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32 GHz Celestial Reference Frame Survey for Dec. $< -45°$

S. Horiuchi [1], *C.S. Jacobs* [2], *C. Phillips* [3], *I. Sotuela* [4], *C. García-Miró* [4]

[1] *Canberra Deep Space Communications Complex/NASA, CSIRO, Canberra, Australia*
[2] *Jet Propulsion Laboratory, California Institute of Technology/NASA, CA, USA*
[3] *Australian Telescope National Facility, CSIRO, Marsfield, Australia*
[4] *Madrid Deep Space Communications Complex/NASA, INTA, Madrid, Spain*
Contact author: S. Horiuchi, e-mail: shoriuchi@cdscc.nasa.gov

Abstract

We have been developing a celestial reference frame at 32 GHz using the 34-m Beam Wave Guide antennas of NASA's Deep Space Network (DSN) to complement the current IAU standard ICRF2 at S/X-band. However, the DSN VLBI network alone can only cover a limited part of the full sky, missing the declination range from −45 to −90 degrees. To extend the 32 GHz frame, we recently initiated a project to survey candidate sources in the southern sky using Canberra's DSS-34 antenna in conjunction with two elements of the Australian Long Baseline Array (LBA) that can observe at 32 GHz: the Mopra Radio Relescope and the Australian Telescope Compact Array (ATCA).

1. Introduction

The International Celestial Reference Frame (ICRF) has been traditionally constructed using catalogs of radio quasar positions measured at 2.3 GHz (S-band) and 8.4 GHz (X-band) with the Very Long Baseline Interferometry (VLBI) technique. NASA Deep Space Network (DSN) has been contributing to the maintenance of the catalogs as part of International VLBI Service (IVS) collaborations and using them for spacecraft navigation. DSN has also been developing a catalog at 32 GHz (Ka-band) with its internal network of 34-m Beam Wave Guide antennas that includes DSS-34 in Tidbinbilla (Jacobs & Sovers, 2009; Jacobs et al., 2011; García-Miró et al., 2012). However, the DSN VLBI network alone can only cover a limited part of the full sky, missing the declination range from −45 to −90 degree. To extend the 32 GHz catalog, we plan to survey 144 candidate sources in the southern sky with the Australian Telescope Compact Array (ATCA) and the Mopra Telescope which can observe at 32 GHz. Tidbinbilla DSS-34 (Tid34) joins a fraction of the time when not being used for spacecraft tracking. The ultimate goal of our project is to establish a reference source catalog at 32 GHz for the south polar cap region, which has never been covered in existing catalogs at that frequency. The catalog will be used for future spacecraft navigation by NASA and other space agencies as well as for radio astronomical observations with southern radio telescope arrays such as ATCA and LBA.

2. Reference Frames at Higher Radio Frequencies Than S/X

For over three decades now, radio frequency work in global astrometry, geodesy, and deep space navigation has been done at S-band (2.3 GHz) and X-band (8.4 GHz). While this work has been tremendously successful in producing 100 micro-arcsecond level global astrometry and sub-cm geodesy (e.g., Ma et al., 2009), developments made over the last decade have made it

possible to consider the merits of moving to a new set of frequencies. VLBI radio frame work has been extended recently to 24 GHz for 268 sources and 43 GHz for 131 sources (Lanyi et al., 2010; Charlot et al., 2010) using VLBA for -40 degrees $<$ declination. Also, using NASA Deep Space Network antennas we have conducted VLBI astrometry and constructed a celestial reference frame catalog at 32 GHz with 469 sources with 200–300 microarcsecond positional accuracy for -45 degrees $<$ declination (Figure 1a, Jacobs et al., 2011; García-Miró et al., 2012). Why Ka-band? Moving the observing frequencies up by approximately a factor of four has several advantages. For our work in the Deep Space Network, the driver is the potential for higher data rates for telemetry signals to probes in deep space. Other advantages include 1) the spatial distribution of flux becomes significantly more compact (Charlot et al, 2010) lending hope that the positions will be more stable over time, 2) Radio Frequency Interference (RFI) at S-band would be avoided, 3) Ionosphere and solar plasma effects on group delay and signal coherence are reduced by a factor of 15(!), 4) because we observe mostly blazars which are characterized by jets pointing near the line of sight, we observe down the 'throat' of the jets thus bringing into consideration opacity effects (Königl 1981). Higher frequency observations may see farther into the jets thus changing the observed position.

