Low Power Compact radio galaxies at high angular resolution

Marcello Giroletti
INAF Istituto di Radioastronomia

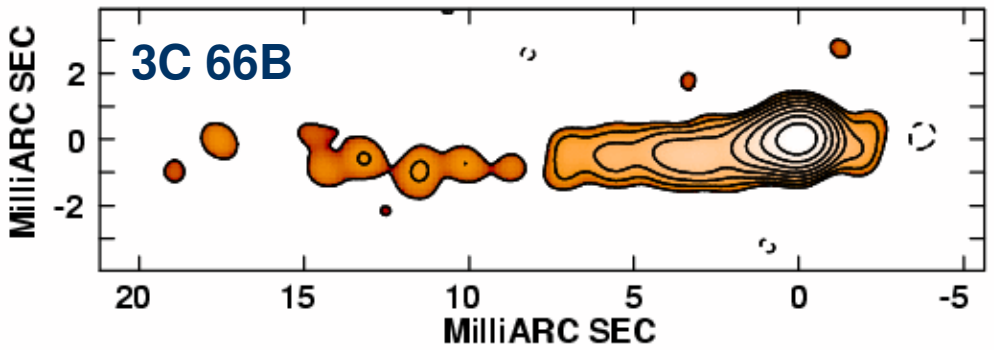
&

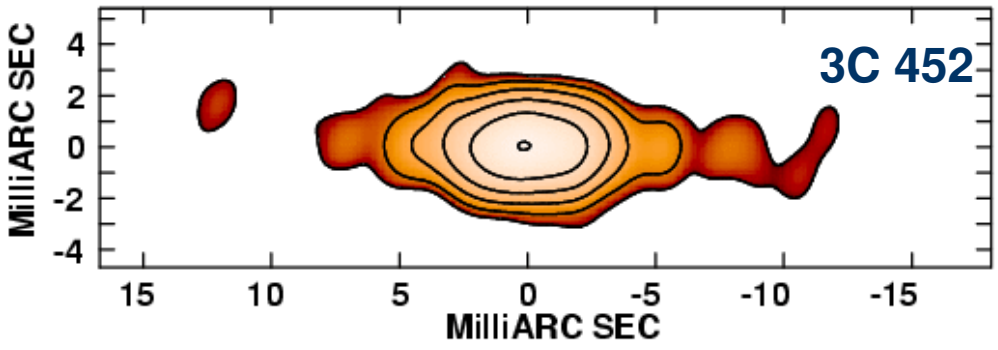
G. Giovannini (UniBO, IRA)
G. B. Taylor (UNM, NRAO)

Outline

- Parsec scale radio jets…
  - …in classical extended radio galaxies
  - …and in compact radio sources
- The Bologna Complete Sample
- Low Power Compact sources
  - New high resolution radio observations
  - Jets, linear size, brightness, spectrum, Doppler factor, evolution
- Conclusions

Parsec scale jets



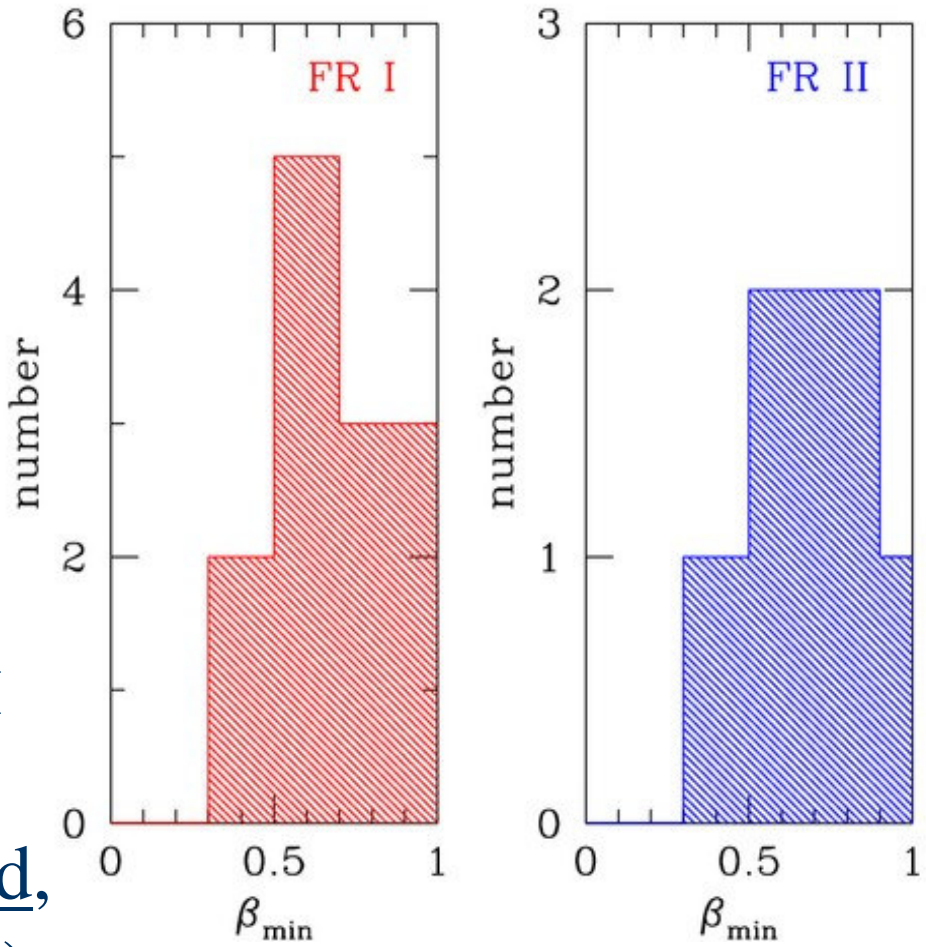


- parsec scale observations with VLBI
  - show both one- and two-sided jets
  - yield support for intrinsically symmetric jets
  - discover superluminal motions
  - suggest that parsec scale jets are relativistic

Images adapted from Giovannini et al. (2001, ApJ)

Relativistic parsec scale jets

- In 19 radio galaxies observed with VLBI (Giovannini et al. 2001) we find
  - proper motions
  - jet/counterjet ratios >1
  - large core dominance
- evidence for:
  - relativistic parsec scale jets
  - without distinction between FRI and FRII
- NB these sources are extended, with a bright core (S>100 mJy)



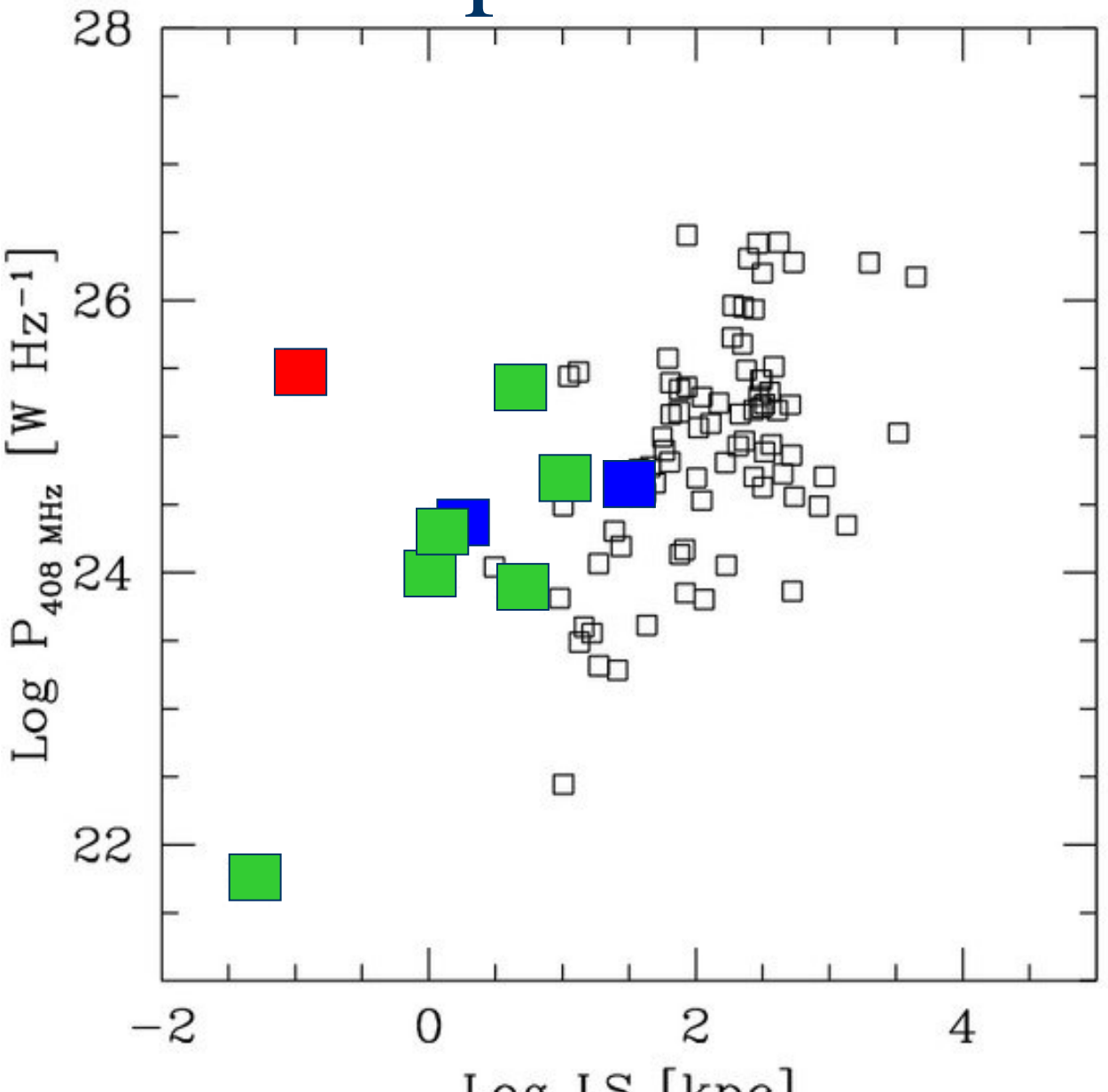
Bologna Complete Sample (BCS)

- Giovannini et al. 2005, ApJ 618
  - 95 sources selected at low frequency (from B2 and 3C surveys) with $z < 0.1$
  - no selection on core properties, thus **no bias in favour of relativistic beaming**
  - VLBI observations in progress (53 pub, 24 red, 18 TBD)
  - 81 extended radio galaxies: 65 FR I, 15 FR II, 1 FRI/II
  - 14 compact sources: nuclei? sub-structures? intrinsic properties (power, dimension)? evolution? young? weak? frustrated?

