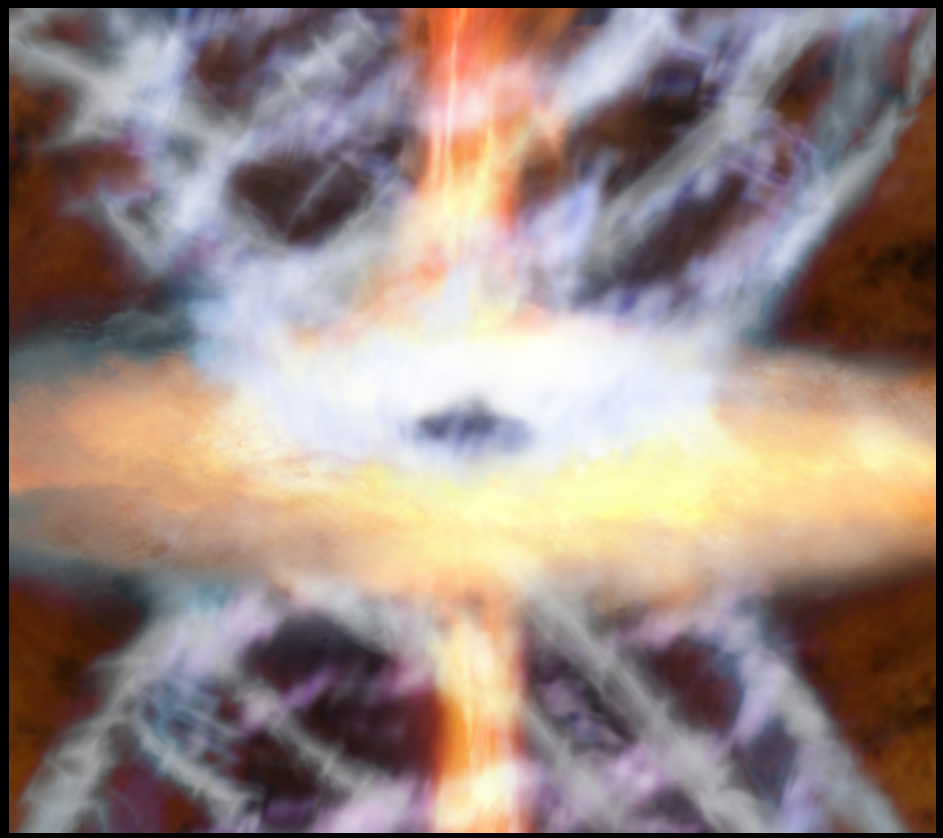
High-z UFOs (aka Ultra Fast Outflows)

Massimo Cappi

INAF/IASF-Bologna



Outline

1. Framework/importance
   A brief recall on AGN feedback and outflows/ winds
2. The "classic" X-ray view of winds/outflows
   WAs in AGNs and QSOs
3. The "new" X-ray view of winds/outflows
   WAs+UFOs in AGNs and QSOs
4. High-z UFOs

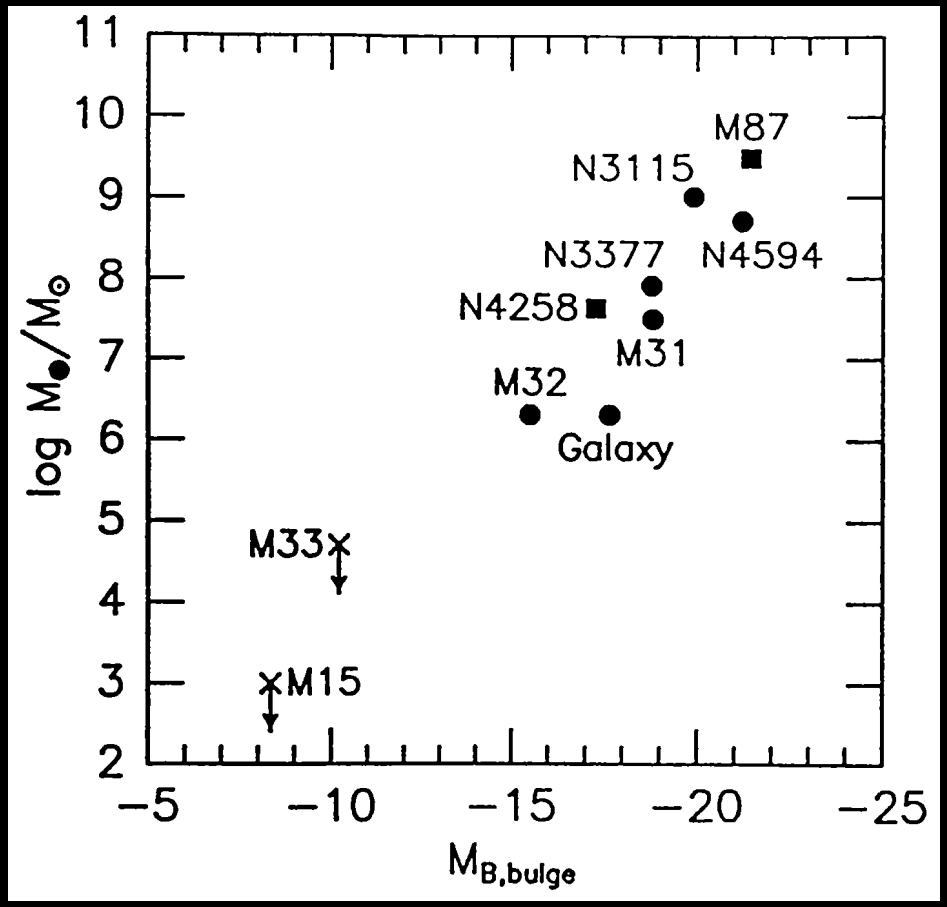
Tombesi F., MC, et al. '10a+b;'11a;'12 in prep. (and ESA/NASA/INAF press release)

Main Collaborators: F. Tombesi, M.Giustini, M. Dadina, V. Braito, J. Kaastra, J. Reeves, G. Chartas, G. Lanzuisi, M. Gaspari

Framework: Co-evolution of galaxies

First unexpected "revolution" in extragal. astrophysics: not only most (all?)

galaxies have SMBHs (MDOs) in their centers, these also correlate with bulge properties



Annu. Rev. Astron. Astrophys. 1995. 33:581–624

INWARD BOUND—THE SEARCH FOR SUPERMASSIVE BLACK HOLES IN GALACTIC NUCLEI

John Kormendy[1]

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Douglas Richstone

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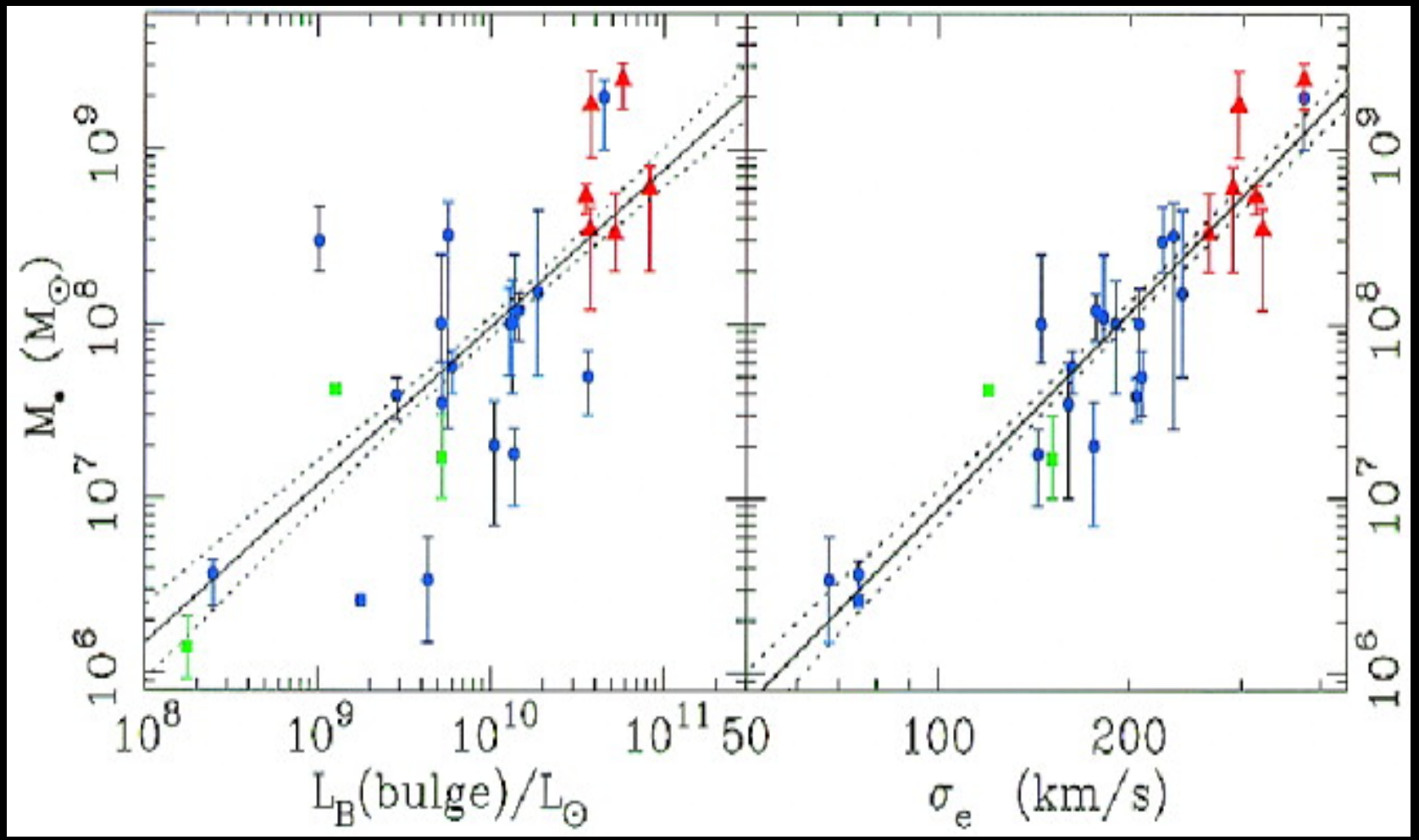
A statistical survey finds BHs in ~20% of nearby E–Sbc galaxies, consistent with predictions based on quasar energetics. BH masses are proportional to the mass of the bulge component. Most candidates are inactive; in some cases, the abundance of fuel is not easily reconciled with BH starvation. Flashes caused by the

Kormendy & Richstone, 1995, ARA&A

Framework: Feedback in the co-evolution of galaxies

⇒evidence for feedback mechanism between SMBH(AGN) and its' host galaxy?



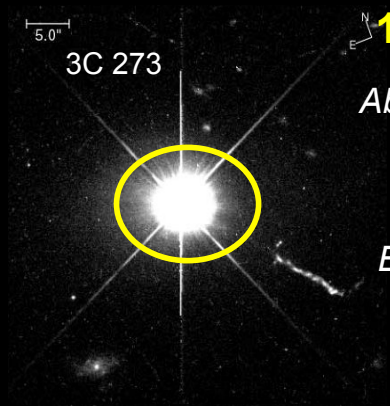
$M_{bh} \sim \sigma^4$

Magorrian et al. '98

Tremaine '02; Gebhardt '02...etc

(see e.g. King and Pounds '03, Crenshaw, Kraemer & George '03, ARA&A)

Framework: *Three major feedback mechanisms between the SMBH and its environment*



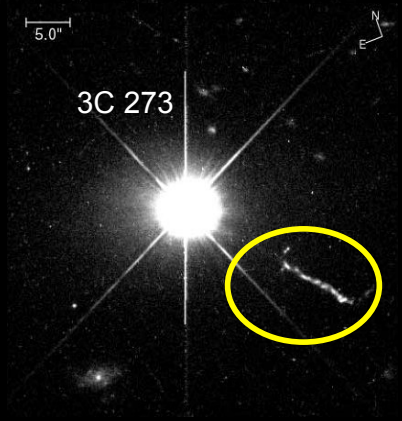
1. radiative feedback: $L_{acc} = \eta\left(\dot{M}_{acc}\right)c^2$

Able to quench the star formation and the cooling flow at the center of elliptical galaxies

e.g. Ciotti & Ostriker 2001, Sazonov et al. 2005

But it is not enough to reproduce the M_{BH}-σ relation

e.g., Ciotti et al. 2009



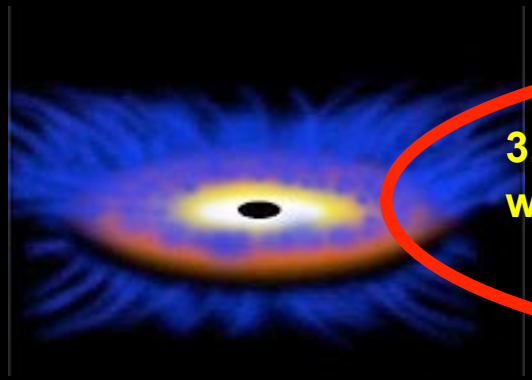
2. mechanical/kinetic feedback: mass outflows from collimated, radiatively bright, relativistic radio jets:

Heat the IGM and the ICM, quench the cooling flow in rich Clusters of Galaxies

e.g. Fabian et al. 2009, Sanders et al. 2009

But jets involve only ~10% of AGN, and are highly collimated:
low global impact for AGN with $L/L_{Edd} > 0.01$

e.g., Ciotti et al. 2009



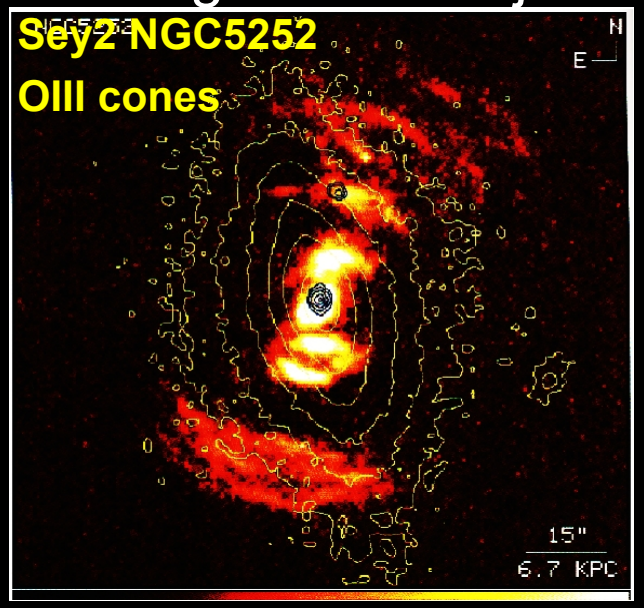
3. mechanical/kinetic feedback: mass outflows from wide angle, radiatively dark, massive winds/outflows

e.g., Silk & Rees 1998
e.g., Begelman 2003

The "classic" view of winds/outflows: Fast winds/outflows/ejecta in AGNs

…known/seen in AGNs since long ago

Wide-angle winds & jets in Sey gal.

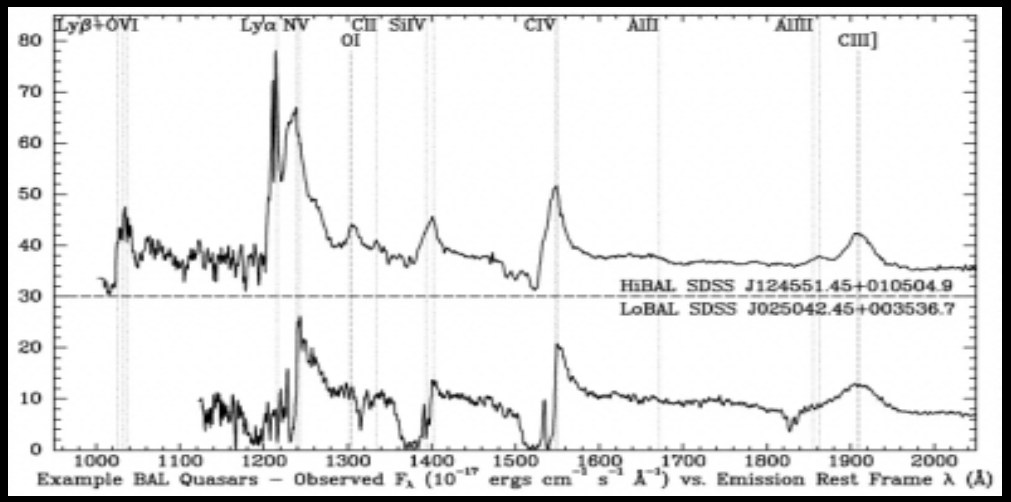


Tadhunter & Tsvetanov, Nature, '89;
Wilson & Tsvetanov, '94
Cappi et al. '95
Morse et al. '98

Jets in radio-loud AGNs

Fast (v up to ~ 50000 km/s) winds in BAL QSOs

(~ 20-40% of all QSOs)

