PART 2: OBSERVATIONS

OVERVIEW

- Observations

  2.1 The X-ray continuum source

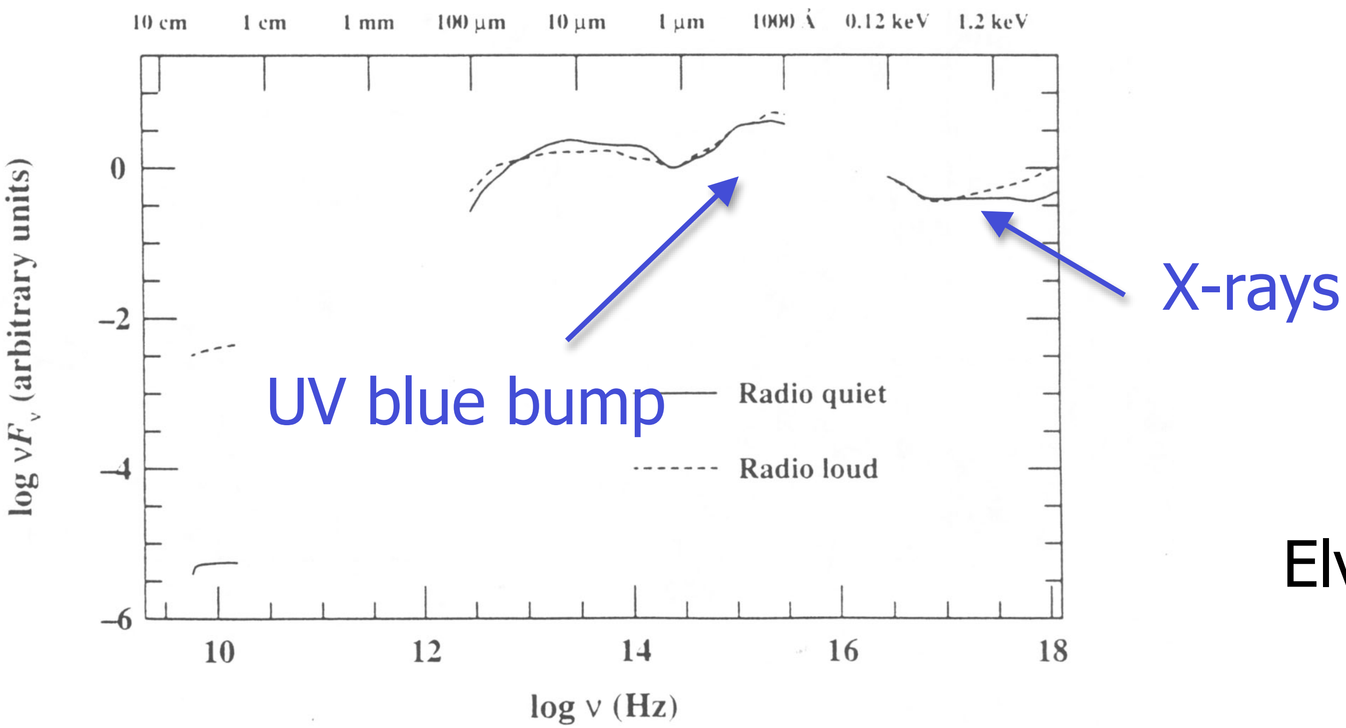
  2.2 The iron Kα line and Compton reflection

  2.3 Absorption

  2.4 The soft excess

2.1 THE X-RAY CONTINUUM

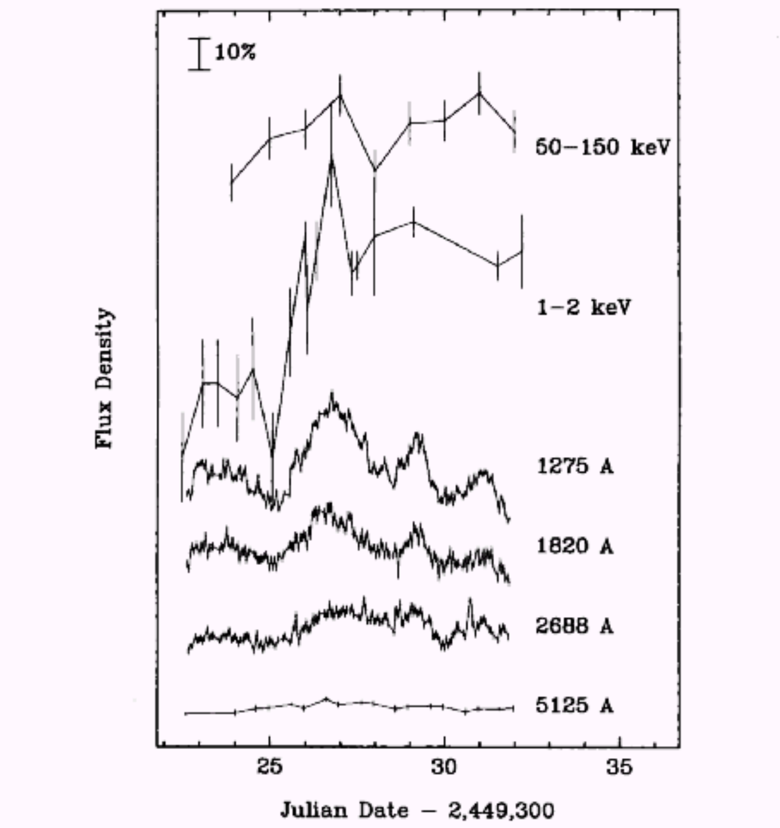
- Standard disk theory predicts T_{max}~10^5K
- XUV “blue bump” in spectral energy distribution (SED)
- Strong X-ray emission also seen – too hot for disk
- Hotter “corona” upscatters disk photons



Elvis et al. 1994

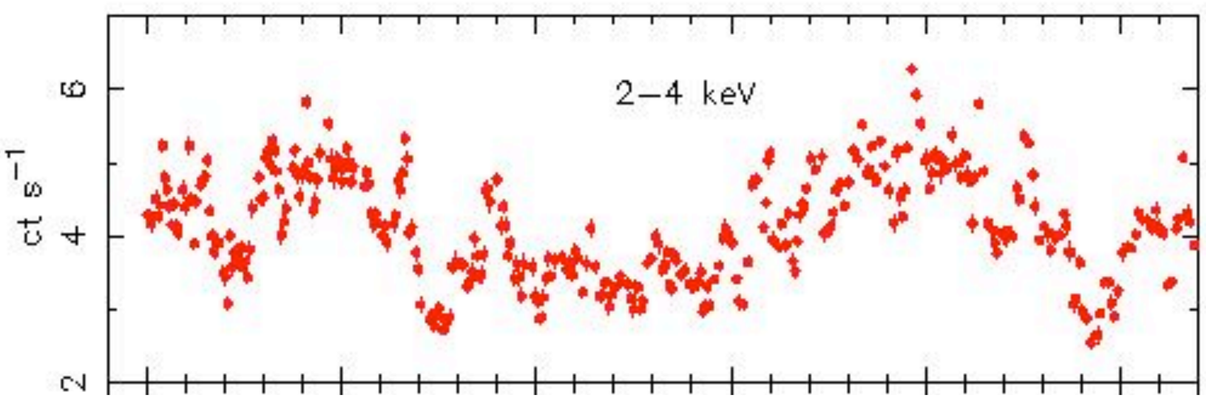
DISK EMISSION

- Primary disk emission in optical/UV/EUV
- Fits well to blackbody disk spectrum
- (Relatively) fast, simultaneous opt/UV variations
- Limited progress: EUV unobservable
- X-rays can probe closer to BH



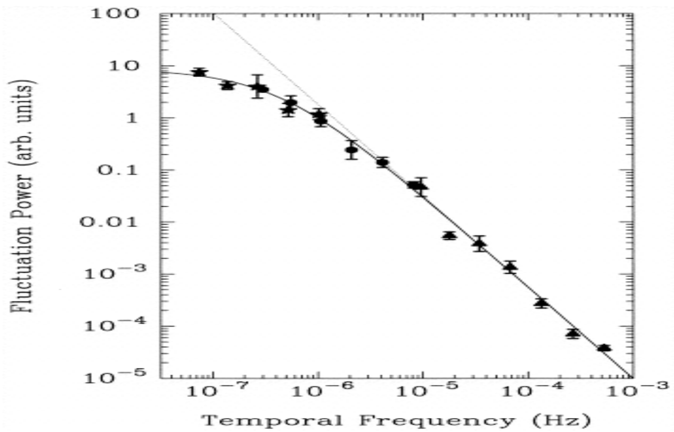
Malkan & Sargent (1982); Peterson et al. (1991); Clavel et al. (1991)

X-RAY VARIABILITY



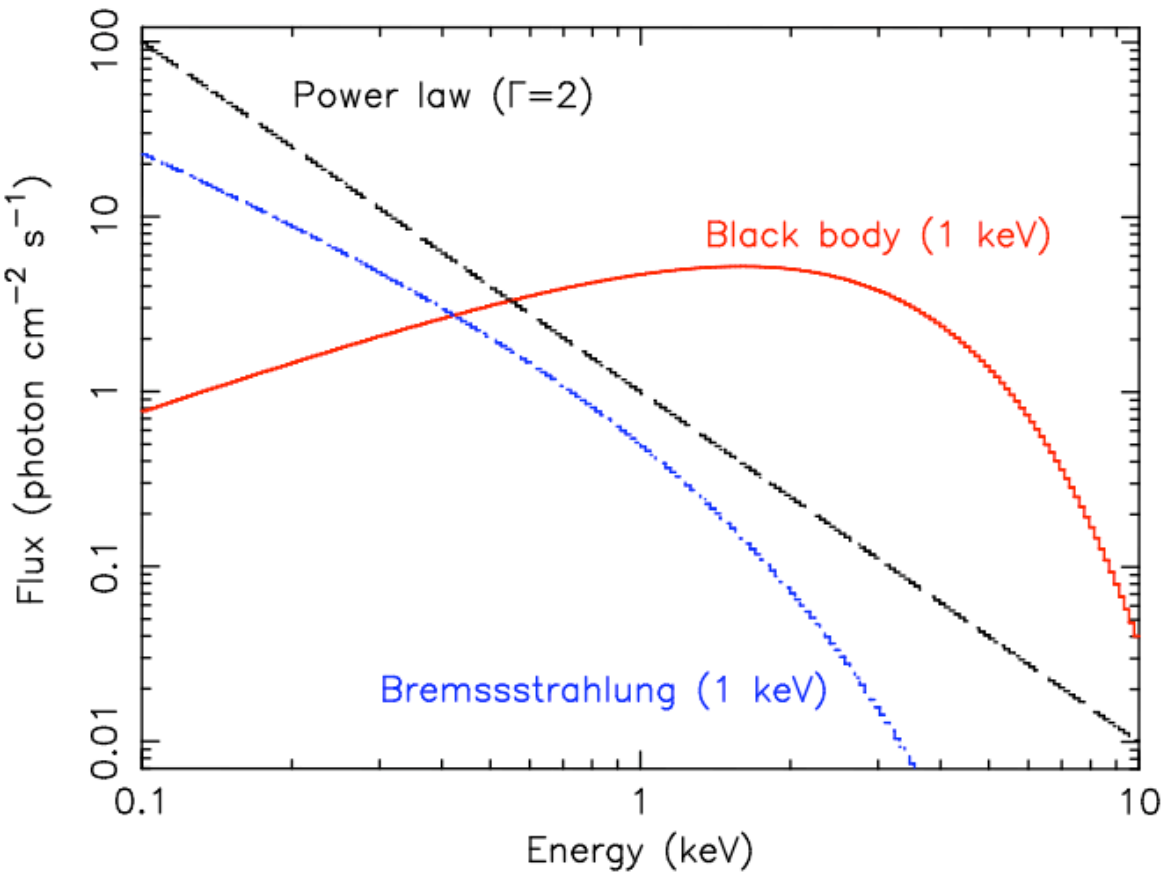
X-rays are most rapidly variable AGN component so come from closest to BH. Naively R~cδt

In reality AGN show continuous stochastic variability.
Characterize with power density spectrum (PSD) in Fourier space:



Edelson & Nandra (1998)

CONTINUUM SPECTRUM



AGN show a power law continuum with Γ=1.9-2

$$F(E) = AE^{-\Gamma} e^{-\sigma(E) N_H}$$

Nandra & Pounds (1994)

INVERSE COMPTON EMISSION

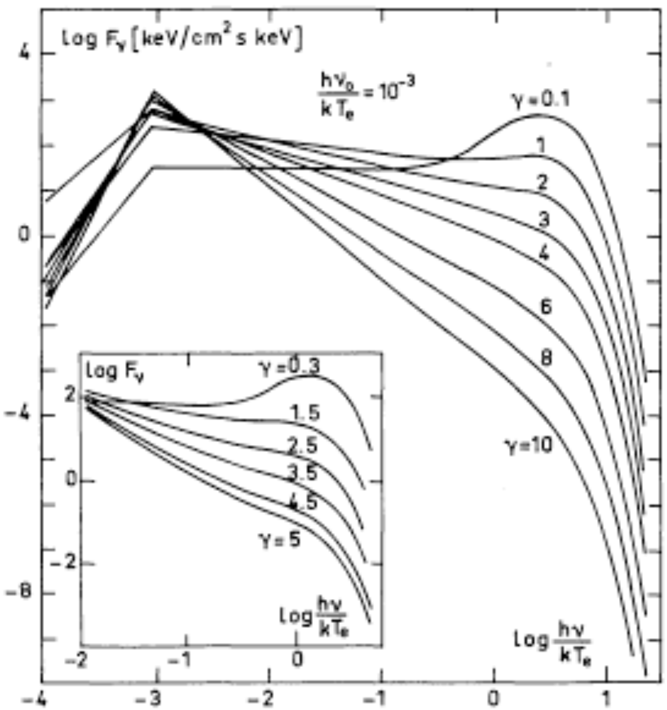


Fig. 5. The spectrum resulting from comptonization of low-frequency photons ($h\nu_0 = 10^{-3}\ kT_e$) in a high temperature plasma clouds with different parameters γ (14)

- ***Power law***

$$F(E) = AE^{-\Gamma} e^{-E/E_c}$$

$$I(E) = BE^{-\alpha} e^{-E/E_c}$$

A,B normalizations

F,Γ ***photon*** flux photon index

I,α ***energy*** flux, index ($\alpha=\Gamma$-1)

