Research on Young Radio Sources

(alias Compact Steep-Spectrum & GHz-Peaked Spectrum radio loud objects)

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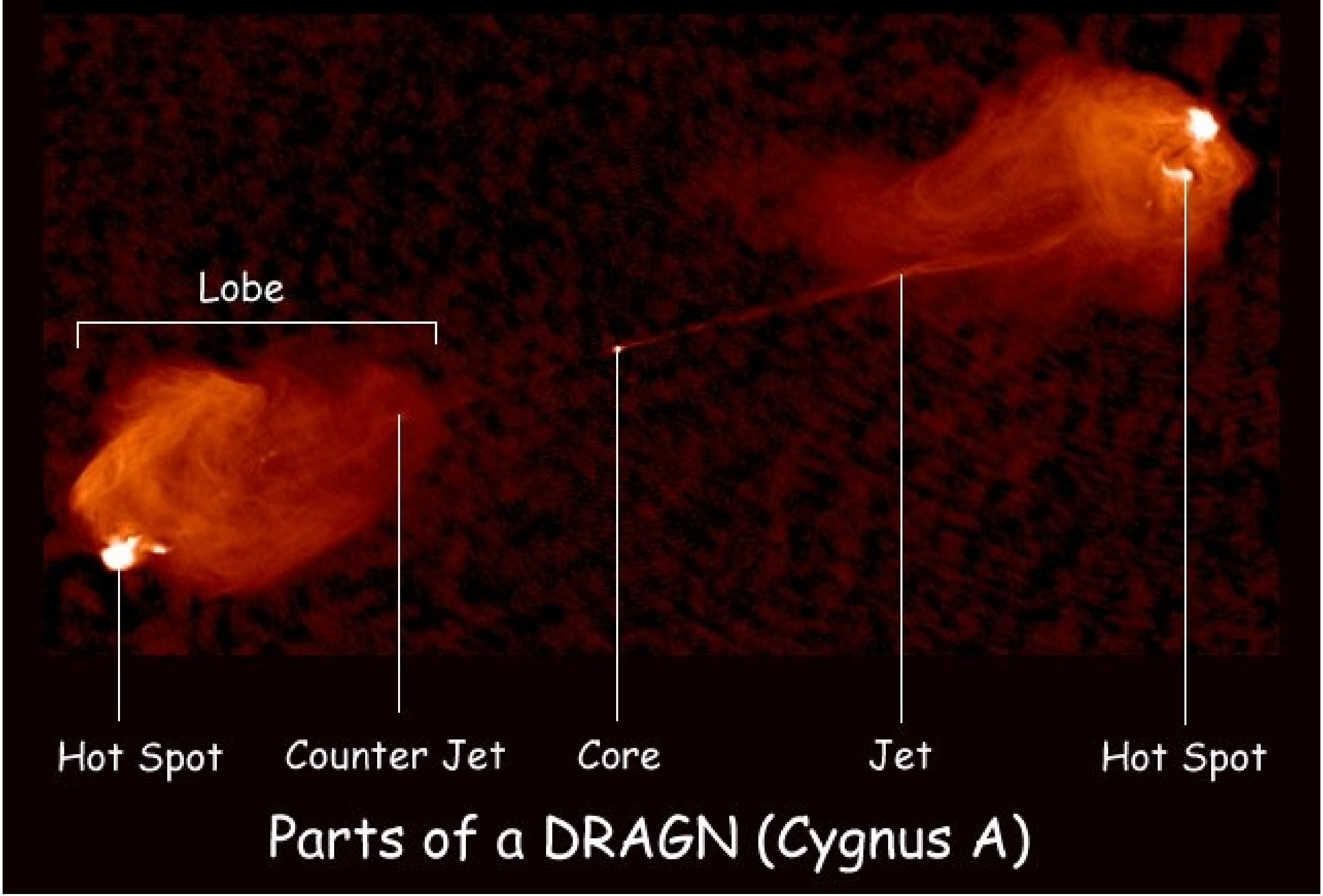
To find appropriate information on YRS, please refer to the following literature

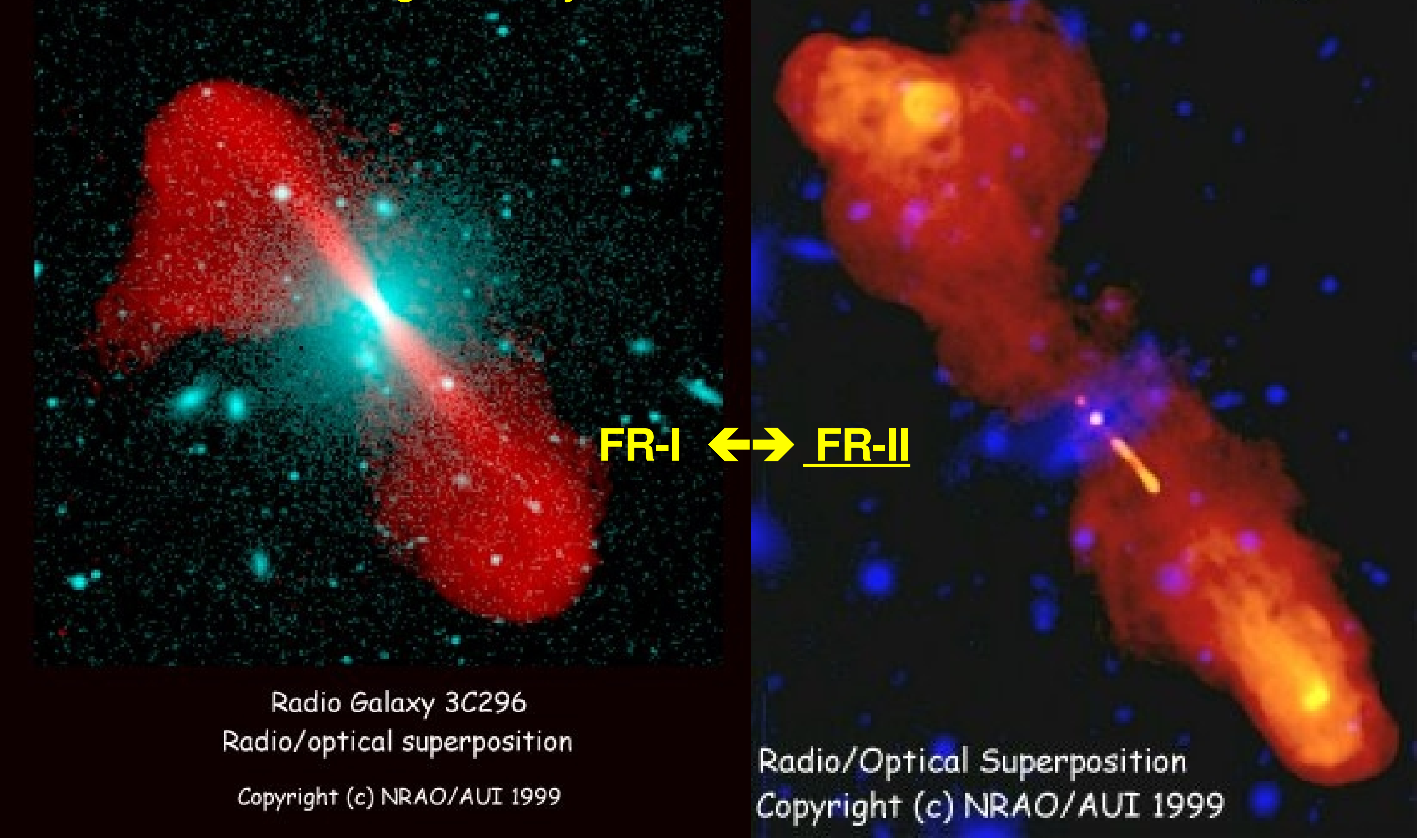
Fanti et al. 1990, A&A, 231, 333
Fanti et al. 1995, A&A, 302, 317
Readhead et al. 1996, ApJ, 460, 612
O'Dea, C.P. 1998, PASP, 110, 493
Stanghellini et al. 1998, A&AS, 131, 303
Owsianik & Conway, 1998, 337, 69
Murgia et al. 1999, A&A, 345, 769
Snellen et al. 2000, MNRAS, 319, 415
Dallacasa et al. 2000, A&A, 363, 887
Polatidis & Conway, 2003, PASA, 20, 69
Tinti et al. 2005, 432, 31
Stanghellini et al. 2005, A&A, 443, 891
Orienti, PhD thesis
Orienti & Dallacasa, 2006, 2007, 2008,....

