NATIONAL RADIO ASTRONOMY OBSERVATORY
Edgemont Road, Charlottesville, Virginia 22903-2475

Dr. Alan H. Bridle, Tel. 804-296-0375, FTS 940-7375

October 20, 1986

Prof. P. P. Kronberg
Department of Astronomy, Univ. of Toronto
60 St. George Street
Toronto, Ont. M5S 1A7 CANADA

Dear Phil:

Enclosed is a 6250 BPI FITS tape containing u,v data on 3C353 and image data at 3 arcsec resolution on 3C219, with a detailed tape index.

I talked with Jack Burns about the 3C219 data and he was indeed concerned that the full data set be available to his student David Clarke in the first instance, as Rick and I had agreed to provide this as part of a collaboration that will yield four-frequency rotation measures and spectral data. However, I do not think I should restrict the image data to this context, hence the enclosed full suite of 3 arc sec resolution images. I am sending I, Q and U maps as well as some derived polarization images so that your student could decide on his own cutoff levels, etc. for evaluating spectral indices and rotation measures. We will publish results on the large-scale structure based on our own interpretation of these images, but your student is welcome to use them for the purposes of his thesis. The tapering used to obtain these images was 75 kilowavelengths in the AIPS tasks MX and APCLN.

There are interesting spectral gradients and some RM structure shown by these images. The spectral data in particular suggest outflow from both recessed hot spots toward the eastern sides of the lobes. There is also a distinct spectral gradient across the ring-like hot spot in the north lobe. We confirm the large-scale gradients across the lobes that were mapped by Burch.

Best wishes.

AHB

The University of New Mexico
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Albuquerque, NM 87131
Telephone 505: 277-2616

February 14, 1986

Dear Dr. Bridle

Jack asked me to send you a copy of our VLA proposal and related matter regarding 3C219. As you can see by the referees' reports, time allotment is presumably imminent and we expect to hear about time scheduling within the month. Also enclosed is a copy of a letter that I sent to Dr Barry Clark several months ago. Jack was concerned that there were some rumblings about the necessity of any further 3C219 observations and so I tried to convey to Dr. Clark how important we felt these new observations to be.

I hope this clarifies for you our current status on the project. Please let me know if you have any other questions.

Yours very truly

David Clarke

The UNM
University of New Mexico

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November 26, 1985

Dr. Barry Clark
NRAO
P.O. Box 0
Socorro, NM 87801

re: project number AC149

Dear Dr. Clark;

Jack Burns has briefed me on his telephone conversation with you today and has suggested that I write to you and explain further why we feel that 3C219 is so crucial to our project.

First, let me say that we do not agree at all with REF& who stated that rotation measure gradients across jets have been unsuccessfully sought in other sources. Although this very type of measurement is frequently suggested at conferences (Taos, for example) as a measurement that ought to be done, we are not aware of any such endeavours in the literature. Rick Perley has stated to me that he is certain that such an experiment has not been done, and is long overdue. We therefore see no reason, based on alleged previous efforts, that a gradient in the rotation measure should not exist across the jet of 3C219.

During numerous conversations with Drs. Rick Perley, Alan Bridle and Frazer Owen, 3C219 was consistently mentioned as the primary source for this type of study. Drs. Perley and Bridle already have a substantial data base on 3C219 and have generously offered it for our use in this project. However, their frequency coverage is insufficient to definitively measure any rotation measures. In particular, subtle gradients in the rotation measure would be lost in the present data base. Data that Dr. Perley has already reduced shows a great deal of polarization in an extended cocoon region. It also suggests that the jet may not be thermally confined. Further, although 3C219 is rather distant (z=.17), its great linear size allows the jet and cocoon features to be resolved significantly. 3C219 is, therefore, an ideal source for the study of magnetic jets, according to the tests described in our proposal. Although we feel that 3C388 is also an excellent source for this project, we think that 3C219 is perhaps even more promising. Here, we are in disagreement with REF& again.

