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The Shroud around the 'Compact, Symmetric' Radio Jets in NGC 1052

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Abstract: This is a paper on young jet material in a frustratingly complex environment.

NGC 1052 has a compact, flat or GHz peaked spectrum radio nucleus consisting of bi-symmetric jets, oriented close to the plane of the sky. Many features on both sides move away at $v_{\rm app} \sim 0.26\,c$ ($H_0 = 65\,{\rm km\,s^{-1}\,Mpc^{-1}}$). VLBI at seven frequencies shows a wide range of spectral shapes and brightness temperatures; there is clearly free–free absorption, probably together with synchrotron self-absorption, on both sides of the core. The absorbing structure is likely to be geometrically thick and oriented roughly orthogonal to the jets, but it is patchy.

HI VLBI shows atomic gas in front of the approaching as well as the receding jet. There appear to be three velocity systems, at least two of which are local to the AGN environment. The 'high velocity system', 125–200 km s^{-1} redward of systemic, seems restricted to a shell 1–2 pc away from the core. Closer to the centre, this gas might be largely ionised; it could cause the free–free absorption.

WSRT spectroscopy shows 1667 and 1665 MHz OH absorption over a wide velocity range. OH and HI profile similarity suggests co-location of molecular and atomic 'high velocity' gas; the connection to H_2O masing gas is unclear. Further, at 'high velocity' we detected the OH 1612 MHz satellite line in absorption and the 1720 MHz line in emission, with complementary strengths.

Keywords: galaxies: active — galaxies: individual (NGC 1052) — galaxies: jets — galaxies: nuclei

1 Introduction

The nearby[1] LINER (e.g., Gabel et al. 2000) elliptical galaxy NGC 1052 has an unusually prominent central radio source (1–2 Jy). It is variable on timescales of months to years (e.g., Heeschen & Puschell 1983) and has a fairly flat spectrum between 1 and 30 GHz, which has sometimes been classified as gigahertz peaked (e.g., de Vries, Barthel, & O'Dea 1997). The overall radio structure is core-dominated, and has two lobes spanning only about 3 kpc (Wrobel 1984), so that NGC 1052 meets the traditional size limit for CSSs, but not for CSOs. With VLBI, detailed sub-parsec scale scrutiny of the active nucleus and its inner environment is possible.

A more extensive analysis of the data presented below is in Vermeulen et al. (2003).

2 Kinematics

Ten epochs of 15 GHz VLBA data (Figure 1) show a two-sided source, with oppositely directed, slightly curved jets and a prominent gap 0.1–0.2 pc west of the brightest feature in most images. At our high linear resolution, NGC 1052 shows complex evolution, which we have quantified using a consistent set of moving components, rank-numbered 'E'ast and 'W'est by decreasing distance to the centre (Figure 1). While not every one of these should be interpreted as a true physical entity (a plasmon or a 'cannon-ball'), we are confident that the set as a whole gives an appropriate representation of the motions in the jets. There is a plausible relative alignment of the epochs, in which the motions of most of the components, on both sides of the centre, are consistent with being ballistic: linear on the sky and constant over time. Features on the two sides move in opposite directions with roughly equal apparent velocities of $0.26 \pm 0.04\,c$. Using these error margins, the jets are oriented at most 33° from the plane of the sky.

[1]We adopt $H_0 = 65\,{\rm km\,s^{-1}\,Mpc^{-1}}$, with no corrections for local deviations from the Hubble flow, so that the optical stellar absorption line heliocentric redshift, $cz = 1474\,{\rm km\,s^{-1}}$ (Sargent et al. 1977), corresponds to a distance of 22 Mpc and implies that 1 mas ≈ 0.1 pc.

