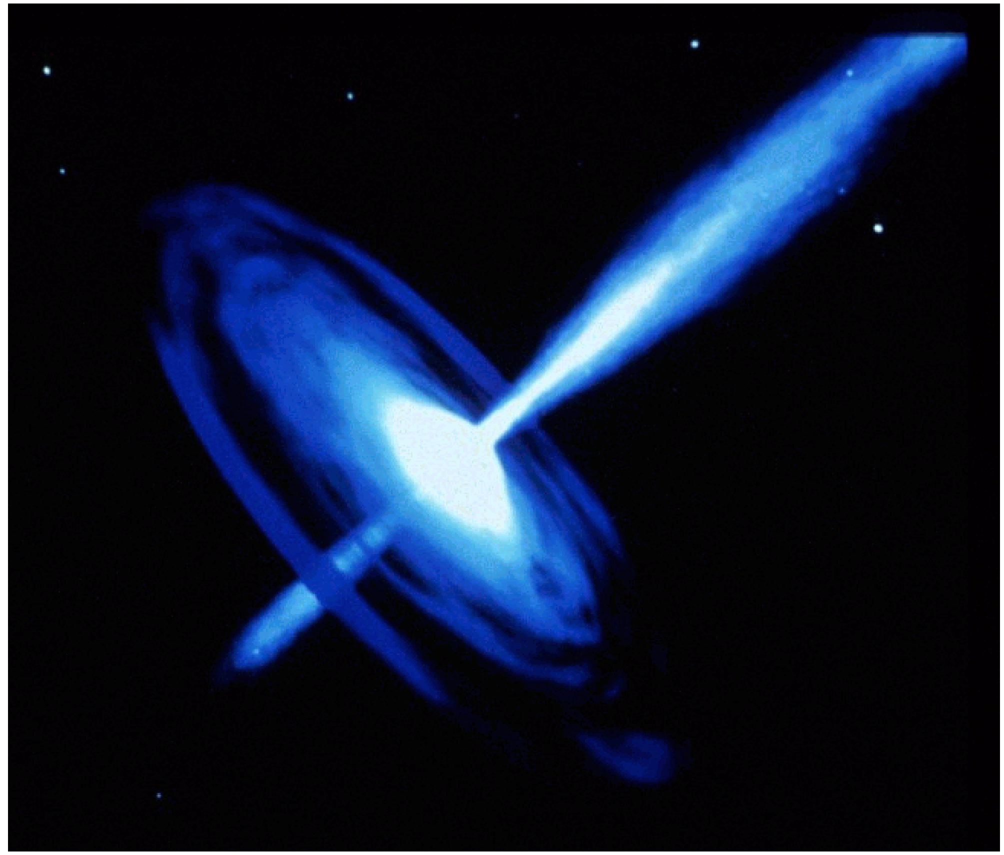
High Velocity Outflows in Near Eddington AGN



James Reeves,
NASA/GSFC & JHU

Collaborators:-

Ken Pounds, Paul O'Brien (Leicester), Ian George, Jane Turner (UMBC/GSFC), Herman Marshall (MIT), Tahir Yaqoob (JHU/GSFC), Paul Nandra (Imperial) Martin Ward (Durham)

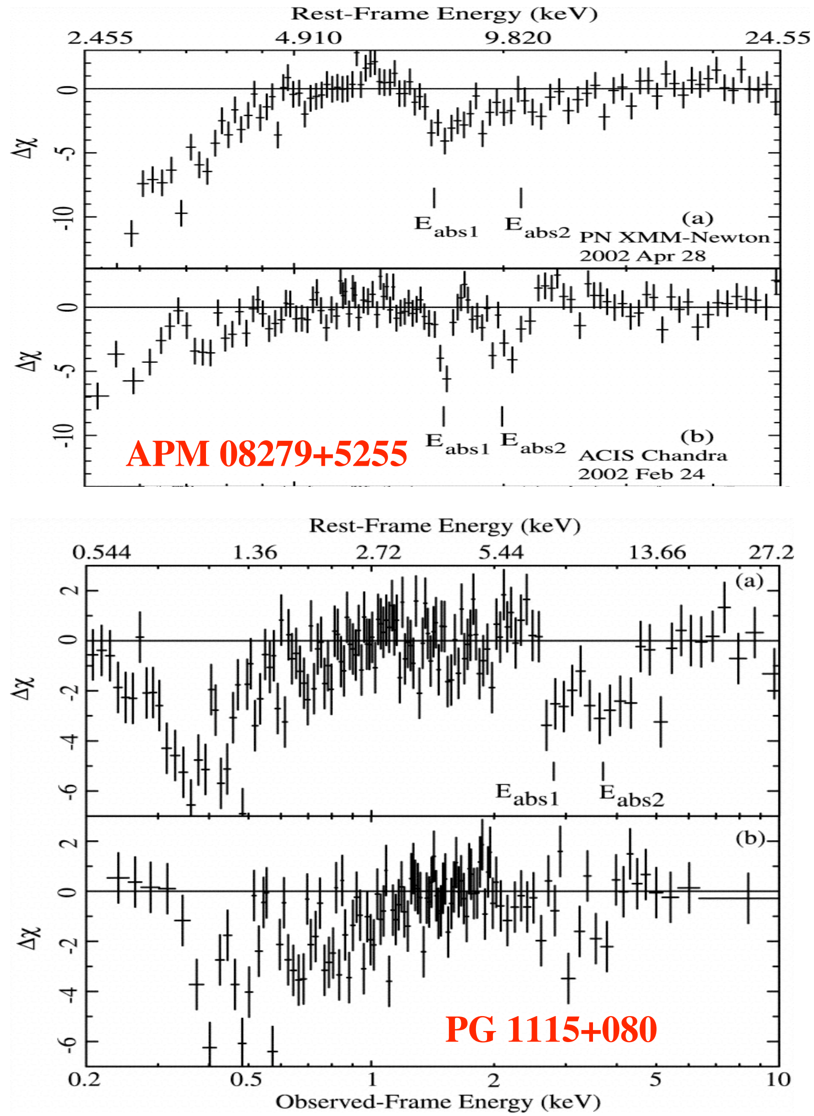
High Velocity X-ray Outflows in AGN

- **High velocity outflows claimed in several AGN, both BAL-like quasars (APM 0827+5255**, Chartas et al. 2002; **PG 1115+080** Chartas et al. 2003, **PDS 456**, Reeves et al. 2003) **and non-BAL AGN** (**PG 1211+143**, Pounds et al. 2003; **PG 0844+349**, Pounds et al. 2004; **Mrk 766**, Turner et al. 2005, in prep; **IC 4329a**, Markowitz et al. 2005, see poster).

- **Fe K-shell shows high opacity absorption lines and/or edges** (e.g. also see **1H 0707-495** and **IRAS 13224-3809**)

- **Evidence for high velocity, large column outflows in high L AGN, PG 1211+143, PDS 456.**

