A COUNTER-JET IN THE QUASAR 1049 +616?

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Abstract

Multi-frequency and high fidelity radio observations of the quasar 1049 + 616 have been made in the frequency range 1.3 - 8.4 Ghz with the NRAO'S VLA and Jodrell Bank's MERLIN. Our new images reveal a prominent knotty jet and a possible counter-jet with an identifiable knot. The jet-to-counter-jet brightness ratio is ~ 39. In the context of the relativistic beaming hypothesis, this implies a value of bcosq ~ 0.62, which is consistent with its degree of core prominence.

Keywords: *Quasars, jets, counter-jets.*

1. Introduction

The twin-beam model of extra-galactic radio sources (Blandford and Rees, 1974) assumes that the central engine produces a pair of highly collimated, oppositely directed outflows that are continuous and symmetric (Lovelace et al., 2005). This has been observed as jets and beams in high resolution radio observations of most quasars and radio galaxies made with MERLIN and the VLA. But, so far, only a few clear and unambiguously two-sided jets have been detected in high luminosity radio sources they are usually one-sided as would be expected if the approaching jet is enhanced due to 'Doppler beaming' (Bridle and Perley, 1984). This implies that counter-jets, although fainter could be detected in very sensitive maps. But concerted efforts (Bridle, 1990) to find counter-jets have yielded only "pieces of counter-jets" in quasars. Indeed, the only good examples of counter-jets so far reported are from relatively nearby radio sources; Cygnus A and 3C353; and the compact steep spectrum source B1524-136 (Mantovani et al., 2003).

In this paper, we report our recent observations of the quasar 1049+616 made with Jodrell Bank's MERLIN (UK) and the VLA (USA), which show the possible presence of a counter-jet. This may be one of the first clear cases of a counter-jet feature that is continuous and connects the core to the counter-jet side of a quasar.

The quasar 1049 + 616 is a powerful (m_v~16.48; Z~0.42; Wills 1974, Wills et al., 1973) double lobed radio source and one of the objects found in the Jodrell Bank's 966 MHz survey (Reid et al., 1995).

2. Observations

The observations were made with the VLA in A and A/B configuration at 1.3, 1.6 and 1.7 GHz and 8.4GHz and in B configuration at 5GHz in order to match the resolution at 1.7GHz. We also observed 1049+616 with MERLIN 2 at 5GHz (Table 1).

The MERLIN 408MHz observations were made with the original array while 5GHz observations were made with the new (upgrade) MERLIN 2 system. The system allows for polarization observations using 6 telescopes including the new 32m dish at Cambridge (Thomasson, 1986). This is a full track observation of about 17 hours at 408MHz and 14 hours at 5GHz.

Table 1: Details of observations

TELL	Freq (GHz)	Configuration	Duration	Date
VLA	1.3	A	5 Min	11/31 Aug., 1991
	1.7	A	5 Min	11/31 Aug., 1991
	5	A	5 Min	11 Aug., 1991
	5	B	5 Min	29 Nov., 1992
	8.4	A	5 Min	11 April, 1990
			5 Min	31 Aug, 1991
MERLIN	0.4		12 hr	10 July, 1981
	4.9		17 hr	29 June, 1992

We have also made a combined VLA and MERLIN map at 5GHz using the usual procedure well developed by Shone et al. (1985), Zhang and Akujor (1996).

3. Results

a. Total intensity structure.

The lower resolution maps (Figs. 1a, b & c) show a fairly double asymmetric structure at all frequencies. At high resolution, our 8.4GHZ map (Fig. 2) clearly gives details of a bright jet and an indication of a counter-jet dominated by a bright knot which is connected to a spur in the counter-lobe. This is consistent with our 5GHz VLA map (Reid et al., 1995). In the higher resolution MERLIN map at 5GHz (Fig. 3a) the counter-jet knot is barely detected obviously due to the absence of short-spacing in the array. But we have combined the VLA and MERLIN data to obtain a vastly improved map (Fig. 3b which clearly shows the counter-jet knot and the counter-lobe spur. The bright knot of the counter lobe is inclined to the main axis of the counter-jet, a trend that is common with the knots of several observed jets. The jet is marked by a bright knot whose axis is also almost perpendicular to the main jet. (the colour grey-scale plot of the structure is shown in Plate 1).

b. Ploarization structure

The polarization structures at low resolution are as shown in images in Figs. 1a, b & c We have estimated the mean (vector) fractional polarization, $m = [(\Sigma Q)^2 + (\Sigma U)^2]^{1/2}/\Sigma I$, the associated mean position angle $\chi = 0.5\tan^{-1}(\Sigma U/\Sigma Q)$ and $DP = M_{20}/M_6$.

