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Extending the ICRF to Higher Radio Frequencies

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Abstract

The ICRF ([1]) forms the basis for all astrometry including use as the inertial coordinate system for navigating deep space missions. This frame was defined using S/X-band observations over the past 20+ years. In January 2002, the VLBA approved our proposal for observing time to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz). The first step will be observations at K- and Q-bands on a subset of ICRF sources. Eventually, K- and Q-band multi-epoch observations will be used to estimate positions, flux density and source structure for a large fraction of the current S/X-band ICRF source list. This work will benefit the radio astronomy community by extending the VLBA calibrator list at these bands.

In the longer term, we would also like to extend the ICRF to Ka-band (32 GHz). A celestial reference frame will be needed at this frequency to support deep space navigation. A navigation demonstration is being considered for NASA's Mars '05 mission. The initial K- and Q-band work will serve to identify candidate sources at Ka-band for use with that mission.

1. Introduction

Early in the development of the VLBI technique, it was appreciated that VLBI observations of distant active galactic nuclei (AGNs) had the potential to form a quasi-inertial celestial reference frame with milli-arcsecond (mas) or better accuracy. In the 1990s the IAU working group on reference frames brought together workers from astrometric groups from around the world to produce a standard celestial reference frame that was to become known as the International Celestial Reference Frame (ICRF - [1]). This foundational work was done at S/X-band (2.3/8.4 GHz) with a parallel realization of the frame at optical frequencies based on HIPPARCOS satellite data. It was appreciated by many that extension of the ICRF to additional frequencies would further enhance the value of the work already done.

A number of developments have converged to make the first decade of the new millennium an opportune time to pursue the extension of the ICRF to radio frequencies in the 24–43 GHz range. First, the S-band environment is increasingly cluttered by radio frequency interference making continued observations at S/X ever more difficult. Second, high frequency radio amplifiers are now (K- and Q-band) or will shortly be (Ka-band) available for use by the VLBI technique. Third, radio systems for planetary probes are moving to Ka-band (32 GHz) and are expected to require sub-mas tracking accuracy. This paper will describe a proposal to extend realizations of the ICRF to K-, Ka-, and Q-bands. Section 2 will describe the team that has been assembled to accomplish the task. Section 3 will highlight our motivations for pursuing this task. Section 4 will outline our observing and data analysis plan.

2. The Collaboration

Historically, the creation of accurate global reference frames has been a large undertaking. The effort described in this paper is expected to be no exception. Based on this expectation, a team of scientists from several institutions was organized in the fall of 2001. The current list of institutions and individuals involved in the collaboration are as follows:

- JPL: C.S. Jacobs, D.L. Jones, G.E. Lanyi, S.T. Lowe, C.J. Naudet, J.A. Steppe, L.D. Zhang
- NRAO: J.S. Ulvestad, G.B. Taylor
- RSA: O.J. Sovers
- GSFC: D. Gordon, C. Ma
- USNO: D.A. Boboltz, A.L. Fey
- Bordeaux Observatory: P. Charlot

Much of the initial impetus for this collaboration came from George Resch of JPL. As noted at the meeting, he died unexpectedly in November 2001. This collaboration is part of his legacy.

3. Motivation

What is our motivation for such a large undertaking as building a high accuracy reference frame at a new set of frequencies? At present there are three main motivations: improving the science of astrometry, enabling better VLBA phase referencing at high frequencies, and preparing for deep space navigation at higher frequencies. Let's briefly look at each of these in turn.

3.1. Astrometry

Current astrometric accuracy (*e.g.* [2] and [3]) is limited by instrumental phase stability, troposphere (*e.g.* [4] and [5]), and source structure (*e.g.* [6] & [7]). At this point, it is unknown whether instrumentation will be more or less stable at K-, Ka-, and Q-bands compared to S/X instrumentation. The troposphere is non-dispersive in the microwave region and thus is expected to contribute the same to the delay error budget. The last error type, source structure, is expected to change with frequency because extended emission in AGN is usually steep spectrum. Thus, there should be less of it at higher frequencies. Consequently, in addition to expecting the centroid of emission to be closer to the central engine and thus more positionally stable, the emission should be more localized (*i.e.* point like). This should enable more precise astrometry at frequencies higher than the current S/X-band standard.

