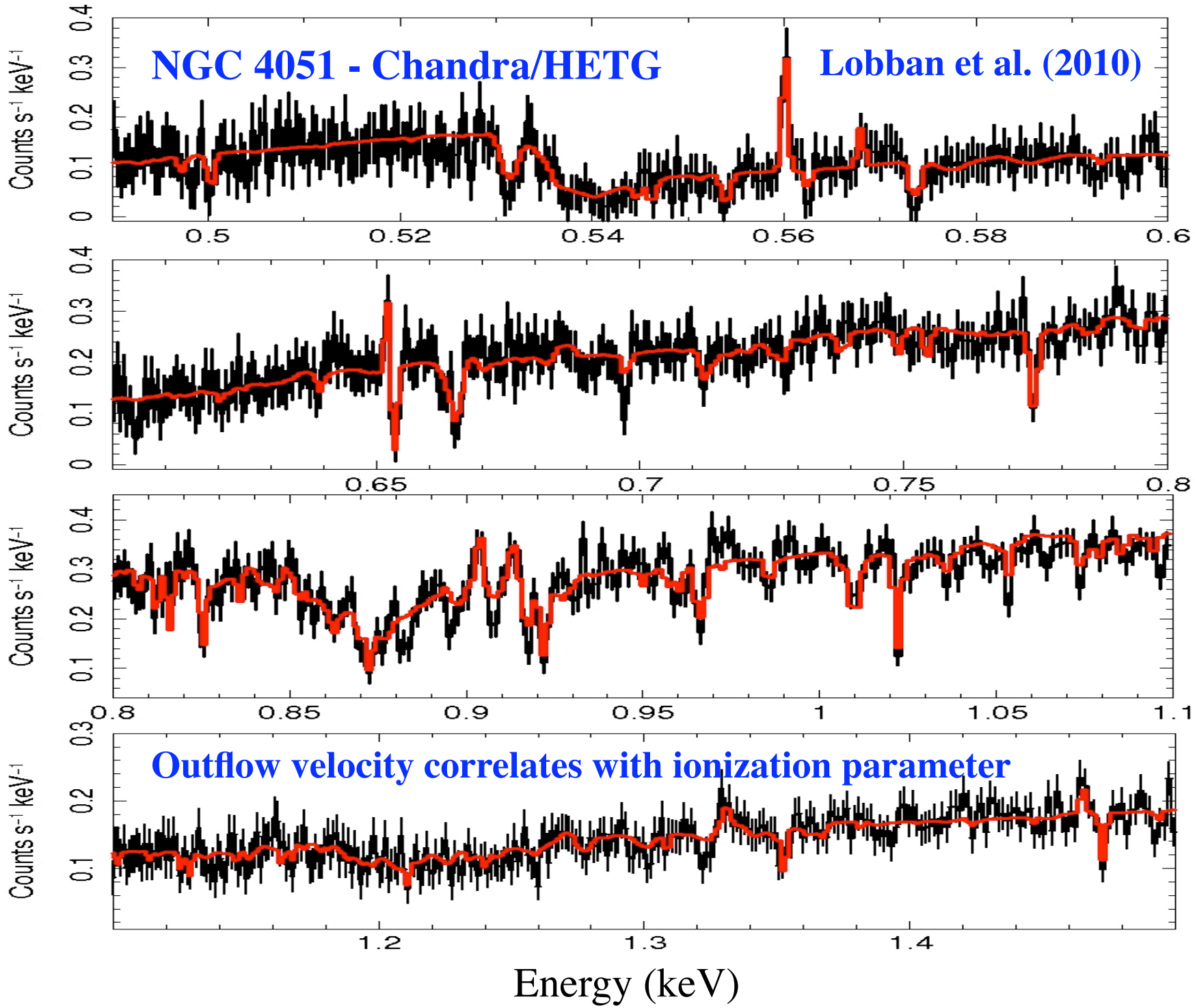


High ionization outflow in NGC 4051 requires $N_H \sim 10^{23}$ cm^{-2}, log $\xi \sim 4$ and v_{out}=0.02c [Note BH mass of NGC 4051 = 1.7x10^6 $M_\odot$; Denney et al. 2010]

Outflowing matter at ~***1 lightday*** (<6000 Rs) from black hole - - **an accretion disk wind?**

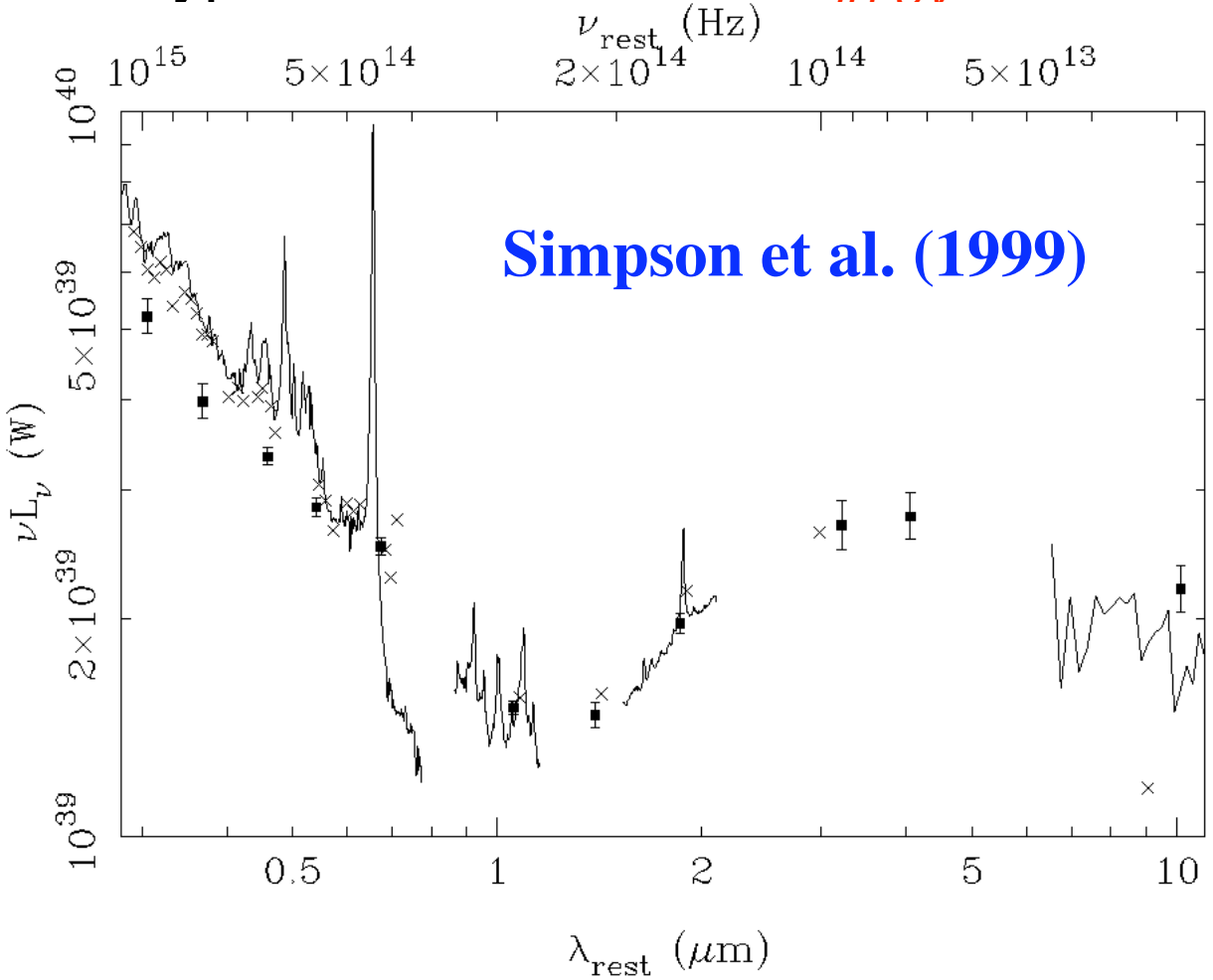
Mass outflow rate ~ 0.05 $M_\odot$ yr^{-1} ⇒ Outward momentum rate = **L_{Edd} / c**

