Proceedings of the 6th European VLBI Network Symposium
Ros, E., Porcas, R.W., Lobanov, A.P., & Zensus, J.A. (eds.)
June 25th-28th 2002, Bonn, Germany

Space VLBI monitoring of AO 0235+164

S. Frey[1], L. I. Gurvits[2], D. C. Gabuzda[3], C. J. Salter[4], D. R. Altschuler[4], P. Perillat[4], M. F. Aller[5], H. D. Aller[5], H. Hirabayashi[6], and M. M. Davis[7]

[1] FÖMI Satellite Geodetic Observatory, P.O. Box 546, H-1373 Budapest, Hungary
[2] Joint Institute for VLBI in Europe, P.O. Box 2, 7990 AA Dwingeloo, The Netherlands
[3] Physics Department, University College Cork, Cork, Ireland
[4] National Astronomy and Ionosphere Center, Arecibo Observatory, HC3 Box 53995, Arecibo, PR 00612, USA
[5] Astronomy Department, University of Michigan, Ann Arbor, MI 48109, USA
[6] Institute of Space and Astronautical Science, 3-3-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
[7] SETI Institute, 2035 Landings Drive, Mountain View, CA 94043, USA

Abstract. The highly compact, variable BL Lac object AO 0235+164 has been identified as the highest brightness temperature AGN observed with the VLBI Space Observatory Programme (VSOP) to date ($T_{\rm B} > 5.8 \times 10^{13}$ K, Frey et al. 2000). Since then, the sub-milliarcsecond radio structure of this source has been studied with dual-frequency (1.6 and 5 GHz), polarization-sensitive VSOP observations during 2001 and 2002. Here we present the first results of this monitoring campaign. The source is weakly polarized and characterized by a radio core that is clearly resolved on space–ground baselines.

1. Introduction

AO 0235+164 is an extensively studied BL Lac object at redshift $z = 0.940$. The source is highly variable over the whole electromagnetic spectrum from radio to γ-rays. The object is seen through a foreground group of galaxies at $z = 0.524$. See e.g. Frey et al. (2000), Raiteri et al. (2001) and references therein for more detailed reviews concerning AO 0235+164.

The milliarcsecond (mas) scale radio structure of the source revealed by ground-based VLBI is characterized by a dominant compact core. Sometimes, faint extensions are seen at various position angles. As opposed to other BL Lac objects, high resolution radio polarization studies using ground-based VLBI at 5 GHz (Gabuzda et al. 1992) and 8.4 GHz (Gabuzda & Cawthorne 1996) found no convincing structure in either total or polarized intensity apart from the compact core.

The source often exhibits brightness temperatures exceeding the inverse Compton limit ($\sim 10^{12}$ K) indicating that its radiation is Doppler boosted. Our first-epoch VSOP (Hirabayashi et al. 1998) Space VLBI (SVLBI) observations at 5 GHz on 1999 Feb 1 led to a brightness temperature $T_{\rm B} > 5.8 \times 10^{13}$ K (Frey et al. 2000), based on an unresolved core component. This is the highest value obtained with VSOP and implies a Doppler factor of ~ 100, in good agreement with independent estimates (Kraus et al. 1999; Fujisawa et al. 1999).

Our monitoring observations were aimed at investigating how the sub-mas scale radio structure of AO 0235+164 varies, and to see whether linear polarization structure can be seen with the superior angular resolution of VSOP. Here we briefly report on our second-epoch 5-GHz SVLBI observations and comment on other preliminary results. When completed, the full analysis of the data will be presented elsewhere.

Table 1. Space VLBI observations of AO 0235+164 at 1.6 GHz (top) and 5 GHz (bottom)

Epoch	Ground network	Correlator	Pol
1999 Jan 31	AT HH NO SH (4)	Penticton	
2001 Feb 4	VLBA AR (11)	Socorro	√
2001 Aug 3	VLBA AR GO (12)	Socorro	√
1999 Feb 1	AT SH UD (3)	Penticton	
2001 Feb 2	VLBA Y (11)	Socorro	√
2001 Aug 2	VLBA AR (11)	Socorro	√
2001 Aug 14	AR AT UD (3)	Mitaka	
2002 Jan 26	VLBA (9)	Socorro	√

2. Observations

AO 0235+164 was observed at 1.6 and 5 GHz at 8 epochs with VSOP. The details of the 3-year monitoring program are summarized in Table 1. Polarization-sensitive observations are marked in the last column. At each observing epoch, multi-frequency measurements of the total radio flux density data were obtained quasi-contemporaneously at the University of Michigan Radio Astronomy Observatory (UMRAO) and the Arecibo Observatory.