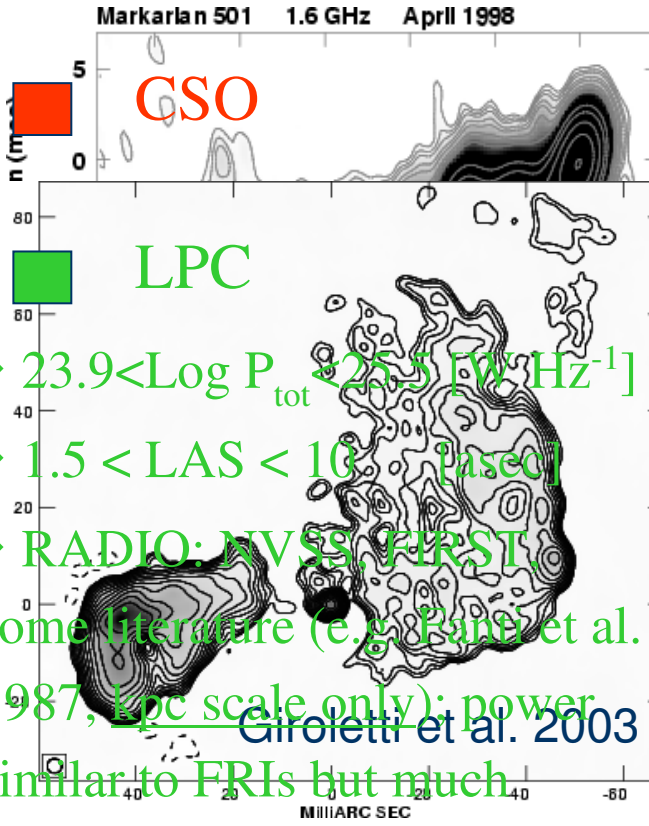
Compact sources in the BCS

	BL Lacs	**CSO/CSS**	**LPC**
Radio spectrum & parsec scale morphology	Flat $\alpha<0.5$, one sided	Steep $\alpha>0.5$, symmetric	not well constrained, intermediate α, unresolved.
Other wavelenghts	Variability, high energy activity (optical, X, γ)	Dust? Synchrotron core?	ellipticals, narrow lines, low X-ray luminosity, similar to LLAGN common in nearby galaxies?
Reason of compactness	Projection	Youth	Weak core? Intermittent activity?
Beaming	relativistic beaming, superluminal motions	not beamed (HS advancing at ~0.1c, relativistic jet)	non thermal emission? YES. relativistic jet? MAYBE
Archetype in BCS	Mkn 421, Mkn 501	4C 31.04	NGC 4278

Radio power vs. linear size



BL Lacs



GSO

LPC

- $23.9 < \text{Log } P_{tot} < 25.5$ [W Hz^{-1}]
- $1.5 < LAS < 10$ [asec]
- RADIO: NVSS, FIRST

some literature (e.g. Fanti et al. 1987, kpc scale only): power similar to FRIs but much smaller size

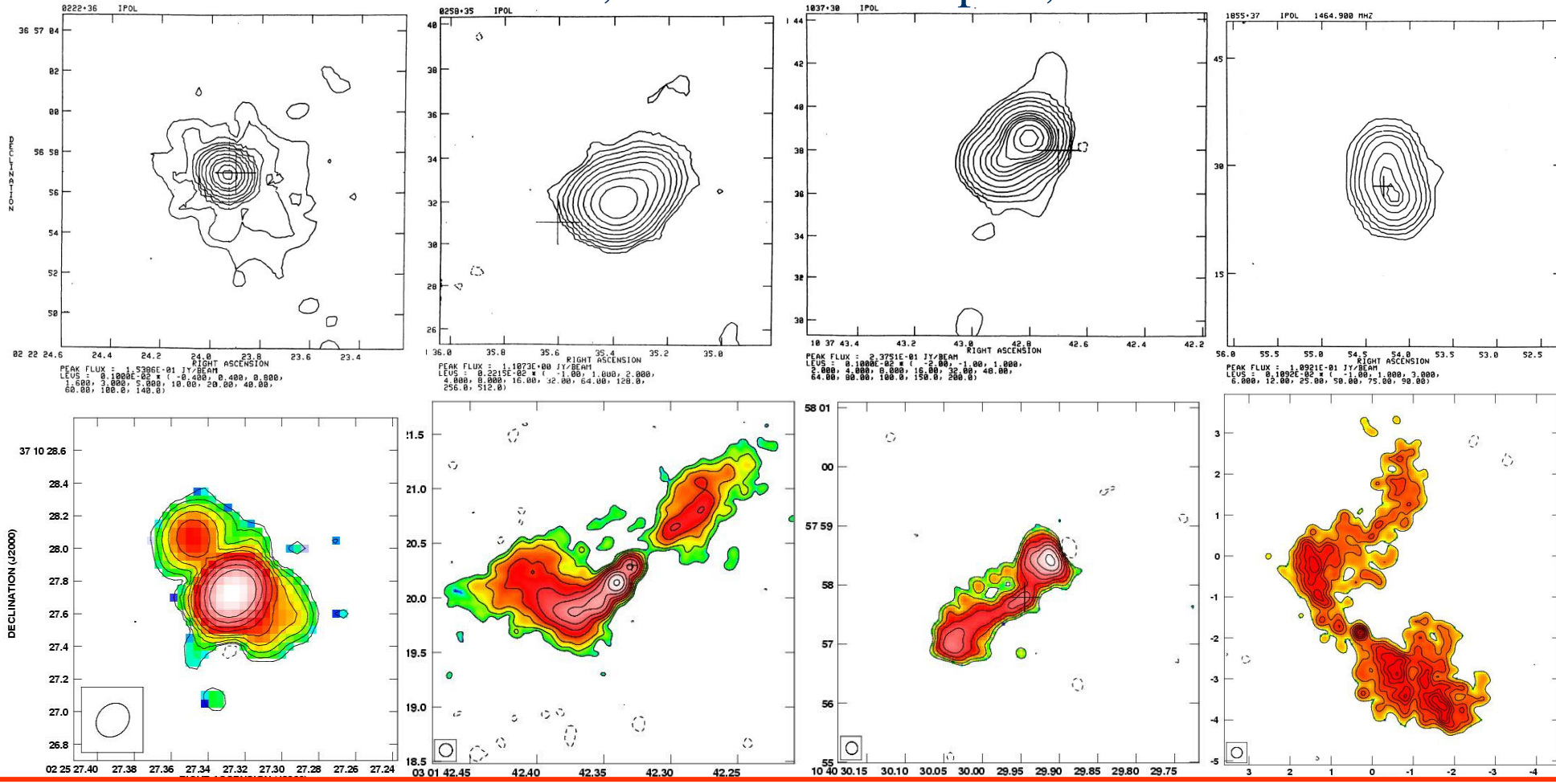
Giroletti et al. 2003

New observations

- 5 sources (+7 new observations)
- High resolution
  - VLA @8, 22 GHz (resolution ≈0.1")
  - VLBA @1.6 GHz, phase referenced (≈5 mas resolution and ≈0.5 mJy sensitivity)
- Main goals:
  - resolve sub-kpc scale structure, e.g. jets
  - identify core
  - study spectral index
  - new accurate measures for parsec scale properties (position, flux density, …)
  - determine intrinsic power, age, evolution…

