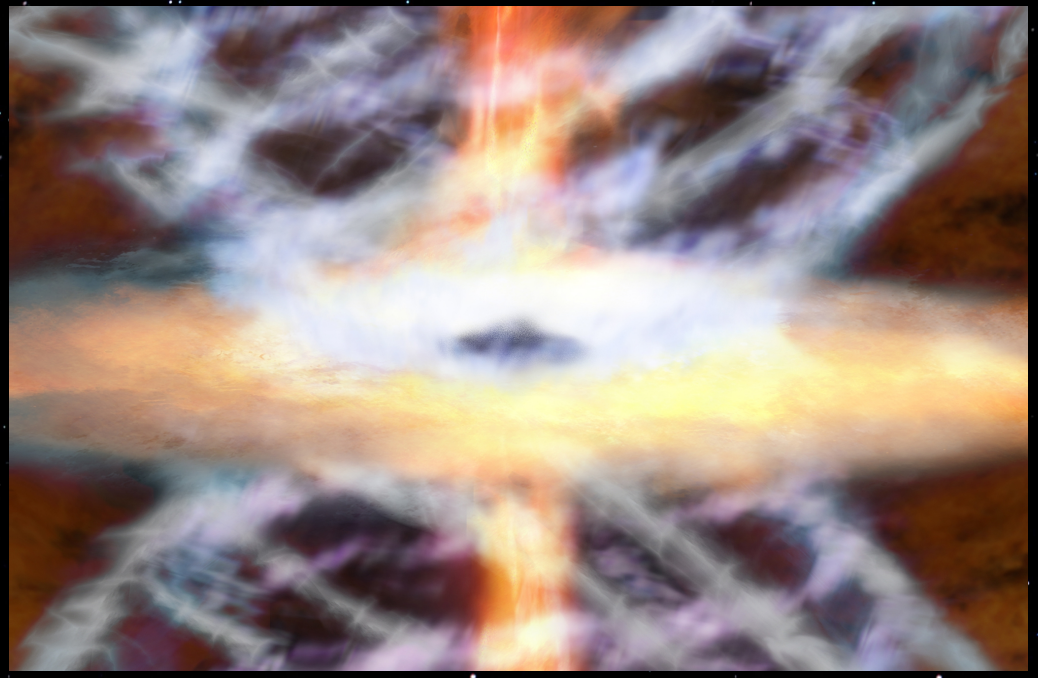
X-ray evidence for ultra-fast outflows in AGNs



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Collaborators: M. Cappi, J. Reeves, R. Sambruna, C. Reynolds, V. Braito, G. Palumbo, M. Dadina, R. Mushotzky, J. Gofford, K. Fukumura, D. Kazanas, R. Nemmen, A. Marscher, …

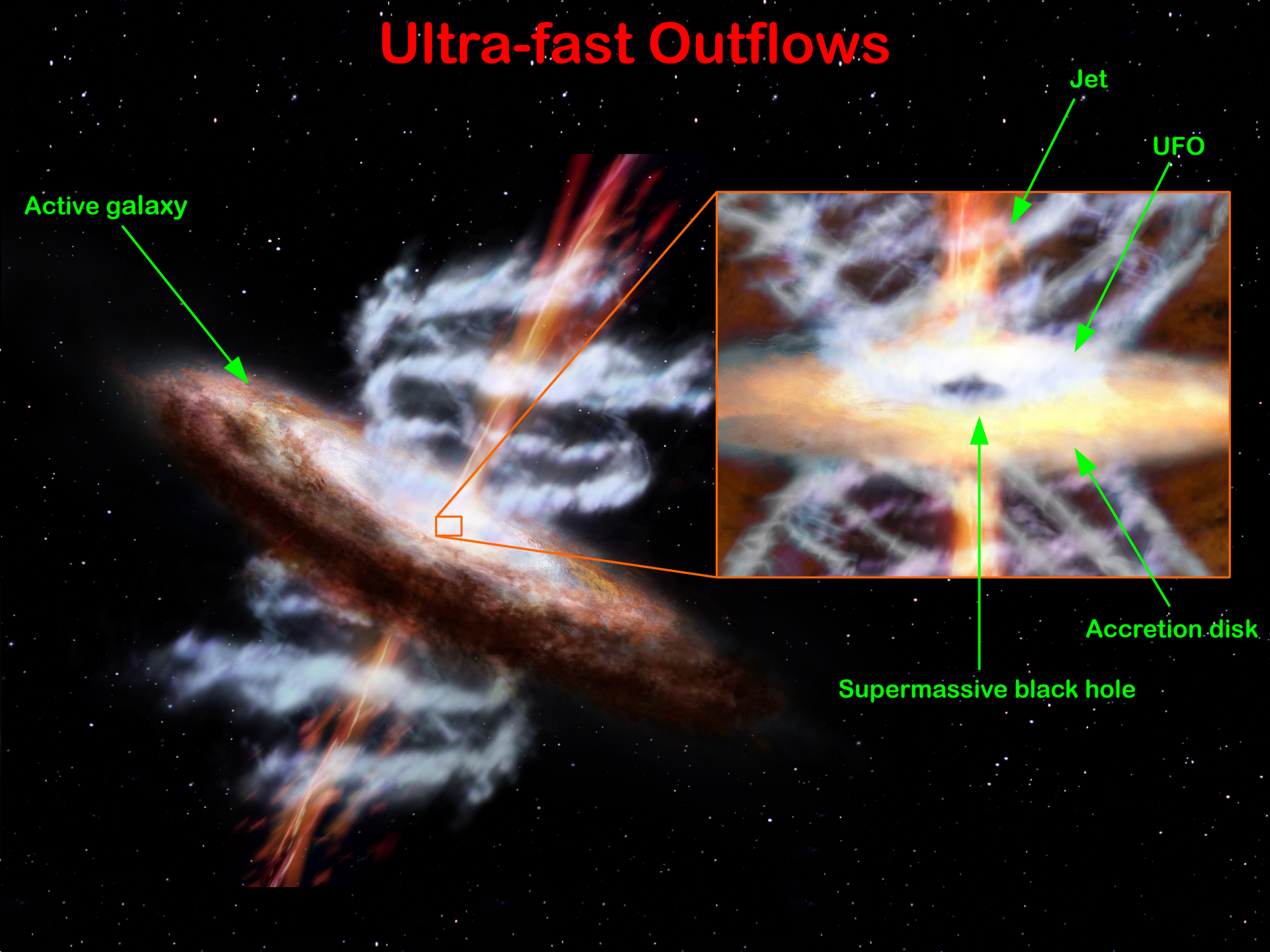
What is a UFO?

A rock band?

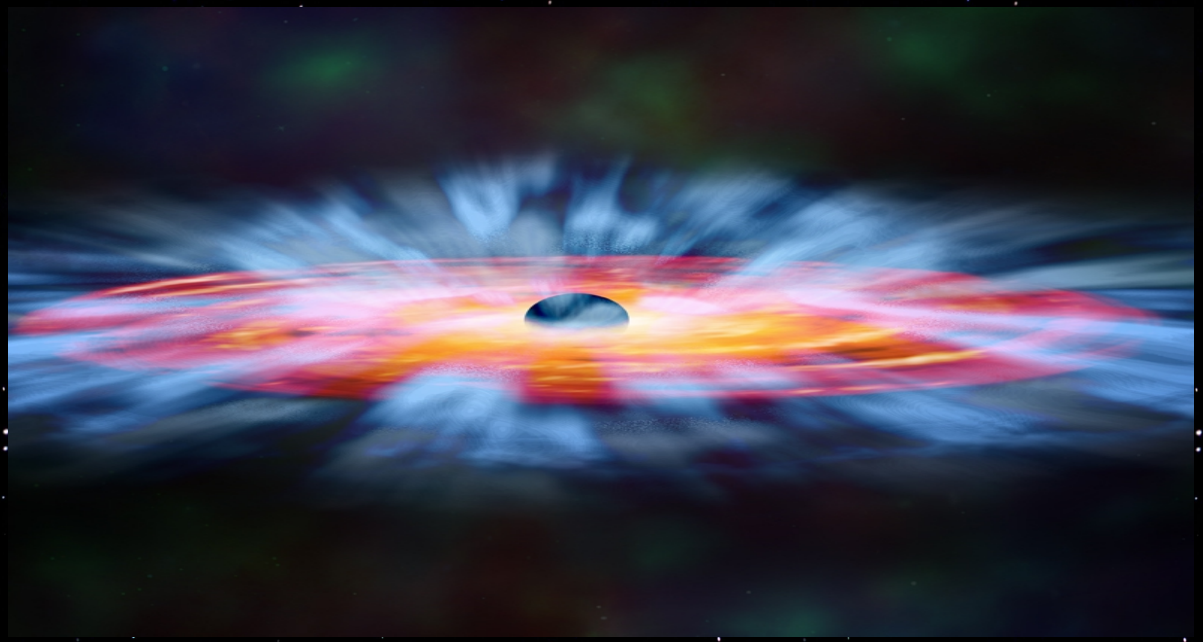
…a beer?