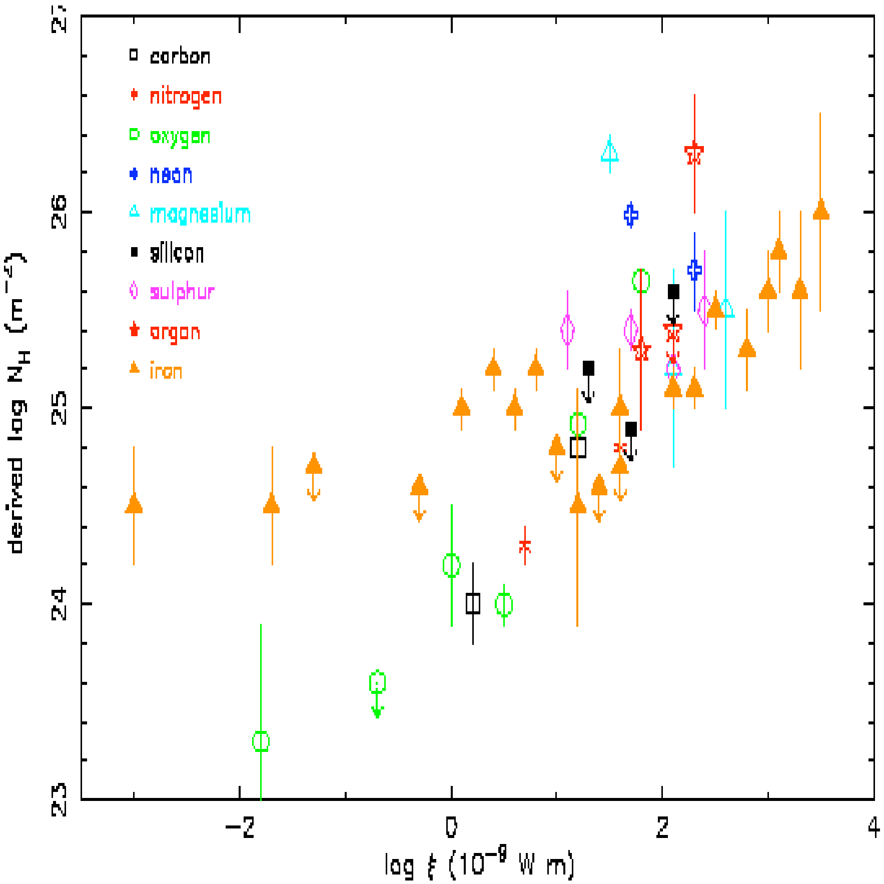
- **Chandra discovery of redshifted iron K absorption lines in PG 1211+143**

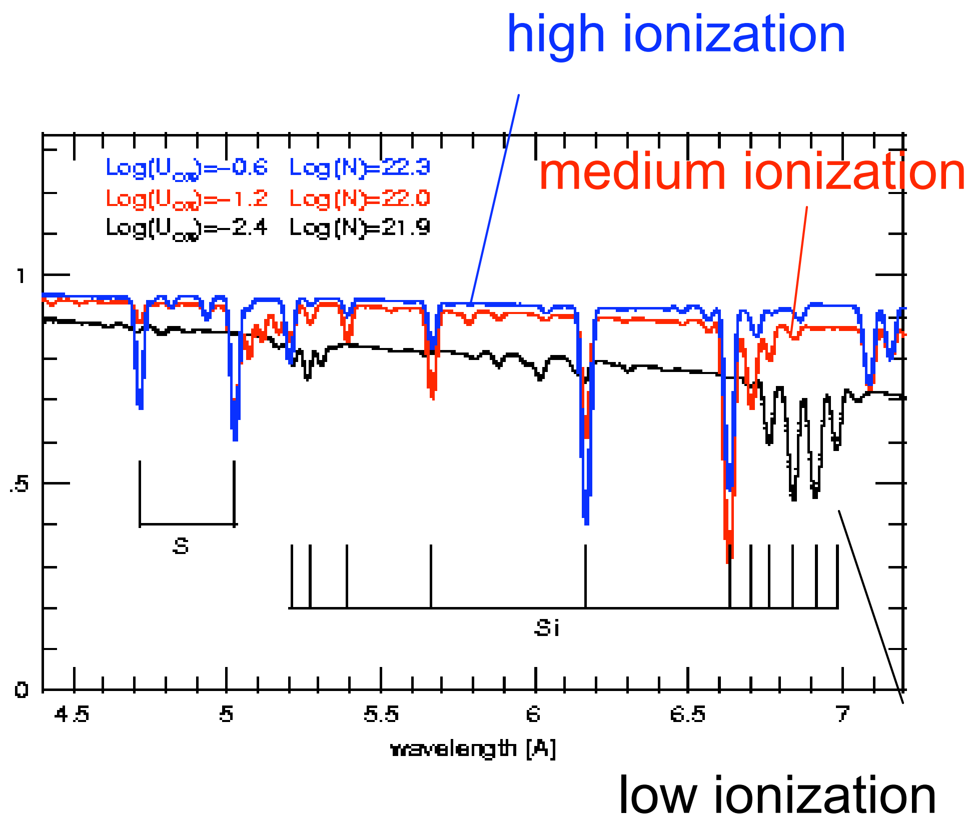


APM 08279+5255 (z=3.91) and PG 1115+080 (z=1.72) show 0.1-0.4c X-ray BAL outflows (Chartas et al. 2002, 2003)

Multiple zones of the Warm absorber

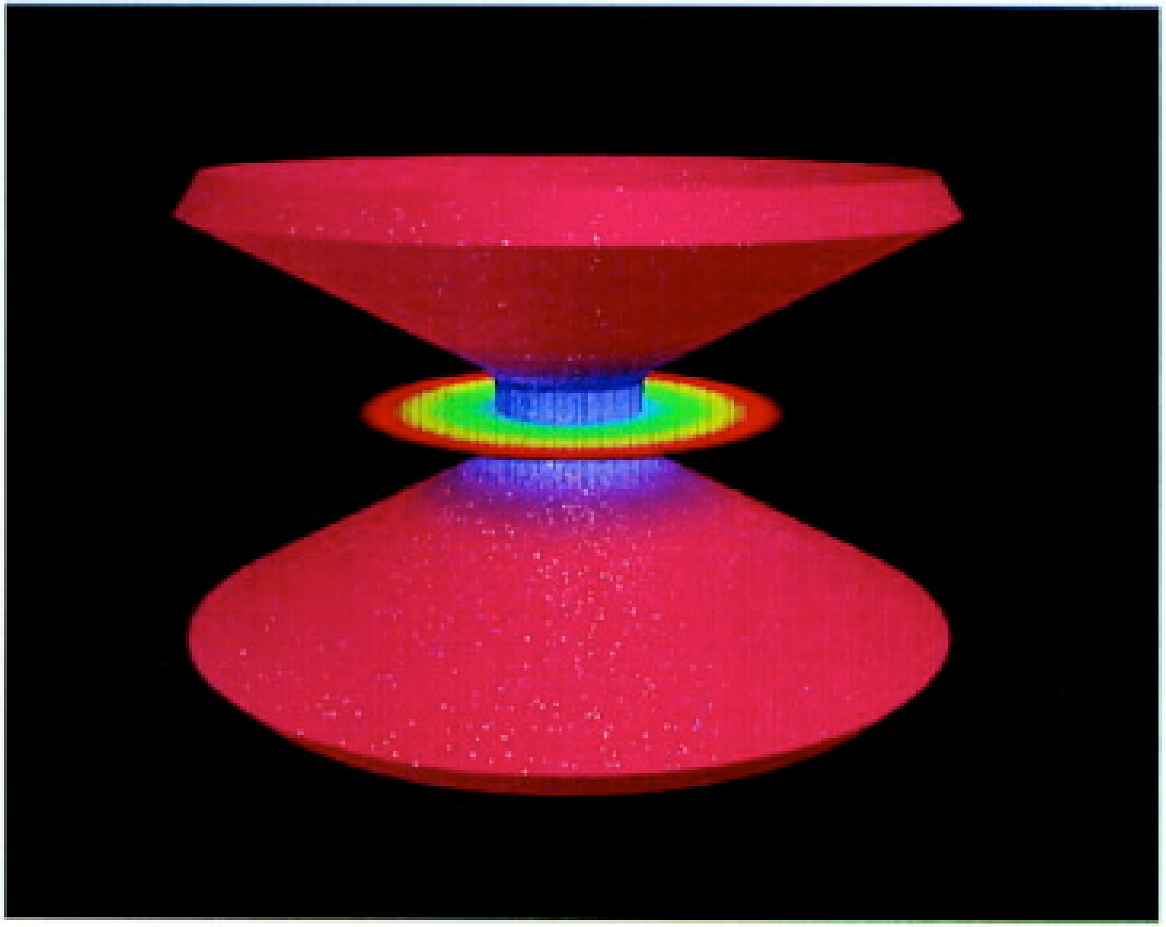
NGC 5548 (Steenbrugge et al 2003); NGC 3783 (Kaspi et al 2001; Netzer et al 2003)





- High resolution spectroscopy shows that one zone models do not describe the data
- For $\tau_{compton}$~0.1 at high ionization - predict high optical depth Fe XXIV-XXVI resonance absorption lines

Origin of the Warm absorber / Outflow



(Outflow Schematic; Elvis 2000)

Some quasars could possess high velocity outflows (compared to Seyfert 1s).

