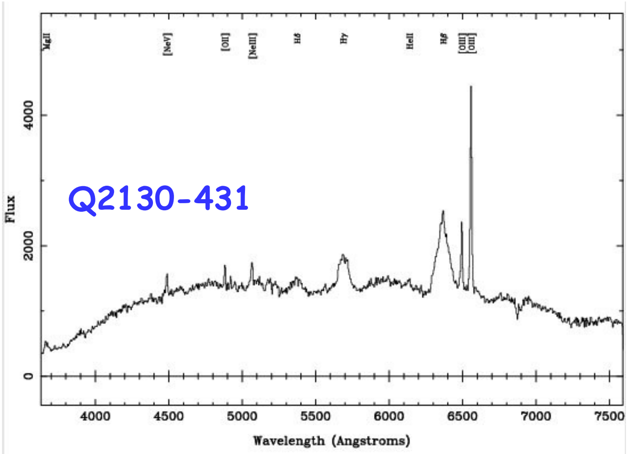
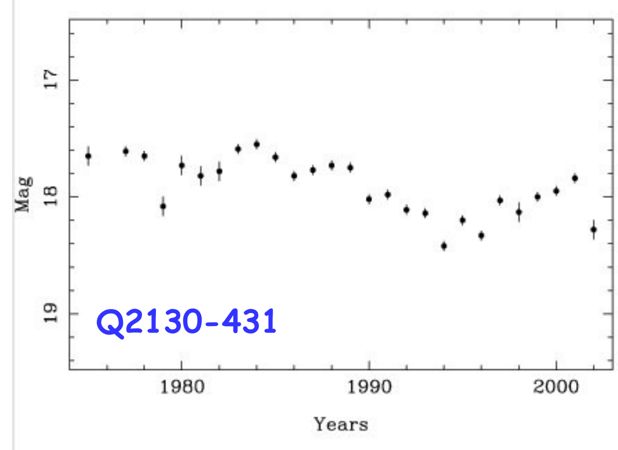
Optical View:

Type I AGN:

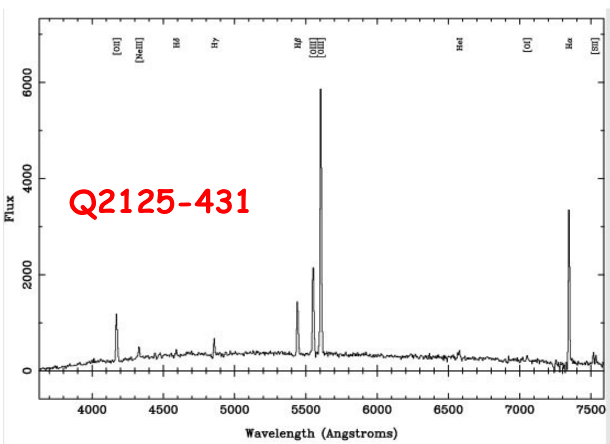


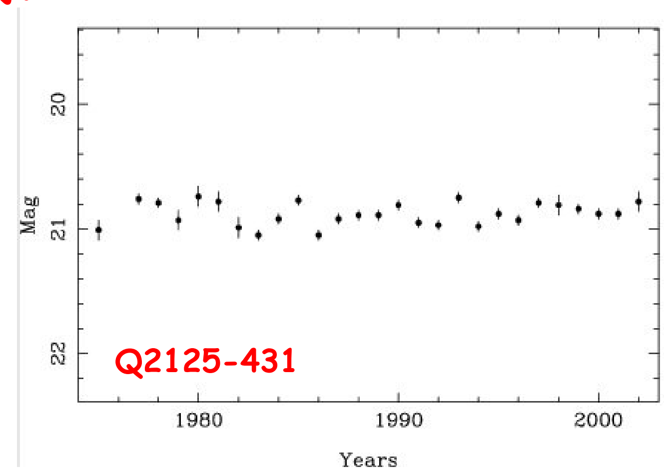


Broad permitted lines

Strong & variable continuum

Type II AGN:





Narrow forbidden & permitted lines

Weak & constant continuum

[Fig. from Hawkins 2004]

Unification Model

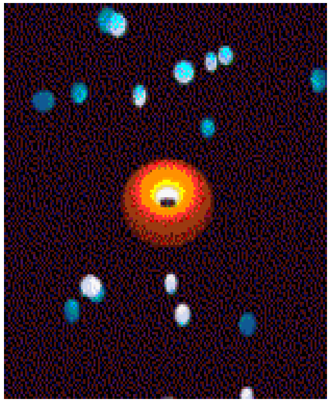
AGN intrinsically the same:

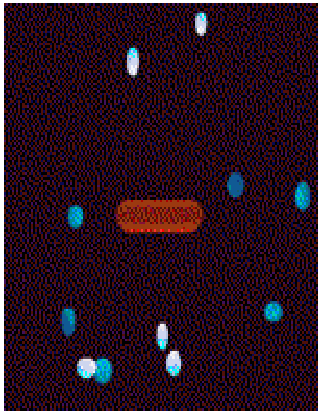
Basic Ingredients mass

*Supermassive BH
*Accretion disk + corona
*BLR: high velocity, high density gas on pc scales
*NLR; lower velocity, lower density gas on kpc scales
*Torus: gaseous & molecular absorbing medium in equatorial plane
embedding BH, ADC, BLR
*Jets: relativistic ejection (10% AGN)

Differences ascribed to viewing angle:

Type I





Type II

Spectropolarimetry

Measure of polarization of light as a function of wavelengths

Instrumental in the development of Unification Model:

Detection of broad permitted lines in polarized light in Sy2 NGC 1068 (Miller & Antonucci 1983) :

* presence of hidden BLR (HBLR)

* constraints on location and geometry of the absorber

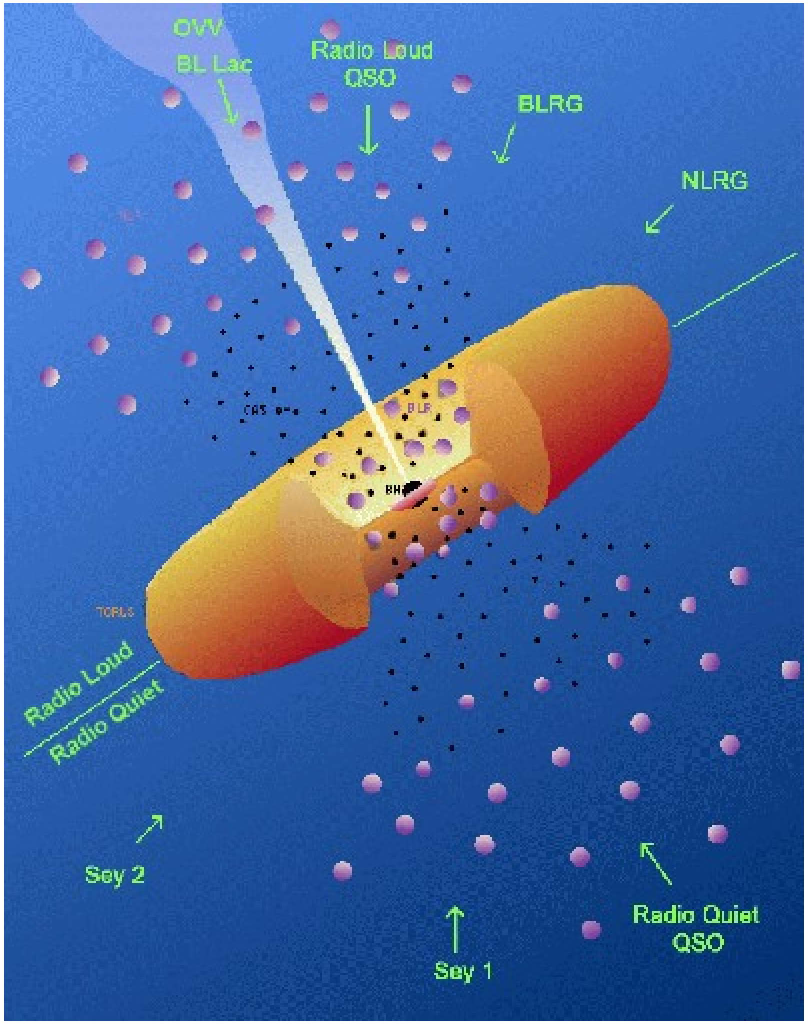
But exceptions exist:

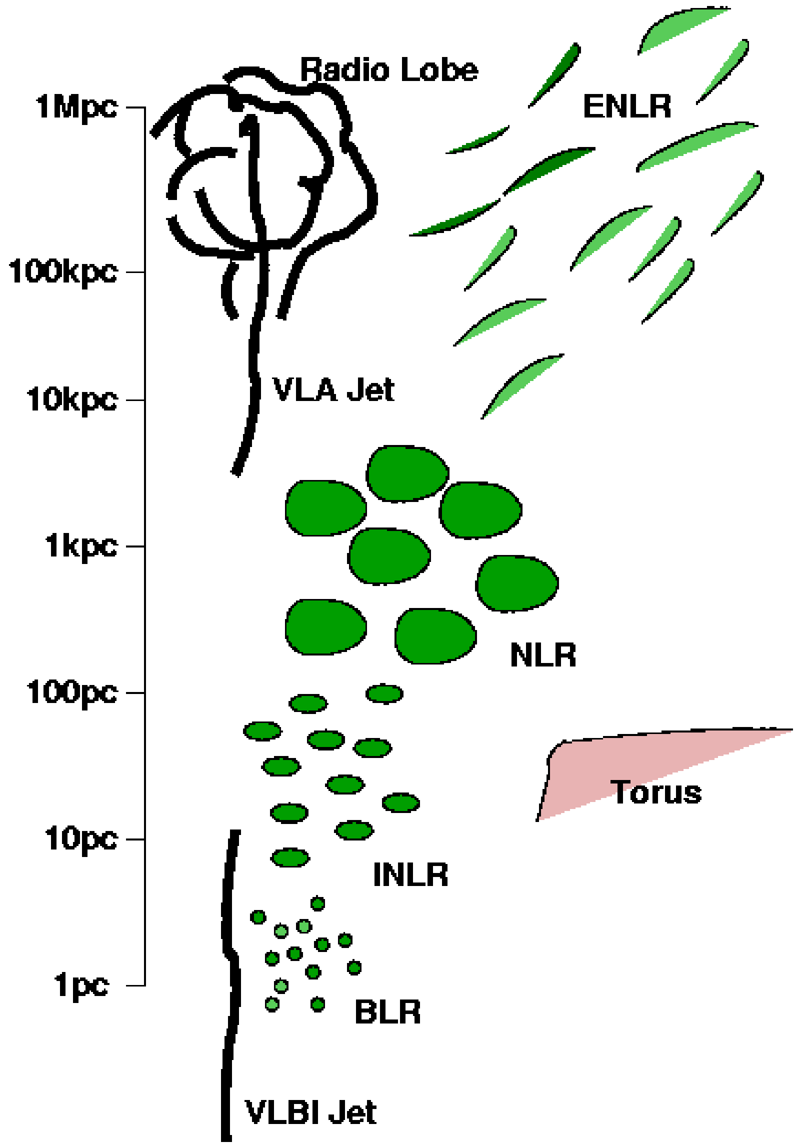
*Only 50% of Sy2 have HBLR (e.g. Tran 2001)
based on 3-m (Lick) and 5-m (Palomar) telescopes

* Result confirmed by Keck 10-m telescope (Moran et al. 2007)

- Blazars
  - BL Lacs
  - OVV
- Quasars
  - Radio Loud
  - Radio Quiet
- Radio Galaxies
  - Narrow Line
  - Broad Line
- Seyfert
  - Type 1
  - Type 2

▪ Low Ionization Nuclear Emission-Line Regions (LINERS)

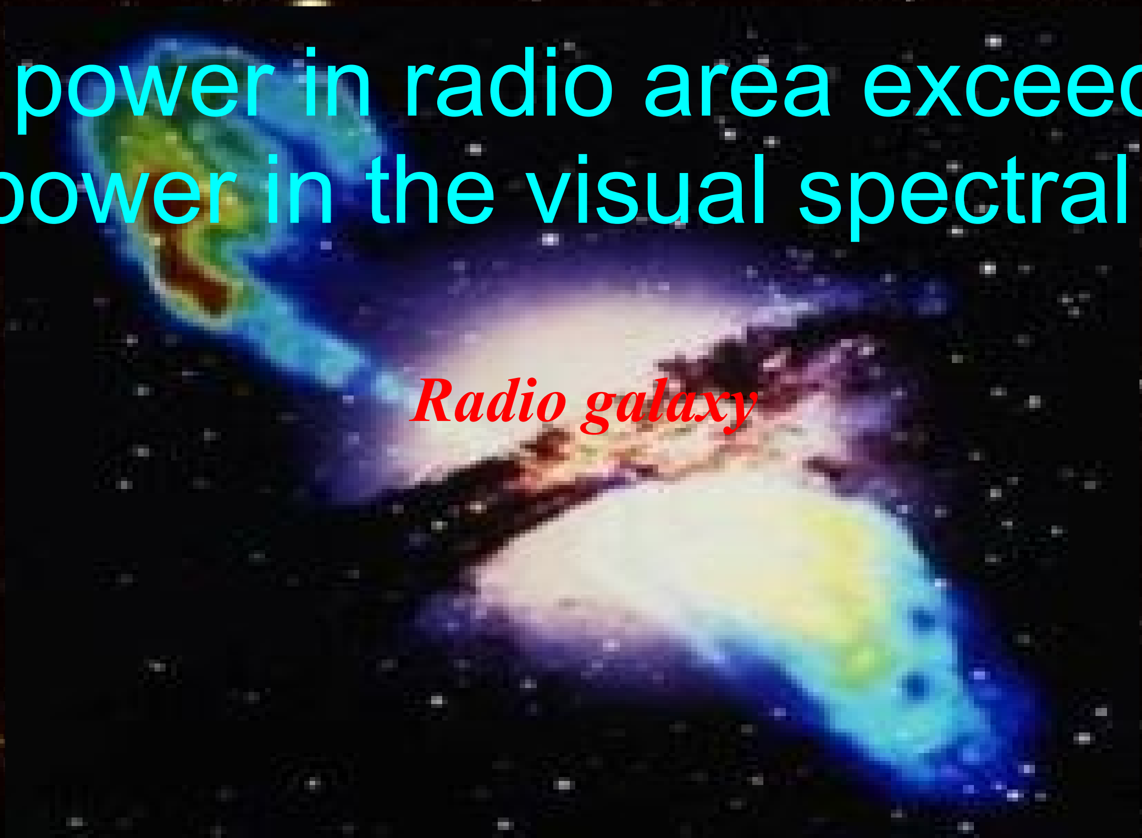




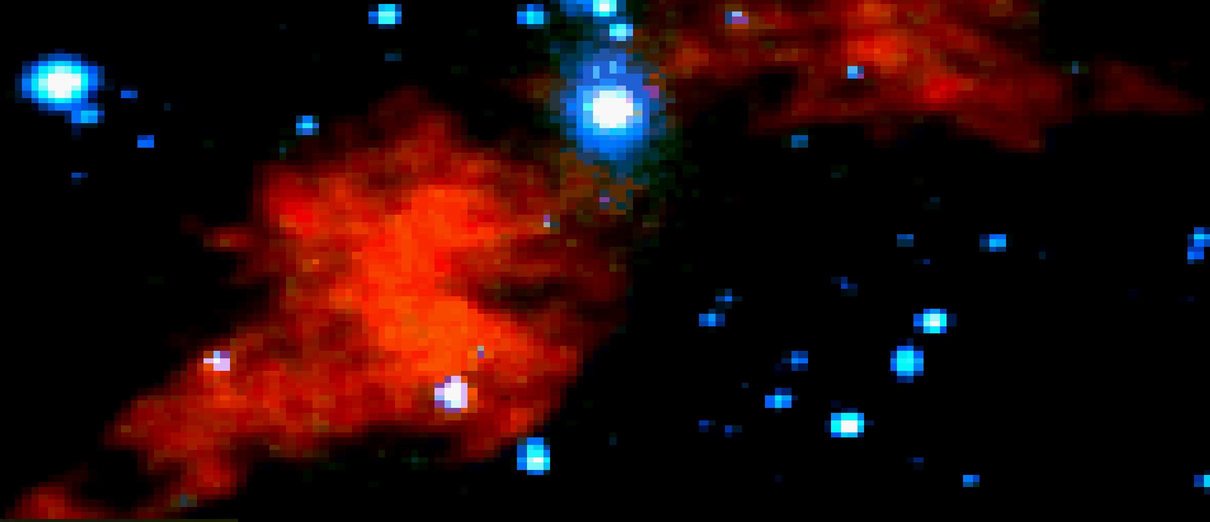
1Mpc
100kpc
10kpc
1kpc
100pc
10pc
1pc
Radio Lobe
ENLR
VLA Jet
NLR
Torus
INLR
BLR
VLBI Jet

Radio galaxies

- associated to Elliptical galaxies
- Radiation power in radio area exceed the radiation power in the visual spectral area



- They could be identified among other dimly objects in the visible light, because...
  - The galaxy in the visible light is not outshined by its core

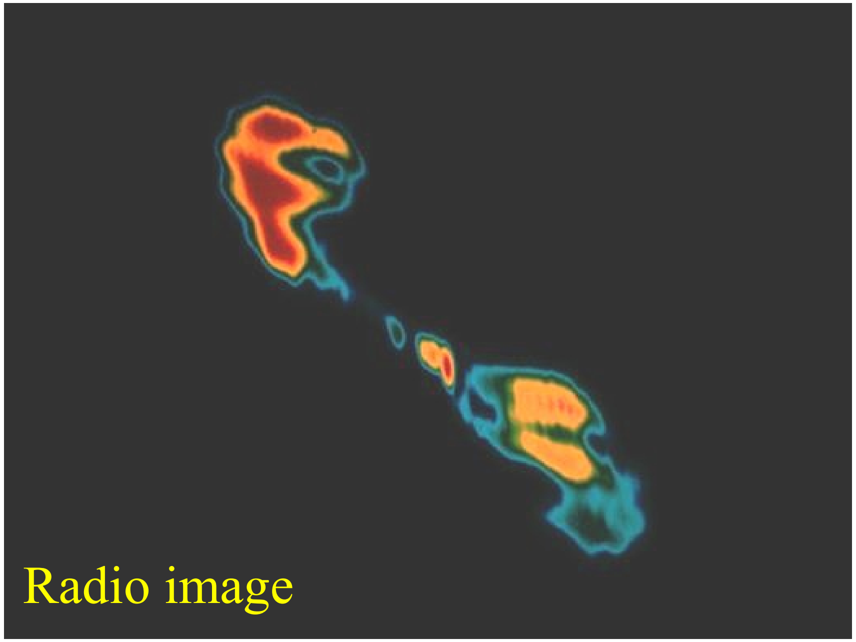


nearest radio galaxy: Centaurus A (NGC 5128)

- RG 10^{38}- 10^{43}erg/s = 10^{31}- 10^{36}J/s
- Quasars 10^{43}- 10^{47}erg/s = 10^{36}- 10^{40}J/s

R

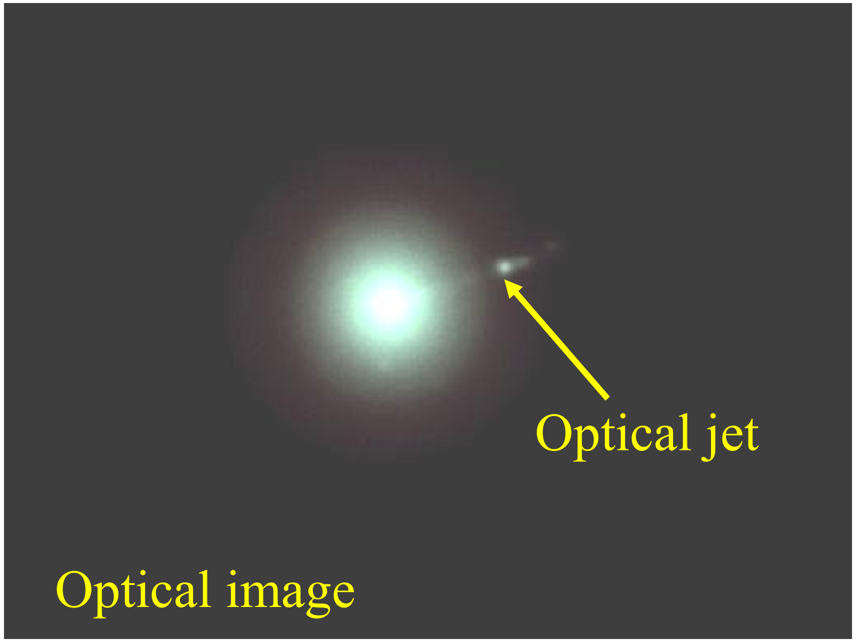
Radio Galaxies

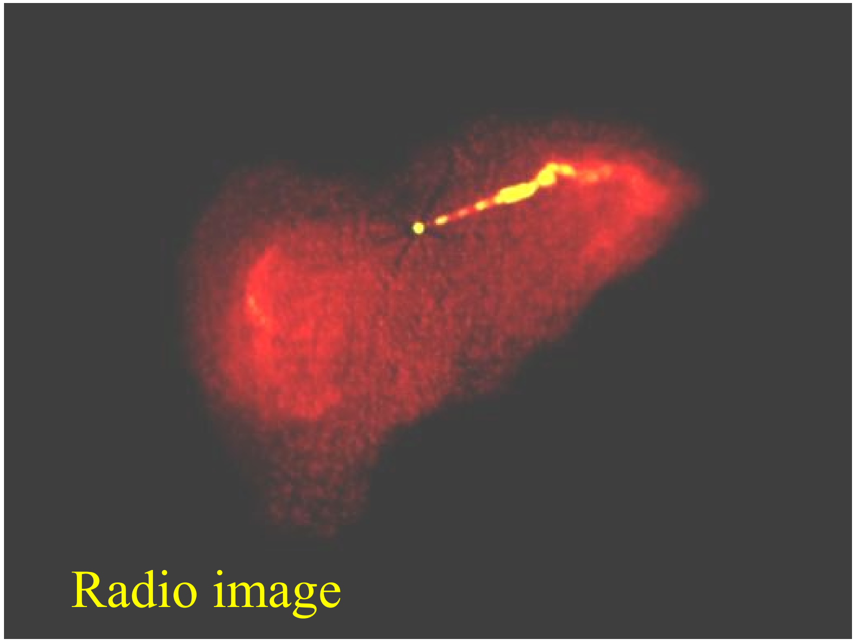


Centaurus A ("Cen A"): the most nearby AGN (3 - 4 Mpc).

