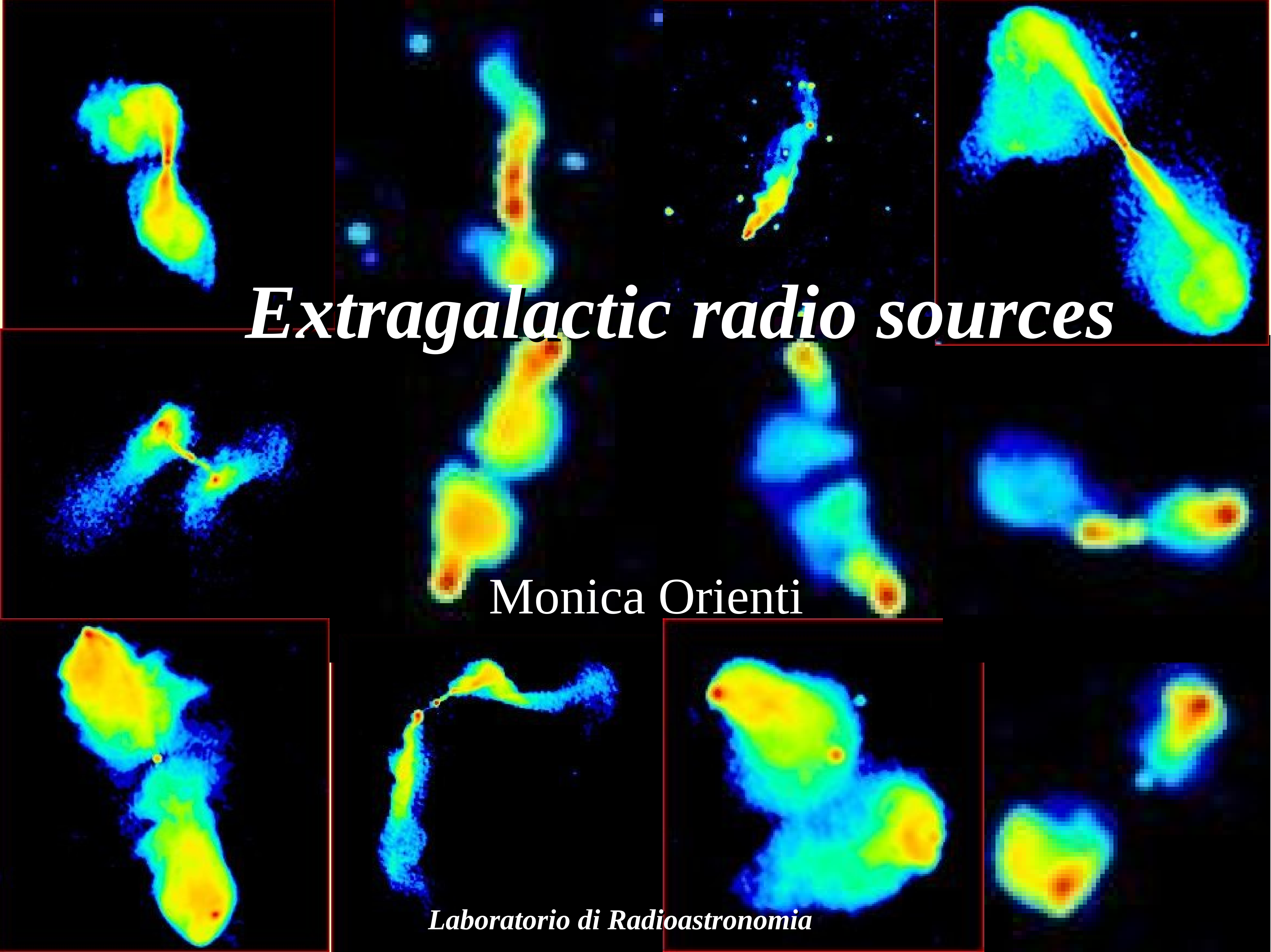
Extragalactic radio sources

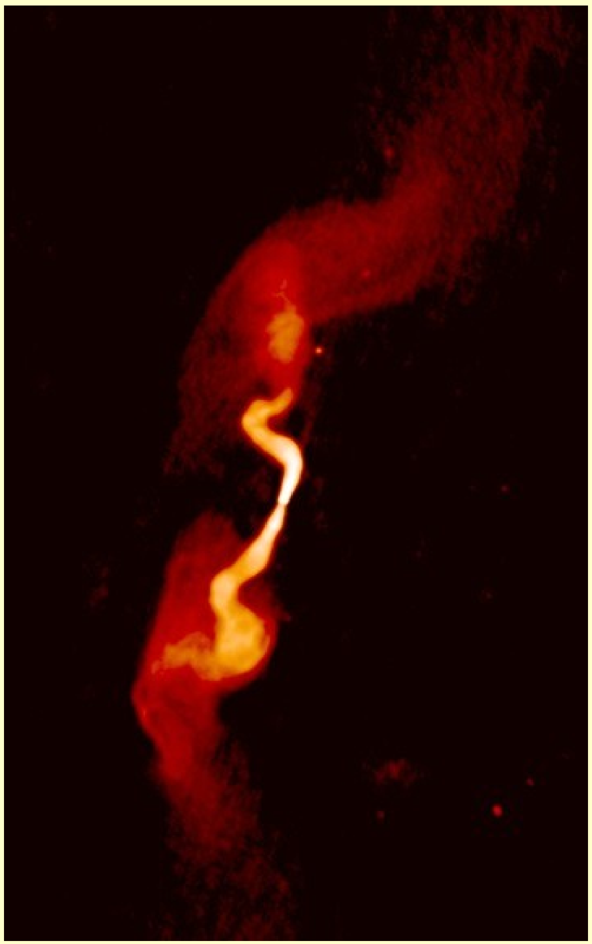


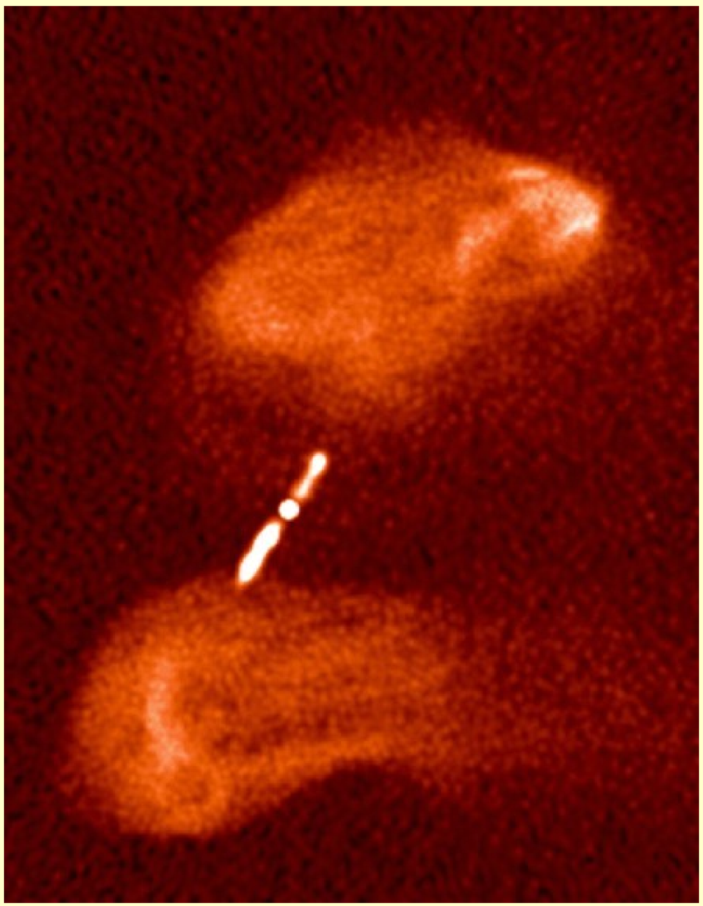
Monica Orienti

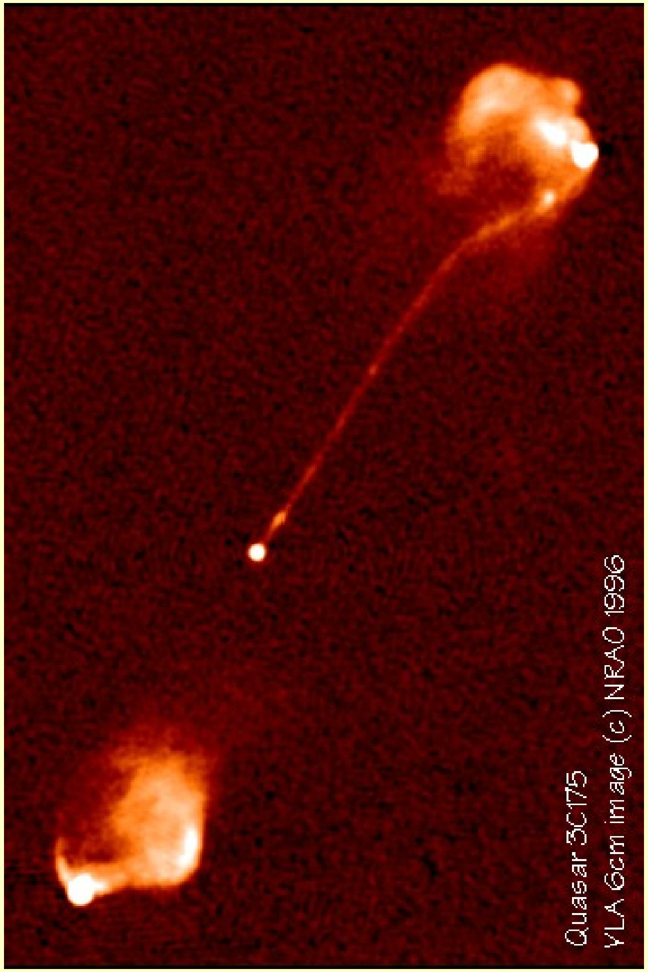
Laboratorio di Radioastronomia

Radio Morphology

Description of the source structure: visual inspection



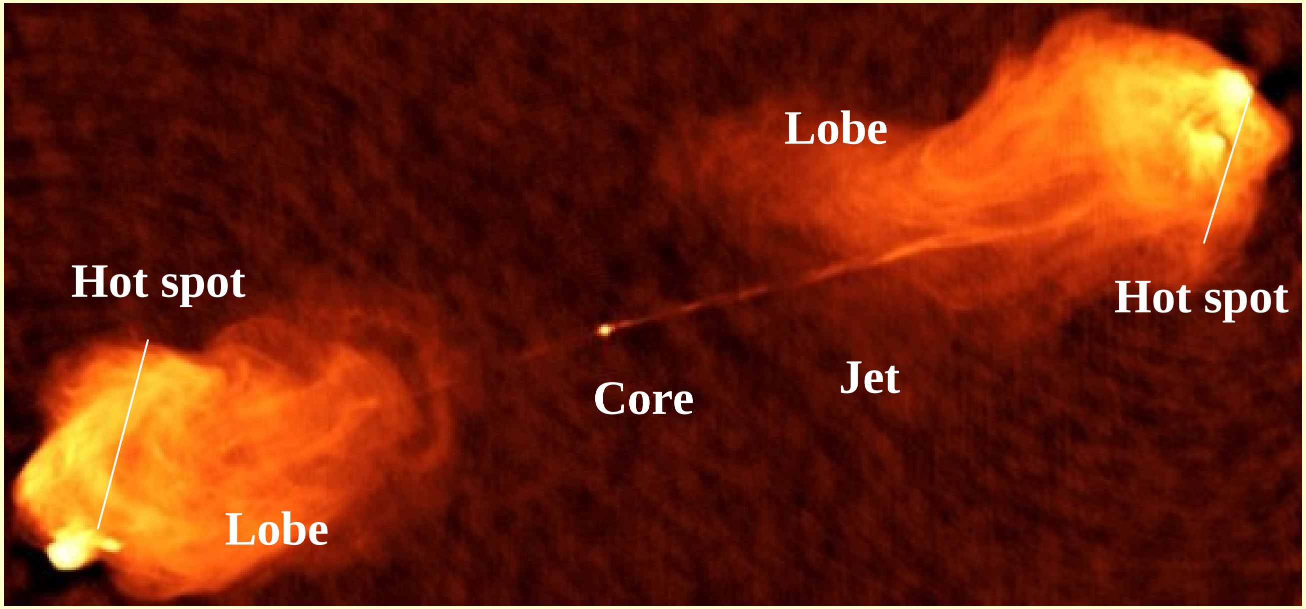




Images courtesy of NRAO/AUI

Main ingredients

Relativistic particles are produced in the core and channeled through the jets towards the outermost regions, the **hot spots**



Relativistic particles are reaccelerated in the hot spot and then deposited in the lobes where they age

