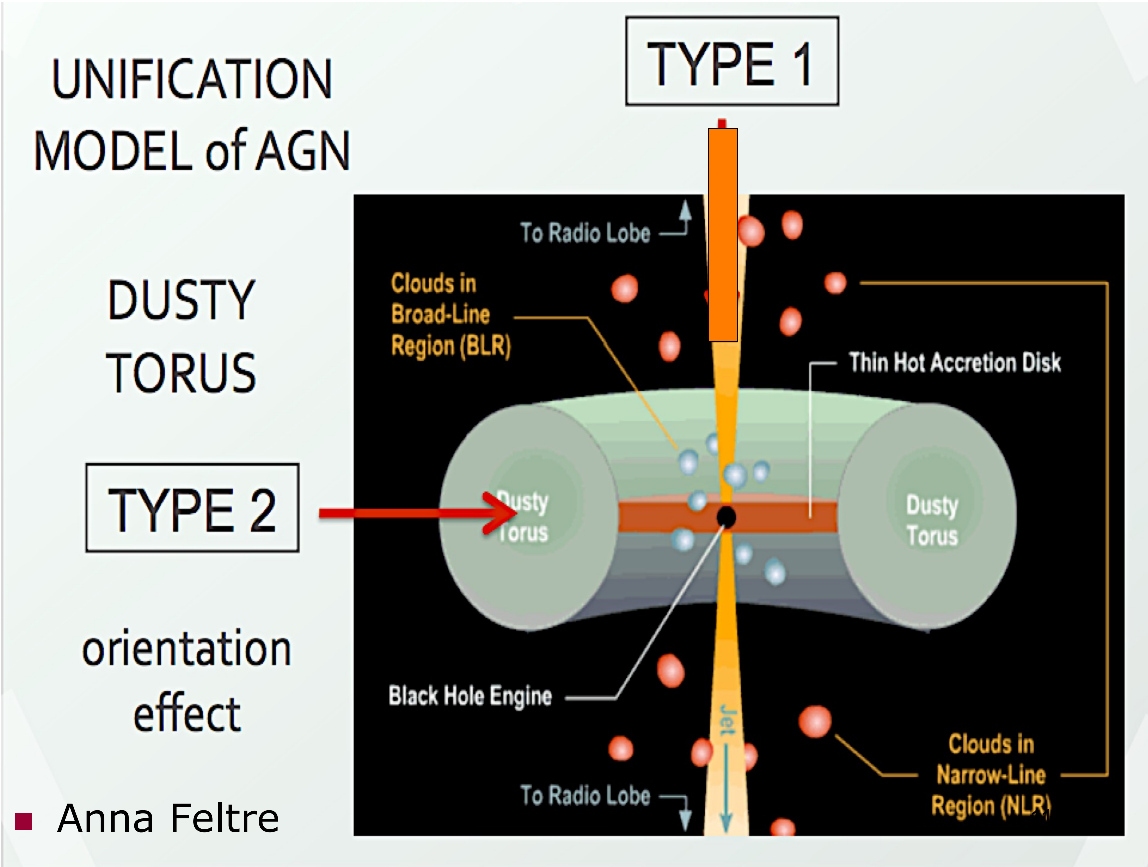
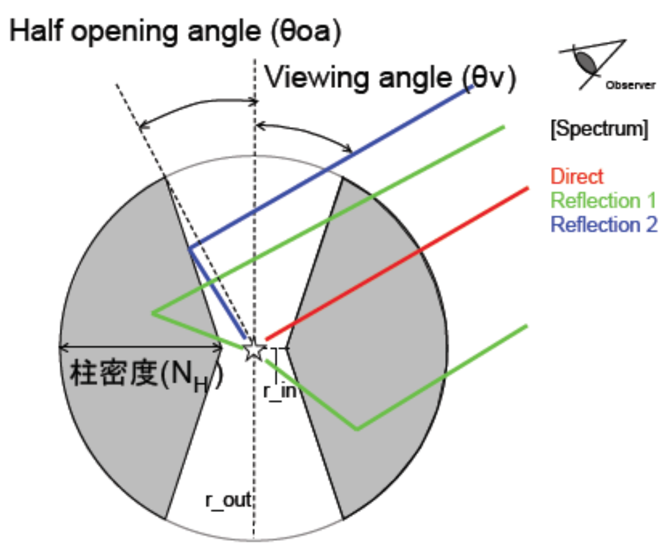
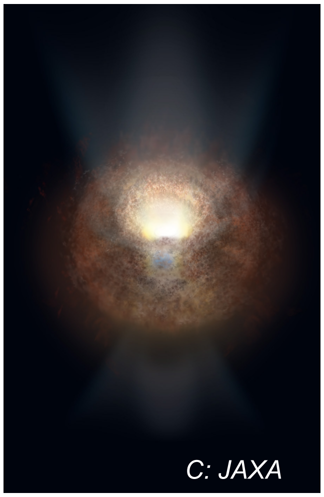


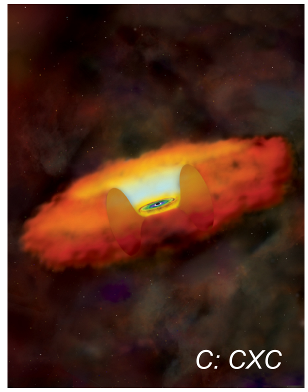
AGN Zoo

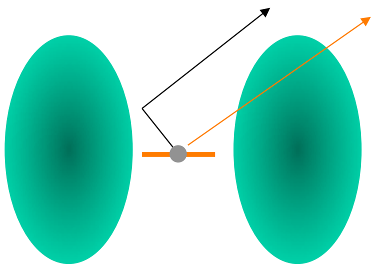
- In a simple unification scenario broad-lined (Type 1) AGN are viewed face-on
- narrow-lined (Type 2) AGN
  - the broad emission line region (BELR) the soft X-rays and much of the optical/UV emission from the AD are hidden by the dust
- However there are other complications like jets and a range in the geometry

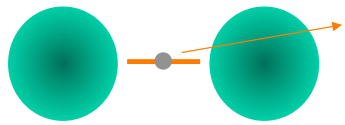


Some Variation in Geometry







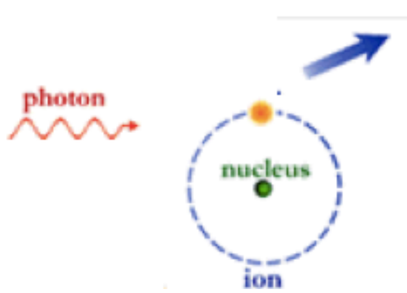


- Effects of geometry can be seen in the spectra

PHOTOELECTRIC ABSORPTION

- Bound-free ionization of e^- by photon
- Threshold energy $E_{th} = h\nu$ depending on ionziation potential of atom (i.e. on Z)
- Abundant elements (C,N,O) are light: absorption dominant at soft (<1 keV) X-rays

