12. Powerful Individual Radio Source Evolution

- *O'Dea & Saikia, The Astronomy and Astrophysics Review, Vol. 29, Issue 1, art. id.3* https://arxiv.org/pdf/2009.02750.pdf
  "Compact steep-spectrum and peaked-spectrum radio sources"

- *O'Dea, 1998, PASP, 110, 493*
  "The Compact – Steep Spectrum and Gigahertz Peaked – Spectrum Radio Sources"

- *Fanti C. +, 1995, A&A, 302, 317*
  "Are Compact – Steep Spectrum Sources Young?"

- *Snellen + 2000, MNRAS 319, 445*
  "On the Evolution of Young Radio – Loud AGN"

Based on a Peter Scheuer's idea (1974), revisited by Baldwin (1982), considering a ***self-similar growth*** *of a radio source generated by the host galaxy: i.e. "intrinsically small radio sources are an early dynamical state of an evolving phenomenon"*

*The r**adio source initially expands within the ISM of the host galaxy**, and **then into the IGM**, **roughly preserving its morphology with time.***

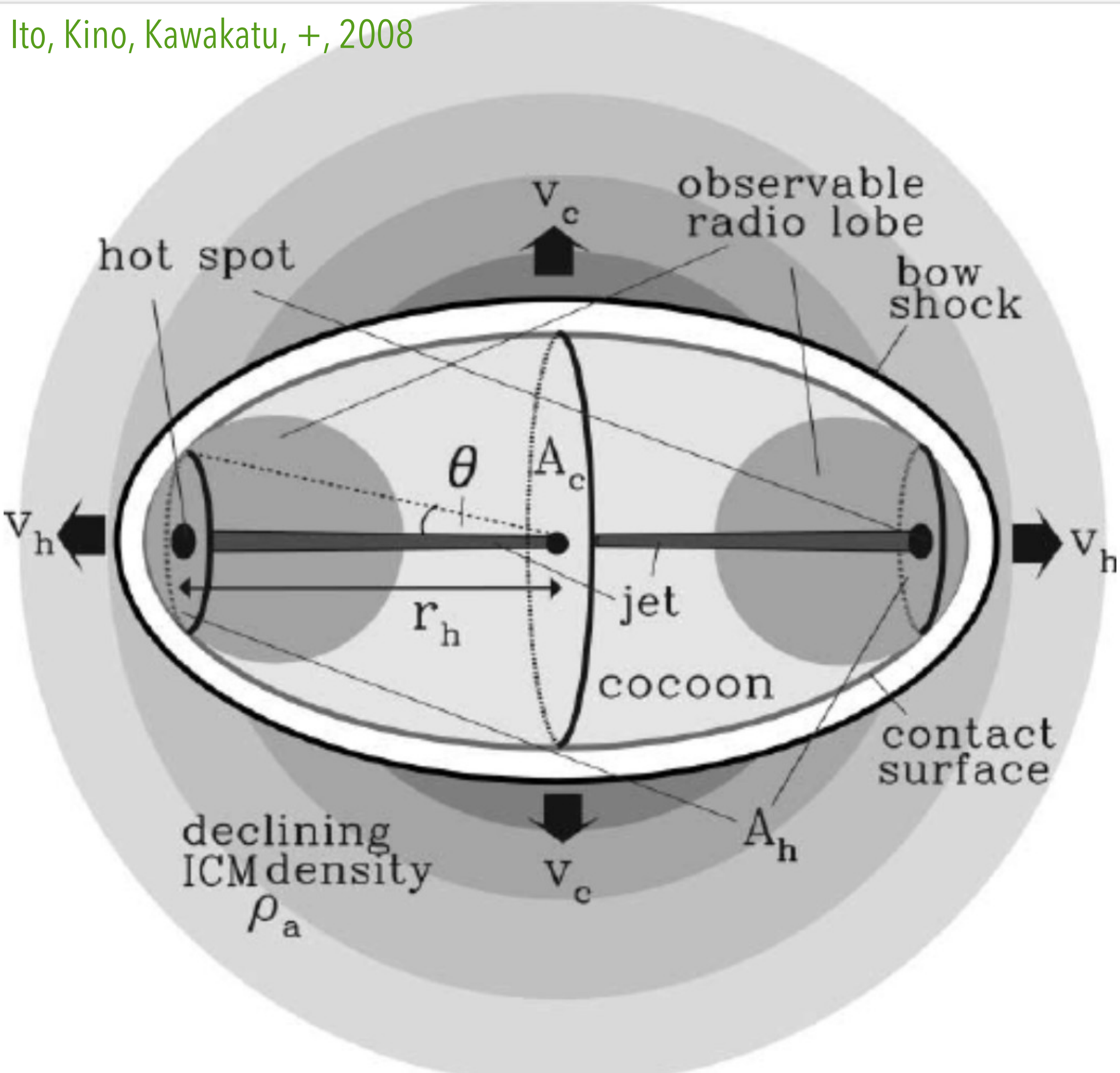
When the supply of energy is over, the radio source ages and progressively fades away.

Radio Sources/Galaxies

- About 10% of the AGN population has substantial radio emission (from AGN activity)
- Radiative ages are at most a few in 10^8 yr
- Linear sizes reach a few Mpc
- Ambient is relevant (isolated/groups/clusters)
- Hosts are in Ellipticals (+ quasars)
- Morphological classification consistent with Unified Scheme Model(s)
- Most of the present day information is based on FR–I & FR–II populations but it is not the whole story!

Powerful Individual Radio Source Evolution (2)

Ito, Kino, Kawakatu, +, 2008



— Cartoon of the employed model. The relativistic jet from FR II radio galaxy interacts with ICM with a declining density. Most of the kinetic energy of the jet is deposited in the cocoon, which is then inflated by the internal energy.

Powerful Individual Radio Source Evolution (2)

Youth Scenario

Small/large radio source population ratio is based on their typical age (a few compact, many extended)

Size/age determines the average expansion speed (growth rate) (kinematic age, to be compared to the radiative age measured on the radio spectra)

Pressure equilibrium / interaction with local ambient medium influence energetics, morphology and asymmetries.vs. size, etc.

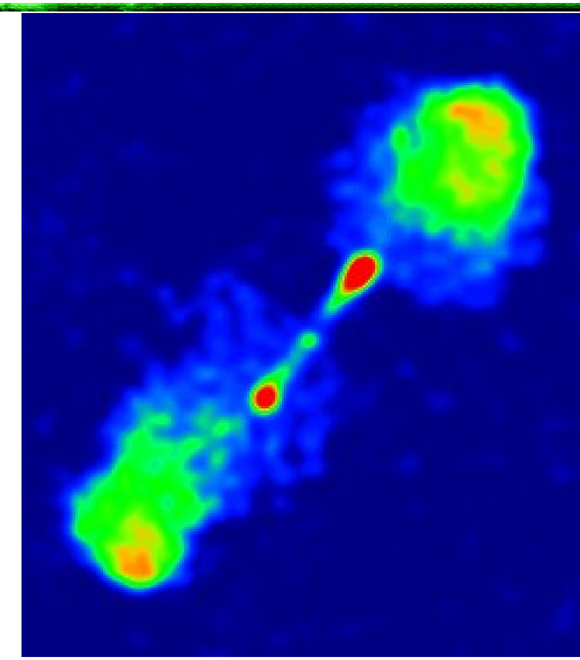
Nuclear variability measures the accretion rate

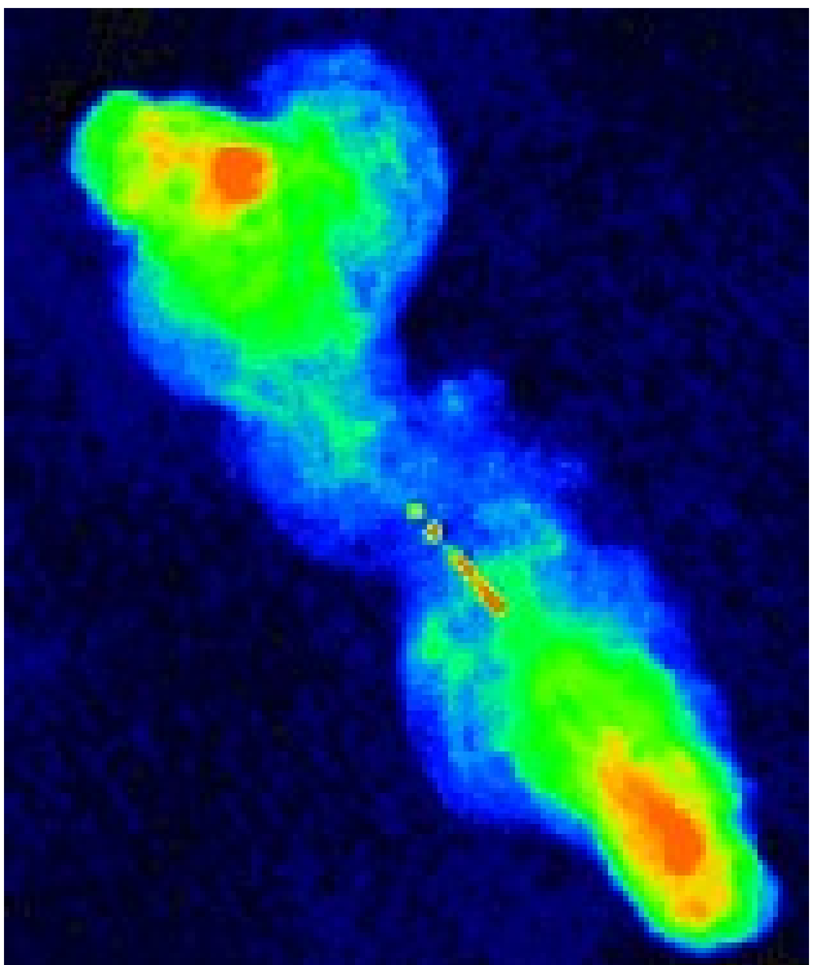
N.B.
Alternative scenario: "**Frustration**", i.e. small sources are as old as large ones, but will never get out of their host given an extraordinarily dense medium. It is not considered anymore, since comparisons between the hosts of compact/extended radio sources show no significant difference.

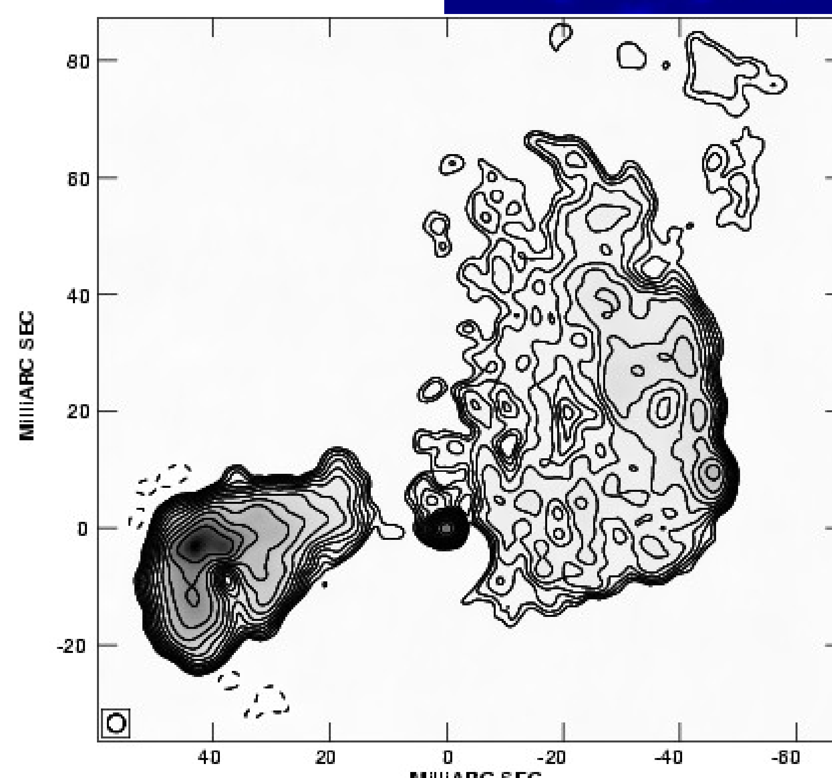
Self -Similar growth

High Frequency Peaker ⇒ GHz- Peaked Spectrum ⇒

Compact Steep – Spectrum ⇒ Extended Steep – Spectrum (FR I & II)







