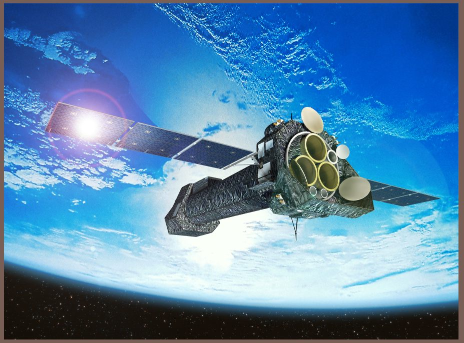
AGN X-RAY SPECTROSCOPIC POPULATION STUDIES

Matteo Guainazzi (ESA-ESAC)

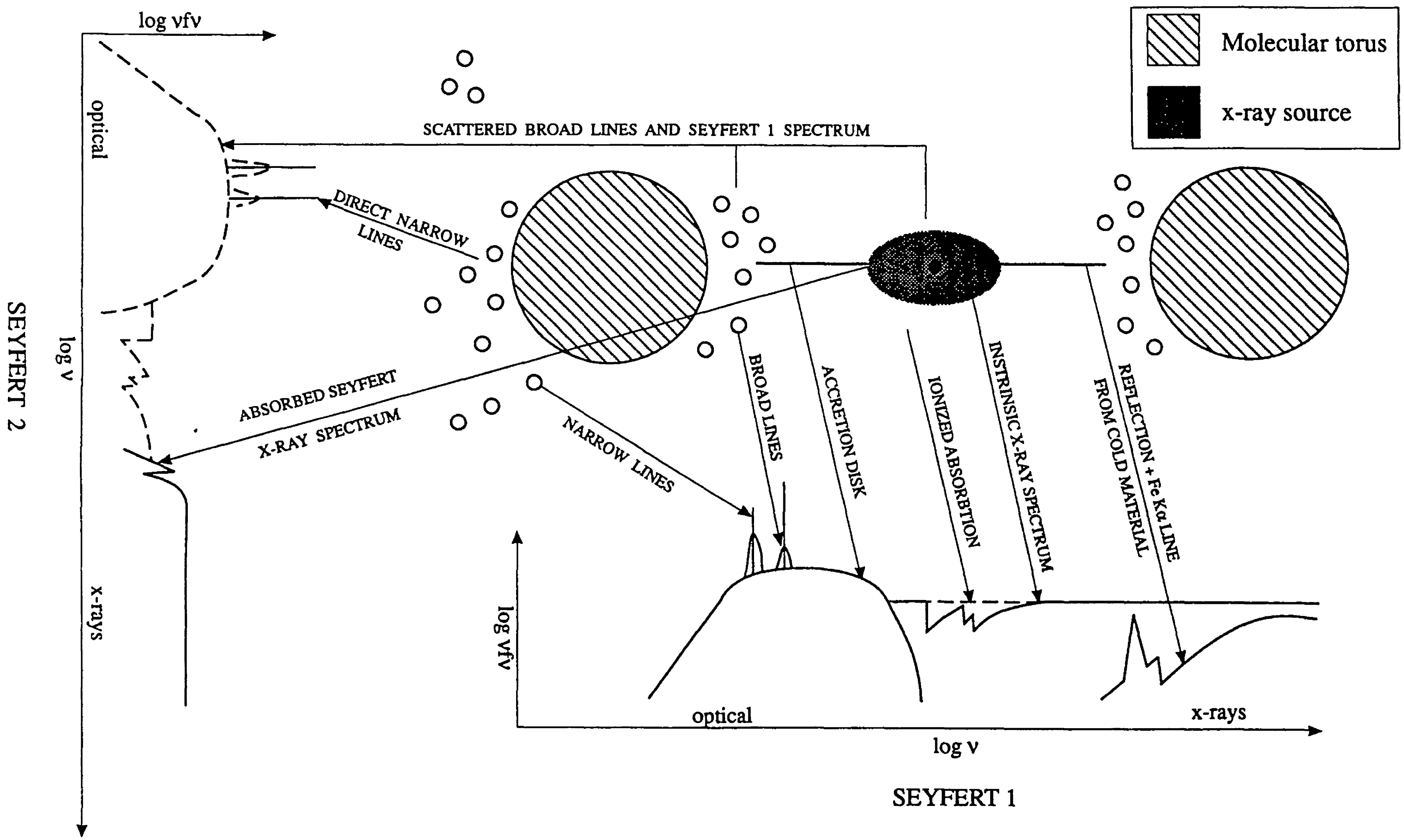
Chandra: 12 yrs

XMM-N: 11 yrs



The (AGN) world 10 years ago

(Mushotzky, Done, Pounds 1993)



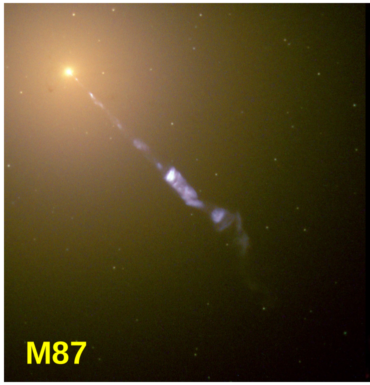
Basic AGN ingredients and questions

(Courtesy ESA)

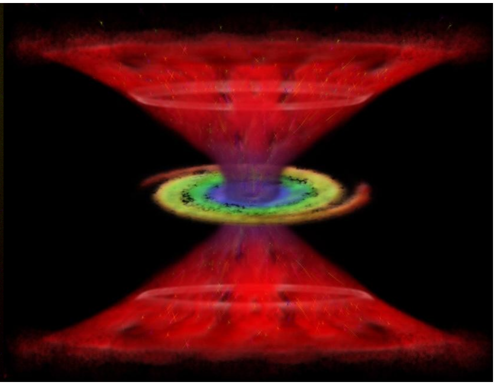
Supermassive black hole + accretion disk

+

(Courtesy NASA & HHT)



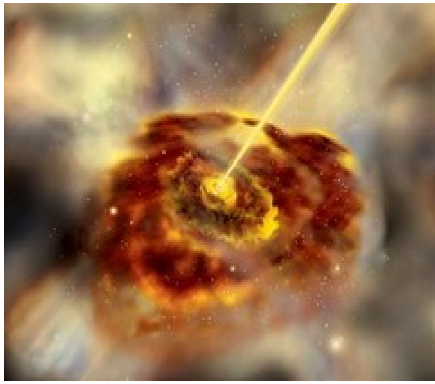
(Elvis et al. 2000)



Jets and outflows

+

(Courtesy NASA & A.Simonet)

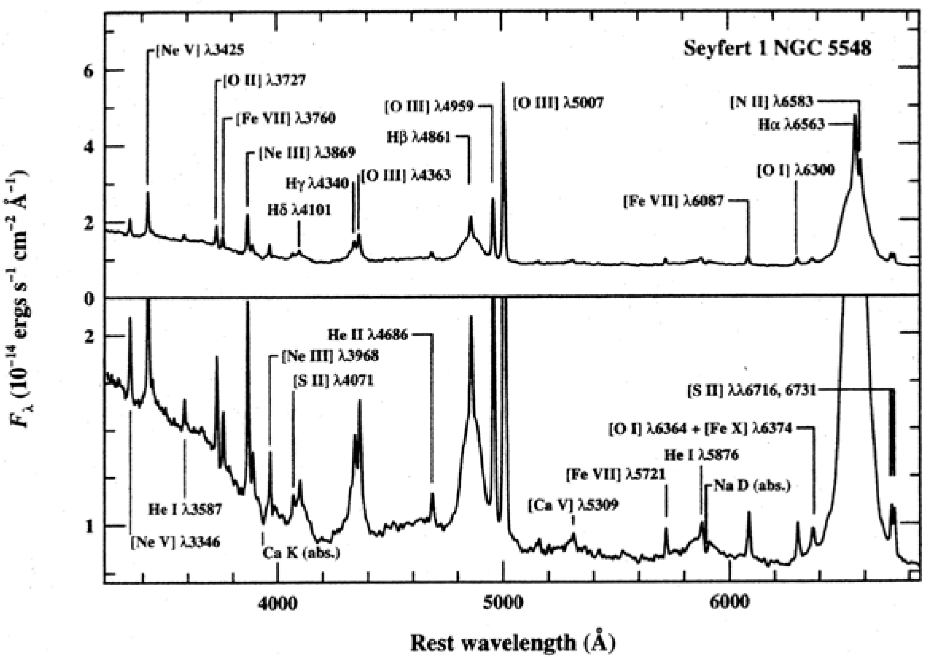


Gas and dust

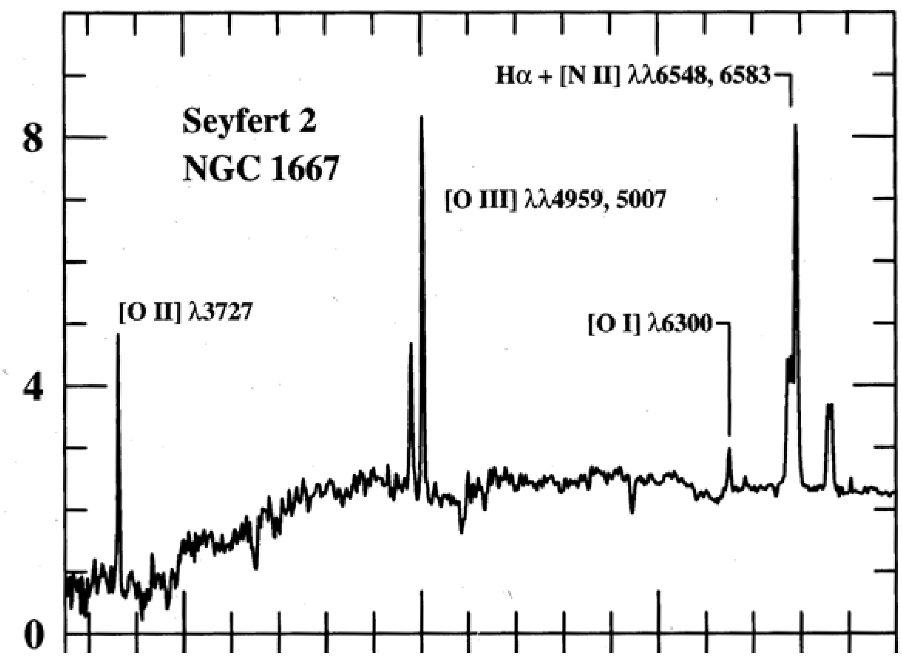
- To which extent do AGN share the same engine?
- To which extent are AGN relativistic machines?
- To which extent do AGN affect their environment?

X-ray versus optical spectra

Optical spectrum of a “type 1 AGN”



Optical spectrum of a “type 2 AGN”



X-ray versus optical spectra

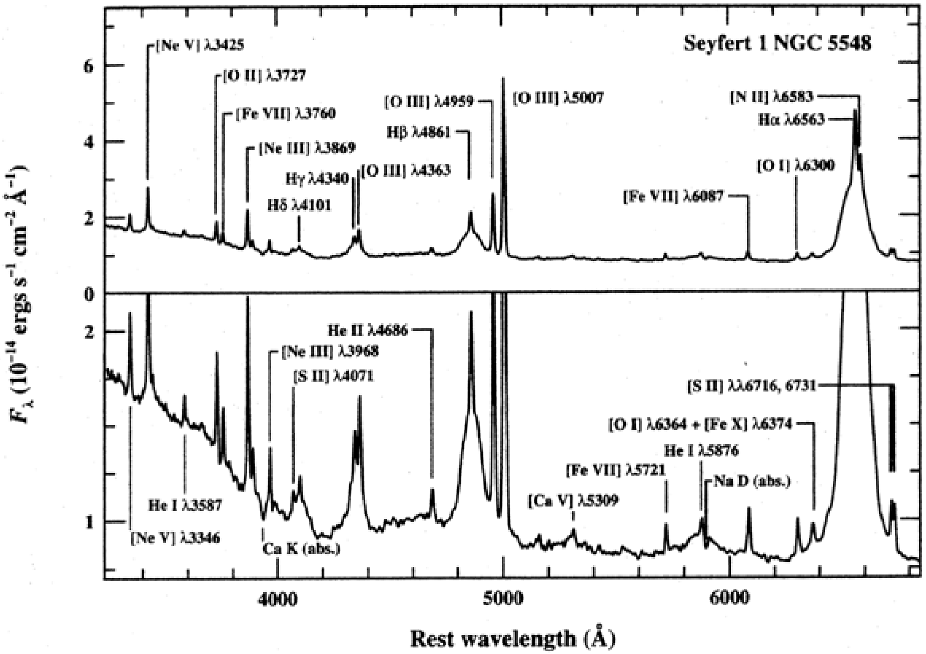
Optical spectrum of a “type 1 AGN”

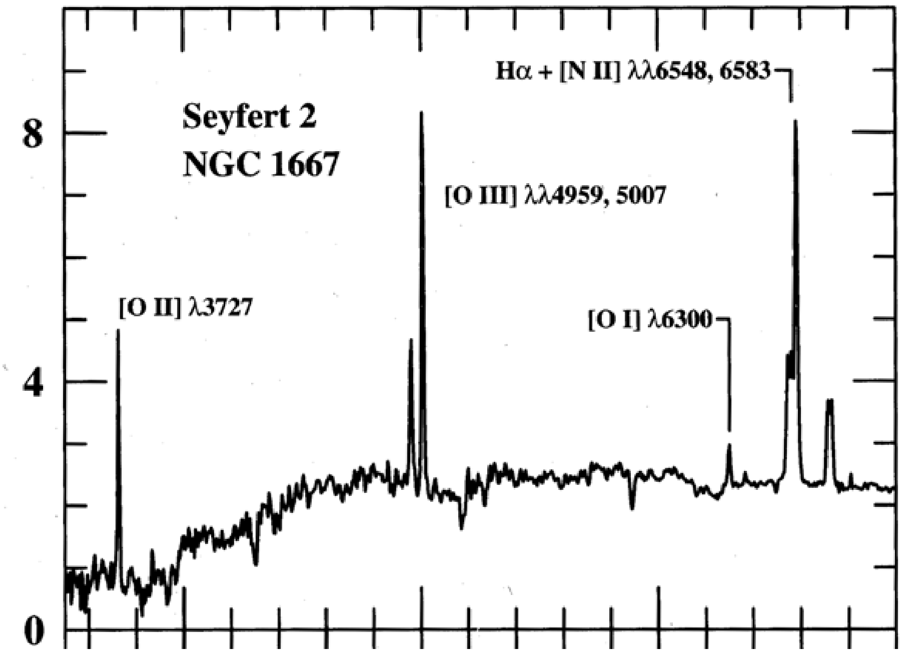
Optical spectrum of a “type 2 AGN”

E>15 kev
Γ_{type1}=1.96±0.04

E>15 kev
$\Gamma_{type1.5}$=1.97±0.05

E>15 kev
Γ_{type2}=1.97±0.05



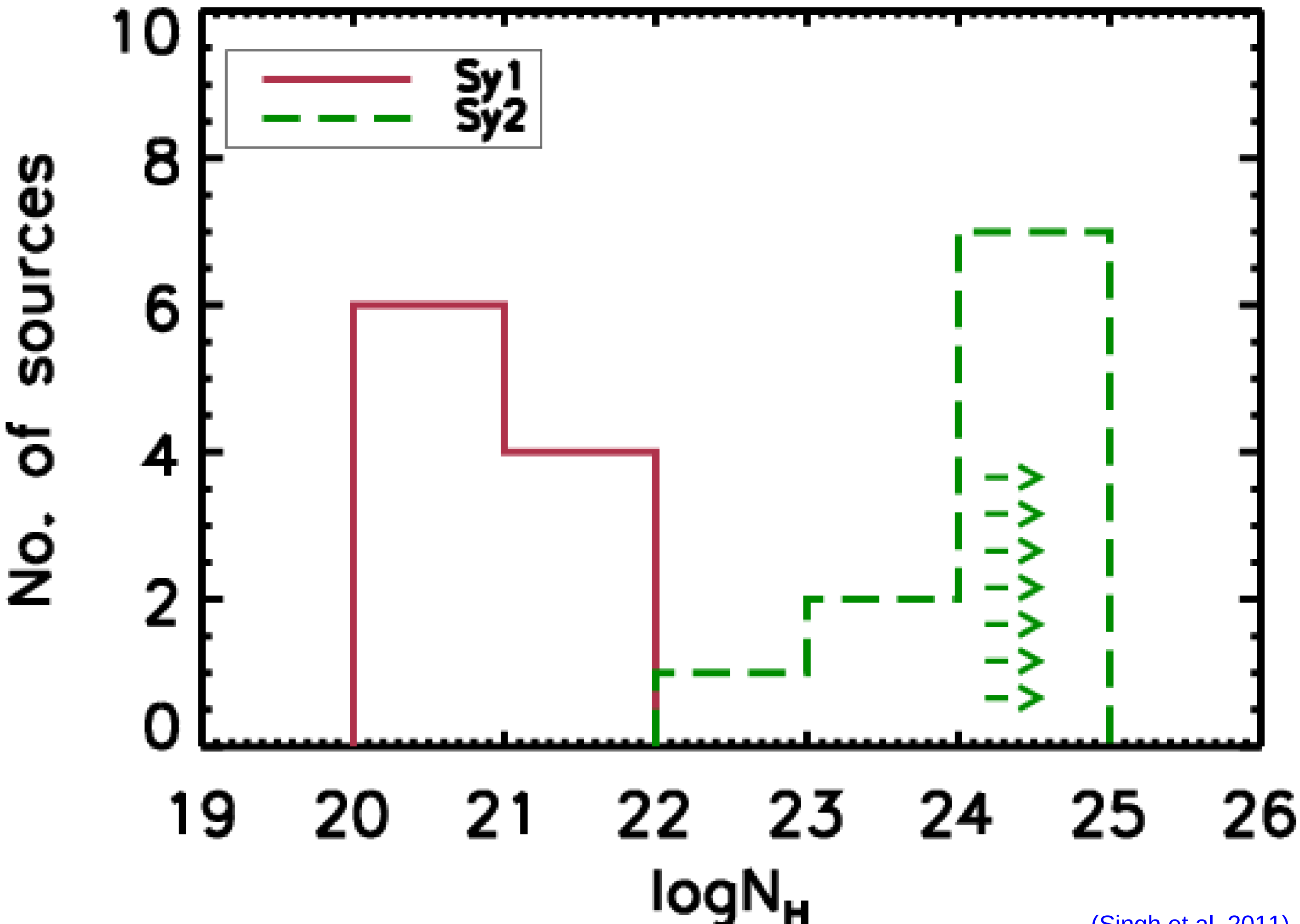


Data from an analysis of 165 Seyfert galaxies in the INTEGRAL/IBIS catalogue, Ricci et al. (2011)