*the proceedings of "**The Fourth CSS/GPS Workshop**" held in Riccione, 26-29 May 2008 available starting from **15 February 2009, Astronomische Nachrichten, volume 330***

What is a radio source? (credit: Bridle & Lehay & NRAO/AUI)



How big are they?



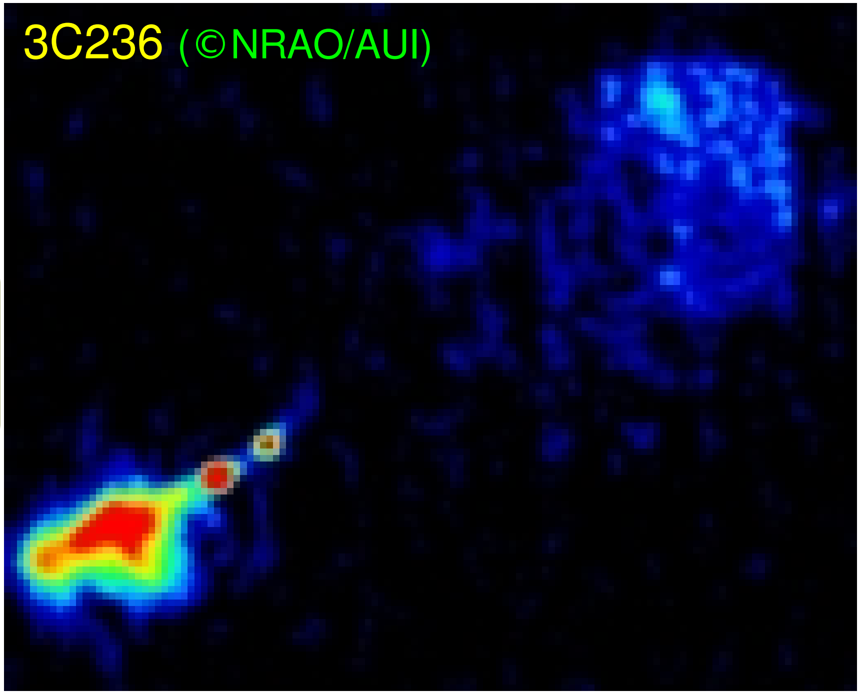
Linear sizes:

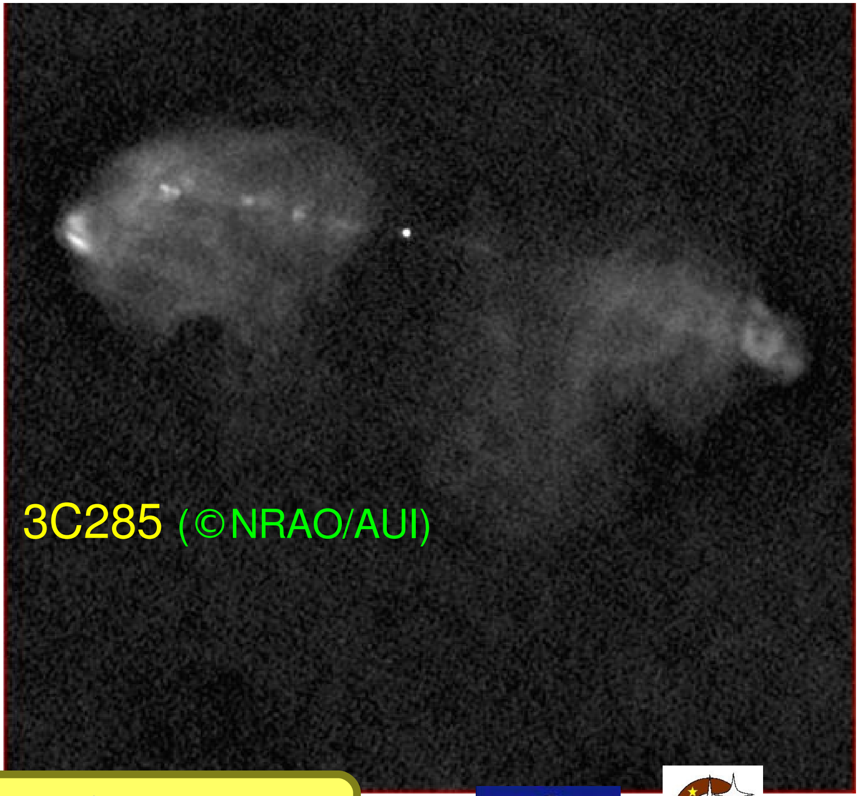
(intrinsically) **Compact radio sources**
as small as .... less than 1 pc

30 kpc ⇔ the size of the host galaxy (giant Ellipticals)

