CSSs Polarimetry at sub-arcsecond resolution

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Compact Steep Spectrum sources

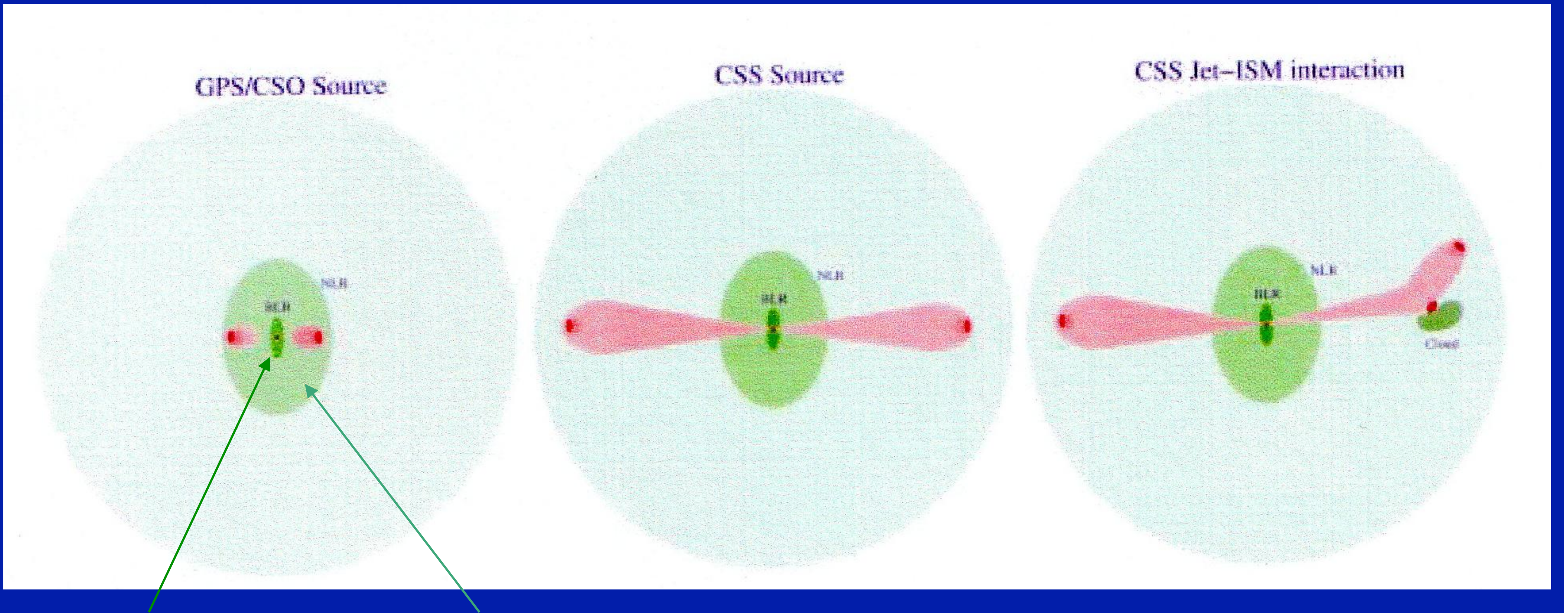
Ages $< 10^{3-5}$ yr

Steep high-frequency radio spectra $\alpha > 0.5$ ($S \propto \nu^{-\alpha}$)

Linear size $\leq$ 20 kpc → sub-galactic dimention
confined to the NLR

(H_o = 71 km sec^{-1} Mpc^{-1}, Ω_m = 0.27, Ω_{vac} = 0.73)

Measurement of polarised emission from CSS sources can give important information about the physical conditions inside and around the region of radio emission



Cotton et al. 2003

VLA A-array observations

Freq (MHz)		m_{tot} median	
		G	Q
8085	0.7	0.3	1.2
8485	0.7	0.3	2.2
14885	1.5	0.7	3.3
23292	1.9	1.7	2.9

$DP_{8485/14885} \approx 0.6$

RM_{rf} = ~ 30 – 20,000 rad m^{-2} (RM median = ~ 900 rad m^{-2})

Observational parameters

- Fractional polarisation $m = S_p / S_t$
- Position Angle of the electric vector $\Delta PA = RM \cdot \lambda^2$
- Faraday Rotation (rad m^{-2}) $RM = 0.81 \int n_e B_{\parallel} ds$

n_e (cm^{-3}) thermal electron density
$B_{\parallel}$ (μG) magnetic field component along the line of sight
ds (pc)

Models of the distribution of Faraday depth

Relations between rotation and depolarisation as a function of wavelength

> Burn model (1966 MNRAS 133, 67)

> Tribble model (1991 MNRAS 250, 726)

RM randomly distributed plus distribution of cell size

$$m (\lambda) = (1 + 8 \sigma^2 \lambda^4 t^2 / s_o^2)^{-1/2}$$

m fractional polarisation
λ wavelength
σ RM dispersion
t resolution
s_o *RM* scale fluctuation

Diagnostic

> λ^2 rotation, no depolarisation:
  a foreground screen is producing the rotation

> λ^2 rotation, depolarisation:
  depend on the range of rotation observed

> deviation from λ^2 :
  quasi-uniform field inside the source
  partially resolved foreground screen

> depolarisation without rotation:
  unresolved foreground screen
  material internal to the source

Radio Polarimetry of 3C119, 3C318, and 3C343 at milliarcsecond resolution

VLBA + VLA1
Observing date: Sept. – Oct. 2001
Frequencies: 5GHz and 8.4 GHz

IFs	MHz	Bandwidth	array
IF1	4619	16 MHz	VLBA + VLA1
IF2	4657	16 MHz	VLBA
IF3	4854	16 MHz	VLBA + VLA1
IF4	5094	16 MHz	VLBA
IF1-4	8421	64 MHz	VLBA + VLA1

