EXTENDING THE K-BAND CELESTIAL FRAME EMPHASIZING SOUTHERN HEMISPHERE

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ABSTRACT. K-band radio observations have the potential to form the basis for the most accurate celestial reference frame (CRF) ever constructed. We present a new collaboration to observe southern hemisphere extra-galactic radio sources at 22 GHz (K-band). The aim of this project is to densify the ICRF at that frequency and to provide calibrators for astronomy. Relative to the standard S/X observing bands, at K-band sources are expected to exhibit more compact source morphology and reduced core shift. This reduction of astrophysical systematics should be advantageous in tying the VLBI radio frame to the Gaia optical frame. Initial fringe demonstrations were carried out on 23 August 2013 between telescopes in Australia, Korea and South Africa. The Korea to South Africa baselines will extend K-band CRF coverage down to about $-45°$ declination. Observations between Australia and South Africa will extend coverage to the south polar cap and thus gain full sky coverage for the K-band CRF. The second phase of our plan includes more extensive astrometric observations to complete sky coverage at K-band as well as observations using a larger network of telescopes in an effort to image source structure.

1. INTRODUCTION

Very long baseline measurements of positions of extragalactic radio sources define and maintain the current International Celestial Reference Frame (ICRF-2, Ma et al., 2009), which forms the underlying basis for positional astronomy. The ICRF-2 is based on dual frequency 2.3 GHz (S-band) and 8.4 GHz (X-band) Very Long Baseline Interferometric (VLBI) observations of 3414 reference sources, including 295 "defining‘ sources which determine the orientation of the frame's axes. Quasars being at great distances do not exhibit any measurable proper motion or parallax, making them ideal reference sources. VLBI observations of weaker sources, VLBI astrometry, spacecraft tracking, navigation and geodetic VLBI all rely on having reference sources which are compact, have strong VLBI detections, and have accurate, stable positions at the sub-milliasrcsecond level.

Unfortunately, at the standard S/X frequencies, many radio sources exhibit spatially extended structure that may vary in both time and frequency. Such structure can introduce significant errors in the VLBI measurements thereby degrading the accuracy of the estimated source positions. Our solution is to observe at higher radio frequencies such as K-band where on VLBI scales (milliarcsecond) sources tend to be more compact (e.g. Bietenholz et al., 2004; Charlot et al., 2010). VLBI observations of extragalactic radio sources have also shown that the location of the peak brightness point often varies with observing frequency due to opacity effects, a phenomenon sometimes called "core-shift". In particular, VLBI images of active galactic nuclei (AGN) show that the observed position of the peak brightness point moves closer to the central black hole as the frequency increases (e.g. Sokolovsky et al., 2011). Thus by observing at frequencies higher than the standard S/X bands we can expect to see more compact structure and also reduce the effect of core shift (Kovalev et al., 2008). This reduction in astrophysical systematics should allow for a more accurate and stable reference frame at higher frequencies and be particularly advantageous in tying the VLBI reference frame to future optical reference frames such as Gaia.

2. HIGH FREQUENCY RADIO FRAMES

At present there are far fewer observations of extra-galactic radio reference sources at high radio frequencies compared to the standard S/X observing bands and many efforts are currently underway to improve the radio frequency coverage. Astrometric VLBI observations at 32 GHz (Ka-band) from NASA's Deep Space Network has already developed a catalogue of ~ 631 observable sources (134 south of $-45°$ declination) with highly accurate positions for improved deep-space navigation (Jacobs, 2013), showing that there are sufficient strong sources at higher frequencies. However, the Ka-band effort involved only a small number of telescopes and no source images were made. Astrometric and imaging observations by Lanyi et al., (2010) and Charlot et al., (2010), provided a foundation for the development of a reference frame at K-band. The current K-band frame consists of only 279 sources with weak coverage in the southern hemisphere, showing a rapid drop in source density at declinations south of $-30°$ (see Figure 1).