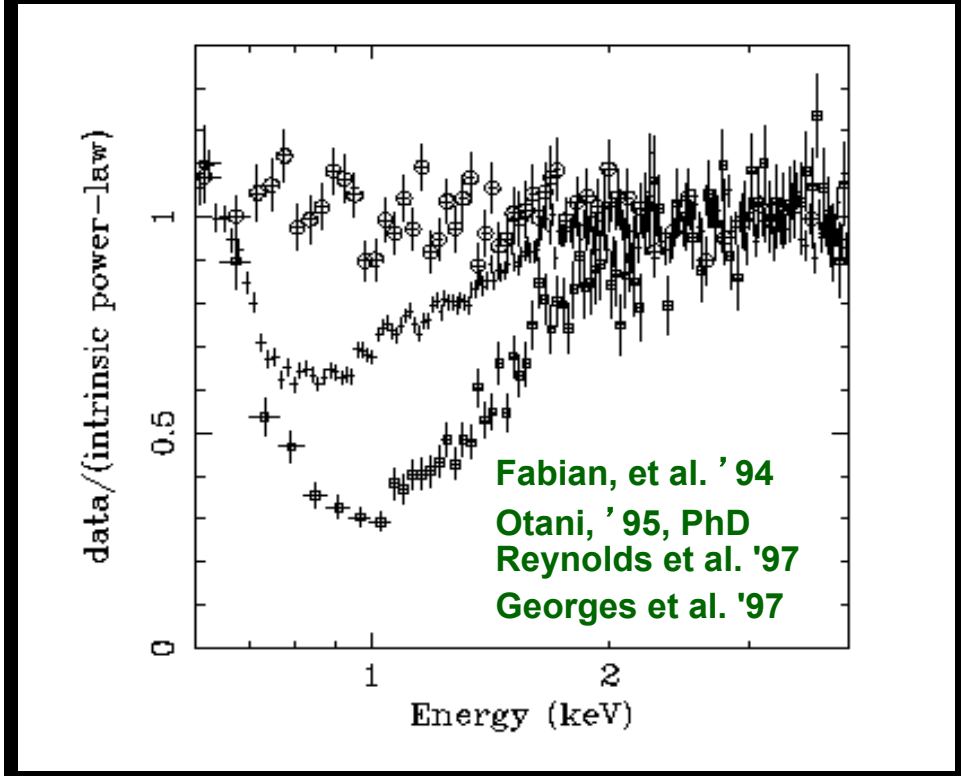


Weymann et al., '91; Reichards et al., '03

The "classic" X-ray view: Warm Absorbers in nearby AGNs

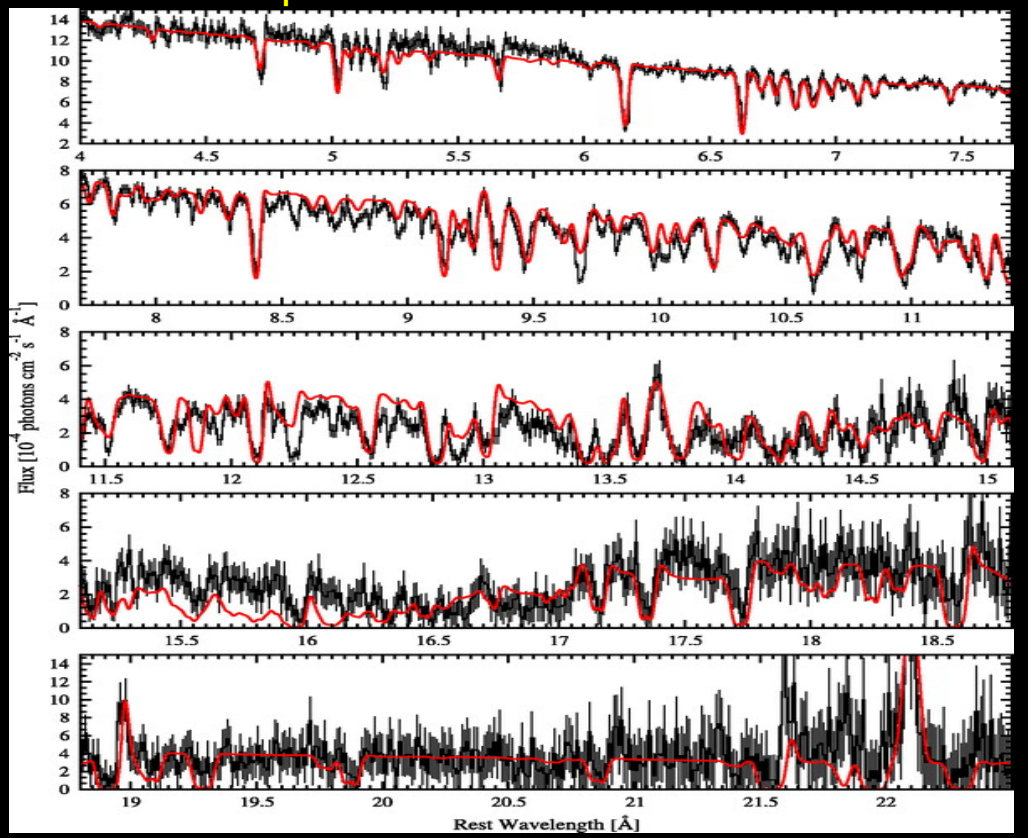
50% of all Sey 1s exhibit WAs

ASCA



Many details from Chandra/XMM gratings

NGC3783 Exp=900 ks

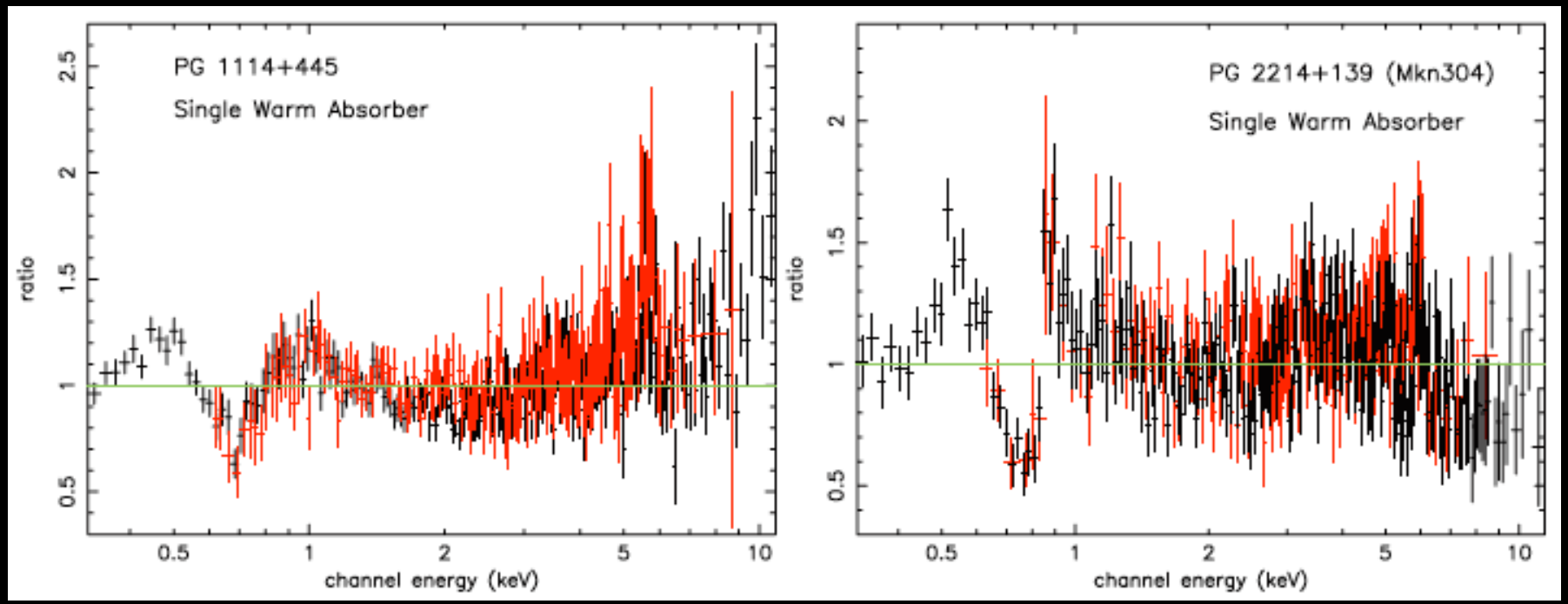


Kaspi et al. '01; Netzer et al. '02;
Georges et al. '03; Krongold et al. '03

⇒ Clear now that often multiple ionization & kinetic components (from Optical, UV and soft X): outflows with v~100-1000 km/s

Blustin et al. 2004

The "classic" X-ray view: Warm Aborbers in nearby QSOs

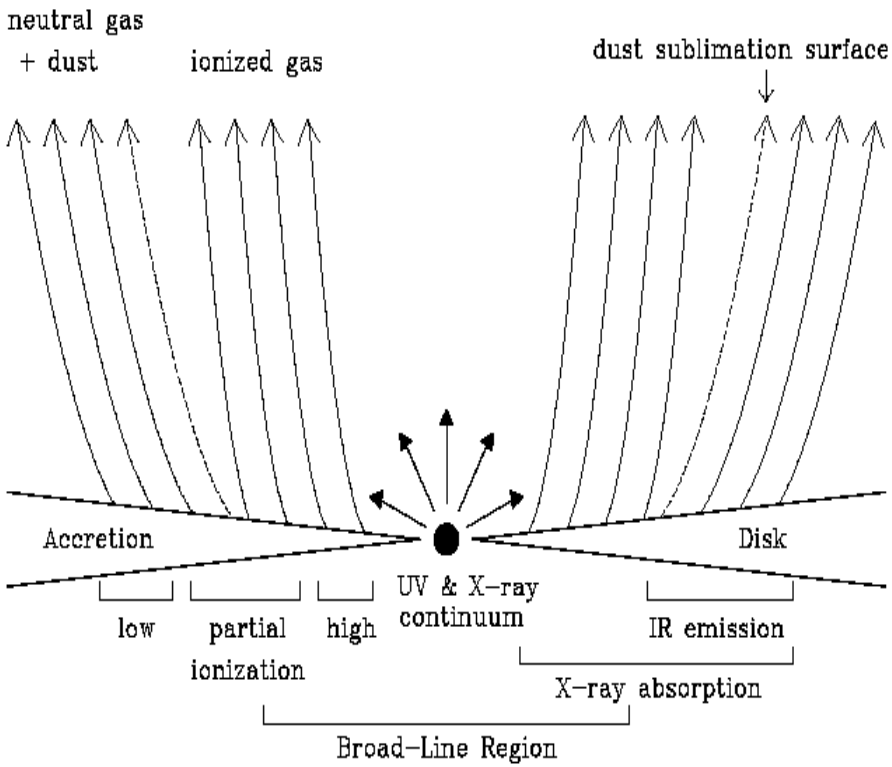


WAs present in ~50% of PG QSOs contrary to older measurements of 5-10%

Porquet et al. 2004
Piconcelli et al. 2005

Main interpretations: *Three (main) AGN wind dynamical models*

i) Thermally driven winds from BLR or torus

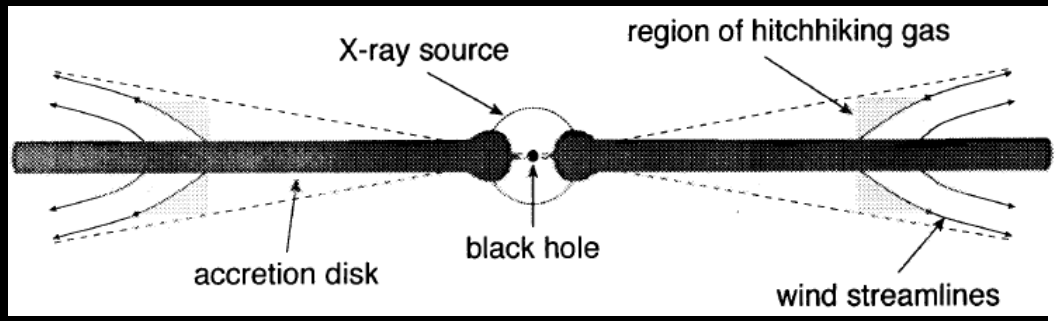


Balsara & Krolik, 93; Woods et al. '96

i) ⇒ Large R, low v

ii) and iii) ⇒ Low R and large v

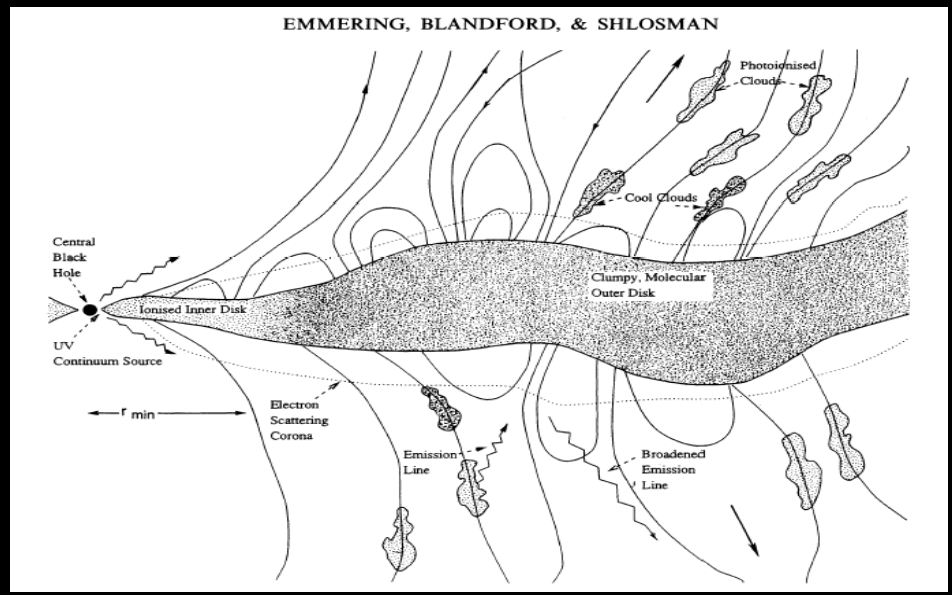
ii) Radiative-driven wind from accretion disk



Murray et al. '95, Proga et al. '00

…and/or…

iii) Magnetically driven winds from accretion disk



Emmering, Blandford & Shlosman, '92; Kato et al. '03

Observationally: most important (open) issues

- ✓ N_w (cm^{-2})
- ✓ Location (R, DeltaR)
- ✓ Ionization state (ξ)
- ✓ Velocity
- ✓ Covering factor
- ✓ Frequency in AGNs
- ✓ Density

Fundamental to:

i) PHYSICS of accelerated and accreted flows (winds?, blobs?, etc.)

ii) COSMOLOGY: i.e. estimate the mass outflow rate, thus the impact of AGN outflows on ISM and IGM enrichment and heating!

WA Location and feedback budget:

- NGC3783: ~25pc (Gabel+05)
- NGC4151: ~0.1 pc (Crenshaw & Kraemer 09)
- NGC5548 < 7pc (Kraemer+09)
- Mrk279 < 29 pc (Ebrero, EC+10)
- NGC3516: 0.2 pc (Netzer+02)
- NGC 4051 0.5-3 l.d. 1-3pc (Krongold+07, Steenbrugge+09)
- Mrk 509: >0.04 pc (Ebrero+11; Detmers+11; Kaastra,+11)

UFOs:

Sample of AGN and QSOs: few 100s to 1000s Rs (Tombesi+11, Reeves+, Chartas+)

Location: Rmin; Rmax

Outflow rate: $\dot{M}_{out} = 4\pi r N_H m_H C_g v_r$ $M_{sun} yr^{-1}$

Kinetic energy: $L_{kin} = 1/2 \dot{M}_{out} v^2$

$\dot{M}_{out} \approx \dot{M}_{acc}$, $\varepsilon_w \approx$ a few %

Filling & covering factors????

WA seem to be energetically unimportant, even if current estimates have order of magnitude uncertainties, and go from: dM/dt ($\propto L_{kin}$) few % to several % dM_{acc}/dt ($\propto L_{edd}$)

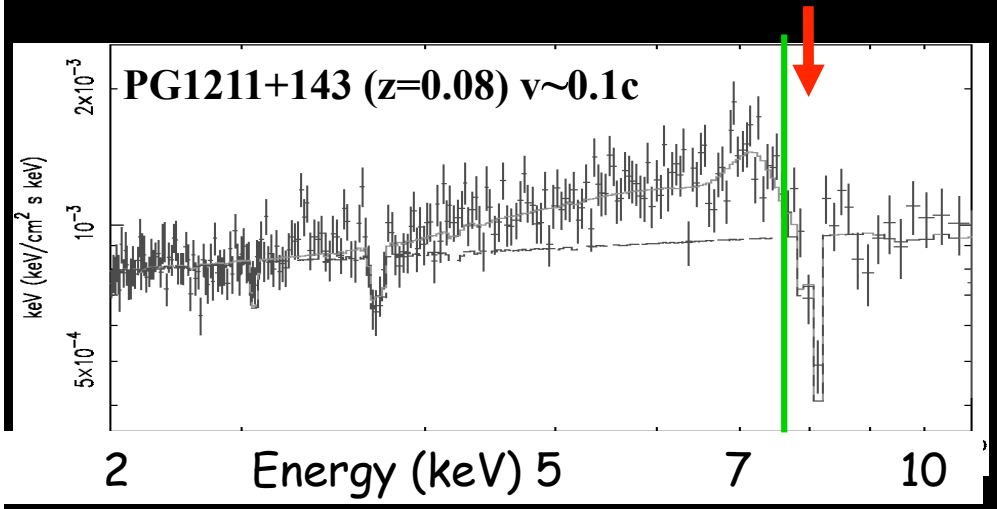
This is a fundamental (and still open) issue

Elvis et al. '00, Creenshaw et al. '03, King et al. '03, Chartas et al. '03,

Yaqoob et al. '05, Blustin et al. '05, Risaliti et al. '05, Krongold et al. '07

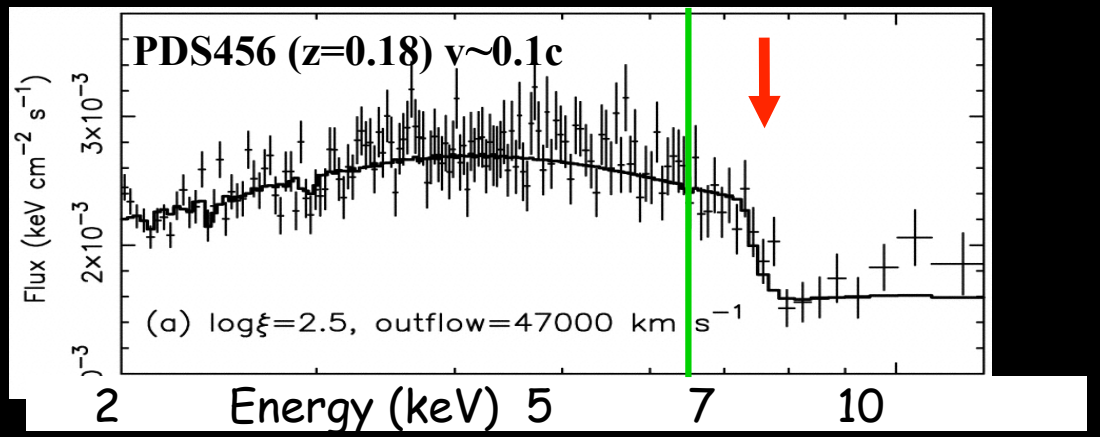
The "new" X-ray view: Blue-shifted absorption lines/edges – High-v, High-ξ

New and unexpected results from Chandra and XMM-Newton observations



Pounds et al. 2003a,b

(If) interpreted as Kα resonant absorption by Fe XXV (6.70 keV) or FeXXVI (6.96 keV)



Reeves et al. 2003

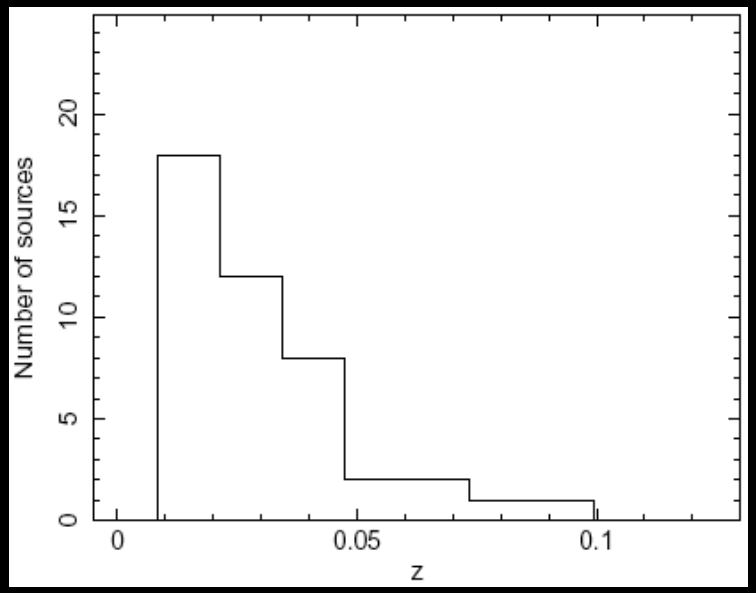
➔ massive, **high velocity** and highly ionized outflows in several RQ AGNs/QSOs

Mass outflow rate: comparable to Edd. Acc. rate (~$M_{\odot}$/yr); velocity ~0.1-0.2 c

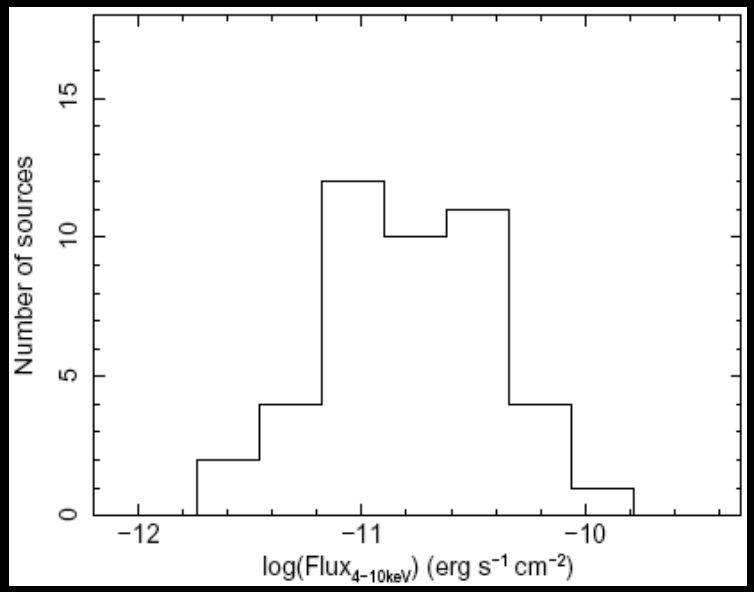
The "new" X-ray view: *Systematic sample analysis - searching for UFOs*

