5th October 2016

Institute of Geodesy and Geoinformation, University of Bonn, Nussallee 17, D-53115 Bonn

08:30-09:00 Registration
09:00-09:10 Axel, Nothnagel – Introduction

- Missions: design/scheduling simulations

[Chairperson: A. Nothnagel]

09:10-09:25 Songtao Han (on behalf of Tang Geshi) - BACC
APOD observation with VLBI geodetic antennas

APOD satellites are rather challenging since mutual visibility depends on the altitude of APOD satellite and the separation of the radio telescopes. And the APOD satellite travel through the field of view very fast. The current status of observing APOD satellite by IVS VLBI radio telescopes will be introduced in the presentation and the tracking mode of direct AzEl input is suggested strongly.

09:30-09:45 Rüdiger Haas - Chalmers University
First VLBI-observations of the APOD-satellite on the Onsala-Wettzell baseline

The Chinese satellite APOD (Atmosferic density detection and Precise Orbit Determination) is a first prototype of a so-called geodetic co-location satellite. This means that te satellite is equipped with instruments for several space geodetic techniqeus. It carries a dual-frequency GNSS-receiver, several corner cube retro-reflector for SLR (satellite Laser Ranging), and an artificial VLBI beacon that can send in S- and X-band. The satellite isa so called Nano-satellite of about 15 kg mass in a near-circular and high inclination (97 degree) orbit with about 450 Km orbital height. We report about first tests to perform VLBI-observations of the APOD satellite on the baseline Onsala-Wettzell. First data were successfully collected in July 2016. In this presentation we report about the planning of the observations, the experience learned, as well as the data correlation and preliminary results.

09:50-10:05 Richard Biancale (on behalf of Yoaz Bar-Sever) - CERS/GRGS
Design of the VLBI Transmitter for GRASP and simulations of positioning performance

I will describe the designed performance of the VLBI transmitter (VT) for the proposed GRASP (Geodetic Reference Antenna in Space) and E-GRASP missions. I will also describe the simulations of VLBI antenna positioning with the VT signal from the planned GRASP orbit.

10:10-10:25 Richard Biancale - CERS/GRGS
E-GRASP/Eratosthenes: a satellite mission proposal submitted to the ESA/Earth Explorer-9 call

E-GRASP/Eratosthenes aims at improving and homogenizing time and space references on Earth and, more directly, at realizing the terrestrial reference system with an accuracy of 1 mm and a long-term stability of 0.1 mm/yr as proposed by the International Association of Geodesy in its GGOS-2020 requirements.
Apart from GNSS, DORIS and SLR tracking systems, E-GRASP/Eratosthenes should be equipped with a VLBI transmitter from JPL - such as in the GRASP proposal – in order to connect these four space-based geodetic systems so that the platform could be considered as a dynamic space tie of these geodetic instruments. All active sensors will be connected through the same Ultra-Stable Oscillator (USO) which would allow to have a temporal measurement of the tie. Moreover a laser detector would allow for a high precision synchronization of the on-board oscillator with ground clocks at SLR stations using a time transfer by laser link (T2L2). The orbit choice for the platform is tending towards a quite eccentric orbit that aims to maximize observability by the various instruments and particularly to offer very long baseline interferometric observations at apogee. A dedicated VLBI tracking schedule should be then organized accordingly.
The selection decision from ESA for a phase A is expected end 2016.

****** 10:30-11:00 Coffe Break

[Chairperson: L. La Porta]

11:00-11:15 Susanne Glaser – GFZ, TU Berlin
VLBI simulations to GRASP-like satellites at GFZ

The proposed satellite missions GRASP (Geodetic Reference Antenna in Space), submitted in Dec. 2015 to NASA, and E-GRASP/Eratosthenes, submitted in June 2016 to ESA, offer a novel approach of co-location in space of all four space-geodetic techniques currently utilized in the realization of global terrestrial reference systems. Both satellites will be equipped with a very long baseline interferometry (VLBI) transmitter on board as a unique feature. At the GFZ German Research Centre for Geosciences we carry out simulations of VLBI observations to the proposed GRASP and E-GRASP/Eratosthenes satellites, employing different station networks. We find that the station position repeatabilities would improve should GRASP or E-GRASP observations be used in addition to quasar ones, compared to quasar only observations. The improvement is larger in case of station networks with more stations. Thus, the number of stations is very important for observing GRASP and E-GRASP. Furthermore, an extended error analysis was performed in order to assess the accuracy of the estimated parameters such as the station positions as well as the spacecraft position.