$L_{out} \sim 10^{42}$ erg s^{-1} ⇒ **10^{57} erg s^{-1}** over AGN lifetime


NGC 4051 - Chandra/HETG
Lobban et al. (2010)
Outflow velocity correlates with ionization parameter
Counts s^{-1} keV^{-1}
Energy (keV)

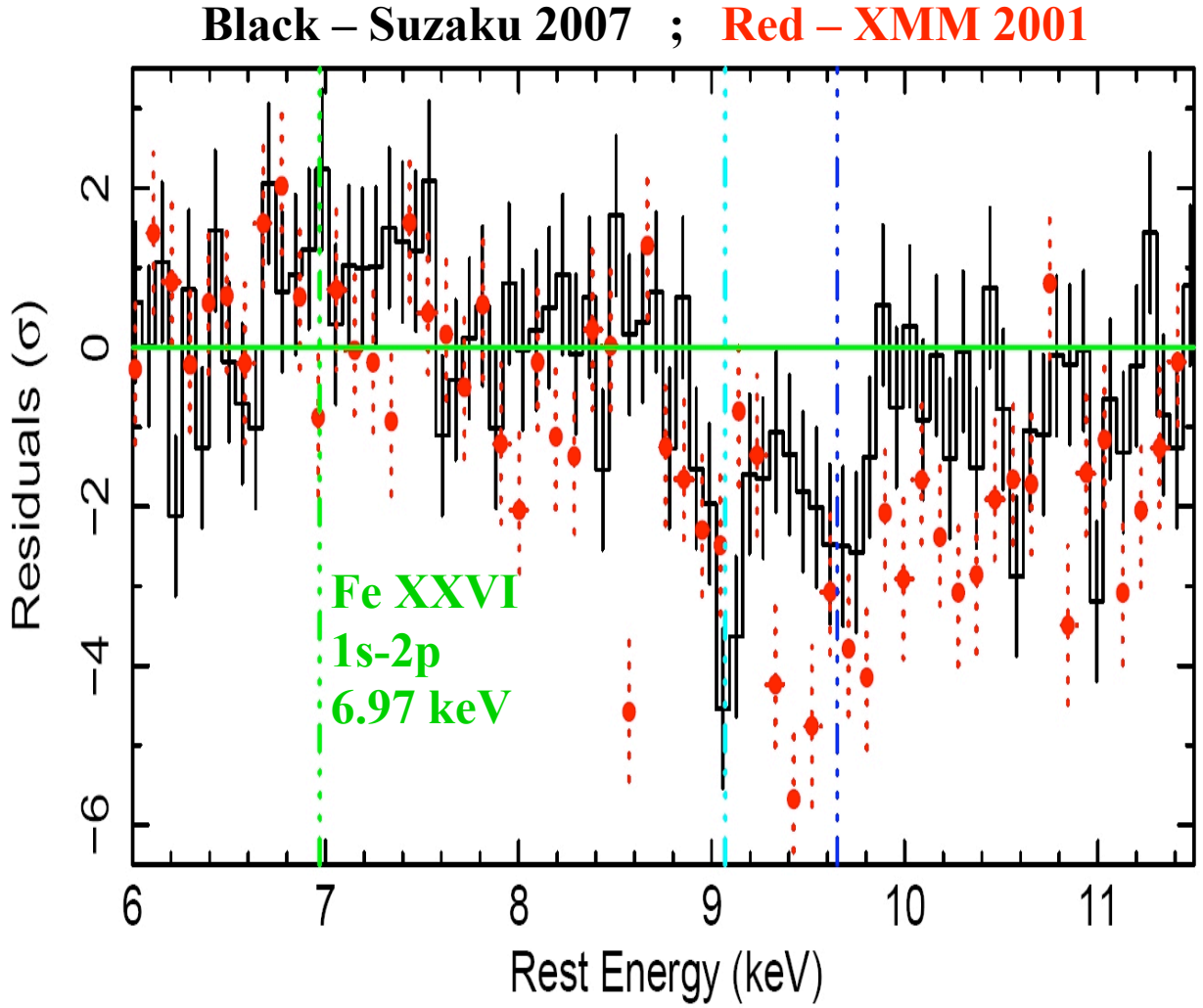
The Most Luminous Nearby Quasar PDS 456

Discovered a decade ago (Torres 1997) - very luminous broad-lined radio-quiet QSO at z=0.184. Most luminous AGN at z<0.3, more typical of z~2 QSOs - *$L_{IR\text{-}UV} \sim 10^{47}$ erg/s (1.7 x 3C 273).*



Relativistic Outflow in PDS 456 (QSO, z=0.184)

(200ks Suzaku Observation; Reeves et al. 2009)



Absorption lines observed with Suzaku at 9.08/9.66 keV (rest frame)

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

Requires N_H=5x10^{23} cm^{-2}, with logξ=4.5 to model strong absorption lines. Detection very robust (MC) >99.9% confidence.