..or an alien invasion?

Ultra-fast Outflows



X-ray evidence for ultra-fast outflows in AGNs



- **Blue-shifted Fe XXV/XXVI absorption lines indicate the presence of highly ionzied and mildly relativistic X-ray outflows in 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; ...)

- **Evidences in stellar-mass black holes are emerging too** (King et al. 2012; Chiang et al. 2012)

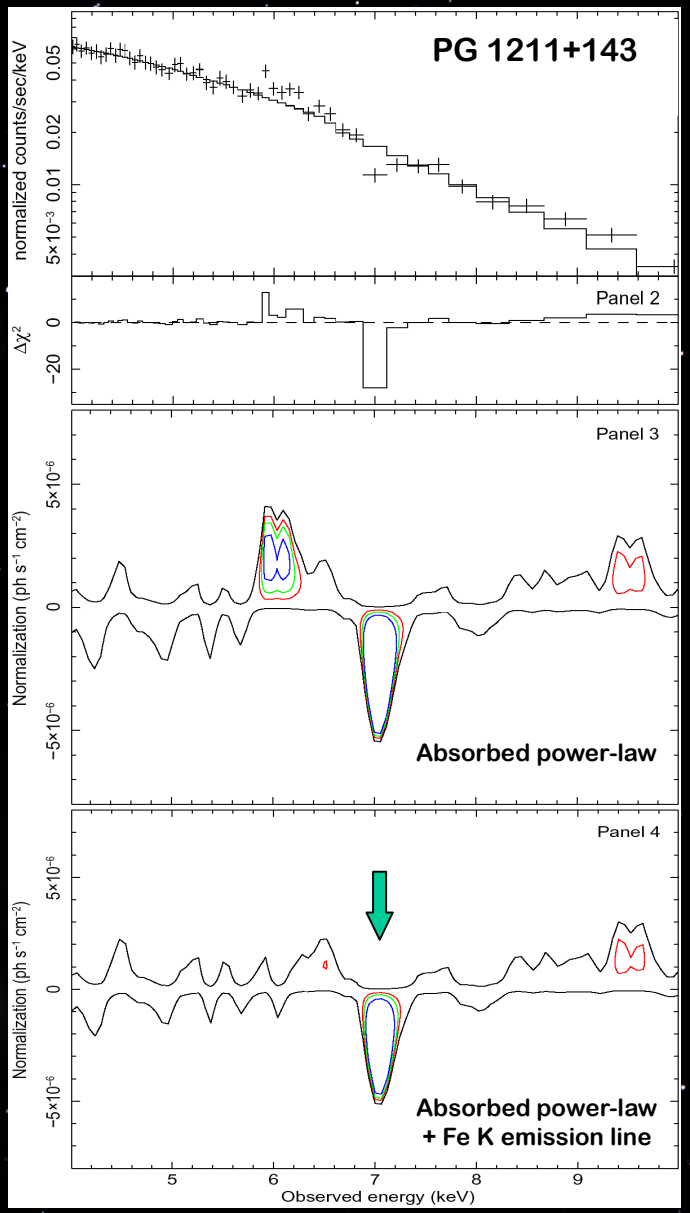
- **Possible connection with accretion disk winds and contribution to AGN feedback**

- **Need for a systematic analysis of a complete sample of sources**

The sample of local Seyferts

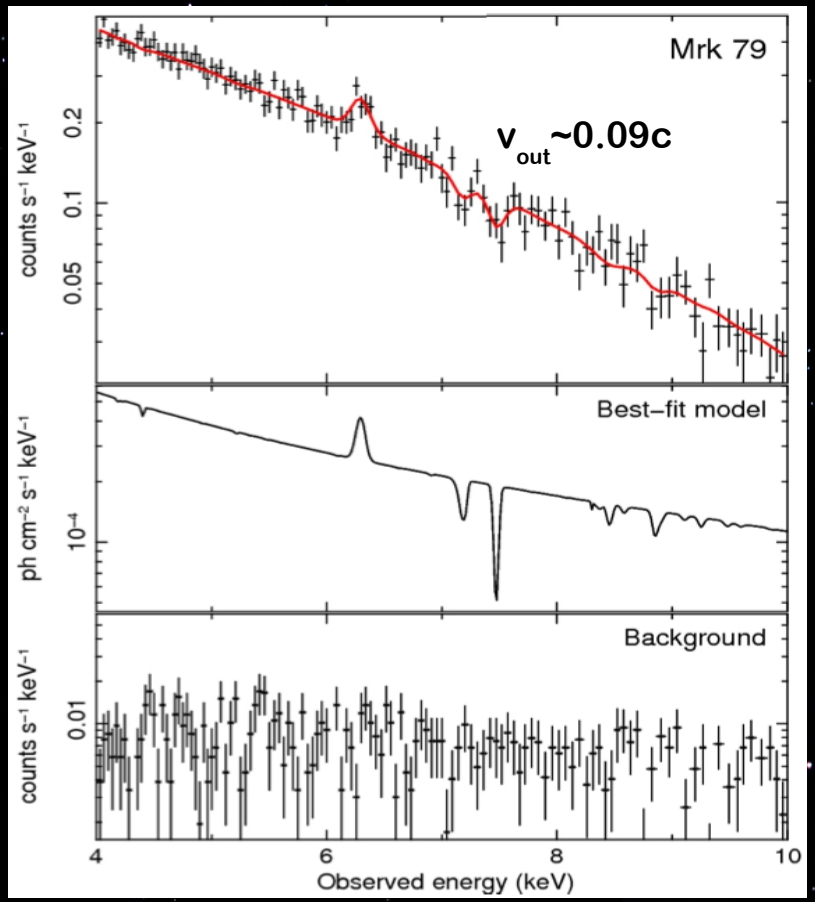
Ultra-Fast Ouflows (UFOs): v≥10,000km/s
(warm absorbers v<1000km/s)

