AGN (accretion & ejection) Physics:

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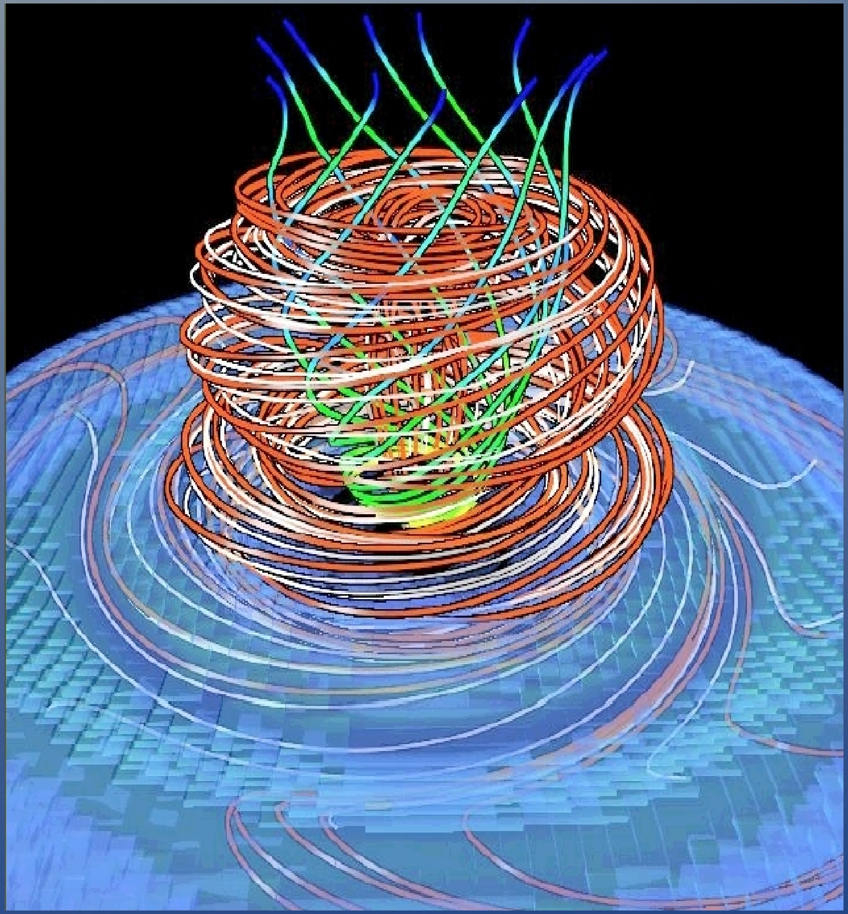
INAF-IASF, Bologna



Plan of the Lectures

(I) General framework (1.5h)

- Paradigm(s)
- The 2 "Unknowns"
- The 3 "Known" (models + basic physics)

(I) The 2 contenders (2h)

- Relativistic reflection (=accretion)
- Relativistic absorption (=ejection)

These lectures are "complementary" to others on evolution of AGNs, and on high energy detectors as well.

Goal of the lectures: Give introductory informations on general "models" of AGNs, and in particular on reflection vs absorption hypothesis in RQAGNs

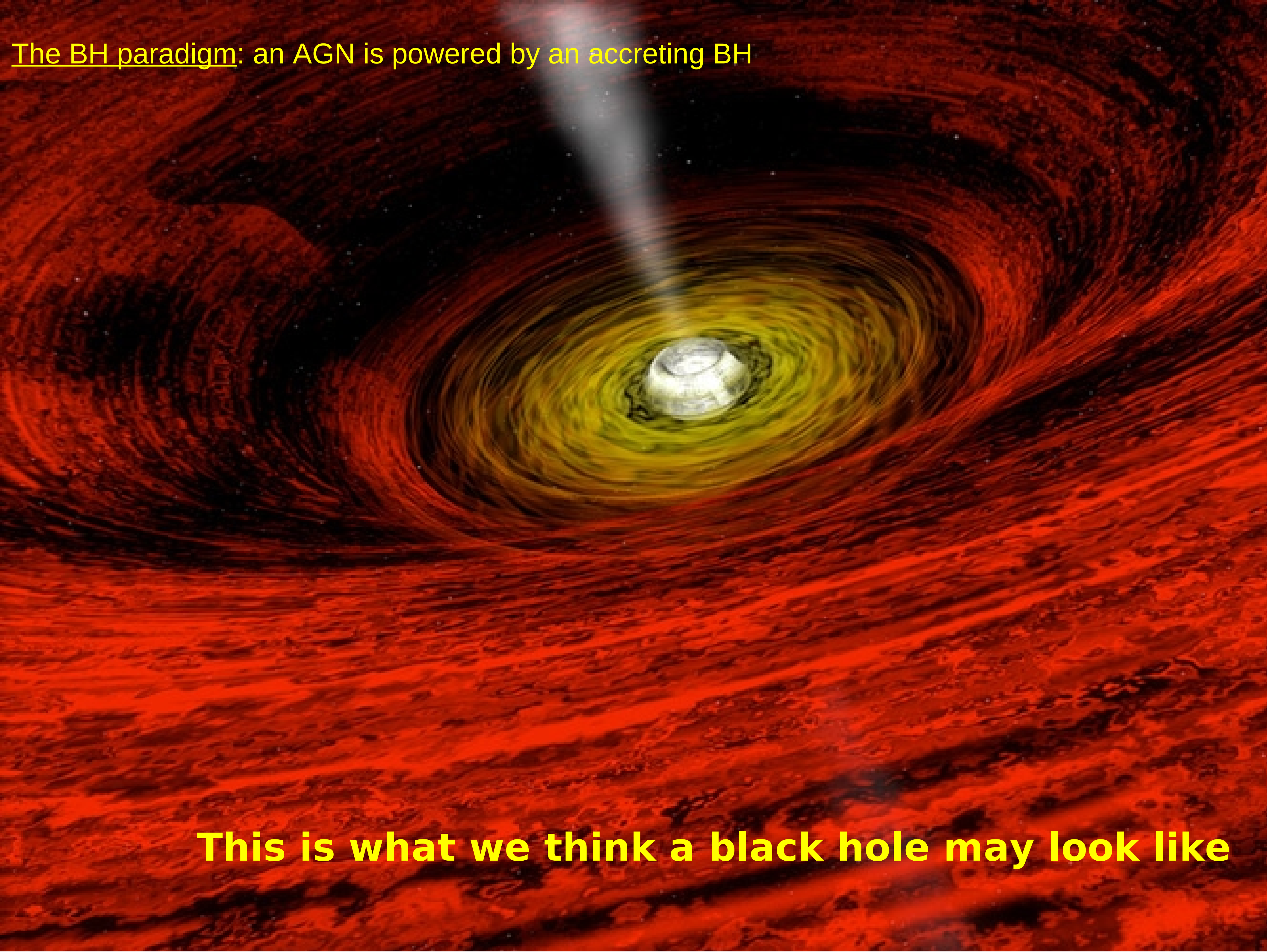
Bibliography:

A. Mueller, PhD Thesis, Heidelberg, 2004

C. Done, Lectures, August 2010, arXiv:1008.2287v1

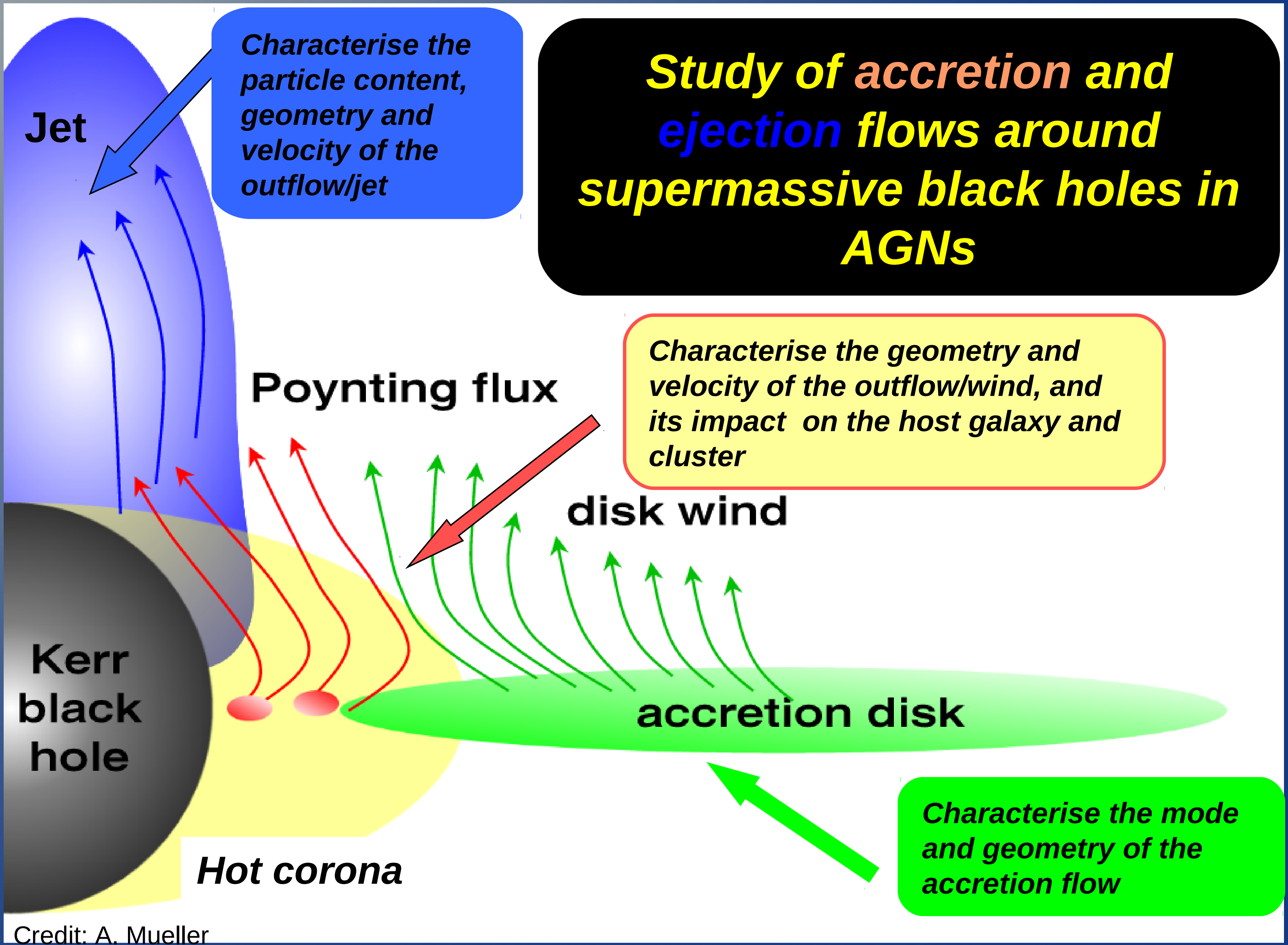
Give a panorama on theoretical models+spectral physics for AGNs&BHs

The BH paradigm: an AGN is powered by an accreting BH



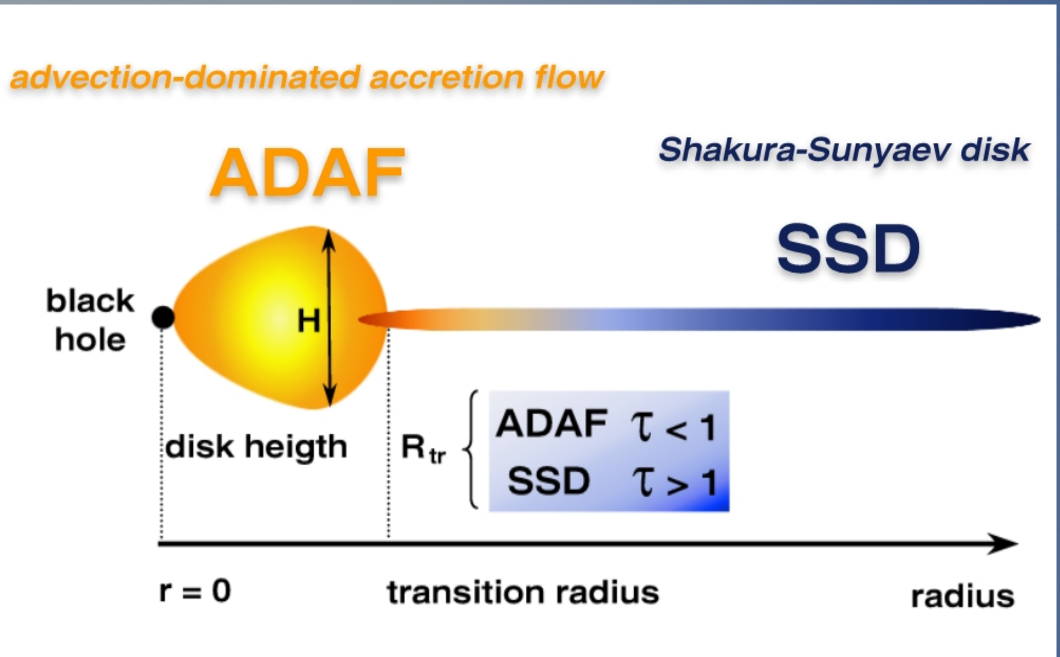
This is what we think a black hole may look like

The „Unknowns" or the Open issues



First major “Unknown”: The type of accretion flow

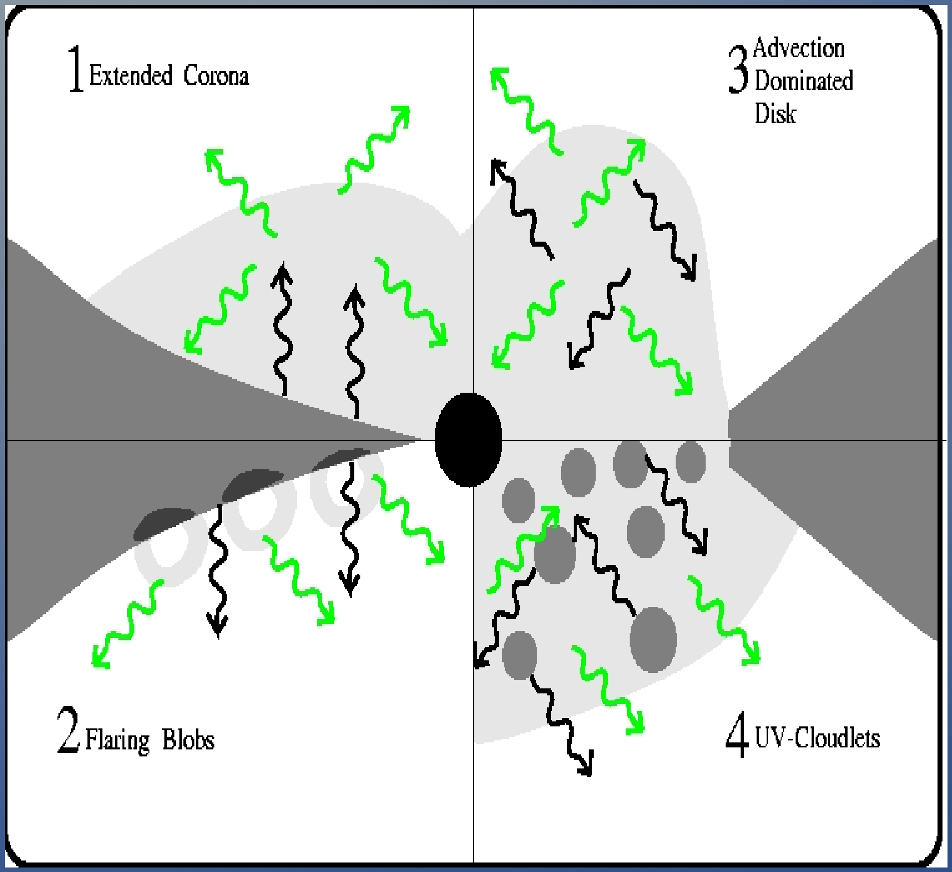
We don't know exactly the accretion mode/type (SAD, ADAF, RIAF, CDAF, etc.)…



(Müller, ‘04)

- Shakura–Sunyaev disk (SSD) or equivalently standard accretion disk (SAD)
- advection–dominated accretion flow (ADAF)
- radiatively–inefficient accretion flow (RIAF)
- convection–dominated accretion flow (CDAF)
- slim disk
- truncated disk – advective tori (TDAT)
- non–radiative accretion flow (NRAF)

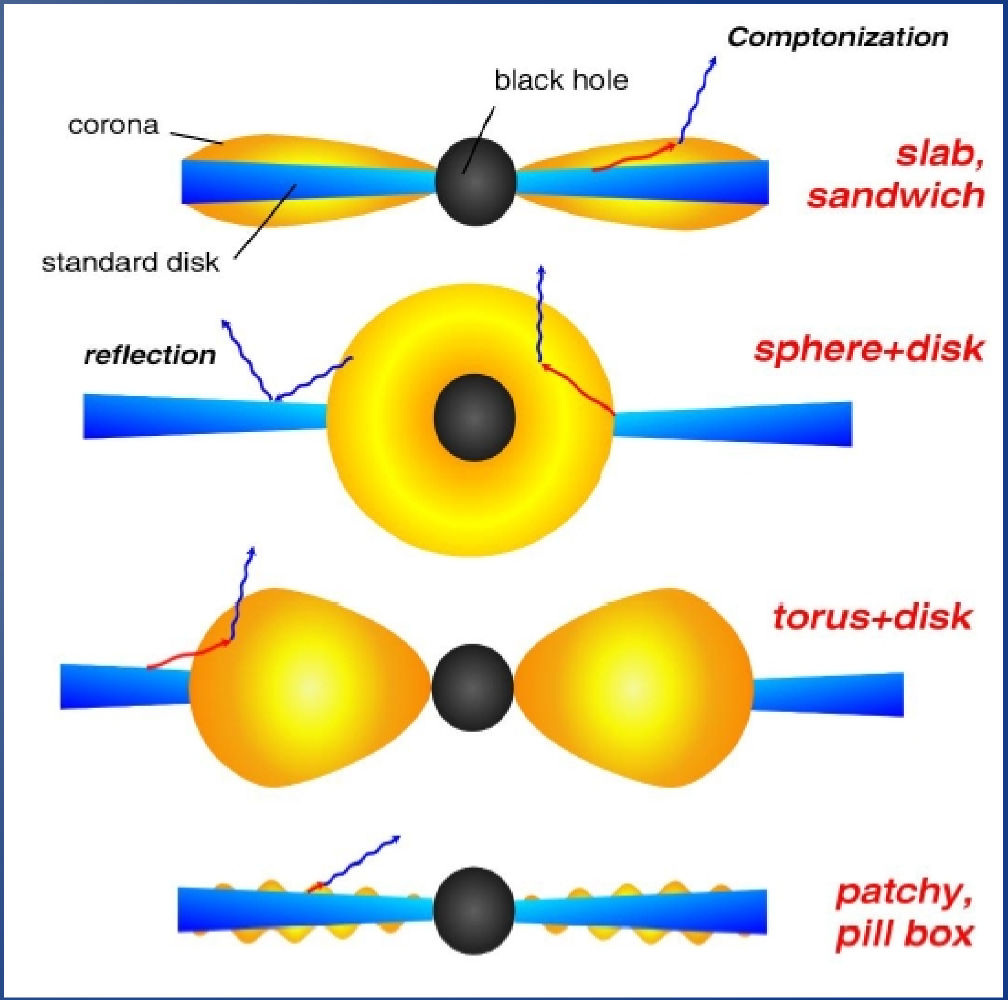
Second major "Unknown": The disk-corona geometry



Lamp-post model

Patchy corona model

(Haardt '96)



Muller '04

The 3 "Knowns"…or the AGN "Models"

BH paradigm + assumptions on geometry + emission mechanisms (physics) + Multi-ν observations

= AGN "Model"

The TWO major RQ AGN models are:

1: 2-Phases model (for Radio Quiet AGNs)

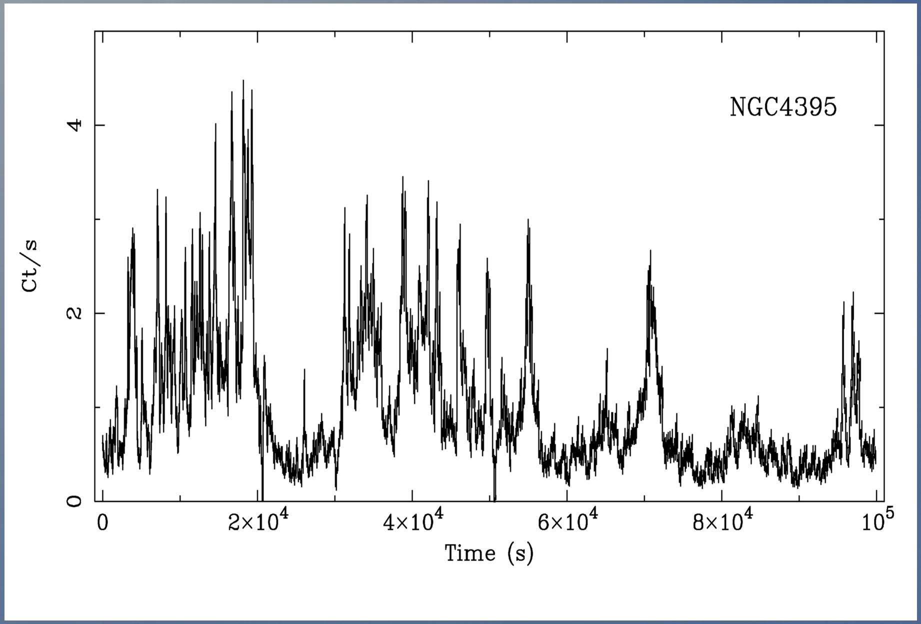
2: Inefficient model (for Low Luminosity AGNs .. also RL)

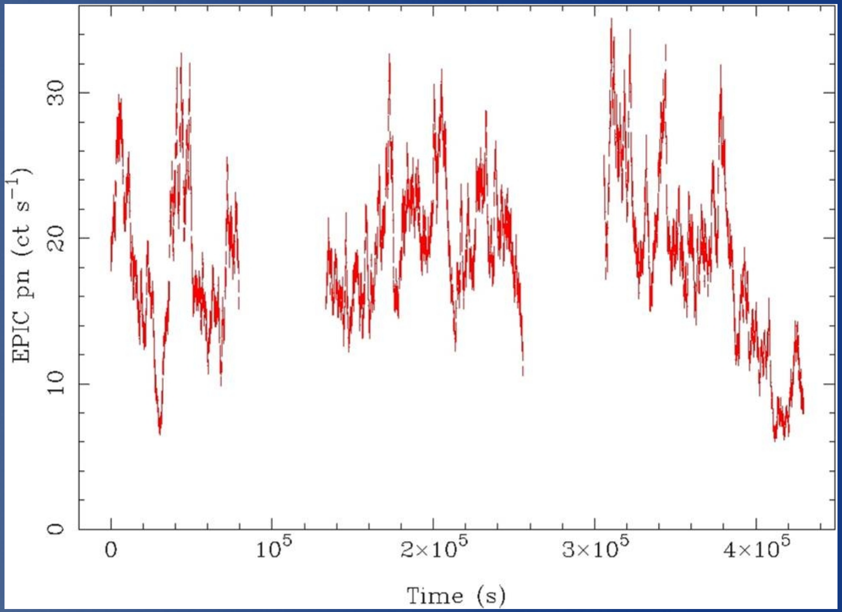
Model 1

The 2-phases (efficient) model (RQAGNs)

Model I (RQ AGN): X-ray observations - Lightcurves

MCG6-30-15





Δ L ~ L ~ up to 10^{44} erg/s

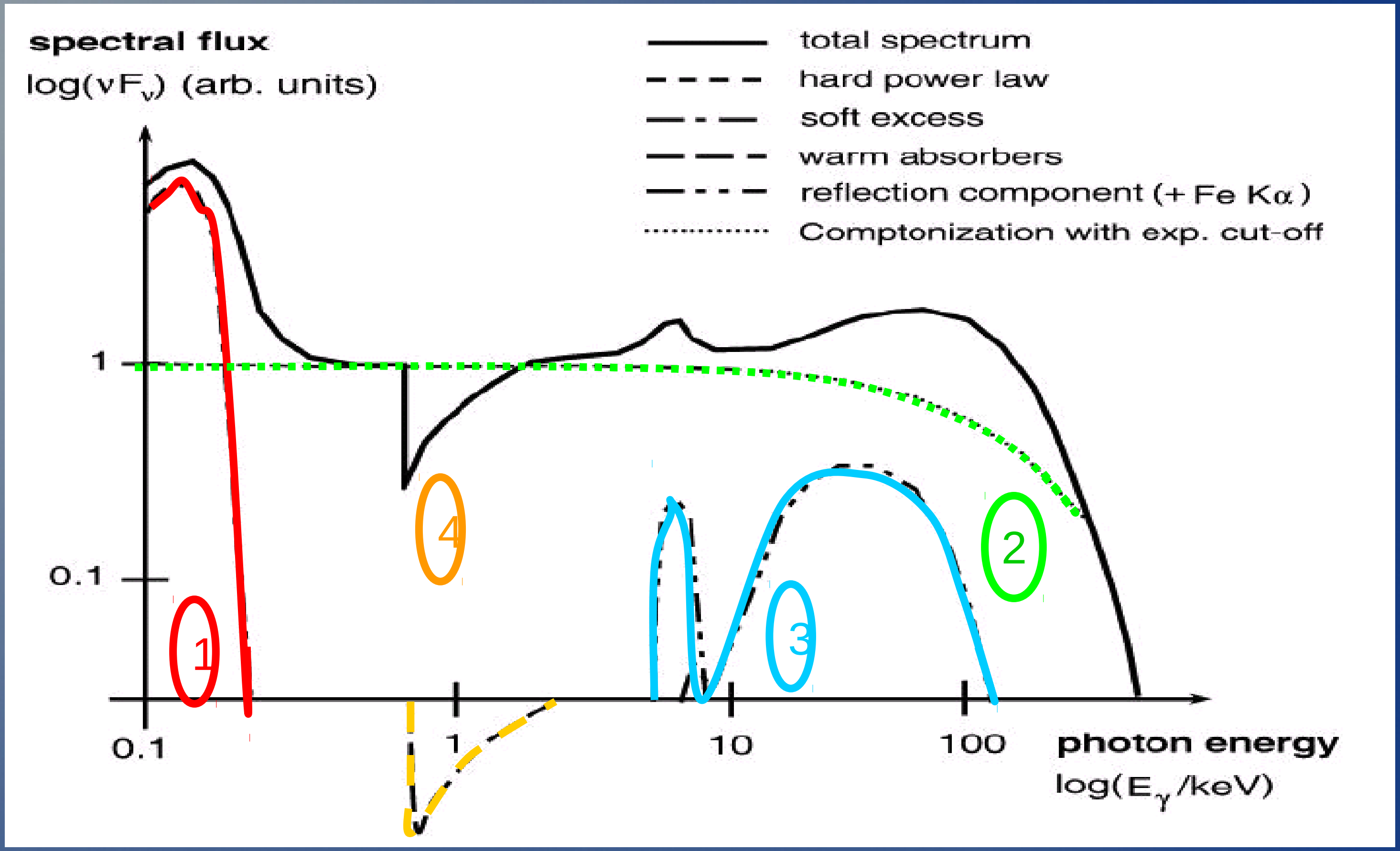
Light curves

N.B: Δt~50 s corresponds to 1 R_g for M=10^7Msol

($t \sim R_g/c \sim GM/c^3 \sim 50\ M_7$ s)

Implies most of radiation from innermost regions

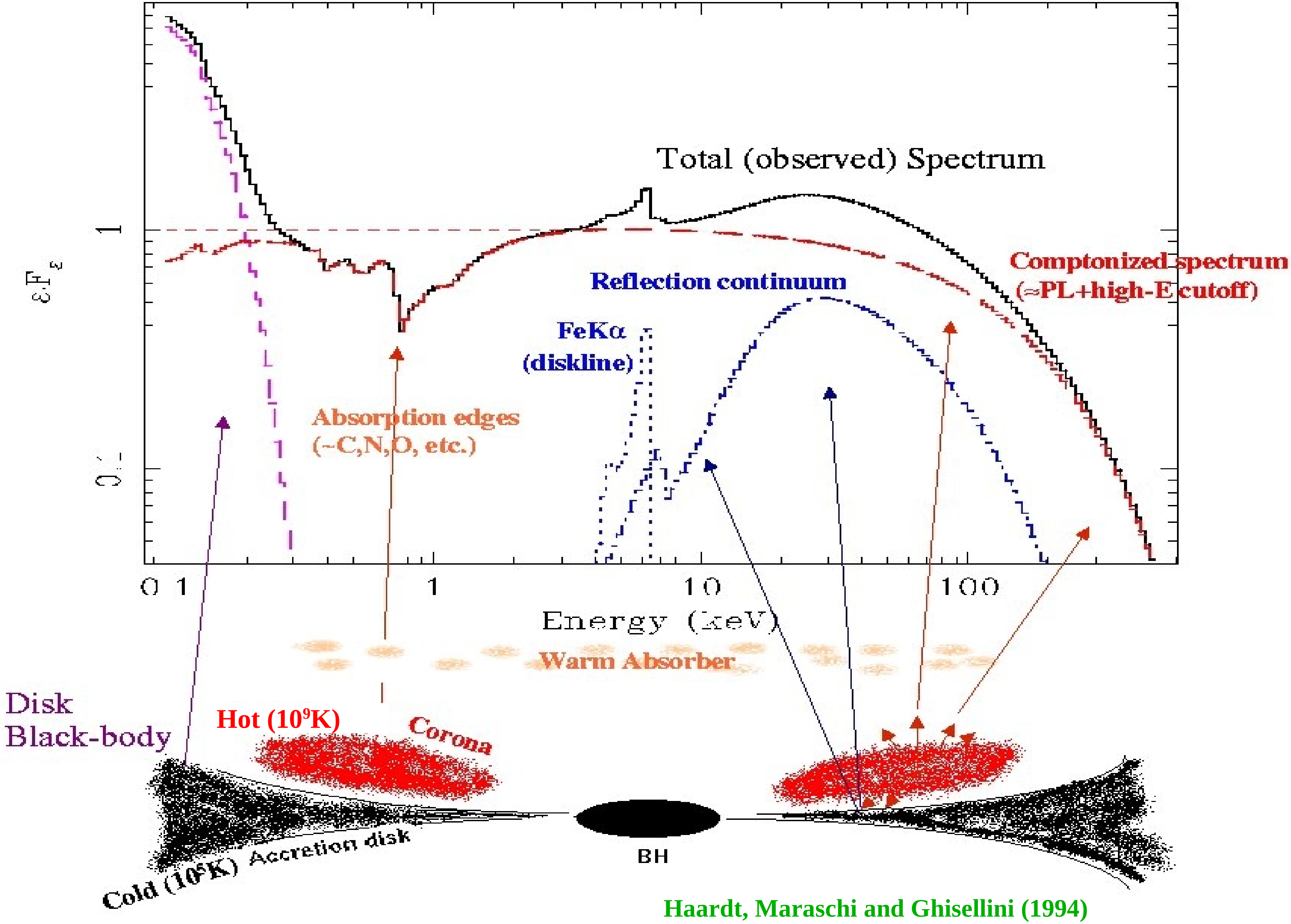
Model I (RQ AGN): X-ray observations - typical spectra