Tombesi et al., '10, PhD Thesis
Tombesi et al., '10a,b; '11a,b; '12

Large, ~complete, sample of the 44 sources
(104 XMM obs.) among the X-ray brightest nearby RQAGNs



z distribution of sources

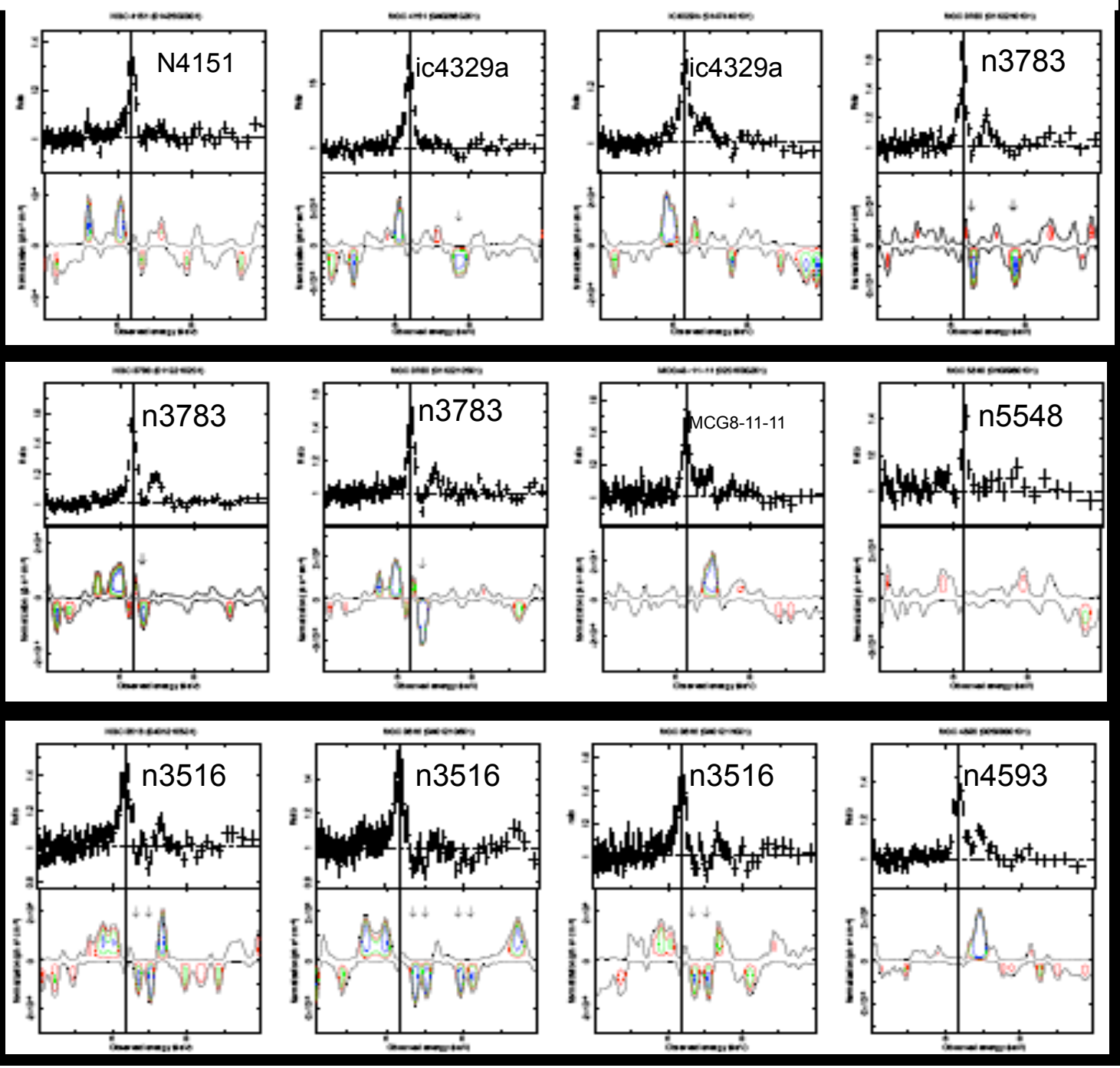


4-10 keV fluxes

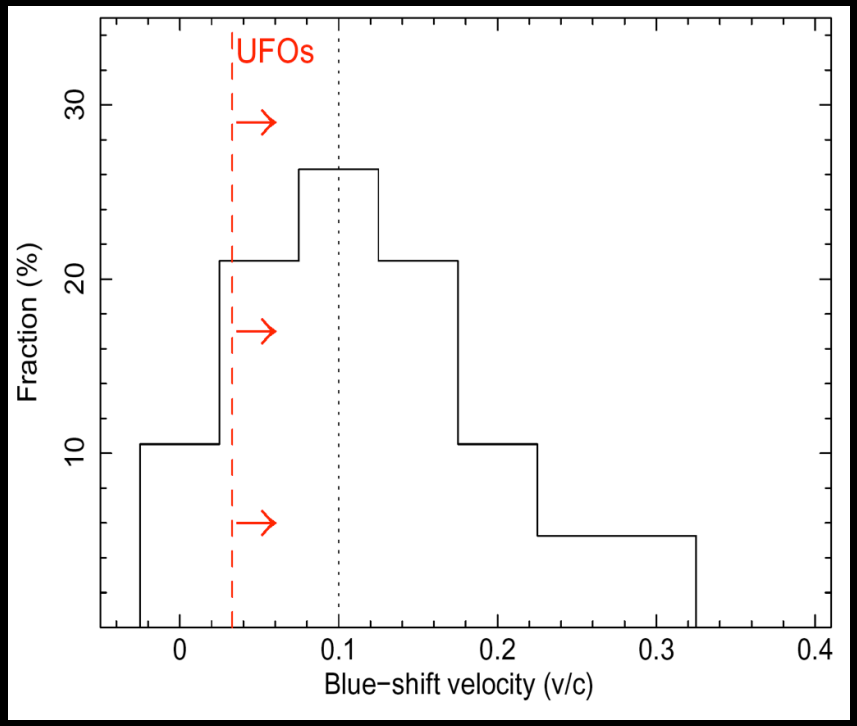
- Selection of all NLSy1, Sy1 and Sy2 in RXTE All-Sky Slew Survey Catalog (XSS; Revnivtsev et al. 2004)
- Cross-correlation with XMM-Newton Accepted Targets Catalog
- 44 objects for 104 pointed XMM-Newton observations
- Local ($z<0.1$)
- X-ray bright ($F_{4\text{-}10keV}=10^{-11}\text{-}10^{-10}$ erg s^{-1} cm^{-2})

The "new" X-ray view: *Systematic sample analysis - UFOs discovered in RQ AGN*

"Scanning" technique
+
Monte-Carlo significance for multiple trials
+
Extensive studies of all systematics



The "new" X-ray view: *UFOs (Ultra-Fast Outflows) are confirmed and are quite common*



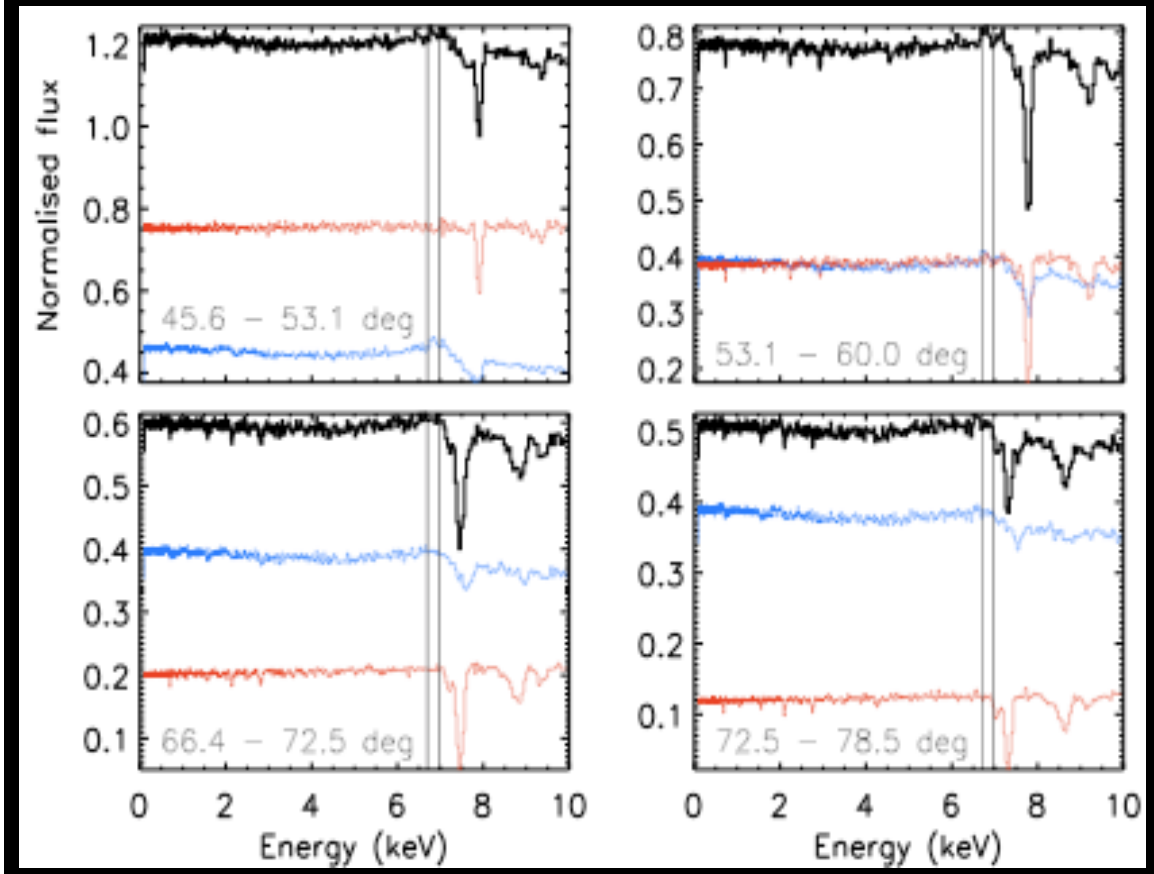
- 36 absorption lines detected in all 104 XMM observations
- Identified with FeXXV and FeXXVI K-shell resonant absorption
- 19/44 objects with absorption lines (≈43%)
- 17/44 objects with blue-shifted absorption lines (lower limit ≈39%, can reach a maximum of ≈60%)
- 11/44 objects with outflow velocity >0.1c (≈25%)
- Blue-shift velocity distribution ~0-0.3c, peak ~0.1c
- Average outflow velocity 0.110±0.004 c

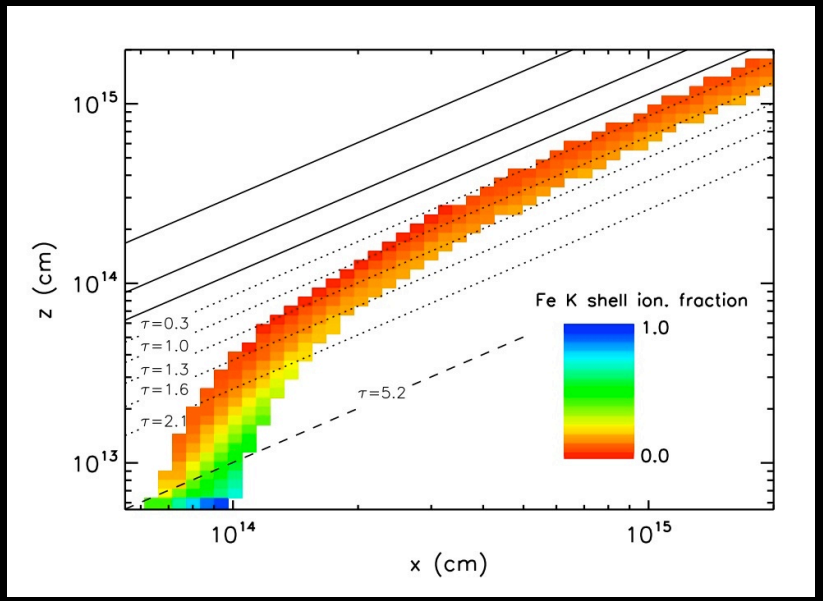
Tombesi, MC, et al. 2010a

(The UFO hunters' commander in chief)

Data Interpretation:

Yes indeed…one expects (mostly/only) strong Fe line absorptions when accounting for proper wind geometries and physics

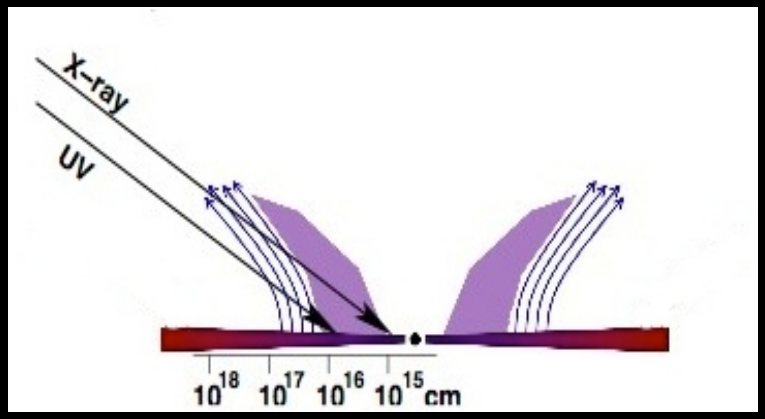




Sim et al., 2008

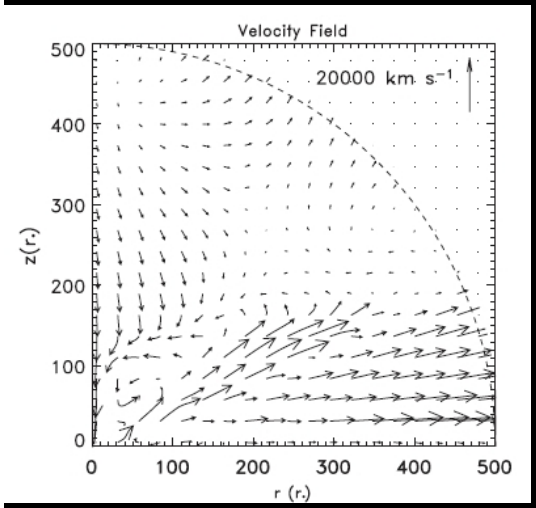
Theoretical Interpretation(s): Still an open issue, but maybe not for long

Radiation driven

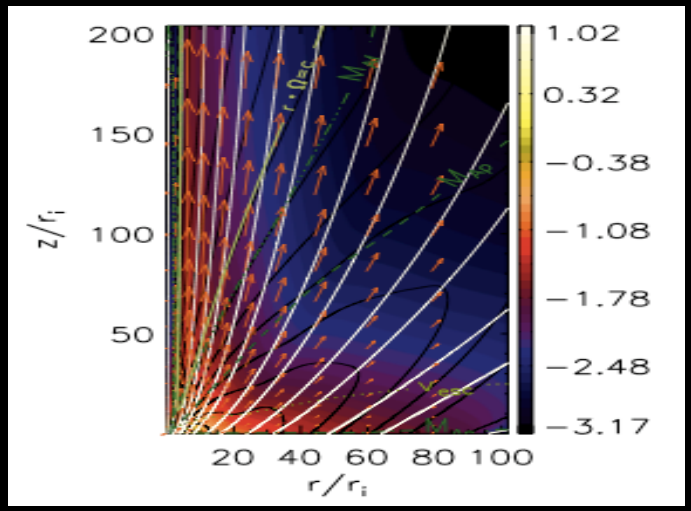


UV Line Driving: effective if the wind is shielded against the central ionizing continuum (Murray et al. 1995)

A "shield" of highly dense gas naturally arises in state-of-the-art hydrodynamical simulations of highly accreting AGN (Proga et al. 2000, 2004)

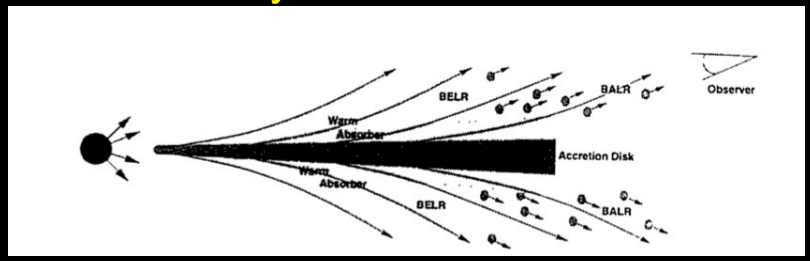


Magnetic driving



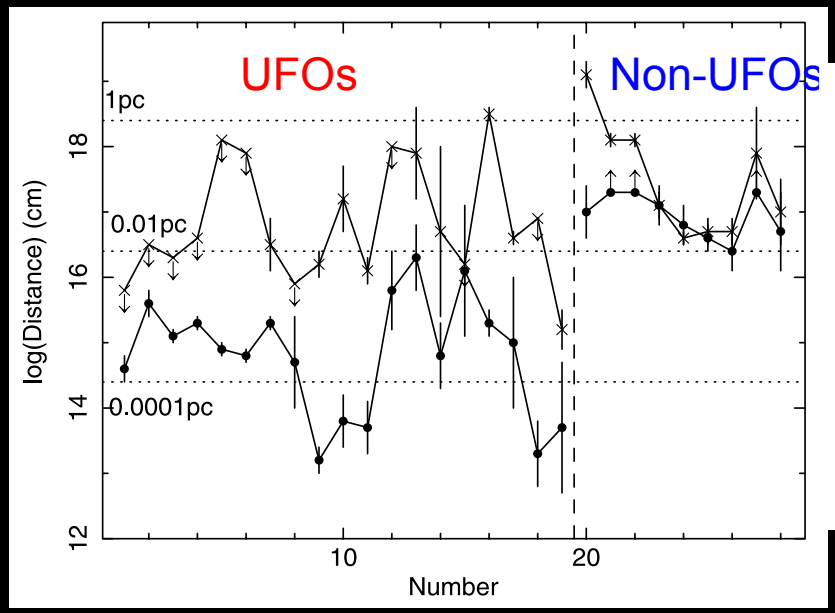
No need for shielding (e.g. Konigl & Kartje 1994, Everett 2005, Porth & Fendt 2009, Fukumura et al. 2010)

Hybrid Models

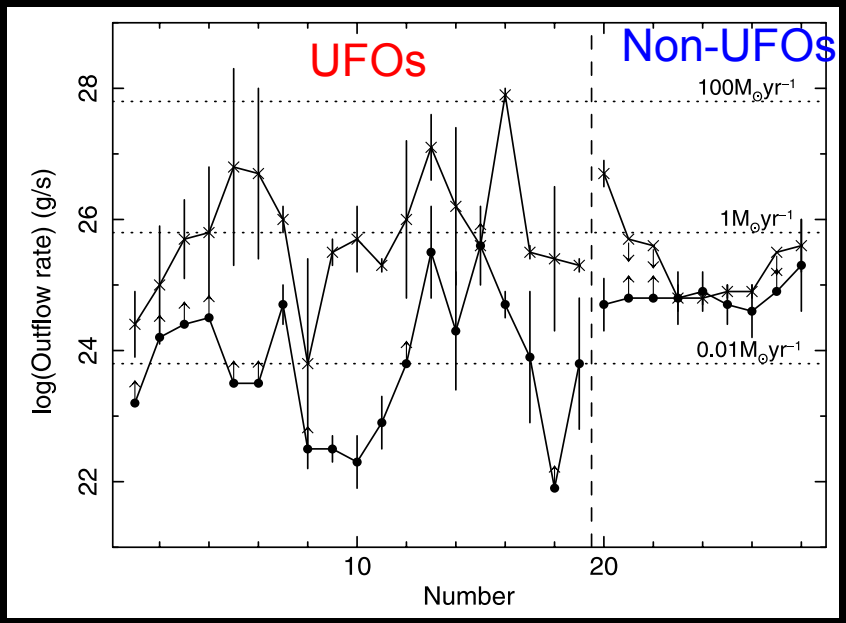


e.g. launched by magnetic pressure, accelerated by radiation pressure (Everett, Konigl & Kartje 2001)

The "new" X-ray view: Location and energetics of UFOs (and non-UFOs)