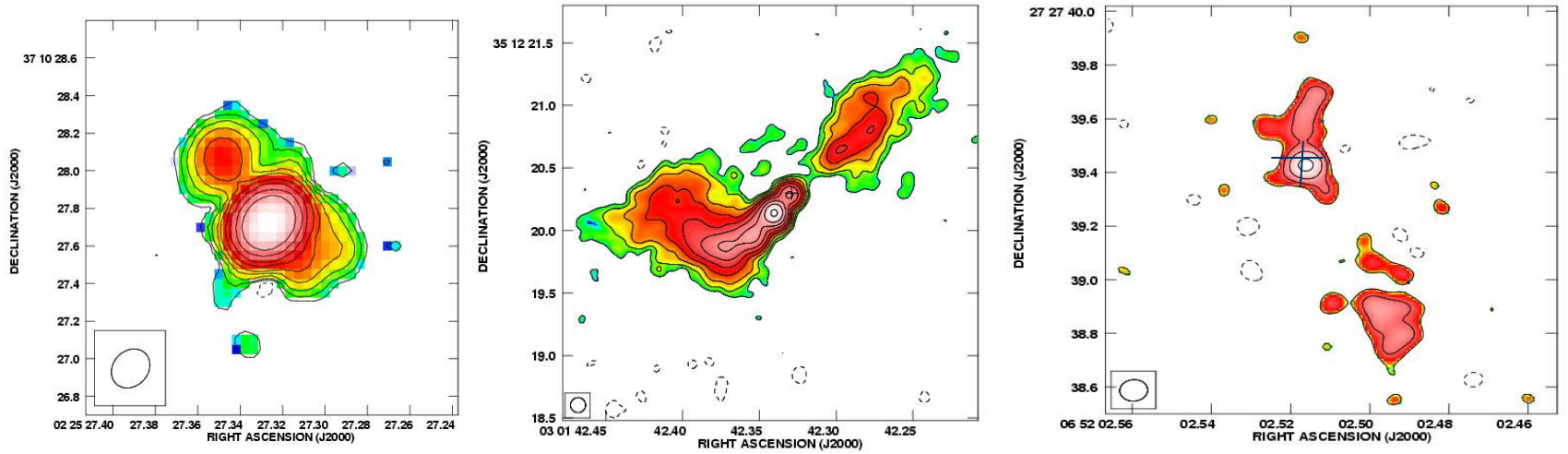
From "*blobs*" to *jets*

At low resolution, sources are compact, core dominated

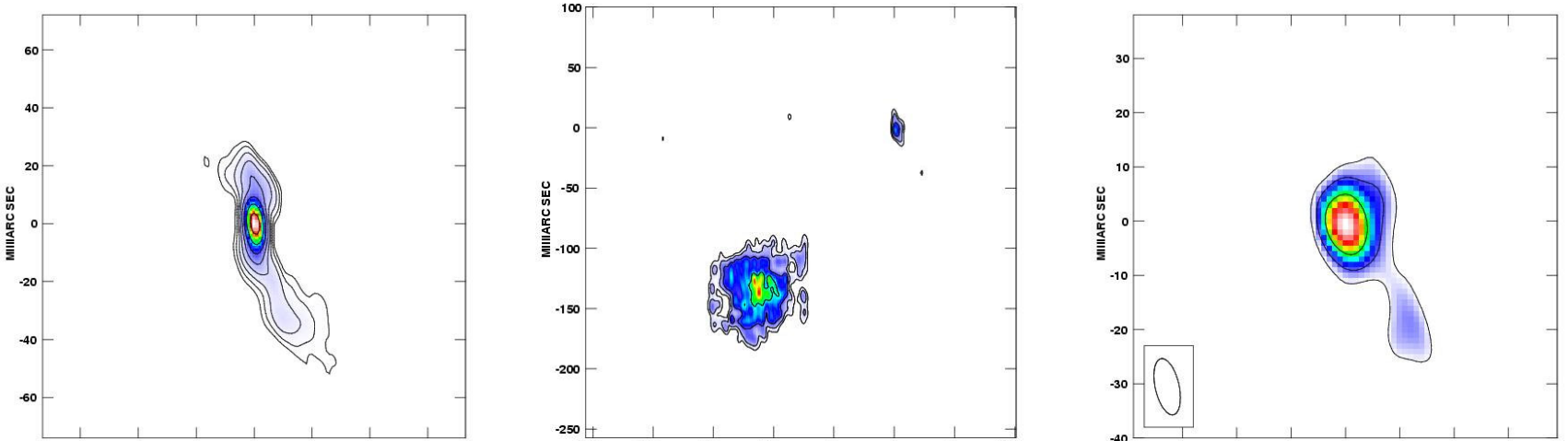


High frequency VLA observations reveal rich substructures, including jets, resembling extended FRI and FRII on 10-1000 times smaller scales

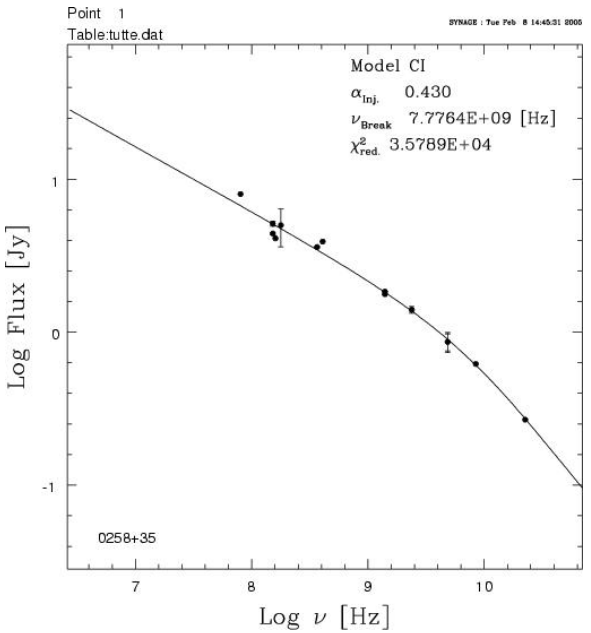
From *jets* to *pc scale structure...*

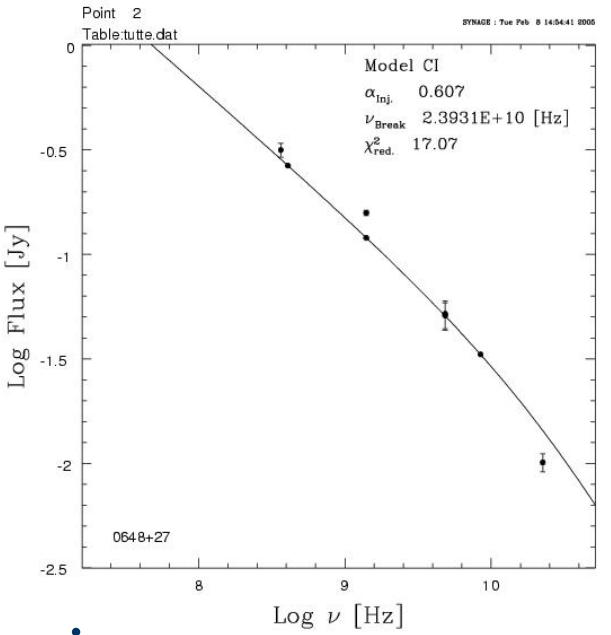


This kpc scale structure are further resolved by the VLBA, which detects pc scale cores, plus other interesting features...



Radio spectra





- One more piece of information…
- little contamination from core
- $B_{eq} \sim 10^2$ μG
- $T_{syn} \sim 10^5$-10^6 yr
- $v_{adv,\,syn} << c$
  - consistent with slow/ceased advance in the external medium

LPCs properties (1)

- LPCs reveal rich, complex structures at high resolution
  - lobes, hot spots, fed by jets typically <1 kpc long
  - structure is often two-sided
- 0222+36: two sided even on parsec scale, $\beta>0.6$, $\theta\sim85°$, possibly restarted (10^5 yrs old lobes surrounded by 10^8 yrs old halo)
- 0258+35: FR I like, but LS ~ 5 kpc, $\beta>0.9$, $40°<\theta<50°$, $T_{syn}= 7 \times 10^5$ yr

LPCs properties (2)

- 0648+27: two-sided, but asymmetric, $T_{syn}=7x10^5$ yr: not CSO as speculated
- 1037+30: FR II like, hot spot detected even with VLBA, tentative $T_{kin} = 4.5 \times 10^4$ yr
- 1855+37: nice two-sided head tail, extremely weak core, fading away?

Why are these sources compact, then?

- no beaming ➔ no projection
- one source with hot spots ➔ youth
- many sources without hot spots ➔ frustration, low power jets, short lived
- one source with worthless core ➔ dying, intermittent
  - *will young sources ever grow to kiloparsec scale size?*

Summary

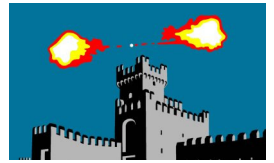
- 5 low power compact radio sources
  - power similar to FR I but size < 1 kpc
- high frequency VLA observations
  - *resolved structures*
  - well identified cores
  - two-sided, one source with hot spots
- phase ref. VLBA observations
  - 4/5 detections
  - *3/5* detections of *parsec scale jets*
- main observational results
  - objects on the plane of the sky (two-sidedness, low core dominance)
  - *intrinsically small*
  - radiative ages about 10^5 – 10^6 yrs

Conclusions

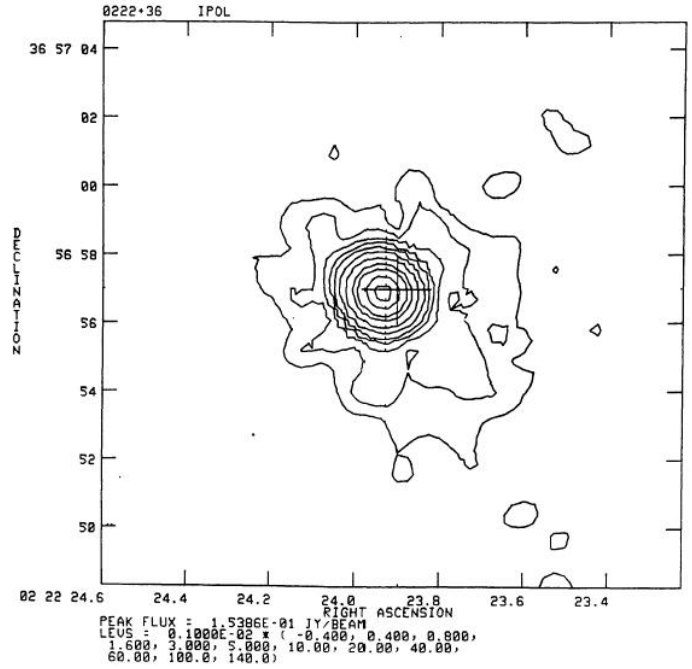
- Reasons of compactness
  - youth
  - frustration or short lived activity, intermittent core
  - (projection)
- LPC in context
  - unified schemes: not projected
  - evolutionary tracks: deviations from CSS to FR radio galaxies
  - lack of hot spots: end of interaction? end of growth? short lived sources?
  - transition to radio quiet and non active nuclei
- Samples as the BCS
  - are important to understand these differences
  - need to be completed to the faintest sources