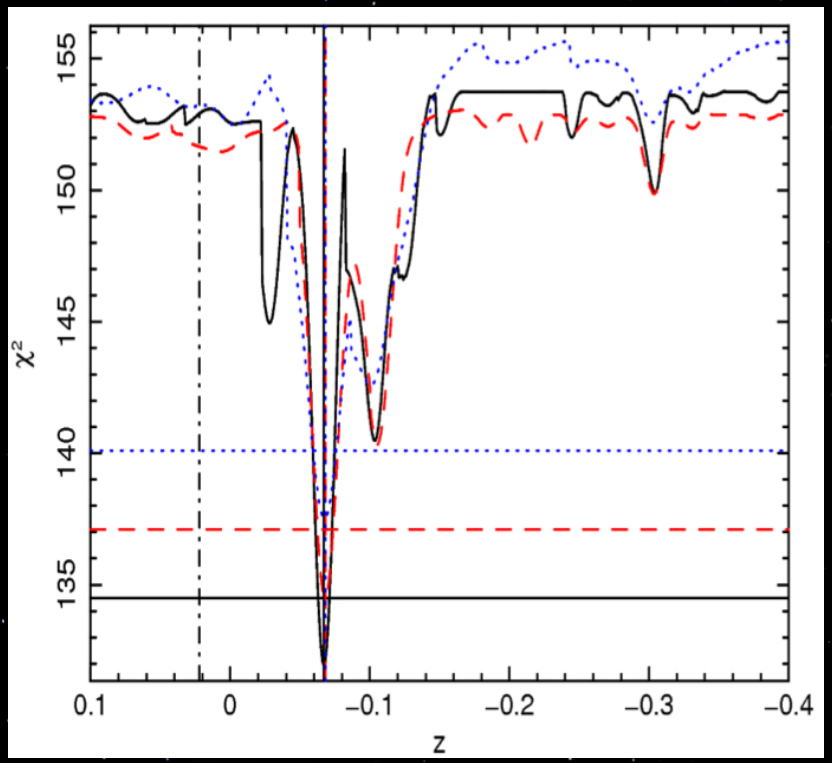
- Selection of all the NLSy1, Sy1 and Sy2 (N_H<10^{24}cm^{-2}) in the RXTE All-Sky Slew Survey Catalog
- Cross-correlation with XMM-Newton Accepted Targets Catalog (as of October 2008)
- Total of 42 sources for 101 pointed XMM-Newton observations
- Local (z<0.1) and X-ray bright ($F_{4\text{-}10keV}$=10^{-12}-10^{-10} erg s^{-1} cm^{-2})
- Uniform 4-10keV EPIC-pn spectral analysis, baseline model absorbed power-law + Gaussian emission lines
- Absorption line search, 36 detections E=6.4-10keV (P_F>99%)
- Extensive MC simulations, 22 lines E>7.1keV (P_{MC}>95%)
- Global random probability in 21/101 obs is <10^{-8} (>5σ)
- Consistency with simultaneous EPIC-MOS observations
- Solved the claimed publication bias (Vaughan & Uttley 2008)



(Tombesi et al. 2010a)

Photo-ionization modeling Fe XXV/XXVI absorption lines

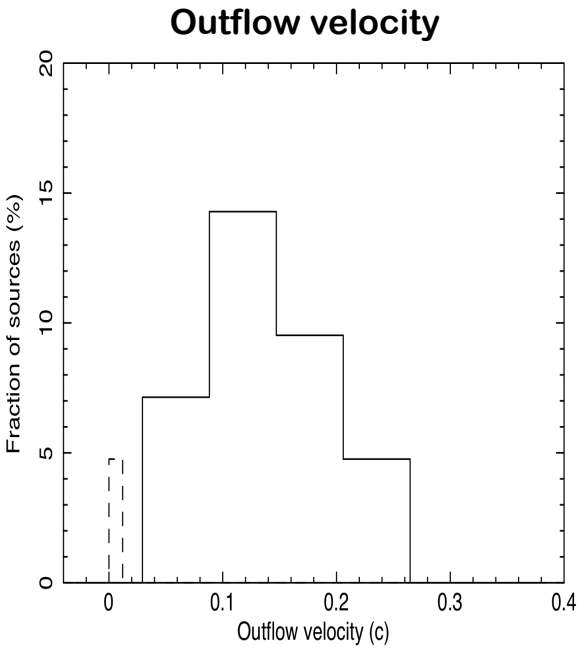


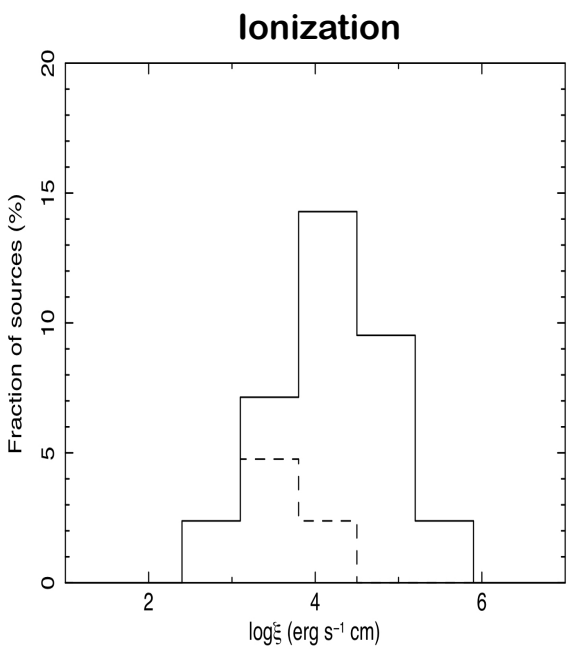


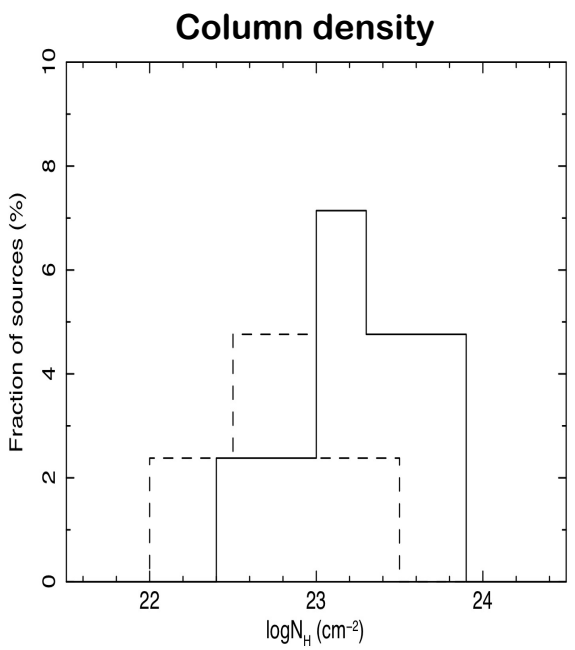
Tombesi et al. (2011a)

- 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



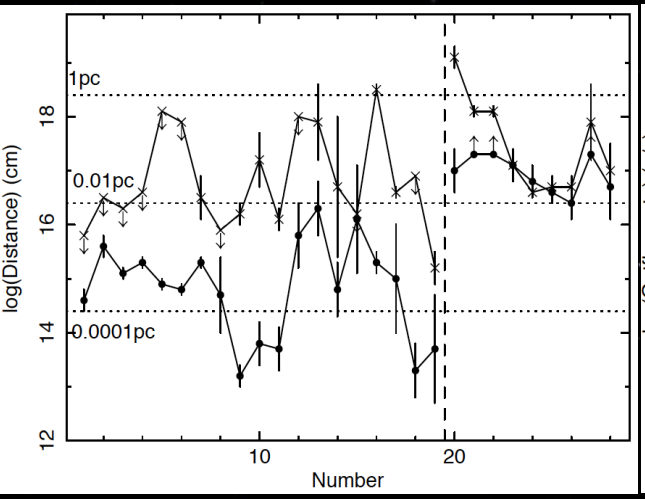




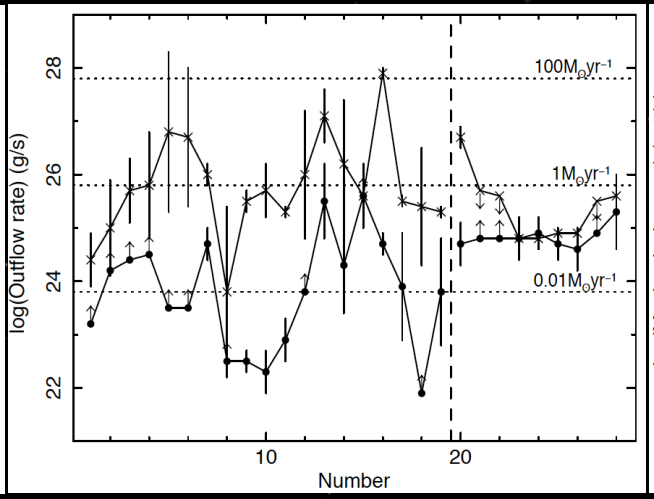
- UFO detected in >40% of the sources, large covering fraction ~0.5
- Spectral variability on time-scales even of ~days, compact absorbers
- Mildly-relativistic outflow velocities, distribution ~0.03-0.3c, with mean ~0.14c
- Highly ionized, logξ~2.5-6 erg s^{-1}cm, with mean ~4.2 erg s^{-1}cm
- Large column densities, N_H~10^{22}-10^{24}cm^{-2}, with mean ~10^{23}cm^{-2}
- Consistent results obtained from a broad-band Suzaku analysis (Gofford et al. in prep)

