Rotation Measure Distribution in Compact Steep-spectrum Sources

Oluwasogo A. Ogungbenro and Chidi E. Akujor

Department of Physics,

Federal University of Technology, Owerri, Nigeria

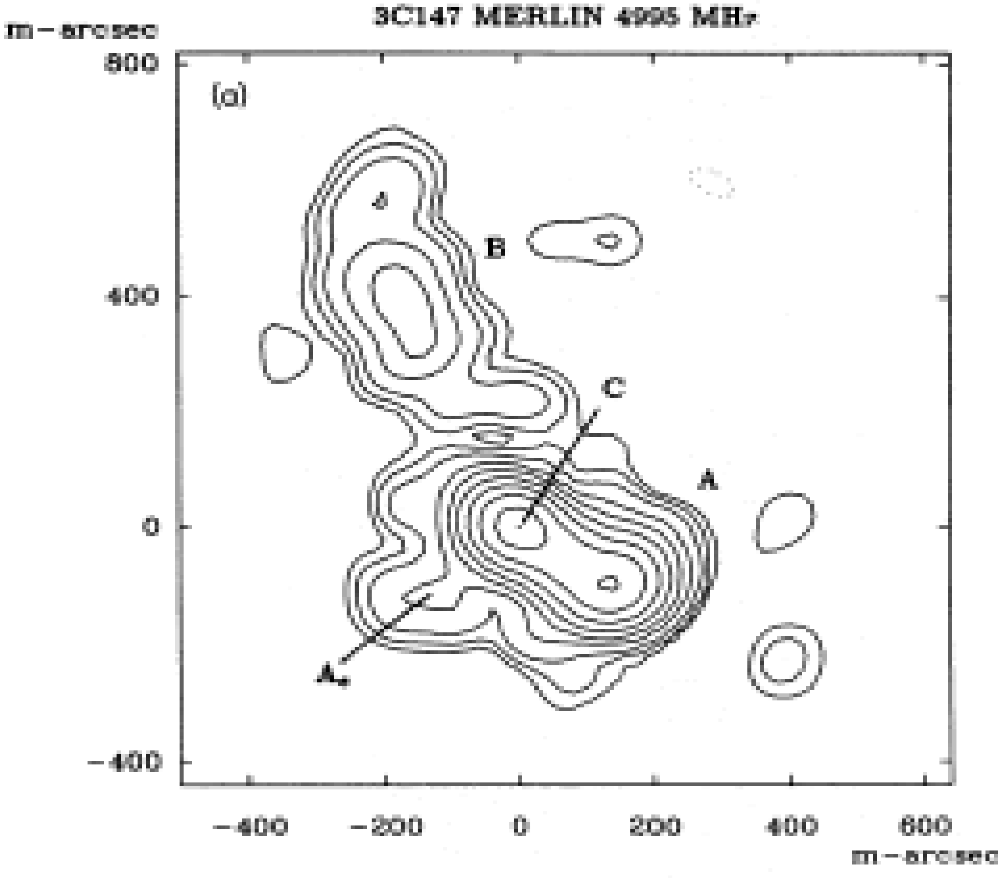
Outline of Presentation

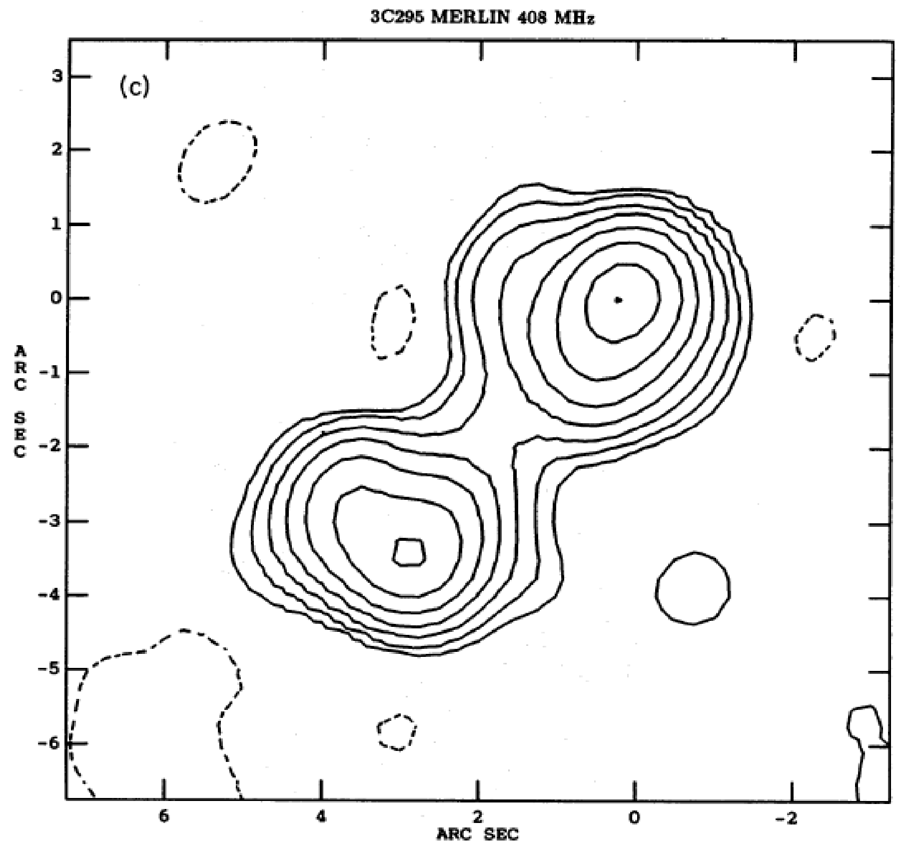
- Compact Steep-spectrum Sources
- Polarisation - Rotation Measure
- Our CSS Sample
- Results
- Discussion and Conclusion
- Further work

