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Near-field VLBI for space and planetary science

Tatiana M. Bocanegra-Bahamon*(1,2), Giuseppe Cimo (3,4), Dominic Dirkx(5), Dmitry A. Duev(2), Leonid I. Gurvits(3,5), Guifre Molera Calves(6) and Sergei Pogrebenko(3).
(1) Jet Propulsion Laboratory, USA., e-mail: tbahamon@jpl.nasa.gov.
(2) California Institute of Technology, USA.
(3) Joint Institute for VLBI ERIC, the Netherlands.
(4) Netherlands Institute for Radio Astronomy, the Netherlands.
(5) Delft University of Technology, the Netherlands.
(6) University of Tasmania, Australia.

The VLBI technique was conceived in the 1960s as a result of an urge to have higher angular resolutions in astronomy when observing natural celestial radio sources. The idea behind the VLBI technique is that by differencing the radio signal received simultaneously at every two (largely separated) ground stations on Earth a very precise measure of the angular position of the radio source can be derived. This is due to the fact that the positions of the receiving stations on the rotating Earth are different and change in time as the spacecraft signal is received. Therefore, from the difference in arrival time due to the geometry of the tracking array, also known as *geometric delay*, the angular position of the source can be derived. This capability was, from the very onset of the technique, recognized for its potential for tracking and positioning of spacecraft in the solar system [*e.g.*,1,2,3]. The main difference in the methodology between 'traditional' VLBI, where the target is a natural radio source, and spacecraft VLBI, is that for the former case, the source of emission can be assumed to be at an infinite distance from the observer (*i.e.*, in the far-field). Therefore, the light paths from the source to the elements of the interferometer can be assumed parallel and the incoming wave front planar. Following the Fraunhofer criterion, a radio source within the solar system transmitting at the typical deep space communication frequencies (S, X or Ka band) is located within the near-field, and thus, the incoming wave front should be considered to be curved. This variation of the technique is commonly referred to as *near-field VLBI*.

In this presentation we will discuss the methodology of near-field VLBI, and the difference between near-field VLBI methods that measure the differential group delay (such as Delta Differential One-way Ranging (ΔDOR)) and the phase delay (via phase-referencing). Additionally, we will discuss the applicability of these techniques for space and planetary science. We will focus on the results obtained so far with the Planetary Radio Interferometry and Doppler Experiment (PRIDE) technique [4] for improvement of planetary ephemerides [5,6], interplanetary plasma diagnostics [7,8] and radio occultation measurements [9]. Finally, we will discuss the potential of using the near-field VLBI technique through the European VLBI Network (EVN) and the Very Long Baseline Array (VLBA) for current and future planetary missions.

References

[1] Ondrasik, V.J. and Rourke, K.H., 1971, August. Paper AAS 71-399. In *AAS/AIAA Astrodynamics Specialists Conference, Fort Lauderdale, USA.*
[2] Salzberg, I.M., 1973. Tracking the Apollo lunar rover with interferometry techniques. *Proceedings of the IEEE*, *61*(9), pp.1233-1236.
[3] Counselman et al., 1979. Wind velocities on Venus: Vector determination by radio interferometry. *Science*, *203*(4382), pp.805-806.
[4] Duev, D.A. et al., 2012. Spacecraft VLBI and Doppler tracking: algorithms and implementation. *Astronomy & Astrophysics*, *541*, p.A43.
[5] Dirkx, D. et al., 2016. Dynamical modelling of the Galilean moons for the JUICE mission. *Planetary and Space Science*, *134*, pp.82-95.
[6] Dirkx, D. et al., 2017. On the contribution of PRIDE-JUICE to Jovian system ephemerides. *Planetary and Space Science*, *147*, pp.14-27.
[7] Molera Calvés, G. et al., 2014. Observations and analysis of phase scintillation of spacecraft signal on the interplanetary plasma. *Astronomy & Astrophysics*, *564*, p.A4.
[8] Molera Calvés, G. et al., 2017. Analysis of an interplanetary coronal mass ejection by a spacecraft radio signal: A case study. *Space Weather*, *15*(11), pp.1523-1534.
[9] Bocanegra-Bahamon, T.M. et al., 2019. Venus Express radio occultation observed by PRIDE. *Astronomy & Astrophysics*, *624*, p.A59.