(Tombesi et al. 2011a)

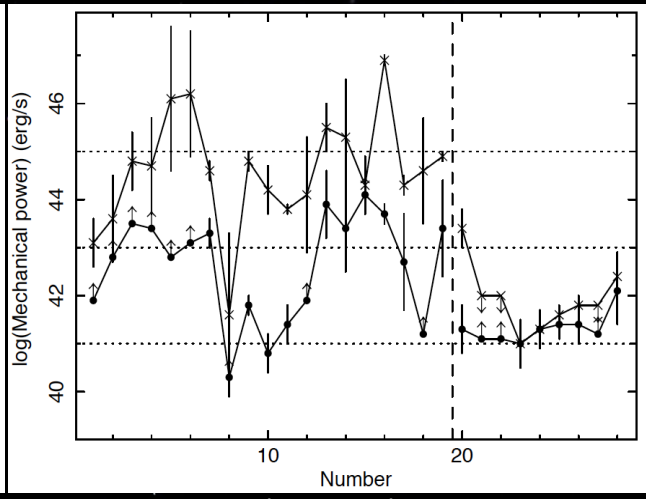
Location and energetics of UFOs



Location



Mass outflow rate

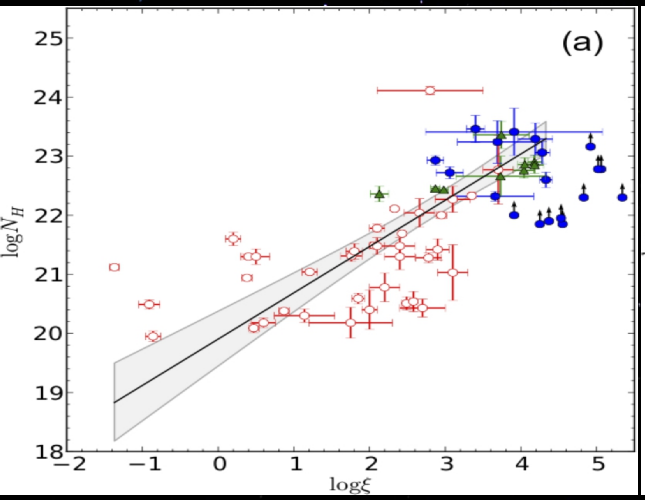


Mechanical power

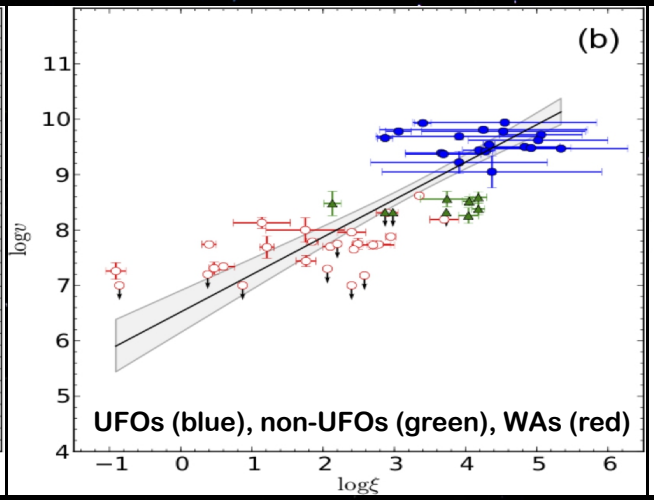
- Distance from BH ~0.0003-0.03pc (~10^2-$10^4 r_s$), accretion disk outflows
- Mass outflow rate ~0.01-1M_{sun}/yr, large solid angle (θ~60°)
- Mechanical power ~10^{42}-10^{45}erg/s, >0.5% L_{bol}
- Powerful enough to contribute to AGN feedback, as required by numerical simulations

(Tombesi et al. 2012a)

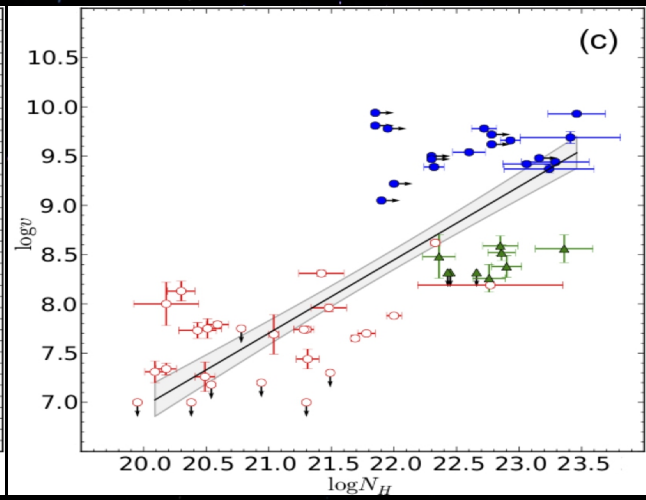
Comparison with warm absorbers (work in progress)



