THE DEEP INTERFEROMETRIC VSOP–ARECIBO SURVEY (DIVAS)

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ABSTRACT

The Deep Interferometric VSOP-Arecibo Survey (DIVAS) program uses space VLBI observations of a faint population of flat-spectrum sources made with the HALCA satellite and the Arecibo telescope to provide the highest possible space VLBI sensitivity at 5 GHz. The main aim of the survey is to compare statistical results on the source structures (e.g., brightness temperatures, sizes, visibilities) with results from the VLBI Space Observatory Programme (VSOP) Survey, to determine whether there are systematic differences in the compact structures of sources selected from samples with limiting flux densities differing by over an order of magnitude.

INTRODUCTION

VLBI surveys of complete flux-limited samples of extragalactic radio sources, such as the Caltech–Jodrell Bank surveys (see [1] and references therein), have provided important statistical information about the different types of radio sources, as well as serving as finding lists for objects with individual properties of exceptional interest. Over the past decade sensitive all-sky surveys have been made, such as FIRST [2], GB6 [3], and NVSS [4], enabling the construction of samples having flux densities much lower than in previous surveys. Such samples of weaker sources are of interest for statistical comparison to the stronger sources. to determine whether, e.g., weaker sources are similar to the strong sources intrinsically but with less preferred alignment and less Doppler boosting, or are they intrinsically weaker sources with more Doppler boosting. The first step in such a study is to determine the statistical VLBI properties of a sample of weak radio sources.

SAMPLE SELECTION

Our sample was selected from the FIRST [2] and GB6 [3] catalogs, with right ascension and declination limits imposed by the progress of the FIRST survey at the time and by the limits of the Arecibo telescope. Sources were required to have a two-point spectral index between 1.4 and 4.85 GHz flatter than -0.5 (i.e., α greater than -0.5, where $S \propto \nu^{\alpha}$). A total of 161 radio sources having 4.85 GHz flux densities greater than 50 mJy were selected.

Observations of all 161 sources were made with the Very Long Baseline Array (VLBA) on 1996 December 19. Eight 8 MHz intermediate-frequency (IF) channels, ranging from 4.6 GHz to 5.1 GHz, were employed so that accurate positions could be determined using bandwidth-synthesis techniques. The 60 sources with a peak flux density greater than 75 mJy were selected as candidate targets for observations as part of the VLBI Space Observatory Programme (VSOP).

VSOP OBSERVATIONS

VSOP observations are made with the HALCA satellite and an array of ground telescopes on baselines up to three times longer than achievable on Earth [5,6]. VSOP observations have been made at 5 GHz of 20 of these 60 sources, and reduction of this data set is on-going. Details of the sources and the VSOP observations are given in Table 1. The ground-arrays used in the observations included a subset of the Arecibo 305 m (AR), the Green Bank 37 m (GB), Noto 32 m (NT), and Torun 32 m (TR) telescopes. Data for these VSOP observations were recorded in the standard VSOP format of two 16 MHz bandwidth, two-bit sampled channels. S2-format recorders were used at all telescopes except Torun, where the data were recorded in VLBA format and later copied to S2 or VSOP format in Japan. The data were correlated at the Penticton correlator in Canada or the Mitaka correlator in Japan.

Table 1: Summary of VSOP Observations

Source	Date	Ground Array	VLBA peak (mJy)	α	Redshift
J0911+3349	29 Jan 1999	AR NT TR	110	−0.36	
J0919+3324	02 May 1999	AR GB NT TR	174	+0.30	
J0949+2920	03 May 1999	AR GB NT TR	103	−0.34	
J0955+3335	25 Jan 1999	AR NT TR	88	+0.39	2.449
J1001+2911	04 May 1999	GB NT TR	143	+0.08	
J1044+2959	01 May 1999	AR GB NT TR	136	+0.62	2.981
J1118+2922	06 Jun 1999	AR GB	86	+0.25	
J1124+3214	26 Jan 1999	AR NT TR	81	+0.02	
J1135+3010	27 Jan 1999	AR NT TR	124	+0.18	
J1152+2930	08 Jun 1999	AR GB	107	−0.31	1.23
J1205+3041	07 Jun 1999	AR GB	122	−0.20	
J1215+3151	03 Jun 1999	AR GB	202	−0.13	
J1228+3128	09 Jun 1999	AR GB	232	+0.04	2.119
J1350+3034	14 Jul 1999	AR NT	221	−0.10	
J1435+3012	19 Jul 1999	AR NT	124	−0.01	
J1437+3002	15 Jul 1999	AR NT	84	+0.58	0.2316
J1442+3234	05 Jun 1999	AR GB	145	−0.13	2.12
J1539+3104	16 Jul 1999	AR NT	140	+0.08	
J1602+3326	27 Jun 1998	AR	1136	−0.27	
J1708+3346	13 Jul 1999	AR NT	98	+0.35	
J1725+3026	14 Jul 1999	AR NT	130	−0.21	