Giroletti + 2003

4C31.04 : 1.1 pc/mas

BABY: *High Frequency Peaker (Dallacasa & Orienti)*

$10^2 - 10^3$ yr

100 pc

CHILD: *GHz- Peaked Spectrum (O'Dea, '98)*

$10^3 - 10^4$ yr

1 kpc

TEENAGER: *⇑Compact Steep – Spectrum*

(Fanti+ '90,'95) $10^4 - 10^6$ yr

1 – 10 kpc

ADULT: *Extended Steep – Spectrum (FR I & II)*

$10^7 - 10^8$ yr

10s kpc

To 100s kpc

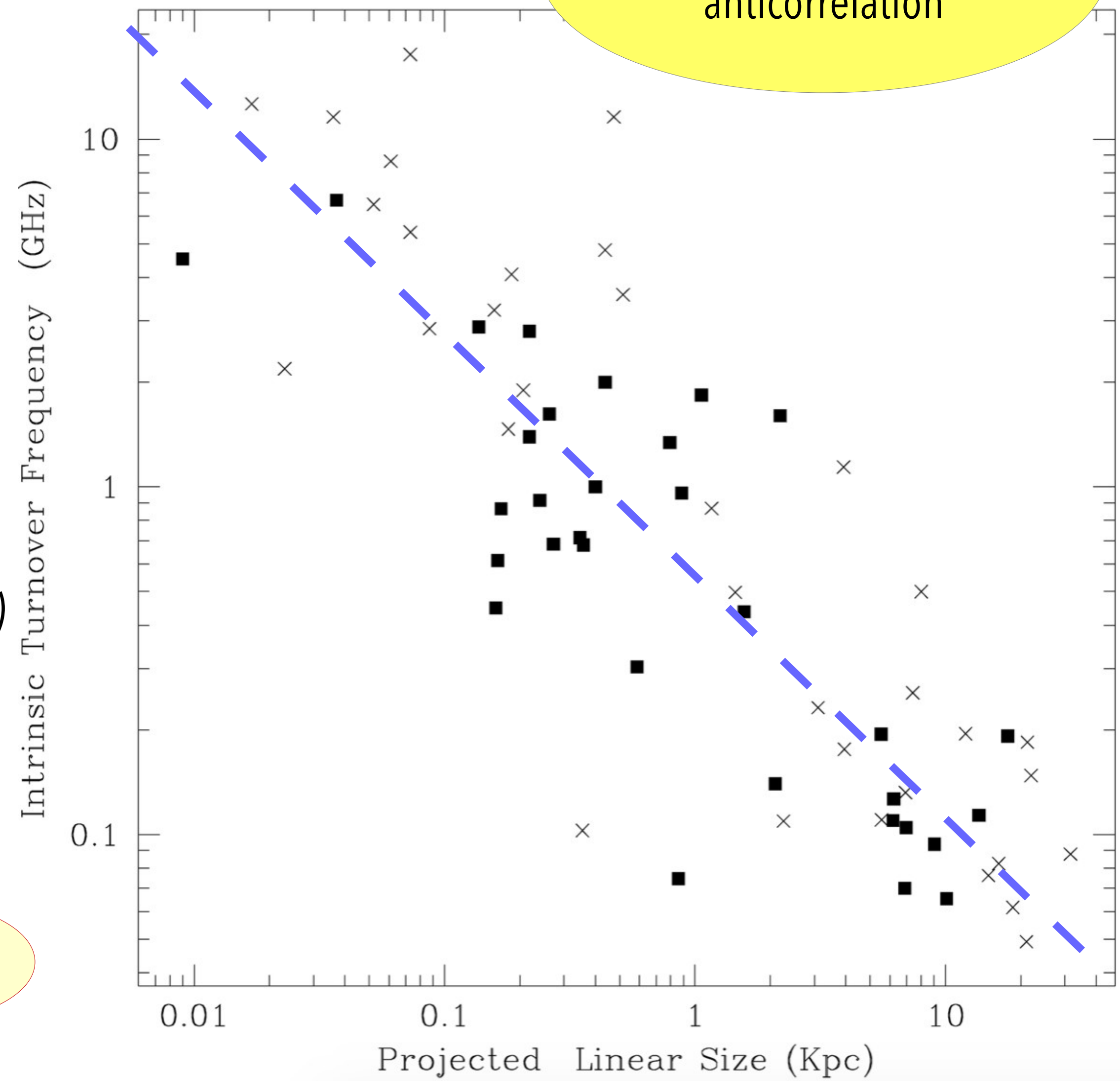
OLD: *Switched-off (fossil) radio galaxies*

> 10^8 yr

100s kpc

To ~ Mpc

There is a LS – ν_{peak} anticorrelation



$$\log(\nu_{peak}) \simeq -(0.21 \pm 0.05) - (0.65 \pm 0.05)\log(LS)$$

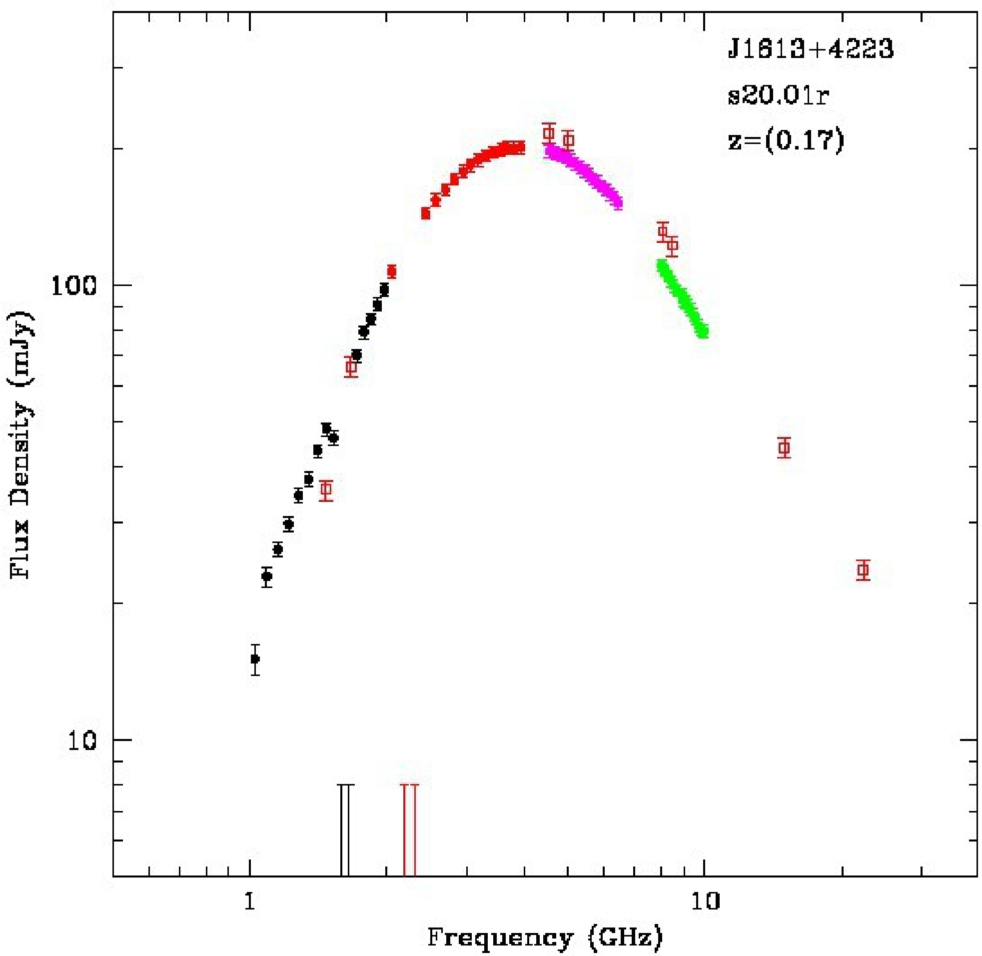
Baby : High Frequency Peakers (Dallacasa & Orienti)

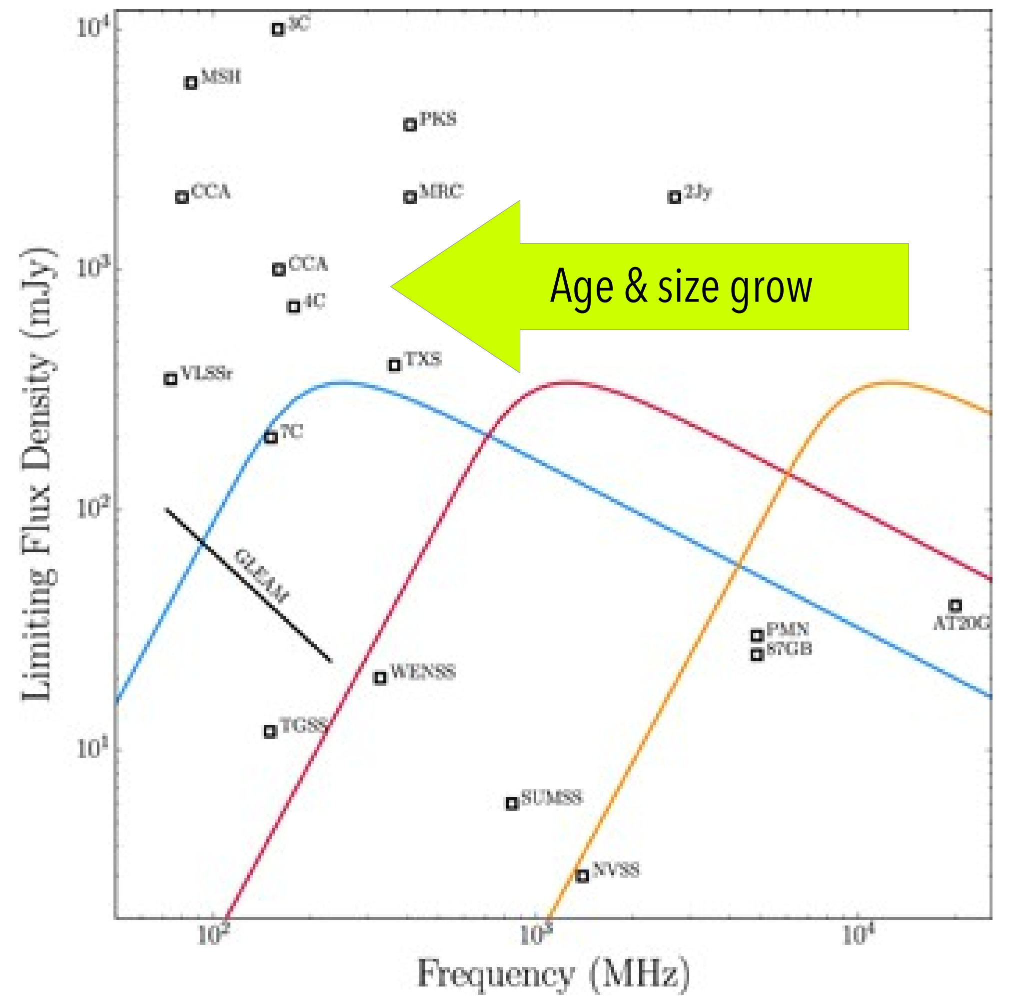
Child: GHz- Peaked Spectrum (O'Dea, 1998)

Teenager: ⇑Compact Steep – Spectrum (Fanti + 1990, 1995)

Adult ⟹ Extended Steep – Spectrum (FR I & II)