(At least) 4 major spectral components:

1. Soft excess (Black body)
2. Power-law Component (Thermal Comptonization)
3. Reflection component (Fluorescence Lines + Compton hump)
4. Warm absorber (photoelectric absorption)

Typical X-ray Spectrum of a Seyfert 1 Galaxy
⇔ Standard two-phase Comptonization model

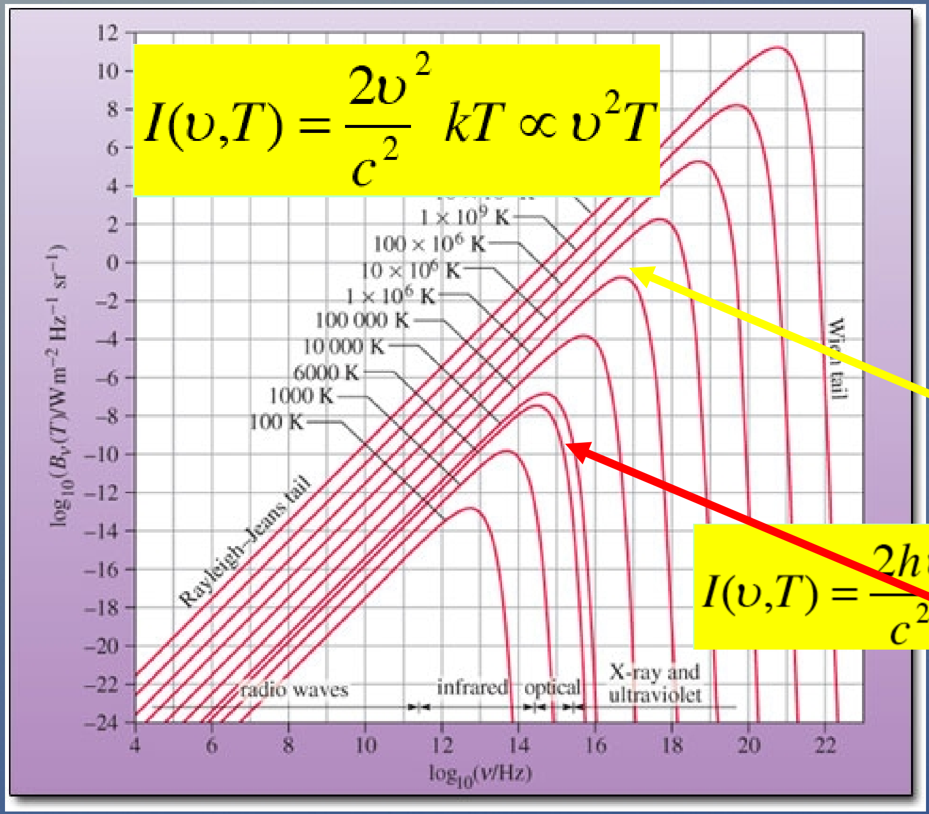


Haardt, Maraschi and Ghisellini (1994)

1- Black Body emission from accretion disk

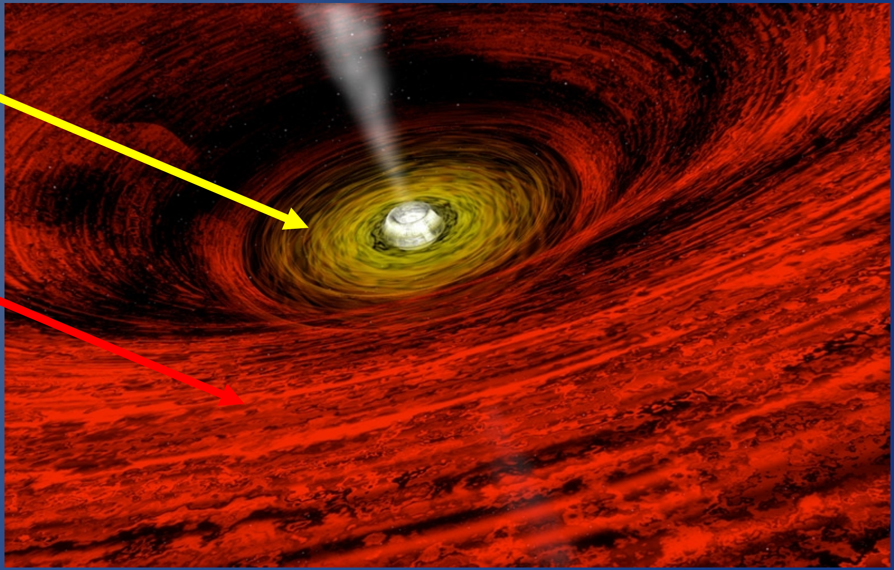
Planck radiation law:

$$I(\upsilon,T)=\frac{2h\upsilon^3}{c^2}\frac{1}{e^{h\upsilon/kT}-1}$$

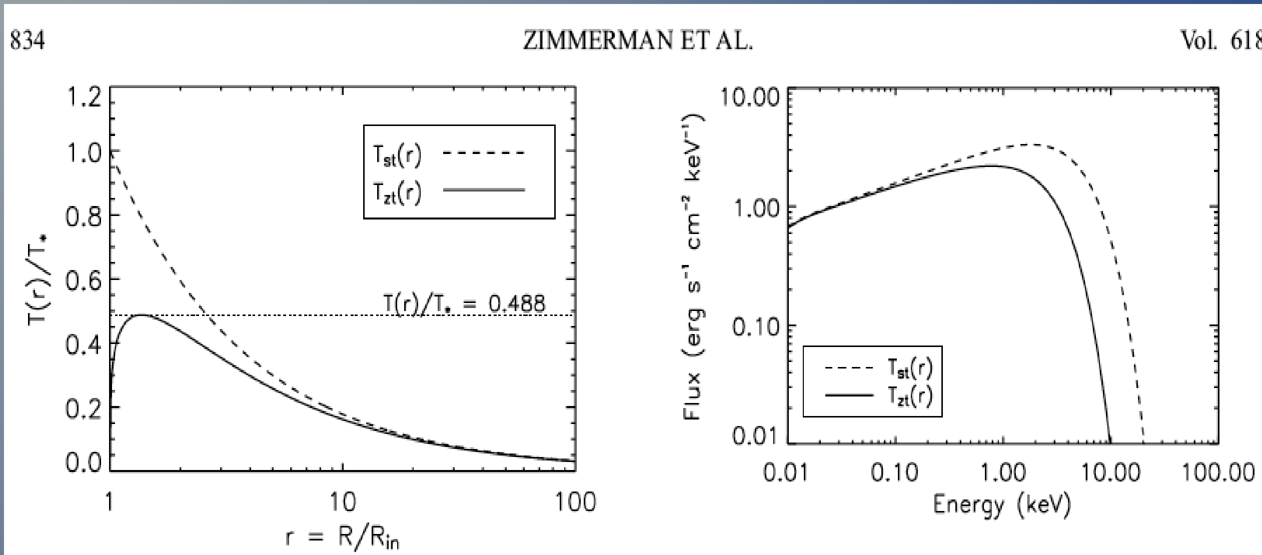


$$I(\upsilon,T)=\frac{2\upsilon^2}{c^2}kT\propto\upsilon^2T$$

$$I(\upsilon,T)=\frac{2h\upsilon^3}{c^2}e^{-h\upsilon/kT}$$



1- Black Body emission from accretion disk



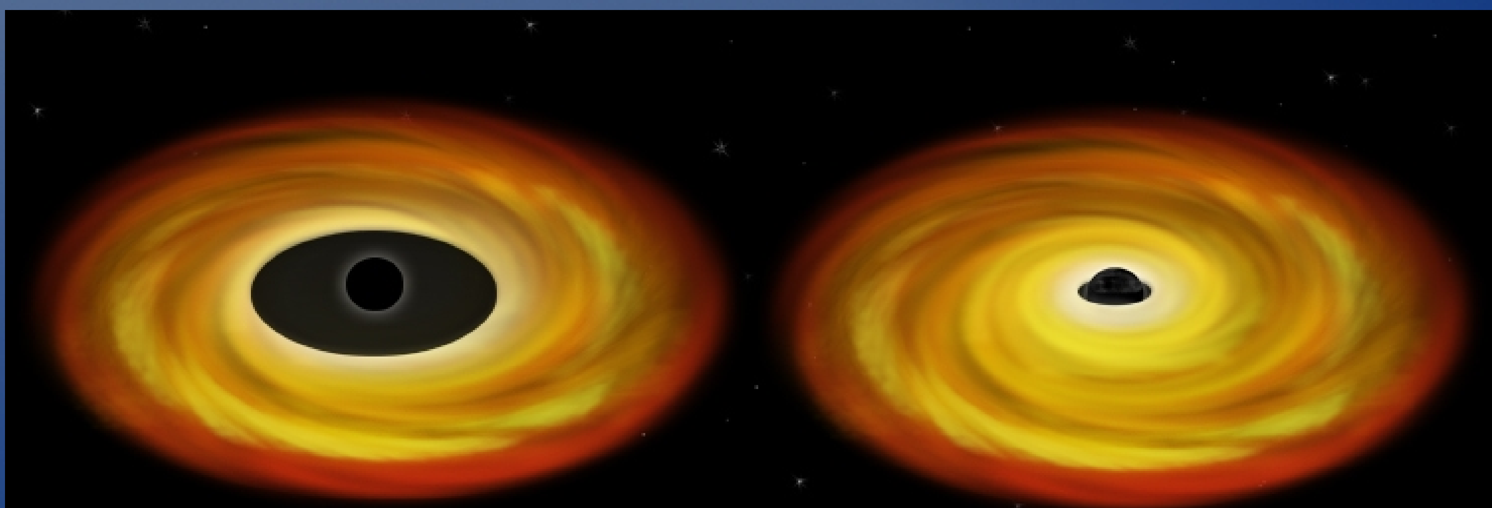
Multi-temperature disk black-body emission (see also "big blue bump")

N.B.: in SADthin disk:

$$L_{acc} \sim 0.1 \dot{M} c^2$$

$$kT \sim 10 \left(\frac{M_{BH}}{10^8 M_{\odot}} \right)^{-1/4} \left(\frac{\dot{M}}{\dot{M}_{Edd}} \right)^{1/4} \text{eV}$$

N.B: Another important consequence/application: Innermost Stable Circular Orbit (ISCO) depends on BH spin (a_*)



$a_* = 0$

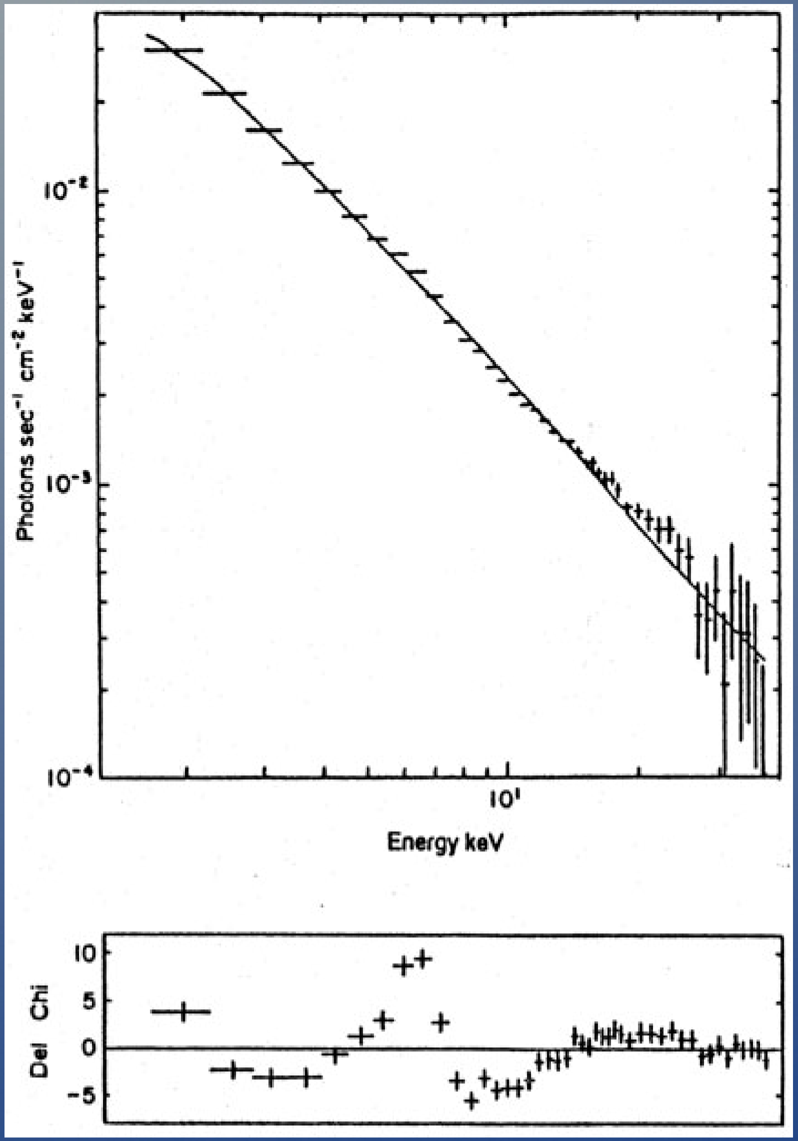
$R_{ISCO} = 6MG/c^2 = 90$ km

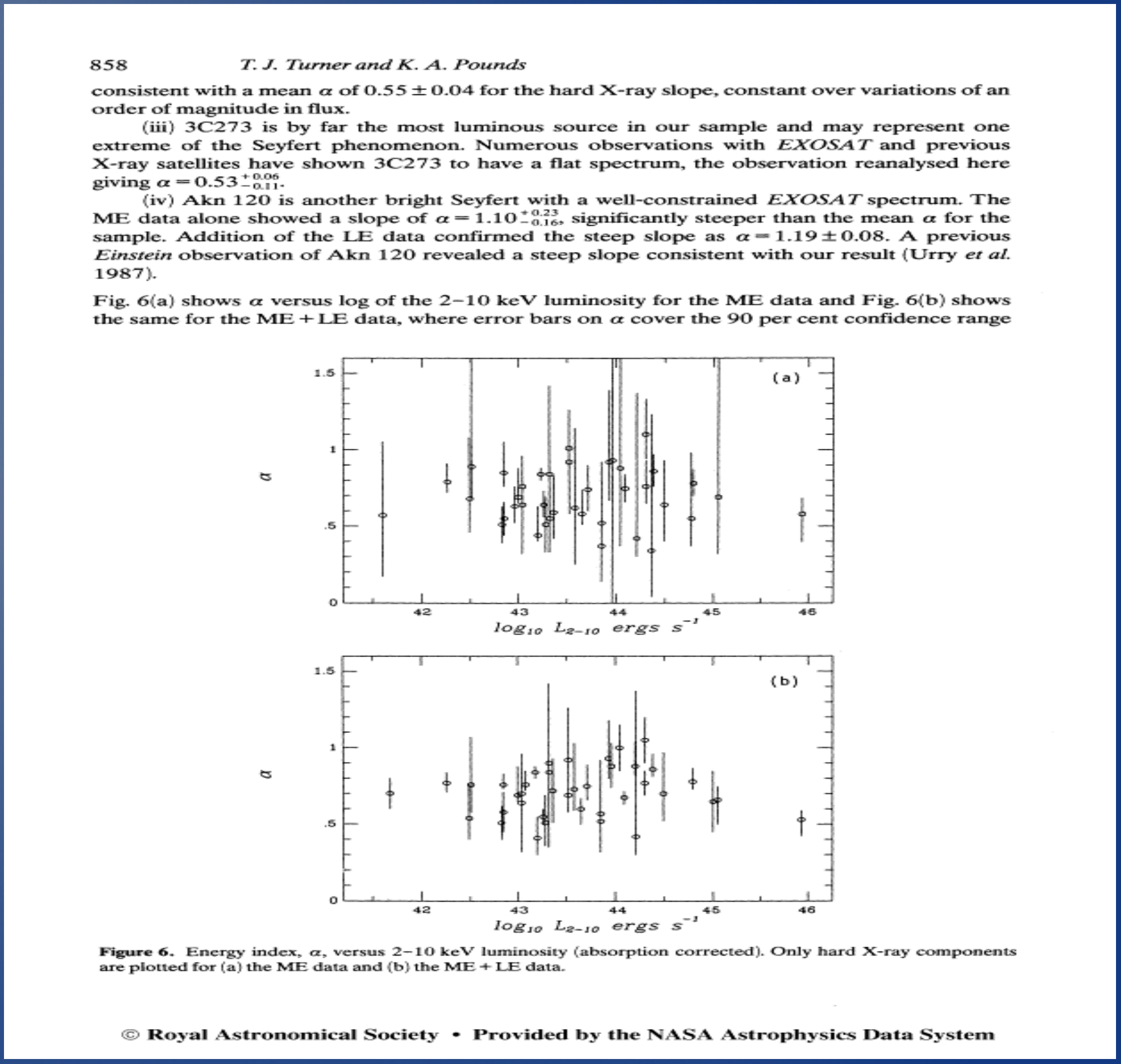
$a_* = 1$

$R_{ISCO} = 1MG/c^2 = 15$ km

(for $M = 10\, M_{\odot}$)

Power-law spectra: an universal law Γ=1.7?





consistent with a mean α of 0.55 ± 0.04 for the hard X-ray slope, constant over variations of an order of magnitude in flux.

(iii) 3C273 is by far the most luminous source in our sample and may represent one extreme of the Seyfert phenomenon. Numerous observations with *EXOSAT* and previous X-ray satellites have shown 3C273 to have a flat spectrum, the observation reanalysed here giving $\alpha = 0.53^{+0.06}_{-0.11}$.

(iv) Akn 120 is another bright Seyfert with a well-constrained *EXOSAT* spectrum. The ME data alone showed a slope of $\alpha = 1.10^{+0.23}_{-0.16}$, significantly steeper than the mean α for the sample. Addition of the LE data confirmed the steep slope as $\alpha = 1.19 \pm 0.08$. A previous *Einstein* observation of Akn 120 revealed a steep slope consistent with our result (Urry *et al.* 1987).

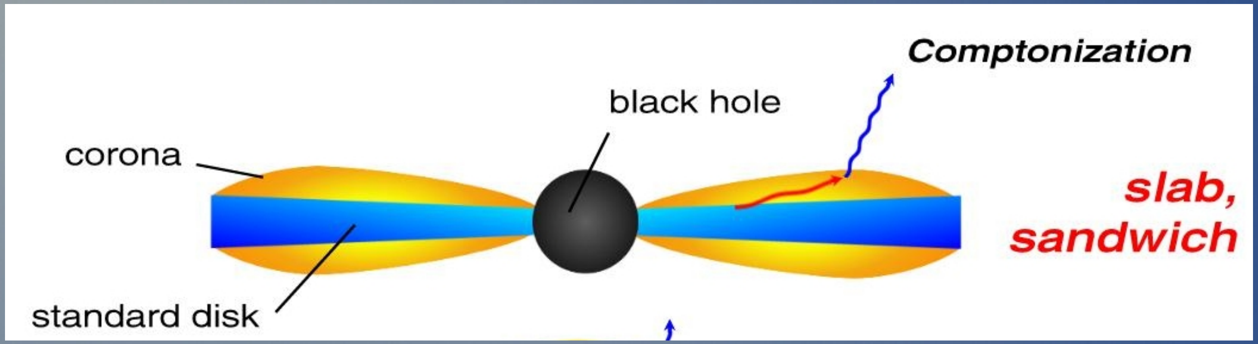
Fig. 6(a) shows α versus log of the 2–10 keV luminosity for the ME data and Fig. 6(b) shows the same for the ME + LE data, where error bars on α cover the 90 per cent confidence range

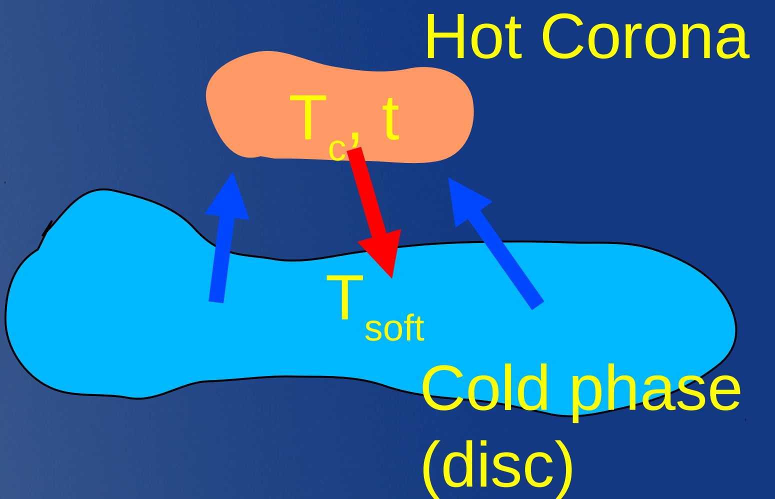
Figure 6. Energy index, α, versus 2–10 keV luminosity (absorption corrected). Only hard X-ray components are plotted for (a) the ME data and (b) the ME + LE data.

Nandra & Pounds 1994

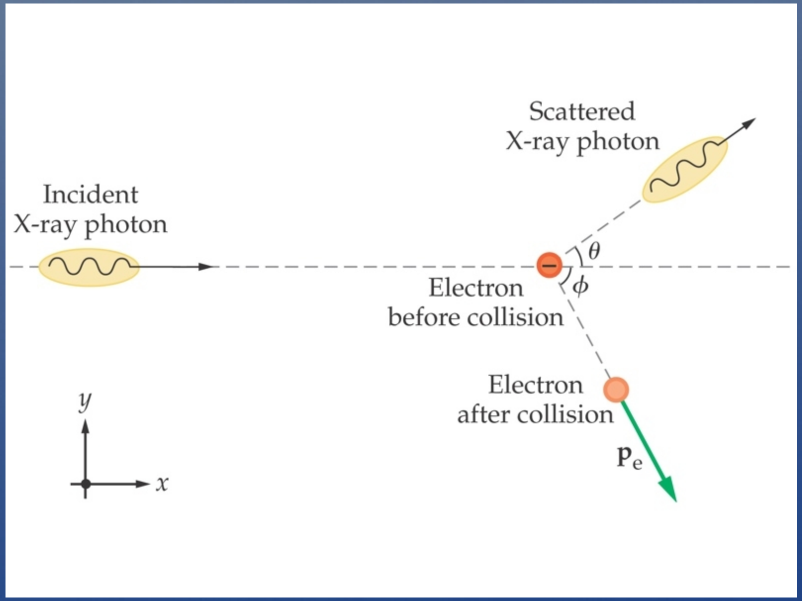
Turner & Pounds 1989

II - Power-law (Thermal Comptonization from the corona)





Thermal comptonization from thermal electrons plasma with kT and optical depth τ



If electron at rest:

$$\Delta E = E' - E \simeq -\frac{E^2}{m_e c^2}(1-\cos\theta)$$

For non-stationnary electron:

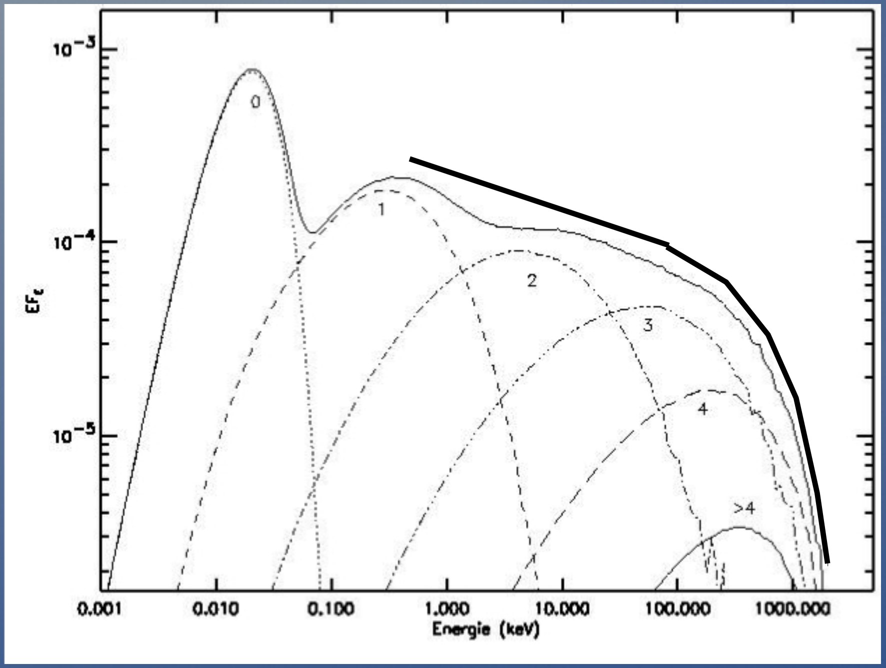
$\Delta E < 0 \rightarrow$ Compton

$\Delta E > 0 \rightarrow$ Inverse Compton

II - Power-law (Thermal Comptonization from the corona)

$$f_\epsilon(\epsilon)\,d\epsilon = \sqrt{\frac{1}{\pi\epsilon kT}}\ \exp\left[\frac{-\epsilon}{kT}\right] d\epsilon$$

Maxwellian Distribution of electron energies
⇒produce power-law + high energy cut-off

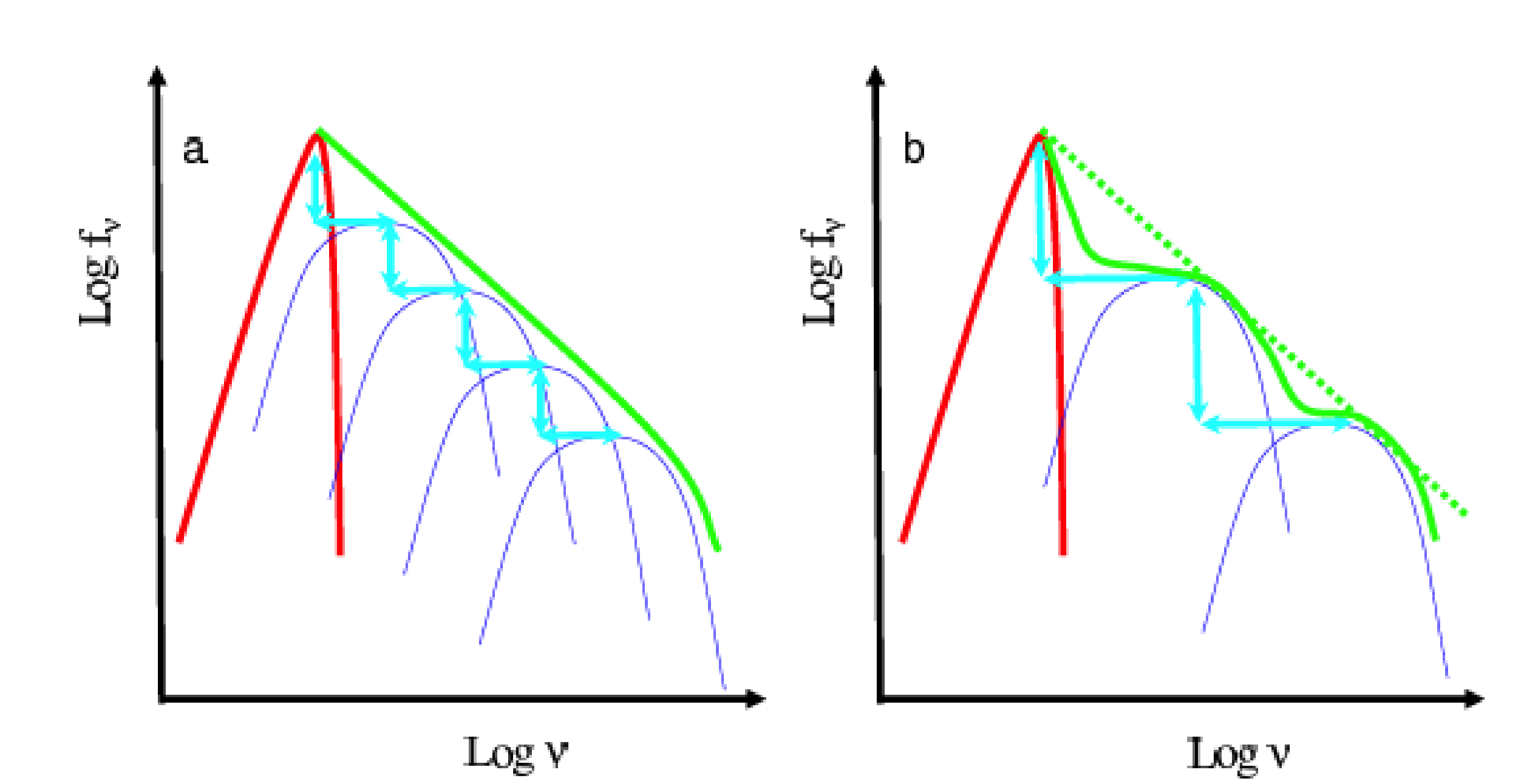


$$F_E \propto E^{-\Gamma(kT,\tau)} \exp\left(-\frac{E}{E_c(kT,\tau)}\right)$$

$$\begin{cases} \Gamma \propto \left(\frac{L_{heat}}{L_{cool}}\right)^{-\delta} \propto f(kT, \tau) \\ E_c \simeq kT \end{cases}$$

