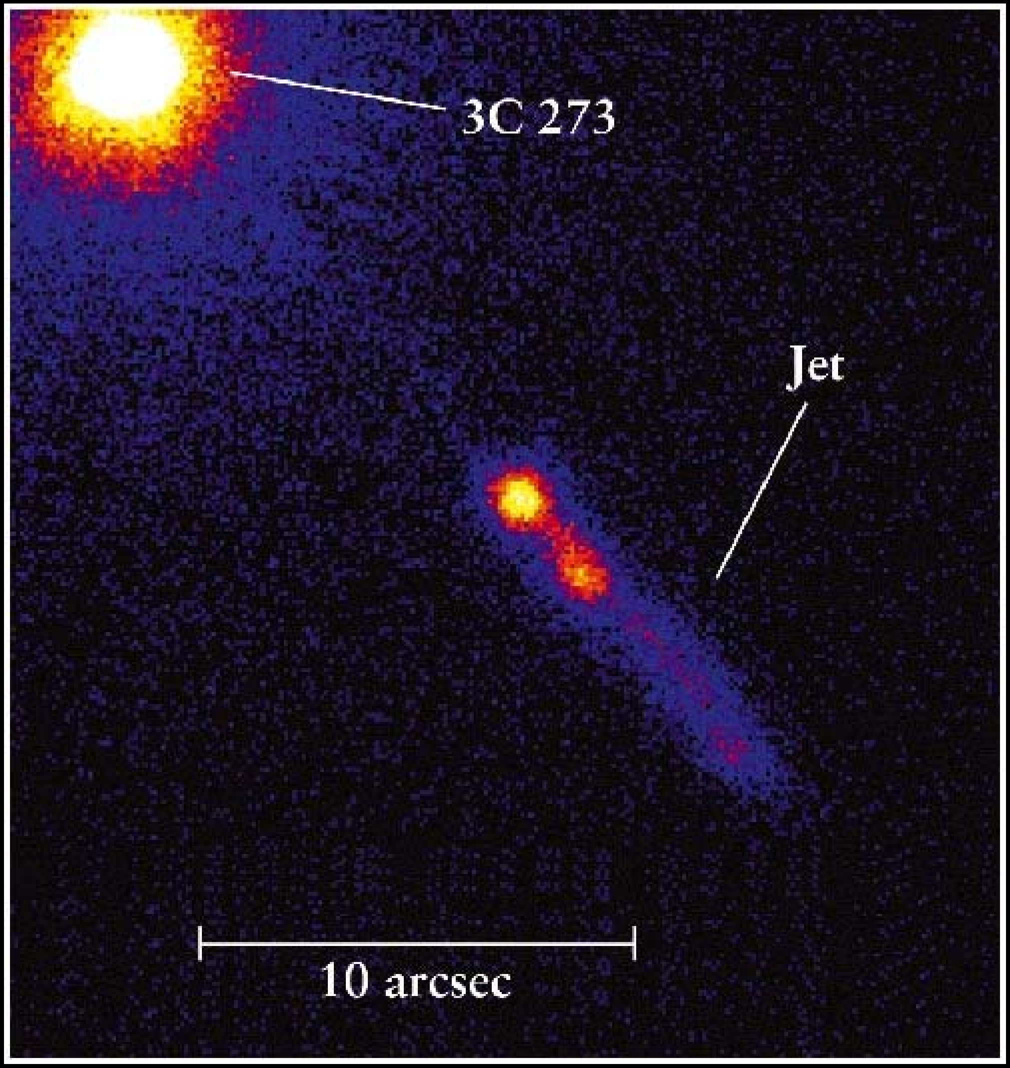


Lecture 9

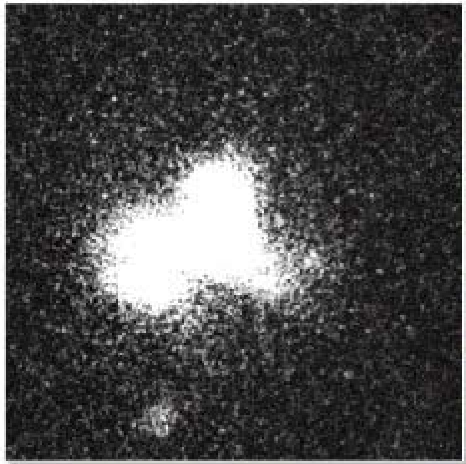
Quasars, Active Galaxies and AGN

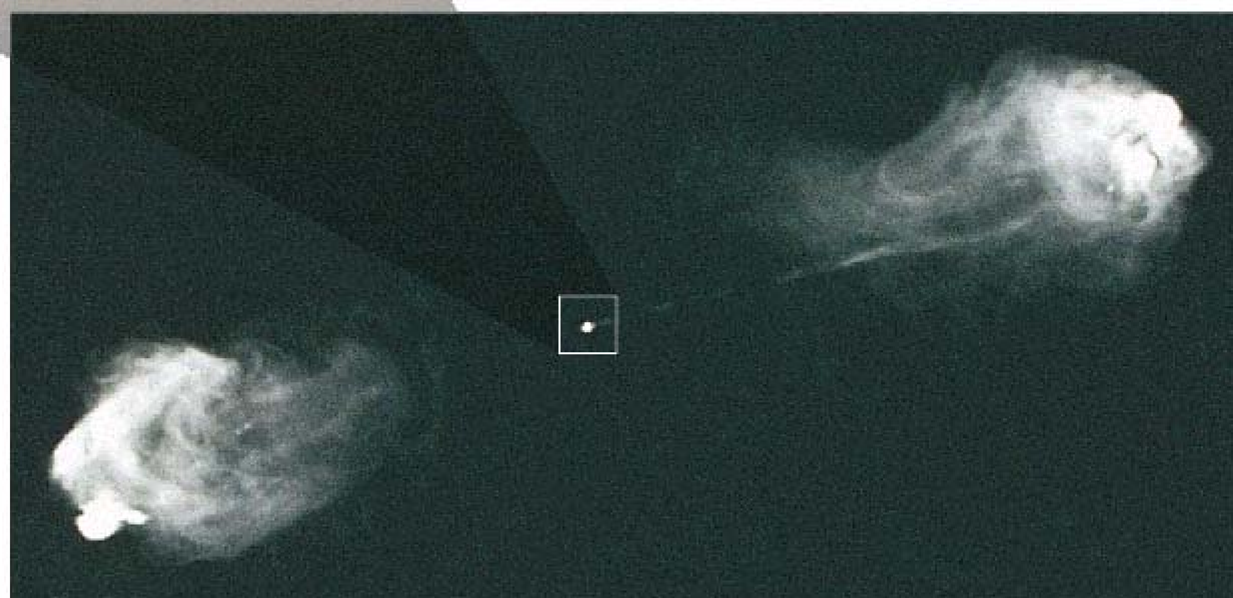
Quasars look like stars but have huge redshifts.

- object with a spectrum much like a dim star
- highly red-shifted
- enormous recessional velocity
- huge distance (*Hubble’s Law*)
- must be enormously bright to be visible at such a great distance
- Quasi-stellar object
- QSO or ***Quasar***

This object that looks like a star must be enormously luminous - its redshift indicates it is 4 billion light years away!

Quasars look like stars but have huge redshifts.