11:20-11:35 Claudia Flohrer – ESA/ESOC
VLBI processing at ESOC

ESA's European Space Operations Centre ESOC, located in Darmstadt Germany, tracks and controls European spacecraft, and develops and manages ground systems. One of the tracking techniques used by ESOC's Flight dynamics team for navigating interplanetary spacecraft is delta-DOR, using ESA's three deep-space antennas.
ESOC's Navigation Support Office (NavSO) is providing the geodetic reference for ESA missions mainly based on the processing of the satellite-geodetic techniques GNSS, SLR and DORIS. Currently NavSO is enhancing its expertise to VLBI processing and analysis. This will extend ESOC's capabilities to determine the absolute orientation of the Earth and therewith enables NavSO to provide a fully independent set of Earth orientation parameters for ESA missions. NavSO's software package NAPEOS will become capable of combining all four geodetic techniques on the observation level and thus supporting GGOS, the Global geodetic Observing System.
We will give an overview of ESOC's and in particular NavSO's activities using VLBI and delta-DOR observations. Even though the current VLBI implementation efforts in NAPEOS focus on the processing of quasar signals, it is not limited to quasars only. As NAPEOS is already capable to process various satellite types and observation techniques, our VLBI implementation will be extendable to near-field targets.

11:40-11:55 Grzegorz Klopotek – Chalmers University
Simulation studies of geodetic VLBI observations with an artificial radio source on the Moon

In order to assess the potential of VLBI near-field observations for prospective planetary missions in our solar system, it is studied how precise the position of an object on the surface of the Moon can be determined. Although a few VLBI experiments have already been carried out with the purpose to determine the Moon lander's position, a thorough study of suitable observation strategies and the impact on selenoidic and Earth based parameters is still pending.Thus, we performed Monte Carlo simulations using the c5++ software in order to evaluate the uncertainty with which a radio transmitter on the surface of the Moon can be located when observing it in a standard geodetic VLBI mode. Our investigations are based on modified R1 session schedules, originally created by the International VLBI Service for Geodesy and Astrometry (IVS).
We present first results of our study and demonstrate how the quantity and quality of lunar observations impact the uncertainty of the position of a non-moving radio transmitter located on the Moon. We also discuss the impact of Moon VLBI observations on the determination of the Earth Orientation Parameters (EOPs) and VLBI station positions. For all Monte Carlo simulations, realistic stochastic processes related to troposphere, station clocks and thermal noise were included in order to consider Moon VLBI observations with current technology. Thus, our preliminary simulation results can provide insights for scheduling and observation of global Moon VLBI and reveal how VLBI can contribute to future Moon exploration missions and scientific studies.

- Observations (VLBI and ΔDOR)

12:00-12:15 Andreas Hellerschmied – TUW
Scheduling of VLBI satellite observations with VieVS

In 2015 and 2016 several sets of test sessions were carried out on the Australian baseline Hobart-Ceduna observing satellites of the GNSS (GPS and GLONASS). The aim of these experiments was to establish a complete process chain for this specific observation type – from scheduling, over data acquisition and correlation, to data analysis. For the scheduling of these sessions the satellite scheduling module of the Vienna VLBI Software (VieVS) was used. It is a convenient and flexible tool for the scheduling of VLBI observations to satellites – not only of the GNSS – and for the generation of the required control and interchange files. Applying this software for multiple VLBI satellite experiments within the last years, it was upgraded with a new automatic scheduling mode to meet the requirements of the Hobart-Ceduna experiments with combined observations to satellites and quasars and several hours duration per session. Besides a general introduction to the VieVS satellite scheduling module and its features, we will give an insight into the scheduling of the VLBI GNSS sessions carried out on the baseline Hobart-Ceduna. Lucia Plank and Jamie McCallum will then discuss the current status, results and technical challenges of this program in other talks.

