JPL VLBI Analysis Center IVS Annual Report for 2003

Chris Jacobs

Abstract

This report describes the activities of the JPL VLBI Analysis Center for the year 2003. We continue to do celestial reference frame, terrestrial reference frame, and spacecraft navigation work using the VLBI technique. Tracking the two Mars Exploration Rover spacecraft was the highlight for the year. We continued improvements in the first sub-milliarcsecond global celestial reference frames at K-band (24 GHz) and Q-band (43 GHz). The K-band catalog more than doubled in size from 108 to 230 sources.

1. General Information

The Jet Propulsion Laboratory (JPL) analysis center is located in Pasadena, California. Like the rest of JPL, it is operated by the California Institute of Technology under contract to NASA. JPL has had a VLBI analysis group since about 1970. Our work is focussed on supporting spacecraft navigation. This includes several components:

1. Radio Reference Frame (RRF) and Terrestrial Reference Frame (TRF) are efforts which provide infrastructure to support spacecraft navigation and Earth orientation measurements.
2. Time and Earth Motion Precision Observations (TEMPO) measures Earth orientation parameters based on single baseline semi-monthly measurements. These VLBI measurements are then combined with daily GPS measurements as well as other sources of Earth orientation information. The combined product is used to provide Earth orientation for spacecraft navigation use.
3. Delta differenced One-Way Range (ΔDOR) is a differential VLBI technique which measures the angle between a spacecraft and an angularly nearby extragalactic radio source. This technique thus complements the radial information from spacecraft doppler and range measurements by providing plane-of-sky information for the spacecraft trajectory.

2. Technical Capabilities

The JPL Analysis Center acquires its own data and supplements it with data from other centers. The data we acquire is taken using NASA's Deep Space Network (DSN).

1. Antennas: Most of our work uses 34m antennas located near Goldstone California, Madrid Spain, and Tidbinbilla Australia. These include the following Deep Space Stations (DSS): the 'High Efficiency' subnet comprised of DSS 15, DSS 45, and DSS 65 (see fig. 1) which has been the most often used set of antennas for VLBI. More recently, we have been using the DSN's beam waveguide antennas: DSS 13, DSS 24, DSS 25, DSS 26, DSS 34, DSS 54 and DSS 55. DSS 26 and DSS 55 were used for VLBI for the first time in 2003. Less frequent use is made of the DSN's 70m network (DSS 14, DSS 43, DSS 63). Typical system temperatures are 35K. Antenna efficiencies are typically well above 50% at X-band.

