EPSC Abstracts
Vol. 9, EPSC2014-381, 2014
European Planetary Science Congress 2014

Near-field VLBI and its applications to Space Science Missions.

G. Cimò (1), G. Molera Calvés (1), D.A. Duev (1), S. V. Pogrebenko (1), T. Bocanegra Bahamon (1,2,3) and L. I. Gurvits (1,2)

(1) Joint Institute for VLBI in Europe, The Netherlands (cimo@jive.nl / Fax: +31-521-596539), (2) Delft University of Technology, The Netherlands, (3) Shanghai Astronomical Observatory, China

Abstract

Near-field Very Long Baseline Interferometry (VLBI) is a radio astronomical technique that, when applied to observations of spacecraft, provides unique insights on those areas of space mission scientific return, which require precise determination of lateral position of spacecraft on the celestial sphere.

The Planetary Radio Interferometry and Doppler Experiment (PRIDE) exploits near-field VLBI for accurate estimation of the state-vector of a spacecraft using arrays of radio telescopes available around the world. We will present new results of recent experiments with current ESA's missions (Venus Express, Mars Express, Gaia) while showing the numerous implementations of the PRIDE technique.

PRIDE science

The PRIDE experiments estimate the state-vector of spacecraft with high accuracy by performing VLBI observations of spacecraft and natural celestial reference radio sources. In the past years, this technique proved to be very efficient in a number of the VLBI experiment, including the tracking of VEGA balloons for determining the wind field in the atmosphere of Venus [1] and the tracking of the descent and landing of the Huygens Probe in the atmosphere of Titan [2]. Currently, ESA's Venus Express is targeted by PRIDE observations for studying the upper atmosphere of Venus as well as the properties of the interplanetary plasma. Moreover, on December 29^{th} 2013, a global VLBI campaign has taken place in order to observe Mars Express on its close fly-by of Phobos.

Due to the ability to provide precise measurements of spacecraft lateral coordinates, radial velocity and its derivatives [3], PRIDE is a multi-disciplinary enhancement of the scientific suite of space missions. The direct measurables of PRIDE are shown in Figure 1. PRIDE provides measurements of the spacecraft differential lateral position relative to ICRF (International Celestial Reference Frame) background extragalactic radio sources with accuracy of $100 - 10\,\mu$as (1-σ RMS) over integration time $60 - 1000\,$s.

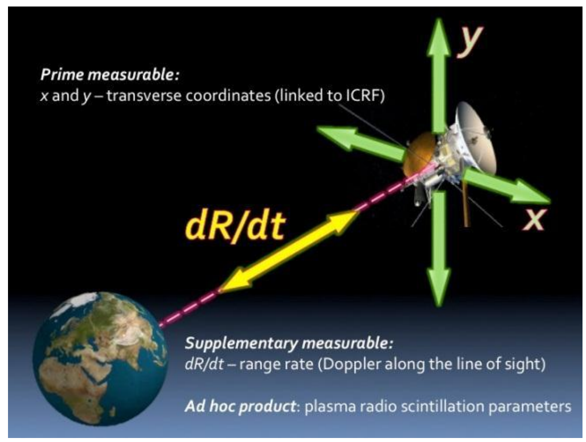

Figure 1: PRIDE measurables.

With such a precision, PRIDE can address the following scientific objectives:

- Improvement of the ephemerides of satellites;
- Accurate input into definition of the Solar System reference frame;
- Ultra-precise celestial mechanics;
- Planetary atmospheres via occultations;
- Solar wind and ionospheric effects on spacecraft trasmissions;

Near-filed VLBI tracking of the spacecraft allows us to firmly tie a planetary system into the reference frame: a major contribution to planetary geodesy and the definition of the Solar System reference system.

Finally, collaboration with on-board radio science experiments will further enhance the scientific capabilities of PRIDE (and, thus, the scientific outcomes of space missions) with the determination of the vertical structure of the planetary atmospheres by means of radio occultation.

PRIDE applications

PRIDE is an instrument with zero impact on the science payload mass, and it offers a high degree of synergy with the typical on-board instrumentation (transmitters, ultra-stable oscillators, antennas), which are developed and used by space mission operations regardless of PRIDE.

Relaying on typical on-board instrumentation allows PRIDE to observe any spacecraft that is equipped with a transmitter. The PRIDE team has exploited such flexibility for the past five years with hundreds of observations of the ESA's Venus Express spacecraft. Scientific outcomes of such tests include solar wind scintillation [4]. New results disentangling the contribution of interplanetary and ionospheric plasma will be presented. For detailed analysis on the study of Venus atmosphere see T. Bocanegra Bohamon's contribution to this conference.

Mars Express is another ESA's planetary mission that is targeted by PRIDE observations. A close fly-by of Phobos occurred on December 29^{th}, 2013. We will present new results from PRIDE observations of the event. This has been observed for 26 hours, thus covering the preceding and following phases, by an array of 36 radio telescopes all around the world [5].

Applications of the accurate lateral positioning provided by PRIDE to the determination of spacecraft orbit in critical phases of a space mission is not limited to planetary probes. Closer to Earth, our team has been involved with the ESA's Gaia mission. Gaia is an ambitious astrometric mission to chart a three dimensional map of the Milk Way. PRIDE observations are important to ensure the optimal orbit determination needed for the highly accurate Gaia measurements. VLBI test observations have been already carried out and VLBI images of Gaia will be presented.

Another project that currently benefits from PRIDE measurements is the Russian-led space mission RadioAstron. In this case, highly accurate determination of the spacecraft position is essential for the success of space VLBI observations.

The flexibility of the PRIDE technique and its many scientific outcomes for the minimal requirements have contributed to make PRIDE one of the selected experiments for JUICE (JUpiter ICy moons Explorer), the next ESA's L-class mission.

Finally, PRIDE can provide support to mission operations, in particular, mission navigation and trajectory determination as well as on-board systems and instrumentation diagnostics. A separate and potentially beneficial application of PRIDE is its ability to provide limited Direct-to-Earth delivery of data from spacecraft [6].

Acknowledgments

The authors acknowledge the EC FP7 project ESPaCE (grant agreement 263466). T. Bocanegra Bahamon acknowledges the NWO-ShAO agreement on collaboration in VLBI.

References

[1] Preston, R., et al. 1986, Science 231, 4744, 1414

[2] Bird, M. K., Allison, M., Asmar, S. W. et al. 2005, Nature 438, 8

[3] D. A. Duev, G. Molera Calvés, S. V. Pogrebenko, L. I. Gurvits, G. Cimò and T. Bocanegra Bahamon: Spacecraft VLBI and Doppler tracking: algorithms and implementation, Astronomy & Astrophysics, Vol. 541, 2012.

[4] Molera Calvés G., Cimò, G., Pogrebenko, S.V. & et al., 2014, A&A 564, A4

[5] Rosenblatt et al, in preparation.

[6] Fridman P.A., L. Gurvits and S. Pogrebenko: The SKA as a Direct-to-Earth Data Acquisition Facility for Deep Space Science Missions, SKA2009 "Wide Field Astronomy & Technology for the Square Kilometre Array", 2009