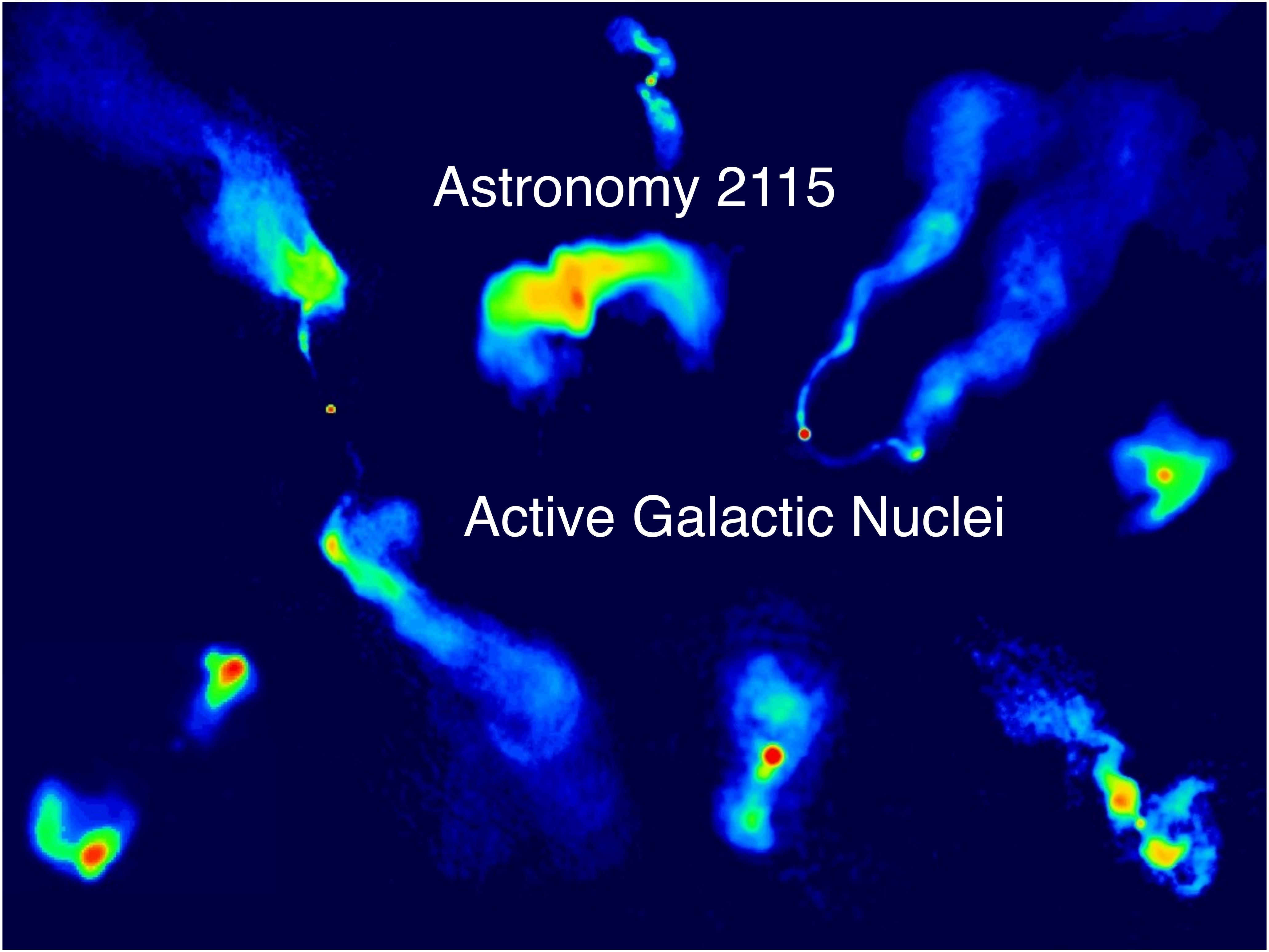

Astronomy 2115
Active Galactic Nuclei

Active Galactic Nuclei: Ch 25

Key points:

- Active Galactic Nuclei: powerful energy sources in nuclei of some galaxies
- Types: Seyferts, quasars, blazars and radio galaxies.
- Central Engine: accretion of matter onto a supermassive black hole.

Galactic Nuclei

Galaxy nucleus:

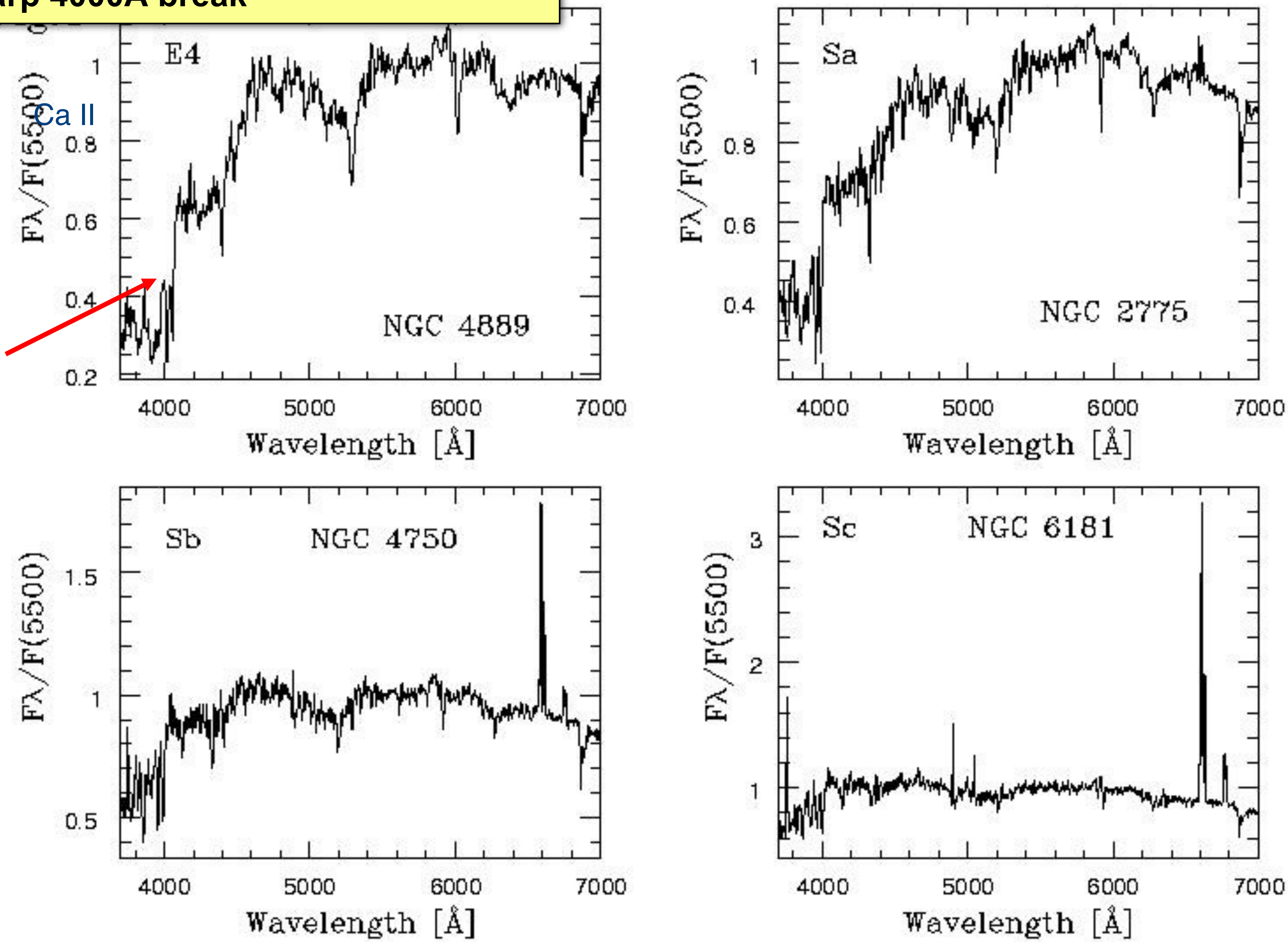
- Exact center of a galaxy
- If a spiral galaxy it is also the dynamical center (center of rotation)

Normal galaxies:

- Dense, central stellar cluster
- Show a composite stellar absorption line spectrum
- Sometimes they show weak nebular emission lines

Absorption from cool, red giant stars
Sharp 4000Å break

Normal Galaxies



Active Galactic Nuclei (AGN)

- ~1% of field galaxies have an *active nucleus*
- Nucleus is compact and bright, sometimes outshining the whole galaxy
- Display strong, broad emission lines from hot, dense, highly excited gas
- Highly variable => small, only a few light days across

Discovery of AGN

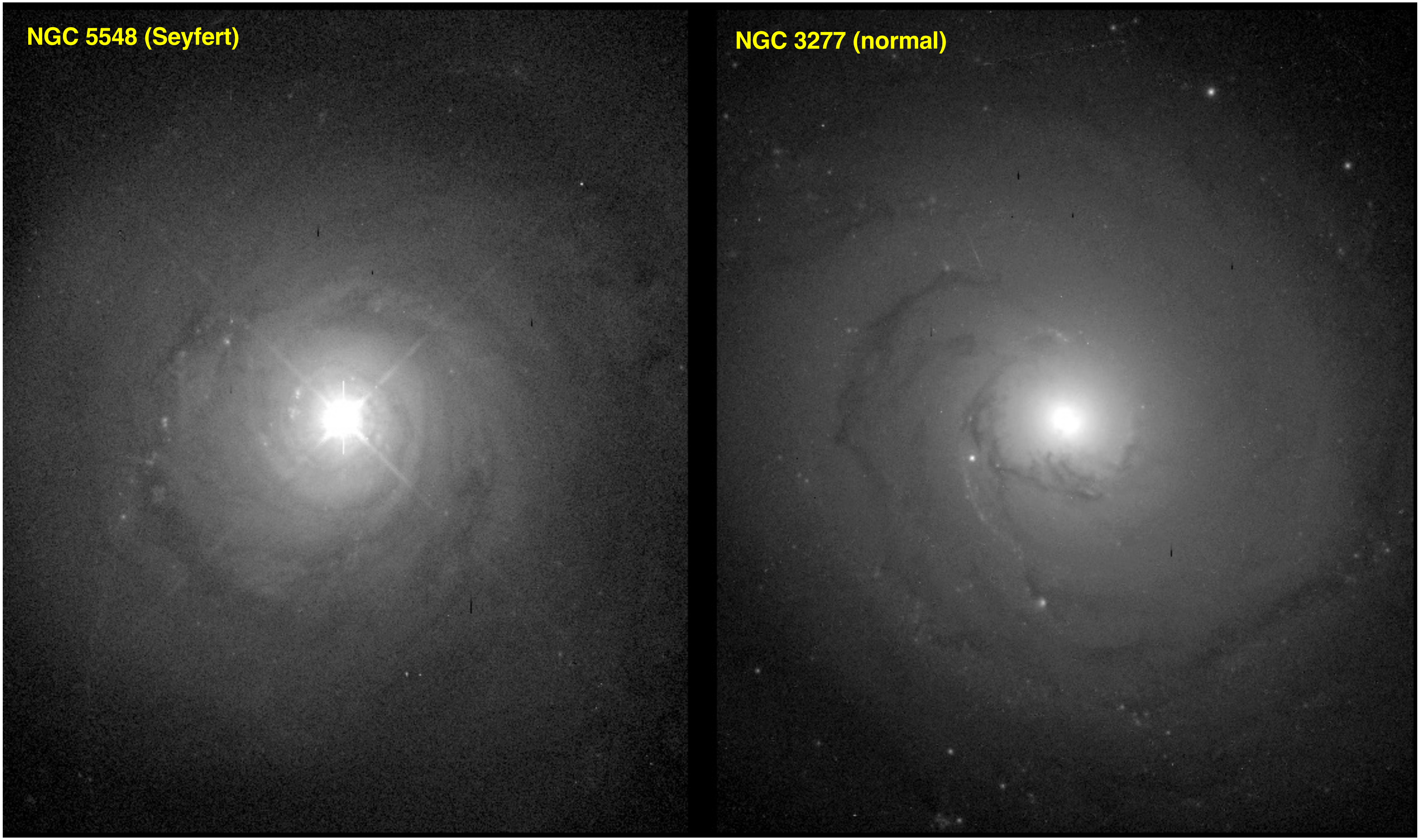
1940's: Carl Seyfert found 6 galaxies with:

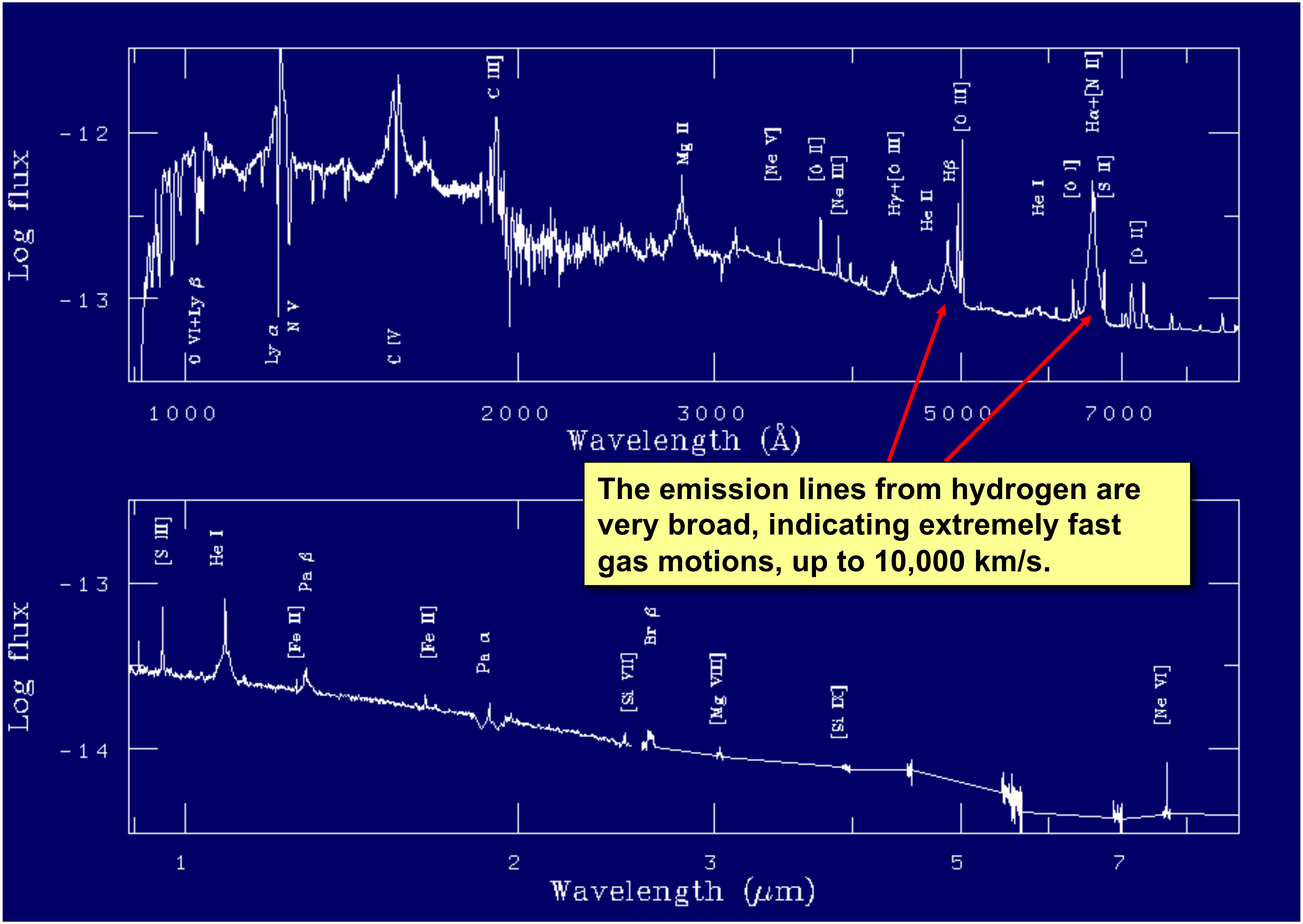
- Strong, broad emission lines.
- Unusually bright, point-like nuclei embedded in spirals.

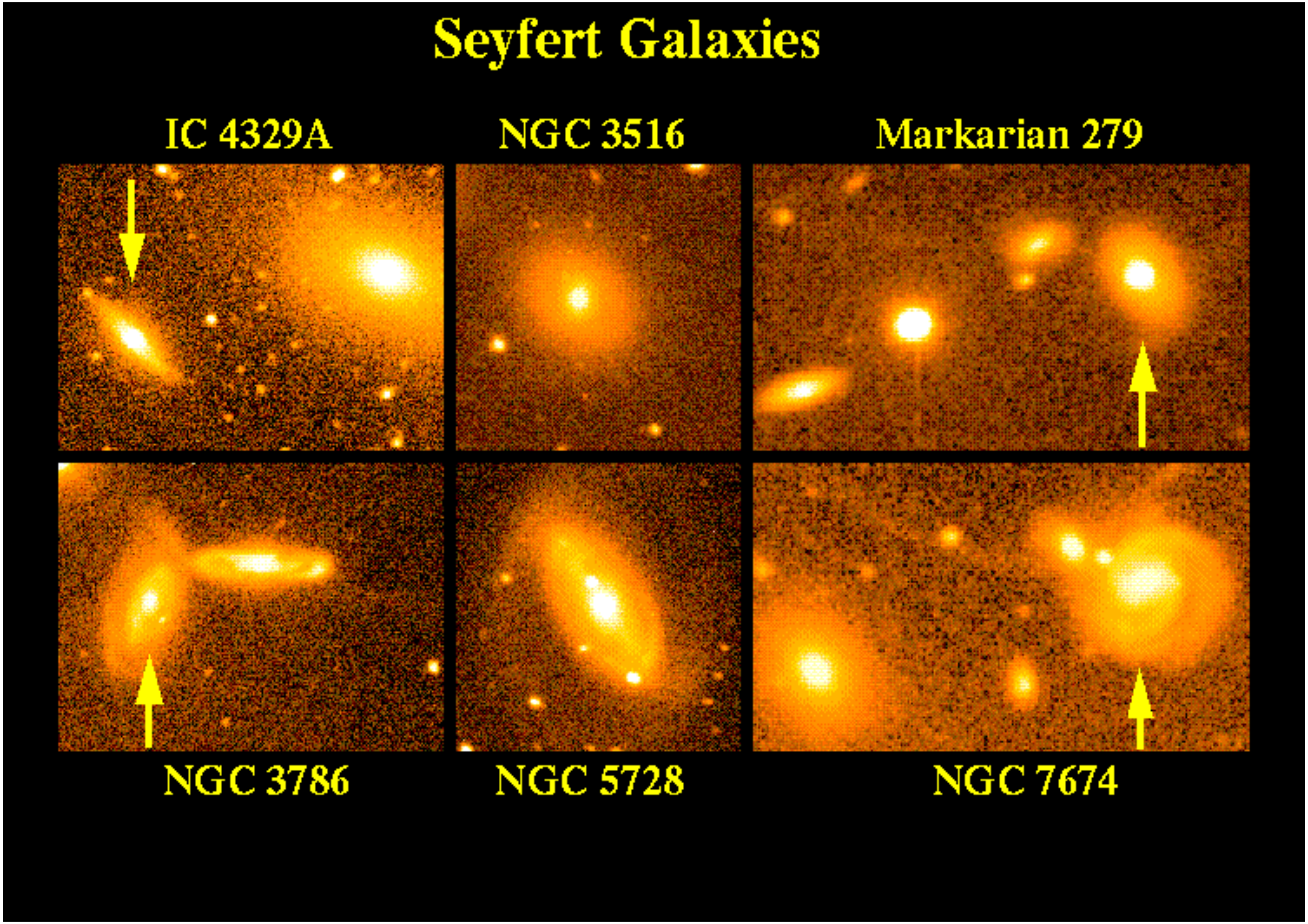
1950: Radio galaxies discovered:

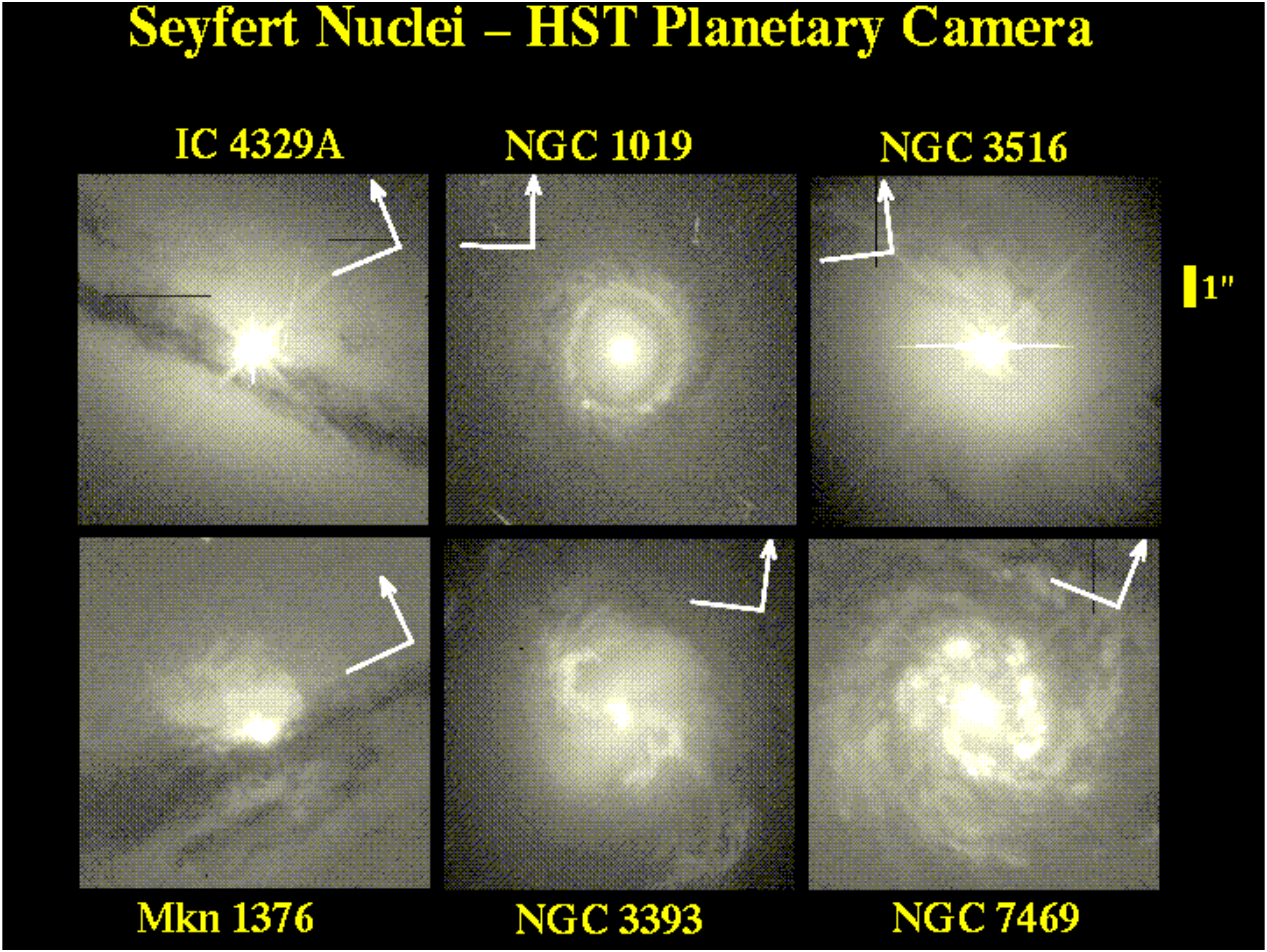
- Faint galaxies at location of intense radio emission
- Sometimes with broad emission-lines in their spectra.

Seyfert vs Normal Galaxy

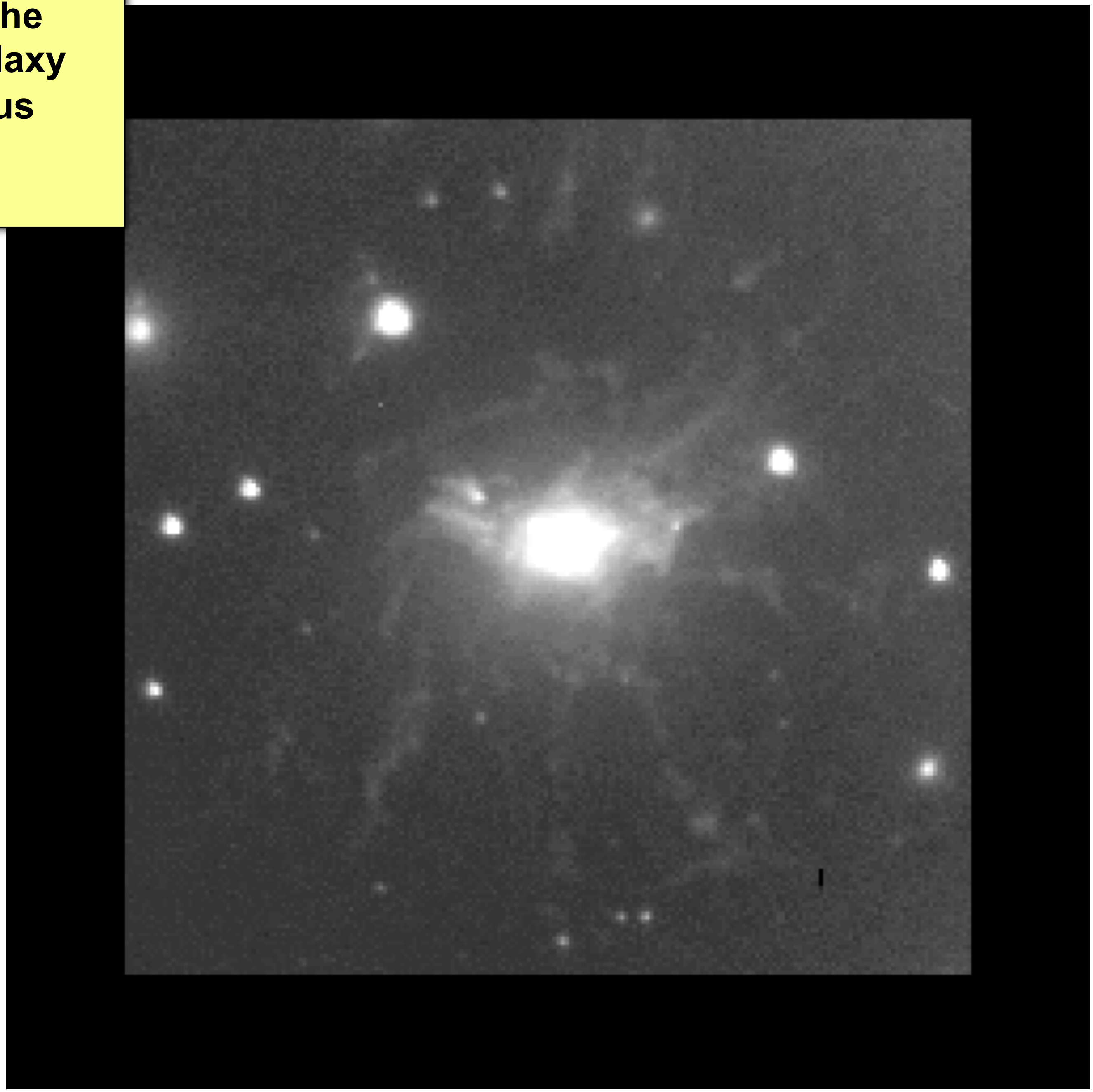



Log flux
-12
-13
O VI+Ly β
Ly α
N V
C IV
C III]
Mg II
[Ne V]
[O II]
[Ne III]
Hγ+[O III]
He II
Hβ
[O III]
He I
[O I]
Hα+[N II]
[S II]
[O II]
1000
2000
3000
5000
7000
Wavelength (Å)
The emission lines from hydrogen are very broad, indicating extremely fast gas motions, up to 10,000 km/s.
Log flux
-13
-14
[S III]
He I
Pa β
[Fe II]
[Fe II]
Pa α
[Si VII]
Br β
[Mg VIII]
[Si IX]
[Ne VI]
1
2
3
5
7
Wavelength (μm)


Seyfert Galaxies
IC 4329A
NGC 3516
Markarian 279
NGC 3786
NGC 5728
NGC 7674

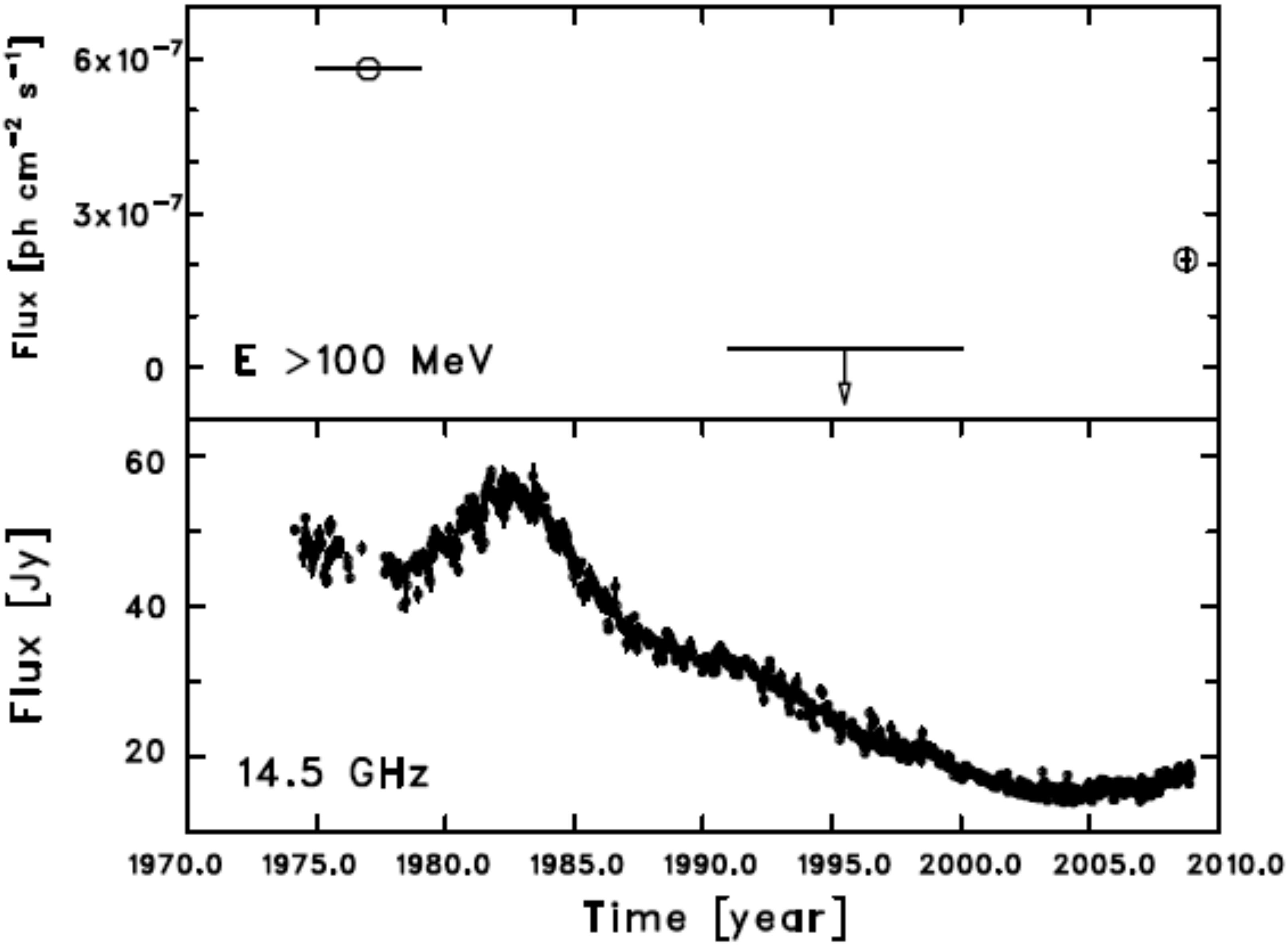

Seyfert Nuclei – HST Planetary Camera
IC 4329A
NGC 1019
NGC 3516
1"
Mkn 1376
NGC 3393
NGC 7469

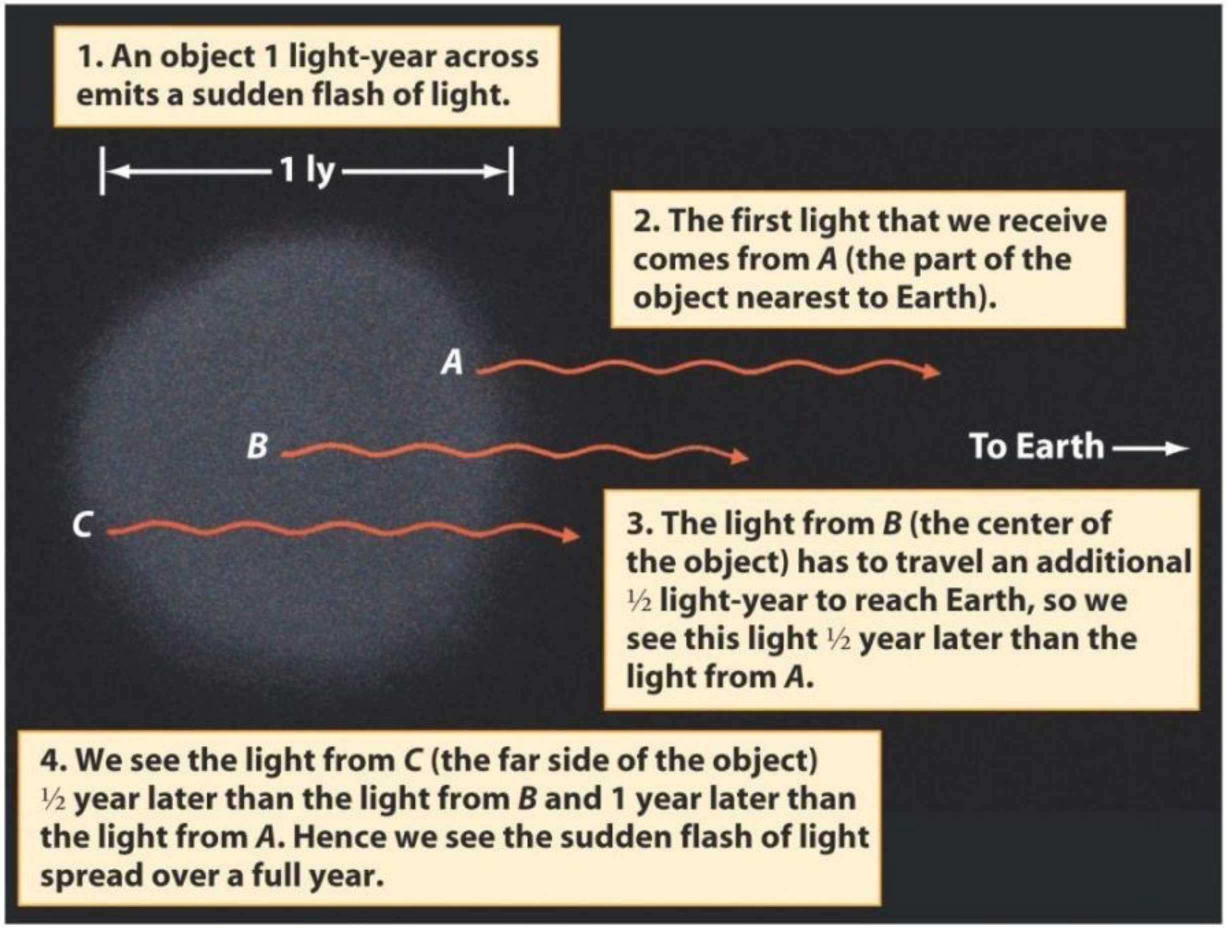
NGC 1275, The brightest galaxy in the Perseus cluster – a Seyfert.



