Active Galaxies

Ishwara Chandra C.H

NCRA-TIFR

Astronomy is ..

Astronomy is the study of planets, stars, galaxies,
and other astronomical objects using the ***light*** they emit

Lab Science vs Astronomy.

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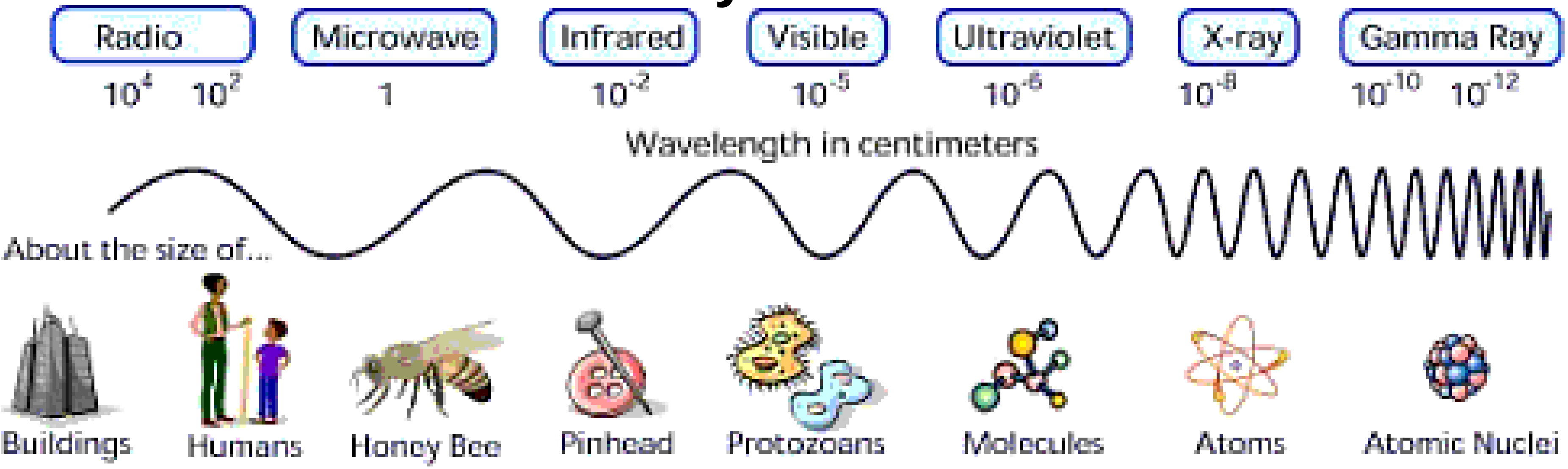
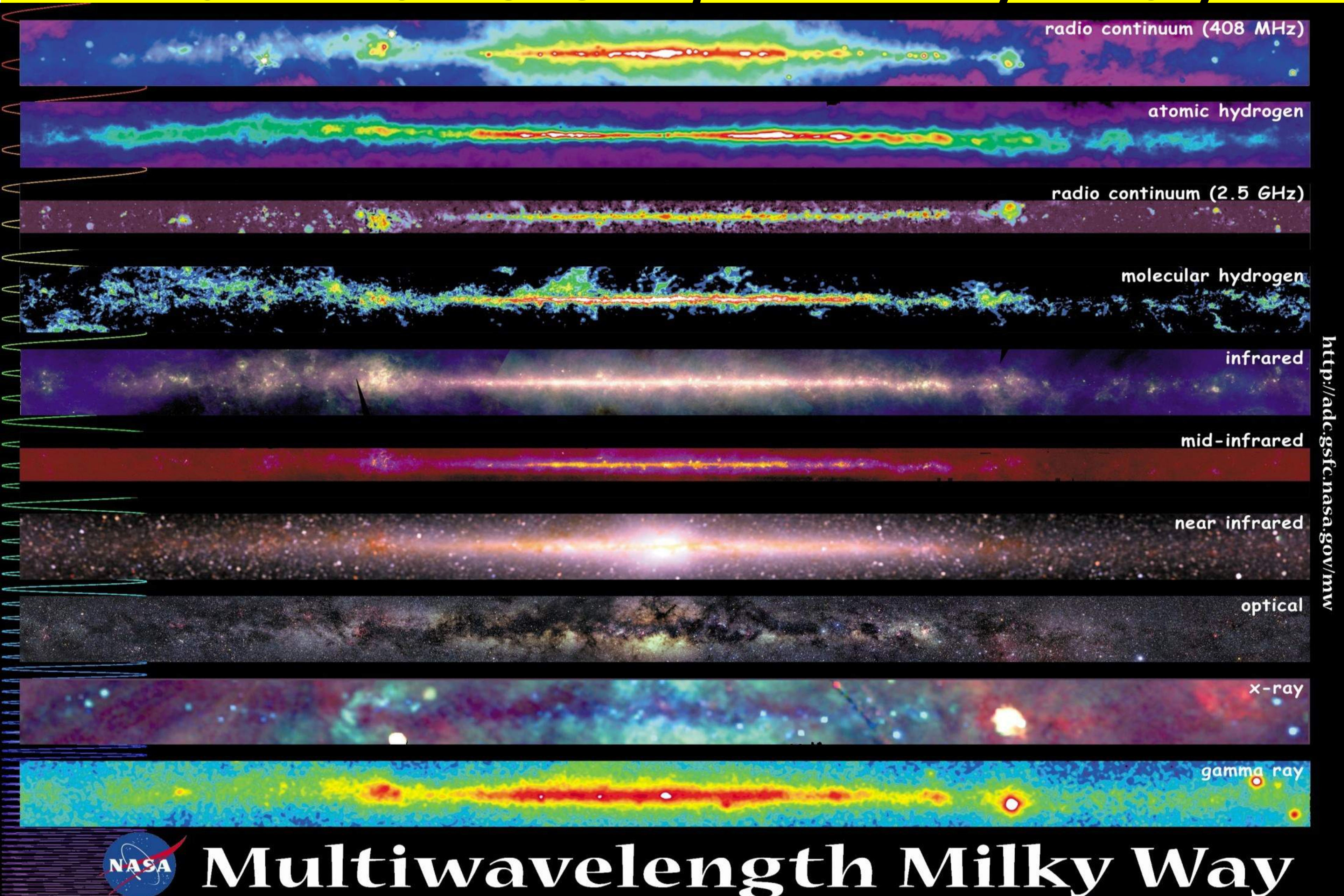


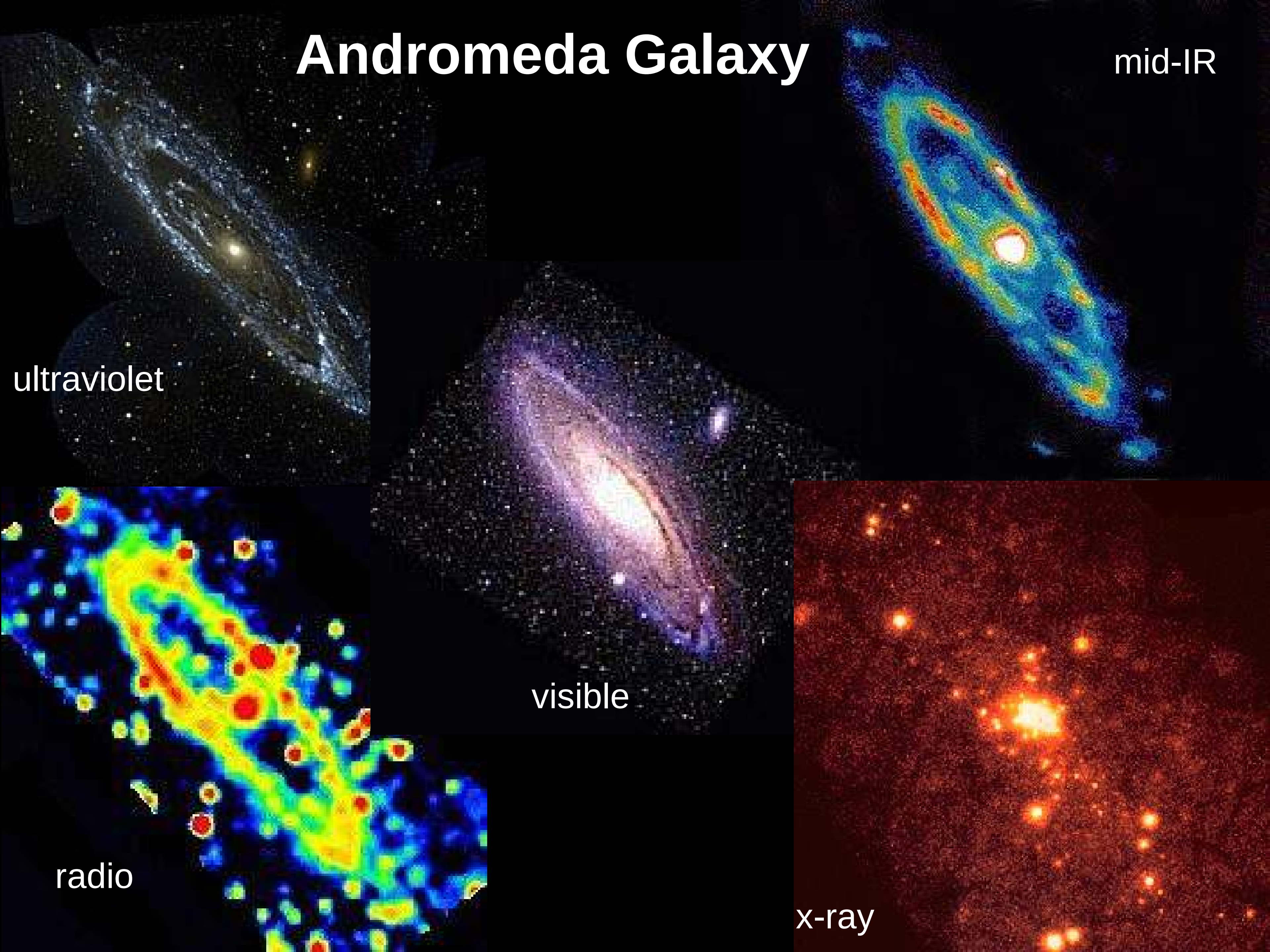
Different branches of astronomy as per branch of EM
  Different observables in each band

Consolidated picture from multi-wavelength data

Multiwavelength Milky Way



Andromeda Galaxy

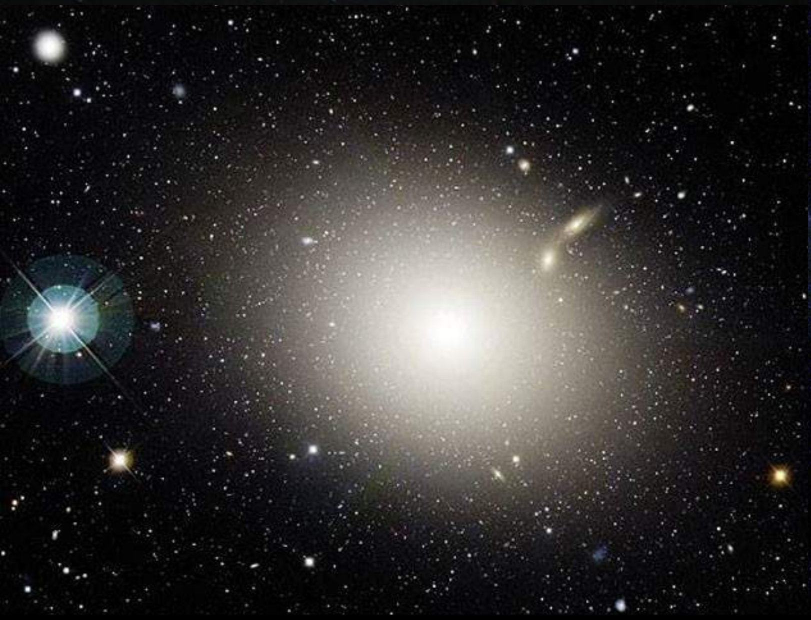


Normal Galaxies

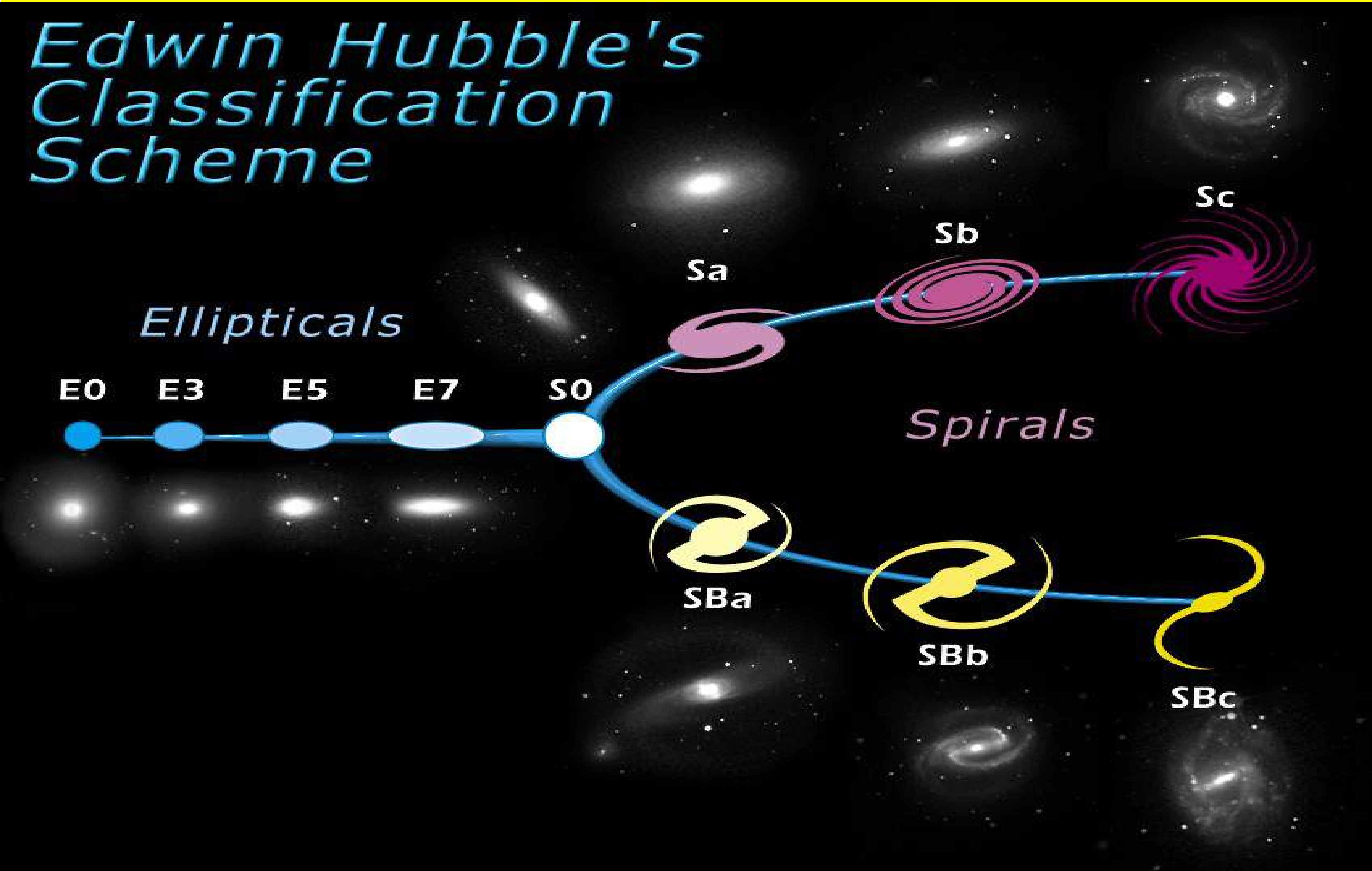
Galaxies are gravitationally bound systems of stars, mass up to 10^{12} solar mass, size upto tens of kpc

Hubble's observation that M31 is a separate galaxy is the birth of Extragalactic Astronomy.

Dwarfs to spirals to Giant Ellipticals; range of morphologies and range of mass (range of 10,000)



Normal Galaxies



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Hubble's observation that M31 is a separate galaxy is the birth of Extragalactic Astronomy.

Dwarfs to spirals to Giant Ellipticals; range of morphologies and range of mass (a factor of 10,000) – Hubble Tuning fork diagram

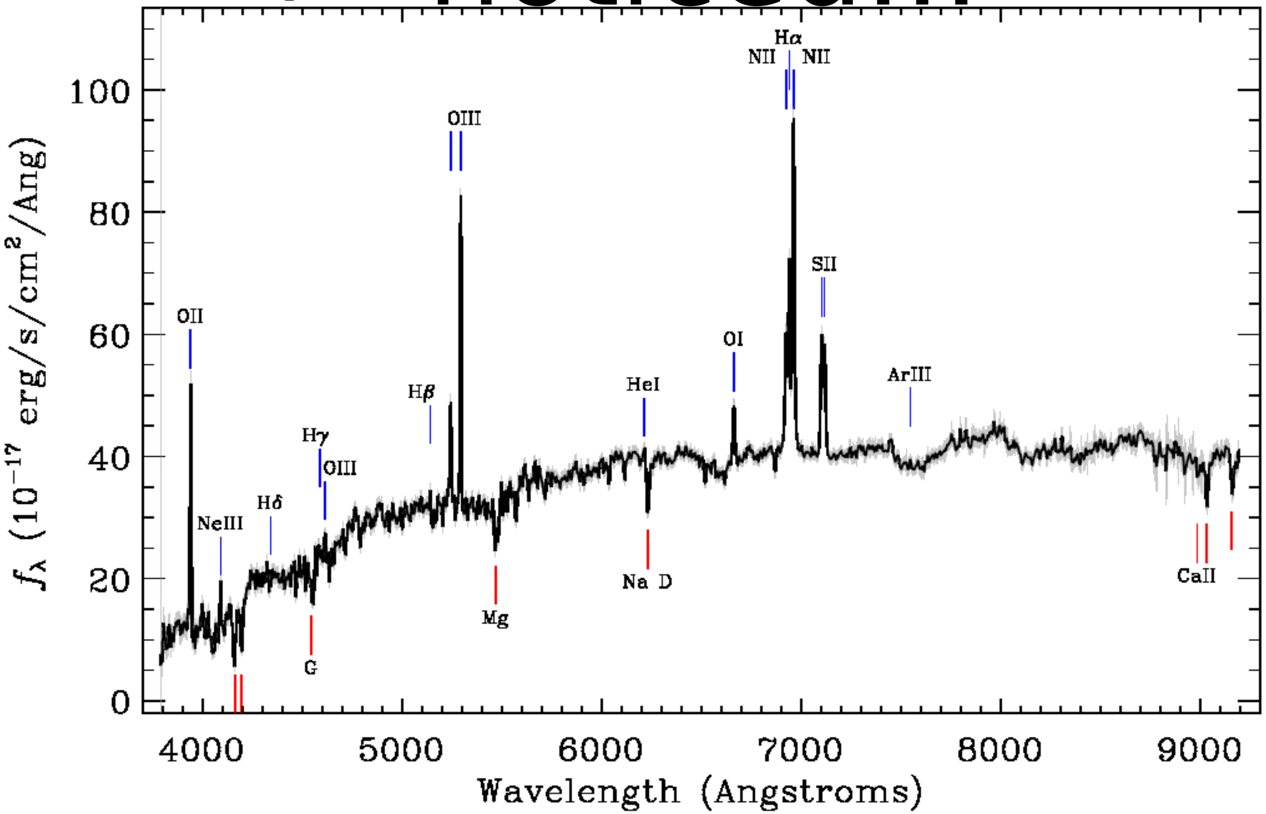
Are the properties same for all range of galaxies?

What are their properties in different branch of EM spectrum?

New phenomena in Galaxies noticed…

Early Days: In 1908, the spectra of nearby spiral galaxiy, NGC1068 showed strong emission lines with large widths – Very different than collective starlight.

New phenomena in Galaxies noticed...



Carl Seyfert, in 1943 noticed that many spiral galaxies has very bright and compact nucleus, appearing like bright star at the center!!


www.creationofuniverse.com


New phenomena in Galaxies noticed...

The spectra dominated by high excitation nuclear emission lines. Many of them broad, with widths close to 10,000 km/s, seen near the centre. Among many lines, hydrogen lines were more broad as compared to other lines.

Why only some spiral galaxies have this peculiar property at the centre?

What is the source of this extraordinary energetic phenomena?

New phenomena in Galaxies noticed…

First, carefully observe and note what you see…

- Small bright nucleus, size < 100 pc
- If material is gravitationally bound, the mass of the nucleus is very high applying virial theorem (M ~ v2.r/G; v ~ 10,000 km/s; r < 100 pc).
- Emission lines are from low density gas, hence size is > 1 pc.

In any case, something extra-ordinary is happening.

Mysterious “Radio Stars”

In late 50’s; about 200 radio sources were known (3C survey). Some were identified with galaxies, some with bright “stars” and some remained unidentified.

They are named as “Quasi Stellar Radio Sources”; or **QUASARS**; originally discovered in RADIO, but the name QUASARS are used even for those which do not emit radio.

One of them had strange spectra, not matching with any known elements till then.