****** 12:30-14:00 Lunch Break

[Chairperson: A. Nothnagel]

14:00-14:15 Lucia Plank - University of Tasmania
Observing GNSS satellites with VLBI on the baseline Hobart-Ceduna

GPS satellites as main targets as well as a few quasars for calibration. So far, only results of L1 are used, applying a simple ionospheric delay correction based on GPS TEC maps.
For sessions up to six hours we find delay precisions at the level of a few tens of picoseconds (1-5 cm) for a 5 minute track and reasonable estimates for station coordinates and zenith wet delays with a session fit of 10-20 cm (wrms). Overall, we think that the developed procedures now allow for almost routine VLBI observations of GNSS satellites, which will hopefully ease future observations and trigger further progress in this exciting area.

14:20-14:35 Jamie McCallum - University of Tasmania

Technical challenges in GNSS observations

Over the last 12 months, several observations of GNSS satellites (primarily GPS) have been carried out using the Australian Hobart and Ceduna telescopes, operated by the University of Tasmania. While the current status and results of this program will be discussed by Lucia Plank in another talk, the aim of this talk is to report on some technical aspects of recent observations. The particular focus is challenges in recording, correlation and fringe-fitting and the results of our efforts to deal with them.

14:40-14:55 Jan Kodet – TU München
Co-location on the ground and in the space

The classical approach for co-locations of the space geodetic instrumentation, namely SLR, VLBI, GNSS and DORIS is to regularly measure local ties between the reference points. At the Geodetic Observatory Wettzell (GOW) we reestablish the local ties every other year, which do not show displacements larger than 1 mm. However one can identify noticeable discrepancies between the local survey the measurements of the techniques of space geodesy. The cause are systematic measurement biases, which are not correlated with the local ties measurements and are not captured by the established calibrations techniques.
To observe near Earth objects like GNSS satellites using classical geodetic VLBI network is a challenging task. Observing the same satellites using VLBI, SLR and GNSS will greatly improve local ties because it provides a tie both in space and on the ground. The ties can be further improved by multi-technique ground

targets, which are concentrating the different measurement systems at a single point on the observatory. The goal is to overcome the problem that local ties monitor only geometric distances between the reference points of the instruments. Multi-technique ground targets use the same signal originating from a common clock and the known respective path delay for tying the instruments to a single point of reference on the observatory. This provides both, intra- and inter- technique comparisons and delay control. The talk summaries the ongoing activities at the GO Wettzell leading to observe GNSS satellites by the VLBI systems on a regular bases and outlines the concept of the multi-technique ground target. Furthermore we show the first experimental results.

15:00-15:15 Frédéric Jaron – IGG
Near-Field VLBI Delay Models

Reliable VLBI delay models are essential for geodetic applications. Near-field targets make it necessary for delay models to take curvature of the wavefronts into consideration. We have implemented two finite-distance delay models (Sekido & Fukushima 2006; Duev et al. 2012) in the VLBI analysis software ivg::ASCOT. VLBI observations of GPS satellites allow us to compare computed delays with observed delays. We introduce the concepts behind these two delay models and present our results.

****** Coffee Break 15:30 – 16:00

- Data processing

[Chairperson: R. Nothnagel]

16:00-16:15 Huang Yidan – SHAO
DOR Theoretical Time Delay Model for CE-3 Experiment

The beacon of CE-3 satellite has several DOR tones used for VLBI tracking. In order to improve data transferring and processing efficiency, we tried the local-correlation method which was different from the one used in CE-3 project. The Time delay model used in local-correlation experiment also differed from normal time delay model.
In this report, DOR theoretical time delay and light-time(or range)model were calculated according to the initial orbit of the CE-3 satellite and the coordinates of VLBI stations. The local-correlation processing method was applied to obtain differential DOR delay observables, which have been used in orbit determination o
f the CE-3 satellite.