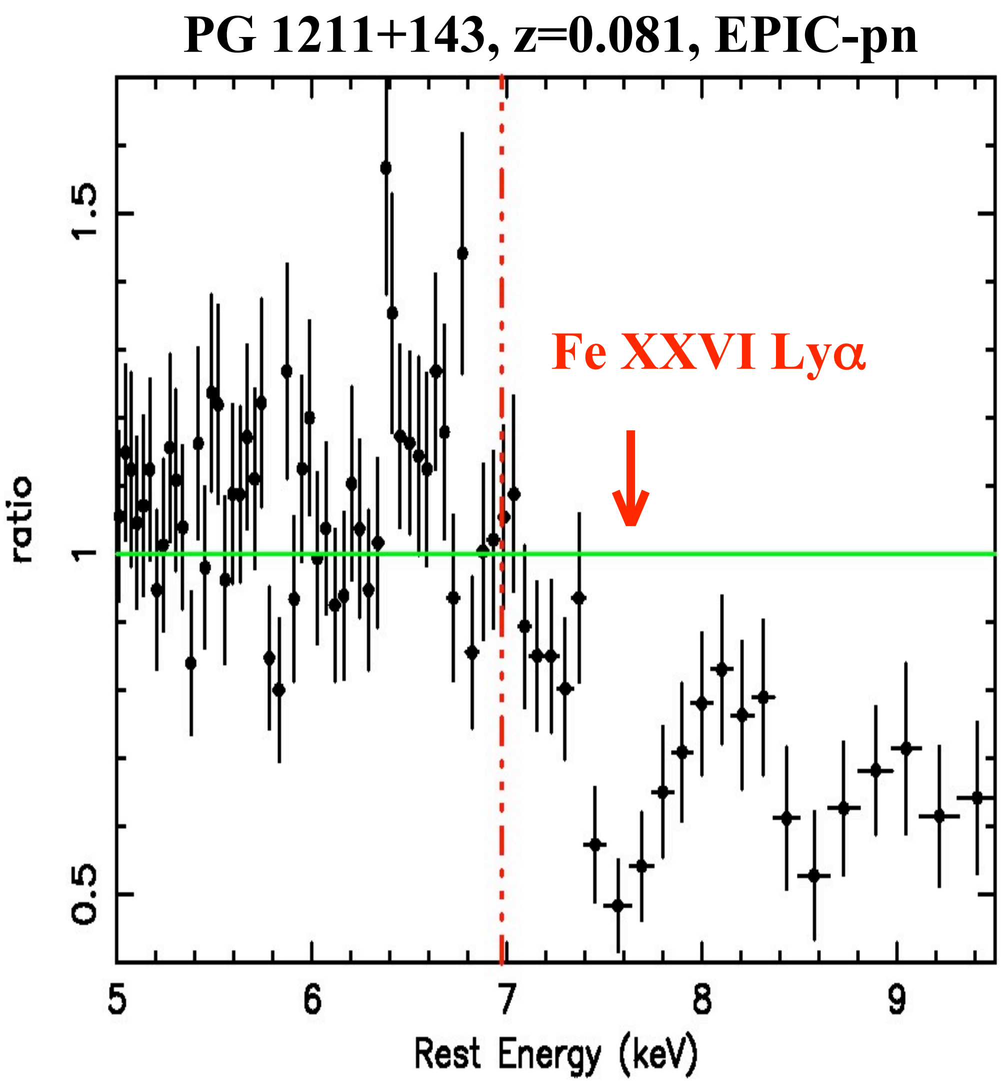
In BAL's QSOs, view directly down the high velocity outflow

High ionization Fe K absorbers - highest column component associated with matter ejected in disk wind

High Eddington rate AGN - KE energy of outflow higher (originates closer to BH?).

High velocity outflows seen in XMM/Chandra data?

A Highly Ionized, Relativistic Outflow in PG 1211+143 (Pounds et al. 2003)



XMM-Newton data reveal a highly ionised outflow

Fe XXVI, Mg XII, S XVI lines (EPIC), Ne X/IX, O VIII/OVII, NVII, CVI in RGS

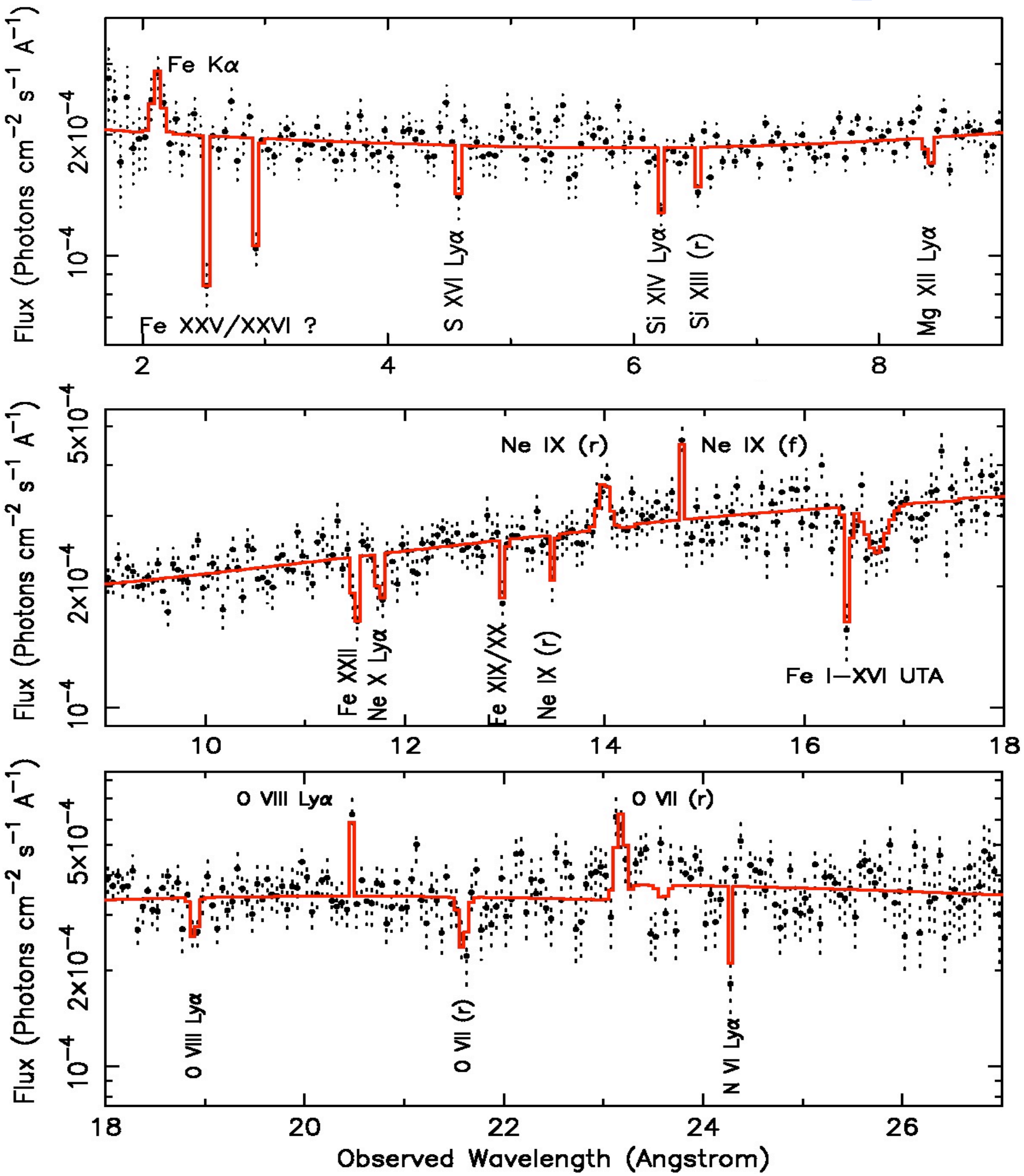
Highest ionization absorber has $\xi \sim 10^{3.4}$ and $N_H \sim 10^{23}$ cm^{-2} outflowing at 0.08c (24000 km/s)

Outflow launched from inner disc at <130Rs

Mass-loss rate ~ 3 $M_\odot$ yr^{-1} (isotropic)
K.E. ~ 10^{45} erg s^{-1} (~L_{BOL})

<u>Iron K features is best fitted with an absorption line at 7.6 keV (requiring blue-shift) rather than an edge.</u>

Chandra LETG Observations of PG 1211+143 show multiple high v lines



Chandra LETG observations of PG 1211+143 confirm the high velocity outflow.