Variability

NGC1275 aka 3C84





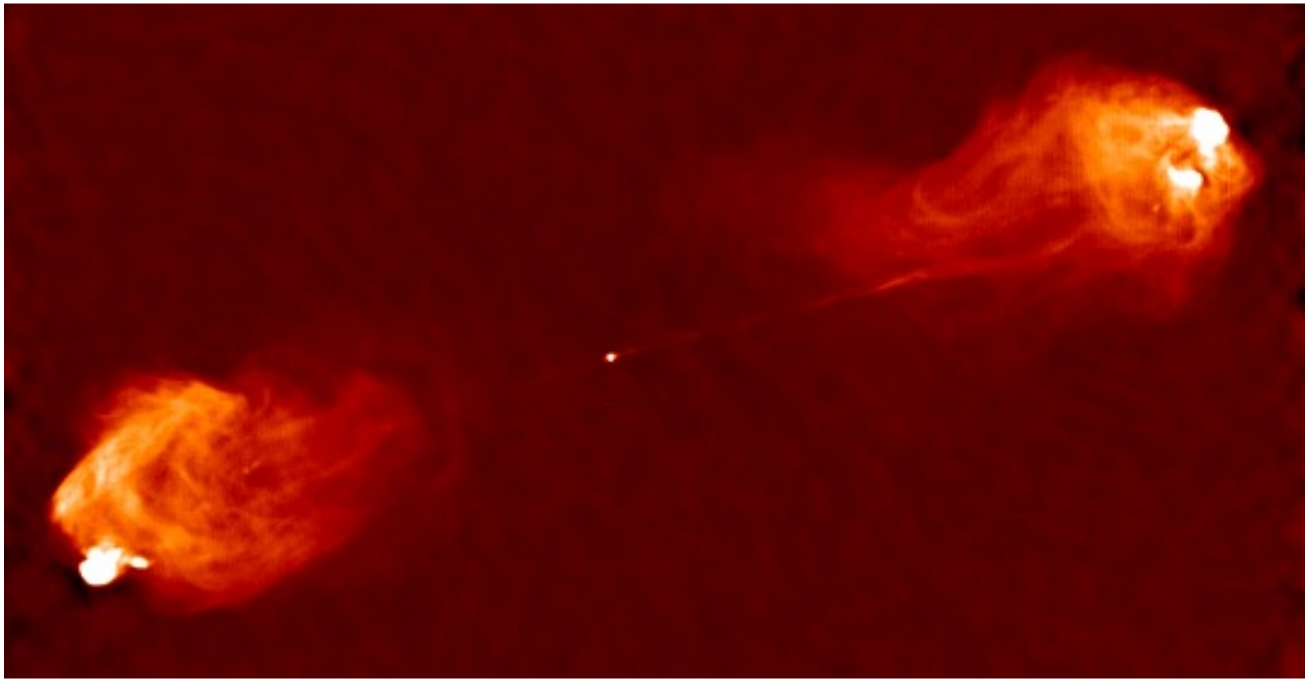
Rapid variability

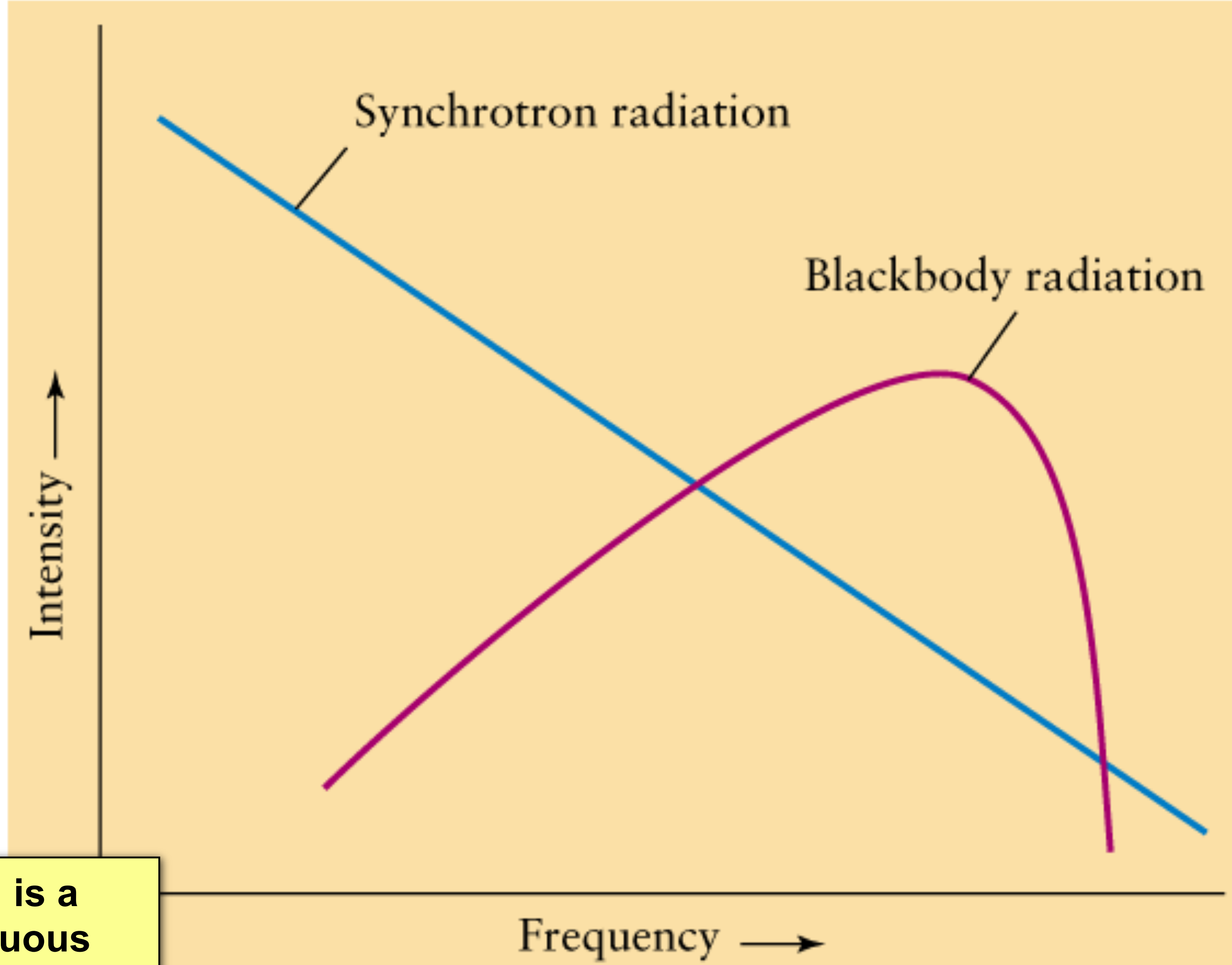
A way of measuring *size* of the object. Big things can't vary rapidly.

Example: an object 1 ly across can't change its brightness in less than a year

Radio Galaxies

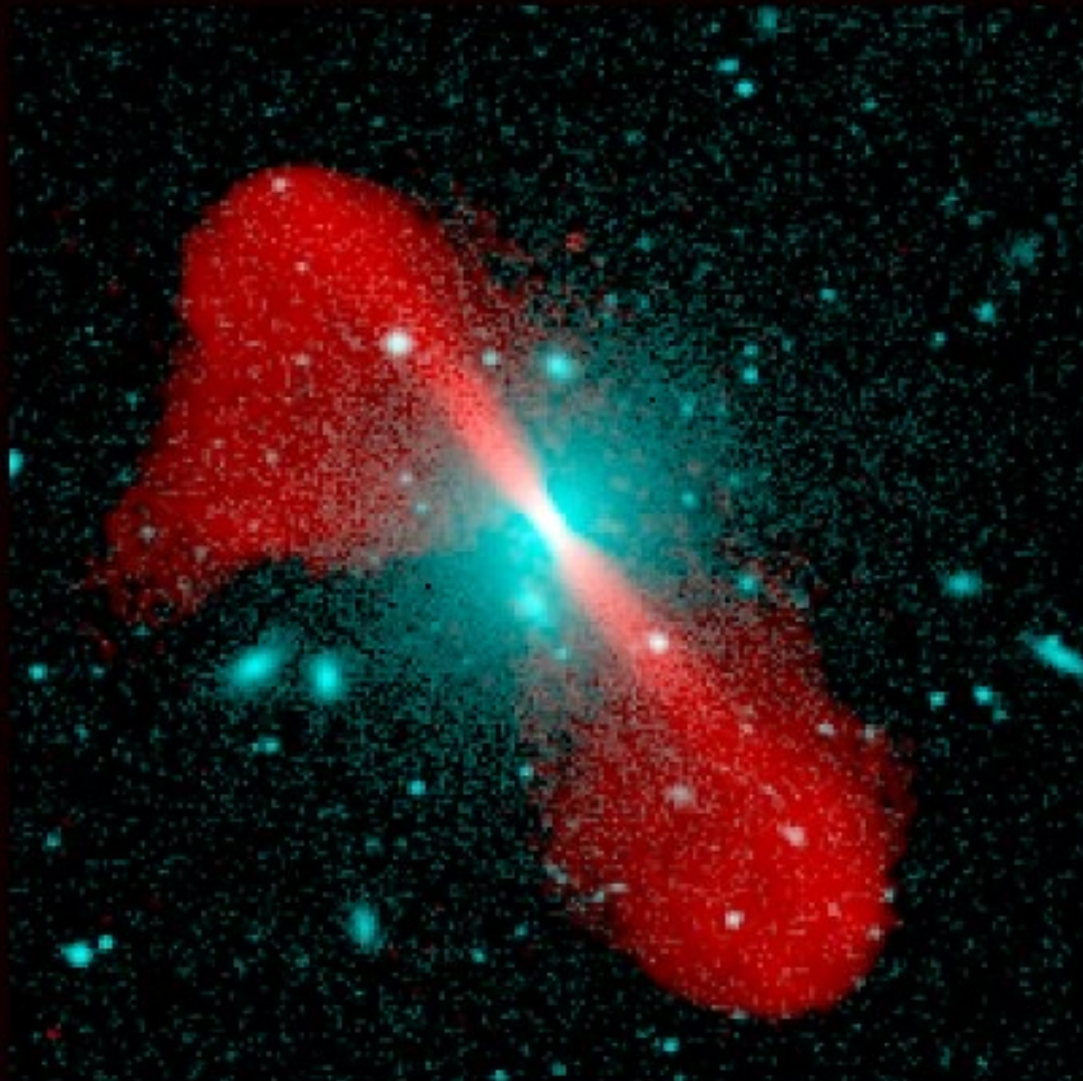
- Most galaxies emit only a modest amount of radio wavelength radiation, but some emit up to 10^5 times as much *(radio loud).*
- *Radio Galaxies* typically have two lobes and *synchrotron* spectra, meaning relativistic electrons moving in magnetic fields.
- Jets of emission are also often seen, as in Cygnus A





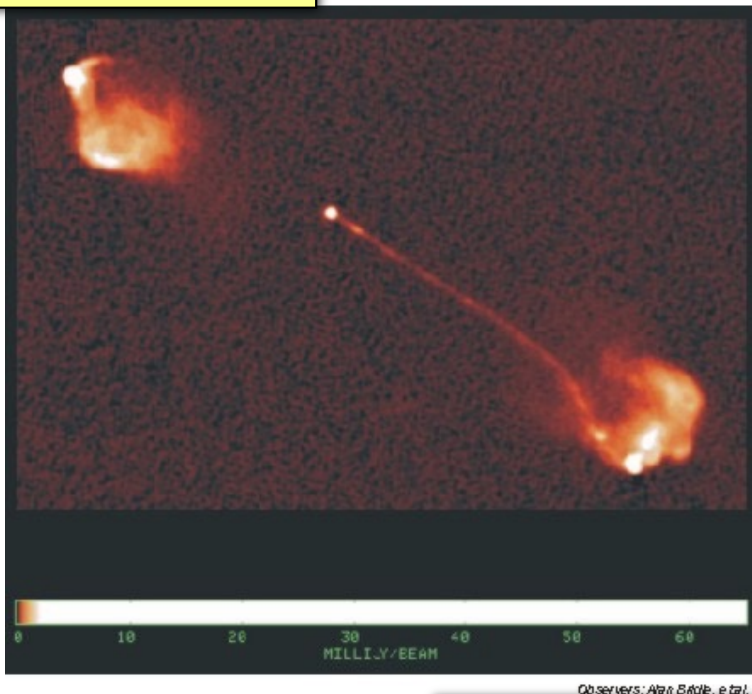
Synchrotron radiation is a second type of continuous spectrum – in addition to the familiar blackbody kind we studied earlier. It is most common in the radio part of the EM spectrum.