16:20 – 16:50 Walter Brisken – LBO [invited]
Near-field correlations with the DiFX Correlator

I will present the basic tool flow for correlating data with the DiFX Software Correlator and will focus on the special features relevant for observations made in the near field. I will discuss some of the practical issues related to observing and correlation as well.

17:15 – 18:15 *Splinter meeting for the IVS WG7 "Observation of satellites using VLBI"*

18:30 - A social gathering will be held on Thursday evening, 5th April, at the Restaurant “Im Stiefel” on Bonngasse 30, 5311 Bonn.

6th October 2016

[Chairperson: A. Nothnagel]

09:00-09:15 Rüdiger Haas – Chalmers University
OCEL – Observations of the Chang'E-3 lander with VLBI

Tang Geshi and several co-Pis proposed in May 2014 to observe the Chinese Lunar Lander Cheng'E-3 with VLBI using the IVS network. The proposal was accepted by the IVS Program Commitee, and a series of RD-sessiosn was allocated for this purpose. For the year 2014 to 2015, fourf sessions each were planned, with varying international VLBI networks and number of participating stations. In this presentation we primarily describe the scheduling and preparation of these sessions and the experience gained during the observations.

09:20-09:30 Laura La Porta – IGG
OCEL - data processing

I will briefly report about the data processing of the OCEL sessions previously presented by R. Haas. In particular I will focus on the issues we have to deal with when correlating/fringe-fitting the OCEL sessions.

09:35-09:50 Zhang Zhongkhai - IGG
Preliminary Fringe Fitting of Chang'E-3 VLBI Observations with PIMA

The Chang'E-3 lunar probe successfully landed on the Moon on December 2013. With on-board beacon emitting a set of X-band Differential One-way Range (DOR) signals, a series of VLBI sessions were scheduled and performed. A number of observations from these sessions were correlated and fringe-fitted preliminarily. Firstly, PIMA and fourfit were compared in fringe fitting quasar observations of common VLBI sessions, with differences in satisfaction. Models and algorithms involved in PIMA were generally described and analyzed. Then fringe fitting Chang'E-3 lander VLBI observations was performed and the results were analyzed. The main goal was to test PIMA and use it as fringe fitting tool for Chang'E-3 VLBI observations.

09:55-10:10 Han Songtao – IGG, BACC
Algorithm and Demonstration of Fringe Fitting for DOR Tones

To enable detal-DOR measurement, spacecrafts usually emit several tones which span some bandwidth. Space agencies, such as ESA, adopt correlator based on phase locking or local correlation algorithm to process DOR tones. While geodesy and astronomy agencies usually deploy correlator(Difx,K5..) mainly for geodetic applications, here comes the problem: is the fringe fitting still effective for DOR tones signal? In this paper, we discussed about the fringe fitting algorithms for DOR tones and we make a comparison between the results of different fringe fitting softwares, both consistency and discrepancy under different parameters and data quality are also analyzed.

****** Coffee Break 10:25 - 10:55

[Chairperson: A. Nothnagel]

10:55-11:25 James Anderson – GFZ/TU Berlin [invited]
Scheduling, Correlating, and Analyzing VLBI Phase-Referencing Observations of Earth-Orbiting Satellites

Very long baseline interferometry (VLBI) is unique among the four major space geodetic techniques in its ability to measure objects in the International Celestial Reference Frame (ICRF), the most stable reference frame available. Conventional geodesy ties the space geodetic techniques through determinations of the