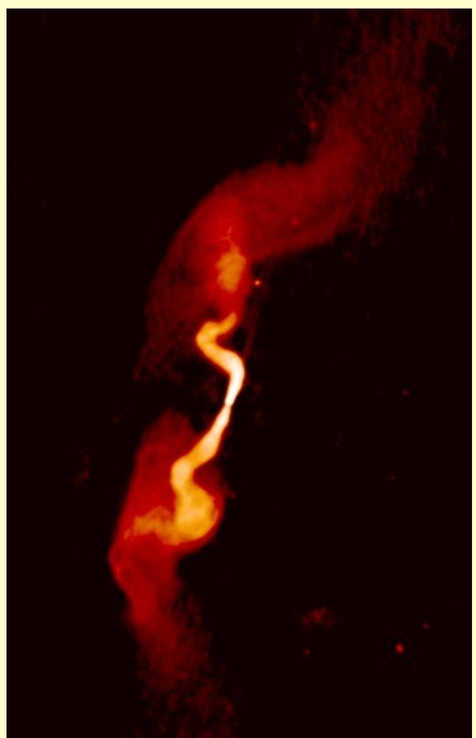
Synchrotron radiation from relativistic particles subjected to the presence of a magnetic field

Two kinds of radio sources

Dichotomy between “bright” and “faint” radio sources

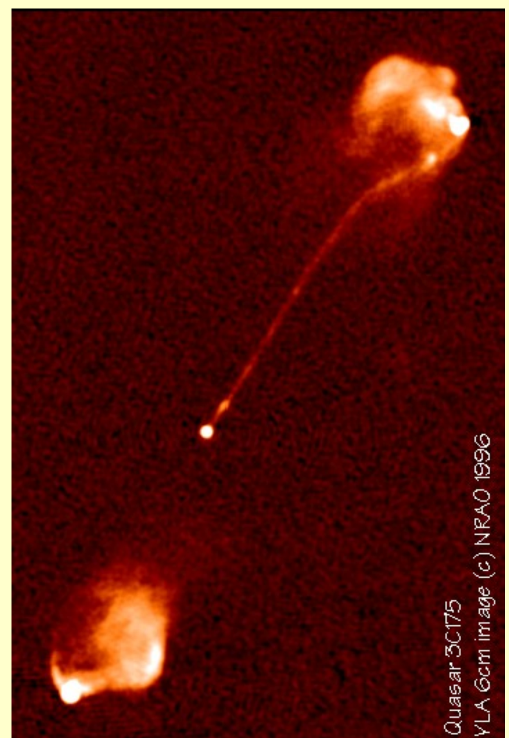
FRI: $L_{1.4\,GHz} < 10^{24.5}$ W/Hz

- Bright two-sided jets,
- “fat” lobes,
- no hot spots.



Edge-darkened

FRII: $L_{1.4\,GHz} > 10^{24.5}$ W/Hz

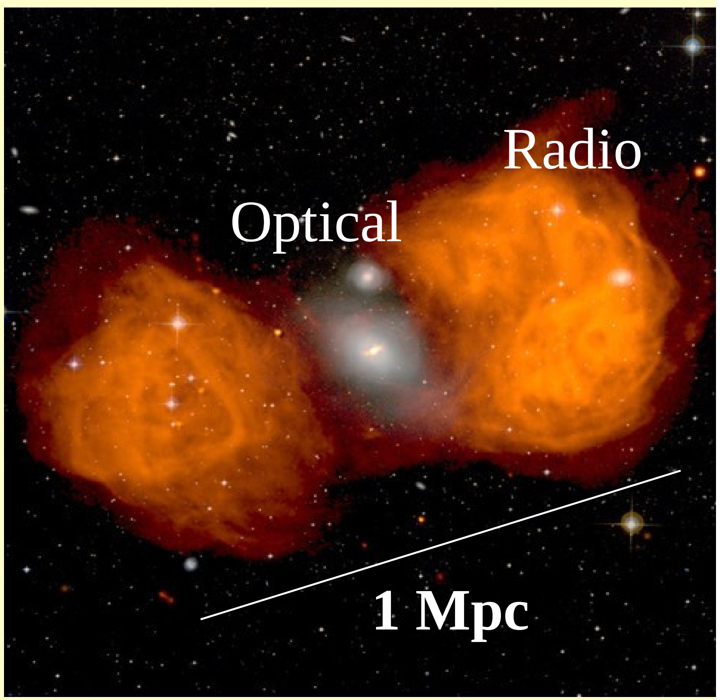


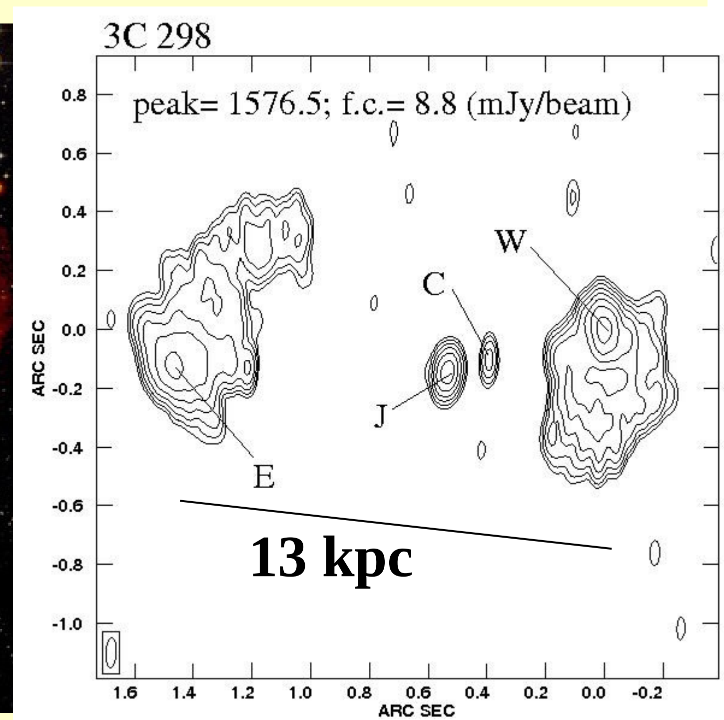
- Faint, one-sided jet
- well-separated lobes,
- bright hot spots.

