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Venus and Mars Express spacecraft observations with Wettzell radio telescopes

Guifrè Molera Calvéś 1,2, Alexander Neidhardt 3, Christian Plötz 4, Gerhard Kronschnabl 4, Giuseppe Cimó 2,5, Sergei Pogrebenko 2

Abstract The ESA Venus, Mars Express and Rosetta spacecrafts were observed at X-band with the Wettzell radio telescopes Wn and Wz in a framework of the assessment study of the possible contribution of the European VLBI network to the upcoming ESA deep space missions and further projects. These observations were extended to regular weekly sessions to routinely run the processing and analysis pipeline. Recorded data were transferred from Wettzell to the JIVE cooperation partners for correlation and analysis. A high dynamic range of the detections allowed us to achieve a mHz level of the spectral resolution accuracy and extract the phase of the spacecraft signal carrier line. Several physical parameters can be determined from these observational results with more observational data collected. Apart from other results, the measured phase fluctuations of the carrier line at different time scales can assess to determine the influence of the Solar wind plasma density fluctuations on the accuracy of the astrometric VLBI observations.

Keywords VLBI, radio telescope, spacecraft signal, solar wind

1 Introduction

The combination of Very Long Baseline Interferometry (VLBI) and Doppler spacecraft tracking has been successfully exploited in a number of space science missions, including VLBI tracking of the descent and landing of the Huygens Probe in the atmosphere of Titan [2], VLBI observations of ESA’s Venus Express and of the Mars Express Phobos flyby [7].

Fig. 1 Scheme of the Planetary Radio Interferometry and Doppler Experiments (PRIDE) observations.

Based on the experience acquired in this projects, the Planetary Radio Interferometry and Doppler Experiment (PRIDE) concept has been developed. PRIDE is an international enterprise led by the Joint Institute for VLBI in Europe (JIVE). It focuses primarily on tracking planetary and space science missions through radio interferometric and Doppler measurements [3]. PRIDE provides precise estimations of the spacecraft state vectors based on Doppler and VLBI phase-referencing techniques [1]. These can be applied to a wide range of research fields.

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5 ASTRON, the Netherlands Institute for Radio Astronomy, Postbus 2, 7990 AA, Dwingeloo, The Netherlands.
Figure 1 shows the basic configuration for the PRIDE observations, where the observations of planetary spacecrafts are combined with natural radio sources.

Table 1 shows the main characteristics of the radio telescopes at the Wettzell observatory used for spacecraft observations. The 20 m Radio Telescope Wettzell (RTW) with station code Wz was finished in the year 1983 and is one of the main systems of the International VLBI Service for Geodesy and Astrometry (IVS). It is equipped with an S/X-receiving system. The antenna Wn with a 13.2 m dish is the northern telescope of the newly build TWIN Radio Telescope Wettzell (TTW), which was finished inaugurated in the year 2013. TTW is a fast-slewing broadband telescope following the specifications of the VLBI Global Observing System (VGOS). The antenna Wn is currently equipped with a standard S/X-receiving system, which is extended with a Ka-band receiver.

Table 1: The radio telescopes at Wettzell used for the spacecraft observations.

<table>
<thead>
<tr>
<th>Station code</th>
<th>latitude</th>
<th>longitude</th>
<th>altitude dish (m)</th>
<th>SEFD-X (Jy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wettzell Wz</td>
<td>49°08'42.0&quot;</td>
<td>12°52'37.9&quot;</td>
<td>661.20</td>
<td>20.0 700</td>
</tr>
<tr>
<td>Wettzell Wn</td>
<td>49°08'38.1&quot;</td>
<td>12°52'39.7&quot;</td>
<td>672.57</td>
<td>13.2 840</td>
</tr>
</tbody>
</table>

2 Observations

The PRIDE team initiated systematic observations of planetary spacecraft in 2009. ESAs VEX spacecraft was selected due to its high-quality signal, suitable transmission frequency, and possibility to observe with European VLBI radio telescopes. The 20 m RTW (Wz) has participated since 2010 in 57 sessions on VEX until the mission ended in 2014, and in 23 sessions on MEX between 2014 and 2016. In 2015, the Wn was additionally included into the network of planetary spacecraft observations. A total number of 17 sessions have been arranged since then with Wn. In our observations, the spacecraft signals are observed in X-band ($\lambda = 3.6$ cm, $f_0 = 8.4$ GHz).