International Terrestrial Reference Frame (ITRF) coordinates of ground geodetic stations via ground-based local ties among the techniques at co-location sites and through commonly estimated Earth Orientation Parameters (EOP). Hence, the dynamic reference frames of various Earth-orbiting satellites are only indirectly tied to the ICRF, with the accuracy often limited by the ground ties, usually measured by classical surveying techniques. Alternatively, measurements of near-field spacecraft can be made directly in the celestial frame through VLBI measurements of spacecraft. Such observations will additionally allow the VLBI technique to determine the geocenter, providing a potential additional global parameter for combination currently only provided by satellite techniques. Two recent satellite mission proposals, GRASP (the Geodetic Reference Antenna is Space) to NASA in 2015 December, and E-GRASP (the European Geodetic Reference Antenna in Space) to ESA in 2016 June, highlight interests in the geodetic community to tie the four major space geodetic techniques together through co-location observations of spacecraft supporting all four techniques, including VLBI. As an alternative to traditional geodetic VLBI measurements, phase referencing, also known as differential VLBI, is a technique that enables high-accuracy relative position and velocity measurements to be determined through additional observations of ICRF calibrators made nearby in time and direction on the sky. At the German Research Centre for Geosciences (GFZ), we are exploring how well VLBI phase referencing can be used for near-field spacecraft measurements. The status of our development efforts will be presented for

1, automated scheduling of phase referencing observations of spacecraft (using modified versions of VieVS@GFZ and NRAO SCHED),

2, software correlator enhancements for near-field targets (for the DiFX correlator), and

3, analysis support for phase referencing observations with significant geocentric parallax differences among stations and support for 3-D/6-D position/state vector determination for near-field targets.

11:35-11:50 Rüdiger Haas – Chalmers University
VLBI with GNSS signals

During the last years a number of test were performed with european radio telescopes to observe GNSS signals with VLBI. These test observations aimed primarily at GLONASS satellites, but attempts were done to observe also other GNSS. Radio telescopes in Sweden, Italy and Germany were used. We describe the setup of these test correlation, the experience gained during the observations, the data correlation, and preliminary results.

11:55-12:10 Dmitry Duev – Caltech
Advancing spacecraft Doppler and interferometric data processing techniques for planetary science

The closest ever fly-by of the Martian moon Phobos, performed by the European Space Agency's Mars Express (MEX) spacecraft, gives a unique opportunity to sharpen and test the Planetary Radio Interferometry and Doppler Experiments (PRIDE) technique in the interest of studying planet - satellite systems. The PRIDE data processing technique has been specifically refined for the observations of MEX during this event to provide high precision positional and Doppler measurements.
We achieved, on average, mHz precision (30 ?m/s at a 10 seconds integration time) for radial three-way Doppler estimates and sub-nanoradian precision for lateral position measurements, which in a linear measure (at a distance of 1.4 AU) corresponds to ? 50 m.

12:15-12:30 Walter Brisken (on behalf of Ed Himwich) – NASA/GSFC
VEX2 and FS Support for Non-sidereal Objects

The VEX2 schedule file format is the emerging standard for the distribution of VLBI schedules. This paper will discuss how non-sidereal objects will be represented in VEX2, using .bsp files for the SPICE kernel. The Field System (FS) is used for VLBI data acquisition at many observatories. Options for support of tracking of non-sidereal objects with the FS will be presented.

***** Lunck break 12:30 – 14:00

[Chairperson: R. Haas]

14:00-14:30 Leonid Gurvits – JIVE/TU Delft [invited]
Deep space probes as near-field VLBI targets: methodology and science applications

A spacecraft emitting radio signals can be treated as a point-like target by VLBI systems. The latter offer an unsurpassed precision of measuring lateral celestial coordinates of a radio source. However, “traditional” astronomical VLBI systems are based, among other things, on the assumption that the target is infinitely far away, i.e. is located in the “far field”. The Fraunhofer distance defines the “border” between “far field” and “near filed”. For all practical VLBI applications with spacecraft, the distance to the target is well within the Fraunhofer value. Thus, “traditional” VLBI algorithms must be modified for estimating lateral coordinates of a spacecraft.
The value of “near-field” VLBI for planetary and space science has been appreciated since the 1970s. A number of planetary and space science missions benefited from spacecraft VLBI tracking. The technique offered a sub-milliarcsecond “positioning” of spacecraft on the celestial sphere that translated, e.g. into ~1 km linear accuracy at the distance to Titan in support to the ESA’s Huygens Probe in 2005. Recently the technique has been demonstrated “in action” for the ESA’s Venus Express and Mars Express missions. The technique is also accepted as a Planetary Radio Interferometry and Doppler Experiment (PRIDE) for the ESA’s Jupiter Icy Satellites Explorer (JUICE) as a multi-disciplinary enhancement of the scientific suite of the mission, which will provide precise measurements of spacecraft lateral coordinates, radial velocity and its derivatives. The presentation will offer an overview of major approaches to near-field VLBI applications in planetary and space science toward achieving “lateral positioning” of planetary probes relative to ICRF background extragalactic radio sources with the accuracy of 100 to 10 microarcseconds.

