Space-VLBI phase-referencing

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We present 5 GHz space-VLBI observations of the quasar pair B 1342+662/B 1342+663 which show the feasibility of using phase-referencing techniques with the HALCA satellite. From residual referenced phases we derive an upper bound of 10 meters to the uncertainty of the HALCA's orbit reconstruction. An analysis of the phase-reference maps of the observed sources also suggests that the above mentioned uncertainty is very likely as small as 3 meters. With errors of this magnitude, HALCA is a useful tool for astrometric studies of close pairs of radiosources.

1. Introduction

VLBI differential astrometry and phase-referencing are efficient techniques to analyze the absolute kinematics of source components in pairs of radio sources. However, the improvement of the precision of these techniques at cm-wavelengths seems difficult: no matter how good the astrometric model is, the lack of a reliable point in the structure of the radio source that may serve as reference is the limiting factor of the precision, even with dense and sensitive arrays, This problem is independent of the separation of the sources in the sky and is a consequence of the intrinsic nature of the observation: ground-based astrometry combines nearly *microarcsecond*-precise relative positions with *milliarcsecond* resolution of the source structure.

Attempts to alleviate this situation should be directed to the extension of VLBI astrometry and phase-referencing to observations at the highest possible resolution, i.e., mm-VLBI and VSOP observations. The feasibility of differential astrometry at mm-wavelengths has been demonstrated for a pair of sources with 5° separation and high antenna elevations (Guirado *et al.* 2000). In this contribution we explore the capabilities of VSOP for phase-referencing and astrometry by means of observations of the pair of sources B 1342+662/B 1342+663 (Morabito 1984). This quasar pair is extremely favorable: the separation of the sources is small enough so that both sources can be observed together within the main antenna beam by HALCA and the VLBA antennas. This particular configuration permits the application of the phase-referencing technique with the advantage that we avoid the interpolation in time of the correlator residuals needed by switching schemes.

2. Observations

We made continuum observations of the radio sources B 1342+662 and B 1342+663 on 1999 May 8 from 12:00 to 08:00 UT. We used the complete VLBA (ten 25m antennas), Effelsberg (100m, Bonn, Germany), and Kashima (34m, Japan), along with the Japanese satellite HALCA (8m) at a frequency of 4.8 GHz, achieving a recording bandwidth of 32 MHz. Since the separation of B 1342+662 and B 1342+663 is only $0\overset{\circ}{.}08$ (4')

