THE ASTROPHYSICAL JOURNAL, 250:66–78, 1981 November 1

ORBITAL MOTION OF THE HEAD-TAIL RADIO GALAXY IC 708

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Received 1981 February 25; accepted 1981 May 4

ABSTRACT

The Very Large Array has been used to map the unusual head-tail radio galaxy IC 708 in the cluster of galaxies Abell 1314 with resolutions from 0.″5 to ~ 3.″3 at 4.89 GHz. The new data strongly suggest that the unusual structure of the source is due to a gravitational interaction between IC 708 and its neighbor IC 709 while both orbit the center of Abell 1314.

The shapes of the radio trails and some details of the variation of intensity along them can be explained by projection effects arising from the orbital motion of IC 708 and by the effects of the variation of the orbital velocity of IC 708 on the motions of its ejecta. We have made numerical simulations of the orbiting head-tail system incorporating various models of the ejecta dynamics. The most satisfactory model for the structure is one in which a pair of continuous supersonic jets bends behind IC 708 under the ram pressure of the intracluster medium. Furthermore, the distributions of intensity and polarization over the trails of IC 708 resemble those observed in straight radio jets in several low luminosity radio galaxies. It appears that external pressures have bent similar jets in IC 708 through almost 90° without disrupting them.

Subject headings: galaxies: individual — galaxies: structure — radio sources: galaxies

I. INTRODUCTION

The head-tail radio galaxies which have been mapped at high resolution and at many frequencies have been used both as probes of the intracluster medium (ICM) in clusters of galaxies (e.g. Jaffe and Perola 1973; Miley, Wellington, and van der Laan 1975; Ekers *et al.* 1978) and as test beds for theories of energy transfer and particle acceleration in extended extragalactic radio sources (e.g. Begelman, Rees, and Blandford 1979; Burns, Owen, and Rudnick 1979). Our knowledge of the head-tail structures has recently been reviewed by Miley (1980) and by Vallée (1977).

Table 1 lists the published observations of the head-tail radio galaxy IC 708 ($m_V = 14^m.4$, $z = 0.0320$) in the (richness 0) cluster of galaxies Abell 1314. IC 708 is unique among the known head-tails because at a resolution of ~ 6″ (Vallée, Wilson, and van der Laan 1979) its twin trails of radio emission appear to flare outwards into diffuse "wings" of emission some 35 kpc ($H_0 = 50$ km s^{-1} Mpc^{-1}) from the center of the optical galaxy. This curious morphology motivated the description of IC 708 as a "papillon" ("butterfly") structure by Vallée, Wilson, and van der Laan (1979), who interpreted the structure in terms of the dynamical effects of a hypothetical thermal pressure gradient downstream of IC 708. Such a gradient might be caused by accretion of the ICM behind IC 708 in its orbit (e.g., Hunt 1971, 1979) or by ablation of the gas lost by stars in IC 708 under the ram pressure of the ICM (e.g., Gisler 1976; Lea and De Young 1976).

Section II of this paper presents new 4.89 GHz observations of IC 708 made with the partially completed VLA (Thompson *et al.* 1980). These observations provide the highest resolution maps so far available of IC 708. The new maps suggest an alternative interpretation of its structure in terms of gravitational interactions between IC 708, its close neighbor IC 709, and the center of mass of Abell 1314. The basis of this new interpretation is outlined in § III. Section IV describes an approach used to make numerical models of the radio trail structure of IC 708, and § V discusses the consequences of these models for the physical parameters of the radio trails. Throughout the paper we adopt a Hubble parameter $H_0 = 50$ km s^{-1} Mpc^{-1} and a deceleration parameter $q_0 = 0.5$.