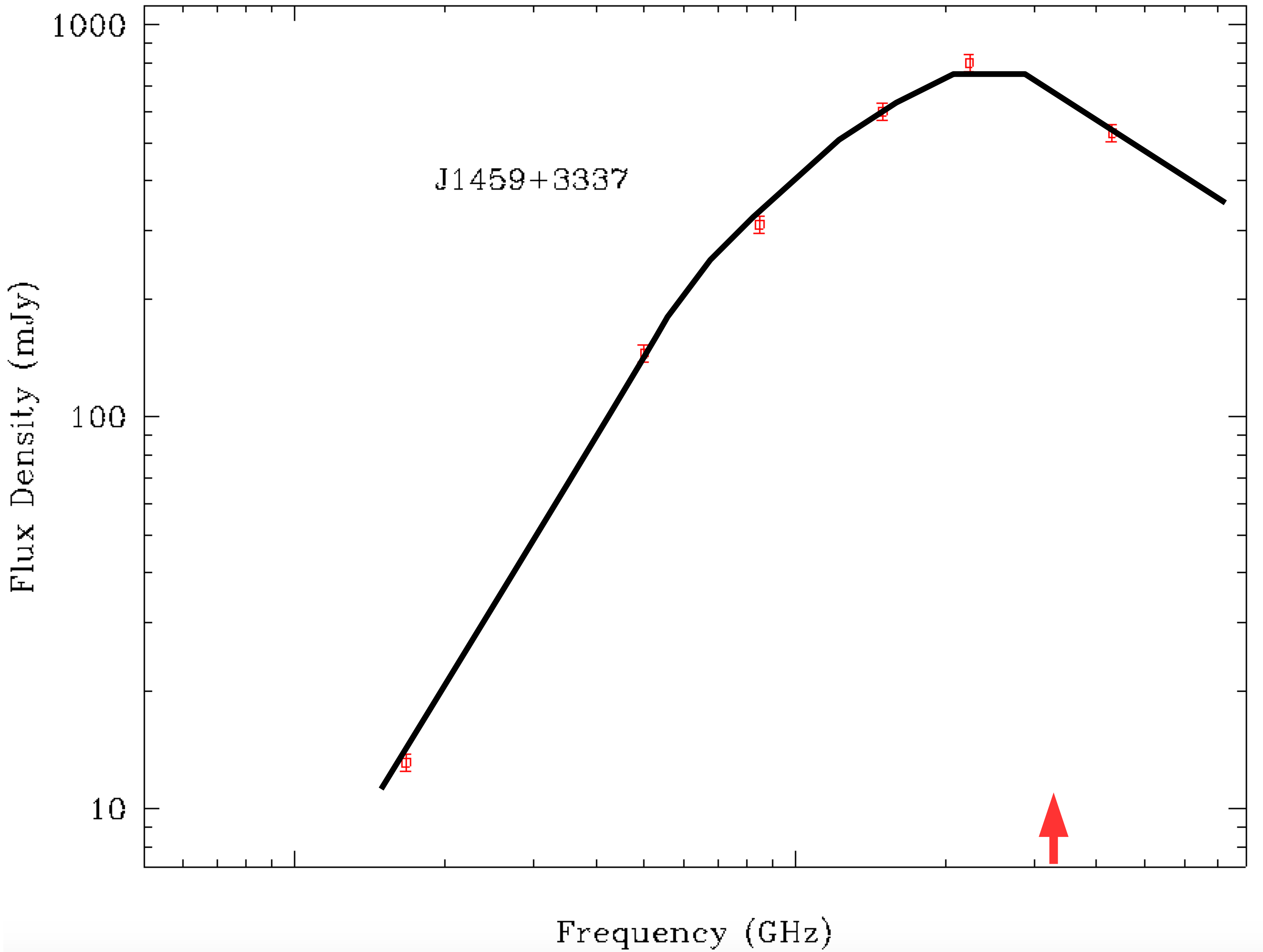
Old: Switched-off radio galaxies





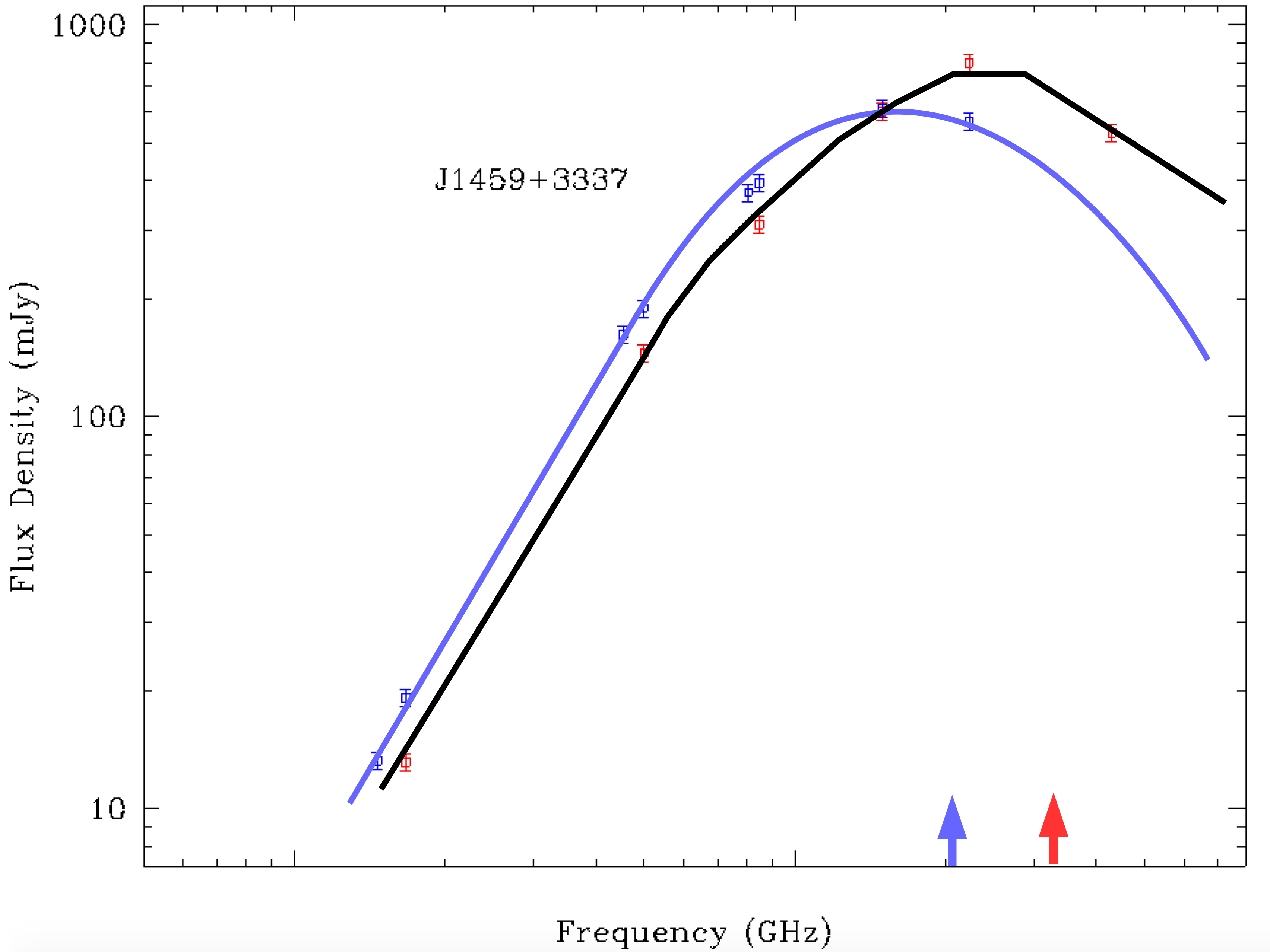
The source: J1459+3337 - a “fast evolving” radio source

Radio data from Edge, 1996



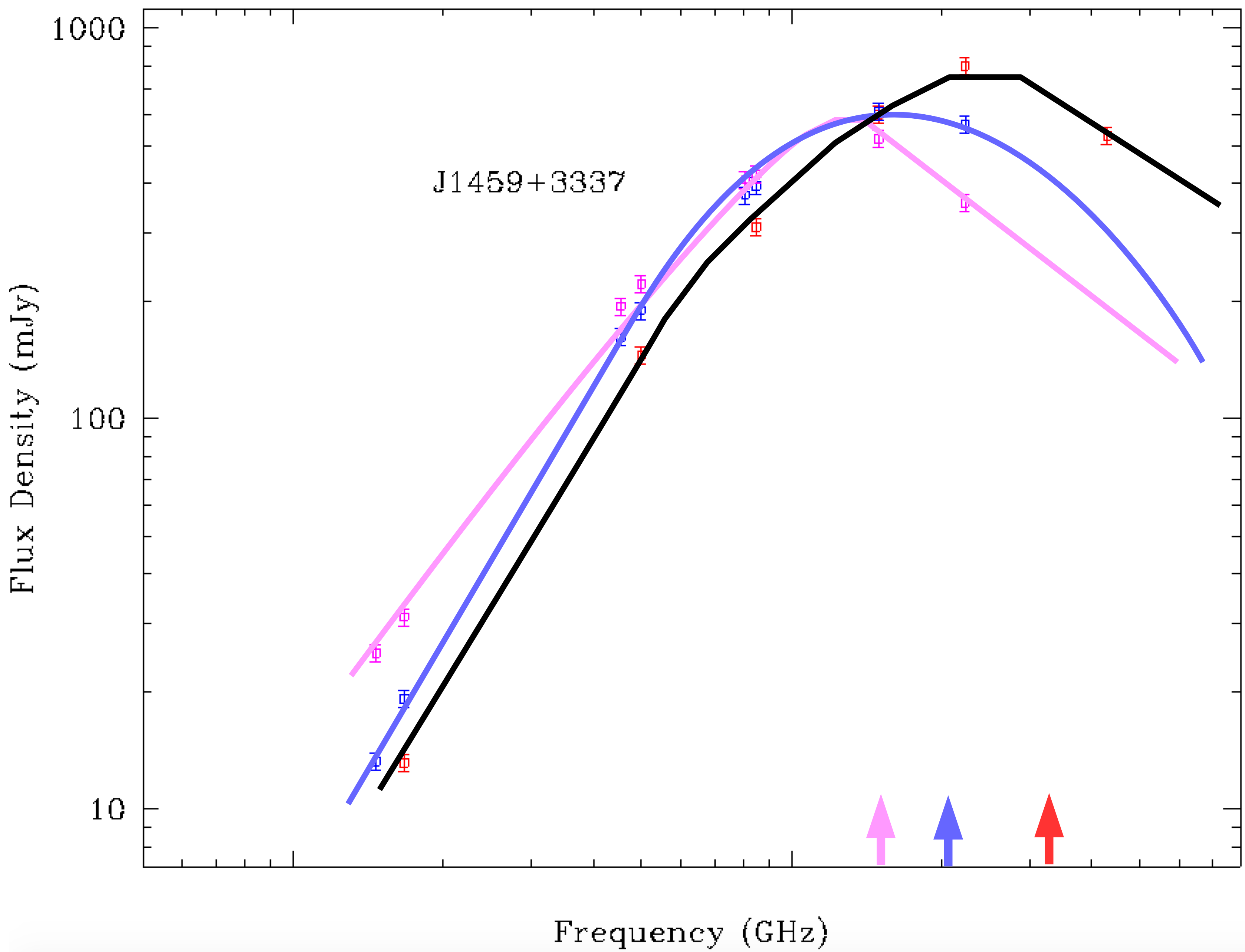
The source: J1459+3337

Radio data from Edge, 1996 ; 1999, Stanghellini, Dallacasa & Orienti (2009)



The source: J1459+3337

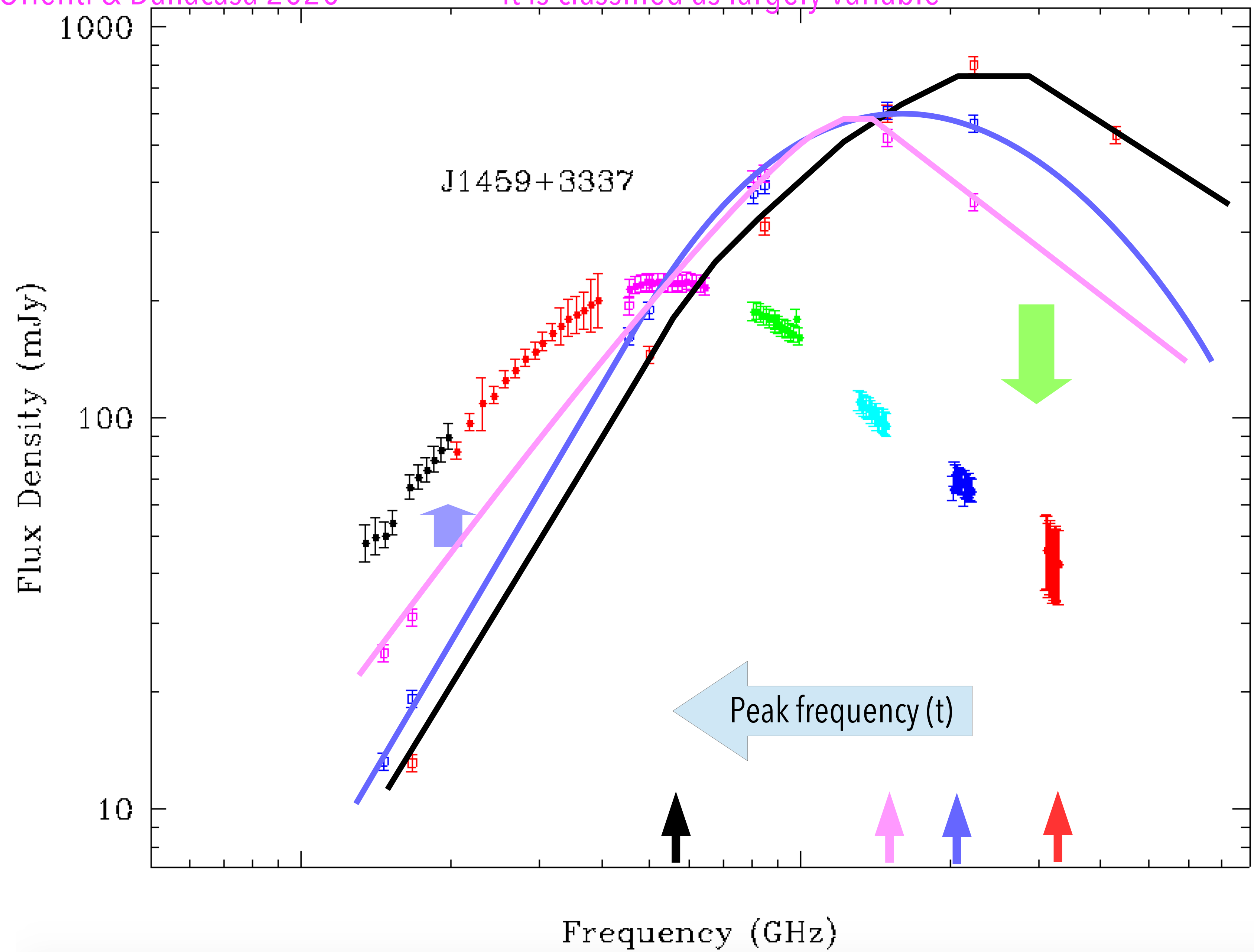
Radio data from Edge, 1996 ; 1999, 2003 Stanghellini, Dallacasa & Orienti (2009)



The source: J1459+3337: **typical behavior of an expanding n-th radio bubble**

Radio data from Edge, 1996 ; 1999, 2003, Stanghellini, Dallacasa & Orienti (2009)

