General Relativity studies through X-ray spectroscopy of Fe (and others) K_α fluorescent lines

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Outline

Relativistically broadened Fe K_α iron fluorescent lines:

- What are they?
- What do they tell us about supermassive black holes?
- What do they tell us about the accretion flow?
- What do they tell us about the origin of high-energy emission in Active Galactic Nuclei (AGN)?

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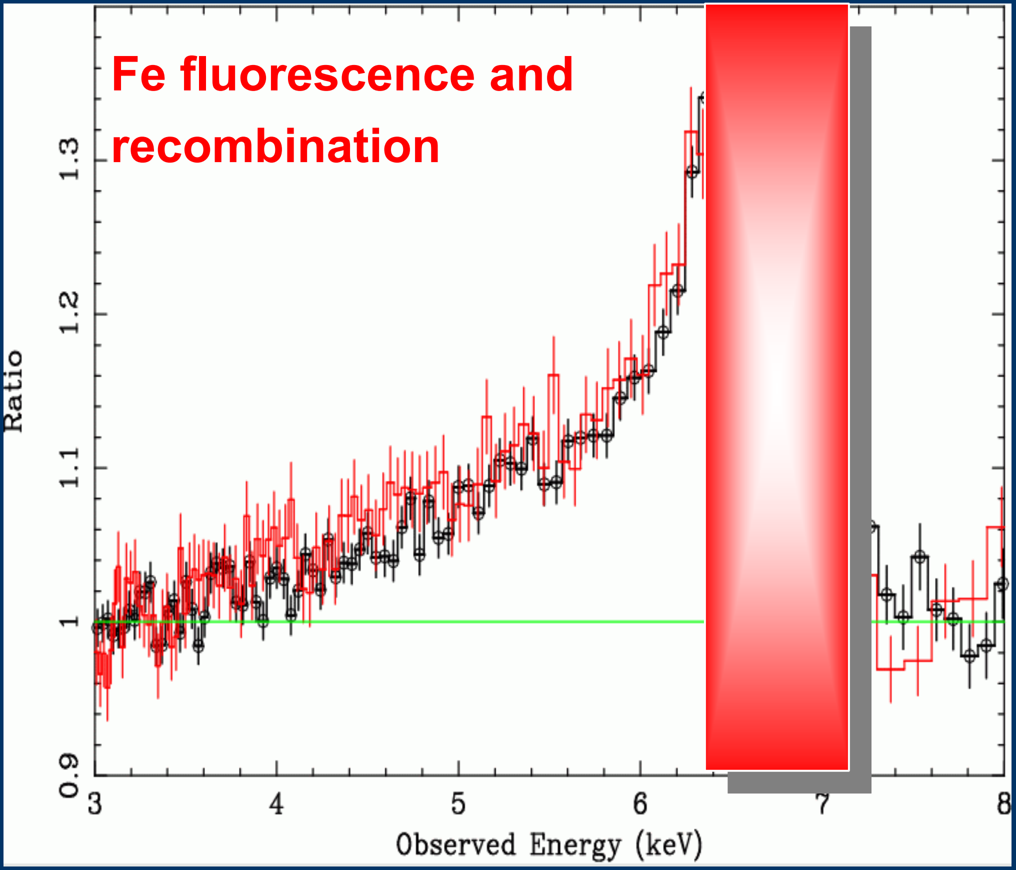
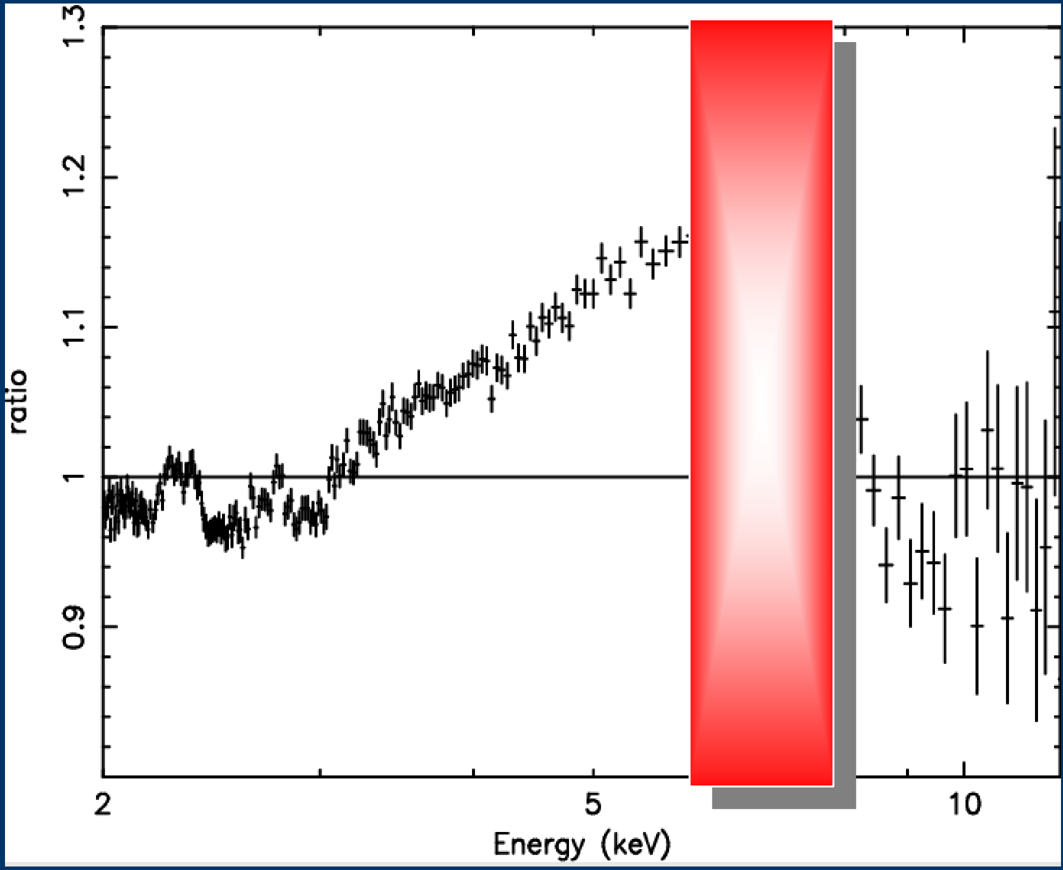
Phenomenological evidence

MCG-6-30-15: Seyfert 1



(Miniutti et al. 2007)

GX334-1: Galactic Black Hole



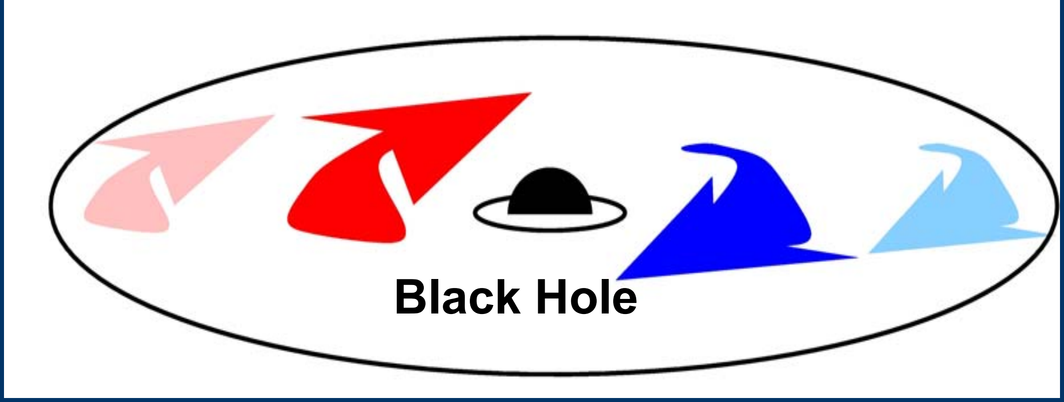
(Miiller et al. 2004)

Which is the origin of the observed broadening?

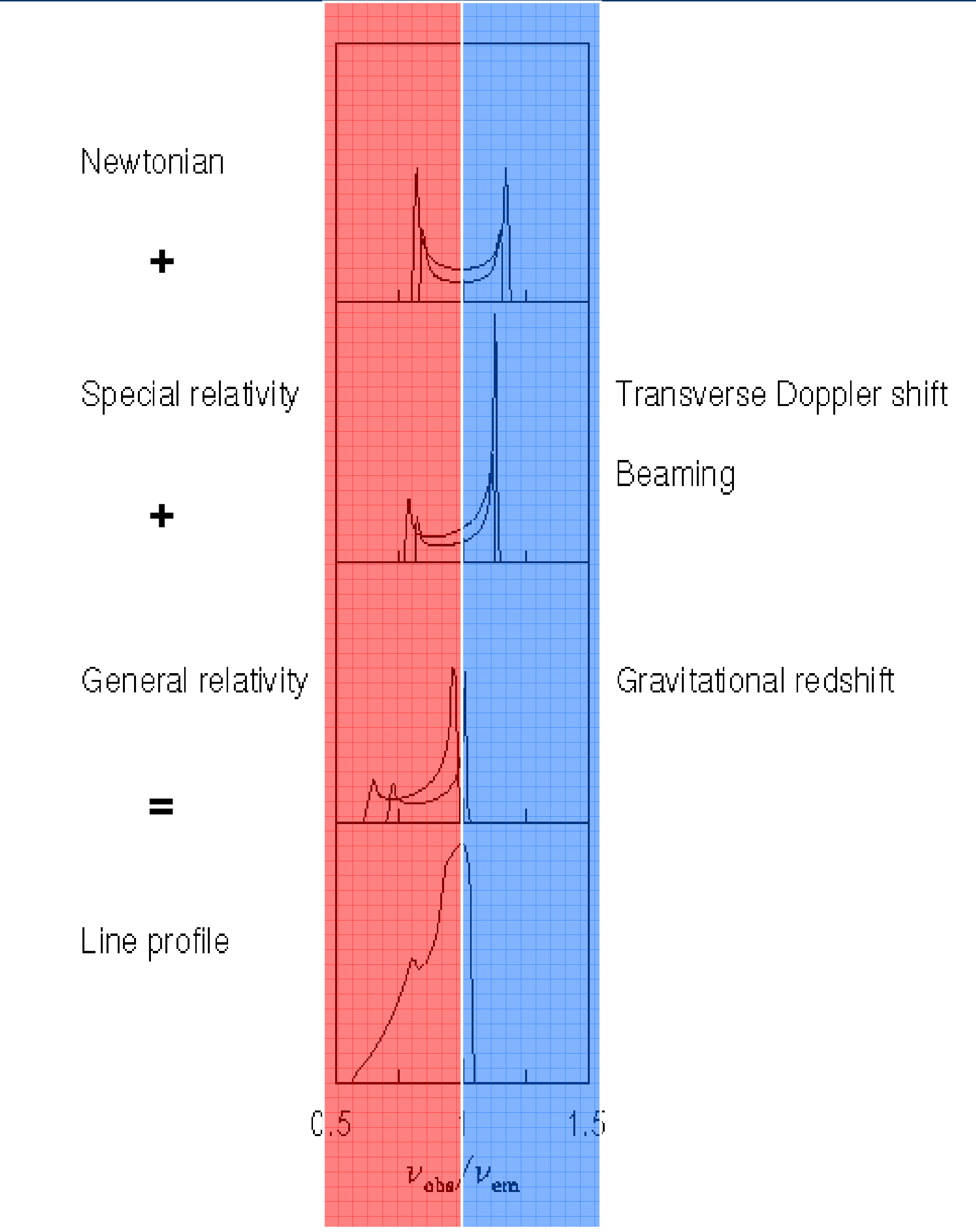
Explanation

The line is produced in an accretion disk rotating around the supermassive black hole