Different observed X-ray spectra

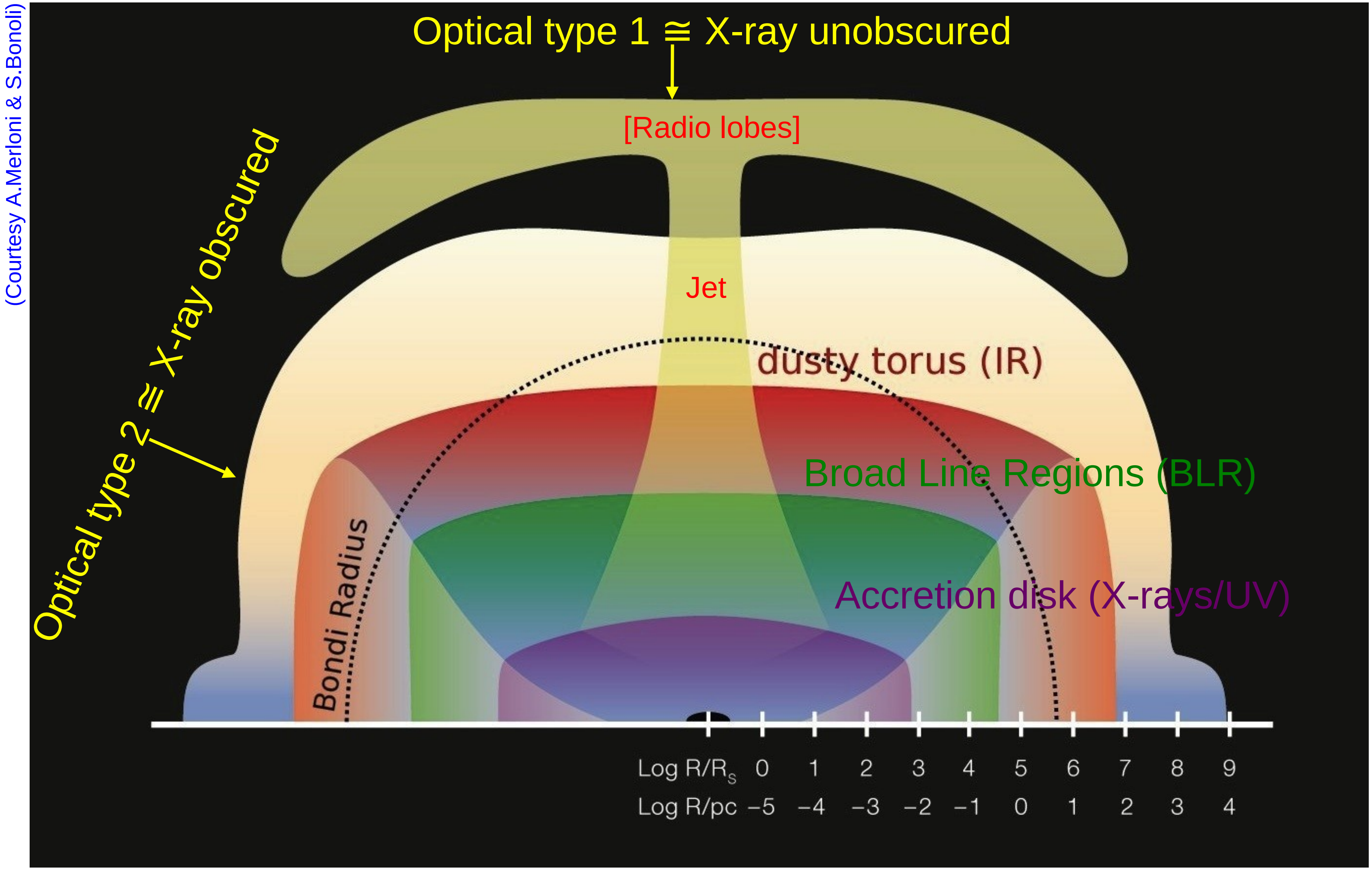
- *Observed* X-ray spectra depend on the *optical* class
- “Type 2” AGN spectra show also a stronger “hump” ≅30 keV (Ricci et al., 2011: 162 IBIS AGN)
- The “Compton hump” is a signature of Compton-reflection by optically thick matter surrounding the nucleus (Ghisellini, Krolik et al. 1994)

Sample of 20 Seyferts, well matched in orientation-independent multi observables



(Singh et al. 2011)

This is the X-ray view of a basic AGN “truth”

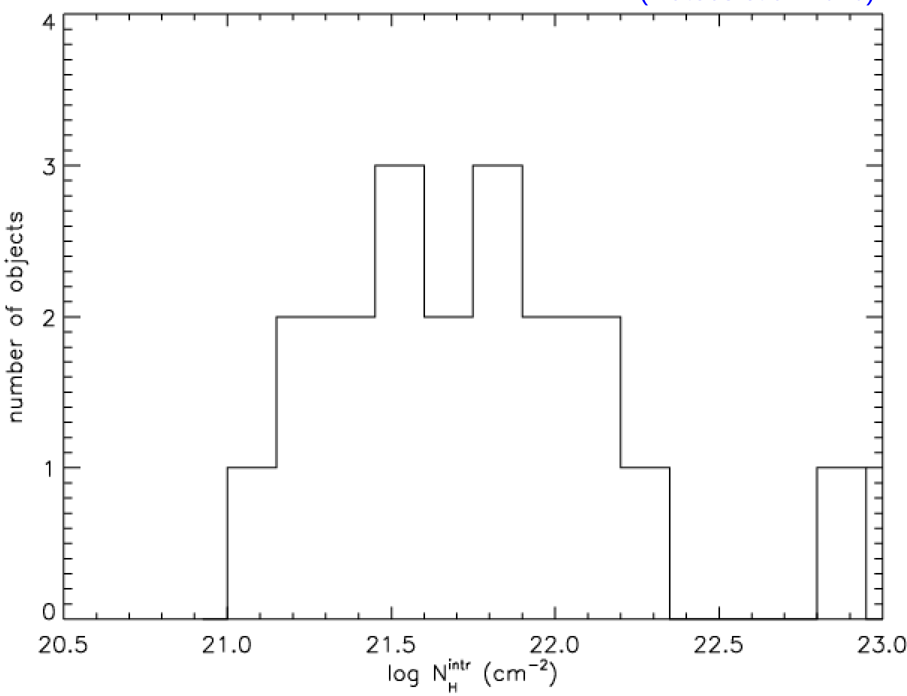


Solution: 3%

- The 0-th order unified scenario is verified at the 97% level:
- 3% of *X-ray obscured* “type 1”
  - Host galaxy
  - Variability/classification issues
  - Ionizing continuum anisotropy
- 3% of *X-ray unobscured* “type 2”
  - Minimum accretion rate to generate BLRs and/or torus (Nicastro 2000, 2003, Eliztur & Shloshman 2006)
  - Variability/classification issues

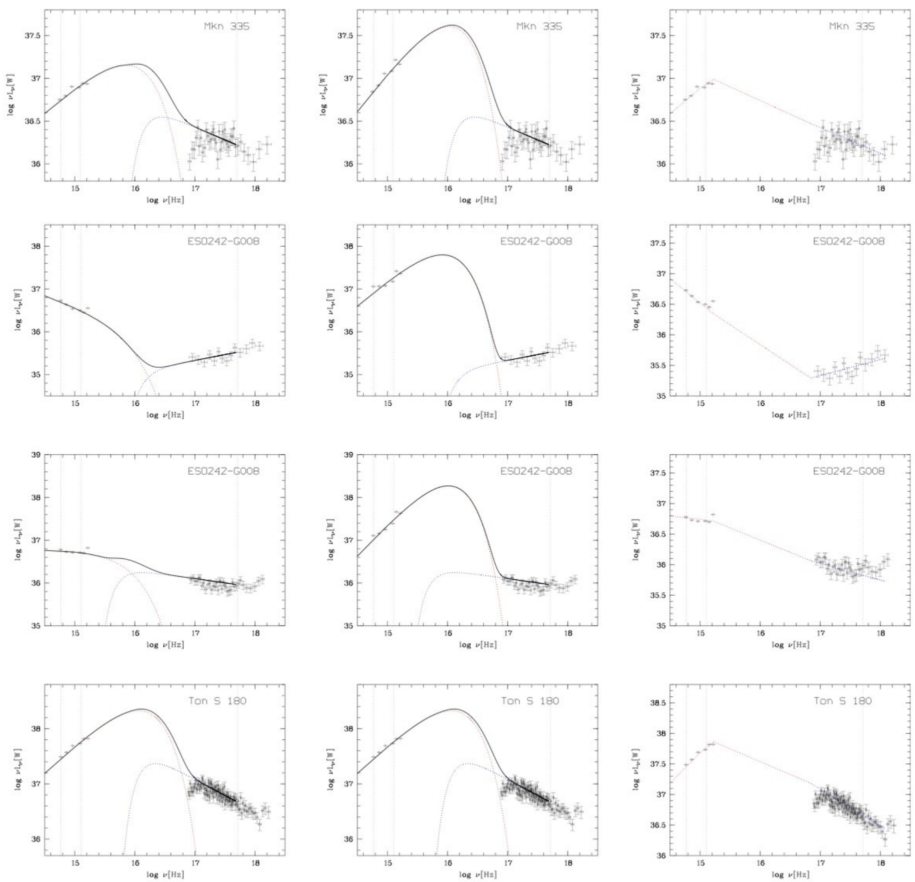
N_H distribution of type 1 X-ray obscured AGN of 486 type 1 AGN in the XMM-Newton Wide Area Survey (XWAS) AGN

(Mateos et al. 2010)

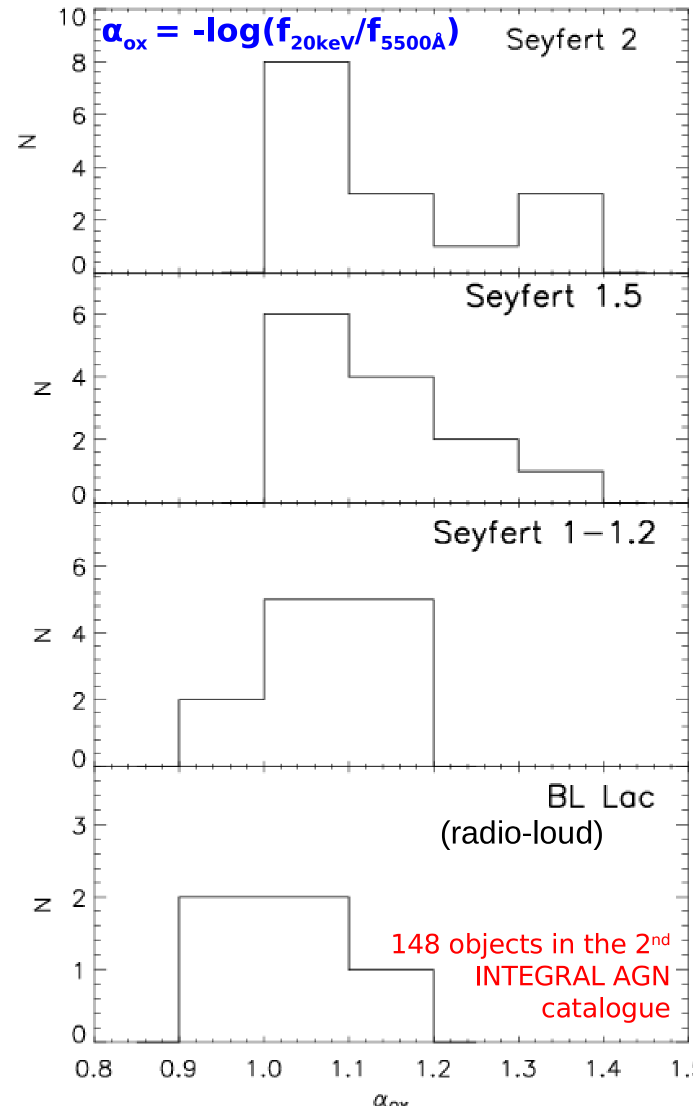


[Earlier works – yielding a wide range of results – by Pappa et al. 2001, Panessa & Bassani 2002, Barcons et al. 2003, Perola et al. 2004, Mateos et al. 2005, Beckmann et al. 2009, LaMassa et al. 2009, 2011, Corral et al. 2011.]

AGN SED and optical classes



(Grupe et al. 2010:
92 AGN observed simultaneously in the X-rays and optical by *Swift*)

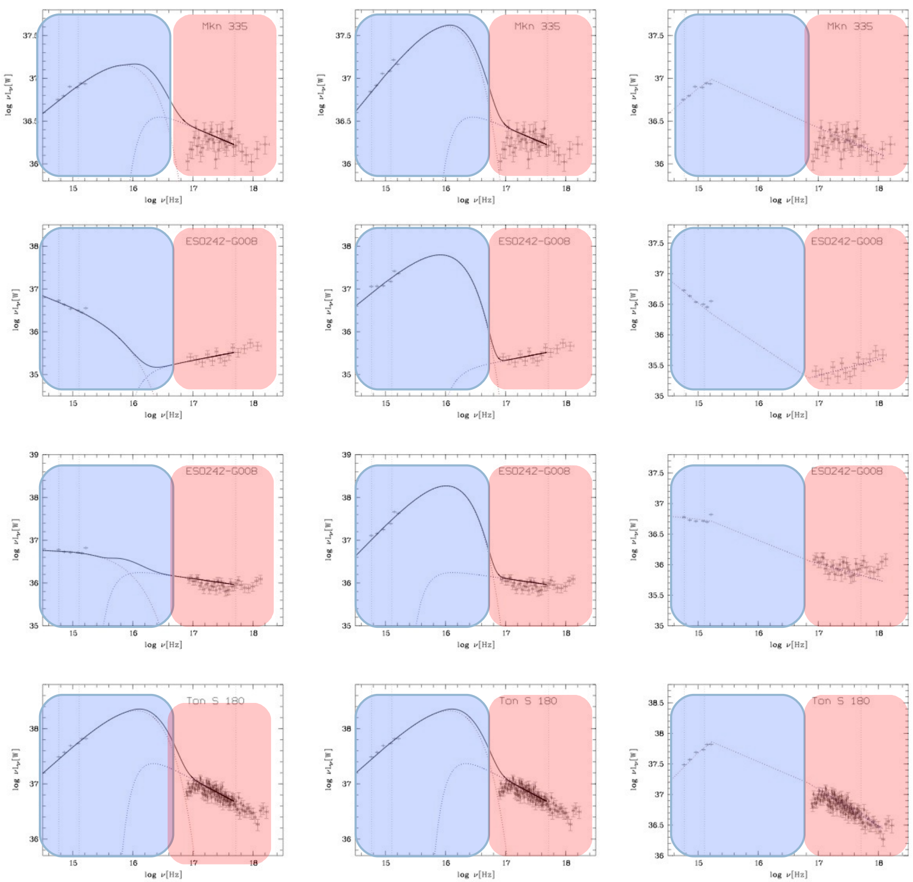


(Beckmann et al. 2009)

AGN SED and optical classes

Thermal, accretion disk

Non-thermal, disk Comptonization



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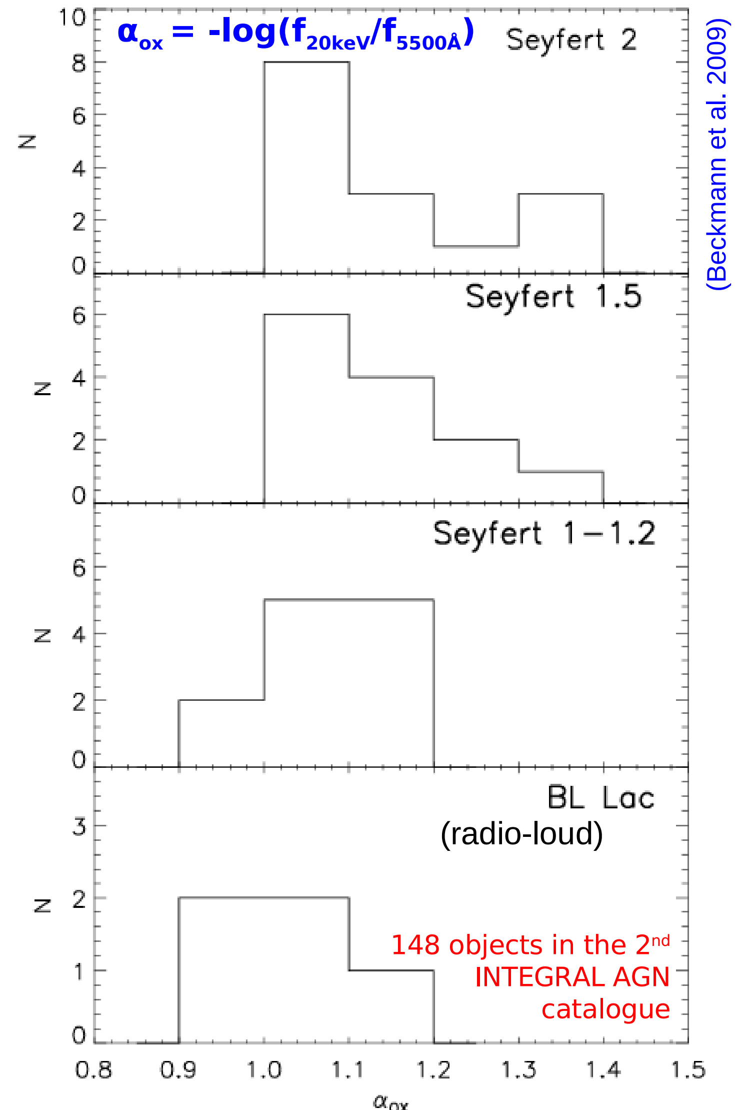
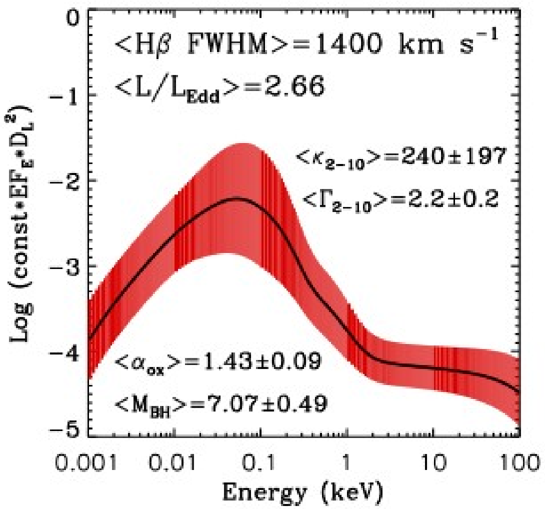


SEDs depend on more fundamental AGN parameters

Average spectra of a sample of 52 *unobscured AGN* with SDSS and XMM-Newton EPIC/OM spectroscopy in bin of 12 sources according to the width of their optical broad lines

