Active Galactic Nuclei (AGNs), Black Holes and their Impact on Galaxy Formation

Overview:

- **Manifestations of "nuclear activity"**
  - **Nearby universe/low-luminosity AGN**
  - **QSO's and AGN in the high-z universe**
- **Ubiquitous super-massive black holes at galaxy centers**
  - **Our Milky Way**
  - **Nearby Galaxies**
  - **High-z galaxies**
- **Cosmic Census of Accretion and Black Hole Growth**

- **The Impact of BH Accretion on Galaxies**

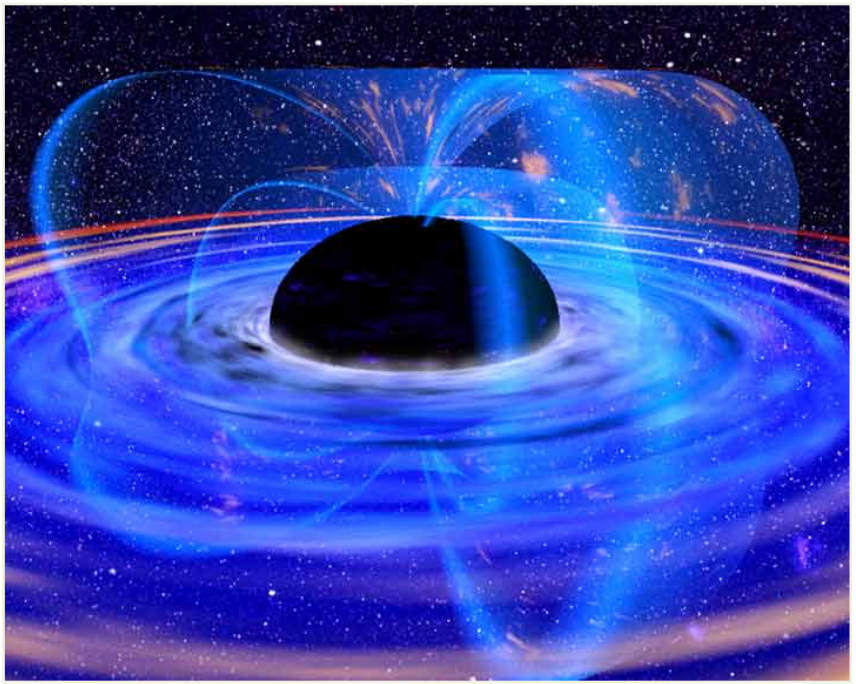
Course evaluations are open ! Due before Dec 11

https://www.irpa.umd.edu/Assessment/CourseEval/CourseEval.html

Have you been challenged and learned new things? Have I been effective, responsive, respectful, engaging, etc?-or dull,boring, stodgy, unprepared?

Your responses are strictly anonymous. I only see the statistics.

Helps me and future students!

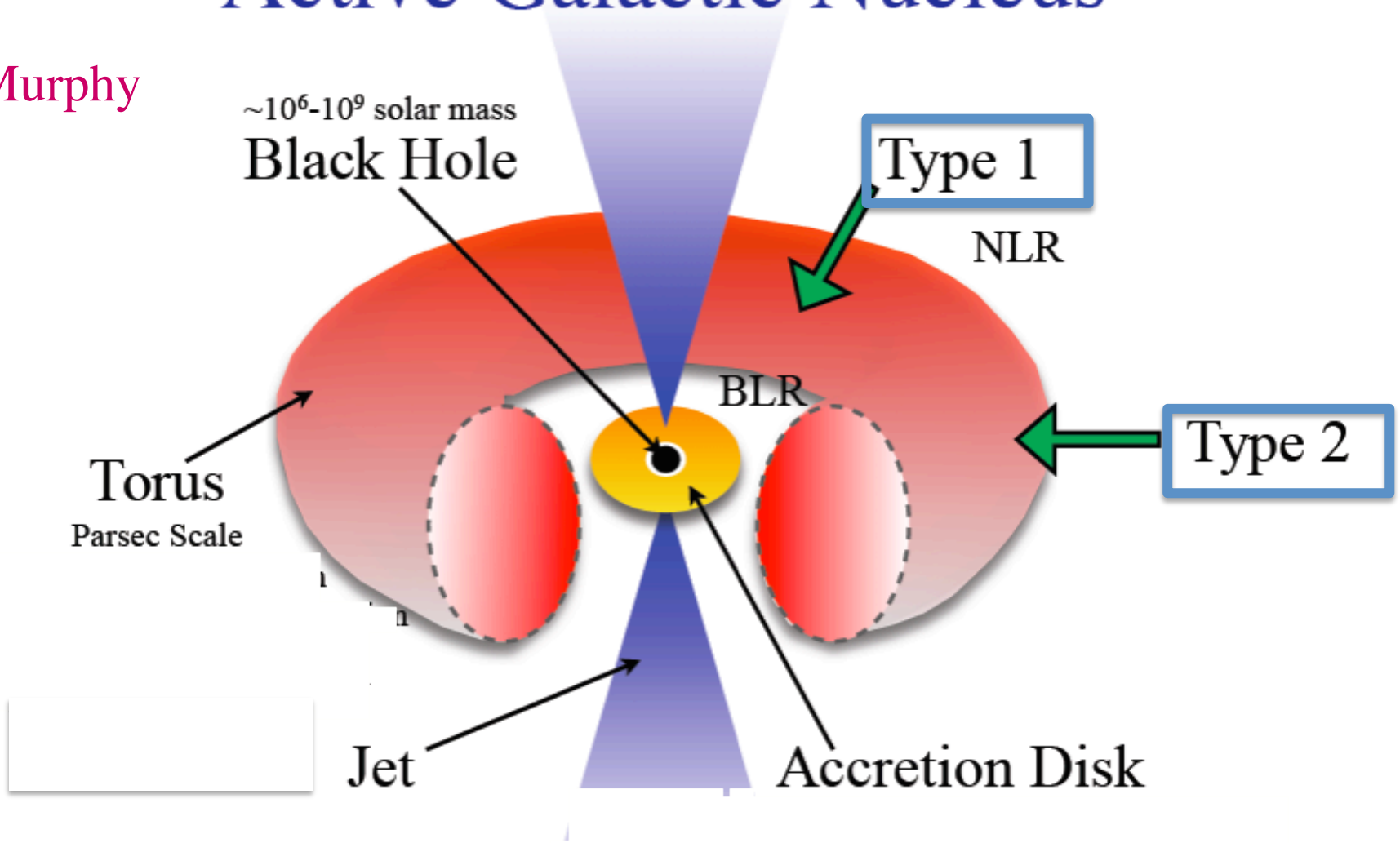


Broad Range of Properties

- Luminosity
  - Range from $<10^{40}$ erg/s to $\sim 10^{48}$ erg/s
  - Fundamental parameters controlling L are **mass and mass accretion rate**
  - Most Powerful objects (quasars)- AGN totally outshines host galaxy
- Level of obscuration- how much material is in our line of sight
  - In some objects, can see all of the way down to the SMBH (type I)
  - In other objects, view at some wavelengths is blocked by obscuring material (some objects are blocked at all wavelengths)- type II
  - Level of obscuration connected to **viewing inclination**
- Presence of powerful relativistic (radio) jets
  - Radio-loud AGN : generate powerful jets, seen principally via synchrotron radiation in the radio band
  - Radio-quiet AGN : lack **powerful** jets (may possess weak jets)
  - Fundamental parameter controlling jet production **unknown (maybe black hole spin; or magnetic field configuration)**

Active Galactic Nucleus

K. Murphy



$R_s = 1.4 \times 10^{13} \mathbf{M_8}$ cm; $R_s/c \sim 500 M_8$ sec

Todays News Spatially resolved rotation of the broad-line region of a quasar at sub-parsec scale GRAVITY Collaboration:1811.11195.pdf

Directly imaging such regions has not hitherto been possible because of their small angular size < 0.1 milli-arcseconds

For 3C 273 at z=0.158 (~670 Mpc)

Table 1 | Estimates of the kinematic BLR model parameters

Parameter	Value	Description
RBLR (μ as)	46 ± 10	Mean angular distance of the cloud from the black hole
Rmin (μ as)	11 ± 3	Minimum angular distance of the cloud from the black hole
i (°)	12 ± 2	Inclination angle of the observer
M_{BH}	$10^8 M_\odot$ 2.6 ± 1.1	Black-hole mass

jet is perpendicular to disk

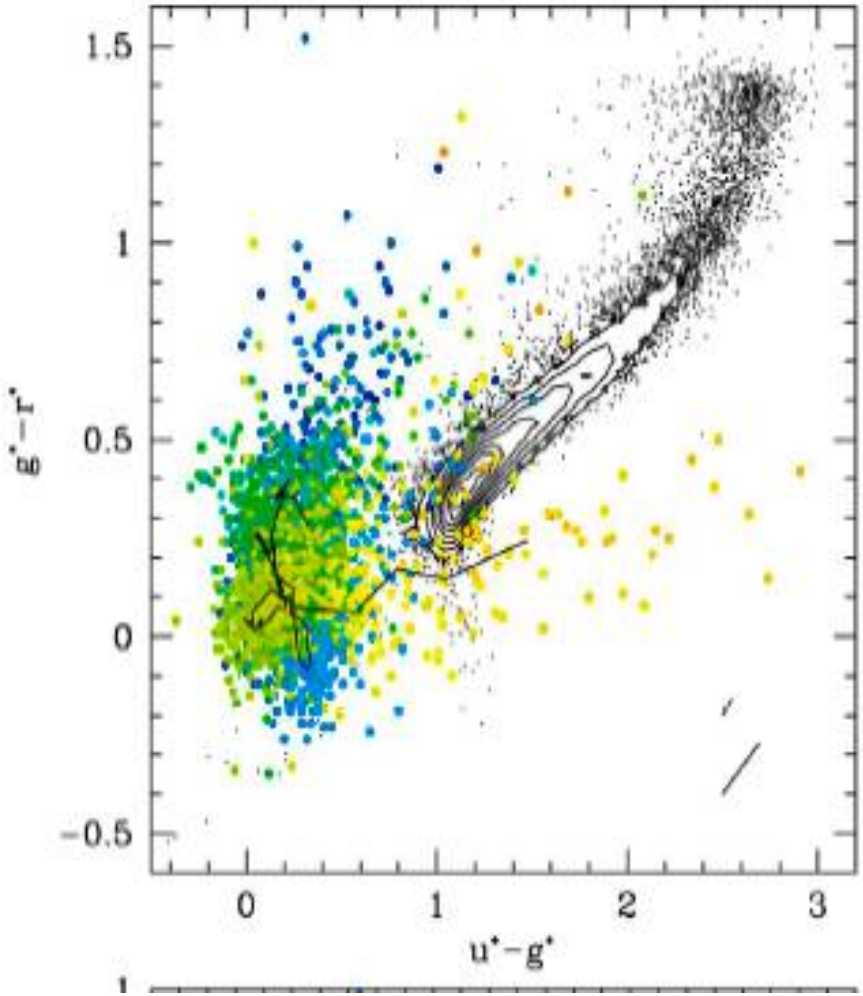
The broad line width is dominated by bound motion in the black hole gravitational potential

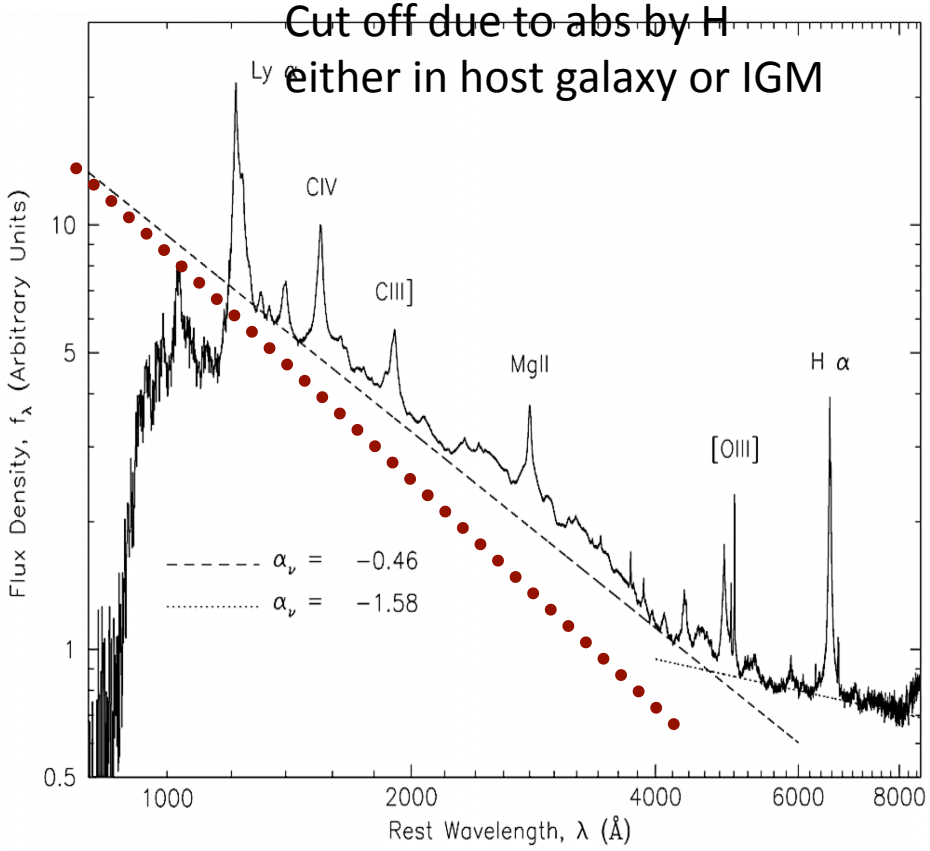
How Luminous Can They Be

- Eddington limit:
  - assuming spherical symmetry infalling matter experiences radiation pressure from the release of energy by the infalling matter
  - Balancing gravity with radiation pressure gives (eqs. 9.3 and 9.4 in S&G)
- $L_{Eddington} \sim 1.3 \times 10^{38} M_{\odot}$ ergs/sec= $1.3 \times 10^{31} M_{\odot}$ W/sec

Optical Properties of AGN

- **Strong lines** of hydrogen, oxygen, carbon,magnesium ….