Receding (redshifted)



Approaching (blueshifted)

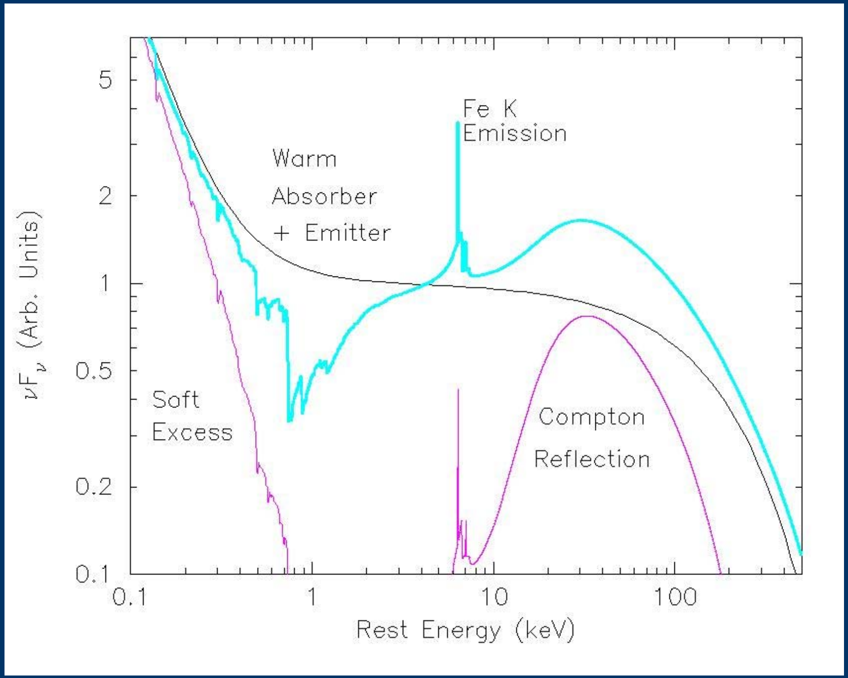


Its profile is hence affected by:

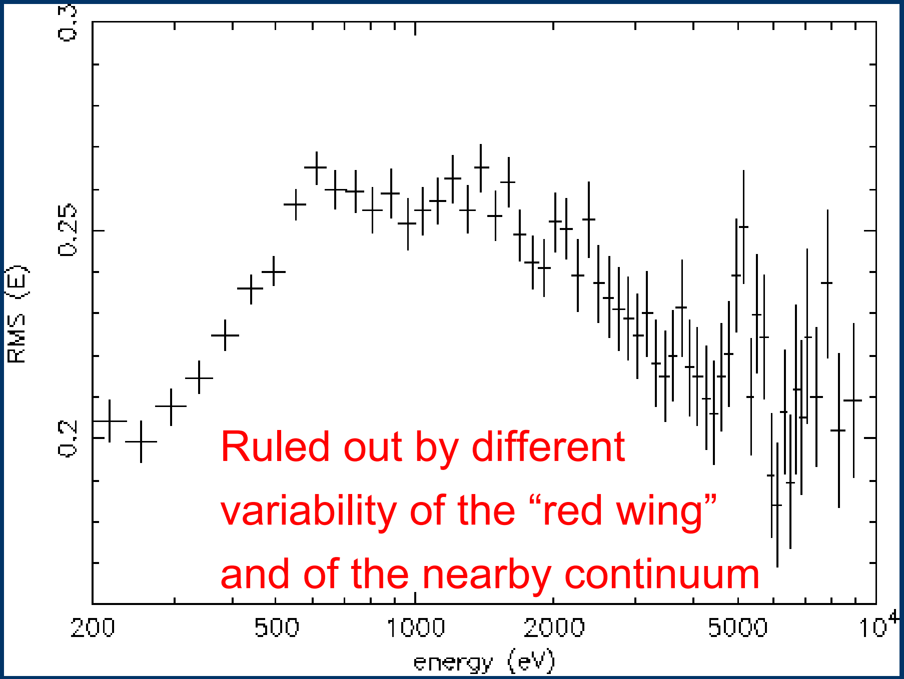
- **Doppler shifts**
- **Relativistic beaming** **(enhancing the "blue" side)**
- **Gravitational redshift**

Alternative explanations

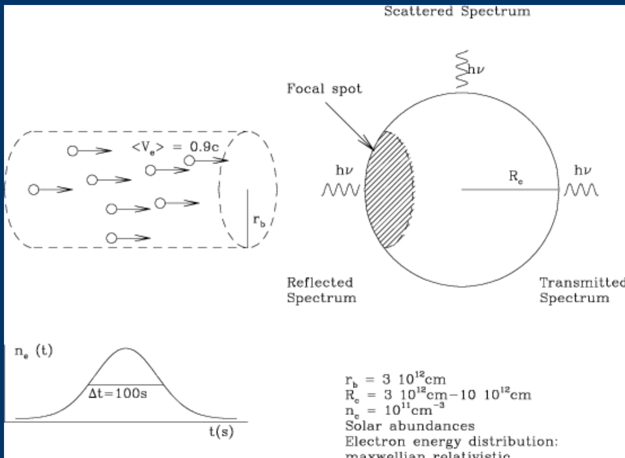
- Comptonization *(Misra & Kembhavi 1998; Misra & Sutaria 1999)*
  - Lack of high-energy spectral break and observed variability patterns are inconsistent with required Comptonization region
  - Implied seed photon blackbody region is unphysical
- Scattering by a relativistic optically-thick wind *(Laurent & Titarchuck 2007)*
  - Ruled out by observed variability timescales and lack of line/continuum correlation
  - Super-Eddington outflows ($L/L_{Edd} > 10$) are required
- “Fake” red-wing generated by absorbption by highly ionized gas:



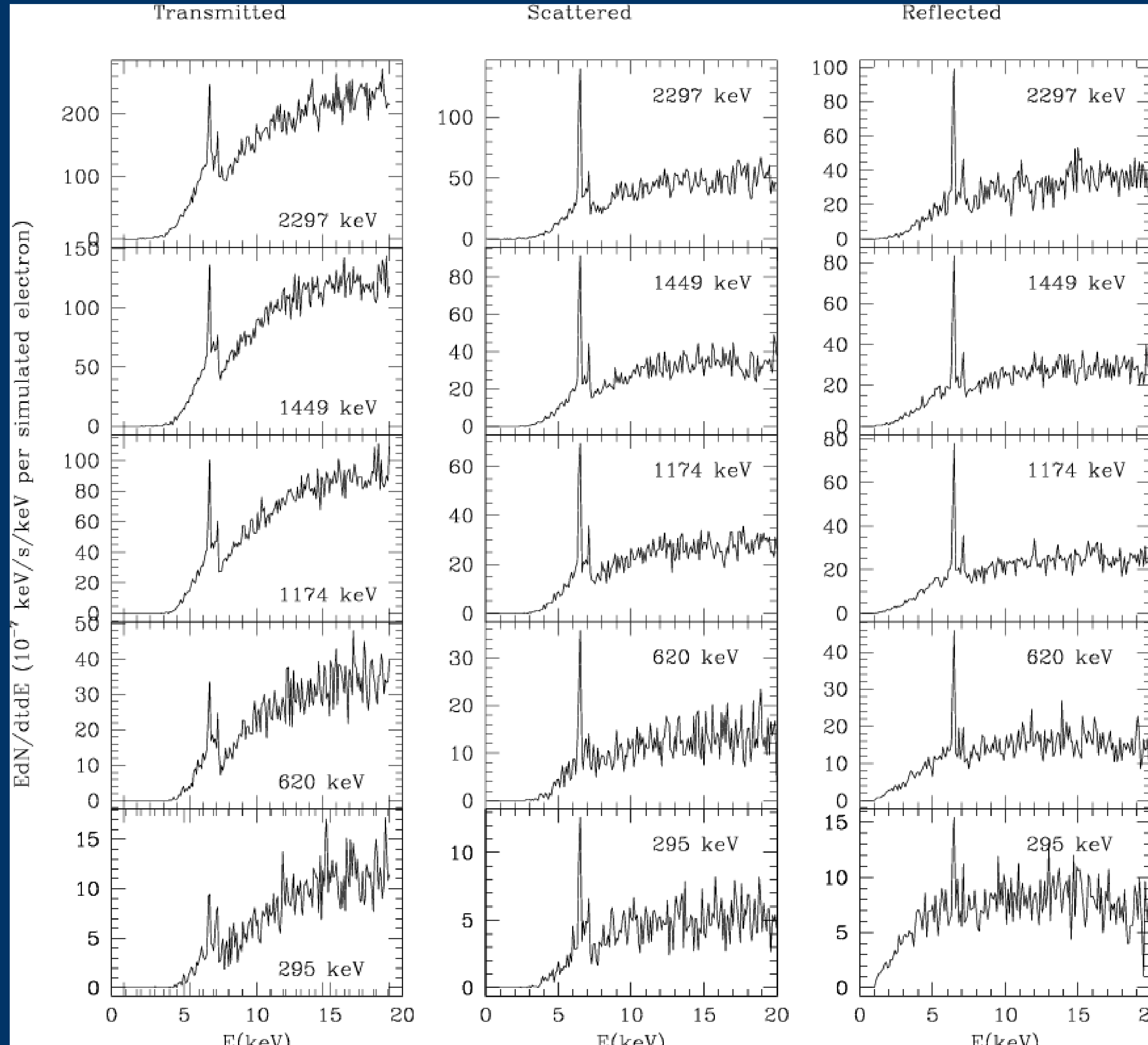
(Ponti et al. 2004)



Role of relativistic electrons



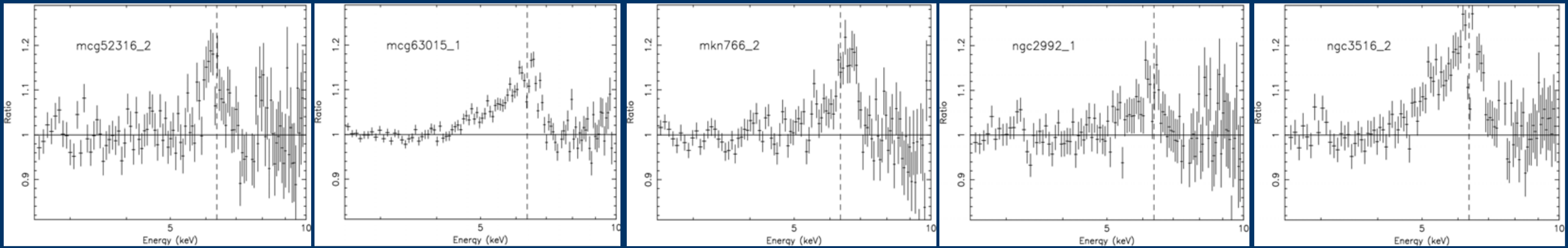
(Antonicci & de Castro 2005)



Effect of transfer of mechanical energy from relativistic electrons produced by magnetic reconnection or shocks to the circumnuclear gas (disk, BLRs)

Climate or whether?