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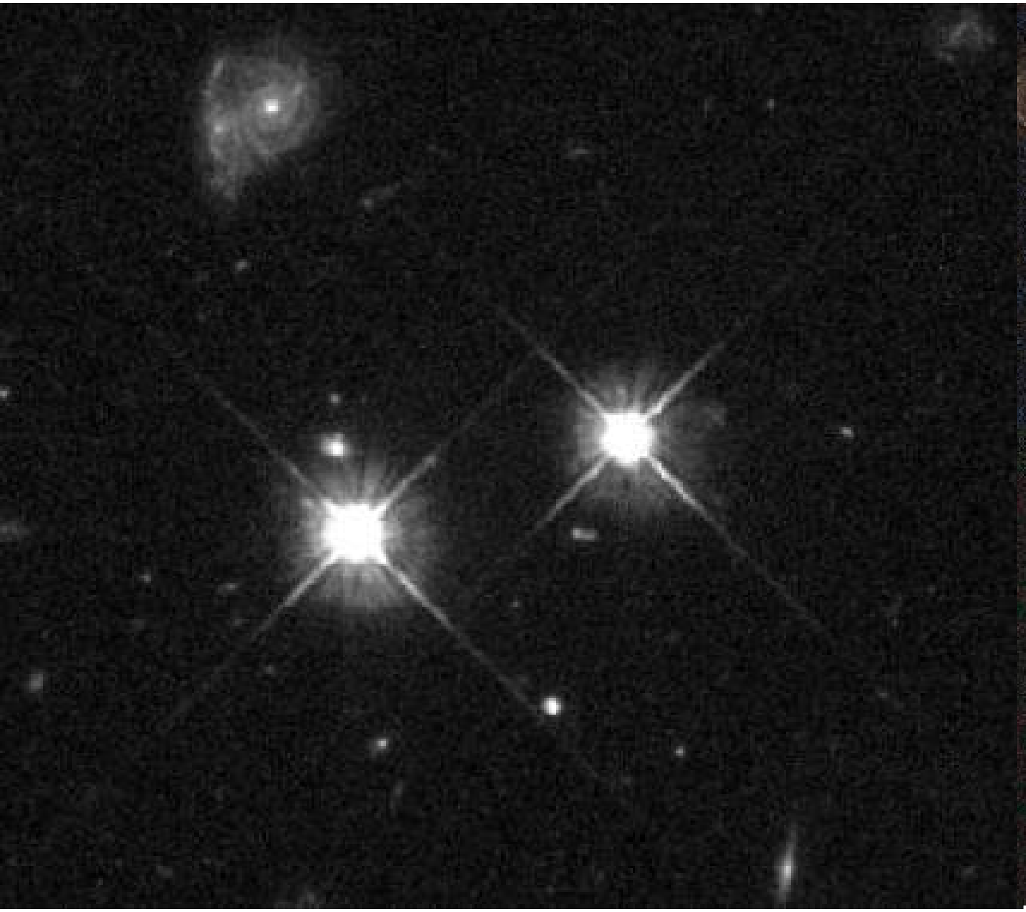
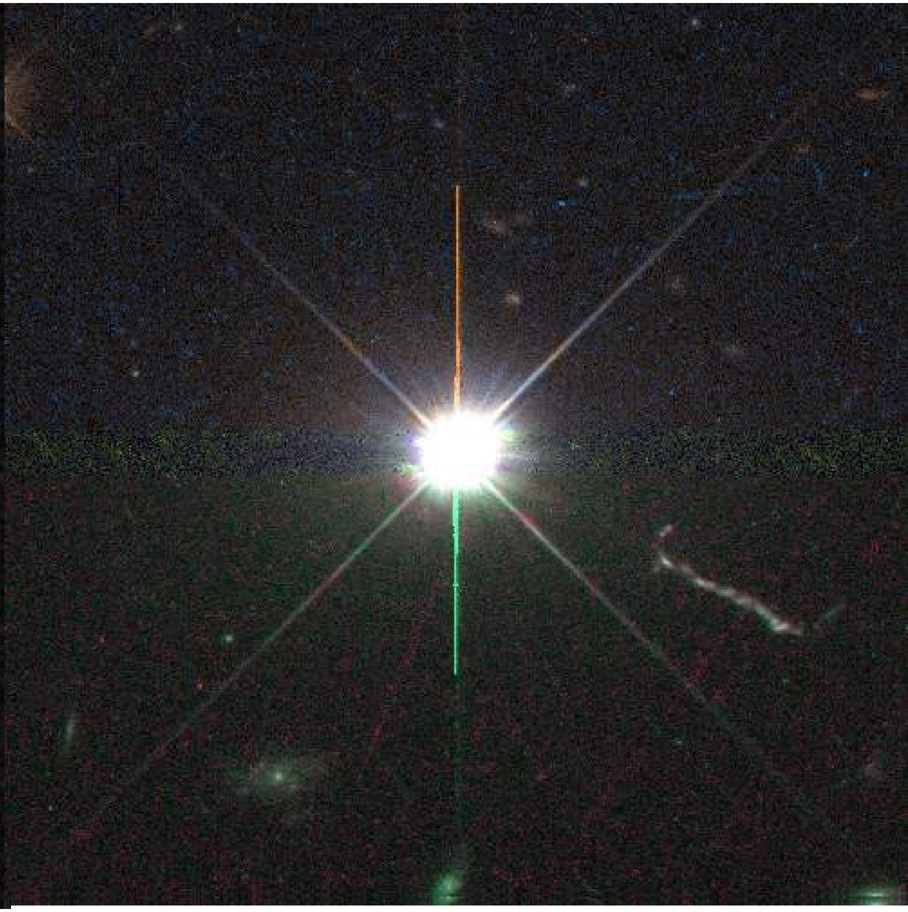
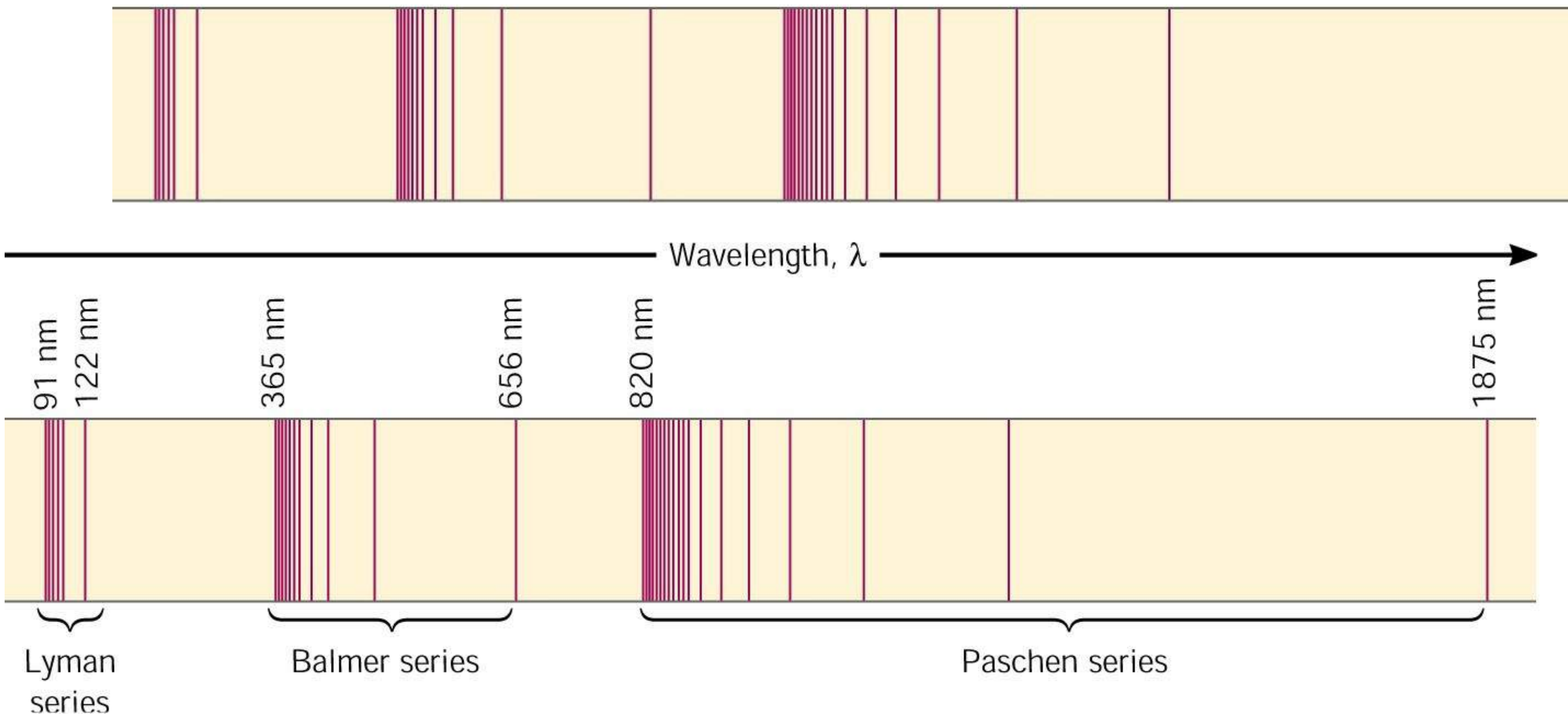
New element QUASARONIUM proposed?

Mystery Solved!

Martin Schmidt just “redshifted” the spectra by z=0.158 and the lines were Hydrogen lines and other known lines..

Mystery Solved!



Mystery Solved!

$$Z = (\lambda_{obs} - \lambda_{rest}) / \lambda_{rest}$$

OR

$$\lambda_{obs} = (1 + z)\, \lambda_{rest}$$

Mystery Solved!

Martin Schmidt just “redshifted” the spectra by z=0.158 and the lines were Hydrogen lines and other known lines..

“Stars” are now much farther compared to Seyferts!

Scientists were quick to realise that these objects can be used as tool to study distant universe, because they are very powerful.

Hoyle and Fowler (1963) and Zel’dovich and Novikov (1964) proposed that black holes must be involved in such extra-ordinary phenomena;

Blackhole physics, implications to galaxy formation, and probing large distance made Quasars mode demanding.

The case for Blackhole

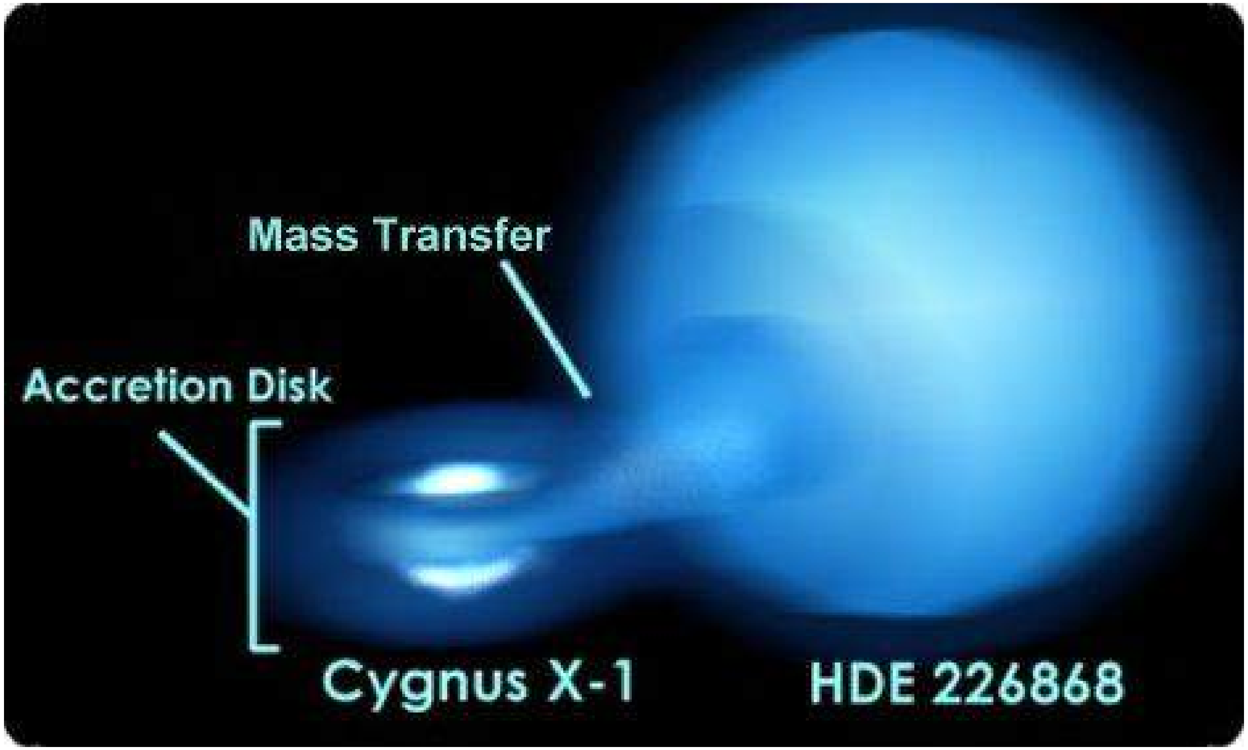
Simple arguments on balance (outward radiation pressure vs self-gravity) indicates that the central mass has to be more than 108 to 109 for quasars.

The limit is also known as Eddington limit, means the object will be blown out by radiation pressure, if less massive object has ultra-high luminosity.

For SUN, it is 10^{38} ergs/s

The case for Blackhole

A few years later, the black-hole accretion disk theory successfully explained galactic X-Ray sources.



For AGNs, the phenomena has to be scaled up by several orders of magnitude.

What are Active Galaxies?

The “**active**” central part of the (otherwise normal) galaxy, is known as “Active Galactic Nuclei”, or AGN

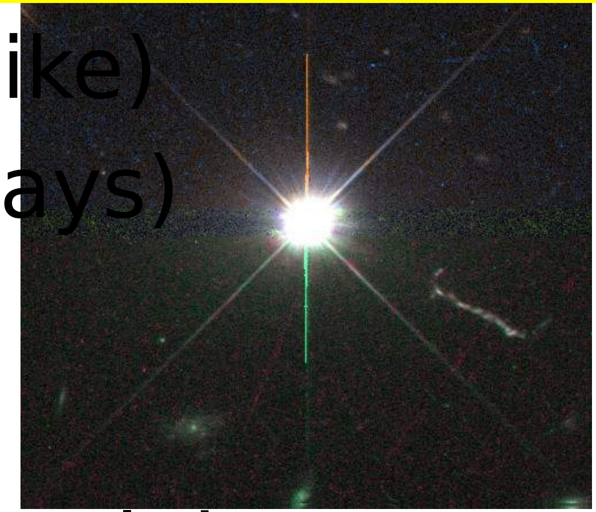
Seyferts - lower luminosity among AGNs, further narrow and broad based on line width

Quasars - The most luminous among the AGNs, radio loud and quiet

Radio Galaxies - Otherwise an ordinary giant elliptical, but “quasar like” center, radio loud

BL-Lacs , OVVs - Absence of strong emission lines, violently variable.

Properties of Quasars



Point like appearance (stellar like)

Variability (as short as a few days)

Large UV flux (UV Excess)

Broad emission lines

(H-alpha, beta, gamma, Lyman-alpha, MgII, CIII, CIV, etc, with large widths (upto 10,000 km/s)

Some are radio LOUD, some radio QUIET

The emission across the EM spectrum often show powerlaw ($F_\nu \propto \nu^{-\alpha}$);

Normal Galaxies vs Active Galaxies

Morphology, characteristics differ (Luminosity, Mass).

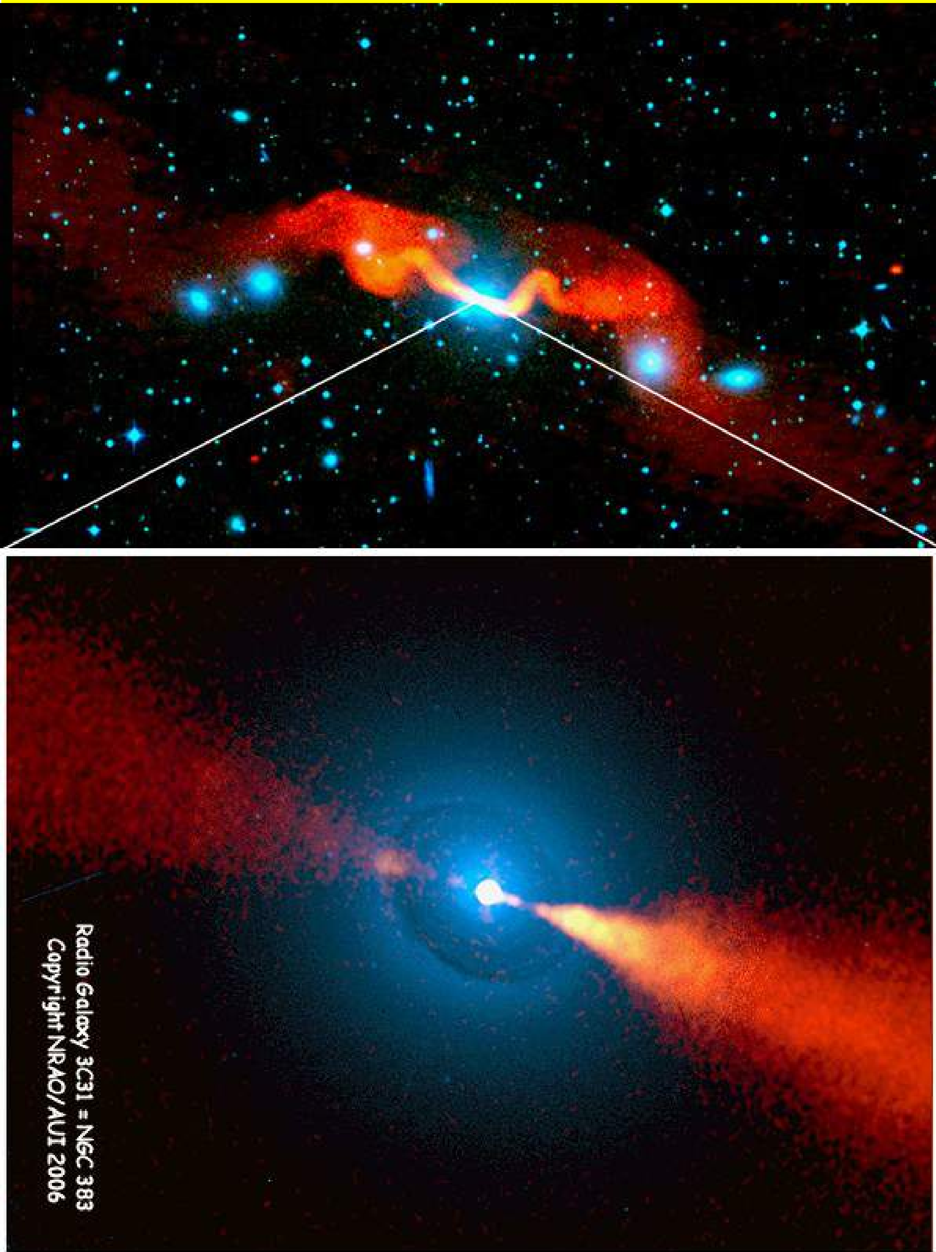
The central part of the galaxy, more powerful than a typical galaxy!

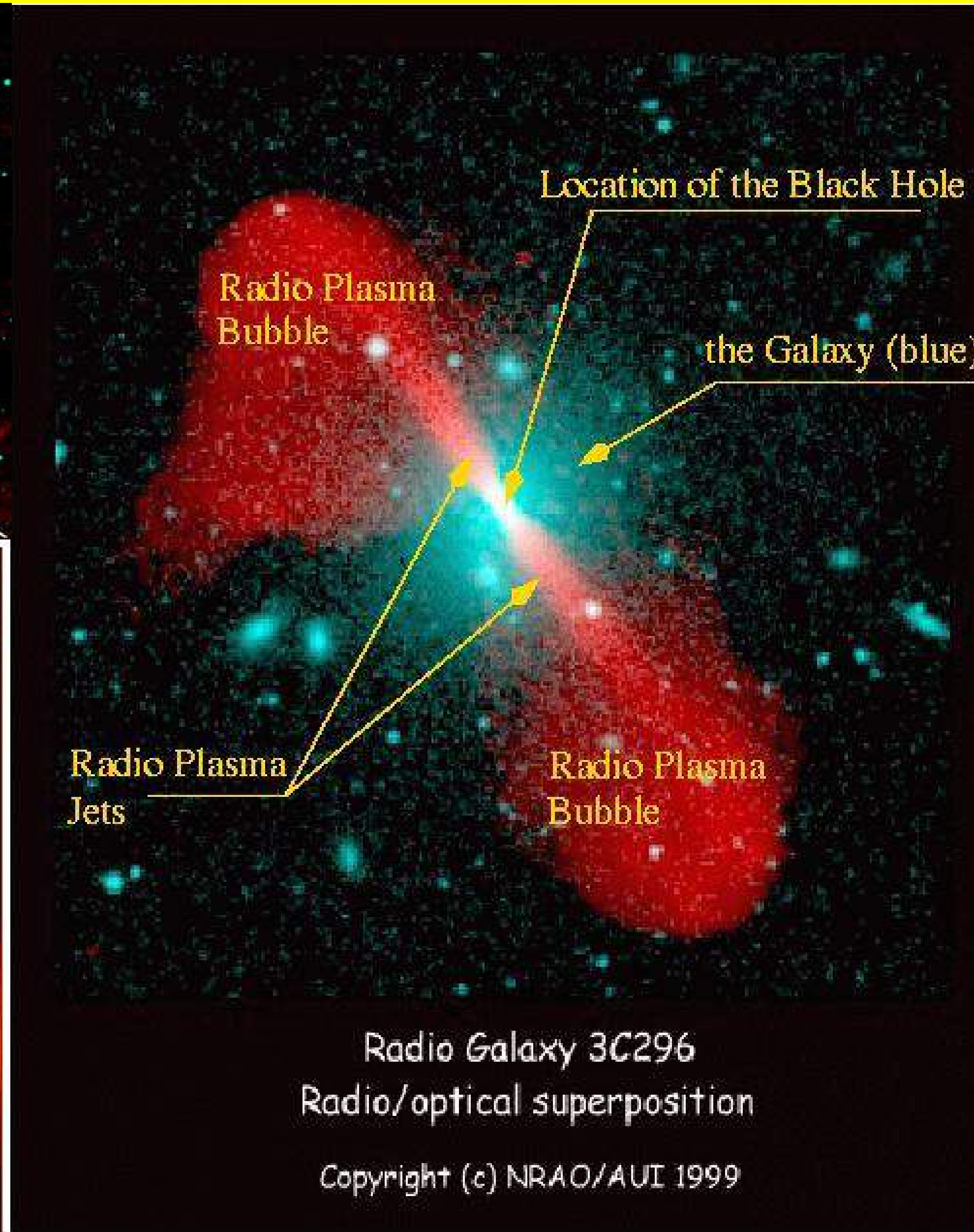
Elliptical galaxies host powerful quasars and radio galaxies (spiral galaxies host 'Seyferts')

Quasars help to locate massive elliptical galaxies at large distances (redshifts)

Are the massive ellipticals the largest single object? ----- Wait…

Radio Galaxies





What are Radio Galaxies?