Naturally, we are not proposing to redo Perley et al's observations. Rather, we wish to complete the frequency coverage with comparable sensitivity. Without complete frequency coverage, the present data, as good as it may be, is insufficient for the measurements that we wish to make. Hence, we are asking for VLA time to observe 3C219 at two more frequencies in the L band (four hours each, for a total of eight hours) in the A configuration and six hours at 6 cm in the B configuration. Perley and Bridle have some 6cm, B configuration data, but this consists of several short scans, taken several months apart. The remaining proposed observing time on this source is to provide the shorter baselines at 20 cm to raise the level of the extended emission regions on the map. The short baselines at 6 cm will be provided by some C configuration data that Perley and Bridle have.

I should point out that the observations of Zukowski earlier this year are not sufficient for our purposes. As he told me on the telephone, he observed 3C219 for no more than 30 minutes at any one frequency.

I cannot emphasize enough the importance we place on the 3C219 observations. Although it is perhaps naive to expect to see the simple-minded effects we described in our proposal, we still feel that 3C219 has all the tell-tale signs of an active magnetic field. In particular, good observations of this source will be their most useful when the numerical models of magnetic jets, which are to be done at Los Alamos, have been completed.

Yours very truly;

David Clarke

David Clarke

A
received:

VLA OBSERVING APPLICATION

SEND TO: Director NRAO Edgemont Rd. Charlottesville, Va. 22901

DEADLINES: 15th of Mar., June, Sept., Dec. for Q 3, 4, 1, 2 respectively

1 Date: September 3, 1985

2 Title of Proposal: A Search for Active Magnetic Field Effects in Extragalactic Radio Sources

3 Authors	Institution	Who will observe?	For Grad Students Only: Observations for PhD Thesis?	For Grad Students Only: Anticipated PhD Year
D. A. Clarke	University of New Mexico (UNM)	X	Yes	1987
J. O. Burns	UNM	X		
M. L. Norman	Los Alamos National Labs and UNM	X		
W. A. Christiansen	University of North Carolina			

4 Related previous VLA proposal number:

5 Contact author for scheduling: D. A. Clarke

6 Telephone: (505) 277-1527

TWX:

Address: Department of Physics and Astronomy
University of New Mexico
Albuquerque, N.M., 87131

7 Scientific category: ☐ planetary, ☐ solar, ☐ stellar, ☐ galactic, ☒ extragalactic

8 Configuration(s) (A, B, C, D, A/B, B/C, C/D, Any)	A	B	C		
9 Wavelength (90 20 18 6 2 1.3 cm)	20, 6	20, 6	6		
10 Time requested (hours or days)	24 hrs.	23 hrs.	6 hrs.		

11 Type of observation: ☒ mapping, ☐ point source, ☐ monitoring, ☒ continuum, ☒ lin poln, ☐ circ poln, ☐ spectral line, ☐ solar, ☐ VLBI, ☐ phased array, ☐ other ________________

12 ABSTRACT (do not write outside this space): The purpose of this investigation is to determine if there are any observational signatures of active magnetic fields in extragalactic jets and cocoons. We propose to make multifrequency, high resolution observations of 3C219 and 3C388 to produce detailed polarization and rotation measure maps. We have developed several analytical tests to identify the presence of active magnetic fields, and will apply these to our observations. Further, we shall be producing detailed numerical MHD models of axisymmetric jets during the next year. By comparing the MHD models (with varying B-field intensities) with the observations, our goal is to distinguish jet features that are produced hydrodynamically, from those that are produced electromagnetically.

NRAO use only

(13) Observing style: ☐ Will be present ☐ Will prepare files & return to reduce ☒ Will use modem ☐ Absentee (NRAO prepares OBSERV file & sends calibrated data)

(14) Reduction: Number of maps many Maximum size of maps 1024 Self-cal maps yes Private disk pack ______

(15) Off-site reduction: ☐ none, ☐ post map, ☒ post calibration, ☐ everything.

(16) Help required: ☒ none, ☐ consultation, ☐ friend (extensive help), ☐ staff collaborator.

