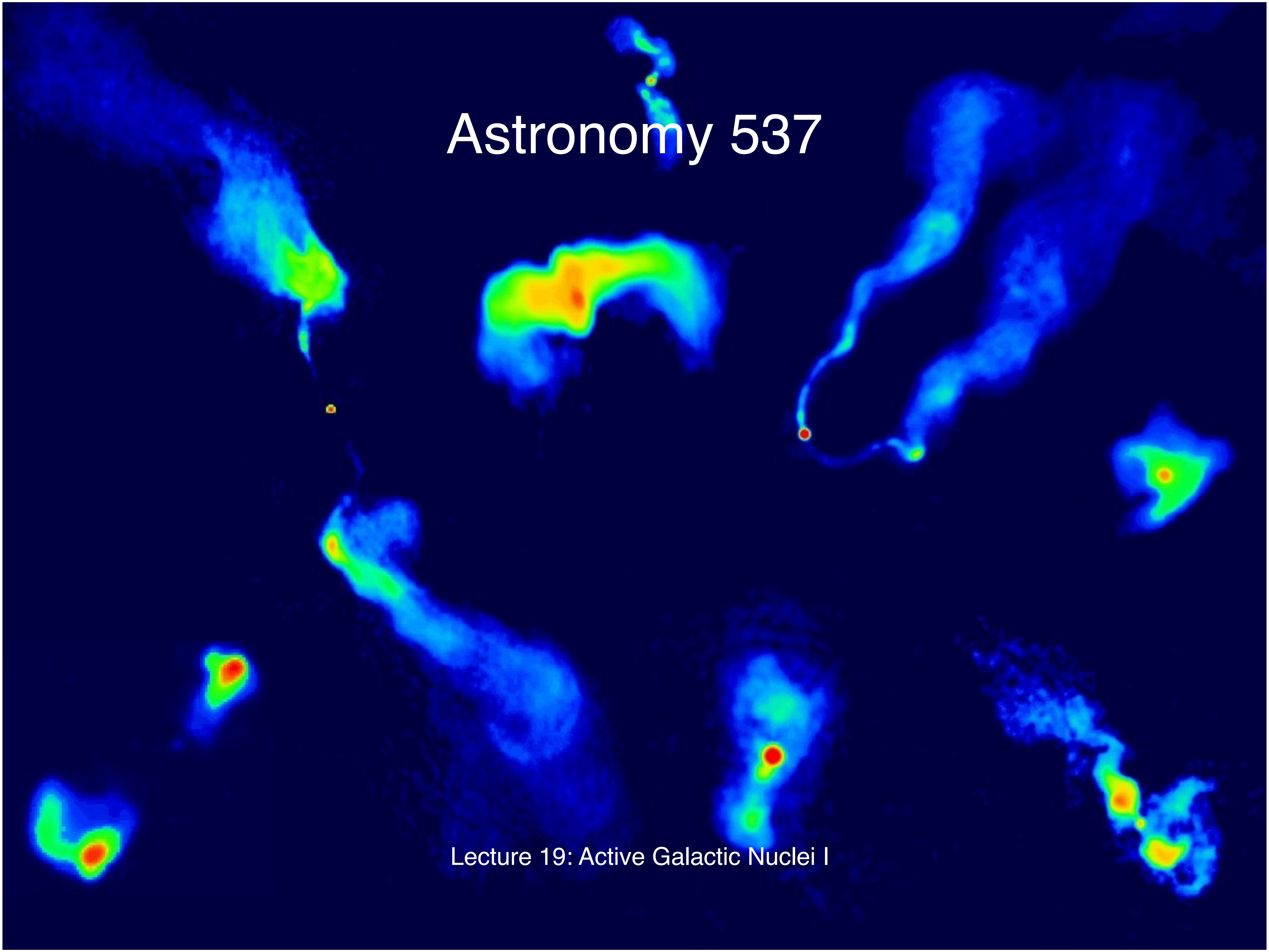
Astronomy 537

Lecture 19: Active Galactic Nuclei I



Announcements:

Monday (4/13): Discuss paper #9 – shadow of a black hole
Wednesday (4/15): Draft Lecture slides due

Today: Active Galaxies

Active galaxies

AGN are the nuclei of galaxies which show energetic phenomena that can not clearly and directly be attributed to stars.

- Signs of AGN activity
  - ?

Active galaxies

AGN are the nuclei of galaxies which show energetic phenomena that can not clearly and directly be attributed to stars.

- Signs of AGN activity
  - Luminous UV emission from a compact region
  - Very broad emission lines
  - Variability on time scales of days to months
  - Strong non-thermal emission
  - Compact radio core
  - Extended linear radio structures (jets, hotspots)
  - X-ray, gamma-ray and TeV emission
  - Cosmic ray production

- Not all AGN show all of these signs, but all AGN exhibit some

Background

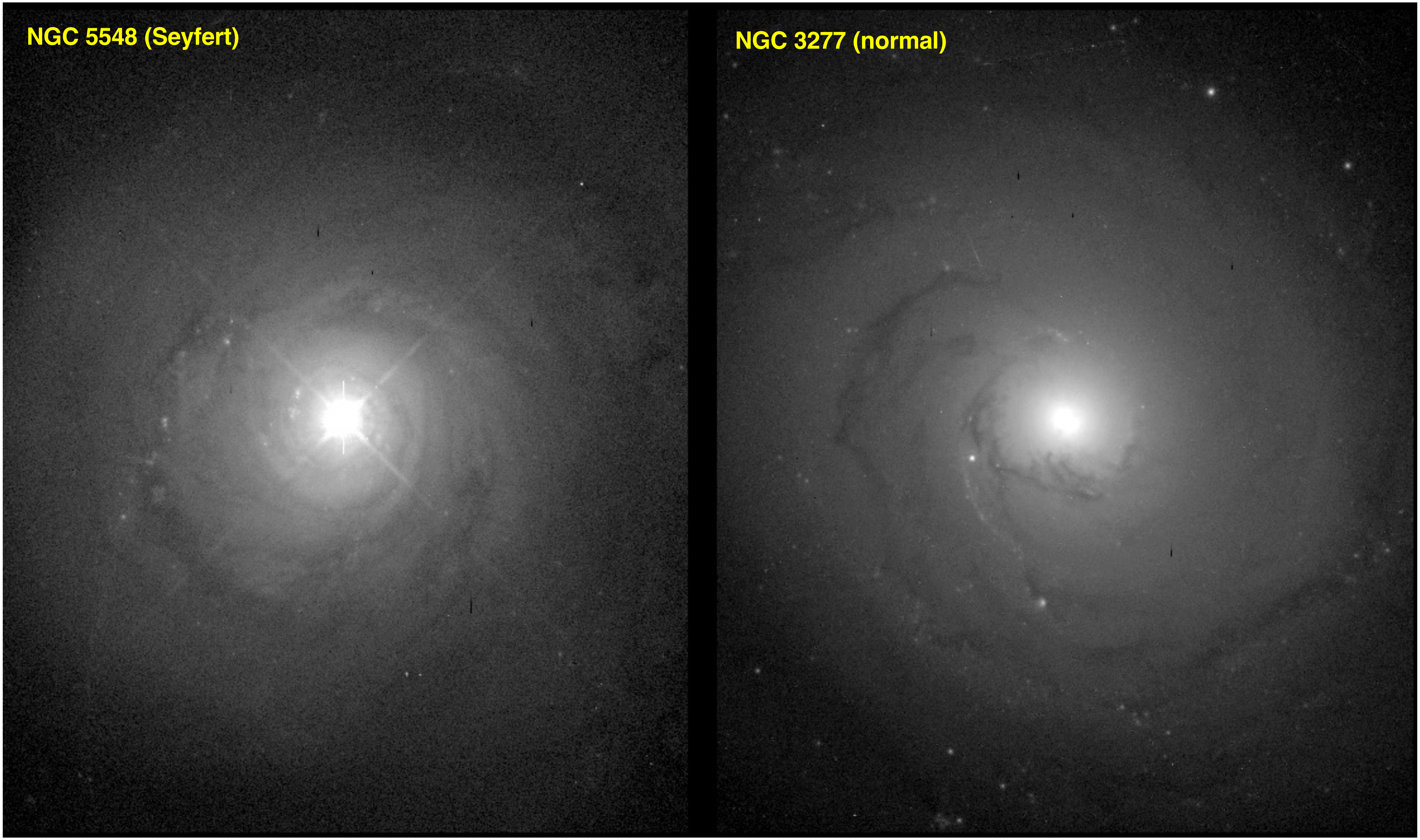
- Two main classes of AGN hosts:
  - Seyfert galaxies - often in spirals, $L \sim L_{gal}$
  - Quasars - often in ellipticals, L up to 100 L_{gal}

- First evidence of strange activity in the spiral galaxy NGC1068 in 1908. Fath & Slipher found strong emission line similar to PNe, with widths of several 100 km/s.

