Relativistic Fe Kα Lines with *XMM-Newton*

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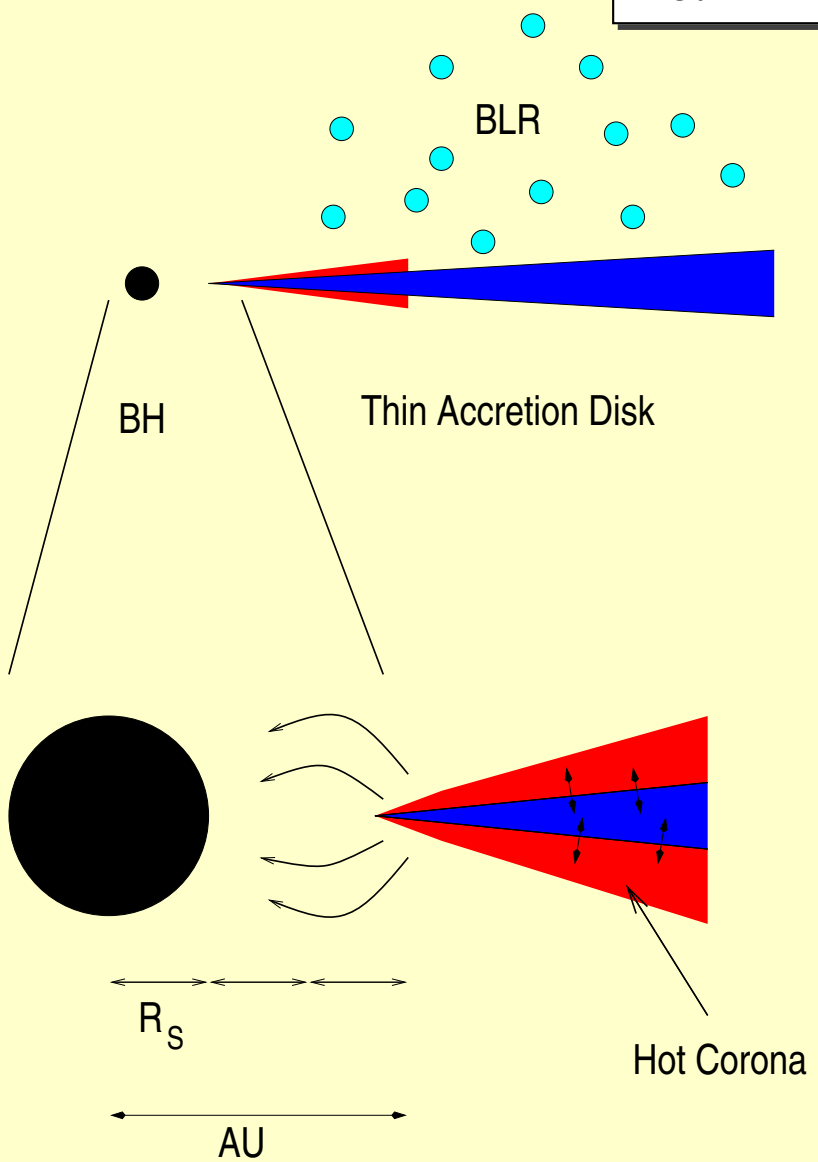
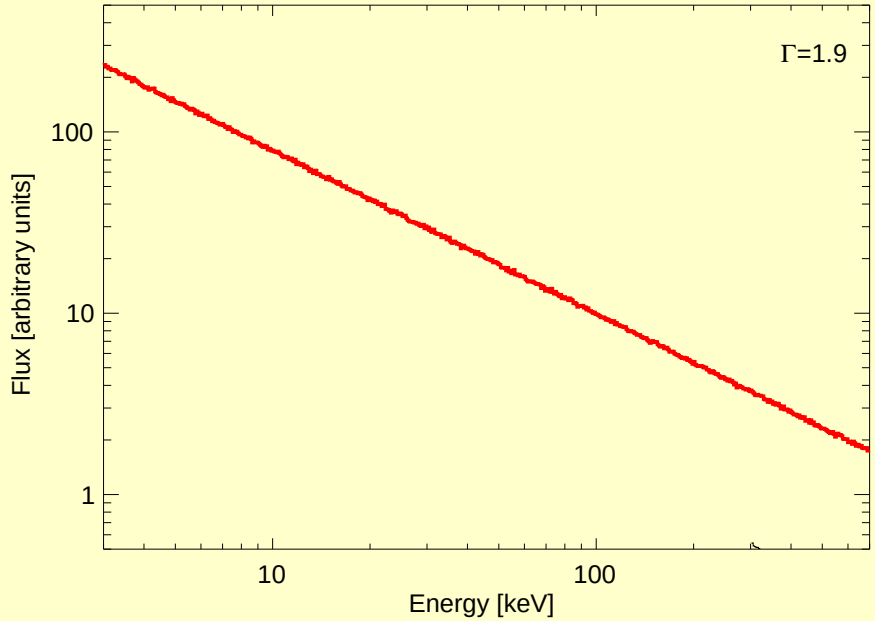
Structure

- Why are Kα Lines Interesting?
  - Accretion geometry
  - Formation of Fe Kα lines
  - Line transfer close to the BH
- There are Broad Lines...
  - MCG$-$6-30-15
  - Other low-z AGN
- ...Are There?
  - NLSy1s
  - QSO statistics
- Summary and Outlook
  - relativistic lines in high-z sources and *XEUS*

Kα Line Diagnostics

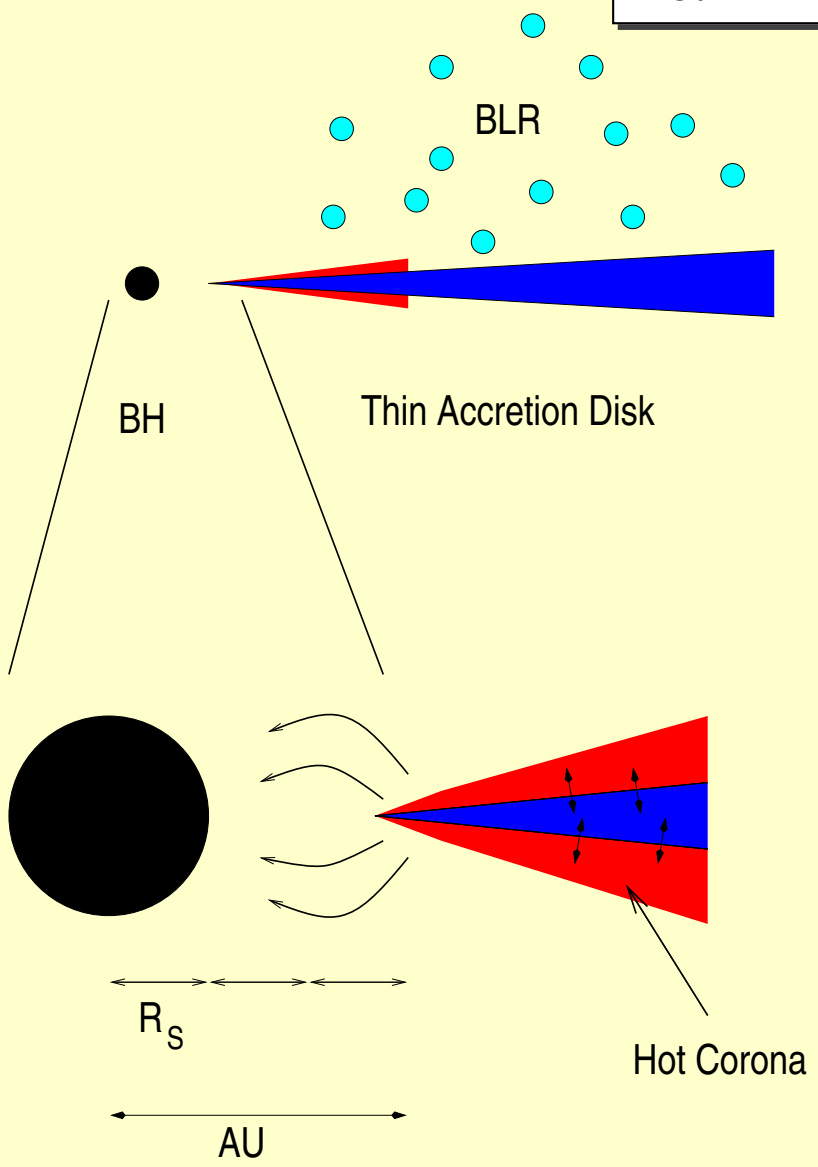


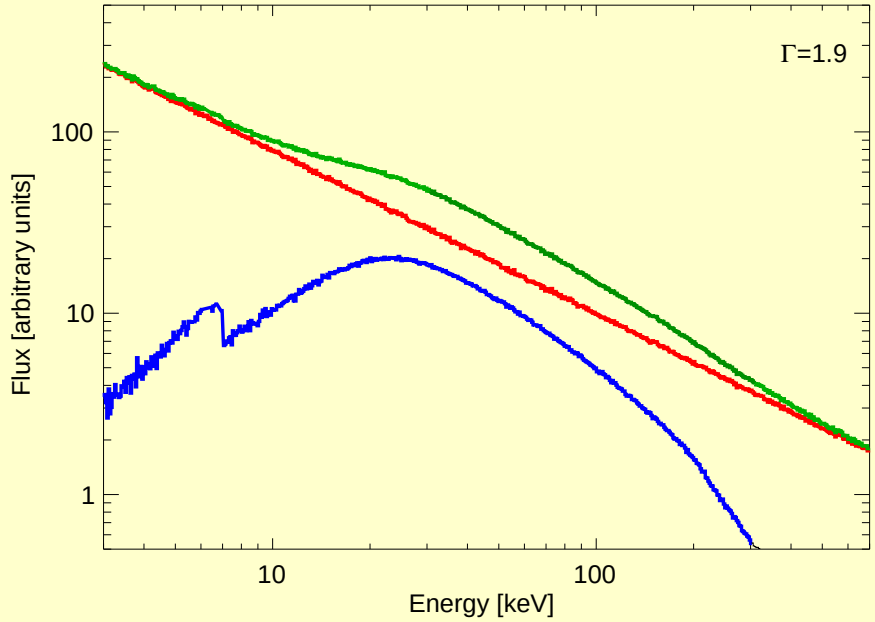


AGN X-Ray Spectrum:

- Comptonization of soft X-rays from accretion disk in hot corona ($T \sim 10^8$ K): power law continuum.