$\Gamma(kT,\tau)$ ➥ Spectral degeneration since different (kT, τ) can yield same Γ

II - Power-law (Thermal Comptonization from the corona)

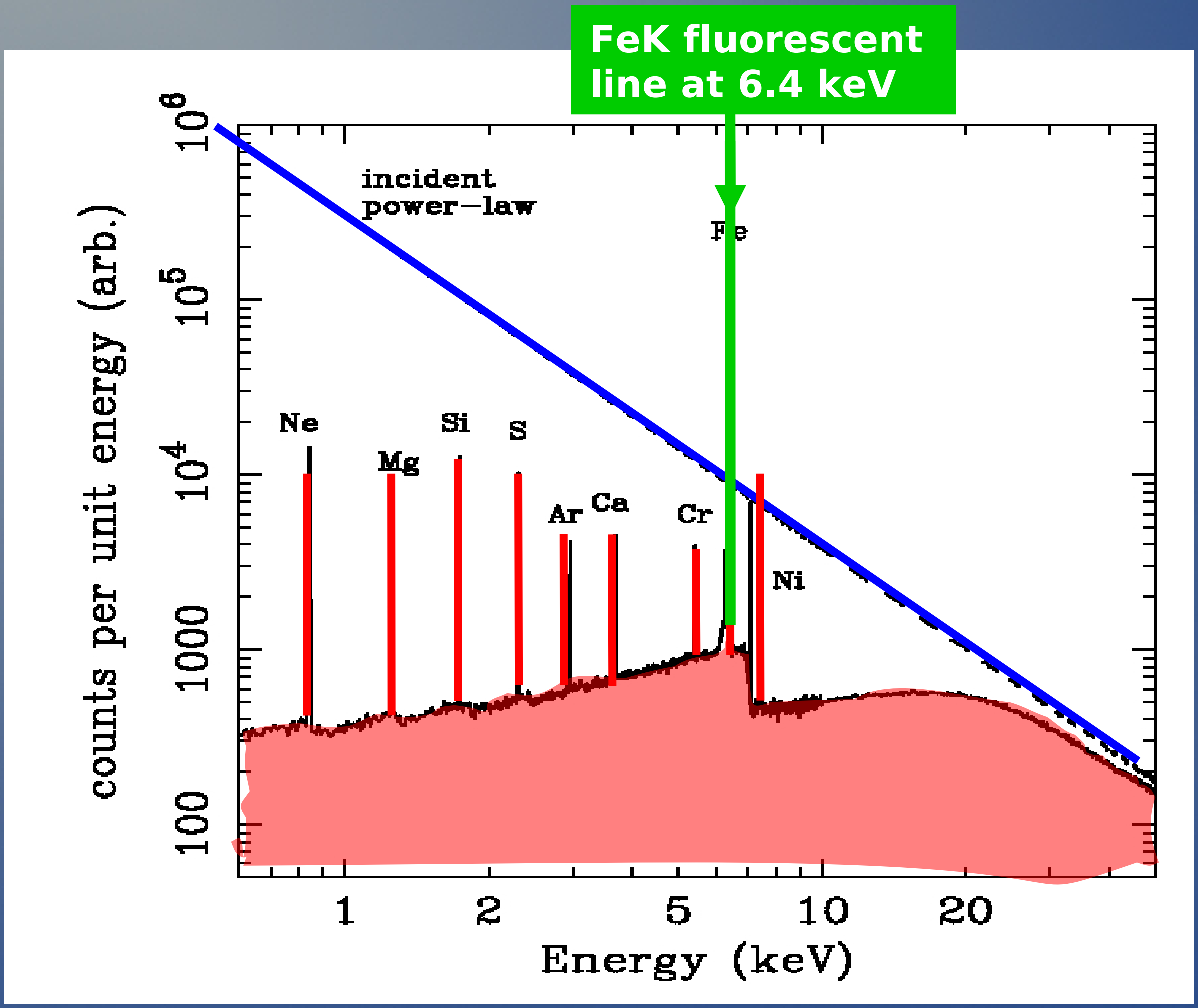


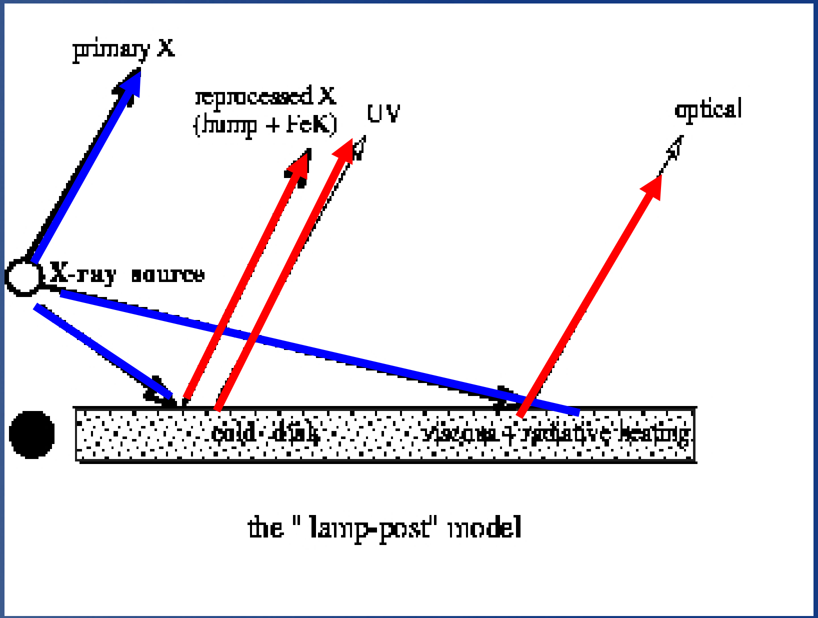
$$\Theta = kT_e/m_ec^2$$

$$\epsilon_{out,1} = (1+4\Theta)\epsilon_{in}$$

$$\log f(\epsilon) \propto \ln(1/\tau)/\ln(1+4\Theta) \text{ i.e. } f(\epsilon) \propto \epsilon^{-\alpha} \text{ with } \alpha = \ln\tau/\ln(1+4\Theta)$$

III - Reflection component (line + continuum)





(e.g. Reynolds et al. '94

- ∝ Inclination
- ∝ $\Omega/2\Pi$ (coverage, isotropy)
- ∝ Ab

Major modifications expected:

a) Ionization effects

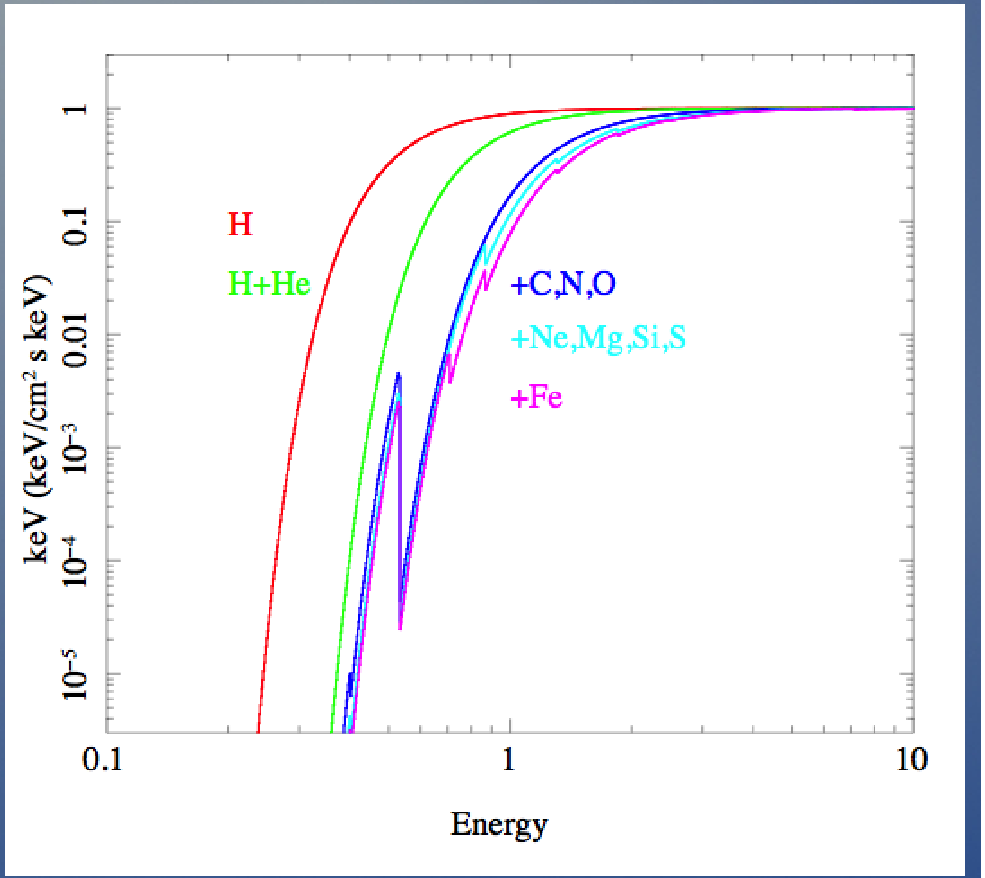
b) Relativistic effects

or a combination of both…

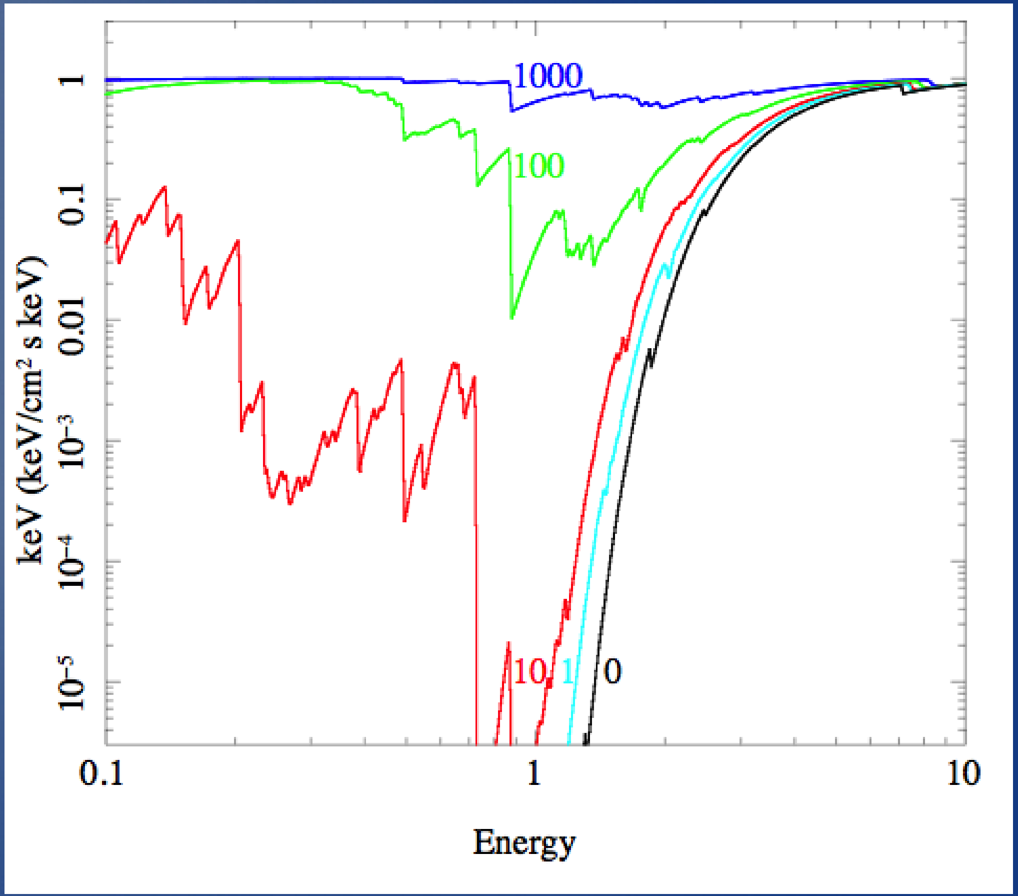
IV - absorption along the line of sight

Photoelectric absorption

Neutral



Ionized (Xi=L/nR**2)

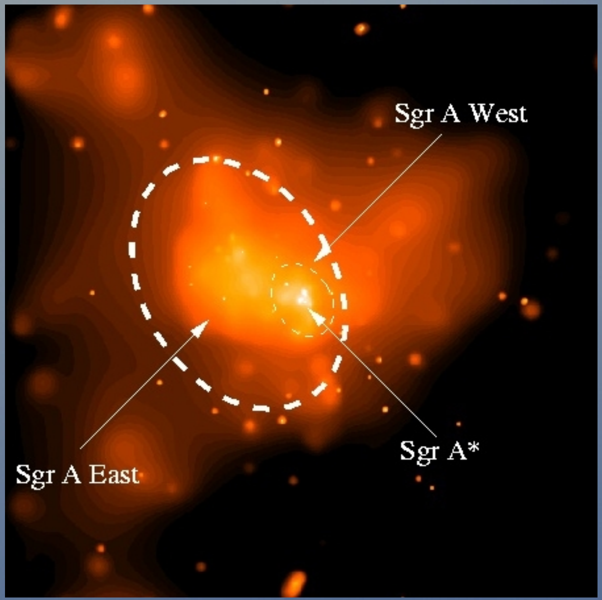


Model 2

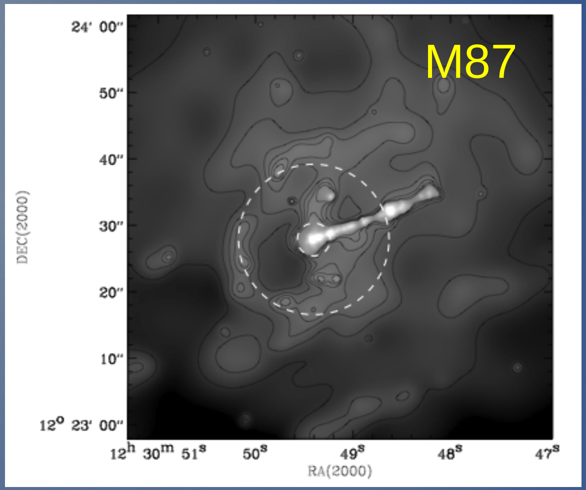
The radiatively inefficient model (LLAGNs)

Modello II (LL AGN): X-ray observations - Images and Lightcurves

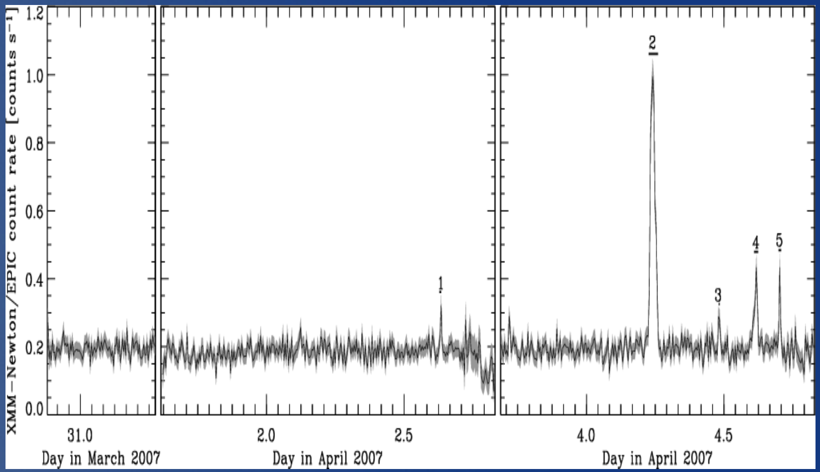
SgrA*



Images + Lightcurves



SgrA*



Low-L and diffuse X-ray source

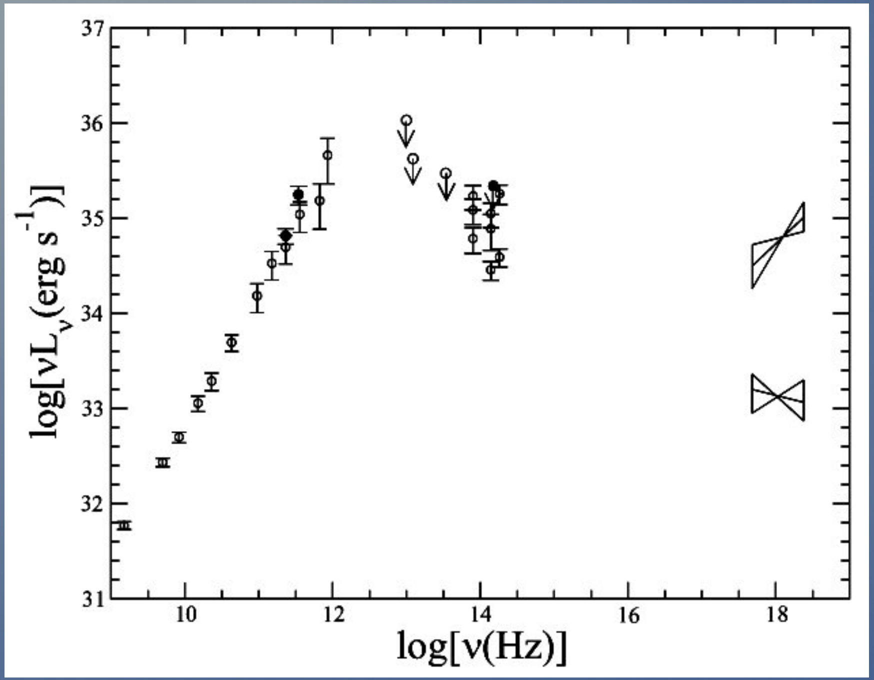
N.B: $\Delta t \sim 50$ s corresponds to 1 R_g per $M=10^7 M$

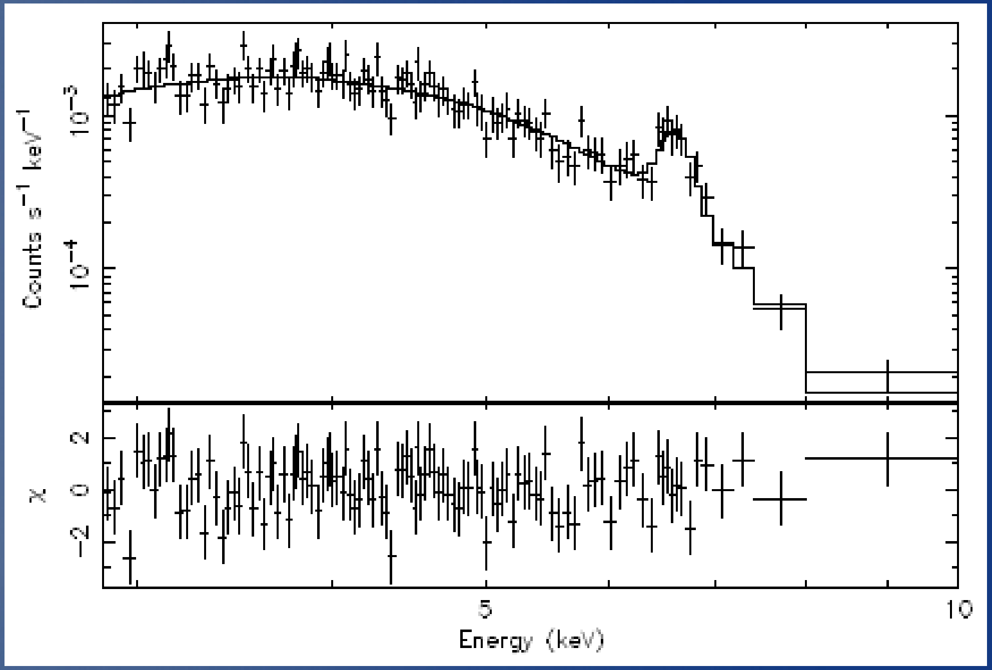
($t \sim R_g/c \sim GM/c^3 \sim 50\ M_7$ s)

Low-L, likely diffused emission
+ isolated flares (otherwise quiescent)

Model II (LL AGN): X-ray observations - Typical Spectra

Spectra:





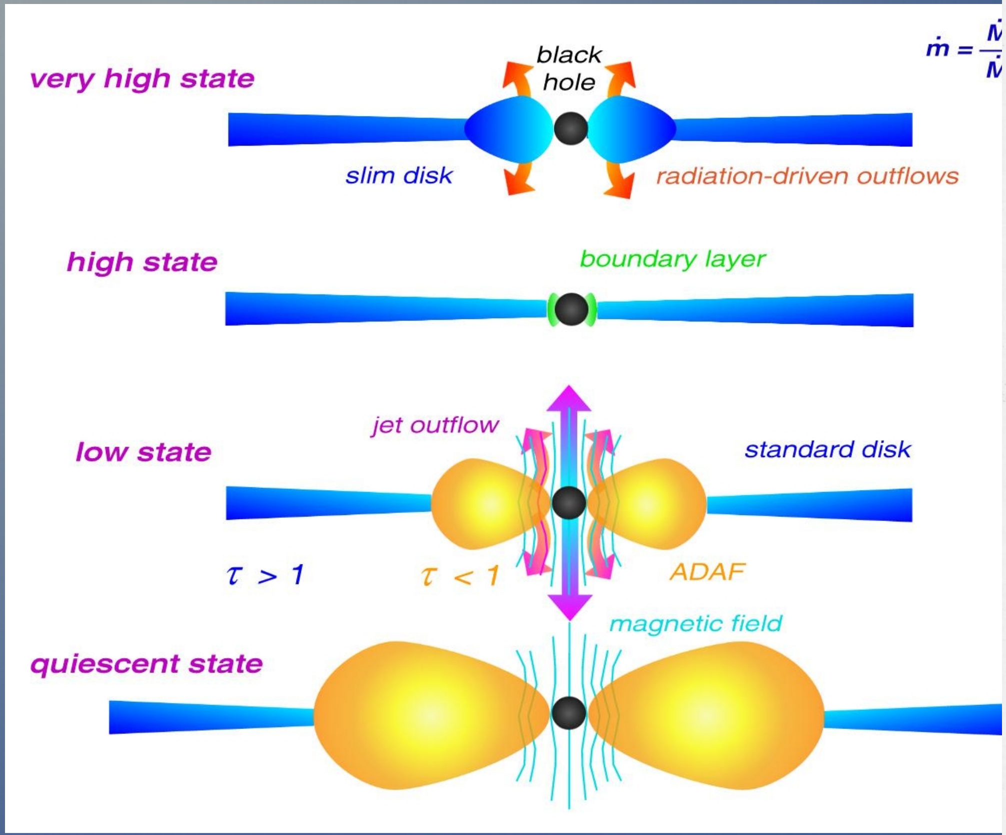
$L_x \sim 2 \times 10^{33}$ erg/s $< 10^{-11}$ L_{Edd}

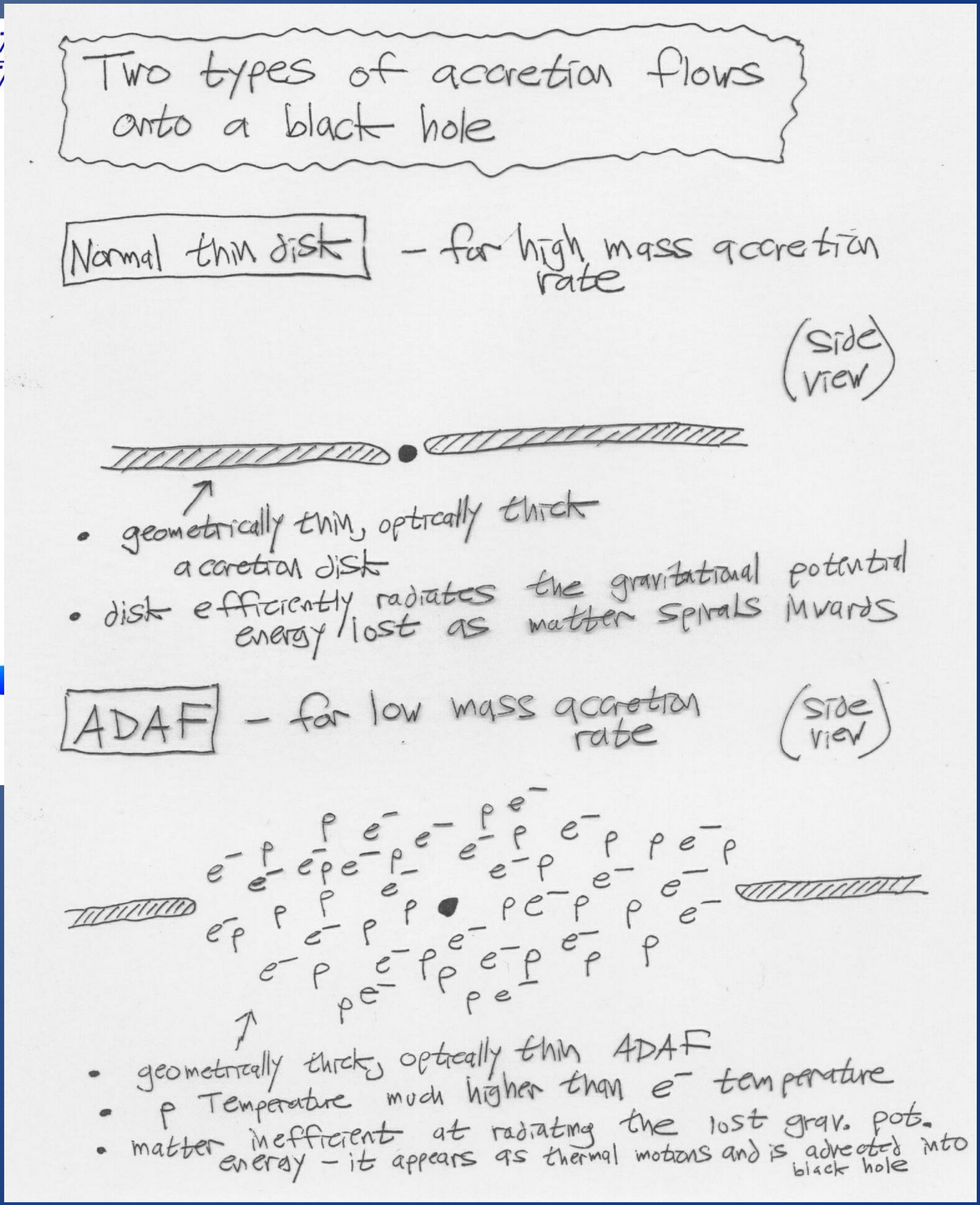
Bremsstrahlung Thermal-like quiescent spectrum

(At least) 2 major spectral components:

1. Synchrotron emission
2. Bremsstrahlung (+ power-laws during flares)

Model II (LL AGN):



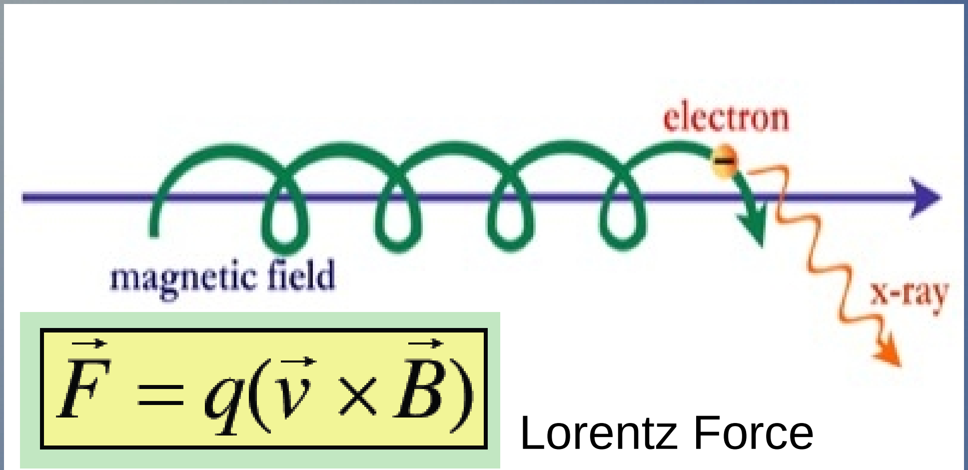


Simil-ADAFs:

- advection–dominated accretion flow (ADAF)
- radiatively–inefficient accretion flow (RIAF)
- convection–dominated accretion flow (CDAF)
- slim disk
- truncated disk – advective tori (TDAT)
- non–radiative accretion flow (NRAF)