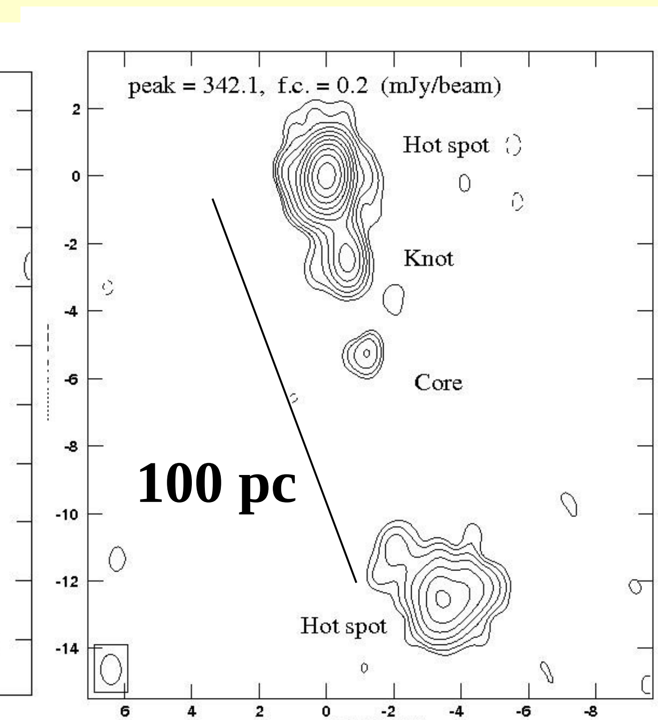
Edge-brightened

Linear size

From parsec to Megaparsec scales

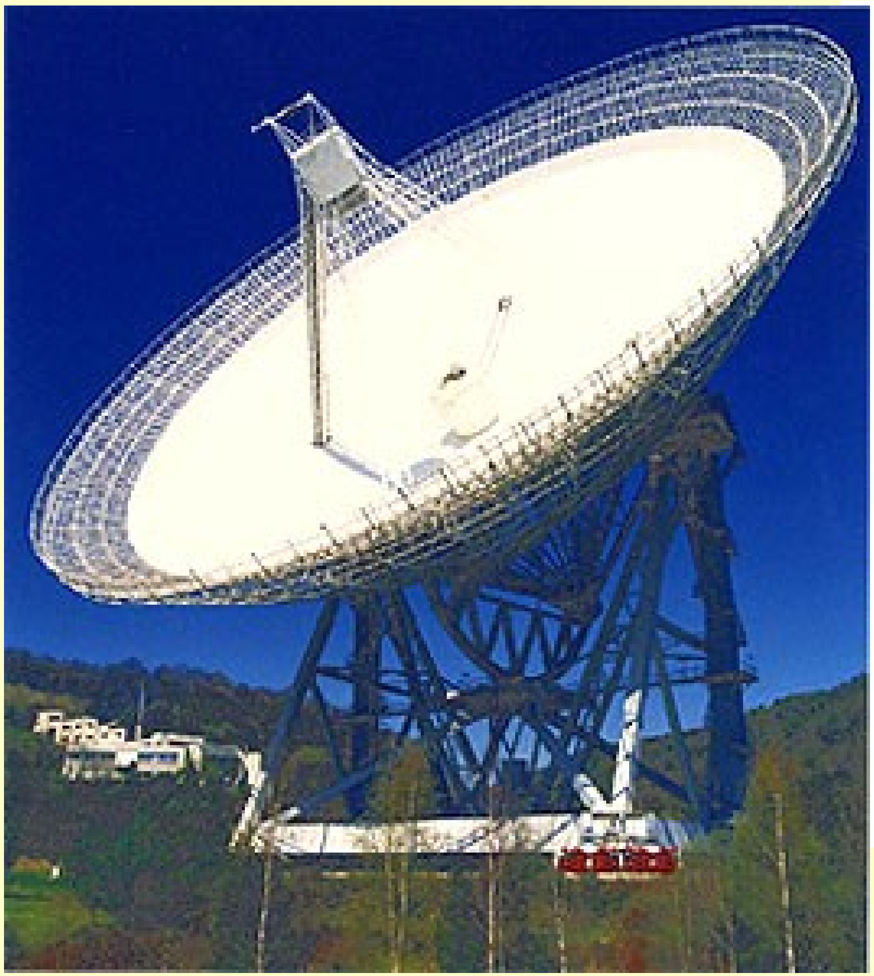






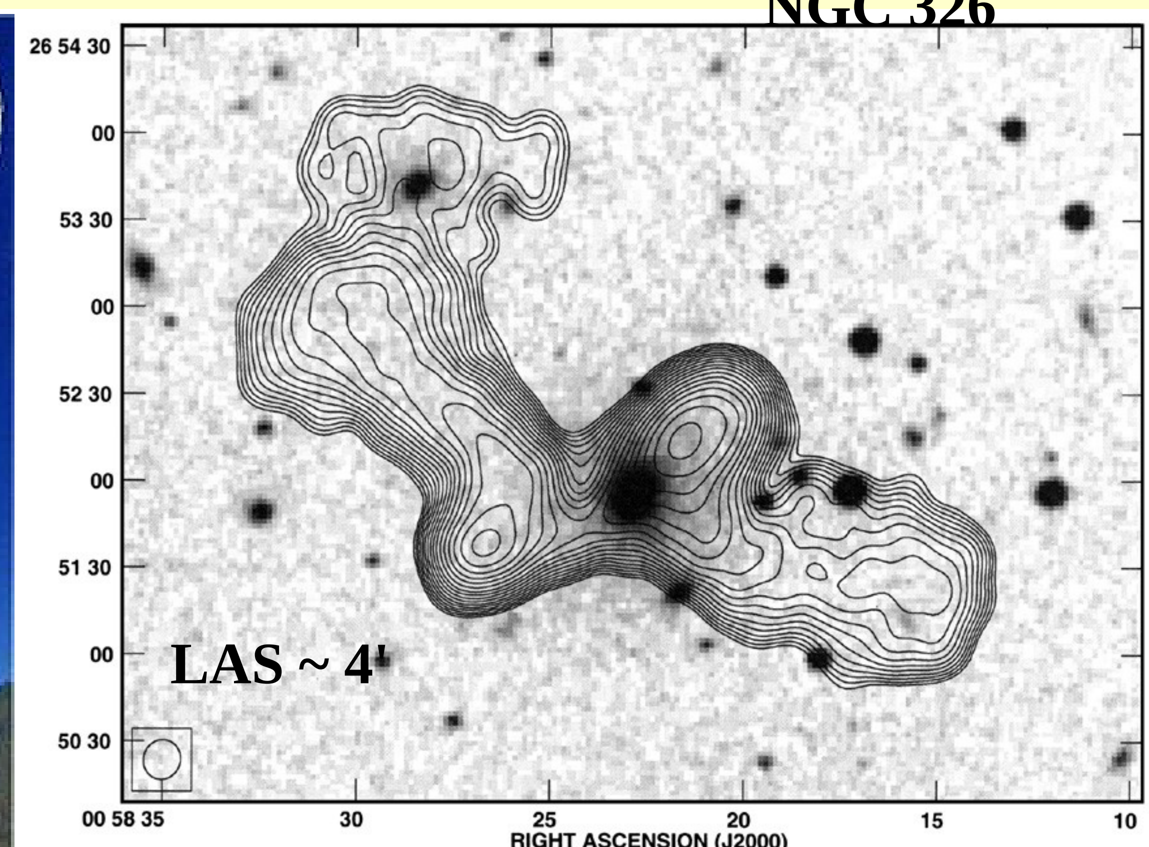
Larger than the host galaxy **Within the host galaxy** **Within the NLR**

The role of the (angular) resolution



Effelsberg 100-m telescope

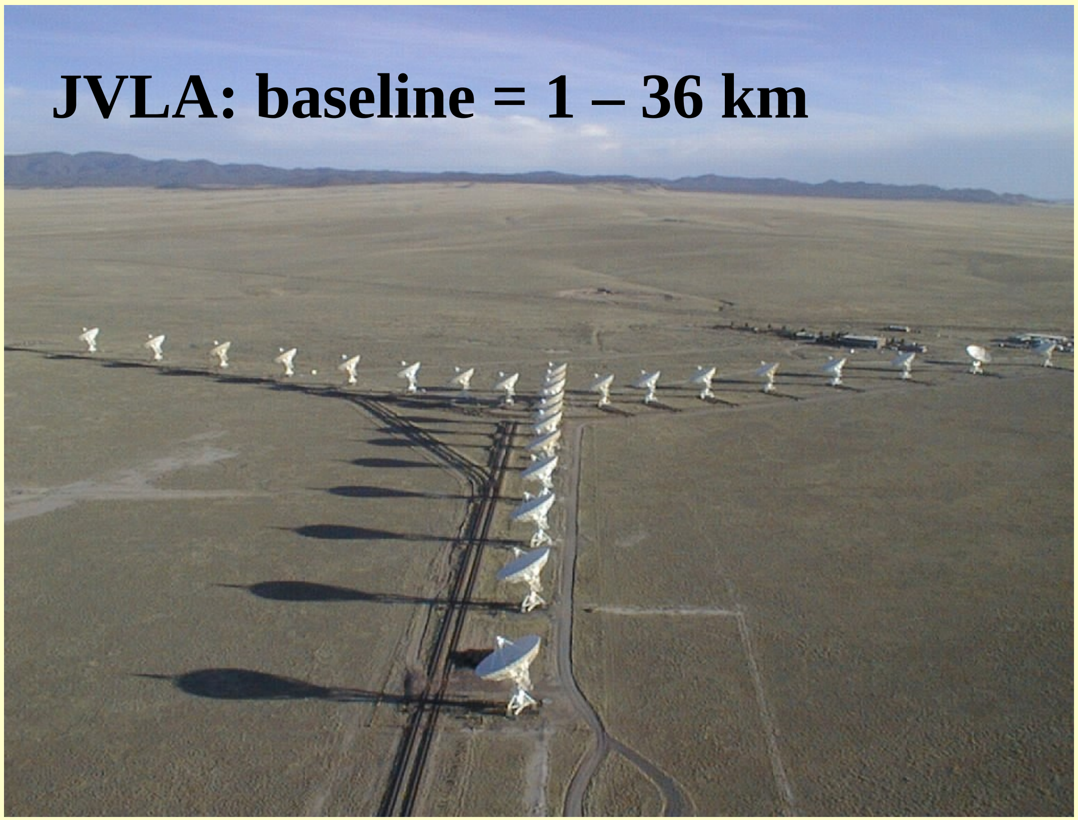
NGC 326

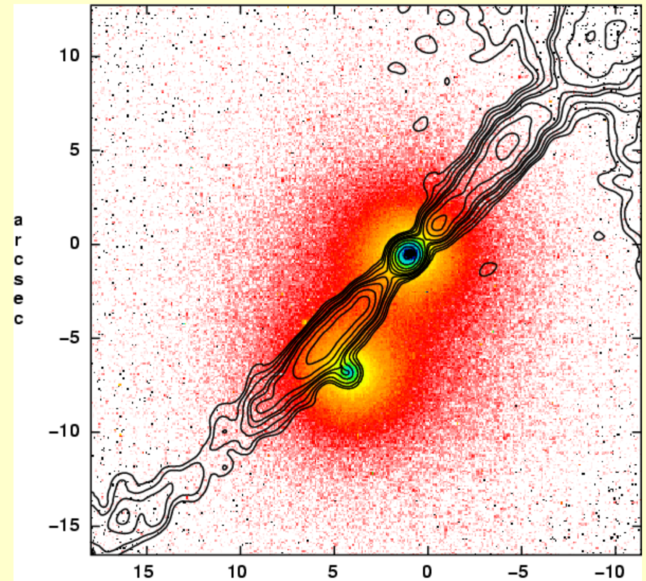


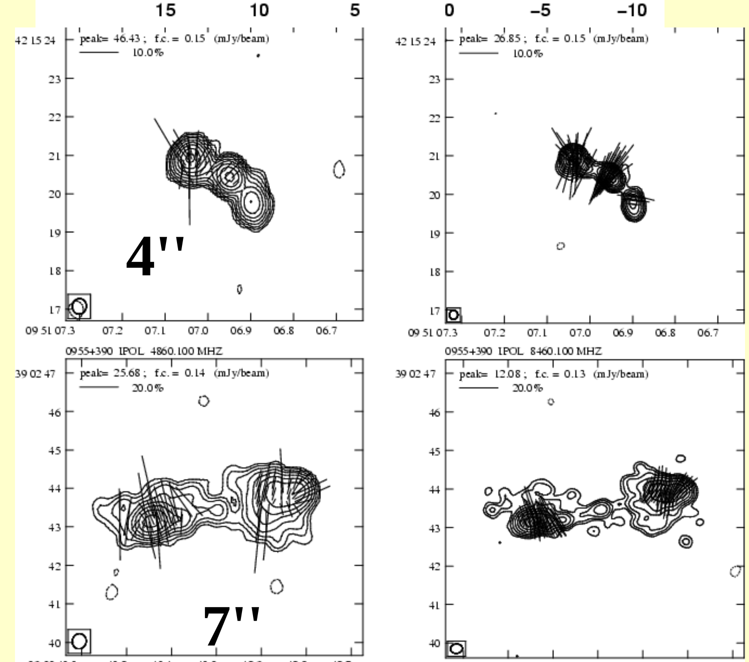
Beam @ 1.4 GHz ~ 7.2'