  - Why is this strange?
  - What type spectrum does a normal spiral show?

- Now, NGC1068 is classified as a *Seyfert galaxy*.

Seyfert vs Normal Galaxy



More observations of Seyfert galaxies

- 1943 Carl Seyfert finds more galaxies similar to NGC1068 (hence the name)

- 1955 Detection of radio emission from NGC1068 and NGC1275

- 1959 Woltjer draws several conclusions on Seyferts:

  - Unresolved nuclei (<100 pc)

  - Nuclear emission lasts for $>10^8$ years
    - 1/100 spirals are Seyferts

  - Nuclear mass is very high if emission-line broadening is caused by bound material ($M \sim v^2 r/G \sim 10^{9\pm1}\ M_\odot$)

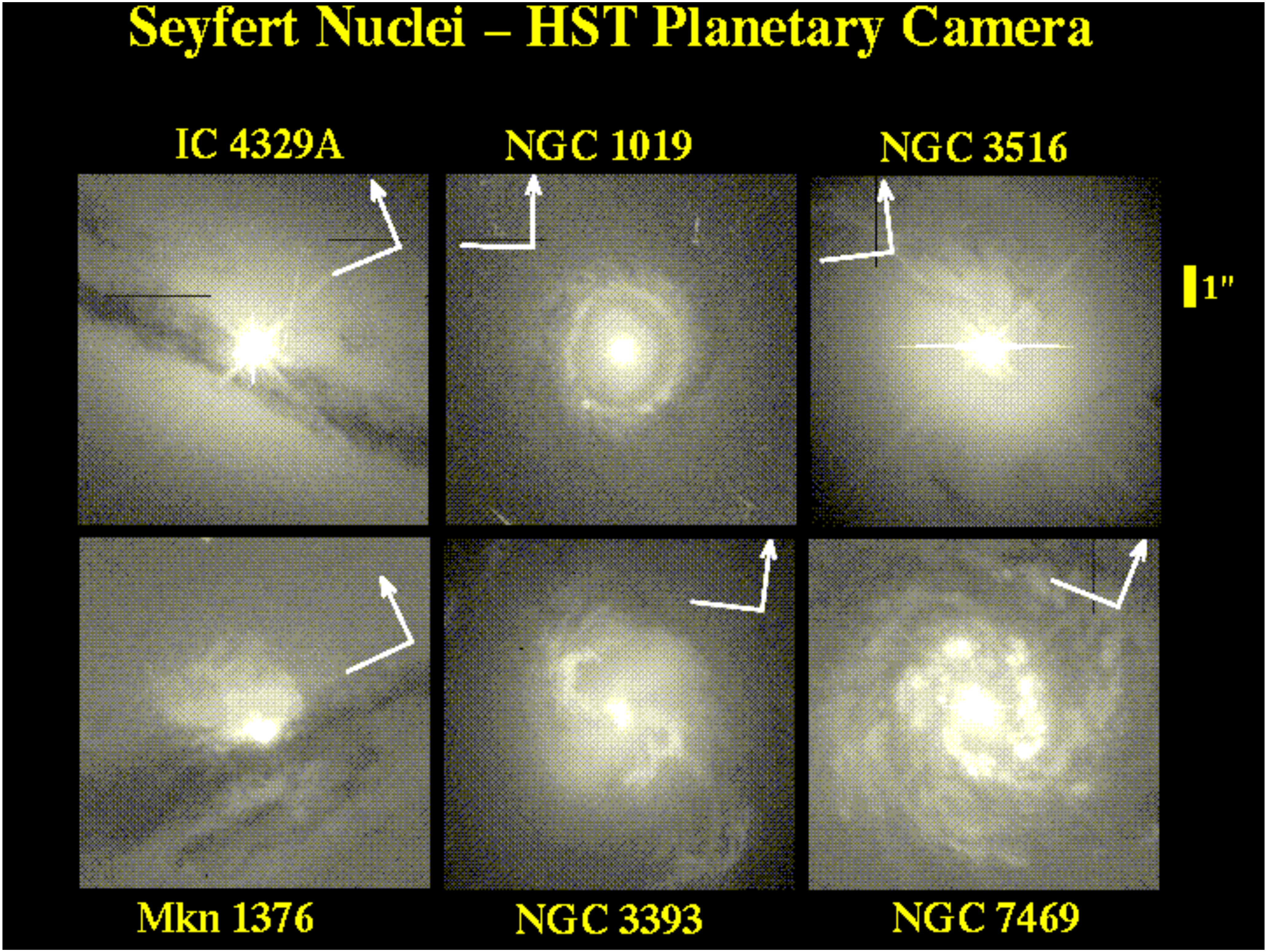
Two slightly different classes of Seyferts found. In addition to the original one (called Seyfert 1) we also have Seyfert 2s:

- Seyfert 2
  - Spectra show narrow lines (not broad)
  - Both permitted and forbidden lines are present
  - V~500 km/s

- Continuum: both types also show continuum radiation from a compact central source. This continuum is brighter for Seyfert 1s.

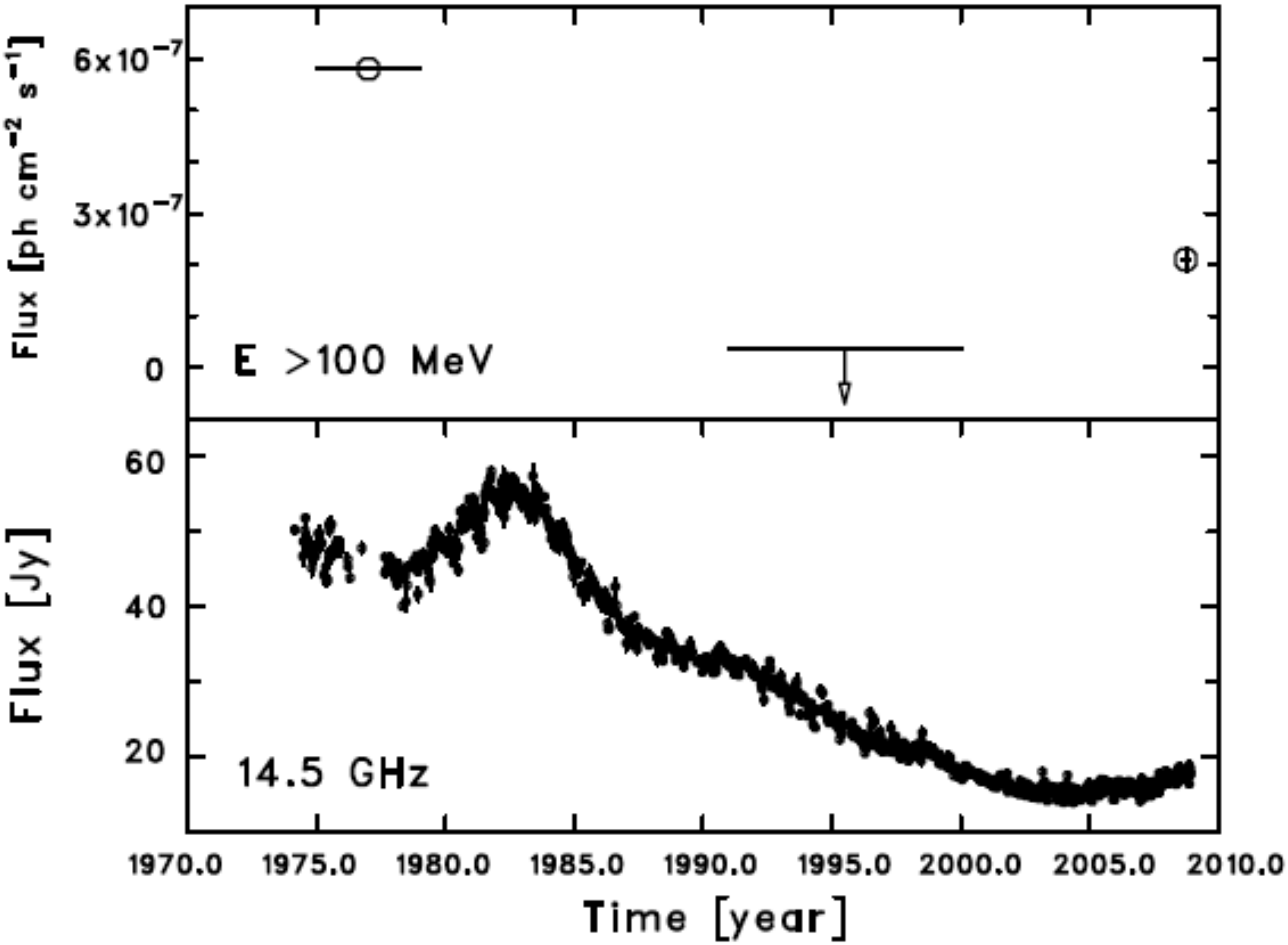
- X-rays: Seyfert 1s are also bright in X-rays, which can vary rapidly.

