Active Galactic Nuclei

- for most galaxies the luminosity is dominated by starlight
- small fraction (higher in the past) the nucleus of the galaxy is very bright

Active Galactic Nuclei (AGN)

Active Galactic Nuclei

Numerous different types of AGN:

- Seyfert galaxies
- Quasars
- Blazars
- Radio galaxies
- …

Different observed properties: *all* thought to be powered by disk accretion on to a central supermassive black hole

Quasars

First radio surveys of the sky done in 1950s

Many bright radio sources out of the plane of the Galaxy were found to coincide with star-like objects on photographic plates

Named “Quasi-stellar radio sources” (quasars)

Nature initially a mystery

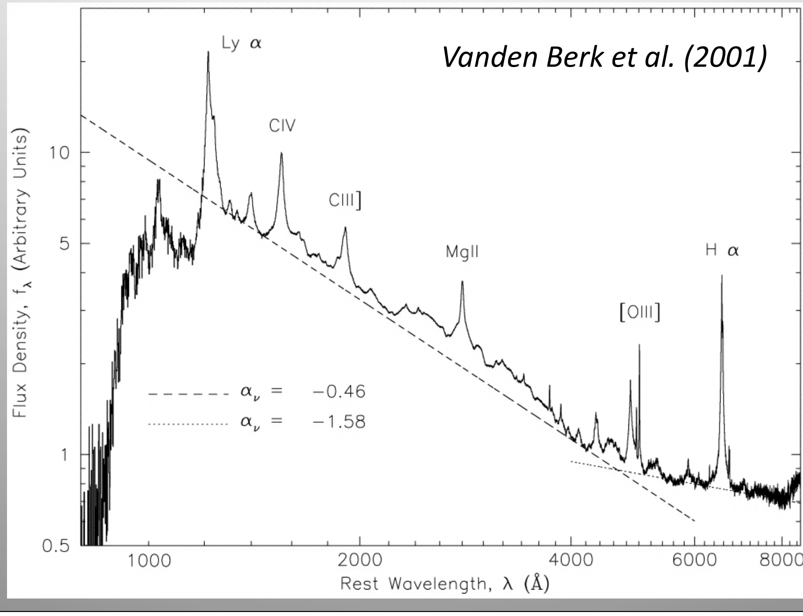
Quasars

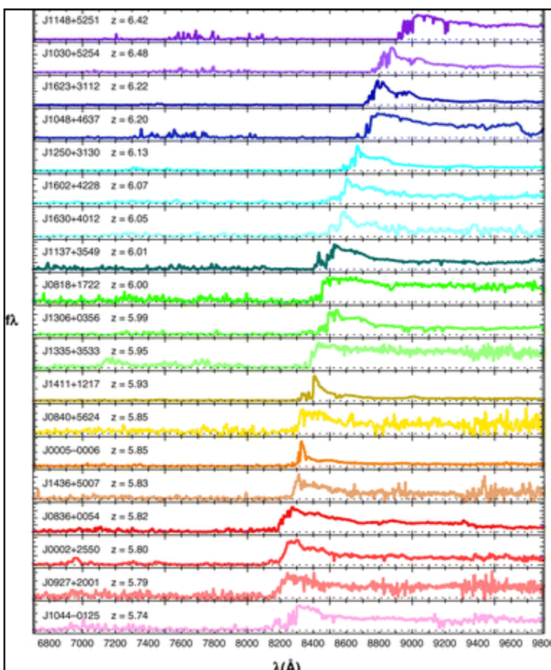
Mystery was solved when it was realized that quasars were very distant objects, whose spectra were red shifted by the expansion of the Universe

If a source emits light at wavelength λ_{emit}, and it is observed at λ_{obs}, define redshift z:

$$z = \frac{\lambda_{obs}}{\lambda_{emit}} - 1$$

Spectrum of a "typical" quasar





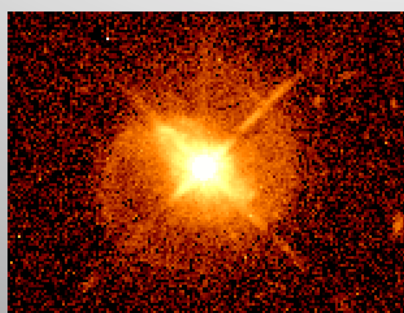
Fan X, et al. 2006.
Annu. Rev. Astron. Astrophys. 44:415–62

