RECURRENT JET ACTIVITY IN RADIO GALAXIES

Marek Jamrozy

Jagiallonian University

Kraków, Poland

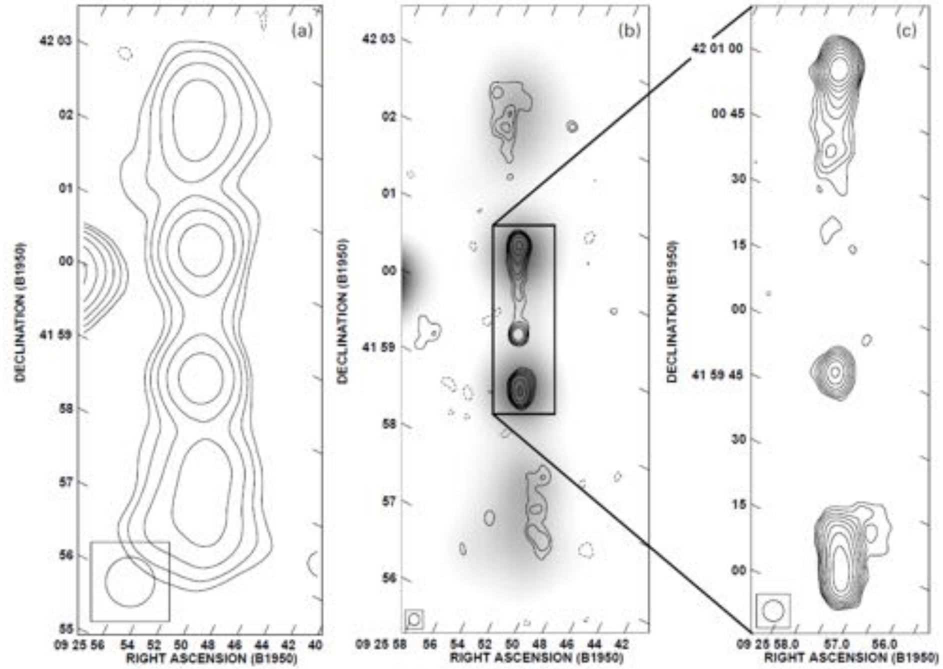
SKA Pathfinders Radio Continuum Surveys 2016

3-5.11.2016

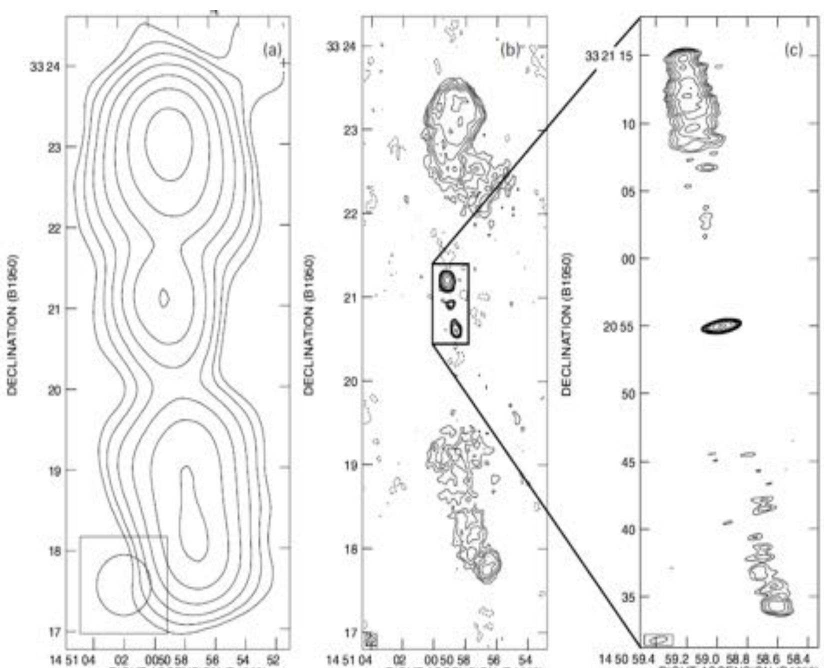
Goa

A. P. Schoenmakers,
A. G. de Bruyn,
H. J. A. Rottgering,
H. van der Laan,
C. R. Kaiser
2000, MNRAS, 315, 371
DDRGs

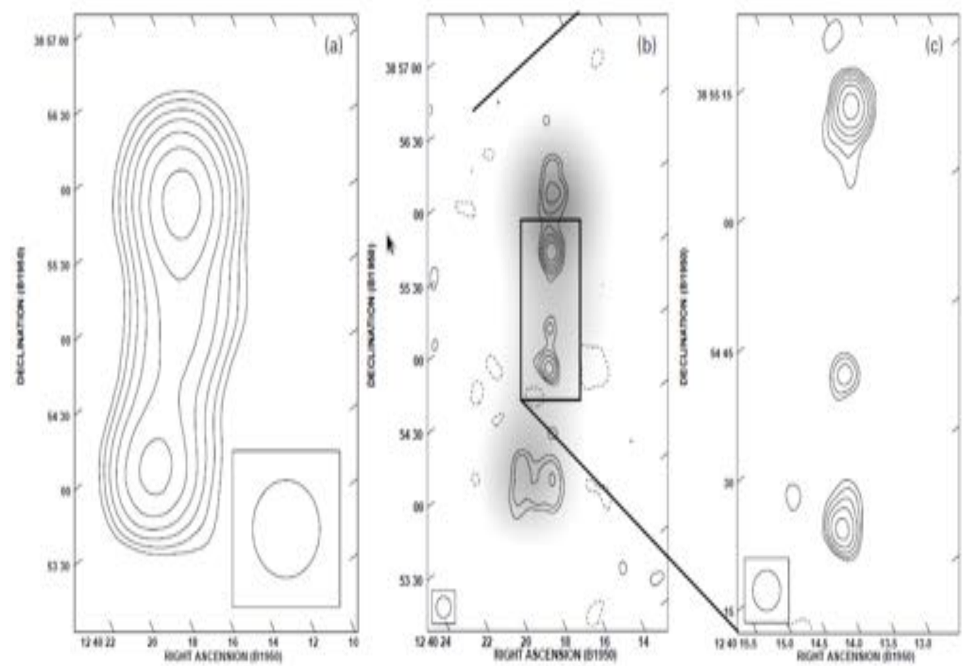
WENSS 326 MHz
Rengelink et al.
1997, A&AS, 124, 259



