The Twin-Jet of NGC 1052 at Radio, Optical, and X-Ray Frequencies

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Abstract

We present results from a combined radio, optical, and X-ray study of the jet-associated emission features in NGC 1052. We analyse the radio-optical morphology and find a good positional correlation between the radio jet and the optical emission cone. Two optical emission knots are directly associated with radio counterparts exhibiting a radio to X-ray broadband spectrum not compatible with synchrotron emission. We discuss the possibility that the thermal soft spectrum of the extended X-ray emission originates from jet driven shocks produced in the interaction between the jet-plasma and its surrounding medium.

1 Introduction

The nearby[1] low-luminosity AGN at the center of NGC 1052 bears a symmetric twin-jet whose parsec-scale properties have been studied in great detail using Very Long Baseline Interferometry (VLBI) observations (e.g., Vermeulen et al. 2003, Kadler et al. 2003). These studies have revealed the presence of a dense circumnuclear absorber covering the inner parsecs of both jets. On larger scales the source shows a radio structure with a very dominant compact core

[1] At the distance of NGC 1052 of about 22.6 Mpc, 1 arcsec corresponds to ∼110 pc. Throughout the paper, we use $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

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and two lobes of extended emission spanning about 15 arcsec east and west of the core (Wrobel 1984). Based on *CHANDRA* data Kadler et al. (2002) reported the detection of an associated X-ray jet with the spectral signature of a 0.5 keV thermal plasma. While the diffuse, extended soft X-ray emission tends to anti-correlate with the kiloparsec-scale radio emission of the lobes, two emission knots east and west of the nucleus coincide positionally with features of the radio jet. In the optical regime, Pogge et al. (2000) detected a conical structure associated with the nucleus as well as emission knots east and west of the core in a *Hubble Space Telescope* Hα image of NGC 1052.

2 Radio-optical morphology

"Structure mapping" (Pogge et al. 2002) is an improved method of image contrast enhancement allowing to study the distribution of absorbing and emitting regions in the circumnuclear regions of galaxies. For comparison of the optical and radio structure of NGC 1052 we analyzed archival MERLIN [2] data from an observation at 1.4 GHz on November 22, 1995. The data post-processing was done applying standard methods within DIFMAP. The resulting tapered MERLIN image is shown in Fig. 1 together with a structure map of NGC 1052 based on the same observational data as used by Pogge et al. (2000). Superimposed are contours of the untapered full resolution MERLIN image. Jet and counterjet extend continuously out to ~1.5 arcsec with a position angle similar to the pc-scale twin-jet. The jet-counterjet structure is aligned with the optical emission cone. The dark band perpendicular to the radio jet might be an artifact of the image processing or might alternatively represent the signature of an obscuring dusty region. The two optical emission knots in the east are located at the edges of two radio sub-components of knot K1. The optical emission knot in the west coincides roughly with a weak ($\sim 1\sigma$) radio feature while the stronger radio knot 1.5 arcsecond further out (K 2) has no corresponding bright optical counterpart. Both knots, however, coincide positionally with an uncertainty of ~4 arcsec with X-ray knots in the jet structure (see Kadler et al. 2002). The origin of the optical emission remains unclear since there is no continuum image to subtract from the Hα filter image of NGC 1052. The morphological similarity of the emission cone in this LINER 1.9 galaxy to the features typically observed in Seyfert 2 galaxies (Falcke et al. 1998), however, suggests an origin in the narrow emission line region. The optical flux density of the two eastern knots of $(68 \pm 1)\,\mu$Jy exceeds the power-law extrapolation from the radio to the X-ray regime by almost three orders of magnitude ruling out synchrotron emission as a possible mechanism.

[2] MERLIN is a National Facility operated by the University of Manchester at Jodrell Bank Observatory on behalf of PPARC. The observation was planned and scheduled by Dr. A. Pedlar.