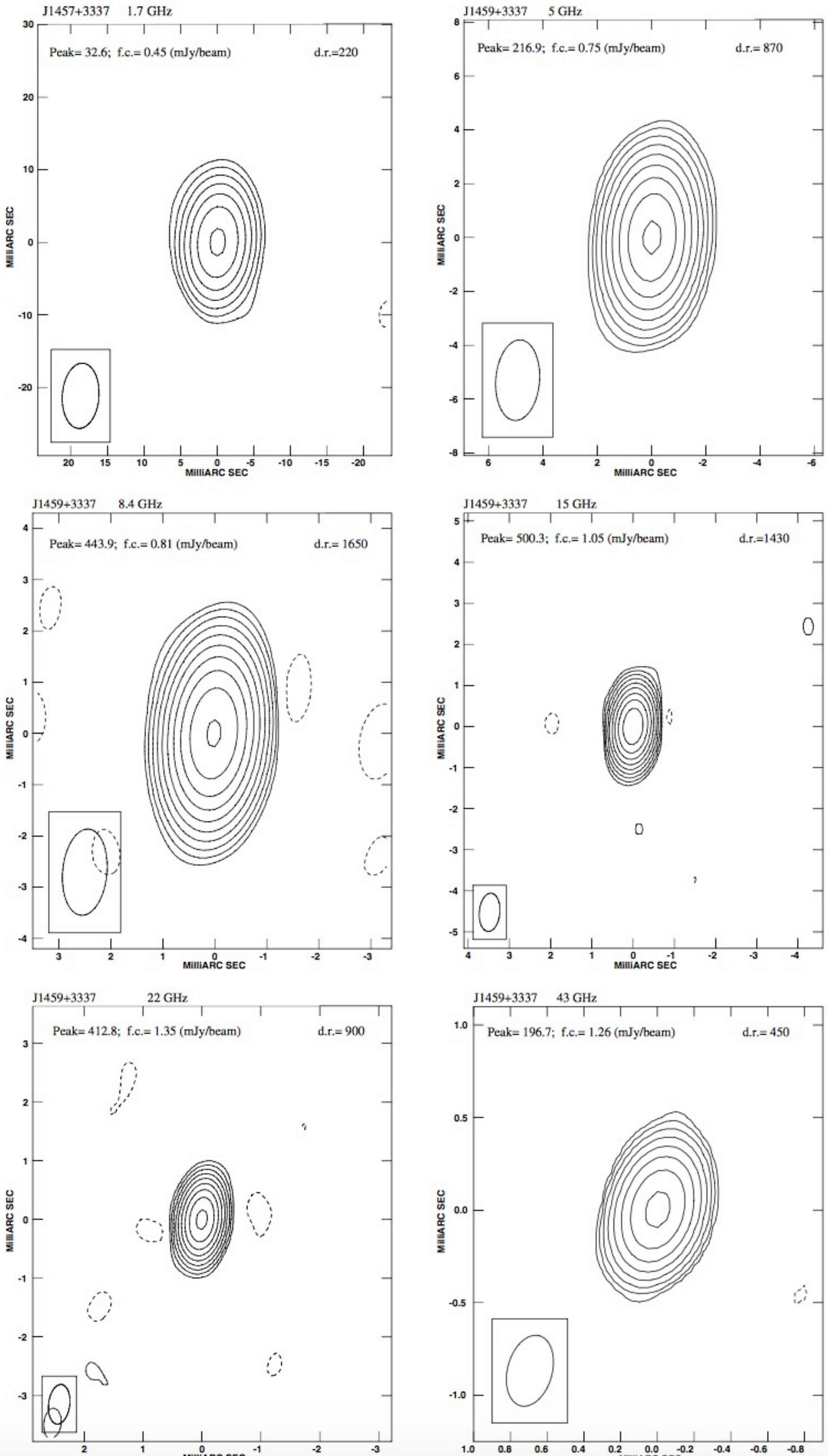
2012 Orienti & Dallacasa 2020 it is classified as largely variable

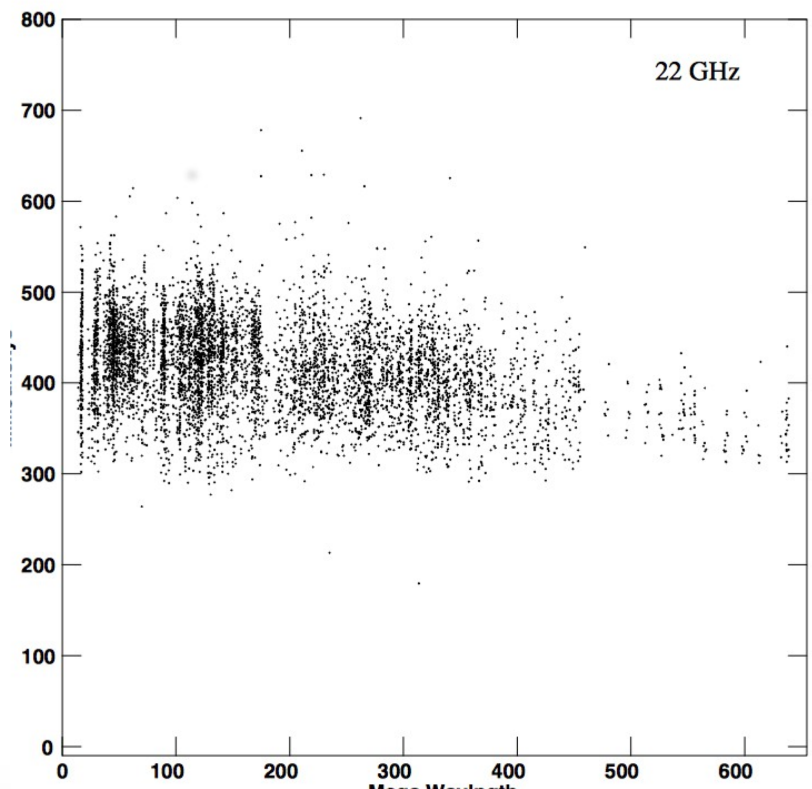


The source: J1459+3337

VLBA 2005

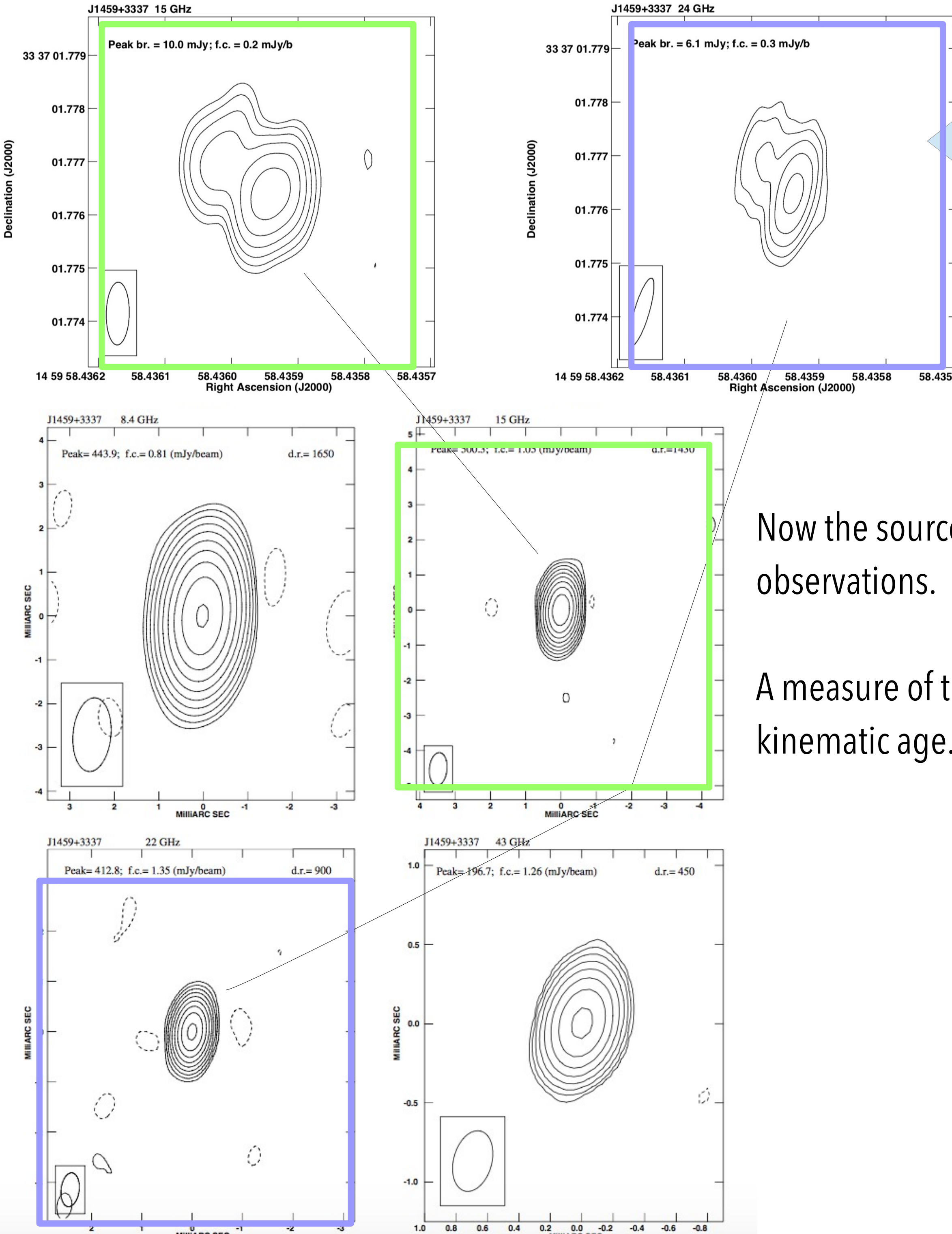
Marginally resolved at 43 GHz





Orienti & Dallacasa 2008

: J1459+3337



VLBA observation, Jan 2019
(Orienti & Dallacasa 2020)

Now the source appears larger, well resolved by the VLBI observations.

A measure of the size over the elapsed time provides the kinematic age.

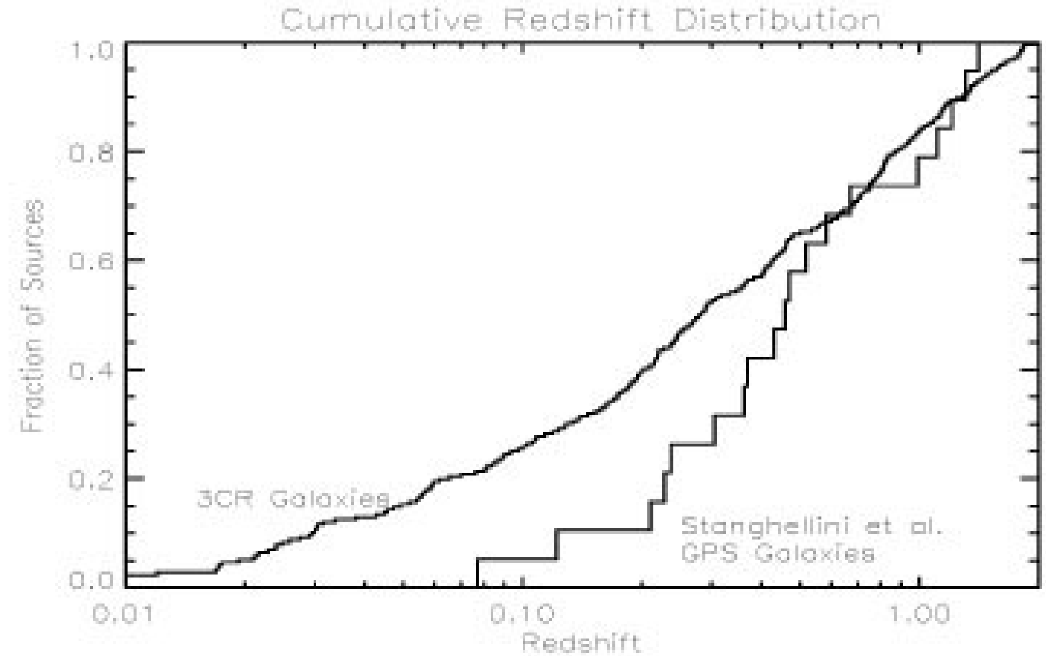
Individual Radio Source Evolution

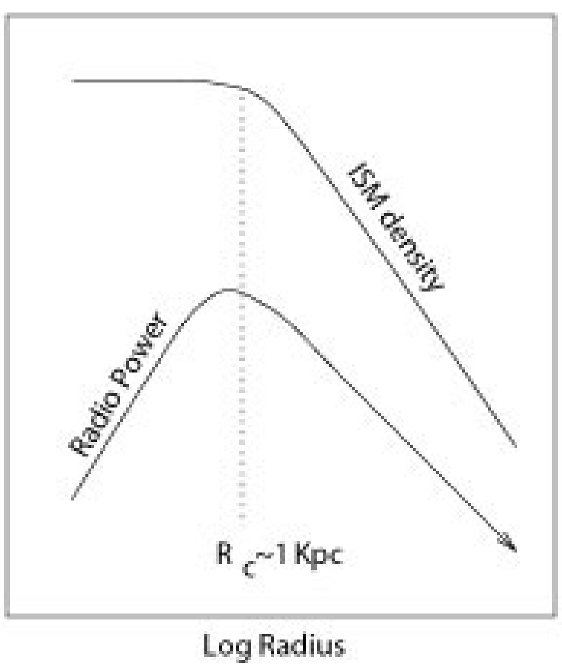
Analogies & differences
Among populations

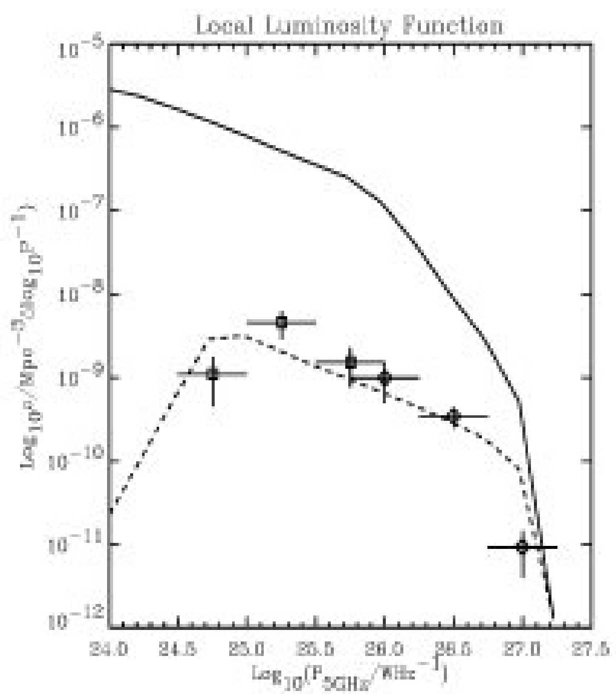
Young objects are @ z higher than 3CR

Limited flux catalogues are
Overpopulated (as high as 10-30%)