High ionization lines seen from **N VI, O VII, OVIII, Ne IX/X** (or Fe L), **Mg XII, Si XIV** and **S XVI**

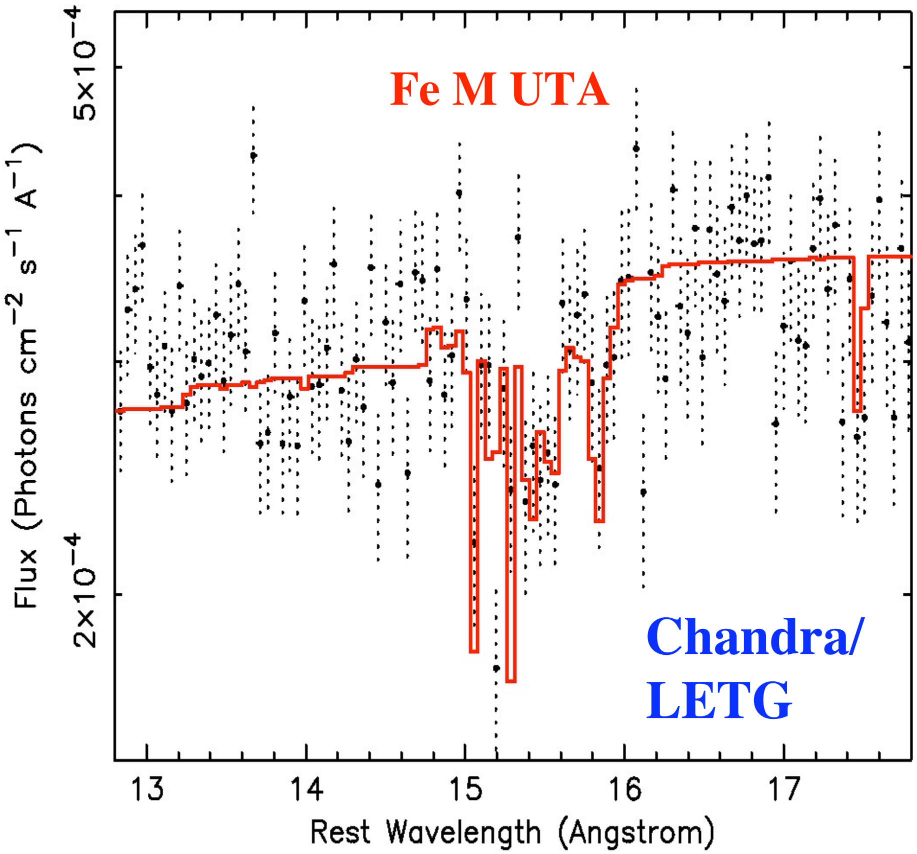
Outflow velocities from **24000-31000** km/s for high xi ions. No sensible Ids exist at lower velocities, except for Ne IX/X (confused with Fe XVII - XXIV).

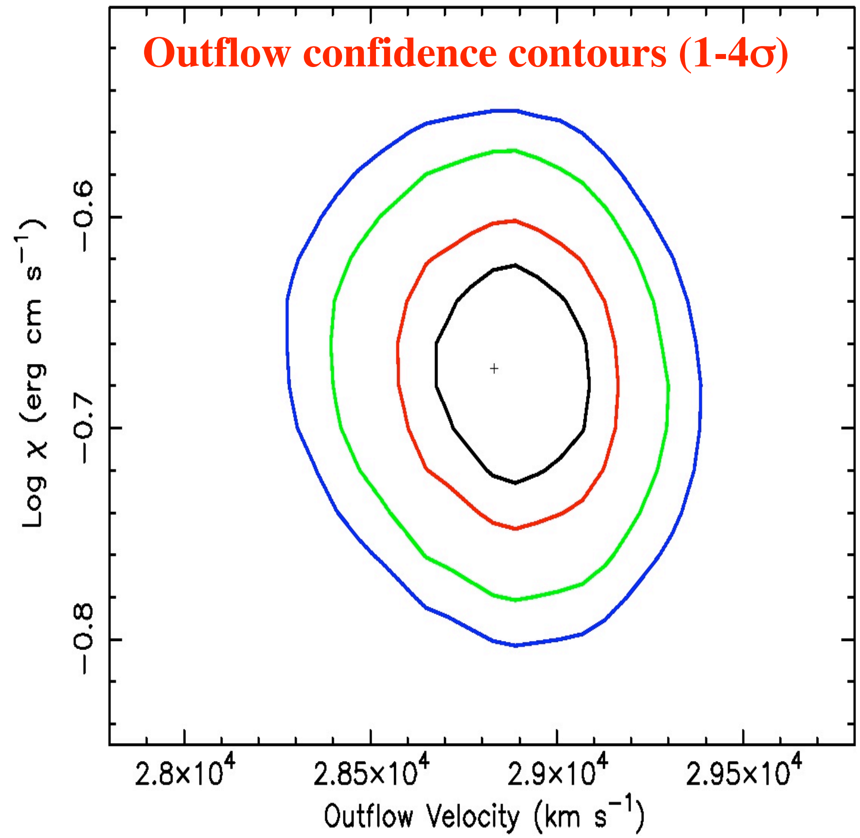
Column density of **10^{22} cm^{-2}** and ionization of **log xi=3** for high ionization absorber. Column density lower than in RGS - variability

Note Low ionization UTA component observed near 16 A.

Strong absorption lines red-wards of Fe K (near 5 keV).

