VLBI and ΔDOR activities at ESOC

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Outline

- Activities of the Navigation Support Office (NavSO)
- NavSO’s interest in VLBI
- Navigating interplanetary spacecraft using ΔDOR
- Cooperation areas

NavSO activities - Overview

- Provision of ESA tracking site directory (geodetic reference for ESA missions)

… containing

- **Antenna Information**, including positions of the geometric Antenna Reference Point (ARP) in the International Terrestrial Reference Frame (ITRF)
- Coordinates and documentation of **local geodetic networks**

NavSO activities - Overview

- Provision of ESA tracking site directory (geodetic reference for ESA missions)
- Leader of the Galileo Geodetic Service Provider (GGSP) consortium

GGSP provides the geodetic reference for Galileo

- Galileo Terrestrial Reference Frame (GTRF): independent realization of the International Terrestrial Reference System (ITRS)
- EOPs

NavSO activities - Overview

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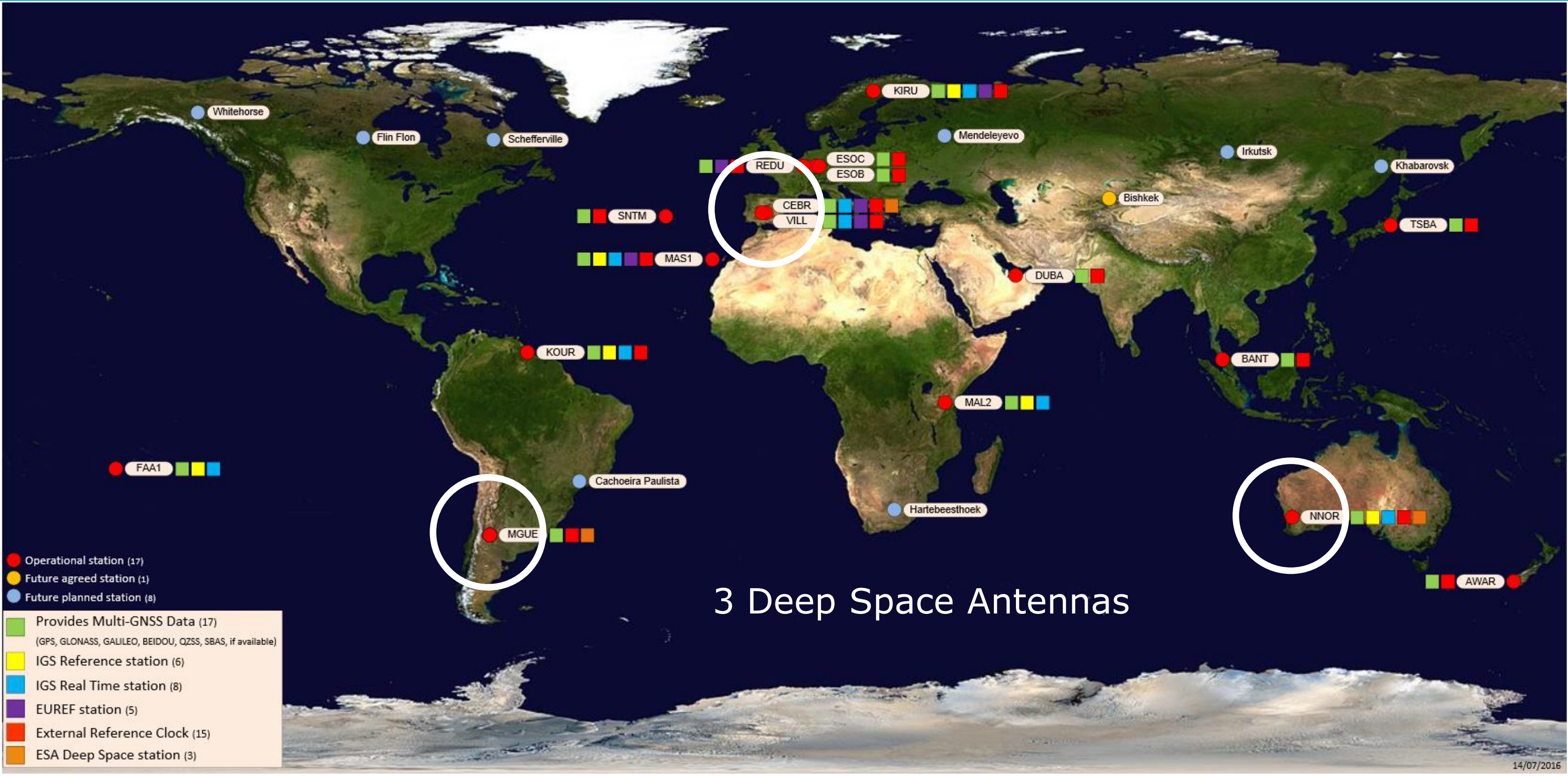
- Operation of own global GNSS sensor station network (17 stations)