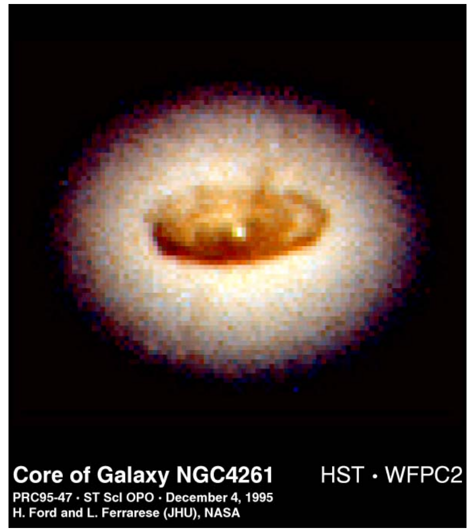
Continuum ⇒

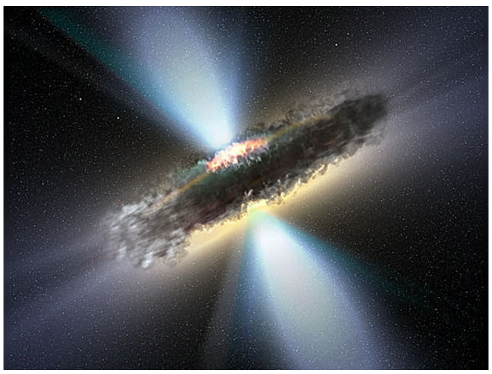


⇐ Observer

The Dark Side of AGN

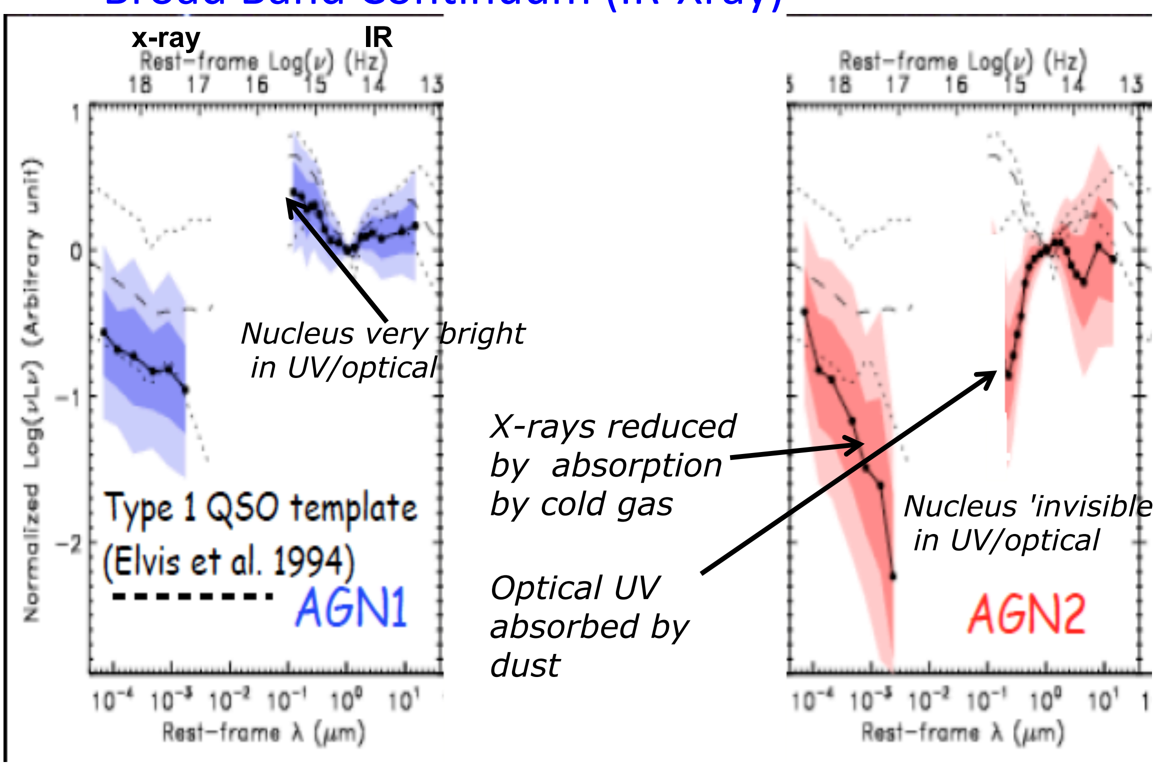
- ***Many AGN are obscured***- obscuring material is of several types
  - Located in the ISM of the host galaxy
  - A wind associated with the AGN
  - Perhaps a 'obscuring torus'
  - Etc
  - Lack of uniform sample not sensitive to absorption or emission from this structure has limited knowledge of true distribution of properties





physical conditions in obscuring regions are not the same from object to object - can be complex with large and unpredictable effects on the spectrum

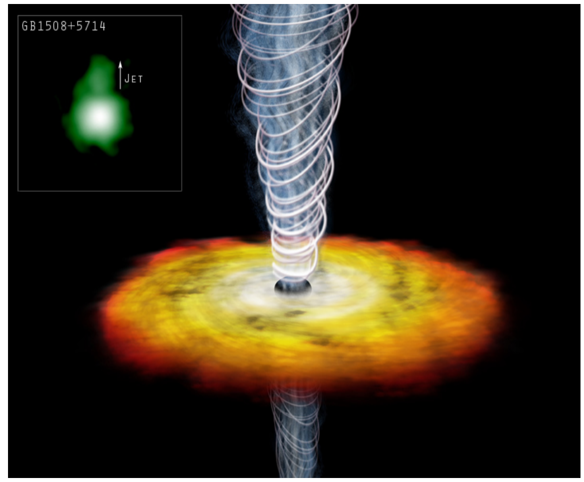
Broad Band Continuum (IR-Xray)



AGN Unification

The Radio-loud/Radio-quiet dichotomy

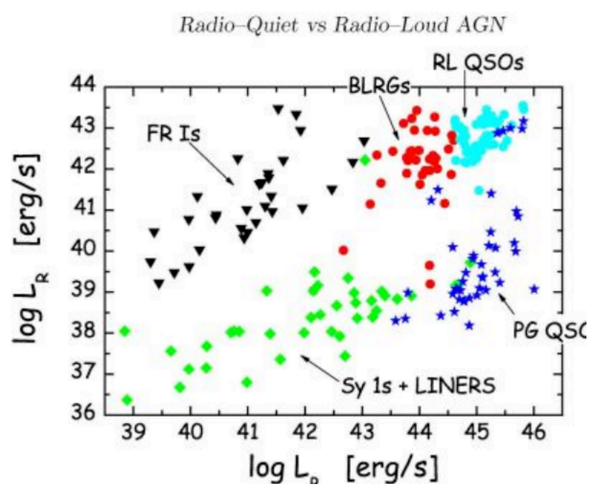
- Origin of the radio-loud/ radio-quiet dichotomy is not understood
- What we know…
  - Radio-loud AGN are only found in elliptical galaxies with massive BHs ($M>10^8 M_{sun}$)
  - Radio-quiet AGN can be found in spirals and ellipticals
- Possible factors at play…
  - Black hole spin
  - Retrograde/prograde spin
  - Magnetic flux threading disk
  - Circumnuclear environment

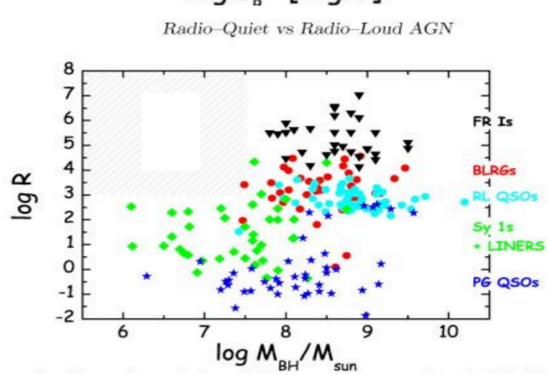


Radio Loud AGN

- Total energy budget can be dominate by relativistic particles
- Wide range of physics from compact jets moving at relativsitic speeds to giant radio lobes (~1 <Mpc in size) ...
- pretty pictures only not equations...