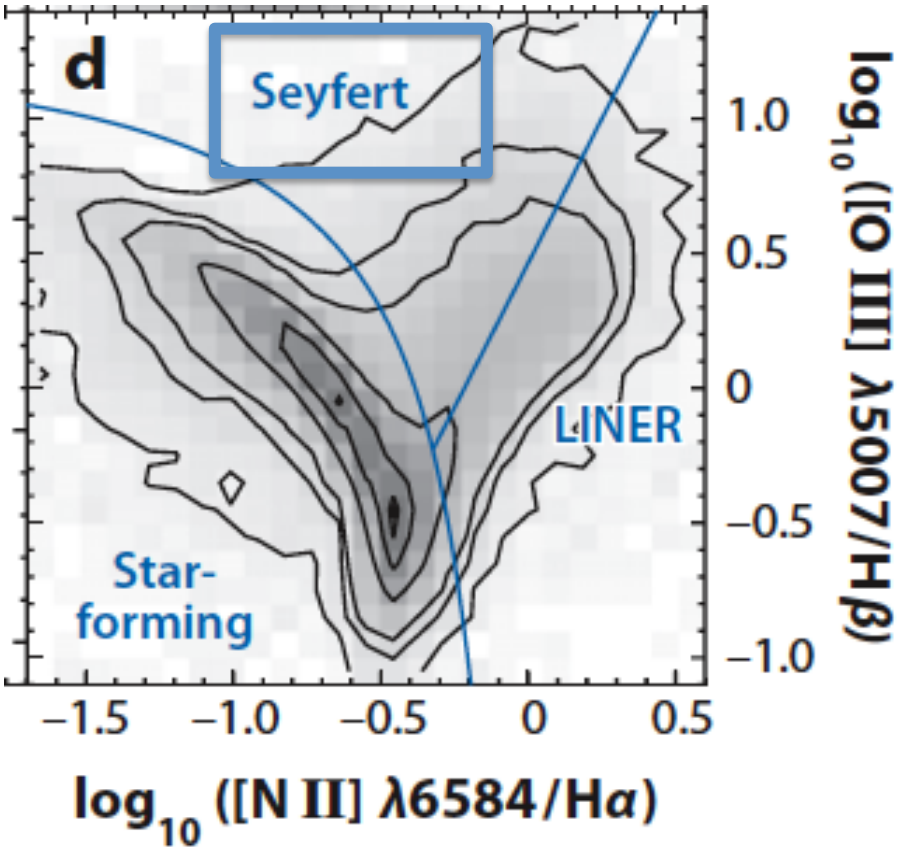


Unusual optical colors (Richards et al SDSS)- quasars in color, stars are black

UV-Optical Continuum is thought to arise via thermal emission in an accretion disk

Optical Emission Lines

- Remember that star forming galaxies also can have strong emission lines
- *AGN emission line ratios are different*- indicating ionization by a different type of source ('harder' spectrum- more energy at shorter wavlengths than stars)



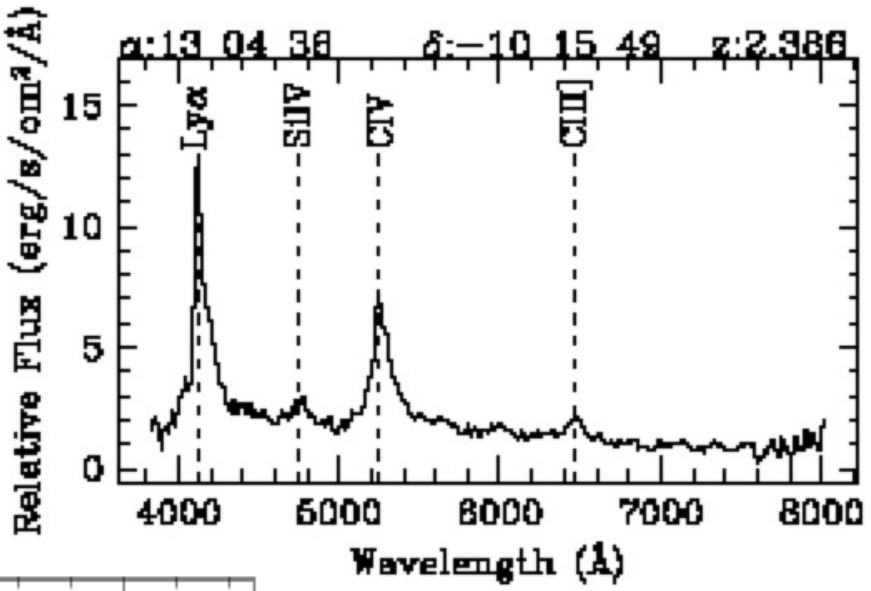
line ratio plot NII/Hα compared to OIII/Hβ−

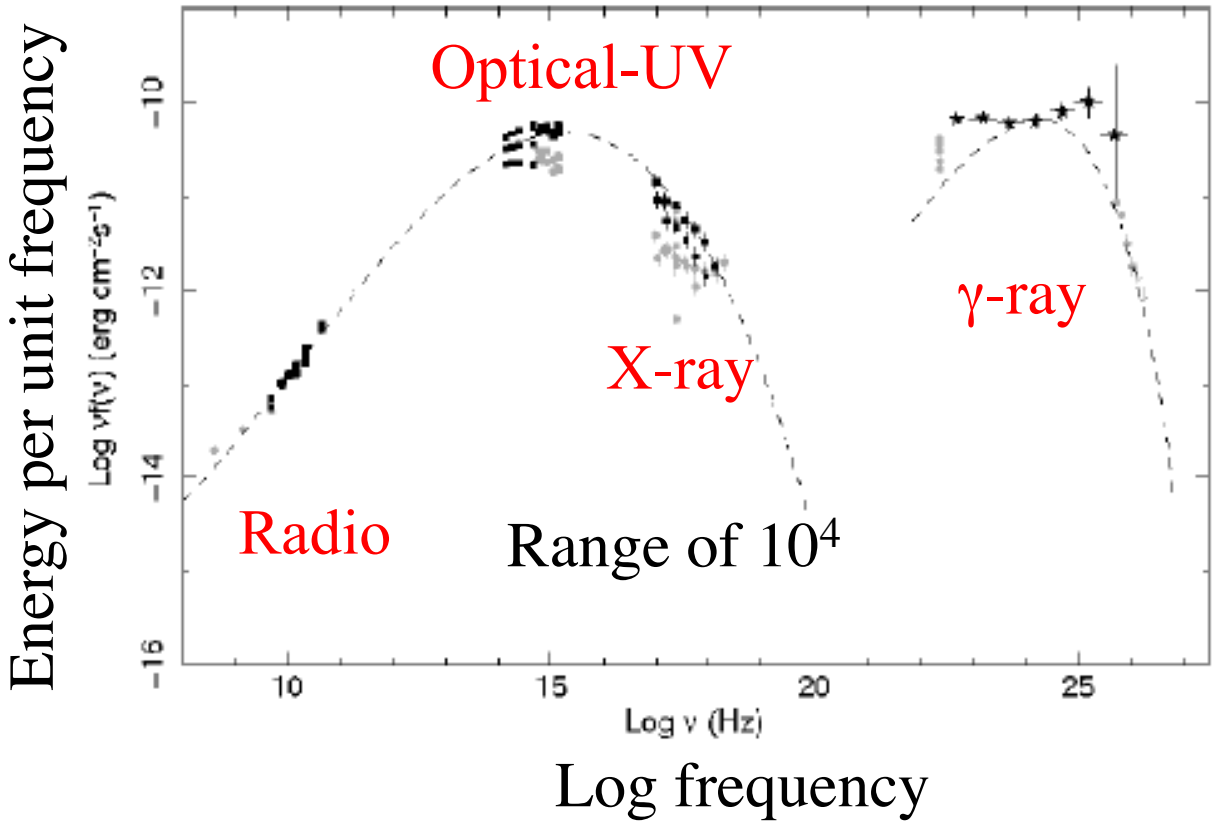
AGN lie in a particular part of this diagram

Darkness of plot is log of the number of objects inside the contour

Broad Band Properties of AGN

- **Broad band continuum- very different from stars or galaxies**
- **Strong UV lines not seen in stars** ….
- Can be very variable



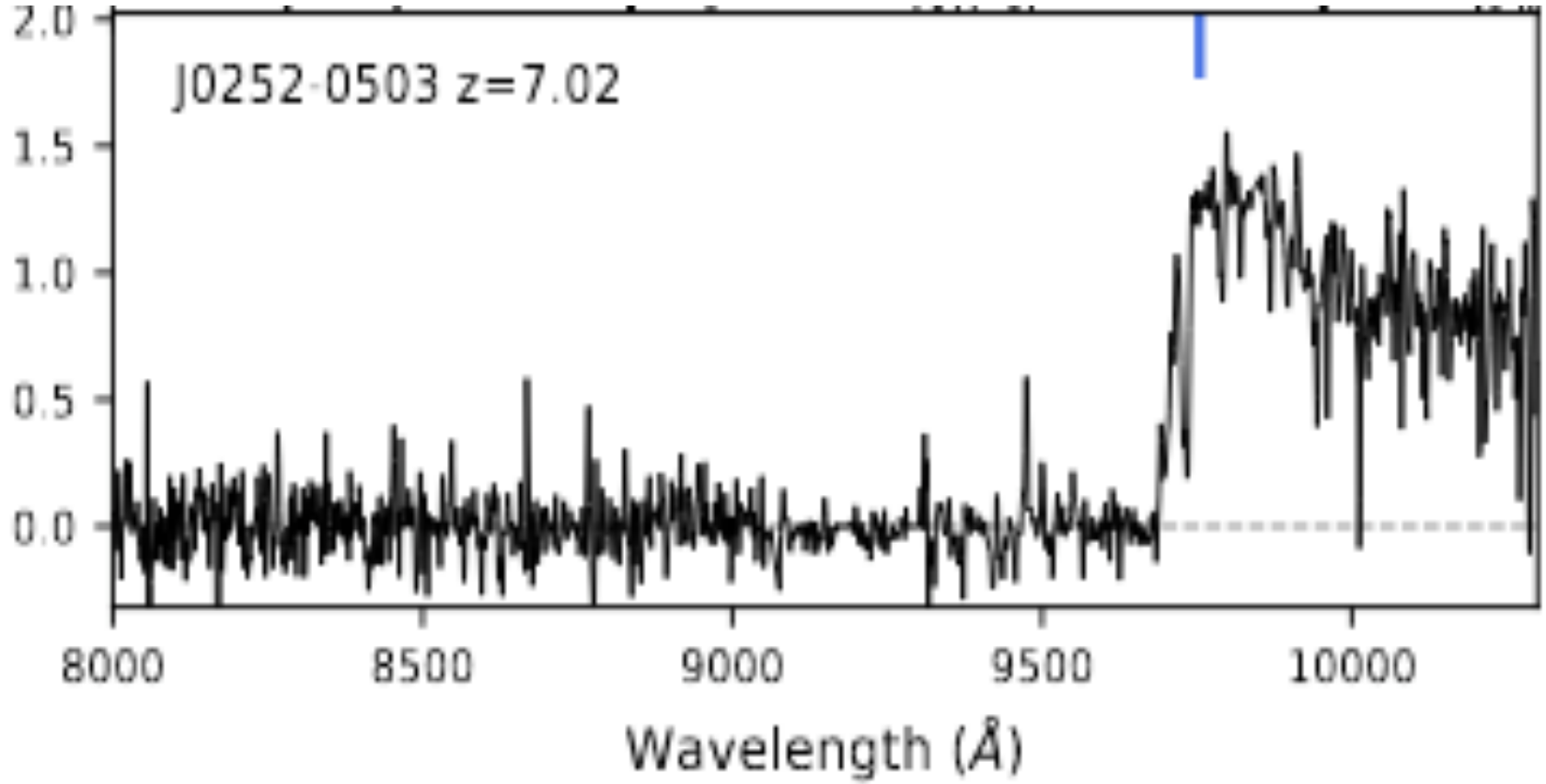


Broad band spectral energy distribution (SED) of a 'blazar' (an active galaxy whose observed radiation is dominated by a relativistic jet 'coming at' us.