- Fraction of **AGN** with relativistically broadened lines is still largely unknown. From XMM-Newton studies:



  - ≈73% of bright Seyfert 1s (Nandra et al. 2006)
  - 42±12% of optimally exposed AGN (50±32% in a complete sample) (Guainazzi et al. 2006)

- **Galactic BHs**? We have basically no idea

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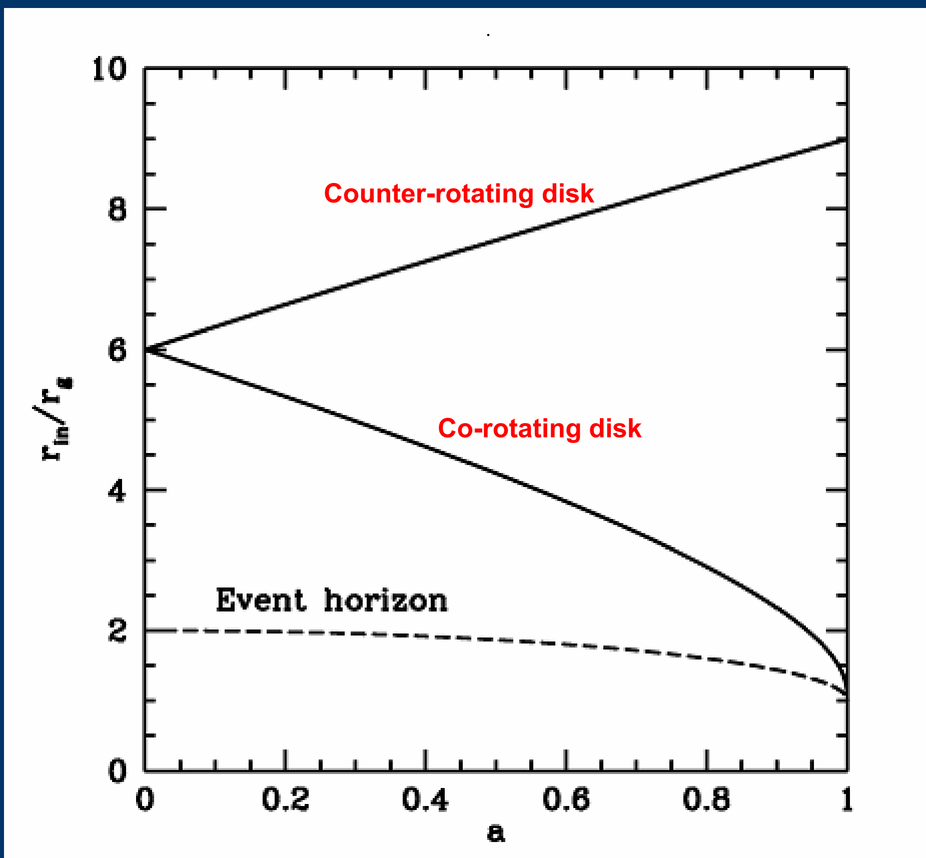
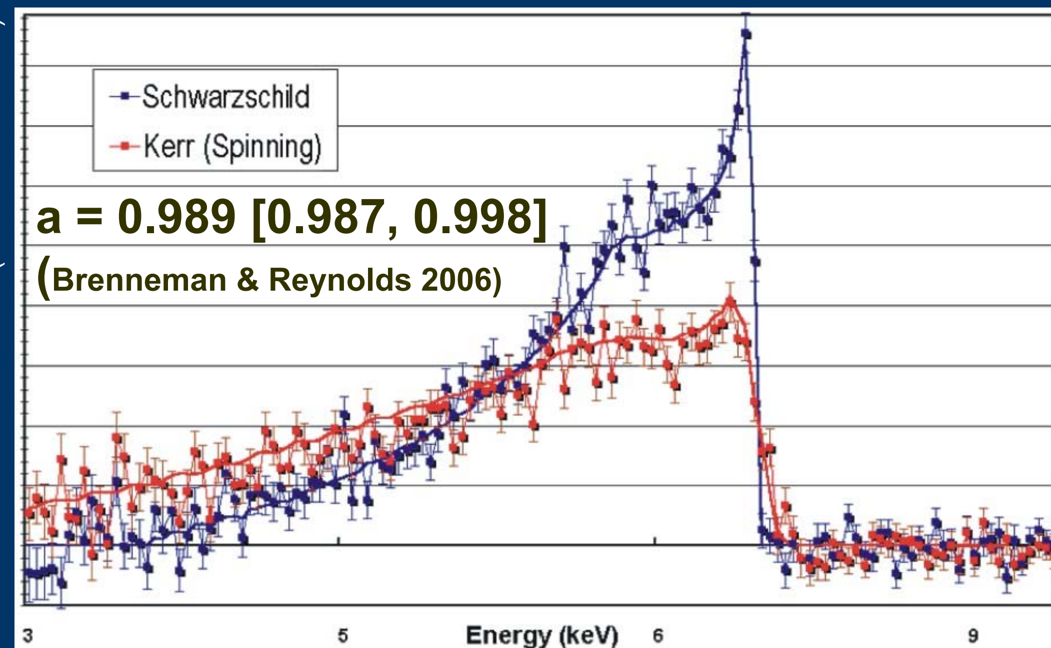
BH spin

The line profile depends on the distance of the Innermost Stable Circular Orbit (ISCO) of the accretion disk from the BH



(Iwasawa et al. 1999)



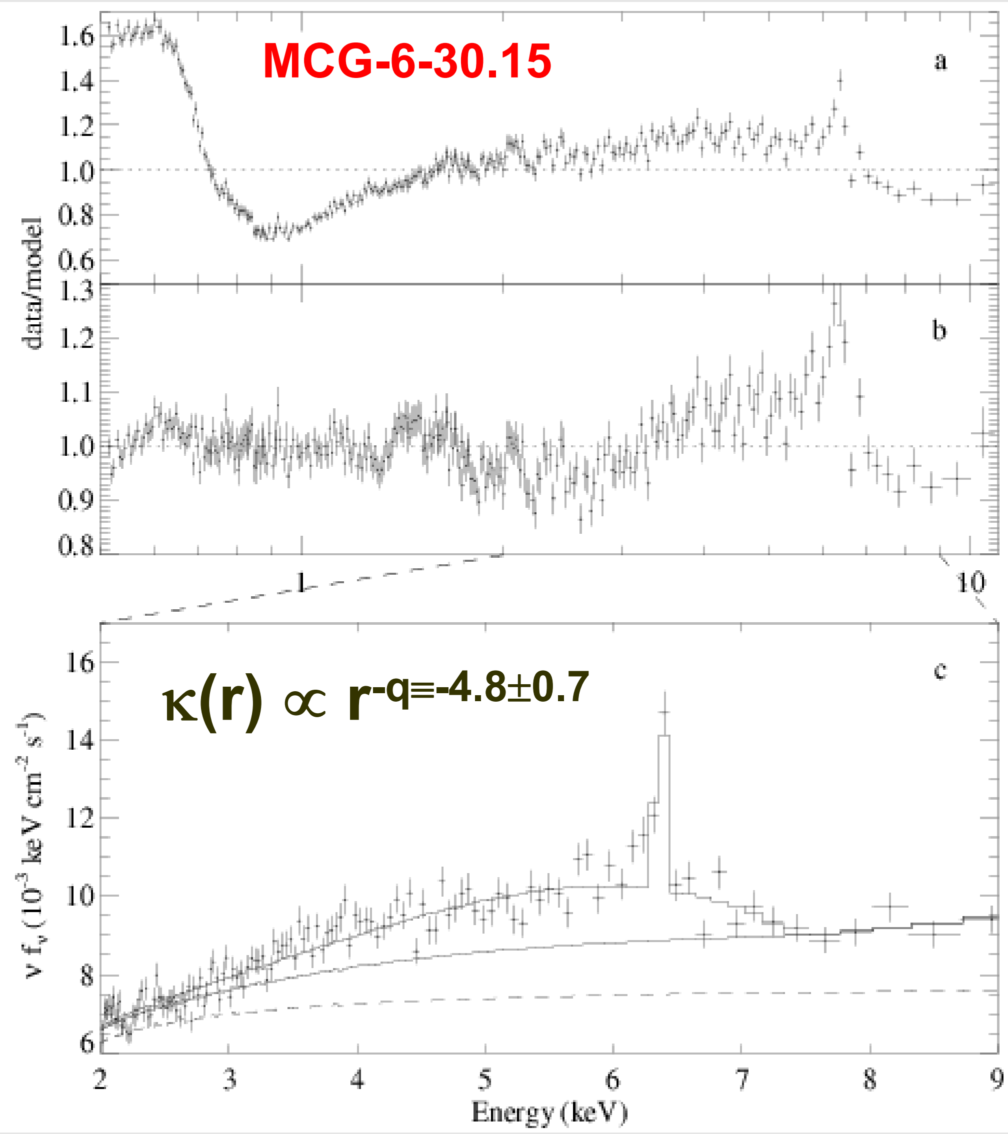
Challenging measurement!

XMM-Newton sample of 6 AGN (*Guainazzi et al. 2006*)

$<a>=0.6\ \sigma_a=0.3$

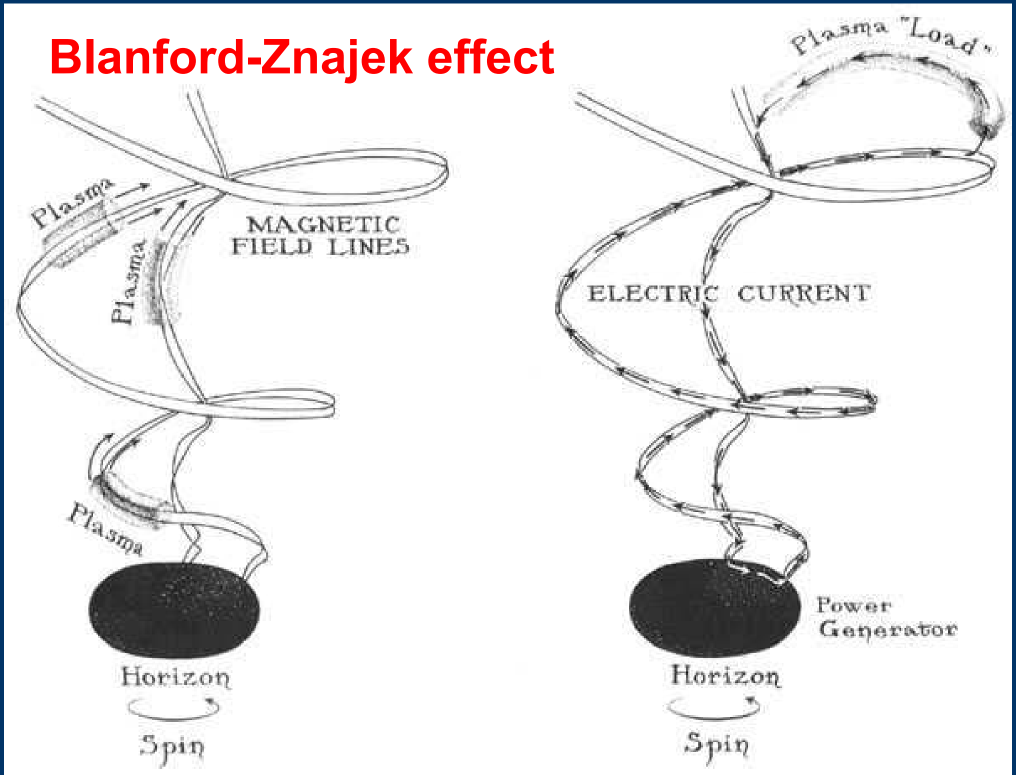
Steep radial emissivity dependence

(Wilms et al. 2001)



For a standard Sakura-Sunyaev accretion disk: $q \approx 3$

- Evidence for the B-Z effect?
- Light bending?



