Observing Application

Date :	May, 29 2008
Proposal ID :	VLA/2008-04-188
Legacy ID :	
PI :	Robert Laing
Type :	Regular
Category :	Extragalactic
Total Time :	48.0

Backflow in FRI Radio Lobes? Relativistic Jet Models of 0206+35 and 0755+37

Abstract:

We propose to observe two bright FR I radio galaxies, B2 0206+35 and B2 0755+37 in the A configuration at 4.9 GHz. In combination with our existing shorter-baseline observations, this will allow us to make very deep, high-resolution images in total intensity and linear polarization which we will then fit with our relativistic jet model. Both sources show convincing evidence for mildly relativistic backflow in the lobe material just outside their twin radio jets. We have already modelled the backflow in B2 0206+35 using images derived from shallower observations and find that a symmetrical, axisymmetric model of a 0.2c backflow surrounding a decelerating relativistic jet fits extremely well. A deeper observation will provide a stringent test of this model. B2 0755+37 is a larger example of the same type of source, for which we will be able to characterize the flow even more precisely.

Authors:

Name	Institution	Email	Status
Robert Laing	European Southern Observatory	rlaing@eso.org	
Alan Bridle	National Radio Astronomy Observatory	abridle@nrao.edu	
Paola Parma	Istituto di Radioastronomia, Bologna Institute	parma@ira.inaf.it	

Principal Investigator: Robert Laing
Contact: Robert Laing
Telephone: +49 89 3200 6625
Email: rlaing@eso.org

Related proposals:

AL604

Joint:

Not a Joint Proposal

Observing type(s):

Continuum, Polarimetry, Single Pointing(s)

VLA Resources

Name	Conf.	Frontend & Backend	Setup
CBAND	A	C Band 6 cm 4200-7700 MHz VLA Correlator - Single Channel Continuum	Rest frequencies: 4885.1,4835.1 MHz Bandwidth: 50 MHz

Sources:

Name	RA / RA Range	Dec / Dec Range	Epoch	Velocity / z	Group
0206+35	02:09:38.5 00:00:00.0	+35:47:50 00:00:00	J2000	Redshift : 0.037	0206
0755+37	07:58:28.3 00:00:00.0	+37:47:13 00:00:00	J2000	Redshift : 0.043	0755

Sessions:

Name	Session Time (hours)	Repeat	Separation	LST minimum	LST maximum	Elevation Minimum
0755	12.00	2	0 day	01:00:00	15:00:00	10
0206	12.00	2	0 day	19:00:00	09:00:00	10

Session Constraints:

Name	Constraints	Comments

Session Source/Resource Pairs:

Session Name	Source	Resource	Time	Figure of Merit	Subarray
0755	0755+37	CBAND	12.0 hour	0.007 mJy/bm	
0206	0206+35	CBAND	12.0 hour	0.007 mJy/bm	

Present for observation: no   Staff support: None   Plan of Dissertation: no

BACKFLOW IN FR I RADIO LOBES? RELATIVISTIC JET MODELS OF B2 0755+37 AND B2 0206+35

1 Backflow in FR I radio galaxies

This proposal addresses observation and modelling of the effects of mildly relativistic backflow in the lobes of low-luminosity (FR I) extragalactic radio sources. It is an extension of our programme to quantify the physics of jet deceleration in this class of objects using deep VLA observations, X-ray imaging and sophisticated models. Images and model fits for five sources in this programme have now been published [4, 2, 3, 6]. Observations for a further two, 3C 270 and NGC 193, were completed in May 2008 (proposal AL693).