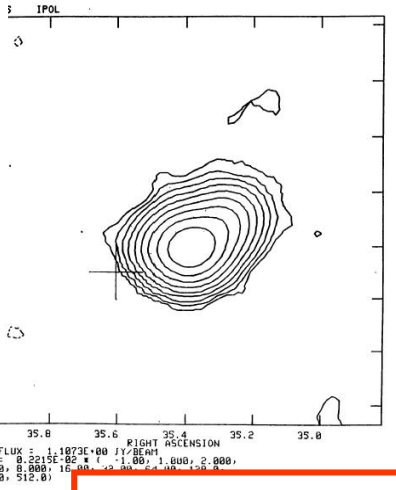

AGN7

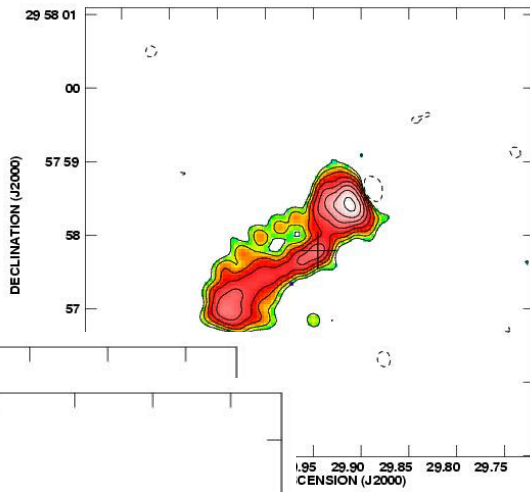
From "*blobs*" to *jets*

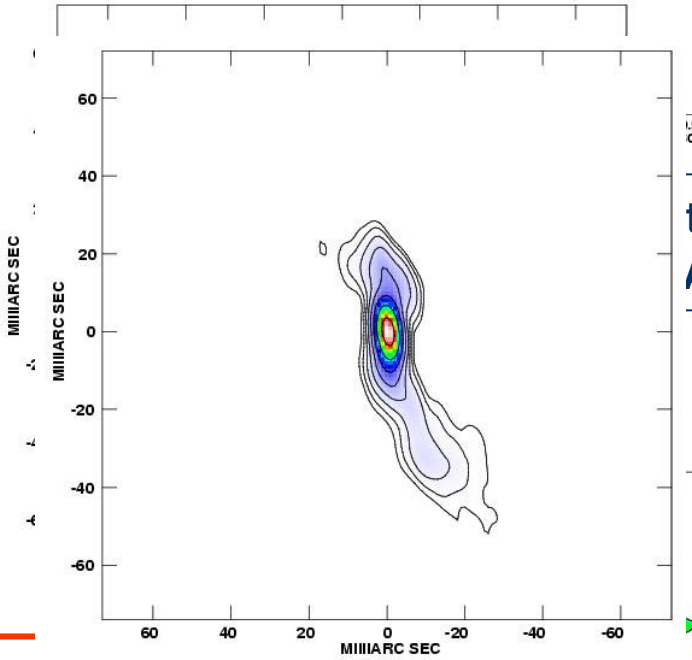


At low resolution, sources are compact, core dominated

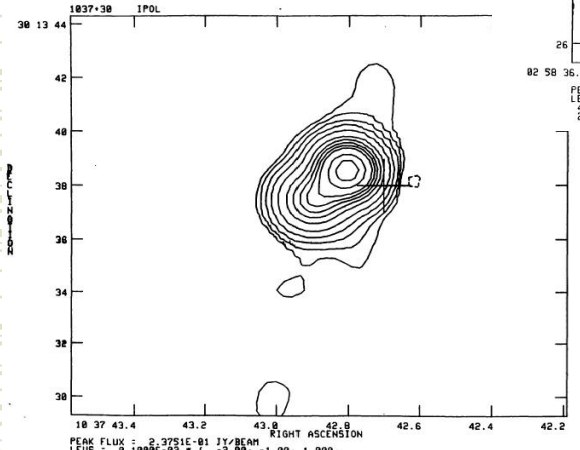


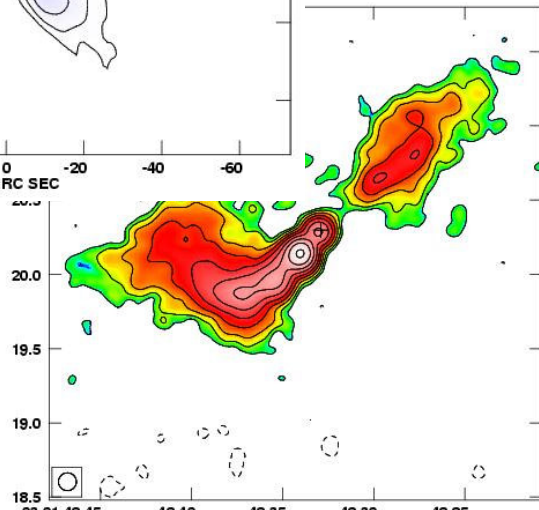






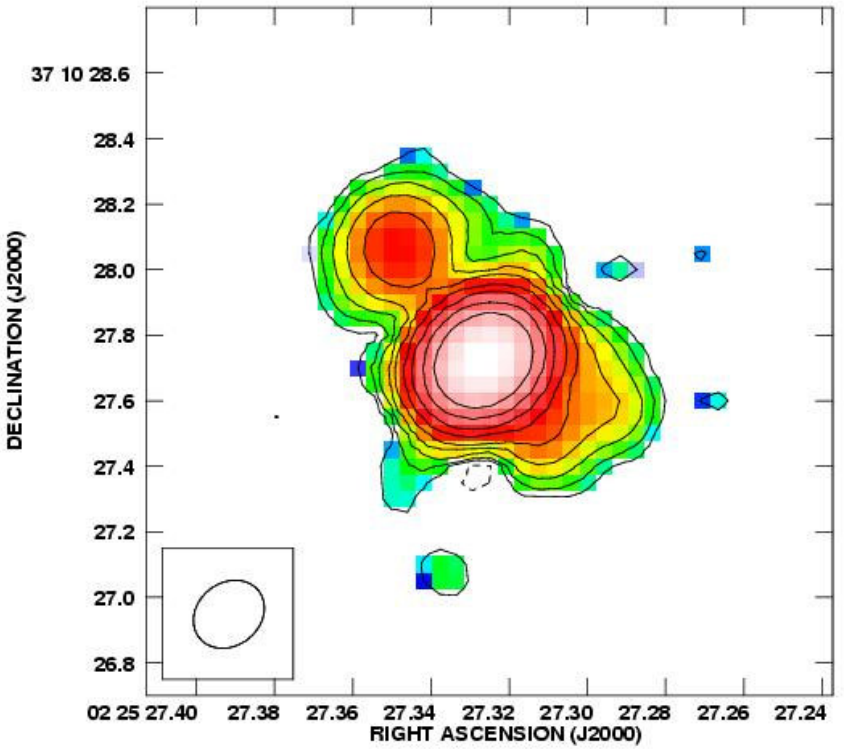
t al. 2005, A, 441, 89





High resolution observations reveal rich substructures, including jets, resembling extended FRI and FRII on 10-1000 times smaller scales.