$E_c=kT$=cutoff energy

Sunyaev & Titarchuk 1980

COMPTONIZATION SPECTRA

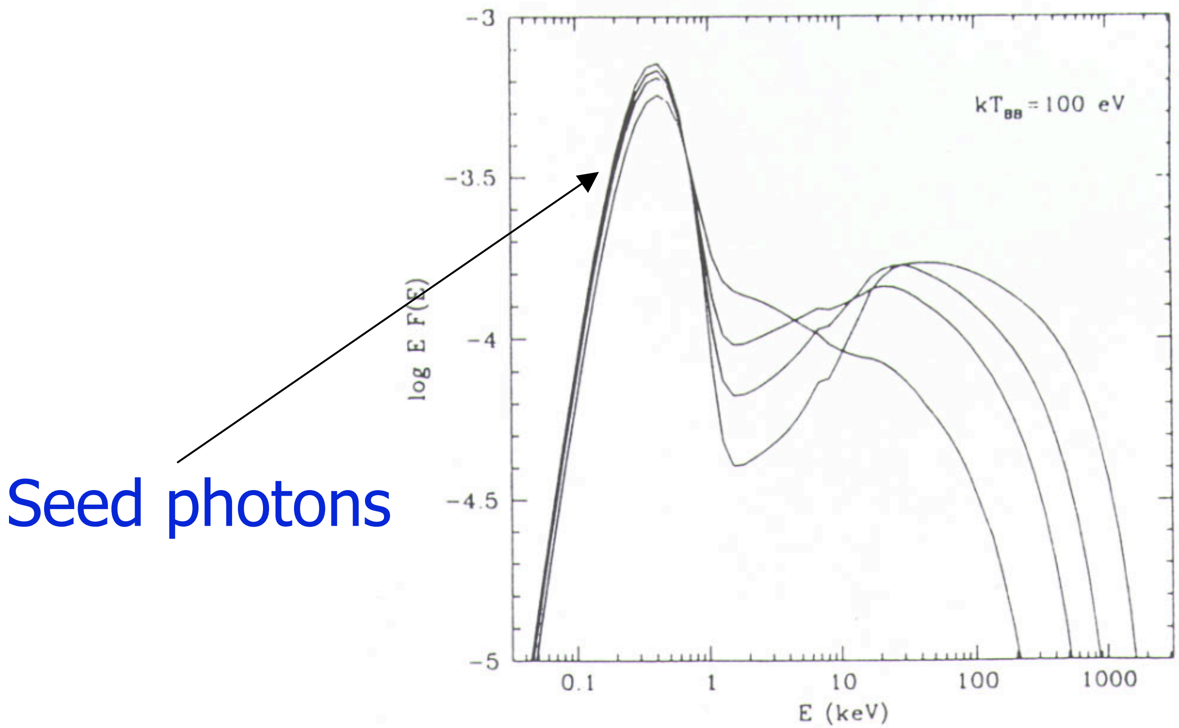
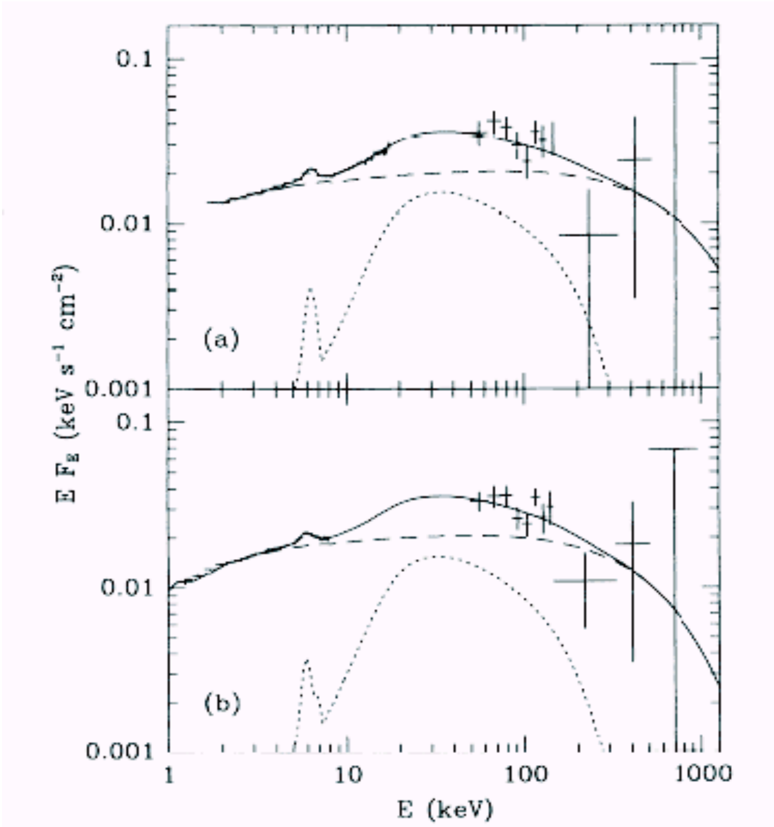


FIG. 6.—Comptonized spectra for different values of (τ, Θ) equilibrium values [(0.63, 0.11), (0.32, 0.21), (0.2, 0.3), (0.1, 0.5)]. kT_{BB} is set to 100 eV, and a face-on line of sight is considered.

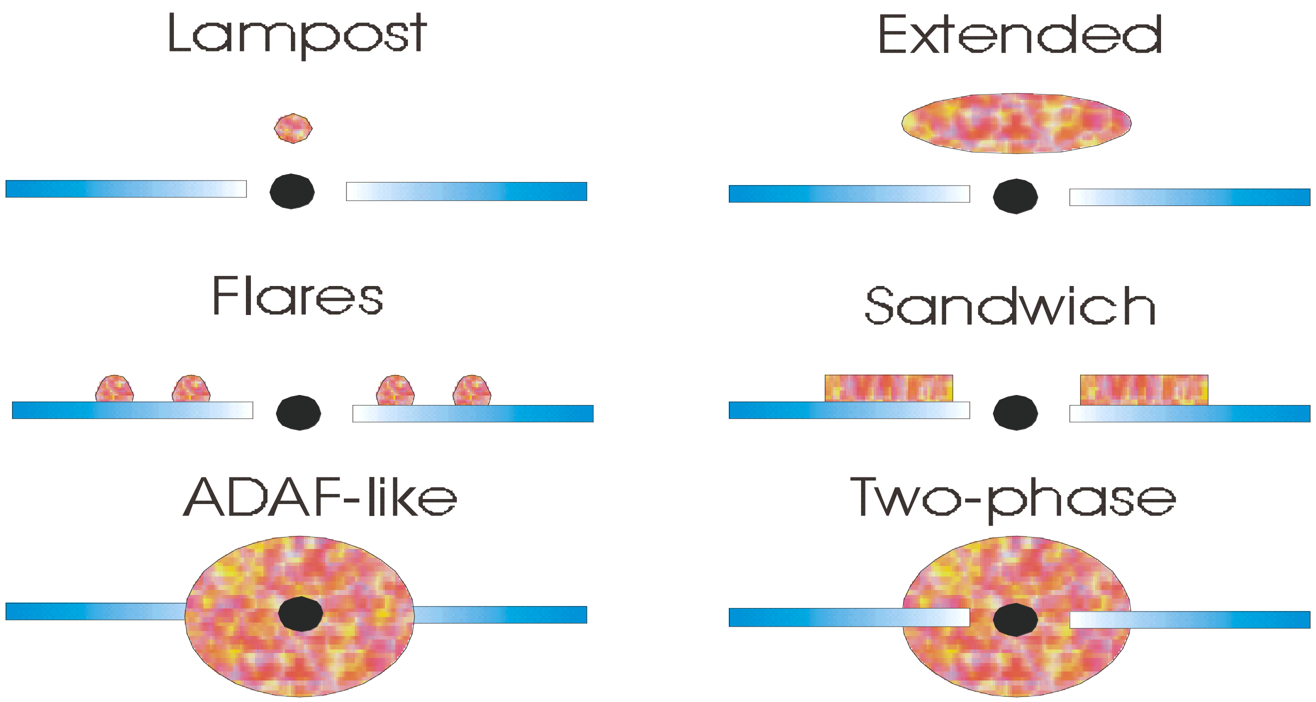
CONTINUUM SPECTRA

- Power-law form
- Photon index Γ=2.0
- High Energy cutoff E_c=100-1000 keV
- Inverse Compton scattering from thermal plasma



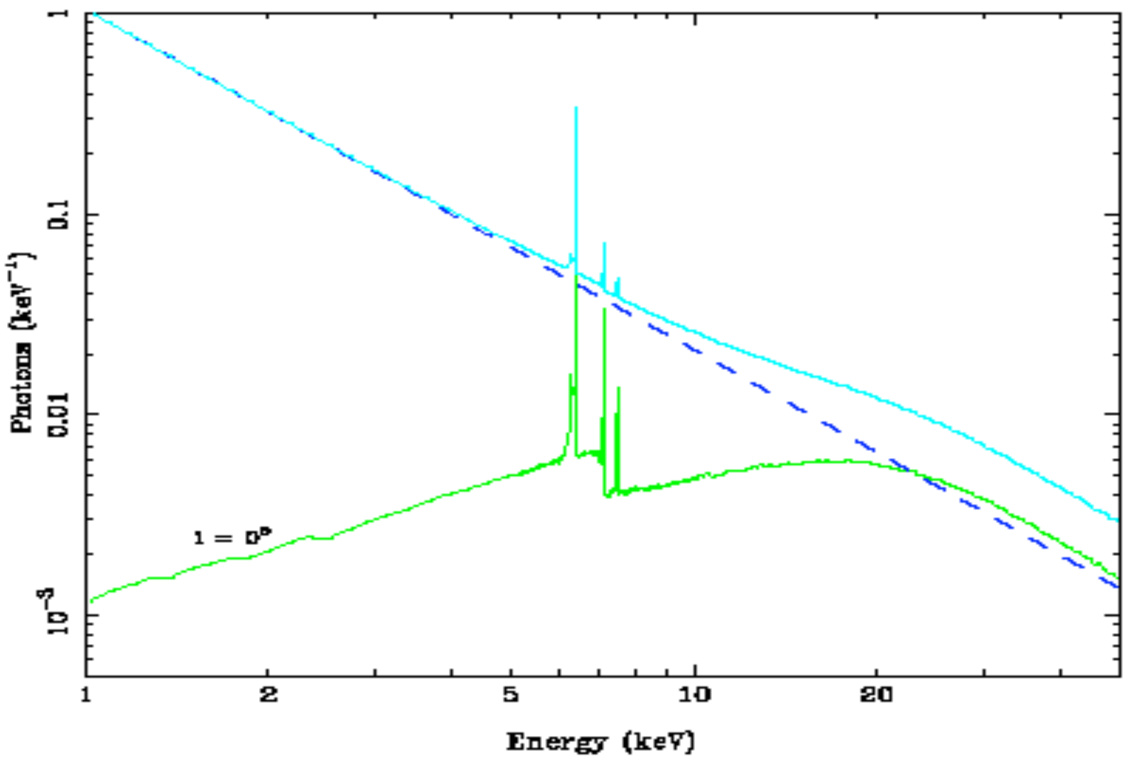
CORONA GEOMETRIES

Haardt & Maraschi (1991, 1993); Haardt, Maraschi & Ghisellini (1994); Narayan & Yi (1994, 1995); Stern et al. (1995); Lasota et al. (1996); Hua, Kazanas & Cui (1997); Reynolds & Begelman (1998); Poutanen & Fabian (1999); Nayakshin (1999); Di Mateo et al. (1999)



Physical process: Magnetic reconnection? Hot accretion flow?

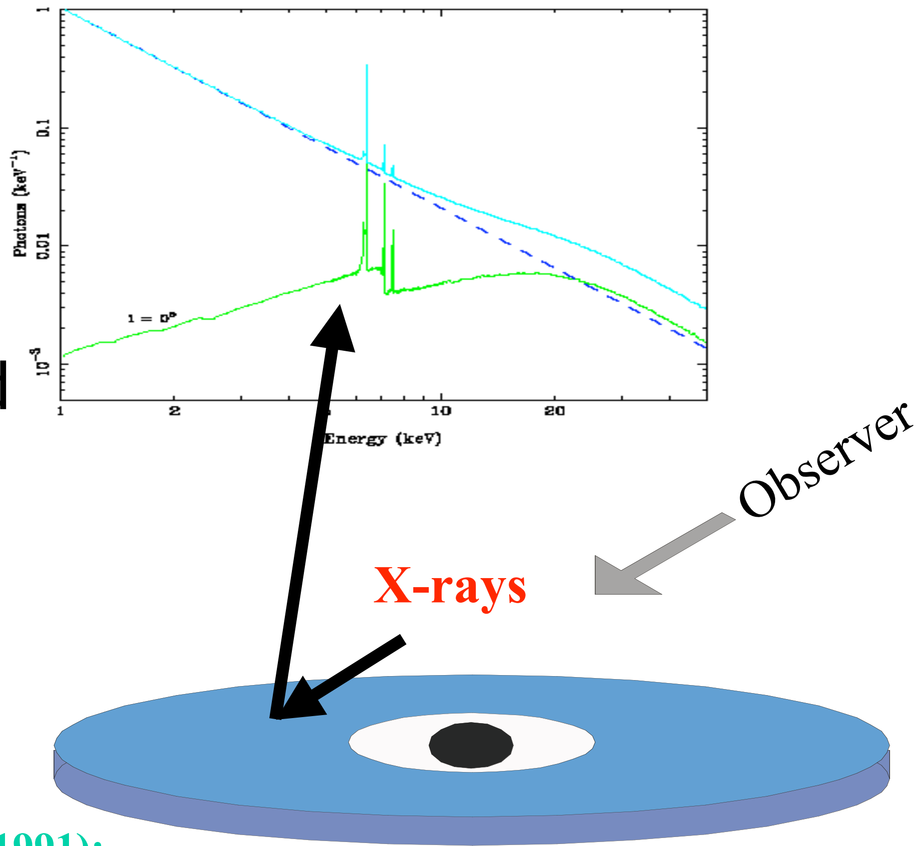
2.2 REFLECTION AND THE IRON Kα LINE



Iron Kα Emission line (fluorescence) at 6.4 keV – also broad.
The line is accompanied by a Compton scattered continuum

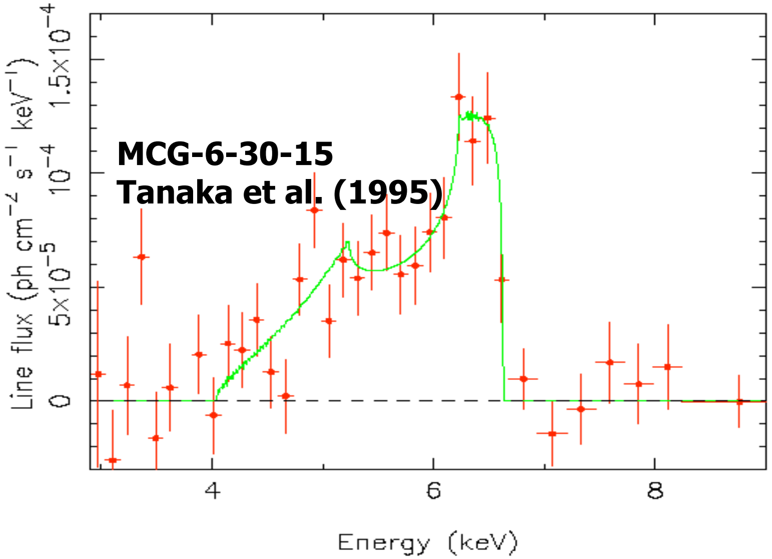
DISK REFLECTION

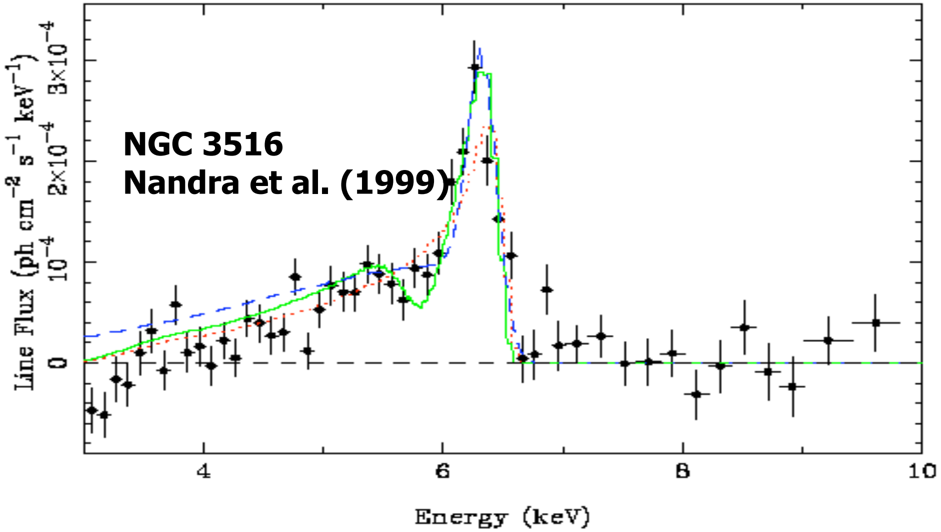
- AGN contain black hole fed by accretion disk
- X-rays illuminate disk: iron Kα fluorescence
- **Predict:** profile distorted by huge velocities and gravitational shifts
- Measure: inclination, R_{in}, R_{out}, emissivity, spin…