In the course of another project (AL604), aimed primarily at imaging of rotation-measure fluctuations, we made deep observations of two other bright, twin-jet radio galaxies, B2 0206+35 ($z = 0.037$) and 0755+37 ($z = 0.043$). These sources are unusual in that their main (brighter) jets appear narrower than the counter-jets at a given distance from the nucleus (Fig. 1), even though they show the basal asymmetries we associate with decelerating relativistic flows. This is impossible to explain by relativistic effects alone if the jets are both *symmetrical* and *purely outflowing*, and we initially assumed that intrinsic or environmental asymmetries were responsible [1]. Close inspection of our new, deep, 1.5-arcsec image of 0755+37 [Fig. 1(a)] suggested, however, that both the main and counter-jets contained limb-brightened structures with the same radii as functions of distance from the nucleus. This led us to wonder whether the jets are indeed symmetrical outflows, but that they are surrounded by slightly relativistic *backflowing* material. This would appear brighter on the counter-jet side, and would lead to the observed differences in width.

Such a hypothesis is physically reasonable: backflow has been an acknowledged ingredient of models of FR II radio sources since the first simulations [7]. It is also expected in those FR I sources, like 0206+35 and 0755+37, in which the jets propagate within well-defined lobes. If the jets are much lighter than their surroundings and initially relativistic, the backflow could still be marginally relativistic. Mildly relativistic backflow extending almost back to the centre of the host galaxy is seen in recent simulations [8] with parameters derived from our models of 3C 31 [4, 5] and including a realistic description of the external density and pressure. The velocity field from the simulation is shown in Fig. 3(a) – we caution that the speed may be overestimated because of the two-dimensional nature of the simulation and the use of open boundary conditions.

In order to test the backflow hypothesis quantitatively, we imaged 0206+35 at higher resolution, using archive data in A, B and C configurations at 4.9 GHz, and fit the central ±10 arcsec using a version of our jet-modelling code modified to allow backflow in the emitting material at large distances from the jet axis (Laing et al., in preparation). As usual, our model assumes that the flow is symmetrical, axisymmetric and relativistic, all apparent differences between the two sides of the source being due to the effects of aberration. We fit both total intensity and linear polarization in order to break the degeneracy between velocity and angle to the line of sight [2]. The fits for an angle to the line of sight $\approx 37^\circ$ are very good (Fig. 2). The derived velocity field is shown in Fig. 3(b). The properties of the jets are similar to those we derive for other sources: they have $\beta \approx 0.8$ where they first brighten and flare, decelerating abruptly to $\beta \approx 0.6$ and thereafter remaining at roughly constant velocity. They are slightly slower at their edges than on-axis. The backflow component which surrounds the jet must have an enhanced emissivity compared with the lobe. Its velocity is $0.1 - 0.2c$ and its magnetic field structure (like that of the jet at large distances from the nucleus) is dominated by the toroidal component.

If the model we describe is correct, then we have made a significant step forward in understanding radio-galaxy dynamics: for the first time we can probe velocities in the lobes as well as the jets, and deduce the three-dimensional structure of the magnetic field around the jets as well as within them.

The one other lobed FR I source we have studied, 3C 296 [6] may also have a backflow. Whilst we could fit the images very well over much of the width of the jets with a pure outflow model, we also noticed that the counter-jet appeared slightly wider than the main jet at low surface brightness, as in 0206+35 but not as extreme. As expected, we do not see this effect in the other sources we modelled: these do not have lobes surrounding their inner jets [4, 2, 3]. We will continue to investigate backflow models for 3C 270 and for our latest sources (3C 270 and NGC 193), but constraining the backflow properties will be hard, because all three objects are likely to have angles to the line of sight $\gtrsim 55°$. On physical grounds and from our model of 0206+35, we expect backflows to have speeds $\lesssim 0.2c$, so relativistic aberration will only lead to slight differences between the brightness and polarization distributions on approaching and receding sides.

The most effective test of the model is provided by observations of highly inclined sources. From the fractional core flux density and basal jet asymmetry, we estimate $\theta \lesssim 30°$ for the second source we suspect of showing strong backflow, 0755+37. We therefore propose a high-resolution observation of this source, together with a much deeper integration on 0206+35.