Ionization vs. column



Ionization vs. velocity

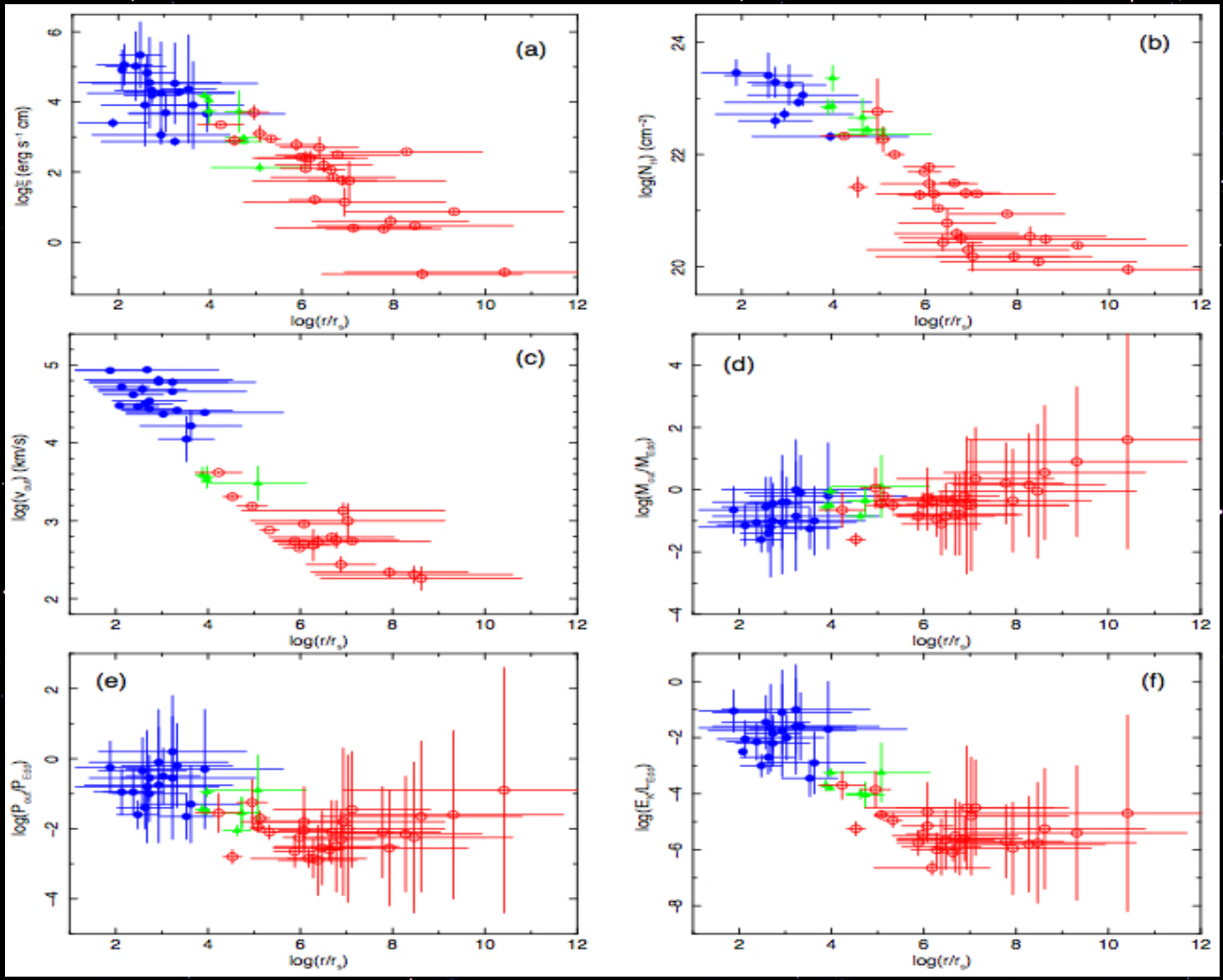


Column vs. velocity

- Literature search for WA analysis 35 type 1 Seyferts of Tombesi et al. (2010a) sample
- Selected studies with XMM-Newton and Chandra gratings (need velocity estimate)
- Fraction of sources with studied WAs is >60% (consistent with previous studies)
- Fraction of sources with UFOs >40%, >70% of these show also WAs
- If high S/N and detailed analysis, ubiquitous presence of ionized absorbers in Seyfert 1s
- Significant correlations between absorber parameters (ionization, column, velocity)

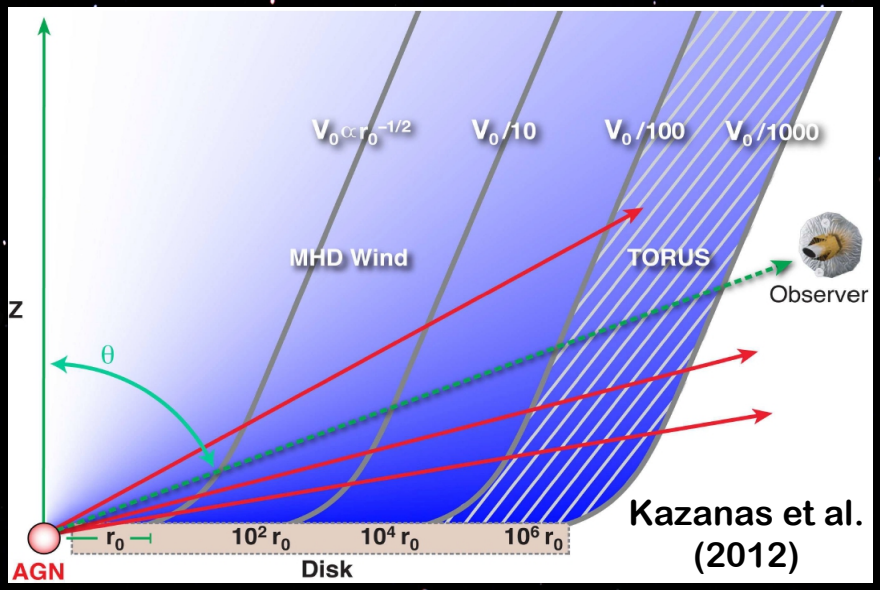
Tombesi et al. (in prep.)

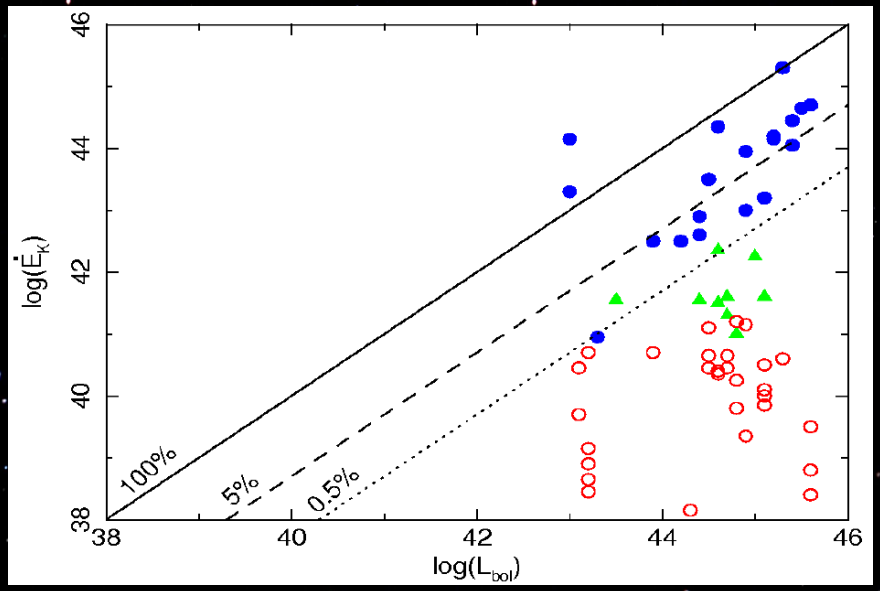
Comparison with warm absorbers (work in progress)



Continuous distribution of outflow parameters from UFOs to WAs

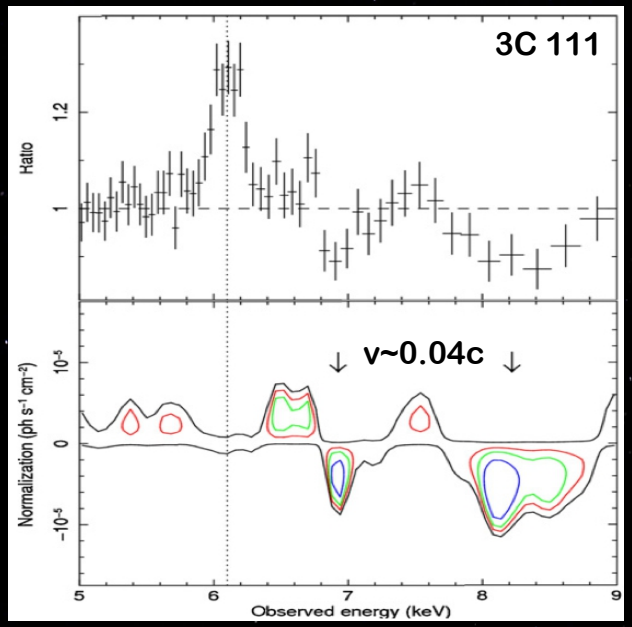
Comparison with warm absorbers (work in progress)

