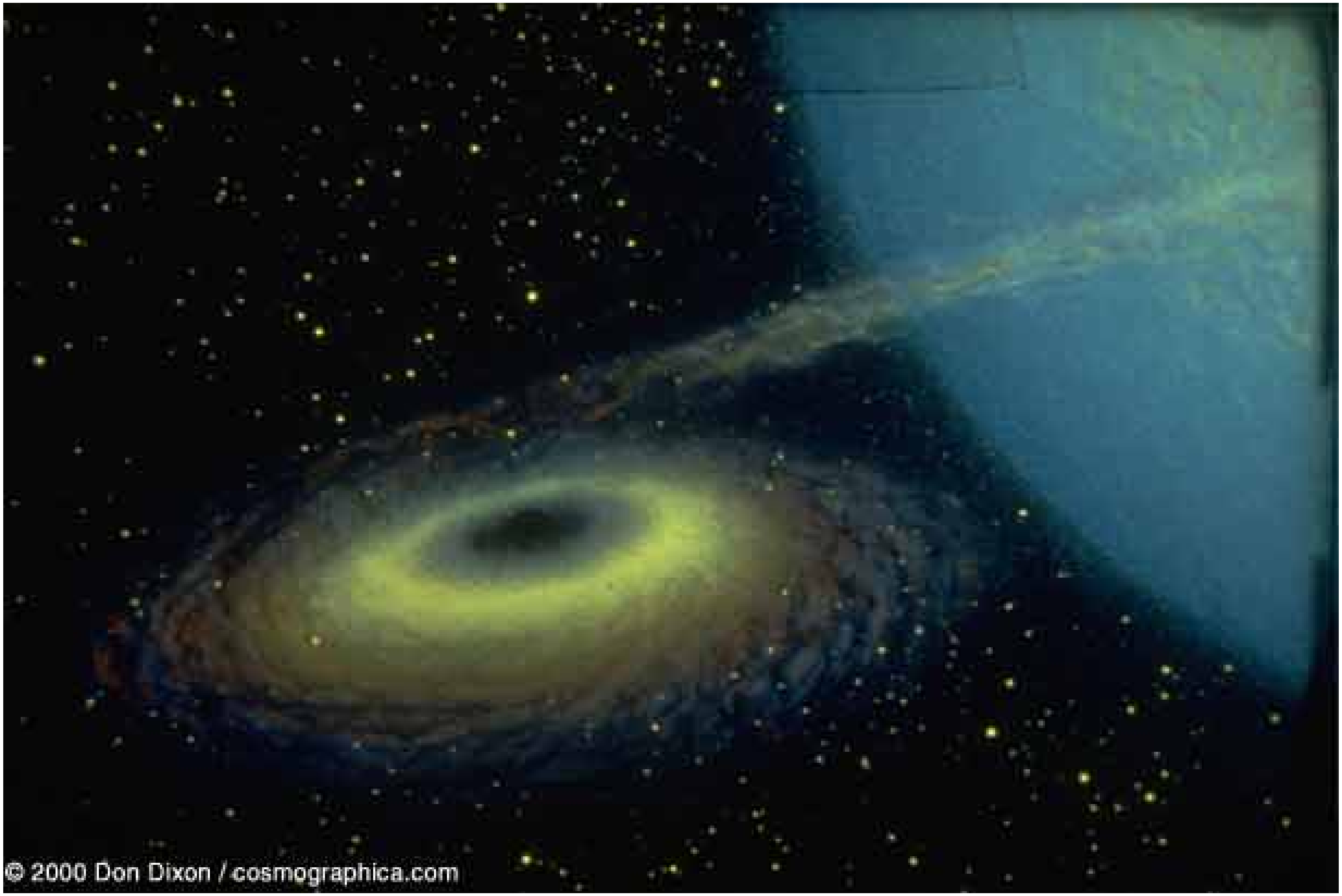
Strong gravity and accreting black holes

- Finish how to get the masses of black holes
- The AGN Zoo
- Black Hole systems
  - The spectrum of accreting black holes
  - X-ray "reflection" from accretion disks
  - Strong gravity effects in the X-ray reflection spectrum

