Improving the X/S Reference Frame With the VLBA

David Gordon[1], Alan Fey[2] and Chris Jacobs[3]

[1]NVI Inc, NASA Goddard Space Flight Center; [2]US Naval Observatory; [3]Jet Propulsion Laboratory, California Institute of Technology/NASA

Executive Summary: The Very Long Baseline Array has been used to improve 2/3 of the sources in the IAU standard celestial reference frame by about a factor of seven.

Abstract: VLBA observations have enabled us to greatly improve the precision of ICRF3, which will be presented for consideration at the 2018 IAU meeting. Of the 3414 sources in the Second Realization of the International Celestial Reference Frame (ICRF2), approximately 2/3 were single epoch VLBA Calibrator Survey (VCS) sources that had average position uncertainties nearly 5 times worse than the other 1/3. Several VLBA observing campaigns since 2014 have been undertaken to re-observe these for ICRF3. Some 32 X/S 24-hr 2-Gb/sec VLBA astrometry sessions have now been run and analyzed. For the sources in the original ICRF2 VCS class, their formal position errors have been reduced by an average factor of ~7. These VLBA observations have also included many other sources resulting in the addition of 438 new sources to the X/S reference frame for ICRF3.

ICRF2: ICRF2 contained precise positions for 3414 compact extragalactic radio sources, as determined by VLBI. However, approximately 2/3 of those sources were from the six VLBA Calibrator Survey (VCS) sessions (Beasley et al. 2002; Fomalont et al. 2003; Petrov et al. 2005, 2006, 2008; Kovalev et al. 2007) and had been observed in only single 24-hr VLBI sessions and had average formal errors approximately five times larger than the other 1/3. Several hundred of these had also been observed in fewer than 10 individual baseline delay measurements (observations). ICRF2 was approved by the IAU in 2009. Work began shortly afterward to re-observe the sources with fewer than 10 observations in the RDV sessions, which were geodetic sessions using the VLBA and several geodetic VLBI stations 6 times per year. These were successful, but they could not address the much larger formal errors of the ~2200 VCS sources.

IAU Working Group for the Third Realization of the International Celestial Reference Frame: The ICRF3 WG was formed in 2012. A major goal was to generate a more precise VLBI reference frame for the alignment of the radio reference frame with the future Gaia optical reference frame. Thus improving the precision of the ~2200 VCS sources in ICRF2 became a major goal.

Second Epoch VLBA Calibrator Survey: VLBA time was requested from NRAO in 2013 for 8 24-hr sessions to re-observe the ICRF2 VCS sources plus a few hundred other observed but not detected sources. This proposal was approved and the observations were made in 2014-2015. X/S dual band observations were made at a recording rate of 2-Gbits/second, or 16 times the bit rate of the VCS1-6 sessions. Some 2062 single epoch VCS sources were re-observed with a resulting improvement in their positional precision by a factor of nearly 5. Also, 324 new sources were detected and added to the VLBI reference frame. Results of these VCS-II observations are published in Gordon et al (2016). The locations of the 10 VLBA antennas are shown in Figure 1.

USNO Reference Frame Sessions: In late 2016, the US Naval Observatory was granted approximately half of the available VLBA time to do reference frame observations through an agreement with the National Science Foundation and the newly formed Long Baseline Observatory. Under the auspices of the USNO time allocation, we requested and received approval for 20 X/S reference frame sessions in 2017, similar to the VCS-II sessions. Some 3300 sources were targeted, some being new sources, but most having been observed previously in 2 or 3 sessions. As a result, the formal uncertainties for the re-observed sources were approximately cut in half. For 2018, we were granted 24 24-hr VLBA sessions. The first four of these have been analyzed and are used in ICRF3.

Results: These 32 2-Gbit/sec VLBA sessions were included in the ICRF3 X/S solution, which is being presented in an IAU resolution at this meeting. A total of **3020 sources were re-observed** in these 32 sessions. The distribution of these sources is shown below in Figure 2, which shows the VLBA's declination cutoff of ~-45°. These 32 VLBA sessions have resulted in a reduction of the average scaled RA/Dec formal errors for these sources from 1.28/2.13 milli-arc-sec to 0.18/0.33 milli-arc-sec, **for an approximately 7-fold improvement**. Figure 3 shows graphically the improvement in the formal errors for these sources as a function of declination.