They are the largest single object in the universe, with a powerful central engine spewing jets in both directions (which may not be visible always) producing strong radio emission at the end of jet

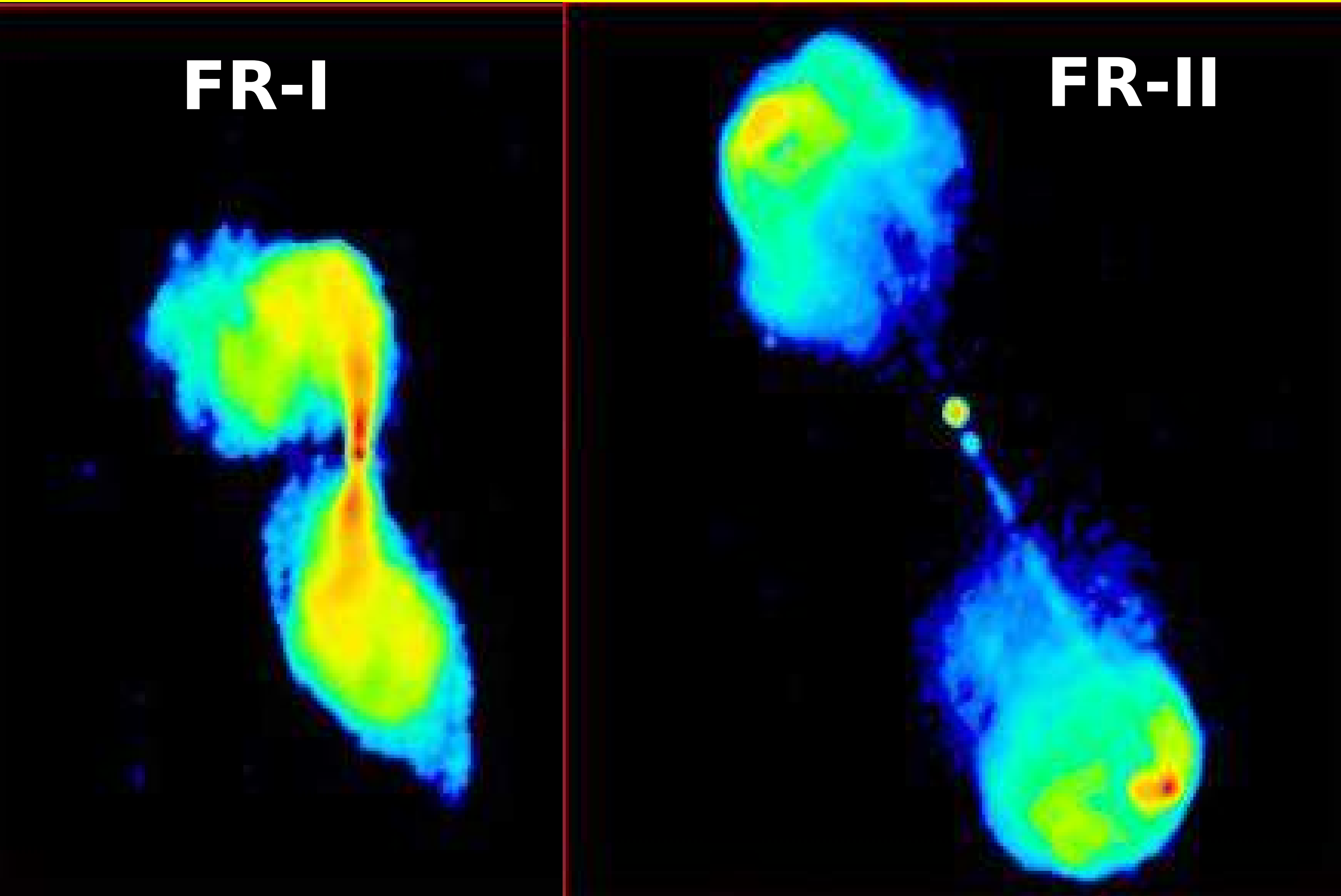
Remember water jet used for washing the car

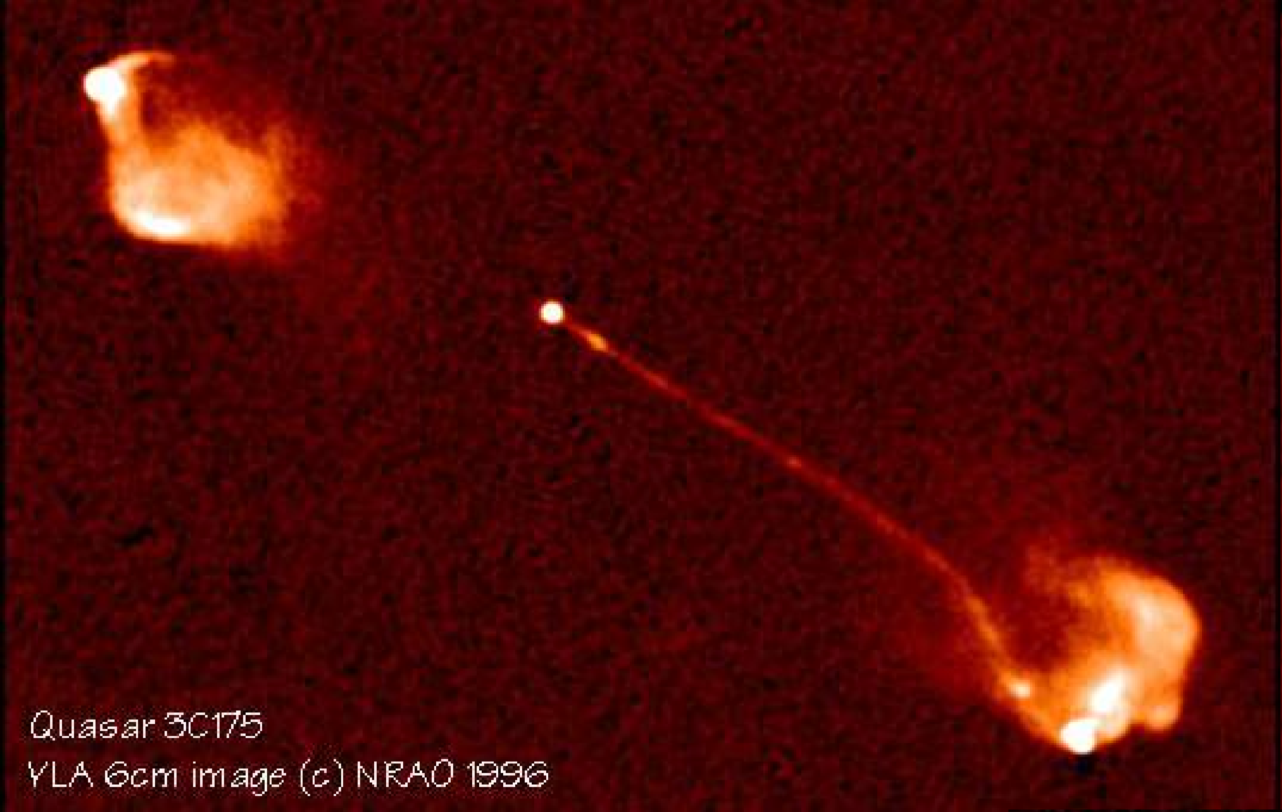
The hosts of the central engine – or the Active Galactic Nuclei – is usually elliptical (giant elliptical if the radio galaxy is most powerful)

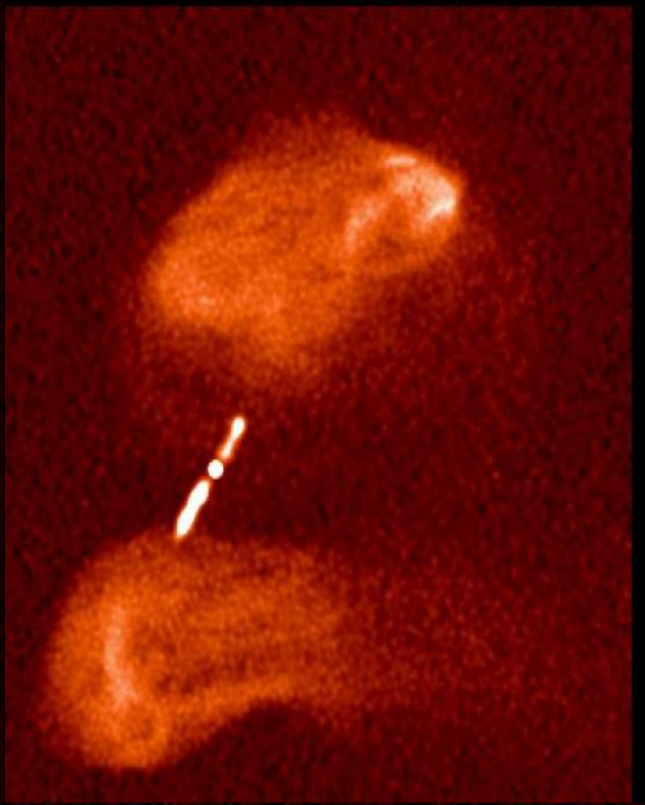
The radio luminosities more than 10 times the optical, upto 10^{29} W/Hz at 1.4 GHz

AGN is a must, but not all AGNs are radio loud.

Two broad class – FRI & FRII

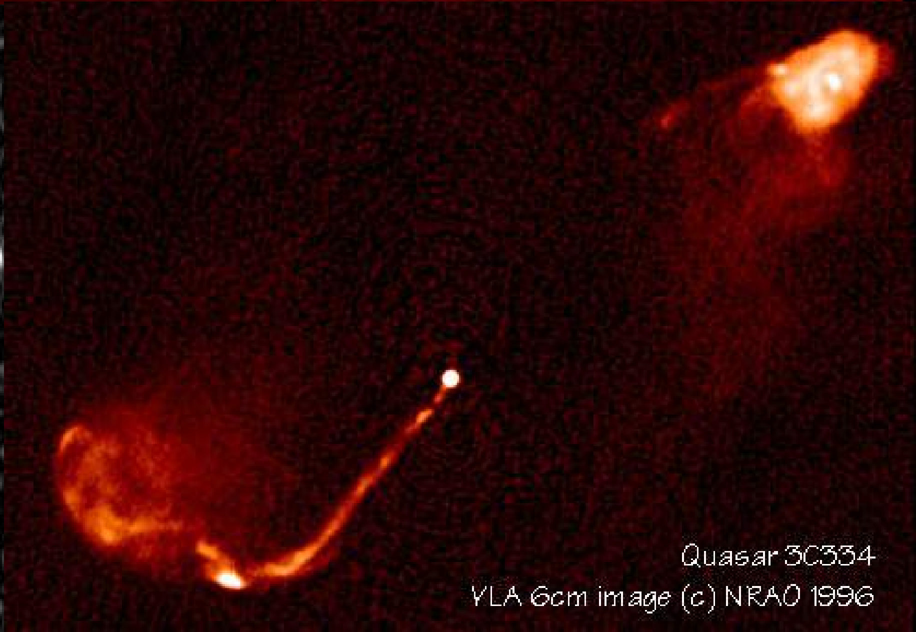


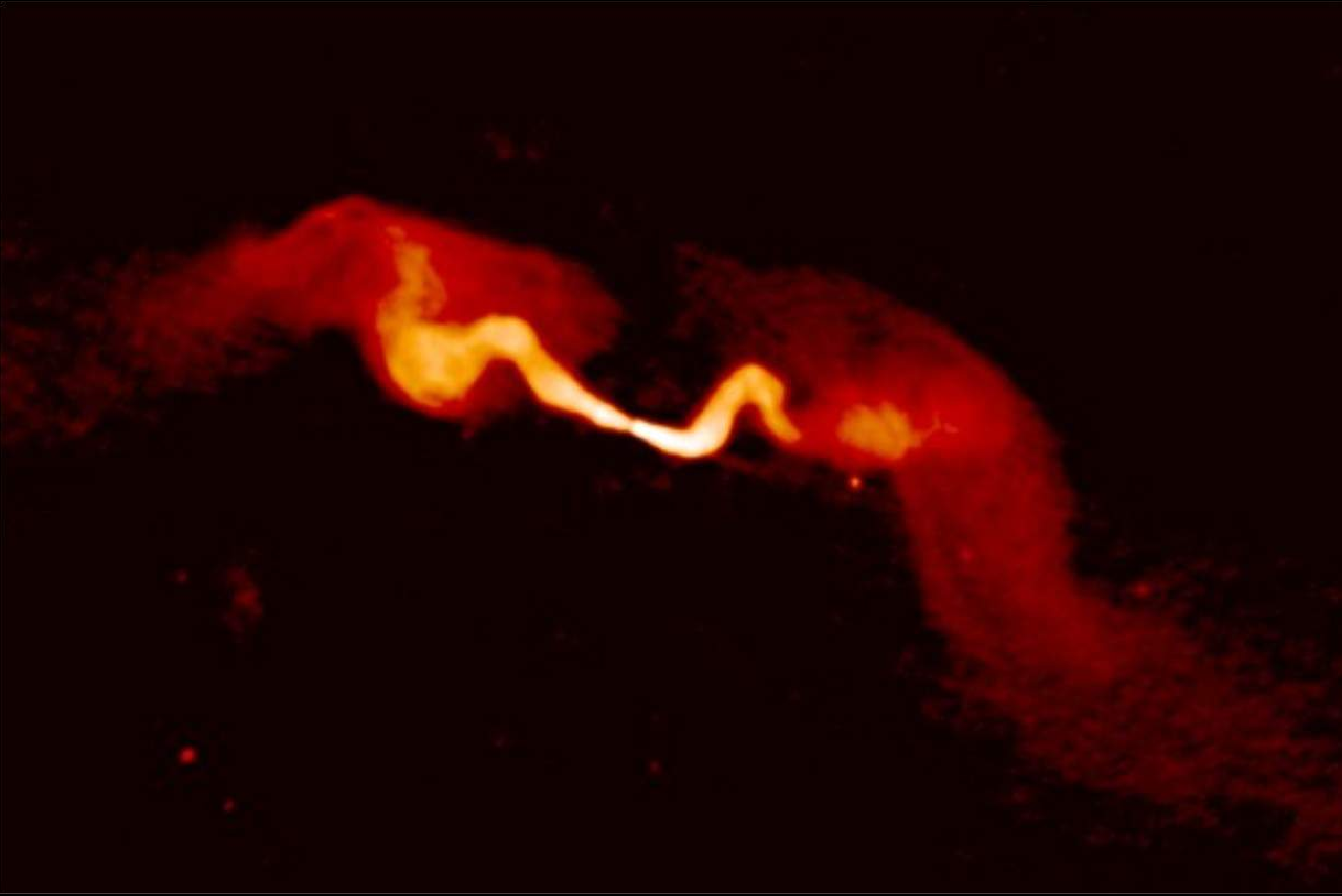


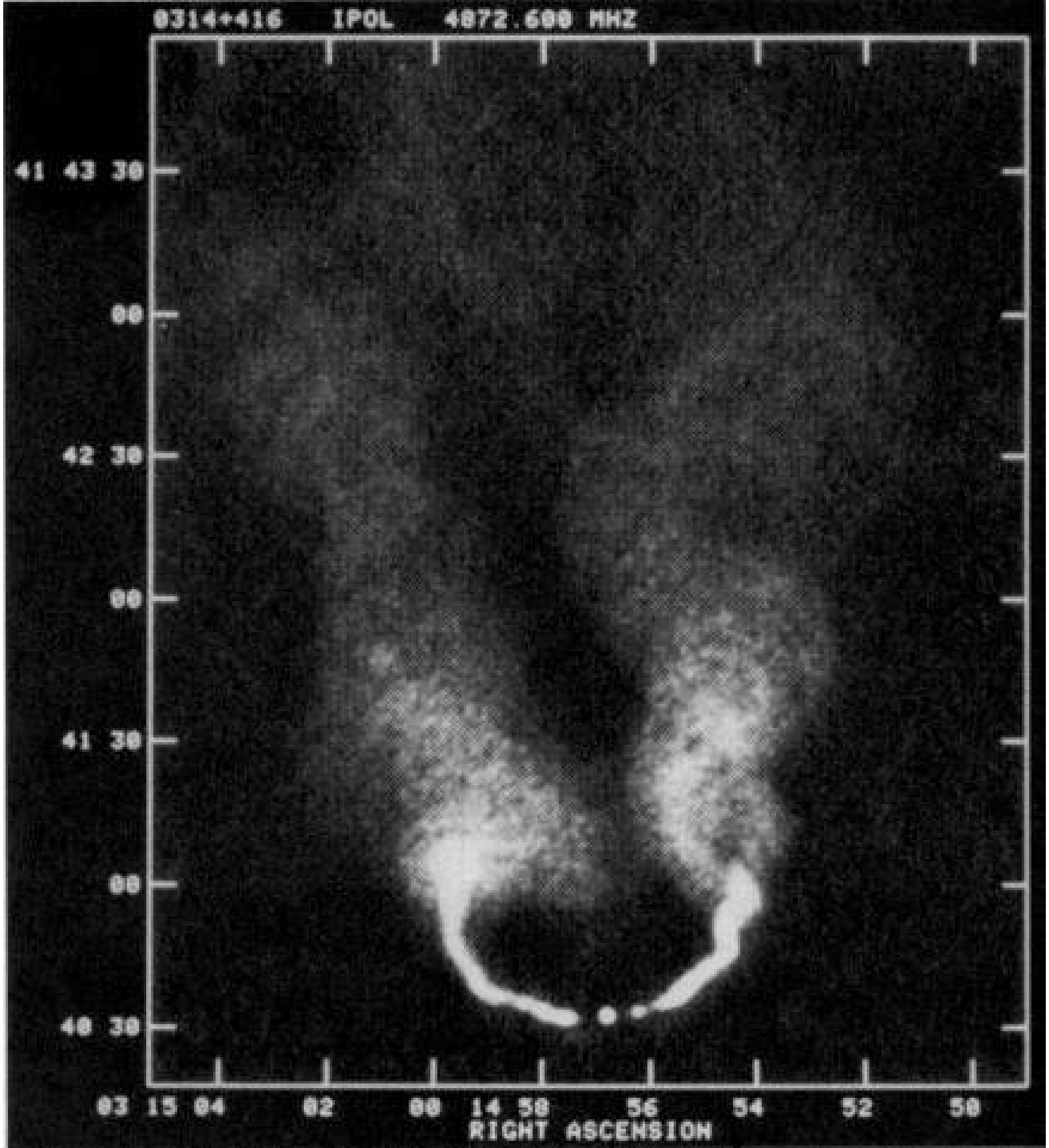


The largest Radio Galaxy

≥ 5 Mpc!







0314+416 IPOL 4872.600 MHZ
41 43 30
00
42 30
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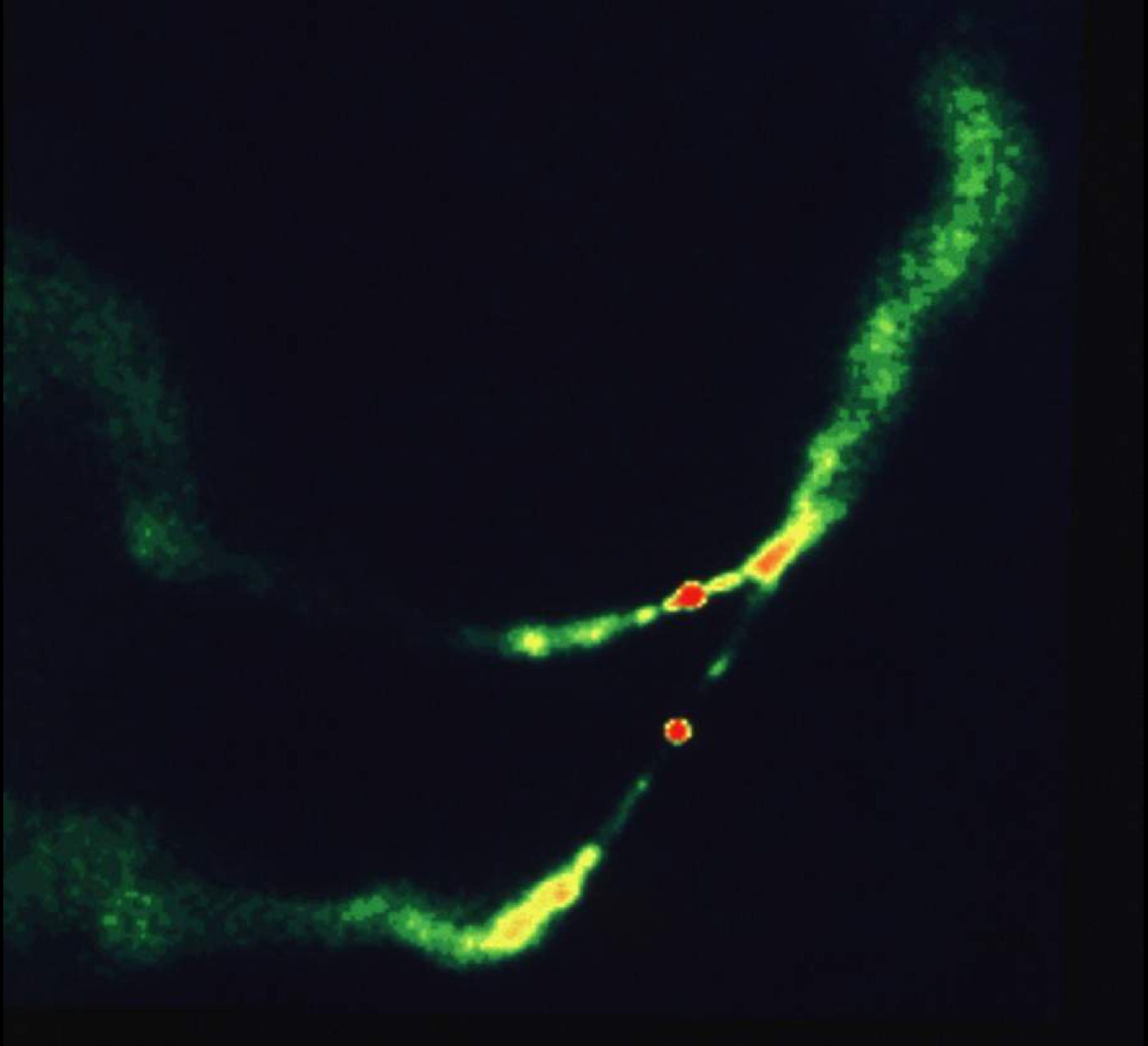
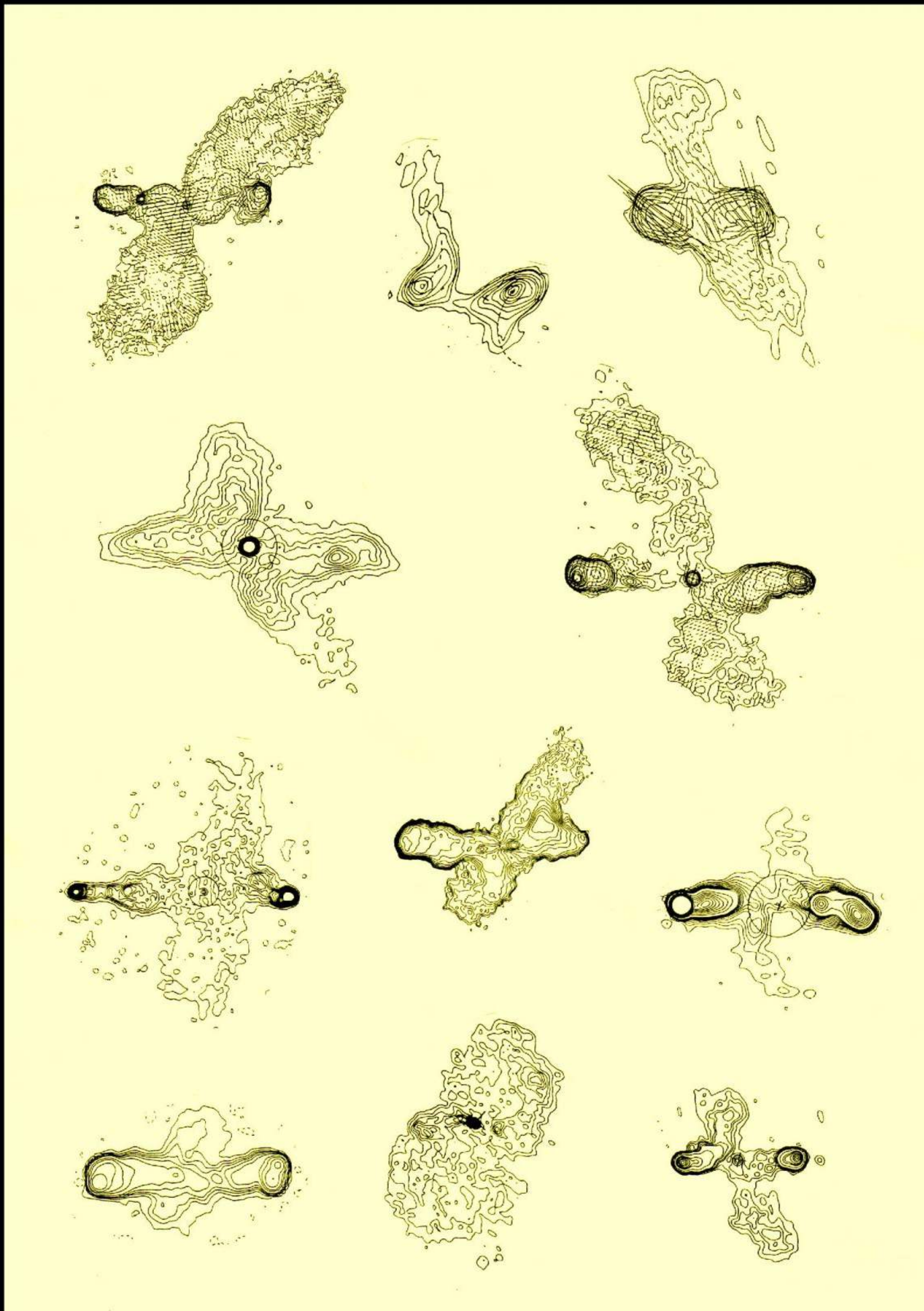
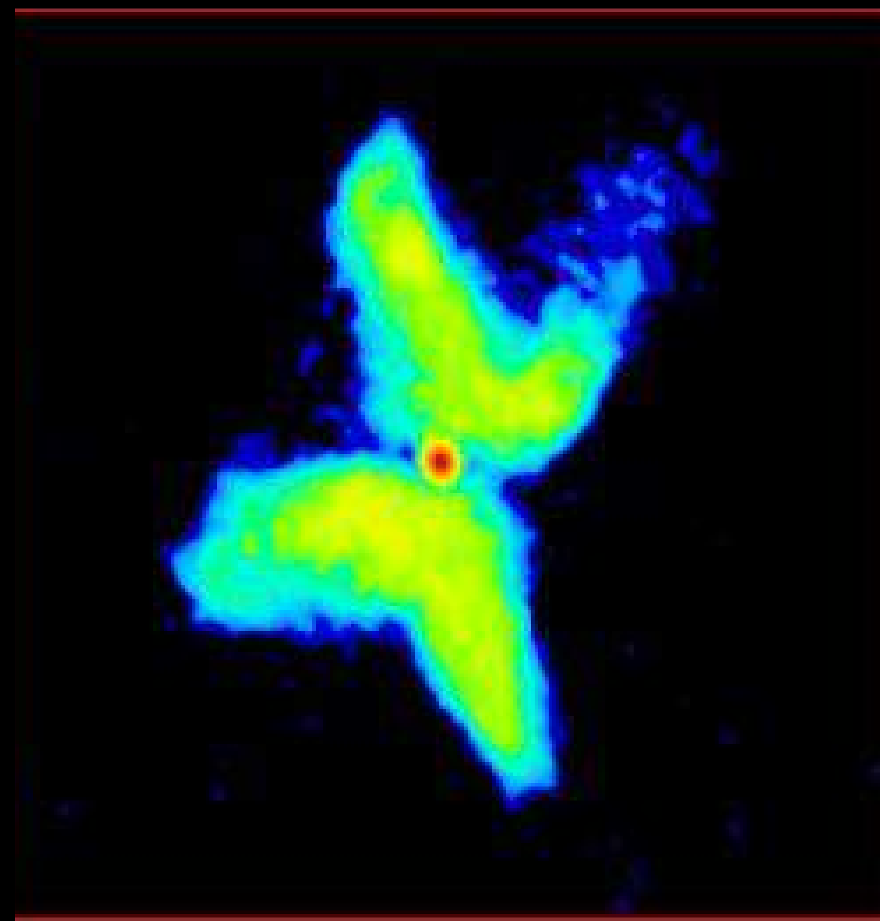
41 30
00
40 30
03 15 04
02
00
14 58
56
54
52
50
RIGHT ASCENSION