Spectra of accreting black holes



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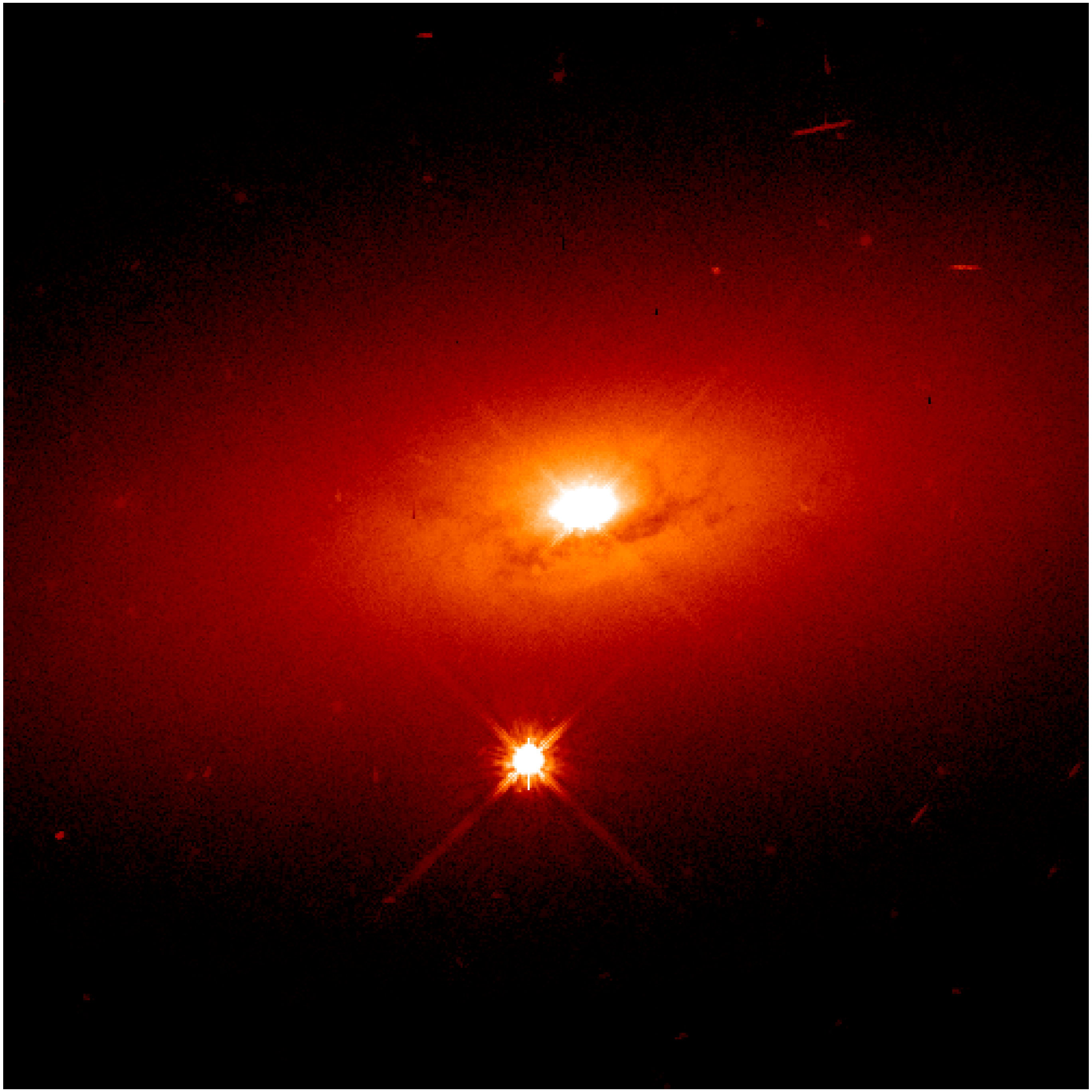
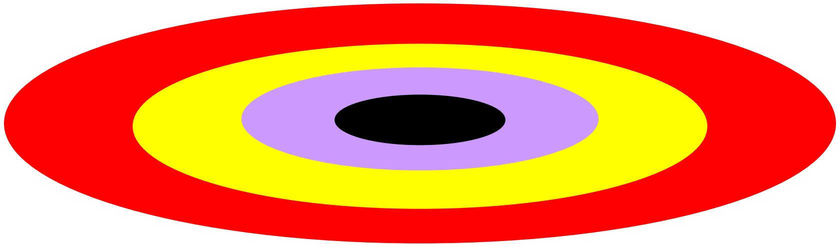
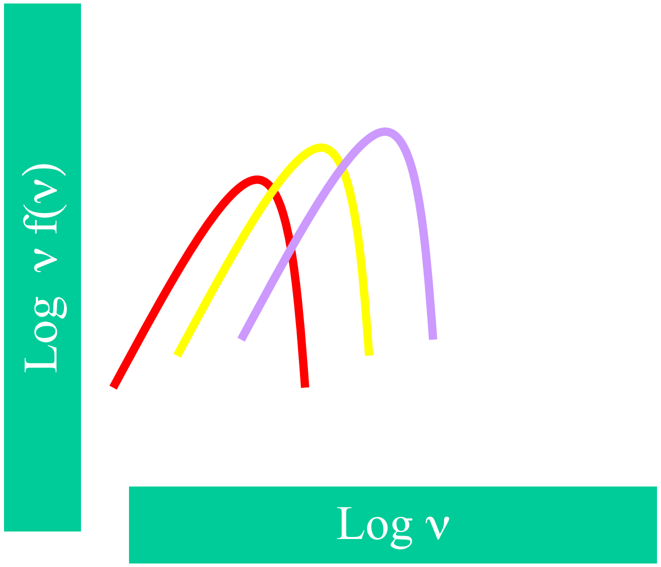


Spectra of accretion flow: disc-

C. Done

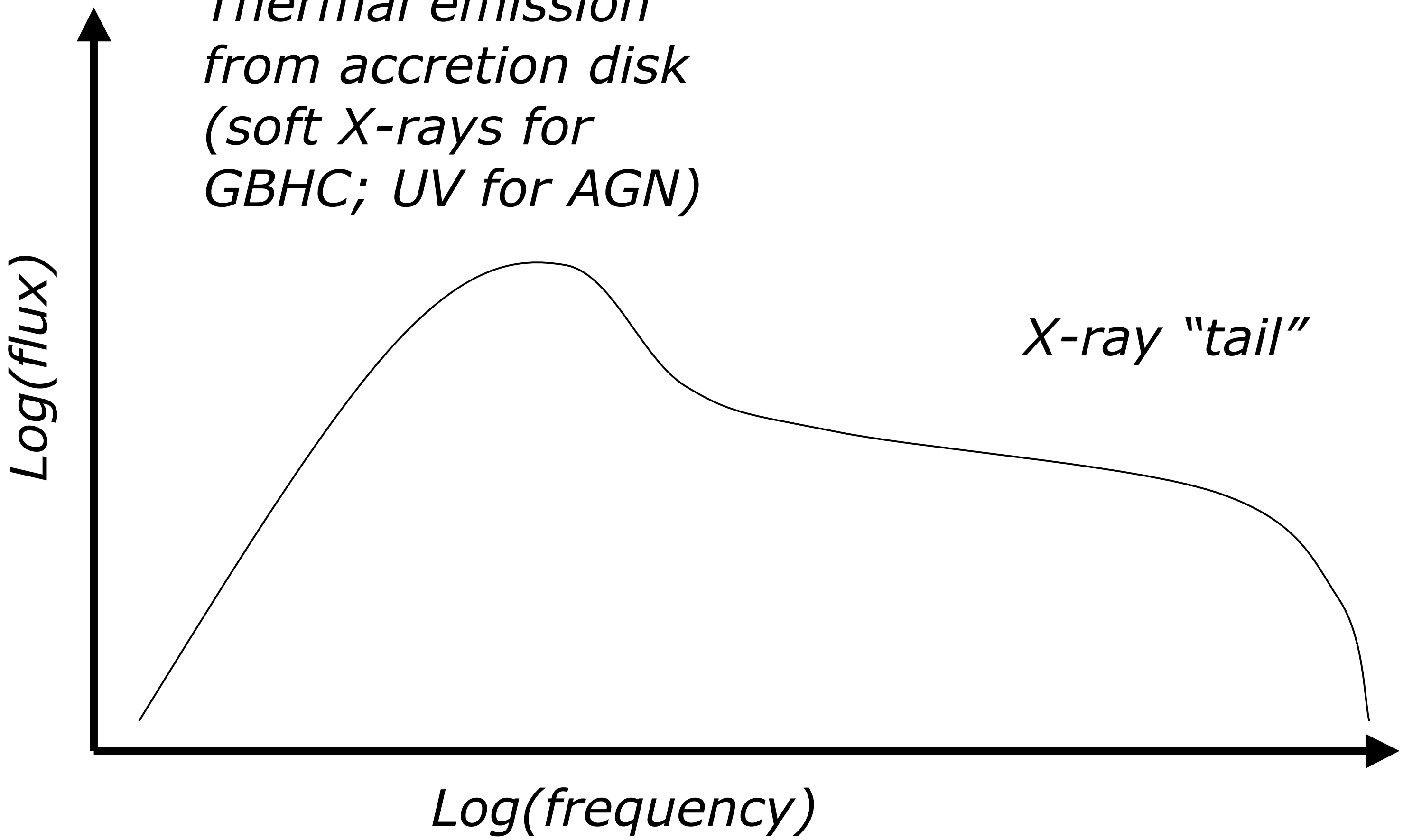
- Differential Keplerian rotation
- Viscosity : gravity → heat
- Thermal emission: $L = A\sigma T^4$
- Temperature increases inwards
- GR last stable orbit gives minimum radius R_{ms}
- a=0: $T_{\mathrm{max}} = (M/M_\odot)^{-1/4} (L/L_{\mathrm{Edd}})^{1/4}$
  - 1 keV (10^7 K) for 10 $M_\odot$
  - 10 eV (10^5 K) for 10^8 $M_\odot$
- a=0.998 $T_{\mathrm{max}} \sim 2.2\ T_{\mathrm{max}}$ (a=0)
- AGN: UV disc, ISM absorption, mass more uncertain. XRB…