.There is strong evidence that Centaurus A is a merger of an elliptical with a spiral galaxy, since elliptical galaxies would not have had enough dust and gas to form the young, blue stars seen along the edges of the dust lane.

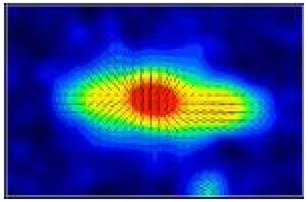
Radio Galaxies





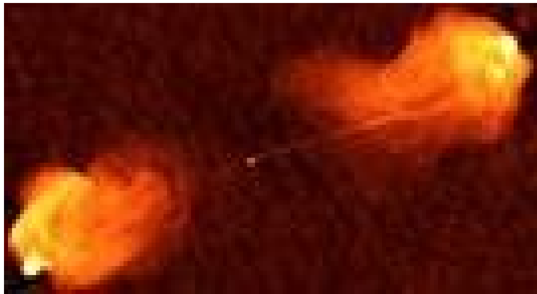
M 87: The central galaxy (giant elliptical galaxy) of the Virgo cluster of galaxies at a distance of 16 Mpc (redshift z=0.00436)

Radio radiation

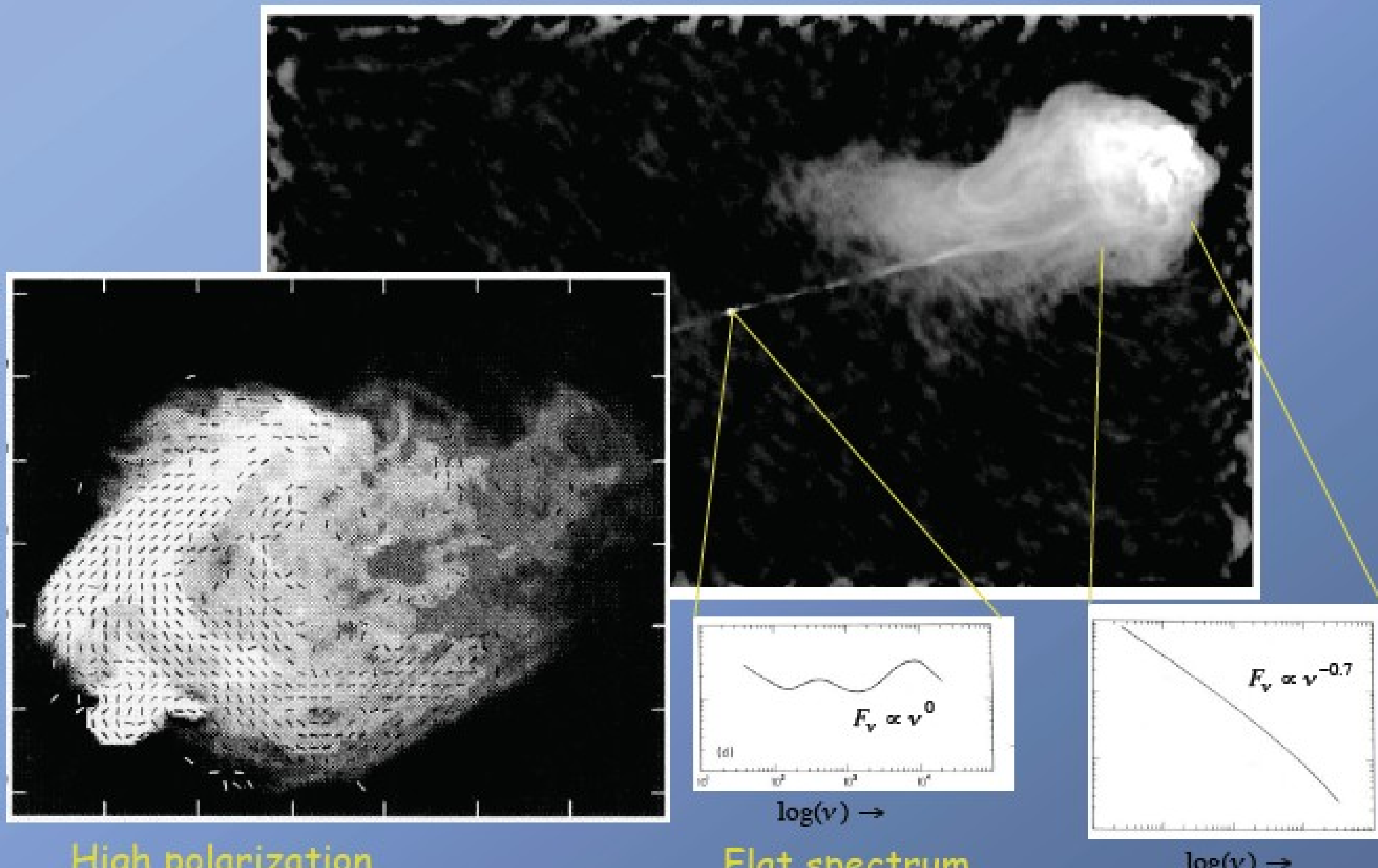


The radio emission is synchroton radiation (emitted from electrons gyrating along magnetic field lines)

The most common large-scale structures are called **lobes**: these are double, often fairly symmetrical structures placed on either side of the active nucleus.



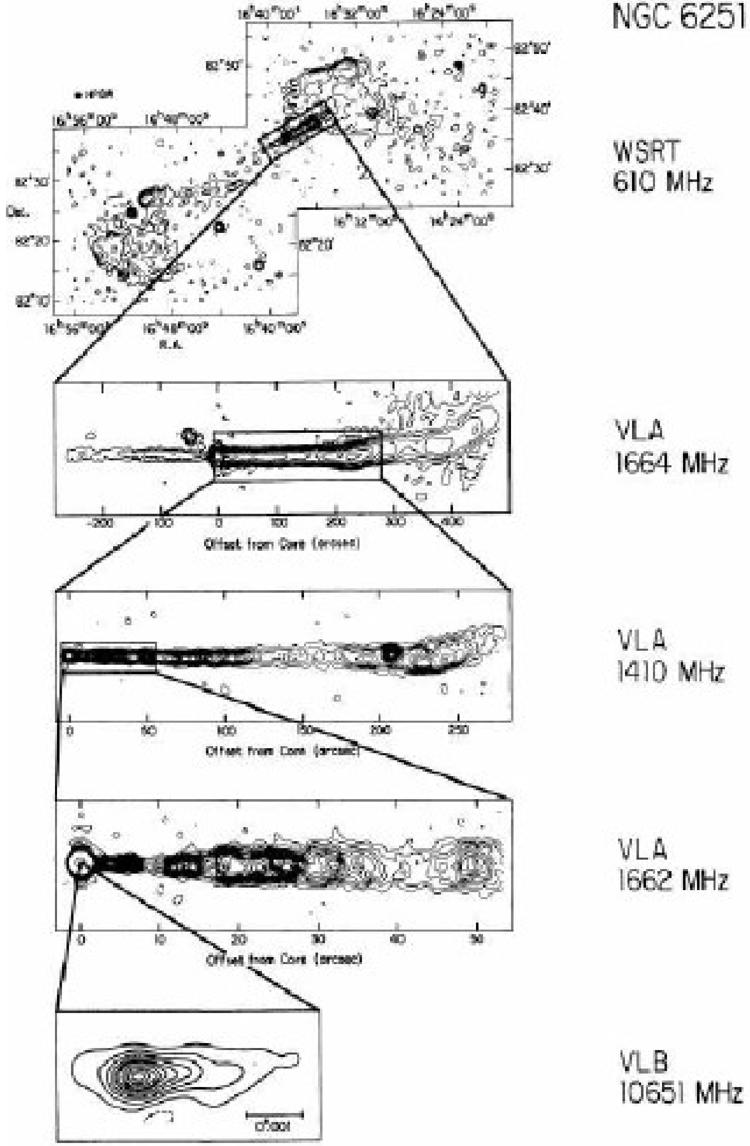
Radio properties



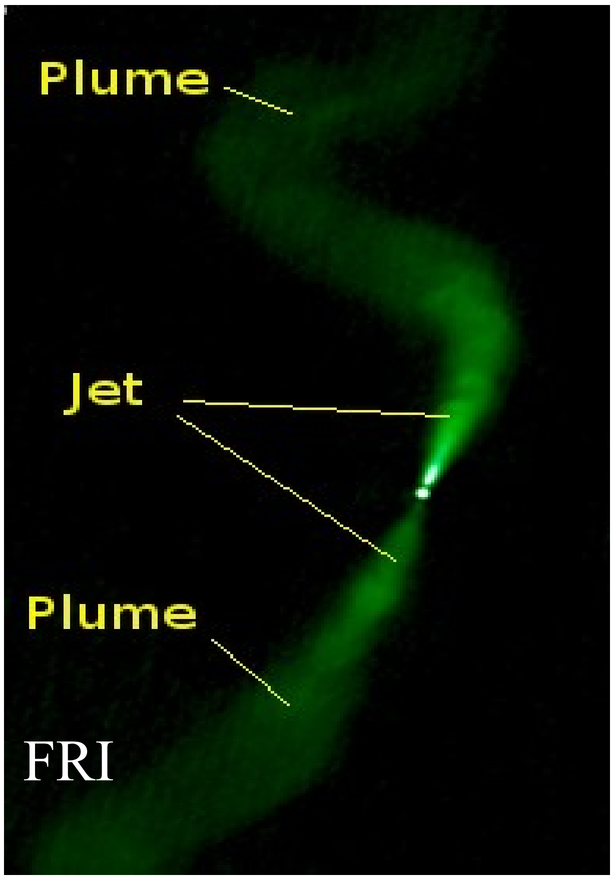
High polarization

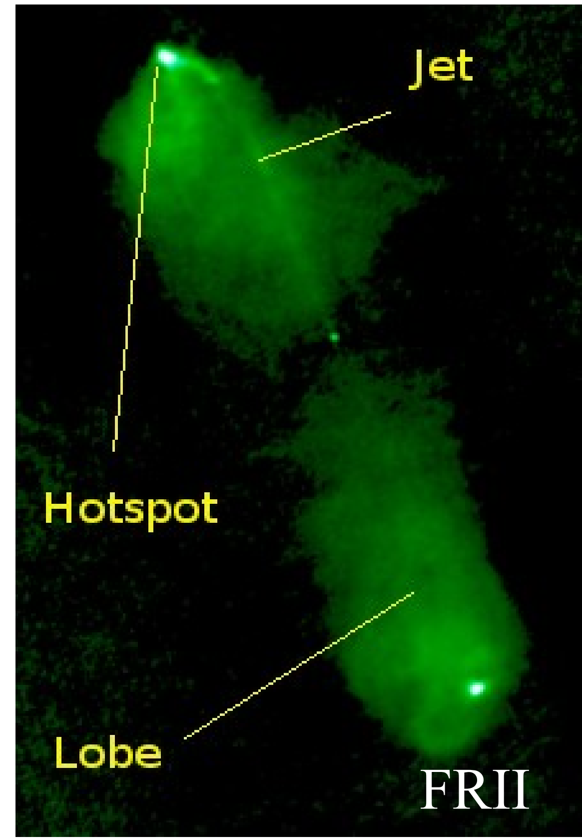
Flat spectrum cores

Steep spectrum lobes


NGC 6251
WSRT
610 MHz
VLA
1664 MHz
VLA
1410 MHz
VLA
1662 MHz
VLB
10651 MHz
Offset from Core (arcsec)
Offset from Core (arcsec)
Offset from Core (arcsec)

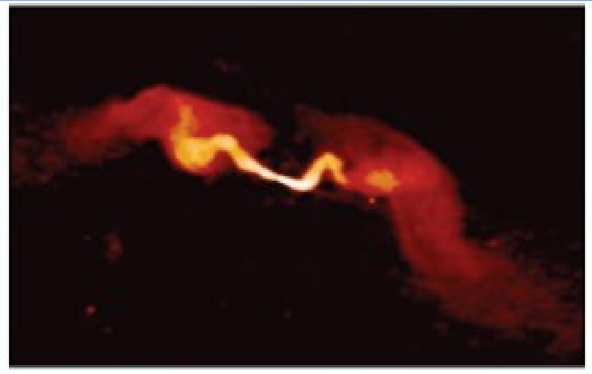
In 1974, radio sources were divided by Fanaroff and Riley into two classes, now known as Fanaroff and Riley Class I (FRI), and Class II (FRII).





FRI/FRII Radio Morphology Classification

Fanaroff-Riley ClassI

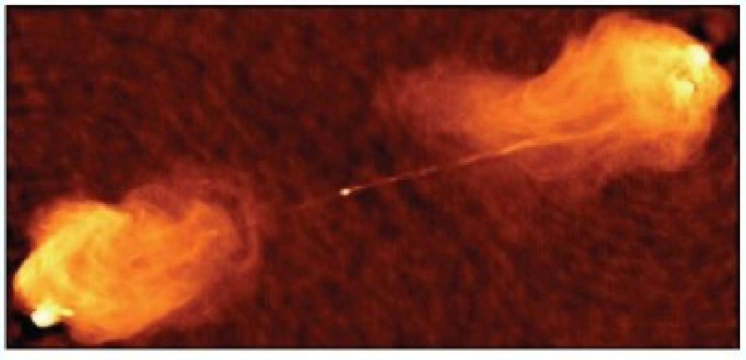


Edge-darkened

$P_{178Mhz} < 5 \times 10^{25}\ W\ Hz^{-1}$

All FRIs classified as WLRG

Fanaroff-Riley ClassII



Edge-brightened

$P_{178Mhz} > 5 \times 10^{25}\ W\ Hz^{-1}$

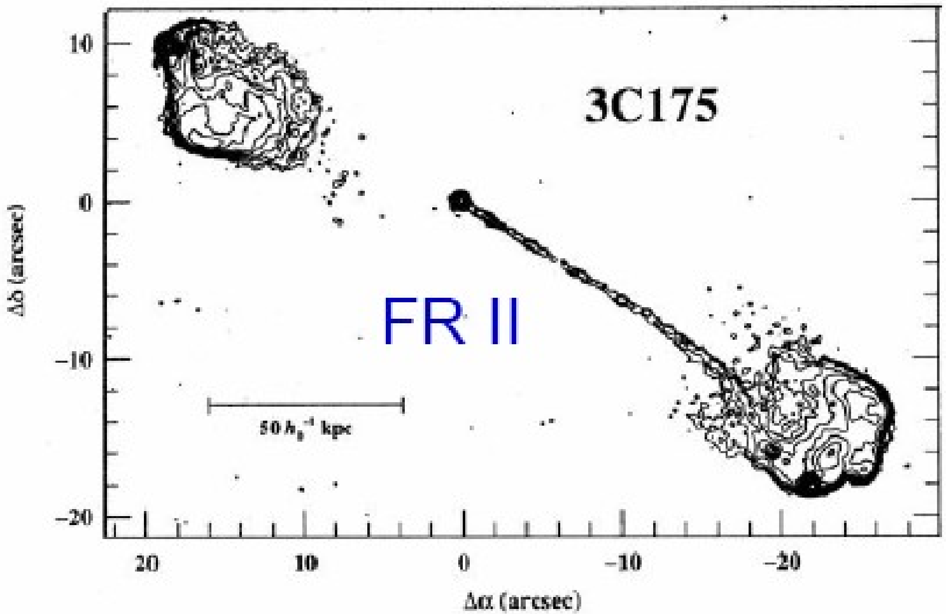
FRIIs mainly classified as NLRG/BLRG/RLQ

- Faranoff-Riley Typ I (FR I)

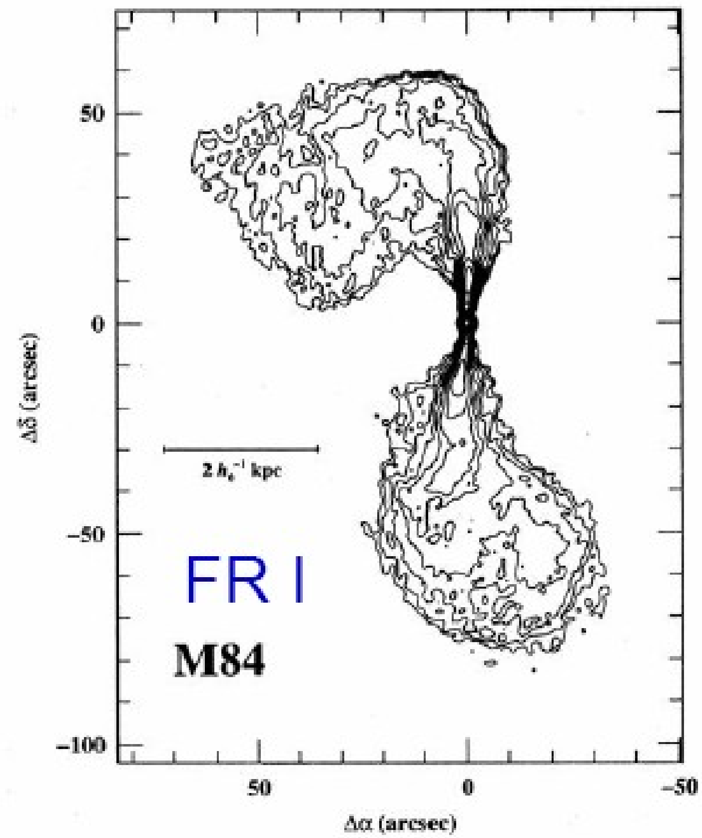
$$L_\nu(1.4\,\mathrm{GHz}) \lesssim 10^{32}\ \mathrm{erg/s/Hz}$$

- Faranoff-Riley Typ II (FR II)