- 0222+36
  - S_{408} = 337 mJy
  - z = 0.03
  - P = $10^{23.9}$ W Hz^{-1}
  - LAS = 8”
  - Literature
    - kpc scale: Fanti et al. (1987)
    - pc scale: ???
- 0258+35
  - S408 = 3.9 Jy
  - z = 0.016
  - P = 1024.4 W Hz-1
  - LAS = 4”
  - Literature
    - kpc scale: Fanti et al. (1987)
    - pc scale: compact, with flux density excess on short spacings
- 0648+27
  - S408 = 0.27 Jy
  - z = 0.04
  - P = 1024.0 W Hz-1
  - LAS = 1.5”
  - Literature
    - kpc scale: Morganti et al. (2003), large amount of HI
- 1037+30
  - S408 = 1.1 Jy
  - z = 0.09
  - P = 1025.4 W Hz-1
  - LAS = 3”
  - Literature
    - kpc scale: Fanti et al. (1987)
    - pc scale: not detected
    - Tkin = 4.5 x 104 yr



VLA

$S_{8\ GHz}$ = 190 mJy

$S_{22\ GHz}$ = 90 mJy

α_{core} = 0.6

halo is resolved

two sided structure

VLBA

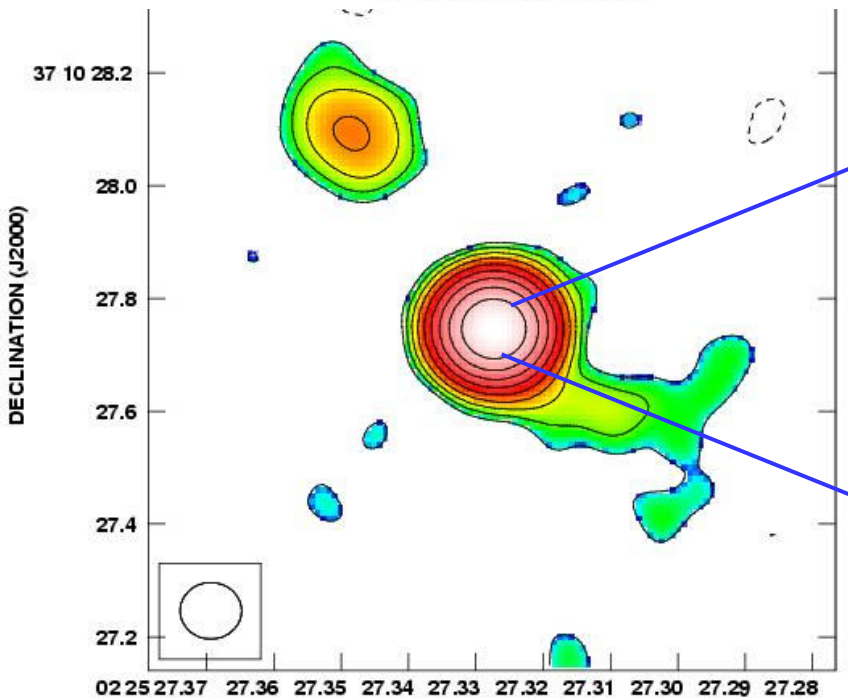
$S_{1.6\ GHz}$ = 102 mJy

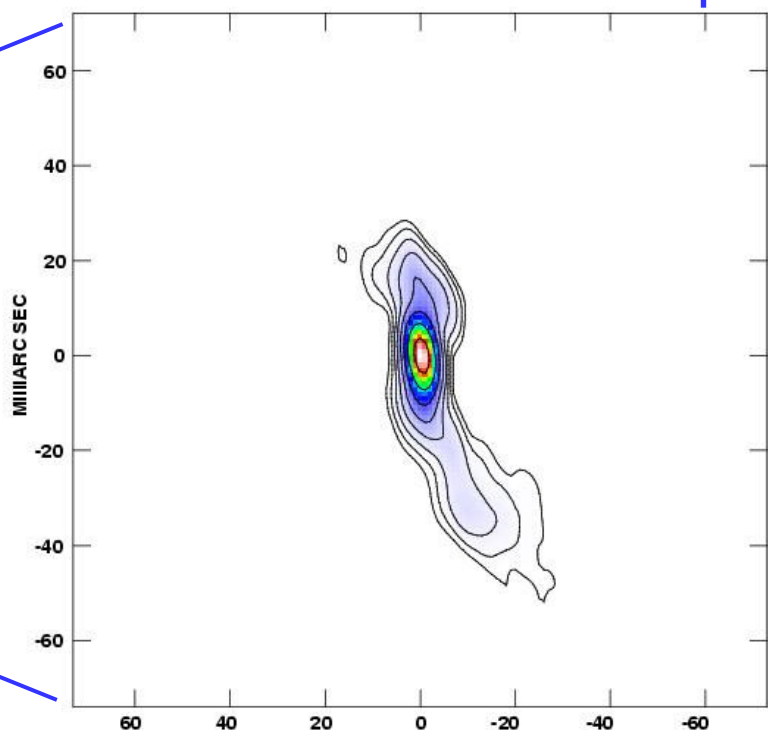
two sided jets

no hot spots

definitely in the plane of the sky

nicely connected to VLA maps

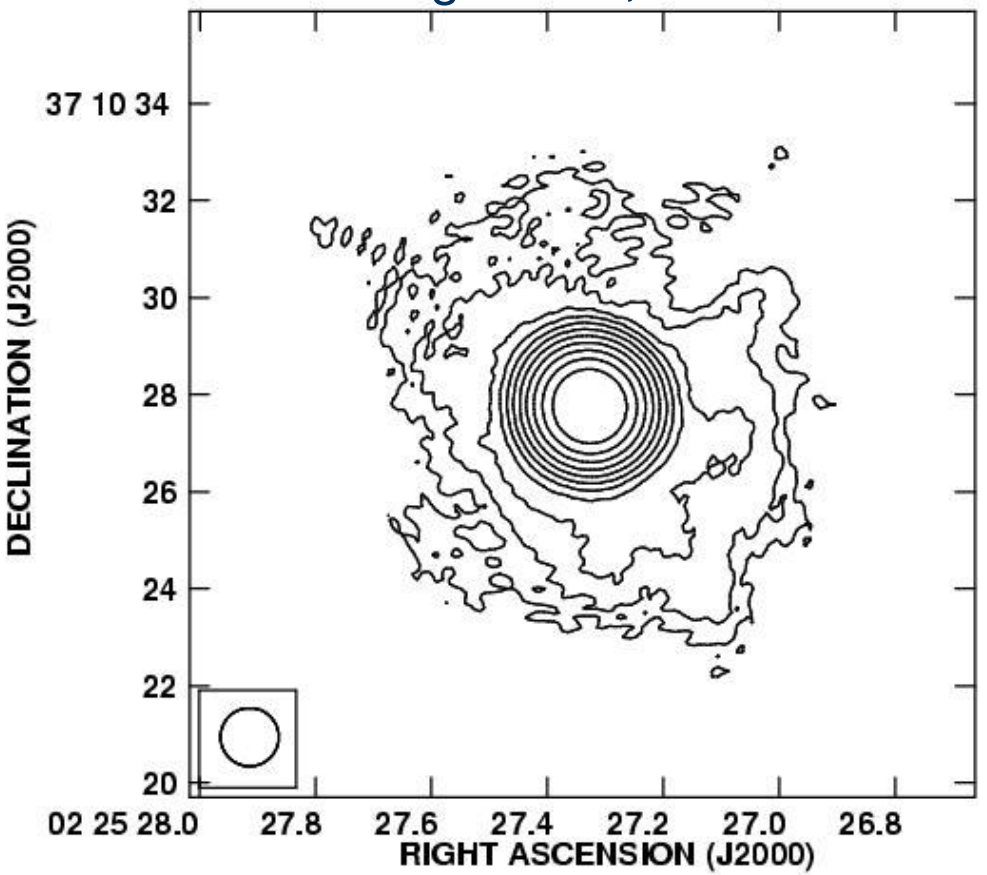




0222+36, spectrum of components

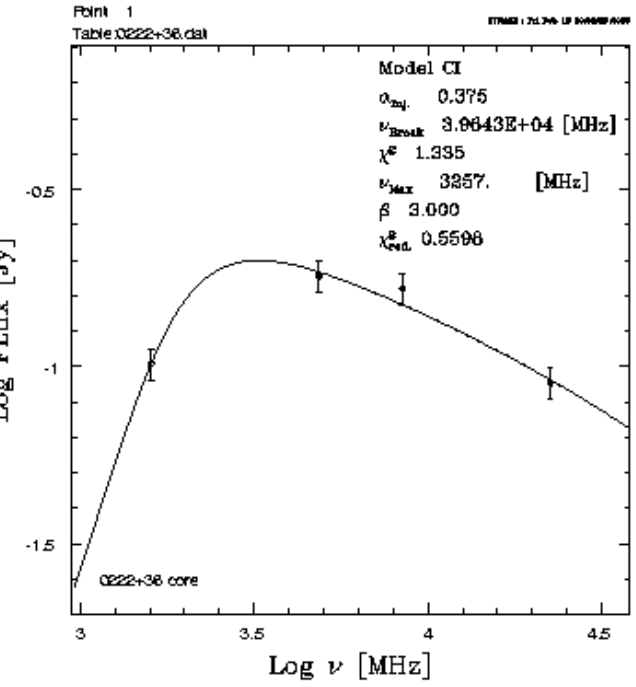
VLA archival data reanalyzed:

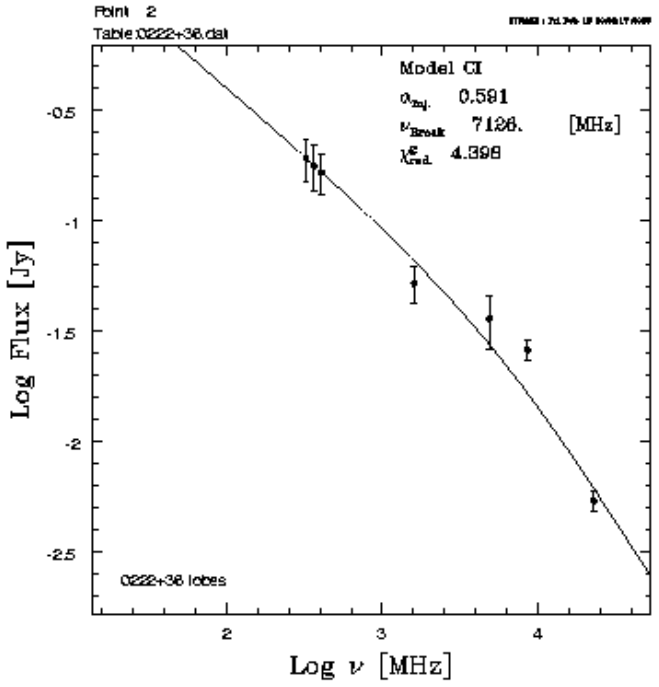
B configuration, 5 GHz

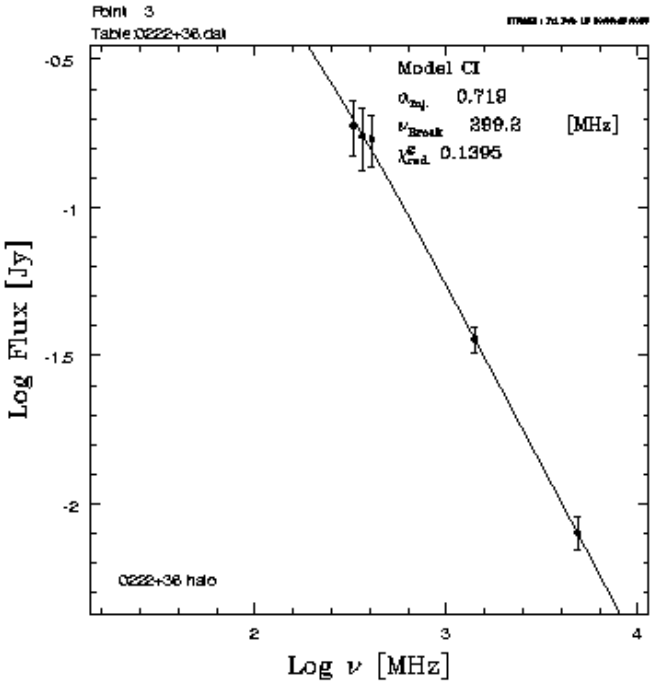


Freq. (GHz)	Halo (mJy)	Lobes (mJy)	Core (mJy)
0.325	188	191	0.9
0.365	174	177	1.2
0.408	170	165	1.8
1.4	36	52	102
5.0	8	36	180
8.4	<1	26	166
22.5	<1	6	90

