Radio Astronomy at the Fringe
ASP Conference Series, Vol. 300, 2003
J.A. Zensus, M.H. Cohen, & E. Ros (eds.)

Ionised, Atomic, and Molecular Gas around the Twin Radio Jets of NGC 1052

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Abstract. The bright radio structure of the LINER elliptical galaxy NGC 1052 is dominated by bi-symmetric jets on parsec scales. Features move outward on both sides of the core at $v_{\rm app} \sim 0.26c$. We have established the occurrence of free-free absorption, and suggest the presence of a patchy, geometrically thick region oriented roughly orthogonal to the jets; components have a wide range of spectral shapes and brightness temperatures. We distinguish three velocity systems in H I absorption. The "high velocity" system is the most prominent of these; it is redshifted from systemic by about 150 km s^{-1}. In H I VLBI it is seen towards both jets, but appears to be restricted to a shell 1 to 2 pc away from the core. The central hole might be largely ionised, and could be connected to the free-free absorption. WSRT spectroscopy shows 1667 and 1665 MHz OH main line absorption over at least the full ∼250 km s^{-1} velocity range seen in H I. In the "high velocity" system, the profiles of the OH main lines and H I are similar, which suggests co-location of molecular and atomic gas. The OH satellite lines are also detected in the "high velocity" system: 1612 MHz in absorption and 1720 MHz in emission, with complementary strength. But we have no satisfactory model to explain all properties; the connection to H_2O masing gas at the same velocity but apparently a different location is also unclear.

NGC 1052, an elliptical LINER galaxy (e.g., Gabel et al. 2000), is at a distance of only 22 Mpc (assuming $H_\circ = 65\,{\rm km\,s^{-1}\,Mpc^{-1}}$ and using $cz = 1474\,{\rm km\,s^{-1}}$ from Sargent et al. 1977), so that detailed sub-parsec scale scrutiny is possible with VLBI (1 mas ≈ 0.1 pc). The unusually bright (1 to 2 Jy) radio structure is core-dominated, and has two lobes with a span of only about 3 kpc (Wrobel 1984). The overall spectrum is fairly flat and has sometimes been classified as Gigahertz peaked (e.g., de Vries, Barthel, & O'Dea 1997).

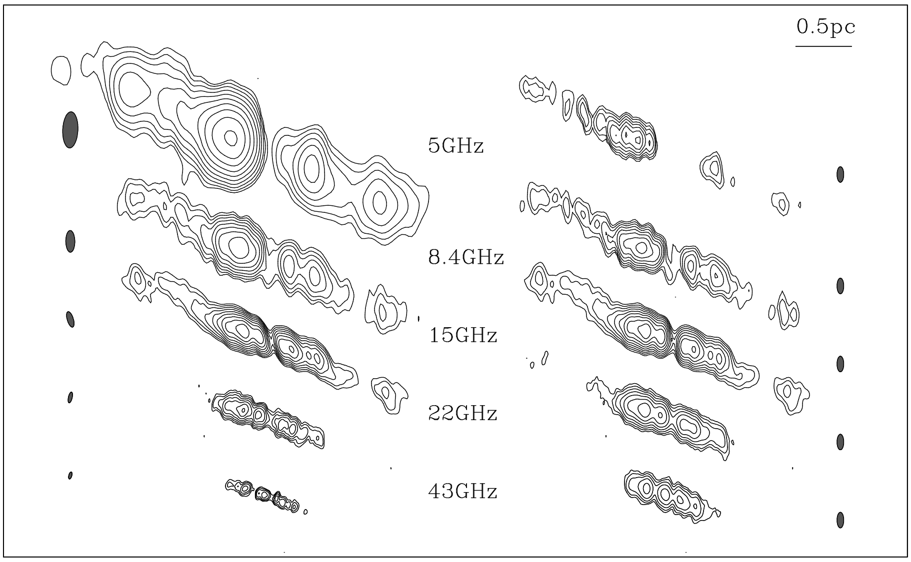

Figure 1. Contour images of NGC 1052 at 43, 22, 15, 8, and 5 GHz, observed at epoch 1997.52. The images on the left-hand side are at a resolution appropriate to the frequency (see restoring beam shown). To facilitate intercomparison, the images in the right-hand column have a fixed restoring beam of 0.14×0.06 pc. The lowest contour levels are 0.83, 1.21, 1.57, 3.44, and 1.04 mJy beam^{-1}, and in all cases the contours increase by factors of $2^{1/2}$. *(Taken from Vermeulen et al. 2003, A&A, 401, 113.)*