- Both types most often look like spirals, with bright, unresolved central source.


Seyfert Nuclei – HST Planetary Camera
IC 4329A
NGC 1019
NGC 3516
1"
Mkn 1376
NGC 3393
NGC 7469

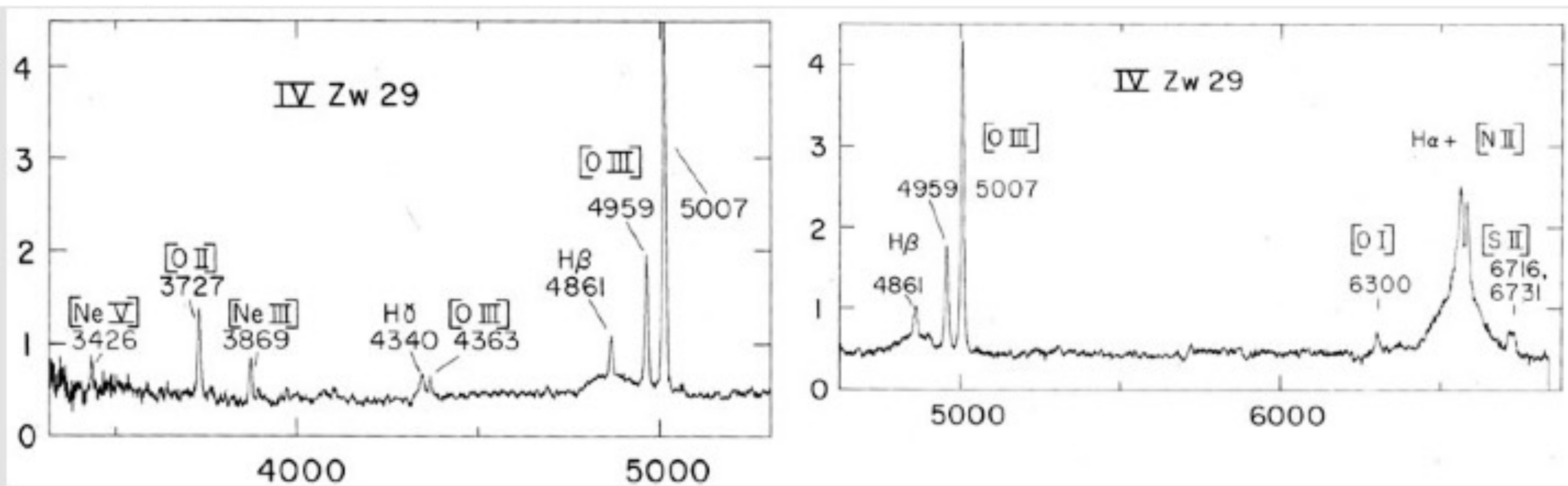
Variability

3C84



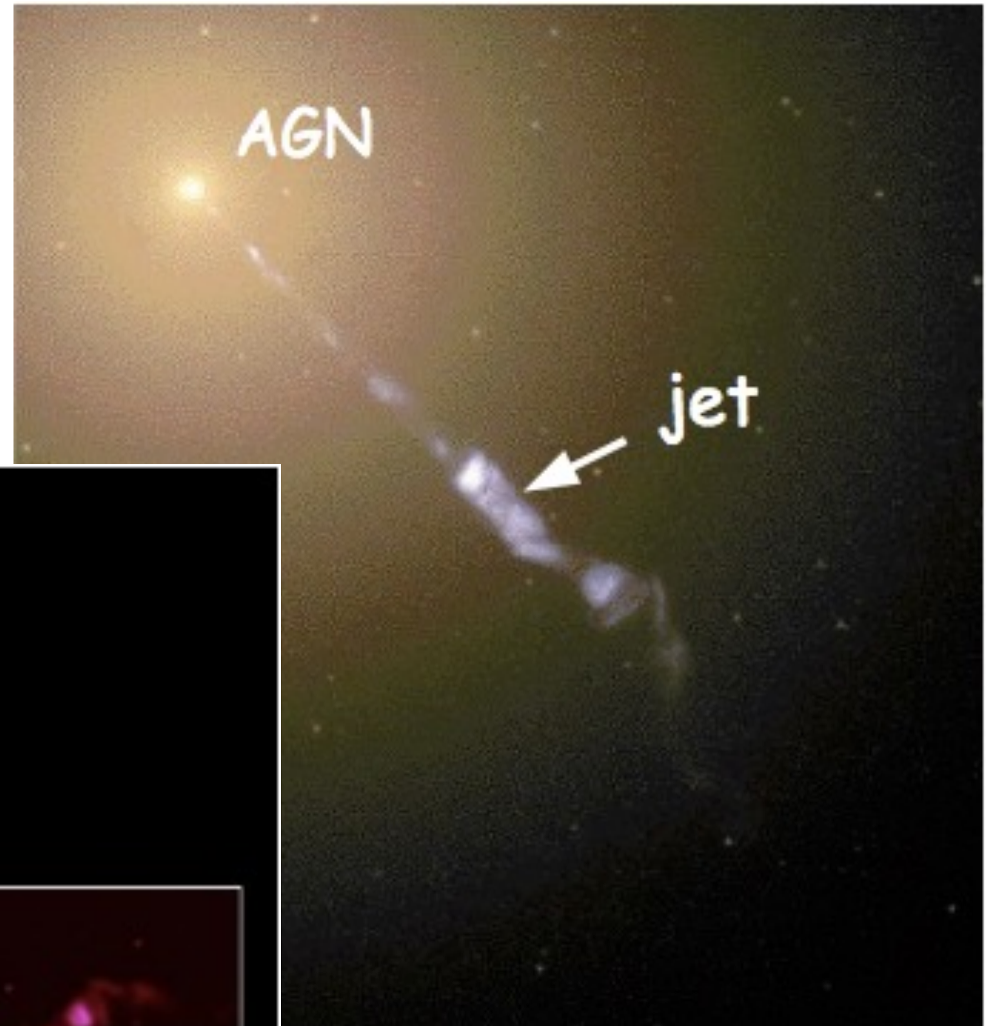
- Seyfert 1:Spectra show broad and/or high-excitation emission lines.
  - Both allowed and forbidden lines.
  - From the presence of forbidden lines, what can you say about density?

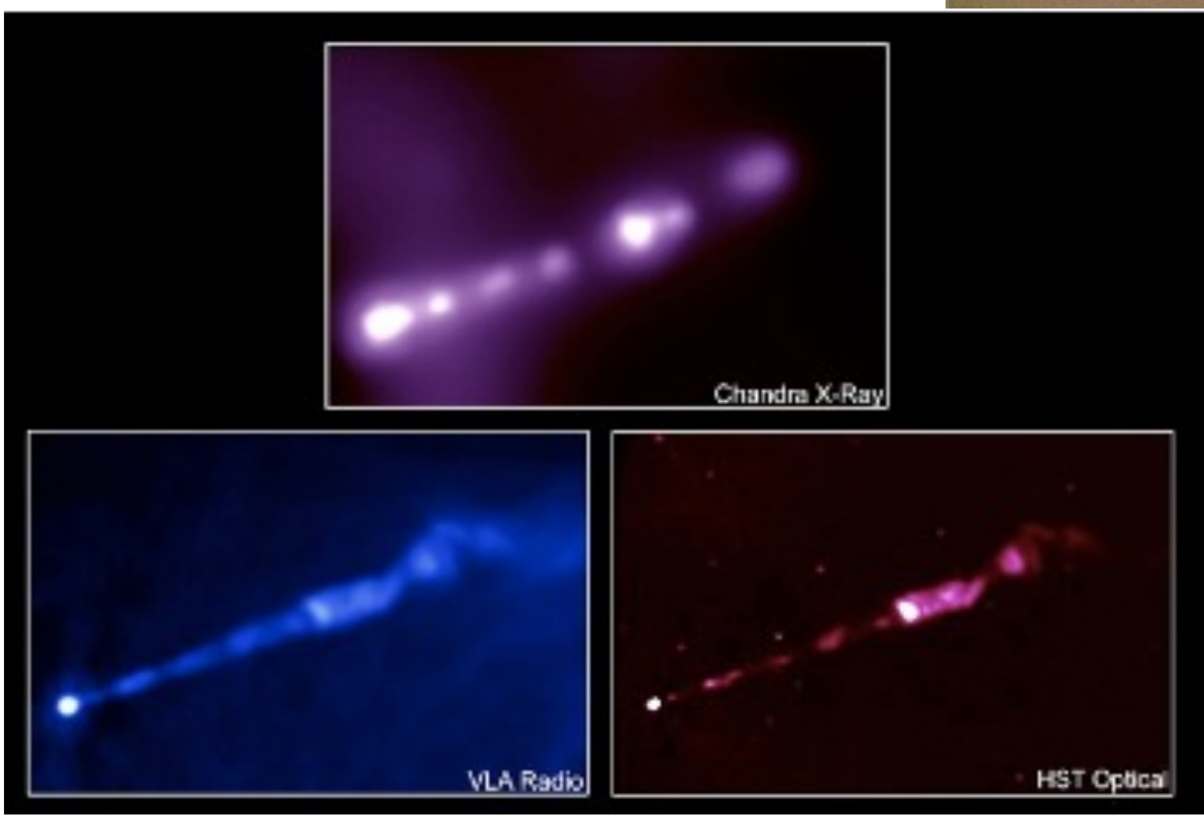
- Width attributed to Doppler broadening:
  - Allowed V~1000-5000 km/s
  - Forbidden V~500 km/s