What Do Broad Band Spectra of Black Holes Look Like

$$T \sim \mathscr{M}^{1/4} M^{-1/4}$$



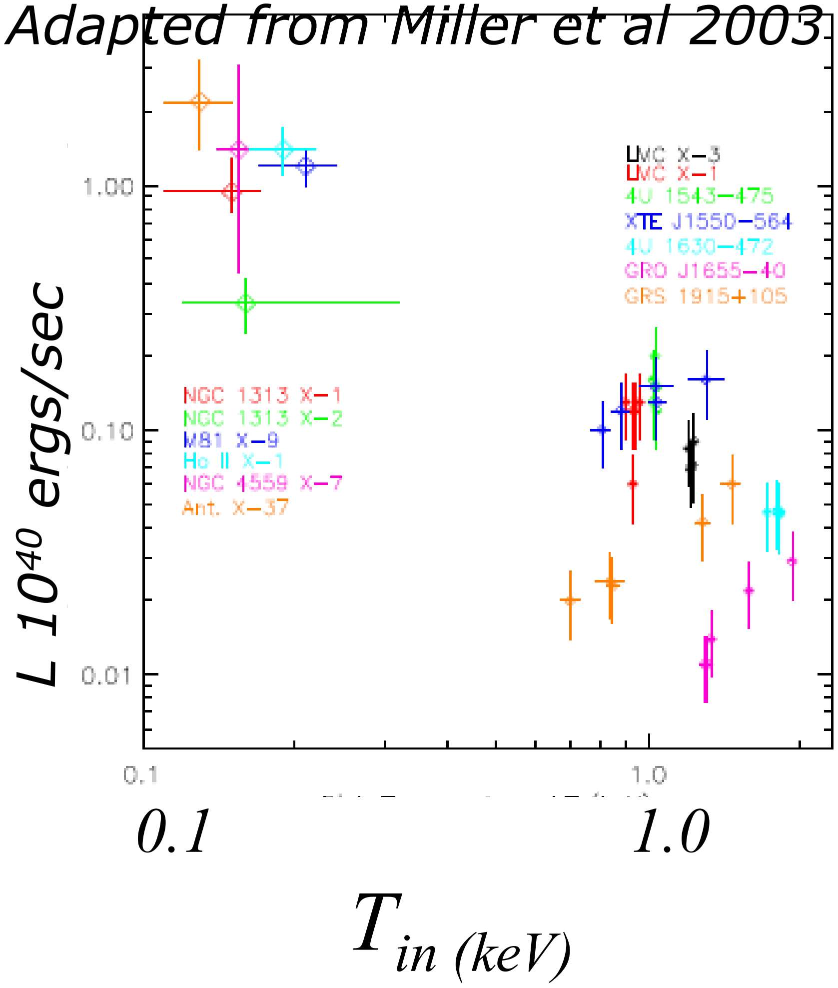
Thermal emission from accretion disk (soft X-rays for GBHC; UV for AGN)

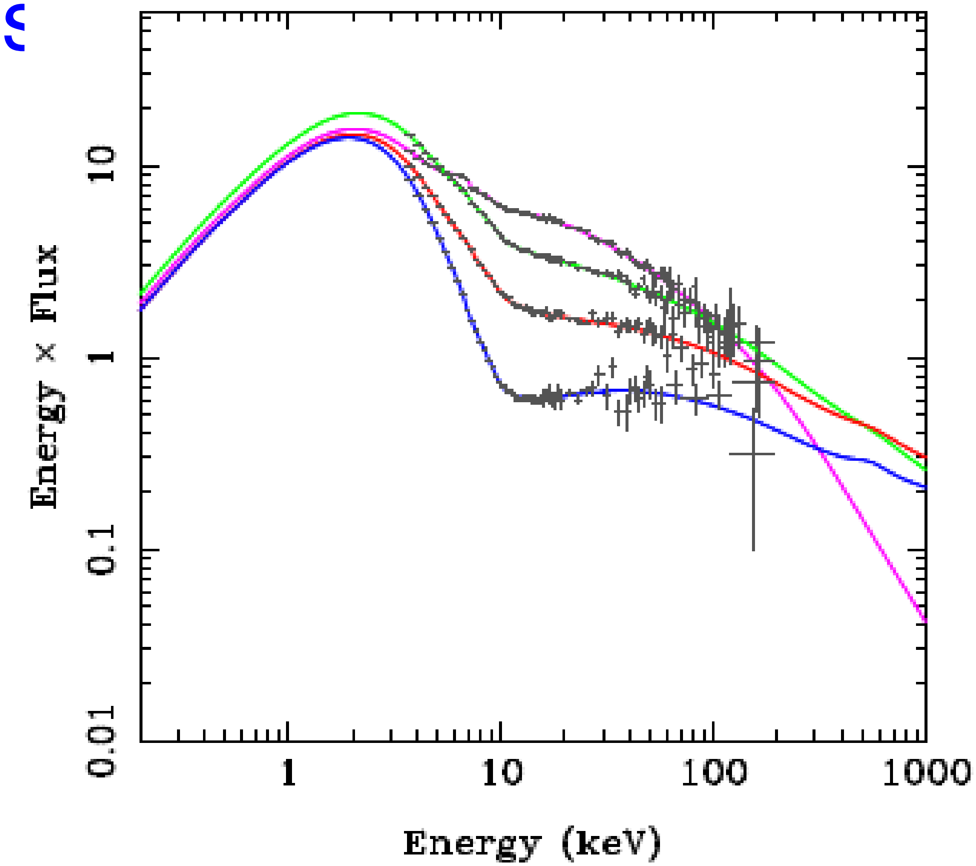
X-ray "tail"

Galactic Black Holes

- Relatively low mass and so the disk are 'hot'

