Outflows, Feedback and SMBH/Galaxy Co-Evolution

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Outline

i. AGN Outflows (very brief review of science case)

ii. The Astrophysics of AGN Outflows

iii. The (Cosmological) impact/feedback of AGN outflows

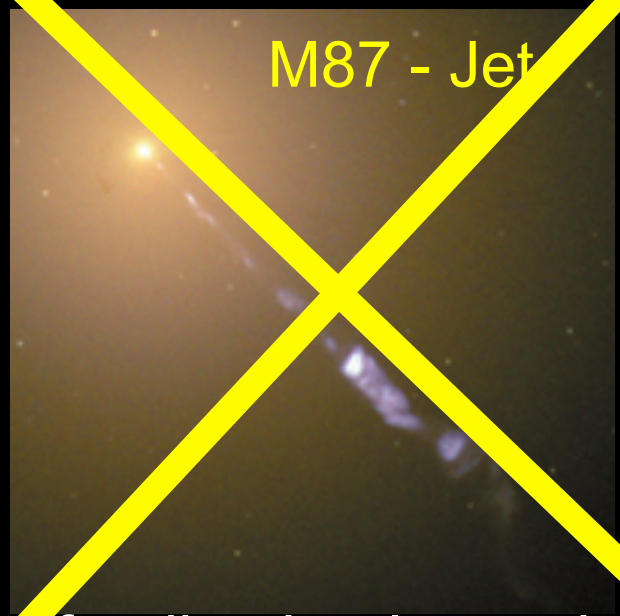
Main Collaborators: M. Dadina, G. Chartas, J. Kaastra, J. Kriss, C. Vignali, G. Lanzuisi, F. Tombesi, M.Giustini, J. Reeves, M. Gaspari, J. Gofford, B. DeMarco, G. Ponti, V. Braito

AGN Outflows

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

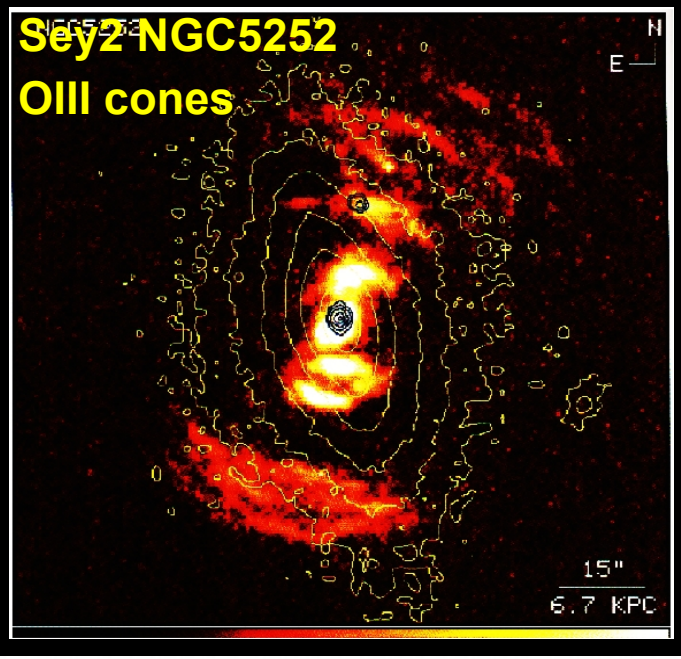
…known/seen in AGNs since >3 decades

Jets in radio-loud AGNs



Jet feedback relevant in LSSs

Wide-angle winds in Sey gal. and QSOs

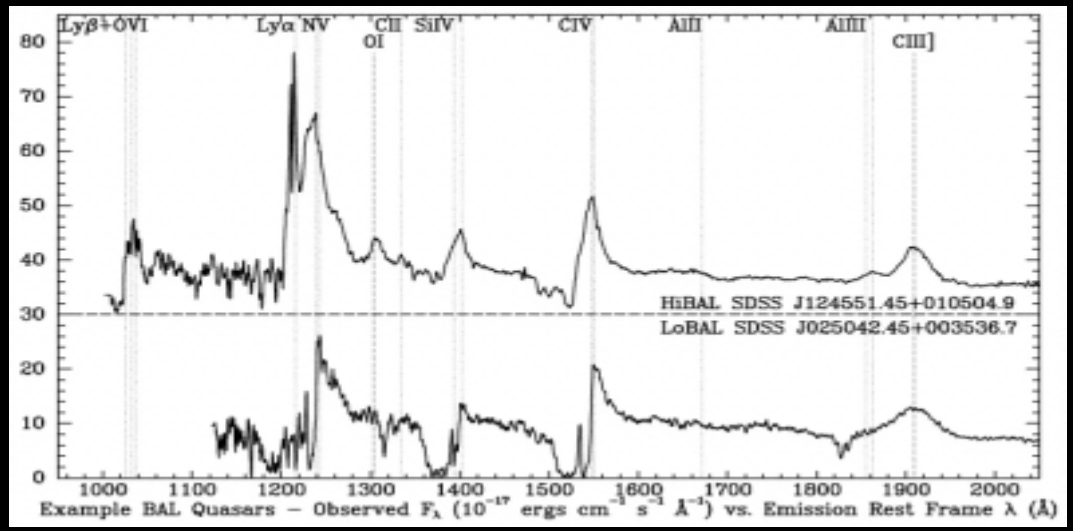


Tadhunter & Tsvetanov, Nature, '89;
Wilson & Tsvetanov, '94
Cappi et al. '95
Morse et al. '98

+ Fischer+ '10, '13, '15

Fast (v up to ~ 50000 km/s) winds in (B/N)AL QSOs

(~ 40-50% of all QSOs)



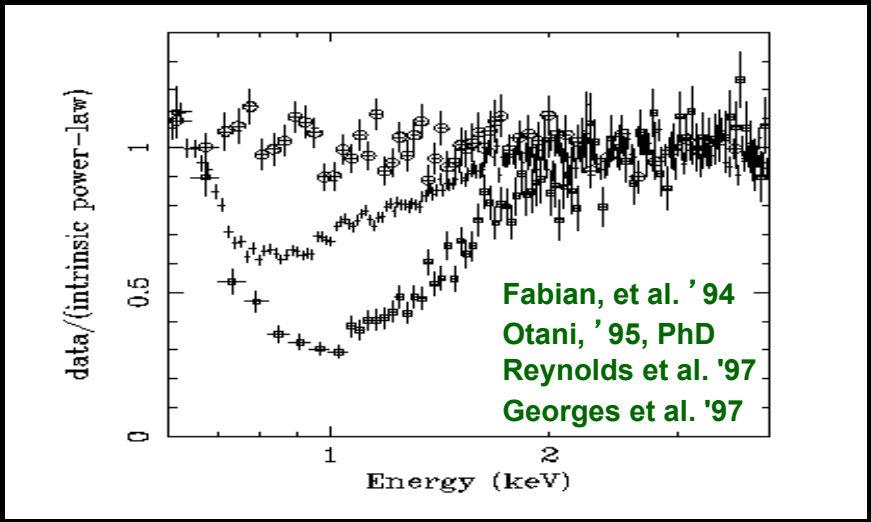
Taking into account the Cf,

→Likely ubiquitous

Weymann et al., '91; Goodrich '97; Reichards et al., '03; Ganguly & Brotherton '08; Hamann+'12

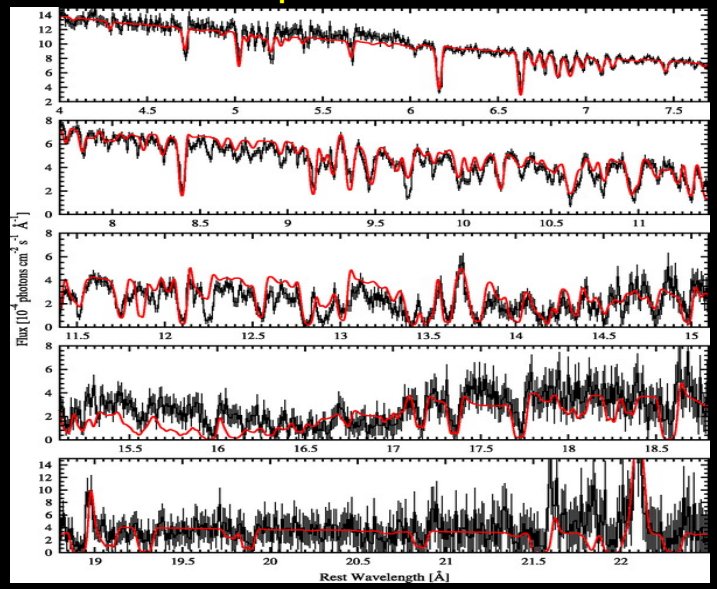
The "classic" X-ray view: Warm Absorbers in nearby Seyferts and QSOs

Seyfert galaxies: *ASCA…*



Many details from Chandra/XMM gratings

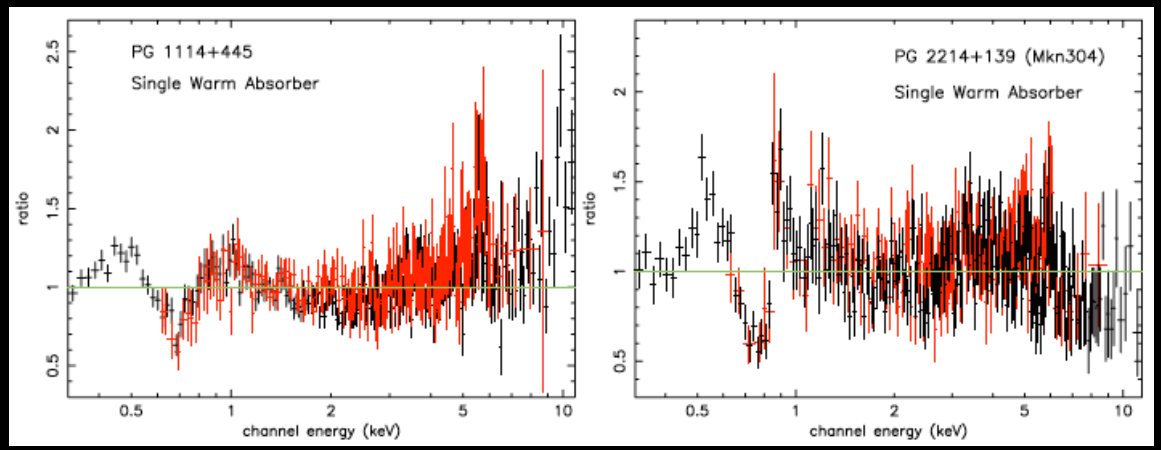
NGC3783 Exp=900 ks



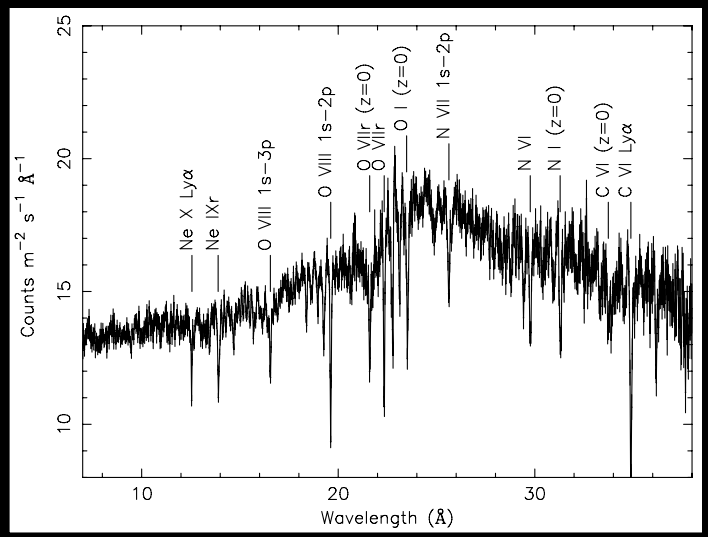
Kaspi et al. '01;
Netzer et al. '02;
Georges et al. '03;
Krongold et al. '03

Mrk 509 RGS: 600 ks

QSOs: *XMM…*



Porquet et al. 2004; Piconcelli et al. 2005



Kaastra et al. 2011, Detmers et al. 2011

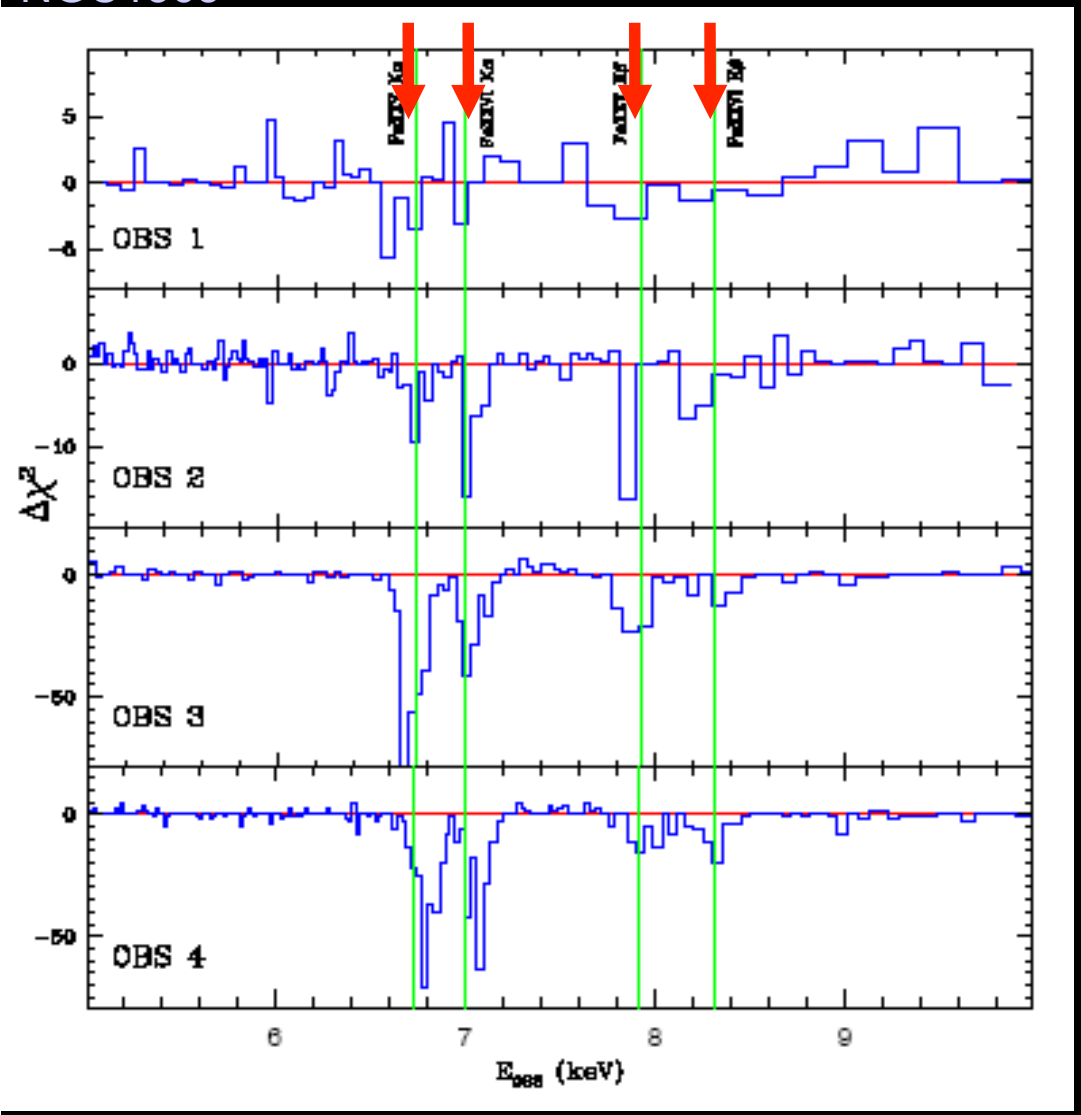
→ Clear now that ~50% of all Seyferts and QSOs present multiple ionization & kinetic components (from Optical, UV and soft X) of outflows/winds with v~100-1000 km/s