The quasar, 1049 + 616, shows depolarization asymmetry as in extended radio sources (Garrington and Conway, 1991; Liang, 1988; Garrington et al., 1988). The counter-jet side is depolarized at lower frequencies with DP~0.52 (Table 2).

As in Garrington and Conway (1991) we estimated the Faraday dispersion as $\nabla \sim 709(1+Z)^2(-\ln DP)^{1/2}$; which is the rms Faraday depth $\phi = \int neB.dl$, while the rotation measure, RM, is estimated as: $RM = \chi/\lambda^2 = 8.1 \times 10^5 \int^1_0 N_e B_{II} dl$, where χ is the polarization position rangle, λ is in meters, N_e = thermal electron density, BII is in gauss and dl in parsec, (Garrington et al., 1991). There is little faraday dispersion on both sides. We obtain RM~115±10radm^{-2} and <5radm^{-2} for the counter-jet and jet sides respectively.

Table 2: Polarization of the jet and counter-jet sides.

	5GHz (%pol)	1.6GHz (%pol)	DP	RM (radm^{-2})	(cm^{-3} ΔGpc)
N	1.35	0.7	0.52	115 10	2400
S	3.82	3.2	0.84	<5	1242

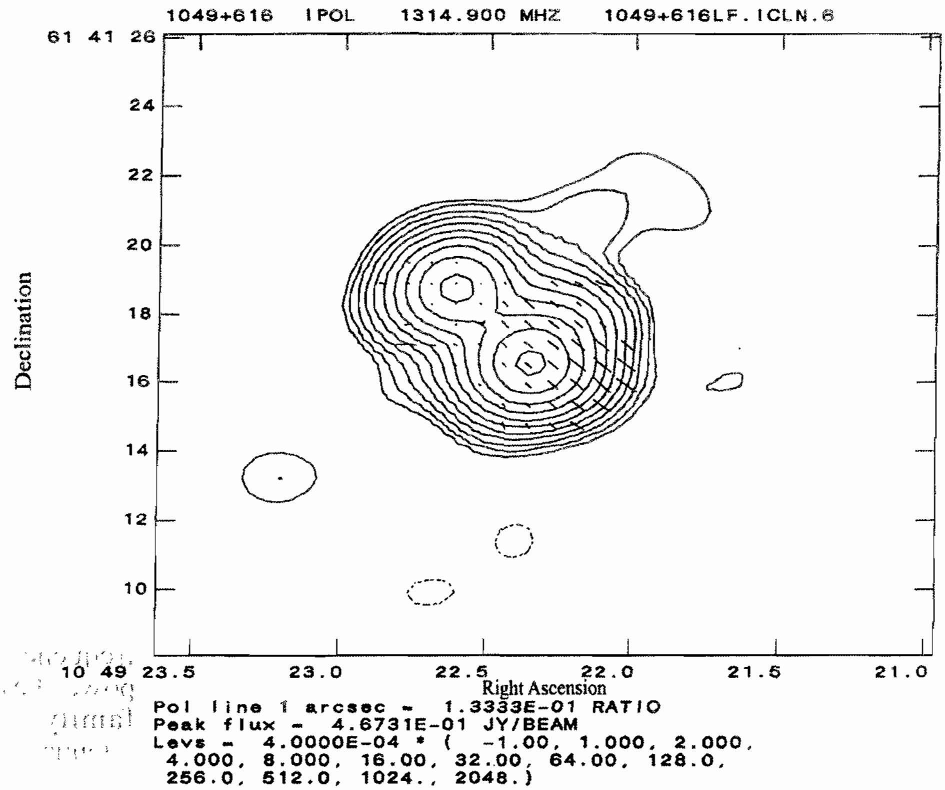

Fig 1(a): VLA 1.3GHz polarization and total intensity map of 1049 + 616

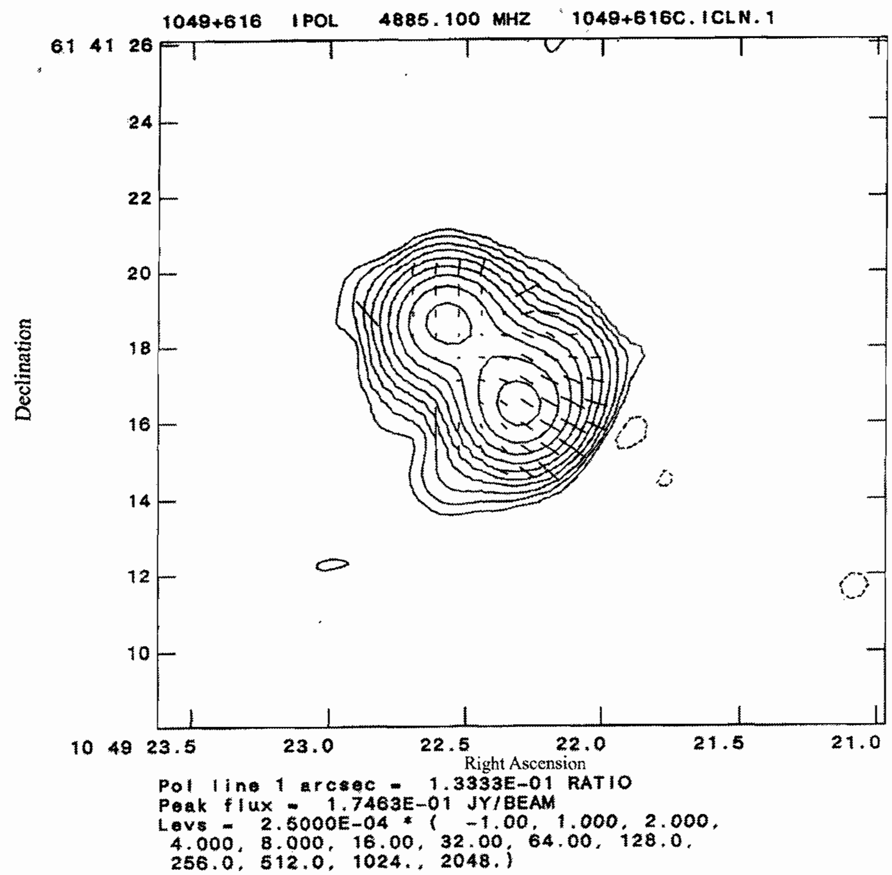

Fig. 1(b): MERLIN 4.9GHz polarization and total intensity map of 1049 + 616.