Adapted from Miller et al 2003





$$L \sim 7\mathrm{x}10^{38}\ \boldsymbol{f}(M_{10})^2(T_{in})^4\ \mathrm{erg/s}$$

Where M_{10} is the mass in units of 10 $M_\odot$ and T_{in} is in keV

f is a factor taking some physics into account

Derivation (See Rosswog and Bruggen sec 8.4)

- Derivation of previous eq
- $L=2\pi R_{in}^2 f(\cos i)^{-1}$; f is the flux from the surface of the disk, R is the radius
- Using the black body law

  $L=4\pi\sigma R^2 T_{in}^4$ σ is the Stefan- Boltmann constant

In fitting the spectrum T_{in} is directly observable

We can thus take the 2 equations to get the innermost radius

$R_{in}=\mathrm{sqrt}(L/4\pi\sigma T_{in}^4)$ and

$T_{in}\sim 3M_{10}^{-1/4}\mathrm{keV}$

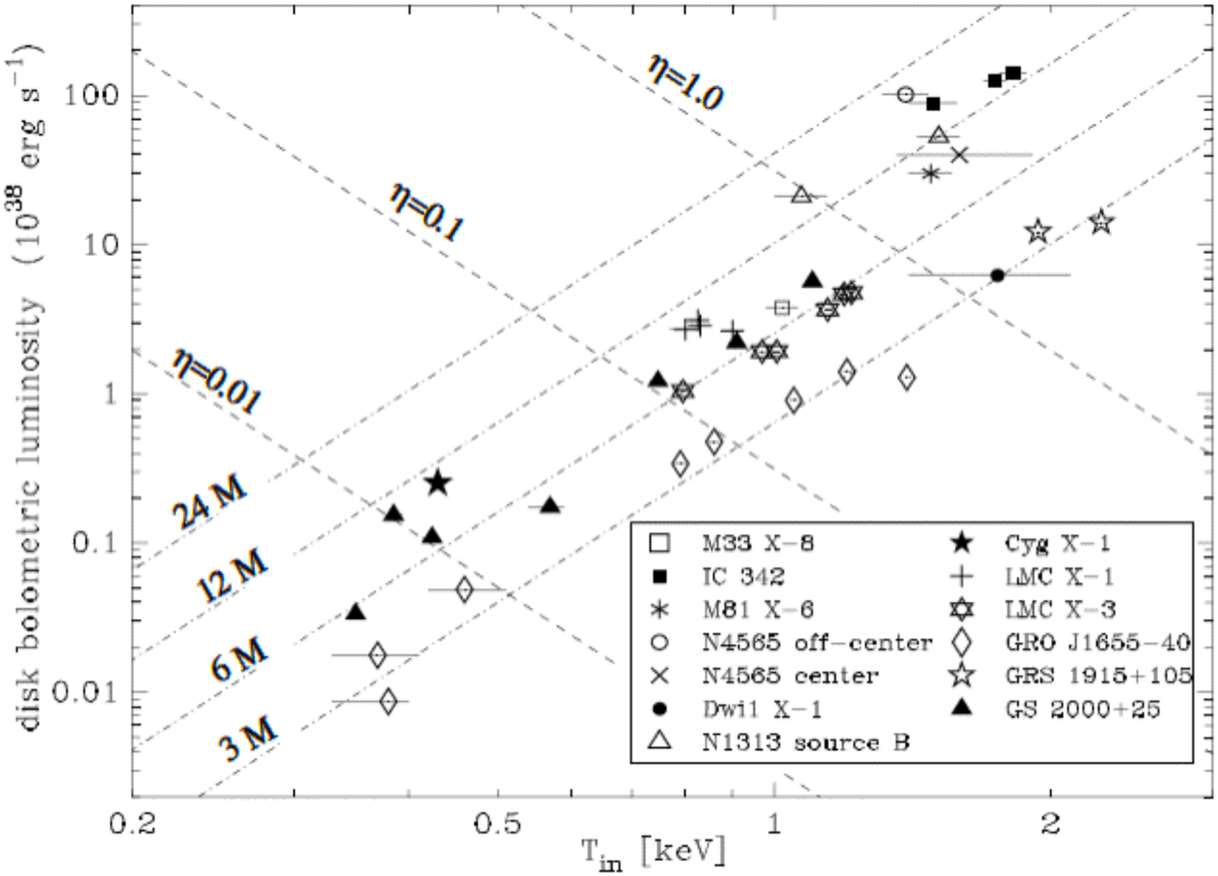
$T(r)=6.3\times10^5\, \mathcal{M}_{\mathcal{Edd}}^{1/4} M_8^{-1/4} (r/r_s)^{-3/4}$

($\mathcal{M}_{\mathcal{Edd}}$ *is the accretion rate in Eddington units,* $T=T_{in}$ for $r=r_s$)