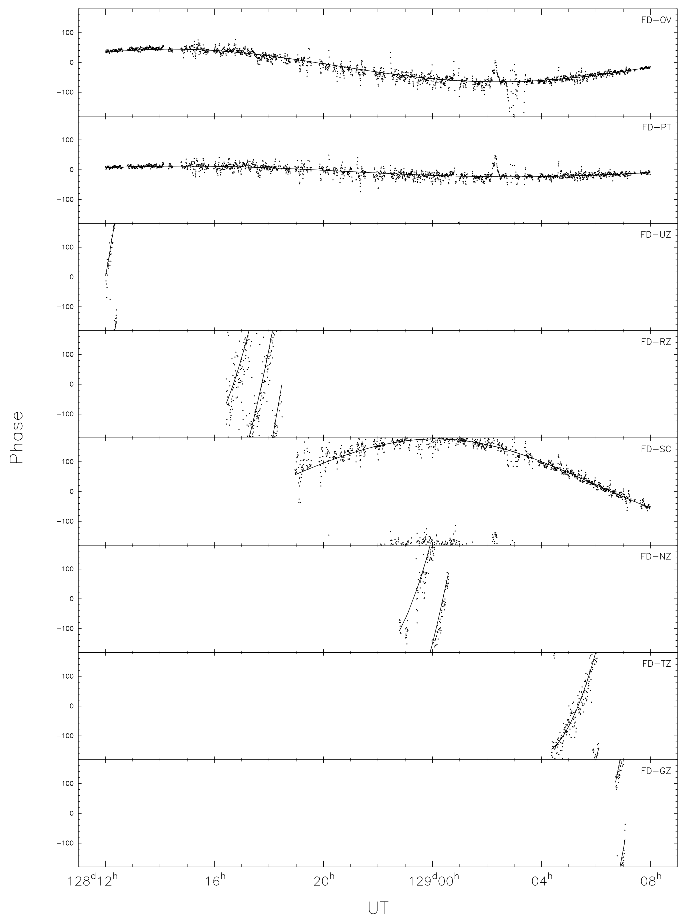

FIGURE 1. 5 GHz phases of B 1342+662 referenced to those of B 1342+663. The plot shows a selection of both ground-ground and ground-space baselines. The symbols correspond to the following VLBA antennas: FD, Fort Davis; OV, Owens Valley; PT, Pie Town; SC, Saint Croix; and the following tracking stations: UZ, Usuda (Japan); RZ, Robledo (Spain); NZ, Green Bank (USA); TZ, Tidbinbilla (Australia); and GZ, Goldstone (USA). The continuous line corresponds to phases derived from the phase-reference map of the left panel of Fig. 2. See text.

in the sky, both sources were observed simultaneously by HALCA and all the ground telescopes, but Effelsberg (whose antenna beam is of 2.5'). The data were correlated at the VLBA Correlator Center of the National Radio Astronomy Observatory (NRAO, Socorro, NM, USA). Two correlator passes were made, one at the position of each of the two sources. For each source, we made an *a priori* visibility amplitude calibration (using system temperatures and gain curves from each antenna), and found 3 min-interval fringe solutions at the correlation position using the NRAO Astronomical Image Processing System (AIPS). Both sources were detected in all baselines, including those to HALCA. Details of the data reduction will be given in a forthcoming paper (Guirado *et al.* 2000b).

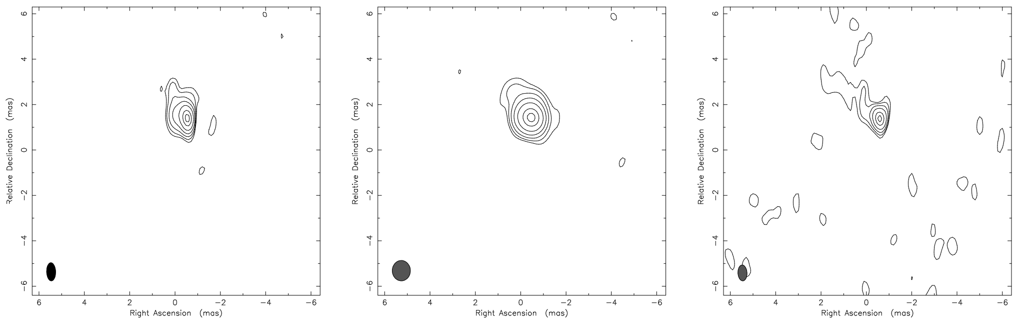

FIGURE 2. Left panel: 5 GHz map of B 1342+662 phase-referenced to B 1342+663 made with all data. Contours are -2,2,4,8,16,32,64, and 90% of the peak of brightness, 0.22 Jy/beam. The restoring beam (shown at the bottom left corner of each map) is an elliptical Gaussian of 0.8×0.4 mas (P.A. 2°). Center panel: same as left panel but with ground-ground data only. Contours are -2,2,4,8,16,32,64, and 90% of the peak of brightness, 0.25 Jy/beam. The restoring beam (shown at the bottom left corner) is an elliptical Gaussian of 0.9×0.8 mas (P.A. 1°). Right panel: same as other panels but with ground-space data only. Contours are -4,4,8,16,32,64, and 90% of the peak of brightness, 0.26 Jy/beam. The restoring beam (shown at the bottom left corner) is an elliptical Gaussian of 0.7×0.4 mas (P.A. 3°).