Data analysis and imaging: AIPS

3C 119

Quasar (?) at $z = 1.023$

$1 \text{ mas} \approx 8 \text{ pc}$

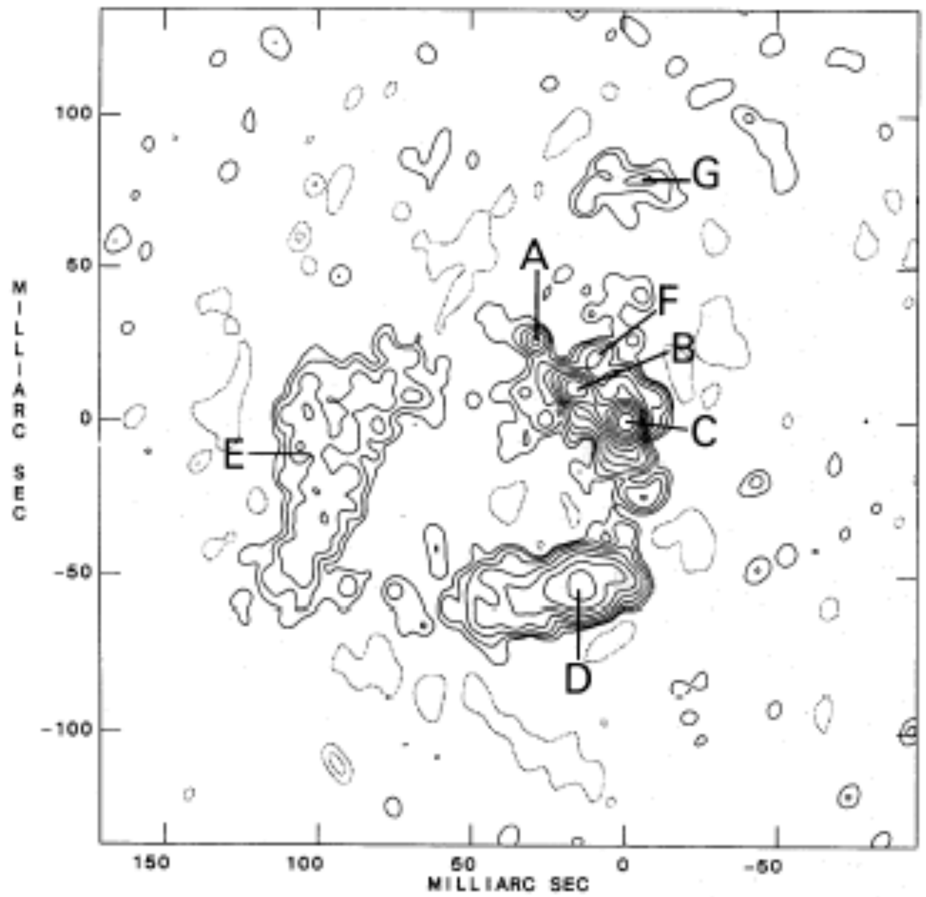
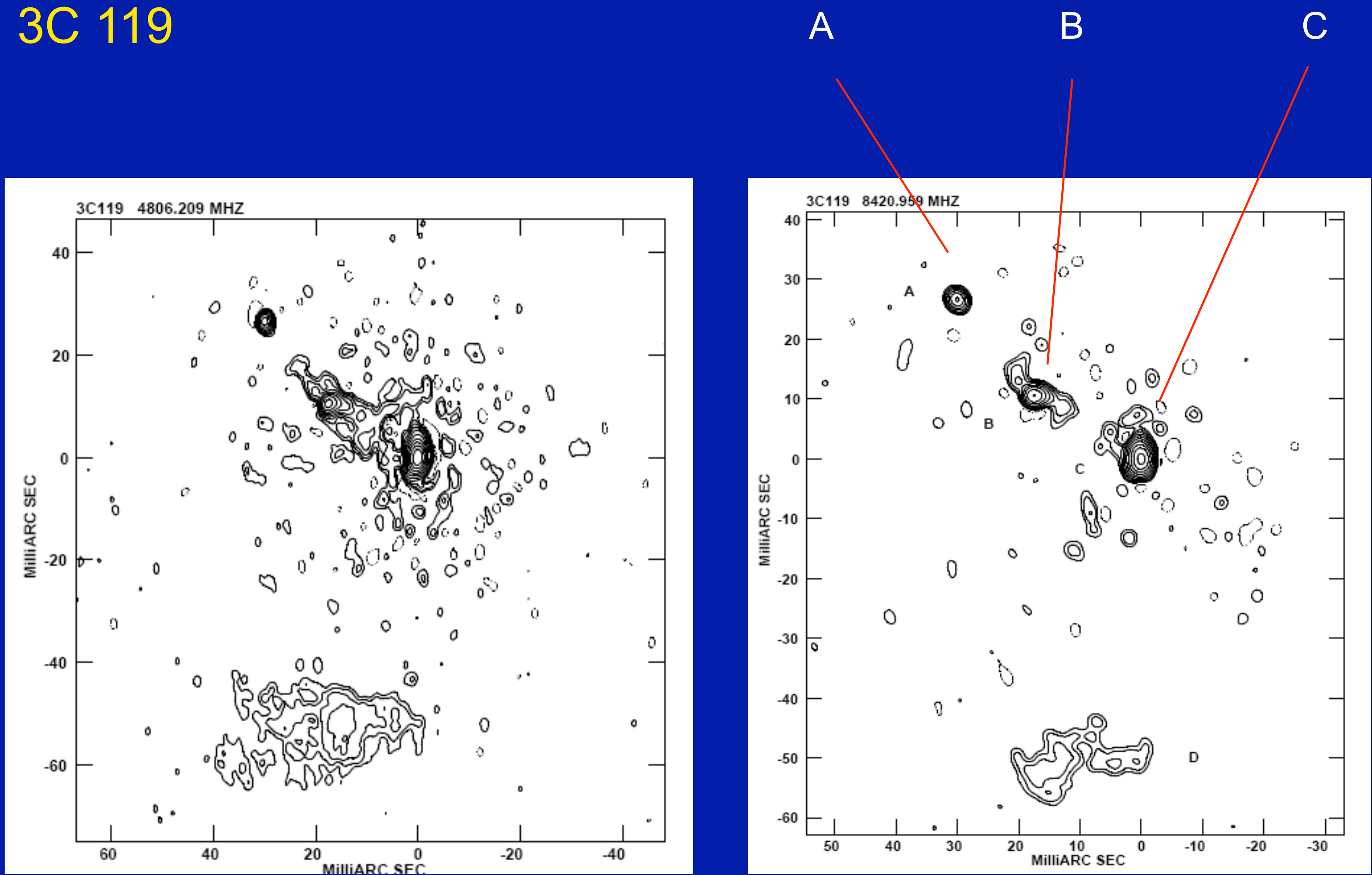


Fig. 1. Brightness distribution of 3C 119 at 18 cm. Beam, $5 \times 5 \text{ mas}^2$; tick separation, 60 mas; peak intensity, 2.993 Jy/beam; contours (%): −0.10, −0.05, 0.05, 0.10, 0.20, 0.40, 0.80, 1.60, 3.20, 6.40, 12.80, 25.60, 51.20. The letters label components described in the text