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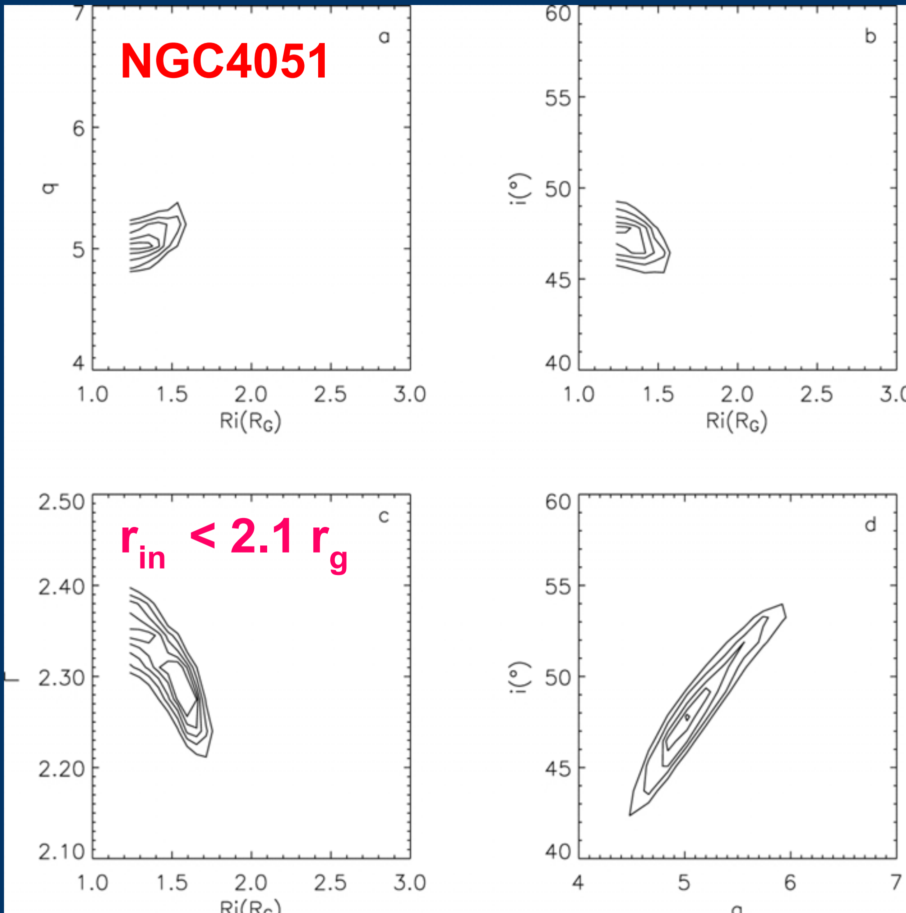
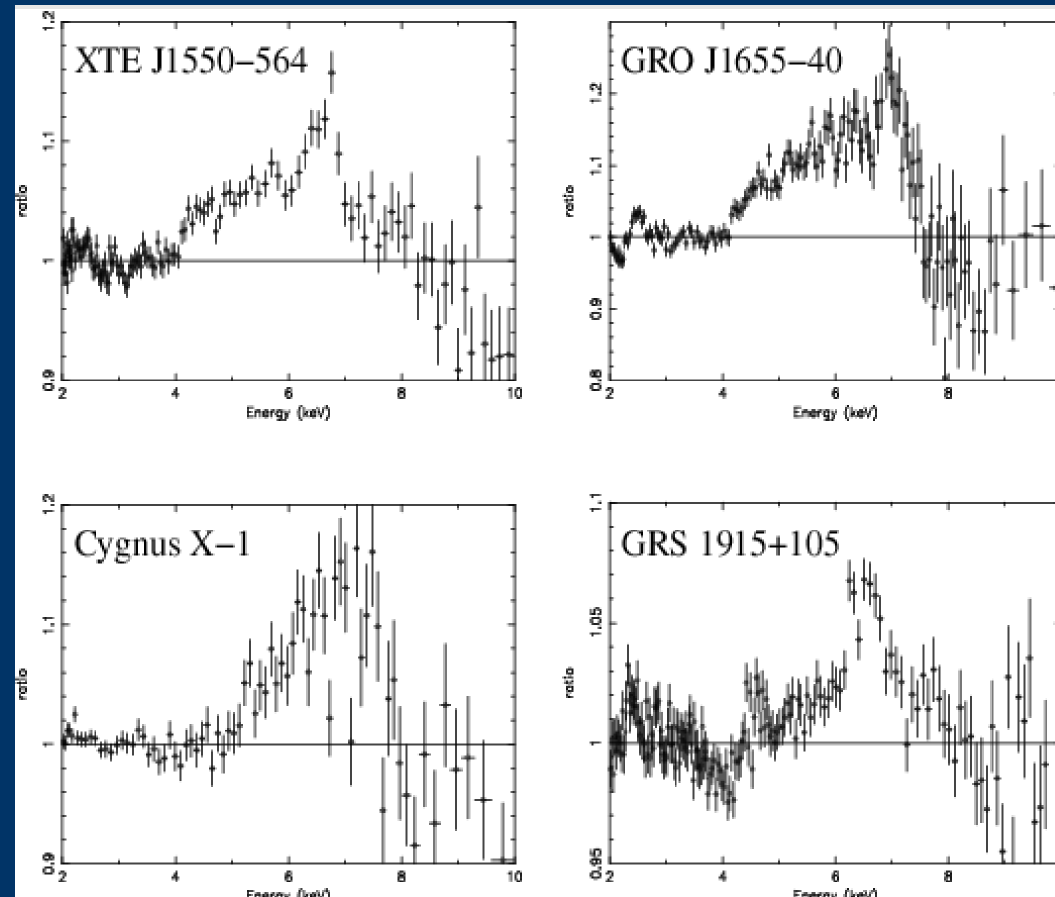
Innermost disk radius



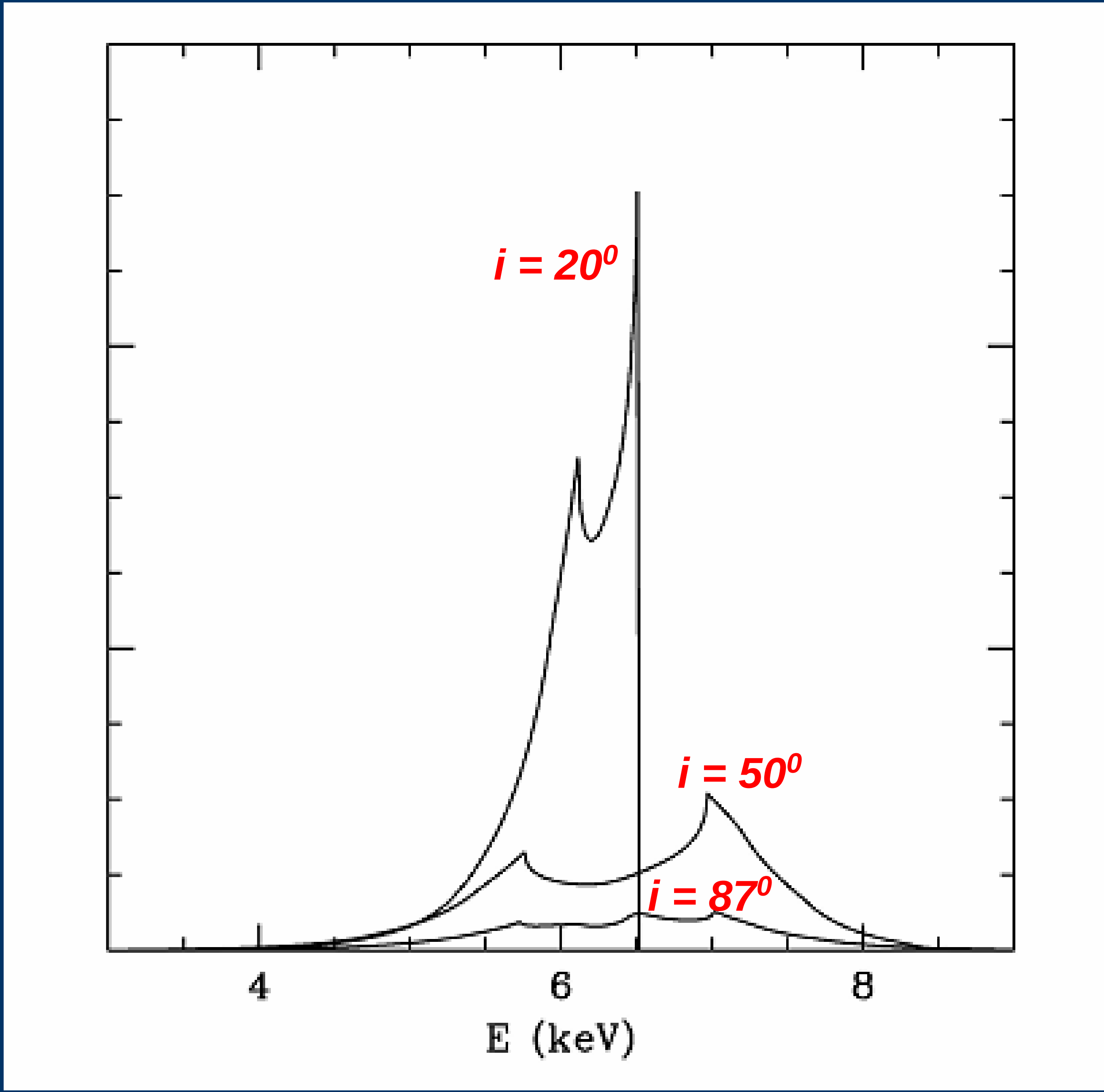
(Mason et al. 2003)



(Miller et al. 2005)

In most cases one must *assume* that the profile is due to a maximally spinning black hole. This assumption consistently yields inner disk radius in the range: 1.24-3 r_g (GBHC), 1-2 r_g (AGN)

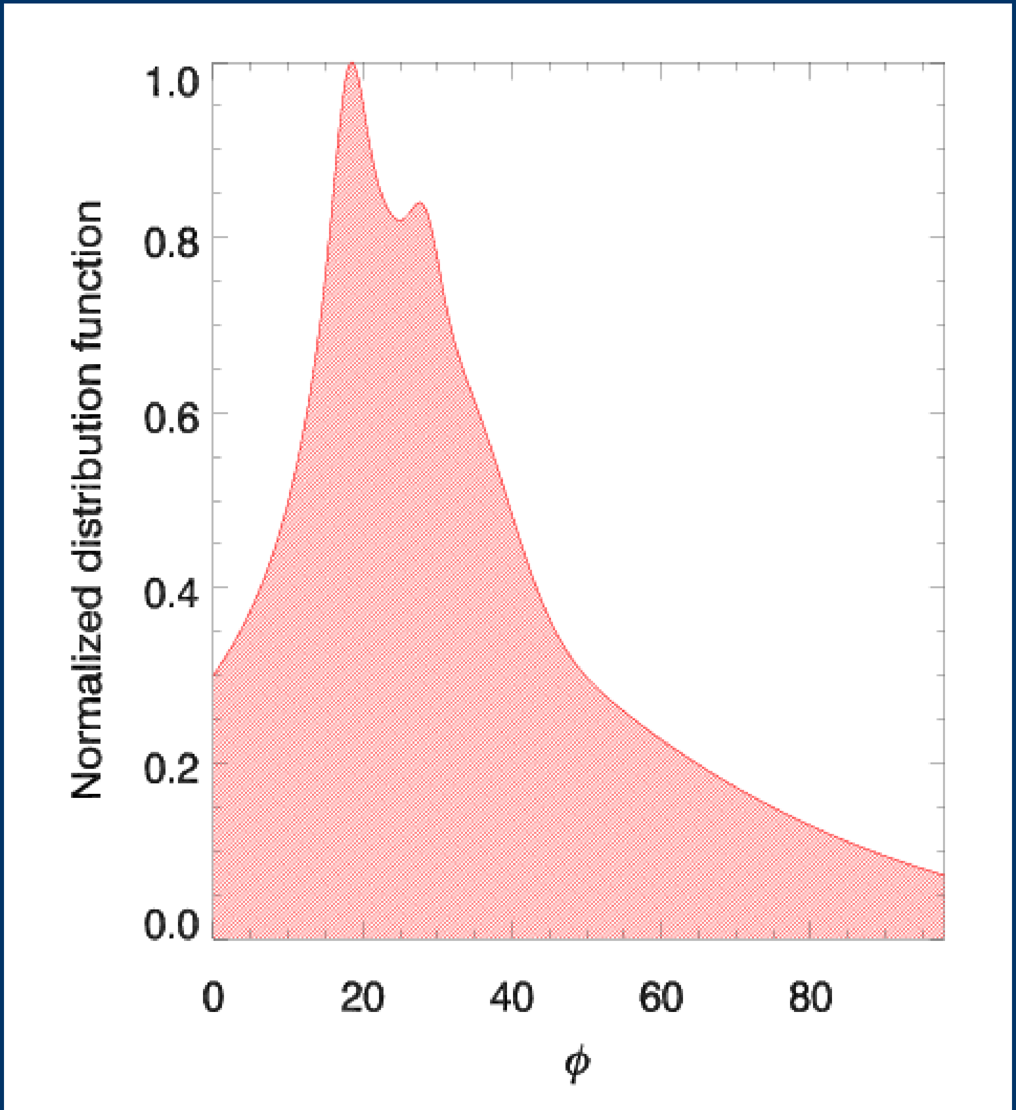
Dependency on disk inclination



(Matt et al. 1992)