Beam @ 8.4 GHz ~ 1.2'

The role of the (angular) resolution





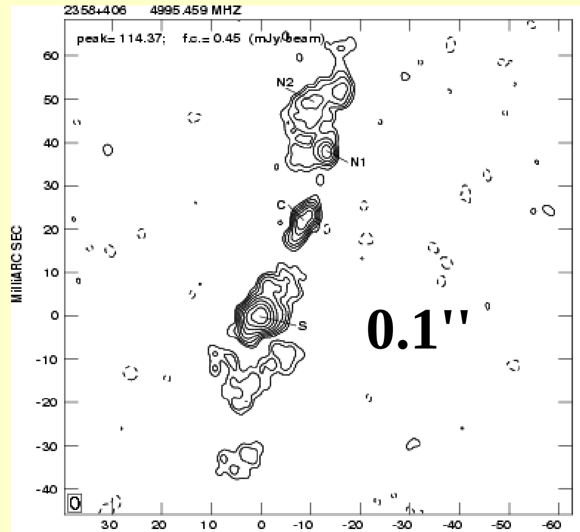


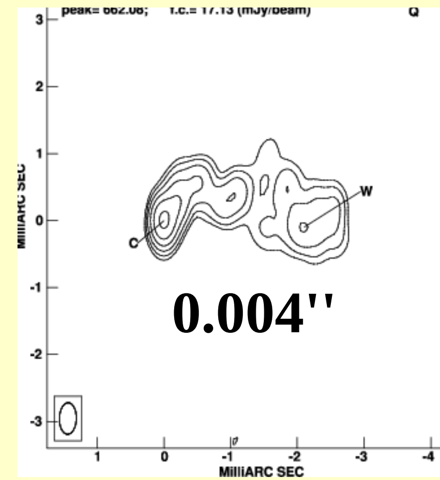
Beam @ 1.4 GHz ~ 46'' – 1.3''

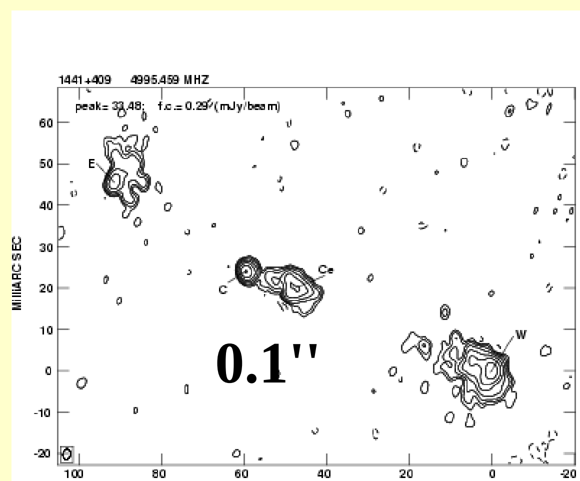
Beam @ 8.4 GHz ~ 7.2'' – 0.2''

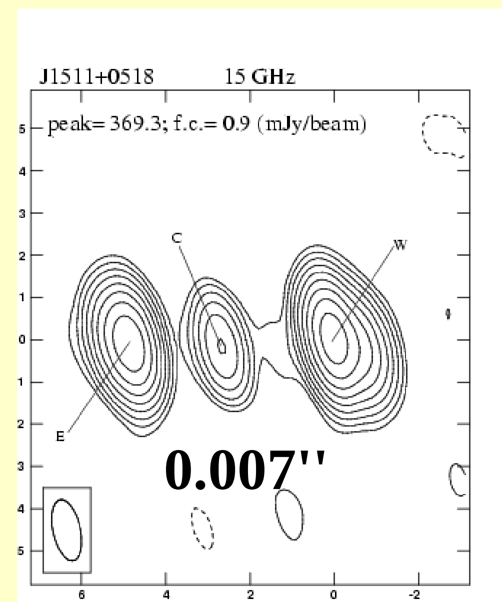
The role of the (angular) resolution

VLBA: baseline 9000 km







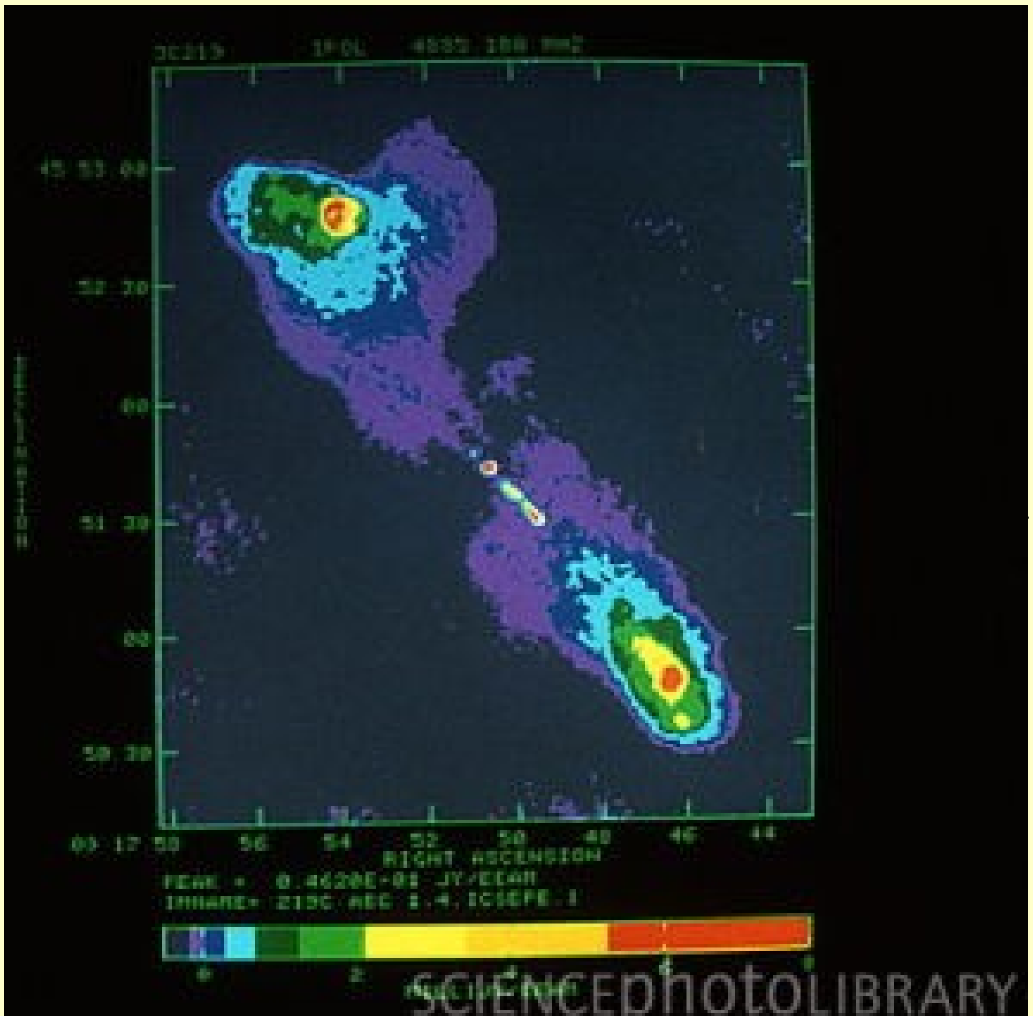


Beam @ 1.4 GHz ~ 0.01''

Beam @ 8.4 GHz ~ 0.001''