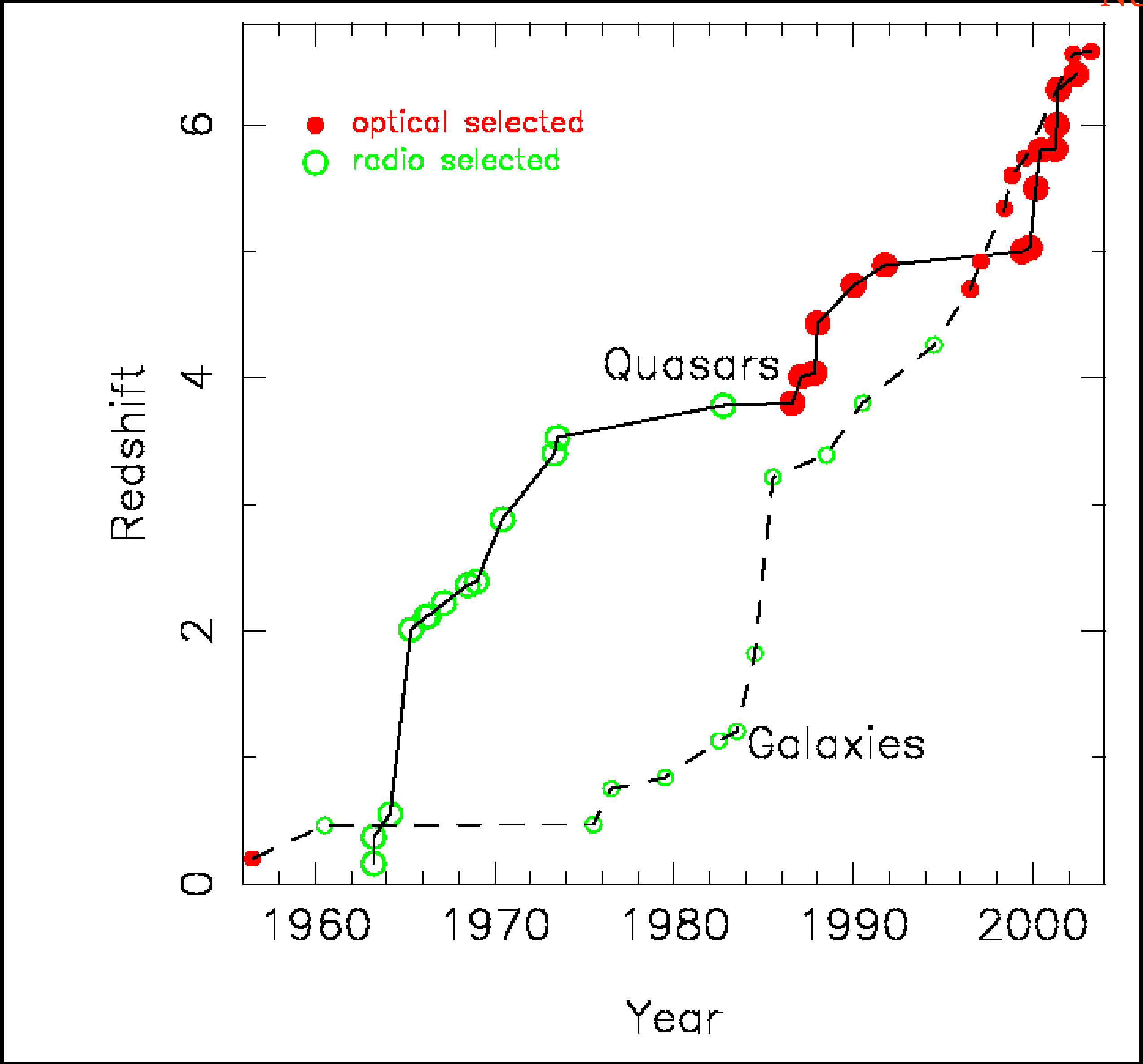




The heart of Cygnus A

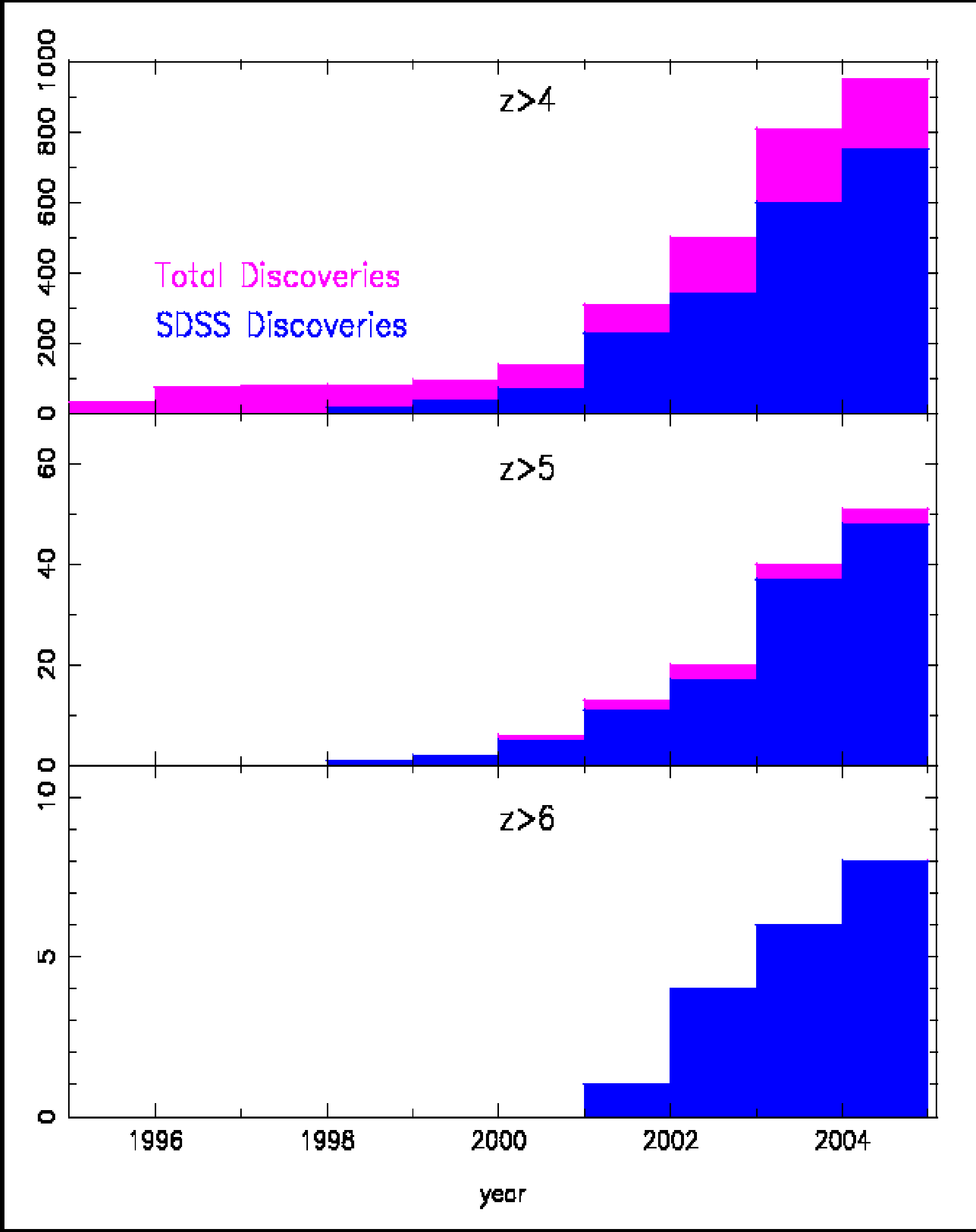
Exploring the Edge of the Universe

New z~7 galaxies

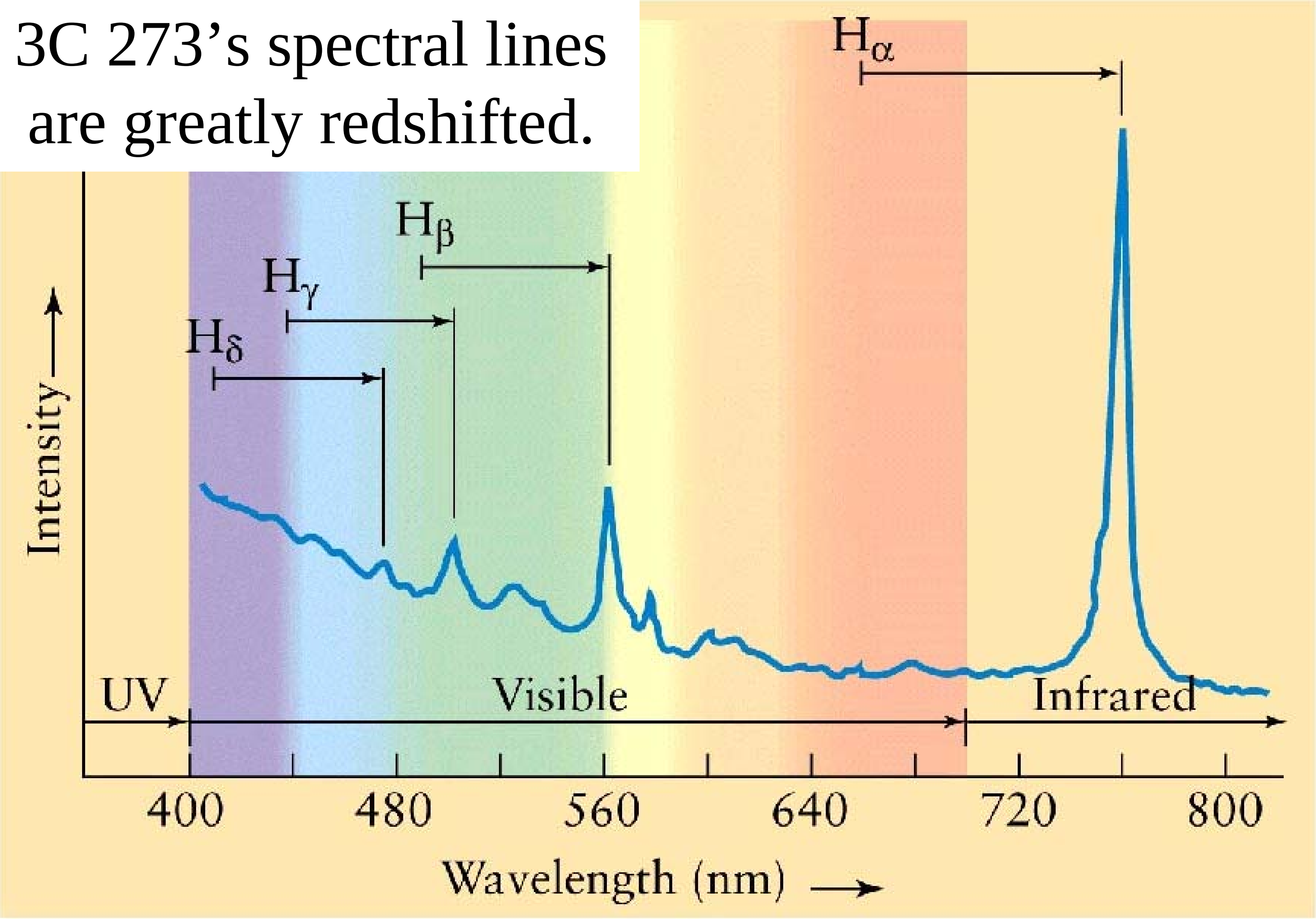


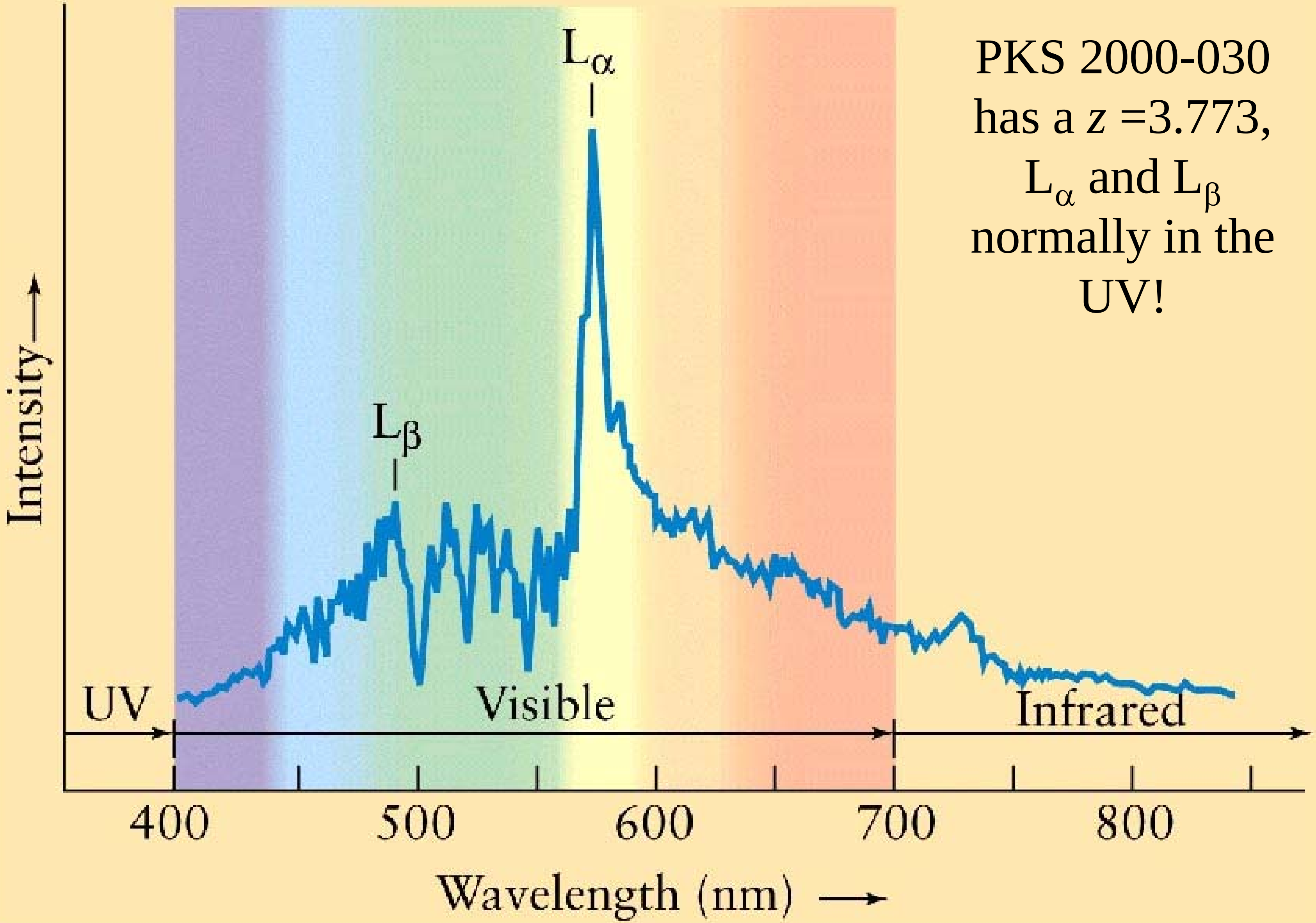
The Highest Redshift Quasars Today

- z>4: >900 known
- z>5: >50
- z>6: 8
- SDSS i-dropout Survey:
  - By Spring 2004: 6000 $\deg^2$ at $z_{AB}<20$
  - Sixteen luminous quasars at z>5.7
  - Five in the last season
- 30 – 50 at z~6 expected in the whole survey



3C 273's spectral lines are greatly redshifted.





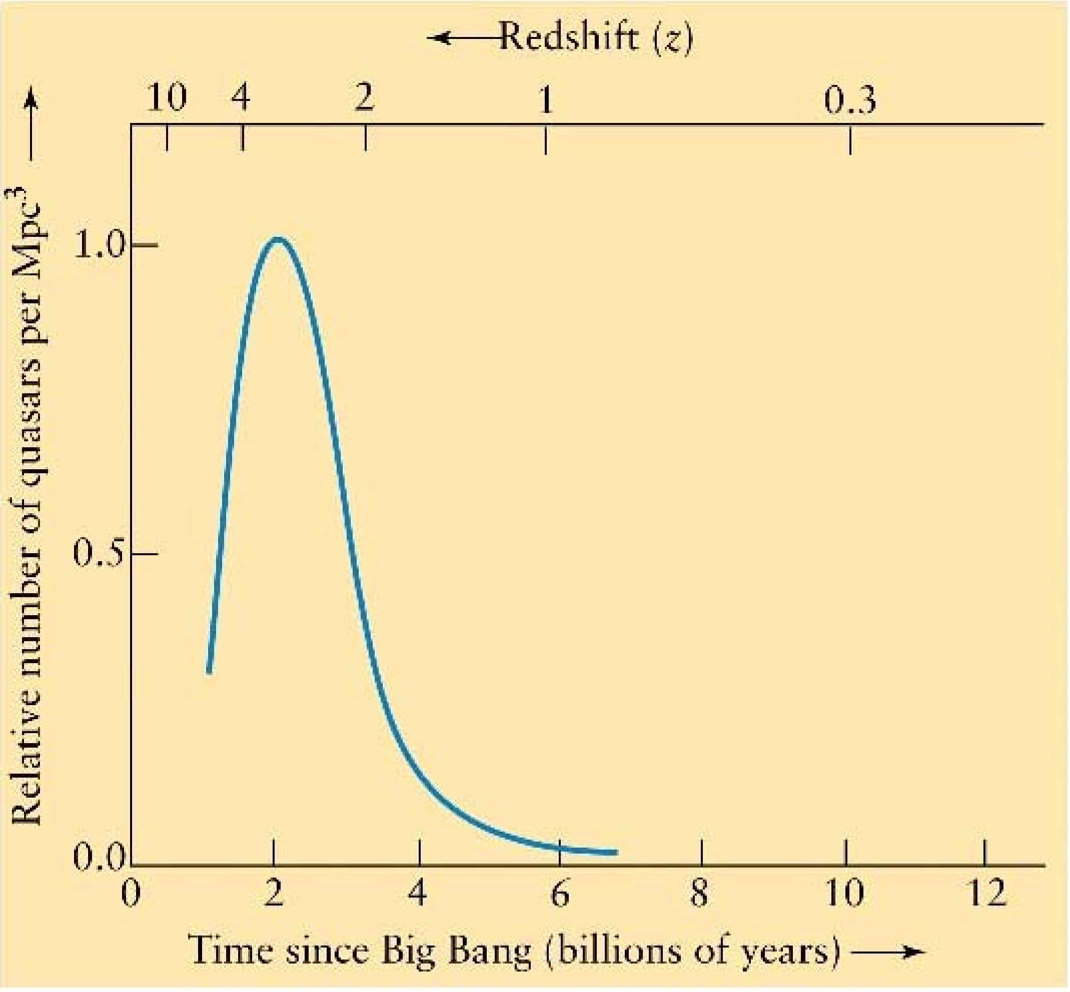
PKS 2000-030 has a z =3.773, L_α and L_β normally in the UV!

Table 27-1 Redshift and Distance

z	v/c	Distance (Mpc)	Distance (10^9 ly)
0.000	0.000	0	0.00
0.100	0.095	400	1.30
0.200	0.180	750	2.43
0.300	0.257	1050	3.42
0.400	0.324	1310	4.28
0.500	0.385	1550	5.04
0.750	0.508	2020	6.57
1.00	0.600	2370	7.71
1.50	0.724	2840	9.27
2.00	0.800	3140	10.2
3.00	0.882	3480	11.4
4.00	0.923	3670	12.0
5.00	0.946	3780	12.3
∞	1.00	4130	13.5

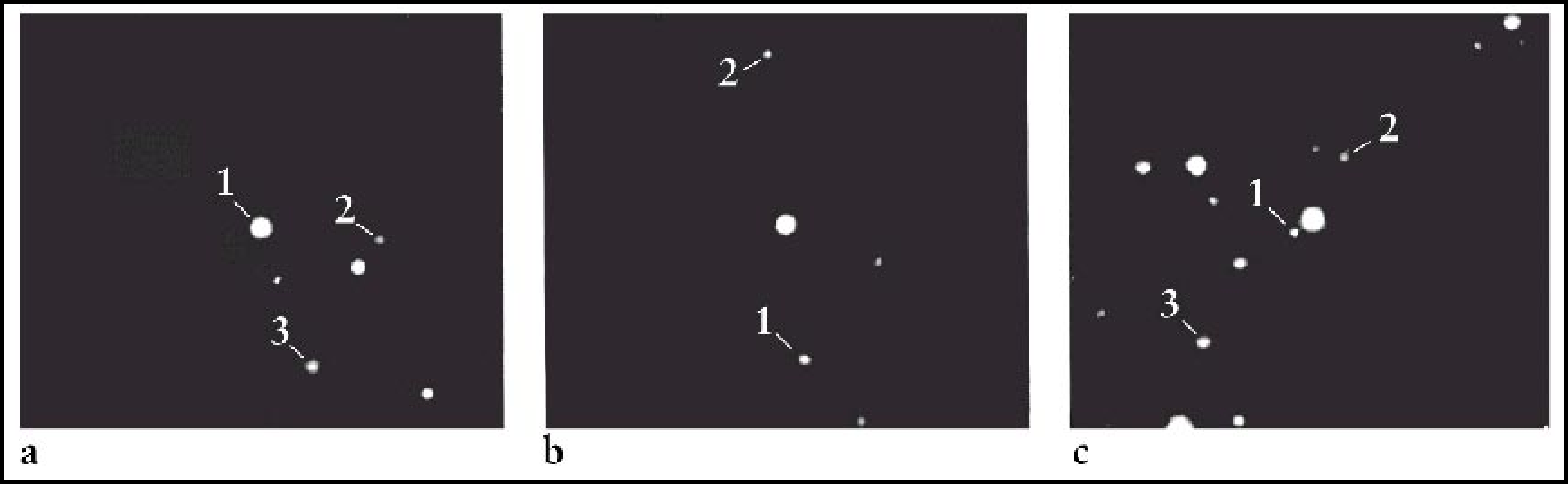
Note: This table assumes a Hubble constant $H_0 = 70$ km/s/Mpc, a matter density parameter $\Omega_m = 0.3$, and a dark energy density parameter $\Omega_\Lambda = 0.7$ (see Chapter 28).

Quasars are the ultraluminous centers of distant galaxies.