Compact Steep-spectrum Sources, CSSs

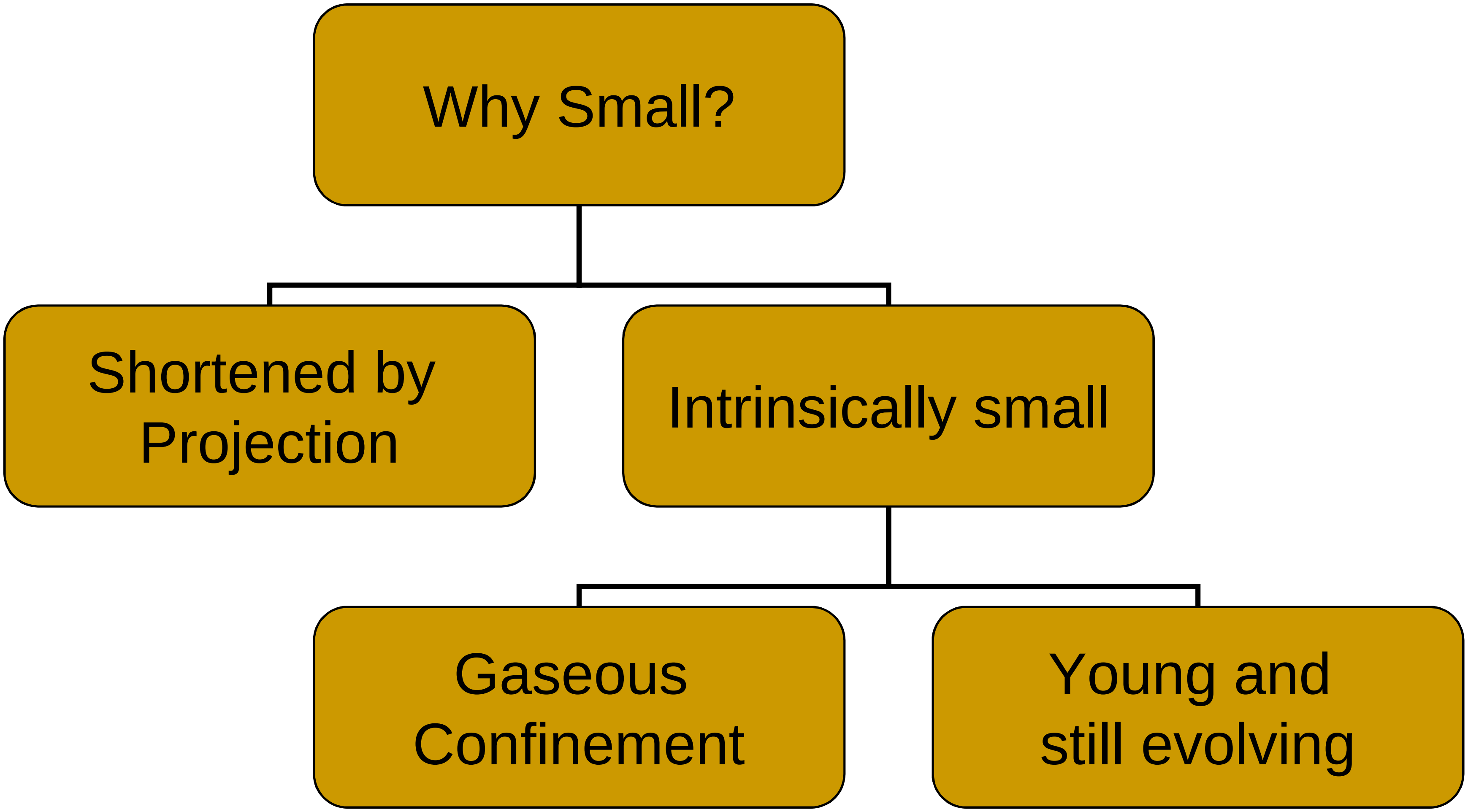
- CSSs are extragalactic radio source of
  - Sub-galactic dimension (i.e. they are small), linear sizes $\leq$ 20kpc (q_o=0 and H_o=100$Kms^{-1}Mpc^{-1}$)
  - Steep radio spectrum, spectral index $\alpha \geq 0.6$ ($S \propto \nu^{-\alpha}$) and
- They account for ~ 30% of the bright (centimeter-wavelength) radio source population with steep spectrum.

Typical CSSs





The question –
Why are they (CSSs) small?

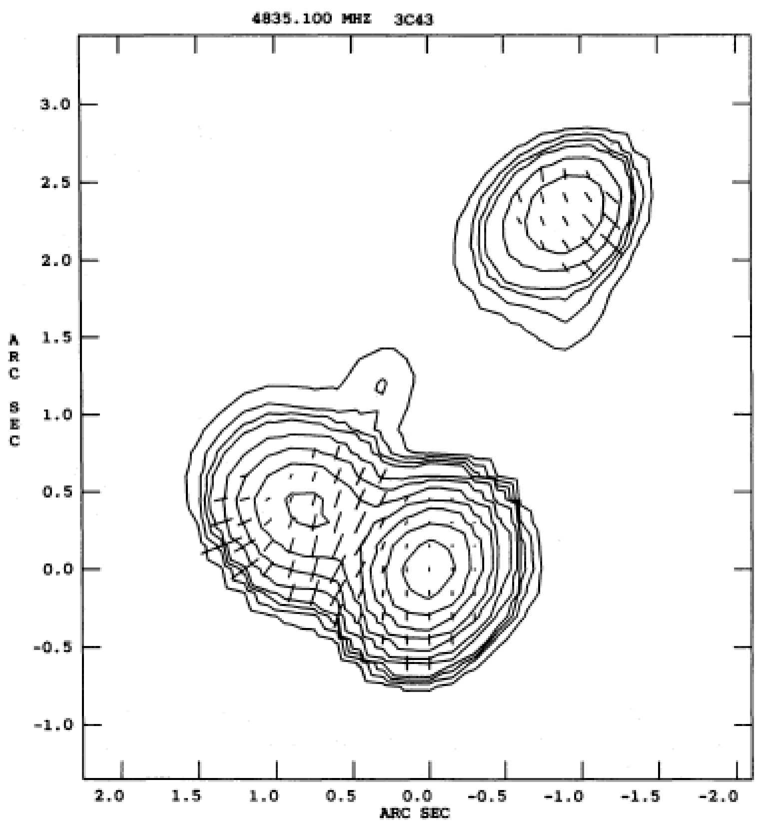


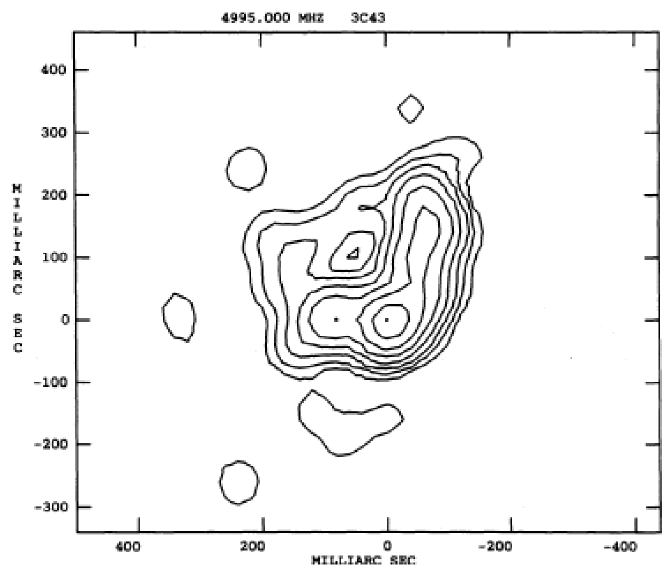
Observational results supporting hypotheses (Projection vs Beam-gas Interaction)

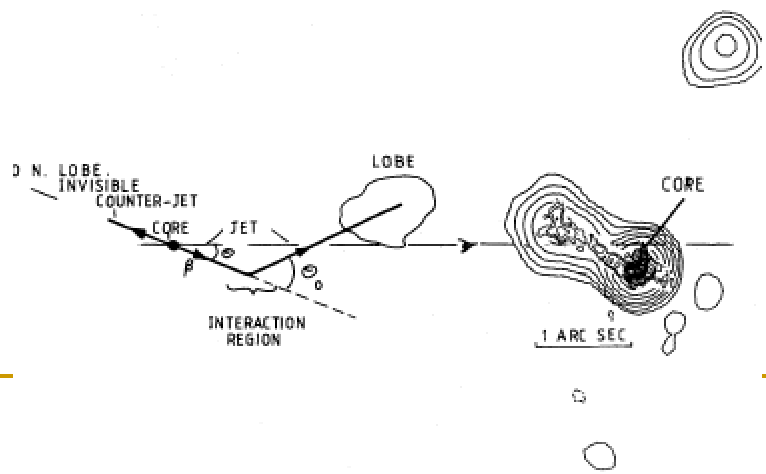
- Projection
  - Detection of one-sided Jets in CSS quasars e.g. 3C247 (Zhang *et al.* 1991, MNRAS **250,** 650).
  - Flux density difference (Quasars are brighter than galaxies) (see for example Fanti *et al.* 1990, A&A **231**, 333; Spencer *et al. 1*989, MNRAS **240,** 657; Wilkinson *et al*. 1984 IAU Symp. 110)
  - Quasars show more core dominance than galaxies (Akujor *et al*. 1991, MNRAS).
  - Superluminal motion is observed in CSS cores (Polatidis and Wilkinson 1998, MNRAS **294,** 327).
  - Detection of complex structure in quasars and extended emissions at low frequencies e.g. 3C 147 (Akujor *et al.* 1990 MNRAS **244,** 362).

