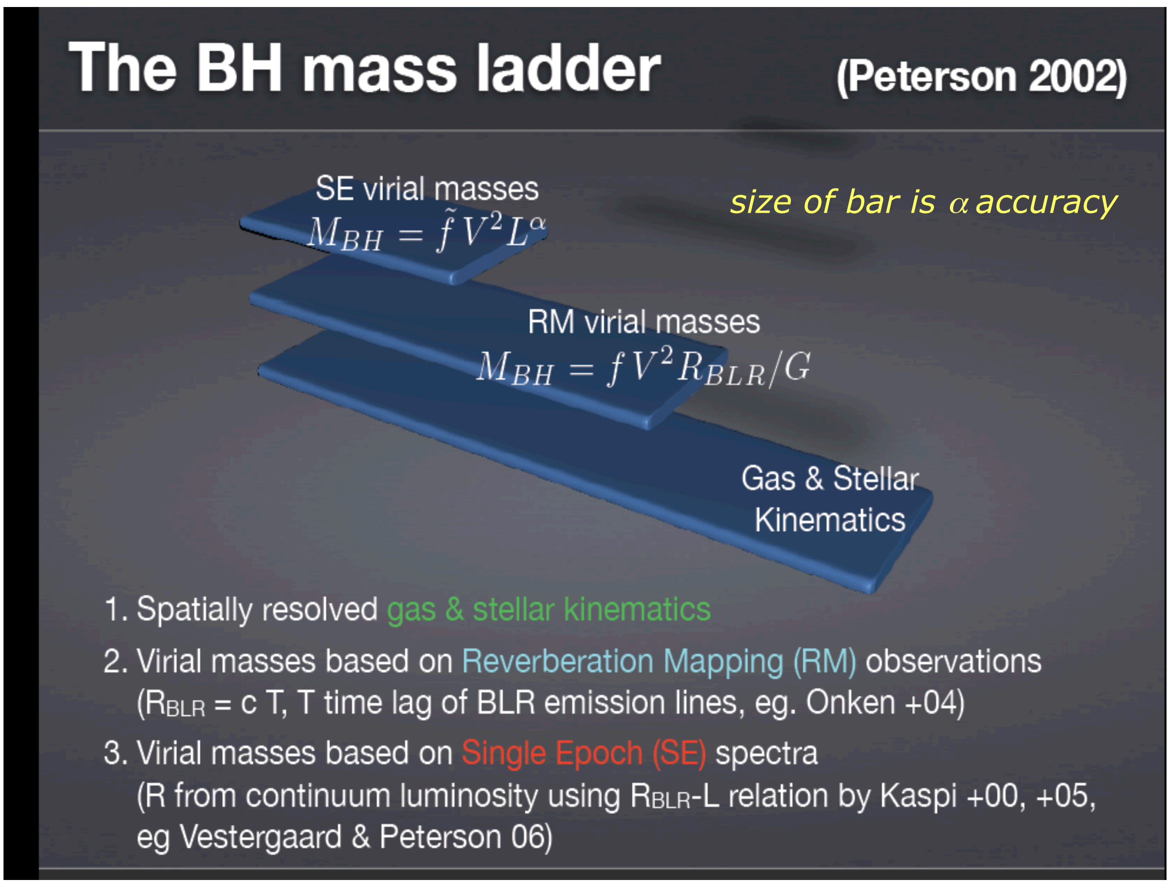
AGN in Longair- chapters 18,19,20,21

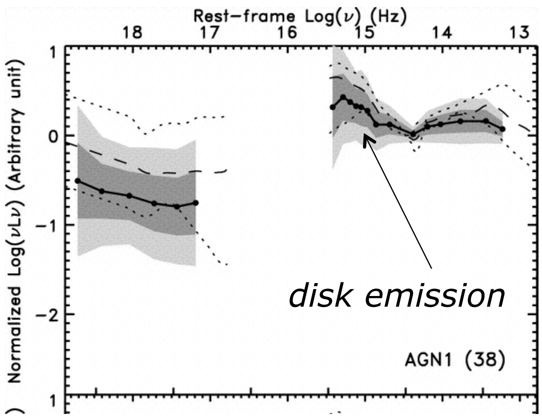
- **18 Active galaxies** 585
- 18.1 Introduction
- 18.2 Radio galaxies and high energy astrophysics
- 18.3 The quasars
- 18.4 Seyfert galaxies
- 18.5 Blazars, superluminal sources and γ -ray sources
- 18.8 X-ray surveys of active galaxies
- 18.9 Unification schemes for active galaxies
- **19 Black holes in the nuclei of galaxies**
- 19.1 The properties of black holes
- 19.2 Elementary considerations
- 19.3 Dynamical evidence for supermassive black holes in galactic nuclei
- 19.5 Black holes and spheroid masses
- 19.6 X-ray observations of fluorescence lines in active galactic nuclei
- 19.7 The growth of black holes in the nuclei of galaxies
- **20 The vicinity of the black hole**
- 20.1 The prime ingredients of active galactic nuclei
- 20.2 The continuum spectrum
- 20.3 The emission line regions – the overall picture
- 20.5 The broad-line regions and reverberation mapping
- 20.7 Accretion discs about supermassive black holes
- **21 Extragalactic radio sources**
- 21.5 Jet physics

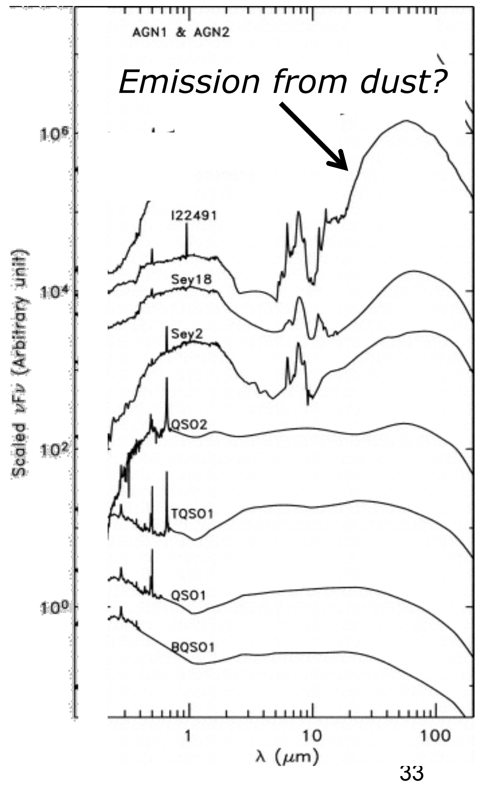
I am covering only a fraction of this material ! (Notice that I have left some sections out entirely)



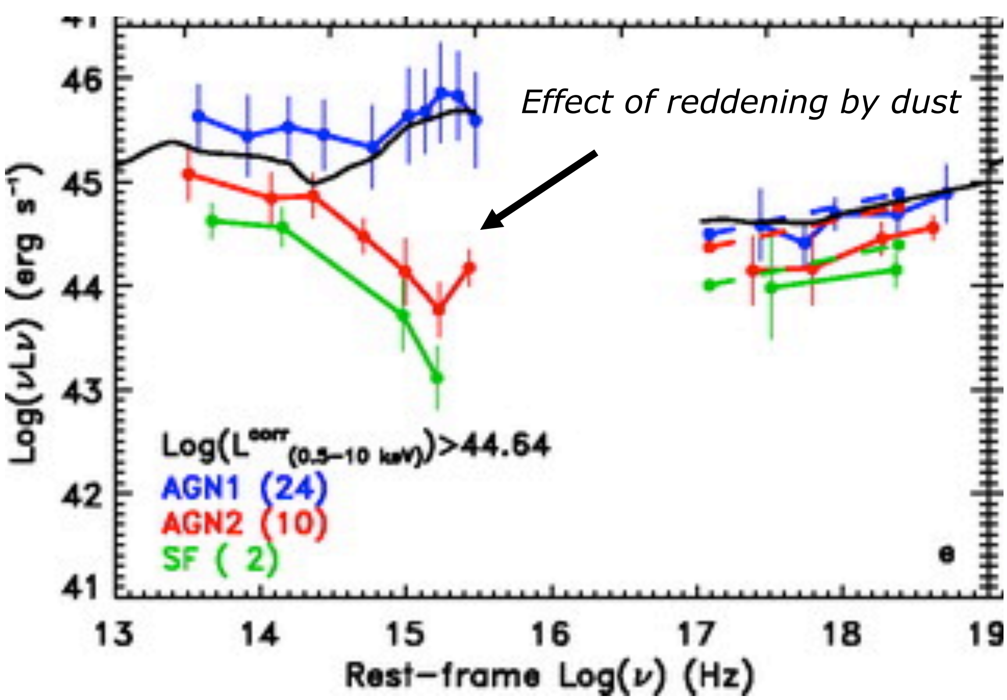
Life is Not So Simple

- The broad band spectra of both AGN and Galactic black holes have major deviations from disk spectra





Adapted from Poletta et al 2007

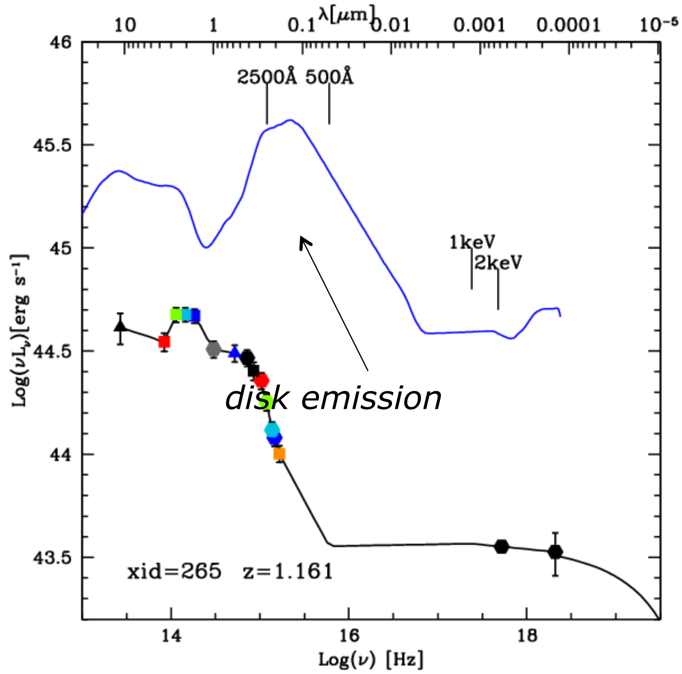


- Average Spectral Energy Distributions for 3 Classes of Objects Selected as X-ray Emitting AGN in a given x-ray luminosity bin (Polletta et al 2007)