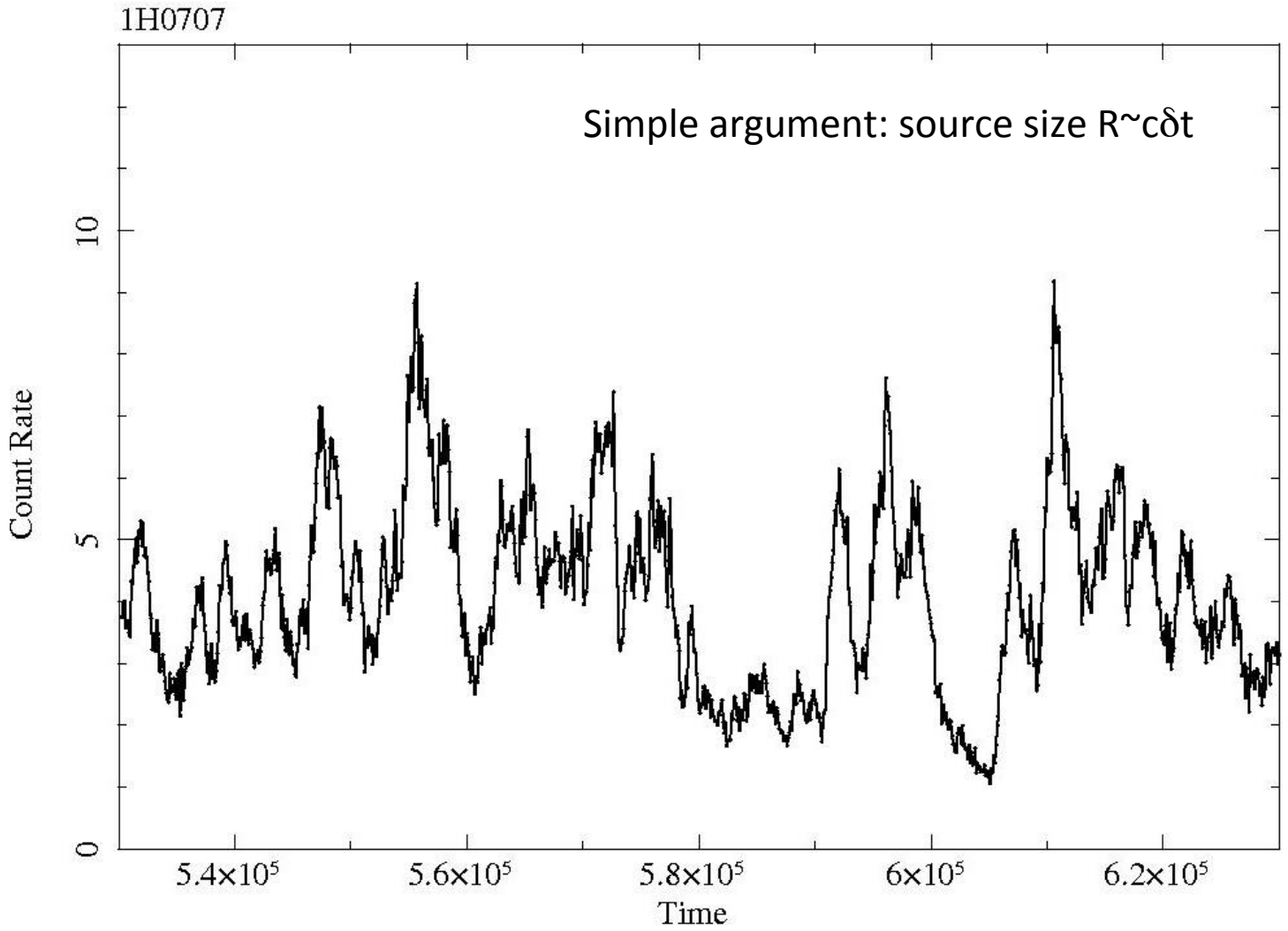
A large fraction of the total observed energy appears in the γ-ray band (due to relativistic beaming)

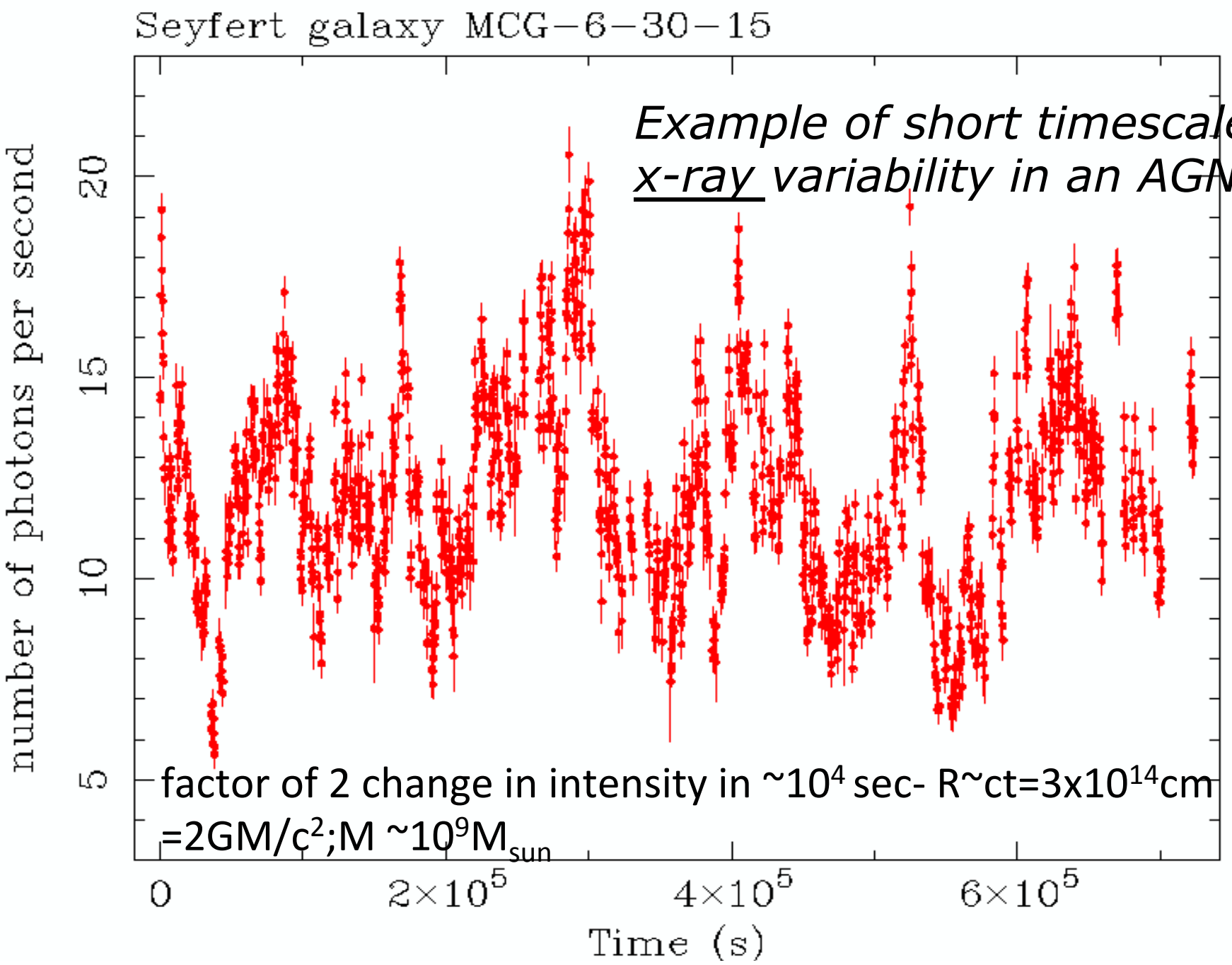
Problems at High Redshift

- At λ <912Å the IGM is opaque and when redshifted to z=7 means that no light is received in the classical optical bands.

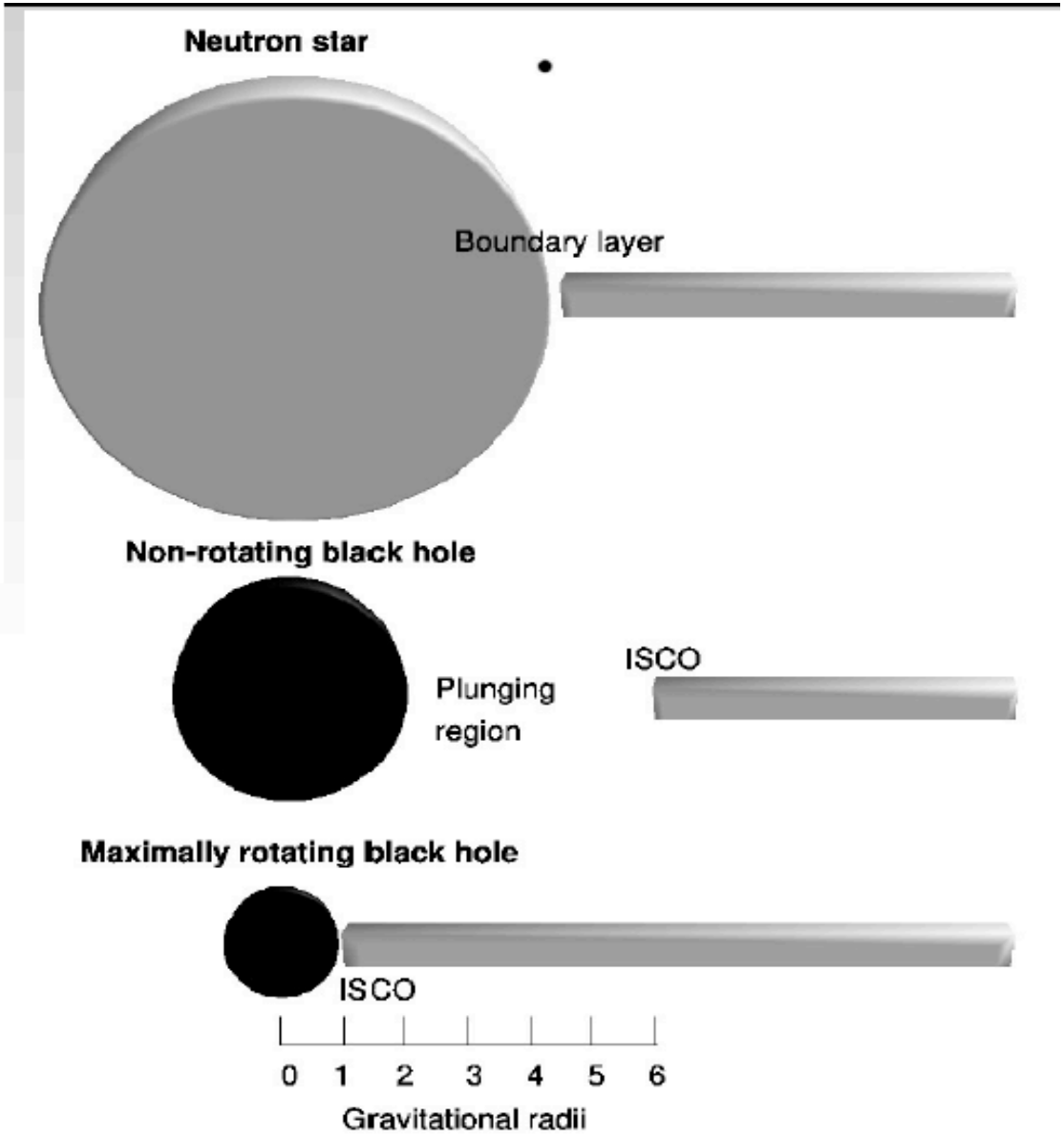


Rapid *x-ray* variability in AGN
Source luminosity ~5×10^{43} ergs/sec




Seyfert galaxy MCG−6−30−15
number of photons per second
5
10
15
20
0
2×10^5
4×10^5
6×10^5
Time (s)
Example of short timescale
x-ray variability in an AGN
factor of 2 change in intensity in ~10^4 sec- R~ct=3x10^14cm
=2GM/c^2;M ~10^9M_sun

ISCO=innermost stable orbit-disk terminates there



What about spin ?