- Beam – gas interaction
  - Detection of complex jets, disrupted by dense gas e.g. 3C43 (Akujor *et al.* 1991 A&A **249,** 337).
  - Observed edge-brightening in jets and hotspots.
  - The presence of flat spectrum knots
  - Observed sharp bends close to the nucleus
  - Comparable Jet pressure to those of H_{II} regions

3C43: jet deflected by dense gas







One way of investigating whether CSSs are intrinsically small or fore-shorethened by projection effect is through polarization studies/observations.

- Radiation from extragalactic radio sources in many cases are partially polarized.
- The polarization properties are conveniently specified in terms of the Stoke's parameters (I,Q,U,V)

- *I* is a measure of the total Intensity of the wave,
- *Q* and *U* represent the linearly polarized component of the intensity
- and *V* represents the circularly polarized component

- Polarisation angle, χ (or the position angle of the plane of palarisation): measured North through East
- Percentage linear fractional polarisation, m_L:
- If the Faraday rotating medium is mixed up with the emitting region, then radiation emitted from different depths along the line of sight are rotated by different amounts, thus reducing the net polarization. This is called *Faraday depolarization, DP*.

$$\chi = \frac{1}{2}\tan^{-1}\frac{U}{Q}$$

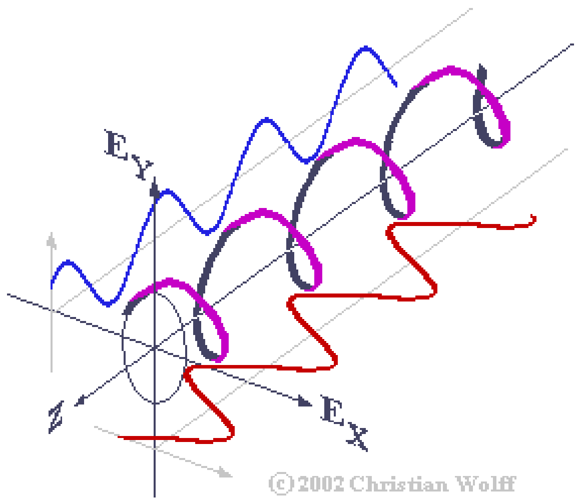
$$m_L = \frac{\left(Q^2 + U^2\right)^{1/2}}{I}$$

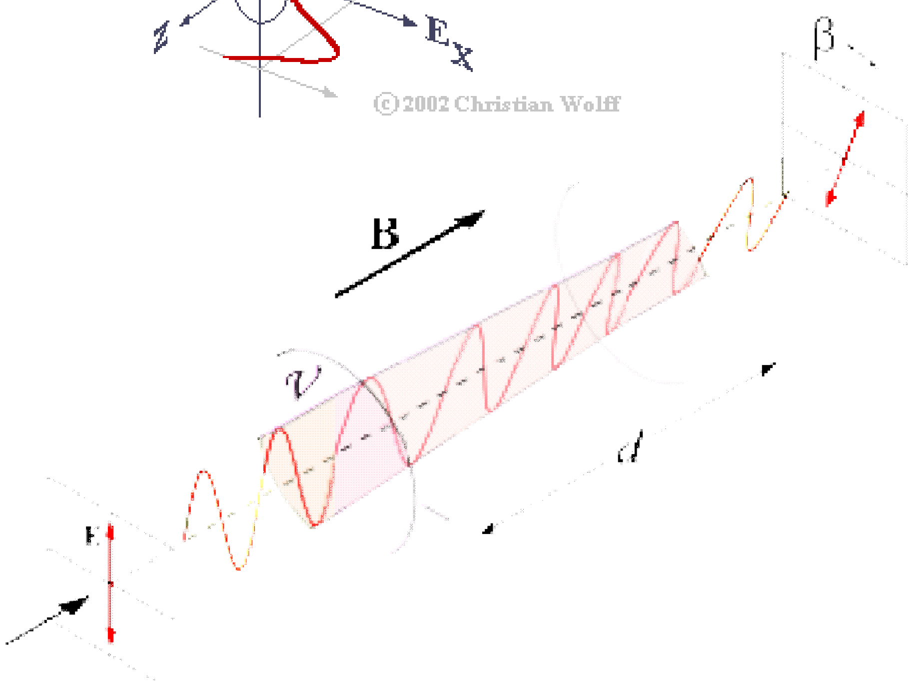
$$DP = \frac{m_{\lambda_1}}{m_{\lambda_2}}$$

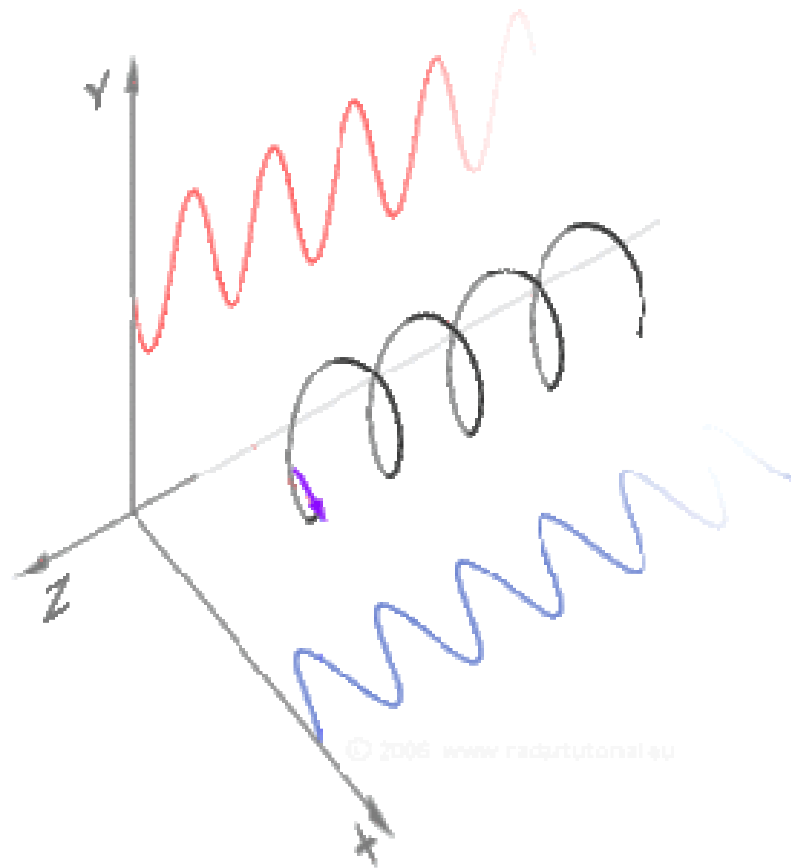
(where $m_{\lambda i}$ is the percentage linear polarization at λ_i, and $\lambda_1 > \lambda_2$).

- A linearly polarised wave can be decomposed into opposite – handed circularly polarised components
- The phase velocities of the opposite – handed waves within the material differs when the wave encounters a region containing magneto-ionic materials (i.e. plasma containing magnetic field).
- This results in the polarisation of plane of polarisation of the linearly polarised wave.