Fabian et al. (1989); Stella (1990); Laor (1991); George & Fabian (1991); Matt et al. (1991, 1992)

BLACK HOLE DIAGNOSTICS





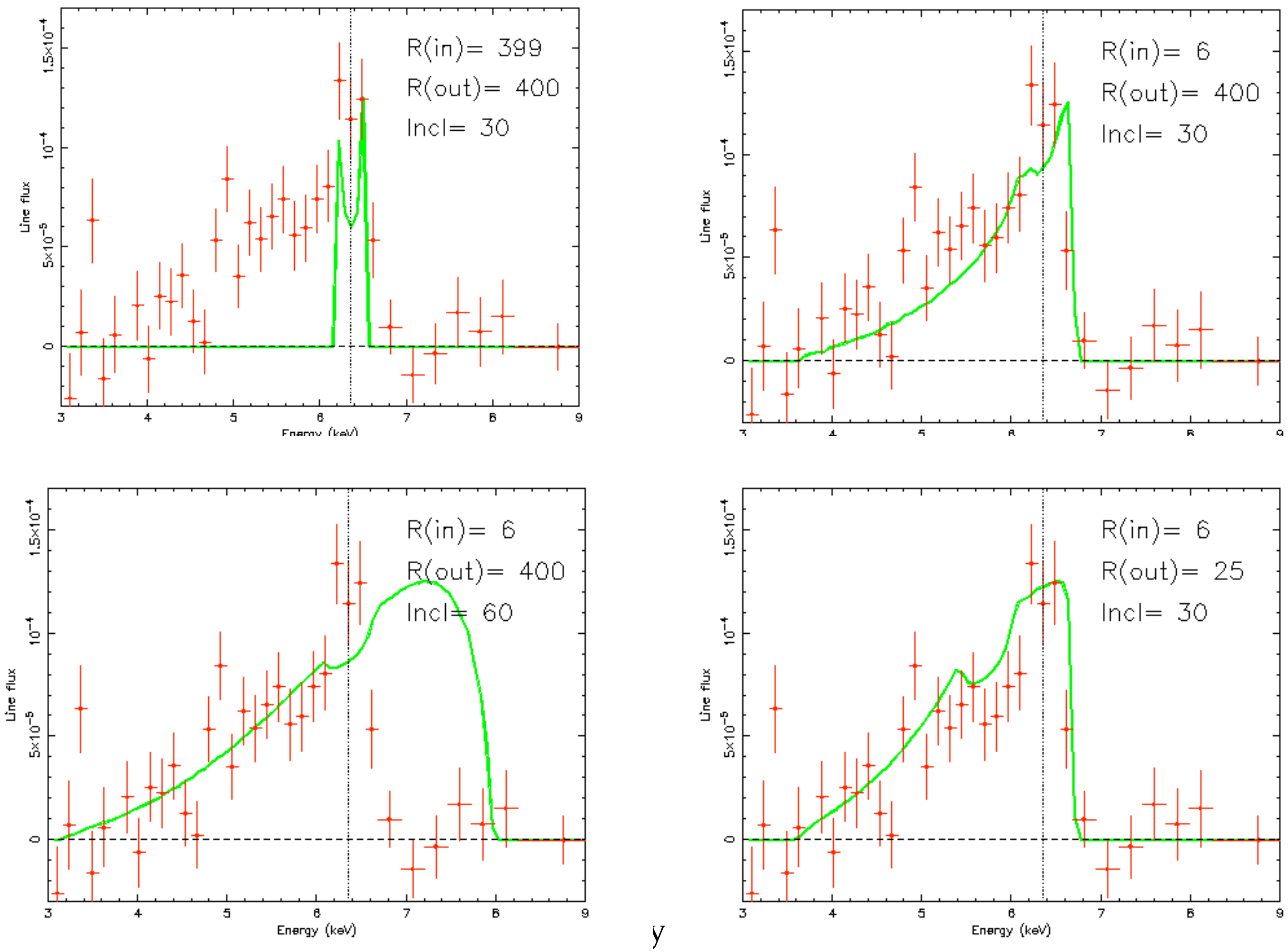
Broad, red wings
⇒gravitational redshift
(also Doppler…)

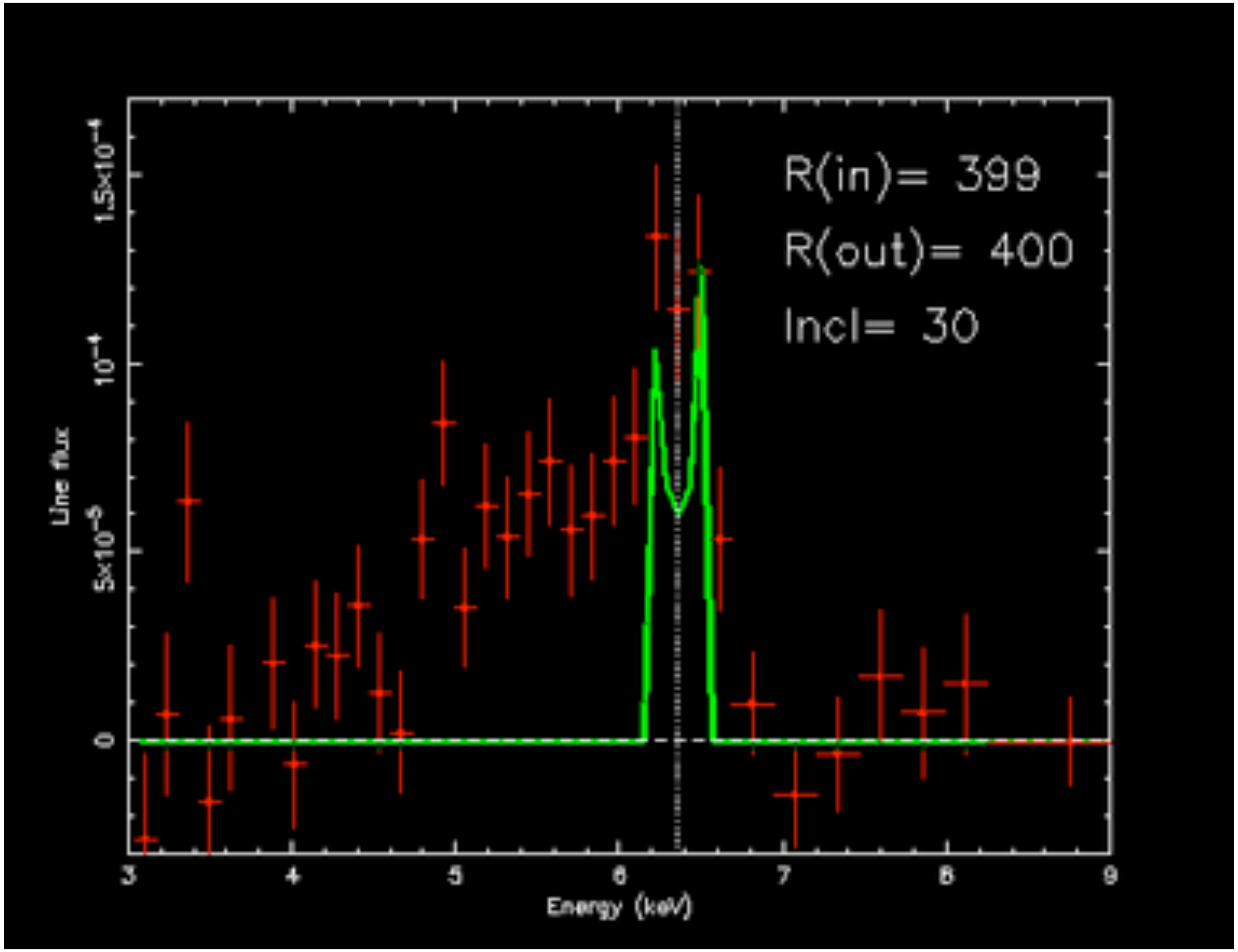
$$E_{obs} = E_{em}\sqrt{1-\frac{2R_g}{R}}$$

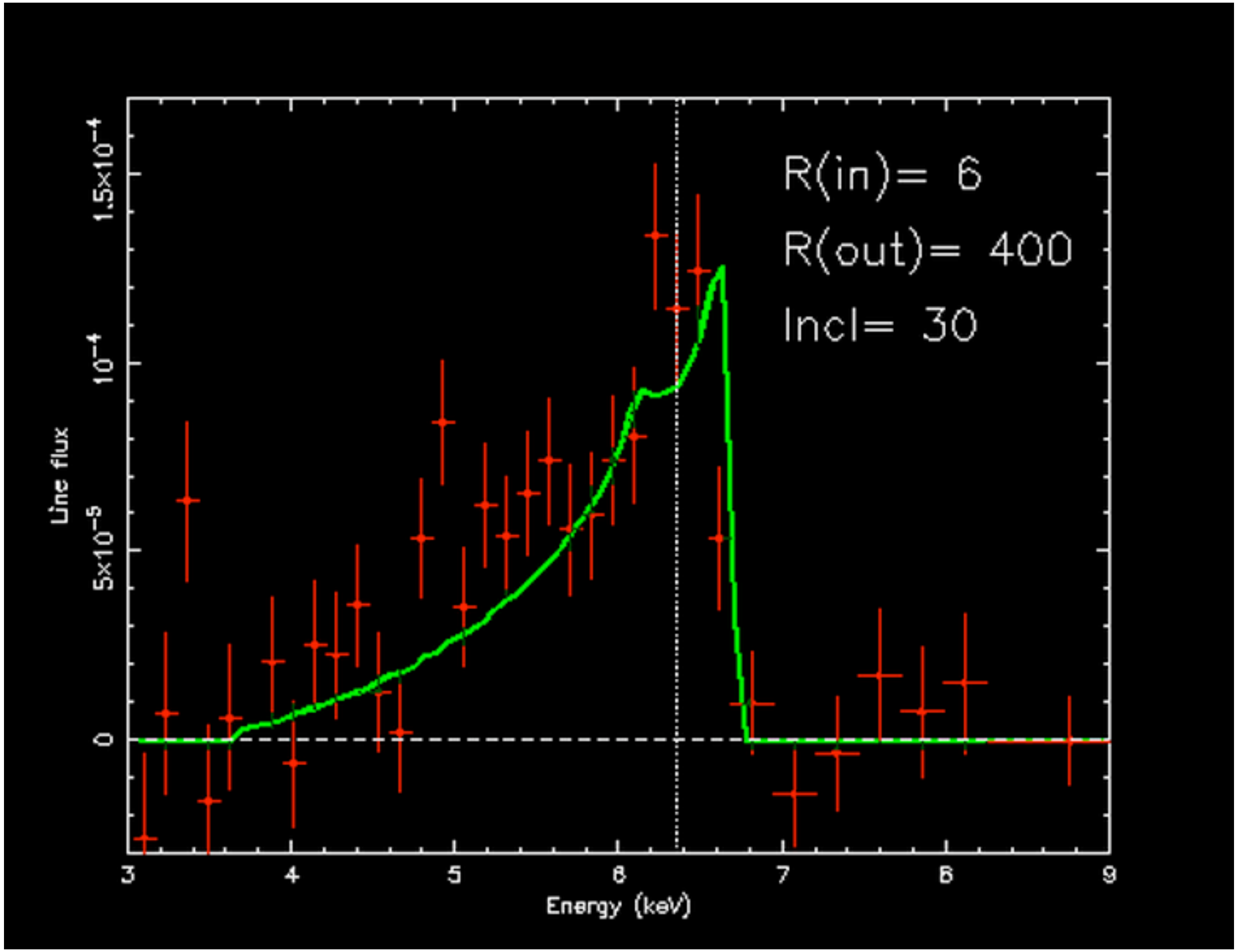
$$R_g = \frac{GM}{c^2} = 1.48\times10^{13} M_8 \text{ cm}$$