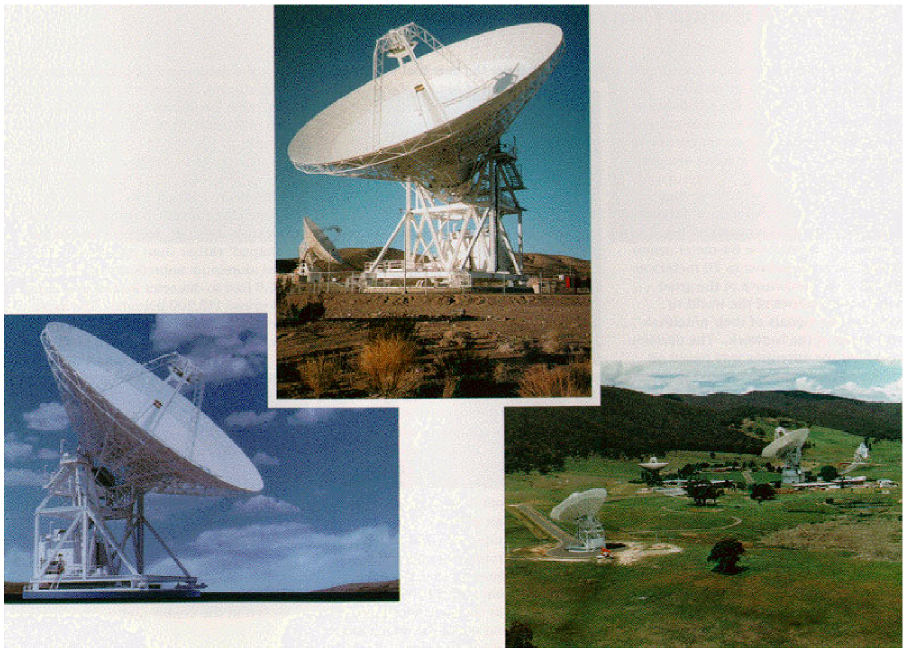

Figure 1. This figure shows the three high-efficiency antennas in the subnet: Goldstone is in the center; Robledo, Spain is in the lower left; Tidbinbilla, Australia is on the lower right. These antennas were designed to have an optimum efficiency at X-band (8.4 GHz), which was to become the standard downlink frequency for solar-system exploration. An important secondary objective was to have a reasonable efficiency at Ka-band (32 GHz) thereby allowing for possible future use at the next highest band allocated for deep space communications. The subnet was completed in 1986 in time for the Voyager encounter with Uranus.

2. Data acquisition: The DSN sites have standard MkIV VLBI data acquisition systems. In addition we have a JPL-unique system called the VLBI Science Recorder (VSR) which has digital "video converters" and records directly to hard disk. The data is later transferred via network to JPL for correlation processing. We have purchased Mark 5 recorders and expect to install them within the coming year.

3. Correlators: The JPL Block II VLBI correlator handles the TEMPO and RRF correlations of Mark IIIA format tapes. The ΔDOR data from the VSR systems are correlated using the SOFTC software correlator running on UNIX or VMS workstations.

4. Solution types: We run several different types of solutions. For ΔDOR spacecraft tracking we make narrow field ($\approx 10°$) differential solutions. The TEMPO solutions typically have a highly constrained terrestrial (TRF) and celestial frame (CRF) as a foundation for estimating Earth orientation parameters. The RRF solves for a full TRF and CRF which is later used by TEMPO and ΔDOR. Experimental CRF work this year has focussed on modelling source structure.

3. Staff

Our staff are listed below with a brief indication of areas of concentration within the VLBI effort at JPL. Note that not all of the staff listed work on VLBI exclusively as our group is involved in a number of projects in addition to our VLBI work.

- Jim Border: ΔDOR
- Sid Dains: Field support of VLBI experiments at Goldstone.
- Chris Jacobs: RRF and TRF
- Peter Kroger: ΔDOR
- Gabor Lanyi: ΔDOR, WVR, RRF, and TRF
- Steve Lowe: Software correlator, fringe fitting software
- Walid Majid: ΔDOR
- Sumita Nandi: ΔDOR
- Chuck Naudet: WVR, Mark IV support, and RRF
- Jean Patterson: ΔDOR
- Ojars Sovers: RRF and TRF. Maintains MODEST analysis code.
- Alan Steppe: TEMPO and TRF.
- L.D. Zhang: RRF

4. Current Status and Activities

This year's highlight was the support of navigation for the two Mars Exploration Rovers. The Mars atmosphere entry point was hit to within a few hundred meters. In preparation for the 2005 Mars mission, JPL is leading a collaboration with Goddard Space Flight center, the U.S. Naval Observatory, National Radio Astronomical Observatory, and the Bordeaux Observatory to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) (*e.g.* Jacobs *et al*, 2004). Figure 2 shows the current K-band CRF which has more than tripled from 65 to 230 sources since last year's report.

A-WVR: The advanced Water Vapor Radiometer (A-WVR) developed for the Cassini gravitational wave experiment, continues to be used in research applications. This device can calibrate water vapor induced delays with fractional stability of roughly a few parts in 10^{15} over time scales of 2,000 to 10,000 seconds.

5. Future Plans

We are also in the planning stage for developing a Ka-band (32 GHz) realization of the ICRF. All this work is motivated by the anticipation that spacecraft navigation will require a 32 GHz reference frame within a few years.

Mark 5 recorders: In 2003 we acquired Mark 5 hard disk recording systems which we hope to integrate into the Deep Space Network over the next year as we continue to move away from tape based recording.