2 Proposed observations

Our first priority is to image and model 0755+37 at a high enough resolution (FWHM < 0.6 arcsec.) to separate the jet/backflow structure from the surrounding lobe emission within ±35 arcsec of the nucleus: we cannot do this with our existing images [Fig. 1(a)]. We have imaged a 1-hour archive observation in A configuration at 4.9 GHz (AH766), but this shows only the brighter jet base. To test our model, we need to be able to measure the linearly polarized emission from the putative backflow *on the approaching side* [the region marked A on Fig. 1(a)] where it is fainter and to compare it with the brighter counterpart R on the receding side. We expect the emission to be highly (≈50%) polarized and we measure a surface brightness of ≈200 μJy/beam for FWHM 1.5 arcsec. For a 3σ detection of polarization using a beam of 0.6 arcsec, we require an rms of ≈ 5μJy/beam.

For 0206+35, our current images [Figs 2(a) and (c)] are limited by the A configuration observation (1.3 hours; AM221; rms ≈ 30 μJy/beam). We require the same resolution (0.35 arcsec) and would like to extend the model to at least ±15 arcsec. The key region is again at the edge of the jet on the approaching side [marked A on Figs 2(a) and (c)]. The surface brightness in I is ≈ 30 μJy/beam, so we would again require an rms of ≈ 5μJy/beam (the corresponding region R on the receding side is already detected).

Our new, short-spacing datasets at 4.9 GHz (B+C for 0206+35 and B+C+D for 0755+37; Fig. 1) are of high quality – the rms noise levels are 9 and 12 μJy/beam respectively. It therefore makes sense to observe in the A configuration at 4.9 GHz and to combine with our existing data to cover the full range of spatial frequencies. The theoretical rms at 4.9 GHz with full bandwidth is 7μJy/beam in 12 hours, so we request two 12-hour runs for each source. In our published multi-configuration observations we have achieved similar noise levels after careful self-calibration and correction for core variability. Note that we are concerned primarily with accurate imaging of the inner jets, and can tolerate significant bandwidth smearing at the source edges. We will use a fairly long calibration cycle (as both targets have bright cores and can be self-calibrated) but need to determine instrumental polarization accurately and to observe 3C 84 in order to correct baseline-dependent errors introduced by bandpass differences between VLA and EVLA antennas.

We can use 3-frequency rotation measure images at 1.5-arcsec resolution from AL604 (the thesis project of D. Guidetti) in order to correct accurately for Faraday rotation and our code has already been developed to model 0206+35, so we should be able to derive definitive results shortly after obtaining the A-configuration data.

References

[1] Bondi, M., Parma, P., de Ruiter, H.R., Laing, R.A., Fomalont, E.B., 2000, MNRAS, 314, 11