3. Results and discussion.

We performed a phase-referencing analysis of our data, within AIPS (e.g. Beasley & Conway 1995). Although both sources have healthy detections, we chose B 1342+663 (the brighter source of the pair) to be the reference source. Therefore, the antenna phase calibrations of B 1342+663 (free from structure effects by using a hybrid map of the source) were applied to the B 1342+662 data.

The resulting referenced phases for B 1342+662 are shown in Fig. 1. In this Figure, we see that the phase can be unambiguously tracked, indicating that the phase-referencing process led to proper detections along the complete experiment. This is hardly a surprise for ground-ground baselines, but extremely important for baselines to HALCA: given two radio sources with similar relative geometry to that of our pair, the uncertainties in HALCA's orbit determination do not prevent the prediction of the phase of one source from knowledge of the phases of the other. The referenced phases in Fig. 1 show a clear sinusoidal behaviour, a result of the combination of the contributions of the structure of the target source, uncancelled effects of correlator model imperfections (necessarily angular-dependent effects), and correction to the relative coordinates of the two sources.

By far, the latter effect is the major contributor to the referenced phases. To show it, we obtained a phase-reference map of B 1342+662 (Fig 2; left panel) by Fourier inversion of its referenced visibilities. Both the offset with respect to the origin and, to a much lesser degree, the source structure (B 1342+662 is almost pointlike) account for most of the systematic effects in the referenced phases (see continuous line in Fig. 1). Once the structure contribution and the offset position of B 1342+662 are removed from the phases, the residual referenced phases do not show significant systematic effects. However, the $\sim$90° peak-to-peak variations of the phases in HALCA baselines (Fig. 1) gives us an estimate of the inaccuracies of HALCA's orbit reconstruction: at 5 GHz and considering the strong cancellation produced by the small separation of our sources (0.08°), a $\sim$90° phase variation corresponds to $\sim$10 m uncertainties in HALCA's position. Further, the phase variations of the phases of some ground-ground baselines are similar to those of the ground-space baselines (see Fig. 1), meaning that a significant part of variation of the ground-space residual phases are due to "conventional" correlator uncertainties (e.g. atmospheric effects over the ground station). Accordingly, our 10 m uncertainty estimate appears as a fairly conservative upper bound to the uncertainty in reconstructing HALCA's orbit. This conjecture can be verified from the astrometry carried out using different phase-referenced maps of B 1342+662; we discuss this in turn.

The measurement of the position of the peak-of-brightness of the phase-reference image in Fig. 2 (left panel) gives us the differential correction to the *a priori* positions used in the correlator model. To calibrate the contribution of the ground-space baselines in this relative astrometry, we made two extra phase-reference maps of B 1342+662, namely, 1) a map using only ground-ground baselines (Fig 2; center panel), and 2) a map using only ground-space baselines (Fig. 2; right panel). The offsets of the three maps in Fig. 2 are extraordinarily similar; for each coordinate, the difference between the offsets measured in any two maps of Fig. 2 is smaller than 50μas. In particular, the difference in the relative position measured in the "ground-only" map (Fig 2; center panel) and "HALCA-only" map (Fig 2; right panel) may be interpreted (conservatively) as a consequence of the uncertainties in HALCA position. Such a difference (once added in quadrature the difference of each coordinate) is $\sim$60μas. Again, taking into account the separation of $0\overset{\circ}{.}08$ of our sources, we derive an estimate of the HALCA fractional baseline error $\sim 2.1\times10^{-7}$. For an average projected baseline of 12,000 kilometers this error corresponds to HALCA's position uncertainty as small as 3 m. This result is in agreement with that provided by Porcas *et al.* (2000) that estimated the error in HALCA's position around 2-5m, for a pair of sources separated by 14'.

In summary: our data show that the phase-referencing technique with the HALCA satellite can be applied to pairs of close radiosources. From our data we derive an upper bound of 10m for the uncertainties of HALCA's position, although likely these uncertainties are as small as 3m, according to the results of the relative astrometry of different sets of phase-reference maps of our sources. With errors of this magnitude, HALCA is a useful tool for astrometry of close pairs.

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