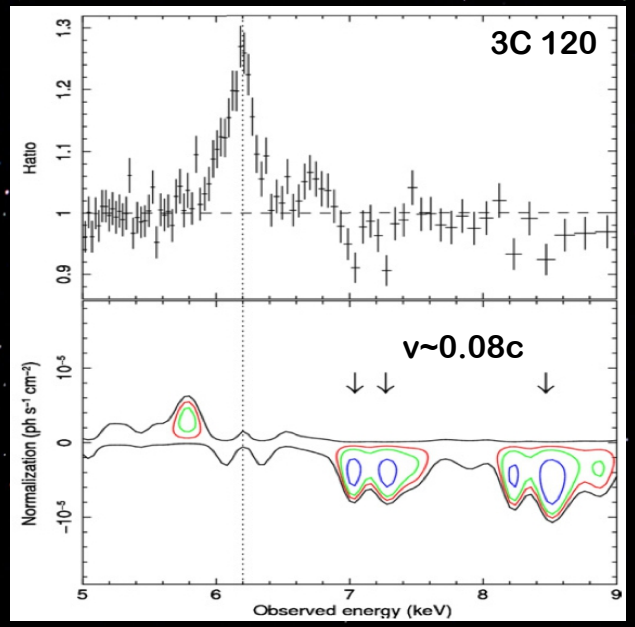


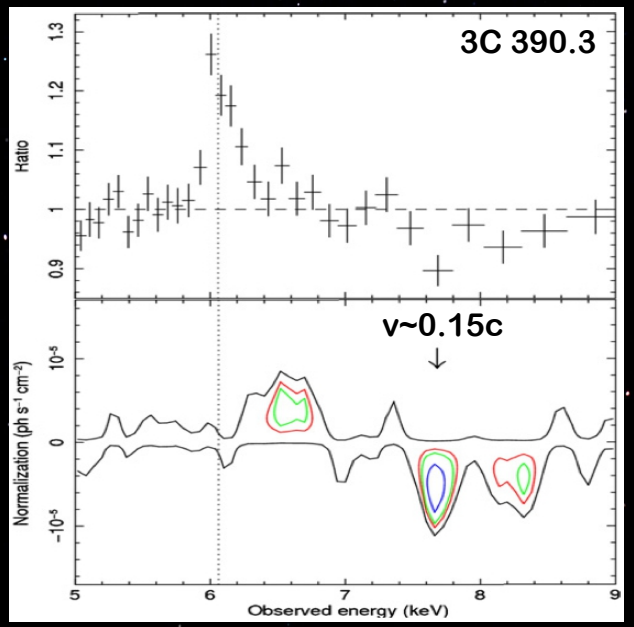


- **Unification in a single, large scale outflow?** (e.g., Pounds & Vaughan 2011; Kazanas et al. 2012)
- **UFOs inner and faster part of the flow, WAs slower and at higher distance**
- **Outflow ~ radiation momentum, UFO kinetic power >>0.5% L_{bol}, required for AGN feedback**
  (also some WAs if added; e.g., Crenshaw & Kraemer 2012)
- **High ionization, no UV line driving. Thomson scattering and/or MHD processes?**
- **Single, extended photo-ionized outflow consistent with ionization cones in Seyferts?**

Ultra-fast outflows in broad-line radio galaxies



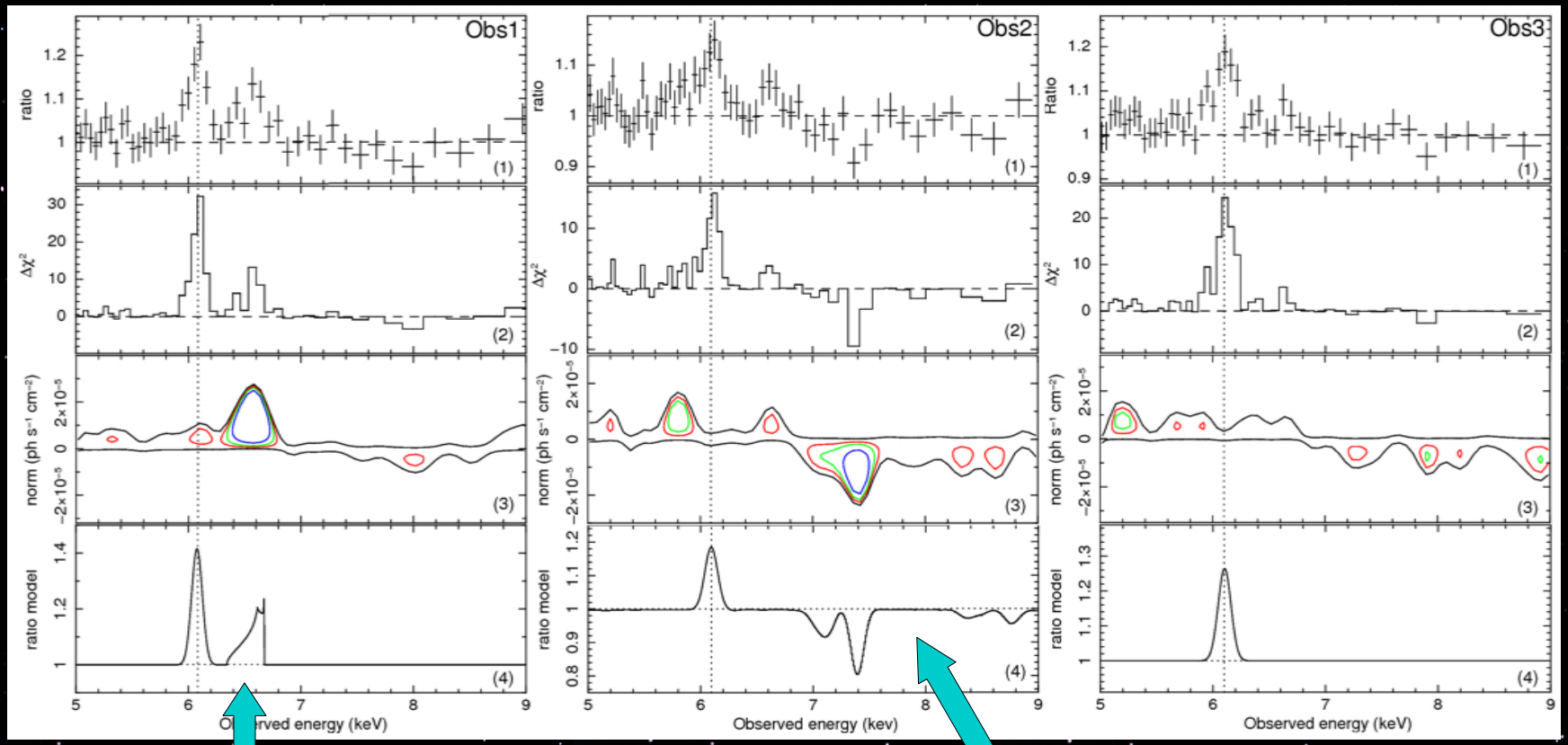




- **BLRGs are the radio-loud counterpart of Seyfert 1s** (N.B., some Seyferts show weak jets too)
- **Analyzed Suzaku observations 5 sources, same analysis as XMM-Newton in 4-10keV**
- **Several blue-shifted Fe XXV-XXVI K-shell absorption lines detected in 3/5 sources, P>99%**
- **High ionization logξ=4-6 erg s^{-1}cm, mildly-relativistic v=0.04-0.15c, high columns N_H >10^{22} cm^{-2}**
- **Characteristics similar UFOs in Seyferts, high mechanical power ~10^{43}-10^{44} erg/s**
- **WAs recently reported in the literature** (e.g., Reeves et al. 2009; Torresi et al. 2010, 2012)
- **Complete sample radio-loud AGNs XMM-Newton + Suzaku** (in progress, with F. Tazaki, Y. Ueda, ...)

(Tombesi et al. 2010b)