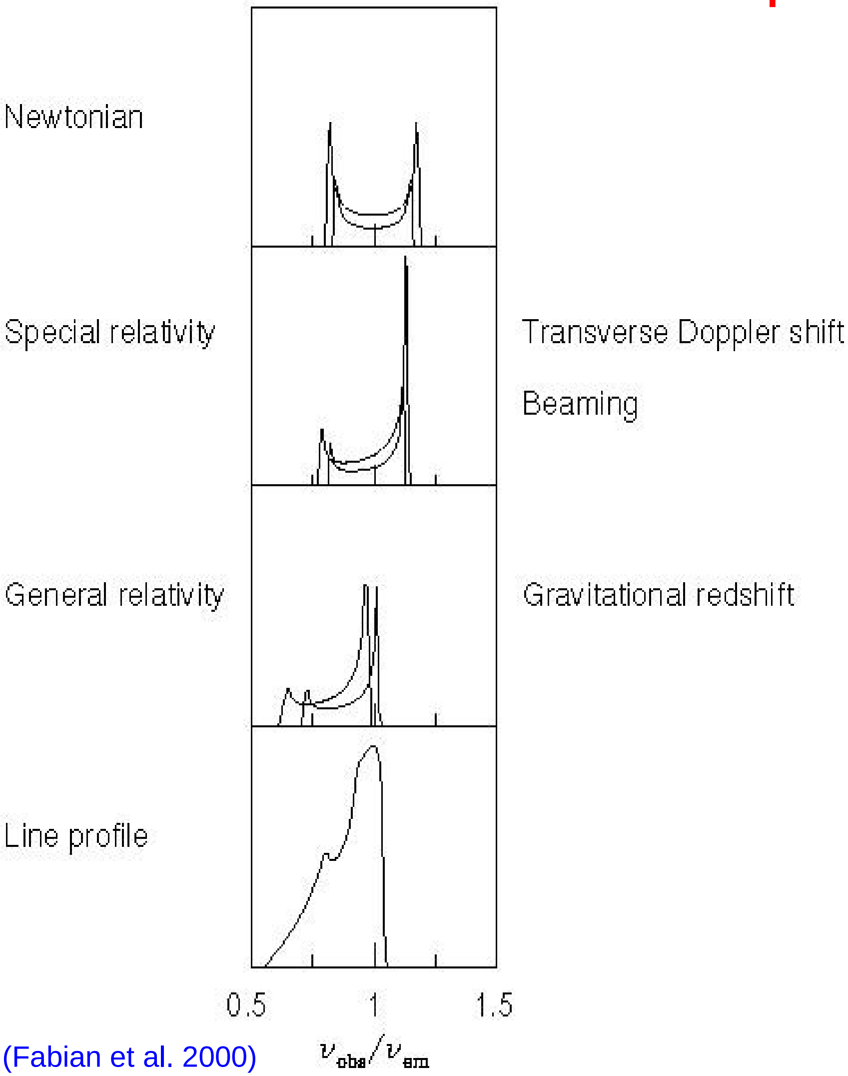


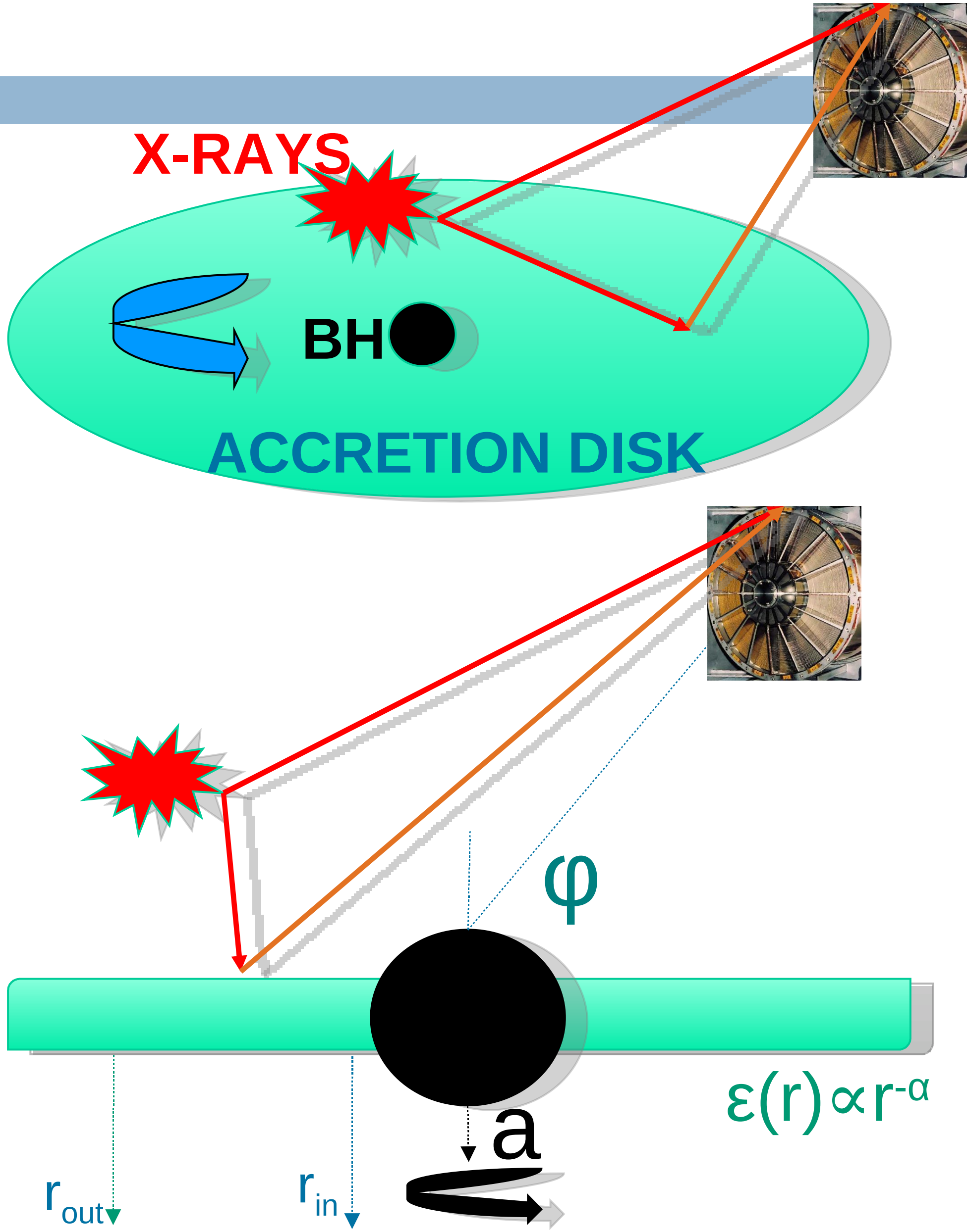
(Jin et al. 2011)

The optical-to-X-ray Spectral Energy Distribution depends on a more fundamental parameter such as the **black hole mass**, the **accretion rate** (or a combination thereof)

An inescapable consequence of accretion disk reflection in the GR regime ...

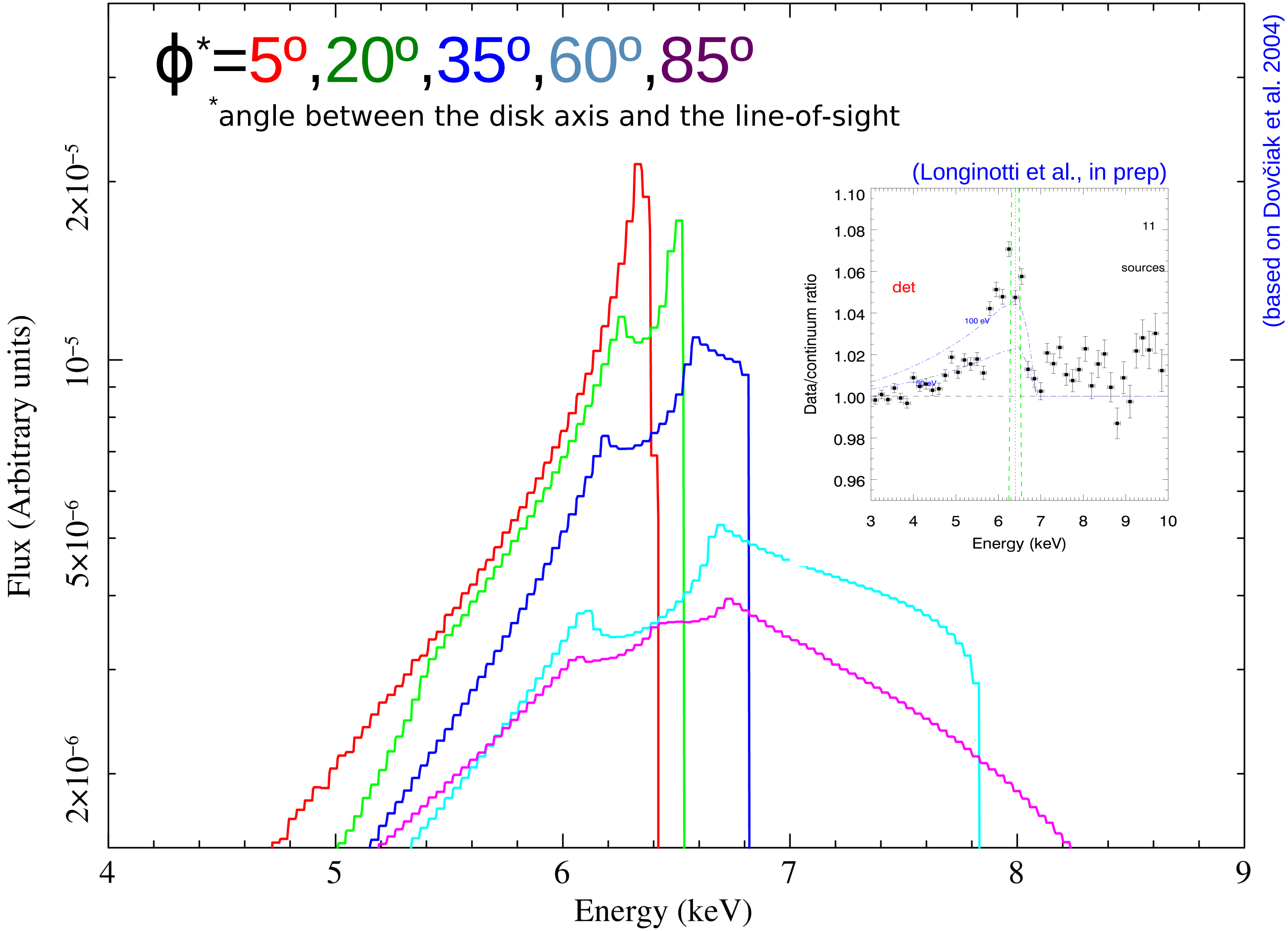
... distorsion of a monochromatic line profile



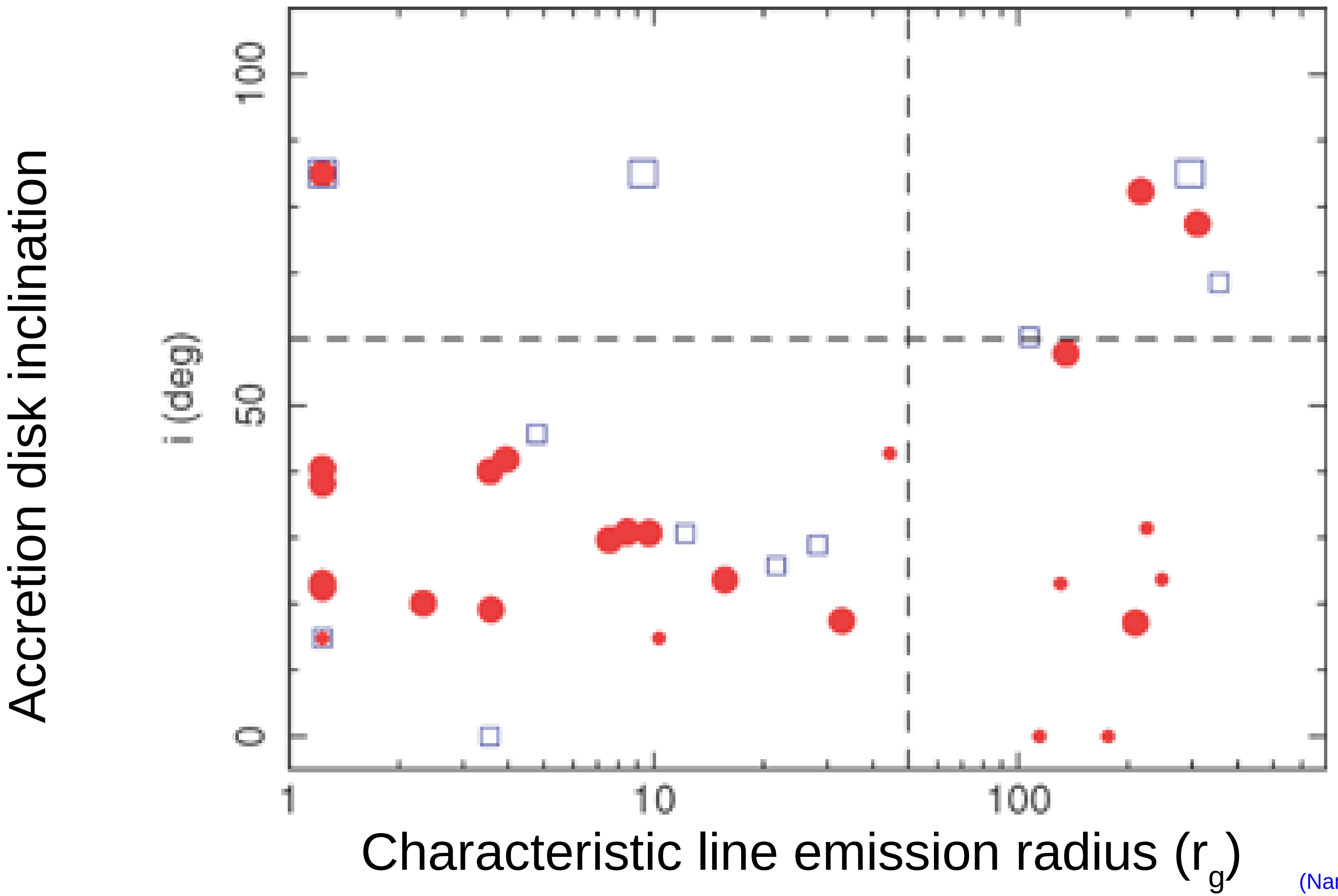


(Fabian et al. 2000)

Dependence on disk inclination

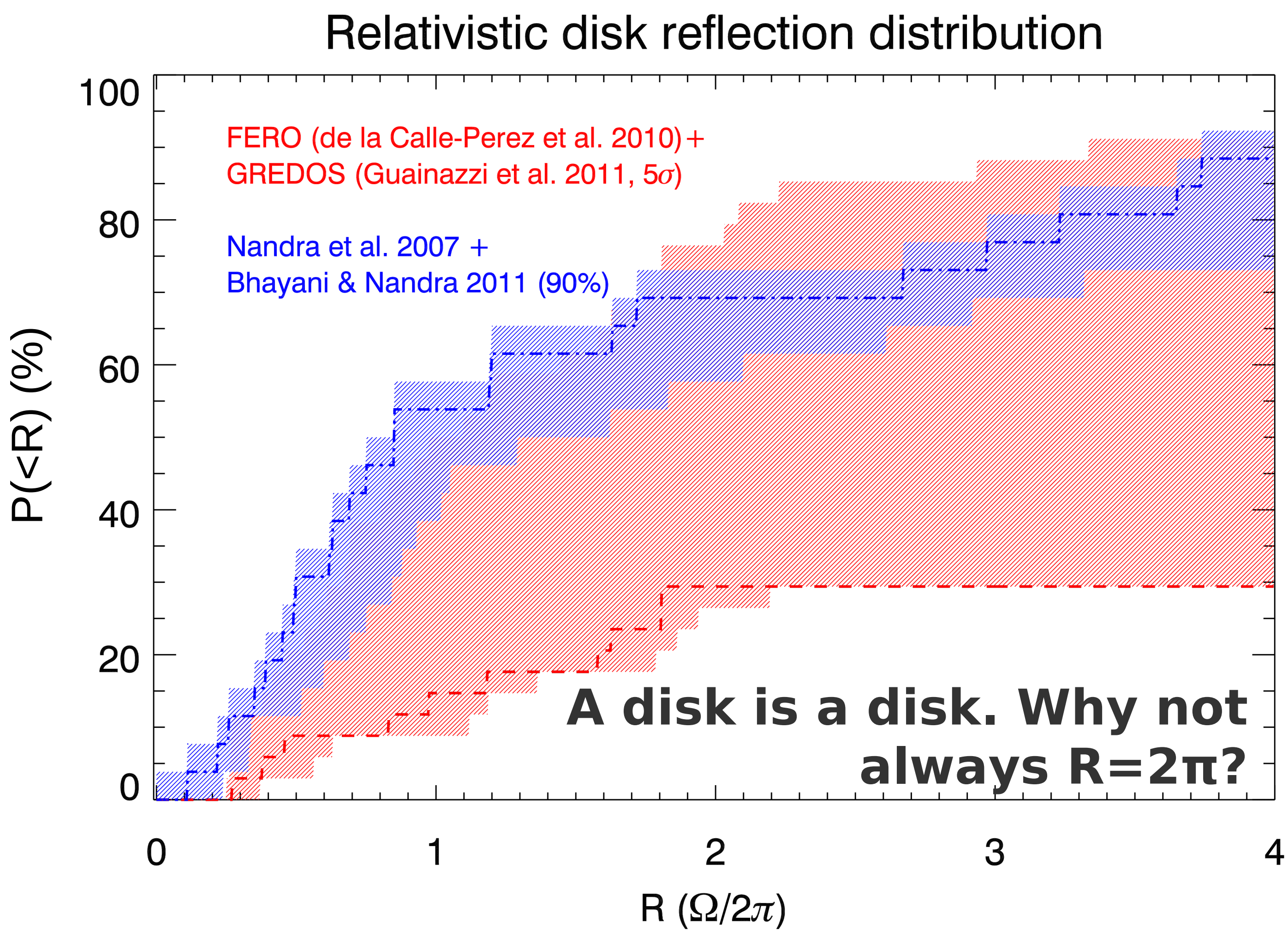


Reflection in truly GR regime



(Nandra et al. 2007)

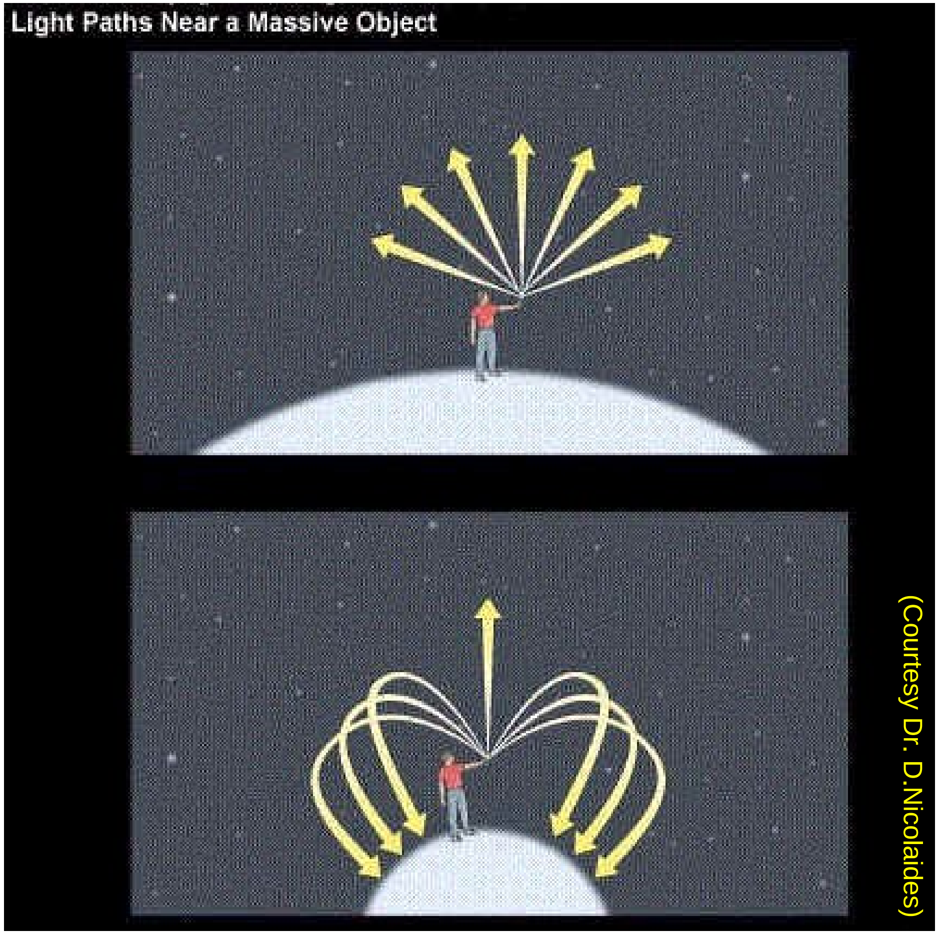
Frequency of relativistic broadened Fe K_α lines in AGN



