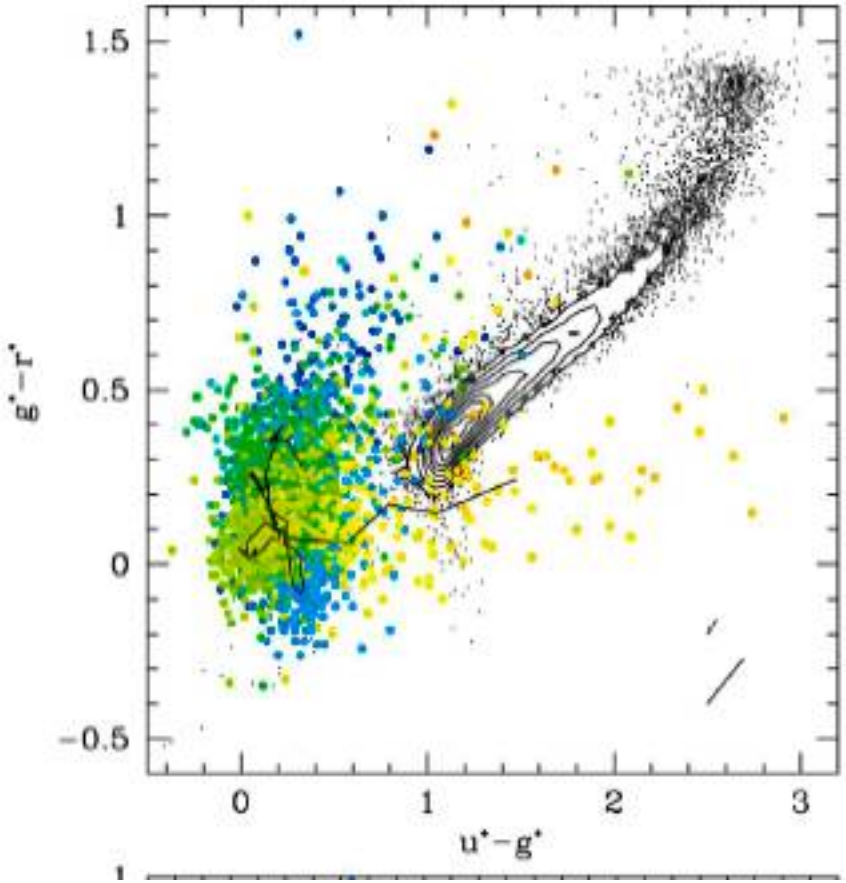
# AGN: Active Galactic Nuclei

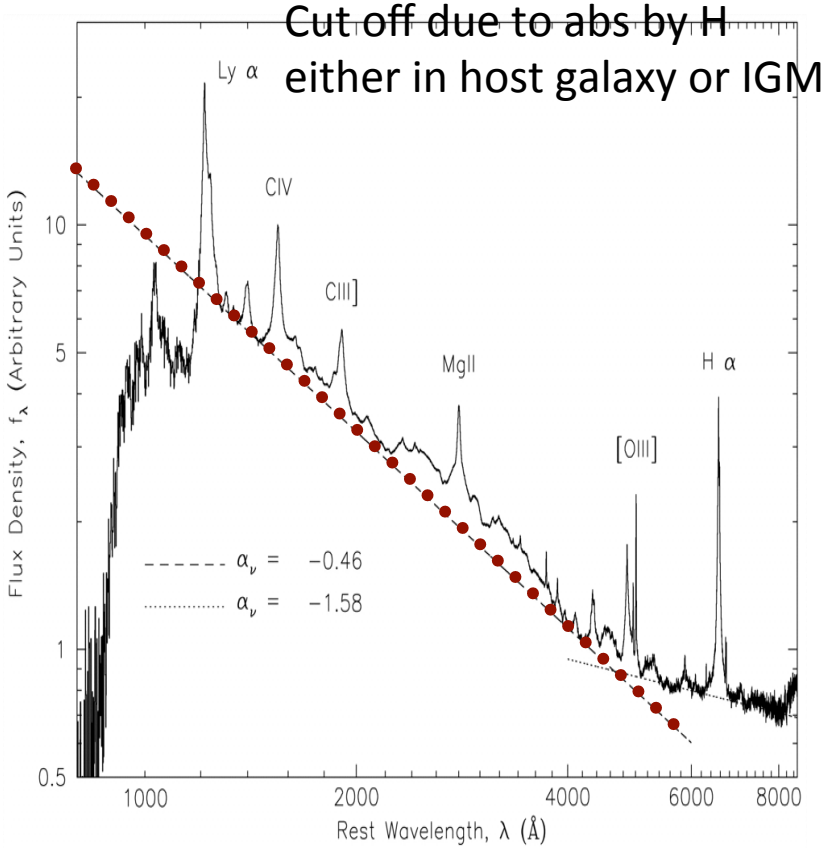
# Course evaluations are open
# Please Respond!

- www.courseevalum.umd.edu
- Why?
  - For the benefit of your peers
  - Because your comments count and we use it to improve our teaching and/or redesign the course
  - Because your opinion is used to evaluate our performance
- Don't put it off till Dec 14th!

# Optical Properties of AGN

- **Strong lines** of hydrogen, carbon, silicon ….



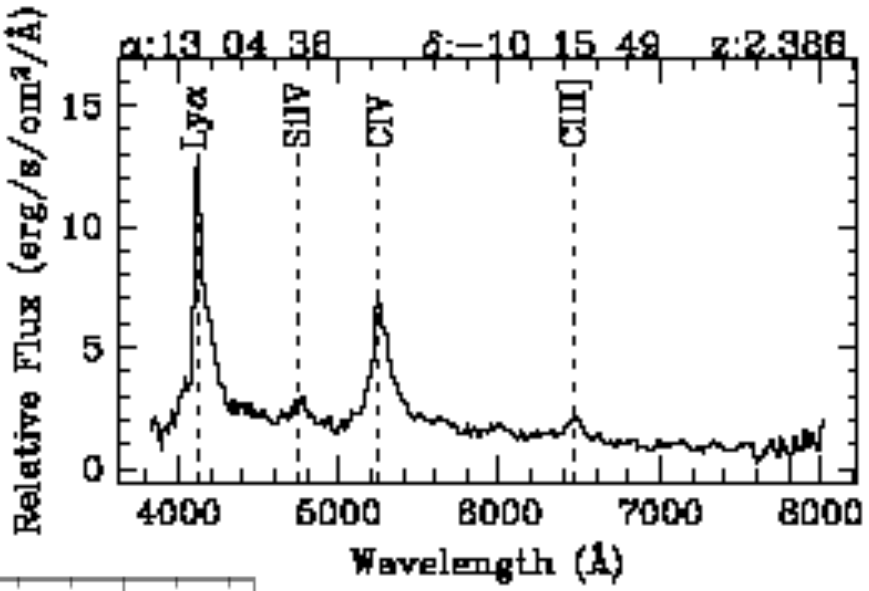

~~Cut off due to abs by H~~ either in host galaxy or IGM

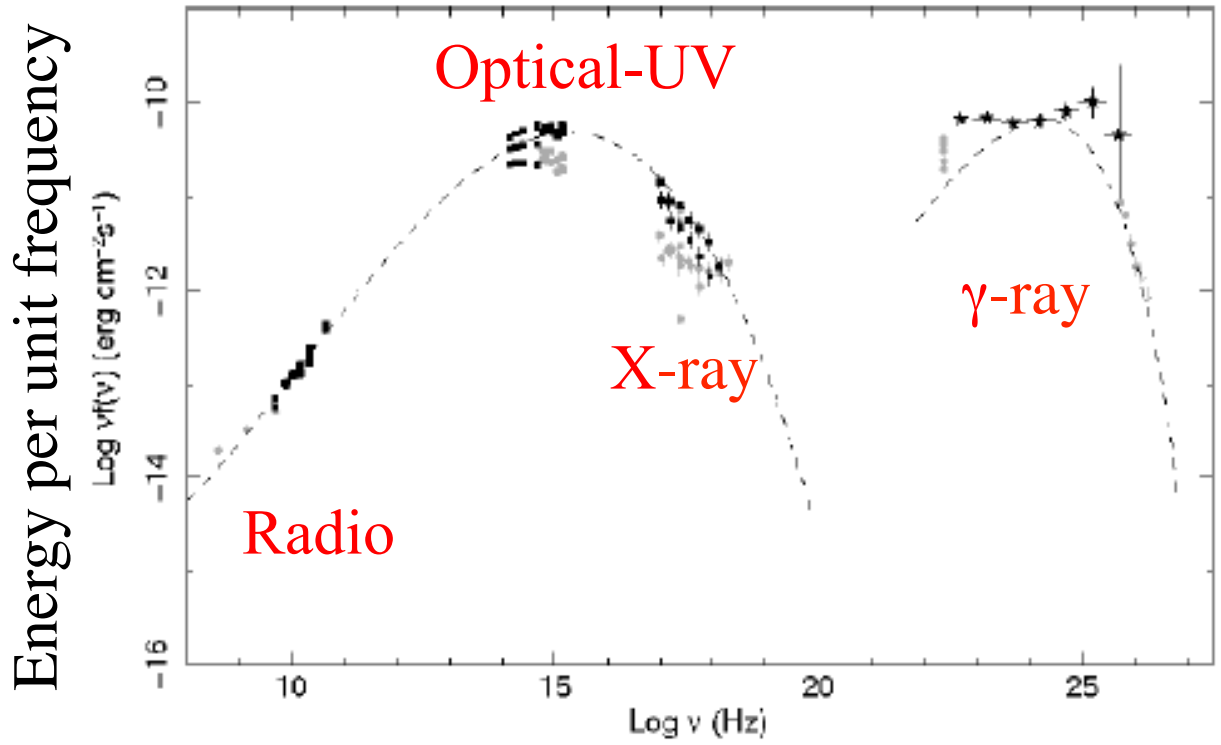
Unusual optical colors (Richards et al SDSS)- quasars in color, stars are black

