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Spacecraft VLBI and Doppler tracking of Venus Express

G. Molera Calvés (1,2), G. Cimó (1), D.A. Duev (1,3), T. BocanegraBahamón (1,3,4), S.V. Pogrebenko (1) and L.I. Gurvits (1)

1 Joint Institute for VLBI in Europe, 7991PDDwingeloo, The Netherlands, e-mail: molera@jive.nl
2 Aalto University MetsähoviRadio Observatory, Metsähovintie 114, Kylmälä, FIN-02540, Finland
3 Faculty of Physics, Lomonosov Moscow State University, GSP-1, Leninskie gory, 119991 Moscow, Russia
4 Department of Astrodynamics and Space Missions, Delft University of Technology, 2629 HS Delft, The Netherlands
5 Shanghai Astronomical Observatory, 80 Nandan Road, Shanghai 200030, China

Abstract

High-accurate Doppler tracking combined with Very Long Baseline Interferometry (VLBI) phase-referencing techniques are used for determination of the state vectors of planetary and deep space spacecraft missions. Ultra-precise estimates of the position and velocity of spacecraft can address to a wide range of research fields. The group has demonstrated successful detections on planetary fly-bys, landing of probes, drag acceleration measurements, and characterization of the interplanetary plasma.

1. Introduction

VLBI and Doppler tracking is one of the most powerful tools for determining accurately the position of a planetary spacecraft. The Planetary Radio Interferometry and Doppler Experiment (PRIDE), an initiative by the Joint Institute for VLBI in Europe, is a multi-purpose, multi-disciplinary enhancement of planetary missions science return. PRIDE is able to provide ultra-precise estimates of spacecraft state vectors based on the VLBI phase-reference and radial Doppler measurements. These experiments have already been demonstrated in the ground-based radio tracking of VEGA balloons for determination of Venus winds [1], the VLBI tracking of the landing of Huygens probe in Titan [2], and the landing of Smart-1 probe on the surface of the moon with EVN radio telescopes [3]. The research fields addressed include: ultra-precise determination of the celestial mechanics of the planetary elements, study of geodynamic processes and structure of the interiors of planets, characterization of the shape and strength of gravitational field of the satellites, measurements of anomalous accelerations of deep space probes and other fundamental physics, measurements of the electron density in plasma media environments, and Direct-to-Earth telemetry of probes and rovers missions.

2. VLBI and Doppler tracking of spacecraft

PRIDEhas been adopted by a number of prospective planetary science missions as a part of their scientific suite. These missions include JAXA and ESA'sBepiColombo/MMO (Mercury Magnetospheric Orbiter), ESA's international ExoMars rover, ESA's MarcoPolo-R mission, ESA's GAIA mission, and ESA's Jupiter Icy moons Explorers (JUICE).As a preparatory stage, PRIDE has been conducting test observations with the ESA Venus Express (VEX) spacecraft for the last three years (2009-2012). This campaign has focussed, among others, oncharacterizing the interplanetary scintillations (IPS) at different solar elongation and at various distances to the target.

In this paper, the analysis of the single-dish observations and the interplanetary plasma are presented, as well as the results of the VLBI and Doppler tracking session with several radio telescopes. This session (em081c) was conducted in 28.03.2011 using10 different antennas located worldwide. The position of the VEX was estimated with high precision after 3 hours of intensive observations. The reconstructed image of the VEX spacecraft with an accuracy of 1km x 100 m is shown in Figure 1.

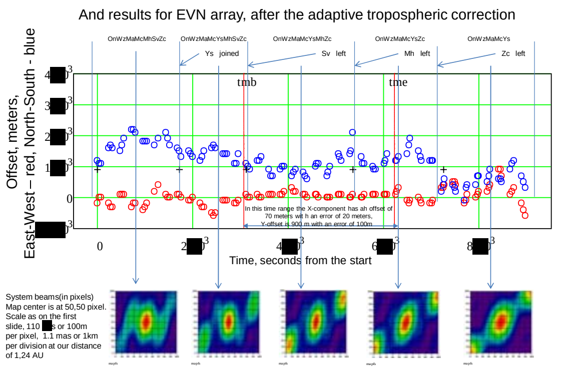

Figure 1 High-precision determination of VEX state vectors observed on 28.03.2011

3. Interplanetary scintillation

Phase scintillations of the spacecraft signal due to the propagation within the solar wind (interplanetary plasma) is one of the main factors limiting accuracy of VLBI observations of spacecraft.Regular monitoring of the phase scintillations of VEX signal at different stations and different solar elongations is helpful to optimization of detection technique and to debug possible problems at observing stations. On the other hand, the study of the phase fluctuations of the spacecraft carrier line is used to characterize the interplanetary plasma along the propagation path. During the two years of research more than 100 observations have been performed studying the propagation of the VEX spacecraft signal. In this exercise, the phase scintillation index and scintillation bandwidth were retrieved from the phase fluctuations.

The phase scintillations have shown direct dependency on the solar elongation, distance to the target, position of the source within the Solar System and solar activity index at the time of the observations. This work wasfocused on the technique of the measurements, dataanalysis and the interpretation of the physicalconsequences of the measurements.The analysis of the phase fluctuations on the spacecraft signal allows us to determine the best time frame for the approach, descent and landing operations for spacecraft to achieve precise estimation of the state vectors with VLBI spacecraft tracking.

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