Mon. Not. R. Astron. Soc. **356,** 734–736 (2005) doi:10.1111/j.1365-2966.2004.08506.x

An 8.4-GHz Long Baseline Array observation of the unusual Seyfert galaxy NGC 7213

D. L. Blank,[1★] J. I. Harnett[2] and P. A. Jones[3]

[1]*School of Engineering and Industrial Design, University of Western Sydney, Penrith South DC, NSW 1797, Australia*
[2]*Faculty of Engineering, University of Technology Sydney, PO Box 123, Broadway, NSW 2007, Australia*
[3]*Australia Telescope National Facility, PO Box 76, Epping, NSW 2121, Australia*

Accepted 2004 October 12. Received 2004 October 12; in original form 2004 August 12

ABSTRACT

We have observed the type 1.5 Seyfert galaxy NGC 7213 with the Australian Long Baseline Array (LBA) at 8.4 GHz to discover whether this object has the high brightness temperature compact core suggested by low-frequency variability. Confirmation would support the hypothesis that radio-intermediate Seyfert galaxies have Doppler-boosted radio jets. Our observation confirms the existence of this core but with a flux density of almost a factor of 6 less than observed 12 yr earlier. Though few studies exist on the long-term radio variability of Seyferts, a decline of this magnitude does appear to be rare.

Key words: techniques: interferometric – galaxies: individual: NGC 7213 – galaxies: Seyfert – radio continuum: galaxies.

1 INTRODUCTION

Recently Roy & Norris (1997) found a rare class of Seyfert galaxies that have radio properties intermediate between the radio-loud and radio-quiet active galaxies. NGC 7213 is an Sa galaxy at a distance of 36 Mpc (for $H_0 = 50$ km s^{-1} Mpc) and is one of the radio-intermediate Seyferts in the Roy & Norris sample. We (Blank & Harnett 2004) found that NGC 7213 has a radio power of $P_{1.4} = 3 \times 10^{22}$ W Hz^{-1}, which, while low for a radio-loud galaxy, is still over an order of magnitude higher than that of a typical Seyfert. Our 1.4- and 2.5-GHz Australia Telescope Compact Array (ATCA) and 0.843-GHz Molonglo Observatory Syntheis Telescope (MOST) observations have shown that NGC 7213 has the extended radio structures that are typical of radio-loud objects, but are rare in the radio-quiet population.

NGC 7213 also shows variability by as much as 30 per cent at 0.843 GHz on a time-scale of weeks (Blank & Harnett 2004). Low-frequency variability such as this is believed to be produced by interstellar scintillation (Shapirovskaya 1978; Rickett, Coles & Bourgois 1984). Following Rickett (1986) the implied upper limit to the core size is about 3 mas, with a corresponding minimum brightness temperature of $T_B \sim 1 \times 10^{10}$ K, which is within an order of magnitude of the inverse Compton limit (Readhead 1994). NGC 7213 is core-dominated, with the ratio of the core to extended flux density at 1.4-GHz being 2.8, which is unusual for a low-power radio source.

Falcke, Patnaik & Sherwood (1996) suggest that active galaxies such as NGC 7213 that have been classified as radio-intermediate may actually be radio-quiet objects that have had their radio power moderately boosted by relativistic beaming. The implied high minimum brightness temperature and core dominance are features associated with objects having Doppler-boosted nuclear radio jets (e.g. Orr & Browne 1982; Ghisellini et al. 1993), and so we have carried out 8.4-GHz very long baseline interferometric (VLBI) observations with the Australian Long Baseline Array (LBA) to examine further the Falcke et al. hypothesis as it may apply to NGC 7213.

We found NGC 7213 to have an unresolved core at the resolution of 3.2 mas consistent with the prediction of the interstellar scintillation model but, unexpectedly, the flux density was found to be much less than previously measured. We discuss the data reduction in Section 2 and results in Section 3.