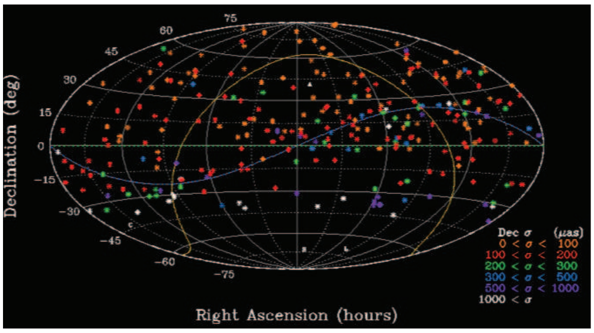

Figure 1: The distribution of celestial reference frame sources at 24 GHz (Lanyi et. al., 2010).

Because many stations across the globe have K-band receivers there is now an opportunity to create a worldwide K-band network with potential for high resolution imaging and astrometry. The advantage of observing at K-band is that radio observatories typically have K-band receivers, while Ka-band receivers are typically only available at tracking stations which are very few in number. The network of telescopes that can observe at K-band is therefore much bigger. For very long baseline observations at K-band, calibrator reference sources are also needed, in particular for trigonometric parallax distances to H_2O (22 GHz) masers as well as phase referenced observations to image the sub-milliarcsecond structure of the most compact regions of emission in AGN. High-resolution K-band observations would be of much value to study wavelength dependent systematic errors due to the core-shift effect.

3. WHY OBSERVE IN THE SOUTHERN HEMISPHERE ?

VLBI observations in the southern celestial hemisphere have always been more difficult both because there are fewer radio telescopes in the south than in the north, and because there are fewer known reference sources in the south. There have been many efforts in recent years to increase the number of known calibrator reference sources in the south, in particular the LBA calibrator survey (LCS), which has already produced a significant improvement at X-band (Petrov et al., 2011). There have also been a few observations at S-band, for example, Hungwe et al. (2011), and southern observations are planned at 1.6 GHz (L-band), to improve the number of calibrator sources for phase-referencing at low frequencies. In 2012 an International Astronomical Union (IAU) working group was formed with the goal of the realisation of the next generation International Celestial Reference Frame (ICRF-3), with specific emphasis on improving the accuracy and coverage in the southern hemisphere. Dedicated astrometric observations to improve the southern celestial reference frame at S/X band are currently underway, as proposed in Lovell et al. (2013). However, at present there are virtually no VLBI observations of reference sources at 22 GHz (K-band). All these low frequency programs thus invite complementary work at K-band.

4. VLBI OBSERVATIONAL PLAN AND NETWORK GEOMETRY

Observations to complete the sky coverage at K-band are under way and preliminary astrometric observations were carried out on 23 August 2013 between telescopes in Australia (Hobart 26m), Korea (Tamna 21m) and South Africa (HartRAO 26m). The Korea to South Africa baselines will extend K-band CRF coverage down to about $-45°$ declination, and observations between Australia and South Africa will extend coverage to the south polar cap and thus gain full sky coverage for the K-band celestial reference frame. Observations between Tamna and HartRAO are limited to about $\pm 45°$ declination and less than 4 hours of mutual visibility. More extensive astrometric observations are planned for the 21st of December 2013 that will also include the Tidbinbilla 70m DSN antenna in Australia.

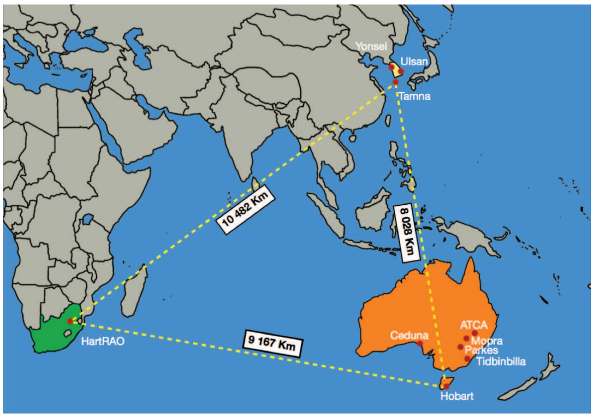

Figure 2: A map showing the proposed telescopes for the southern hemisphere K-band observations.