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

# 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



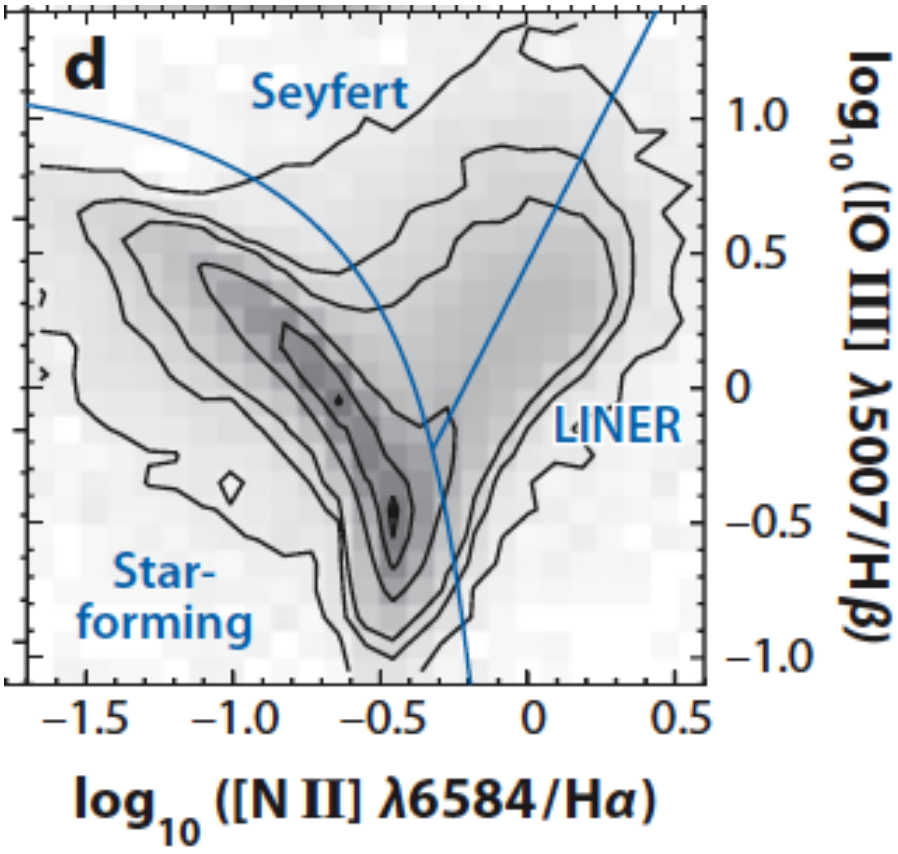




Broad band spectral energy distribution (SED) of a 'blazar' (an active galaxy whose observed radiation is dominated by a relativistic jet 'coming at' us)

A large fraction of the total energy appears in the γ-rays!

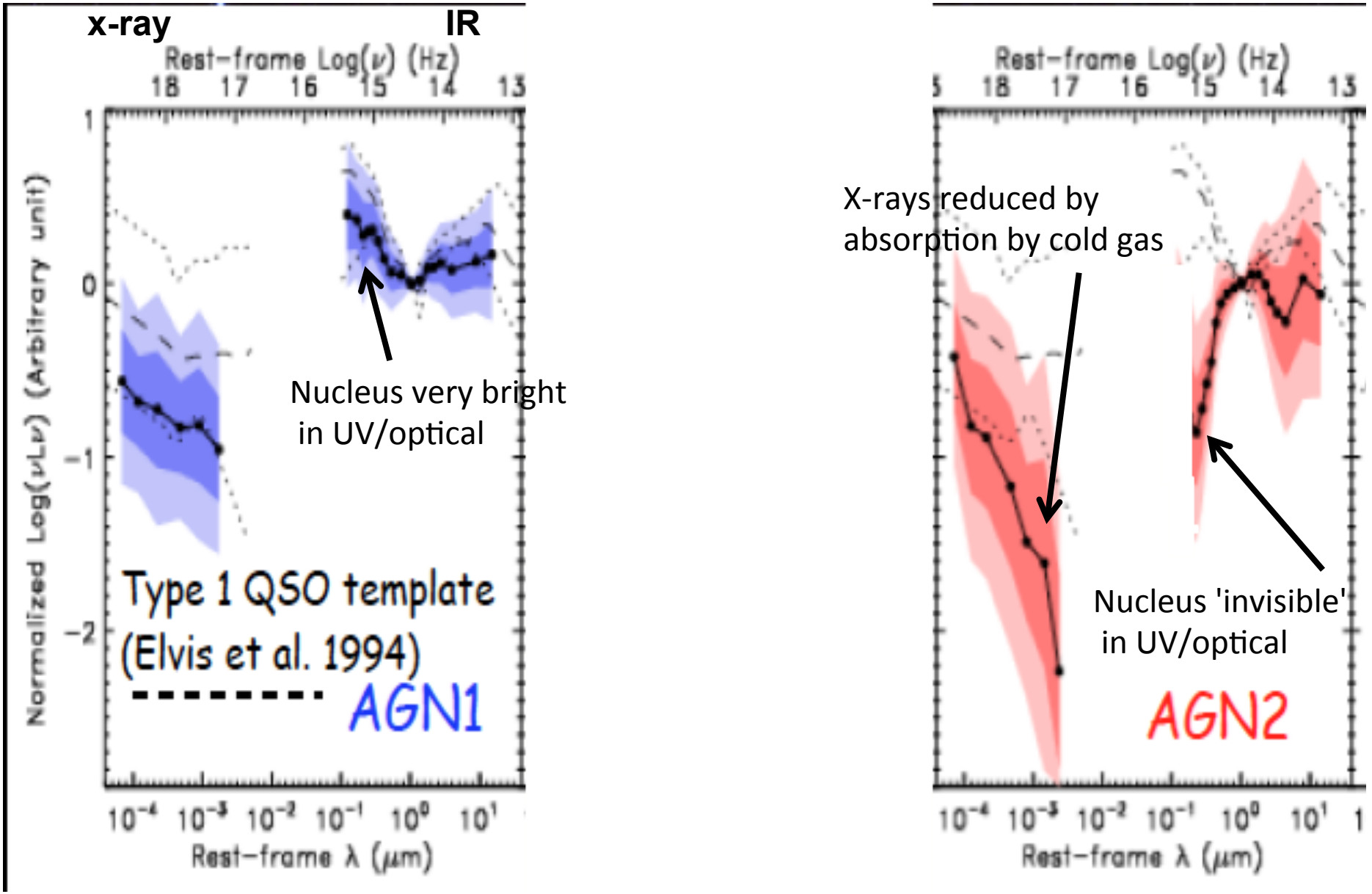
# Optical Emission Lines

- 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 region of this diagram Darkness of plot is log of the number of objects inside the contour

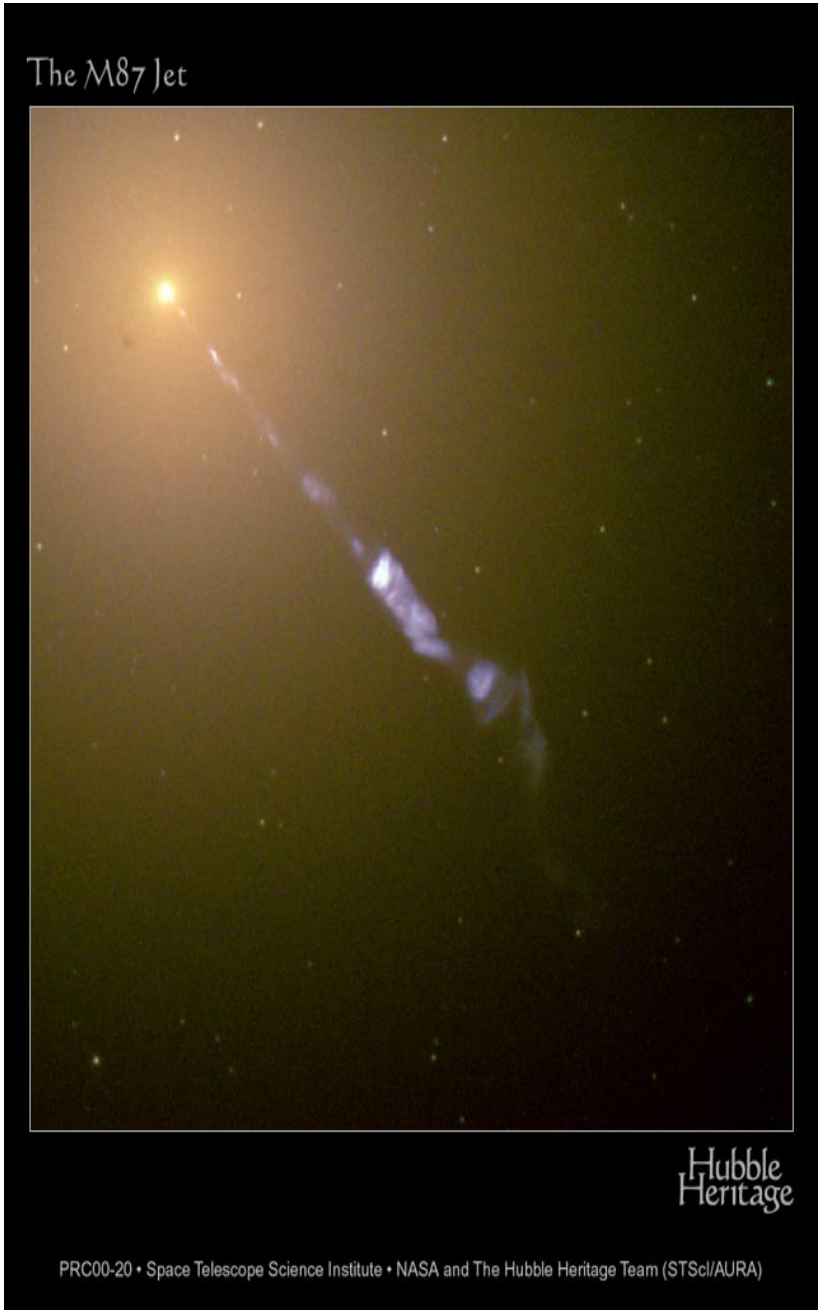
# Broad Band Continuum (IR-Xray)