B0925+420



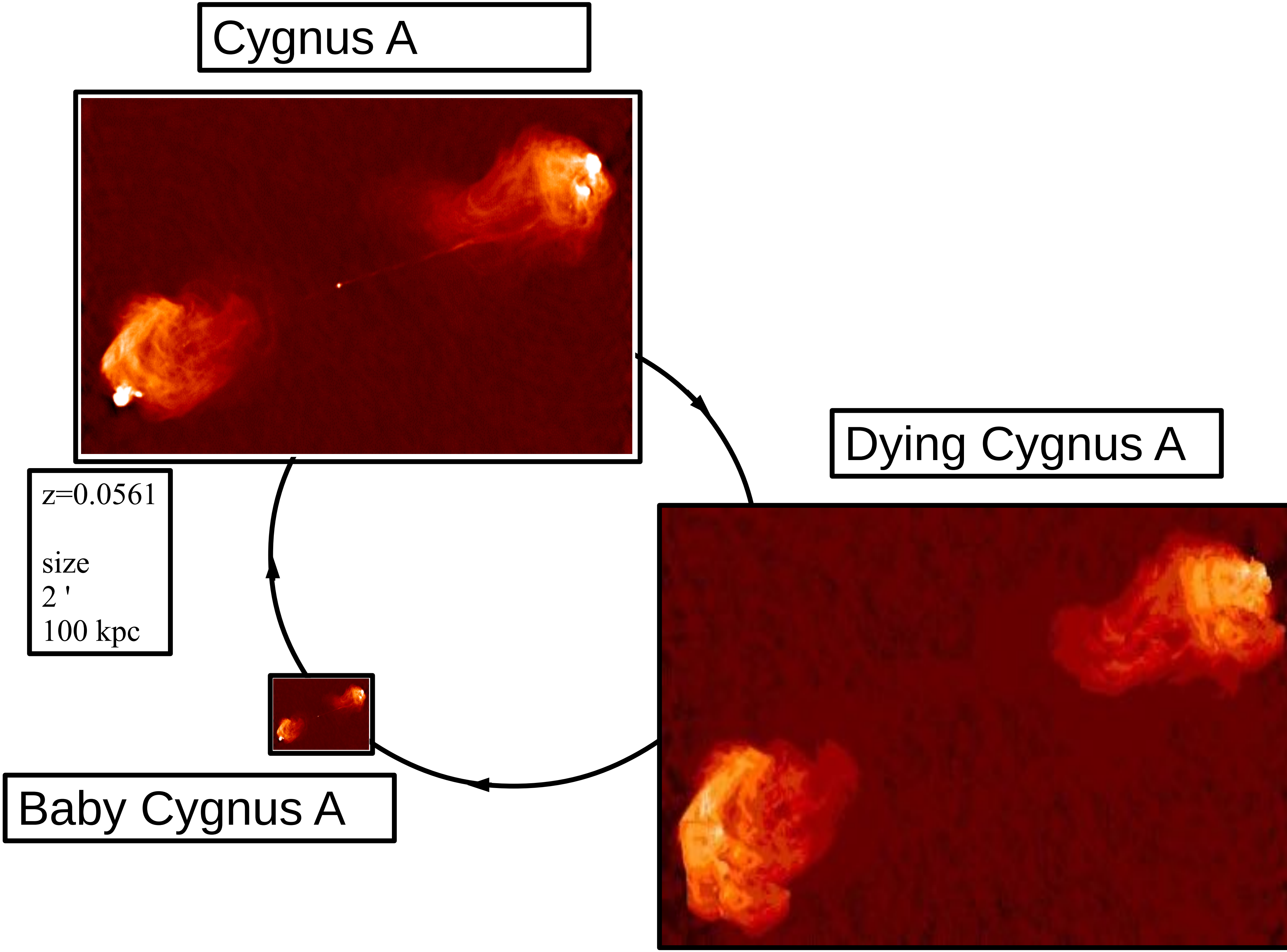
B1450+333



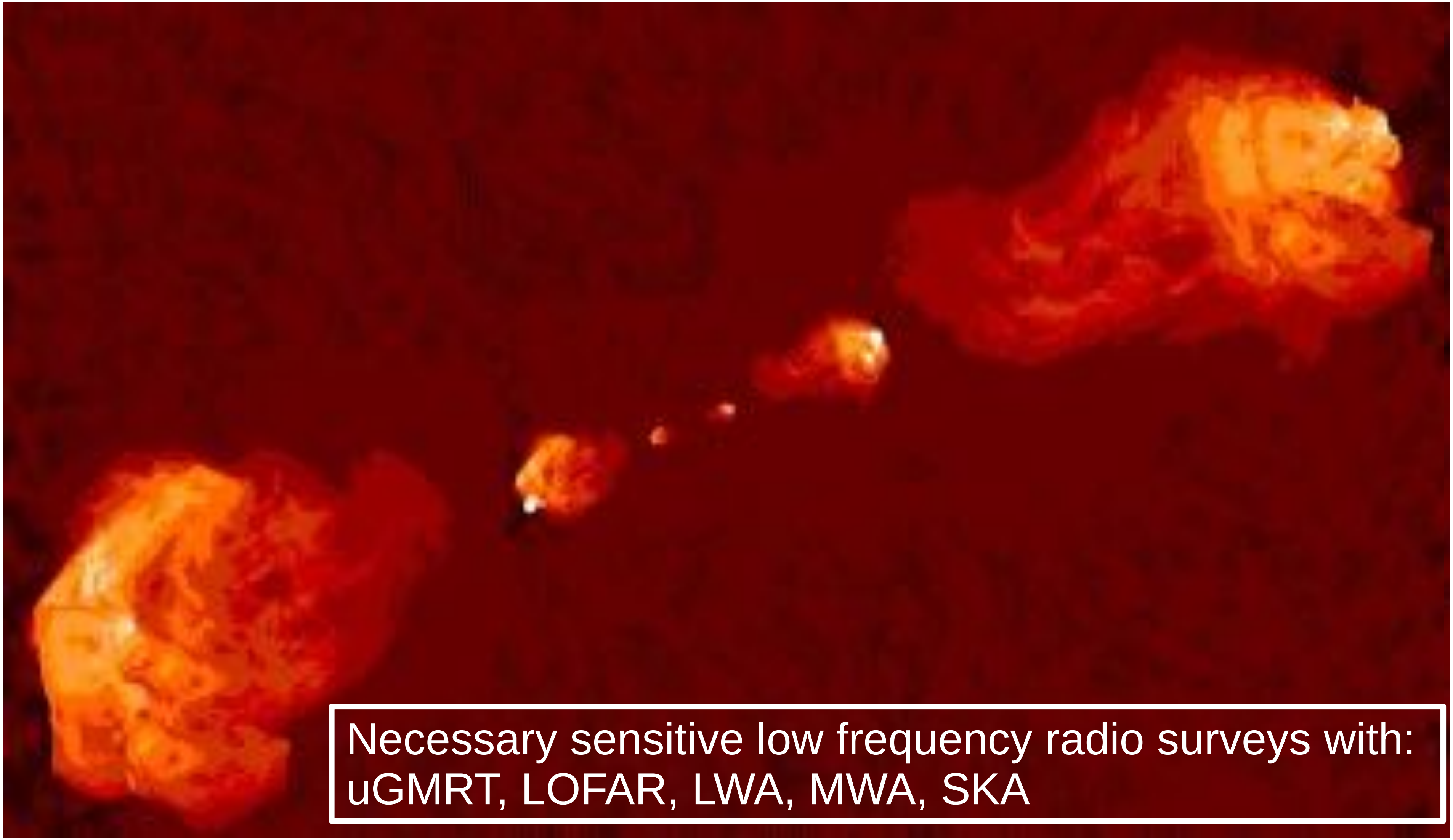
B1240+389

All sky radio surveys

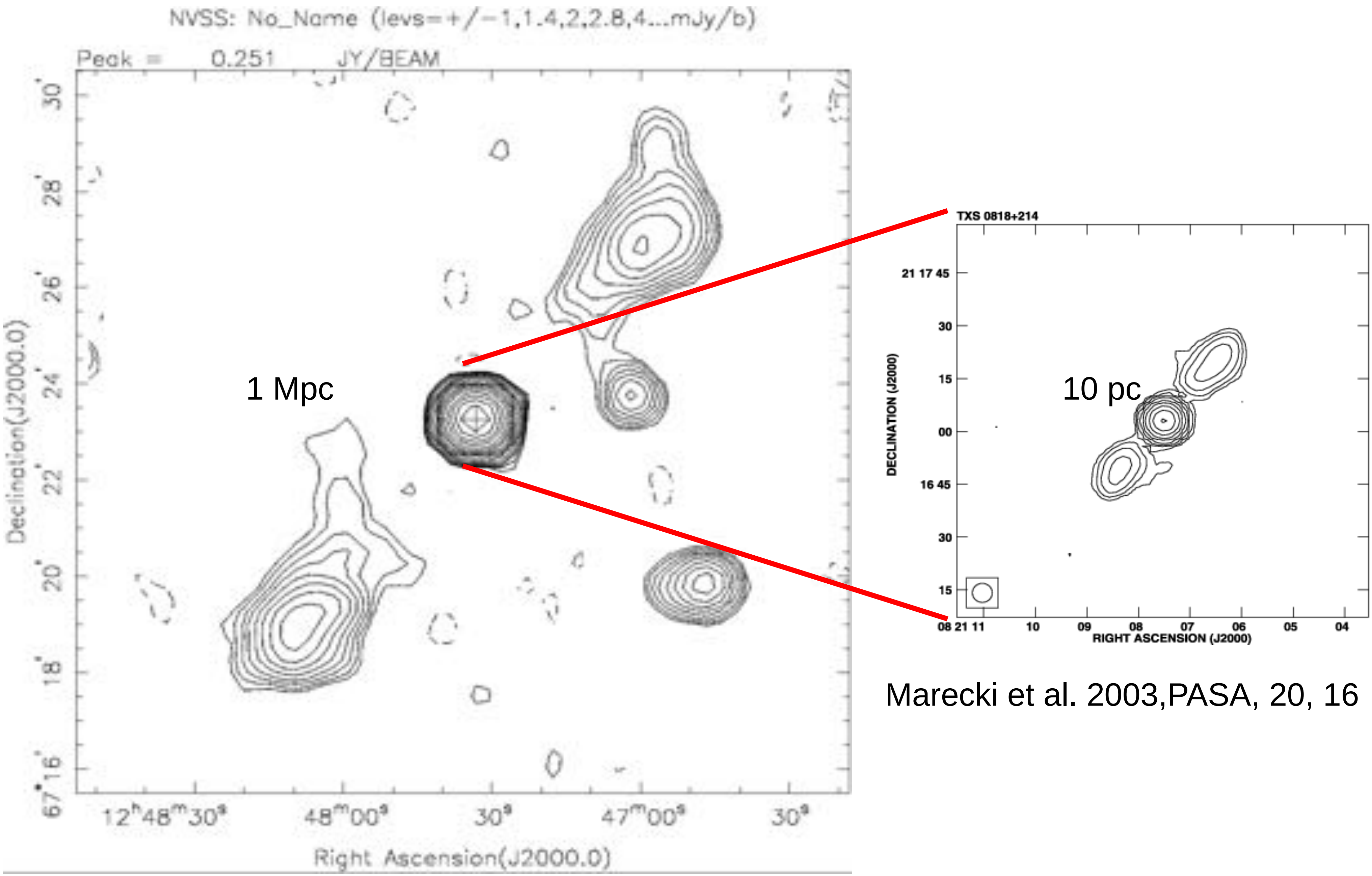
- 74 MHz The VLA Low-frequency Sky Survey (**VLSSr**)
  http://www.cv.nrao.edu/4mass/VLSSlist.shtml
- 38, 151 MHz The Cambridge Low Frequency Radio Surveys: **8C, 6C, 7C**
  http://www.mrao.cam.ac.uk/facilities/surveys/
- 150 MHz TIFR GMRT Sky Survey (**TGSS**)
  http://www.ncra.tifr.res.in/~ngk/150MHz/index.html
- 326 MHz Westerbork Northern Sky Survey (**WENSS**)
  http://www.astron.nl/wow/testcode.php?survey=1
- 843 MHz Sydney University Molonglo Sky Survey (**SUMSS**)
  http://www.physics.usyd.edu.au/sifa/Main/SUMSS
- 1400 MHz NRAO VLA Sky Survey (**NVSS**)
  http://www.cv.nrao.edu/nvss/
- 1400 MHz Faint Images of the Radio Sky at Twenty-cm (**FIRST**)
  http://sundog.stsci.edu/top.html
- 4850 MHz Parkes-MIT-NRAO Radio Surveys (**PMN**)
  ftp://ftp.atnf.csiro.au/pub/data/pmn/maps/PMN/
- 20 GHz Australia Telescope Survey (**AT20G**)
  http://www.atnf.csiro.au/research/AT20G/


Cygnus A
Dying Cygnus A
Baby Cygnus A
z=0.0561
size
2 '
100 kpc

Reincarnated Cygnus A



J1247+6723



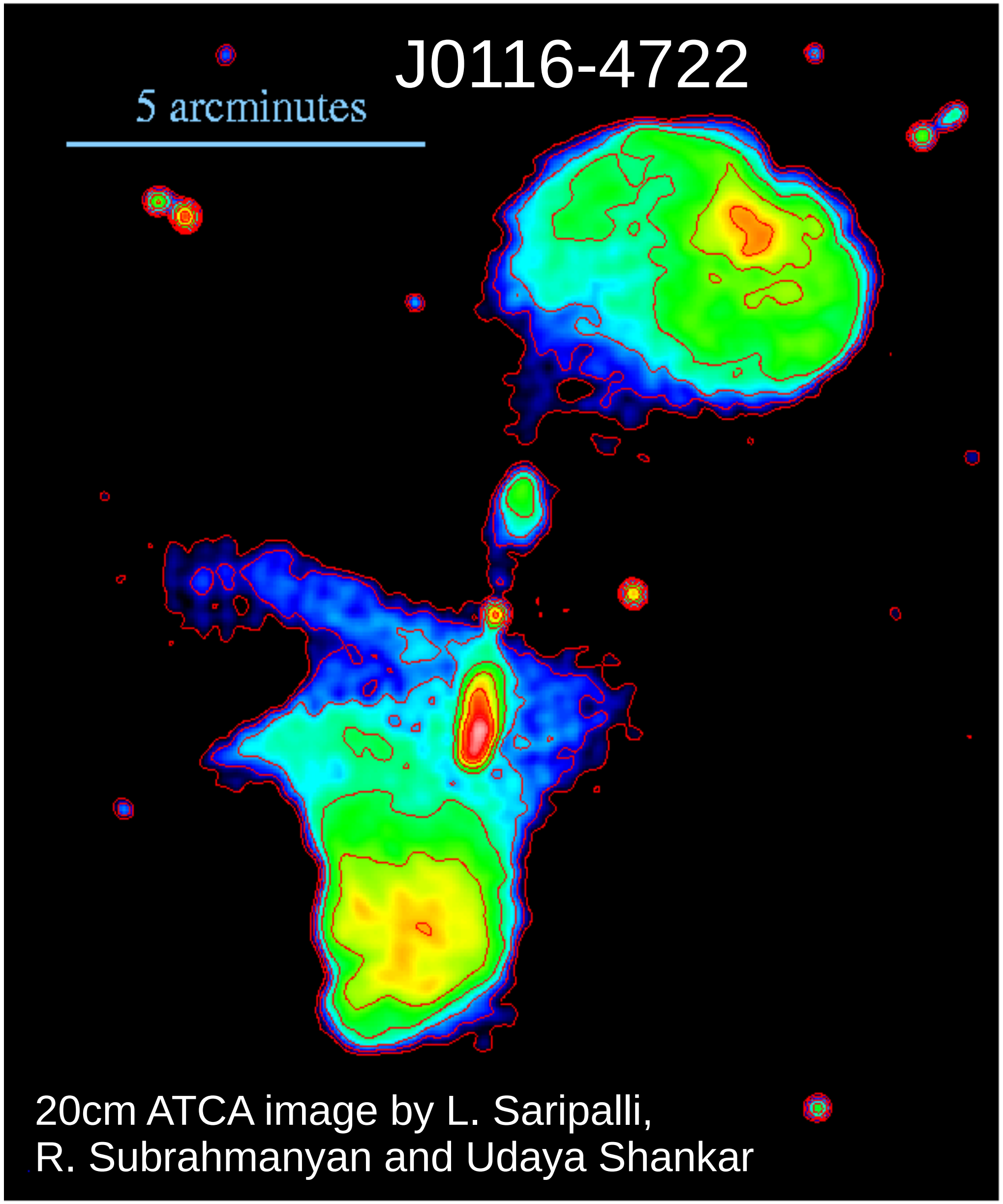
Marecki et al. 2003,PASA, 20, 16

Table 1: Sources with evidence of recurrent activity

Source	Alt. name	Opt. Id.	Red-shift	l_{in} kpc	l_o kpc	Notes	References
J0041+3224	B2 0039+32	G	(0.45)	171	969	DDRG	1
J0116−4722	PKS 0114−47	G	0.1461	460	1447	DDRG	2
J0821+2117	TXS 0818+214	G	(1.0)	5.4	547	DDRG	19,20
J0840+2949	4C29.30	G	0.0647	36	639	DDRG	18
J0921+4538	3C219	G	0.1744	69	433	DDRG	3,4,5
J0929+4146		G	0.3650	∼30, 652	1875	TDRG	6,39
J0935+0204	4C02.27	Q	0.6491	70	470	DDRQ	16
J1006+3454	3C236	G	0.1005	1.7	4249	DDRG	7,8,9
J1158+2621	4C26.35	G	0.1121	138	483	DDRG	10
J1242+3838		G	0.3000	251	602	DDRG	6
J1247+6723	VII Zw 485	G	0.1073	0.014	1195	DDRG	11,12
J1325−4301	Cen A	G	0.0018	∼12	∼600	DDRG	28,29,30,31,32,40
J1352+3126	3C293	G	0.0450	1.6	190	misaligned DDRG	36,37,38
J1406+3411	3C294	G	1.7790		126	relic X-ray	45,46
J1453+3308	4C33.33	G	0.2481	159	1297	DDRG	6,17
J1504+2600	3C310	G	0.0538	∼90	320	Flatter-α bubbles	25,26
J1548−3216	PKS 1545−321	G	0.1082	313	961	DDRG	13,35,41,43
J1651+0459	Her A	G	0.1540		513	Steep-α relic	23,24
J1835+6204	8C 1834+620	G	0.5194	369	1379	DDRG	6,27,44
J1844+4533	3C388	G	0.0917		∼70	Steep-α relic	21,22
J1959+4044	Cyg A	G	0.0561		136	relic X-ray jet	33,34,42
J2223−0206	3C445	G	0.0562	130	612	DDRG	14,15