Modeling The Fe UTA feature



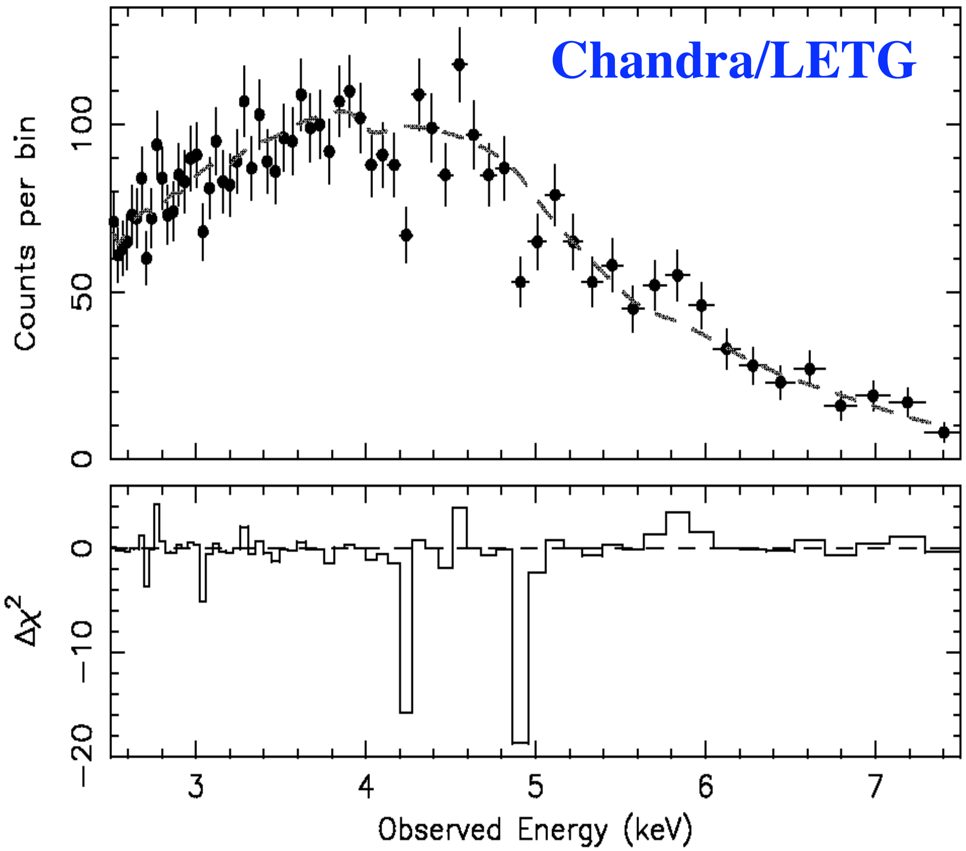


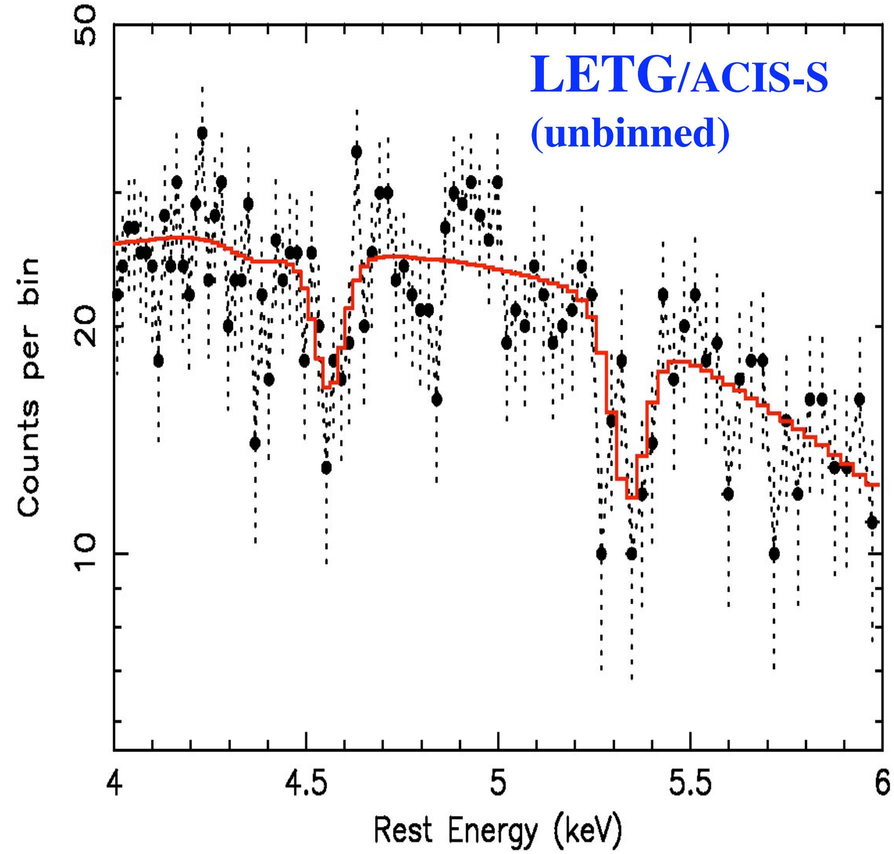
Fe UTA is measured near 15 A in the rest frame of PG 1211+143 (at z=0.0809). Feature is seen in both LETG and RGS spectra. Expected UTA occurs at 16-17A (Behar et al. 2001)

Constrain UTA outflow velocity from both the position and width (profile) of the feature. Outflow velocity measured is **28800±300 km s^{-1}**. Can rule out low velocity solution at high confidence (>5σ)

Evidence of Gravitational Infall in PG 1211+143?

(Reeves et al. 2005, ApJL, in press)





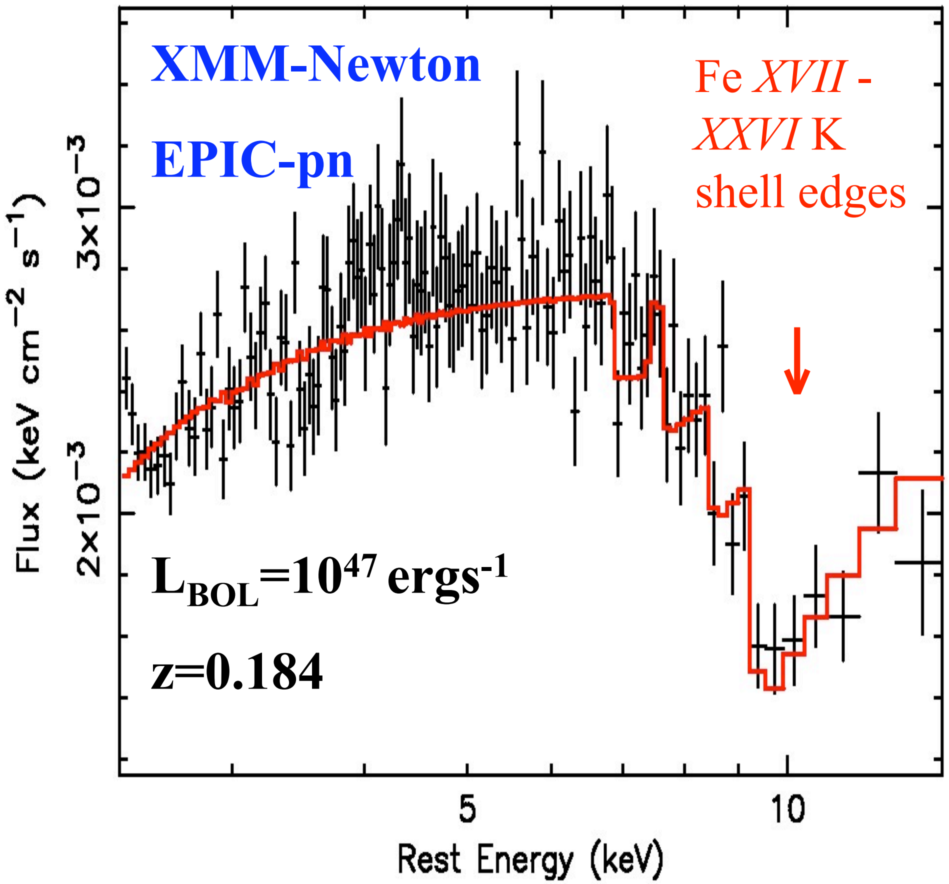
Redshifted absorption lines at 4.56 keV and 5.33 keV (rest frame). Closest known lines are from Sc XXI (4.53 keV) and V XXIII (5.43 keV) , but very low abundance.