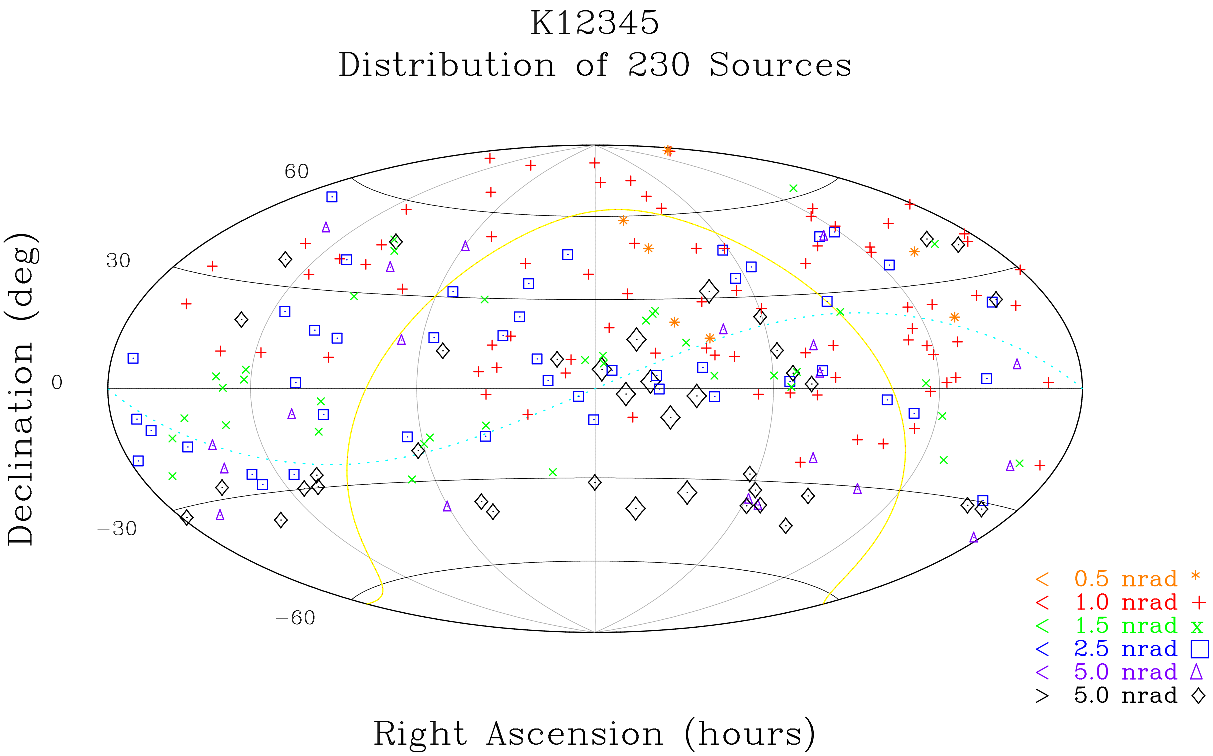

Figure 2. Celestial Reference Frame at K-band (24 GHz). There are 230 sources spread over the sky north of −30 deg declination. The label K12345 indicates that the frame is based on data from the 5 sessions of an ongoing program of observations. The shading and symbols in the legend indicate the formal declination precision. Note the highest precision is toward the north with precision lessening towards the south by as much as a factor of ≈two. This is a result of using the VLBA which is a northern array. The dotted line indicates the ecliptic plane. The central solid curved line indicates the galactic plane.

6. Acknowledgements

The research described in this paper was in part performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

[1] C. S. Jacobs, P. Charlot, D. Gordon, G. E. Lanyi, C. Ma, C. J. Naudet, O. J. Sovers, L. D. Zhang, and the KQ VLBI Survey Collaboration, 'Extending the ICRF to Higher Radio Frequencies: 24 & 43 GHz,' Proceedings of IAU GA XXV Joint Discussion 16, R. Gaume & J. Souchay eds., U.S. Naval Observatory, Washington D.C., 2004.