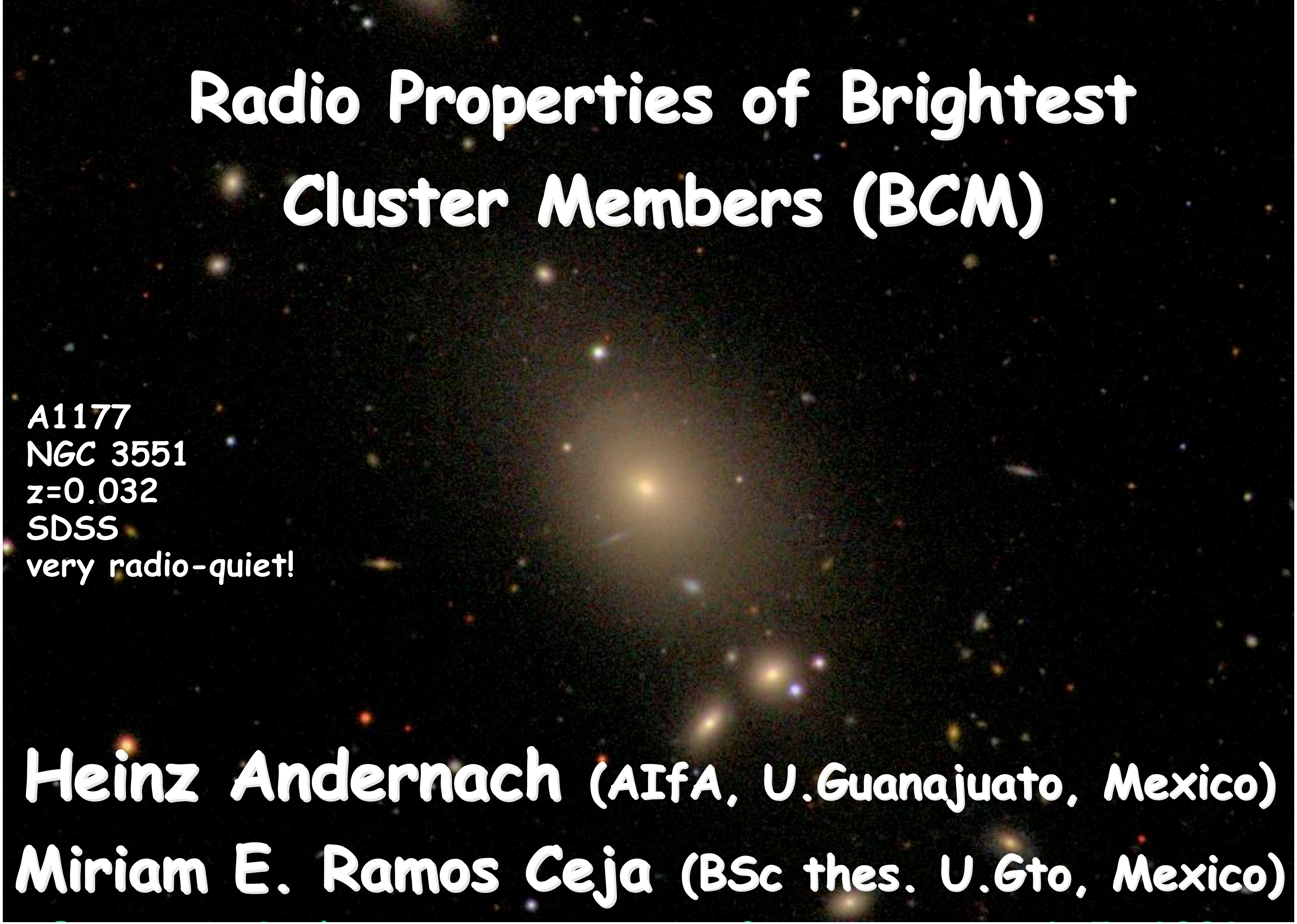
Radio Properties of Brightest Cluster Members (BCM)

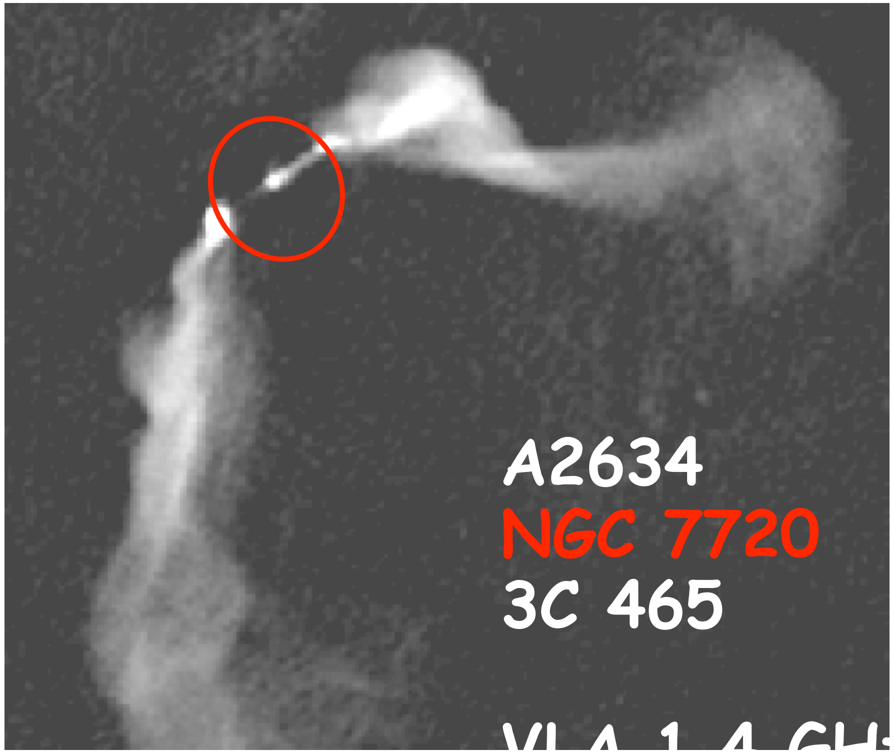


Heinz Andernach (AIfA, U.Guanajuato, Mexico)

Miriam E. Ramos Ceja (BSc thes. U.Gto, Mexico)

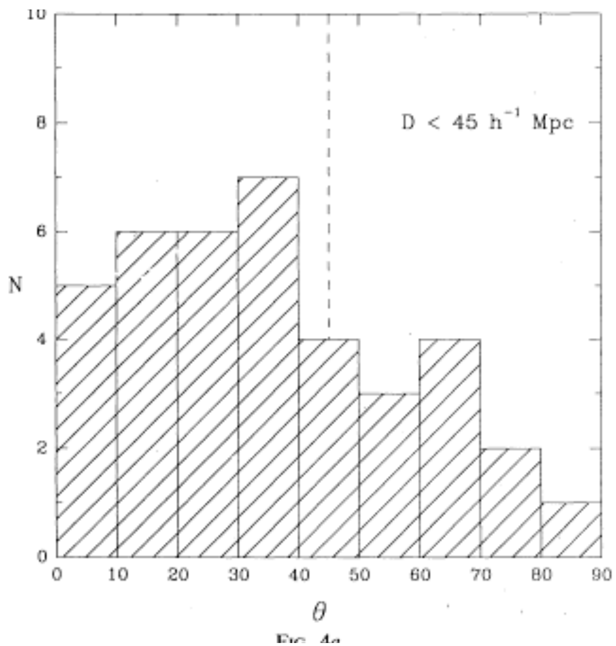
Brightest cluster members:

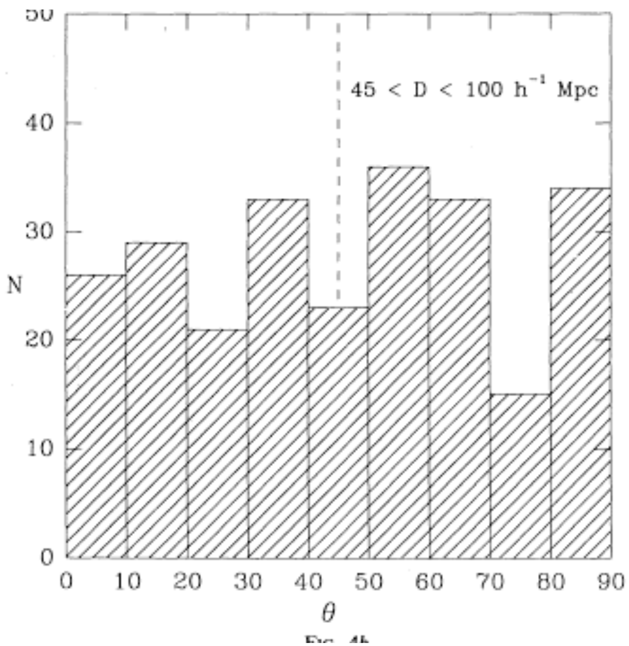
- often at the geometric (dynamical?) center of clusters
- used to probe peculiar motions (deviations from Hubble flow)
- many show multiple nuclei (galaxy mergers, “cannibalism”)
- some of them are unique: “cD” galaxies
  - have very extended optical “envelopes”
  - are the most luminous galaxies in the Universe
  - definition of a cD galaxy is problematic
    Schombert 1992: radial profile of surface brightness flattens at large radii (often unseen on DSS)
- some host a special type of radio source “wide-angle tails” (WAT), but ... what bends WATs?
- many other radio morphologies



Motivation

- Binggeli 1982
  Optical alignments between BCM & clusters' galaxy distribution (up to ~20/h_{75} Mpc) + LSS (up to ~70/h_{75} Mpc)
- Chambers et al. 1987
  Radio-optical alignments in powerful high-z radio galaxies
- Djorgovski 1987, West 1991, Miley & deBreuck 2008
  Under the hypothesis that high-z RGs are precursors of BCMs, one expects to see similar alignments at low z





West 1991: compiled 600 radio sources, $z \geq 0.5$ with PA_{maj} available

Misaligment of PA_{maj} with direction to nearest neighbou source has a mean of $<45°$ for mutual distances $<60/h_{75}$ Mpc
and is uniform beyond that

➔ Suggestion: the alignment of radio axes of high-z RGs with the direction to the nearest neighbor RG and the alignment of BCMs with surrounding LSS ("Binggeli effect") are related via an anisotropic merging scenario

➔ If high-z RGs are precursors of present-day BCMs, then a signature of this alignment should be present in these BCMs

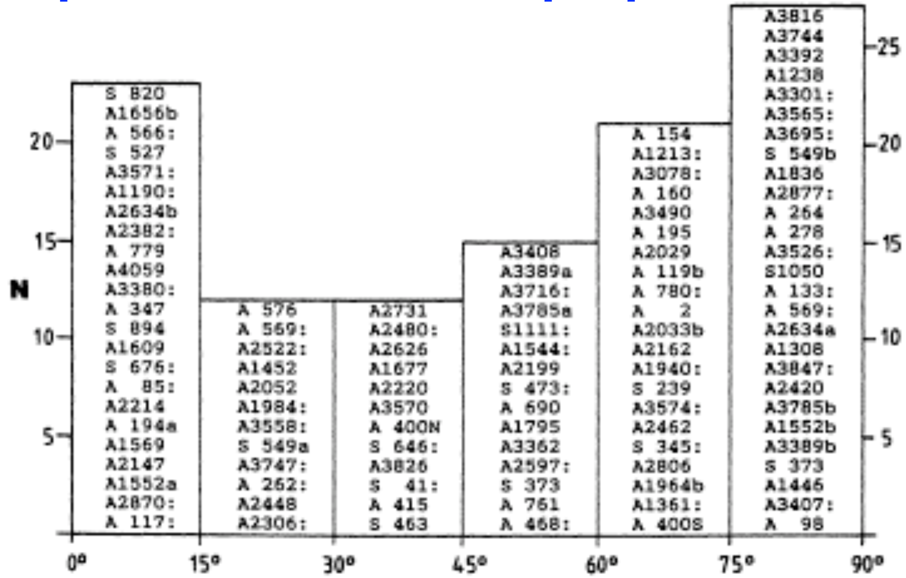
Previous radio-optical alignment studies:

- Palimaka et al. 1970, Condon et al. 1991

  78 radio E's: radio axes prefer opt. minor axes (esp. for sources >170 kpc
  319 "field" radio ellipticals: prefer opt. minor axes (no relation with size)
- Sansom et al. 1987: joined data from 11 previous studies based partly on inner or outer optical isophotes and inner radio axes (jets):

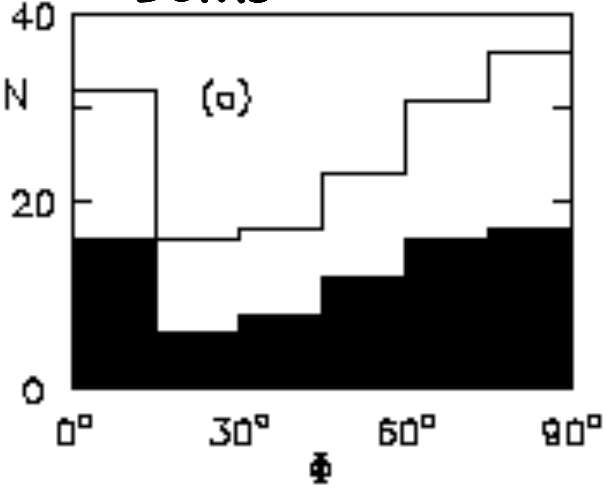
  197 objects with small preference for radio axes along optical minor axis
- Andernach et al. 1993; Andernach 1995

  Radio-optical orientation for 155 cluster BCMs: bimodal distribution parallel perpendicular

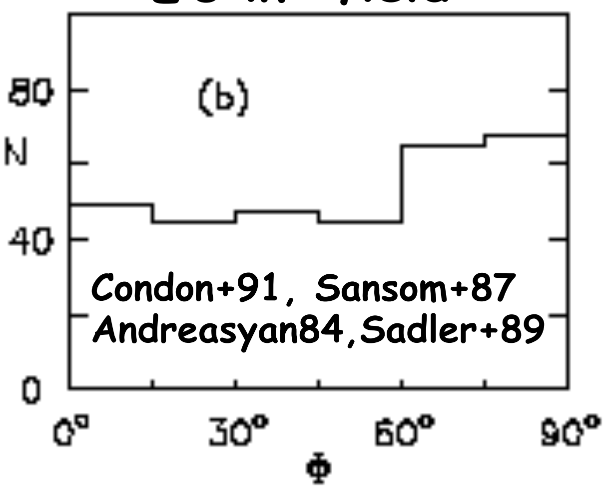


Andernach et al. 1993:
Difference angle between
RPA(radio, inner) and OPA(optical, outer)
for 100 Abell cluster BCMs

BCMs



E’s in “field”



Andernach 1995:
|RPA – OPA| for:

(a) 155 BCM in Abell clusters
(black area: ΔPA ≤ 10°)

(b) 319 “field” radio ellipticals
from four compilations

“Field” ellipticals: no evidence for West’s anisotropic merging scenario
but BCMs indeed show a small (~20%) aligned population
So what “makes” the aligned sources? Not clear: not cluster R or BM,
[illegible] but some indication that steep radio spectrum “helps”

➔PRESENT PROJECT: obtain significantly larger sample, using modern radio surveys (NVSS, SUMSS, ...) and the largest existing collection of radio source lists (cf. POSTER)

Answer following questions:

* Are BCMs different from "field" ellipticals, e.g. in their radio-optical alignment distribution?
  [BCMs are more radio luminous for same stellar mass, Best+05]

* What causes the small excess of radio-optically aligned sources among the BCMs?