II. THE VLA OBSERVATIONS

The new 4.89 GHz observations were made in 1979 February with 14 VLA antennas. Important parameters of the observations are listed in Table 2. All available

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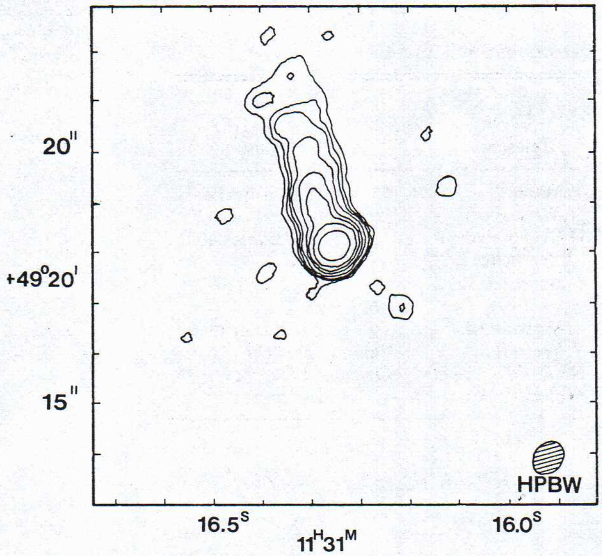

FIG. 1.—4.89 GHz brightness distribution over IC 708 with resolution 0".51 by 0".63 (major axis in p.a. 140°). Contours are drawn at 2%, 3%, 4%, 6%, 10%, 15%, 25%, and 50% of the peak of 49 mJy per beam. The FWHM of the synthesized beam is indicated by the shaded ellipse.

Owen, Hardee, and Bignell 1980; de Vaucouleurs and Nieto (1979), and (3) to those of several one-sided jets found in quasars by VLBI mapping (Wilkinson *et al.* 1977; Readhead *et al.* 1979). No counterjet is detected at this resolution.

At the resolution of this map, the position angle χ of the E-vector of the linear polarization is aligned roughly perpendicular to the jet from the radio core up to 2" (1.8 kpc) along the jet, where the polarized intensity decreases to the rms noise of about 0.3 mJy per beam area. The percentage of linear polarization, $p = 100(Q^2 + U^2)^{1/2}/I$, increases from about 1% at the radio core to about 10% at 1".33 (1.2 kpc) along the jet.

b) Map at ~ 1".3 Resolution

Figure 2 shows the CLEANed map at 1".3 by 1".4 resolution (major axis in p.a. 35°) obtained by tapering the observed visibility amplitudes with a Gaussian function falling to $1/(e)^{1/2}$ at 5 km from the center of the (u, v) plane. At this resolution the "jet"-like feature of Figure 1 blends into an arclike or **U**-shaped structure whose apex is at the unresolved radio core. As depicted in Figure 2, the bending occurs well within the 30" overexposed central region of the image of IC 708 on the red-sensitive Palomar Sky Atlas print. This emission arc appears to have structure on a scale of about 4" (3.5 kpc), reminiscent of that found in NGC 1265 at 6 cm by Owen, Burns, and Rudnick (1978).

c) Map at ~ 3".3 Resolution

Figure 3 shows the CLEANed total intensity map at 3".3 by 3".9 resolution (major axis in p.a. 24°) obtained by applying a 2 km Gaussian taper to the observed visibility amplitudes. This map has better sensitivity to the large scale structure of the radio trails. The two "flares" at the western ends of the trails observed at 6" by 8" resolution by Vallée, Wilson, and van der Laan (1979) are each resolved on this map into a "hook" structure. This hook structure can also be seen on the map at ~ 1".3 resolution in that area, although the signal-to-noise is poorer in that map. Both trails contain substructure on a scale of about 6" (5 kpc). Their widths slowly increase with distance from the galaxy, from 7" (6.2 kpc) between 24" and 80" (21 and 70 kpc) from IC 708 to 13" (11.5 kpc) at 95" (84 kpc) from the galaxy and 15" (13 kpc) beyond 100" (88 kpc).