Saikia & Jamrozy, 2009, BASI, 37, 63
Nandi & Saikia, 2012, BASI, 40, 121

~ 60 DDRGs



Double-Double Radio Galaxies

DDRG – two unequall sized , two sided, double lobed, edge-brightened (FRII) radio sources from two different cycles of activity (Schoenmakers, 2000, MNRAS, 315, 371)

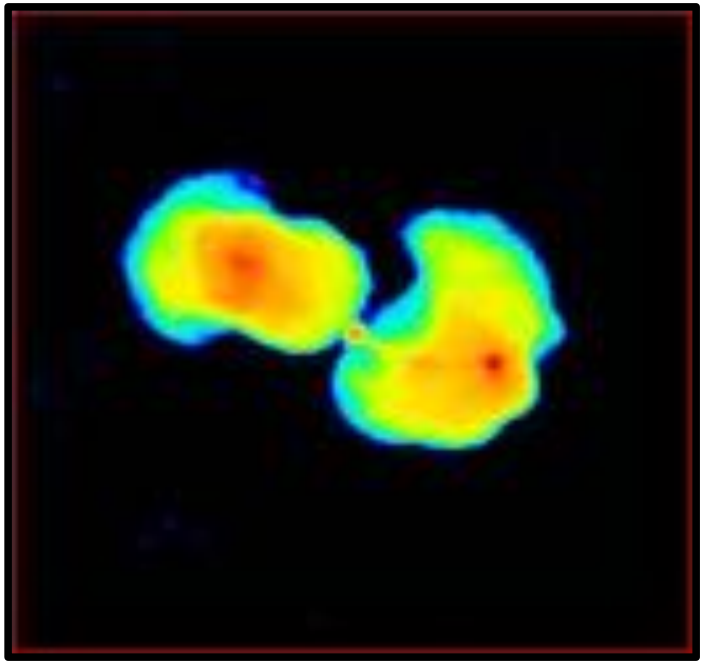
interruptions related to:
- refueling of the central engine
- instabilities in the accretion disk
- jet production machanism

~60 objects known (Saikia & Jamrozy 2009, Nandi & Saikia 2012)

Saripalli, Subrahmanyan, Udaya Shankar, 2003, ApJ, 590, 181

Easy to recognise

Difficult to recognise



3C388 z=0.0917 size=1'

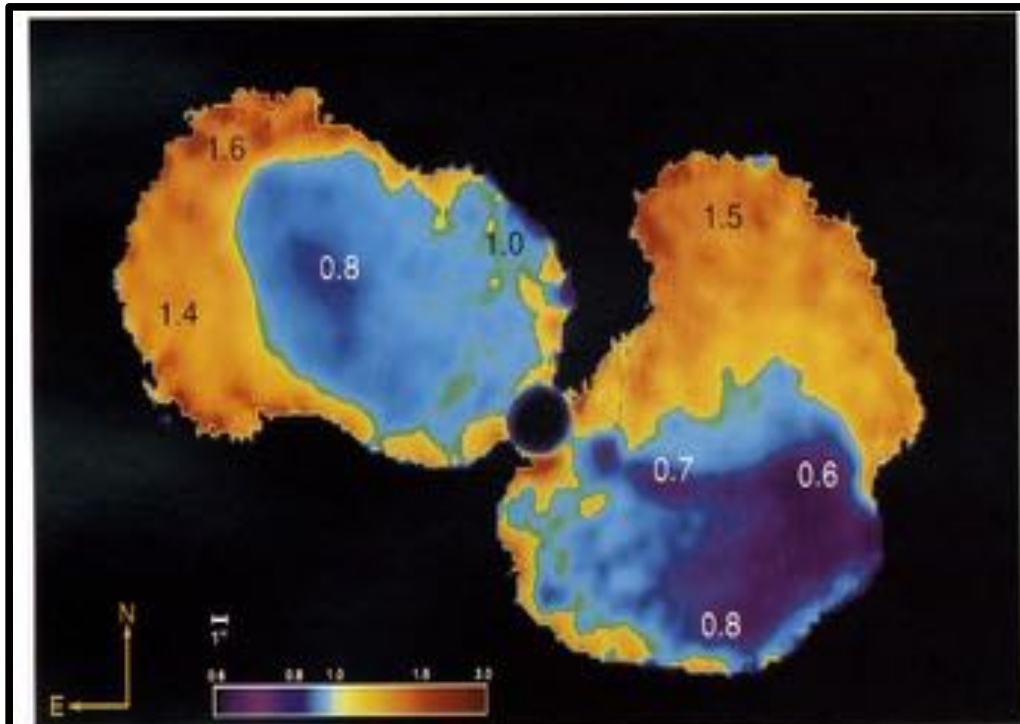


FIG. 2—Spectral index (4.847–1.385 GHz) map of 3C 388. Several regions are labeled with typical spectral index values.

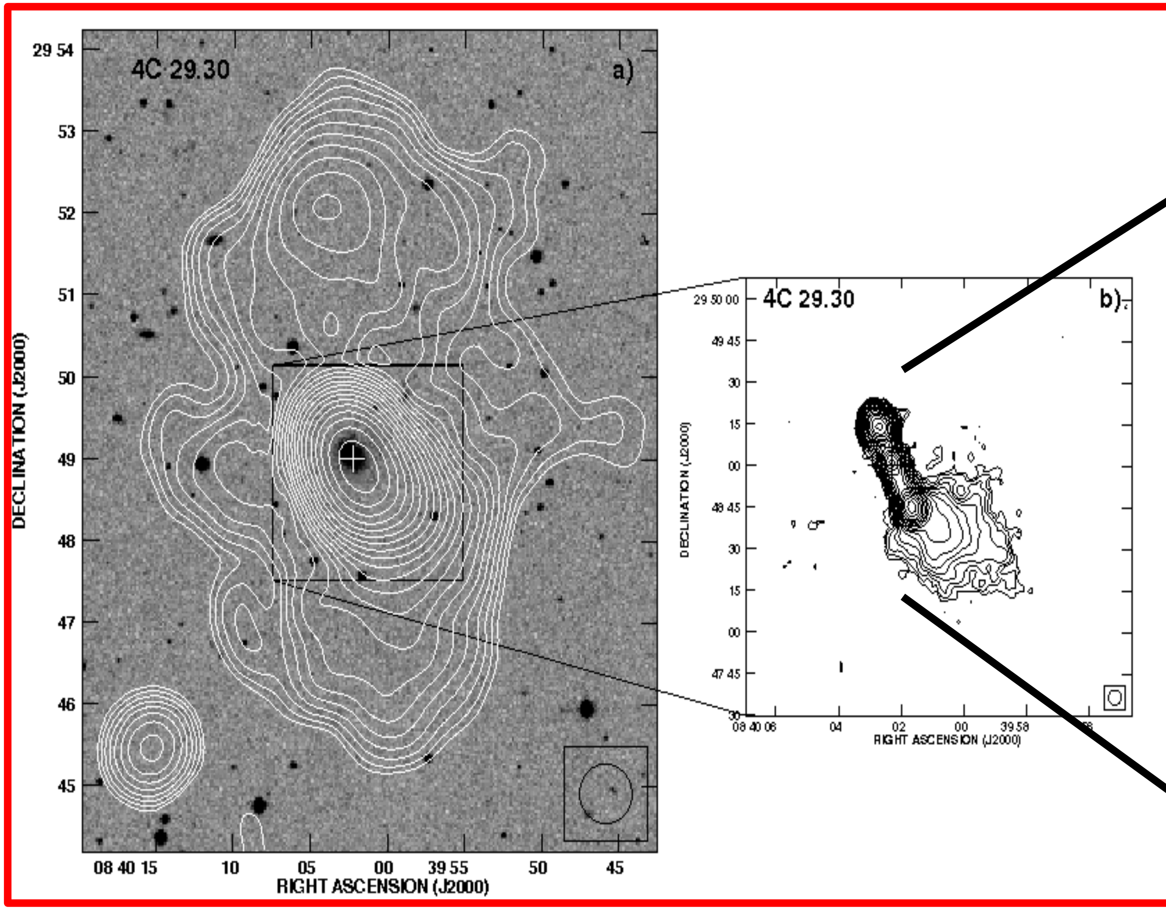
Roettiger, Burns, Clarke, & Christiansen, 1994, ApJ, 421, L23

Relic radio emission in 3C388

Abstract

New VLA images of the radio galaxy **3C 388 have revealed an intriguing distribution** of spectral indices which is **quite different from that of typical classical double sources**. We observe two distinct regions of emission separated by a well-defined transition layer delineated by a dramatic jump in the spectral index, particularly in the eastern lobe. We interpret these data as **evidence of at least two distinct epochs of jet activity** in which the current jets have resumed penetration of the IGM and are inflating younger, more energetic lobes into the relic lobes of the previous epoch. To the best of our knowledge, 3C 388 is the **first radio galaxy in which multiple epochs of activity** are clearly visible in the large-scale radio structure.