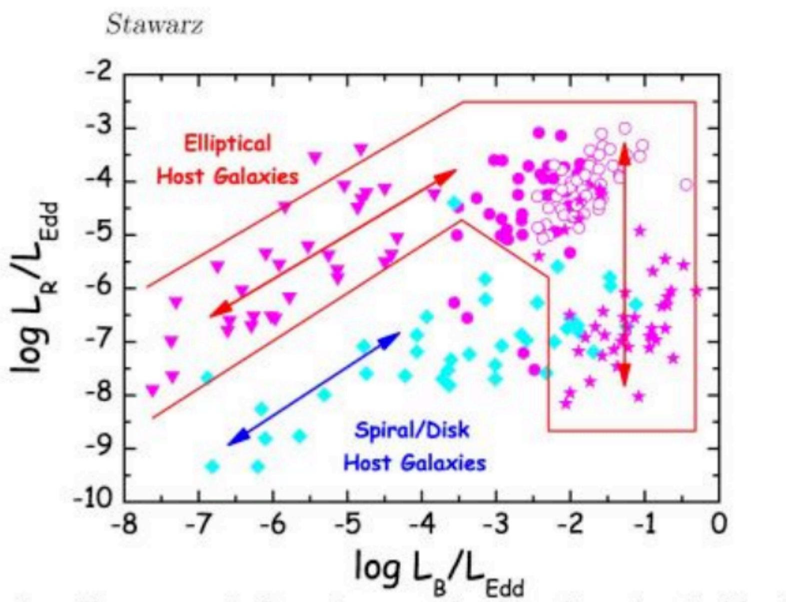
L. Stawraz

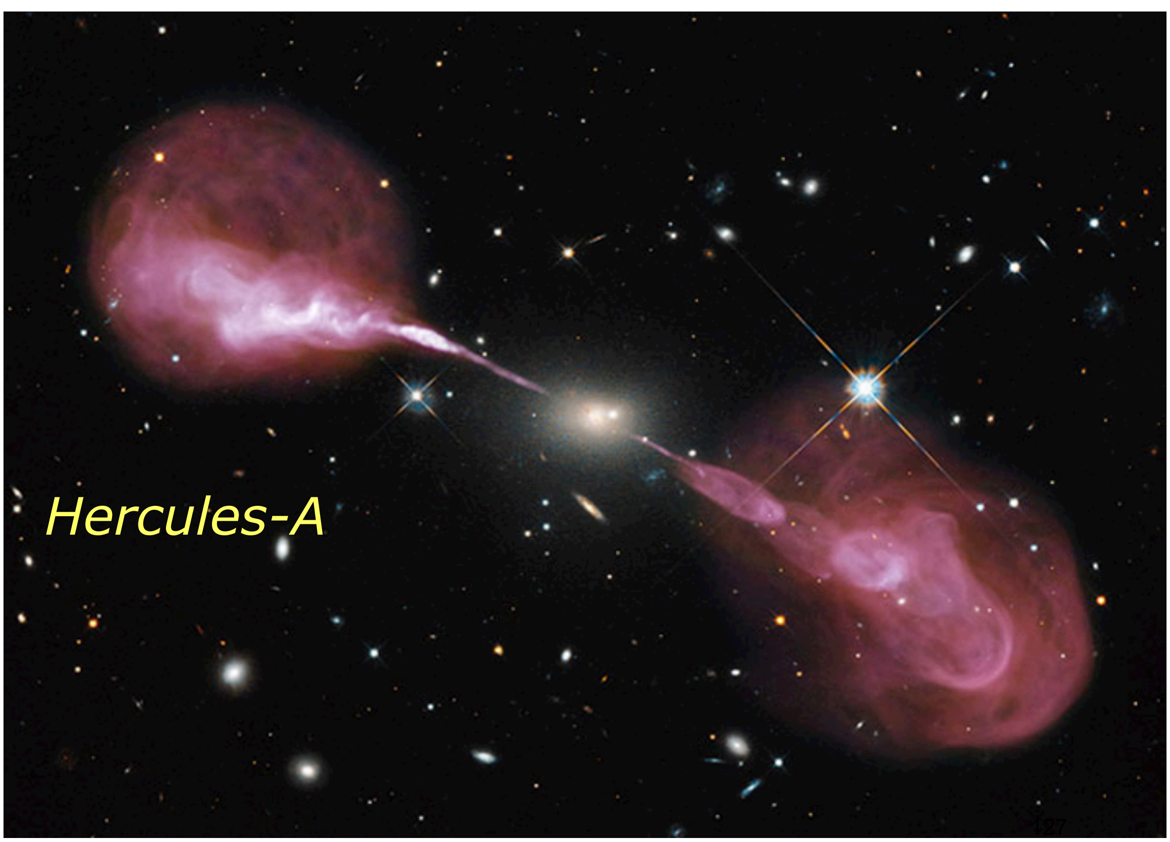


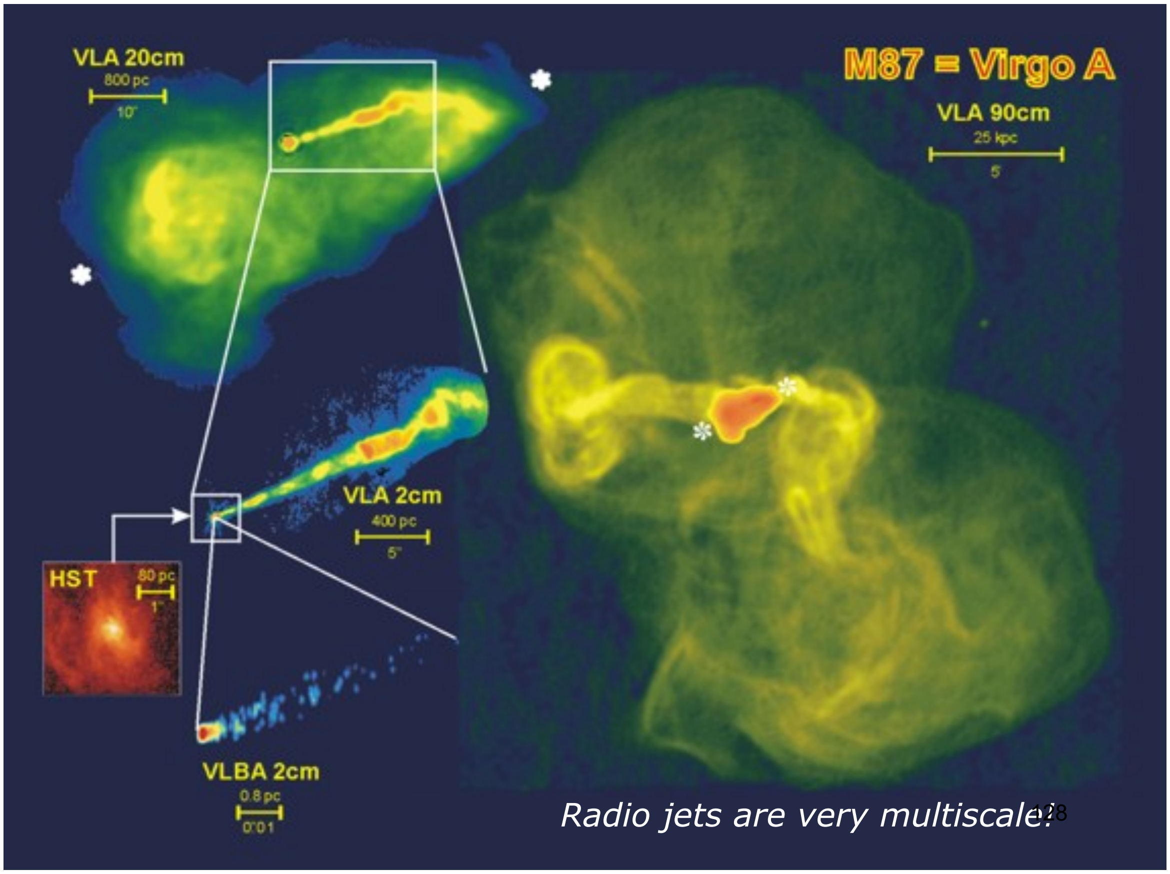


Nature of Host Galaxy for Radio Loud/Quiet

- virtually all radio loud AGN are in ellipticals
- what is it about the galaxy that natures the 'nature' of the AGN?

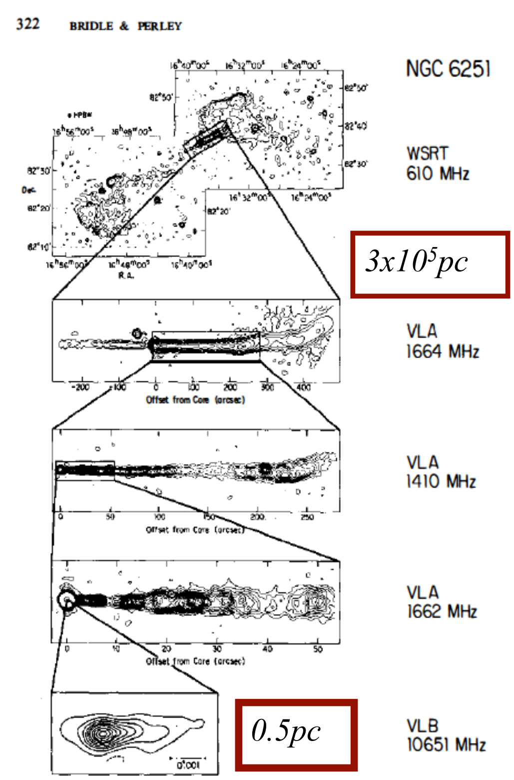






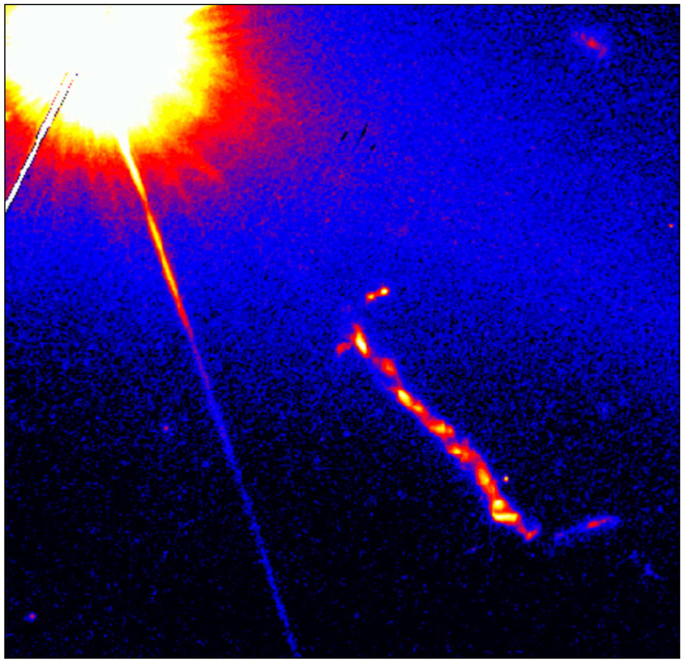
Collimated over enormous range of scales

- jet power budget and in which form energy is transported not fully understood: can be
  - ordered kinetic energy of the plasma
  - Poynting flux
  - energy of particles
- composition of plasma unclear: electrons-protons or electron positron pairs?
- indications in powerful blazars jet is dominated by a proton-electron component.
- **Jets can be 'super luminal'**



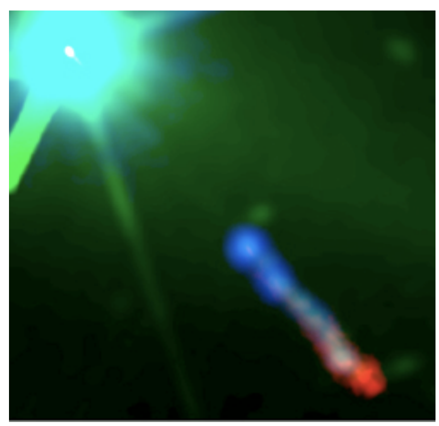
Examples:
Powerful quasar 3C273

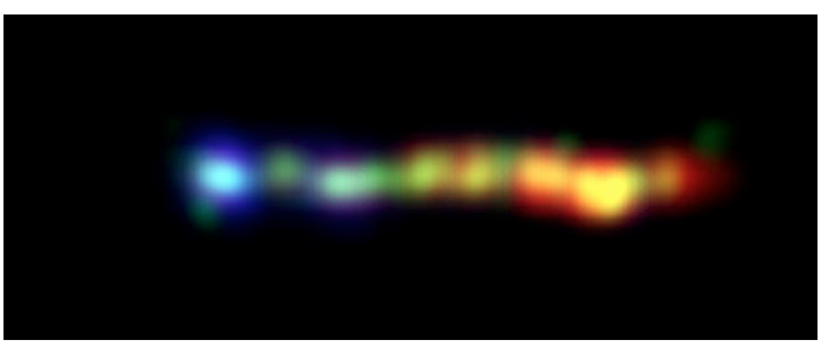
HST



"Radio Loud" AGN

- The energy of extragalactic jets ≤10^{46} erg/s and 10^{60} ergs over its lifetime
- Over limited energy bands spectrum fit by a power law- power law <u>does not</u> describe the broad band spectrum