Extended radio sources
as large as ..... a few Mpc

⇒ *THEY LOOK VERY SIMILAR* ⇐





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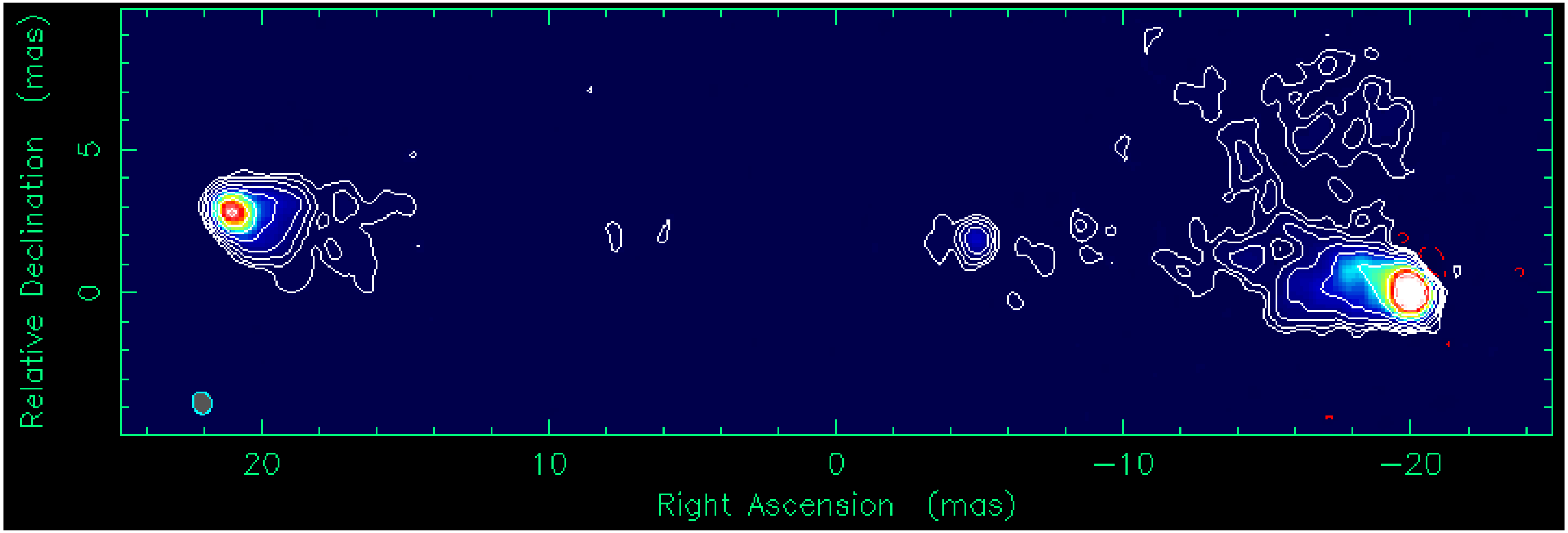
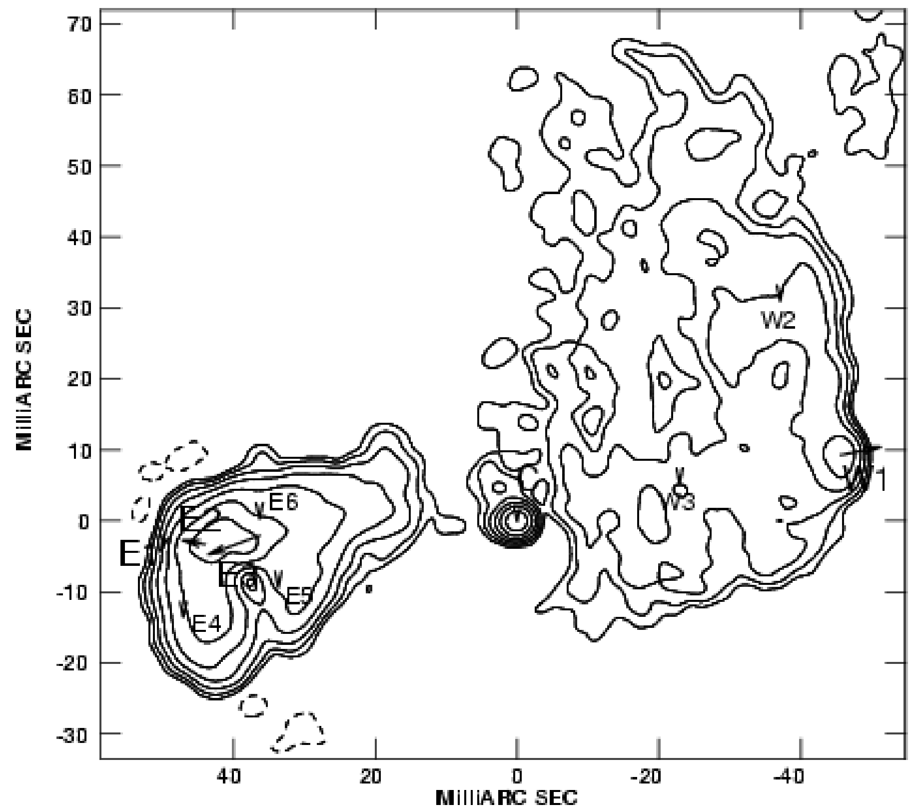


Relative Declination (mas)
5
0
20
10
0
−10
−20
Right Ascension (mas)



MilliARC SEC
70
60
50
40
30
20
10
0
-10
-20
-30
40
20
0
-20
-40
MilliARC SEC
E6
E2
E1
E3
E5
E4
W2
W3
W1

Samples of young & small radio sources:

"**Historical**" **samples** are from flux limited catalogues and the necessity of VLBI observations implied the selection of the brightest sources.

(Spencer et al. 1989, Fanti et al. 1990, Stanghellini et al. 1998, Snellen et al. 1998, Dallacasa et al. 2000, Snellen 2004, Stanghellini et al. 2009)

Optical identifications are generally evenly divided into G and Q (but related to ν_{turn} and to the flix density limit)

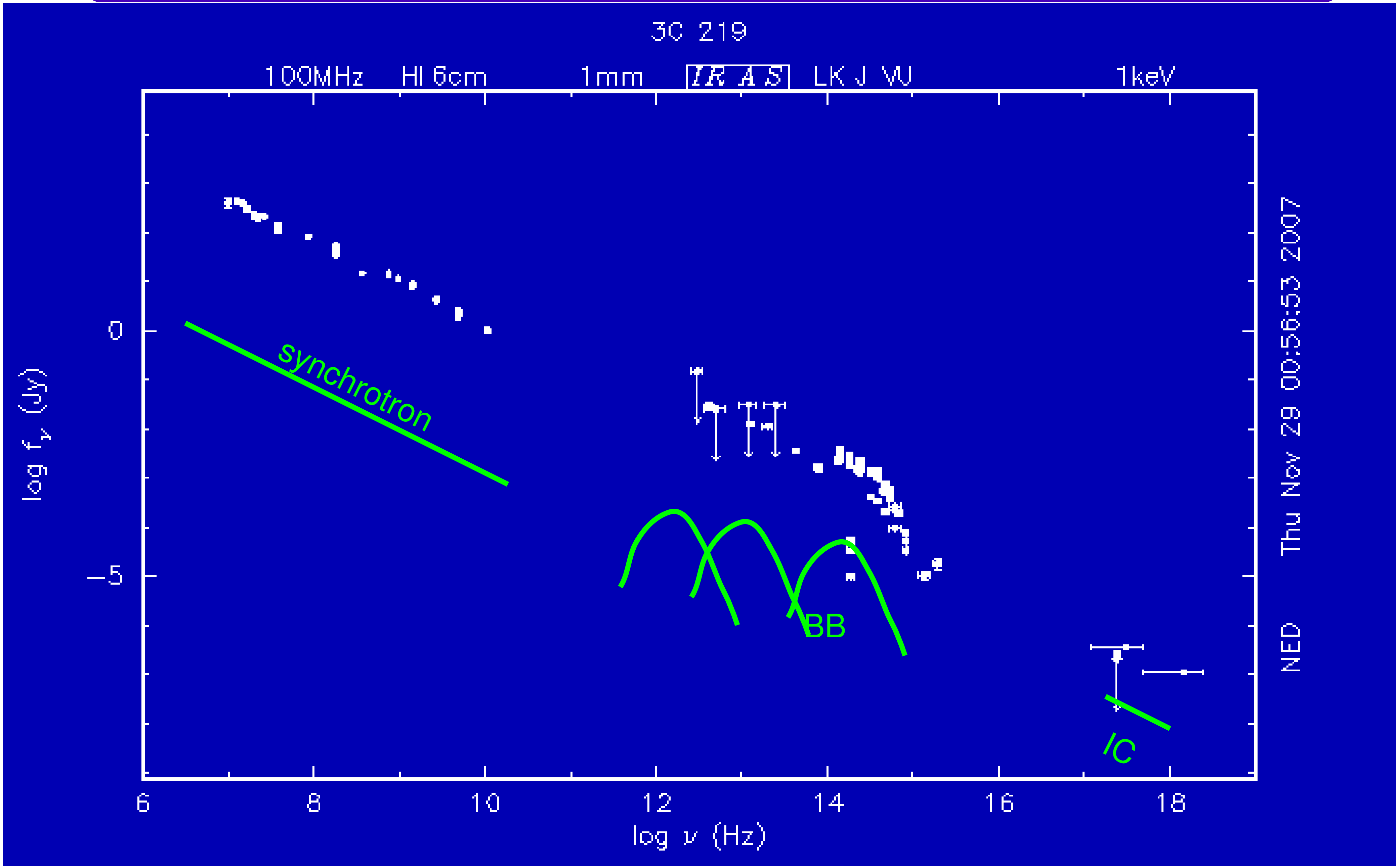
Redshift distribution: G are within ~0.1 – ~1.5
Q are within ~0.5 – ~3.5