ESA's GNSS Sensor Station Network
operated by NavSO



NavSO activities - Overview

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- Provision of media calibrations for ESA Spacecraft Tracking Data

NavSO provides **tropospheric and ionospheric calibrations** for Flight Dynamics support of ESA deep space missions (ΔDOR) using ESA's 3 Deep Space Antennas

These calibrations are computed from **GNSS-derived tropospheric zenith delays and STEC data** obtained from dual-frequency measurements, as part of NavSO's routine processing for the IGS

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- Realization of UTC (ESOC)

NavSO has developed and is operating a UTC realization at ESOC

- Can be used as time reference for ESA missions
- Implementation fully in line with BIPM requirements
- Official contribution to UTC is in preparation

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- Precise Orbit and Clock Determination for satellites in LEO, MEO, GEO, HEO

  - Development of state of the art models and algorithms for high-precision GNSS/SLR/DORIS/Altimetry data processing
  - In-house developed own software package: NAPEOS
    Capable of combined processing of data from all different satellite-geodetic techniques within one single s/w package

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- Contribution to Geodetic Reference Frame Realization via IGS, ILRS, IDS analysis center activities and product generation including reprocessing

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- Enhancement of processing capabilities for VLBI tracking data

NavSO's interest in VLBI (1)

Enhancing the processing capabilities of NAPEOS for VLBI tracking data will allow NavSO to …

- complete ESOC's capabilities in generating independent EOPs
    - become independent of external services to ensure the operational capability of ESOC
- contribute to the IVS service as analysis centre
- enhance our contribution to the IERS service with UT1-UTC and nutation products
- enable NAPEOS to combine all space-geodetic techniques at the observation level

The current VLBI implementation efforts focus on the processing of quasar signals, but extension to Earth-orbiting satellites is intended.

NavSO's interest in VLBI (2)

The missing elements …

	Parameter	GNSS	SLR	DORIS	VLBI
CRF	Quasar positions				x
	Satellite orbits	x	x	x	
EOP	Nutation				x
	UT1-UTC				x
	LOD	x	x	x	x
	Polar motion	x	x	x	x
TRF	Station positions	x	x	x	x
	Geocenter	x	x	x	

VLBI implementation into NAPEOS (1)

NAPEOS implementation steps	Status
• Read observations from NGS card format	☺
• Set up database for source and site coordinates	☺
• Set up new observation type “VLBI group delay”	☺
• Set up observation equation	☺
• Compute observation corrections	☺
• Enable parameter estimation (compute partial derivatives)	😐
• Enable combination at observation level (different observation types contribute to the same parameter, different observation weighting)	☹

VLBI implementation into NAPEOS (2)

Observation corrections

$$\tau_0 = \tau_g + \tau_{rel} + \tau_{clk} + \tau_{trp} + \tau_{ion} + \tau_{inst}$$

Observation corrections	Maximum order of magnitude	Status
• Geometric delay	Earth radius	☺
• Relativistic corrections	1000 m	☺
• Clock synchronisation (offset w.r.t. reference clock)	Several km	☺
• Tropospheric delay	10 m	☺
• Ionospheric delay	2 m	☺
• Instrumental delay (axis offset)	1 m	☺

Current O-C residuals: ~ 10 cm level
(without parameter estimation)

Navigating interplanetary spacecraft using ΔDOR

Today navigation of interplanetary spacecraft relies on three tracking methods:

- Ranging → s/c range along line-of-sight
- Doppler → s/c velocity along line-of-sight
  - Angular position against sky-background only indirectly obtained from motion of ground station due to Earth's rotation
  - When observation is close to celestial equator: North-South position is poorly determined
- ΔDOR → s/c angular position
  - At least ΔDOR observations from 2 baselines with different orientation (orthogonal) needed for full direction information
  - Short observation duration (<1h)

ESA's Deep Space Antennas
35-metre diameter

DSA1 - New Norcia (Australia)

- in service since 2003
- S-, X-band
- Ka-band upgrade planned

DSA2 - Cebreros (Spain)