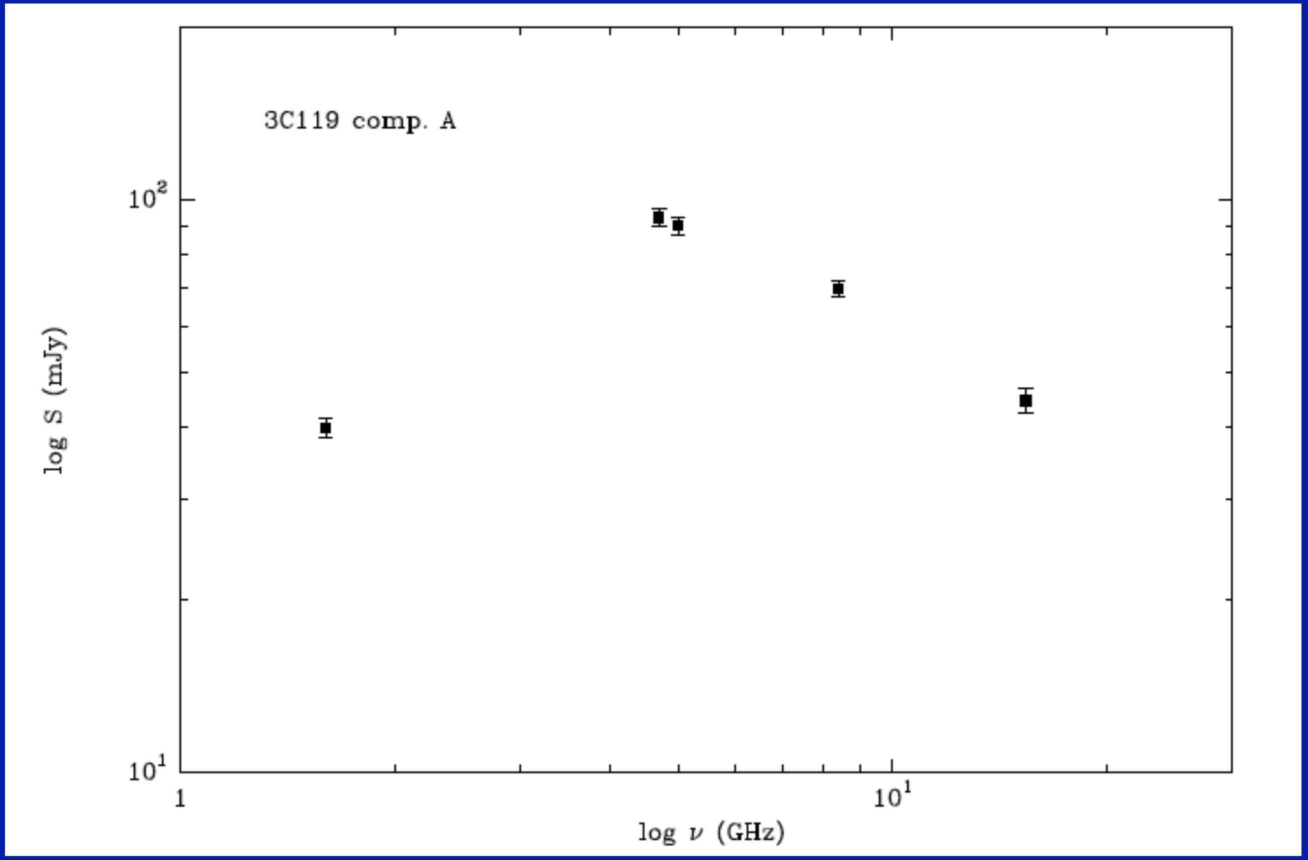
18 cm

Nan Ren-Dong et al. 1991

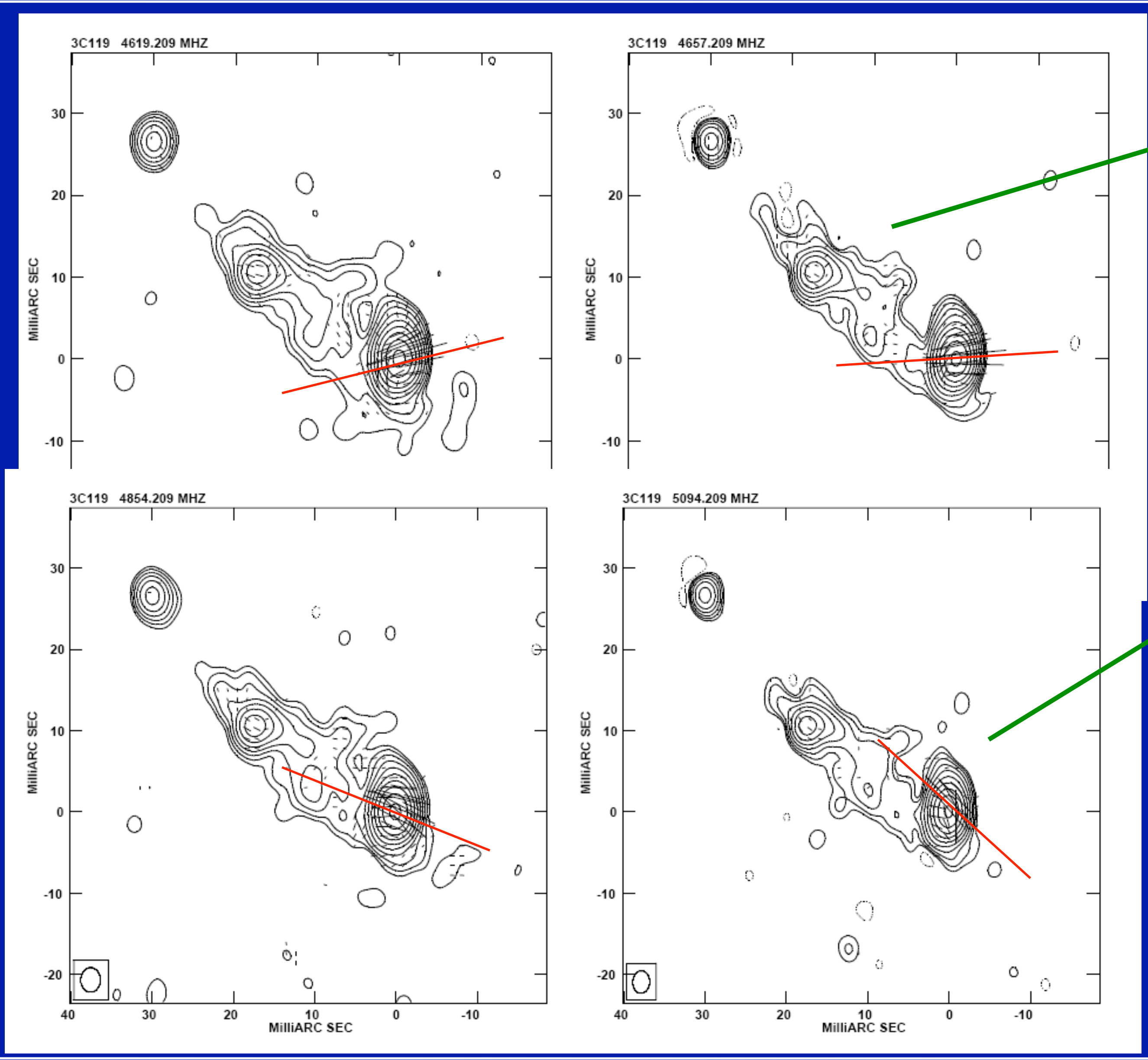
3C 119


A
B
C
3C119 4806.209 MHZ
MilliARC SEC
MilliARC SEC
3C119 8420.959 MHZ
A
B
C
D
MilliARC SEC
MilliARC SEC