X-Shaped radio galaxies





Summary till now....

Some galaxies hosts active galactic nuclei –

Supermassive BH is needed for active galactic nuclei.

Seyferts hosted in Spirals and Quasars in Ellipticals.

Some Quasars produce powerful radio emission (about 10%)

There is range of morphology and diversity among the radio sources –

Models of AGN

1. Compact Star Clusters (NO BH):

Supernovae outshines the galaxy for a short duration.

PROBLEMS:

The poison statistics would imply, less luminous AGN to have less SN and large variability. The ‘connected SN activity’ is needed to maintain steady luminosity.

Can’t explain how radio components move in a fixed direction (jets and hotspots)

The lifetime of such massive cluster is $< 10^7$ years, through random encounters, small stars will escape and massive stars will fall into center and evolve to a BH.

Models of AGN

2. Supermassive stars:

In principle, a star can have mass up to 10^8 $M_\odot$, without violating Eddington limit.

PROBLEMS:

(a) Can not be supported by gas pressure for long and becomes unstable in $< 10^7$ yrs.

(b) How to produce collimated radio jets travelling at relativistic speeds to millions of pc.

(c) GTR predicts such systems will eventually form BH

Basic properties of BH

The schwarzschild radius is Rs = 2GM/c2; for Sun, Rs ~ 3 km.

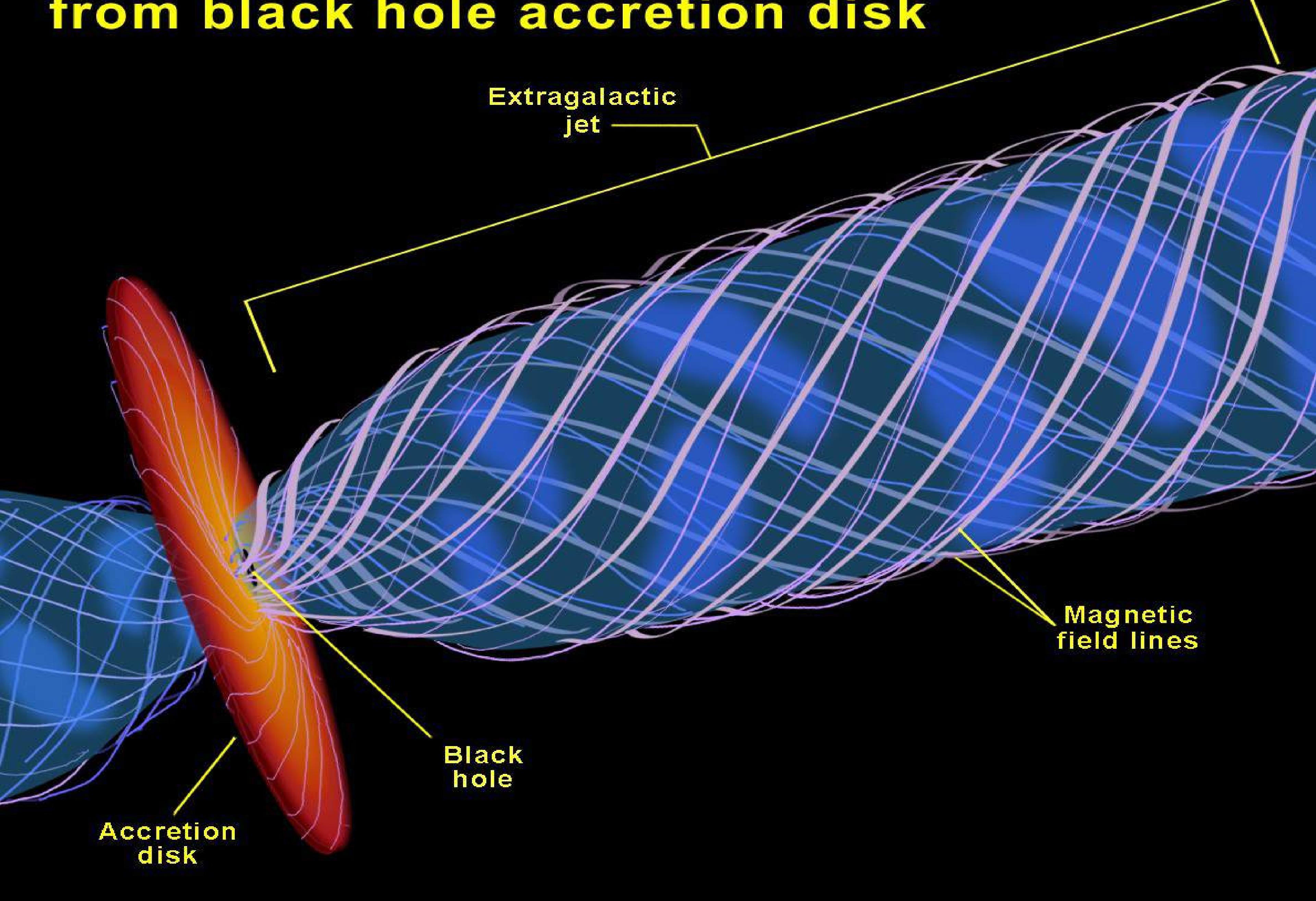
If all disappears into BH, how can it be a source of energy?

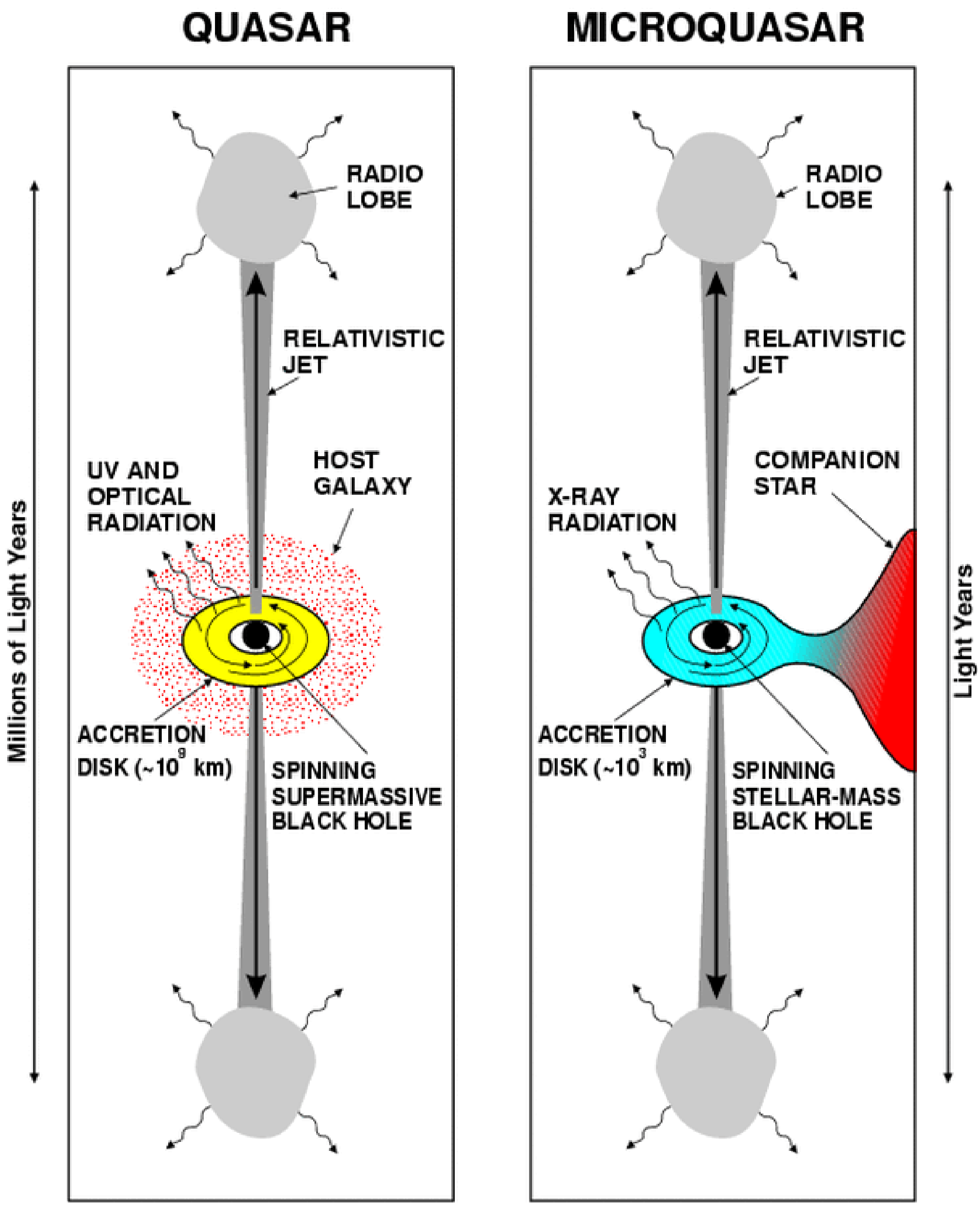
The spin and the mass of BH can convert gravitational energy into KE of particle. For rotating BH, the ‘dragging of inertial frames’ (Lense – Thirring effect) puts the falling matter into orbital motion in the same direction as it rotates.

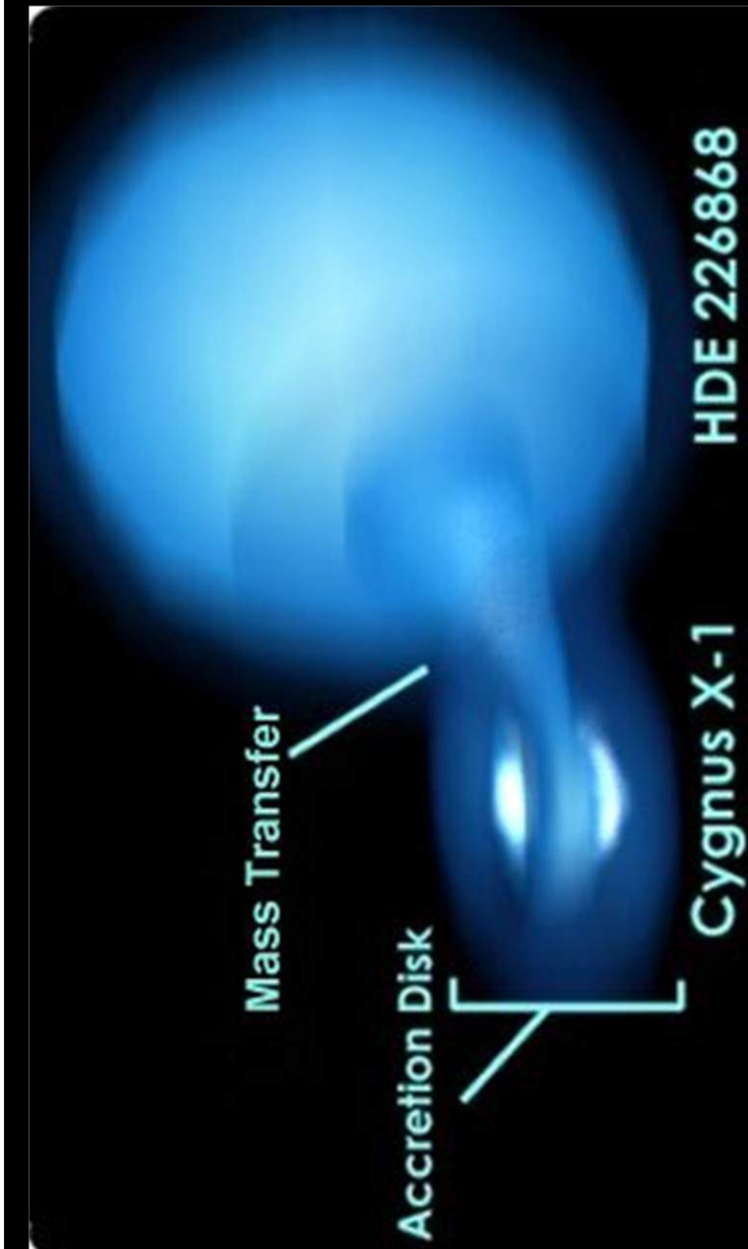
The region between Rs and ‘static radius’ where everything has to rotate with BH is called ‘ergosphere’. The particle can escape from this region with huge energy (Penrose process) – this is one way to extract the energy.

The best evidence for BH comes from galactic X-Ray binaries.

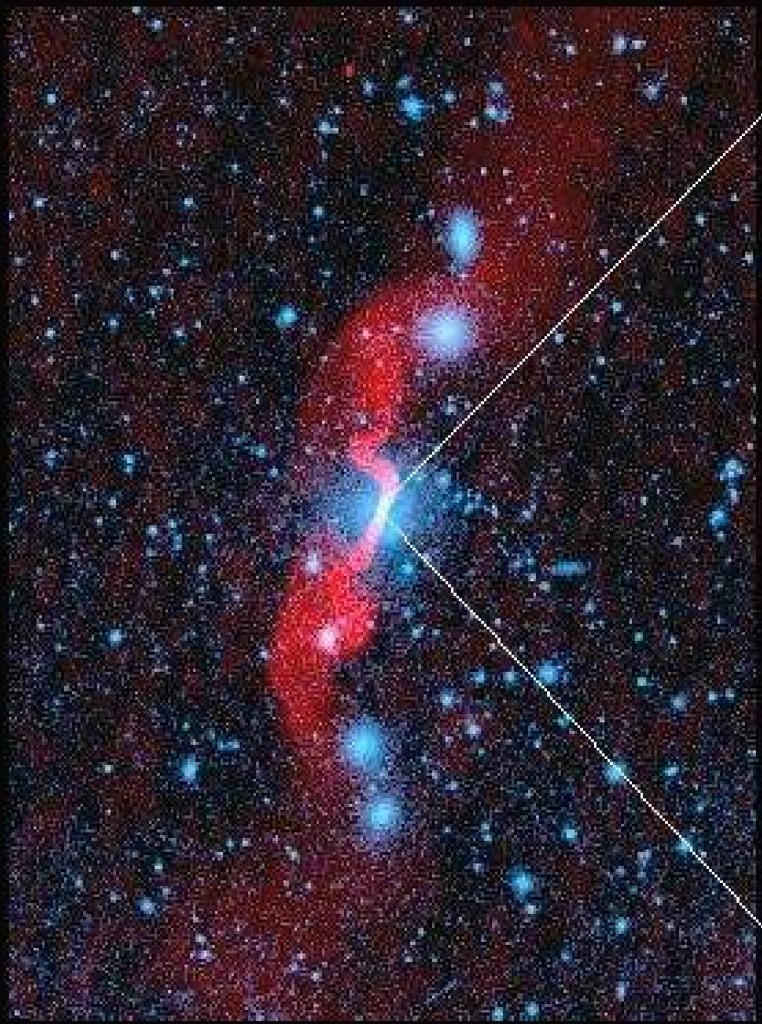
Formation of extragalactic jets from black hole accretion disk