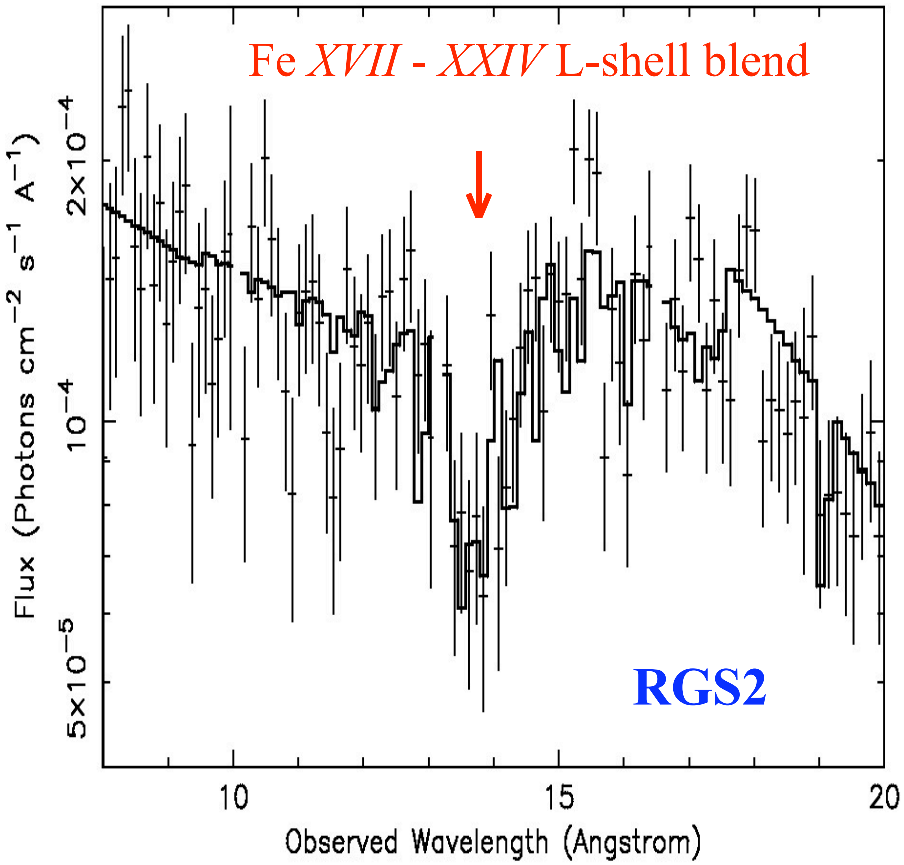
Most likely identification is with Fe XXV (6.7 keV) or Fe XXVI (4.97 keV), with velocities 0.26/0.4c. <u>Requires gravitational redshift either within <6Rg or direct infall of matter onto the black hole.</u>

A Massive outflow in the Quasar PDS 456? (Reeves et al. 2003)

PDS 456 is the most luminosity nearby quasar ($z=0.184$ $L_{BOL}\sim10^{47}$ erg s^{-1}). Deep Fe K-shell absorption seen in XMM-Newton spectrum.

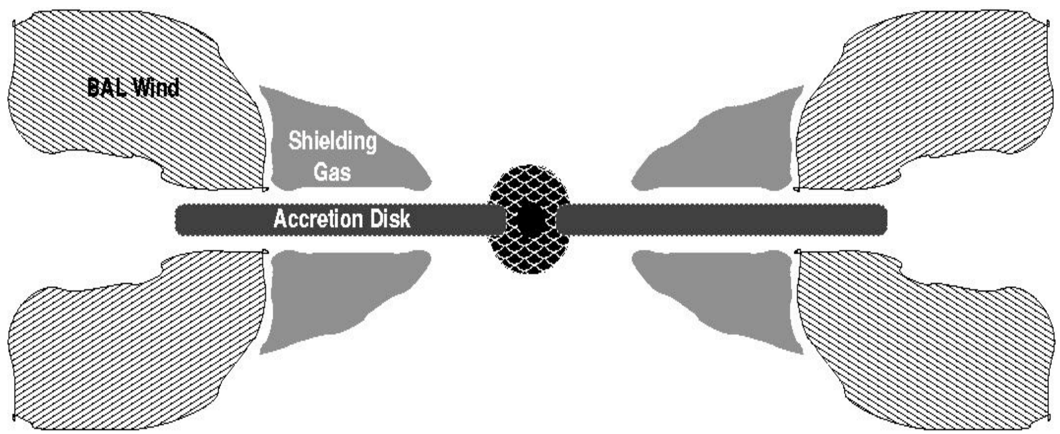
X-ray column density 5×10^{23} cm^{-2} and outflow vel 50000 km s^{-1}. Mass outflow rate huge (10 solar/yr, similar to M_{EDD}). UV BAL absorption features seen (HST-STIS) in Lyα and CIV. Velocity 12000-22000 km/s (O'Brien et al. 05)



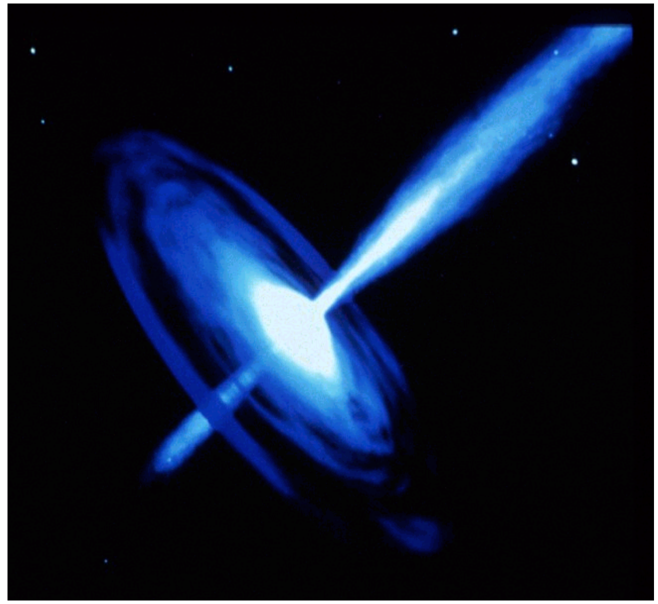


Outflow geometry and driving mechanism

Flow along disk plane (BAL) ?



Flow along BH axis?



Black holes accreting at Eddington or above can produce optically thick winds, driven by continuum radiation presssure (King & Pounds 2003). Optically thick within ~100Rs. Mass outflow rate similar to Eddington ($M_{out} \sim M_{edd}$).

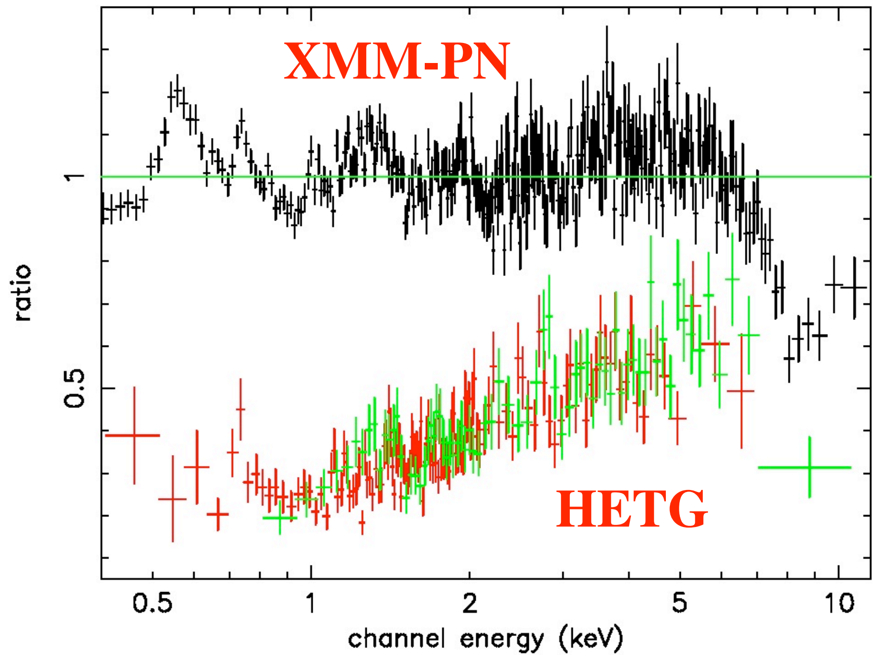
Alternative is magnetic field driving. Significant energy in magnetic field in PDS456 from rapid X-ray variability, e.g. factor x2 within 10ks with $E_{flare}=10^{51}$ erg (Reeves et al. 2002).