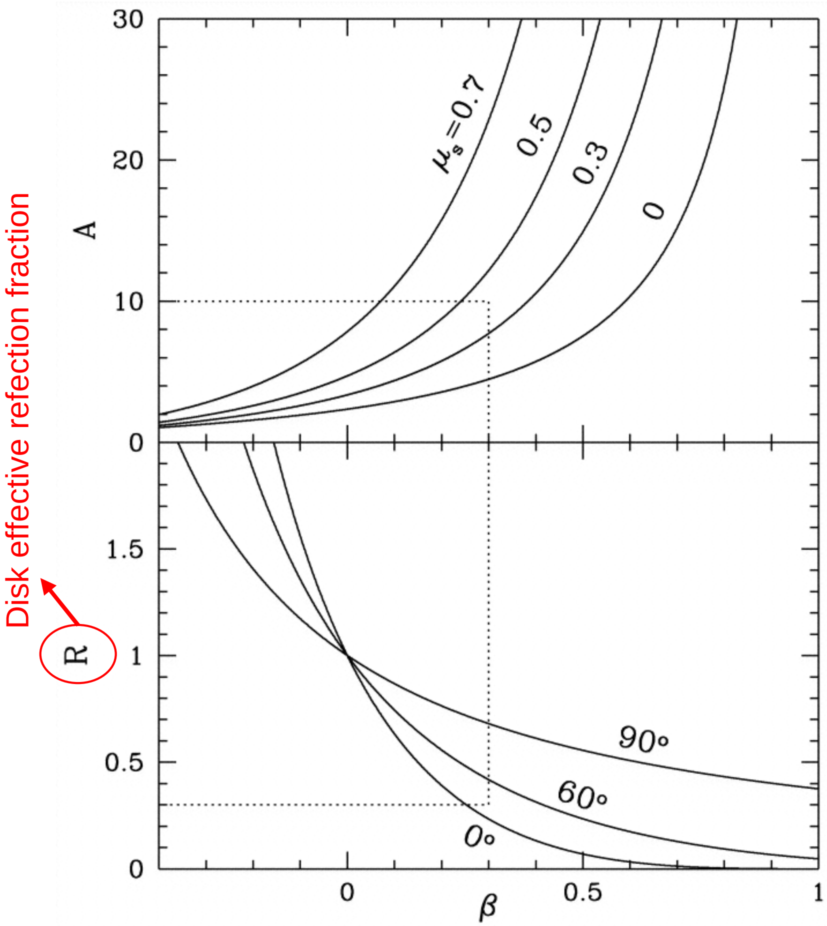
Caveats: common (de Marco et al. 2009) and not understood variability (Bhayani & Nandra 2009).

Wide spread in reflection strength

High EW: Light bending (Minutti & Fabian 2004)



Low EW: outflowing corona (Beloborodov 1999)

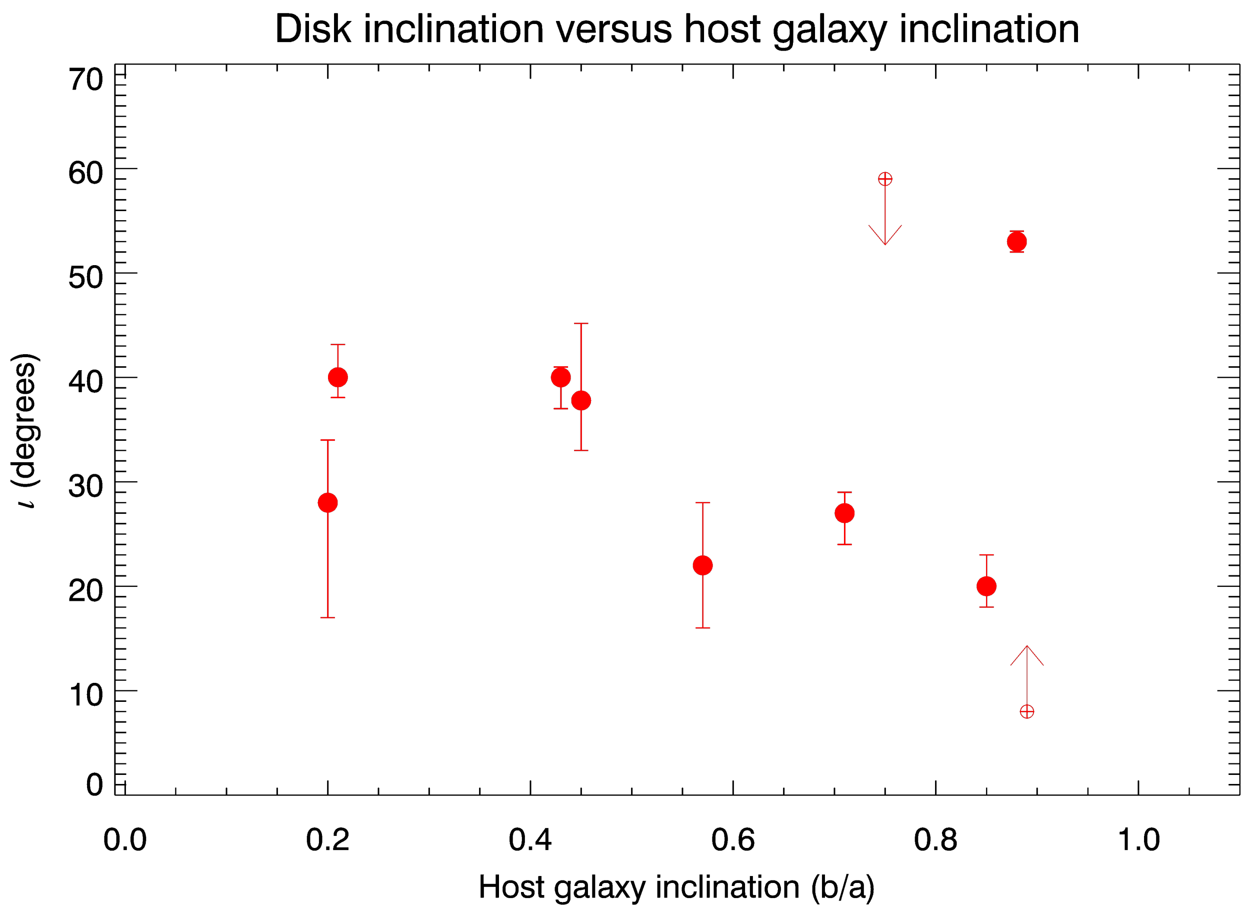


Accretion disk inclination

<u>Similar conclusions:</u>

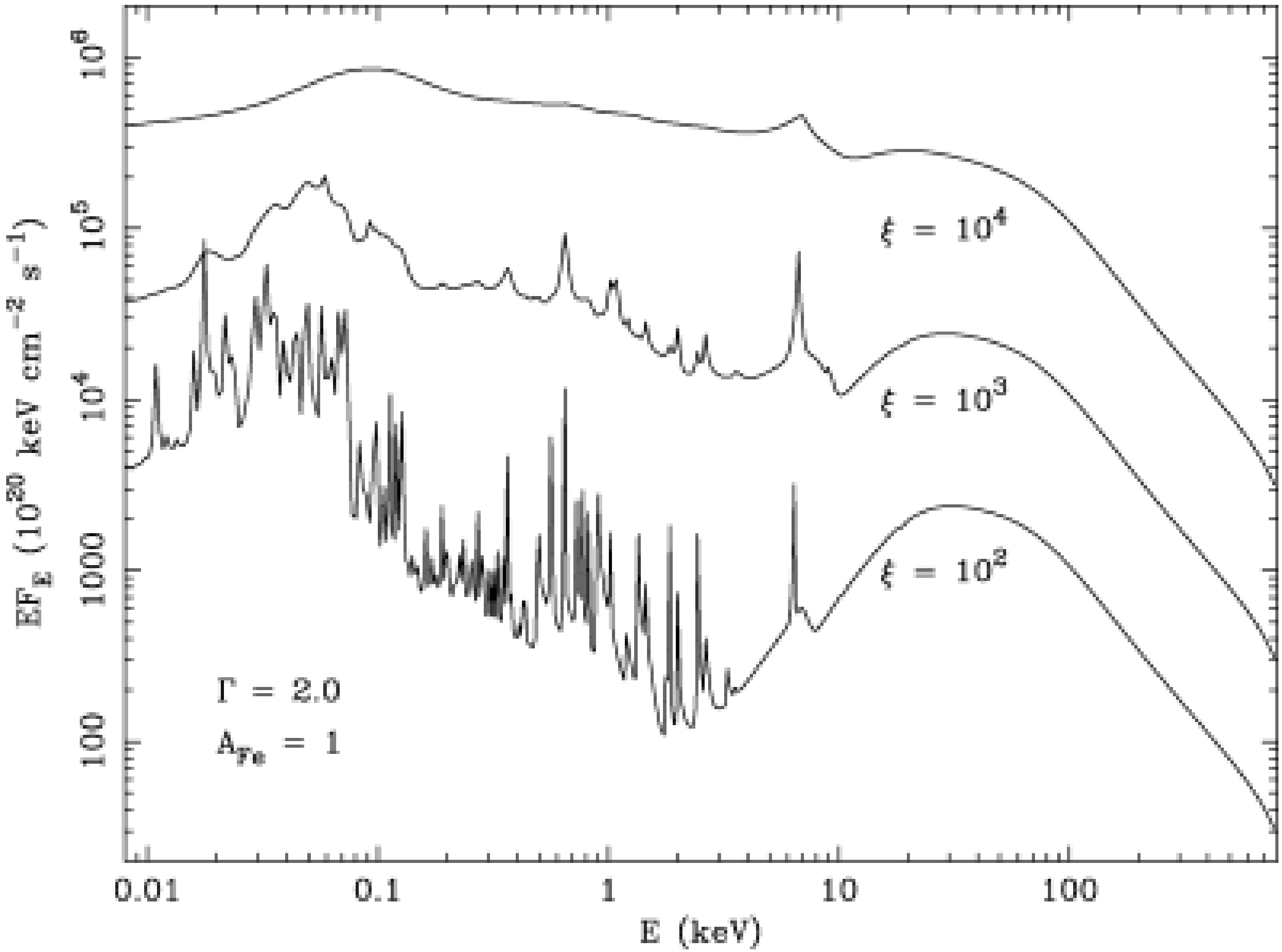
- Disk inclination is random in the range ϕ=0-80º (from X-ray spectra fit with self consistent ionized disk refection: Crummy et al. 2006)

- Distribution of angles between radio jets and host galaxy disks consistent with being random (Kinney et al. 2000, Schmitt et al. 2001)



(Guainazzi et al. 2011)

The X-ray reflection spectrum

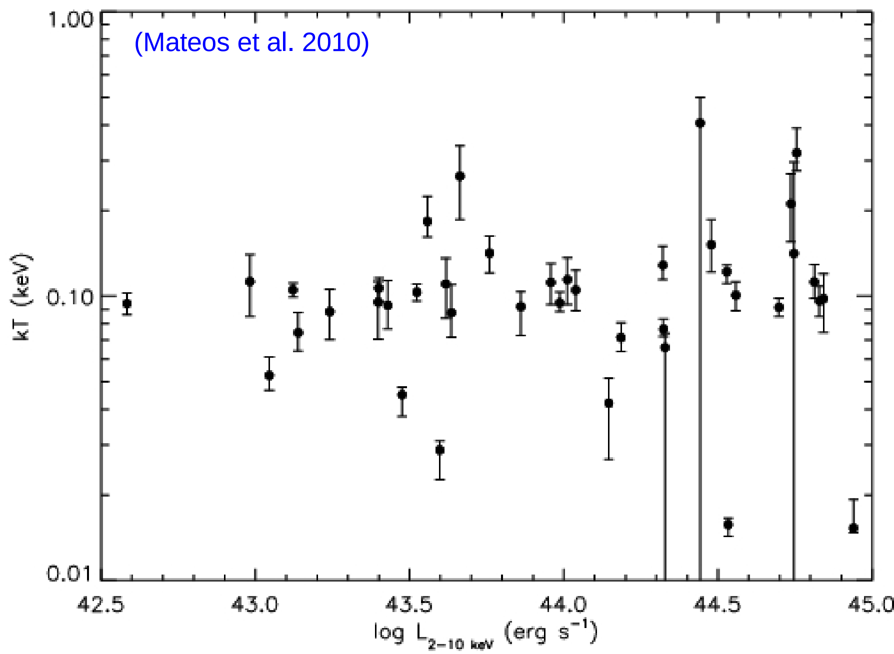


(Ross & Fabian 2005)

Soft excess(es) in AGN

- [Loose] definition: excess emission on top of a spectral model defined for E≥1 keV (Turner & Pounds 1991)
- Common phenomenology:
  - 50-60% of ASCA AGN (George et al. 1998, Reeves & Turner 2000)
  - 80% of PG-QSO (Piconcelli et al. 2005)
  - ≅70% of XAWS AGN (Scott et al. 2011)
- *Smooth*! ➔ if driven by atomic physics, it requires extreme relativistic smearing in reflection (Crummy et al. 2006) or partial covering (Turner & Miller 2009)
- Unlikely to be due to thermal emission from the disk due to constant kT (point made originally by Gierlinski & Done 2004)

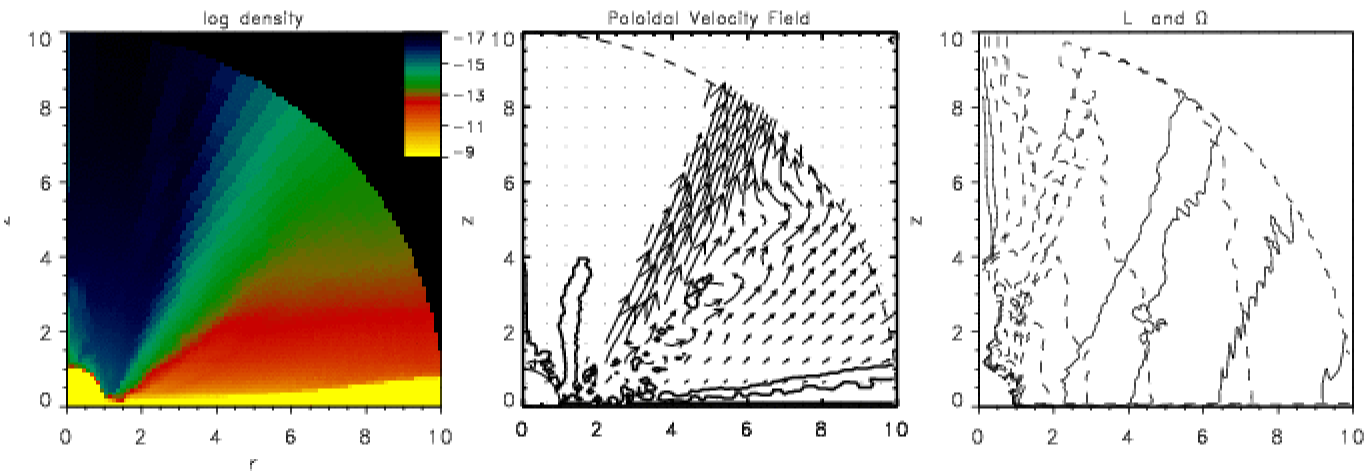
Nominal best-fit temperature of the XAWS AGN soft excess if fit with a multi-kT blackbody [$\propto M_{BH}^{-1/4}$]

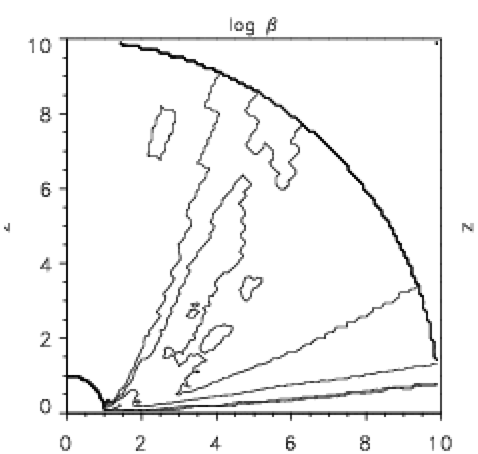


[see also Bianchi et al. 2009, Winter et al. 2009, LaMassa et al. 2009 among others]