Rotation of the Plane of Polarisation







Plane of polarisation rotated

- The Polarization Angle at a wavelength λ (meters) will be rotated by an angle χ (radians)
  - N_e is electron density in the plasma in m^{-3},
  - $B_{||}$ is magnetic filed in Gaussian
  - l is the path length in parsecs

$$\chi = 8.12 \times 10^3 \lambda^2 \int_0^l N_e B_{||} \, dl$$

- From multi-wavelength polarisation observations of the Polarisation angle:

  (see Rossetti *et al.* 2009, A&A **504(3),** 741).

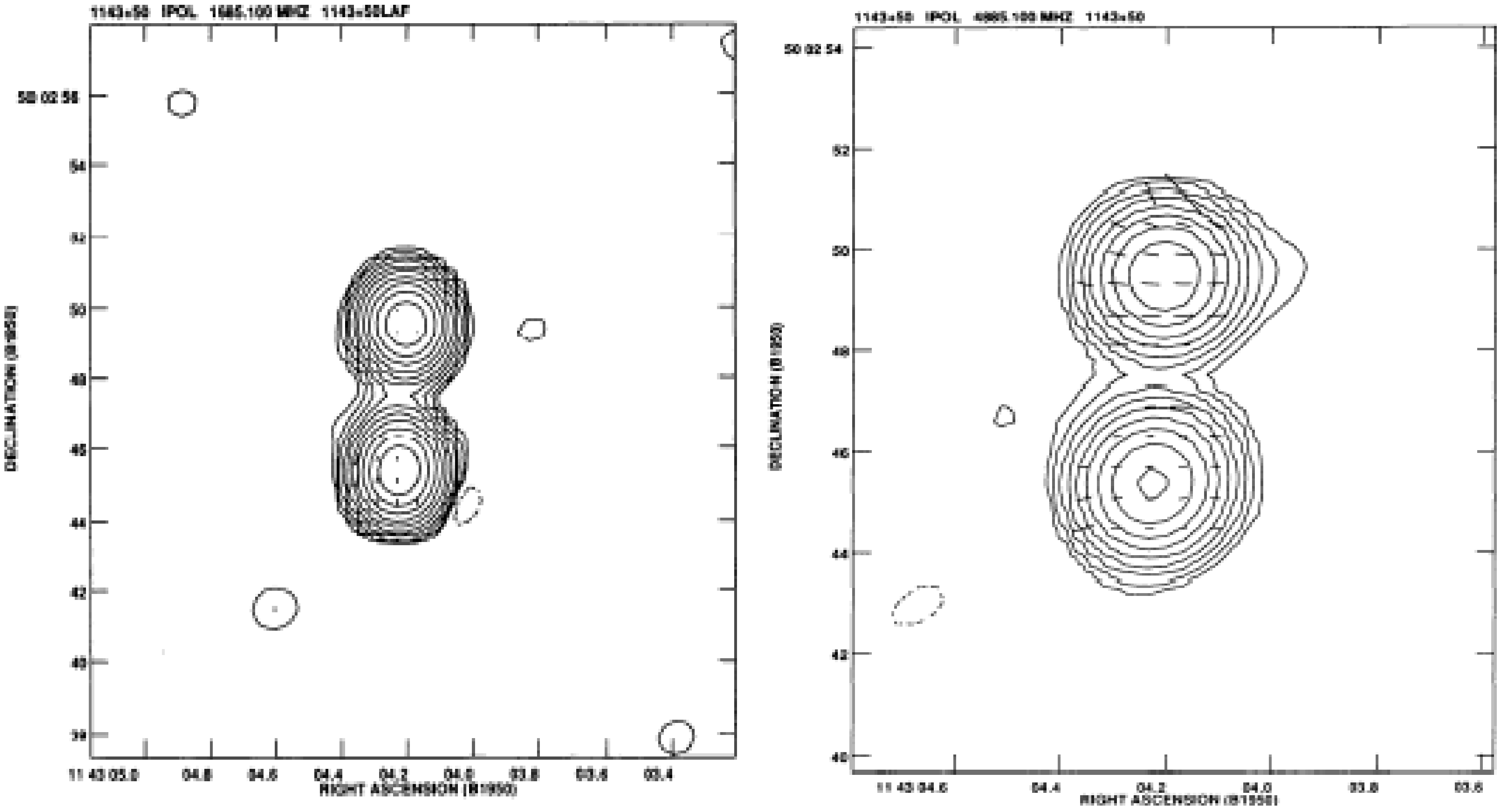
- The RM is the rotation measure and is a "polarised emission-weighted" mean of the Faraday depth ϕ

  (see Saikia and Salter 1988, A&A **26,** 93)

$$\chi(\lambda) = RM\ \lambda^2 + \chi(\lambda = 0)$$

- It is the slope of a linear fit of the polarization angle χ as a function of λ^2 and measured in *radians* m^{-2}.

Rotation of the electric field vector **E** in 3C67 for example



Why Study Rotation Measure?

- RM tells us about the density and distribution of gas around extragalactic radio sources.
  - Large RM indicate dense ISM
- We obtain an indication of the dependence of the nature of the radio source on the Interstellar Medium, ISM.

The CSS Sample

- the third Cambridge Radio Source (3CR) Catalog (Laing, Riley and Longair 1983, MNRAS **204,** 151; Spencer *et al*. 1989, MNRAS **240,** 657), and
- the Peacock and Wall (1982, MNRAS **198,** 843)

samples of extragalactic radio sources as presented in Sanghera *et al*. 1995, A&A **295,** 629).

Selection Criteria

- The sources are bright with flux density at 1.4GHz, $S_{1.4GHz} \geq 1Jy$
- The sources have steep spectrum of $\alpha \geq 0.6$
- The sources galactic latitude /b/>10^o and declination > 10^o
- The sources are of sub-galactic size, with linear size $\leq$ 20Kpc

The sample consist of:

- 62 sources
  - 28 quasars
  - 31 galaxies
  - 3 empty fields
- The core has been identified in 35% of the sample, and a possible core candidate (i.e. weak “core” which requires confirmation from further observations) has been identified in another 35% of the sample.

The sample is grouped thus:

Morphology	Galaxies	Quasars	Empty Fields	Total
Triples	17	18	1	36
Doubles	11	6	1	18
Core-Jet / Complex Sources	3	4	1	8

Polarisation Data

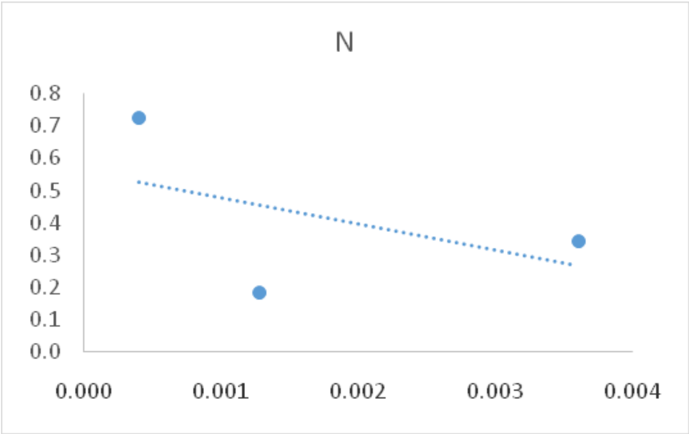
- Obtained from available polarization data over a frequency range of 1.3 – 22GHz.
- Only about 58% of our sample show polarization in at least one of its components.