Real Objects

- Amazingly data for galactic black holes agrees with the simple theory

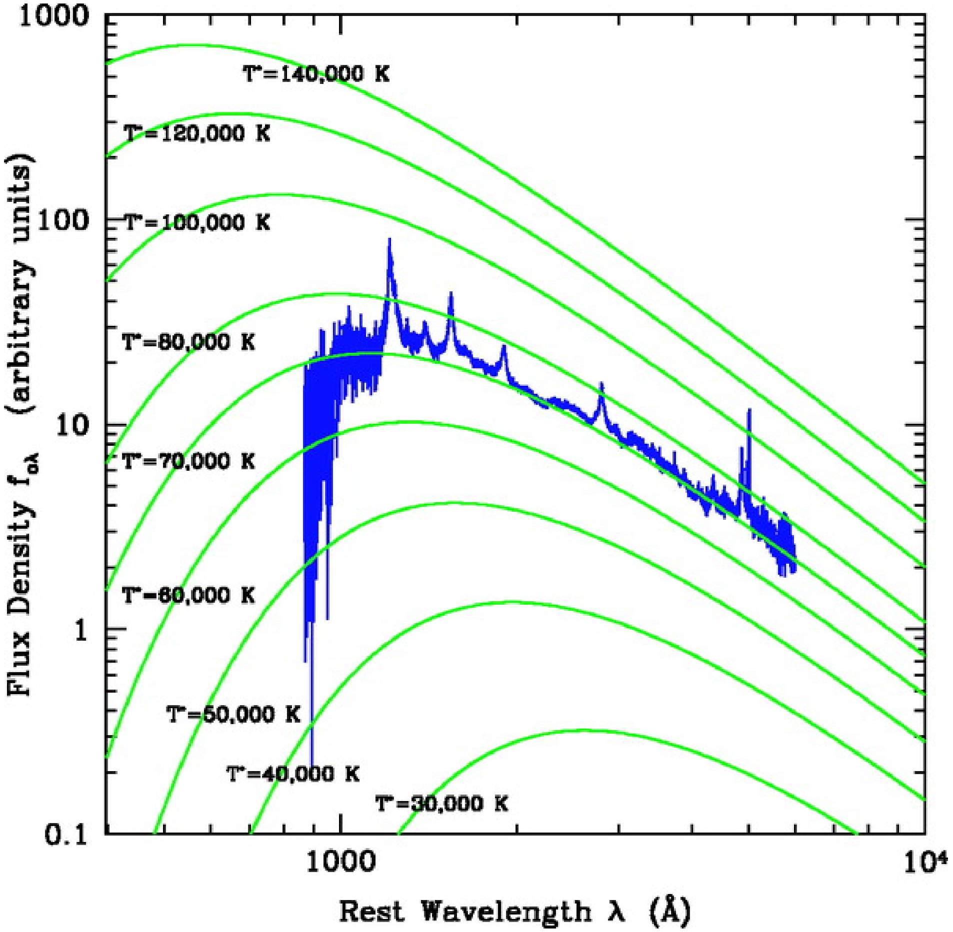
Makishima et al 2000



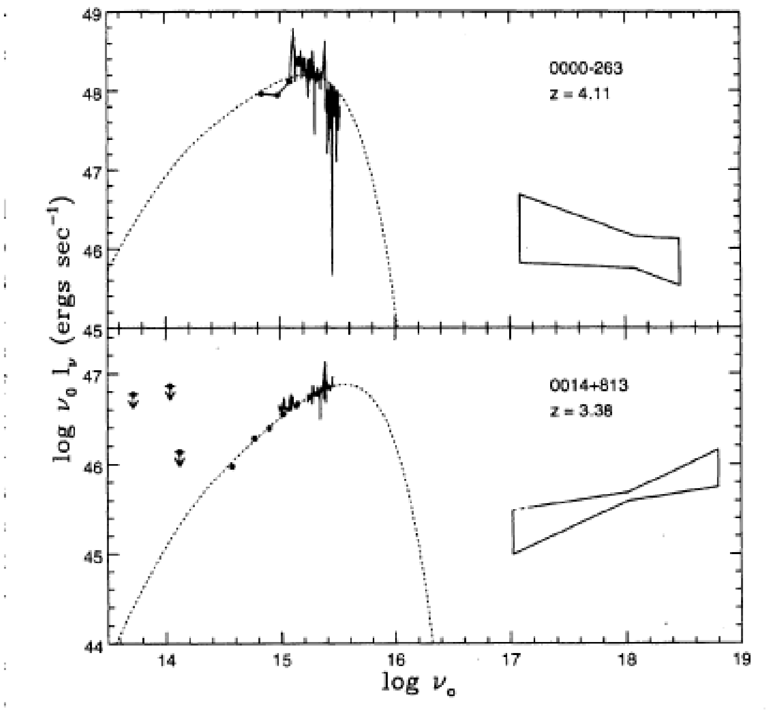
$$L_{\rm bol} = \eta L_{\rm E} \propto \eta M \ ,$$

AGN

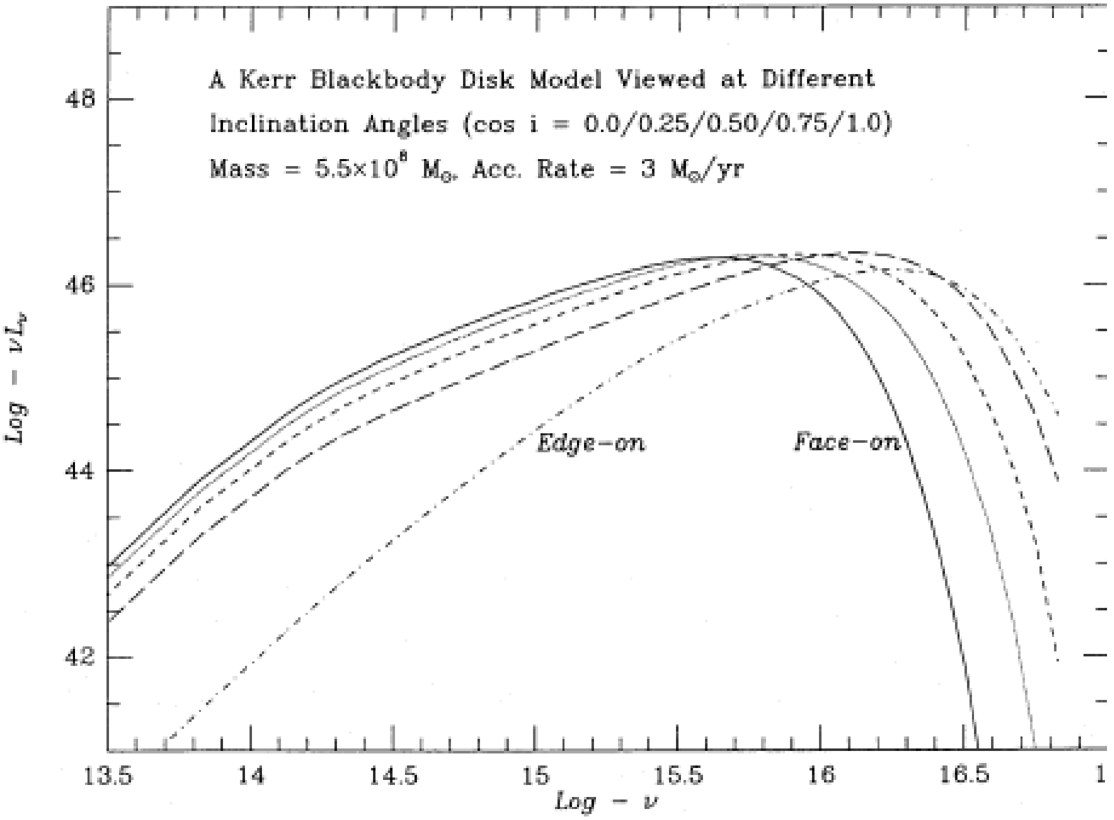
- AGN are very massive and so the predicted spectrum of the accretion disk is 'cool'
- T~8x10^4 k for a Eddington limited M~$10^8 M_\odot$ black hole