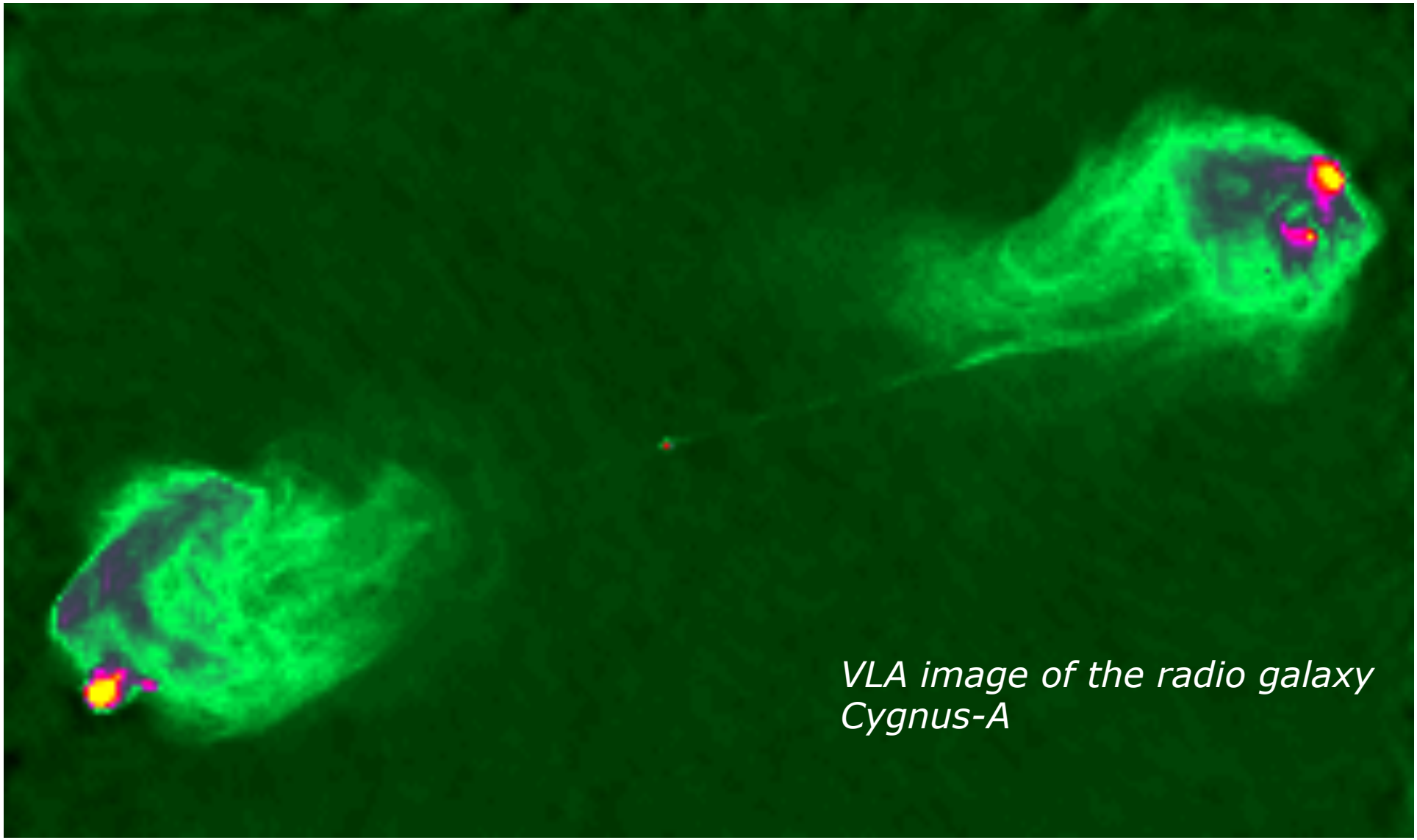
# Active Galactic Nuclei

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

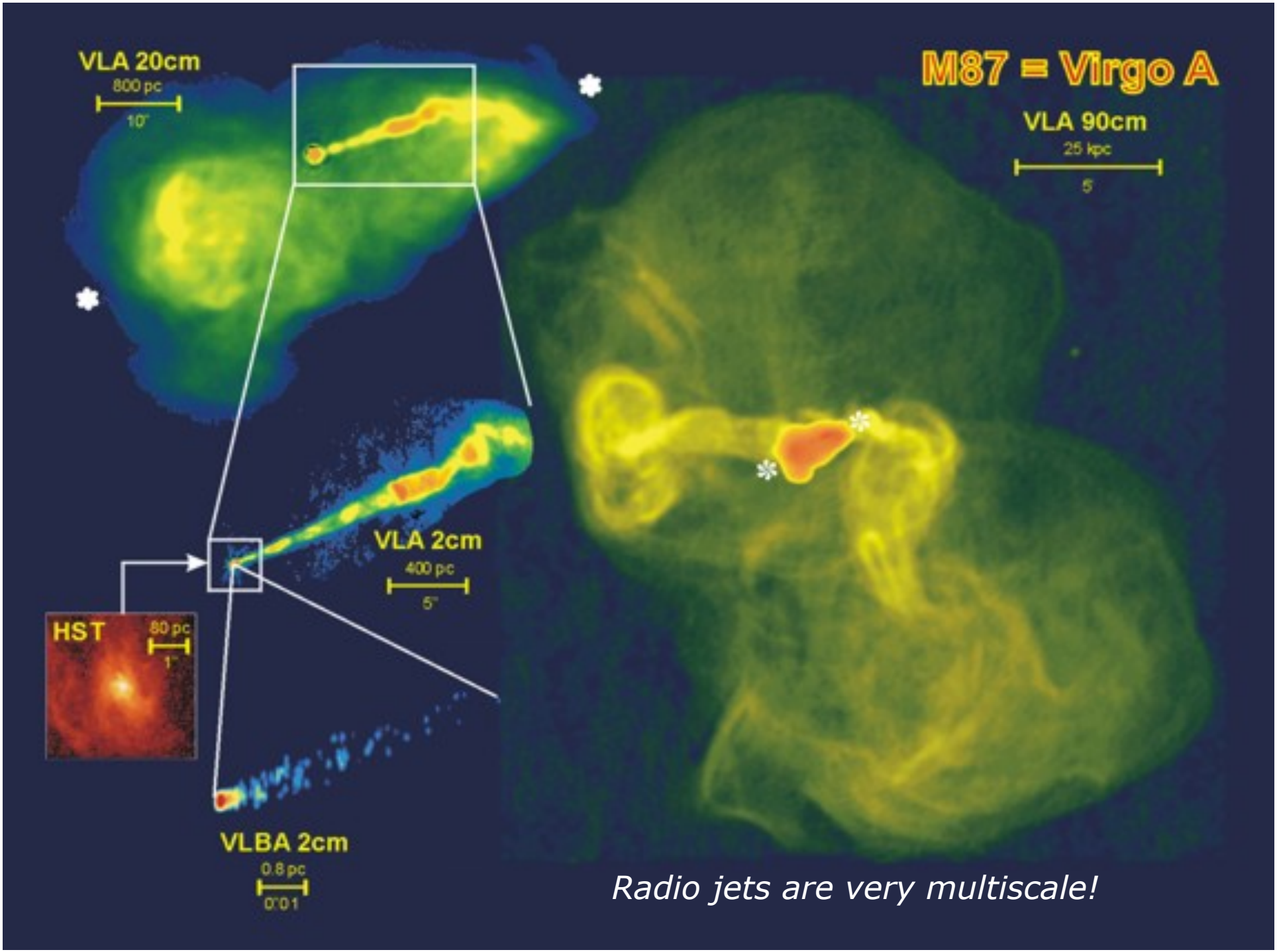
- The Jet
  - Jet of material squirted from vicinity of SMBH
  - Lorentz factor of >6
  - Can be very energetic (particle luminosity)
  - in radio to x-ray band jet radiation is primarily synchrotron (see text)- in gamma-ray it is inverse Compton
- What powers the jet?
  - Accretion power
  - Extraction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