(17) Spectral line only:

	line 1	line 2	line 3		line 1	line 2	line 3
transitions to be observed				number of channels (N)			
channel bandwidth (KHz) (Δ)				number of antennas			
observing frequency (±NΔ/2)				rms noise after 1 hour (mJy)			

(18) Number of sources 2 (If more than 10 sources please attach list. If more than 30 give only selection criteria and LST range(s).)

Name	Epoch 1950 ☒ 2000 ☐ RA hh mm	Dec ±xx°x	Config.	Band (cm)	Band width (MHz)	Total Flux line (Jy)	cont. (Jy)	Largest ang. size	Weakest signal (mJy/beam)	Required dynamic range	Possible LST range hh - hh	Time requested
3C219	9 18	45°9	A	20	25		5	3'	0.05	5000	3 - 16	8 hrs.
			B	20, 6	25		5	3'	.05, .03	6000	3 - 16	14 hrs.
3C388	18 43	45°5	A	20, 6	25		1	1'	.06, .025	>1000	12 - 25	16 hrs.
			B	20	25		1	1'	0.06	>1000	12 - 25	9 hrs.
			C	6	25		1	1'	0.03	>1000	12 - 25	6 hrs.

(19) Special hardware, software, or operating requirements: none

(20) Preferred range of dates for scheduling: Jan., 1986 - Dec., 1986

(21) Dates which are not acceptable: none

(22) Please attach a self-contained Scientific Justification not in excess of 1000 words.

When your proposal is scheduled, the contents of this cover sheet become public information. (Any supporting documents are for refereeing only)

Scientific Justification

I Background

To model structures seen in extragalactic jets, astrophysicists generally invoke ordinary hydrodynamics. Magnetic fields are introduced in a passive manner only, and are frozen in the fluid. This is reasonable provided the flow is dominated by hydrodynamical pressure gradients (i.e., $\beta \gg 1$, where β is the ratio of thermal to magnetic pressures). However, when $\beta \lesssim 1$, this assumption breaks down.

Many of the features seen in jets are ambiguous in their origin. Both hydrodynamical (HD) and magnetohydrodynamical (MHD) explanations often apply. It is the purpose of this investigation to determine if there are any observables in extragalactic jets that are characteristic of active magnetic fields and cannot be explained using ordinary HD. Analytically, we have determined several properties of magnetically dominated jets, which could be observed with the VLA. These are discussed below. Further, as part of his Ph.D. dissertation, D. Clarke will be working with M. Norman (starting this fall) to develop a fully MHD 2-D code for axisymmetric jets. The numerical calculations will be more illuminating than the analytical models since β's of order unity can be considered, and the nonlinear regime of the flow can be explored.

The following properties of magnetically dominated jets may be observable:

1. If the jet is magnetically confined, the jet should appear overpressured. That is, the minimum internal pressure of the jet is greater than the external thermal pressure (computed from X-ray data).

2. A poloidal field confining a jet in the plane of the sky would be pointing toward the observer on one side of the jet, and away from the observer on the other. Hence, the rotation measure (RM), which is proportional to the **B**-field, would have opposite signs on the two sides of the jet. Thus, an RM gradient would be observed across the jet.

3. In the limit where $\beta \ll 1$, the jet's **B**-field could be arranged in a force-free configuration (defined by $\nabla \times \mathbf{B} = \mu \mathbf{B}$). Such jets would exhibit several characteristic features that would distinguish them from jets where $\beta \gg 1$ (Konigl and Choudhuri, 1985). In particular, the total intensity distribution should show side to side oscillations with a wavelength of about 5R (R = radius of the jet). The oscillations are not fluid wiggles, but arise because the regions of intense magnetic fields alternate from side to side along the jet. This model also predicts that the maximum fractional polarization is anticorrelated with the maximum total intensity. These predictions seem applicable to the inner portion of the jet in NGC 6251, and may also apply to the sources that are the subject of this proposal.

4. Another prediction from the force free model is that jets which impinge on a conducting barrier (a hot IGM for example), form a spheromak configuration at their head. The situation is shown in figure 1, and should be compared with laboratory steady state spheromaks (see Jarboe, 1982). Thus, at the head of a magnetically dominated jet, poloidal **B**-fields would produce a gradient in the RM across the lobe, in a direction perpendicular to the jet axis. This is unlike the lobe produced by a $\beta \gg 1$ jet, where a strong poloidal field, and hence an RM gradient, is not expected.