- Can Fit AGN UV-optical data with accretion disk models



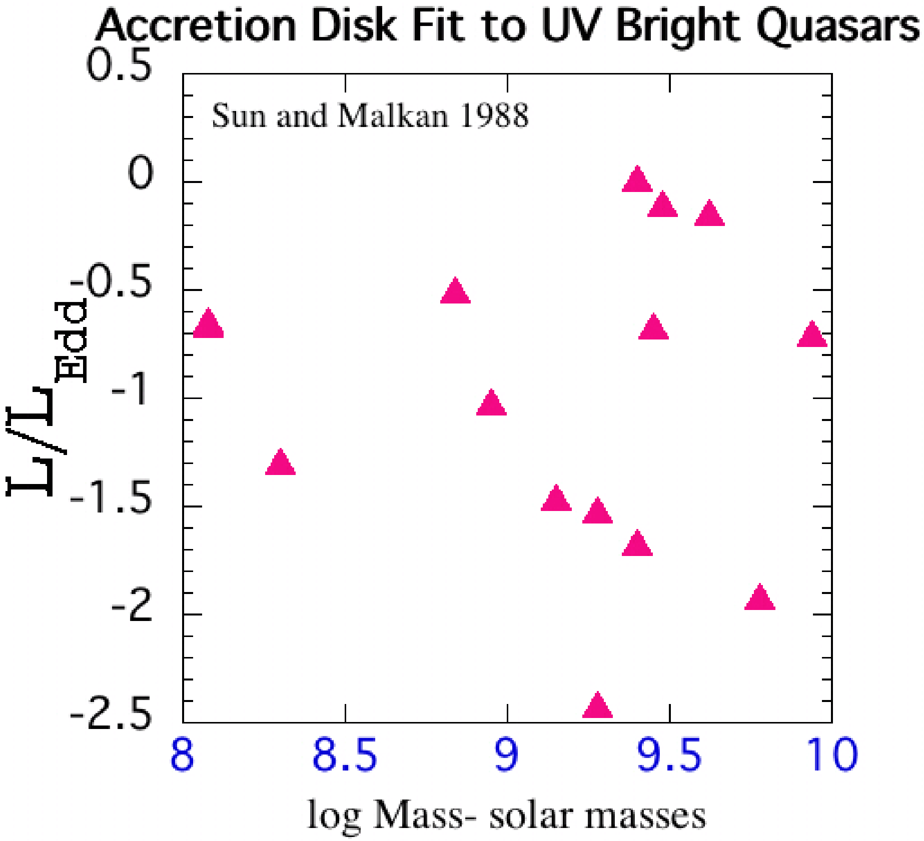
Malkan and Sun 1989



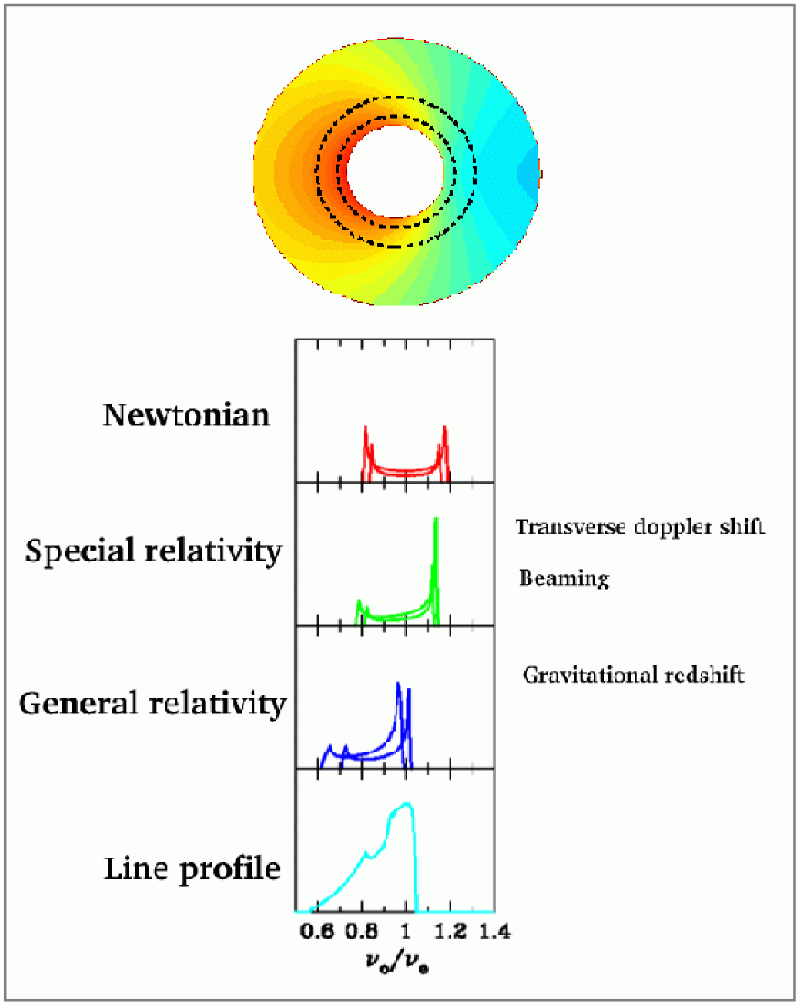
Fitted Parameters for UV Disk Fits

- Results are 'reasonable' but not unique
- Now have independent mass estimates- results can be checked
- Find that values are not quite right- need more complex accretion disk models (surface is not BB

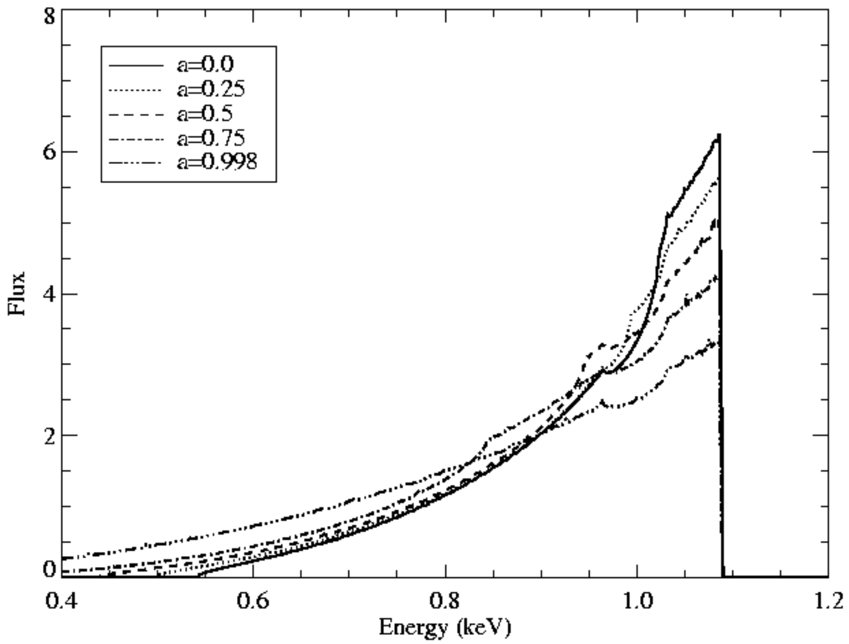
  relativistic effects)



