Active Galactic Nuclei

Basic picture of Active Galactic Nuclei (AGN):

- Most galaxies have **supermassive black holes** at their centers. Masses range from ~10^6 Solar masses to ~10^9 Solar masses.

- Gas **accreting** onto the black hole releases a large amount of gravitational potential energy:

$$L = \epsilon \dot{M} c^2$$

Efficiency

Accretion rate

Both the efficiency and the accretion rate vary across orders of magnitude between different galaxies.

Accretion process produces a host of observational phenomena. Important examples:

- Very high luminosity from a point source in the nucleus. Small physical size of the emission region allows rapid variability
- Broad spectral lines due to Doppler shift of gas orbiting the black hole
- X-ray emission from high temperature plasma close to the black hole
- Mechanical power in the form of outflows and **jets** from the central regions

In the most powerful AGN these phenomena dominate over starlight. What we see in a particular system reflects both the **accretion rate** and the **viewing angle** to the central engine.

Classes of AGN

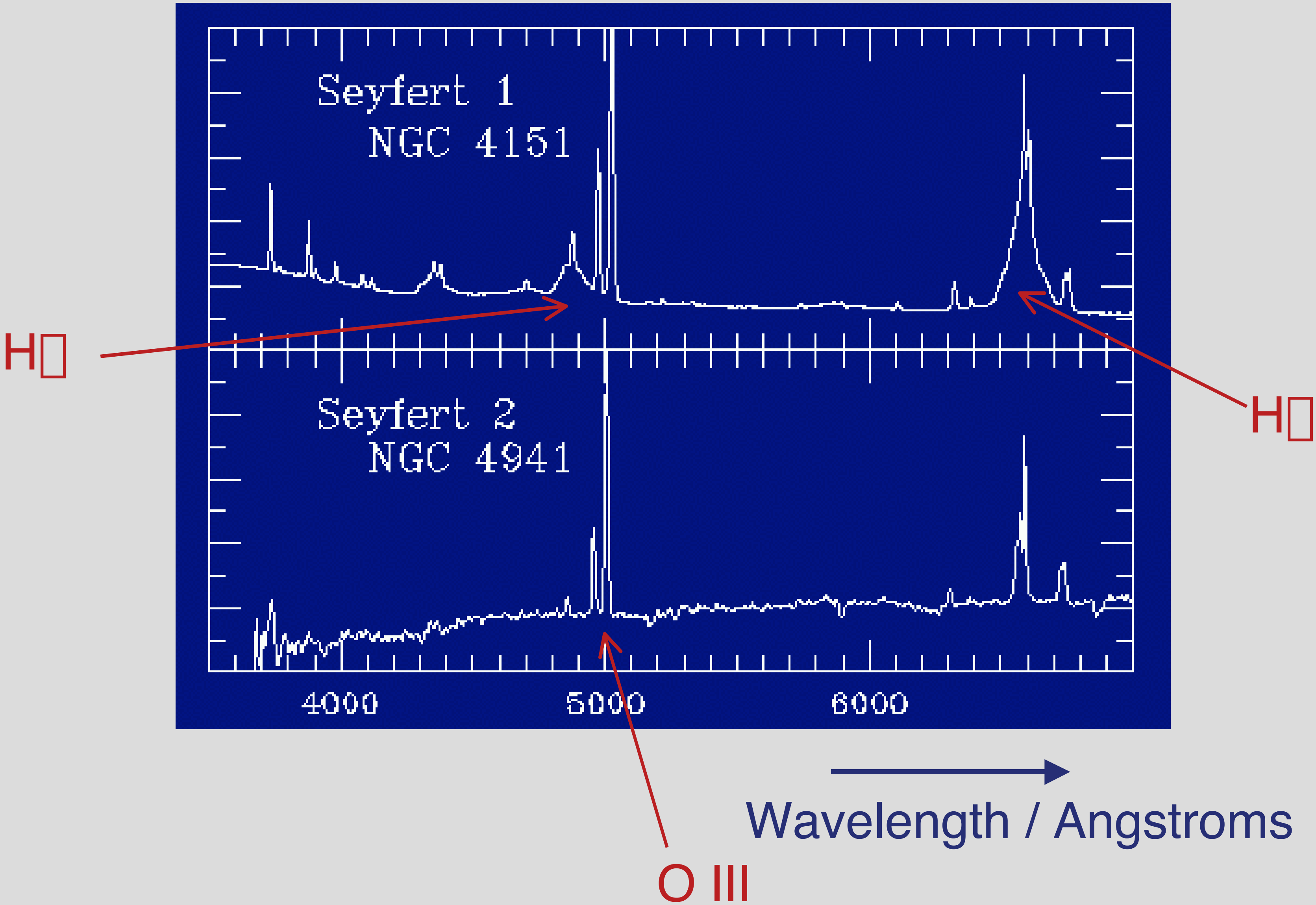
AGN are classified into numerous types depending (mostly) upon their luminosity in different wavebands (especially the optical and radio).