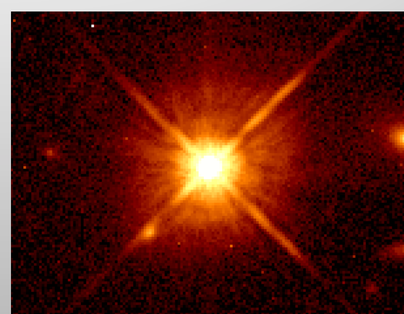
In an expanding Universe, redshift is a measure of distance: more distant quasars have higher redshift

Quasars

Large distance implies a very high luminosity: emission from the point source in the nucleus vastly outshines rest of the galaxy!

Quasars

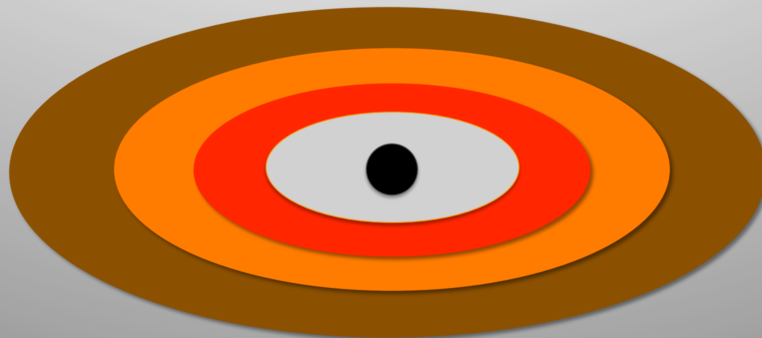




Hubble Space Telescope images of quasars and host galaxies

Quasars

Interpret high luminosity as due to disk accretion of gas on to a supermassive black hole



Accretion rate $\dot{M}$ - kg s^{-1} (Solar masses per year)

Quasars

Conversion of rest mass of accreting gas to radiated energy is about 10% for disk accretion on to a black hole, i.e. for 1 kg accreted get:

$$E = 0.1\,\mathrm{kg} \times c^2$$ of energy in the form of radiation

Generally, luminosity:

$$L = \varepsilon \dot{M} c^2 \approx 0.1 \dot{M} c^2$$

↑ radiative efficiency of accretion

Quasars

Example: suppose a billion Solar mass black hole is accreting gas at 1 Solar mass per year

$$\dot{M} = \frac{2 \times 10^{30} \text{ kg}}{3.16 \times 10^{7} \text{ s}} = 6.3 \times 10^{22} \text{ kg s}^{-1}$$

Expect a luminosity of:

$$L \approx 0.1 \dot{M} c^2 \approx 5.7 \times 10^{38} \text{ Watts}$$

Quasars

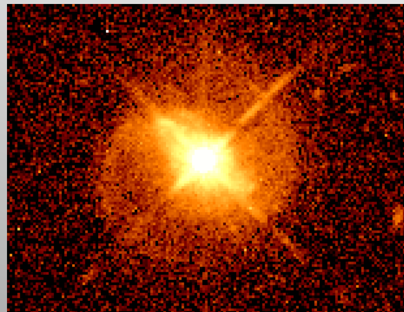
$$L \approx 0.1 \dot{M} c^2 \approx 5.7 \times 10^{38} \text{ Watts}$$

Compare to luminosity of Sun, 3.8 x 10^{26} Watts

Luminosity from the accreting black hole is equal to 1.5 trillion (1.5 x 10^{12}) stars like the Sun!