Relativistic effects imprint characteristic profile on the emission line…



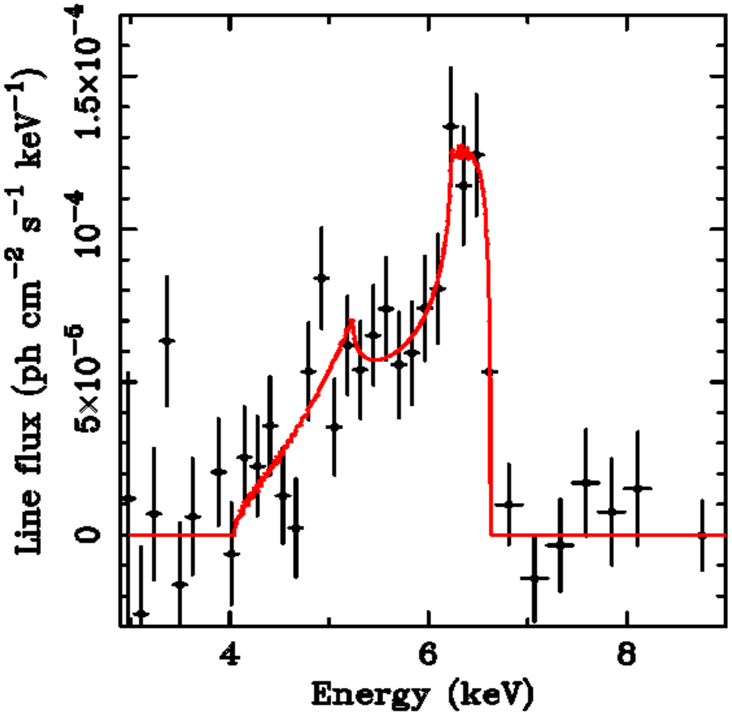
Andy Young



Theoretical line profiles [Laura Brenneman]

Observations of relativistic emission lines

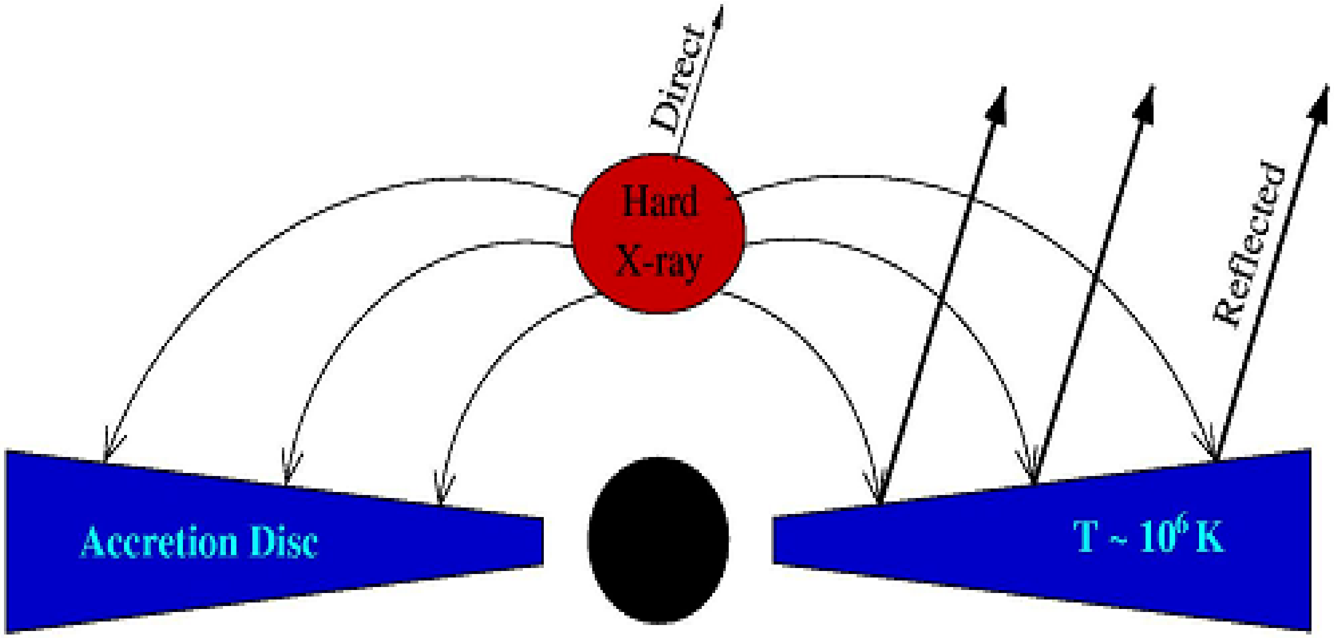
- First seen in 1994 with ASCA observatory
- 5 day observation of Seyfert-1 galaxy MCG-6-30-15
- Needed long observation to collect enough photons to form detailed spectrum



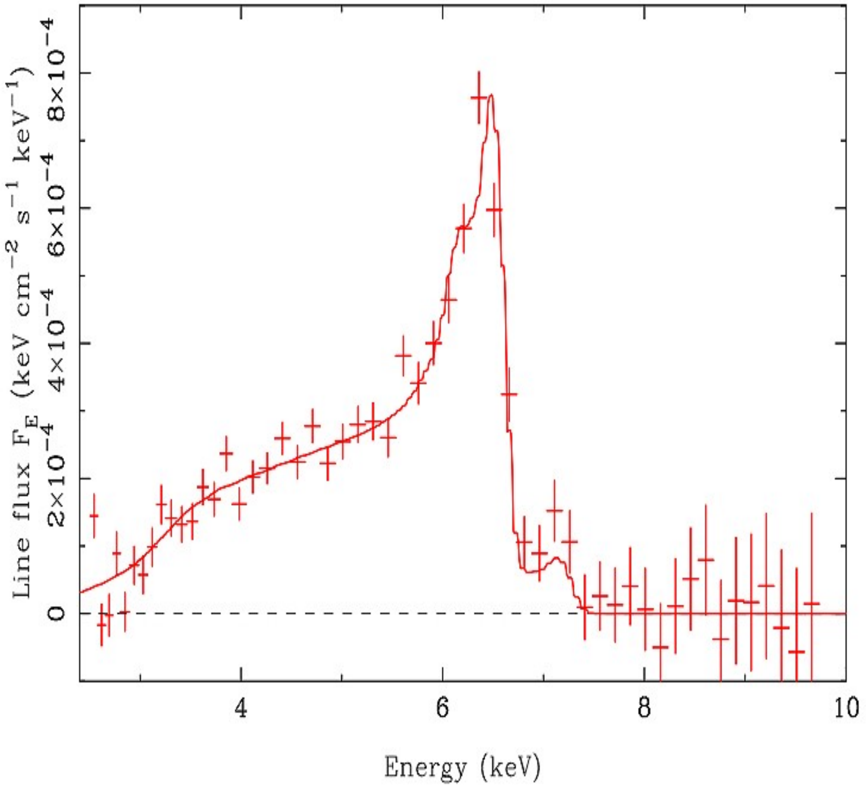
Power-law continuum subtracted
ASCA: Tanaka et al. (1995)