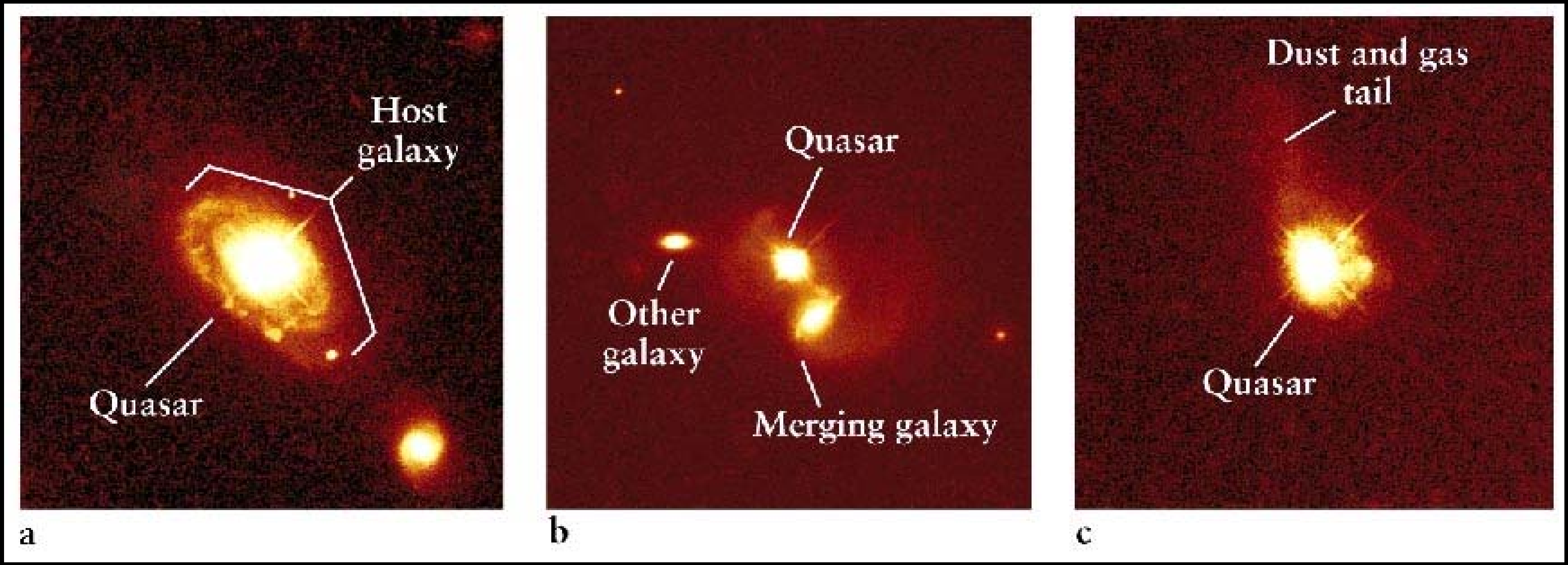
The greater the redshift, the farther back in time we are seeing it. There were numerous quasars after the Big Bang, but in today's universe, quasars have disappeared.

Quasars are the ultraluminous centers of distant galaxies.



A quasar is found in the center of each of these galaxy clusters. The galaxies, identified by numbers, have the same redshift as the quasar, reinforcing the theory that quasars are distant objects too.

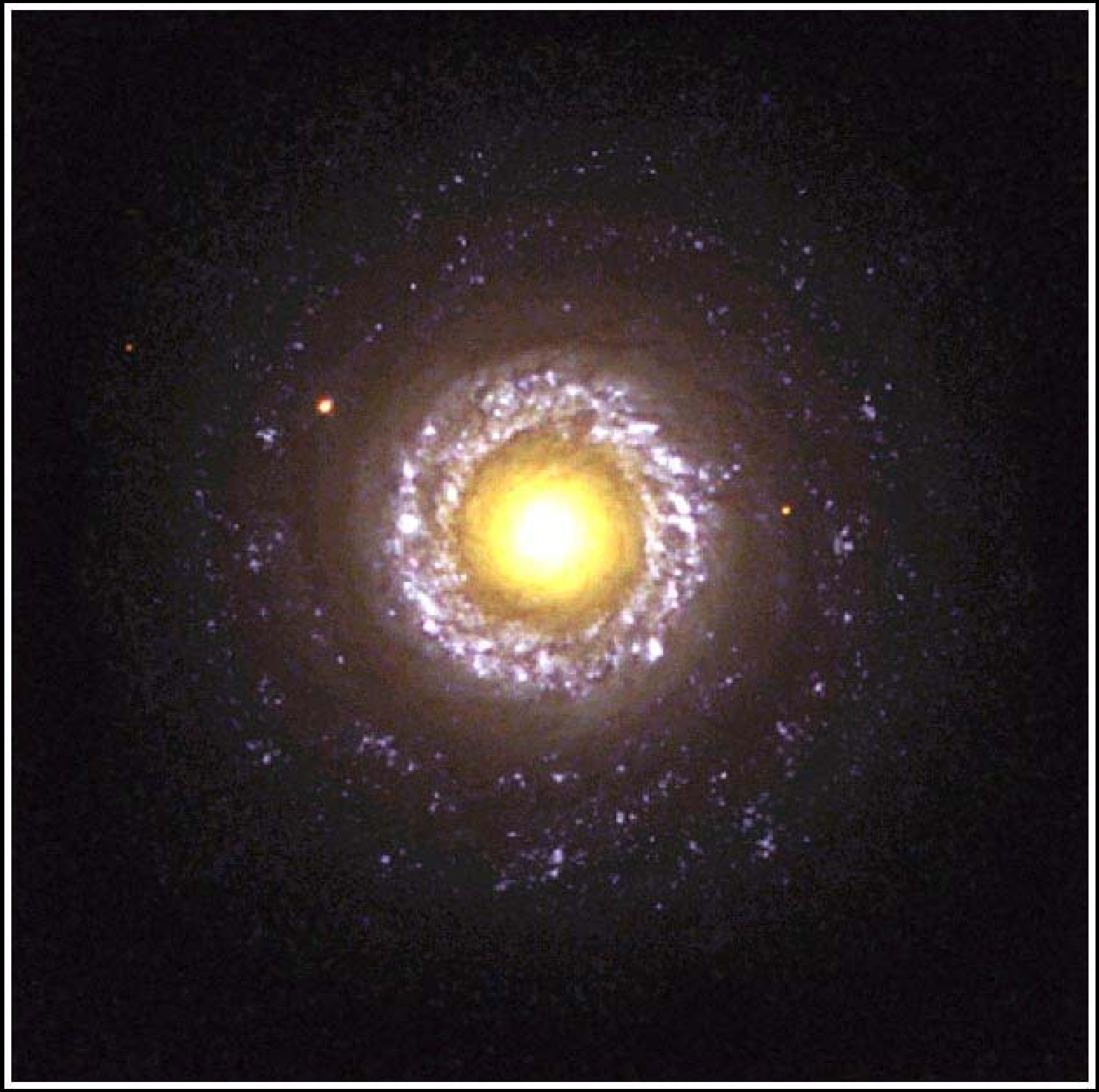
Quasars are the ultraluminous centers of distant galaxies.

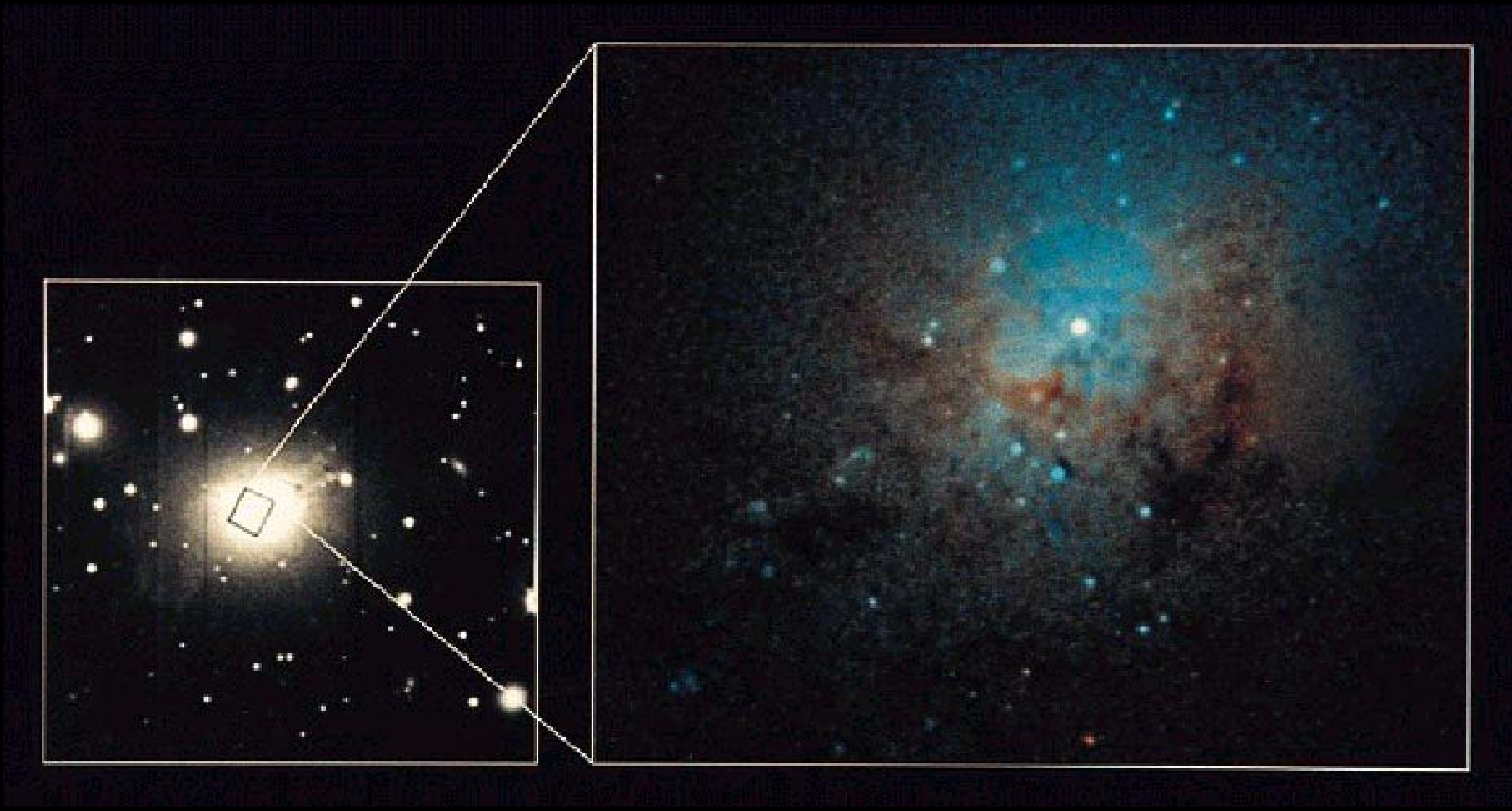


Quasars are often observed to be at the center of distant galaxies. The wispy material is likely gas that has been pulled out of the hot galaxy by gravitational interactions with nearby galaxies.

Active Galaxies bridge the gap between normal galaxies and quasars.

- Seyfert galaxies
  - luminous, star-like nuclei with strong emission lines.

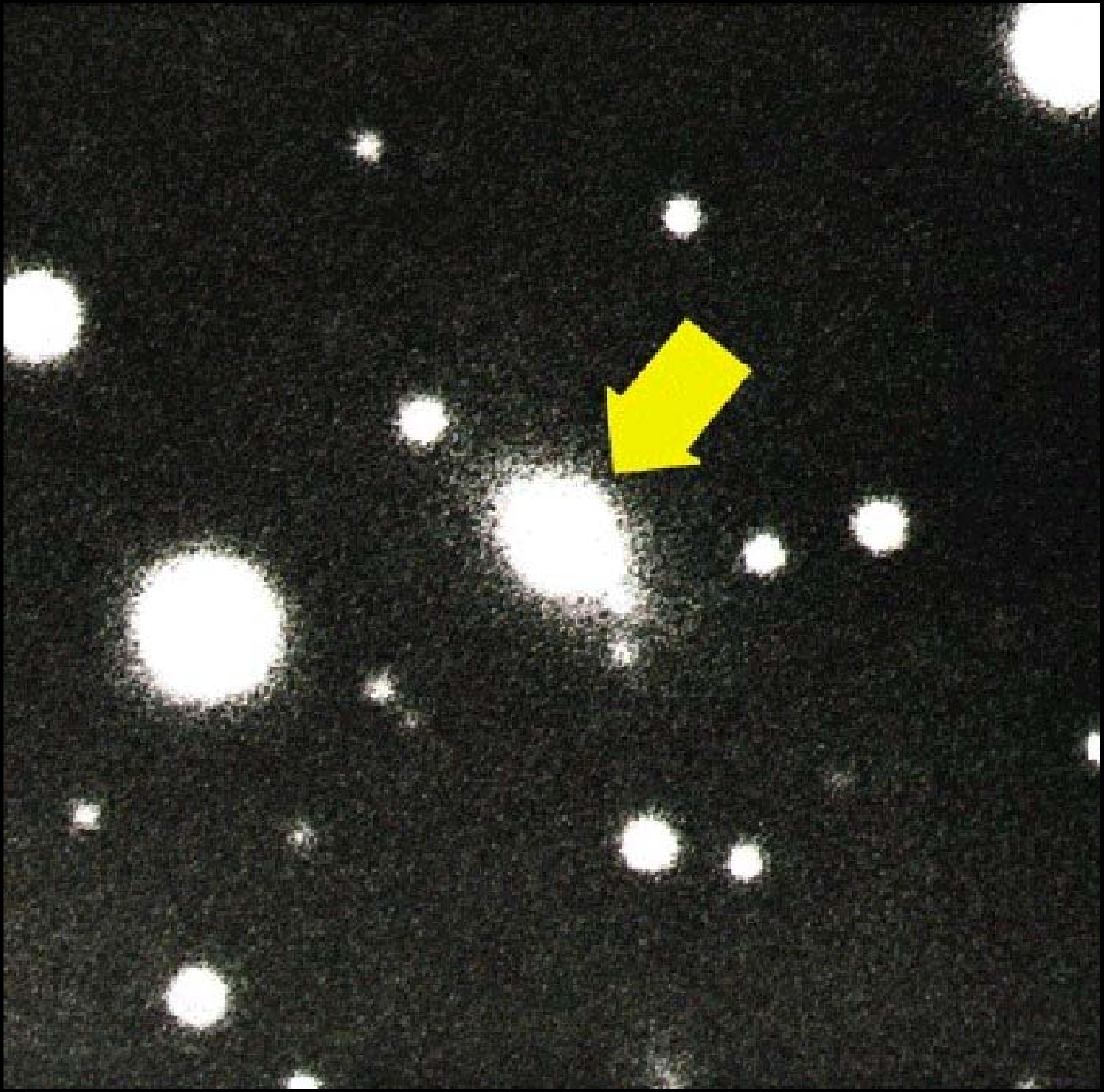




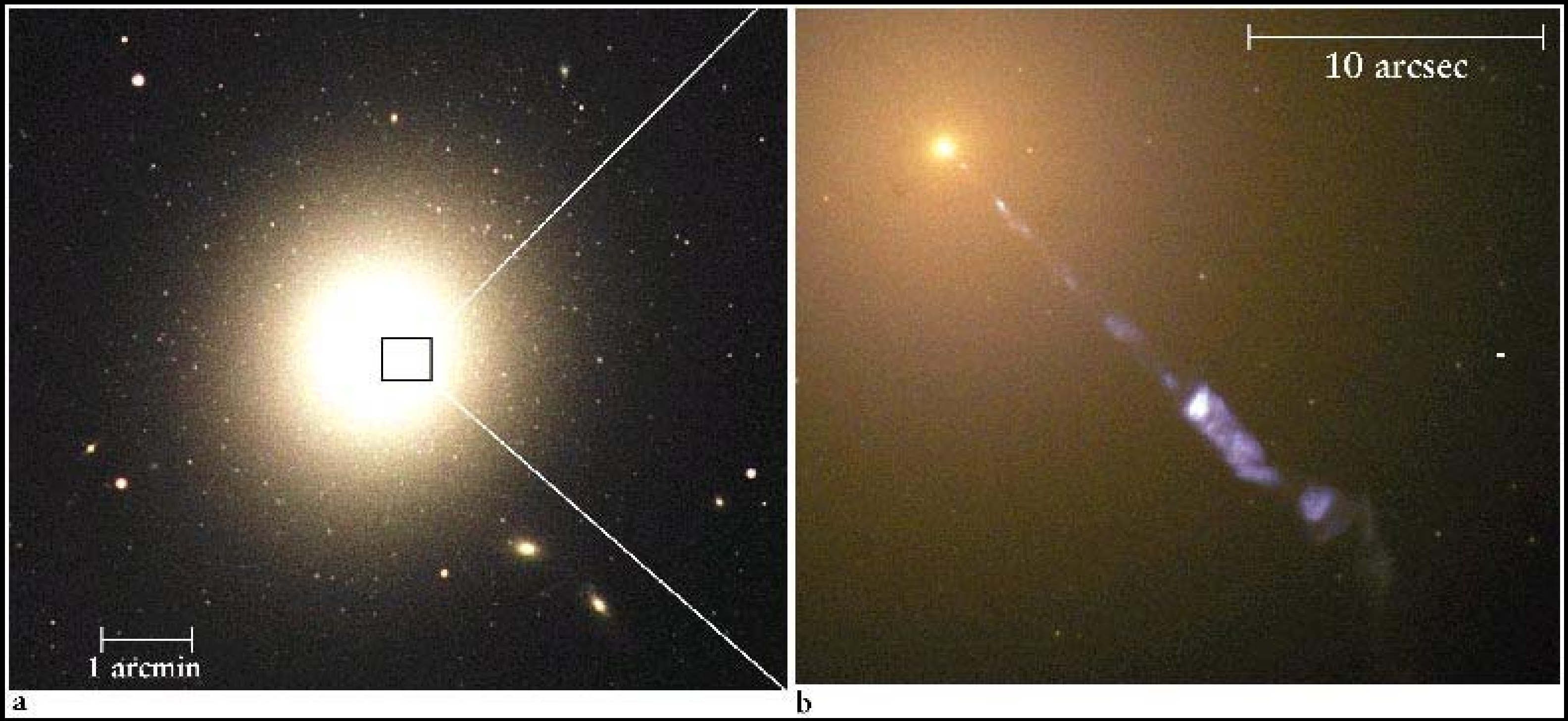
This distant Seyfert Galaxy is likely two galaxies undergoing collision.