14:40-14:55 Ma Maoli - SHAO
Local Correlation and Orbit Determination for DOR signals in Chang’E-3

The X-band Delta-Differential One-way range is first normally used in Chang’E spacecraft in our country, and will be continuously used in the future deep space navigation. For the single-frequency of each DOR tone, we carried out researches on the local correlation which is quite different from the conventional VLBI correlator. The CE-3 signal interference processing are completed with this method. High precision Delta-DOR after bandwidth synthesis and radio source correction are obtained, and successfully used in orbit determination. The phase noise from local correlation are significantly smaller than that from the existing VLBI correlator. The ephemeris from local correlation is about 20m different from the precise ephemeris in CE-3 project, and the corresponding equivalent residual delay is about 0.4ns. Local correlation could be used for the future moon and deep space exploration projects in China.

15:00 – 15:15 Dmitry Litvinov - Sternberg Astronomical Institute, Moscow, Russia
Probing the gravitational redshift effect with VLBI observations of the RadioAstron satellite

A test of a cornerstone of general relativity, the gravitational redshift effect, is currently being conducted with the RadioAstron satellite, which is on a highly eccentric orbit around Earth. Using ground radio telescopes to record the spacecraft signal, synchronized to its ultra-stable on-board H-maser, it is possible to probe the varying flow of time on board with unprecedented accuracy. The observations performed so far have already resulted in a relative accuracy of 4x10^{-4}. We expect to reach 2.5x10^{.5} with additional observations in 2016, an improvement of almost a magnitude over the 40-year old result of the GP-A mission. The following specific topics are to be covered in the talk: general account of the experiment, scheduling and observational issues, data processing.

15:20 – 15:30 Axel Nothnagel – Concluding remarks

Posters

Posters will be displayed at the same place where the coffee breaks will take place, i.e., in the foyer in front of the lecture hall, for the whole duration of the workshop. Authors are asked to put up their posters on Wednesday early in the morning (fixing material will be provided).

Georg Beyerle – GFZ/ TU Berlin
Simulated orbitography of a spacecraft in low Earth orbit using VLBI station networks

The accuracy of current terrestrial reference frames are still one of the limiting factors in the error budget of certain geophysical observations such as tectonic plates movements, sea level changes or variations in Earth rotation. To identify the dominating error sources, satellite missions using two or more space geodetic techniques are being considered to connect terrestrial reference frames derived from GNSS, VLBI, SLR and/or DORIS observations and provide space-based ties between the corresponding frames, which are not affected by signal delay uncertainties induced by the neutral atmosphere or the ionosphere.
Here we report on preliminary results derived from a simulation study of simplistic orbit determinations of a satellite in low to medium Earth orbit, solely based on range measurements between the spacecraft and those VLBI stations in view of the spacecraft. Several orbits with eccentricities varying between 0.03 and 0.35 and orbit plane inclinations ranging from 70 to 116 degrees are considered. Atmospheric noise on the range measurements is assumed to be elevation dependent and modelled as Gaussian random values;
in addition, an arc-wise constant bias is applied.
Presently, dispersion effects on the range measurements are not considered. We investigate three scenarios of VLBI networks consisting of 10, 20 and 30 stations, respectively. Solar and lunar gravitational forces, as well as solar radiation pressure are taken into account. For numerical efficiency only the lowest five orders and degrees of the EIGEN-1S gravity model are included. Sampling time is taken to be 30 s and the (dynamic) orbit determination is performed for a 24 h observation period.
The simulation results suggest that the residuals, the difference between retrieved and true orbits, are smaller in the radial direction compared to the cross-track and along-track residuals. In addition to the atmospheric noise effects on the range data, the minimum elevation angle at the VLBI locations and the fraction of the orbit covered by observations from the VLBI sites affect the simulated orbit residuals. With a near-circular orbit the observation percentage increases from about 30% for 10 station network and 15 degree elevation cut-off to more than 60% for the 30 station network and a 5 degree cut-off. The highly elliptical orbits allow fractions of more than 90% at the lowest elevation thresholds.