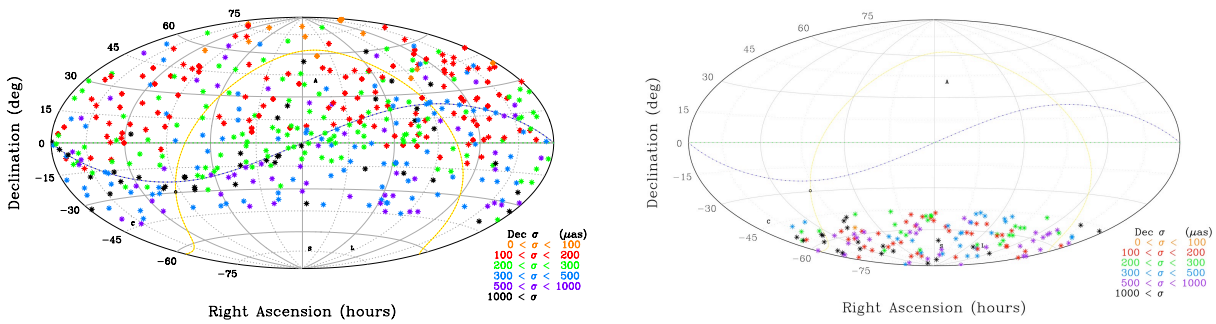
3. South Pole Observations

Following the successful project to establish the 32 GHz reference frame for $-45 <$ declination $< +90$ degrees with the DSN/NASA network, the next logical step is to explore the southern sky toward the southern polar cap limit. Our ultimate goal is to establish the catalog for the missing part of the sky with comparable accuracy to catalogs for the northern sky. This will require an additional station in either South Africa or South America on top of existing telescopes in Australia. We are pursuing intercontinental collaborations in the southern hemisphere, see Jacobs et al., 2012. Toward that goal we need to first establish a list of sources for which VLBI can detect fringes. This requirement led us to plan a pilot survey within Australian baselines. The survey will allow us to select sources as well as obtain positions of sources to an order of 1 milli-arcsecond accuracy, at least 100 times more accurate than that of the AT20G survey (e.g., Murphy et al., 2010, for the full AT20G catalog).

Our work will also contribute to the Gaia space mission that plans to measure 10^9 objects with 10s of micro-arcsecond precision including 500,000 quasars of which approximately 2000 are expected to be both optically bright (V $<$ 18) and radio loud (30-300+ mJy) (Lindegren et al, 2008, Gaia 2012). Our existing catalog at 32 GHz has 336 sources with optical counterparts (Veron-Cetty & Veron, 2010) with visual (500–600 nm) magnitude, V, bright enough to be detected by Gaia (V $<$ 20 mag). Of these, 130 are bright by Gaia standards (V $<$ 18). Using existing X/Ka-band position uncertainties and simulated Gaia uncertainties (corrected for ecliptic latitude, but not for $V - I$ color), we did a covariance study which predicts that the 3-D rotation between the X/Ka frame and the Gaia frame could be estimated with a precision of 10–15 mas per rotation angle (1-σ) (Jacobs et al., 2011). The result is dominated by X/Ka uncertainties which have potential for a factor of two or more improvement by the time of the final Gaia catalog in 2021. Thus a frame tie precision of 5–10 μas may be possible, and our work has the potential to be the most accurate independent check of Gaia because X/Ka systematics (core shift and source structure) are expected to be smaller than S/X systematics.

4. Source Selection

We constructed a list of our new Ka band candidate sources (531 over the whole sky) with an estimate of the 32 GHz flux based on the peak brightness provided by the AT20G survey at 20, 8.6, and 4.8 GHz (Murphy et al., 2010). The list is based on the RFC 2011c catalog of Petrov (2011) and the sources were selected based on X-band unresolved flux components larger than 200 mJy with the percentage of the flux in the unresolved component being greater than 70%. Sources already observed by us for the X/Ka catalogs (Jacobs et al., 2011) were removed, so finally we have 531 sources not previously observed at this frequency. A cross search has been made in the AT20G catalog. Spectral indexes for the three AT20G frequencies 4.8, 8.6, and 20 GHz were calculated, and a rough estimation of the 32 GHz peak brightness based on the AT20G spectral index between 20 and 8.6 GHz was derived. We found 268 sources out of our initial 531 candidates which have been detected with the ATCA survey at 20 GHz. Among these sources we formed a list of 144 sources with declinations below −45 degrees (Figure 1b). We use this sample for our preliminary survey.



a) Existing X/Ka catalog. b) South Pole X/Ka catalog candidates.