3. Preliminary results

The full-resolution 5-GHz image of AO 0235+164 is shown in Fig. 1. The SVLBI network on 2001 Feb 2 included the HALCA satellite, the NRAO VLBA and the VLA as a phased array. No jet component is visible. The linear polarization structure is similarly simple. The degree of polarization (1.3%) is rather low, in agreement with the UMRAO total polarized flux density measurements at the same time. Notably, the source is clearly resolved on space–ground baselines. Its brightness distribution is well fitted by a circular Gaussian component of 0.2 mas (FWHM), implying a brightness temperature of about 2×10^{12} K, more than an order of magnitude less than that derived in 1999 (Frey et al. 2000). The source has apparently expanded and, according to the total flux density monitoring data, faded (from 1.6 to 1.2 Jy) since 1999. Also interesting to note is that the correlated flux density on the shortest VLBI baselines is less than the total flux density by $\sim$ 100 mJy, a phenomenon often encountered at different epochs by various investigators as well. At the same time, the VLA data taken during the SVLBI observations account for the total flux density. The VLA image (Fig. 2) with about 3 orders of magnitude lower resolution shows weak extended emission surrounding the core. We suspect that diffuse low surface brightness emission is present on intermediate angular scales as well. This emission is resolved out with VLBI. At later epochs (2001 Aug and 2002 Jan), the sub-mas scale source structure at 5 GHz is remarkably similar in terms of brightness temperature. The degree of polarization is $\sim$ 1% (at the detection threshold, always consistent with UMRAO total flux density data).

As argued by e.g. Fujisawa et al. (1999), the radio jet in AO 0235+164 may be oriented very close (within 1°) to the line of sight. Qualitatively, this explains a wide range of phenomena observed in the source, including (some) variability, rapid changes in the VLBI jet component position angles (when observed), and the diffuse radio emission surrounding the core at larger scales. With our SVLBI monitoring, we are able to conclude that a jet component was ejected towards the observer, appearing extremely bright and compact soon after the corresponding outburst in total emission. Later, it expanded and became fainter. Indeed, brightness temperature estimates from long-term VLBI data seem to correlate with total flux density variations (Frey et al. 2000).

Acknowledgements. We gratefully acknowledge the VSOP Project, which is led by the Institute of Space and Astronautical Science (Japan) in cooperation with many organizations and radio telescopes around the world. The National Radio Astronomy Observatory is a facility of the National Science Foundation (NSF) operated under cooperative agreement by Associated Universities, Inc. The Arecibo Observatory is operated by Cornell University under cooperative agreement with the NSF. This research has made use of data from the University of Michigan Radio Astronomy Observatory which is supported by funds from the University of Michigan and the NSF. SF acknowledges financial support received from the Netherlands Organization for Scientific Research and the Hungarian Scientific Research Fund (grant no. N31721 & T031723).

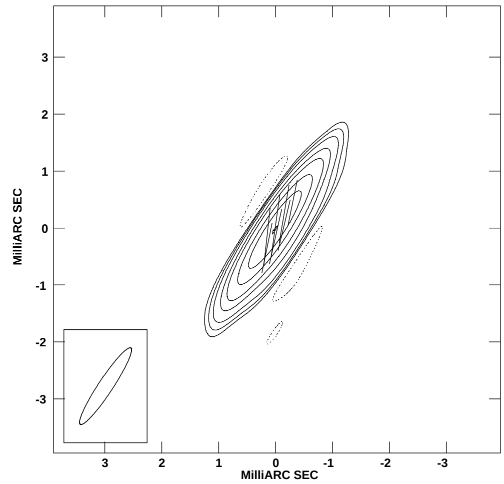

Fig. 1. 5-GHz SVLBI image of AO 0235+164 on 2001 Feb 2. Total intensity contours are at −0.5, 0.5, 1, 2, 5, 10, 25, 50 and 99% of the peak brightness of 859 mJy/beam. The restoring beam is 1.61 mas × 0.25 mas at PA=−34°. Electric vectors are superimposed, 1 mas corresponds to 10 mJy/beam polarized intensity.

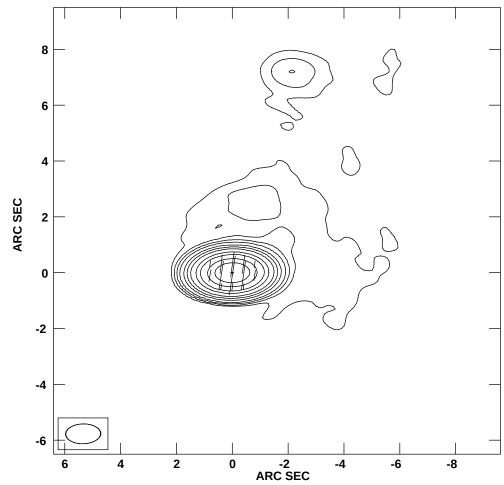

Fig. 2. 5-GHz image of AO 0235+164 made from the VLA data only (2001 Feb 2). Total intensity contours are at −0.02, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 25, 50 and 99% of the peak brightness of 1249 mJy/beam. The restoring beam is 1.25" × 0.71" at PA=−89°. Electric vectors are superimposed, 1 arcsec corresponds to 10 mJy/beam polarized intensity.

References

Frey S., Gurvits L.I., Altschuler D.R., et al. 2000, PASJ 52, 975

Fujisawa K., Kobayashi H., Wajima K., et al. 1999, PASJ 51, 537

Gabuzda D.C., Cawthorne T.V., Roberts D.H., Wardle J.F.C. 1992, ApJ 388, 40

Gabuzda D.C., Cawthorne T.V. 1996, MNRAS 283, 759

Hirabayashi H., Hirosawa H., Kobayashi H., et al. 1998, Science 281, 1825

Kraus A., Quirrenbach A., Lobanov A.P., et al. 1999, A&A 344, 807

Raiteri C.M., Villata M., Aller H.D., et al. 2001, A&A 377, 396