Follow-up on 3C 111 with Suzaku



Obs1

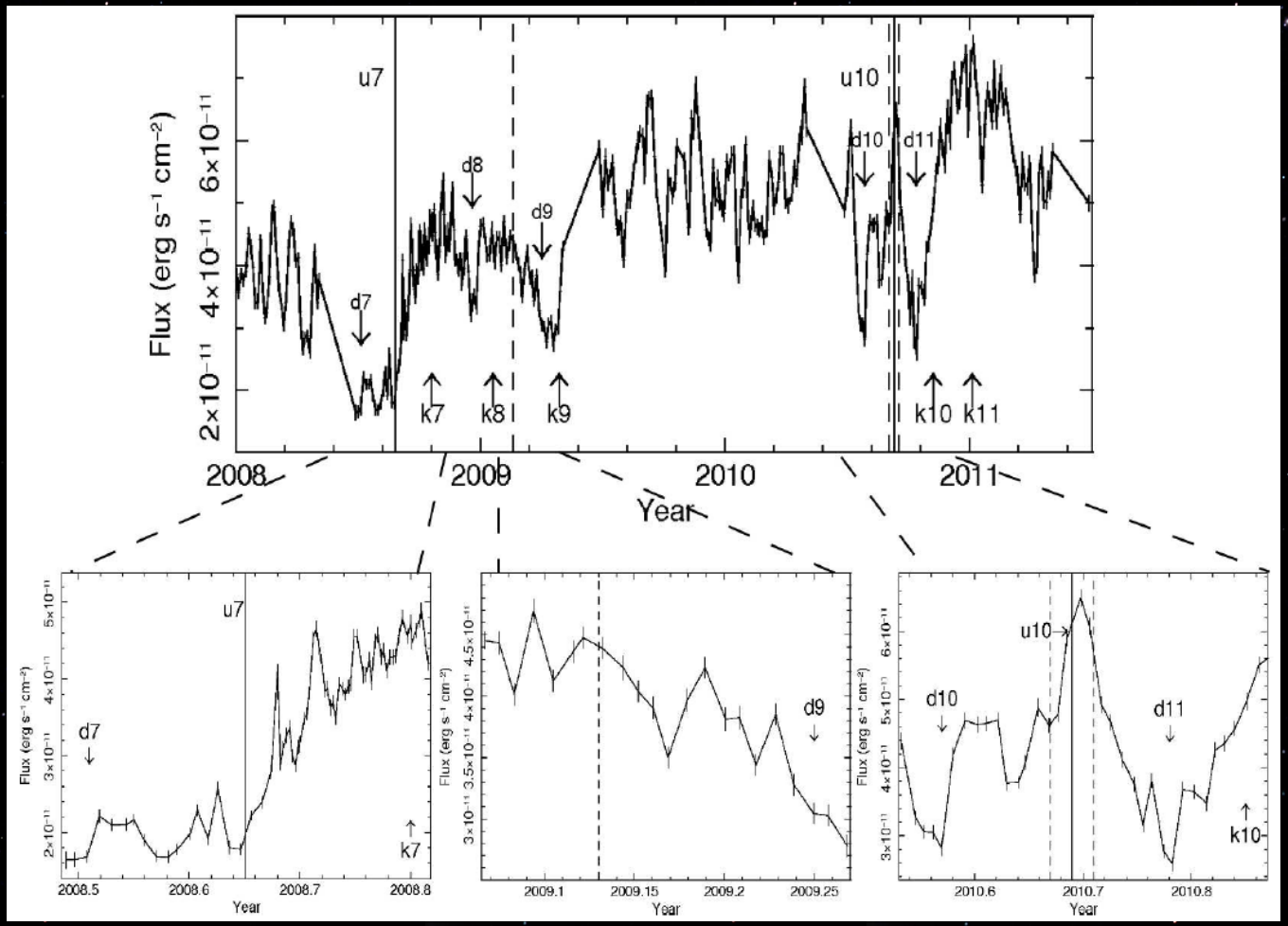
- Variable ionized Fe XXV/XXVI emission line
- If reflection accretion disk, ~20-100r_g,i~18°
- ADAF? photoionized gas? (work in progress)

Obs2

- UFO, v_{out}=0.106±0.006c
- logξ=4.32±0.12 erg s^{-1}cm, Fe XXV/XXVI
- N_H=(7.7±2.9)x10^{22} cm^{-2}

3x60ks Suzaku obs spaced by ~7 days in Sept. 2010 (Tombesi et al. 2011b)

Comparison with jet ejection events in 3C 111

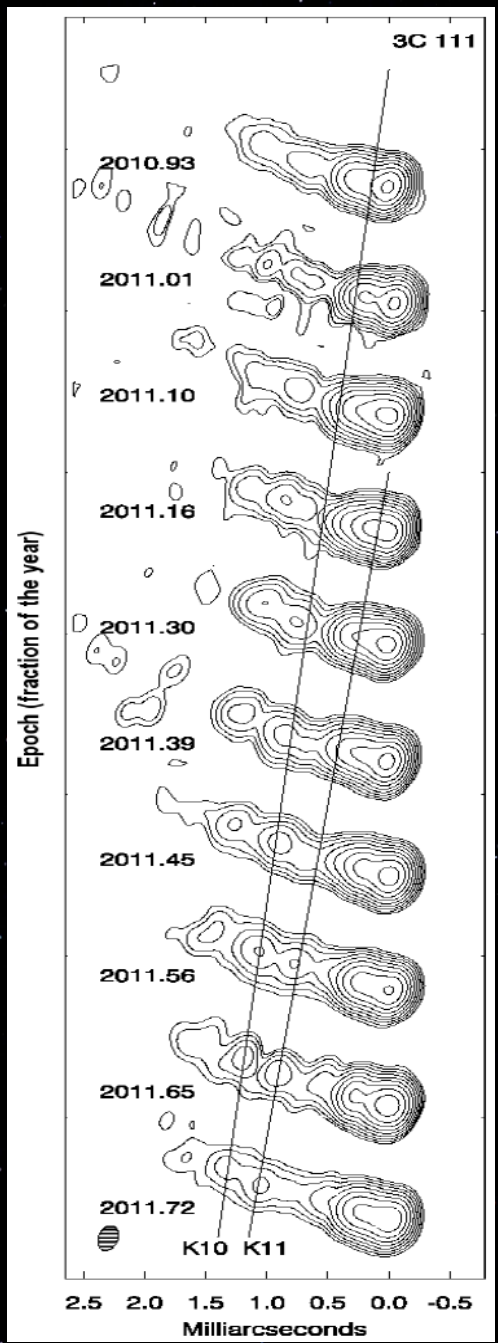


- **Placement of UFO detection episodes on long term 2-10keV RXTE light curve (2008-2012)**
- **Tracking jet knot ejections with VLBA radio images** (using also Chatterjee et al. 2011 results)

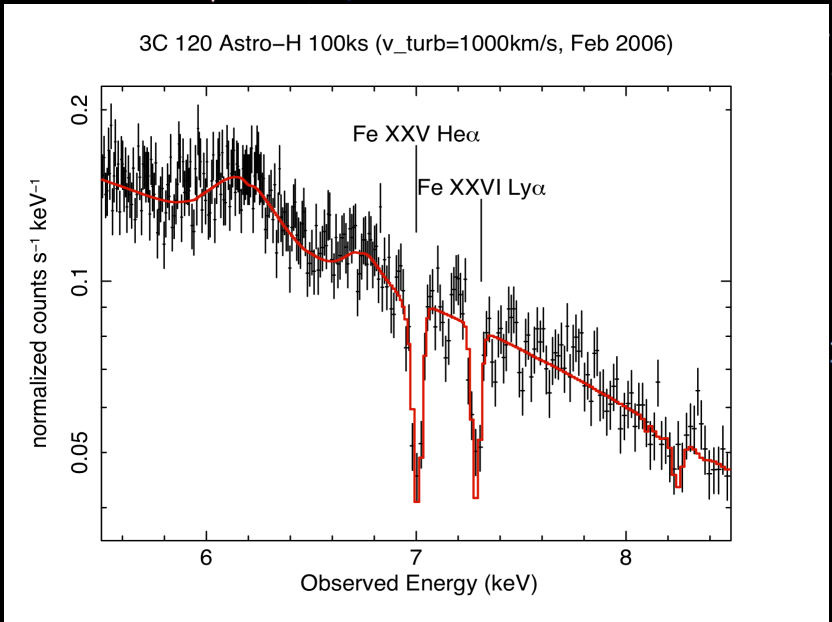
(Tombesi et al. 2012b)

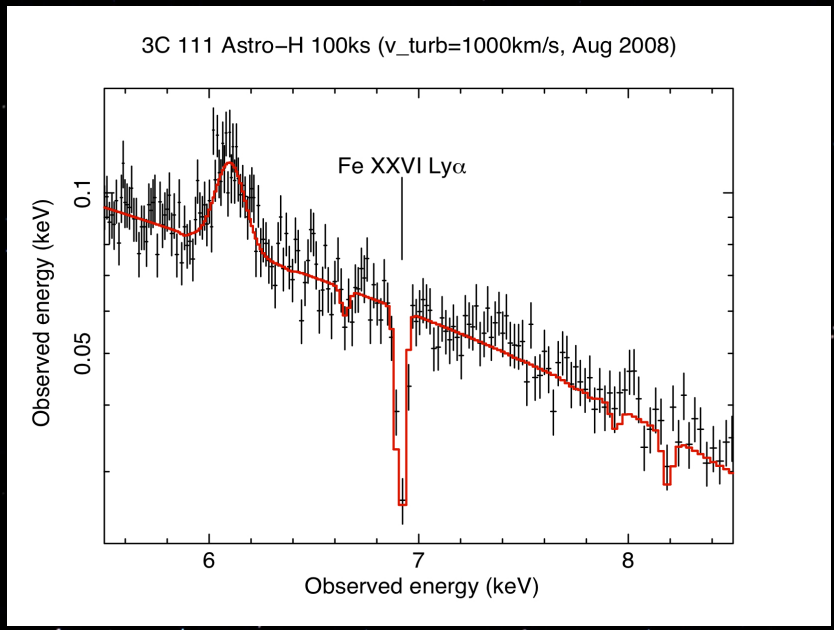
Comparison with jet ejection events in 3C 111