As the shortest baseline in the VLA observations was 90 m, 28% of the total intensity in the 6 cm WSRT map (Vallée, Wilson, and van der Laan 1979) is missing from our maps. A comparison with the WSRT map shows that this missing intensity would partly fill the regions within the two "hooks" in Figure 3.

d) Polarization and Magnetic Field Configuration

Figure 4 shows the large scale distribution of the E-vector of the linear polarization at the resolution of Figure 3. The polarized signal is weak, but its distribution agrees well with that found by Vallée, Wilson, and van der Laan (1979) after allowing for their lower resolution. The E-vectors are roughly parallel to the lengths of the radio trails between 8" (7.0 kpc) and 50" (44 kpc) from the radio core. Further from the core, where the ridges begin to turn

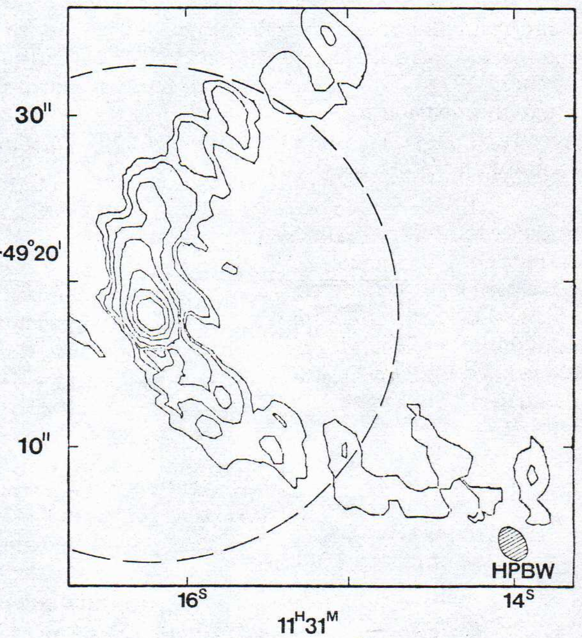

FIG. 2.—4.89 GHz brightness distribution over IC 708 with resolution 1".3 by 1".4 (major axis in p.a. 35°). Contours are drawn at 0.75%, 1.5%, 3%, 6%, 15%, 30%, and 50% of the peak of 59 mJy per beam. The FWHM of the synthesized beam is indicated by the shaded ellipse. The dashed curve depicts the boundary of the overexposed core of IC 708 on the red print of the Palomar Sky Atlas.

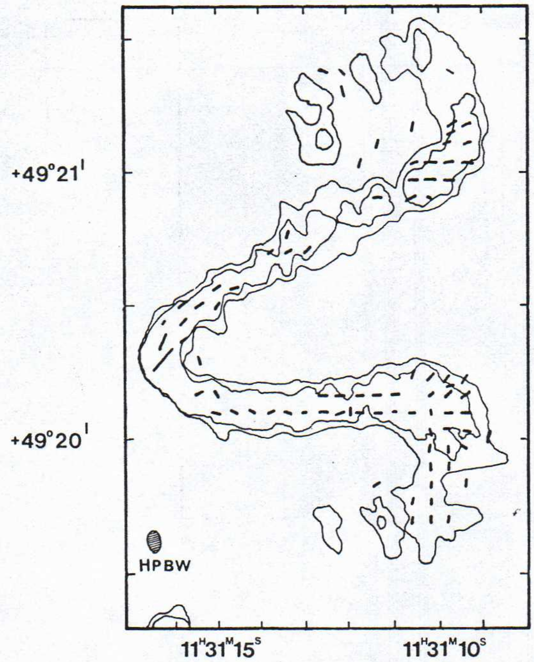

FIG. 4.—Intensity and position angle of linearly-polarized emission from IC 708 at the resolution of Fig. 3. Each vector has a length proportional to the polarized intensity $(Q^2 + U^2)^{1/2}$ and a position angle equal to that of the observed *E*-vector. The maximum polarized intensity plotted is 2.6 mJy per beam. Outer contours of Fig. 3 are shown for reference.

identification is apparent on the Palomar Sky Atlas prints, (3) its percentage of linear polarization is < 3%, and (4) its spectral index $\alpha \sim 0.65$ $[S(\nu) \propto \nu^{-\alpha}]$ between 1.4 and 5.0 GHz. Our VLA data at ~ 0".5 resolution show the source to be double with a component separation of 1" in p.a. ~ 85°. It is probably a background source unrelated to Abell 1314.