A non-rotating ("Schwarzschild") black hole has its event horizon at 2 R_G and its ISCO at 6 R_G

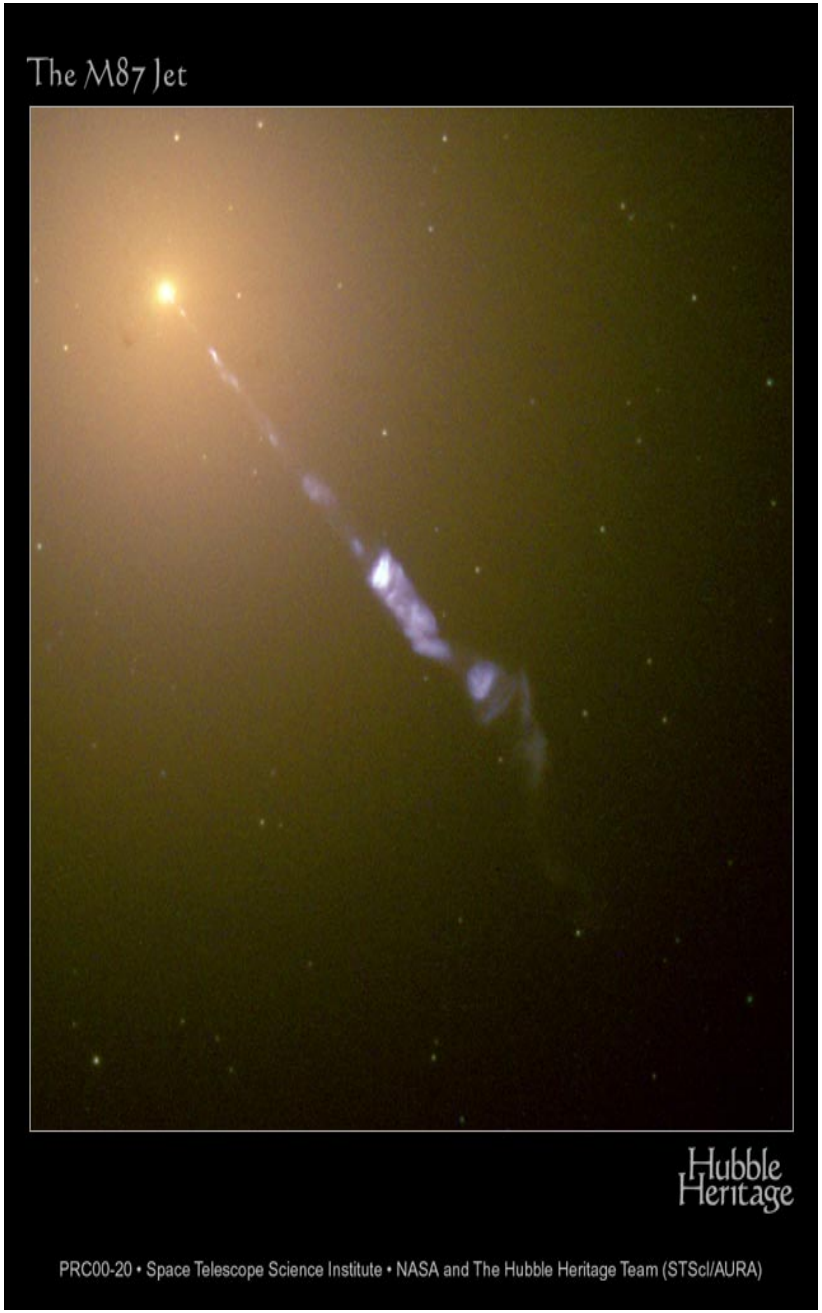
A maximally rotating ("Maximal Kerr") black hole has both its event horizon and ISCO at R_G

→ Spinning black holes are more compact → potentially more radiatively efficient

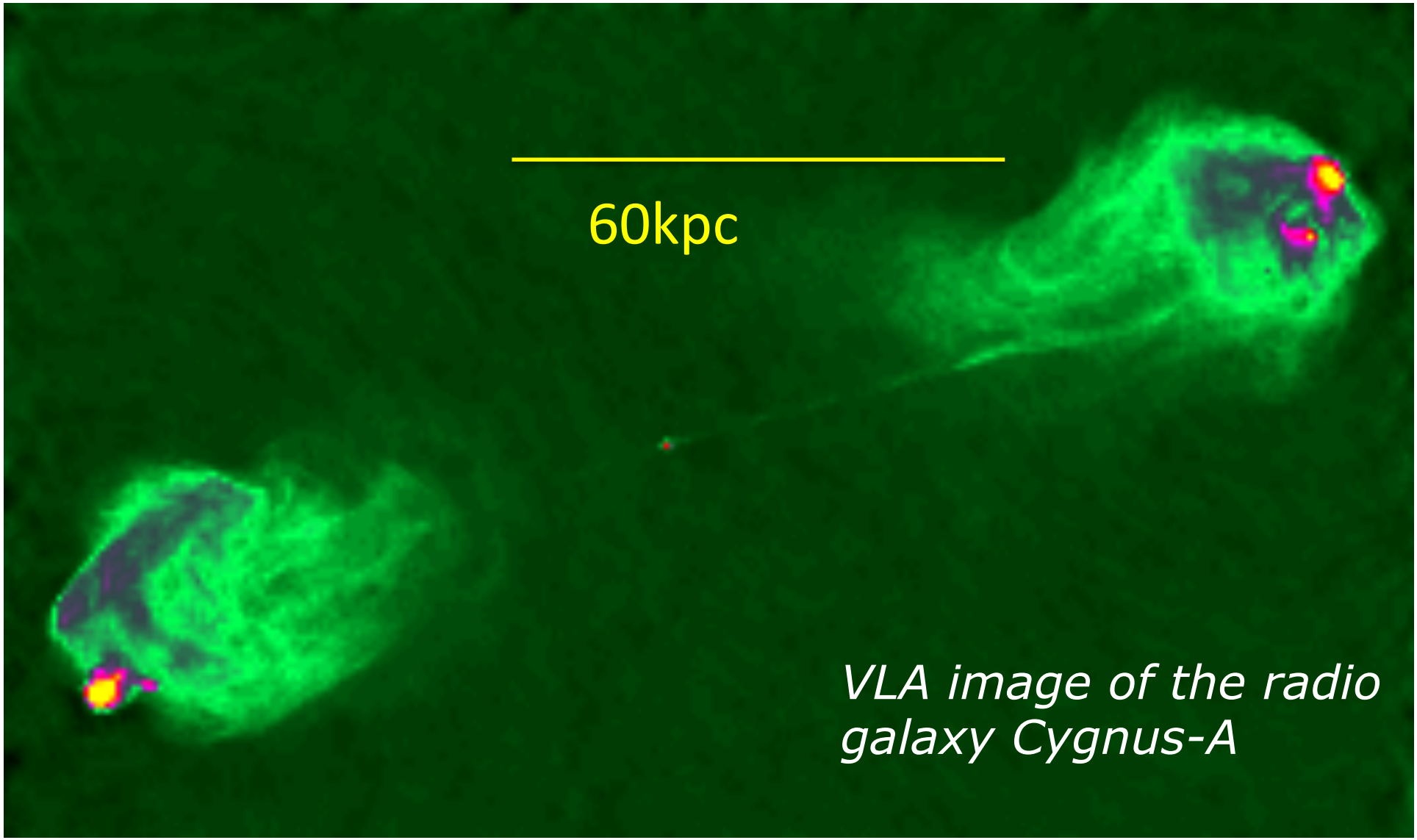
Radio Loud Active Galactic Nuclei

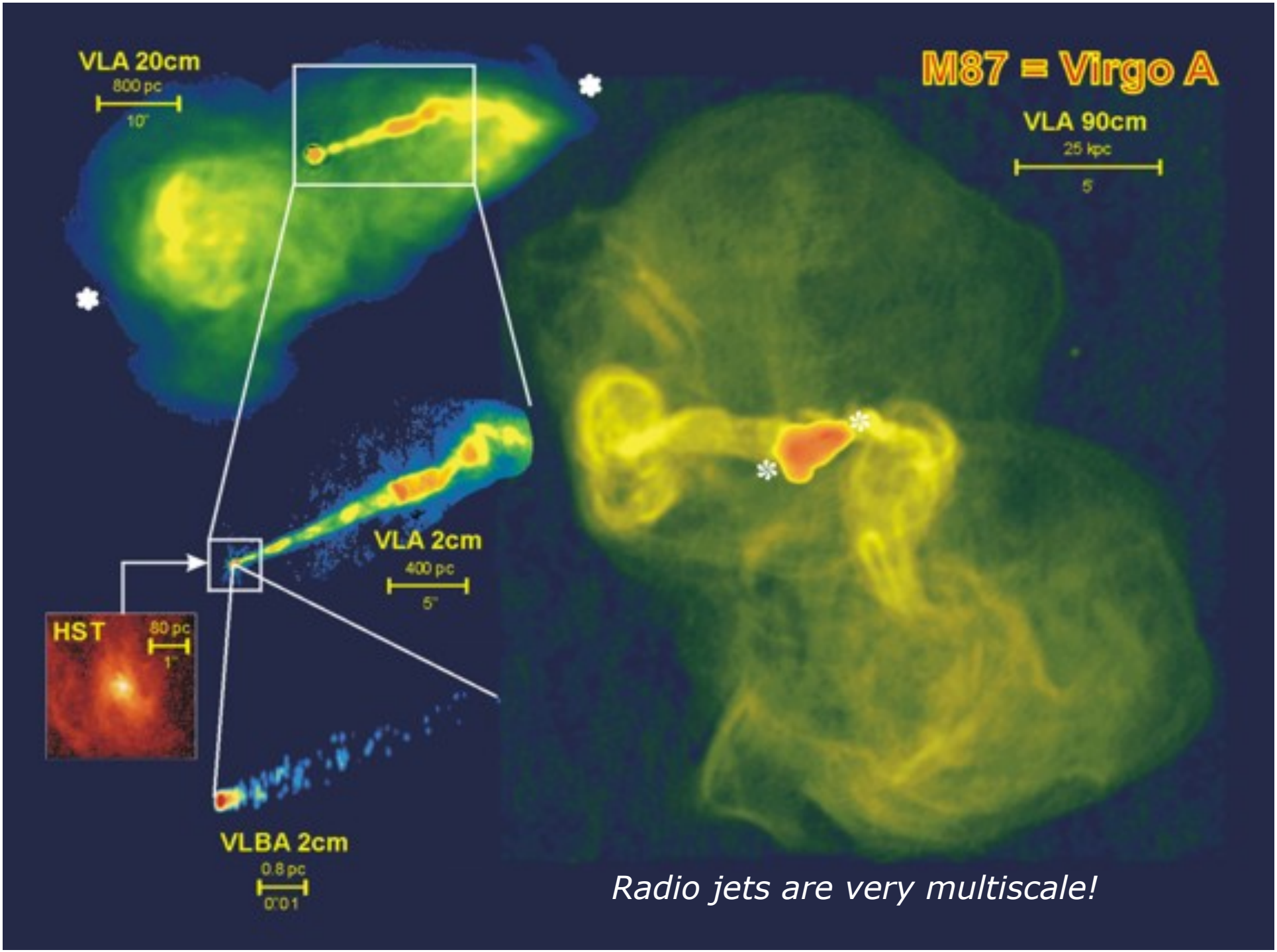
- M87 is example of a *radio loud* "active galactic nucleus"
- Material flows (accretes) into black hole
- Energy released by accretion of matter powers energetic phenomena

- The Jet
  - Jet of material "squirted" from vicinity of SMBH
  - Lorentz factor (γ=sqrt(1/(1-v^2/c^2)of >6
  - Can be very energetic (particle luminosity)
  - in radio to x-ray band jet radiation is primarily synchrotron (see text)- in gamma-ray it is inverse Compton
- What powers the jet?
  - Accretion power
  - Extraction of spin-energy of the black hole