$$P = \frac{4}{3}\sigma_T c\beta^2\gamma^2 U_B$$

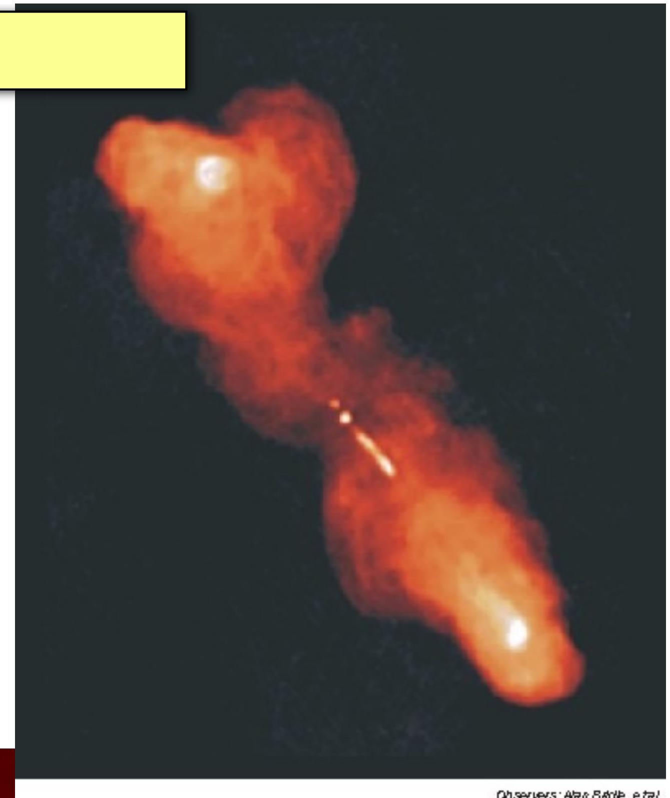


Radio Galaxy 3C296
Radio/optical superposition

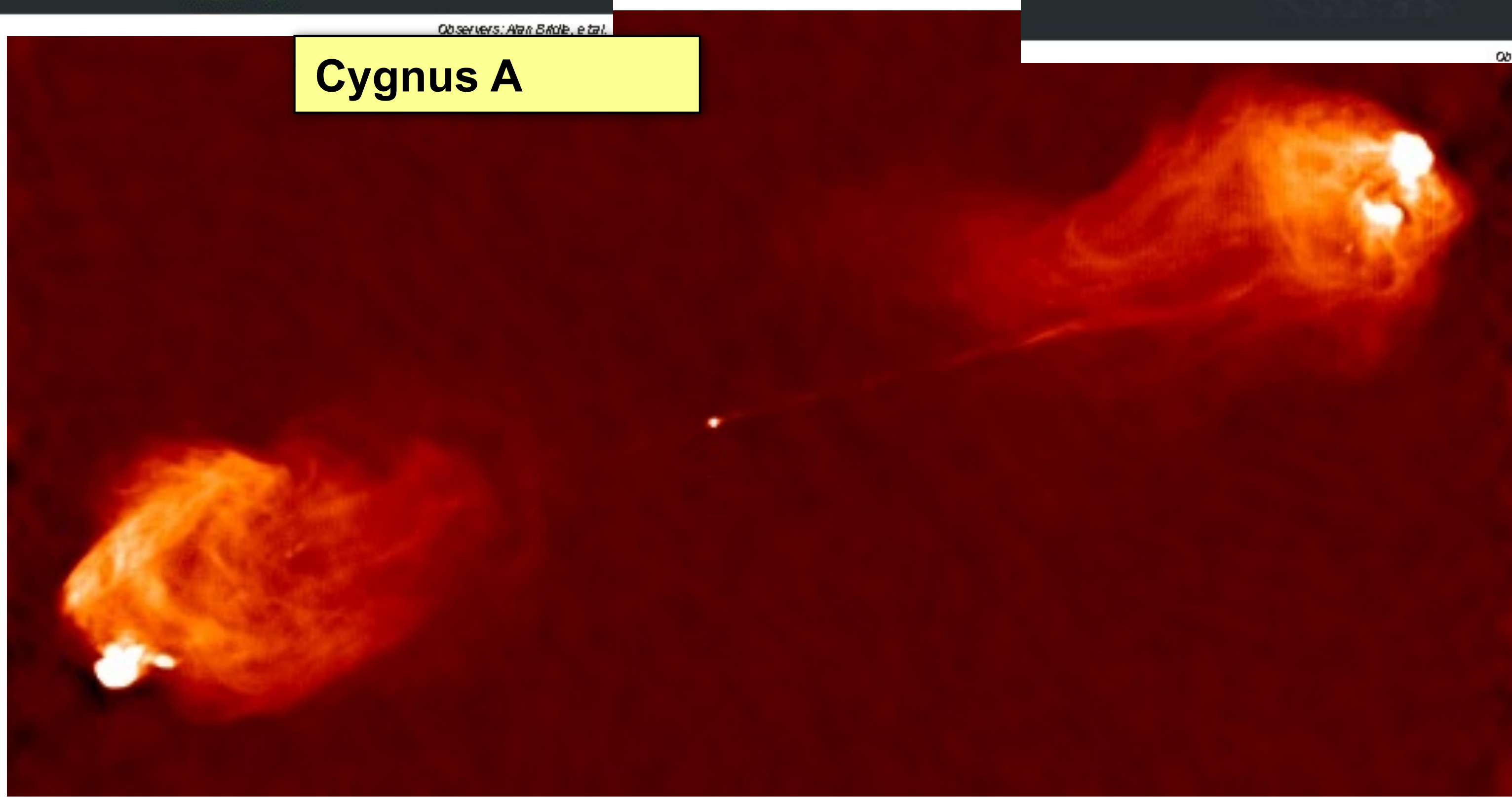
3C175



3C219



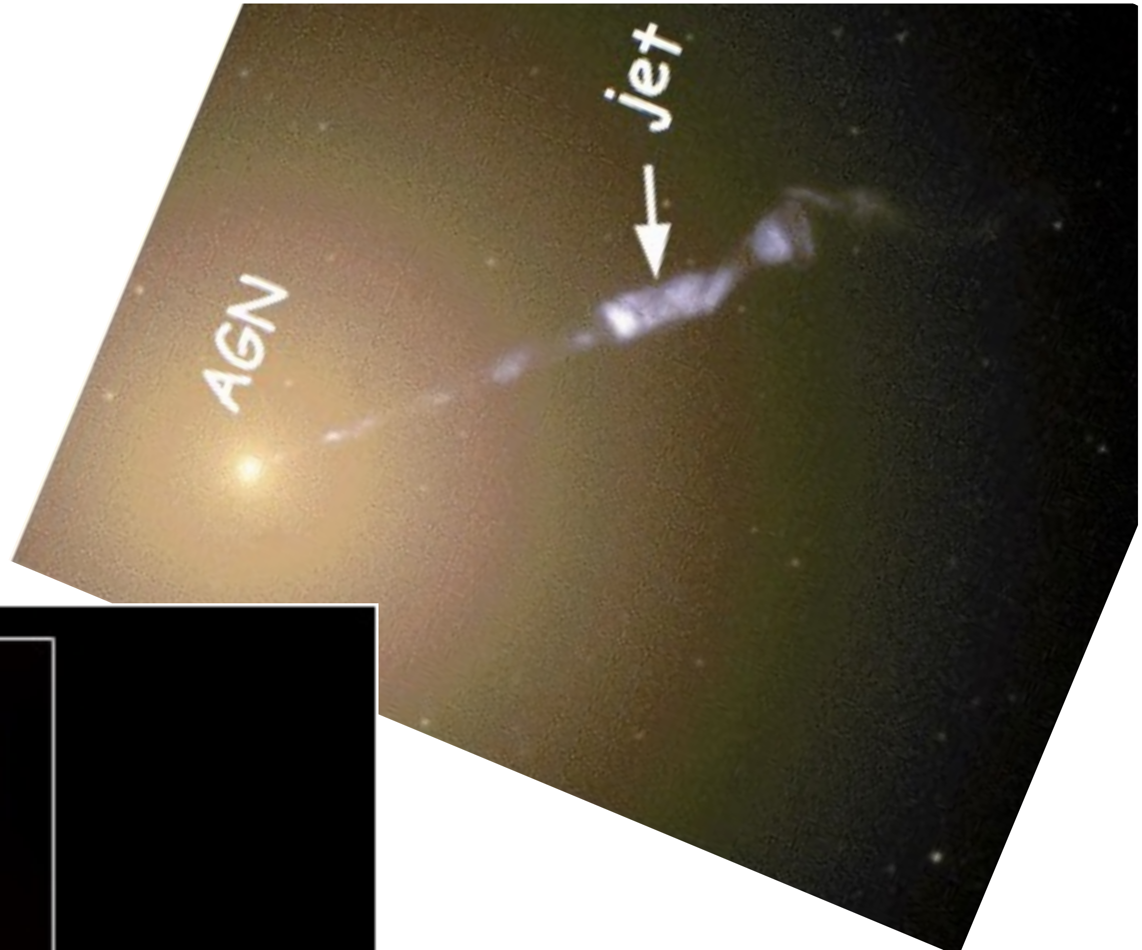
Cygnus A

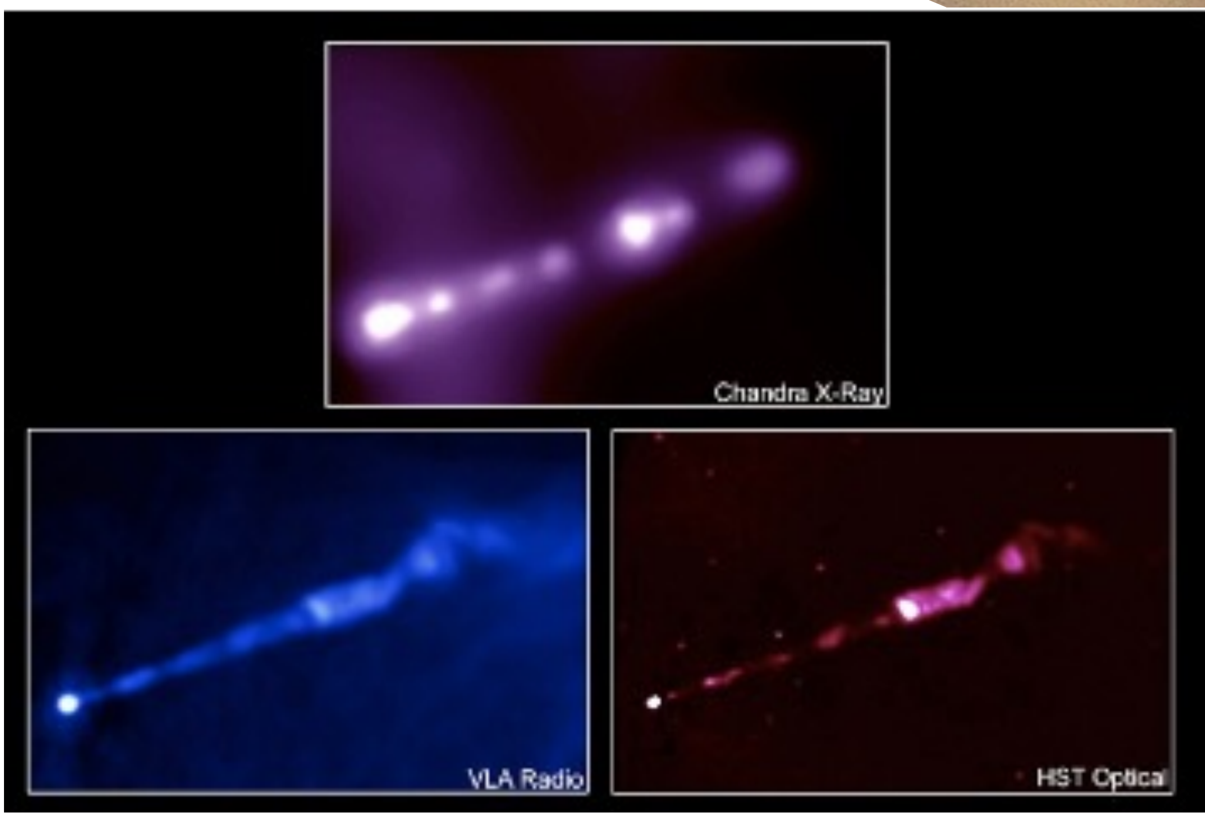


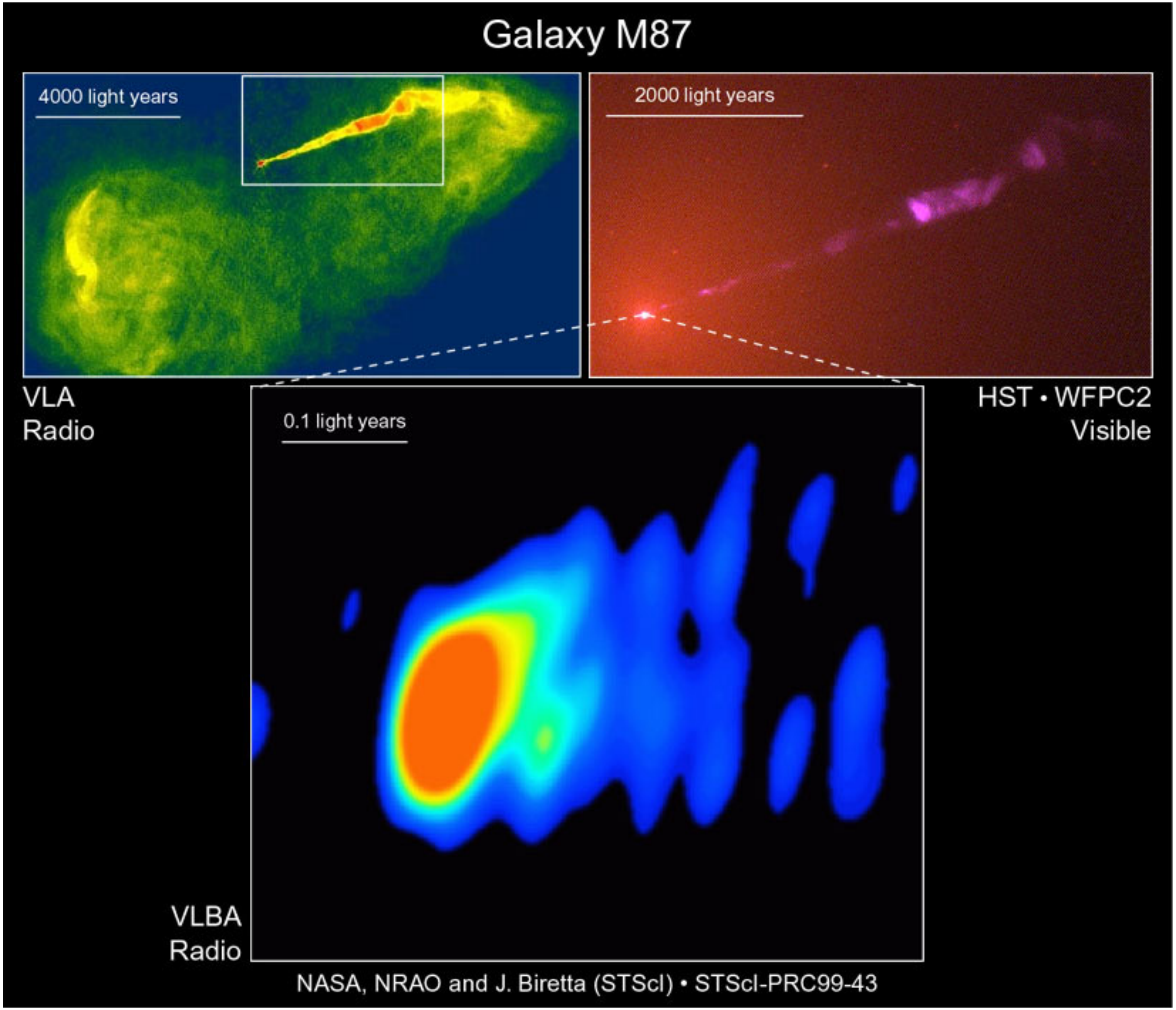

M87 © Anglo-Australian Observatory
Photo by David Malin

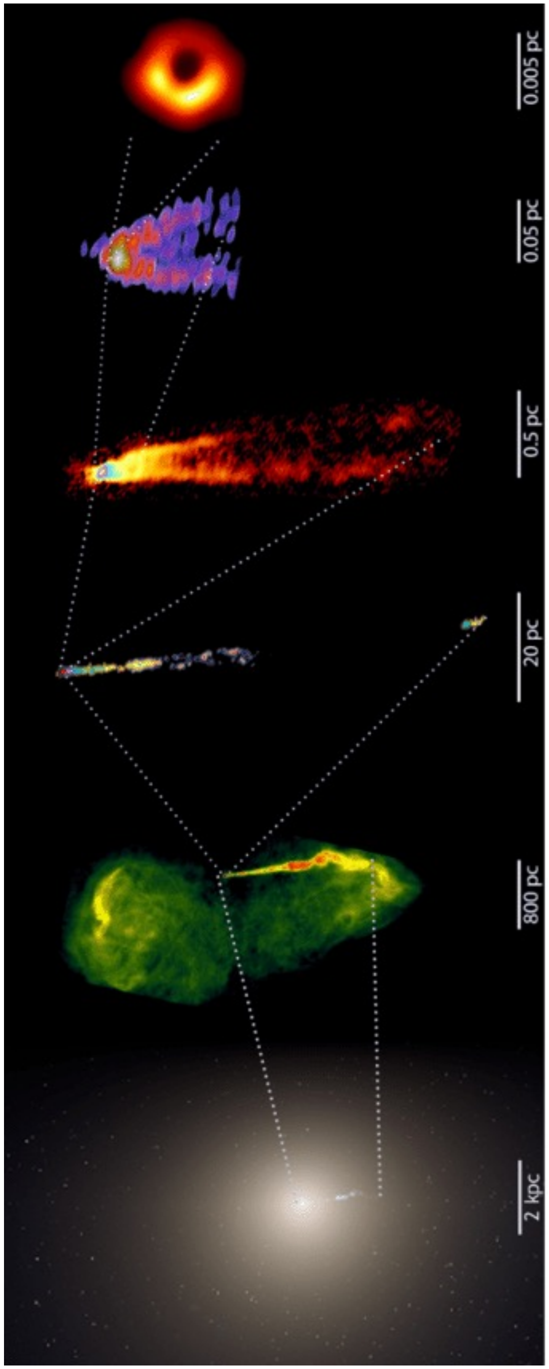
Detections of optical jets

First made in 1913 by Curtis in M87

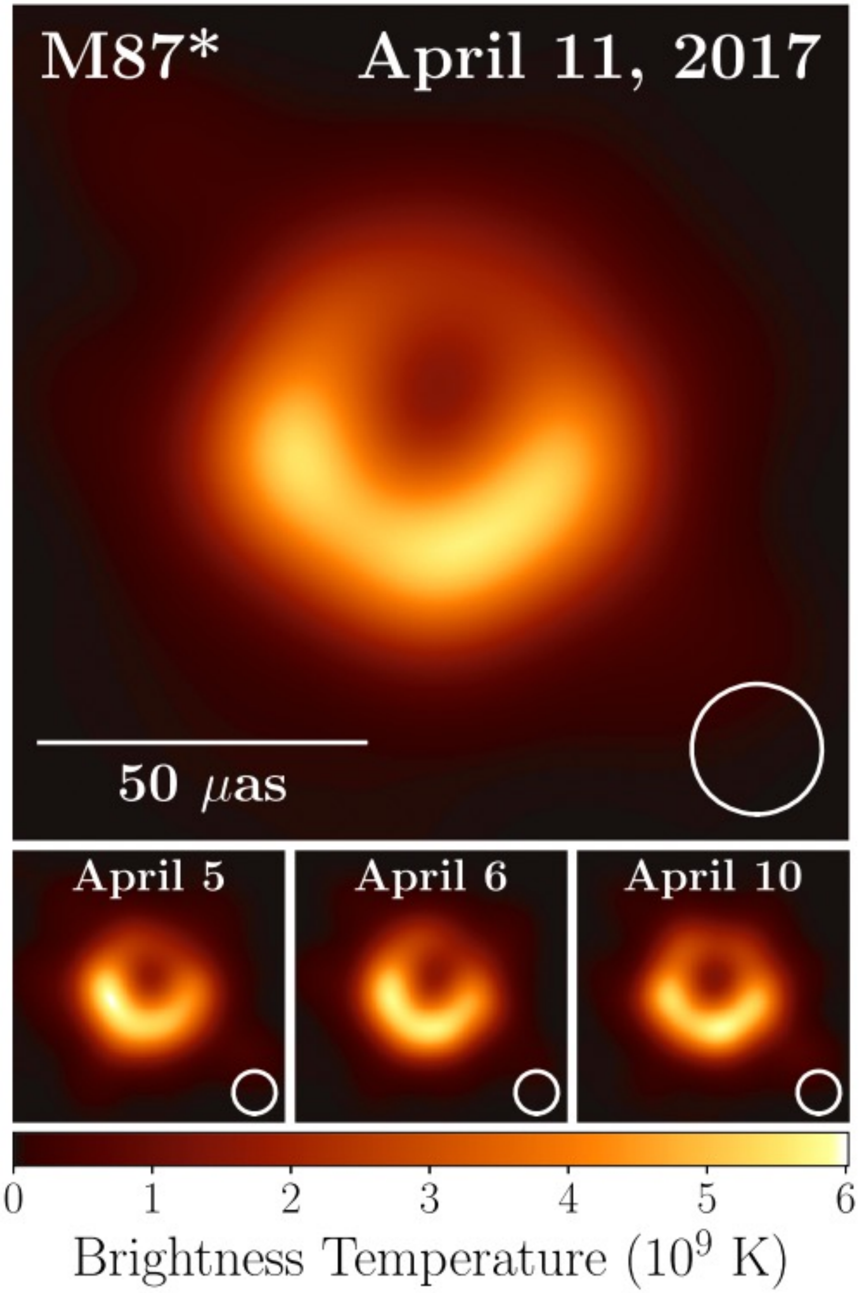





Galaxy M87
4000 light years
2000 light years
VLA
Radio
HST • WFPC2
Visible
0.1 light years
VLBA
Radio
NASA, NRAO and J. Biretta (STScI) • STScI-PRC99-43



EHT Collaboration image 2019



First radio surveys

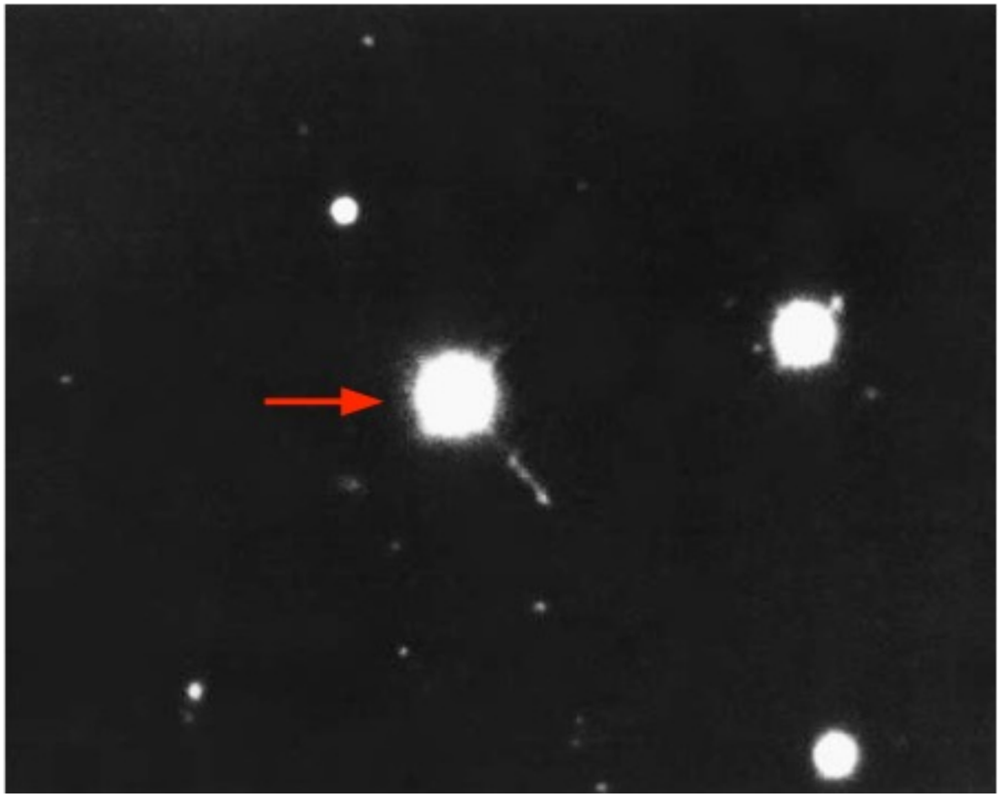
Early radio surveys played an important role in the discovery of quasars.

- 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.

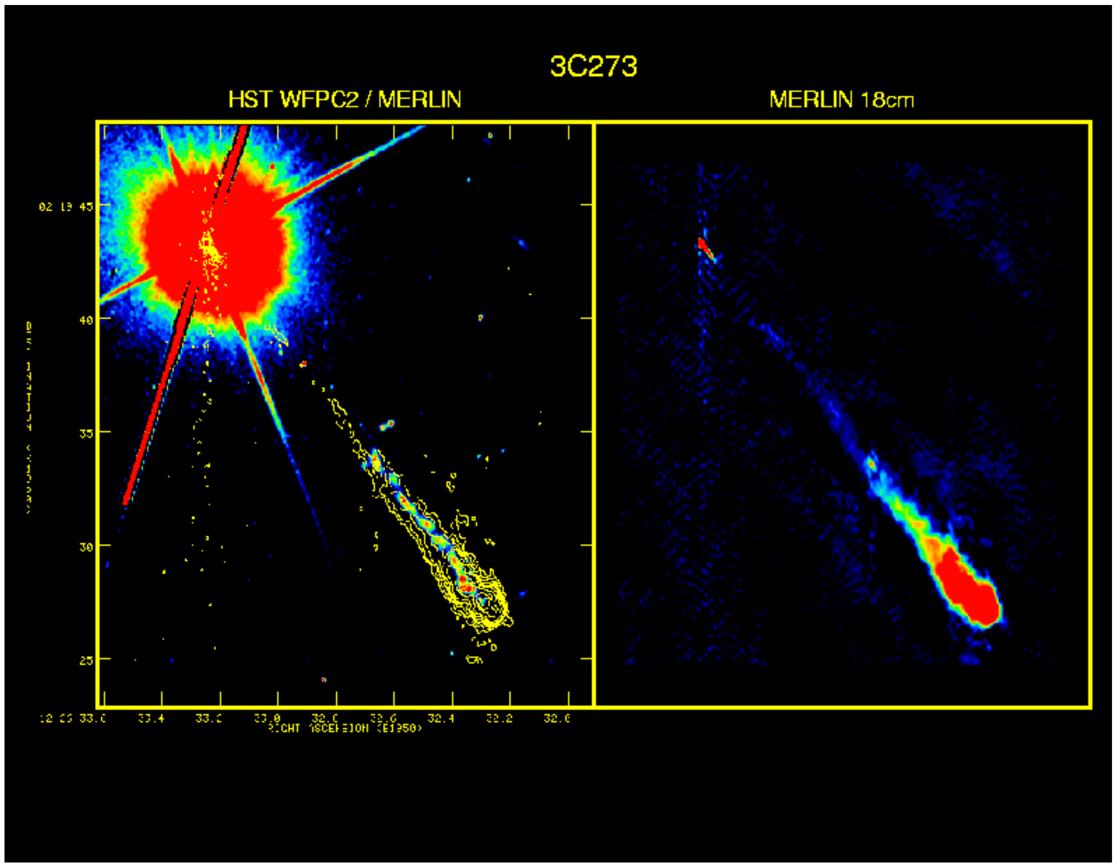


Their optical counterparts are "starlike", thereby the name "quasi-stellar radio sources", or quasars.