Jakob Gruber – TUW
Project SORTS: Satellite Observations by Radio Telescopesfor Superior Reference Frame Interconnections

Satellite observations by radio telescopes have the potential to dramatically improve the frame ties between the International Celestial Reference Frame (ICRF) realized with Very Long Baseline Interferometry (VLBI) observations to extragalactic radio sources and satellite orbits realizing celestial frames dynamically. At the same time, the consistency of the International Terrestrial Reference Frame (ITRF) as a multi-technique solution from VLBI and satellite geodesy observations will benefit substantially, which otherwise solely relies on local tie measurements at co-located terrestrial observing sites. Accurate frame ties are fundamental for precise navigation in space and are a prerequisite for the observation of sea level rise and other global geodynamic processes.
Project SORTS (Satellite Observations by Radio Telescopes for Superior Reference Frame Interconnections) is funded by the Austria Science Fund (FWF) and the Deutsche Forschungsgemeinschaft (DFG). It is a joint project between Technische Universität Wien and Universität Bonn in close co-operation with the University of Tasmania, Chalmers University of Technology/Onsala Space Observatory, and Technische Universität München/Geodetic Observatory Wettzell. Project SORTS covers all technical aspects which are necessary for the realization and analysis of VLBI-like observations to satellites dedicated to such space-tie projects. In this presentation, we review all goals of the project and summarize first results and achievements with contributions by SORTS, like VLBI observations to GNSS satellites or the APOD satellite.

Frank Lemoine – NASA/GSFC
VLBI modeling in GEODYN for application to interplanetary orbit determination and geophysical parameter estimation

The NASA GSFC precise orbit determination and geodetic parameter estimation program (GEODYN) has routinely processed Earth-based tracking data to determine precise orbits for interplanetary spacecraft including Mars Global Surveyor, Mars Odyssey, Mars Reconnaissance Orbiter, MESSENGER, SELENE/Kaguya, and Magellan. The observables most frequently used have been DSN ramped Doppler and range, usually at X Band. GEODYN also has been adapted to process differential VLBI data tracking between two of the Kaguya sub-satellites and two stations on the Earth. In addition we have also processed Delta-DOR data (acquired during interplanetary cruise) to the MESSENGER mission, as part of the preparations for the OSIRIS-REx and the MAVEN missions. We give a summary of the modeling of these observables, briefly describe the orbit and geophysical results, and discuss the scenarios where VLBI tracking of interplanetary space orbiters would be most useful.

Walter Max-Moerbeck – MPIfR
Demonstration of Near Real-Time Astrometry for Spacecraft Navigation with the VLBA

We present the results of a demonstration of near real-time spacecraft astrometry with the VLBA (Max-Moerbeck et al. 2015 PASP, 127, 161). We detect the X-band downlink signal from Mars Reconnaissance Orbiter and Odyssey with the VLBA and transmit the data over the internet for correlation at the VLBA correlator in near real-time. Quasars near Mars in the plane of the sky are used as position references. In the demonstration we were able to obtain initial position measurements within about 15 minutes of the start of the observation. The measured positions differ from the projected ephemerides by a few milliarcseconds, and the repeatability of the measurement is better than 0.3 mas as determined from measurements from multiple scans. We demonstrate that robust and repeatable offsets are obtained even when removing half of the antennas. These observations demonstrate the feasibility of astrometry with the VLBA with a low latency and submilliarcsecond repeatability.