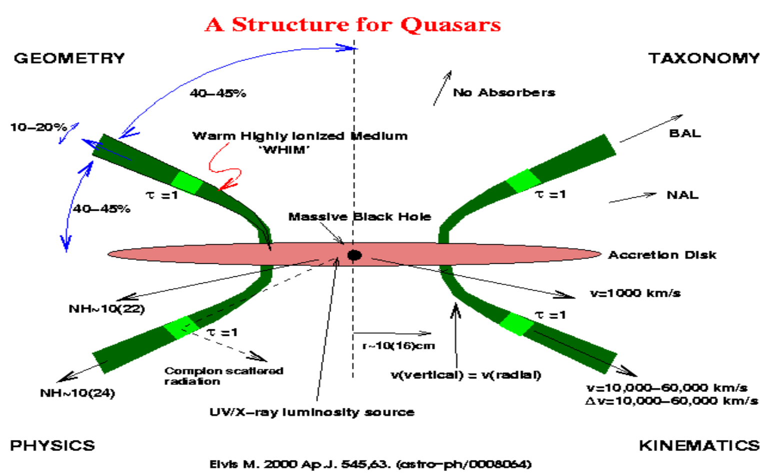
Accretion disk winds

Most accretion disk simulation predicts Compton-thick winds



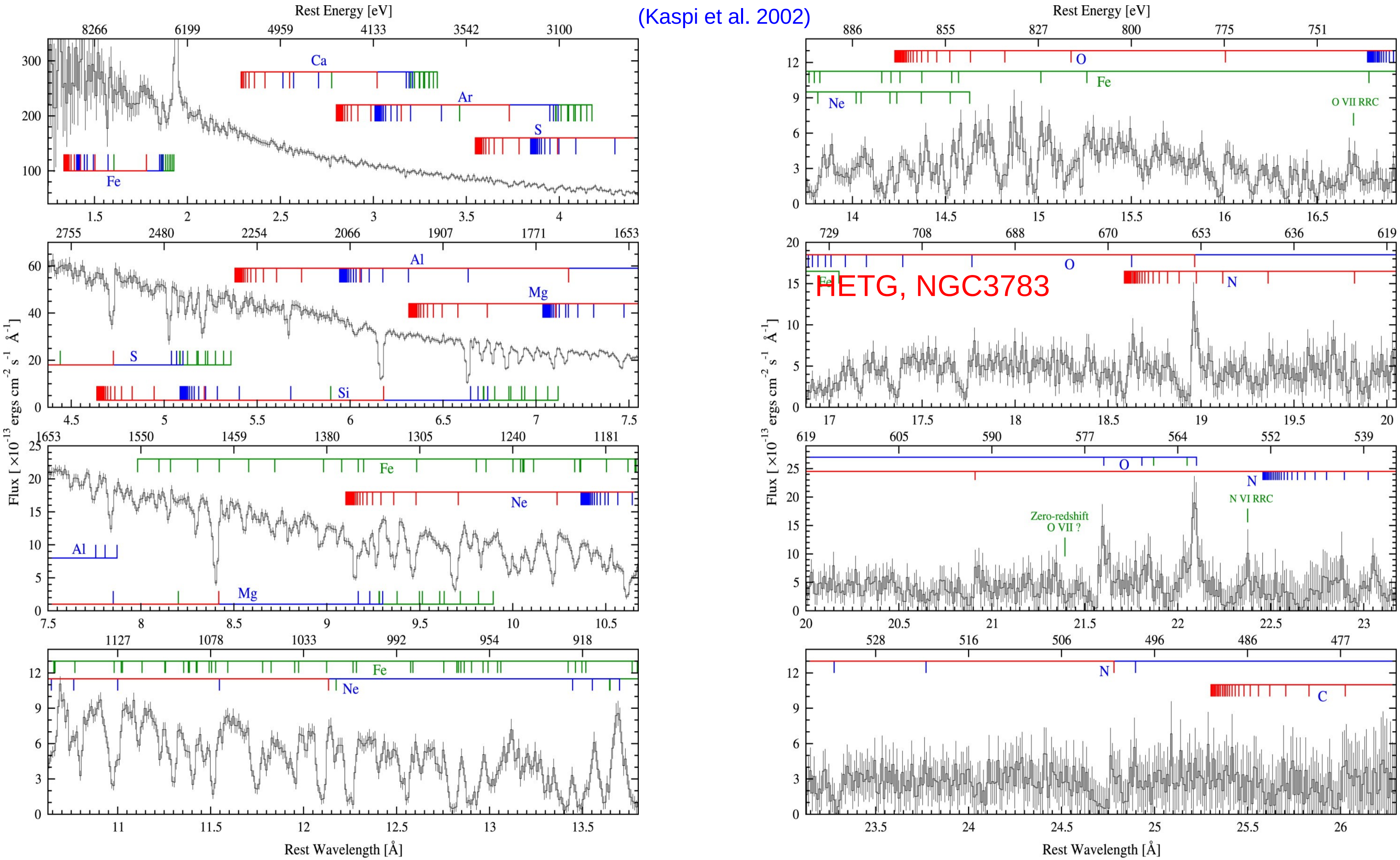


(Proga et al. 2008)



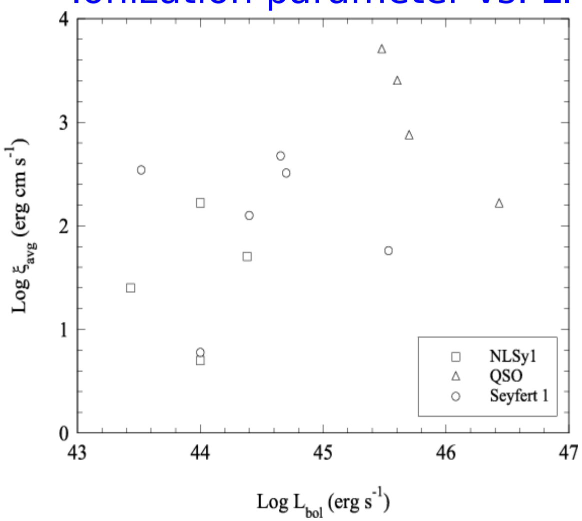
(Elvis 2000)

High-resolution measurements of WA



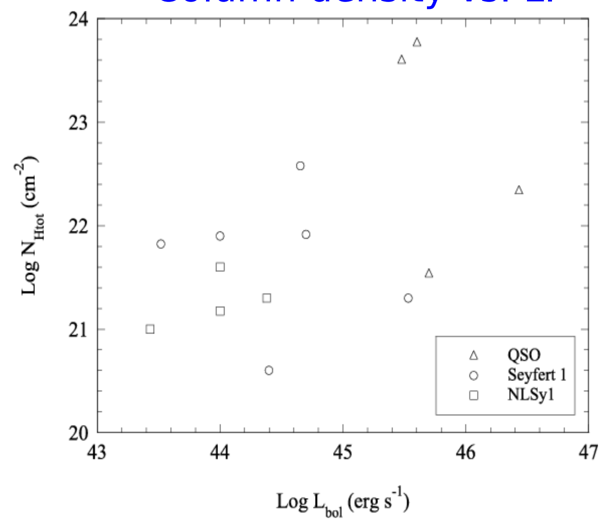
Summary of warm absorbers properties

Ionization parameter vs. L.

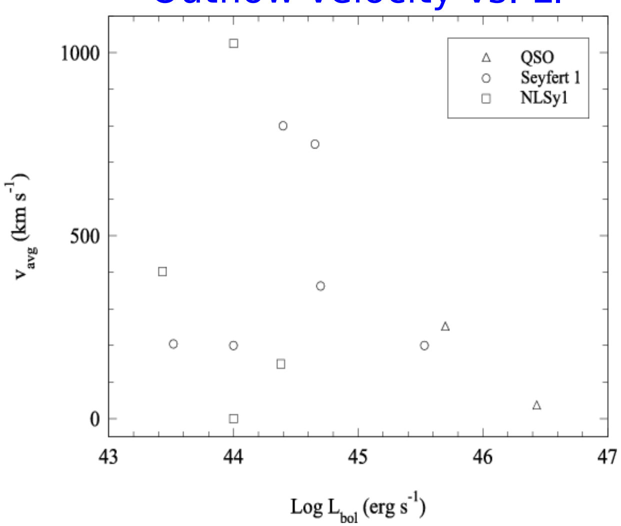


Sample of 23 warm-absorbed AGN observed by the RGS [see also McKernan et al. 2007 for a *Chandra* view]

Column density vs. L.

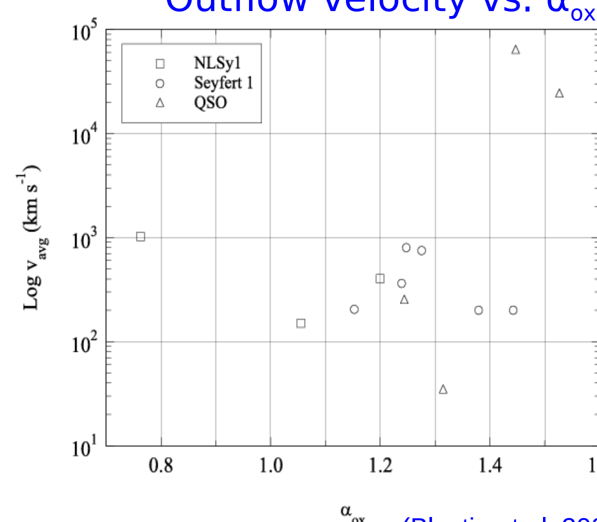


Outflow velocity vs. L.



Typical distances between 0.1 pc-100 pc (see also Blustin et al. 2007)

Outflow velocity vs. α_{ox}.



(Blustin et al. 2005)

Summary of warm absorbers properties

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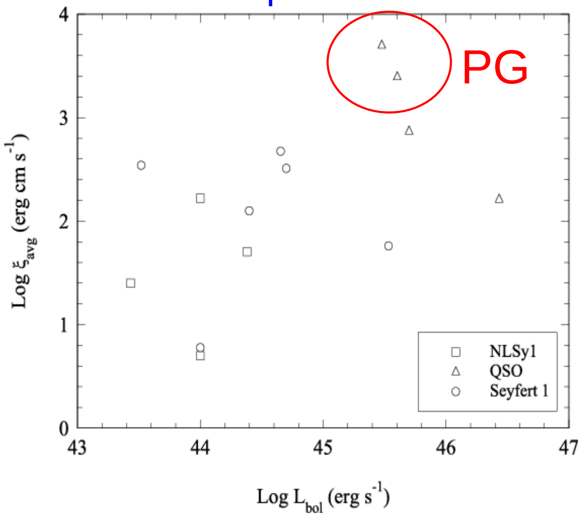
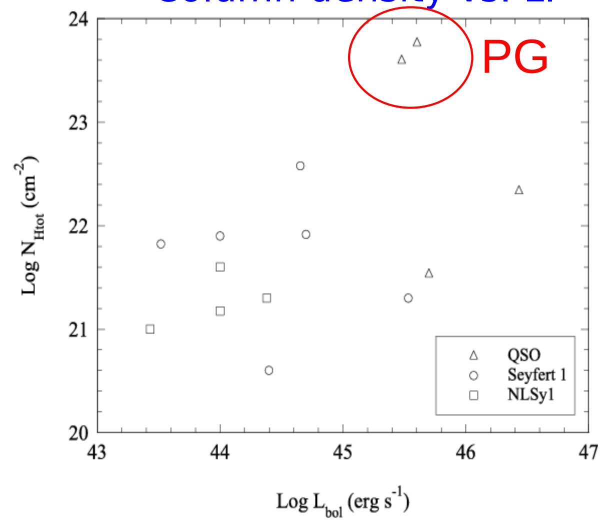


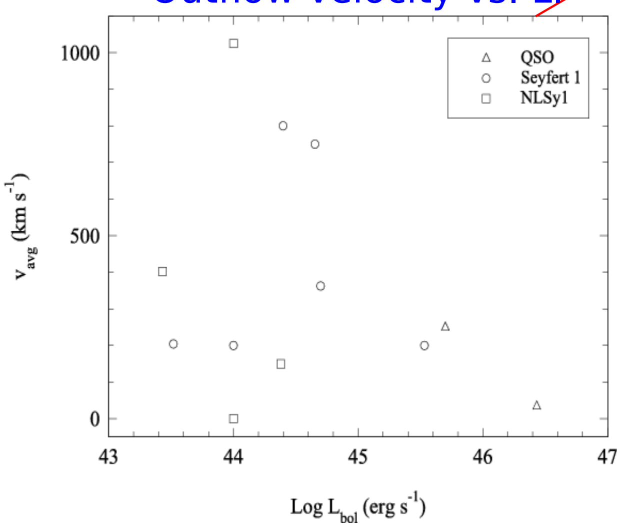
Column density vs. L.



Sample of 23 warm-absorbed AGN observed by the RGS [see also McKernan et al. 2007 for a *Chandra* view]

Two PG quasars lay above this plot

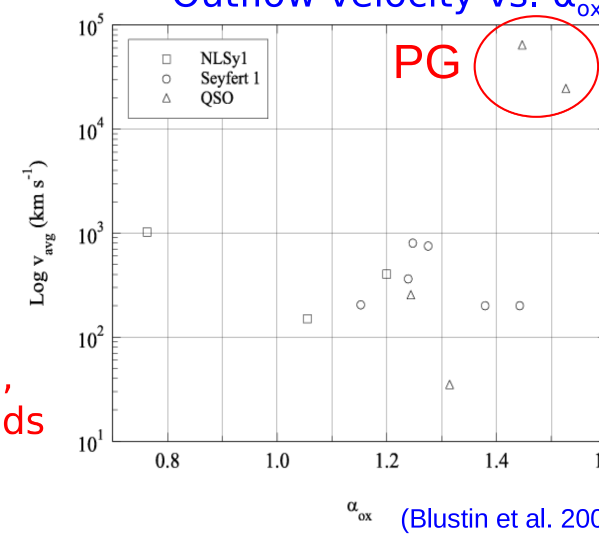
Outflow velocity vs. L.



Typical distances between 0.1 pc-100 pc (see also Blustin et al. 2007)

10^{-4}-10^{-6} pc (Turner et al. 2002, Pounds et al. 2003, King & Pounds 2003, Reeves et al. 2004)

Outflow velocity vs. α_{ox}.



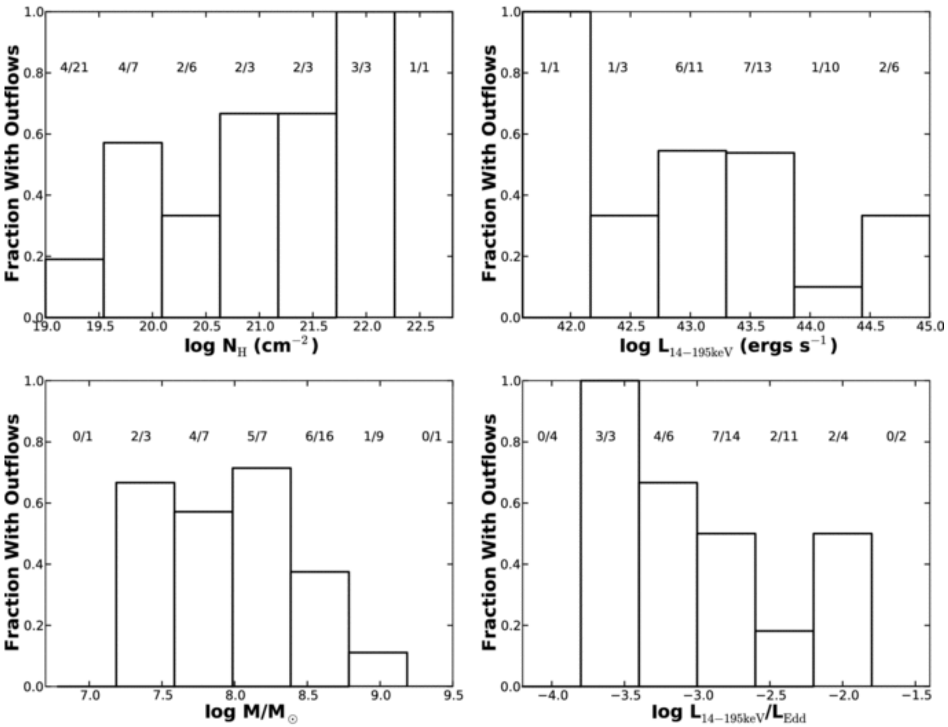
(Blustin et al. 2005)

Fraction of outflows

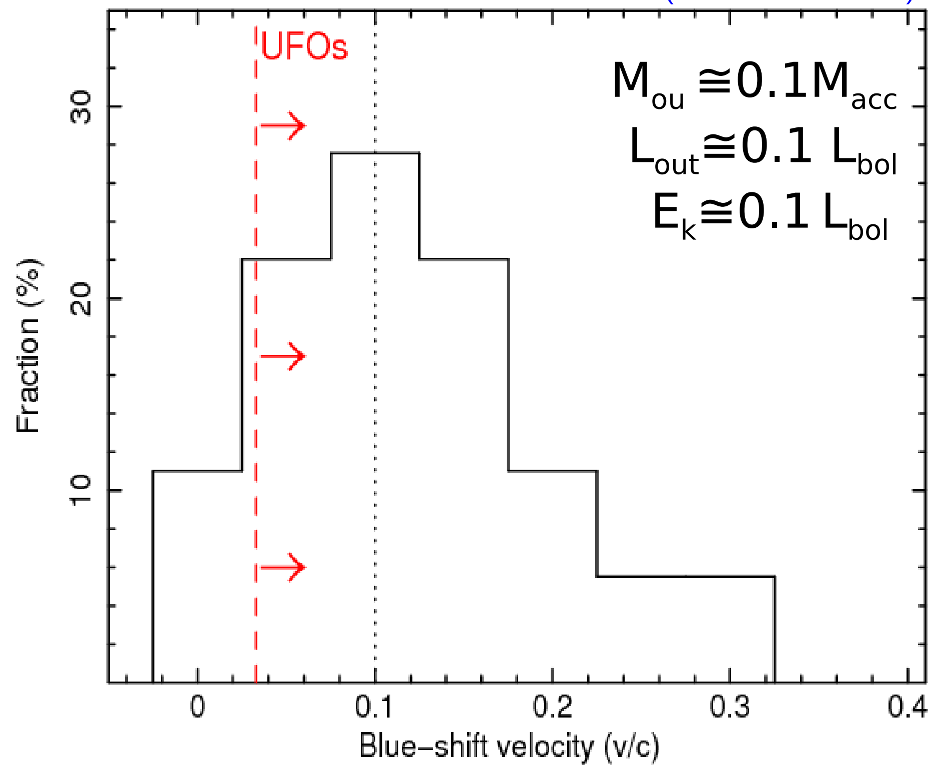
“Seyfert-like” warm absorbers:
≥80% in hard X-ray selected samples

PGQSO-like outflows:
40%-60% in the FERO sample

(Winter et al. 2010)



(Tombesi et al. 2010)



[Earlier works by Reynolds 1997, George et al. 1998, Porquet et al. 2004, Piconcelli et al. 2005, Brocksopp et al. 2006]

Outflow mass rates

- Do ionised outflows have an impact on the host galaxy matter enrichment?

$$\dot{M}_{\rm out} = 8\pi r N_H \mu m_p C_g v_r$$

(spherical flow)

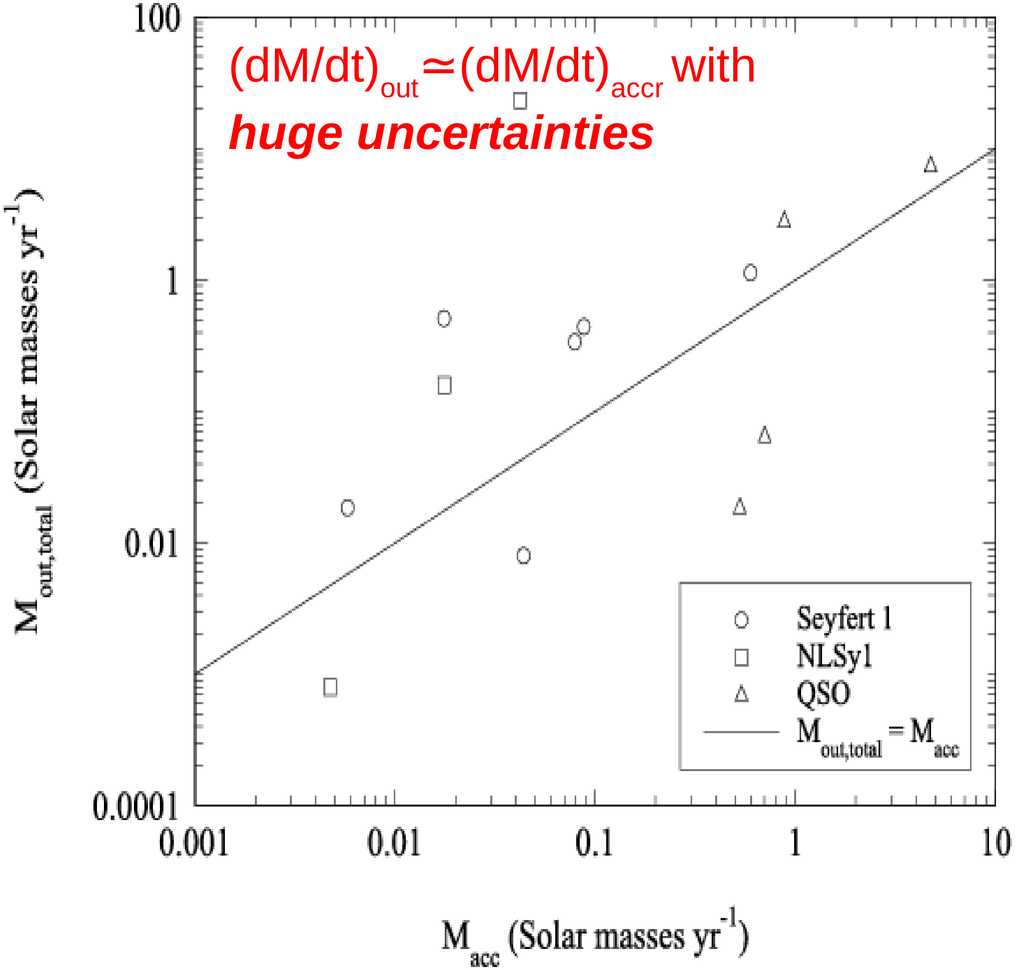
$$\dot{M}_w = 0.8\pi m_p N_H v_r R f(\delta, \phi)$$