* Are there relations between:
  - radio luminosity and galaxy ellipticity (rounder E's more radio luminous)?
  - radio morphology (distortions of tails, etc) and peculiar velocity of the galaxy in the cluster?
  - radio spectral index and intracluster medium density

Constructing a new cluster sample

Coziol, Andernach, Caretta, Alamo Martinez, Tago, AJ 137, 4795, Jun09

Use cluster catalog of Abell, Corwin & Olowin (ACO, 1989):

- 4073 rich A-clusters + 1176 supplementary S-clusters
- Redshift range z = 0.01... 0.2..
- We selected clusters likely to have dominant galaxies:
  - Bautz & Morgan type BM = I or I-II
  - Rood & Sastry type RS = cD (only northern clusters)
  - Textual notes by ACO89 indicate that brightest galaxy is "cD" or has a "corona" (= envelope → cD?)

→ total of 1207 Abell clusters fulfil the above criteria

From DSS2: RA,DEC, ε, OPA; get v_{rad} (NED, our comp

discard 238 "BCMs" in fore- (218) or background (20!)

discard 38 clusters: BCM in fg or bg or no dominant galaxy

Curious: 85% of sample is in southern hemisphere ($\delta < 0^\circ$)

→ there is a **bias** in assigning lower BM types for clusters from the "new" (1989) *ACO* cluster sample

➔ sample is certainly **representative**, but **statistically valid ?**
better: quantify the BCM dominance with quantitative measures (m1 – m2; m1 – m10; m1 – m*) → future!

Obvious problem: BM and RS types and textual notes in *ACO89* did NOT include redshift information

Before extracting radio data we got distracted by...

Peculiar Velocities of Brightest Cluster Members

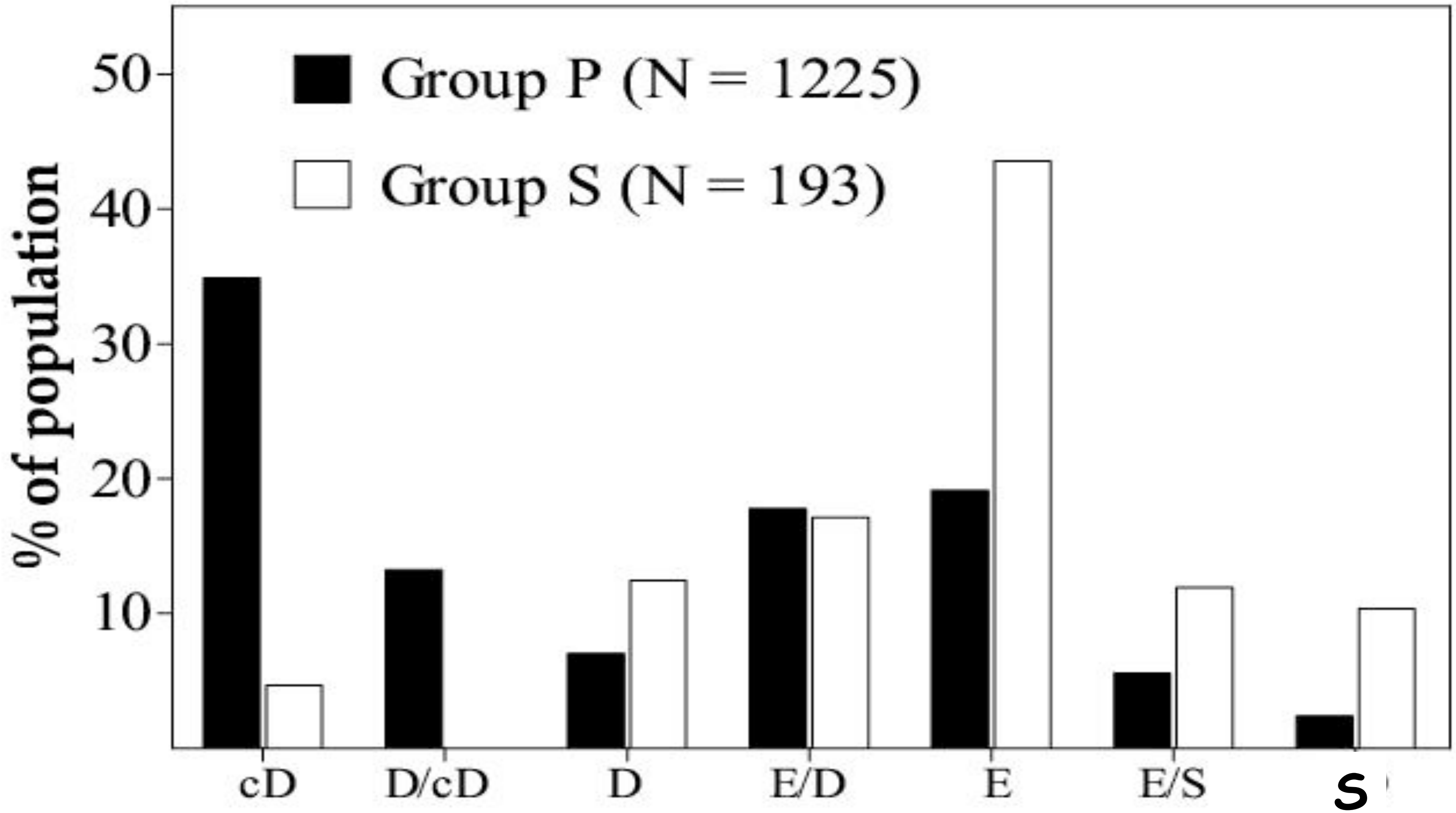
Not unknown from previous observations but largely ignored . . .
Standard Paradigm: BCMs tend to be cD galaxies
at the bottom of the potential well of clusters
i.e. with small relative velocity w.r.t. cluster mean velocity

NED/Simbad/LEDA: no homogeneous morph. classes

➔ we classified the BCMs ourselves

➔ among the 1st-ranked galaxies the fraction of cDs is much higher than among 2nd- or 3rd-ranked ones

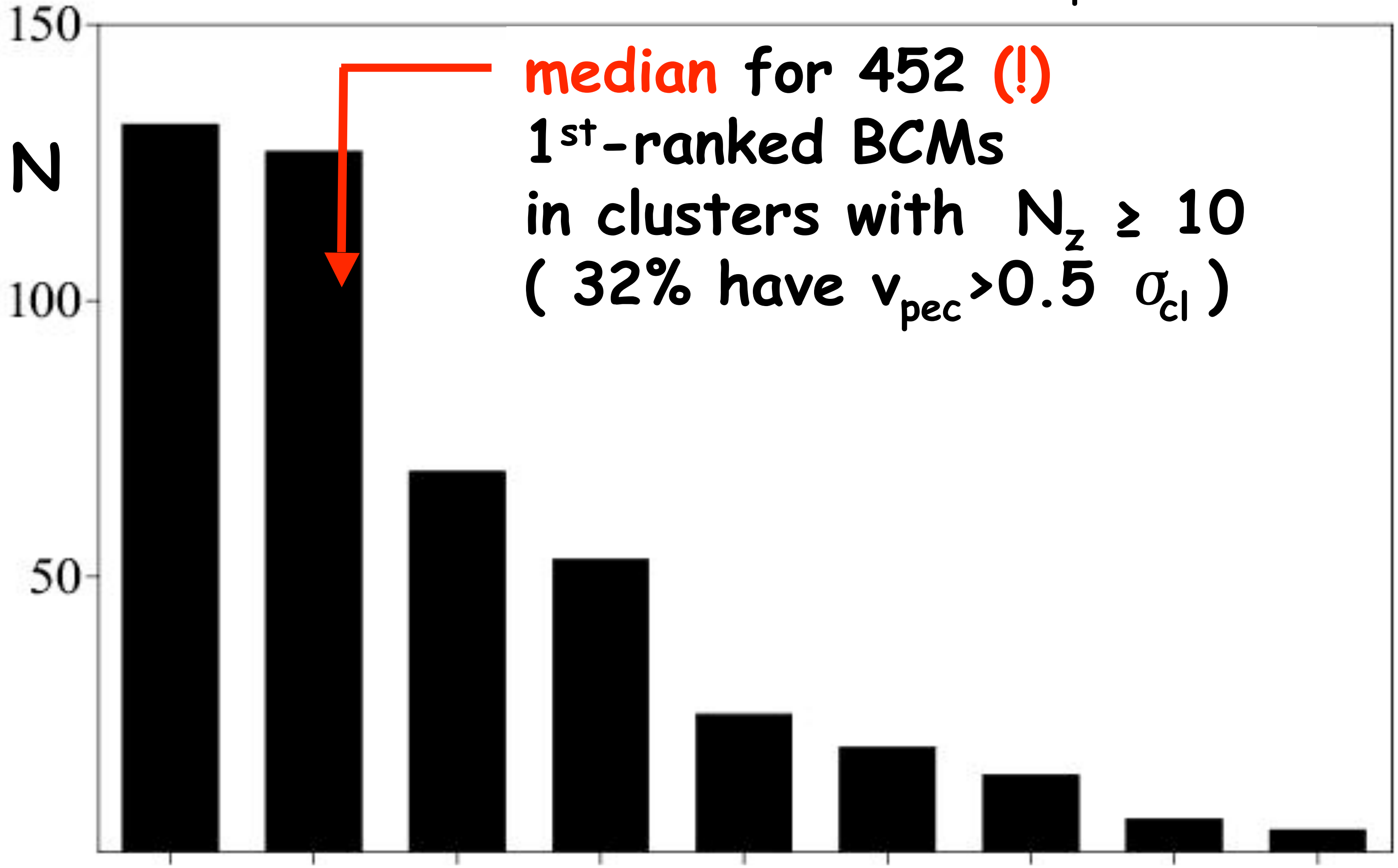
➔ cD galaxies make only ~40% of the 1st-ranked galaxies



For clusters with $N_z \geq 10$: $v_{pec} = (v_{BCM} - \langle v \rangle_{cl})/(1+z)$

➔ $\sigma(v_{pec}) = 0.60\ \sigma_{cl}$, i.e. less than for just any cluster member, but much more than commonly assumed

➔ many BCMs are not at rest at the bottom of grav. potential; cD-type galaxies have a lower median v_{pec}, but not much!



What is the interpretation of this ...?
clusters form from merging of groups
(see Coziol et al. 2009 for details)

NOW: we have a list of BCMs, positions, velocities, peculiar velocities, ellipticities, OPA's . . .

so let's return to the original objective

RADIO PROPERTIES OF BRIGHTEST CLUSTER MEMBERS

Collection of Radio Data for BCMs (I)

A) **Image extraction** from major surveys (NVSS, SUMSS, ...)
- necessary to control extent of the sources (catalog fluxes tend to be fitted, not integrated)
- for large enough sources → morphological classification
- with overlays on DSS images → pertinence of source components to a single physical entity
- for some BCMs we get inner RPAs (resolution usually insufficient, except for large sources or for FIRST)

B) **Flux extraction** from catalogue browsers

i) Catalogue collection CATS (cats.sao.ru)
~350 catalogs with >5.4 10^6 entries (incl. NVSS, SUMSS, ...)

ii) VizieR @ CDS: 540 source lists with >5.2 10^6 records

iii) further ~800 source lists collected by H. Andernach (not fully searchable, but many were cross-correlated with ACO89 clusters) → incompletely used !

Results of image extraction (via web scripts):

N(images)	Survey	image size	contour maps via:	
979	NVSS	(15′ x 15′)	directly	
822	VLSS	(15′ x 15′)	directly	
797	SUMSS	(15′ x 15′)	AIPS	
83 *	WENSS	(15′ x 15′)	AIPS	* (δ>+30°)
144	WISH	(15′ x 15′)	AIPS	(50% missing)
160	FIRST	(3′ x 3′)	AIPS	

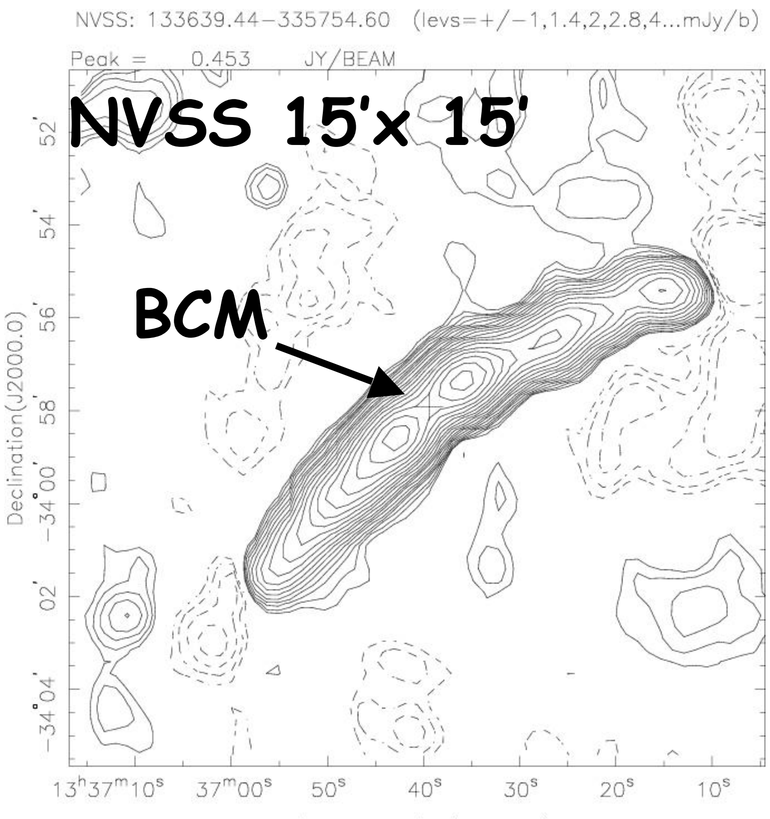
➔ Total of 2985 images → contour maps

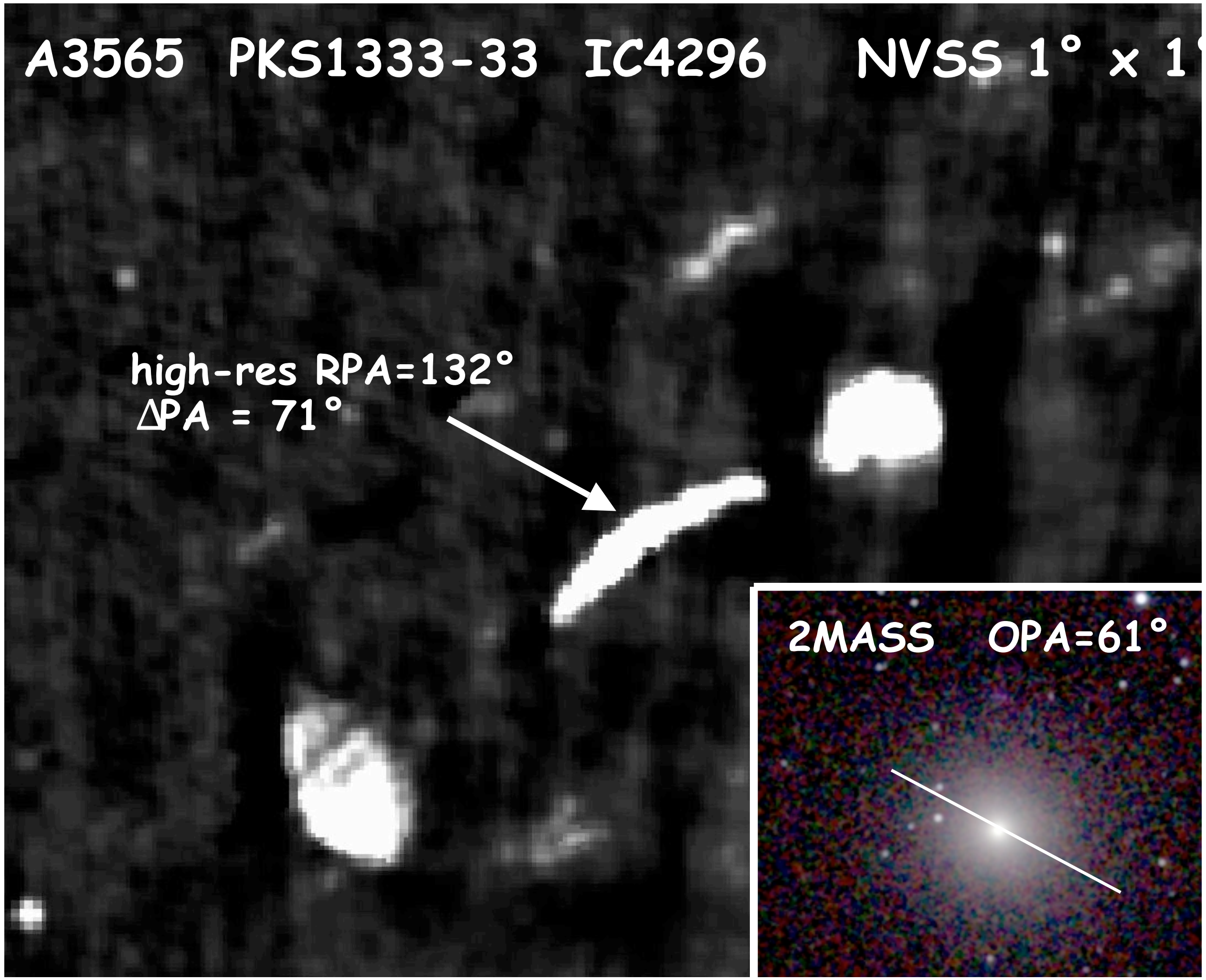
Images with no coincident catalogued source:
if a weak source coincides with BCM→ determine flux (~115)
if no source visible → assign upper limit of 5 σ (or better 3 σ ?)
→ (2700 flux limits)