AGN

- A huge amount of work has gone into observing AGN across the entire electromagnetic spectrum
- There is a strong relationship between the optical-UV and the x-ray

Brusa et al 2009



Effects of Dust Can Be Dominant

- Remember for the M~10^8 T~5×10^5 K so 'roll over' is in the FUV
- E_{max}~3kT~ 10^{16} hz
- The effects of dust (Reddening) go at λ^{-2}
- much bigger effects at shorter (UV) wavelengths- major effect on determination of temperature of accretion disk fits to quasars.

average amount of reddening in the Milkyway at b=50^0

Massive thin accretion discs – III 377

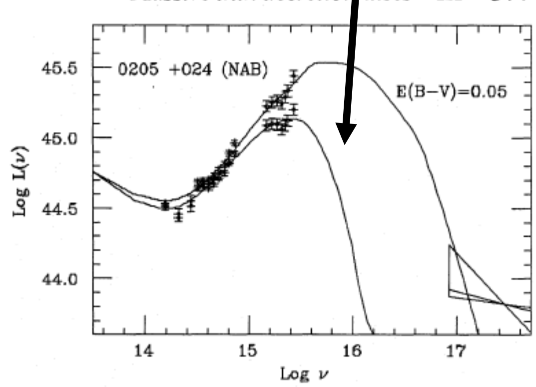
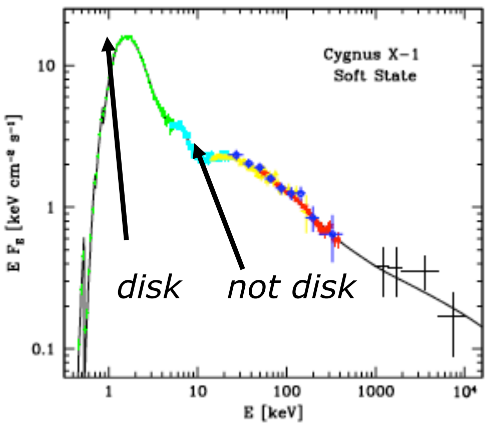


Figure 6. A fit for 0205+024 with and without a correction for internal reddening of $E(B-V)=0.05$. The best fit parameters are

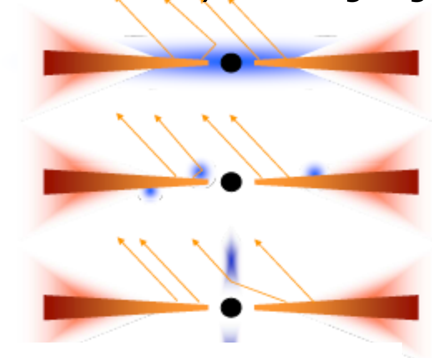
Laor 1990

Real Data For Galactic BH

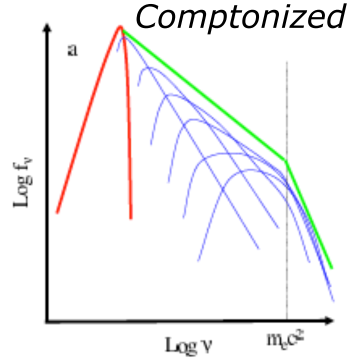


Where do the high energy photons arise?
In both AGN and Black Hole binaries it is thought that this spectral component is due to Comptonization of a 'seed photon' population off of highly energetic electrons produced 'above' the disk

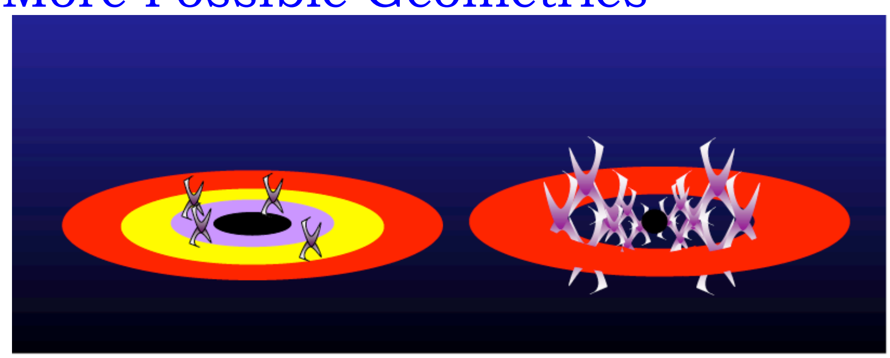
Possible geometries
-blue is x-ray emitting region

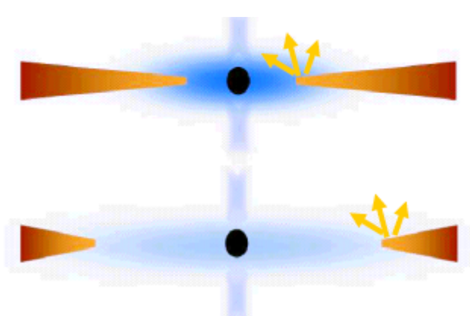


Comptonized spectra

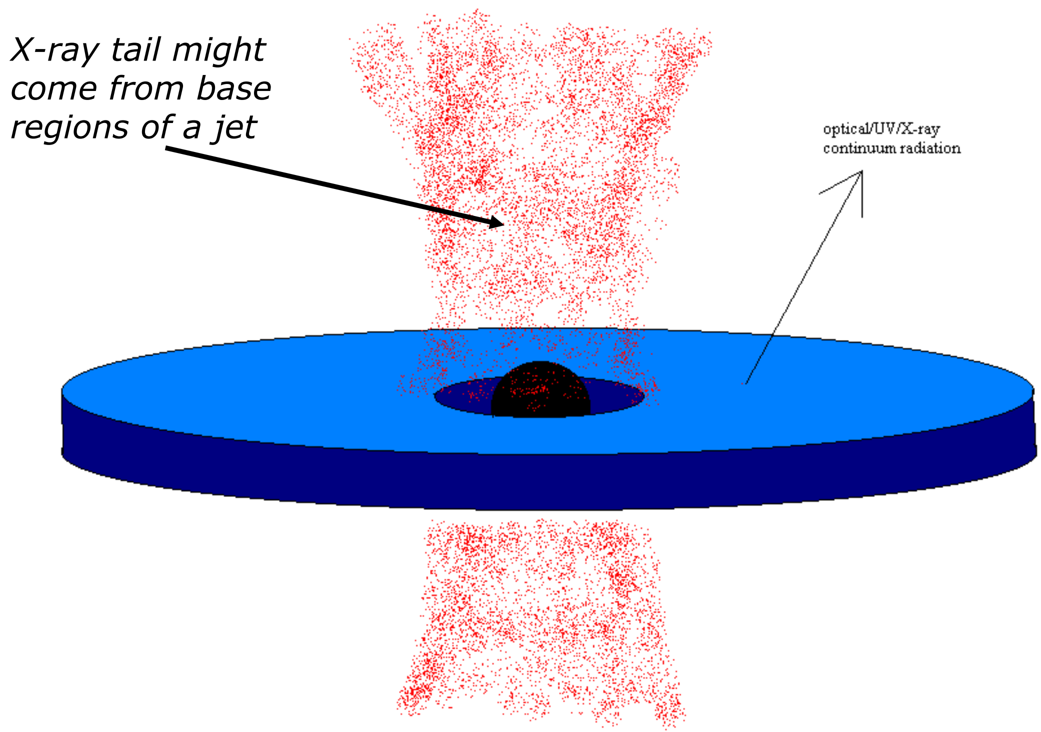


Even More Possible Geometries





From C. Done



Comptonized Spectra

- The free parameter for the power law slope is y which controls the spectral slope
- However the smaller τ is, the larger T has to be to get the same slope - the 'bumpier' the spectra are
- spectrum steeps at high E (max T)
- y~1 is the usual case

- $y \sim 4kT/m_ec^2(\max \tau,\tau^2)$
- slope $\alpha \sim -3/2+(9/4+y)^{1/2}$

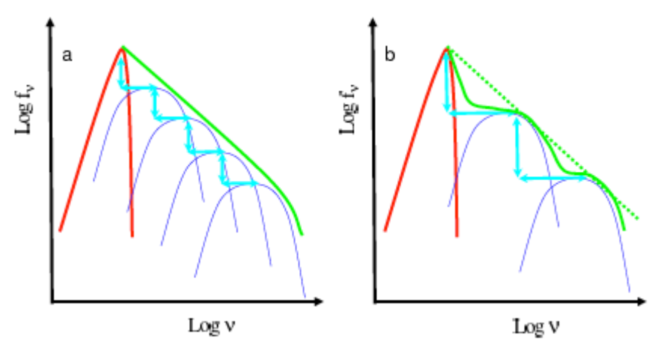
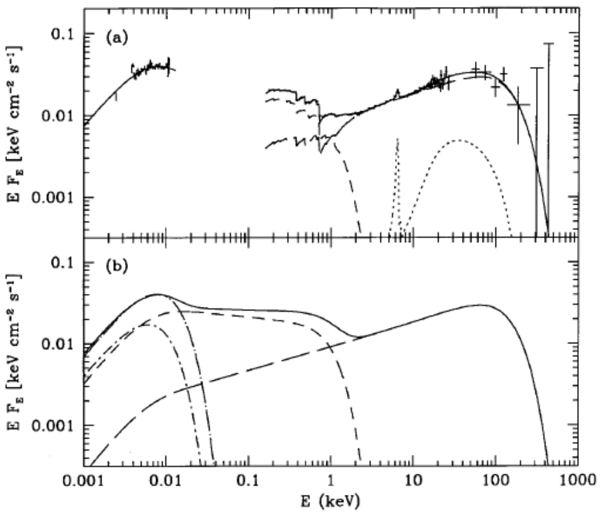


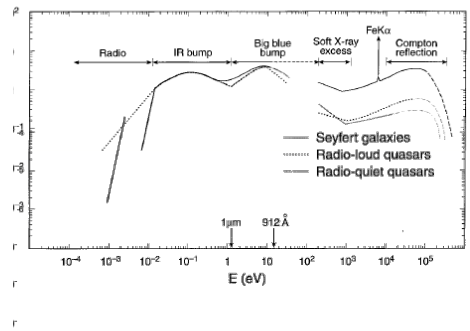
Figure 1.8 a) shows how the spectrum built up from repeated thermal Compton up scattering events for optically thin ($\tau \lesssim 1$) material. A fraction τ of the seed photons (red) are boosted in energy by $1+4\Theta$ and then these form the seed photons for the next scattering, so each scattering order (thin lines: blue in electronic version) is shifted down and to the right by the same factor, as indicated by the arrows (cyan), giving a power law (green solid line). b) shows that the same spectral index can be obtained by higher Θ and lower τ but the wider separation of the individual scattering orders result in a bumpy spectrum (green solid line) than a smooth power law (green dotted line).