3C 119 comp. A : a GPS



1.6 GHz, Nan et al. 1991; 15 GHz, Lister et al. 2009 (MOJAVE)
Not detected at 50cm, Nan et al. 1991



B comp

Small depolarisation

$m_{5GHz} \approx 0.7\ \%$

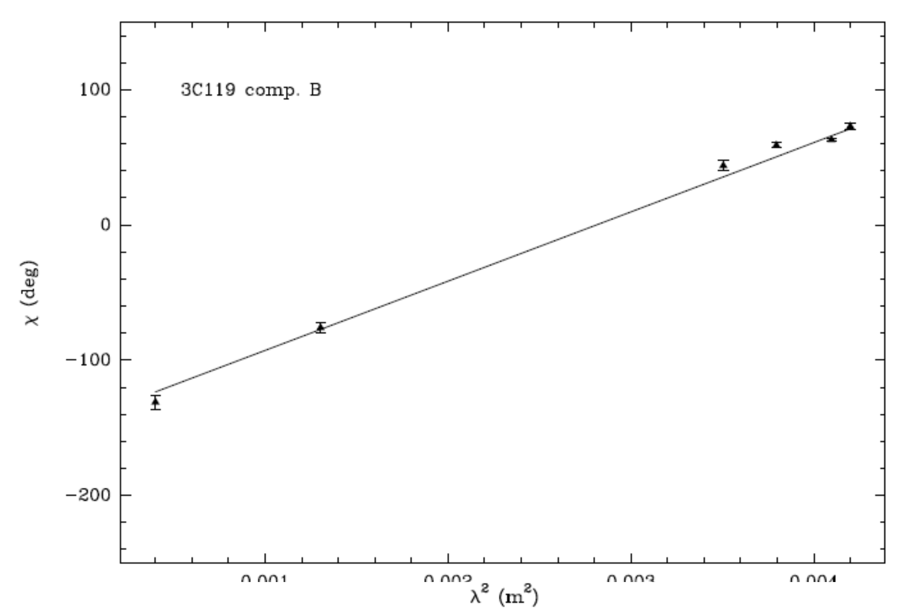
$m_{8.4GHz} \approx 0.5\ \%$

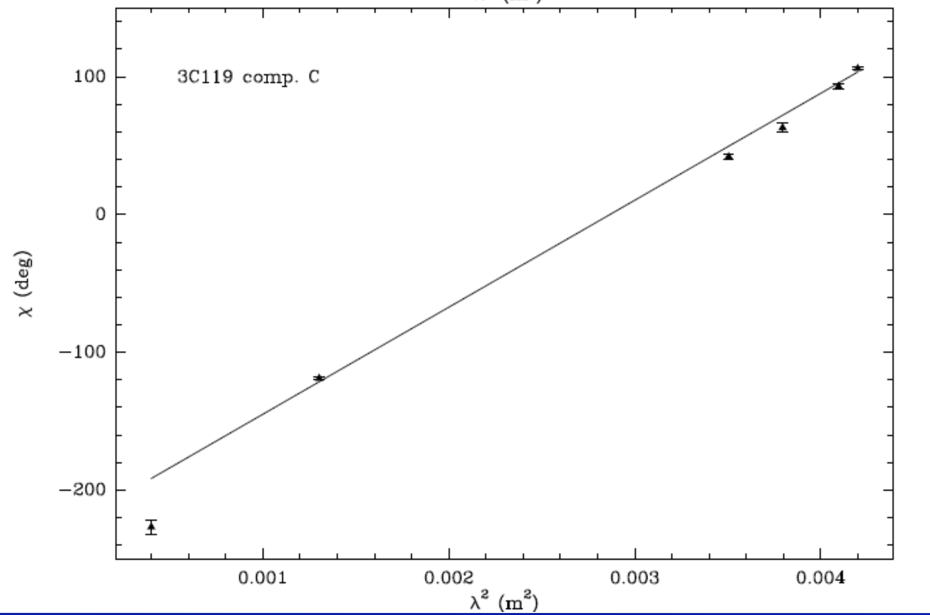
C comp

Large depolarization

$m_{5GHz} \approx 1.2\ \%$

$m_{8.4GHz} \approx 14.4\ \%$

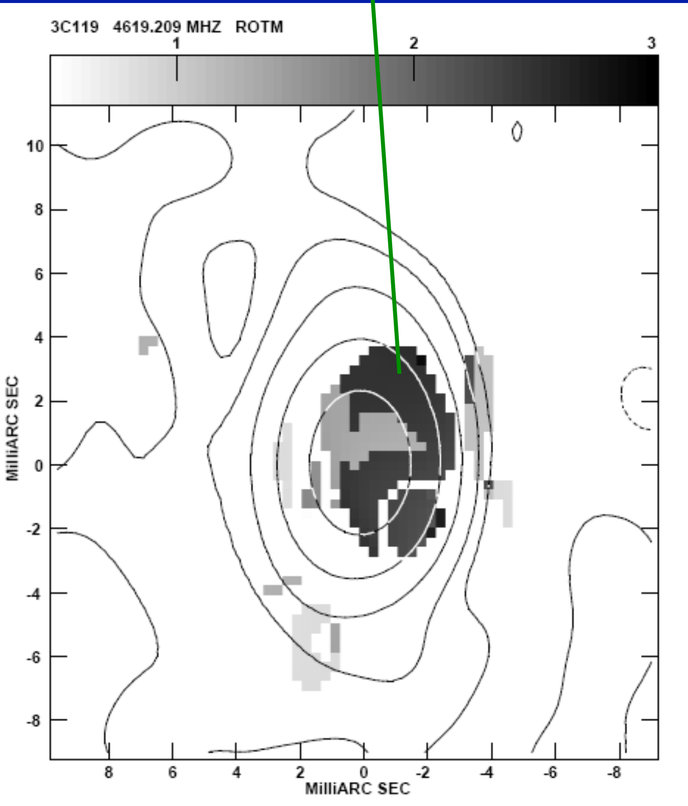




B $RM_{rf} = 3618$ rad m^{-2}

C $RM_{rf} = 5620$ rad m^{-2}

= 9400 — 10200 rad m^{-2}



3C 318

Galaxy at z = 1.574
1 mas ≈ 8.5 pc

Heavily resolved at 4.8 GHz

Fringes not detected at 8.4 GHz

Image made using the full bandwidth at 5 GHz

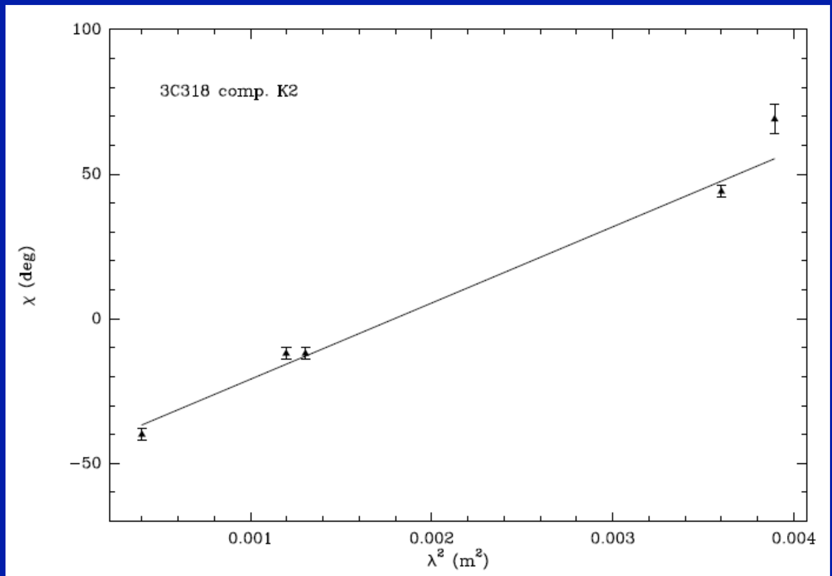
Resolution 35 x 33 mas ^{2} in PA 46 deg