PDS 456 Outflow Energetics

- PDS 456 observables:- $N_H \sim 10^{24}$ cm^{-2}, log $\xi \sim 4.5$ and $v_{out}=0.25c$, $L_{ion}=3\times10^{45}$ erg s^{-1}, $L_{bol}\sim10^{47}$erg s^{-1}. BH mass estimate $M_{BH}=2\times10^{9}M_{sun}$.

- Outflow Rate $M_{out} = 4\pi bnR^2 m_p v_{out} = 4\pi b m_p v_{out} L_{ion}/\xi \sim 100\ M_{sun}\ yr^{-1}$

- Kinetic output $L_{out} = 1/2\ M_{out} v_{out}^2 \sim 10^{47}$ erg s^{-1} $\sim L_{bol} \sim L_{Edd}$.

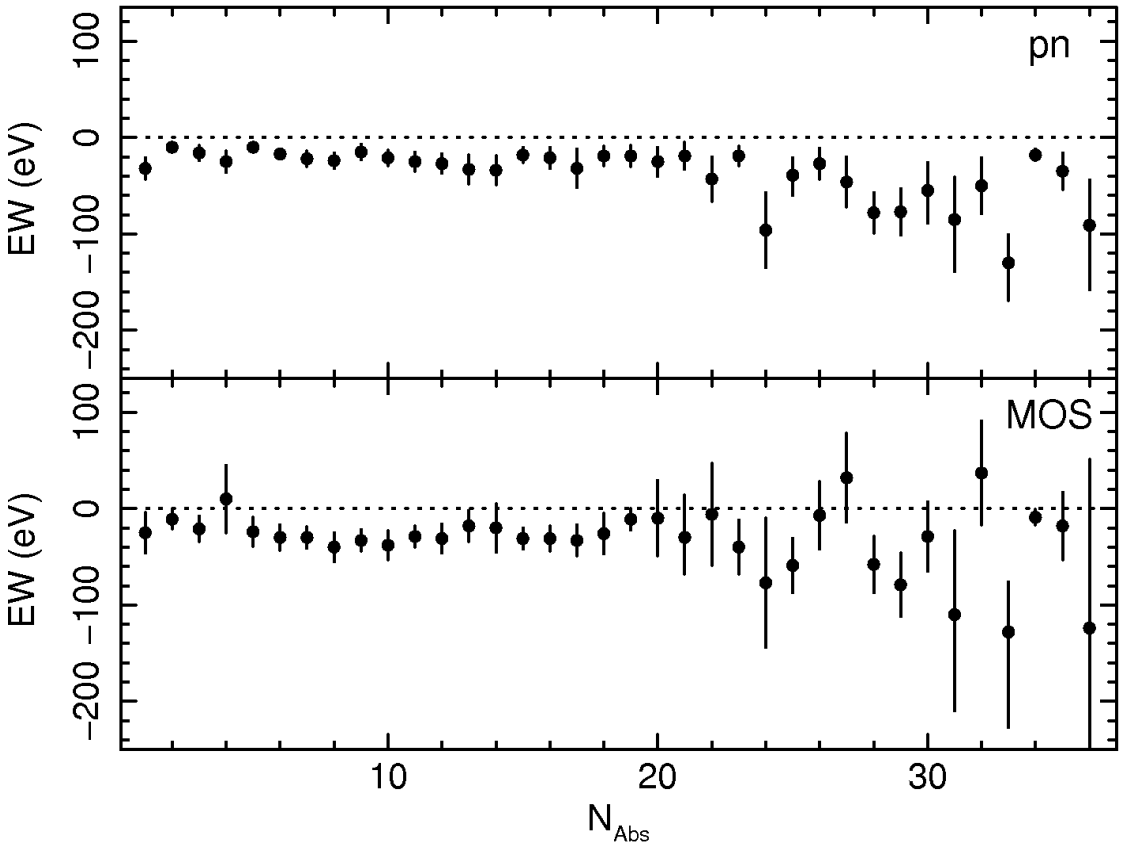
- Likely wind radius $\sim 30 - 300\ R_g$

- If $L_{out} \sim 10^{47}$ erg/s for lifetime of QSO phase ($t > 10^7$ yr) then *$E > 10^{61}$ erg* [c.f. $E=10^{59}$ erg binding energy of a bulge with 10^{11} M_{solar} and σ=300 km/s.] $\Rightarrow$ **May produce significant feedback**.

Critically depends on the covering fraction and outflow duty cycle.

XMM-Newton Sample of Iron K Absorption Lines
"The search for UFOs" (Tombesi et al. 2010)

Tombesi et al. (2010) have systematically analysed a sample of X-ray bright AGN selected from the RXTE slew survey and observed by XMM-Newton to compile a sample of Fe K absorption lines



36/101 observations with Fe K absorption.