Quasars: some history

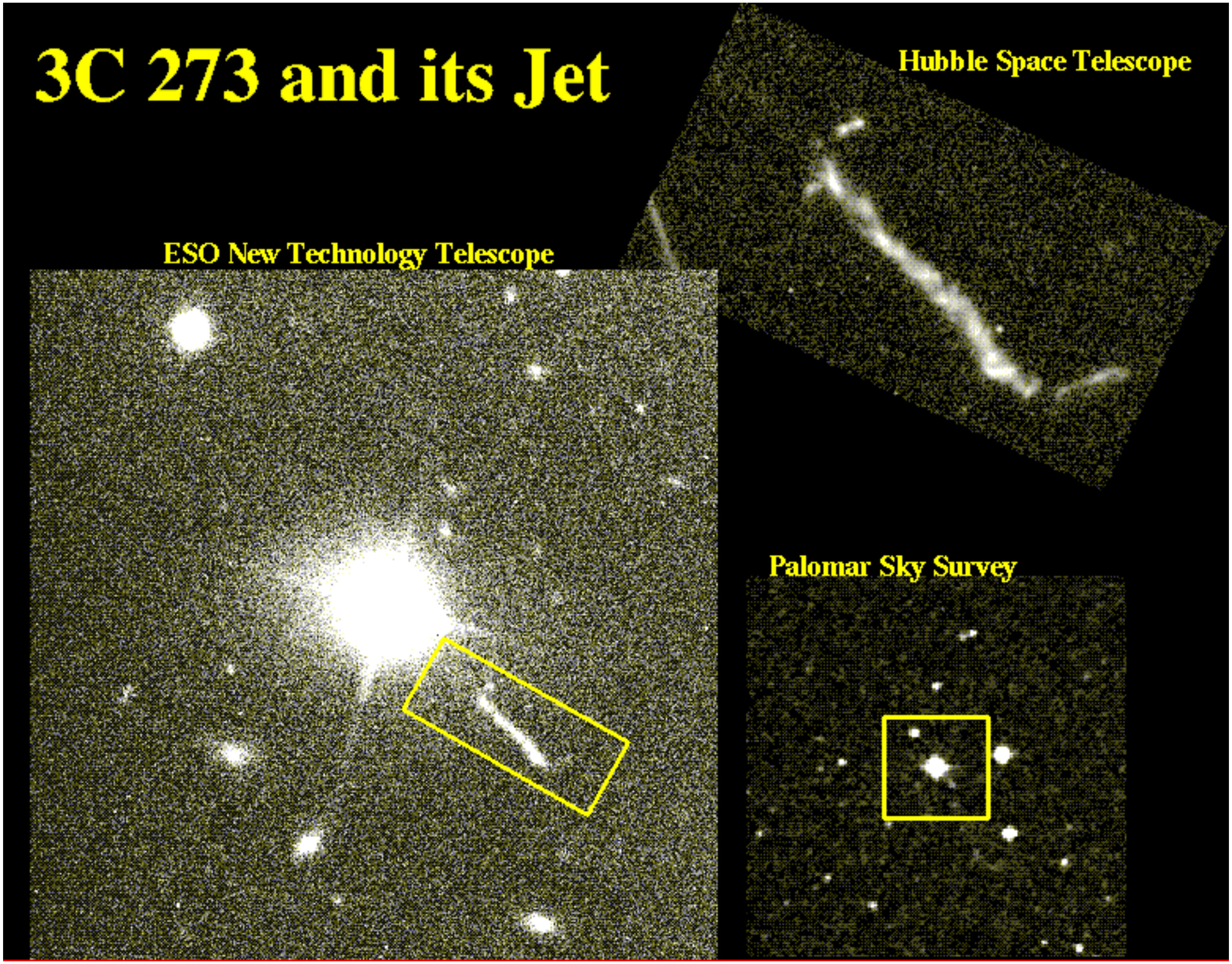
- Stars are typically not strong sources of radio wavelength emission.

Optical

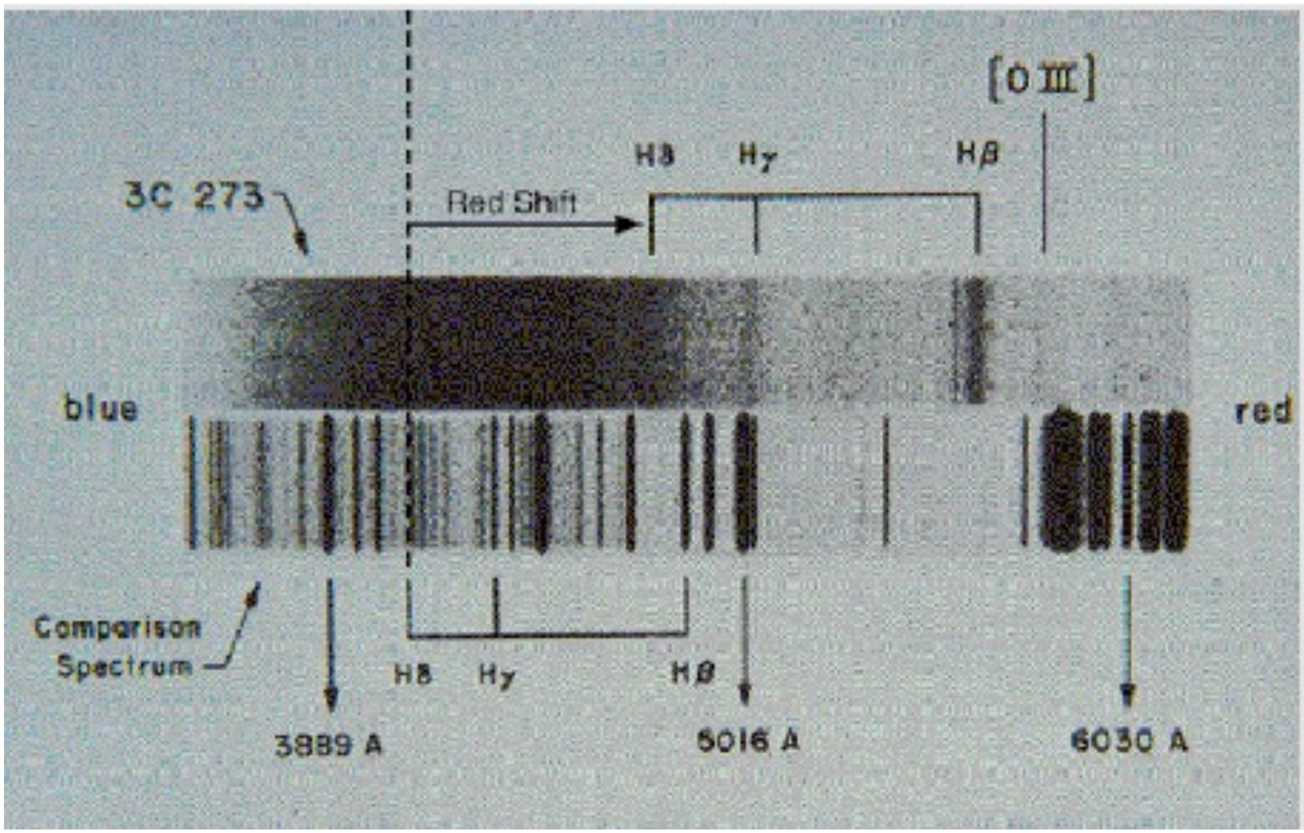


Radio

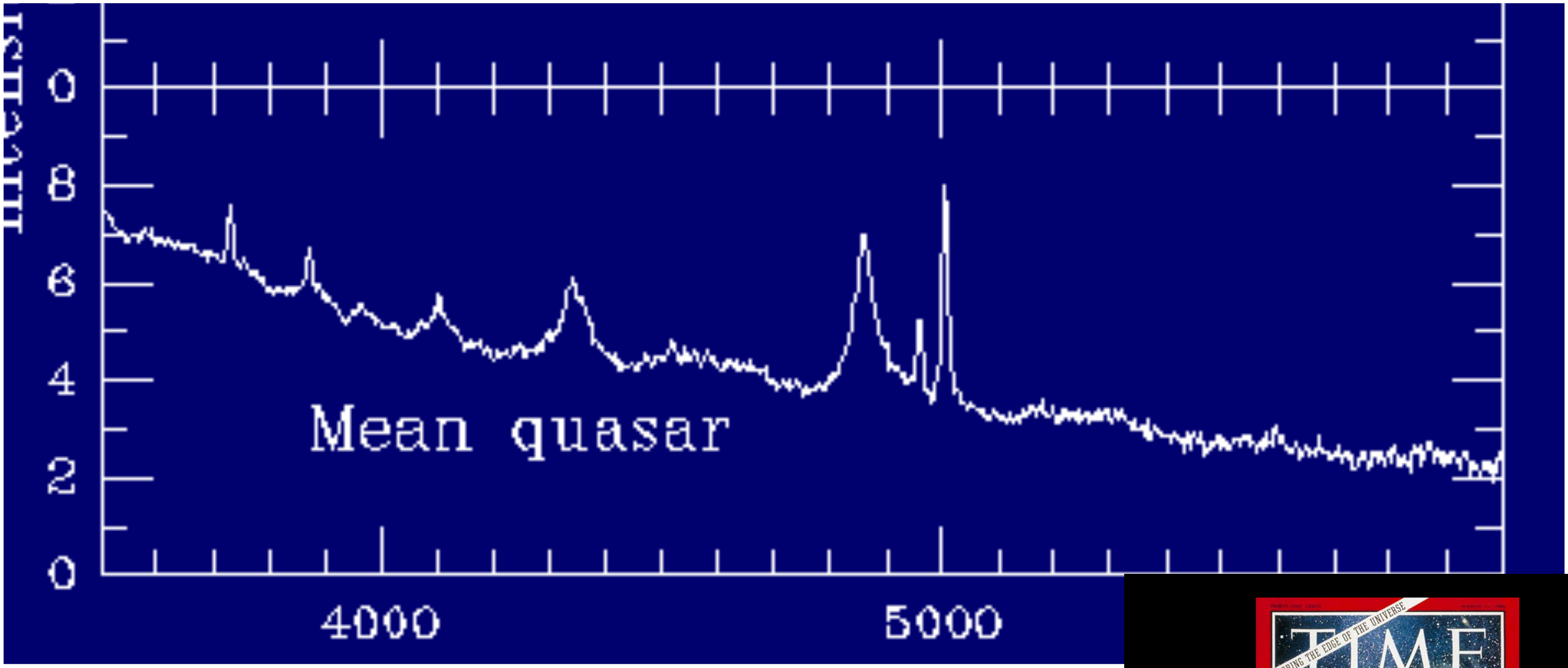
3C 273 was starlike but had a jet, indicating something quite strange for a star.

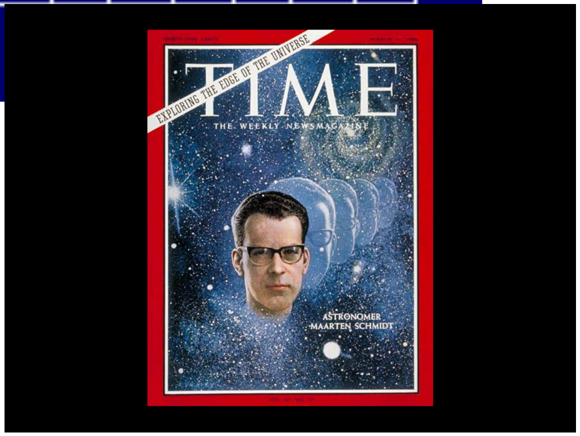


Broad emission lines at odd positions



In 1963, Maarten Schmidt (Caltech) explained the optical spectra. The unidentified emission lines were simply hydrogen lines that were redshifted farther than anyone had ever seen previously. For 3C273 z=0.158





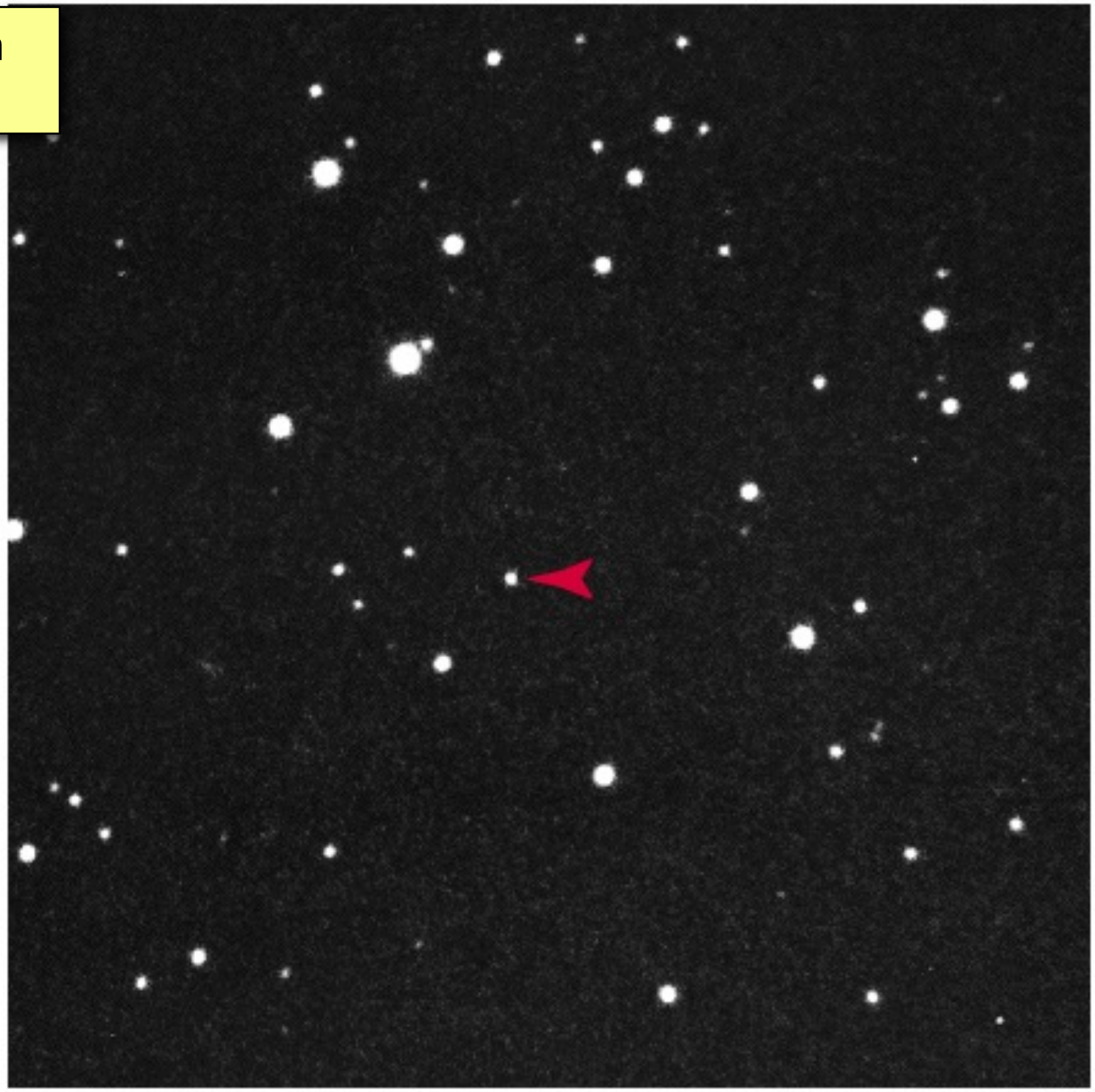
Why is 3C273 at redshift z=0.158 so special?

$$z = \frac{\Delta\lambda}{\lambda_0} \qquad \text{and } v = cz$$

Worksheet: Calculate the optical luminosity of 3C273 and compare it to that of our Milky Way galaxy (2 x 10^10 L_{sun}).

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

Quasar 3C48 in the visible.



z=0.369
d = 1994 Mpc

~2 times further
Away than 3C273

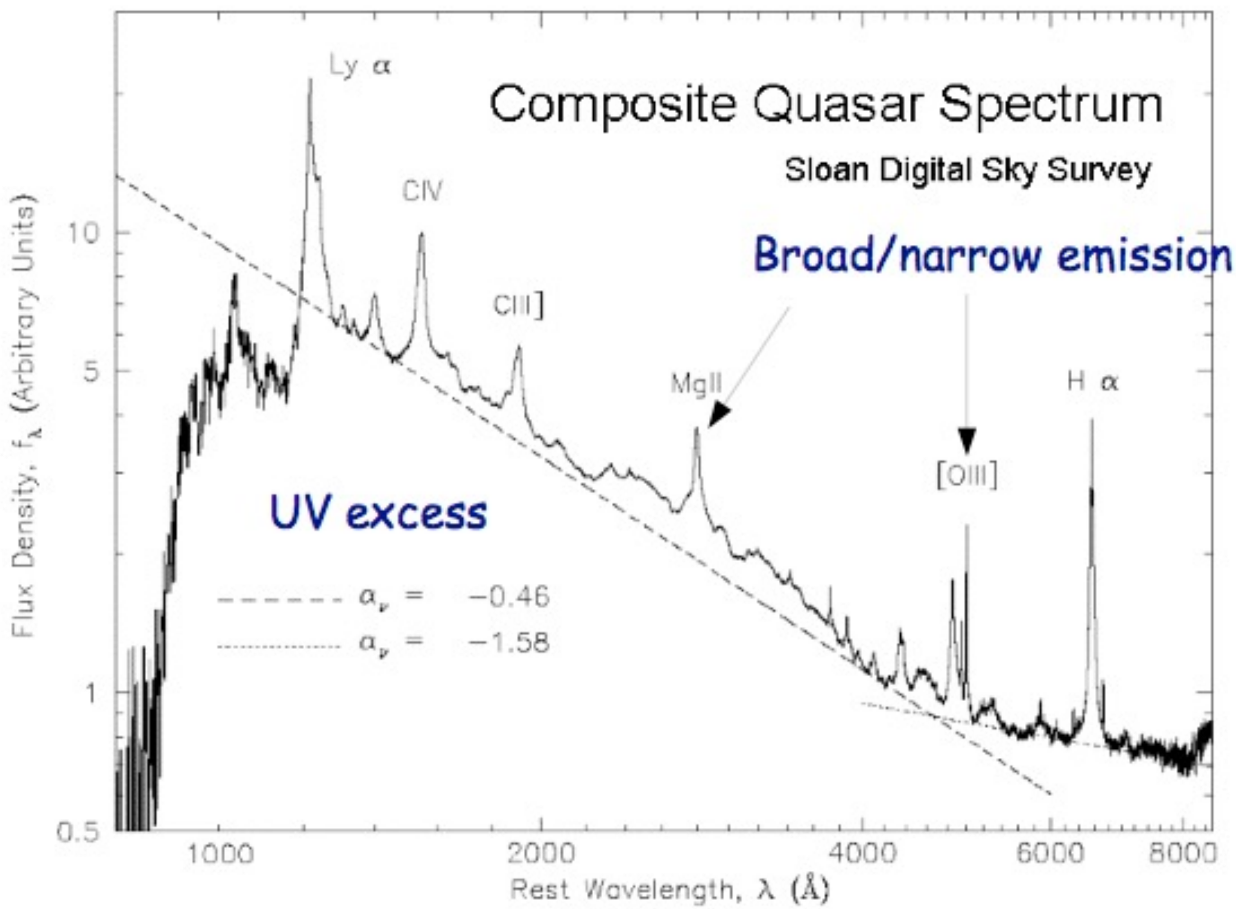
1964: Maarten Schmidt studied several quasars and found that:

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

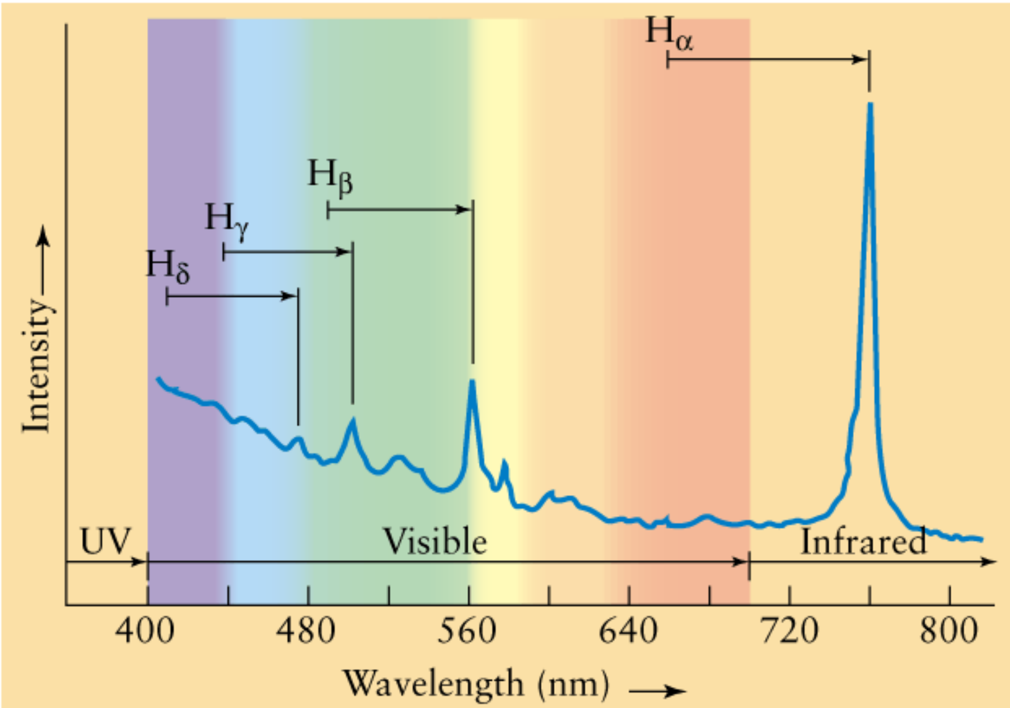
Again, not all quasars have all these properties, but most are X-ray luminous (Elvis et al 1978)

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

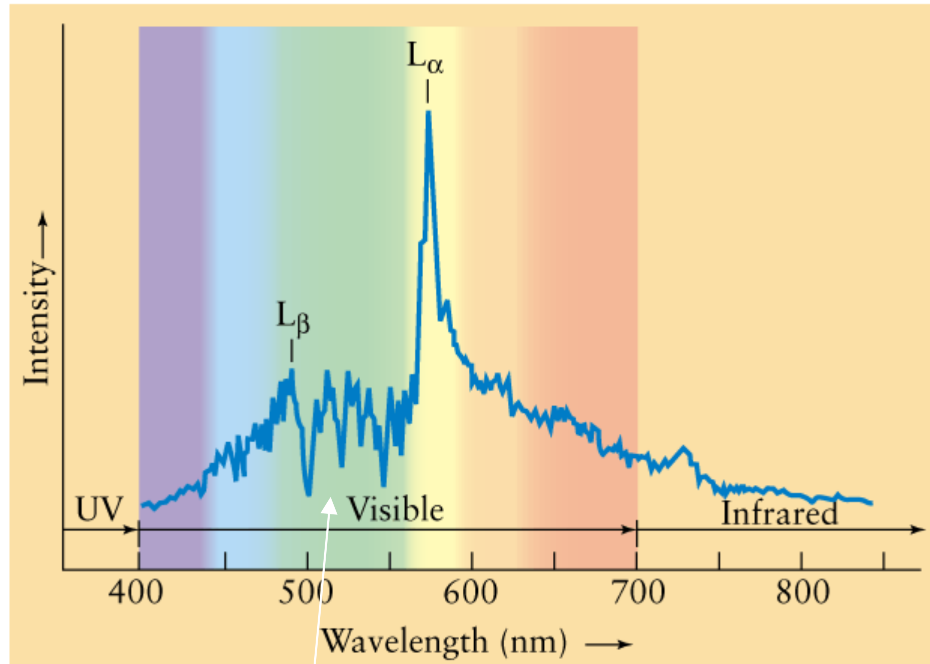
Composite Quasar optical/UV spectrum



Spectrum of a low-z quasar (3C 273), z=0.158.



Spectrum of a high-z quasar, z=3.773. UV em shifted into optical.



(These absorption lines are due to hydrogen between us and the quasar – "the Lα forest").

Huge redshifts

- What is the meaning of these huge redshifts?
- Think about the Hubble Law: $V = H_0 d$
- and the definition of recession velocity: $V = zc$

=> $z = H_0 d/c$

$z = (\lambda_{obs} - \lambda_{em}) / \lambda_{em}$

- Quasars are at enormous distances.

- They are nuclei somewhat like Seyferts but typically 10 to 100 times more powerful.

- The highest known redshifts are about $z=7.6$. What does this mean? Are the objects really moving 7.6 times the speed of light? No!

- In the non-relativistic Doppler formula

$$z = v/c,$$

so a redshift of 7.5 implies that an object is moving at 7.5 times the speed of light. This is silly.

- We need a relativistically correct version:

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

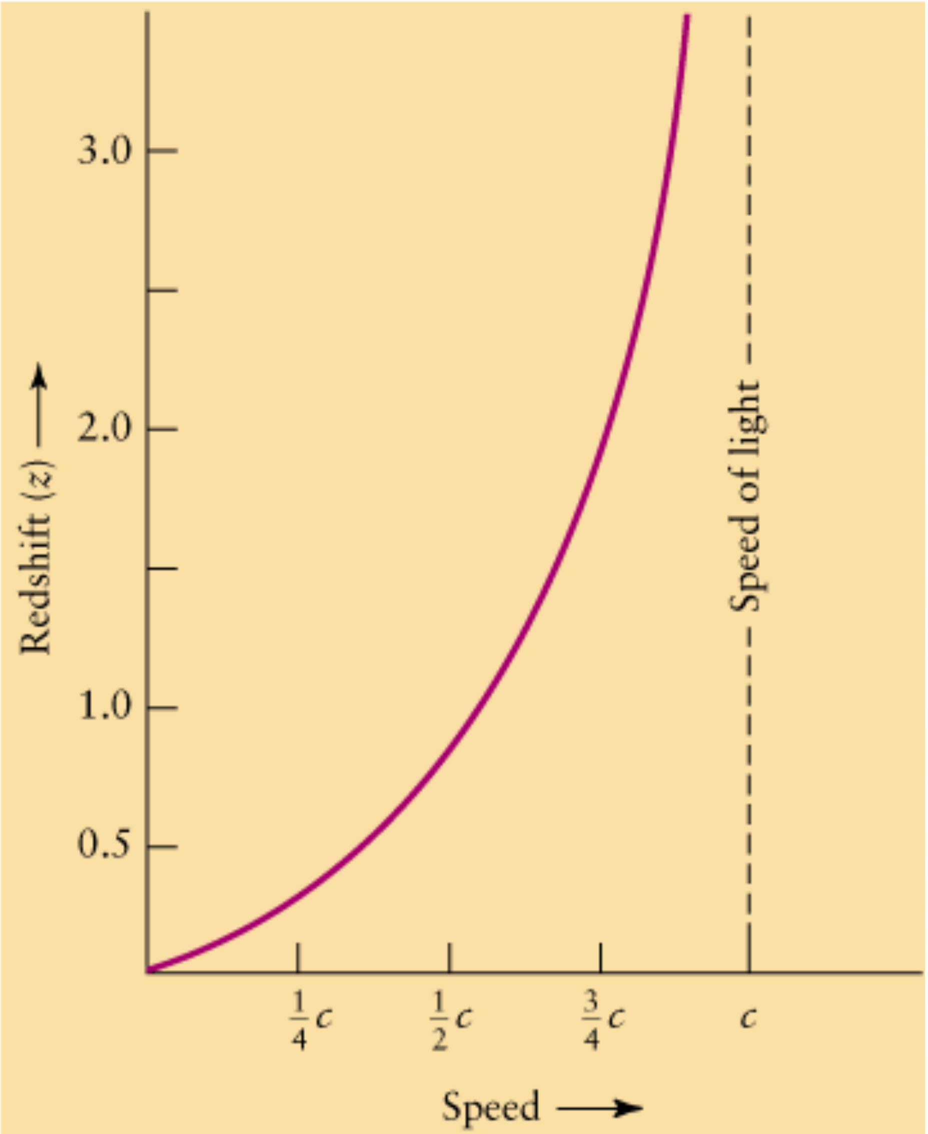


table 27-1 Redshift and Distance

Redshift z	Recessional velocity v/c	Distance (Mpc)	Distance (10^9 ly)
0	0	0	0
0.1	0.095	394	1.29
0.2	0.180	739	2.41
0.3	0.257	1040	3.39
0.4	0.324	1310	4.26
0.5	0.385	1540	5.02
0.75	0.508	2010	6.57
1	0.600	2370	7.73
1.5	0.724	2860	9.32
2	0.800	3170	10.3
3	0.882	3520	11.5
4	0.923	3710	12.1
5	0.946	3830	12.5
10	0.984	4040	13.2
Infinite	1	4190	13.7

This table assumes a Hubble constant $H_0 = 71$ km/s/Mpc, a matter density parameter $\Omega_m = 0.27$, and a dark energy density parameter $\Omega_\Lambda = 0.73$ (see Chapter 28). The distance in light-years is equal to the light travel time in years.

Elliptical galaxy spectrum

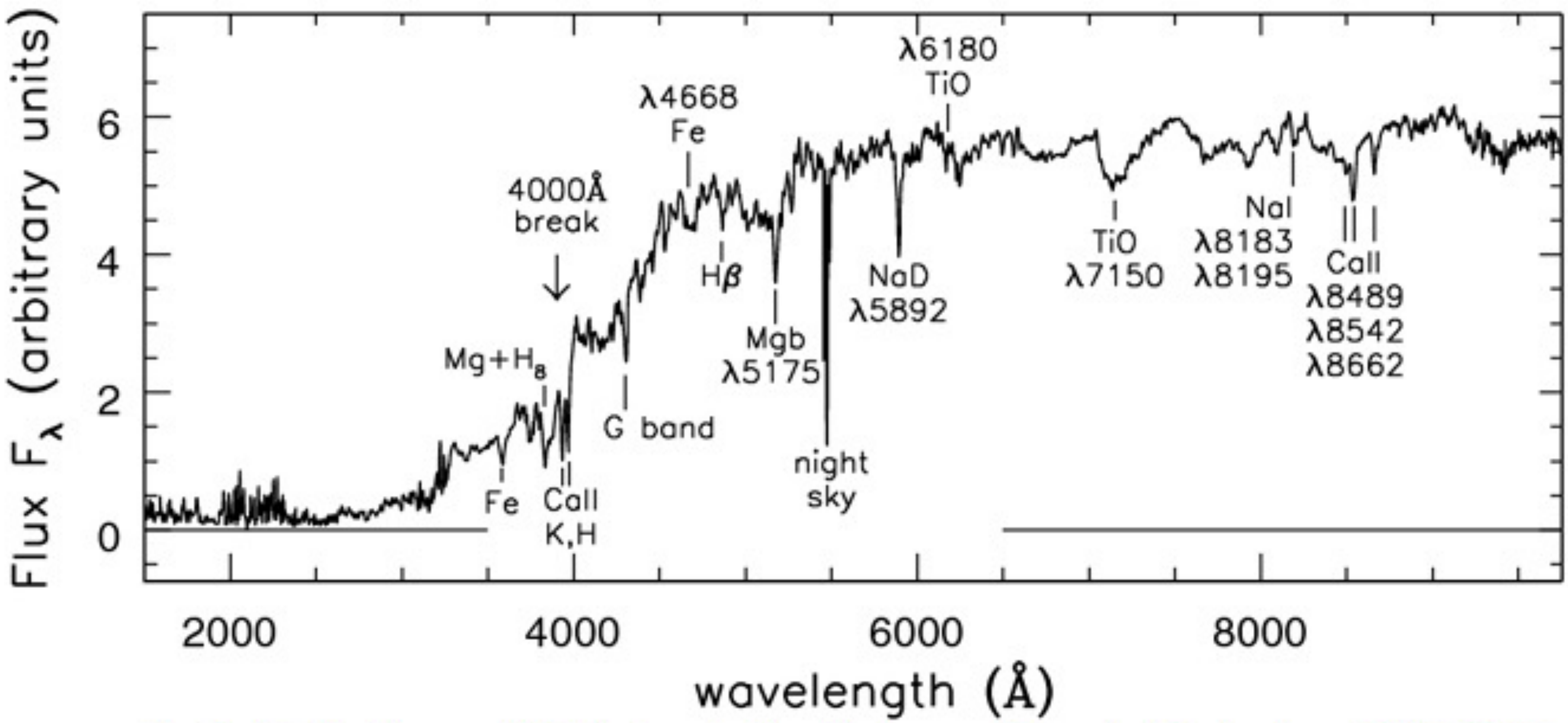
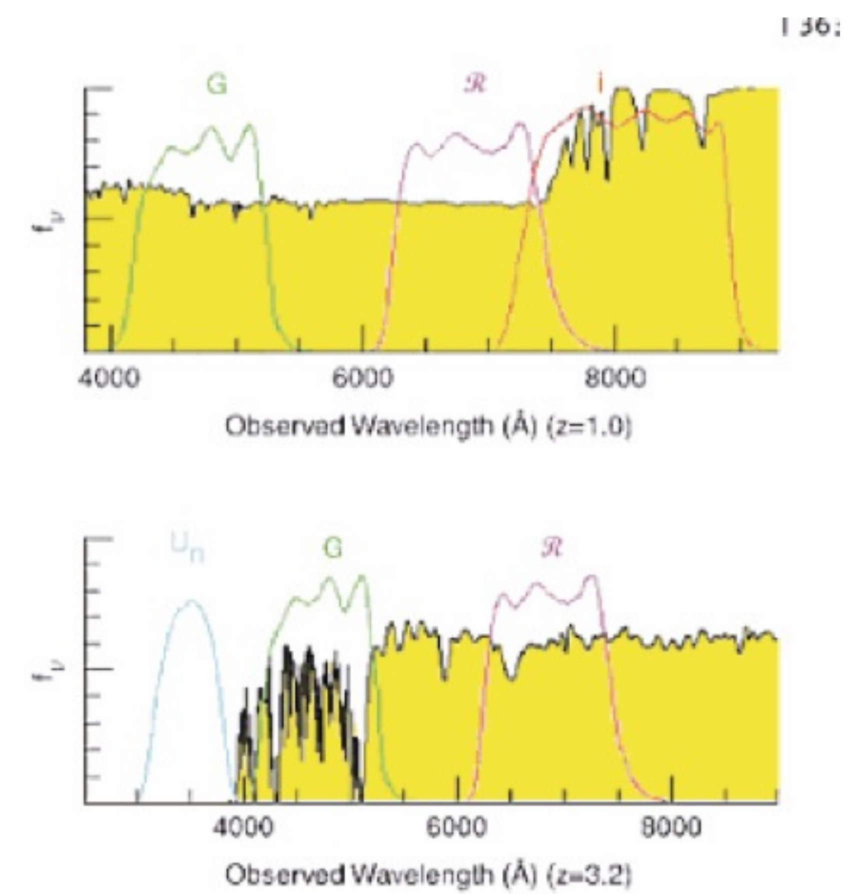
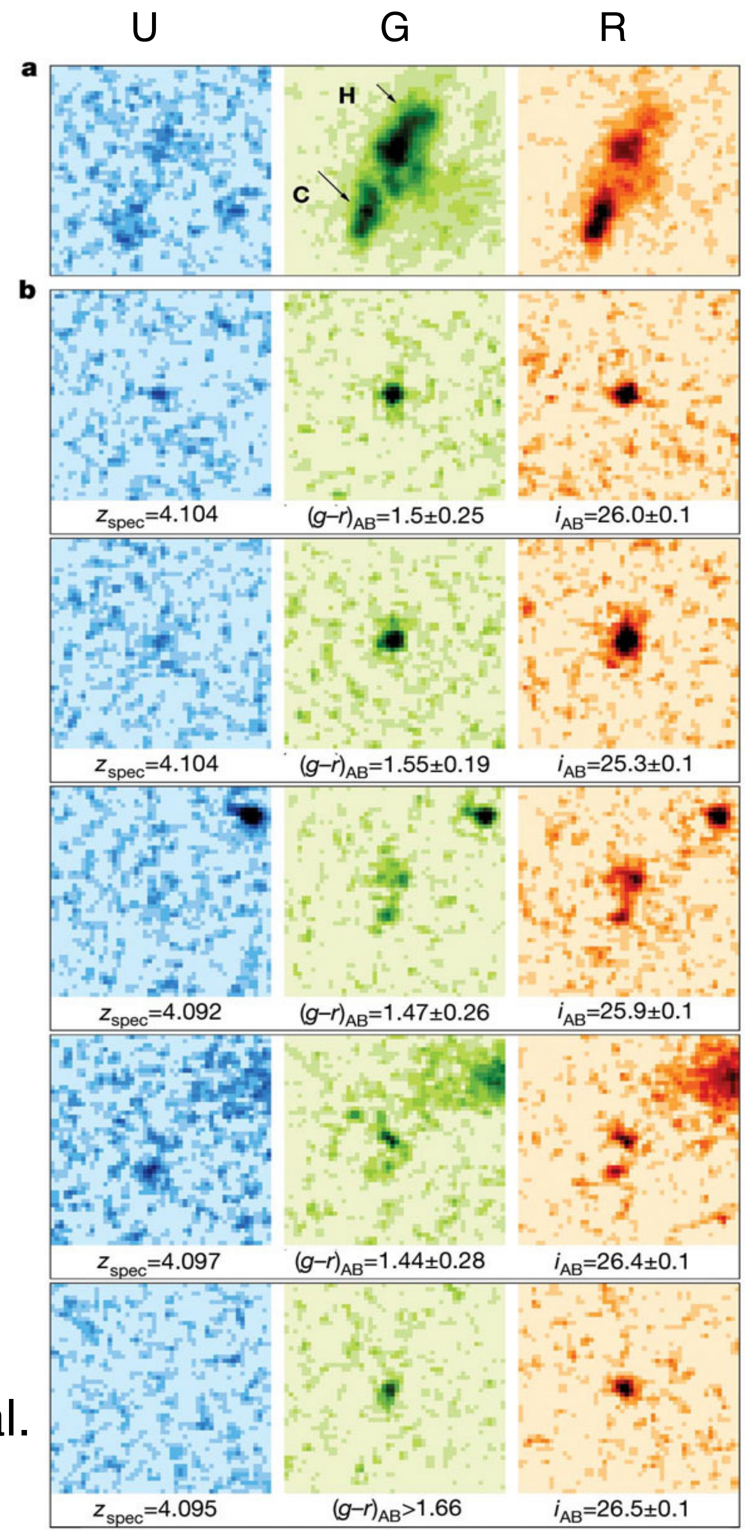