Kα Line Diagnostics





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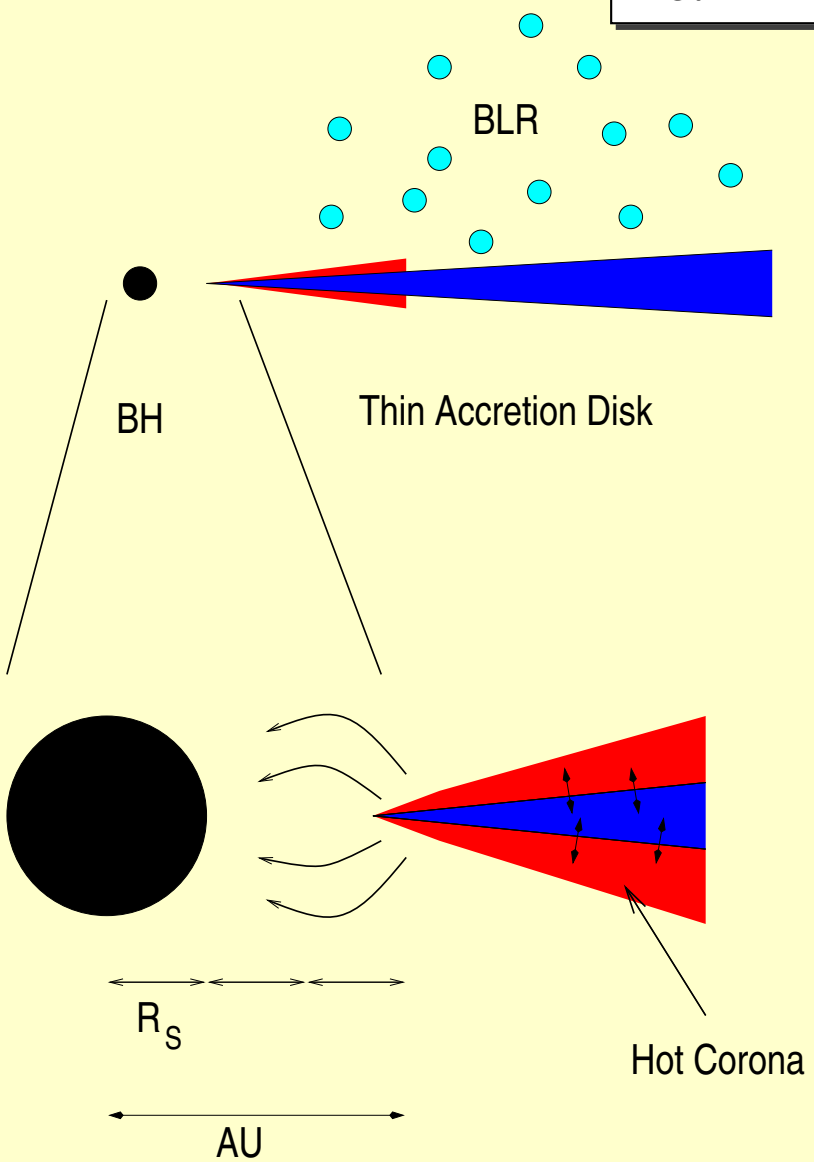
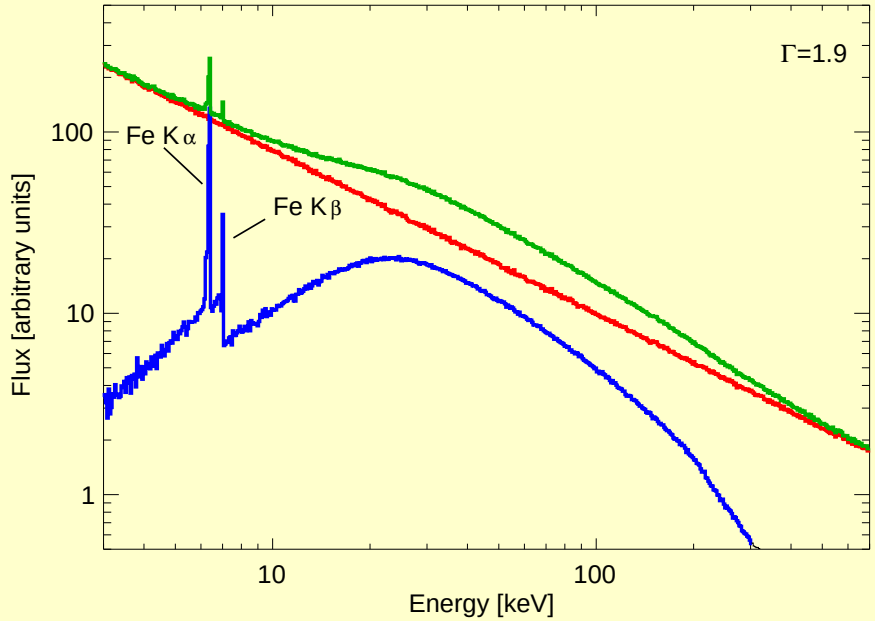
- Comptonization of soft X-rays from accretion disk in hot corona ($T \sim 10^8$ K): power law continuum.
- Thomson scattering of power law photons in disk: Compton Reflection Hump

Kα Line Diagnostics

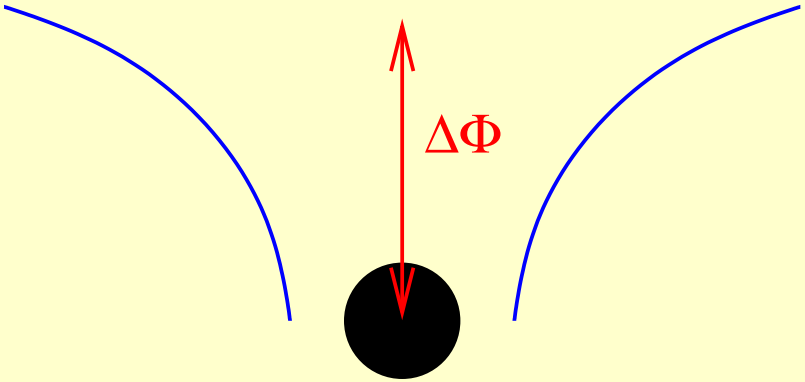


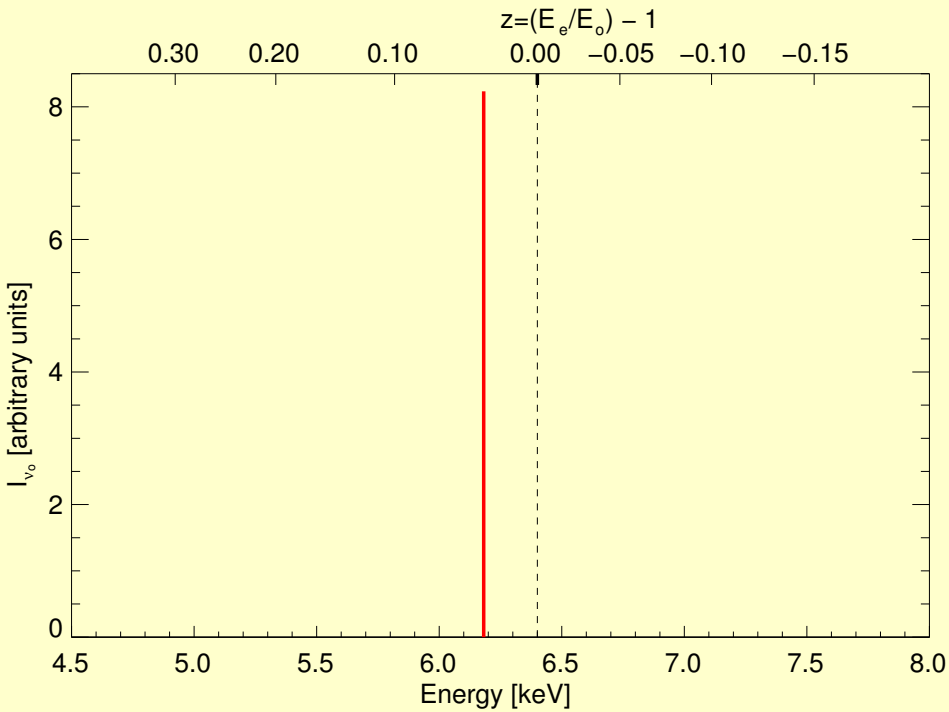


AGN X-Ray Spectrum:

- Comptonization of soft X-rays from accretion disk in hot corona ($T \sim 10^8$ K): power law continuum.
- Thomson scattering of power law photons in disk: Compton Reflection Hump
- Photoabsorption of power law photons in disk: fluorescent Fe Kα Line at $\sim$6.4 keV

