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Counterjets in Classical Double Radio Quasars

D. H. Hough (NASA/JPL), A. H. Bridle (NRAO), J. O. Burns (U. New Mexico), R. A. Laing (RGO)

The lobes of powerful classical double radio sources are usually roughly symmetrical in brightness and in shape, but their jets are usually much brighter on one side of the nucleus than on the other. As very few counterjets have been detected in sources with powers above 10^{26} W Hz^{-1} at 1.4 GHz, there are only upper limits to the jet-counterjet intensity ratios for most such sources. We have made 5 GHz images of 12 3CR quasars with angular sizes $> 10''$ drawn from the sample of Laing, Riley, and Longair (1983, *MNRAS*, **204**, 151). We have combined data from the VLA in its A and B configurations to obtain typical rms noise fluctuations of 20 μJy/beam at an angular resolution of $0\overset{''}{.}35$. These 12 sources, together with 3C47 observed separately by D. Clarke and J.O.B., include all 10 3CR quasars with largest projected linear sizes $> 100h^{-1}$ kpc ($H_0 = 100h$ km s^{-1} Mpc^{-1}, $q_0 = 0.5$). We detect jets in all of them, including 7 in which no jet was previously known. In 5 sources, we detect probable counterjet emission between the nucleus and the lobe on the side opposite to the obvious jet. This is the first time that probable counterjet structures have been systematically found in extended 3CR quasars. The jet/counterjet brightness ratios are typically below a few tens to one, and can be explained by Doppler favoritism with more modest Lorentz factors than those needed to account for superluminal motion in compact radio cores. Even if Doppler favoritism produces the jet brightness asymmetries in these 5 quasars, their jets must emit higher intrinsic radio powers than the symmetric jets in lower-power radio galaxies. Our images also reveal much new fine detail in the radio lobes of these quasars, including multiple hot spots and filamentary structures. (D.H.H. is a National Research Council-NASA Resident Research Associate at the Jet Propulsion Laboratory.)

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PAPER PRESENTED BY D. H. Hough
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Abstract Submitted for the 172nd Meeting, Kansas City, Missouri

Date Submitted 3/29/88
Form Version 1/88

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I. INTRODUCTION

• Extragalactic radio sources often display twin lobes straddling a central component (which is coincident with the optical object).

• The source properties change substantially around a luminosity of $\sim 3 \times 10^{24}$ W/Hz at 1.4 GHz:

– LOW-LUMINOSITY radio galaxies tend to have *relatively bright two-sided jets* feeding *edge-darkened* lobes.

– HIGH-LUMINOSITY radio galaxies and quasars, i.e., "classical doubles", tend to have *relatively weak one-sided jets* feeding only one of two *edge-brightened* lobes.

• WHAT CAUSES THE STRONG JET ASYMMETRY IN THESE POWERFUL "CLASSICAL DOUBLES":

– **(1)** intrinsically two-sided, symmetric relativistic jets;
– **(2)** intrinsically two-sided, asymmetric jets; or
– **(3)** intrinsically one-sided, "flip-flopping" jets?

II. OBSERVATIONS AND REDUCTIONS

- We have selected a complete, flux density-limited sample of 21 classical double 3CR quasars with largest angular size $> 10''$ (see table below); we believe this sample has minimum orientation bias and will be well-suited to statistical analyses of source properties.

- A deep search for counterjets (i.e., the "missing jets" in one-sided jet sources), is being carried out with the VLA at 5 GHz, with typically 6-8 hours in A-array and 3-4 hours in B-array $\rightarrow$ resolution $0.35''$, rms sensitivity $\approx 20\ \mu$Jy/beam.

- AIPS reductions performed at NRAO-Charlottesville (Convex), NRAO-VLA (Convex, Vax), and U. of New Mexico (Vax).

- Phase and amplitude self-calibration, CLEANing with APCLN done separately for each of two IF pairs (AC = 4885 MHz, BD = 4835 MHz, 50 MHz bandwidth each); images added for final A+B array, AC+BD IF pair images.

- Sometimes deconvolution schemes combining CLEAN and Maximum Entropy have been used to minimize artifacts (e.g., 3C175 and 3C249.1).