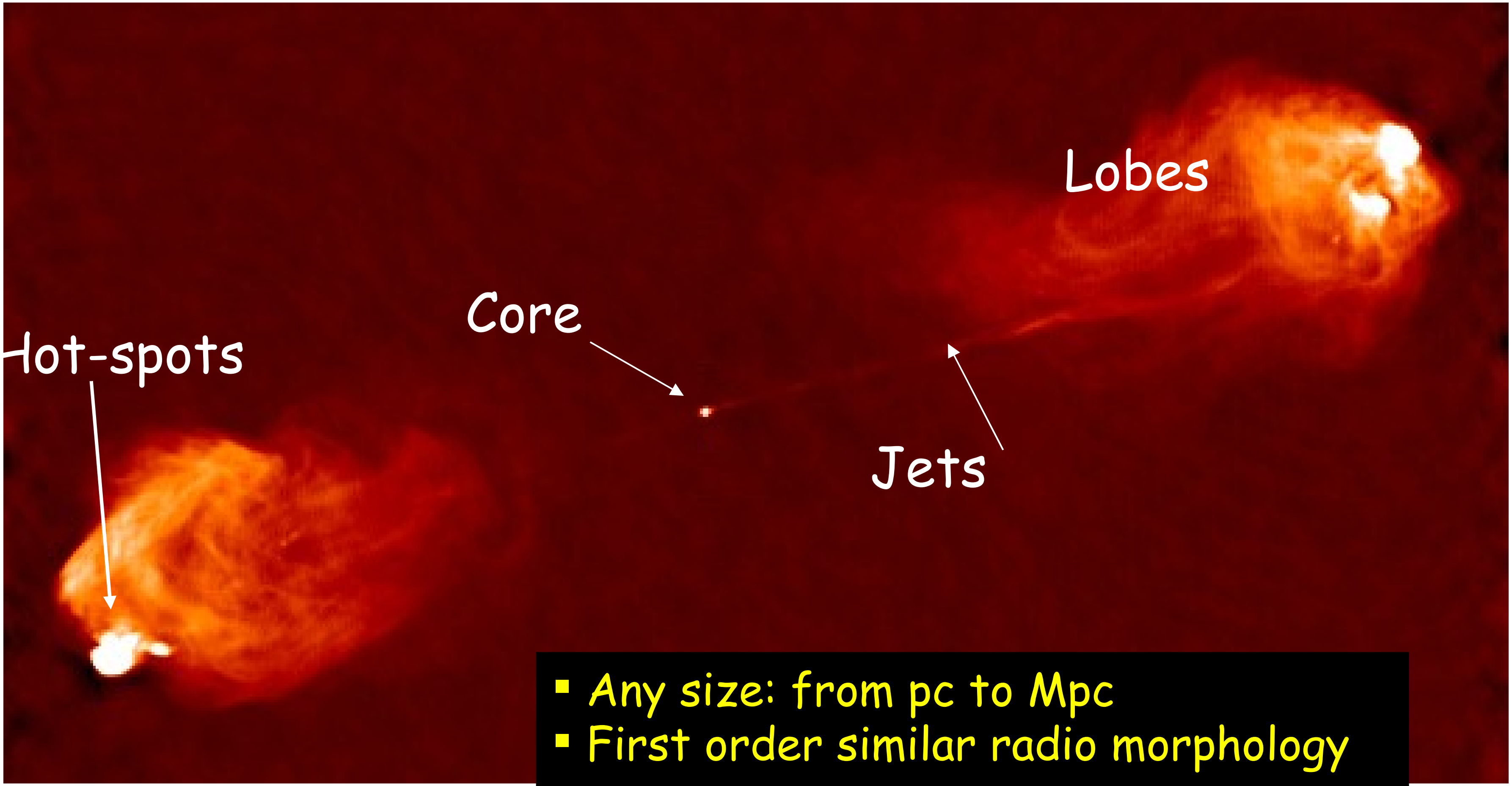
$$L_\nu(1.4\,\mathrm{GHz}) > 10^{32}\ \mathrm{erg/s/Hz}$$



3C175
FR II
50 h_0^{-1} kpc
Δδ (arcsec)
Δα (arcsec)



FR I
M84
2 h_0^{-1} kpc
Δδ (arcsec)
Δα (arcsec)

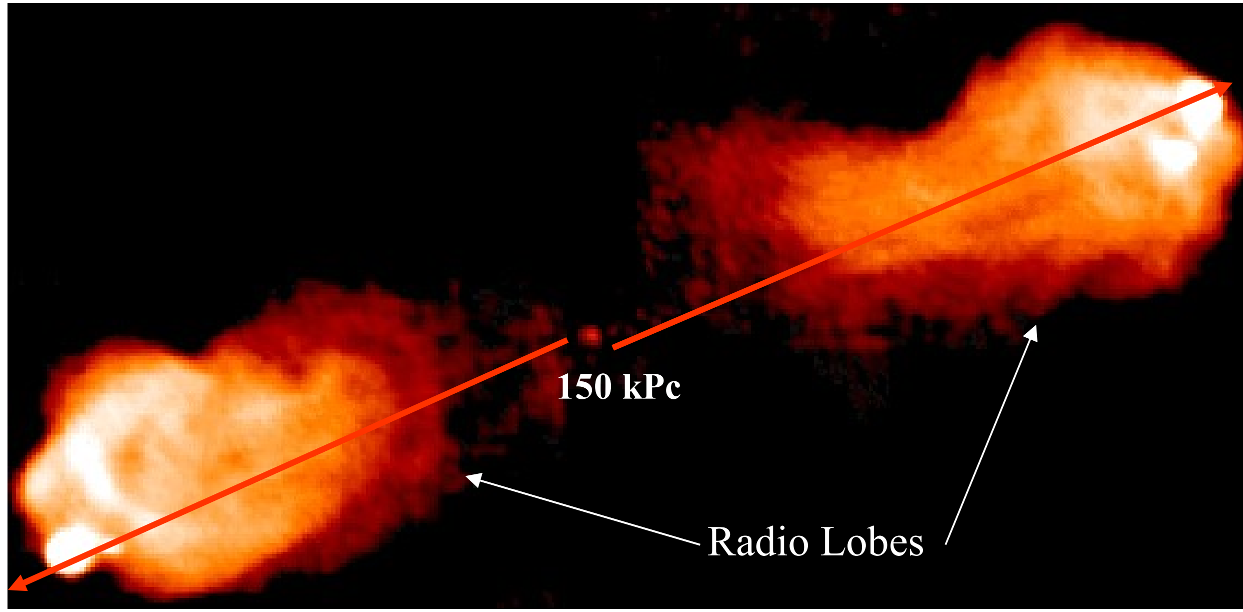


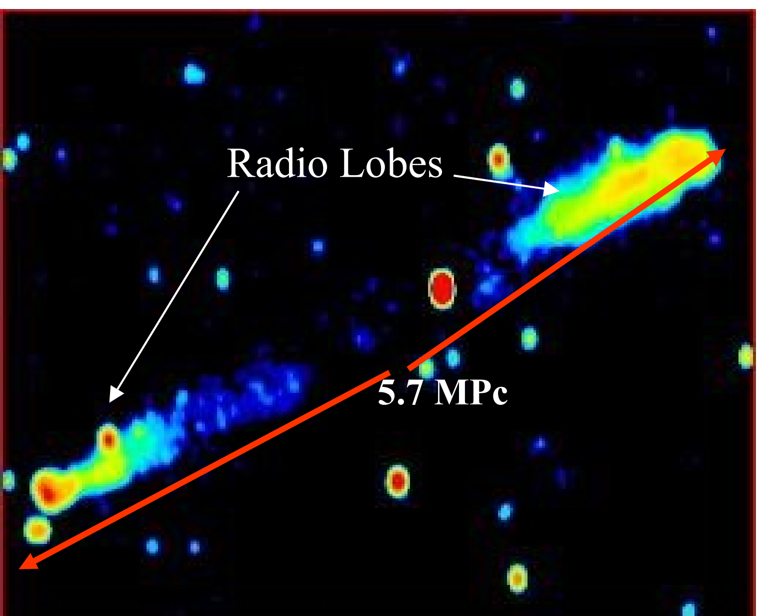
- Any size: from pc to Mpc
- First order similar radio morphology

  (but differences depending on radio power, optical luminosity & orientation)
- Typical radio power 10^{23} to 10^{28} W/Hz

Radio Galaxies and Jets

Cygnus-A →
VLA radio image at
-ν = 1.4.10⁹ Hz
(d = 190 MPc)





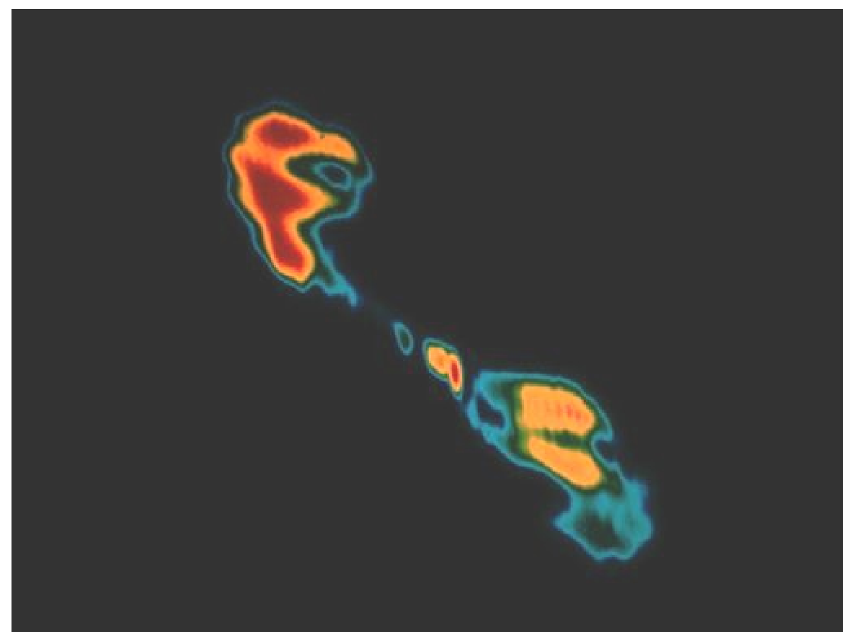
← 3C 236 Westerbork radio image at $\nu = 6.08.10^8$ Hz – a radio galaxy of very large extent (d = 490 MPc)

Jets, emanating from a central highly active galaxy, are due to relativistic electrons that fill the lobes

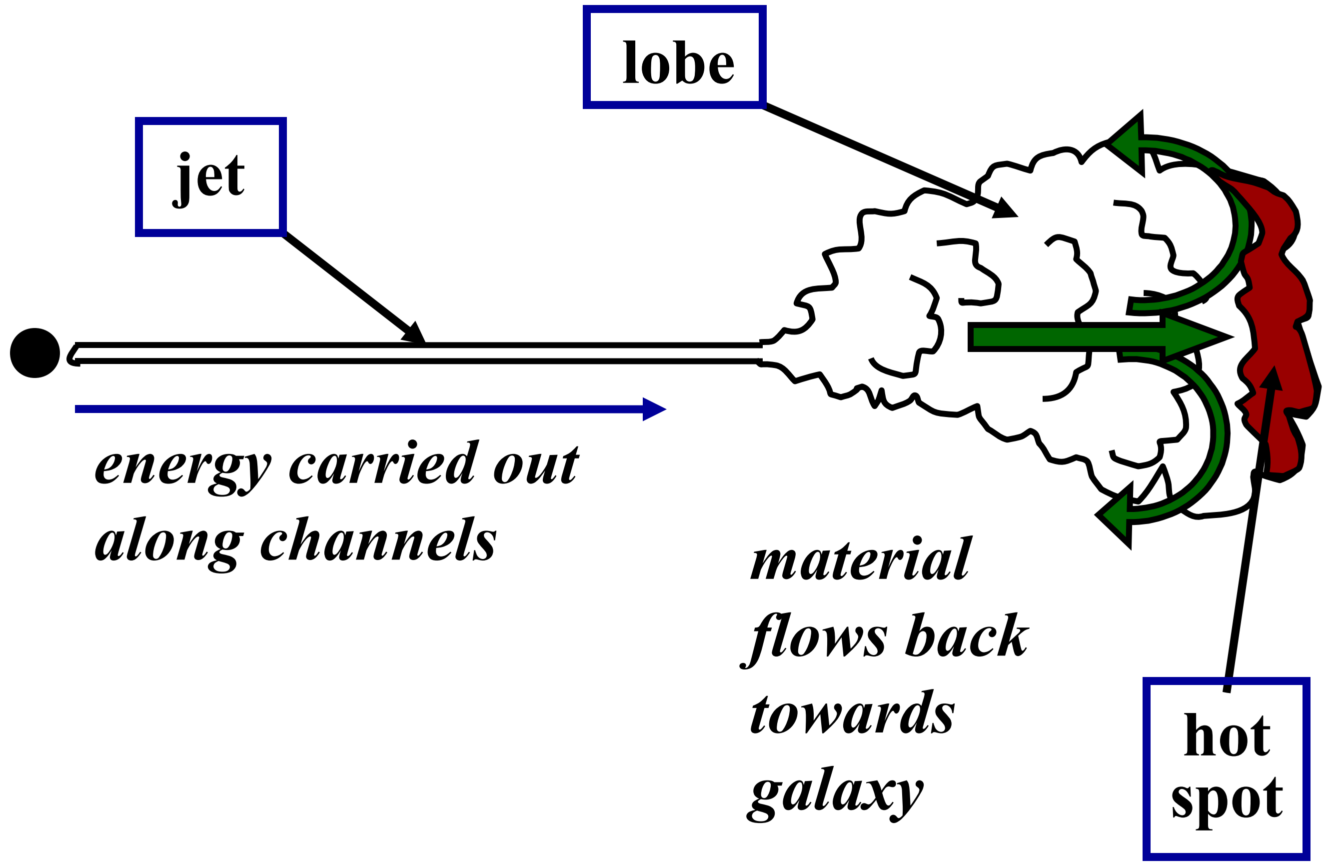
Cen A as an active galaxy is usually classified as a

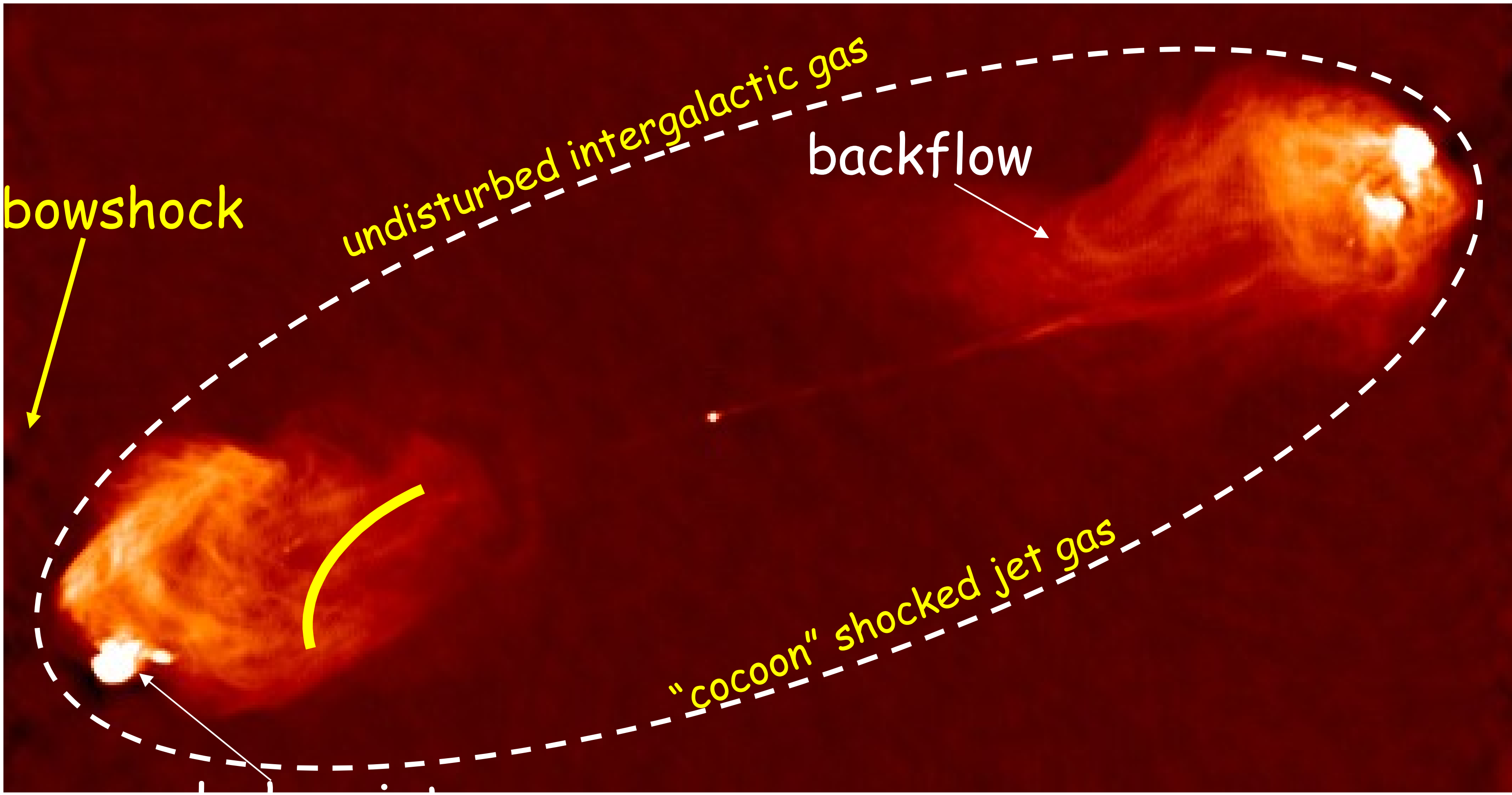
. FR I type radio galaxy,
. as a Seyfert 2 object in the optical (Dermer & Gehrels 1995), . . . and as a "misdirected" BL Lac type AGN at higher energies (Morganti et al. 1992).

It is one of the best examples of a radio-loud AGN **viewed from the side (~ 70 degree)** of the jet axis (Graham 1979; Dufour et al. 1979; Jones et al. 1996).



Jets: Focussed Streams of Ionized Gas

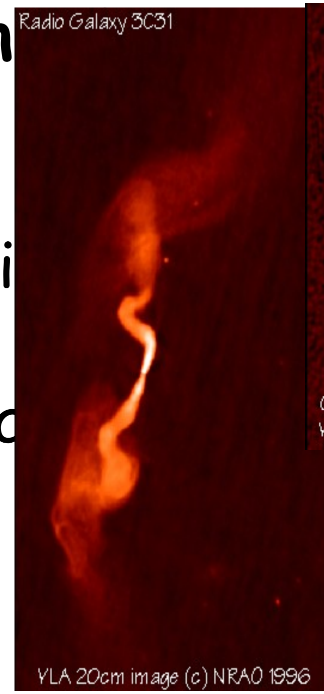


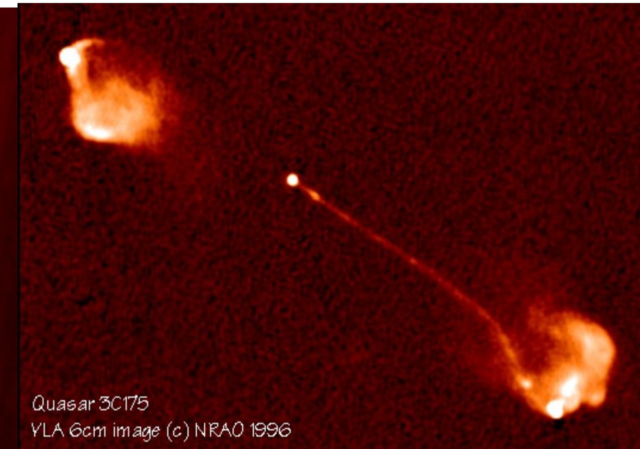

undisturbed intergalactic gas
backflow
bowshock
"cocoon" shocked jet gas

What makes the differen

Well known dichotomy:
low *vs* high power radio galaxi

Differences not only in the ra



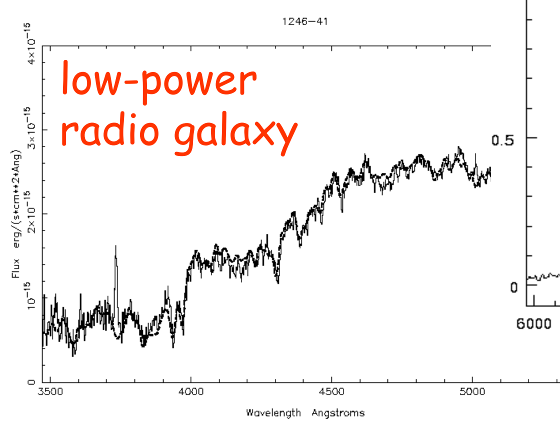


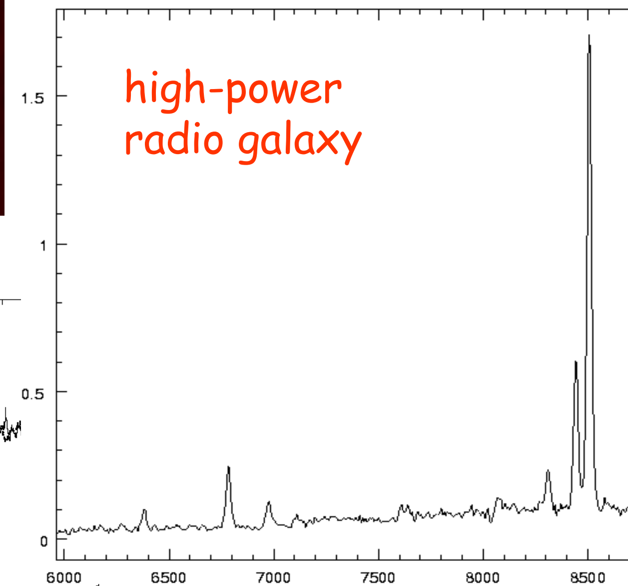
WHY?

Intrinsic differences in the nuclear regions?

Accretion occurring at low rate and/or radiative efficiency?

No thick tori?