Active Galaxies bridge the gap between normal galaxies and quasars.

- Seyfert galaxies
  - luminous, star-like nuclei with strong emission lines.
- BL Lacertae objects (BL Lacs)
  - featureless spectrum with a brightness that can vary by a factor of 15 times in a few months.
  - Most commonly known as a Blazar.

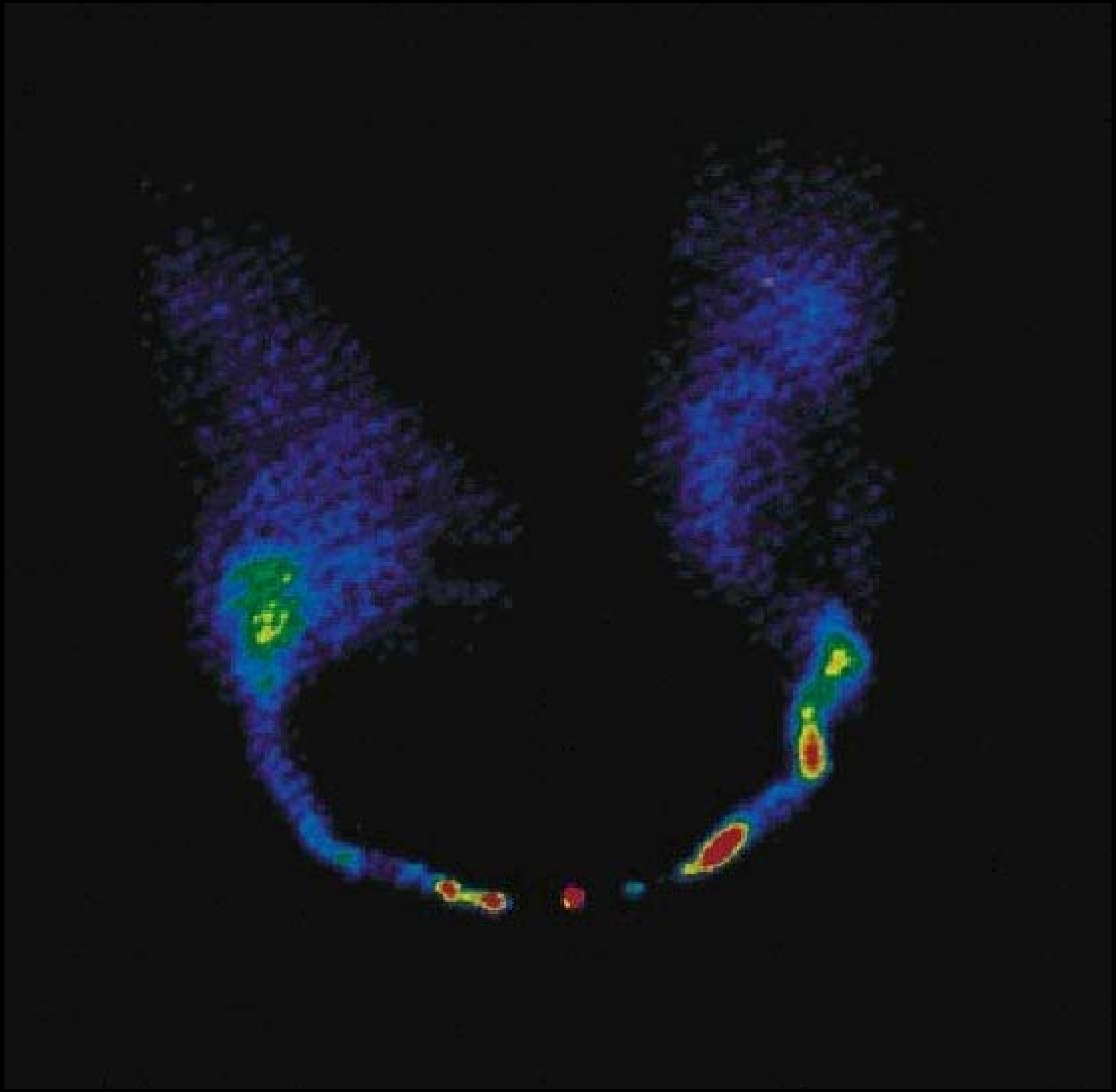


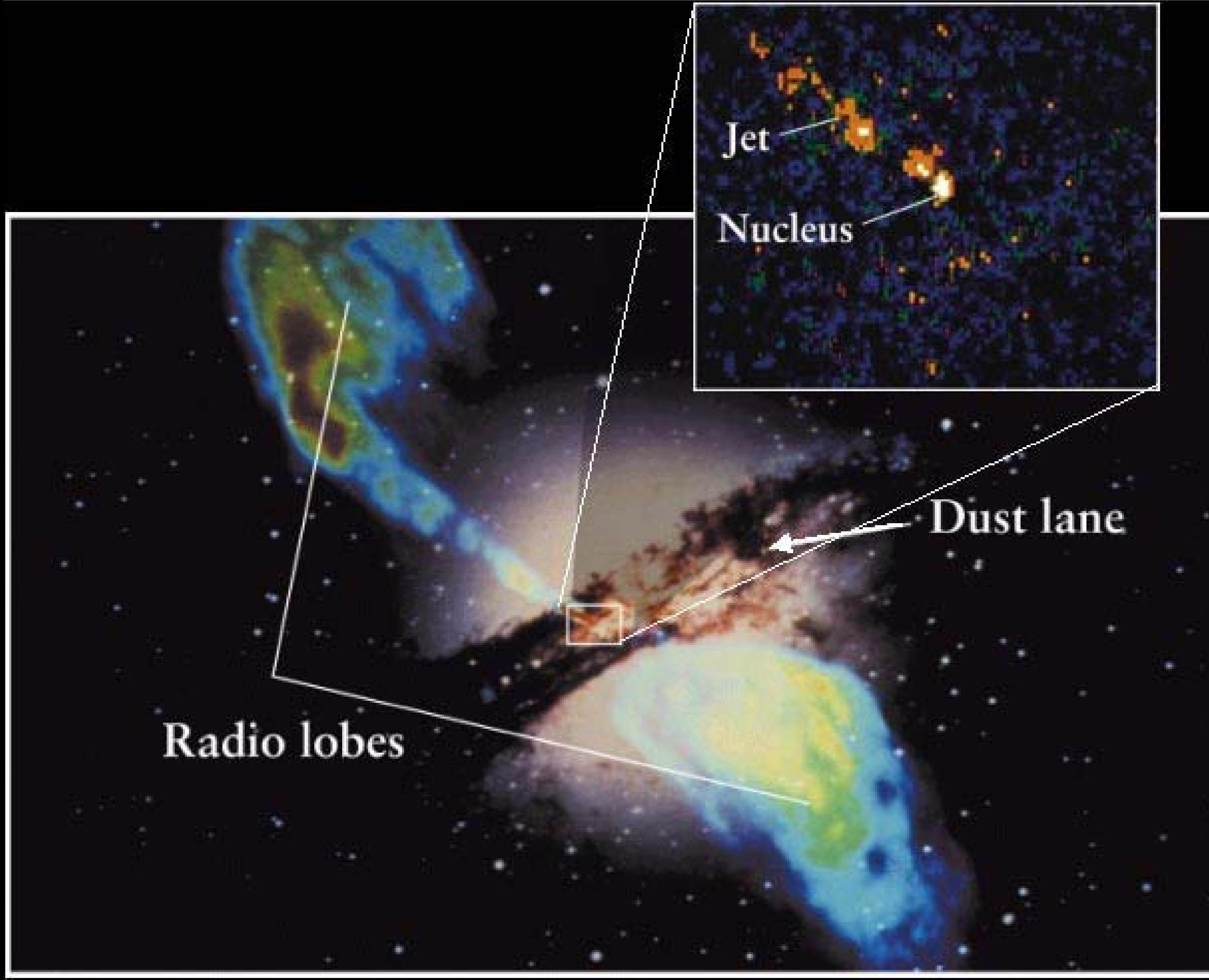
Quasars, blazars, Seyferts, and radio galaxies are active galaxies.



This radio galaxy M87 is like a dim, radio loud quasar. The central core shows thermal radiation whereas the jet shows polarized synchrotron radiation from relativistic electrons.

Active galaxies lie at the center of double radio sources.





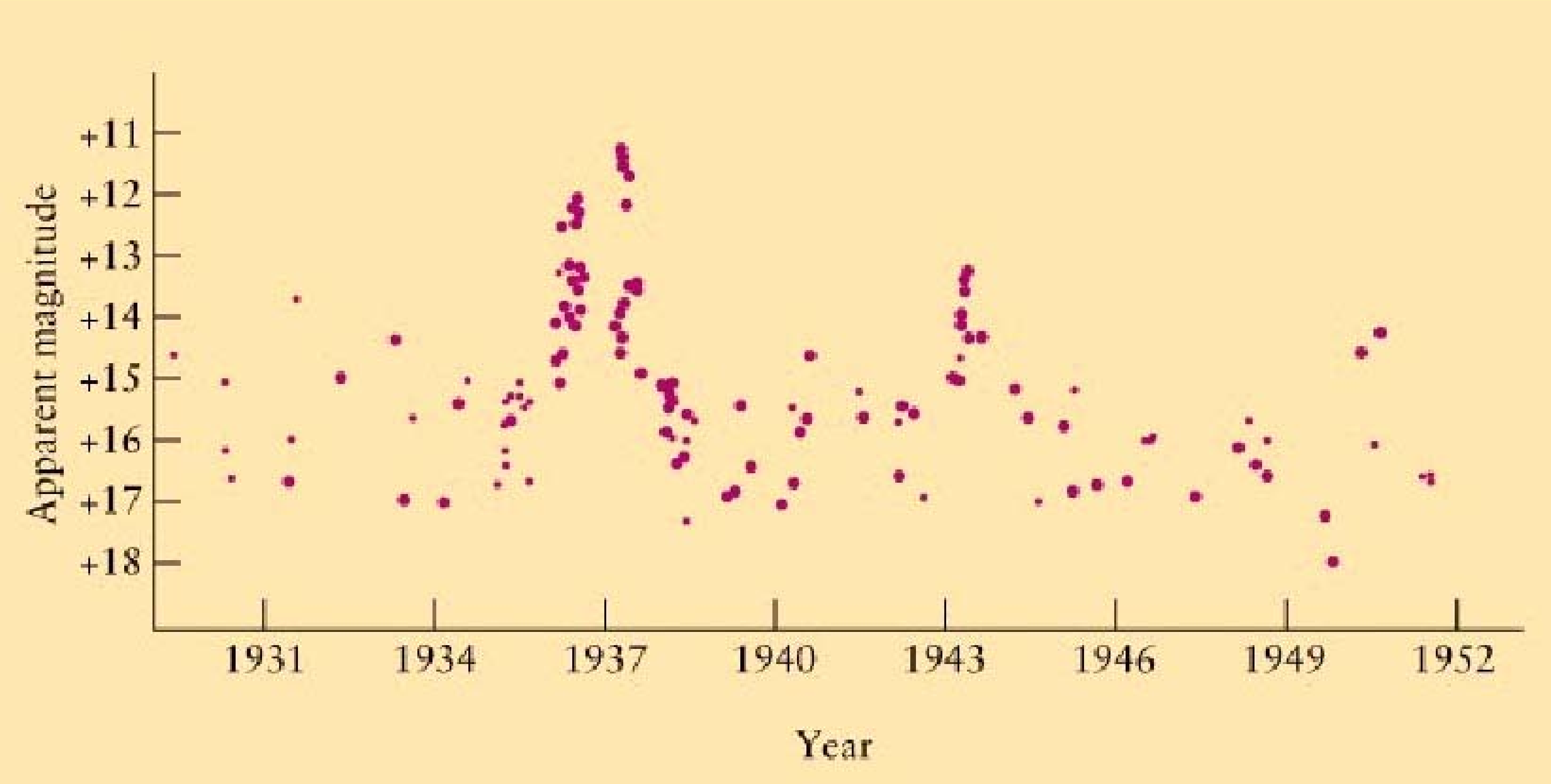
Active galaxies lie at the center of double radio sources.

Quasars, blazars, Seyferts, and radio galaxies are active galaxies.