Images with complex (non-Gaussian) sources
→ integrate the (supposed) source extent with AIPS

In few (usually well-known) cases bigger images were extracted:

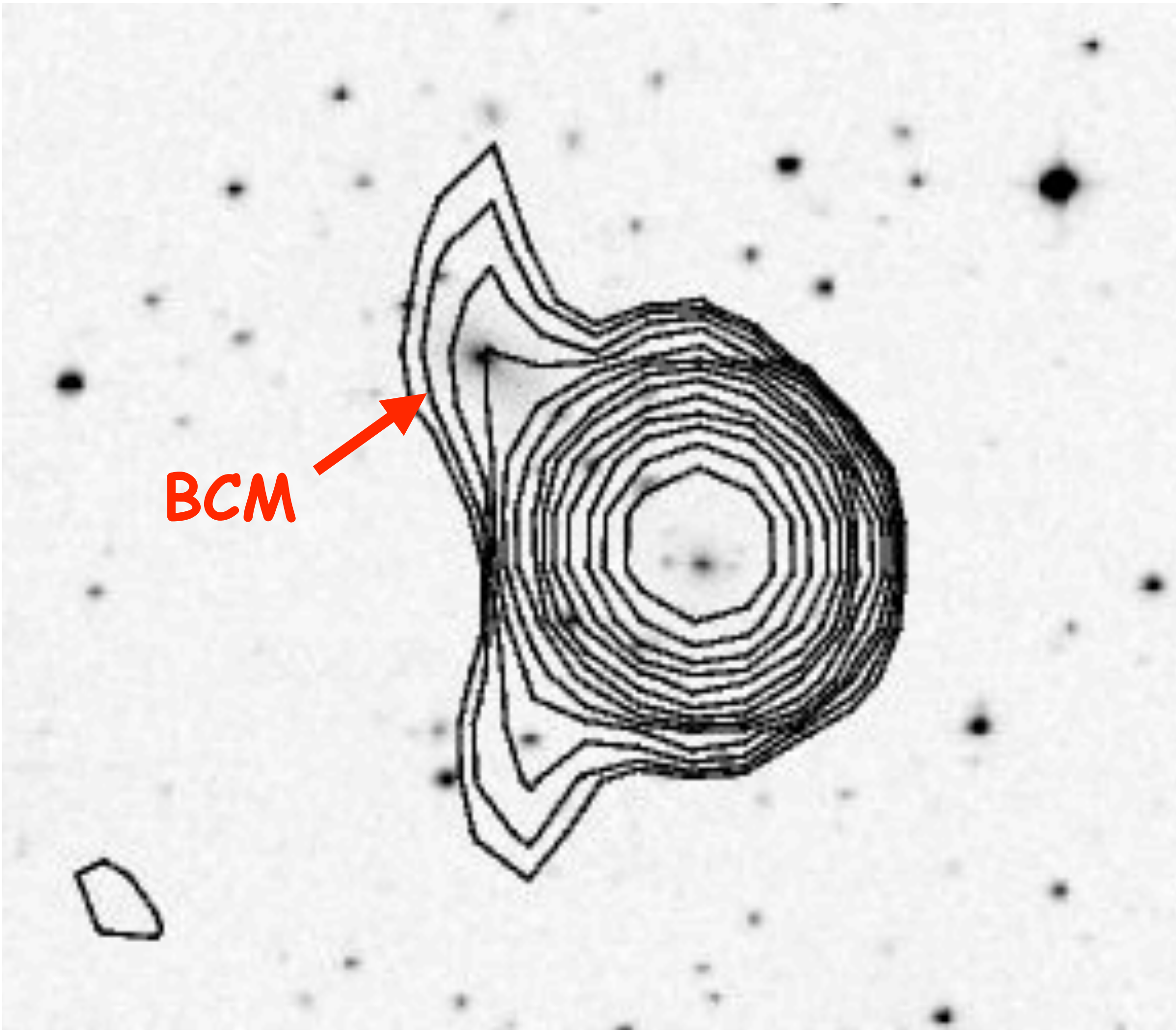
Abell 3565 (IC 4296): LAS ~35' (500 /h_{75} kpc)
detailed VLA images by Killeen et al. (1986)





Contour maps with complex sources or doubtful radio extent
➔ overlay onto Digitized Sky Survey image

Abell 3480 NVSS

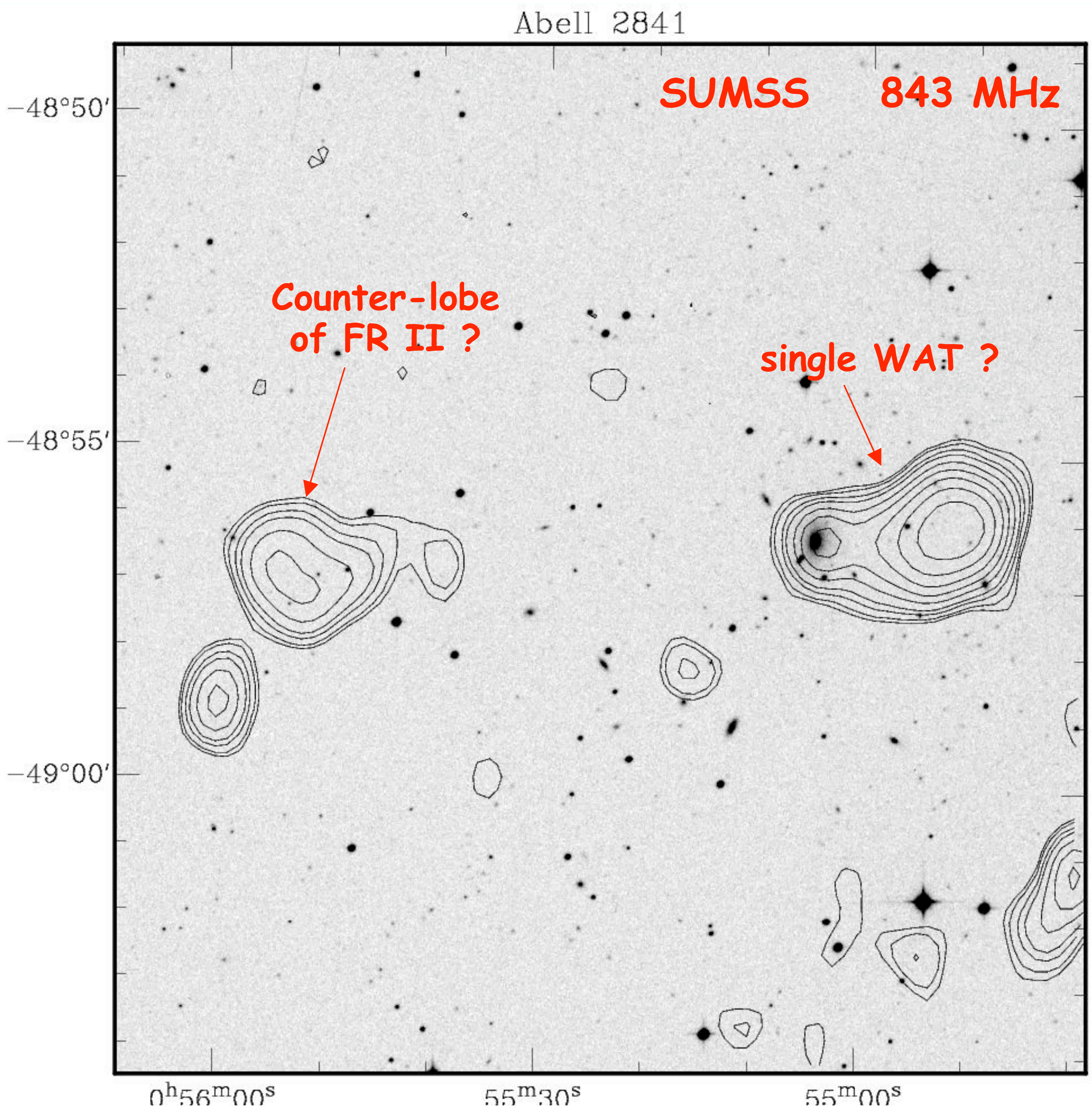


extensions due NE and SE have opt. IDs
➔ souce is "compact" at NVSS resolution

Doubtful or intriguing cases (for future follow-up?):

Abell 2841
LAS ~10' at z=0.0643
(if one source,
then
LLS ~ 750/h_{75} kpc

rather unlikely, but ...



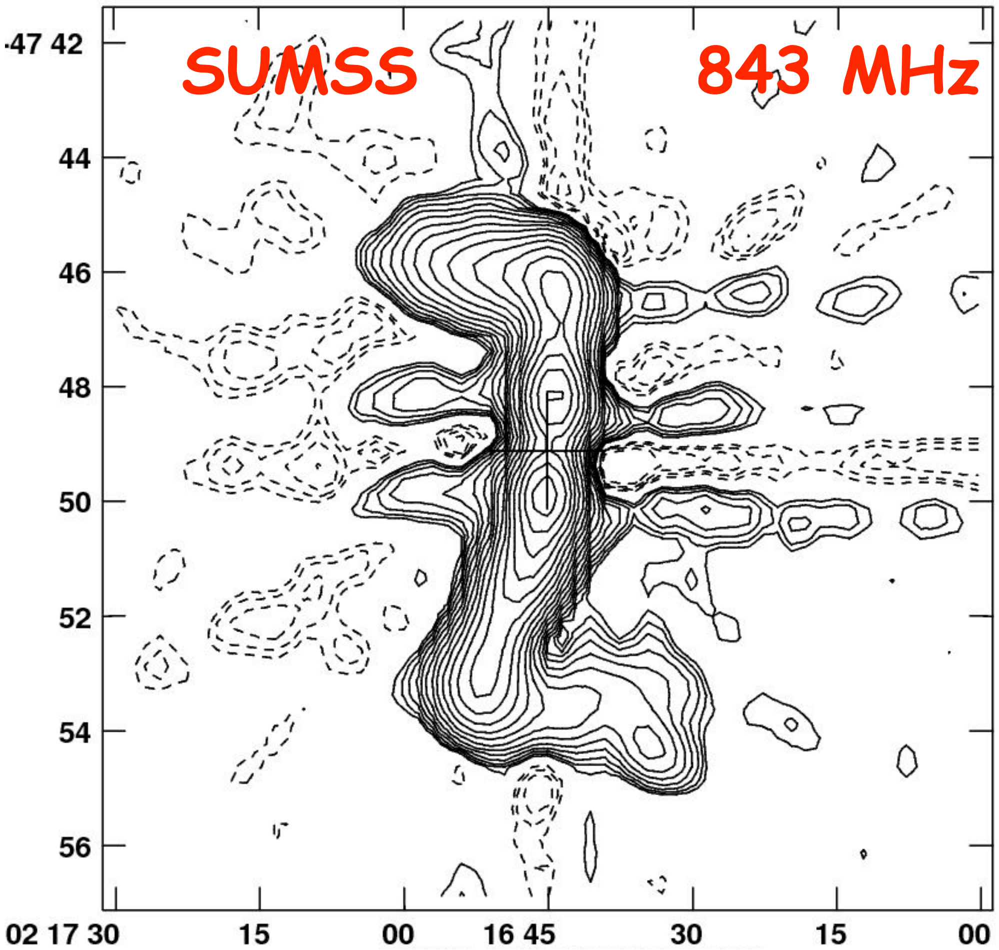
S0239: rare Z-shaped morphology artefacts in SUMSS, but no doubt about physical entity of the source

