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VLA OBSERVATIONS OF THE MULTIPLE JET GALAXY 3C 75

FRAZER N. OWEN AND CHRISTOPHER P. O'DEA
National Radio Astronomy Observatory[1]
MAKOTO INOUE
Nobeyama Radio Observatory, Tokyo Astronomical Observatory
AND
JEAN A. EILEK
Department of Physics, New Mexico Institute of Mining and Technology
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ABSTRACT

We present VLA observations of the central radio source in Abell 400, 3C 75, at 6 and 20 cm. The VLA maps show that this radio source consists of a pair of twin jets originating in the apparently double nucleus of the central galaxy in this cluster. On larger scales the jets merge into two tails resembling the wide angle tail class of radio sources.

Just as for the wide angle tail radio source, 3C 465 (as discussed by Eilek and colleagues in 1984), we find that the standard models for bending this source fail quantitatively. The problem becomes even harder because of the low velocity dispersion and temperature for Abell 400 and the fact that the jets from both nuclei bend in the same direction. Models with jet velocities less than 1000 km s^{-1} at the first bends seem necessary if the sources are bent by the motion of the galaxy through the ICM. Particle acceleration seems necessary in the most diffuse parts of the source with the energy source likely to be the ICM itself.

Subject headings: galaxies: clustering — galaxies: nuclei — interferometry — radio sources: galaxies

I. INTRODUCTION

Radio observations of rich clusters of galaxies have over the last 15 yr or more provided images of some of the most interesting sources in the sky. These sources often seem to be the result of interactions between jets of relativistic fluid and the intracluster medium as the galaxies move about in the cluster. However, when the parent galaxy is the central cD in a cluster, the standard picture has trouble explaining the bent radio sources quantitatively (Eilek *et al.* 1984). In this *Letter* we present new observations of the radio galaxy 3C 75 which is associated with the central galaxy in Abell 400. The unique appearance of this system and the parameters of the cluster further emphasize the problems with the current models and seem to push us toward a reconsideration of our basic assumptions about cluster radio sources.

II. THE RECENT HISTORY OF OBSERVATIONS OF 3C 75

The radio source 3C 75 has been known for more than 25 yr. However, early mapping attempts (e.g., Fomalont 1971) did not reveal its true nature due to the low declination of the source (6°). The first good maps of the source occurred during the VLA Abell cluster snapshot survey (F. N. Owen *et al.*, in progress). The source was clearly very unusual and a more extensive observing program was planned. Also during this period deep CCD images were obtained by F. N. Owen and R. A. White (in preparation) which show that the identification is a D or cD system which dominates the cluster. In addition Jones and Forman published X-ray surface brightness profiles for Abell 400 (Jones and Forman 1984). They show that Abell 400 is a particularly good fit to a modified King law. All these results give us a particularly clear picture of the environment of Abell 400/3C 75. We will present detailed observational results and models in later papers. In this *Letter* we show the basic structure of the source and point out the problems and general implications of the data.

III. CALIBRATION AND IMAGE CONSTRUCTION

Observations were made of 3C 75 in the VLA B, C, and D arrays (Thompson *et al.* 1980) at 6 cm and 20 cm during 1982 and 1983. All of the VLA data were calibrated in the usual way using a nearby point source as an external calibrator and data quality monitor. The flux density scale was bootstrapped to the scale of Baars *et al.* (1977) by means of observations of 3C 48. Data were then processed into final images using the mapping and deconvolution algorithims in the AIPS software package.