III. THE BASIS OF AN ORBITAL INTERPRETATION OF THE STRUCTURE

The most interesting large scale feature revealed by the new VLA maps of IC 708 is the striking "double-hooked" morphology of the source (Fig. 3). As the twin trail structure within 50 kpc of the center of the galaxy can clearly be explained by the conventional radio "head-tail" hypotheses (e.g. Miley *et al.* 1972), it is natural to retain these while seeking an explanation for the hooked shapes of the ends of the trails. Our basic proposal is that IC 708 has followed a curved trajectory through Abell 1314, with our line of sight lying almost in the plane of the orbit. Superposed on this motion is the usual increase in separation between the two trails characteristic of twin head-tail galaxies such as NGC 1265 (Owen, Burns, and Rudnick 1978). Figure 5 illustrates the basis of such a model for the radio structure.

Orbital interpretations for curvature in head-tail sources with *single* radio trails have previously been proposed, in varying amounts of detail, for 3C 129 (Miley *et al.* 1972; Byrd and Valtonen 1978) and for NGC 4874

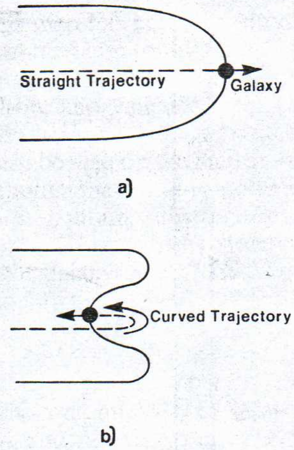

FIG. 5.—Schematic illustration of the basis of orbital models for the trail structure of IC 708. (*a*) The planar twin-trail structure of a head-tail galaxy traveling in a straight line at constant velocity. (*b*) The same structure in the case of orbital motion of the galaxy around a neighboring mass center.

(Jaffe, Perola, and Valentijn 1976; Valtonen and Byrd 1979). In the case of IC 708, the fact that the trail is *double* allows us to match many physical characteristics of the observed structure by varying the parameters of an orbital model, once the center of gravitational attraction for the orbit has been identified.

To begin this identification, we note that the plane of the past orbit of IC 708 must be indicated approximately by the bisector of the two radio trails. The dominant attracting center should therefore be located eastwards from IC 708 along position angle ~ 108°. Figure 6 shows the optical field of IC 708 in the central area of Abell 1314.

a) IC 709 as the Attracting Center

We believe that the 15 mag galaxy IC 709 is primarily responsible for the distortions of the radio trails of IC 708 for four reasons. First, as shown in Figure 6, IC 709 is the brightest galaxy in the immediate field near the bisector of the double radio trail of IC 708. Second, IC 709 is only 165" (145 kpc) in projected separation from IC 708. Third, IC 709 is only 0.8 mag fainter than IC 708 (Zwicky and Herzog 1966), so it should have sufficient mass to deflect IC 708 significantly. Fourth, the IC 708/709 pair is kinematically isolated in Abell 1314: the radial velocities of the two galaxies differ by only 64 ± 210 km s^{-1} from each other but by 568 km s^{-1} from the mean radial velocity of 16 cluster galaxies measured by Coleman *et al.* (1976). Assuming the radial velocities to be Gaussian distributed with a standard deviation of 708 km s^{-1} (Coleman *et al.* 1976), this apparent isolation has only a 5.0% probability of being due to chance. We therefore attempted initially to find "single-orbit" models for the radio structure of IC 708, based on the assumption that IC708 orbits IC 709 alone.

b) Initial Values for Single-Orbit Parameters

In this subsection we obtain *rough* values for the orbital parameters of the IC 708/709 pair. These were used as

5. Using Kepler's law, the orbital period

$$P = 3 \times 10^{12} \left(\frac{a}{\text{kpc}}\right)^{3/2} \left(\frac{M}{M_\odot}\right)^{-1/2} \text{ yr} \tag{5}$$

which for $M = 1.5 \times 10^{11}\ M_\odot$ gives $P > 9 \times 10^8$ yr and for $M = 1.5 \times 10^{12}\ M_\odot$ gives $P > 3 \times 10^8$ yr.