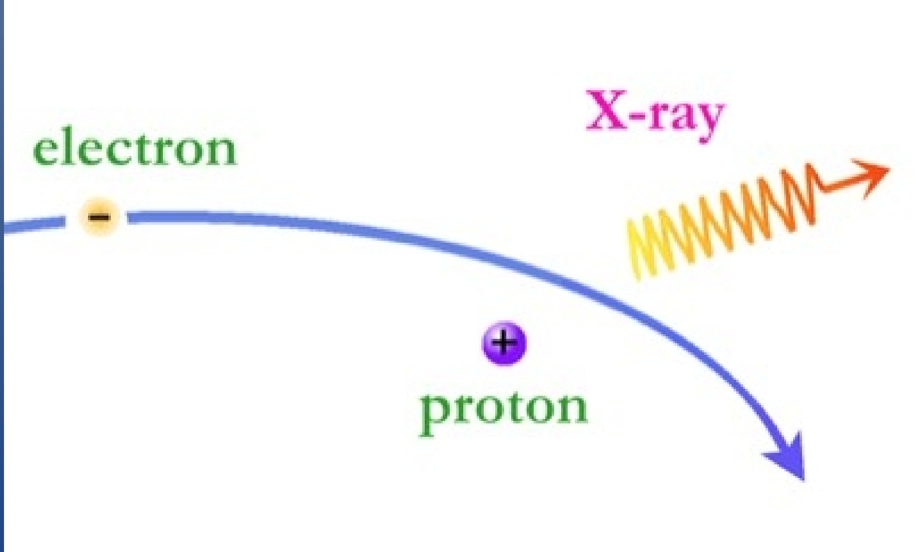
From N. Brandt (I think)

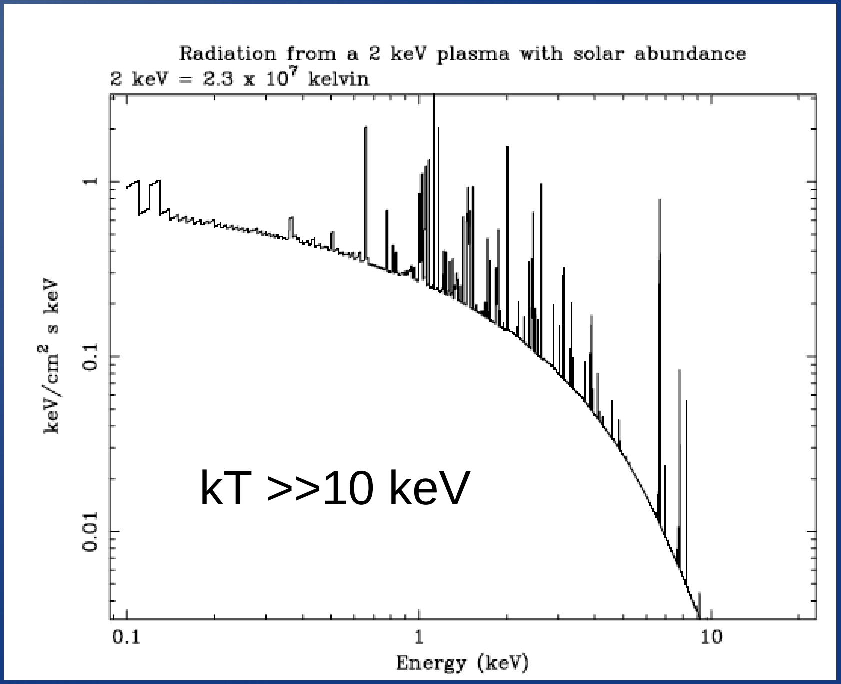
Modello II (LL AGN): ADAFs model



Synchrotron
(non-thermal emission)

+ Thermal Bremsstrahlung from a very hot, optically thin, geometrically thick flow





Summary

After introducing the BH and AGN paradigm, we have reviewed 3 major "models" of AGN:

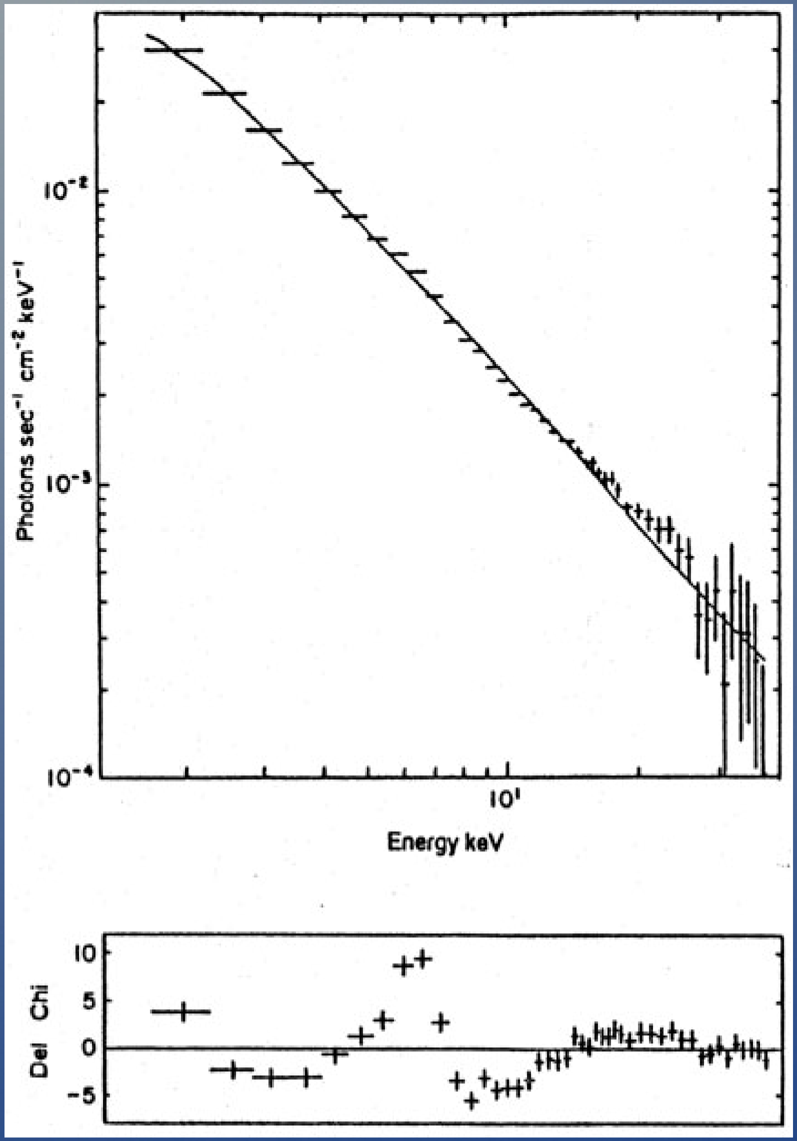
Model I: 2-phase model (radio-quiet AGNs)

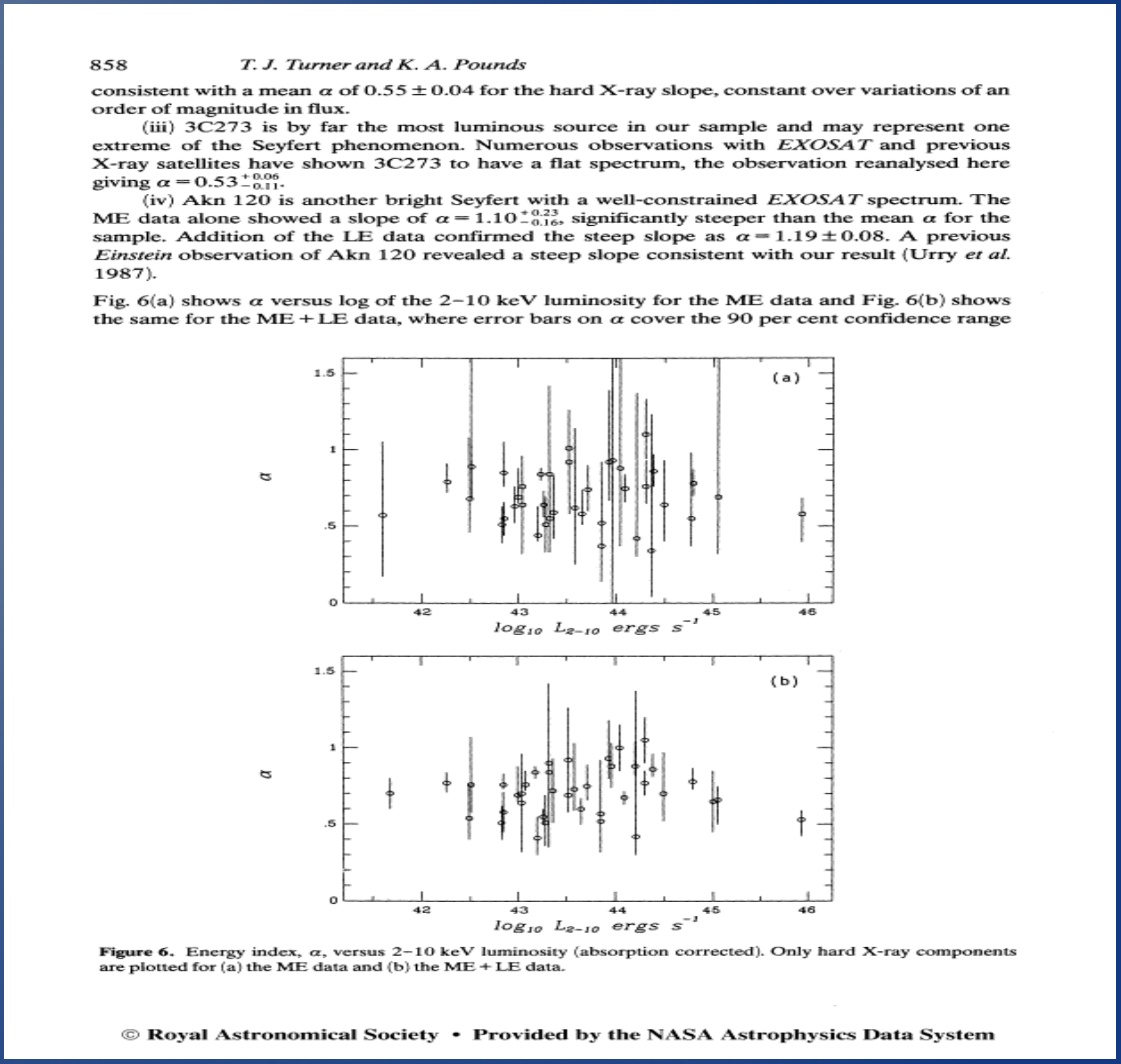
1. Multi-T black-body emission (soft-excess)
2. Thermal Comptonization (power-law)
3. Reflection (FeK line + Compton hump)
4. Absorption (ionized, partially covering, etc.)

Model II: Inefficient model (LLAGNs)

1. ~~Synchrotron~~
2. Bremsstrahlung (thermal)

Power-law spectra: an universal law Γ=1.7?





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consistent with a mean α of 0.55 ± 0.04 for the hard X-ray slope, constant over variations of an order of magnitude in flux.

(iii) 3C273 is by far the most luminous source in our sample and may represent one extreme of the Seyfert phenomenon. Numerous observations with *EXOSAT* and previous X-ray satellites have shown 3C273 to have a flat spectrum, the observation reanalysed here giving $\alpha = 0.53^{+0.06}_{-0.11}$.

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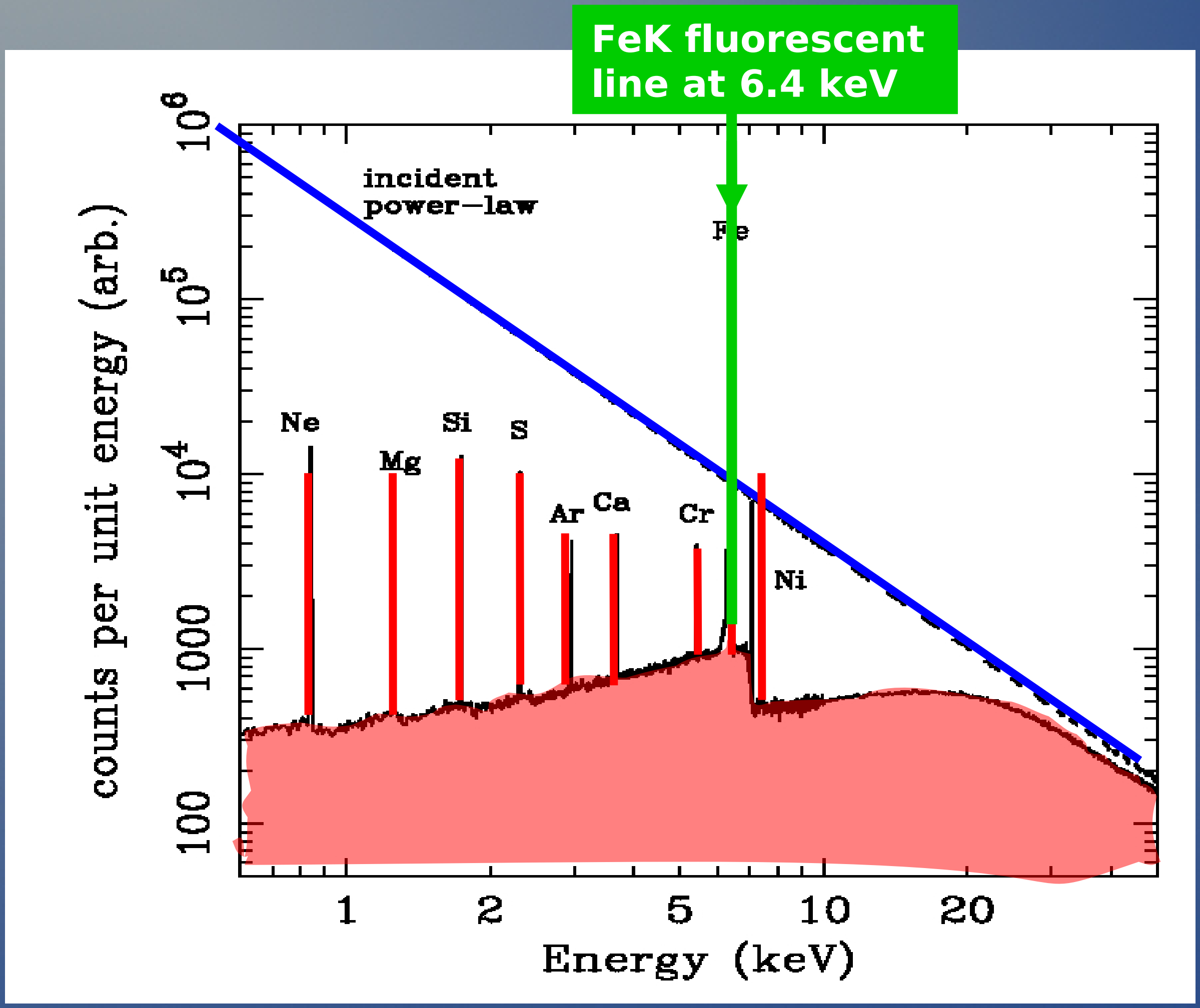
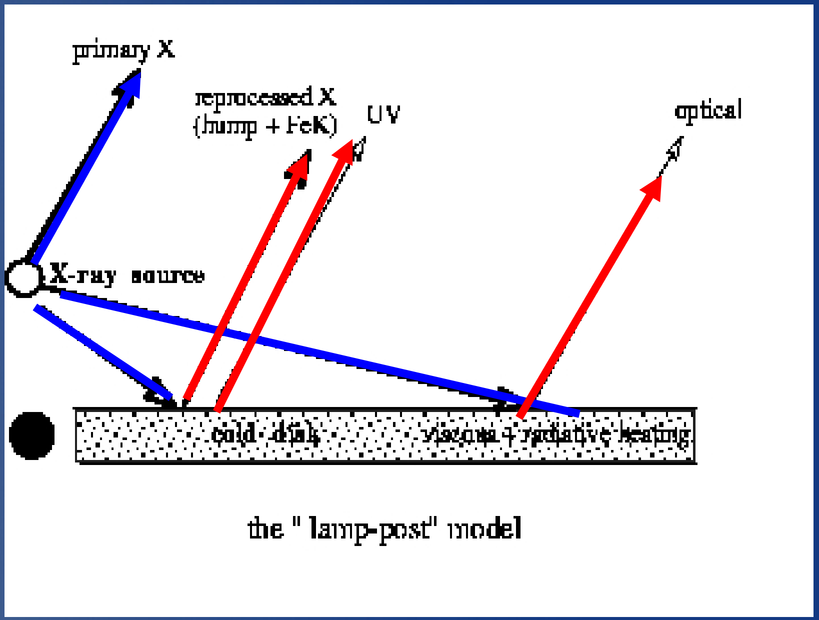
Figure 6. Energy index, α, versus 2–10 keV luminosity (absorption corrected). Only hard X-ray components are plotted for (a) the ME data and (b) the ME + LE data.

Nandra & Pounds 1994

Turner & Pounds 1989

III - Reflection component (line + continuum)





(e.g. Reynolds et al. '94

- ∝ Inclination
- ∝ Ω/2Π (coverage, isotropy)
- ∝ Ab

Major modifications expected:

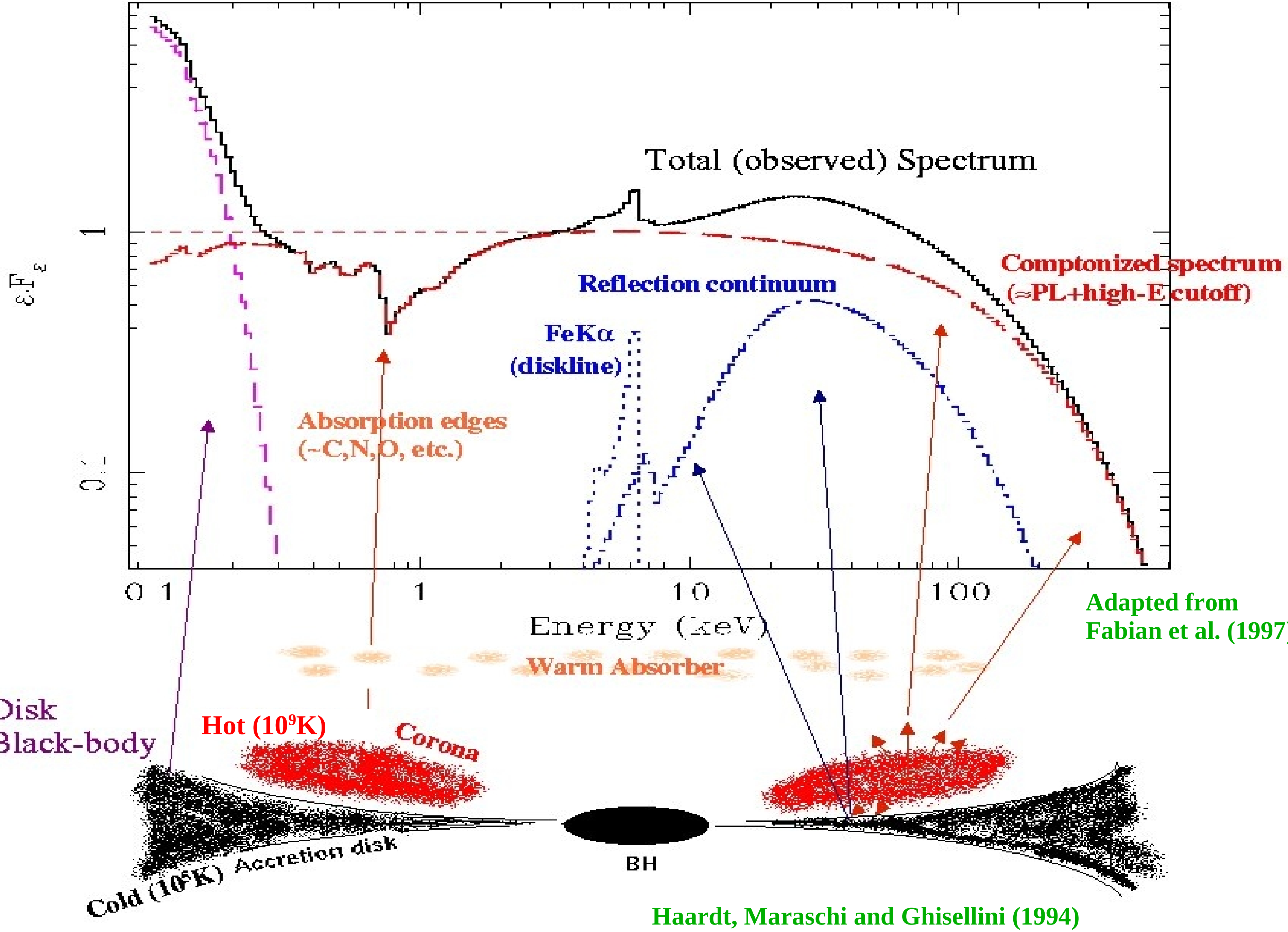
a) Ionization effects

b) Relativistic effects

or a combination of both…

Reflection(s)
(i.e. accretion)

Typical X-ray Spectrum of a Seyfert 1 Galaxy
⇔ Standard two-phase Comptonization model



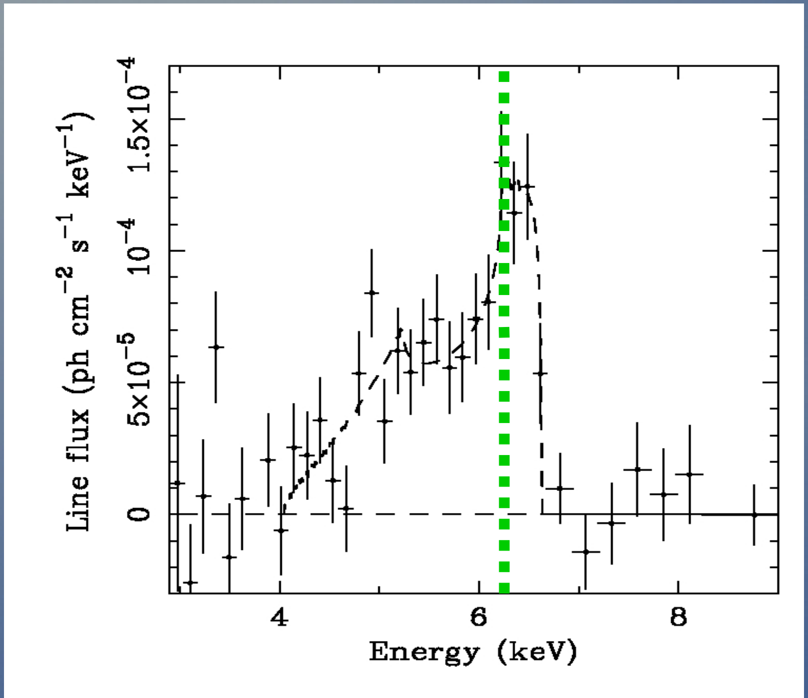
Adapted from
Fabian et al. (1997)

Haardt, Maraschi and Ghisellini (1994)

Reflection: Observations

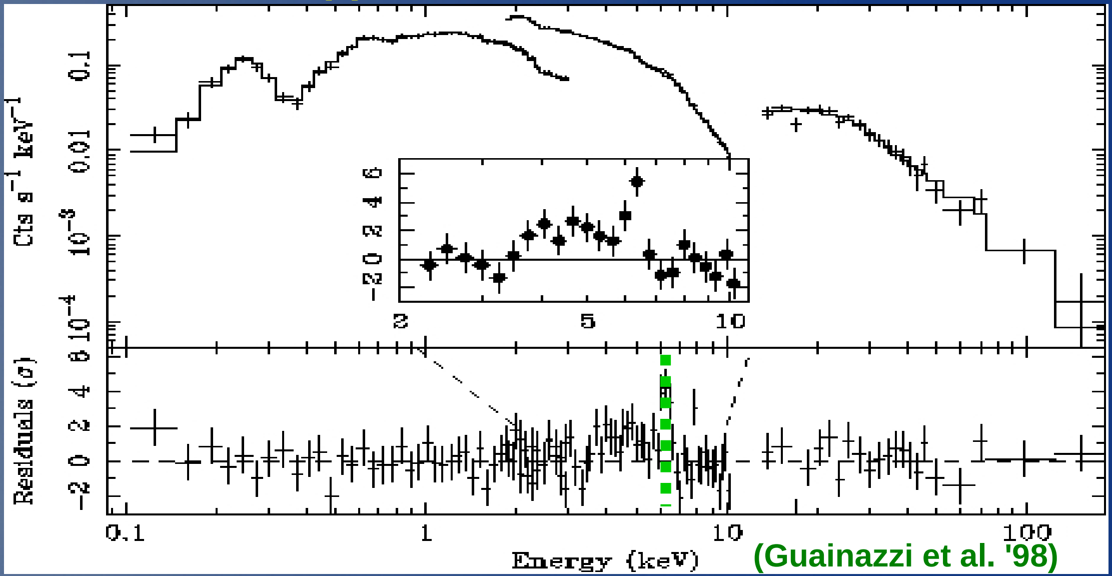
Pre-Chandra & XMM-Newton

ASCA obs. of Sey1 MCG-6-30-15

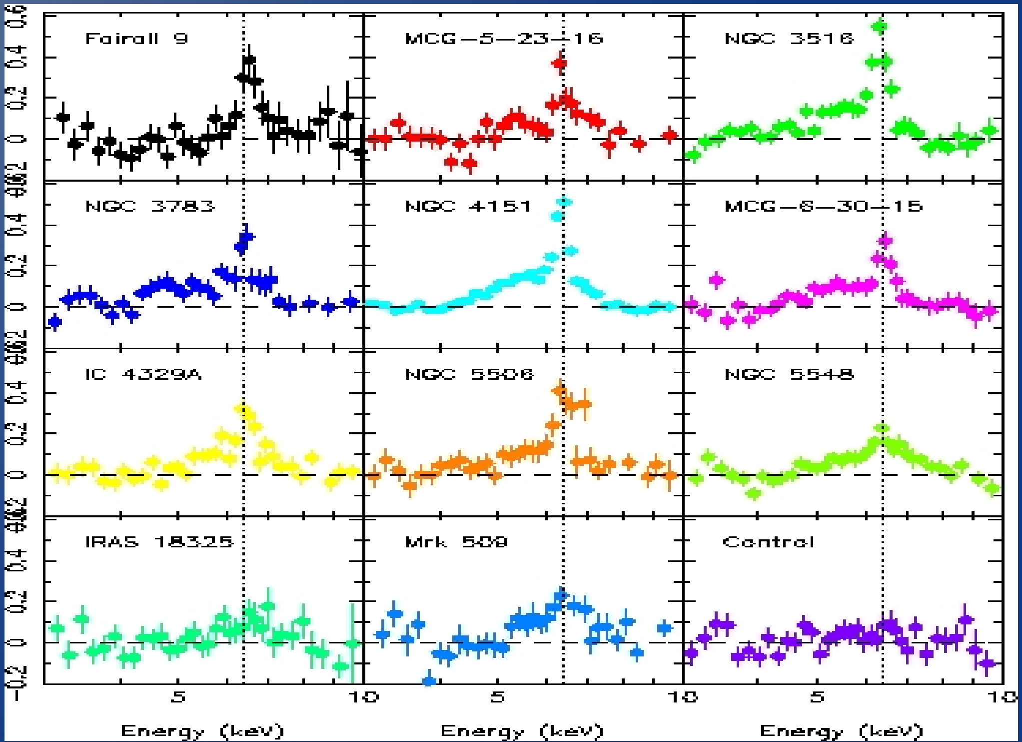


(Tanaka et al. '95)

BeppoSAX obs. of MCG-6-30-15



(Guainazzi et al. '98)



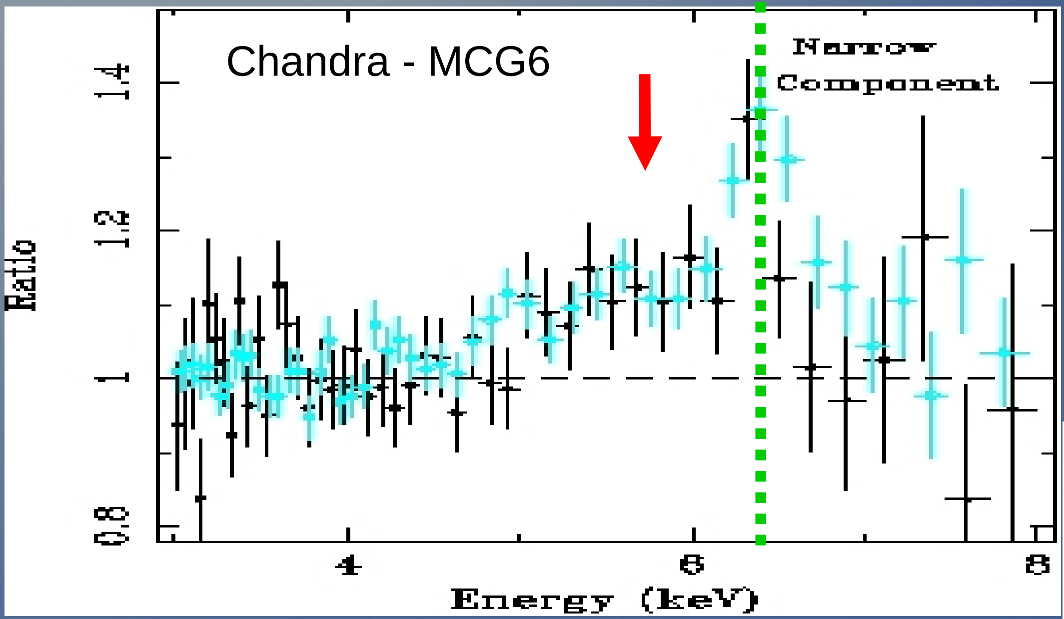
(Nandra et al. '98)

ASCA ---> Broad (relativistic) lines are common, and ubiquitous (?) in Seyfert1s!