Done 2007

AGN- Summary of Spectral Components

- 3 Broad bands of energy
- Disk dominates in optical-UV
- Comptonization in X-ray
- **Reprocessed radiation in IR**





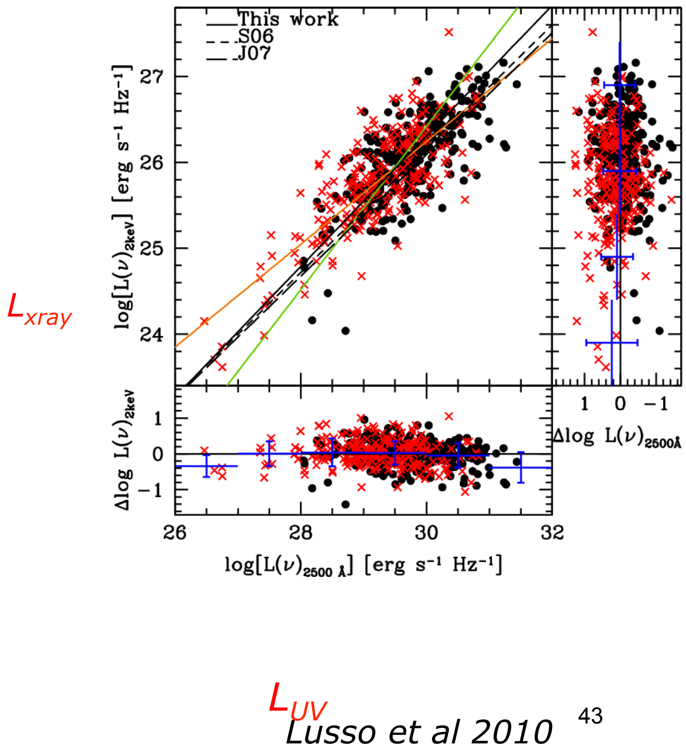
Magdziarz et al 1998

More On BH Spectra

- Relationship of components
- Why do we think disk exists
- Geometry of central regions
- Reprocessing- how can we learn about the material in and around the black hole from spectral and temporal signatures in the spectra
- Spin and its influence

X-ray to UV Relationship

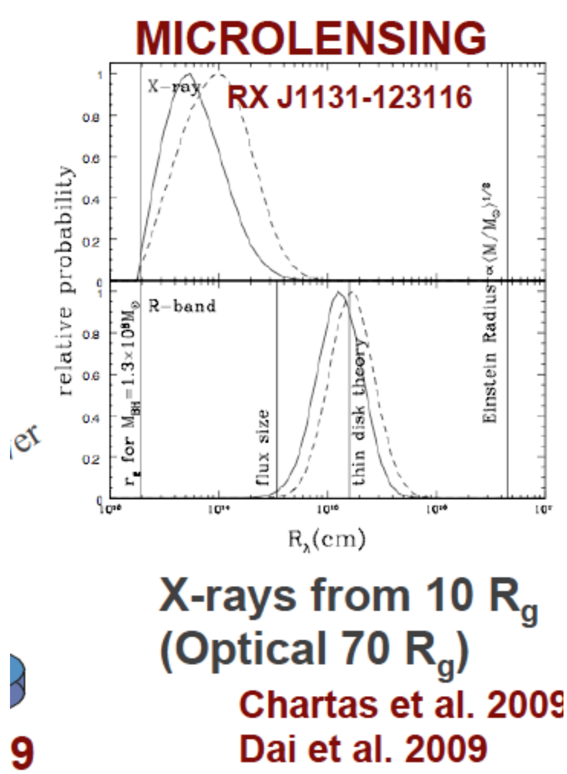
- Over 10^3 in luminosity the UV and x-ray track each in type I AGN
- Direct connection of disk emission to x-rays



Lusso et al 2010

How do we know that there really is a disk??

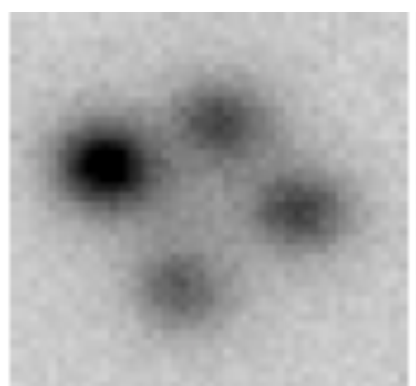
- Recent microlensing observations of a few QSOs have 'resolved' the x-ray and optical sources
- The optical source size and dependence of luminosity on wavelength are consistent with standard disk theory- e.g. Microlensing perturbations to the flux ratios of gravitationally lensed quasar images can vary with wavelength because of the chromatic dependence of the sources apparent size.

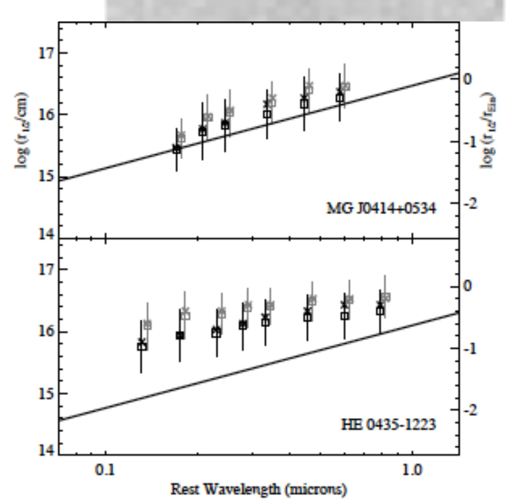


MicroLensing

- As we saw last time in a disk $T(r) \sim T_{max} r^{-3/4}$
- Writing it out in full
- $T_{eff}(r)=\{(3G^2M_{BH}{}^2 m_p f_{Edd})/2c\sigma_{SB}\varepsilon r^3)\}^{1/4}\ (1-r_{in}/r)^{1/4}$
  - f_{Edd} is the Eddington ratio , M_{BH} is the BH mass,s_{SB} the Stefan Boltzman constant , ε is the relation between energy generation and mc^2
- Thus the disk emits most of its short wavelength light at small radii
- Integrating the disk temperature profile (Blackburne et al 2010) one gets that the half light radius as a function of size is
- $r_{1/2} \sim 1.7\times10^{16}\text{cm}(M_{BH}/10^9M_\odot)^{2/3}(f_{Edd}/\varepsilon)^{1/3}(\lambda/\mu)^{4/3}$
- In other words the effective size $\sim\lambda^{4/3}$

- The size of the disk is in Einstein radius units which are converted to cgs units with a model of the grav potential of the lensing galaxy
- To compare to model disks, have to assume M_{BH}, f_{Edd}/ε





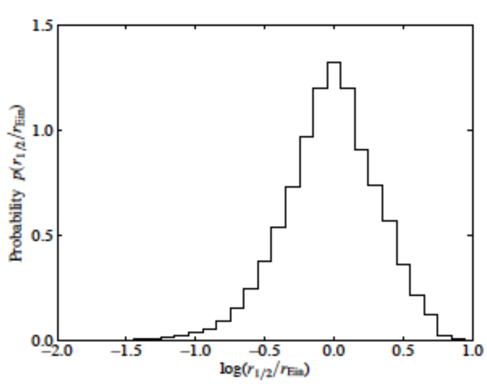
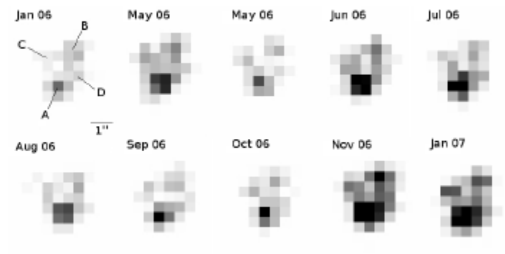
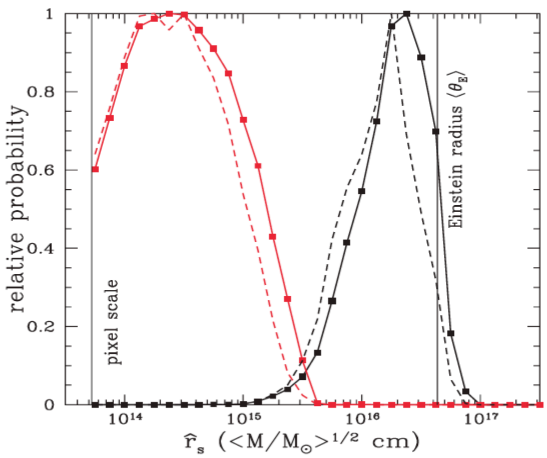


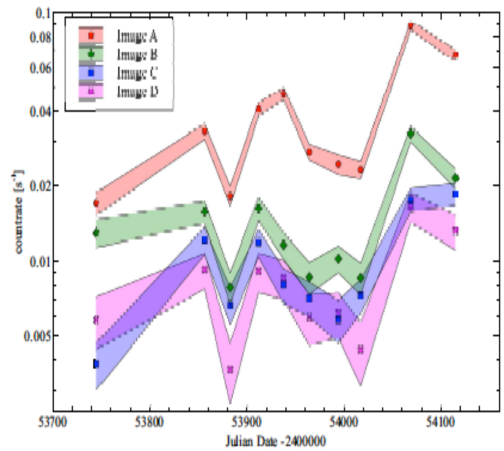
Figure 5. Posterior probability distribution for the size of PG 1115 in th
i' band, resulting from considering both i'-band and X-ray flux ratios. Th

X-ray MicroLensing Also

- Probability distribution of optical and x-ray source size (Zimmer et al 2010 , Chartas et al 2008)