Also, **428 new sources were observed** in these sessions and added to the X/S VLBI reference frame. Their distribution is shown in Figure 4. Most of these were first observed in the VCS-II sessions, and many were subsequently re-observed in the USNO sessions. The ICRF3 X/S catalog contains 4536 sources, or 1122 more than ICRF2. Many of the other new sources were added in the RDV VLBA sessions since 2009, while a few hundred were added in southern hemisphere sessions.

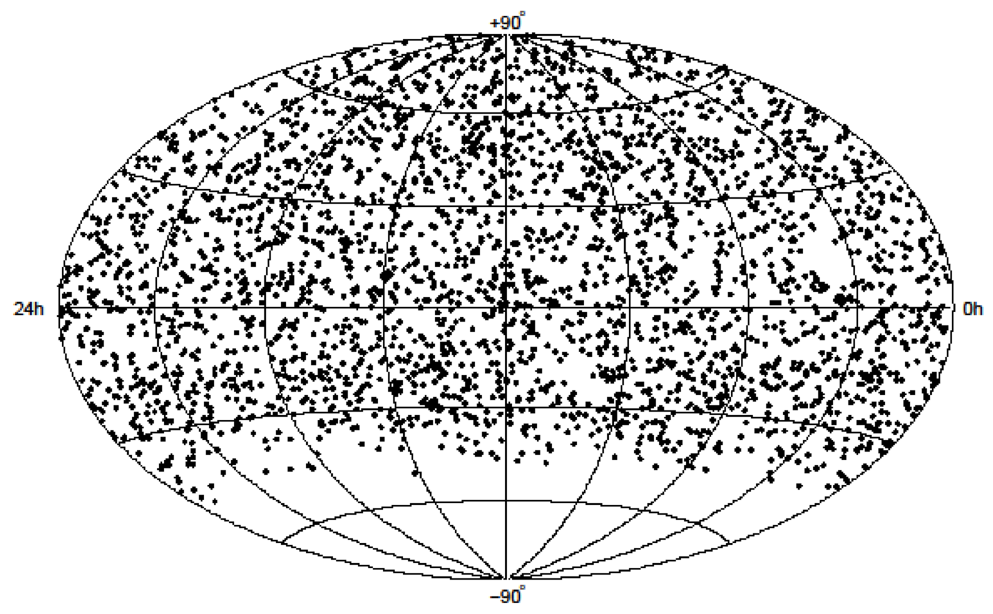

Figure 2. Distribution of the 3020 sources re-observed in 32 X/S VLBA 2-Gb/sec sessions.

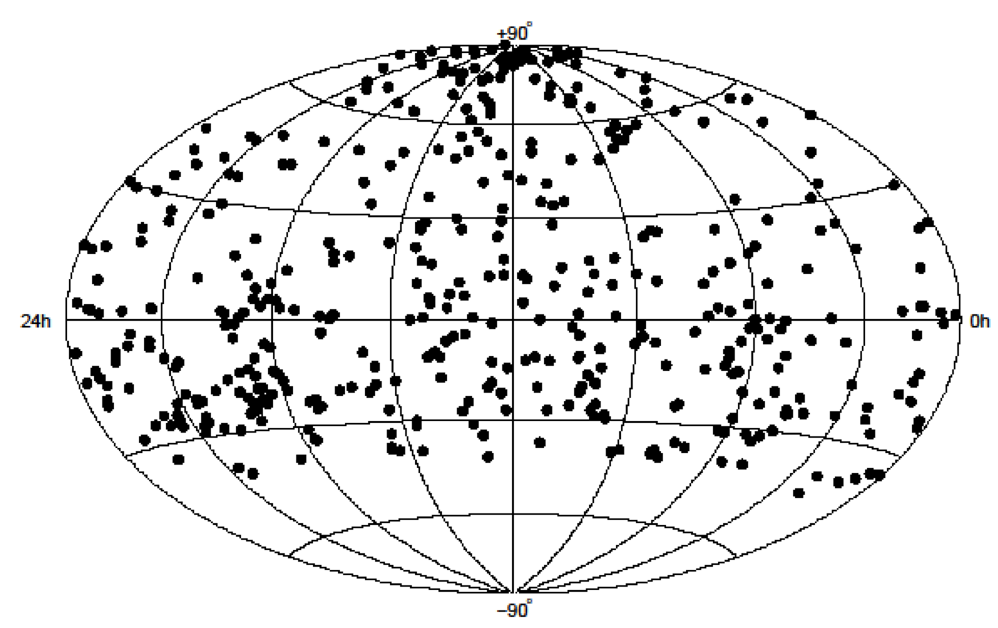

Figure 4. Distribution of the 438 new sources added to ICRF3 in 32 X/S VLBA 2-Gb/sec sessions.