The Fanaroff-Riley Dichotomy

Is the dichotomy

- Environmental?
    - Interaction of the jet with ambient medium either causes the jet to decelerate (FRI) or propagate supersonically to large distances (FRII)
- Intrinsic?
    - Properties of the central engine govern large-scale morphology (FRI/FRII)

Radio Galaxies

Emit most of their energy at radio wavelengths
Emission lines from many ionization states
Nucleus does not dominate galaxy’s emission
Host galaxies are Elliptical/S0

Radio morphology first classified by Fanaroff & Riley (1974)

- FR I: less luminous, 2-sided jets brightest closest to core and dominate over radio lobes
- FR II: more luminous, edge-brightened radio lobes dominate over 1-sided jet (due to Doppler boosting of approaching jet and deboosting of receding jet)

Spectroscopic classification of radio galaxies

- NLRGs (Narrow line …): like Seyfert 2s; FR I or II
- BLRGs (Broad line …): like Seyfert 1s; FR II only

Optical Emission Line Properties

	Type2 narrow line	Type 1 broad line	Type 0
Radio quiet	Seyfert 2	Seyfert 1	
	?	Quasars	Broad absorption line QSO
Radio loud	low power		BL Lac
	Narrow-line radio galaxies		OVV
	high power	broad-line RG	
		lobe/core dominated QSR	

Decreasing angle to line of sight →

Radio galaxies.:

These objects can broadly be divided into low-excitation (WLRG) and high-excitation classes (Hine & Longair 1979; Laing et al. 1994).

Low-excitation objects show **no broad but also no strong-narrow emission lines**, and the emission lines they do have (only weak narrow lines) may be excited by a different mechanism (Baum, Zirbel & O'Dea 1995).

Their optical and X-ray nuclear emission is consistent with originating purely in a jet (Chiaberge, Capetti & Celotti 2002; Hardcastle, Evans & Croston 2006).

They may be the best current candidates for AGN with radiatively inefficient accretion.

High-excitation classes

By contrast, high-excitation objects (narrow-line radio galaxies) have emission-line spectra similar to those of Seyfert 2s.

The small class of broad-line radio galaxies, which show relatively strong nuclear optical continuum emission (Grandi & Osterbrock 1978) probably includes some objects that are simply low-luminosity radio-loud quasars.

The host galaxies of radio galaxies, whatever their emission-line type, are essentially always ellipticals.

Problems with simple unification - II
How do the WLRG fit in?

- *All* low power FRI radio sources are WLRG
- A minority of FRII radio sources (~10-20%) are WLRG (most are NLRG or BLRG/RLQ)

- Unlikely that WLRG have powerful, obscured quasar nuclei because they are also weak in the far-IR

➔It has been proposed that WLRG unify with BL Lac objects, rather than RLQ

Main AGN Classifications

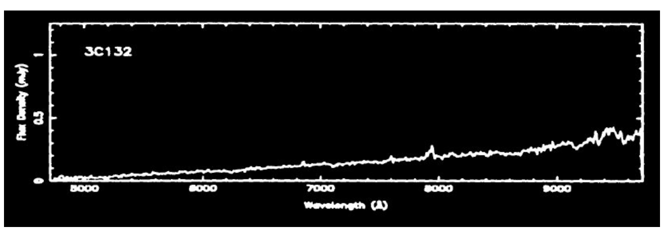
Radio quiet		Radio loud
Radio quiet quasar (RQQ) *Broad absorption line (BAL)* **Seyfert 1** *Sy 1.0.....1.9* *Narrow line Sy 1 (NLS1)*	Type 1	**Radio loud quasar** (RLQ) *Steep radio spectrum (SSQ)* *Flat radio spectrum FSQ)* **Broad line radio galaxy** (BLRG)
Seyfert 2 *NL X-ray galaxy (NLXG)*	Type 2	**Narrow line radio galaxy** (NLRG)
LINER	Type 3	**Weak line radio galaxy** (WLRG)
	Type 0	**BL Lac/Blazar/OVV**

http://www.vlti.org/events/assets/3/documents/torun2c.pdf

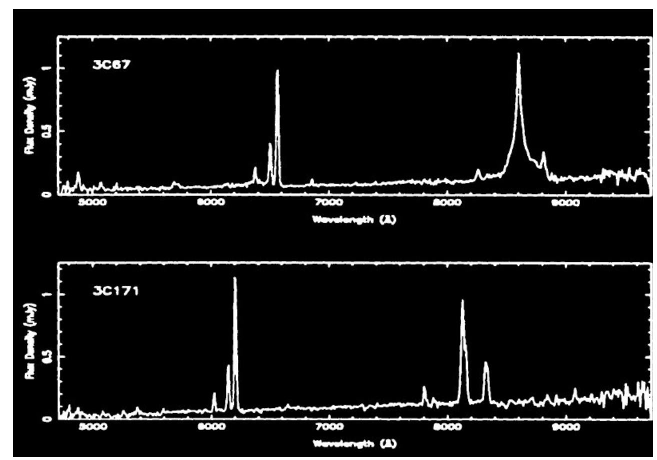
Low- and High-Excitation Radio Galaxies

Based on strength of high-excitation lines , e.g., [OIII] (Laing et al. 1994)

- FRIs are almost entirely low-excitation
- Significant population of low-excitation FRIIs at $0.1<z<0.5$

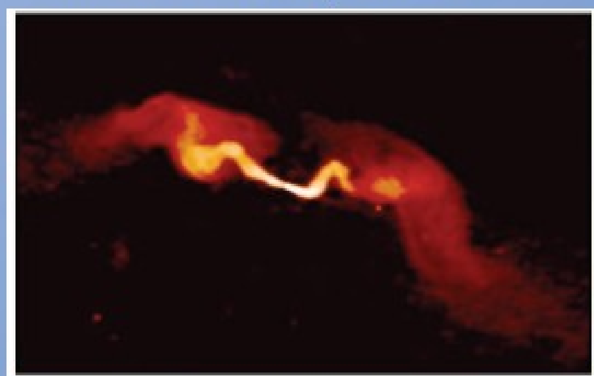


- Encompass all NLRGs and BLRGs
- Almost entirely FRIIs



FRI/FRII Radio Morphology Classification

Fanaroff-Riley ClassI

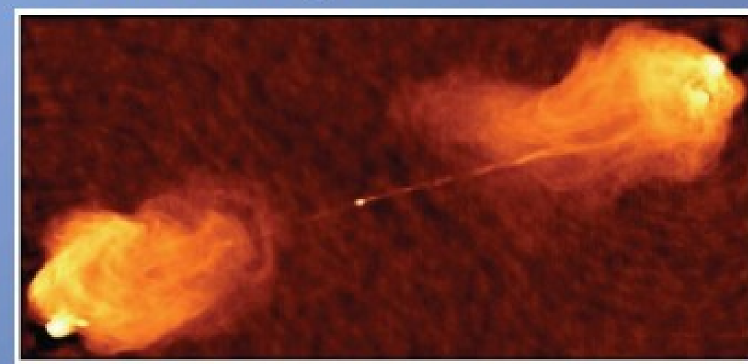


Edge-darkened

$P_{178Mhz} < 5 \times 10^{25}\ W\ Hz^{-1}$

All FRIs classified as WLRG

Fanaroff-Riley ClassII



Edge-brightened

$P_{178Mhz} > 5 \times 10^{25}\ W\ Hz^{-1}$

FRIIs mainly classified as NLRG/BLRG/RLQ

On <u>small scales</u> (< 15 kpc): 3 types of sources

Compact, Flat Spectrum (CFS)

usually < 1”,   physically small < 10 pc

$f_\nu \sim \nu^{-\alpha}$, $\alpha \sim 0 - 0.3$

variable, polarized, superluminal on VLBI scales

Compact, steep spectrum (CSS)

alpha = 0.7 – 1.2

sizes 1-20 kpc (within host galaxy)

peak at < 500 MHz

(limited by Ionospheric cutoff is at 10 MHz)

30% of cm-selected radio sources

GigaHertz Peaked Spectrum (GPS)

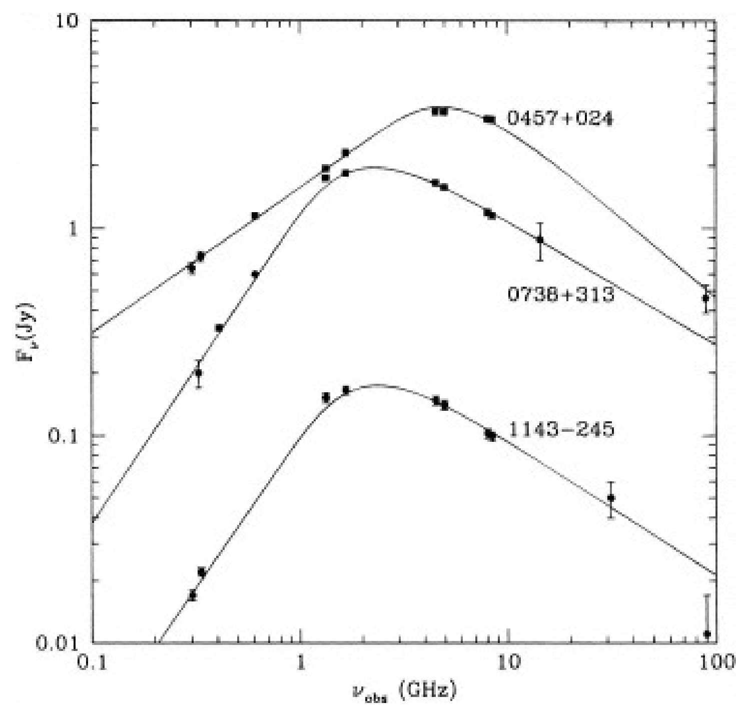
radio spectrum peaks at 500 MHz to 10 GHz

sizes < 1 kpc (within NLR)

not very polarized

alpha ~0.77 for E>E(peak)

10% of cm-selected radio sources



Bicknell + 1997 ApJ 485, 112

Spectral shape and Lifetimes

Radio sources "age" → spectrum steepens

Energy loss from radiation, adiabatic expansion

Electron lifetime $$t \simeq 2.6 \times 10^4 \frac{B^{1/2}}{B^2 + B_R^2} \left[(1+z) \nu_b \right]^{-1/2} yr$$

Break freq.

Equivalent magnetic field of the microwave background

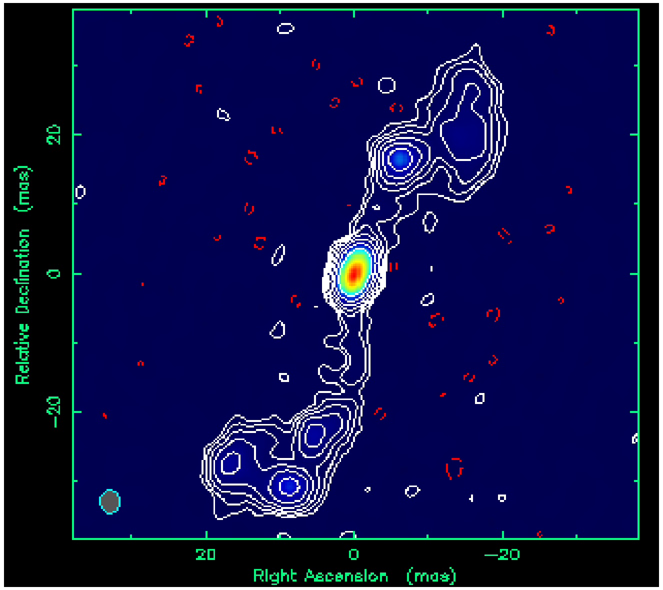
Van der Laan & Perola 1969

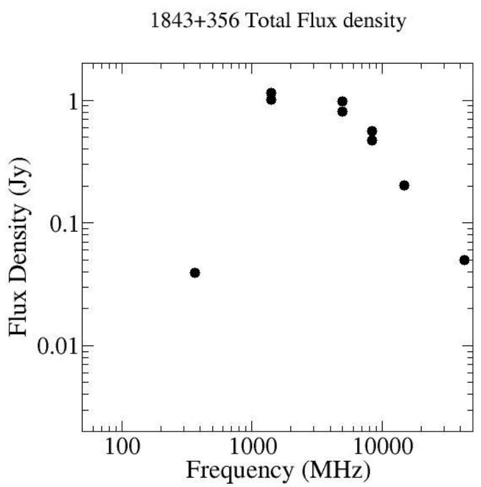
GPS: B=10-3 G, nu_b=100 GHz → t=2000 years
100 Mhz → t=70,000 years

CSS: B=10-4 G, nu_b=100 GHz → t=70,000 years
100 MHz → t=2 million years

"Compact Steep Spectrum" Radio Galaxies

- small radio sources (<1kpc) with steep spectral index: really small (no shortened by projection effects!)
- Morphologically similar to kpc-Mpc double-sided radio galaxies (i.e. they have mini-lobes and/or jets on scales 1pc – 1kpc).
- The centre of activity, the "core" has an inverted radio spectrum and does not dominate the radio emission at cm wavelengths





They are considered to be newly-born radio galaxies

CSS

Compact steep spectrum sources (=CSS)

≤1“ in size, steep spectrum , peak at ca. ≤100 MHz – not visible

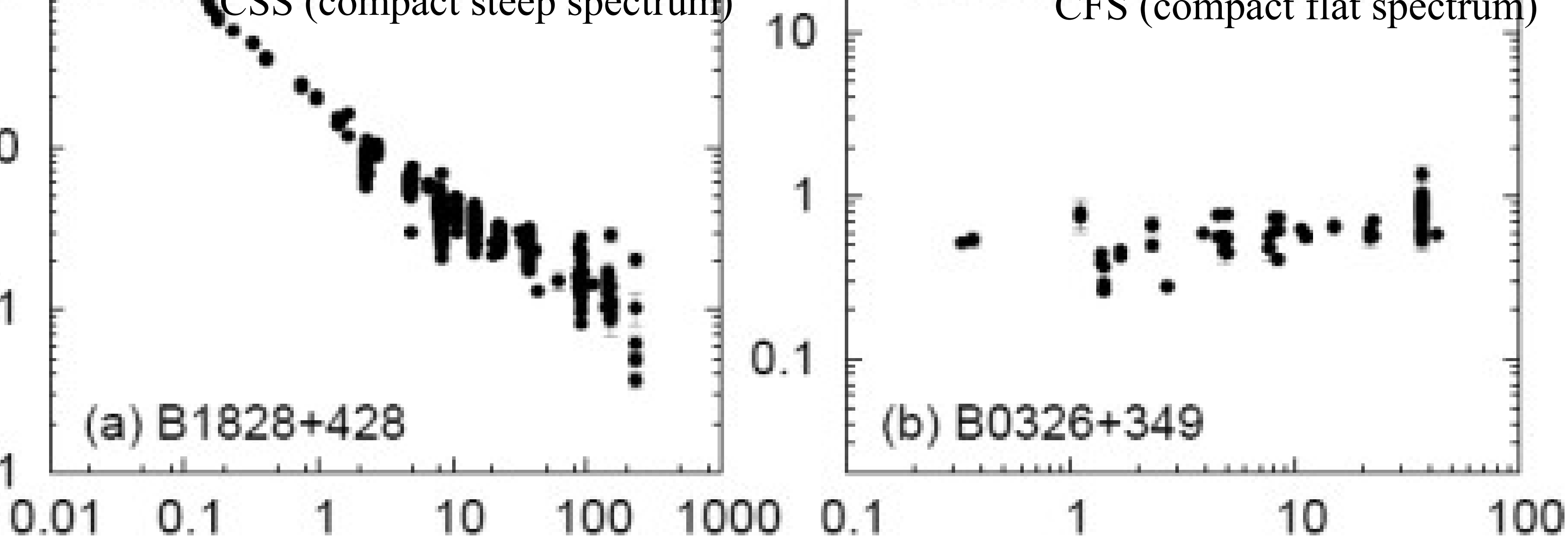
CSS sources are 10000-100.000 years old

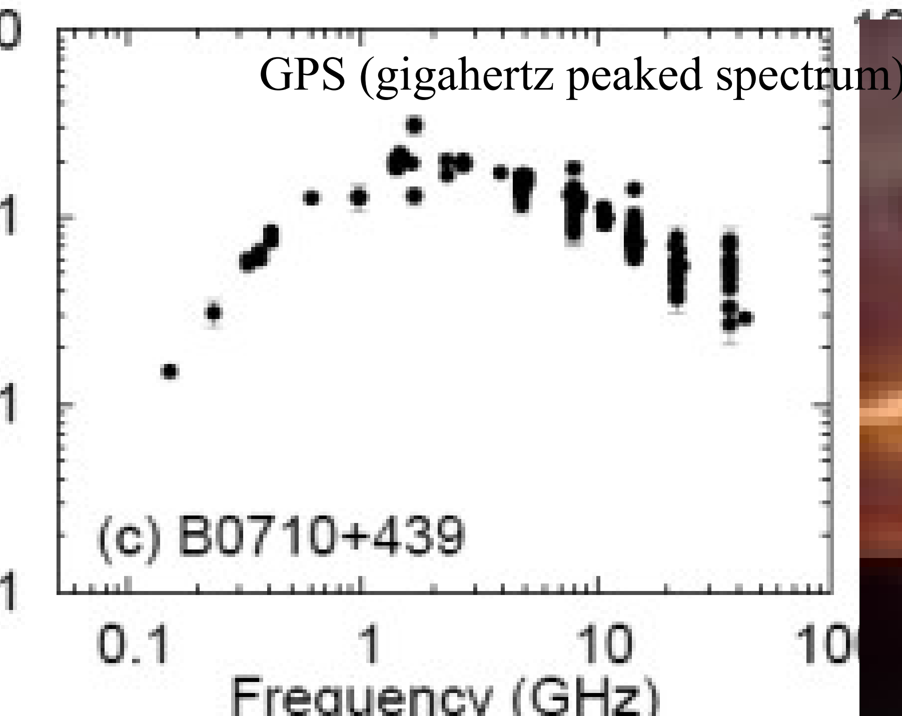
CFS

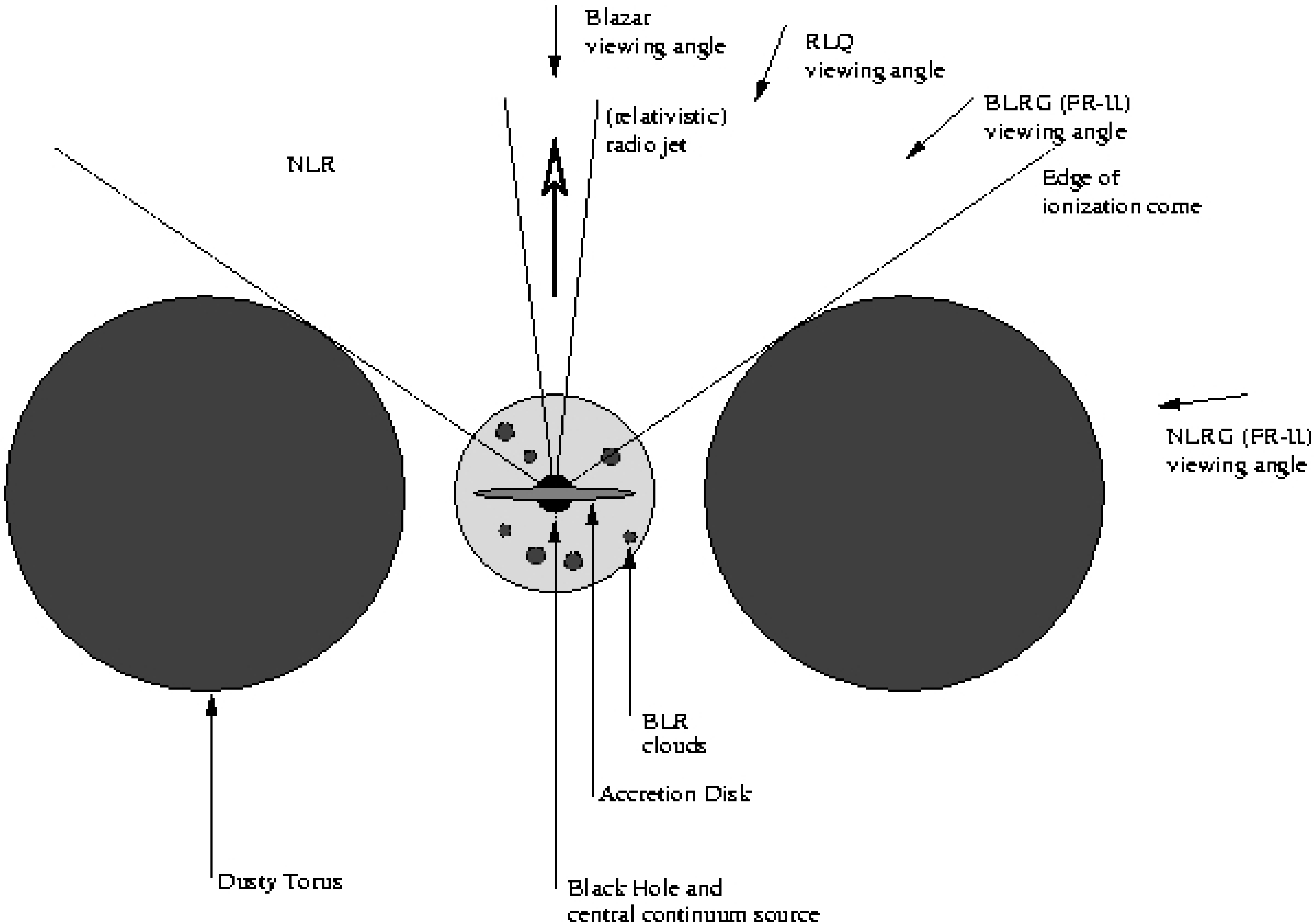
Compact flat spectrum (=CFS)