IV. VLA RESULTS

In Figures 1 (Plate L1) and 2 we present the high-resolution image at 6 cm (4852 MHz) 3C 75 cleaned and restored with a circular Gaussian beam with a FWHM of 1.″4. This image shows the basic multiple jet structure of the source. Two point sources at ($02^h55^m03^s.08$, 05°49′20.″9) and ($02^h55^m02^s.99$, 05°49′37.″0) (1950.0) coincide with the two nuclei of the

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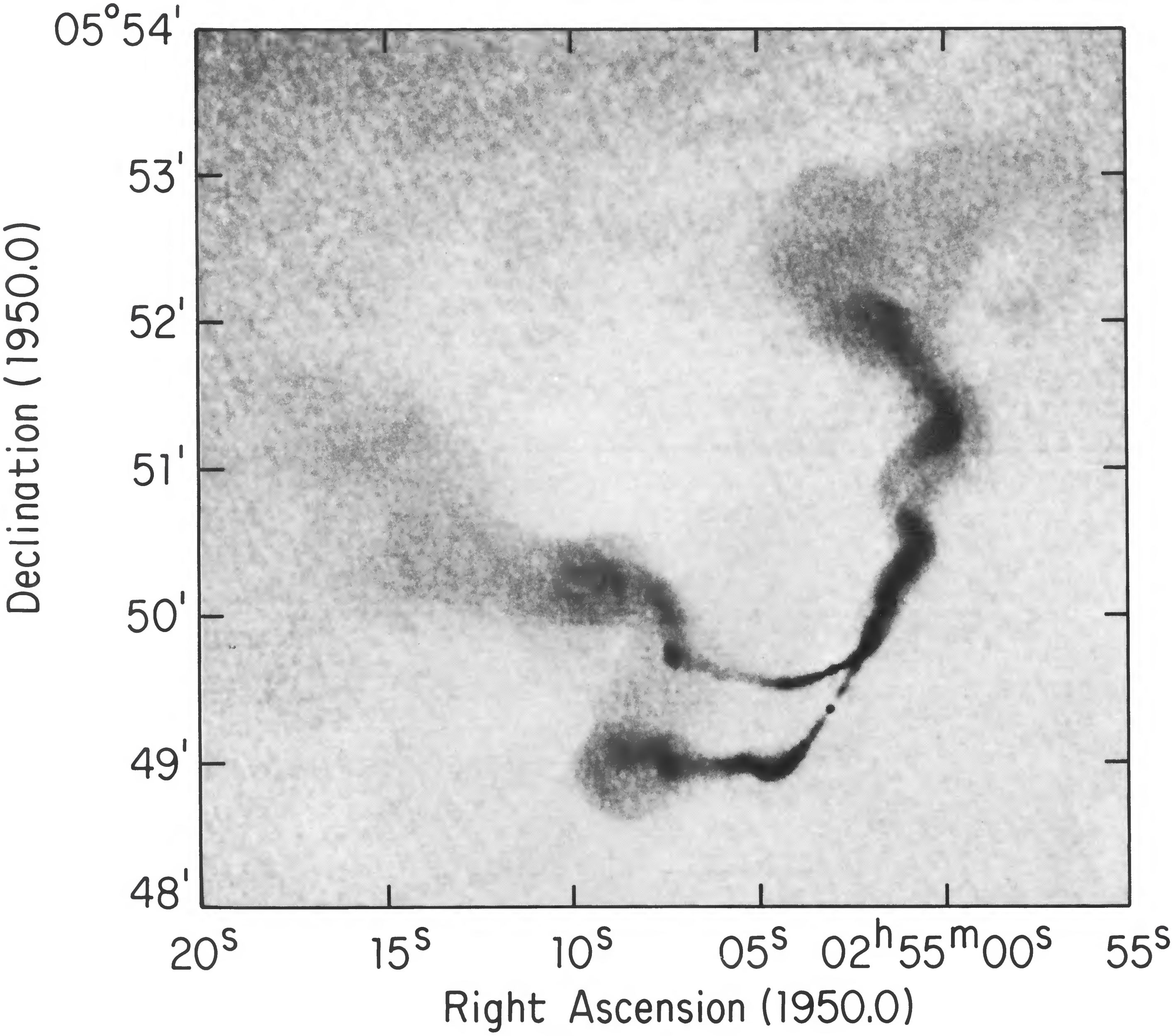