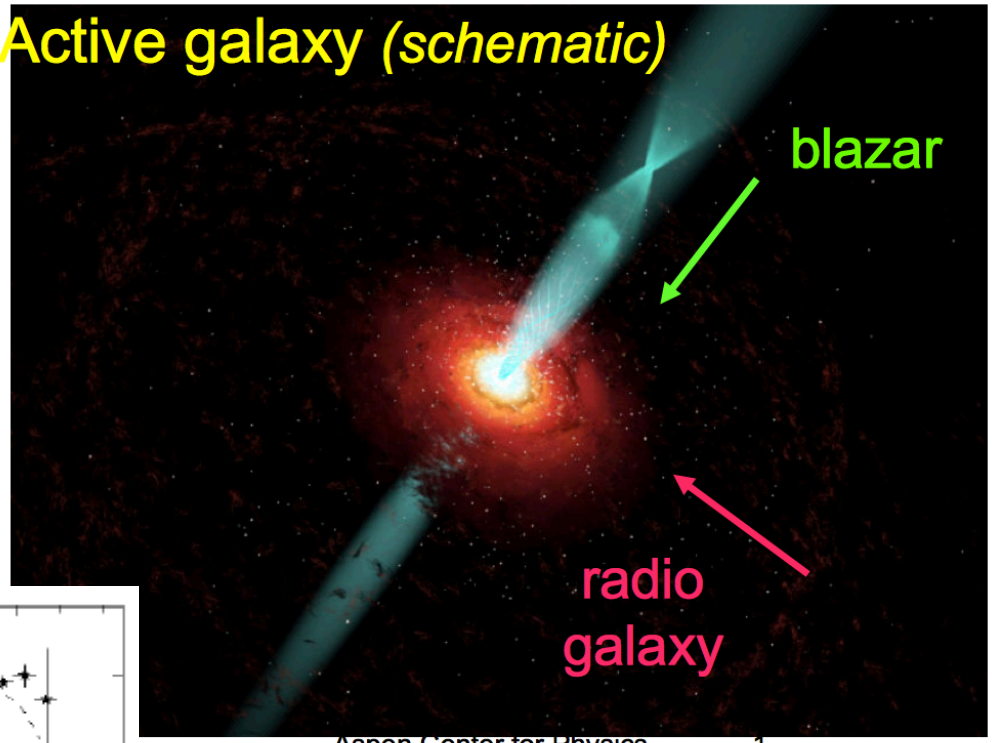
AGN 'Types' The Radio-loud/Radio-quiet dichotomy

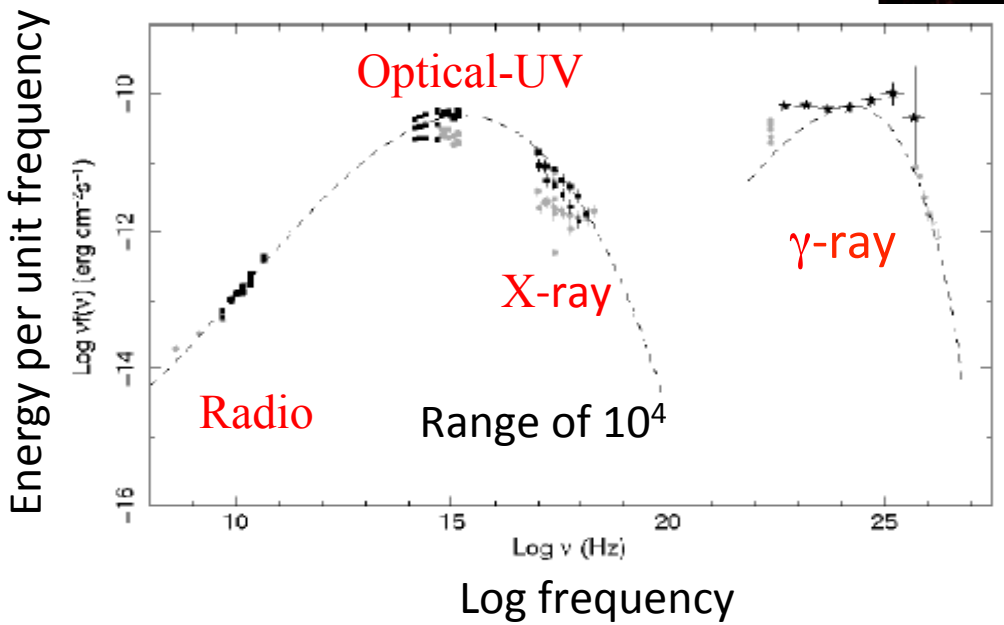



VLA 20cm
800 pc
10'
M87 = Virgo A
VLA 90cm
25 kpc
5'
VLA 2cm
400 pc
5"
HST
80 pc
1"
VLBA 2cm
0.8 pc
0"01
Radio jets are very multiscale!

AGN types Blazar

- Featureless (no lines) broad band continuum radio-gamma rays
- Thought to be due to emission from jet in our line of sight
- Can be very luminous – most luminous γ-ray emitters



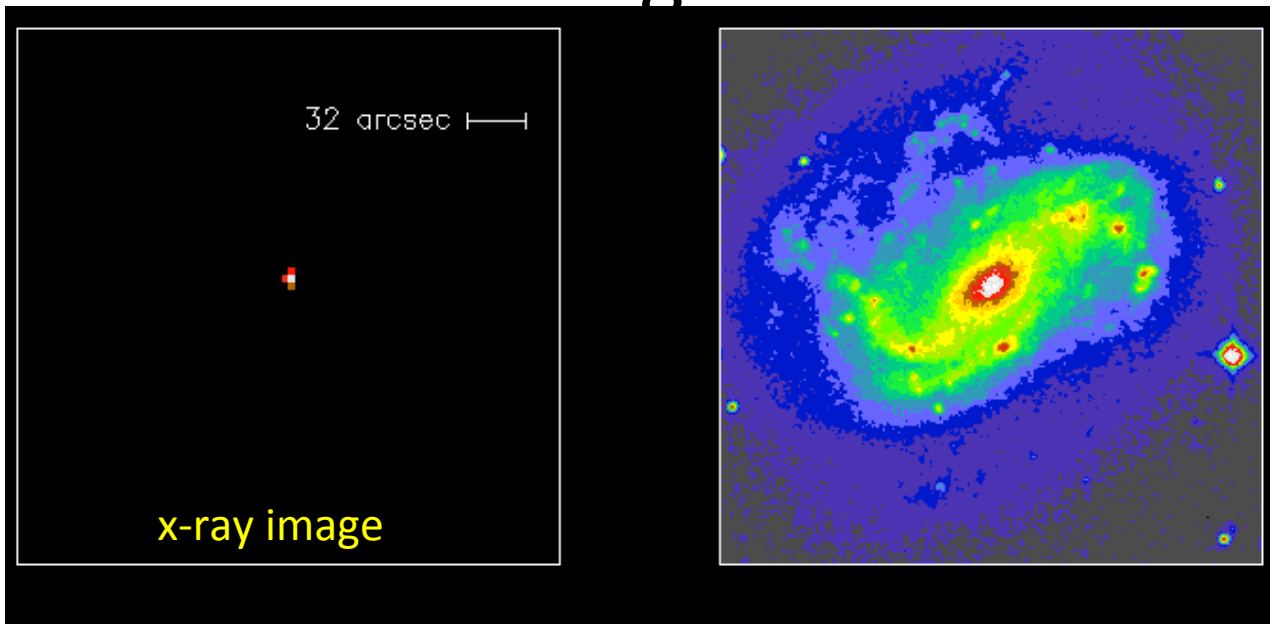


Notice spectrum is peaking in the gamma-ray band !

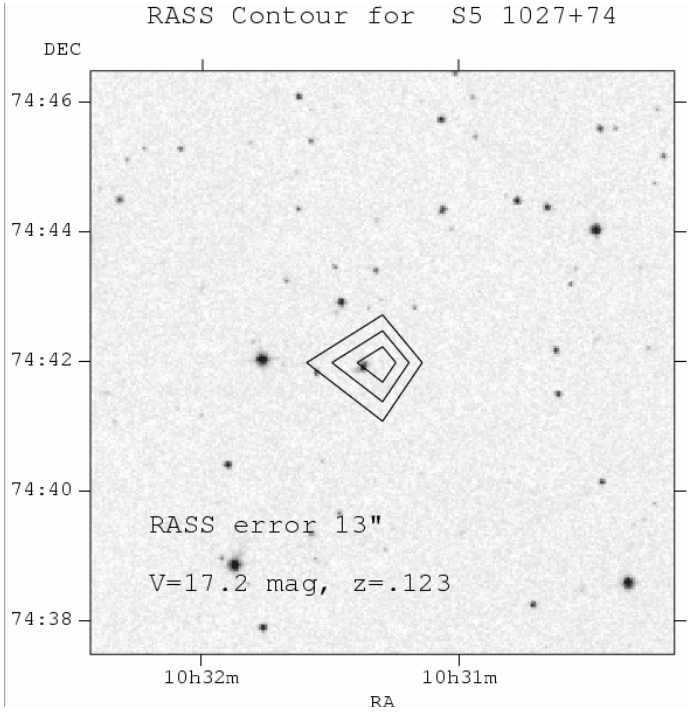
X-ray Selection of Active galaxies

- X-ray and optical image of a nearby AGN NGC4051-
- Note the very high contrast in the x-ray image
- Find x-ray AGN via
  - luminous* pointlike x-ray source in nucleus of galaxy
  - hard x-ray spectrum
  - frequently variable

* Find lots of AGN 'hidden' at other wavelengths



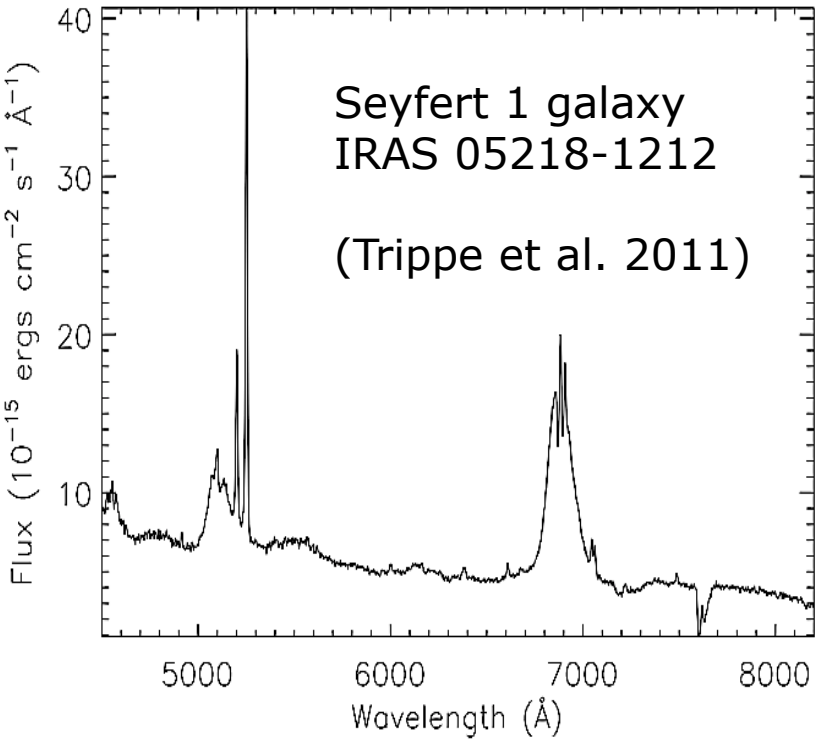
Rosat x-ray all sky survey image overlaid on sky survey image



