The X-ray view of winds in Active Galactic Nuclei

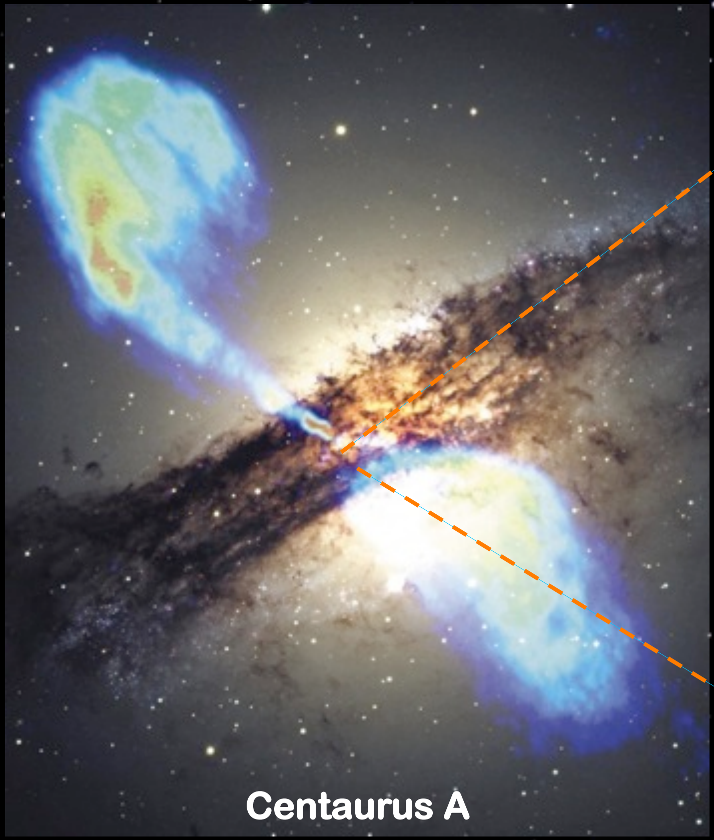
Francesco Tombesi

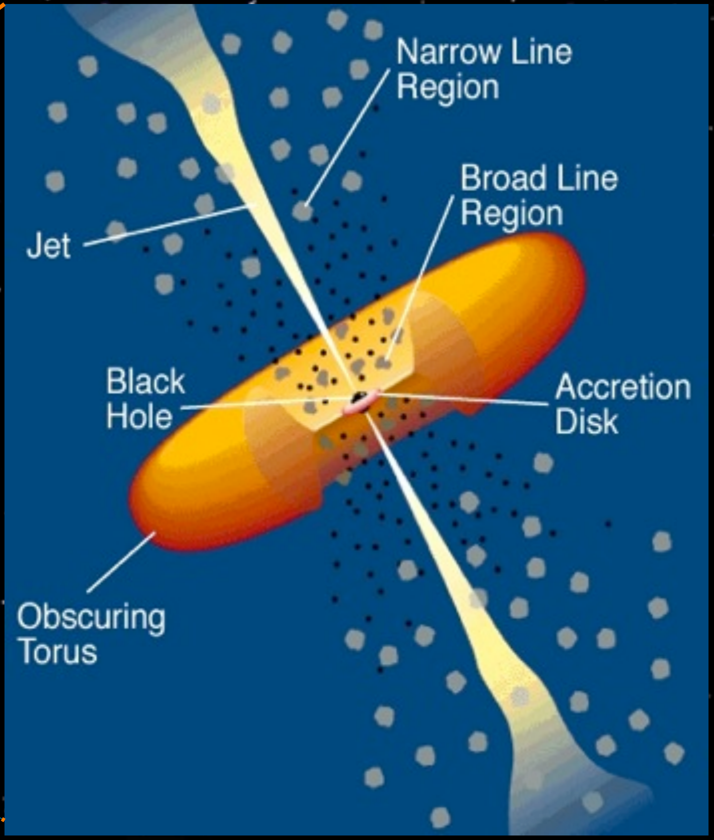
NASA/GSFC/CRESST, Greenbelt, MD (USA)

University of Maryland, College Park, MD (USA)

Main collaborators: M. Cappi, J. Reeves, C. Reynolds, V. Braito, R. Mushotzky, J. Gofford, K. Fukumura, D. Kazanas, F. Tazaki, Y. Ueda, …

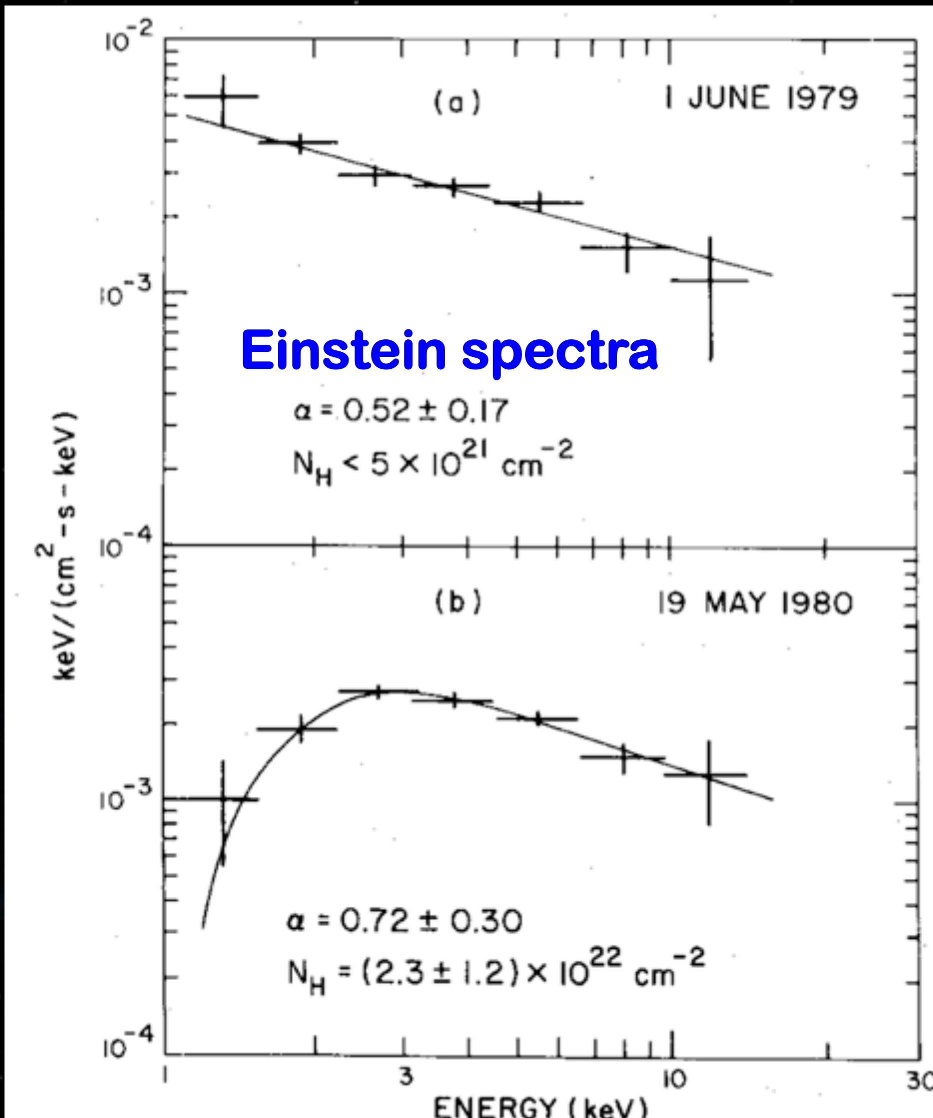
Active Galactic Nuclei

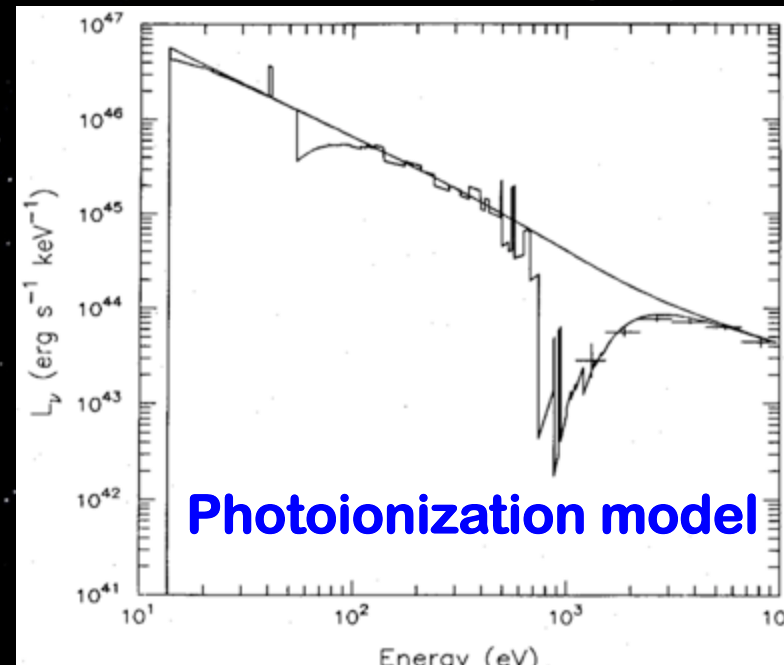




- Powered by accretion onto the central SMBH, $M_{BH}=10^{6}$-$10^{9}\ M_{\odot}$
- AGN can be very luminous, $L_{bol}>10^{11}\ L_{\odot}$
- "Winds" are missing from the classic schematic
- X-ray emission produced very close to SMBH