GPS

- Gigahertz peaked spectrum sources (=GPS)
  - Spectrum with convex form, peaks at ca. 1 Ghz
  - High frequency peakers (HFP)
    - Like GPS, peak at >5 Ghz
- GPS galaxies are young radio sources (~100-1000 years old)

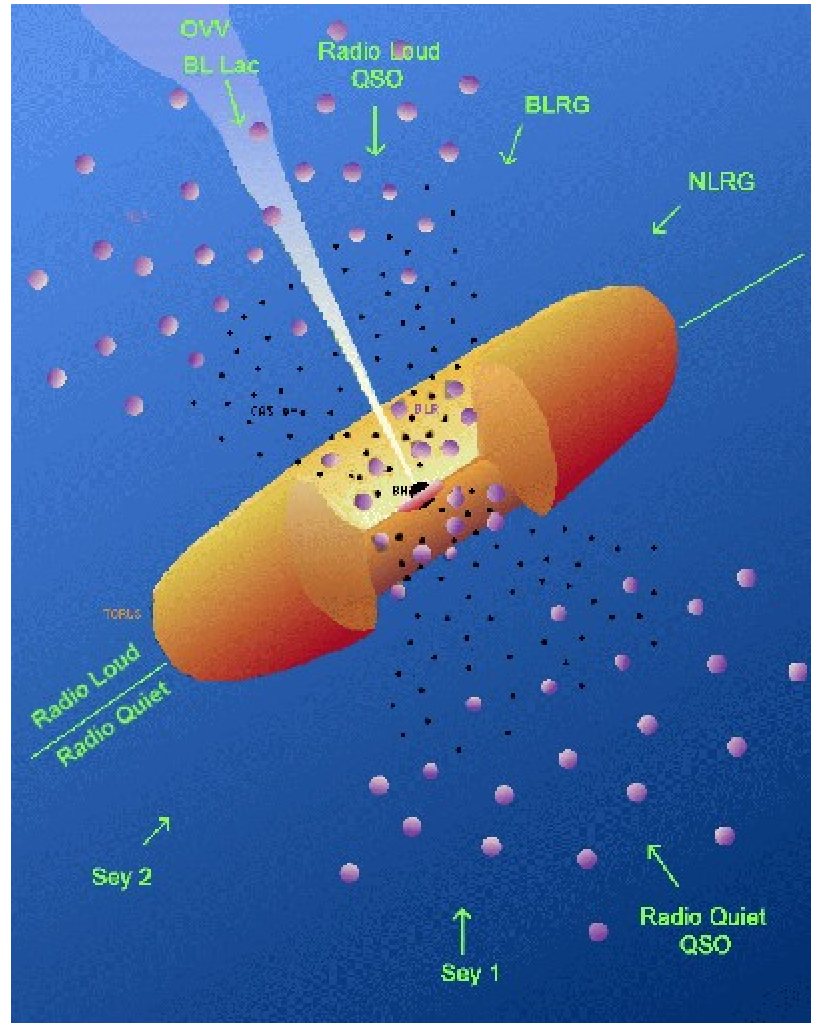

CSS (compact steep spectrum)
CFS (compact flat spectrum)
(a) B1828+428
(b) B0326+349


GPS (gigahertz peaked spectrum)
(c) B0710+439
Frequency (GHz)


Blazar
viewing angle
RLQ
viewing angle
BLRG (FR-II)
viewing angle
(relativistic)
radio jet
NLR
Edge of
ionization come
NLRG (FR-II)
viewing angle
BLR
clouds
Accretion Disk
Dusty Torus
Black Hole and
central continuum source

Different classifications.
The same object!

- Blazars
  - BL Lacs
  - OVV
- Quasars
  - Radio Loud
  - Radio Quiet
- Radio
  - Narrow Line
  - Broad Line
- Seyfert
  - Type 1
  - Type 2



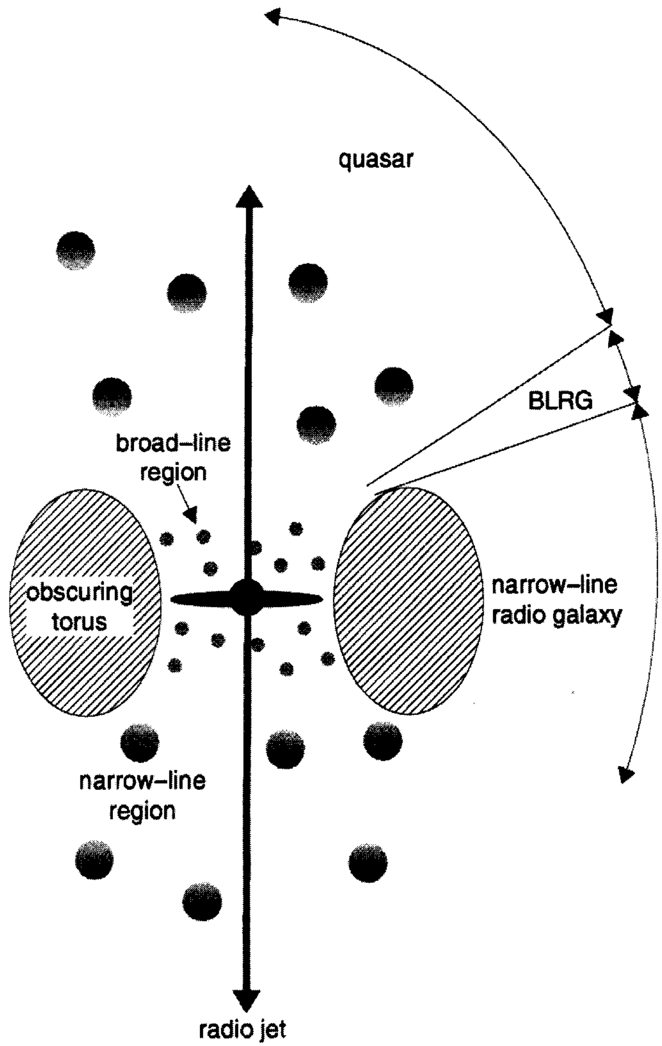
What do we need to start a radio galaxy?

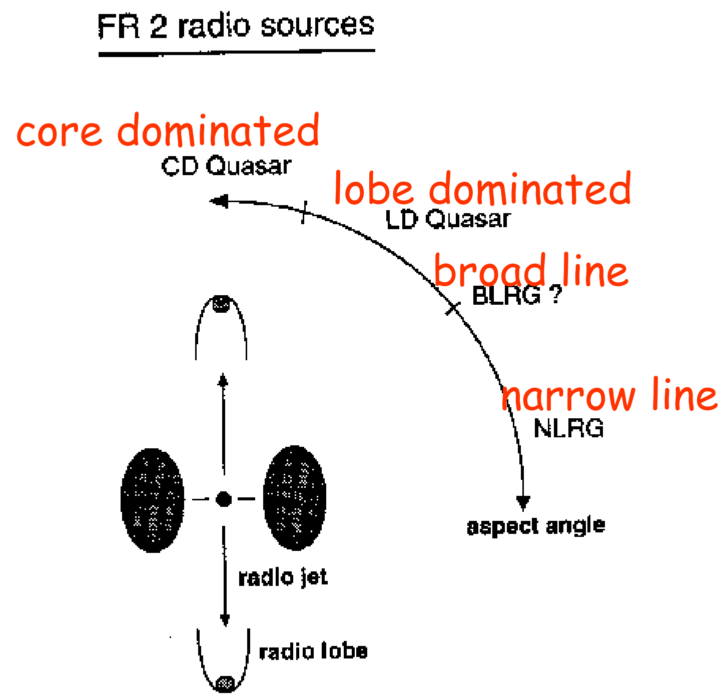
(or how do you make a black-hole active?)

- Supermassive BH seem to be common among big early-type galaxies: but only a minority are active.
- They need <u>fuel</u>!
- Interactions/merger can bring gas to the central regions to feed the monster!

Possibility: the AGN-phase (including the radio activity) is only a “short” period in the life of a galaxy.
Possibly, every galaxy goes through it.

Powerful radio galaxies





→ characteristics that are not orientation depended should be similar between powerful radio galaxies and quasars

Central

Type	Normal Galaxy	Radio Galaxy	Seyfert Galaxy	Quasar	Blazar
Examples	Milky Way	M87, Cygnus A	NGC4151	3C273	BL Lac, 3C279
Galaxy Type	Spiral	Elliptical, irregular	Spiral	Irregular	Elliptical?
Luminosity (Solar units)	$< 10^4$	$10^6 - 10^8$	$10^8 - 10^{11}$	$10^{11} - 10^{14}$	$10^{11} - 10^{14}$
Central Mass (Solar units)	2.6×10^6	3×10^9	$10^6 - 10^9$	$10^6 - 10^9$	$10^6 - 10^9$
Radio	Faint	Central object + jets +lobes	Only 5% are radio bright	Only 5% are radio bright	Bright, rapidly variable
Optical/IR	Totally obscured	Pop II stars continuum	Broad Emission lines	Broad Emission lines	Spectral lines weak or absent
X-rays	Faint	Bright	Bright	Bright	Bright
Gamma Rays	Faint	Faint	Moderate	Bright	Bright
Variability timescale	Unknown	Months - years	Hours – months	Weeks – years	Hours - years

Quasars

- Radio Quiet Quasars:
  - Strong emissions in both the optical and X-ray spectrums.
  - Within the optical spectrum, both broad and narrow emission lines are present, similar to a Type 1 Seyfert Galaxy.
  - Host is usually an elliptical galaxy. But less commonly, it might be a spiral.
- Radio Loud Quasars:
  - All the same characteristics of a Radio Quiet Quasar with the addition of having strong radio emissions.

Quasars

First discovered in the 1960s.

Detected radio sources with optical counterparts appearing as unresolved point sources.

Unfamiliar optical emission lines.

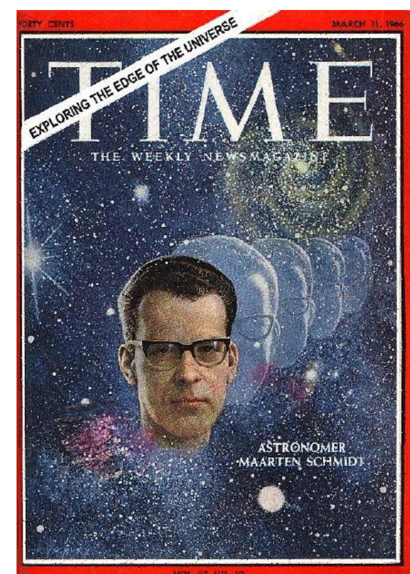
Maartin Schmidt was the first to recognize that these lines were normal Hydrogen lines seen at *much* higher redshifts than any previously observed galaxies.

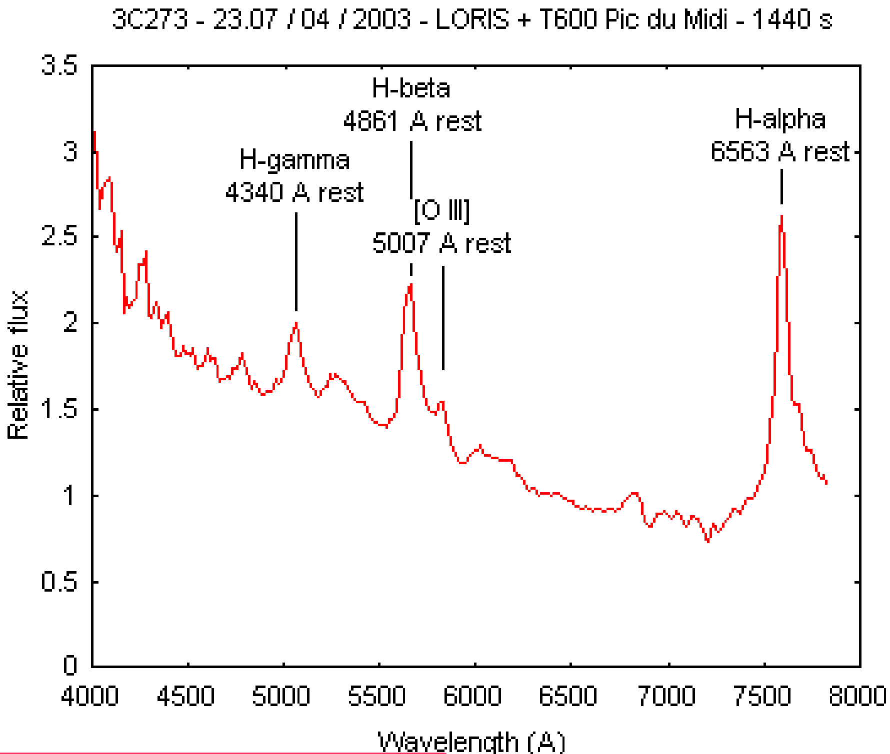
D = 660 Mpc (2.2 billion light years) for 3C273

1340 Mpc (4.4 billion light years) for 3C 48

$L = 2 \times 10^{13}\ L_{sun}$ for 3C273.

- Within ~2 years, quasars were discovered with: $z > 2$ and $L \approx 10^{14}\ L_{sun}$
- *Most distant QSO discovered today - z = 6.42*





λ_{emit} wavelength emitted by the source

$$z = \frac{\lambda_{obsv} - \lambda_{emit}}{\lambda_{emit}}$$

$$1 + z = \frac{\lambda_{obsv}}{\lambda_{emit}}$$

$$z = \frac{f_{emit} - f_{obsv}}{f_{obsv}}$$

$$1 + z = \frac{f_{emit}}{f_{obsv}}$$

$$\boxed{1 + z = \frac{1 + v\cos(\theta)/c}{\sqrt{1 - v^2/c^2}}}$$

for motion solely in the line of sight (θ = 0°), this equation reduces to: $$1 + z = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}$$

For v<<c $\quad z \approx \frac{v_{\|}}{c}$

For the special case that the source is moving at right angles (θ = 90°) to the detector, the relativistic redshift is known as the transverse redshift: $$1 + z = \frac{1}{\sqrt{1 - v^2/c^2}}$$

3C 273 is one of the closest quasars with a redshift, z, of 0.158 (spectral lines shifted to the red by 16 %)
It is also one of the most luminous quasars known, with an absolute magnitude of -26.7

Quasars

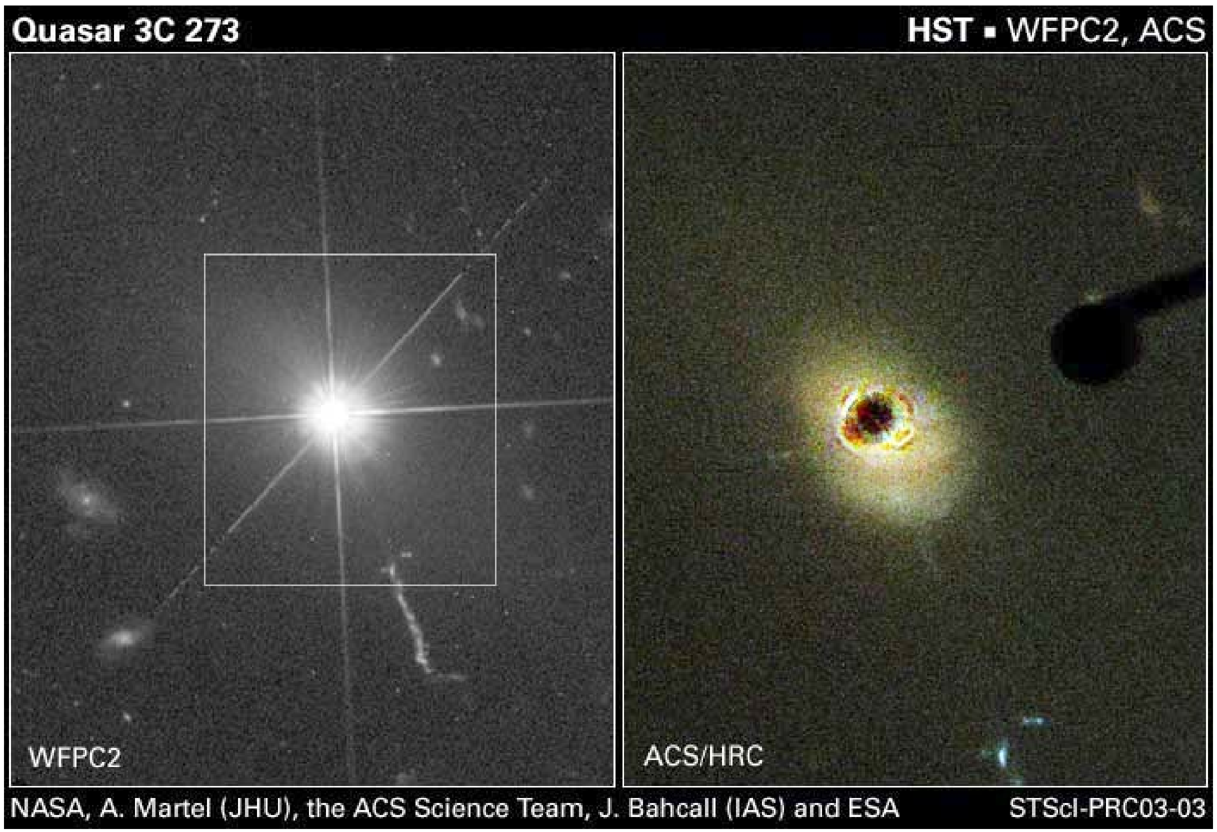
- $M_B < -23$, strong nonthermal continuum, broad permitted ($\sim 10^4$ km/s) and narrow forbidden ($\sim 10^{2-3}$ km/s) emission lines

  - Radio quiet (RQQ): elliptical or spiral host galaxies
  - Radio loud (RLQ): 5-10% of all quasars, elliptical hosts

- Broad Absorption Lines (BAL) Quasars: normal quasars seen at a particular angle along the l.o.s. of intervening, fast-moving material.

  - High-ionization (HIBAL): Lyα, NV, SiIV, CIV
  - Low-ionization (LOBAL): AlIII, MgII

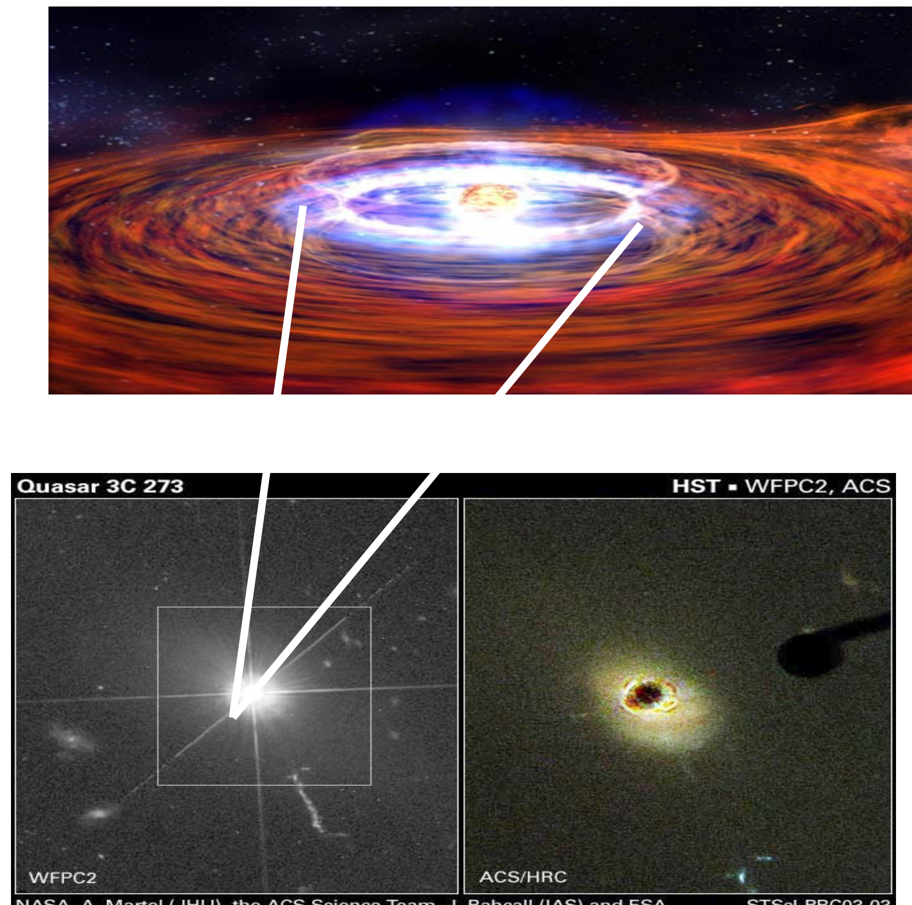
If we block out the light of luminous quasar, we can see evidence of an **underlying host galaxy**.
Quasar hosts appear to be a mixed bag of galaxy types - from disturbed galaxies to normal E’s and early type spirals.