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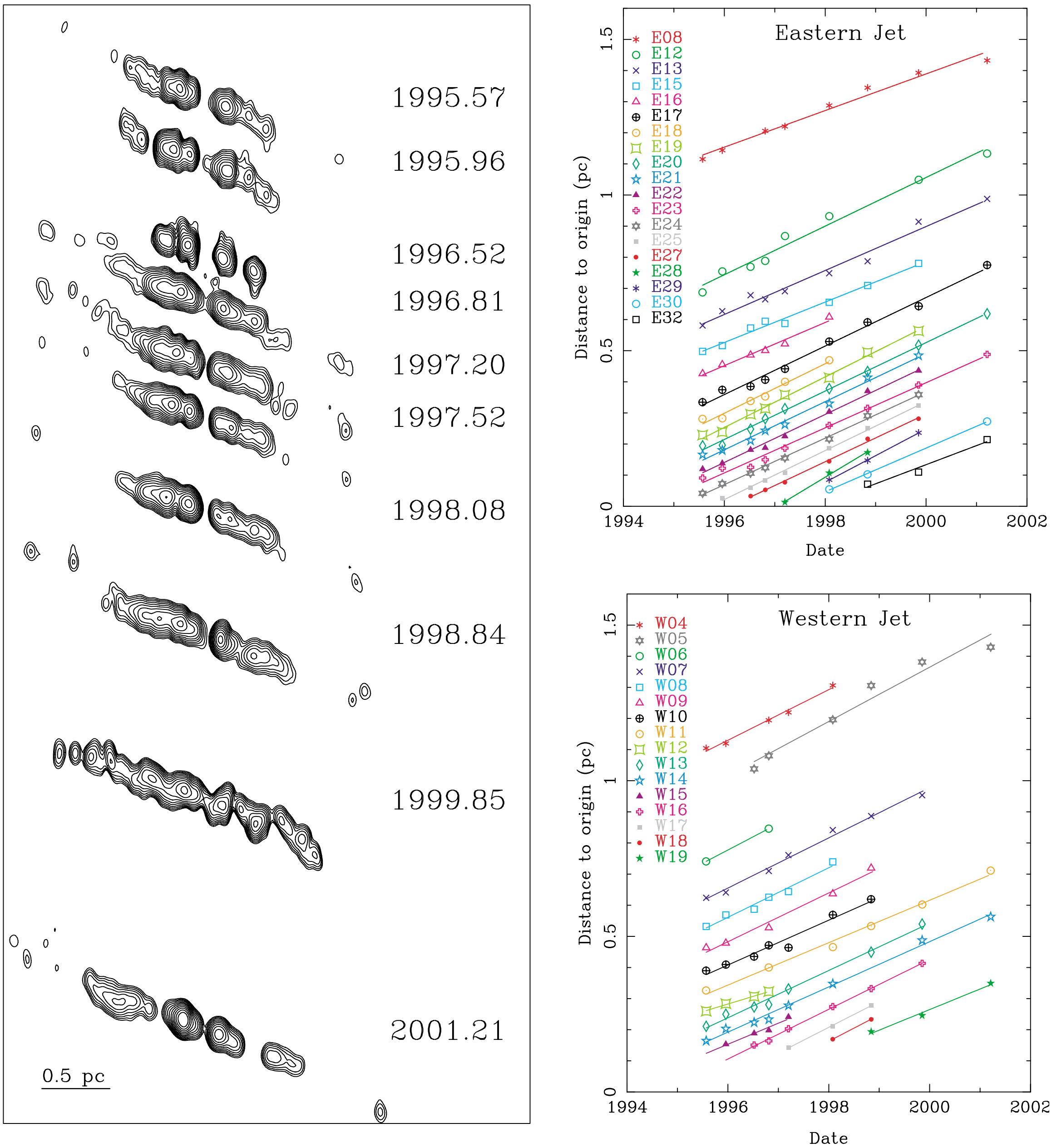

Figure 1 Left: VLBA 15 GHz contour images of NGC 1052 at ten epochs, aligned following the kinematic analysis of Section 2, and shown spaced by their relative time intervals. All contour levels increase by factors of $3^{1/2}$, starting at 0.58% of the peak brightness in each image. The restoring beams are all 0.1×0.05 pc in PA 0°. Right: Distances to the adopted origin for the Gaussian components (see Section 2) fitted to these datasets. Lines show the best fit linear velocities.

3 Ionised Gas

The left panel in Figure 2 shows data at 43, 22, 15, 8, 5, 1.6, and 1.4 GHz from VLBA observations within a few days of each other in July 1997. There is a wide range of spectral shapes, which proceed from steep, through convex, to highly inverted, from the outer jets towards the middle, and produce a distinctive central hole in the VLBA images. On both sides of the gap there are components with a low-frequency brightness temperature well below 10^{10} K, and a low-frequency spectral cutoff steeper than $\alpha = 3$ if expressed as a power law. As first reported in Kellermann et al. (1999), we find that the only plausible explanation is free–free absorption from ionised gas, a conclusion also reached from other data by Kameno et al. (2001) and Kadler et al. (2002). At about 0.5 pc along the eastern jet, and 1–2 pc along the western jet, the signature of free–free absorption becomes hard to distinguish from synchrotron self-absorbed spectral shapes. If conditions are such that similar peak frequencies result, the two absorption mechanisms are difficult to disentangle, but it is likely that both play a role.