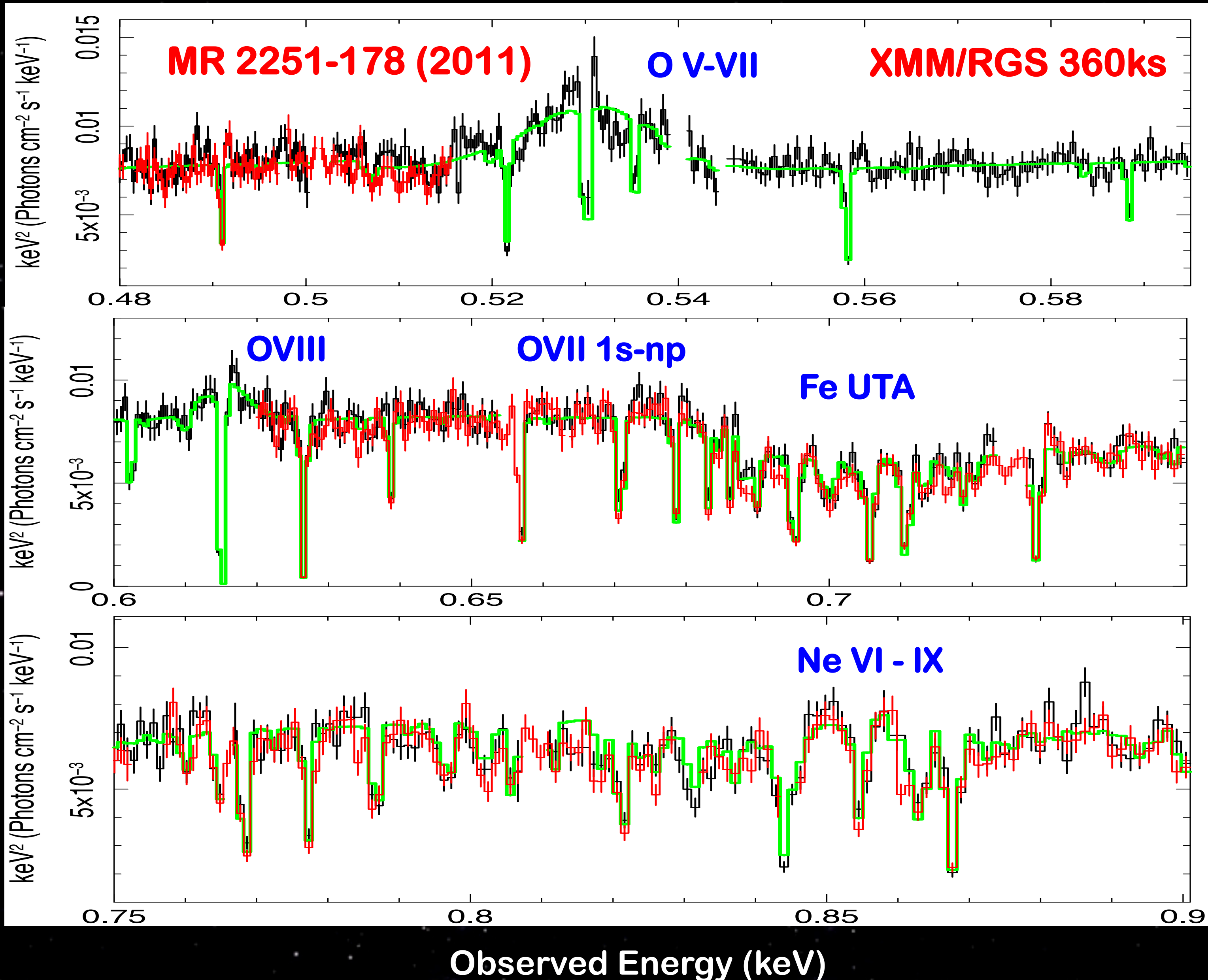
First Detection of a Warm Absorber in the QSO, MR 2251-178 (Halpern 1984)





- Einstein data showed variability of low energy absorption in MR 2251-178
- First indication of a "warm" absorber in an AGN - clouds photo-ionized by the inner AGN

X-ray warm absorbers

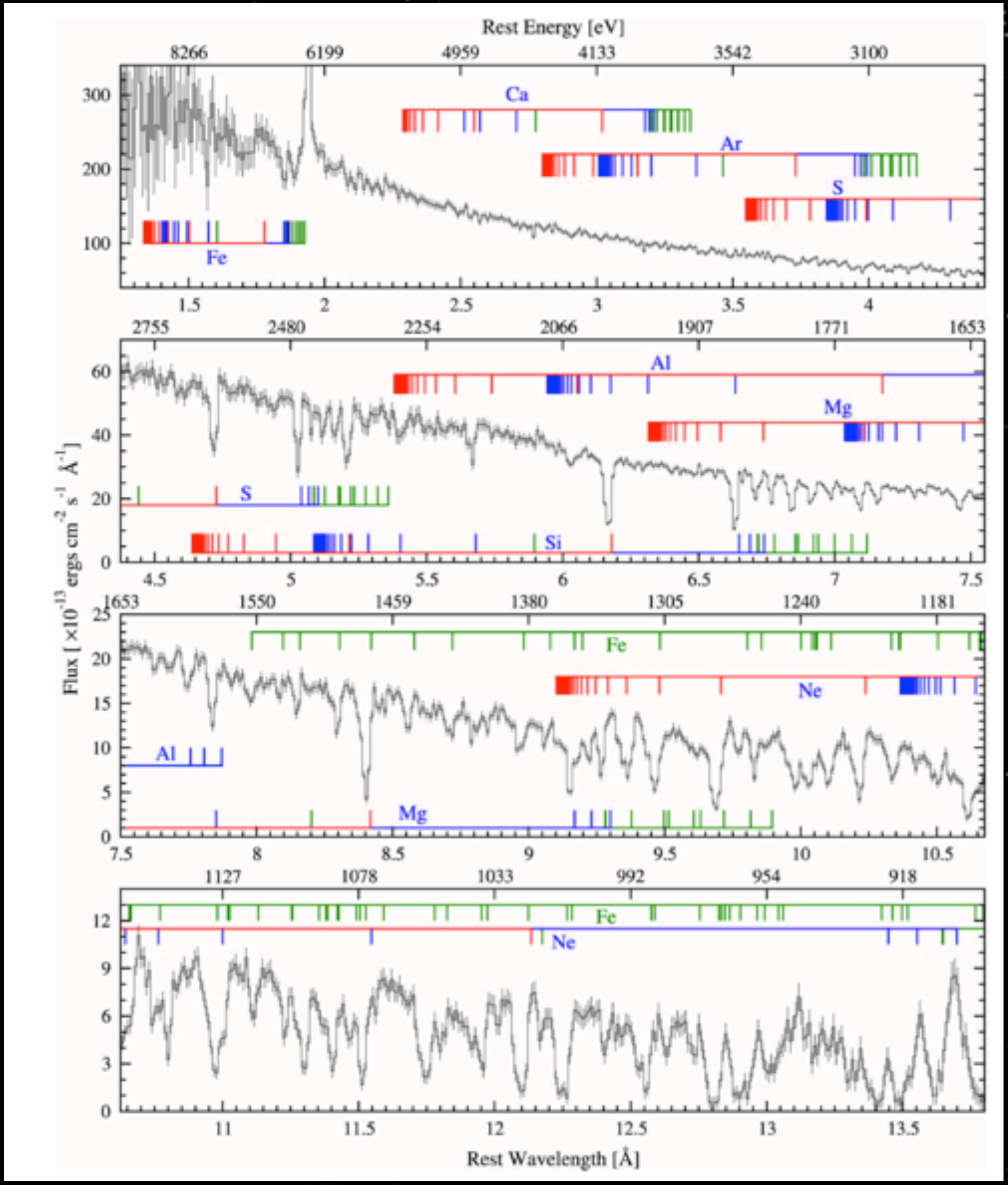


Courtesy of James Reeves

X-ray warm absorbers

- ~50% Seyfert 1 galaxies
- Mainly absorption in soft X-rays (C, O, Ne, Mg, Si, S, Ar, Ca, Fe)
- Lines systematically blue-shifted
- Photo-ionized by AGN radiation
- Mildly ionized logξ~0-3 erg s^{-1} cm
- Outflow velocity v~100-1000 km/s
- Column density $N_H = 10^{20}-10^{23}$ cm^{-2}
- Distance from SMBH d~1-100pc
- Winds from torus or accretion disk?
- Radiatively or MHD accelerated?

(e.g., Reynolds 1997; George et al. 1998; Crenshaw, Kraemer & George 2003; Blustin et al. 2005, McKernan et al. 2007; Crenshaw & Kraemer 2012)



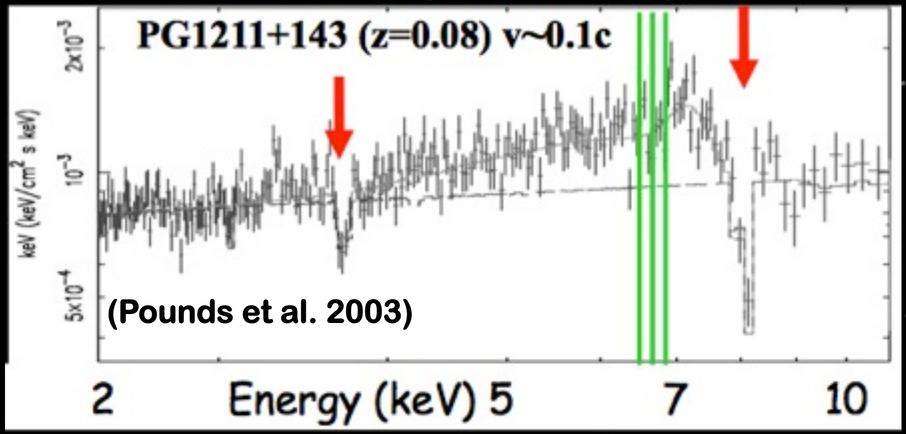
900ks Chandra obs of NGC 3783 (Kaspi et al. 2002)

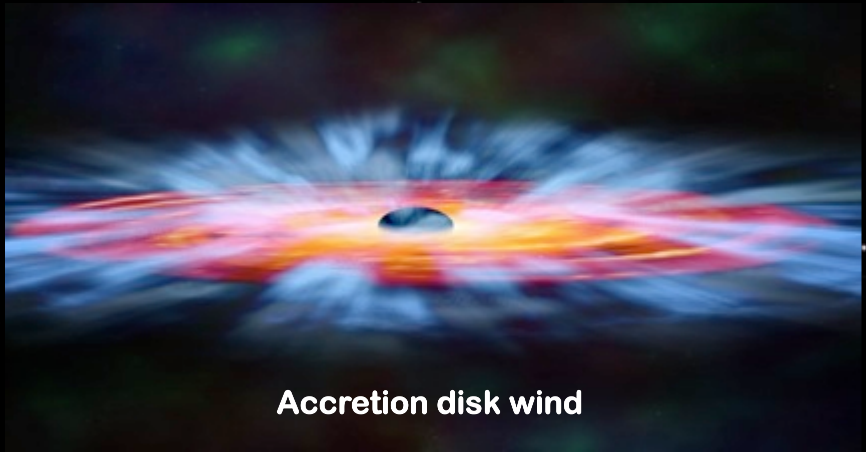
X-ray evidence for ultra-fast outflows

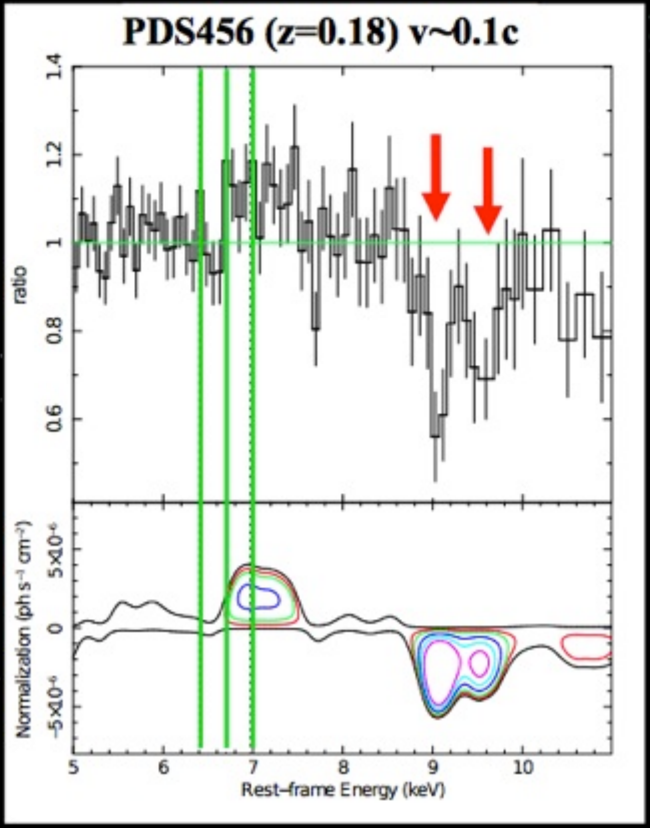
- **Blue-shifted Fe XXV/XXVI absorption lines in the X-ray spectra of AGNs**
(e.g., Chartas et al. 2002, 2003; Pounds et al. 2003; Dadina et al. 2005; Markowitz et al. 2006; Braito et al. 2007; Cappi et al 2009; Reeves et al. 2009; Giustini et al. 2011; Dauser et al. 2011; Gofford et al. 2011; Lobban et al. 2011; Lanzuisi et al. 2012; Gofford et al. 2013; ...)