3.2. VLBA Phase Referencing

The astrometry and fluxes that come from these observations will be useful in extending the VLBA calibrator list at K- and Q-bands. This would enhance high accuracy phase referencing observations, enabling weaker sources to be observed as well as providing the associated differential astrometry at these bands. This would be of direct scientific benefit and also would enhance the VLBA's infrastructure for the radio astronomy community at large.

3.3. Deep Space Navigation

Interplanetary spacecraft are navigated in the inertial reference frame defined by the ICRF. Increasing radio frequency interference at S-band (2.3 GHz) and the need for higher telemetry rates are both pushing spacecraft radio systems to higher frequencies. The next allocation for deep space communications is at Ka-band (32 GHz). The ability to have an accurate astrometric frame tied to the ICRF at Ka-band would enhance or enable a number of deep space missions by providing improved accuracy for landers, atmospheric entry/aerobraking, allowing tracking closer to the Sun, and greatly reducing the plasma error budget (which was the dominant error for the Mars 2001 Odyssey mission). The Mars 2005 mission is considering a Ka-band navigation demonstration, thus lending an air of urgency to this work. The proposed K- and Q-band work will bracket the Ka-band telemetry band until NASA's Deep Space Network is fully equipped to acquire Ka-band VLBI—currently expected in mid 2003.

4. Experimental Details

As indicated above, we plan to observe a subset of the sources from the S/X-band ICRF during our initial K- and Q-band experiments. Based on past experience, we expect that much of the early effort will be spent on learning to observe in a regime unfamiliar to many of us.

4.1. Observing Sequences

At the time of the second IVS General Meeting, our initial observing proposal had just been accepted by the VLBA. Detailed planning for the initial observing sequence is now underway. The source list for the first round included approximately 40 sources. For the most part, these sources were chosen to have > 0.7 Jy of estimated flux density based on VLA multi-frequency observations. The early efforts will concentrate on stronger sources with some effort to favor sources near the Mars '05 trajectory. Once we gain more experience with observing at higher frequencies, we will venture into the weaker parts of the ICRF source list.

Our plan is to point to a given source, record a few minutes of data at K-band and then record a few minutes of data at Q-band before slewing to the next source. Our goal is to take three to five snapshot observations for each source on our observing list. Based on simulated uv coverage, we expect that the VLBA—even with this small number of snapshots—will provide enough data to make images (see fig. 1). We intend to take data roughly three times per year. This is necessary in order to observe a large fraction of the ICRF source list and also in order to sample the effects of intrinsic source variability and weather induced variability. The constancy of sources is of special concern in applications to spacecraft navigation where there is often only one calibrator source and often no chance to re-observe.

4.2. Data Analysis

After collecting the data, the long process of analysis will begin with the goal of extracting both astrometric positions and images from the data set. To achieve this goal, we plan to draw on the varied talents of our collaborators. In brief outline, the plan is to correlate at NRAO Soccoro's VLBA correlator. The fringe fitting/phase tracking will use the AIPS software. The results will be archived in GSFC Calc/Solve database format for astrometric analysis at GSFC and USNO. Bordeaux Observatory will convert the group delay and delay rate data to JPL/MODEST database format. This will enable analysis using JPL's astrometric analysis software ([3]).

5. Conclusion

While it has long been understood that the value of the ICRF would be enhanced by extending its realization to many observing bands, the time has now come to wholeheartedly pursue such an effort. A collaboration of observers and analysts has been assembled. The motivations for the extension to three specific bands (K, Ka, Q) have been enumerated. An initial observing proposal has been written, submitted and accepted by the VLBA. We anticipate beginning to collect data within the next few months. We hope to realize high accuracy ICRFs at K-, Ka-, and Q-bands well before the end of the decade.