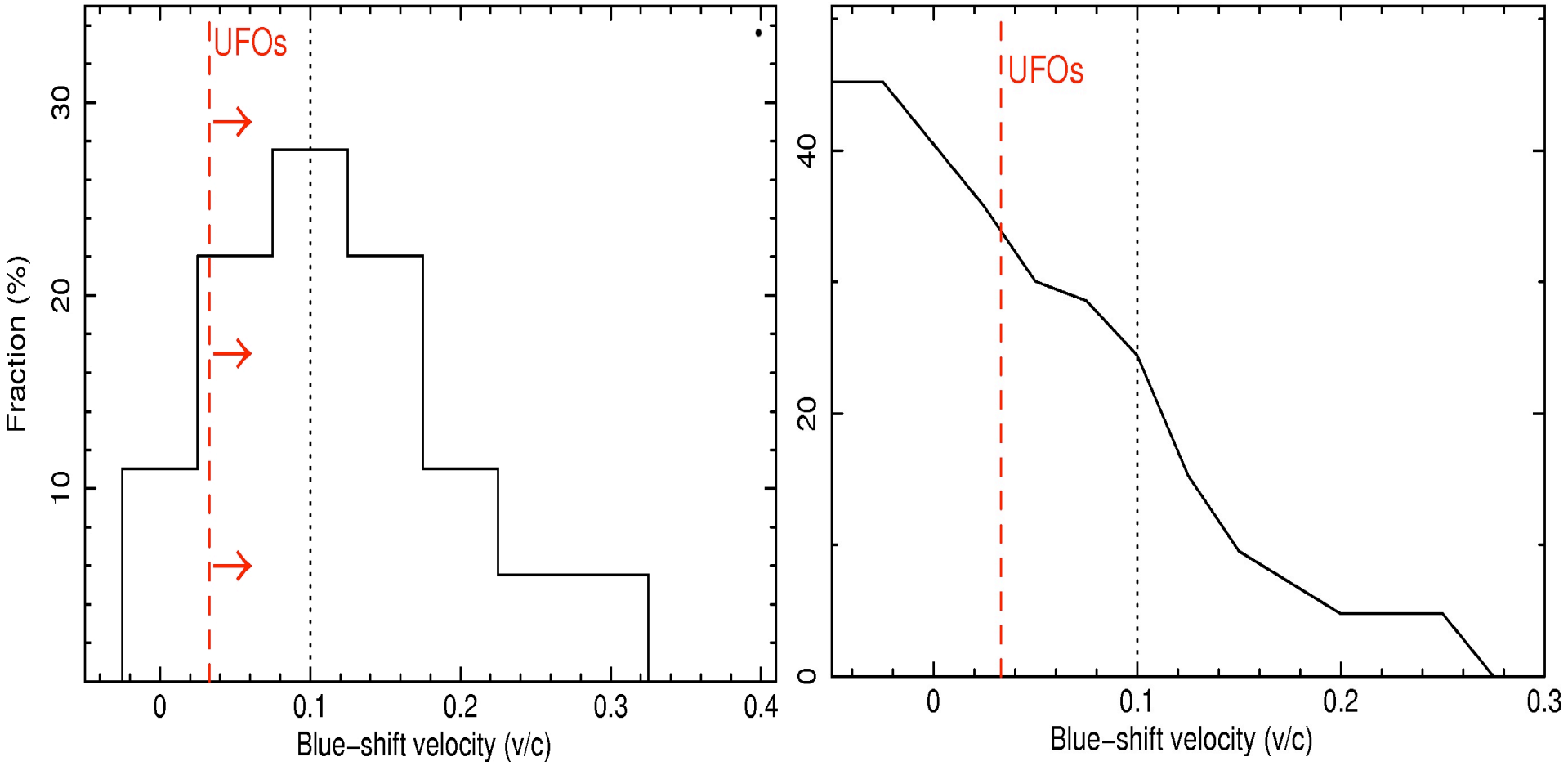
35% of AGN have blue-shifted lines at >95% confidence (Monte-Carlo.

Overall null probability of **$P<3\times10^{-8}$** (pn only). **11/42 AGN with v>0.1c.**

MOS observation independently confirm detections.

Covering Fractions are high - at least 40% of local AGN likely to contain such outflows.