Kα Line Diagnostics

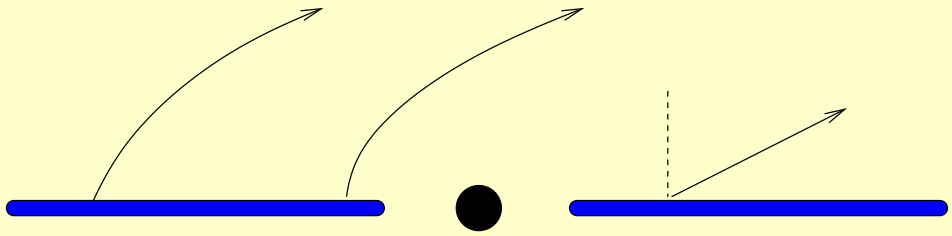


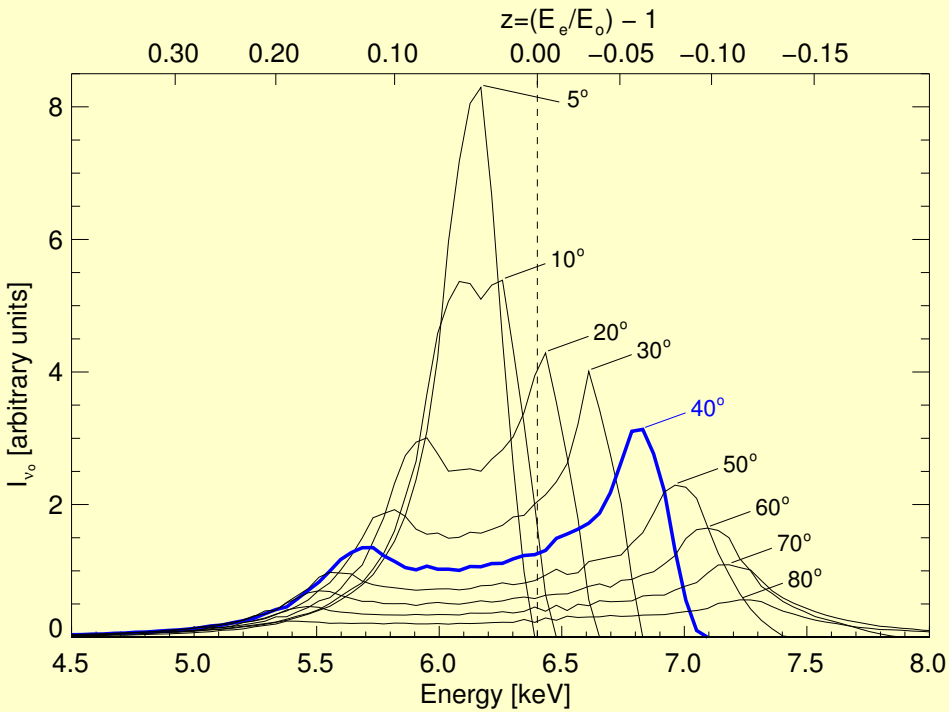


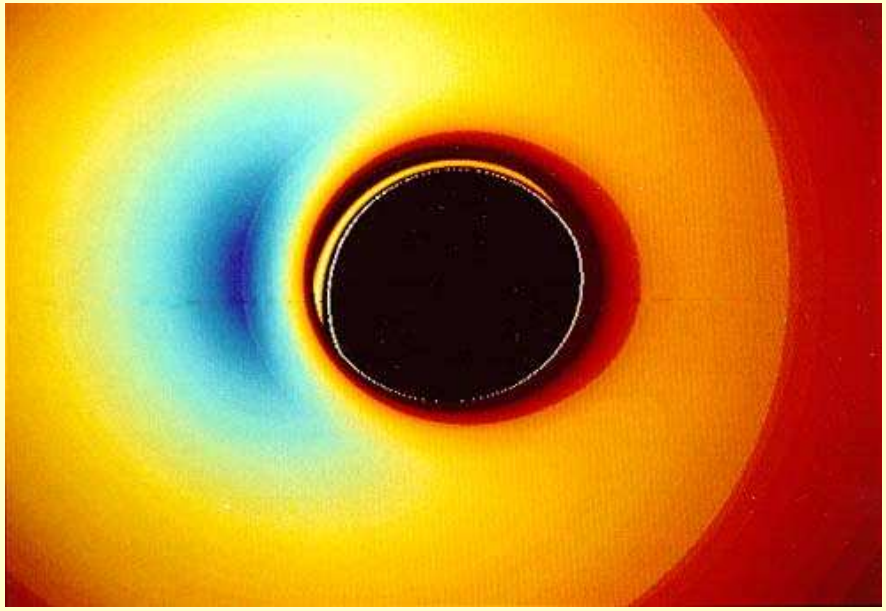
Total observed line profile affected by

- grav. Redshift

Kα Line Diagnostics



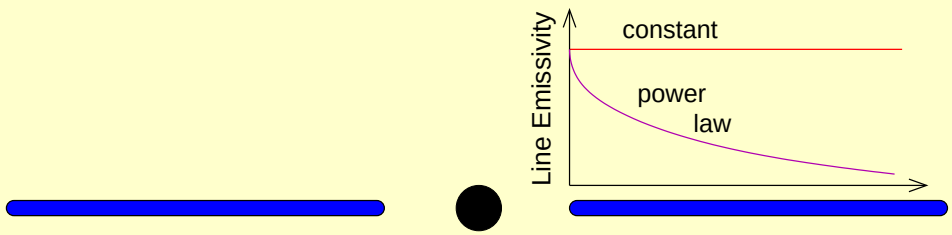


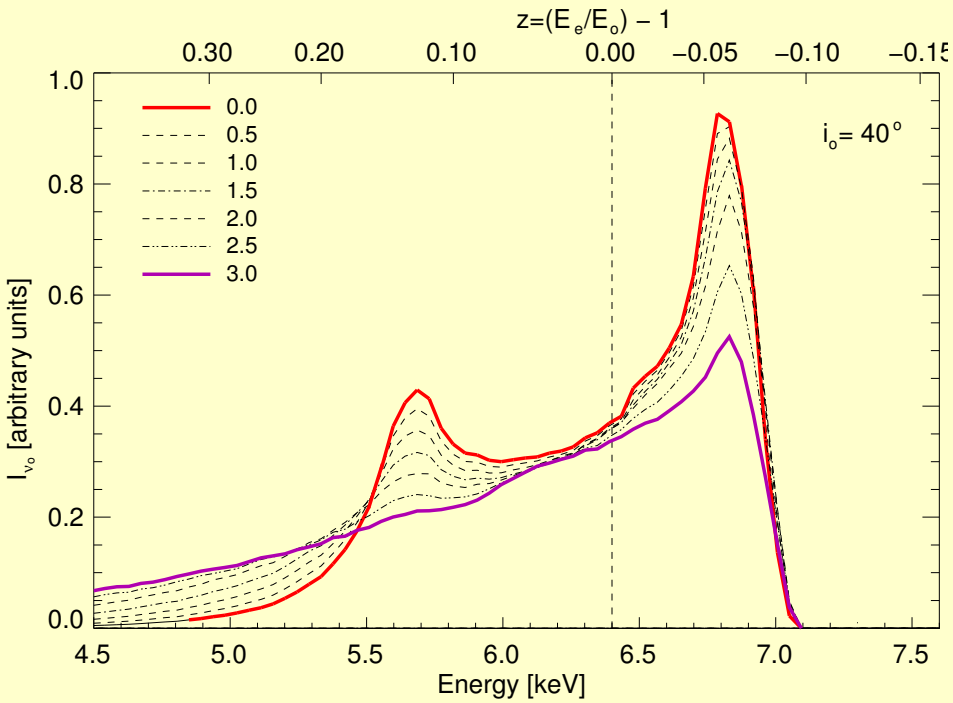


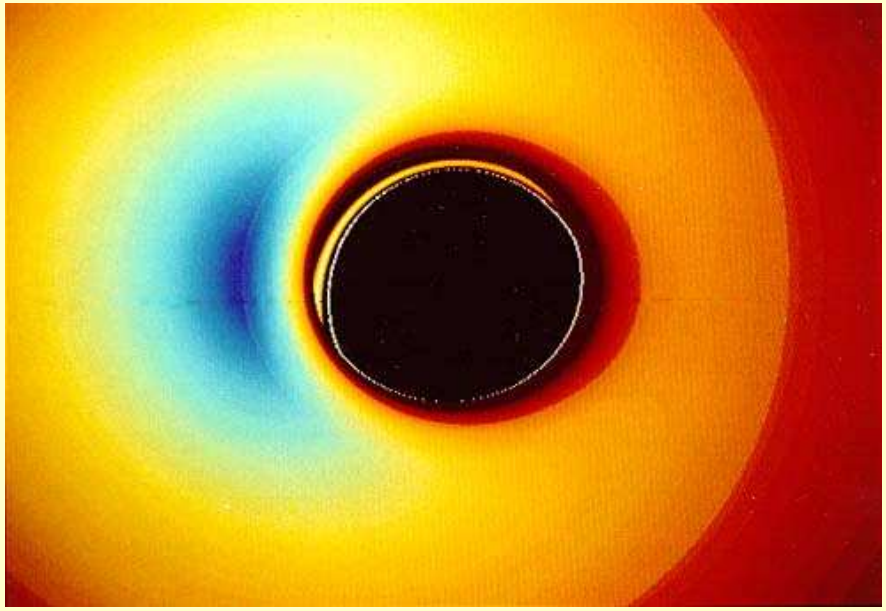
Total observed line profile affected by

- grav. Redshift
- Light bending
- rel. Doppler shift

Kα Line Diagnostics



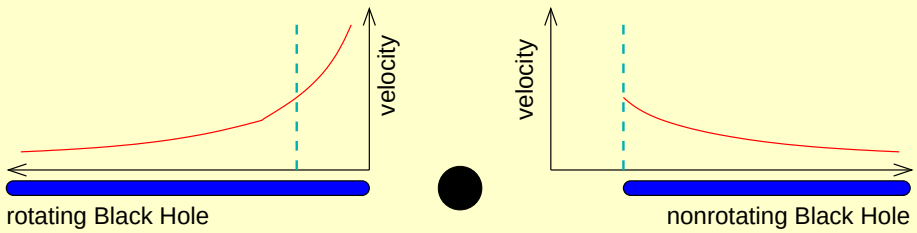


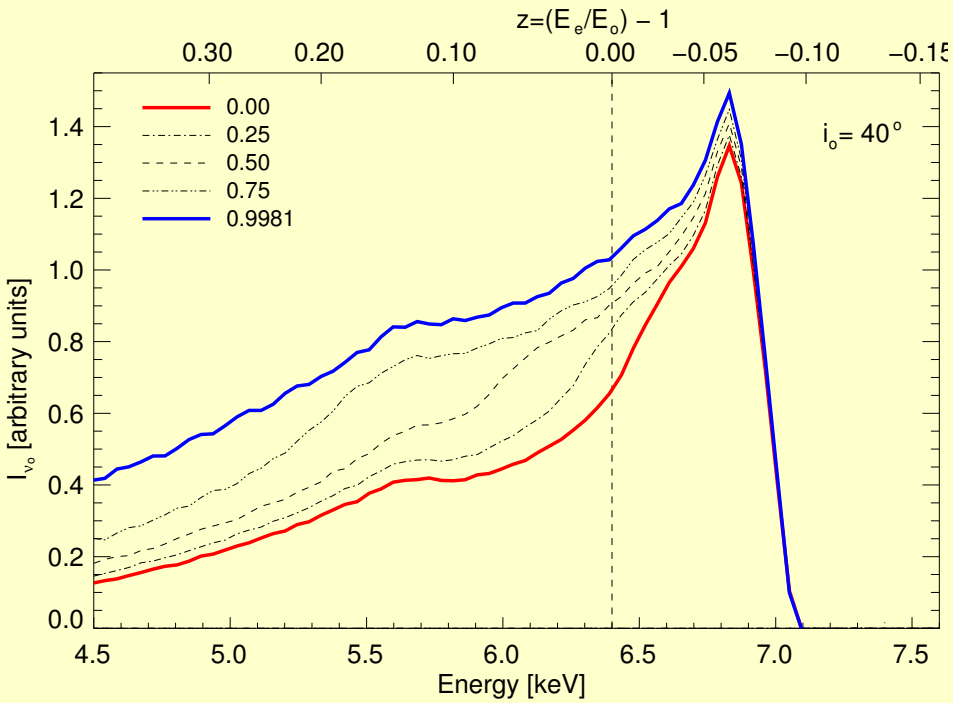


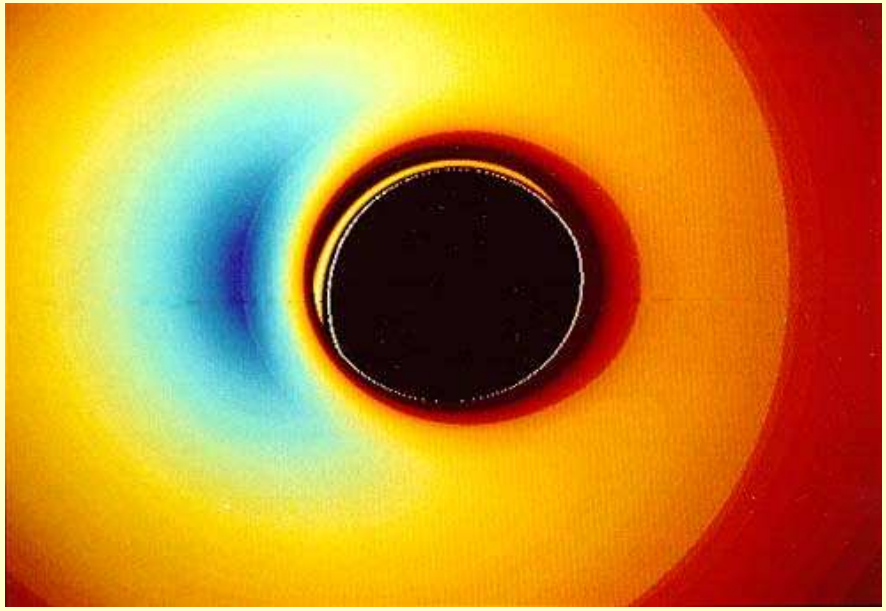
Total observed line profile affected by

- grav. Redshift
- Light bending
