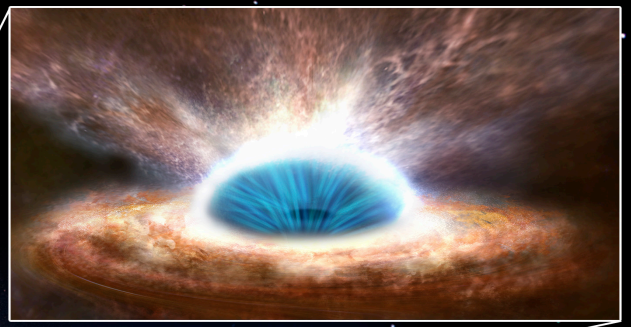
Accretion disk winds in Active Galactic Nuclei:
X-ray observations, models and feedback



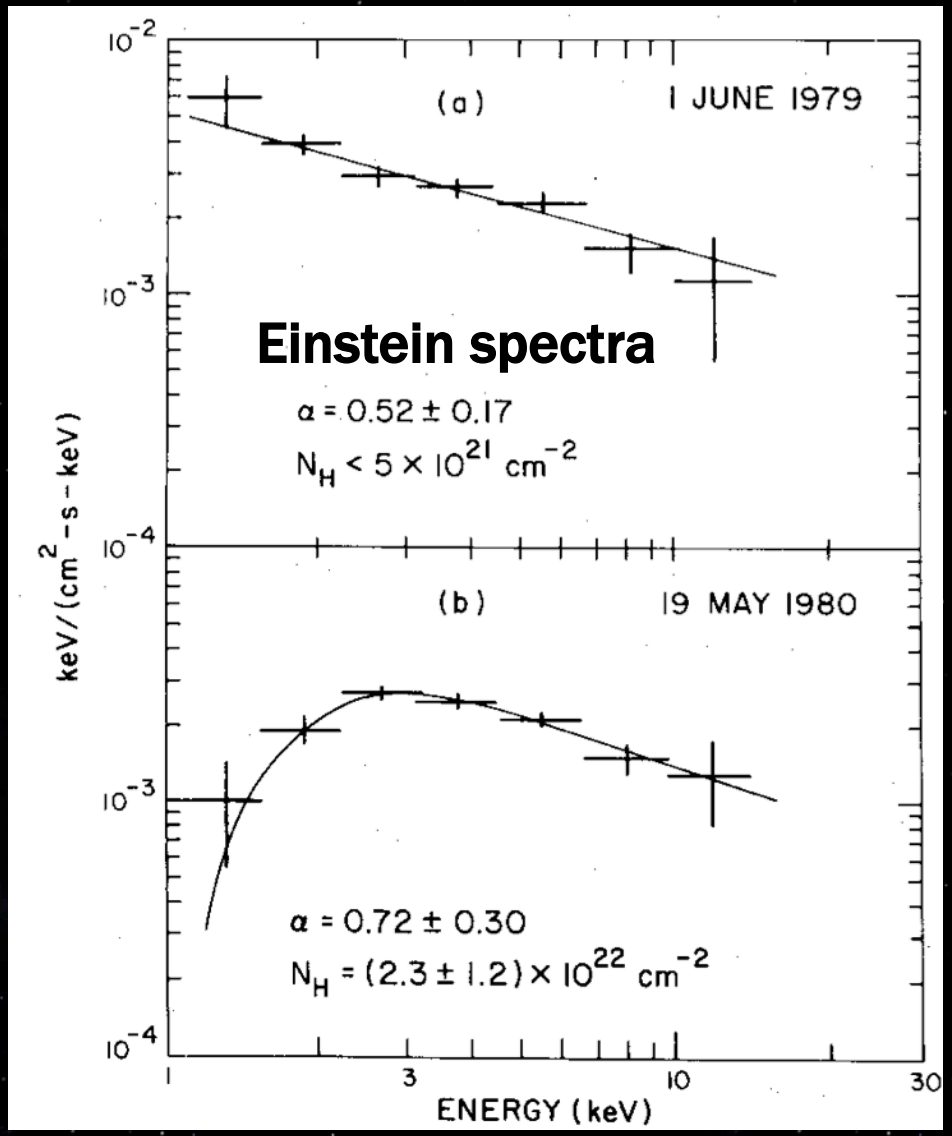
Francesco Tombesi

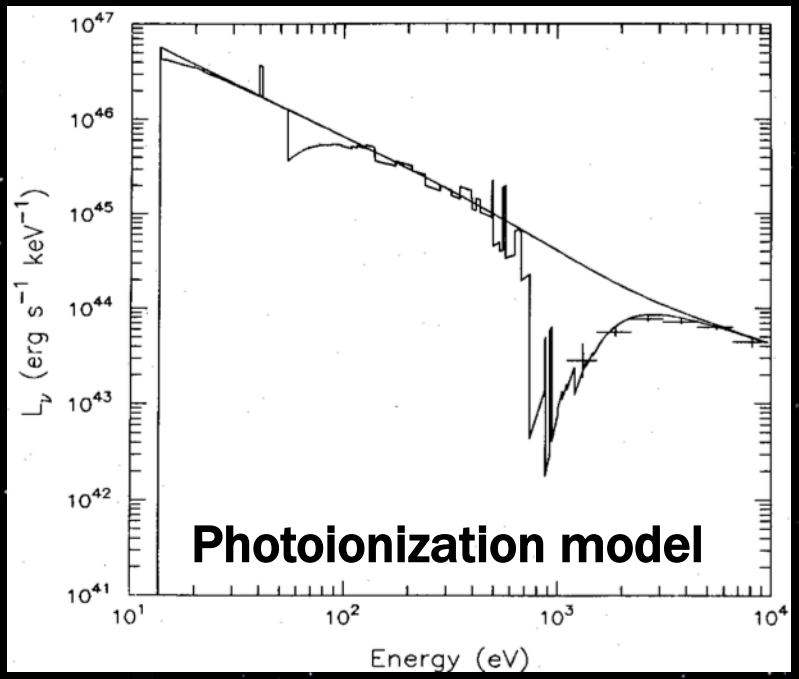
NASA – Goddard Space Flight Center

University of Maryland, College Park

X-ray observations of disk winds

First detection of a "warm absorber" in the quasar MR 2251-178

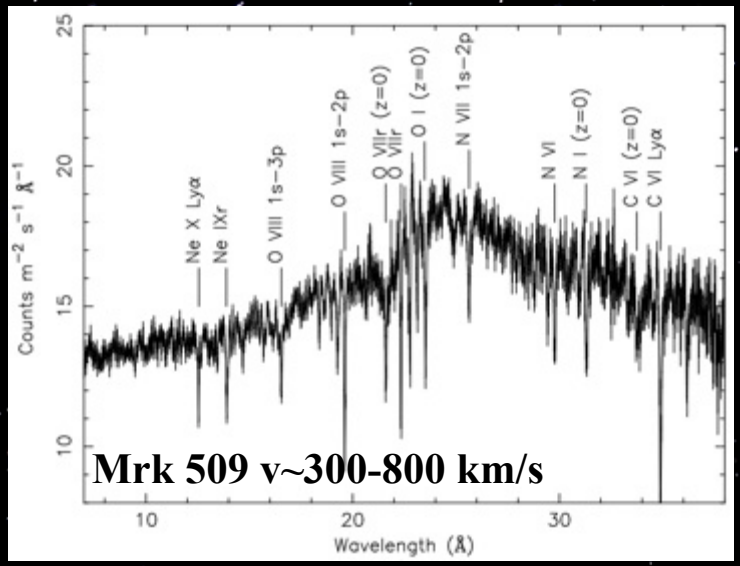




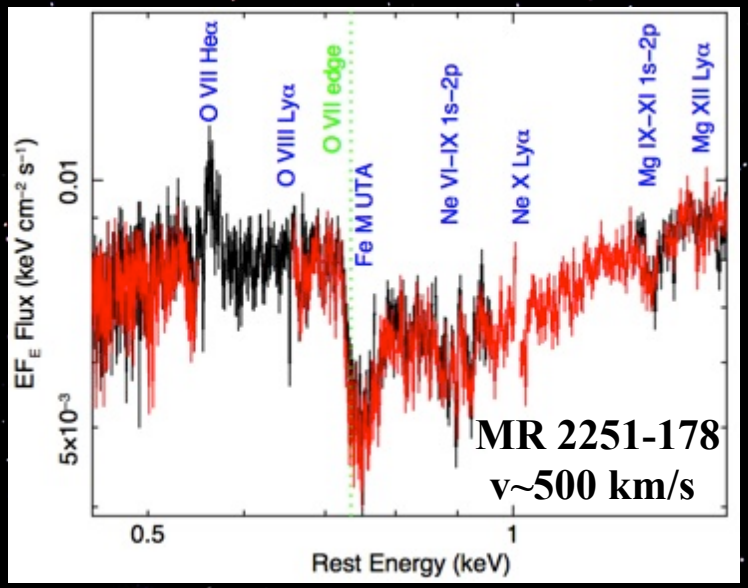
- Einstein data show absorption variability in MR 2251-178
- First indication of an ionized "warm absorber" in an AGN

(Halpern 1984)

X-ray warm absorbers (WAs)



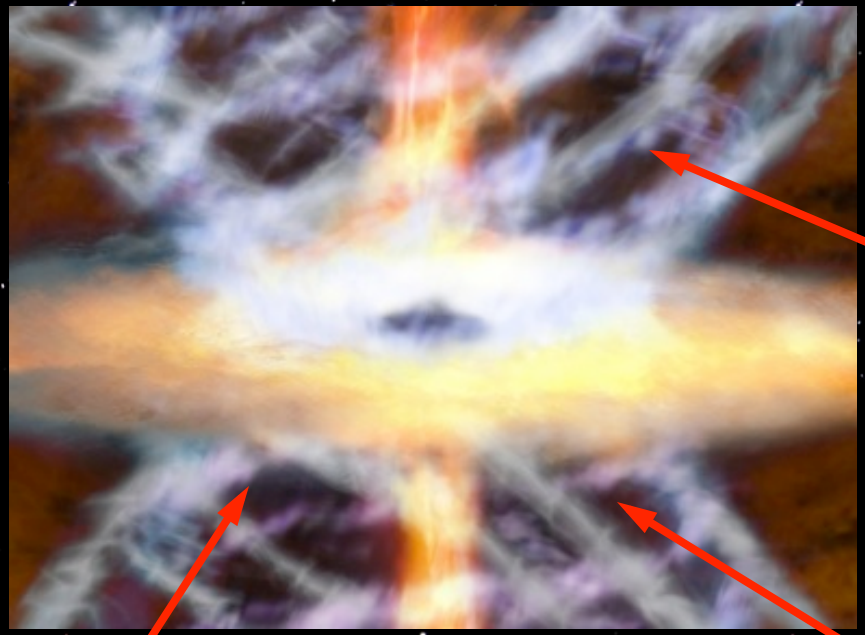
(Detmers, Kaastra et al. 2011)

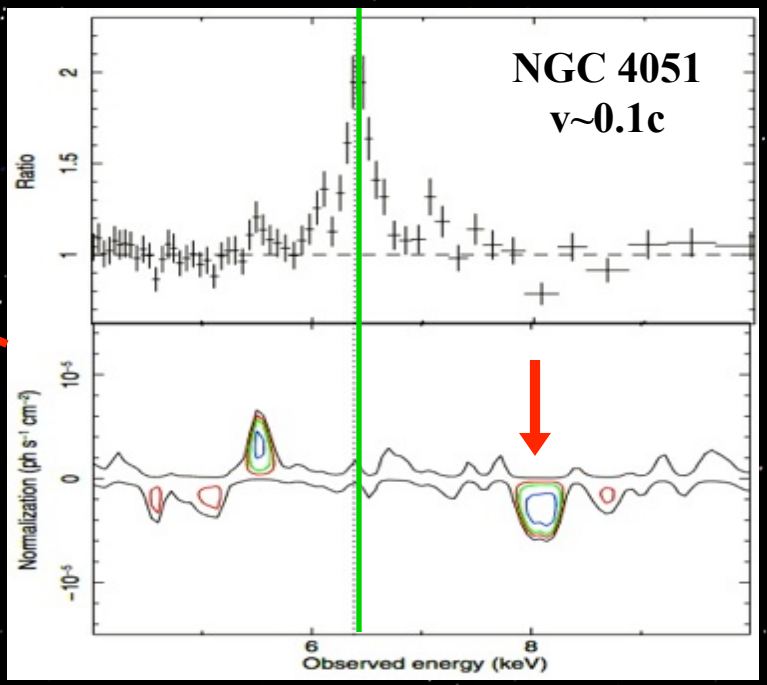


(Reeves et al. 2013)

(see Cappi's and Braito's talks)