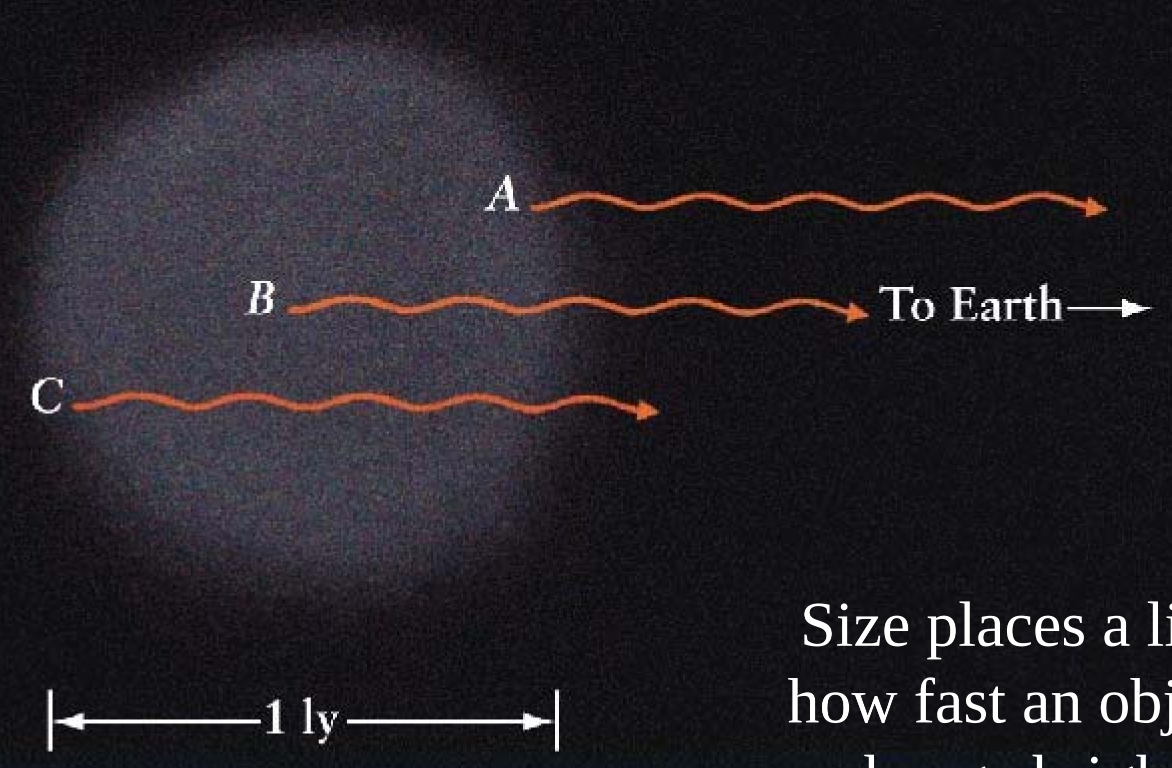
table 27-2 Galaxy and Quasar Luminosities

Object	Luminosity (watts)
Sun	4×10^{26}
Milky Way Galaxy	10^{37}
Seyfert galaxies	$10^{36} - 10^{38}$
Radio galaxies	$10^{36} - 10^{38}$
Quasars	$10^{38} - 10^{42}$

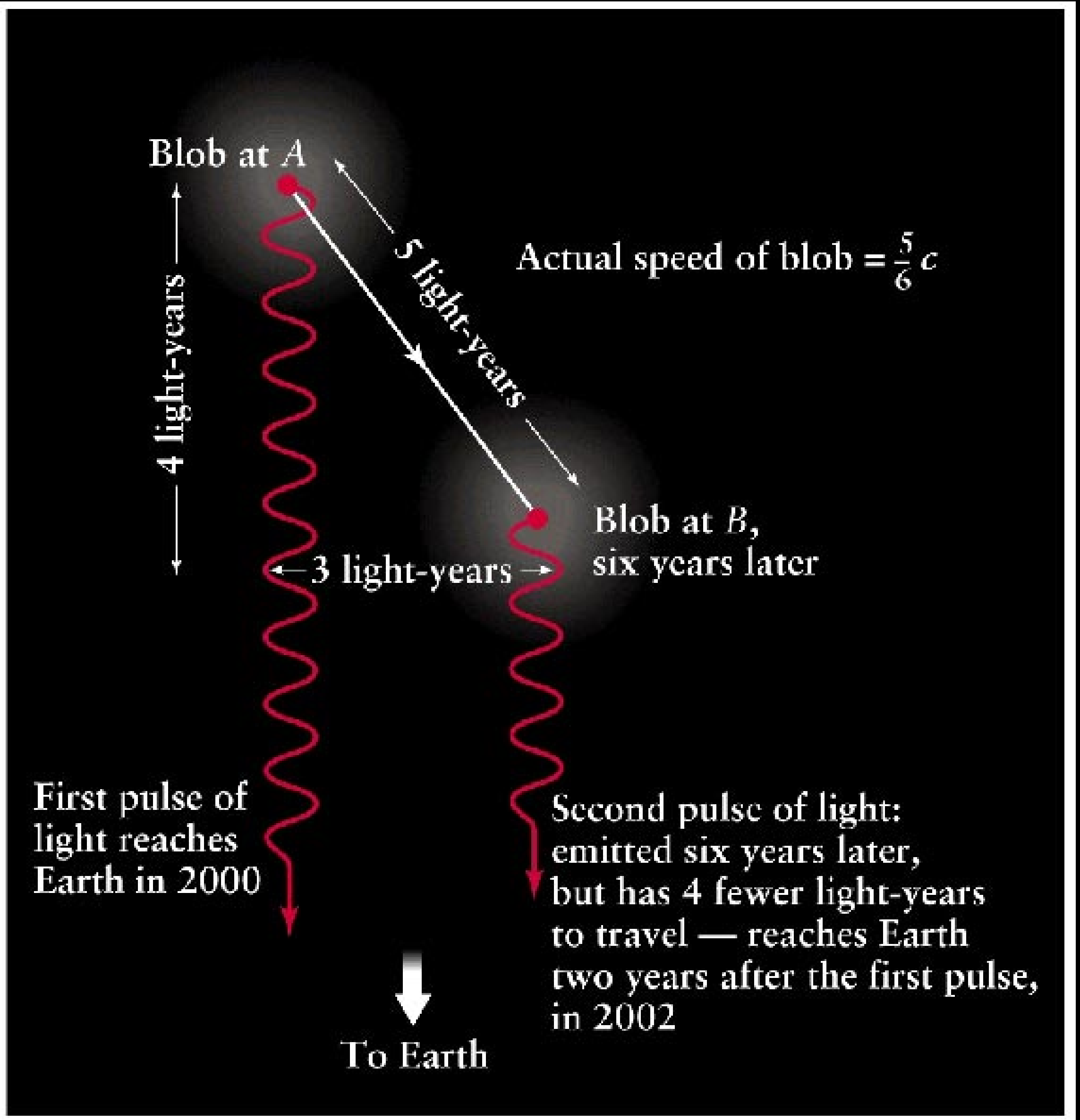
A quasar emits a huge amount of energy from a small volume.



Such rapid changes in brightness can only result from changes small objects.



Size places a limit on how fast an object can change brightness.



a View from above

Supermassive black holes may be the "central engines" that power active galaxies.

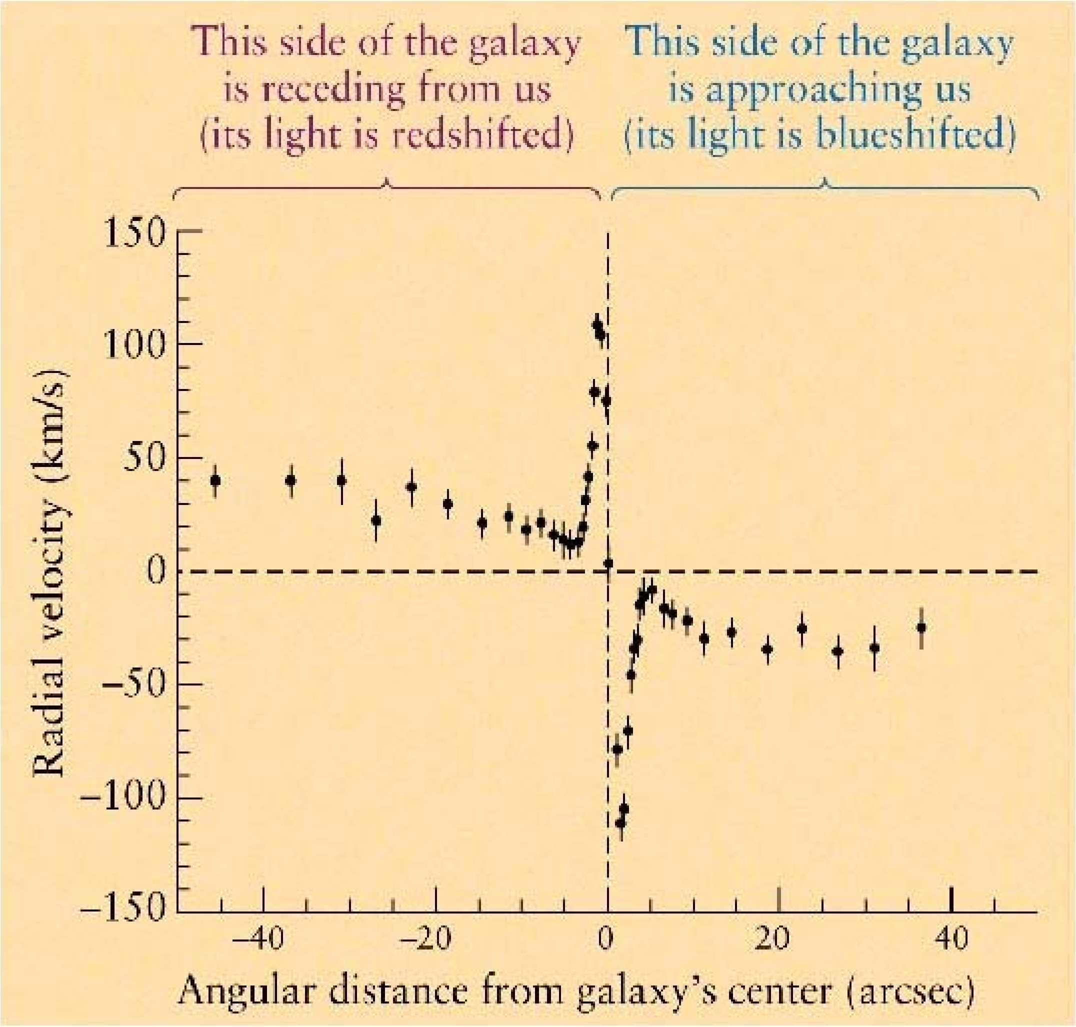
- The *Eddington limit* describes how large a supermassive black hole must be to power an active galactic nucleus:

$$L_{Edd} = 30{,}000\ (M/M_\odot)\ L_\odot$$

  - L_{Edd} is the maximum luminosity that can be radiated by accretion onto a compact object.
  - M is the mass of the compact object.

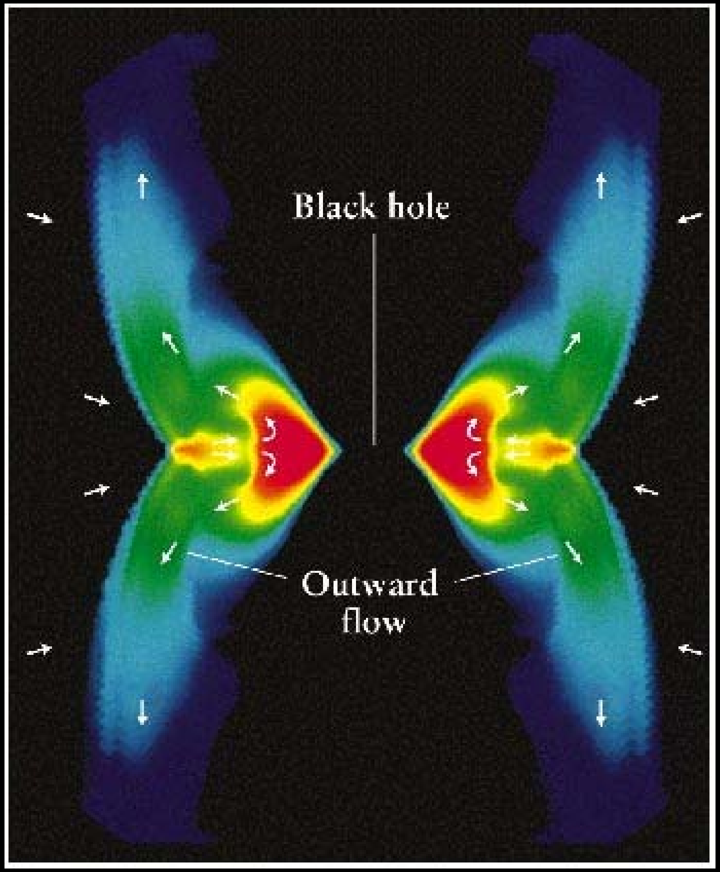
Supermassive black holes may be the "central engines" that power active galaxies.

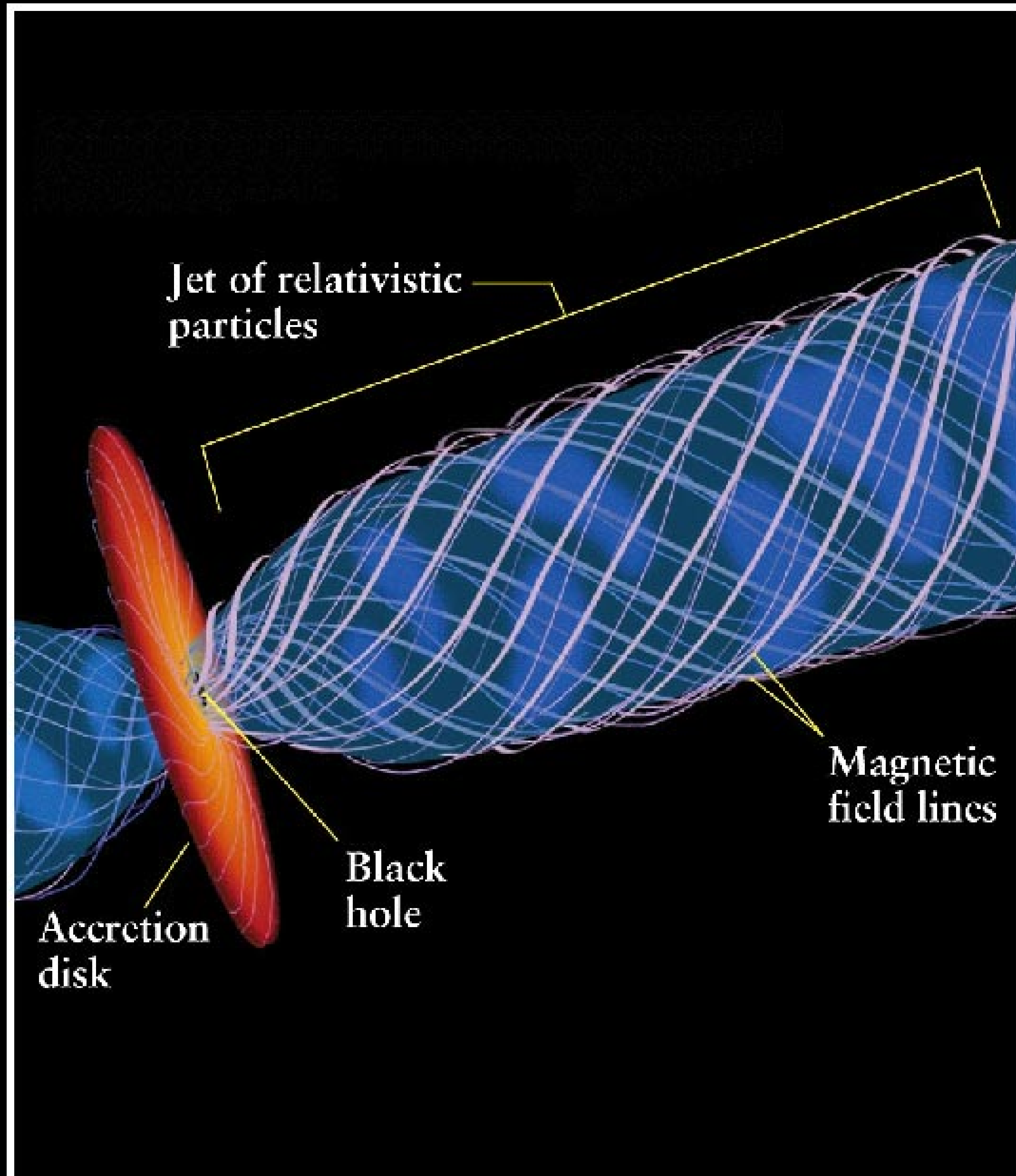
The rotation curve of M31 suggests a massive compact object at the center.