- rel. Doppler shift
- emissivity profile

Kα Line Diagnostics



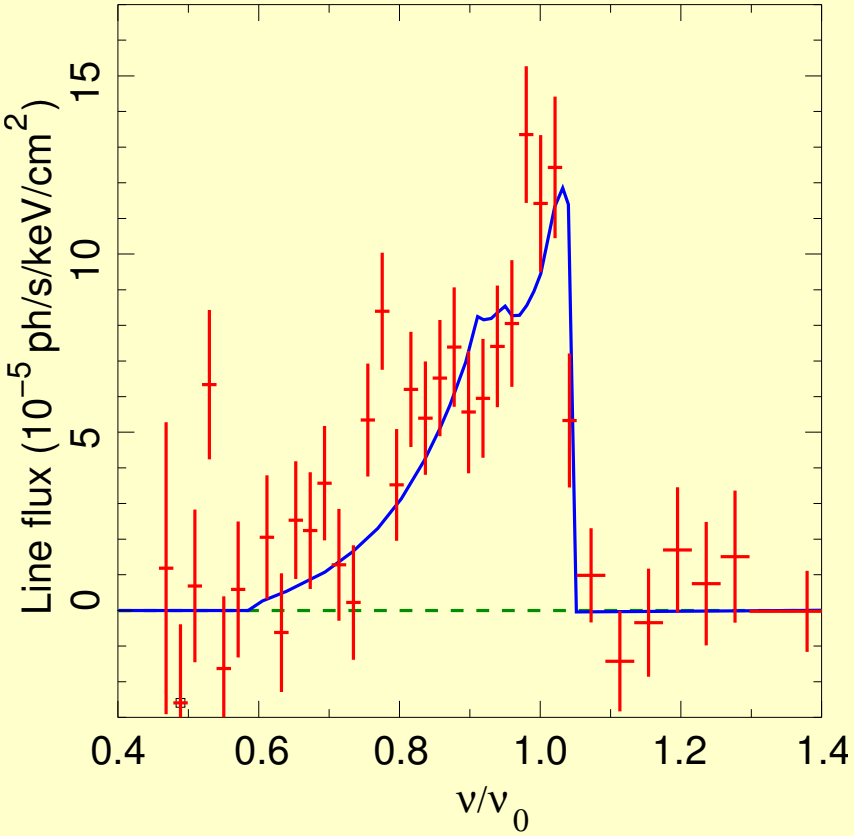


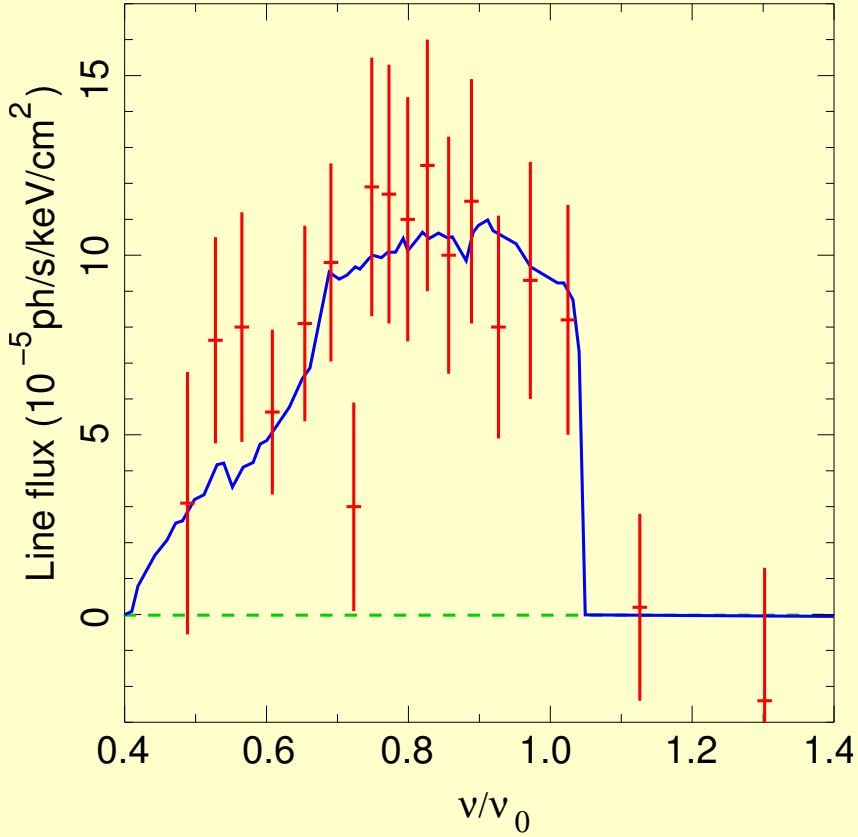


Total observed line profile affected by

- grav. Redshift
- Light bending
- rel. Doppler shift
- emissivity profile
- spin of black hole

MCG−6-30-15





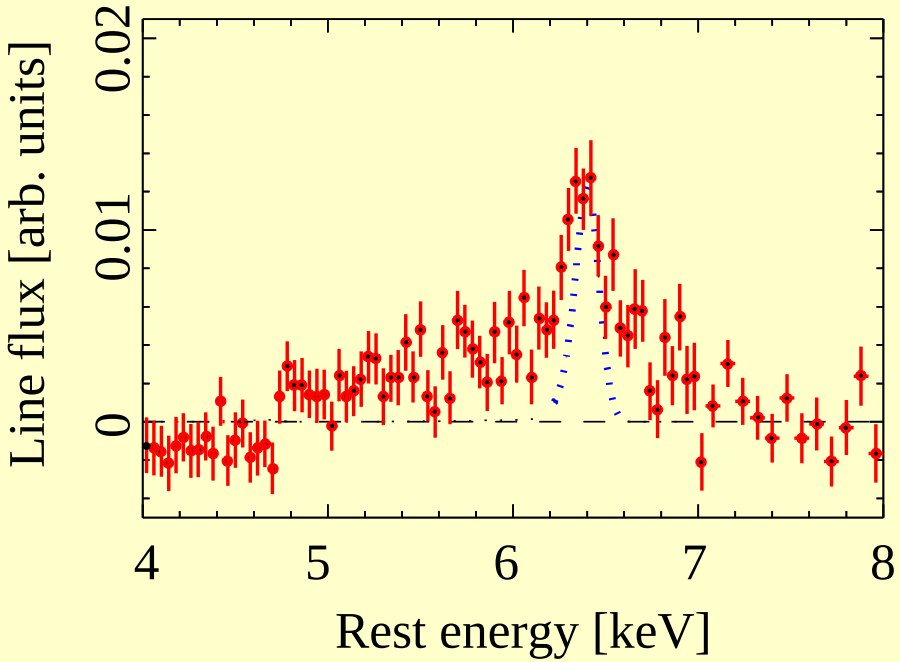
MCG−6-30-15 ($z = 0.008$): first AGN with relativistic disk line

Tanaka et al. (1995): time averaged *ASCA* spectrum: line skew symmetric $\Longrightarrow$ Schwarzschild black hole.

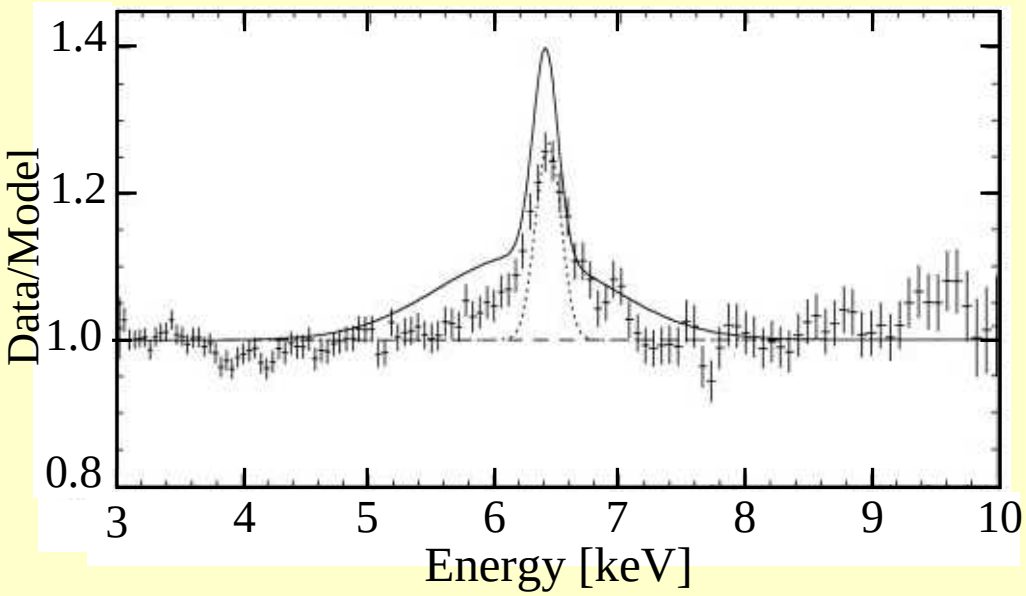
Iwasawa et al. (1996): "deep minimum state": extremely broad line $\Longrightarrow$ Kerr Black Hole.