Fortunately, given all of the valuable information which has now emerged about it, NGC 1052 was bright enough to be included in the 15 GHz VLBA survey (Kellermann et al. 1998), which was initiated by Ken when it became possible to undertake such a substantial effort at a relatively high frequency. The first 15 GHz VLBA observation, in July 1995, revealed that, in contrast to most of the sources in the sample, NGC 1052 has a bi-symmetric morphology (see also Fig. 1). We therefore not only included NGC 1052 in many of our regular VLBA 15 GHz monitoring observations, but also initiated dedicated observations of this source. The first report on those was given by Ken, and included our discovery of two-sided motions as well as of free-free absorption (Kellermann et al. 1999). We have since then written a comprehensive paper on all of our findings (Vermeulen et al. 2003). The main results can be summarised as follows:

1. In the slightly curved bi-symmetric jets (e.g., Fig. 1), multiple sub-parsec scale features have been traced in ten 15 GHz VLBA epochs over five years. They move outward, reasonably linearly, at typically $v_{\rm app} \sim 0.26c$ on both sides. Given their symmetry, the jets must be oriented near the plane of the sky.

2. Nearly simultaneous VLBA observations were made at up to seven frequencies; some of the images are displayed in Figure 1. They show a central gap in the radio emission, which widens at lower radio frequencies. Detailed spectra demonstrate that it is due to free-free absorption. The western jet is covered more extensively, showing partial obscuration along at least 1 pc; this must be the receding jet. But the eastern jet is also partially covered, along approximately 0.3 pc, and so the free-free absorber is probably geometrically thick, and oriented roughly orthogonal to the jets. The ionised gas near the core, if distributed uniformly along a path-length of 0.5 pc, would have a volume density of $n_e \sim 10^5\,\mathrm{cm^{-3}}$. The opacity globally decreases away from the centre, but the variability of moving components, acting as "probes behind the screen", suggests considerable patchiness, and the wide range of component spectral shapes suggests that synchrotron self-absorption and free-free absorption both play a role in the inner parsecs of the jets.

3. VLBI observations show that H I absorbing atomic gas is distributed in front of the approaching as well as the receding jet, and has sub-pc scale structure. This is illustrated in Figure 2. We distinguish three absorption systems with different characteristics. From their substructure, at least two of them are situated close to the AGN rather than in the galaxy as a whole. The most prominent absorption system, with a peak optical depth of 20–25%, is at "high velocity", receding by 125–200 km s^{-1} with respect to the systemic velocity. Under the uncertain assumptions that this atomic gas has a spin temperature $T_{sp} = 100\,\mathrm{K}$, and uniformly fills a path-length of 0.5 pc, we derive a column depth of $N_H \sim 10^{21}\,\mathrm{cm^{-2}}$, and a density of $n_H \sim 1000\,\mathrm{cm^{-3}}$. This absorber may have a continuous velocity gradient of some $10\,\mathrm{km\,s^{-1}\,pc^{-1}}$ across the nucleus, but while it is seen at a distance of 1–1.5 pc on both sides of the centre, there is a deficit in the innermost parsec; this "central hole" in atomic gas may be largely ionised.