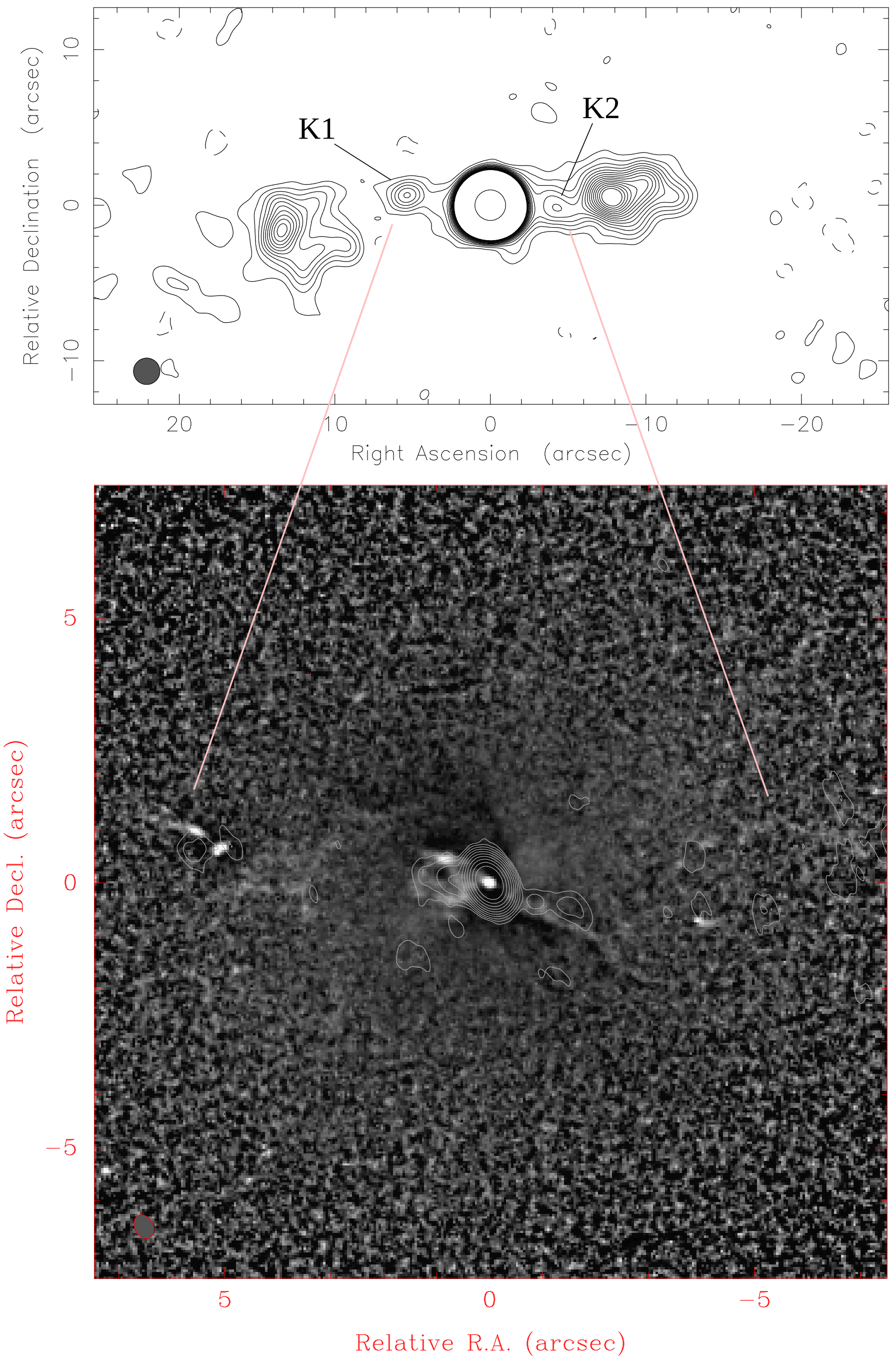

Fig. 1. Top: Tapered (circular beam of 1.7 arcsec FWHM), naturally weighted MERLIN map of NGC 1052 at 1.4 GHz with contours shown for (-1, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 800) $\times$ 0.5 mJy/beam. Bottom: Structure map for NGC 1052 in the F 658 N filter. Dark regions represent dust obscuration while bright regions are locations of enhanced emission. Overlaid is the pure naturally weighted MERLIN map showing the core of NGC 1052 with sub-arcsecond resolution (beam FWHM: 0.47×0.34 arcsec at $27.5°$). Contours at (-1, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024) $\times$ 0.5 mJy/beam are shown.

3 X-ray emission from jet-driven shocks

The above data provide circumstantial evidence that shocks are implicated in the production of the jet-associated X-ray emission, produced as a result of the dissipation of some fraction of the jets kinetic power in jet-cloud collisions. Given a 1.4 GHz flux density of 0.15 Jy of both radio lobes, the corresponding radio luminosity is $L_{1.4} \sim 10^{29}\,\mathrm{erg\,s^{-1}\,Hz^{-1}}$. Using the expressions given in Bicknell et al. (1998) the kinetic power in both jets is $2F_E \sim \kappa_{1.4}^{-1} L_{1.4}$, where $\kappa_\nu \sim 10^{-14} - 10^{-10}\,\mathrm{Hz^{-1}}$ is the ratio of monochromatic radio power to kinetic power. Thus the kinetic power per jet is $F_E \sim 5{\cdot}10^{41} (\kappa_{1.4}/10^{-13})^{-1}\,\mathrm{erg\,s^{-1}}$. The 0.3–8 keV X-ray luminosity associated with the jets is $L_{X,\mathrm{obs}} \sim 1.2{\cdot}10^{40}\,\mathrm{erg\,s^{-1}}$, i.e., approximately 2.5% of the estimated jet energy flux. This is expected since shocks driven into dense clouds by a light jet only tap a small fraction of the jet power. The energy flux into the shock is given by $F_E \cdot f(M_\mathrm{jet}, \Delta\theta) \cdot (v_\mathrm{sh}/v_\mathrm{jet})$, where v_sh is the shock velocity and the numerical factor $f(M_\mathrm{jet}, \Delta\theta)$ depends upon the jet Mach number, M_jet, and the deflection angle, $\Delta\theta$, but is mainly sensitive to the latter. It is approximately 0.2 for a 10° deflection and 1 for a head-on collision. The immediate post-shock temperature is $T_\mathrm{sh} \sim (3\mu m_p/16k) v_\mathrm{sh}^2$ where m_p is the proton mass and μ is the mean molecular weight of the shocked particles, so that 0.5 keV corresponds to a shock velocity, $v_\mathrm{sh} \sim 640\,\mathrm{km\,s^{-1}}$. In a radiative shock, approximately half of the energy flux into the shock is radiated in the hot continuum so that the expected X-ray luminosity is $L_X \sim 1.7{\cdot}10^{39} f (v_\mathrm{sh}/10^3\,\mathrm{km\,s^{-1}}) (v_\mathrm{jet}/c)^{-1}\,(2F_E/10^{42}\mathrm{ergs^{-1}})\,\mathrm{erg\,s^{-1}}$. This estimate is compatible to the observed value for a mildly relativistic jet with $v_\mathrm{jet} \sim 0.25c$ (see Vermeulen et al. 2003) if $f \sim 1$, which would imply the complete disruption of the jet rather than a glancing deflection.

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