- **Suggest the existence of highly ionized and mildly relativistic outflows**

- **Accretion disk winds/outflows, maybe important for AGN feedback**

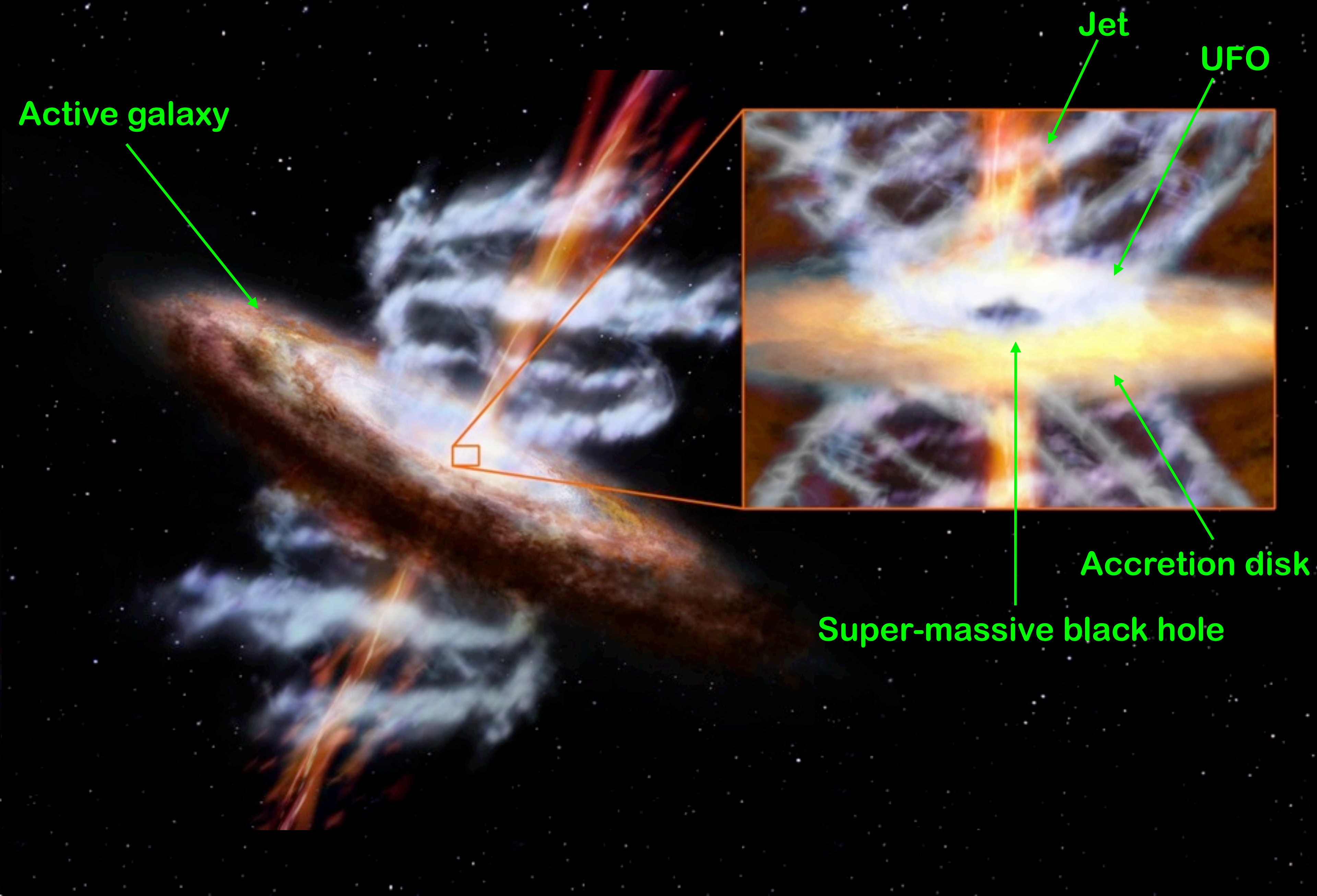






Reeves et al. (2009), Gofford et al. (2013)

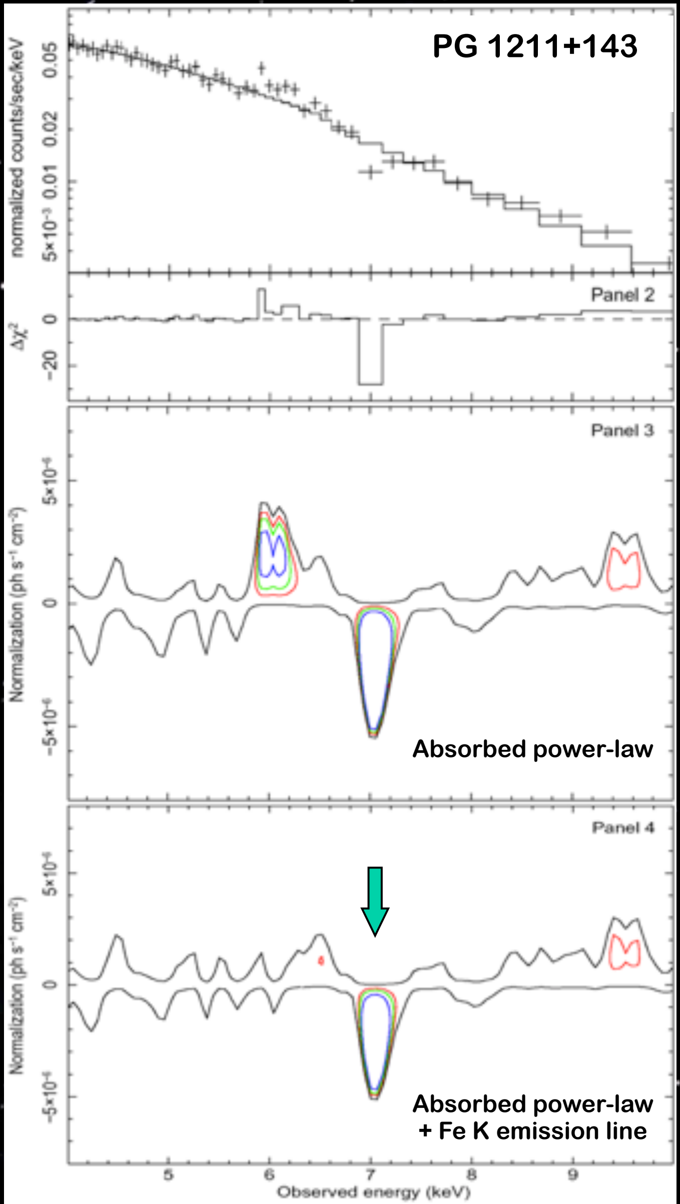
Ultra-fast Outflows



The sample of local Seyferts

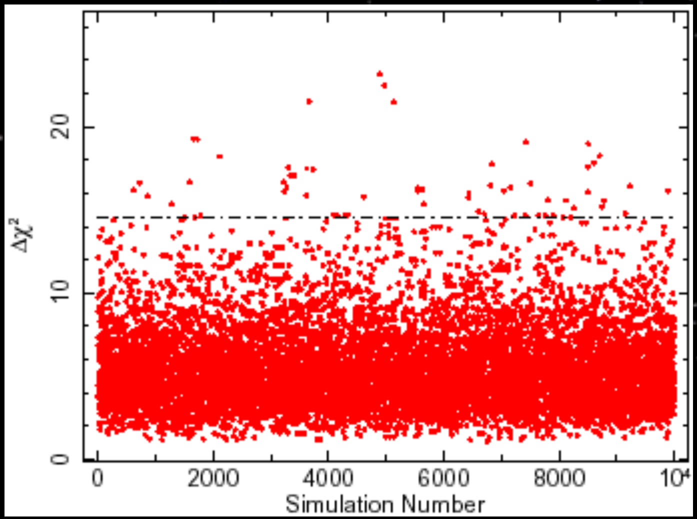
Ultra-Fast Ouflows (UFOs): v≥10,000km/s
(warm absorbers v<1000km/s)

- Systematic analysis of a complete sample of sources
- Selection of all Seyferts 1-2 in the RXTE catalog
- Cross-correlation with XMM-Newton archive
- Total of 42 sources for 101 XMM-Newton observations
- Complete, local (z<0.1) and X-ray bright sample
- Uniform 4-10keV EPIC-pn spectral analysis, baseline model absorbed power-law + Gaussian emission lines
- Absorption line search using energy-intensity contour plots
- Detected 36 absorption lines E=6.4-10keV (P_F>99%)

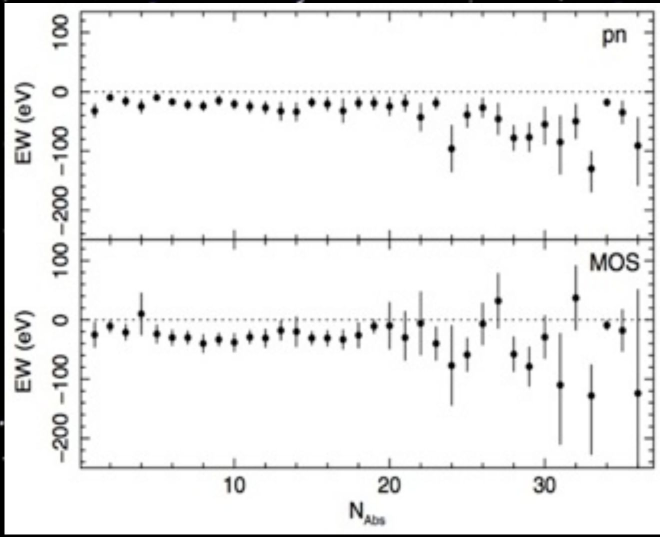


(Tombesi et al. 2010a)