→ Typically energetically unimportant for feedback i.e. Blustin et al. 2005, but see Crenshaw & Kraemer, 2012

The "new" X-ray view: Not (only) a static WA but also variable Ultra Fast Outflows (UFOs)

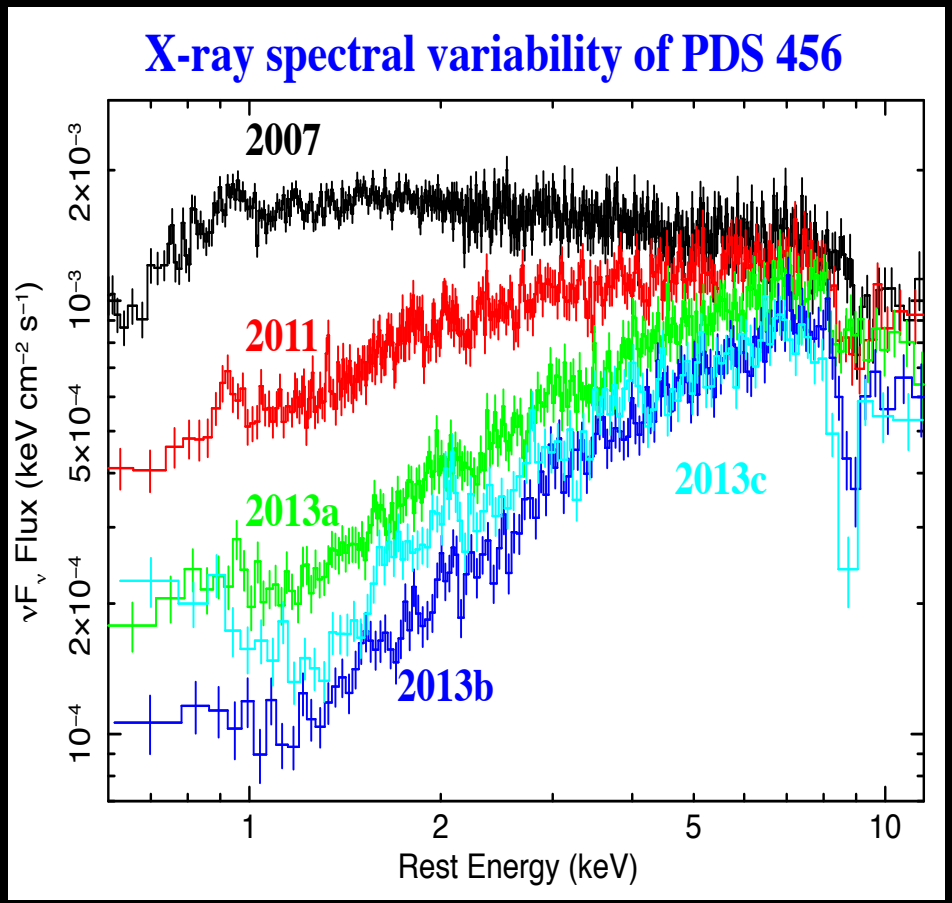
Absorbers variability on timescales 1000-10000s, and v up to ~0.2c

NGC1365



Risaliti et al. 2005

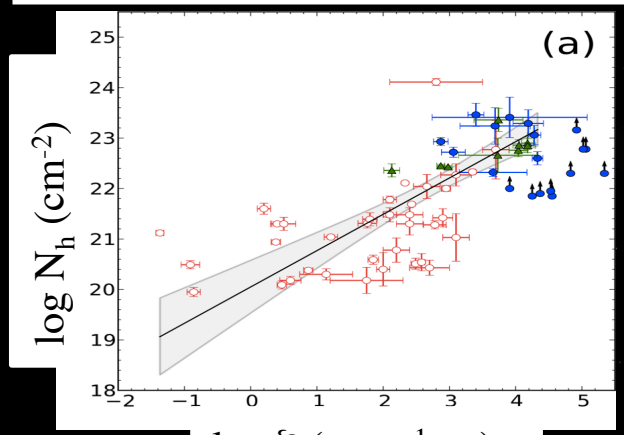
(See also Krongold et al. 2007 on NGC4051; Behar et al. 2010 on PDS456, Braito et al. 2007 on MCG5-23-16; MC et al. 2009 on Mrk509 etc.)



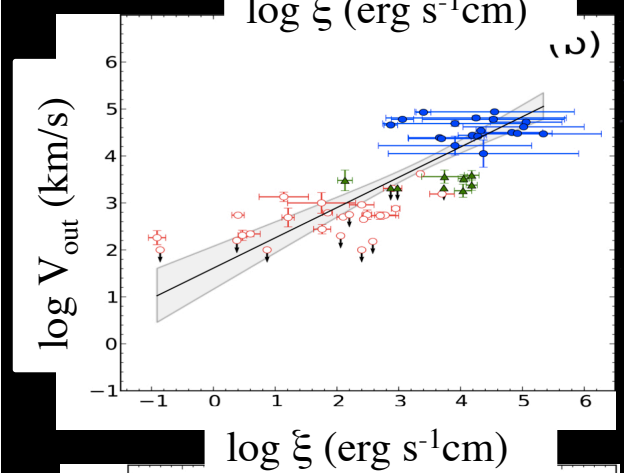
Reeves et al. '10, '13, '15

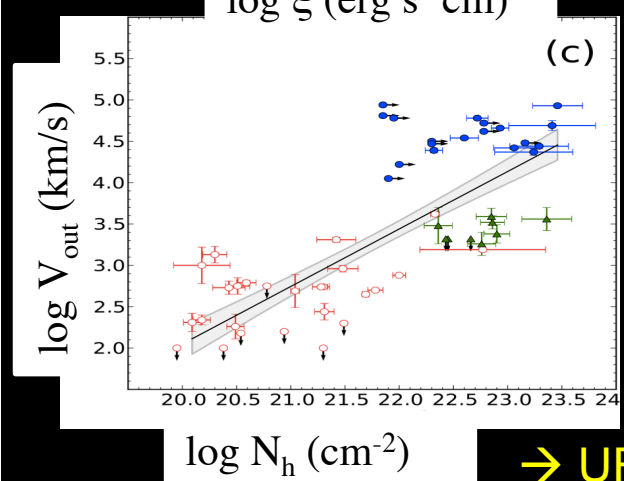
N.B: Variability allows to place robust limits on location, mass, etc.

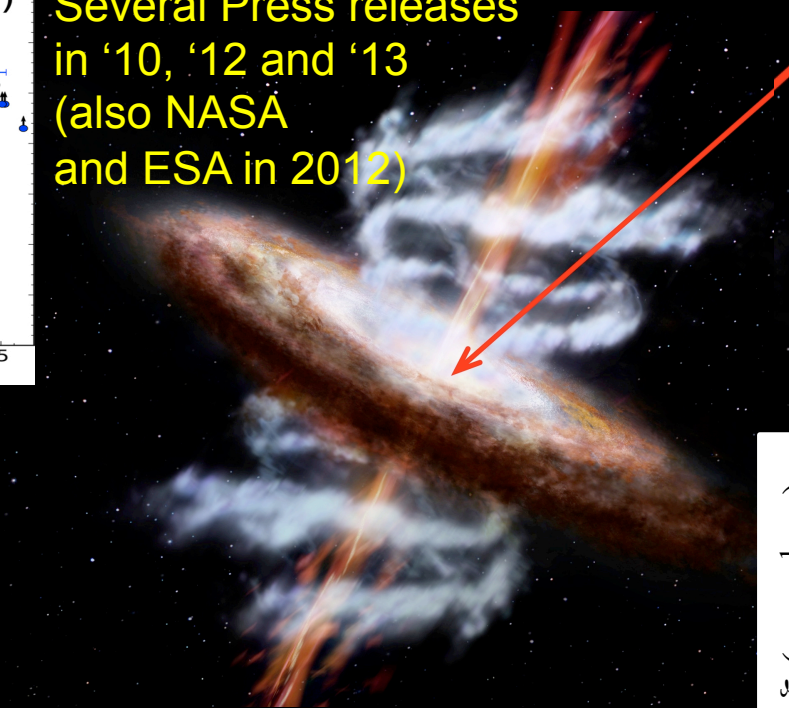
The "new" (unifying) X-ray view of UFOs and non-UFOs (WAs)

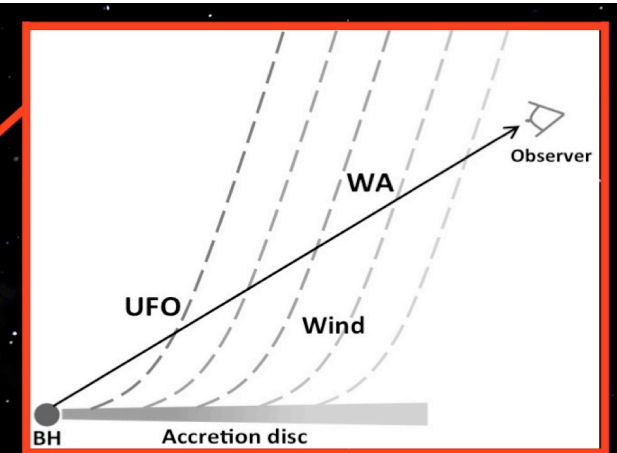


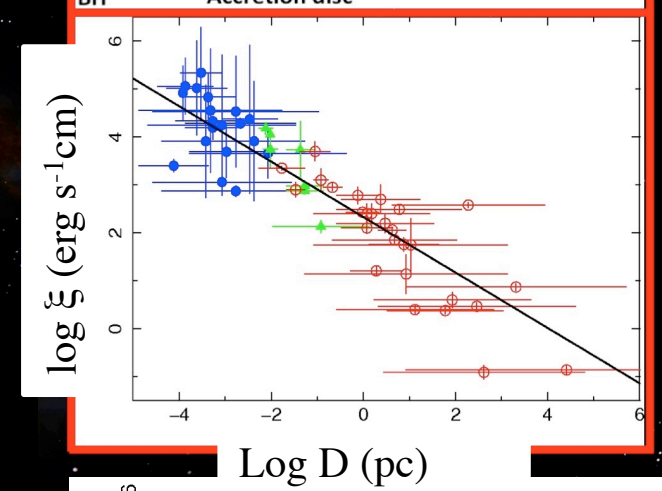
Several Press releases in '10, '12 and '13 (also NASA and ESA in 2012)



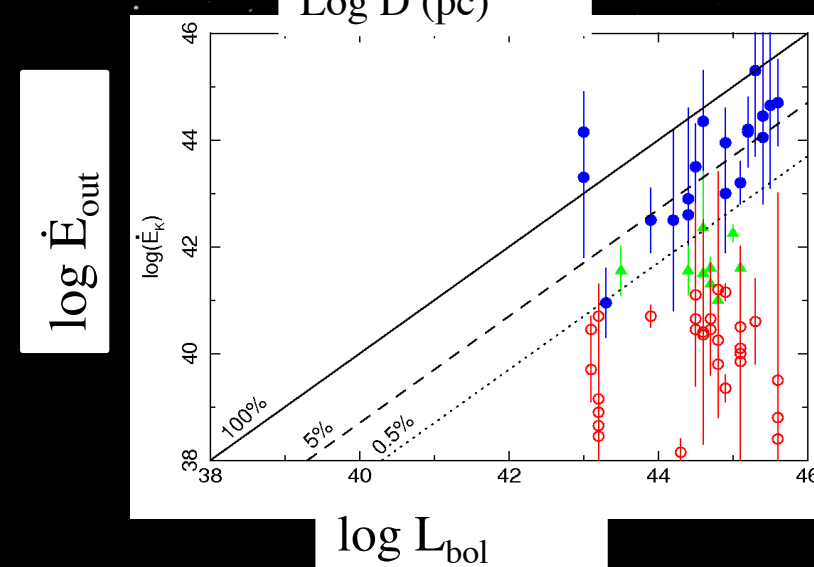








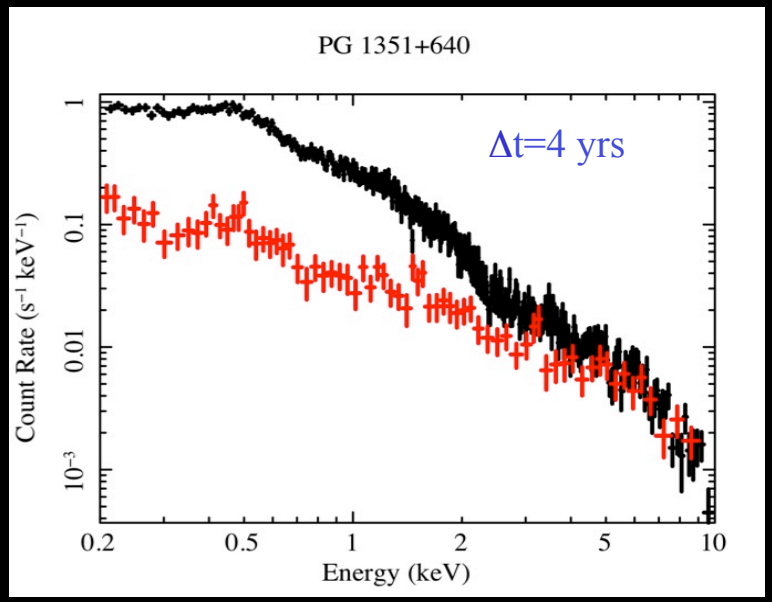
Tombesi, MC et al., '12b, '13



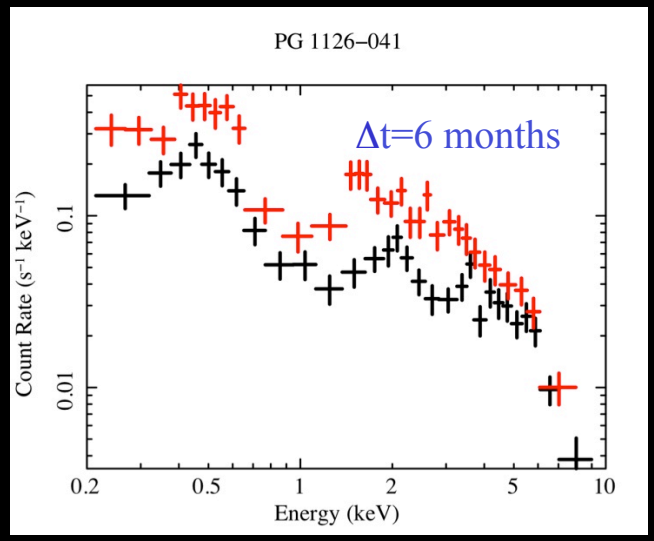
→ UFOs kinetic energy >1% of Lbol
→ Feedback (potentially) effective!