[2] Canvin J.R., Laing R.A., 2004, MNRAS, 350, 1342

[3] Canvin J.R., Laing R.A., Bridle A.H., Cotton W.D., 2005, MNRAS, 363, 1223

[4] Laing R.A., Bridle A.H., 2002, MNRAS, 336, 328

[5] Laing R.A., Bridle A.H., 2002, MNRAS, 336, 1161

[6] Laing R.A., Canvin J.R., Bridle A.H., Hardcastle M.J., 2006, MNRAS, 372, 510

[7] Norman, M.L., Winkler, K.-H.A., Smarr, L., Smith, M.D., 1982, A&A, 113, 285

[8] Perucho, M., Marti, J., 2007, MNRAS, 382, 526

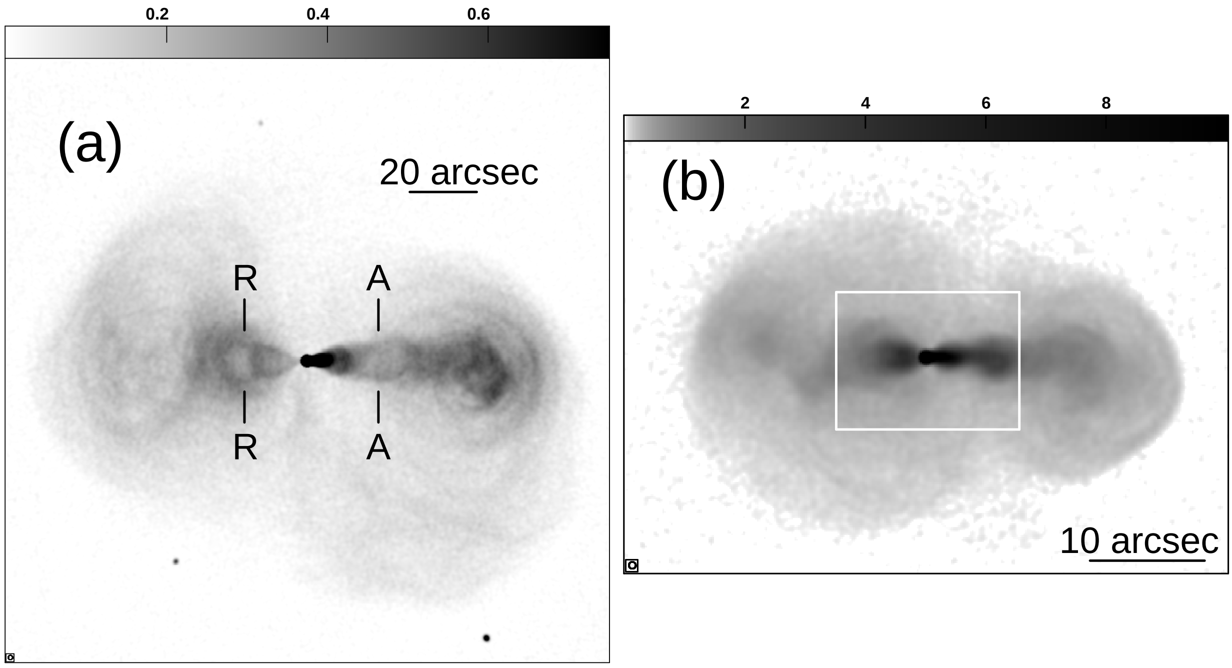

Figure 1: Images at a resolution of 1.5 arcsec FWHM, from our B+C+D configuration data (AL604). (a) 0755+37. The regions marked A and R correspond to backflow in the approaching and receding lobes, as described in the text. (b) 0206+35. The area we model (shown at higher resolution in Fig. 2) is indicated by the white box.