The sample of local Seyferts

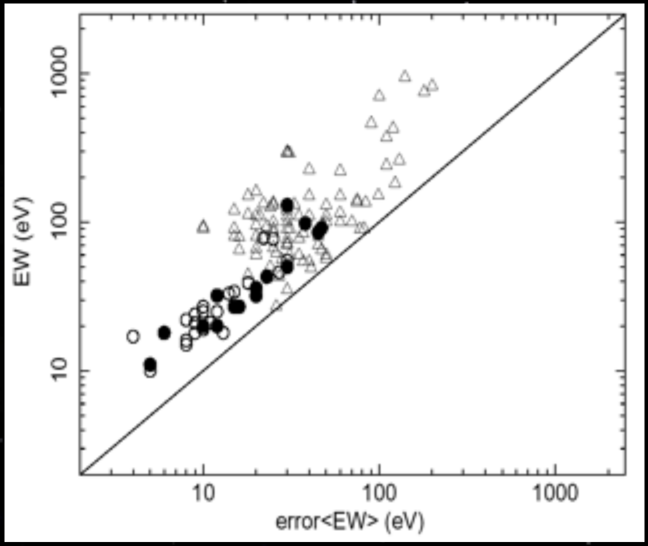


Monte Carlo simulations



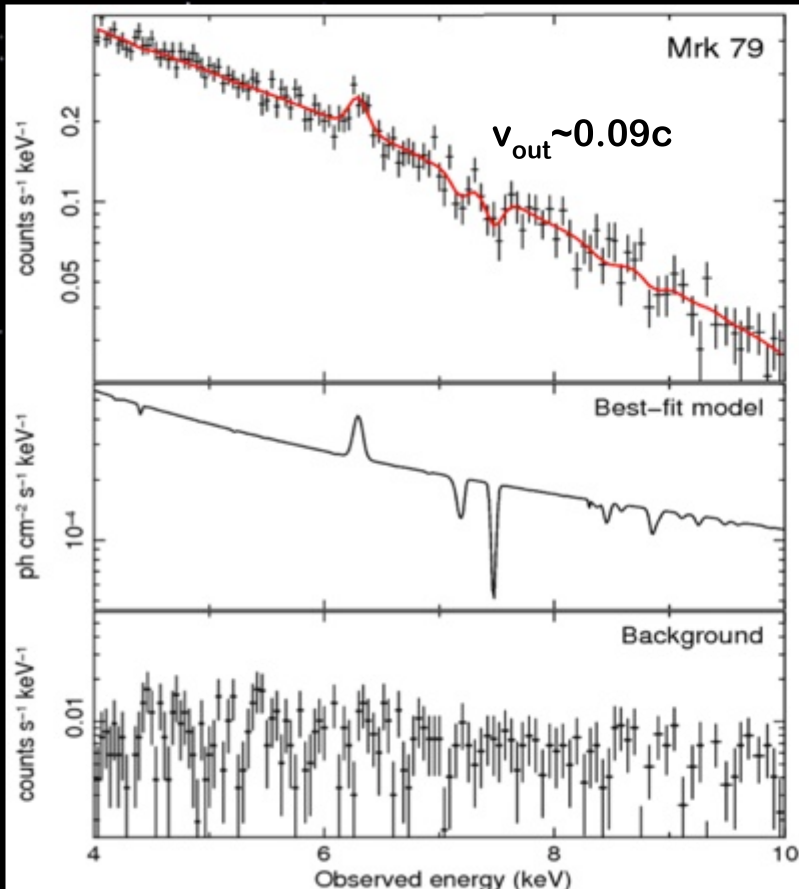
EPIC pn and MOS comparison

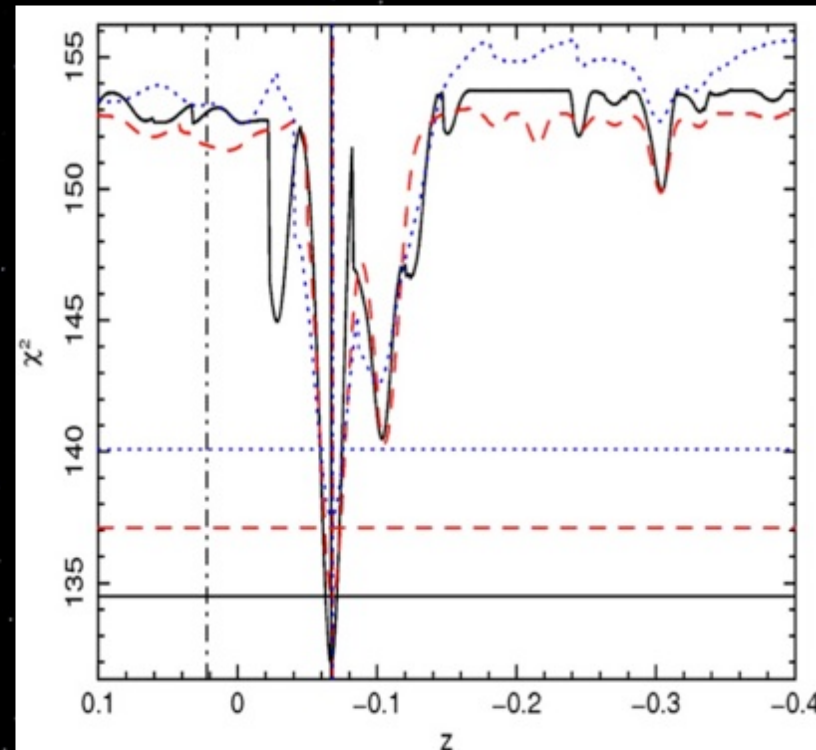
- **Extensive Monte Carlo spectral simulations, 22 lines E>7.1keV (P_{MC}>95%)**
- **Global random probability in 21/101 obs is $<10^{-8}$ (>5σ)**
- **No EPIC-pn background or calibration problems**
- **Consistency with simultaneous EPIC-MOS observations**
- **Solved the publication bias, reporting the detection fraction for the whole sample**
- **Blue-shifted absorption lines follow same trends as the more significant 6.4keV Fe Kα emission lines**



(Tombesi et al. 2010a)

Photo-ionization modeling of Fe XXV/XXVI absorption lines

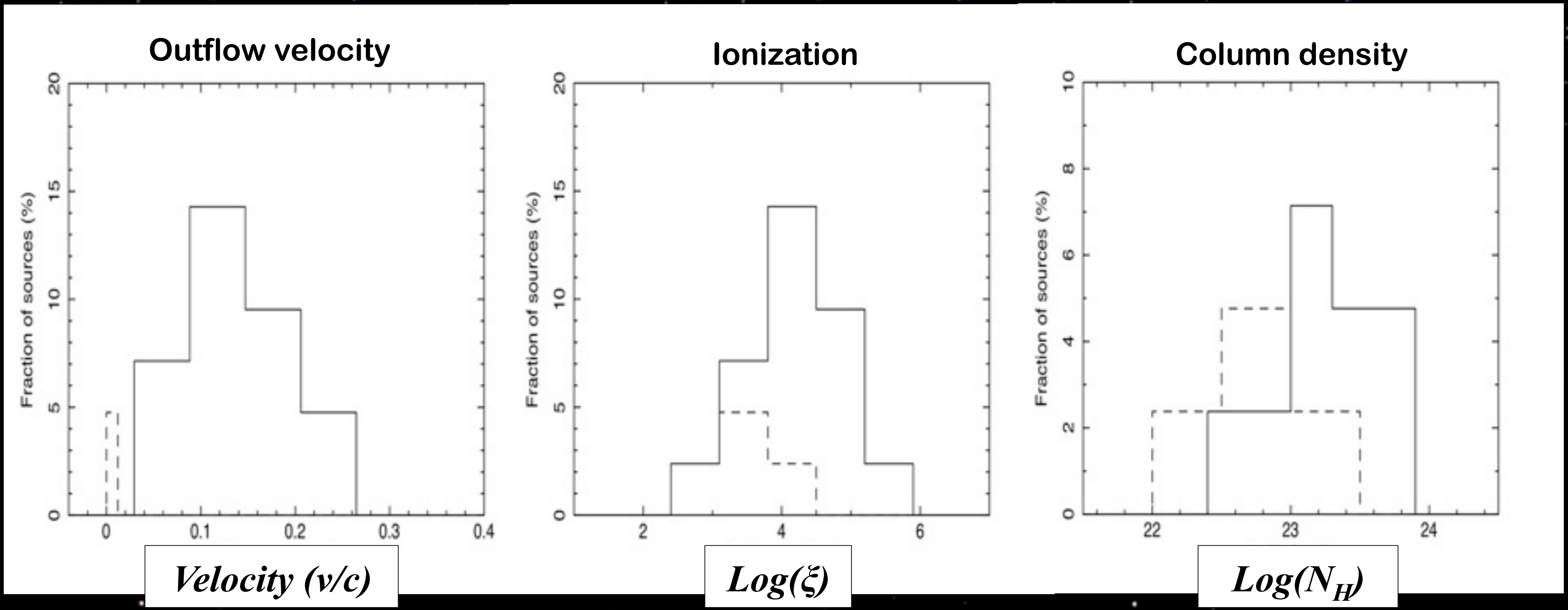




Tombesi et al. (2011a)

- Extensive curve of growth analysis Fe XXV-XXVI absorption lines
- Blind search for Xstar solution(s) stepping redshift between 0.1 and -0.4, min χ^2
- Fits take into account lines and edges from ions of all elements
- If two equivalent solutions, averaged parameters and included identification errors
- Fits significance >99%, line velocity broadening σ~1000-5000km/s