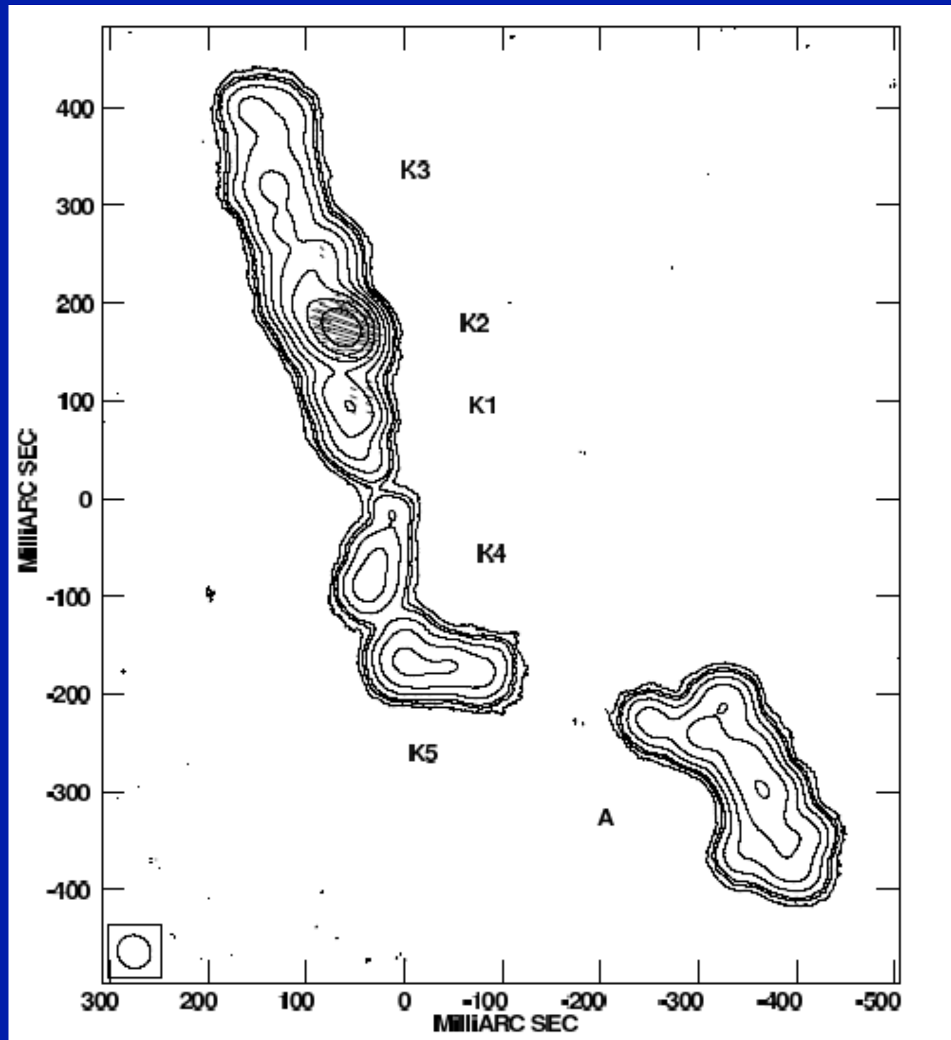
About 61% recovered compared to Lüdke et al. (1998)

Core not detected

3C 318

$RM_{rf} = 3030 \text{ rad m}^{-2}$



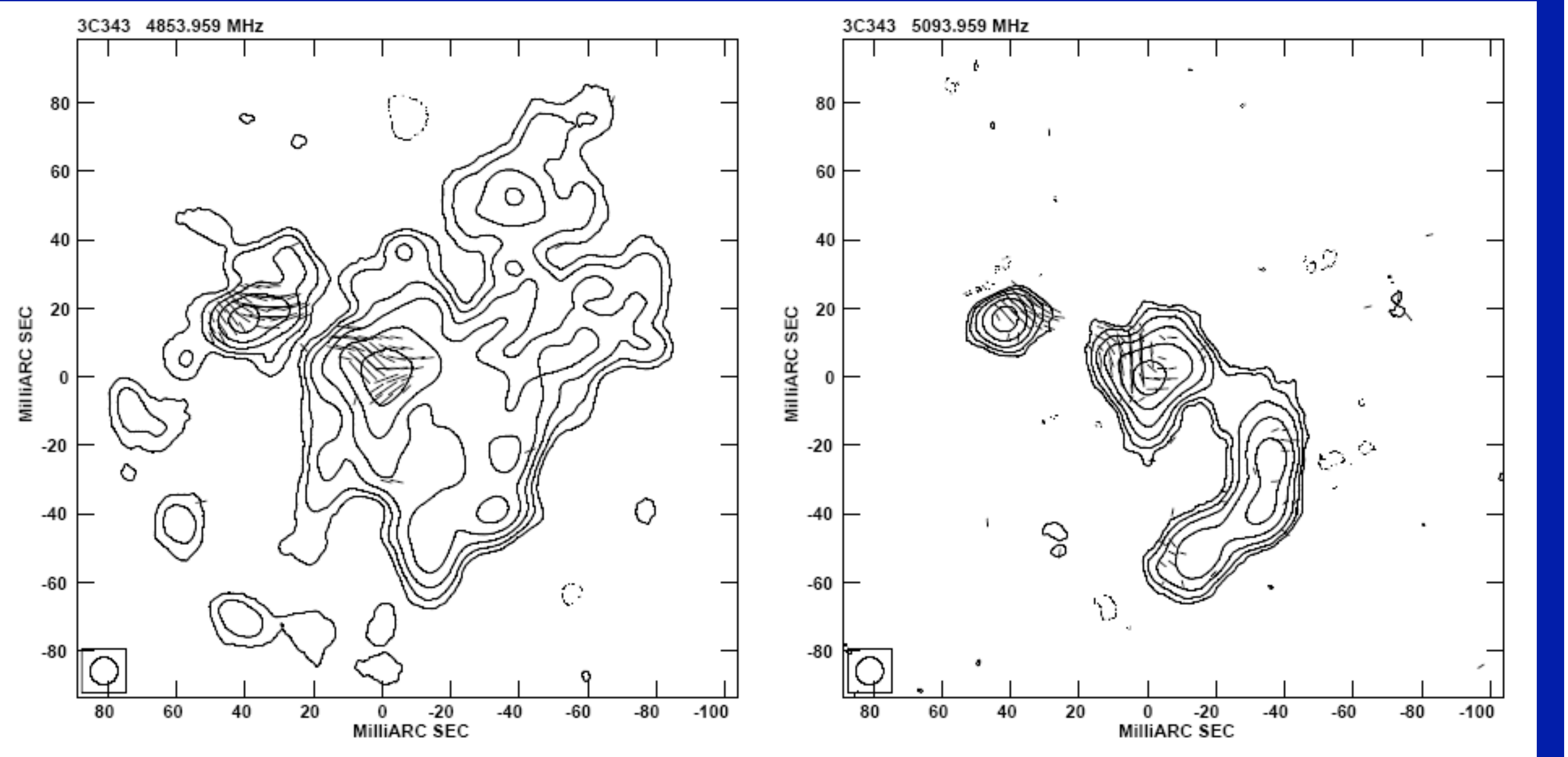


EVPA values:
4996 MHz (Lüdke et al. 1998)
8414 MHz (Akujor & Garrington 1995)
8515 MHz (Taylor et al. 1992)
15 GHz (van Breugel et al. 1992)

3C 343

Quasar at $z = 0.988$

1 mas ≈ 8 pc



3C 343

Total flux density detected at 5GHz:

- 89% of the flux density detected by MERLIN (Lüdke et al. 1998)

- 85 % of the flux density detected by Effelsberg measurements (Mantovani et al. 2009)

Low level of polarisation

Changes of by up to 90 degrees in the orientation of the EVPAs

Significant polarisation not always detected → difficult to make a reliable RM map