0222+36, age of components







CORE

ν_{self} = 3.3 GHz

B = 50 mG

LOBES

ν_{br} = 9 GHz

B_{eq} = 130 μG

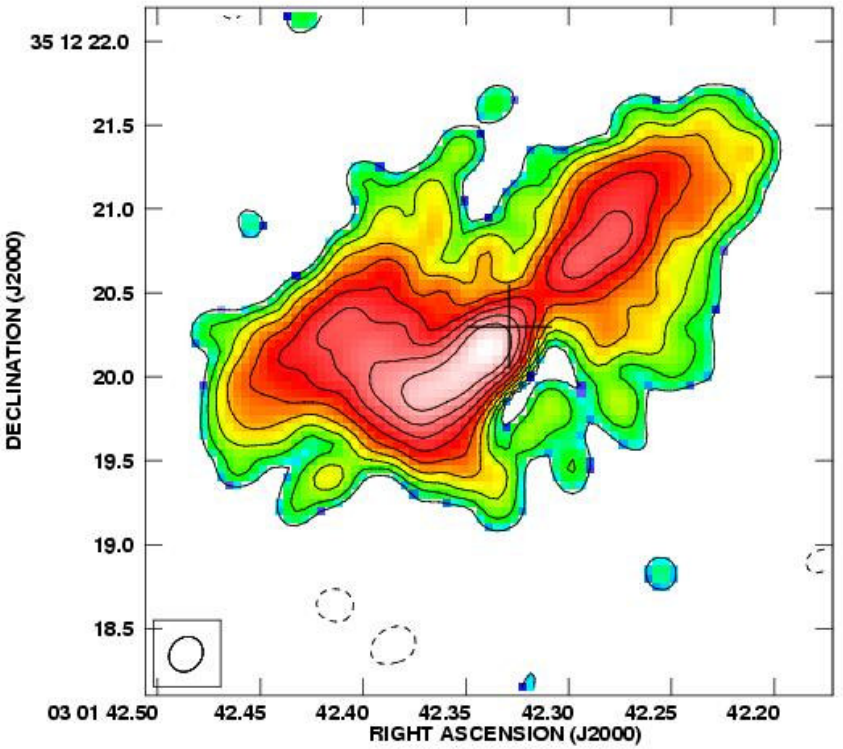
$T_{syn} = 4 \times 10^5$ yr

HALO

ν_{br} = 300 MHz

B_{eq} = 7 μG

$T_{syn} = 1.3 \times 10^8$ yr



VLA

$S_{8\ GHz}$ = 620 mJy

$S_{22\ GHz}$ = 270 mJy

symmetric FRI-like, but LS ~ 5 kpc

two knots in jet

zero hot spot

VLBA AGN7

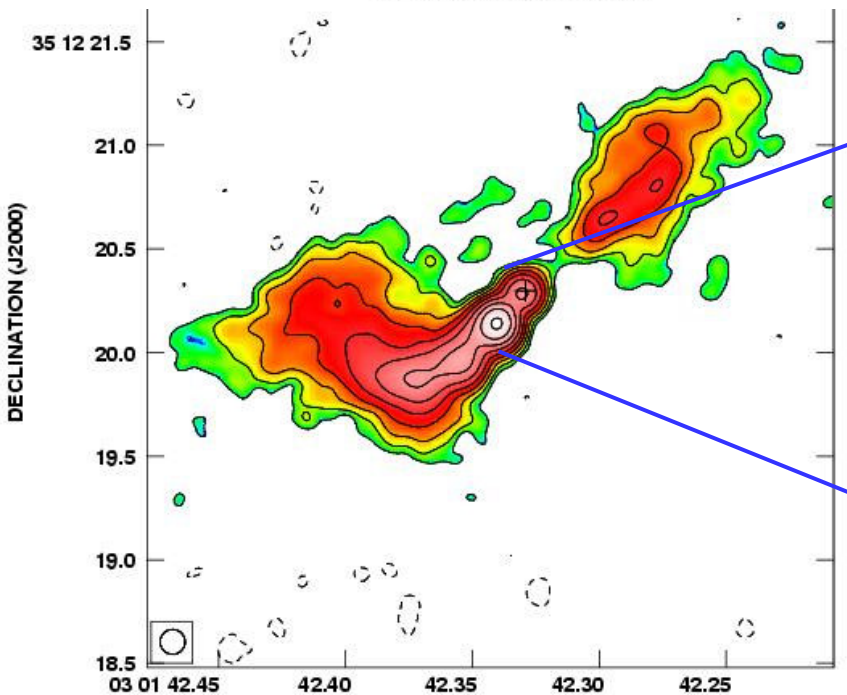
phase-ref essential

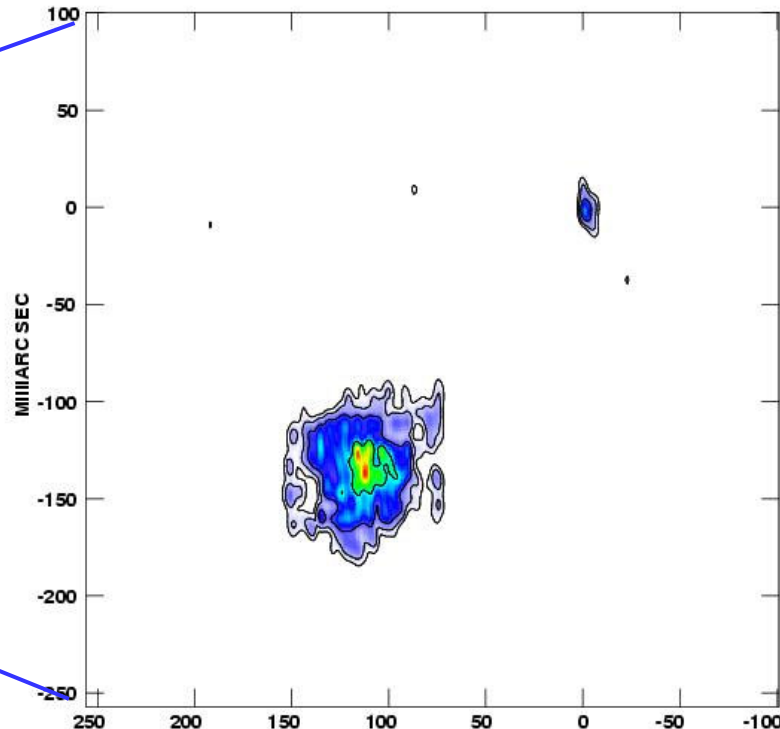
S_{core} = 7 mJy

S_{blob} = 240 mJy

one-sided

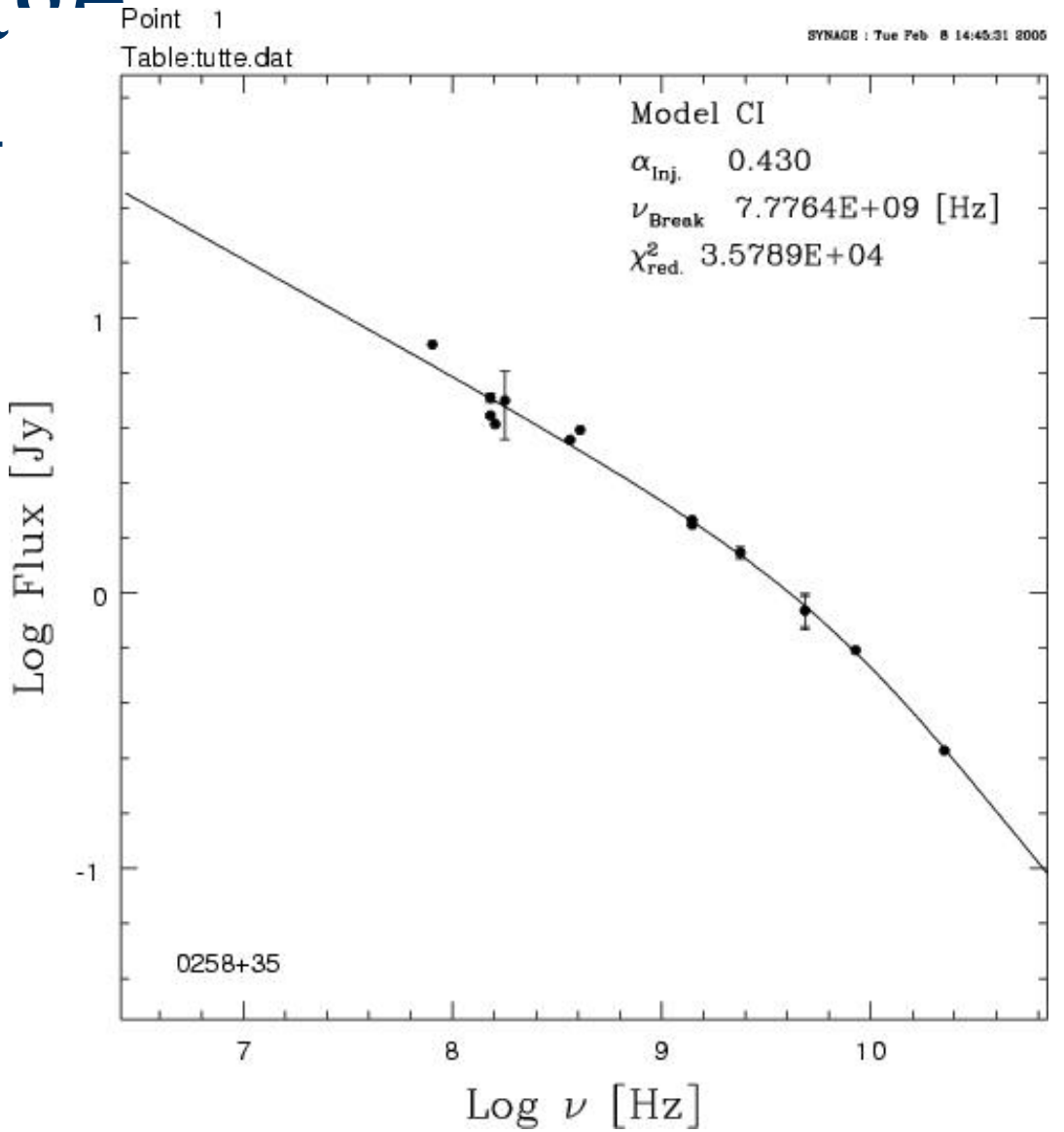
jet/blob/shock/more?

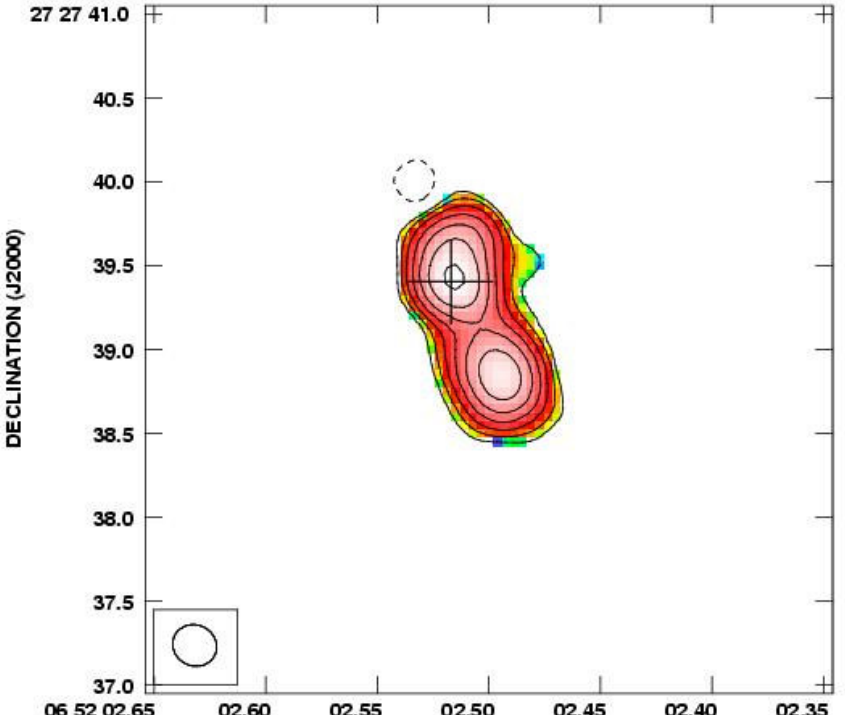




0258+35: spectrum and age

- good coverage between 74 MHz and 22 GHz
- little contamination from core
- $B_{eq} = 90\ \mu G$
- $T_{syn} = 7 \times 10^5$ yr
- $v_{adv,\ syn} = 0.005\ c$





VLA

$S_{8\ GHz}$ = (19 + 14) mJy

$S_{22\ GHz}$ = 10 mJy

symmetric double at 8 GHz…

…resolved with compact core at 22 GHz!

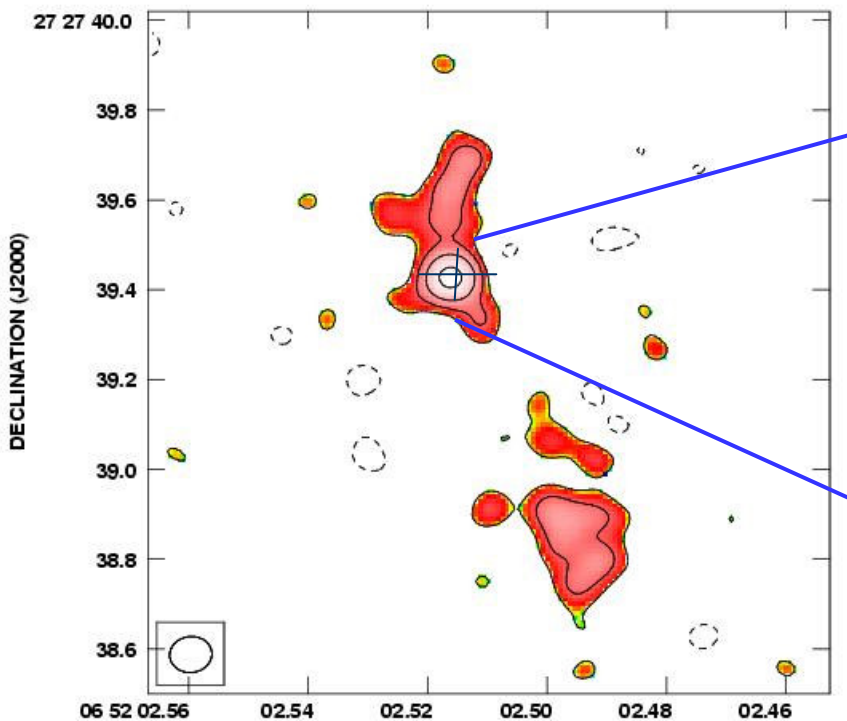
NO HS!

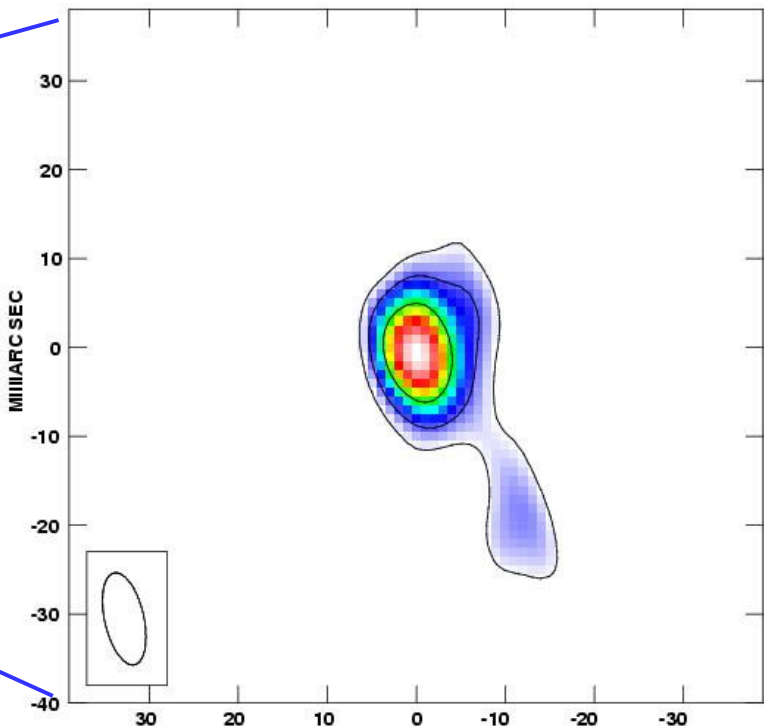
AGN7

VLBA

phase-ref provides:

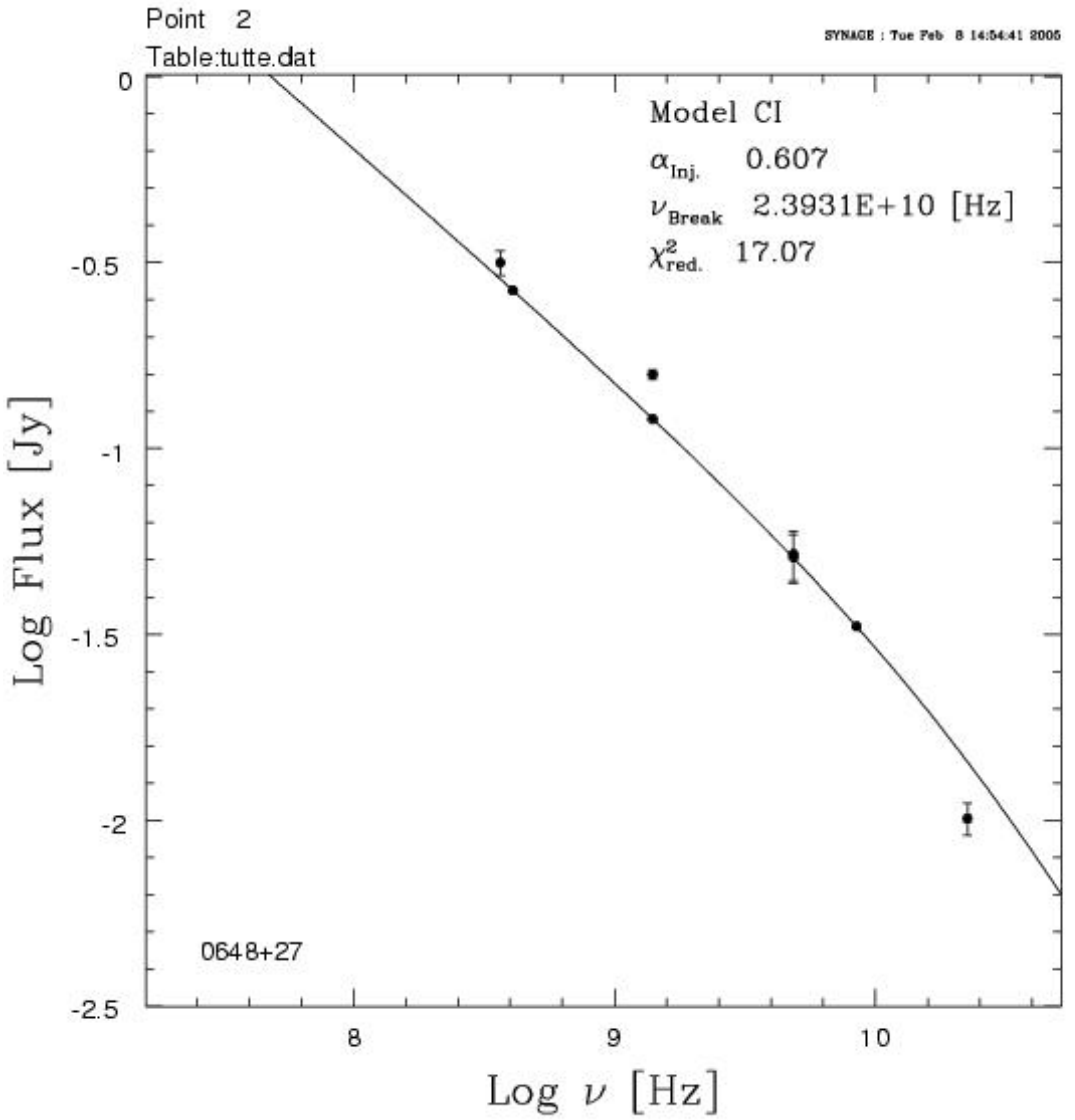
1. **DETECTION** (S_{core} = 4 mJy)
2. **POSITION**
3. tentative **JET**

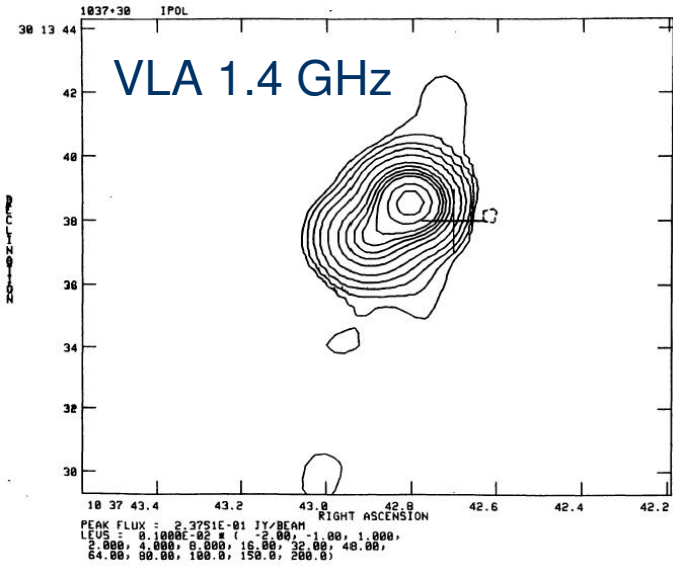


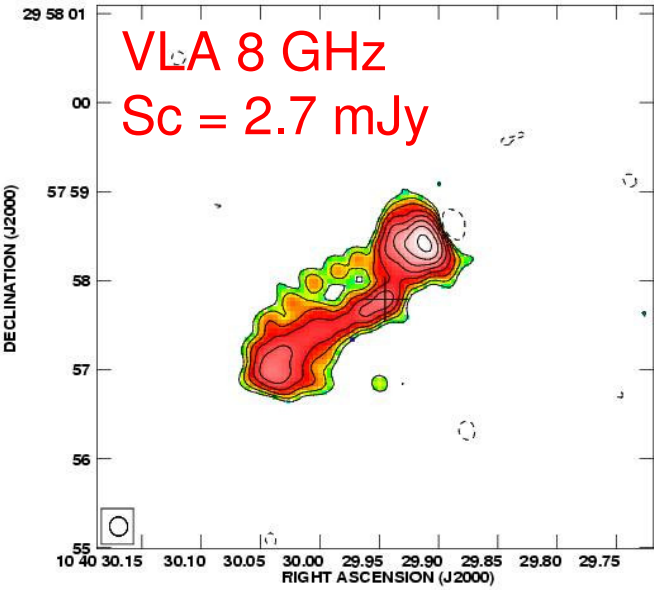


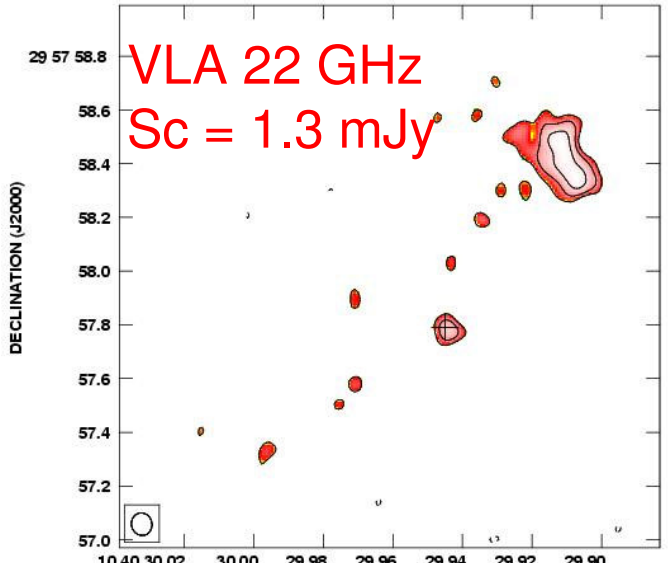
0648+27: spectrum and age

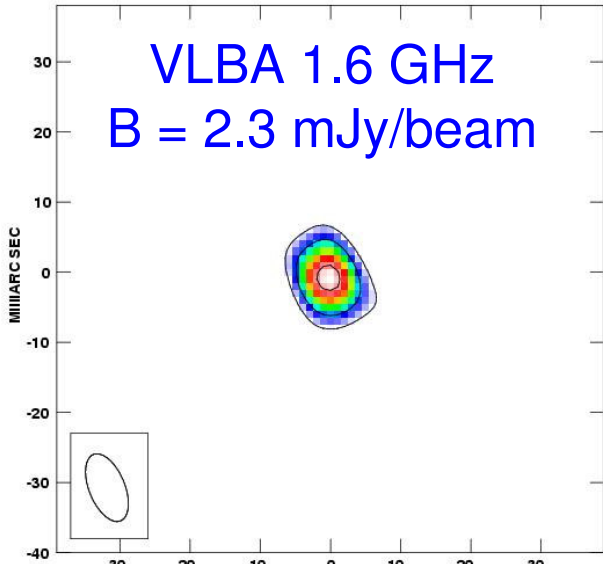
some literature data at low freq.
dominant core
B_{eq} = 95 μG
T_{syn} = 3.5 x 10^5 yr
large uncertainty




1037+30 IPOL
VLA 1.4 GHz
RIGHT ASCENSION
PEAK FLUX : 2.3751E-01 JY/BEAM
LEVS : 8.1000E-02 * (-2.00, -1.00, 1.000,
2.000, 4.000, 8.000, 16.00, 32.00, 48.00,
64.00, 80.00, 100.0, 150.0, 200.0)


VLA 8 GHz
Sc = 2.7 mJy
DECLINATION (J2000)
RIGHT ASCENSION (J2000)


VLA 22 GHz
Sc = 1.3 mJy
DECLINATION (J2000)


VLBA 1.6 GHz
B = 2.3 mJy/beam
MILLIARC SEC