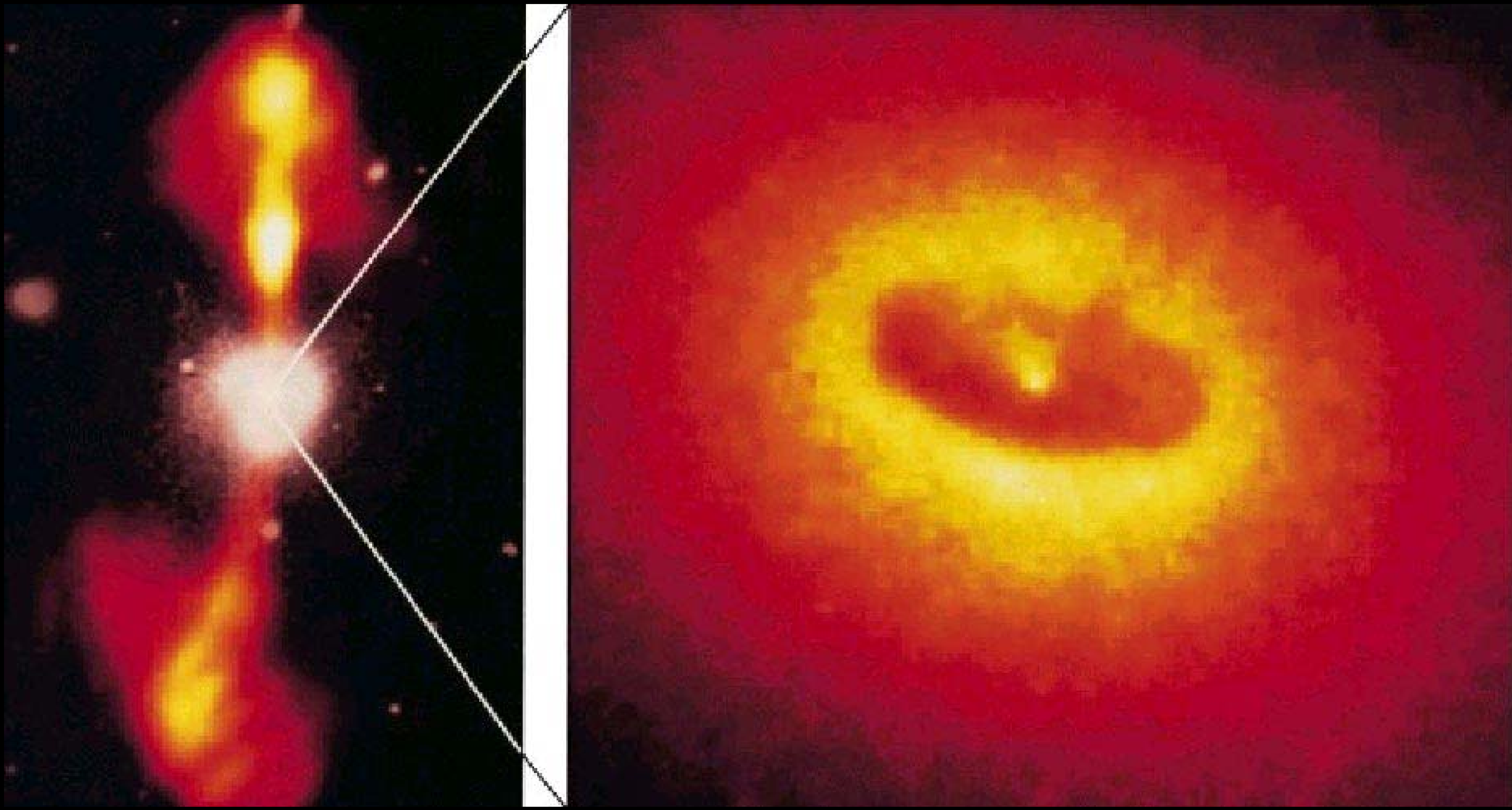


A unified model may explain active galaxies of several different types.

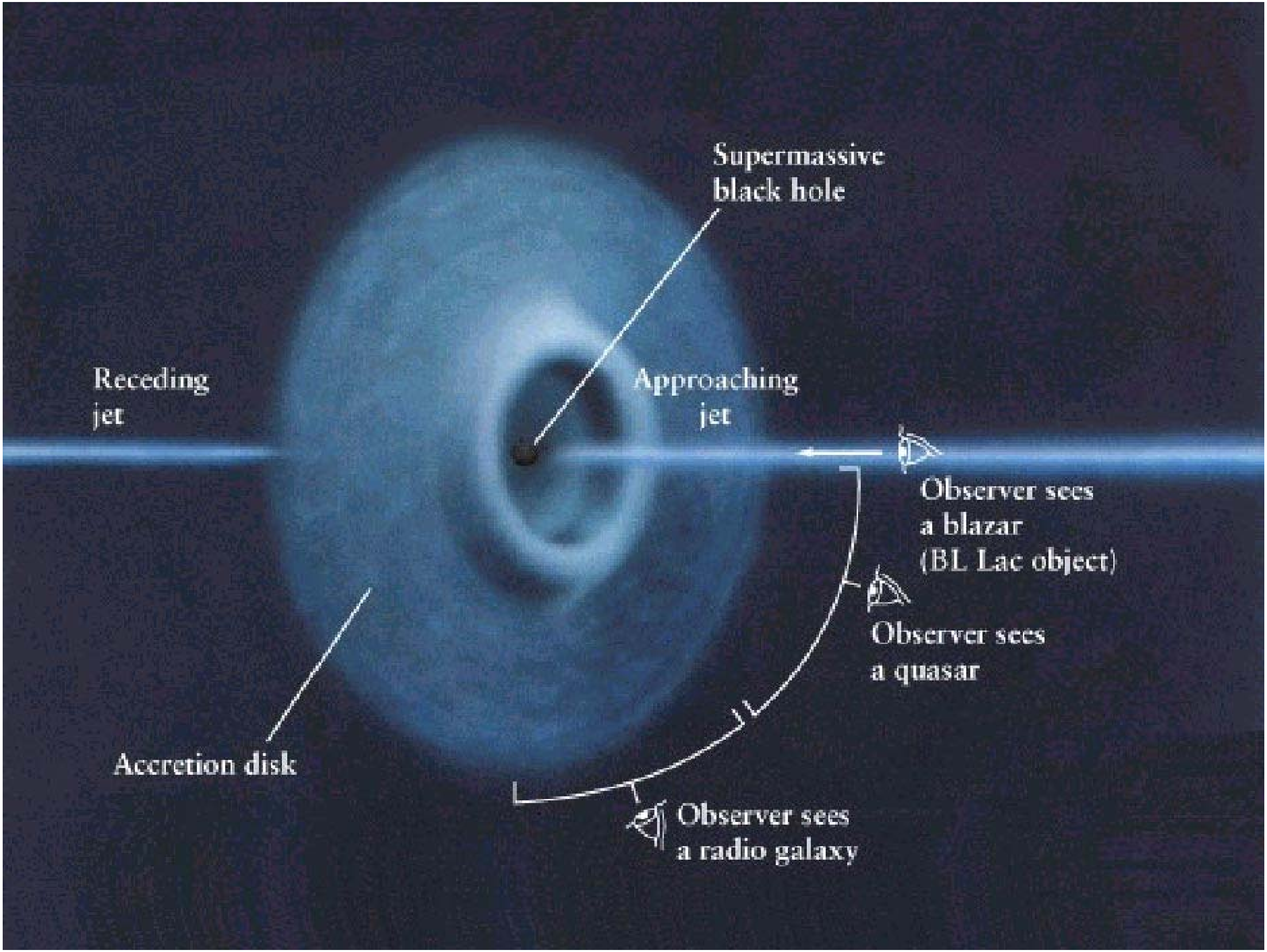
- The general consensus is that the center of active galaxies contain a super massive black hole surrounded by a luminous accretion disk.
- Variations in the density of the disk will account for variations in brightness.
- Magnetic forces will cause jets of material to move outward.




Jet of relativistic particles
Magnetic field lines
Black hole
Accretion disk

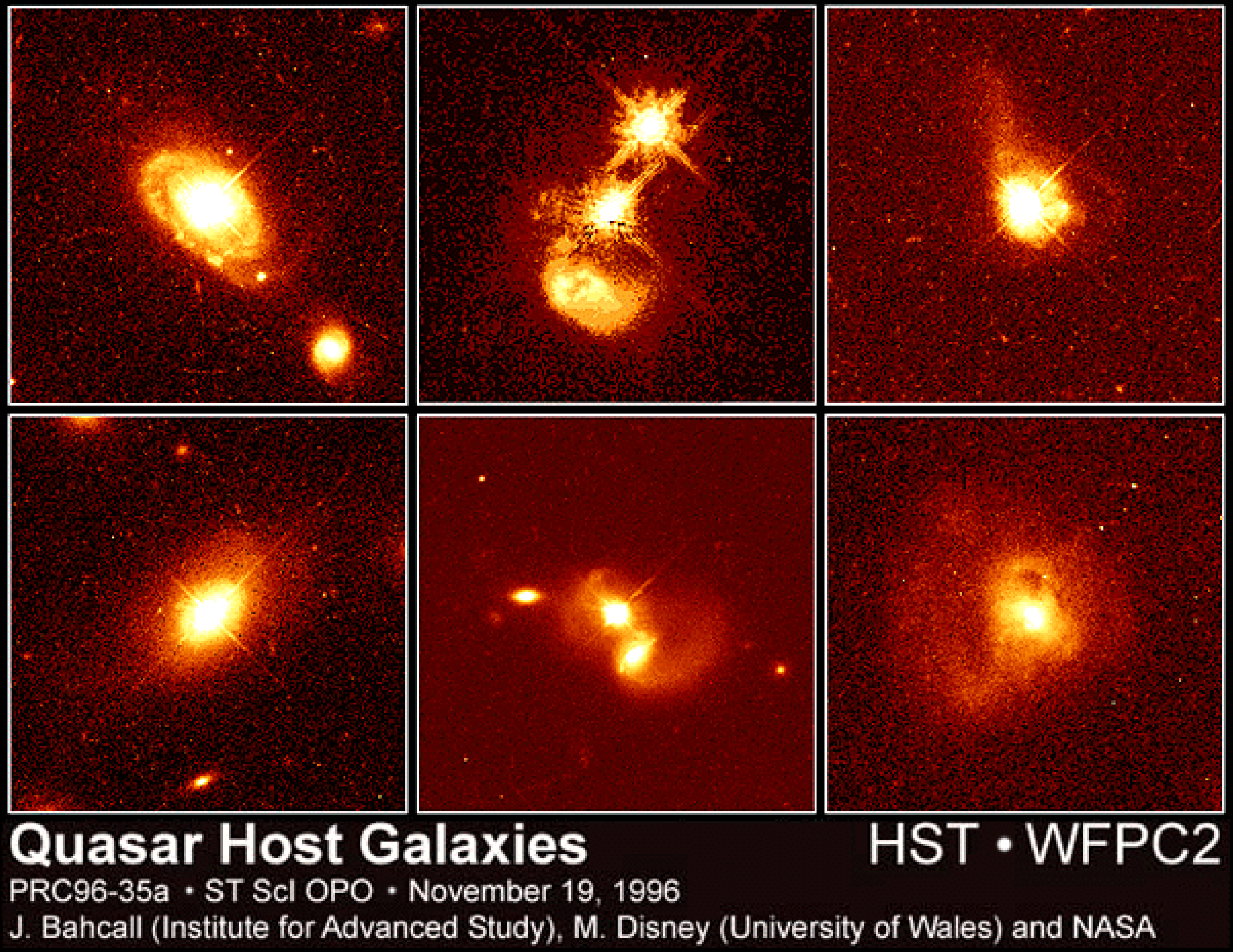


Jets of matter ejected from around a black hole may explain quasars and active galaxies.



Supermassive
black hole
Receding
jet
Approaching
jet
Observer sees
a blazar
(BL Lac object)
Observer sees
a quasar
Accretion disk
Observer sees
a radio galaxy

Hubble ST shows us that quasars do live in galaxies…they are Active Galactic Nuclei!



Seyfert Galaxies

- spiral galaxies with an incredibly bright, star-like center (nucleus)
- they are very bright in the infrared
- their spectra show strong **emission** lines

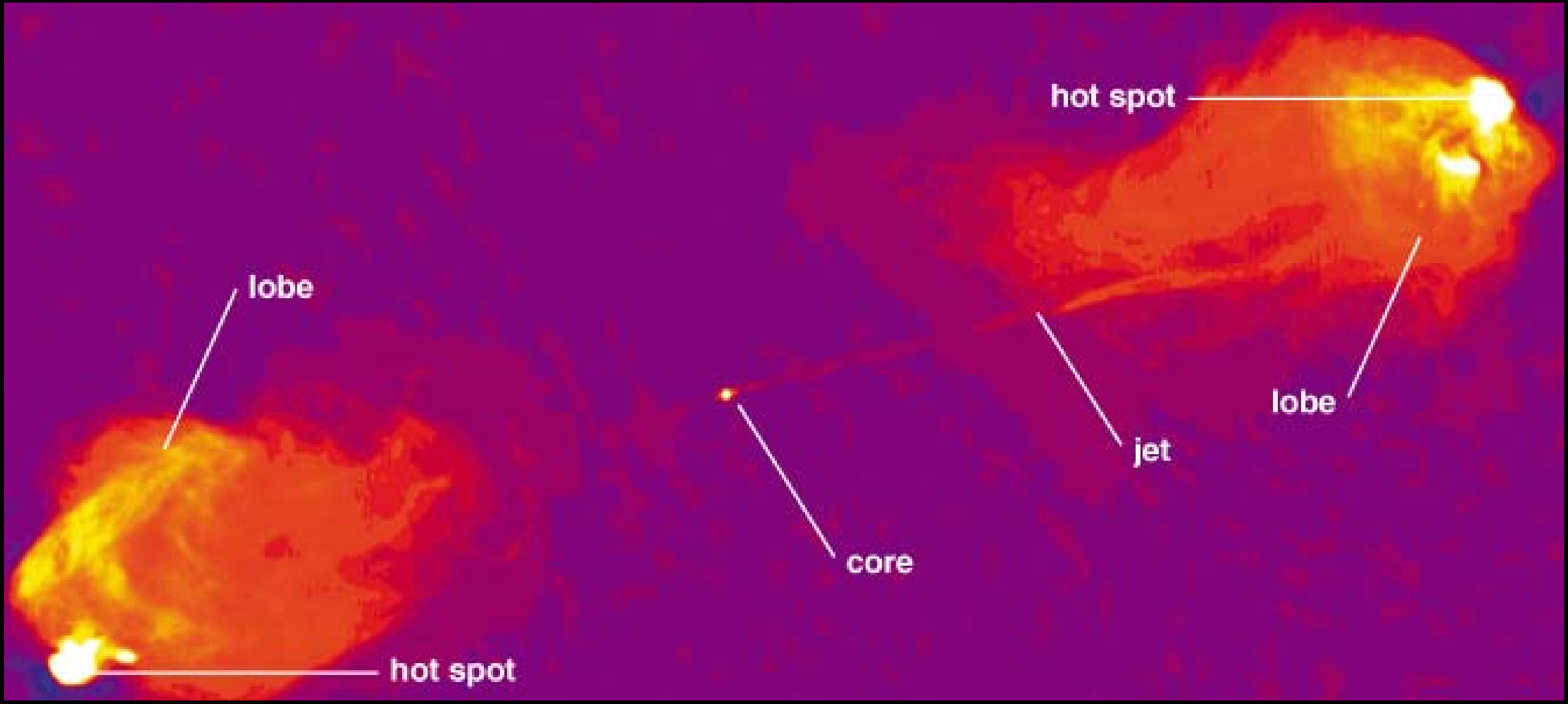
Circinus

The luminosity can vary by as much as the entire brightness of the Milky Way Galaxy!!