The "new" X-ray view: *Variability and complex absorption in (nearby) PG QSOs*

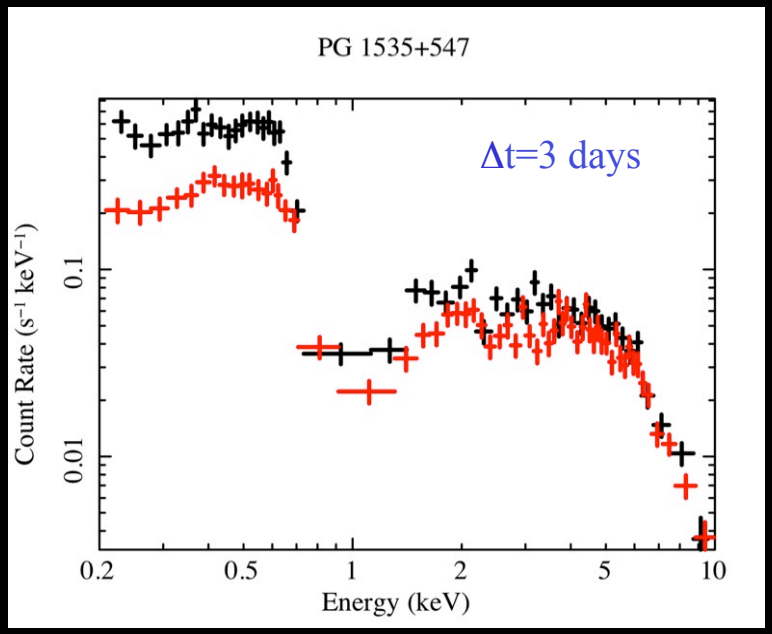
Sample: 15 UV *AL QSOs with 32 XMM exposures



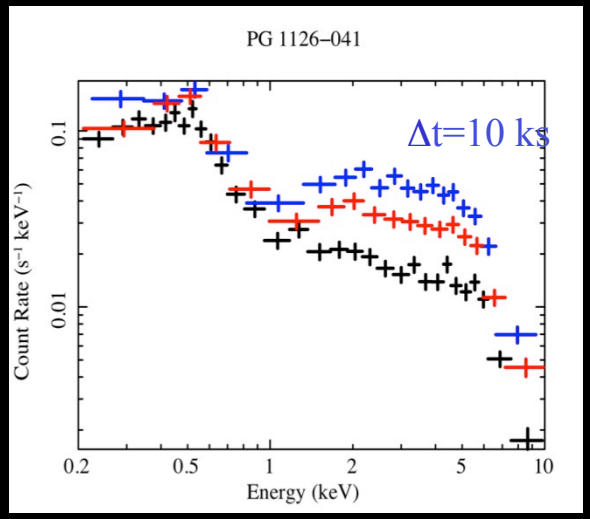
on time scales of years



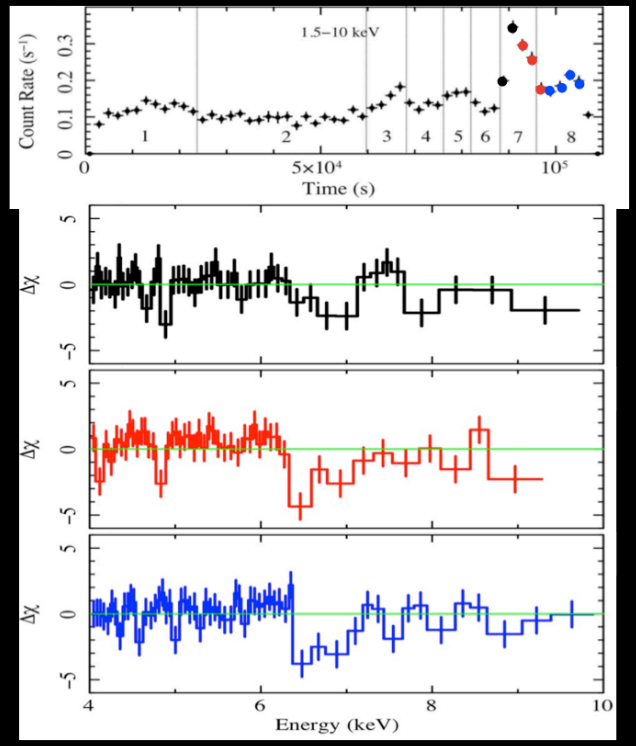
on time scales of months



on time scales of days



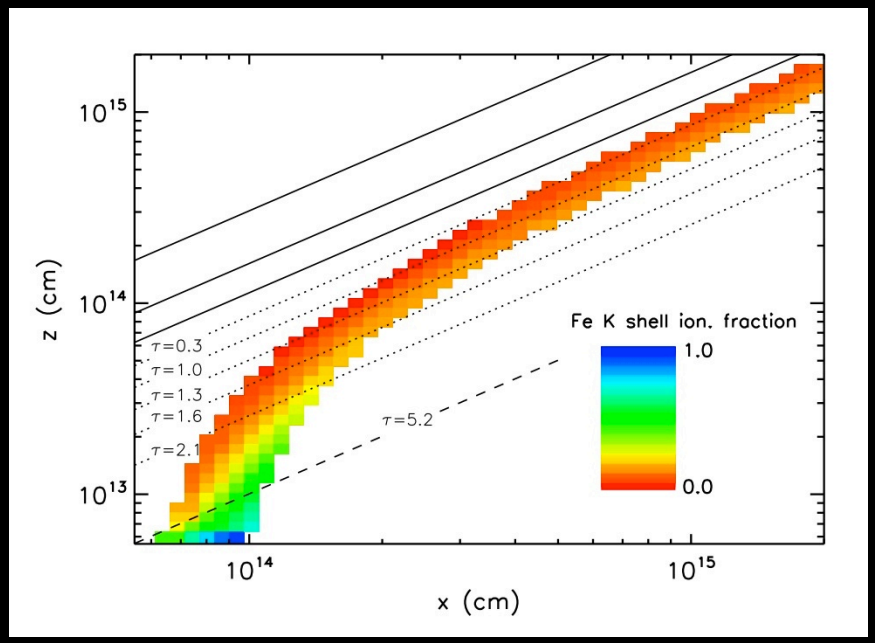
on time scales of hours

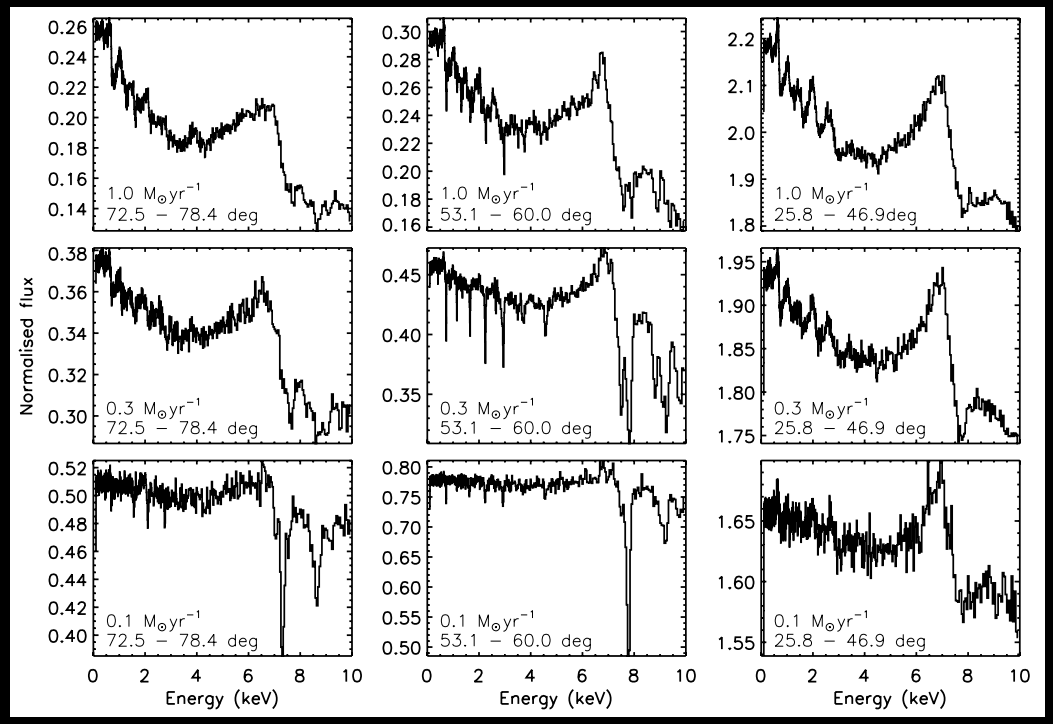


Giustini, MC, et al. 2012

Open issues (1/2): Astrophysics of outflows in AGN/QSO: Acceleration models?

Radiatively driven accretion disc winds



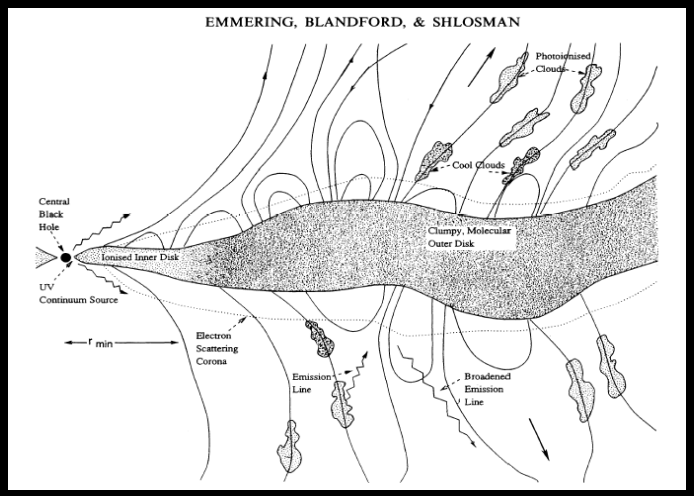


Sim et al., ’08, ’10ab

Murray et al. ‘95,

…and/or…

Magnetically driven winds from accretion disk

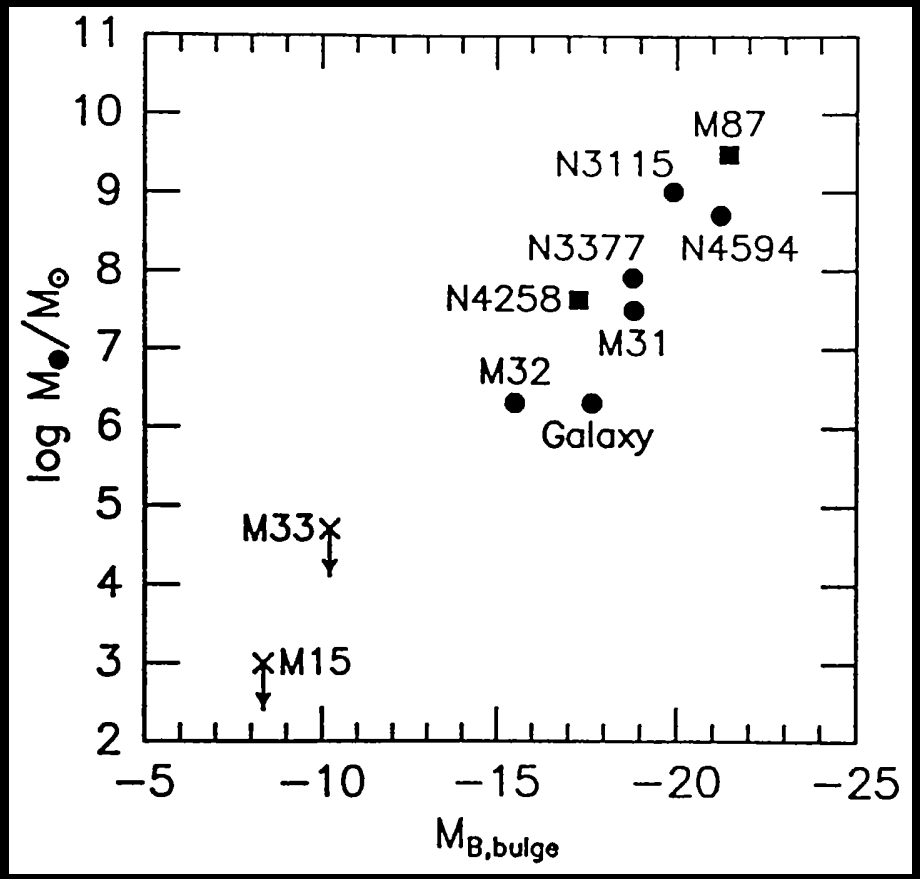


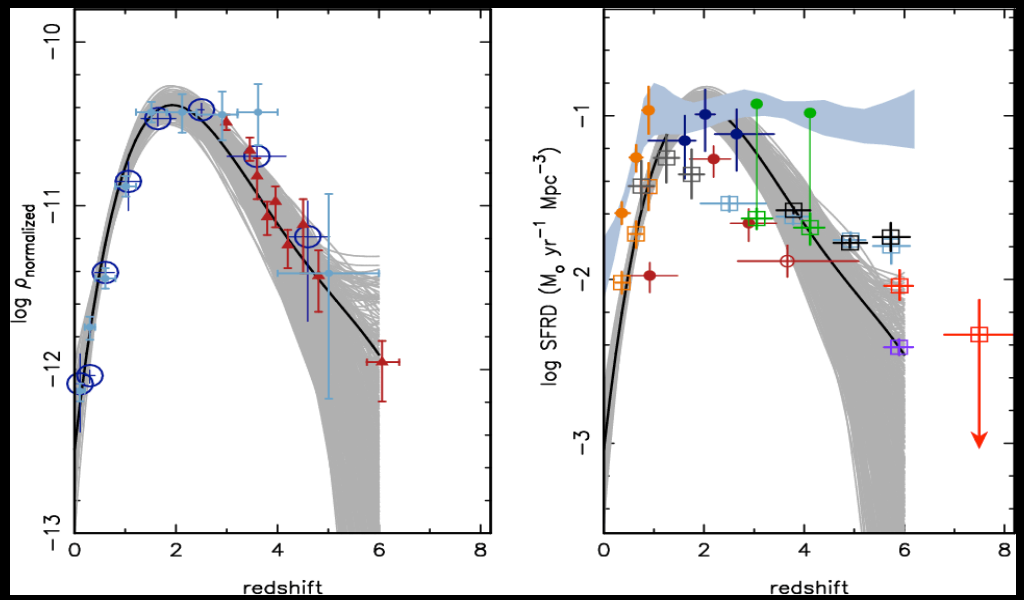
Emmering, Blandford & Shlosman, ’92;
Kato et al. ‘03

Fukumura, et al. 2010
Kazanas et al. 2012

Proga et al. ’00; ‘10

Open issues (2/2): AGN outflows and Feedback, i.e. SMBH/Gal co-evolution

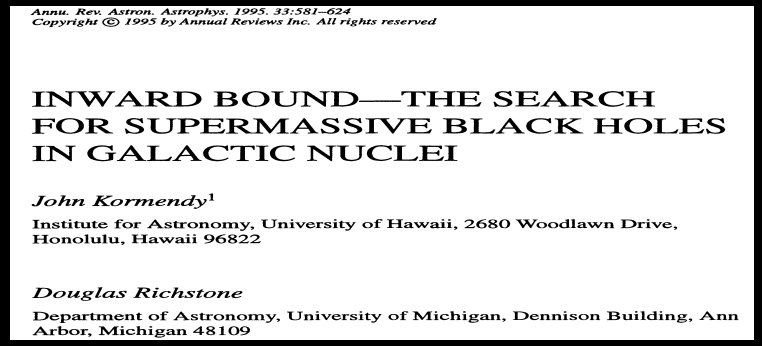




QSO space density — Madau et al. '96;

SFR space density — Wall et al. '05

M_{bh}-σ relation, AGN-gal coevolution, L-Tx relations, Heating cooling flow, Galaxies colors & sizes



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

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

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Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, Hawaii 96822

Douglas Richstone
Department of Astronomy, University of Michigan, Dennison Building, Ann Arbor, Michigan 48109

→ AGN Feedback !

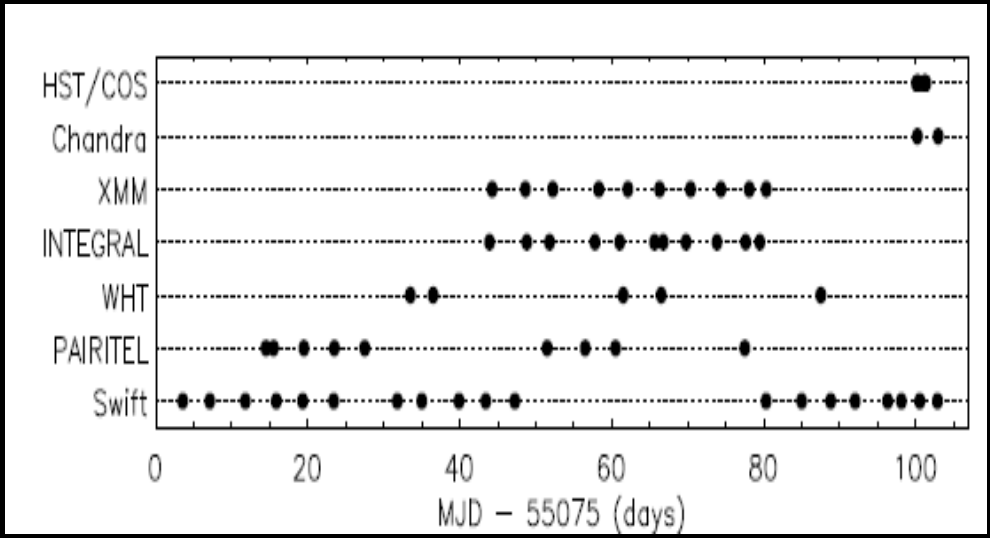
BUT HOW?