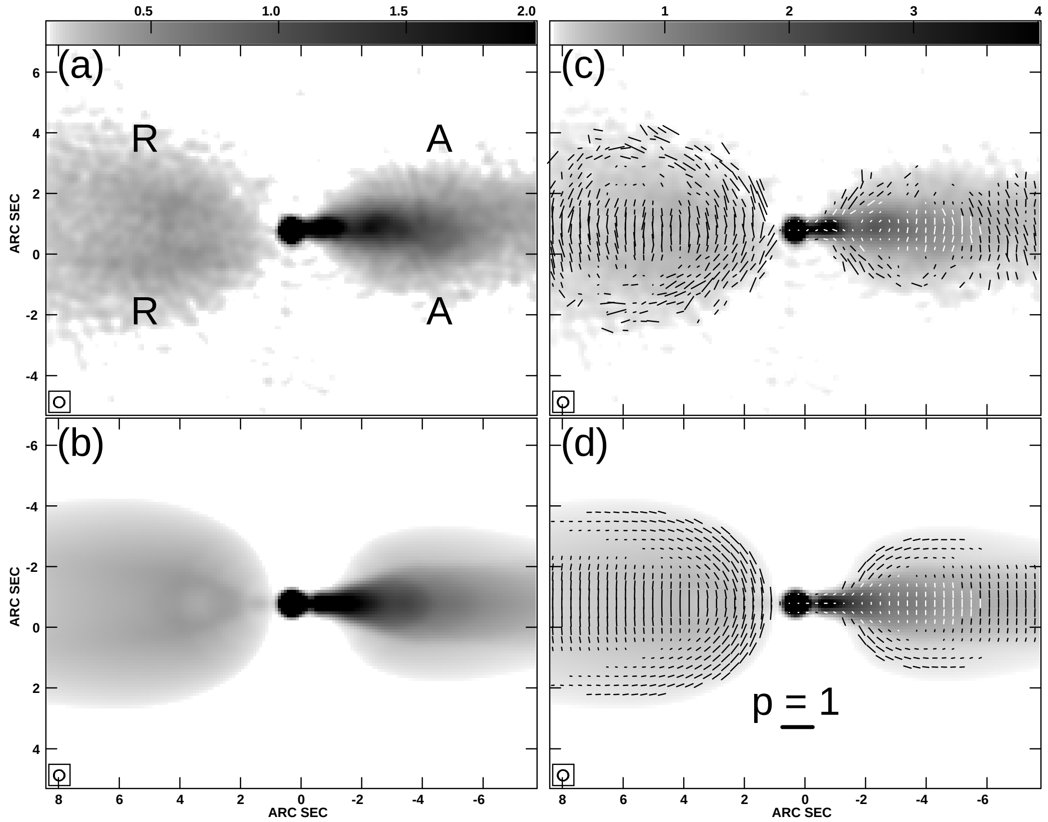

Figure 2: Comparison between model and observed images for 0206+35. Panels (a) and (c) show the observations; (b) and (d) the model. The grey-scales all represent total intensity and the vectors have lengths proportional to degree of polarization p [with the scale given by the bar in panel (d)] and directions along the apparent magnetic field.

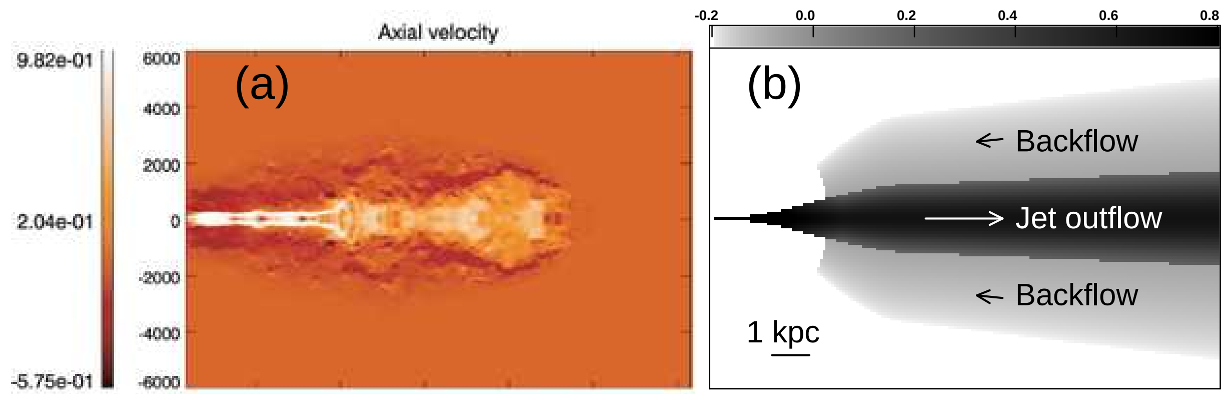

Figure 3: (a) Simulated velocity field from [8]. The relativistic jet enters from the left and propagates for ≈14 kpc. The velocity scale, in units of c, is shown by the labelled bar; outflow (to the right) and backflow (left) have positive and negative speeds, respectively. Note that there is an extended lobe around the jet, but no hot-spot, as the flow is transonic at the end of the lobe: the simulation describes the evolution of a young FR I source.(b) Velocity field for the model of 0206+35 corresponding to the fits shown in Fig. 2. The labelled wedge shows speed in units of c (positive values for outflow; negative for backflow).