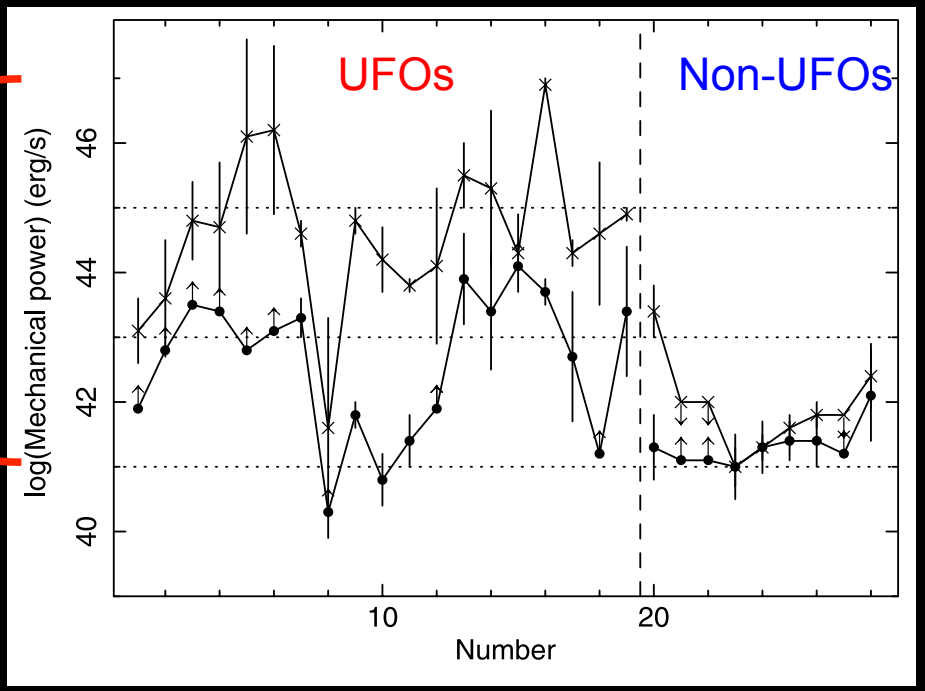
~10^2-10^4 Rs; 10^4-10^5 Rs



$$r \leq r_{\rm max} = L_{\rm ion}/\xi N_{\rm H}.$$

$$r \geq r_{\rm min} = 2\,G M_{\rm BH}/v_{\rm out}^2$$

~0.5-100 % L_{bol}



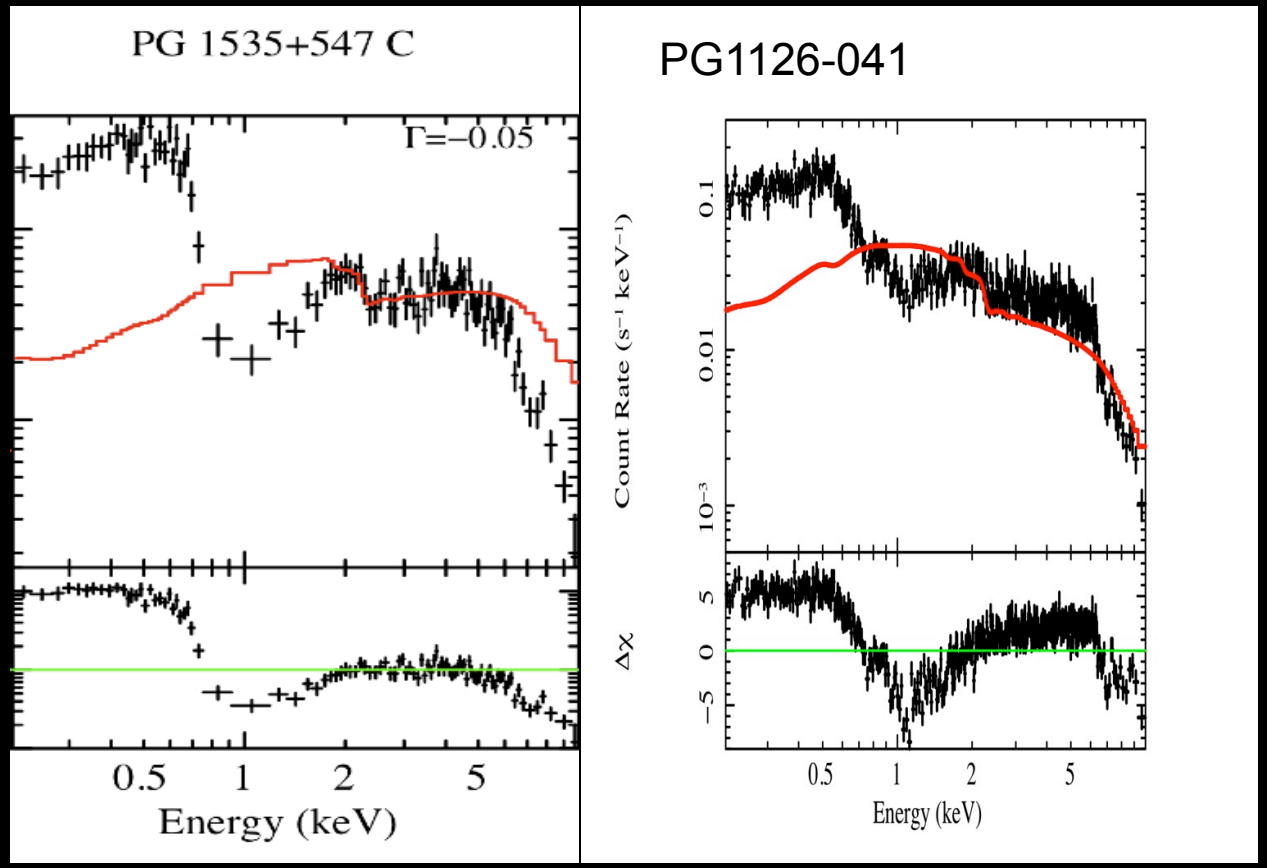
$$E_{\rm K} = (1/2) M_{\rm out} v_{\rm out}^2$$

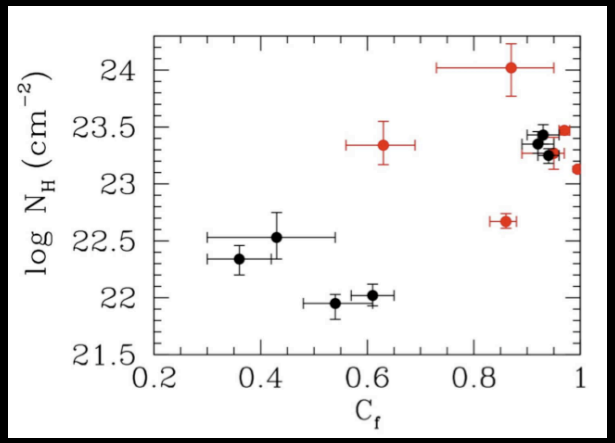
~0.02-1 % L_{bol}

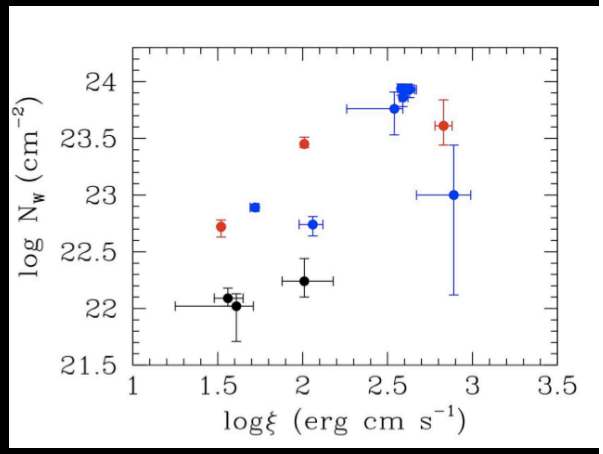
Tombesi, MC, et al., '12

The "new" X-ray view: *Sample of (nearby) PG QSOs*

Typical spectra







15 UV *AL QSOs with 32 XMM exposures

UFOs (not only WA) clearly detected in several nearby QSOs,
though fraction and covering factors still to be defined

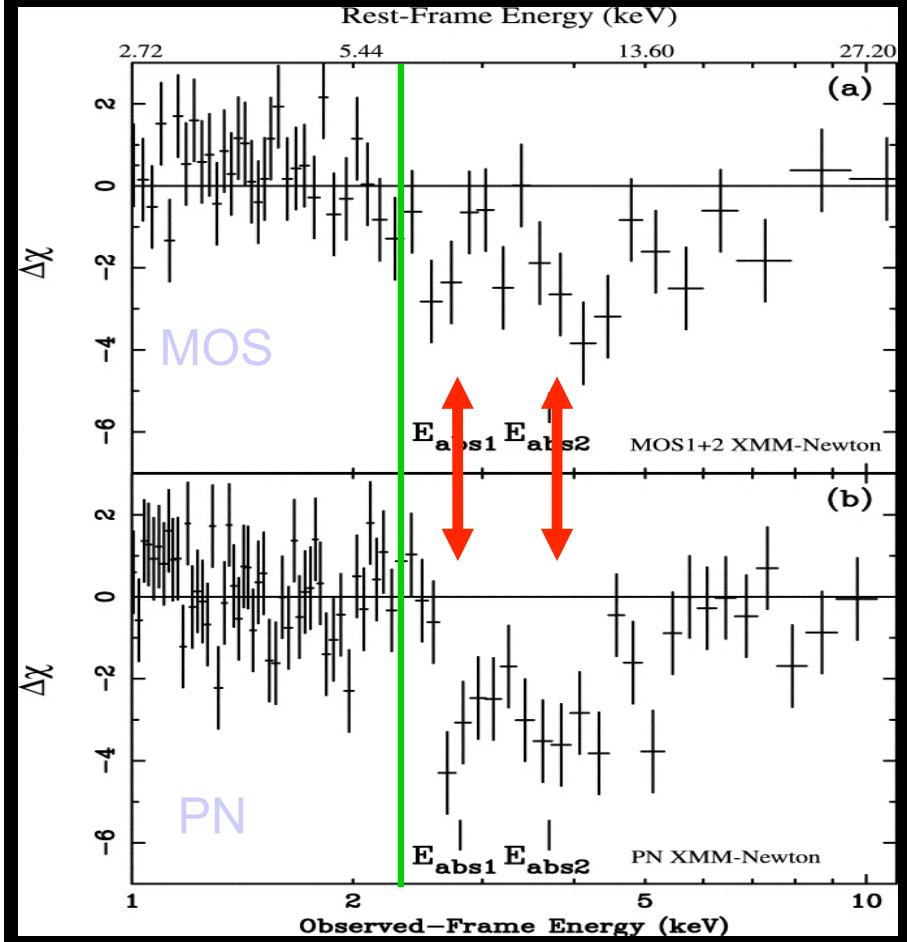
Giustini et al. 2012, in prep.

The "new" X-ray view: Blue-shifted absorption lines/edges – in High-z QSOs

Massive outflows…also (mostly?) at high redshift

2 high-z BAL QSOs

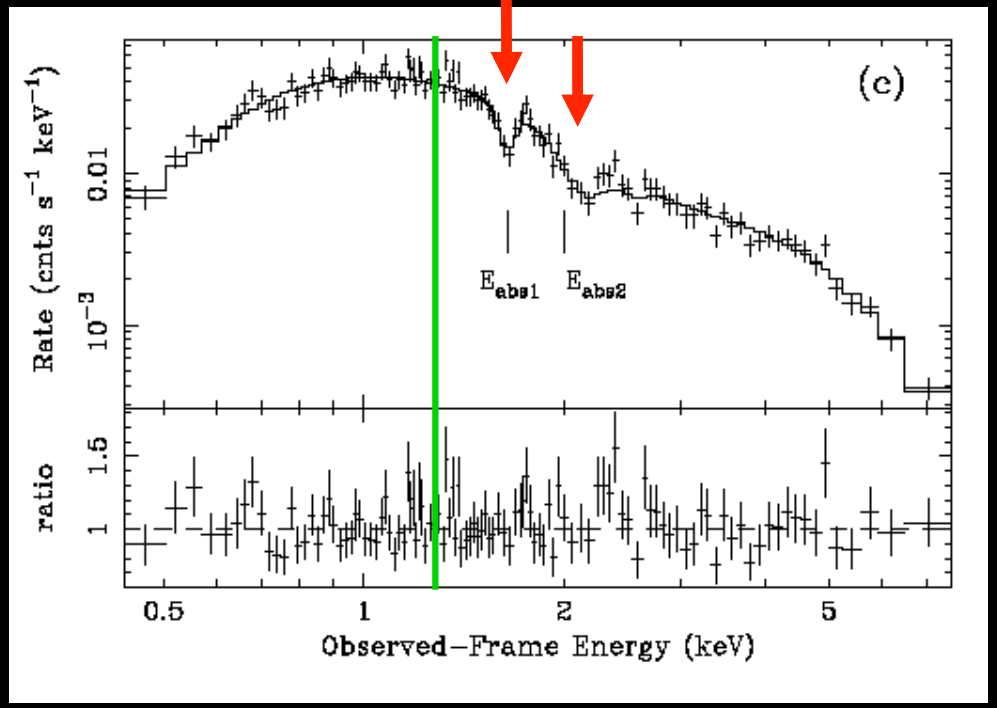
PG 1115+080 (z=1.72) v~0.1-0.3c



Chartas, Brandt & Gallagher, 2003

Chartas et al. 2002,
Hasinger, Schartel & Komossa 2002

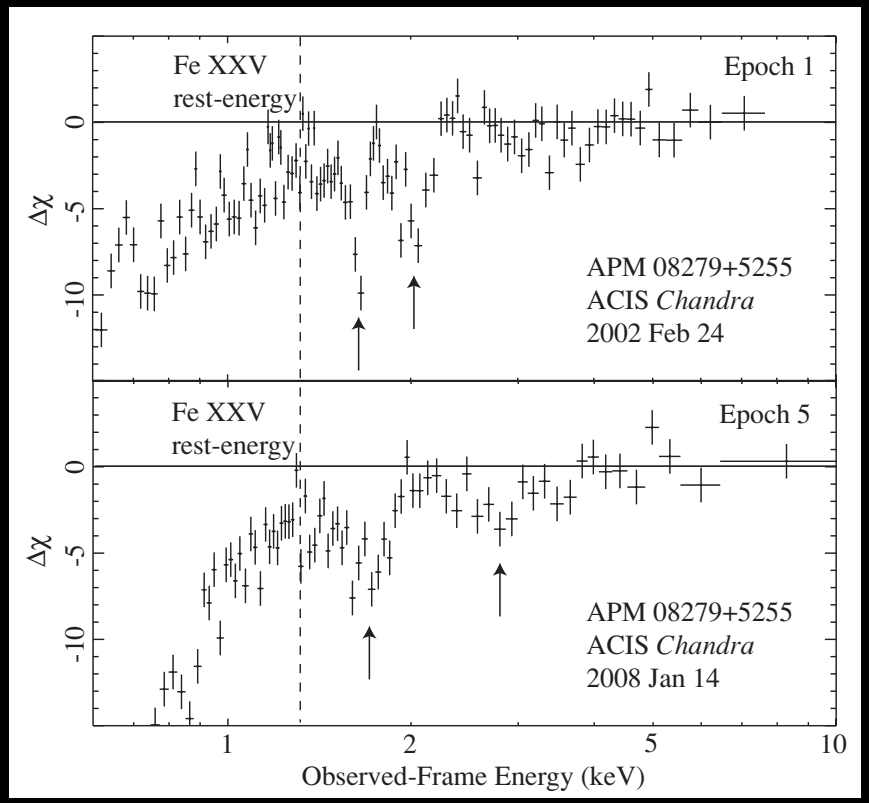
APM 08279+5255 (z=3.91) v~0.2-0.4c

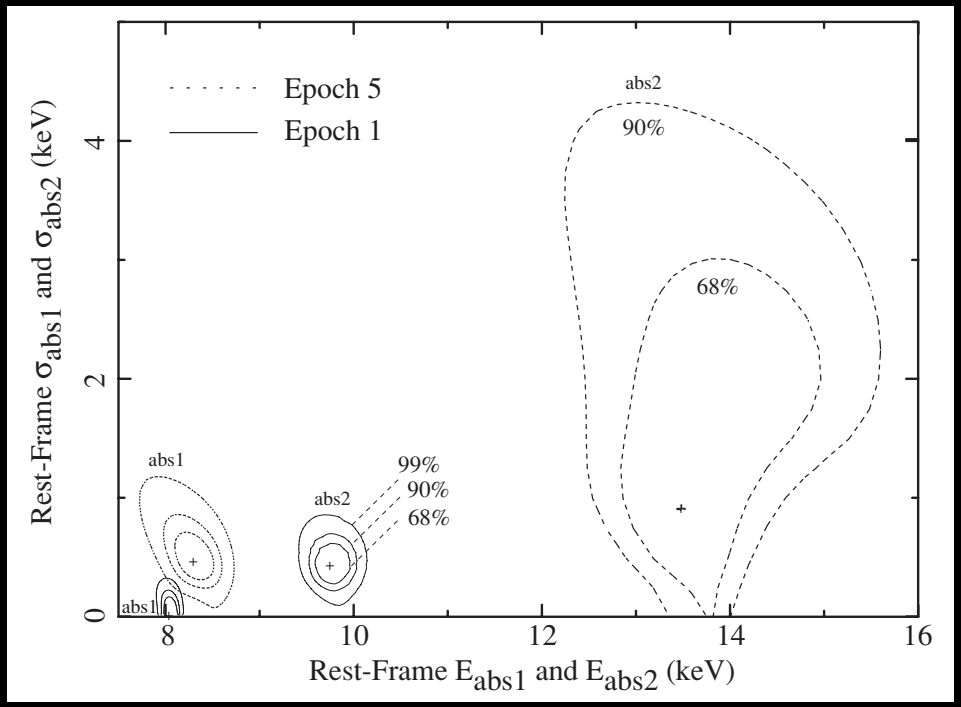


See also Wang et al. '05 (v=0.8c in qso@z=2.6)

N.B.: Would have been undetected at z=0...

APM 08279+5255 (z=3.91): also absorption variability

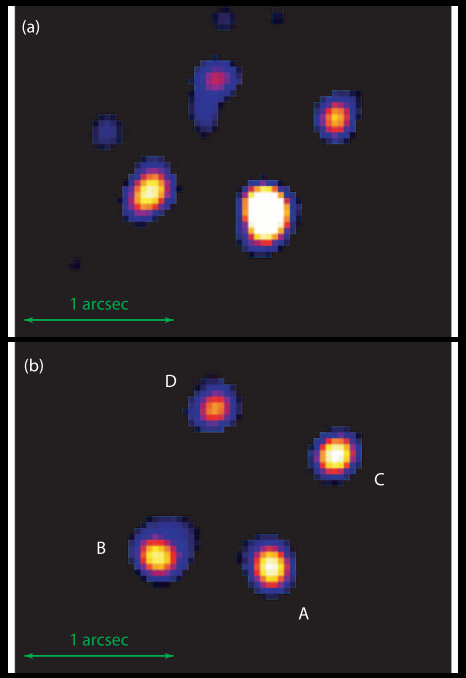


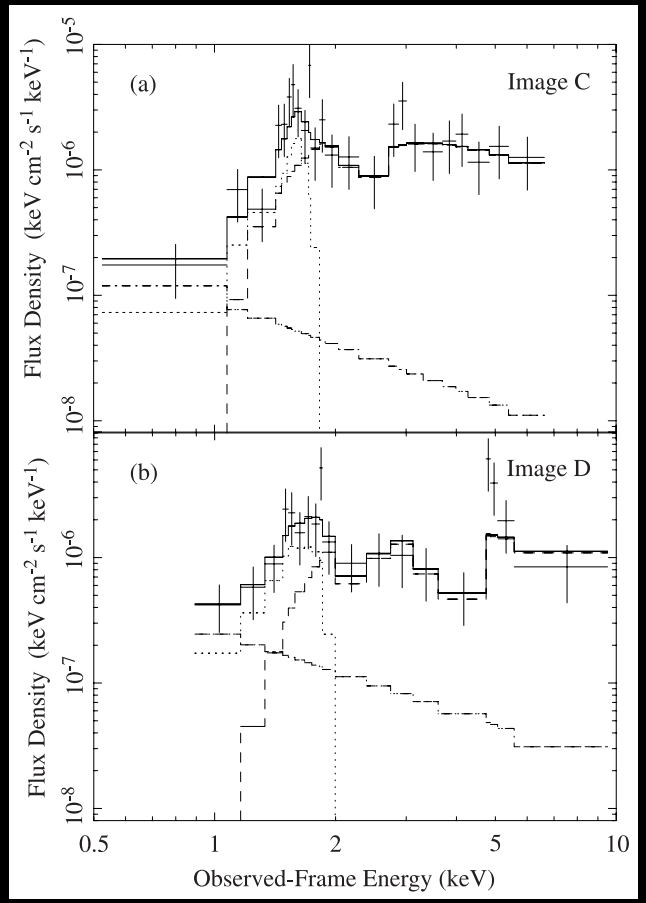


Chartas et al. 2009

V_{out}~0.2-0.76 c
Delta lines in Δt~3 days (rest) implying R~10 R_g (for both X-ray source and absorbers)

Cloverleaf (LoBAL) quasar H1413+117 (z=2.56)
Chandra observation

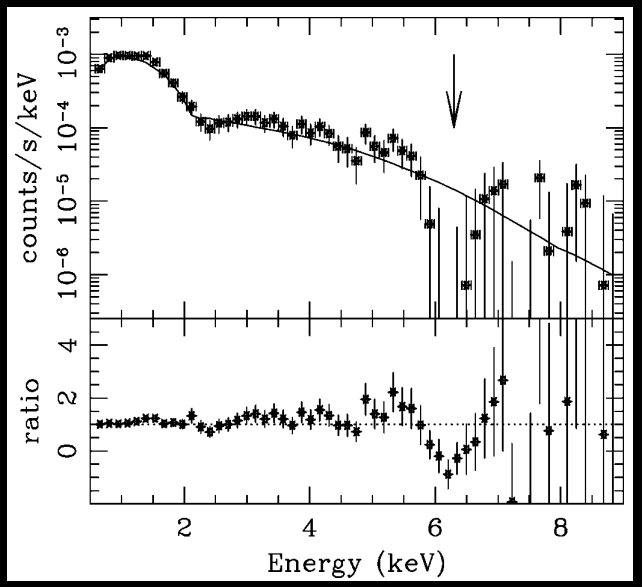




v~0.3-0.7 c (+ disc emission line)
Outflow variability on t (size-scale) < time-delays (microlensing)