Detections of optical jets

First made in 1913 by Curtis in M87





First radio surveys

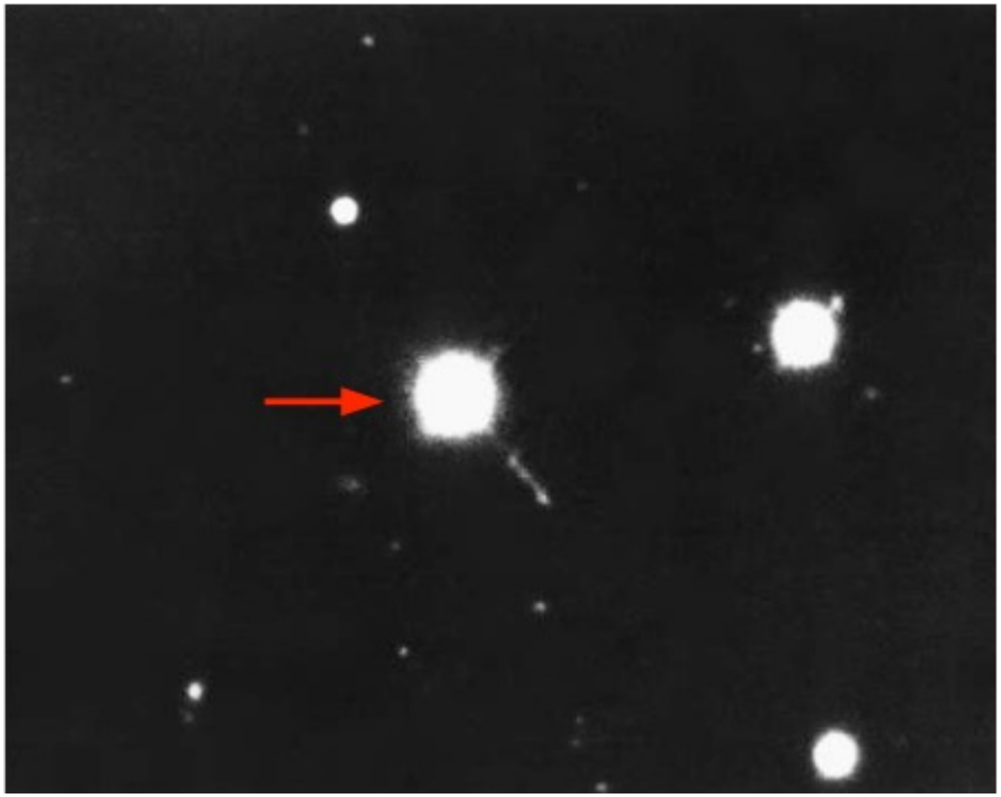
Early radio surveys played an important role in the discovery of quasars.

- 3C and 3CR: Third Cambridge Catalog (Edge et al 1959) at 159 MHz.
- Parkes (Australia, Ekers et al 1959) survey of southern sky at 408 MHz and 1410 MHz
- 4C: 4th Cambridge survey (latest one 8C). Deeper and smaller.
- AO: Arecibo occultation survey (Hazard et al 1967). Occultation by the Moon

- Sources found:
  - Surveys excluded Galactic Plane
  - Mostly normal galaxies (thermal emission of spiral galaxies like MW)
  - "Stars" with strange, broad emission lines

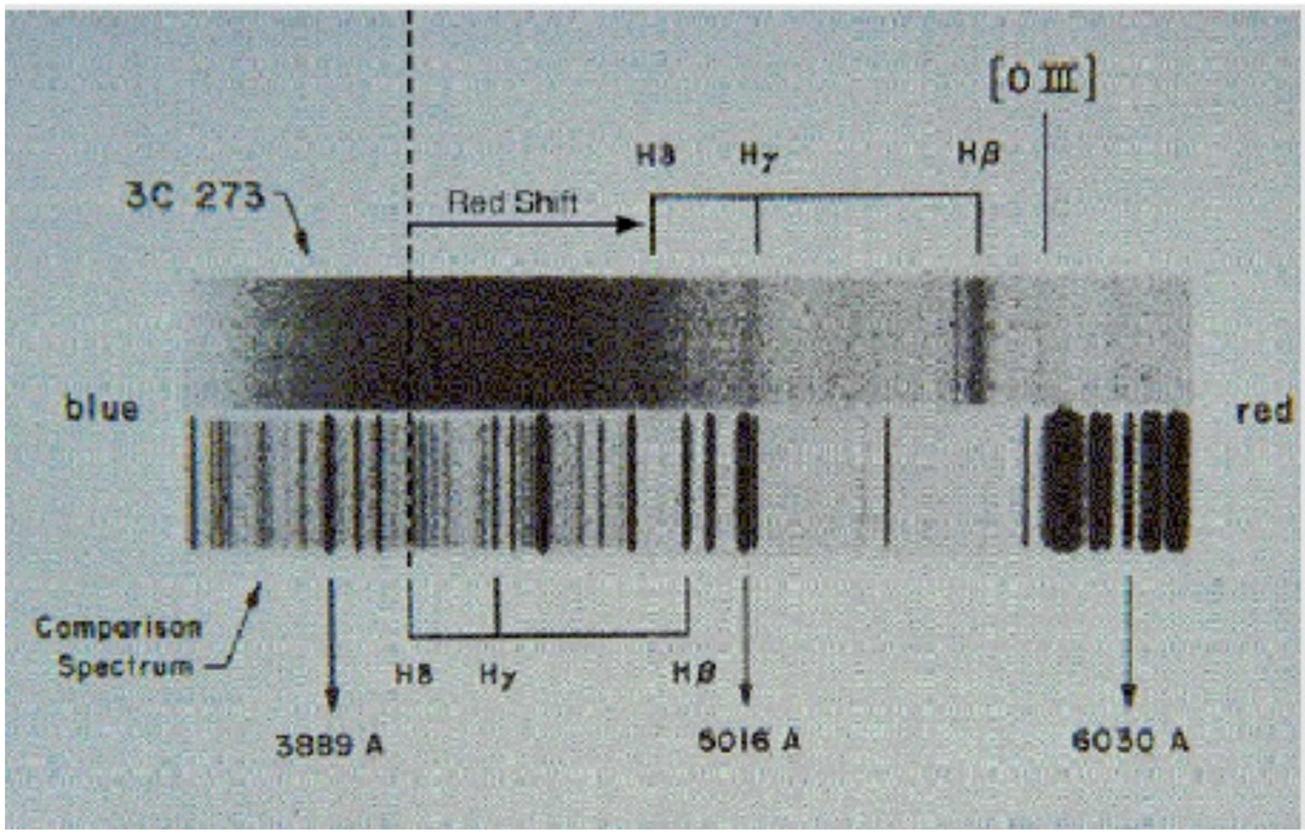
3C273

The 273rd radio source in the Cambridge catalog: a compact radio source that looks like a star except for a 'wisp' of light.



Their optical counterparts are "starlike", thereby the name "quasi-stellar radio sources", or quasars.

Broad emission lines at odd positions



Why is this object at redshift z=0.158 so special?

$$z = \frac{\Delta\lambda}{\lambda_0}$$

$$d = \frac{cz}{H_0} \simeq 470 h^{-1}\,\mathrm{Mpc}$$

$$m - M = 5\log(d/pc) + 5$$

$$m_B = 13.1\,\mathrm{mag} \;\; \Rightarrow \;\; M_B = -23.3 + 5\log h^{-1}$$

This is almost 100 times brighter than normal galaxies!!!

Optically, quasars have unresolved nuclei in a surrounding 'fuzz'. The nuclei are VERY bright, up to L~10^5 L_{MW}!