$$R_{ms} = 6R_g \quad (\sim 20\% \text{ shift})$$

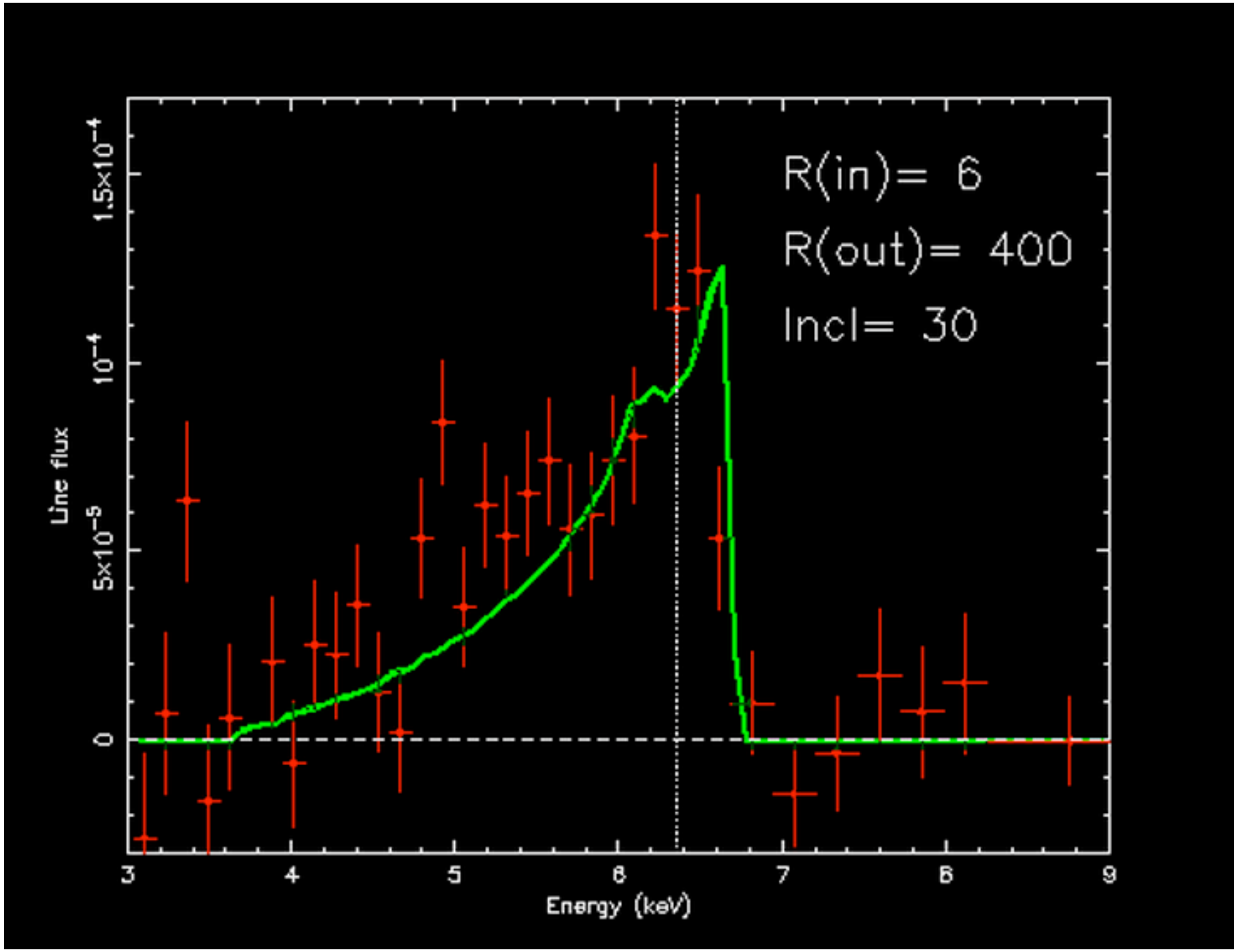
FITTING THE PROFILE

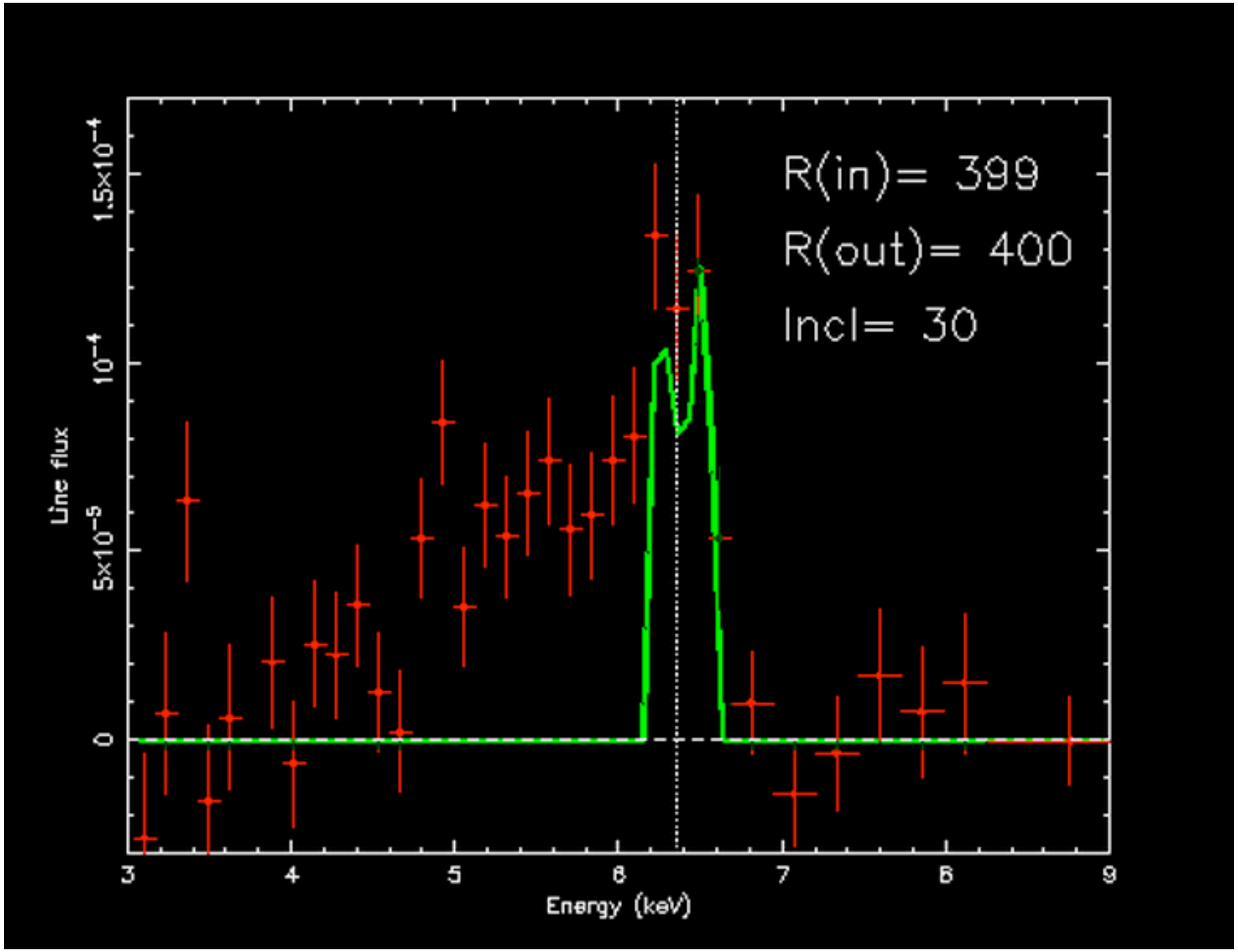


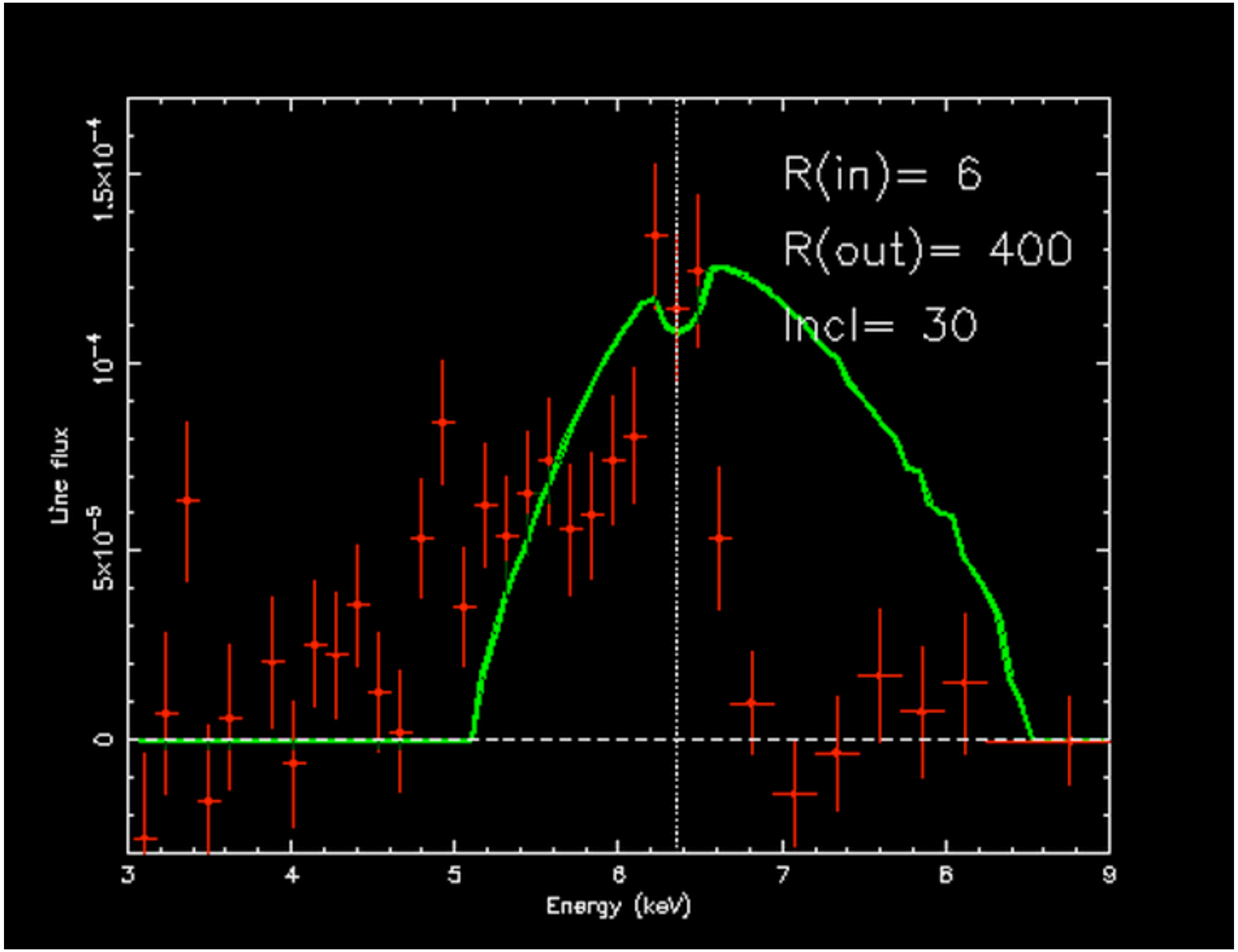

R(in)= 399
R(out)= 400
Incl= 30
Line flux
Energy (keV)
1.5×10⁻⁴
10⁻⁴
5×10⁻⁵
0
3
4
5
6
7
8
9



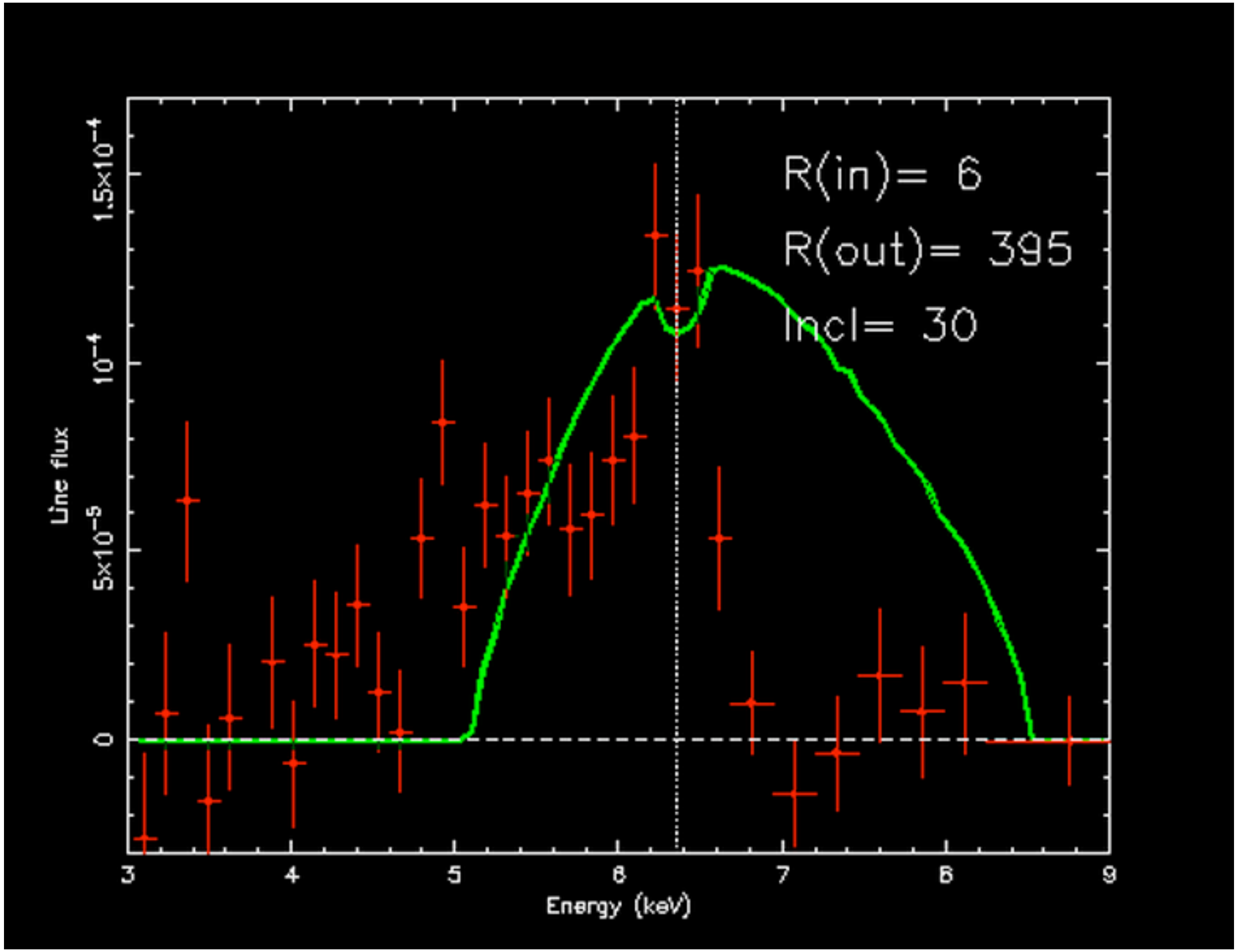
R(in)= 6
R(out)= 400
Incl= 30
Line flux
1.5×10⁻⁴
10⁻⁴
5×10⁻⁵
0
3
4
5
6
7
8
9
Energy (keV)


R(in)= 6
R(out)= 400
Incl= 30
Line flux
Energy (keV)
1.5×10⁻⁴
10⁻⁴
5×10⁻⁵
0
3
4
5
6
7
8
9

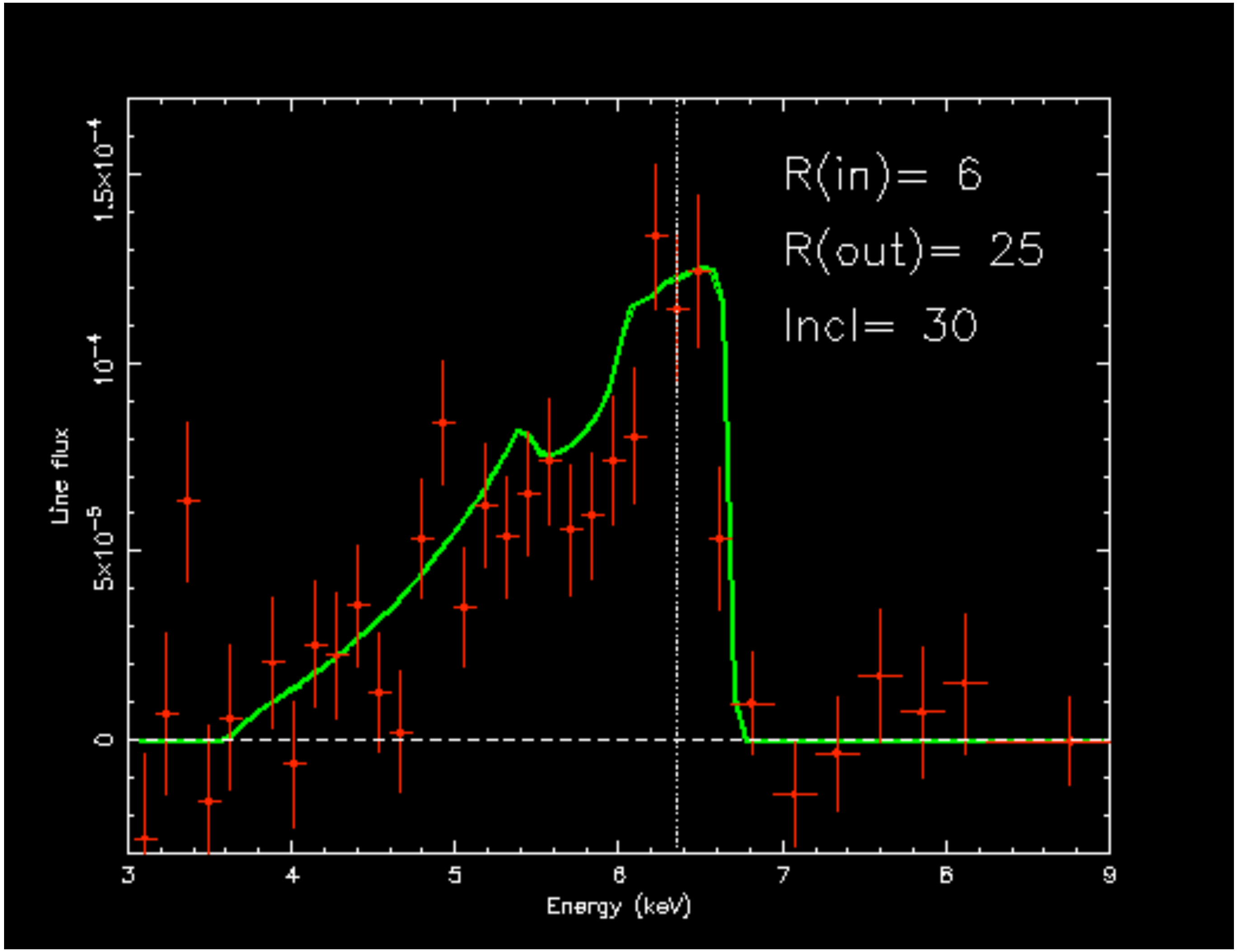

R(in)= 399
R(out)= 400
Incl= 30
Line flux
1.5×10⁻⁴
10⁻⁴
5×10⁻⁵
0
Energy (keV)
3
4
5
6
7
8
9