(biconical outflow, Krongold et al. 2007)

- Do ionised outflows have an impact on the host galaxy evolution?

$$L_{\rm KE} = \frac{1}{2}\dot{M}_{\rm out} v^2$$

(Blustin et al. 2005)



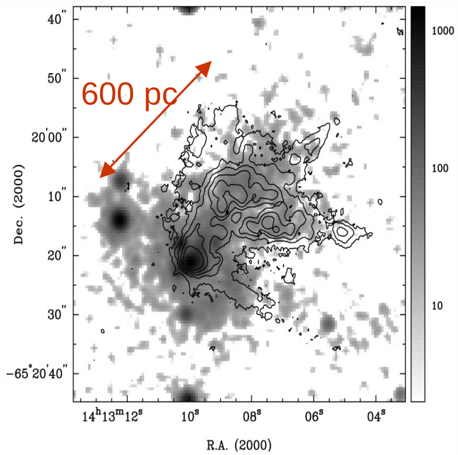
Outflow energy and feedback

- Some reference energies
  - **10^{57}** ergs are needed to heat the ISM to a temperature ($\sim 10^7$ K) required to “evaporate” it
  - **10^{59}** ergs is the binding energy of a $10^{11} M_\odot$ bulge with $\sigma \sim 300$ km/s
  - **10^{60}** ergs are required to control host-galaxy and surrounding IGM evolution (King 2003, Scannapieco & Oh 2004, Hopkins et al. 2005, Natarayan et al. 2006)
    - The initial momentum or energy requirement for an outflow to induce feedback can be relaxed by a factor ~10 if the outflow drives a secondary wind in the ISM (Hopkins & Elvis 2010)

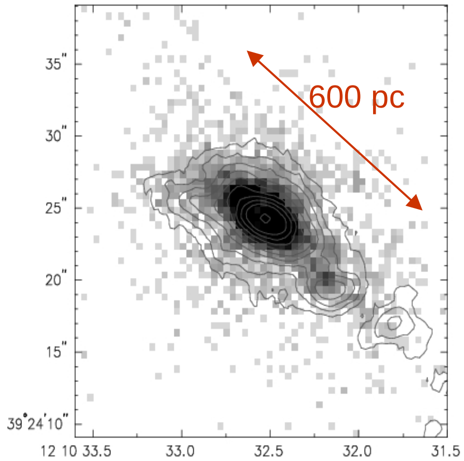
- Some estimates:
  - NGC4051 (low M_{BH} and L_{bol} Seyfert): $KE_{out} \sim$ **$(0.4\text{-}1) \cdot 10^{53}$** ergs (Krongold et al. 2007)
  - NGC5548 (standard Seyfert): $KE_{out} \sim$ **$3.3 \cdot 10^{57}$** ergs (Krongold et al. 2010)
  - PG1211+143 (QSO): $KE_{out} \sim$ **10^{60}** ergs (King & Pounds 2003)
  - PDS456 (powerful QSO): $KE_{out} \sim$ **$10^{61\text{-}62}$** ergs (Reeves et al. 2009)

Narrow Line regions in optical and X-rays

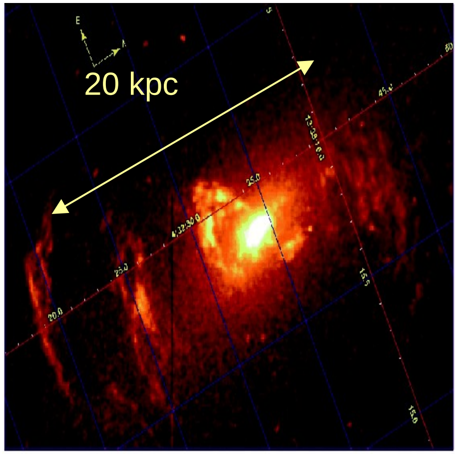
Images: O[III] – Contours: soft X-rays



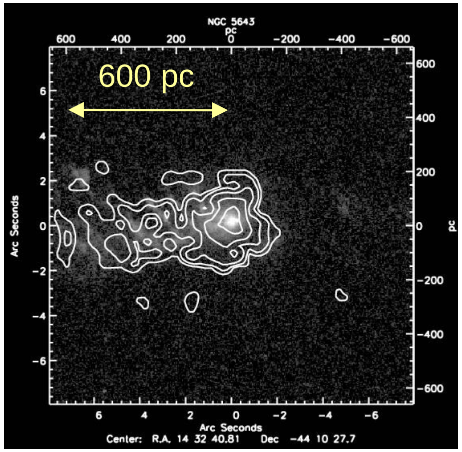
Circinus Galaxy
(Smith & Wilson 2001)



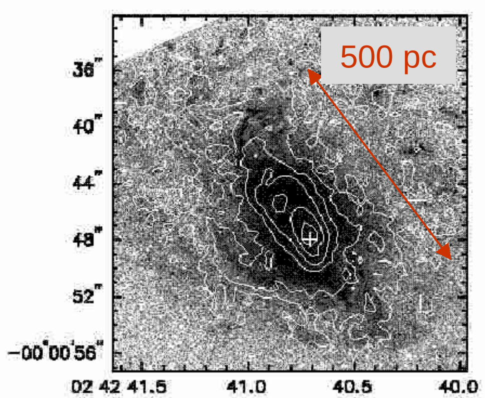
NGC4151
(Yang et al. 2001, Wang et al. 2009, 2010)



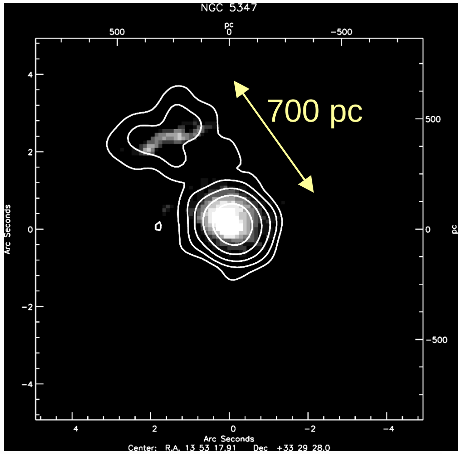
NGC5252
(Dadina et al. 2010)



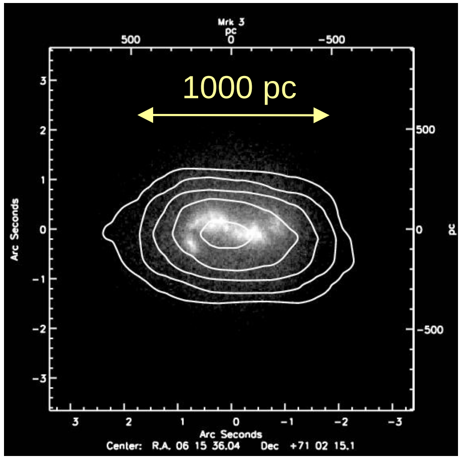
NGC5643
(Bianchi et al. 2006)



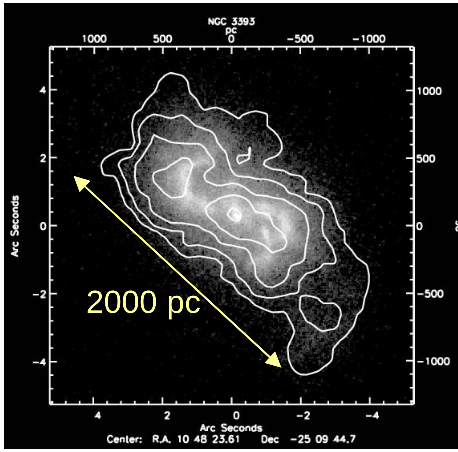
NGC1068
(Young et al. 2001)



NGC5347
(Bianchi et al. 2006)

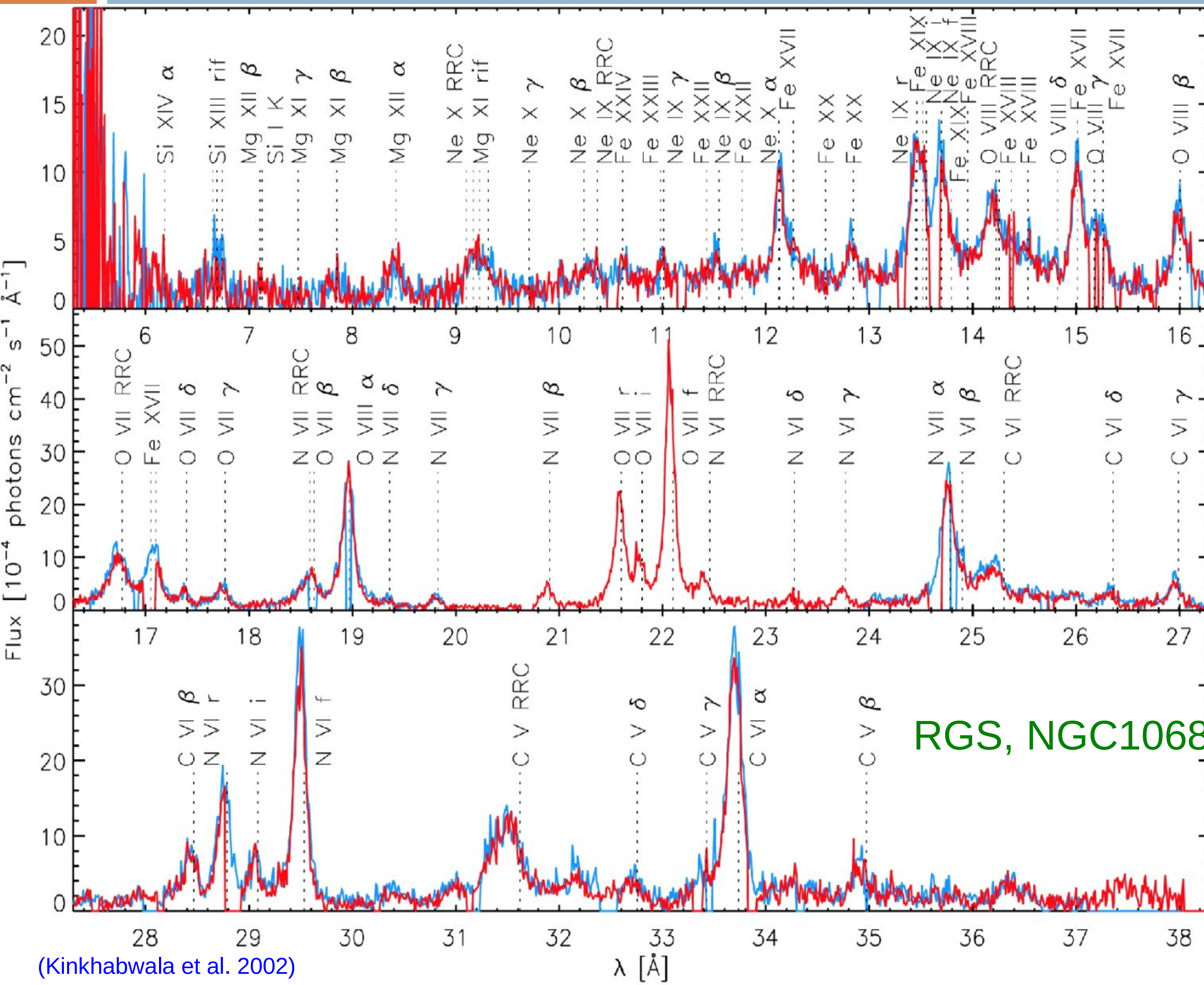


Mkn3
(Sako et al. 2000)



NGC3393
(Bianchi et al. 2006)

Photoionised emitters in obscured AGN



(Kinkhabwala et al. 2002)

Important diagnostics:

1) RRC

2) He-like triplets

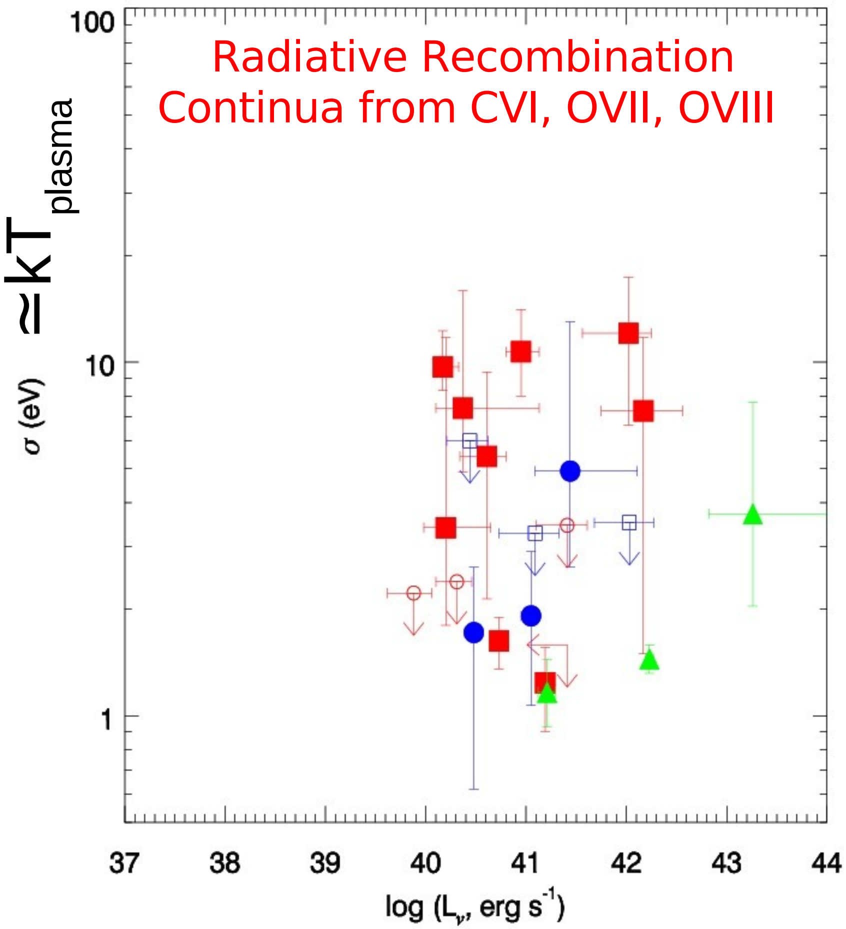
3) Higher-order lines

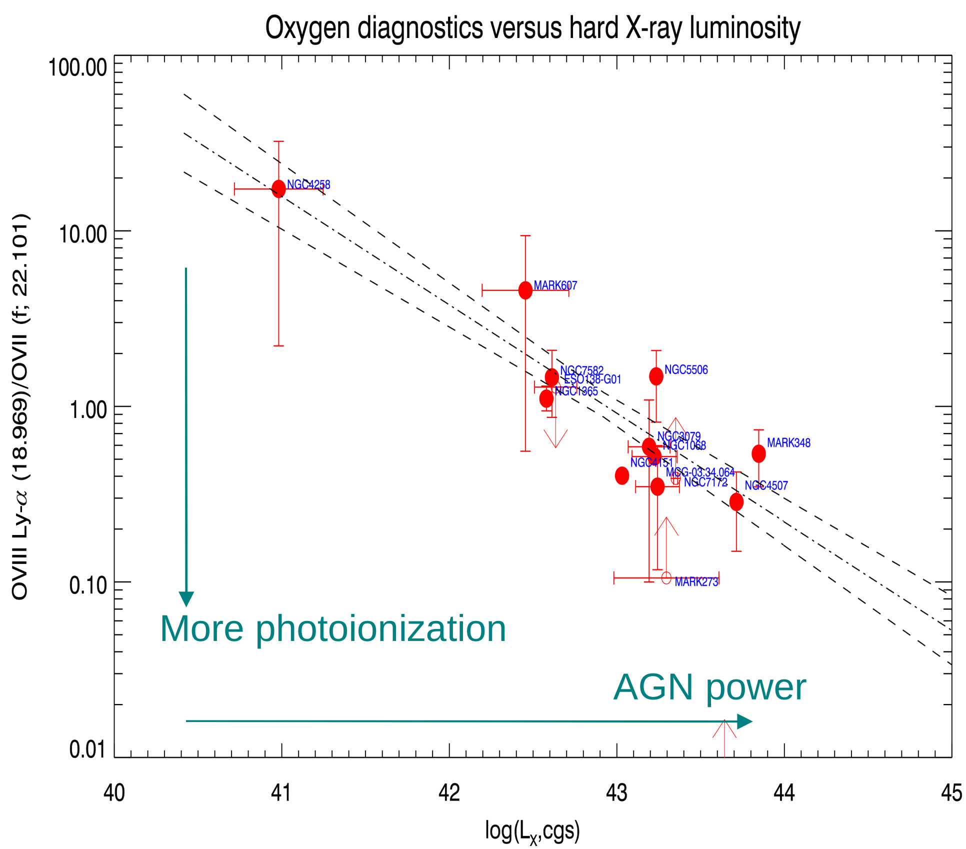
4) Continuum (N_H)

Similar spectra in:
- Mkn3 (Sako et al. 2000)
- Circinus Galaxy (Sambruna et al. 2001)
- NGC4151 (Armentrout et al. 2007)
- Mkn573 (Bianchi et al. 2010)
- NGC5252 (Dadina et al. 2010)
- NGC424 (Marinucci et al. 2011)
- and many others ... (Guainazzi & Bianchi 2007)

The X-ray NLRs are photoionised …

CIELO-AGN: *Catalogue Ionized Emission Lines in Obscured AGN* (92 Seyferts observed by the RGS)





(Guainazzi & Bianchi 2007)

(Guainazzi et al., eternally in prep)