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

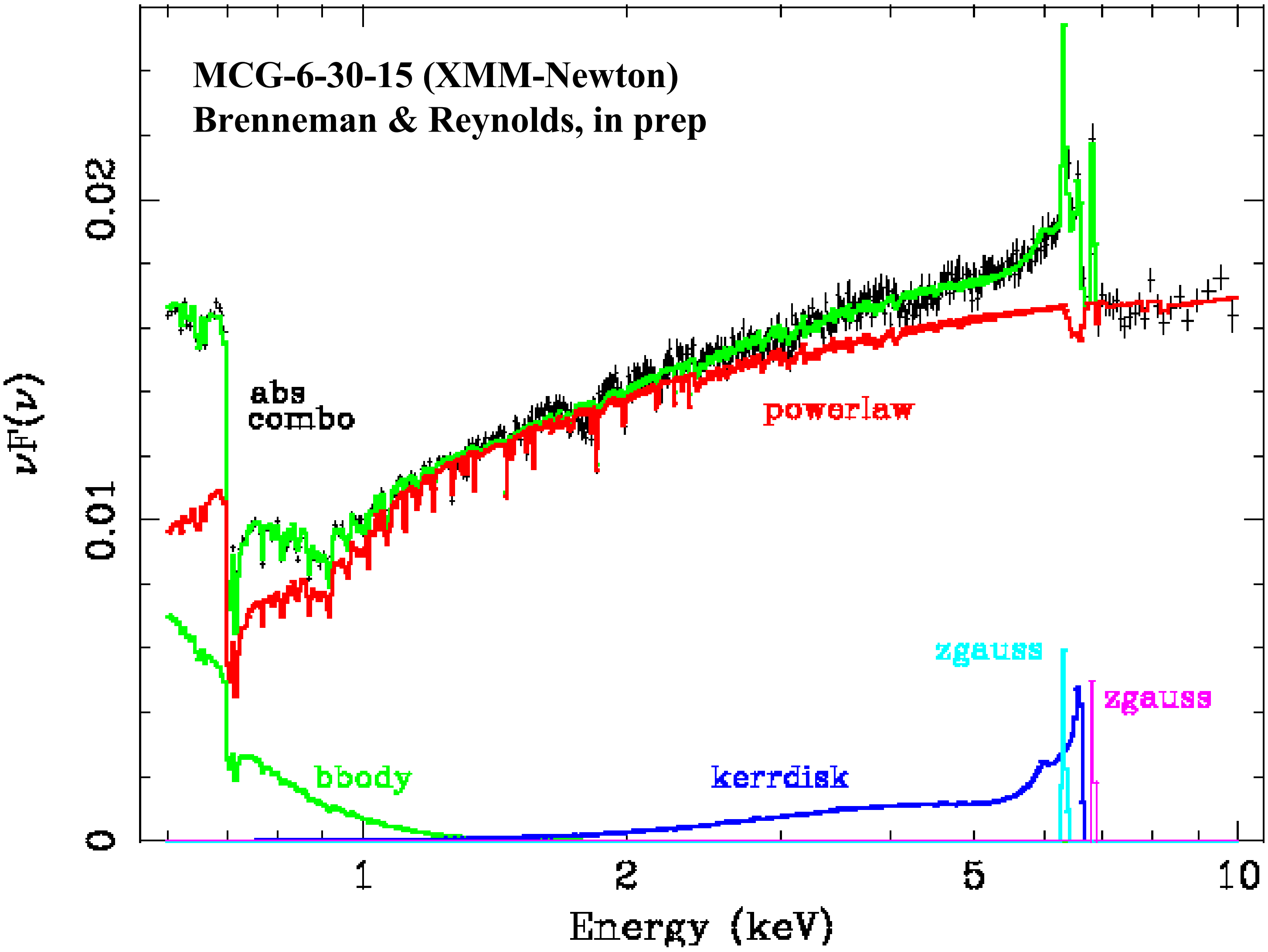


- Modern XMM-Newton observations
- Confirm relativistic line with extreme redshifts
- If no line emission from within ISCO, need to invoke spinning black hole to get strong enough redshifting

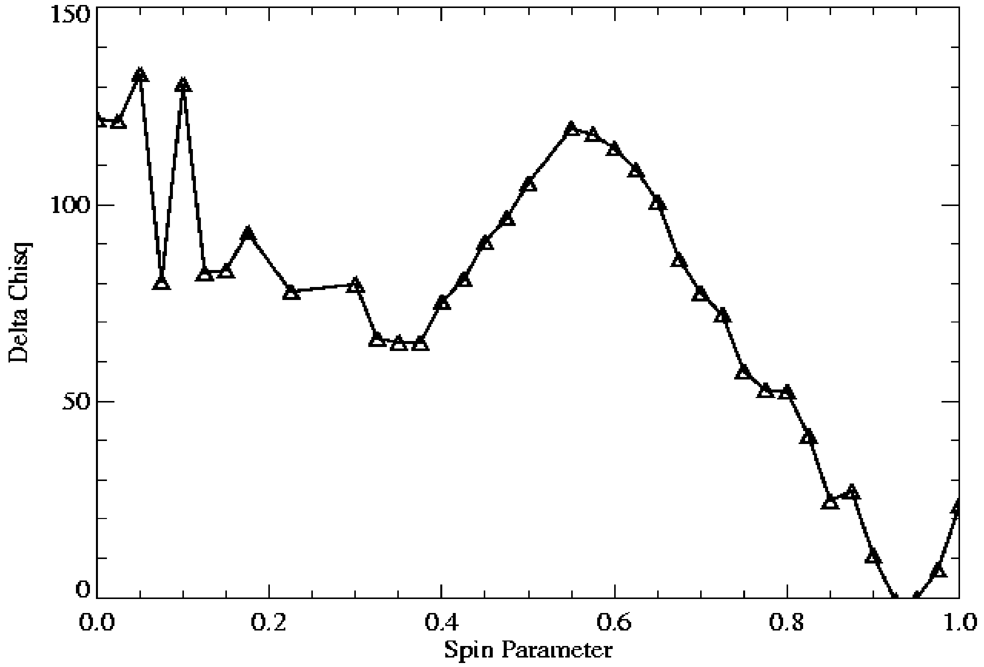


Power-law continuum subtracted
XMM: Fabian et al. (2002)

Spectra are quite complex…



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



L.Brenneman