Distribution of Outflow Velocities

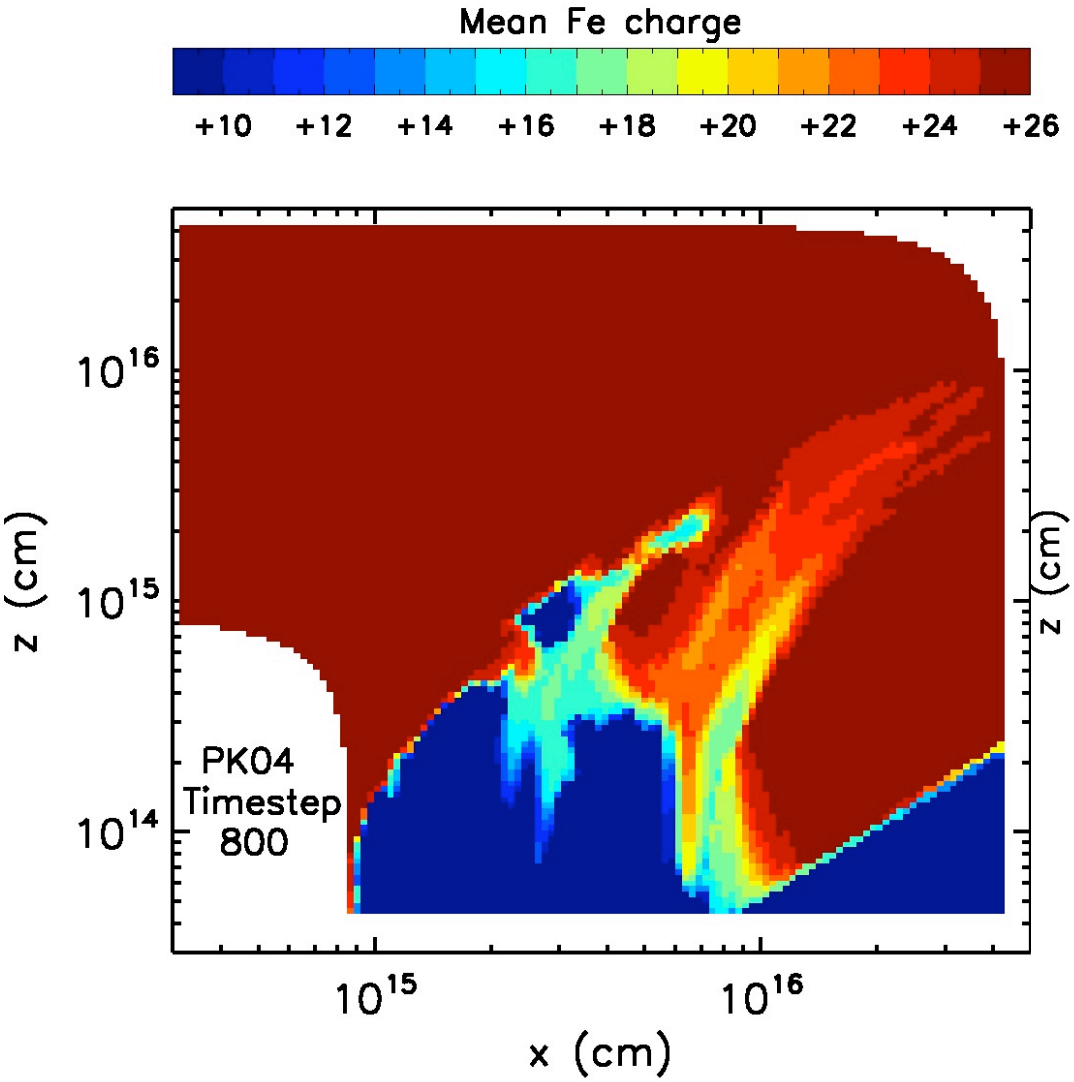


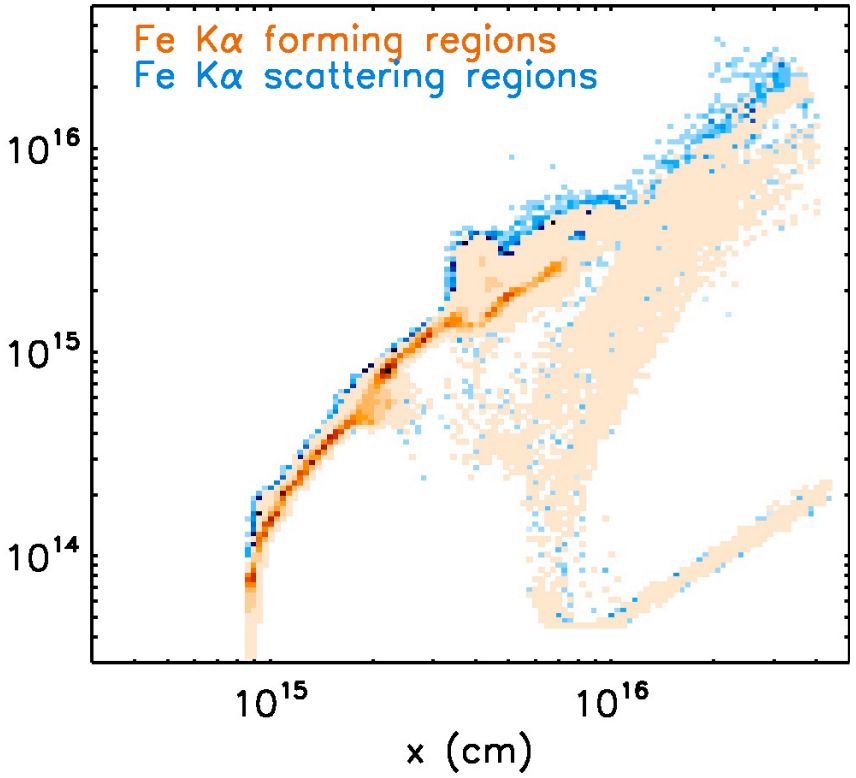
Mean blue-shift v_{out} = -0.103 ± 0.004c

(i.e. v~0.1c as predicted for a momentum driven outflow - see Andrew King talk)