R(in)= 6
R(out)= 400
Incl= 30
Line flux
Energy (keV)



R(in)= 6
R(out)= 395
Incl= 30
Line flux
Energy (keV)
1.5×10⁻⁴
10⁻⁴
5×10⁻⁵
0
3
4
5
6
7
8
9

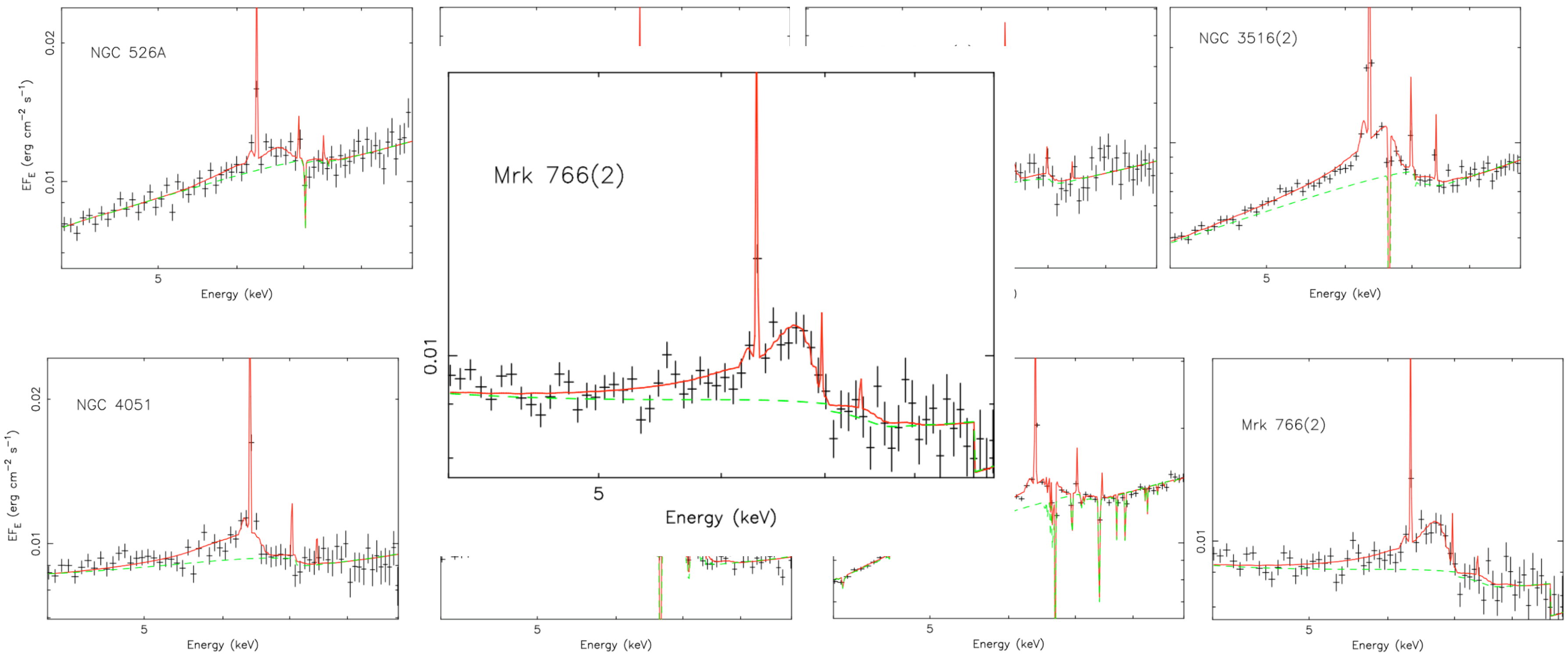


R(in)= 6
R(out)= 25
Incl= 30
Line flux
Energy (keV)
1.5×10⁻⁴
10⁻⁴
5×10⁻⁵
0
3
4
5
6
7
8
9

RELATIVISTIC DISK LINES

45% of XMM AGN Sample

Nandra et al. (2007)



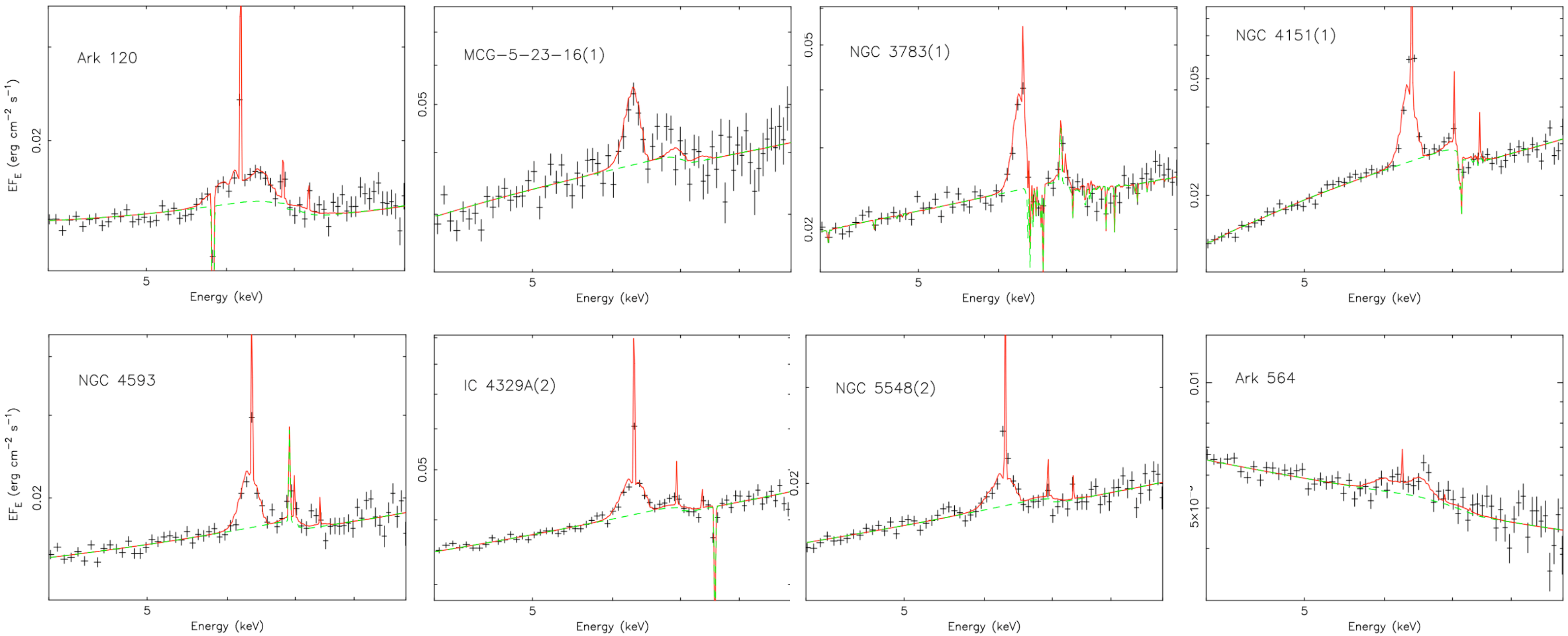
Criteria: >99% significance, r_{break} < 50 Rg (~2% GR shift)

17/37 total: NGC 3516(1), NGC 3783(2), MCG-6-30-15(1), NGC 4395, NGC 5506(2), NGC 7314, Mrk 766(1), NGC 7469(2)

NON-RELATIVISTIC BROAD LINES

25% of XMM AGN Sample

Nandra et al. (2007)



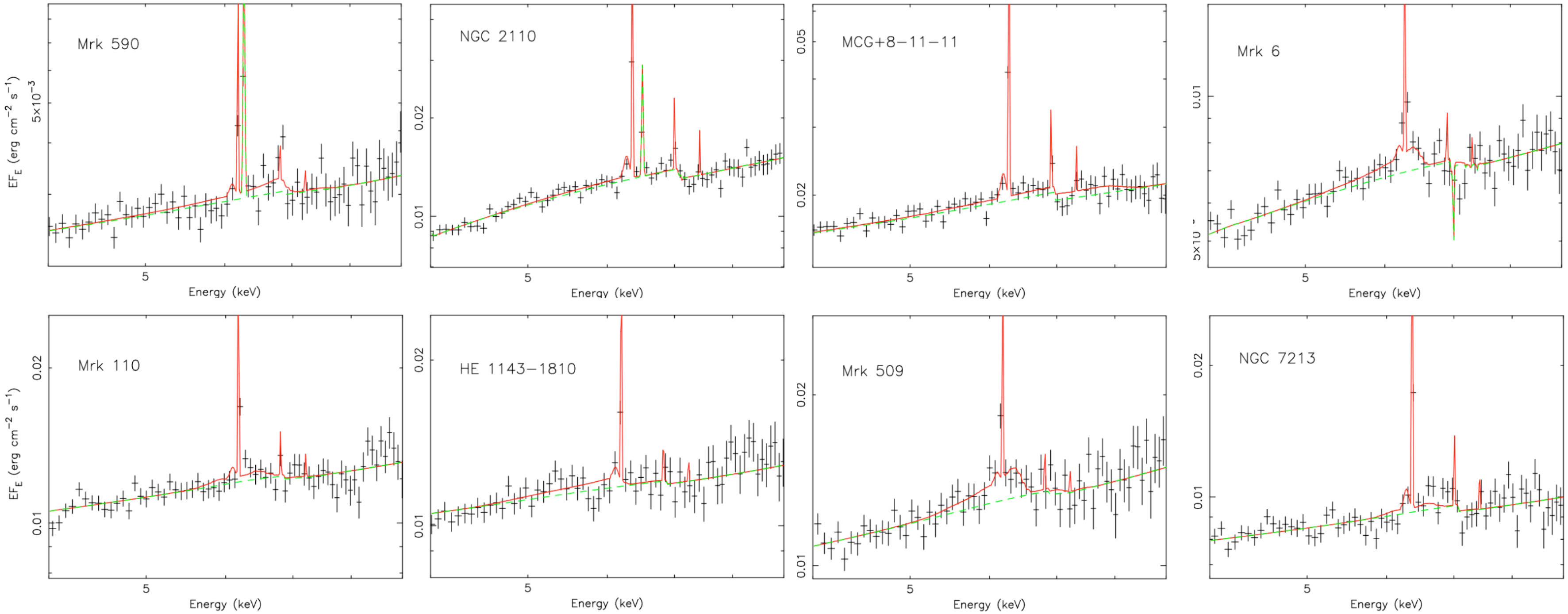
Criteria: >99% significance, r_{break} > 50 Rg

9 total: NGC 4151(2)

NARROW LINES

30% of XMM AGN Sample

Nandra et al. (2007)



Criteria: <99% significance for blurred reflection
12 total: IC4329A (1) NGC 5506(1), NGC 5548(1) NGC 7469(1)

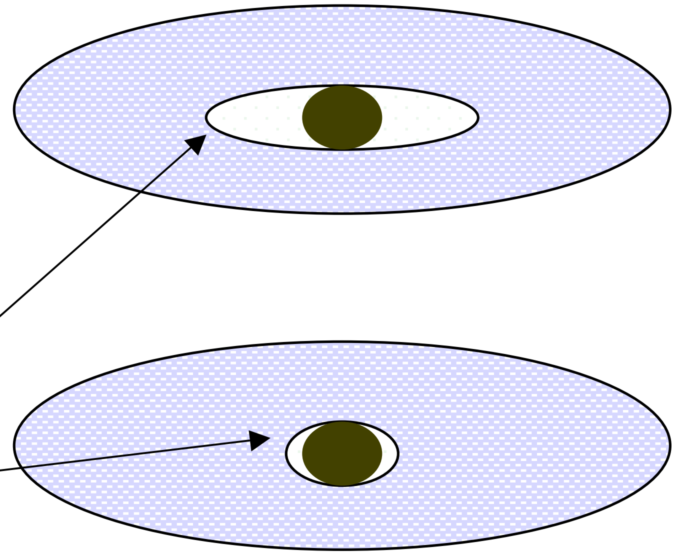
Disk line upper limits typically 50-100 eV

WHY ARE DISK LINES ABSENT?

- High inclinations
  - Predicts very weak line
- Extreme relativistic effects
  - Too broad to distinguish from continuum
- Ionization of inner disk
  - Fe completely
- Truncation of radiatively efficient inner disk
  - Possible hot "ADAF" inner flow
- Variability
  - Changes in profile observed
- ***Geometry/GR/beaming***
  - All spectra consistent with average R=0.5

BLACK HOLE SPIN

- Radius of marginal stability r_{ms} depends on black hole spin



SCHWARZSCHILD (a=0): $r_{ms} = 6\ r_g$
MAXIMAL KERR* (a~1): $r_{ms} \sim r_g$

Broader line for rotating Hole[**]

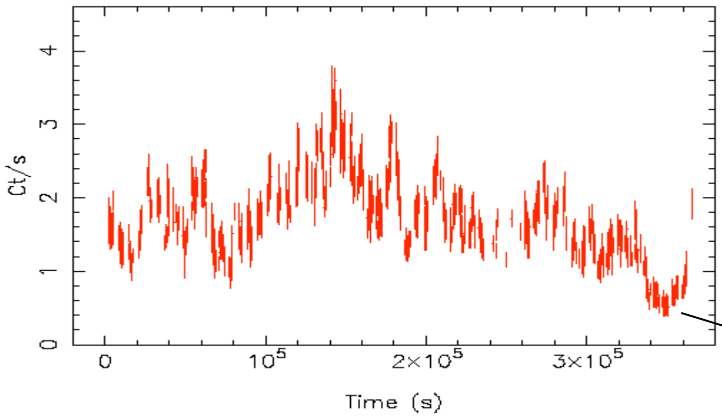
KERR = ROTATING
SCHWARZSCHILD = NON-ROTATING

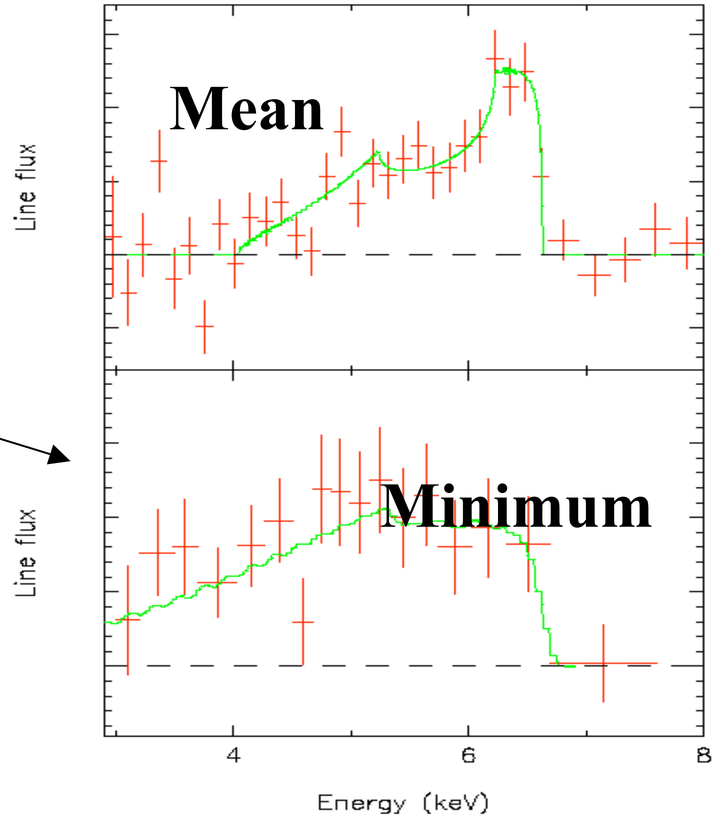
**a=1, retrograde, $r = 9\ r_g$*

***But emission within r_{ms} possible for Schwarzschild (Reynolds & Begelman 1997)*

A SPINNING BLACK HOLE?