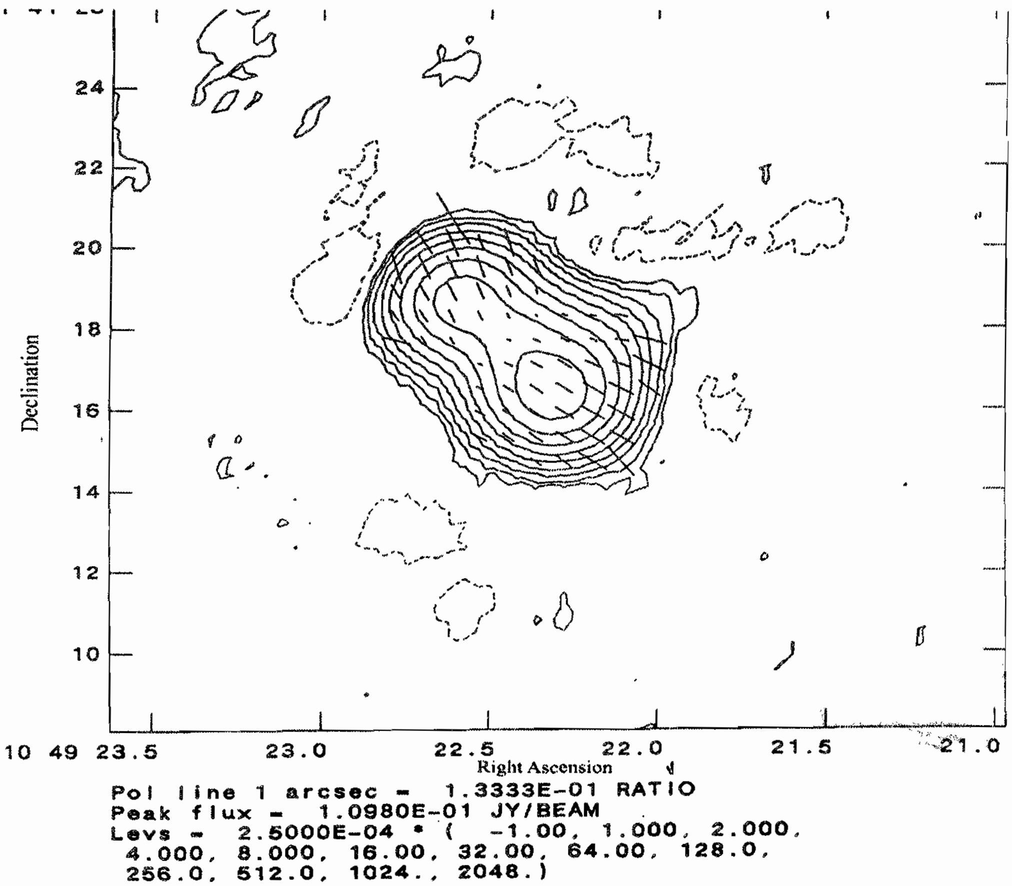

Fig. 1(c);VLA 8.4GHz polarization and total intensity map of 1049 + 616

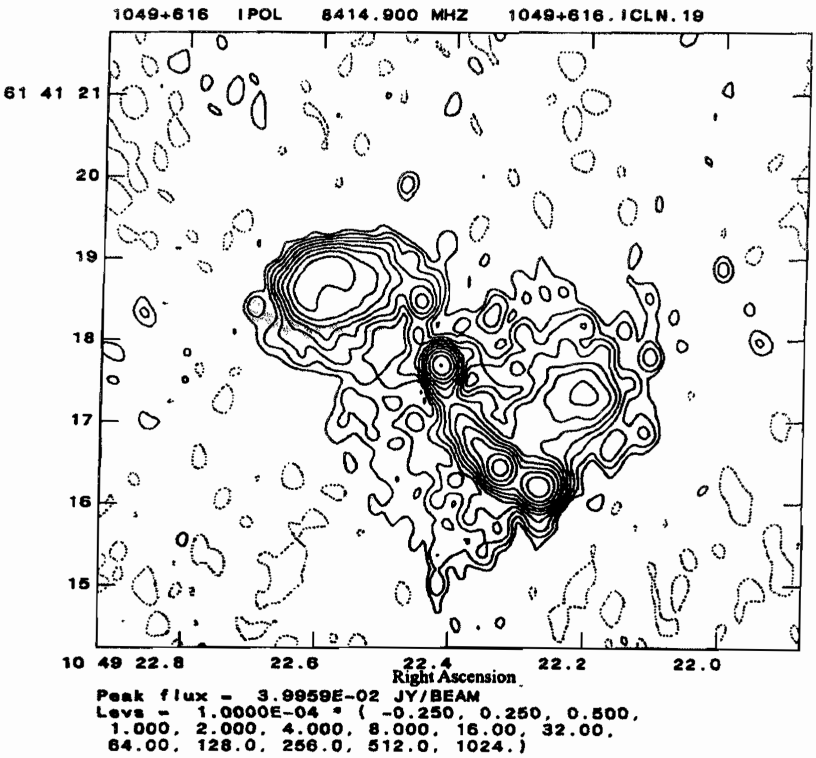

Fig. 2:VLA 8.4GHz map of 1049 + 616 with peak brightness of 30mJ/beam.