# AGN 'Types'
# The Radio-loud/Radio-quiet Dichotomy

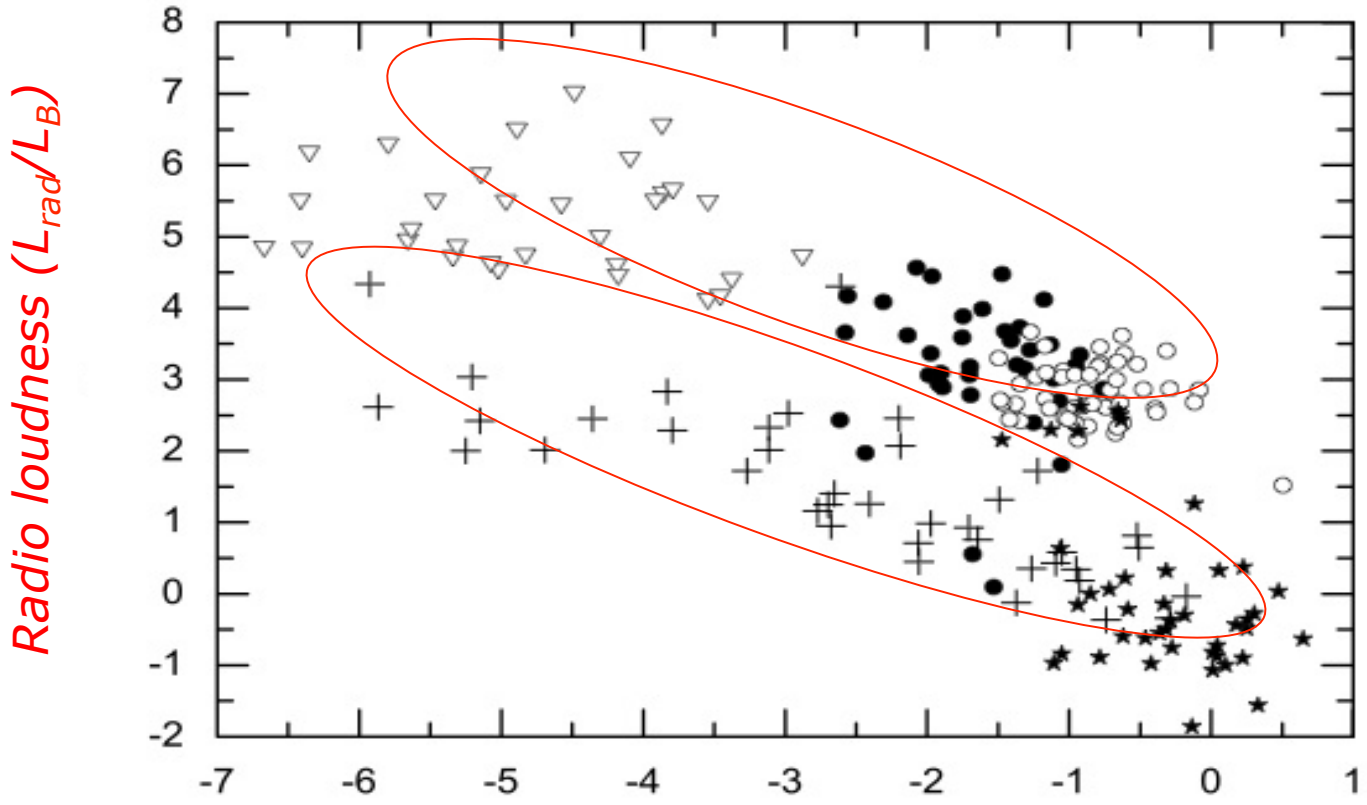


*VLA image of the radio galaxy Cygnus-A*


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!

# The Radio-loud/Radio-quiet dichotomy

Define relative importance of radio emission by ratio of radio luminosity $L_{rad}$ to optical luminosity $L_B$ - *8 order of magnitude range*