Courtesy: K. Iwasawa





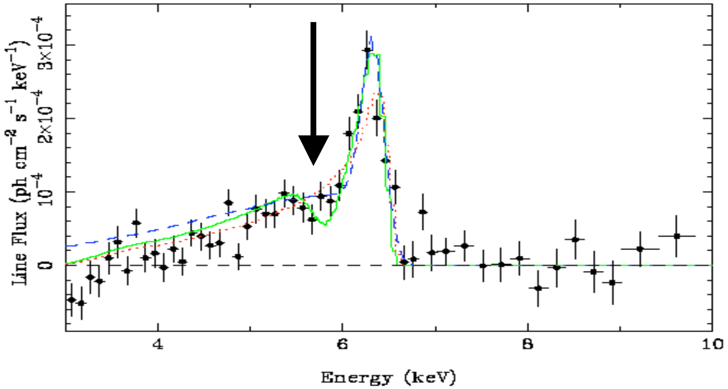
- **Profile variability seen on short time scales in MCG-6-30-15**
- **Deep minimum: shows extreme redshifted profile**
- **Requires emission from within 6 R_g**

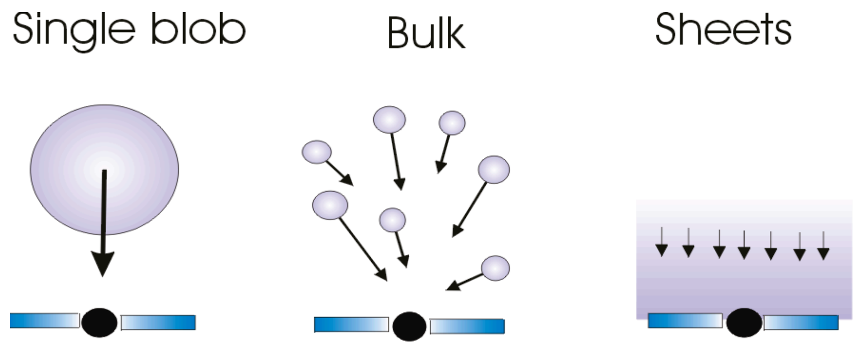
Iwasawa et al. (1996); Dabrowski et al. (1997); Bromley et al. (1998); Reynolds & Begelman (1999)

Spinning black hole?

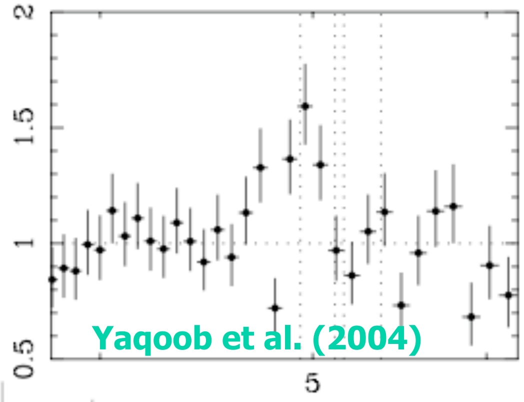
PROBING MATTER FALLING INTO A BH?

Nandra et al. (1999)



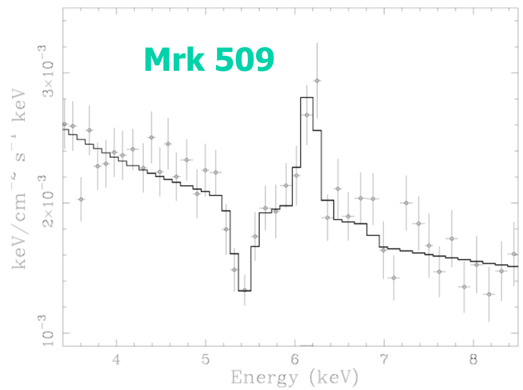


E1821+643



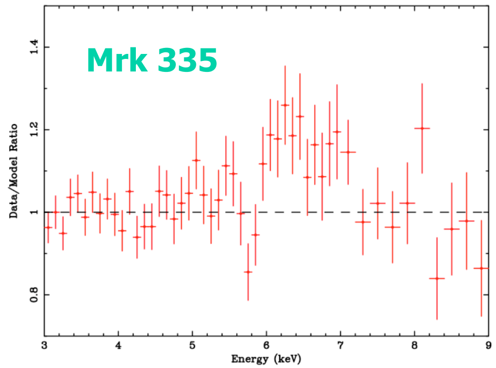
Yaqoob et al. (2004)

Mrk 509



Dadina et al. (2005)

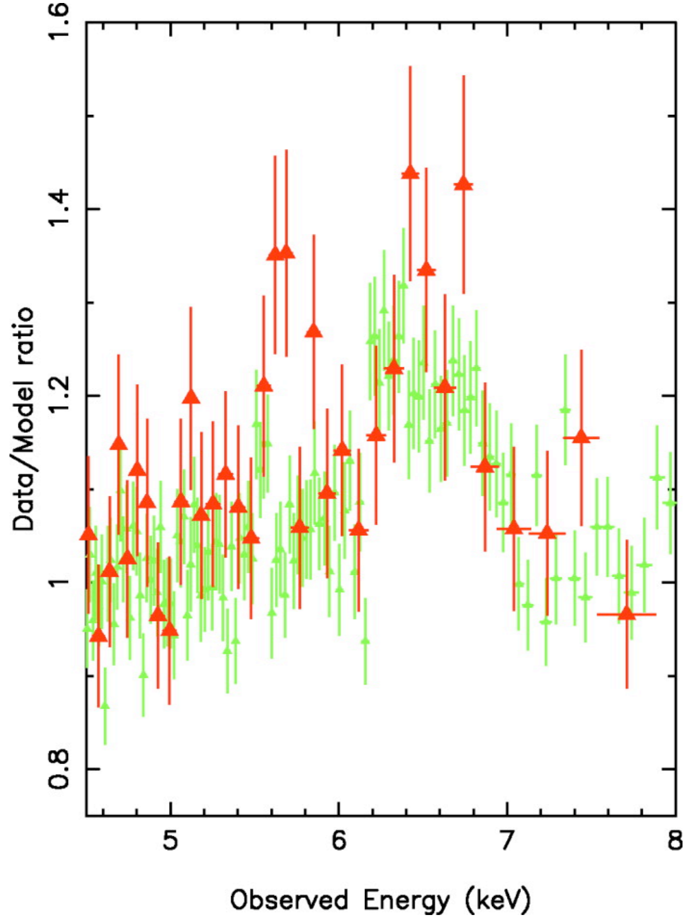
Mrk 335



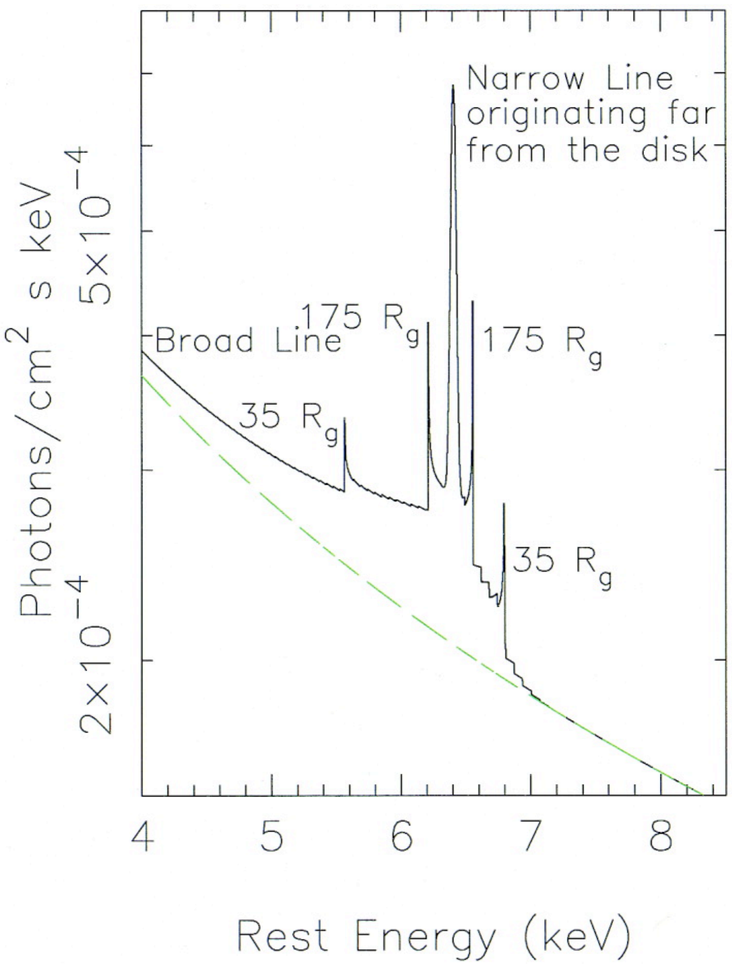
Longinotti et al. (2005)

Redshift can also be gravitational (Ruzkowski & Fabian 2000)

Narrow shifted lines

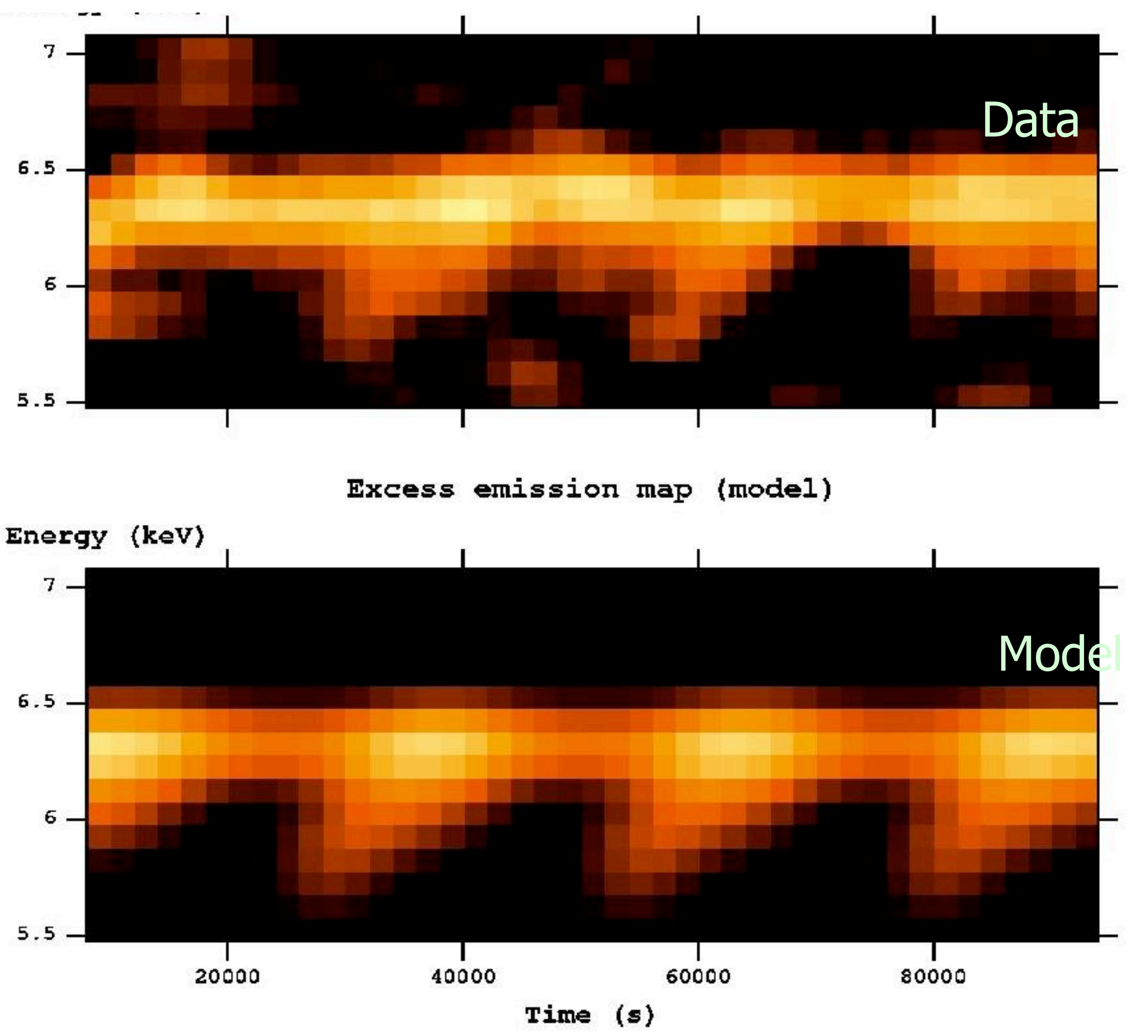


Turner et al. (2002)



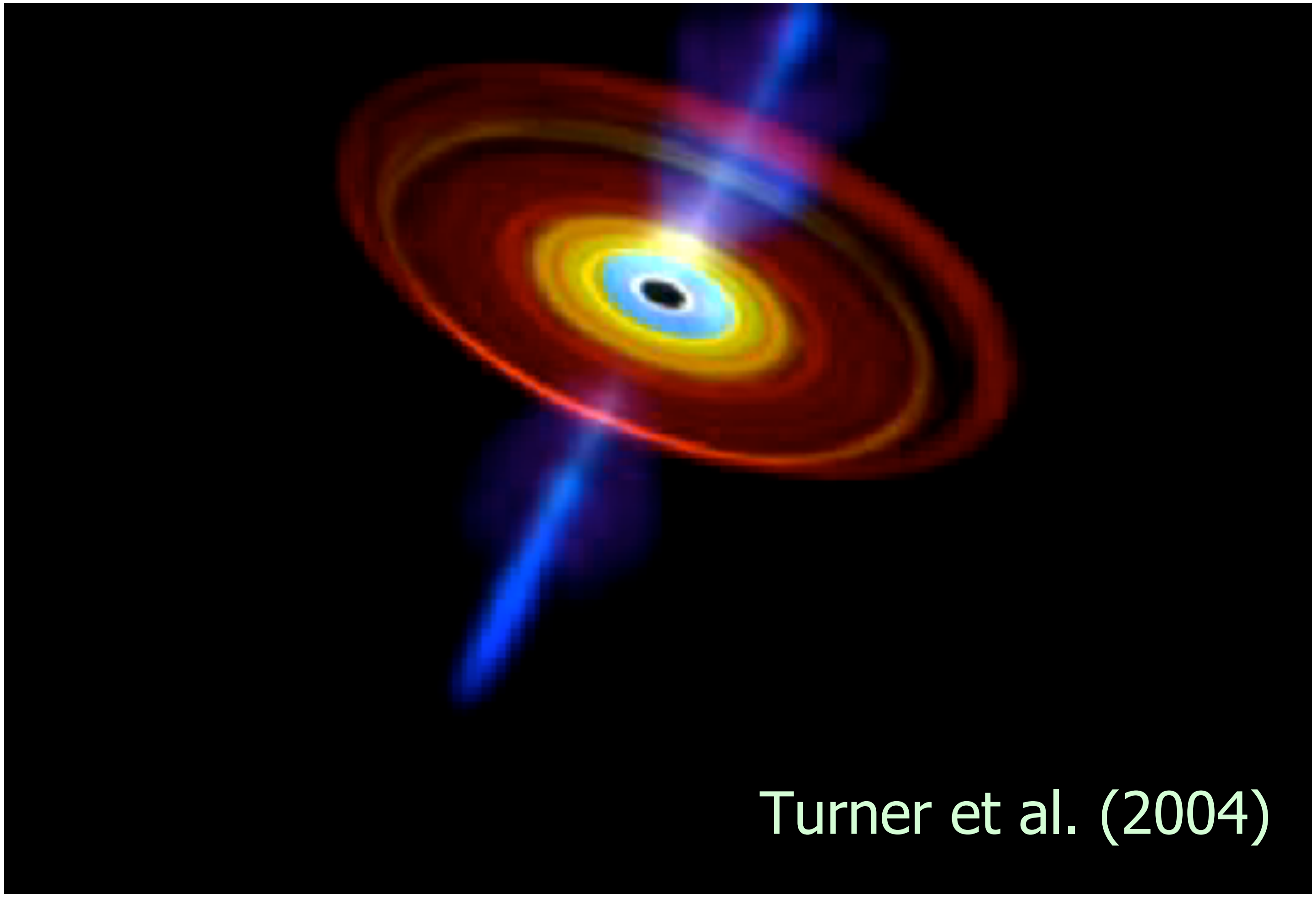
NGC 3516: ORBITAL MOTION?