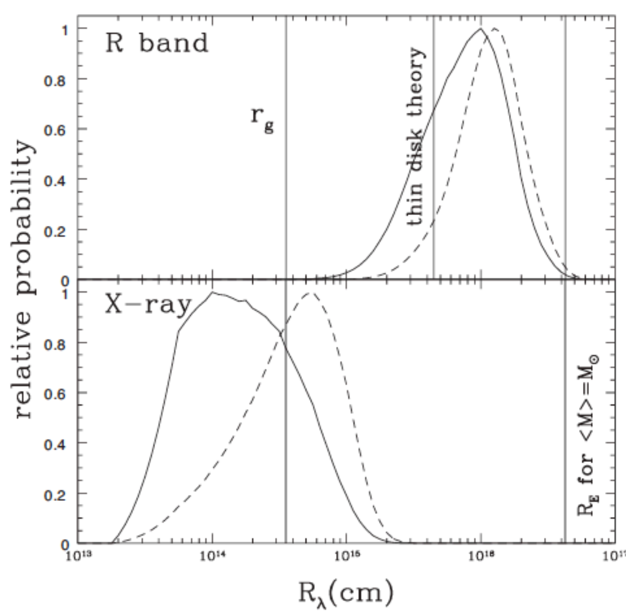






Results are In Rough Agreement With Theory

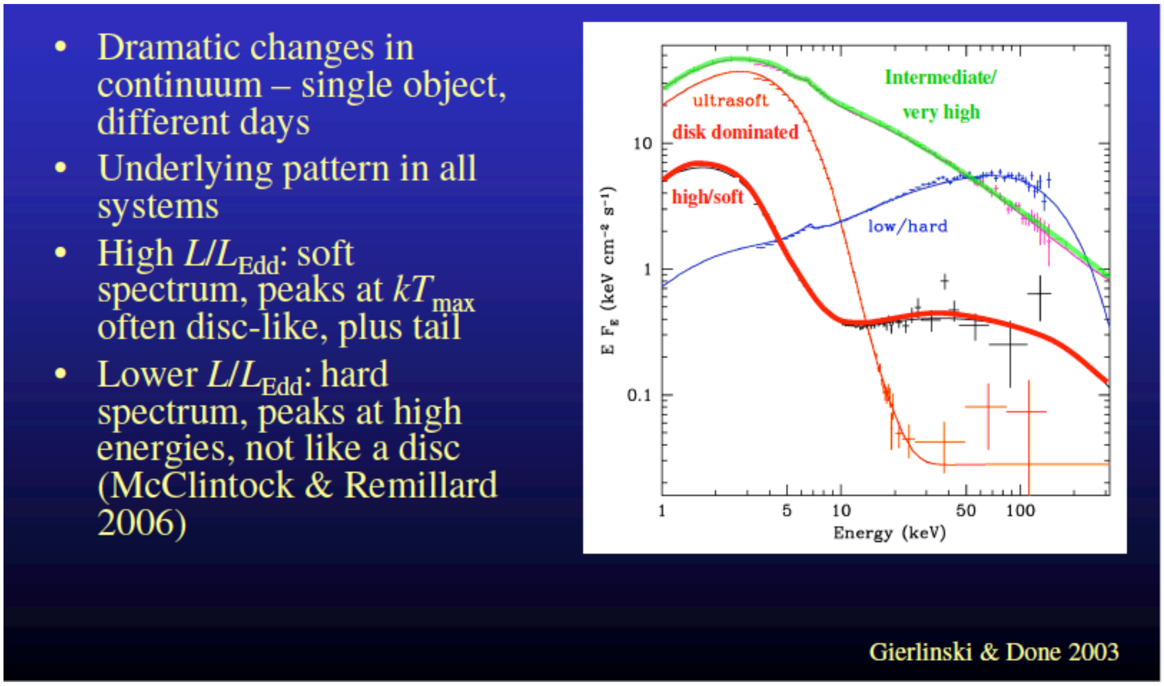
- X-rays are emitting near the Schwarzschild radius
- Optical ~10x further out



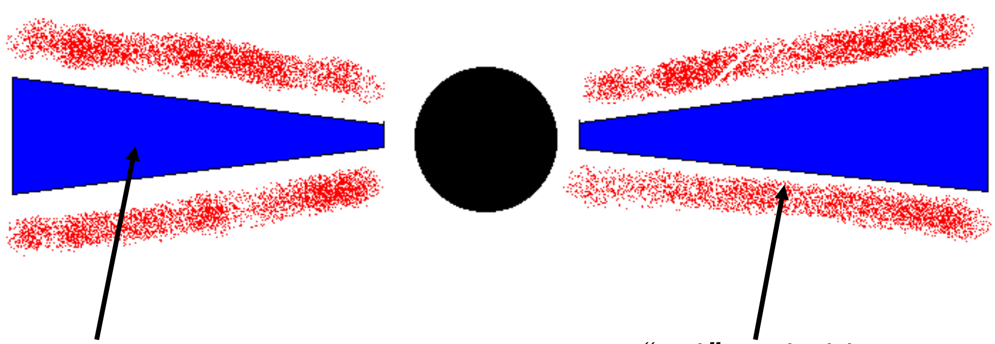
Chartas 2008

Spectral States of Black Hole Binaries

- thought to be due to changes in disk structure - not seen in AGN (yet)



Where do the Spectral Components Arise?

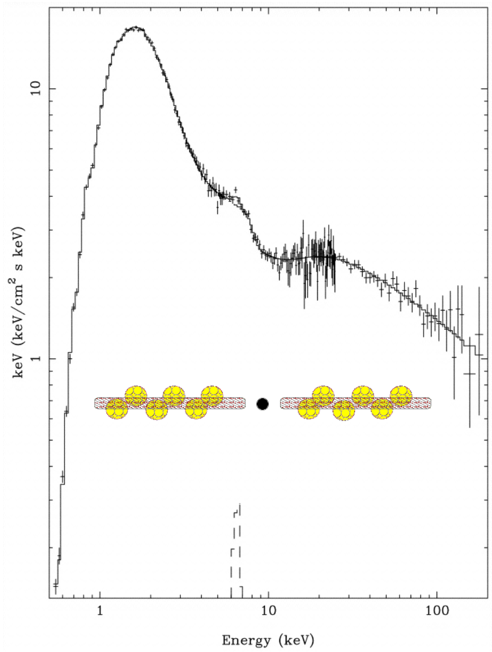


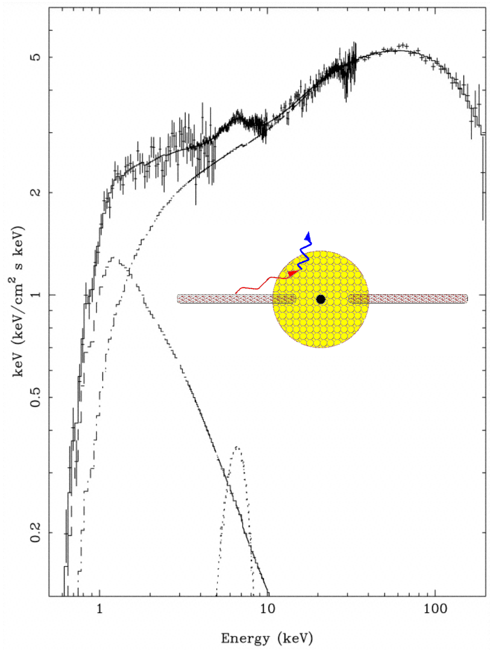
Optically-thick part of the accretion disk emits thermal spectrum… black body radiation with

$$T = \left(\frac{3GM\dot{M}}{8\pi r^3 \sigma_{\rm SB}} \right)^{1/4}$$

X-ray "tail" probably comes from a hot corona that sandwiches the disk… inverse Compton scattering of thermal disk emission by electrons with T~10⁹K

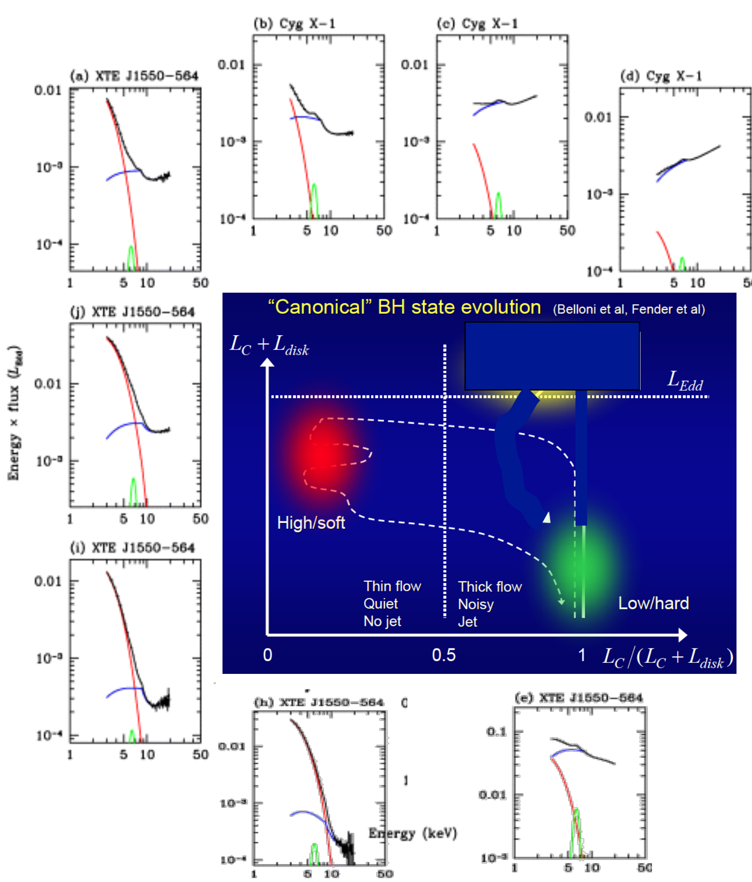
Cygnus X-1 Spectral States and Ideas on Geometry





Soft (high) state; thermal disk emission + hard tail

Hard (low) state; hard X-ray spectrum, little/no thermal disk



Wide Variety of Spectra in Galactic Accreting Black Holes- (Gierlinski and Done 2003)