Global parameters of UFOs



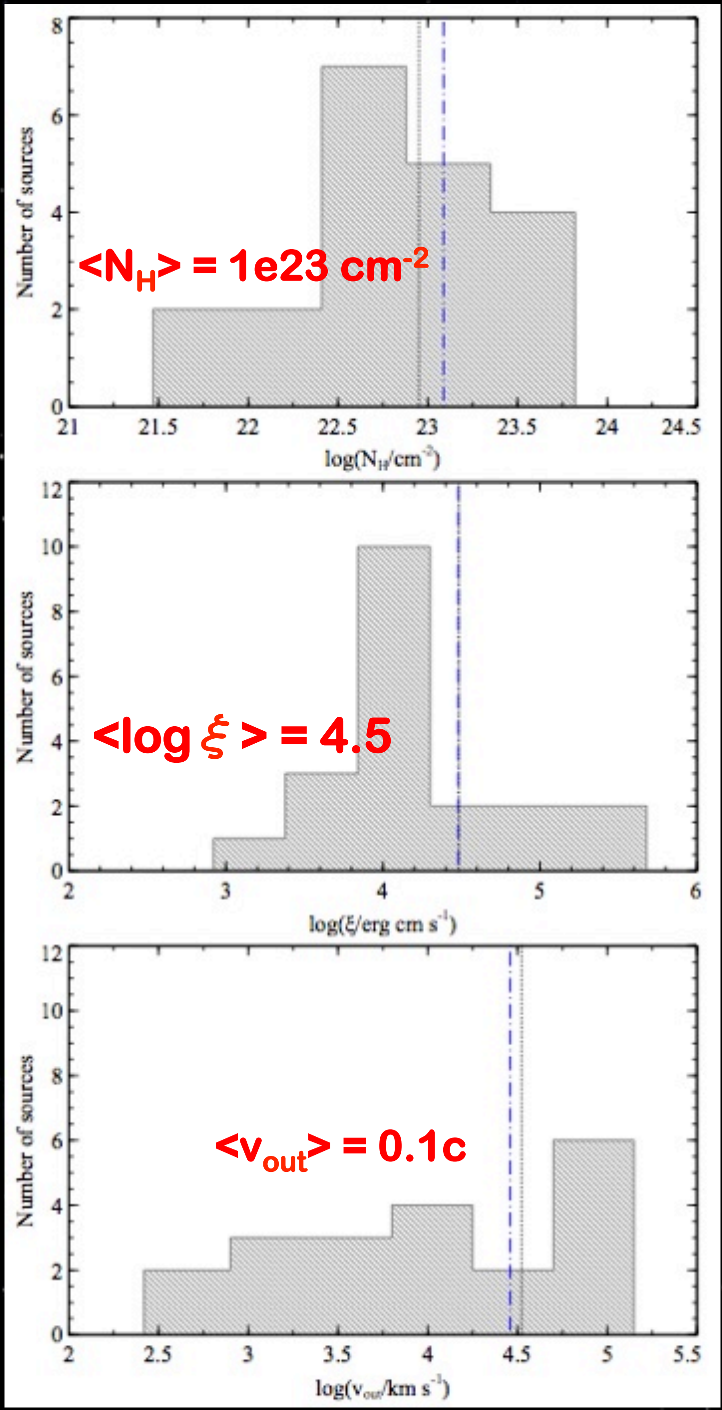
- UFO detected in >40% of the sources, large covering fraction ~0.5
- Spectral variability on time-scales even of ~days, compact absorbers
- Mildly-relativistic outflow velocities, distribution ~0.03-0.3c, with mean ~0.1c
- Highly ionized, log ξ ~2.5-6 erg s^{-1}cm, with mean ~4.2 erg s^{-1}cm
- Large column densities, N_H~10^{22}-10^{24}cm^{-2}, with mean ~10^{23}cm^{-2}

(Tombesi et al. 2011a)

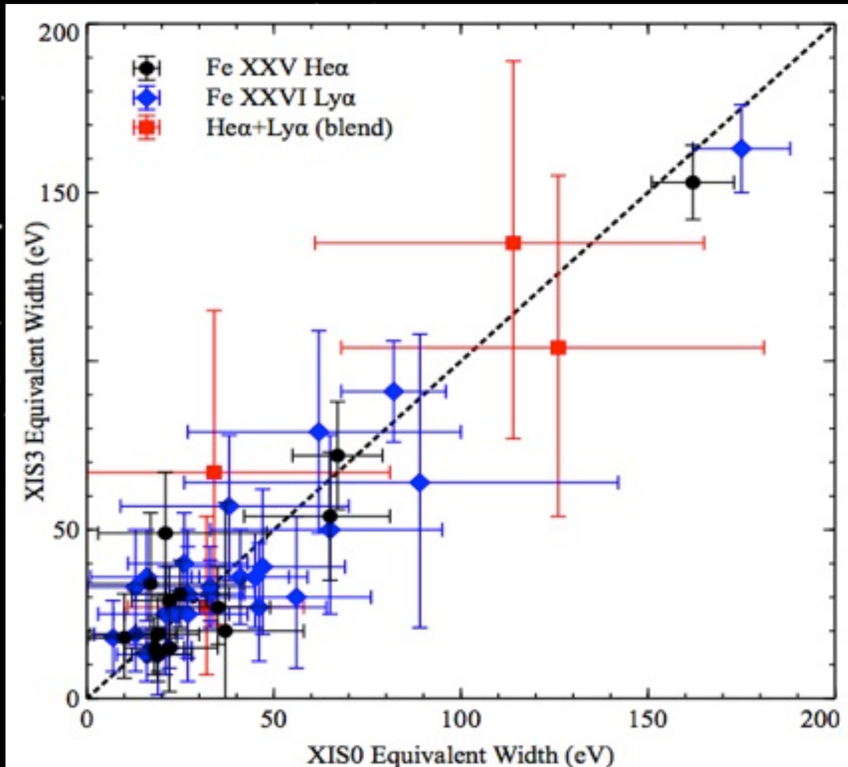
Independent Suzaku analysis

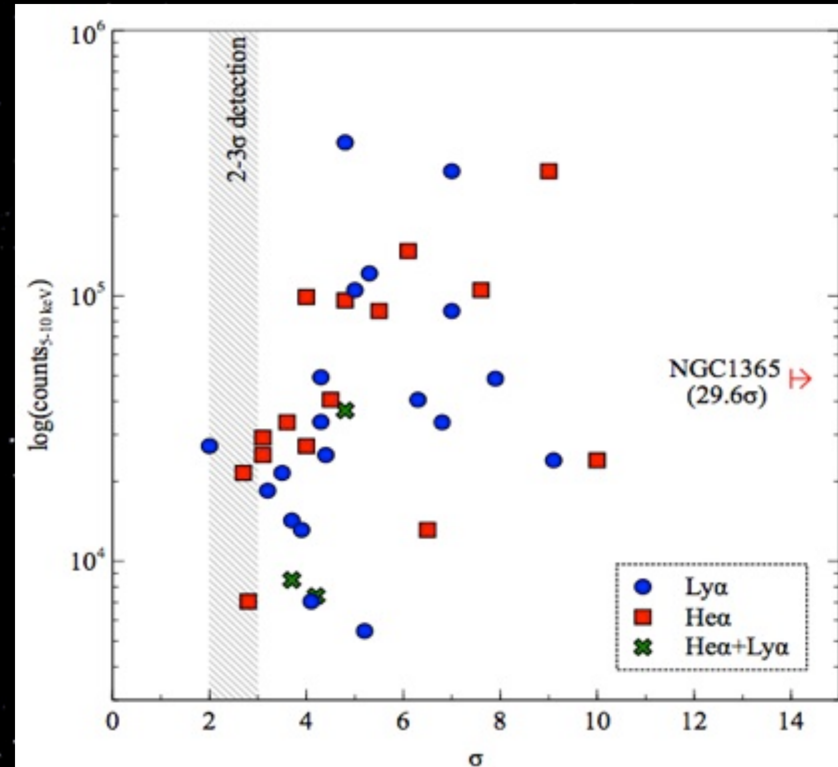
(Gofford et al. 2013)

- Heterogeneous sample of 51 AGNs (Quasar, Seyferts, radio galaxies) for 99 observations
- No restriction on redshift, z~0-4
- No velocity threshold at 10,000km/s
- Systematic broad-band E=0.6-40keV spectral analysis using complex models
- Fe XXV/XXVI absorption line search and extensive Monte Carlo simulations
- Xstar photo-ionization modeling
- UFO detected in ~40% of the sources
- Consistent with XMM-Newton based results



Independent Suzaku analysis

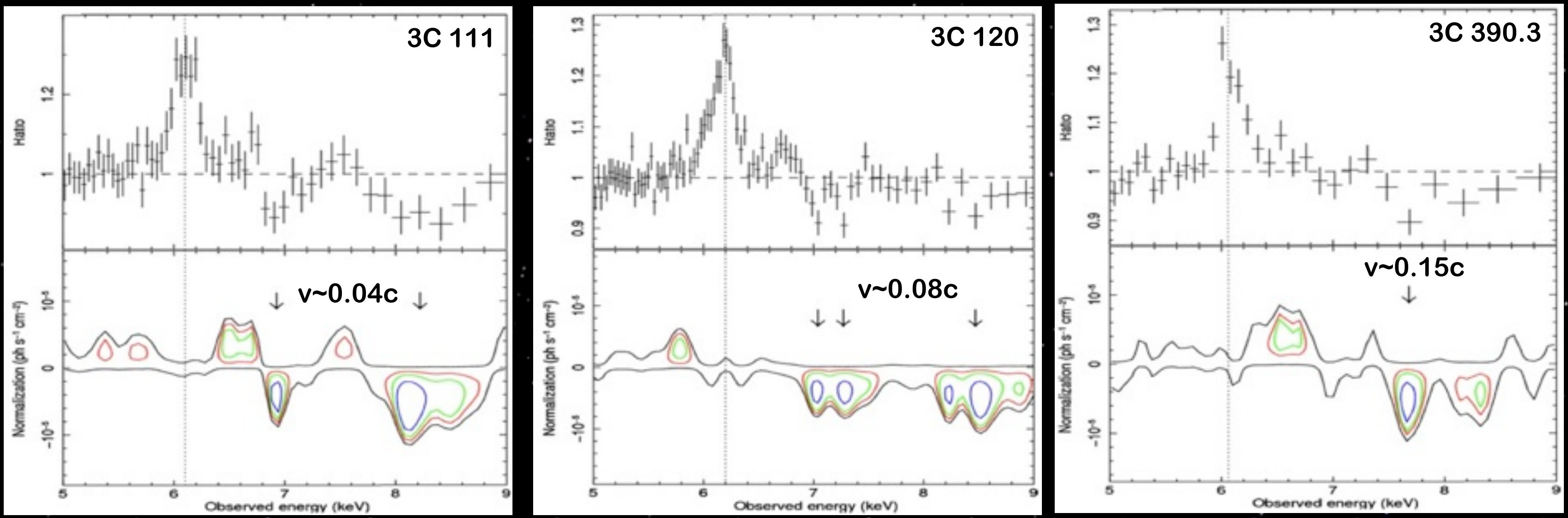




- No background or systematic problems
- Consistent results between separated XIS cameras
- Majority single lines detected at >>3σ
- Significant trend (>99%) of increasing detection level for higher counts
- Global random probability of Fe K abs lines is very low, $P_{null}<5\times10^{-18}$

(Gofford et al. 2013)