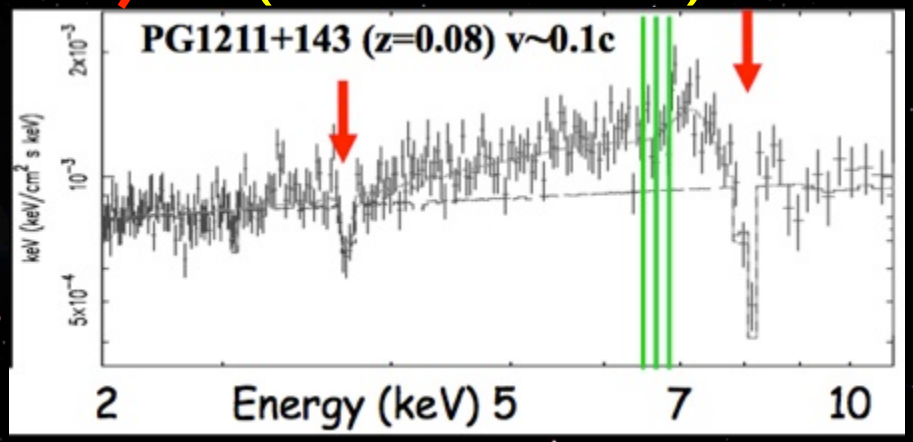
Ultrafast outflows ("UFOs") in AGNs



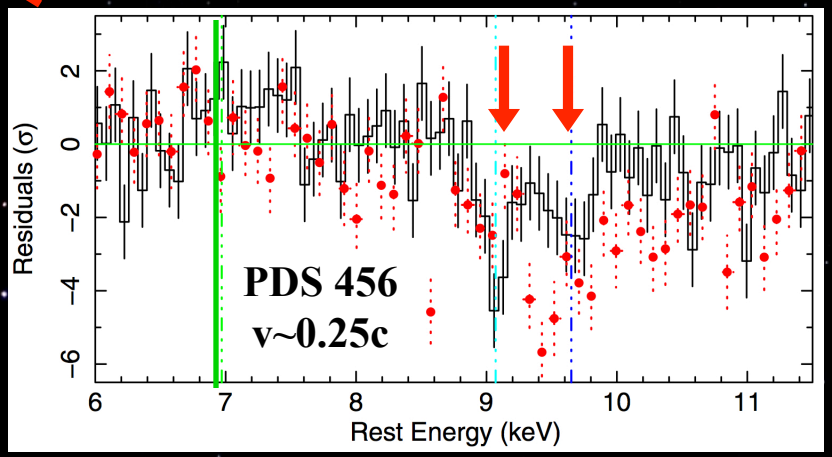


(Tombesi et al. 2010a)

(see Pound's talk)

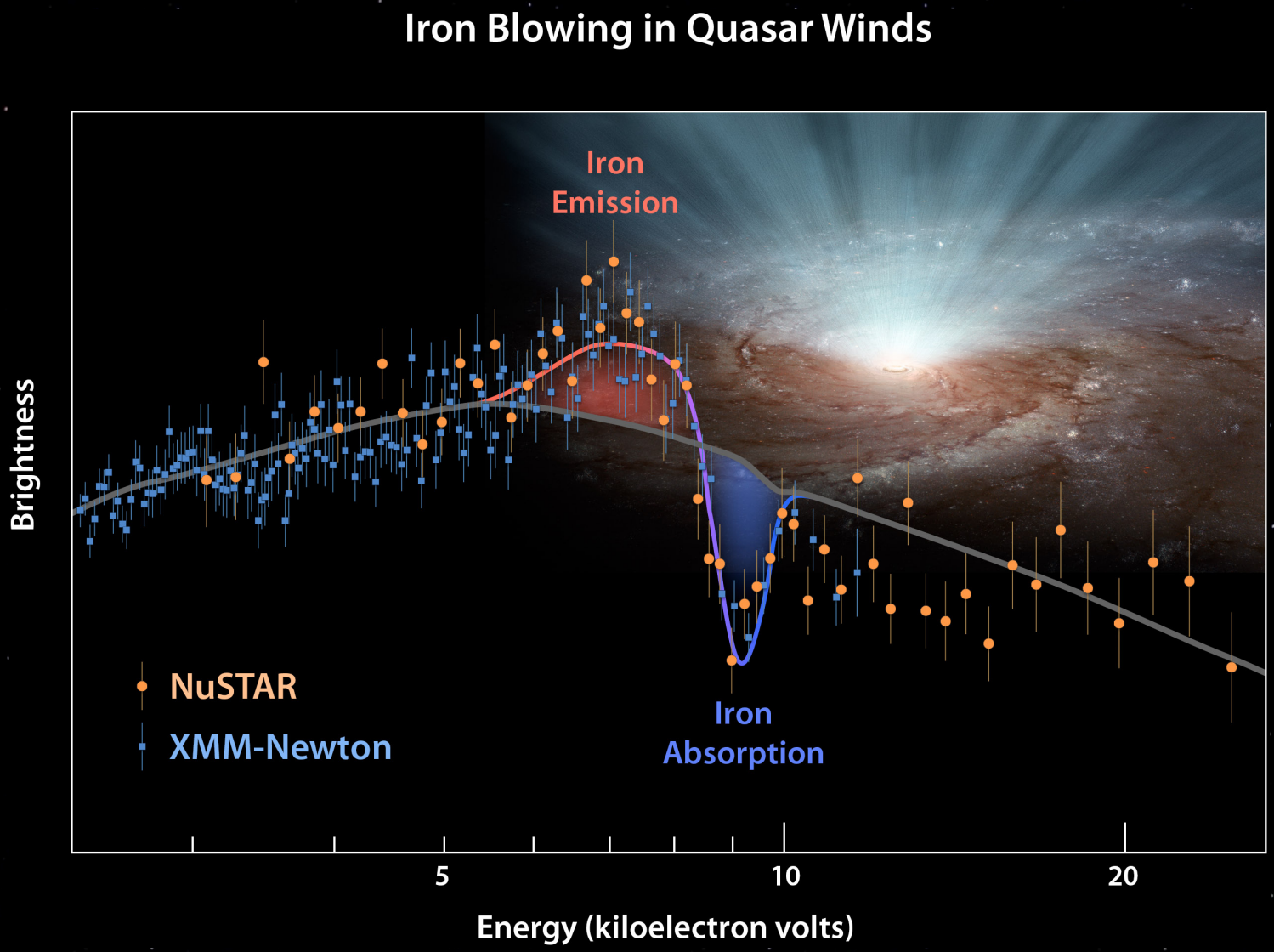


(Pounds et al. 2003)



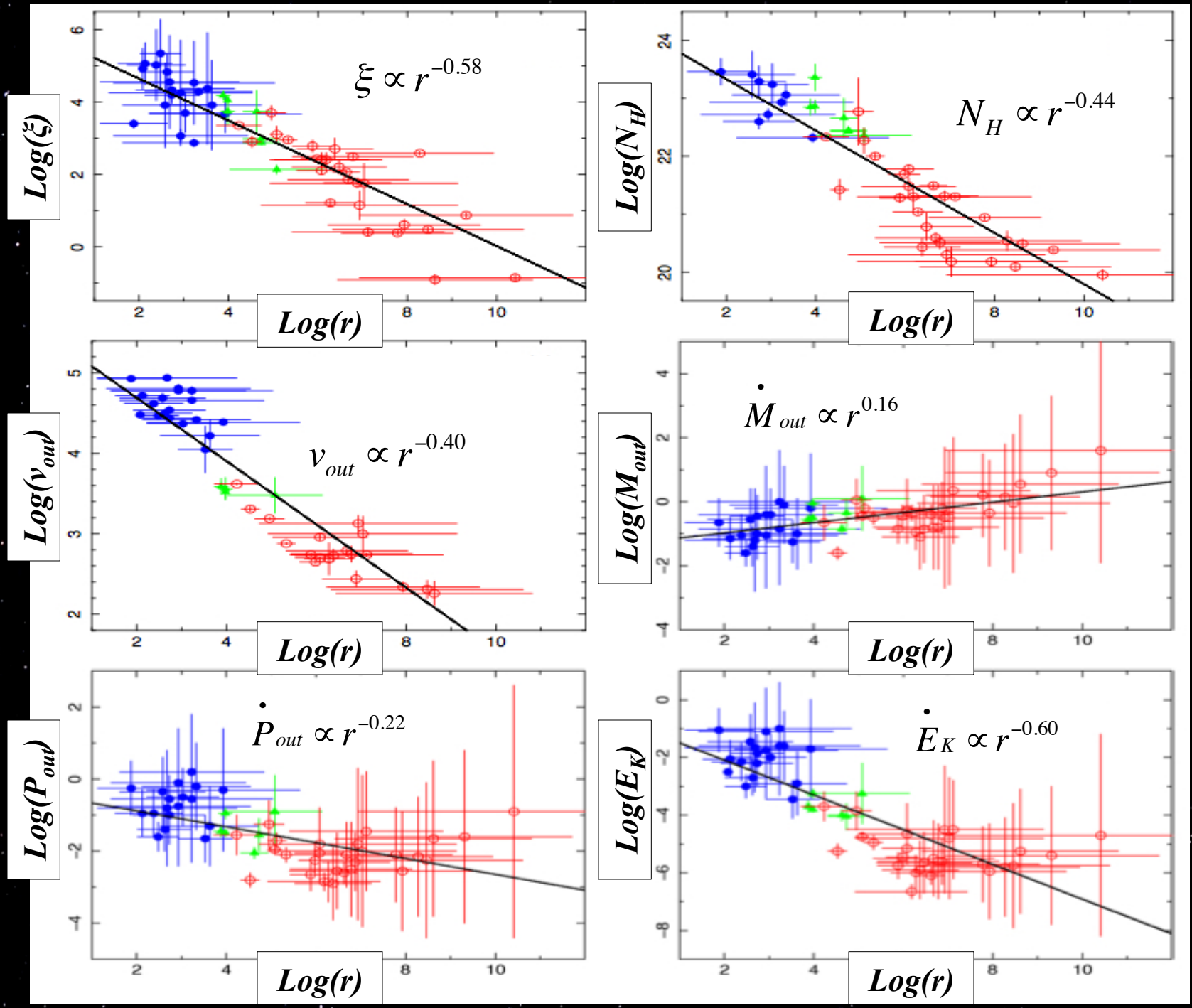
(Reeves et al. 2009)

Wide-angle UFO in the quasar PDS 456



(see Reeves' and Matzeu's talks)

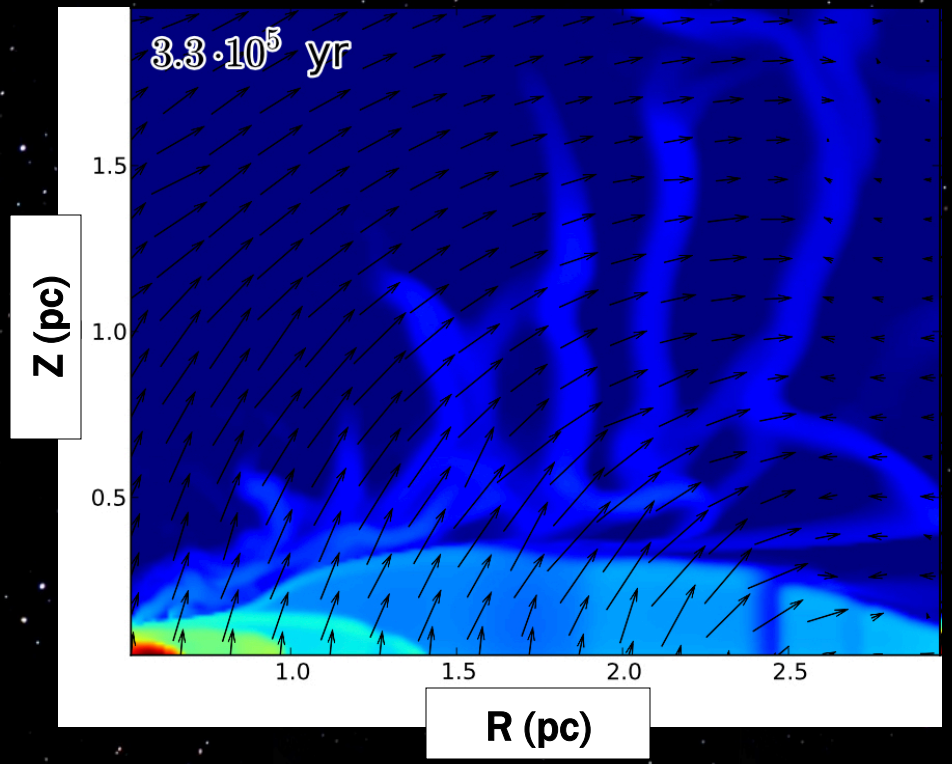
(Nardini et al. 2015, *Science*)



(Tombesi et al. 2013)