FIG. 1.—Gray scale image of 3C 75 at 6 cm

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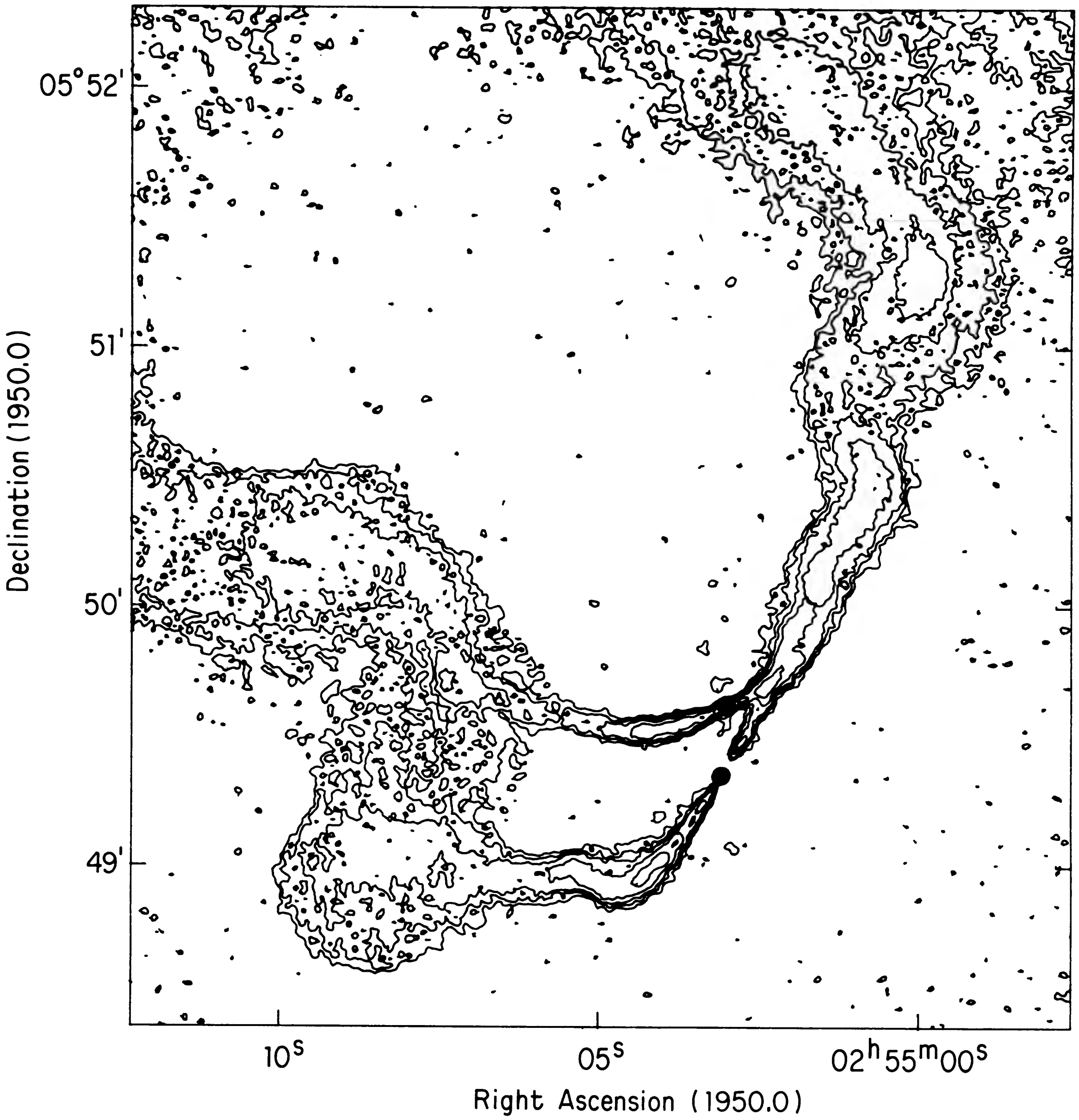

FIG. 2.—Contour plot of 3C 75 at 6 cm. Contour intervals are (−1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512) × 0.1 mJy per clean beam.

central galaxy in Abell 400. Each of the nuclei has a twin jet structure emanating from it. On the east side of the galaxy, the two jets bend and roughly parallel each other. On the west side the jets appear to cross and then become tangled with each other.