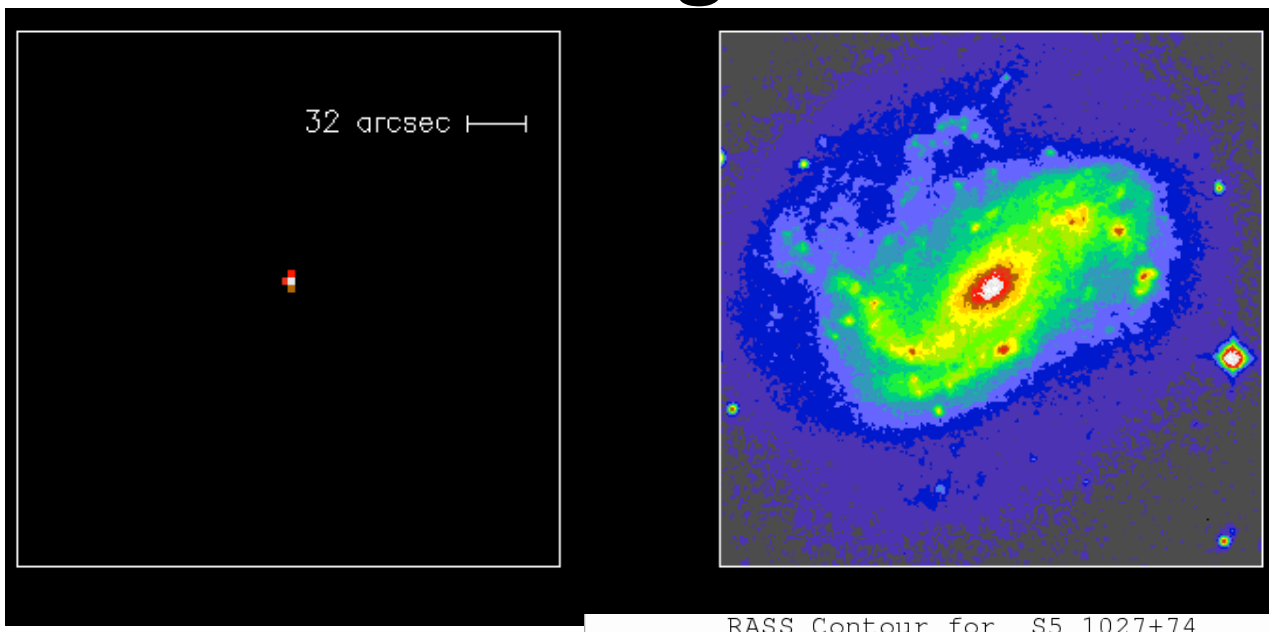



*Sikora et al. (2007)*

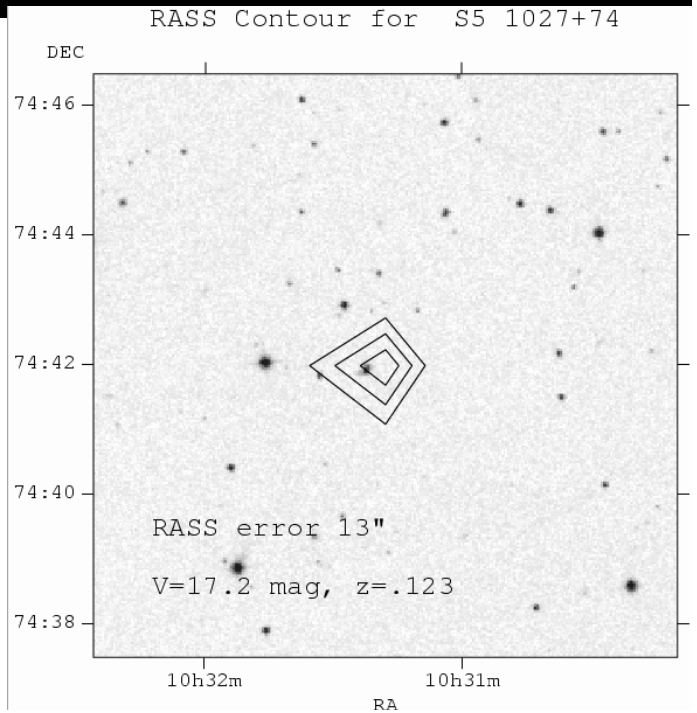
# X-ray Selection of Active galaxies

- 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

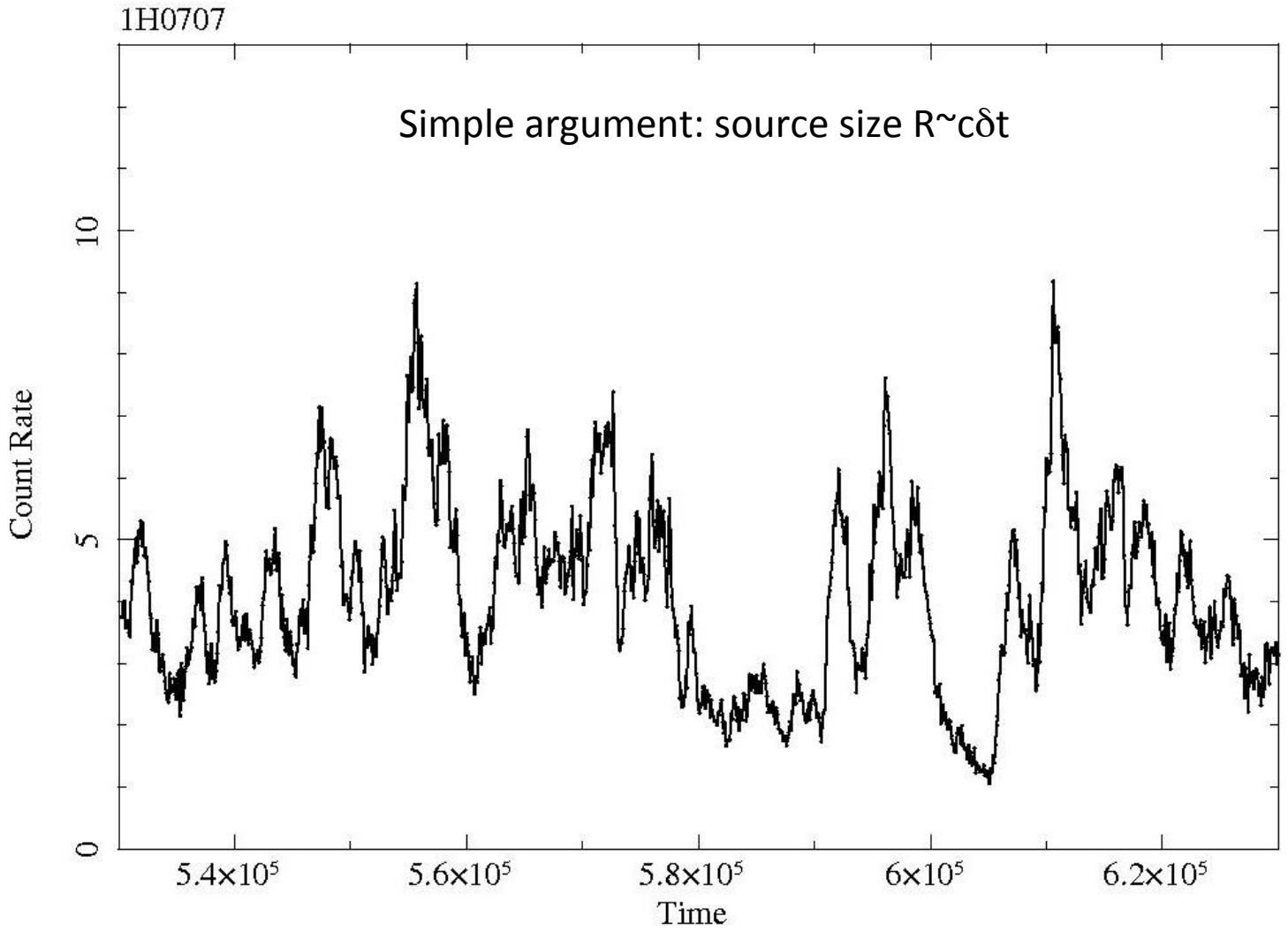



Rosat x-ray all sky survey image overlaid on sky survey image



# Rapid variability in AGN

## Source luminosity ~$5 \times 10^{43}$ ergs/sec

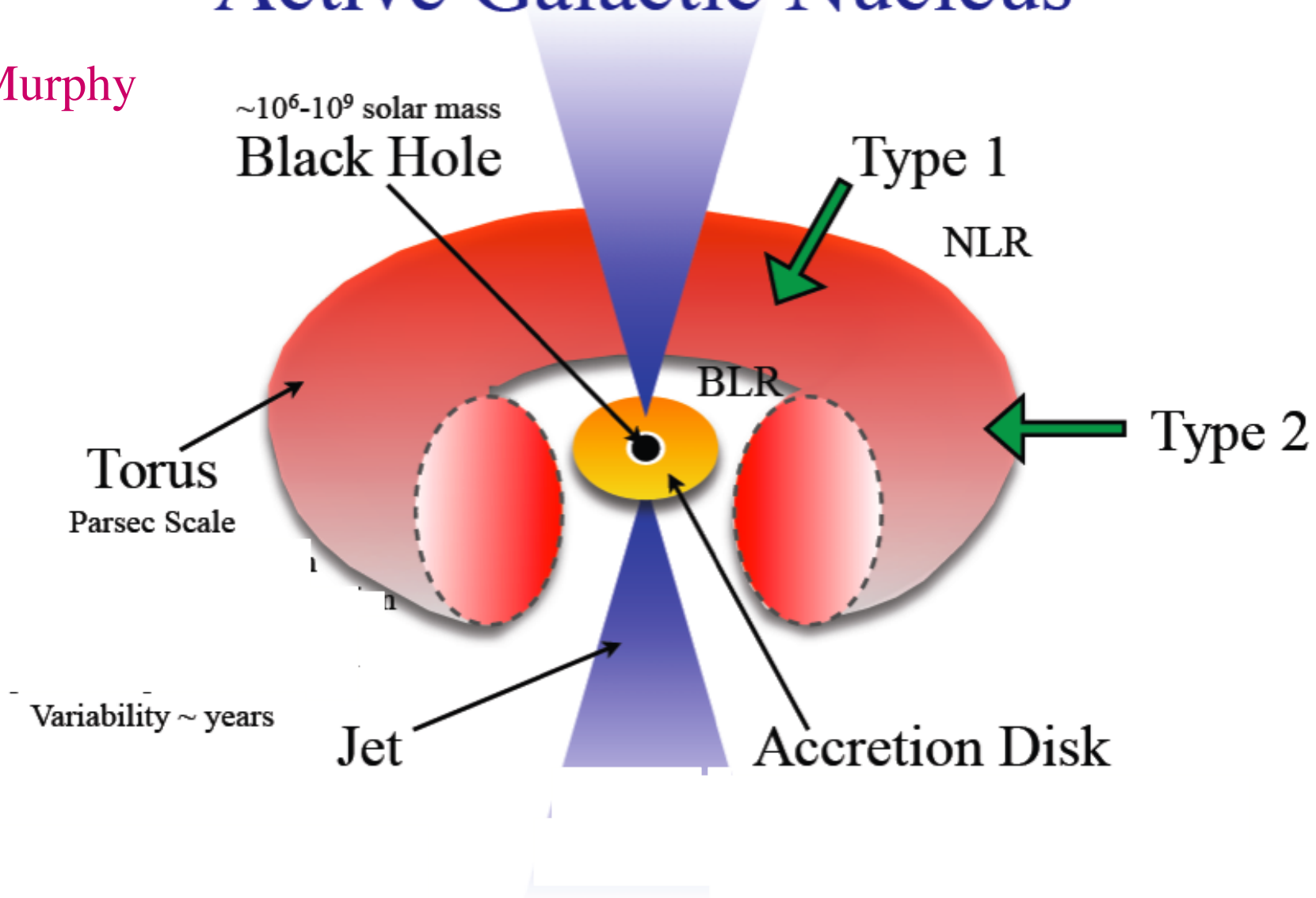


# Broad Range of Properties

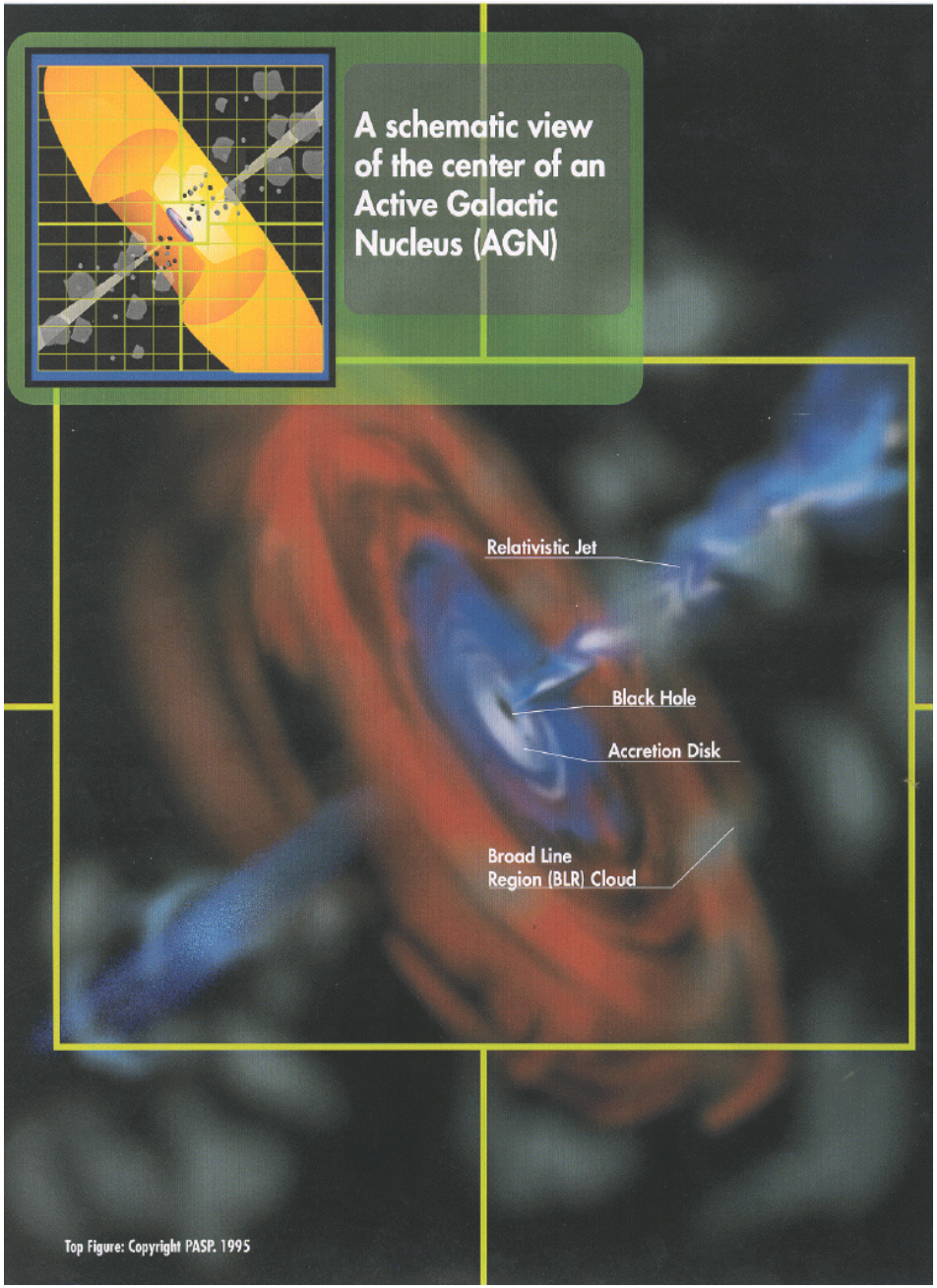
- Luminosity
  - Range from $<10^{40}$ erg/s to $\sim 10^{48}$ erg/s
  - Fundamental parameters controlling L are **black hole mass and mass accretion rate**
  - In most powerful objects (quasars) - AGN totally outshines host galaxy
- Level of obscuration - how much material is in our line of sight
  - In some objects, can see all of the way down to the SMBH (type 1)
  - In other objects, view at some wavelengths is blocked by obscuring material (some objects are blocked at all wavelengths) (type 2)
  - 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 (often possess weak jets)
  - Fundamental parameter controlling jet production **unknown** **(maybe black hole spin; or magnetic field configuration)**