Later confirmed with *BeppoSAX* (Guainazzi et al., 1999) and *RXTE* (Lee et al., 1999).

Broad Lines with ASCA



(Nandra et al., 1997, Fig. 4b)

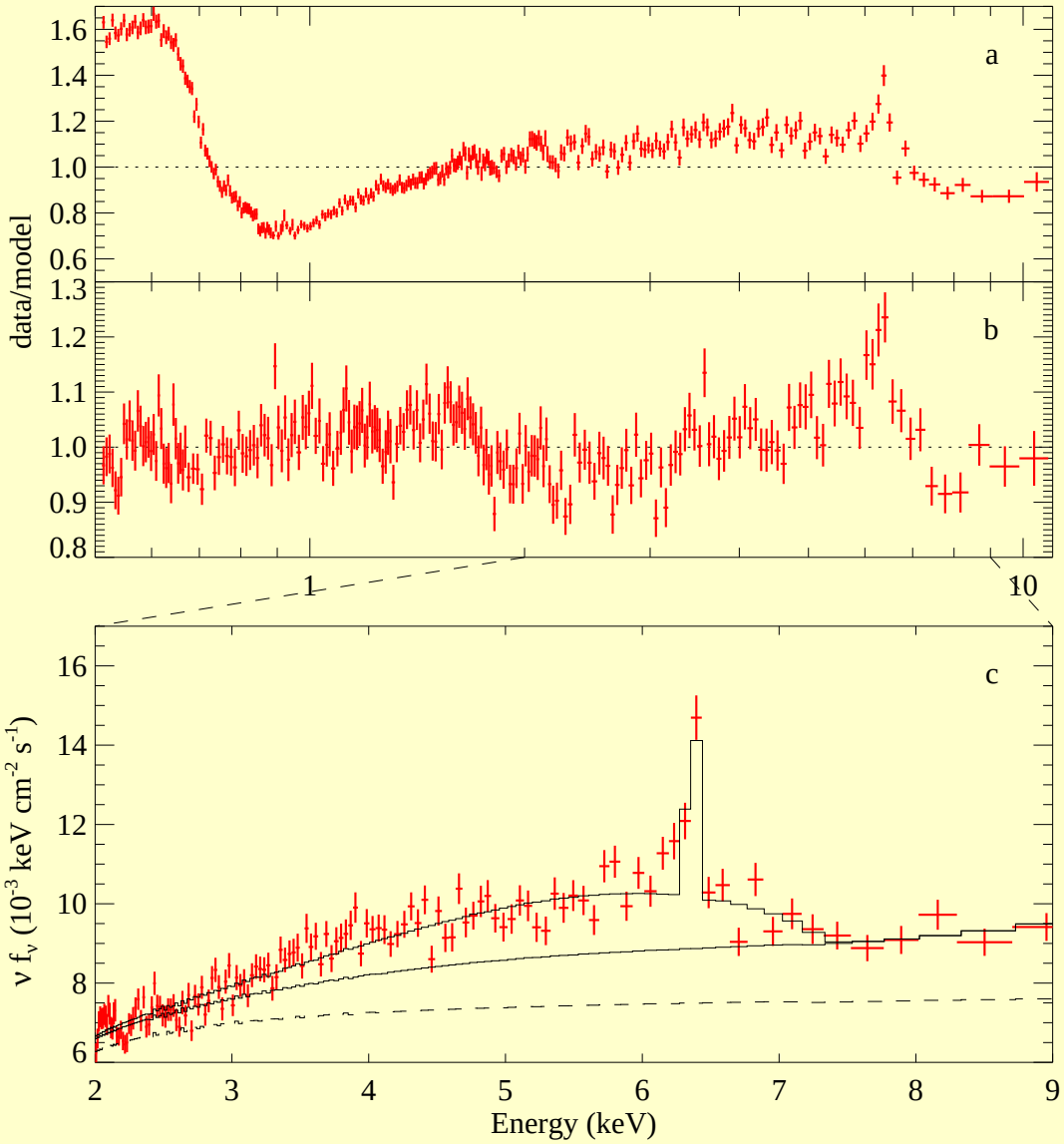


(Lubiński & Zdziarski, 2001, Fig. 2a)

ASCA: Average Seyfert Fe Kα profile contains a narrow core and a red and blue wings, but they are much weaker than MCG−6-30-15.

Best case: MCG−6-30-15

MCG−6-30-15, II



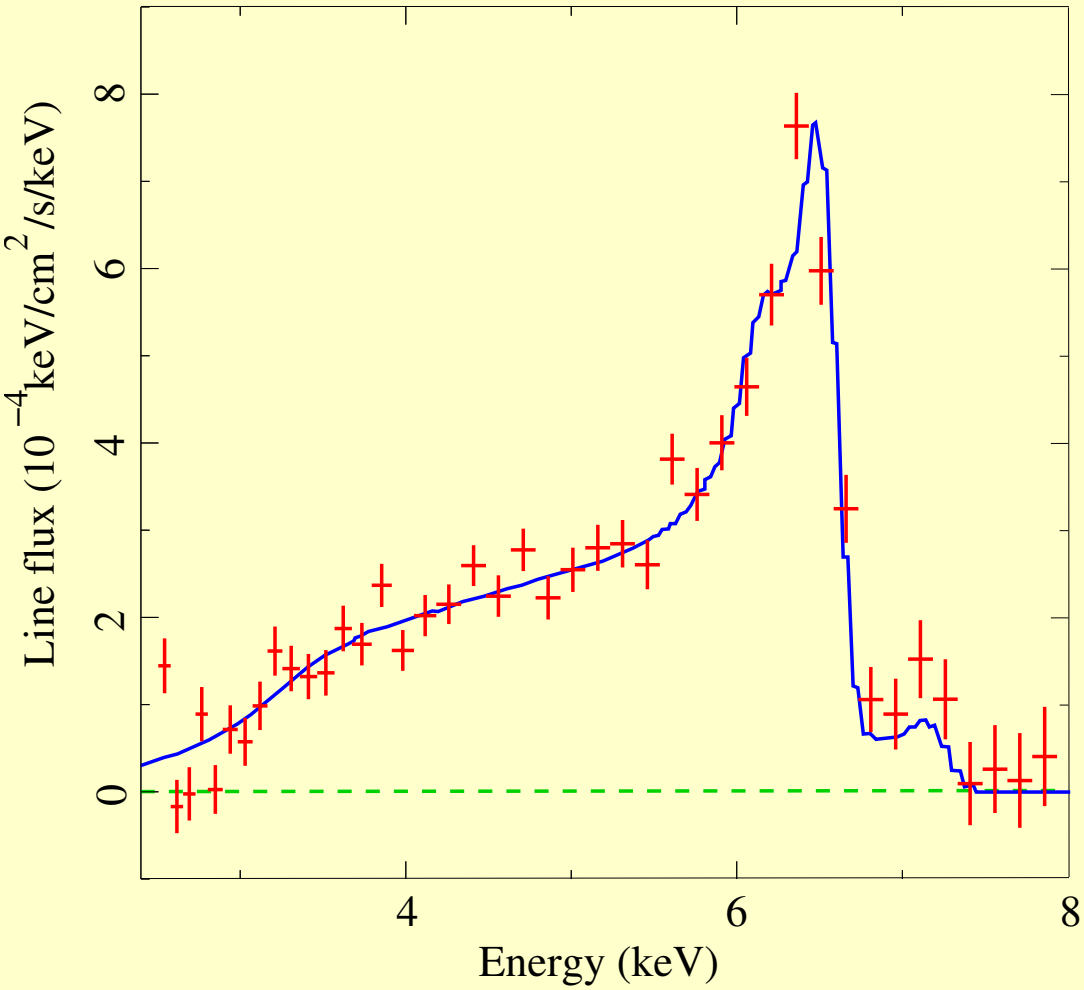
pure PL fit

Better modeling of soft excess and reflection $\Longrightarrow$ Fe Kα line has extreme width and skewed profile.

Components of the final fit.
$\Longrightarrow$ Line emissivity is strongly concentrated towards the inner edge of the disk ($\epsilon \propto r^{-4/6}$; cannot be explained with standard α-disk)

(*XMM-Newton*, June 2000, 100 ksec; Wilms et al., 2001)

MCG−6-30-15, III



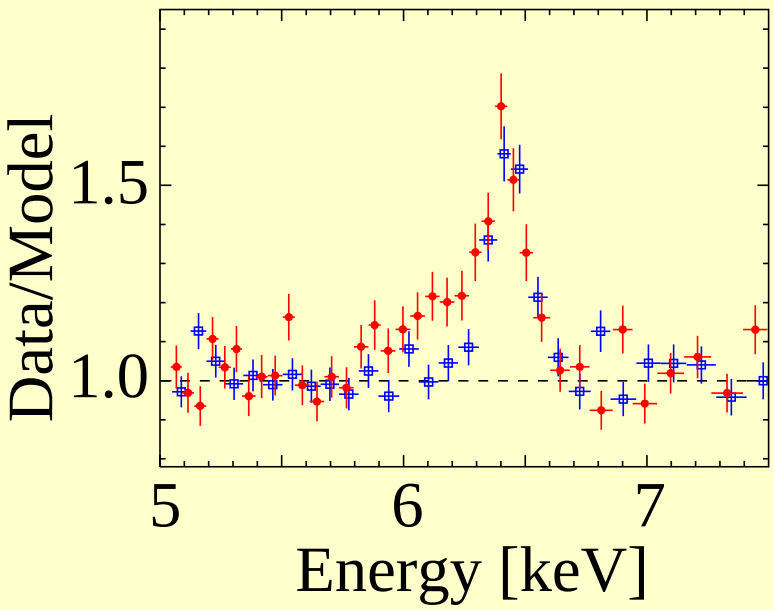
Fabian et al. (2002)