6. The circular velocity

$$v_c = 2 \times 10^{-3} \left(\frac{a}{\text{kpc}}\right)^{-1/2} \left(\frac{M}{M_\odot}\right)^{1/2} \text{ km s}^{-1} \tag{6}$$

is < 158 km s^{-1} for $M = 1.5 \times 10^{11}\ M_\odot$ and < 500 km s^{-1} for $M = 1.5 \times 10^{12}\ M_\odot$. As v_1 was only 21 ± 68 km s^{-1}, it is therefore likely that we are viewing IC 708 at a large angle to its spatial velocity. This conclusion could, however, be incorrect either if Δv is underestimated or if the orbit of IC 708 is highly eccentric and IC 708 is near its closest approach to the center of mass.

c) The Cluster Center as the Attracting Center

We have used positions for the galaxies in Abell 1314 privately communicated by Dr. A. Oemler to estimate that the cluster center is at 1950.0 coordinates $11^h32^m12^s \pm 12^s$, $+49°20' \pm 2'$. Sastry and Rood (1971) give the position of the cluster centroid as $11^h32^m06^s \pm 12^s$, $+49°20' \pm 2'$. The mean radial velocity of the 16 cluster members measured by Coleman *et al.* (1976) is $10{,}150 \pm 180$ km s^{-1}. We therefore surmise that the 15 mag galaxy IC 712 ($11^h32^m06^s.5 \pm 0^s.1$, $+49°21'16'' \pm 1''$, $v_r = 10{,}054$ km s^{-1}) may be resting at the cluster center to within the positional and velocity uncertainties. As the cluster center, or IC 712, can be a secondary center of attraction for IC 708 we have also constructed "double-orbit" models based on the assumption that IC 708 orbits both IC 709 and the cluster center. With this assumption the IC 708/709 pair describes an orbit in the cluster for which $l_1 \sim 460$ kpc and $v_1 \sim -570$ km s^{-1}. The distance traveled around the center of the cluster in 6×10^8 yr (a likely value for the period P of the "local" orbit of IC 708 around IC 709) is thus ~ 350 kpc, much larger than the probable size of the major axis ($2a > 47$ kpc) of the local orbit. For consistency with the observed shape of the trails, most of the distortion produced by the orbital motion around the cluster center must lie along the line of sight, which must therefore be almost tangent to the larger orbit. The assumption of the additional orbital motion about the cluster center does not directly improve the fit to the trail *shapes*, but it increases the fitted ejection velocities and decreases the time scales associated with the formation of the radio structure (see § V).

IV. DETAILED MODELS

We now compare the observed radio structure of IC 708 with detailed numerical simulations of an orbiting head-tail galaxy. The simulations have four main stages: (1) obtaining the shapes of the trail ridge lines in the planar case (Fig. 5*a*); (2) superposing on the planar structure the three-dimensional curvature resulting from the orbital motion of the galaxy; (3) imposing an assumed variation of radio emissivity with distance from the galactic nucleus throughout a finite volume around each ridge; and (4) projecting the resultant three-dimensional source model into a two-dimensional intensity map of specified resolution to simulate observations made from a specified line of sight. We now describe these steps in more detail.

a) The Ridge Structure

We adopt a Keplerian variation of the velocity $\boldsymbol{v}_g$ of the galaxy in magnitude and direction as in an elliptical orbit:

$$v_g^2 = GM \cdot \left(\frac{2}{r_1} - \frac{1}{a}\right). \tag{7}$$

This provides both the twisting into three dimensions of the basic planar double trail shape (Fig. 5*b*) and a modification of the trail shape due to the variation of the space velocity $\boldsymbol{v}_0$ with which the matter is ejected into the trails. (This velocity is $\boldsymbol{v}_0 = \boldsymbol{v}_g + \boldsymbol{v}_e$, where $\boldsymbol{v}_e$ is the velocity of ejection of the trail material relative to the nucleus of the galaxy, which we assumed to be fixed in magnitude and direction). Variations in $\boldsymbol{v}_0$ around the orbit result in asymmetries between the two trails even if they would be completely symmetrical in the planar case (Fig. 5*a*).