# Active Galactic Nucleus

K. Murphy



# Model of Central Region of AGN



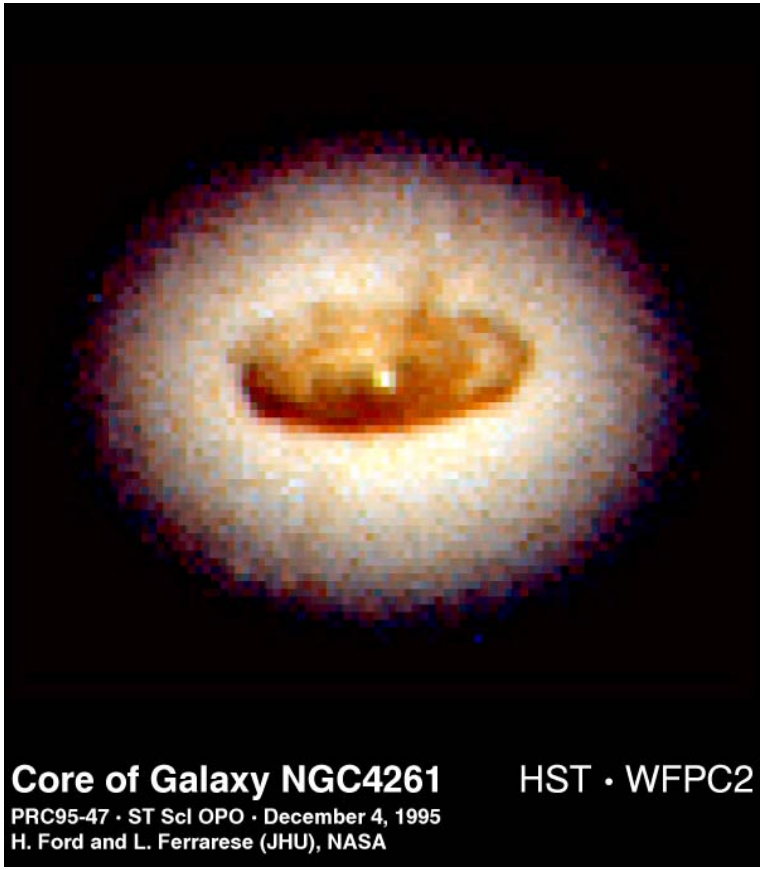

| Source | Distance from central source |
|---|---|
| X-Ray Fe K$\alpha$ | 3-10 $R_S$ |
| Broad-Line Region | 600 $R_S$ |
| Megamasers | $4 \times 10^4$ $R_S$ |
| Gas Dynamics | $8 \times 10^5$ $R_S$ |
| Stellar Dynamics | $10^6$ $R_S$ |

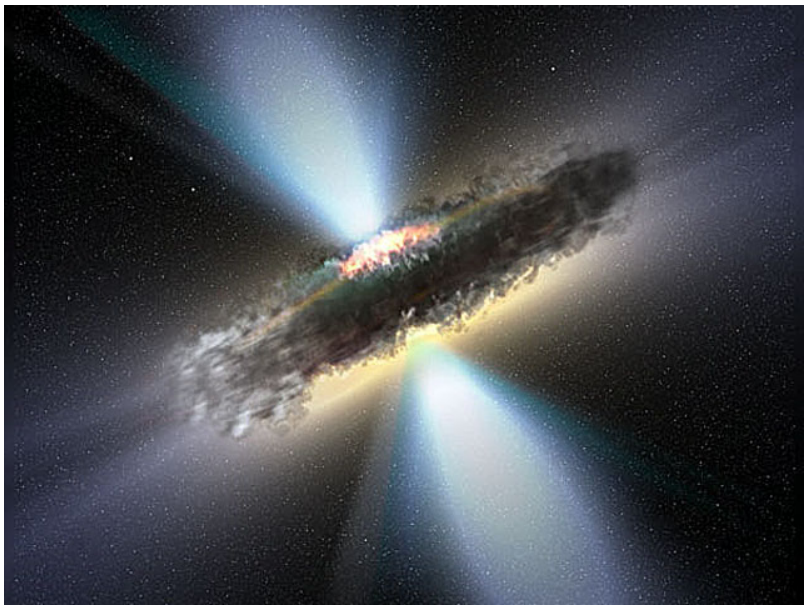
$R_s$= Schwarschild radius=$2GM/c^2$

$R_s=1.4\times10^{13}M_8$cm; $R_s/c\sim500M_8$ sec

# 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

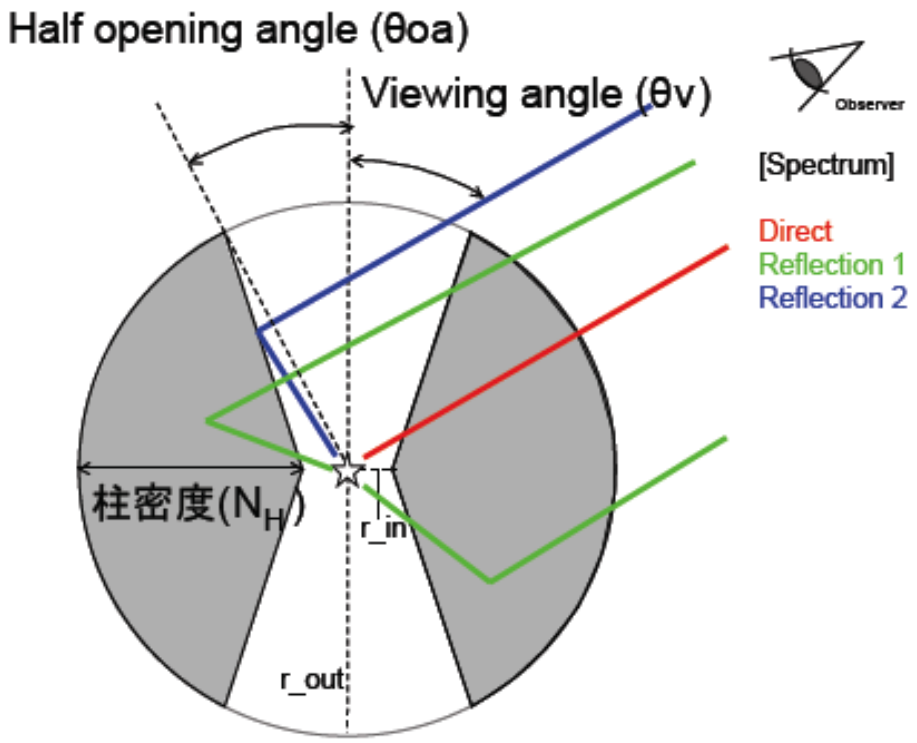


Physical conditions in obscuring regions are not the same from object to object - can be complex with large and unpredictable effects on the spectrum

# AGN Zoo

- 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 Accretion Disk are hidden by the dust




- However there are other complications like jets and a range in the geometry
- 'Radio loud' objects- e.g. with strong jets and/or luminous extended radio emission lie ONLY in elliptical galaxies!