Reflection: Observations

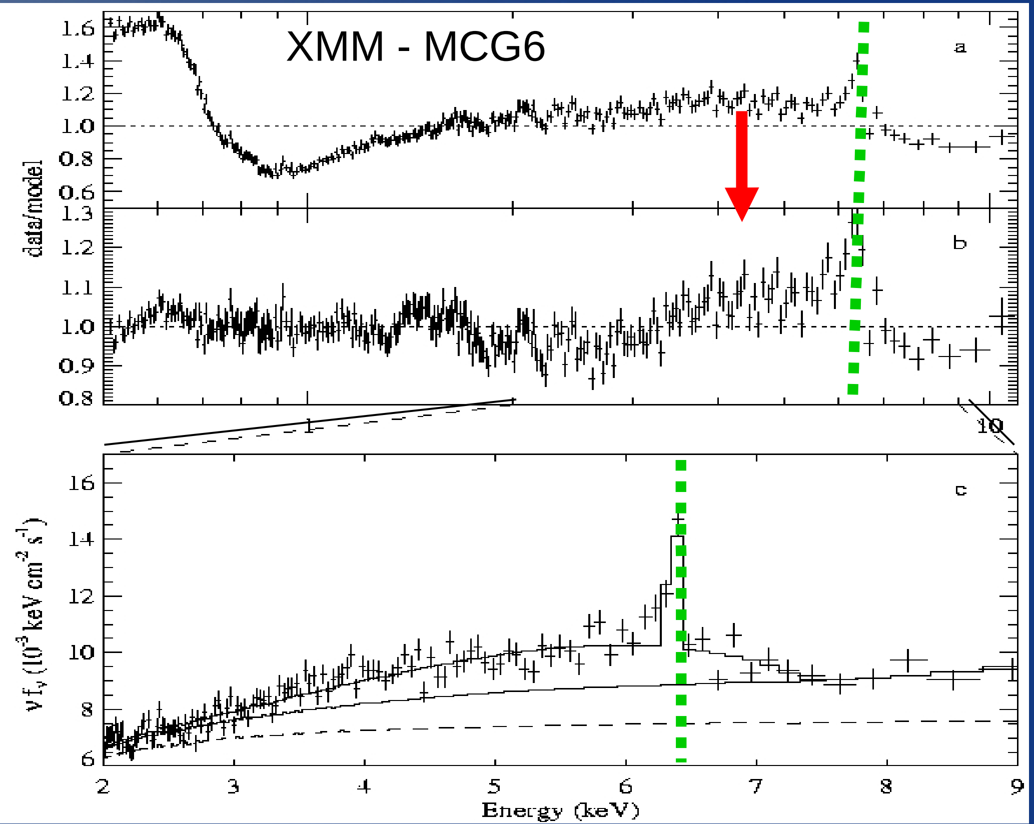
Post-Chandra & XMM-Newton

Yes, we see broad lines indeed!



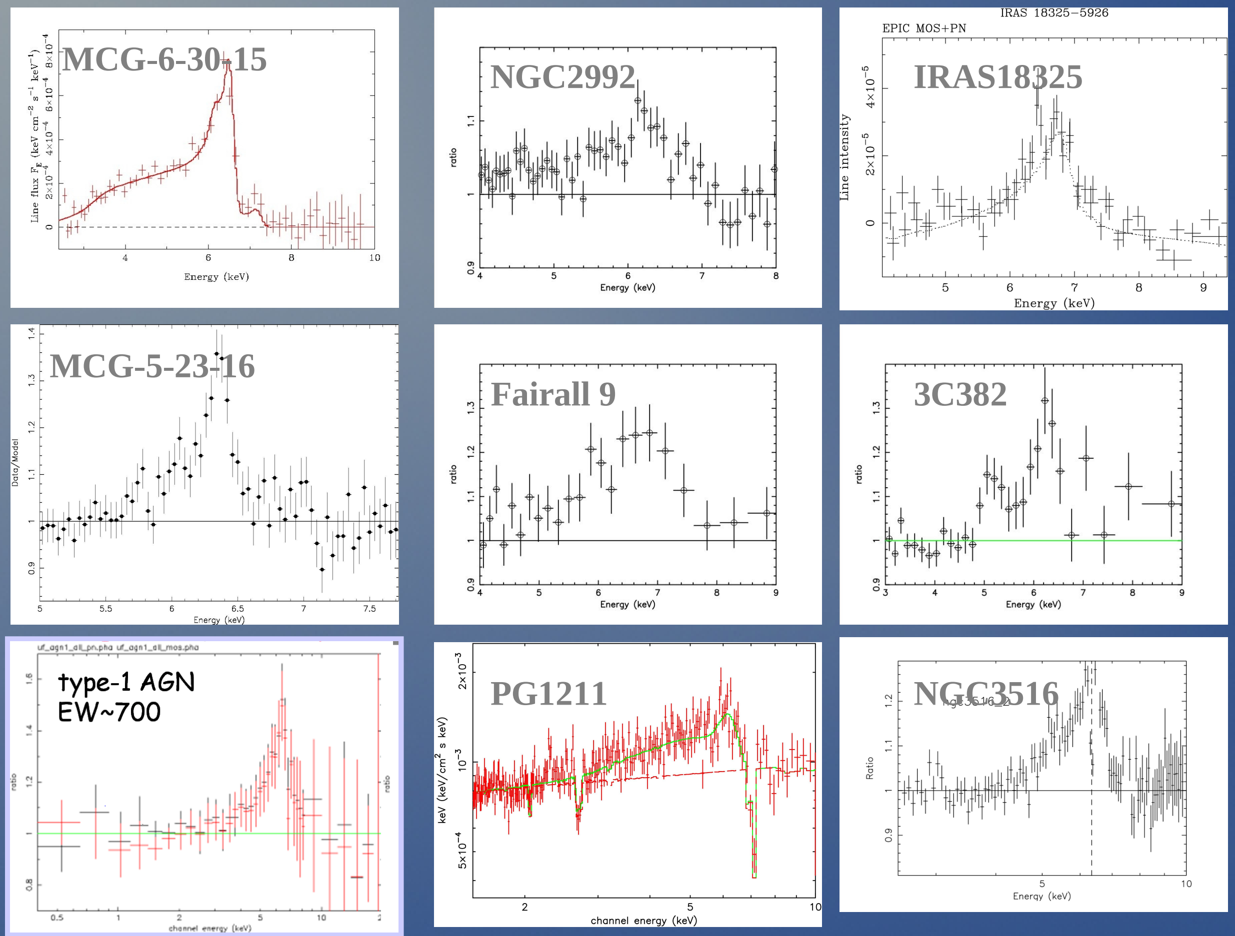
(Lee et al. '02)

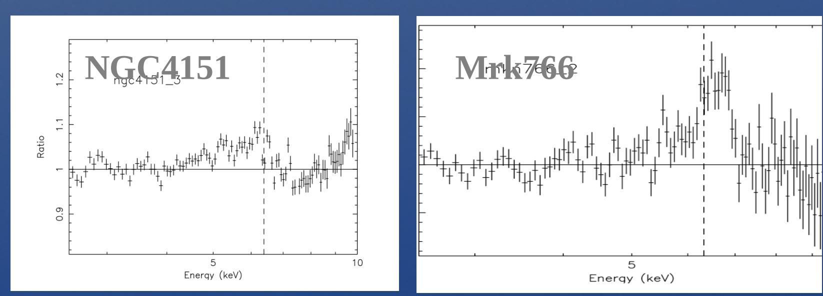
(Wilms et al. '02
Fabian et al.'04)

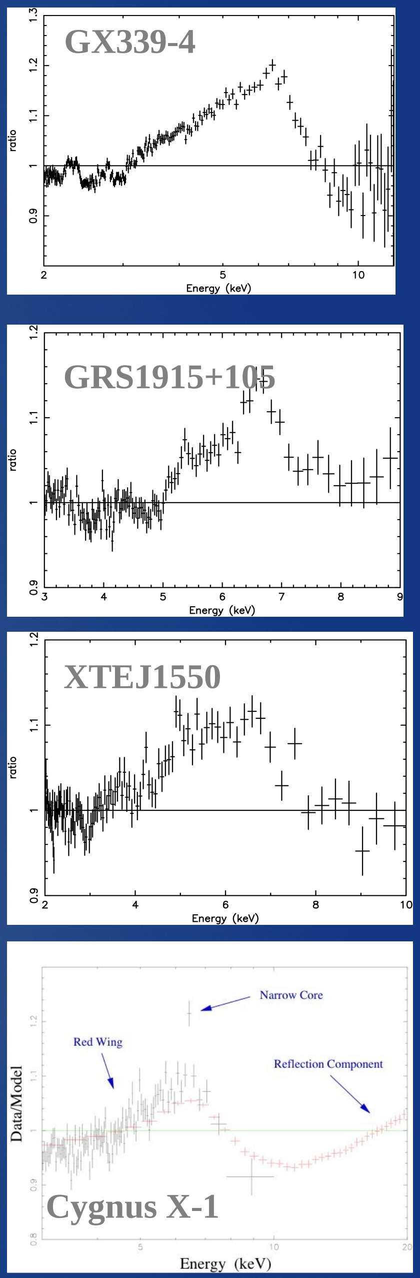


➡ Origin in innermost regions of accretion disk

Reflection: Re-affirmed importance of broad iron lines







Similar line profiles from stellar-mass and super-massive black hole systems… demonstrates insensitivity of line profile to mass

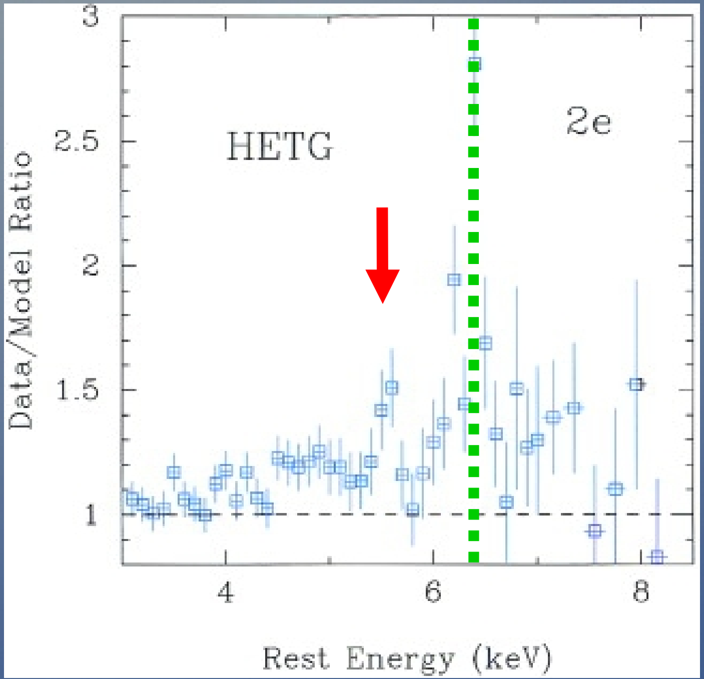
Nandra et al., 2007,
De La Calle et al., 2010

Reflection: Observations

Post-Chandra & XMM-Newton

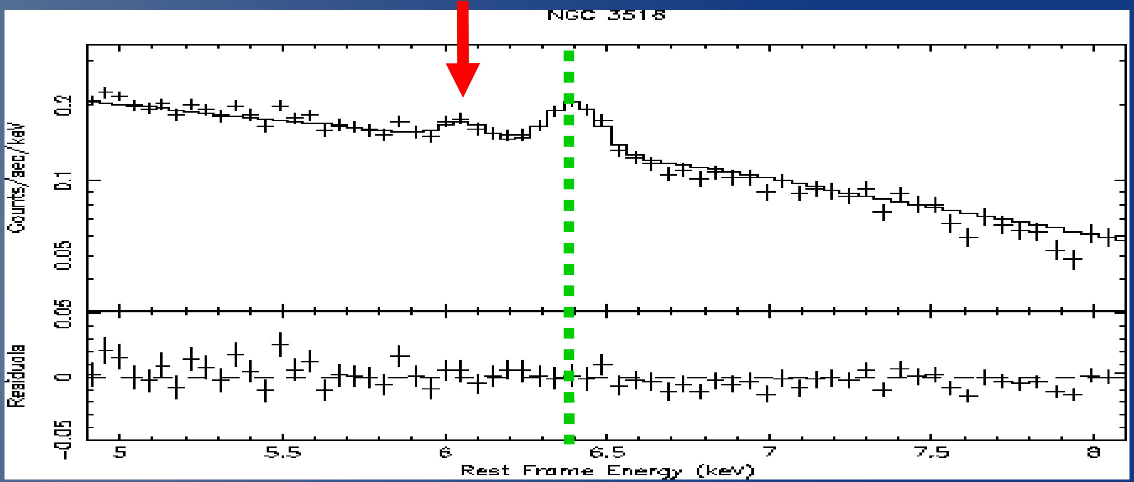
Also some narrow redshifted lines...

Chandra – NGC3516



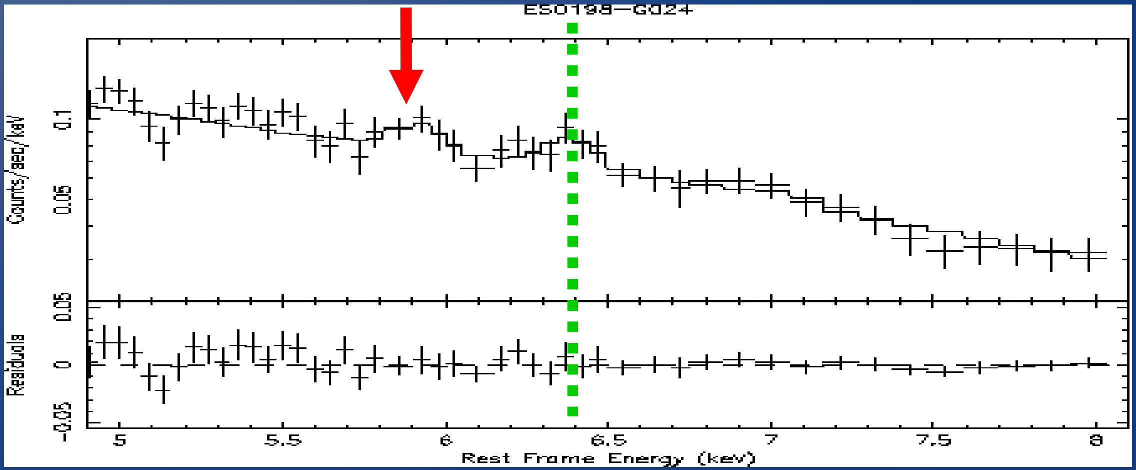
(Turner et al. '02)

XMM – NGC3516



Bianchi et al., 2004

XMM – ESO198-G024



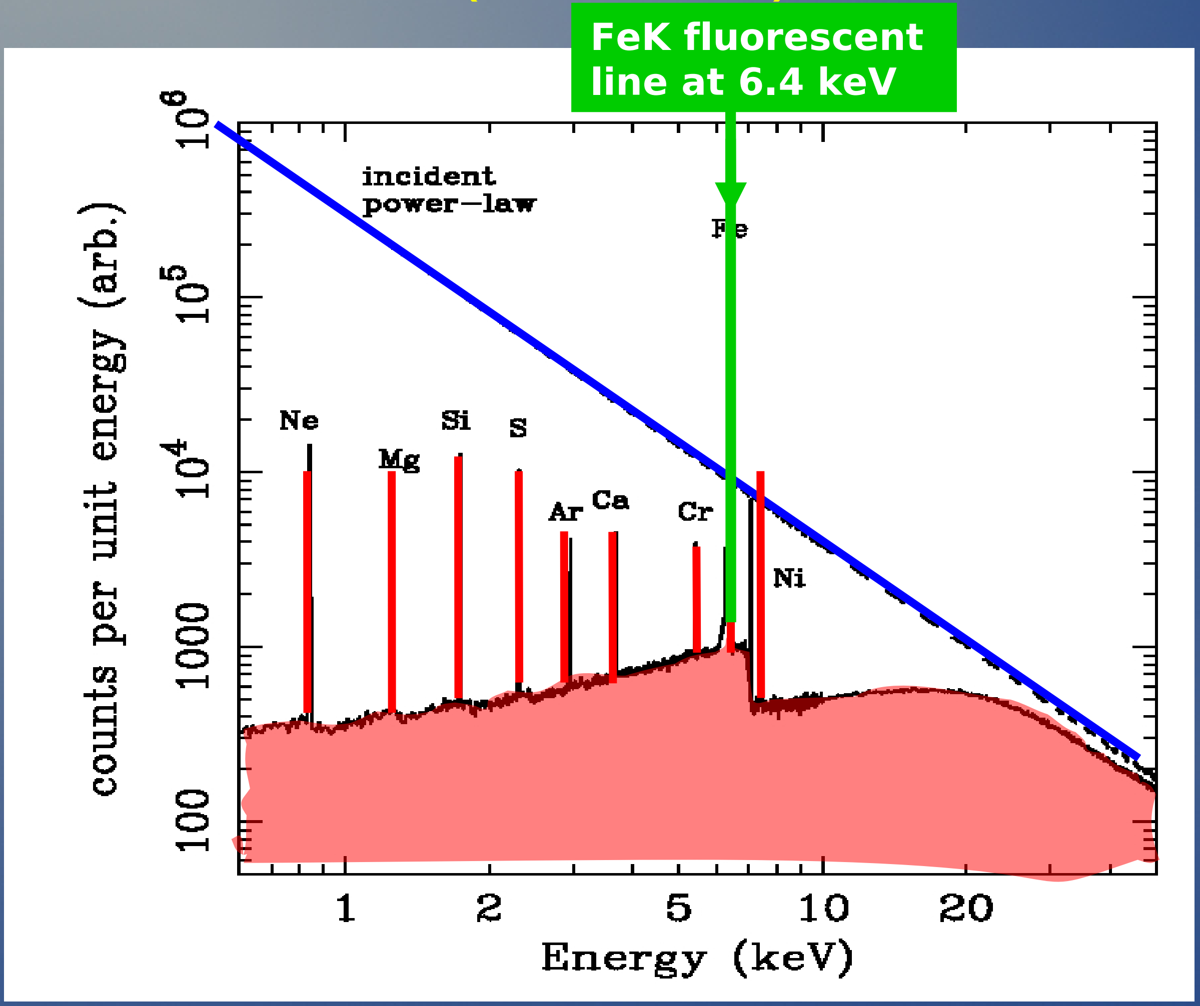
Guainazzi et al., 2003

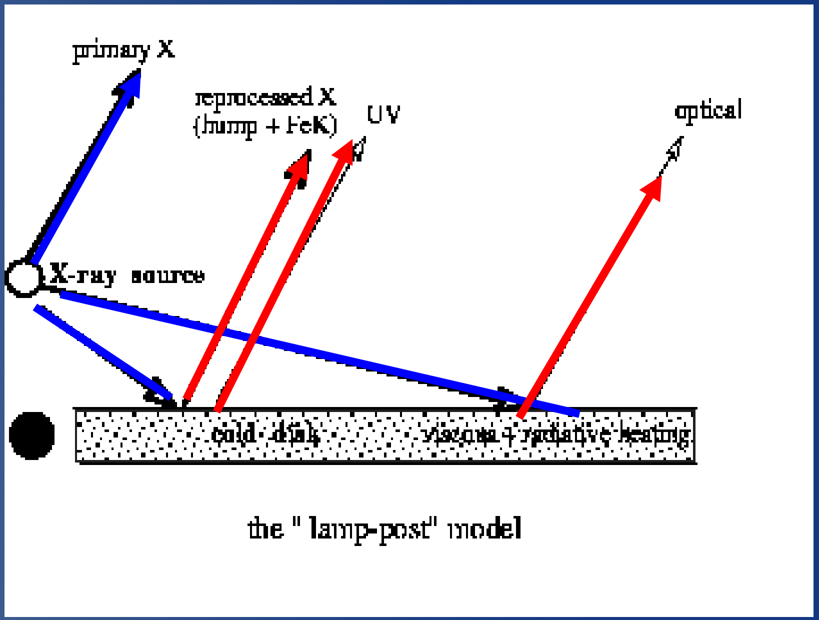
Origin in innermost regions of accretion disk+ blob-like structure (or inflowing blobs?)

Dovciak et al., 2004

Reflection: Interpretation

We understand (theoretical) reflection models... don't we? ;-)





(e.g. Reynolds et al. '94

- ∝ Inclination
- ∝ Ω/2Π (coverage, isotropy)
- ∝ Ab

Major modifications expected:

a) Ionization effects

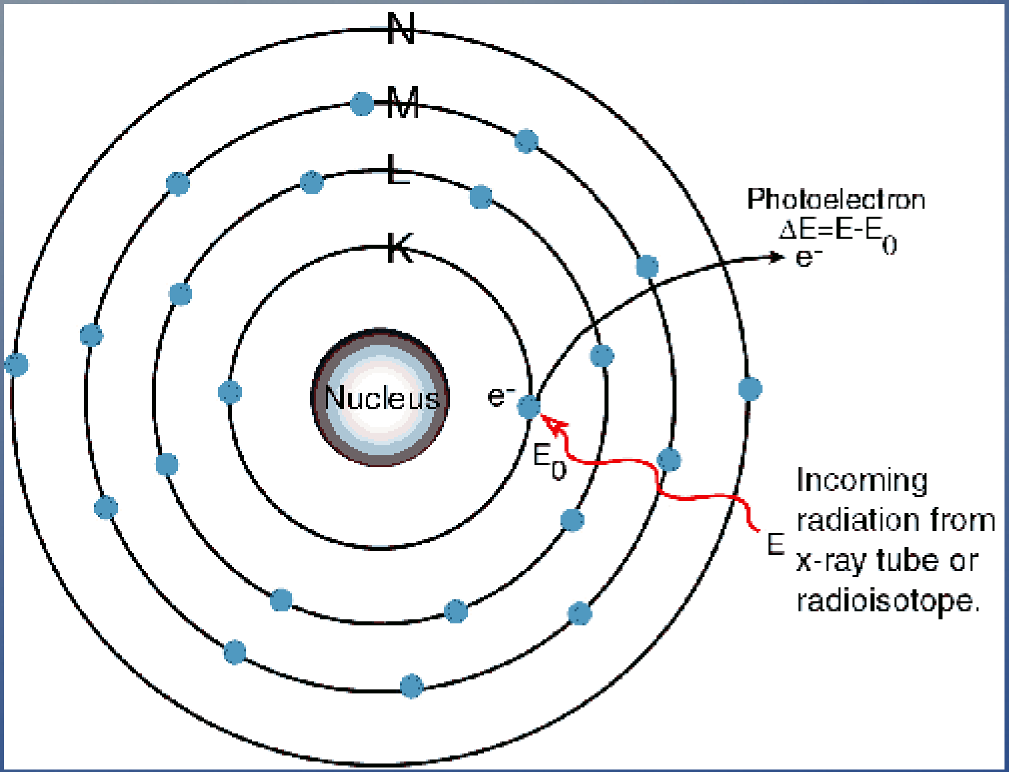
b) Relativistic effects

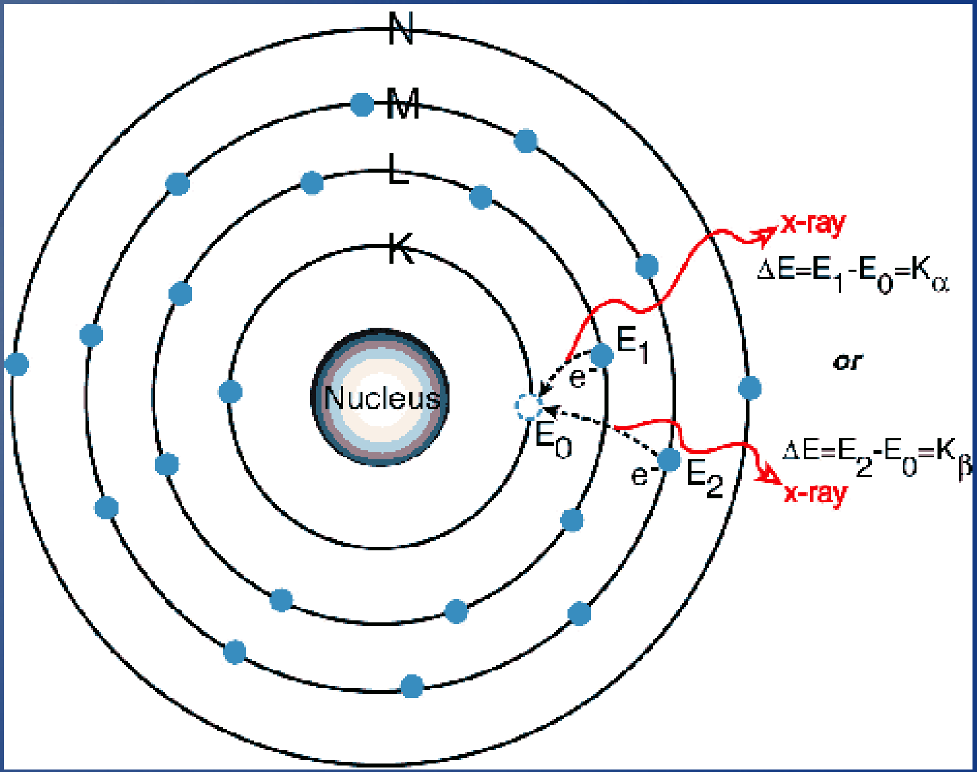
or a combination of both…

Reflection: (Fe) Fluorescence Line

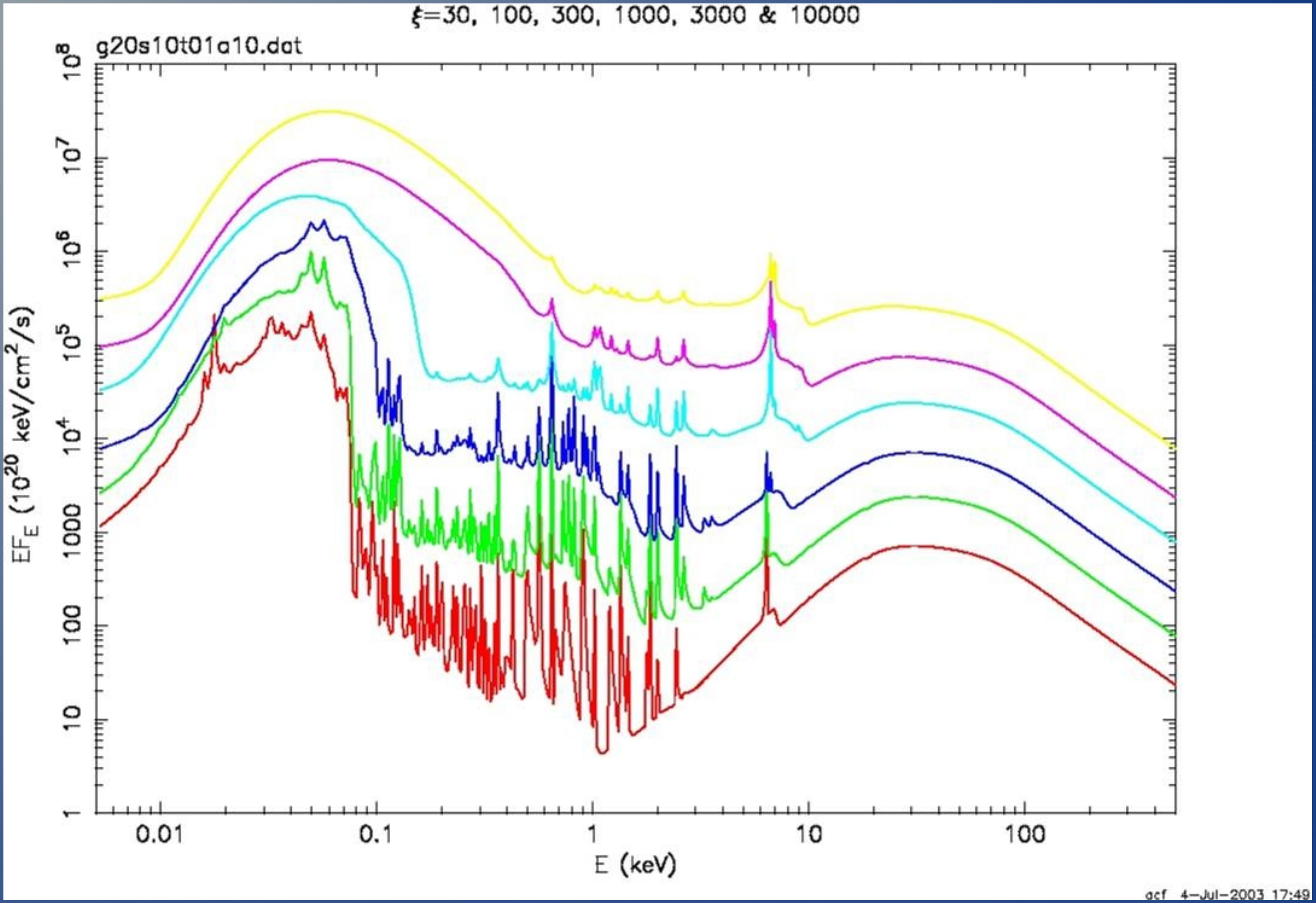
Photoelectric Absorption

Fluorescence (+ Auger for 60%)