AGN Types

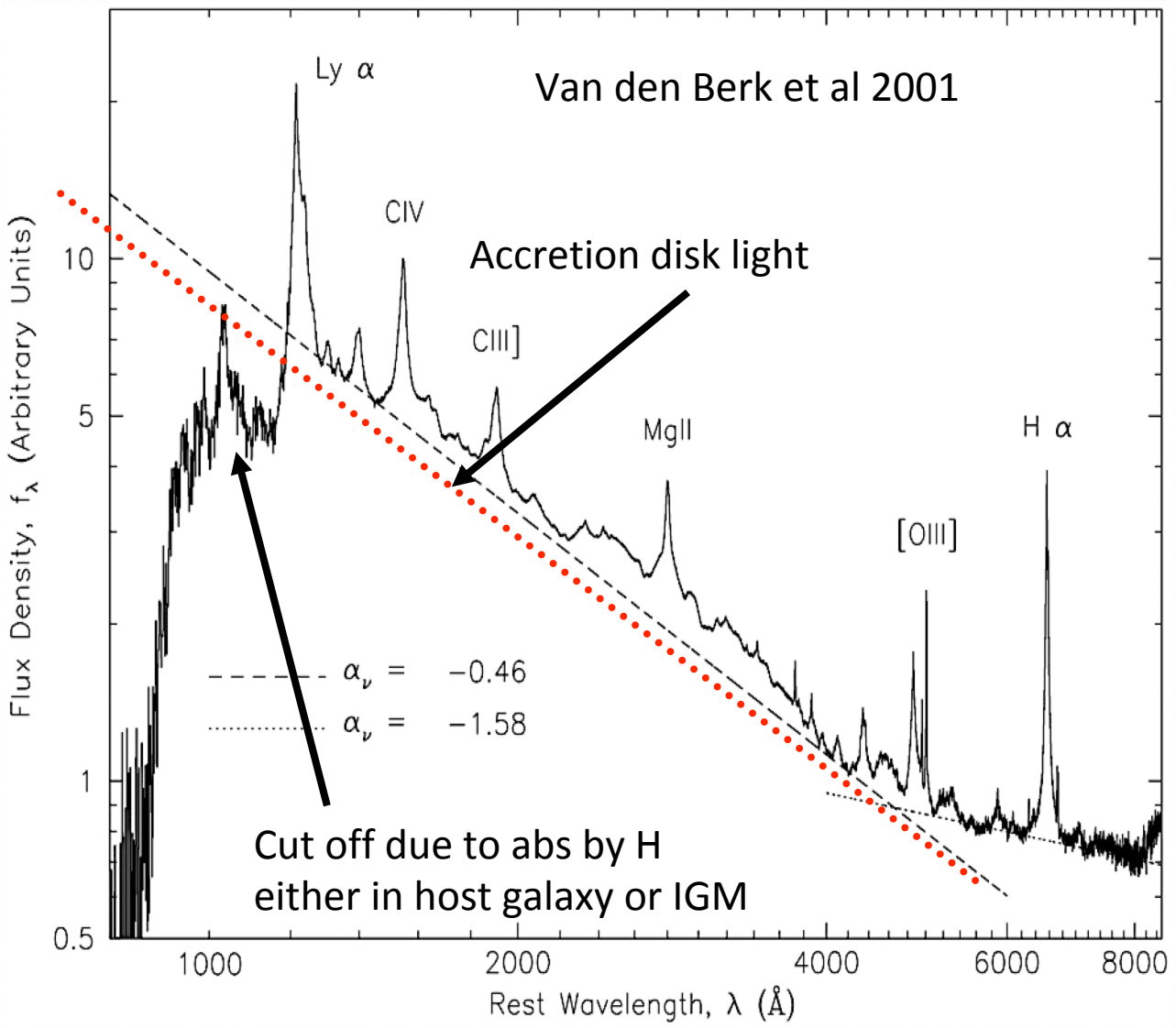
Optical Broad line (type-1) objects

- 'Blue' optical/UV continuum
- Broad optical/UV lines
  - Emission lines from permitted (not forbidden) transitions
  - Photoionized matter $n>10^{9}cm^{-3}$
  - FWHM~2000-20,000 km/s
- Narrow optical/UV lines
  - Emission lines from both permitted and forbidden transitions
  - FWHM~500km/s
  - Spatially resolved 0.1-1kpc



Hβ, [OIII], [NII],Hα

- AGN (type I) optical and UV spectra consist of a 'featureless continuum' with strong 'broad' lines superimposed
- Typical velocity widths (σ, the Gaussian dispersion) are ~2000-5000km/sec
- The broad range of ionization is due to the 'photoionzation' of the gas- the gas is **not** in collisional equilibrium
- At short wavelengths the continuum is thought to be due to the accretion disk