To construct the ridge shapes we use equation (7) to find $\boldsymbol{v}_g$ (and hence $\boldsymbol{v}_0$) for successive positions of the galaxy, and then the appropriate trail-dynamics equation to find the distance from the galaxy traveled by the ejected material in the time between its ejection and the observation. We consider four models for the trail dynamics (eqs. 8 to 10 and the Appendix).

Jaffe and Perola (1973) (JP) obtained the relation

$$d = D[1 - \exp(-v_0 t/D)] \tag{8}$$

for the separation d of trail material from a parent galaxy at time t following the hypersonic ejection of the material. The JP dynamics were derived for a gravitationless independent-blob model of 3C 129 and were later shown by Owen, Burns, and Rudnick (1978) to give a fair representation of the ridge shapes in the double trail structure of NGC 1265.

Cowie and McKee (1975) (CM) modified the JP independent-blob model, arguing that the ejection of the material should be only mildly supersonic with respect to the external medium. The cross sections of ejected plasmoids could then be treated as constant, as they are determined by the external thermal (not ram) pressure. In this "CM" model equation (8) must be replaced by

$$d = D \ln(1 + v_0 t/D), \tag{9}$$

but otherwise the trail shapes are derived as before.

Blandford and Icke (1978) (BI) attributed the bending of the twin jets in 3C 31 to the acceleration experienced by the galaxy during a gravitational encounter with a near neighbor. In their model the trails are "heavy" jets which are neither decelerated nor bent by the ram pressure of the ICM; they are deviated by the "jerk" experienced by the galaxy near perigalacticon of its orbit. We have

TABLE 3

PARAMETERS OF BEST-FITTING ORBITAL MODELS

Model Type (orbit type, dynamics)	Equivalent[a] Mass at Focus ($M_{\odot}$)	Eccentricity[a] Inclination (e, θ, ϕ)[b]	Semimajor[a] Axis (kpc)	Ejection Velocity (km s^{-1})	Stopping Distance (kpc)	Age at end of Trails (yr)	s_{max}[c] (kpc)
Single, JP	1×10^{10}	0.70, 336°, 3°	125	12	85	2×10^{10}	270
Single, CM	1×10^{10}	0.70, 336°, 3°	125	17	36	2×10^{10}	270
Single, BRB	1×10^{10}	0.70, 336°, 3°	125	550	80	6×10^{9}	160
Double,[d] JP	3.3×10^{11}	0.87, 354°, 89°	41	100	320	8×10^{8}	65
Double,[d] CM	3.3×10^{11}	0.87, 354°, 89°	41	85	270	1×10^{9}	86
Double,[d] BRB	3.3×10^{11}	0.87, 354°, 89°	41	7800	900	1×10^{8}	20

[a] Parameters in these columns refer to orbit of IC 708 about IC 708/709 center of mass.

[b] Angle θ: azimuth of line of sight from x-axis (in x-y plane); angle ϕ: polar angle of line of sight from z-axis (orbit of IC 708 around IC 708/709 center of mass is in x-z plane with its major axis parallel to z-axis).

[c] In all models, $\epsilon(s) = \exp(-2s/s_{max})$; see § V of text.

[d] Cluster orbit is assumed to be circular in double-orbit models.