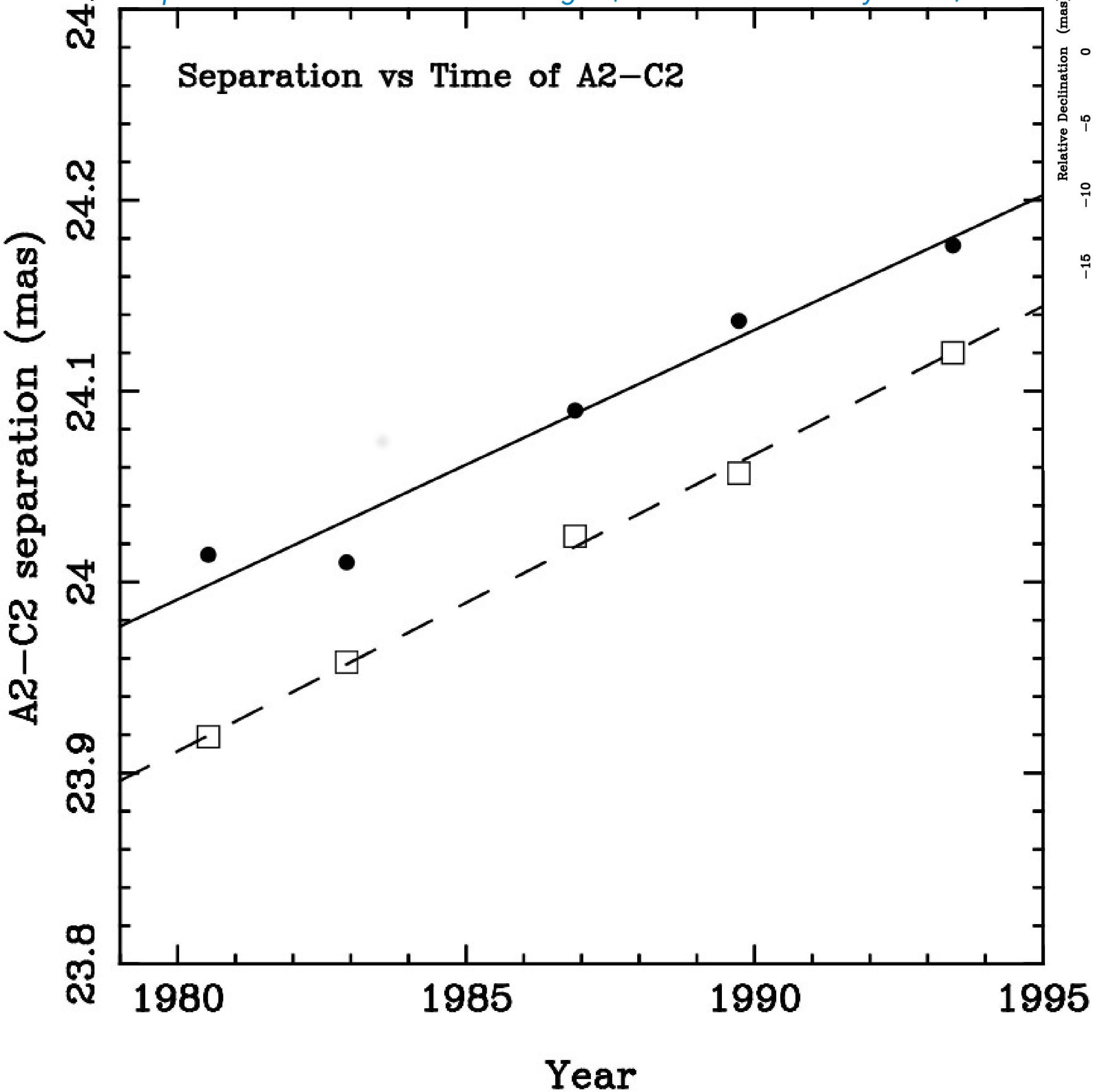
Lack of a significant population of
Local young sources

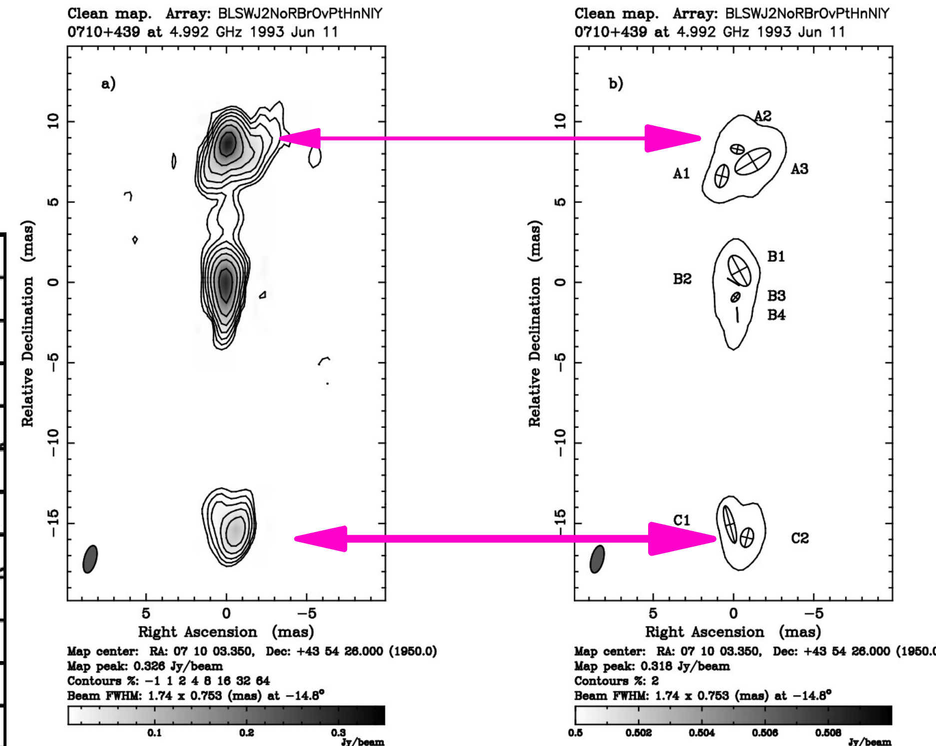






Proper motion of H-S: kinematic age: (Owsianik & Conway 1998)





The outer edges of the radio source are increasing their projected angular distance with time

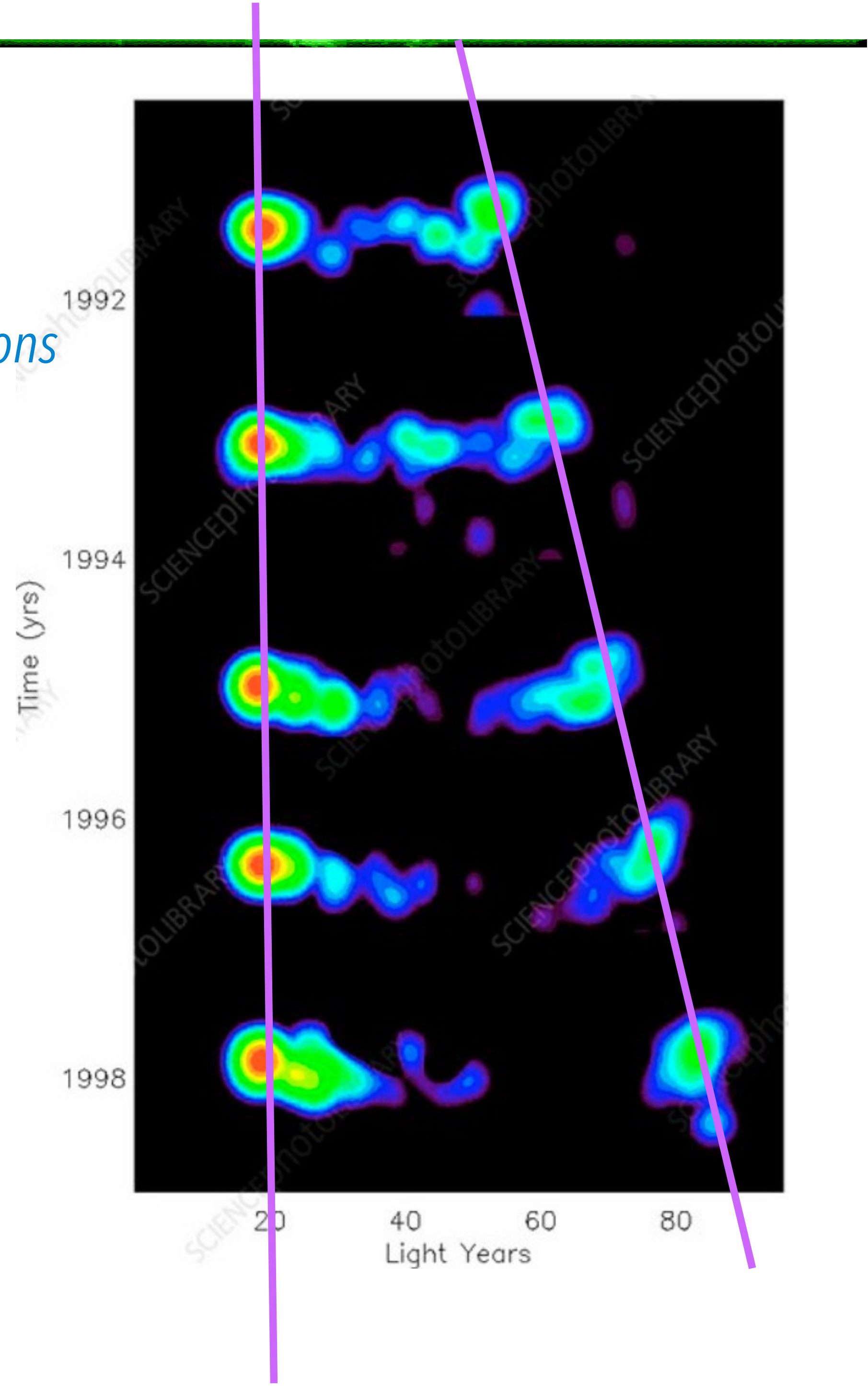
Kinematic ages

Motions and average expansion speed

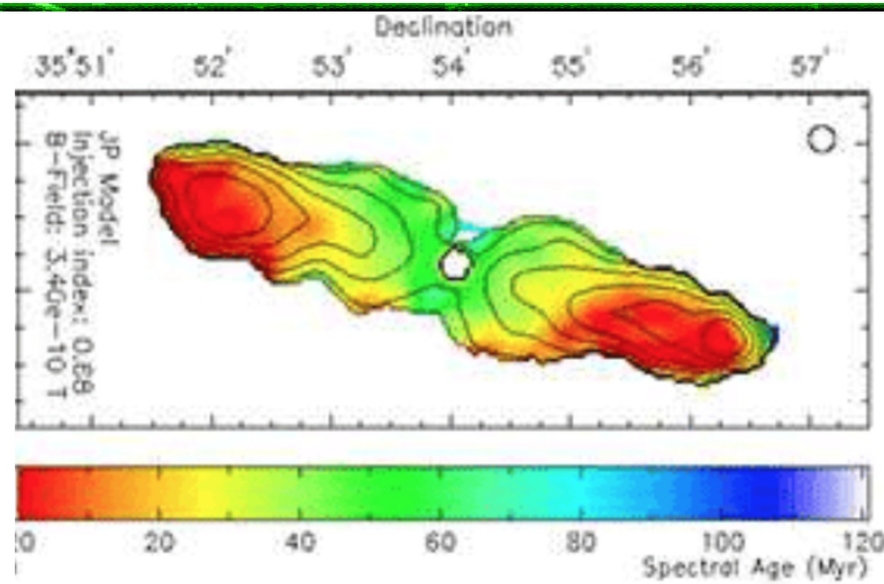
Technique similar to (VLBI) measures of size and positions of "components" in jets..