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Dropouts



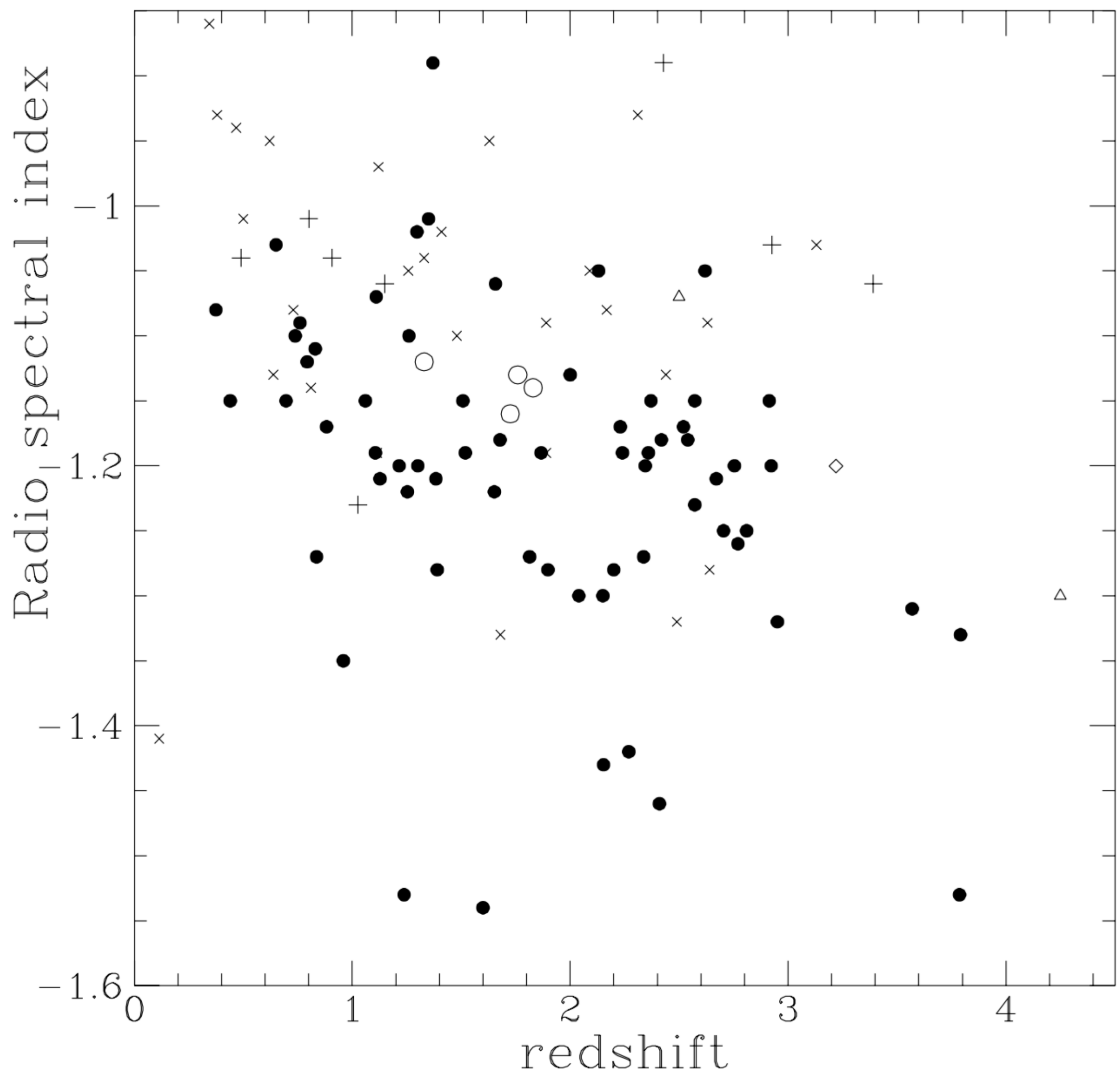
Schneider



Miley et al.

Finding High Redshift Galaxies

- Ultra Steep Spectrum radio sources tend to be at high redshifts



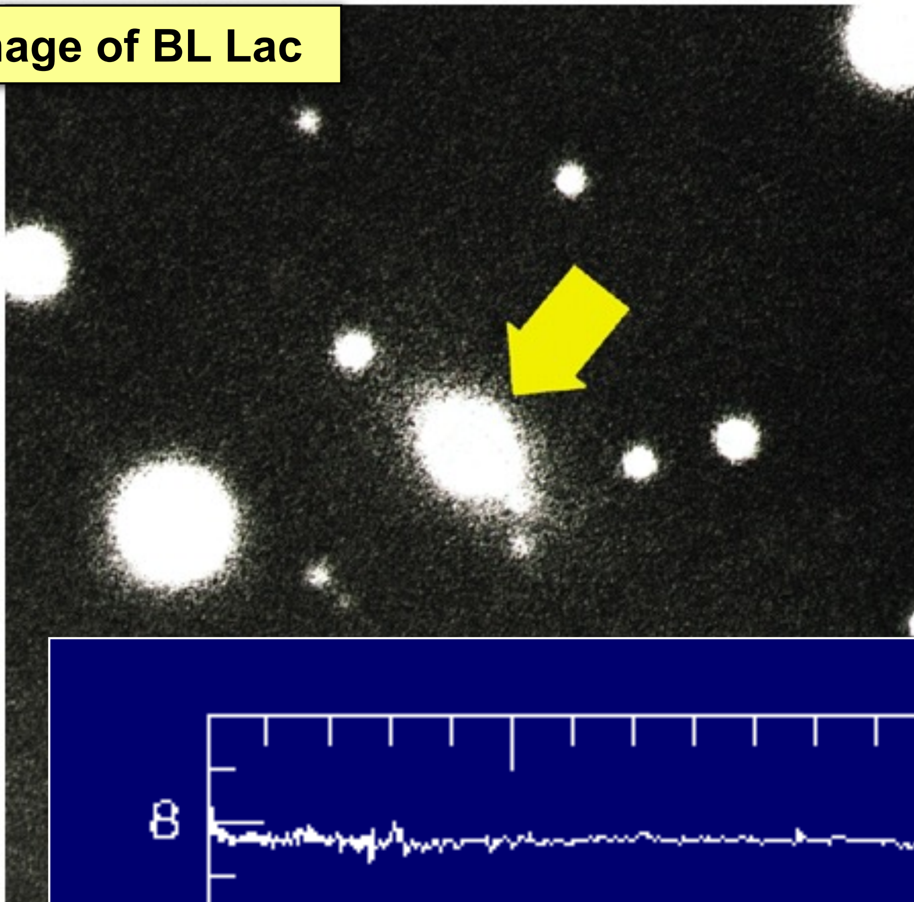
Rottgering et al. 1996

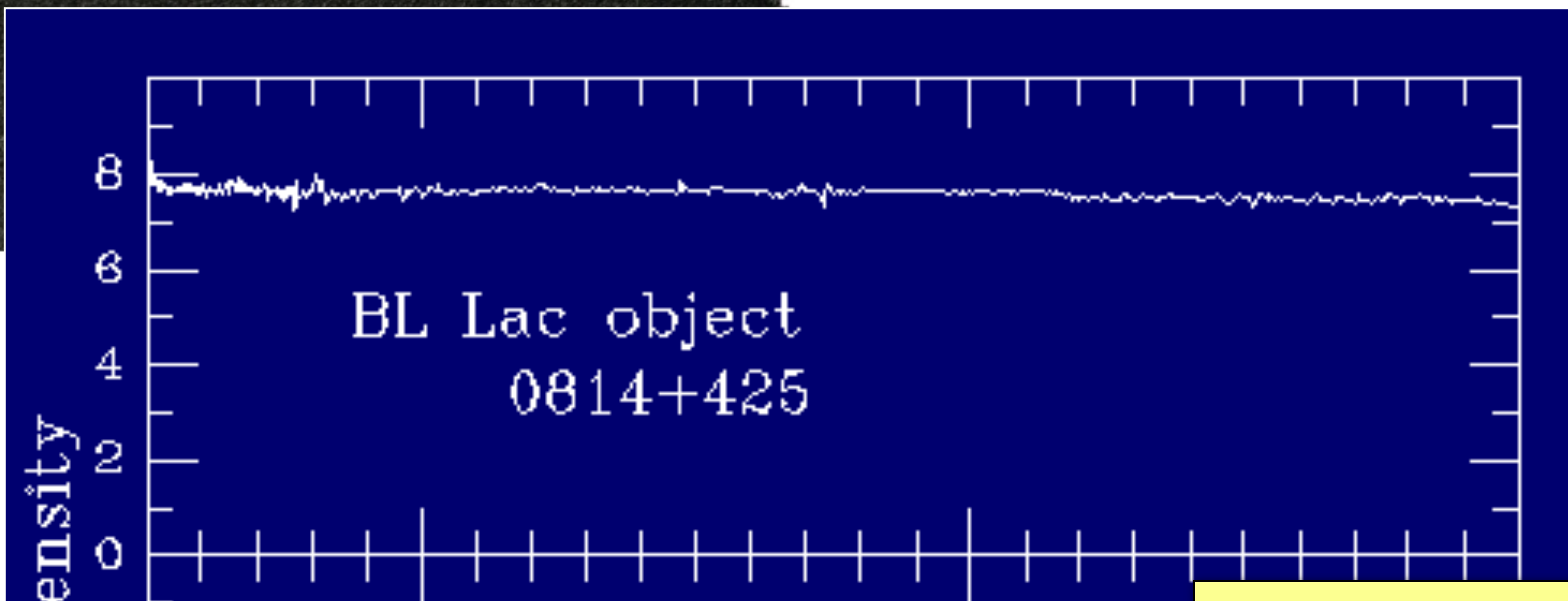
BL Lac objects (blazars)

- Named after a strange 'star' with featureless spectrum (early 1900's), but spectrum synchrotron.

- Have
  - Featureless spectra (hard to get z)
  - 'Stellar' on optical images
  - Always a strong, flat spectrum compact radio source
  - Highly variable in optical and radio
  - Large non-thermal optical contribution (weak 4000Å break, large non-thermal/starlight ratio)

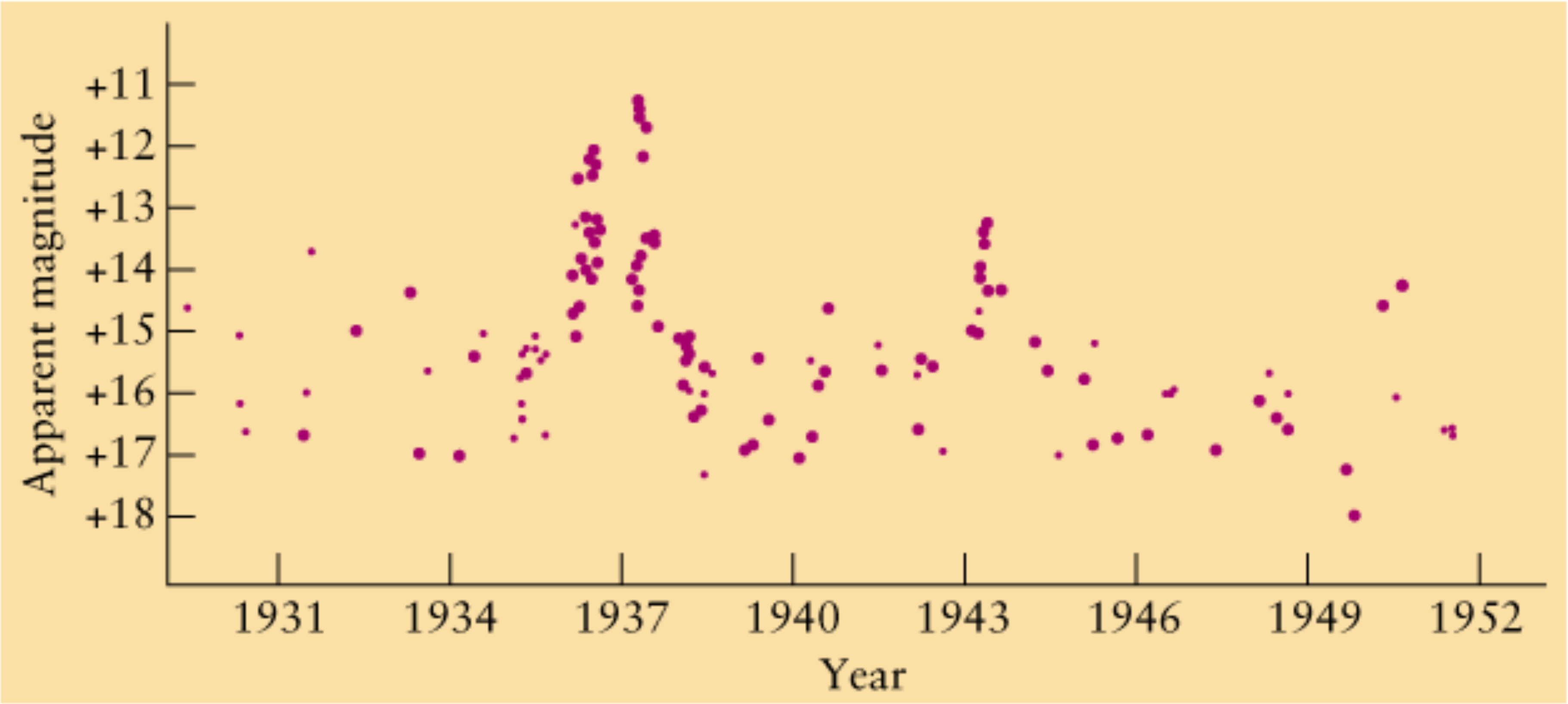
Image of BL Lac



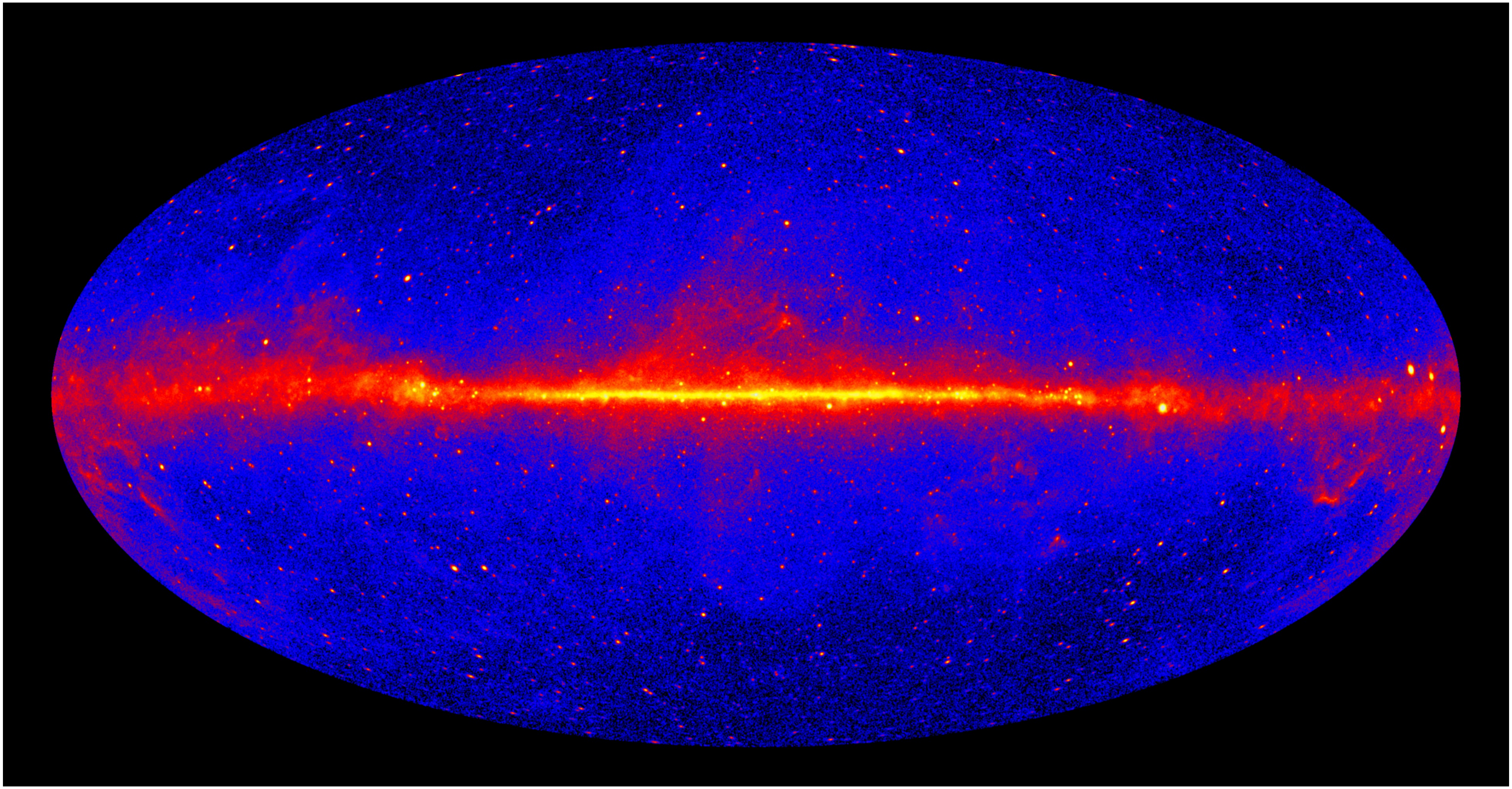


Spectrum of BL Lac

The light curve of BL Lac over a long period of time.