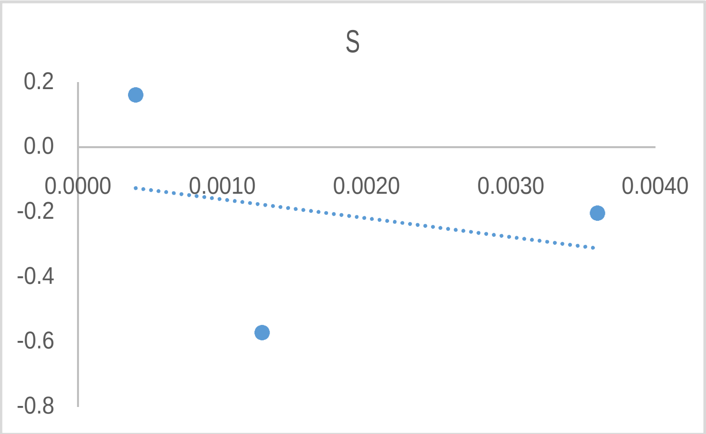
- Consequently, we obtain RM for the components of 26 sources
  - 12 quasars
  - 14 galaxies

- This translates into 60 components (consisting of
  - 8 core components
  - 2 jet components (of 3C287 and 3C343.1)
  - 50 lobe components

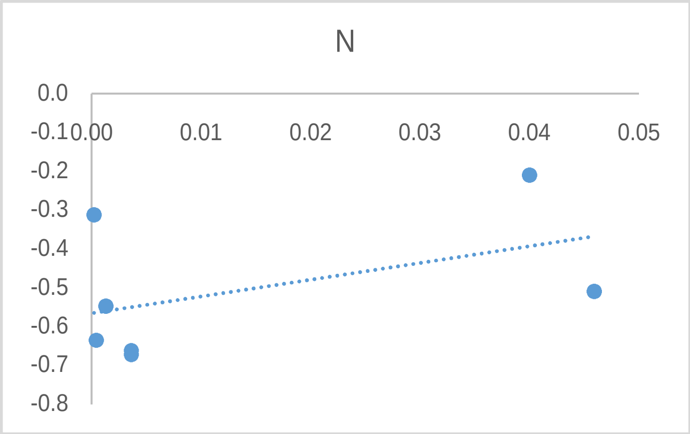
Some of the plots of rotation measure of the components of the CSS sample