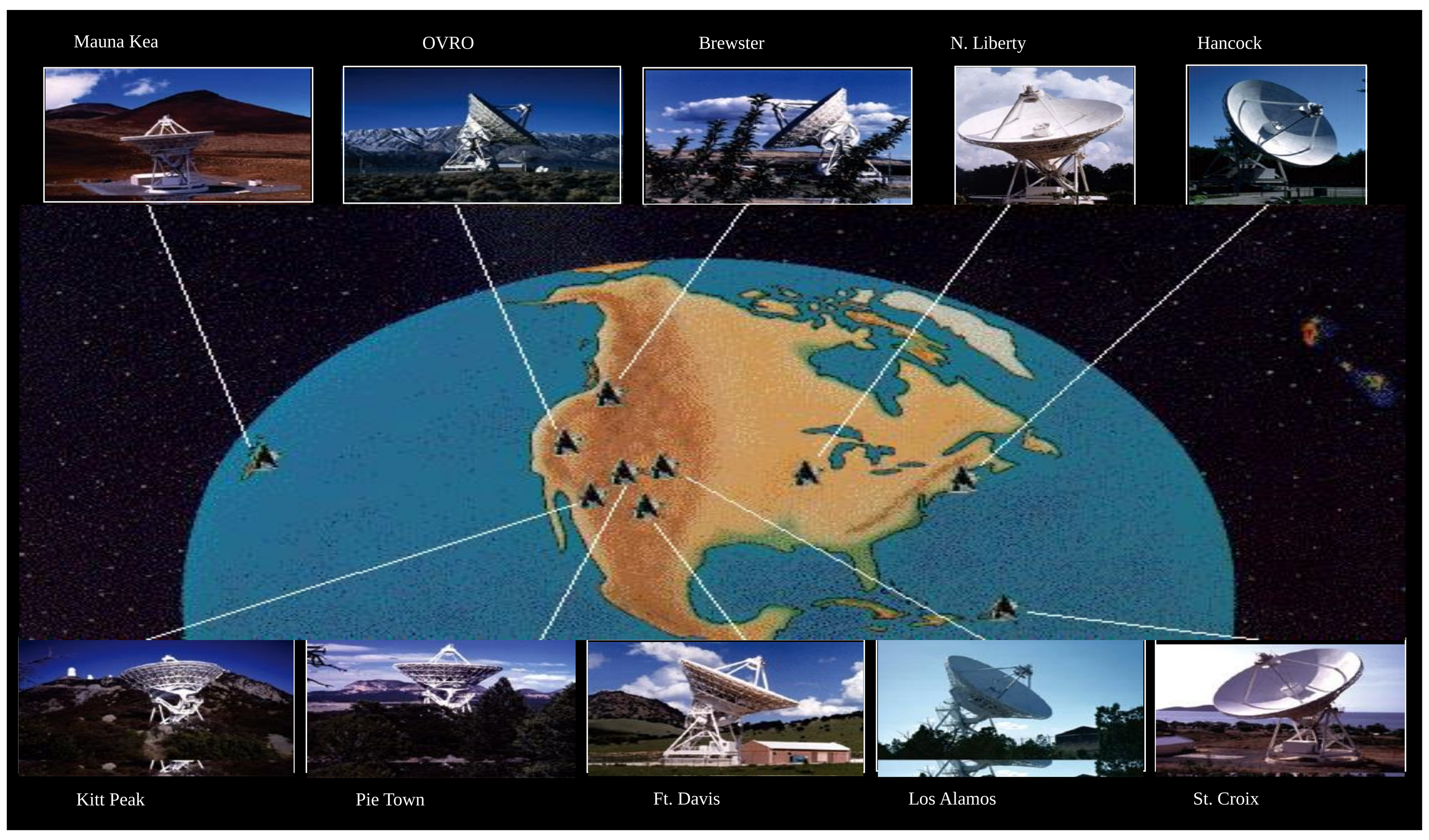

Figure 1. The Very Long Baseline Array (VLBA) of 10 VLBI antennas. Graphic credit: NRAO/AUI.