Changes in the EVPA by more than 30 deg → RM > 1500 rad m $^{-2}$

3C 343

A component B

α ≈ 1.6 1.2

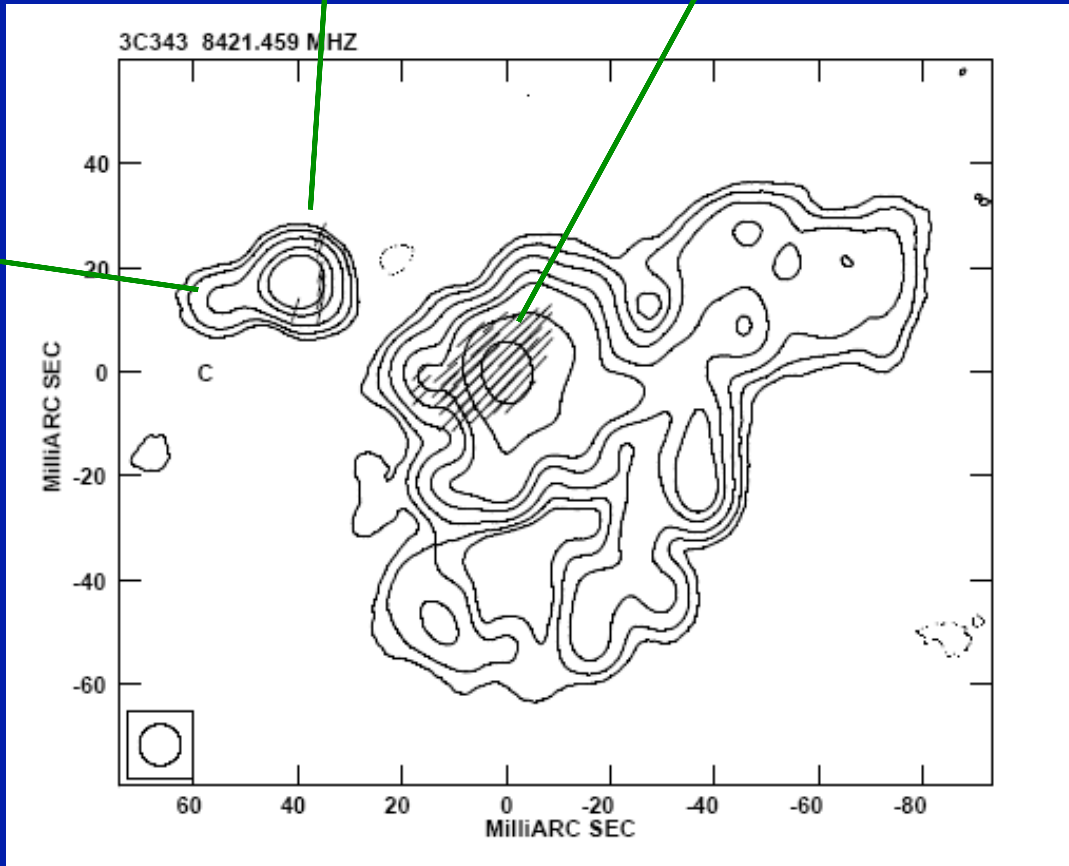
$RM_{rf} > 6000$ rad m^{-2}

C α inverted

Fractional polarisation m:

5 GHz 0.96 %

8.4 GHz 1.3 %



Discussion

Three different structures:

3C119 Q

Complex shape at low resolution
Strong jet structure on resolutions of few mas
The jet mantains its collimation
Overall spiral-like structure

Strong depolarisation between 8.4 and 5 GHz in comp. C
Comp. C has high rotation measure

→ Indication of strong interaction between jet and clouds in the ISM

3C 318 G

Elongated jet with “wiggles”

Unable to identify the core

High Rotation Measure

3C343 Q

Unusual structure

The two brightest polarised components embedded in a diffuse region of weak emission

It is unlikely that either is the core of the source

Component C (east of A) suggested has the possible core

Magnetic field strengths:

3C119	0.1 – 0.6 μG
3C318	0.04 – 0.2 μG
3C343	0.07 – 0.4 μG

Assuming:

Electron density ~ 10^{3} cm^{-3} (NRL clouds; Peterson 1997)

Cloud sizes ~ 20 – 100 pc

Similar values found by: Zavala & Taylor (2002)
Mantovani et al. (2002)

A discussion of CSS quasars

Table 5. Polarisation parameters of CSSs from mas-resolution observations

Name	Alt. Name	z	Id.	m (%)	DP	RM_{rf} ($\mathrm{rad\,m^{-2}}$)	Notes
3C 43 ★	B0127+233	1.459	Q	$0.4_{1.6\,\mathrm{GHz}}$		14236	E, ∼1600 pc from core
3C 119[a] ★	B0429+415	1.023	Q?	$14.4_{8.4\,\mathrm{GHz}}$	$0.08_{5.0/8.4}$	10200	C, ∼325 pc from core
3C 138	B0518+165	0.759	Q	$3.6_{5.0\,\mathrm{GHz}}$		−5287	B1, ∼40 pc from core
3C 147 ★	B0538+498	0.545	Q	$6.6_{8.4\,\mathrm{GHz}}$		−4872	BN, ∼37 pc from core A_0
4C 16.14[b]	B0548+165	0.474	Q	$6.2_{8.4\,\mathrm{GHz}}$	$0.26_{4.6/8.4}$	−4275	5C, ∼540 pc from core
3C 216	B0906+430	0.670	Q	$30.0_{8.4\,\mathrm{GHz}}$	$0.97_{4.8/8.4}$	2200	Arc, ∼1050 pc from core
3C 286[c]	B1328+307	0.849	Q	$11.0_{5.0\,\mathrm{GHz}}$			Core unclear
3C 287[d]	B1328+254	1.055	Q	$4.6_{5.0\,\mathrm{GHz}}$		∼0	Based on only 8.15 and 8.54 GHz
OQ 172[e] ★	B1442+101	3.529	Q	$2.7_{8.4\,\mathrm{GHz}}$		40000	Within ∼20 pc from core
3C 309.1	B1458+718	0.905	Q	$1.5_{15\,\mathrm{GHz}}$	$0.10_{8.4/15}$	−1633	Core *RM* between 8.4 and 15 GHz
3C 318 ★	B1517+204	1.574	NG	$3.5_{4.8\,\mathrm{GHz}}$		3550	K2, Core unclear
OR−140[f] ★	B1524−136	1.687	Q	$30.2_{8.4\,\mathrm{GHz}}$	$\sim1_{4.6-5.1/8.4}$	−10000	C, ∼810 pc from core F
3C 343[g] ★	B1634+628	0.988	Q	$4.8_{8.4\,\mathrm{GHz}}$	$0.91_{4.6-5.1/8.4}$	>6000	core unclear
3C 454	B2249+185	1.757	Q	$10.9_{1.6\,\mathrm{GHz}}$		5334	B, ∼300 pc from possible core

12 out of 24 quasars in the list of CSSs from the 3C and PW catalogues (Fanti et al. 1990) have published polarimetric VLBI observations

A discussion of CSS quasars

Almost all of them show core-jet structure

Cores are usually weak and polarisation not detected
(in contrast to flat spectrum quasars)

Polarised emission detected along the jets

RM ranging from ~ 1600 to 4 x 10^4 rad m^{-2}

Distance from the core of the component of highest RM:
~ 37 to 1600 pc (median value ~ 400 pc)

→ clearly in the NLR of host galaxy

Fractional polarisation

Component with the highest RM in

3C119 and 3C309.1 are strongly depolarised DP ~ 0.1
(unresolved structures in the screen and / or
thermal plasma mixed with radio emitting material)

3C216 and OQ-172 DP ~ 1 (external screen)

Several examples suggest that the RM is due to a foreground screen,
With the NLR contributing to the observed RM

In all cases examined a λ^2 law is closely followed

The jets are often distorted → jet – cloud interactions

In many core – jet CSS quasars high integrated RM occurs where bends
in the jet are found