Models of disk winds

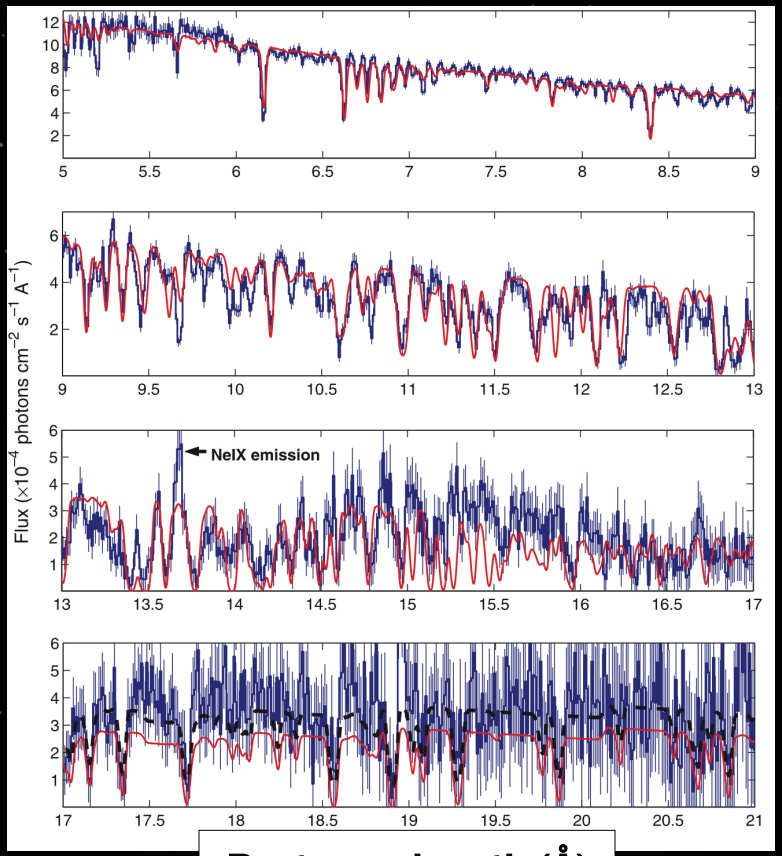
Thermal driven wind models



- Wind accelerated by thermal pressure (and radiation pressure)
- Maximum outflow velocity ~1000 km/s
- Ejected at ~1pc from SMBH, possibly connected with WAs and/or obscuring torus

(e.g., Dorodnitsyn & Kallman 2011, 2012)

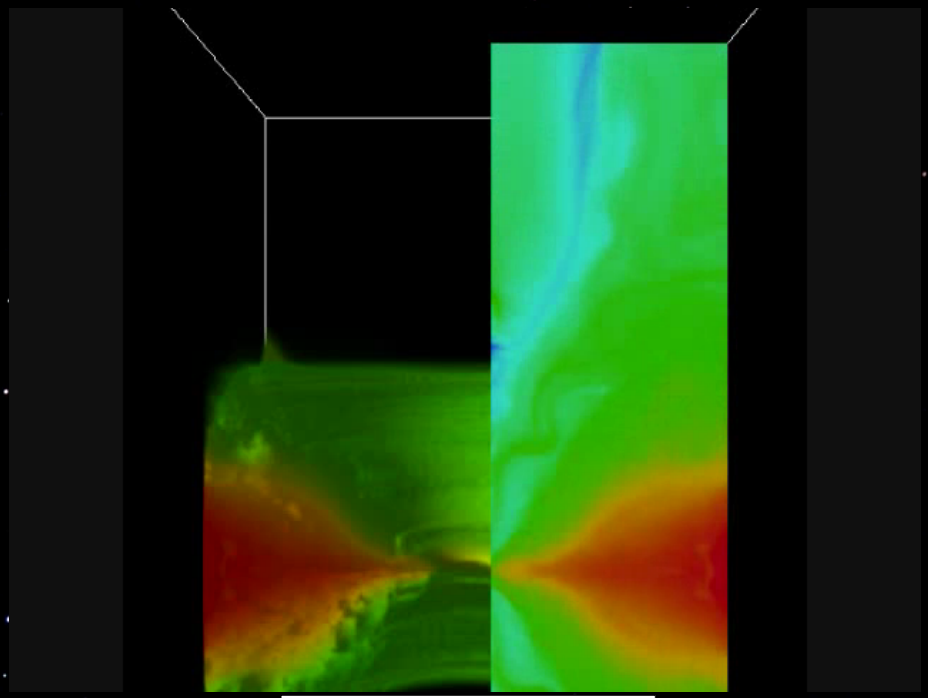
Thermal driven wind: spectral fitting



- Case study: 900ks Chandra HETG spectrum of NGC 3783
- Highly ionized WA component well fit with thermal wind model
- Wind ejected at ~1pc from SMBH with v_{out}~1000 km/s

(Chelouche & Netzer 2005)

Radiation driven wind models

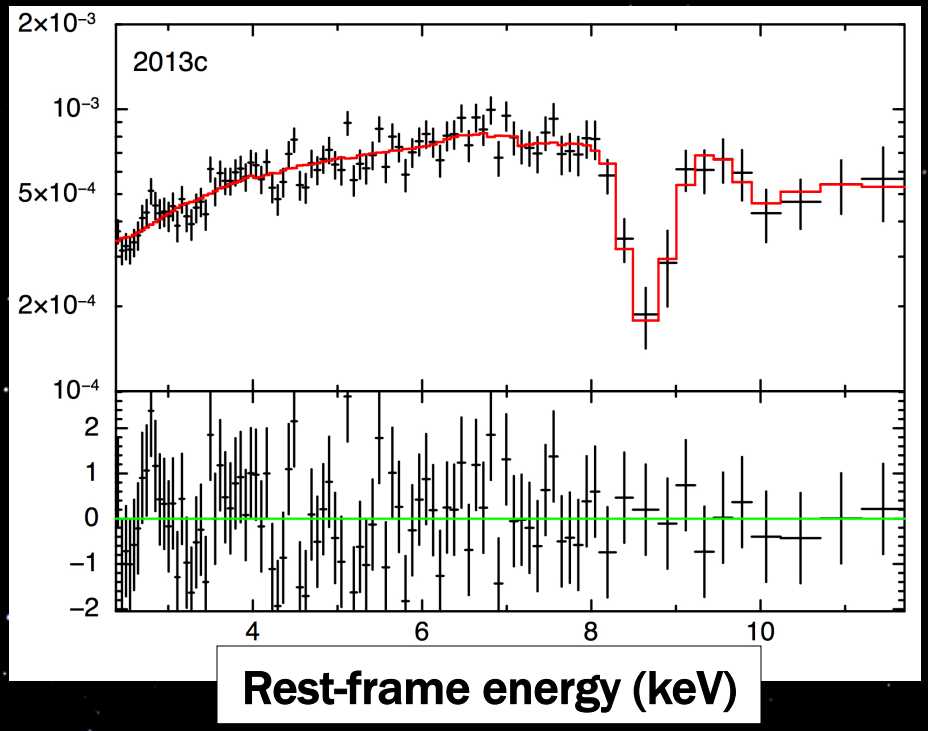


(Ohsuga et al. 2009)

- Wind accelerated by radiation pressure (Compton scattering and/or abs lines)
- Require high luminosity L~0.1-1L_{Edd}, problems with high ionization
- Wind ejected from different locations on accretion disk, high variability
- Velocity up to mildly relativistic values of ~0.3c

(e.g., Elvis 2000; King & Pounds 2003; Proga & Kallman 2004; Everett & Ballantyne 2004; Sim et al. 2008, 2010, 2012; Schurch et al. 2009; Higginbottom et al. 2014)

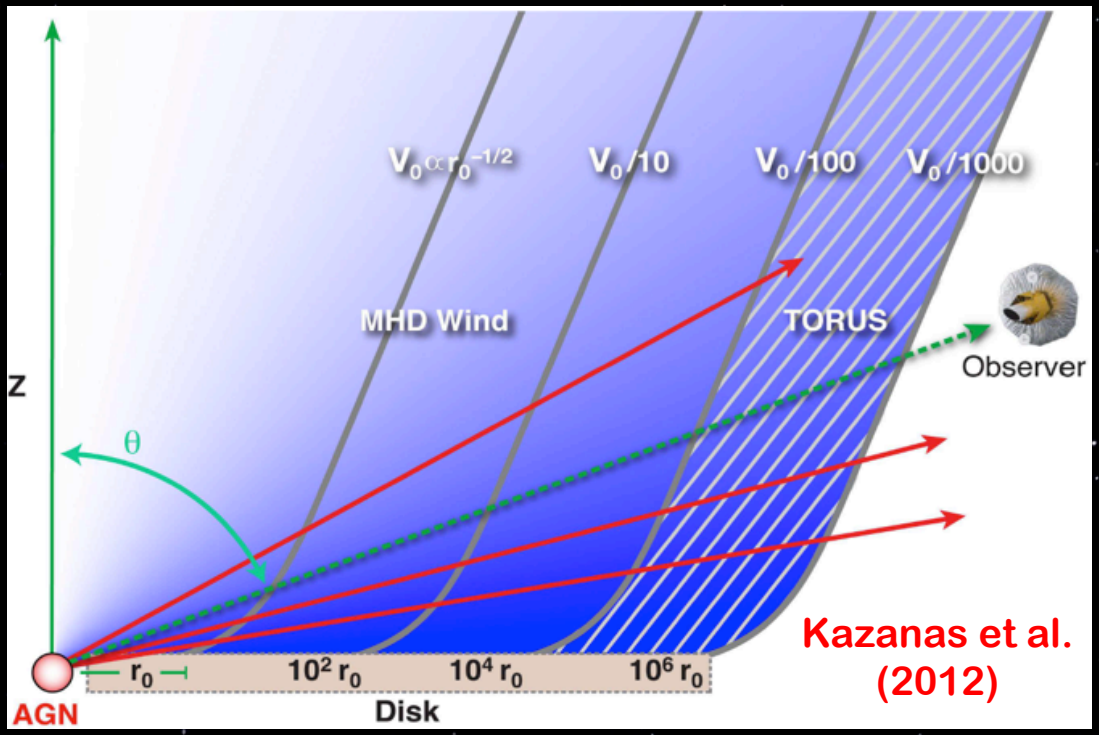
Radiation driven wind: spectral fitting



- Case study: Suzaku observations of PDS 456
- *"MONACO"* code for radiation transfer (Fe XXV-XXVI ions)
- Wind accelerated by Compton scattering and UV lines (if out of line of sight)
- Absorption/emission from wind + contribution from disk reflection
- Fit of 5 Suzaku obs: r_{in}~20r_g, θ~48°, v_{out}~0.25-0.3c, dM/dt~10$M_\odot$/yr

(Hagino et al. 2014; see also Sim et al. 2008, 2010; Tatum et al. 2012)

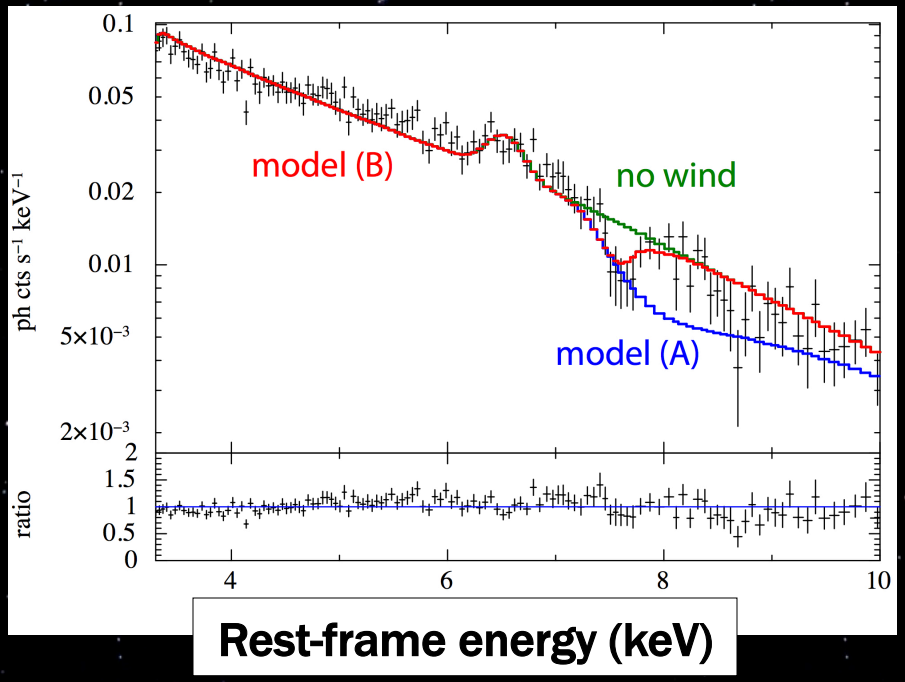
MHD driven wind models

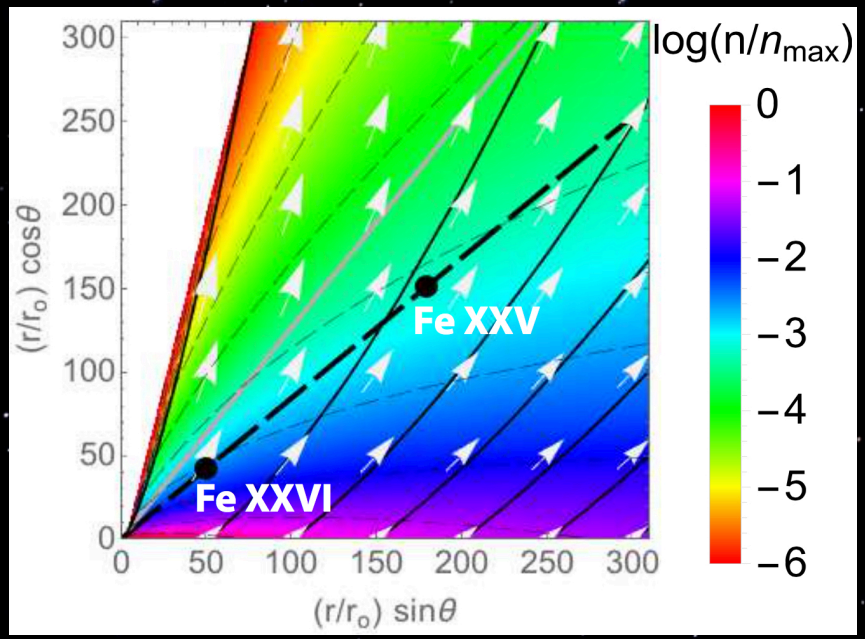


- Wind accelerated by magnetic pressure and centrifugal force
- Highly ionized, stratified wind, ejected at different locations of the disk
- Velocity ~ disk rotational velocity, faster closer to SMBH (up to relativistic values)
- Potentially originating from ~r_s up to outer disk/torus