$\Downarrow$

"Bright" Y&S radio sources are also among the **most radio powerful** in the Universe
They are as powerful as the largest (Mpc size)

The **host galaxies** are giant ellipticals, with a passively evolving stellar population ($z - m_R$; $z - m_K$ relations: Snellen et al. 1996)

What is the emission mechanism across the SED?



What is the emission mechanism across the SED?

Synchrotron (radio) relativistic electrons & magnetic field

$$S(\nu) \approx \nu^{-\alpha}$$

Black Body (IR to optical, UV and X-rays) thermal matter / plasma

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

Inverse Compton (X-rays) relativistic electrons & seed photons

$$S(\nu) \approx \gamma^2 \langle U_{rad} \rangle$$

What is the relation between the small and large radio sources?

A. *Compact radio sources are* ***very small*** *when* ***very young***

They grow larger and larger as time passes, and then will exit their host boundary

They will become ***old and die*** *(10^7 – 10^8 years later)*

B. *They are small because their expansion is impeded by an anomalously dense ambient medium (ISM). In other words, they are* ***"frustrated"***

They are ***as old as*** *the large radio sources*

They ***will never*** *grow large*

How do we measure the age?

A. Synchrotron theory helps us!

*Aging introduces a **break** in the spectrum which progressively moves to lower and lower frequencies as time passes (assumptions on time evolution of energy output, particle and field confinement, the radio spectrum is the sum of the various populations with various ages & .....)*

$$t_{age} \approx 5 \cdot 10^4 \left(\frac{H}{mG}\right)^{-3/2} \left[(1+z)\,\frac{\nu_{br}}{GHz}\right]^{-1/2} \; yr$$

*B. Measure the linear size and the **expansion speed***

Determine the projected LS and v_{exp} (assumed constant over the whole radio source lifetime)

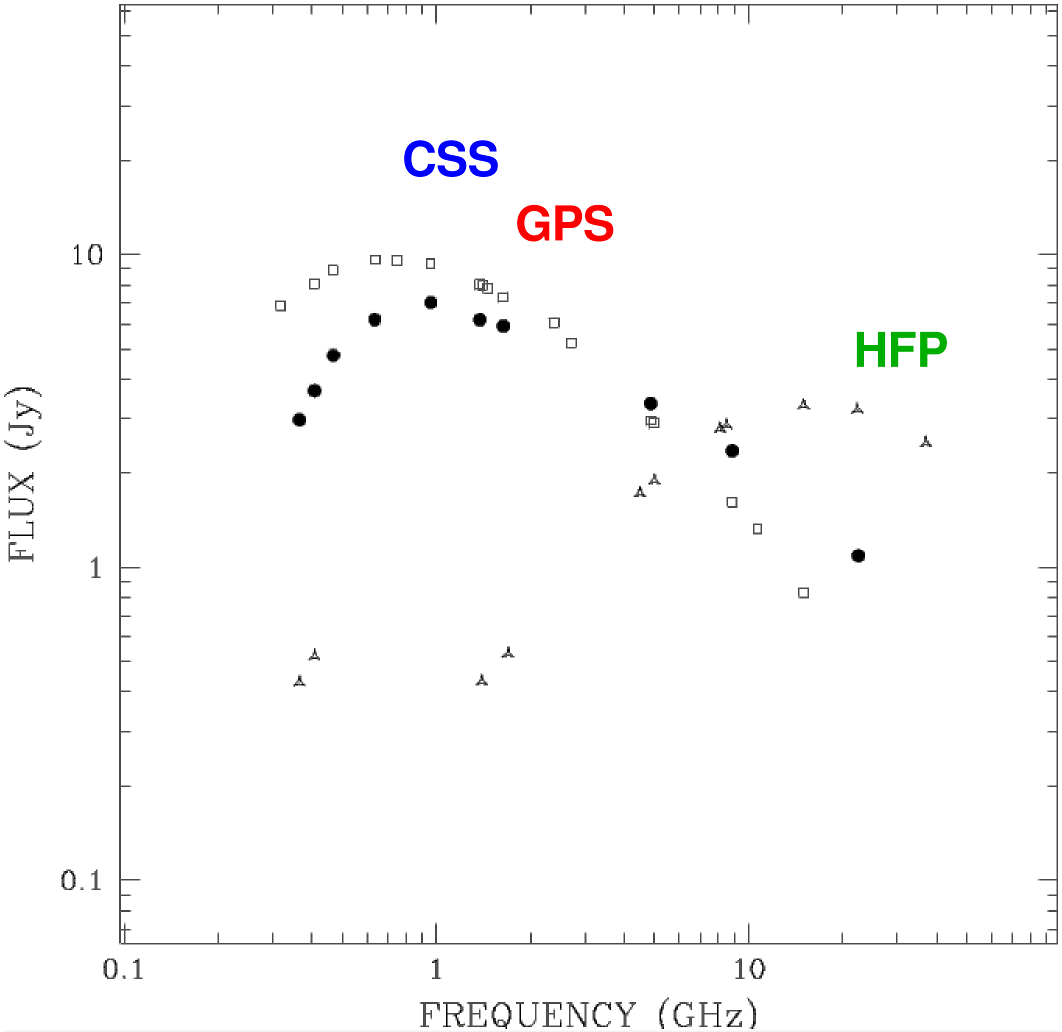
$$t_{age} \approx \frac{LS}{v_{exp}}$$

OK in small objects where, however, constant v_{exp} is questionable....

Conversely, v_{exp} impossible to measure in the large (> a few kpc) ones

What are the key elements for defining a small source?

many of them can be used as selection tools among the radio source catalogues



– intrinsically small
(conventionally < 20 – 30 kpc)

⇓

self–absorption (synchrotron, free-free ?):
optically thin steep spectra turn over at frequencies ranging from ~100 MHz (CSS) to ~ 1 GHz (GPS) & finally > a few GHz (HFP)

What are the key elements for defining a small source? -2-

many of them can be used as selection tools among the radio source catalogues

– low/absent linear polarization:

*the smallest objects are unpolarized; those larger than a few kpc become weakly polarized at mm/cm wavelengths (**Cotton effect**, Cotton et al. 2003)*