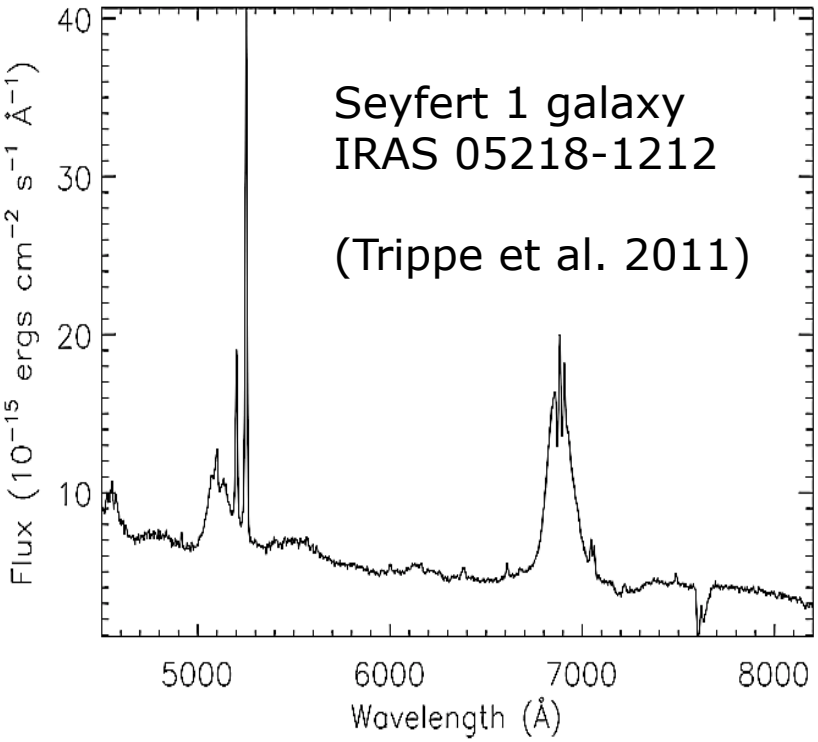
| **Radio Loudness** | **Optical Emission Line Properties** | | |
|---|---|---|---|
| | **Type 2** (Narrow Line) | **Type 1** (Broad Line) | **Type 0** (Unusual) |
| Radio-quiet: | Seyfert 2 | Seyfert 1<br>QSO | |
| Radio-loud: | NLRG { FR I / FR II | BLRG<br>SSRQ<br>FSRQ | Blazars { BL Lacs / (FSRQ) |
| | decreasing angle to line of sight -> | | |

**Table 1:** AGN Taxonomy: A Simplified Scheme.

# AGN Types

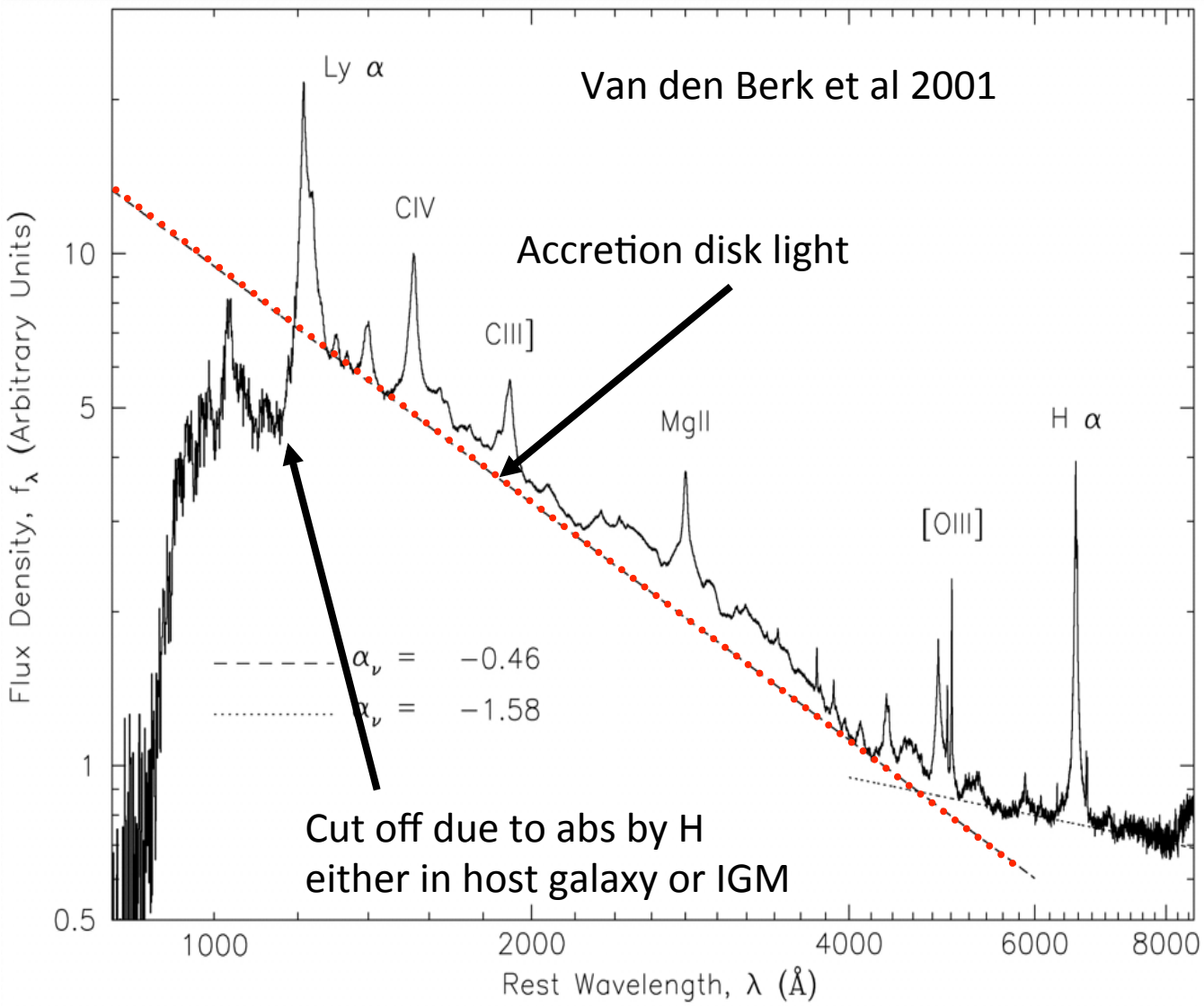
## Broad line (type-1) objects

- '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 'feature less continuum' with strong 'broad' lines superimposed
- Typical velocity widths ($\sigma$, the Gaussian dispersion) are ~2000-5000km/sec
- The broad range of ionization is due to the 'photoionization' 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

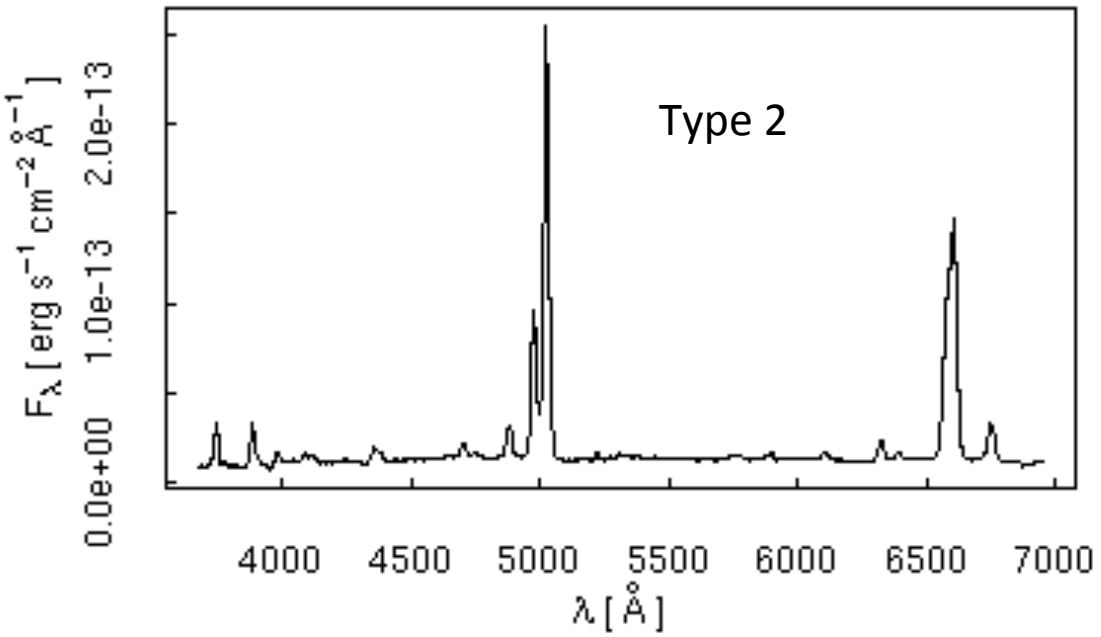
# AGN Types
## Narrow line (type-2) objects

- 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 ($N_H > 10^{22} cm^{-2}$)**
- Intermediate type objects (type-1.2, 1.5, 1.8, 1.9) have obscurers which become transparent at sufficiently long/short wavelengths