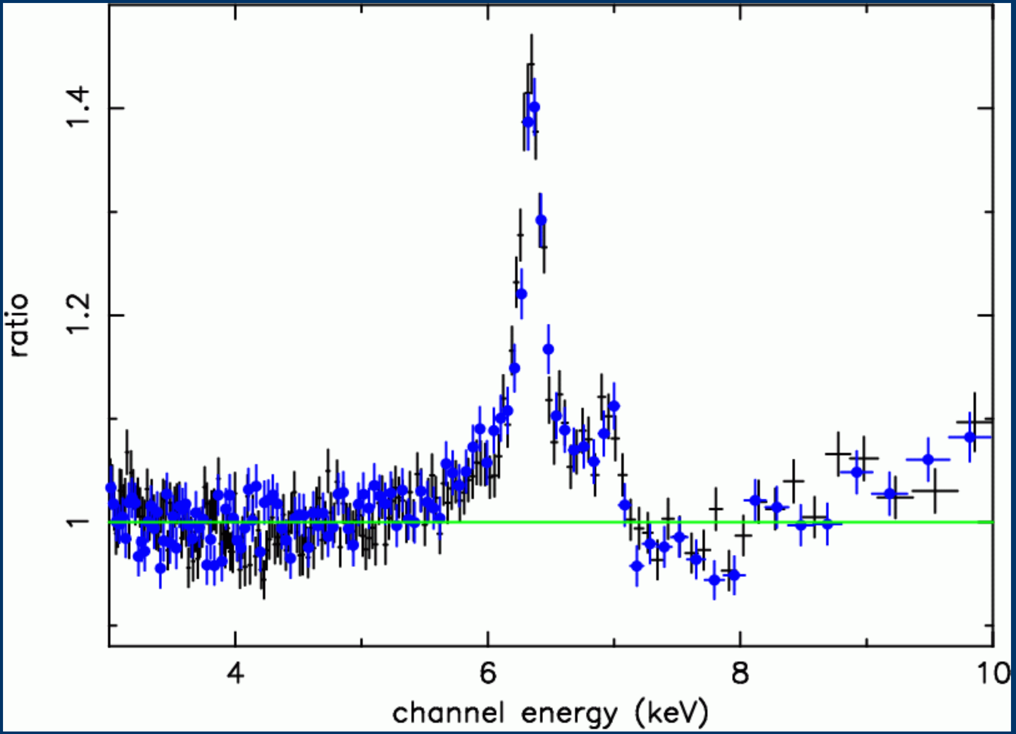
Measurements of inclination

(Guainazzi et al. 2006)



Sample of ≈20 type 1 AGN observed with XMM-Newton

In the Seyfert 2 MCG-5-23-16 the inclination angle is larger (≥47^0) *assuming that* the line is produced in a Kerr metric



(Dewagan et al. 2003, Balestra et al. 2004, Reeves et al. 2007)

First order expectation from the AGN unification scenario

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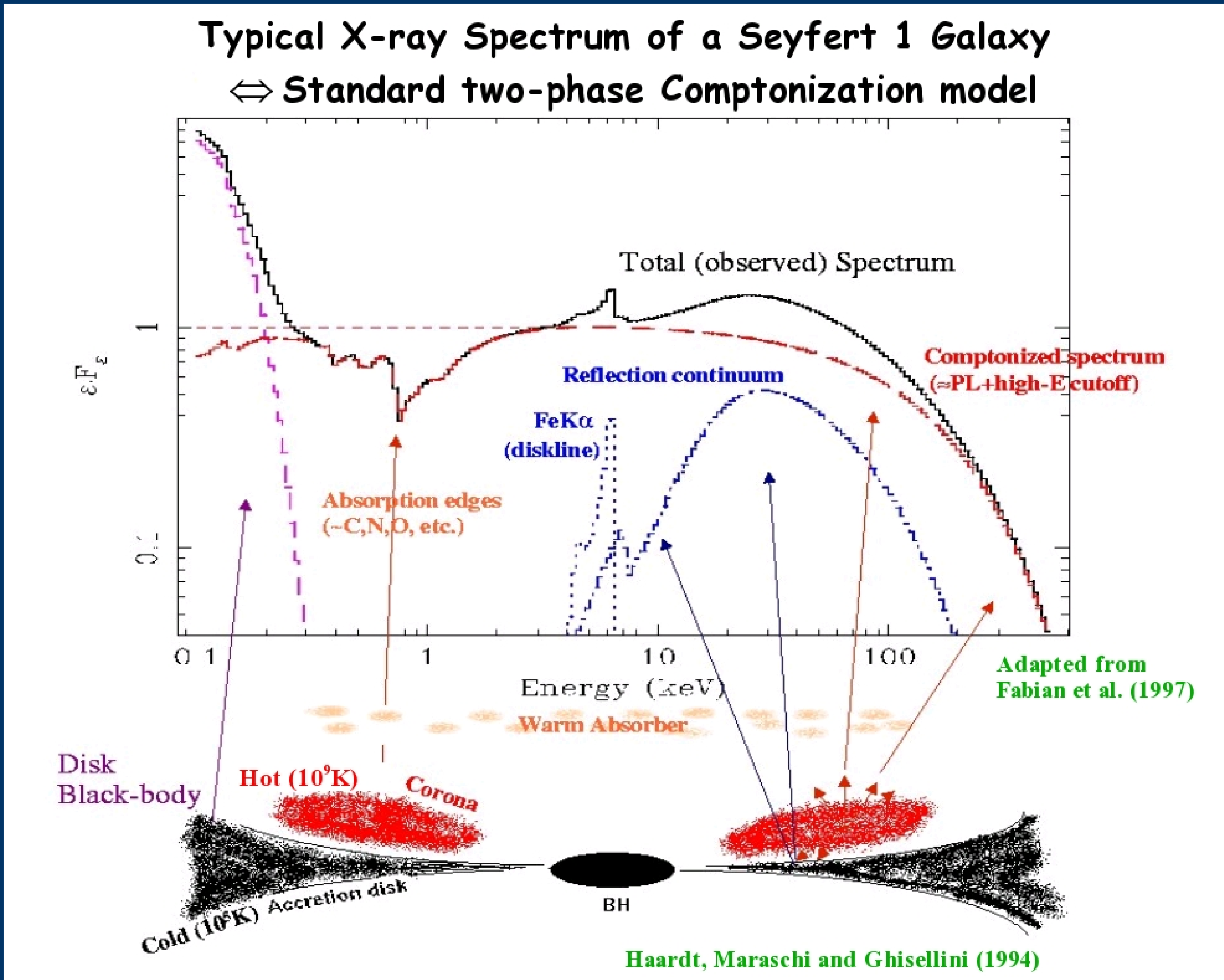
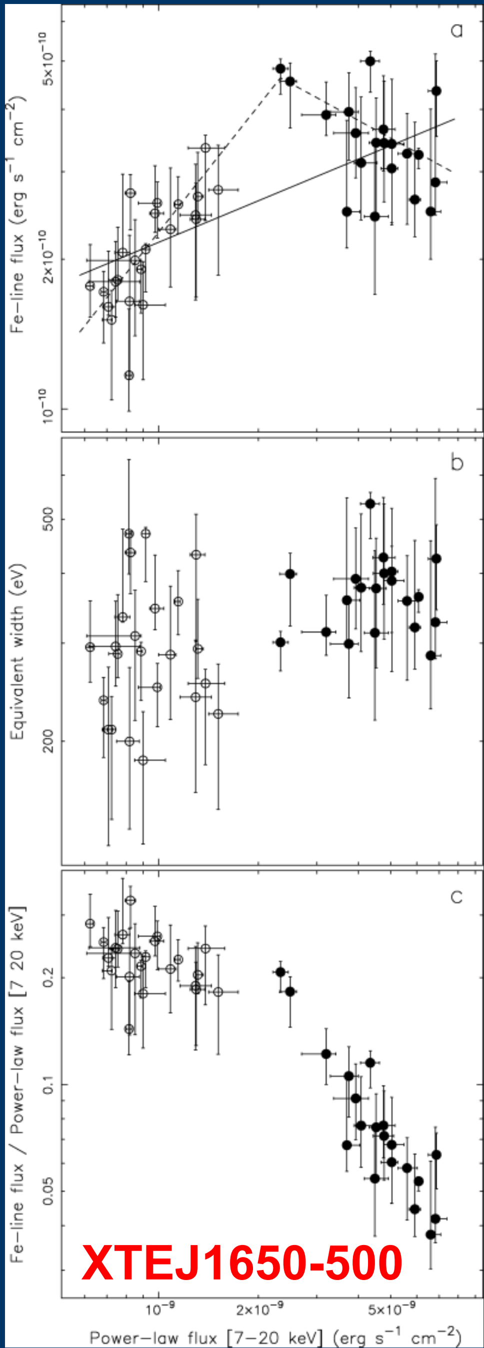
The inner region of an AGN