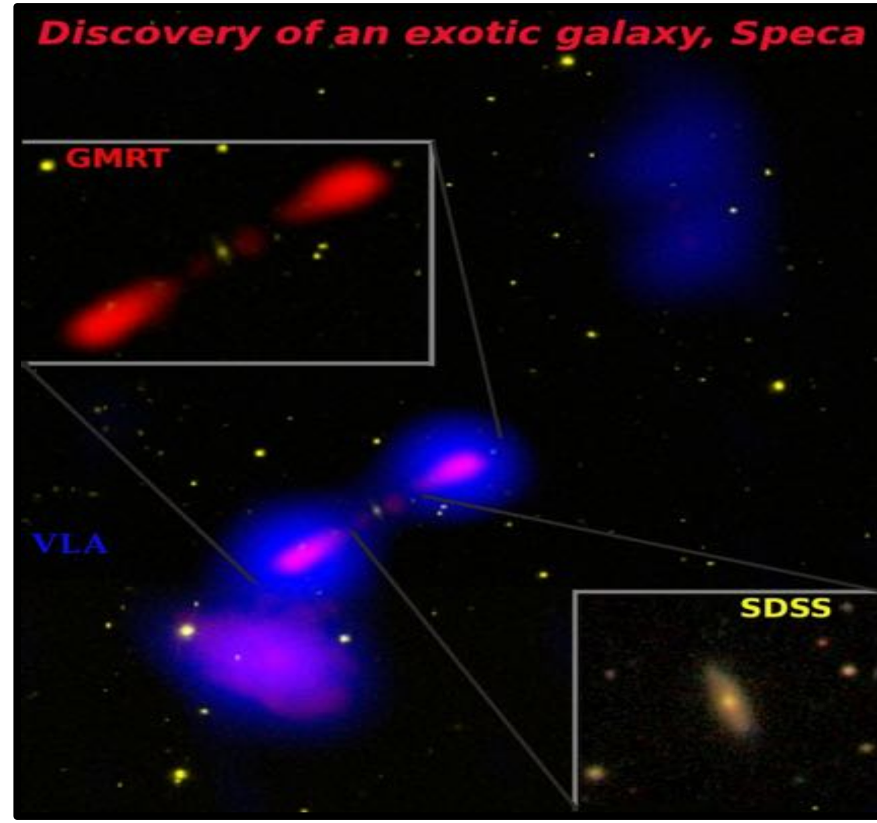
4C 29.30



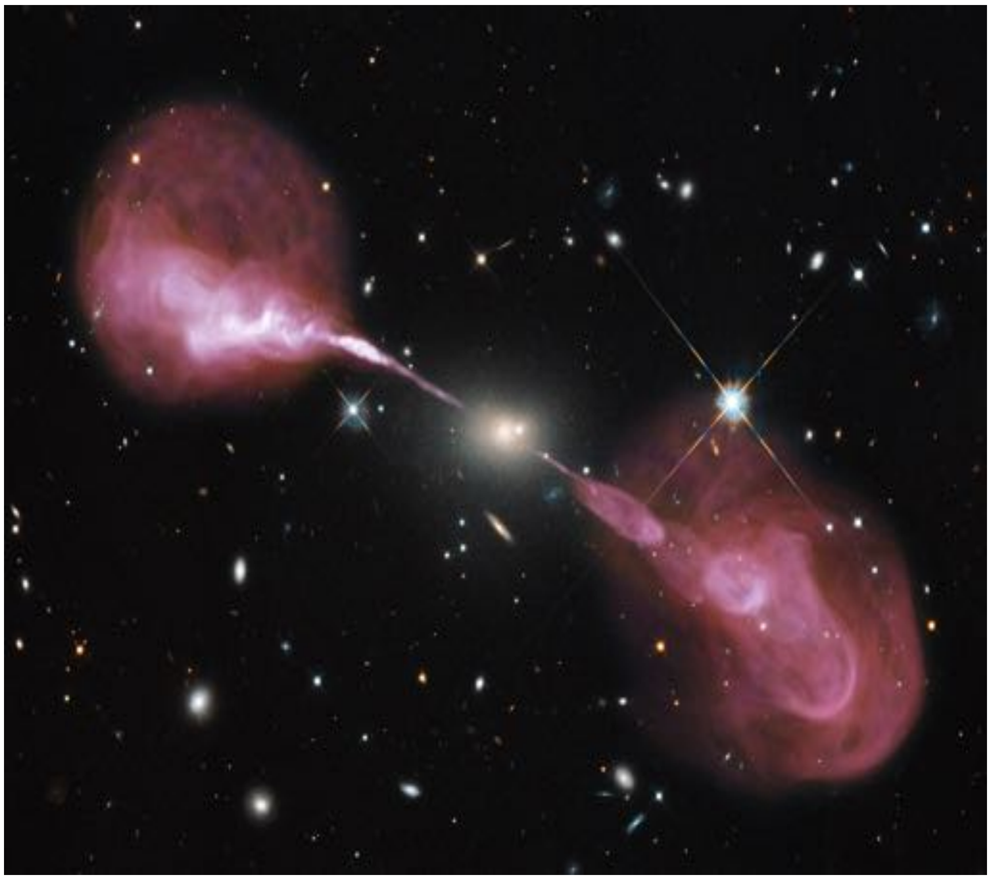
Jamrozy et al., 2007, MNRAS, 378, 581

Siemiginowska, et al. 2012, ApJ, 750, 124

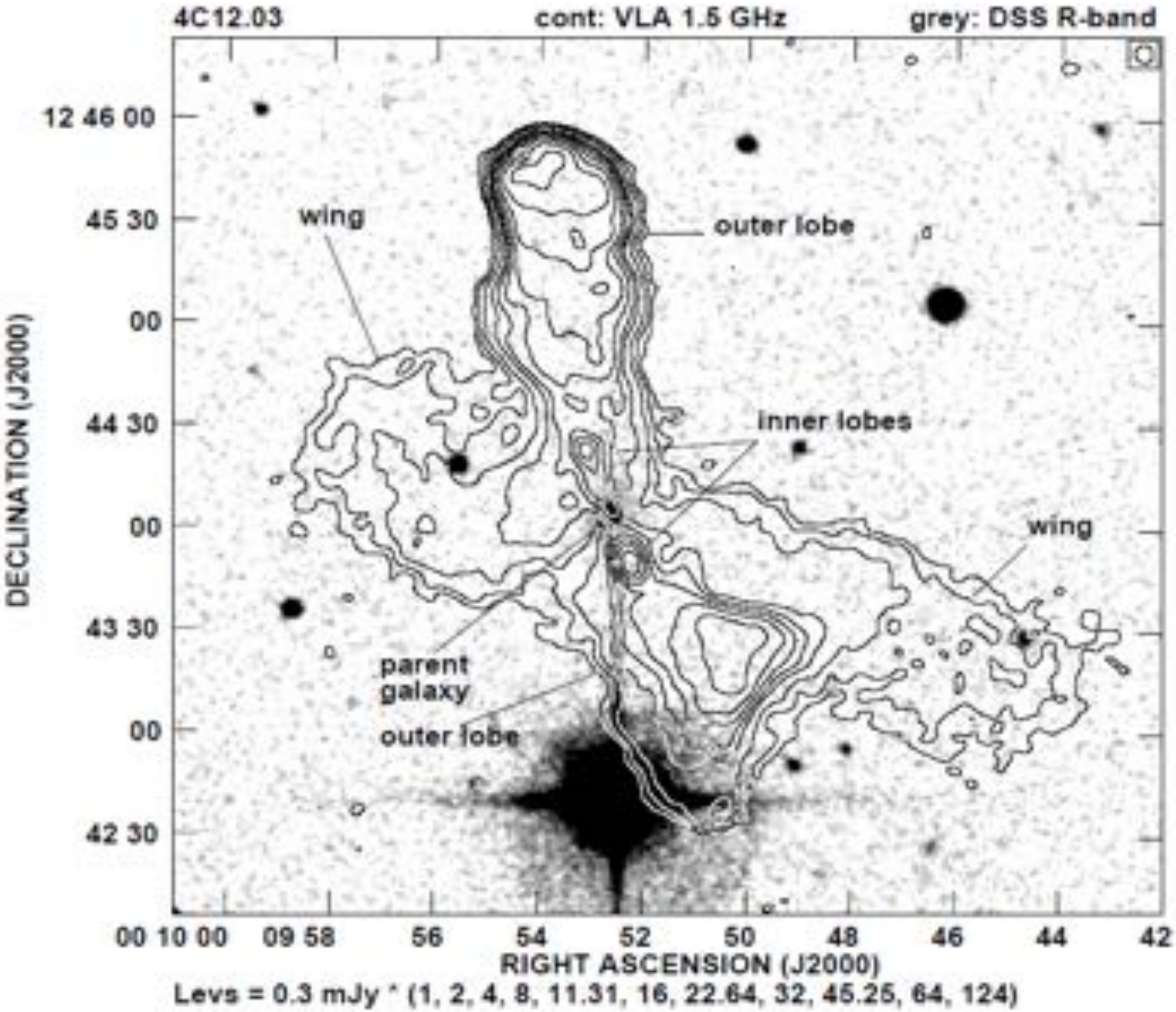
z= 0.137,
spiral-host
triple-double radio galaxy