(e.g., Blandford & Payne 1982; Konigl & Kartje 1994; Proga 2000, 2002; Everett 2005; Kazanas et al. 2012; Fukumura et al. 2010, 2014, 2015)

MHD driven wind: spectral fitting



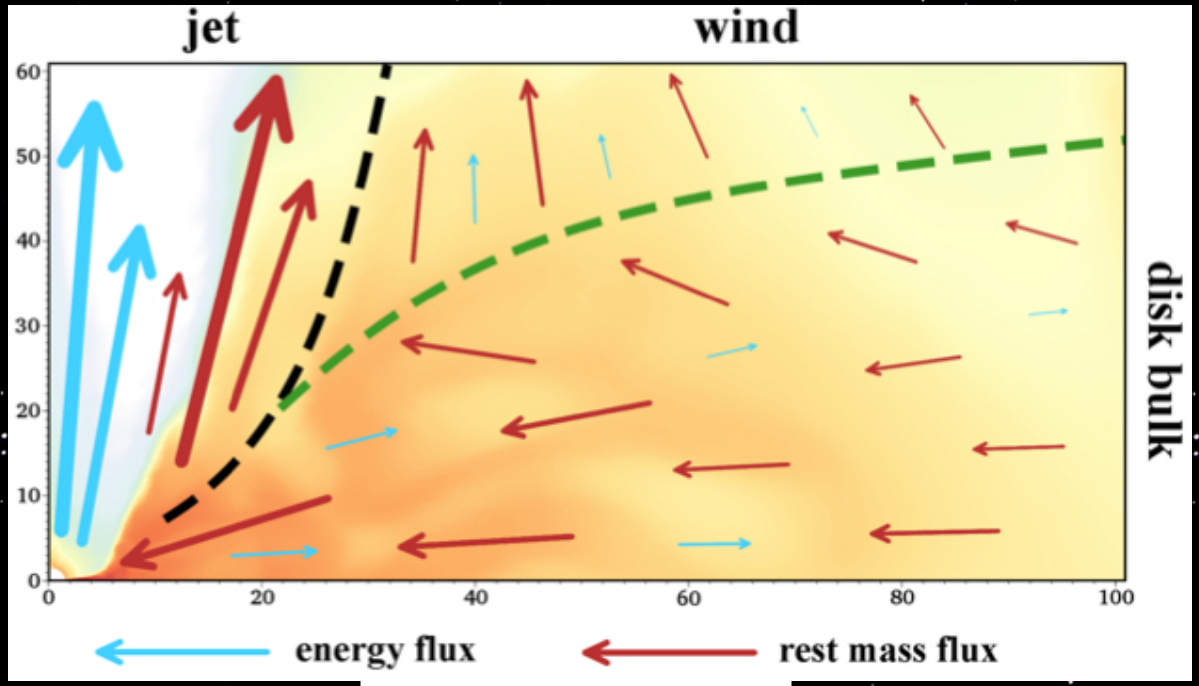


- Case study: 2001 XMM-Newton observation of PG 1211+143
- *"mhdwind"* model in XSPEC: model A $r_{in}=r_{ISCO}$; model B r_{in} free
- Best-fit model B: Fe XXV-XXVI, $r_{in}\sim30r_s$, $\theta\sim50^o$, $v_{out}\sim0.1$-$0.2c$, $N_H\sim10^{23}cm^{-2}$
- Next steps: expand *mhdwind* model, make it freely available in XSPEC, systematic fit of a sample of AGNs, fit UFO and WAs, include P-Cygni emission

(see Fukumura's talk)

(Fukumura, Tombesi et al. 2015)

Models for accretion and ejection



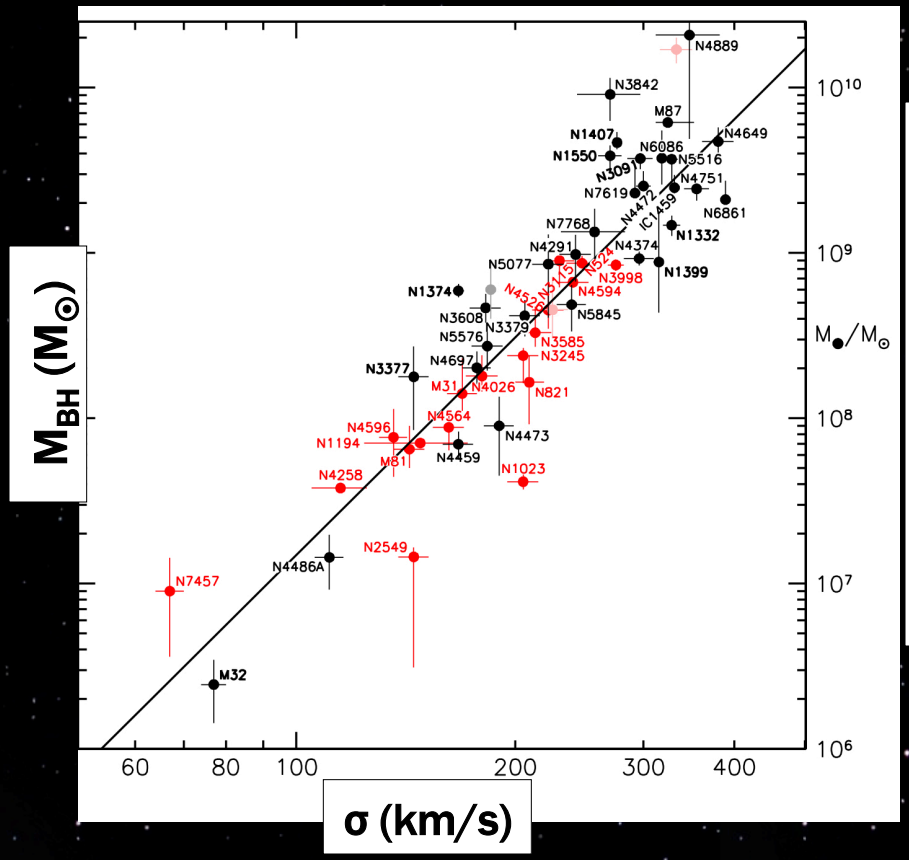
(Sadowski et al. 2013)

- **Accretion and ejection are connected,** need to study both disk, wind and jet
- **Compare with observations, such as radio galaxies 3C 111, 3C 120, ...**

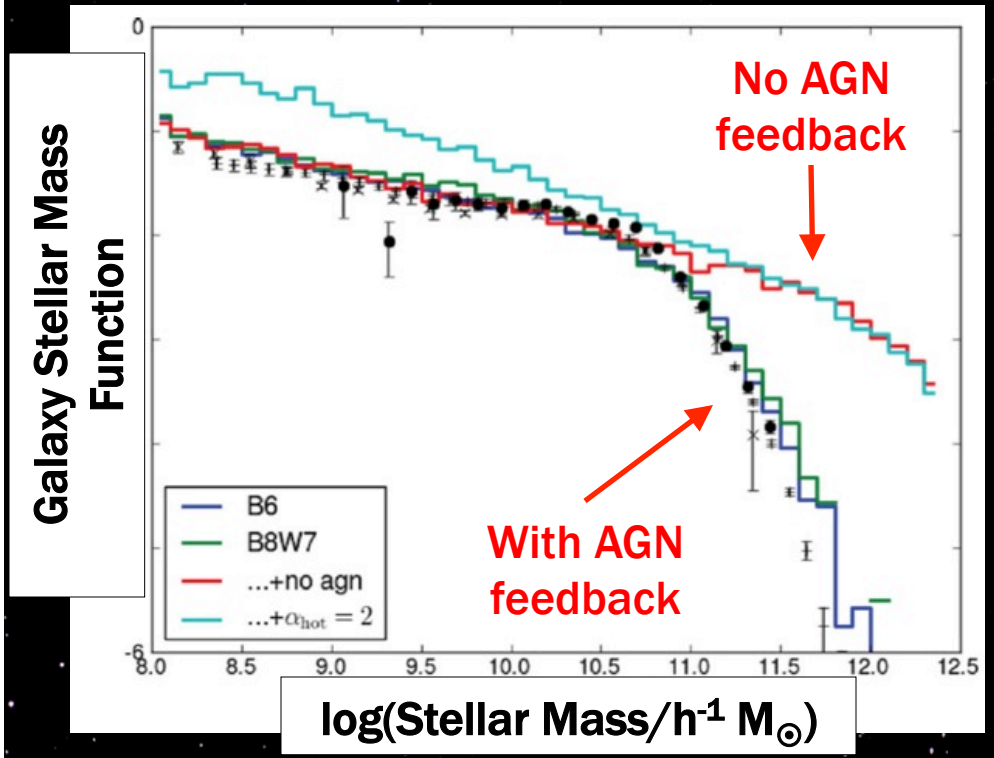
(e.g., Ohsuga et al. 2009; Tchekovskoy et al. 2011; Sadowski et al. 2013, 2014; McKinney et al. 2014; Fukumura et al. 2014; Yuan et al. 2015)

AGN wind feedback

Relations between SMBHs and host galaxies



(Kormendy & Ho 2013)