Figure 1. Distribution of (a) existing 469 X/Ka sources, and (b) 144 candidate south pole sources, plotted using a Hammer-Aitoff projection to show their locations on the sky. $\alpha = 0$ is at the center. The ecliptic plane is shown by the dashed blue-gray line and the Galactic plane is indicated by the yellow-red dashed line. The sources are color coded according to their 1-σ formal $\alpha \cos\delta$ and δ uncertainties with the value ranges indicated in the legend. Note the drop in precision below $\delta = -20°$ in the existing catalog where the CA-Spain baseline coverage can no longer reach.

Our list of 144 South Polar Cap objects has 46 ICRF2 sources (Ma et al., 2009) which agree at the level of their formal errors. Included in that set of 46 are 29 "Defining" Objects from the ICRF2. These would allow cross-checking with the S/X results of ICRF2. The source positions of the sub-sample should be quite good enough for scheduling and correlation. Most position errors are < 1 mas. The 29 Defining sources will give schedules a very solid tie to the ICRF2 frame. The spatial distribution is quite uniform—especially for a first list of candidates.

5. Observation Strategy

Our goal is to survey the 144 candidate catalog sources in the southern sky with two of the Australian Telescope National Facilities (ATNF) telescopes that can observe at 32 GHz, the Australian Telescope Compact Array (ATCA, Figure 2), and the Mopra Radio Telescope (Figure 3).

NASA's DSN Tidbinbilla DSS-34 (Tid34) joins a fraction of the time when not used for spacecraft tracking. One 24-hour track with both ATCA and Mopra is required to cover different parts of the sky. The 24-hour block does not have to be during a normal LBA session. The data are recorded to the LBA-DR system at 512 Mbps for 4 IF×16 MHz dual-polarization mode (except Tid34, which can only observe single polarization) and correlated at Curtin Institute of Radio Astronomy with the DiFX software correlator. We spend one minute integration per scan which gives a sensitivity of 7.4 mJy for the ATCA-Mopra or Mopra-Tid34 baselines, and 3.3 mJy for the ATCA-Tid34 baseline, according to the LBA sensitivity calculator. Assuming overhead of another minute per scan that includes slew time and every calibrator scans 90 minutes for a few strong sources in the existing 32 GHz catalog, the 24-hour block allows five scans per source to cover a variety of u-v spacings. A typical DSS-34 tracking gap for about six hours or so would allow us to observe sources near the south pole with three baselines at least once, which helps visibility modeling to estimate structure. For sources with fringes detected we will propose for multi-epoch astrometry sessions in the following ATNF proposal deadline in order to refine source positions and to measure source variability.

Figure 2. Australian Telescope Compact Array.

Figure 3. The Mopra Radio Telescope.

6. Initial Results

We conducted a short fringe test with Mopra and DSS-34 on 2 December 2011, observing a strong quasar 1921-293 centered at 32.0 GHz for 2 IF×16 MHz bandwidth. The second fringe test was conducted on 7 and 9 February 2012 with ATCA, Mopra and DSS-34, observing a strong quasar 0537−441, centered at 32.0 GHz for 2 IF×64 MHz bandwidth. However both experiments were unsuccessful due to system problems yielding no fringe detection.

Note added after IVS meeting: The first 24-hour block of the 32 GHz Pilot Survey was scheduled on 1 May 2012 for ATCA and Mopra with a short DSS-34 block for fringe testing. Pointing at 1921-293, the first LBA 32 GHz fringe was detected on the DSS-34 to Mopra baseline. However because we were unable to find fringes to ATCA, the survey was postponed. Schedule coordination continues to be a challenge.

7. Conclusions

We are conducting an LBA survey of compact radio sources at 32 GHz near the south pole region. This is the first attempt to fill the gap in the existing 32 GHz catalog established by NASA Deep Space Network toward completing the full sky celestial reference frame at 32 GHz. The catalog will be used for future spacecraft navigation by NASA and other space agencies as well as for radio astronomical observations with southern radio telescope arrays such as ATCA and LBA.

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