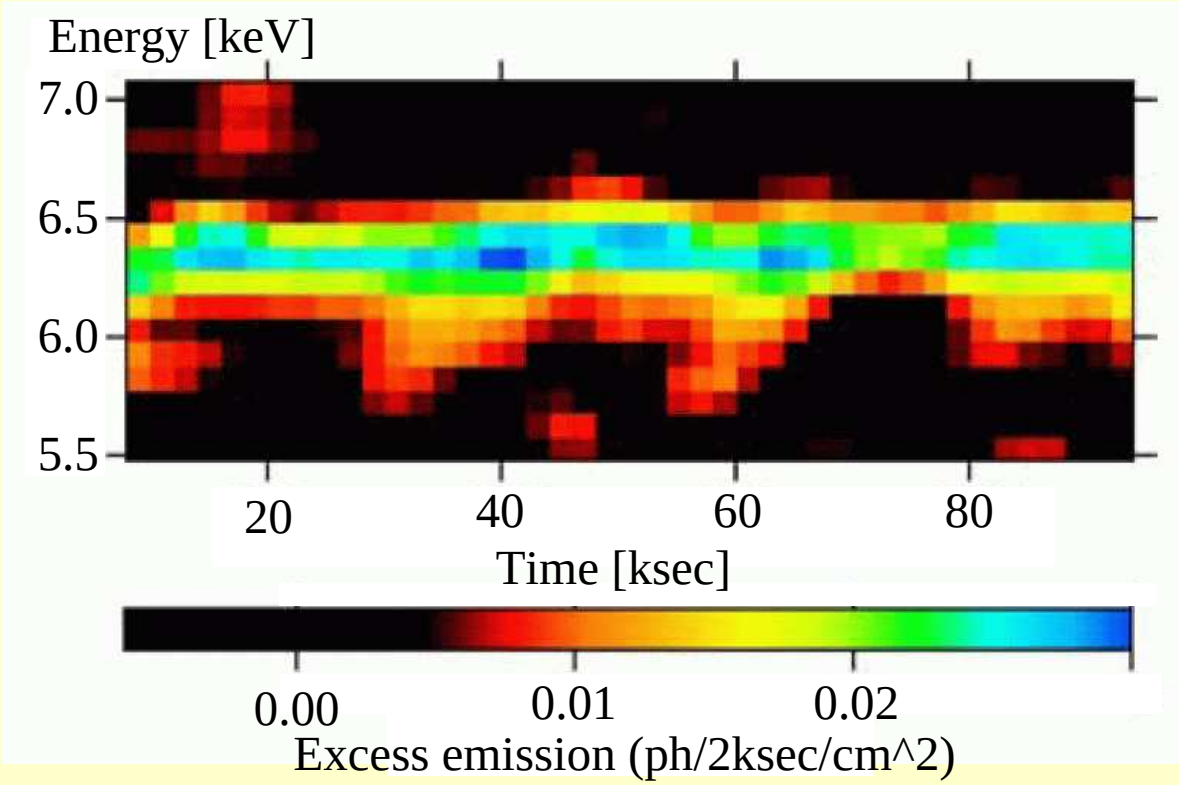
2001 July/August: 315 ksec observation (Fabian et al., 2002)

- Strong narrow line
- broad line clearly present
- emissivity profile very steep for radii close to $r_{\rm in}$

  $I_{\rm Fe\,K\alpha} \propto r^{-5.5\pm0.3}$ for $r < 6.1^{+0.8}_{-0.5} r_{\rm g}$, $\propto r^{-2.7\pm0.1}$ outside that; Fabian & Vaughan (2003); confirms Wilms et al. (2001)

Other Sources



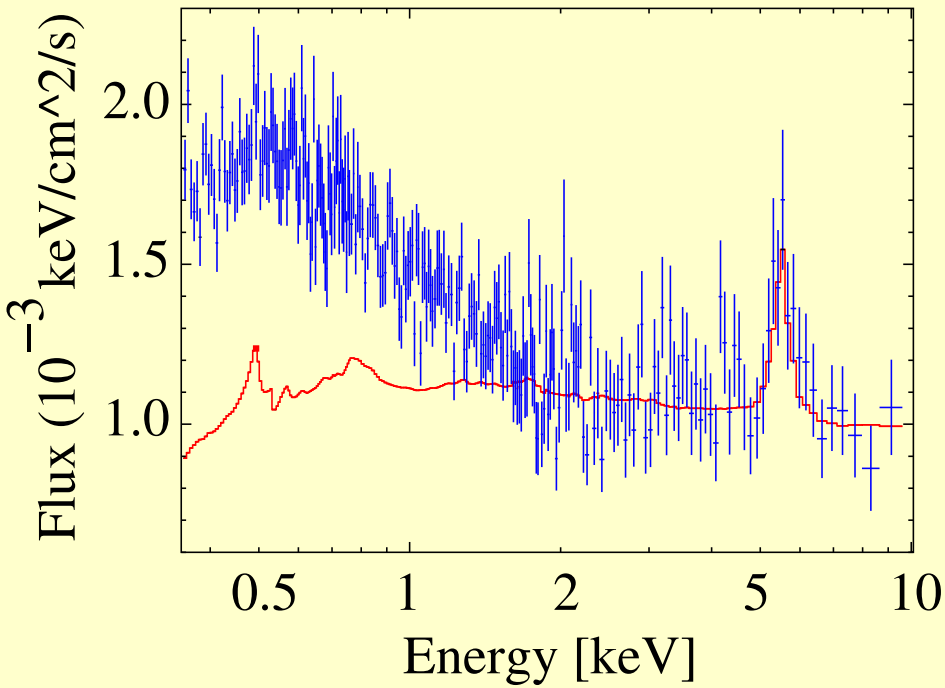


(Iwasawa, Miniutti & Fabian, 2004, Figs. 3,4)

Line profile variability in NGC 3516 $\Longrightarrow$ Corotating flare? ($7r_g \lesssim r \lesssim 16r_g$)

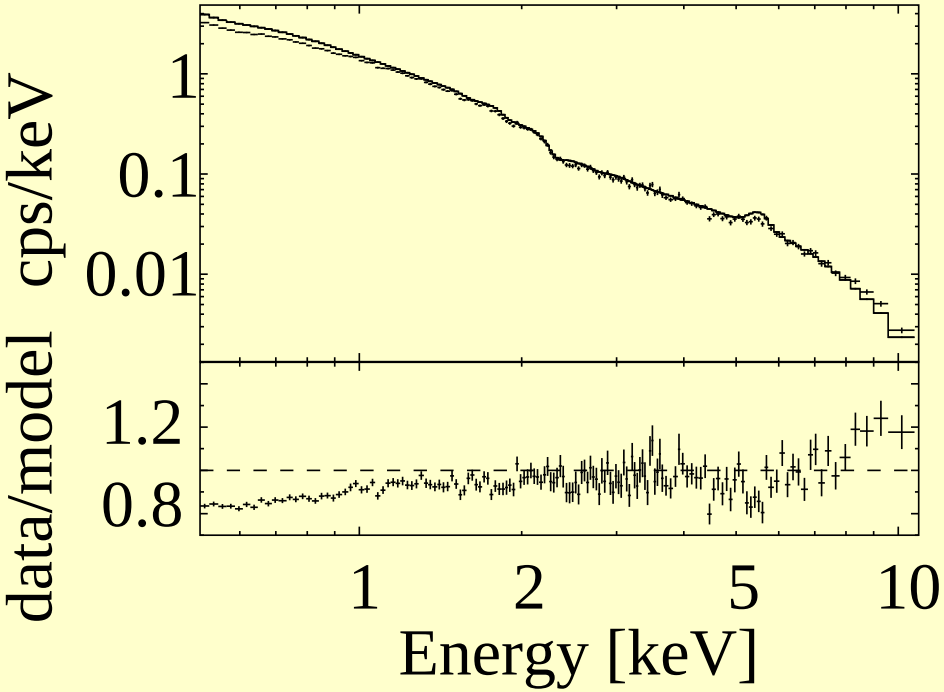
If interpretation is pushed further, gives $M \sim (1 \ldots 5) \times 10^7\, M_\odot$.

Other Sources



(Porquet & Reeves, 2003, Fig. 3)

XMM data from 2001



(Matt et al., 2005, Fig. 1)

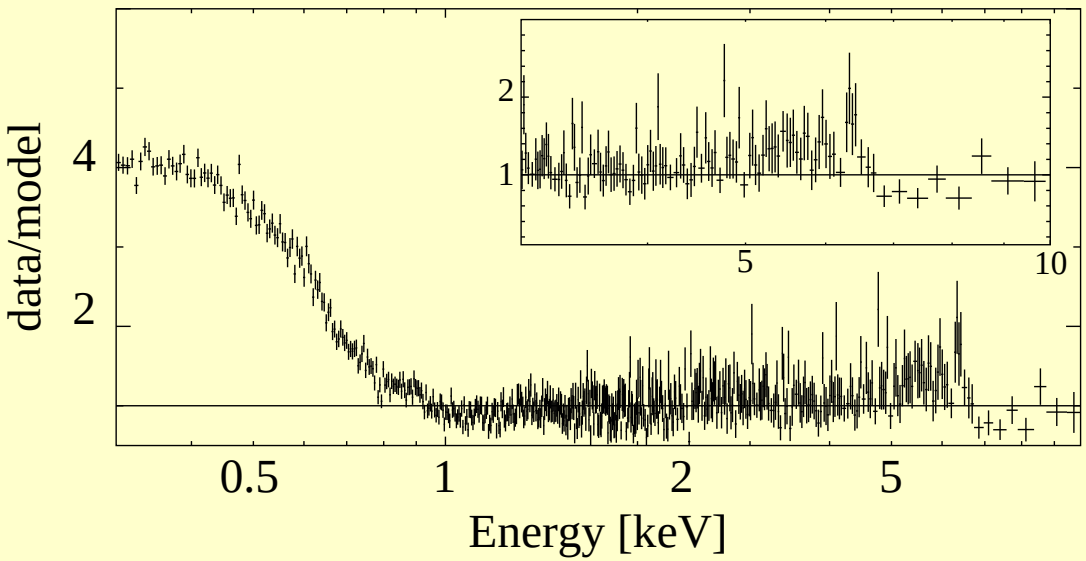
comparison 2003 vs. 2001 data

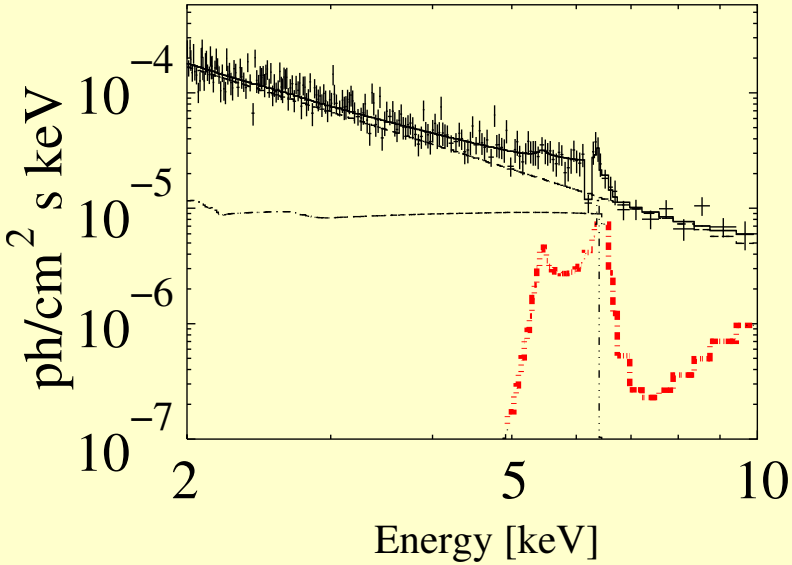
Q0056−363 (broad line radio-quiet quasar, $L_X > 10^{45}$ erg s^{-1}):

Fe Kα has FWHM 24500 km s^{-1}, EW 275 eV

Q0056−363 is highest luminosity radio-quiet QSO with broad Fe Kα line.