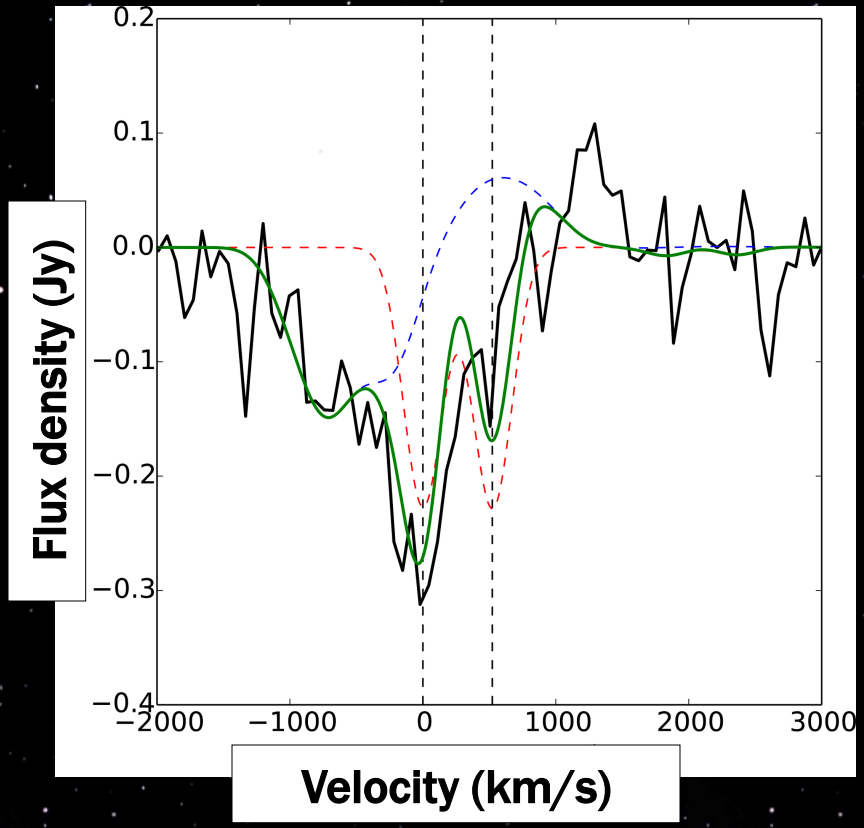


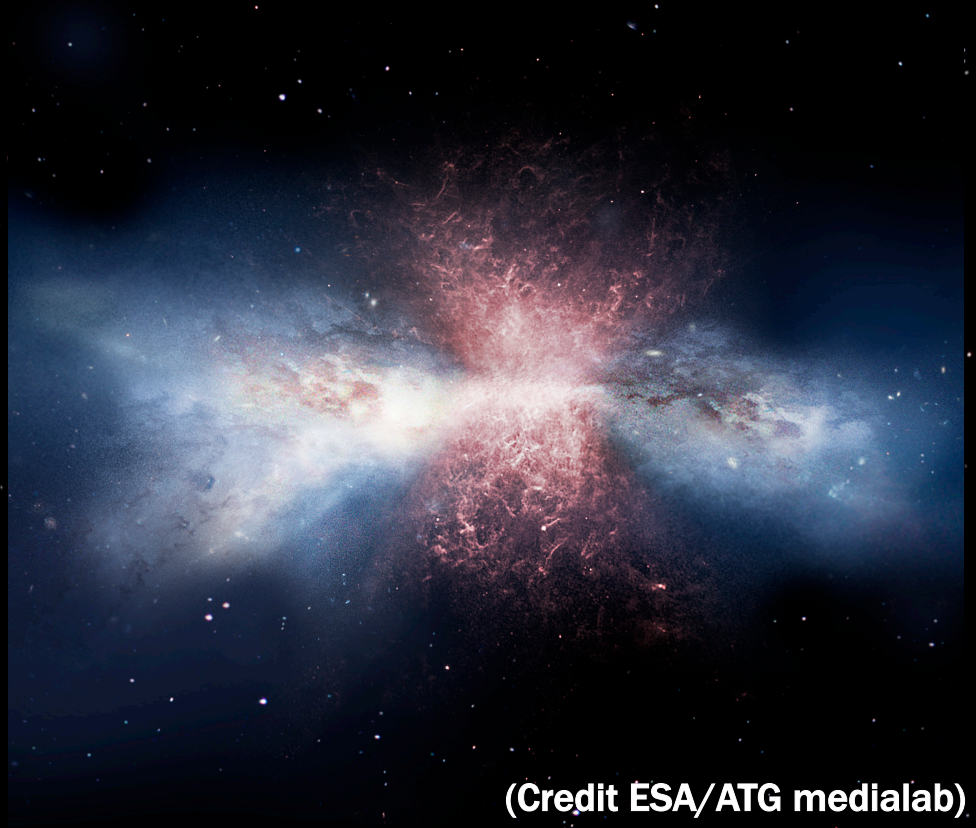
(Bower et al. 2012)

- SMBH size ~10^9 smaller typical galaxy (~atom 10^5 nucleus)
- SMBH mass is ~1% stellar bulge mass
- SMBH gravitational energy ~ binding energy galaxy bulge!

Tombesi et al. (2015)

Large-scale molecular outflow with Herschel



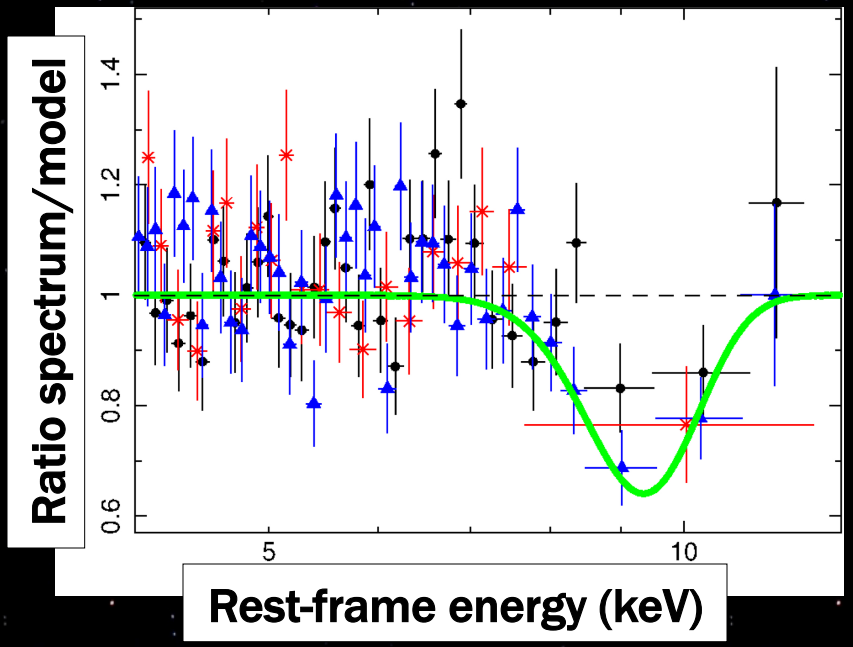


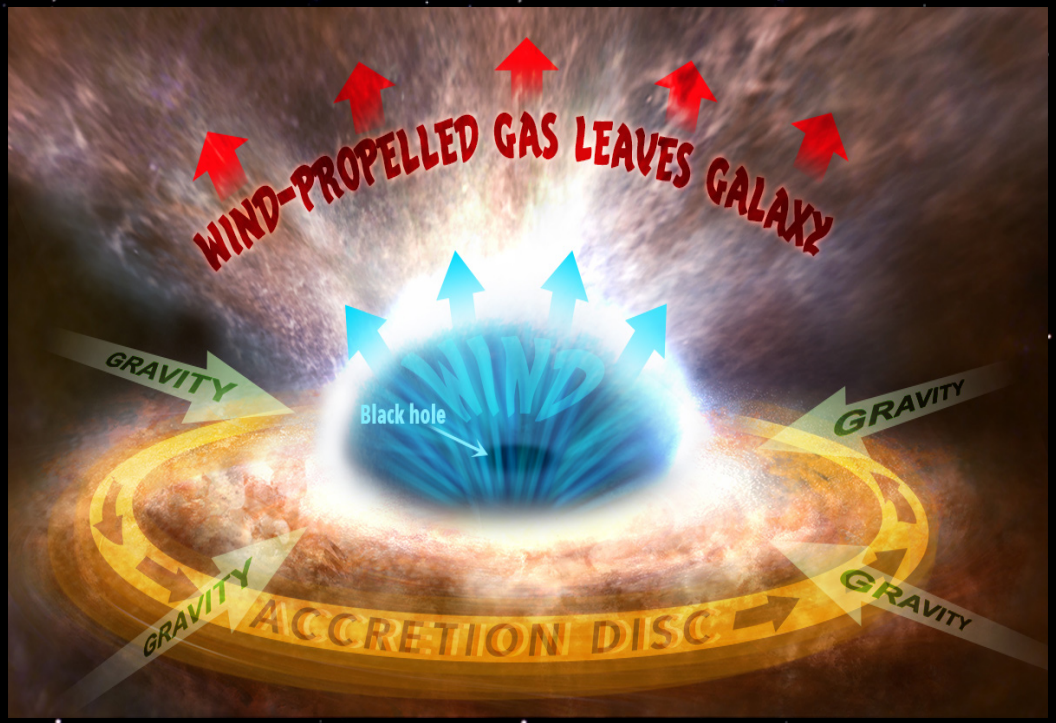
(Credit ESA/ATG medialab)

- IRAS F11119+3257, ULIRG z=.189, QSO luminosity 10^{46}erg/s
- Herschel spectrum of the OH 119μm P-Cygni line profile
- Molecular outflow 1000 km/s, 800 $M_\odot$ yr^{-1} at >300 pc
- Depletion of the reservoir of "star-making" gas

Tombesi et al. (2015, *Nature*)

Accretion disk wind detected with Suzaku



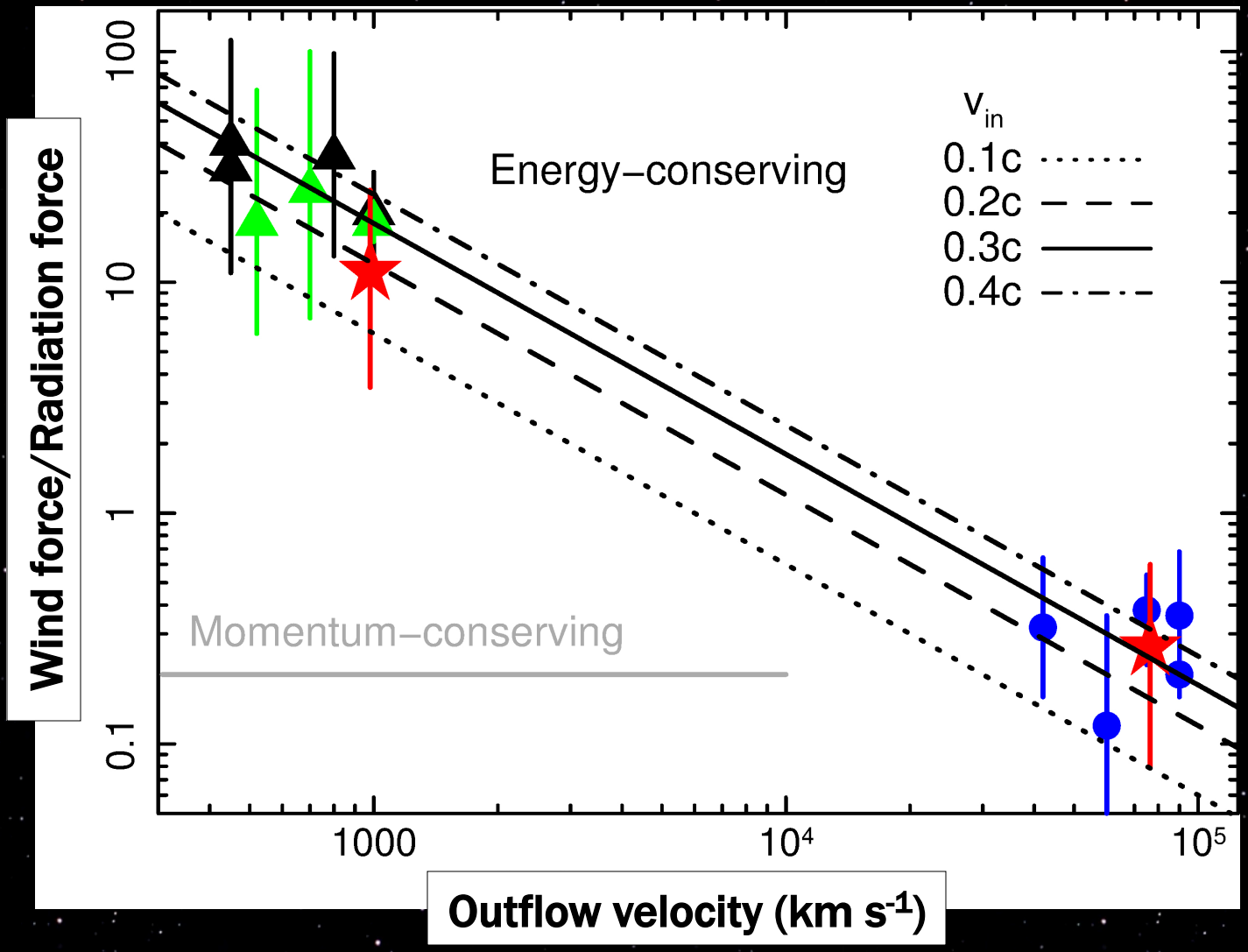


(Credit ESA/ATG medialab, The Why Files)

- Long 250ks Suzaku observation in May 2013
- Detection (6.5sigma) broad absorption line at rest-frame E=9.82keV
- Excluded slower absorber (edge) and disk reflection (variability, luminosity)
- XSTAR fit: v=0.255c, logxi=4.11, Nh=6×10^{24}, covering fraction >0.85