# Type 2 AGN

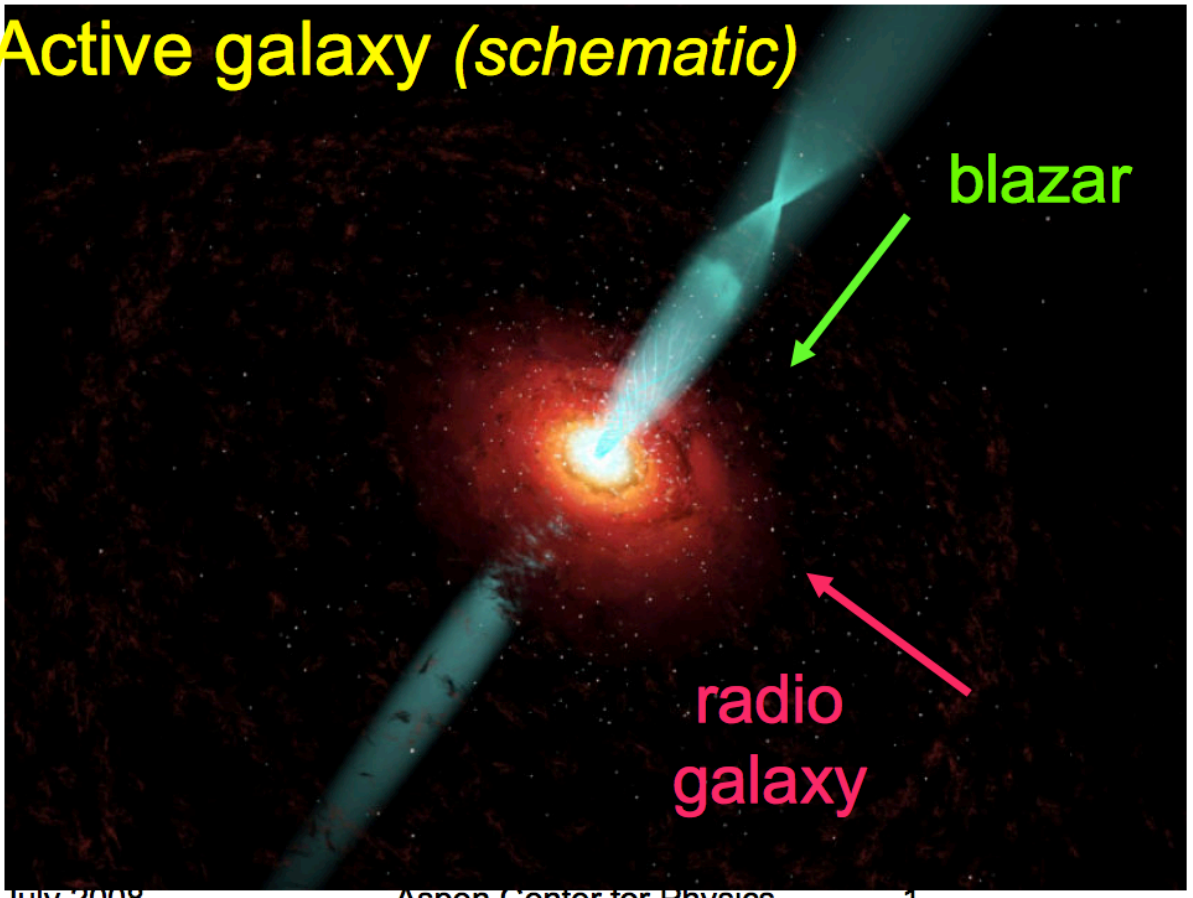
- Type 2 **<u>do not</u> have broad lines and have a weak or absent 'non-stellar' continuum**

- **Depending on the type of survey and luminosity range ~50% of all AGN are of type 2**



# 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



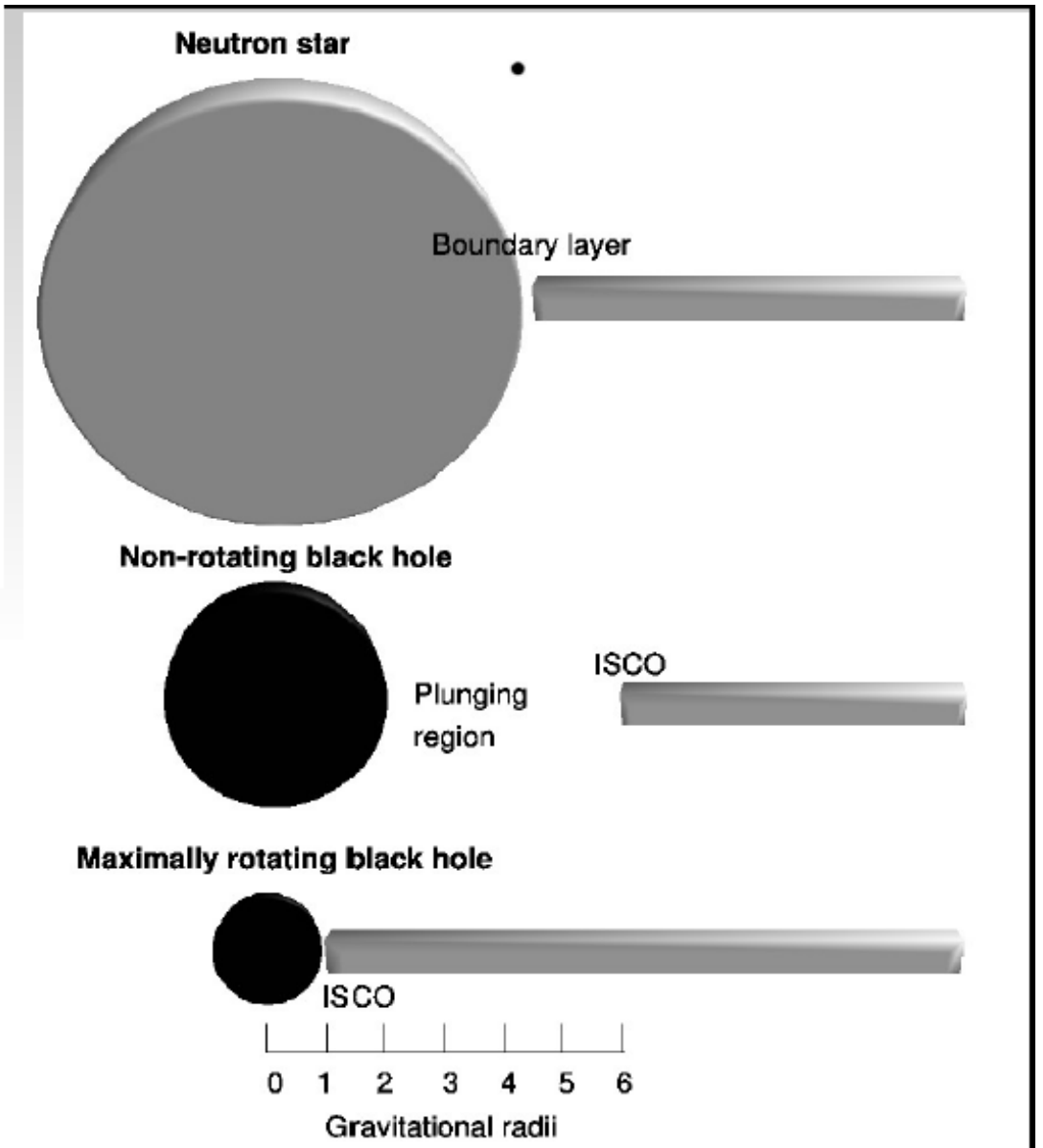
| Radio Loudness | Names and Properties | | No Lines |
|---|---|---|---|
| Radio quiet<br>(weak or no jet) | Type II (narrow forbidden lines)<br>Seyfert 2 | Type I (broad permitted lines)<br>Seyfert 1<br>QSO | |
| Radio Loud (strong jet)-<br>**ONLY in ELLIPTICAL Galaxies** | FR I<br>NLRG<br>FR II | BLRG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

**table 27-2 | Properties of Active Galactic Nuclei (AGNs)**

| Object | Found in which type of galaxy | Strength of radio emission | Type of emission lines in spectrum | Luminosity (watts) | Luminosity (Milky Way Galaxy = 1) |
|---|---|---|---|---|---|
| Blazar | Elliptical | Strong | Weak (compared to synchrotron emission) | $10^{38}$ to $10^{42}$ | 10 to $10^5$ |
| Radio-loud quasar | Elliptical | Strong | Broad | $10^{38}$ to $10^{42}$ | 10 to $10^5$ |
| Radio galaxy | Elliptical | Strong | Narrow | $10^{36}$ to $10^{38}$ | 0.1 to 10 |
| Radio-quiet quasar | Spiral or elliptical | Weak | Broad | $10^{38}$ to $10^{42}$ | 10 to $10^5$ |
| Seyfert 1 | Spiral | Weak | Broad | $10^{36}$ to $10^{38}$ | 0.1 to 10 |
| Seyfert 2 | Spiral | Weak | Narrow | $10^{36}$ to $10^{38}$ | 0.1 to 10 |

- Some of the different classes of AGN are truly different 'beasts' - (e.g. radio loud vs radio quiet) ***but***
- Much of the apparent differences are due to geometry/inclination effects- this is called the Unified Model for AGN (e.g. type I vs Type I radio quiet objects, blazars - radio loud objects observed down the jet)
- The ingredients are: the black hole, accretion disk, the jet, some orbiting dense clouds of gas close in (the broad line region), plus a dusty torus that surrounds the inner disk, some less dense clouds of gas further out (the narrow line region) (adapted from T. Treu)

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