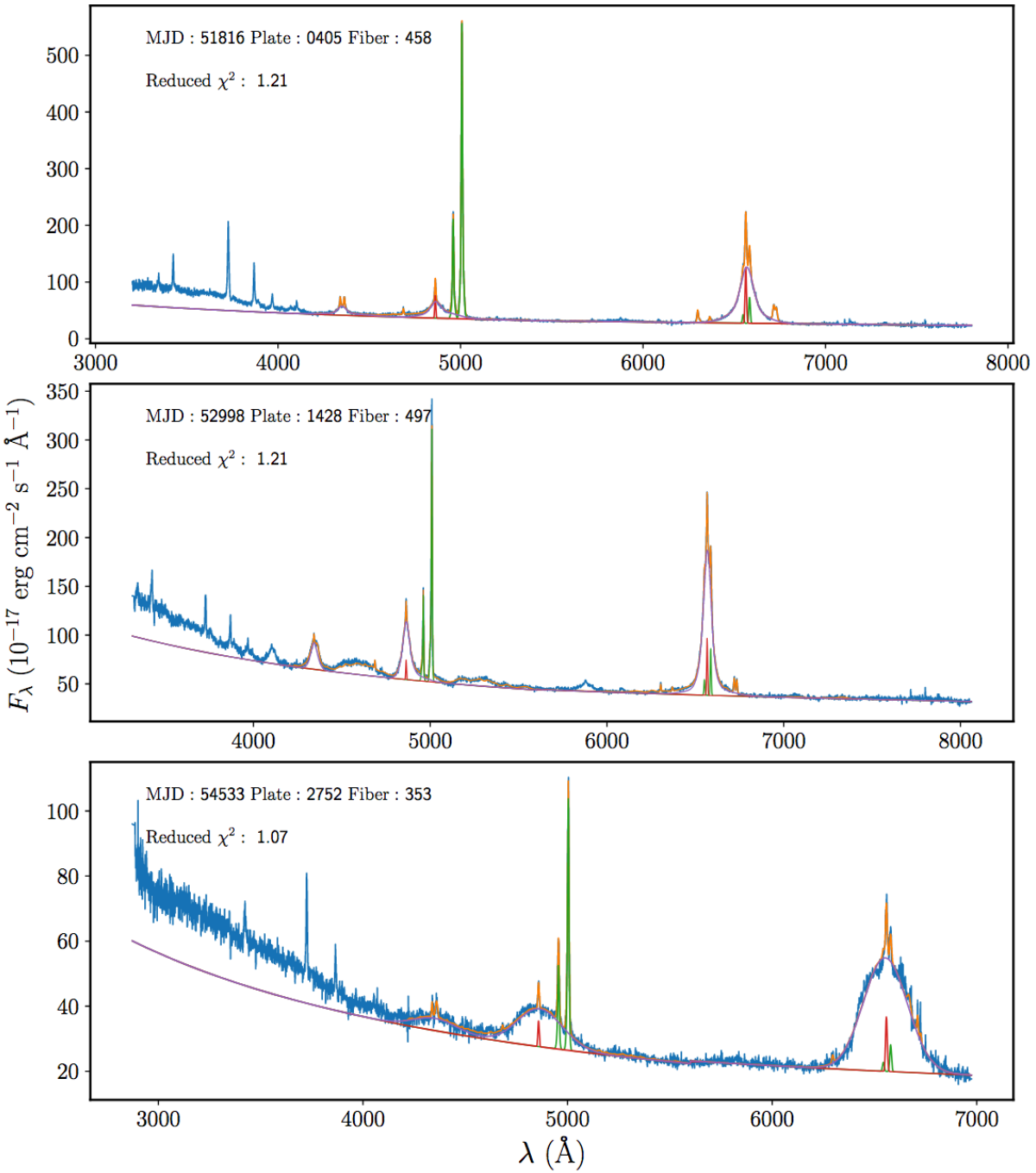


Origin of λ>4000Å continuum not known

Seyfert Is

- Set of optical spectra at different

redshifts

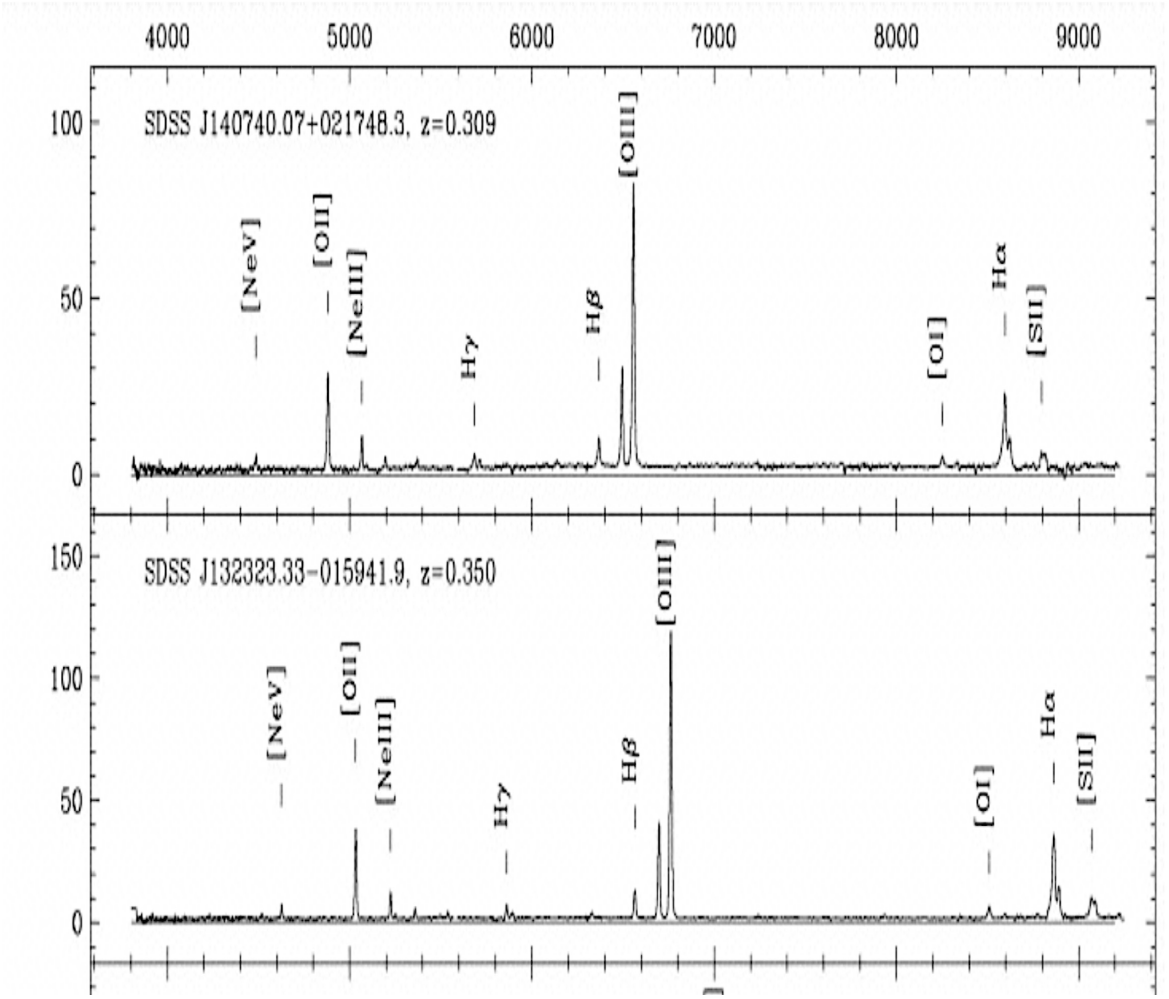


AGN Types
Narrow line (type-2) objects

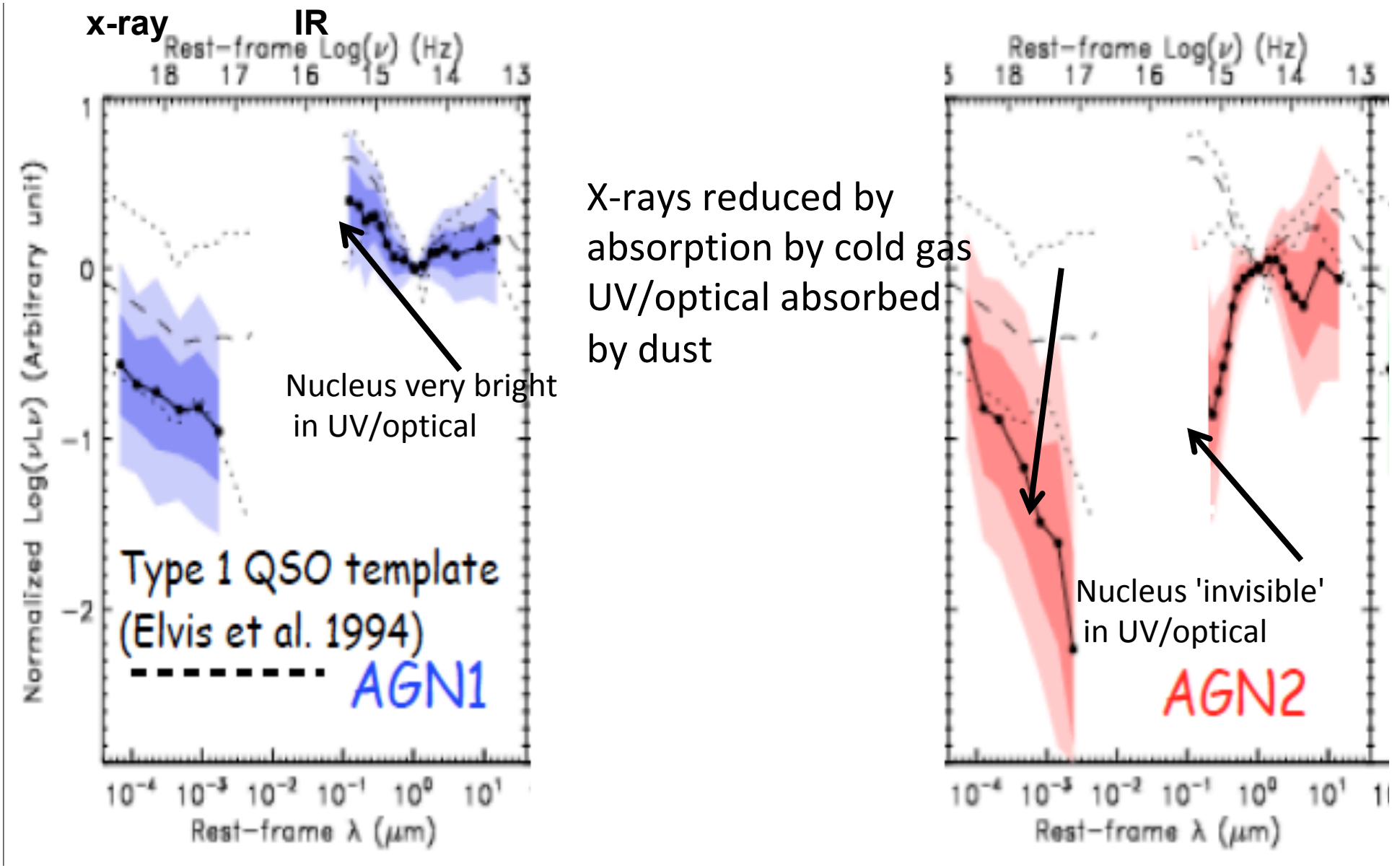
- Reddened Optical/UV continuum
- Optical Emission line spectrum
  - "Full light" spectrum only shows narrow (~500km/sec) optical/UV lines
  - Broad optical/UV lines seen in *polarized* light… shows that there is a hidden broad line region seen via scattering (Antonucci & Miller 1985)
- **X-ray spectrum usually reveals highly absorbed nucleus ($N_H > 10^{22} cm^{-2}$)**

Objects without a Strong Continuum-e.g type II

- type II do not have broad lines and have a weak or absent 'non-stellar' continuum
- Strong absorption in x-ray band $N_H > 10^{22} cm^{-2}$
- Depending on the type of survey and luminosity range ~50% of all AGN are of type II

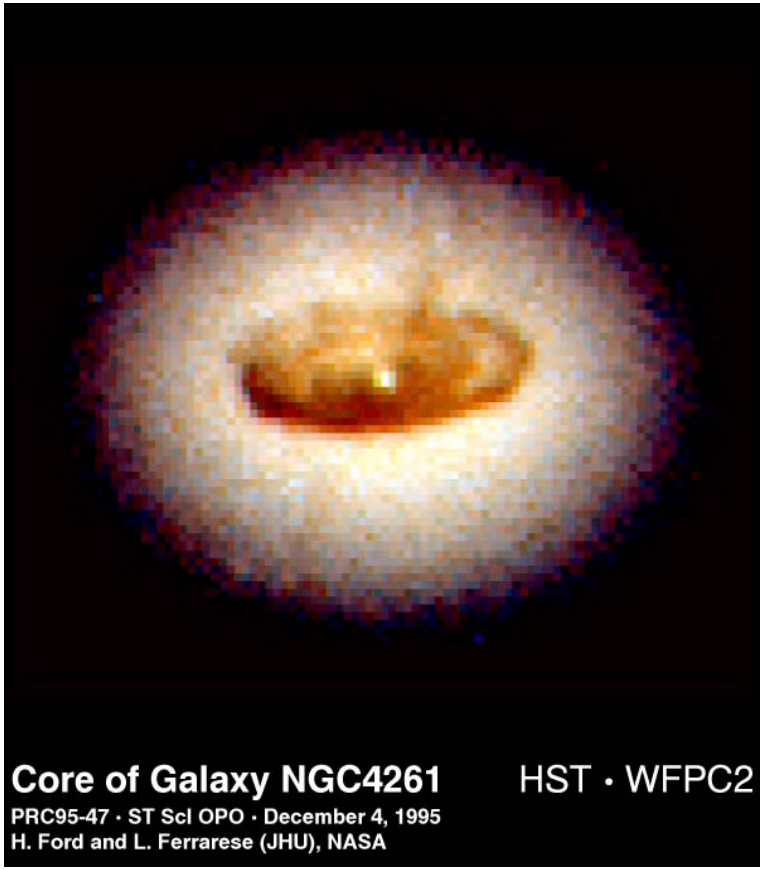


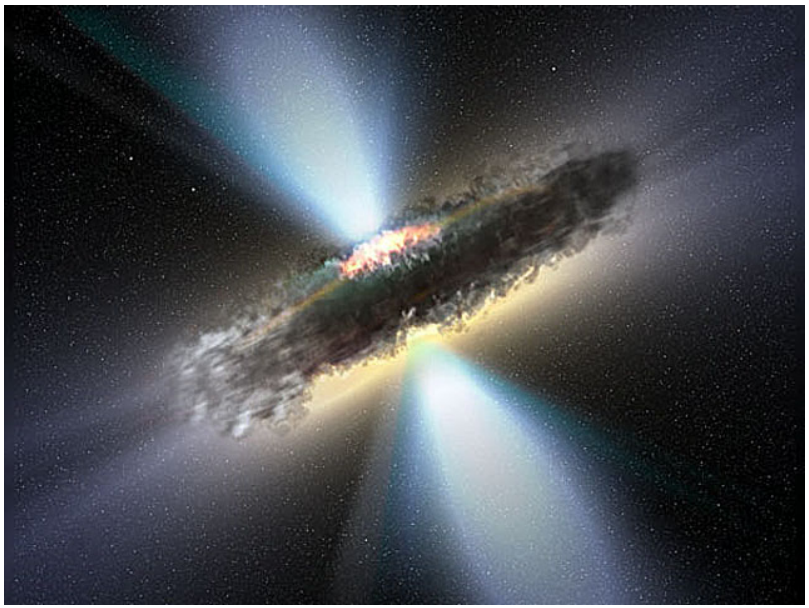
Broad Band Continuum (IR-Xray)



The Dark Side of AGN

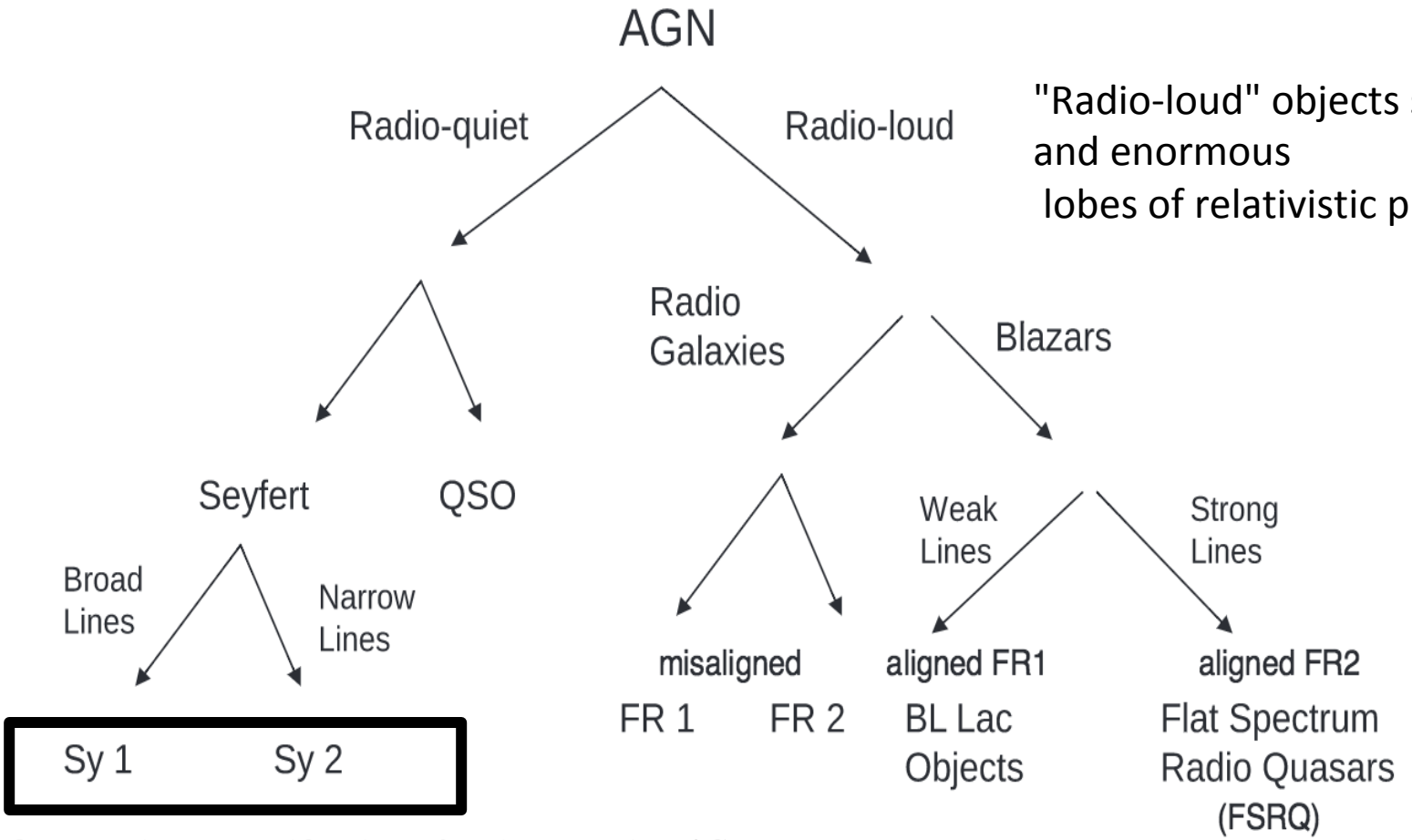
- ***Many AGN are obscured***- obscuring material is of several types
  - Located in the ISM of the host galaxy
  - A wind associated with the AGN
  - Perhaps a ‘obscuring torus’
  - Etc
  - Lack of uniform sample not sensitive to absorption or emission from this structure has limited knowledge of true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

AGN Zoo



"Radio-loud" objects show jets and enormous lobes of relativistic plasma

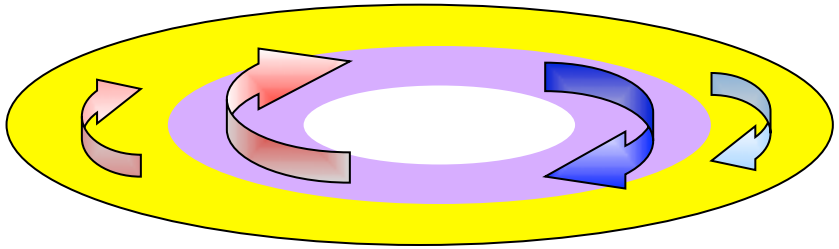
Figure 1. **Observational classification of active galaxies.** AGN are subdivided into classes depending on observational aspects, such as their radio loudness or the presence of optical lines in their spectra. QSO = quasi-stellar objects; Sy1 and Sy2 = Seyfert 1 and 2; FR1 and FR2 = Fanaroff-Riley 1 and 2.