Seyfert Galaxies

First class of AGN to be identified. Carl Seyfert obtained spectra of several nearby galaxies with very bright cores, and found emission lines that were unusually broad (up to 8500 km/s).

These AGN are reasonably common - around 1% of spirals. Thus numerous nearby examples.

Modern spectra of Seyfert galaxies



Quasars

First radio surveys of the sky were completed in the late 1950's.

Many prominent radio sources at high galactic latitudes were found to coincide with star-like objects on photographic plates.

Named **quasi-stellar radio sources** (quasars).

Spectra did not initially seem to match those of known galaxies or other sources.

Mystery was solved with the realization that most quasars are distant (luminous) objects with highly redshifted spectra:

Define the redshift z via: $z = \frac{\lambda_{obs}}{\lambda_{emit}} - 1$

Brightest known quasar (m_B=13.1 mag) has z=0.158

Convert this redshift into distance using Hubble's law (valid for small z only):

$$d = \frac{cz}{H_0} = 670 \text{ Mpc}$$

Distance implies a luminosity (absolute magnitude) ~100 times greater than galaxies such as the Milky Way.

Proposal that black holes were involved was made by Zeldovich & Novikov within ~ year of the identification.

Properties of quasars

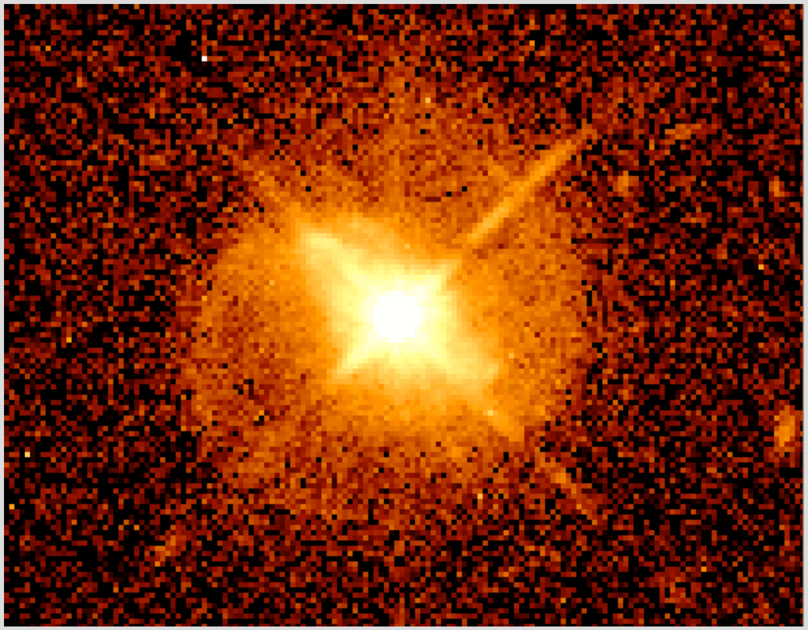
Characteristic of quasars include:

- Point-like sources (originally associated with radio sources, though these **radio loud** quasars are actually small fraction of the total)
- Broad spectral energy distribution, with large UV flux
- Time variable continuum
- Broad emission lines
- Typically high redshift (record now z=6.4)