We emphasize that identification of active magnetic fields will come only when several or all of the features discussed above are seen simultaneously. Further confirmation will follow once the numerical MHD and HD models have been compared with the observations.

II Proposed Observations

For a proper comparison between theoretical models and observations, we need to observe sources that are highly luminous, overpressured, nearby, and have jets embedded in extensive cocoons, where confining poloidal **B**-fields would be located. (Here, we define a cocoon as an extended region of backflowing jet material coming from the head of the jet.) The highly luminous jets associated with QSO's are clear candidates for magnetic confinement, but are too distant to be well resolved by the VLA. Of the nearby jets, only a few are clearly overpressured and possess substantial cocoons. Our choice of promising candidates is therefore limited.

We have chosen two sources which provide the best hope of detecting active magnetic fields. The jets in 3C219 (figure 2) and 3C388 (figure 3) are relatively nearby, appear overpressured and are embedded in extensive cocoons (Perley et al, 1980, Burns et al. 1982). Figures 2 and 3 were produced with the incomplete VLA, whose uv coverage best resembles that of the present day B configuration. If the cocoons contain confining poloidal **B**-fields, the VLA can resolve these sources sufficiently so that polarization data can map them. The VLA also provides the proper combination of frequency coverage and resolution to measure any RM gradients across the jet and the hotspot in the radio lobe.

Both Perley and Bridle have indicated that their VLA data on 3C219 would be available for this project. This includes: 9 hours at 6 cm in the A configuration, 3 hours at one frequency in the L band in each of the A and B configurations and 6 hours at 6 cm in the C configuration. To determine if there is a gradient in the RM across the jet, we will require two more frequencies in the L band (A configuration) with four hours of integration at each frequency (theoretical RMS=.05 mJy). Six hours of 6 cm B configuration will complete the frequency coverage. The badly needed shorter baselines will be provided by the 20 cm B configuration observations that are being requested and Perley and Bridle's 6 cm C configuration data.

Using a confining azimuthal **B**-field of 44 μG (determined by equating the magnetic stress exerted by such a field to the internal pressure quoted in Perley et al, 1980), a jet diameter of 2 kpc and an electron number density of 10^{-4} cm^{-3}, we expect to see an RM of 7 rads/m². This will result in a 30 degree difference in the 20 cm polarization position angle on opposite sides of the jet. It is emphasized that these values are estimates only. Random components to the **B**-field, an angle of inclination of the source in the sky, a non-confining azimuthal field and a smaller cocoon density will reduce the RM gradient. Hence, it is necessary to have high sensitivity and accurate position angles of the polarization **E**-vectors in order to detect subtle RM gradients. On the other hand, higher cocoon densities will increase the RM gradient, so it is necessary to have observations at several frequencies to detect any $n\pi$ ambiguities.

In order to compare observed **B**-field structures with the theoretical models, it will be necessary to obtain high sensitivity and high resolution polarization data. Because 3C219 is so bright and highly polarized, it is the ideal source for this type of mapping. Hence, we propose to combine Perley and Bridle's 6 cm A and C configuration data with the B configuration data proposed here (yielding a theoretical RMS of .015 mJy). Of particular interest is how far the poloidal field penetrates into the cocoon, and how it diminishes with distance from the jet axis. Does the poloidal field drop off as 1/r, characteristic of a current induced field?

We already have some VLA data for 3C388 (6 cm, incomplete B-array). To determine if there is a gradient in the RM (which we expect to be 7.5 rads/m²), we will require 3 hours in each of three frequencies in the L band in the A configuration. This will yield a theoretical RMS of .06 mJy which will be sufficient for our purposes. The shorter baselines will be provided by the 20 cm B configuration and the 6 cm C configuration observations that are being requested.