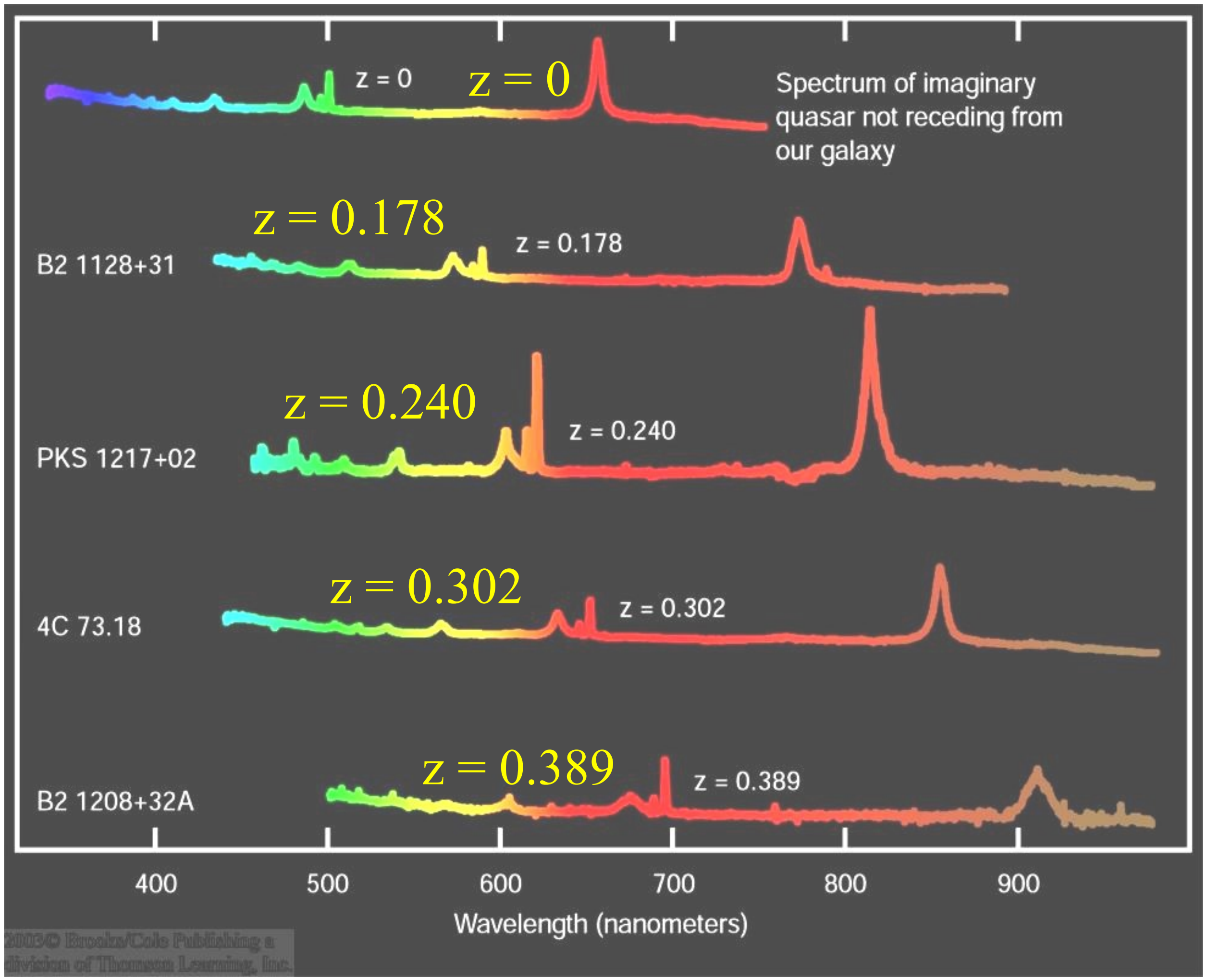
Quasars

$$M_{\mathbf{BH}} \sim 10^{9} M_{\mathrm{Sun}}$$

$$L_{\mathrm{Quasar}} \sim 10^{13} L_{\mathrm{Sun}} = 100\, L_{\mathrm{Galaxy}}$$



Quasar Red Shifts



Quasars have been detected at the highest red shifts, up to

$z \sim 6$

$$\boxed{z = \Delta\lambda/\lambda_0}$$

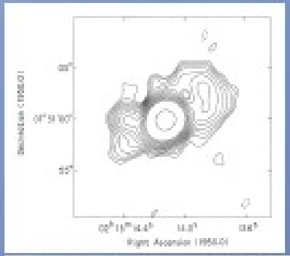
Major types of radio-loud quasars

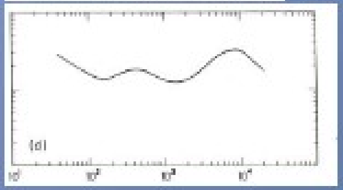
Flat spectrum radio quasar (FSRQ)

* Flat radio spectrum integrated emission
* Core dominated
* Often rapidly variable:

  Optically violent variable (OVV)

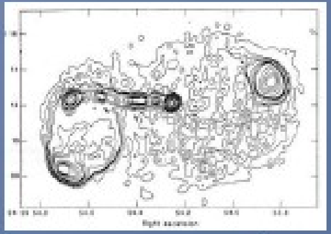
  or Blazar

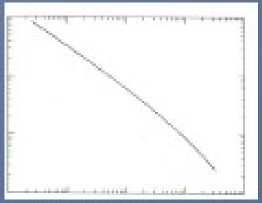




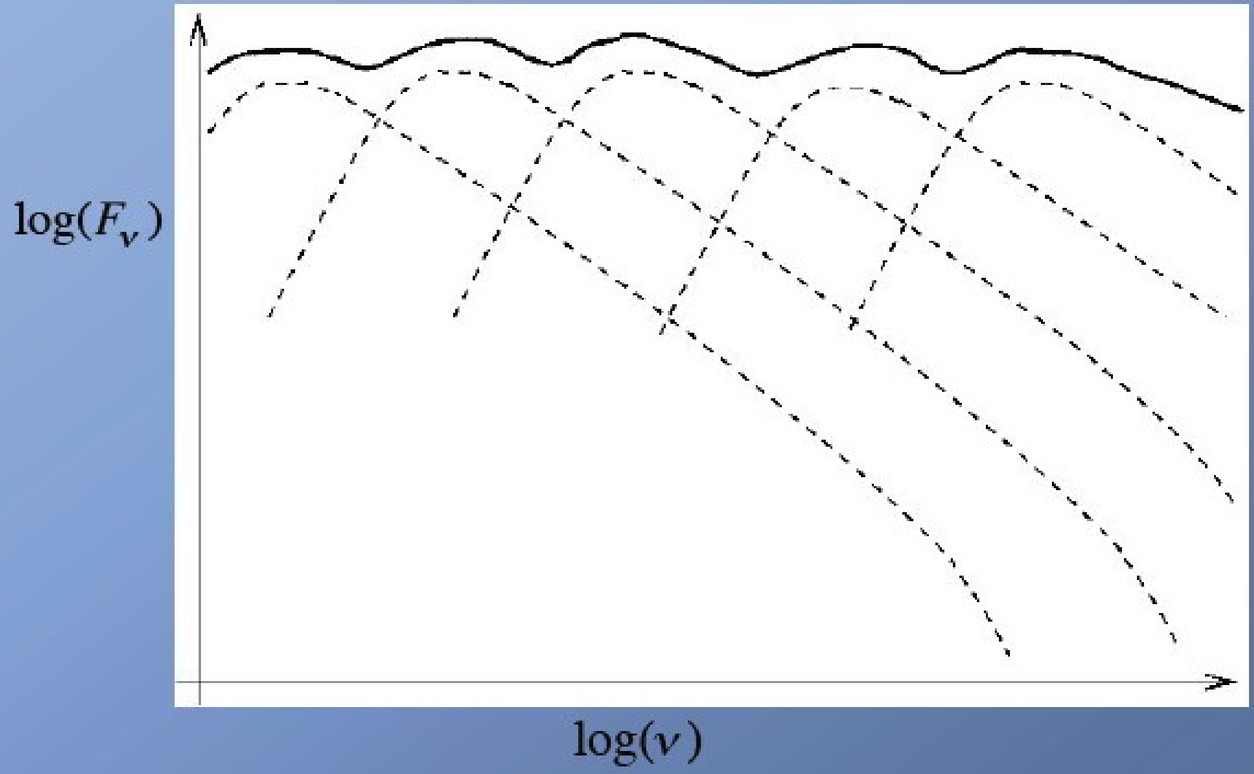
Steep spectrum radio quasar (SSRQ)

* Steep radio spectrum integrated emission
* Dominated by core and jet emission



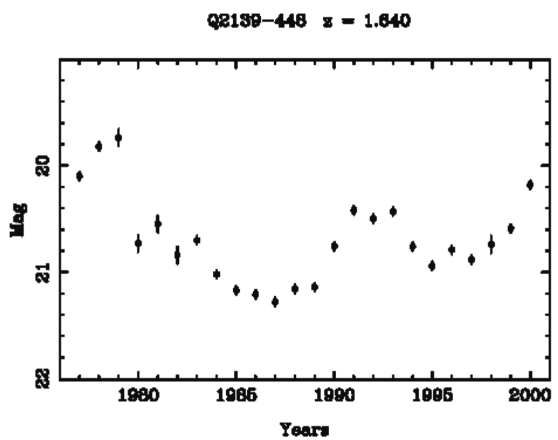


Steep spectrum/flat spectrum components

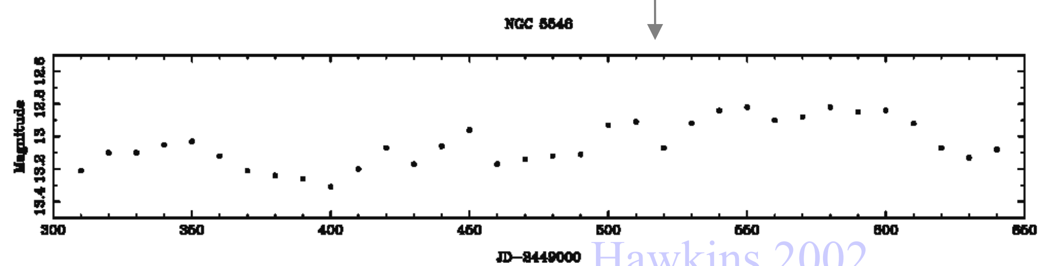


Variability in AGNs

QSOs and Seyfert nuclei have long been recognized as variable
Optical flux changes occur on timescales of months to years
Cause of variability? – instabilities in accretion disk, SN or starbursts, microlensing…..



Quasar light curve ~25 years
Seyfert light curve over ~11 months

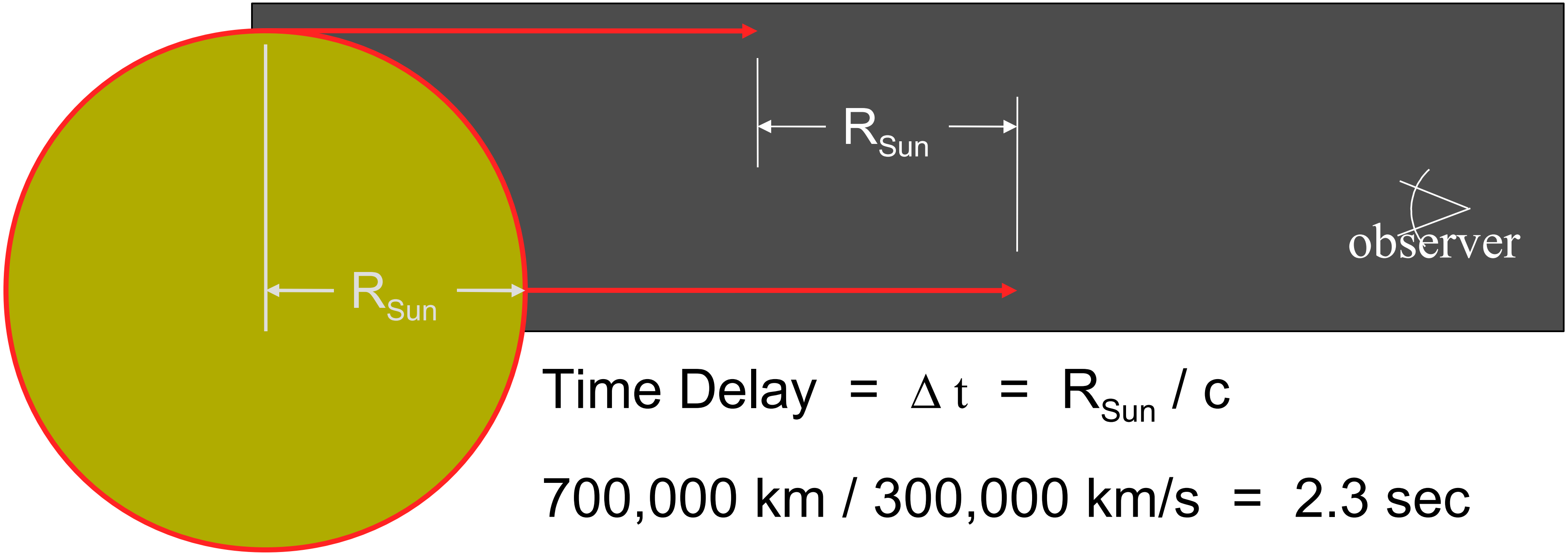


Hawkins 2002

Variability occurs at most wavelengths - X-rays through radio. This indicates that the fluctuations are originating from a very tiny object.

Why does rapid variability indicate small physical size of the emitting object?

Consider an object like the Sun. Any instantaneous flash would appear "blurred" in time by $\Delta t = R_{Sun} / c$.



Time Delay $= \Delta t = R_{Sun} / c$

700,000 km / 300,000 km/s = 2.3 sec

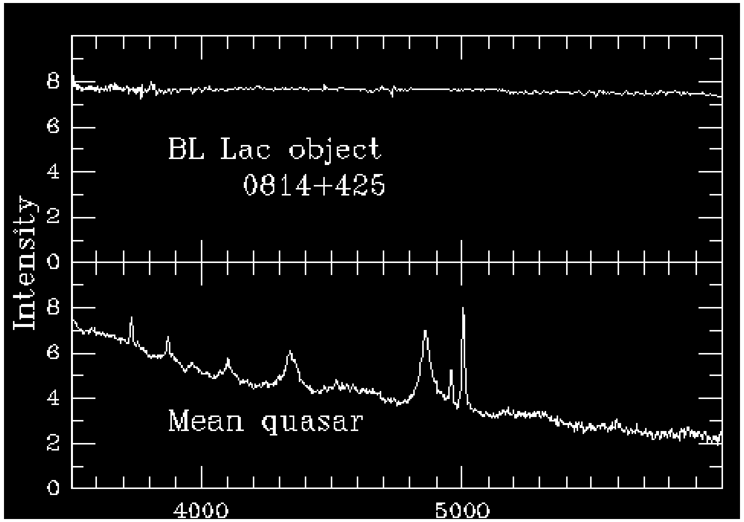
Seyfert continuum luminosity varies significantly in less than a year (some variation occurs on timescales of days or weeks.
This implies an emitting source less than a few light-weeks across!

Blazars

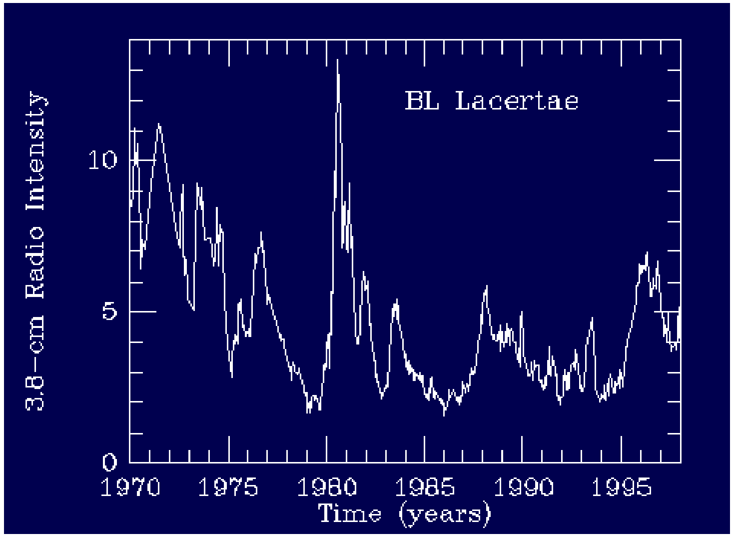
- Strongly variable, highly polarized nonthermal continua, weak/absent emission lines
- Variability faster and higher amplitude than normal quasars and Seyferts
    - BL Lac - high polarization

    - OVVs (Optically Violent Variables) - lower polarization, emission line EW decreases as continuum brightens

Spectrum



Light Curve



* 'Blazars' (BL Lac objects and OVV quasars). These classes are distinguished by rapidly variable, polarized optical, radio and X-ray emission. BL Lac objects show no optical emission lines, broad or narrow, so that their redshifts can only be determined from features in the spectra of their host galaxies.

OVV quasars **behave more like standard radio-loud quasars** with the addition of a rapidly variable component.

In both classes of source, the variable emission is believed to originate **<u>in a relativistic jet oriented close to the line of sight.</u>** Relativistic effects amplify both the luminosity of the jet and the amplitude of variability.

BL-Lac objects

Firstly detected by Cuno Hoffmeister in 1929

1968: detected as strong radio source

Angle between jet axes and observing direction is very humble (direct view into the jet)

Continuous spectrum <u>without</u> absorption- and emissionlines

Strong emission in gamma-rays

- Characteristics of both classes of Blazars:
  - Blazars are strong sources of high energy emissions (energies greater than 100 MeV). However they are luminous over the entire range of the spectrum, from radio up through gamma emission.
  - The host galaxies of Blazars are often Giant Elliptical galaxies.

Blazars

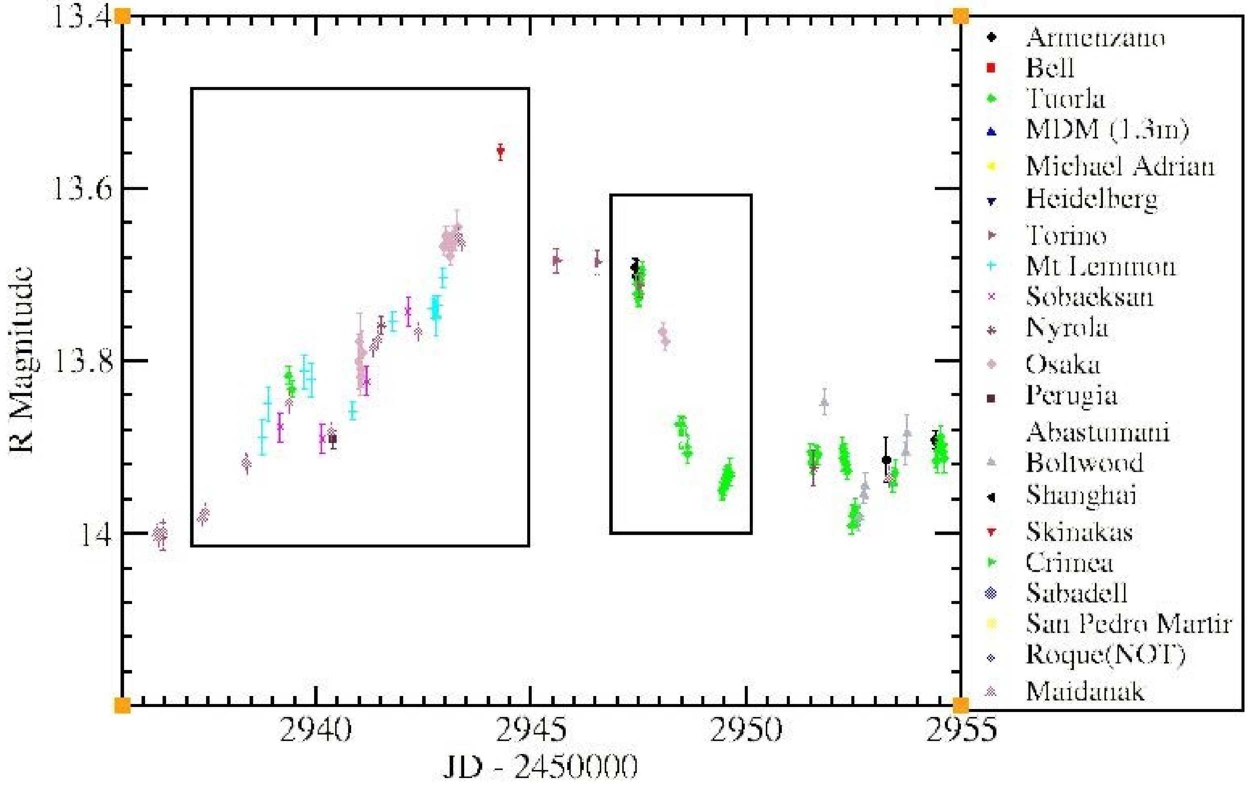
Light curves of the

BL Lac object 3C66A

Highest luminosities of all active galaxies

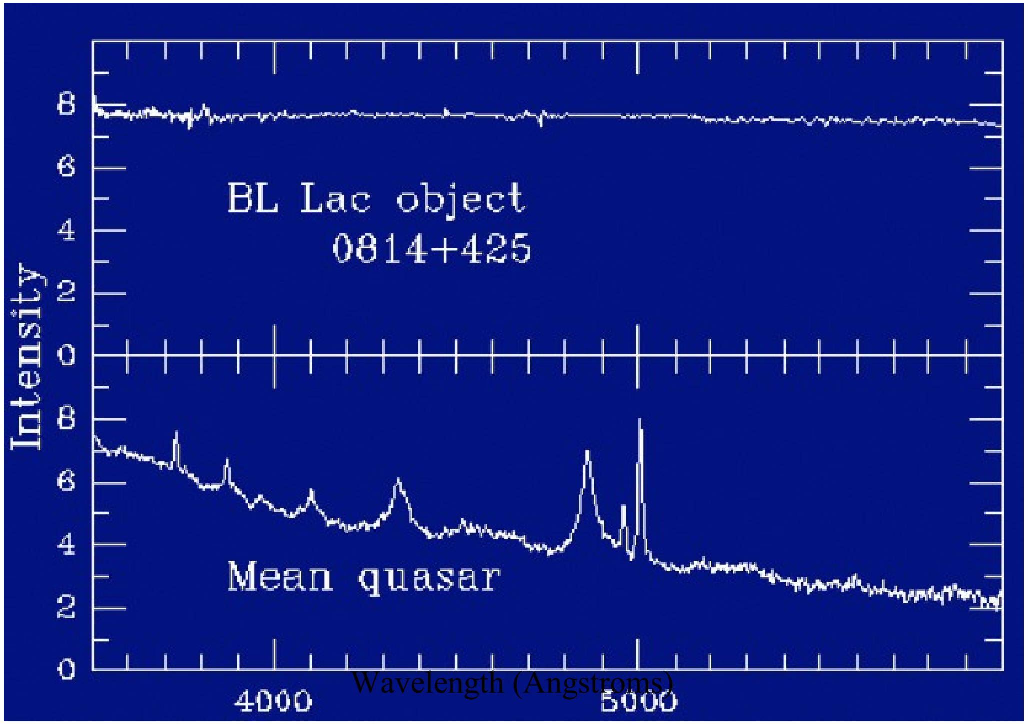
Variable on very short time scales (a few hours)

Sources of very strong X-ray and gamma-ray emission



Comparison of BL Lac and quasar Emission Lines:

BL Lac emissions shown on top, emission of a quasar shown below.
Note: The BL Lac has no emission lines.