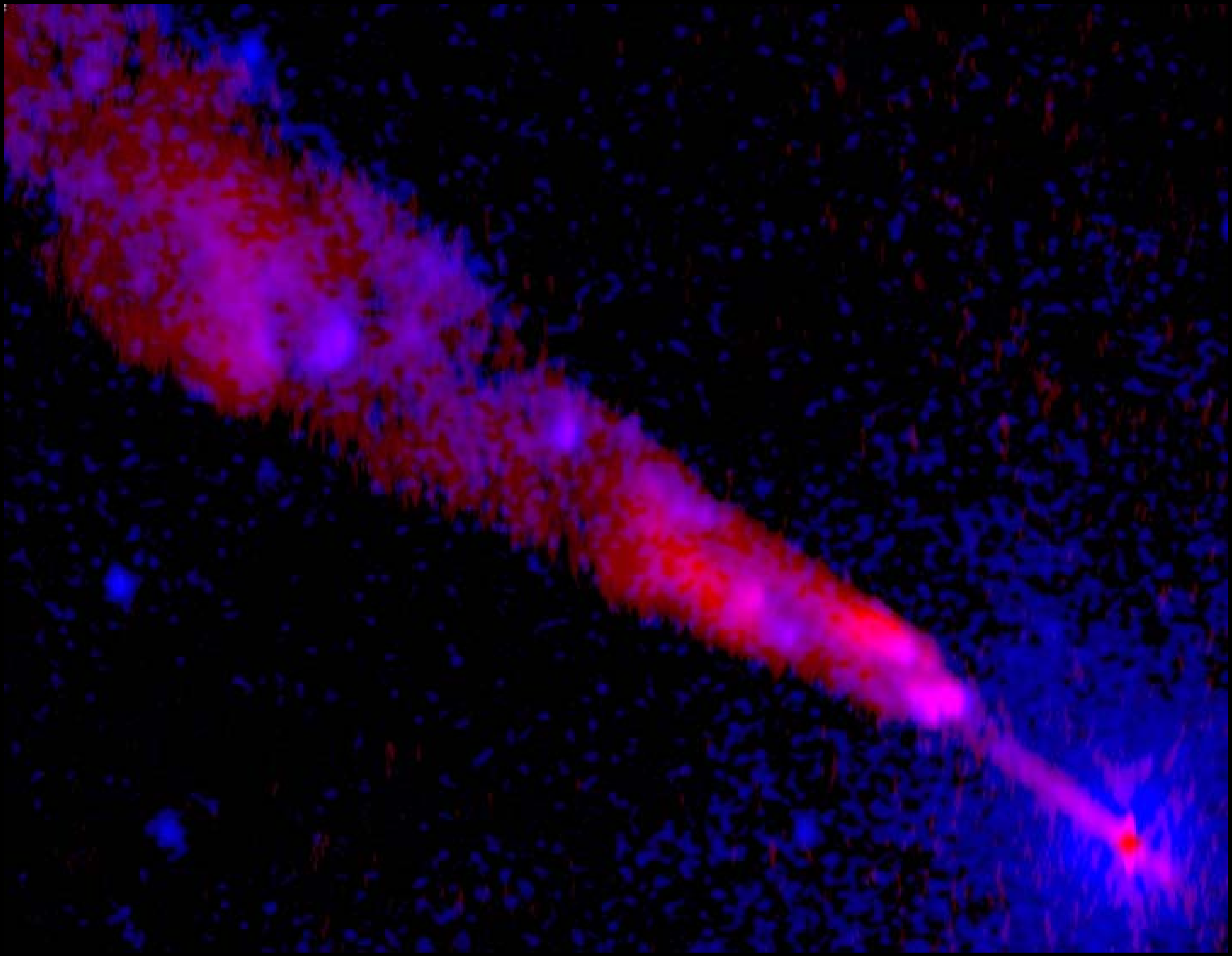
Radio Galaxies

- galaxies which emit large amounts of radio waves
- the radio emission come from *lobes* on either side of the galaxy; **not** the galaxy itself

Cygnus A



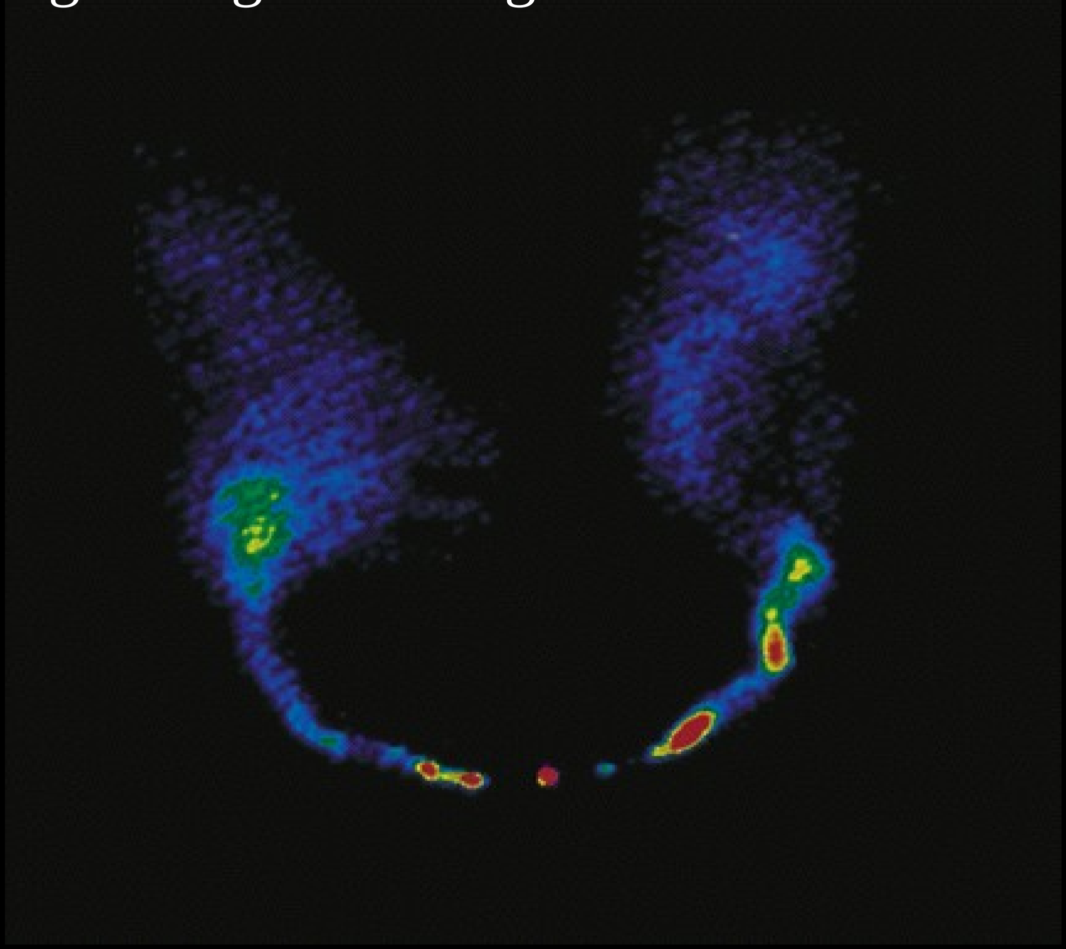
X-ray/Radio Image of Centaurus A



X-ray is blue   Radio is red

Radio Galaxy Lobes

These lobes are swept back because the galaxy is moving through an intergalactic medium.

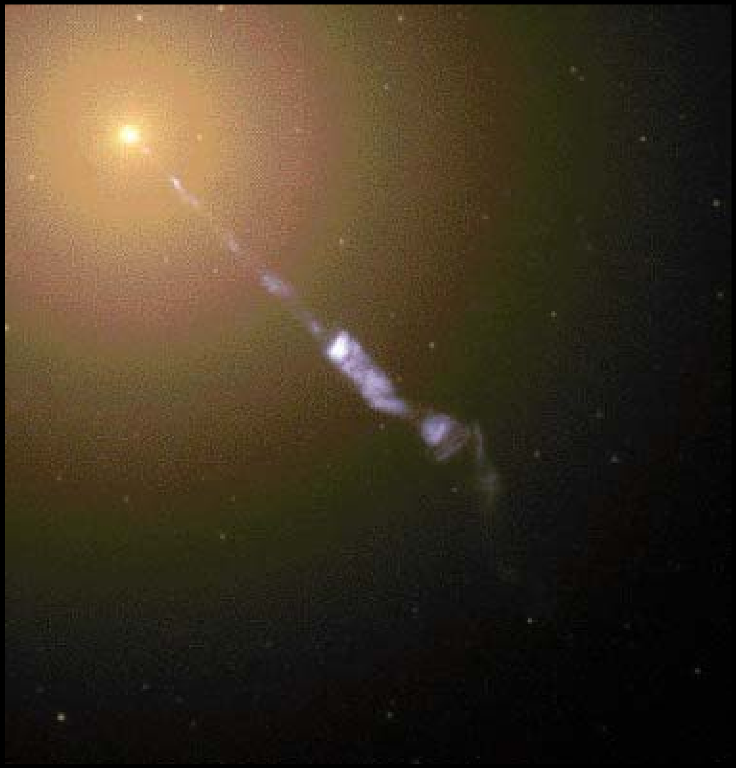


NGC 1265

Active Galactic Nuclei

Jets of matter are shooting out from these galaxies and emitting radio waves, but the matter is **not** cold!

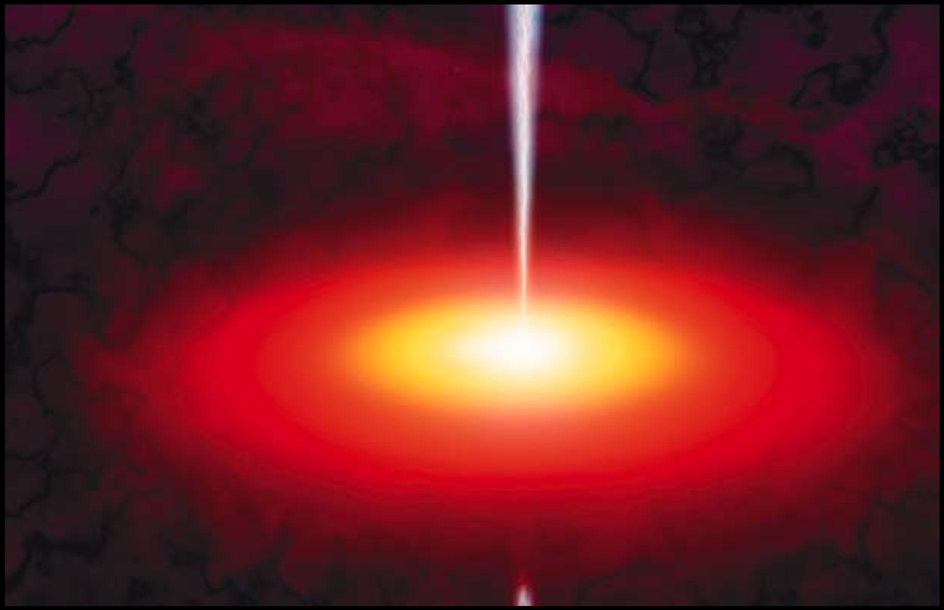
Synchotron emission --- non-thermal process where light is emitted by charged particles moving close to the speed of light around magnetic fields.



M 87

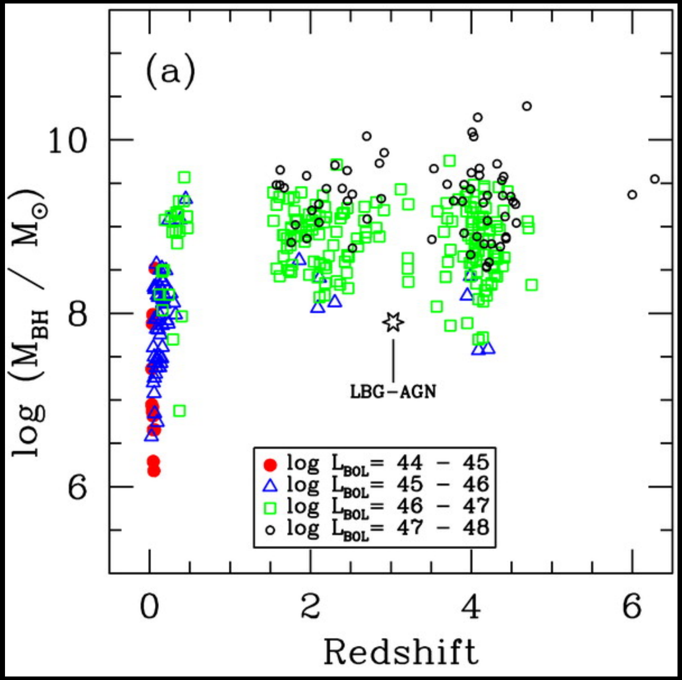
Active Galactic Nuclei

- The energy is generated from matter falling onto a **supermassive black hole**…
  - $1.2 \times 10^9\ M_\odot$ for NGC 4261
  - $3 \times 10^9\ M_\odot$ for M87
- …which is at the center (nucleus) of the galaxy.



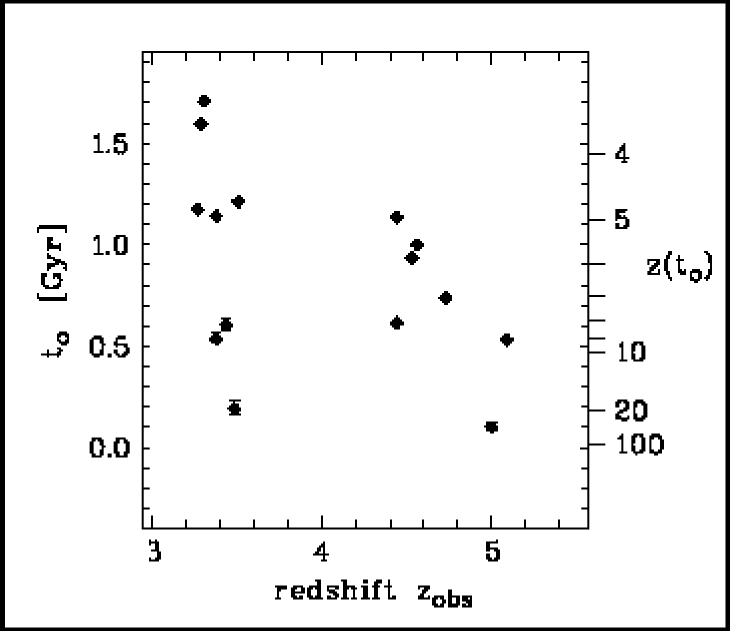
- Matter swirls through an accretion disk before crossing over the event horizon.
- Gravitational pot. energy lost
  - $= mc^2$ the mass energy
  - 10 – 40% of this is radiated away
- Process is very efficient for generating energy.