(Jet, Winds/UFOs, L_{AGN}, mix?)

The Astrophysics of AGN winds

Long and multiwavelength campaigns (e.g. Mrk509, NGC5548, NGC7469, ToOs, etc.)

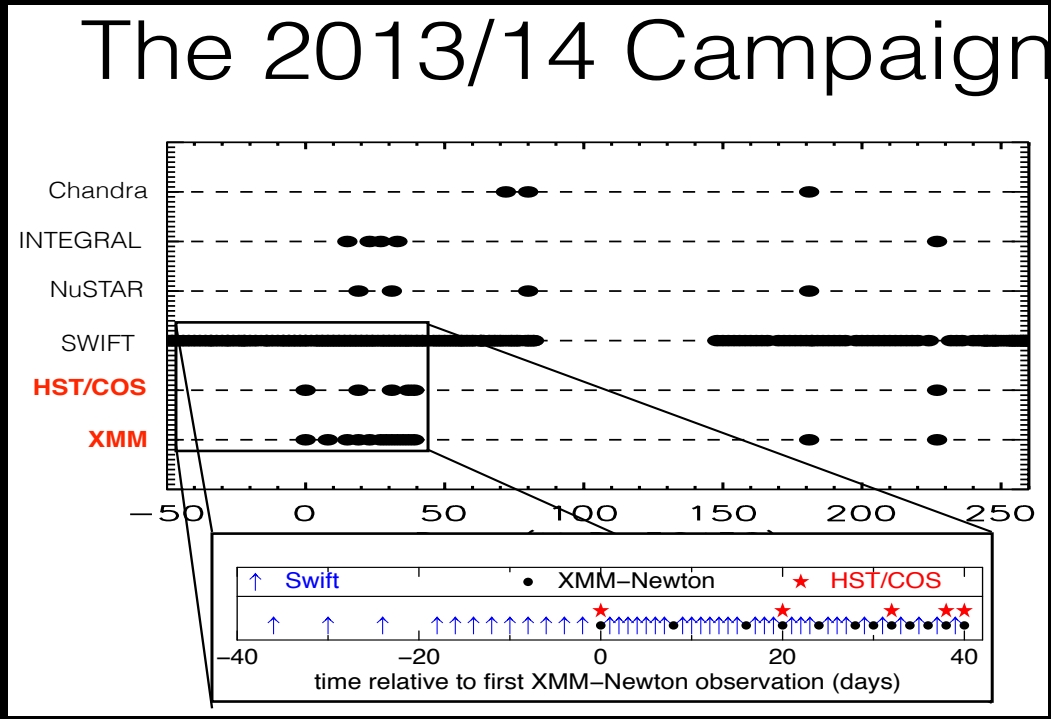
Mrk509 (2009)



Key: XMM LP 10x60ks + 10 HST COS orbits

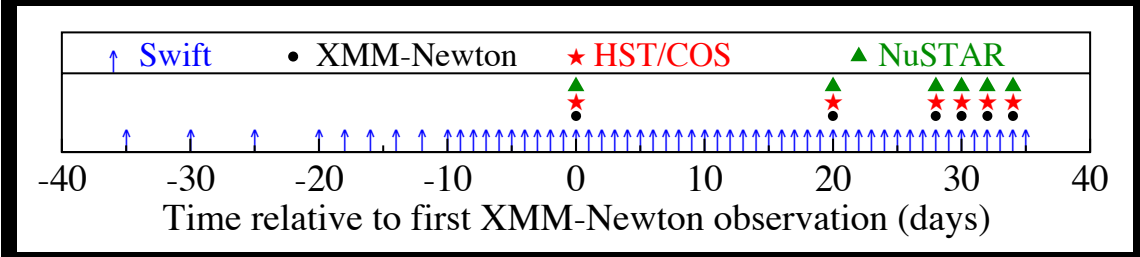
Kaastra, et al., 2011, paper I,
+14 papers

NGC5548 (2013/2014)



Key: XMM LP 10x50ks + 10 HST COS orbits

Kaastra, Kriss, MC, et al., 2014, Science
+8 papers



Key: XMM LP 7x90ks simultaneous HST/COS + Nustar
Behar, et al., 2016, in preparation

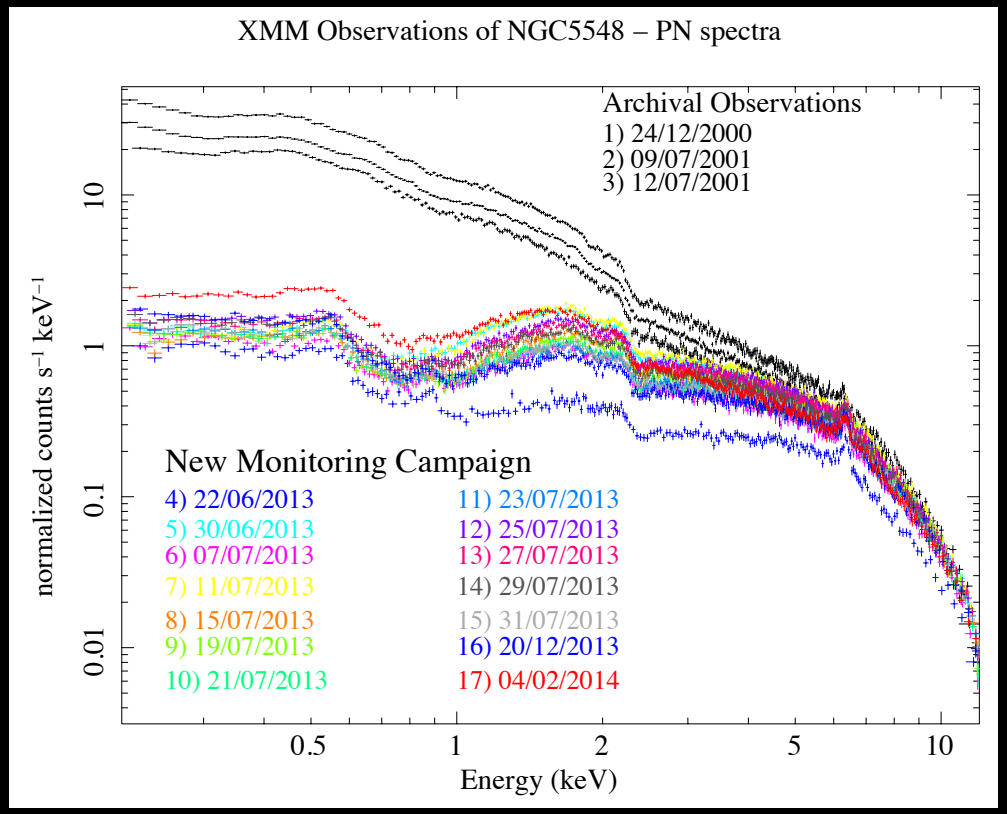
Key: Swift monitoring of 8 brigth Sey1s
Trgger if obscuration →XMM+HST+Nustar

PI: Kaastra

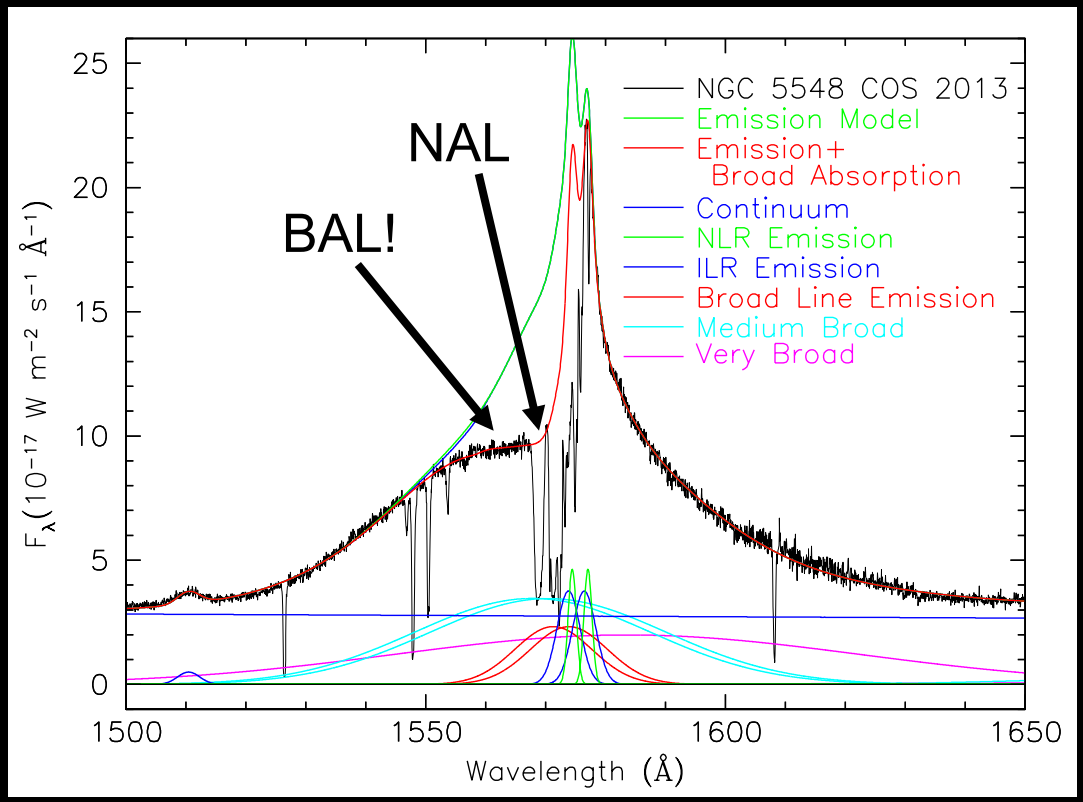
Unexpected discovery in NGC5548: *Absorber variability measured simultaneously in X-rays and UV!*

Kaastra, Kriss, MC, et al., 2014, Science
+ 8 papers published

XMM-Newton Large Program (+ Nustar + Chandra)



Simultaneous HST/COS



→ Simultaneous appearance and best detailed measurements of obscurer and (shadowed) warm absorber, possible only with a massive multi-*ni* campaign!

Detailed IMAGING at multi-ni: How WAs/UFOs compare/relate to colder molecular/gas outflows?

NGC6240

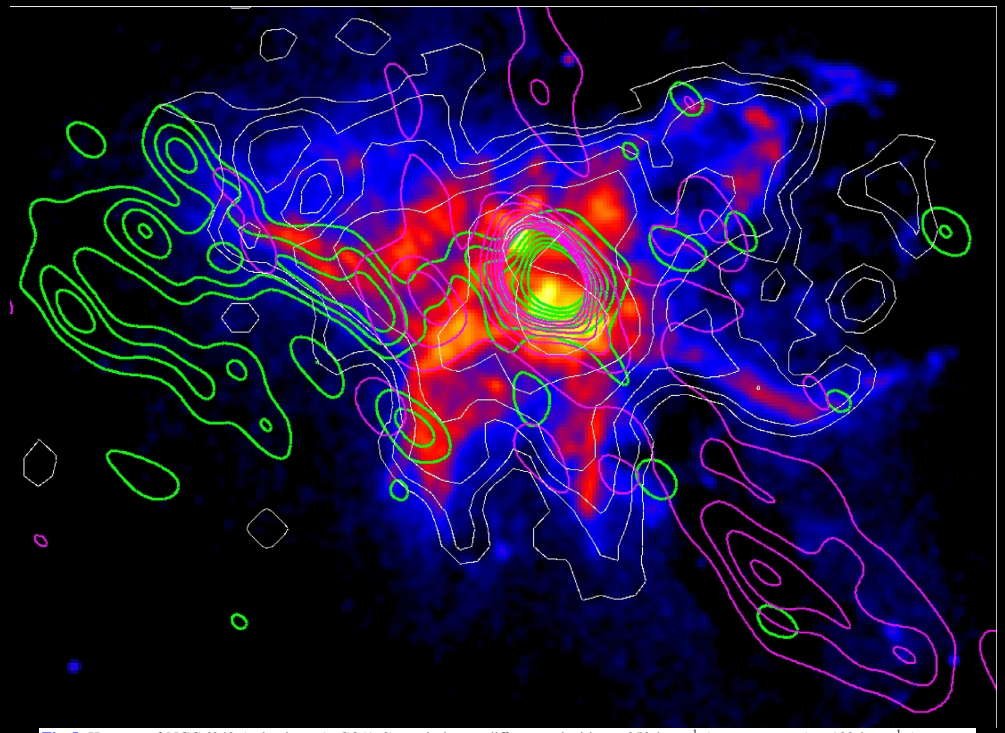
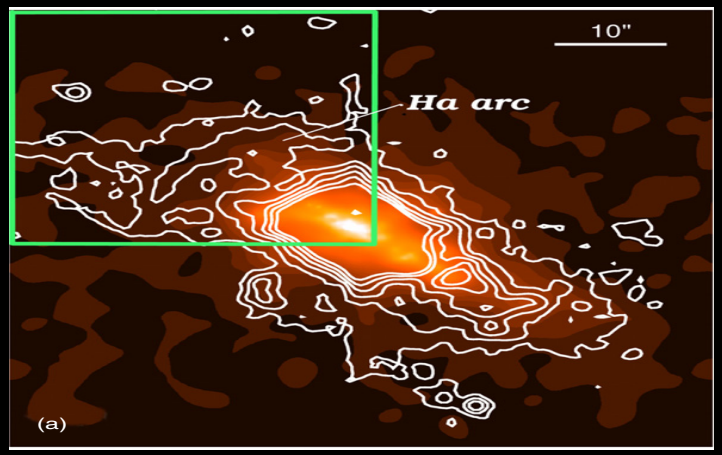
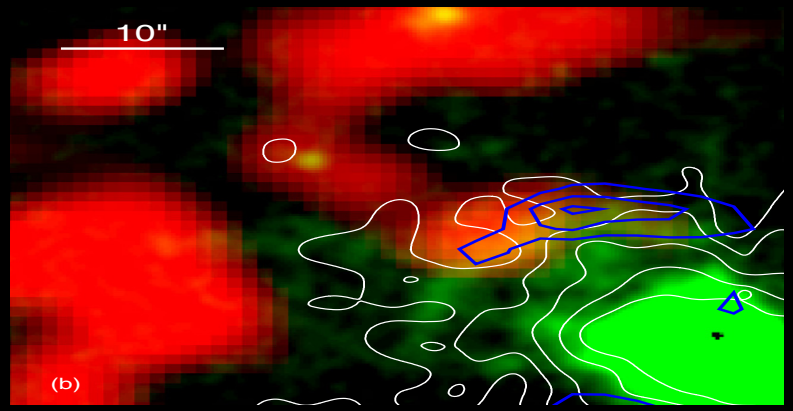
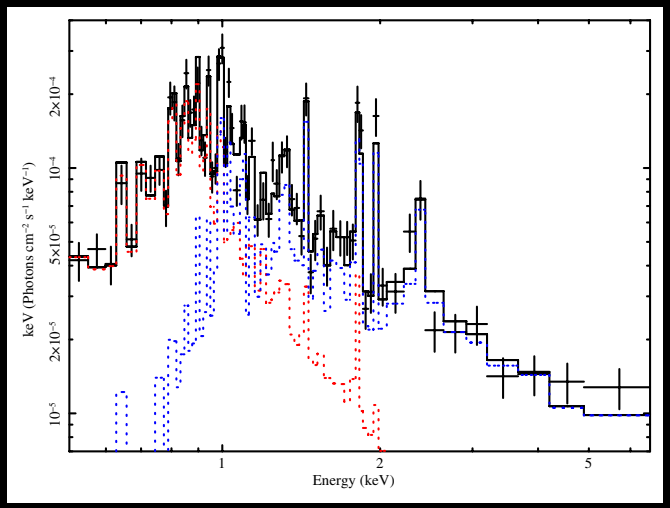


Fig. 5. Hα map of NGC 6240 (color image). CO(1–0) emission at different velocities: −350 km s^{-1} (green contours), −100 km s^{-1} (magenta contours), with respect to the system velocity. Contours are calculated by merging D and A configuration data. *Chandra* 1.6–2 keV emission is shown by white contours.