Hota et al., 2011, MNRAS, 471L, 36

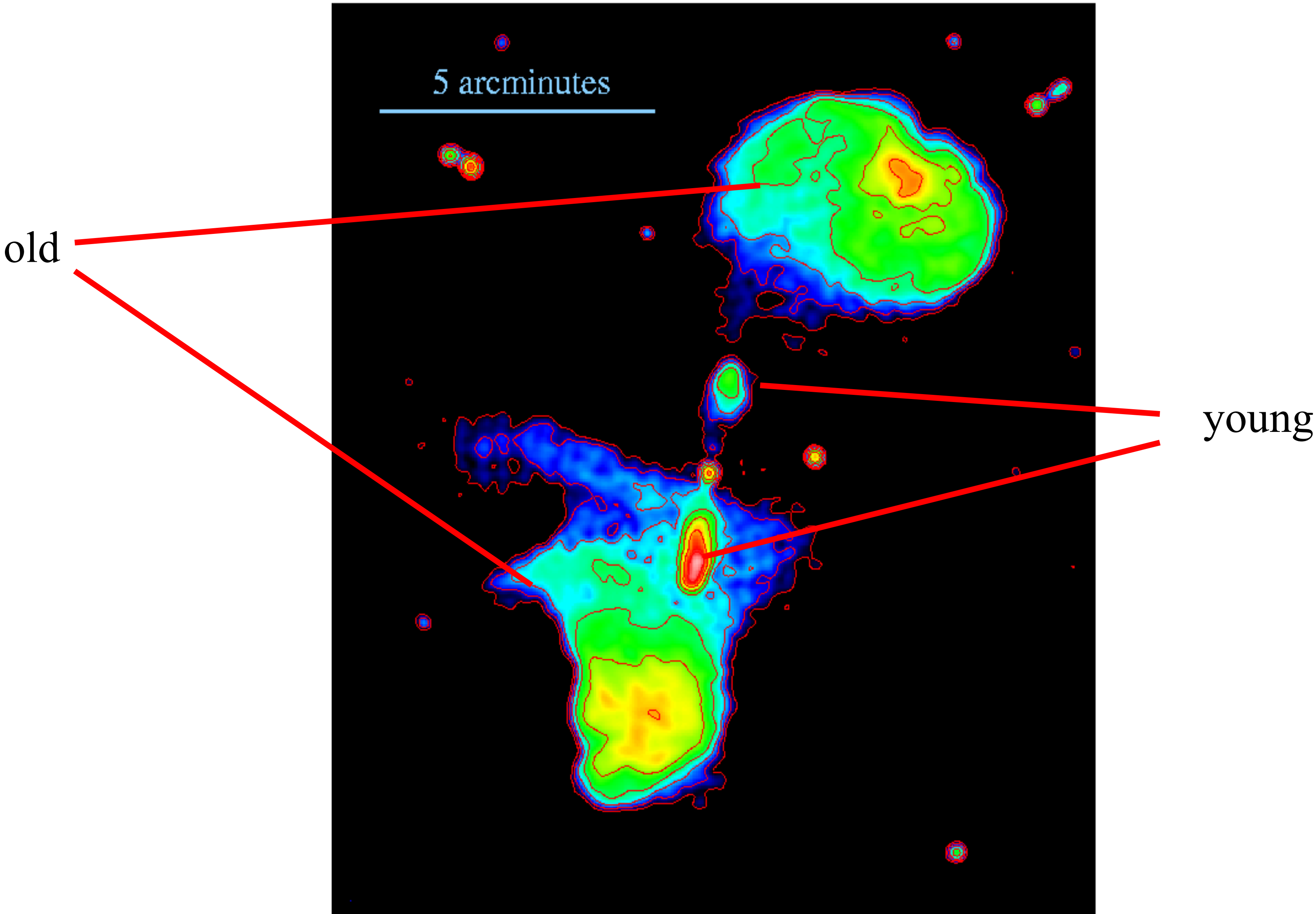


HERCULES A (3C 348) z=0.154
JVLA 4-9 GHz
R. Perley and W. Cotton

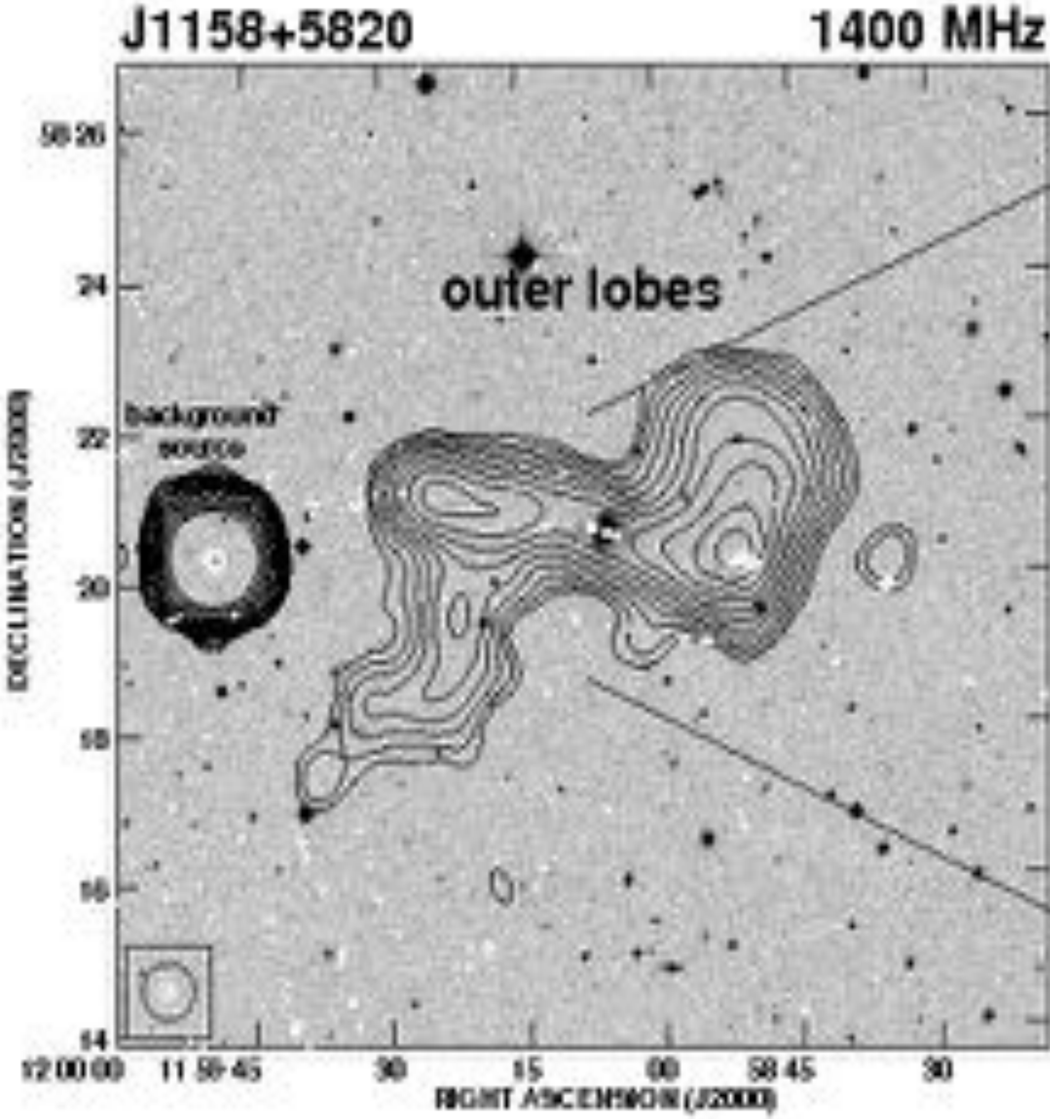


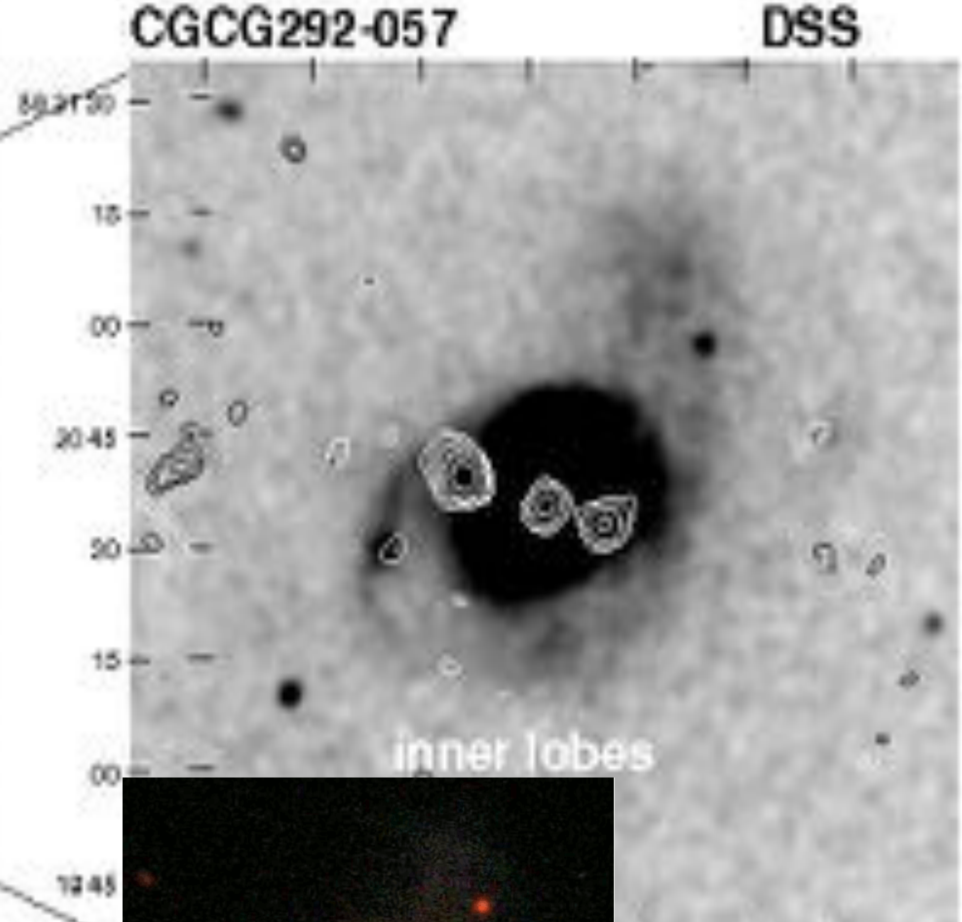
4C12.03
cont: VLA 1.5 GHz
grey: DSS R-band
wing
outer lobe
inner lobes
wing
parent
galaxy
outer lobe
12 46 00
45 30
00
44 30
00
43 30
00
42 30
DECLINATION (J2000)
00 10 00
09 58
56
54
52
50
48
46
44
42
RIGHT ASCENSION (J2000)
Levs = 0.3 mJy * (1, 2, 4, 8, 11.31, 16, 22.64, 32, 45.25, 64, 124)

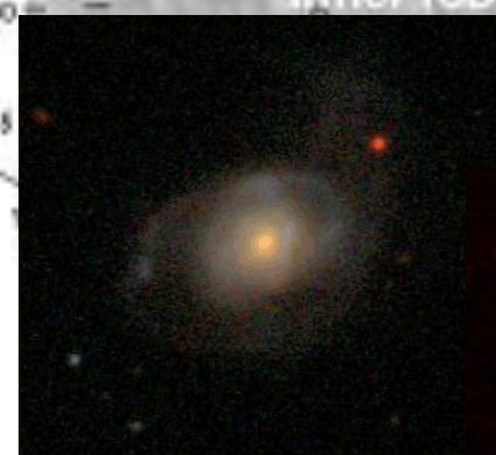
Age determination

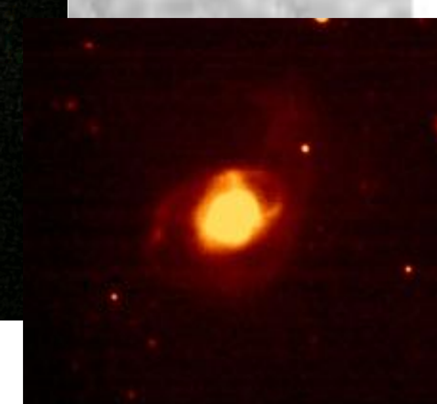


CGCG292-057

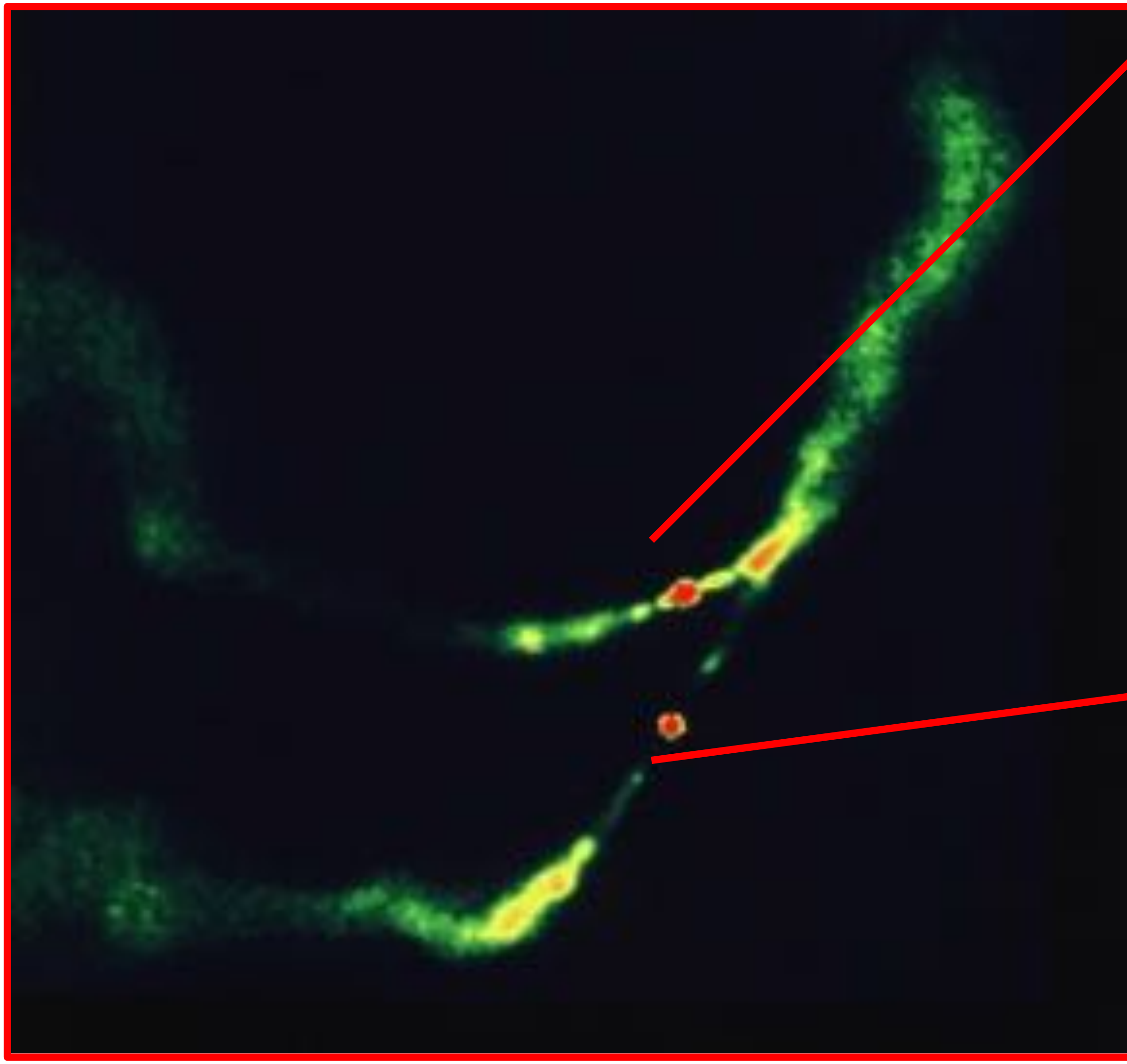




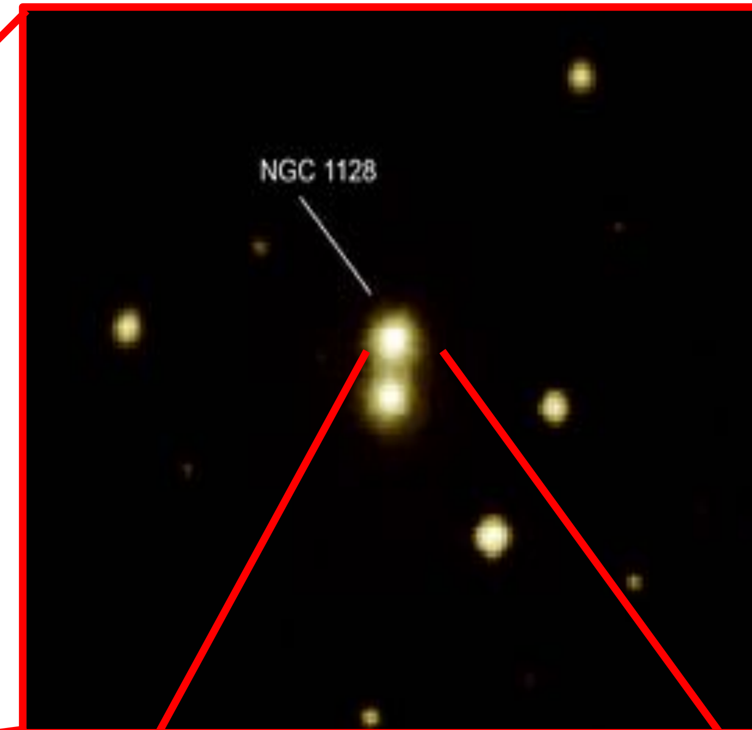


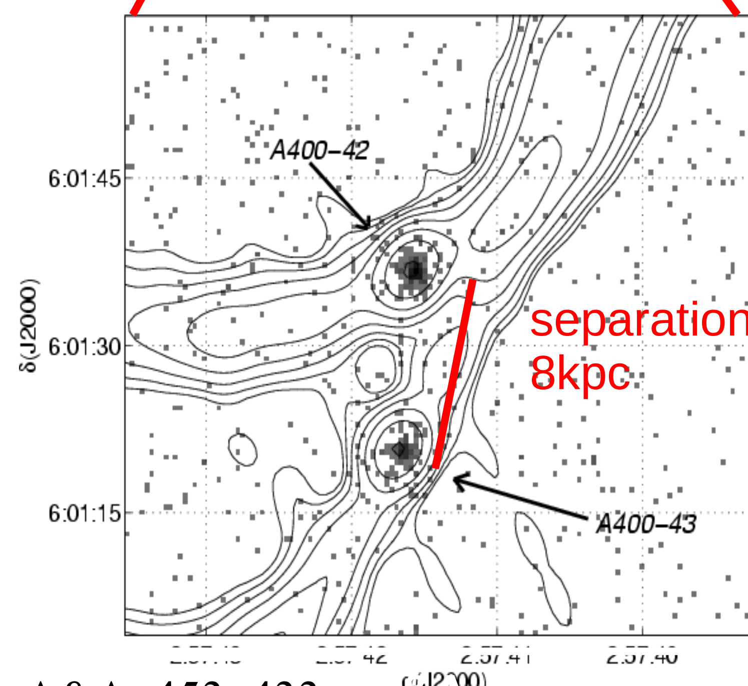


Koziel-Wierzbowska, et al., 2011, MNRAS, 422, 1546,



3C75





Hudson et al., 2006, A&A, 453, 433

Super Massive Black Hole Binaries

X-shaped structures may be due to a realignment of the SMBHB interacting with the accretion disc.