Early Growth of Supermassive Black Holes



Vestergaard 2004

Formation timescale



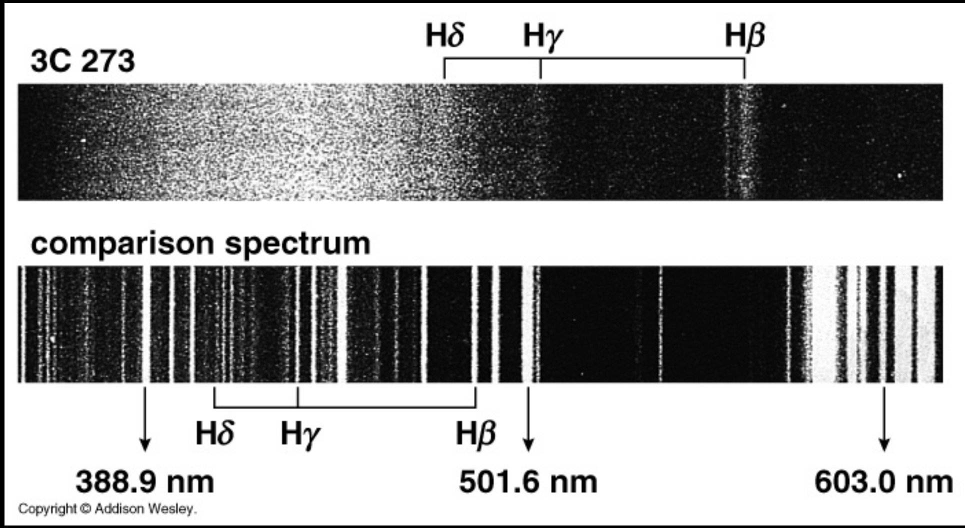
Dietrich and Hamann 2004

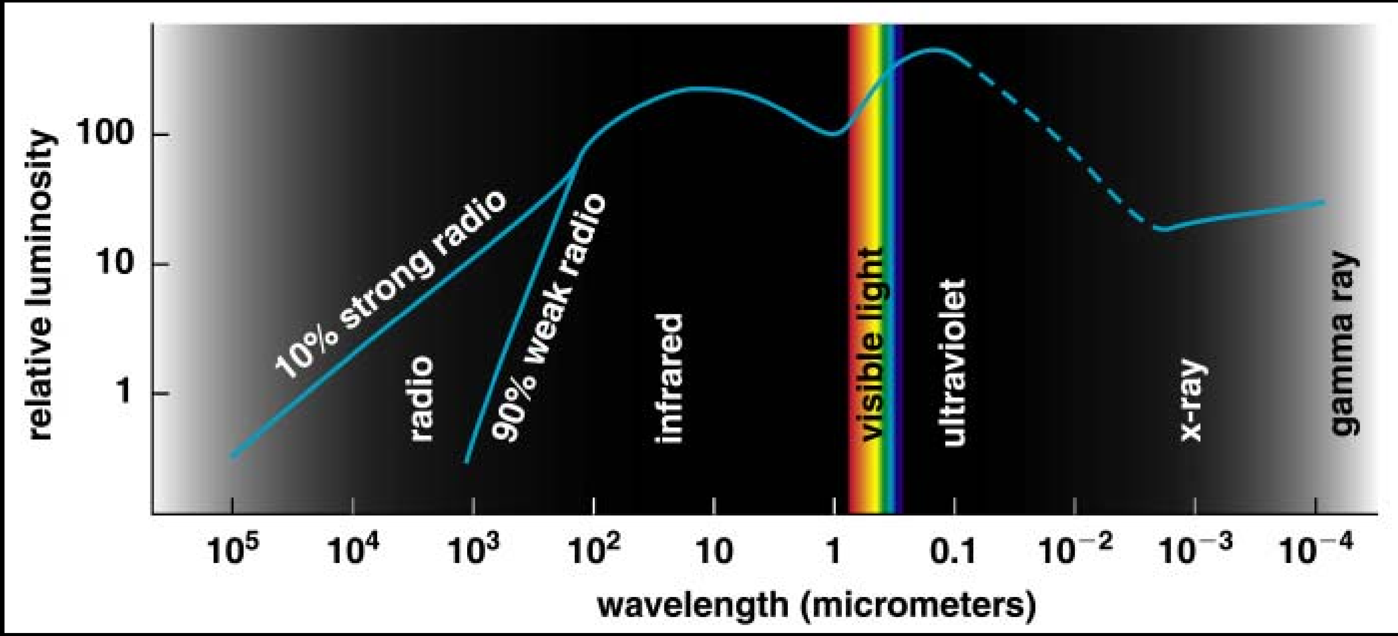
Lack of spectral evolution in high-redshift quasars → quasar BH estimate valid at high-z

- Billion solar mass BH indicates very early growth of BHs in the Universe

Quasar Spectra

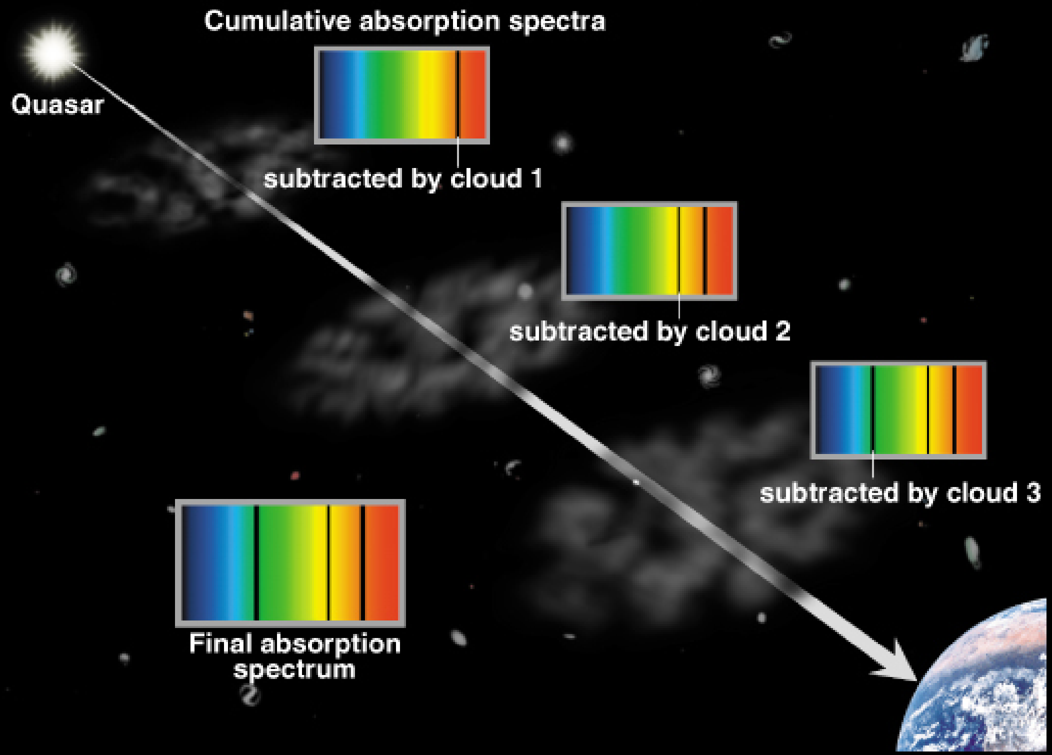
- Star-like objects which:
  - have spectra that look nothing like a star
    - highly redshifted
  - can be strong radio sources
    - turns out that 90% are **not**
  - emit light at all wavelengths



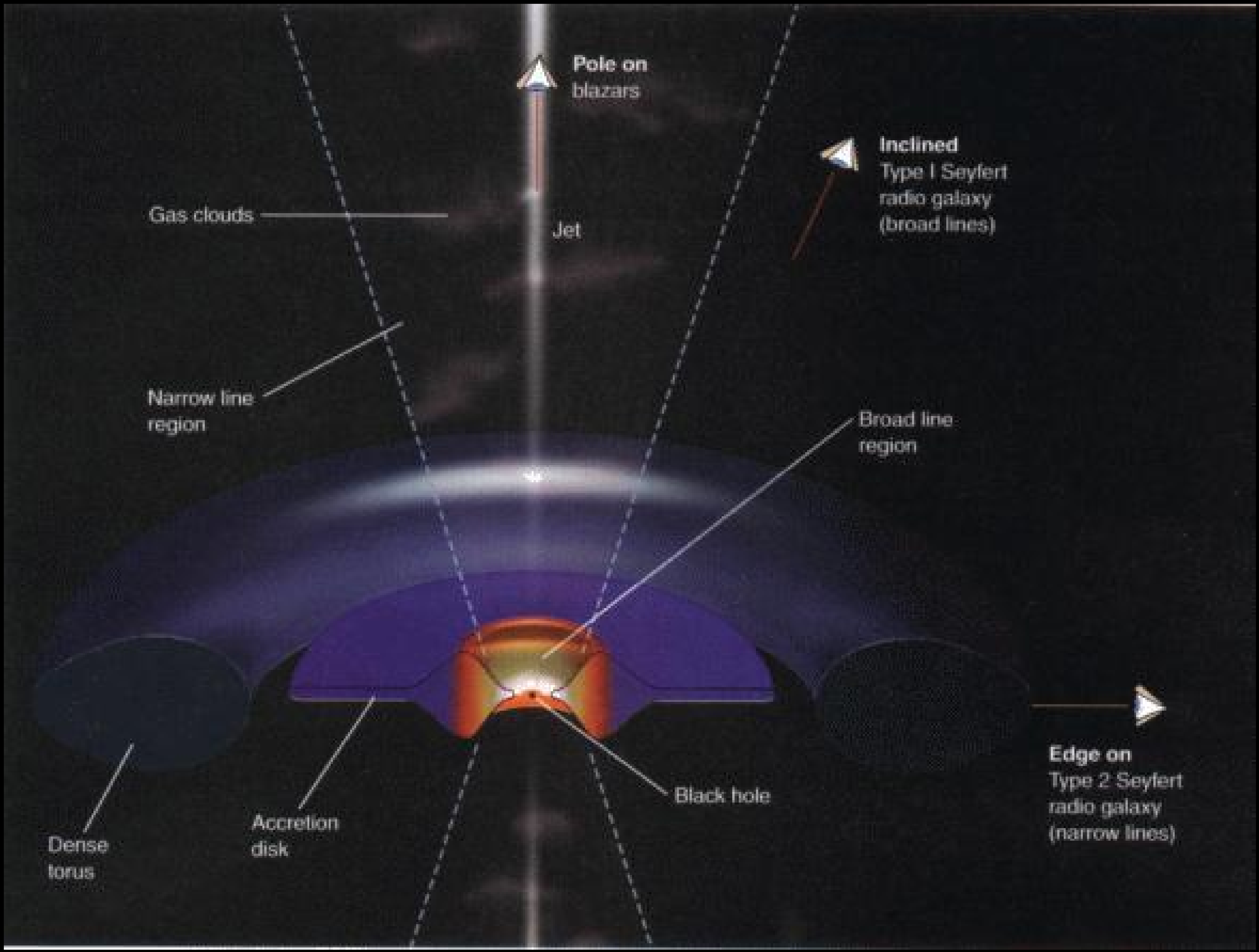


A “Forest” of Absorption Lines

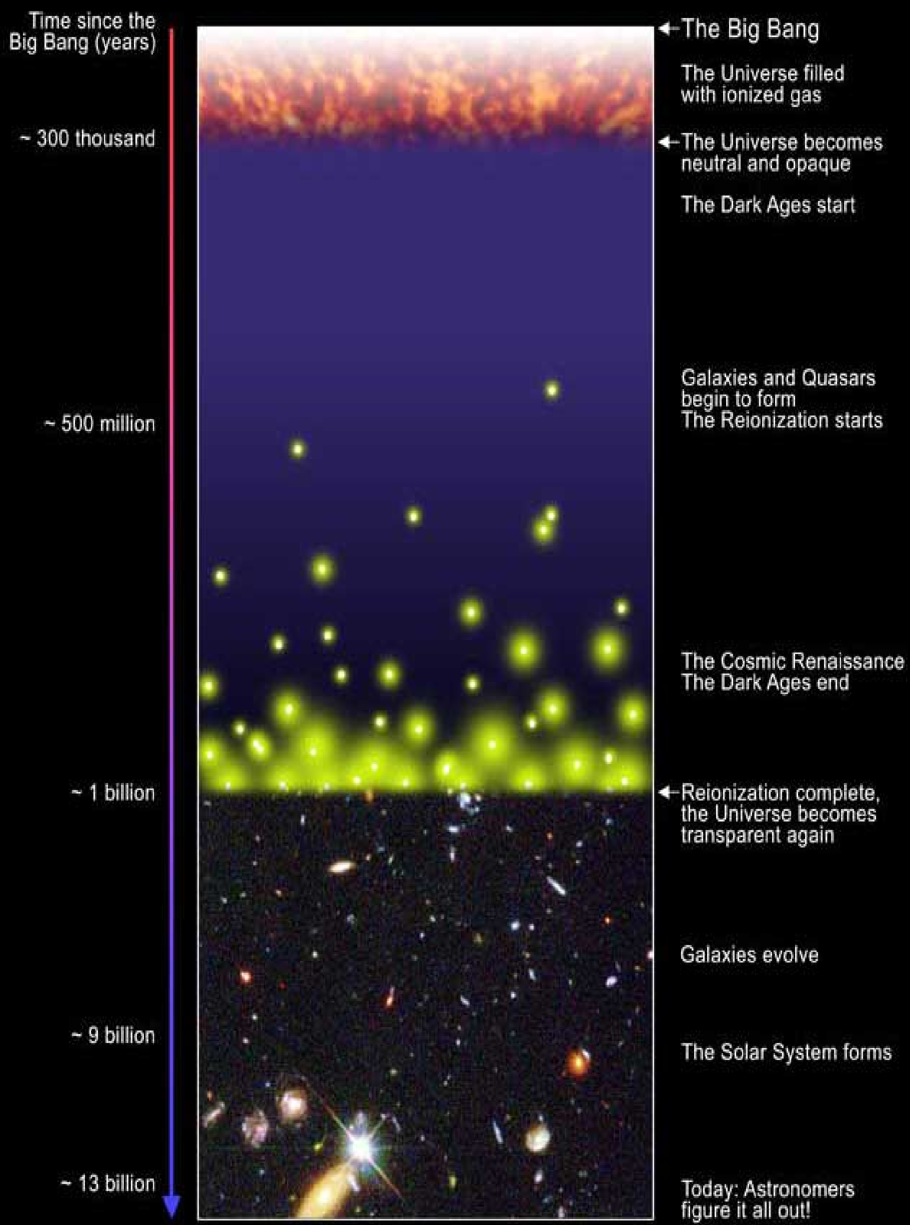
- As light from a quasar travels toward Earth…
  - it passes through intergalactic Hydrogen clouds and galaxies
  - each cloud leaves absorption lines at a *different* redshift on quasar spectrum
  - this is the only way we can “observe” protogalactic clouds



- Analysis so far has shown:
  - H lines at high redshift are broader than those at low
  - implies that the gas content of clouds/galaxies is higher in the early Universe
  - more heavy element lines are seen at low redshift
  - supports element enrichment of galaxies by supernovae
- These data support our models of galaxy evolution


Pole on
blazars
Inclined
Type I Seyfert
radio galaxy
(broad lines)
Gas clouds
Jet
Narrow line
region
Broad line
region
Edge on
Type 2 Seyfert
radio galaxy
(narrow lines)
Black hole
Accretion
disk
Dense
torus

A brief cosmic history



←recombination

←Cosmic Dark Ages: no light
no star, no quasar; IGM: HI

←First light: the first galaxies
and quasars in the universe

←Epoch of reionization: radiation
from the first object lit up and ionize
IGM : HI → HII

←HII regions overlap,
reionization completed,
the universe is transpartent and
the dark ages ended

← today