NGC4151

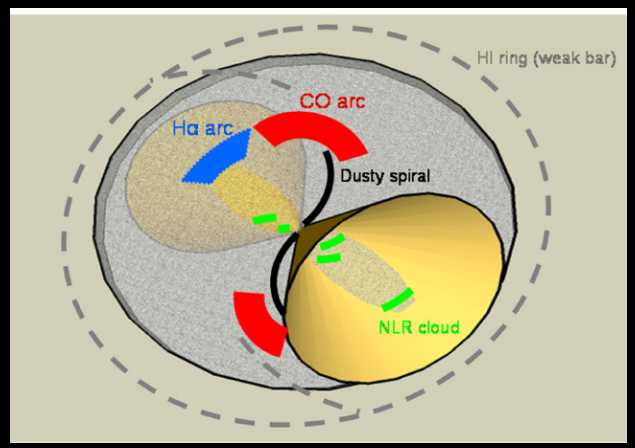






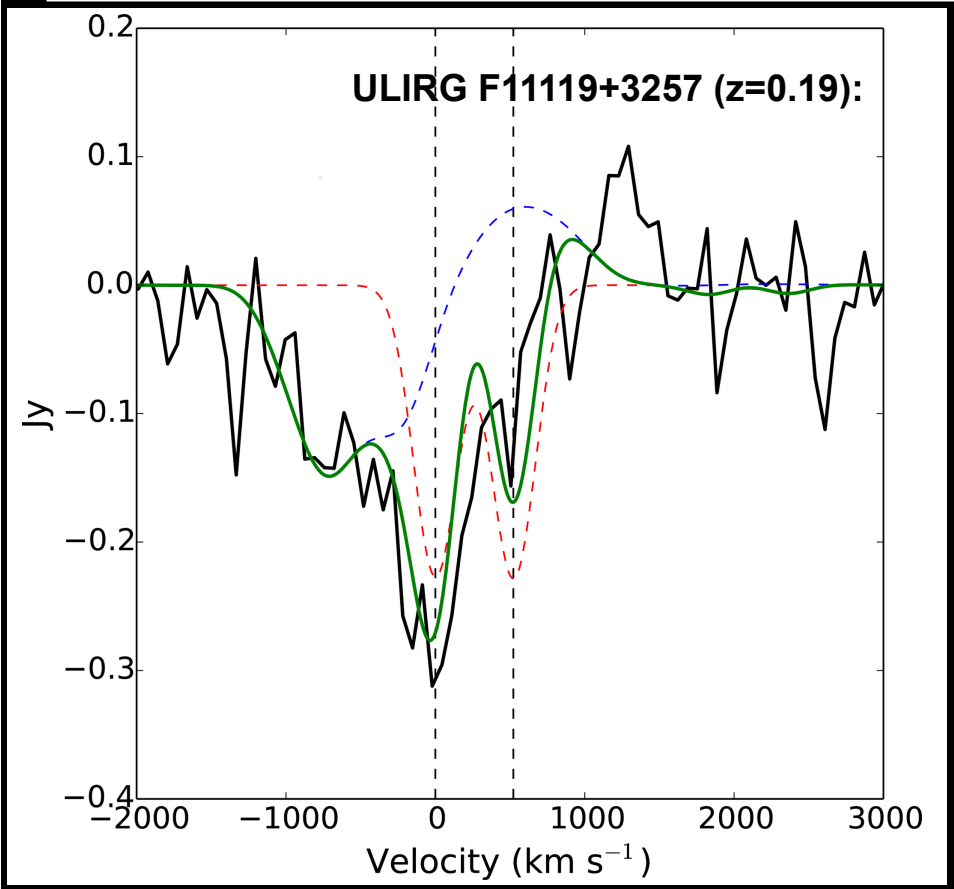
Feruglio et al. 2013

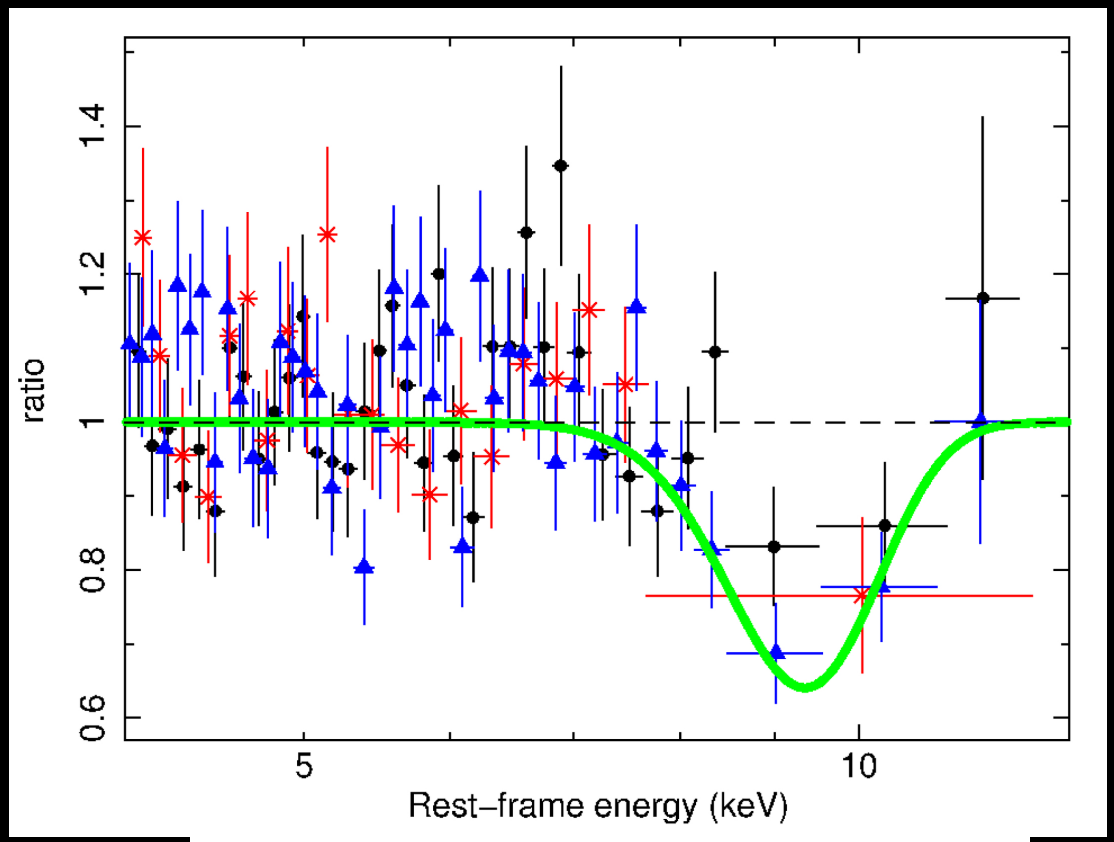
+ Fischer et al.'13; Genzel et al. '14; Harrison et al. '16; Brusa et al., 2015; Cresci et al. 2015, etc.) and molecular gas (Cicone et al.'15; Feruglio et al. '15, etc.)



Wang et al. 2012a,b,c

Multi-ni obs. of nearby QSO: How WAs/UFOs compare/relate to colder molecular/gas outflows?

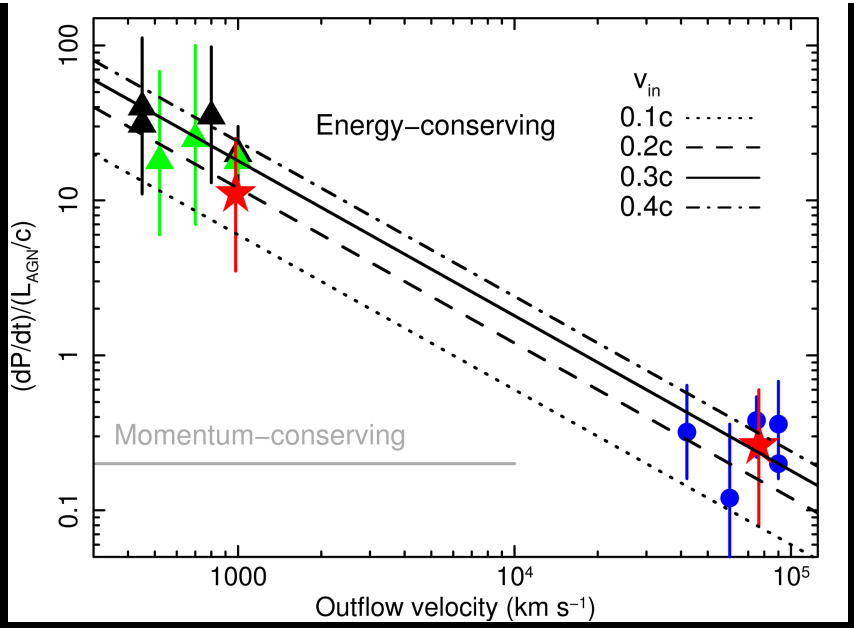




OH doublet at 1000 km/s Veilleux et al. 2013

UFO detection (v~0.3c) consistent with energy-conserving outflow from Inner X-rays to outer molecular outflow

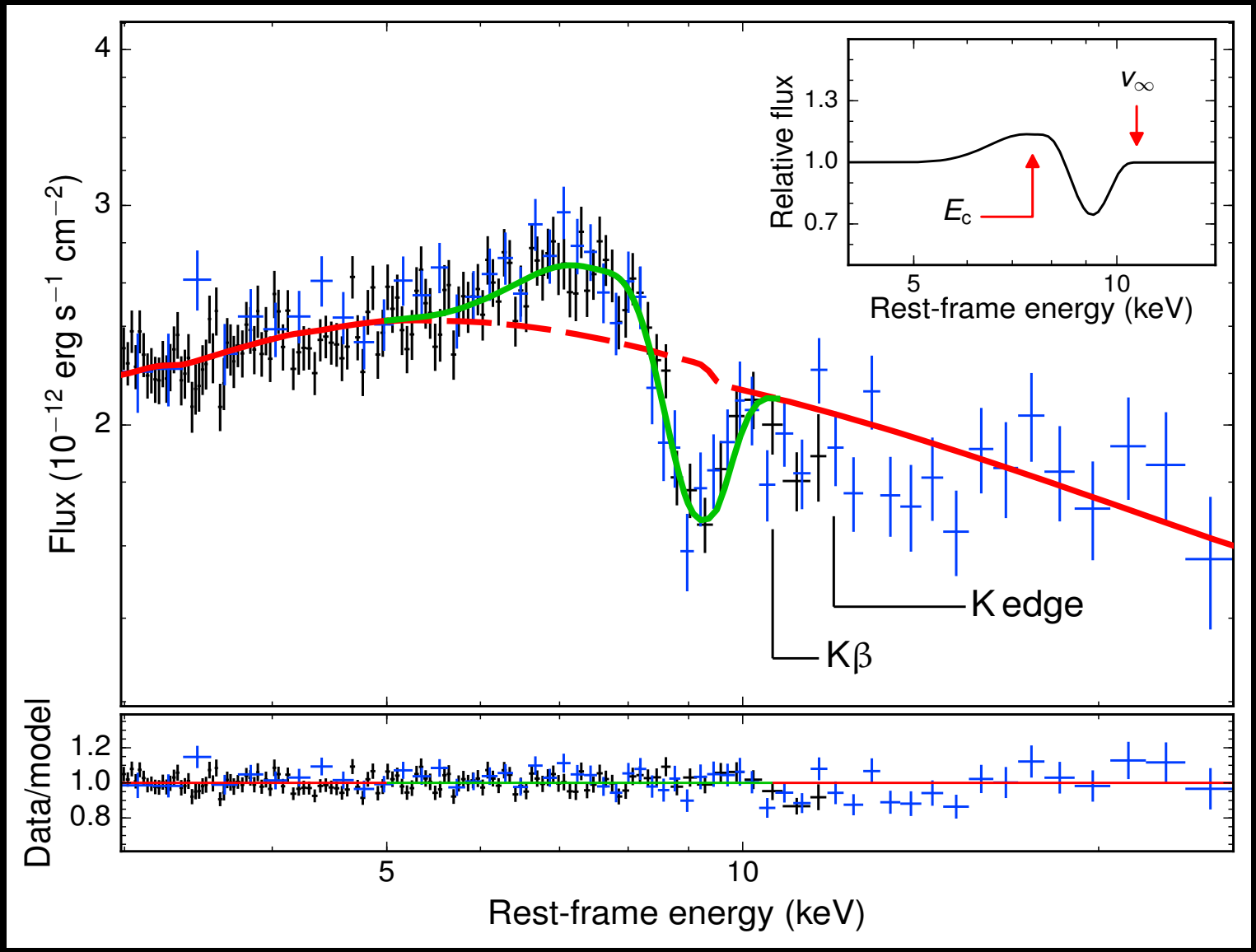
Tombesi et al. 2015, Nature



Detailed X-ray spectra: Geometry and covering factor of UFOs?

P-Cygni profile gives direct measure of covering factor

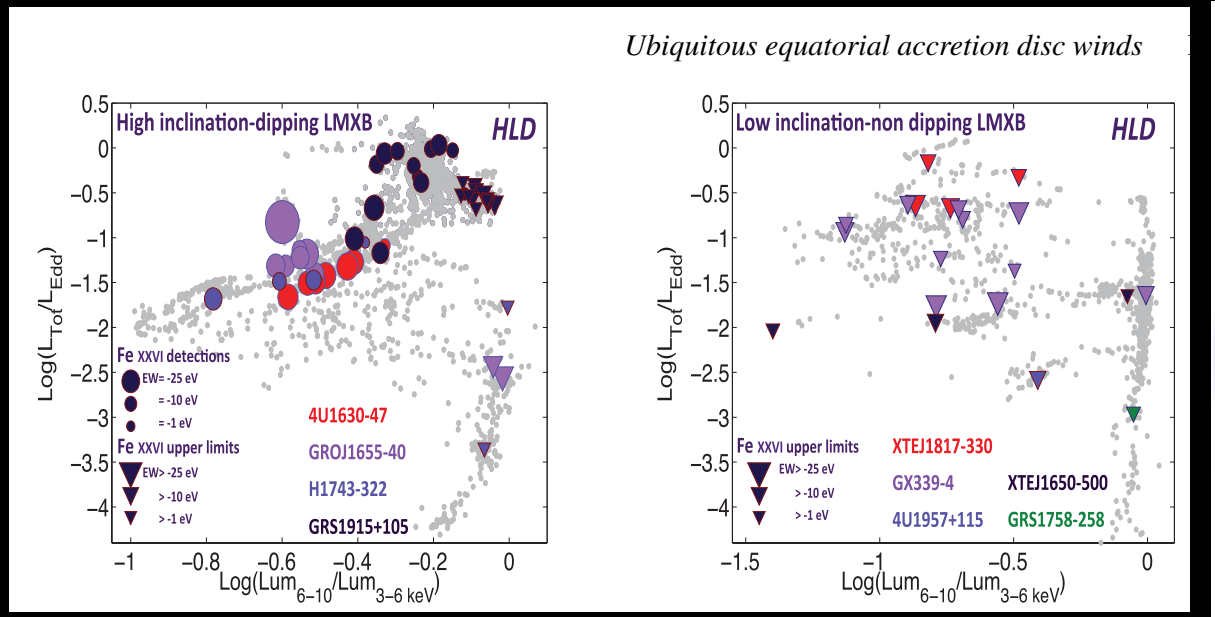
PDS456 (z=0.18)

