RADIO JETS AS A PROBE OF THE COOLING FLOW ENVIRONMENT

D M Sumi, M L Norman, and L L Smarr
National Center for Supercomputing Applications
University of Illinois at Urbana-Champaign
152 Computing Applications Building
605 East Springfield Avenue
Champaign, IL U S A 61820

ABSTRACT We discuss the use of radio jets as a probe of the structure of cooling flows on length scales inaccessible to the currently available X-ray data The radio structure of one such cooling flow galaxy, IC 1101, suggests a shock disruption of a supersonic beam This type of radio structure is also found associated with other cooling flow galaxies The shock disruption is discussed in terms of an interaction of the beam with the cooling flow environment The current sophistication of these disruption mechanisms and of the radio observations does not compel one to favor one mechanism over another Each mechanism, however, may be useful in studying the central regions of cooling flows

1 INTRODUCTION

Radio jets associated with the central galaxy of a cooling flow can provide an interesting probe of the structure of this environment The gas beams associated with radio jets react to changes in the pressure and density of the external medium (see Norman, 1986) This reaction of the beam is recorded in the observed structure of the jet In principle, one could then use the structure of the jet to study the structure of the cooling flow

A benefit of studying cooling flows through the radio structure of a jet instead of the X-ray structure of the flow is the higher resolution that can be achieved by radio aperature synthesis arrays For example, HRI data from the Einstein Observatory has a FWHM resolution of approximately 3" In contrast, the radio source in M87 (3C 274) has been resolved by the VLA at 15 0 GHz in the A config with a FWHM of approximately 0 15" (Biretta et al , 1983) Consequently, radio sources would allow the study of changes in the cooling flow structure on scales up to twenty times smaller than the X-ray observations

A. C. Fabian (ed.), Cooling Flows in Clusters and Galaxies, 257–261.
© 1988 by Kluwer Academic Publishers.

2 RADIO OBSERVATIONS OF COOLING FLOW GALAXIES

2 1 IC 1101

We have conducted a high resolution study of the radio structure of one such cooling flow galaxy, IC 1101 This galaxy is the dominant central cluster member in Abell 2029 and is believed to have a mass inflow rate onto the galaxy of approximately 100 solar masses per year (Johnstone et al , 1987 for a Hubble constant equal to 100)

Figure 1 shows a 0 6" resolution 4 9 GHz map from a combination of A and B config data taken at the VLA The most interesting feature of this map is the symmetric knots on either side of the nucleus The knots appear to delineate two very different parts of each jet Inward from the knots, the map suggests a weakly radiating flow, with a beam width less than 0 6" and little evidence of bending The lack of bending is suggested by the colinearity of the knots Outward from the knots, the map suggests a strongly radiating flow, with a beam width spread over 2" and observable bends In the southeastern jet, there is evidence of an embedded oscillation superimposed on the larger bend

Figure 2 shows a 1 3" resolution map at 1 5 GHz from A config data taken at the VLA This map is more sensitive to broad low surface brightness structures and shows further extensions of the jets seen in figure 1 There is evidence of strong twists and bends in both jets There are no outer hotspots or radio lobes The emission from each jet simply fades into the noise at the outer edge of the jet in the manner characteristic of FR I type radio sources (Fanaroff & Riley, 1974)

The overall jet structure seen in these maps of IC 1101 suggests a disruption of a supersonic beam into a turbulent subsonic beam by a single shock event (Sumi et al , 1987)

2 2 Other Cooling Flow Galaxies

High resolution observations of three other radio sources associated with cooling flow galaxies, 3C 274 (Biretta et al , 1983), 4C 26 42 (van Breugel et al , 1984), and 3C 84 (Pedlar et al , 1983), all show structure similar to IC 1101 The symmetric knots found in IC 1101 are also found in 4C 26 42 3C 84 and 3C 274, however, both lack a counter knot This may be the result of relativistic beaming or inherent onesideness and not the result of a lack of symmetry All the knots are found close to their radio nucleus In IC 1101, the knots have a projected galactocentric radius of 1 4 kpc In 4C 26 42, 3C 84, and 3C 274, the galactocentric radius of the knots are 0 9, 0 8, and 1 4 kpc, respectively