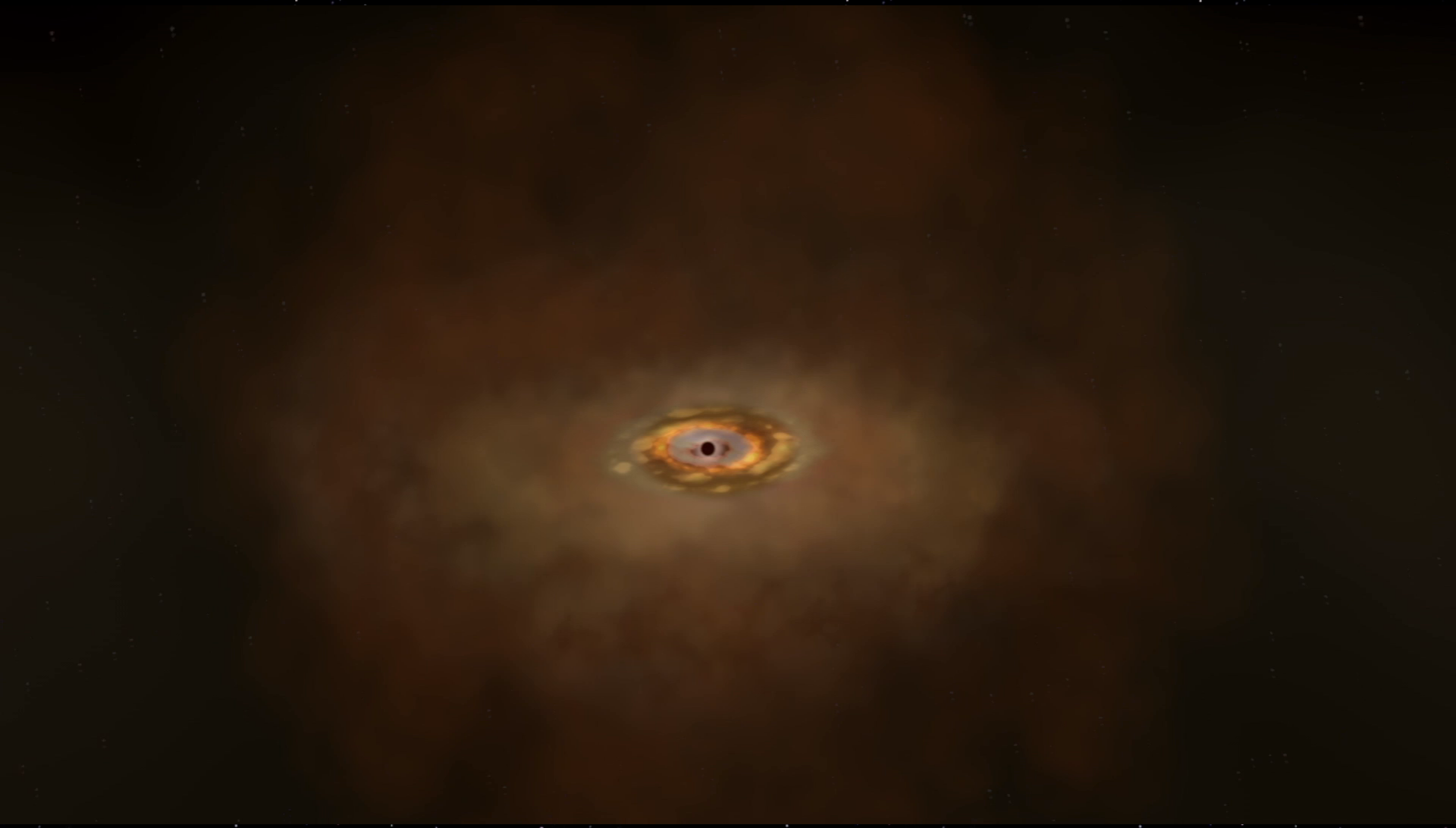
Tombesi et al. (2015, *Nature*)

AGN feedback from accretion disk winds



Tombesi et al. (2015, *Nature*)

SMBHs affect star formation in galaxies



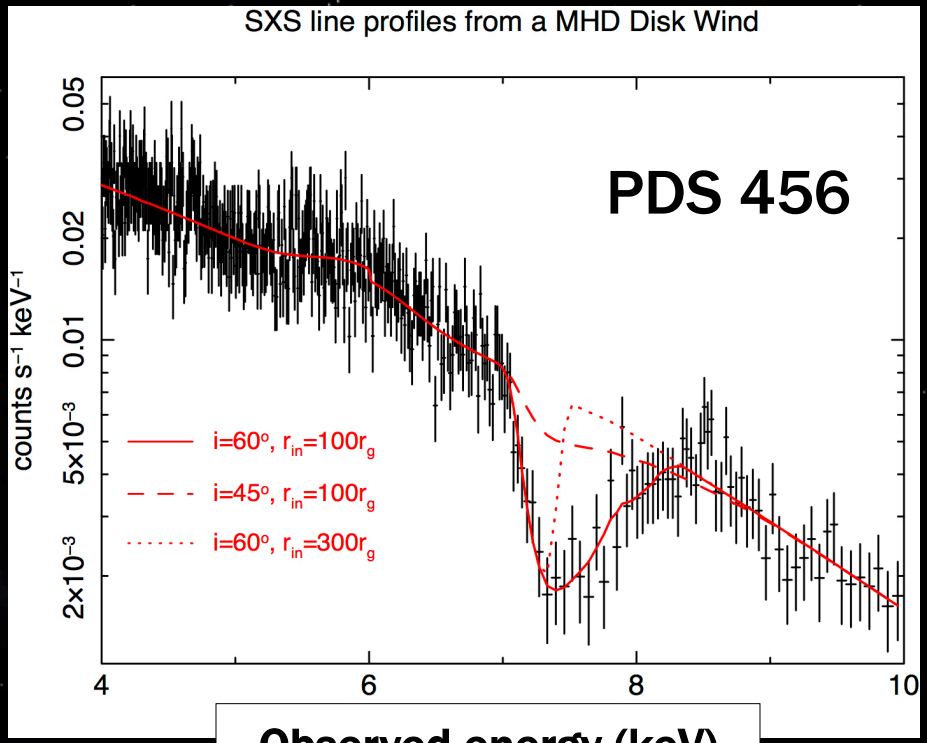
(Credit NASA/GSFC)

Will be launched in early 2016... stay tuned!

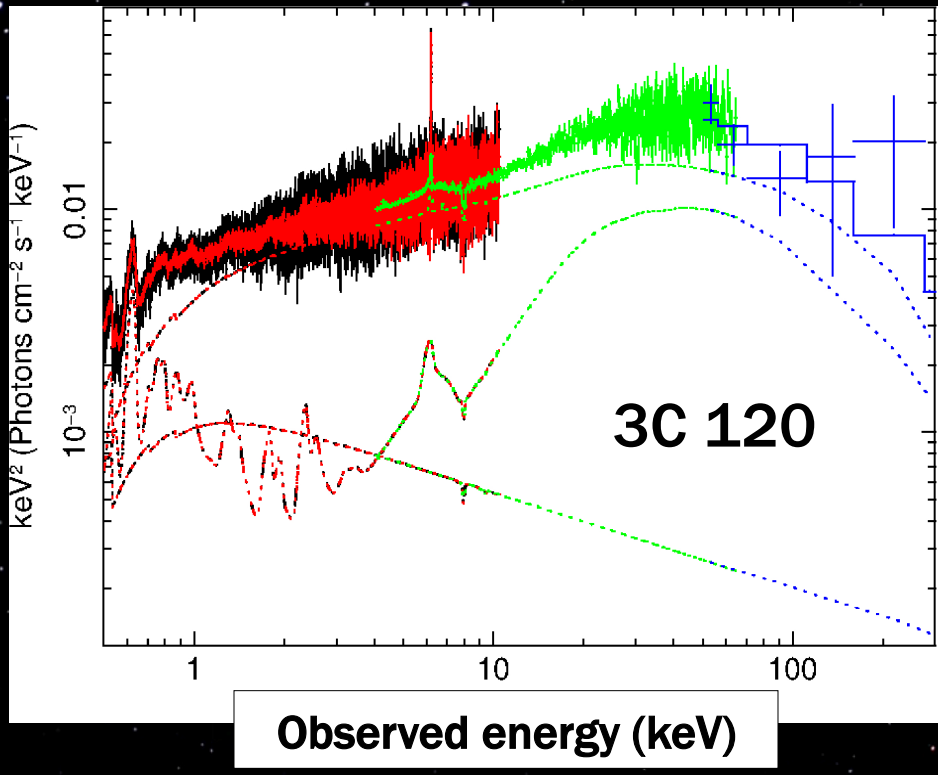
ASTRO-H observations of AGNs

- SXS calorimeter unprecedented energy resolution (6eV) and sensitivity
- Simultaneous broad-band coverage 0.5-500 keV (SXS+SXI+HXI+SGD)

Disk winds in quasars

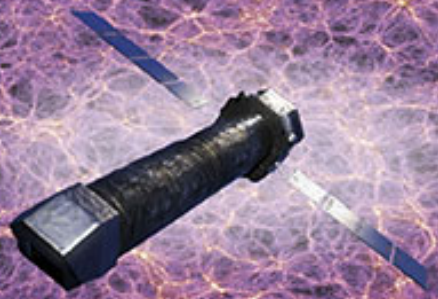


Radio galaxies



ATHENA

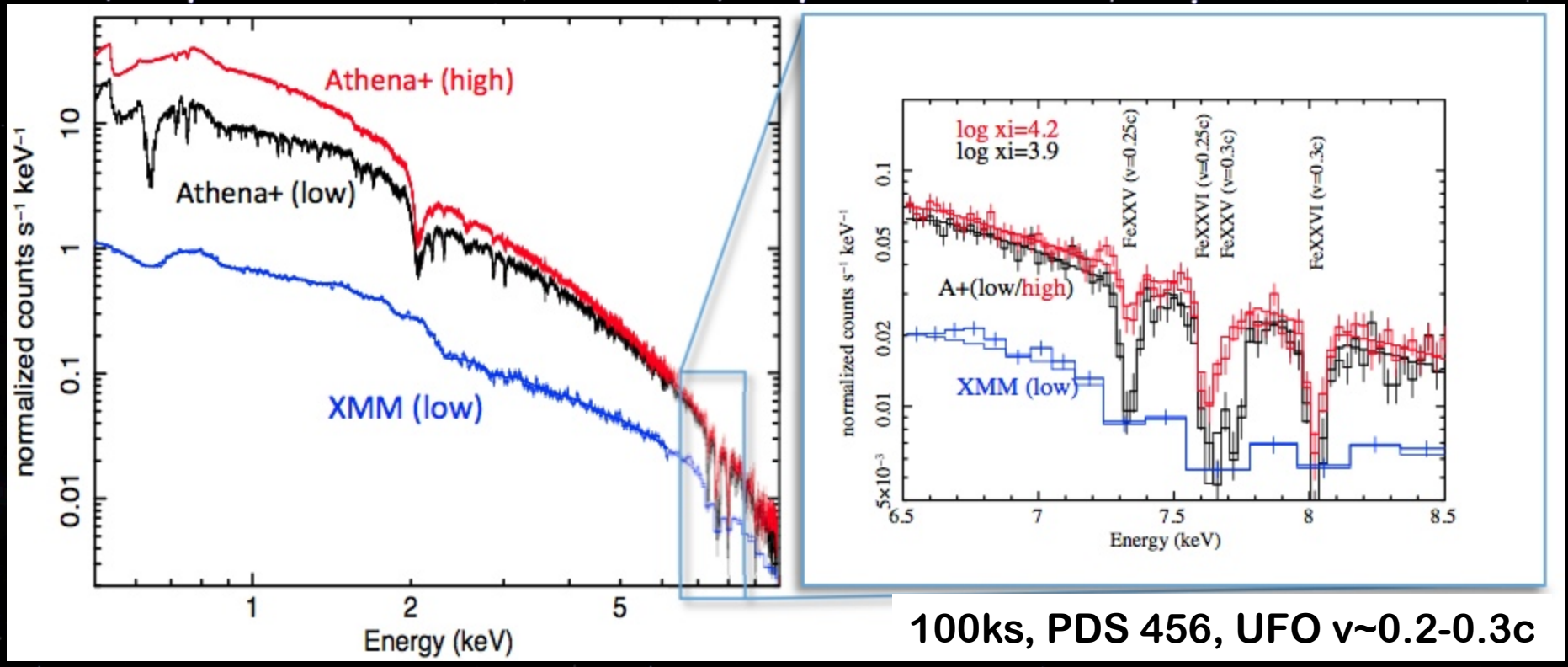
THE ASTROPHYSICS OF THE HOT AND ENERGETIC UNIVERSE



HOW DOES ORDINARY MATTER ASSEMBLE INTO THE LARGE SCALE STRUCTURES THAT WE SEE TODAY?

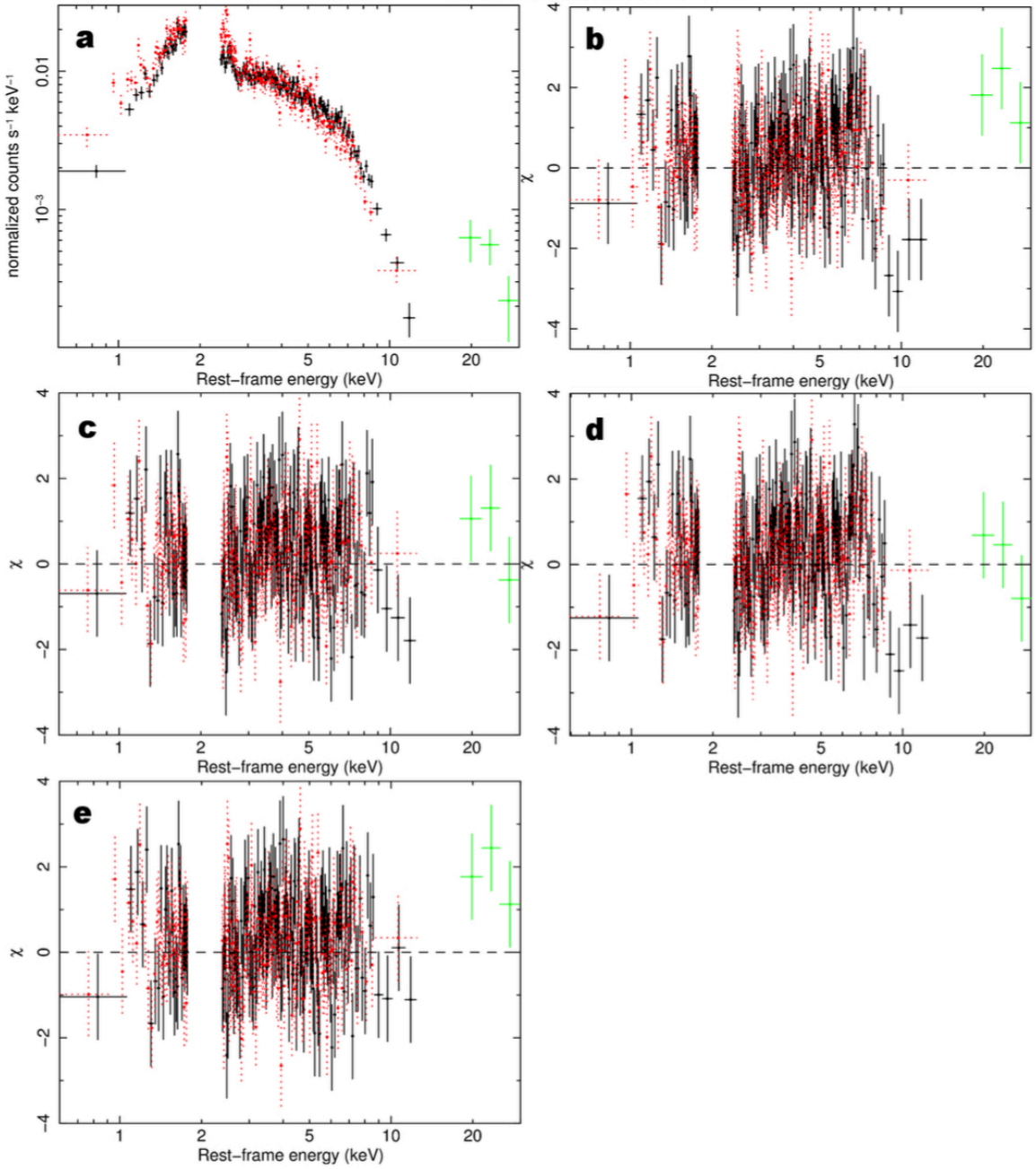
HOW DO BLACK HOLES GROW AND SHAPE THE UNIVERSE?