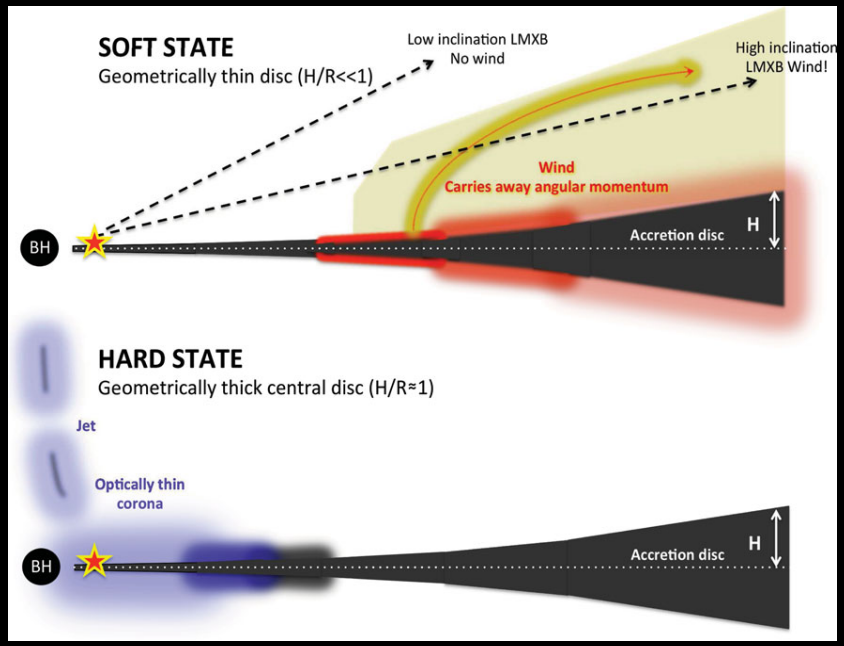


Vout~0.3c and Ω>2π sr

Nardini, Reeves et al., Science '15

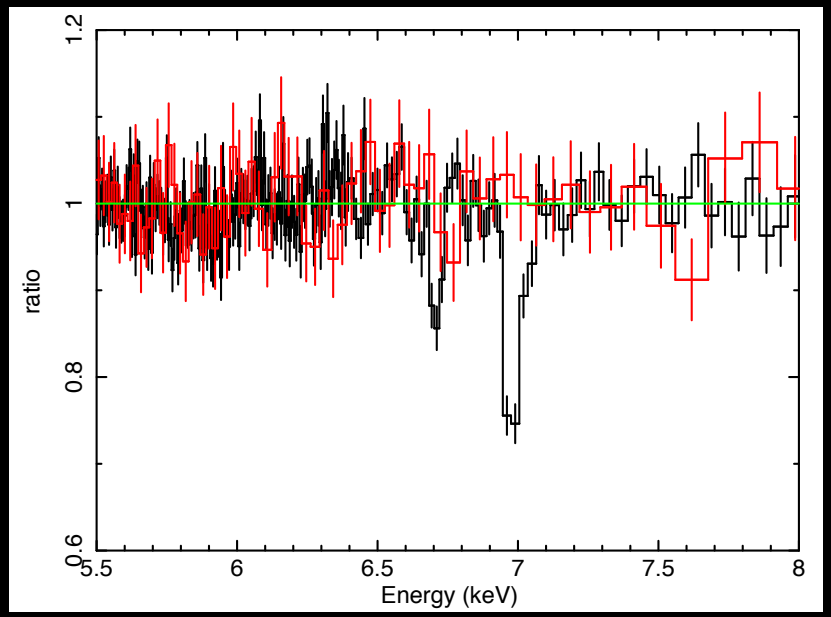
Detailed spectra of X-ray binaries in soft state: How WAs/UFOs compare/relate to binaries winds and jets?





H1743-322 disk-wind detected in soft, disc-dominated state

Ponti et al., 2011



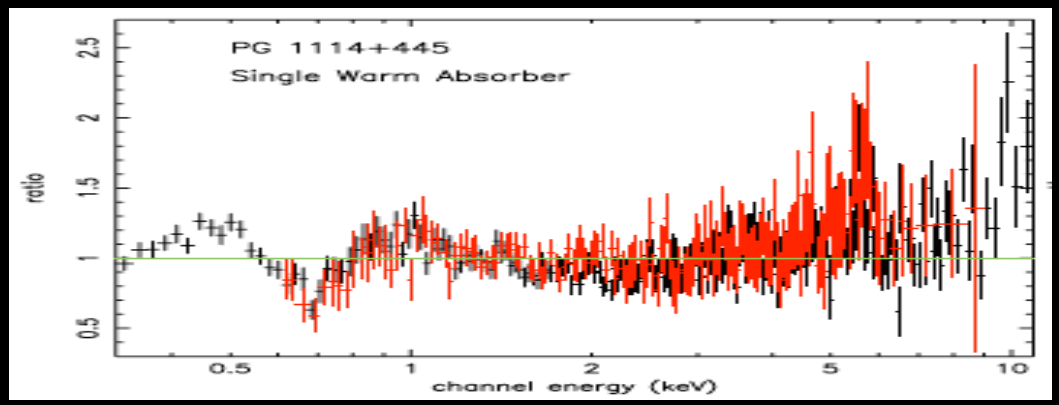
FeXXV and FeXXVI are variable, and have V_{out}~300-670 km/s

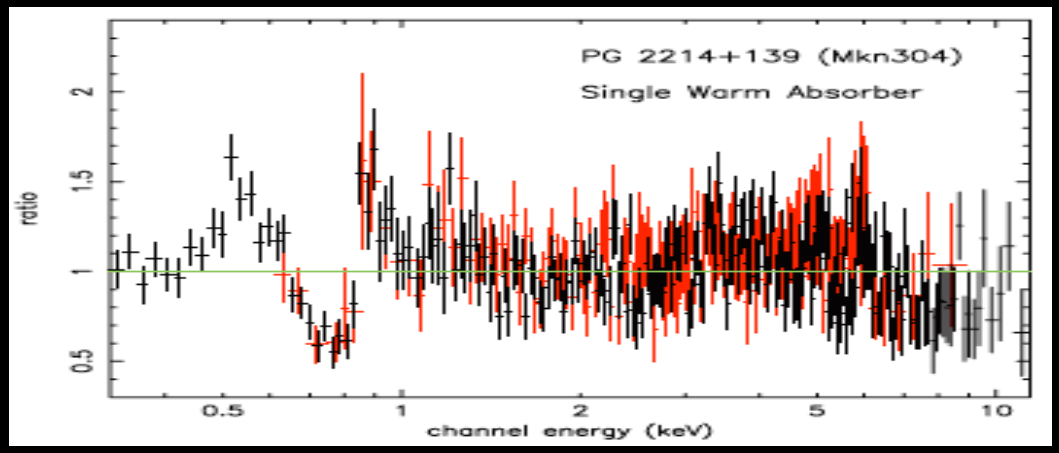
Ionization, Nh, variability similar to UFOs
Large velocities (wrt mass) too

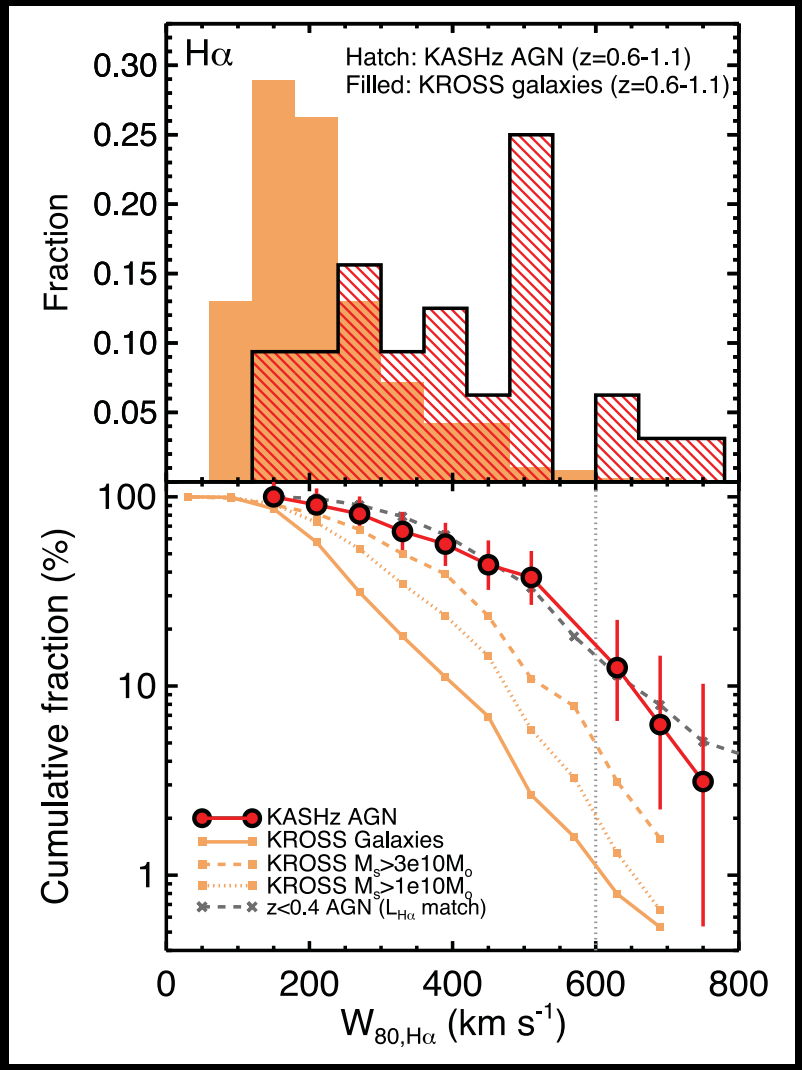
Miller et al., 2006, 2012

The (cosmological) impact/feedback of AGN outflows

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







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

→ Frequent, but low v (1000 km/s) and low Nh make these winds energetically not very important (fractions of Msol/year)

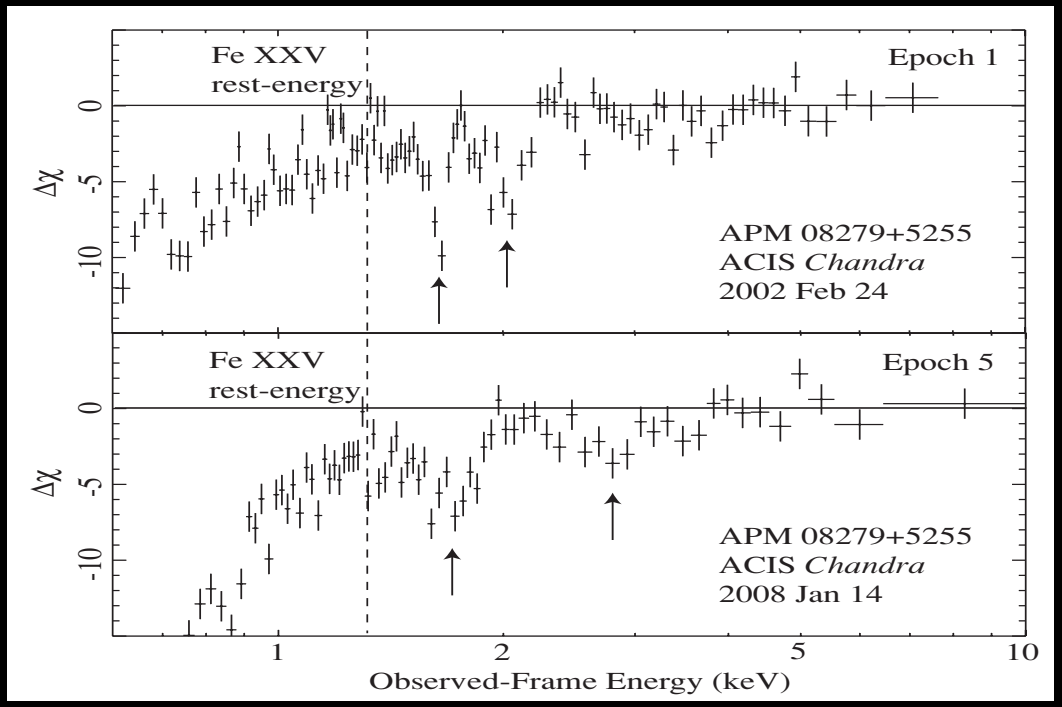
Porquet et al. 2004, Piconcelli et al. 2005

AGN/QSO-driven outflows ubiquitous in QSOs?

Harrison et al. 2016

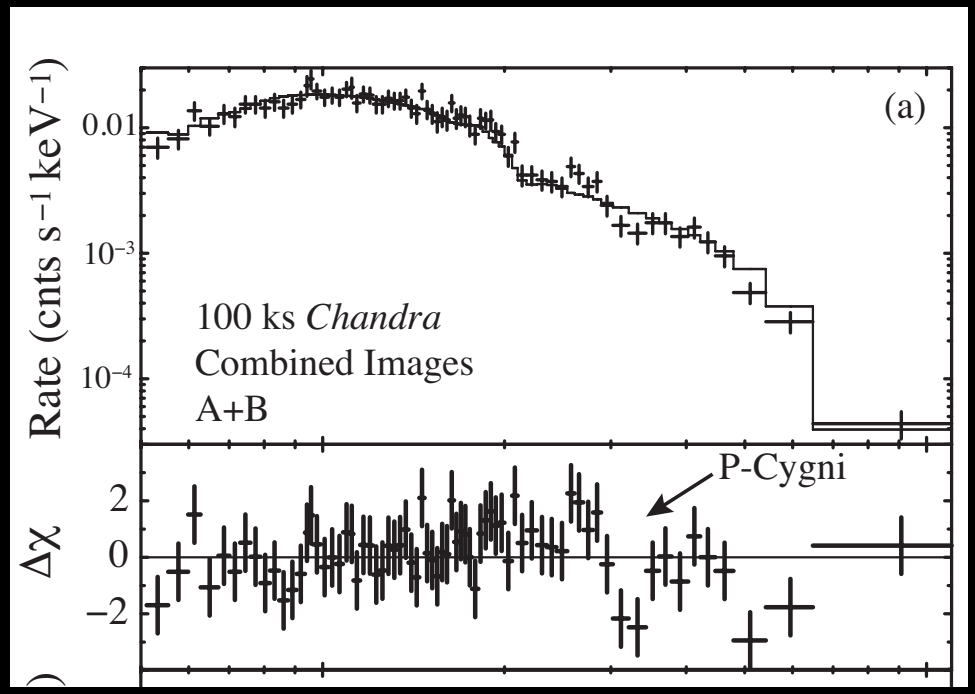
The new X-ray view: UFOs and/or FeK complex features seen in lensed high-z QSOs

APM 08279+5255 (z=3.91)
V_{out}~0.2-0.76 c



Chartas et al. 2009

HS0810+554 (z=1.5)

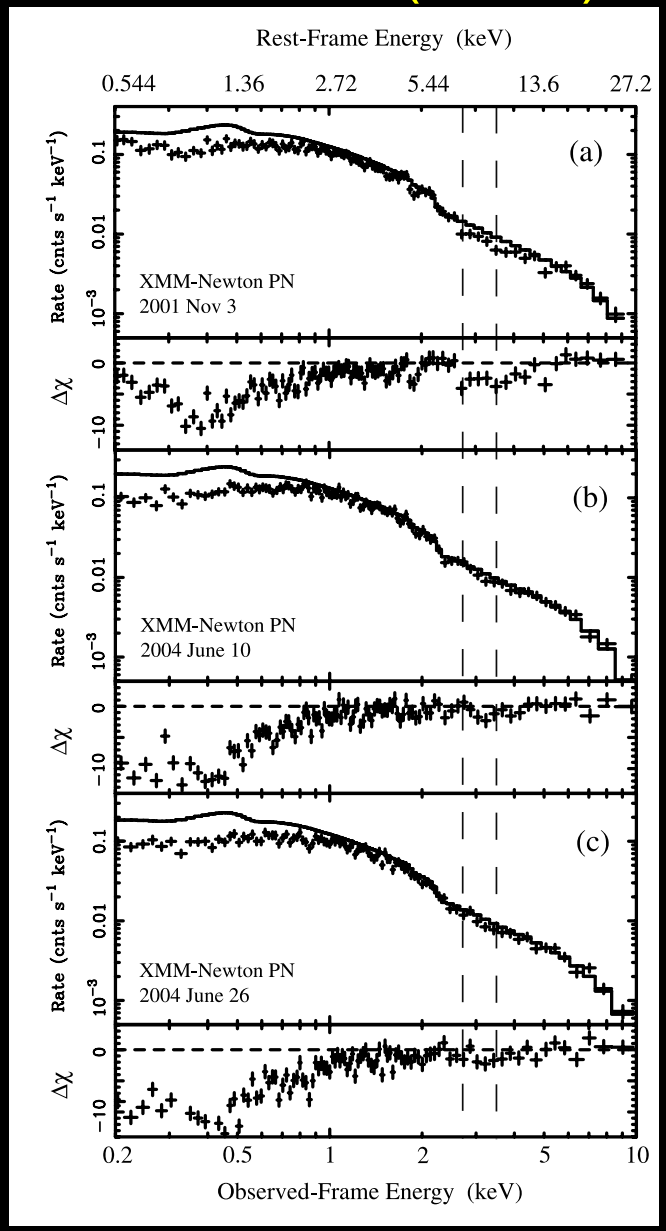


Chartas et al. 2014, 2015

→ Ubiquitous complex (i.e. ionized and/or partially covering) absorption?
→ Desperately need more and longer XMM observations on high-z QSOs