2 3 Low Resolution Surveys

As a class, radio sources associated with cooling flow galaxies tend to be more compact than other radio sources (Owen et al , 1984) In low resolution surveys, their structure generally consists of a bright unresolved core source with diffuse FR I type jets and/or a diffuse halo (O'Dea & Baum, 1987) This same morphology is observed in IC 1101, 4C 26 42, 3C 84, and 3C 274 at a resolution comparable to these surveys Therefore, it is at least not inconsistent for the diffuse structures in these surveys to be the result of a shock disruption of their beams inside the unresolved radio core Clearly, high resolution observations of more cooling flow galaxies are needed to understand the origin of the diffuse structures in these sources

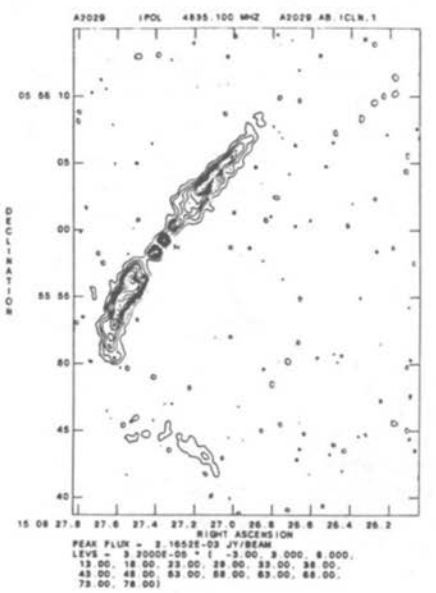


Figure 1. CLEANed untapered 4.9 GHz intensity contour maps of IC 1101 from concatenated A and B configuration data taken at the VLA. The FWHM resolution of the map is 0.58″ x 0.56″ and the RMS noise level is 0.000032 Jy per beam. The nucleus of the galaxy is designated by N.

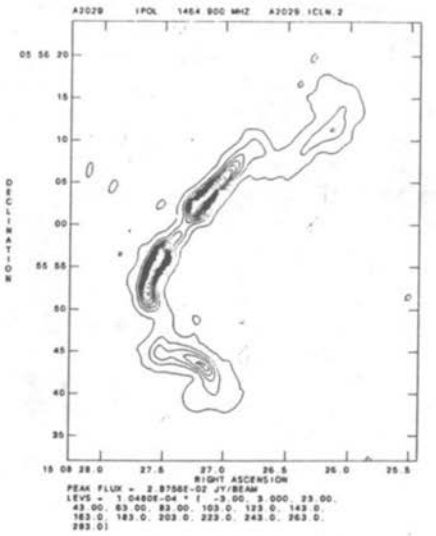


Figure 2. CLEANed untapered 1.5 GHz intensity contour map of IC 1101 from A configuration data taken at the VLA. The FWHM resolution of the map is 1.34″ x 1.27″ and the RMS noise level is 0.00011 Jy per beam.

2.4 Exceptions

Two notable exceptions are 3C 405 (Arnaud et al., 1984) and 3C 295 (Henry & Henriksen, 1986) which have FR II type radio structure (Perley et al., 1984 and Wilkinson, 1982). These sources, however, are much more powerful than the sources previously mentioned, approximately one thousand times the 1.4 GHz power of IC 1101. High powered radio sources may have a disruptive effect on the environment. This disruption may make them less sensitive to their propagating environment (Norman, 1987).

3 DISCUSSION

The present trend cited above suggests that some factor in the cooling flow environment is responsible for the shock disruption observed in IC 1101 and others. Several possible mechanisms may cause disruptive shocks in beams propagating through a cooling flow. These mechanisms are collisions with dense gas clouds (Blandford & Königl, 1979), growth of ordinary mode Kelvin-Helmholtz instabilities (Sumi & Smarr, 1986), and pressure walls in the pressure distribution of transonic cooling flows (Burns, 1986, Burns et al., 1987, and Soker & Sarazin, 1987). In order to explain the apparent symmetric nature of the knots in IC 1101, and 4C 26.42, the cloud collision and Kelvin-Helmholtz shock mechanisms require an additional symmetrizing mechanism (see Sumi et al., 1987). The pressure wall mechanism is naturally symmetric in a spherical cooling flow.