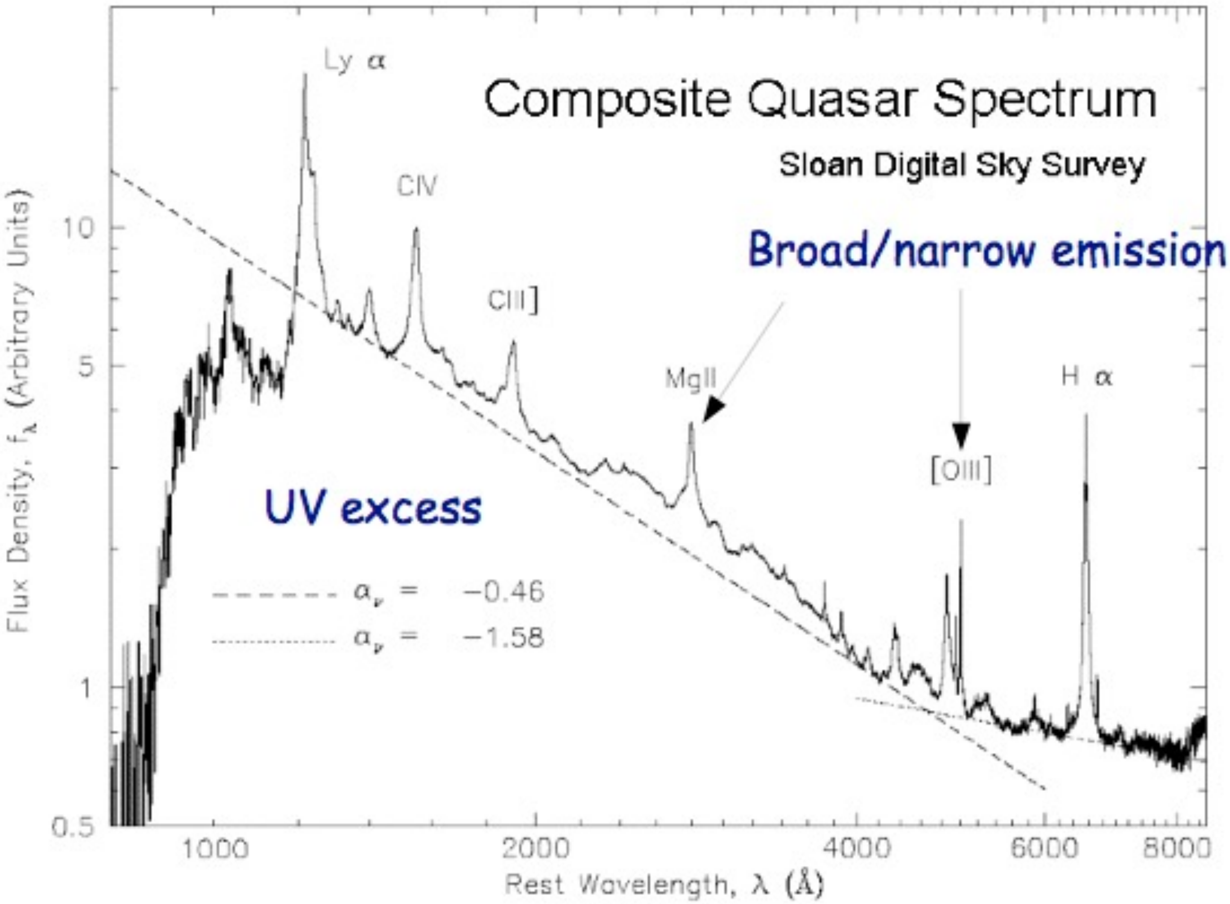
1964: Maarten Schmidt studied several quasars and found that:

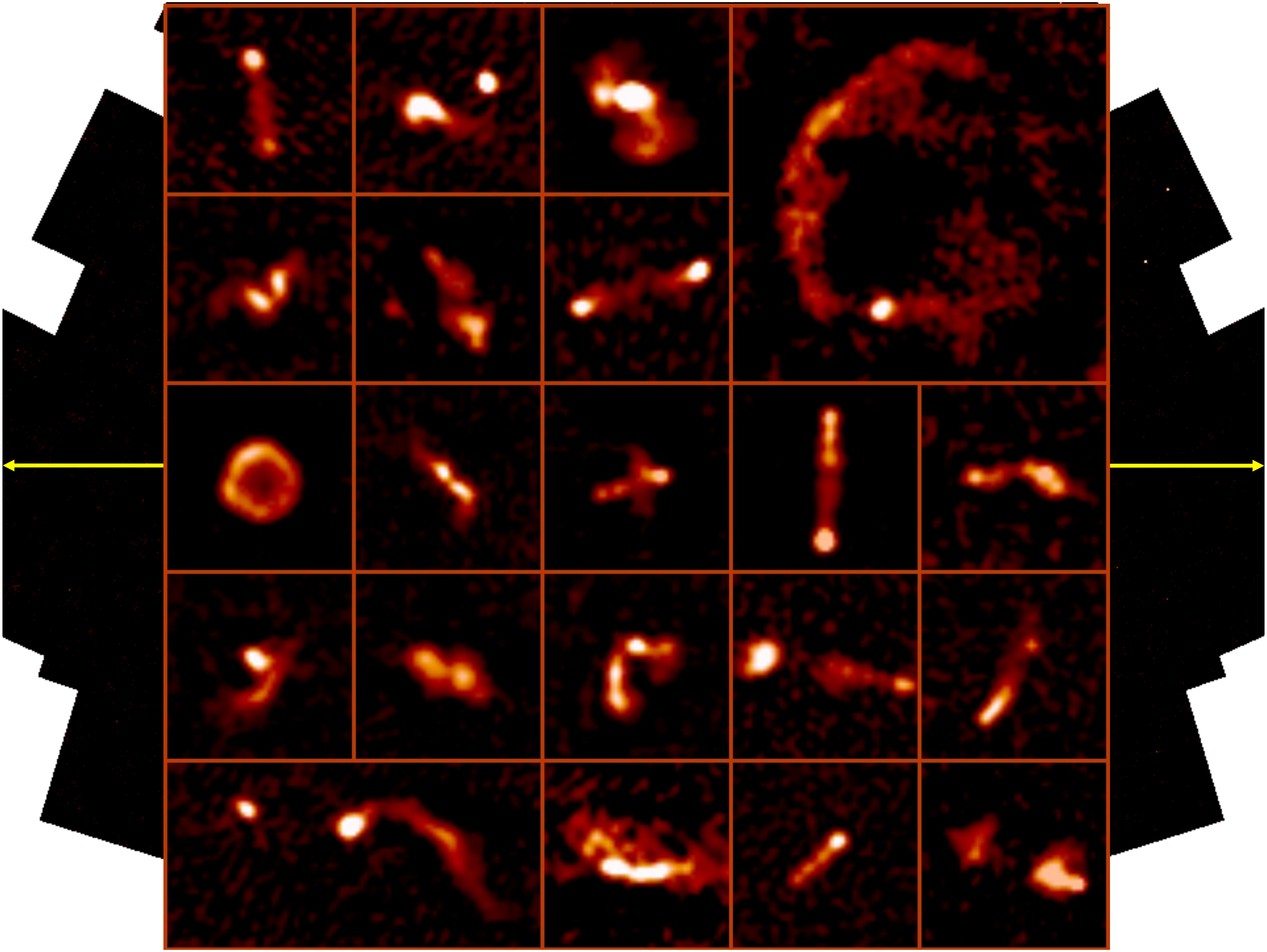
- Star-like, associated with radio sources
- Time-variable in continuum flux
- Large UV fluxes
- Broad emission lines
- Large redshifts

Again, not all quasars have all these properties, but most are X-ray luminous (Elvis et al 1978)