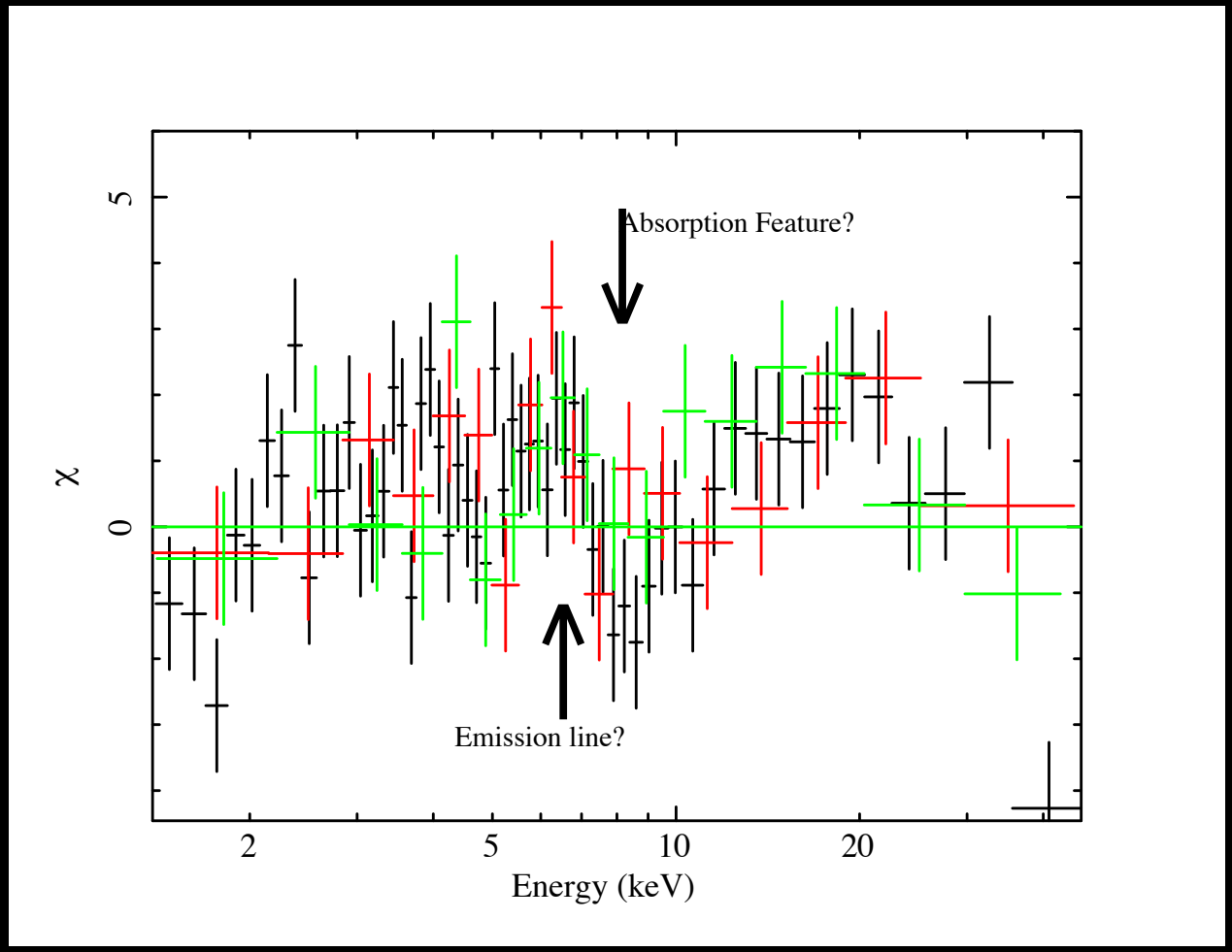
The new X-ray view: UFOs or Extreme reflection measured in lensed high-z QSOs?

PG1115+080 (z=1.7)



Chartas et al., ’07

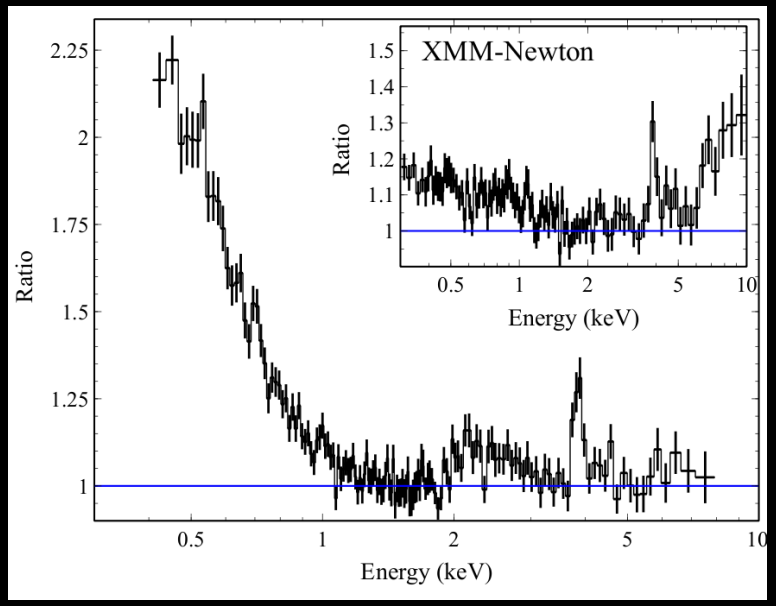
B1422+231 (z=3.6)



Dadina et al., ’16, submitted

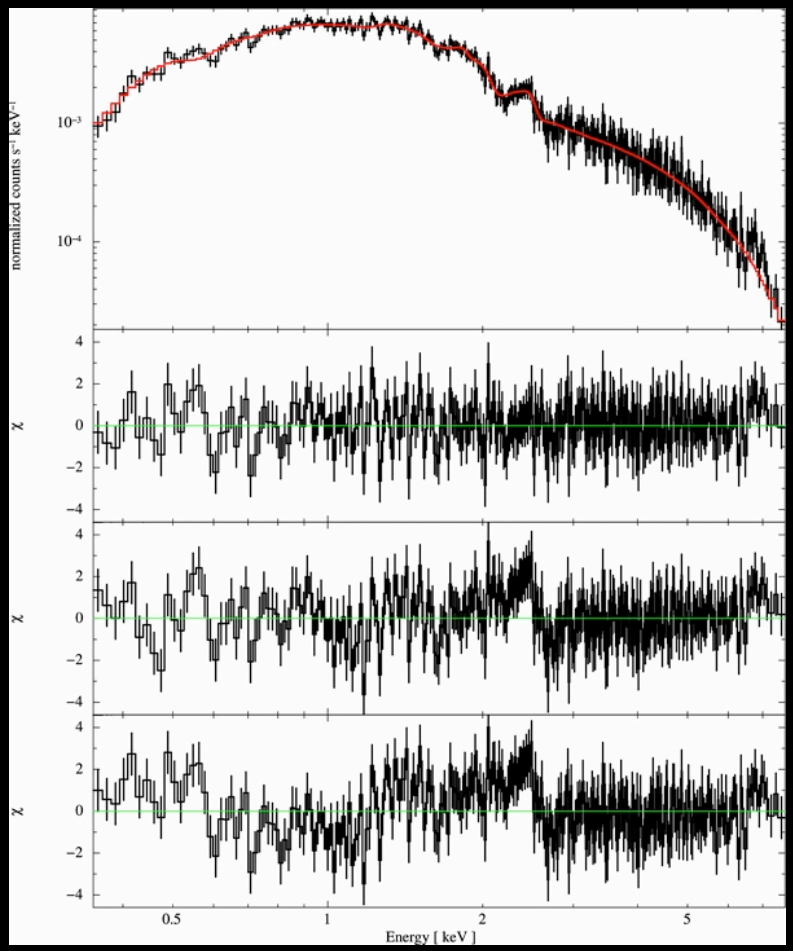
The new X-ray view: UFOs or Extreme reflection measured in lensed high-z QSOs?

RX J1131-1231 (z=0.6)



Reis et al., ’14

The Einstein Cross (z=1.7)

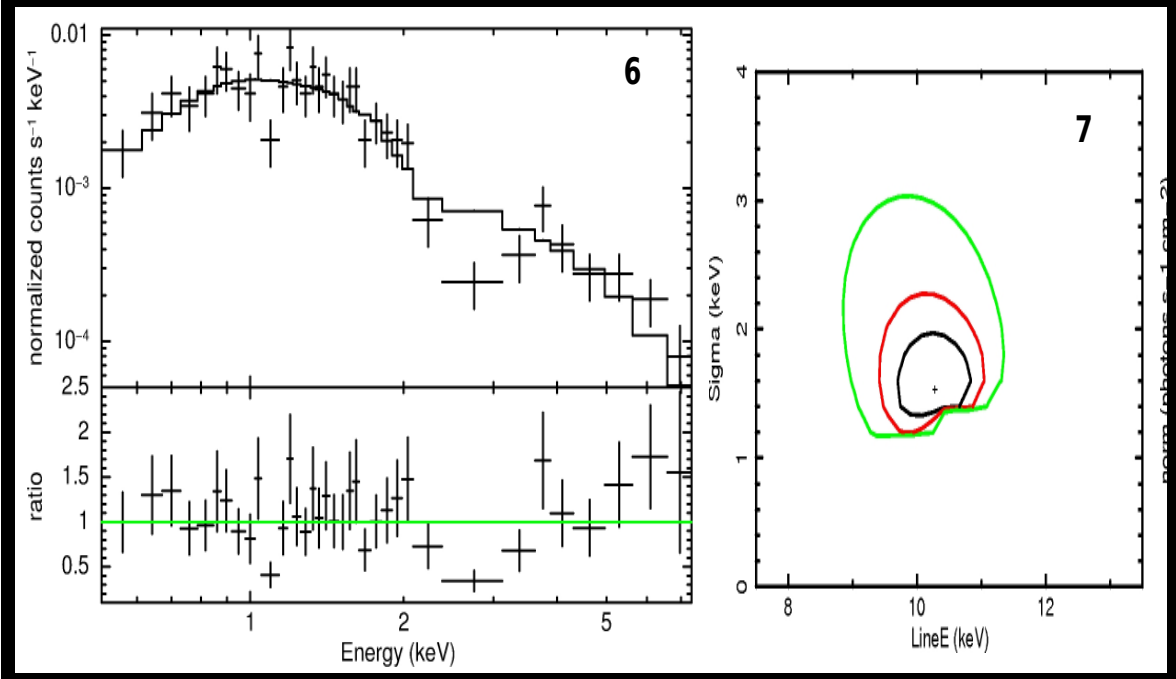


Reynolds et al., ’14

→ Ubiquitous complex (i.e. ionized and/or partially covering) absorption?
→ Desperately need more and longer XMM observations on high-z QSOs

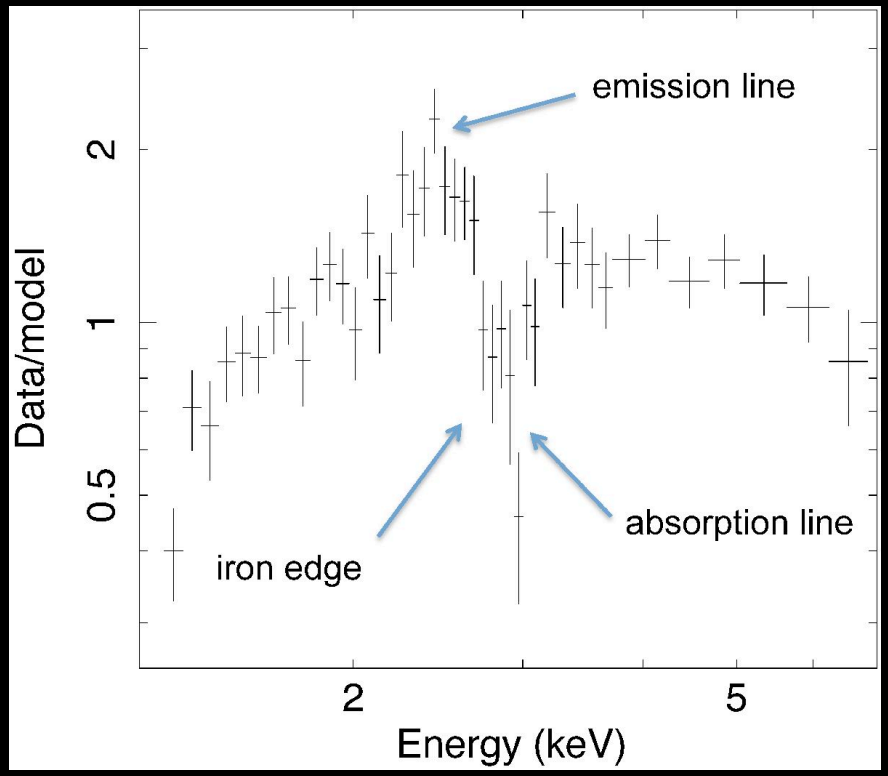
The new X-ray view: UFOs seen also in non-lensed high-z QSOs