Redline is accretion disk

Blue line is from Comptonization

The wide range in the ratio of the two is related to the Eddington ratio- states

At L→ L_{Edd} Spectrum more disk dominated

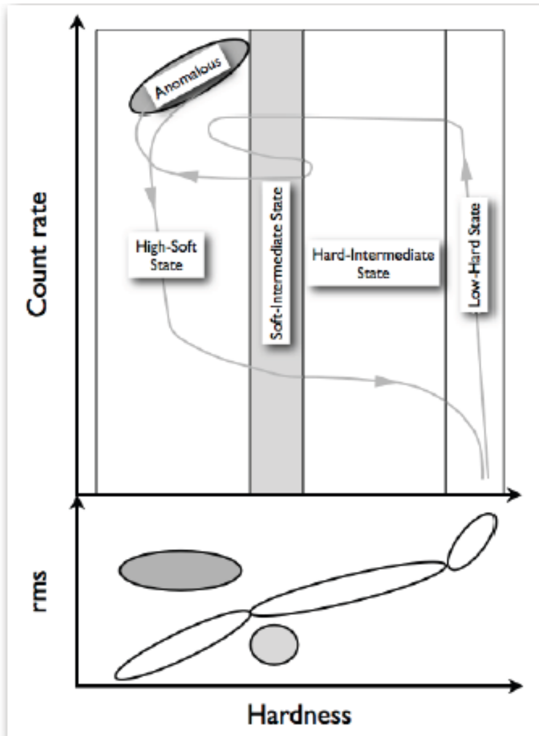
In galactic black holes there is a pattern to the spectral/ intensity changes

The high soft state is disk dominated

The low hard state is dominated by the x-ray power law

The 'variability' - represented by the root mean square (RMS) variations is also related to the state

It is believed that these states are related to the geometry of the accretion flow



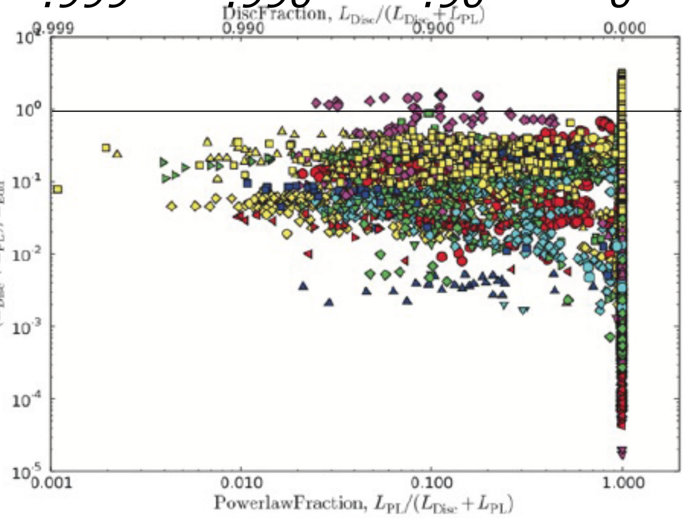
Belloni (2010)

- Many (but not all) black hole binaries follow a similar track
- (each color is a different object)

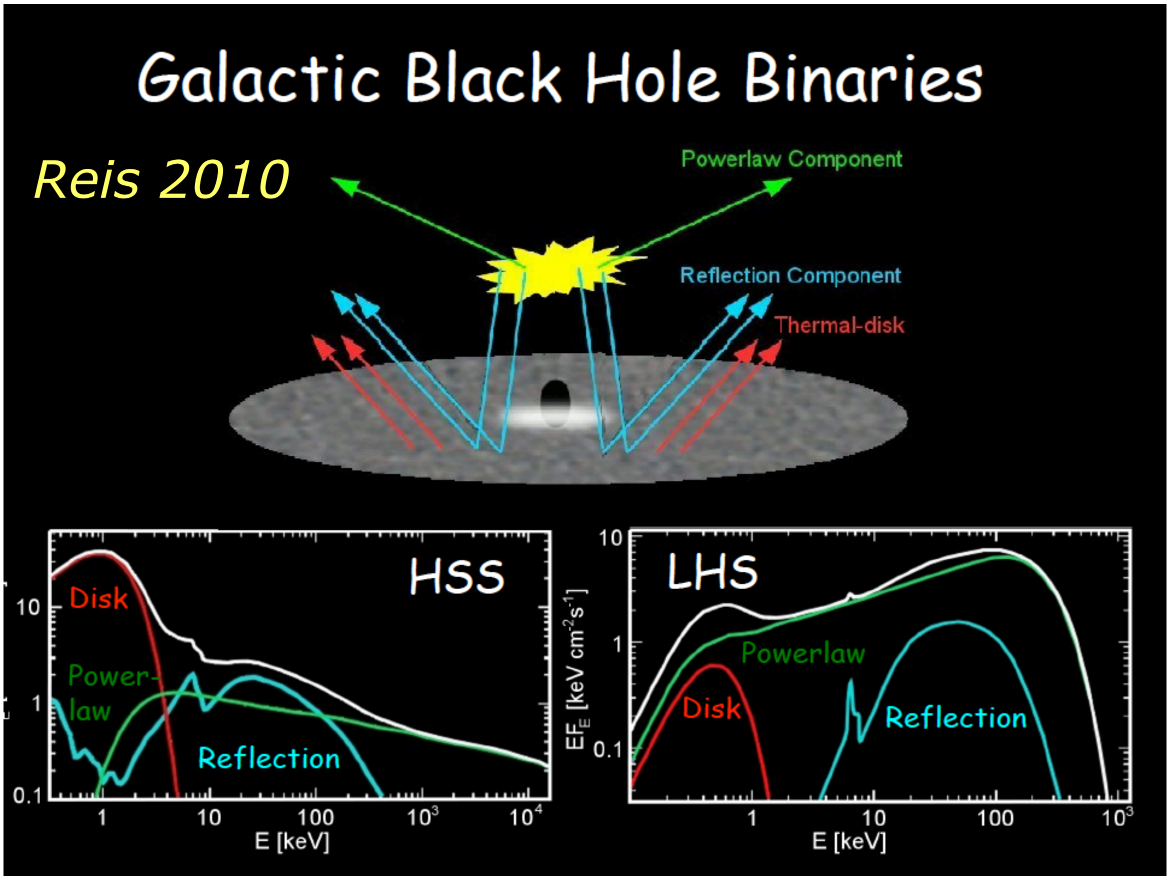
Fraction of luminosity from disk

.999 .990 .90 0

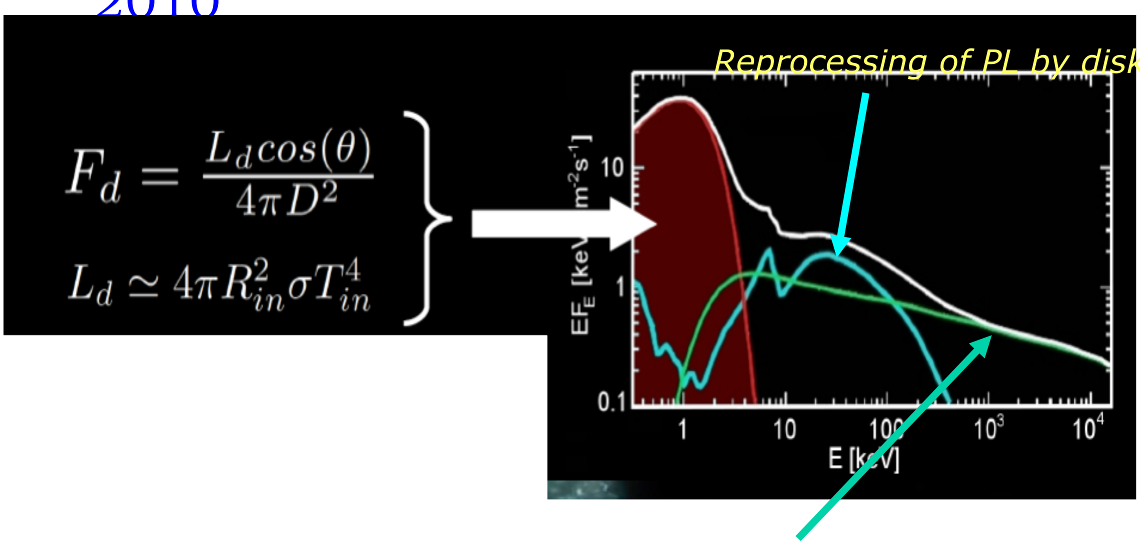
log L_{total}/L_{Edd}



adapted from Belloni



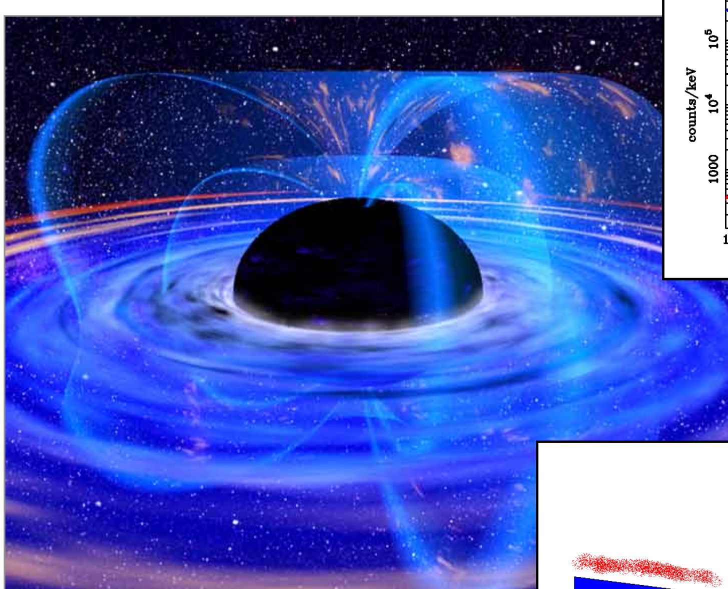
Components in High State- R. Reis 2010

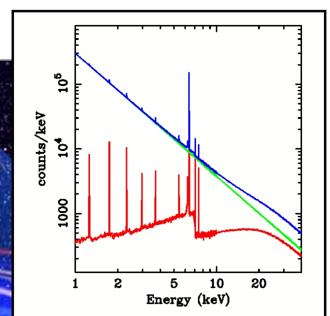


'Power Law'- Comptonization

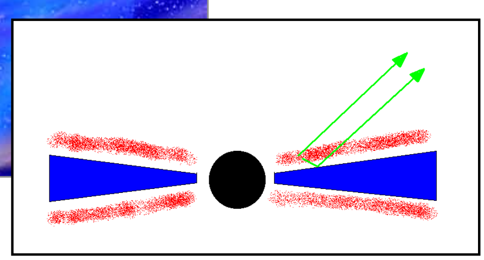
Todays Lecture and …

- Need your project titles on today
- Reprocessing- how can we learn about the material in and around the black hole from spectral and temporal signatures in the spectra
- Spin and its influence