Determine the "expansion speed"

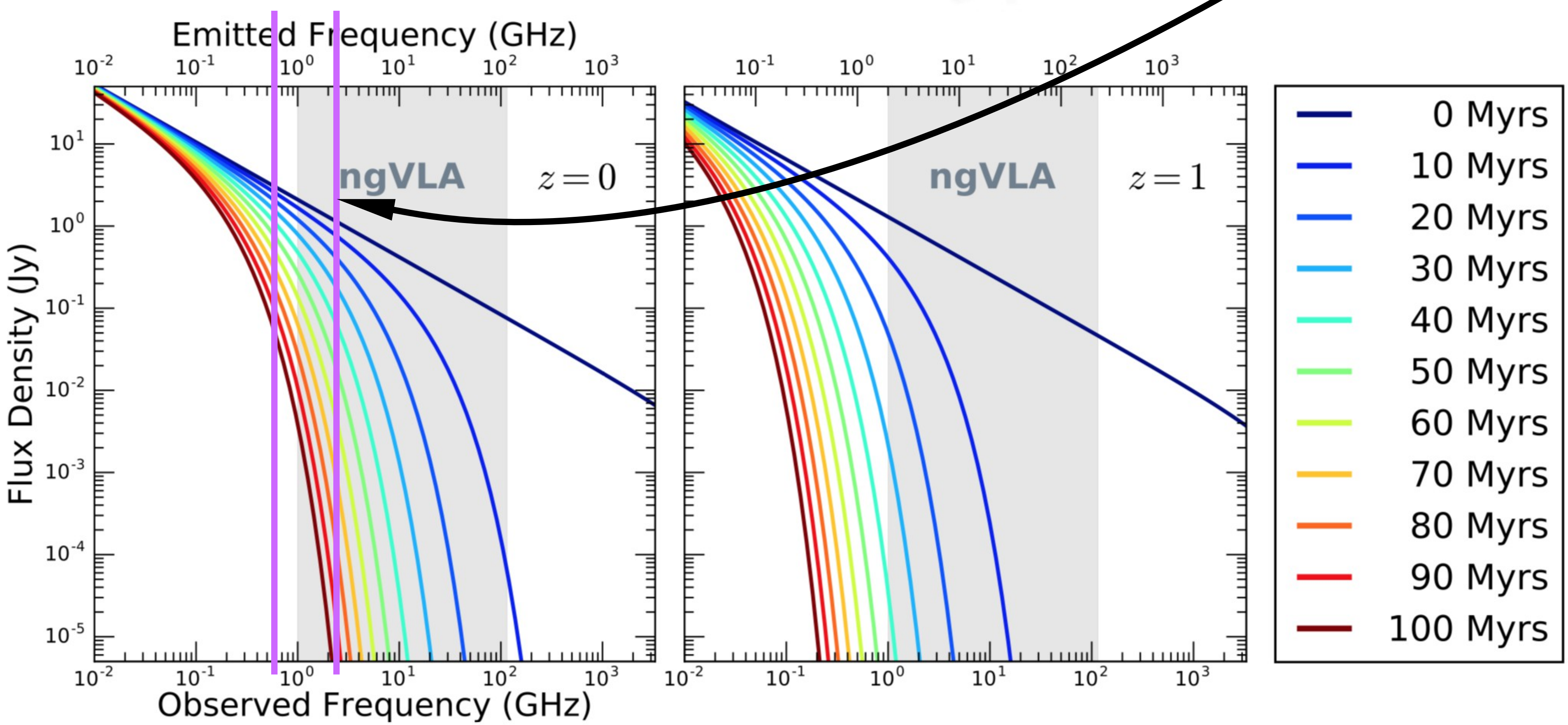
Size/Expansion speed = AGE!



Spectral Ageing



The spectral index between two frequencies is a measure of the radiative age of the radio emitting plasma

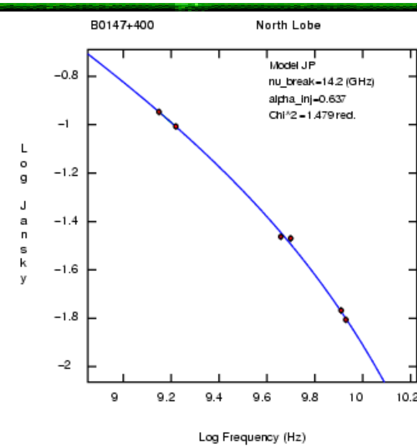


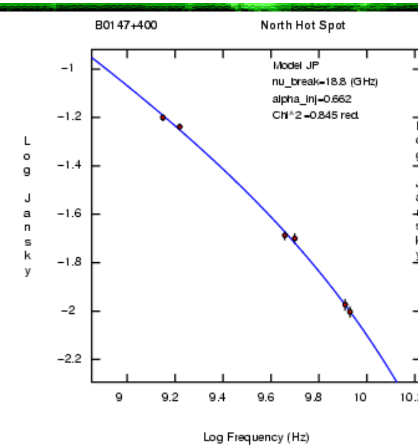
Individual Radio Source Evolution *Proofs for Youth Scenario*

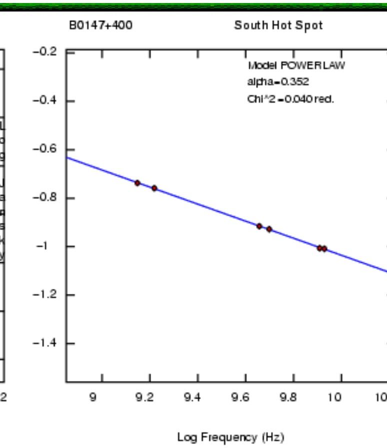
Spectral aging in lobes of intrinsically small radio sources

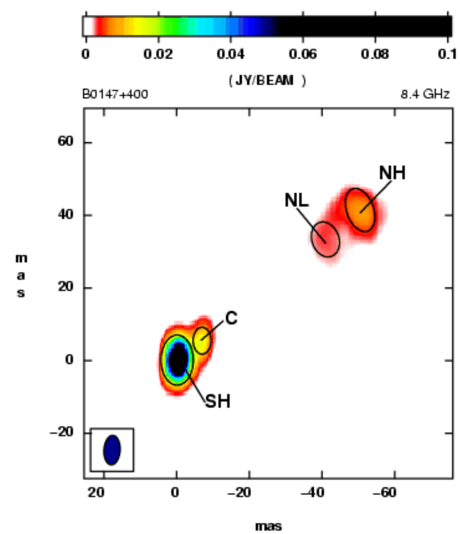
Magnetic fields, local spectral break, radiative age

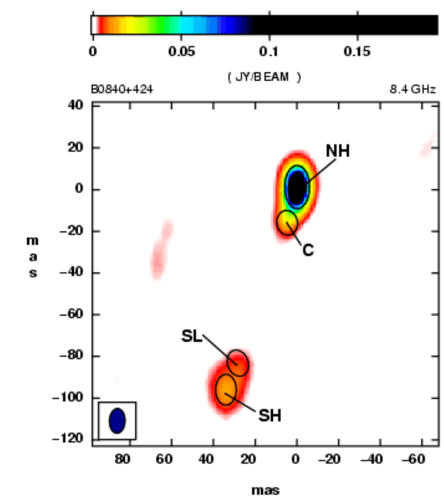
Orienti, Dallacasa & Stanghellini 2007

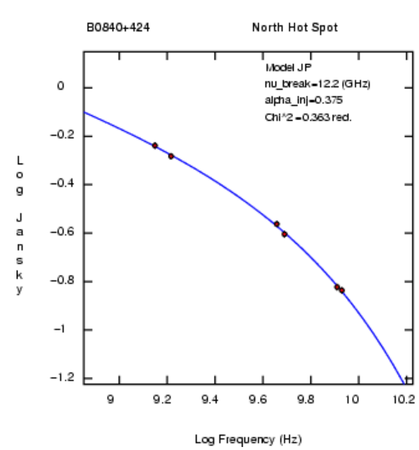


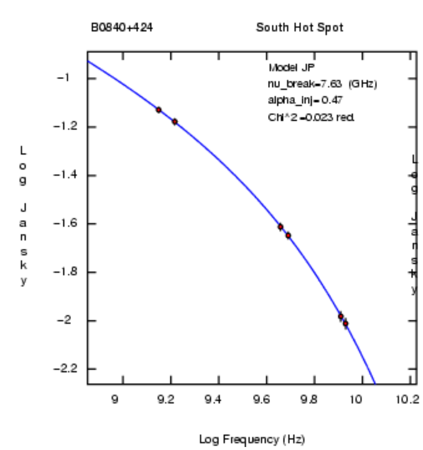


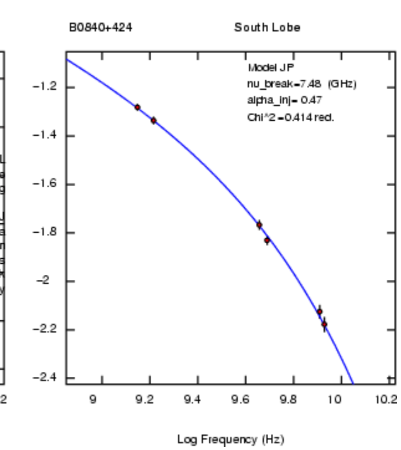




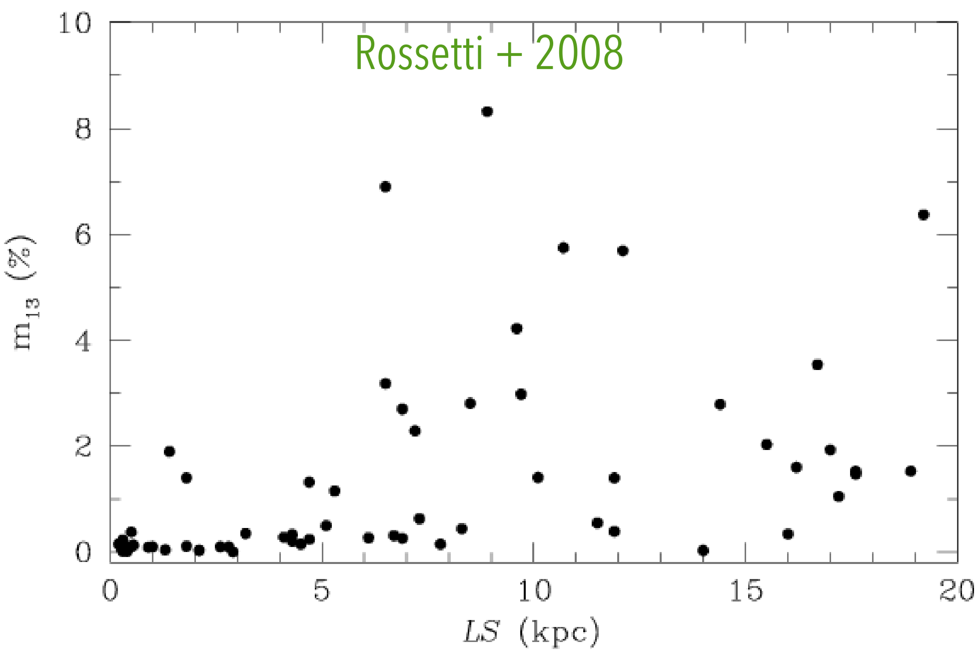








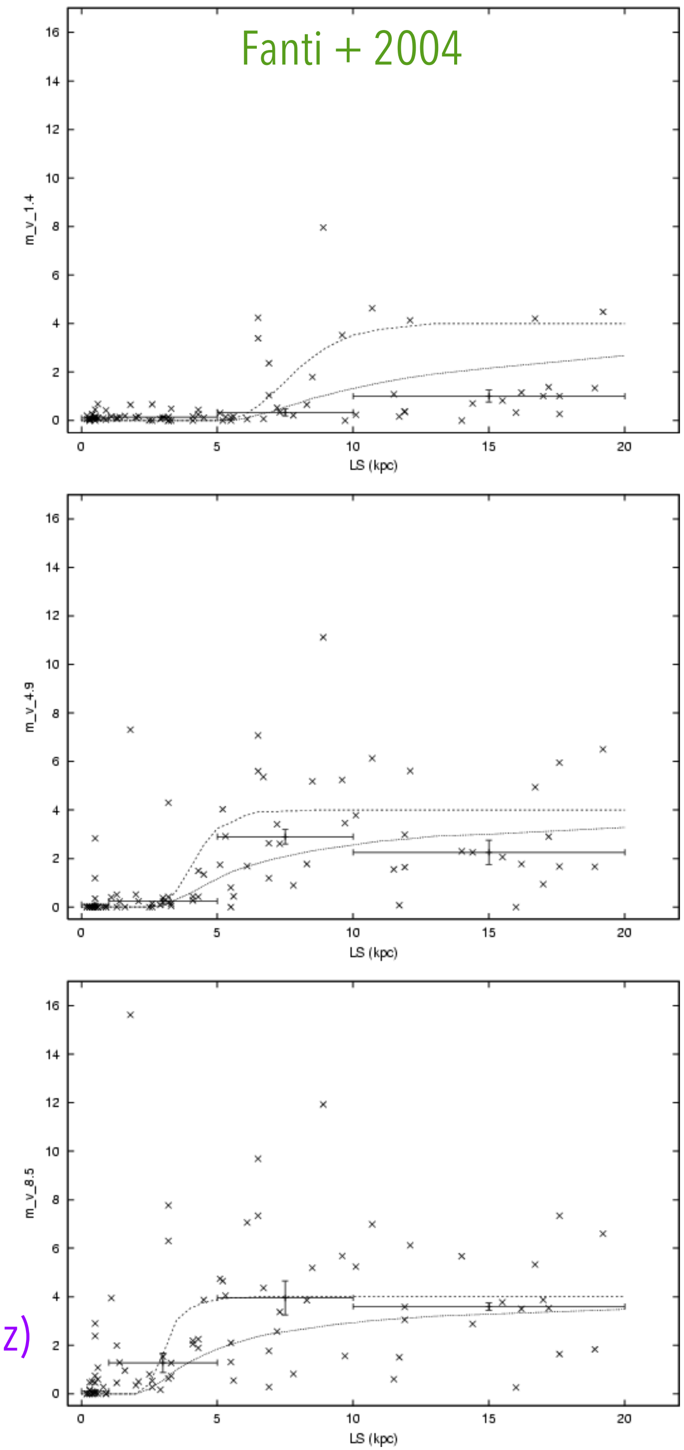
Polarization: increase of fractional polarization with frequency & source linear size (Cotton effect; Cotton + 2003)