For a high resolution map of the polarization **E**-vectors in 3C388, we will require 7 hours in the A configuration at 6 cm. Combined with our present data and the proposed C-configuration data, the expected RMS of the 6 cm map will be 0.015 mJy, which should be sufficient to map much of the **B**-field structure in the jet and the cocoon.

References

Burns, J.O., Christiansen, W.A., Hough, D.H., 1982, Ap. J., 257, 538

Jarboe, T.R., 1982, Fifth Symposium on Physics and Technology of Compact Toroids in the Magnetic Fusion Energy Program

Konigl, A., Choudhuri, A.R., 1985, Ap. J.

Perley, R.A., Bridle, A.H., Willis, A.G., Fomalont, E.B., 1980, A. J., 85, 499

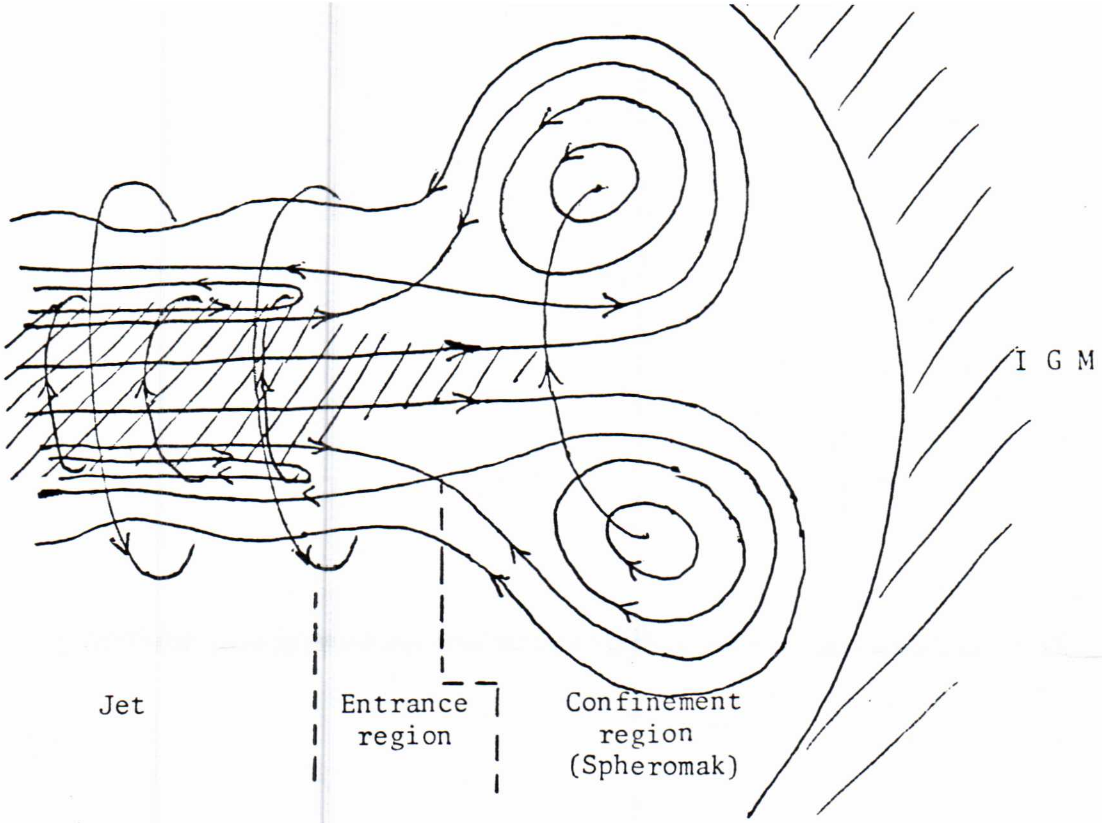

Figure 1 - The spheromak, as applied to the head of an astrophysical jet.