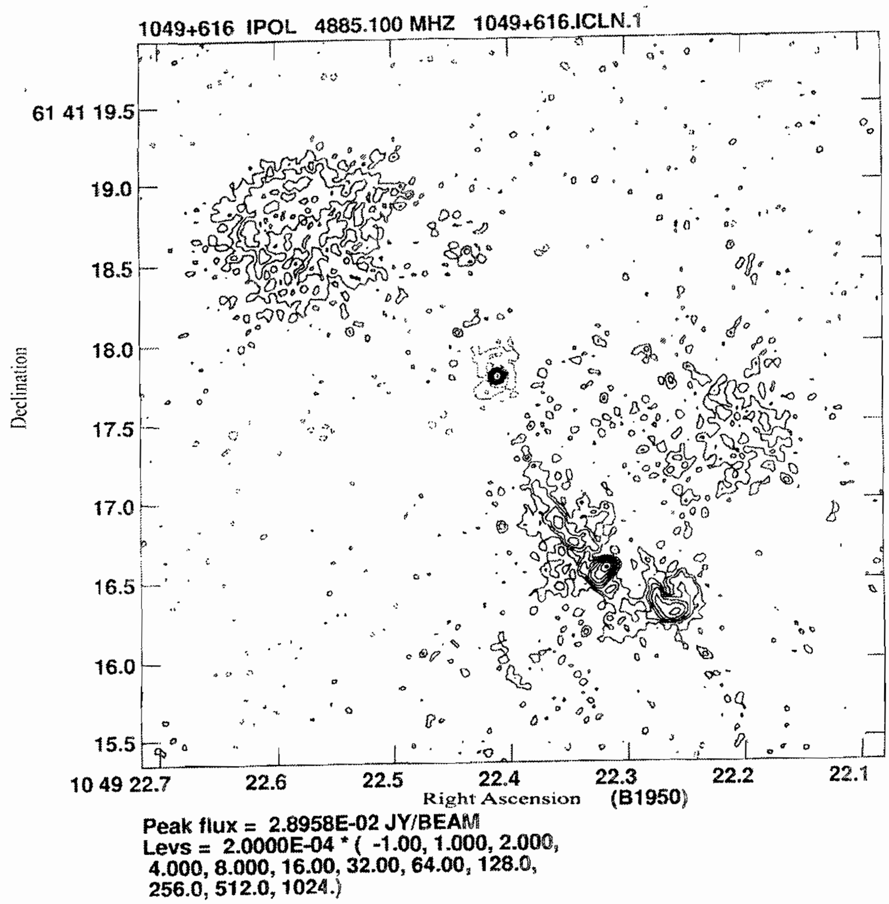

Fig. 3(a): A.MERLIN 4.9GHz map of 1049 + 616 with a peak brightness of 29mJ/beam.

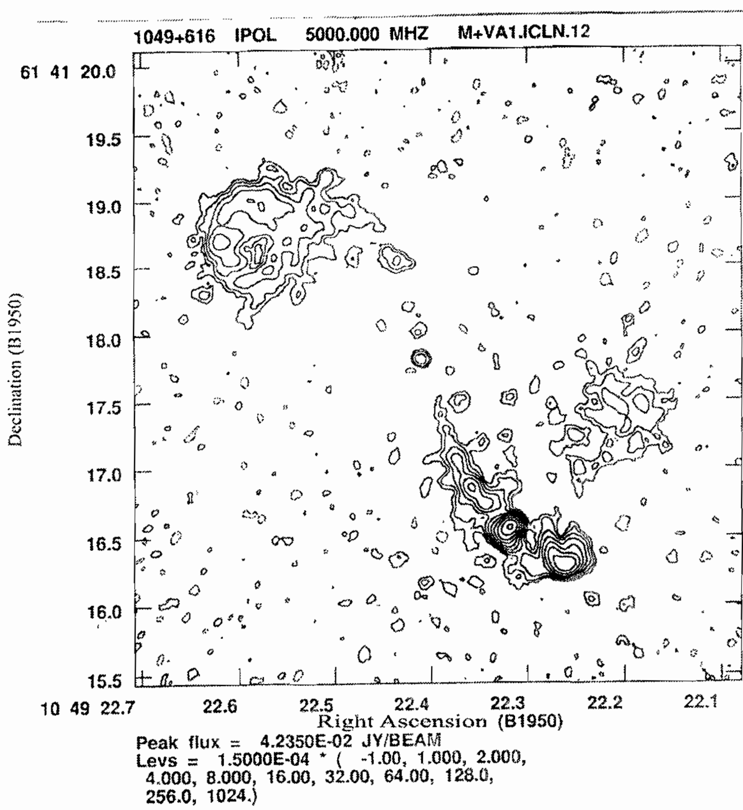

Fig. 3(b): VLA + MERLIN 5GHz map of 1049 + 616 with a peak brightness of 42mJy/6161