The secondary black hole migrates inwards, disrupting the inner parts of the accretion disc. The gap in the accretion disc expands after the binary black hole coalesces, leading to an interruption in jet formation. Jet activity restarts following the inflow of new material into the central region.

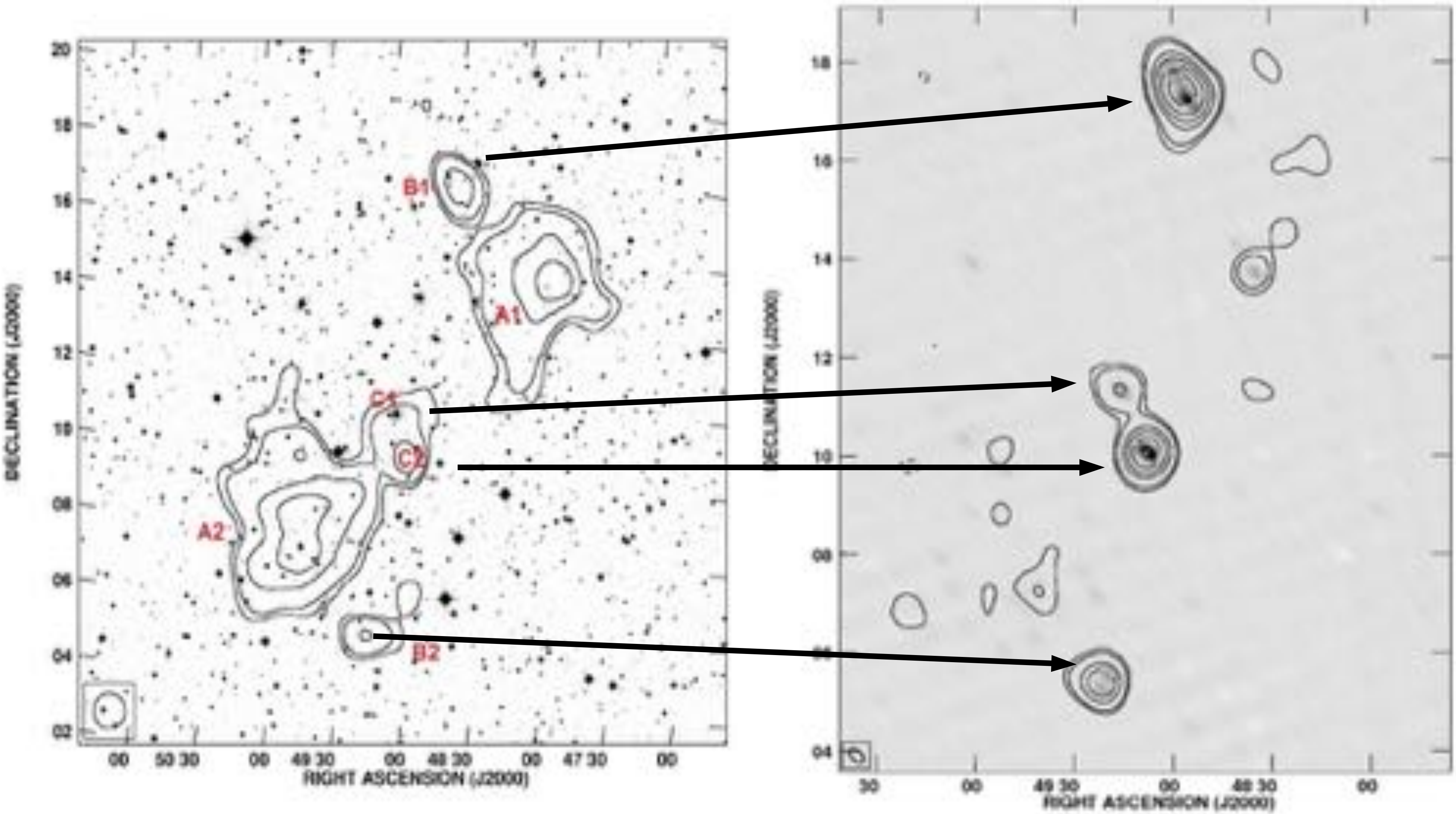
Liu, 2004, MNRAS, 347, 1357
Liu., Wu, Cao, 2003, MNRAS, 340, 411
Liu, Wang, Chen, 2012, ApJ, 746, 176L