Reflection: A- Ionization effects



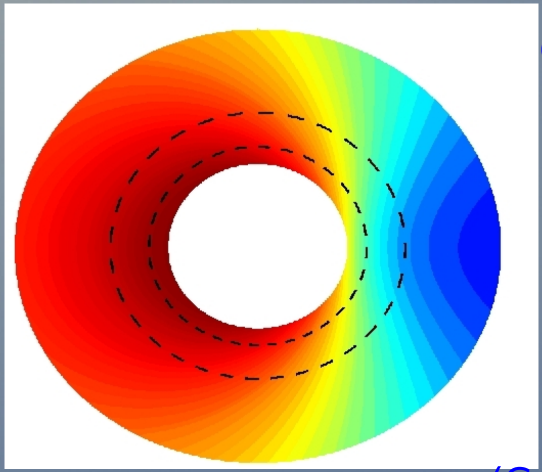
$\xi = L/nR^2$

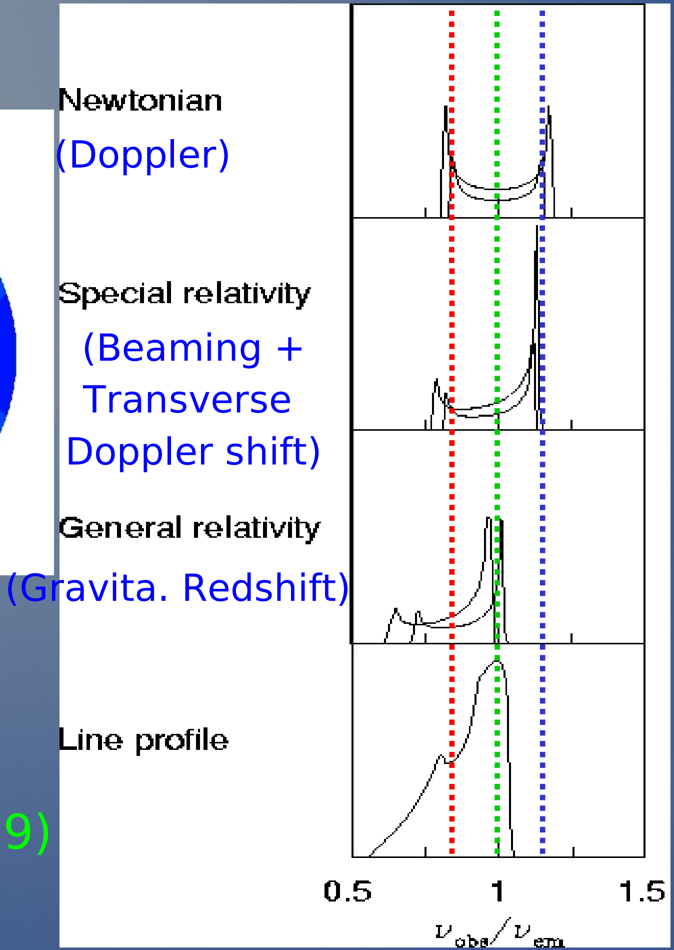
Major variations:

1) FeK energy (↑)
2) FeK intensity (↓,↑,↓)
3) Soft lines intensity/energy (↑,↓)

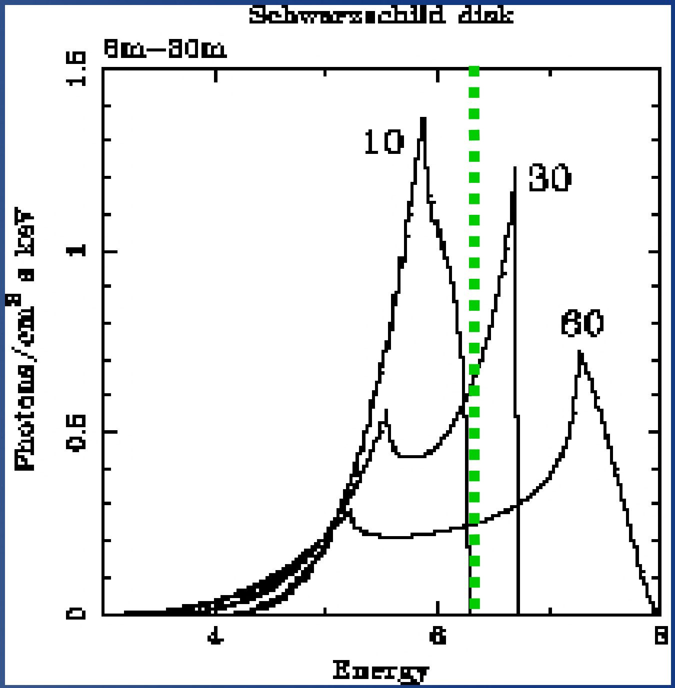
Ballantyne & Fabian '02, Ross & Fabian '93, '05, Young+, Nayakshin+, Ballantyne+, Rozanska+, Dumo

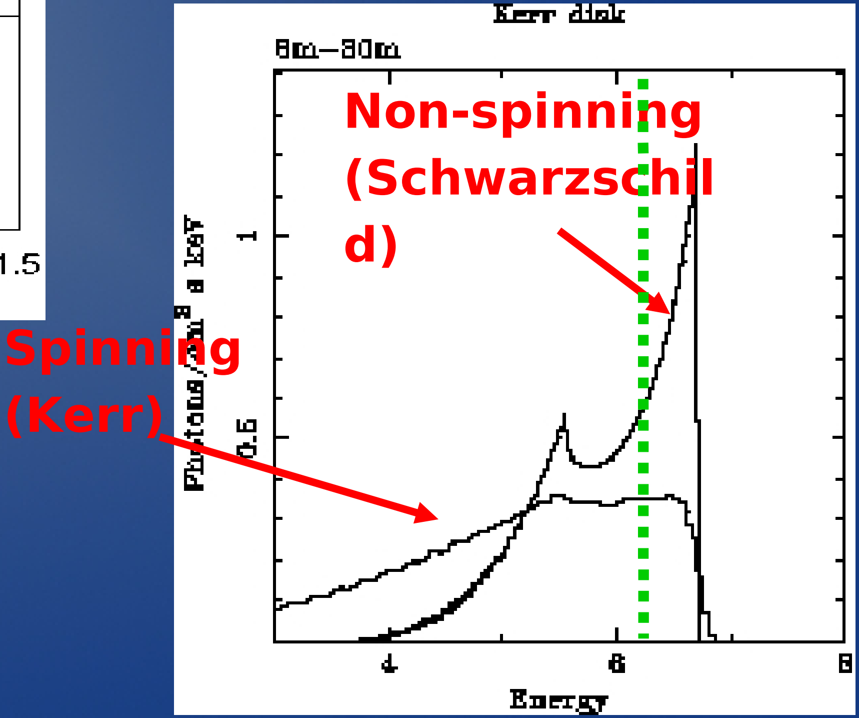
Reflection: B - Relativistic effects



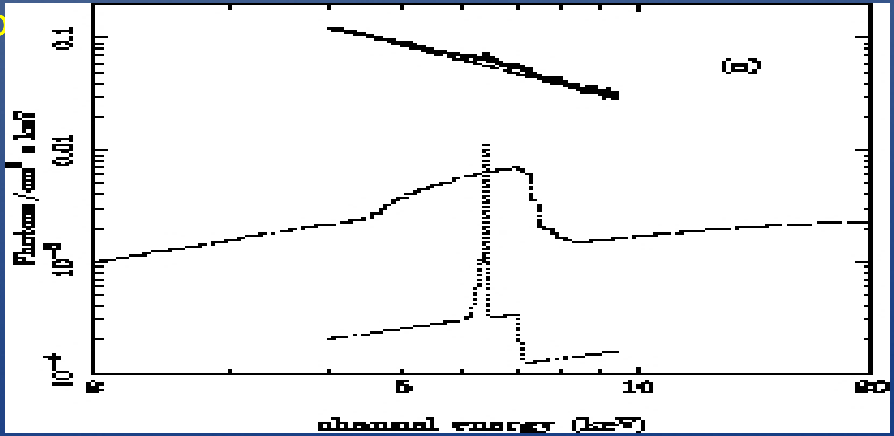


(e.g., Fabian et al. '89)





N.B: Not only relativistic lines, but also reflection
co



(Done & Zycki, '98)

(Fabian et al. '00)

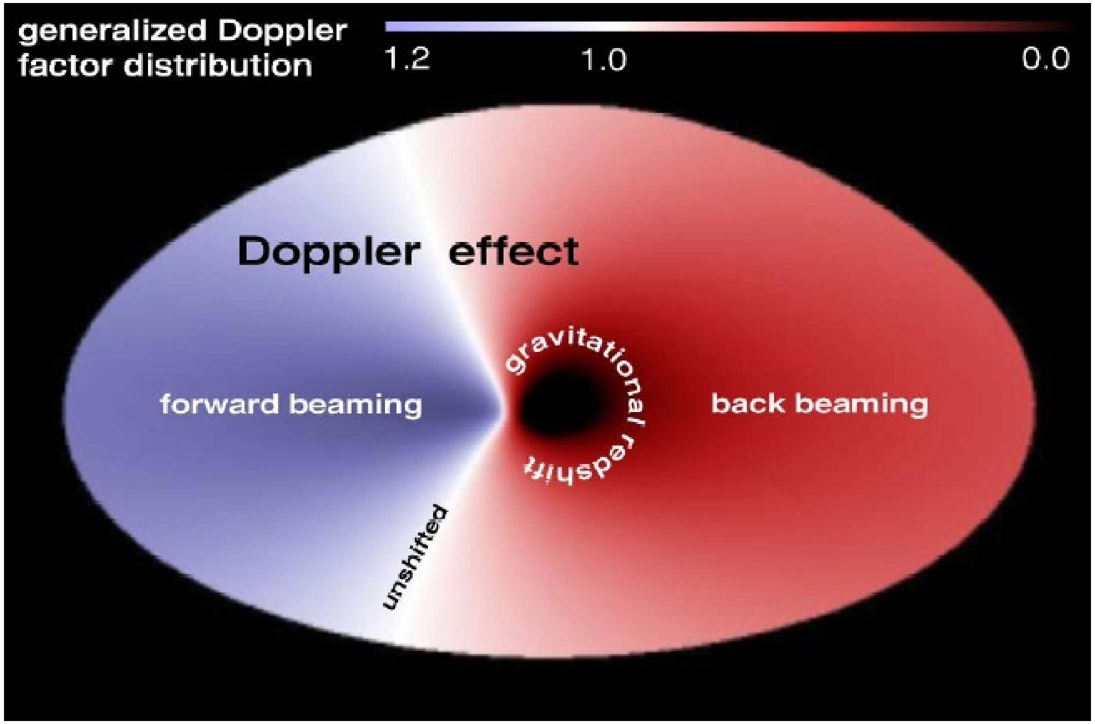


Figure 6.2: Simulated disk image around a central Kerr black hole color–coded in the generalized Doppler factor g. The distribution illustrates redshift $g < 1$ (*black* to *red*), no shift $g = 1$ (*white*) and blueshift $g > 1$ (*blue*). Regions of Doppler effect, beaming and gravitational redshift are marked. The inclination angle amounts $i = 60°$.

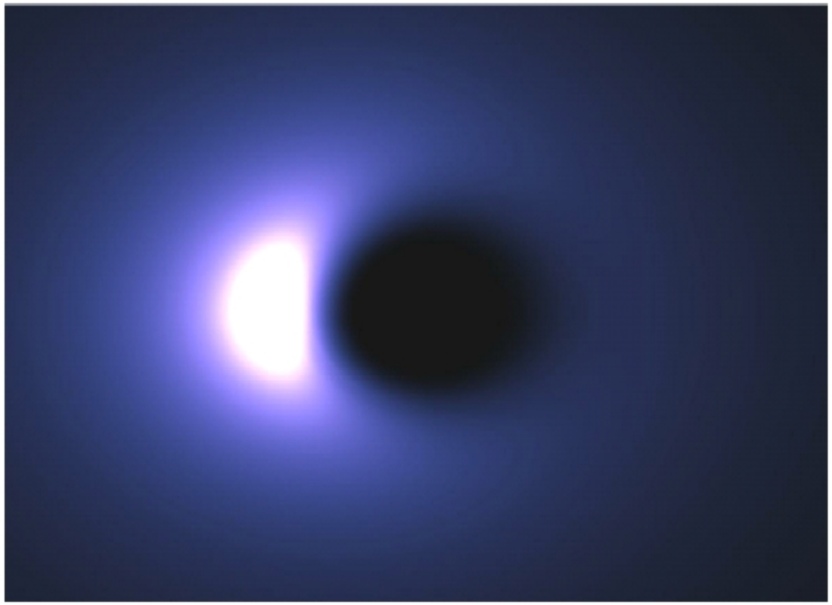
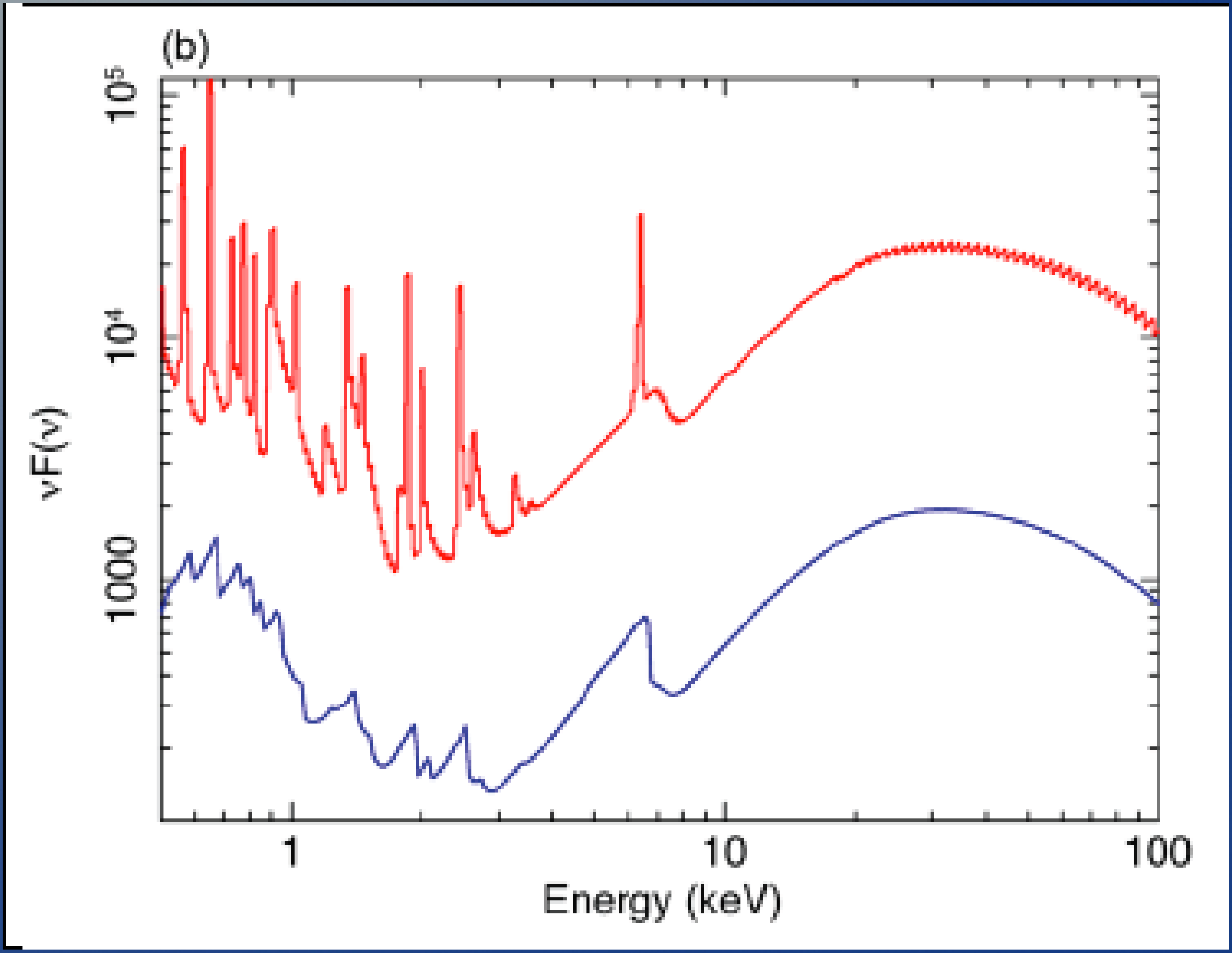
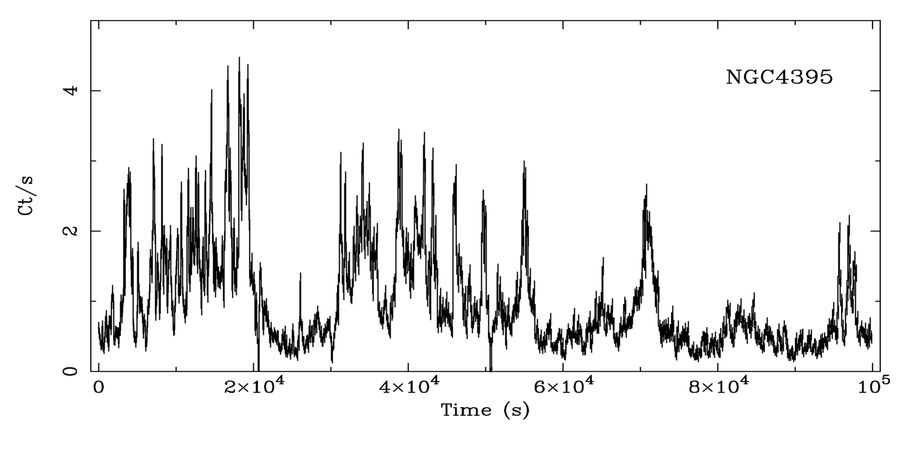
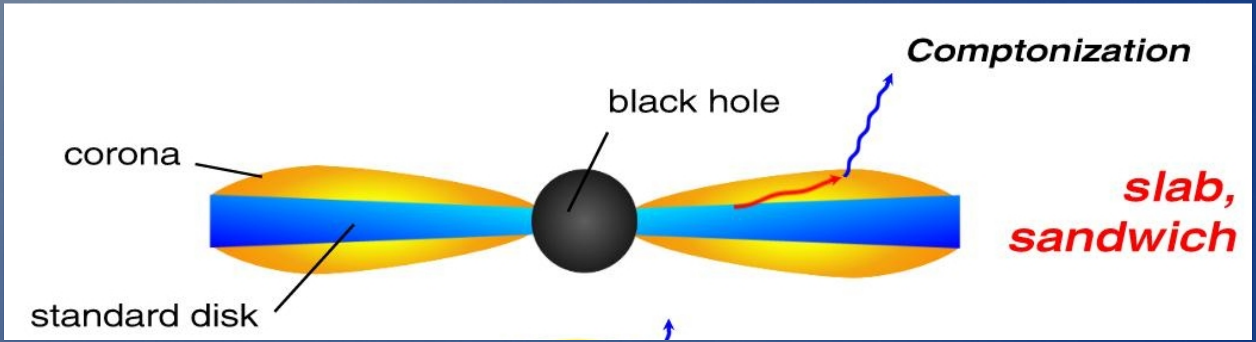


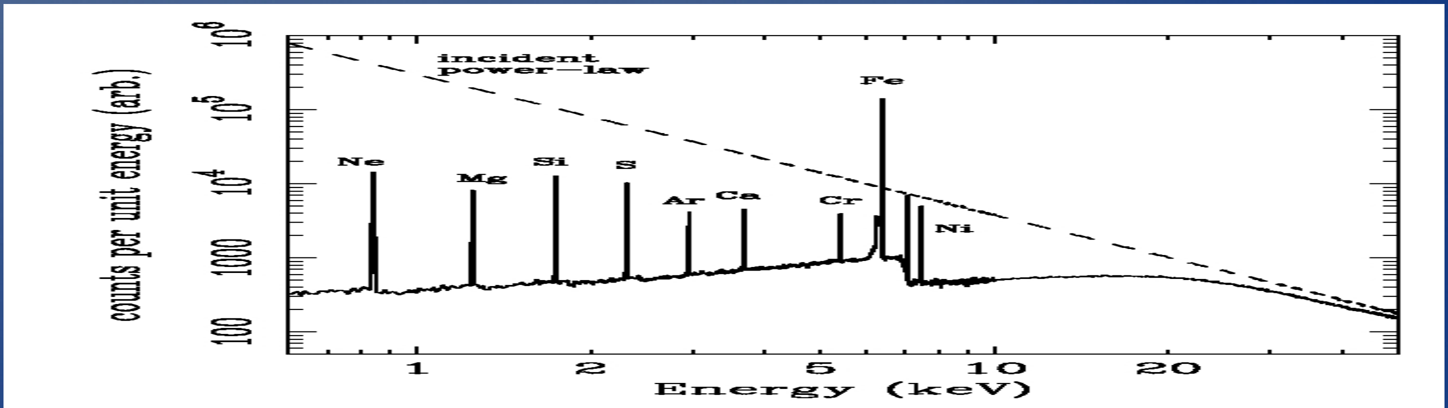
Figure 6.3: Simulated appearance of a uniformly luminous standard disk around a central Kerr black hole, $a \simeq 1$. The emission is color–coded and scaled to its maximum value (*white*). The disk is intermediately inclined to $i = 40°$. The forward beaming spot of the counterclockwisely rotating disk is clearly seen on the left whereas the right side exhibits suppressed emission due to back beaming. The black hole is hidden at the Great Black Spot in the center of the image.

Reflection: C - Ionization + relativistic effects




NGC4395
Ct/s
0
2
4
0
2×10^4
4×10^4
6×10^4
8×10^4
10^5
Time (s)

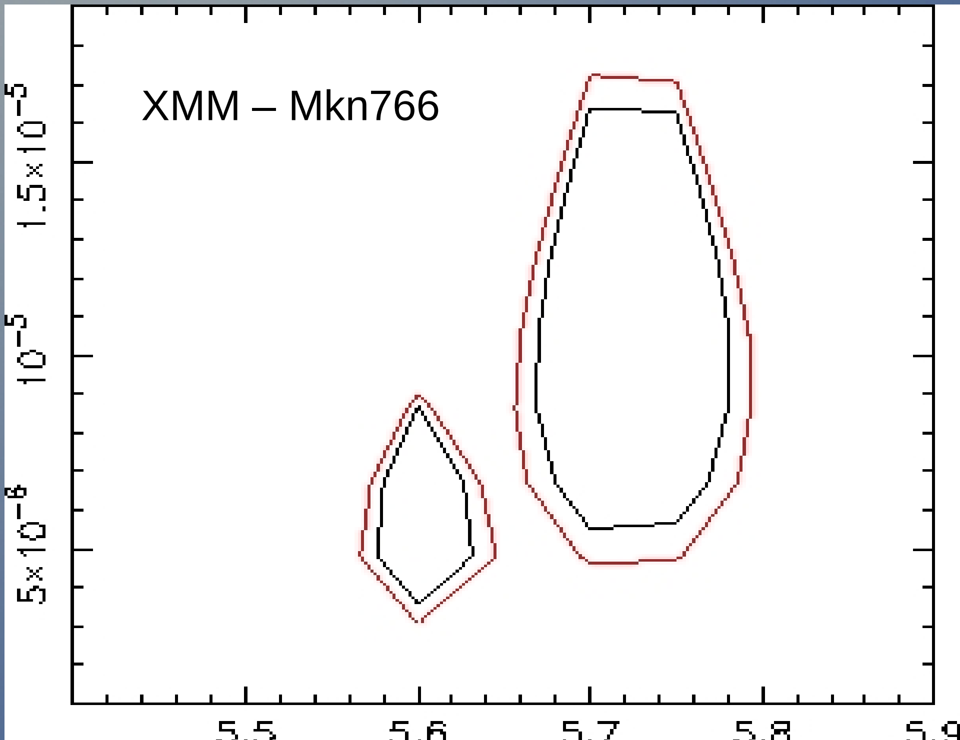

Comptonization
black hole
corona
standard disk
slab,
sandwich


incident
power−law
Fe
Ne
Mg
Si
S
Ar
Ca
Cr
Ni
counts per unit energy (arb.)
100
1000
10^4
10^5
10^6
1
2
5
10
20
Energy (keV)

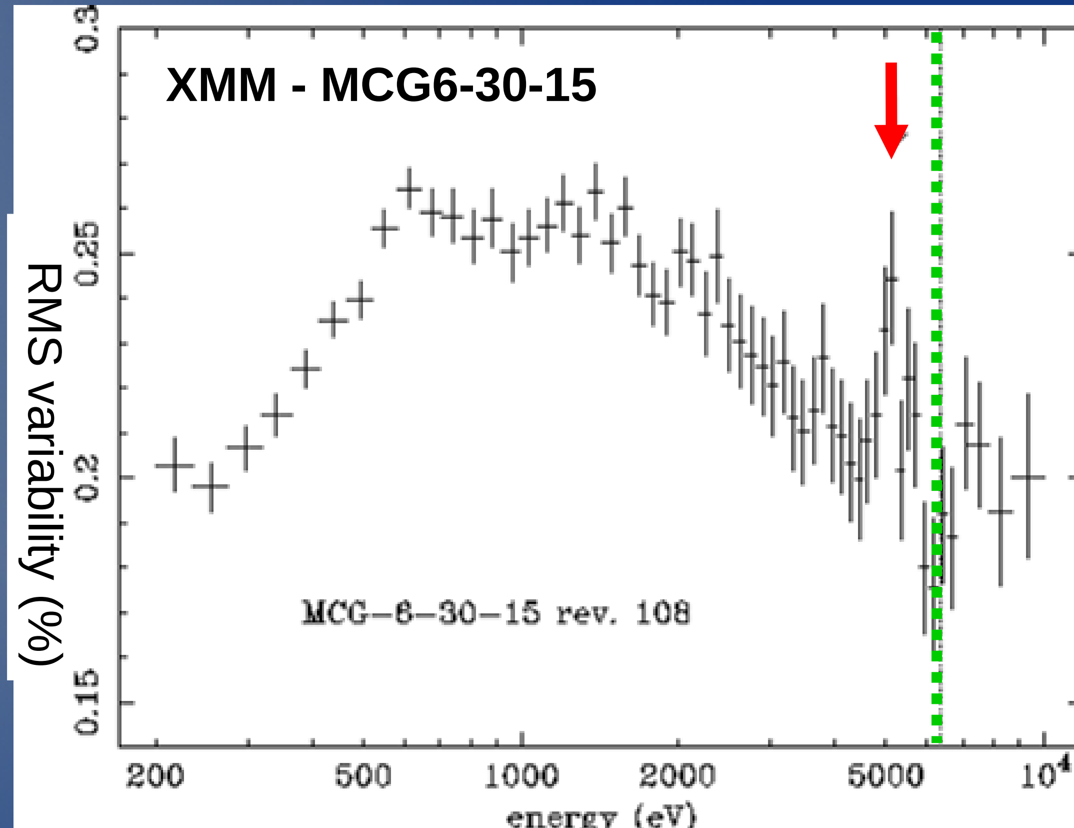
Reflection: Variability

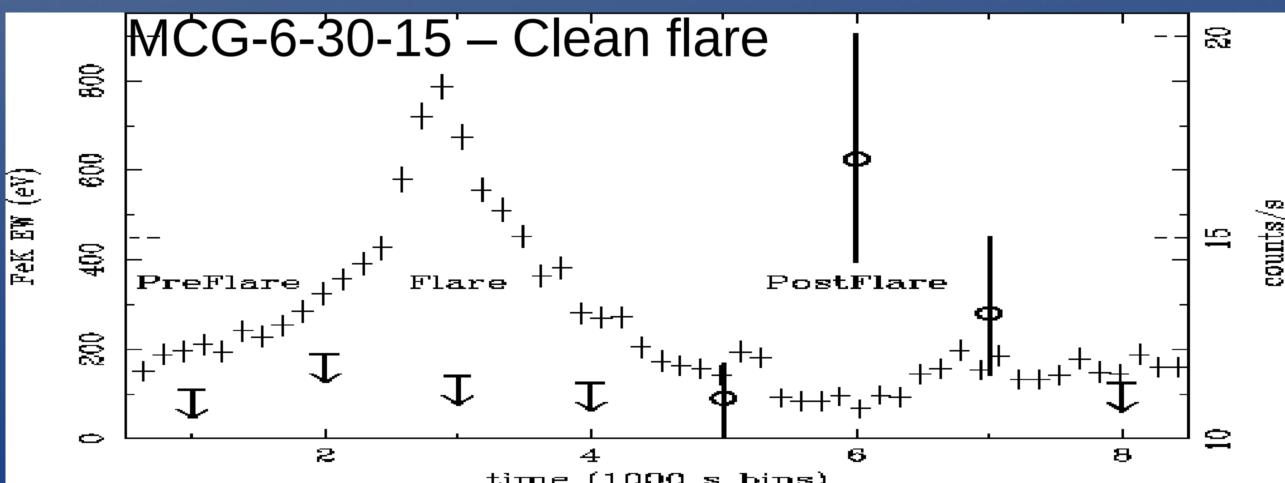
Post-Chandra & XMM-Newton

…other independent evidence of FeK line variability…



Turner et al., 2003



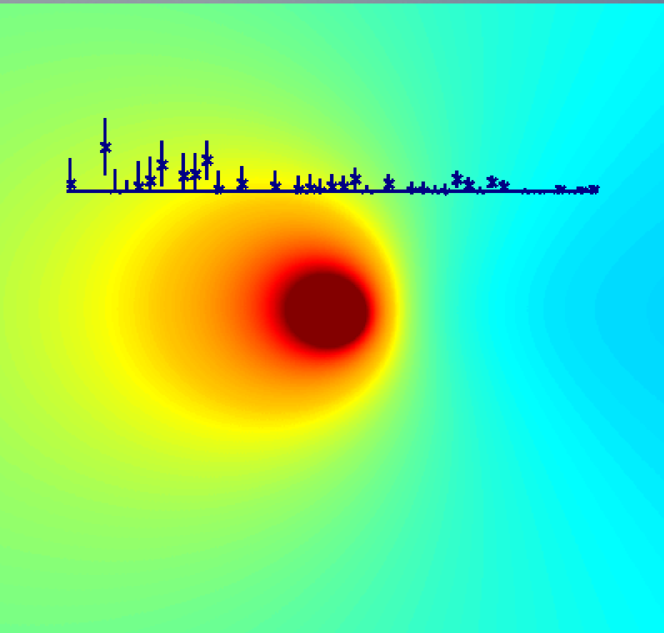


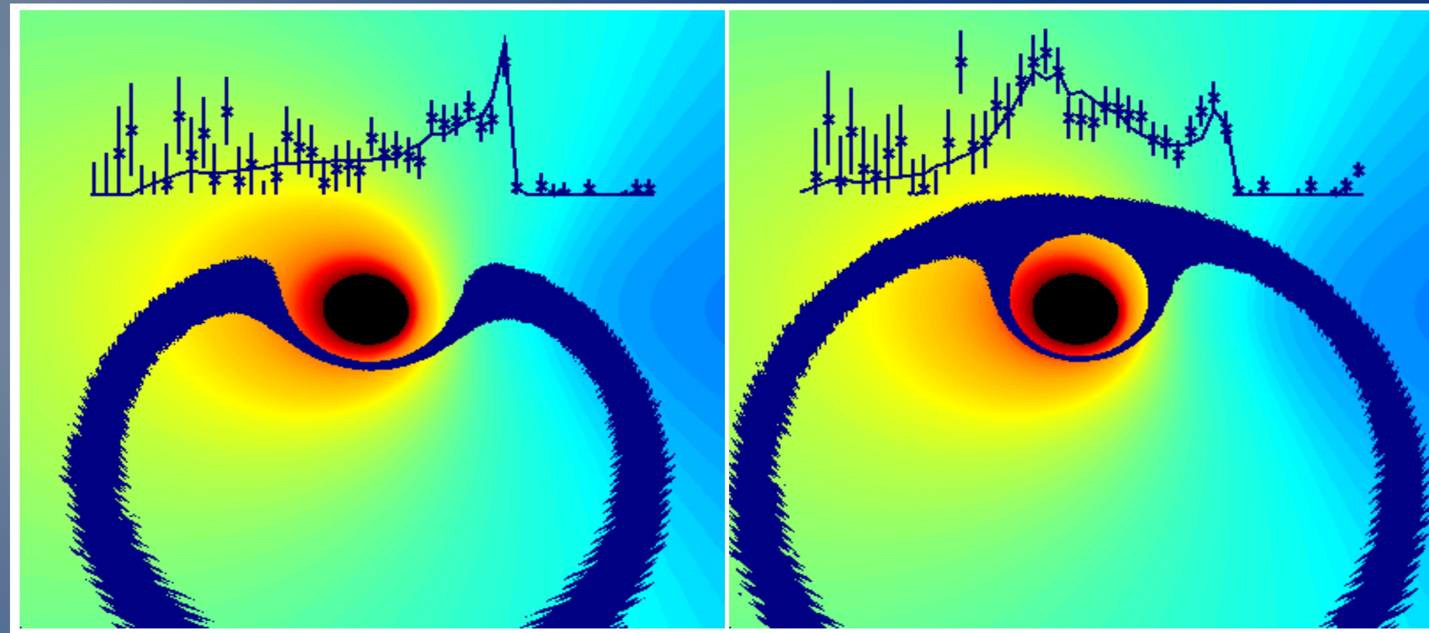
Ponti et al., 2004, (and INAF press-release)