Fermi Gamma-Ray Sky

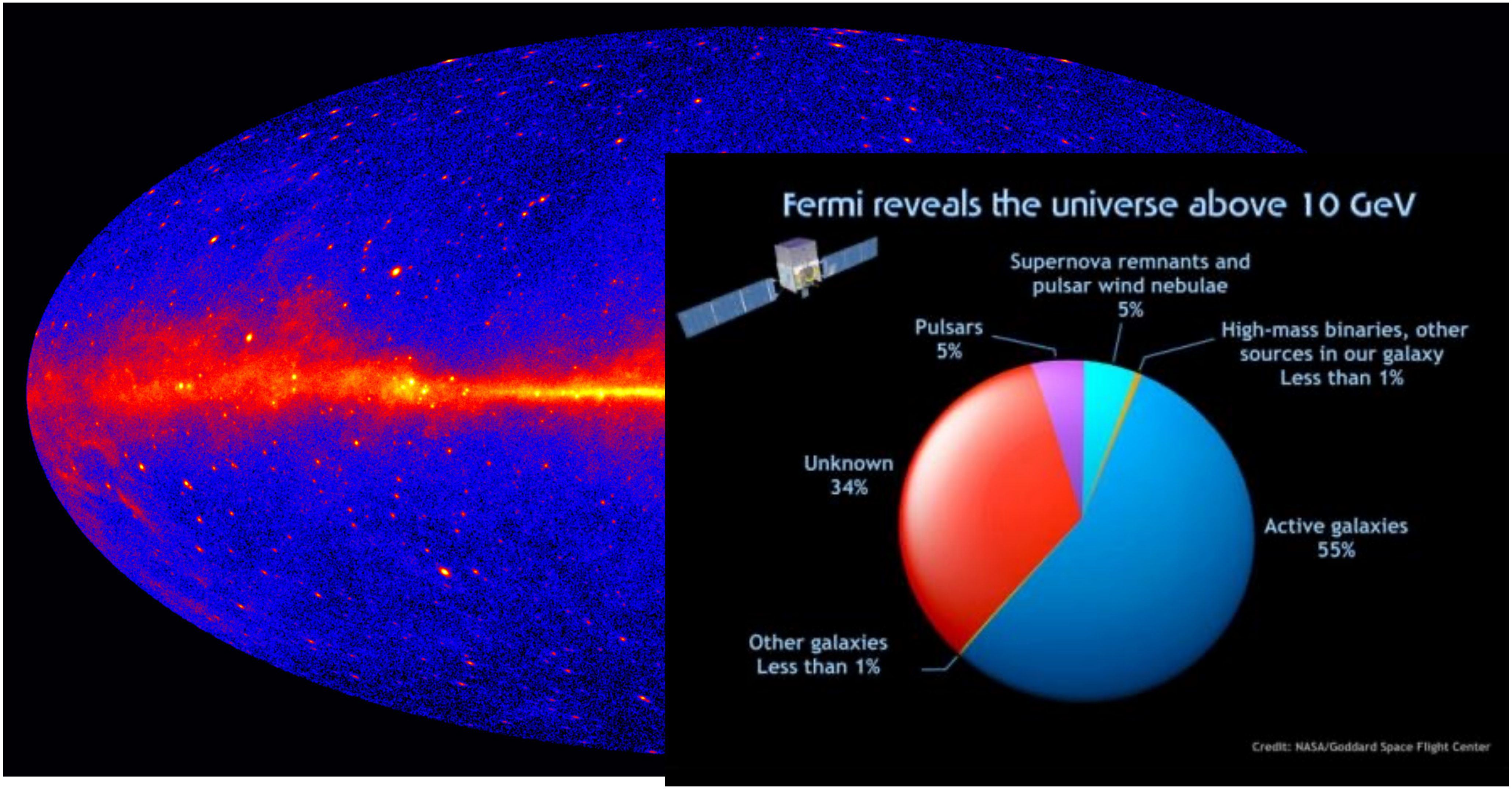


Fermi 12 year sky map NASA's Goddard Space Flight Center

The Radio Sky

5 GHz image from 300 ft,Condon et al.

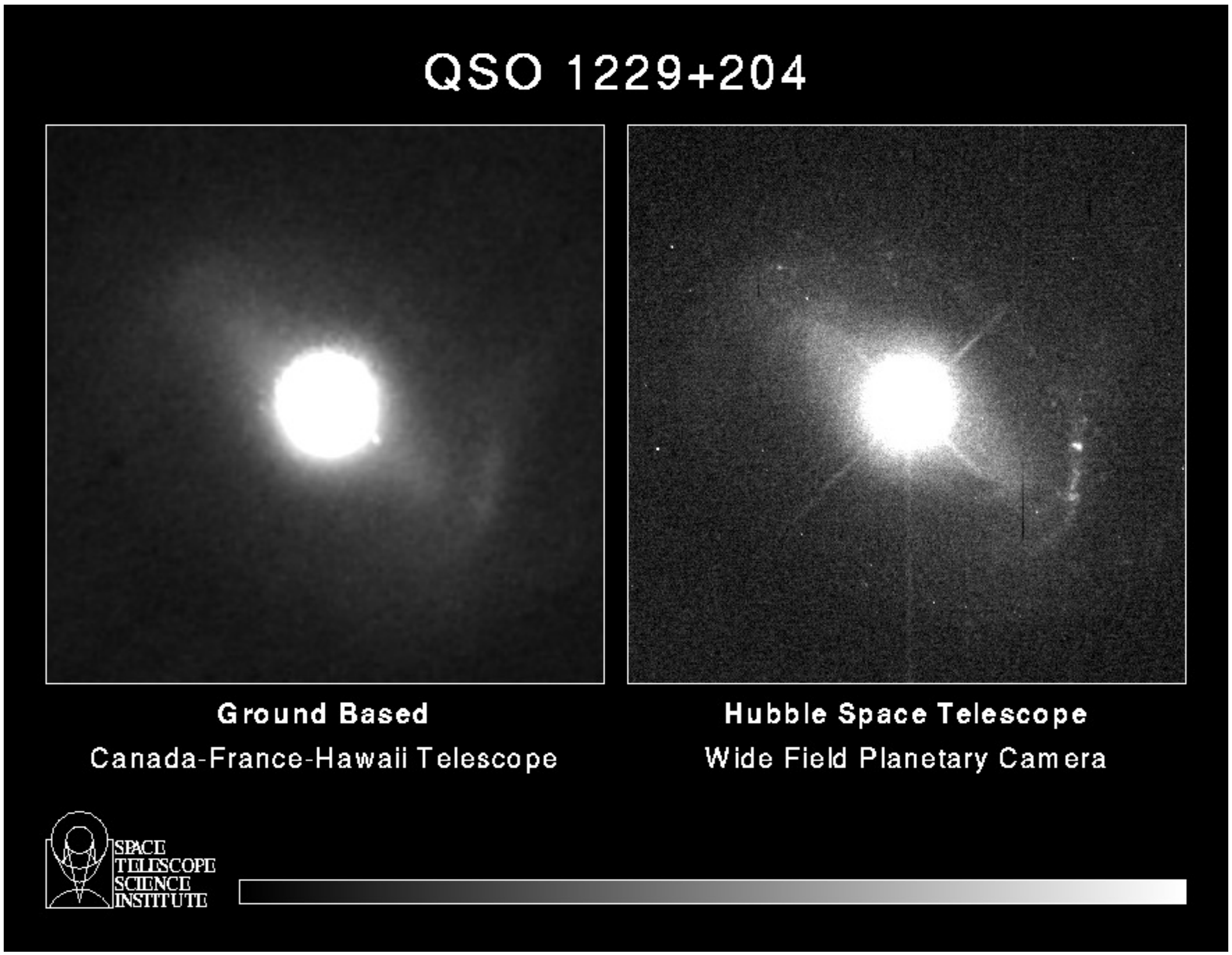
Fermi Gamma-Ray Sky

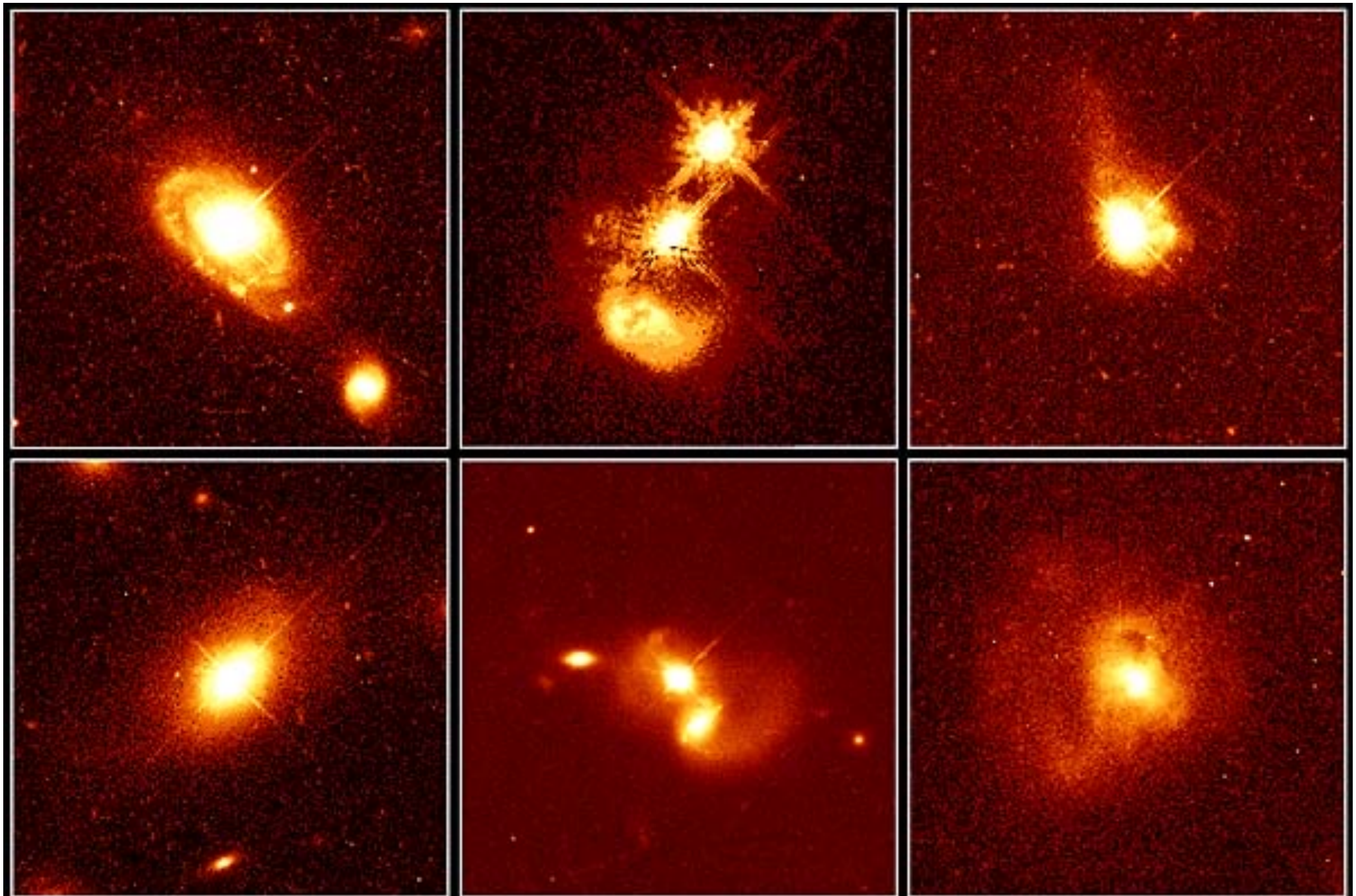


Fermi 5 year sky map

Are quasars really pointlike? No!

New images show quasars embedded in "fuzz" – they’re in galaxies.

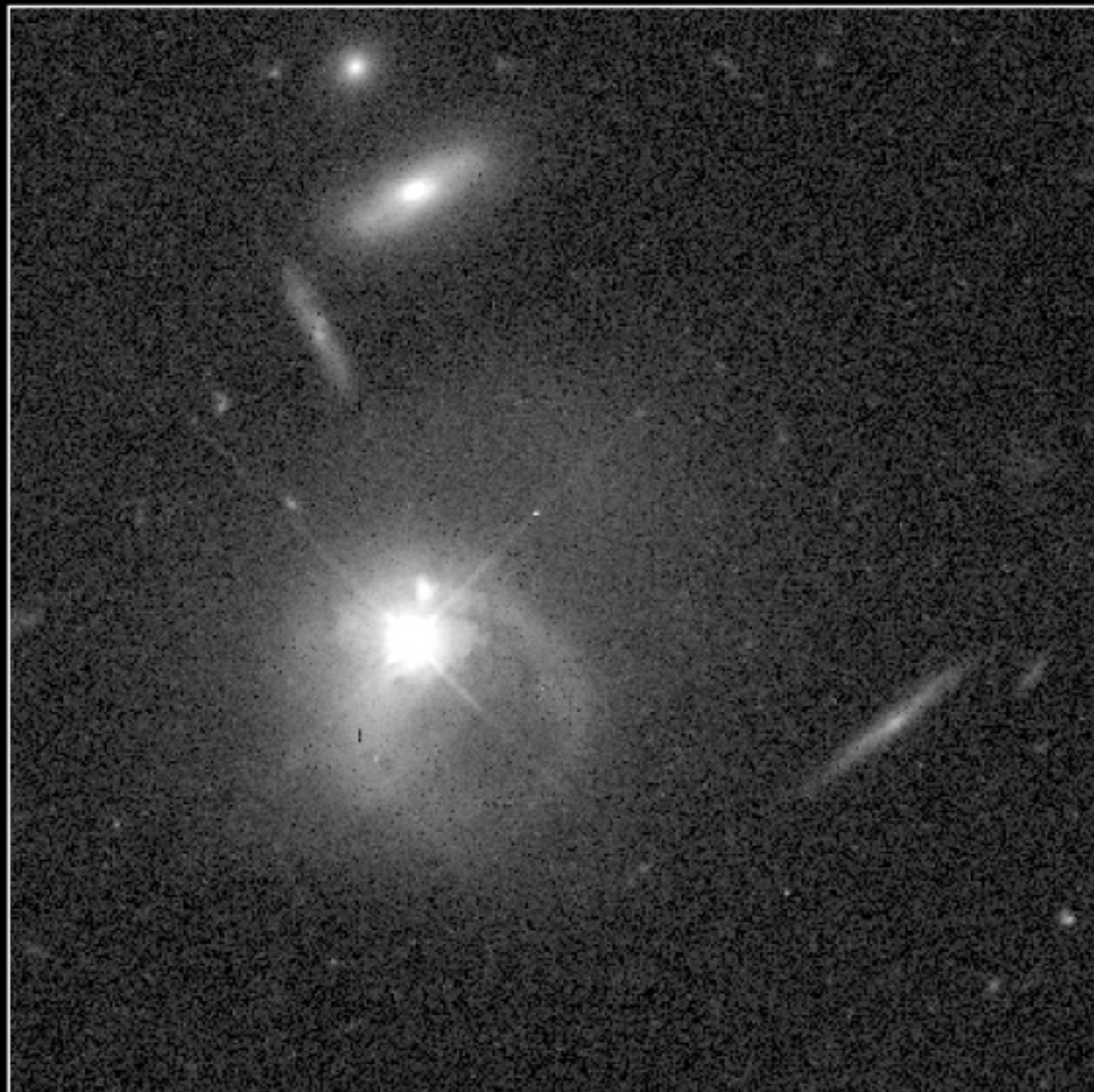




Quasar Host Galaxies HST • WFPC2

PRC96-35a • ST ScI OPO • November 19, 1996

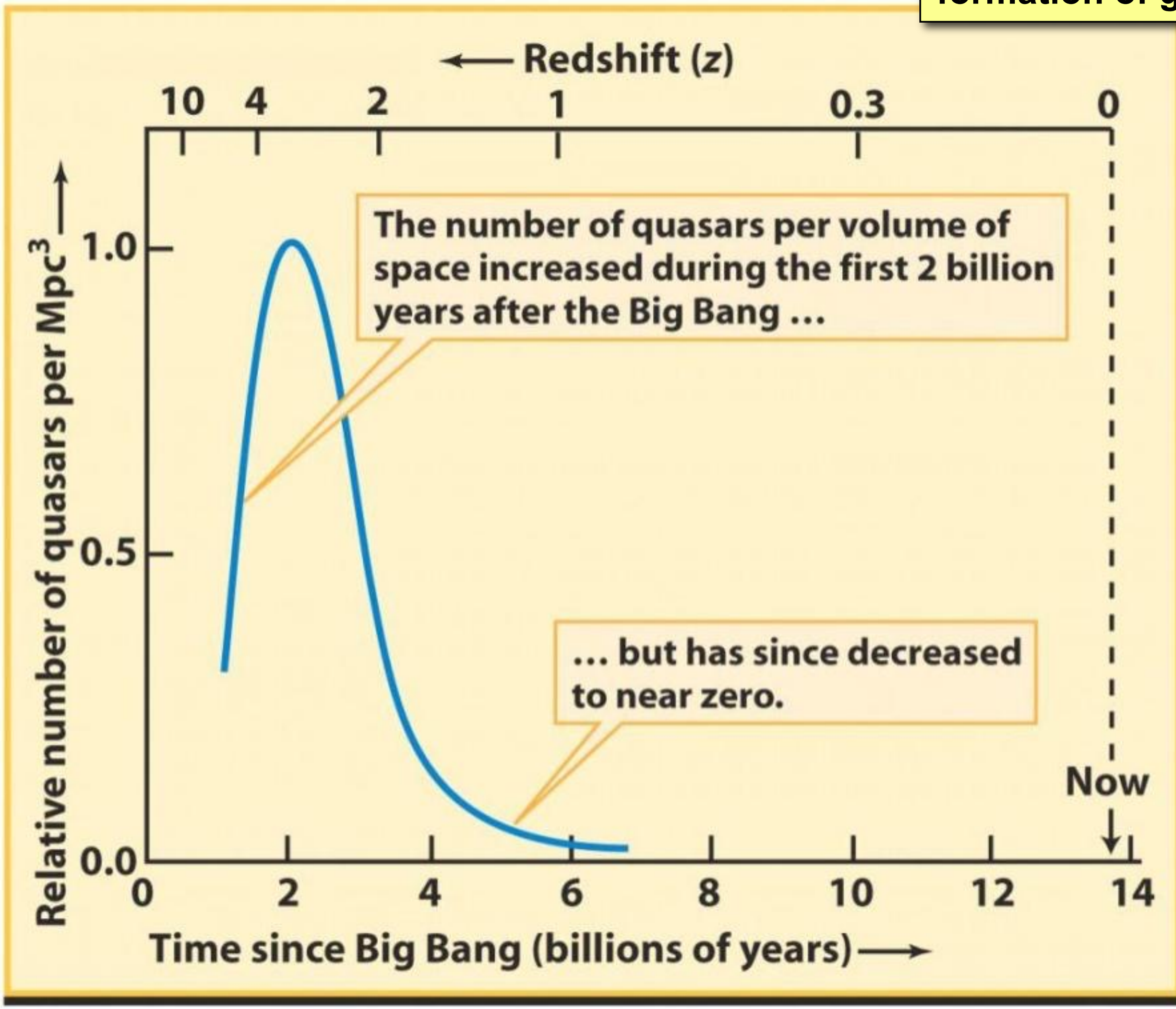
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA



Quasar PKS 2349 HST • WFPC2

ST ScI OPO • January 1995 • J. Bahcall (Princeton), NASA

Quasars are extinct. They were a feature of the early formation of galaxies.



What are quasars and active galaxies?

- Probably the same phenomena: a supermassive black hole at the nucleus of a galaxy. The differences come from:

  - how fast the black hole is fed
  - rotation rate
  - how much dust is near it
  - what angle we view it

  The unified phenomena are termed "AGNs" for Active Galactic Nuclei.

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

TORUS (The Obscuration Required by Unified Schemes)