Observational parameters

Quantitative analysis



Measure of the flux density (S) and linear size (LS) of the entire source

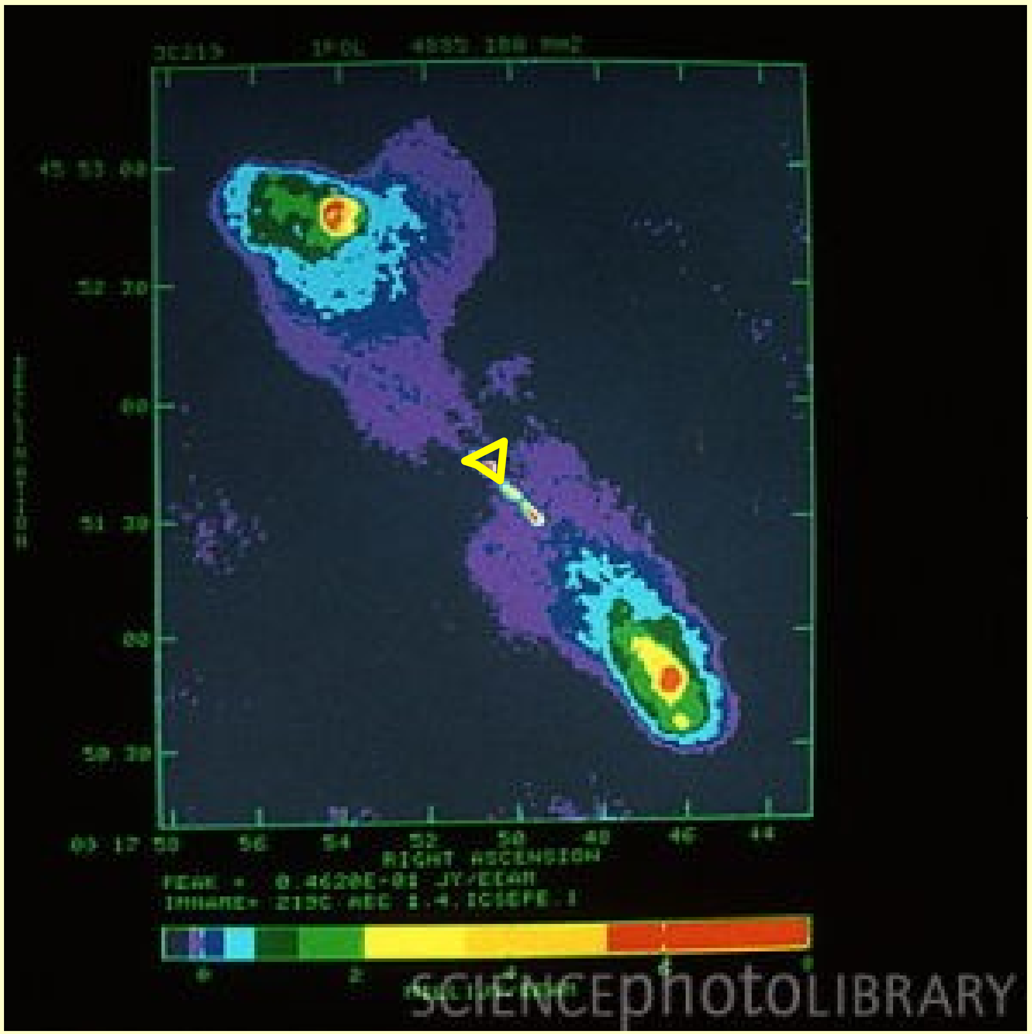
$$L = 4\pi D_L^2 S(1+z)^{(\alpha-1)}$$

$$LS_{\rm pc} = 4.8\ \theta_{\rm arcsec} D_{\rm L,Mpc} (1+z)^{-2}$$

z = redshift
α = spectral index
θ= angular size
D_L = luminosity distance

Observational parameters

Quantitative analysis



Measure of the flux density (S) and linear size (LS) of single components

Are the different regions characterized by the same properties?

Physical parameters

Minimum energy condition

Brightness temperature: $$T_B = \frac{1}{2k} B(\nu) \frac{c^2}{\nu^2}$$ K

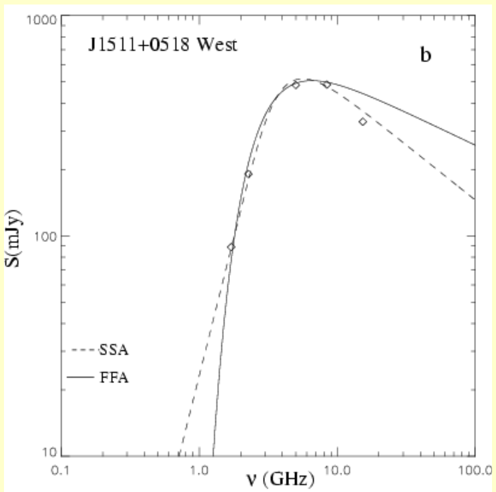
Total energy: $$U_{tot} = 2 \times 10^{41} \left(\frac{L\eta}{(Watt/Hz)} \right)^{4/7} \left(\frac{V}{(kpc^3)} \right)^{3/7}$$ erg [Hz]

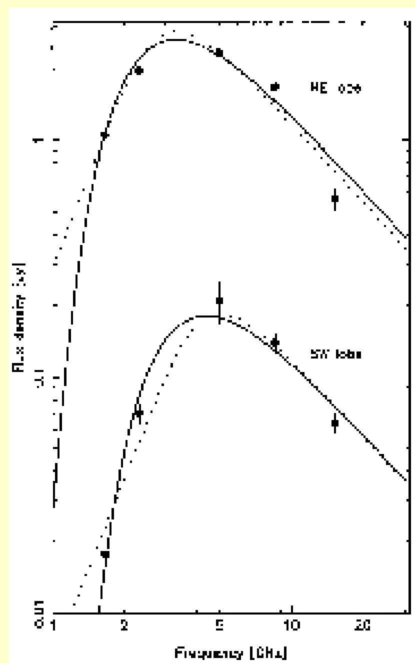
Minimum energy density: $$u_{min} = \frac{U_{tot}}{V}$$ erg/cm^3

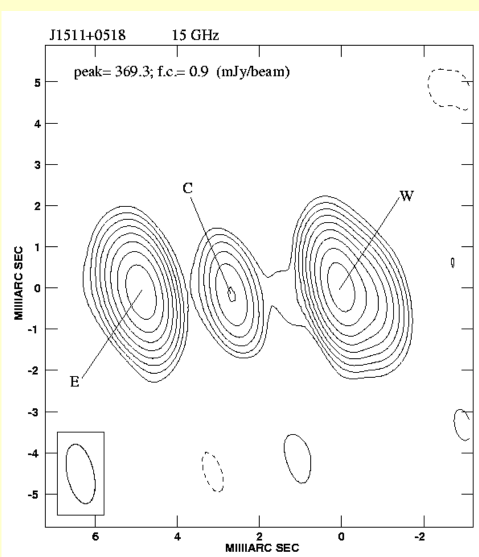
Equipartition magnetic field: $$H_{eq} = \sqrt{\frac{24\pi}{7} u_{min}}$$ Gauss

Physical parameters

Does equipartition hold?







The magnetic field can be directly computed if the source/component is Synchrotron self-Absorbed:

$$H_{SSA} = \frac{\theta^4 \ \nu_p^5}{f(\alpha)^5 \ S_p^{\ 2} \ (1+z)}$$

$$\mathbf{H_{SSA} \sim H_{eq}}$$

z = angular size

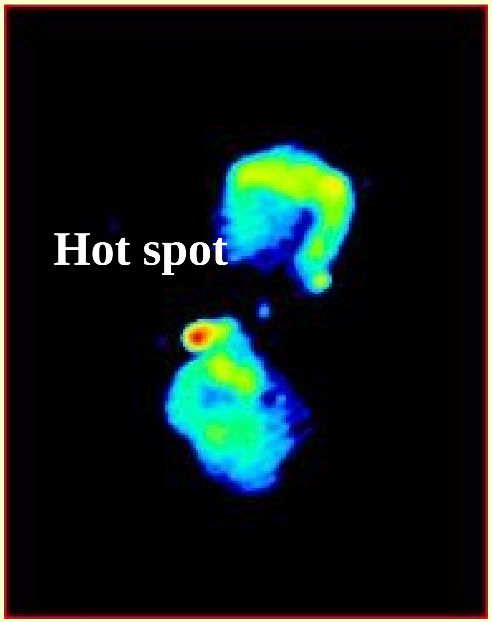
ν_p = peak frequency

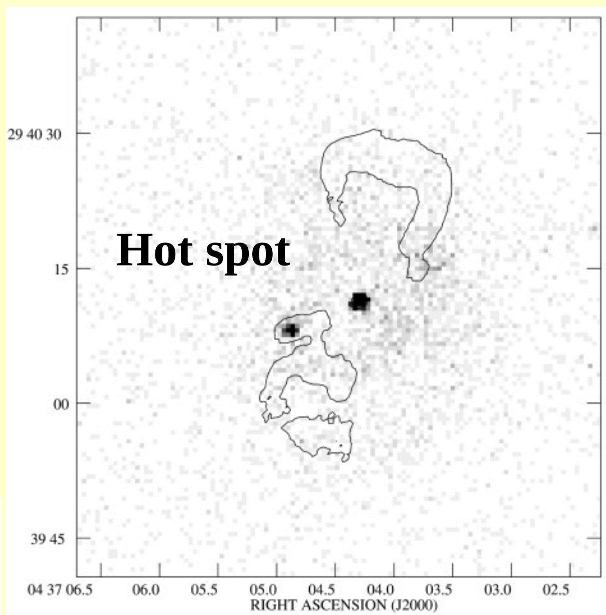
S_p = peak flux density

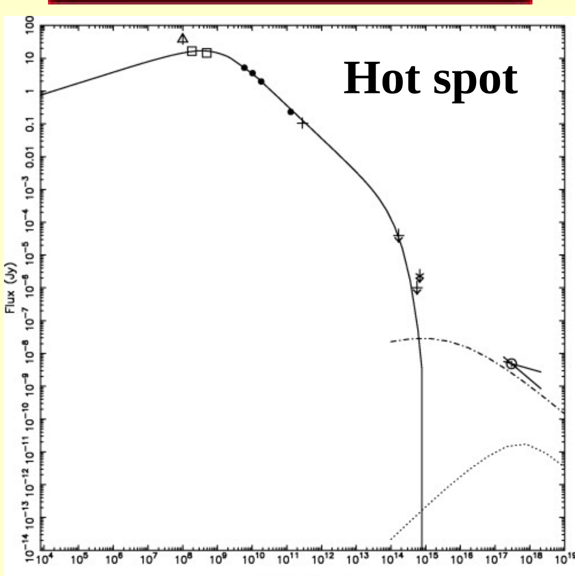
$f(\alpha)$ = spectral index function

Physical parameters

Does equipartition hold?







If the radio source emits in X-rays for Inverse Compton, we have an independent way to estimate the magnetic field.

$$\frac{L_{IC}}{L_{syn}} \sim \frac{8\pi w_f}{H^2}$$

L_{IC} = Inverse Compton lum

L_{syn} = synchrotron lum

w_f = photon density

The X-ray flux from the HS is SSC emission.