6. Acknowledgements

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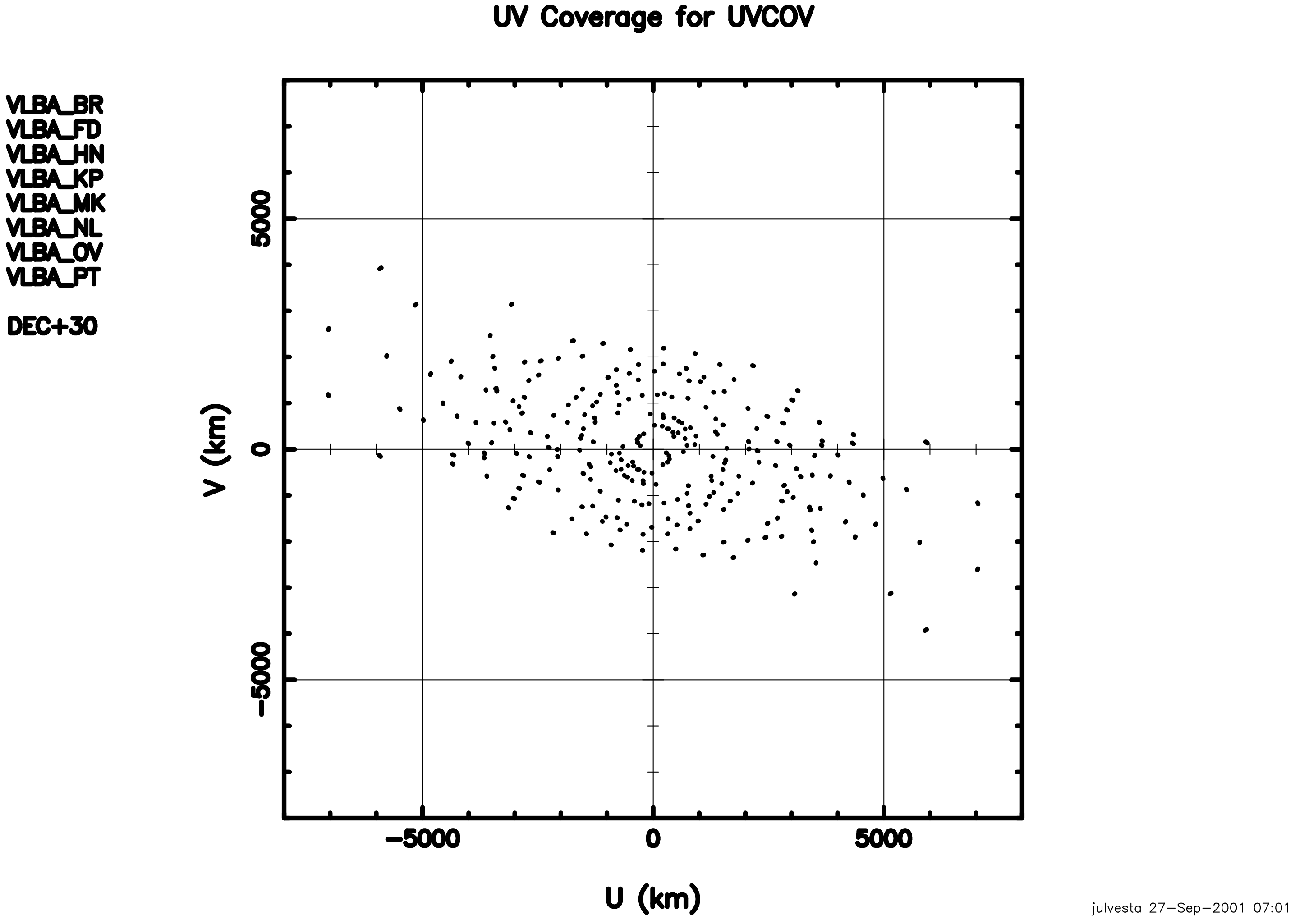

Figure 1. Simulated UV coverage based on five snapshots each 2 minutes in duration and separated by 1.5 hours. Horizontal axis, U, in km, vertical axis, V, in km, source declination 30 degrees. Eight VLBA antennas are included: BR, FD, HN, KP, MK, NL, OV, PT. Two antennas (LA, SC) were excluded to simulate imperfect (*i.e.* realistic) observing conditions. The consequences of the VLBA having a much greater East-West than North-South extent are apparent.