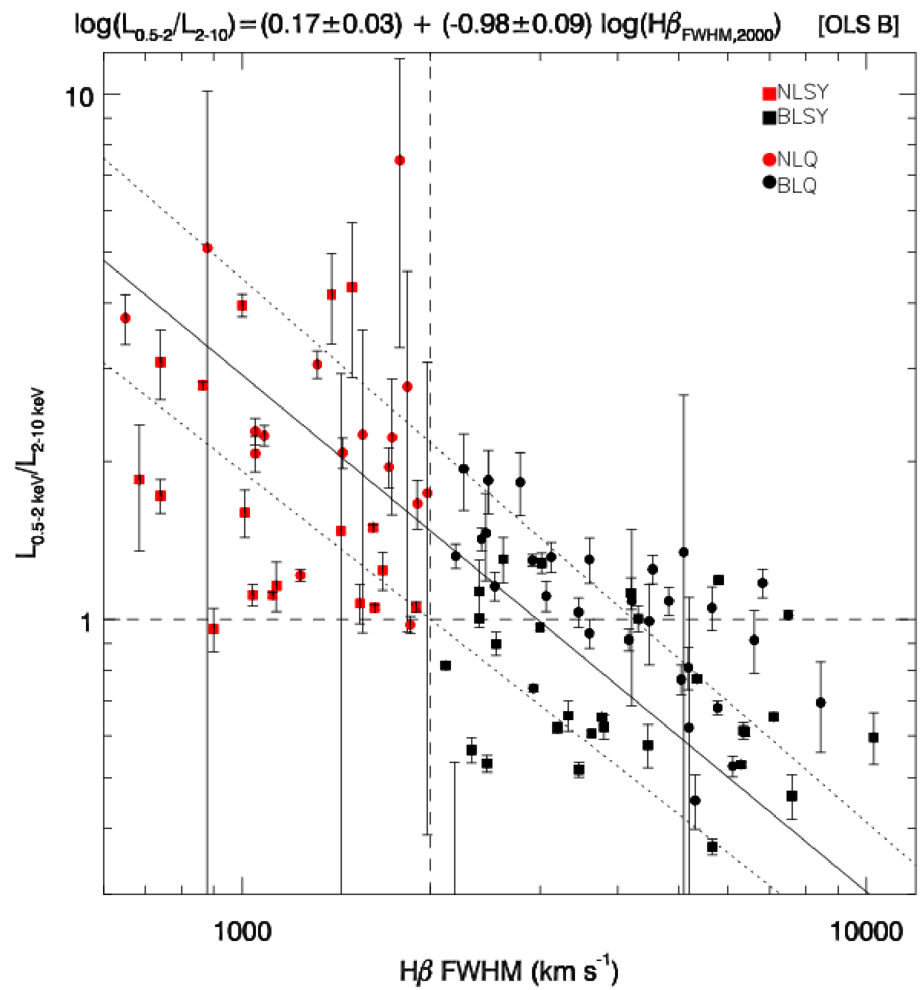
Conclusions

- To which extent do AGN share the same machine?
  - Exceptions to the orientation-dependent scenario at the 3-4%
- To which extent are AGN relativistic machines?
  - A interpretative scenario exists, which is consistent with the bulk of activity in AGN occurring within 10s of gravitational radii from the BH, and shaped by General Relativity effects
- To which extend do AGN effect the environment
  - Direct evidence of AGN driving the ionization on scales as large as several kpc. Even moderately relativistic outflows in powerful QSOs may have an impact on the evolution of the host galaxy and surrounding IGM
- To understand the astrophysics, we need the global view provided by large samples of good quality spectroscopic measurements

ADDITIONAL MATERIAL

Soft excess strenght

- $\alpha_{X,soft} \propto \alpha_{X,hard}$ (Porquet et al. 2004, Brocksopp et al. 2006, Scott et al. 2011)
- The X-ray soft excess strength is correlated with the FWHM(H_β) (Laor et al. 1994, Boller et al. 1997; ➔)
- α_{ox} is:
  - correlated with L_{UV}, L_{bol}/L_{edd}
  - anticorrelated with α_{UV}
  - uncorrelated with α_X and FWHM(H_β) (Puchnarewicz et al. 1996, Grupe et al. 2010)



(Bianchi et al. 2009, CAIXA)

X-ray variability

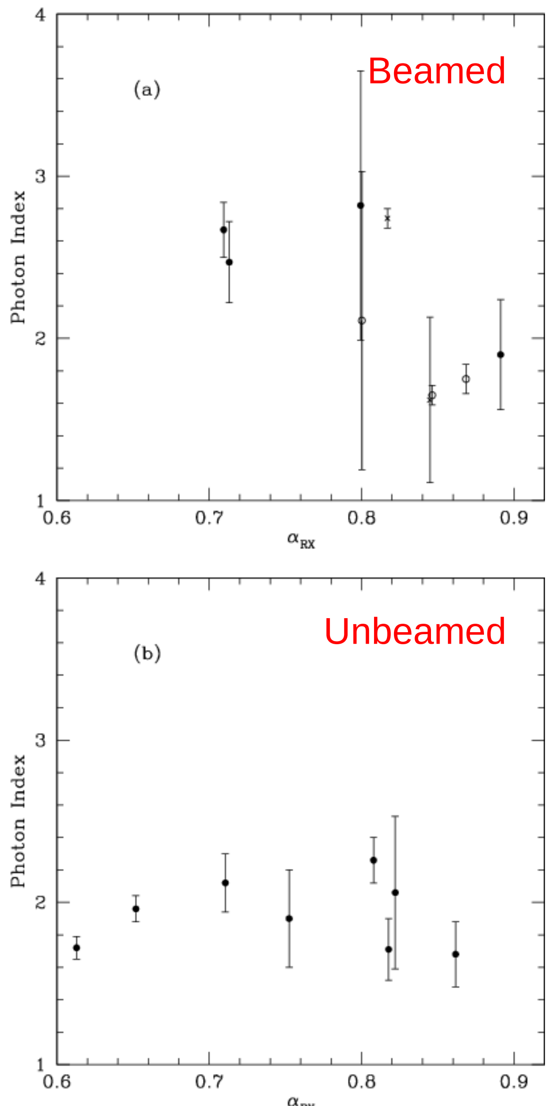
- Months-timescale variability (3σ level) in 123 AGN observed in the Lockman Hole (Mateos et al. 2007): type 1, 68±11%, type 2: 48±15%

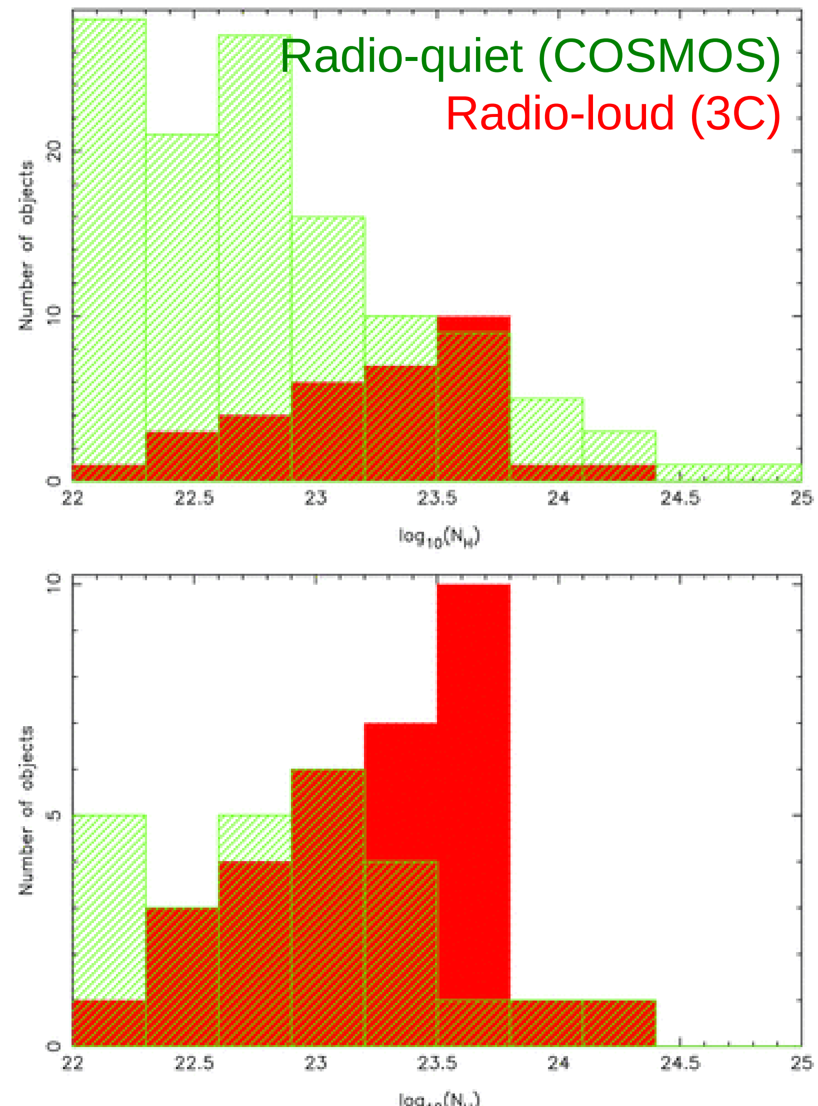
- Hour-day timescale variability amplitude is class-independent but anti-correlated with luminosity/black hole mass/accretion rate (Leighly 1999).

- Fig. from Slew Survey presentation

Radio-loud versus radio-quiet

(Galbiati et al. 2005)





(Hardcastle et al. 2010)

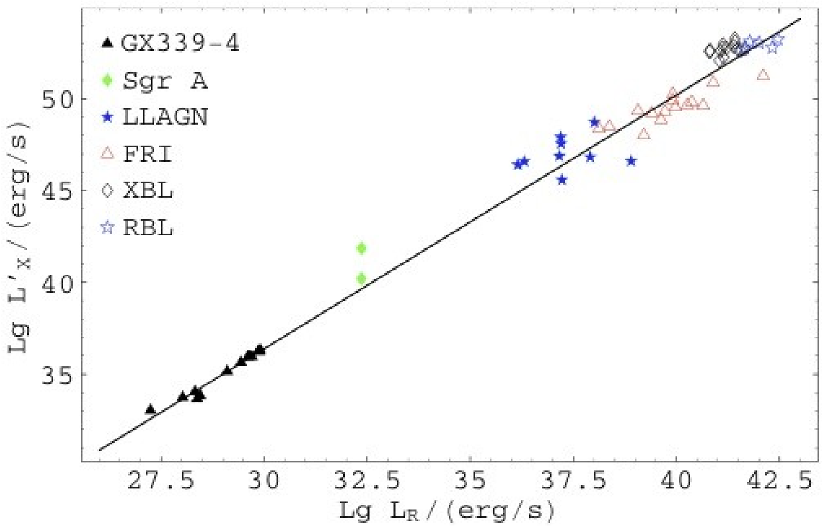
Synopsis of local AGN properties

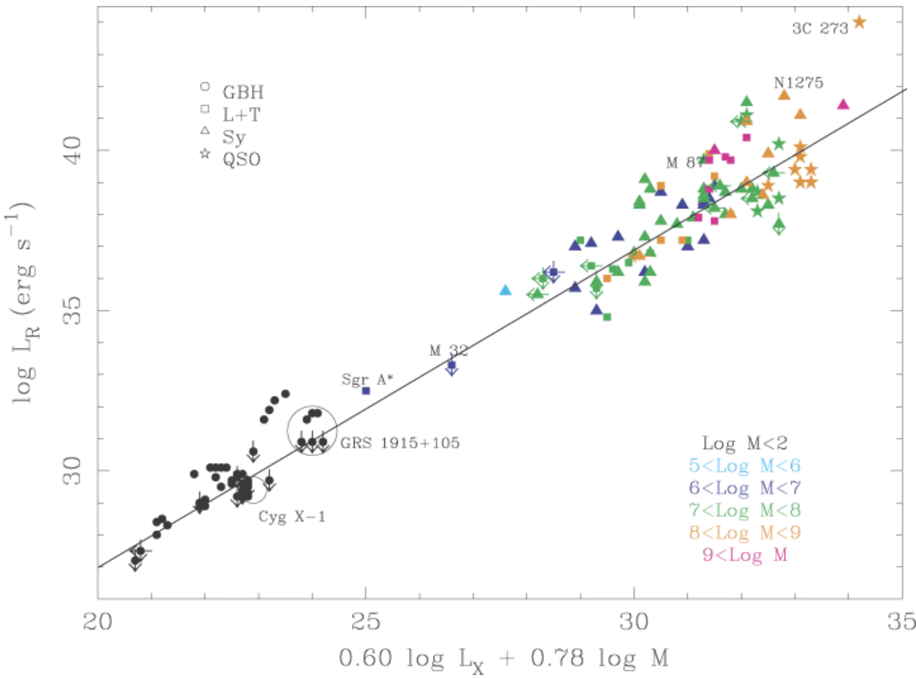
- Hard X-ray samples are optimally unbiased against environment
  - Swift/BAT (≥600 AGN; Tueller et al. 2008, 2010, Aiello et al. 2008, Winter et al. 2009, Cusumano et al. 2010, Burlon et al. 2011, Baumgartner et al. 2011; poster by La Parola)
  - INTEGRAL ISGRI/IBIS (≅260 AGN; Beckmann et al. 2009, Bird et al. 2010, Ricci et al. 2011)
- Fraction of obscured AGN 45-55% (cf. also Sazonov et al. 2007)+20% C-Thick
- $<L/L_{edd}> \cong 0.01$-0.06 (cf. also Middleton et al. 2008; Vasudevan et al. 2010)
- Hosted primarily in spiral galaxies (Winter et al. 2010)
- Larger fraction of merging systems with respect to optically-selected AGN (≅30%, Koss et al. 2010)
- Hosted in Dark Matter Halo with 12.5≤log(M)≤13.5 (≅12.5 for optically selected; Cappelluti et al. 2010)
- Duty-cycle≅0.2-1.2 Gyrs (Cappelluti et al. 2010)

Fundamental planes of BH activity

Jet-dominated X-ray emission

Accretion-dominated X-ray emission

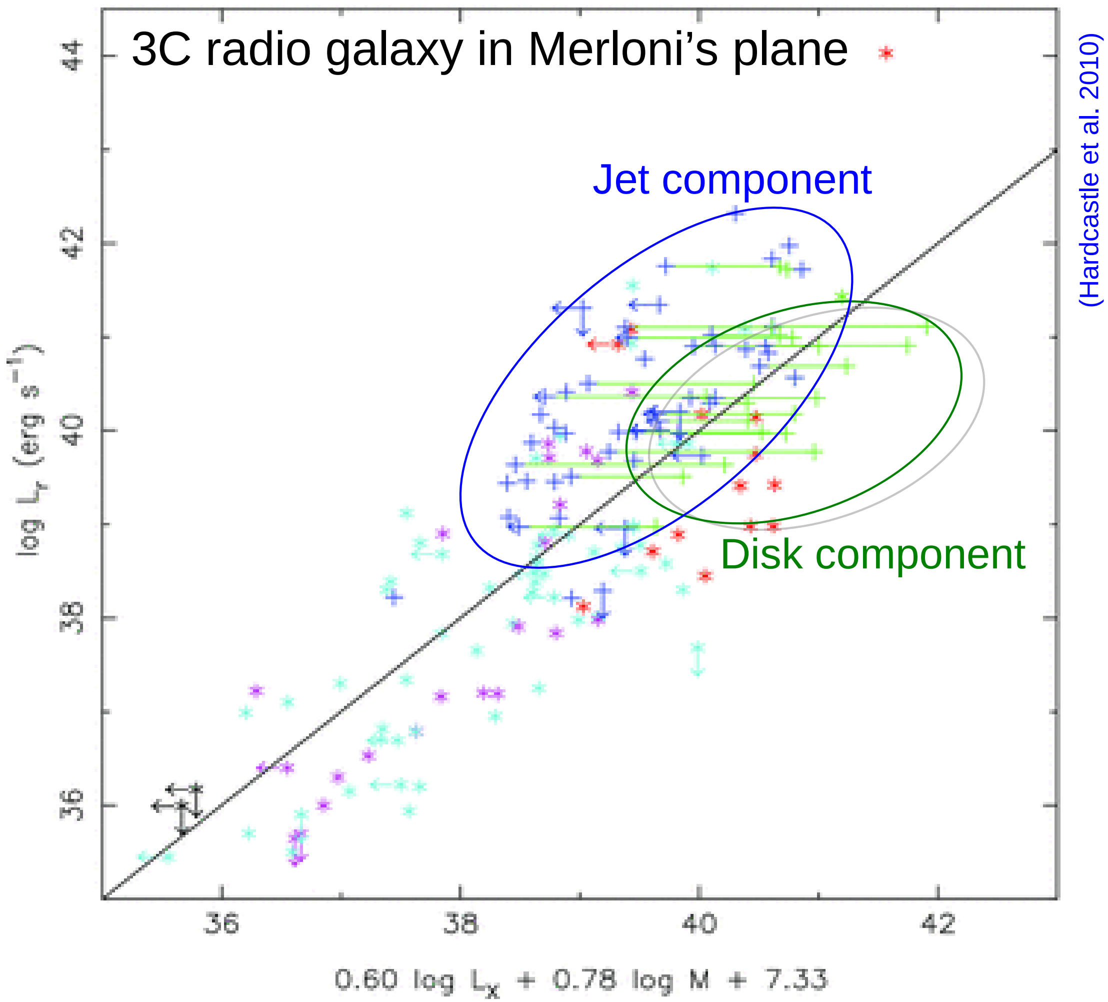




(Falcke et al. 2003; see also Körding et al. 2006)

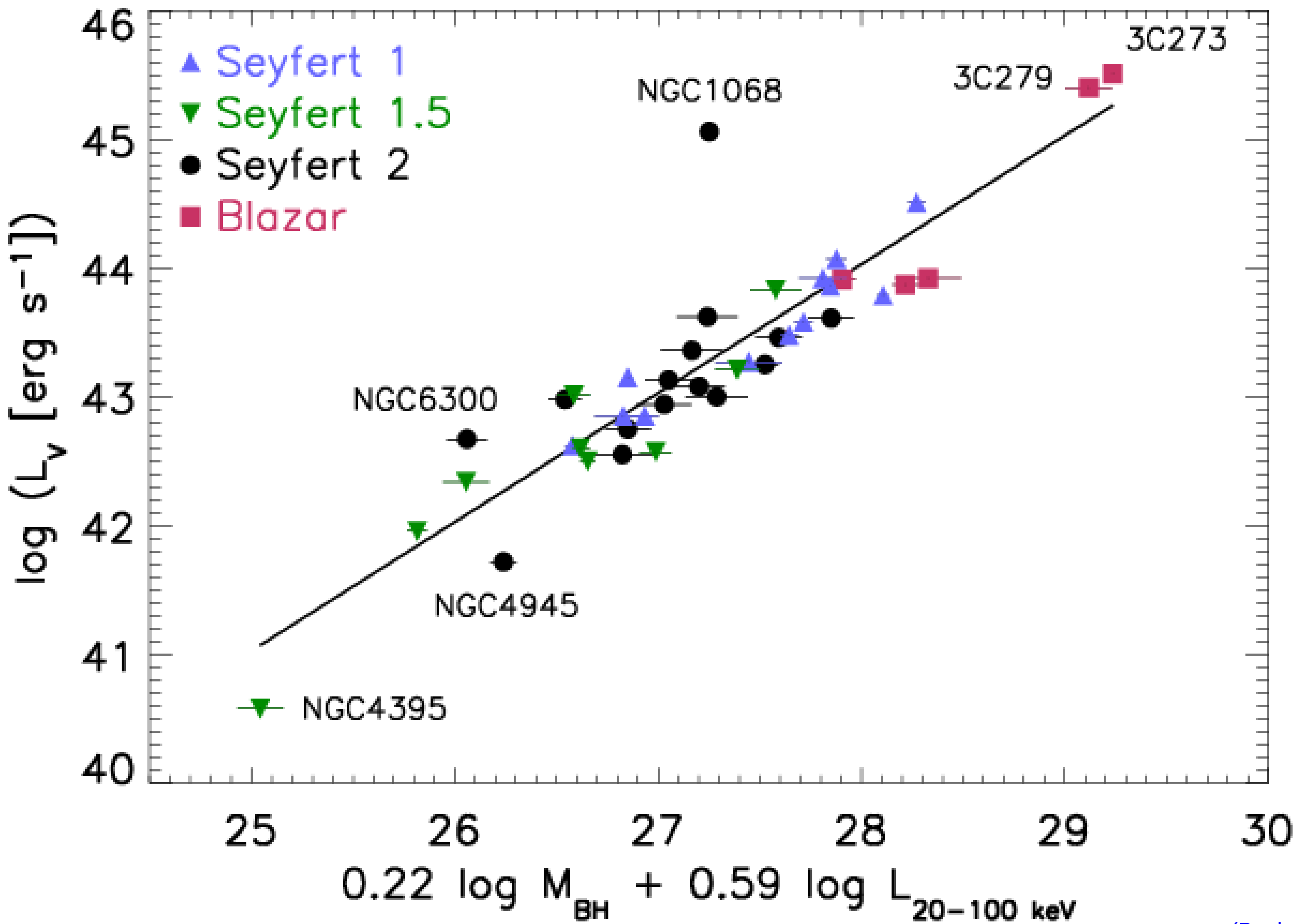
(Merloni et al. 2004)

Where are radio-galaxies?