Origin in innermost regions of accretion disk

Reflection: Reverberation mapping - simulation

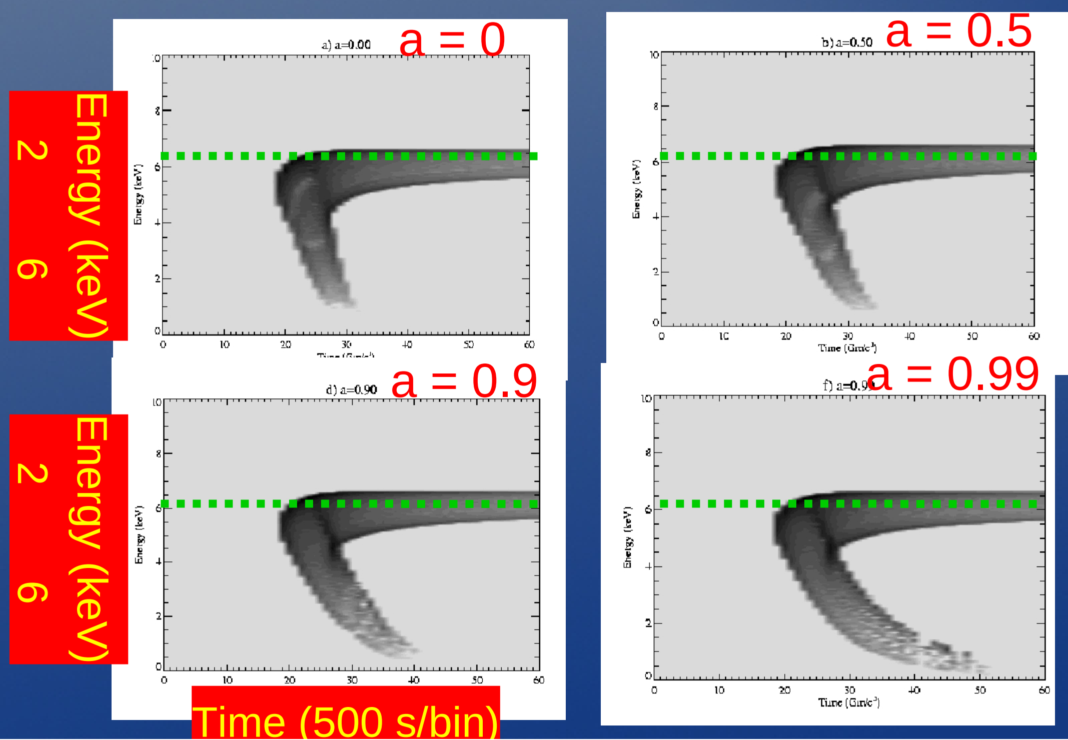
...The idea would be to perform FeK (disk)line reverberation/echo mapping...





Transfer function for a single flare:

M and a !



(Reynolds '00)

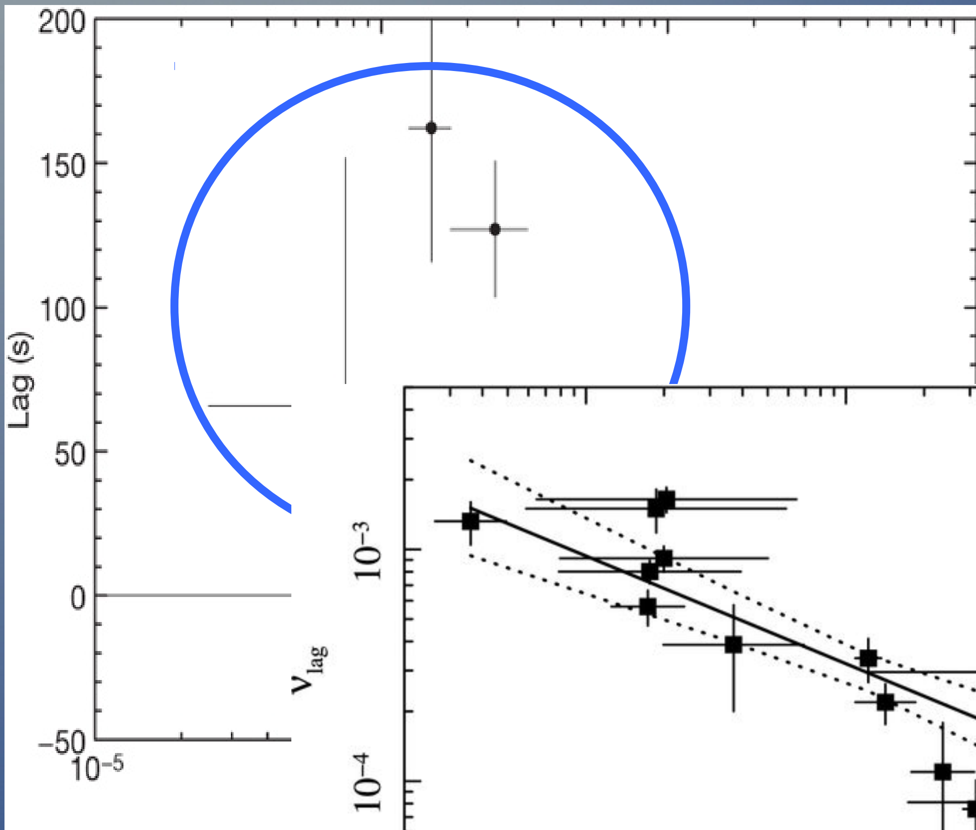
(But see also:
Stella '90,
Matt & Perola '92,
Campana & Stella '93)

(Young & Reynolds, '01)

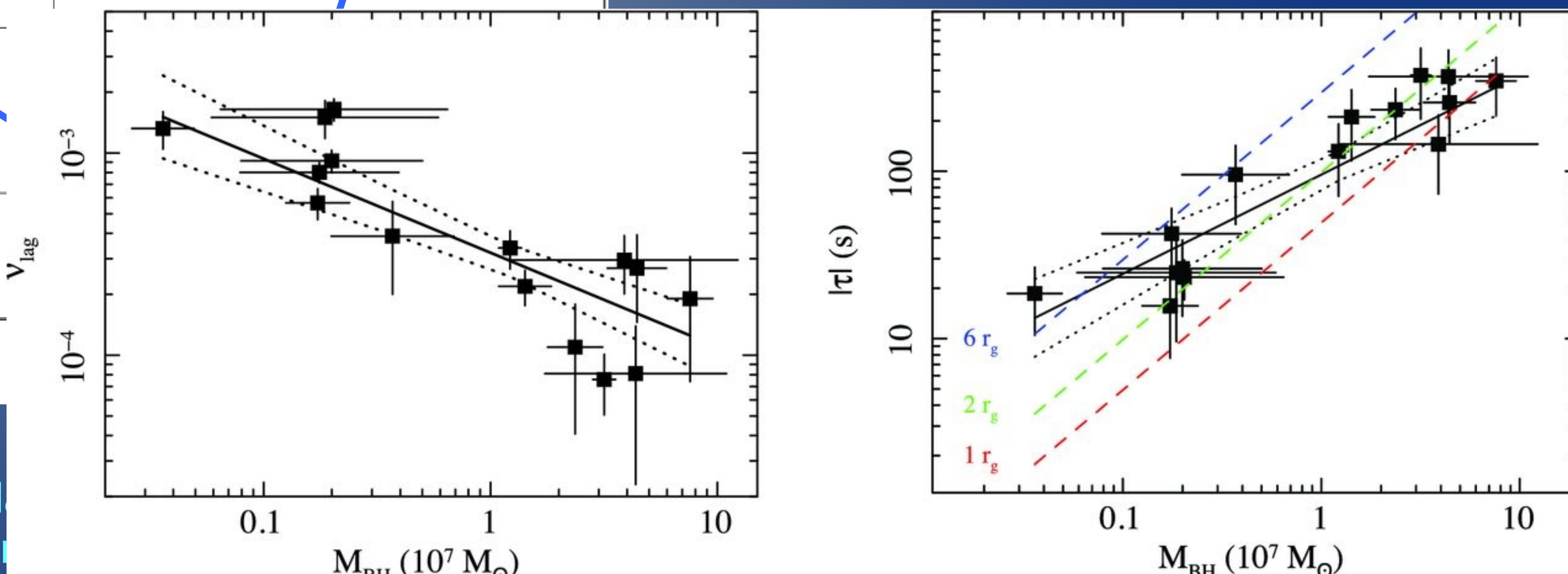
Reflection: Reverberation mapping - real data

Lags in frequency space

1H0707



De Marco et al. 2013



Hard l

⇒Fro

Soft lags on short time-scales

⇒From FeL reverberation, 25s light travel time corresponds to 2 R_g

Absorption(s)
(i.e. ejection)

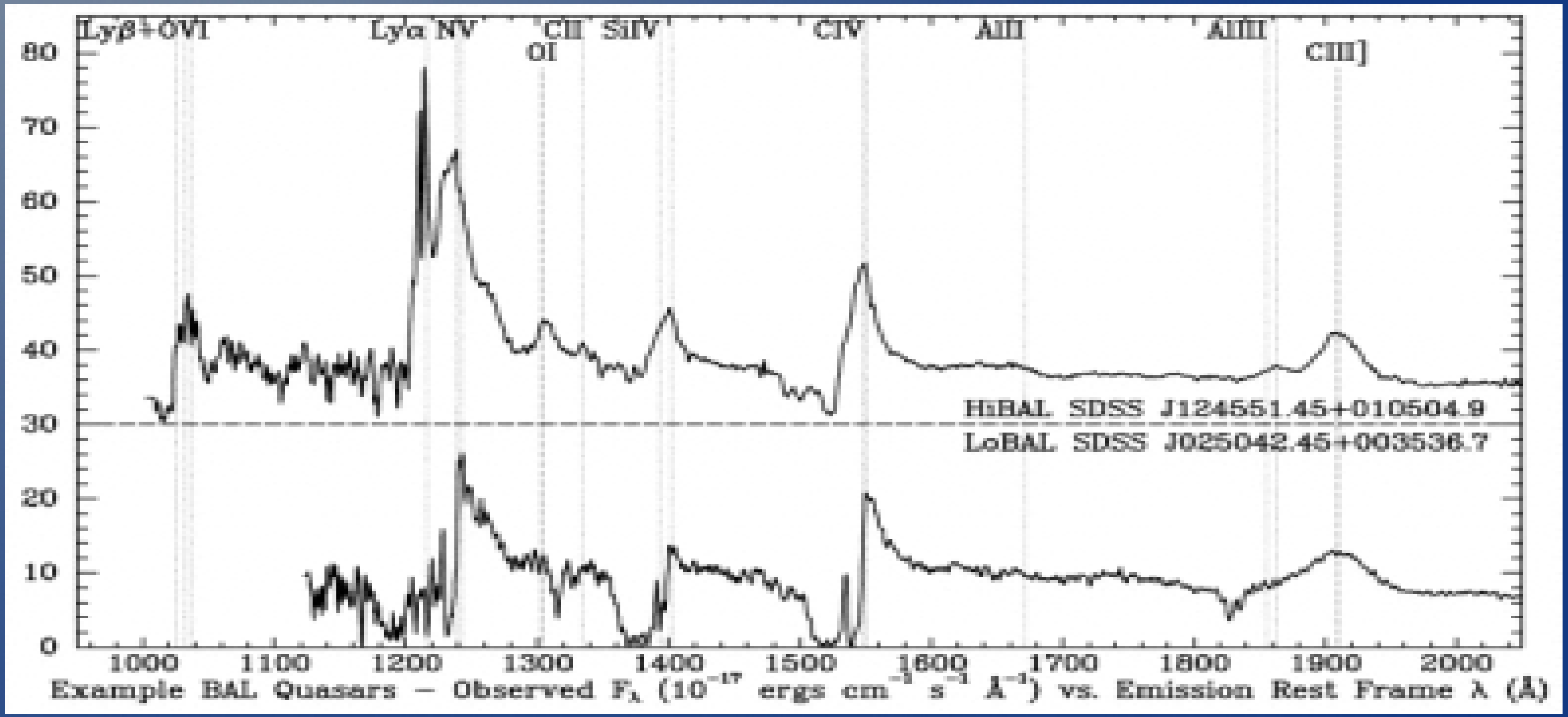
Absorption: BAL QSOs

Evidence of absorbers along the line of sight to AGNs

…known/seen since long ago

Fast (v up to ~ 50000 km/s) winds in

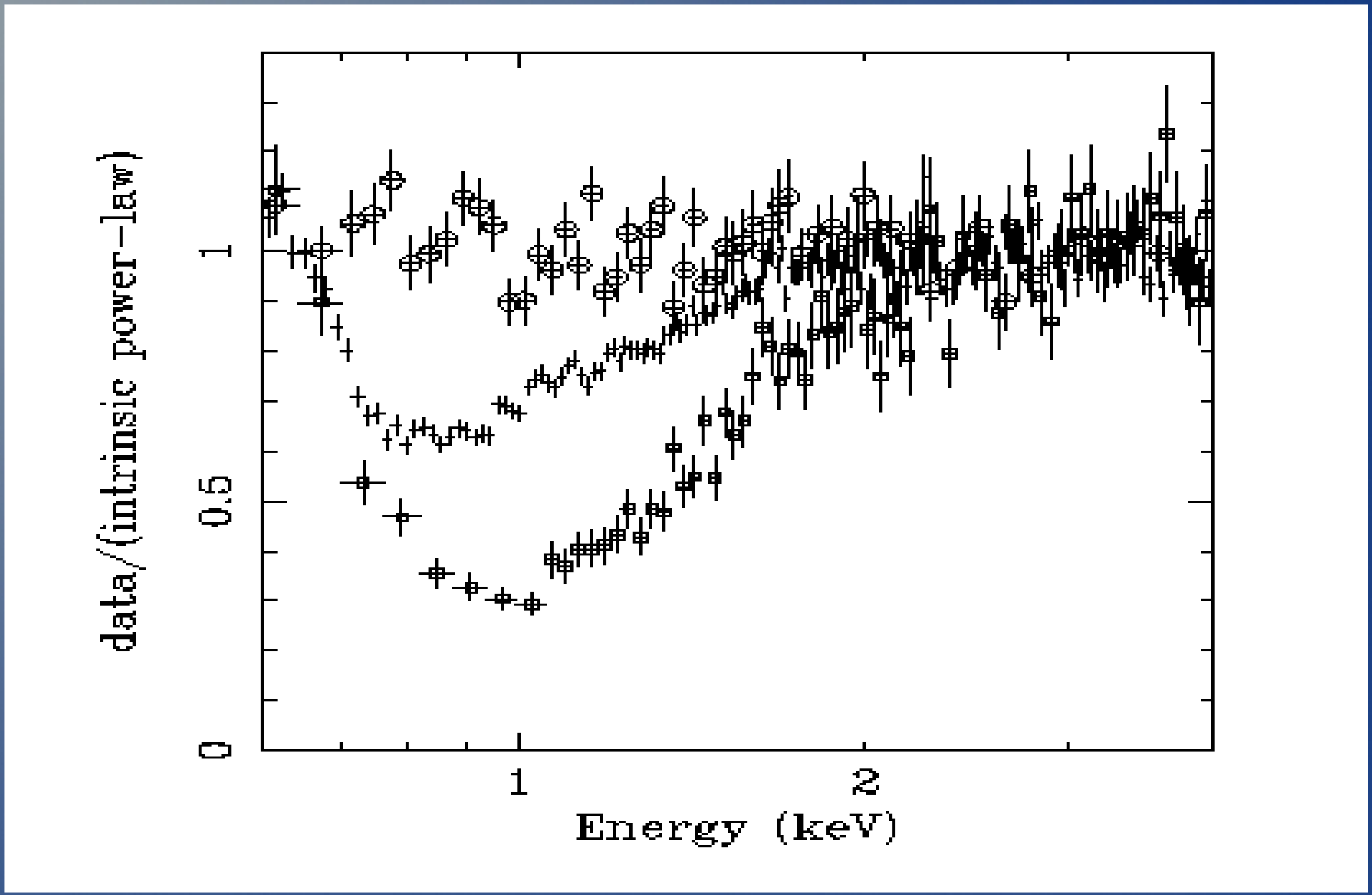
BAL QSOs (~ 20% of all QSOs)



Weymann et al., '91;
Reichards et al., '03

Pre-Chandra & XMM-Newton

Most (>50%) Seyfert 1 galaxies exhibit Warm Absorbers



Reynolds et al. '97
Georges et al. '97

→ Clear since years that warm absorbers must be dynamically important (radiatively driven outflow located in BLR and NLR)

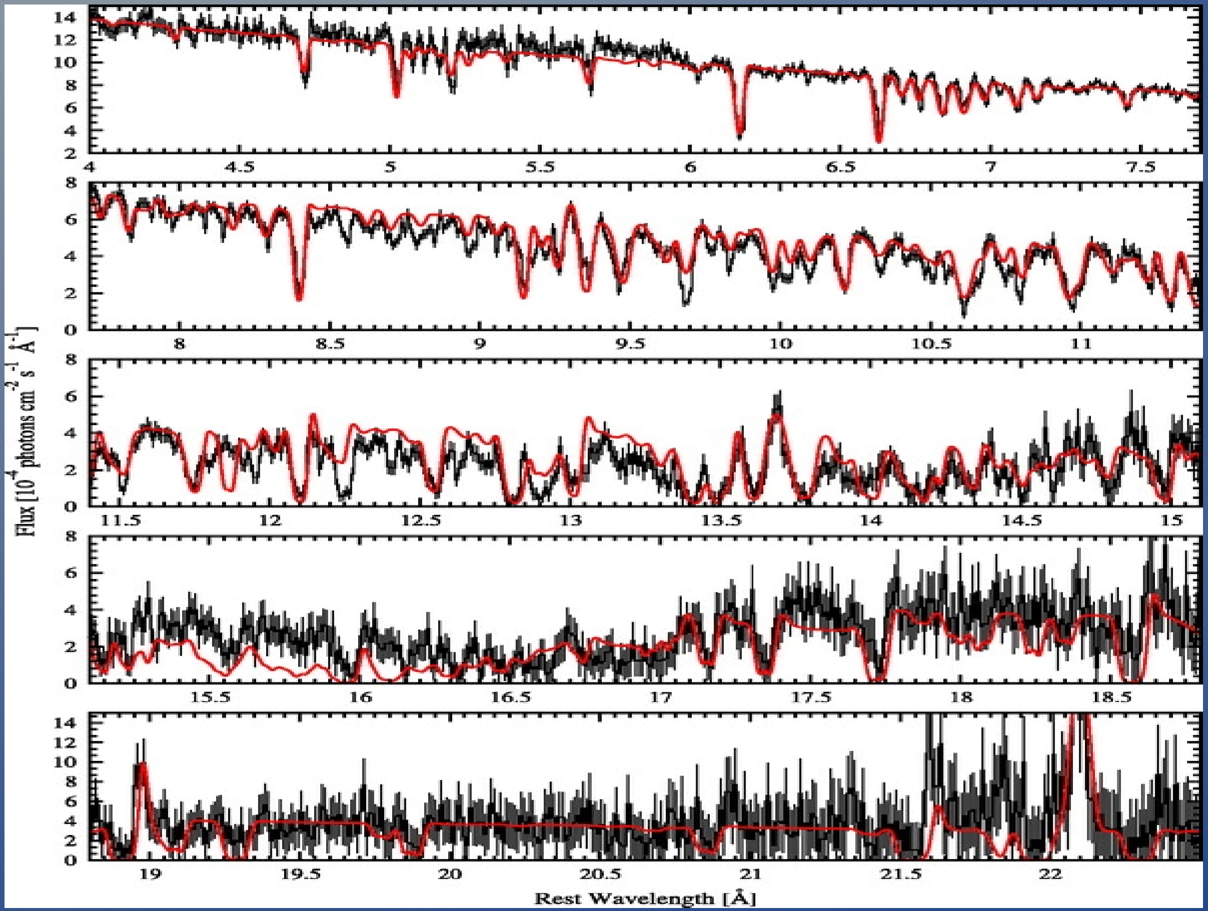
Open Problem: Characterisation of warm absorber? (cov. Factor, ion. state, mass/energy outflow, etc.)

Absorption: warm absorbers

Post-Chandra & XMM-Newton

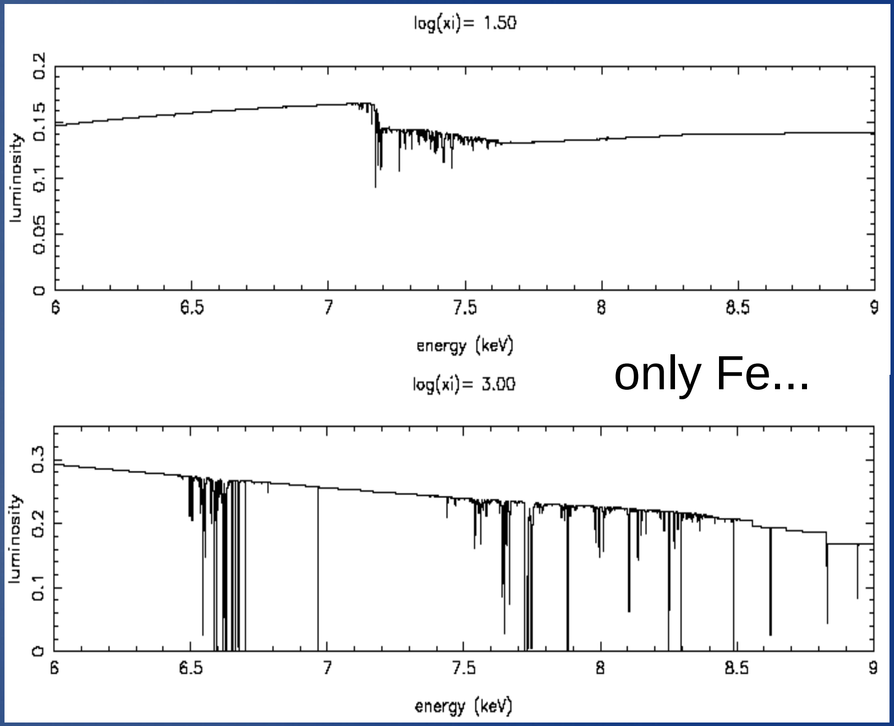
Many more details from Chandra gratings

NGC3783 Exp=900 ks



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

Consistent with models which predict many absorption features



only Fe...