Radiatively Driven Accretion Disk Winds

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

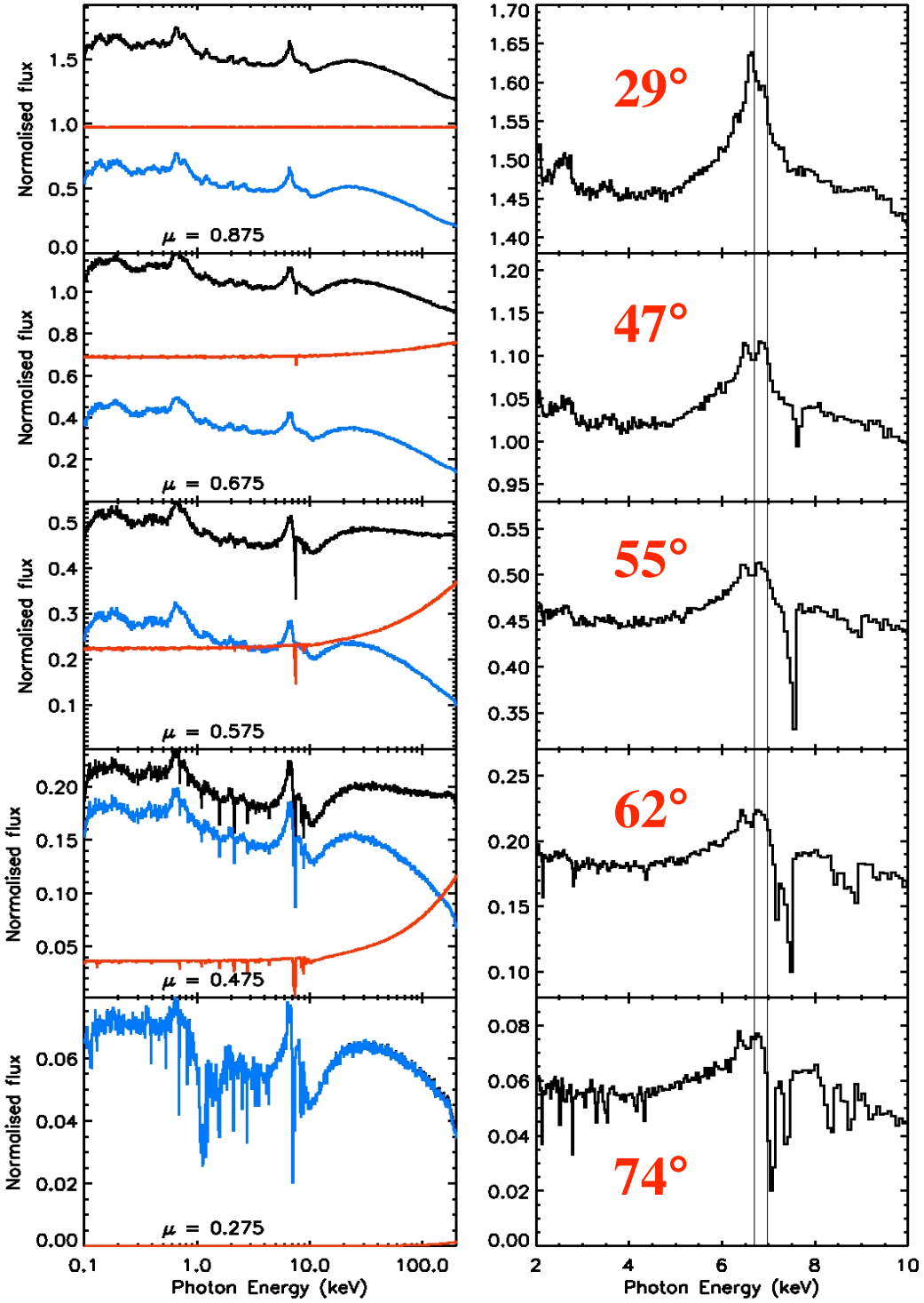


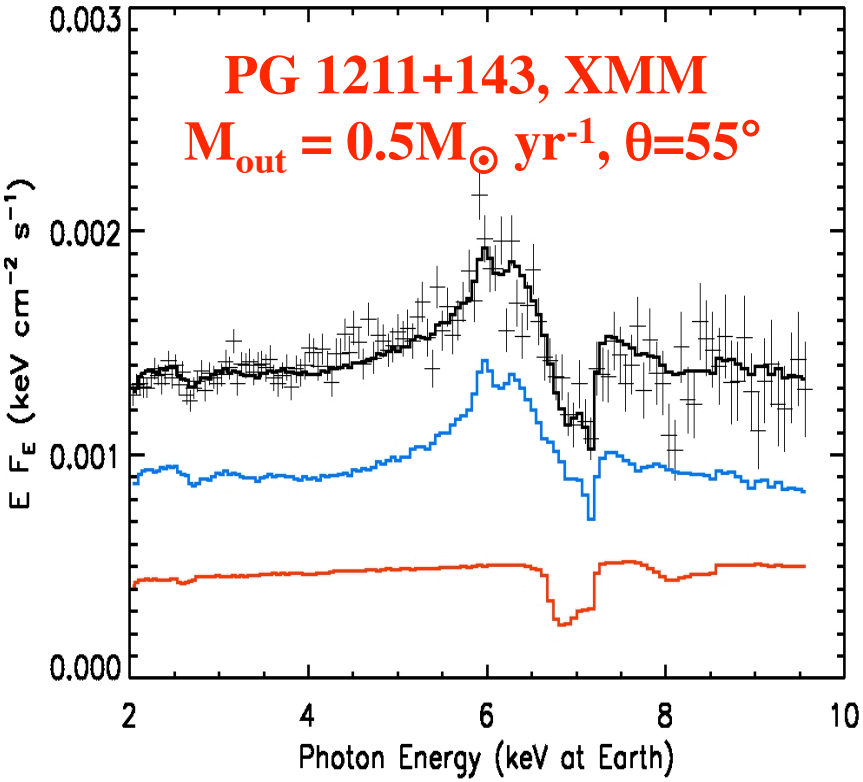


Accretion Disk Winds
(Sim et al. 2010)

Wind spectra vs inclination

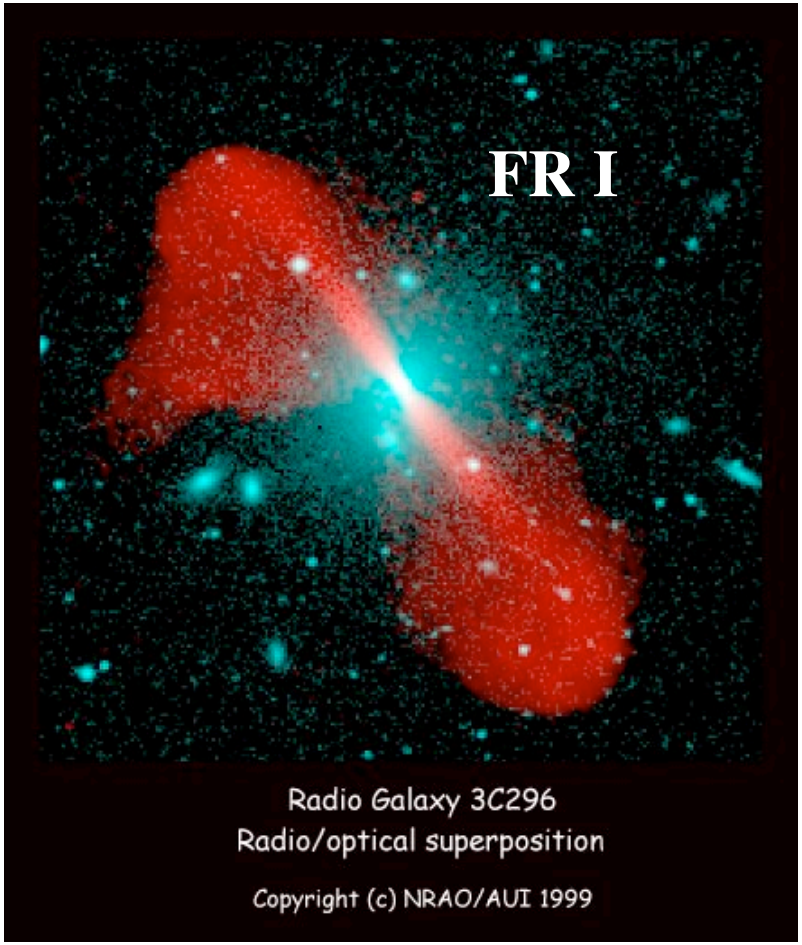
Reproduces P-Cygni like Fe K absorption in PG 1211 (e.g. Pounds & Reeves 2009)