Ultra-fast outflows in broad-line radio galaxies

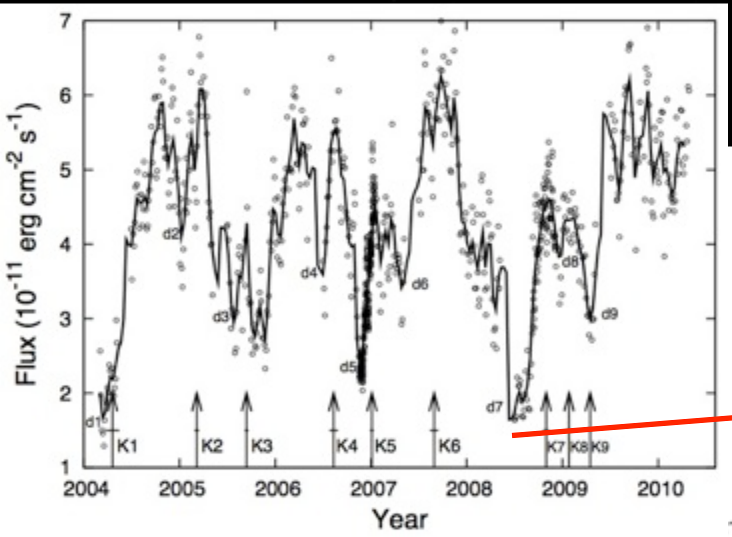


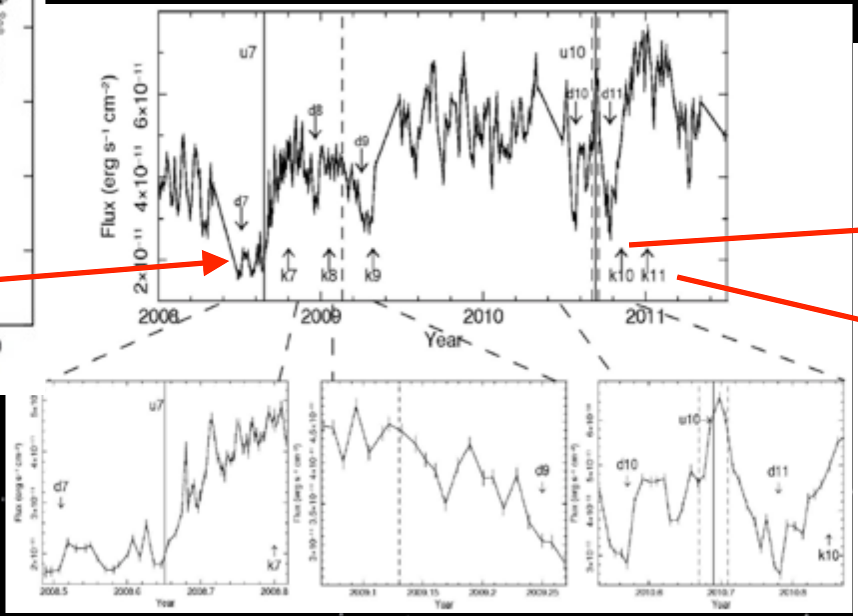
- **BLRGs are the radio-loud counterpart of Seyferts** (some Seyferts show jets too)
- **Suzaku observations 5 sources, same analysis as XMM-Newton in 4-10keV**
- **Blue-shifted Fe XXV-XXVI absorption lines detected in 3/5 sources, P>99%**
- **High ionization logξ=4-6 erg s^{-1}cm, v=0.04-0.15c, high columns $N_H > 10^{22}$ cm^{-2}**
- **WAs recently reported** (Reeves et al. 2009; Torresi et al. 2010, 2012)

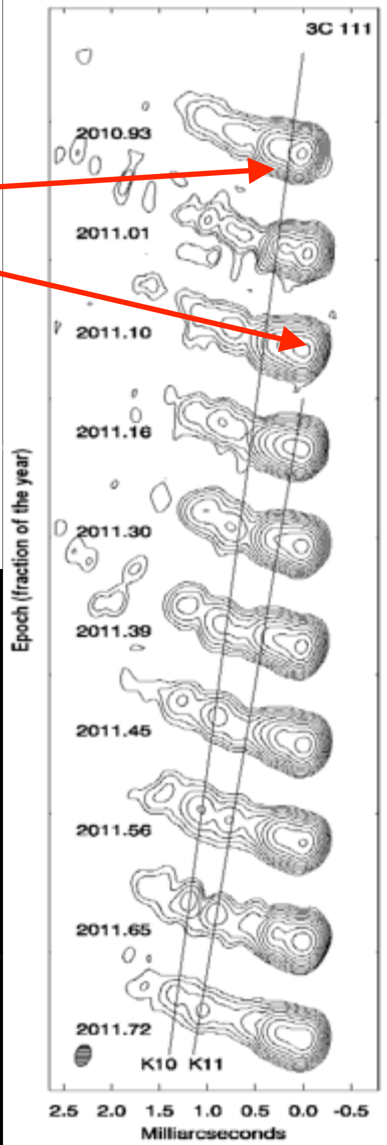
(Tombesi et al. 2010b)

Comparison with jet ejection events in 3C 111

(Tombesi et al. 2012b)

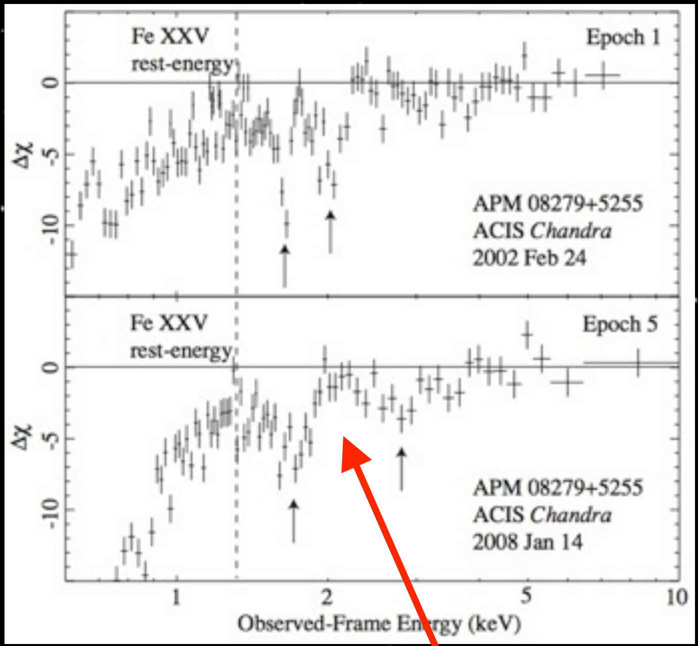


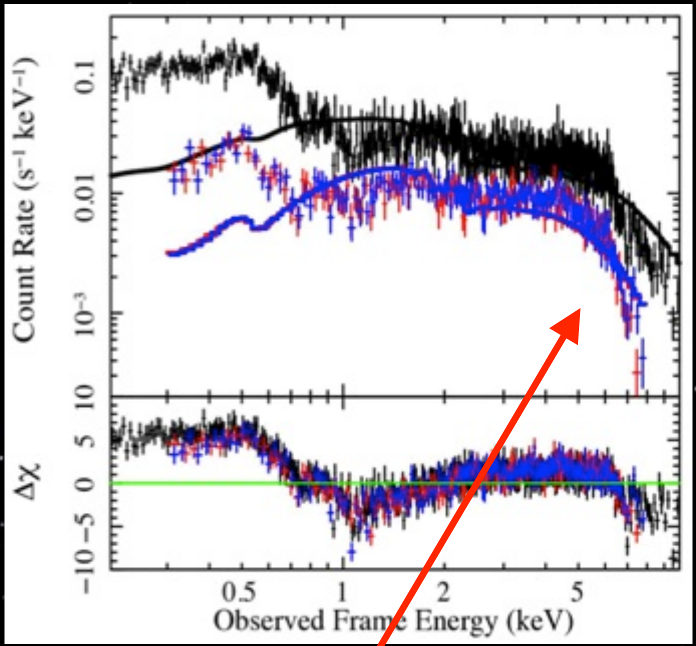


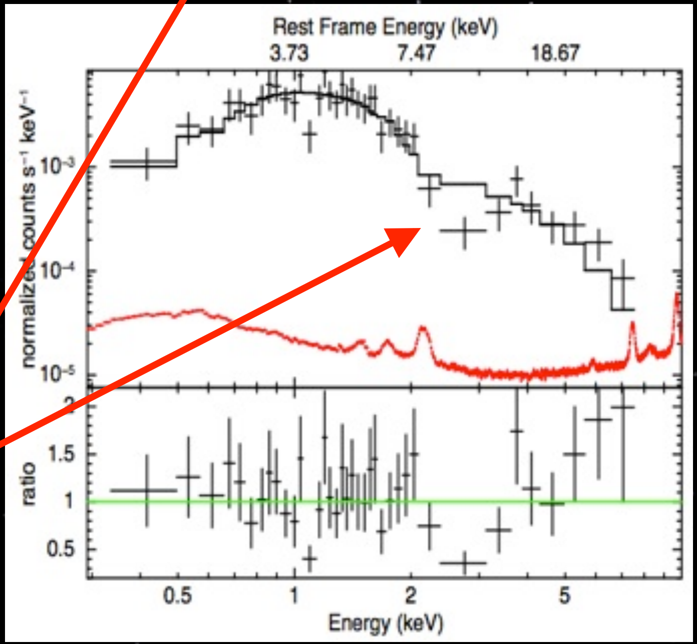


- Correlation between X-ray dips & new radio jet knots (Chatterjee+ 2011)
- UFO detection episodes on long term 2-10keV RXTE monitoring
- Tracking jet ejections with milliarcsec resolution VLBA radio images
- UFOs possibly stronger during X-ray dips/disk-jet ejection cycles
- MHD disk outflows may provide pressure support for the jet collimation (Fukumura, Tombesi et al. ApJ submitted)