On 20.05.2015, we operated the first simultaneous observation of spacecraft by using both Wn and Wz. After that, eight similar experiments were arranged.

Fig. 2 Detection of the spacecraft signal transmitted by Rosetta by the Wettzell radio telescopes on 24.07.2015.

The figure below shows the relative power to noise ratio, the Doppler frequency residuals, and their difference detected on 26.10.2015.

Fig. 3 Upper panel: relative power Wz (blue) and Wn (red). Middle panel: residual frequencies for same data. Lower panel: difference between both telescopes residuals. MEX data observed at Wz and Wn on 26.10.2015. Standard deviation of Frequency detections are 1.78 mHz for Wn, 1.76 for Wz and 0.5 mHz for the difference.

Spacecraft observations are research and development approaches to open new domains for geodetic VLBI. The geodetic benefit is the interrelation to other techniques to tie the different reference frames. VGOS supports spacecraft tracking, while mostly Earth orbiting satellites in the near field are in the focus [6]. But the IVS encourages developments which use VLBI on sources beside quasars (see different sessions of the past IVS General Meetings). It opens doors to space-
craft navigation which is strongly related to the application of reference frames. Besides this, the observations of spacecrafts are checks of the accuracy of the techniques at the location of the antennas and throughout the whole processing chain. Additionally, they are technical tests for possible future domains of VLBI which are currently already possible. Another aspect is that one of the pillars of geodesy is the gravity and the gravitational field [10]. In a wider sense, spacecraft observations with VLBI enable the determination of gravitational fields of planetary objects. From the point of view of a geodetic observatory the observations are quite valuable. Using two telescopes provides the possibility of more observations, because one telescope might be able to observe while the other is occupied by another session. It would also offer possibilities of new observation modes for differential VLBI, so that one telescope observes quasars close to the spacecraft while the other tracks the spacecraft itself. Current implementations do not take too much care on these possibilities.

3 Analysis

The data processing is conducted using the on-purpose software developed for multi-tone tracking of planetary spacecraft signals. The software is divided into three parts: the SWspec, the SCtracker and the digital Phase-Locked-Loop. All three software packages were described in [7]. Figure 3 shows a block diagram of the spacecraft tracking software.

The three most important parameters out of our detections are the Doppler noise, the Signal-to-Noise Ratio (SNR) of the carrier and the phase scintillation indices. The two first output results of a regular observation are shown in Figure 2. The results are utilized for a wide field of research:

- studies of the interplanetary scintillation caused by the solar wind at different solar elongations and positions with respect to the Sun [7].
- characterization of the properties of Coronal Mass Ejections (CME) and monitoring of similar events in almost real-time [8].
- determination of the speed of the solar wind using VLBI techniques.
- studies of the planetary atmosphere on Venus, using radio signal and aerobreaking techniques [9].
- determination of gravitational fields of planetary objects (moons, comets) by using fly-by techniques [5].
- radio occultation experiments to evaluate ingress and egress phenomena.
- orbit determination of the space missions, such as Radio Astron [3]
- enhancement and support of future planetary space missions: JUICE, ExoMars, Bepi-Colombo, etc.

4 Conclusions

Planetary spacecrafts as targets for radio observations of ground-based radio telescopes provide an unique opportunity to investigate a wide range of scientific fields. Tracking observations of spacecraft, ESA’s MEX and Rosetta, will continue in order to improve detection measurements and the processing pipeline. Future space mission, like ESAs Jupiter Icy Moon Explorer (JUICE), will benefit of such precise knowledge.

Radio science studies like this one allows us to disentangle the contributions from the interplanetary plasma and the Earth’s ionosphere. The research will continue with the goals of characterizing the atmospheric and ionospheric structure of planets and media, small bodies fly-byes, atmospheric drag campaigns, radio occultations, detection of coronal mass ejections or precise orbit determination of satellites. Besides the scientific output, the tests are technical feasibility study of the technical workflow from scheduling to analysis.
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References


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