– galaxies rather than quasars

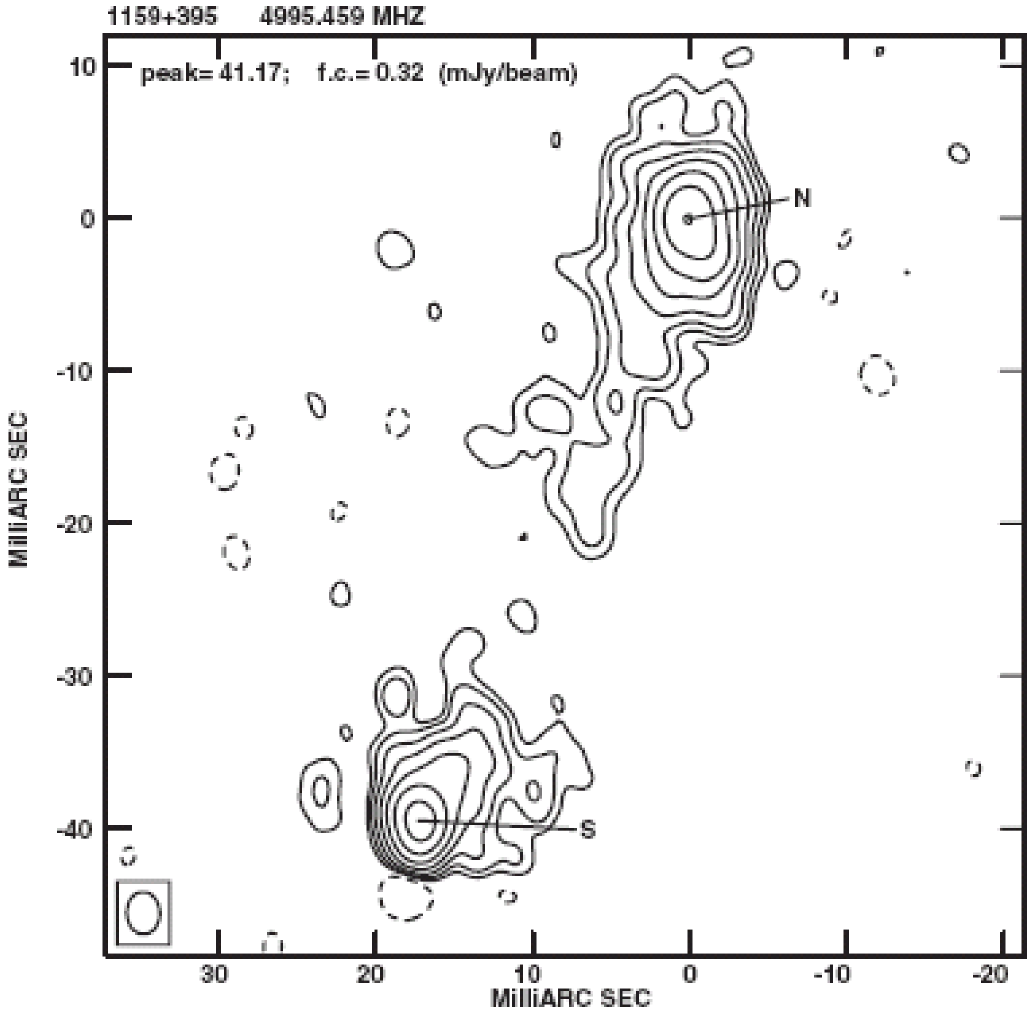
consequence of Unified Scheme models, galaxies are welcome, quasars are not!

– no significant flux density variability

consequence of earlier item

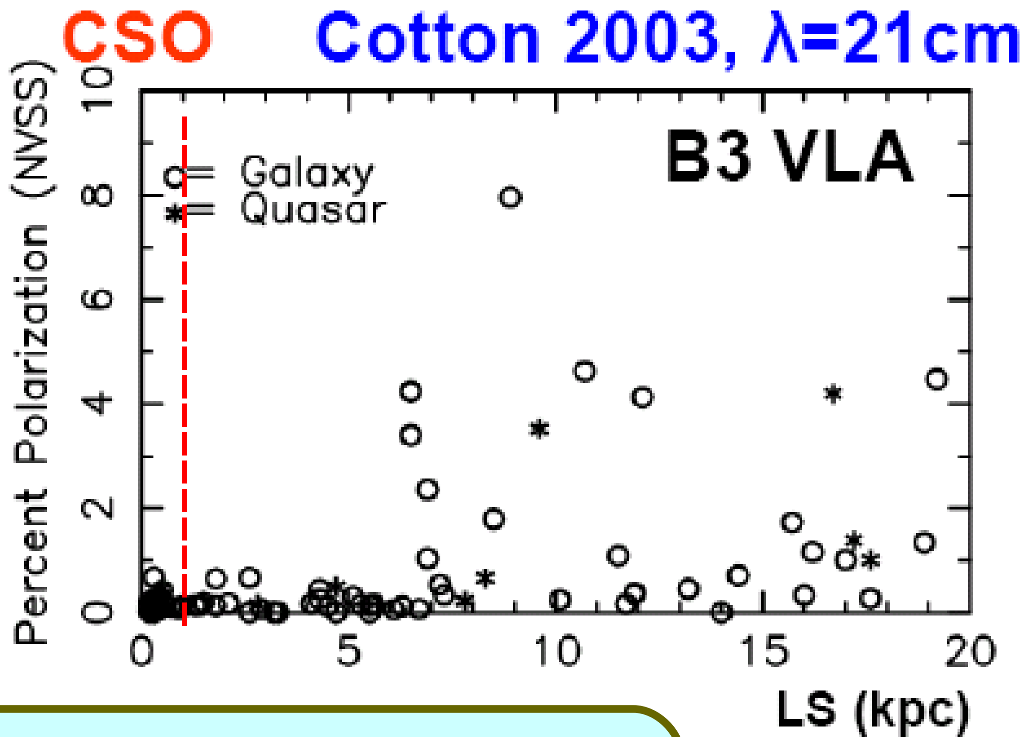
A more detailed picture:

- *The aspect of the radio emission in small & young radio sources is the same as the large, extended radio sources*
- *Lobes and HS account for the dominant contribution to the total flux density*
- *Cores are either weak or undetected*
- *Jets are sometimes detected*
- *Selection effects may have influenced this picture*



NB: VLBI images are made with a smaller number of antennas and lower dynamic range wrt VLA images

A more detailed picture:



High n_e and μG ambient H within host galaxies:

Faraday Rotation and Depolarization most relevant to small sources

Only sources larger than a few kpc are weakly polarized at cm wavelengths. The cutoff at which this transition occurs is a function of wavelength (Cotton effect)

Beam depolarization is not effective: even with milliarcsecond resolution no polarized emission in generally observed.

A more detailed picture:

Extended emission in compact objects?