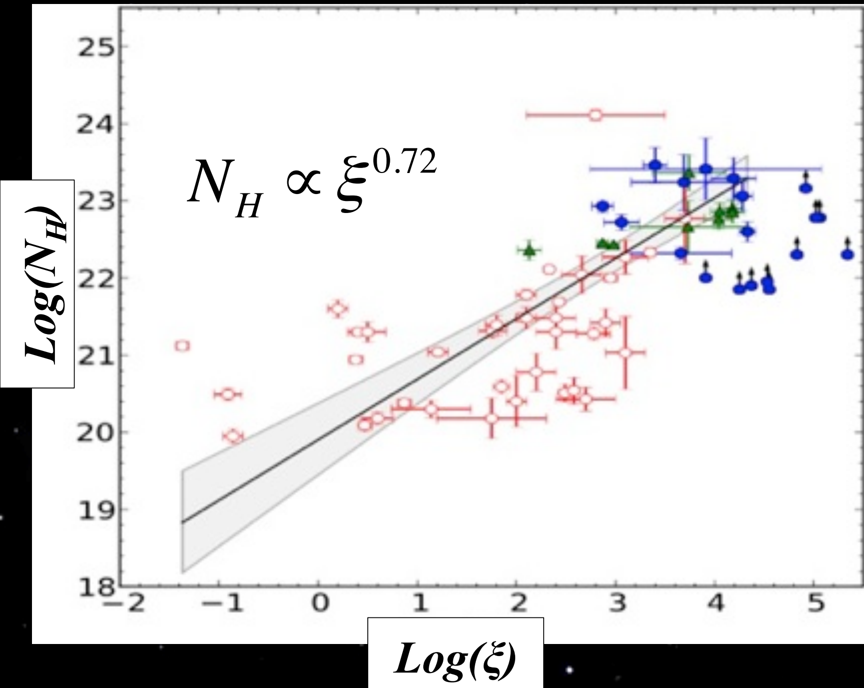
UFOs in quasars

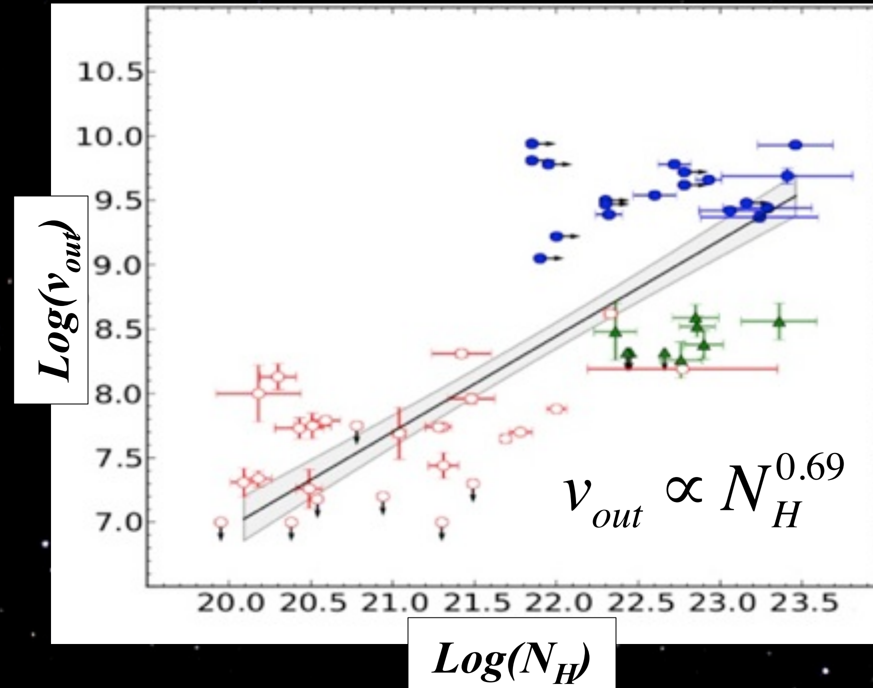


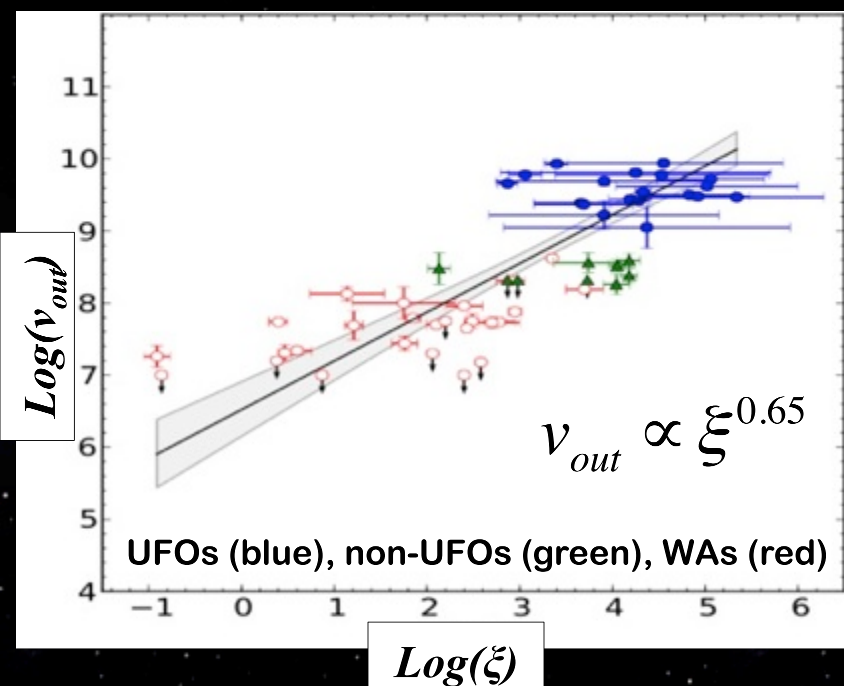




- **Gravitationally lensed BAL quasar APM08279+5255 (z = 3.9), XMM-Newton and Chandra observations, v_{out}~0.2-0.7c (Chartas et al. 2009)**
- **Mini-BAL QSO PG1126-041, XMM-Newton obervations, v_{out}~16,500 km/s (Giustini et al. 2011)**
- **NAL QSO HS1700+6416 (z= 2.7) ,Chandra observations, v_{out}~0.1-0.6c (Lanzuisi et al. 2012)**

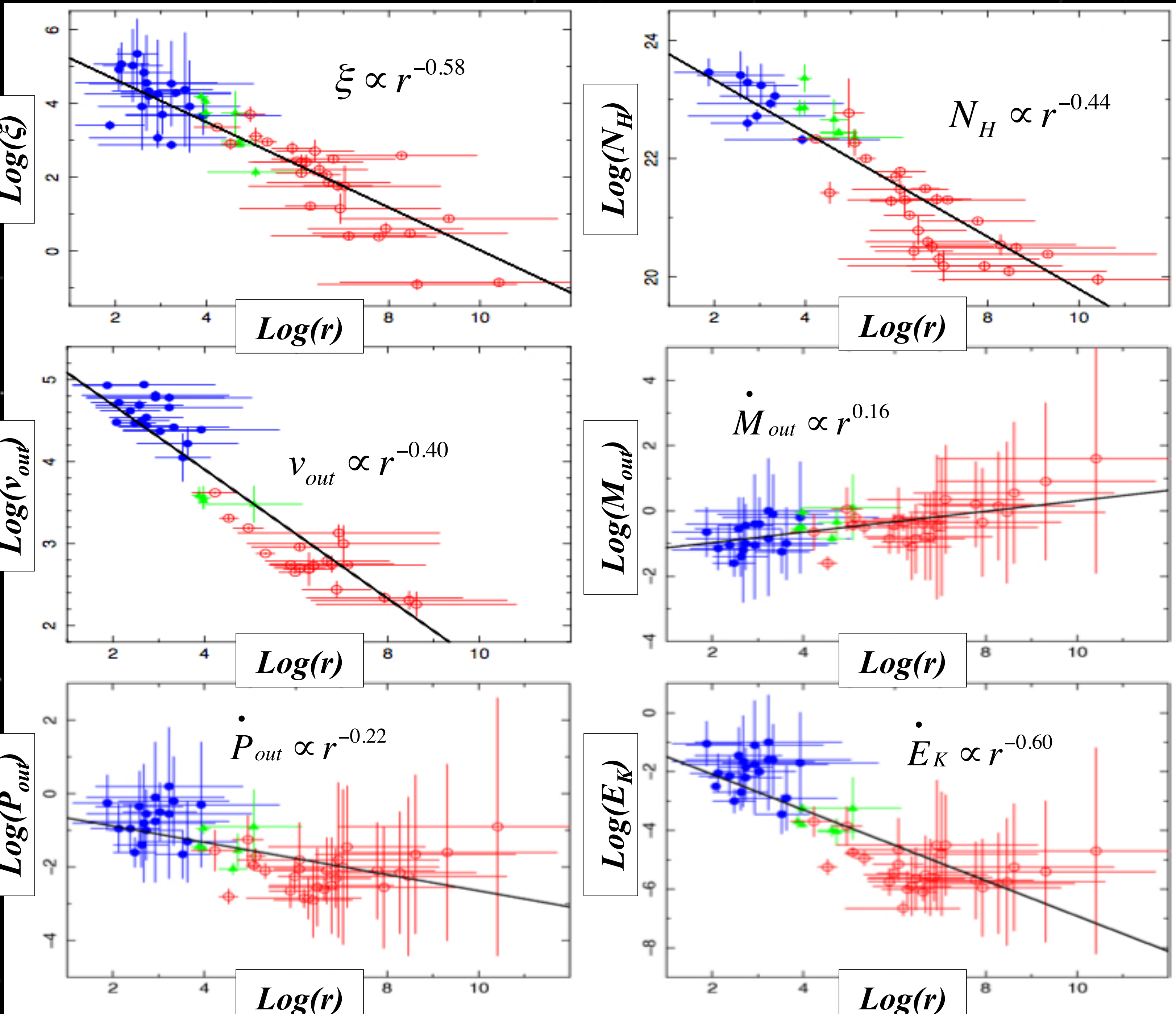




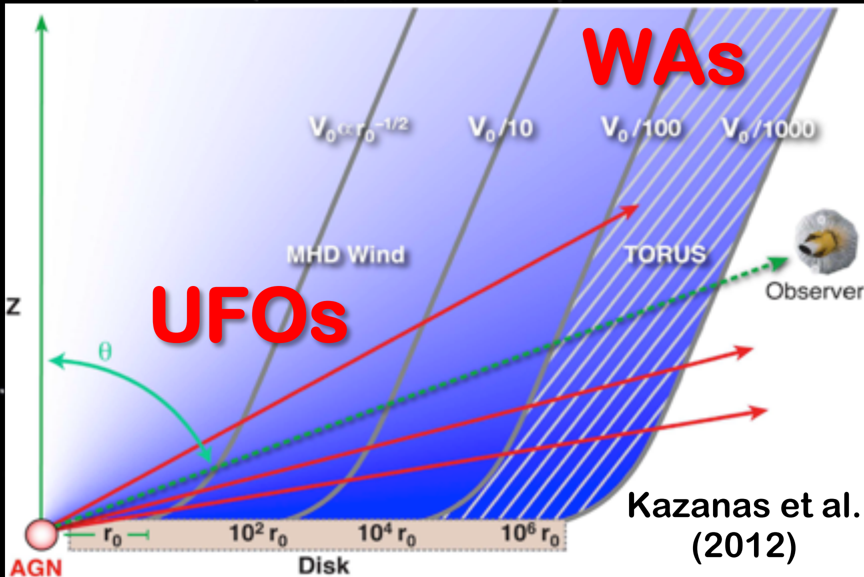


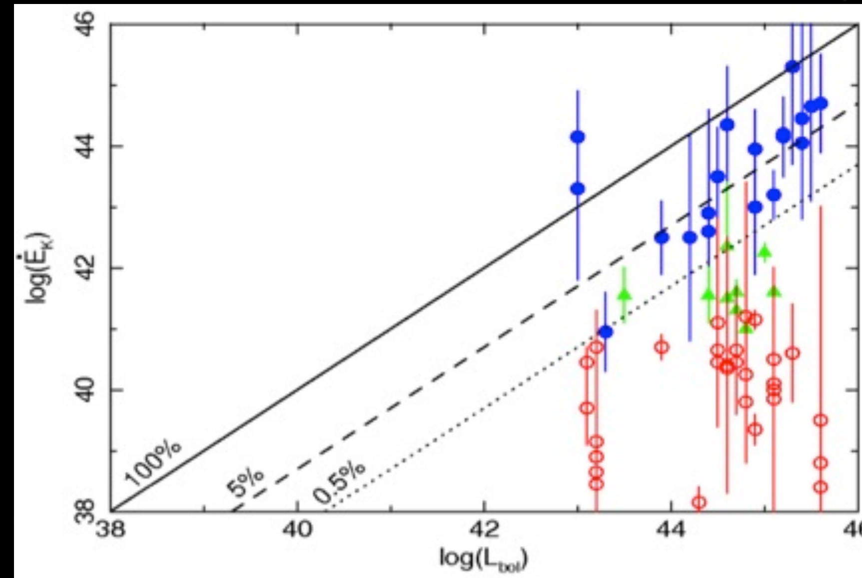
- **Comparison of UFOs and WAs in sample of 35 Seyfert 1 galaxies**
- **WAs found in >60% sources**
- **UFOs in >40%, >70% also WAs**
- **Significant (>6σ) correlations**