Chartas et al. 2007

(1 Ms) CDFS quasar (z=2.58)
v~0.7-0.8 c



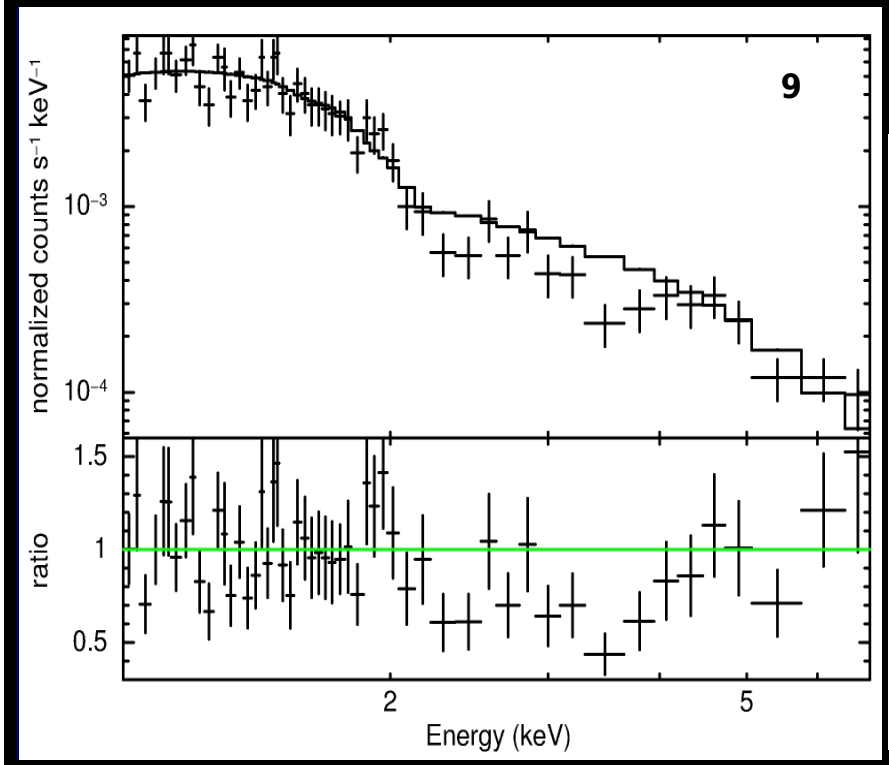
Wang et al. 2005

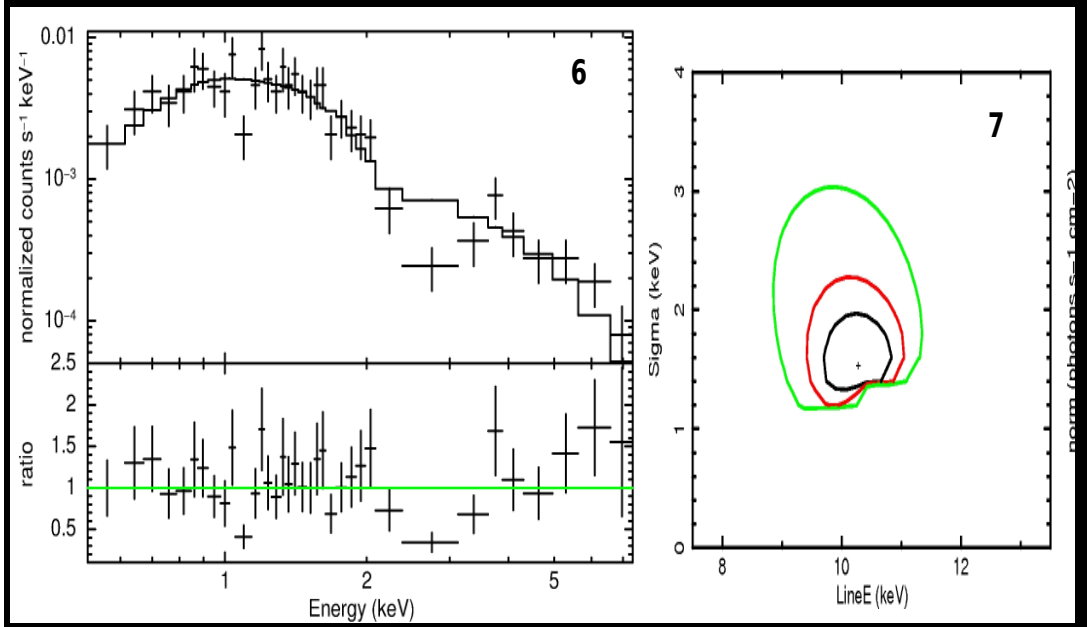
To be confirmed??

The "new" X-ray view: Also in a non-lensed high-z QSO

Chandra and XMM (3 sigma) detections in the

(z=2.73) high-z RQ (NAL) QSO HS1700+6416





Lanzuisi et al., '12, arxiv:1205.6587

The fourth high-z QSO to show variable,
high-v, high-Xi absorbers, but the first non-lensed

N.B.: Would be nice also to confirm it via longer XMM observations

The final impact of UFOs: Further progress on QSOs much needed

- ✓ Nw (cm^{-2}) ⇒ up to 10^{23}-10^{24}
- ✓ Location (R, DeltaR) ⇒ down to few Rs
- ✓ Ionization state (ξ) ⇒ up to log ξ ~ 4-5
- ✓ Velocity ⇒ up to z~0.3c (even more at high-z?)
- ✓ Covering factor ⇒ >40%, up to 60% in AGNs, in QSOS??
- ✓ Frequency in AGNs/QSOs ⇒ ??
- ✓ Filling factor ⇒ ??

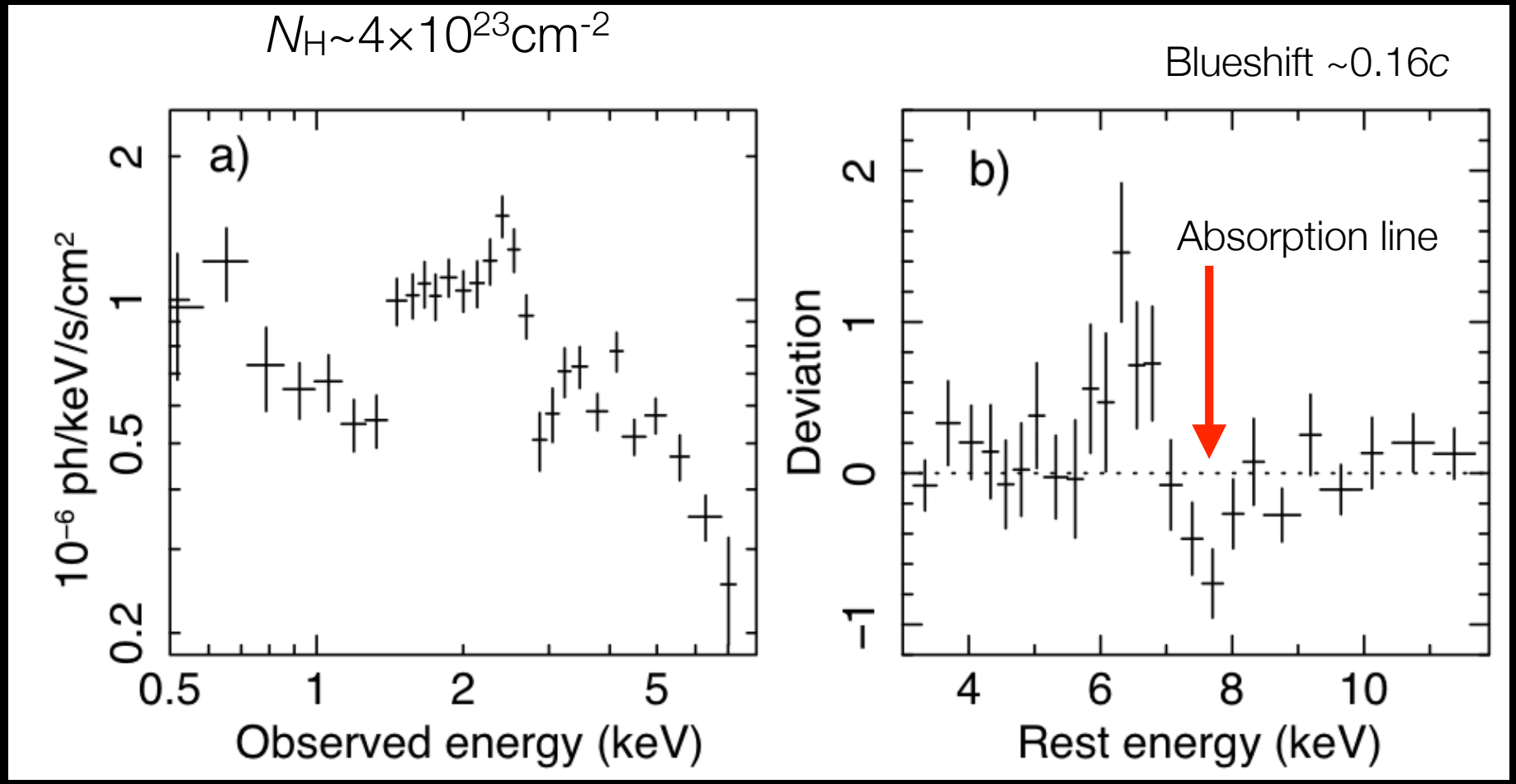
UFOs in AGNs ⇒ kinetic energy 10-1000 x > Warm abosrbers

UFOs in QSOs ⇒ still large unkowns (Cov. Fact.), even more if at z~2

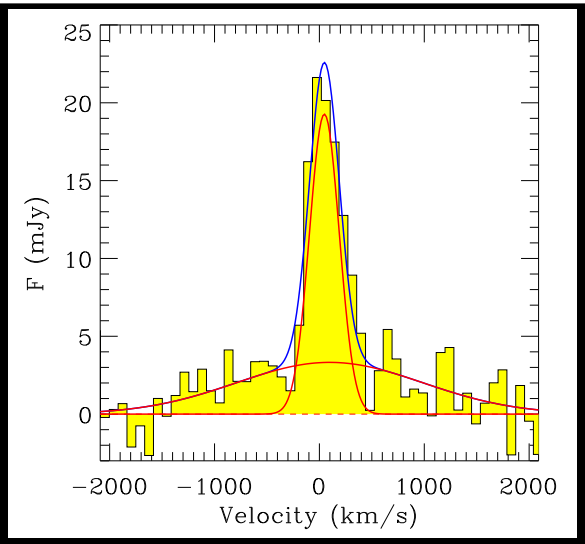
But clearly, energetically, UFOs could have a significant impact on (energizing, momentum driving, and chemically enriching) their host galaxies.

Future: need of higher X-ray throughput and energy resolution (in general) but check (today) spectra from current surveys/high-z QSOs too…(you never know)

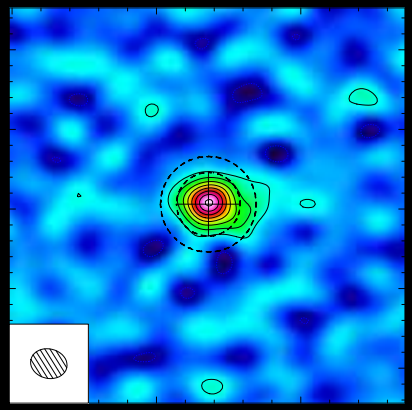
PID352 @ z=1.7 (Iwasawa et al. in prep.)

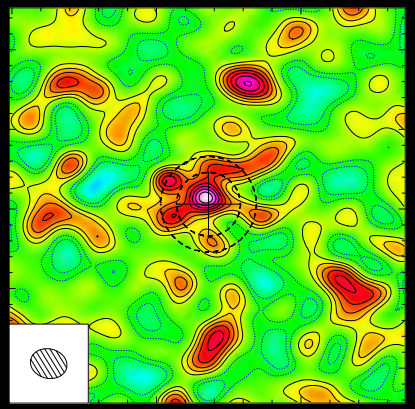


How UFOs relate to colder gas and molecular outflows??



SDSSJ1 14816.64+525150.3 (z=6.42) – IRAM PdBI



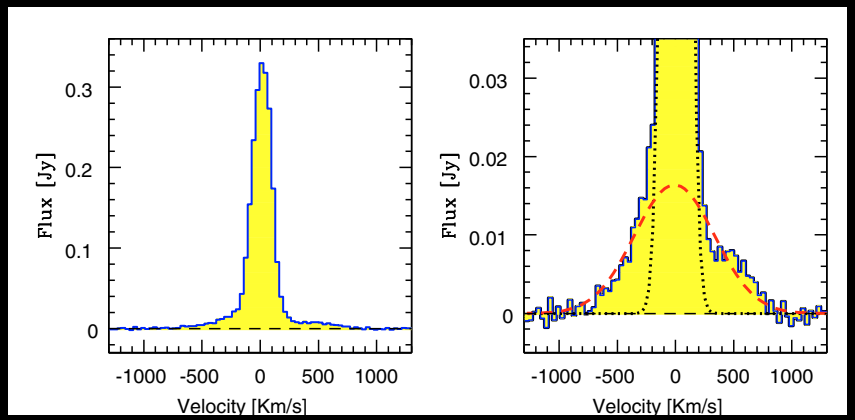


[CII] 158 μm broad wings (FWHM~2000 km/s) + extension →

Maiolino et al. 2012

- $\dot{M}_{out}$ > 3500 $M_\odot$ yr^{-1}; and Quasar driven outflow (not SB)

Mrk231 - CO (resolved) map
FWHM~700 km/s, M_{out} ~ 250-2200 $M_\odot$ yr^{-1}

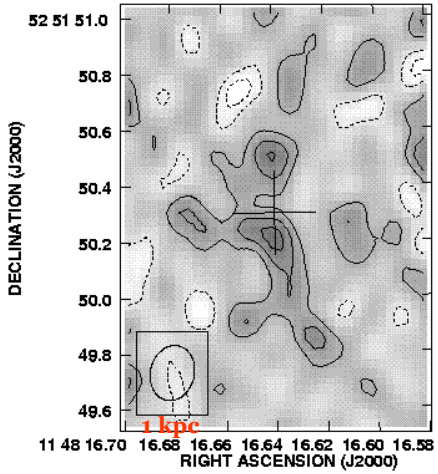


Feruglio et al. 2010

Z=6.42 quasar
CO (resolved) map
V~250 km/s

Bertoldi et al. 2003
Walter et al. 2004

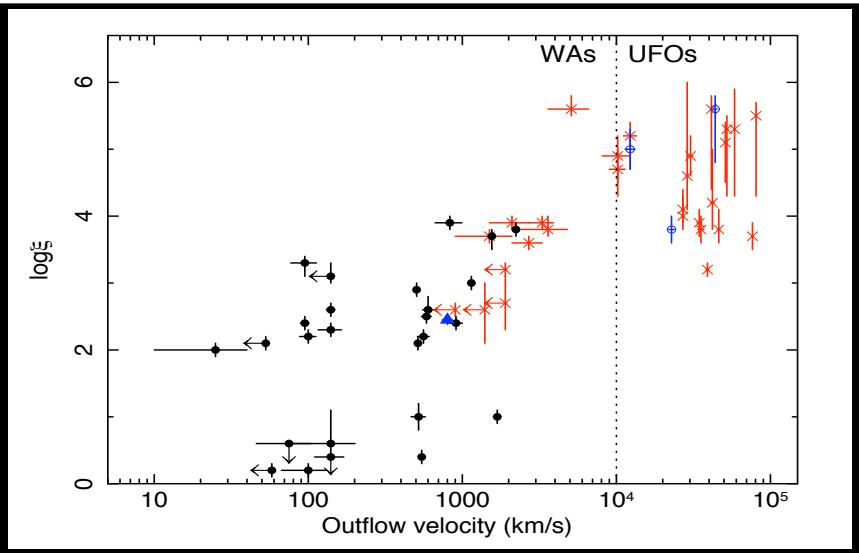
VLA CO 3—2 map

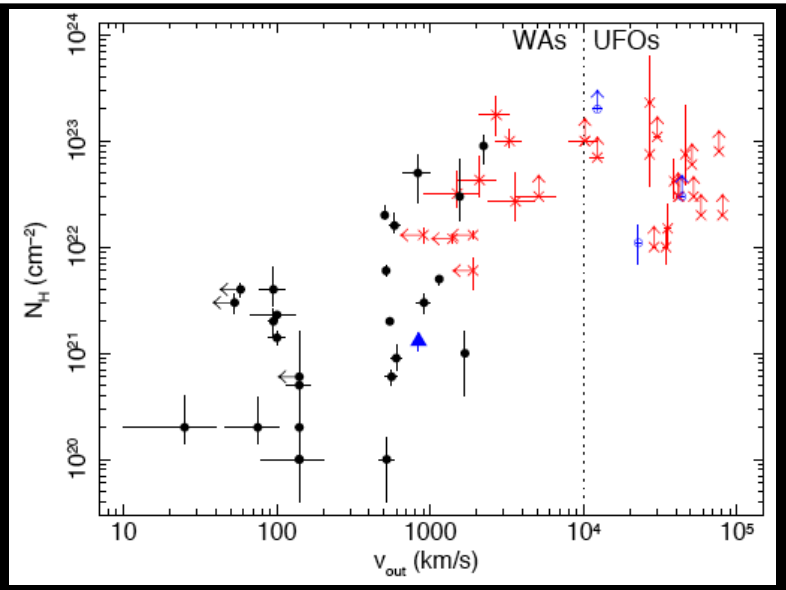


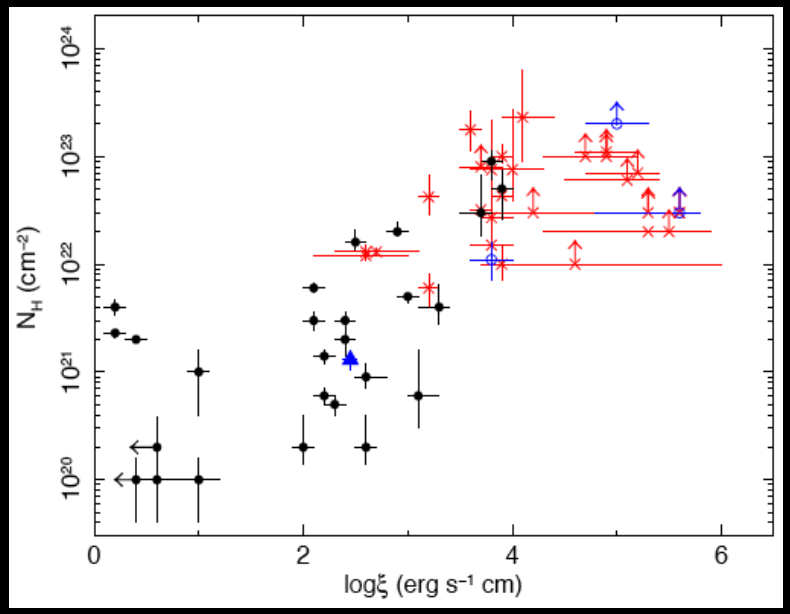
Walter et al. 2004

Thank you very much for your attention

The "new" X-ray view: *UFOs compared with WAs…*

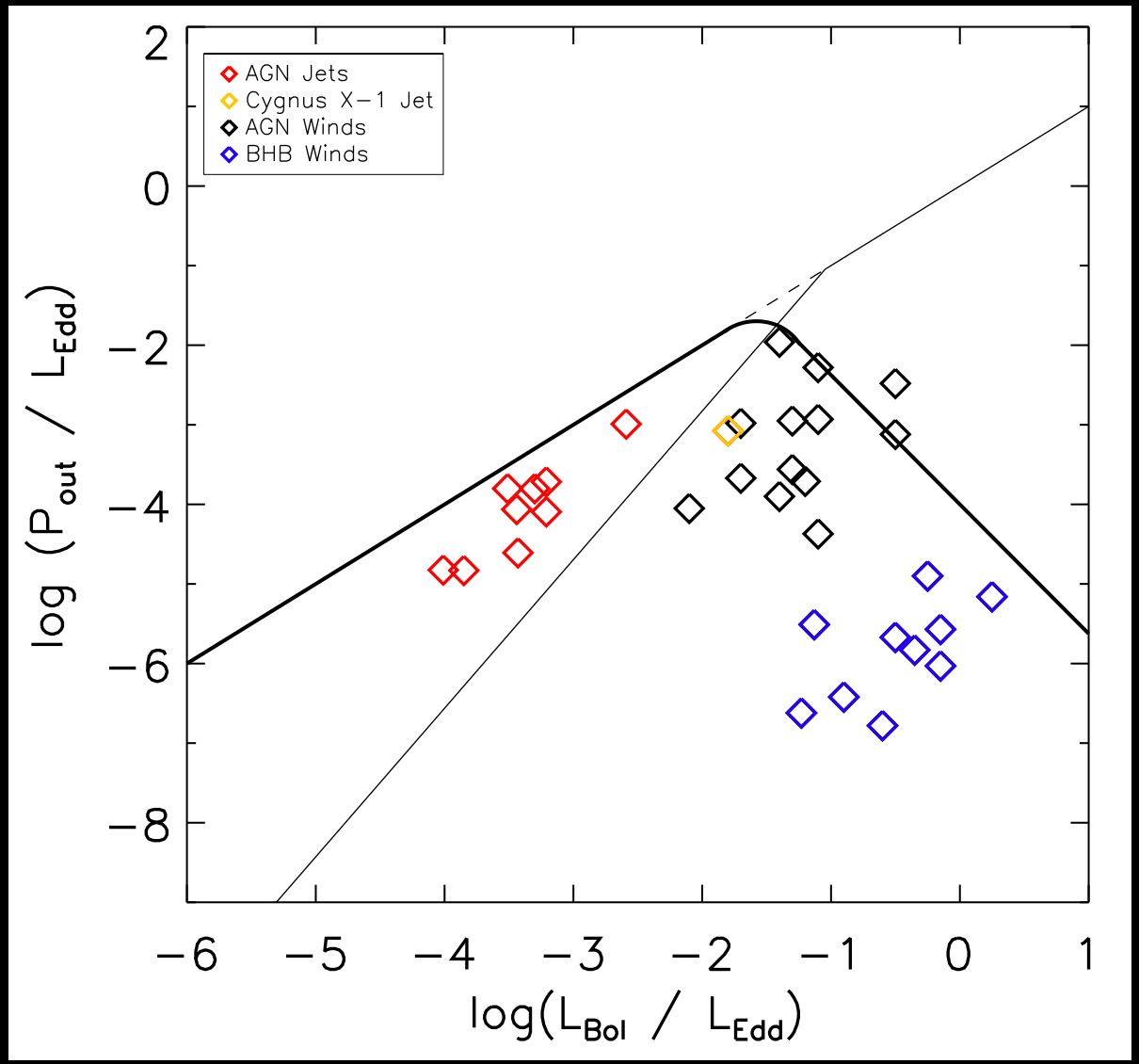






Tombesi et al., 2012,
In prep.