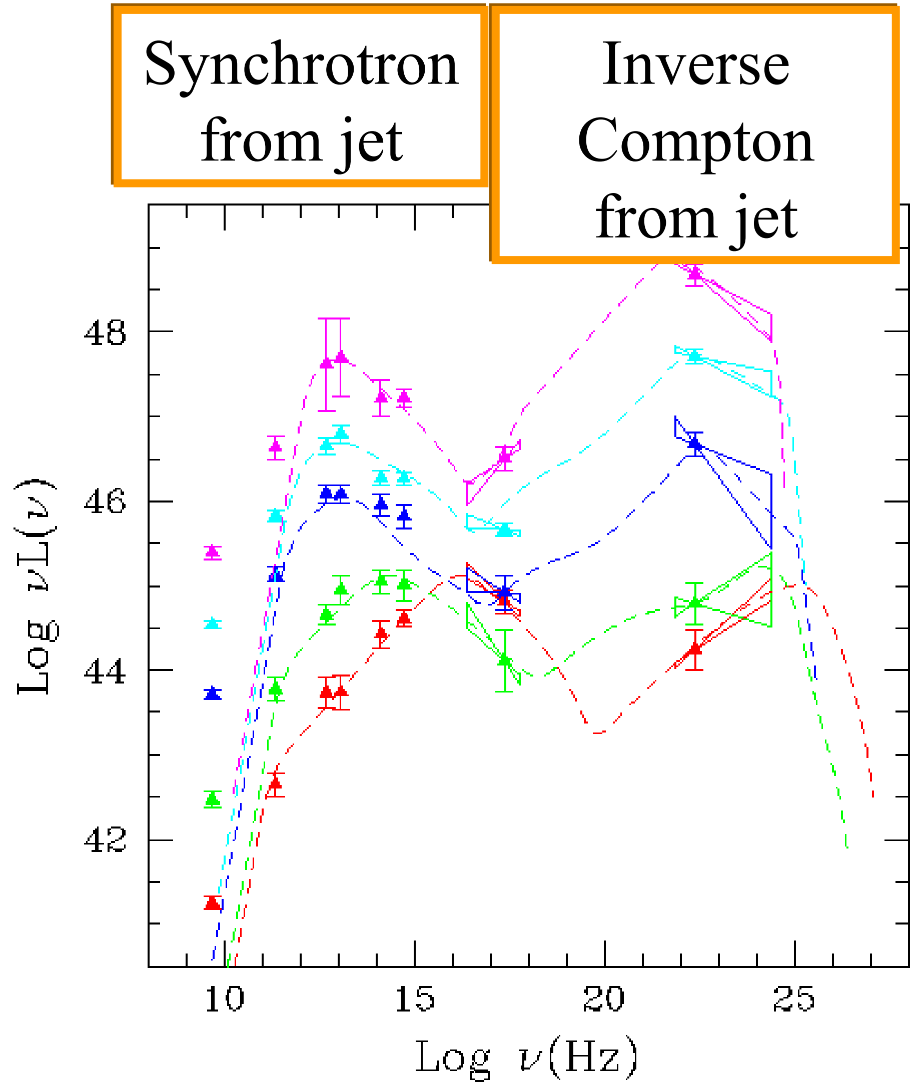
BL Lac

named after BL Lacertae, first identified example found in the constellation Lacerta and originally thought to be a variable star) www.astro.isas.ac.jp/conference/bh2003/program/ppt/20031029am/KyotoBH2003_Falcke.ppt

BL Lacs – A Pure Jet Spectrum

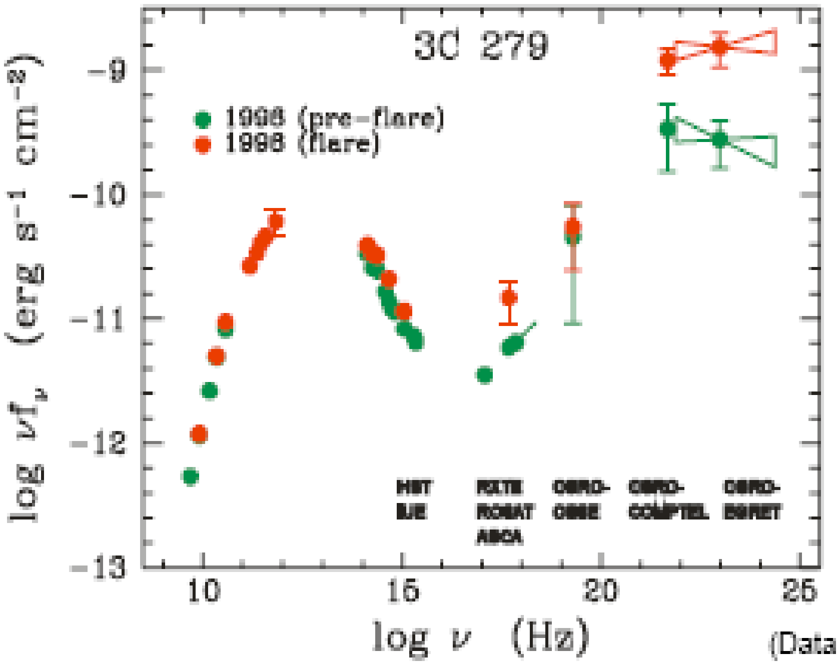
- **BL Lacs are thought to be beamed FRI radio galaxies (low power!)**
- In BL Lacs the emission is dominated by the jet due to **relativistic beaming.**
- But there is also **no** evidence for any disk spectrum.
- The jet spectrum resembles a „camel‘s back“.
- Radio – optical – X-rays: synchrotron from jet
- X-ray – TeV: inverse Compton from inner jet

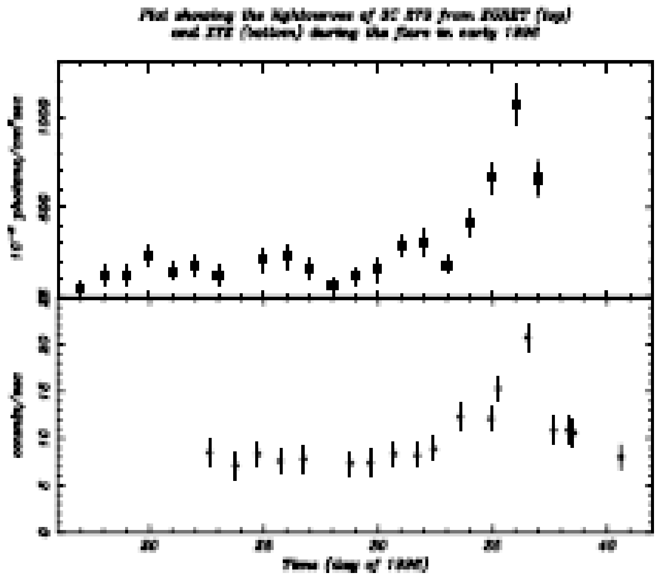
– **“Two-component” spectrum**
  - Lo freq. peak ranges from < IR ⇒ X
  - Hi freq. peak at GeV ⇒TeV



Fossati et al. (1998)

Broad-band spectrum and time variability of the archetypal GeV blazar 3C279 in 1996



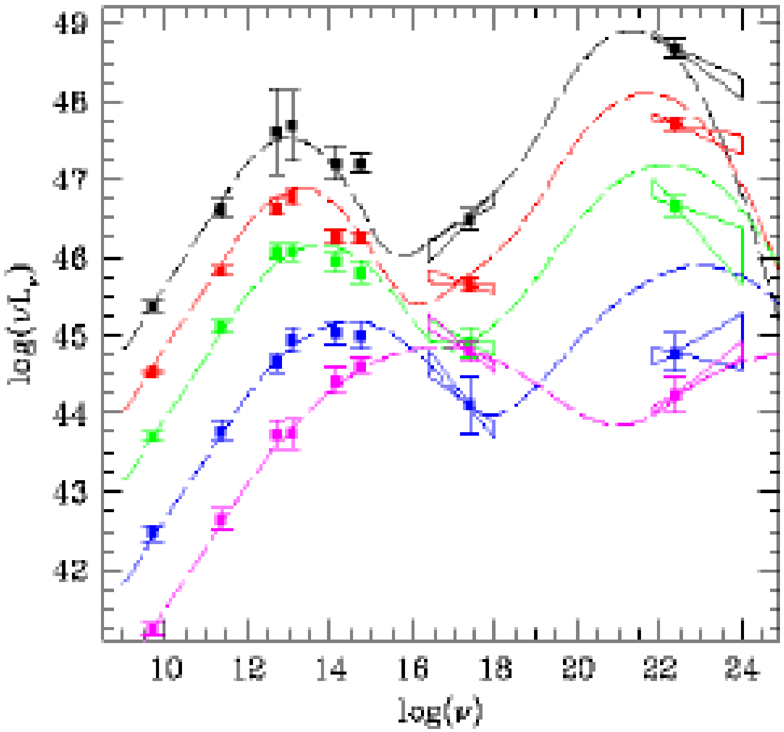


(Data from Wehrle et al. 1998)

* GeV emission dominates the observed flux -> blazars are "extreme accelerators"

* Correlated variability on day time scales is common

The “blazar sequence”



* Work by G. Fossati, G. Ghisellini, L. Maraschi, others (1998 and on)

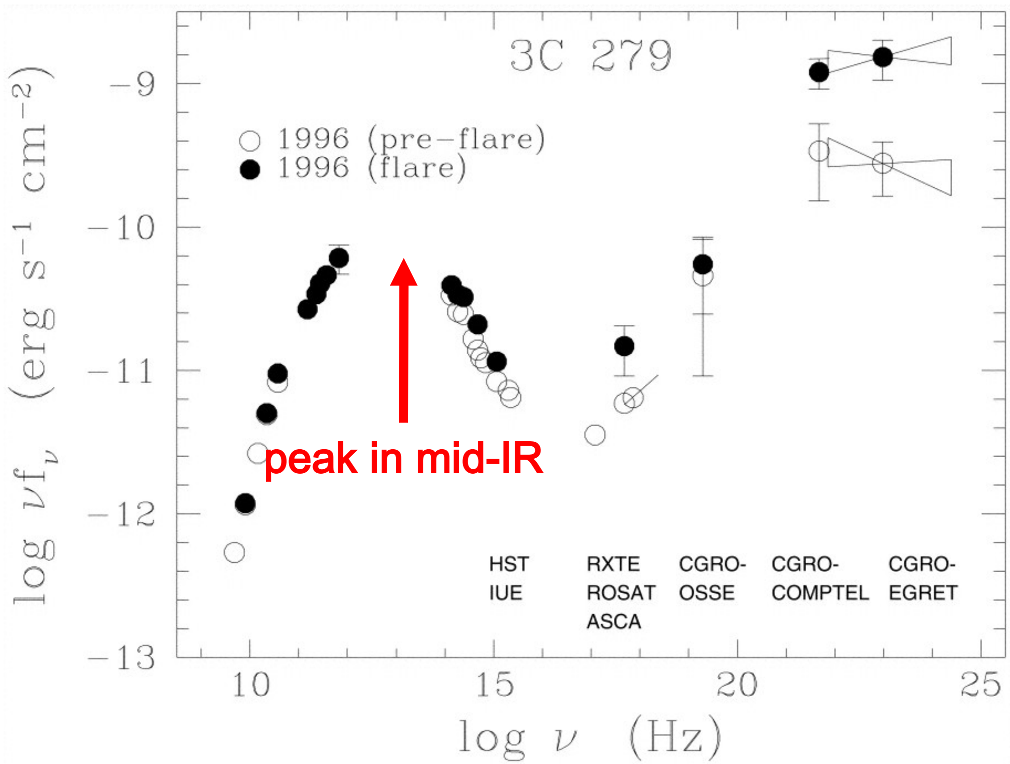
* Multi-frequency data on blazars reveals a “progression” –

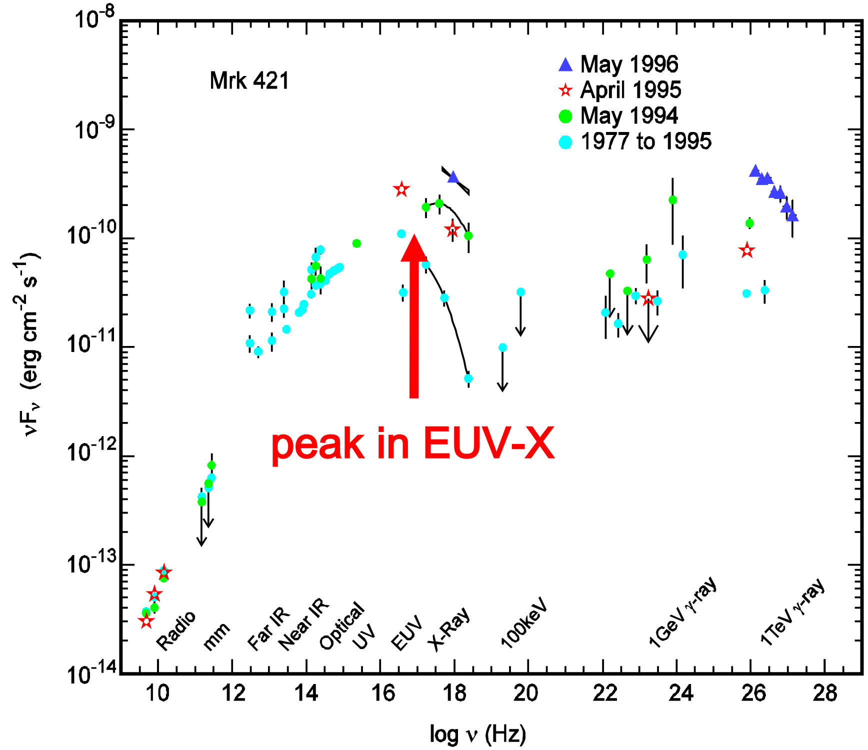
* As the radio luminosity increases:

  - Location of the first and second peaks moves to lower frequencies

  - Ratio of the luminosities between the high and low frequency components increases

  - Strength of emission lines increases


3C 279
1996 (pre-flare)
1996 (flare)
peak in mid-IR
HST
IUE
RXTE
ROSAT
ASCA
CGRO-
OSSE
CGRO-
COMPTEL
CGRO-
EGRET
log νf_ν (erg s^-1 cm^-2)
log ν (Hz)


Mrk 421
May 1996
April 1995
May 1994
1977 to 1995
peak in EUV-X
Radio
mm
Far IR
Near IR
Optical
UV
EUV
X-Ray
100keV
1GeV γ-ray
1TeV γ-ray
νF_ν (erg cm^-2 s^-1)
log ν (Hz)

BLAZARS

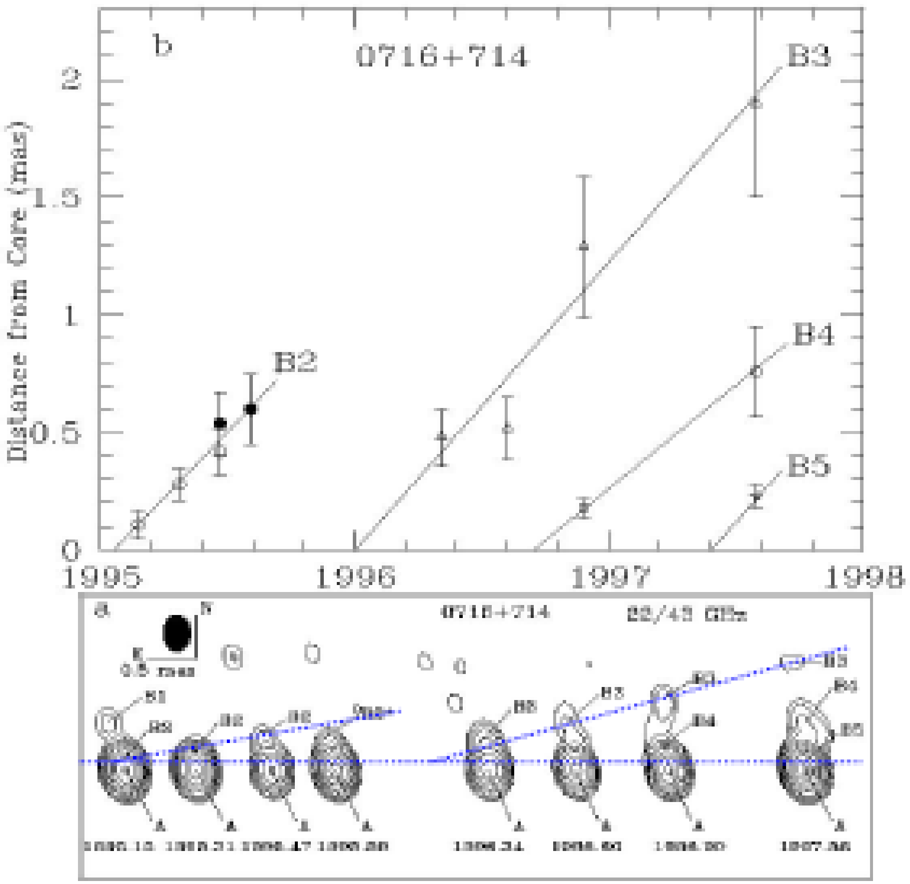
“Two-component” spectrum

- Lo freq. peak ranges from < IR ⇒ X
- Hi freq. peak at GeV ⇒TeV

Rapid variability

- ~1 day with EGRET, limited by sensitivity
- Shorter var. seen at TeV in brightest cases