Tombesi et al. (2013)



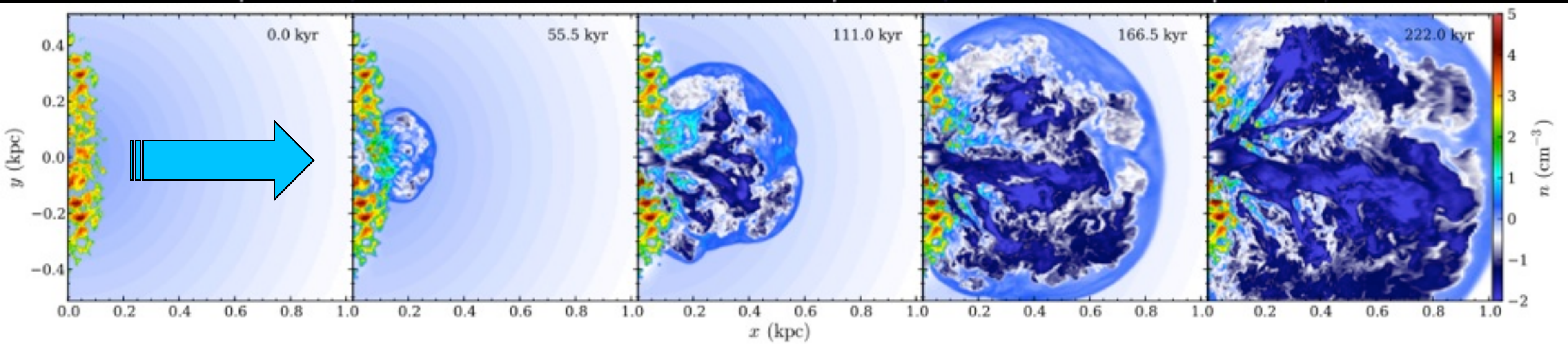
$\xi \propto r^{-0.58}$
Log(ξ)
Log(r)
$N_H \propto r^{-0.44}$
$Log(N_H)$
Log(r)
$v_{out} \propto r^{-0.40}$
$Log(v_{out})$
Log(r)
$\dot{M}_{out} \propto r^{0.16}$
$Log(M_{out})$
Log(r)
$\dot{P}_{out} \propto r^{-0.22}$
$Log(P_{out})$
Log(r)
$\dot{E}_K \propto r^{-0.60}$
$Log(E_K)$
Log(r)





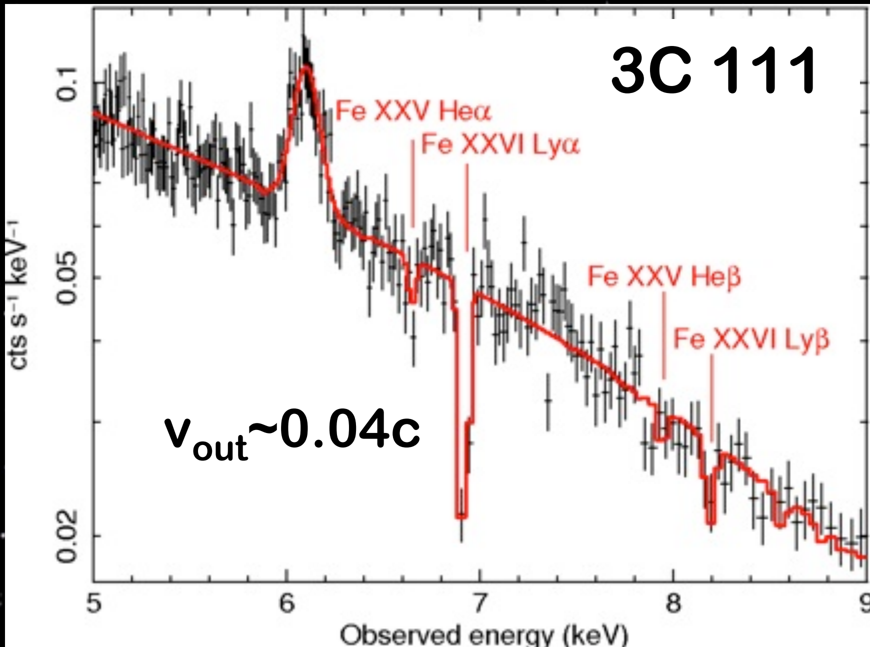
- Unification as large-scale, multi-phase AGN outflow
- UFOs inner/faster part of the flow. Interaction with ISM at large distances
- Density $n \sim r^{-1.4}$, conical/bipolar geometry; velocity $v_{out} \sim r^{-1/2}$, escaping wind
- High ionization and velocity. Acceleration through Compton scattering (e.g., King & Pounds 2003; King 2010) and/or MHD (e.g., Ohsuga et al. 2009; Fukumura et al. 2010; Kazanas et al. 2012)
- UFO mechanical power >>0.5% L_{bol} (Tombesi et al. 2012a), some WAs as well if added (Crenshaw & Kraemer 2012), > minimum for AGN feedback (e.g., Di Matteo et al. 2005; Hopkins & Elvis 2010)

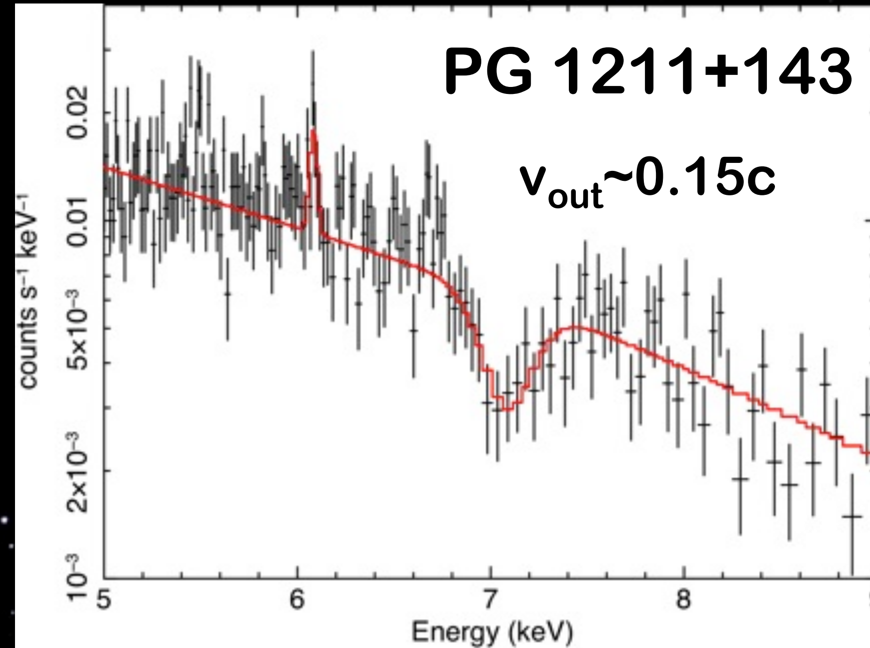
Simulations of UFO feedback

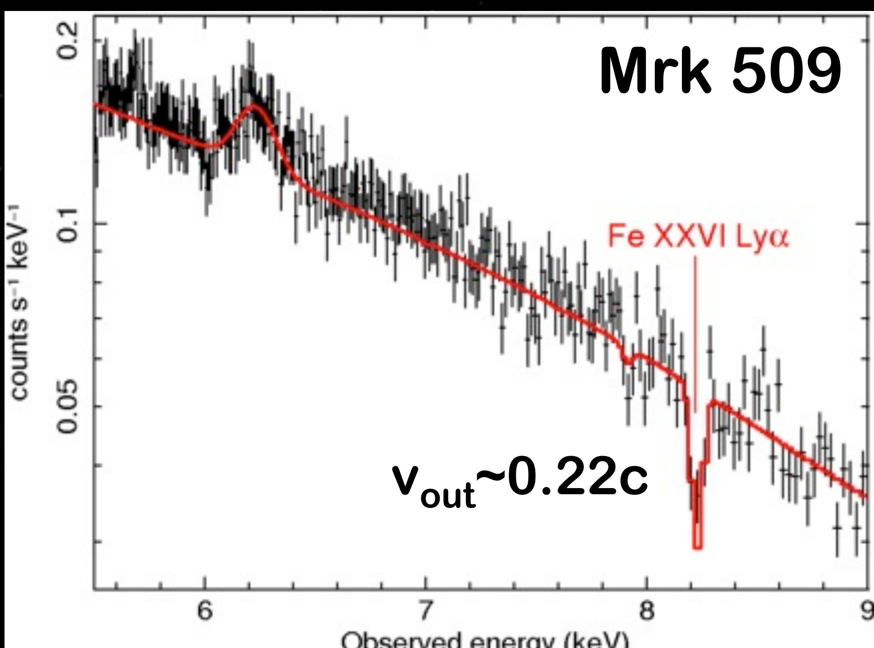


(Wagner et al. 2013)

- Simulations show that UFOs, and AGN winds in general, can induce significant feedback
- UFOs are wide angle, massive, mildly-relativistic, > incidence than jets
- Can explain SMBH-galaxy relations (e.g., King 2010; Zubovas & King 2012)
- Quench or sometimes trigger star formation (Nayakshin & Zubovas 2012)
- Mass loss can limit SMBH growth
- Can influence galaxy evolution (e.g., Gaspari et al. 2012; Wagner et al. 2013)







X-RAY OBSERVATORY
ASTRO-H