708. The presence of similar intensity maxima in the data supports the basic interpretation of the source structure as arising from an orbital motion of IC 708. The large eccentricity ($e = 0.70$) of the orbit is needed in order to explain the lengths of the sections of the trails between points A1 and C1, and A2 and C2 on the northern and southern trails respectively. As the ejecta in these sections are highly decelerated by the ram pressure of the ICM, the lengths of A1 to C1 and A2 to C2 along the line of sight must significantly exceed the lengths from the radio core to A1 and A2, if the projected structure is to form "hooks" that are as open as those observed. These geometrical constraints can be satisfied only if the orbit is eccentric with the major axis oriented near the line of sight.

While the model shown in Figure 7 fits the shape of the hook structure far from IC 708 and the variation of intensity along the trails quite well, the modeled angle between the trails within 20″ of the core is clearly too small. No single-orbit model using equation (8) was found to fit this close-in structure better while retaining the fit to the "hooks." In effect, the trails in IC 708 appear to separate more rapidly near the galaxy, and less rapidly further away, than would be predicted by equation (8). Furthermore, the ejection velocities required by the model's dynamics are very low (a few tens of km s^{-1}) in all models that gave reasonable fits to the data.

Such low velocities raise at least three serious objections to the dynamical basis of such models. First, the deduced ages of the material at the ends of the trails are so high (of the order of the Hubble time) that the assumption that IC 708 and IC 709 have remained a closed dynamical system over the lifetime of the radio source is untenable. Second, the low ejection velocities cannot be hypersonic, as the model assumed. Third, at such low ejection velocities the assumption that the trajectory of the material would be unaffected by gravitation cannot be maintained.

We therefore regard the model shown in Figure 7 as a useful demonstration of the ability of an orbitally derived *shape* to reproduce the observed radio map, but we find its underlying dynamics to be unacceptable. Guided by the orbital parameters which simulate the trail shapes successfully in this model, we made further models using the CM dynamics embodied in equation (9). The best-fitting CM models differed only in minor details from those obtained using equation (8); the parameters of the best fit obtained in 30 trials are given in row 2 of Table 3. Single-orbit models based on equation (9) are therefore subject to the first and third objections made above to the JP models. We therefore also reject these models.

All attempts to simulate the observed structure using the BI "heavy jet" dynamics failed completely to reproduce the outer (hooked) half of the trails, showing that the ICM must in fact strongly decelerate material ejected from IC 708, in contrast to the hypotheses implicit in the BI dynamics.

We achieved most success in fitting single-orbit models to the observations using the continuous-jet dynamics given in the Appendix, with JP dynamics describing the motion of the material beyond the empirically determined "disruption point" where the jet is presumed by Begelman, Rees, and Blandford (1979) to share its momentum with shocked ICM. Although the implied age of the particles at the ends of the trails is significantly reduced in the best-fitting model of this kind (Table 3, row 3), it remains very long (6×10^{9} yrs). We must still have serious reservations about the assumption of dynamical isolation of the IC 708/709 system over such a time scale. Furthermore, this model "particle age" is much longer than the expected radiative lifetime (3×10^{7} yrs) of particles emitting at 4.9 GHz in the equipartition magnetic field of the trails and in the equivalent magnetic field of the 2.7 K background.

This time scale problem in the single-orbit models arises primarily from the apparently small difference in radial velocities, $\Delta v = 64 \pm 210$ km s^{-1}, between IC 708 and IC 709. Unless the uncertainties in the two radial velocities are utilized to postulate $\Delta v \gg 64$ km s^{-1}, low ejection velocities are required in order to obtain the observed trail curvature; these in turn lead to large "ages" for the ends of the trails. We therefore conclude that unless the true radial velocity difference between IC

The modeled ejection velocity of 7800 km s^{-1} and the required critical angle of 87° for disruption of the jets are similar to those of 10^4 km s^{-1} and 75° derived by Begelman, Rees, and Blandford (1979) for their fit to the structure of NGC 1265. In both cases the large values of the critical angle require that the jets be remarkably stable against disruption by their interaction with the ICM through which the parent galaxy is traveling.