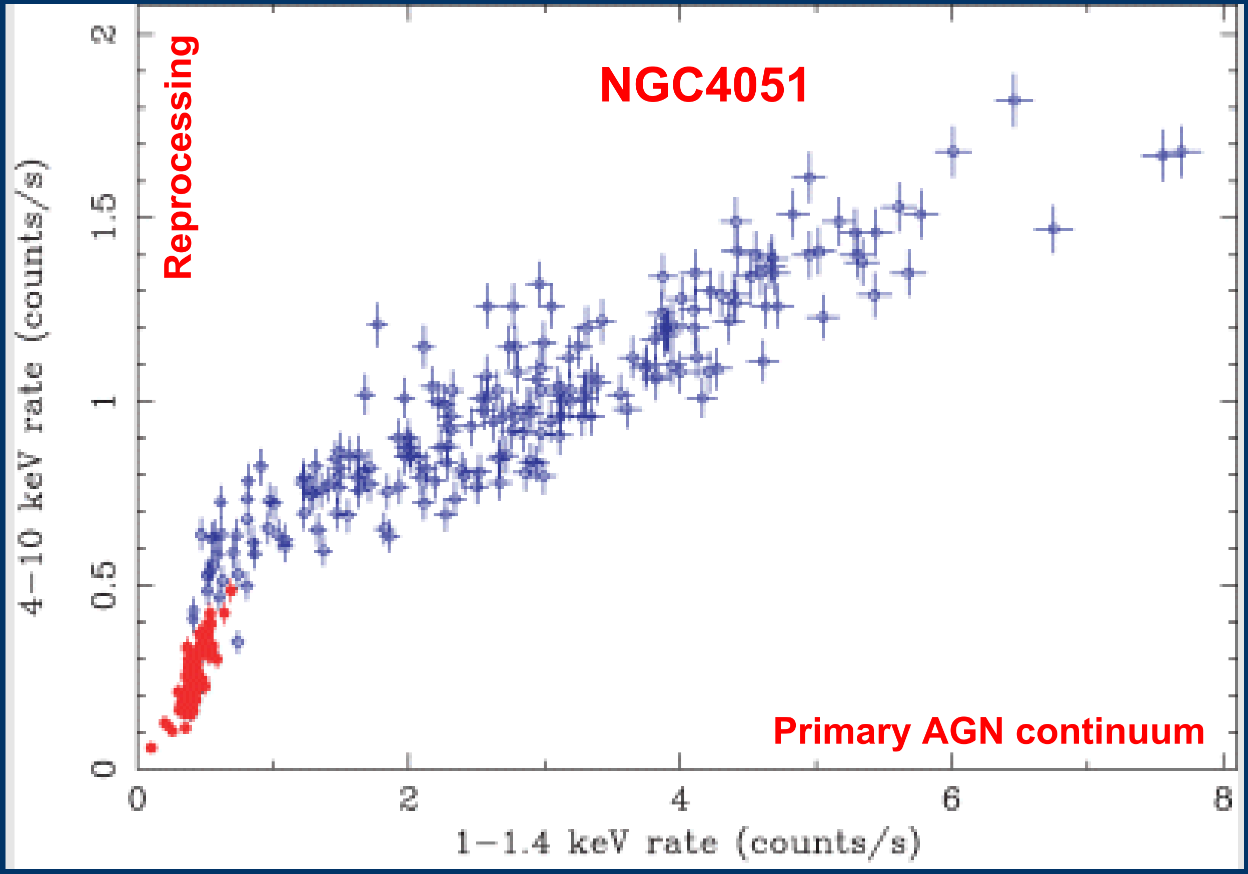


Uncorrelated line-continuum



(Rossi et al. 2005)

If the relativistic lines (or the reflection continuum) are produced very close the BH, they should vary correlated to the primary continuum However, this generally **does not happen**

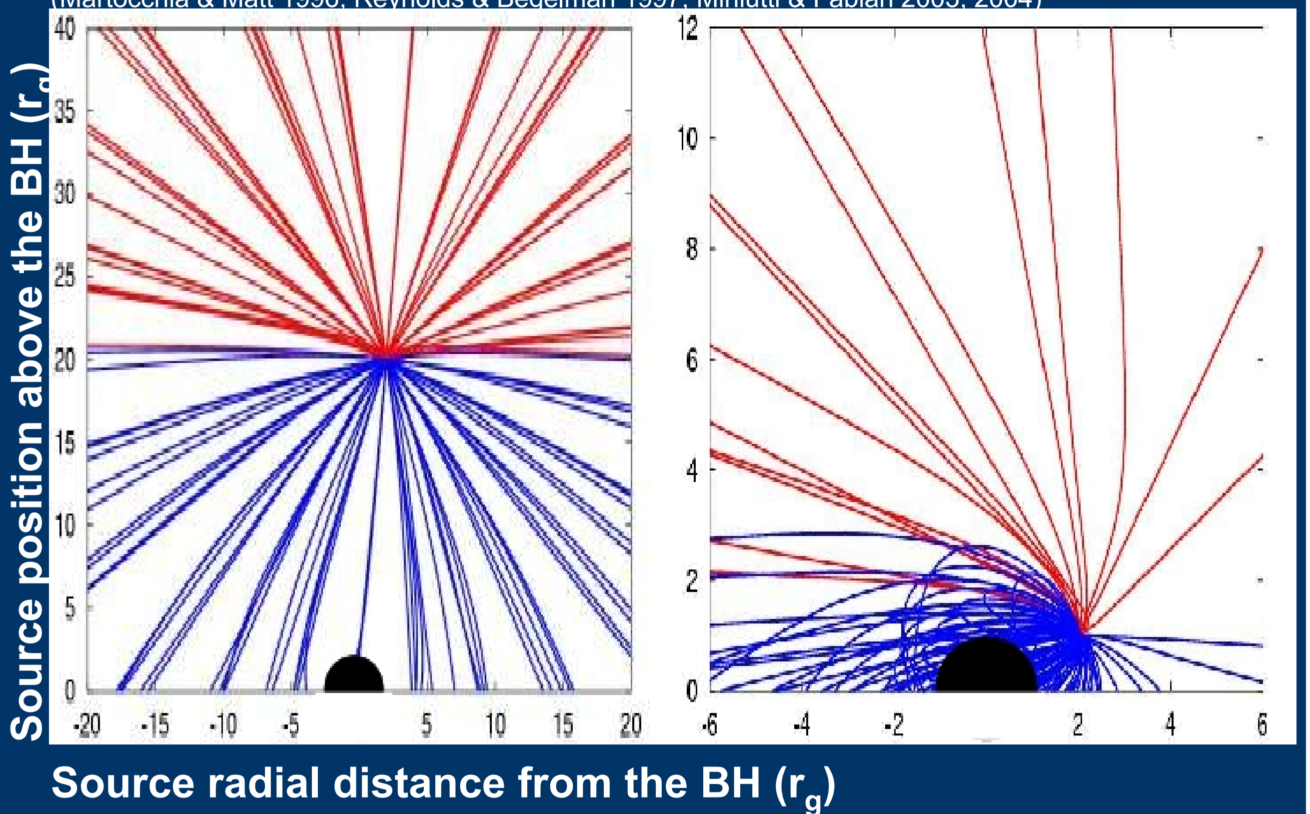


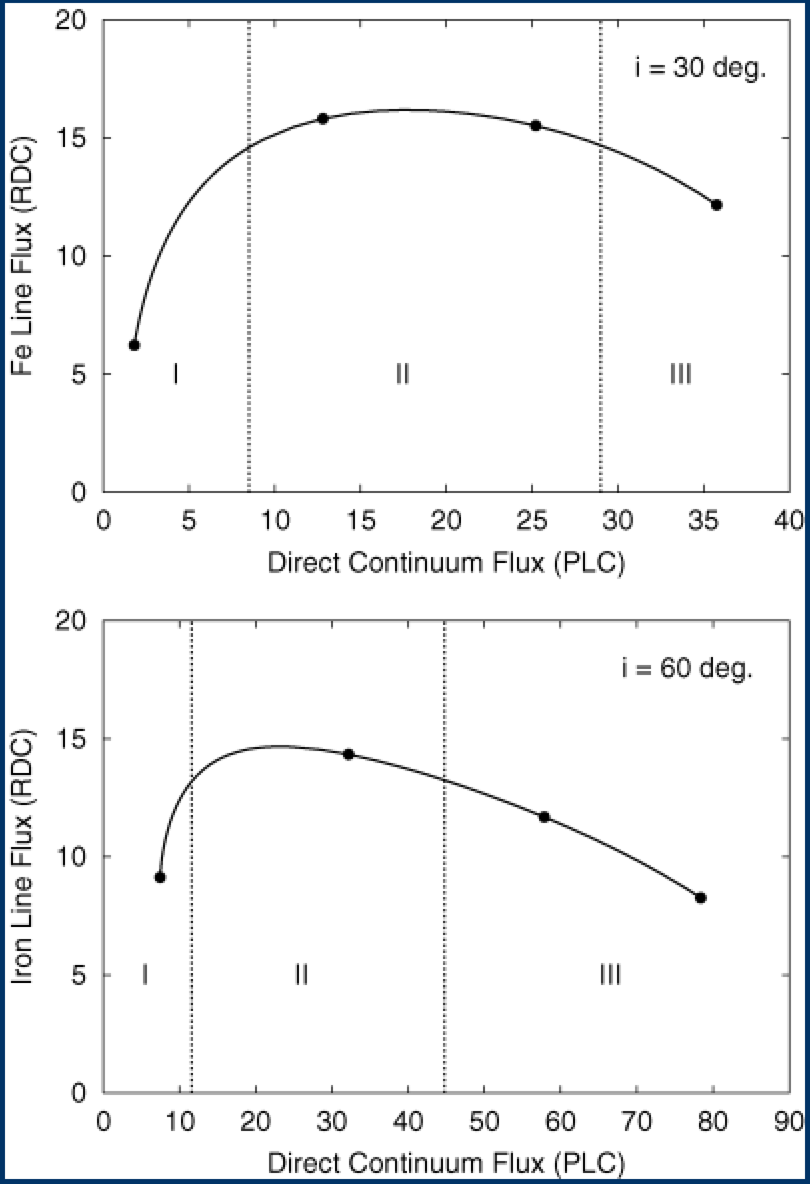
(Ponti et al. 2006)

Light bending

A solution is the bending of light in the vicinity of the BH potential well

(Martocchia & Matt 1996; Reynolds & Begelman 1997; Miniutti & Fabian 2003, 2004)