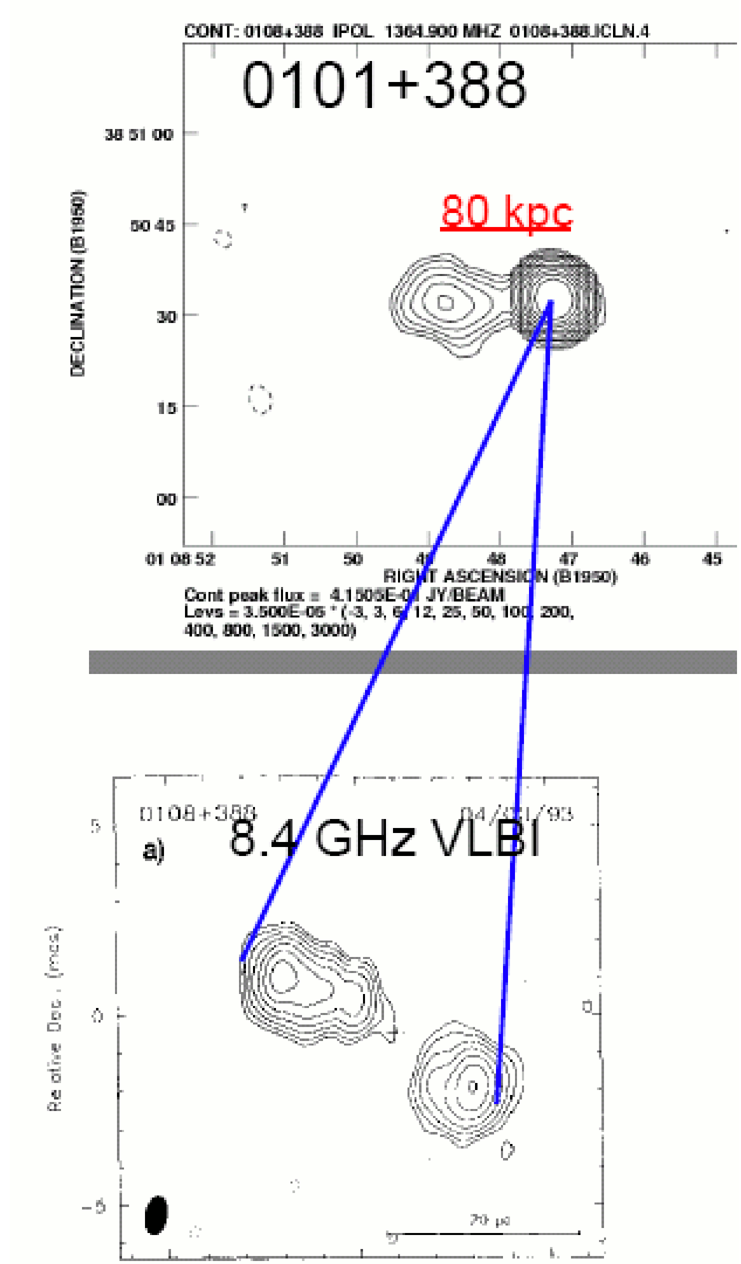
In a substantial fraction of the compact sources extended emission is found, well beyond the compact & young radio source
(e.g. Stanghellini et al. 2005).

- *confusing source*

- *relic of earlier activity*

- *discontinuous start if extended emission is on intermediate scale*

- *young radio sources are found in restarted radio galaxies*



The growth of the radio source:

Models:

=> assume that relativistic plasma expands in a rather uniform ambient medium with $\rho \sim r^{-\delta}$ and with a constant jet power

=> produce a symmetric radio source. Galaxies should appear symmetric and evolve (i.e. grow) self-similarly

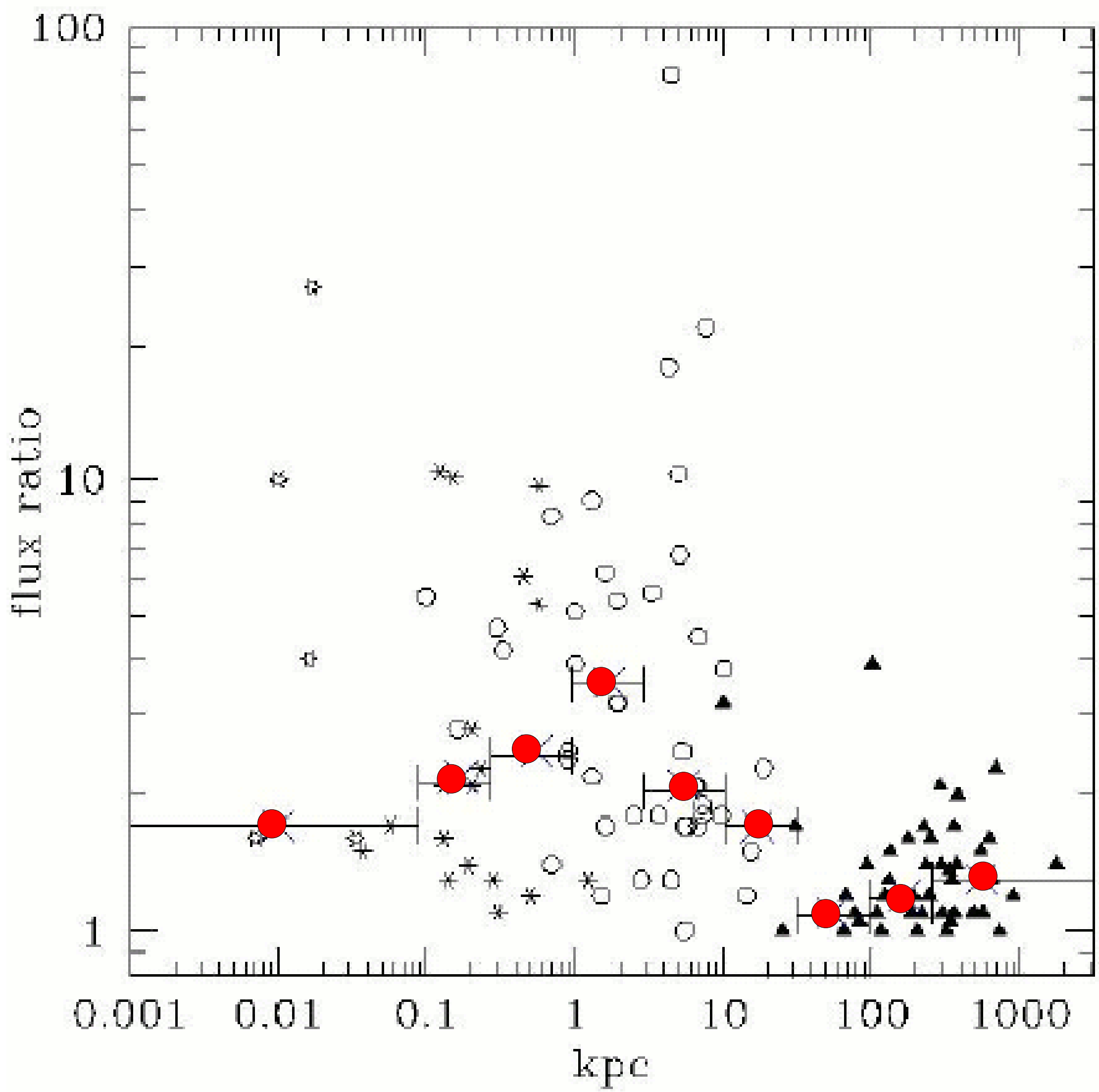
Relativistic particles and H field are originated in the AGN and then transferred to the radio lobes, where radiation and expansion losses ......

The total radio luminosity varies with time (i.e. linear size), mainly depending on the external density profile. It gets to its maximum when the source size is about ~ 1 kpc

However....

... small sources are asymmetric!