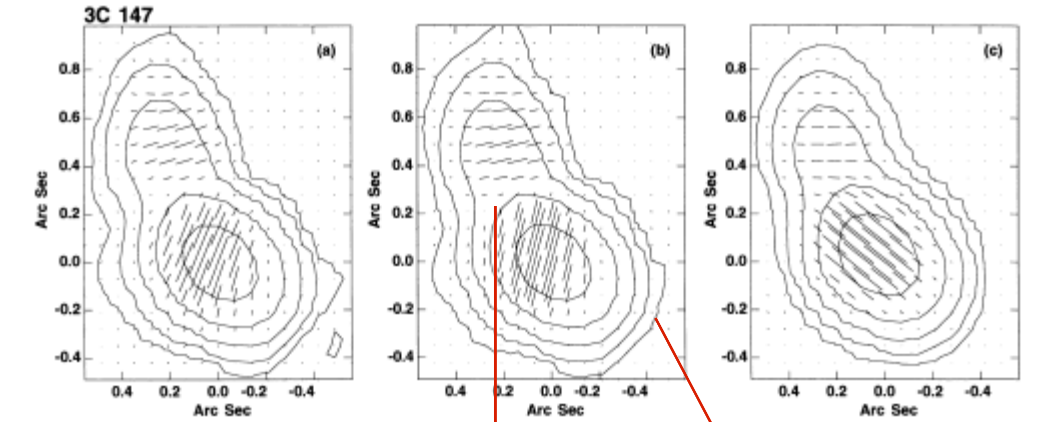
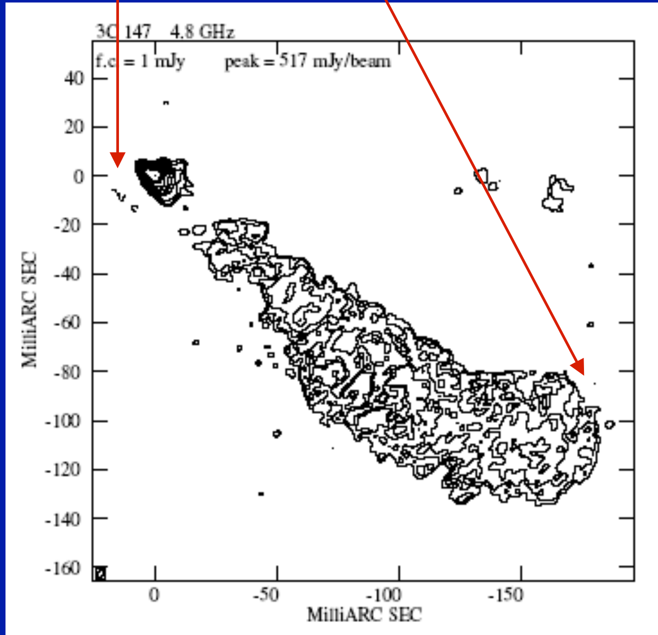
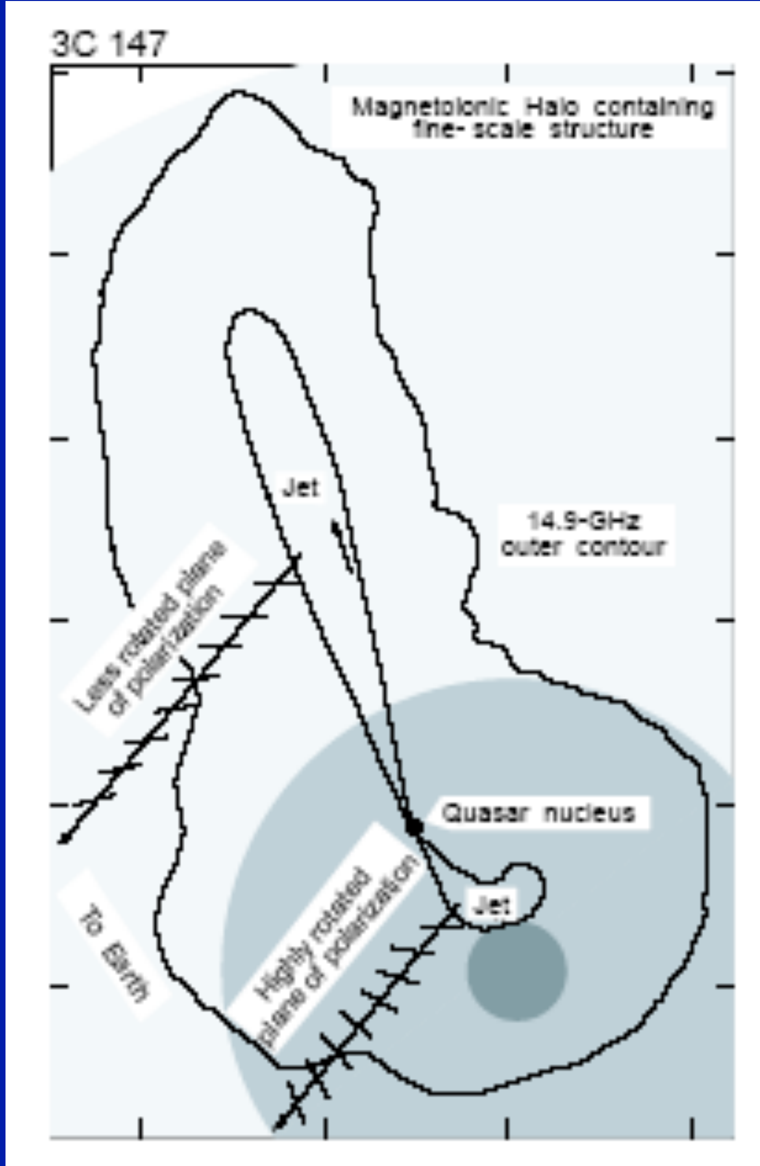


Figure 2. Images of 3C 147 at 8.1, 8.5 and 14.9 GHz in panels (a), (b) and (c) respectively, all with a resolution of 0.28 × 0.23 arcsec² along 24°.3. Polarized-intensity vectors are superimposed on the total-intensity contours. The contours are plotted at (1, 4, 16, 64, 256) × 6 mJy beam⁻¹ for 8.1 and 8.5 GHz, and at × 3 mJy beam⁻¹ for 14.9 GHz. The lengths of the polarization vectors are 114 mJy beam⁻¹ arcsec⁻¹ at 8.1 and 8.5 GHz, and 190 mJy beam⁻¹ arcsec⁻¹ at 14.9 GHz.