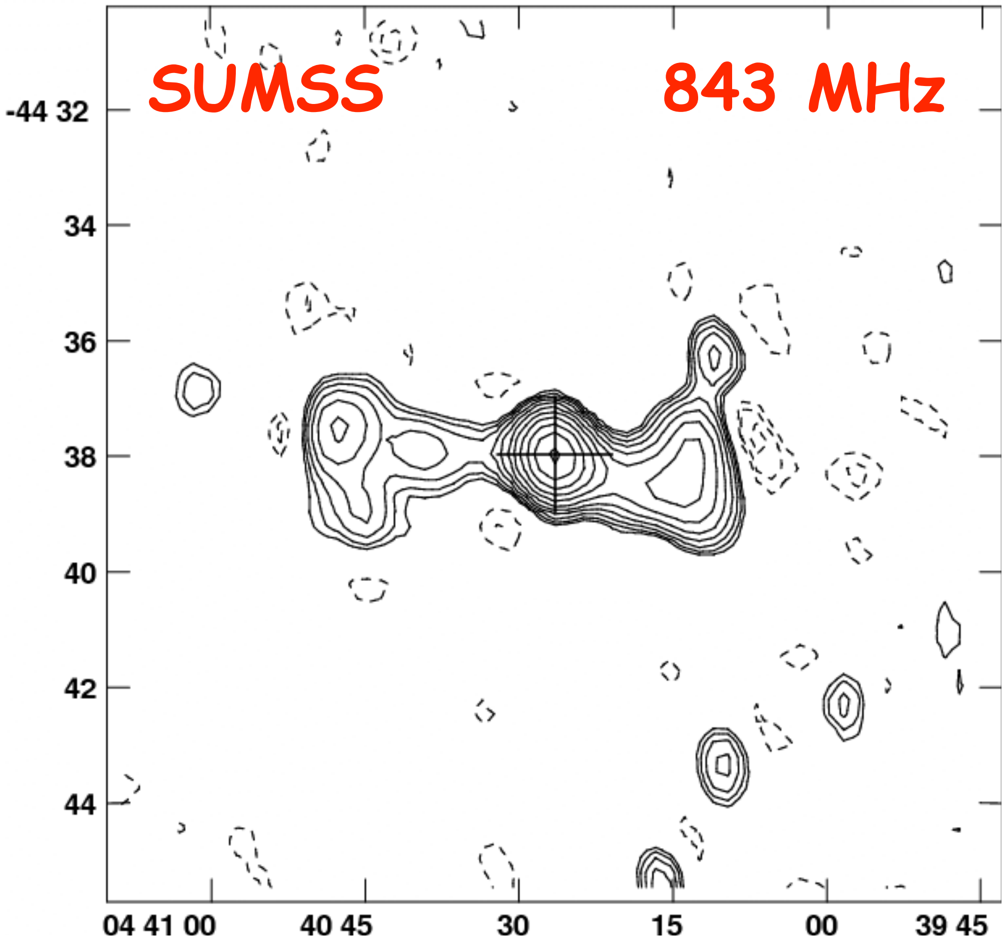
LAS ~10′ z=.0648

➔ LLS ~750/h_{75} kpc

S0487: Z rotated by 90°

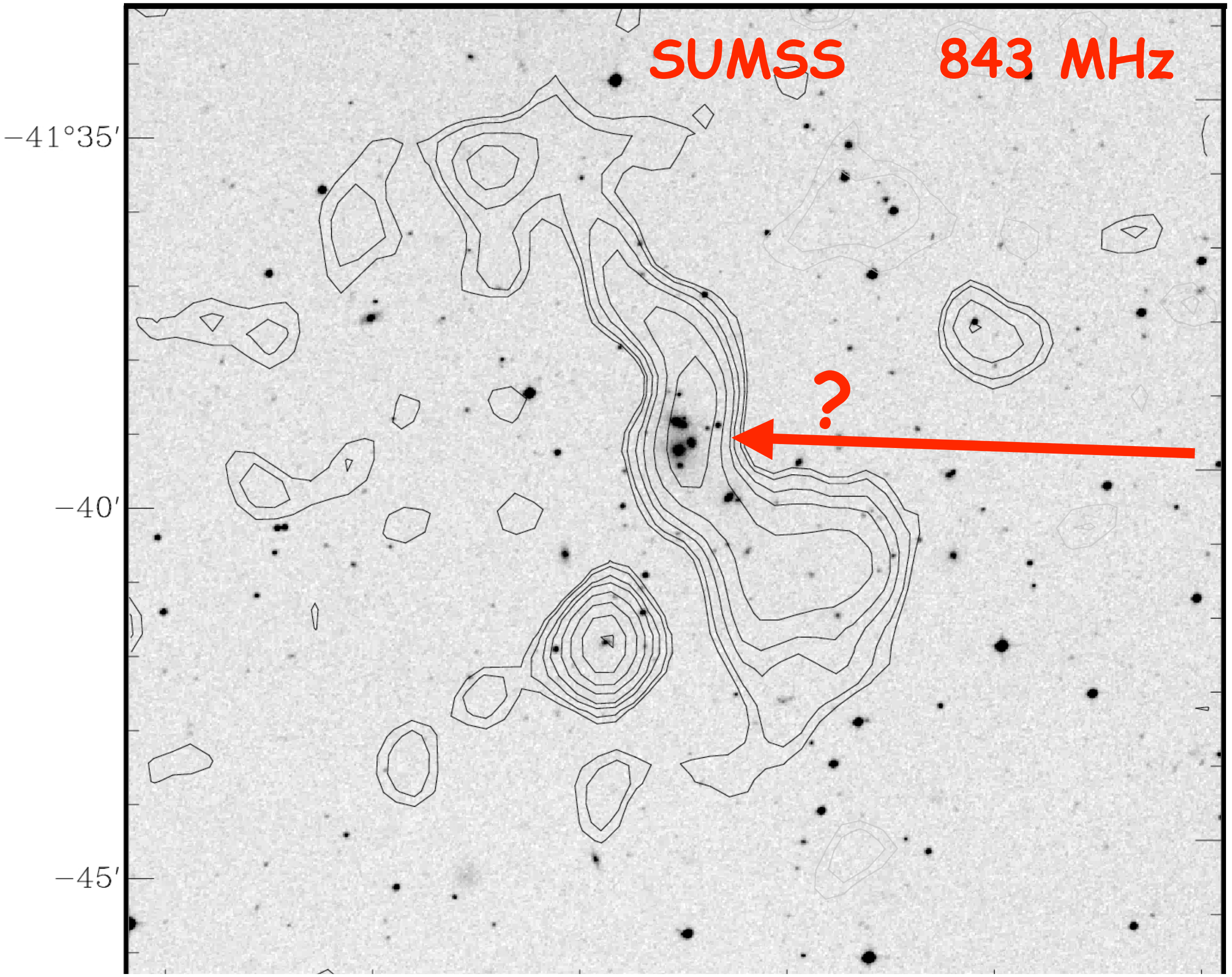
z=.0325 LLS~260 kpc





Actually: 210 sources with LAS → LLS_{med} = 160 /h_{75} kpc
28 sources with LLS > 500 /h_{75} kpc
7 of these with LLS > 750 /h_{75} kpc

➔ two absolutely largest sources (previously unknown):



S0122 (z=.097) LAS~9'

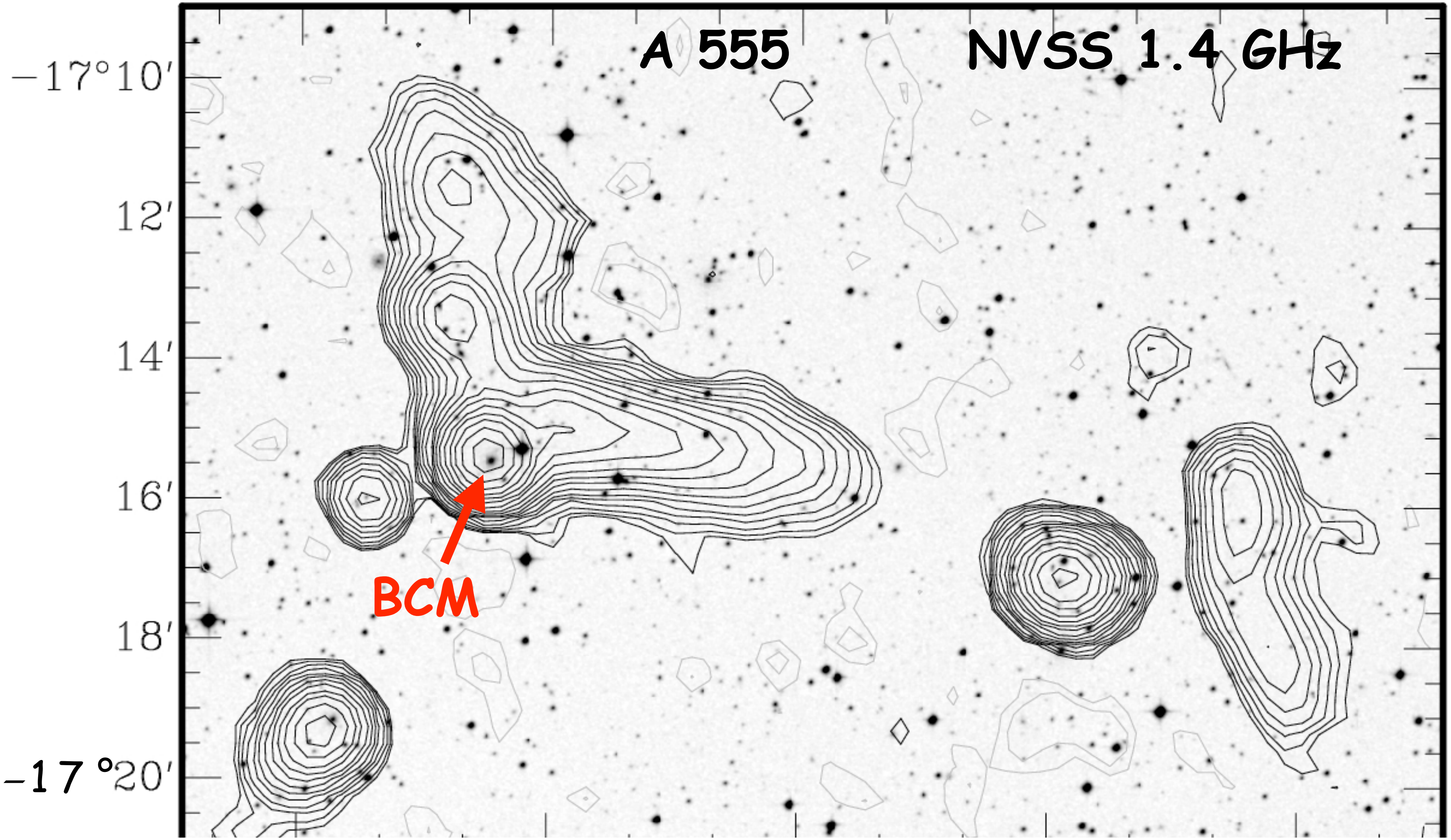
→ LLS ~ 1 Mpc !

not clear yet which of central galaxies is ID

A 555 (z_{est} = 0.1, N_z=1)   LAS~9' → LLS ~ 1 Mpc !

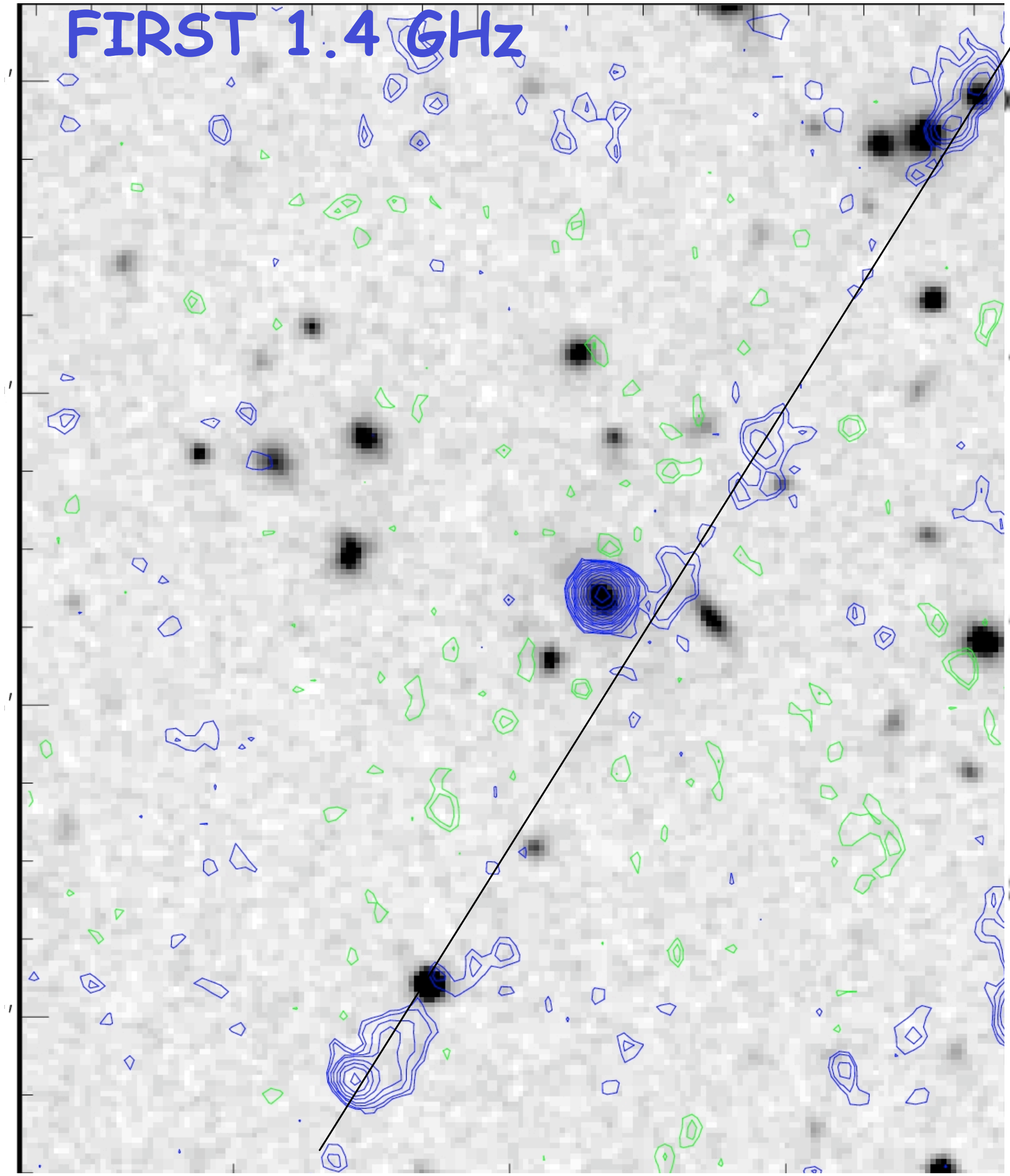
radio core is VCS5 source (compact flat spectrum)

Do we see a single WAT or a blend of several sources...?

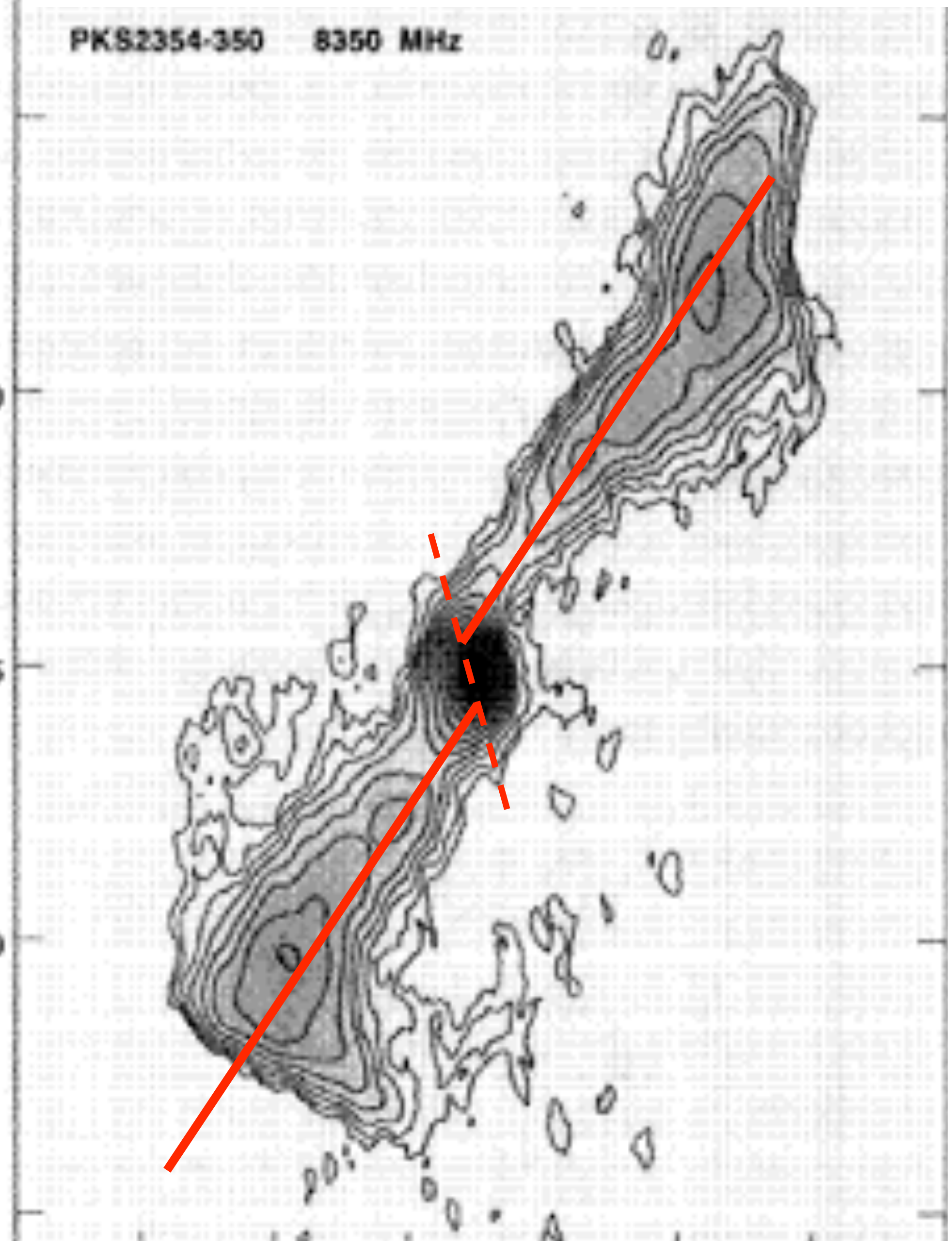


Possible new types of rare radio morphologies ?