Asymmetries in both length and flux density more evident for linear sizes of ~ 1 kpc



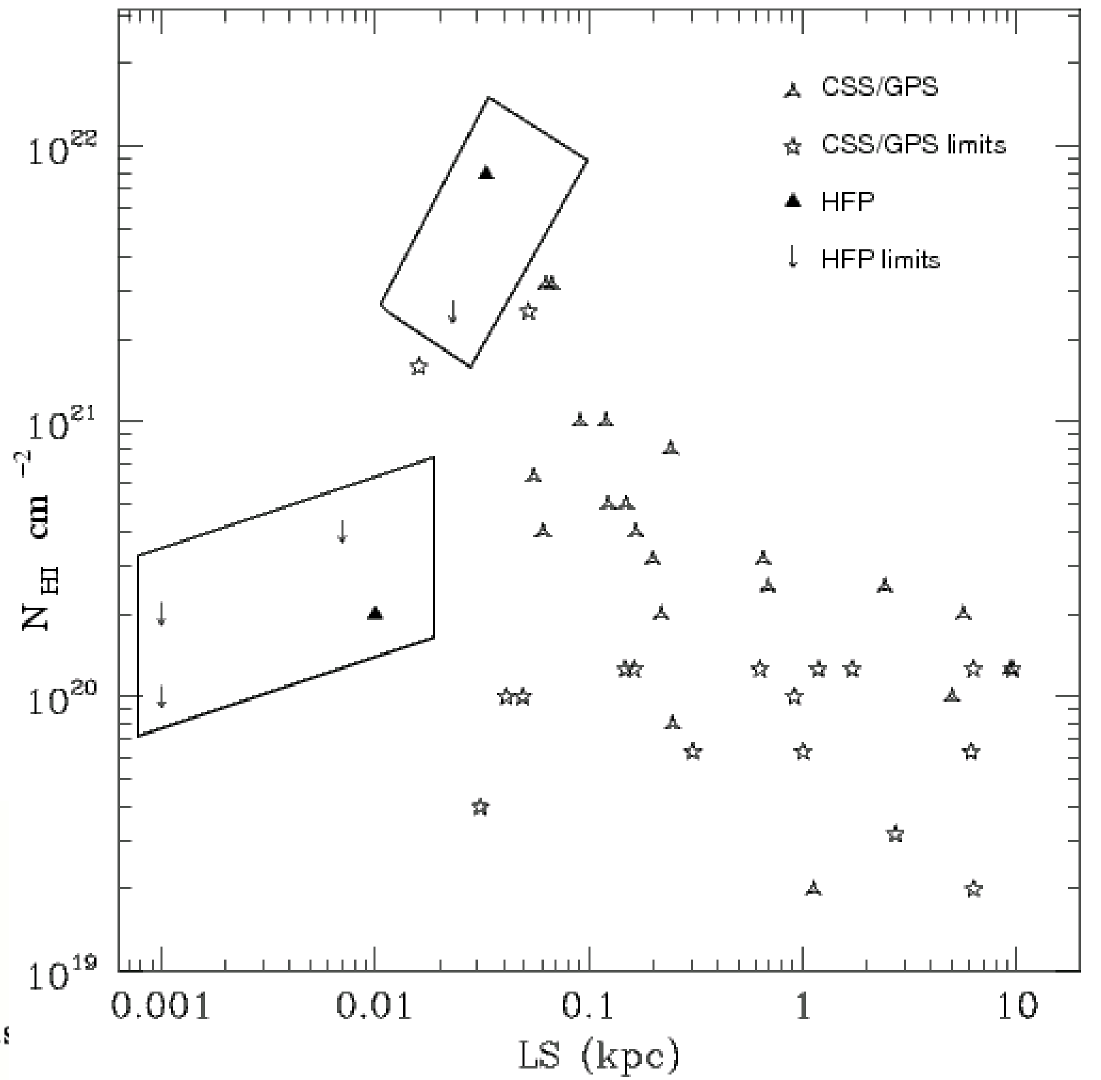
jet-cloud impact?

⇒ *the jets propagate within an* ***inhomogeneous*** *ambient medium (ISM)*

... small sources are asymmetric!-2-

– *rather broad forbidden lines* *(supposed to be narrow!)*

(Gelderman & Whittle 1994)



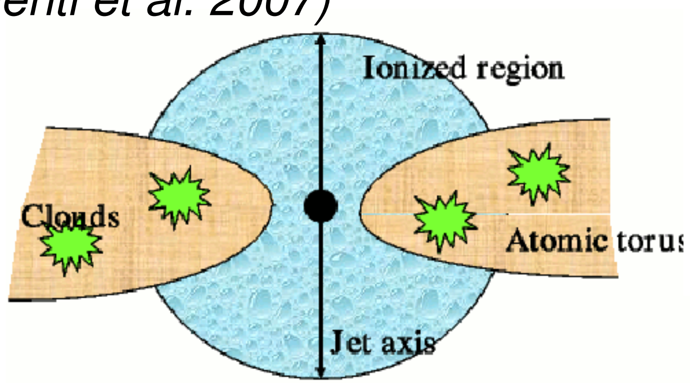
– *occurrence of HI absorption*

in small objects much larger than in extended radio galaxies

(Pihlström et al. 2003, Gupta et al., 2006)

– *... but! ... not true for the smallest sources*

(10 pc; Orienti et al. 2007)



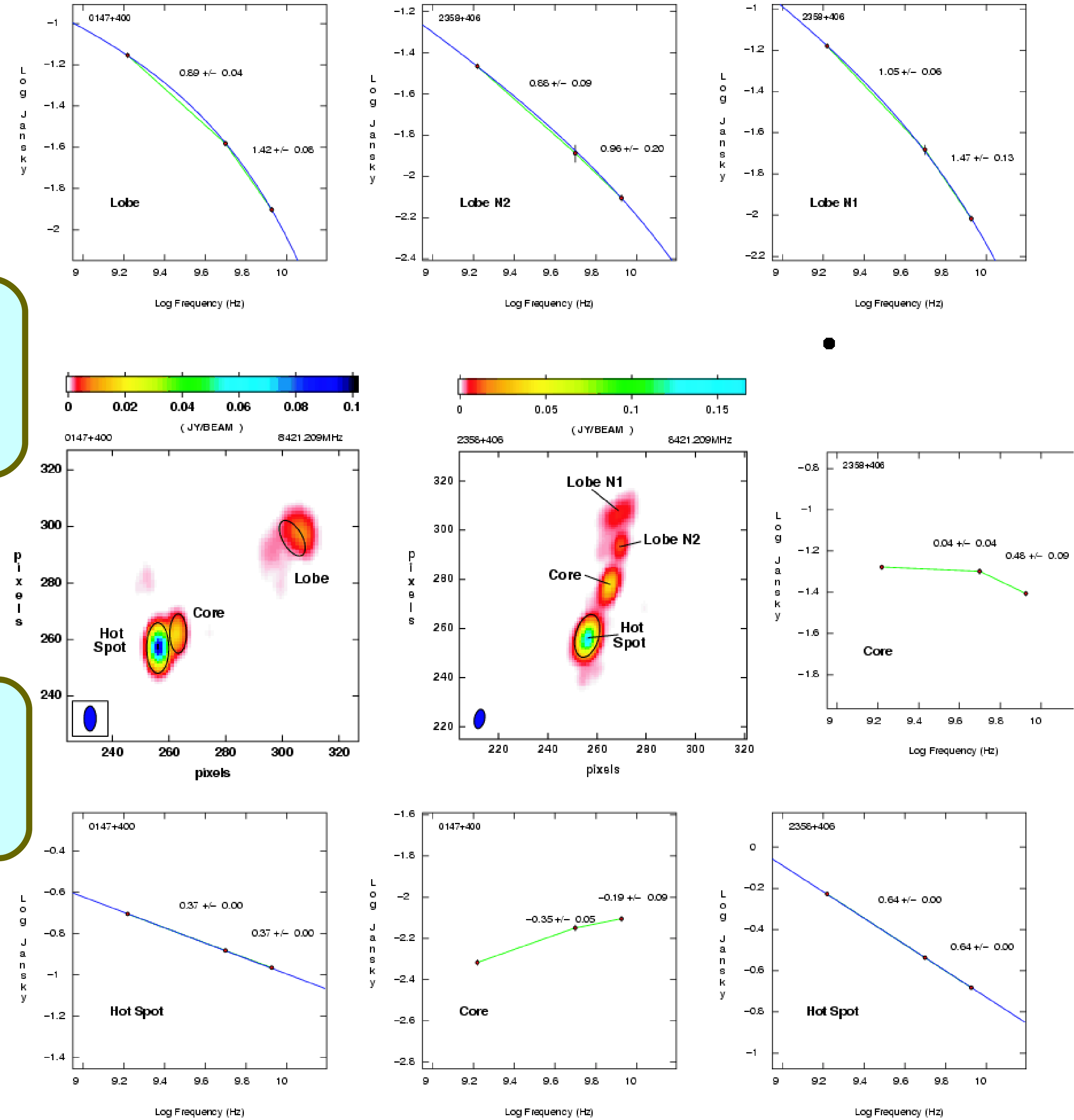
"Spectral" age of small radio sources:

the "local" spectrum provides an estimate of the radiative age of the electrons in that region

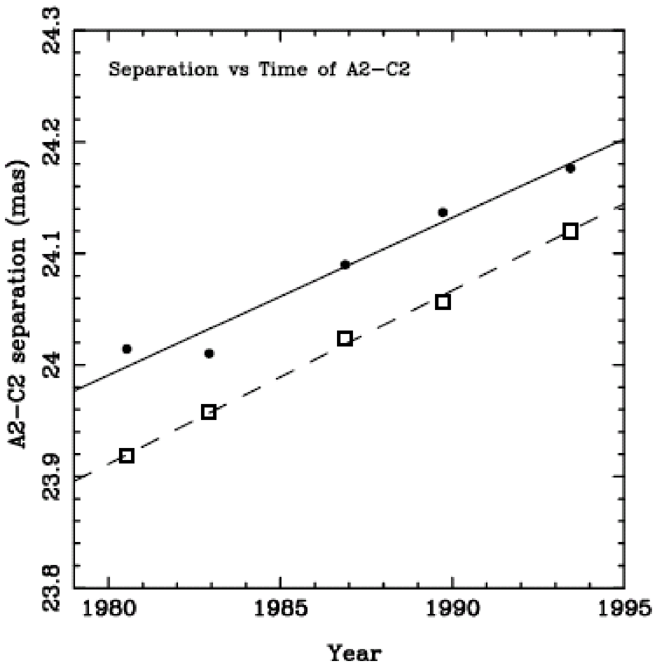
the oldest electron population provides a lower limit to the radiative age of the radio source

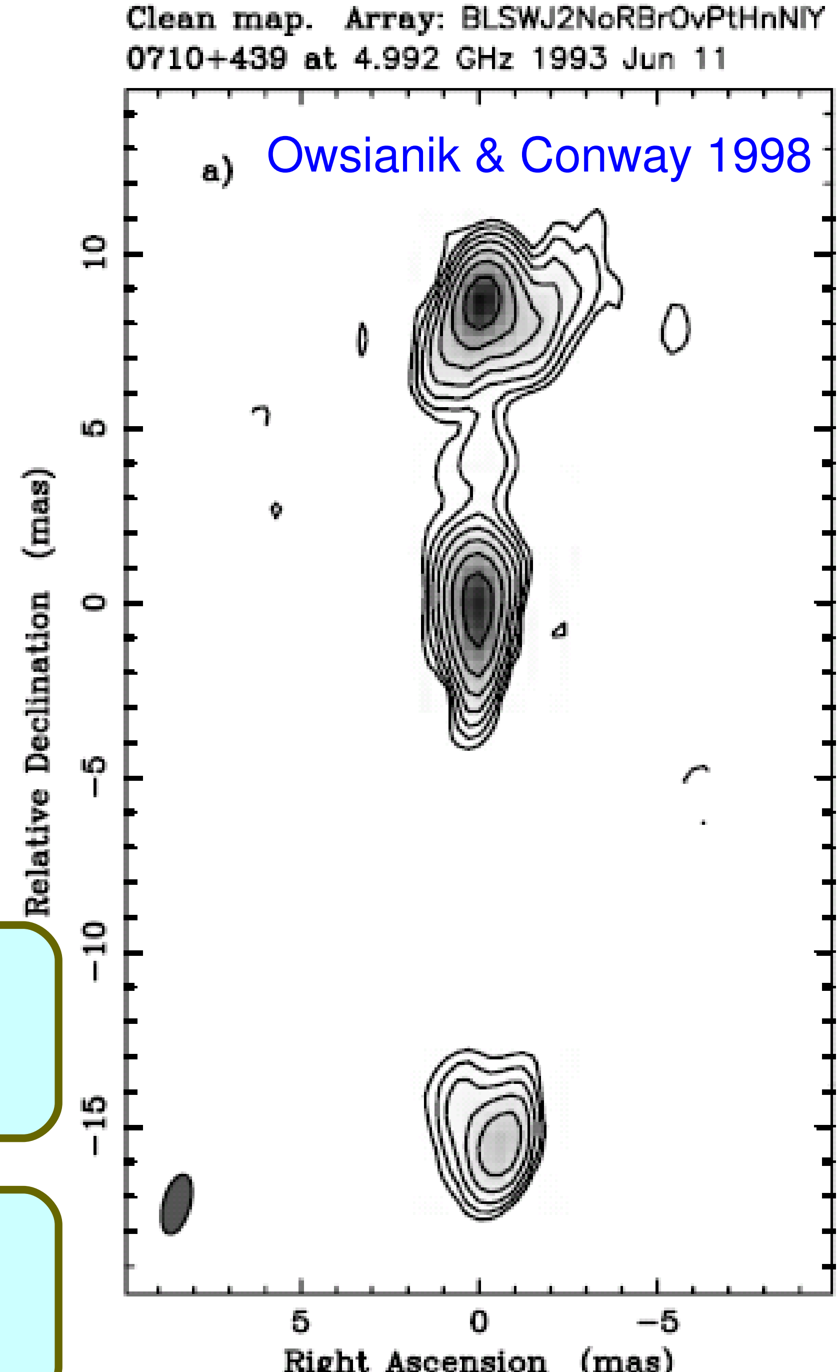
typical ages:

10^3-10^4 yr



Kinematic age:





Repeated radio observations over many (5 – 20) years measure the growth speed (available for a few tens of r-gals)

Typical velocities around 0.1 – 0.2 c [objects with sizes of ~ a few x 100 pc] (Polatidis & Conway 2003)

Lateral motions (jet precession?) have been detected (Stanghellini et al. 2009)

Summary

– Intrinsically small sources are in an early stage of their own evolution
– Radiative and kinematic ages are in excellent agreement
– Many failed attempts to find a very dense ambient medium in compact radio sources
– Fully embedded in the host galaxy ISM
– Powerful radio emitters (beware of selection effects!)
– They have (roughly) constant flux densities in the radio window
– They are unpolarized in their very early days, then they becomes progressively polarized as they find their way out of the innermost and most ionized ambient medium
– Jet-cloud interactions are likely responsible for
asymmetries & “broad – narrow” lines as found in the optical spectra
– “Extended” emission is found in about ¼ of the objects
either an earlier activity, or a “sputtering” start
– A fraction of these small radio sources may not live long enough to become extended (faders)