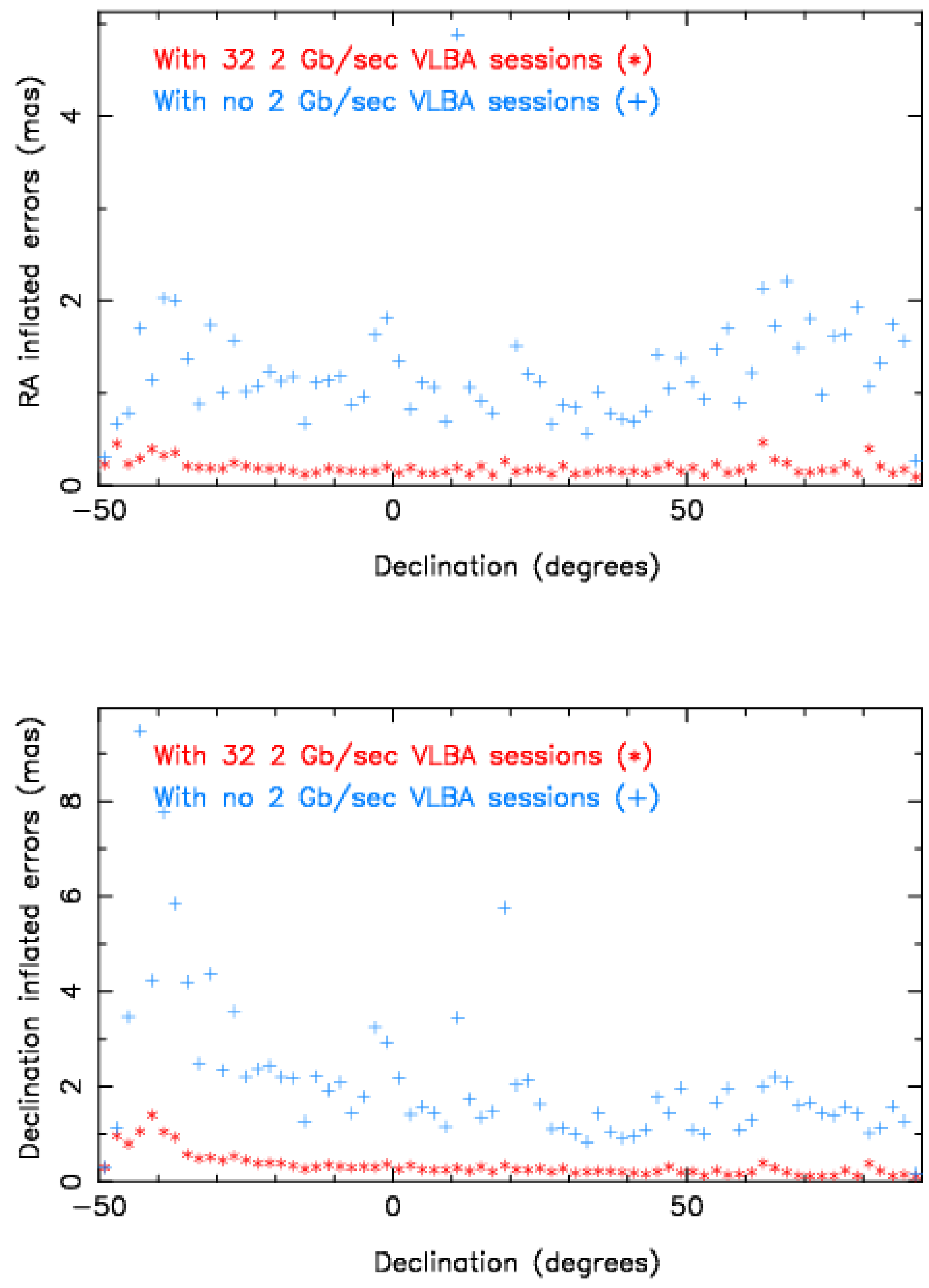

Figure 3.: The improvement in scaled formal errors for 3020 X/S sources re-observed in 32 2-Gb/sec VLBA sessions in 2014-2018. Average values in 2 degree declination bins are shown. **Source precision has been improved by an average factor of ~7.**

Future Work/Goals: The current USNO sessions will continue through December 2018. A follow-up series of X/S VLBA sessions will be requested for 2019. Our goals are to continue to improve and expand the X/S reference frame through VLBA sessions and to work with our southern hemisphere colleagues to improve and expand the X/S reference frame in the south. This will have benefits for VLBI phase referencing, spacecraft navigation, alignment of the radio and Gaia optical reference frames, and for a future ICRF4.

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Email: David.Gordon-1@nasa.gov, Alan.Fey@navy.mil, Christopher.S.Jacobs@jpl.nasa.gov.