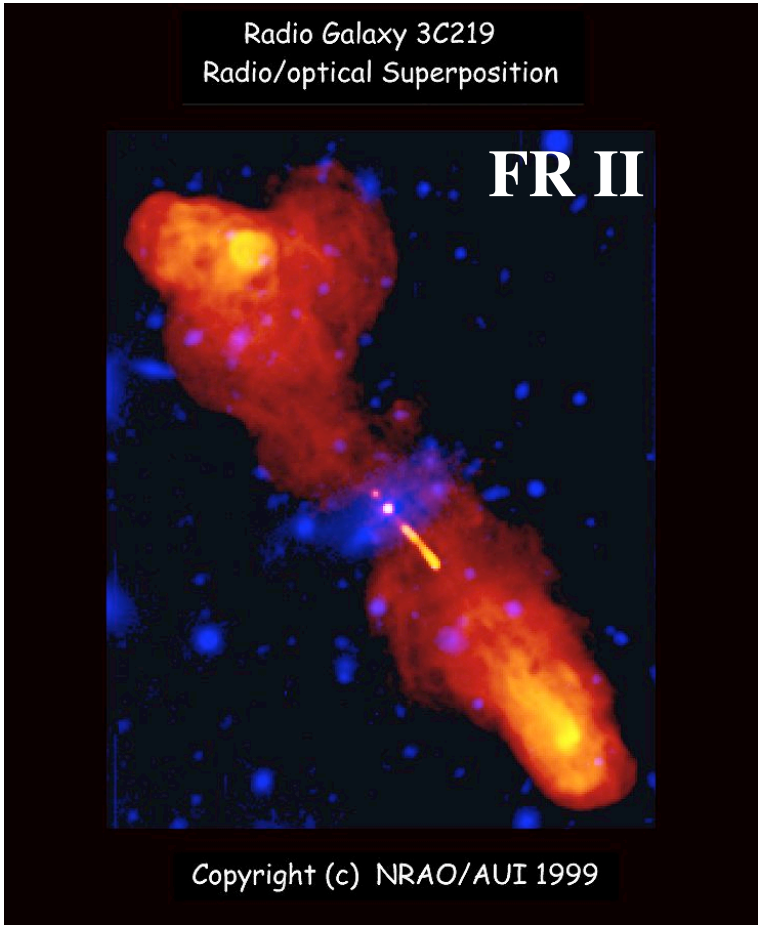


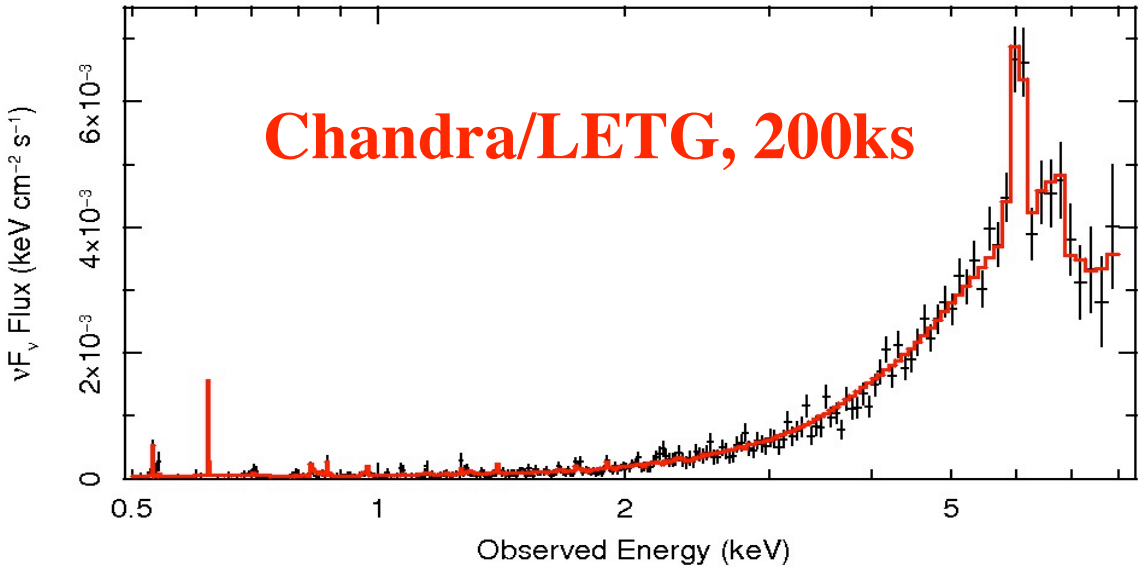


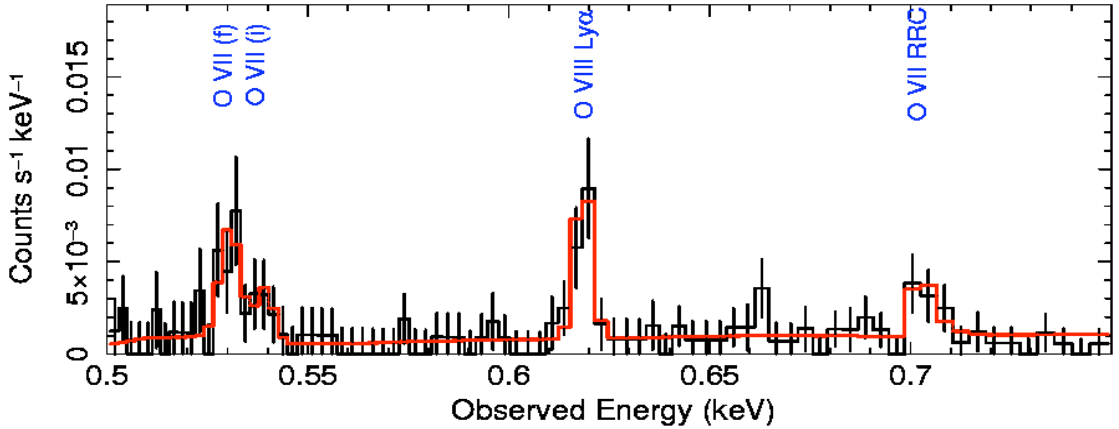
Do both RL and RQ AGN have outflows?