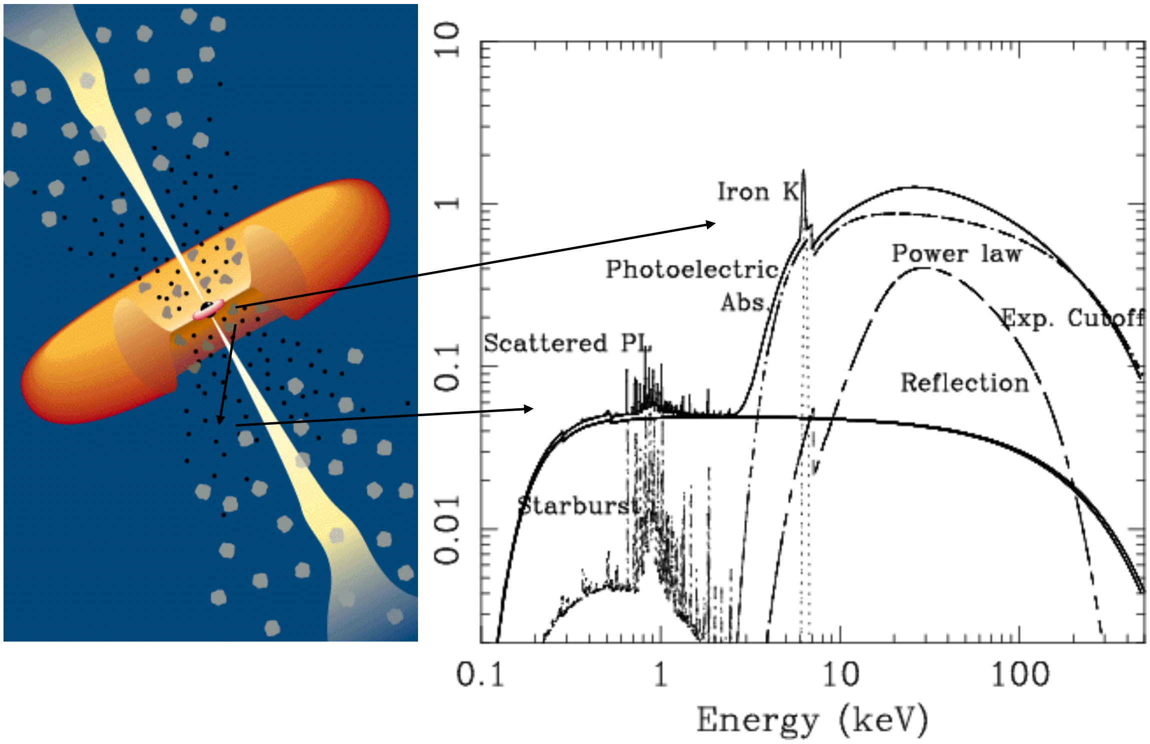


Reynolds (1996)

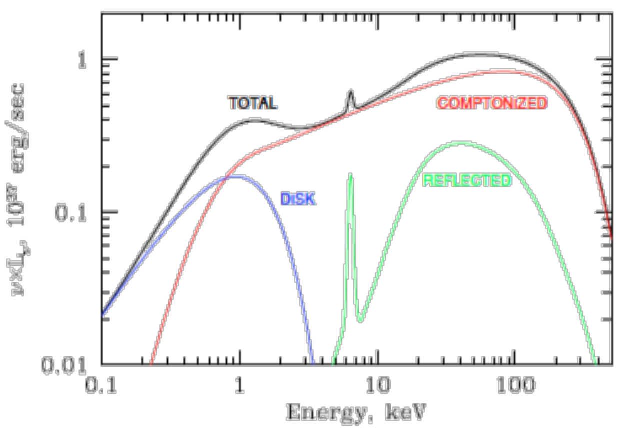


- X-ray "reflection" imprints well-defined features in the spectrum

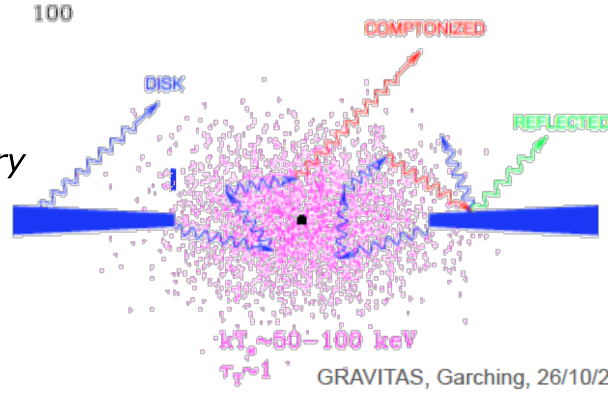
■ .