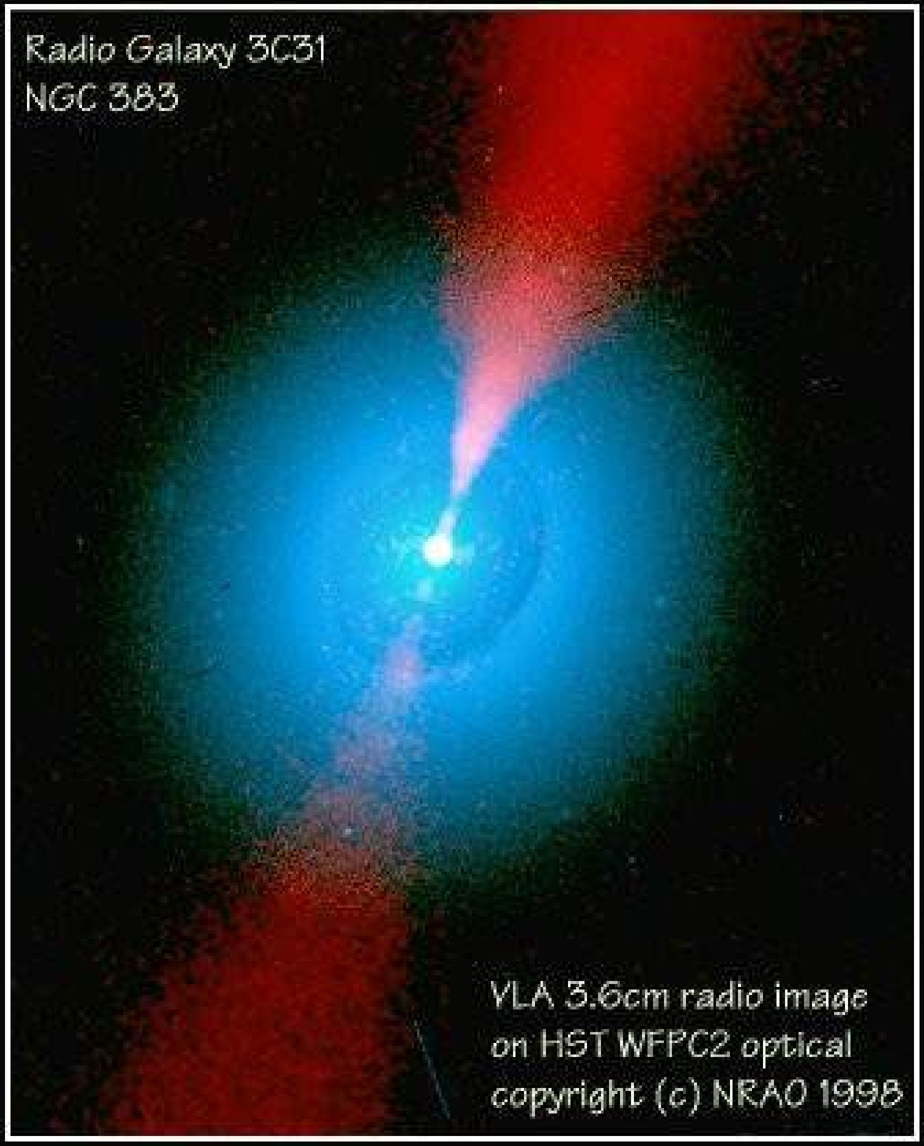


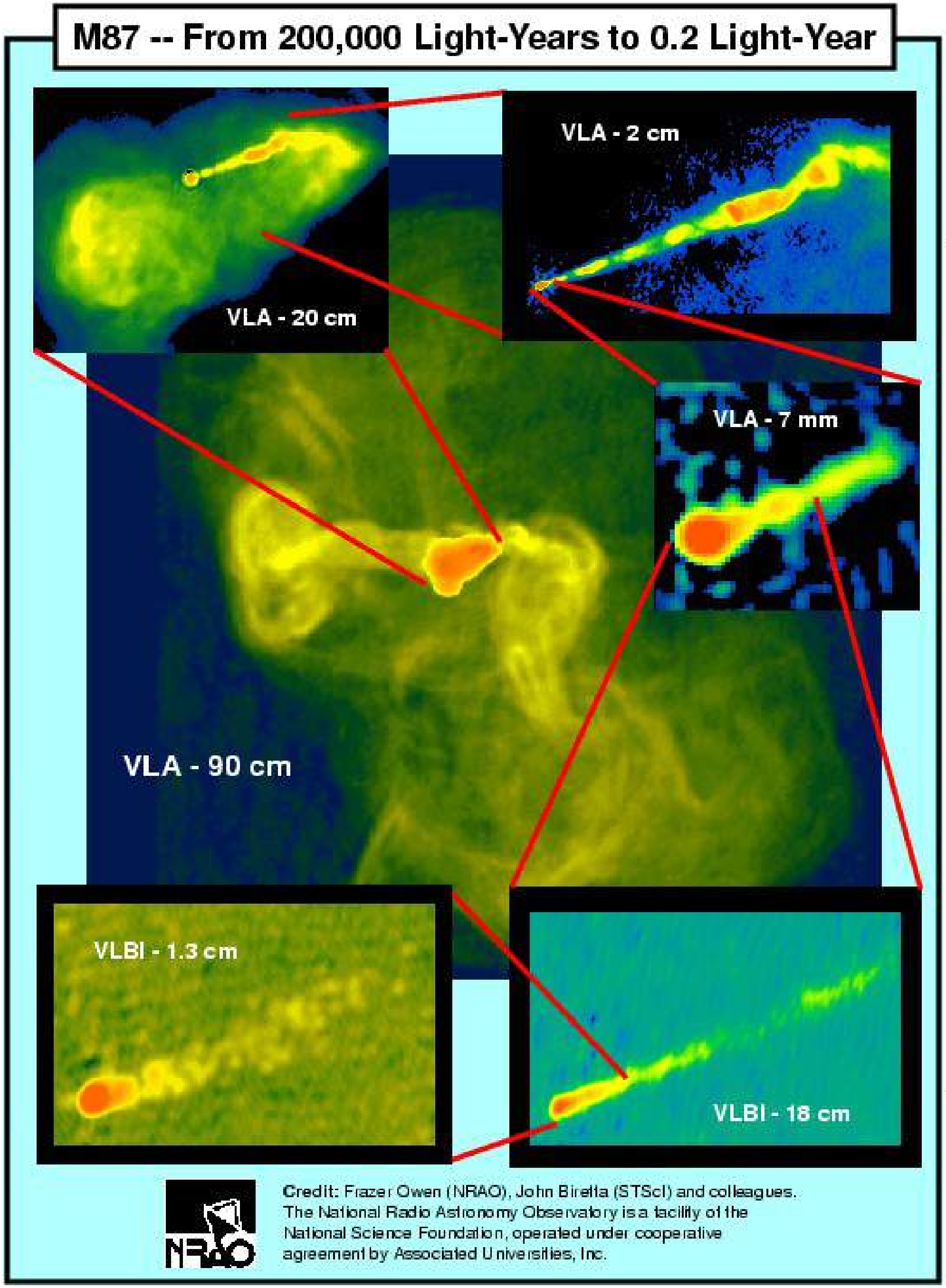

QUASAR
MICROQUASAR
Millions of Light Years
RADIO LOBE
RELATIVISTIC JET
HOST GALAXY
UV AND OPTICAL RADIATION
ACCRETION DISK (~10^9 km)
SPINNING SUPERMASSIVE BLACK HOLE
Light Years
RADIO LOBE
RELATIVISTIC JET
COMPANION STAR
X-RAY RADIATION
ACCRETION DISK (~10^3 km)
SPINNING STELLAR-MASS BLACK HOLE

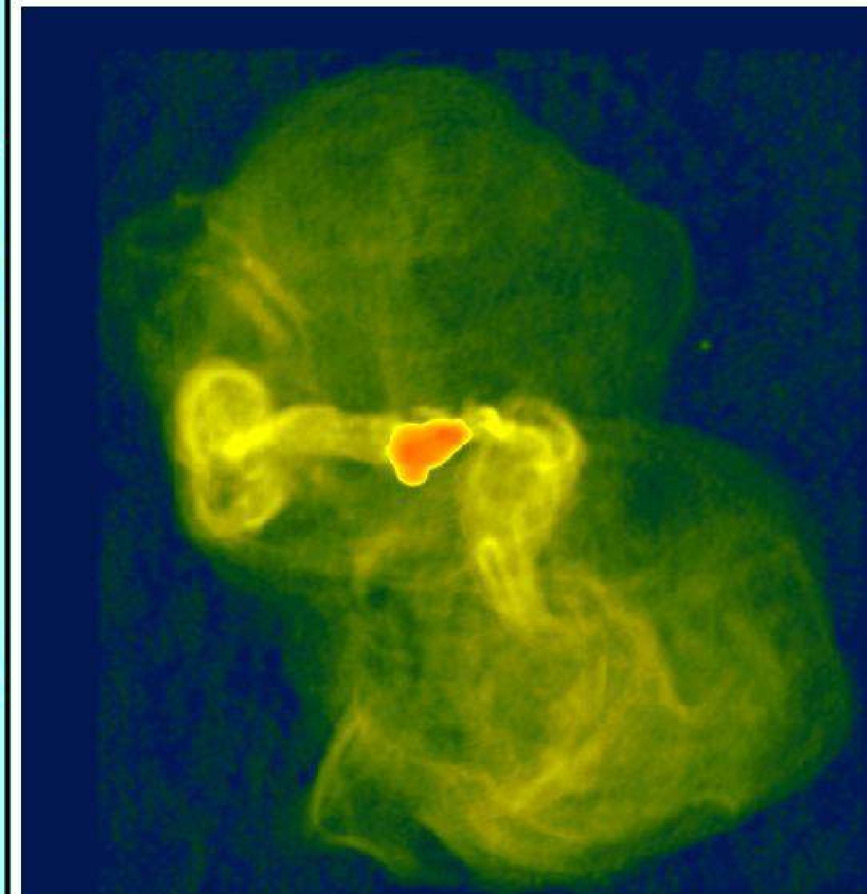

HDE 226868
Cygnus X-1
Mass Transfer
Accretion Disk

An Example: 3C31

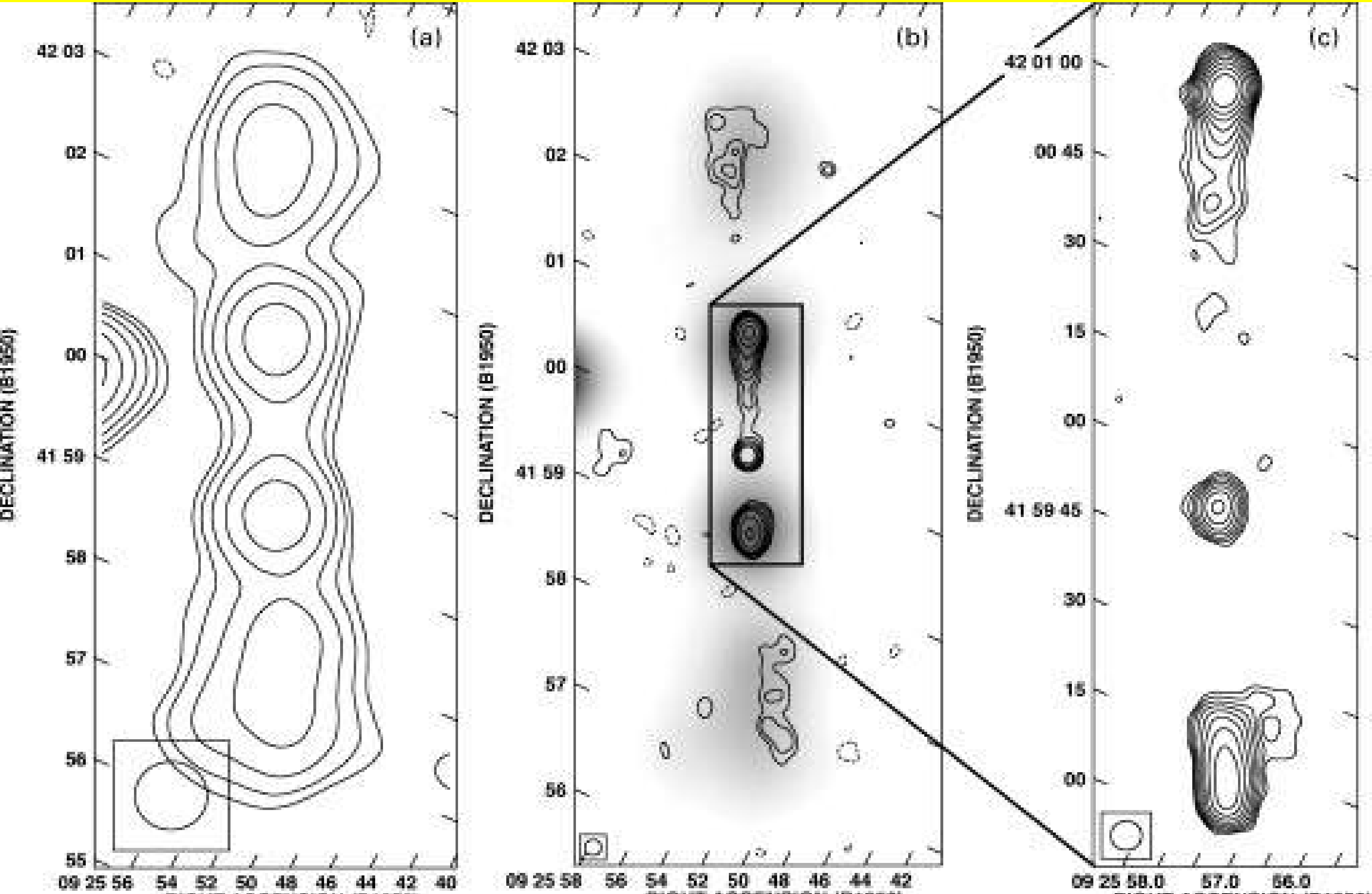




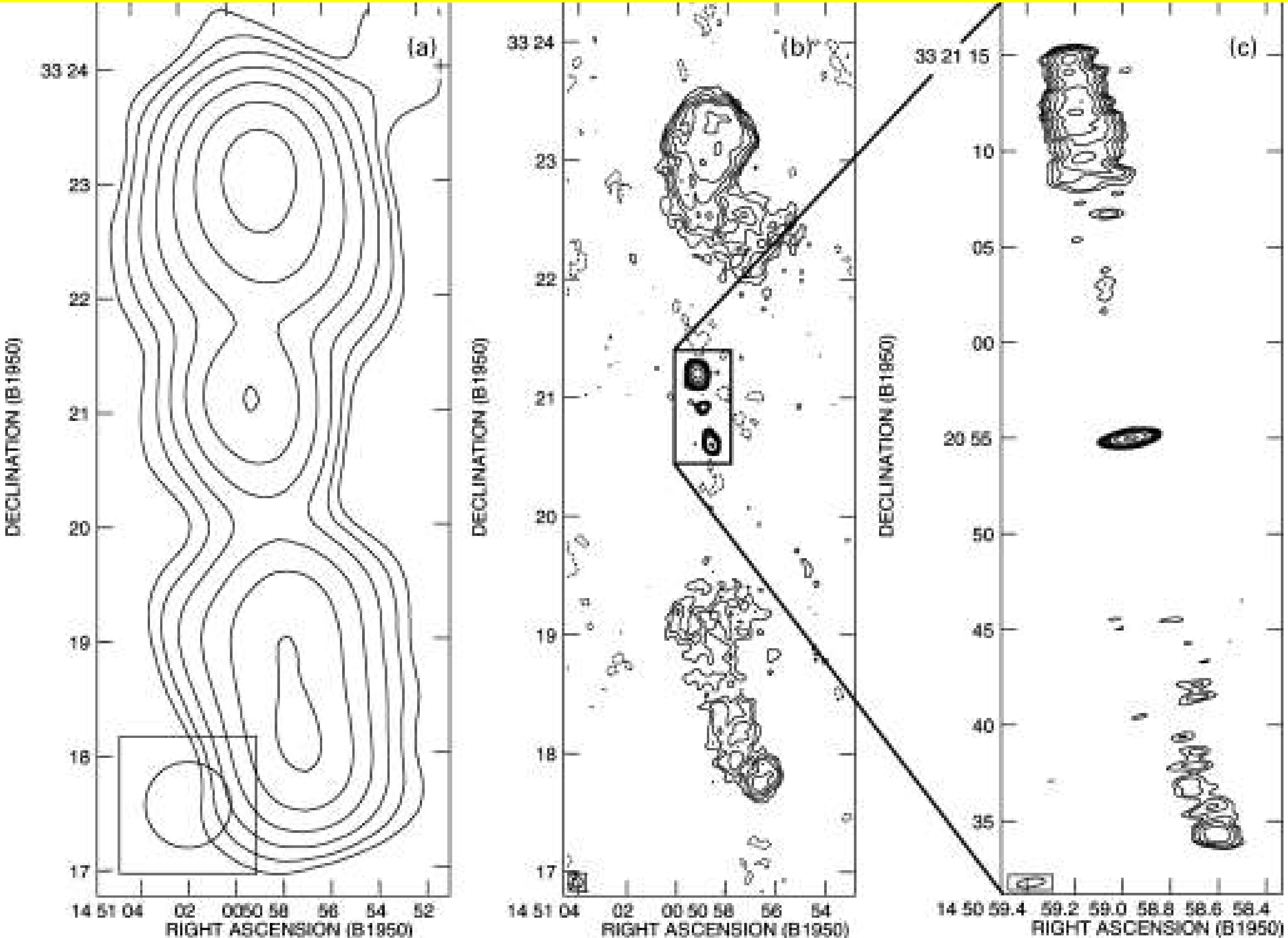

M87 -- From 200,000 Light-Years to 0.2 Light-Year
VLA - 20 cm
VLA - 2 cm
VLA - 7 mm
VLA - 90 cm
VLBI - 1.3 cm
VLBI - 18 cm
NRAO
Credit: Frazer Owen (NRAO), John Biretta (STScI) and colleagues.
The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.



Double-Double Radio Galaxies



Double-Double Radio Galaxies



What does this say?

1. The radio phenomena can stop and start

What if the jet stops are does not restart?

2. Does every AGN goes through radio phase ???

Radiation from AGNs

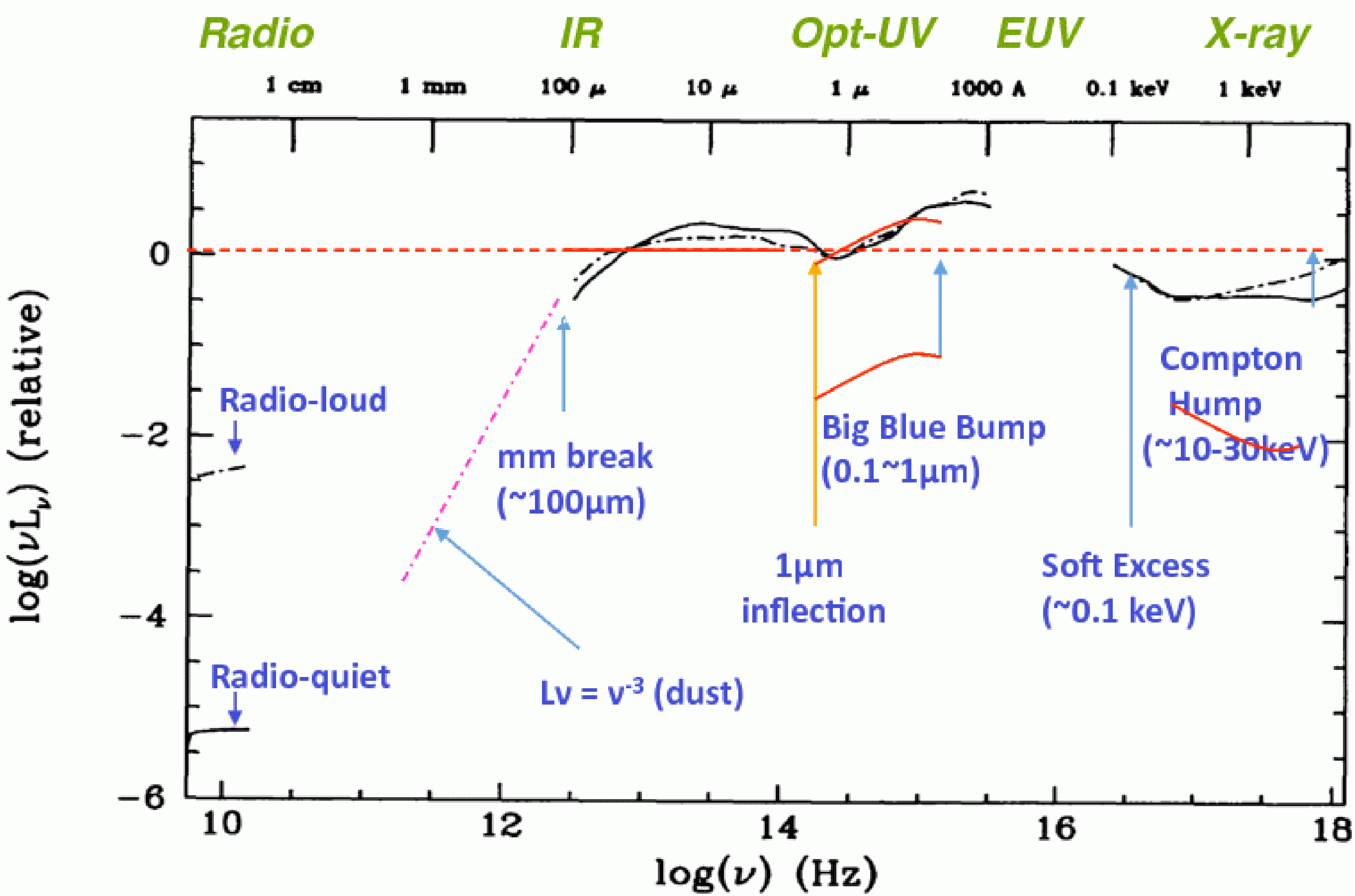
Most luminous "central engine", also drive secondary radiation (like I/C; re-radiated IR).

The spectral energy distribution of AGN is by power-law.

$F_\nu = C\nu^{-\alpha}$ OR $\nu F_\nu \approx$ Constant for $\alpha \approx 1$

Where F_ν is the observed flux per unit frequency interval, C, the proportionality constant, α is the power-law index (or the spectral index).

AGN exhibits strong emission from TeV to Radio band, a factor of 10^{20}!



Elvis et al., 1994, ApJS, 95, 1

ow is the radiation produced
(Emission Mechanism)

Continuum

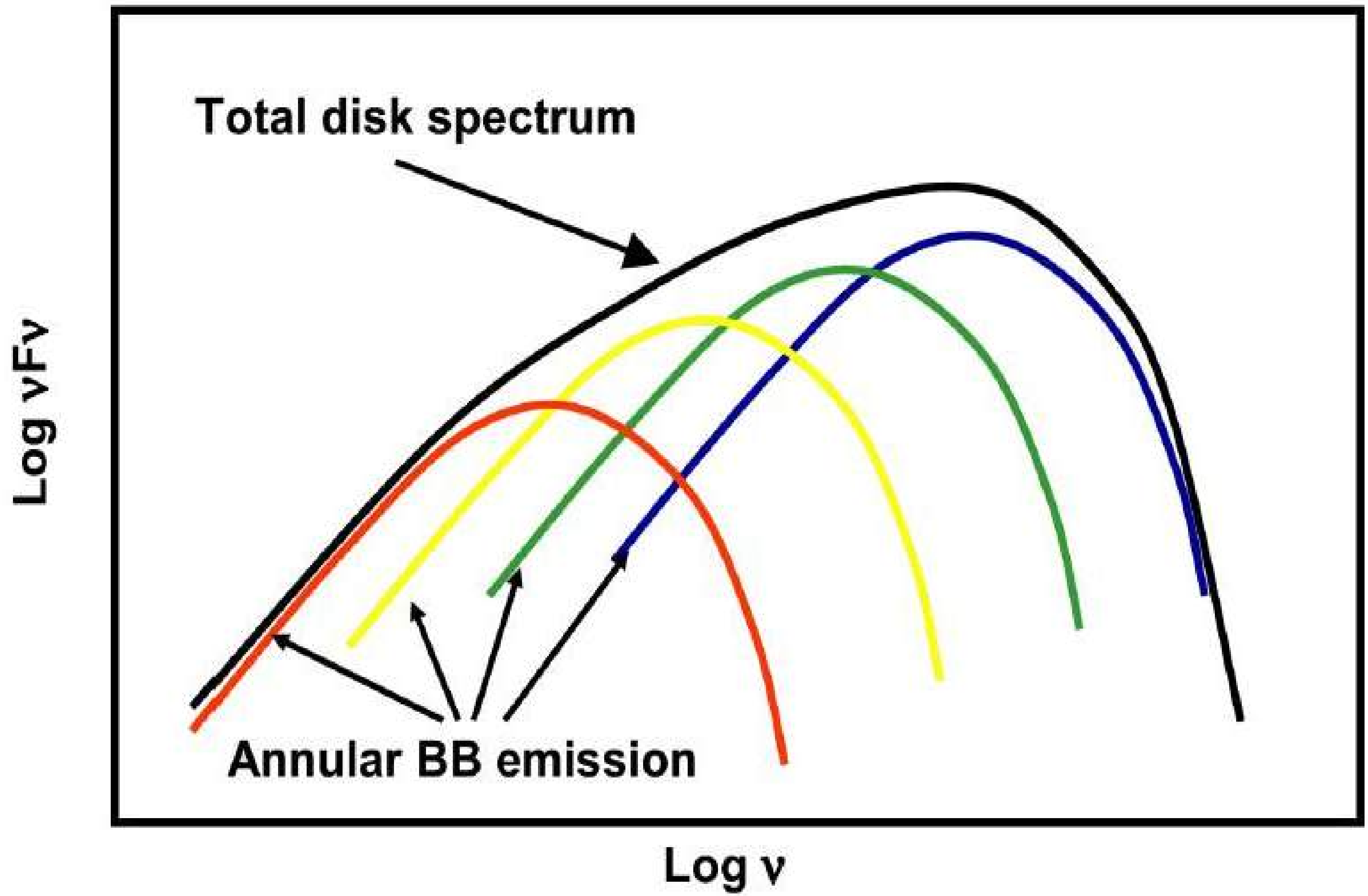
Blackbody
Synchrotron
Bremsstrahlung

Lines

21 cm
Hydrogen
Maser lines

UV-Optical Continuum

The superposition of these BB spectra will thus look like:



IR Continuum

The IR continuum can be produced by dust (thermal emission) and/or synchrotron radiation (non-thermal).