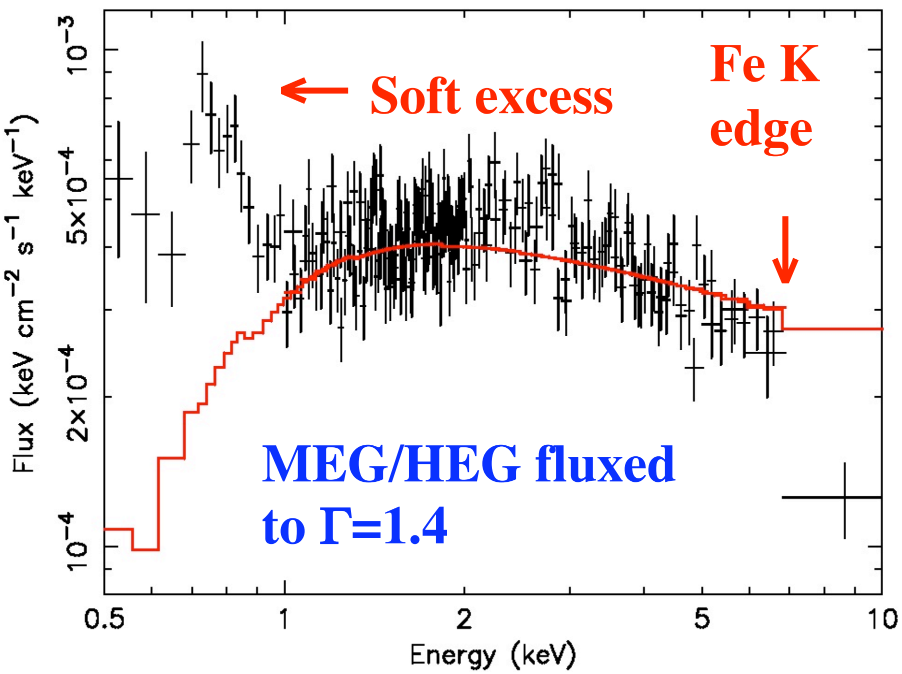
Chandra/HETG observations of PDS 456

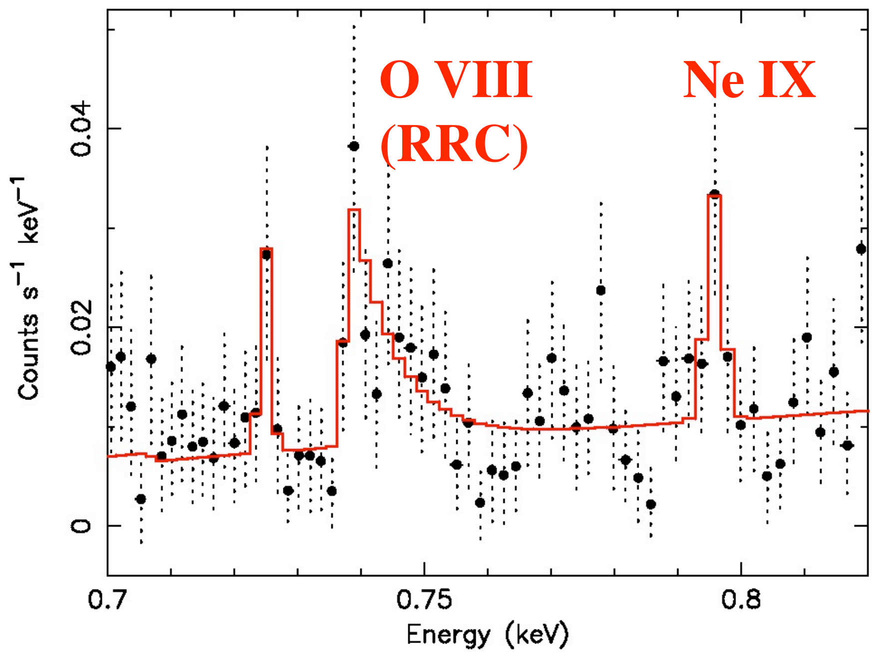
Flux a factor of 3 lower than XMM.

Deep (τ~2) Fe K edge 9 keV rest frame.

Soft excess shows cool (7x10^4 K) recombining plasma (e.g. O VIII RRC)