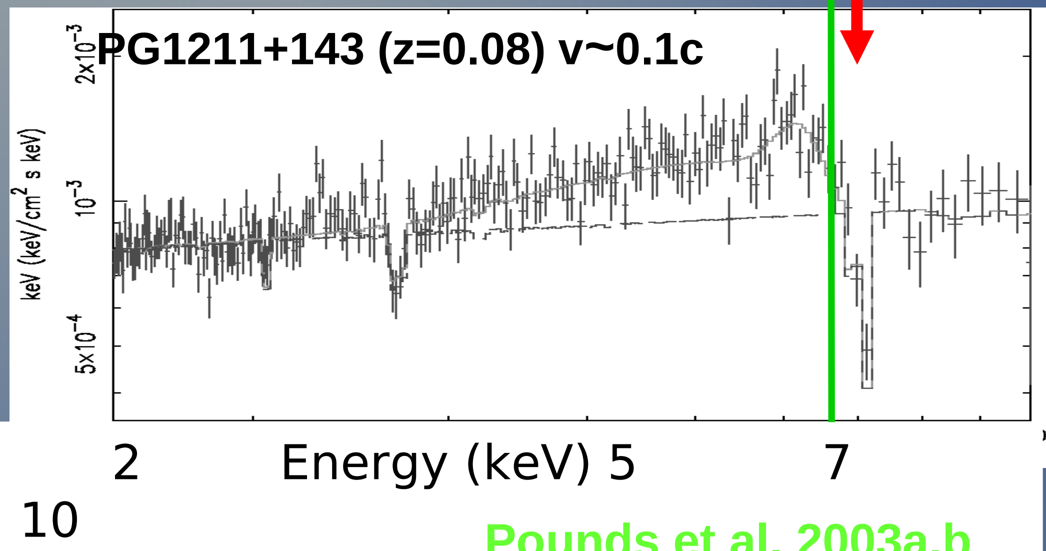
Kallman et al. '05

→ Clear now that often multiple ionization & kinetic components: outflows with ~100-1000 km/s

Absorption: UFOs

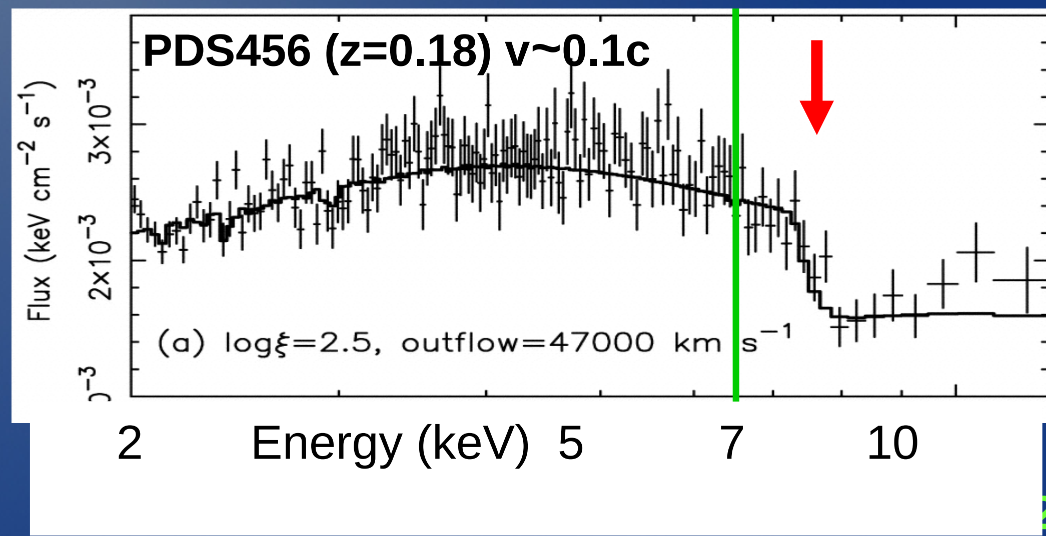
Post-Chandra & XMM-Newton

New and unexpected results from Chandra and XMM-Newton observations



Pounds et al. 2003a,b

Blue-shifted absorption lines/edges – **High-v**



2003

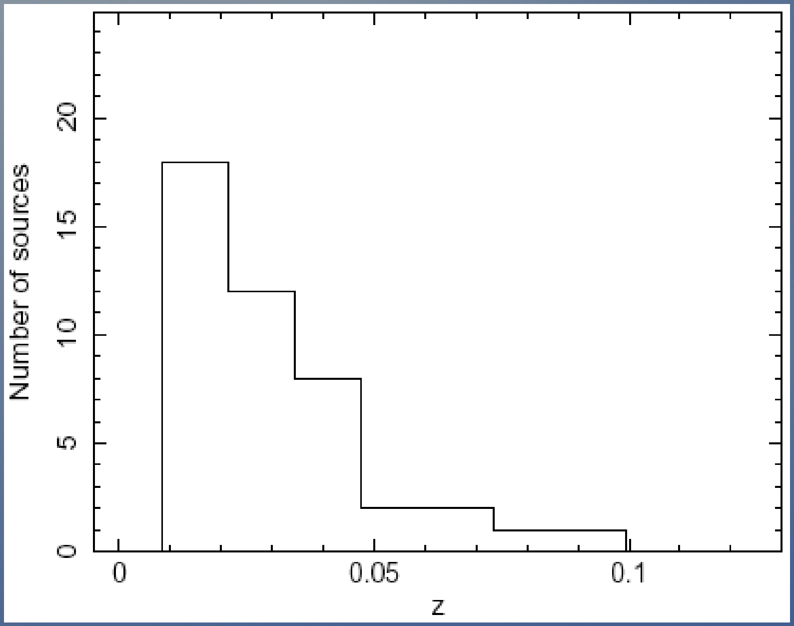
(If) interpreted as Kα resonant absorption by Fe XXV (6.70 keV) or FeXXVI (6.96 keV)

⇒ massive, **high velocity** and highly ionized outflows in several RQ AGNs/QSOs

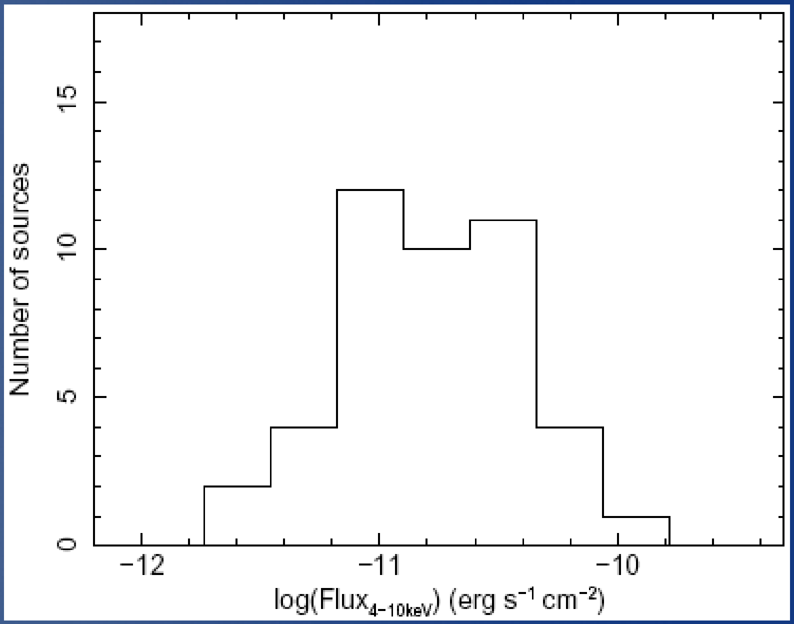
Mass outflow rate: comparable to Edd. Acc. rate (~$M_\odot$/yr); velocity ~0.1-0.2 c

Absorption: UFOs

Tombesi et al. (2010) analysed in a systematic and uniform way, a (almost) complete sample of nearby, X-ray bright, radio-quiet AGNs



z distribution of sources

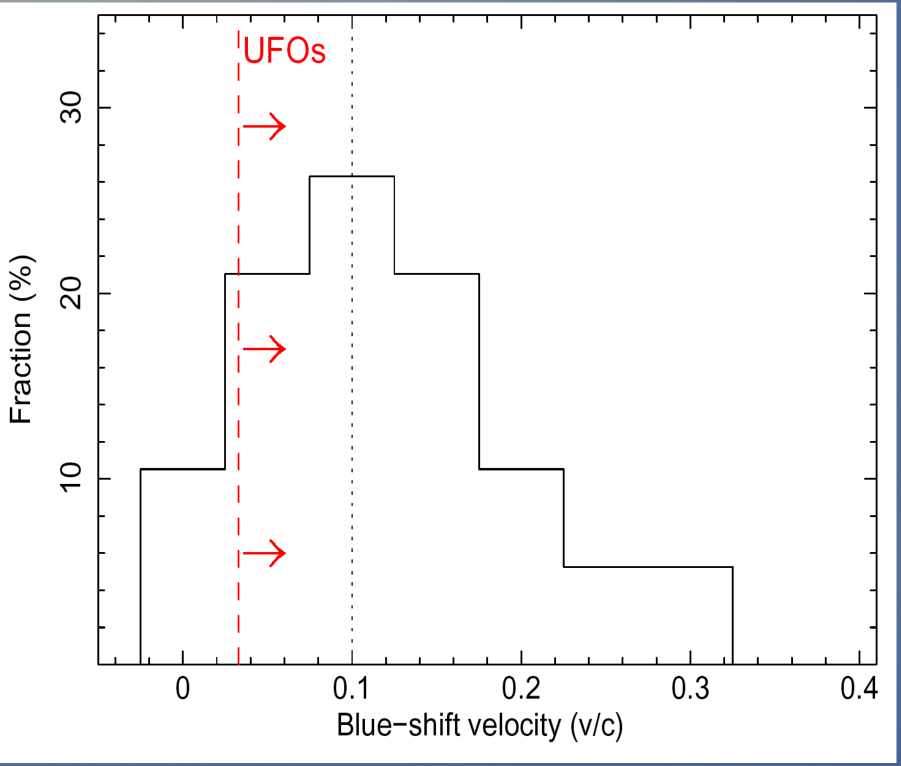


4-10keV fluxes

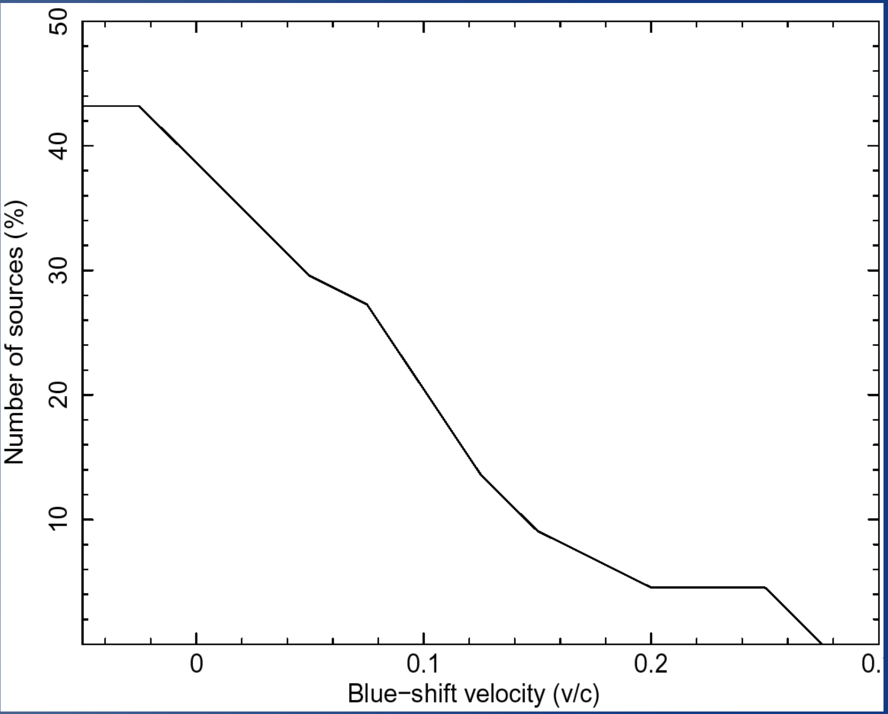
- Selection of all NLSy1, Sy1 and Sy2 in RXTE All-Sky Slew Survey Catalog (XSS; Revnivtsev et al. 2004)
- Cross-correlation with XMM-Newton Accepted Targets Catalog
- 44 objects for 104 pointed XMM-Newton observations
- Local (z<0.1)
- X-ray bright ($F_{4\text{-}10keV}=10^{-12}$-$10^{-10}$ erg s^{-1} cm^{-2})

Absorption: UFOs

Main result: UFOs (Ultra-Fast Outflows) are confirmed and are quite common



Blue-shift velocity distribution



Cumulative velocity distribution

- 36 absorption lines detected in all 104 XMM observations
- Identified with FeXXV and FeXXVI K-shell resonant absorption
- 19/44 objects with absorption lines (≈43%)
- 17/44 objects with blue-shifted absorption lines (lower limit ≈39%, can reach a maximum of ≈60%)
- 11/44 objects with outflow velocity >0.1c (≈25%)
- Blue-shift velocity distribution ~0-0.3c, peak ~0.1c
- Average outflow velocity 0.110±0.004 c

Tombesi et al. 2010a

(The UFO's hunters commander in chief)

Absorption: Results on UFOs

- estimated distances $r<0.01$-0.1pc ($<10^2$-10^5 r_s)

(accretion disk winds? e.g. Elvis 2000; King & Pounds 2003)

- Often $v_{out} > v_{esc}$, but not always, material shall fall back sometimes? (“aborted jet”? e.g. Ghisellini et al. 2004, Dadina et al. 2005)

- variability time scales t~1day – 1year

- L_{bol}/L_{Edd}~0.1-1

- M_{out}/M_{acc}~0.1-1

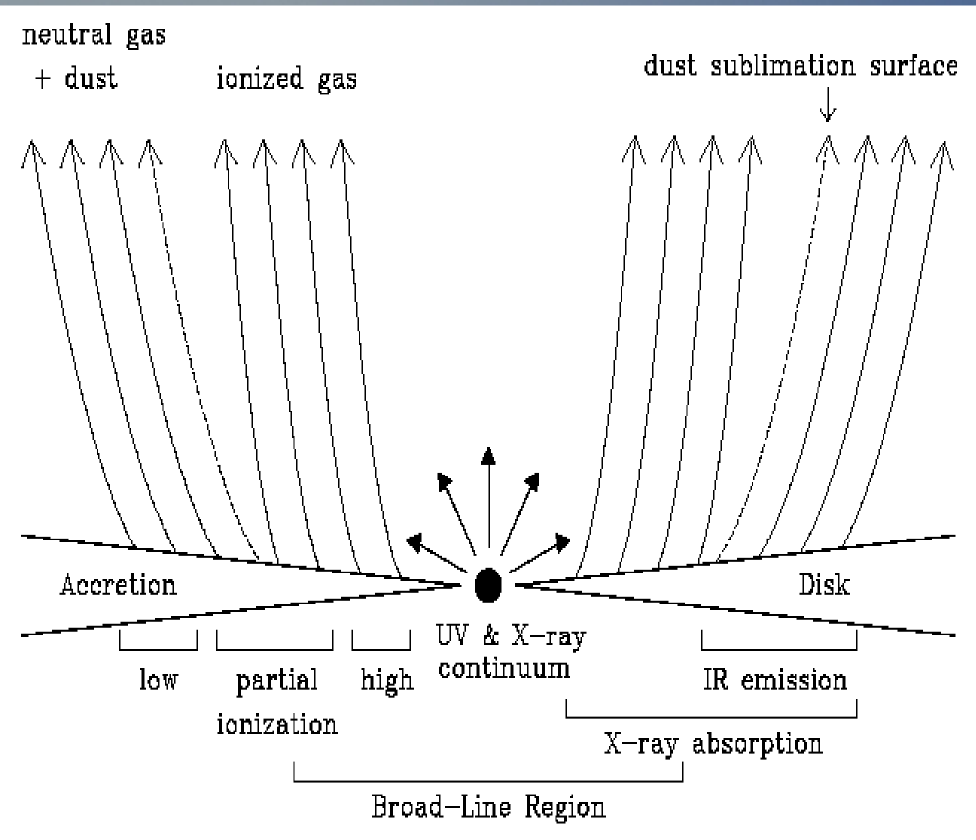
- E_k~10^{44}-10^{45} erg s^{-1} ~0.1 L_{bol}

(last two estimates depend on covering fraction C)

- Acceleration mechanism? Line, magnetically or momentum driven?

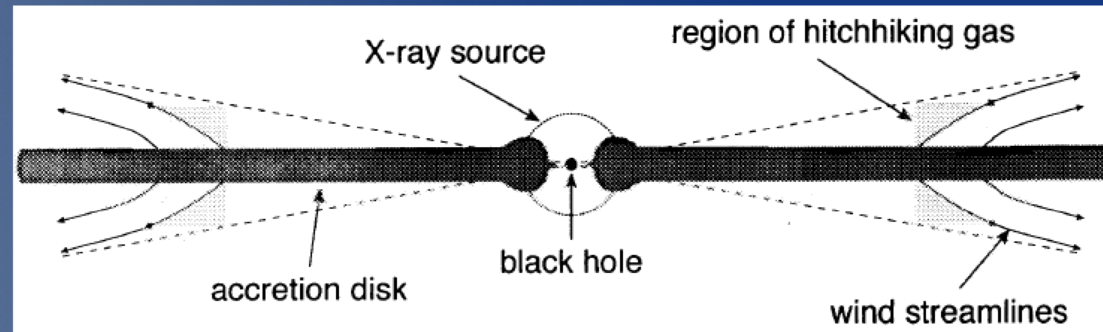
Absorption: Interpretation - Three main wind dynamical models

i) Thermally driven winds from BLR or torus



Balsara & Krolik, 93; Woods et al. '96

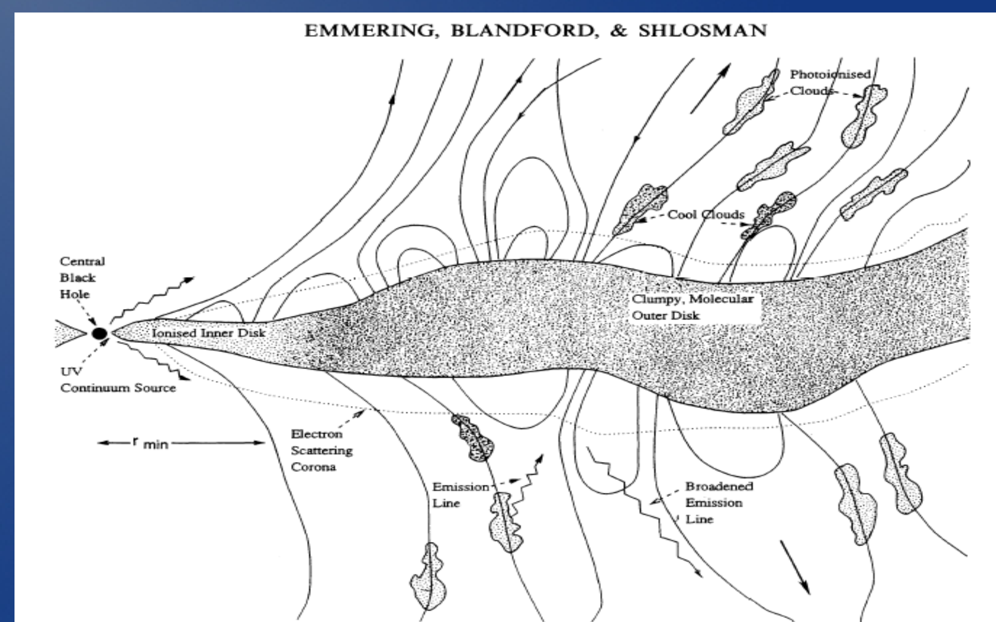
ii) Radiative-driven wind from accretion disk



Murray et al. '95, Proga et al. '00

…and/or…

iii) Magnetically driven winds from accretion disk



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

i) ⇒ Large R, low v

ii) and iii) ⇒ Low R and large v

Absorption: Final impact - An open issue

- Nw (cm^{-2})
- Location (R, DeltaR)
- Ionization state (ξ)
- Velocity
- Covering factor
- Frequency in AGNs

Fundamental to:

i) PHYSICS of accelerated and accreted flows (winds?, blobs?, etc.), i.e. understand how BHs accelerate earth-like quantities of gas to relativistic velocities

i) COSMOLOGY: i.e. estimate the mass outflow rate, thus the impact of AGN outflows on ISM and IGM enrichment and heating!

Elvis et al. '00, Creenshaw et al. '03, King et al. '03, Chartas et al. '03,

Yaqoob et al. '05, Blustin et al. '05, Risaliti et al. '05, Krongold et al. '07

Current estimates have order of magnitude uncertainties, they go from:

dM/dt ($\propto L_{kin}$) few % to several times dM_{acc}/dt ($\propto L_{edd}$)

This is a fundamental (open) issue

Reflection vs. Absorption? conclusions

- Reflection hypothesis is robust and its predictions are consistent with all existing data.

- Nevertheless, absorption **is** present and potentially very complex.

ü

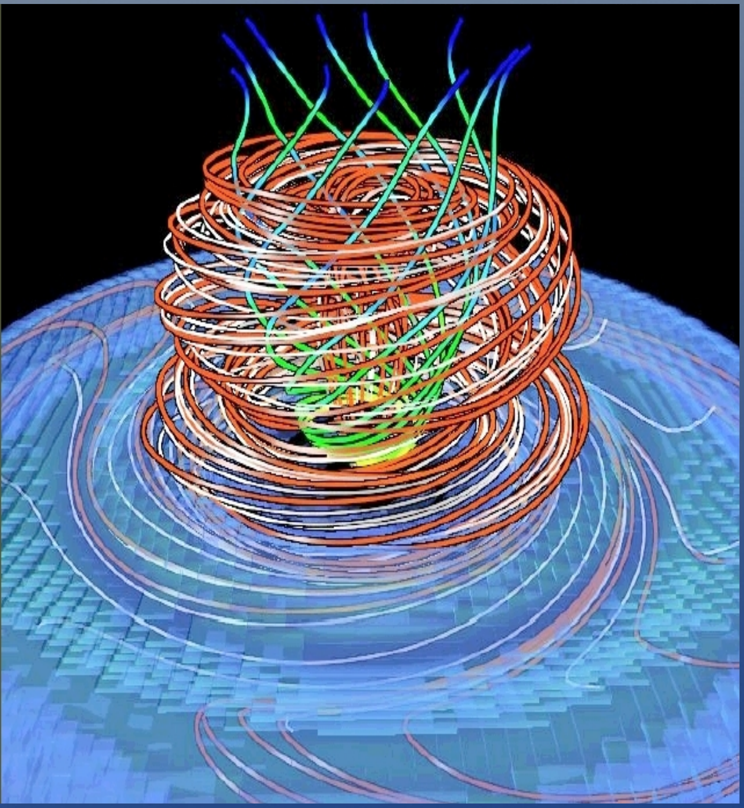
- Both phenomena are interesting because probe “extreme” (inflow/outflow) conditions.

Disentangling between the two requires the combination of:

High throughput @ 6 keV
and
calorimeter-type energy resolution
(future telescopes...)

Conclusions & Summary

Goal of the lectures: Give introductory informations on general “models” of AGNs, and in particular on reflection vs absorption hypothesis in RQAGNs



We have reviewed basic physics with basic assumptions for 3 major “models” of AGN

1- The 2-Phases model (RQAGNs)
2- The Inefficient model (LLAGNs)
3- The Jet model (RLAGNs)

We have focused on 1, and address the reflection vs. absorption hypothesis to explain the X-ray spectra of RQAGNs

Not a “mere” fitting exercise but major physical differences in the two hypothesis:

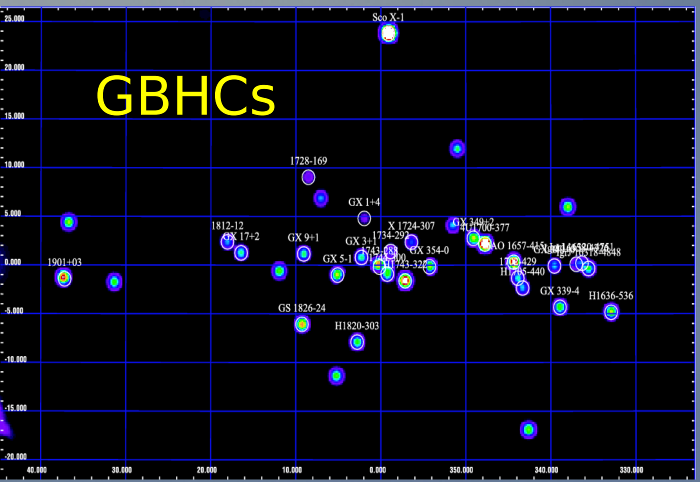
Relativistic Reflection: Produced within few (<10) R_g and carries information on BH spin and mass

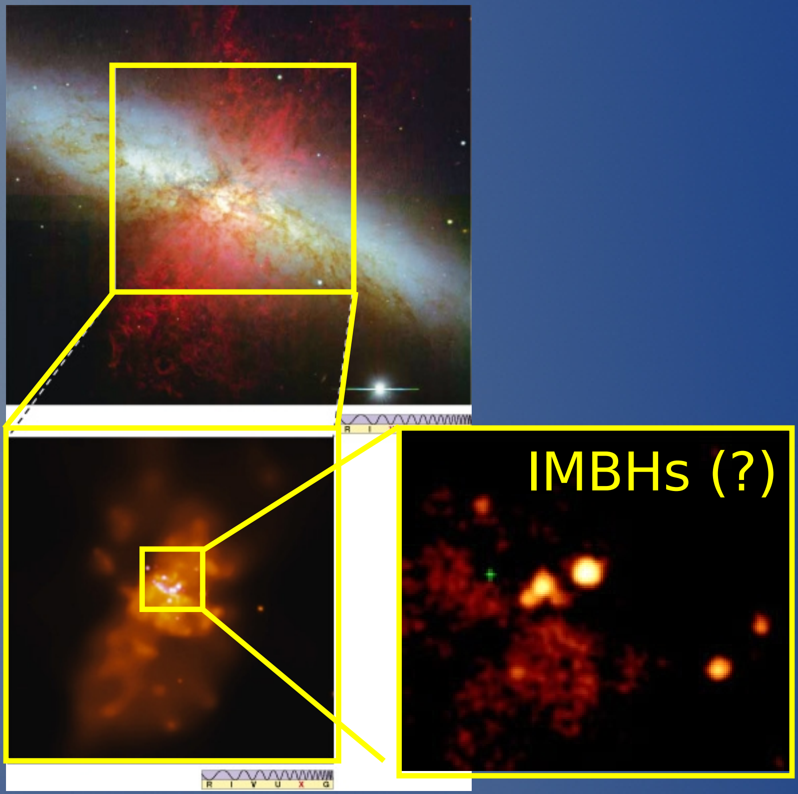
(Very) Complex Absorption: Produced farther at 100s R_g and carries information on wind/jet base

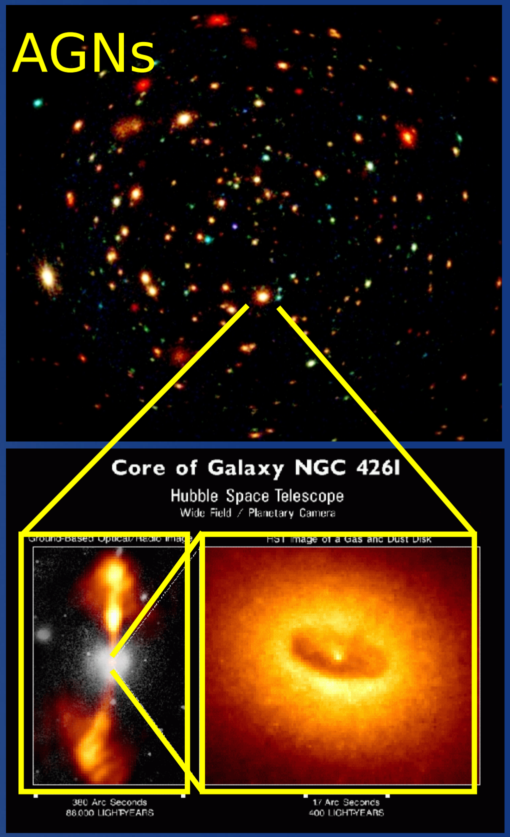
This is the END....

Questions ?

Why studying BHs in distant/faint AGNs rather than nearby/bright GBHC







What really matters in these studies is the n. of photons (i.e. flux, F_{obs}) per unit of light crossing time scale $t_{reverb} \sim R_g/c \sim GM/c^3 \sim 500\ M_8$ s

GBHCs

$F_{obs,gbhc} \sim$ Crab $\sim 10^{-8}$ erg/cm²/s

$T_{reverb,gbhc} \sim 50$ µs

$R_{gbhc} = F_{obs} / t_{reverb}$

IMBHs (?)

$F_{obs,imbh} \sim$ µCrab $\sim 10^{-14}$ cgs

$T_{reverb,imbh} \sim 50$ ms

$R_{imbh} = 10^{-2} R_{gbhc}$

AGNs

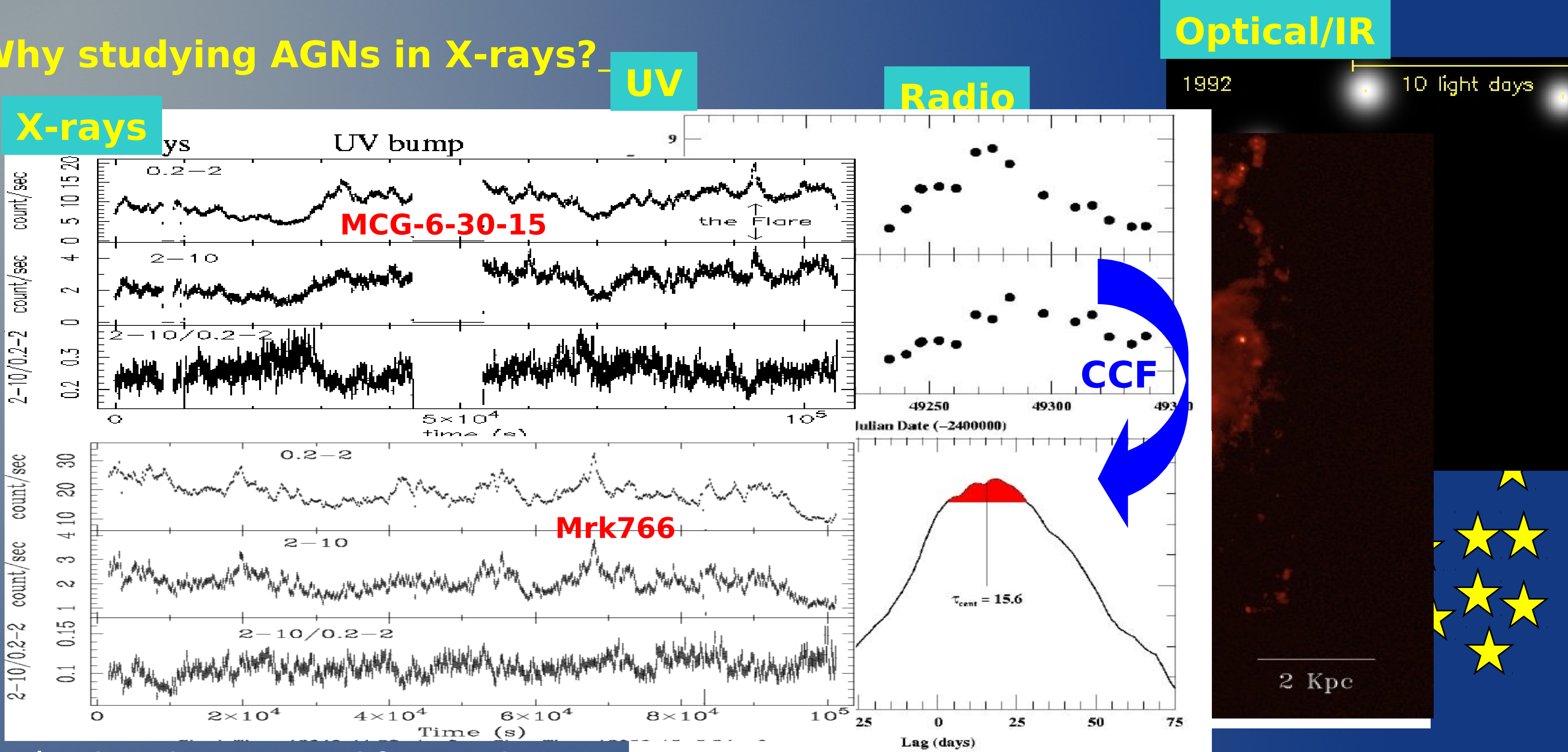
$F_{obs,agn} \sim$ mCrab $\sim 10^{-11}$ cgs (10^{-3} x gbhc)

$T_{reverb,agn} \sim 50$ s (10^7 x gbhc)

$R_{agn} = 10^4 R_{gbhc}$

Possible to probe AGNs with 10^4 times more (X-ray) photons per unit of Rs than GBHCs

Why studying AGNs in X-rays?



Delta L ~ L ~ up to 10^{44} erg/s

IN ⟷ **OUT**

Disklines reverberation mapping (X-rays)

⇓ ⇓

$M_\bullet$, a

(Probe GR within 10 Rs, i.e. strong field)

BLR reverberation mapping (optical)

(v~FWHM∝delay~dist.)

⇓ ⇓

$M_\bullet$

Stellar motions dynamics (rot. Curves) +water masers

(v and б ∝ dist.)

⇓ ⇓

$M_\bullet$

X-ray spectra of winds/outflows