3C273 jet
X-ray blue,optical white, radio red
strong variations in spectral shape with position

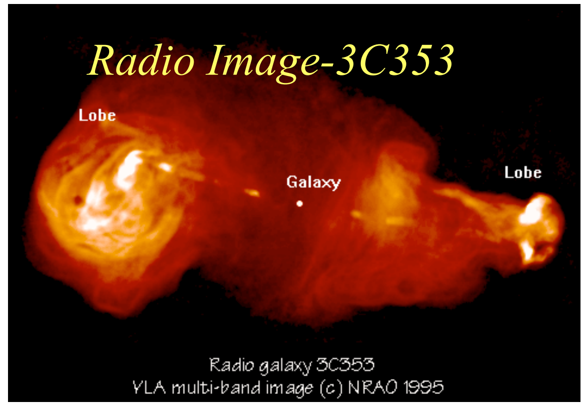
Radio Galaxies

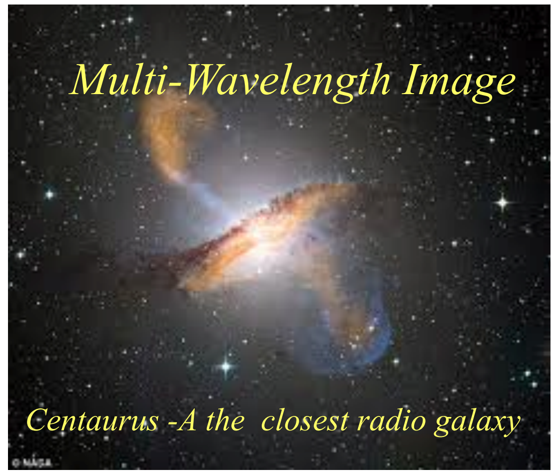
to maintain luminosity of lobe need ~$10^{42\text{-}45}$ ergs/s in jet .

For many objects jet energy> photon radiated energy

A minimum value - assumes all of the energy supplied is radiated away:

- minimum energy requirement for the black hole
- lower limit since all of energy does not go into radiating particles (relativistic electrons)
  - (e.g energy into protons or magnetic fields)

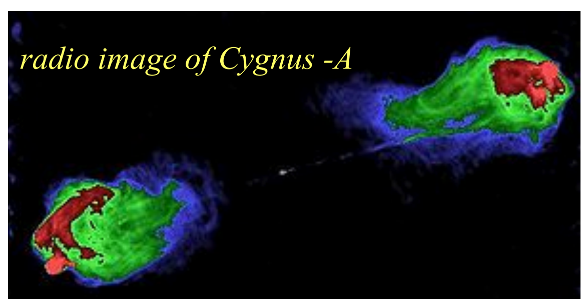


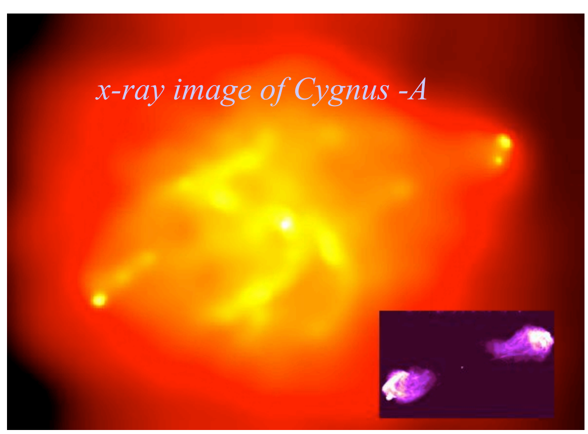


- Most AGN Jets are 'one-sided' (exceptions exist)

  thought to be due to relativistic beaming (not always works out)

  Double sided nature of most radio lobes argues for energy being transferred to both of them (continuous or episodic??)

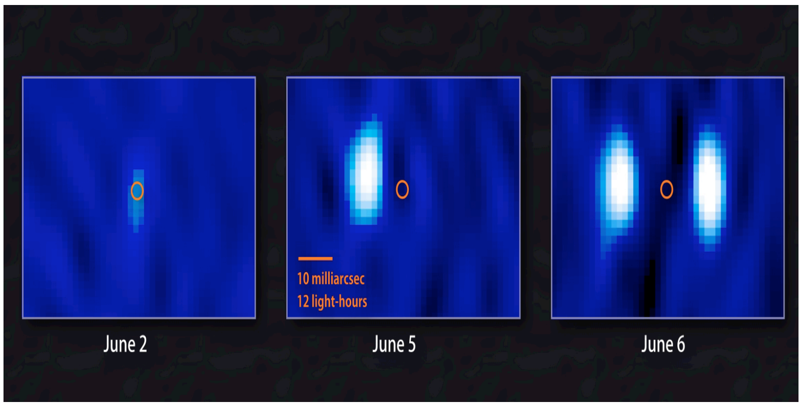


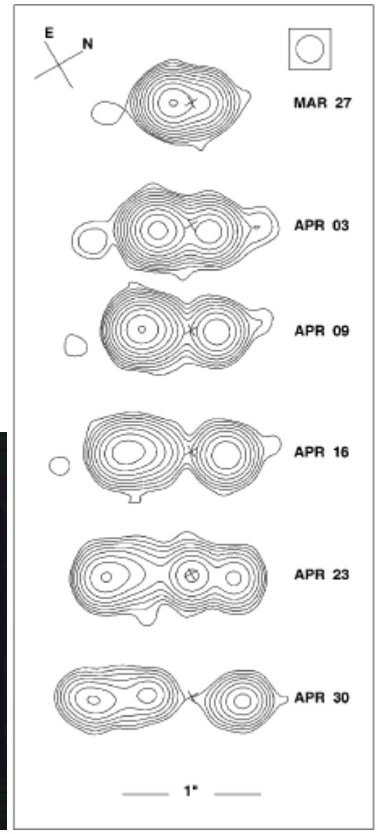


Galactic Black Holes

- Called microquasars: can have highly variable jets which can exhibit 'super luminal' expansion
- apparent velocities ~ 0.15-1.7c

Mirabel and Rodriguez Annu. Rev. Astron. Astrophys. 1999. 37:409–43



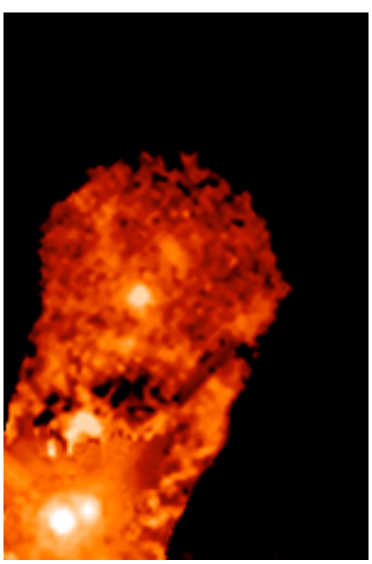


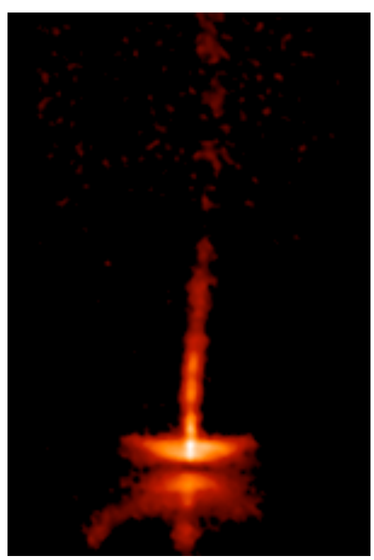
Jets and Outflows In Stars

material ejected episodically by young stars along magnetic poles, v~80-250 km/s (highly supersonic) confined by magnetic fields (?)