Other Sources





(Longinotti et al., 2003)

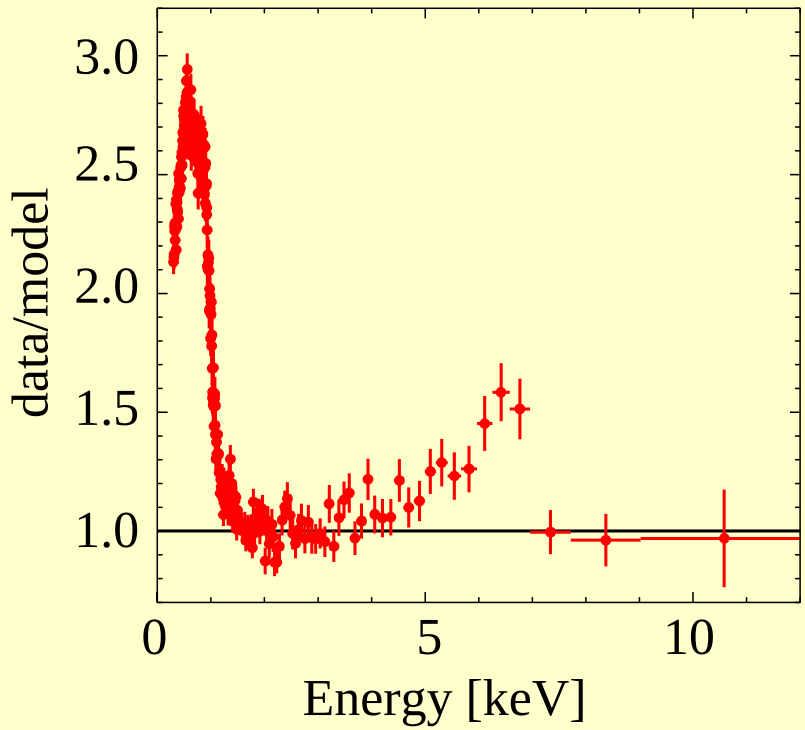
IRAS 13349+2436:

- Model either 2 broad emission lines *or*
- relativistic line from Fe XXIII/XXIV plus narrow absorption feature

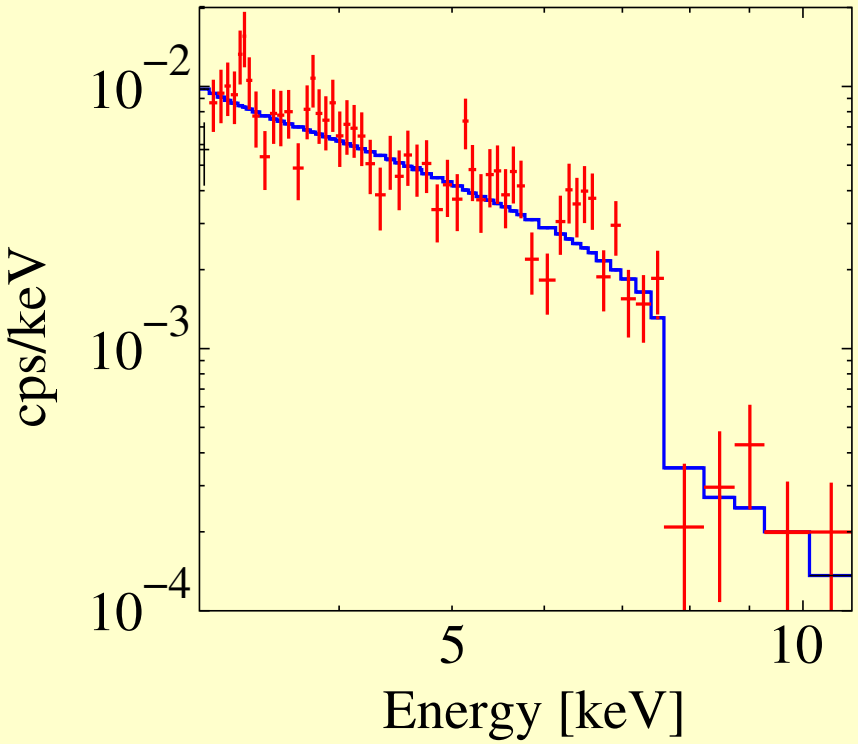
Line shape can be rather complex!

Other examples include *blue*shifted lines, e.g., in Mkn 205 (Reeves et al., 2001) or Mkn 766.

Absorption or Lines?



(1H0707−495; Fabian et al., 2004)



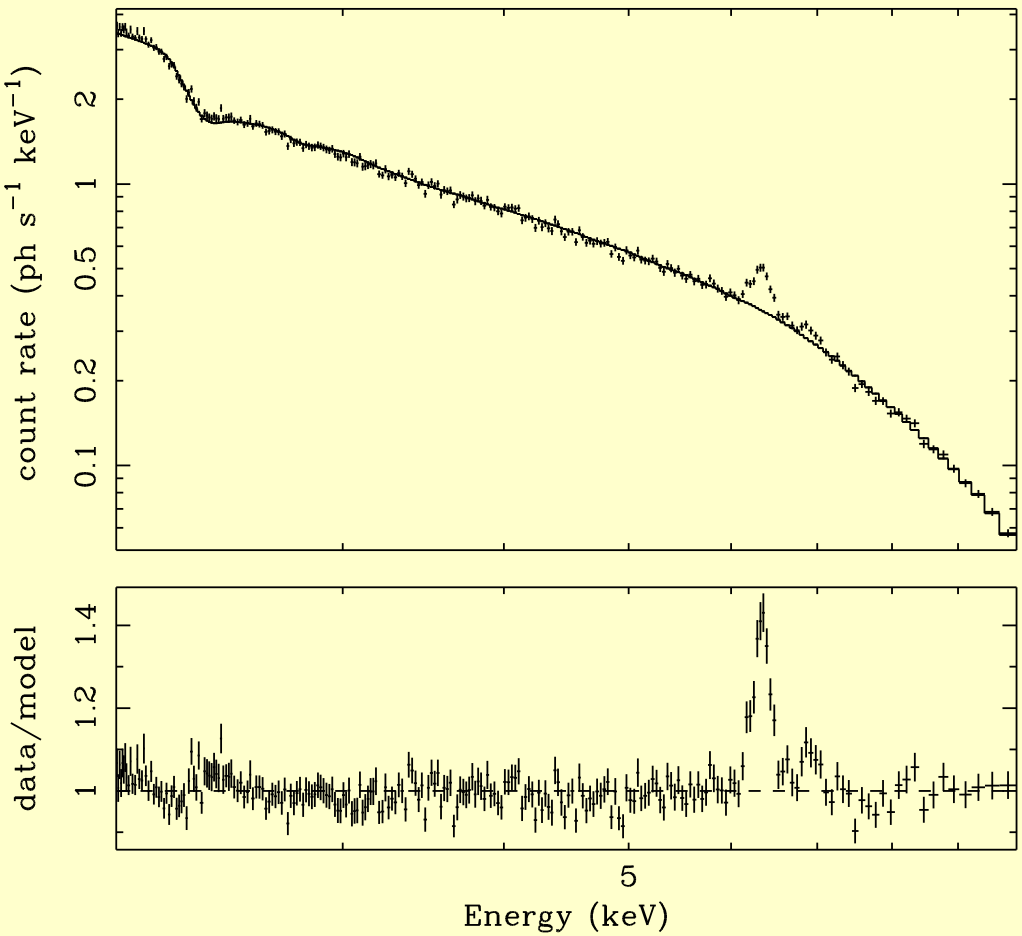
(IRAS 13224−3809; Boller et al., 2003)

NLSy1: Strong absorption or a relativistic line fron a reflection dominated spectrum both describe the data equally well!

Similar results have been found by Pounds et al. in a variety of sources. . .

But: strong absorption models contradict observations where data >10 keV available.