IR emission from dust grains heated by optical and UV light from the nucleus is least disputed.

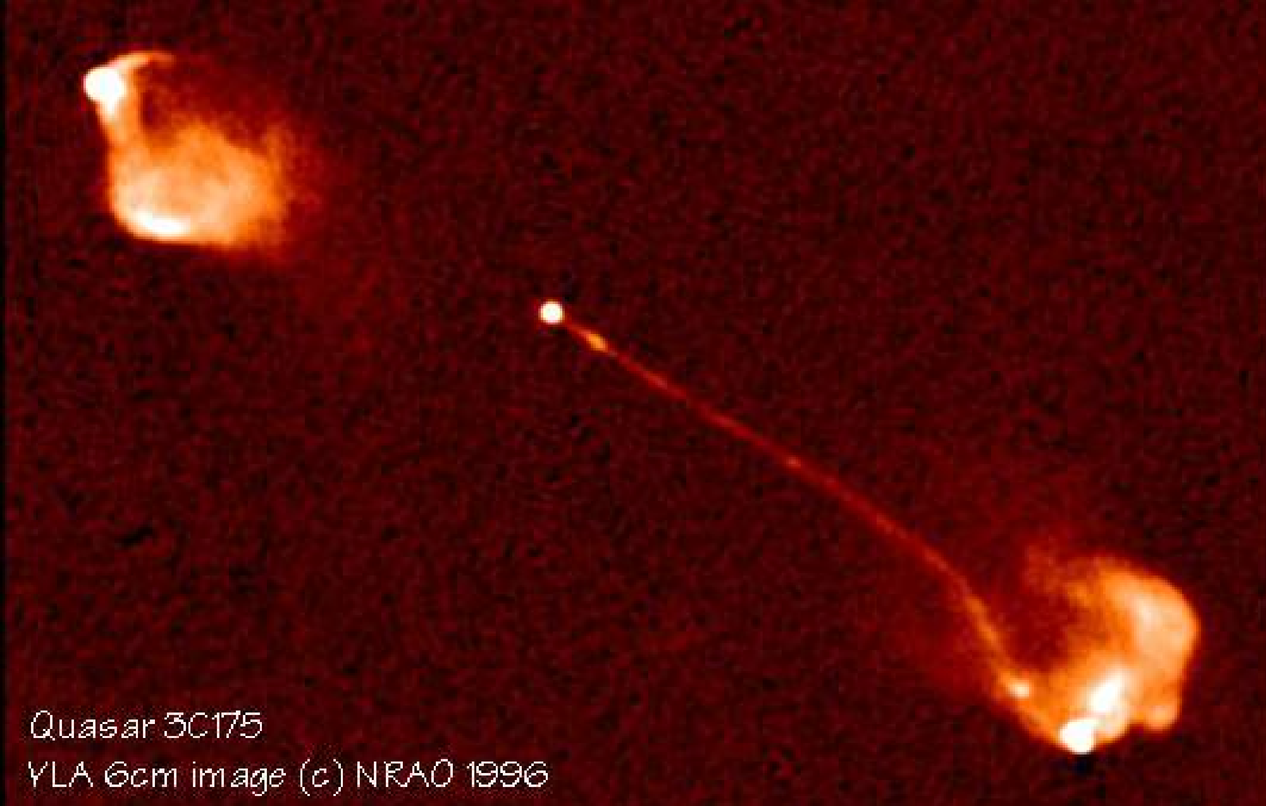
In cases of Ultra-Luminous IR Galaxies, this can go considerably up. Dust mass can be upto 10^{10} $M_{\odot}$

In radio loud AGNs, some fraction of IR was also found to be due to synchrotron radiation from jets.

Radio Continuum

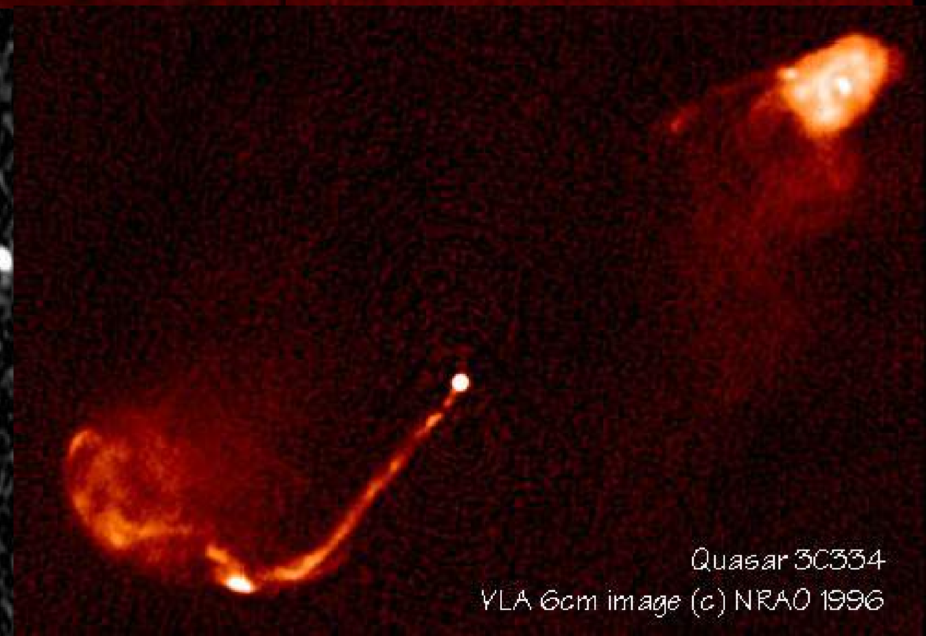
Strong radio emission (radio luminosity comparable or higher than optical luminosity) is seen from about 10% of AGNs.

The most important difference is that the radio emission is well beyond the central engine, sometimes as far as a few million light years from the engine.

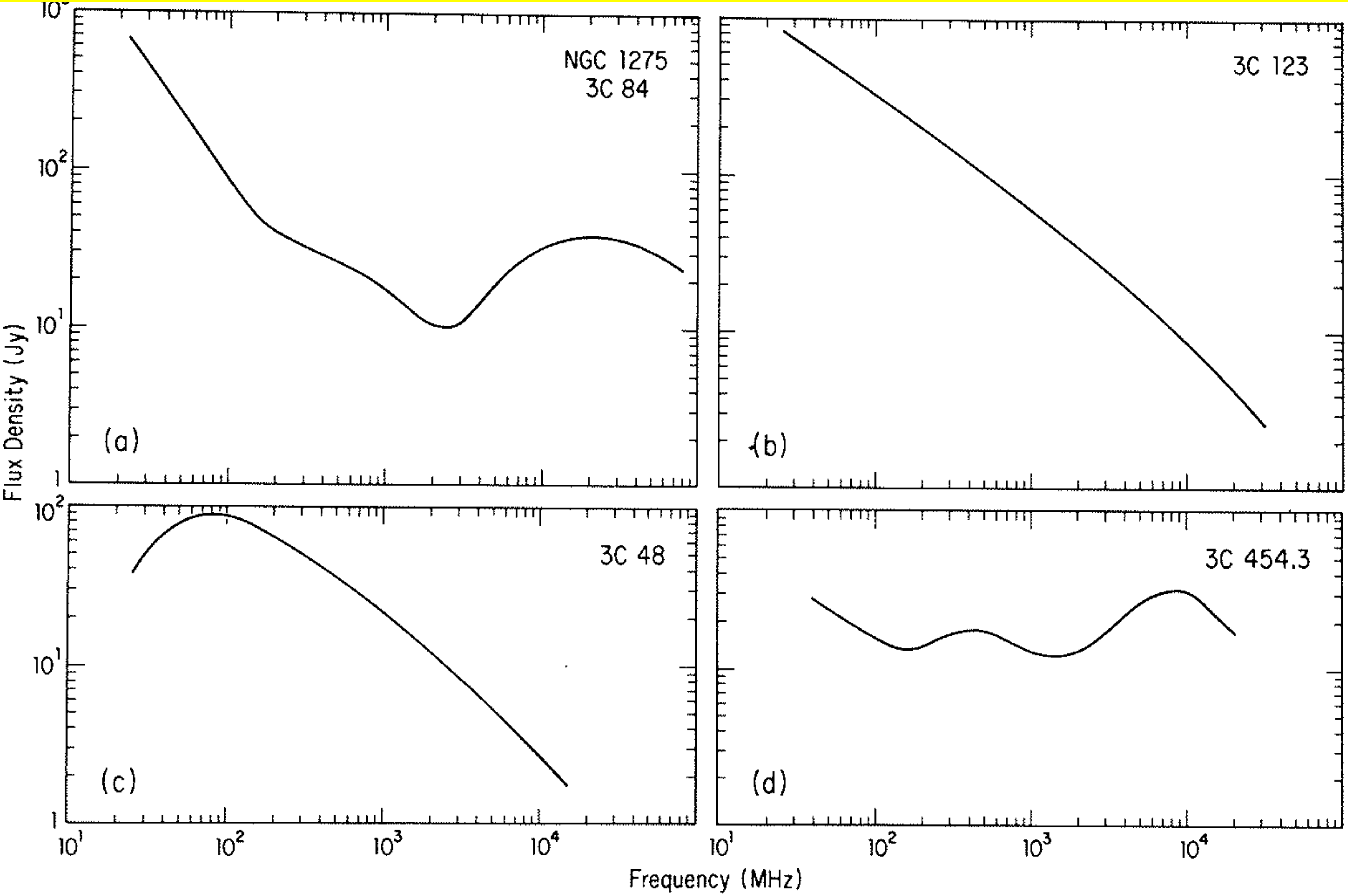


The largest Radio Galaxy

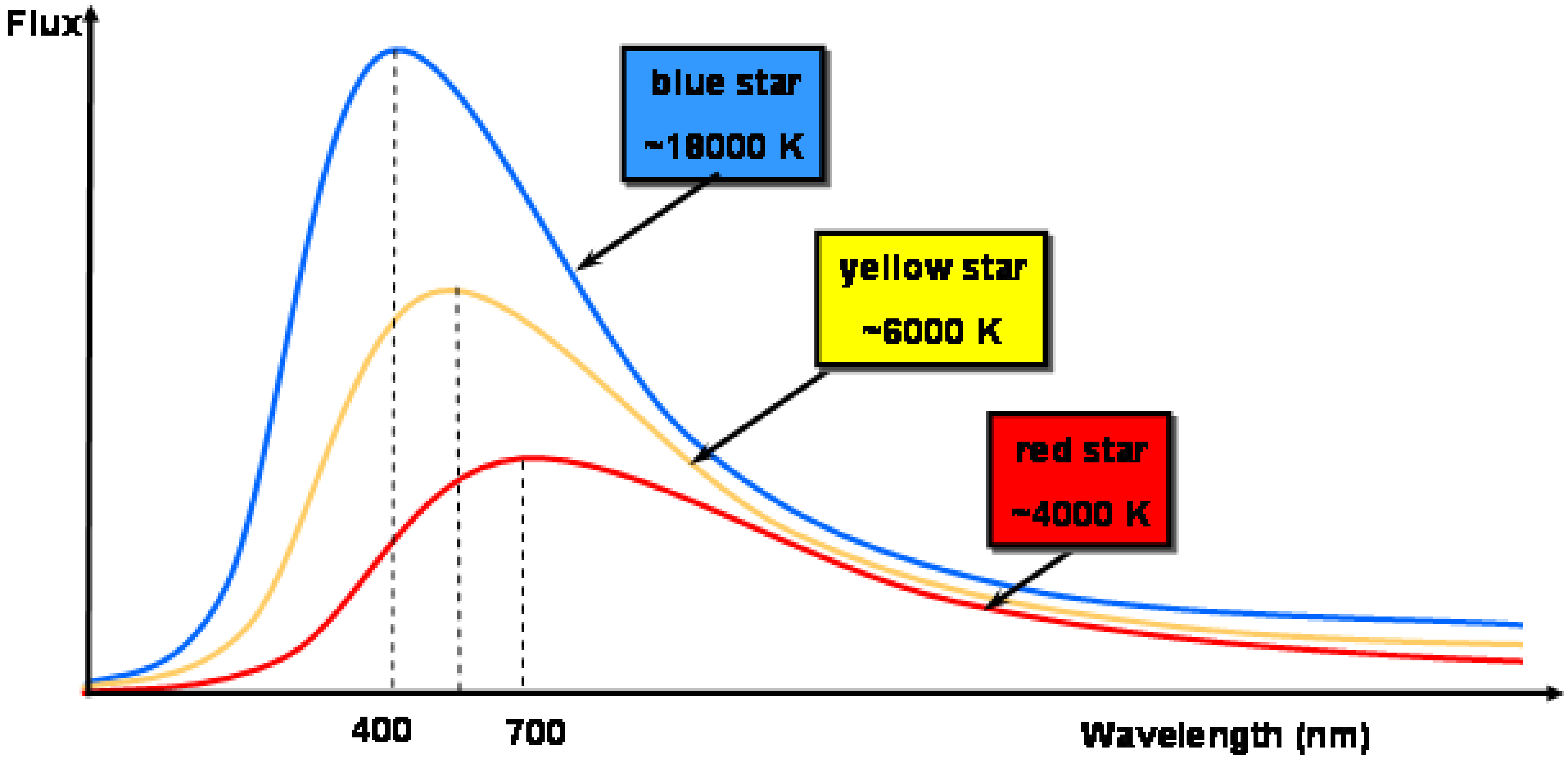
≥ 5 Mpc!



Spectra (flux vs frequency)

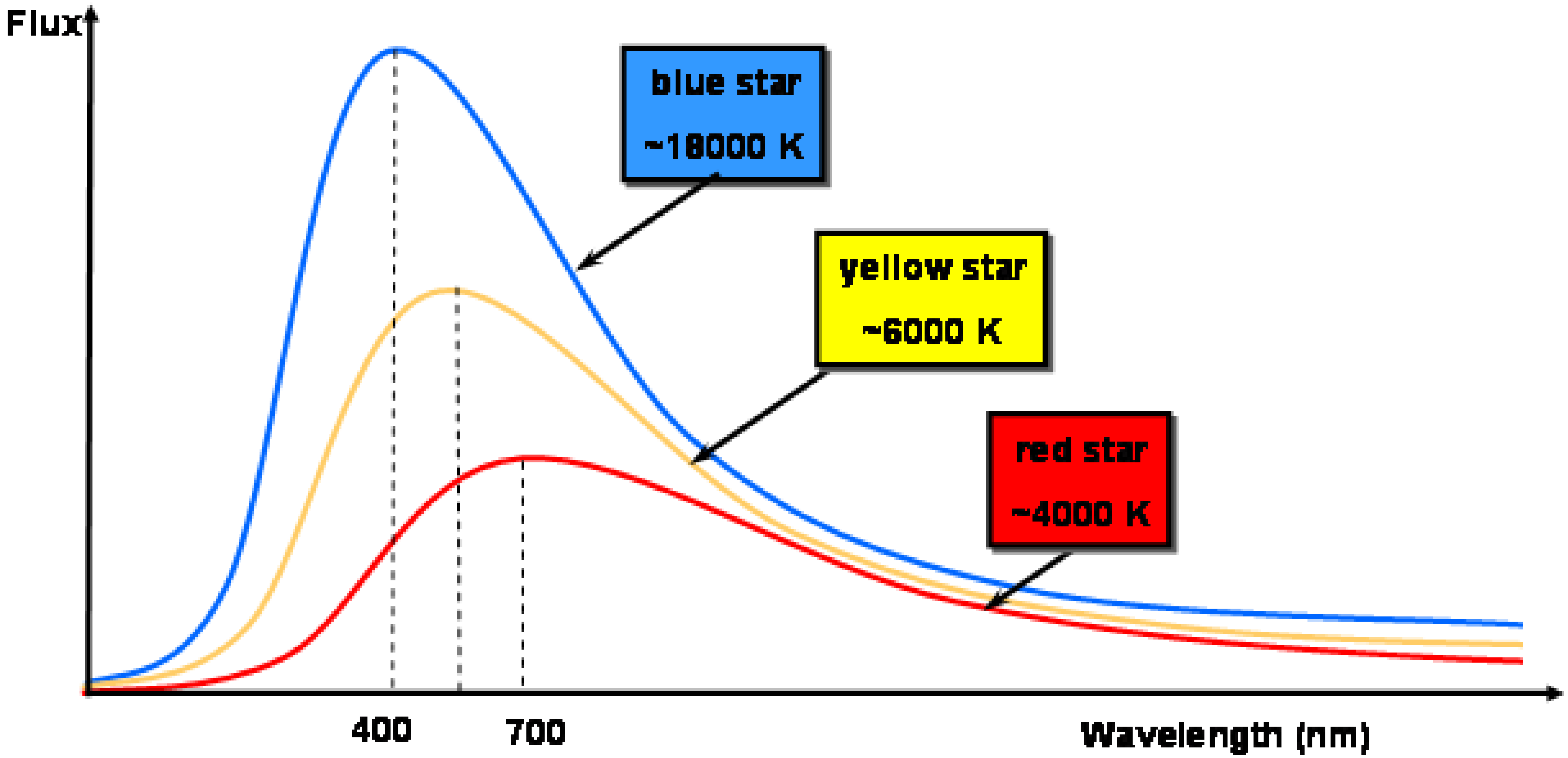


Blackbody Radiation



$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Blackbody Radiation



OK for UV and Optical.
For RADIO, the Temp required is unrealistic; increase in power at

$$I(\nu, T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Bremsstrahlung Radiation

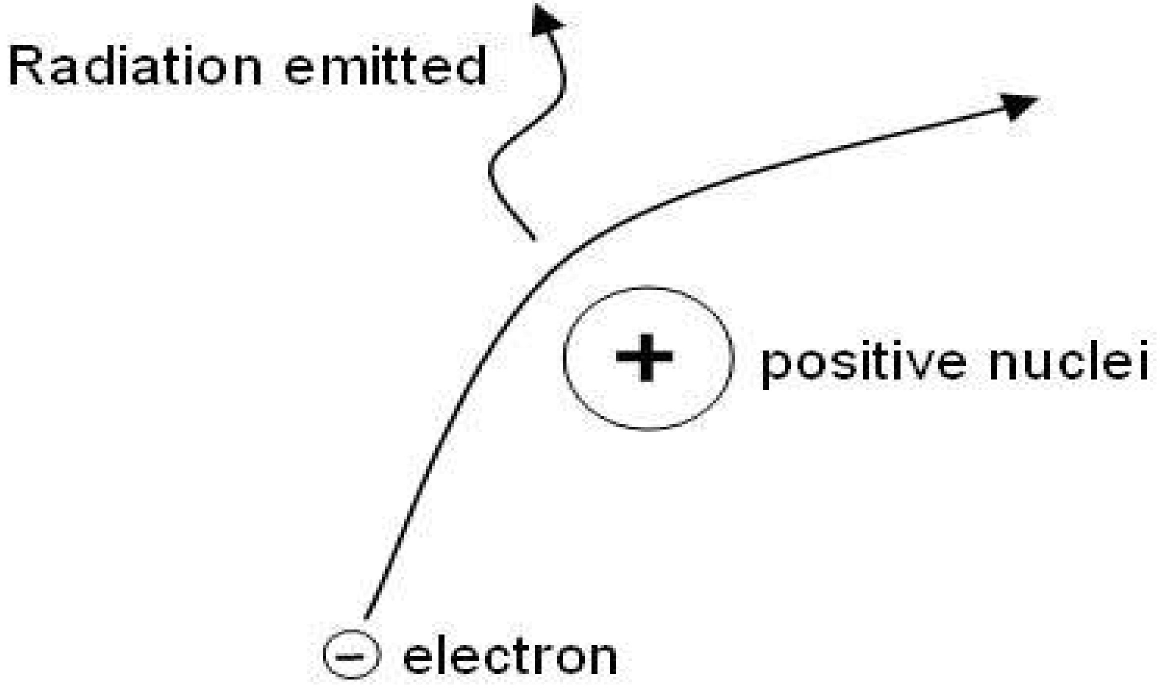
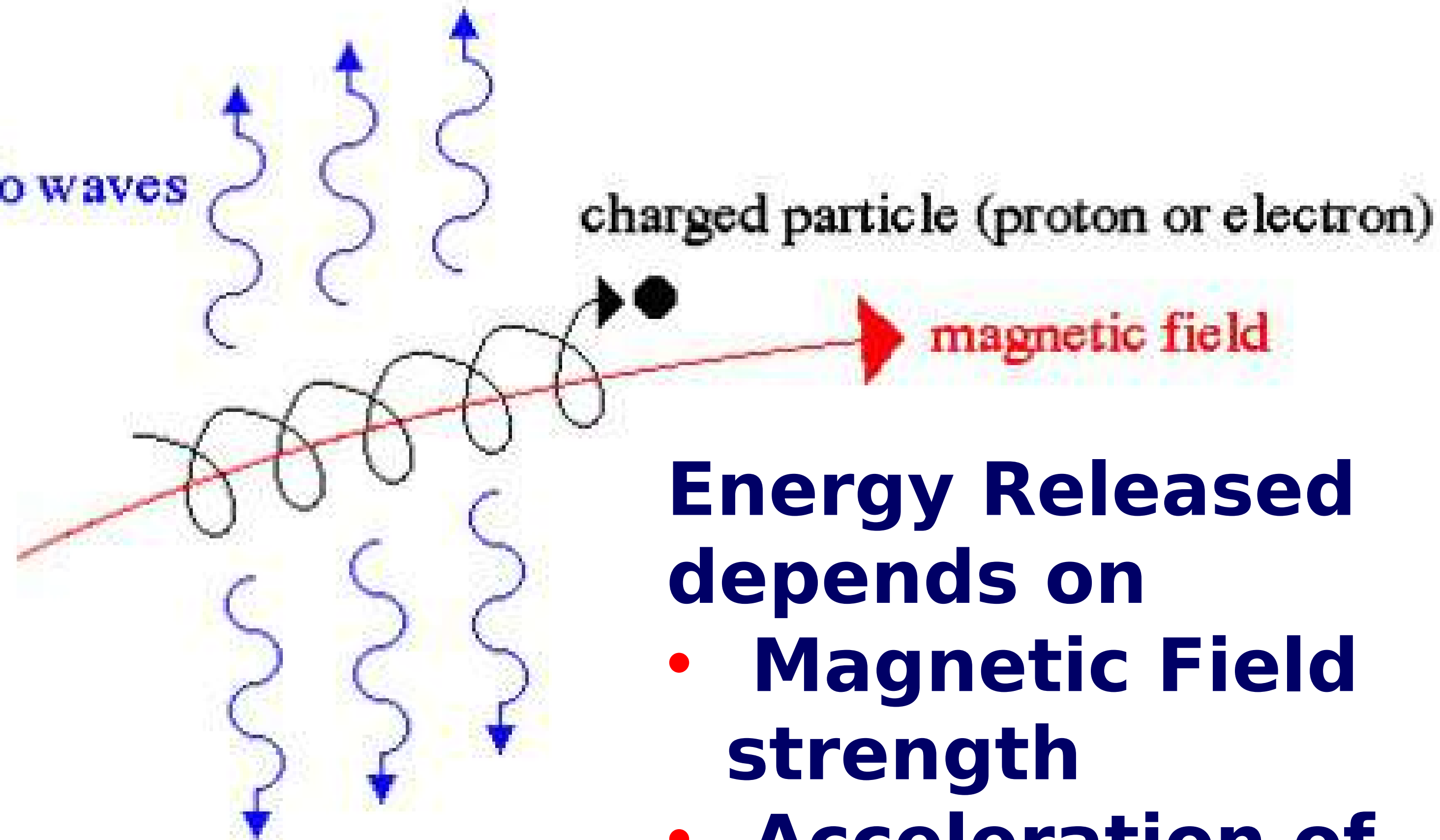


Figure 1: Bremsstrahlung (or 'braking') radiation is emitted when the path of a charged particle such as an electron is deviated by another charged particle. The acceleration of the electron causes it to emit a photon of light with an energy indicative of the electrons kinetic energy.