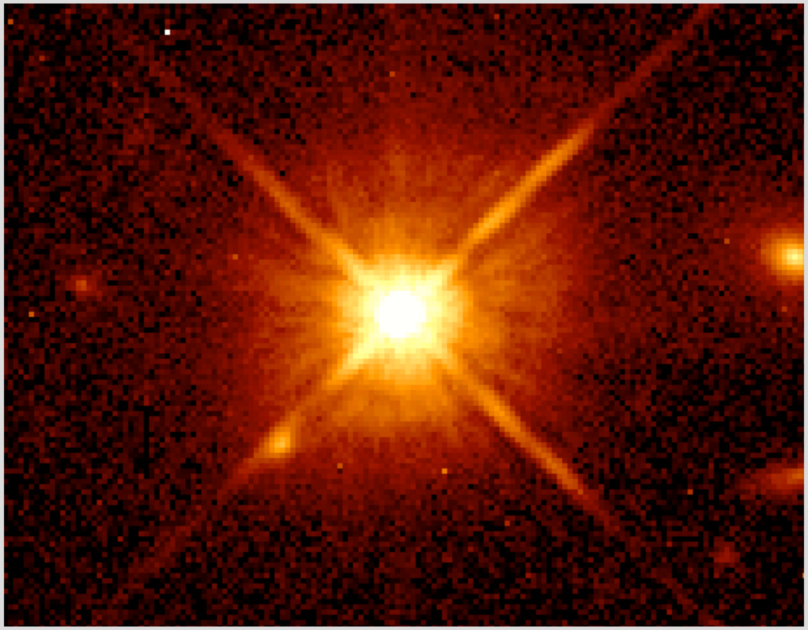
High redshift is mainly because quasars are rare and luminous
Other properties more useful for understanding the physics.

Quasar images

Even with HST imaging, difficult to detect the light of the host galaxy due to the high luminosity of the nucleus



Spiral host - unusual



Elliptical host - more common case

Imagine how difficult using only photographic plates…

Spectral energy distributions

Quasars have a very broad spectral energy distribution (SED). Spectra *cannot* be described as blackbodies.

Characterize (crudely) as a power-law: $F_\nu = C\nu^{-\alpha}$

- α is the power-law index
- C is a constant
- F_ν is the specific flux (i.e. per frequency interval, units of erg s^{-1} cm^{-2} Hz^{-1})

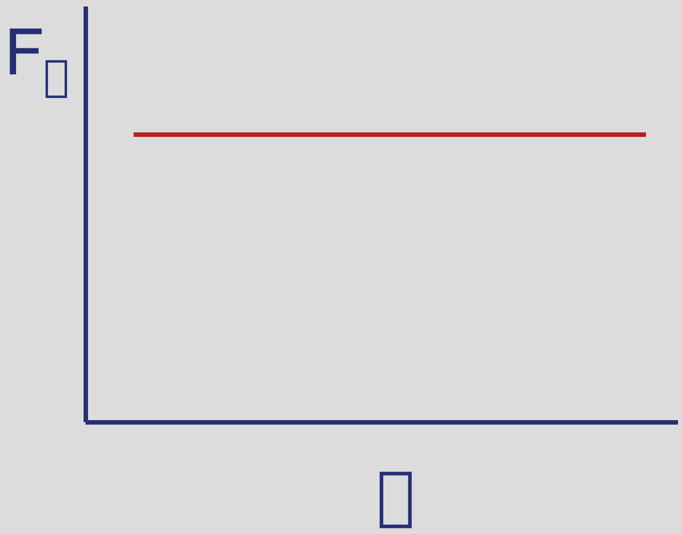
Integrate to get power between frequency ν_1 and ν_2:

$$P = \int_{\nu_1}^{\nu_2} F_\nu d\nu$$

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

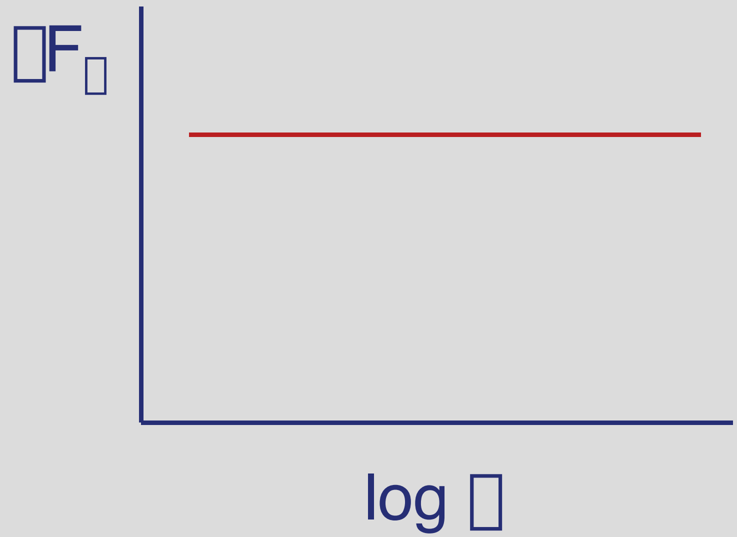
$$= C\ln\left(\frac{\nu_2}{\nu_1}\right), \quad \alpha = 1$$