$H \sim H_{eq}$

Physical parameters

The contribution of the CMB

CMB photons are homogeneously distributed and they can be scattered by relativistic particles to higher energies:

$$\nu_f = \gamma^2 \nu_i$$

Starting from the energy density of the CMB we can derive the IC luminosity and the equivalent magnetic field

$$L_{IC} = \frac{4\sigma_{\rm T}}{3}\gamma^2 \, c \, u_{\rm CMB}$$

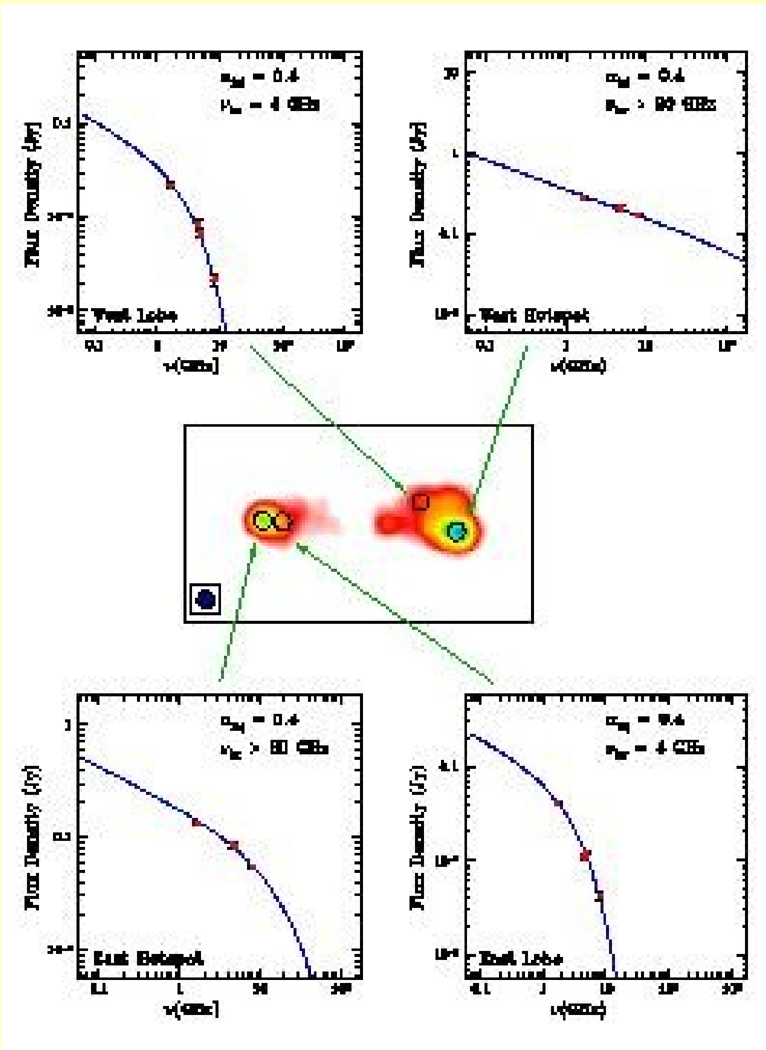
$u_{CMB} = 0.26$ eV/cm^2

$$H^2_{\rm CMB} = 8\pi \;\; u_{\rm CMB}(1+z)^4$$

It is possible to compare equipartition magnetic field and the H_{CMB} to estimate the role played by synchrotron and inverse Compton losses.

Radio spectrum

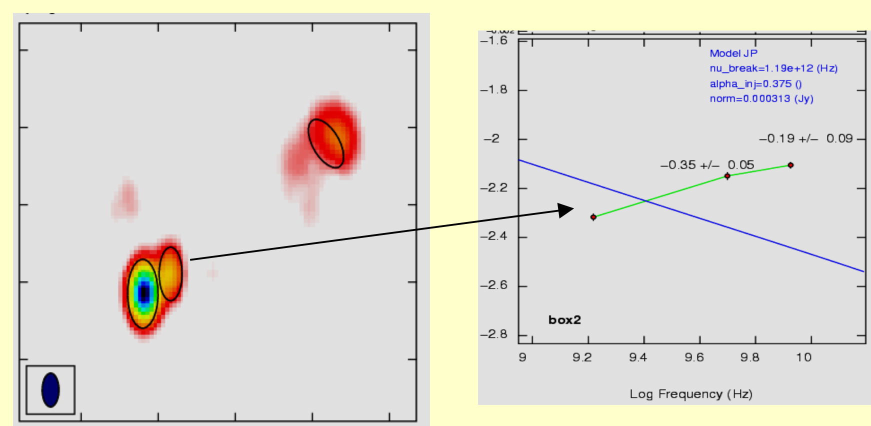
Different regions different spectra



Hot spot: power-law = particle acceleration

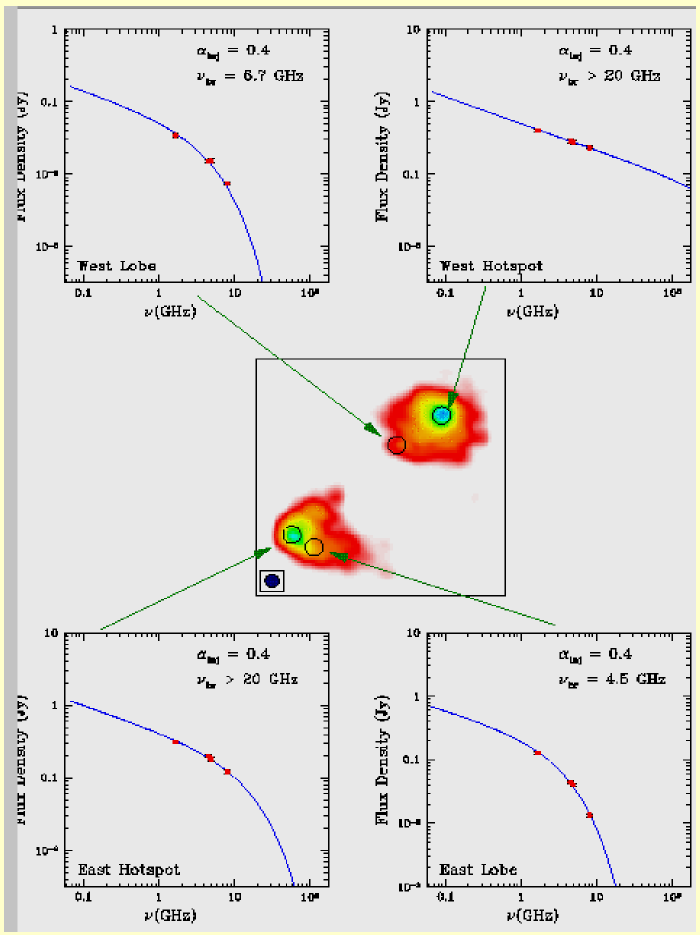
Lobes: steep spectrum = particles are deposited and age. Much steeper in region far away from the HS

Core: inverted/flat spectrum = synchrotron self-absorption



Radio spectrum

The radio source age



Once the magnetic field is known, we can derive the radiative age from the break frequency ν_{br} of the spectrum:

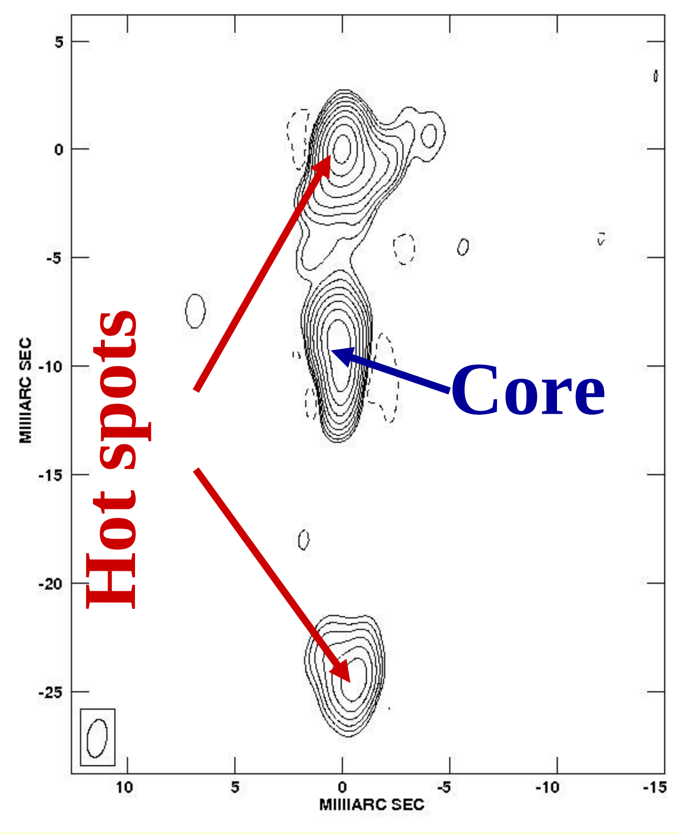
$$t_{rad} \propto \nu_{br}^{-1/2} \, H^{-3/2} \, (1+z)^{-1/2}$$

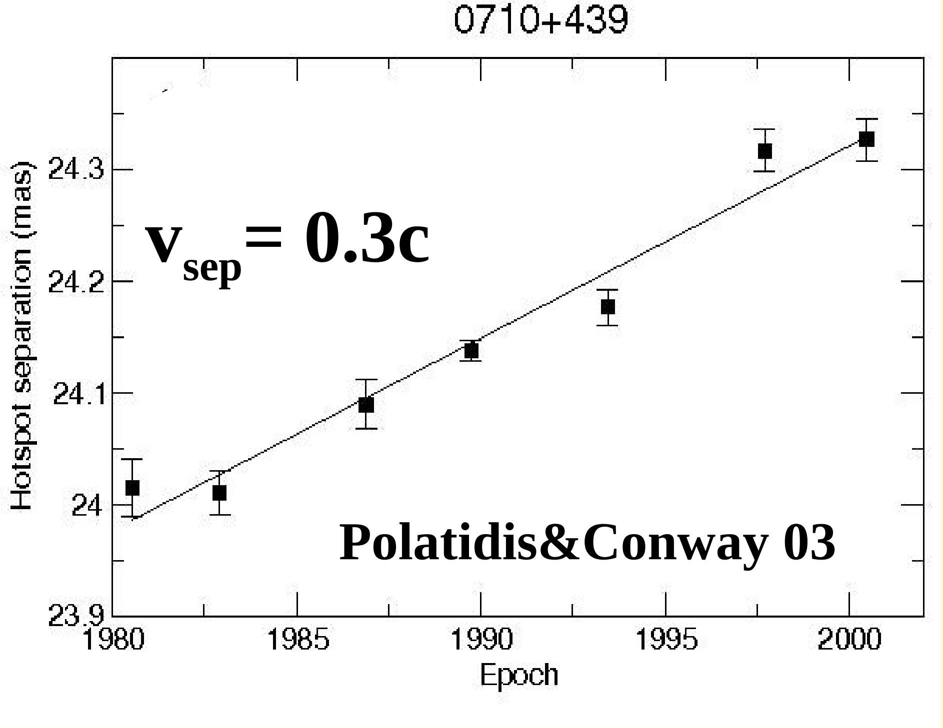
$\nu_{br} = 4.5$ GHz; $H_{eq} = 6.7$ mG

$$\mathbf{t_{rad} \sim 1.3x10^{3}\ yr}$$

Kinetic age

If we have a number of observations spanning a large time range we can measure the separation velocity of the hotspots.