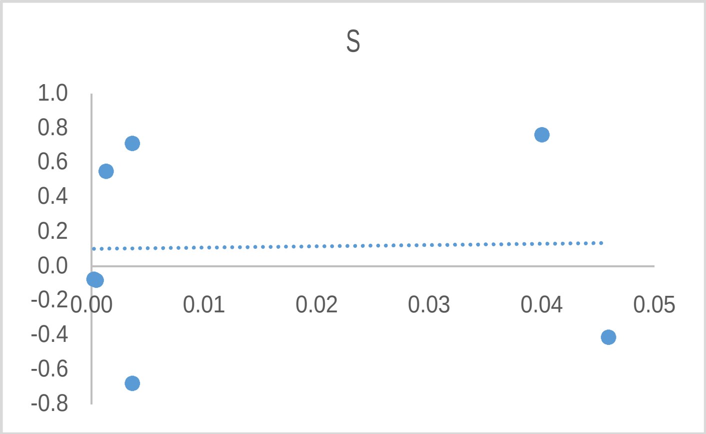
3C43



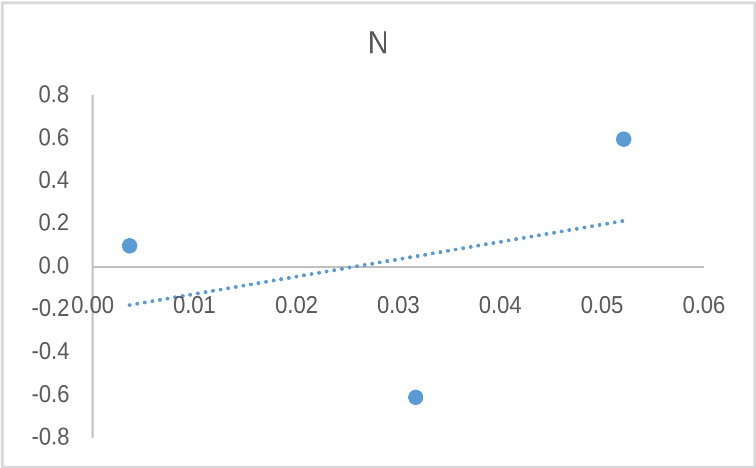


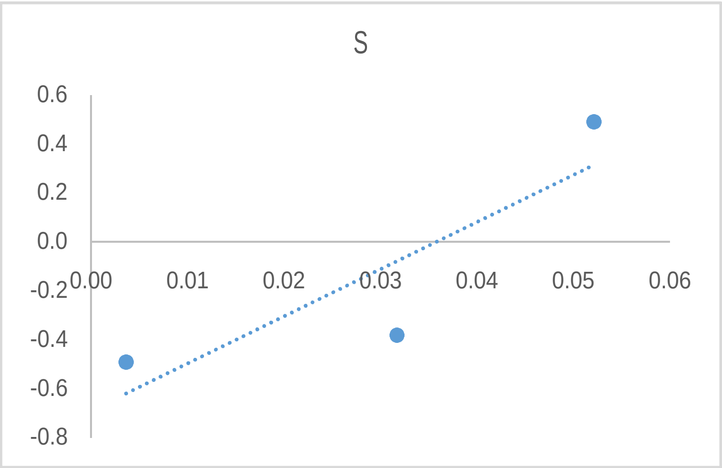
3C67



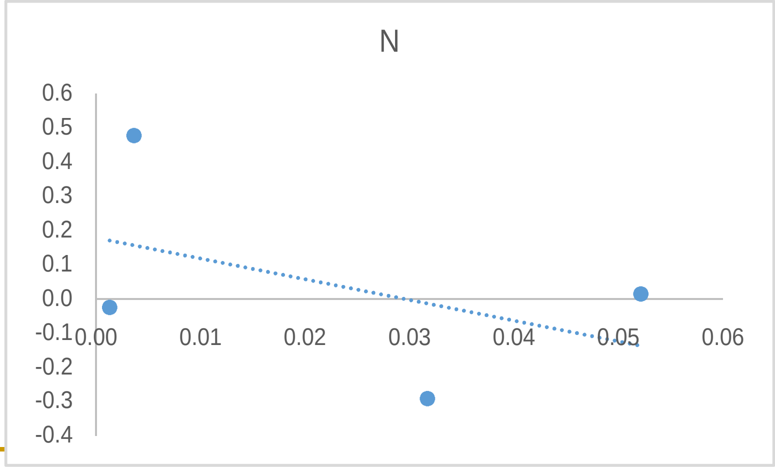


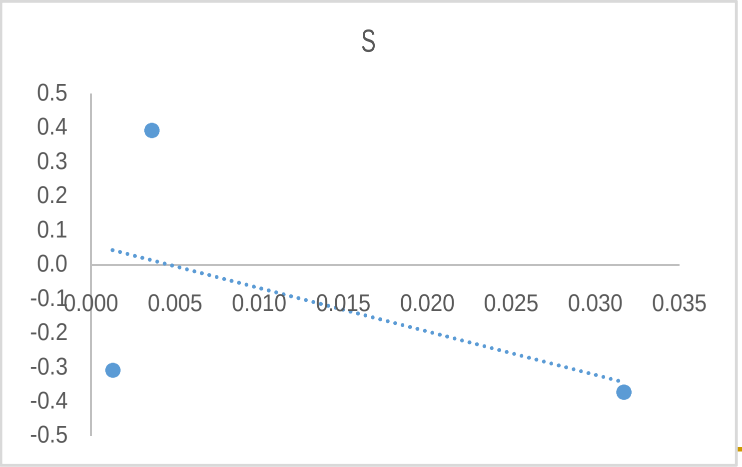
3C190



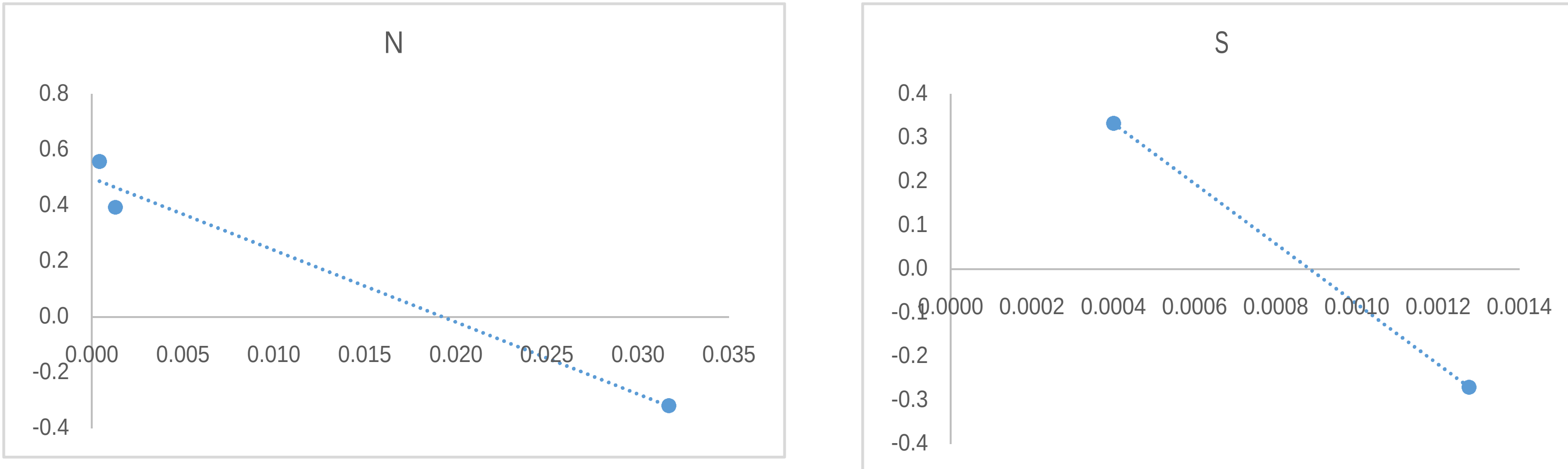


3C213.1





3C216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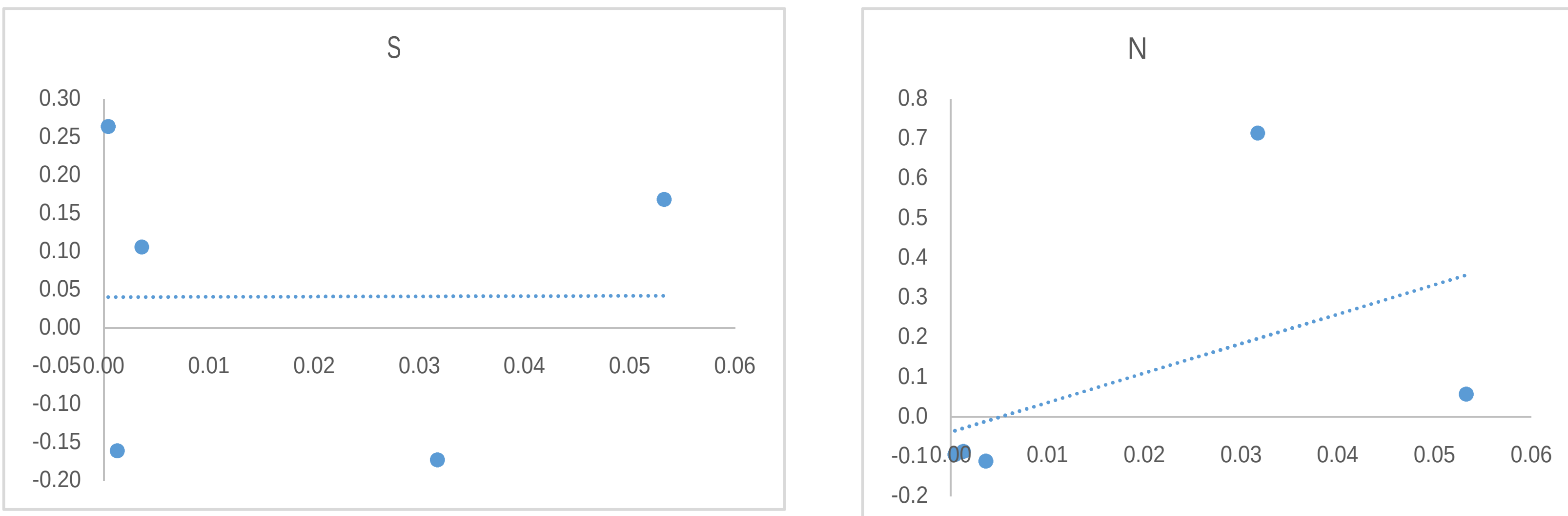
0.6
0.4
0.2
0.0
-0.2
-0.4
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
S
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
0.0014

3C266


S
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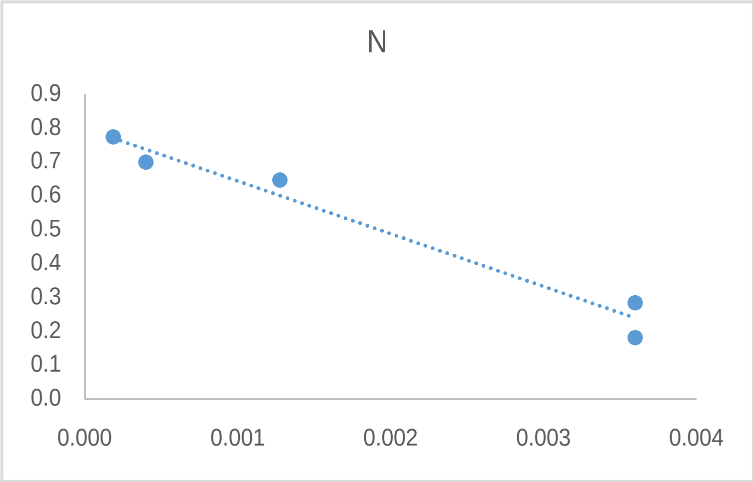
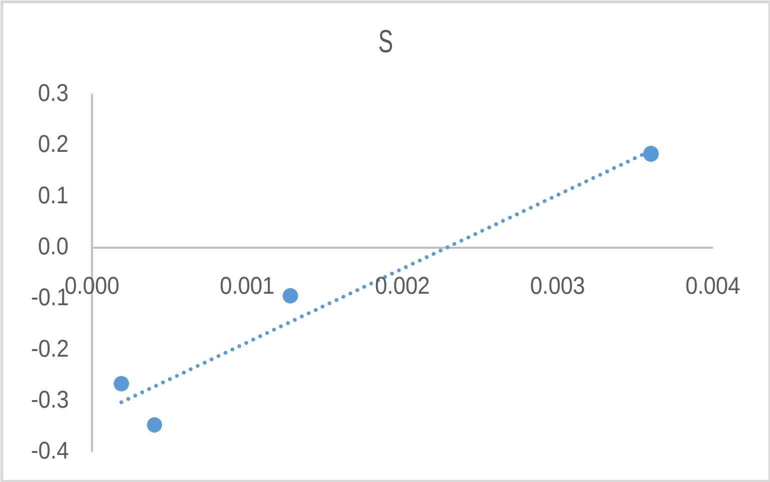
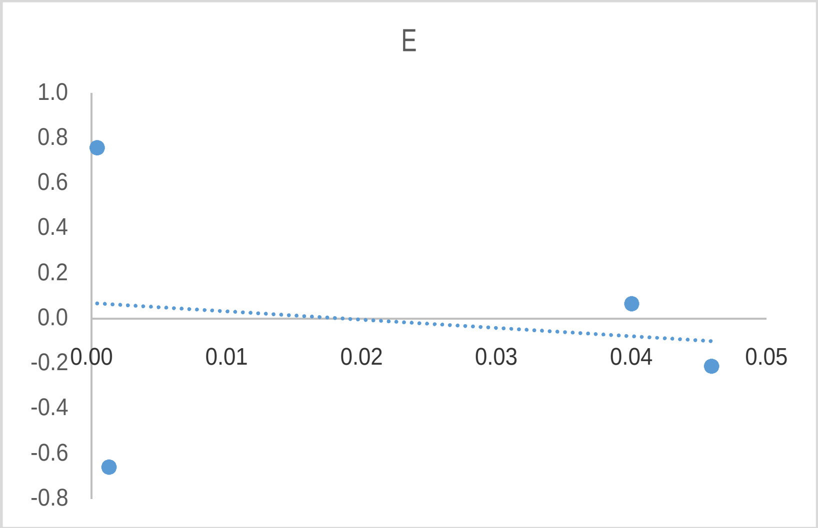
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0.00
0.01
0.02
0.03
0.04
0.05
0.06
N
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0.00
0.01
0.02
0.03
0.04
0.05
0.06