□ = 0



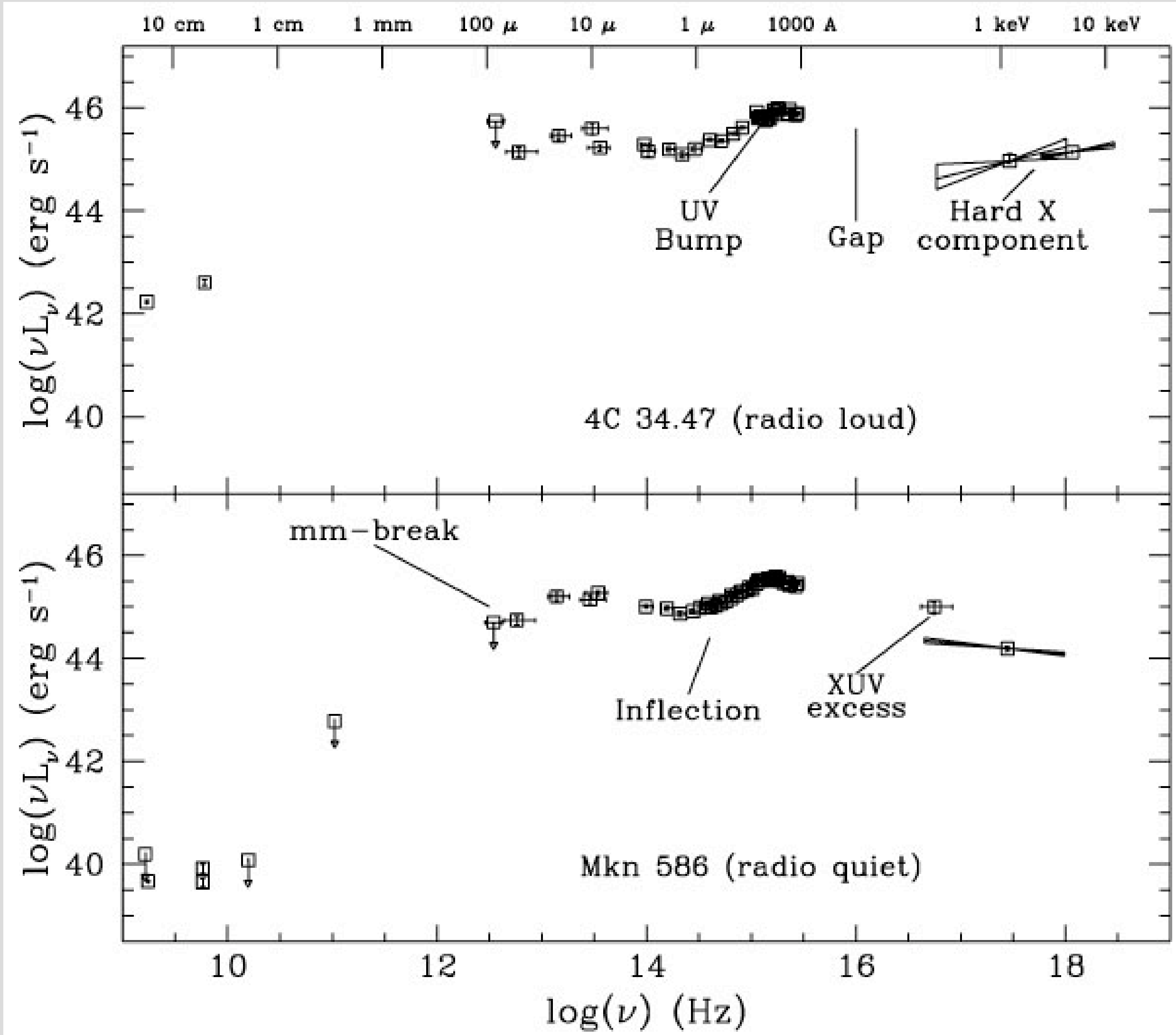
Flat spectrum source - equal energy output per unit frequency interval

□ = 1



Equal energy per unit logarithmic frequency interval - most useful way of plotting AGN spectra

Observed SED of radio loud and radio quiet quasars



~flat from far-IR through to hard X-rays

Optical spectra show strong, broad emission lines