At high resolution, polarization is detected at the bright jet knot and the hotspot (Fig. 4). At the knot the polarization position angle (of projected magnetic field) has two components, one parallel to the jet structure and the other being perpendicular. This is likely due to a twist in the jet structure at the knot. Such a twist may arise if the jet is precessing. Such a precessing jet model has been used to explain the observed remarkable jet of the quasar 1150 + 497 (Akujor and Garrington, 1991). Polarization is also detected at the hotspot where the projected magnetic field is parallel to the edge.

4. Discussion

Does the feature on the North-East qualify as a counter-jet? Bridle (1990) criteria for "jet-hood" include a "4:1" elongation of the feature and a brightness contrast of the feature relative to the lobe emission. From our most sensitive VLA map at 8.4GHz, the counter-jet feature has a width 0."2 and length 0."9 which gives an elongation of 4.5:1. The counter-jet has a clearly defined length that is not embedded in the counter-lobe with a total flux density of 1.46mJy (peak = 1.005mJy/beam). In the VLA maps the counter-jet is continuous and connects the core to the counter-lobe, while in the combined VLA-MERLIN map there is a knot.

The brightest knot in the jet has a peak ~ 39.55mJy/beam at 8.4GHz the jet and counter-jet have spectral indices of 0.4 and 0.64 respectively. The apparent flatter spectral index of the jet may be due to the fact that the jet is dominated by very compact knots and possibly contaminated by the hotspot.

There are three arguments chiefly employed to explain the paucity of twin jets in quasars (Bridle 1990):

a. Intrinsic asymmetry (one-sidedness) in
b. The central engine reverses itself after some time i.e. (Flip-flop).
c. Intrinsic identical twin beams but one beam appears brighter because its synchrotron emission towards the observer is enhanced by bulk relativistic motion.

In 1049 + 616 there is at least lobe emisenergy transport by the beams because the central engine supplies little or no power to the other side.sion on the two sides so (a) above does not apply to this quasar. Moreover, there is preponderance of data on two sided emission in radio sources, offering convincing evidence of the two sided emission. We can also reject the flip-flop mechanism in this source since the counter-jet side is far shorter from the core. Since the brighter jet side would be the currently supplied side (by the jet) the counter-jet side which could be the result of an earlier jet supply should have advanced further from the core. Also, the spectral indices in the diffuse lobe emission on the two sides are not different suggesting that they are associated with electrons of comparable age.

We are left to consider 1049 + 616 radio structure in terms of (c) above. Usually the predicted jet-to-counter-jet ratio, which is the brightness ratio between the approaching and receding jets, can be expressed as (Scheur and Readhead, 1979; Ghisellini et al., 1993):

$$D = \left[\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right]^p \qquad (1)$$

where $p = 2+\alpha$ or $3+\alpha$; β= bulk velocity in terms of the speed of light, the corresponding Lorenz factor, $\gamma = (1-\theta^2)^{-1/2}$

From the jet-to-counter-jet ratio we obtain

$$\beta\cos\theta \sim \frac{D^{1/p}-1}{D^{1/p}+1} \qquad (2)$$

Which for 1049 + 616 gives a value of $\beta\cos\theta$ ~0.62. This gives an estimate of θ~51° for γ~5.