A1050B (z=.125) LAS~3.7' (540 kpc)



A4059 Taylor et al. 1994

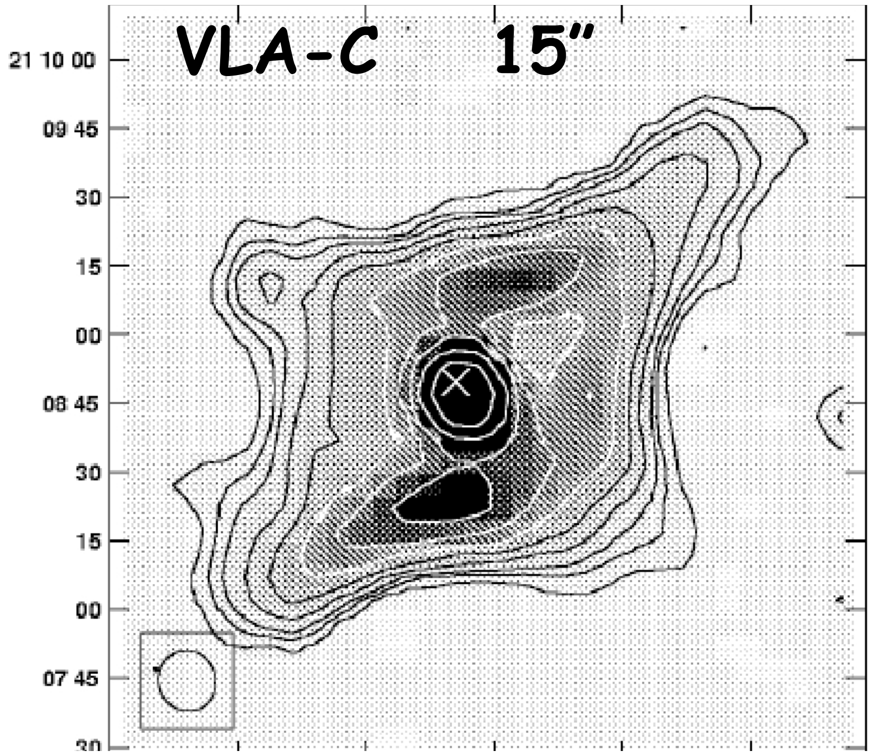


The “crazy” sources:

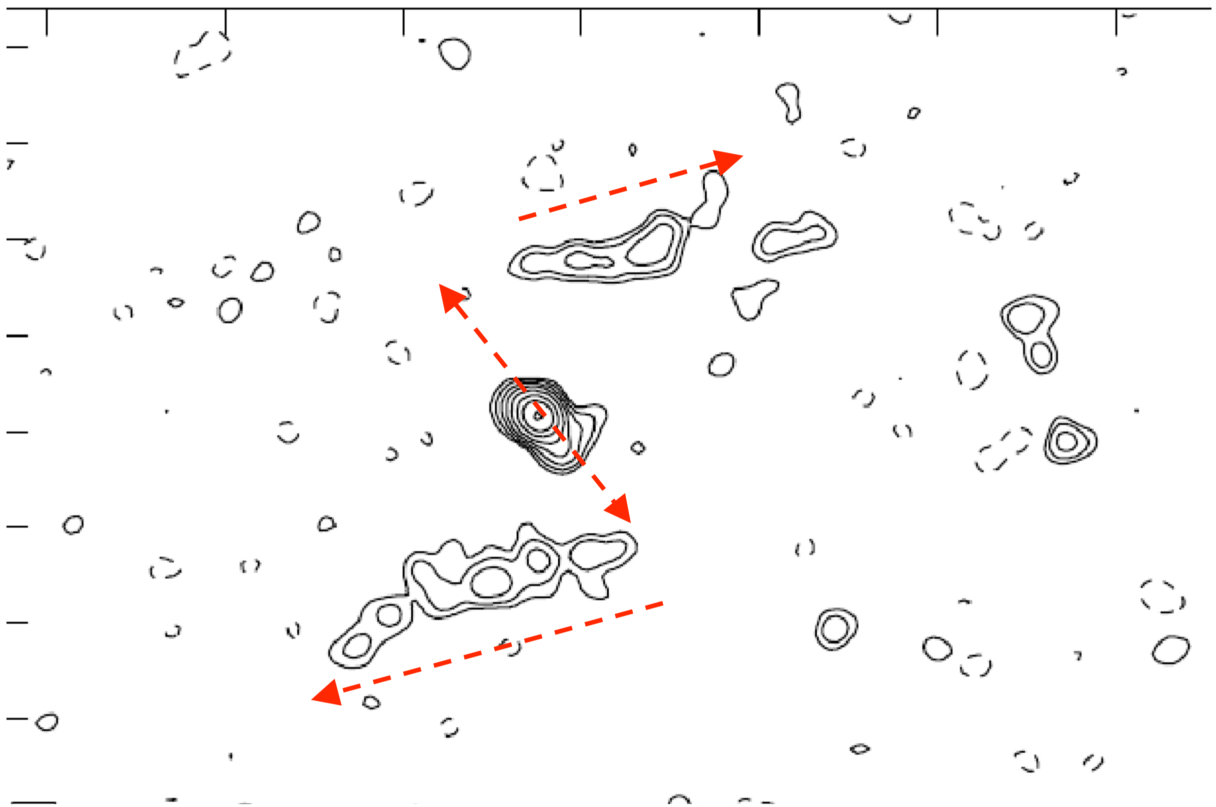
- typically very steep radio spectrum
- located at center of X-ray luminous clusters

A2626: box-shaped source

Markovic et al. 2004

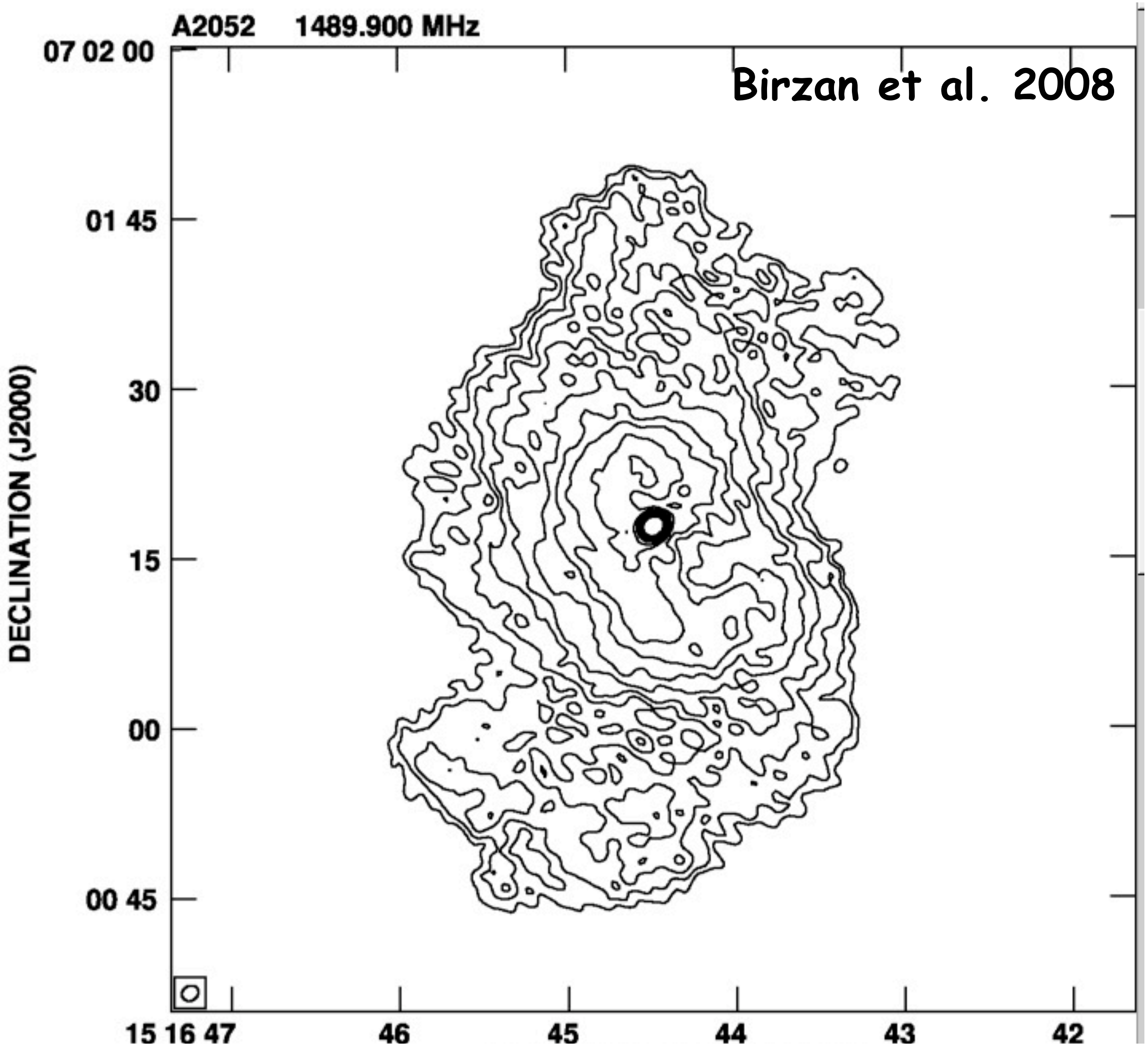


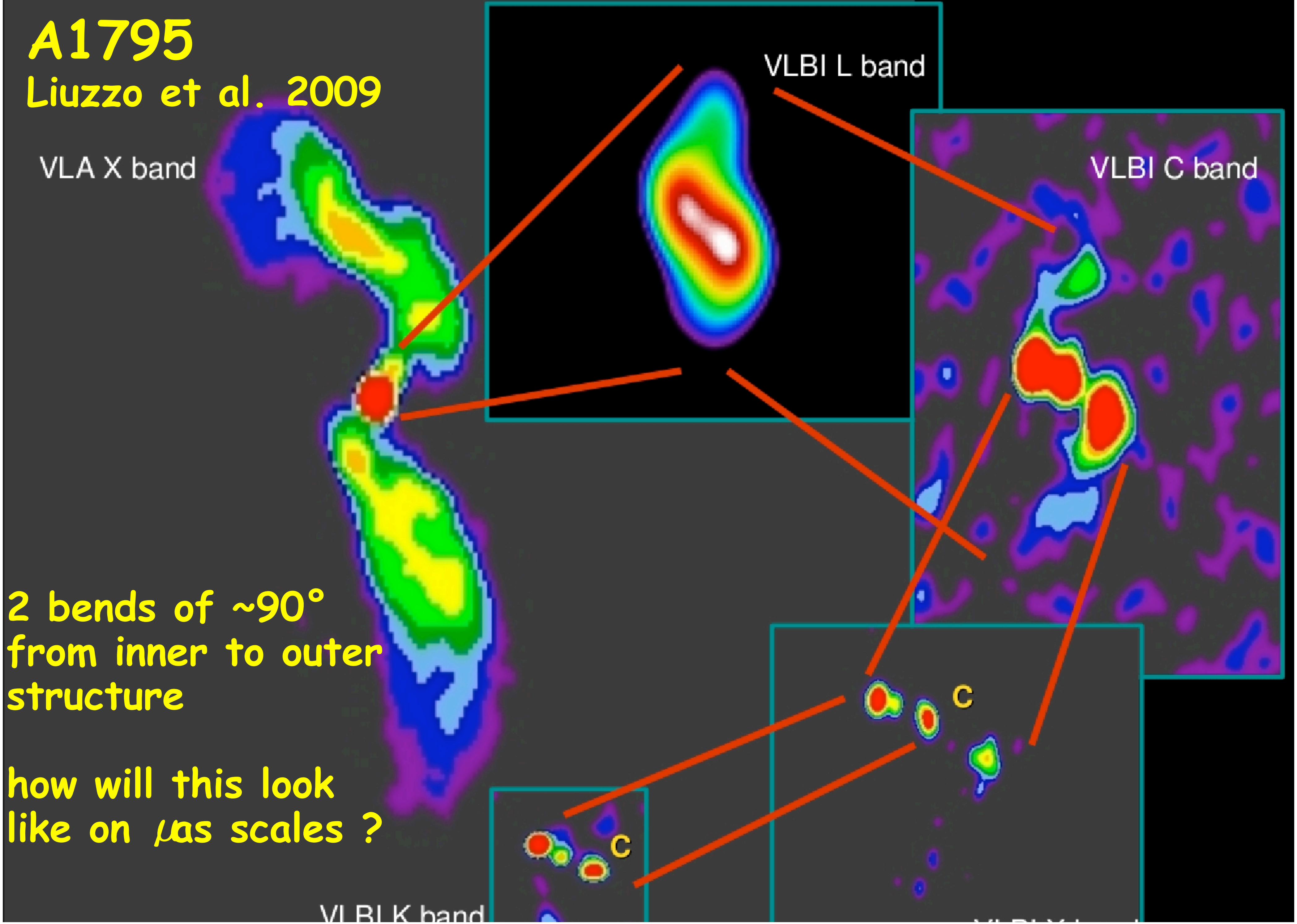
Gitti et al. 2004 VLA-B 5″



3C317 in A2052: ultra-steep spectrum, amorphous morphology

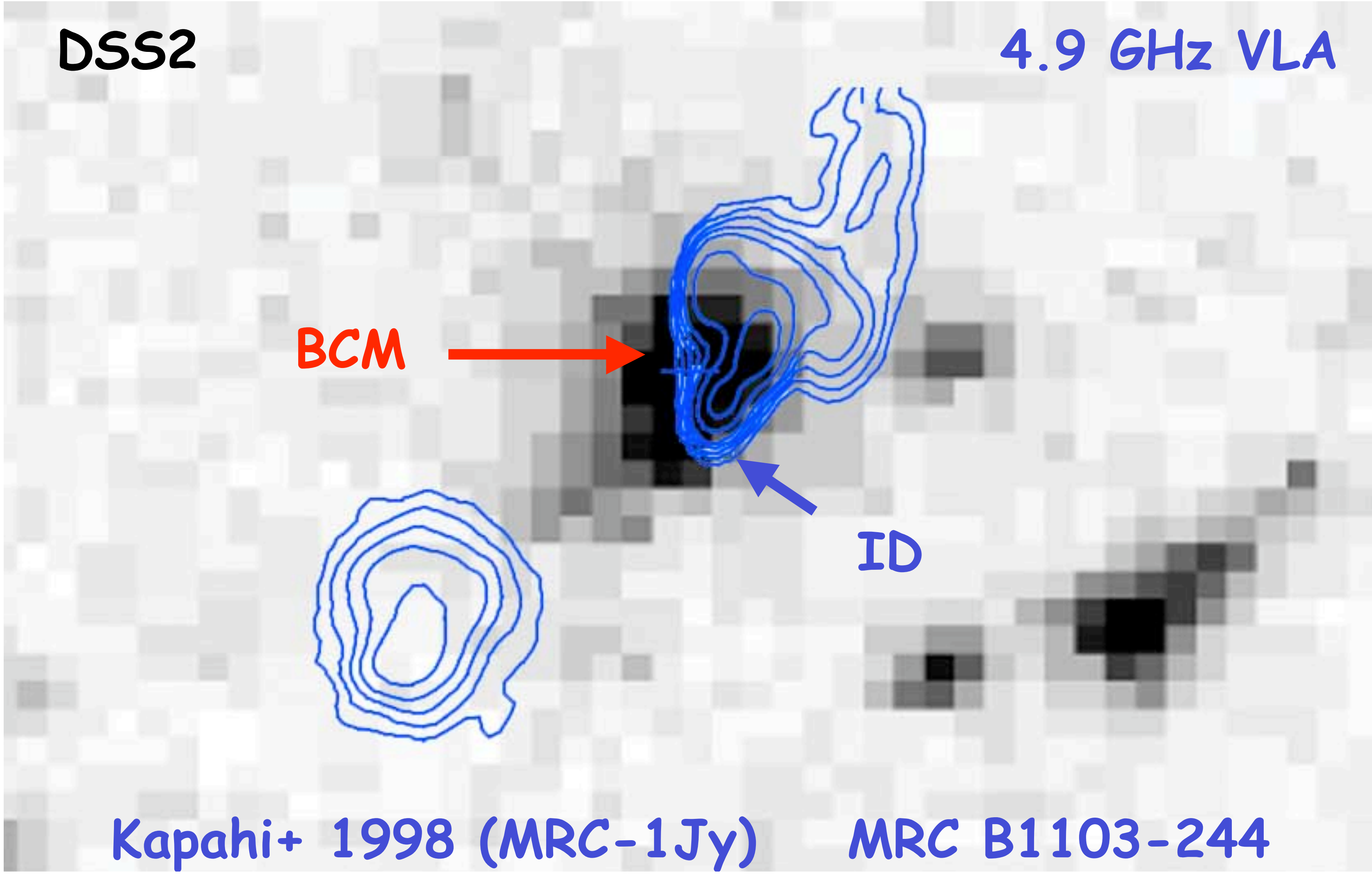
no RPA can
be assigned




A1795
Liuzzo et al. 2009
VLA X band
VLBI L band
VLBI C band
2 bends of ~90° from inner to outer structure
how will this look like on μas scales ?
C
C
VLBI K band