In Figure 3 we show a contour map of the 20 cm (1452 MHz) image of 3C 75 with a 4″ restoring beam. The same general structure can be seen except an additional large-scale feature can be seen extending perpendicular to the 6 cm structure. These large ears cannot be seen on a similar resolution map at 6 cm because the spectral index steepens between 6 and 20 cm as one goes out along the tails.

V. DISCUSSION

The images of 3C 75 present many interesting questions. In this *Letter* we will address only two general areas. First, we will discuss the general radio morphology and its relationship to the optical properties of the cluster. Second, we will discuss the problems encountered in making a model of the sources given the radio and optical data and outline a possible solution to the problem.

First, three general points can be made about the unusual radio morphology.

1. This source is the first example of a multiple nucleus galaxy in which both nuclei are radio sources with complex, twin jets.

2. Both sets of jets bend and, perhaps surprisingly, bend in the same general direction.

3. On the northwest side of the source the jets appear to interact and/or merge with each other.

Point (1) shows that these systems are not due simply to a single, cluster-wide, continuous gravitational potential with a

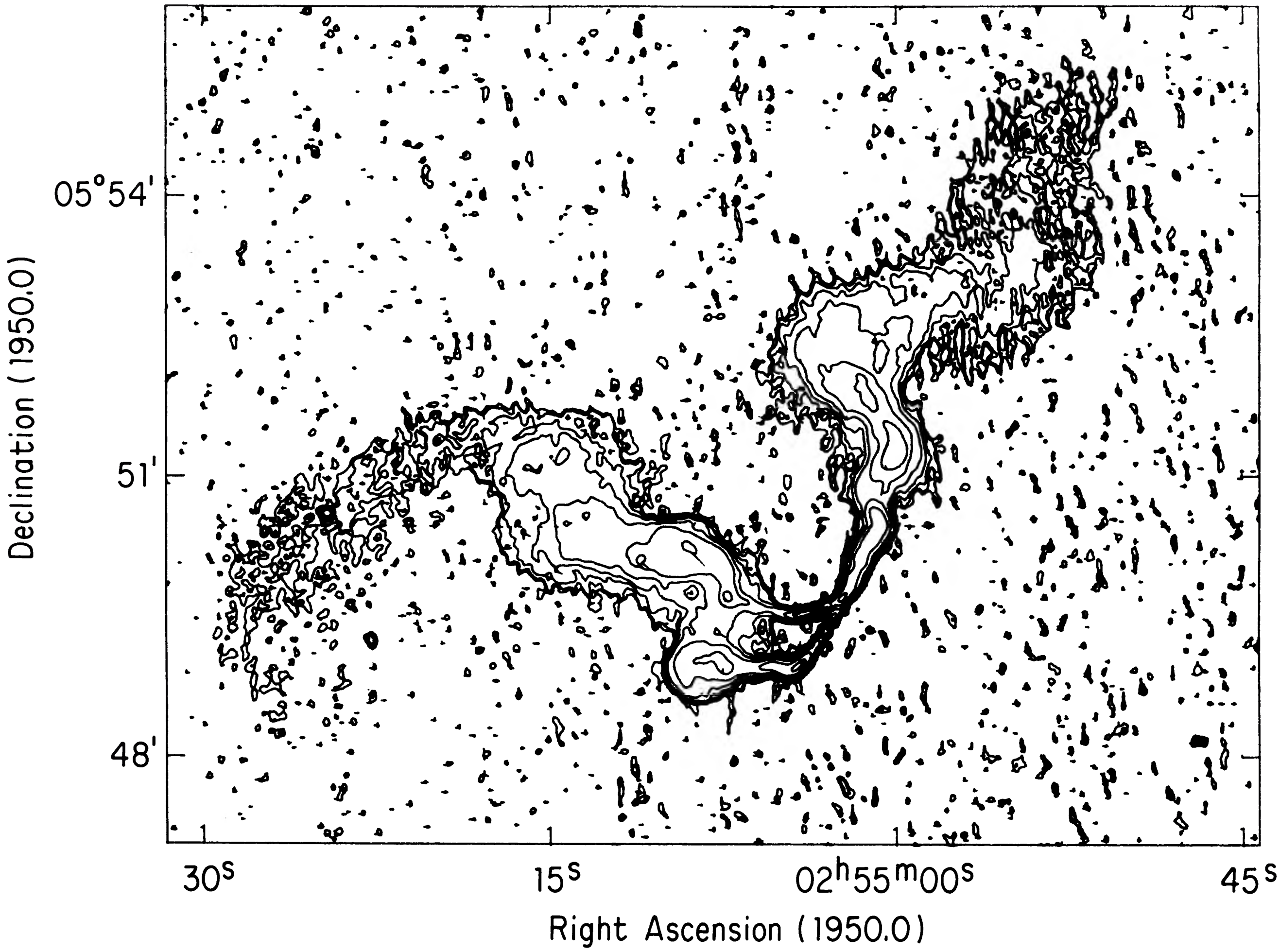

FIG. 3.—Contour plot of 3C 75 at 20 cm. Contour intervals are $(-1, 1, 2, 4, 8, 16, 32, 64, 128, 256) \times 0.15$ mJy per clean beam.

black hole or some other object in its center (e.g., Blandford and Smarr 1984), since we can see two such sources in the center of Abell 400.

The fact that the jets bend in the same direction and either interact strongly or at least follow the same wiggling path at least in projection seems hard to understand if they are not close together in space. The two nuclei appear to be the two brightest such objects in the cluster. They are separated by only 7.2 kpc in projection ($H_0 = 75$ km s^{-1} Mpc^{-1}). Their radial velocities differ by 330 ± 50 km s^{-1} (Hintzen *et al.* 1982). All these facts argue that both of these nuclei are really near the cluster center and not just a random projection. These systems may be at the merging stage of cD formation when both nuclear star systems have not yet been disrupted by tidal friction. If this is the case, 3C 75 may yield information about the dynamical evolution of merging galaxies and the mass supply mechanism to each galactic nucleus (Yokosawa and Inoue 1985). However, as we shall see below, the bending arguments and spectral index data are consistent with both nuclei having been in close interaction for $> 10^8$ yr. If this is the case, we may be observing a stable binary pair.