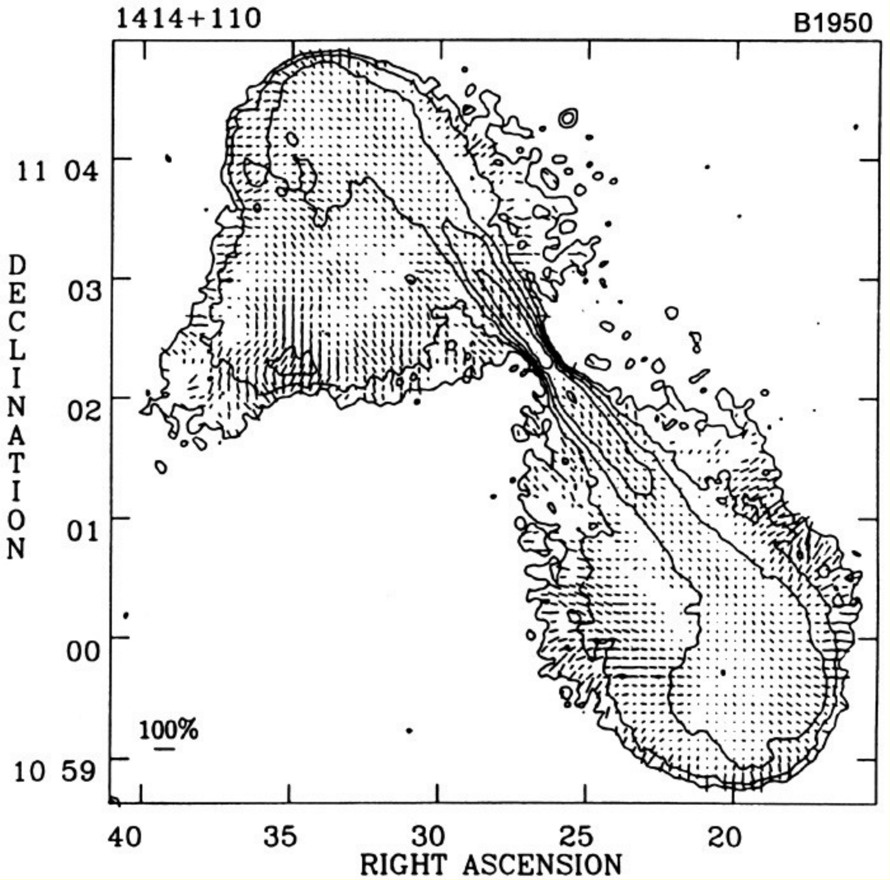


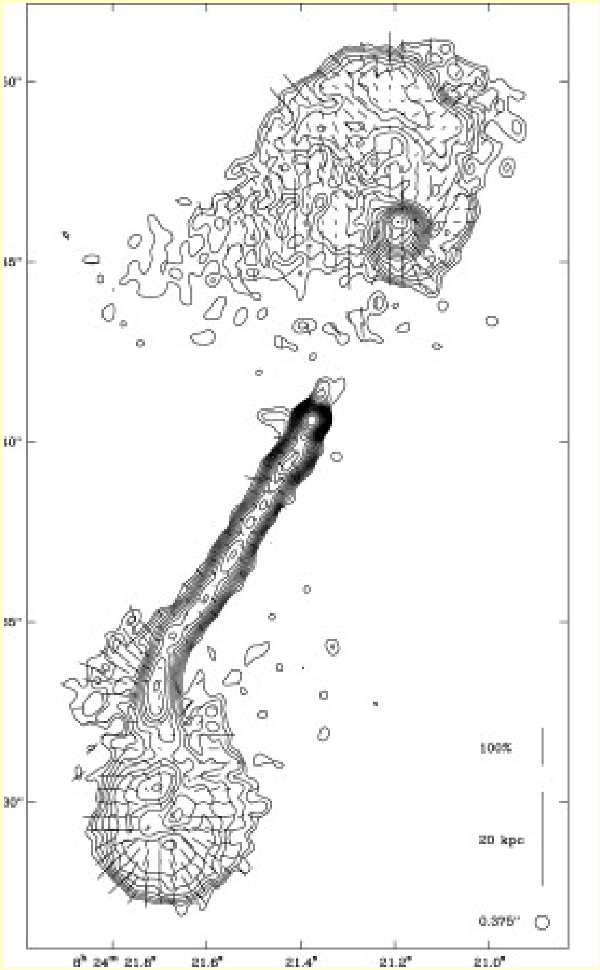
v_{sep} = 0.1c – 0.3c

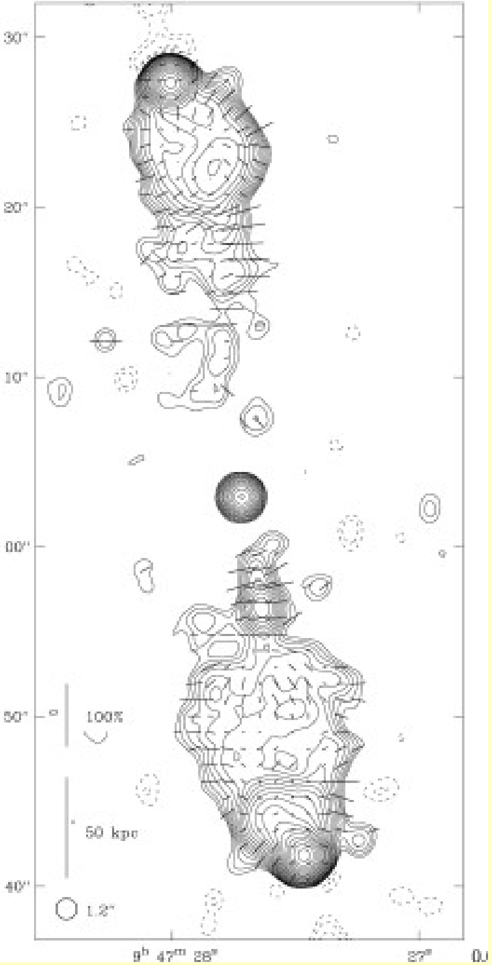
$$t_{kin} \sim \frac{LS}{v_{sep}} \sim 10^3 \text{ yr}$$

Polarization

The structure of the magnetic field





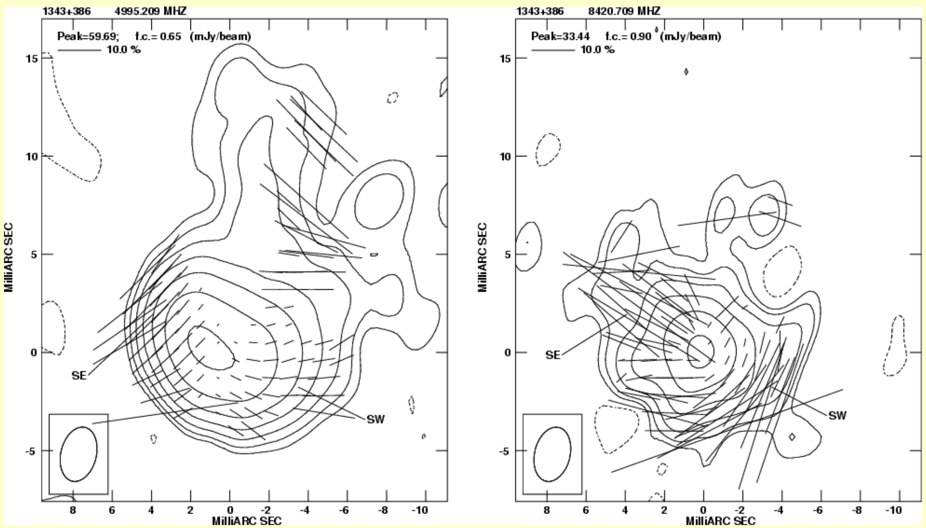


FR I : B ⊥ jet direction

FR II : B ∥ jet direction

Polarization

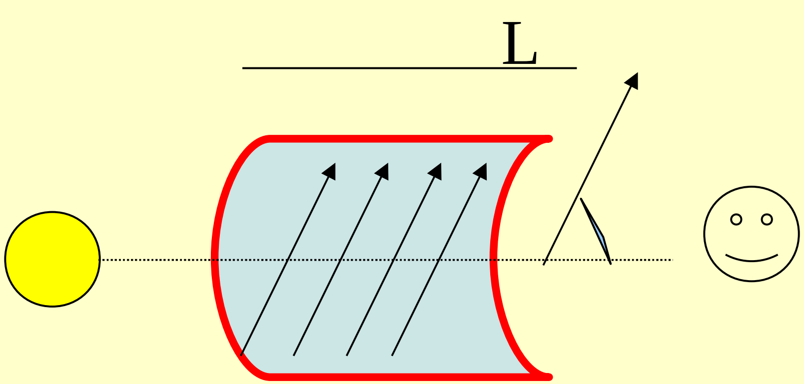
The structure of the ambient medium: Faraday rotation



Rotation of the electric vector position angle at the different wavelengths

$$RM_{oss} = \frac{\Delta\chi}{\lambda_1^2 - \lambda_2^2}$$

$$\lambda_1 > \lambda_2$$



$$RM \sim 0.81 \int_{\mathrm{L}} \frac{n_e}{cm^{-3}} \frac{B_{||}}{\mu G} dL \quad \text{rad/m}^2$$