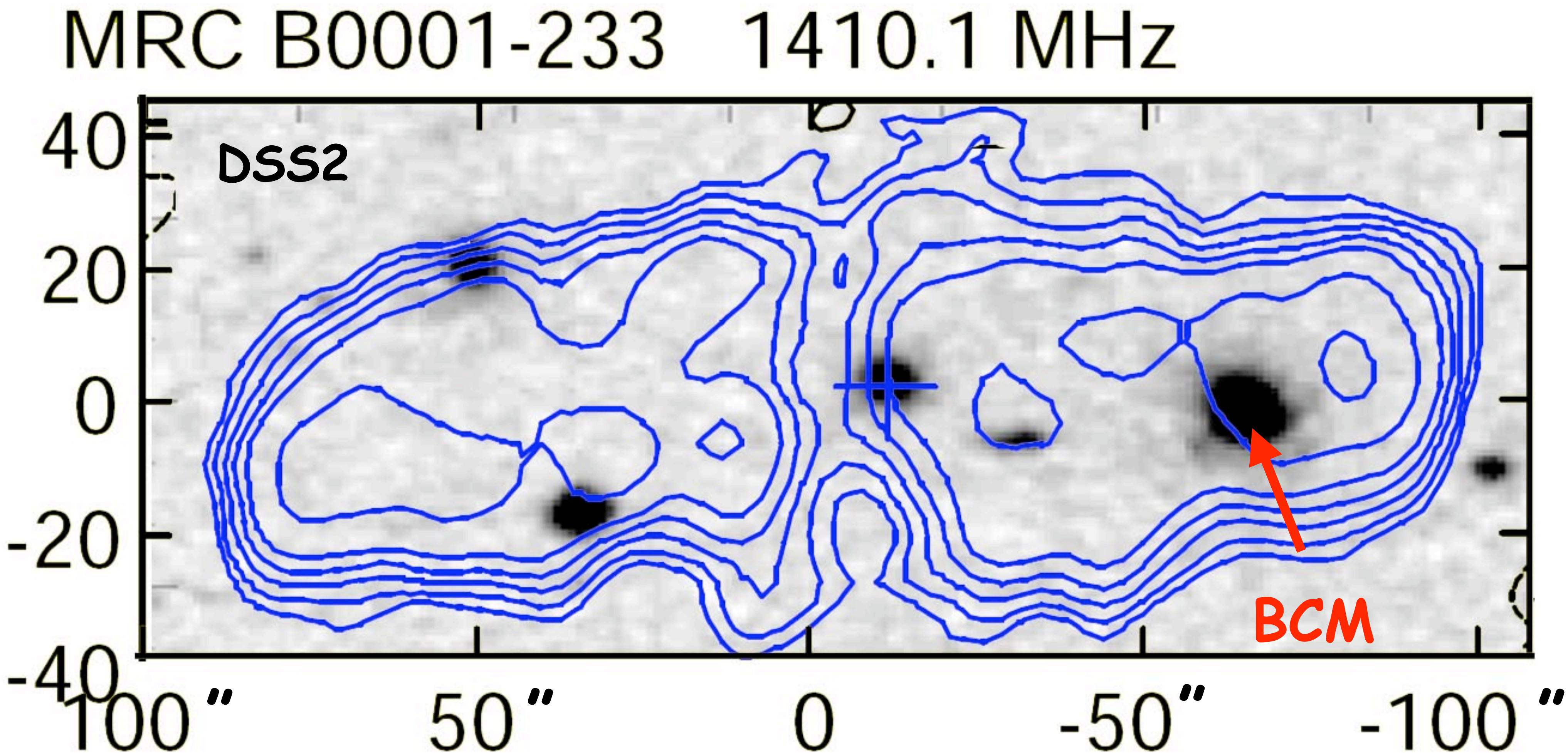
The "nasty" sources: BCM not the ID at high resolution

A1165 ID is a faint galaxy ~2" of BCM

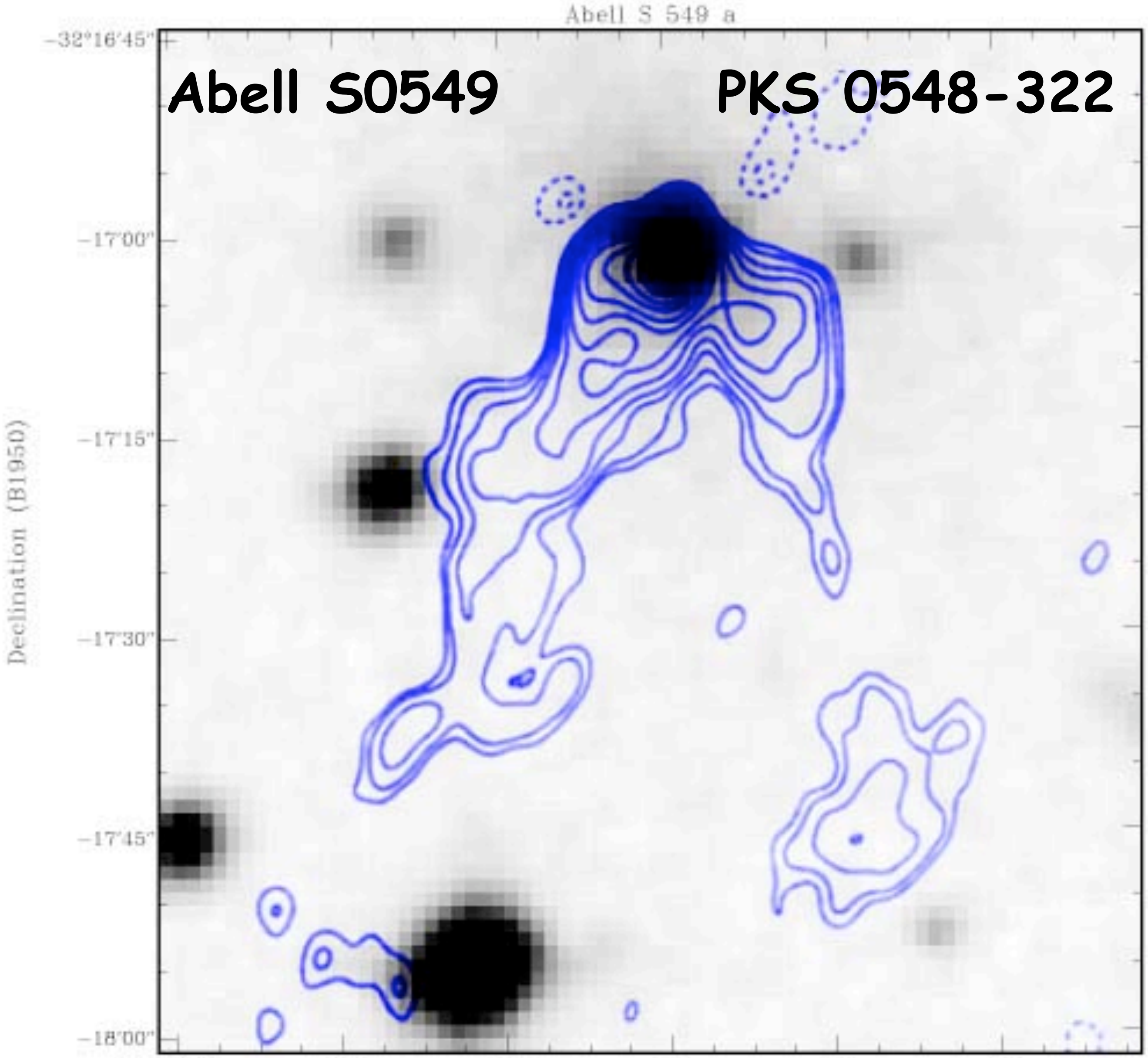


A2719: W lobe of "fat double" is superposed on BCM

Kapahi et al. 1998 (MRC-1Jy)



A few BCMs are even BL Lac objects:



Antonucci & Ulvestad 1984: WAT structure, but no inner jets detectable at various higher resolutions

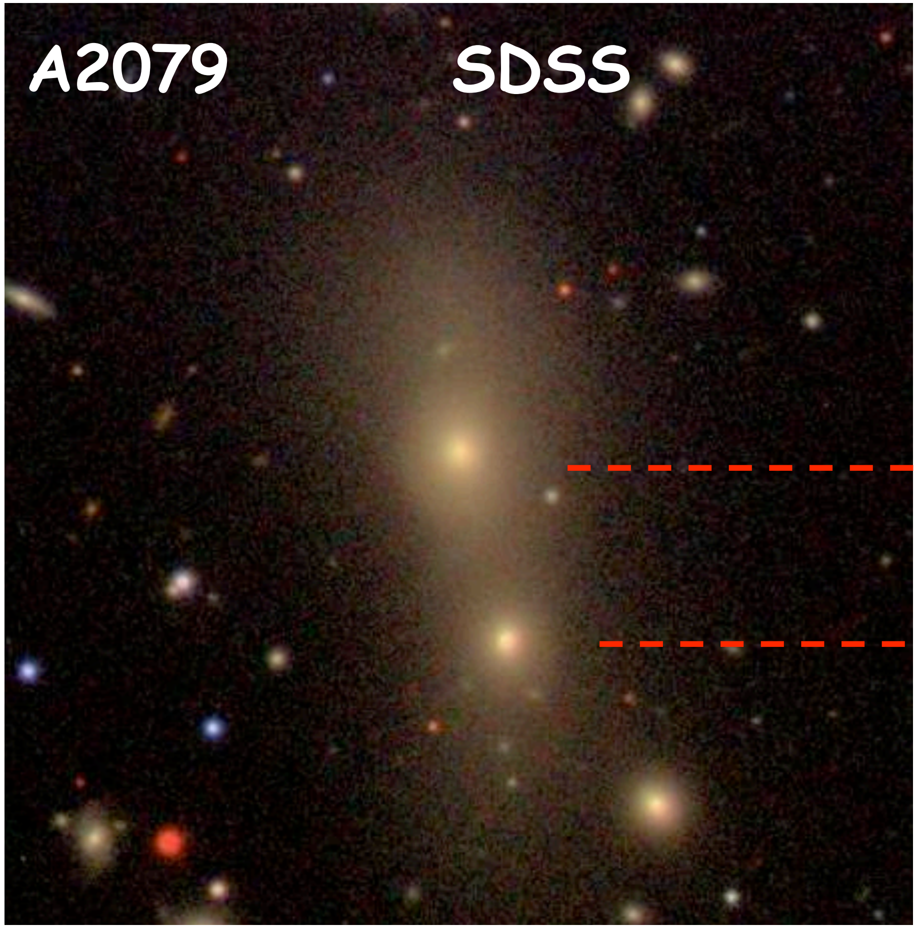
other clusters with BL Lac BCMs:

A3537
A3581
S0780

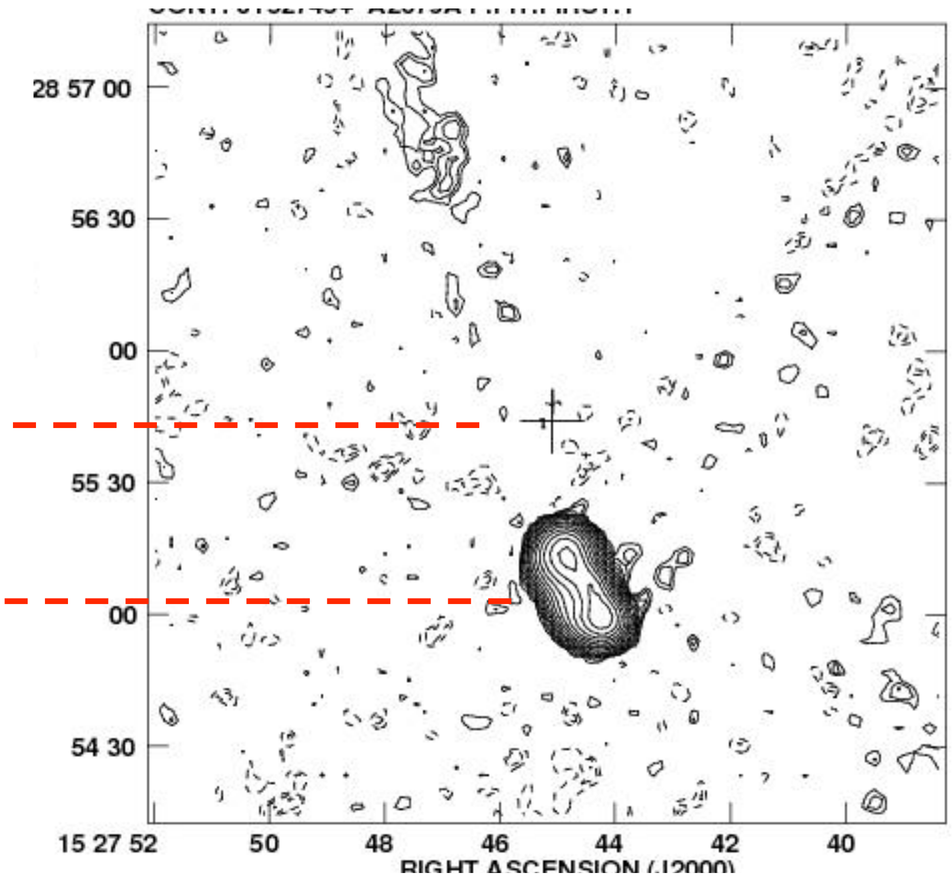
The most radio-quiet BCMs found

A1177 (NGC3551) z=.032
S(1.4) < 1mJy P(1.4) < 2.4 10^{21} W/Hz

A2079 (UGC 9861) z=.067
S(1.4) < 1mJy P(1.4) < 5.1 10^{21} W/Hz



A2079 FIRST 1.4 GHz



Collection of Radio Data for BCMs (II)

C) Collection of additional flux densities or radio images
to complete the structural or spectral information
- there are no databases to offer radio images systematically
- bibliographical search in NED (currently only up to 2007!)
or SIMBAD (up to date!) and recognize relevant papers
from experience ! [include ref's from private compilation...]