The absorption is more pronounced along the western jet than at corresponding locations along the eastern jet. This suggests a geometrically thick disk- or torus-like

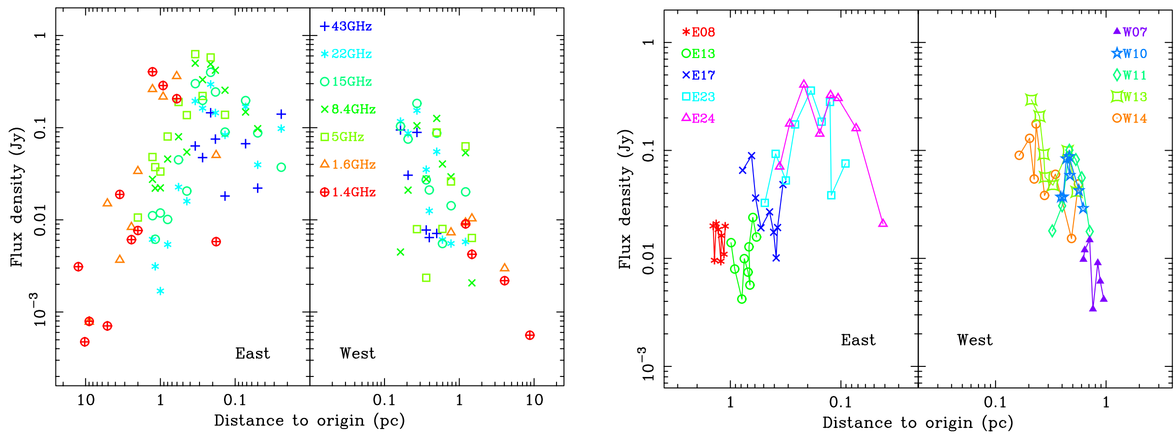

Figure 2 Left: All flux densities from a multifrequency multicomponent VLBI analysis. The diversity of spectral shapes is emphasised by the frequency colour coding. Right: Flux density changes with time for some Gaussian components fitted to the multi-epoch 15 GHz observations shown as a function of their distance to the origin.

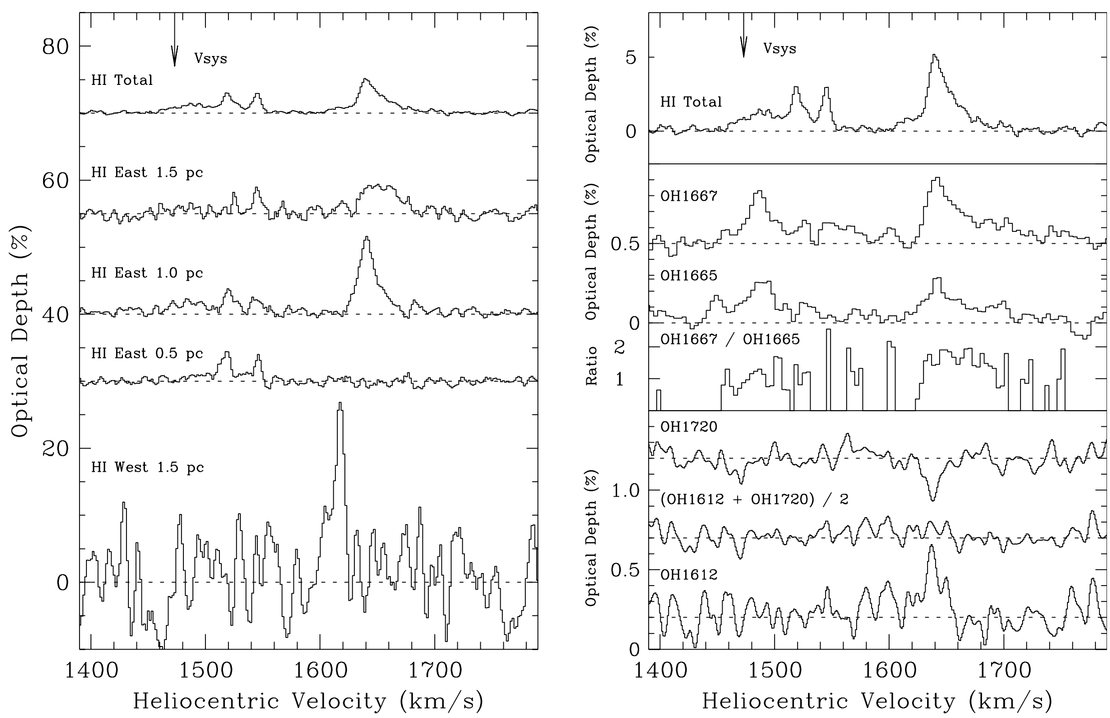

Figure 3 Left: Hɪ optical depths observed in 1998 at various locations along the jets of NGC 1052. Multiple offsets are used for clarity; dotted lines show the zero levels. Right: WSRT optical depth measurements (negative is emission) for all four 18 cm OH lines. The offset zero lines are indicated; also note the different scale for our integrated VLBI Hɪ spectrum, shown convolved to the same resolution for comparison.