Whereas, the is a poor agreement between the jet component and Falcke’s plane

A fundamental plane of optical activity

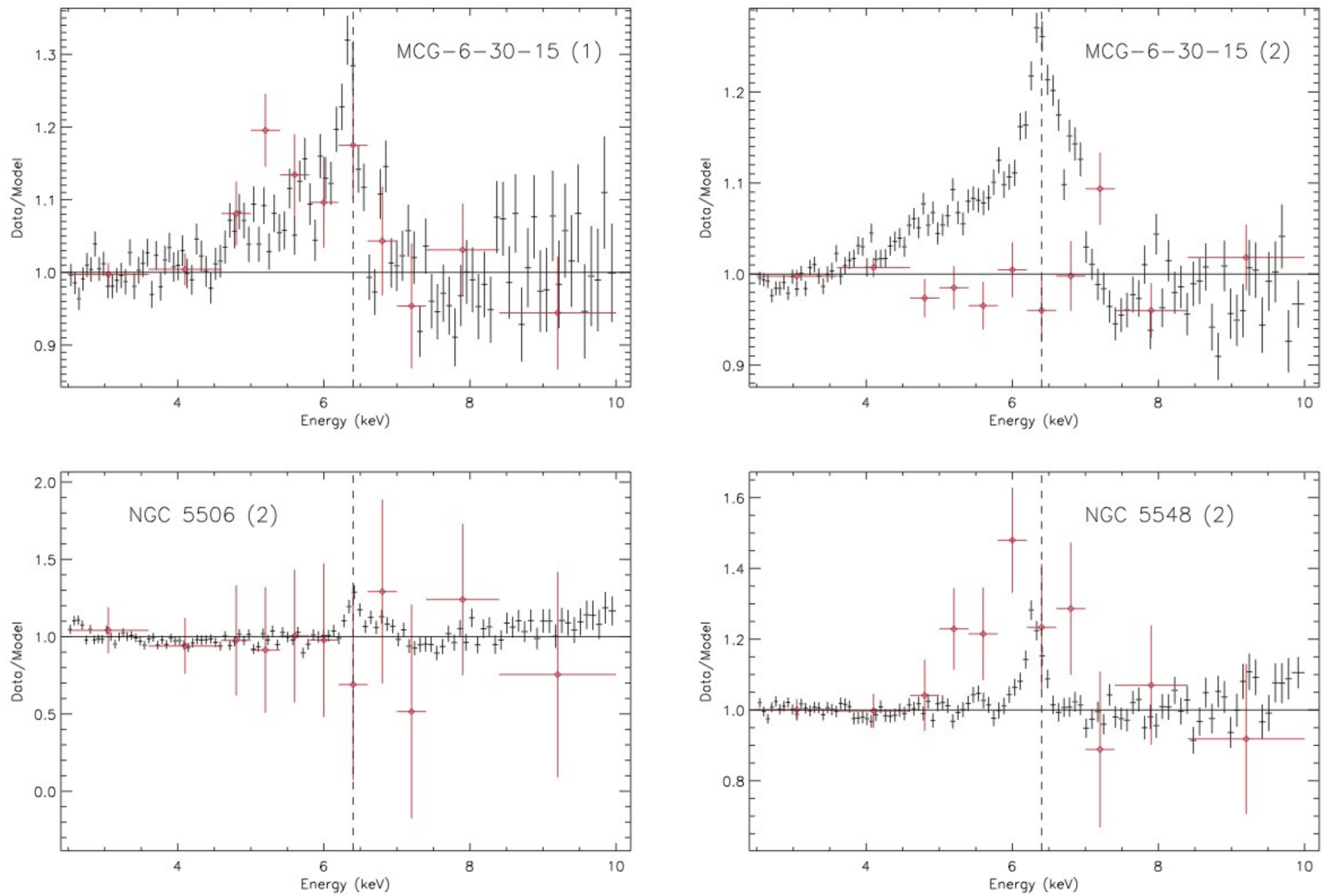


(Beckmann et al. 2009)

Fe-K variability

- Purely spectral interpretation is controversial (Turner & Miller 2009)
- 30% of FERO sources are variable at ≥3σ (De Marco et al. 2009). <t>≅15.5 ks ➔ <r>≅8.5r_g if due to orbital motions
- Does variability help to solve the controversy? Little:

Energy versus r.m.s. spectra: very different patterns!



(Bhayani & Nandra 2009)

Caveats

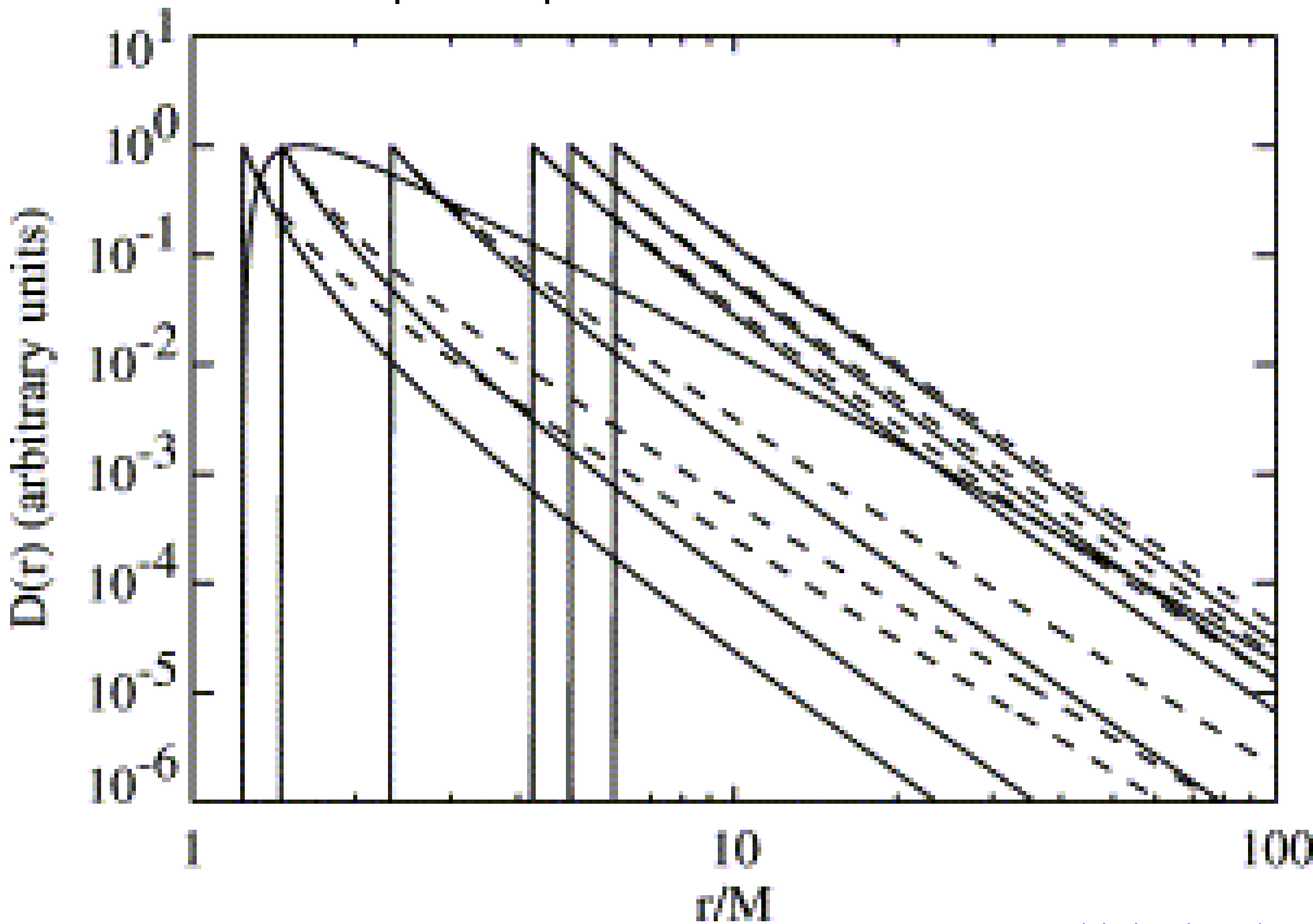
This talk is:

- Conformist
  - It primarily deals with mainstream *radio-quiet* AGN
- Short-sighted
  - This is *not* a talk on the cosmological history of AGN. It mainly deals with local ($z \leq 0.1$) objects
- Democratic
  - Each object is *one point* in a plot/histogram, notwithstanding how bright, famous or archetypical it is (or claimed to be)

Why do X-rays come from very close to the BH?

- X-ray variability on time scales ≥hours (Barr & Mushotzky 1986 ...)
- Direct measurement of the X-ray size through: occultation: $\leq 10^{14}$ cm (Risaliti et al. 2007, 2009) or microlensing: $\leq 6r_g$ (Chartas et al. 2007)
- Theoretical prejudice on the accretion flow

Accretion disk dissipation profiles as a function of disk radius



(Algol et al. 2000)

On constraining the geometry of optically thick matter

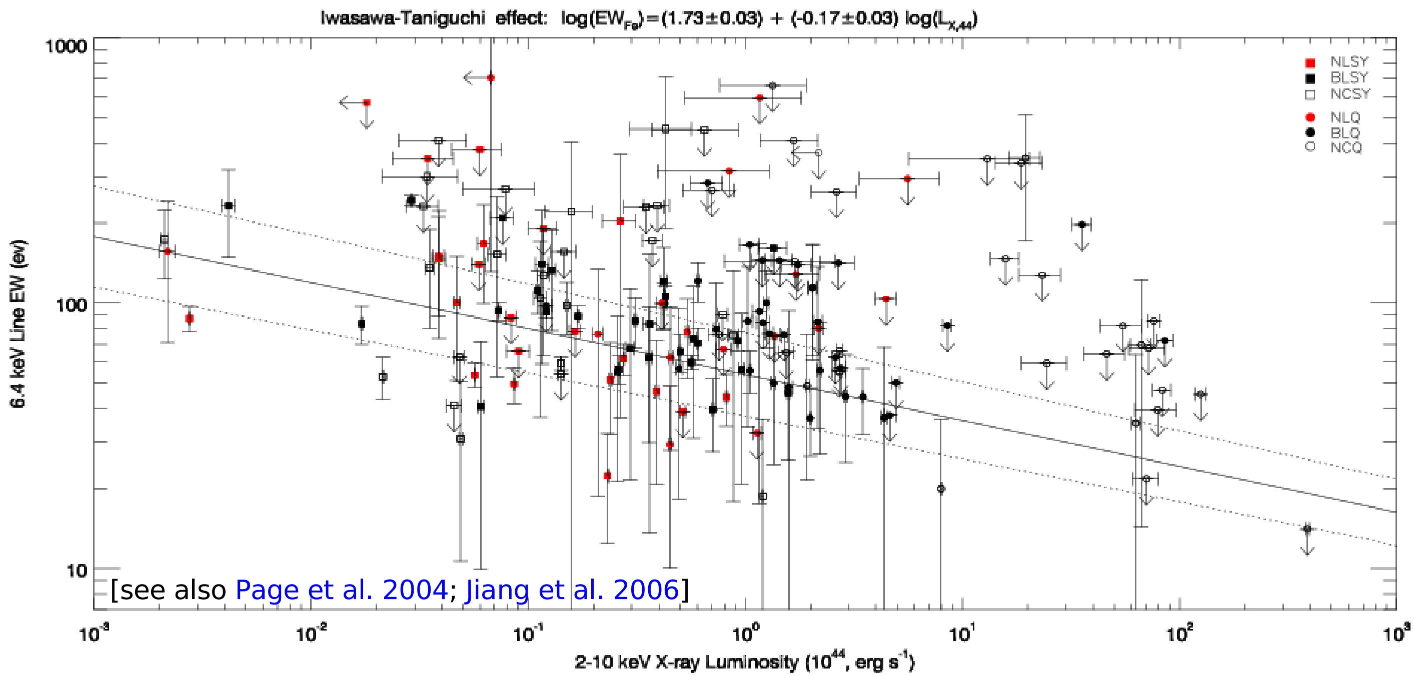
- “Iwasawa-Taniguchi effect”. Explanation: *either*

  a) the covering fraction as driven by MHD disk winds (Konigl & Kartle 1994), *or*

  b) the probability of intercepting a LOS optically-thick clump in a radiation-limited torus (Simpson 2005; Nenkova et al. 2008)

  decrease with AGN luminosity

CAIXA (*Catalogue of AGN In the XMM-Newton Archive;* *Bianchi et al. 2007*)*:* 156 AGN



Consistent with decrease in the fraction of obscured AGN with X-ray (La Franca et al. 2005, Sazonov & Revnivtsev 2004, Ballantyne at al. 2006, Triester & Urry 2006, Sazonv et al. 2007, Della Ceca et al. 2008, Tueller et al. 2008, Beckmann et al. 2009, Winter et al. 2009, Brusa et al. 2010) and other-λ (Maiolino et al. 2007) luminosities

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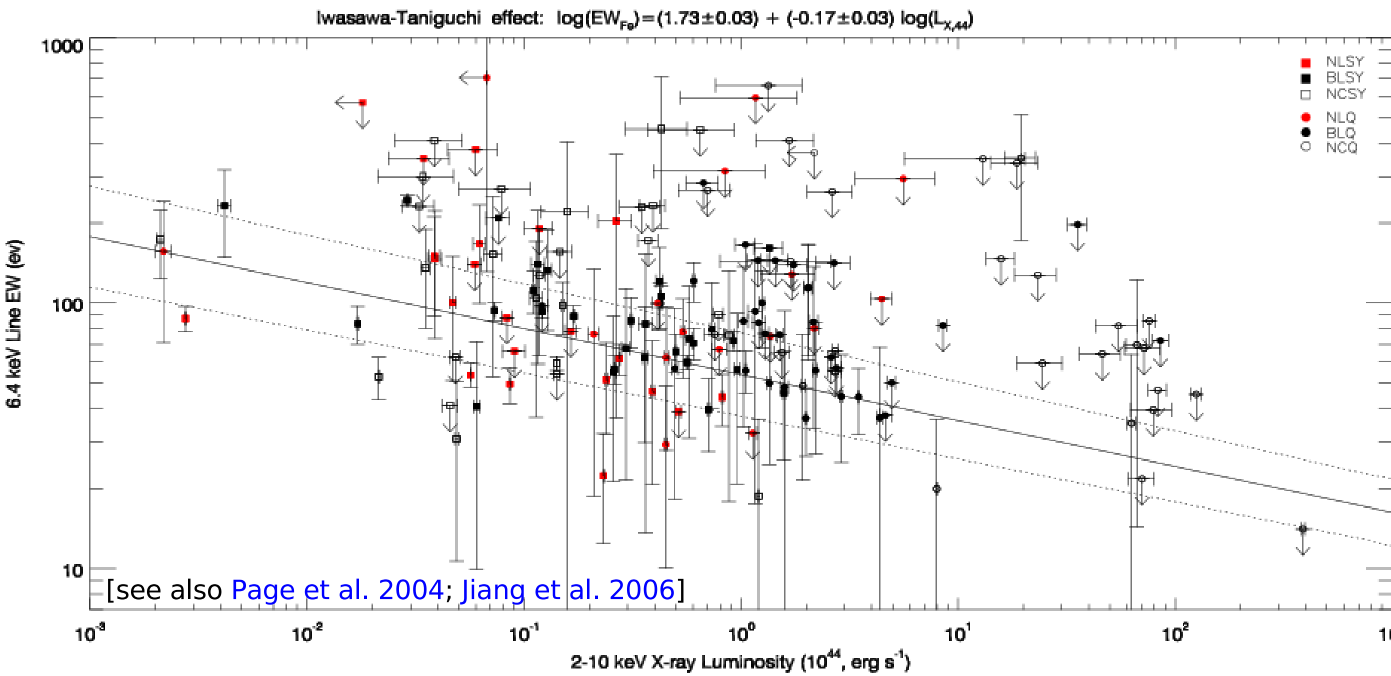

[see also Page et al. 2004; Jiang et al. 2006]

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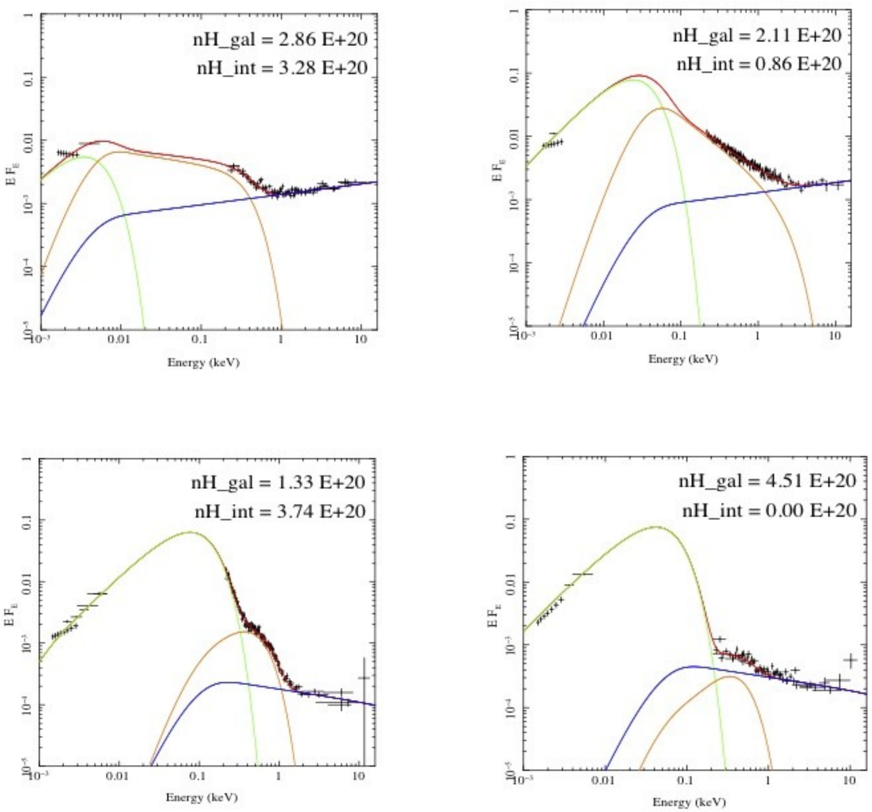
Disk+corona SED fits

(Jin et al. 2011)



- Multiwavelength AGN can be quantitatively explained by a disk-corona scenario, with three components:
  - Optically-thin, high-temperature disk Comptonization corona
  - Optically-thick, low temperature disk Comptonization
  - Multi-temperature disc emission