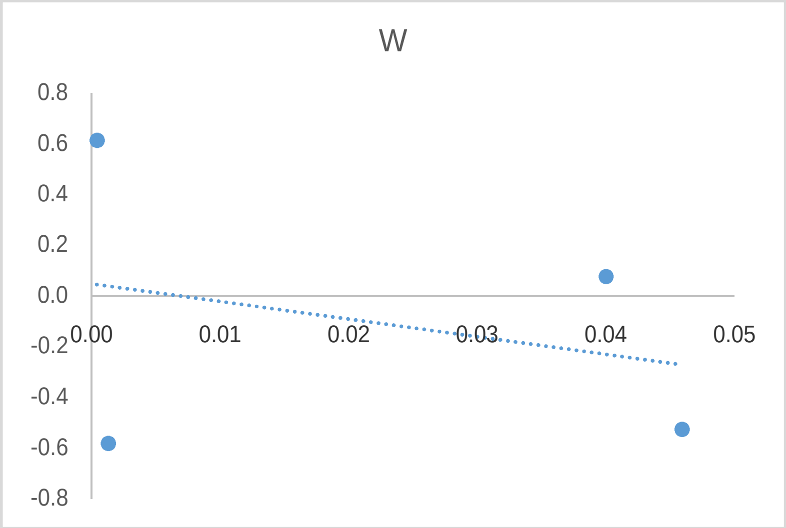
3C268.3



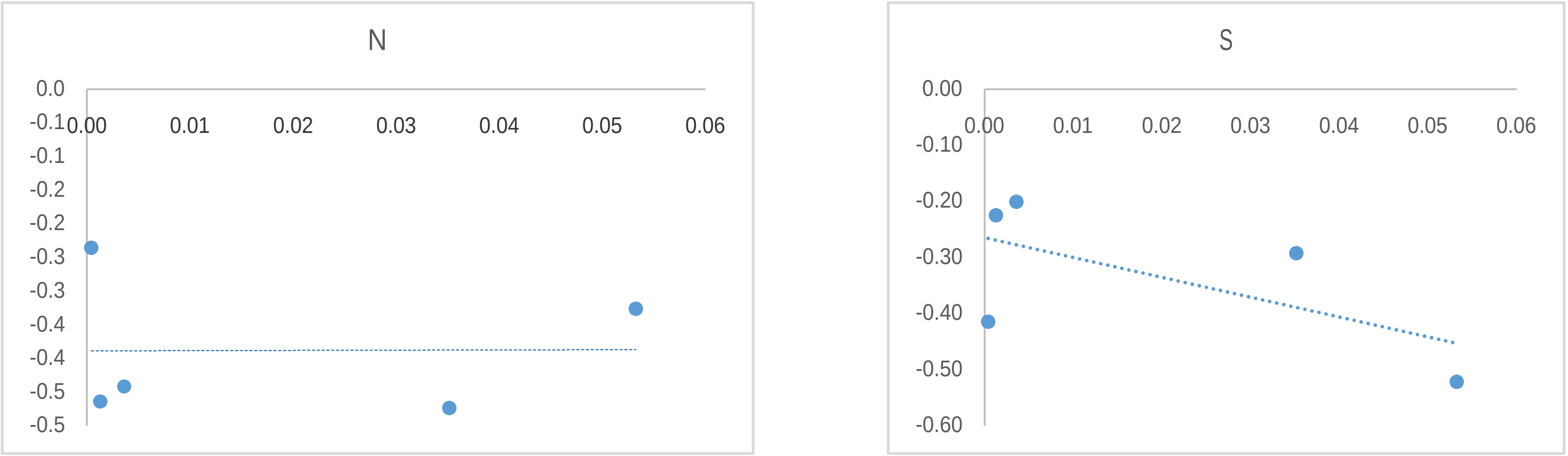


3C298

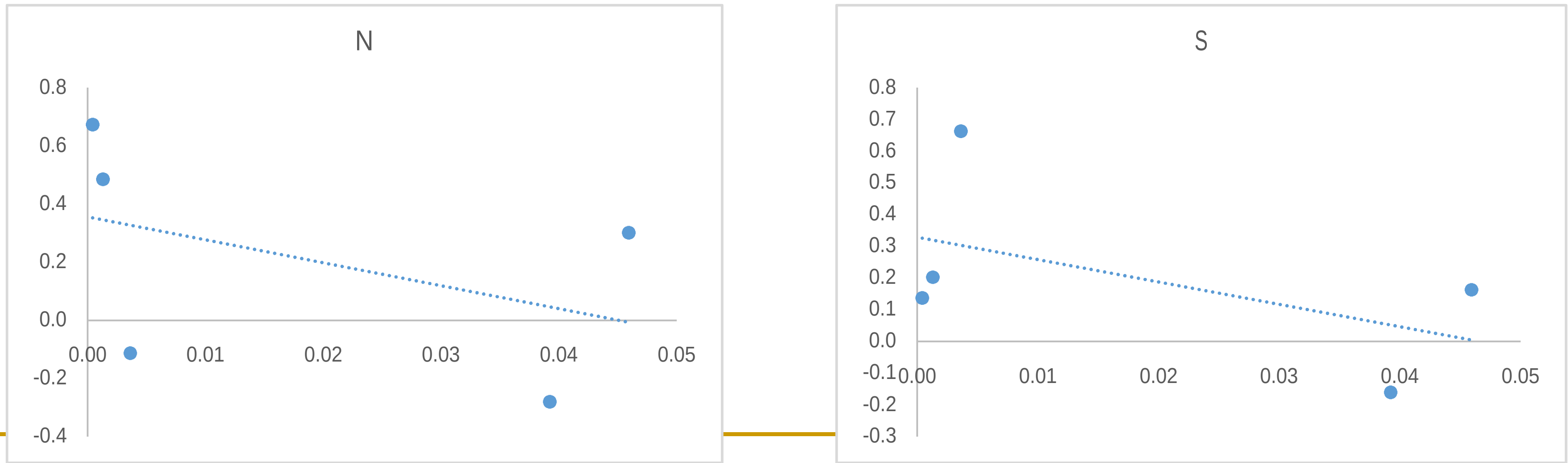




3C299



3C305.1



Results

- Nine sources (3C48, 3C49, 3C147, 3C191, 3C216, 3C237, 3C241, 3C277.1 and 3C318) show large absolute source frame RM > 1000 $rad\,m^{-2}$ in either of or both lobe components;
  - similar high (rest frame) RM have been observed for the entire source of 3C147, 3C216 and 3C318 (see for example, Taylor, Inoue and Tabara 1992, A&A **264(2),** 421; Nan *et al.* 2000, A&A **357,** 891; Mantovani *et al*. 2009, A&A **502,** 61; Rossetti *et al*. 2009, A & A **504(3),** 741).
- 3C241 (a galaxy) shows almost a symmetric (rest frame) RM for both lobes

