JPL VLBI Analysis Center Report for 2012

Chris Jacobs

Abstract

This report describes the activities of the JPL VLBI Analysis Center for the year 2012. The highlight of the year was the successful MSL rover Mars landing, which was supported by VLBI-based navigation using our combined spacecraft, celestial reference frame, terrestrial reference frame, earth orientation, and planetary ephemeris VLBI systems. We also supported several other missions with VLBI navigation measurements. A combined NASA-ESA network was demonstrated with first Ka-band fringes to ESA's Malargüe, Argentina 35 m. We achieved first fringes with our new digital back end and Mark 5C recorders.

1. General Information

The Jet Propulsion Laboratory (JPL) Analysis Center is in Pasadena, California. Like the rest of JPL, the center is operated by the California Institute of Technology under contract to NASA. JPL has done VLBI analysis since about 1970. We focus on spacecraft navigation, including:

1. Celestial Reference Frame (CRF) 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 provides Earth orientation for spacecraft navigation.
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 are taken using NASA's Deep Space Network (DSN).

1. Antennas: Most of our work uses 34-m antennas located near Goldstone (California, USA), 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 which has been the most often used set of JPL antennas for VLBI. More recently, we have been using the DSN's beam waveguide (BWG) antennas: DSS 13, DSS 24, DSS 25, DSS 26, DSS 34, DSS 54, and DSS 55. Less frequent use is made of the DSN's 70-m network (DSS 14, DSS 43, and DSS 63). Typical X-band system temperatures are 35K on the HEF antennas. The

70-m and BWG temperatures are about 20K. Antenna efficiencies are typically well above 50% at X-band.

2. Data acquisition: We use the Mark IV DAT and Mark 5A VLBI recorders. In addition, we have JPL-unique systems called the VLBI Science Recorder (VSR) and the Wideband VSRs (WVSR) which have digital baseband converters and record directly to hard disk. The data are later transferred via network to JPL for processing with our software correlator. ROACH-based Digital Back Ends and Mark 5C recorders are now being tested for deployment in 2013.

3. Correlators: JPL VLBI Correlator has been exclusively based on the SOFTC software which handles the ΔDOR, TEMPO, and CRF correlations as well as tests of antenna arraying.

4. Solution types: We run several different types of solutions. For ΔDOR spacecraft tracking we make narrow field ($\approx 10^\circ$) differential solutions. The TEMPO solutions typically have a highly constrained terrestrial (TRF) and celestial frame (CRF) as a foundation for estimating Earth orientation parameters. These reference frames are produced from global solutions which then provide the framework needed for use by TEMPO and ΔDOR.

3. Staff

Our staff are listed below along with areas of concentration. 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 VLBI.

- Durgadas Bagri: TEMPO and Ka-band phase calibrators.
- James Border: ΔDOR spacecraft tracking.
- Cristina García-Miró: Madrid data acquisition, NASA-ESA southern declination collaboration, educational outreach.
- Shinji Horiuchi: Canberra data acquisition, NASA-ESA southern declination collaboration.
- Chris Jacobs: NASA-ESA southern declination collaboration, X/Ka CRF, TRF, S/X CRF.
- Christina King: source stability studies.
- Peter Kroger: ΔDOR spacecraft tracking.
- Gabor Lanyi: MODEST, fringe fitting and correlation support, ΔDOR, and TRF.
- Steve Lowe: Software correlator, fringe fitting software, ΔDOR.
- Walid Majid: pulsars, ΔDOR, VLBA phase referencing.
- Chuck Naudet: NASA-ESA southern declination collaboration, source stability studies.
- Andres Romero-Wolf: ΔDOR, CRF and TRF, MODEST scripts, source stability studies.
- Lawrence Snedeker: Goldstone data acquisition, NASA-ESA southern declination collaboration.
- Ioana Sotuela: Madrid antenna calibration, NASA-ESA southern declination collaboration.
- Ojars Sovers: S/X and X/Ka CRFs and TRF. Maintains MODEST analysis code.
- Alan Steppe: TEMPO and TRF.