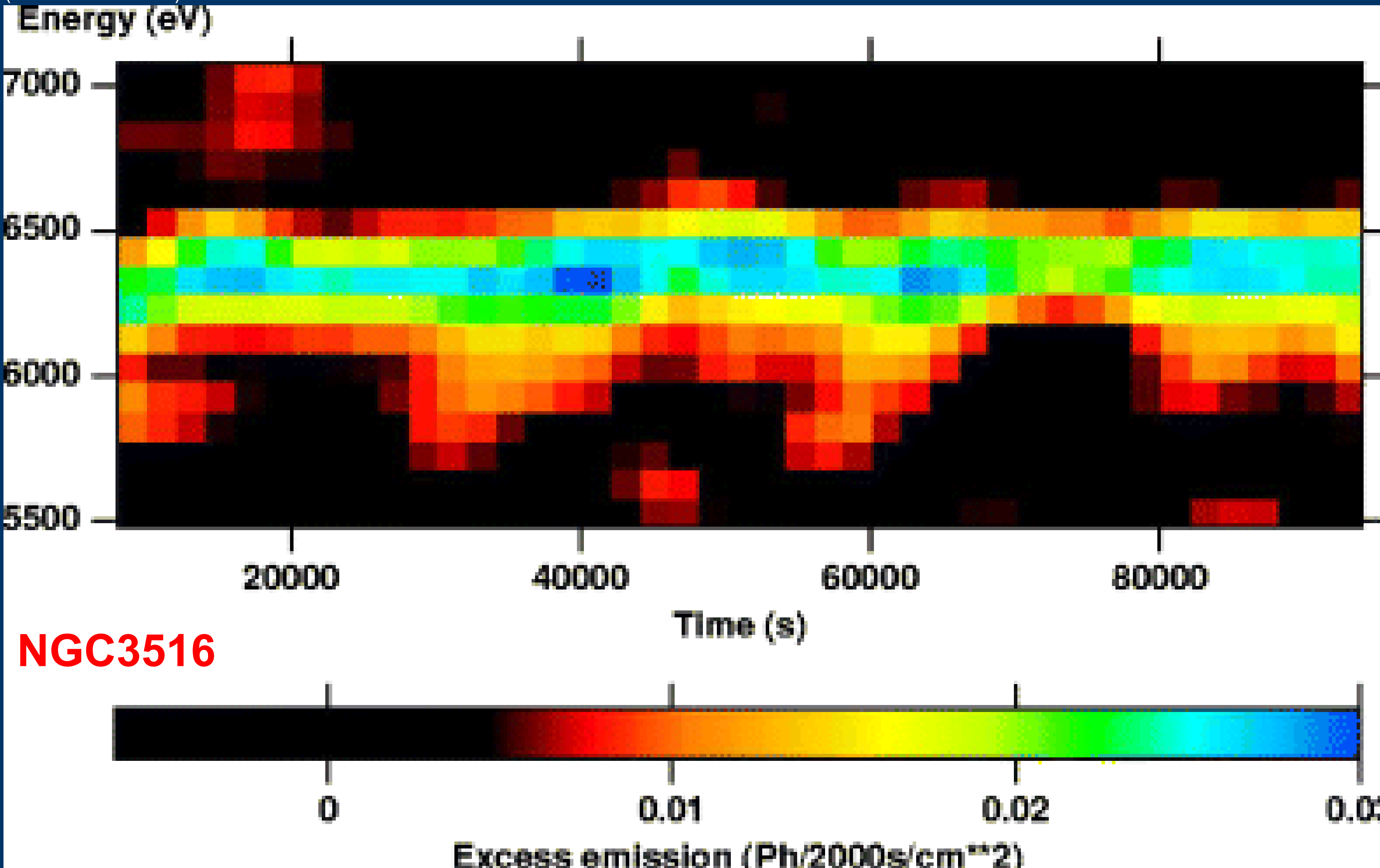


Red = to observer

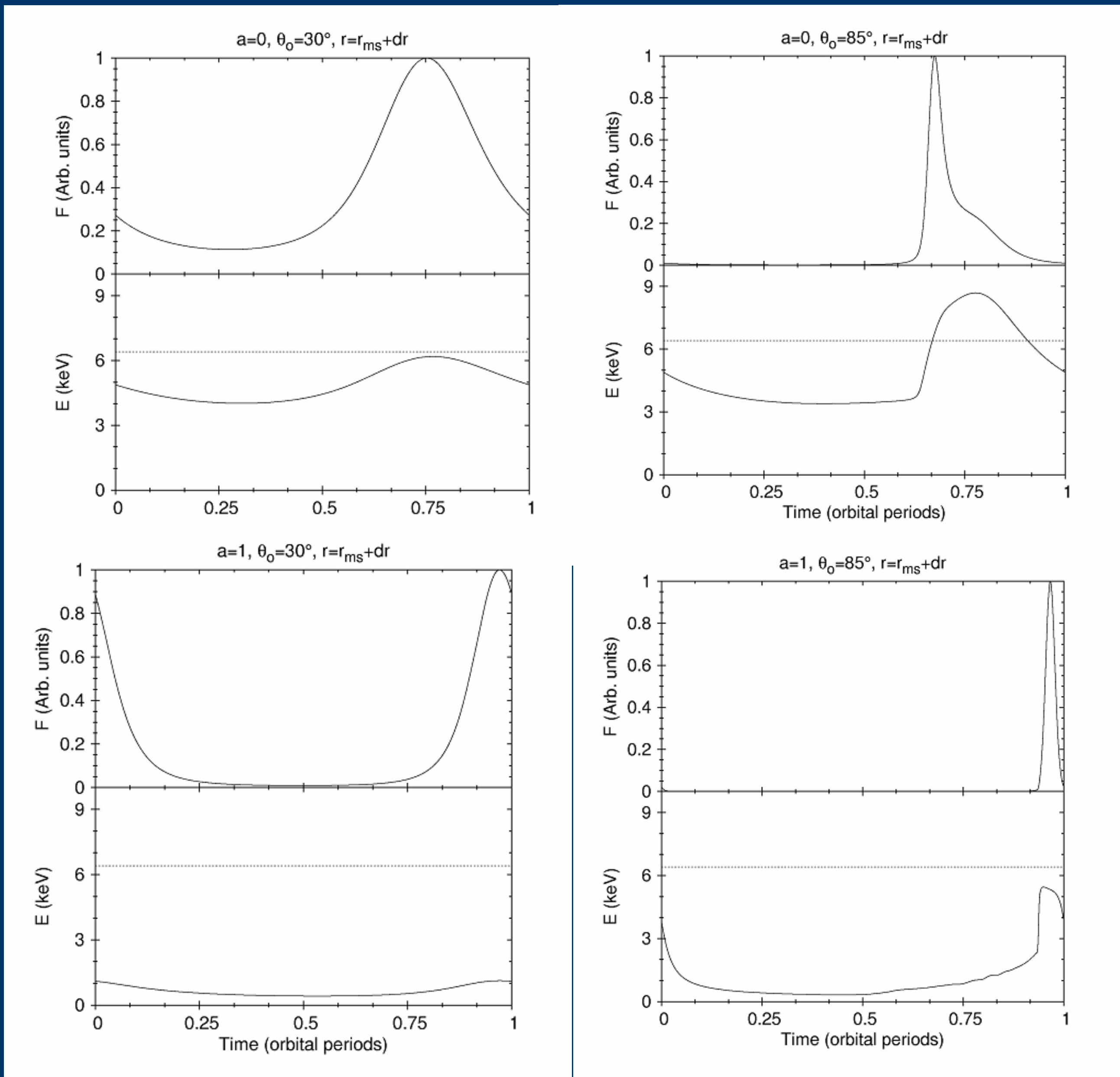
Blue = to the accretion disk

Transient redshifted (?) lines

(Iwasawa et al. 2004)



Solution: orbiting spots



(Dovčiak et al. 2004)

$a = 0,\ r = 6\ r_g$

X-ray flare co-rotating with the disk. The disk illumination produces the iron line

About 8 cases of the signatures of these spots known. Apart NGC3516, none of these cases is statistically compelling.

$a = 1,\ r = r_g$

BH mass measurement

These orbiting spots may allow a direct measurement of the BH mass, if the spot is small and corotating with the disk. A spot at radius *r* has an orbital period (as seen by us):

$$T_{orb} = 310\ (r^{3/2}+a)\ M_7\ (s)$$

In NGC3516:

M_7 = 1-5 **(orbiting spot; *Iwasawa et al. 2004*)**

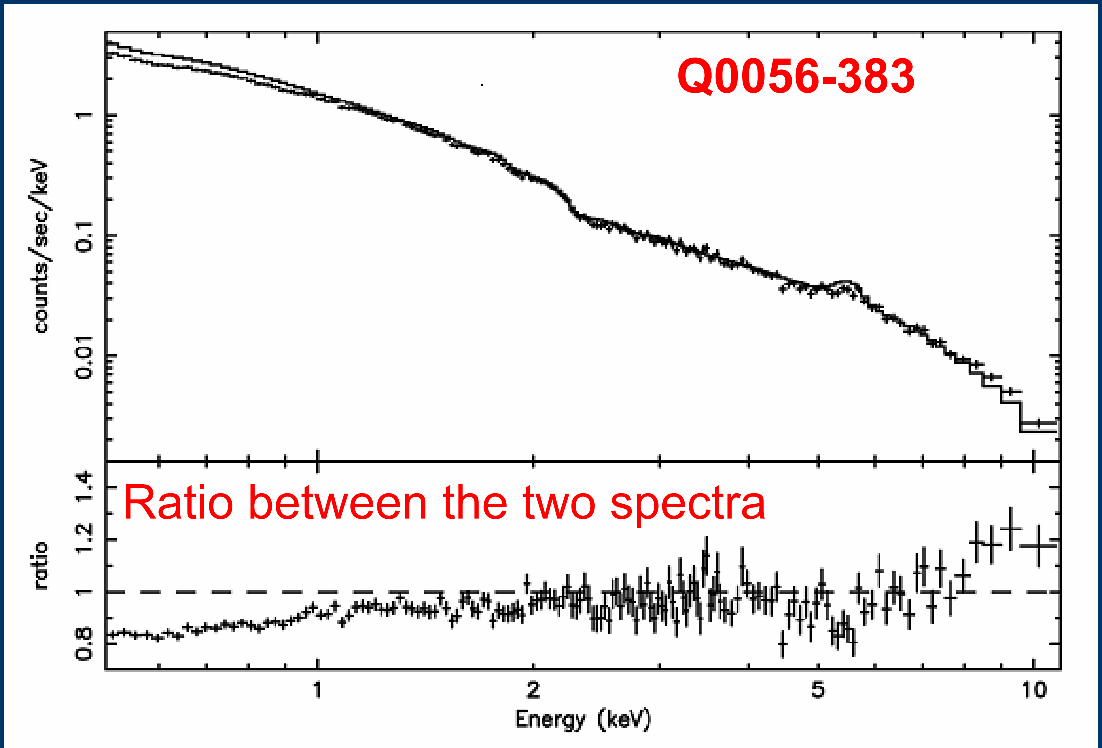
$M_7 = 1.7 \pm 0.3$ **(optical lines reverberation mapping; *Onken et al. 2003*)**

Conclusions

- **XMM-Newton** (and now *Suzaku*) has provided us with the ultimate evidence that relativistic effects can be studied through spectroscopy of AGN and GBHC
- They tell (or *can tell*) us about:
  - BH spin
  - Disk geometry and illumination
  - Validity of the unification scenario
- Variability studies (best possible with future generation X-ray missions) may tell us more about
  - Accretion flow physics
  - BH mass

Truncated disk? An AGN case

(Matt et al. 2000)



Two observations 3 years apart.

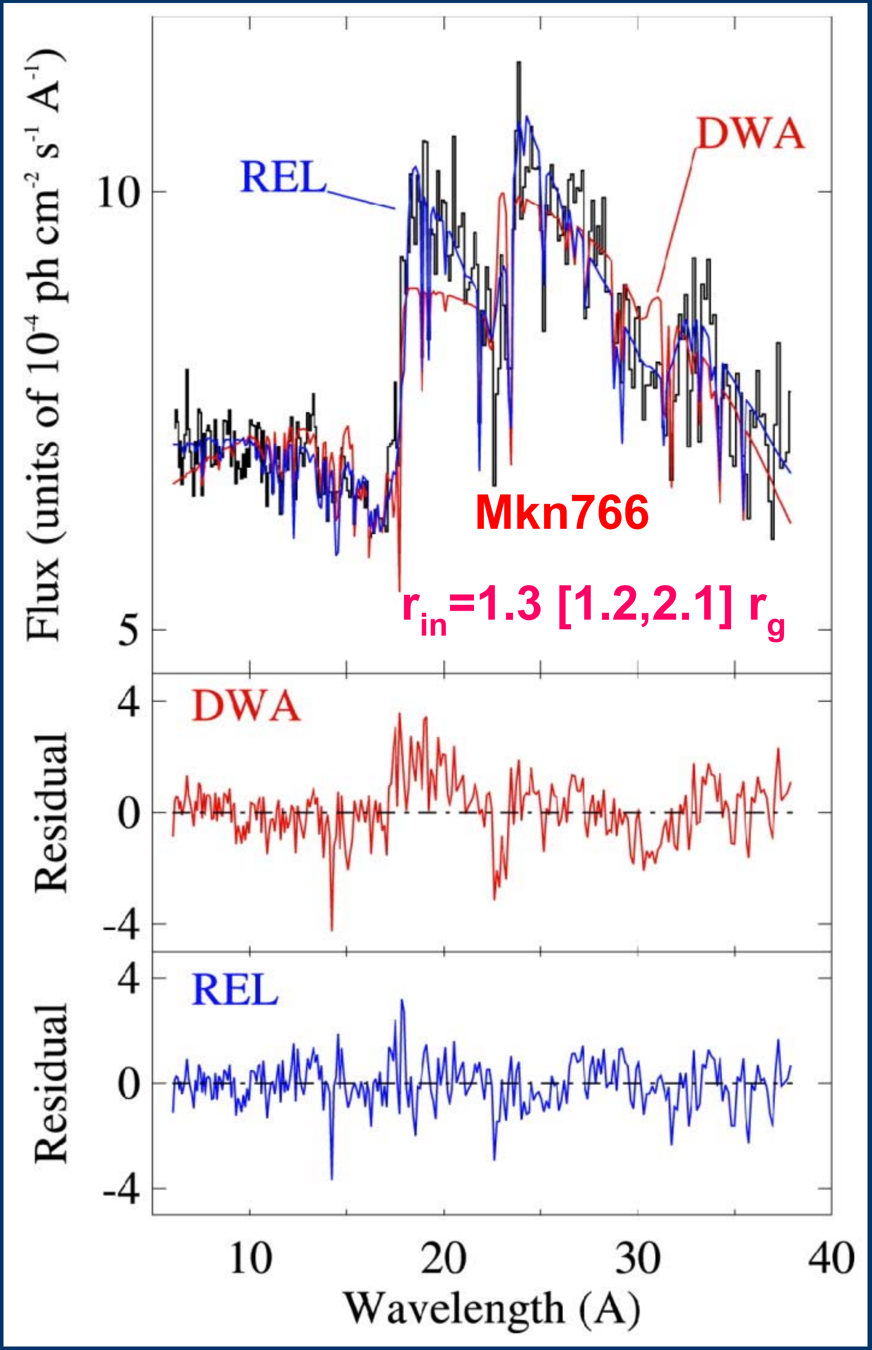
In the latest:

- Soft X-ray emission is fainter
- Hard X-ray emission is flatter
- Iron line is halved

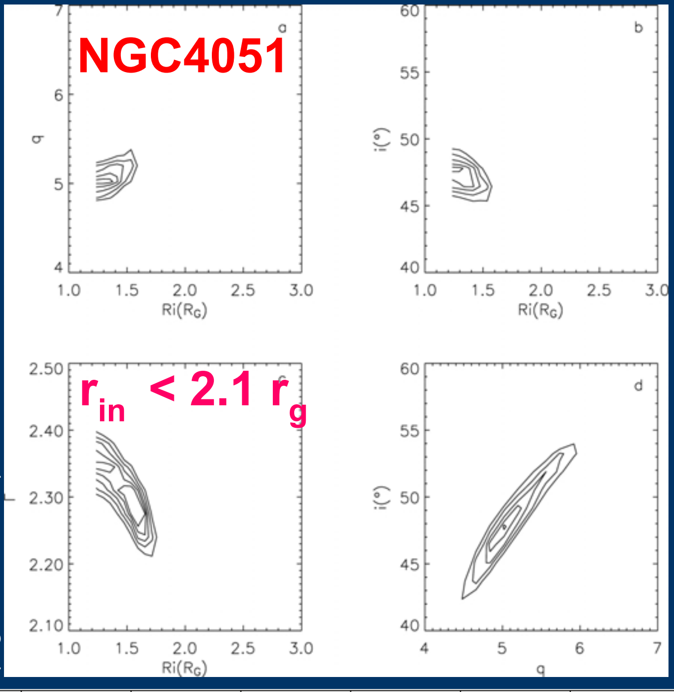
Truncated disk?

Truncated disks could explain also the low/hard state of Galactic BH binaries, where iron lines are detected primarily in high/soft states

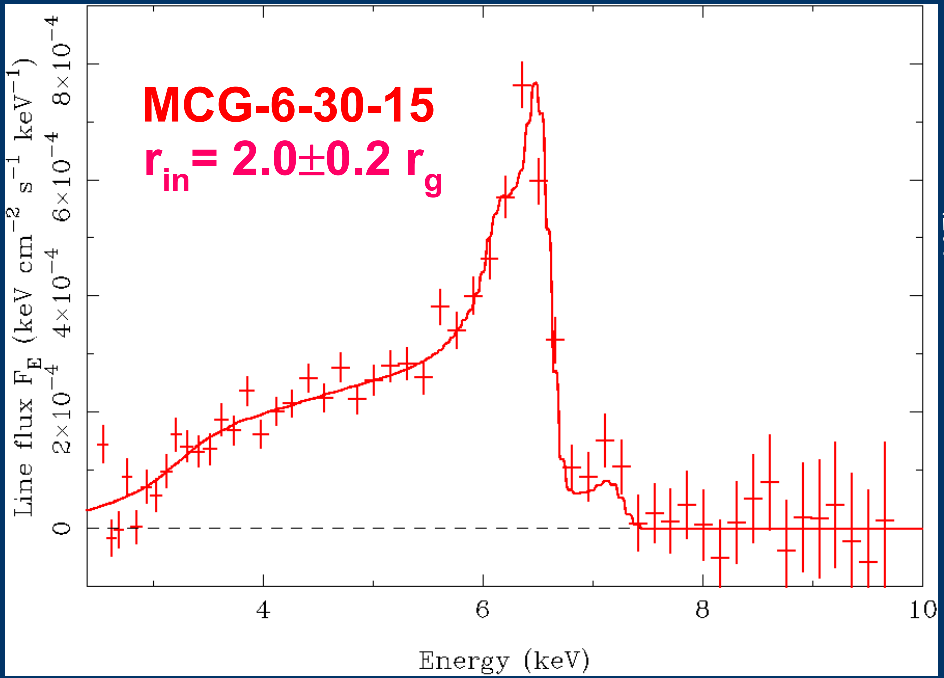
Innermost disk radius in AGN



(Mason et al. 2003)

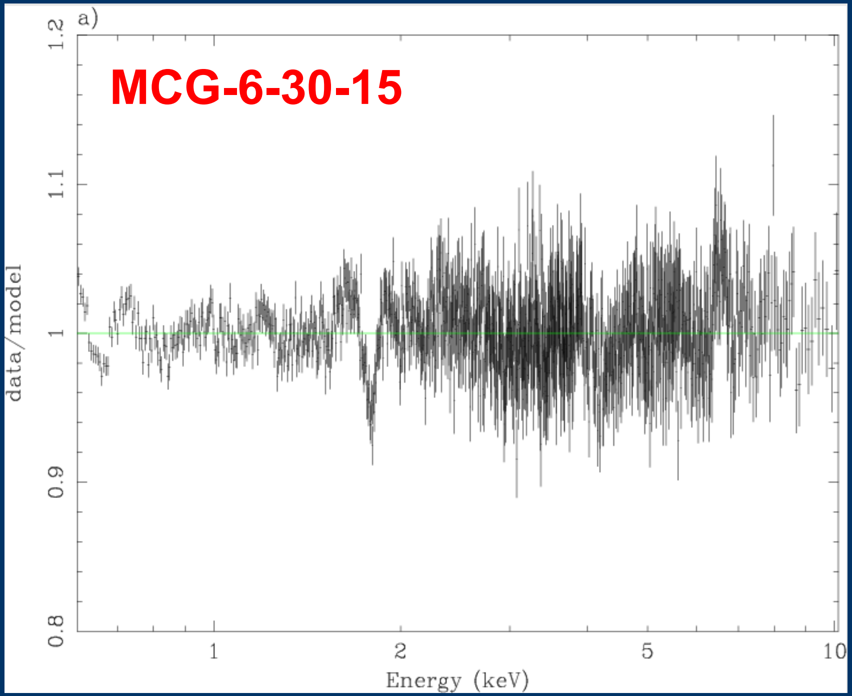


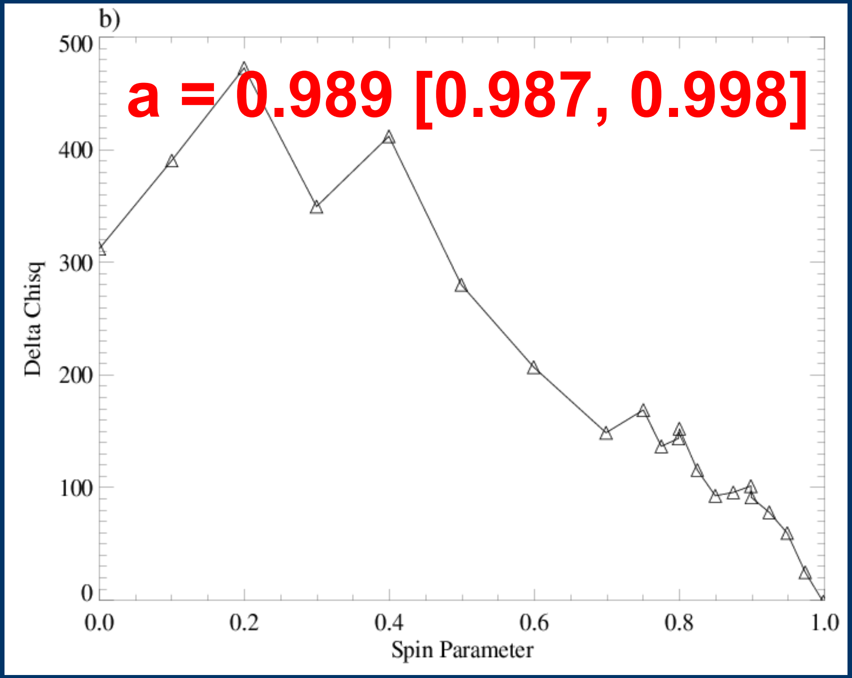
(Ogle et al. 2004)

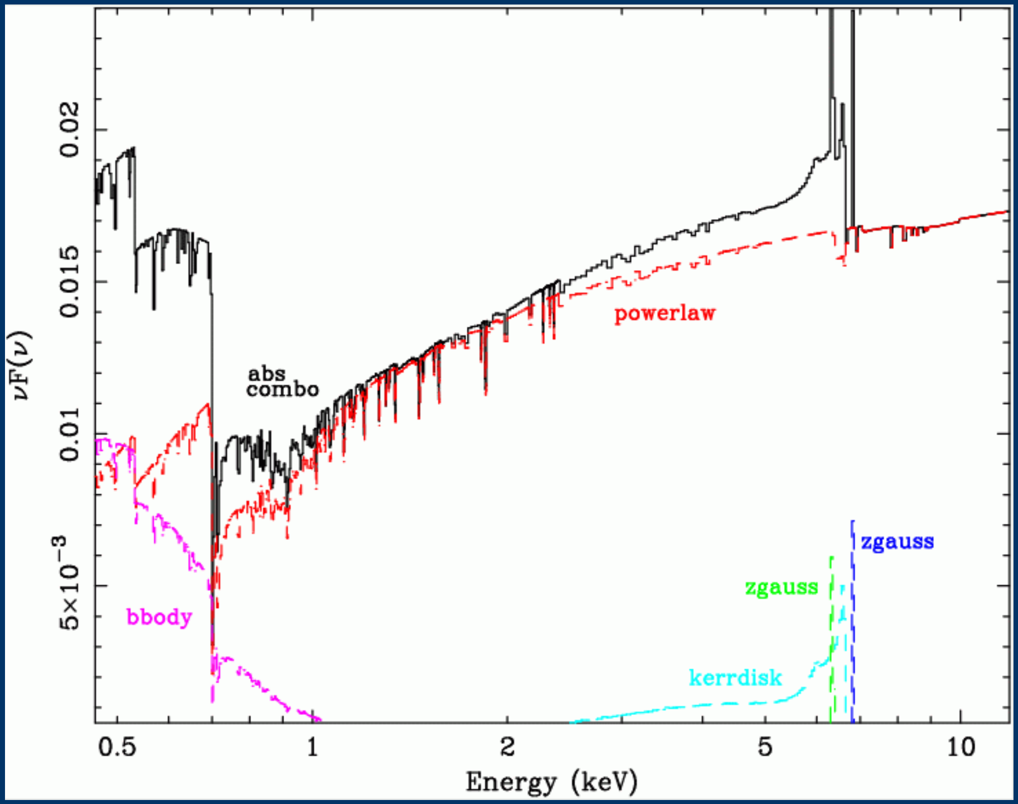


(Fabian et al. 2003; Miniutti et al. 2007)

The only measurement of the BH spin in an AGN







In an XMM-Newton sample of 6 AGN (MCG-6-30-15 included; *Guainazzi et al. 2006*):

$\langle a \rangle = 0.6$ $\sigma_a = 0.3$