Iwasawa et al. (2004)



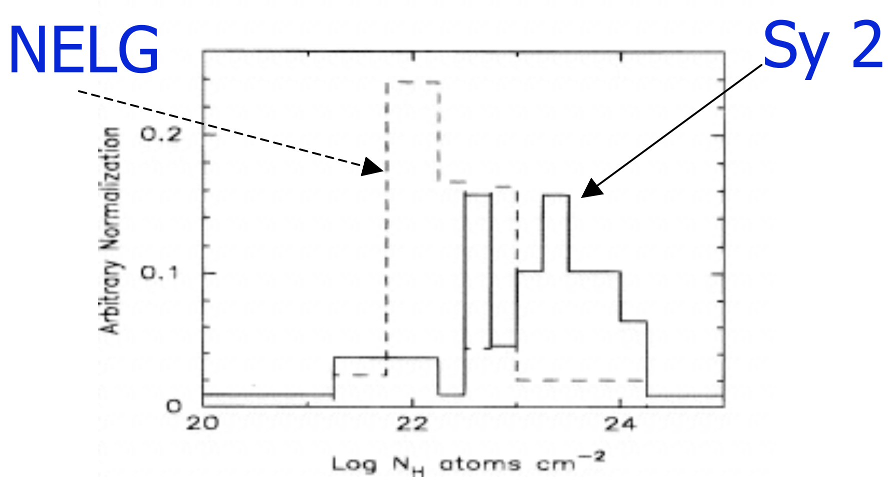
Narrow features shifting in apparently periodic fashion

ORBITAL MOTIONS?

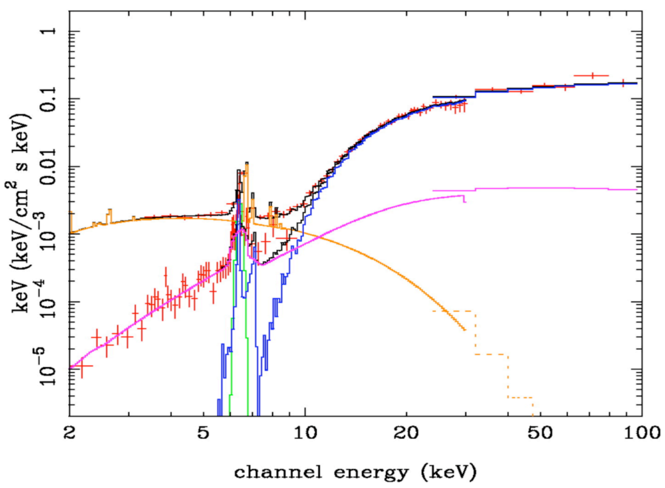


2.3 ABSORPTION IN AGN

- Galactic absorption: typical $N_H = 10^{20-21}$ cm^{-2}
- Large scale in AGN host (e.g. NELGs) $N_H = 10^{21-22}$ cm^{-2}
- Seyfert 2s are extreme: $N_H = 10^{23-24}$ cm^{-2}
- Most extreme: Compton thick AGN ($N_H = 10^{25}$ cm^{-2})



Turner et al. (1997)



NGC 4945 Done et al. (2003)

IONIZED ABSORBERS

- In practice gas may be hot (collisionally ionized) or, more importantly, photoionized
- Ionization parameter (flux/density):

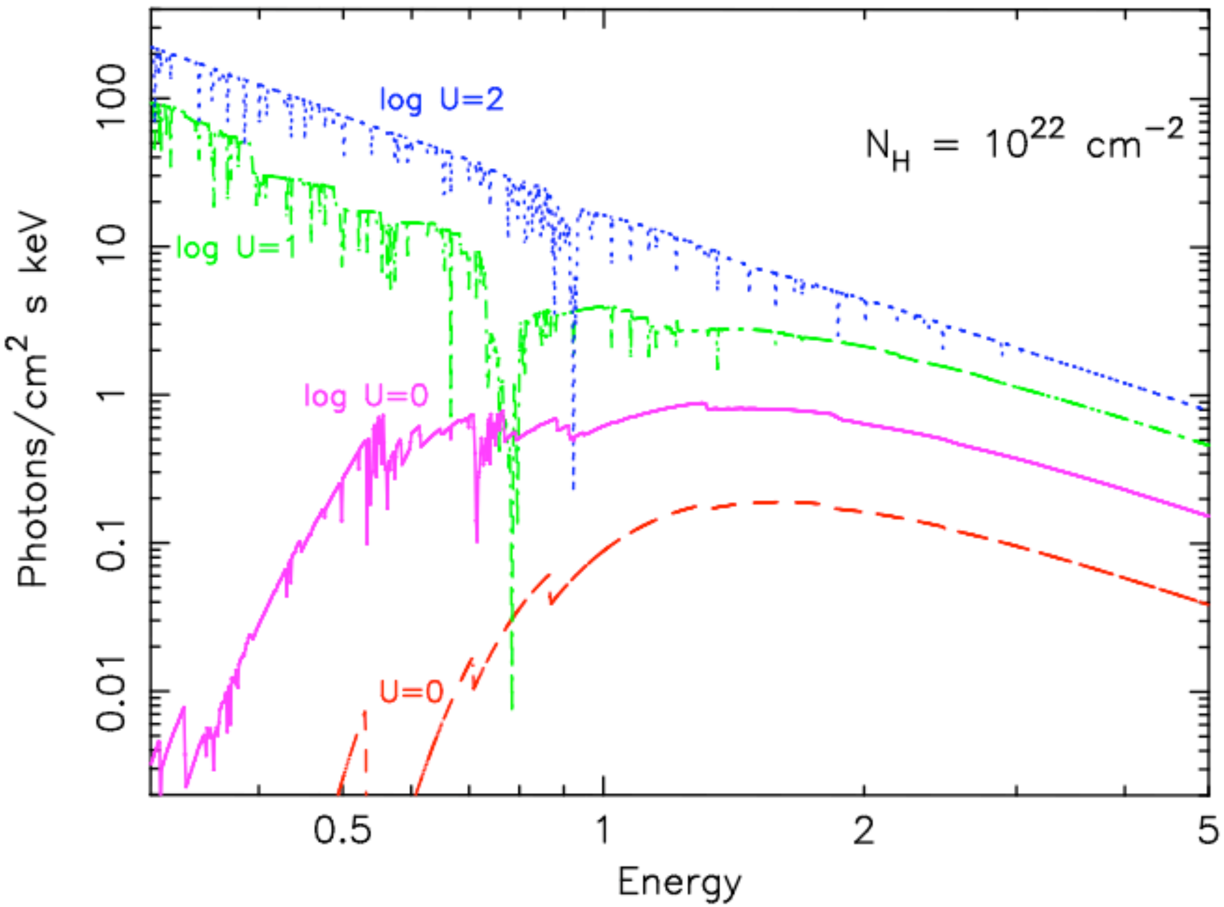
$$\xi \equiv \frac{L_X}{n_e R^2} \quad \text{Tarter, Tucker \& Salpeter (1969)}$$

$$U_X \equiv \frac{N_X}{4\pi R^2 n_e c} \qquad \text{Davidson (1974)}$$

$$L_X \equiv \int_{E_{\min}}^{\infty} L(E)\,dE \qquad N_X \equiv \int_{E_{\min}}^{\infty} \frac{L(E)}{E}\,dE$$

$$E_{\min} = 13.6\text{eV, } 0.1 \text{ keV, } 0.7 \text{ keV (Davidson, Netzer, George)}$$

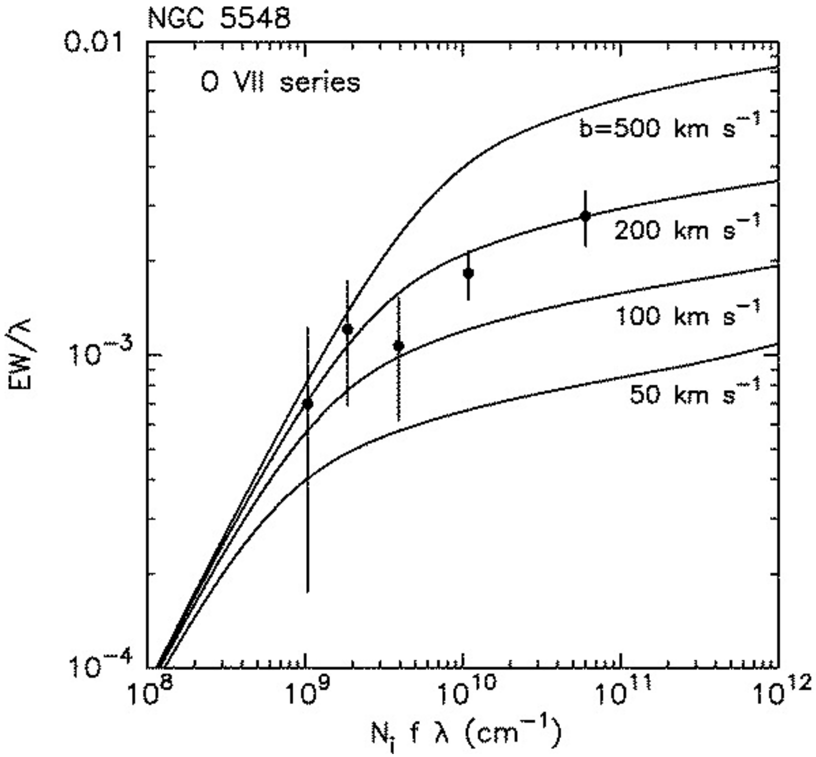
IONIZED ABSORPTION

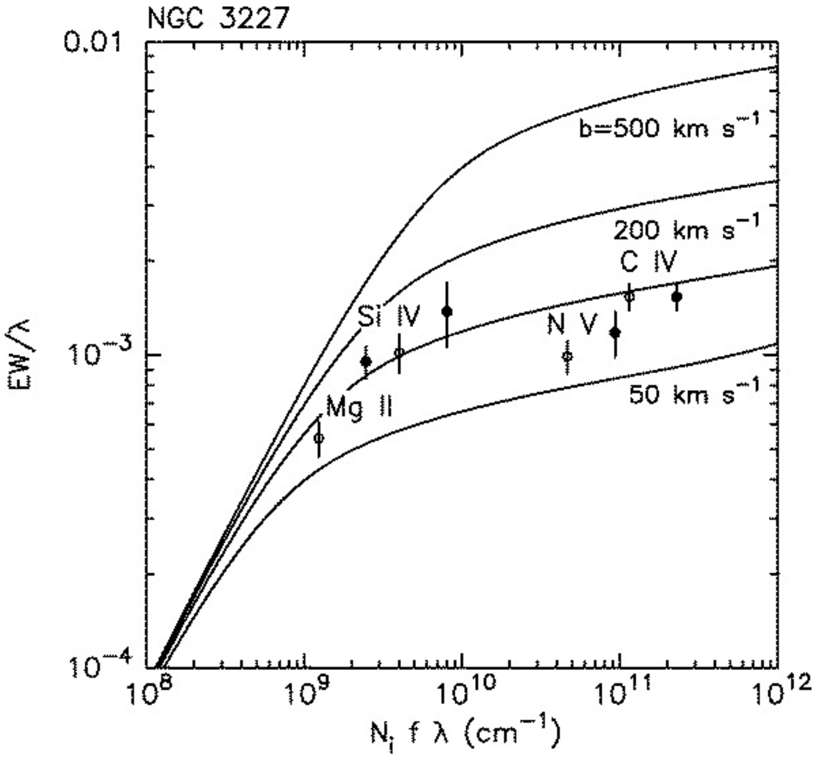


Continuum absorption profile still can be dominated by bound-free edges of abundant elements but….

CURVES OF GROWTH

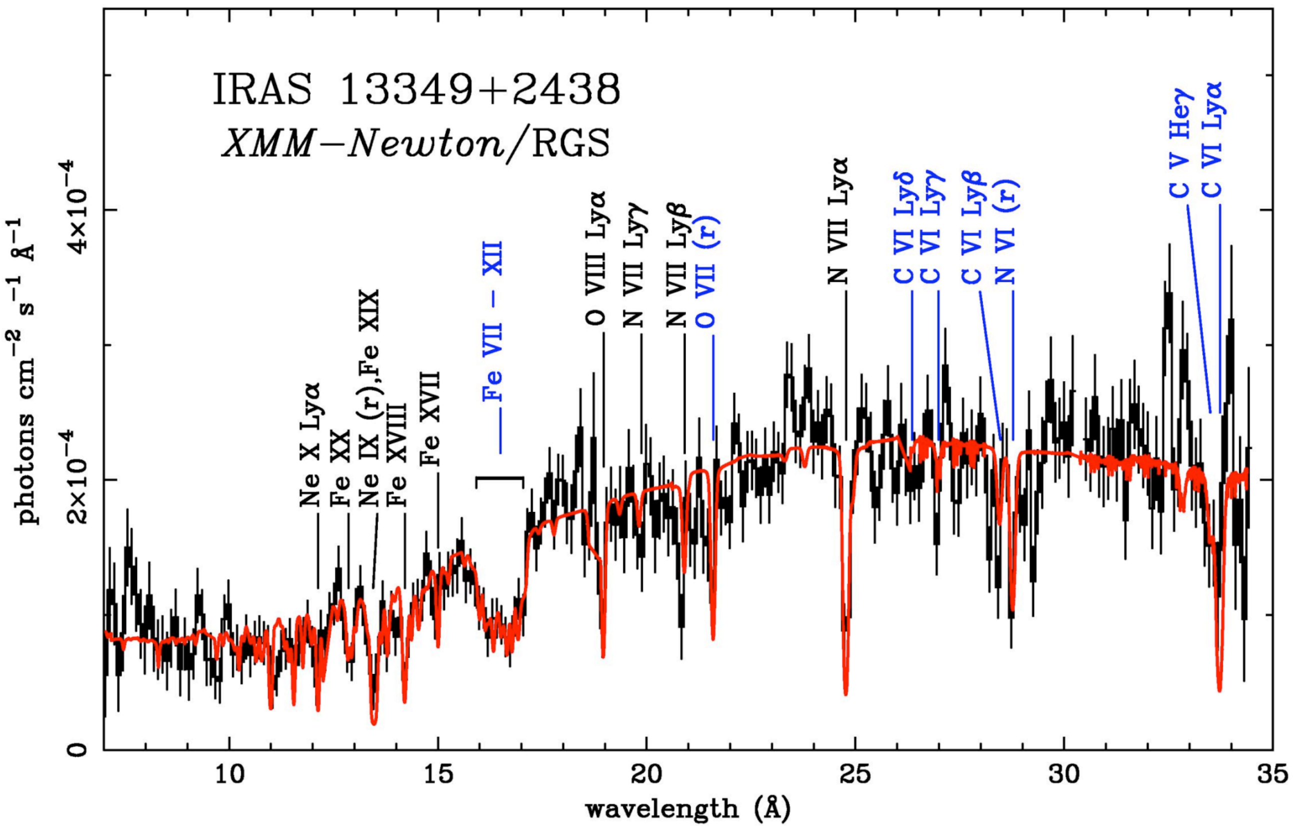
Crenshaw, Kraemer & George (2003)