However, for imaging of source structure, as oppose to astrometry, a larger network of telescopes that provide a variety of baseline lengths and orientations is needed. For this purpose we have also submitted a proposal to observe and image a set of potential K-band reference sources at declinations below $-30°$. We will use the full Australian Large Baseline Array (AT-LBA), that will additionally also include the ATCA (6 x 22m), Ceduna (30m), Mopra (22m) and Parkes (64m) telescopes in Australia (see Figure 2). It should be noted, however, that although the AT-LBA provide a large network of antennas, we are still missing intermediate baseline lengths of a few 1000 km.

5. PRELIMINARY OBSERVATIONS AND RESULTS

In this study we tested the capability of the antennas to generate fringes, given the chosen setup. The observation ran for 4 hours on August 23rd, 2013, and about 20 sources from the LCS catalogue were observed. The frequency range that we selected serves to optimise the delay resolution function given all the constraints. Table 1 shows the selected frequencies for our observations and Figure 2 shows the obtained multi-band delay (MBD) resolution function.

BBC 1	BBC 2	BBC 3	BBC 4	BBC 5	BBC 6	BBC 7	BBC 8
22120.49	22152.49	22184.49	22232.49	22360.49	22424.49	22456.49	22488.49

Table 1: Centre sky frequency in MHz (channels are $\pm$ 16 MHz wide).

The standard deviation in the estimate of the MBD function derived from bandwidth synthesis is given by

$$\sigma_\tau = \frac{1}{2\pi \cdot SNR \cdot \Delta\nu_{rms}} \qquad (1)$$

where the $\Delta\nu_{rms} = \sqrt{\frac{\sum(\nu_{BBC}-\bar{\nu})^2}{N-1}}$ with ν_{BBC} equal to the frequency of the baseband converter (BBC) channels, $\bar{\nu} = \frac{\sum \nu_{BBC}}{N}$ is the mean frequency and N is the number of BBCs (Clark et al., 1985). From Equation 1, the integration time and bandwidth are the only parameters that can be adjusted to improve the precision of the group delay measurements. However, the integration time should be kept short to permit collecting observations at as many different geometries as possible for a good estimate of the atmospheric delay at the radio telescopes. Short integrations are also desirable because at higher radio frequencies the coherence time is short (often only $1 - 2$ minutes). As example, if we consider a source giving an SNR of 70, the uncertainty on the source position is about 0.1 mas, a typical value for astrometric VLBI. For historical reasons, astrometric data are taken using only the right circular polarisation (RCP) channel of the receiver. For consistency we also adopted this convention.

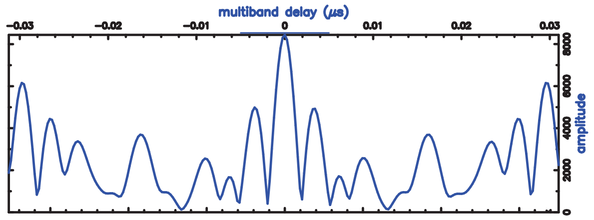

Figure 3: Measured delay resolution function using frequencies from Table 1.

We found fringes although the weather has been bad at all the sites. Figure 3 shows, as an example, the detection of ICRF J1427-4206 between HartRAO and Hobart (SNR = 70). Given the positive results of the test, we will proceed with a 24 hour observation, planned for the 21st of December 2013 .

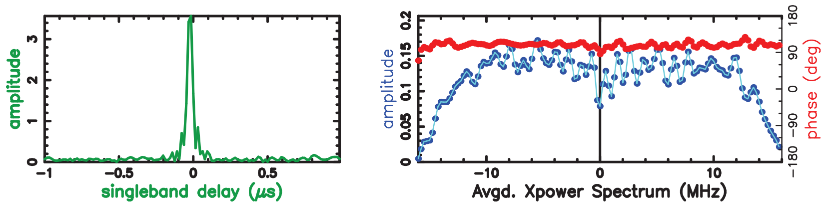

Figure 4: HOPS fourfit plot, showing the single-band delay (left) and the averaged power spectrum between HartRAO and Hobart26 for ICRF J1427-4206.

6. REFERENCES

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