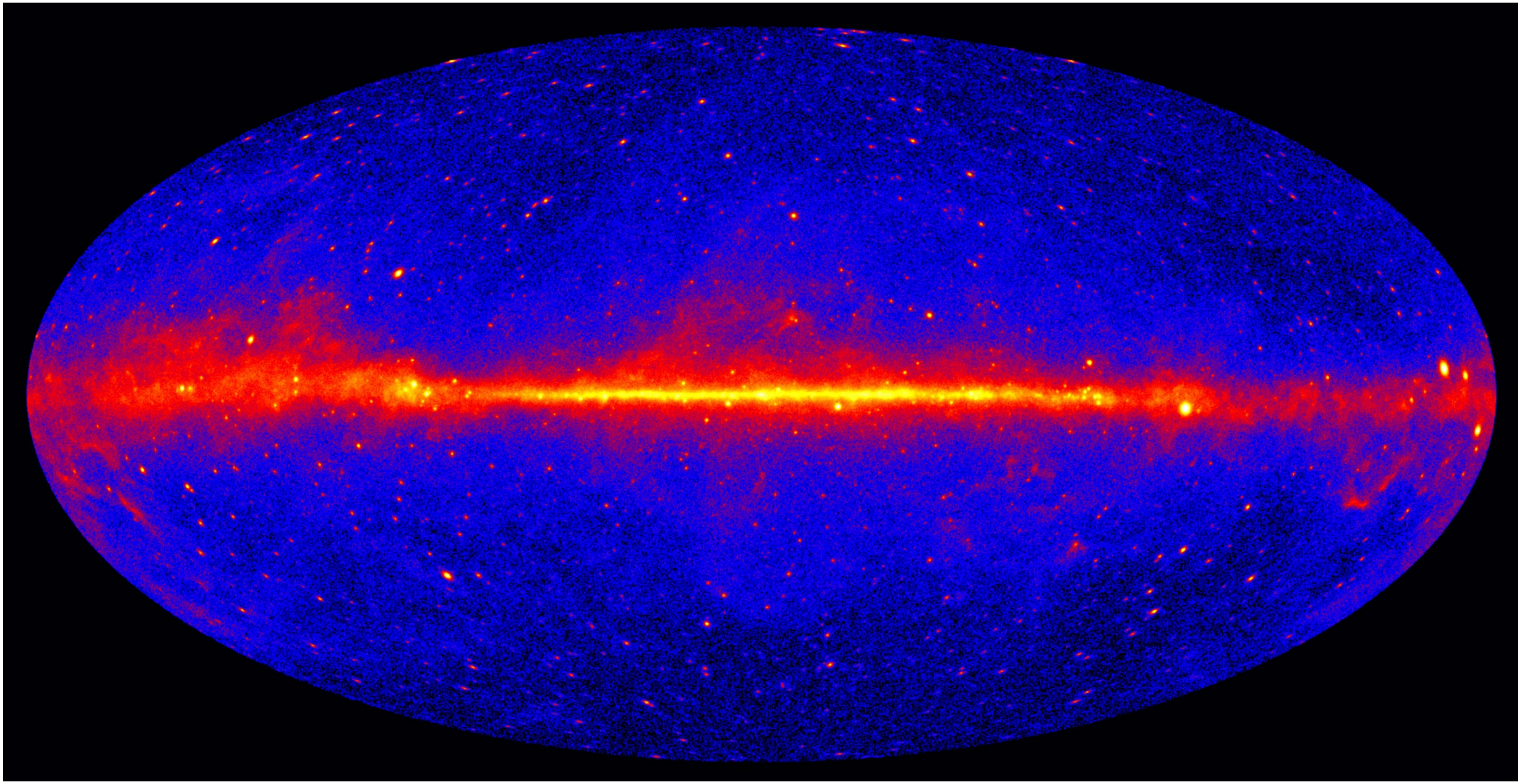
Quasars are found at high redshift, and they have radio emission from lobes or central source.

Composite Quasar optical/UV spectrum



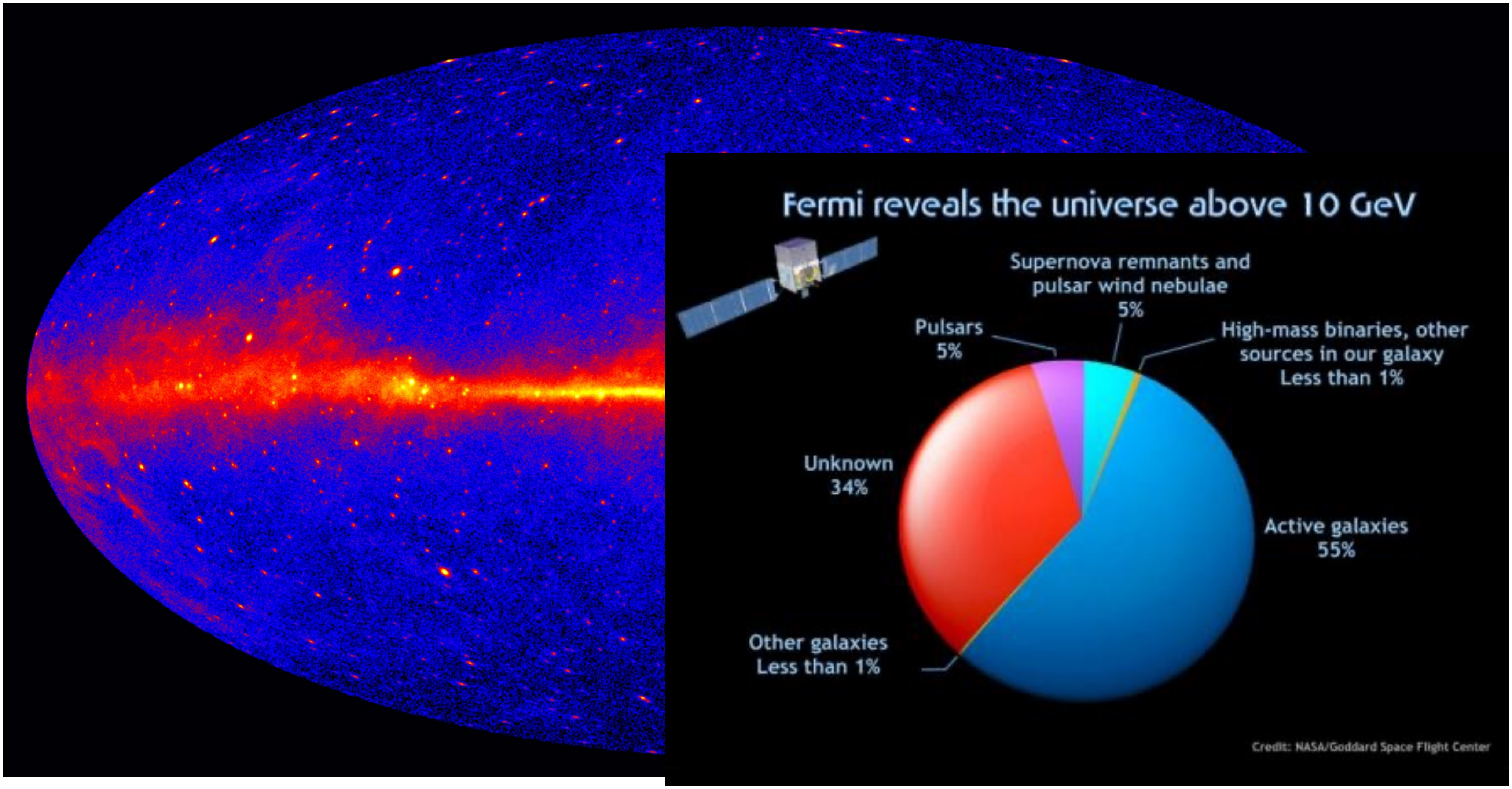


Fermi Gamma-Ray Sky



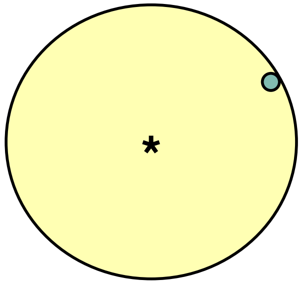
Fermi 5 year sky map

Fermi Gamma-Ray Sky



Fermi 5 year sky map

Accretion



$$v = (2GM/R)^{1/2}$$

$$= c\,(Rg/R)^{1/2}$$

$$L = 0.5\,\dot{M}\,c^2\,(Rg/R)$$

$$L = \varepsilon\,\dot{M}\,c^2$$

c = speed of light
v = velocity
R = object radius
Rg = gravitational radius
ε = efficiency

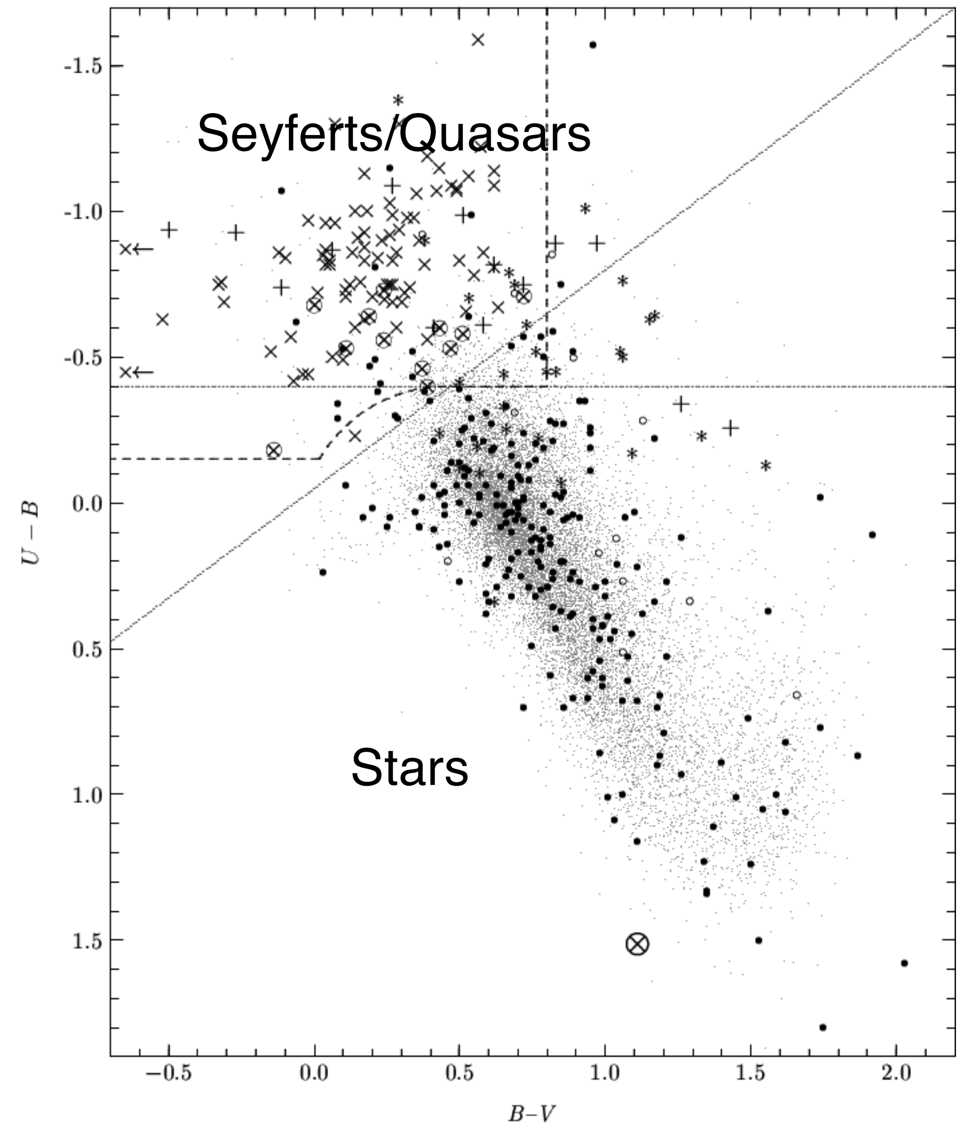
$\varepsilon = 3 \times 10^{-4}$ for a white dwarf, 0.15 for a neutron star
ε up to 0.5 for a rotating black hole