4. Current Status and Activities

TEMPO EOP and S/X CRF work continues. X/Ka-band (8.4/32 GHz) CRF took a major step forward with the integration of ESA's Malargüe, Argentina antenna into our network thus adding much needed southern coverage.

VLBI spacecraft tracking continues to provide measurements of angular position in support of mission navigation and planetary ephemeris development. The New Horizons trajectory toward Pluto was verified in May-June. MSL was targeted to a near perfect aim point at the top of the Martian atmosphere in August. The Juno Deep Space Maneuver in August-September was supported to target the Earth flyby in October 2013. Dawn is being supported during its low thrust cruise from Vesta to Ceres. Monthly measurements of MRO and Mars Odyssey continue to improve the ephemeris of Mars.

5. Future Plans

In 2013, we hope to improve our VLBI system by increasing data rates to 2048 Mbps. Operational Ka-band phase calibrators have been built and are planned for deployment in 2013. Work on the Digital Back End (DBE) continues. Our next generation fringe fitting program is also expected to come online. We expect the combined NASA-ESA deep space network to start producing Ka-band CRF results. On the spacecraft front, we plan to continue supporting a number of operational missions while further improving techniques for using VLBI for spacecraft tracking.

Acknowledgements

Research described herein done in part under contract with NASA. Government sponsorship acknowledged.

References

[1] C.S. Jacobs, A. Romero-Wolf, C. García-Miró, S. Horiuchi, W.A. Majid, L.G. Snedeker, I. Sotuela, 'Dual Frequency VLBI Monitoring of Large Sample of Compact Extragalactic Sources at 8 & 32 GHz,' 219th AAS, 435.09, BAAS, 44, 2, Austin TX, 12 Jan 2012.

[2] C.S. Jacobs, et al, 'The Potential for a Ka-band (32 GHz) Worldwide VLBI Network,' IVS 2010 Workshop on Technical Specifications, Wettzell, Germany, 1-2 March 2012. http:/www.fs.wettzell.de

[3] C. García-Miró, S. Rogstad, R. Navarro, J.E. Clark, C.J. Naudet, C.S. Jacobs, C.E. Goodhart, L.A. White, J. Trinh, M. Soriano, D. Wang, E. Sigman, J. Luvalle, I. Sotuela, P. Pope, S. Horiuchi, J. Lobo, 'VLBI Data Acquisition Terminal modernization at the Deep Space Network,' IVS General Meeting, Madrid, 4-9 March 2012. http://www.oan.es/gm2012/pdf/oral_id_36.pdf

[4] A. Romero-Wolf, C.S. Jacobs, 'The Effect of Correlated Noise on the Analysis of Space Geodetic Data,' IVS General Meeting, Madrid, 2012. http://www.oan.es/gm2012/pdf/oral_id_119.pdf

[5] C.S. Jacobs, J.E. Clark, C. García-Miró, S. Horiuchi, A. Romero-Wolf, L. Snedeker, I. Sotuela, 'Celestial Reference Frame at X/Ka-band (8.4/32 GHz),' IVS General Meeting, Madrid, 4-9 March 2012. http://www.oan.es/gm2012/pdf/oral_id_89.pdf

[6] C.S. Jacobs, et al., 'The Potential for a Ka-band (32 GHz) Worldwide VLBI Network,' IVS General Meeting, Madrid, 4-9 March 2012. http://www.oan.es/gm2012/pdf/poster_id_91.pdf

[7] W.A. Majid, C. García-Miró, S. Horiuchi, C.S. Jacobs, A. Romero-Wolf, L. Snedeker, I. Sotuela, 'Dual Frequency VLBI Flux Monitoring of a Large Sample of Compact Extragalactic Sources at 8 and 32 GHz,' IVS General Meeting, Madrid, 4-9 March 2012. http://www.oan.es/gm2012/pdf/oral_id_60.pdf

[8] S. Horiuchi, C. Phillips, I. Sotuela, C.S. Jacobs, C. García-Miró, '32 GHz Celestial Reference Frame Survey for Dec $< -45°$,' IVS General Meeting, Madrid, 4-9 March 2012. http://www.oan.es/gm2012/pdf/oral_id_85.pdf

[9] A. Romero-Wolf, O. Lutz, C.S. Jacobs, 'Capturando Susurros del Universo con la Red de Espacio Lejano,' (Capturing Whispers from Space: The Deep Space Network),' MDSCC Visiting Scientist Seminar, Robledo de Chavela, Spain, 8 March 2012. http://www.mdscc.org/web/index.php/noticias

[10] C.S. Jacobs,'A Boy becomes a Scientist,' Educational outreach, Robledo de Chavela, Spain, Mar 2012.