The strong asymmetry of the source to the north and east might suggest motion of both nuclei relative to the cluster gas to the southwest. However both nuclei are very close to the center of the diffuse optical light (F. N. Owen and R. A. White, in preparation) and the X-ray distribution (C. Jones, private communication). If one or both of the nuclei are the center of the cluster mass distribution, then it seems unlikely that the source structure is due to the motion of the nuclei through the cluster gas. Either large-scale motion of the cluster gas relative to the gravitational frame of reference of the cluster or some sort of electromagnetic effect seems to be required to explain 3C 75 (e.g., Eilek *et al.* 1984).

The bending of the jets due to motion of the cluster gas relative to the galaxy raises the same problems as encountered in 3C 465 (Eilek *et al.* 1984). From the arguments in that paper, we find that motion of 3C 75 relative to the cluster gas must be at least 1000 km s^{-1} in order to explain the bending of the jets by dynamic pressure while maintaining an energy flux along the jet which is strong enough to account for the radio luminosity of the source. However, such a high velocity seems quite unlikely. As argued in Eilek *et al.* (1984), the central galaxy almost certainly cannot move this fast relative to the gravitational reference frame of the cluster (noting also that both nuclei produce jets which bend in the same direction, so that orbital motion of one of the nuclei cannot be the explanation). Nor is it likely that the cluster gas is flowing through the cluster center at such a high velocity. Both the X-ray data on Abell 400 (which suggest a low temperature, 3×10^7 K; Jones and Forman 1984) and optical velocity dispersion measurements (which find a low value, $345[+79, -51]$ km s^{-1}; Hintzen *et al.* 1982) indicate a low sound speed for the cluster gas, on the order of 500 km s^{-1}. The exceptionally smooth X-ray surface brightness map is not consistent with a highly supersonic flow in the cluster center.