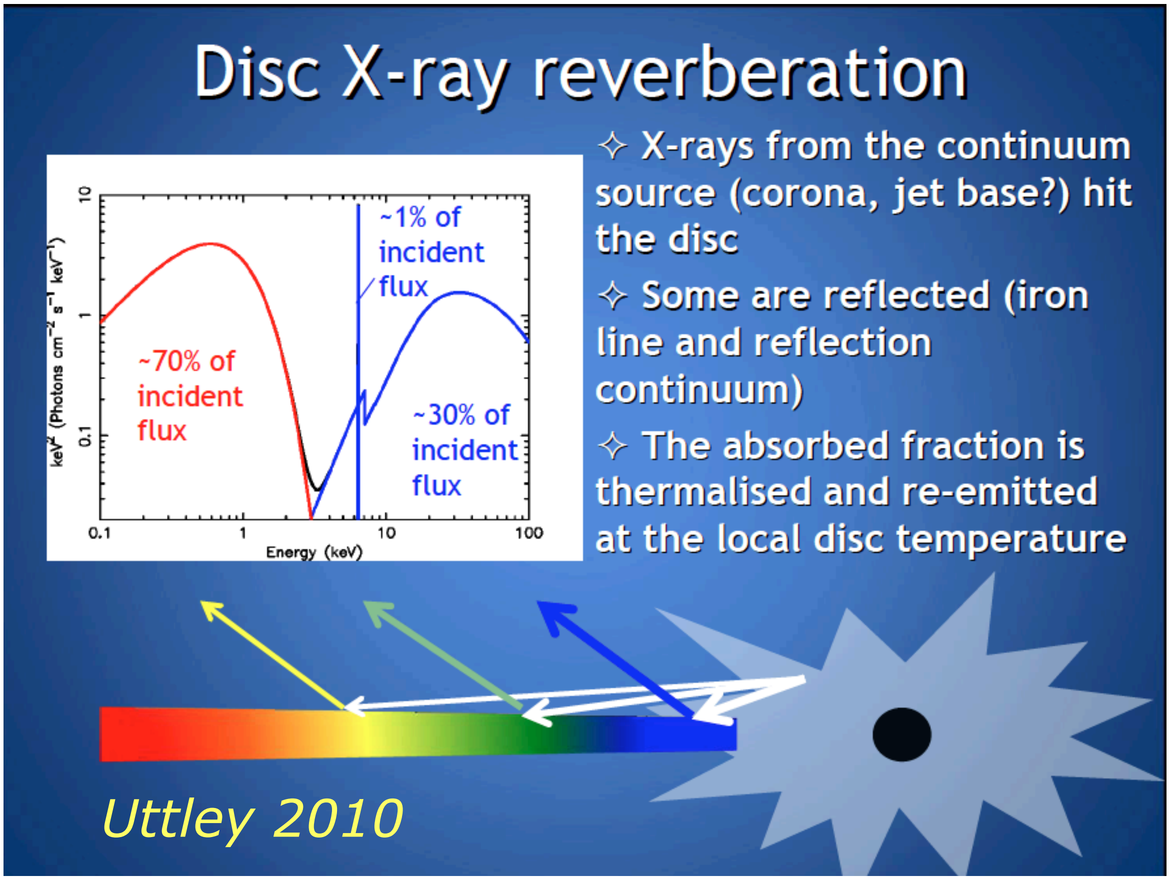


Connection Between Source Geometry and Spectra in an Black hole binary

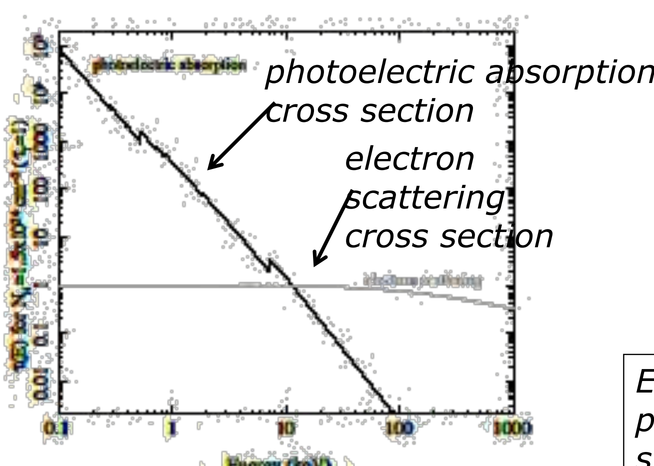


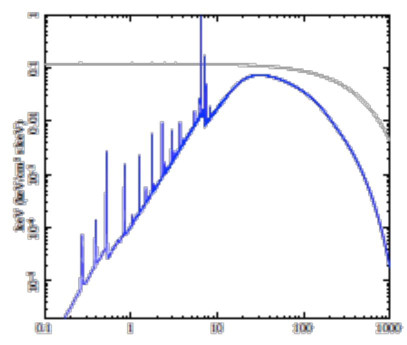
An Alternative Geometry





'Reflection'- Reprocessing of Photons in the Disk

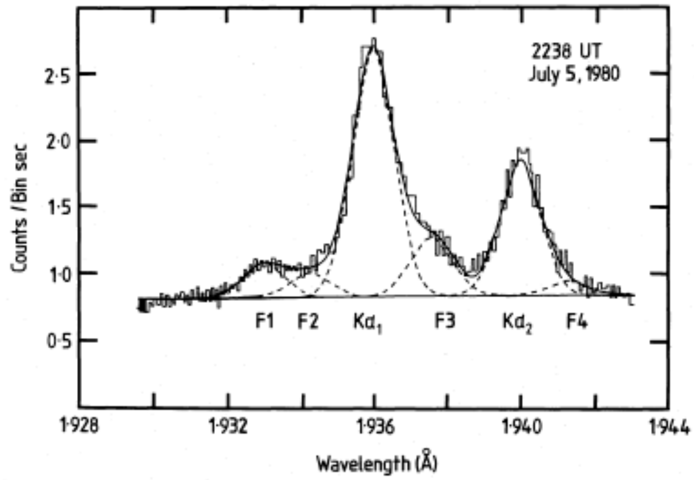


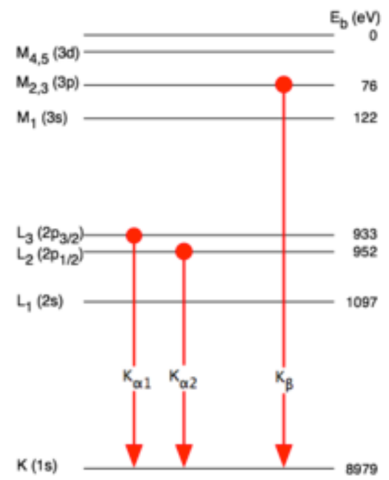


Emission due to the two processes from a cold slab of thickness $\tau_{Thompson}=1$

The larger cross section at low energies of photoelectric absorption means that low E photons are absorbed not scattered and some are re-emitted as lines via fluorescence. Compton scattering reduces the energy of the high energy photons. The combination produces a characteristic peak in the spectrum.

Iron Kα fluorescence from the Sun





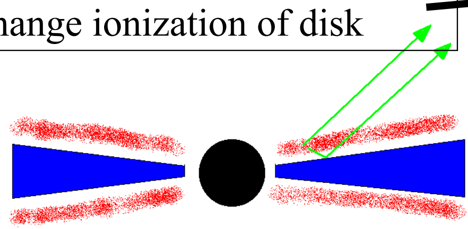
energy levels for Cu

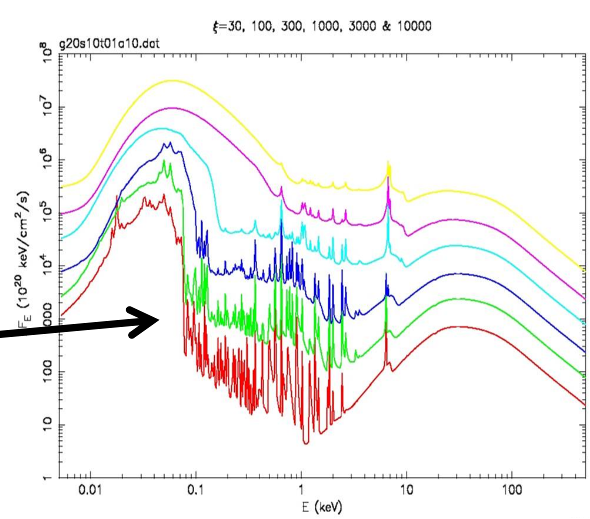
Parmar et al. (1984)
Solar Maximum Mission
(Bent Crystal Spectrometer)

With very high resolution there are 2 Fe K flourescent feature Kα1, Kα2

X-ray reflection
"Reflection' is Compton scattering

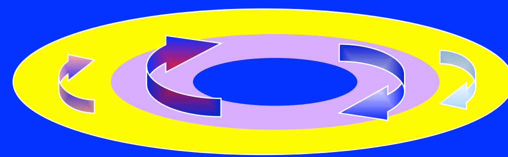
Important consequence of corona: underlying disk is irradiated by intense X-ray source… results in a characteristic spectrum being "reflected" from the disk surface layers
Different amounts of flux can change ionization of disk

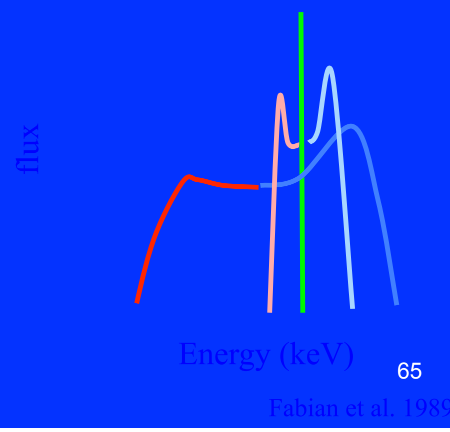




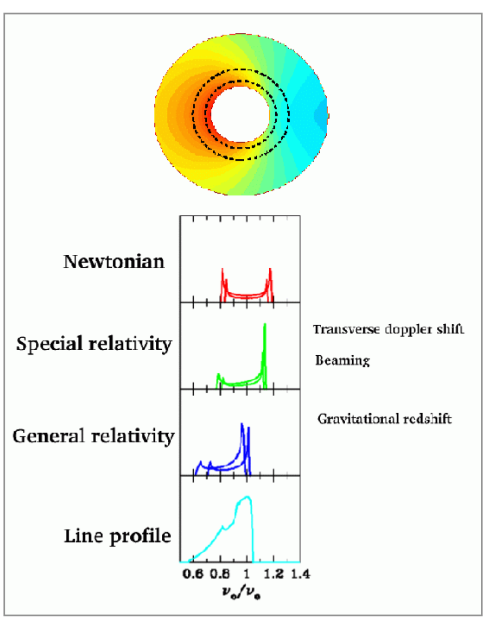
Relativistic effects- C. Done

- Relativistic effects (special and general) affect all emission (Cunningham 1975)
- Hard to easily spot on continuum components
- Fe Kα line from irradiated disc – broad and skewed! (Fabian et al 1989)
- Broadening gives an independent measure of Rin – so spin if ISO (Laor 1991)
- Models predict increasing width as go from low/hard to high/soft states

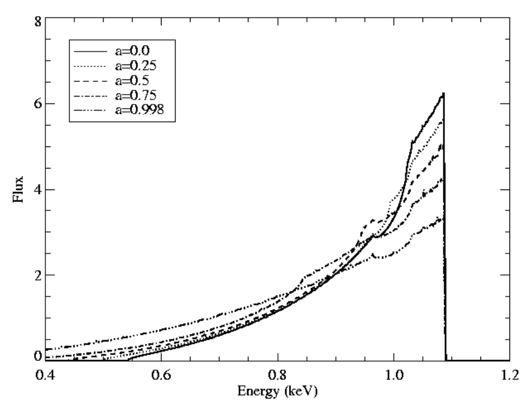




Relativistic effects imprint characteristic profile on the emission line...



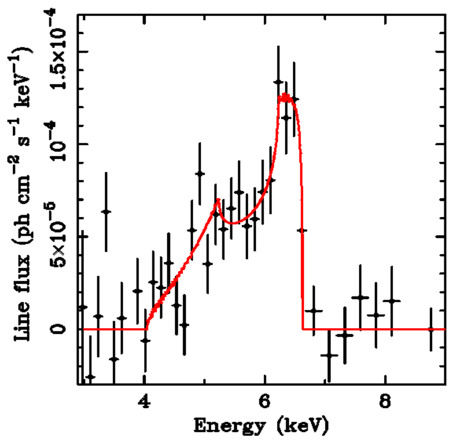
Andy Young



Theoretical line profiles [Laura Brenneman]

Observations of relativistic emission lines

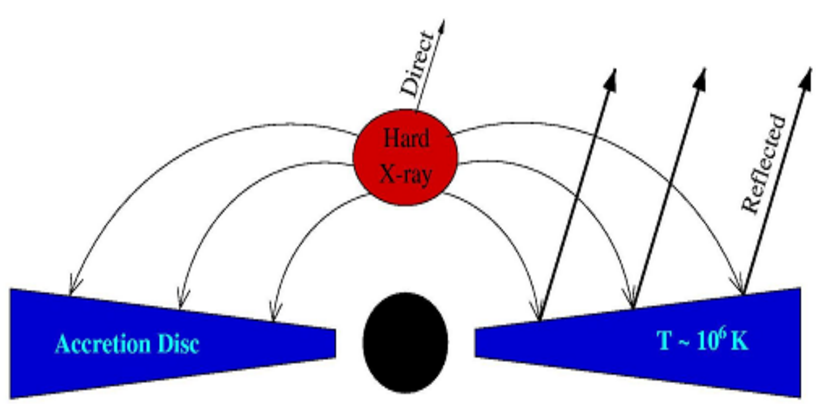
- First seen in 1994 with ASCA observatory
- 5 day observation of Seyfert-1 galaxy MCG-6-30-15
- Needed long observation to collect enough photons to form detailed spectrum



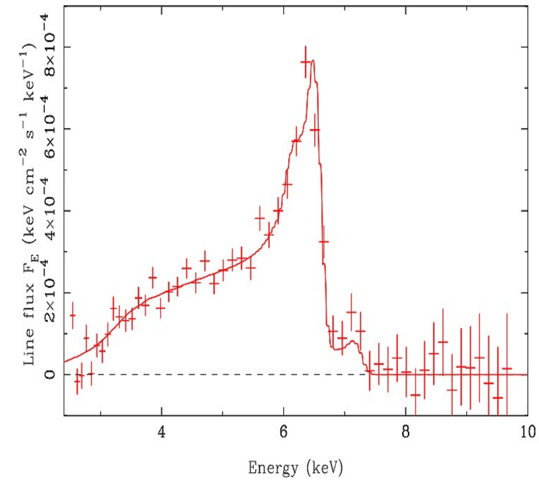
Power-law continuum subtracted
ASCA: Tanaka et al. (1995)

Relativistic Effects

- Light rays are bent by strong gravity- making the geometry rather complicated
- Do not know 'where' x-ray source is - try to use data to figure it out