We may also look at the relative core strength of the source within the relativistic beaming hypothesis (Orr and Browne, 1982; Browne and Perley, 1986). The angle to the line of sight, θ may be related to the relative core strength R_T thus

$$\cos\theta \sim \frac{1}{\beta}\left[\frac{1}{2R}\{2R + R_T - [R_T(8R+R_T)]^{1/2}\}\right]^{1/2} \qquad (3)$$

where RT is the relative core strength expected at θ=90°

At 5GHz the total flux density of 1049 + 616 estimated from our map and the raw visibilities is ~373.63mJy, and from our map at high resolution, the core has a flux density, S_{5GHz} ~ 28.42MJy. This gives an R ~ 0.076 while estimates of R_T ~ 0.024 (Orr and Browne, 1982); thus $\beta\cos\theta$ ~0.87. For γ~5 gives θ~52°. this is consistent with θ~51° which we obtain considering the jet asymmetry. The assumption that the main axis of the nuclear jet emerging from the core maintains same direction as the kpc-scale jet might not be true for

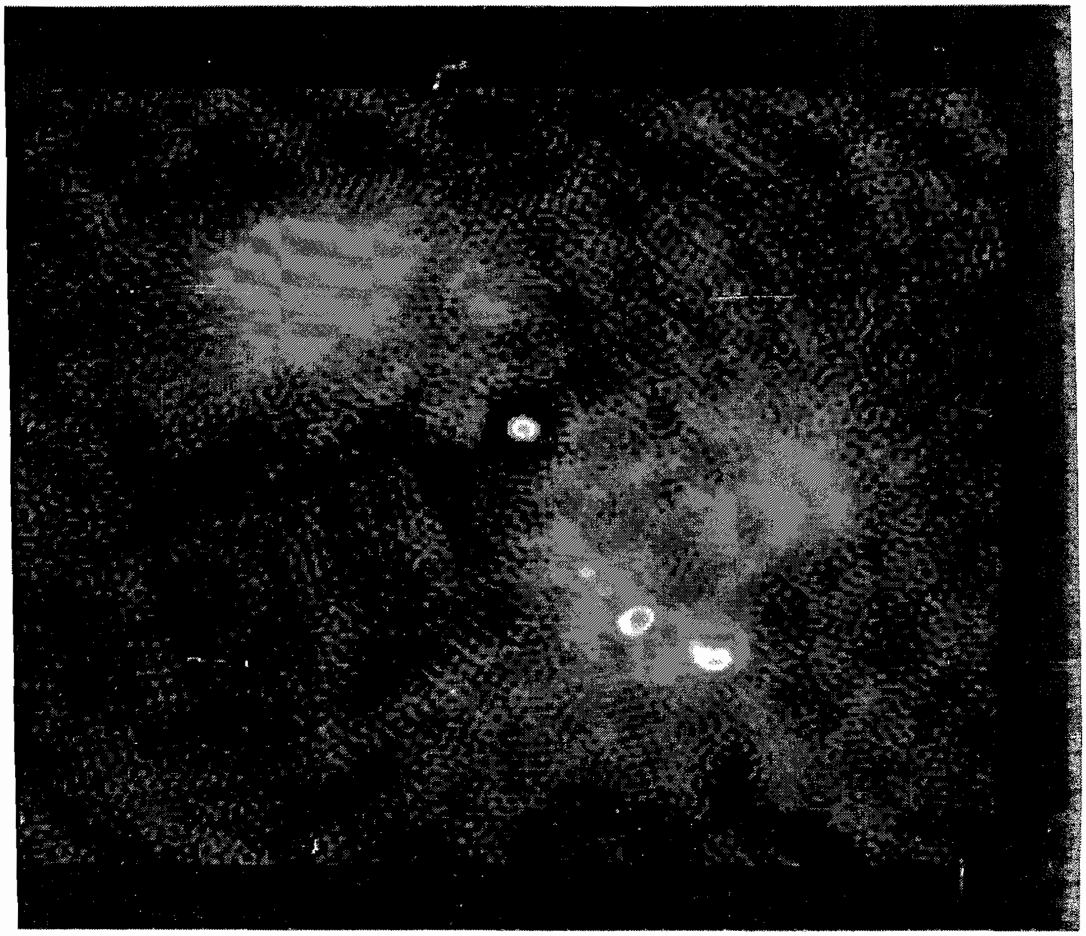

Plate 1: The gray scale plot of 1049 + 616 using the combined VLA and MERLIN array at 5GHz.