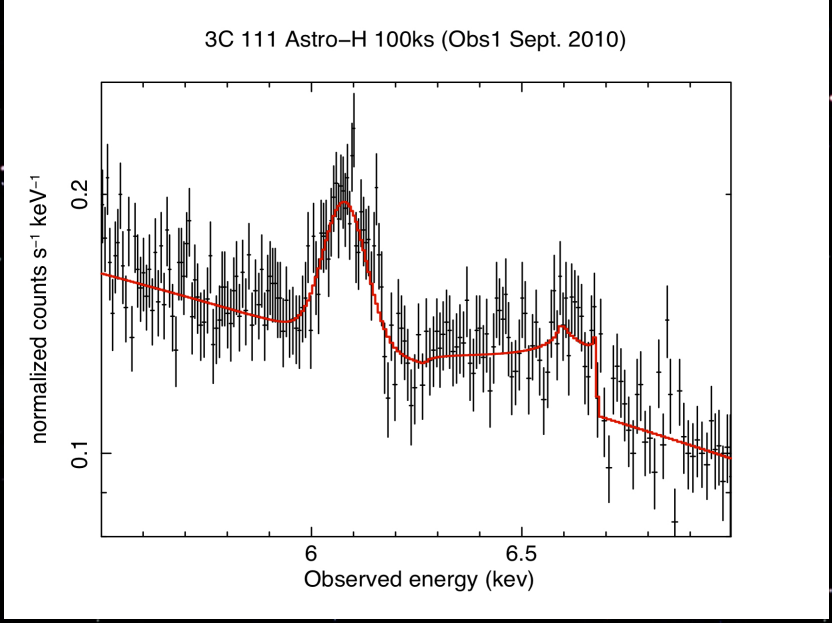
- Hints of UFOs preferentially detected during X-ray rising periods
- UFOs possibly stronger during X-ray dips/disk-jet ejection cycles (stellar-mass BH GRS 1915+105 in β state? e.g., Neilsen et al. 2012) (need additional monitoring; planned extensive project on 3C 390.3)
- Superluminal jet coexists with mildly relativistic UFOs at sub-pc scales (some Seyferts show weak jets as well)
- Disk outflows provide additional pressure support for the initial jet collimation (also Fukumura et al. in prep.)
- Connection if MHD origin, but also radiation important for UFOs
- UFOs massive, mechanical power ~0.1 jet, but similar momentum
- UFOs are massive and wide angle, mildly-relativistic, mechanical power ~0.1 jets but similar momentum, detected in >40% sources (also radio-quiet)
- UFOs comparable/higher AGN feedback on host galaxy than jets, as required by scale relations (e.g., M-sigma)

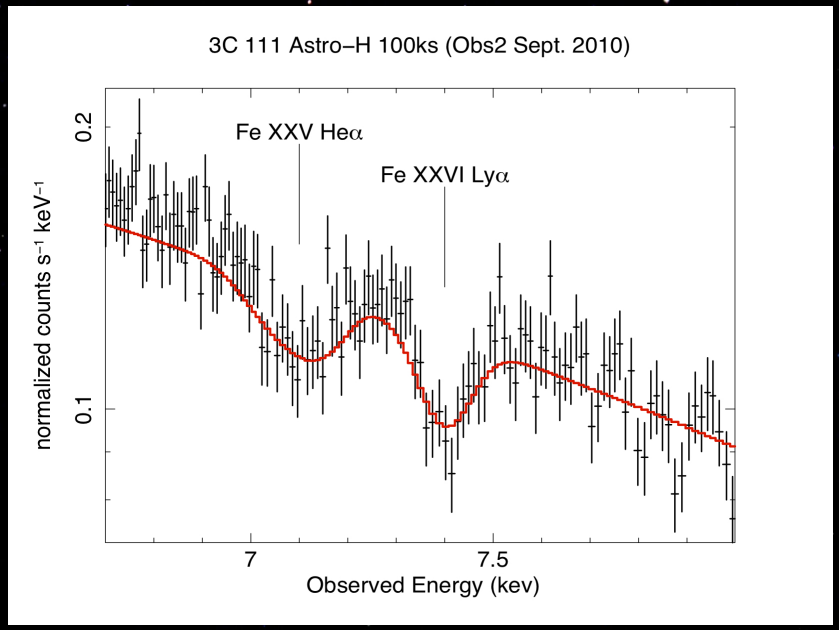


Astro-H micro-calorimeter simulations



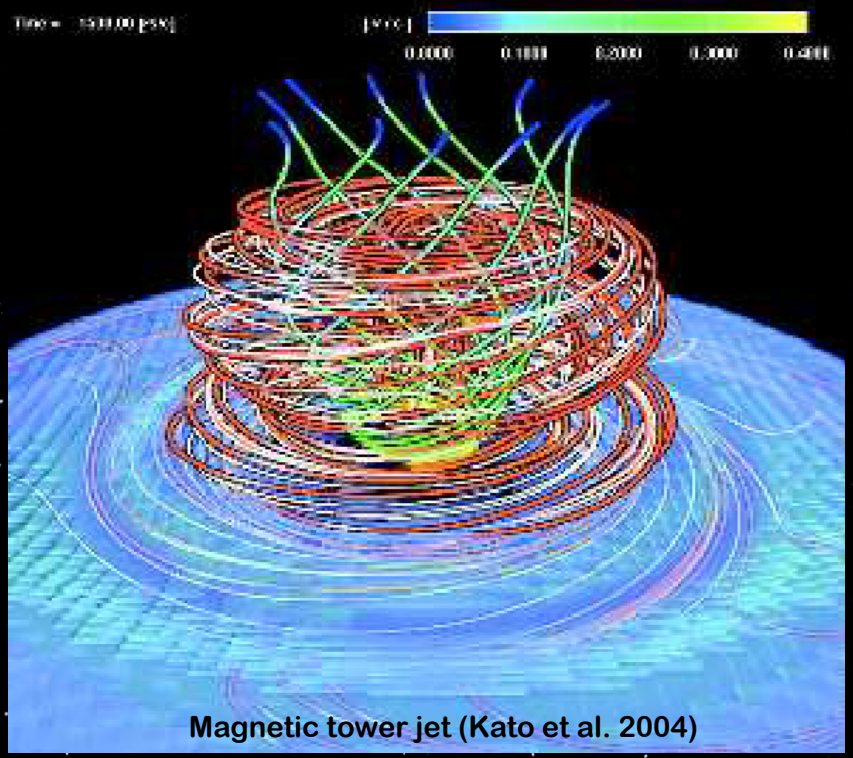






Conclusions

- UFOs are highly ionized and mildly-relativistic
- Common (>40%) in Seyferts and BLRGs
- Location on sub-pc scales, accretion disk winds
- Massive, wide angle, intermittent
- Mechanical power >>0.5% L_{bol}, AGN feedback
- Important improvements from Astro-H



Magnetic tower jet (Kato et al. 2004)

Several still open questions:

- What is the duty cycle of UFOs? (need monitoring, also to increase detection significance)
- What is their dependence on the line of sight inclination?
- What is their connection with the accretion state? What triggers them?
- What is the acceleration process, radiation and/or MHD? (in progress, with K, Fukumura, …)
- What is their connection with the jet in radio-loud sources and global incidence? (in progress)
- What is their detailed feedback impact? (in progress, with M. Gaspari, …)
- What is their connection with the warm absorbers? (in progress, Tombesi et al. In prep.)

Thank you!