On the other hand, the smooth increase of spectral index ($S \propto \nu^{-\alpha}$) going along the tails might suggest a model in which the radiating electrons are initially energized in the core and simply lose energy without reacceleration as they flow along the tail (e.g., Bicknell 1984). Such a model removes the need for local acceleration and thus weakens the inertial term, nv^2 (where n is the particle density and v is the jet velocity), which opposes the bending (cf. Eilek *et al.* 1984). This model can easily be tested. For an adiabatically expanding jet with the magnetic field parallel to the jet axis one expects the magnetic field falls off with jet radius as $B \propto r^{-2}$. In this case one can show that the luminosity per unit length within a fixed frequency band should go as $L \propto r^{-(1+5s)/3} v^{-(2+s)/3}$ if the electron energy distribution $N(E) \propto E^{-s}$. For a dominantly azimuthal field, $B \propto r^{-1} v^{-1}$ and $L \propto r^{(1-7s)/6} v^{-(7+5s)/6}$. From analysis of the polarization data at 20 and 6 cm, which will be presented fully in a longer paper on 3C 75, the magnetic field appears to be dominantly azimuthal out to the first bend in both western jets. Since s appears to be about 2 in both inner jets, the velocity must decrease only by about a factor of 3 out to the bends to explain the brightness of the jet. From the first bend out to the rapid increase in radius at about R.A. = $(02^{\mathrm{h}}55^{\mathrm{m}}08^{\mathrm{s}})$ in both western jets, either field configuration requires no change in the velocity. However, beyond that point the field geometry becomes dominantly parallel to the jet axis. This change from azimuthal to parallel field requires a drop of about 10,000 in the velocity to explain the brightness of the jet (but would also require an increase in the velocity if magnetic flux were conserved). From the spectral index data, the minimum average velocity required in order that particles in the northwest jet reach the diffuse part of the source, about 120 kpc from the nucleus, is 3000 km s^{-1}. This average velocity together with the large deceleration inferred from the surface brightness would require a velocity well above the speed of light at the first bend. Thus, from the change in field geometry and the inferred particle lifetime, it appears that simple adiabatic deceleration models cannot explain this source. Particle acceleration and/or field enhancement must be occurring in the outer parts of the source.

Since it appears difficult to account for the source structure and luminosity using the standard kinetic luminosity arguments or by slowing down the jet, it appears that some other source of energy is needed. One might suspect the cluster gas itself. If the cluster gas is turbulent, it may be that the gas entrained by the jet could power the radio source by mechanisms such as those proposed by Eilek (1979). More detailed discussions of these ideas will be made in future papers.

VI. CONCLUSIONS

The peculiar and spectacular radio source 3C 75, together with the wealth of radio and optical data available, provides us with a unique opportunity to understand the properties of radio jets and clusters of galaxies. The pattern strongly suggests that the two nuclei of the parent galaxy are close together in space and that the jets are physically interacting. If the bending is due to the motion of the nuclei relative to the cluster gas, then there it is likely that there is large-scale subsonic motions of the gas or the gravitating matter in the cluster.

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JEAN A. EILEK: Department of Physics, New Mexico Institute of Mining and Technology, Socorro, NM 87801

MAKOTO INOUE: Nobeyama Radio Observatory, Tokyo Astronomical Observatory, Nobeyama, Nagano, Japan

CHRISTOPHER P. O'DEA: National Radio Astronomy Observatory, Edgemont Road, Charlottesville, VA 22901

FRAZER N. OWEN: National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801