Europe's next generation X-RAY OBSERVATORY

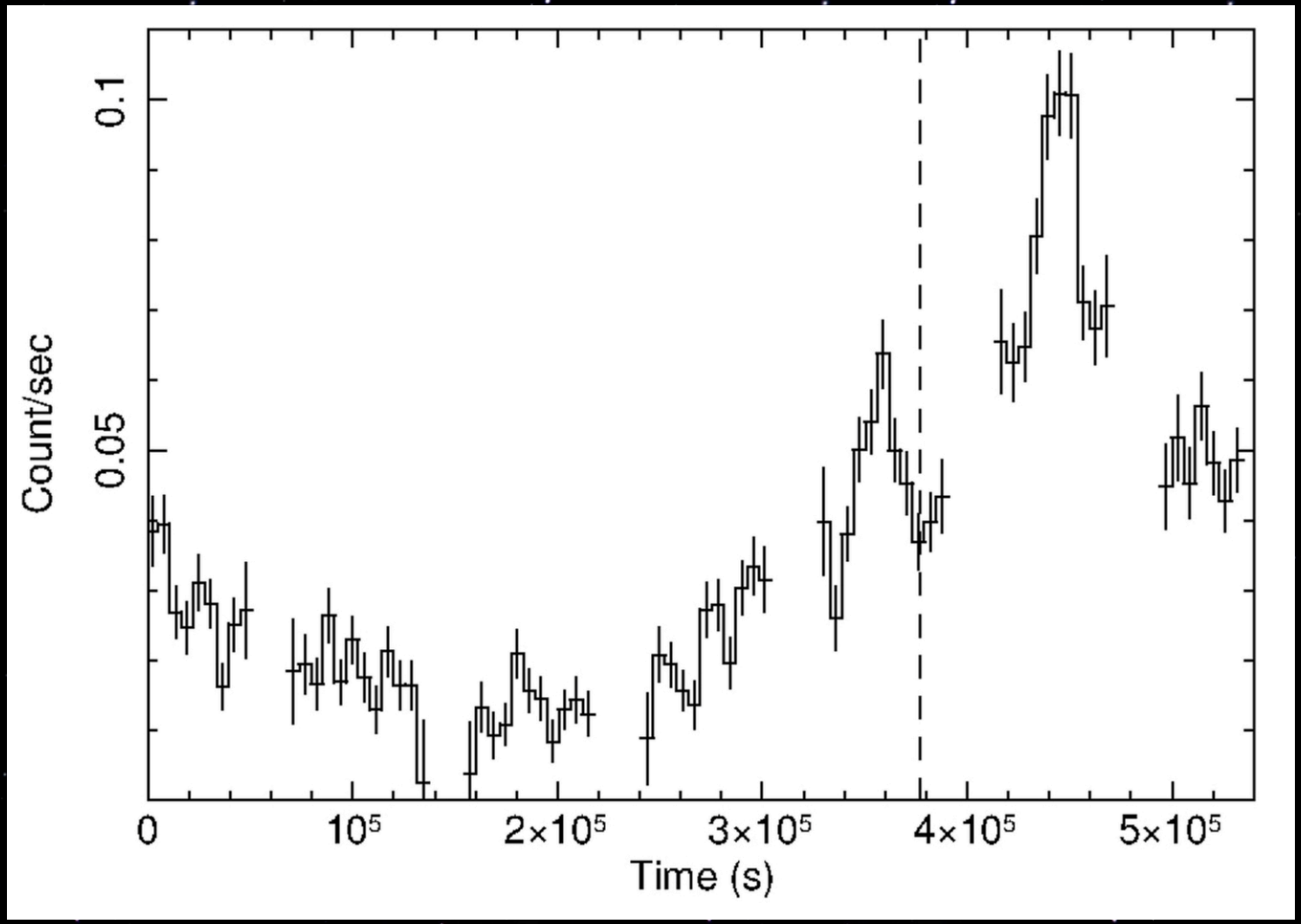


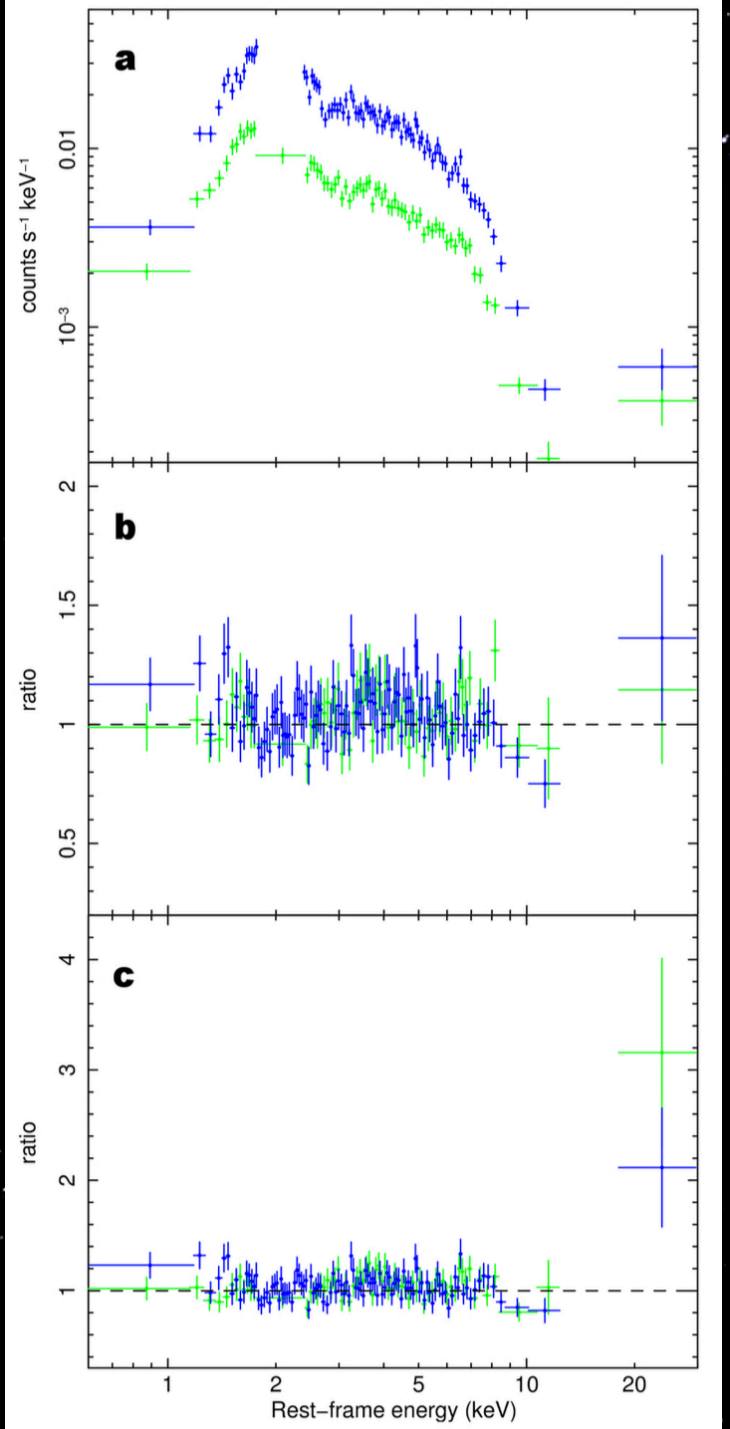
100ks, PDS 456, UFO v~0.2-0.3c

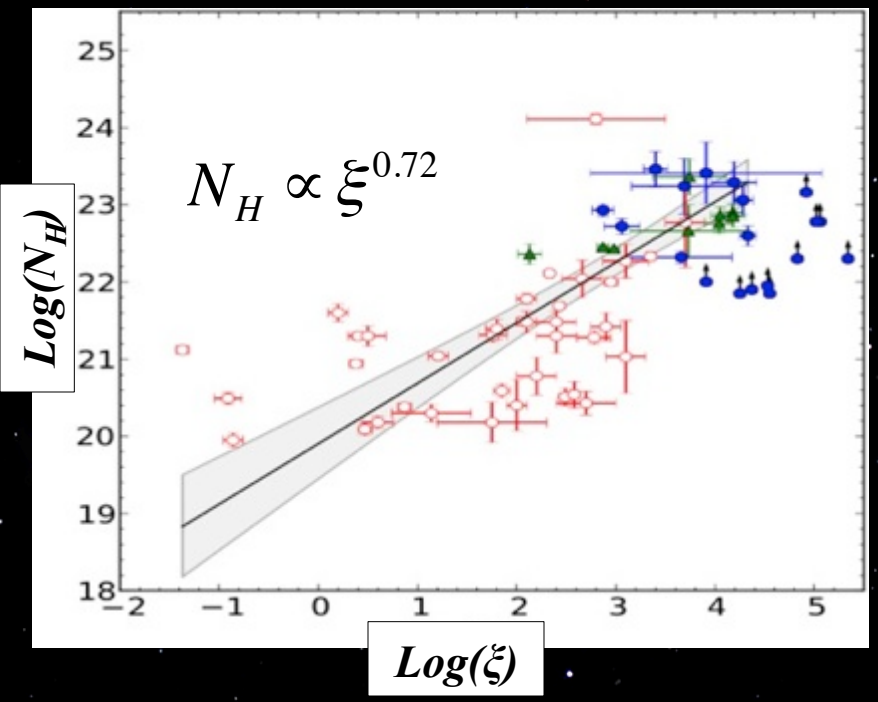
Thank you for your attention!