[11] M.J. Molina, C. García-Miró, C.S. Jacobs, 'Una cita con... radioastrónomos,' Madrid DSN (MDSCC Newsletter), 1 Apr 2012.

[12] C.S. Jacobs, 'Celestial Reference Frames for Deep Space Navigation,' Sec 343 Seminar: Numerical Algorithms for Space Flight 31 May and 4 June 2012, JPL, Pasadena, CA. http://nasf.jpl.nasa.gov/data/talk053112/053112.pdf

[13] S. Horiuchi, C. Phillips, C. Jacobs, I. Sotuela, C. García-Miró, 'Towards an All-Sky 32 GHz Celestial Reference Frame,' Astronomical Society of Australia, U. New S. Wales, Sydney, Australia, July 2012. http://www.asa2012.phys.unsw.edu.au/pdfs/POSTERS-1.pdf

[14] C.S. Jacobs, 'Celestial Reference Frame Realizations at Multiple Radio Frequency Bands,' IAU General Assembly, Joint Discussion 7, Beijing, China, 28 August 2012. http://referencesystems.info/uploads/3/0/3/0/3030024/4-02.pdf

[15] C.S. Jacobs, J. Alonso, J.E. Clark, L. Gamborino, C. García-Miró, S. Horiuchi, J. Lobo, R. Maddè, M. Mercolino, C.J. Naudet, L. Snedeker, I. Sotuela, L. White 'The Celestial Reference Frame at X/Ka-band: Status & Prospects for Improving the South,' 11th European VLBI Network Symposium, Bordeaux, France, 10 Oct 2012. http://evn2012.obs.u-bordeaux1.fr/documents/presentations/121_Jacobs_EVN2012_Oral.pdf

[16] C.S. Jacobs, C. García-Miró, E. Hoar, 'El "GPS" Estelar: Navegando por el Sistema Solar,' (Stellar-GPS: Navigating in the Solar System),' MDSCC Visiting Scientist Seminar, Centro de Entrenamiento y Visitantes INTA-NASA, Robledo de Chavela, Spain, 17 Oct 2012. http://www.mdscc.org/index.php?Section=Noticias&Id=74
Conferencia, Planetario de Madrid, Madrid, Spain, 18 Oct 2012. http://www.planetmad.es/PDFs/CONFERENCIA%20CHRIS%20JACOBS(2).pdf

[17] C.S. Jacobs, W.A. Majid, A. Romero-Wolf, C. García-Miró, S. Horiuchi, L.G. Snedeker, I. Sotuela, 'Frequent VLBI Monitoring on Parsec-Scales of 450+ Extragalactic FERMI Sources at 8 and 32 GHz,' 4th FERMI Symposium, Monterey CA, 29 Oct 2012. http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2012/

[18] C.S. Jacobs, J.E. Clark, C. García-Miró, S. Horiuchi, A. Romero-Wolf, L.G. Snedeker, I. Sotuela 'A Celestial Reference Frame at X/Ka-band (8.4/32 GHz) for Deep Space Navigation,' 23rd International Symposium on Space Flight Dynamics, Pasadena CA, 30 Oct 2012. https://issfd.jpl.nasa.gov/home/assets/papers/ISSFD23_IMD1_1.pdf

[19] S. Horiuchi, C.S. Jacobs. C. Phillips, I. Sotuela, C. García-Miró, 'VLBI monitoring of SgrA* at 32 GHz,' ALMA-JAXA Workshop, Japan, Nov 2012.