➔ inspect over 100 radio images in the literature

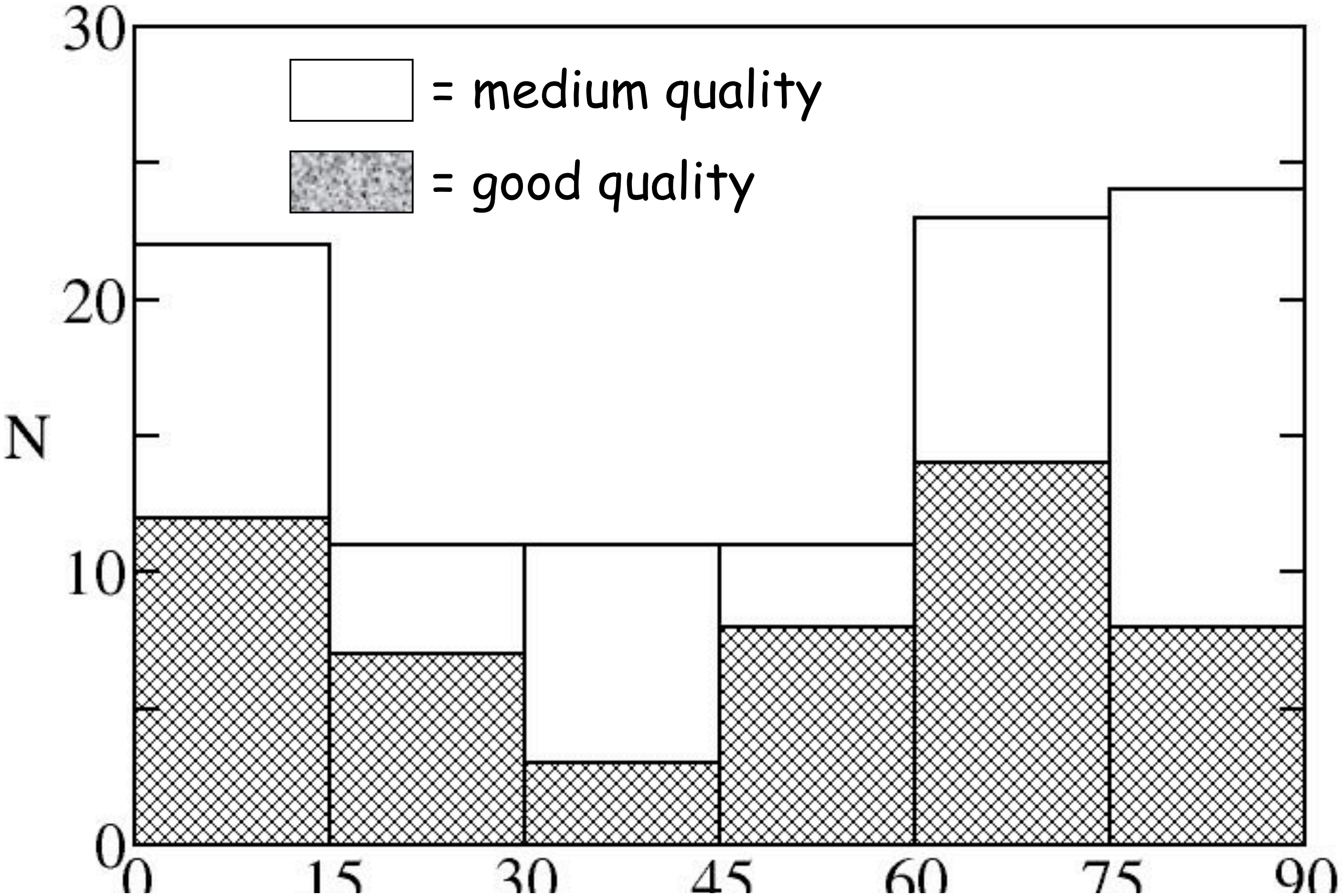
Collection of relevant data in one ASCII table:

one record per measurement or bibliographical reference
(some have only flux, others only structure data)

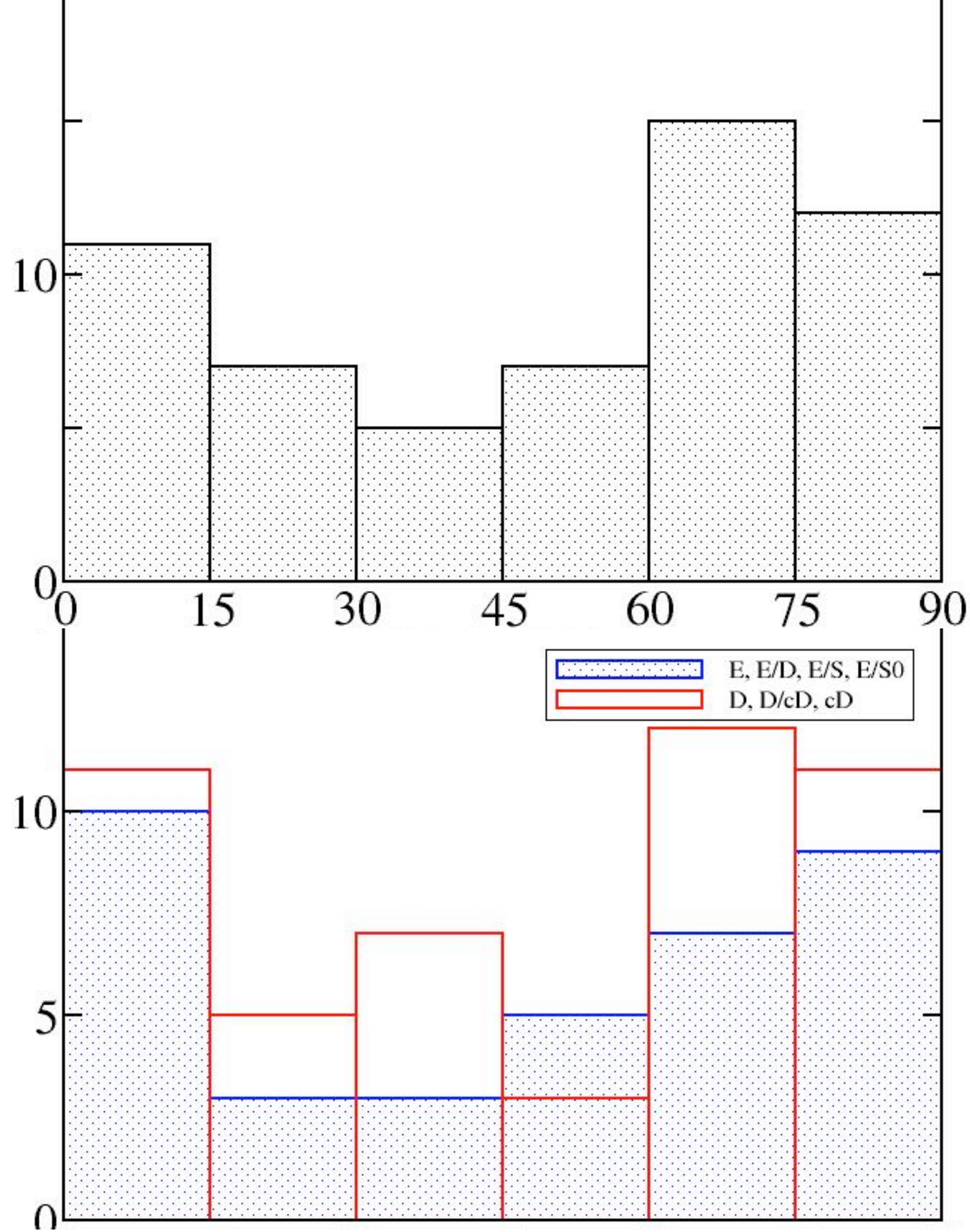
Parameters we record:

BCMname, RA/DEC, frequency, flux, error (flags for upper or lower limits), major/minor axis size, RPA(catalog), innermost RPA (or best available), largest angular size (LAS), Current status:

- 5270 data records, of which 2370 are upper limits
- 2900 are detections: 590 BCMs in 554 clusters
- However: 233/590 detected at only one frequency (weak!)
- only ~130 have useful RPAs, of which only ~100 reliable



bimodality confirmed
BUT: sample is smaller than Andernach 1995 (no restriction to cluster type)



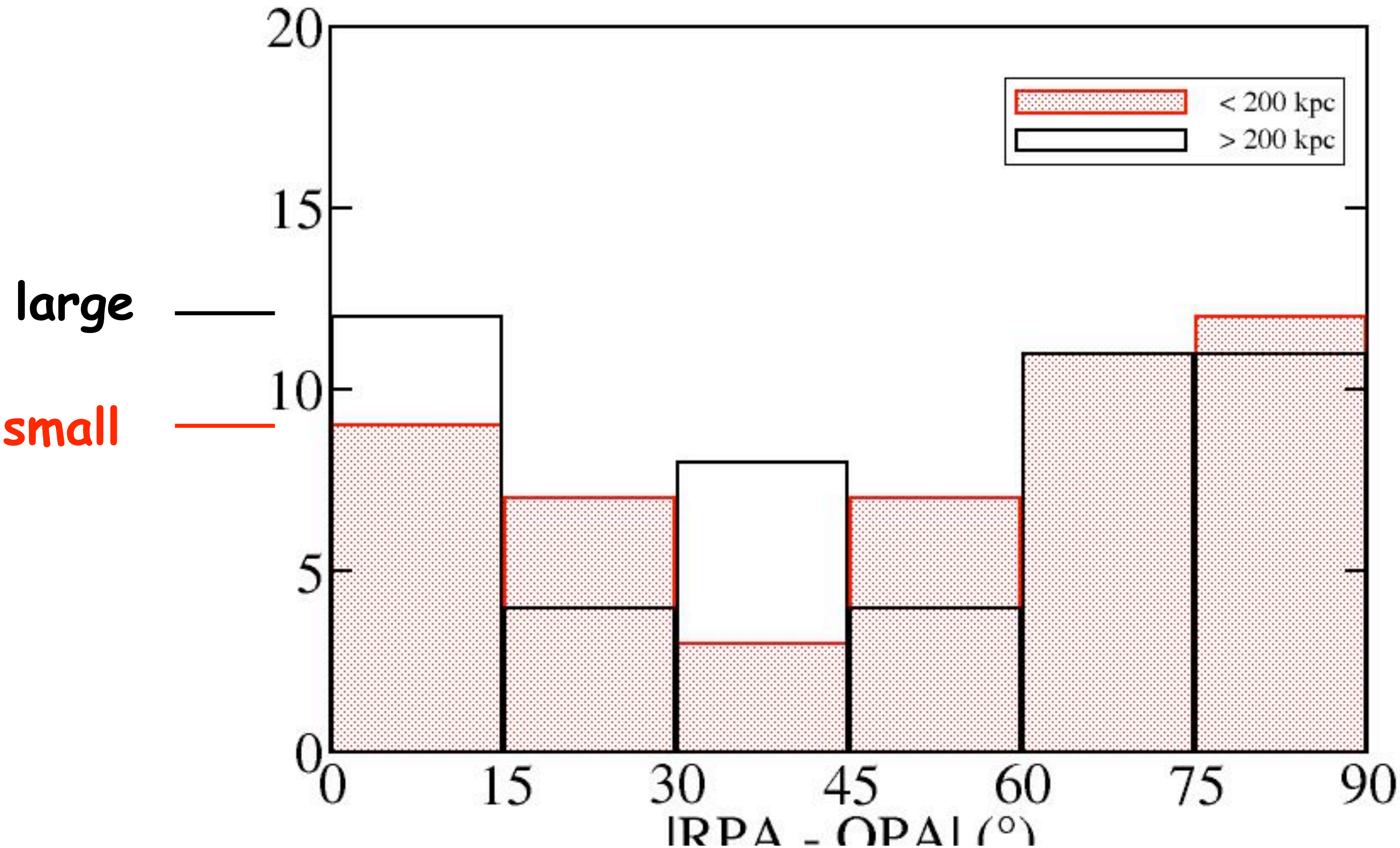
only BCMs with
opt. ellipticity > 0.2

Separation by optical morphological type

E-type galaxies
vs.
D/cD type galaxies

Separation of sample by LLS

→ does not affect the (mis)alignment angle



Conclusions

No real evidence for anisotropic merging scenario, at least from radio-optical alignments of BCMs

Not easy to increase BCMs sample with good images from existing radio surveys → E-FIRST would be great!

Plans for the future:

- check VLA/AT archives for further images
- derive radio spectra and luminosities, correlate with other properties
- classify (quantitatively?) radio morphology and correlate with peculiar velocities of BCMs

→ is the radio distortion related to v_{pec} or not ?
(previous studies of NATs and WATs showed no evidence)

- ➔ SKA precursors should have the best possible
- sensitivity for extended sources

New **very steep-spectrum** sources (α > 1.4)

A 122, A 733, A1650, A2110, A2533, A2554, A3497, S 651

Very **flat spectrum** sources (α ~0)

A 1644, A2292, A2631 (inverted), A2660, A3407

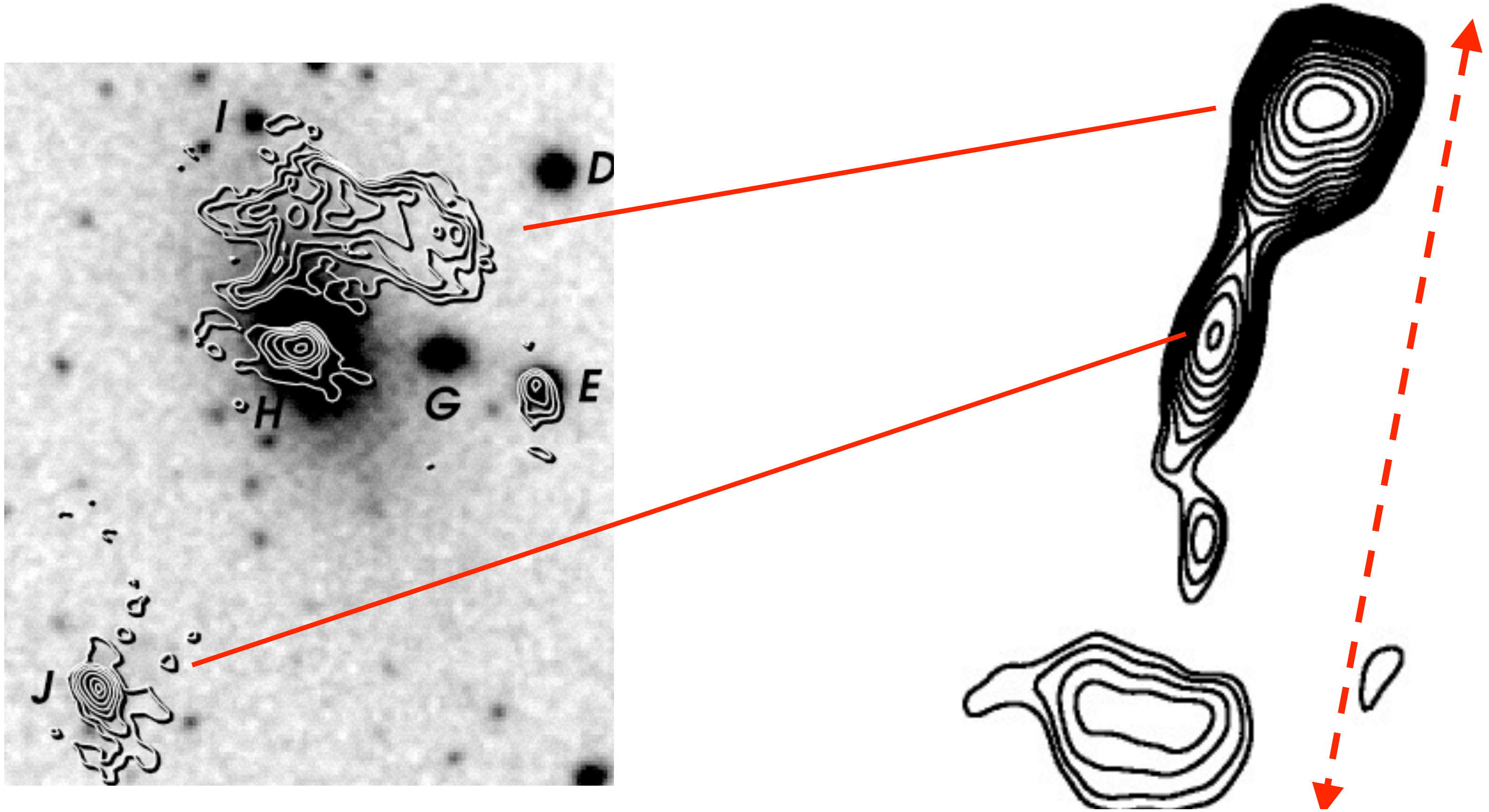
New examples of **WAT** sources

A 555, A 941, S 793, ...