1.4

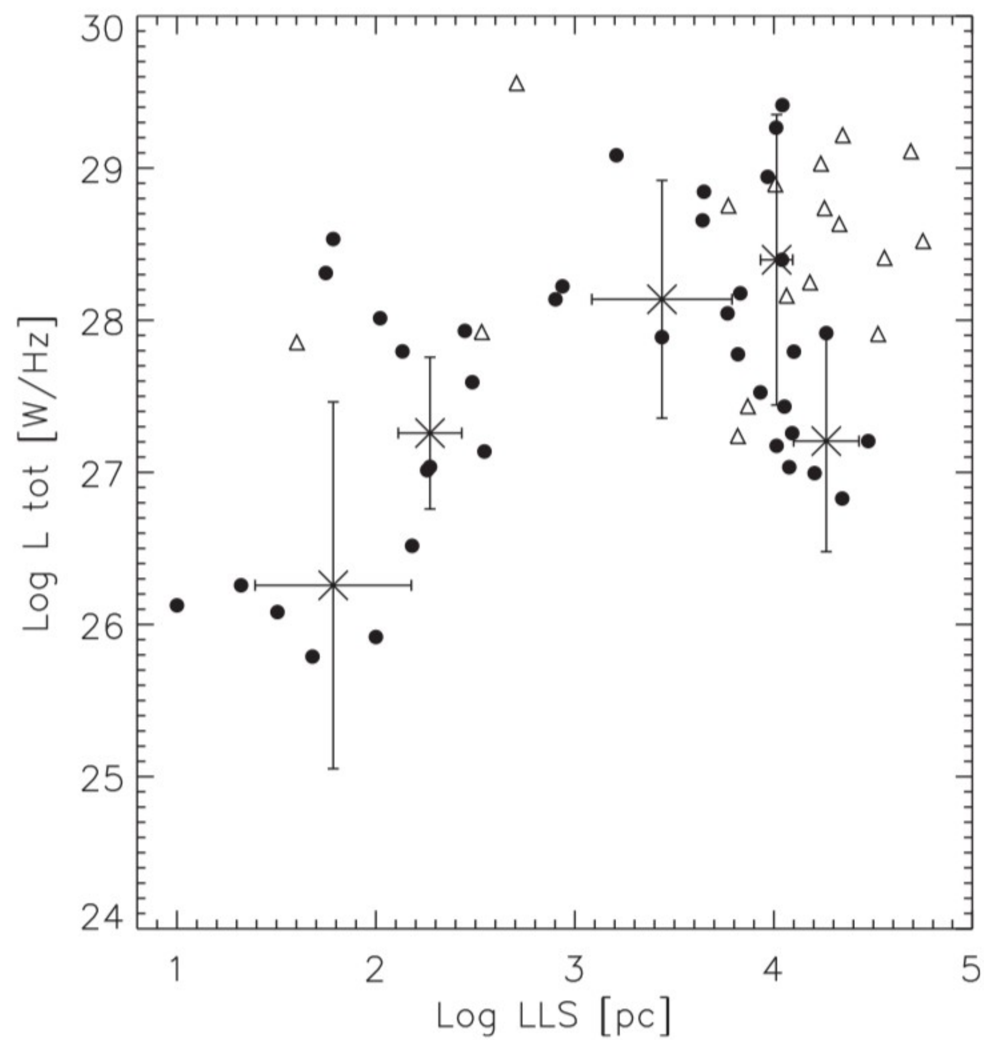
5.0

8.4 (GHz)



M. Orienti and D. Dallacasa

Luminosity .vs. Linear size in flux limited sample ⇨



⇩ Asymmetries in the radio lobes/hot-spots

Orienti 2015

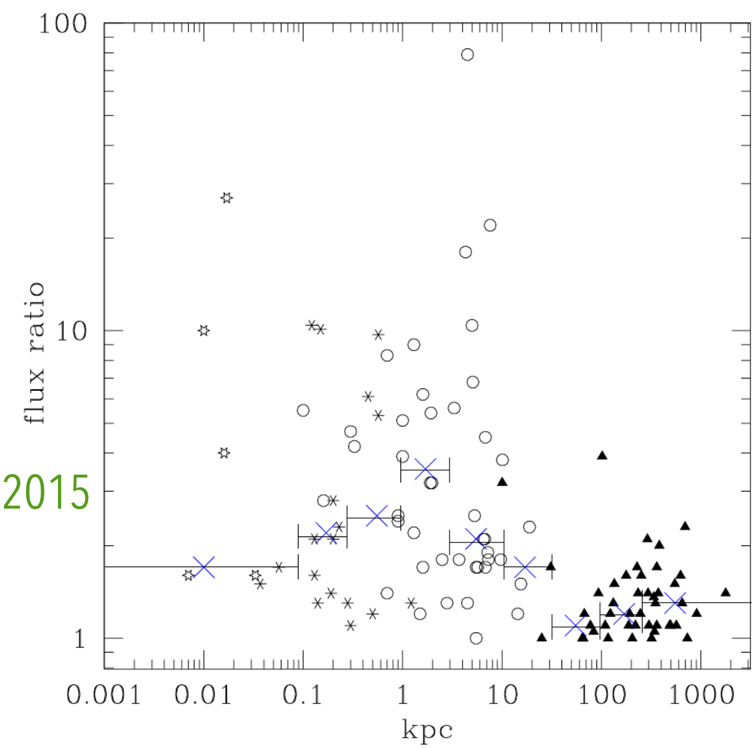
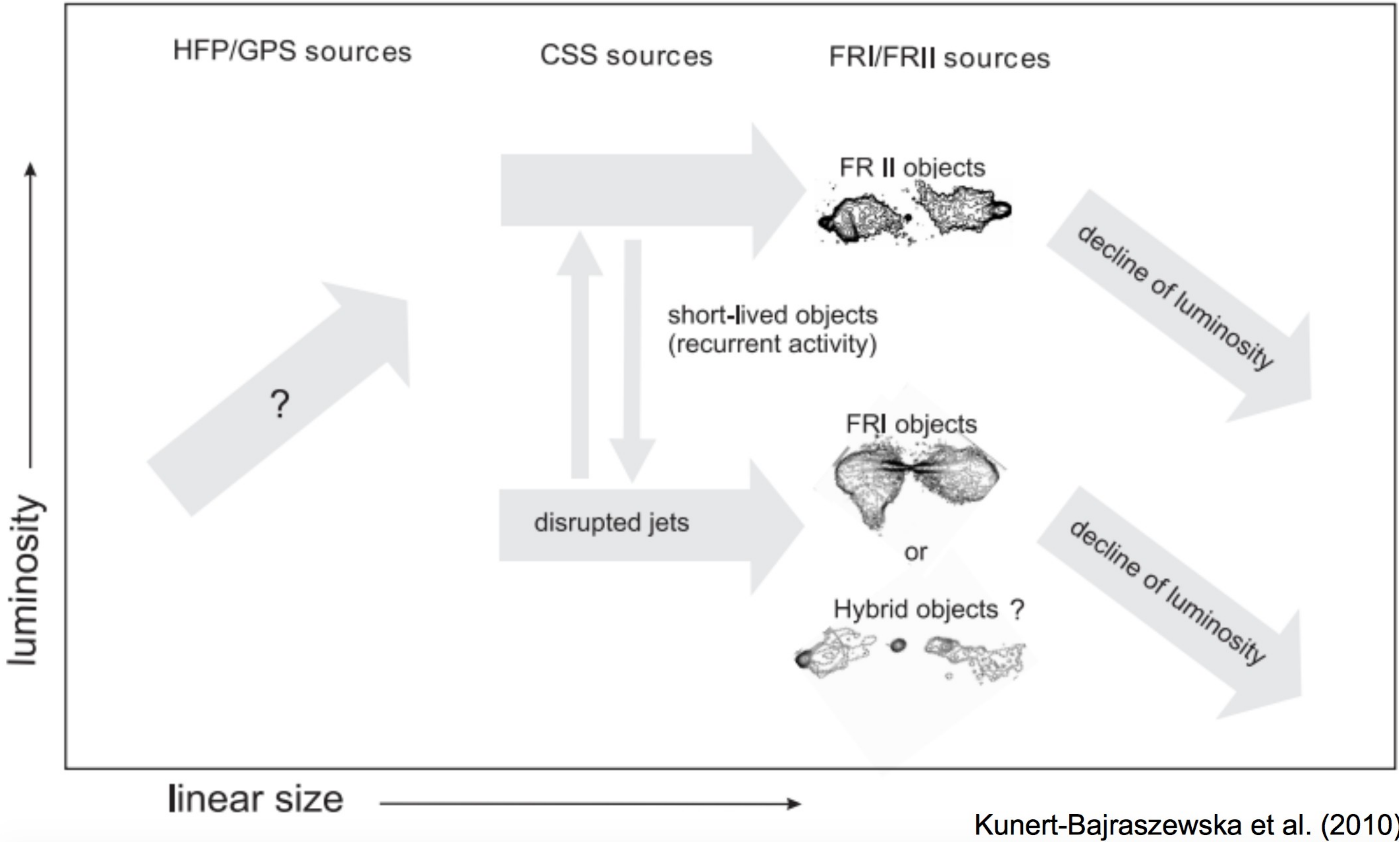


Fig. 4 The flux density ratio of the lobes versus the source linear size. Crosses represent the median value computed on various range of linear sizes. Adapted from Orienti & Dallacasa (2008d).



NO CLUE ON THE LOW POWER RADIO SOURCE POPULATION

Fanti + 1995, Readhead + 1995, O'Dea 1998, Snellen + 2000:

Self -Similar growth for radio galaxies: proper parametrization of the individual radio source evolution: main driver " External density rules the evolution"

+ source counts (more or less)
+ asymmetries (Orienti & Dallacasa)
+ polarization (Cotton Effect)
+ activity duty cycle (double double)
+ Failed Radio Sources (Faders)
+ spectral ages & radiative ages

– valid for powerful objects
– irregular (early) accretion (?... variability) [HFPs]
– source counts (less...)
– FR I progenitors? If OK, what are the FR II progenitors?
– Quasars?

NO CLUE ON THE LOW POWER RADIO SOURCE POPULATION

Biases against the FAINT RADIO SOURCE POPULATION

View based on powerful objects, RL!

All the 3CRR (Laing +, 1983) objects (Dec > 10, S178 >10 bII >10) are RG / RLQ

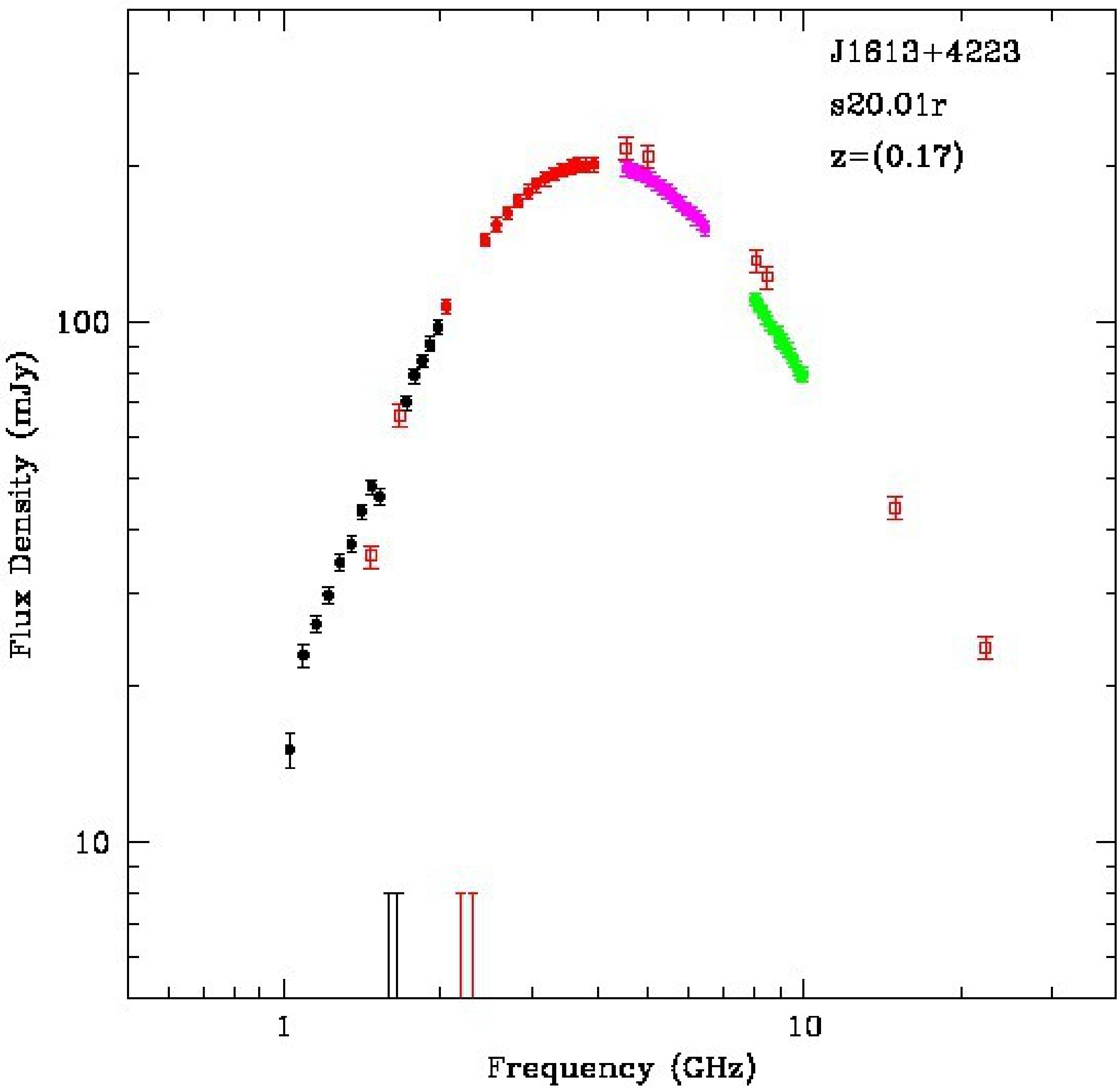
Among the 527 sources in the 1 Jy catalogue (Kuhr +, 1981) only 2 (very nearby!) are not RG/RLQ/Blazar