How Does Accretion Work

- Because of conservation of angular momentum, as the material falls in, it produces an accretion disk (fig 9.3)
- The accretion disk is hotter in the center and has a relatively simple temperature and emissivity profile
  - but as the gas spirals into the black hole special and general relativistic effects become large, strongly effecting the emergent spectrum

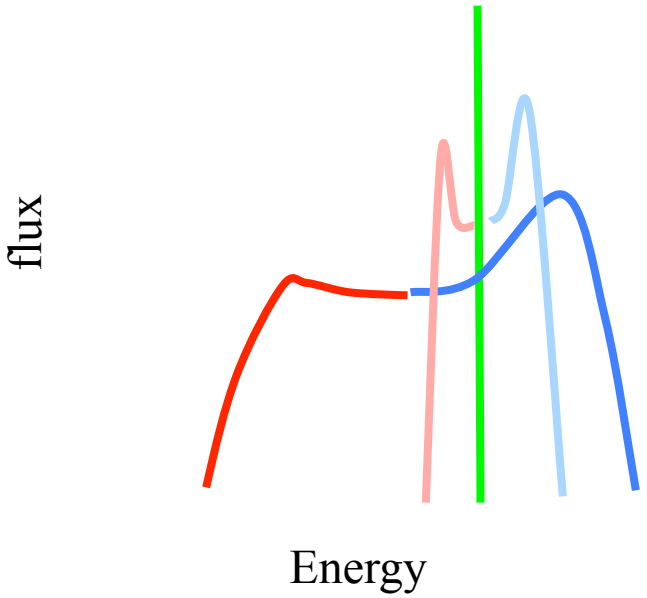
Relativistic effects- C. Done

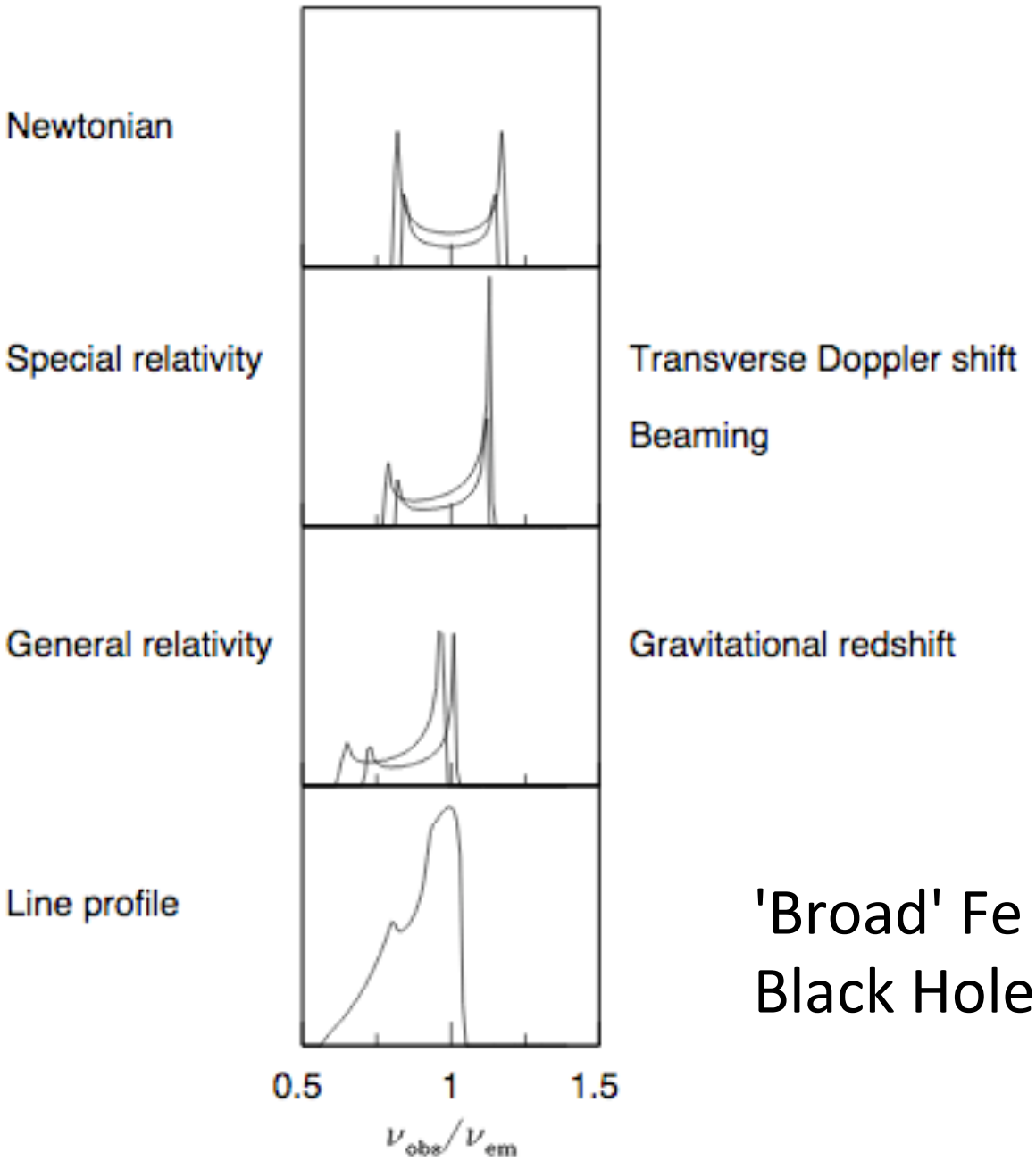
- Relativistic effects (special and general) affect all emission (Cunningham 1975)

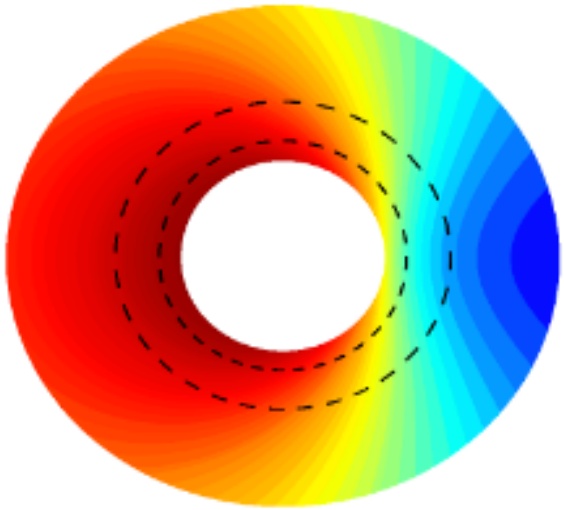


- Fe Kα line from irradiated disc – broad and skewed! (Fabian et al 1989)

- Broadening gives an independent measure of R_{in} –(Laor 1991)



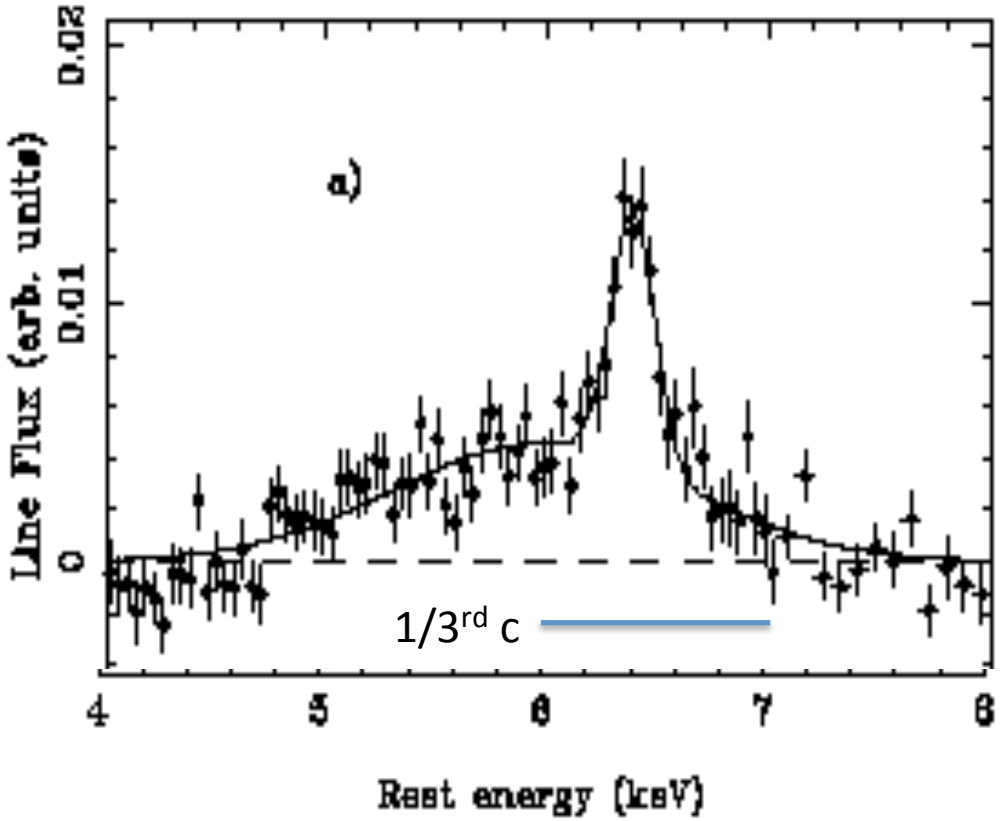




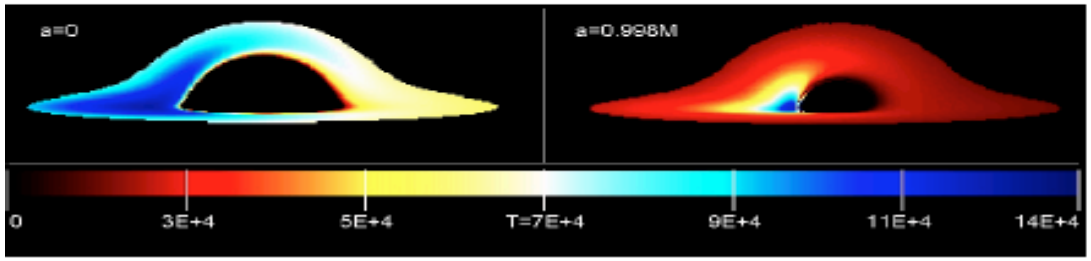
'Broad' Fe K ' Lines in AGN and Black Hole Binaries

Signature of Relativistic Motion

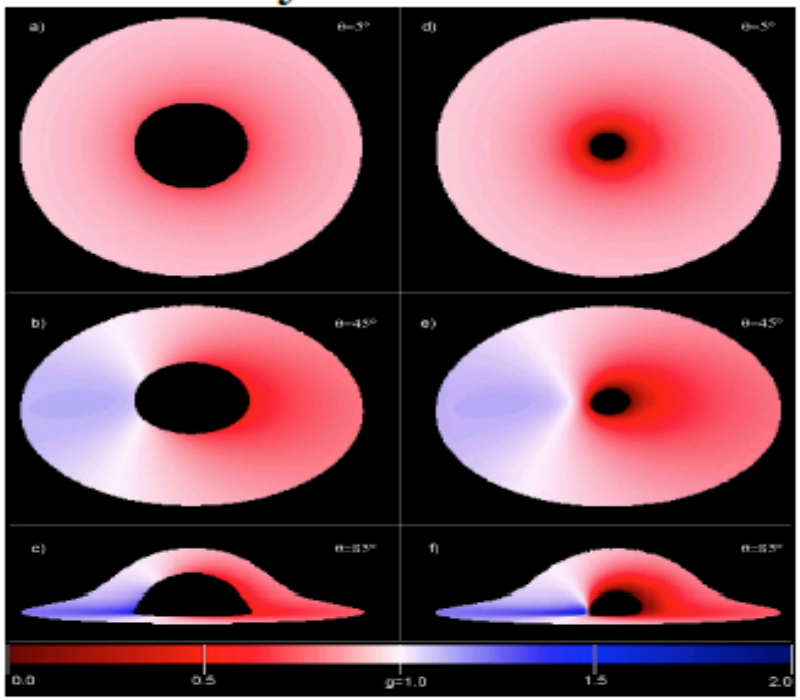
- **X-ray spectroscopy of AGN reveals an Fe K-line (transition in tightly bound electrons of Iron). Its rest-energy is 6.4 KeV**
- **Very broad (50.000km/s) line-profiles, offset to the red → gravitational redshift+ doppler broadening !**



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



Courtesy of M. Calvani



l. 2006; McClintock et al. 2006;
ota et al. 2010

Radio Loudness	Names and Properties		No Lines
Radio quiet (weak or no jet)	Type II (narrow forbidden lines) Seyfert 2	Type I (broad permitted lines) Seyfert 1 QSO	
Radio Loud (strong jet)- **ONLY in ELLIPTICAL Galaxies**	FR I NLRG FR II	BLRG	Bl Lac Blazars FSRQ
X-ray Properties	Highly Absorbed-strong narrow Fe K line, strong low E emission lines	Not absorbed- or ionized absorber often broad Fe K line-low energy spectrum with absorption lines	Featureless continuum-highly variable γ-ray sources

The End