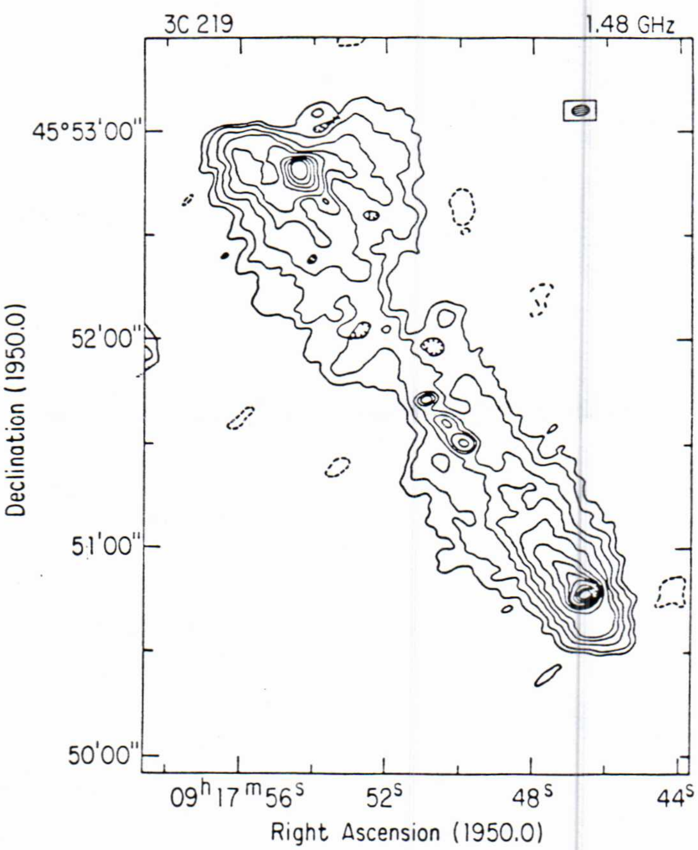

Figure 2 - 20 cm B configuration data of 3C219 (Perley et al, 1980). Contour levels are at -5,5,10,20,30,40,60,80, 100,120,160,200 and 240 mJy per beam.

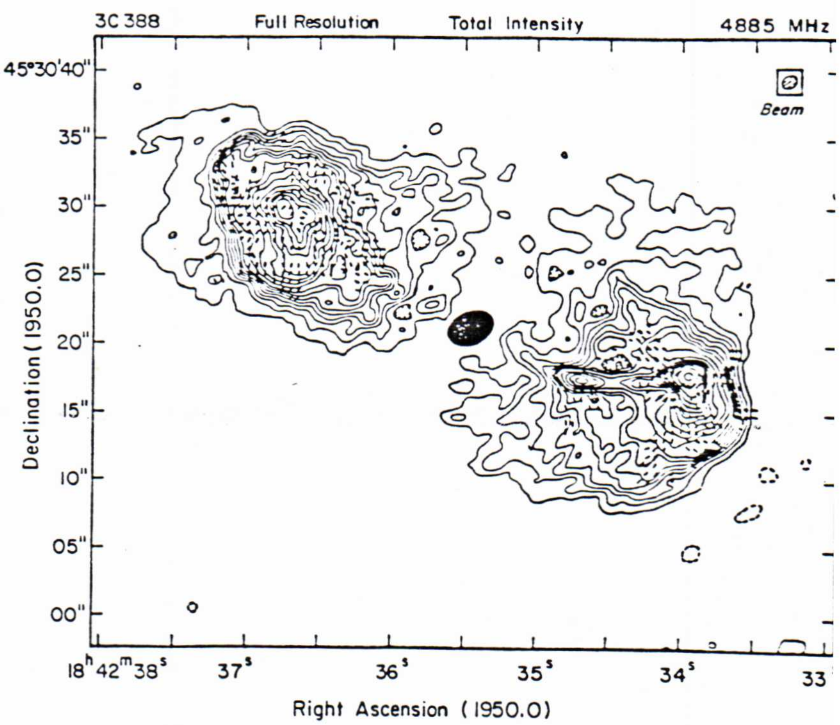

Figure 3 - 6 cm incomplete VLA B configuration data of 3C388 (Burns et al, 1982). Contour levels are at -1,1,2,3,4,5,6,7,8,10,12,15,16, 18,20,22,25,30,40,60,80 and 100% of peak (61.7 mJy per beam). Dashed lines are polarization E-vectors.