Possible in certain special cases, but spectral shape not steep. Require dense clouds of ionized

Synchrotron

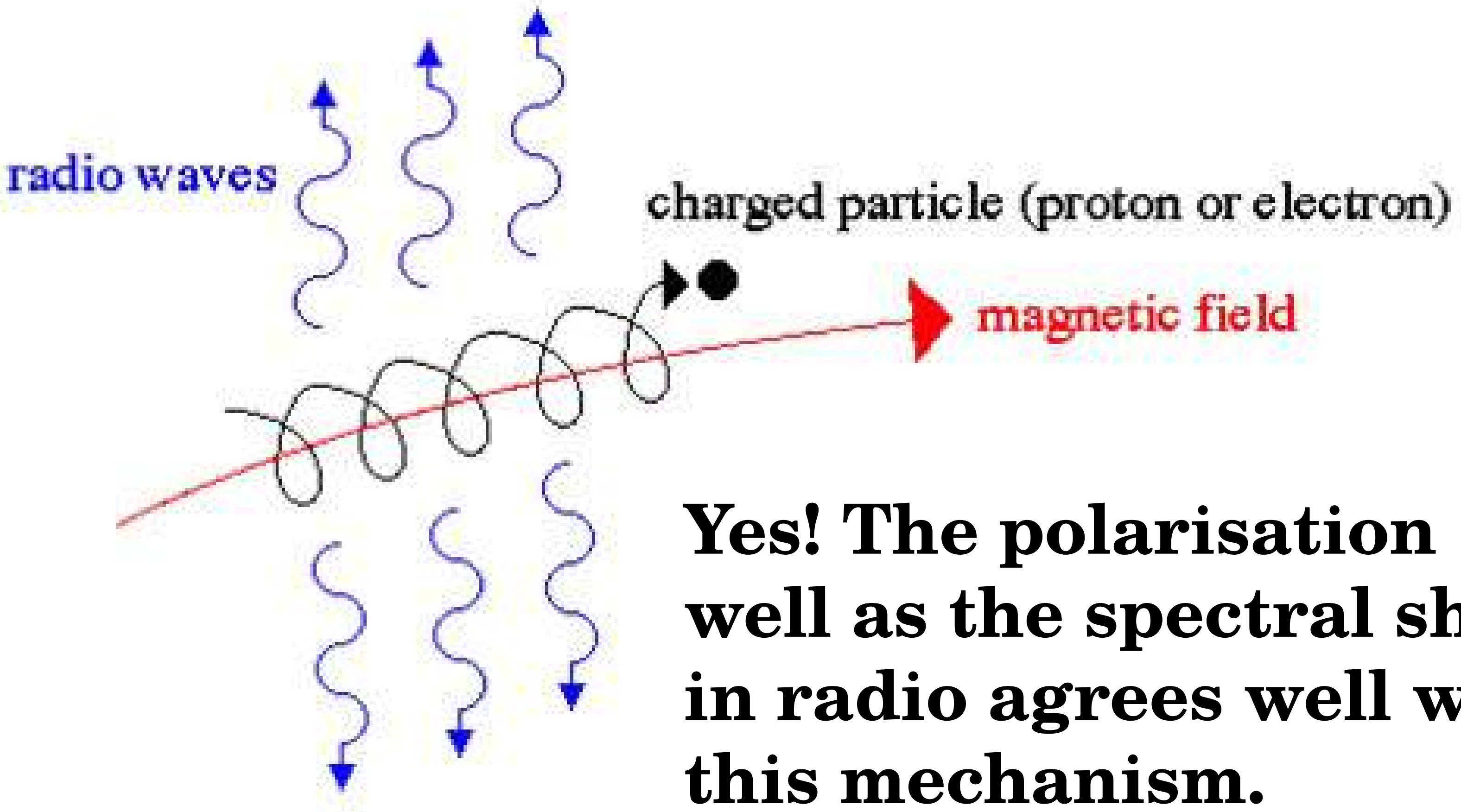


Energy Released depends on

- **Magnetic Field strength**
- **Acceleration of Electron**
- **Electron Energy Distribution**

synchrontron radiation occurs when a charged particle encounters a strong magnetic field – the particle is accelerated along a spiral path following the magnetic field and emitting radio waves in the process – the result is a distinct radio signature that reveals the strength of the magnetic field

Synchrotron

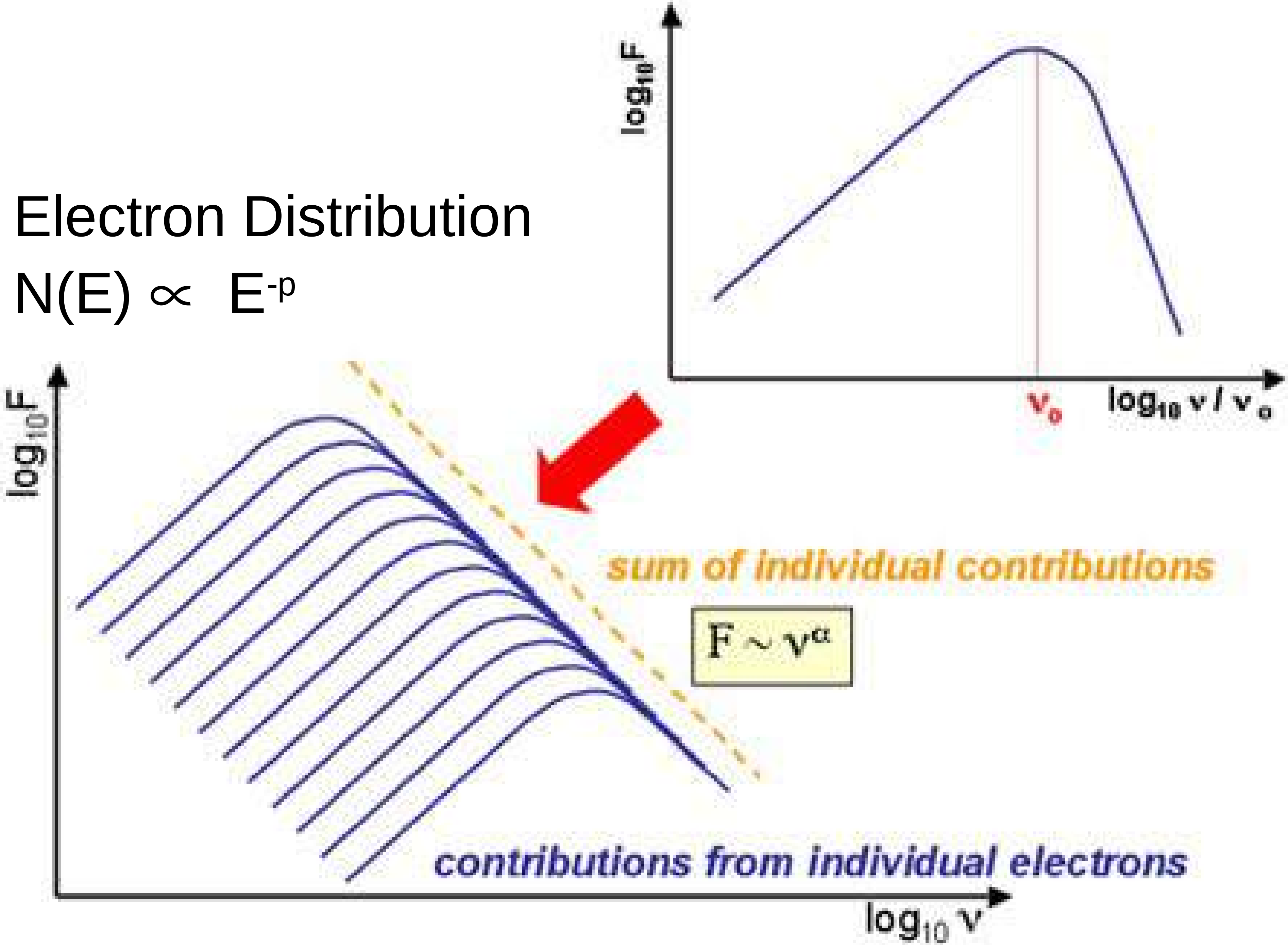


Yes! The polarisation as well as the spectral shape in radio agrees well with this mechanism.

synchrontron radiation occurs when a charged particle encounters a strong magnetic field – the particle is accelerated along a spiral path following the magnetic field and emitting radio waves in the process – the result is a distinct radio signature that reveals the strength of the magnetic field

Electron Distribution

$N(E) \propto E^{-p}$



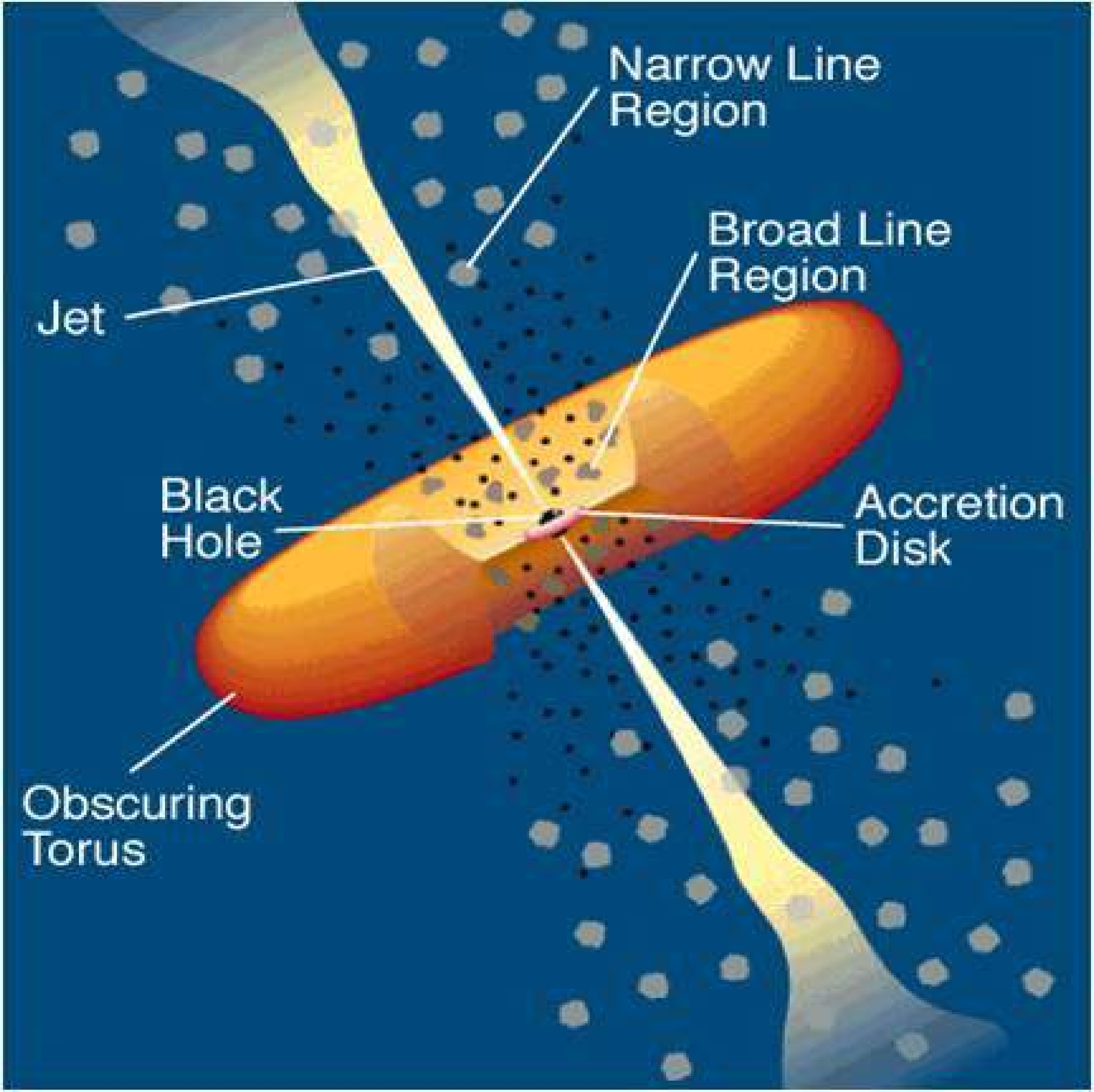
Synchrotron Self Absorption..

For every emission process, there is a corresponding absorption process – For synchrotron, is "synchrotron self-absorption".

The "brightness temperature" of synchrotron source is obtained by equating (S/Ω)= 2kTb/λ2. The brightness temperature is the equivalent BB temperature which will produce the observed brightness (Rayleight-Jeans limit).

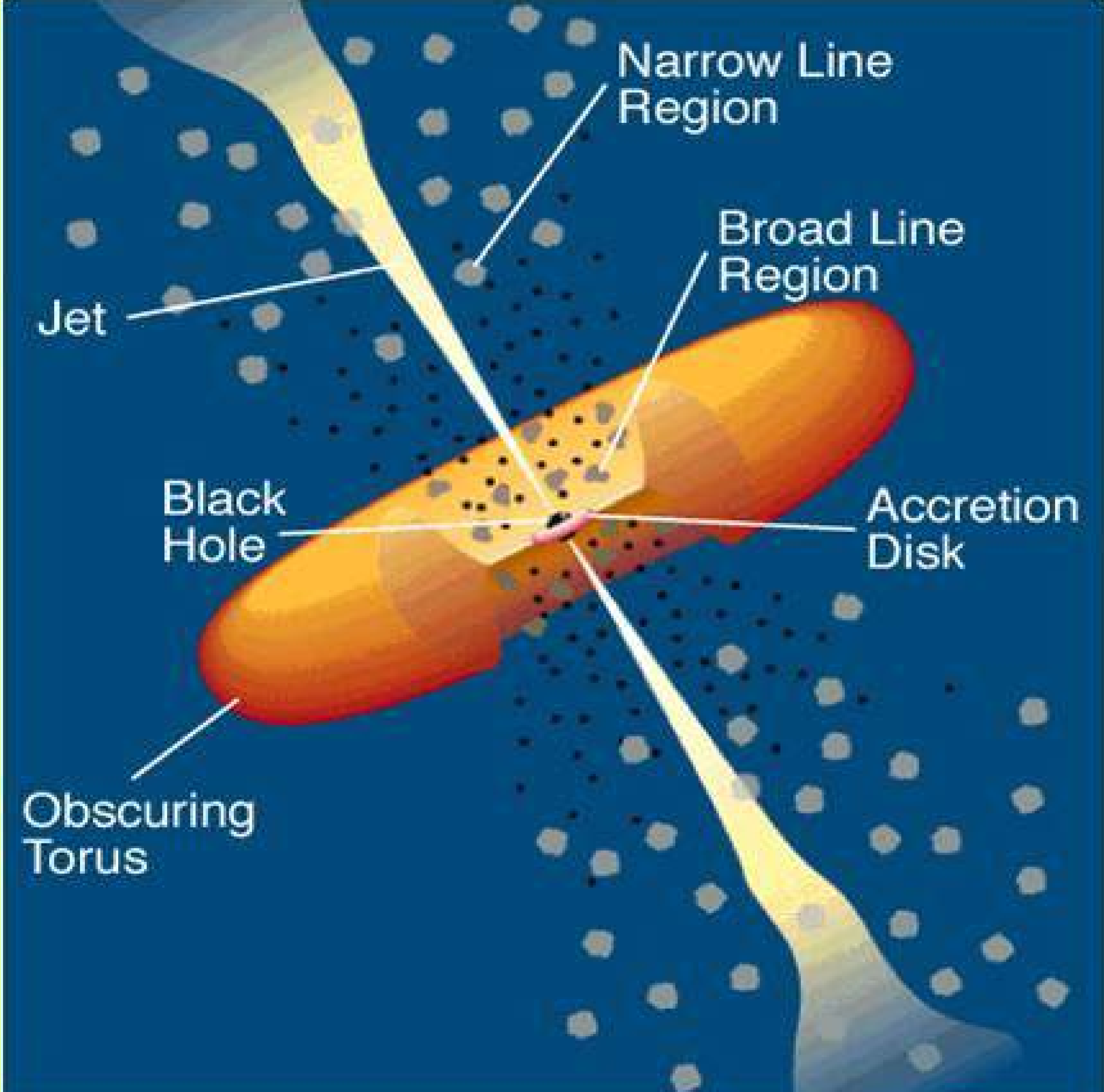
At low frequencies, the Tb may approach kinetic temperature, and absorption will occur.

But, N(E)dE ∝ E-p, which is NOT Maxwellian.

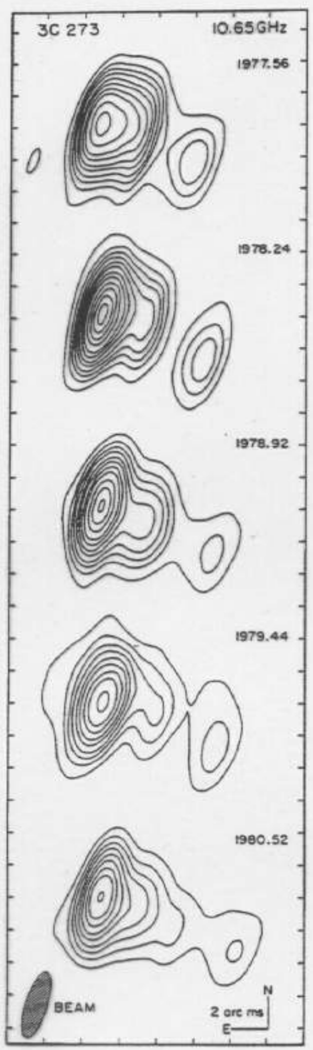

Narrow Line
Region
Broad Line
Region
Jet
Black
Hole
Accretion
Disk
Obscuring
Torus

Unified Scheme

How about seeing this object in different angles?



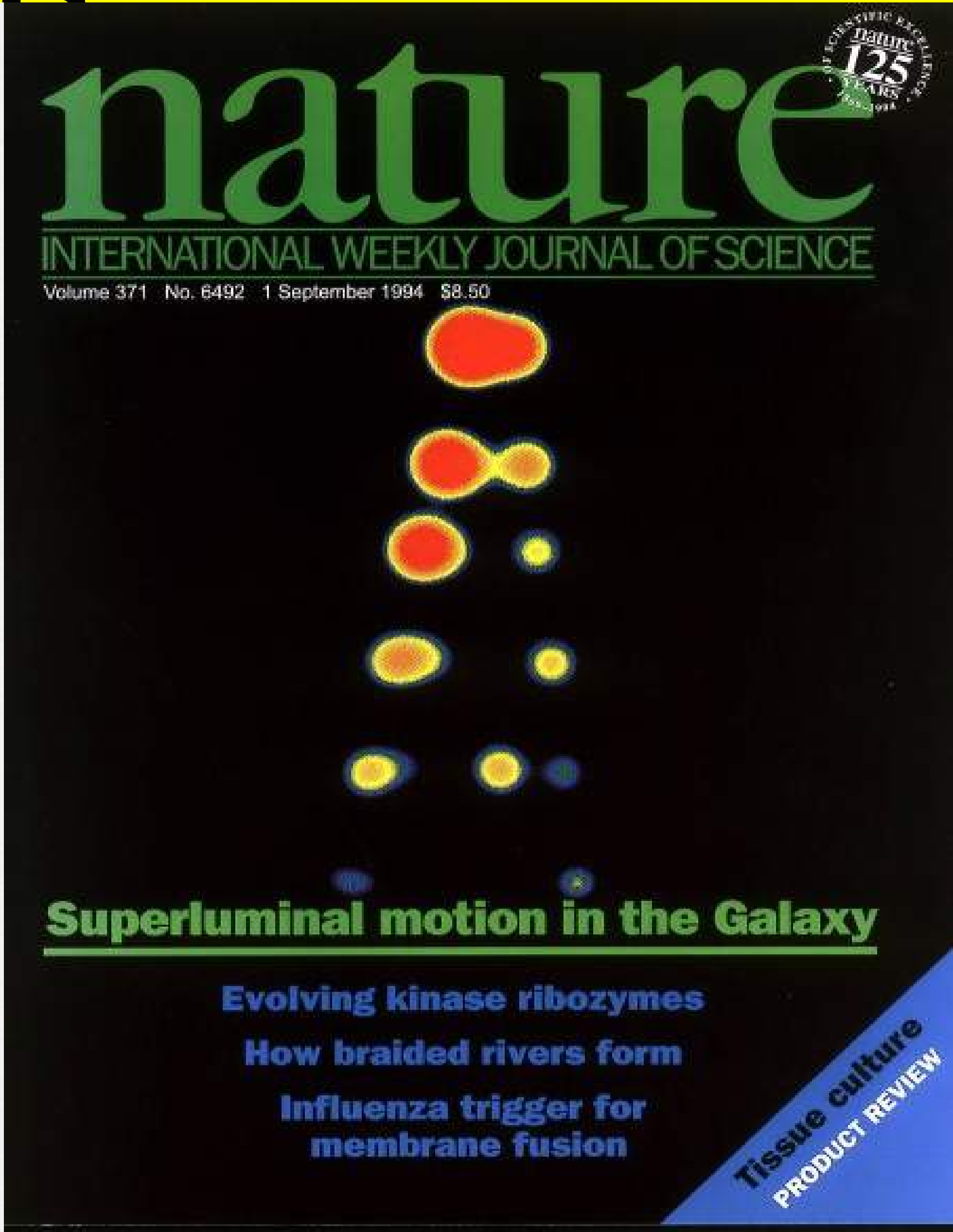
Faster than light (super-luminal) motions