Example of VLBI superluminal expansion of a (potential) GLAST blazar: 0716+714



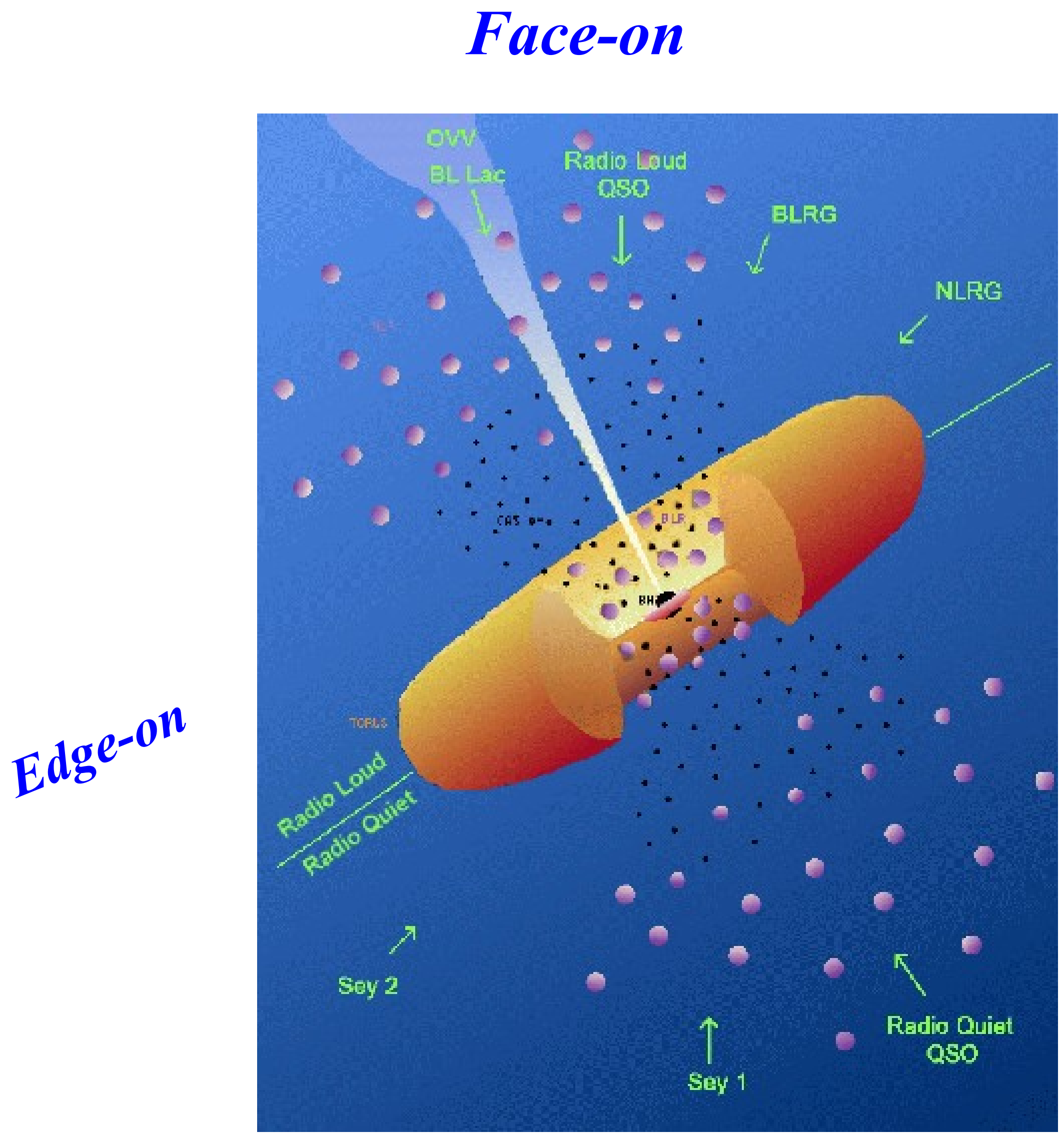
- All known EGRET blazars show powerful radio jets
- 0716+714 is just one example, - most bright EGRET blazars are monitored with VLBI (Jorstad et al. 2001)
- Lorentz factors Γ of jets inferred from VLBI (multi-parsec scales) can be compared against Γ inferred from variability (sub-parsec scales)
- -> Γ_{jet} as a function of distance from the black hole? - > constraints on acceleration process of the jet

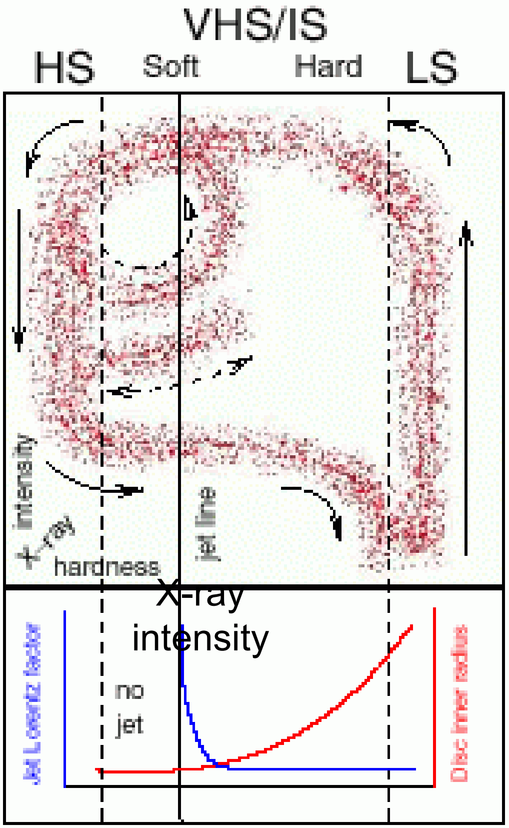
Differences due to geometry:
In the standard unification model for AGNs, a dusty torus covers a significant portion of the viewing angles to the accretion disk

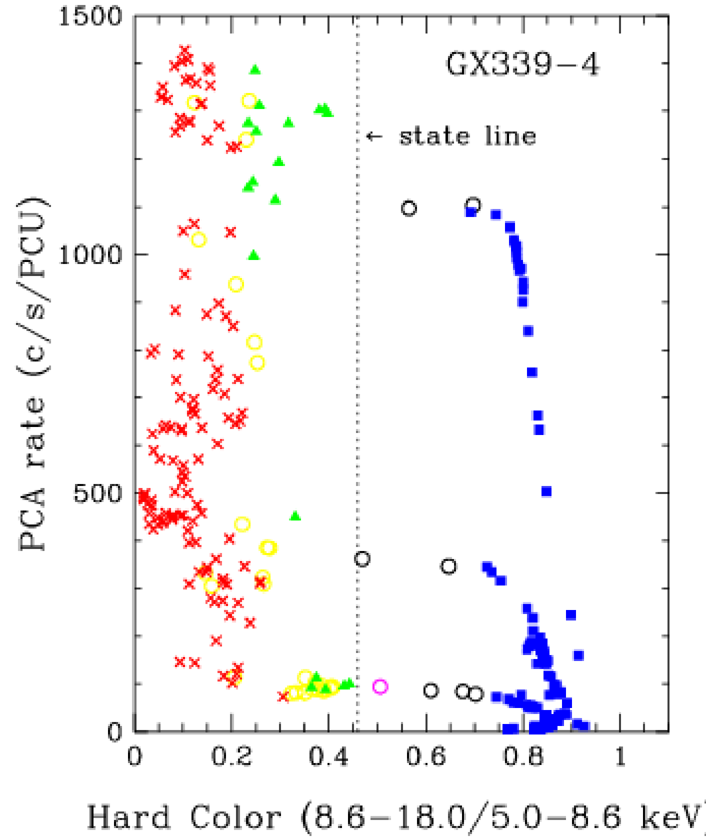
Intrinsic differences:
In X-ray binary sistems, the differences are due to variations in the accretion disk.

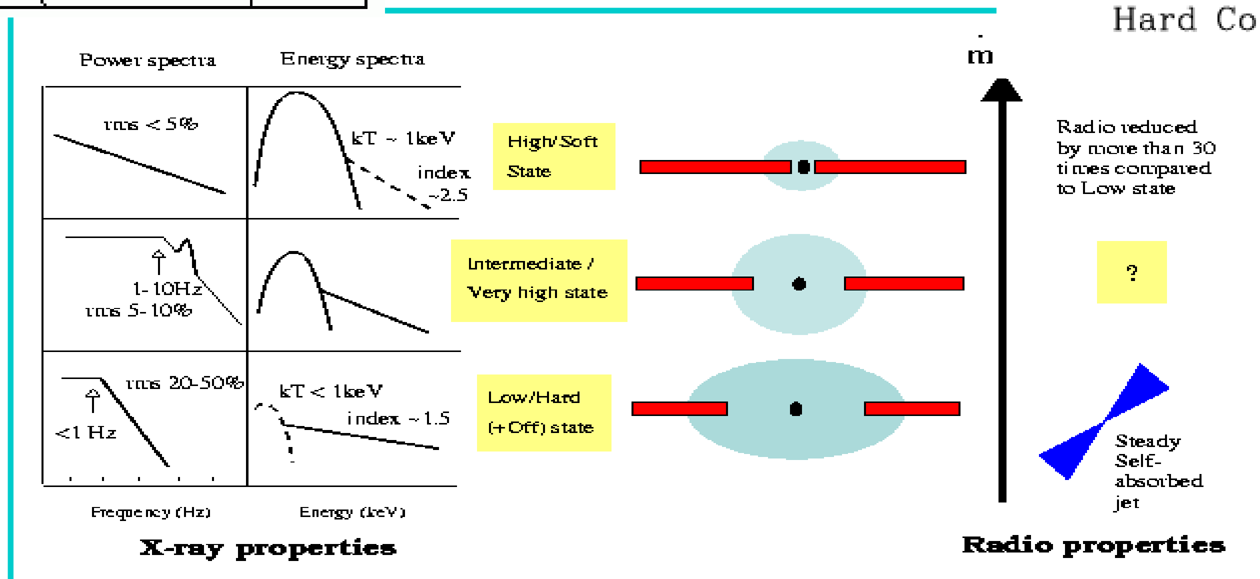
The same object! Different viewing angle to obscuring torus

- Blazars
  - BL Lacs
  - OVV
- Quasars
  - Radio Loud
  - Radio Quiet
- Radio
  - Narrow Line
  - Broad Line
- Seyfert
  - Type 1
  - Type 2



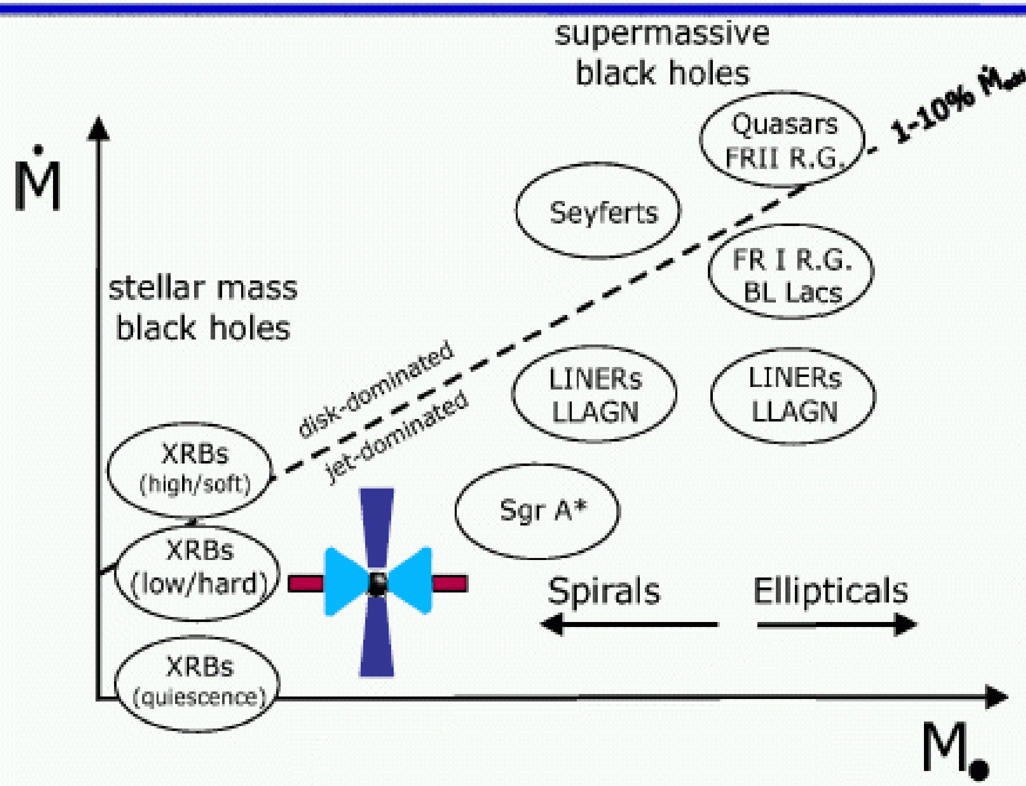

VHS/IS
HS
Soft
Hard
LS
X-ray intensity
hardness
jet line
X-ray
intensity
no
jet
Jet Lorentz factor
Disc inner radius


GX339−4
← state line
PCA rate (c/s/PCU)
Hard Color (8.6−18.0/5.0−8.6 keV)
1500
1000
500
0
0
0.2
0.4
0.6
0.8
1


Power spectra
Energy spectra
rms < 5%
kT ~ 1keV
index ~2.5
High/Soft State
1-10Hz
rms 5-10%
Intermediate / Very high state
rms 20-50%
<1 Hz
kT < 1keV
index ~1.5
Low/Hard (+Off) state
Frequency (Hz)
Energy (keV)
X-ray properties
ṁ
Radio reduced by more than 30 times compared to Low state
?
Steady Self-absorbed jet
Radio properties

http://www.mpifr-bonn.mpg.de/bonn04/presentations/koerding.pdf

Power Unification of Compact Objects



Falcke, Koerding, Markoff (2004)

Main parameters: orientation, BH mass, accretion power

Classification through broadband SED properties:
Lines, "big blue bump", ADAF signatures

All jet dominated sources should be described with the same model.

Körding E. (2007) Ap&SS

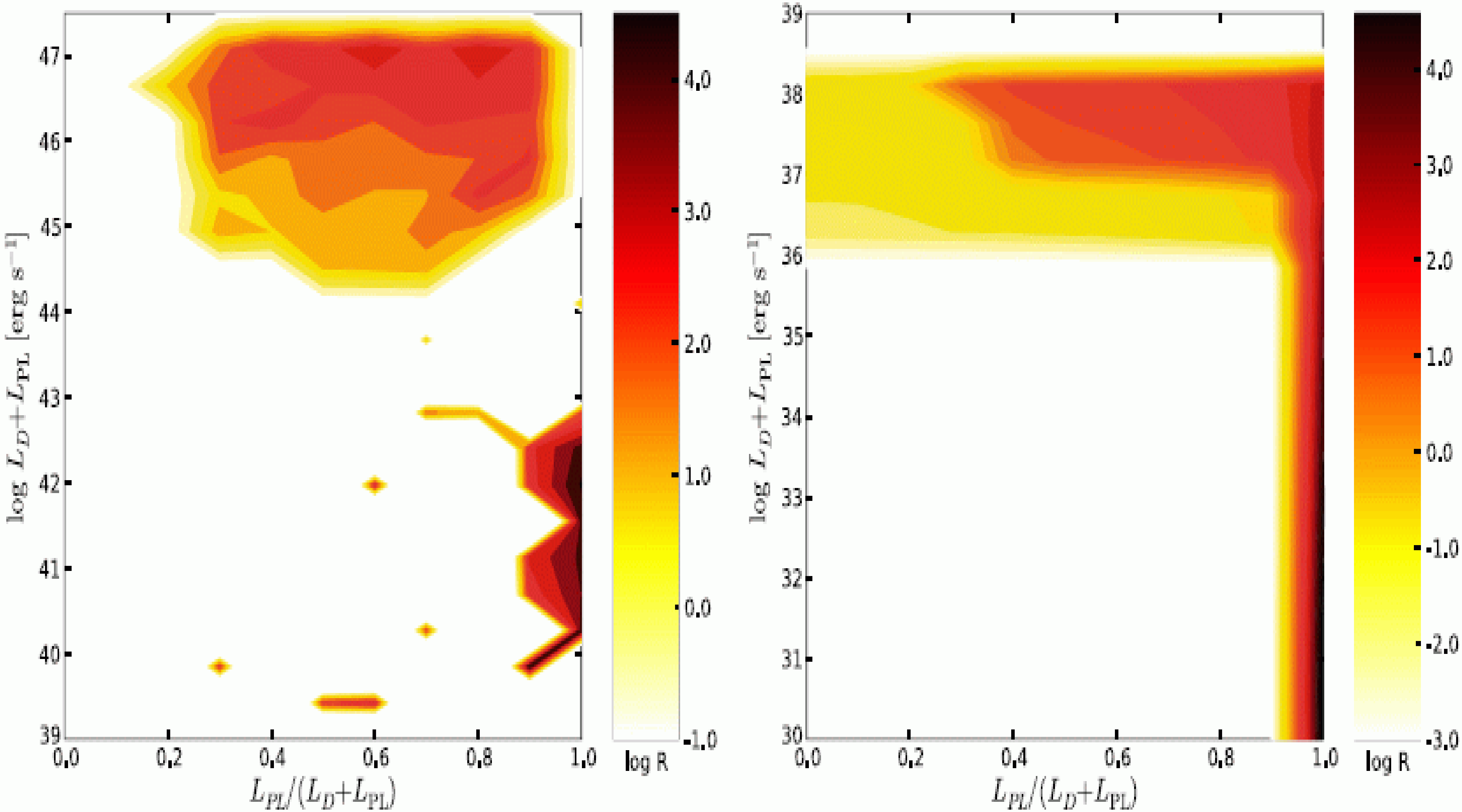


Fig. 4 Average radio loudness as a function of the position on the DFLD. *Left panel*: SDSS sample together with a low-luminosity sample. *Right panel*: Monte Carlo simulation of 100 XRB outbursts

against the X-ray hardness (e.g, counts in a hard band divided by counts in a soft band). A sketch of such a diagram is shown in Fig. 3. Jet launching hard state objects are found on the right side of the diagram while soft state objects are found on the left side. During the transition from a hard to a soft state, the source first enters the hard IMS—associated with an increasingly unstable jet, which is quenched once the source moves to the soft IMS crossing the so called "jet line" (Fender et al. 2004).

As an important check of XRB-AGN unification, we consider whether we can identify accretion states in an equivalent diagram for AGN. One of the reasons why HIDs work

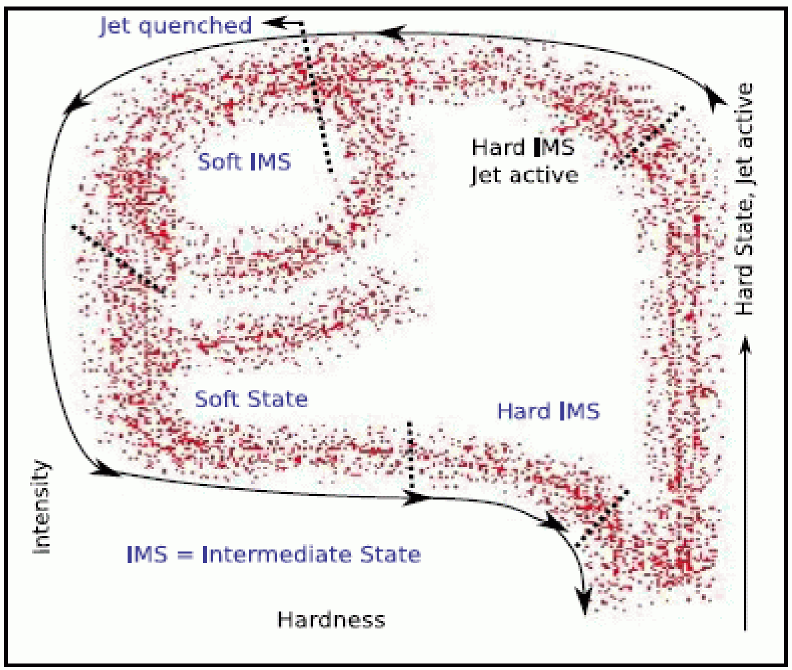


Fig. 3 Sketch of an hardness-intensity diagram. On the X-axis we plot the X-ray color while the Y-axis corresponds to the total measured counts ($\propto$ flux)

for XRBs is that both the power-law contribution (due to Comptonization or jet emission) and the disc emission is found in the X-ray band. The hardness measure compares the blackbody flux to the power law flux. However, for AGN the disc contribution is in the optical or the UV. We therefore have to generalise the hardness measure to the non-thermal fraction, a ratio of the power law flux to the total flux:

$$f = \frac{L_{PL}}{L_{PL} + L_D}, \tag{5}$$

where L_D is the disc luminosity and L_{PL} is the power law luminosity. For XRBs both quantities can be measured in the X-rays. For AGN the power law luminosity is still measurable in the X-ray band, but the disc emits in the optical or UV. We will refer to plots showing the total luminosity $(L_D + L_{PL})$ as a function of the non-thermal fraction as disc-fraction luminosity diagrams (DFLD).

To study the dependency of the jet emission on the position DFLD we crosscorrelate the quasars of the Sloan Digital Sky Survey (SDSS, data release 5) with the ROSAT all sky survey and the FIRST radio catalogue. For each source detected in the SDSS and by ROSAT we can calculate the non-thermal fraction. As a measure of the jet activity we use the radio-loudness parameter R defined as the ratio of the radio flux to the B-band flux. To extend the DFLD to lower luminosities we also include a sample of low-luminosity AGN with radio measurements from Nagar et al. (2005).

In the left panel of Fig. 4 we show a contour map of the radio loudness R as a function of the position in the DFLD. We have divided the diagram into 10×20 bins. For each bin we calculate the average R if there are more than 10 SDSS quasars in the bin.

The top part of the diagram is due to the SDSS quasars while the lower part is due to the low-luminosity AGN. In