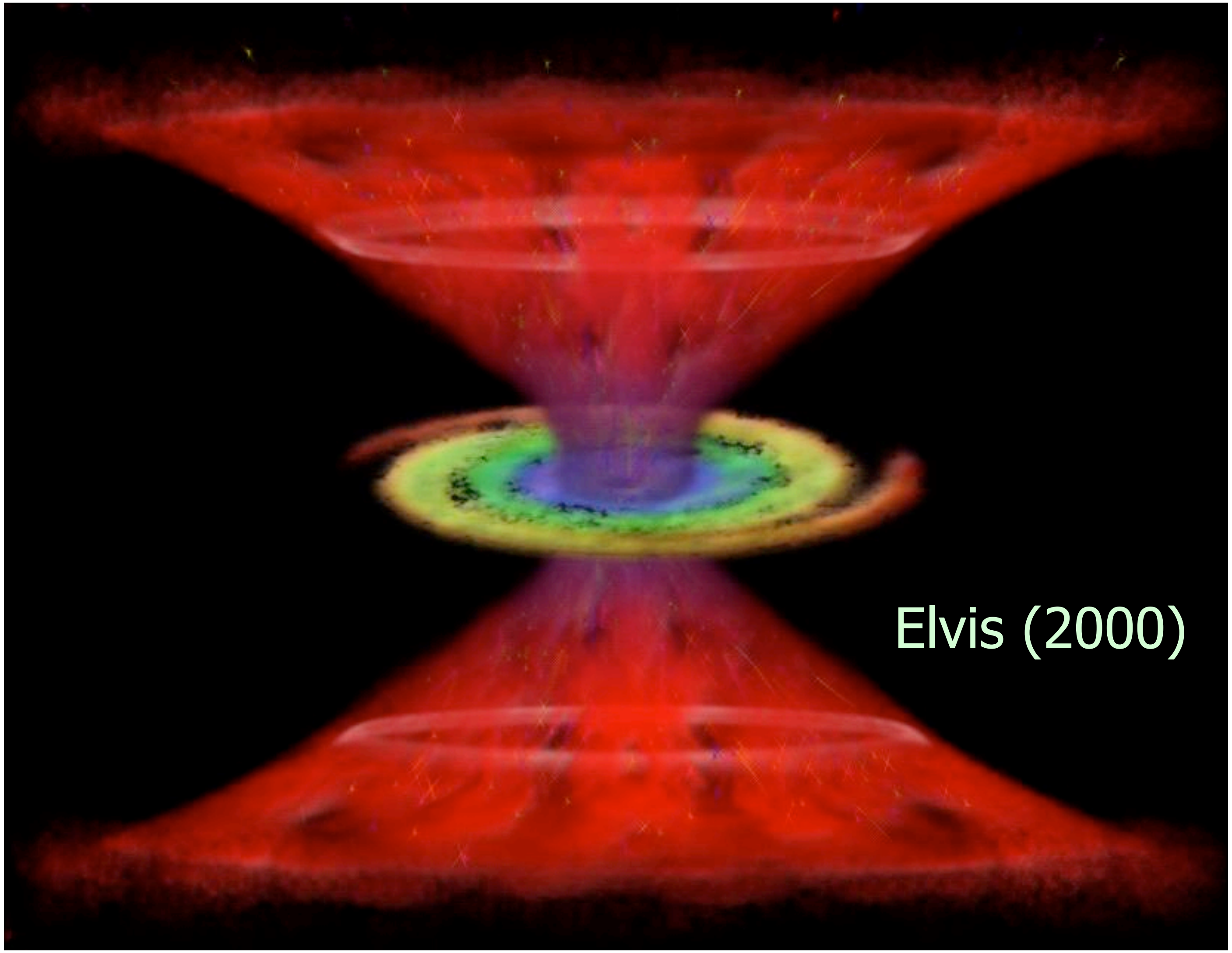
Use lines to determine total N_H, *U*, kinematics (*v*, *b*)
BUT critical missing information is <u>location</u>

WARM ABSORBERS

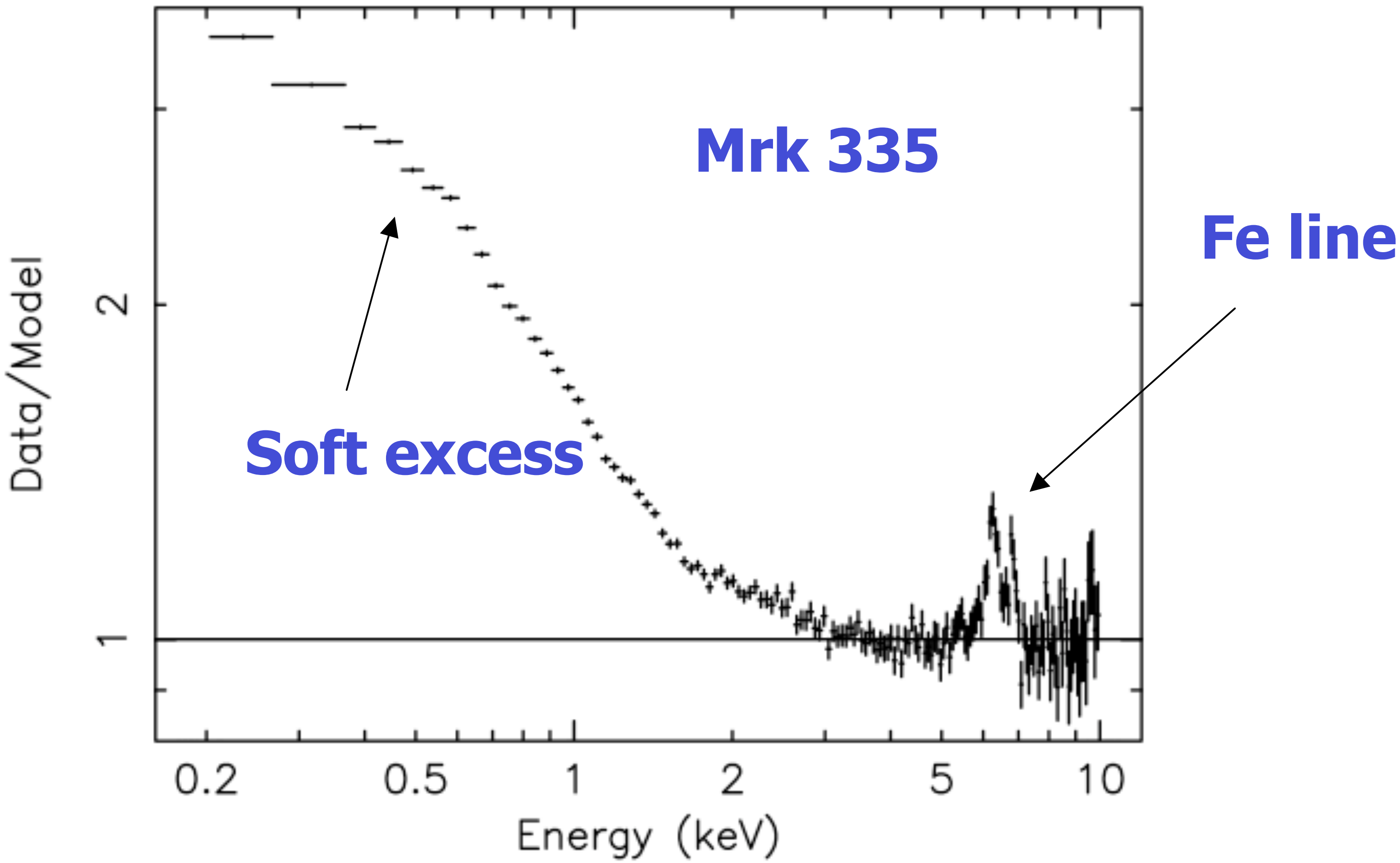


Blueshifted absorption lines, outflow 100-1000 km s^{-1}
Disk wind? Material blown off torus?

AGN WIND MODELS

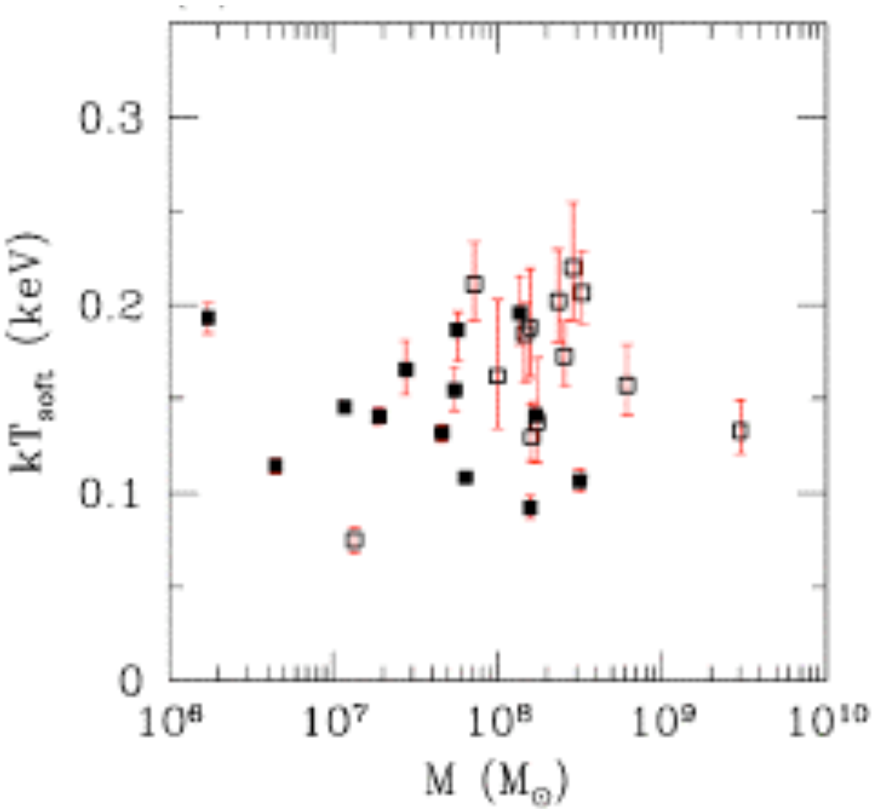


2.4 THE SOFT EXCESS



SOFT EXCESS ORIGIN?

- Direct disk flux (*)
- Comptonized Disk
- Reprocessing
- Relativistic disk emission?
- Relativistically blurred absorption?

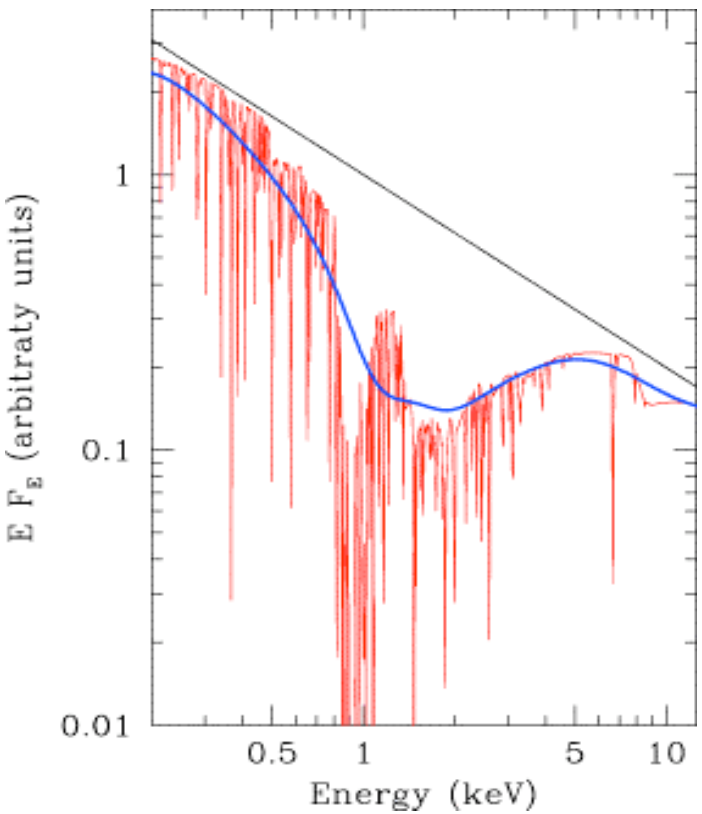


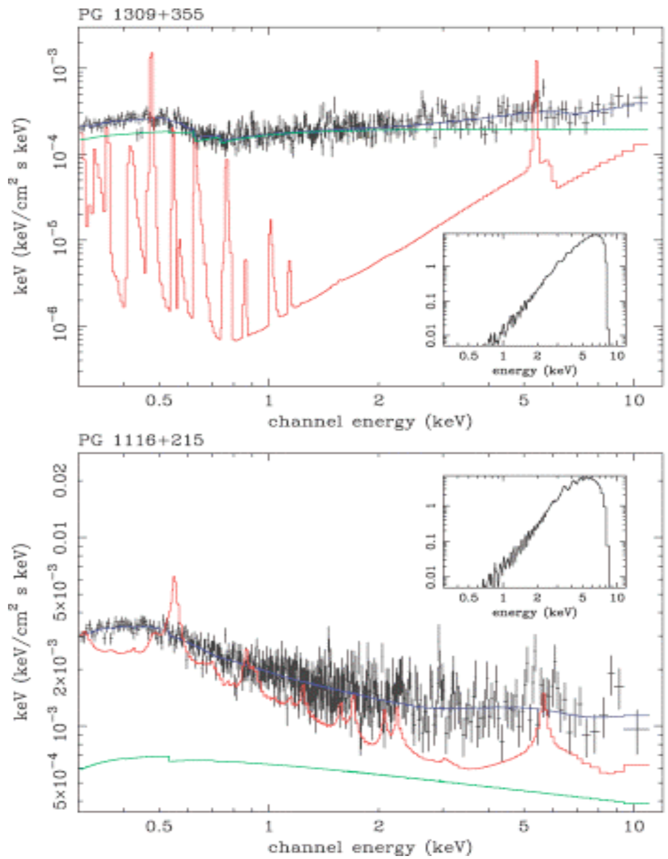
(Gierlinski & Done 2004)

** Unlikely - but accretion disk provides "seed" photons*

1. Absorption in relativistic outflow

2. Emission in relativistic disk





Gierlinski & Done 2004

Crummy et al. 2006

Both require extreme relativistic effects

SOME OUTSTANDING PROBLEMS

- What is the **physical structure** of the disk?
- Where do **X-rays** arise (geometry/dissipation)?
- Why do AGN **vary** (especially in X-ray)?
- What is the **warm absorber**? Is it important?
- Is the black hole **spinning**?
- What connects AGN and normal galaxies?
- How do AGN evolve with cosmic time?