Results cont. (Rotation Measure)

- 15 sources (9 galaxies, 6 quasars) show greater absolute *RM* on the jet side.
  - Implies denser gaseous medium / environment on the jet side?
- 10 sources (5 galaxies, 5 quasars) show greater *RM* on the counter-jet side.
  - Implies denser gaseous medium / environment on the counter jet side?

Results cont. (Rotation Measure)

- We obtain absolute (rest frame) rotation measure median values of
  - ~110.23$rad\,m^{-2}$ and 96.51$rad\,m^{-2}$ for the jet and counter-jet side lobe components respectively (for the entire sample).
    - Implies asymmetry in the ISM around these sources
  - ~195.86$rad\,m^{-2}$ and 351.11$rad\,m^{-2}$ for the jet and counter-jet side lobe components of the CSS quasar sub-sample
    - Implies asymmetry in the ISM around these sources
  - 43.00$rad\,m^{-2}$ and 35.20$rad\,m^{-2}$ for the jet and counter-jet side lobe components of the CSS galaxy sub-sample.
    - Implies asymmetry in the ISM around these sources

Results cont. (Rotation Measure)

- The CSS quasars sub-sample show greater average RM difference between their lobes than the CSS galaxies;
  - On the average, we found RM difference values of
    - ~13.72 $rad\,m^{-2}$ for the entire sample
    - ~155.25 $rad\,m^{-2}$ for the CSS quasar sub-sample
    - ~7.8 $rad\,m^{-2}$ for the CSS galaxy sub-sample.
  - Is this suggestive of orientation effect? since we have more RM difference value in quasars than galaxies

Results cont. (Rotation Measure)

- The result (i.e. asymmetry in lobe RM) shows that:
  - The environment around CSS quasars may be denser than that around galaxies.
  - the density of the gaseous medium around (jet side and counter-jet side) lobes may be different.
- The observed greater difference in RM between the jet side and the counter-jet side lobes of the CSS quasars than that of CSS galaxies may be taken at first thought to be a consequence of projection effect.
  - if this is the case, we would expect a strong anti-relationship between RM and α;
  - a strong positive relationship between RM and α would also mean that the asymmetry in lobe RM is predominantly intrinsic in nature.

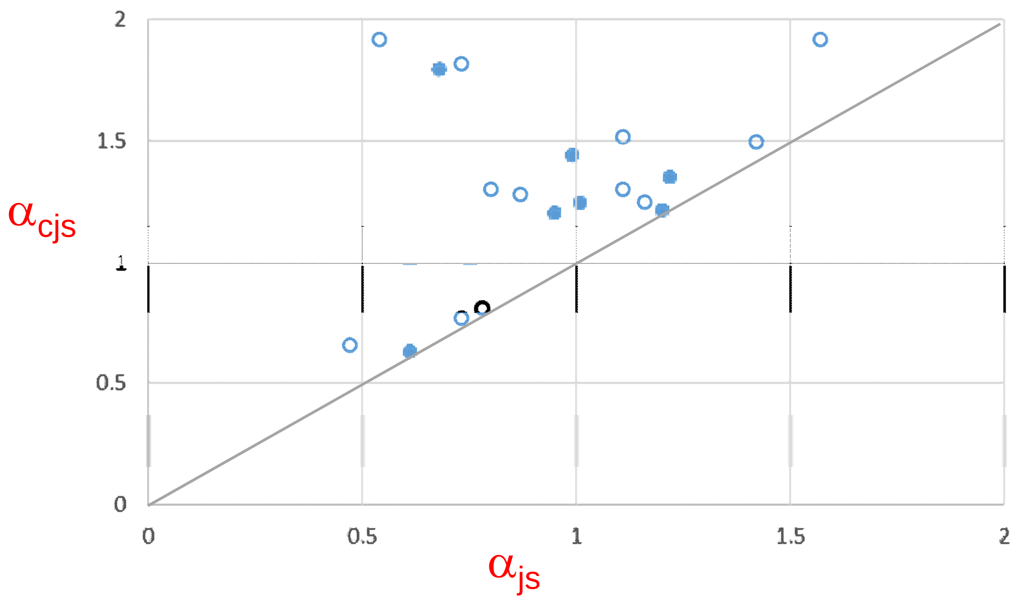
Spectral Index

- Consequently, we also determine the spectral index, α for each lobe component using the total flux at two frequencies; $S \propto \upsilon^{-\alpha}$

Results cont. Spectral Index

- For sources with no detectable jet, we chose jet side based on the spectral index of the lobe components, $\alpha_{js} < \alpha_{cjs}$
  - The CSSs sample has spectral index median values of ~0.80 and ~1.24 for the jet and counter-jet side components.
  - The quasar sub-sample has spectral index median values 0.84 and 1.30 for the jet and counter jet side components.
  - The galaxy sub-sample has spectral index median values 0.80 and 1.09 for the jet and counter jet side components.

Component spectral index of the counter-jet side versus the jet side (• galaxies ◦ quasars); the drawn line at 45° to the normal denotes symmetry.



Results (Spectral Index Asymmetry) cont.

- We define $\Delta\alpha = \alpha_{cj} - \alpha_{j}$ as the difference in spectral index between the two components
  - Median spectral index difference of 0.27 and 0.23 were obtained for the CSS quasar sub-sample and CSS galaxy sub-sample
    - Implies a clear asymmetry in the spectral index distribution in the radio components of these sources (irrespective of whether they are quasars or galaxies).
  - This result agrees with Liu and Pooley (1991, MNRAS **249,** 343) and Garrington, Conway and Leahy (1991, MNRAS **250,** 171) findings for a samples of double radio sources with one sided jet and that of powerful radio sources.

Results (Spectral Index Asymmetry) cont.

- Liu and Pooley (1991, MNRAS **249,** 343) and Garrington, Conway and Leahy (1991, MNRAS **250,** 171) noted that the spectral asymmetry is intrinsic, i.e. it is not due to any aberration such as orientation or beaming.

Results (RM and α correlated) cont.

- We found very weak correlations between RM and α for both sub-samples.
- The RM asymmetry may not be a consequence of orientation neither is it predominantly intrinsic in nature
- It may be traced to beam gas interaction!

Conclusion

- Consequently, CSS may have been confined to their small sizes by their environment as much as they may be young also and be expected to evolve with time.

Further Work

- There is the need for imaging of more CSSs at resolutions comparable to the radio using the VLA and the VLBI in order to boost the sample.
- The same observational survey and analysis should be done for a sample of the more extended powerful radio sources.

Thank you!