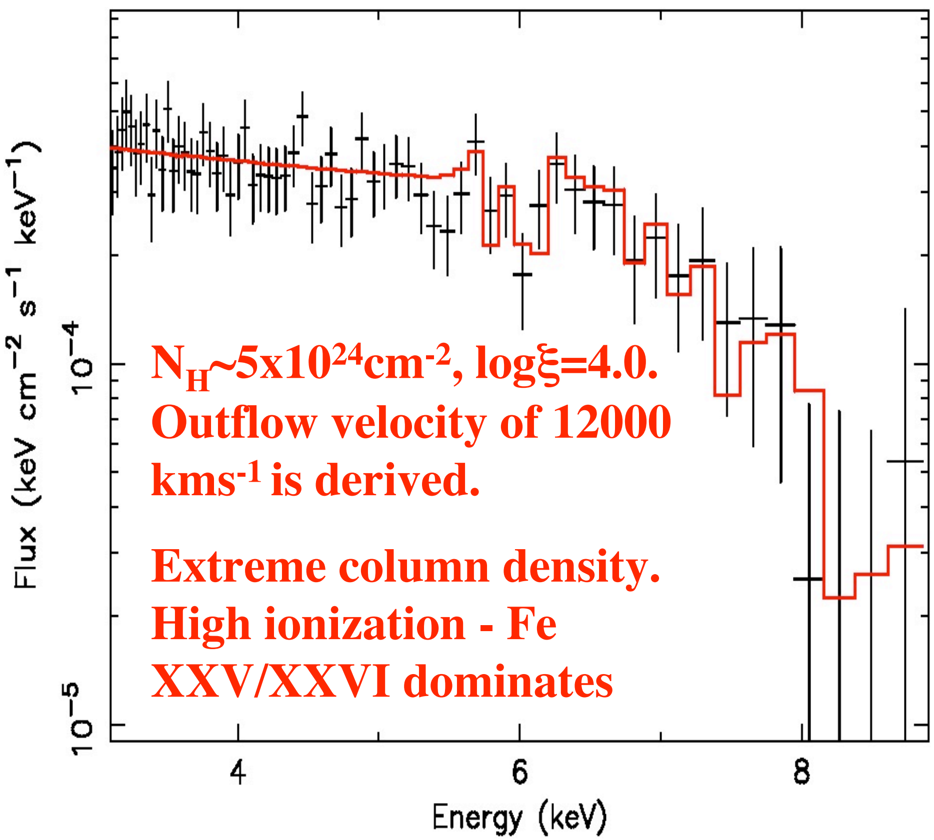




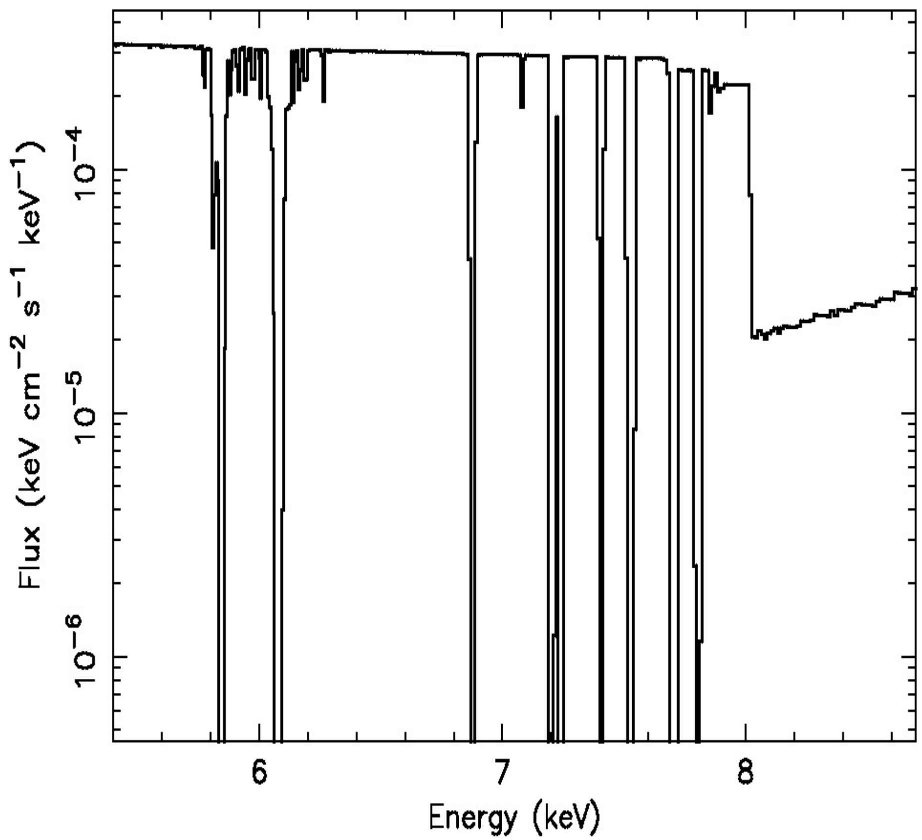


The Fe K Edge at High Resolution

HEG Data, Fe K region



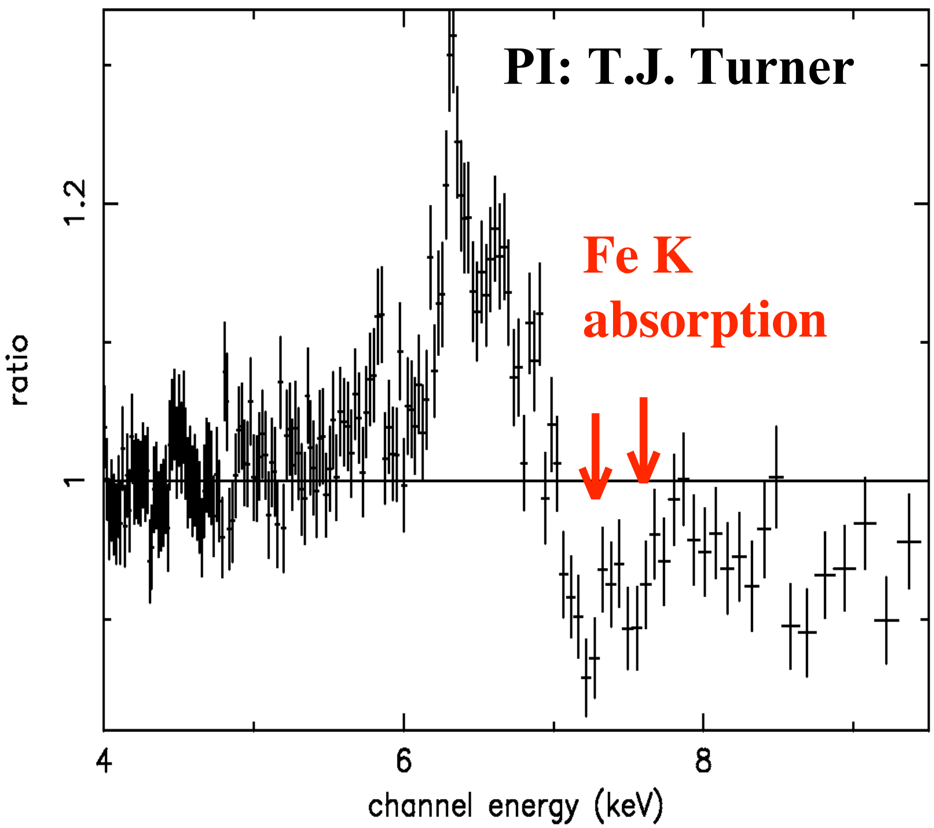
Xstar Model (Kallman et al. 2004)



HEG spectrum shows Fe K edge is ***broadened***. Resonance lines below the Fe K threshold smear the edge. ***Lower outflow velocity of 12000 kms^{-1} is consistent with UV outflow in PDS 456.***

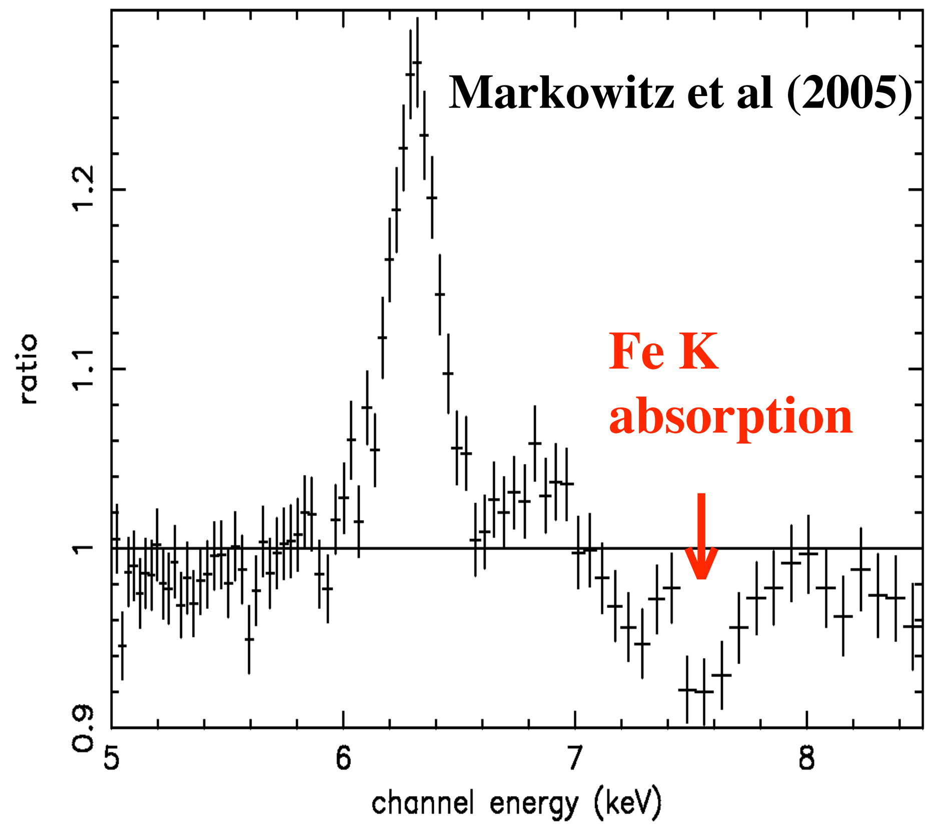
Other Possible high velocity Fe K outflows (Mrk 766 and IC 4329a)

Mrk 766, 500ks XMM-Newton obs



Absorption lines in Mrk 766 spectrum at 7.3 keV and 7.6 keV (rest-frame). If associated with Fe XXV or Fe XXVI, then outflow velocity is 27000 km s^{-1}

IC4329a, 100ks XMM-Newton obs



Absorption lines in IC 4329a spectrum at 7.67 keV (rest-frame). If associated with Fe XXVI, then outflow velocity is 30000 km s^{-1}

Conclusions - AGN high velocity outflows

- Highly ionized Fe K-shell absorber is present in observations of several AGN. (e.g. BAL QSOs, NLS1s, Seyfert galaxies). This adds to the complexity of the iron K band analysis (e.g. deconvolving emission from absorption).

- High column outflows discovered in **PG 1211+143** and **PDS 456** in iron K band. High ionization lines of Fe, C, N, O, Ne, Mg detected in PG 1211 RGS and LETG spectra. PDS 456 shows very deep and broadened Fe K edge.

- Low ionization (Fe UTA) absorber detected in PG 1211. High and low ionization absorption both require high outflow velocity near 0.1c.

- If the velocity is correct, mass outflow rates are VERY high - up to ***several solar masses per year***. Outflow rates close to Eddington for quasars.

- High mass outflow may be common in high accretion rate AGN. Carries a significant proportion of bolometric output. Outflow may be optically thick at ~100Rs.