J0349+7511

1.3 Mpc diffuse radio source with extremely steep spectrum fading radio lobes

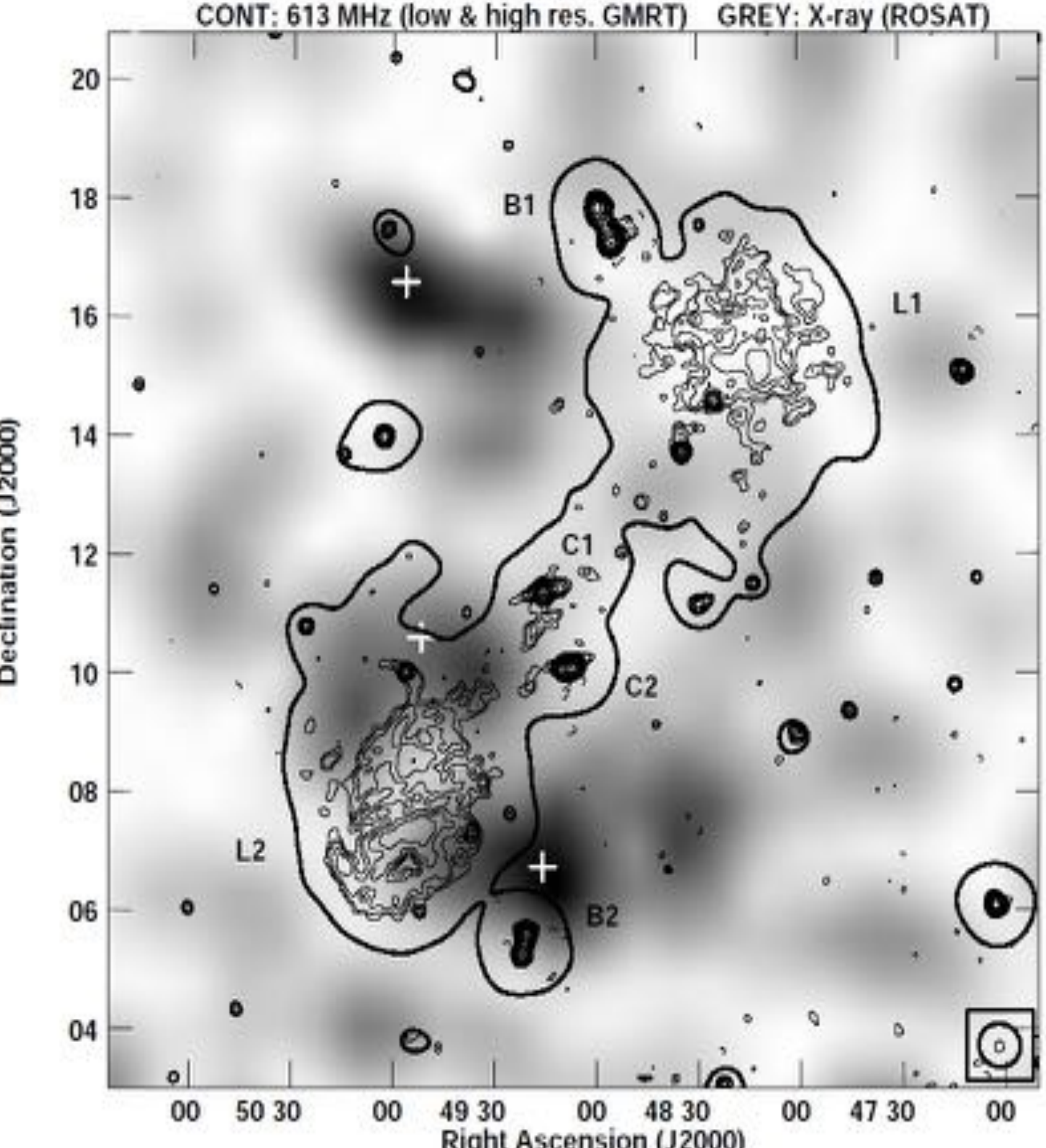
Abell449

z=0.08



WENSS

NVSS



613 MHz GMRT
beam=7”x5” rms=0.03mJy/beam

low-luminosity radio source
power of $P_{613MHz} = 2.57 \times 10^{24}$W Hz^{-1}

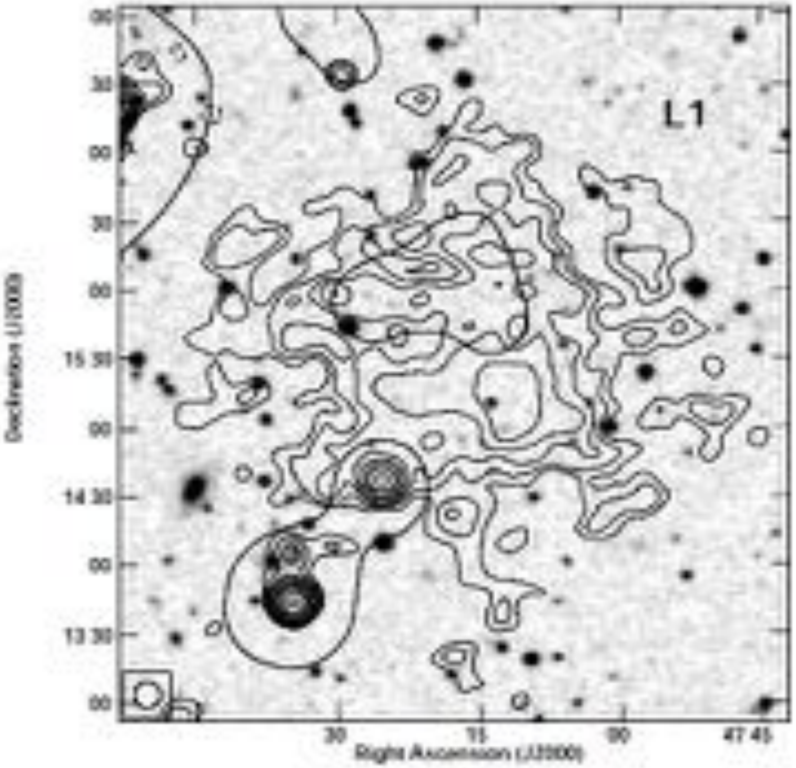
volume $V = 4.8 \times 10^{72}$ cm^3

magnetic field strength
of the lobes B=0.113±0.015 nT

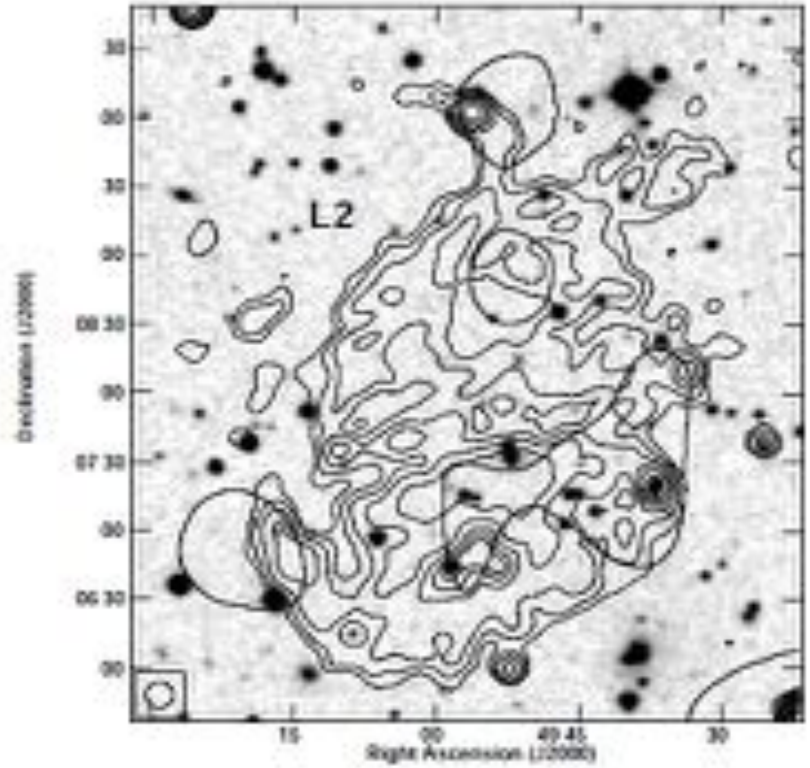
u_{eq}=7.7±2.2 x10^{-21} J cm^{-3}

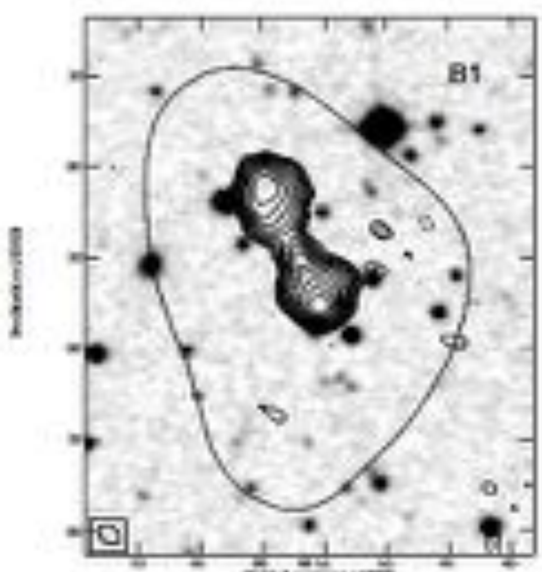
Hunik & Jamrozy, 2016, ApJ, 817L, 1

northern lobe

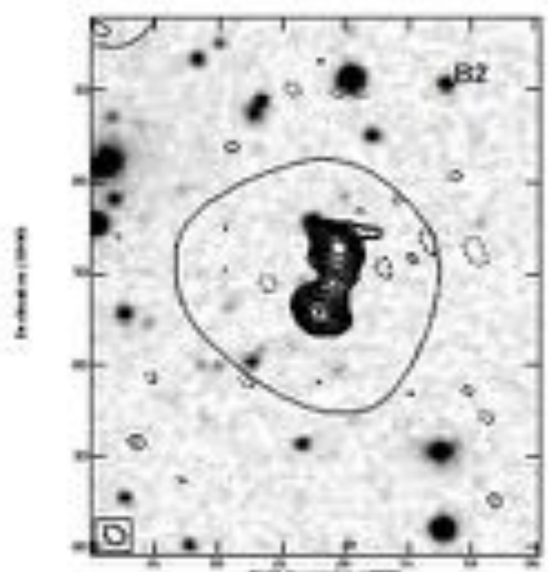


southern lobe

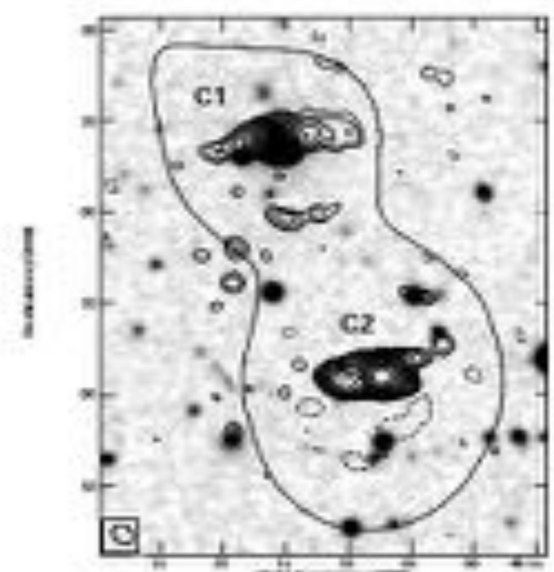




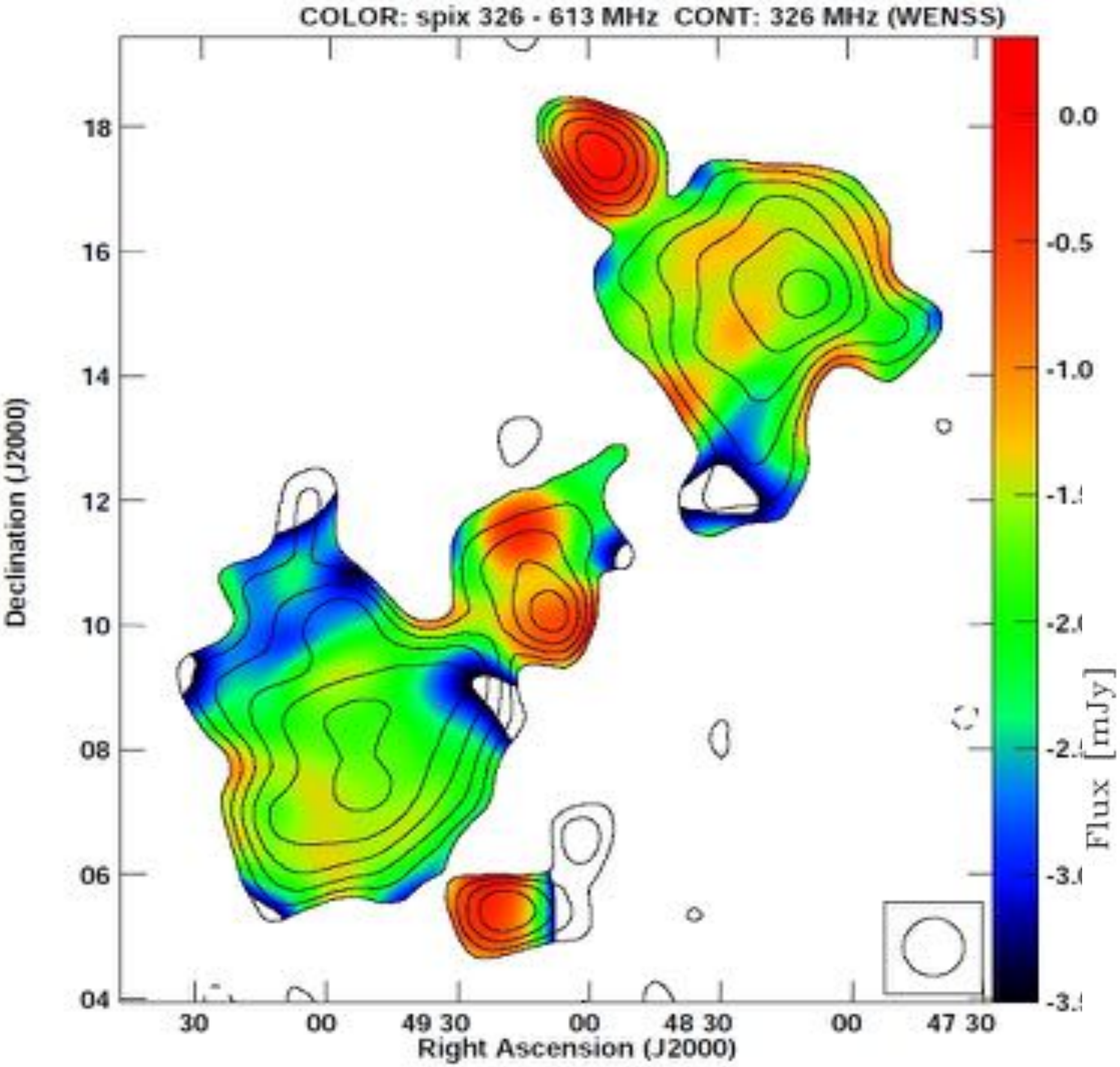
beckground

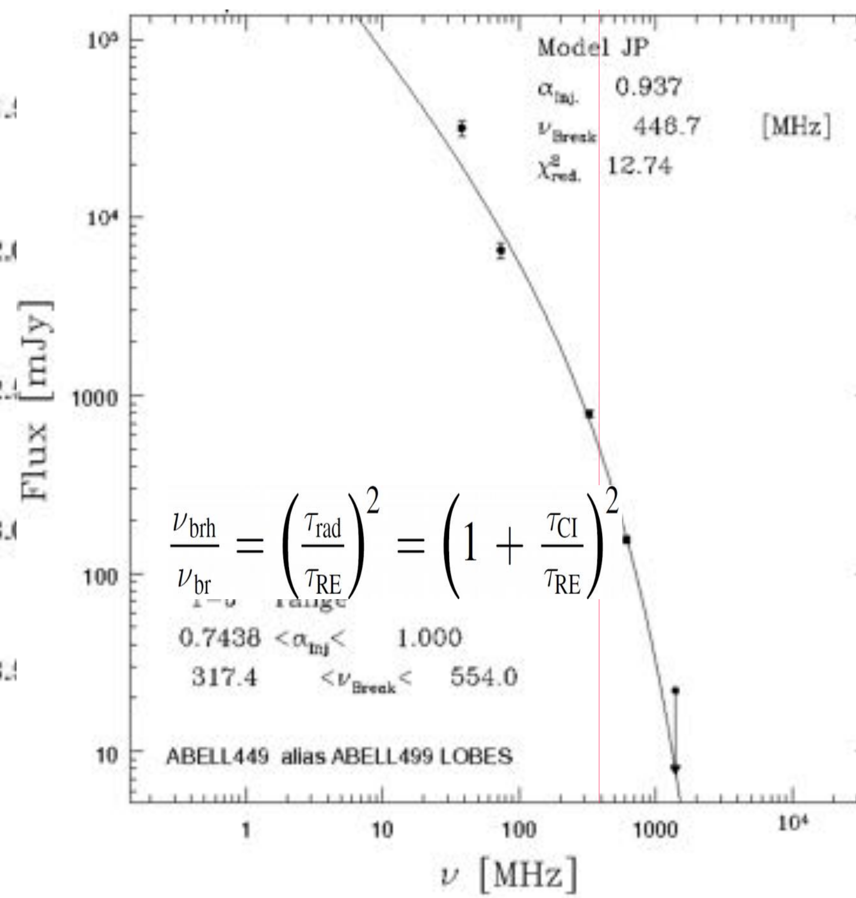


beckground



center

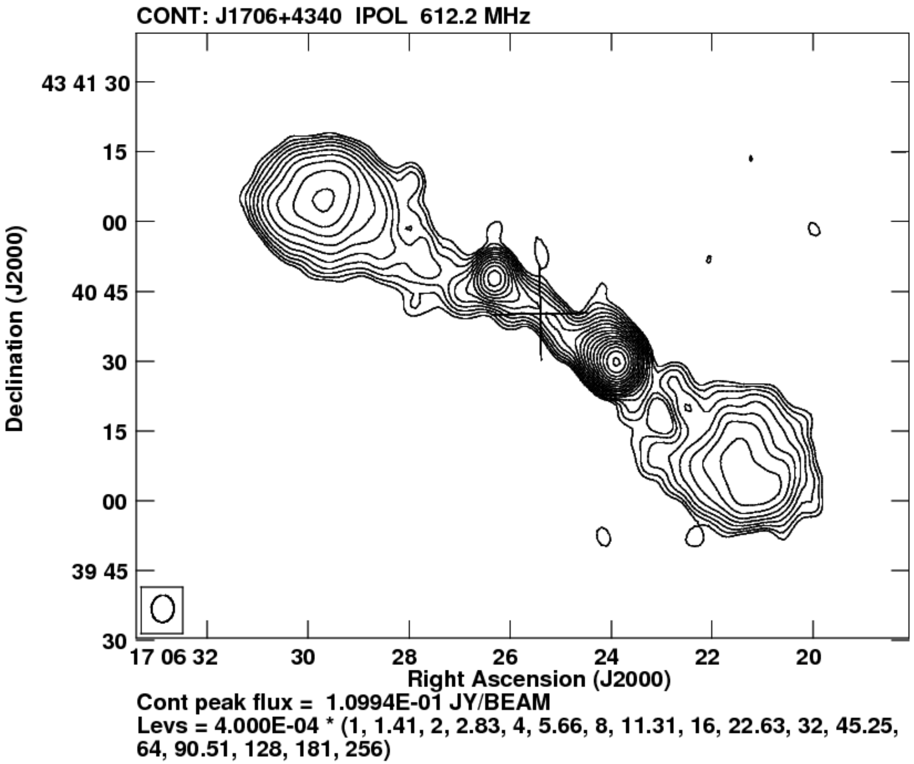


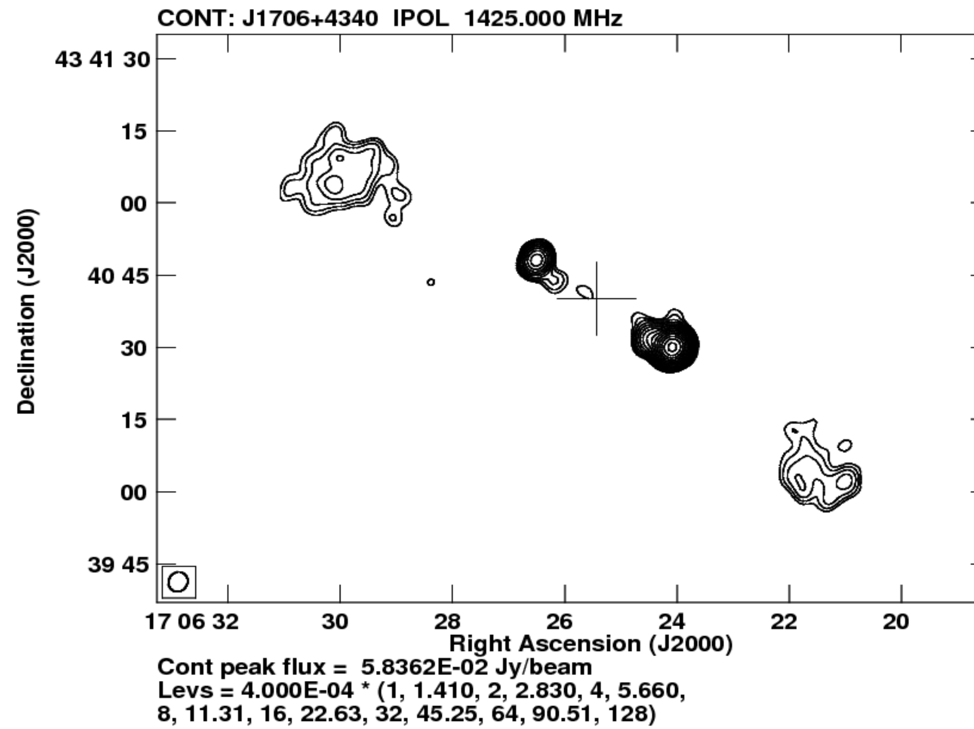


$$\frac{\nu_{brh}}{\nu_{br}} = \left(\frac{\tau_{rad}}{\tau_{RE}}\right)^2 = \left(1 + \frac{\tau_{CI}}{\tau_{RE}}\right)^2$$

mean synchrotron age of the lobes' particles is about **160±20Myr** (ν_{br} =450 ±120 MHz)

J1706+4340 Marecki et al. 2016, MNRAS, 463, 338





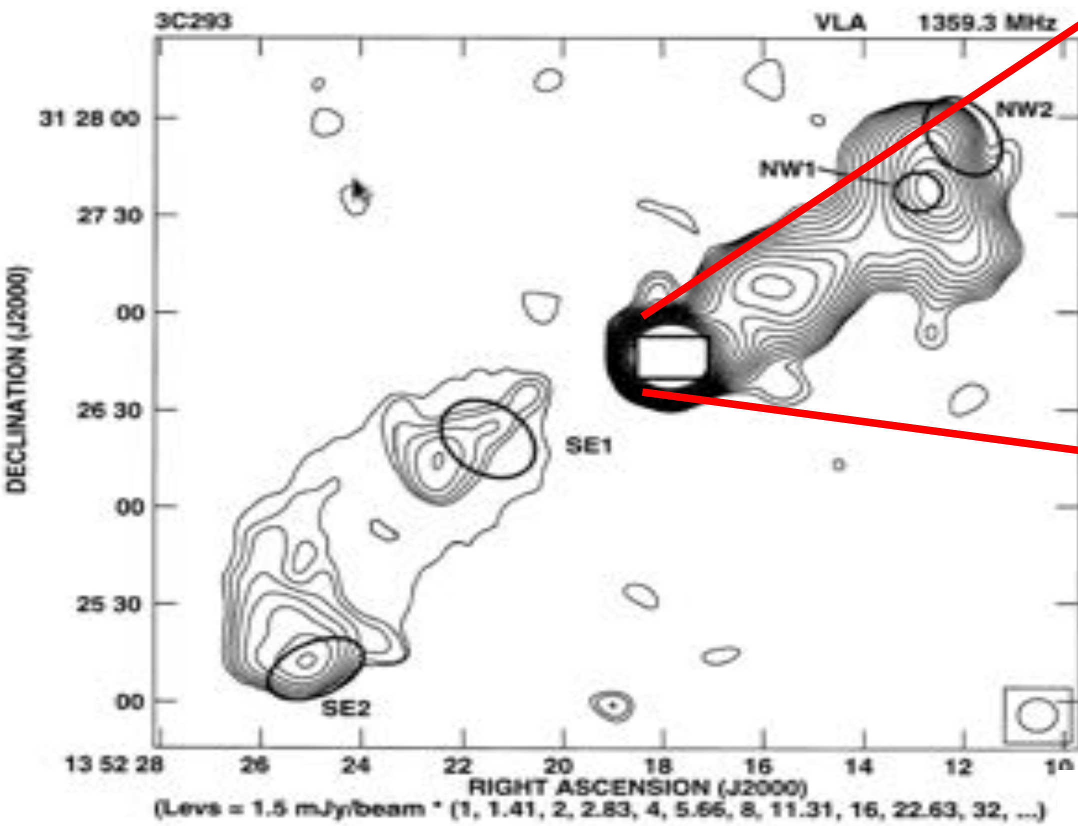
- age:
  of the large-scale outer lobes is in the range 260-300 Myr.
  of the inner lobes 12 Myr

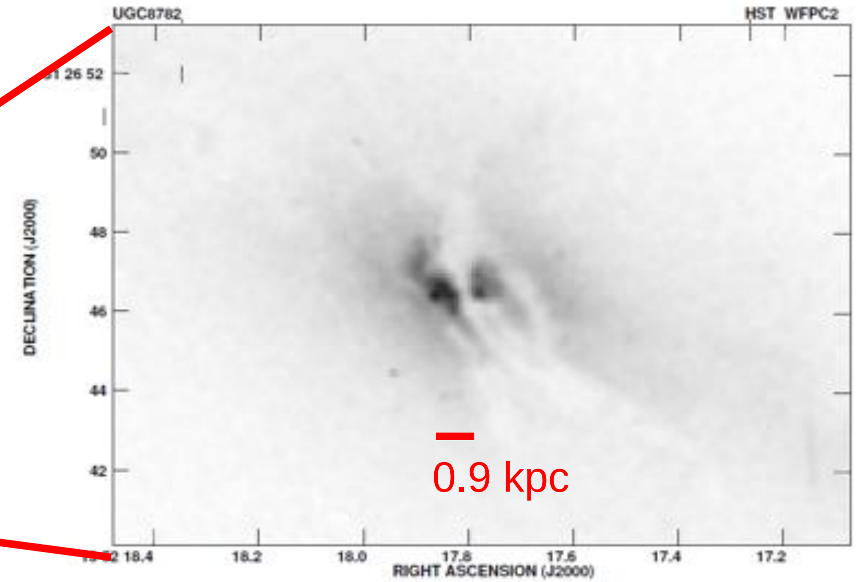
- quiesence period about 27 Myr

- injection spectral indices and the jet powers for the inner and the outer doubles are very similar.

=> the spin of the supermassive black hole rather than e.g. an instability of the accretion disc is likely responsible for the jet production and its properties.

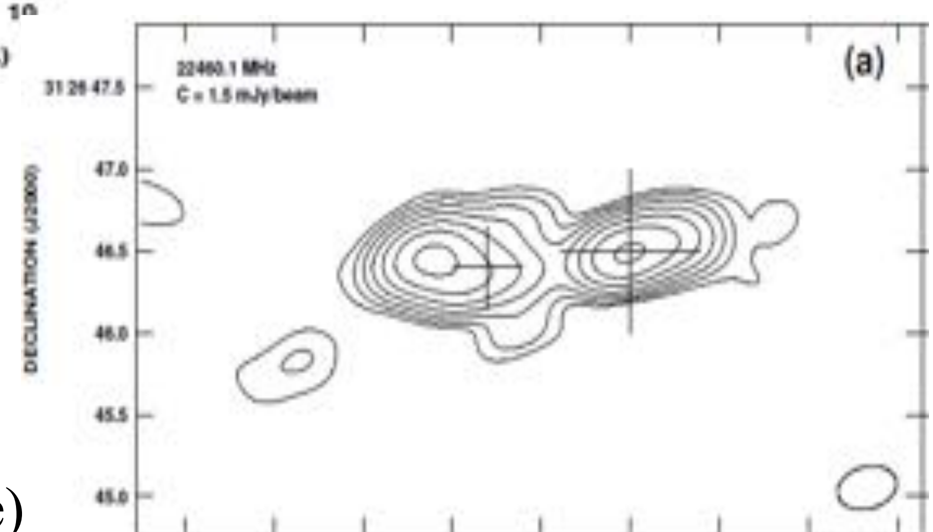
3C293





UGC8782

Machalski et al. 2016, A&A, 595, 46



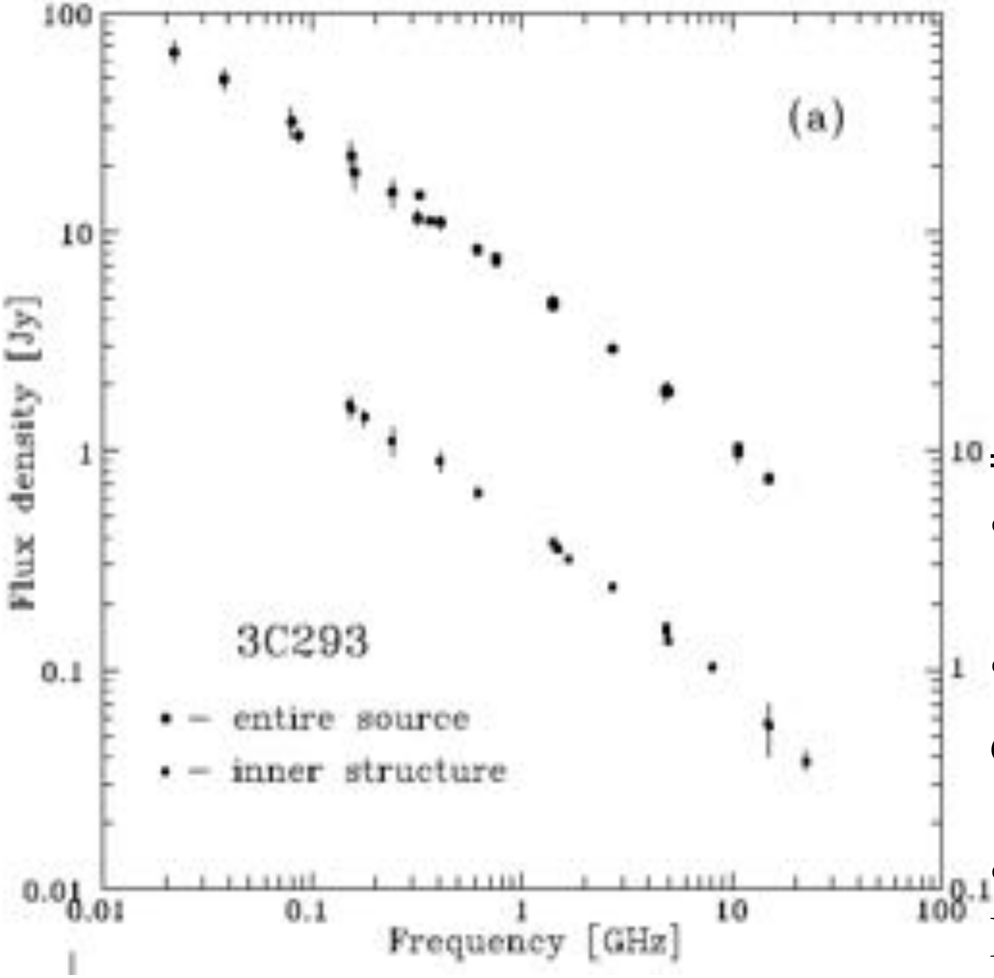
$z = 0.0452$

size

outer 240 kpc

inner 4 kpc

inclination 40^{o} (X-shape structure)



outer lobes ~60 Myr

inner lobes ~0.3 Myr

quiesence period about 1 Myr

=>

- a rapid realignment of the jet axis in 3C293

- the total jet kinetic power, $Q_j \sim 2\mathrm{x}10^{36}$ W, did not change after the realignment episode

- the accretion rate is relatively high, $\dot{M}_{acc}/\dot{M}_{Edd} \sim 0.1$

- relatively low value of the black hole spin, a ~ 0.2

===>

Tilted accretion disk + low value of black hole spin =>
rapid realignment of the jet axis, leading to the formation
of winged radio morphologies <= the Lense-Thirring precession model

Thank you