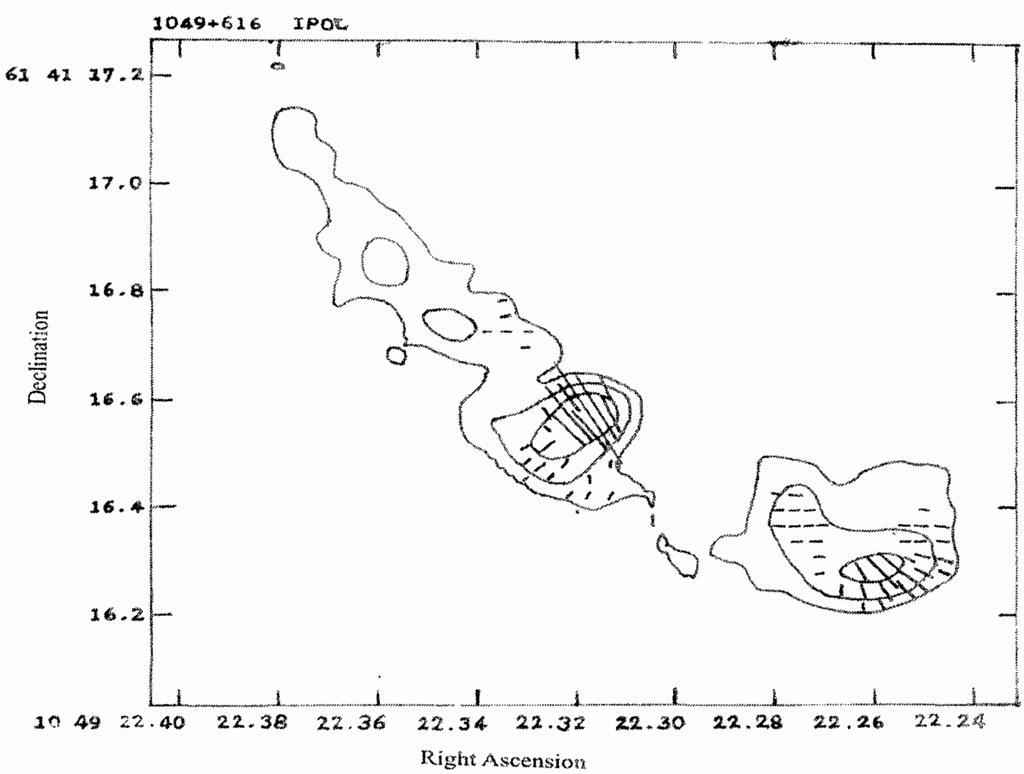

Fig. 4: Polarization Map of 1049 + 616

all quasars. Many core-and lobe-dominated quasars have misligned structures in terms of the core and the twin jets, which may be the case in 1049 + 616. (Hintzen et al. 1993).

Also, 1049 + 616 shows the jet-sidedness depolarization asymmetry in the sense that the counter-jet side (S) has higher depolarization (Table 2). This is consistent with the Doppler boosting model if the source is viewed at angle, θ such that the lobe with the brighter jet is nearer to us and its jet suffers relativistic enhancement. If the depolarizing medium occurs in a magnetic-active medium associated with the central region or surrounding the source, then counter-jet side will be viewed through a longer line-of-sight through the medium than the nearer jet side. In the case of 1049 + 616 the small differences in orientation indicators between the jet and counter-jet sides is consistent with the rather low jet-to-counter-jet ratio and large viewing angle ~ 50° which we estimate.

5. Conclusion

We have presented multi-frequency and high resolution radio observations of the quasar 1049 + 616 made with the VLA and MERLIN.

The high resolution images show a bright knotty jet and a fainter counter-jet emission connected to the northern lobe. The jet-to-counter-jet ratio is ~39; this implies a viewing angle of ~ 50° for $\gamma \sim 5$. This is consistent with a viewing angle, $\theta \sim 50°$ for fractional core strength, R ~ 0.076.

Also the lower resolution maps show that 1049 + 616 exhibits depolarization asymmetry as is found in extended radio sources and compact steep spectrum sources. This also implies that this object is viewed at a moderate angle to the line of sight such that the counter-jet side is seen through greater depth of the magneto-tonic medium. The approaching jet would then be enhanced by relativistic Doppler boosting.

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