III. RESULTS

- We have observed 12 sources to date; *all* 10 objects with projected linear size $>$ 100 kpc have already been observed (counting 3C47 done by D. Clarke and J.O.B.)

- BEFORE these observations, *the jet detection rate was $<<$ 100% and no counterjets were known.*

- AFTER these observations, *the jet detection rate is 100% and there is probable/possible counterjet emission in $\approx$50% of the cases.*

- We find 7 new jets and 7 probable/possible counter-jets.

- Jets: many continuous (e.g., 3C175), some have quasi-periodic knots (e.g., 3C204), dominant curvature mostly at either end.

- Counterjets: *none* continuous, only "bits and pieces" — knots, stubs, arcs.

- New detail in lobe structures: filaments, cusps, wisps, multiple "hot spots", etc.

IV. DISCUSSION

• There are no absolutely guaranteed counterjets; some of the suspected counterjets could be interpreted as lobe filaments, others comprise only a single knot.

• It seems that sources with a more "disturbed" appearance have stronger counterjet evidence; the better-defined classical doubles, many with quasi-periodic knots in their jets, have little or no counterjet evidence.

• The counterjets occur in both small (e.g., 3C9) and large (e.g., 3C351) sources, and in both weak-cored (e.g., 3C68.1) and strong-cored (e.g., 3C334) objects.

• Irrespective of whether Doppler effects are responsible for jet- counterjet brightness asymmetries, the counterjets have higher *intrinsic* powers than the symmetric jets in low luminosity radio galaxies; thus some of the increase in jet strength in more luminous sources has a cause other than Doppler boosting.

• Preliminary jet-counterjet brightness ratios typically a few to a few tens (as measured by peak or integrated emission) $\rightarrow$ the relativistic beaming model explains this with modest bulk Lorentz factors ($\gamma \leq 2$), but also suggests a bias in source orientations of $\leq 70°$ to the line of sight.

V. FUTURE GOALS

- Finish remainder of sample to same level as first dozen sources to permit statistical analyses of complete sample.

- Pursue one or two particularly tantalizing counterjet candidates with extremely deep (e.g., 48 hours) VLA observations.

- Observe a "control sample" of broad-line radio galaxies, i.e., radio galaxies with optical lines similar to those of quasars.

- Attempt a counterjet search at $\lambda = 20$ cm in a source with little confusing diffuse emission between the core and counterjet lobe.

The Complete Sample of Classical Double Quasars

3CR Name	Redshift	Core Emission / Extended Emission ($\nu_{emitted} = 5\ GHz$)	Projected Linear Size (kpc)	Largest Angular Size ($''$)	Observed?
3C9	2.01	0.004	57	14.0	Yes
3C14	1.47	0.010	100	23.4	No
3C47	0.43	0.050	247	74.4	Yes (D. Clarke)
3C68.1	1.24	0.0007	225	52.2	Yes
3C175	0.77	0.024	215	52.7	Yes
3C204	1.11	0.044	162	37.6	Yes
3C205	1.53	0.018	79	18.6	No
3C207	0.68	0.49	50	12.7	No
3C208	1.11	0.048	62	14.5	Yes
3C212	1.05	0.12	48	11.1	No
3C215	0.41	0.039	176	54.1	Yes
3C249.1	0.31	0.12	116	41.3	Yes
3C263	0.65	0.10	195	50.1	Yes
3C268.4	1.40	0.046	48	11.2	No
3C270.1	1.52	0.11	45	10.5	No
3C275.1	0.56	0.11	69	18.7	No
3C334	0.56	0.23	206	55.7	Yes
3C336	0.93	0.024	113	26.7	Yes
3C351	0.37	0.006	209	67.5	Yes
4C16.49	1.88	0.010	73	17.7	No
3C432	1.81	0.009	63	15.0	Yes

Friedman cosmology: $H_0 = 100$ km/s/Mpc, $q_0 = 0.5$.

Parent sample is Laing, Riley, and Longair 1983, *M.N.R.A.S.*, **204**, 151.

ACKNOWLEDGMENTS

Colin Lonsdale of Haystack Observatory recently joined in the fun and is responsible for the 3C249.1 image. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation. This work at the University of New Mexico is supported under NSF grant AST-8611511. The research described in this paper was performed while DHH held an NRC-NASA Resident Research Associateship award at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.