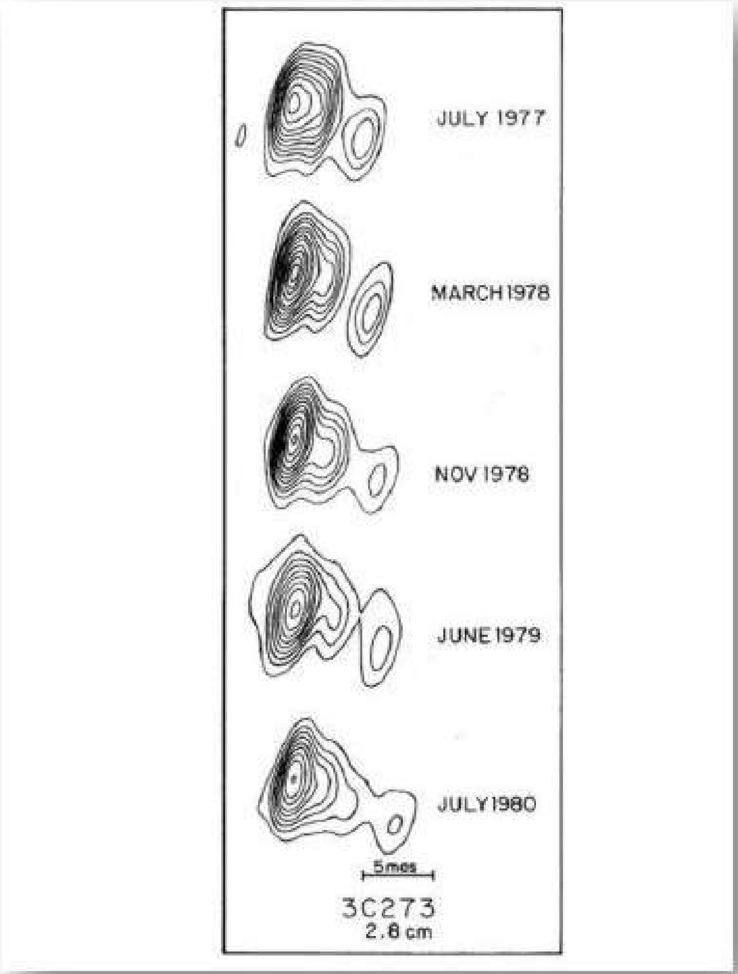


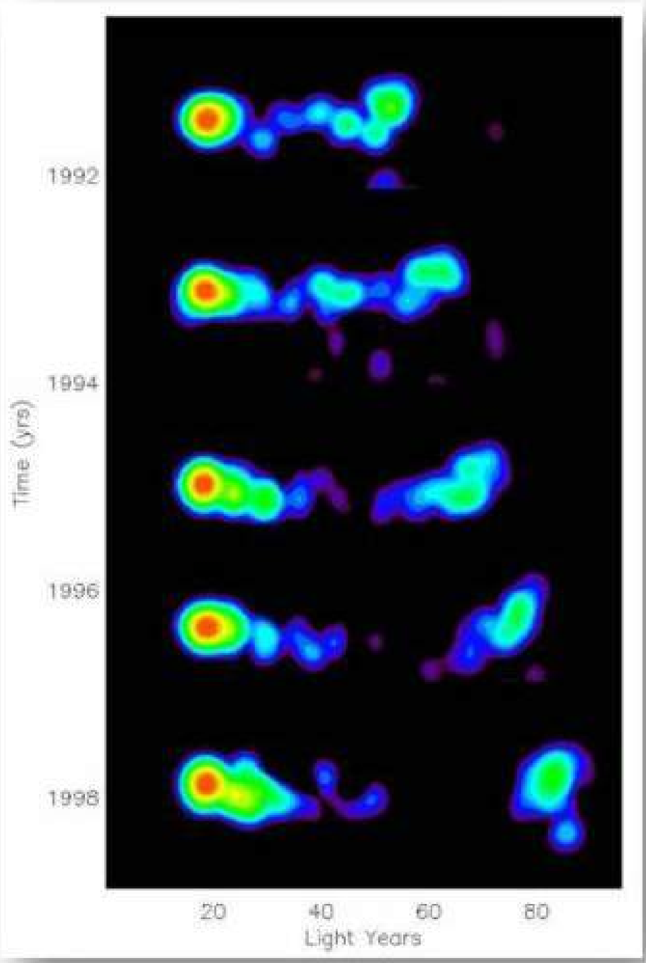
Superluminal Motion

$V_{app} = (9.6 \pm 0.8)\,c$

Fig. 4.5. VLBI maps at a frequency of 10.65 GHz of the quasar 3C 273 ($z = 0.158$) made at five different epochs, showing apparent 'superluminal' (i.e., faster than light) expansion of the source (from Pearson *et al.* 1981). Figure courtesy of T. J. Pearson and the California Institute of Technology. Reproduced by permission from *Nature*, Vol. 290, pp. 365–367. Copyright 1981 Macmillan Journals Limited.







3C273 V ≈ 8c

3C 279 V ≈ 8c

Faster than light (super-luminal) motions

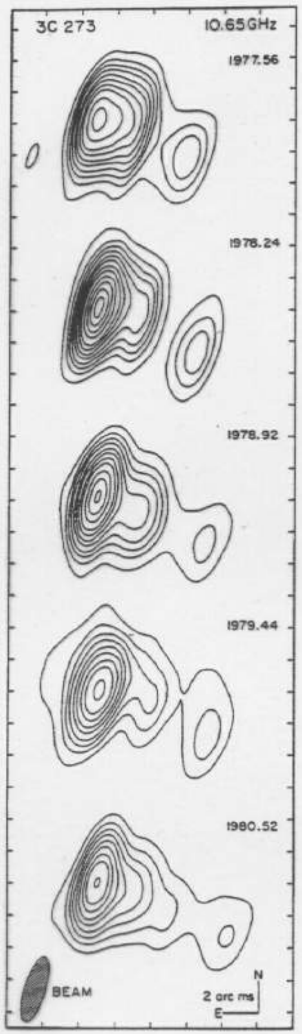
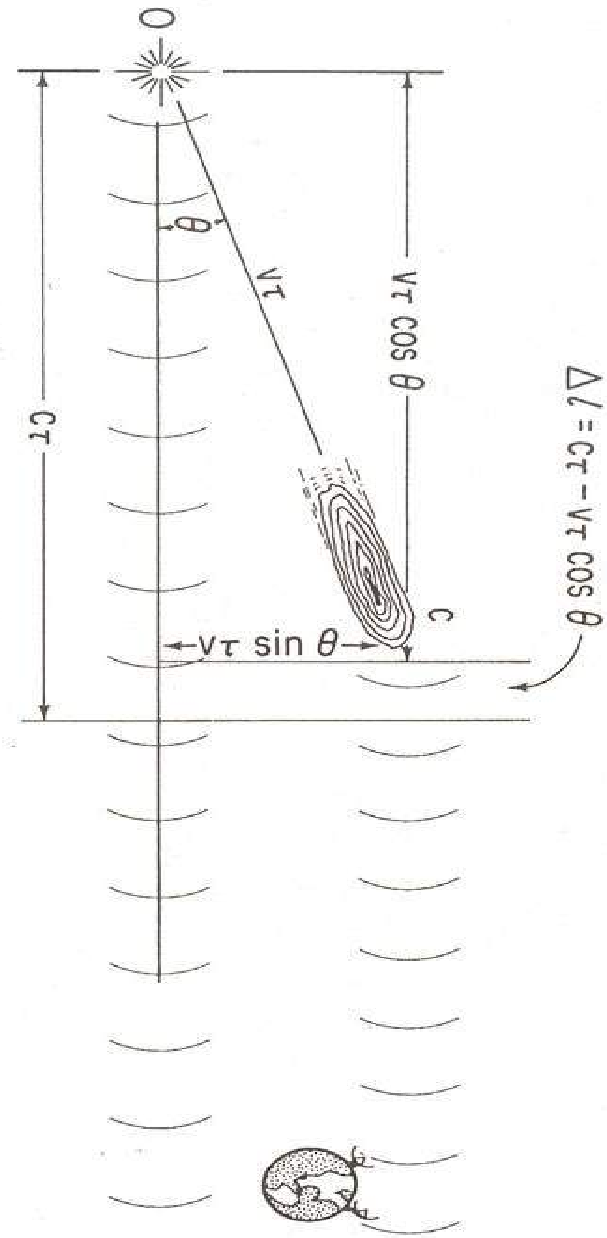


Fig. 4.5. VLBI maps at a frequency of 10.65 GHz of the quasar 3C 273 ($z = 0.158$) made at five different epochs, showing apparent 'superluminal' (i.e., faster than light) expansion of the source (from Pearson *et al.* 1981). Figure courtesy of T. J. Pearson and the California Institute of Technology. Reproduced by permission from *Nature*, Vol. 290, pp. 365–367. Copyright 1981 Macmillan Journals Limited.

Superluminal Motion

$$V_{app} = (9.6 \pm 0.8)\, c$$

$$v_a = \frac{v \sin\theta}{1 - \beta \cos\theta}$$



Summary

- Active Galaxies are subset among galaxies, exhibiting highly energetic phenomena at the center.
- Black-hole OR ultra-compact energy source is needed to explain this phenomena.
- Strong radiation is seen across the EM spectrum.
- AGNs are excellent tools to probe early universe
- The objects attain gigantic scales in

Looking for distant AGNs

When did the universe born?

When did the FIRST star/galaxy born?

When did the FIRST AGN born?

Were they different than our neighbors?

How to detect them?

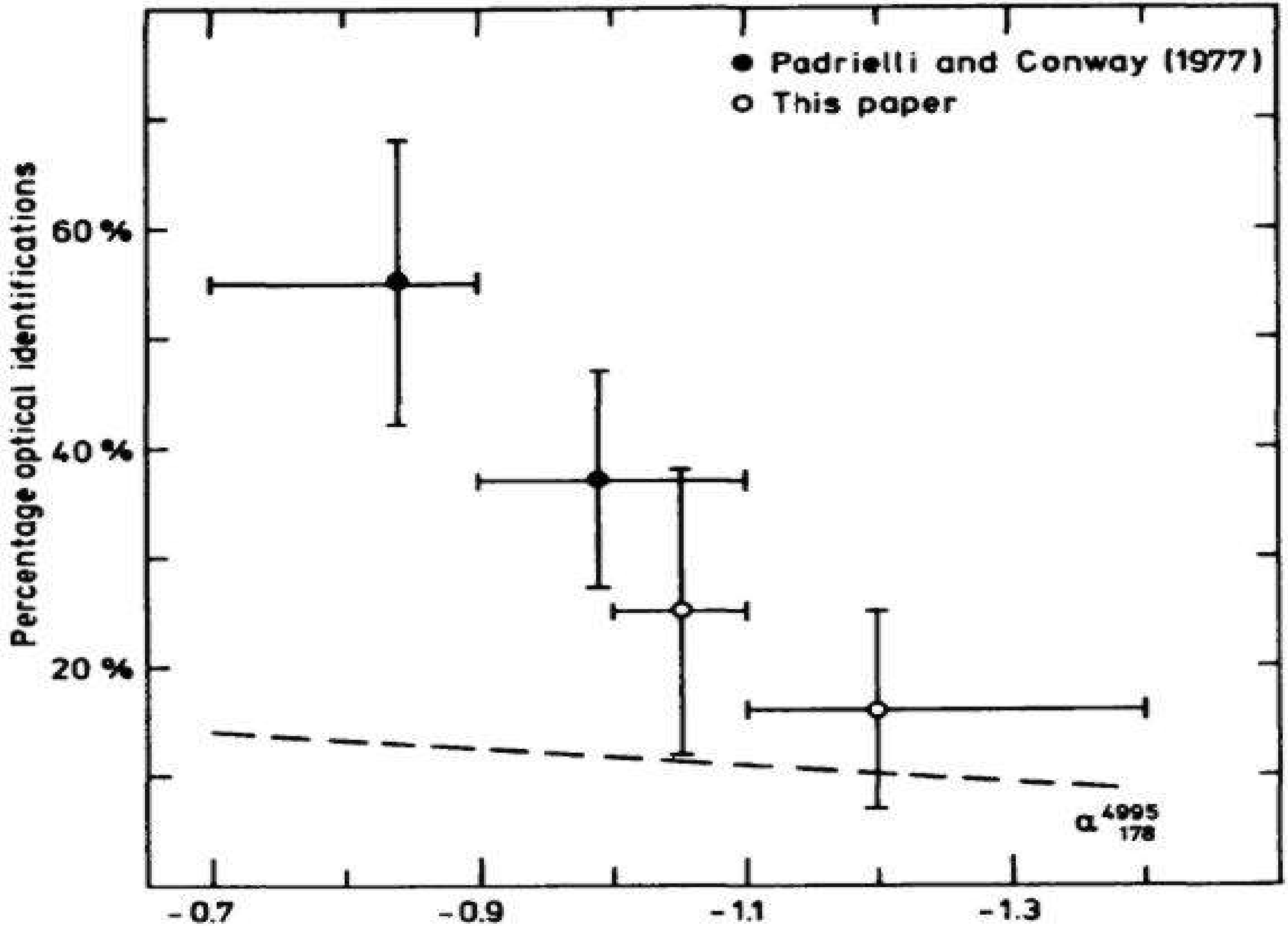
Radio Advantage: Dust obscuration not an issue

The AGN in host galaxy has strong emission lines which makes it easier to get redshift

The hosts are always **massive** ellipticals

Optical identification of RGs

- *It has been first noticed in early 80's that the fraction of 3C radio sources that can be optically identified are* ***<u>3 times less</u>*** *for those with radio spectral index steeper than 1 (stronger at lower radio frequencies).*



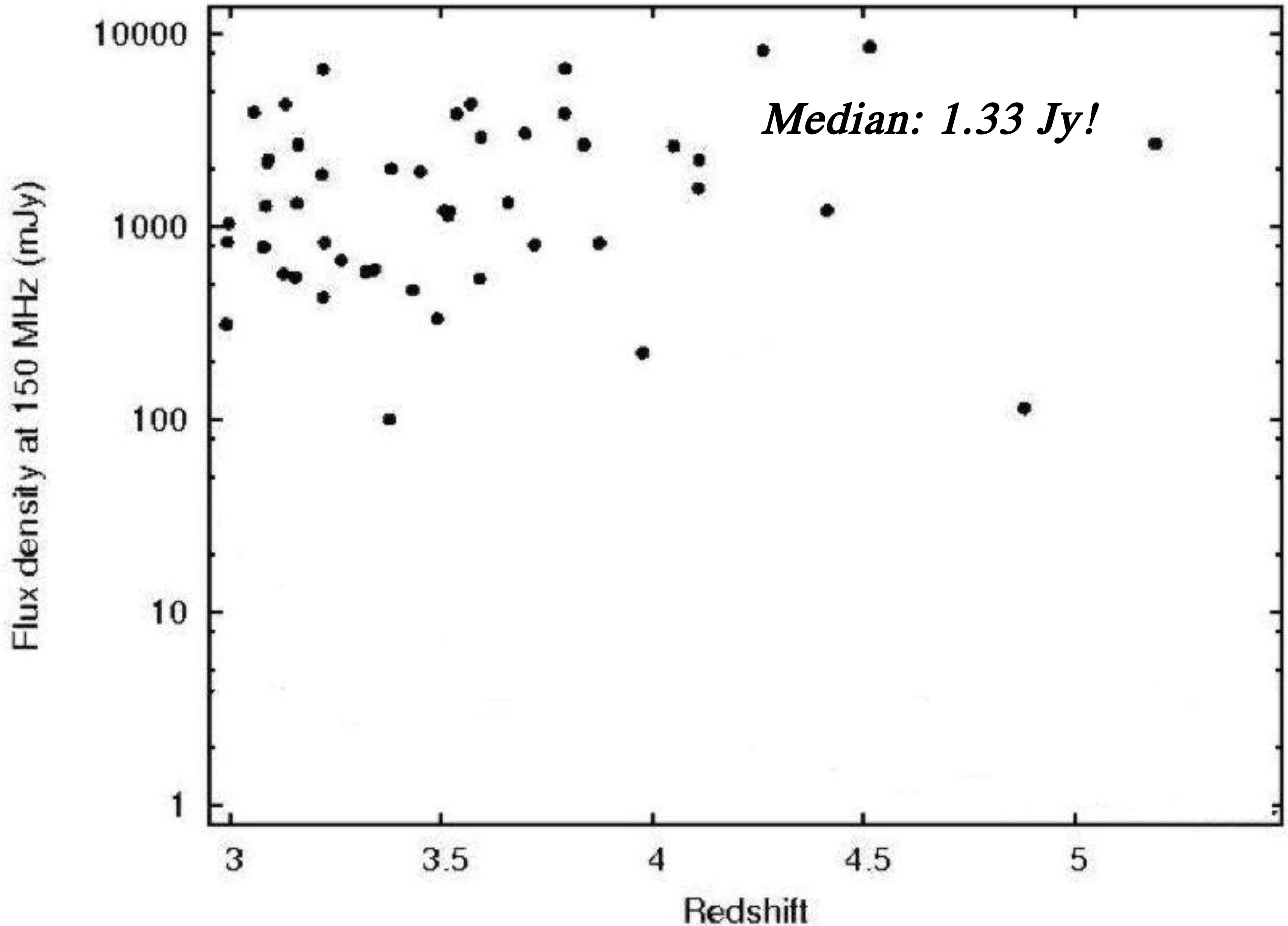
Radio Spectral Index between 178 MHz and 5 GHz

(The dashed line is the chance coincidence rate)

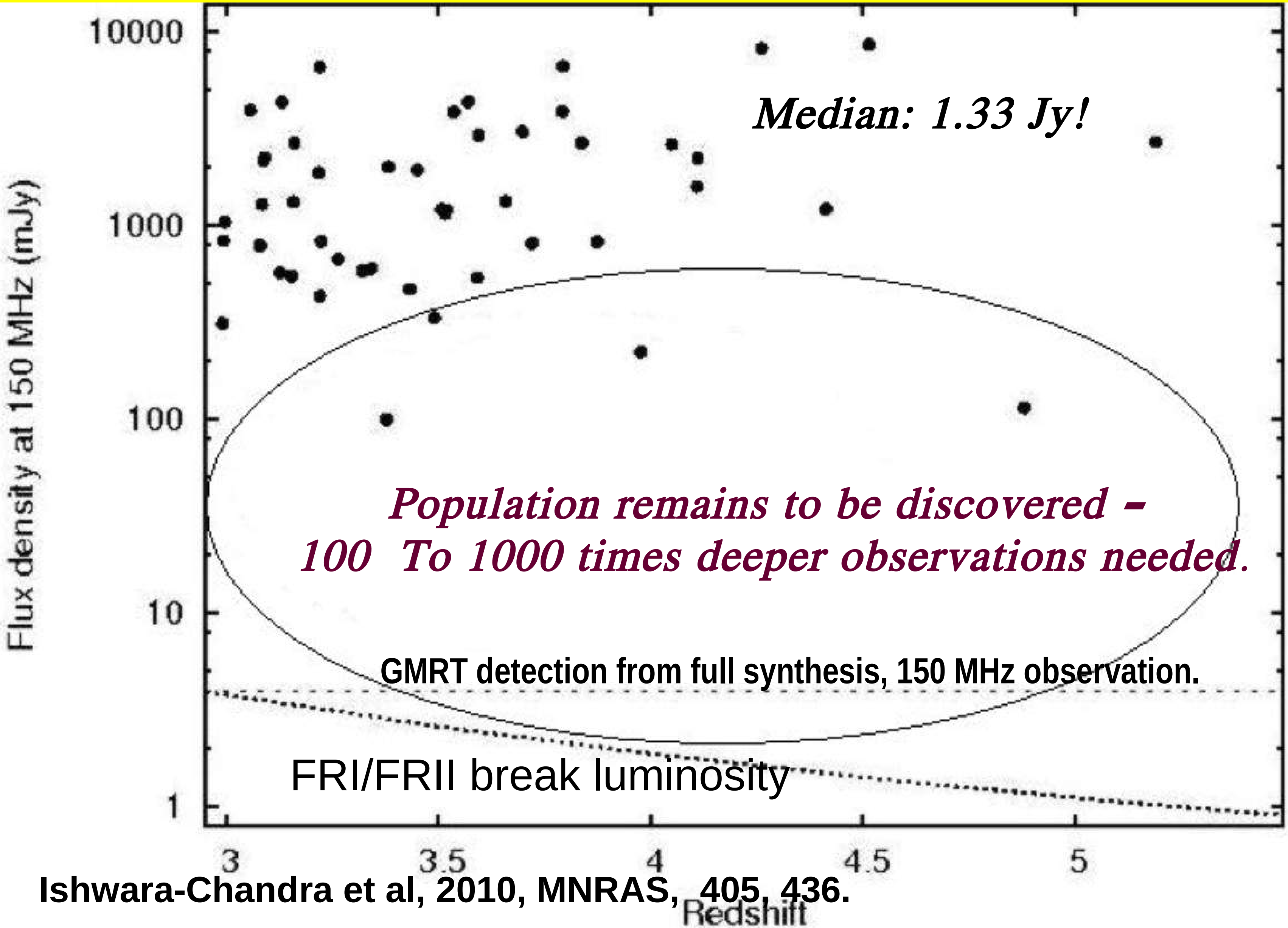
Optical identification of RGs

- *It has been first noticed in early 80's that the fraction of 3C radio sources that can be optically identified are* ***<u>3 times less</u>*** *for those with radio spectral index steeper than 1 (stronger at lower radio frequencies).*
- This finding that the steep spectrum sources are more distant as compared to the sources with normal spectra, has been exploited since then to find more high-redshift radio galaxies.
- *Most of the High-z radio galaxies known today (~ 45) are discovered using this correlation.*
- ***(Blumenthal and Miley, 1979, Tielens, Miley and Willis, 1979; Miley and de-Breuck, 2008 for review).***

Known HzRGs:- Tip of the iceberg?



Known HzRGs:- Tip of the iceberg?



Ishwara-Chandra et al, 2010, MNRAS, 405, 436.

The GMRT Programme....

- To optmize the search, 'well known deep fields' are chosen for observing *at 150 MHz* for this purpose, most of which don't have much radio data below 1.4 GHz ***(in 'reverse' direction)***
- **LBDS** – ***Ishwara-Chandra et al, 2010, MNRAS, 405, 436***
- **DEEP-II-1,2,3** (~2 deg X 0.5 deg/field & 50,000 spectra).
  – ***scrutiny underway – wealth of data from DEEP2 survey.***
- **VIRMOS-VLT** – (~ 4 degree^2 and 10,000 spectra)
- **VLA-COSMOS** - (~ 2 degree^2 and 40,000 spectra)
- **HDF/GOODS-N** – small field of view, but wealth of data .
- **TIFR-GMRT Sky Survey**

Active Galaxies

Active Galaxies