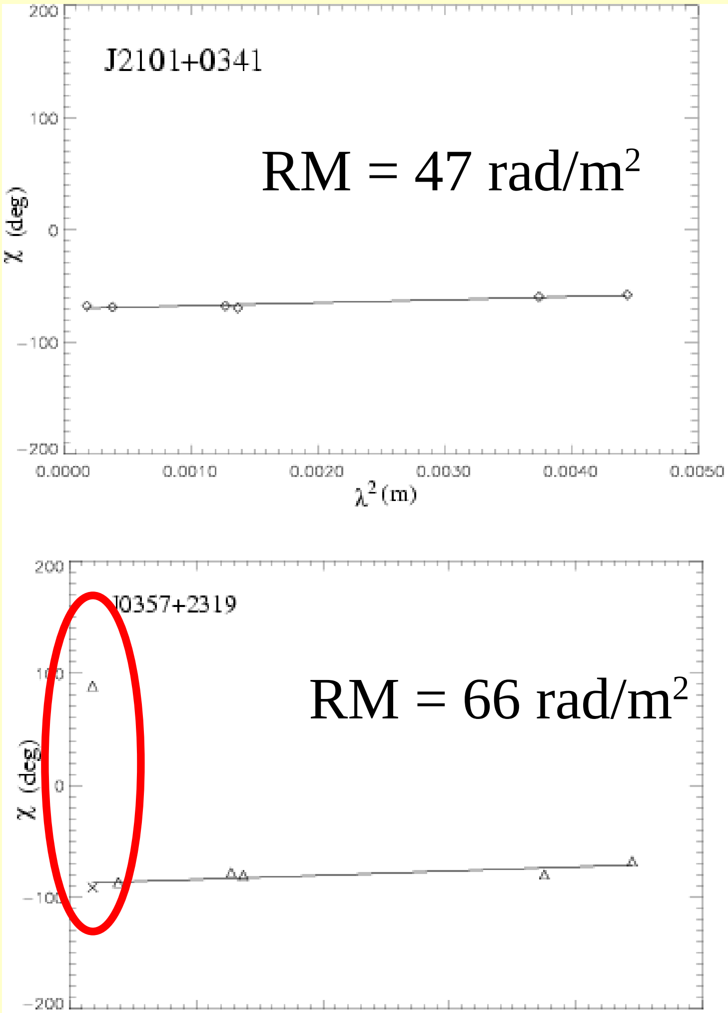
RM = Rotation Measure

n_e = electron density

L = path length in parsecs

Polarization

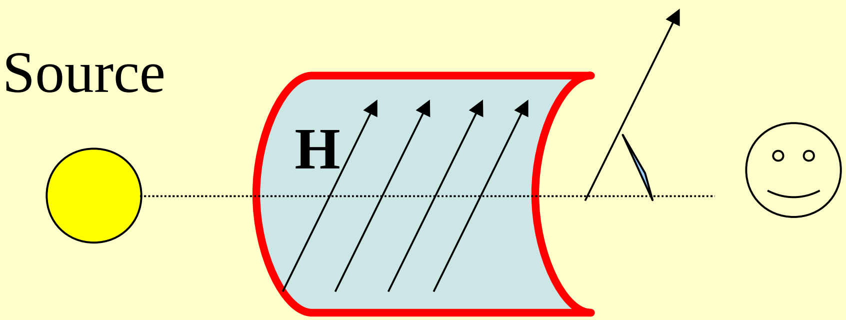
The structure of the ambient medium: Faraday rotation



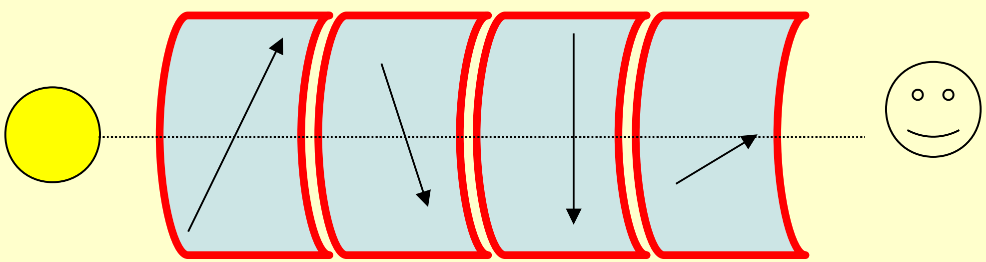
Observations at various frequencies enable the determination of the RM by fitting χ vs λ^2 with a linear function.

However angles have an $n\pi$ ambiguity, therefore at least three frequencies must be available to determine the RM.

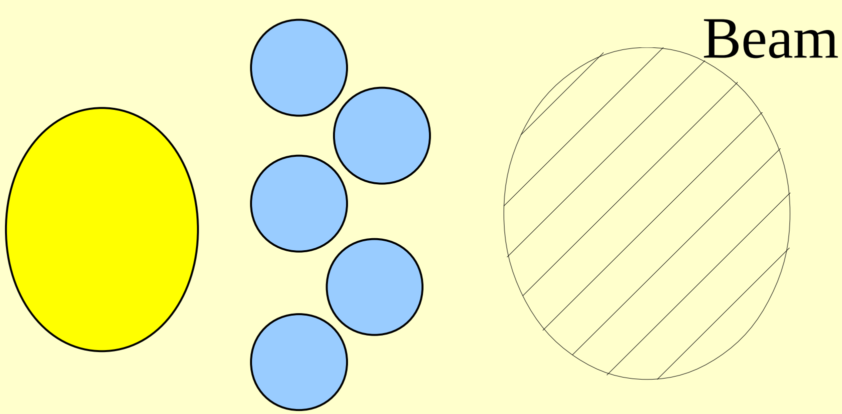
De-polarization

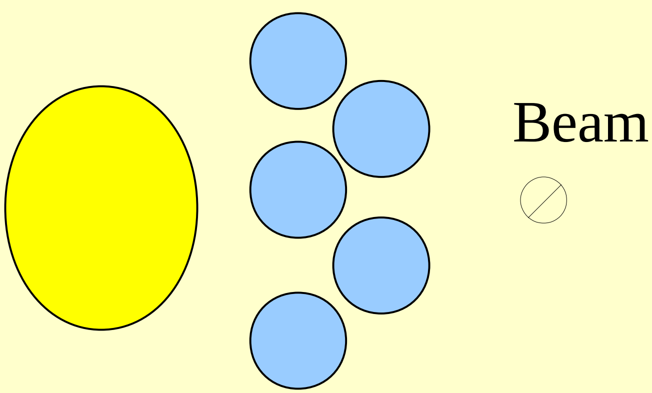


Rotation of the polarization vector



Depolarization due to the external medium

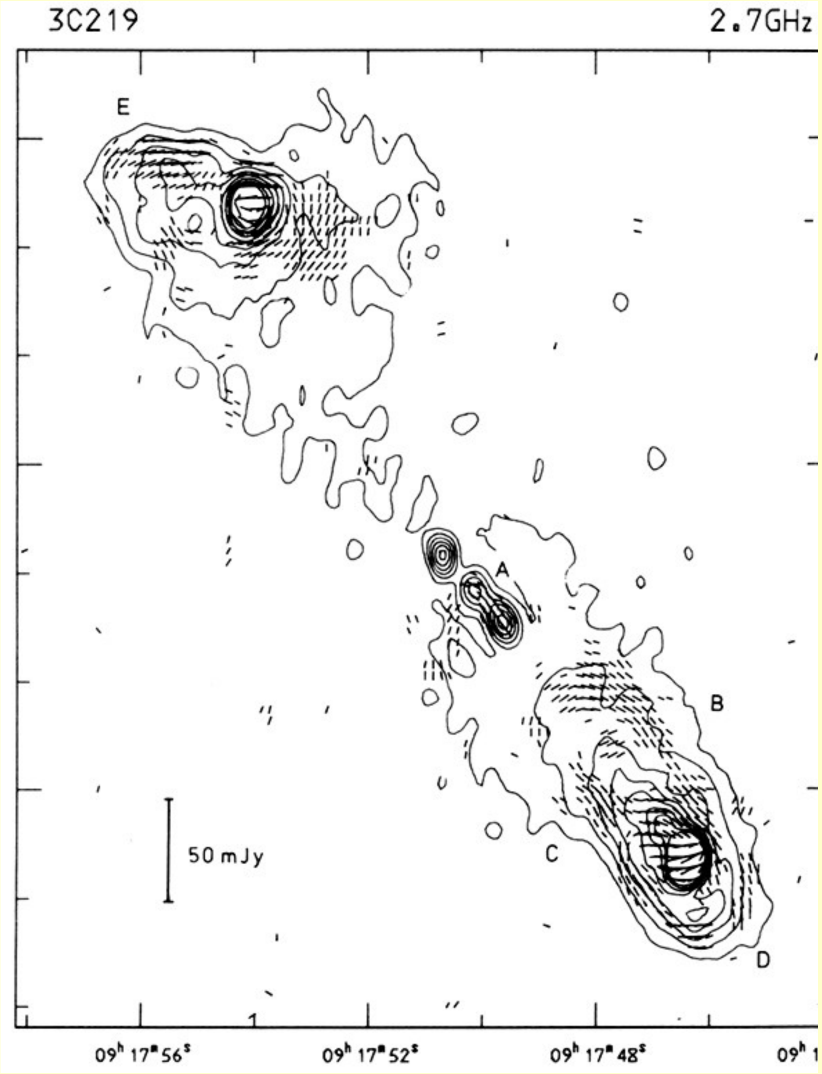




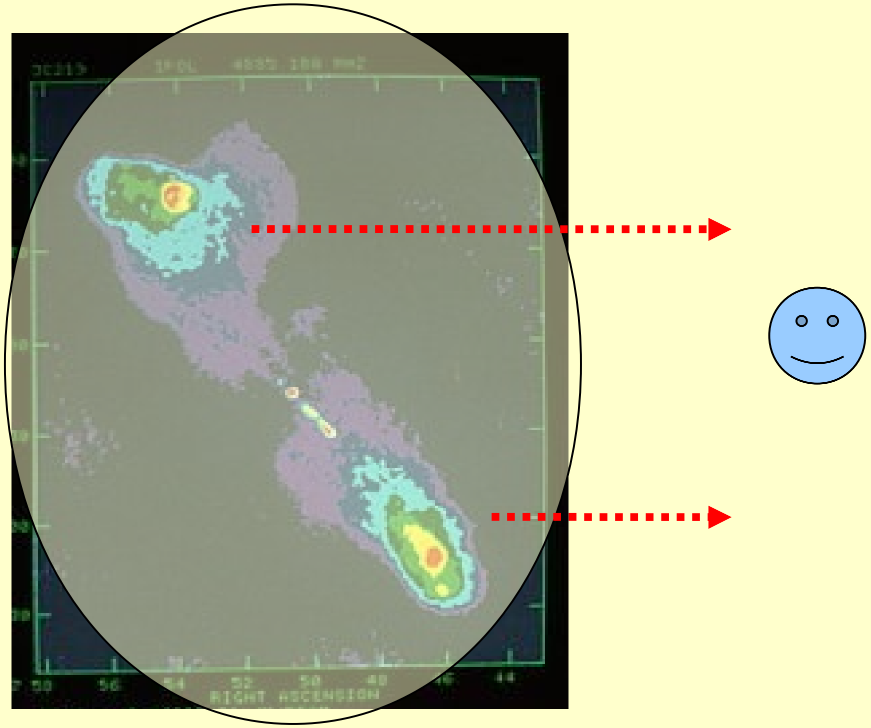
Beam-depolarization

No Beam-depolarization

Laing-Garrington effect



The brighter lobe is the less depolarized



Beaming effects + ambient medium

Summary

1) Morphology of the radio source

- Which regions dominate the radio emission?

2) Observational and physical parameters

- What is the magnetic field strength?
- Is there any evidence of particle acceleration?
- What is the source age?

3) Polarized emission

- Is the source polarized?
- What is the structure of the magnetic field across the source?

Basic information: NED database

Information on the extragalactic sources (redshift, host galaxy, photometry, publications, images.....)

http://ned.ipac.caltech.edu/

Then search for your preferred source "By name"

Compute cosmological parameters (luminosity distance, angular-to-linear scale....)

http://www.astro.ucla.edu/~wright/CosmoCalc.html

Insert the source redshift and choose the cosmology