Data quality analysis of data from the Penticton correlator revealed fringes on baselines to HALCA for at least some of the observation for 11 of 17 of the sources in Table 1. The data quality analysis is not exhaustive, however, and fringes may still be found in some of the other six observations. The sparse ground arrays will preclude imaging in many cases, although model-fitting will still be possible. A significant amount of information can be gleaned from plots of correlated flux density against (u, v)-distance. Data from VSOP Survey Program observations has been used to plot the weighted mean of the normalized correlated flux density against (u, v)-distance, revealing that beyond baseline lengths of 200 mega-lambda, the visibility amplitude drops more slowly, indicating that a less resolved component tends to dominate on the space-VLBI scale at 5 GHz and that most of the more extended structure is resolved out [7]. DIVAS observations will help determine whether such a trend continues for fainter radio sources.

We are also studying the properties of these sources as a function of their classification. The FIRST team are supplementing their radio observations by taking optical spectra of selected sources [8]. Of the 161 sources in the original survey list, 15 are classified as quasars, and 5 as BL Lacs. Redshifts are available for $\sim$20 sources, many from the follow-up FIRST observations [8]. At present, little or no information is available for many of the sources, however this situation is expected to change in the near future as more extensive optical survey programs are carried out.

SUMMARY

VSOP observations of 289 AGN are being conducted at 5 GHz for the VSOP Survey Program, as part of a complete sample of 402 sources with cataloged flux densities greater than 0.95 Jy. The Deep Interferometric VSOP–Arecibo Survey is somewhat smaller, but the VSOP observations of 21 sources, and the preparatory VLBA observations of 161 sources, will enable us to search for differences in the properties of sources from two quite distinct flux density classes.

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REFERENCES

[1] G.B. Taylor, R.C. Vermeulen, A.C.S. Readhead, T.J. Pearson, et al.
"A complete flux-density limited VLBI survey of 293 flat-spectrum radio sources."
Astrophysical Journal Supplement vol. 107, pp. 37–68

[2] R.L. White, R.H. Becker, D.J. Helfand, and M.D. Gregg,
"A Catalog of 1.4 GHz Radio Sources from the FIRST Survey"
Astrophysical Journal, vol. 475, pp. 479–493, 1997

[3] P.C. Gregory, W.K. Scott, W. K., K. Douglas, and J.J. Condon,
"The GB6 Catalog of Radio Sources,"
Astrophysical Journal Supplement, vol. 103, pp. 427–432, 1996

[4] J.J. Condon, W.D. Cotton, E.W. Greisen, Q.F. Yin, R.A. Perley et al.

"The NRAO VLA Sky Survey"
Astronomical Journal, vol. 115, pp. 1693–1716, 1998

[5] H. Hirabayashi, H. Hirosawa, H. Kobayashi, Y. Murata, P.G. Edwards et al.,
"Overview and Initial Results of the Very Long Baseline Interferometry Space Observatory Programme," *Science*, vol. 281, pp. 1825–1829, 1998 (and erratum, vol. 282, p. 1995).

[6] H. Hirabayashi, H. Hirosawa, H. Kobayashi, Y. Murata, Y. Asaki, et al.
"The VLBI Space Observatory Programme and the Radio-Astronomical Satellite HALCA",
Publications of the Astronomical Society of Japan, vol. 52, pp. 955–965, 2000.

[7] H. Hirabayashi, E.B. Fomalont, S. Horiuchi, J.E.J. Lovell, G.A. Moellenbrock, et al.
"The VSOP 5 GHz AGN Survey I. Compilation and Observations",
Publications of the Astronomical Society of Japan, vol. 52, pp. 997–1014, 2000.

[8] R.L. White, R.H. Becker, M.D. Gregg, S.A. Laurent-Muehleisen, M.S. Brotherton et al.
"The FIRST Bright Quasar Survey. II. 60 Nights and 1200 Spectra Later,"
Astrophysical Journal Supplement, vol. 126, pp. 133–207, 2000