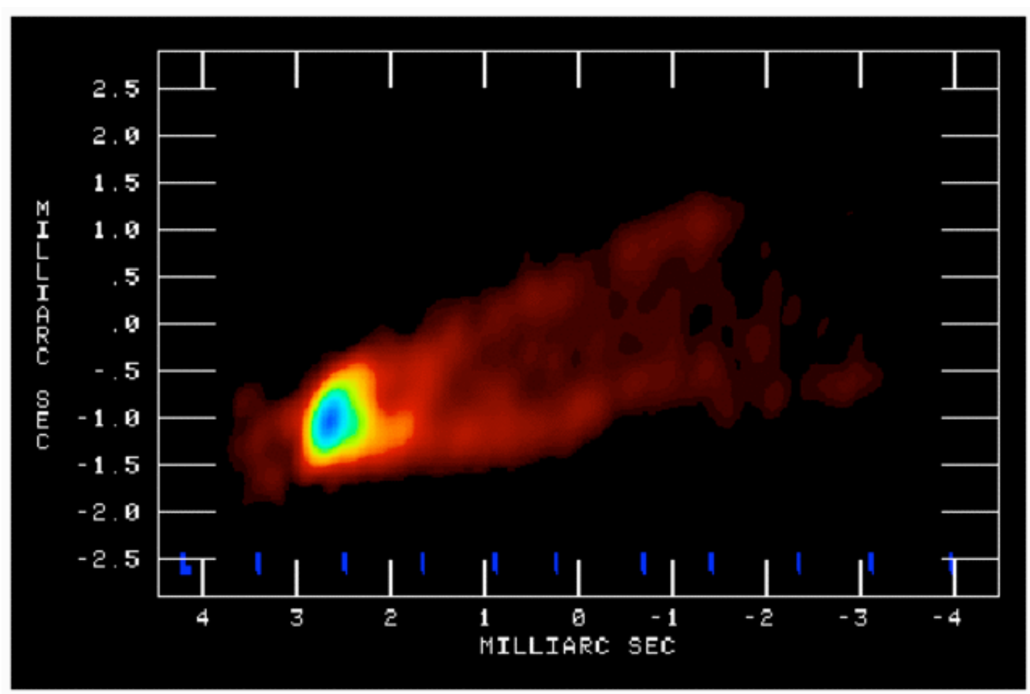
Stellar jets are observed at optical wavelengths (hot ionized gas)

- Short lived phenomena-during the first 10^{5-6} years





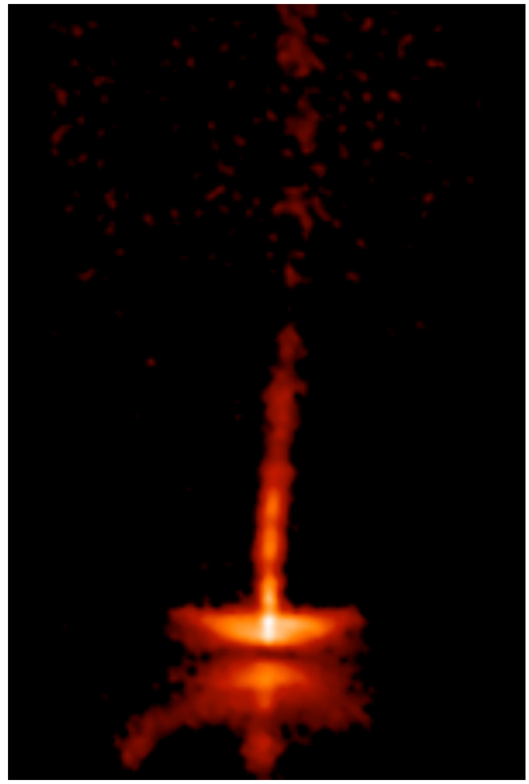
M87 Jet Movie



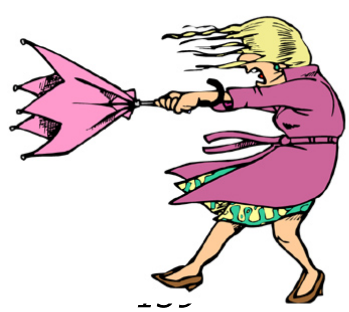
- $100R_s$=0.37mas

Disk Jet Connection

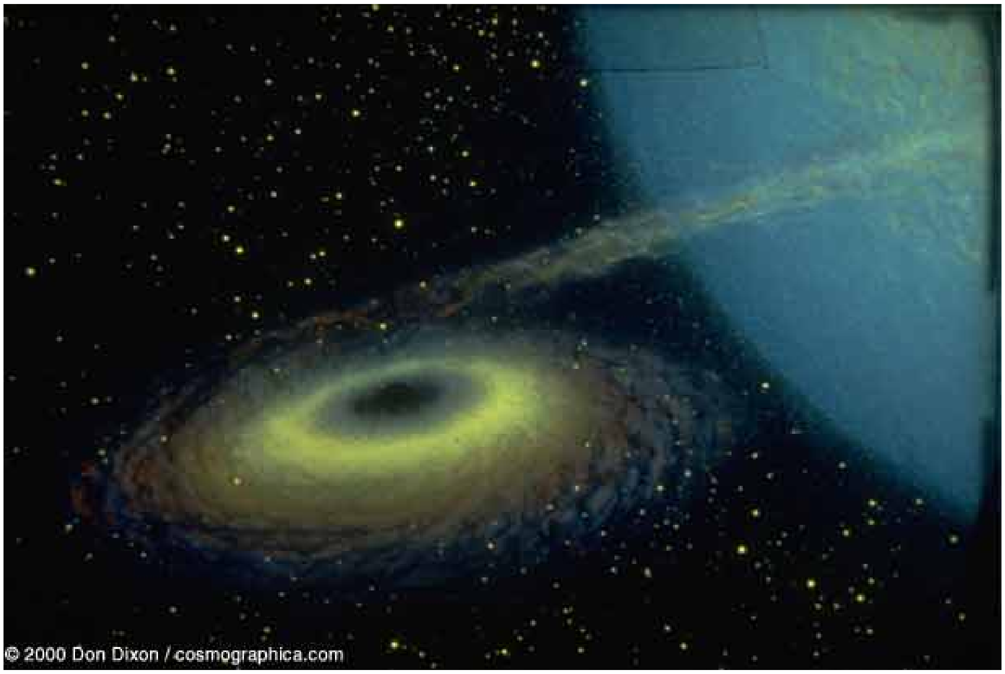
- jets exert an external torque on underlying disks - efficiently remove angular momentum and act as major drivers of disk accretion.
  - predicted effects seen in HST measurements of the jet rotation and angular momentum transport in low mass protostellar systems (Pudritz and Banarjee)
- in x-ray binaries there is a strong connection between the existence of a jet and the 'state' of the source



Jets, Winds, Disks and Their Interaction



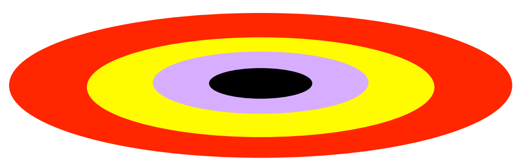
Spectra of accreting black holes

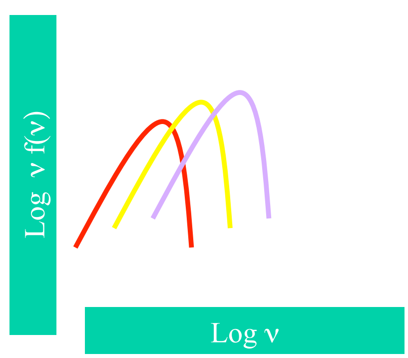


Spectra of accretion flow: disc-

C. Done Review

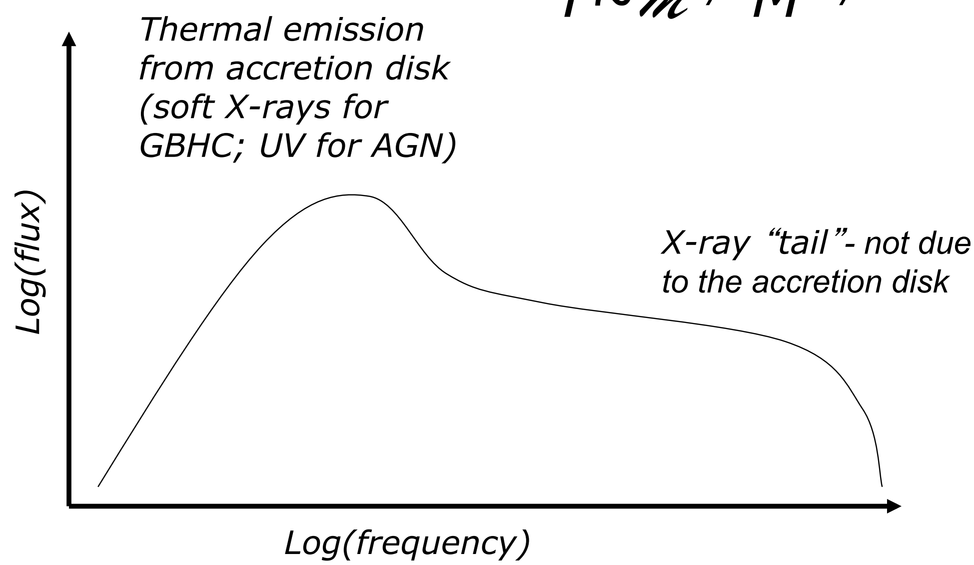
- Differential Keplerian rotation
- Viscosity : gravity → heat
- Thermal emission: $L = A\sigma T^4$
- Temperature increases inwards
- GR last stable orbit gives minimum radius R_{ms}
- a=0: $T_{max} = (M/M_\odot)^{-1/4} (L/L_{Edd})^{1/4}$
  - 1 keV (10^7 K) for 10 $M_\odot$
  - 10 eV (10^5 K) for 10^8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