Note that each mechanism would give information about structures or regions in the cooling flow that cannot be resolved by the available X-ray data. A collisional mechanism gives information on inhomogeneities in the flow. Kelvin-Helmholtz instabilities give information on the density and pressure distribution at the center of the flow. A pressure wall would give information about very sharp changes in the pressure distribution at the center of the flow and could indicate the existence of a sonic point.

At the present time it is not possible to rule out any of these mechanisms. However, the ubiquity of symmetric knots in a large sample of cooling flow galaxies would help to rule out cloud collisions as the primary shock mechanism. Symmetric collisions in all the sources would be improbable. We are in the process of observing ten cooling flow galaxies with the VLA at a resolution of approximately 0.4". These observations will allow us to resolve the core structures of the sample at approximately one kpc or better. In addition, an investigation of the propagation of beams in cooling flows using two dimensional beam simulations (Norman et al., 1985) is currently in progress. It is hoped that these simulations will determine the circumstances in which a pressure wall or Kelvin-Helmholtz instabilities can cause beam disruptions similar to those observed.

4 ACKNOWLEDGEMENTS

DS would like to thank Roger Blandford and the Theoretical Astrophysics group at the California Institute of Technology for their hospitality while this study was being conducted.

5 REFERENCES

Arnaud, K A , Fabian, A C , Eales, S A , Jones, C , and Forman, W (1984), *Monthy Notices R Astr Soc* , **211** , 981

Biretta, J A , Owen, F N , and Hardee, P E (1983), *Astrophys J* , **274** , L27

Blandford, R D , and Konigl, A (1979), *Astrophys Lett* , **20** , 15

van Breugel, W , Heckman, T , and Miley, G (1984), *Astrophys J* , **276** , 79

Burns, J O (1986), *Can J Phys* , **64** , 373

Burns, J O , Norman, M L , and Clarke, D A (1987), in *Radio Continuum Processes in Clusters of Galaxies*, Proc NRAO Workshop No 16 (NRAO Green Bank, WV), eds C P O O'Dea and J M Upson, 175

Fanaroff, B , and Riley, J M (1974), *Monthy Notices R Astr Soc* , **167** , 31

Henry, J P , and Henriksen, M J (1986), *Astrophys J* , **301** , 689

Johnstone, R M , Fabian, A C , and Nulsen, P E J (1987), *Monthy Notices R Astr Soc* , **224** , 75

Norman, M L (1986), in *Radiation Hydrodynamics in Stars and Compact Objects*, eds D Mihalas and K-H A Winkler (Springer-Verlag Berlin), 425

Norman, M L (1987), *Bull Amer Astr Soc* , **19** , 651

Norman M L , Smarr, L L , and Winkler, K-H (1985), in *Numerical Astrophysics*, eds J Centrella, J LeBlanc, and R Bowers (Jones and Bartlett Portola Valley, CA)

O'Dea, C P O , and Baum, S A (1987), in *Radio Continuum Processes in Clusters of Galaxies*, Proc NRAO Workshop No 16 (NRAO Green Bank, WV), eds C P O O'Dea and J M Upson, 141

Owen, F N , Burns, J O , and White, R A (1984), in *Clusters and Groups of Galaxies*, eds F Mardirossian, G Giuricin, and M Mezzetti (Reidel Dordrecht), 295

Pedlar, A , Booler, R V , and Davies, R D (1983), *Monthy Notices R Astr Soc* , **203** , 667

Perley, R A , Dreher, J W , and Cowan, J J (1984), *Astrophys J* , **285** , L35

Soker, N , and Sarazin, C L (1987), Preprint

Sumi, D M , Norman, M L , Smarr, L L , and Owen, F N (1987), In Preparation

Sumi, D M , and Smarr, L L (1986), in *Physics of Energy Transport in Extragalactic Radio Sources*, Proc NRAO Workshop No 9 (NRAO Green Bank, WV), eds A H Bridle and J A Eilek, 168

Wilkinson, P N (1982), in *Extragalactic Radio Sources* , Proc IAU symp No 97 (D Reidel Dordrecht), eds D S Heeschen and C M Wade, 149