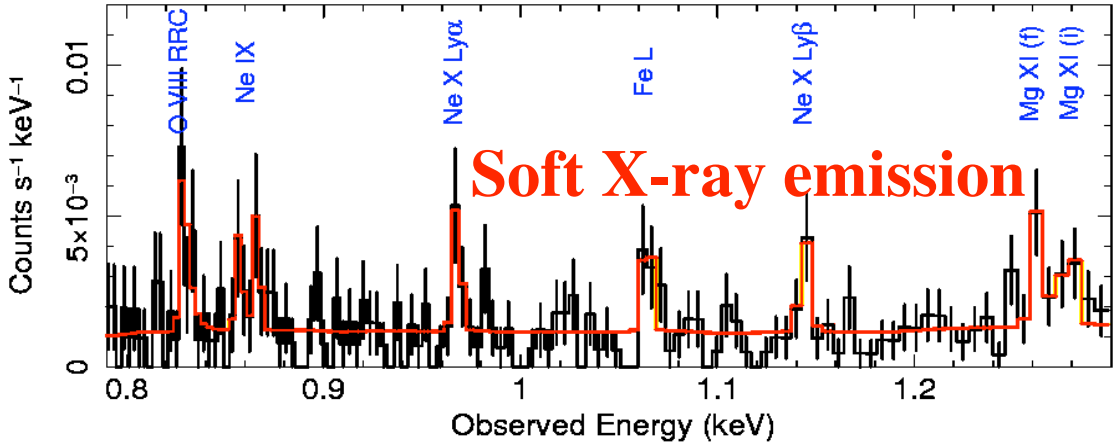
- Radio-Loud AGN have powerful, relativistic jets on Mpc scales
- Radio-quiet AGN sub-relativistic disc winds instead of jets?
- Some RL AGN may also have winds (Tombesi et al. 2010b)











Outflow in 3C 445

(see poster by Jason Gofford)

BLRG at z=0.0562.

Luminous $L_{bol} > 10^{45}$ erg s^{-1}, $M_{BH} = 10^8\ M_\odot$

Highly absorbed X-ray continuum:-

$N_H = 2 \times 10^{23}$ cm^{-2}, log xi = 2-4

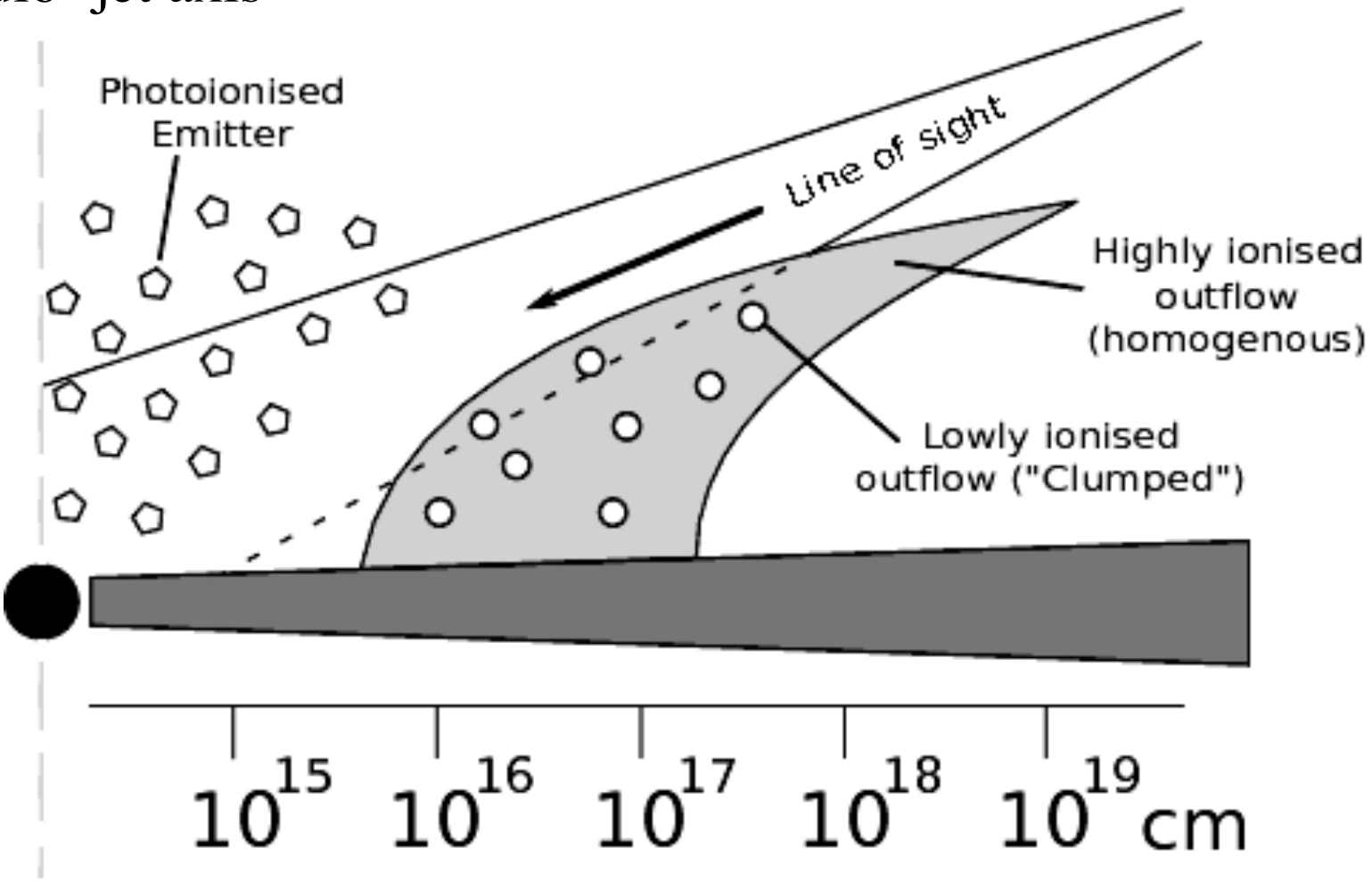
$v_{out} = -10000$ km s^{-1}

Photoionised soft X-ray emission lines - originating from BLR scale gas.

Geometry of 3C 445

Inclination ~60°

Radio- jet axis



Ultrafast outflows in AGN

- How much mass is carried out of the AGN by the outflow?

In the high v outflows, mass outflow rates can be a few x solar.
Global covering at least 40% - disk driven outflows appear common in both radio--quiet and radio-loud AGN.

- How does it compare to the amount of matter being accreted?

For high accretion rate AGN, a substantial fraction is driven in the outflow, i.e. $M_{out} \sim M_{Edd}$.

- Does the ionized outflow carry a significant fraction of the energy output of the AGN?

Yes, for some AGN (e.g. PDS 456, up to $L_{out} \sim 10^{47}$ erg/s).

- Can the outflow regulate the growth of the black hole and the galaxy (bulge) through feedback?

- Yes - given high covering, velocities and duty cycles of outflows.