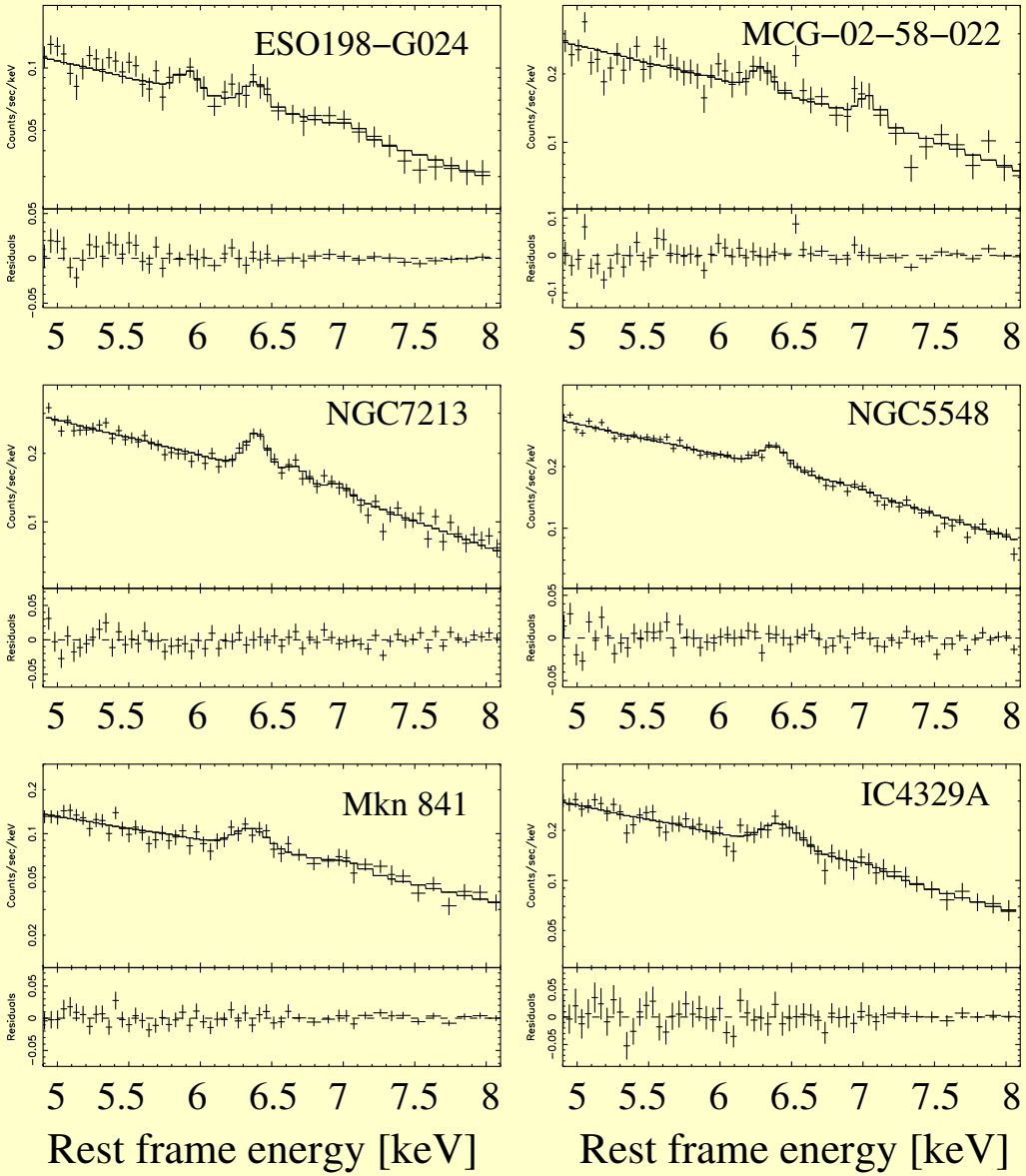
Narrow Lines



(NGC 4258; Reynolds et al. 2004)

The majority of Seyfert galaxies and QSOs do *not* show evidence for broad Fe Kα lines!

Narrow Lines



The majority of Seyfert galaxies and QSOs do *not* show evidence for broad Fe Kα lines!

statistics for PG-QSO: 20/38 show Fe Kα line, of these 3 have broad line (Jiménez-Bailón et al., 2005)

Bianchi et al. (2004, Fig. 4)
[Sample of Seyferts with simultaneous *BeppoSAX* observations.]

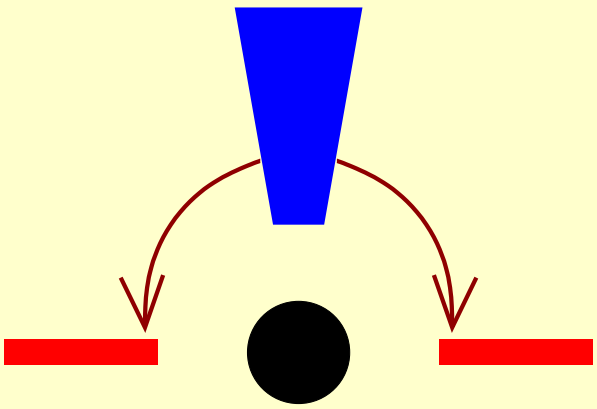
Conclusions, I

Relativistically broadened Fe Kα lines clearly do exist in a variety of different AGN

We need to rethink the details of the accretion process and the accretion geometry close to black hole:

- Energy extraction for extremely broad lines?

  Coupling BH – disk, structure of the inner disk (no torque condition?, structure of the infall region,. . .)



- "Lamppost model"?

  (Petrucci & Henri, 1997; Martocchia, Matt & Karas, 2002; Miniutti & Fabian, 2004)

  $\Longrightarrow$ X-rays focused down from the jet base?

  $\Longrightarrow$ If true, is continuum Comptonization?

  Fender et al. (2004), Markoff, Nowak & Wilms (2005) for galactic BHs

Conclusions, II

To be successful, models will have to consider:

- Broad Fe Kα lines are rare:
  - Truncated Disks?

    e.g., invoked by Zdziarski et al. (1999) to explain $\Omega/2\pi$-Γ-correlation
  - Disk ionization (but needs fine tuning!)
  - And what about the Unified Model?

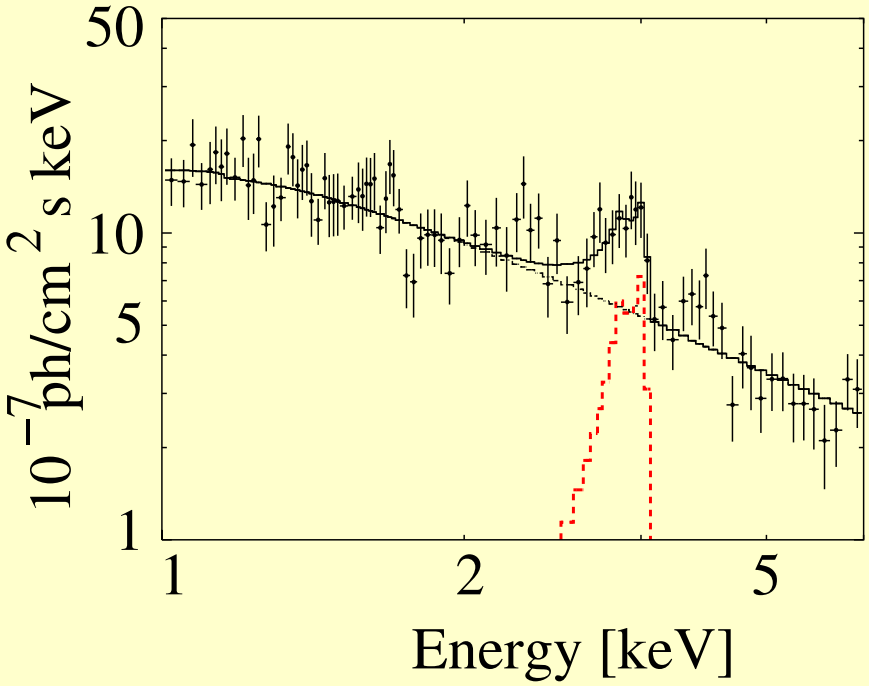
    Is the viewing angle really edge on?
- Narrow lines are ubiquitous:
  - Are they formed in the torus?

    but narrow lines often have FWHM$\sim$4000–7000 km s^{-1}

    $\Longrightarrow$ too large for torus! (expect $\sim 760\,\mathrm{km\,s^{-1}}(M_8/r_{\mathrm{pc}})^{1/2}$)
  - Do they originate in the BLR or an ionized disk?

. . . and we should not forget the observational constraints: Strong Fe Kα variability $\Longrightarrow$ we need a larger collecting area (XEUS!)

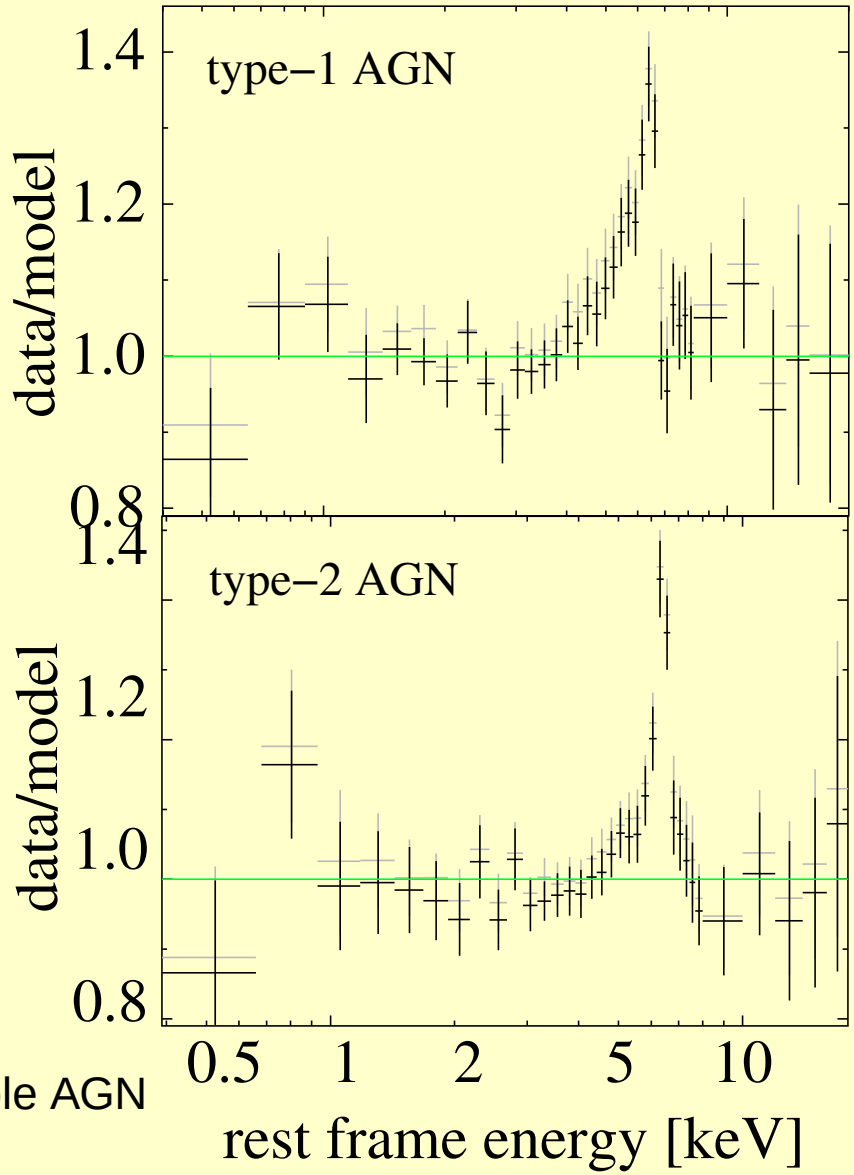
The Future



(Comastri, Brusa & Civano, 2004, *Chandra*)

CXO J123716.7+621733 (CDF-N; $z = 1.146$)

Broad Fe Kα lines already present in high-z universe!



Average Fe line for the Lockman hole AGN (Streblyanska et al., 2005)

*

Bianchi, S., Matt, G., Balestra, I., Guainazzi, M., & Perola, G. C., 2004, A&A, 422, 65

Boller, T., Tanaka, Y., Fabian, A., Brandt, W. N., Gallo, L., Anabuki, N., Haba, Y., & Vaughan, S., 2003, MNRAS, 343, L89