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



Lanzuisi et al., ’12

(z=1.6) PID352

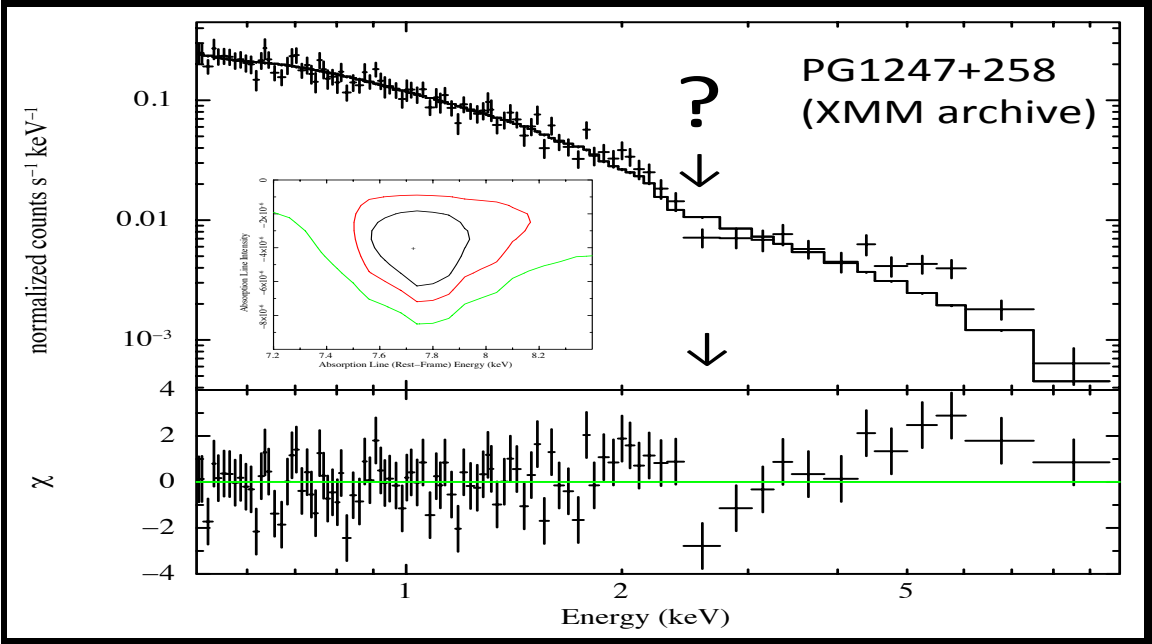


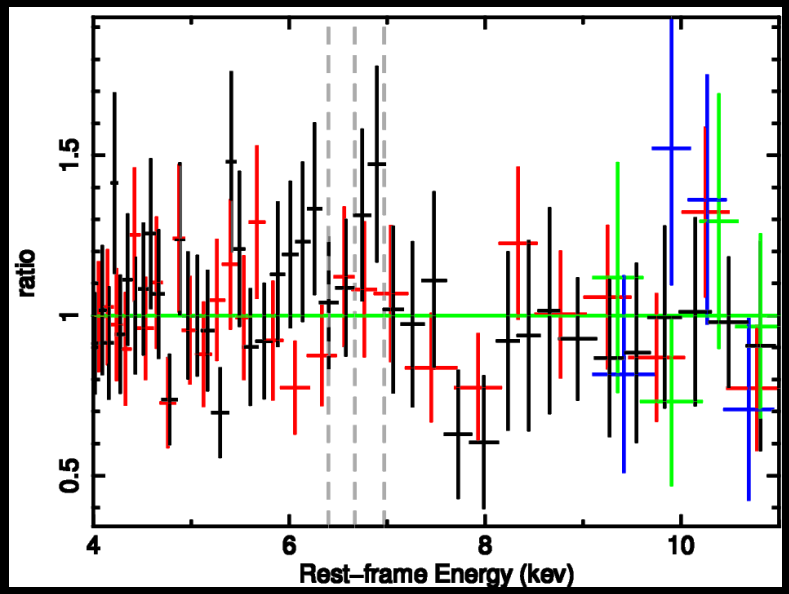
Vignali et al., ’15

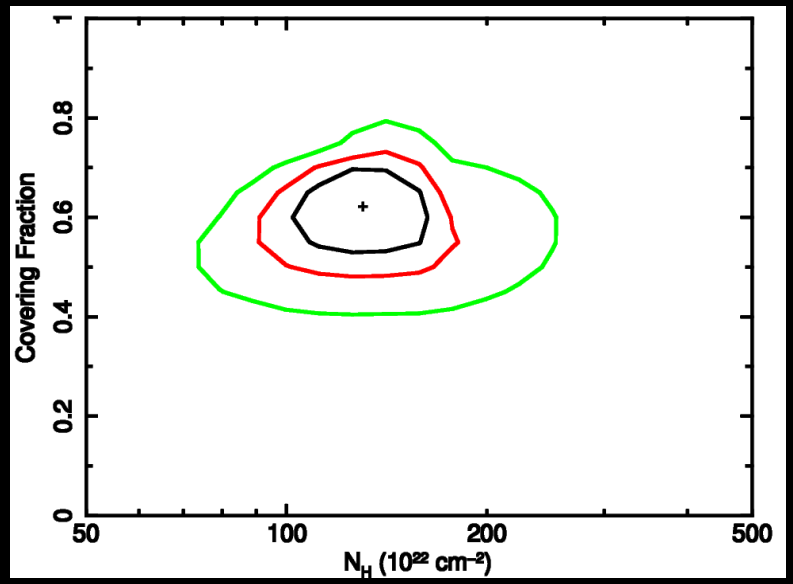
→ Ubiquitous complex (i.e. ionized and/or partially covering) absorption?
→ Desperately need more and longer XMM observations on high-z QSOs

UFOs seen also in non-lensed high-z QSOs

(z=2) PG1247+268







Another high-z UFO candidate?
Or again strong reflection?

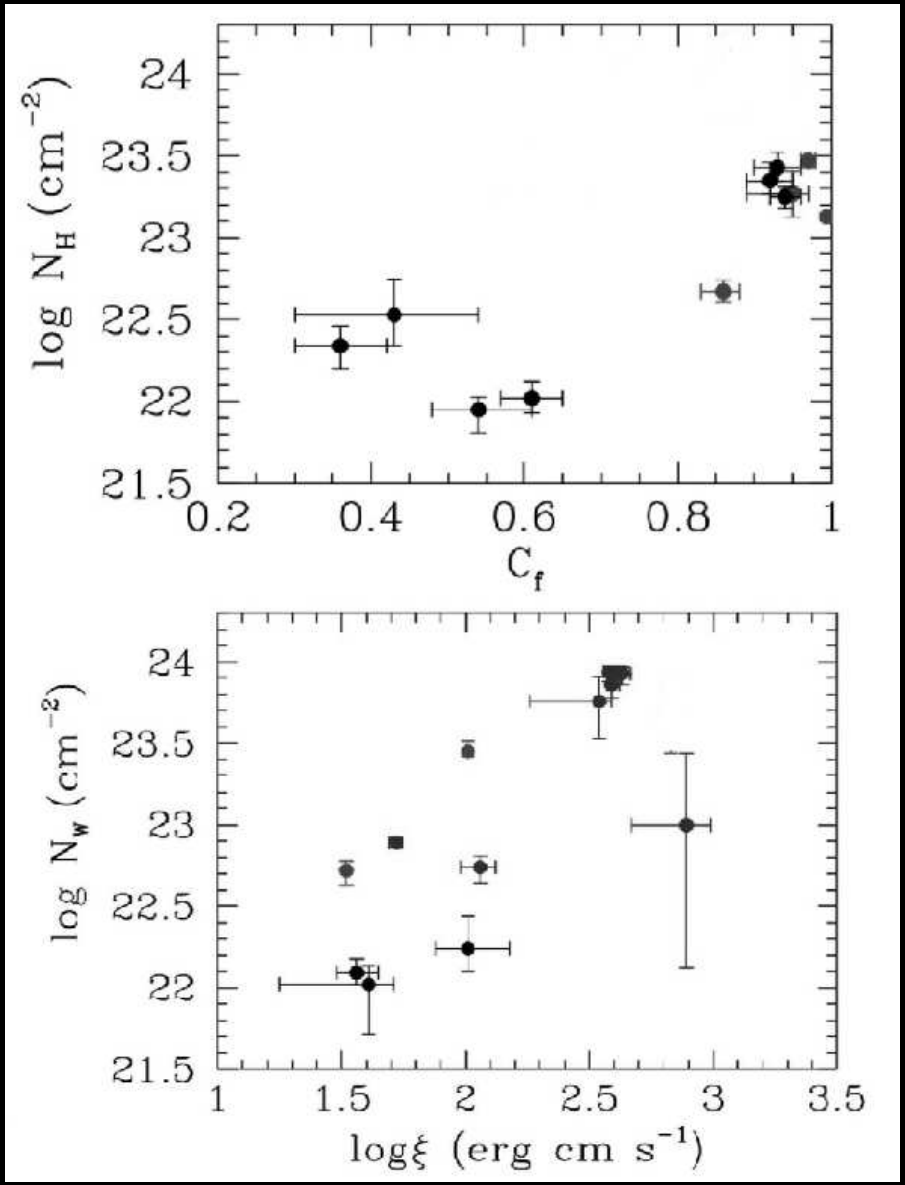
Lanzuisi et al., ’16

→ Ubiquitous complex (i.e. ionized and/or partially covering) absorption?
→ Desperately need more and longer XMM observations on high-z QSOs

In BAL and mini-BAL QSOs (a dozen with z~0.1-0.5-2)

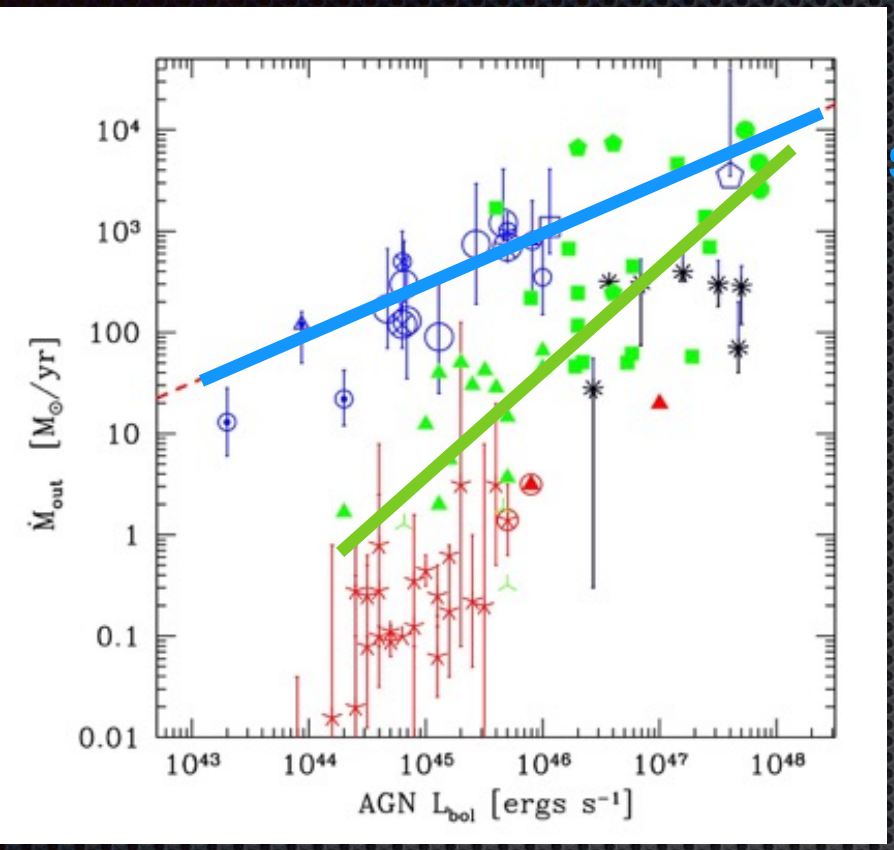
Giustini 2015

…the best sample available to date….



→ Ubiquitous complex (i.e. ionized and/or partially covering) absorption?
→ Desperately need more and longer XMM observations on high-z QSOs to characterize the outflows in a representative sample of high-z QSOs

Need X-ray and multi-ni coverage of a representative sample of high-z QSOs.

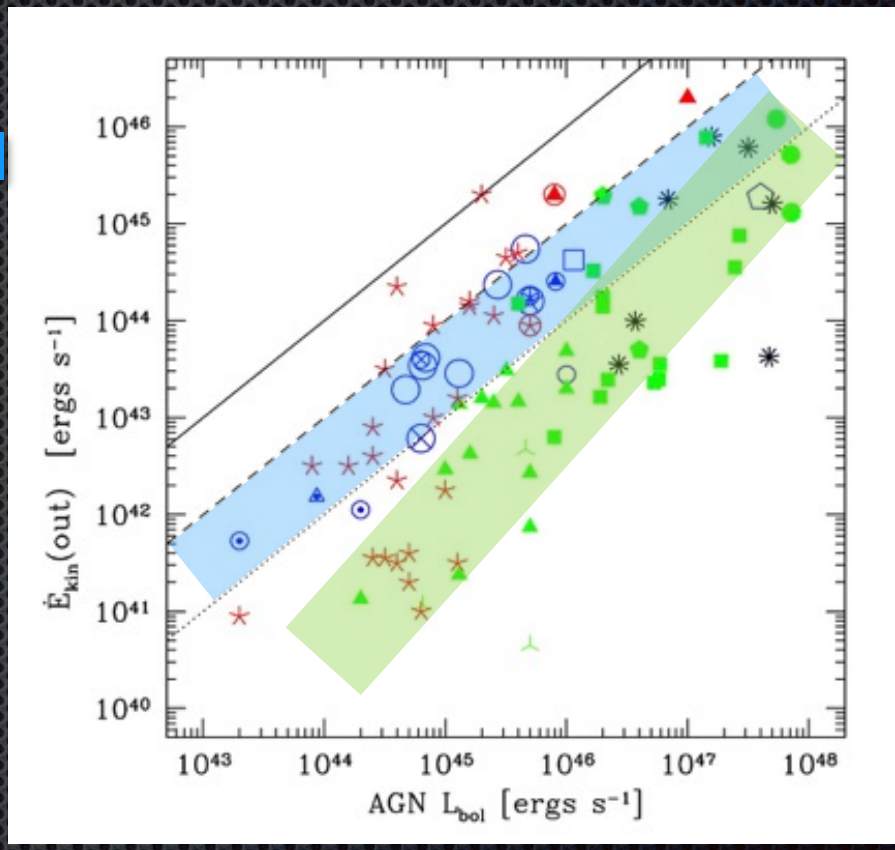


Molecular
small=nucl
large=gal.

Ionized

BAL

X-ray



Remarkable correlation between wind mass outflow rate and AGN bolometric luminosity: $M_{out} \sim L_{bol}^{0.5}$ for molecular winds $M_{out} \sim L_{bol}$ for ionized winds

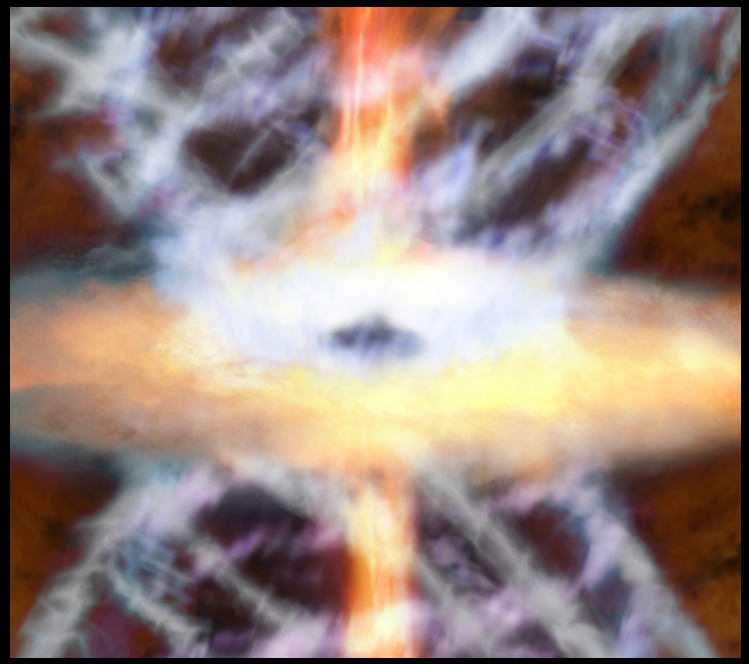
E_{kin}(out) = 1-10% L_{bol} (molecular)

E_{kin}(out)=0.1-10% L_{bol} (UFOs, BALs)

E_{kin}(out) = 0.1-1% (ionized low L_{bol}) = 1-10 % (ionized high L_{bol})

Fiore et al., ’15

Summary and personnel view:



- Science Case (outflows)
  - *Recognized importance, and "pathfinder" to future missions/observatories (from ground based Obs. ALMA, MUSE, SINFONI to Athena).*
  - *Important implications for both astrophysics of winds/outflows formation and acceleration, and the cosmological impact/feedback of AGN winds.*

- Astrophysics of AGN winds
  - Will need (to continue) massive campaigns of spectra/imaging/timing often/mostly using a multi-ni approach on low-z AGN

- Cosmological impact/feedback:
  - Desperate need to have representative samples of good quality X-ray spectra of high-z QSOs to characterize and measure the frequency of massive and energetic outflows in high-z QSOs. Need multi-ni coverage to obtain full outflow energetics. Multi-ni would also "guarantee" more publications per XMM-ks, like experience in low-z AGNs.

N.B1: Few high-z QSOs spectra available ALL show features in their X-ray spectra
N.B2: Reflection vs absorption uncertainties could be two facets of the same phenomenon

Thank you very much
for your attention