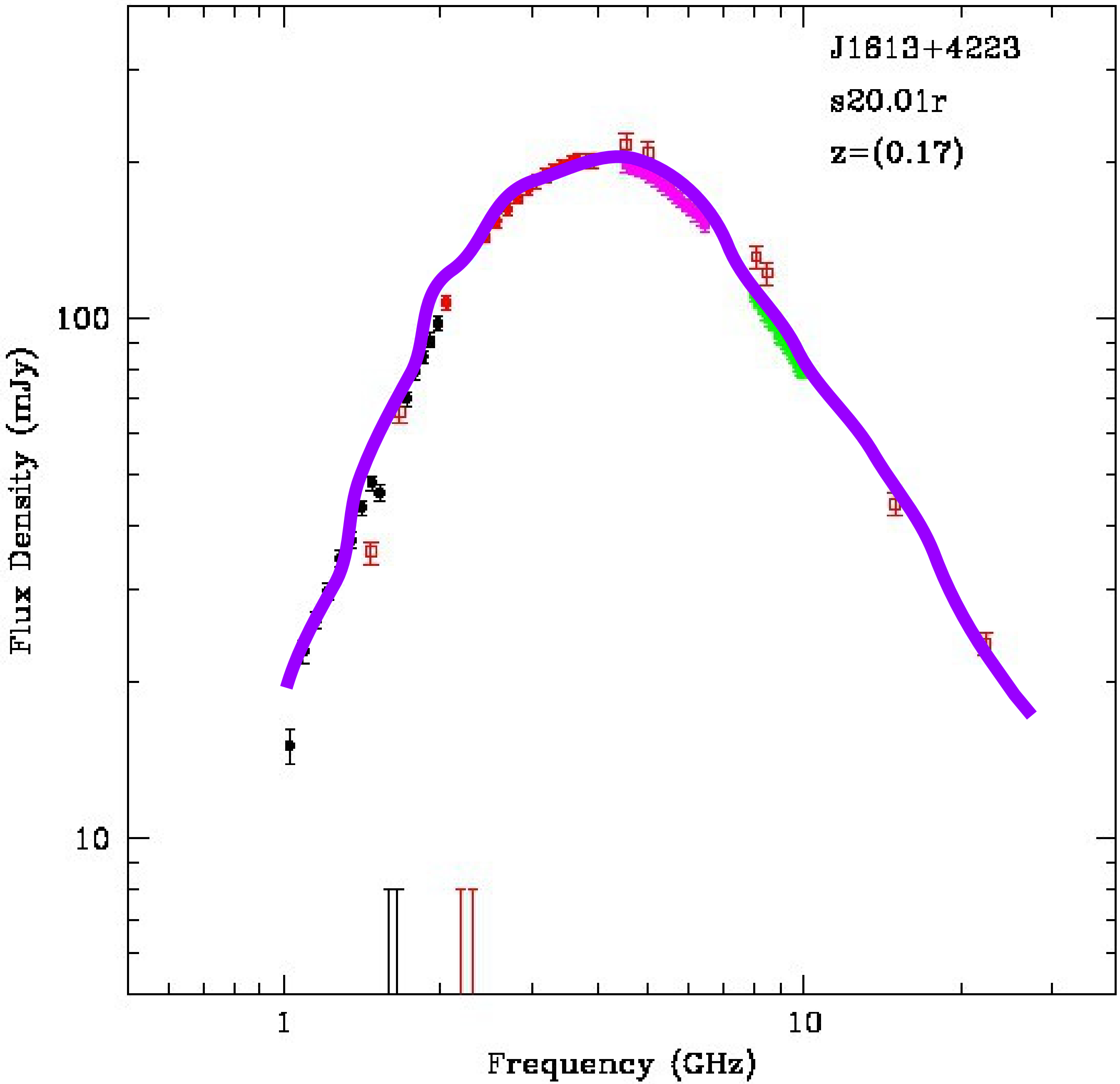
Easier work in terms of sensitivity and optical identifications!

The main problem when going to low flux densities is the proper classification of the hosts

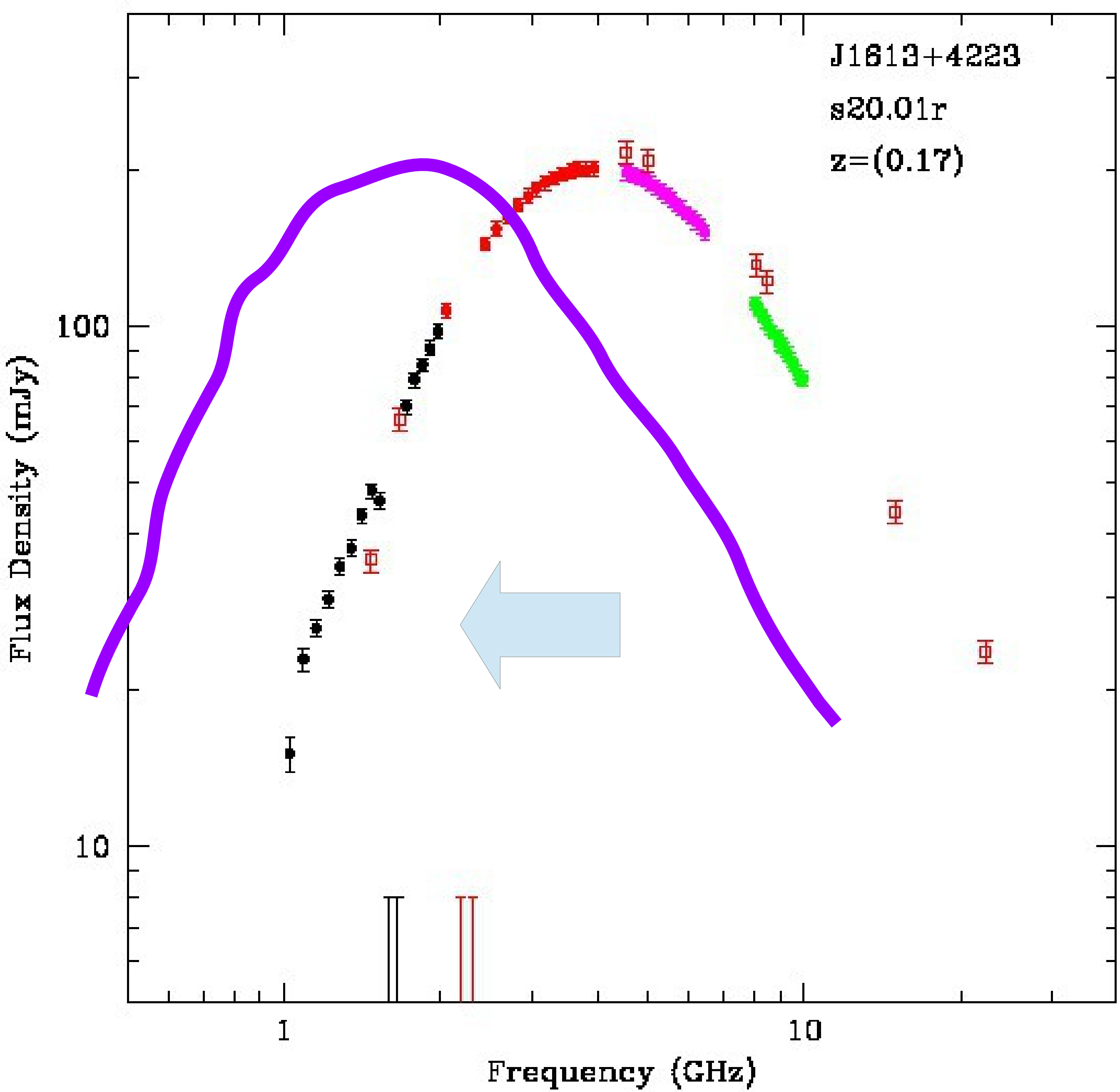
What are the tools?

1. FIR- radio correlation (+SFG, and + radio excess)
2. X-ray luminosity (+ AGN, also RQ, may be limited in very obscured objects, + nearby SFG)
3. IRAC color-color diagram (+ for obscured AGN, where a power law is expected, but high luminosity only $L_X > 10^{44}$ erg s^{-1})
4. X ray spectrum & variability
5. Radio spectrum, morphology, power, polarization (VLBI detection?)
6. Optical spectra and diagnostic diagrams
7. R value (combination of 5 & 6, but not very useful, nowadays)


J1613+4223
s20.01r
z=(0.17)
100
10
Flux Density (mJy)
1
10
Frequency (GHz)


J1613+4223
s20.01r
z=(0.17)
100
10
Flux Density (mJy)
1
10
Frequency (GHz)

redshift: the effect of the k – correction: $\nu_{obs} = \nu_{em}$ (1+z)

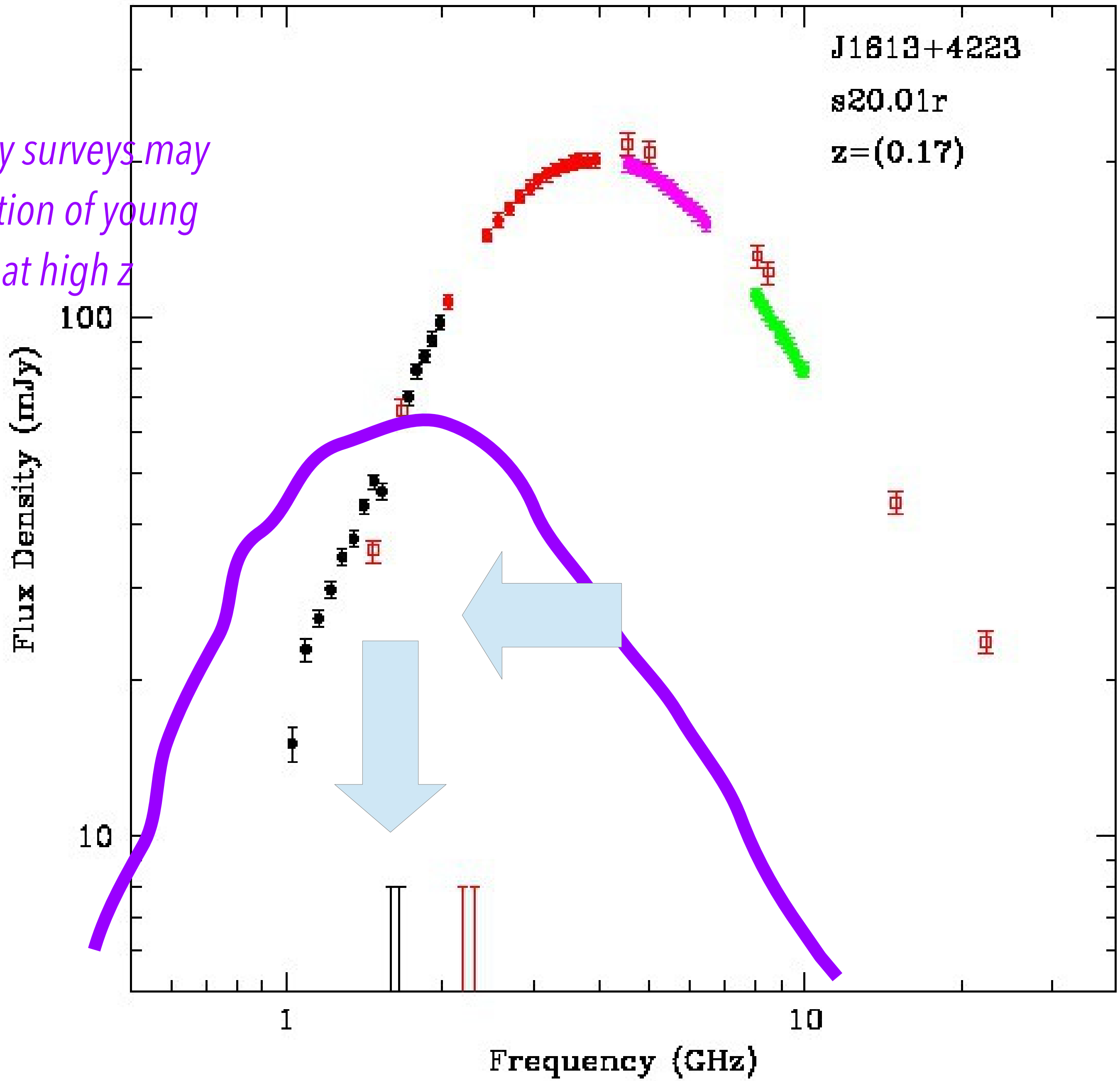


redshift: the effect of the k – correction: $\nu_{obs} = \nu_{em}\ (1+z)$

& the distance (D^{-2})

➔ *Many high z faint radio sources in low frequency surveys*

Low-frequency surveys may find a population of young radio sources at high z



Summary:

- *Biased towards high luminosity objects (samples are in [high] flux limited samples)*
- *Very important: multifrequency information *necessary* to fully characterize the radio source in terms of interpretation/spectral index distribution – leading to an estimate of the radiative age.*
- *VLBI observations are necessary to observe compact radio sources.*
- *Multiepoch observations test variability in flux density/structure and overall size. This may lead to determine the speed of growth.*
- *The self–similar evolutionary model for powerful radio sources requires a decline of the radio source luminosity for LS > 1 kpc, as well as a high "failure" rate to reach the full – size & e old – age conventional FR – I & II*