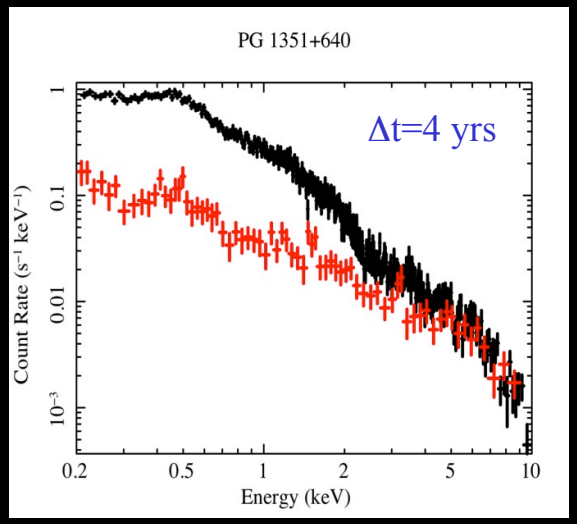
WAs in RQ from McKernan et al. (2007) (filled black circles), WA in RL from Torresi et al. (2009) and Reeves et al. (2009) (filled blue triangle), UFOs in RQ (red crosses)



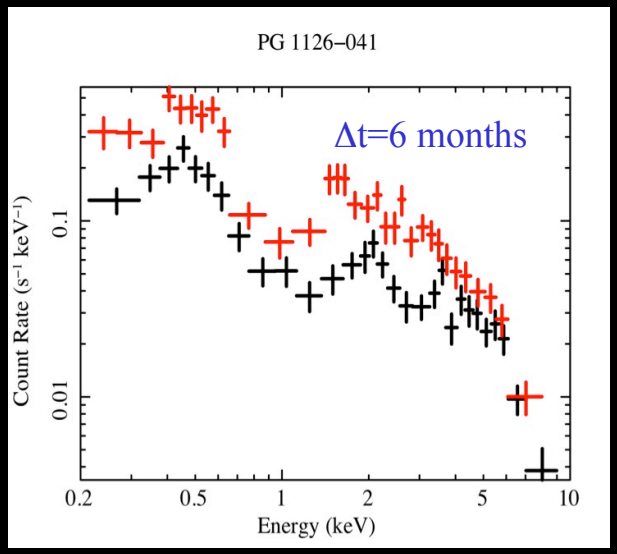
King A. et al. 2012, submitted to ApJ (arxiv: 18 May 2012)

The "new" X-ray view: *Variability of a few PG QSOs*

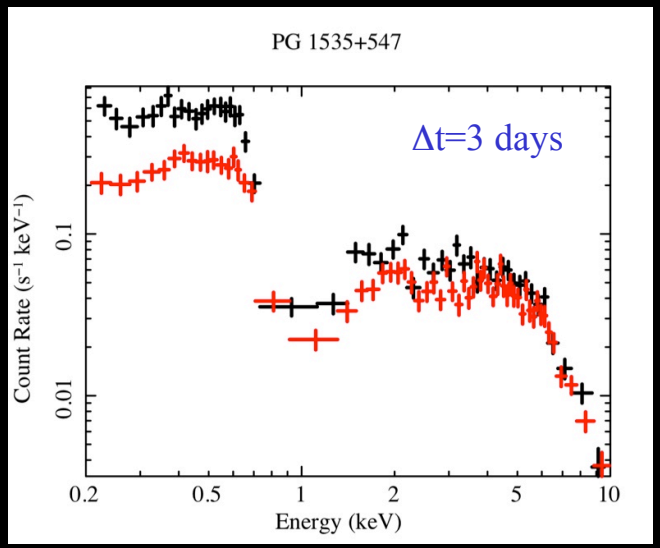
15 UV *AL QSOs with 32 XMM exposures



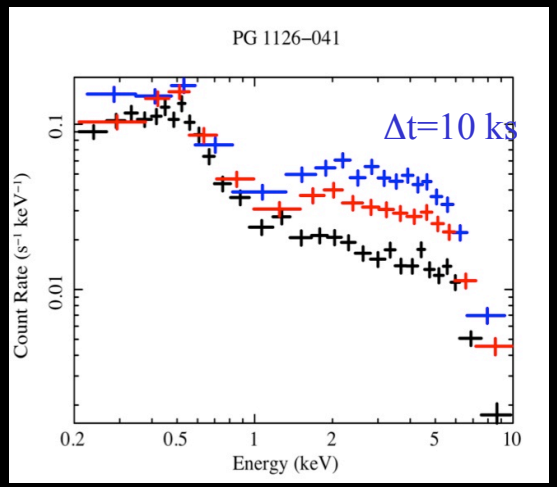
on time scales of years



on time scales of months



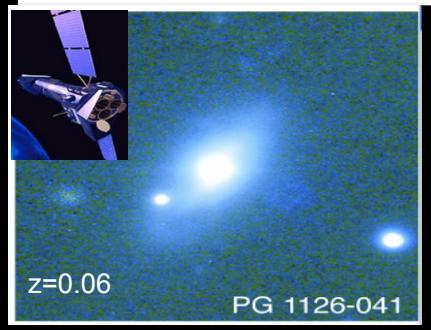
on time scales of days



on time scales of hours

Giustini, MC, et al. 2012, in prep.

The "new" X-ray view: *Variability of a mini-BAL QSO*



The longest X-ray look ever at a mini-BAL QSO (PG1126-041)

Giustini, MC et al., '11

- *Moderately ionized absorber*

  $N_W \sim 8 \times 10^{22}$ cm^{-2} , log $\xi \sim 1.5$ erg cm s^{-1}
- *Highly ionized outflowing absorber*

  $N_W \sim 8 \times 10^{23}$ cm^{-2} , log $\xi \sim 3.5$ erg cm s^{-1}

  $v_{out}(X) \sim 0.055\ c \sim 3\ v_{ut}(UV)$
- *Typical intrinsic continuum,*
- *Secondary soft component:*
- *Variability over time scales*

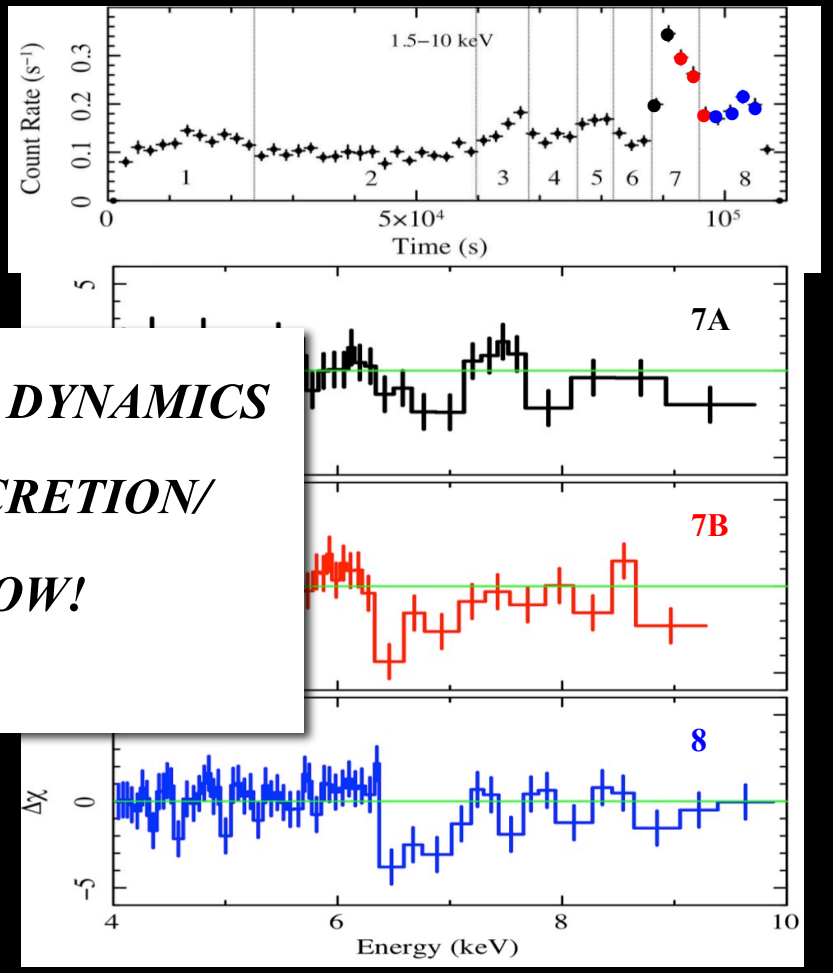
  variable continuum and mo

  ionized absorber
- *Variable* α_{ox}
- ***Variability over time scales of hours:***

  variable continuum and highly

  ionized absorber

START TO PROBE THE DYNAMICS OF THE INNER ACCRETION/ EJECTION FLOW!

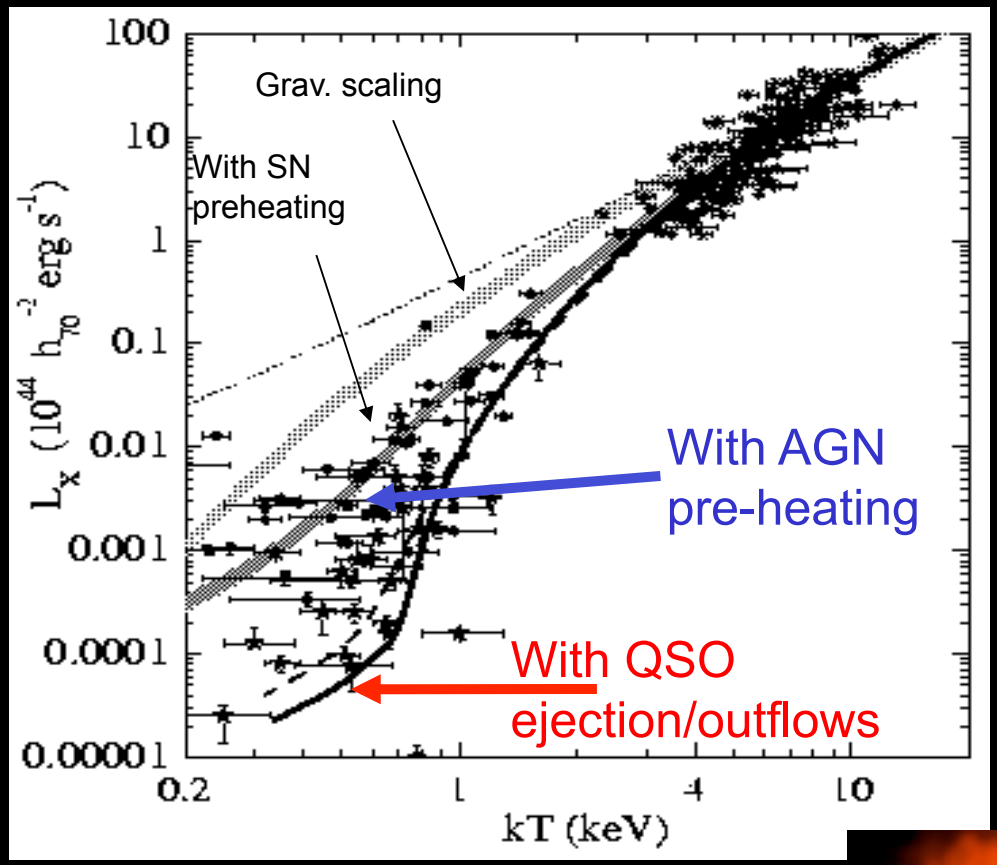


Framework (iii/v): (P)re-heating of groups and clusters of galaxies

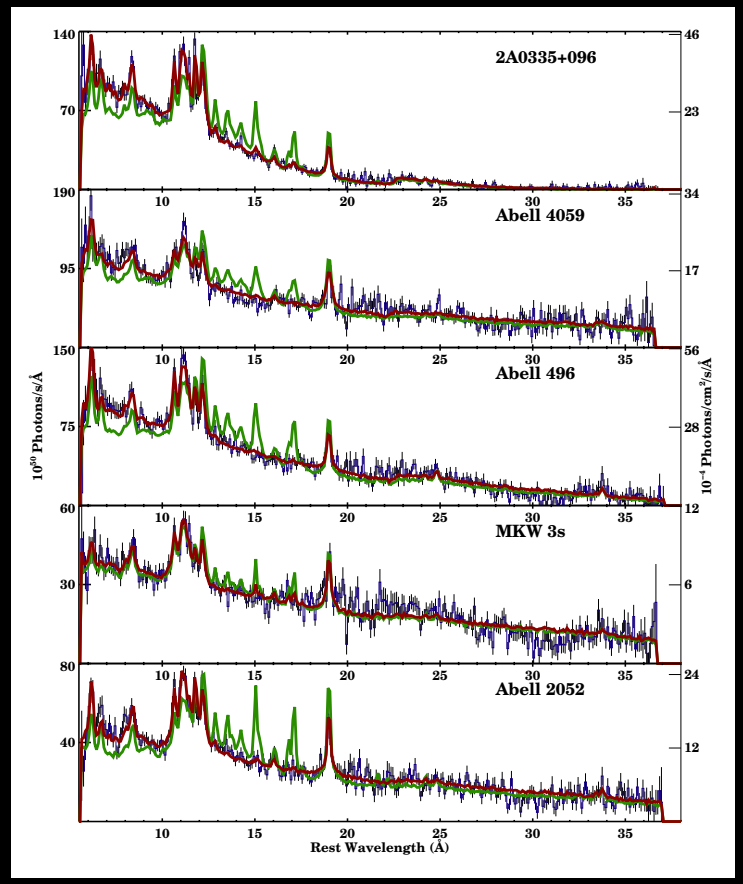
Second unexpected "revolution" in extragal. astrophysics:

need preheating to recover L-T relations & cooling flows extra-heating

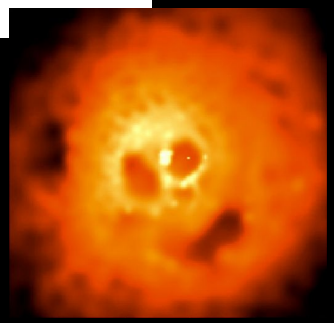
⇒ Energy feedback from AGNs/QSOs in groups&clusters?



Lapi, Cavaliere & Menci, '05

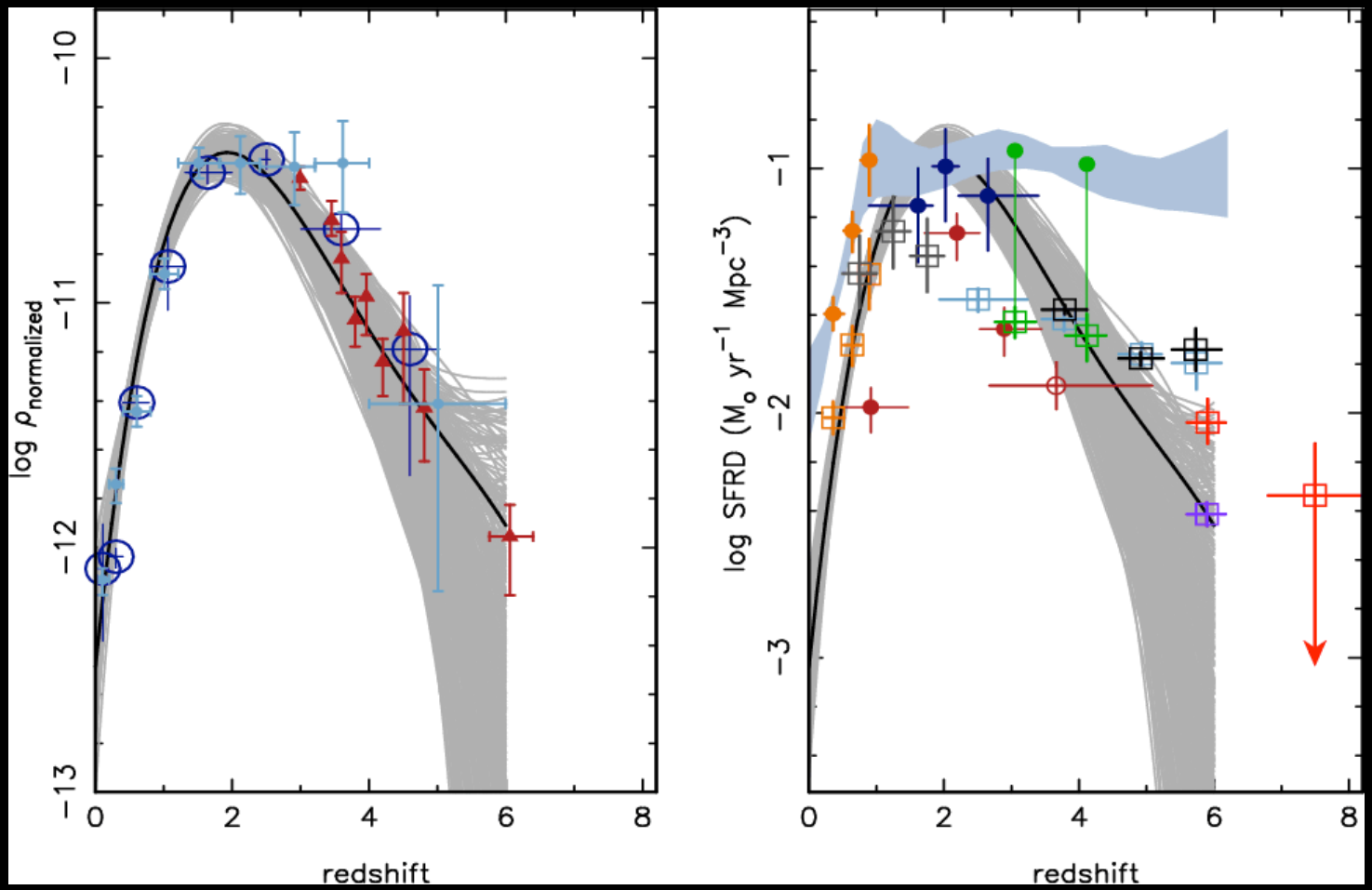


Peterson et al., '03



Perseus Cluster
Fabian et al. '05

Framework (iv/v): MBH vs SFR, which switched on/off first at z~2-3?



QSO space density

SFR space density

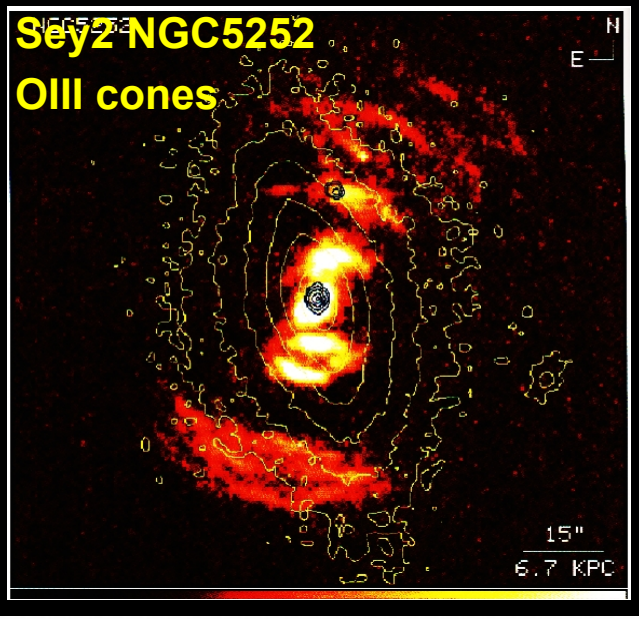
Madau et al. ’96; Wall et al. ‘05

The "classic" view of winds/outflows: Fast winds/outflows/ejecta in AGNs

…known/seen in AGNs since long ago

Wide-angle winds & jets in Sey gal.