3C147 Q

Southern Component
RM = –3140 rad m^{-2}

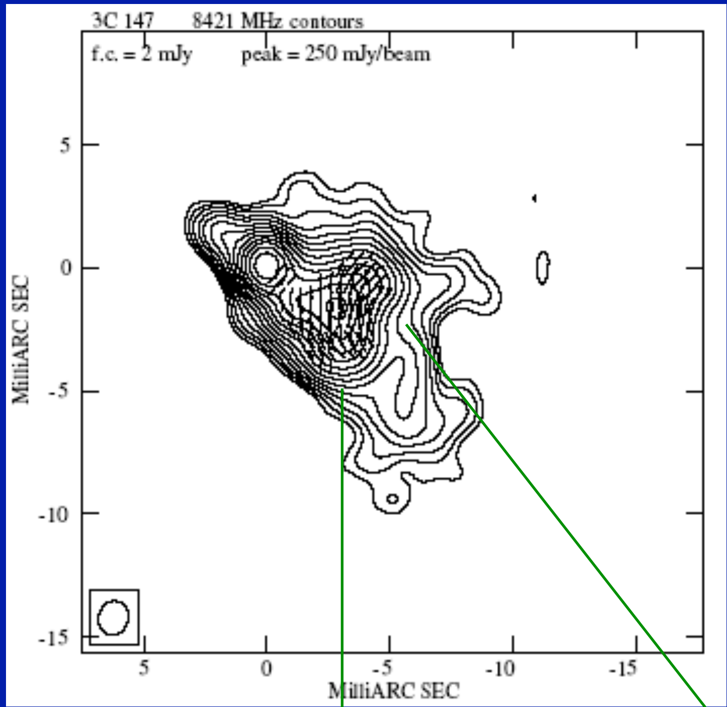
Northern Component
RM = +630 rad m^{-2}

Junor et al. 1999

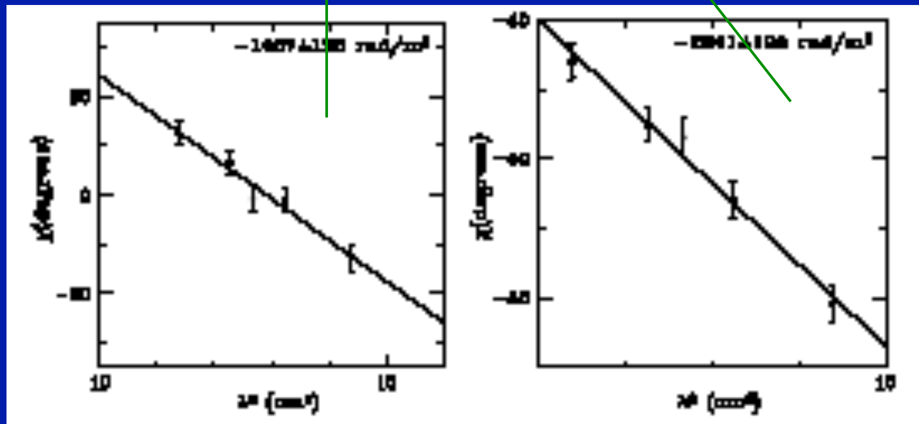
Rossetti et al. 2009

3C147

Rossetti et al. 2009

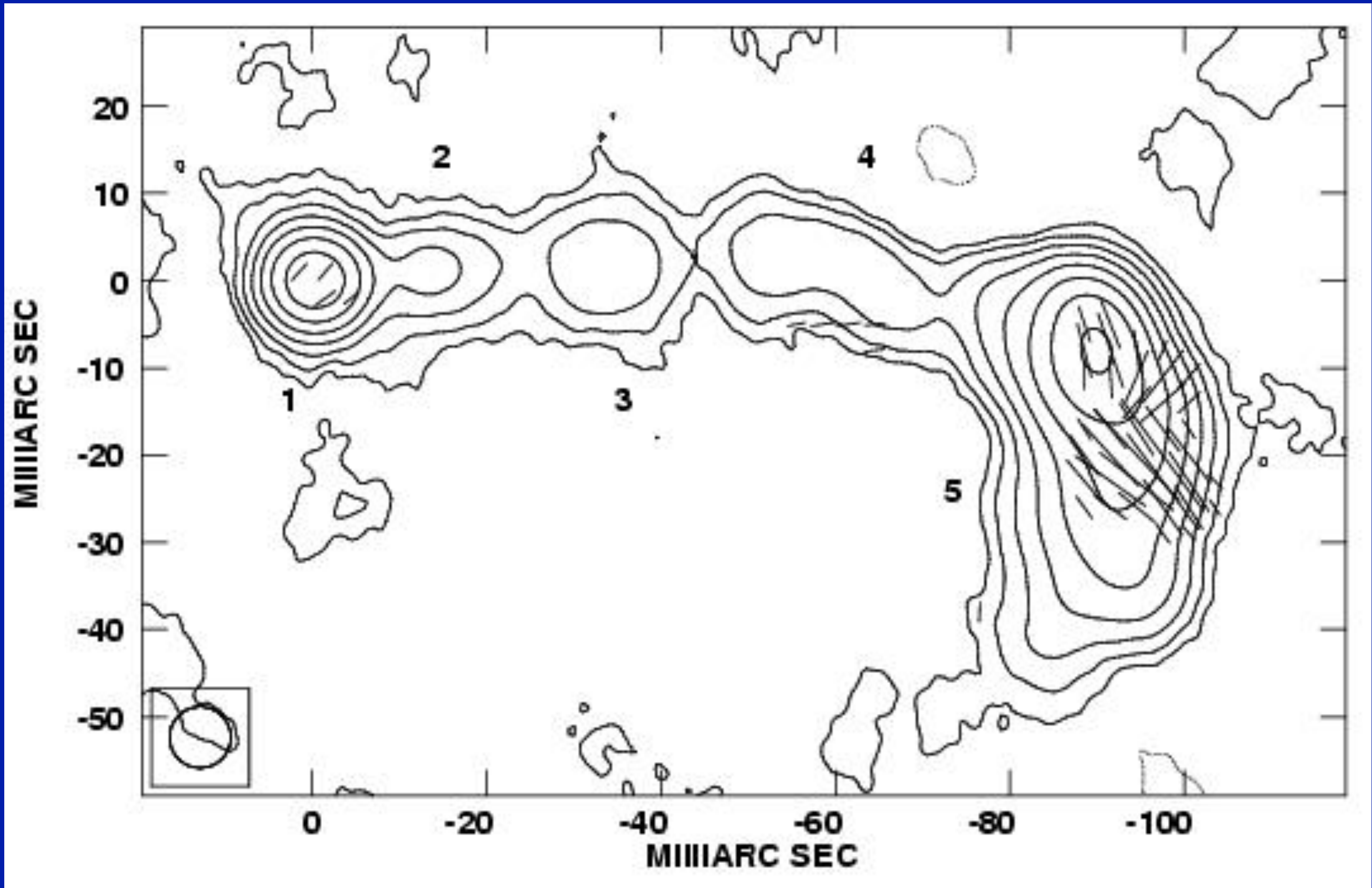


RM = – 2041 rad m^{-2}



RM = – 1457 rad m^{-2}

B0548+165 4C16.14



RM = – 4275 rad m $^{-2}$

$DP_{4.6/8.4}$ = 0.26

Distance fom the core ~ 540 pc

Mantovani et al. 2002

Comparison with pc-scale RMs in other AGNs

Most of the pc – scale RM estimates for other AGNs made for core – dominated quasars or BL Lac objects
(but 3C111, 3C120, M87)

Quasars:

core $\quad RM_{rf}$ ~ up to 10^{4} rad m^{-2} (median ~ 1860 rad m^{-2})
distance ~ 10 pc from the core

BL Lac objects:

RM_{rf} ~ 1000 rad m^{-2} (median ~ 440 rad m^{-2})

The RMs of pc – scale jets decreases rapidly:

quasars:	median value	~ 460 rad m^{-2}
BL Lac objects:	median value	~ 260 rad m^{-2}

Radio galaxies show a similar behaviour

Zavala & Taylor 2002, 2003, 2004; O'Sullivan & Gabuzda 2009

CSS sources

RM_{rf} median value ~ 5000 rad m $^{-2}$ (up to ~ 10,000 rad m $^{-2}$)

Distances from the core ~ 300 to 1600 pc

Environmental vs orientation effects

– Sub-arc and milliarcsec scale polarisation measurements:

Quasar cores more polarised than galaxy cores
BL Lac objects more polarised than the quasar cores

(Saikia et al. 1985, 1987; Cawthorne et al. 1993;
Gabuzda et al. 1992; Pollack et al. 2003)

– Arcsecond scale observations:

BL Lac and core-dominated quasars higher levels of core polarisation than lobe-dominated quasars and radio galaxies

→ Orientation effects

(attributed to depolarisation by the obscuring torus)

CSSs sources

- Cores are usually weak and polarisation is not detected
- Polarised emission detected along the jets
- Distance from the core ~ 300 to 1600 pc
- *RM* ~ 1600 to 4×10^{4} rad m^{-2} (median ~ 5000 rad m^{-2})
- Fractional polarisation decreases with decreasing frequency
- λ^{2} is closely followed

Jets interacting with dense clouds of gas in the circumstellar region of the host galaxy

Thanks for your attention