What Do Broad Band Spectra of Black Holes Look Like

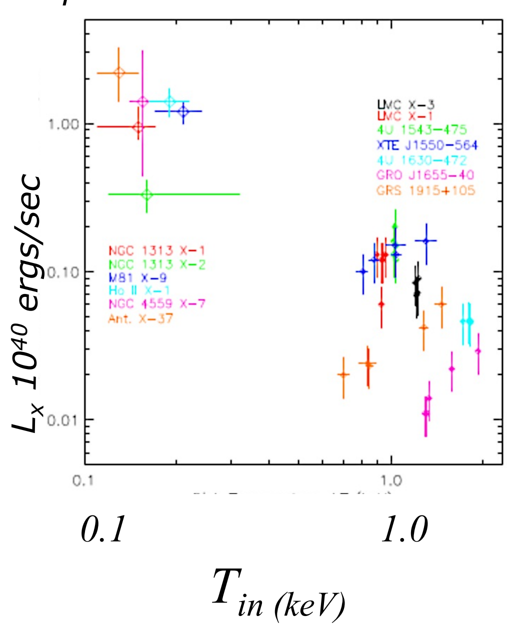
$T \sim \dot{m}^{1/4} M^{-1/4}$

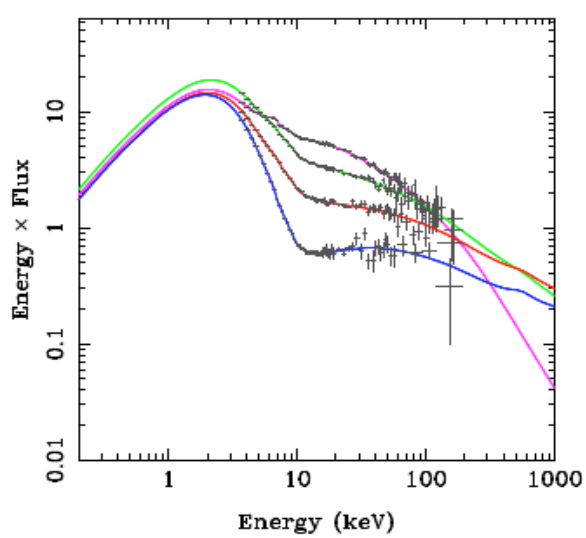


Galactic Black Holes

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

Adapted from Miller et al 2003





$L \sim 7 \times 10^{38}\ f (M_{10})^2 (T_{in})^4$ 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`

Reminder of Accretion Disk Spectrum

- 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

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

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

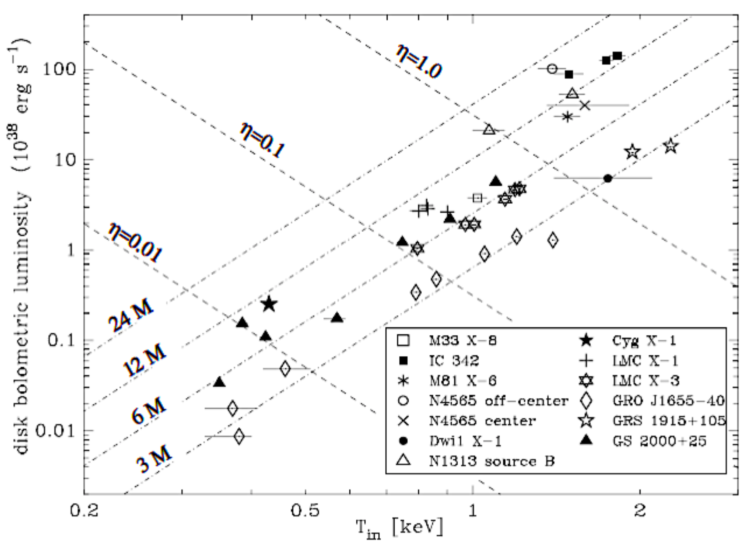
$$T(r)=6.3\times10^5\,(\mathcal{M}/\mathcal{M}_{Edd})^{1/4}M_8^{-1/4}\,(r/r_s)^{-3/4}$$

($\mathcal{M}_{Edd}$ 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
- E.g assume that M_{BH} does not change and all changes due to changes in $\mathcal{M}$- *if so then expect* $T_{in}\sim\mathcal{M}^{1/4}\sim L^{1/4}$

Makishima et al 2000

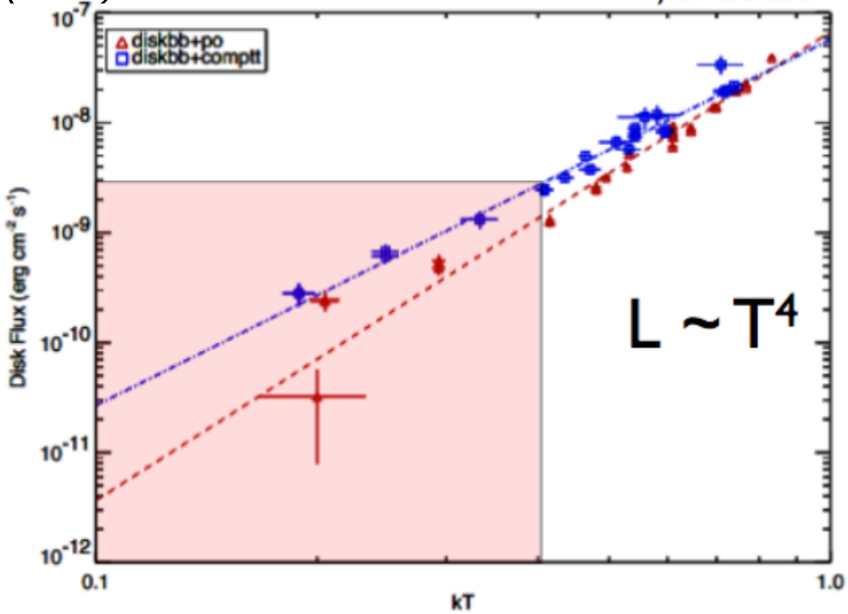


Fitted T_{in}

Swift Obs. of XTE J1817

Miller (2013)

Rykoff et al. 2007



No strong evidence of disk truncation. 146

Modifications to Disk Black Body

The disk model that is most widely used ("diskbb"; Mitsuda et al. 1984) does not include the inner torque condition.

$$D(R) = \frac{3GM\dot{M}}{8\pi R^3}\left[1 - \left(\frac{R_{in}}{R}\right)^{1/2}\right]$$

And, it was realized that radiative transfer through a disk atmosphere hardens spectra. kT too high, R too small (e.g. Shimura & Takahara 1995; Merloni, Fabian, Ross 2000).

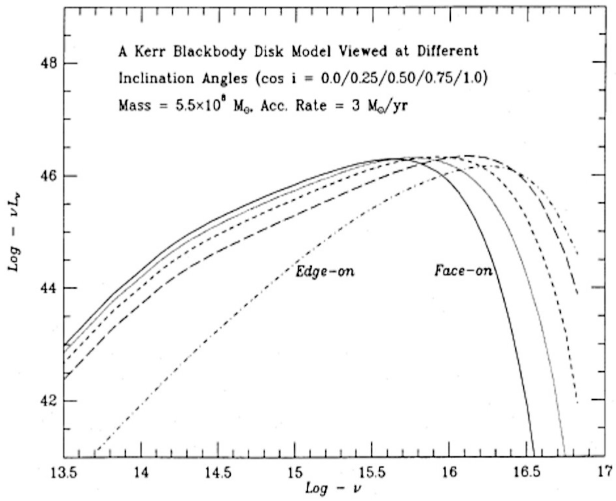
And there are other corrections needed to get a "true" inner disk radius:

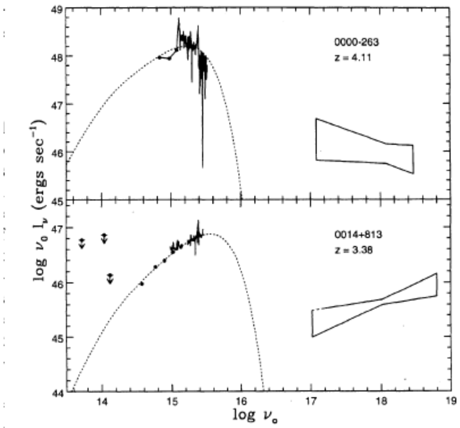
$$r_{in} = \eta g(i) f^2_{col} r_{col}$$

r_{in} is the "true" disk radius.
η ~ 0.65, corrects for real peak of disk emissivity.
$g(i)$ ~ 0.75, accounts for relativistic effects.
f_{col} ~ 1.7-3.0++, corrects for radiative transfer.
r_{col} is the color radius, related to sqrt(norm).