Compared to 7×10^{-3} for hydrogen fusion

Accretion is a very efficient energy source

UV Excess

- Quasars/Seyferts often have unusually blue colors as compared to stars
- Bluer than most A stars!
- Quasars have flat spectrum from B to U



Brunzendorf & Meusinger 2002

Searches for very blue objects found:

- QSOs: Quasi-stellar objects.
  - Optically like quasars, but radio quiet.
  - Most have spectra like Seyfert 1s (and BLRGs, see next slides)
  - ~90,000 known, with spectra measured by the Sloan Digital Sky Survey.
- QSOs are high redshift objects: peak at z ~2
- Large distances imply *enormous* luminosities!

Spectral energy distribution (SED) of AGN

Broad-band SED of AGN can often be approximated by

$$F_\nu = C\nu^{-\alpha}$$

The power in a given frequency range is

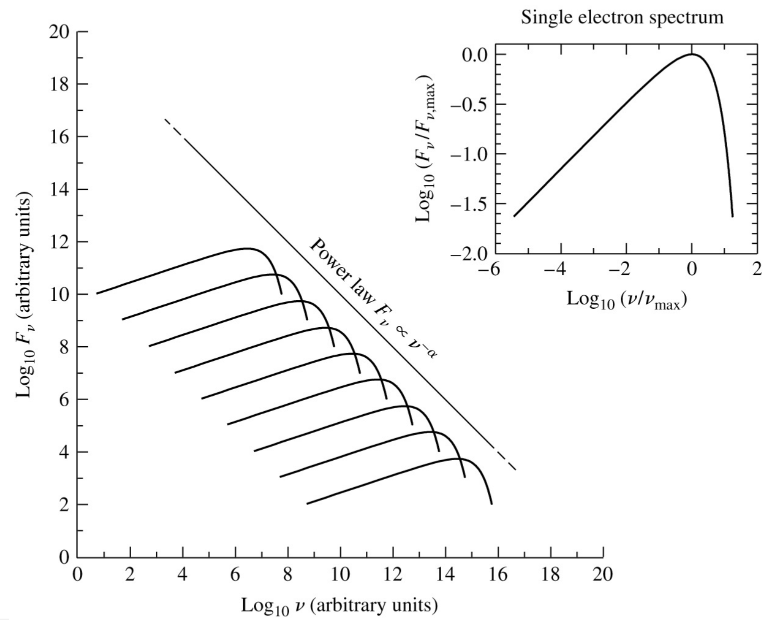
$$P = \frac{C}{1-\alpha}\left(\nu_2^{1-\alpha} - \nu_1^{1-\alpha}\right) \quad (\alpha \neq 1)$$

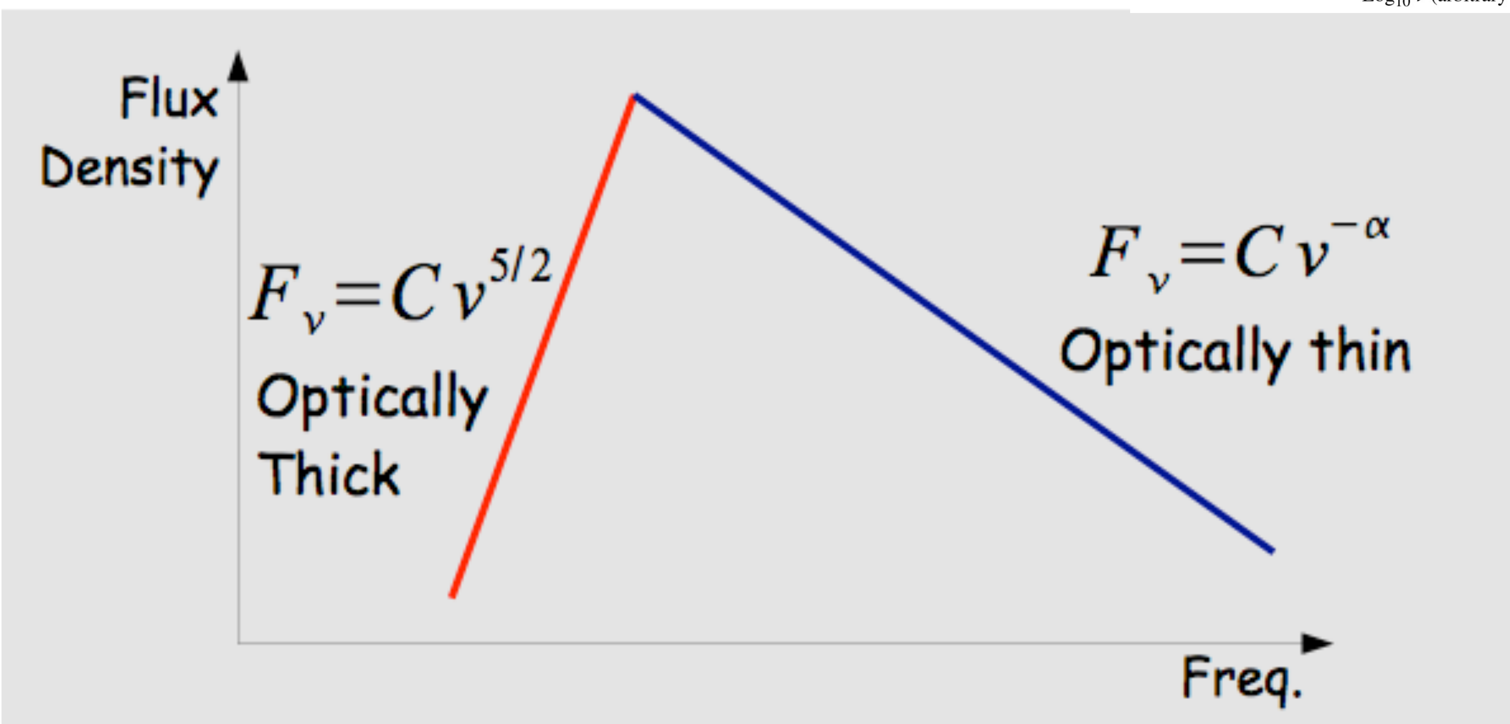
$$P = C \ln\left(\frac{\nu_2}{\nu_1}\right) \quad (\alpha = 1)$$

In the radio frequency range:

Electron energy distribution:

$$N(E)dE = N_0 E^{-s} dE$$

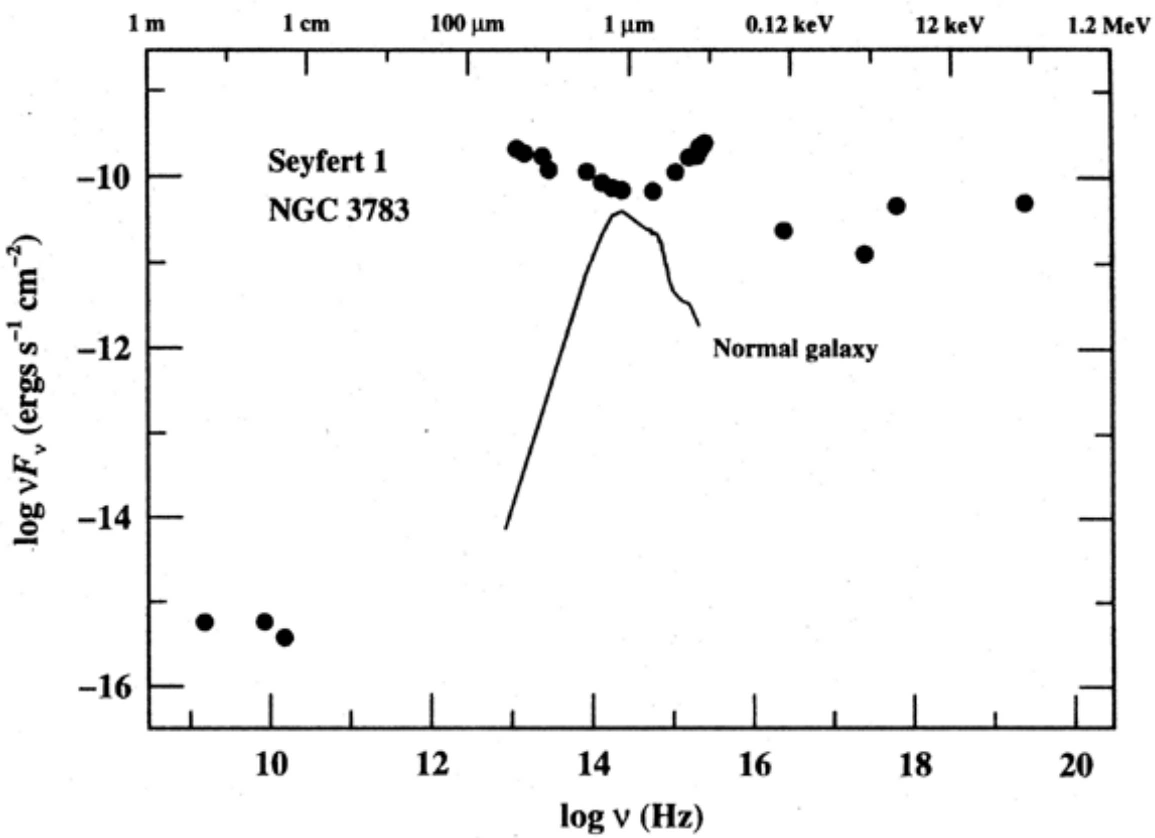




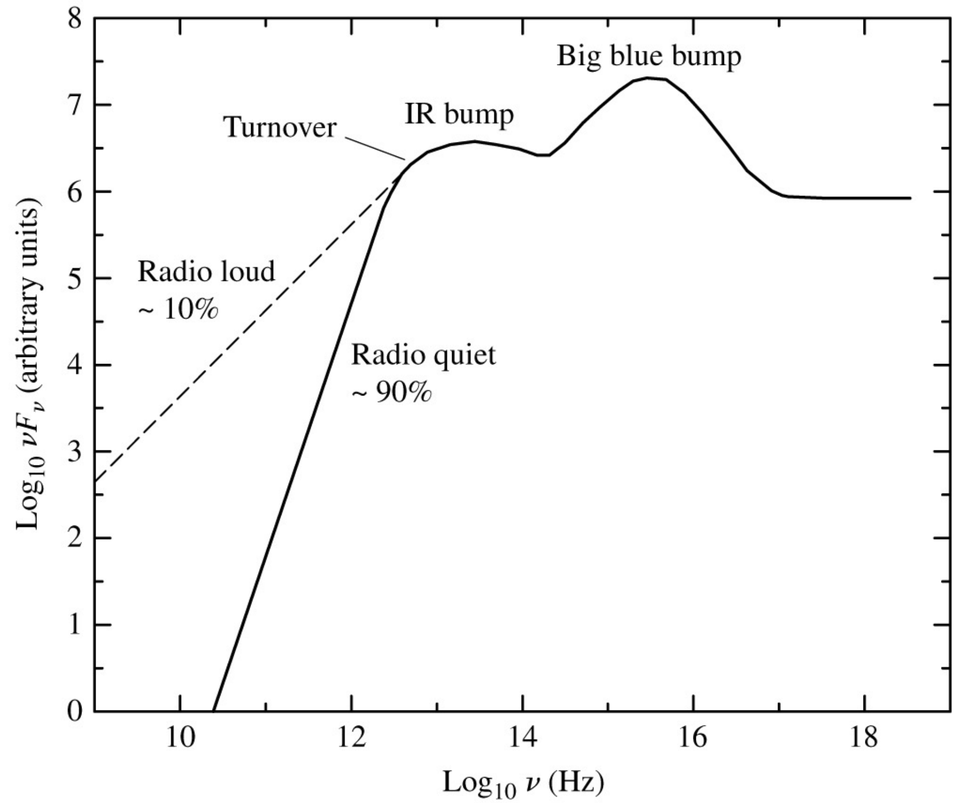
- **Worksheet:** Calculate the spectral index for two unresolved (size less than 0.1 arcsecond) radio sources A and B both observed to have a flux density of 10 mJy at 1400 MHz but source A is 63 mJy at 100 MHz and source B is 0.05 mJy at 100 MHz. What is the spectral index for each and the likely emission mechanism?

SED of NGC3783 (Seyfert 1 galaxy)

The constant value of νF_ν implies equal energy output per frequency bin. That is more than an entire galaxy.



SEDs for AGN



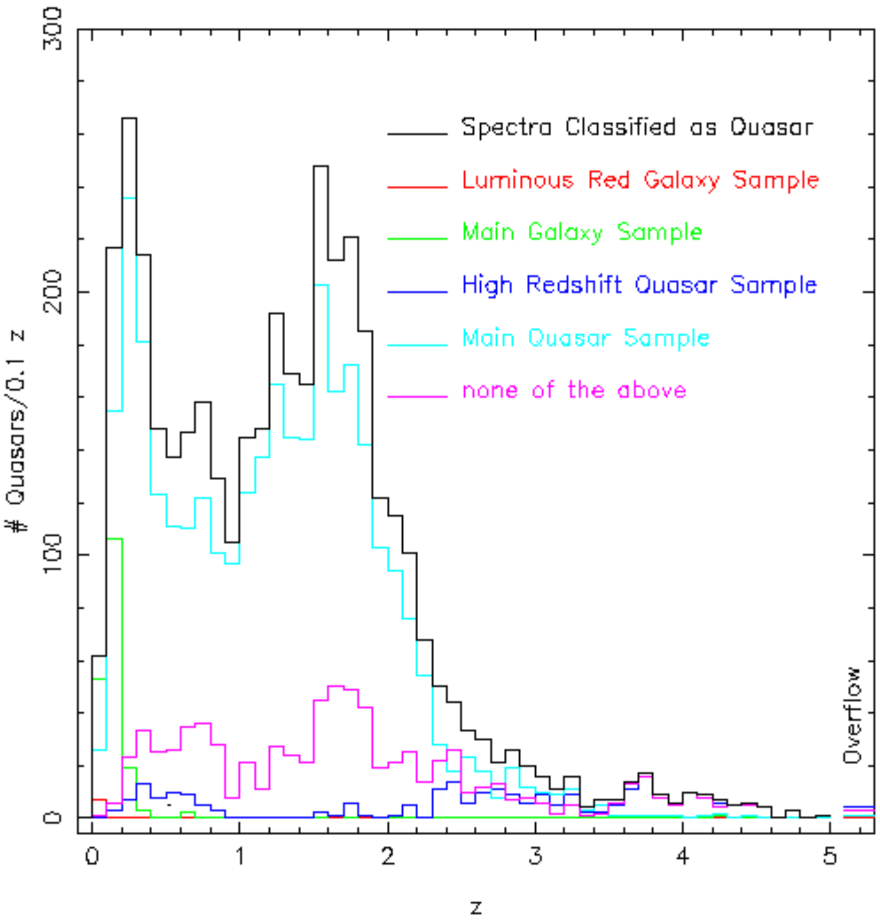
L_{IR} contains up to 1/3 of the bolometric luminosity

L_{BBB} contains a large fraction of L_{bol} as well

IR bump due to dust reradiation

BBB due to blackbody emission from accretion disk

Redshift distribution of quasars



- The quasar redshift distribution seems to peak around z~2
- Not only a selection effect, but is real after bias corrections
- Could be related to the formation of galaxies and LSS, and the star-formation history of the universe

Luminosity function of quasars

The number of quasars per unit co-moving volume whose absolute magnitude lies between M and M+dM.

The co-moving volume is a volume that expands with the expansion of the universe. This allow us to test if QSOs were more numerous or luminous in the past.

A strong evolution with z, and probably more luminous since not enough large galaxies to give so many quasars at z=2.

Quasars and Seyferts have similar luminosity evolutions:

Same type of objects, just that Seyfert's less luminous!

Journal Class

- **First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole**
- The EHT Collaboration 2019

Discussion leader: **Mark Burch**

Note: To encourage discussion everybody must pose at least one question during the group discussion