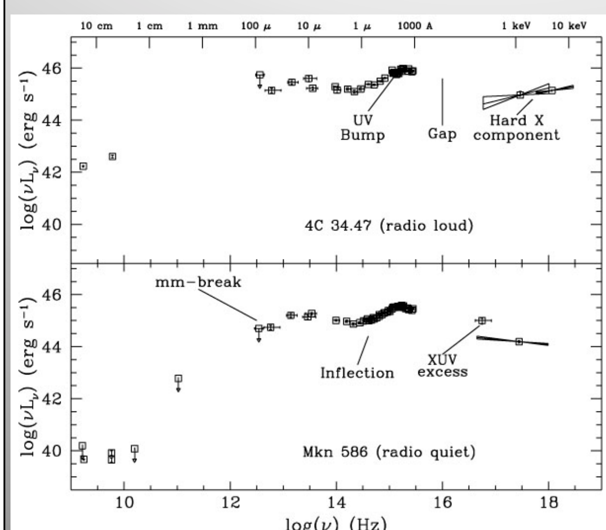
Consequence of the high efficiency of black hole accretion vs nuclear fusion (10% vs 0.7%)

Quasars



Hard even to see the stars in the galaxy: the nucleus is so bright

Quasars

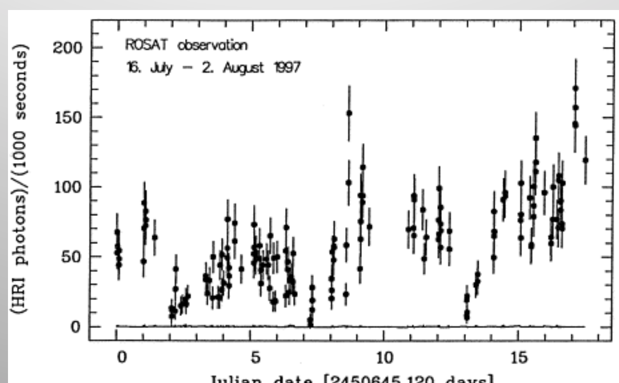


Emit most energy in UV and optical light, but also shine brightly across the whole electromagnetic spectrum

Quasars

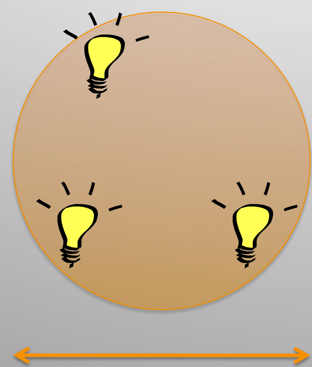
Luminosity from hot gas in the accretion disk, also from a *jet* possibly powered by black hole spin energy

Maximum size from variability



Quasars (and other AGN, this is a Seyfert) are seen to vary on time scales of a day or less

Maximum size from variability


one light day

For a source of size one light day, fastest time for a signal to cross the source is one day

Don't expect to see co-ordinated variations on less that 1 day time scale

Maximum size from variability

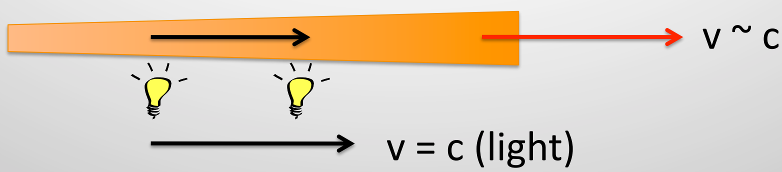
Observe variability on 1 day time scale

Infer quasars are less than 1 light day across

$L \sim (24 \times 3600\ \mathrm{s}) \times 3 \times 10^{8}\ \mathrm{ms^{-1}}$

$= 2.6 \times 10^{13}\ \mathrm{m} = 170\ \mathrm{AU}$

luminosity of a whole galaxy originates from region ~size of the Solar System!



A loophole: if the emitting source is moving toward us at close to the speed of light:

- source *almost* keeps pace with light emitted earlier
- "slow" variability appears faster to us
- source can be bigger than light travel time argument suggests

A mystery:

- at z = 7, time since the Big Bang was less than a billion years
- very few galaxies had formed by that time
- how did a billion Solar mass black hole grow that large in the time available?