2 OBSERVATIONS

NGC 7213 was observed with the LBA (Tzioumis 1997) on 2000 February 20. The LBA consists of six stations: Parkes Observatory (64-m dish), Mopra Observatory (22-m dish), ATCA (six 22-m dishes as a tied array), the Mount Pleasant 26-m antenna of the University of Tasmania, the Ceduna 26-m antenna also of the University of Tasmania, and the Tidbindilla Deep Space Tracking Station near Canberra (70-m dish for the first 90 min of observations, 34-m dish for the remainder). The central frequency was 8.425 GHz and the bandwidth was 16 MHz in right circular polarization. The calibrators PKS B0104−408 and PKS B1921−293 were observed for respectively 10 and 20 min. Data were recorded using the S2 recording system and were correlated using the LBA S2 VLBI correlator system at Marsfield near Sydney. Observational details are listed in Table 1.

The data were first edited and calibrated in AIPS and then exported into DIFMAP (Shepherd 1997) for further editing, model fitting and

★E-mail: dblank@physics.usyd.edu.au

Table 1. Log of LBA observations.

Observing date	2000 February 20
Central frequency	8.425 GHz
Bandwidth	16 MHz
Synthesized beam	3.2×2.8 mas^2
Shortest baseline	113 km
Longest baseline	1705 km
Total observing time	12:00 h
Total flux density	57.6 ± 1.3 mJy

imaging. Two cycles of phase self-calibration and cleaning were applied. No amplitude self-calibration was carried out since the signal-to-noise ratio was insufficient. The antenna-based flux density calibration using antenna system temperatures and gains was corrected by empirical gain factor corrections of the order of 10 per cent. Uniform weighting and a restoring beam of 3.2×2.8 mas^2 was applied for imaging. The final image is shown in Fig. 1 and the rms was about 0.75 mJy beam^{-1}. The uncertainty in the core position is greater than a single beam size, but less than two beam widths, because the core position is set by the initial model used by self-calibration.

3 RESULTS

The LBA image (Fig. 1) reveals a point source. The peak flux density is 57.1 mJy beam^{-1} and the total flux density is 57.6 ± 1.3 mJy. Since the source is unresolved, this flux density corresponds to a minimum brightness temperature of 1.5×10^8 K and shows that the emission is non-thermal.

The 8.4-GHz flux density of NGC 7213 has been declining since at least the two-element Parkes–Tidbindilla Interferometer (PTI) observation of 1988. The PTI flux density was 334 ± 33 mJy (Slee et al. 1994) measured with a fringe spacing of 26 mas. More recent *X*-band measurements yielded values of 176 ± 1 mJy (Bransford et al. 1998, using the ATCA with 1 arcsec beam) and 181 ± 1 mJy (Thean et al. 2001, using the VLA with a 0.25×1.0 arcsec^2 beam).

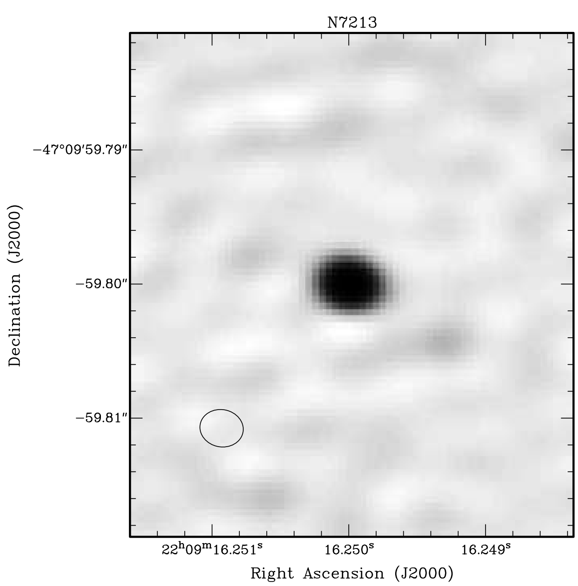

Figure 1. LBA 8.425-GHz grey-scale image. The image is unresolved with a peak flux of 57.1 mJy beam^{-1}. As discussed in Section 2, the uncertainty in the position is not reliable to one beamwidth. The beam is the ellipse in the lower left of the panel.