absorbing region, more or less perpendicular to the jets, which are oriented close to the plane of the sky, with the eastern jet approaching and the western jet receding. Variations on this scenario with a thinner disk or torus, either not oriented orthogonal to the jets, or warped, are possible. Furthermore, the range of spectral shapes and the flux density variations of components tracked over time at 15 GHz (Figure 2, right panel) suggest that the absorbing region has a fairly well-defined overall geometry but substantial patchiness in detail. It is then not very meaningful to use a single epoch for detailed modelling. The deepest absorption seen, $\tau \sim 1$ at 43 GHz over the central region, implies a volume density of $n_e \sim 10^5\,\mathrm{cm}^{-3}$ if the free–free absorbing gas were distributed uniformly along a pathlength of 0.5 pc with a temperature $T = 10^4$ K.

4 Atomic Gas

Figure 3 depicts Hɪ VLBI spectra from July 1998 at all locations where the signal-to-noise ratio allowed detection of absorption at the level of a few per cent. We think there are three different absorption systems, at least two of which are probably due to atomic gas on parsec or sub-parsec scales, local to the AGN environment.

The most remarkable system is at 'high velocity', redshifted by 125–200 km s^{-1} with respect to the stellar systemic velocity. It gives rise to 5–20% absorption at 1–2 pc along both the western, receding jet, and the eastern, approaching jet, with a possible west-to-east velocity gradient of some 10 km s^{-1} pc^{-1}. But the high velocity system is absent closer to the core, at least on the eastern side, where it could easily have been detected. The combination of free–free absorption covering the inner parsec, and atomic gas in an annulus at 1–2 pc, is quite natural: the innermost region and/or the surface of an accretion disk or torus receive the most intense ionising radiation. Weaver et al. (1999), Guainazzi & Antonelli (1999), Guainazzi et al. (2000), and Kadler et al. (2003) discuss soft X-ray absorbing gas towards the nuclear continuum source, with large column depths ($N_\mathrm{H} = 10^{23}$–10^{24} cm^{-2}), and possibly a patchy distribution, or involving two components with a substantially different density, which matches the evidence we see for patchiness in the radio spectra and flux density evolution of jet components. An HI optical depth of 20% with a FWHM of 20 km s^{-1} implies a column depth of $N_\mathrm{H} = 10^{21} T_{\mathrm{sp},100}$ cm^{-2}, but close to an AGN the spin temperature T_sp may well be one or two orders of magnitude above 100 K (e.g., Maloney, Hollenbach, & Tielens 1996).

5 Molecular Gas

Figure 3 shows WSRT spectra of the 18 cm OH lines. We find that 1667 and 1665 MHz absorption, recently detected by Omar et al. (2002), extends over at least as wide a velocity range as HI. The peak 1667 MHz depth, 0.4% in the high velocity system, suggests a column depth of order 10^{14} cm^{-2}. The 1667/1665 ratio ranges from near 1 at low velocities to approximately 2 in the high velocity system. We have discovered that the satellite lines are also present: 1612 MHz in absorption and 1720 MHz in emission. Their conjugate profiles probably result from excitation in a far infrared radiation field when the OH column density is sufficiently large; competing pumping mechanisms determine which line is in emission and which one is in absorption in specific density and temperature regimes, as modelled for Cen A by van Langevelde et al. (1995).

The OH main lines and the total HI profile are remarkably similar in the high velocity system, and we suggest co-location of these high velocity atomic and molecular gas components. They probably do not coincide with the H_2O masers at 0.1–0.2 pc along the receding jet (Claussen et al. 1998), even though these are at the same velocity. Other questions also remain regarding the nature of the high velocity system. Interpretation of the velocity gradient in HI as evidence for a structure rotating around the nucleus is contradicted by the fact that the centroid is redshifted by 150 km s^{-1} or more from the systemic velocity. But if it is instead infalling gas, the nature of the central hole in HI is unclear.

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