The age of the ends of the trails in this model is 10^8 yrs. While this is still somewhat longer than the radiative lifetime of 3×10^7 yrs for the electrons emitting at 4.89 GHz in the equipartition magnetic field, the discrepancy is no longer as serious as in the other double-orbit models and in all single-orbit models. Observations of the distribution of the radio spectral index over the trail structure are necessary in order to establish how serious a constraint the remaining time scale discrepancy actually places on the continuous-jet interpretation. The radial velocities of IC 708 and IC 709 should also be redetermined with greater precision, for a velocity difference $\Delta v > 64$ km s^{-1} would assist in removing the time scale problem (if any) from this model.

The double-orbit model also removes the constraints on the barycentric mass M discussed at the end of § V*a* and leads to estimates of $M \sim 3.3 \times 10^{11} M_{\odot}$ (Table 3) that are more consistent with our initial expectations for this parameter (§ III*b*).

VI. CONCLUSIONS

Orbital models of the trail structure of IC 708 appear to be attractive provided (1) that the orbital velocities significantly exceed the small radial velocity difference between IC 708 and IC 709, and (2) that continuous-jet dynamics are employed to describe the motions of the radio ejecta. The orbital models avoid the need to invoke asymmetric diffusion of relativistic particles perpendicular to the motion of IC 708 in order to explain the radio "wings" (cf. Vallée, Wilson, and van der Laan 1979). The broad intensity maxima near the beginnings of the hooked structures can also be explained by the same projection effects that account for the asymmetries between the trails. The basic geometry of the orbital models therefore offers a simple explanation for several of the major features of the radio structure of IC 708. Double-orbit models, while having the unpleasant aspect of larger numbers of adjustable parameters, provide a plausible means of satisfying the velocity (and time scale) constraints required for an acceptable description of the source.

The fact that continuous-jet dynamics appear to be required in order to fit the trail *shapes* reinforces the analogies drawn directly from the maps in § II between the intensity and polarization distributions over IC 708 and over the straight jets in 3C 31, NGC 315, and 3C 449. The one-sidedness of the high brightness features within ~ 2 kpc of the radio core, the probable orientation of the magnetic field parallel to the extension of these features, and the subsequent transition to a predominantly perpendicular orientation further from the core, all resemble observed features of straight jets in low luminosity radio galaxies. Our results strongly suggest that in IC 708 we are viewing a system intrinsically similar to the low luminosity "twin-jet" radio galaxies, but whose jets are bending backwards into a **U**-shape without significant modification of their internal structure. These observations therefore add to the growing body of evidence for the stability of large scale supersonic jets against disruption by external pressures or by the growth of internal perturbations, even while bending through angles approaching 90° due to interactions with the ICM.

Finally, we note that high resolution radio observations may now be able to contribute to studies of galaxy-galaxy interactions by identifying galaxies whose radio structures exhibit the effects of gravitational encounters. Orbital parameters have now been suggested for 3C 129, NGC 4874, 3C 31, and IC 708 on the basis of radio structural data. These putative "binary galaxies" are situated at the long period end of the period distribution for such systems and extend the range that can be sampled by optical observations alone.

We thank Drs. R. C. Bignell and F. N. Owen, and the staff of the VLA, for their help and cooperation during the observations and their reduction. We also thank Dr. R. N. Henriksen for many discussions of jet dynamics and Dr. M. J. L. Kesteven for advice on map simulation using the Astronomy Computing Facility at Queen's University. This research was supported by grants to A. H. B. from the Natural Sciences and Engineering Research Council of Canada (NSERC), and to the Astronomy Computing Facility from NSERC, from the Advisory Research Committee and from the Department of Physics at Queen's University.

A. H. B. also thanks the National Radio Astronomy Observatory and the University of New Mexico for their hospitality during a sabbatical leave in which this work was completed.

APPENDIX

CONTINUOUS JET DYNAMICS

If the flow along the trail approximates a constant speed (v_e) jet of scale height h transverse to the flow direction, and if the flow is mass-conserving and adiabatic we will have

$$\rho_j h^2 = \text{constant} \quad \text{and} \quad p_j \propto \rho_j^{\Gamma} \propto h^{-2\Gamma} , \tag{A1}$$

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