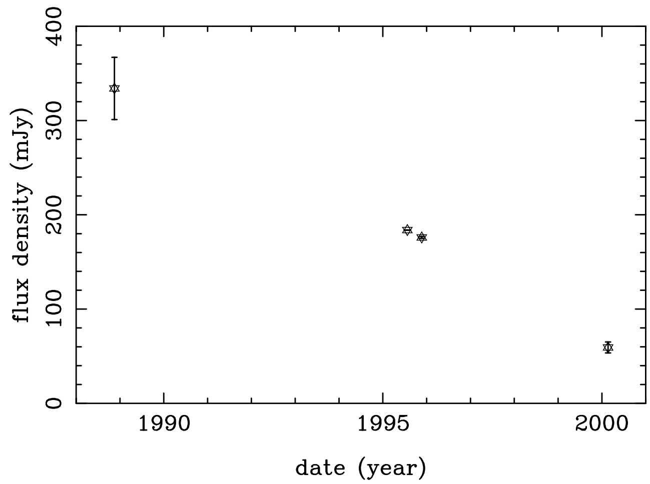

Figure 2. *X*-band flux density with time. 1σ error bars are shown.

Fig. 2 shows these flux densities with respect to date of observation. Note that, except for our LBA observation, the Slee et al. observation had a resolution higher than all later observations. Therefore, the decline of nuclear flux density with time given in Fig. 2 is not a resolution effect and could even be greater since larger-scale emission could be contributing to the flux densities measured by the connected element interferometers. Furthermore, our LBA observation includes the Parkes–Tidbindilla baseline and we see no change in flux density with baseline length, so the steep decline in flux density between the PTI observation and our later LBA observation is also real.

Images at 1.4 and 0.843 GHz with resolution of 34 to 43 arcsec show large-scale emission strongly suggestive of jet-fed radio lobes (Blank & Harnett 2004), yet the emission is unresolved in all published images with resolution from 3 mas to 1 arcsec. This could be because the radio jet starts out pointed towards us and at some point changes direction, or it could be that the higher-resolution images lack sufficient sensitivity or (*uv*)-plane coverage. The previously mentioned constancy of flux density versus baseline length implies that there is no missing flux, so that we have indeed imaged an unresolved point source. Schmitt et al. (2003) found that the nuclear [O III] emission was unresolved even in *HST* imaging with a spatial resolution 0.1 arcsec. Since narrow-line region [O III] emission often traces the radio emission (e.g. Wilson 1997, and references therein), this observation is consistent with a nuclear jet pointing along our line of sight.

The angular resolution corresponds to a linear scale of 0.5 pc. The nuclear velocity dispersion measured from the near-infrared calcium triplet line by Nelson & Whittle (1995) when put in the velocity dispersion–black hole mass relationship in Ferrarese & Merritt (2000) shows NGC 7213 to have a central black hole mass of about 9.6×10^7 $M_{\odot}$. Thus our angular scale corresponds to 1.2×10^4 Schwarzschild radii.

4 DISCUSSION

That NGC 7213 has a core less than 3 mas across and a minimum brightness temperature of 1.5×10^8 K confirms our prediction on core size upper limit based on low-frequency variability (Blank & Harnett 2004). This result is also consistent with the Falcke et al. (1996) hypothesis that radio-intermediate objects are radio-quiet objects with moderate beaming from the parsec-scale jets pointing in the observer's direction.

The jets in NGC 7213 bend somewhere roughly between the scale of 1 arcsec (150 pc) and 10 arcsec (1.5 kpc). Bending in radio jets on the hundreds of parsec scale is common in Seyferts (Middelberg et al. 2004). For example, the jets in NGC 7674 (Momjian et al. 2003) and Mrk 231 (Ulvestad et al. 1999) both at some point bend 90°. Bending has been attributed to interactions of the jet and the interstellar medium of the host galaxy.

Long-term radio variability is not well known in Seyferts (Falcke et al. 2001). Middelberg et al. (2004) have obtained multi-epoch VLBI data of 16 Seyferts both from their own observations and from the literature. While NGC 5506 and 7674 showed some correlated changes of flux density and milliarcsec-scale radio emission, more extreme cases can be found in the radio-intermediate Seyferts Mrk 348 (Peck et al. 2003; Ulvestad et al. 1999) and III Zw 2 (Brunthaler et al. 2000). Perhaps variability in NGC 7213 is linked with changes in the parsec-scale jets, as have been found with these two other radio-intermediate Seyferts. Slee et al. (1994) may have observed an outburst in 1988, whereas observations in the mid-1990s recorded the dimming of the ejected components, which had completely faded by the time of our 2000 observation. We speculate that extreme radio variability may be a general property of radio-intermediate Seyferts.