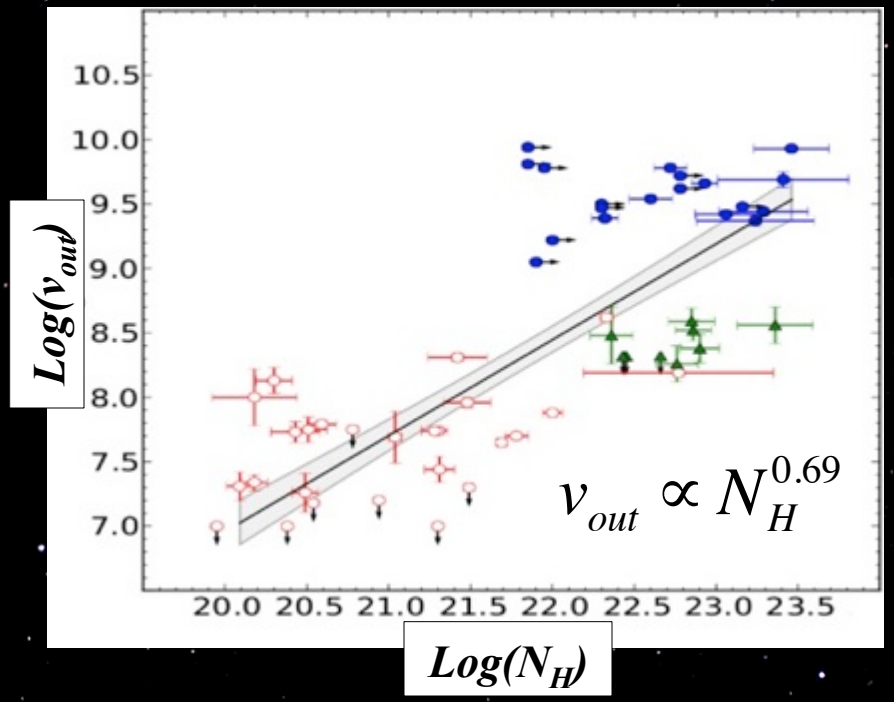


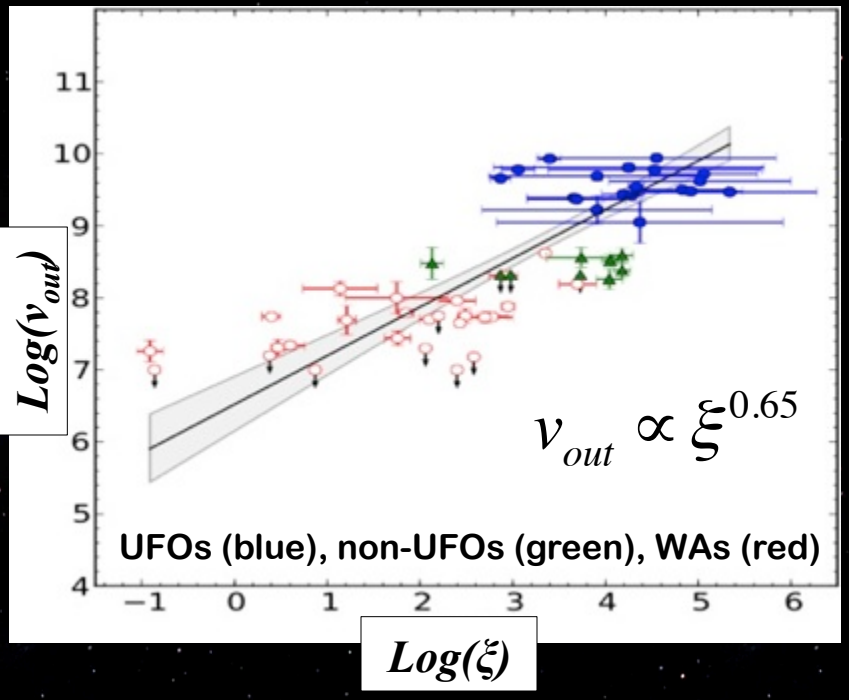
Extended Data Figure 1 | Broad-band Suzaku spectrum in the $E = 0.5$–30 keV band. **a**, The time-averaged Suzaku XIS03 (solid black), XIS1 (dotted red) and PIN (solid green) spectra binned to 10σ, 5σ and 3σ, respectively. The data-to-model residuals in units of sigma with respect to the absorbed power-law model, the fast-wind model, the slow-wind model and the relativistic reflection model are shown in **b**, **c**, **d** and **e**, respectively. The energy is in the rest-frame and errors are at the 1σ level.


Count/sec
0.1
0.05
0
10^5
2×10^5
3×10^5
4×10^5
5×10^5
Time (s)


a
b
c
counts s⁻¹ keV⁻¹
10⁻³
0.01
ratio
0.5
1
1.5
2
3
4
1
2
5
10
20
Rest−frame energy (keV)





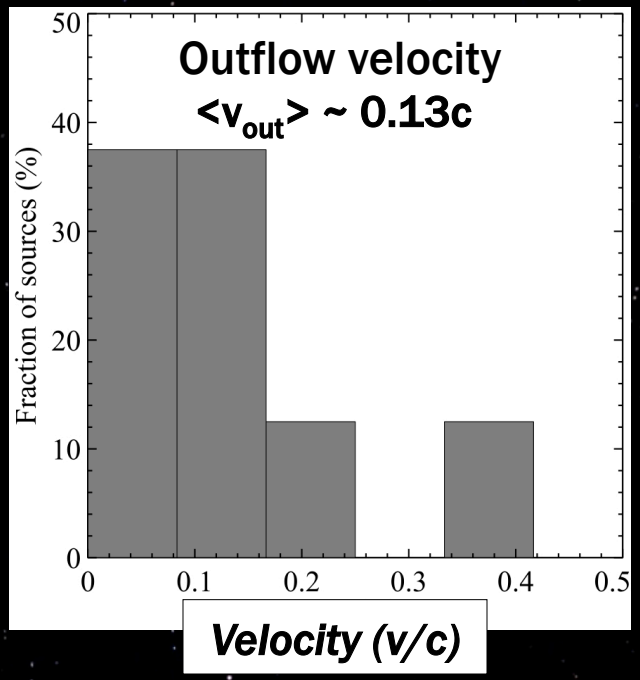


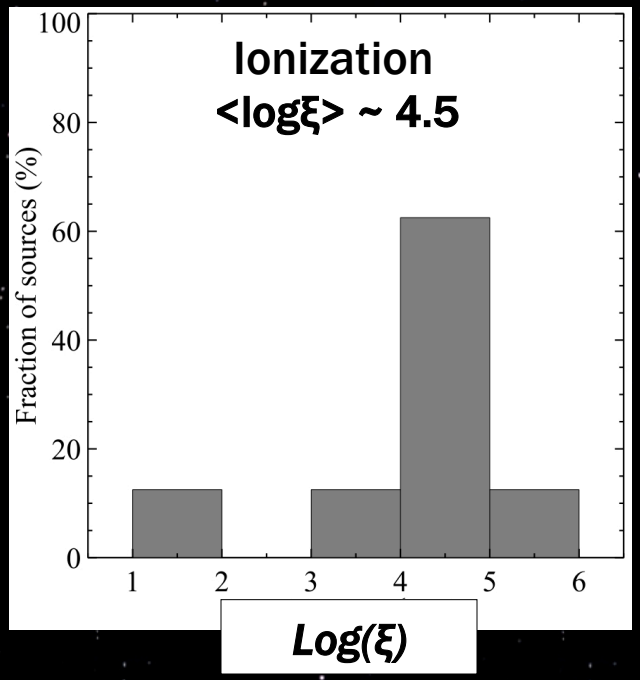
Comparison of UFOs and WAs in sample of 35 Seyfert 1 galaxies

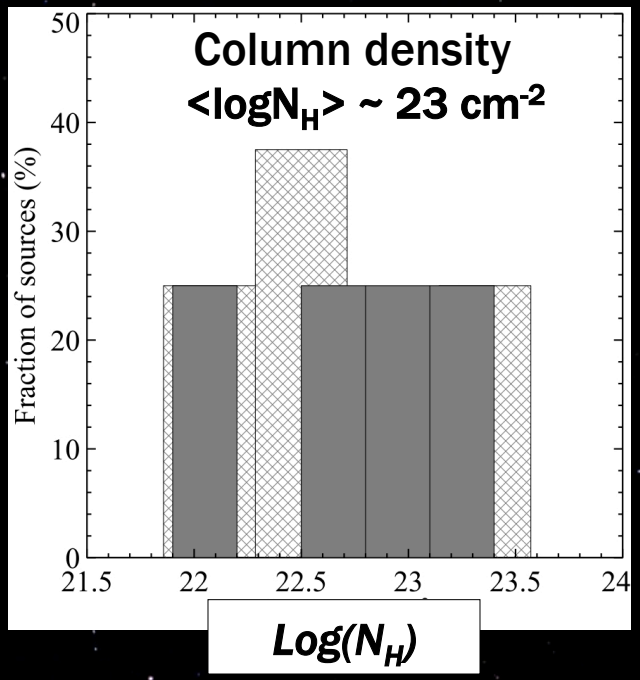
- WAs found in >60% sources
- UFOs in >40%, >70% also WAs
- Significant correlations (>6σ)

(Tombesi et al. 2013a)

Disk winds in radio galaxies



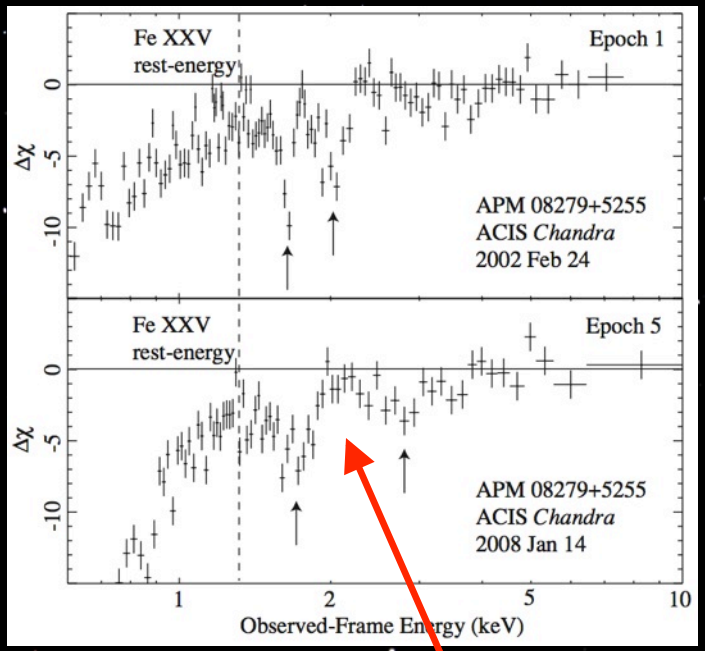


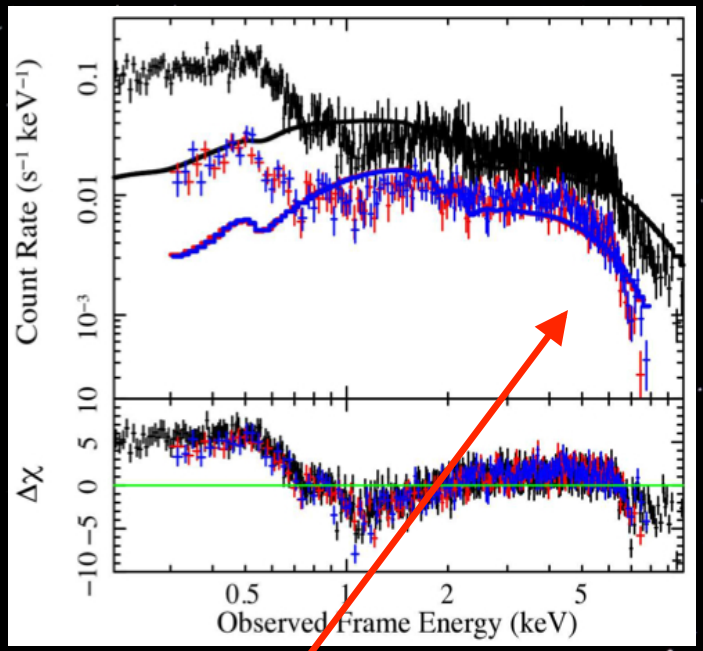


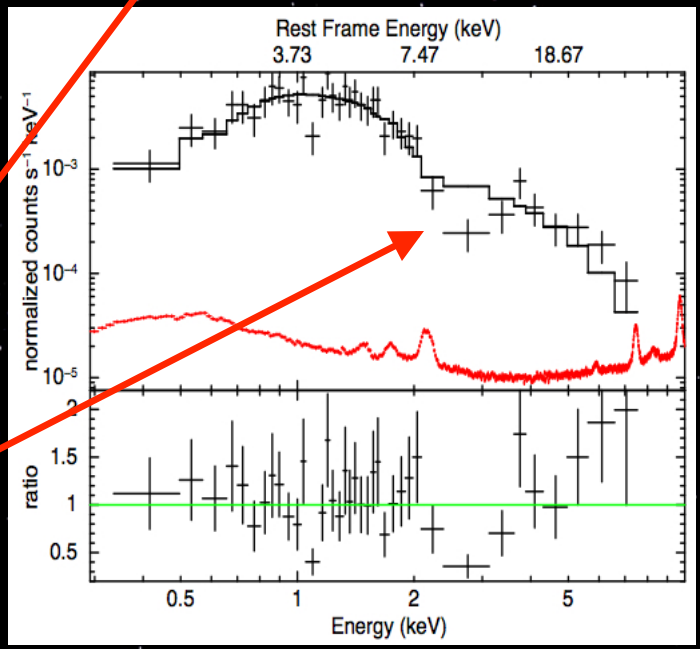
- **Both WAs and UFOs are detected in radio galaxies (mostly FR IIs)**
- **Frequency of detection of UFOs is f=(50±20)%**
- **Similar to RQ AGNs: jet related RQ/RL dichotomy does not apply to disk winds?**

(e.g., Reeves et al. 2009; Torresi et al. 2010, 2012; Braito et al. 2011; Gofford et al. 2013; Tombesi et al. 2010, 2011, 2014)

Disk winds in high-z quasars







- Gravitationally lensed BAL quasar APM 08279+5255 (z = 3.9), XMM-Newton and Chandra observations, v_{out}~0.2-0.7c (Chartas et al. 2009)
- Mini-BAL QSO PG1126-041, XMM-Newton obervations, v_{out}~16,500 km/s (Giustini et al. 2011)
- NAL QSO HS 1700+6416 (z= 2.7) ,Chandra observations, v_{out}~0.1-0.6c (Lanzuisi et al. 2012)