Malkan and Sun 1989

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

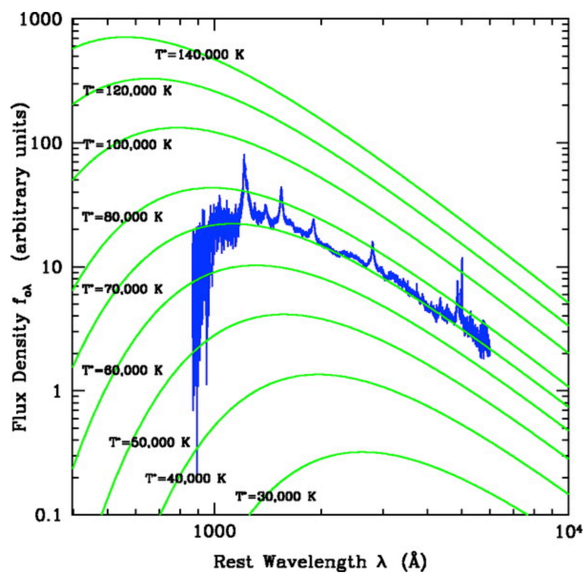




Effects of inclination on disk spectrum for $5x10^8 M_{\odot}$ BH

AGN

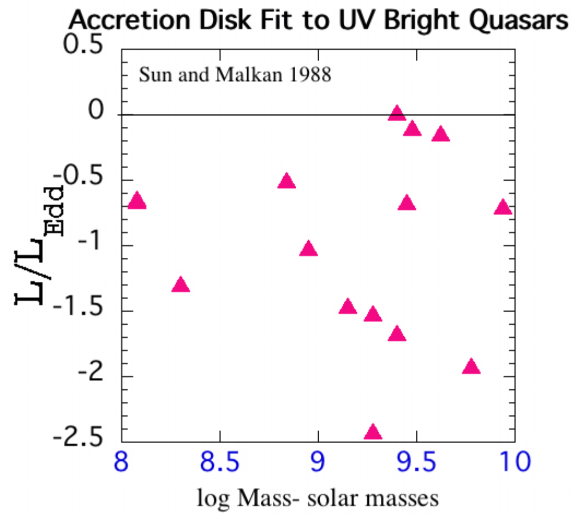
- AGN are very massive and so the predicted spectrum of the accretion disk is 'cool'
- T~$8x10^4$ k for a Eddington limited M~$10^8 M_{\odot}$ black hole



Fit of SS AD models to AGN spectrum (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 simple BB, need to include relativistic effects)

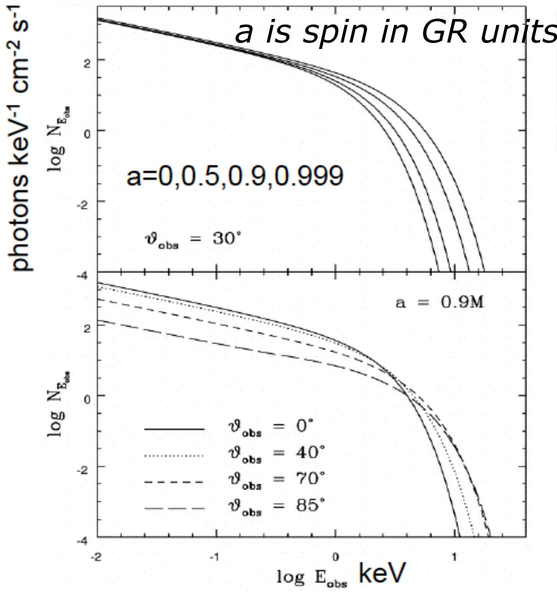


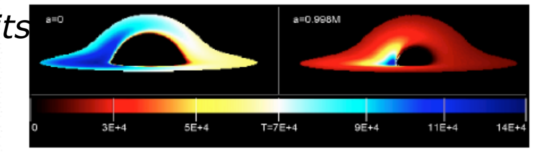
- Accretion Disk fits to AGN spectra

- Broad band spectra are not so simple- what's there in addition to the accretion disk
  - the geometry of the innermost regions
  - brief review of Comptonization

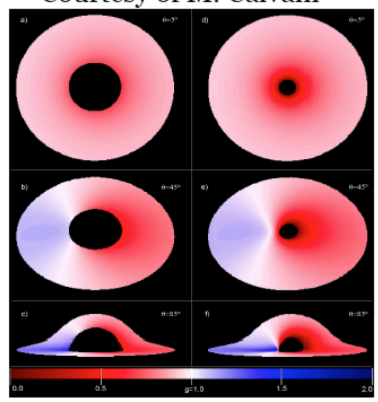
- Effects of 'reprocessing' - the disk 'sees' the hard x-ray radiation and there are measurable effects

Effects of Strong Gravity (Spin), Inclination Angle on Spectrum of Disk (Merloni 2010)





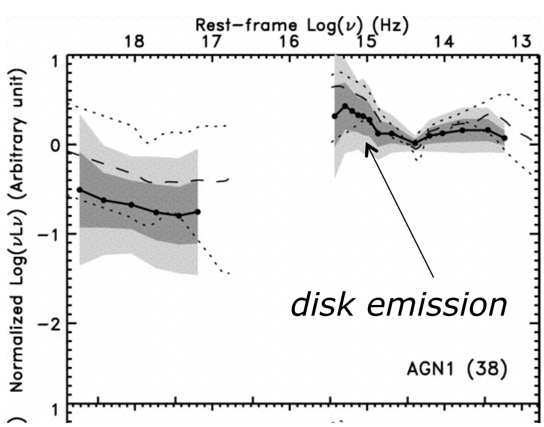
Courtesy of M. Calvani

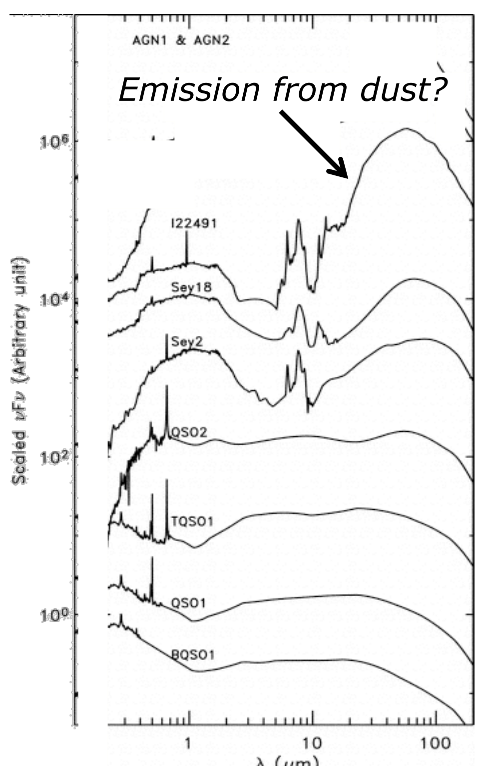


Zheng et al. 1997; Li et al. 2005; Shafee et al. 2006; McClintock et al. 2006; Nowak et al. 2008; Steiner et al. 2010; Kubota et al. 2010

Life is Not So Simple

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

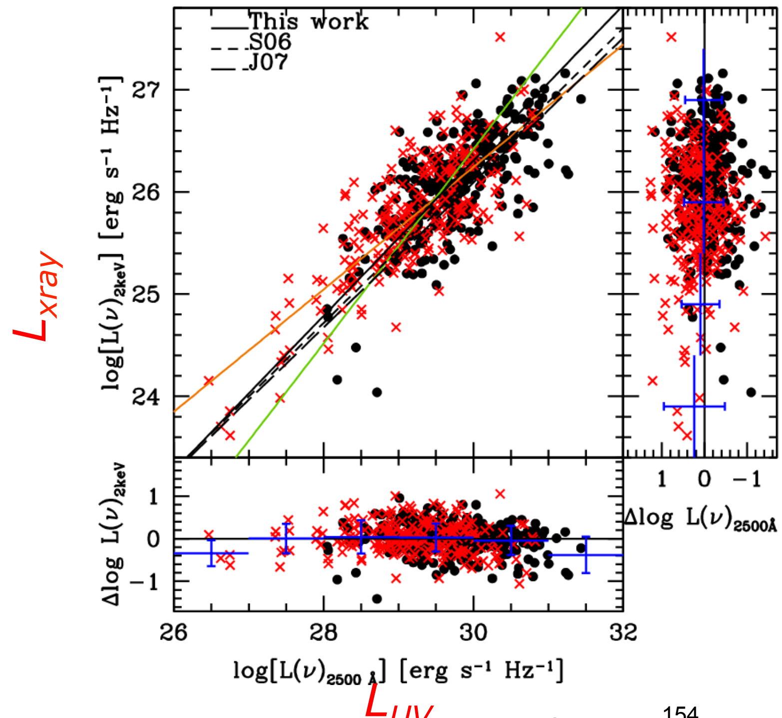




Adapted from Poletta et al 2007

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 (seen in UV) to x-rays



Lusso et al 2010

General Shape of the Optical-X-ray SED

- As the luminosity of the source increases the ratio of x-ray to optical luminosity (α_{ox}) decreases slightly (α_{ox}=log (F_x)-log (F_{UV})/2.605)