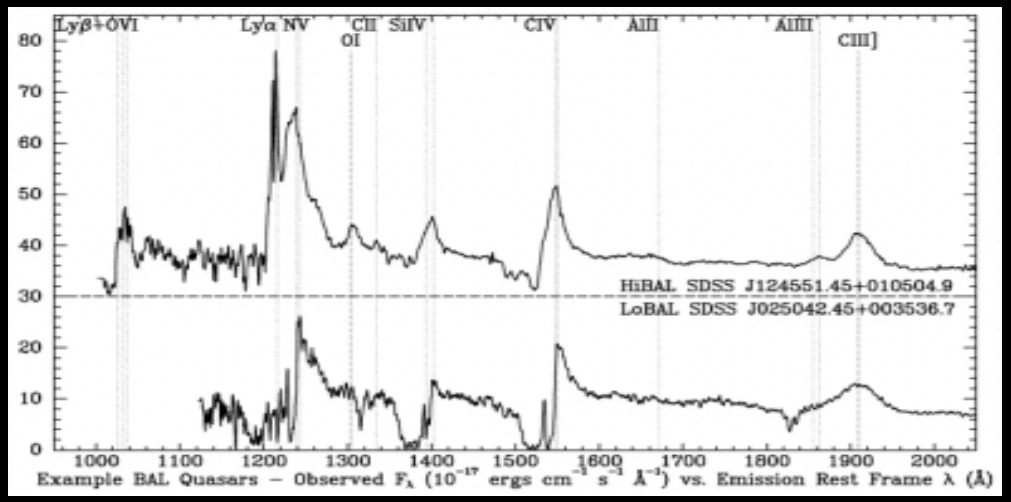
Jets in radio-loud AGNs



Tadhunter & Tsvetanov, Nature, '89;
Wilson & Tsvetanov, '94
Cappi et al. '95
Morse et al. '98

Fast (v up to ~ 50000 km/s) winds in BAL QSOs

(~ 20-40% of all QSOs)



Weymann et al., '91; Reichards et al., '03

The "new" X-ray view: *Results on UFOs (location and energetics)*

- Most frequent detected line is FeXXVI Lyα

- Estimated global covering factor from fraction of sources with lines ($C=\Omega/4\Pi$)≈0.4-0.6 (i.e. similar to WA)

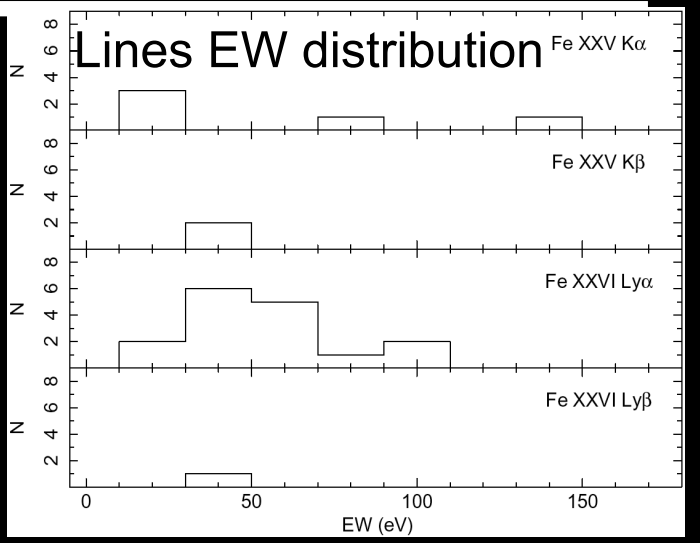
- estimated distances r<0.01-0.1pc (<10^2-10^5 r_s)

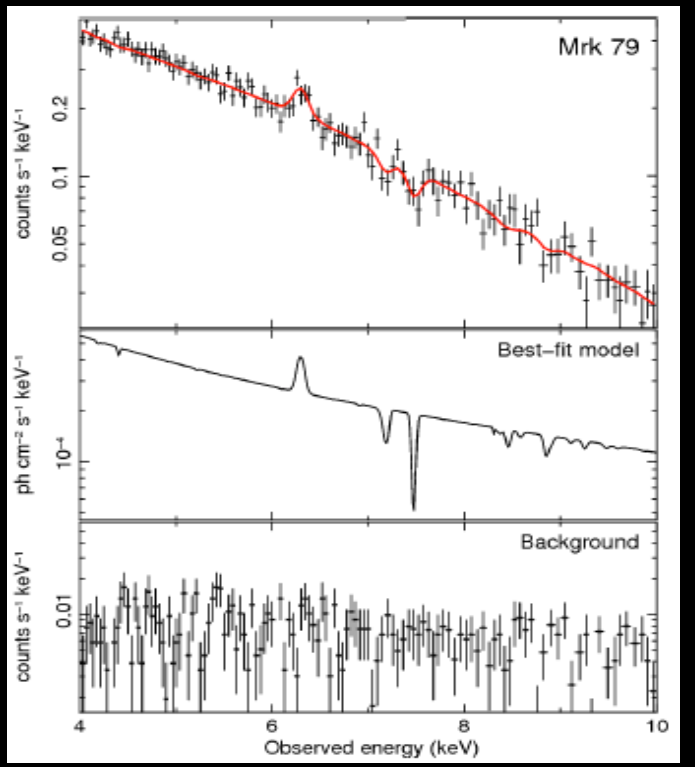
(accretion disk winds? e.g. Elvis '00; King & Pounds '03)

- Often $v_{out} > v_{esc}$, but not always, material shall fall back sometimes? ("aborted jet"? Ghisellini et al. '04, Dadina et al. '05)

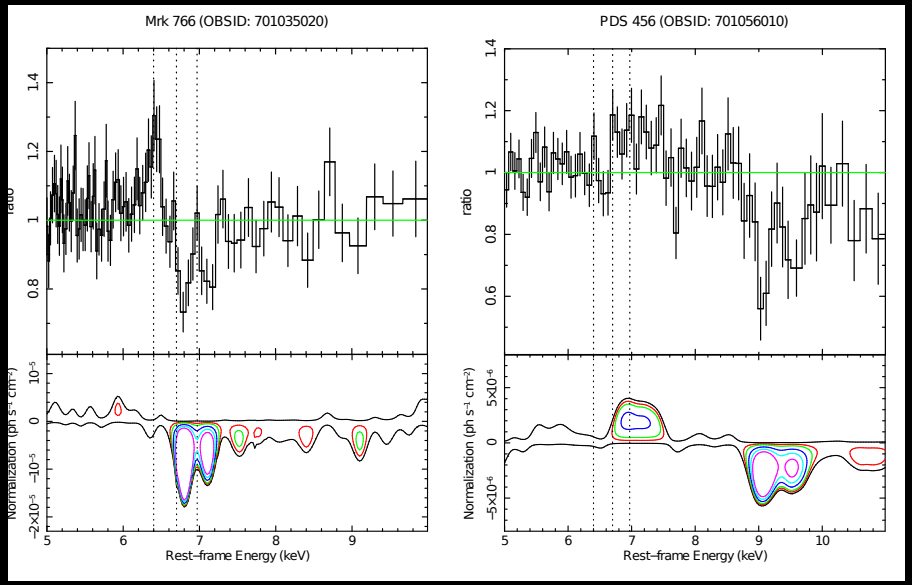
- variability time scales t~1day – 1year
- M_{out}/M_{acc}~0.1-1
- E_k~10^{44}-10^{45} erg s^{-1} ~0.1 L_{bol}

(last estimates depend on covering factor)

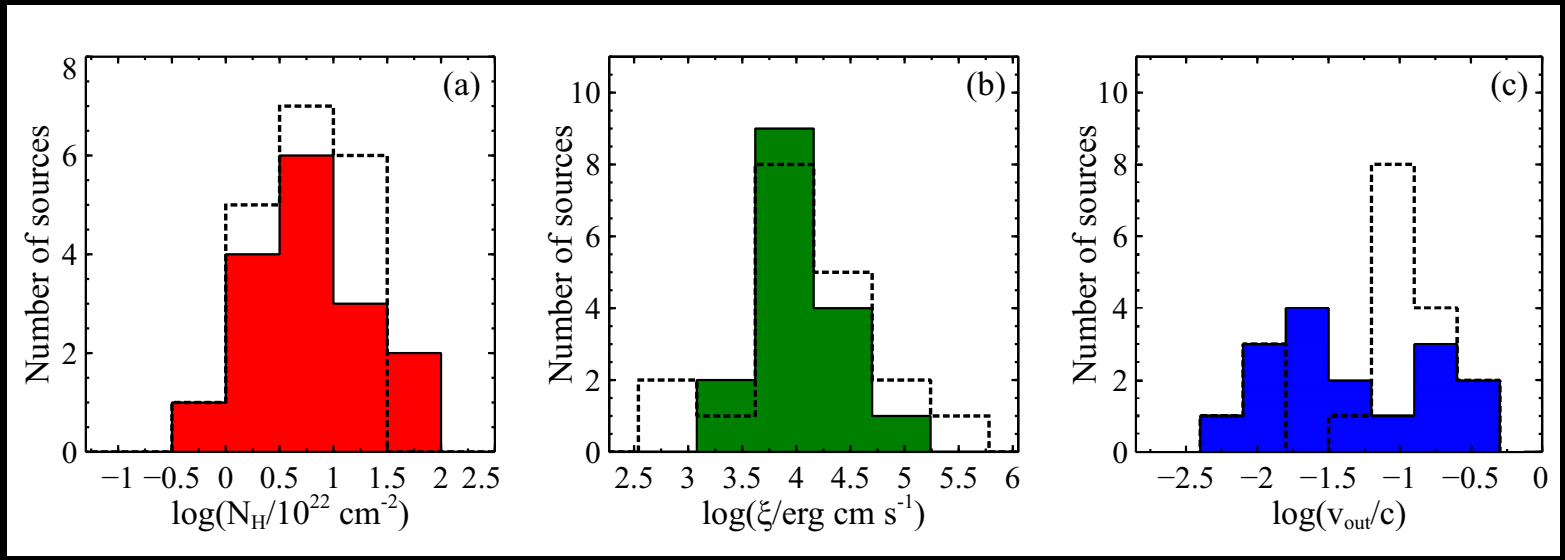




Suzaku analysis confirms XMM results



~35%(16/35) sources with UFOs

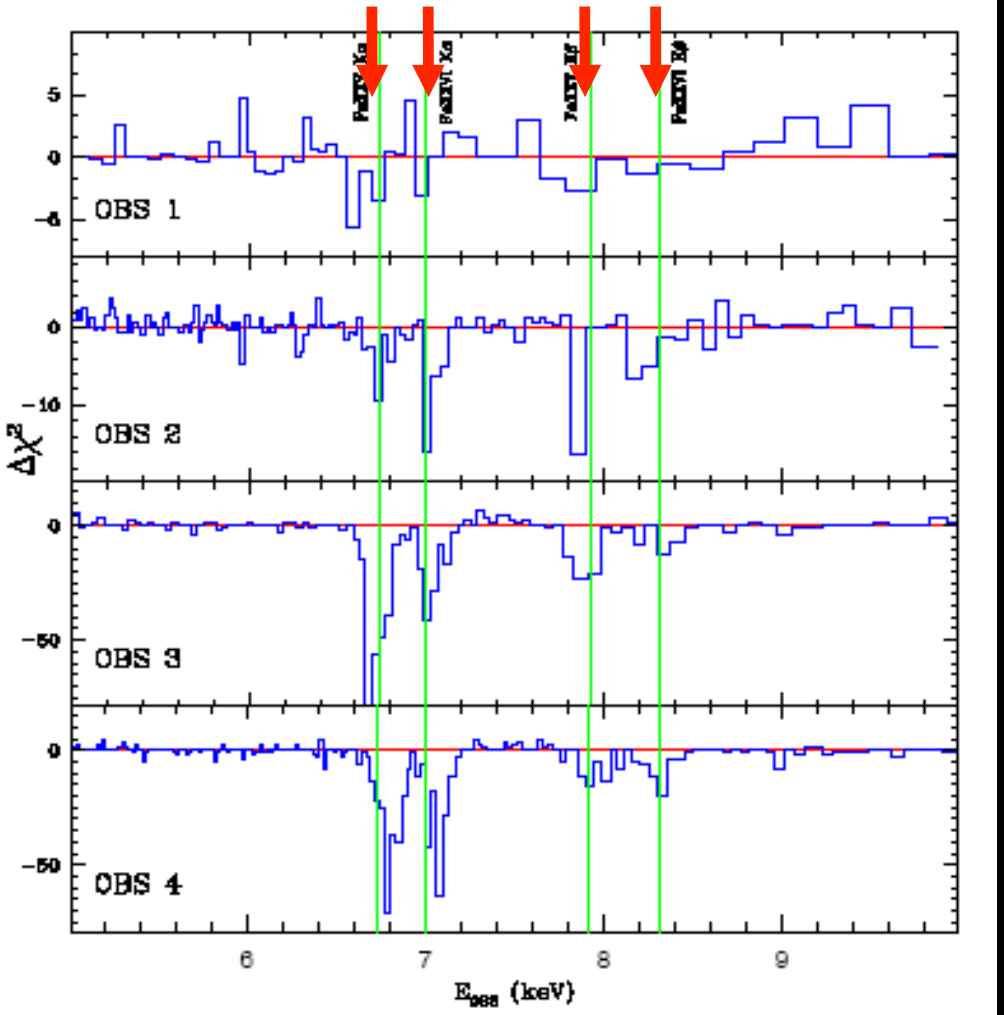


Gofford et al. 2012, in prep.

The "new" X-ray view: *Variable absorption lines*

Absorbers variability on timescales 1000-10000s

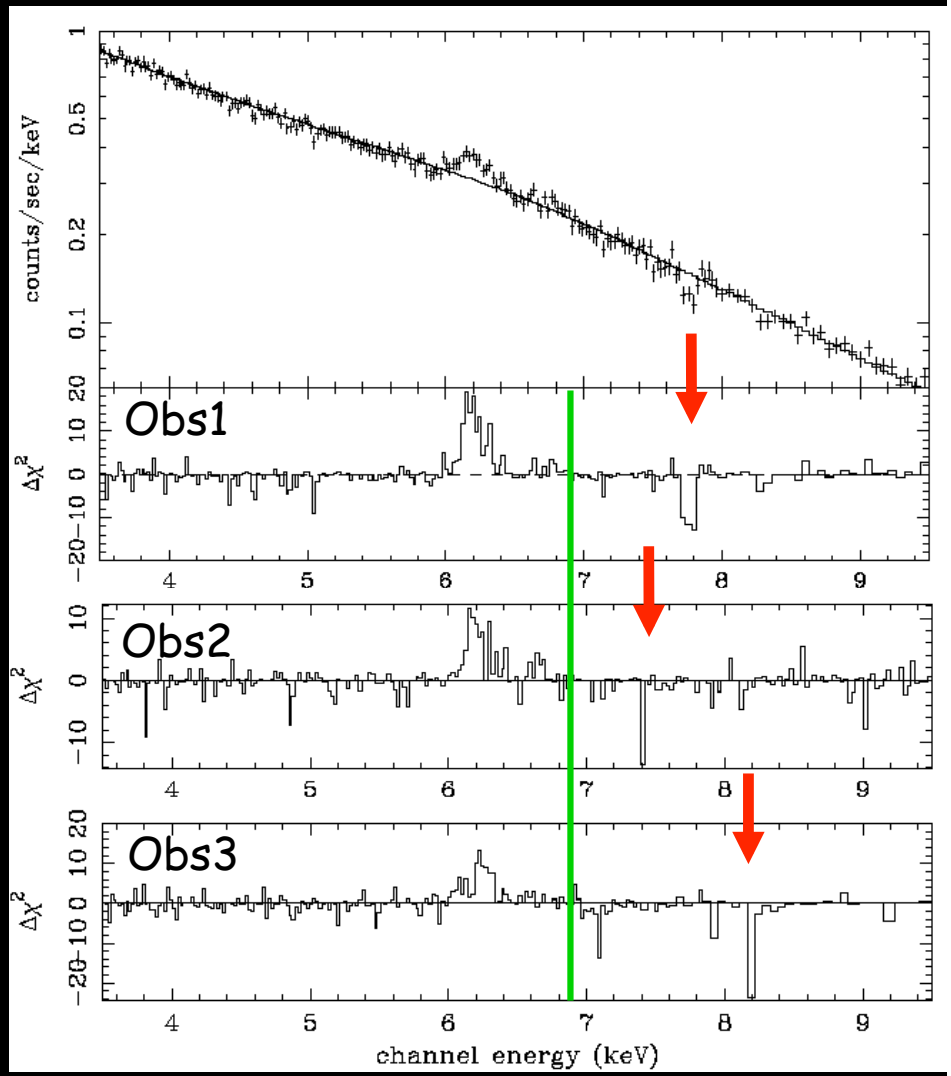
NGC1365



Risaliti et al. 2005

(See also Krongold et al. 2007 on NGC4051)

Mrk 509 (long-look, 200ks)



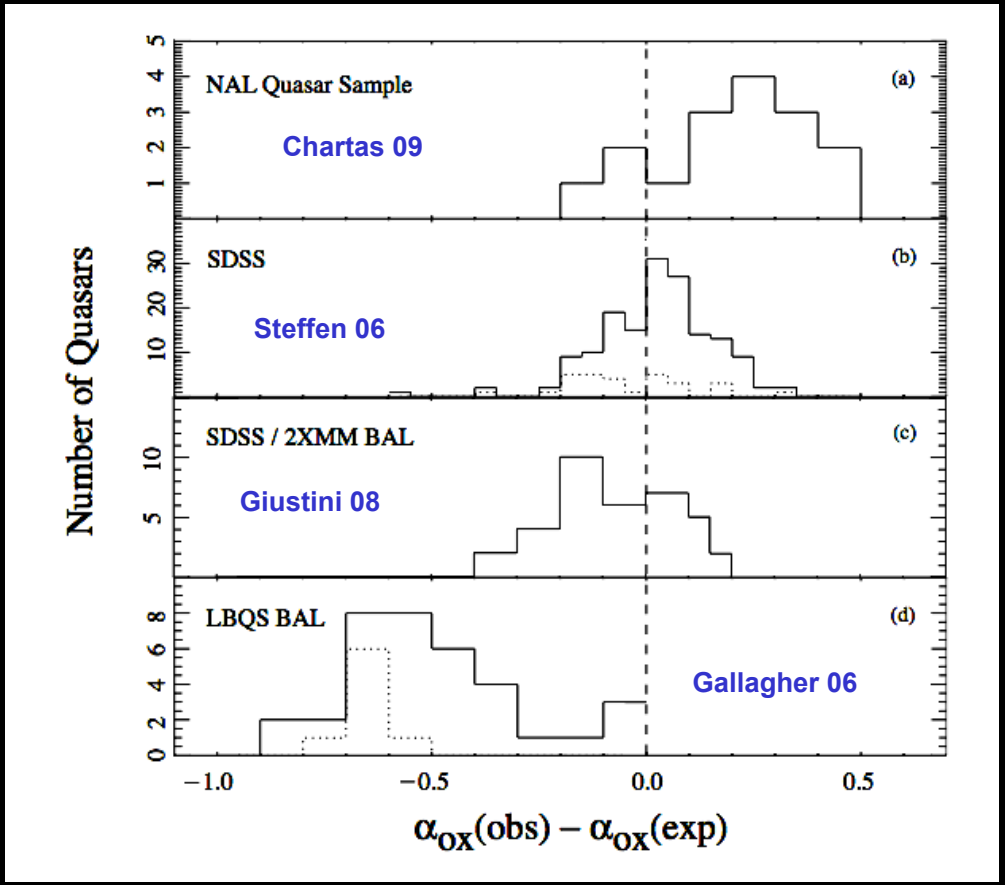
MC et al., 2009

Dadina et al. '05

Variability allows to place limits on location, mass, etc.

