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RADIO JETS IN COLLIDING GALAXIES: TESTING THE INTERACTION-ACTIVITY CONNECTION

Kirk D. Borne (Space Telescope Science Institute, Baltimore, Maryland)
and
Luis Colina (Universidad Autónoma de Madrid, Spain)

The idea that galaxy interactions and merging are related to the generation of starburst and AGN activity in galactic nuclei has been the subject of intensive investigations over the past several years and is still a matter of lively debate (for reviews, see: Hernquist 1989, Nature, 340, 687; Stockton 1990, in *Dynamics and Interactions of Galaxies*, p. 440; and Heckman 1990, in *Paired and Interacting Galaxies*, IAU Colloquium #124, p. 359). Peculiar morphologies, indicative of tidal interactions, have been detected in high-luminosity radio galaxies (Heckman *et al.* 1986, ApJ, 311, 526), in quasars (Hutchings 1987, ApJ, 320, 122), and in ultraluminous IRAS galaxies (Sanders *et al.* 1988, ApJ, 325, 74). In addition, low-luminosity radio and active galaxies show similar evidence for a recent merger or for nearby companions (MacKenty 1989, ApJ, 343, 125; Colina & Pérez-Fournon 1990*a*, ApJS, 72, 41; Colina & Pérez-Fournon 1990*b*, ApJ, 349, 45; Macchetto *et al.* 1990, ApJ, 356, 389; and Colina *et al.* 1991, ApJ, 370, 102).

In a recent CCD optical study of galaxies selected on the basis that they all contain well defined radio jets, it was found that almost half of the sample consists of pairs of elliptical galaxies (Colina & Pérez-Fournon 1990*a*,*b*). Many of these low-luminosity radio galaxies with companions (*e.g.*, 3C 31, 3C 278, 3C 449, and NGC 1044) show a well defined distorted radio jet structure at the VLA scale with an *S*- or *C*-shaped morphology.

We have developed a general numerical simulation algorithm for ballistic radio jets with the intention of applying this model to the study of the bent jets seen in colliding pairs of galaxies and with the hope of testing the well documented interaction-activity connection. In our model the morphological evolution of the jets is determined by their response to the simple mechanical forces (*i.e.*, gravity and ram pressure) imposed on them from both the host and the companion galaxies. Radiative losses, jet precession, magnetic effects, relativistic terms, and hydrodynamic instabilities have all been ignored.

Starting with a previously derived collision model for the interacting pair of elliptical galaxies NGC 4782/4783, we have used our algorithm to simulate the specific two-sided jet morphology seen in the radio source 3C 278, associated with NGC 4782. *This is the first time that such jet simulations have been produced for a galaxy pair whose relative orbit was determined independently from the jet modeling.* The masses of the galaxies and their relative orbit (including its 3-dimensional de-projection) were all derived from numerical simulations by Borne, Balcells, & Hoessel (1988, ApJ, 333, 567). Their best-fit collision model (as used here in the radio jet simulations) was constrained by a combination of optical morphological and kinematic data for this strongly disturbed pair of galaxies.

Our jet models constrain the initial jet parameters (*i.e.*, ejection speed, direction, and starting time), the properties of the hot (x-ray emitting) gaseous medium into which the jets are ejected, and the relative importance of gravitational deflection versus ram pressure bending in influencing the jet morphology. For 3C 278, *we find that the effects of ram* *pressure dominate the structural evolution of the jets.* In our best-fit model the jet ejection speed is of order 10^4 km s^{-1}, the jets are ejected within $\sim 5°$ of the line-of-sight, the hot ISM in the non-jet galaxy (NGC 4783) has a much larger effect on the jet deflection than does that of the host galaxy (NGC 4782), and the jet activity began just over 70 million years ago, roughly 50 million years before the pericenter passage of the two galaxies ($H_0 = 60$ km s^{-1} Mpc^{-1}). *If there is a causal connection between the collision and the radio source generation, as indicated here, then it must become important early in the interaction.* This is not unreasonable since the derived collision model for the NGC 4782+4783 pair indicates that they have suffered a very strong tidal encounter, approaching one another on a deeply penetrating trajectory that had the cores of the galaxies separated by a little less than one galaxy diameter at the time that our model jet activity began. Therefore, *the onset of nuclear activity in 3C 278 appears to be related to the kinematically observed tidal shock* (*i.e.*, very large central stellar velocity dispersion, 392 km/sec [Tonry & Davis 1981, ApJ, 246, 666]) *and the very high central surface brightness* (Burbidge *et al.* 1964, ApJ, 140, 1462) *that have been induced in the core of NGC 4782 as a result of its deeply penetrating collision with NGC 4783.*

The general morphological features of the jets seen in 3C 278 (e.g., position angles, lengths, curvature, and deflection angles) are well matched by our simulations, indicating that our model for the mechanical forces acting on the jets can indeed reproduce most of the basic details of the jet morphology. High-resolution x-ray imaging (*e.g.*, from ROSAT) can be used to test our model by determining the true spatial distribution of the hot ISM within this system; it is this gas that is primarily responsible for the jet deflections observed here. Alternative jet-bending models have been investigated (*i.e.*, collisions with cold gas clouds, and flow against an external, intergalactic gaseous medium), but these produce jets that are not consistent with the observations. Other workers have found that the morphology of some bent radio jets could only be reproduced when some degree of artificiality was introduced into their models. Our simulations do not suffer the same defect, but they provide opportunities both to model a combination of detailed optical, radio, and x-ray data for a wide variety of interacting radio-jet galaxies and to investigate the causal connection between the interaction and activity seen in these systems.

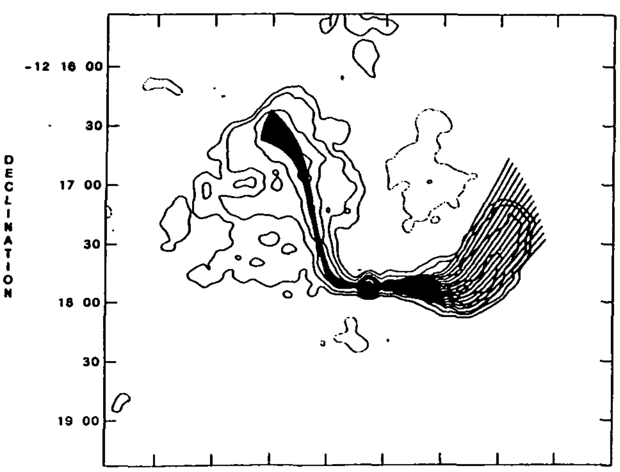

Figure — Comparison between the observed radio morphology and our best-fit jet model for 3C 278. The model is plotted over the VLA radio map (provided by Baum *et al.* 1988, ApJS, 68, 643), demonstrating the good match between the simulated and observed jet parameters: position angles, lengths, deflection locations, deflection angles, and curvature. The small open circle 40″ northeast of the jet nucleus, at position angle 15°, indicates the position of the center of NGC 4783. The broad, diffuse emission that is observed around the east jet probably resulted from the strong deceleration and deterioration of that jet induced by the ram pressure forces; that effect is not modeled here.