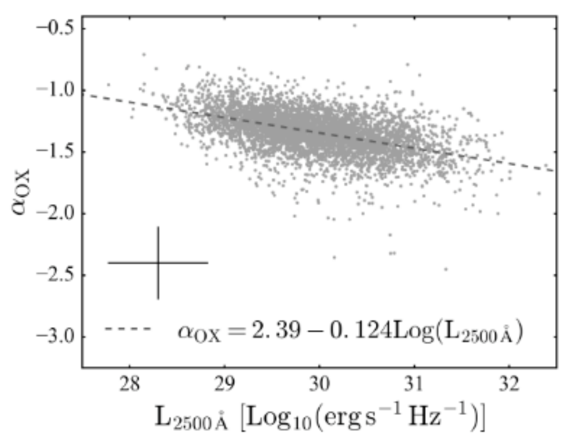
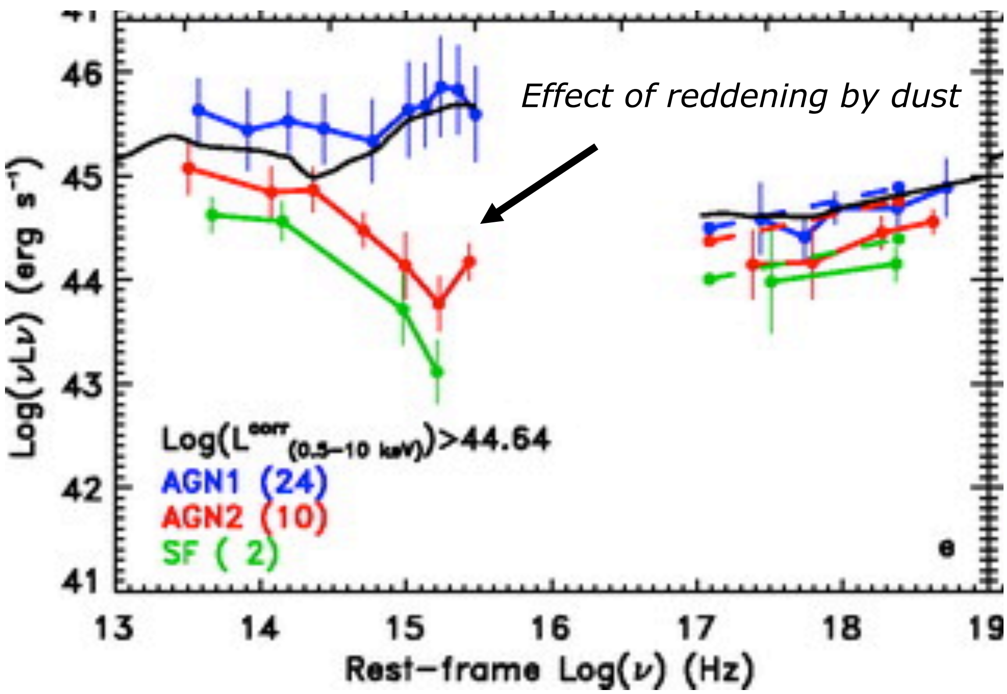


Fig. 14: α_{OX} versus UV luminosity. The dashed line is the best linear fit

Coffey et al 2019



- 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)

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

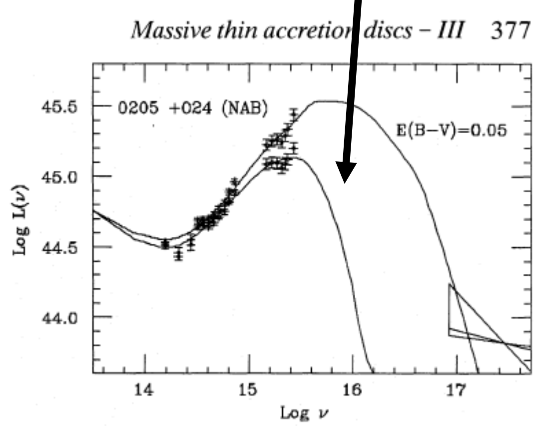
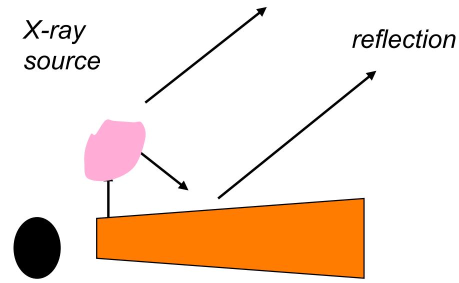


Figure 6. A fit for 0205+024 with and without a correction for internal reddening of $E(B-V)=0.05$. The best fit parameters are

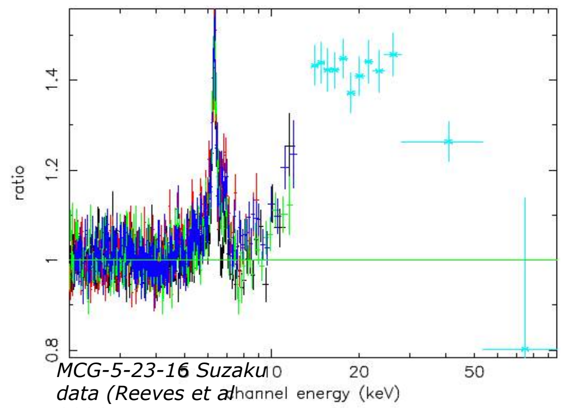
Laor 1990

Connection of Fe K line and the Reprocessing Regions

Cartoon or reality??



- The **most prominent** spectral features in most x-ray AGN spectra are
  - the Fe K line complex
  - The Compton reflection 'hump'
- Where are these regions
  - How are they connected
  - What do we learn about the geometry and chemical abundance of the central regions?
  - What is the physical state of the gas and how is it connected to other 'places' - e.g the regions responsible for producing the optical/UV/IR radiation
  - Is there a 'unified' model and if so what are its parameters
  - What can we learn about accretion

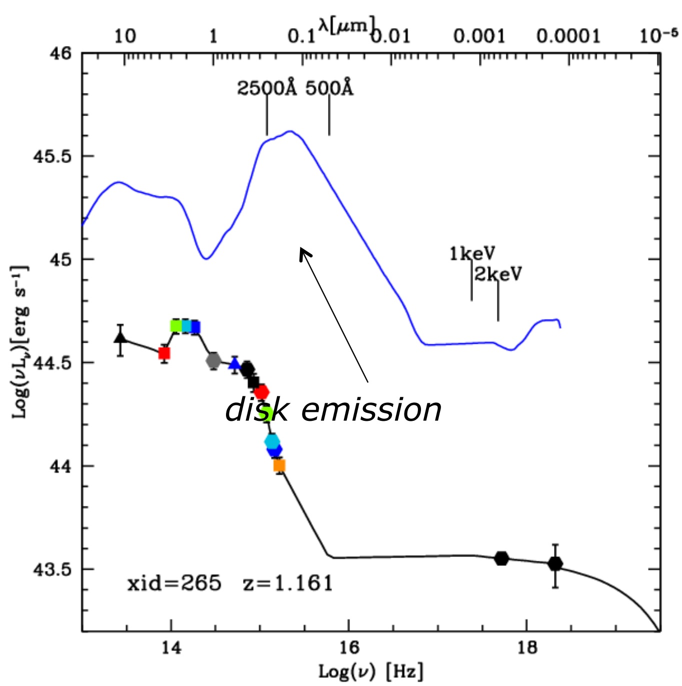


MCG-5-23-16 Suzaku data (Reeves et al 2006

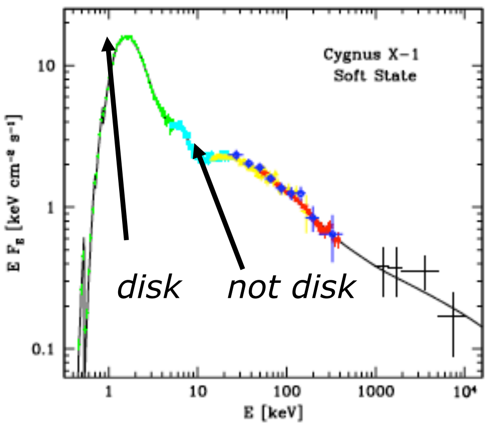
AGN

- 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

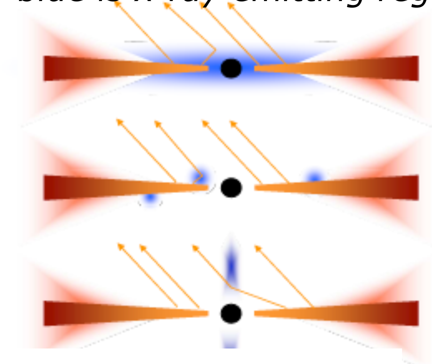


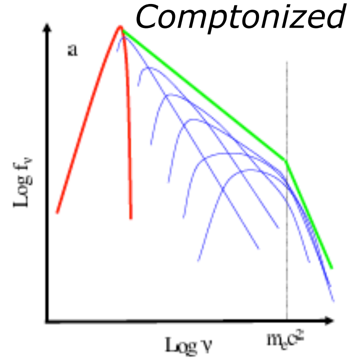
Real Data For Galactic BH



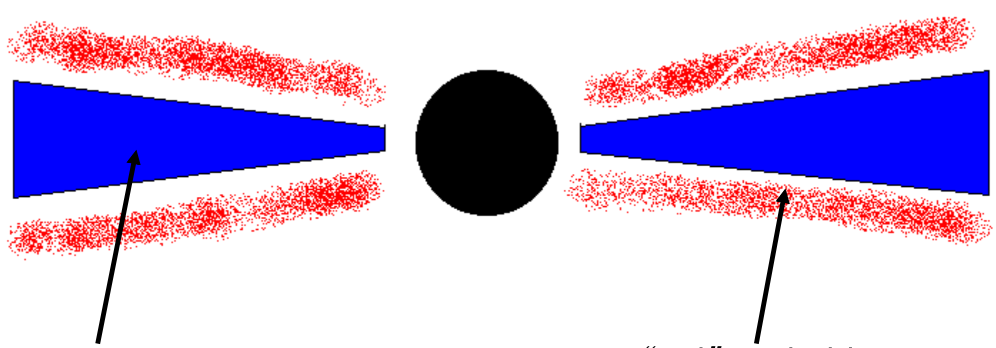
Where do the high energy photons arise?
In both AGN and Black Hole binaries it is thought that this spectral component is due to Comptonization of a 'seed photon' population off of highly energetic electrons produced 'above' the disk

Possible geometries
-blue is x-ray emitting region





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~10^{9}K