5 CONCLUSION

We have used the Australian LBA to obtain 3 mas images at 8.4 GHz of the nearby Seyfert galaxy NGC 7213. The nucleus of NGC 7213 is unresolved, confirming our earlier prediction based on low-frequency variability. NGC 7213 has decreased in flux density by nearly a factor of 6 during the period from 1988 to 2000. While the issue of long-term radio variability in Seyferts is not well known, variability of the kind in NGC 7213 does not appear to be common. Perhaps radio variability in NGC 7213 is linked with parsec-scale outbursts, as has been found in two other extremely variable radio-intermediate Seyferts.

ACKNOWLEDGMENTS

The Long Baseline Array is funded by the Commonwealth of Australia for operation as a national facility managed by the CSIRO. We thank the LBA team for doing the observations. We thank the referee, Alan Roy, for a useful conversation and for a thorough review of the draft. DLB and JIH thank the ATNF staff at Epping for their hospitality. DLB also thanks the Astrophysics Department at the University of Sydney for kindly allowing use of their facilities. This work has made use of the NASA Astronomical Data System (ADS) and the NASA Extragalactic Database (NED).

REFERENCES

Blank D. L., Harnett J. I., 2004, MNRAS, submitted
Bransford M. A., Appleton P. N., Heisler C. A., Norris R. P., Marston A. P., 1998, ApJ, 497, 133
Brunthaler A. et al. 2000, A&A, 357, L45
Falcke H., Patnaik A. R., Sherwood W., 1996, ApJ, 473, L13
Falcke H., Lehar J., Barvainis R., Nagar N. M., Wilson A. S., 2001, in Peterson B. M., Pogge R. W., Polidan R. S., eds, ASP Conf. Ser. Vol. 224, Probing the Physics of Active Galactic Nuclei by Multiwavelength Monitoring. Astron. Soc. Pac., San Francisco, p. 265
Ferrarese L., Merritt D., 2000, ApJ, 539, L9
Ghisellini G., Padovani P., Celotti A., Maraschi L., 1993, ApJ, 407, 65
Middelberg E. et al., 2004, A&A, 417, 925
Momjian E., Romney J. D., Carilli C. L., Troland T. H., 2003, ApJ, 597, 809
Nelson C. H., Whittle M., 1995, ApJS, 99, 67
Orr M. J. L., Browne I. W. A., 1982, MNRAS, 200, 1067
Peck A. B., Henkel C., Ulvestad J. S., Brunthaler A., Falcke H., Elitzur M., Menten K. M., Gallimore J. F., 2003, ApJ, 590, 149
Readhead A. C. S., 1994, ApJ, 426, 51
Rickett B. J., 1986, ApJ, 307, 564
Rickett B. J., Coles W. A., Bourgois G., 1984, A&A, 134, 390
Roy A. L., Norris R. P., 1997, MNRAS, 289, 824
Schmitt H. R., Donley J. L., Antonucci R. R. J., Hutchings J. B., Kinney A. L., Pringle J. E., 2003, ApJ, 597, 768
Shapirovskaya N. Y., 1978, SvA, 22, 544
Shepherd M. C., 1997, in Hunt G., Payne H. E., eds, ASP Conf. Ser. Vol. 125, Astronomical Data Analysis Software and Systems VI. Astron. Soc. Pac., San Francisco, p. 77
Slee O. B., Sadler E. M., Reynolds J. E., Ekers R. D., 1994, MNRAS, 269, 928
Thean A., Pedlar A., Kukula M. J., Baum S. A., O'Dea C. P., 2001, MNRAS, 325, 737
Tzioumis A. K., 1997, Vistas Astron., 41, 311
Ulvestad J. S., Wrobel J. M., Roy A. L., Wilson A. S., Falcke H., Krichbaum T. P., 1999, ApJ, 517, L81
Wilson A. S., 1997, in Peterson B. M., Cheng F. Z., Wilson A. S., eds, ASP Conf. Ser. Vol. 113, Emission Lines in Active Galaxies. Astron. Soc. Pac., San Francisco, p. 264

This paper has been typeset from a TEX/LATEX file prepared by the author.