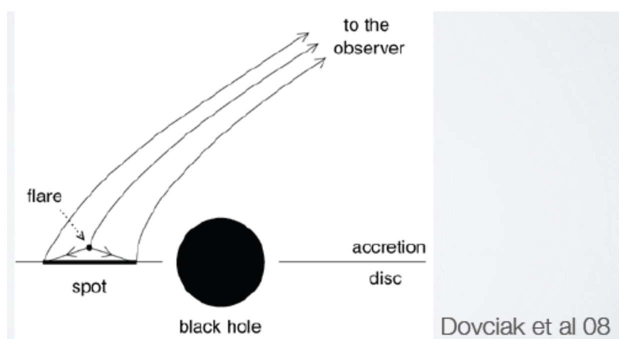


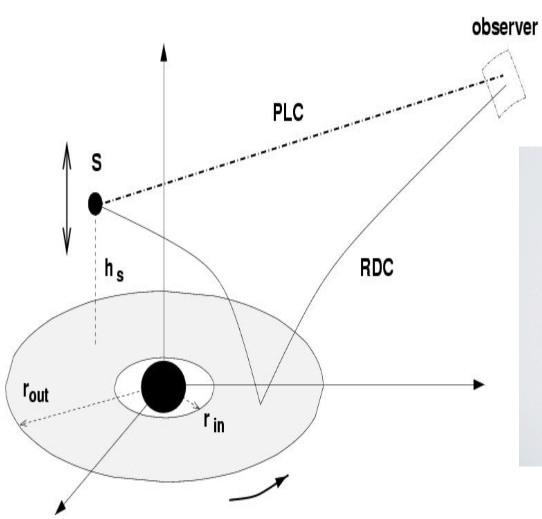
- Modern XMM-Newton observations
- Confirm relativistic line with extreme redshifts
- If no line emission from within ISCO, need to invoke spinning black hole to get strong enough redshifting

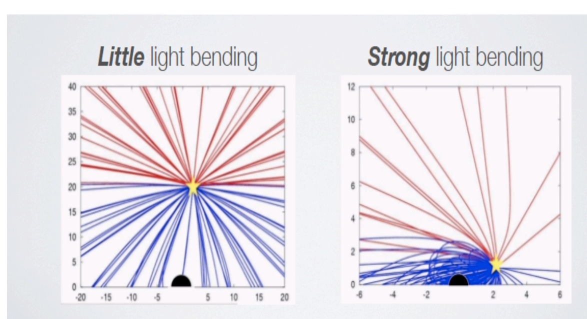


Power-law continuum subtracted
XMM: Fabian et al. (2002)

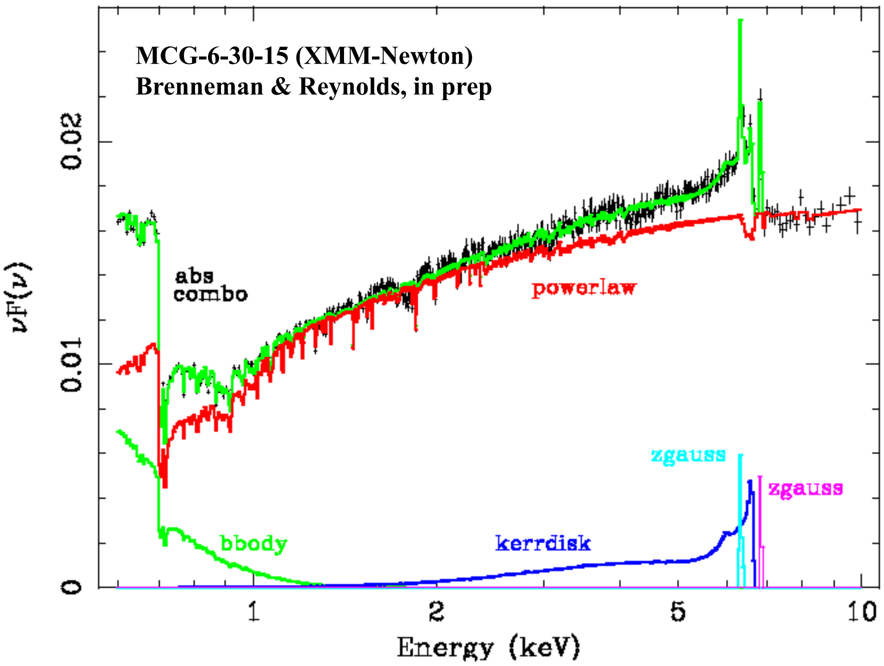
- if we only knew where the x-rays come from (h_s ~ r_s) from time variability arguments



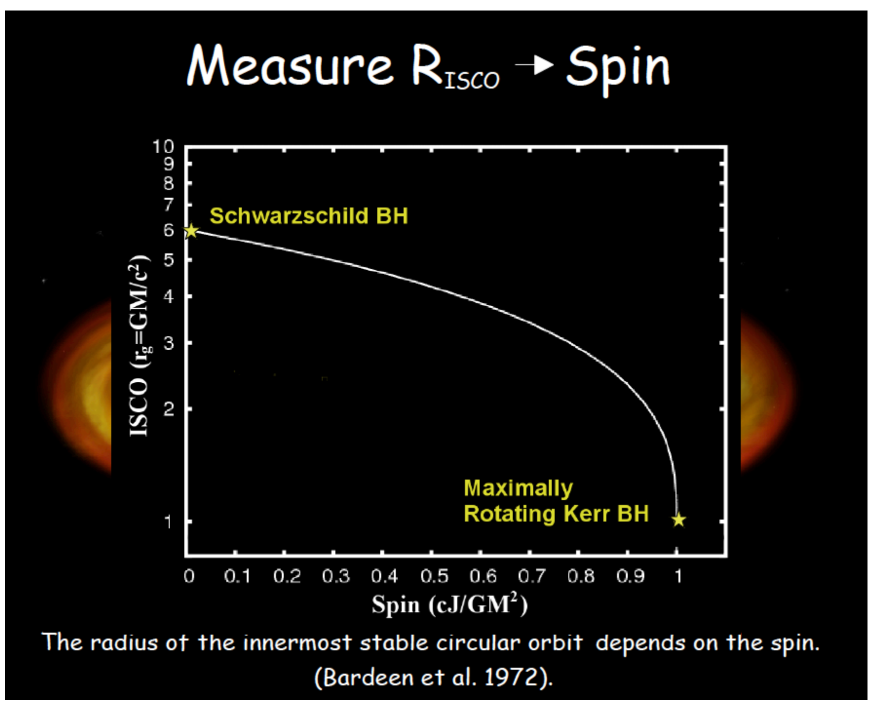




Spectra can be complex...



- Spin- is measured in units of c/GM^2

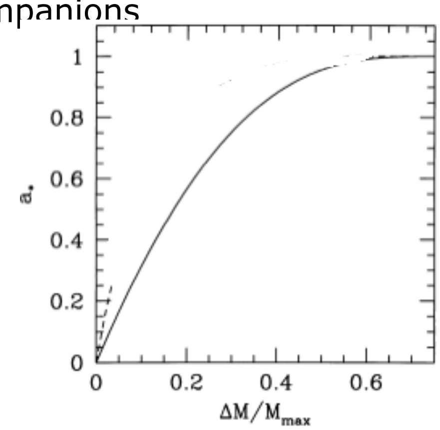


Why Measure Spin

- BH has only 3 measurable properties Mass, spin, charge.
- Black hole spins affects
  - the efficiency of the accretion processes, hence the radiative output
  - how much energy is extractable from the hole itself
  - the retention of black holes in galaxies
  - gravitational wave signature
  - possible origin of jets.
- Origin of BH Spin
  - natal
  - history

Spin

- For galactic black holes- not enough accretion to account for spin being due to accretion of angular momentum- need to accrete ~3/4 of the mass to spin it up to the maximal spin
- If accreting at the Eddington limit takes a very long time (~10^8 yrs)
  - too long for wind fed or Roche Lobe systems
  - too much mass for low mass companions
- Spin is natal

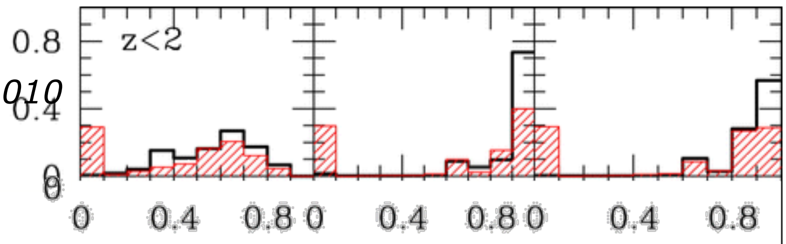


Spin

- For supermassive black holes- If accreting at the Eddington limit (~10^8 $M_\odot$ accretes 0.25 $M_\odot$/yr) so takes 4×10^8 yrs to double its mass and spin up
- Spin can be due to accretion
- Requires 'organized' accretion of angular momemtum

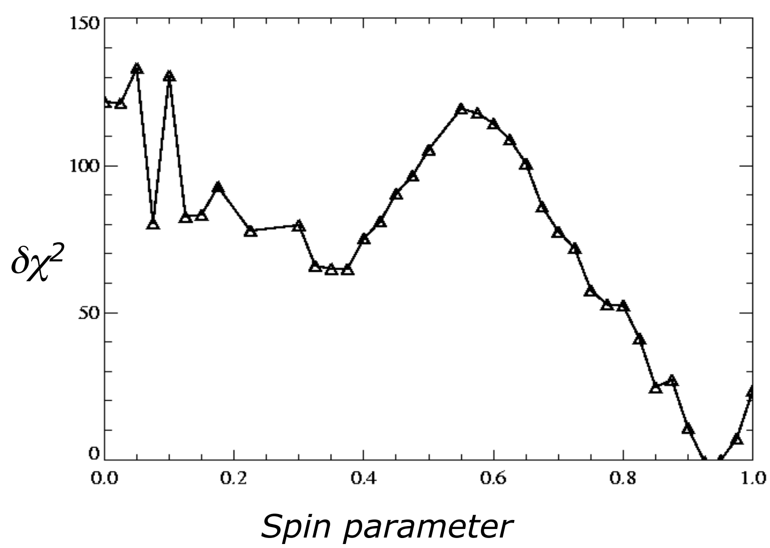
Alternatively spin could be due to mergers of black holes

Volontieri et al 2010



mergers only (left), mergers and prolonged accretion (center), and mergers and chaotic accretion

- Applied models to long (350ks) XMM dataset for MCG-6-30-15
  - Data strongly prefers rapidly spinning BH solution
  - a ~ 0.93



L.Brenneman