A 133: Relic or USS lobe of double radio galaxy?

Slee et al. 2001 1.4GHz

Birzan et al. 2008 320 MHz



$\alpha > -3$!

is this one double source?

LAS ~6'
z=.056
LLS~260 kpc

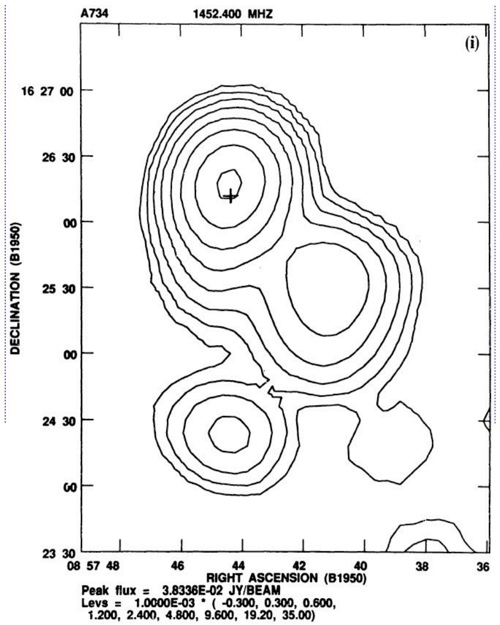
How structure depends on sensitivity and resolution: Abell 734

Bagchi & Kapahi 1994

1452 MHz

30" x 30"

σ ~ 1 mJy

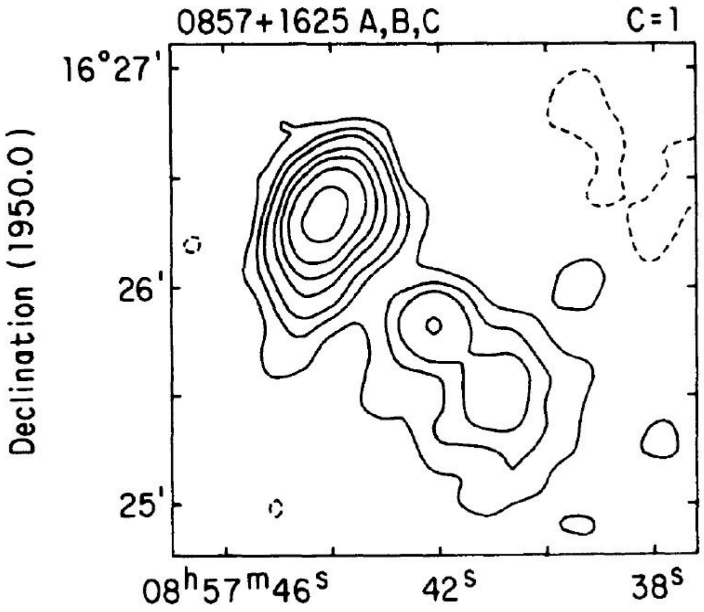


Coleman et al., 1985

1411 MHz

22" x 18"

σ ~6 mJy

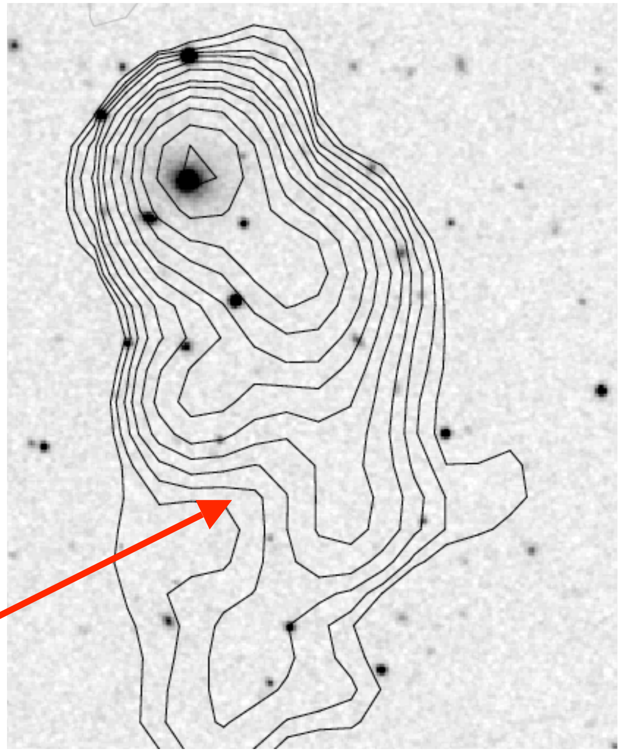


NVSS

1400 MHz

45" x 45"

σ ~ 0.5 mJy



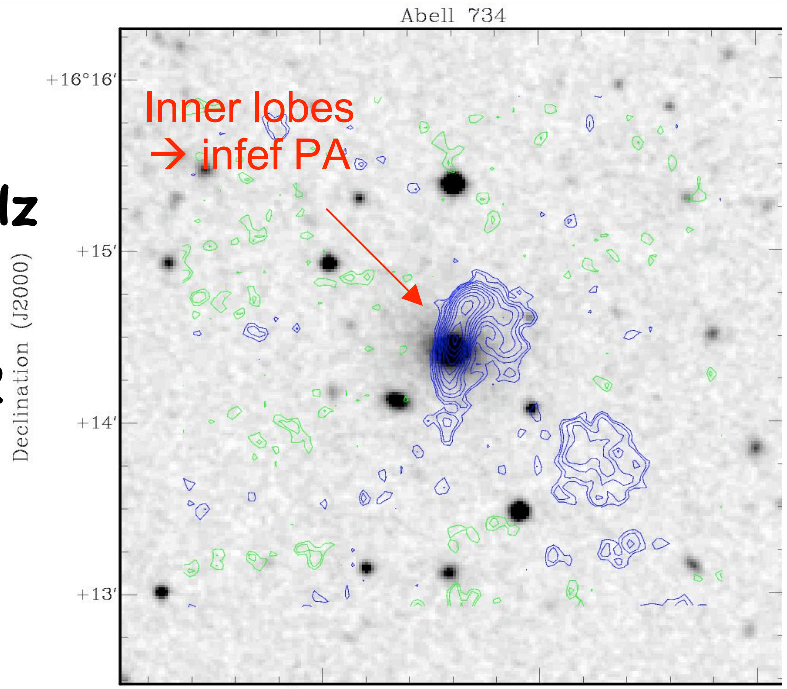
No obvious IDS → belongs to

FIRST

1400 MHz

5" x 5"

σ ~ 0.2 mJy



	h m s d m s	Freq		mJy		mJy	"	"	< "	deg	deg	deg	"		"		
Name	RADec_J2000	MHz		Flux		eFlu	Maj	Min	LAS	RPA	ePA	RPA*	Dist	Source name	Resol	Reference	Notes
A0002__		74.		6048.7	^	300.0			450%						80	2007AJ....134.1245Cohen+ (VLSS)	
A0002__	000817.5 -194029	80.		7000.									48	0005-199	222	1995AuJPh..48..143Slee (CUL)	
A0002__		160.		2200.0												1989MNRAS.236..737Ekers+	
A0002__		160.		3000.			372	<108						0005-199*	111	1983PASAu...5..114Slee&Siegman	
A0002__	000817.5 -194029	160.		2500.									48	0005-199	114	1995AuJPh..48..143Slee (CUL)	
A0002__	000815.81-193832.7	352.		2096.									71	WNB0005.7-1955	54	2002UNPUB.........De Breuck+ (WISH)	
A0002__	000818.82-193949.6	365.		721.0		37.0							29	B0005-199		1996AJ....111.1945Douglas+ (TXS)	P
A0002__		408.		1800.										0005-199	170	1977AuJPh..30..509Mills&Hoskins	
A0002__	000816.6 -193958	408.		1320.		60.							17	MRC B0005-199	160	1991Obs...111...72Large+ (MRC)	
A0002__		410.		2080.0												1989MNRAS.236..737Ekers+	
A0002__	000818.25-193936.8	960.		832.		83.							20	J0008-1939	177	1998BSAO...46...28Mingaliev+ (PMNMi)	
A0002__		1400.		790.0												1989MNRAS.236..737Ekers+	
A0002__@	000818.66-193943.1	1400.		708.4	^	20.0	46.3	18.7	420	107	0	82#	25		45	1998AJ....115.1693Condon+ (NVSS)	NAT
A0002__	000818.25-193936.8	2300.		296.		15.							20	J0008-1939	74	1998BSAO...46...28Mingaliev+ (PMNMi)	
A0002__	000816.8 -193948	2700.		450.									6	PKS B0005-199	435	1990PKS90.C...0000Wright&Otrupcek (PKS90)	
A0002__	000818.25-193936.8	3900.		198.		10.							20	J0008-1939	43	1998BSAO...46...28Mingaliev+ (PMNMi)	
A0002__	000815.9 -193937	4850.		241.		16.							14	PMNJ0008-1939	210	1996ApJS..103..145Wright+ (PMN)	
A0002__		5000.		250.											25	1989MNRAS.236..737Ekers+	
A0002__	000816.8 -193948	5000.		250.									6	PKS B0005-199	235	1990PKS90.C...0000Wright&Otrupcek (PKS90)	
A0002__	000818.25-193936.8	7700.		81.		4.							20	J0008-1939	22	1998BSAO...46...28Mingaliev+ (PMNMi)	
A0002__	000818.25-193936.8	11200.		44.		2.							20	J0008-1939	15	1998BSAO...46...28Mingaliev+ (PMNMi)	
A0005__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0005__		325.	<	18.5											54	1997A&AS..124..259Rengelink+ (WENSS)	
A0005__	001009.09+330716.4	1400.	<	2.0											45	1998AJ....115.1693Condon+ (NVSS)	
A0017__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0017__	001706.38+084944.9	1400.	<	2.0											45	1998AJ....115.1693Condon+ (NVSS)	
A0021__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0021__		325.	<	18.5											54	1997A&AS..124..259Rengelink+ (WENSS)	
A0021__	002037.19+283933.6	1400.	<	2.0											45	1998AJ....115.1693Condon+ (NVSS)	
A0022B_		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0022B_		330.		71.5											60	1994JApA...15..275Bagchi&Kapahi	
A0022B_		1400.		21.4					105%						30	1994JApA...15..275Bagchi&Kapahi	
A0022B_	002042.96-254239.5	1400.		22.7		0.8	< 23.9	< 17.2					11		45	1998AJ....115.1693Condon+ (NVSS)	
A0034A_		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0034A_	002733.30-085311.4	1400.		2.0	*	1									45	1998AJ....115.1693Condon+ (NVSS)	
A0034B_		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0034B_		1400.	<	1.0											5	1995ApJ...450..559Becker+ (FIRST)	
A0034B_	002704.76-084703.3	1400.	<	2.0											45	1998AJ....115.1693Condon+ (NVSS)	
A0035__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0035__		352.	<	18.5											54	2002UNPUB.........De Breuck+ (WISH)	
A0035__	002723.58-213257.5	1400.		2.8		0.5	< 56.6	< 50.8					4		45	1998AJ....115.1693Condon+ (NVSS)	
A0038__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0038__	002819.87+135504.8	1400.		5.4		0.5	< 73.8	< 34.9				0#	5		45	1998AJ....115.1693Condon+ (NVSS)	
A0049__		74.		1963.8	^	200.0			300						80	2007AJ....134.1245Cohen+ (VLSS)	
A0049__@	003128.00-112422.4	1400.		265.2	^	15.0	< 95.3	31.5	300%	43#	1		26		45	1998AJ....115.1693Condon+ (NVSS)	NE-BD/AT
A0049__	003126.5 -112343	4850.		118.		12.							59	PMNJ0031-1123	210	1996ApJS..103..145Wright+ (PMN)	
A0077__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0077__		325.	<	47.2											54	1997A&AS..124..259Rengelink+ (WENSS)	
A0077__		330.		15.0											60	1994JApA...15..275Bagchi&Kapahi	
A0077__		1400.		13.3											30	1994JApA...15..275Bagchi&Kapahi	
A0077__	004028.21+293321.5	1400.		14.8		0.6	< 21.3	< 19.6					0		45	1998AJ....115.1693Condon+ (NVSS)	
A0077__	004028.34+293321.0	1400.		12.									2	0037+292	15	1995AJ....109..853Ledlow+ (CLL95)	
A0077__		-1400.		0.0					10%			110#				1997ApJS..108...41Owen+	
A0077__		1500.		12.0												1993ApJS...87..135Owen+	
A0077__		5000.		4.7		0.3	2.3	1.2		108					1.5	1993AJ....105...53Ball+	
A0085A_	004150.52-091808.8	74.		1130.0		160.0	< 71.4	< 71.1					3		80	2007AJ....134.1245Cohen+ (VLSS)	
A0085A_		408.		300.										0039-095	170	1977AuJPh..30..509Mills&Hoskins	
A0085A_	004150.4 -091811	408.	>	450.									2	0039-095B	174	1986USydn.T00J....Reynolds (CL_Re)	
A0085A_		-775.	<	1200.		200								B0039-096	1200	1976AJ.....81..571Owen	
A0085A_	004150.4 -091811	843.		92.									2	0039-095B	47	1986USydn.T00J....Reynolds (CL_Re)	
A0085A_		-968.	<	1000.		200								B0039-096	960	1976AJ.....81..571Owen	
A0085A_		-1400.		0.0					20%							1997ApJS..108...41Owen+	
A0085A_	004150.36-091811.0	1400.		48.									3	0039-095B	15	1995AJ....109..853Ledlow+ (CLL95)	
A0085A_@	004150.38-091813.7	1400.		56.7		2.5	16.2	15.3		8	27		3		45	1998AJ....115.1693Condon+ (NVSS)	
A0085A_	004150.47-091811.3	1400.	>	45.0		2.0	2.8	1.3		1				J004150.4-091811	5	1995ApJ...450..559Becker+ (FIRST)	
A0085A_	004150.4 -091811	1415.		70.									2	0039-095B	50	1986USydn.T00J....Reynolds (CL_Re)	
A0085A_	004150.50-091811.4	-1450.		46.2				17							5	2009UNPUB.........Islas Islas J.M.+	faint radio companion ~20"SW
A0085A_	004150.47-091811.8	1500.		46.2									1	B0039-0934	14	1996AuJPh..49..977Slee+ (CLS3)	
A0085A_	004149.8 -091751	2700.	<	85.									24	A 85.1	276	1979A&AS...36..237Waldthausen+ (CL_An)	
A0085A_	004150.1 -091739	2700.	<	125.		16.							34	A 85.1	276	1986A&AS...65..561Andernach+ (CL_An)	
A0085A_	004149.3 -091752	4850.	<	46.		11.							27	PMNJ0041-0917	210	1996ApJS..103..145Wright+ (PMN)	
A0085A_	004149.3 -091752	4872.		11.								0?			1	1993AJ....105...53Ball+ (see their notes)	image in 1990AJ.....99...14Bur
A0096__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0096__		325.	<	18.5											54	1997A&AS..124..259Rengelink+ (WENSS)	
A0096__	004621.14+393231.1	1400.	<	2.0											45	1998AJ....115.1693Condon+ (NVSS)	
A0099__		74.	<	500.0											80	2007AJ....134.1245Cohen+ (VLSS)	
A0099__		352.	<	18.5											54	2002UNPUB.........De Breuck+ (WISH)	