- in service since 2005
- X-, Ka-band

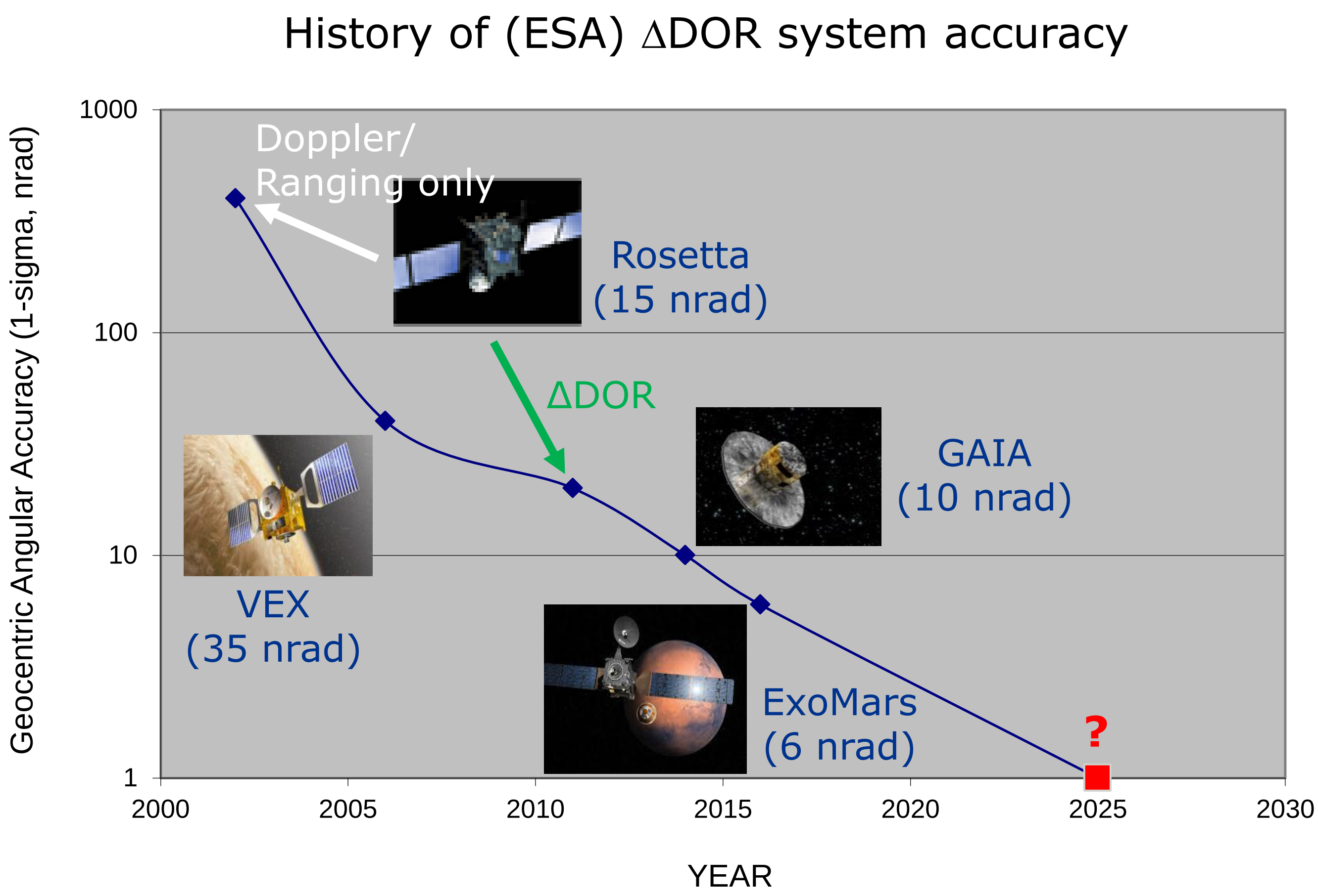
DSA3 – Malargüe (Argentina)

- in service since 2013
- X-, Ka-band

Why ΔDOR?

- Improves plane-of-sky knowledge at critical navigation phases
- Improves orbit determination (OD) accuracy → saves propellant
- Independent confirmation of conventional OD solutions → improves robustness
- Fast recovery of orbit knowledge after unknown ΔV → e.g. safe mode entry with unbalanced thrusters

ESA ΔDOR system accuracy



Cooperation areas

- Interoperability with other Agencies
  - With JPL: ESA baseline CEB-NNO is almost perfectly orthogonal to JPL baseline Goldstone-Canberra, thus providing complementary information for OD
  - With JAXA: NNO is almost in a North-South direction with Japanese stations (and declination is the coordinate which is worse determined by Doppler and ranging only solutions). CEB would provide a very long baseline when in conjunction with one Japanese antenna.
- Interoperability with VLBI network
  - Helpful to build X/Ka-band quasar catalogue
  - Enlarge number of usable baselines

The NASA-ESA X/Ka-band network

- A Fort Irwin, USA
- B Tidbinbilla, Australia
- C Malargüe, Argentina
- D Robledo de Chavela, Spain

- Malargüe (ESA DSA3) adds 3 baselines
- Full sky coverage by accessing south polar cap
- Near perpendicular mid-latitude baselines: AC to BC

Summary

- ESA's NavSO is currently enhancing the processing capabilities of NAPEOS for VLBI tracking data
- ESA's ΔDOR system was implemented in 2005 and is used to support interplanetary spacecraft navigation
- ESA is in cooperation with other agencies for ΔDOR observation and VLBI network densification (X/Ka-band quasar catalogue)