The "future" X-ray view: *Spectra for samples of QSOs at high-z (~2-3)*

- *All X-ray detected*
- *Typical continuum $< \Gamma > \sim 1.9$*
- *Very low measured neutral absorbing $< N_H > \sim < N_{H,GAL} >$*
- *All X-ray bright*



Conclusions

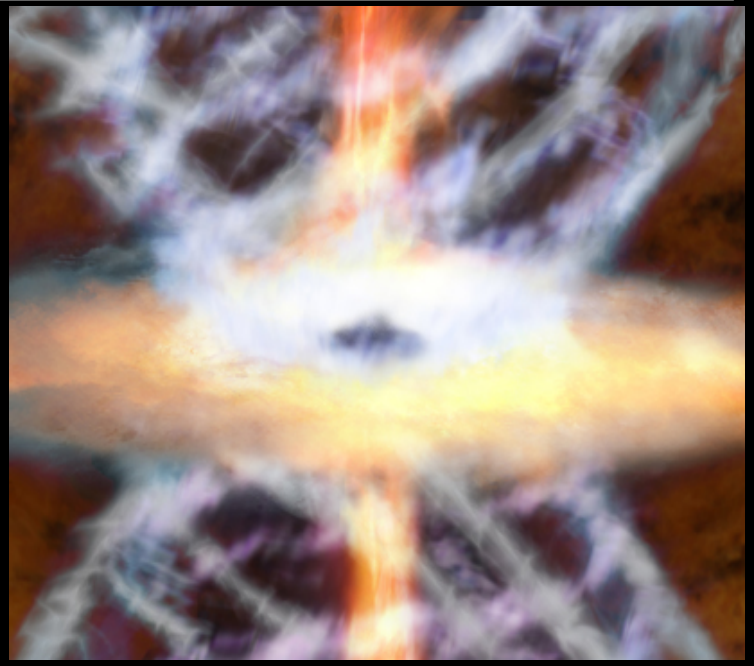
- General framework/importance
  ⇒ *Need for AGN feedback mechanism*

- The "classic" X-ray view of winds/outflows
  ⇒ *Optical/UV/WAs in AGNs and QSOs frequent but maybe insufficient to have significant energetical impact*

- The "new" X-ray view of winds/outflows
  ⇒ *UFOs in AGNs likely frequent and significant*
  ⇒ *UFOs in QSOs at z~2 **may** be frequent and significant too*

- Critical/remaining open Issues for UFOs/winds
  ⇒ *Filling factor in AGNs ?*
  ⇒ *Covering & filling factor in high-z QSOs ?*

- Future
  Near-Future: Astro-H
  Far-future: ????



(near-) Future: ASTRO-H

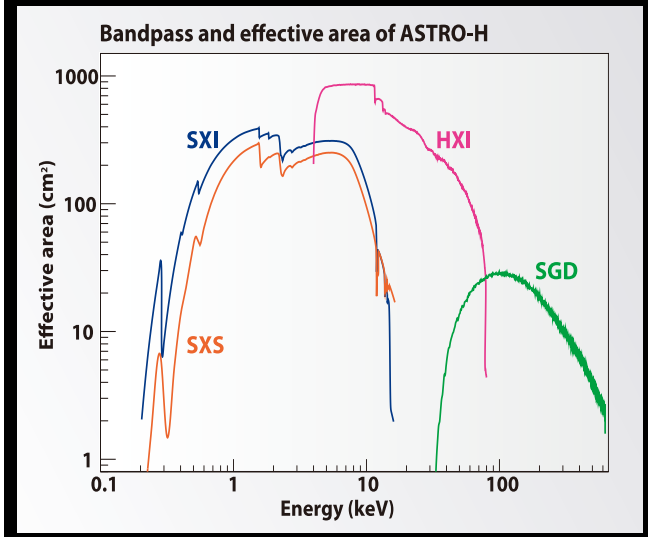
Launch site	Tanegashima Space Center
Launch vehicle	JAXA HII-A rocket
Orbit Altitude	550 km
Orbit Type	Approximate circular orbit
Orbit Inclination	< 31 degrees
Orbit Period	96 minutes
Total Length	14 m
Mass	< 2.6 metric ton
Mission life	> 3 years

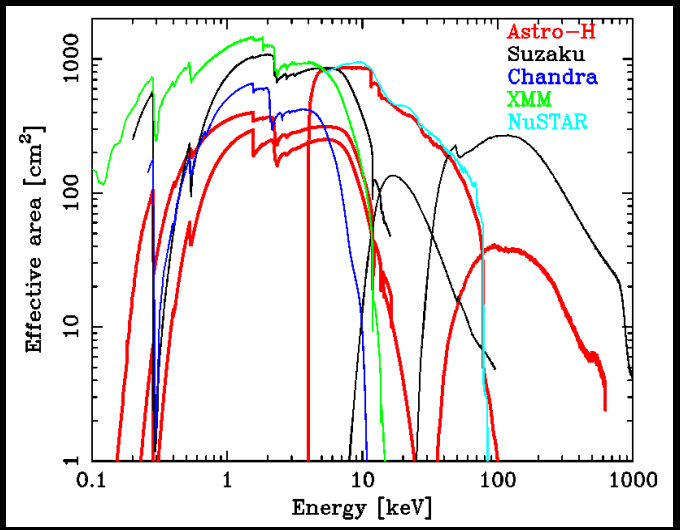
To be launched in <Feb 2014

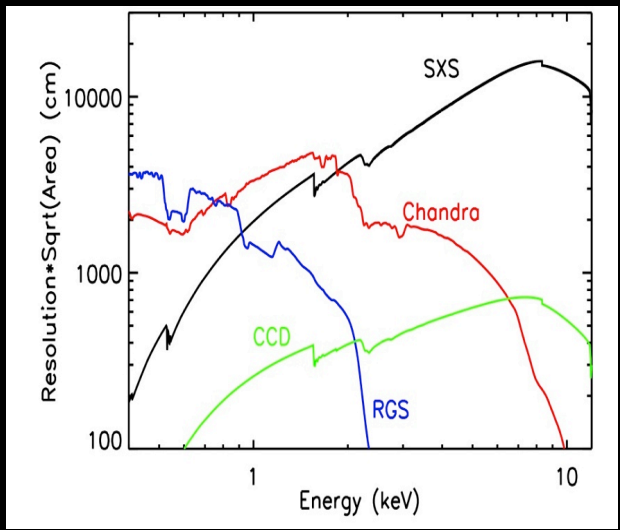
(near-) Future: ASTRO-H

Performance of ASTRO-H instruments

	Soft X-ray Spectrometer (SXS)	Soft X-ray Imager (SXI)	Hard X-ray Imager (HXI)	Soft Gamma-ray Detector (SGD)
Technology	X-ray microcalorimeter	X-ray CCD	Si/CdTe double-side detector	Si/CdTe Compton Camera
Focal length	5.6 m	5.6 m	12 m	–
Effective area	210 cm^2 @ 6 keV	360 cm^2 @ 6 keV	300 cm^2 @ 30 keV	>20 cm^2 @ 100 keV
Energy band	0.3–12 keV	0.5–12 keV	5–80 keV	40–600 keV
Energy resolution (FWHM)	<7 eV	150 eV @ 6 keV	2 keV @ 40 keV	2 keV@ 60 keV
Angular resolution	<1.3 arcmin	<1.3 arcmin	<1.7 arcmin	–
Field of view	3 arcmin x 3 arcmin	38 arcmin x 38 arcmin	9 arcmin x 9 arcmin	–







(near-)Future: ASTRO-H

Final characterisation of outflows from AGNs & QSOs and their feedback impact on galaxies/groups/clusters:

Most important is to:

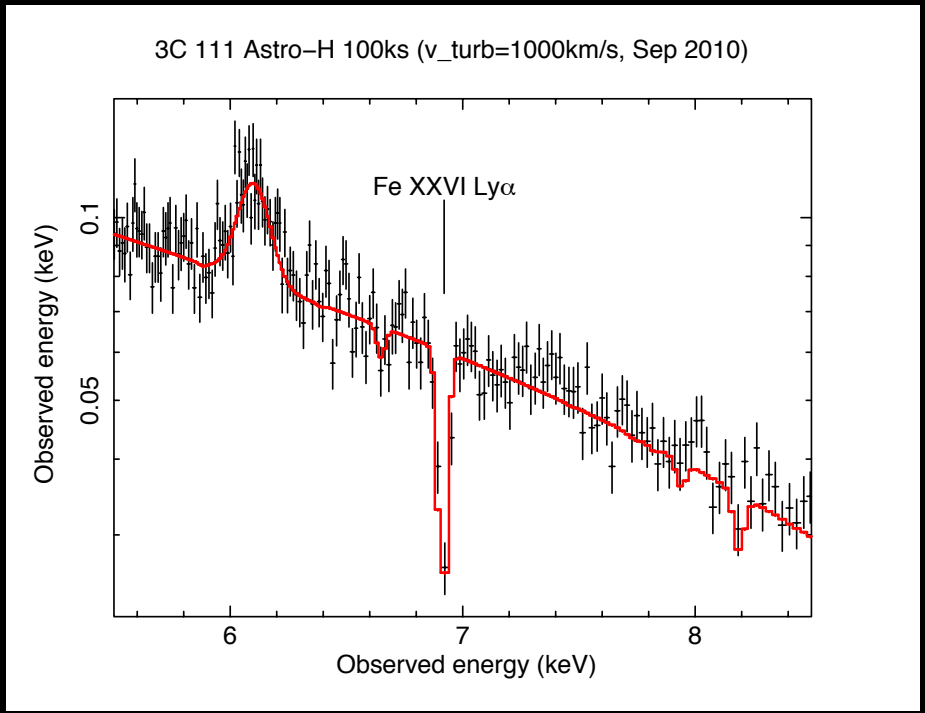
i) Do detailed modeling and probe the outflow dynamics in brightest AGNs (to constrain geometry and location, hence energetics);

ii) Characterize the outflow properties (N_w, ξ, υ_{out}) in QSOs (ideally up to z=2).

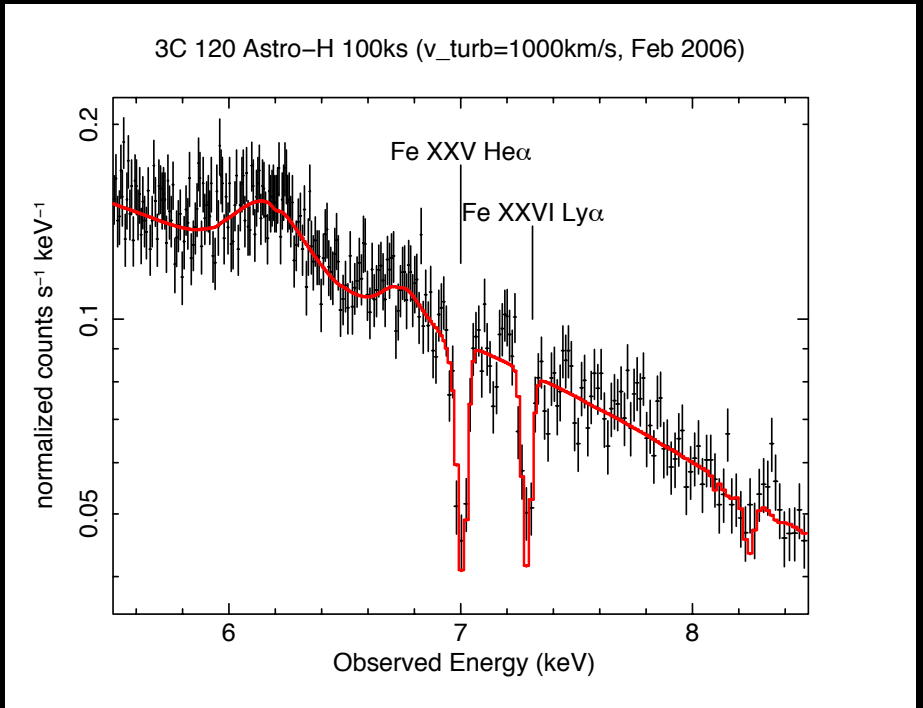
(near-) Future: SXS absorption spectroscopy

Absorption spectroscopy with calorimeter resolution (<5 eV) up to 8-10 keV will revolutionize the field

First probes of absorption line profiles (P-Cygni?)



Probe of flow dynamics on short time-scales

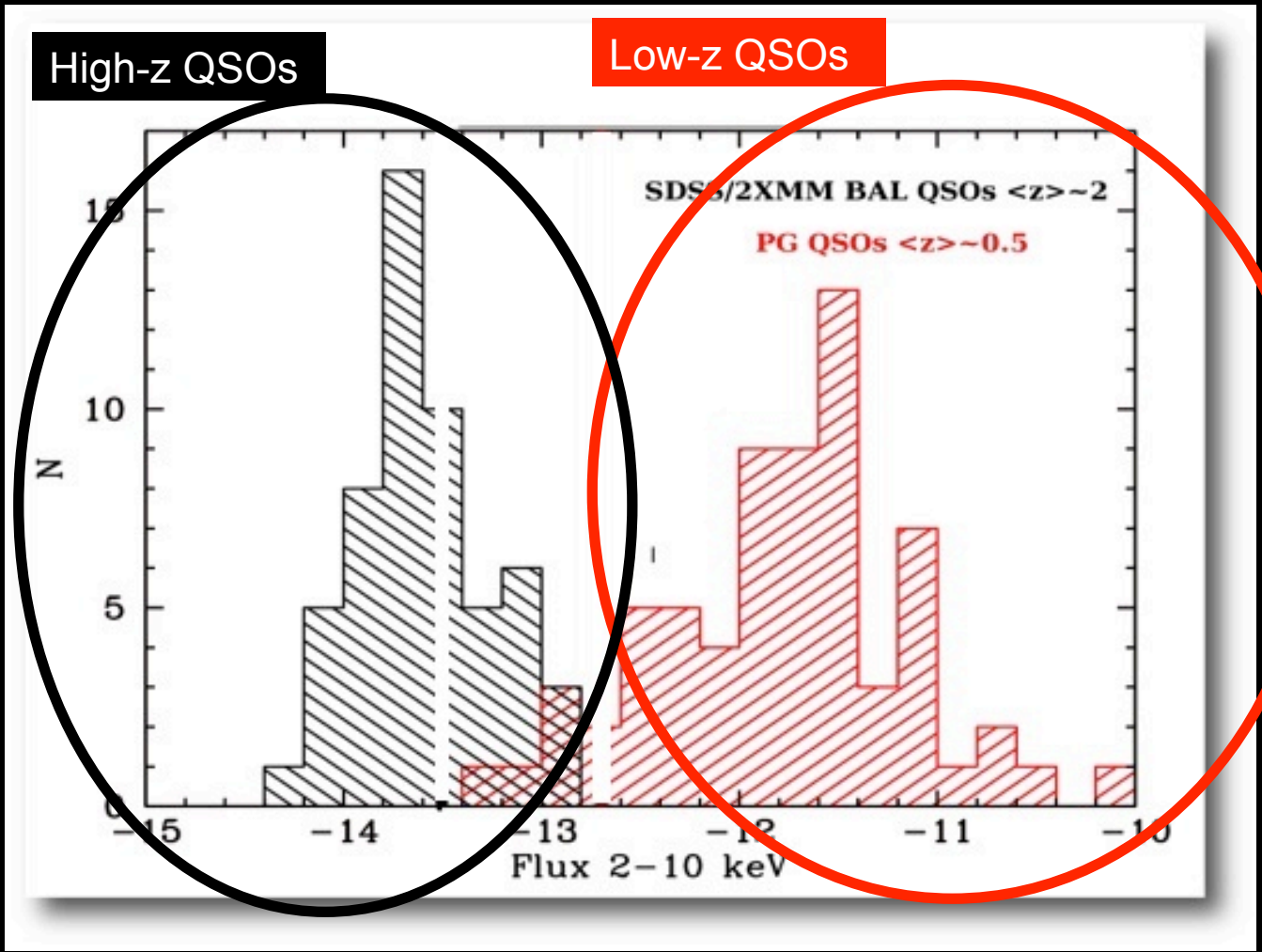


Simulations by F. Tombesi

Important to probe unambiguously the geometry and location of the outflow, and therefore the total mass outflow and the kinetic power associated to AGN feedback.

(Far-?) Future: Study UFOs/absorbers in QSOs up to z~2 (= the "smoking gun")

Typical 2-10 keV fluxes of QSOs (to constrain (N_W, ξ))

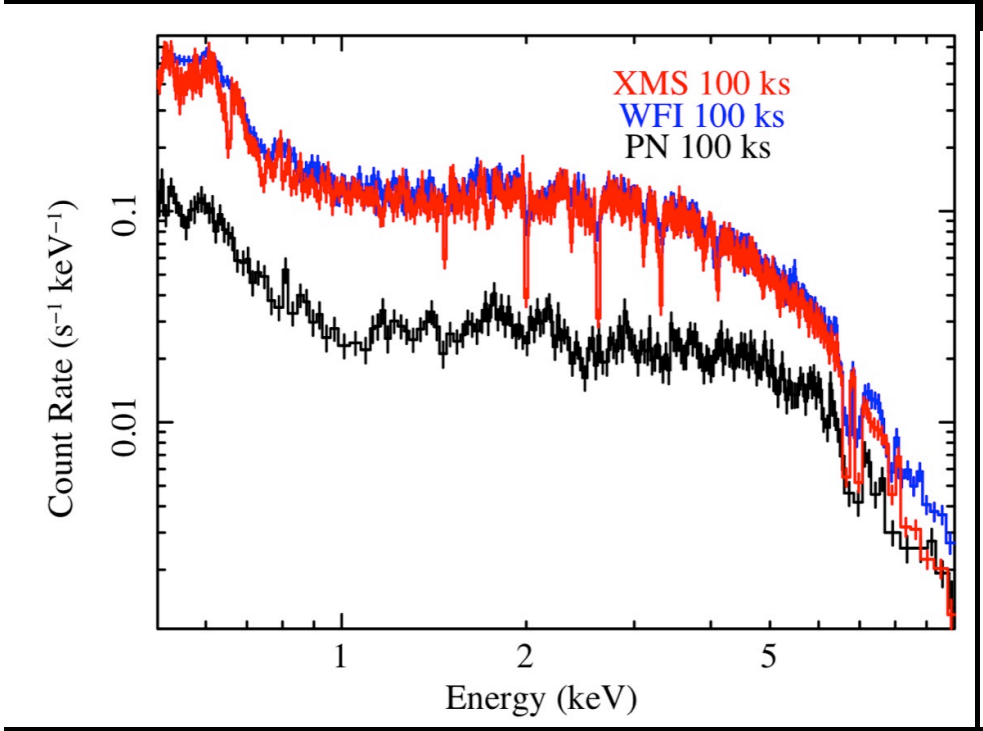


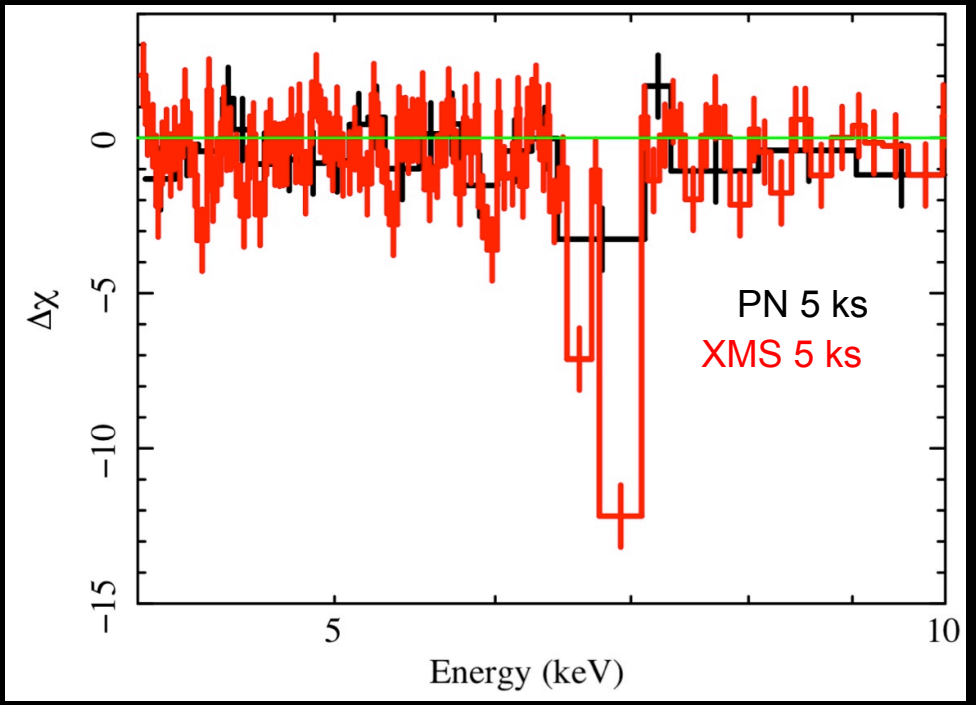
To quantify AGN feedback up to z~2

Will need 10-100 times more throughput between 2-10 keV than Astro-H

(near-) Future: Individual detailed studies in nearby/bright QSOs

The ASTRO-H view of a mini-BAL QSO





UNVEIL THE DYNAMICS OF THE INNER ACCRETION/EJECTION FLOW