4. WSRT observations show, from 1667 and 1665 MHz OH main lines seen in absorption, that molecular gas exists along the full velocity span found also in atomic gas, roughly −30 to 200 km s^{-1}. The peak absorption depth, about 0.4%, occurs in the "high velocity" system, and indicates a column depth of order $10^{14}\,\mathrm{cm^{-2}}$. The ratio between the OH 1667 and 1665 MHz lines is about 2 in the "high velocity" system, but closer to 1 at lower velocities. In the "high velocity" system, the 1612 and 1720 MHz OH satellite lines have also been detected, both with a peak strength near 0.25%, but with conjugate profiles, in absorption and emission, respectively. The profiles of the OH main lines and the integrated H I line are remarkably similar in the "high velocity" system, which suggests co-location of the atomic and molecular gas at these velocities. But H_2O masers, which cover the same velocity range, were found very close to the nucleus, at 0.1–0.2 pc along the receding jet (Claussen et al. 1998) We have no satisfactory model to explain this, in light of the central hole in H I, the OH and H I profile similarity, the velocity gradient across the core (suggestive of rotation), and the substantial overall velocity offset compared to systemic (suggestive of infall).

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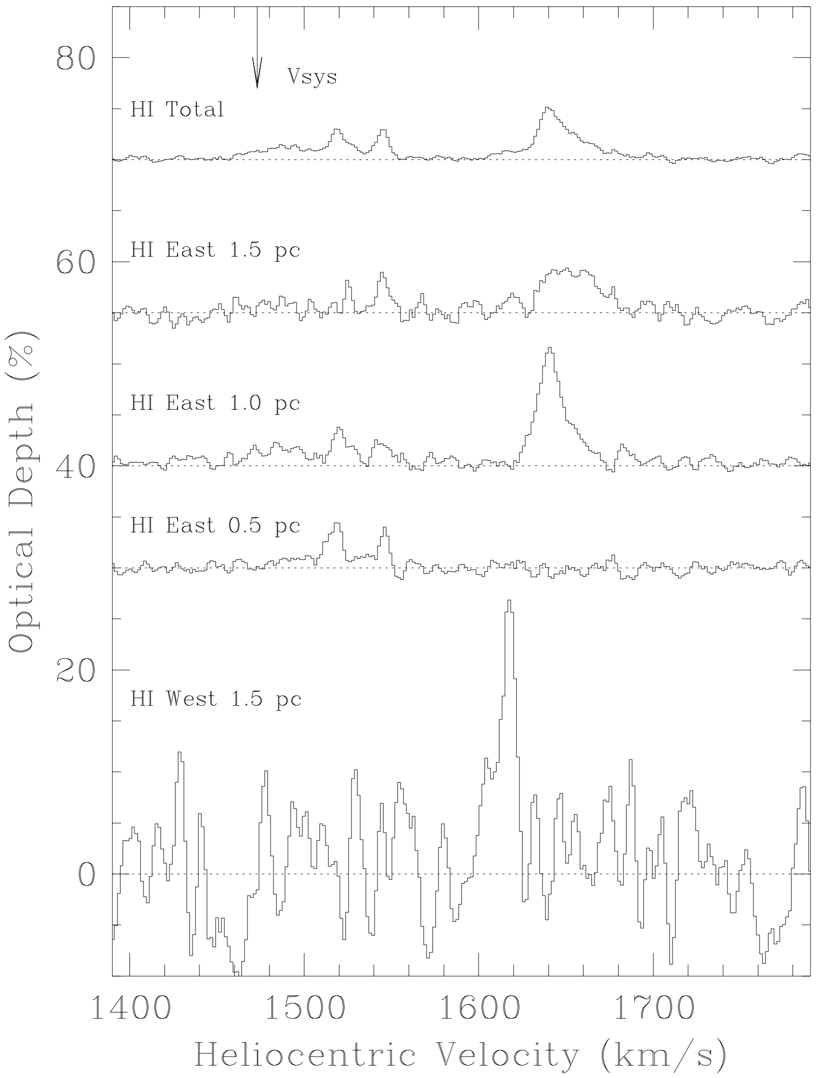

Figure 2. H I optical depths as function of velocity, at various locations along the jets of NGC 1052, as observed with VLBI in July 1998. Offsets between the spectra are used for clarity; dotted lines show the zero levels. *Taken from Vermeulen et al. (2003, A&A, 401, 113).*

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