8th International Colloquium on Scientific and Fundamental Aspects of GNSS
14 - 16 September 2022 | Sofia, Bulgaria

VLBI Observations to Satellites: Achievements and Opportunities

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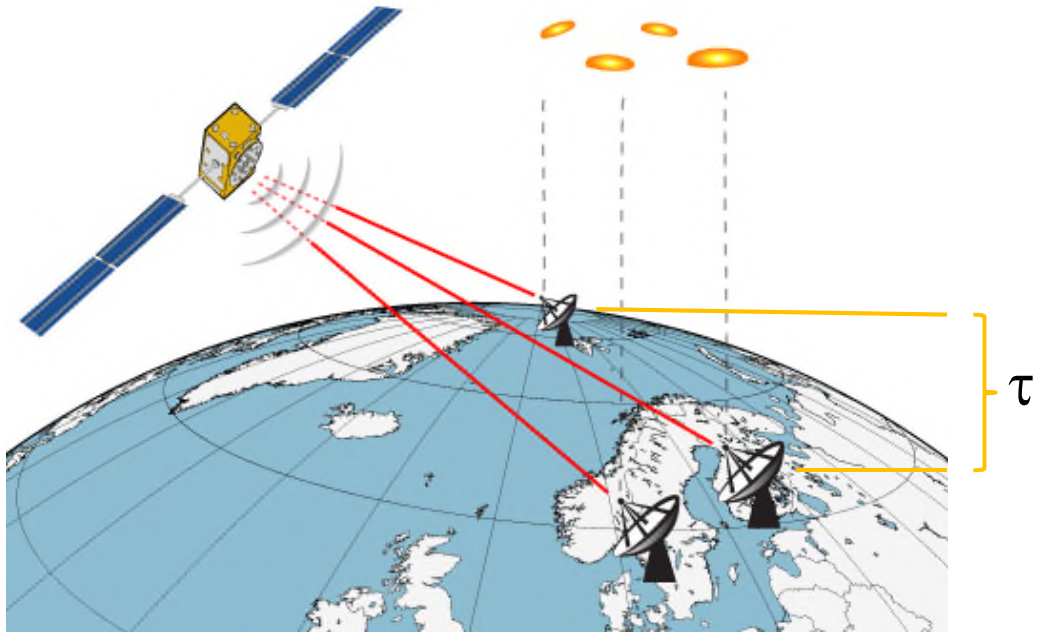
Der Wissenschaftsfonds.

Why should we observe satellites with VLBI radio telescopes?

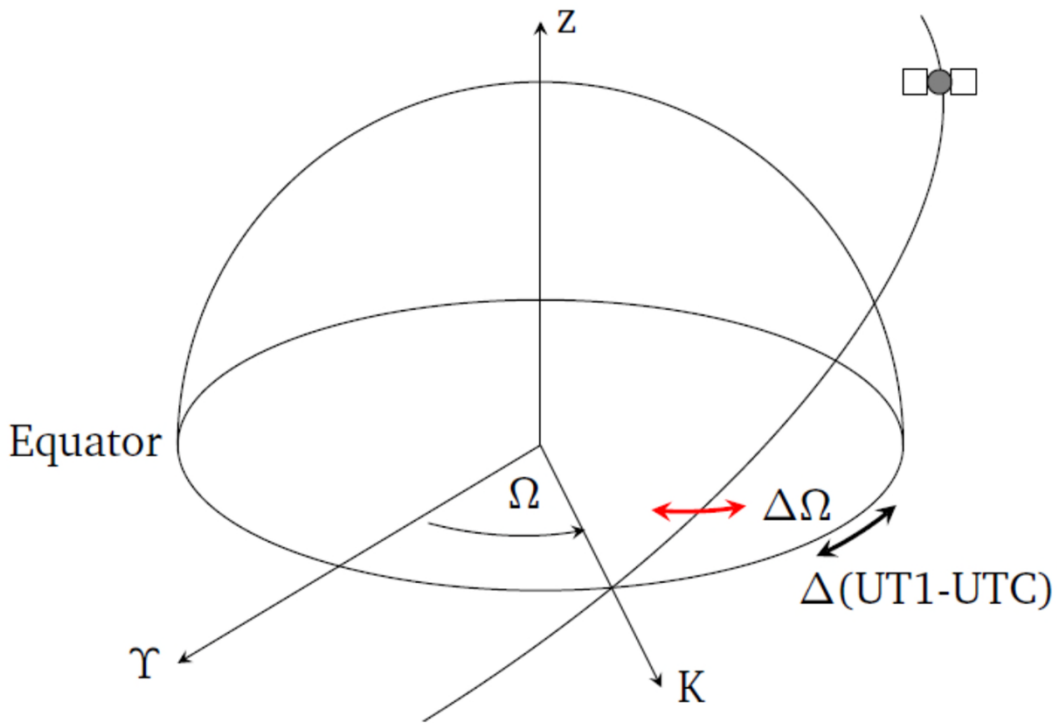
- Very Long Baseline Interferometry (VLBI) measures the difference in arrival time τ of signals (noise) from quasars at radio telescopes
- VLBI observations to satellites are the missing link in space geodesy
  - Satellites are routinely observed with GNSS, SLR, and DORIS



Why should we observe satellites with VLBI radio telescopes?

- We could (better) tie the satellite orbit to the International Celestial Reference System
- With satellite techniques alone, we cannot distinguish between a rotation of the satellite orbit and the rotation of the Earth (UT1-UTC)
  - e.g., due to errors in solar radiation pressure modelling
- Integrated Length-of-Day values from GNSS drift

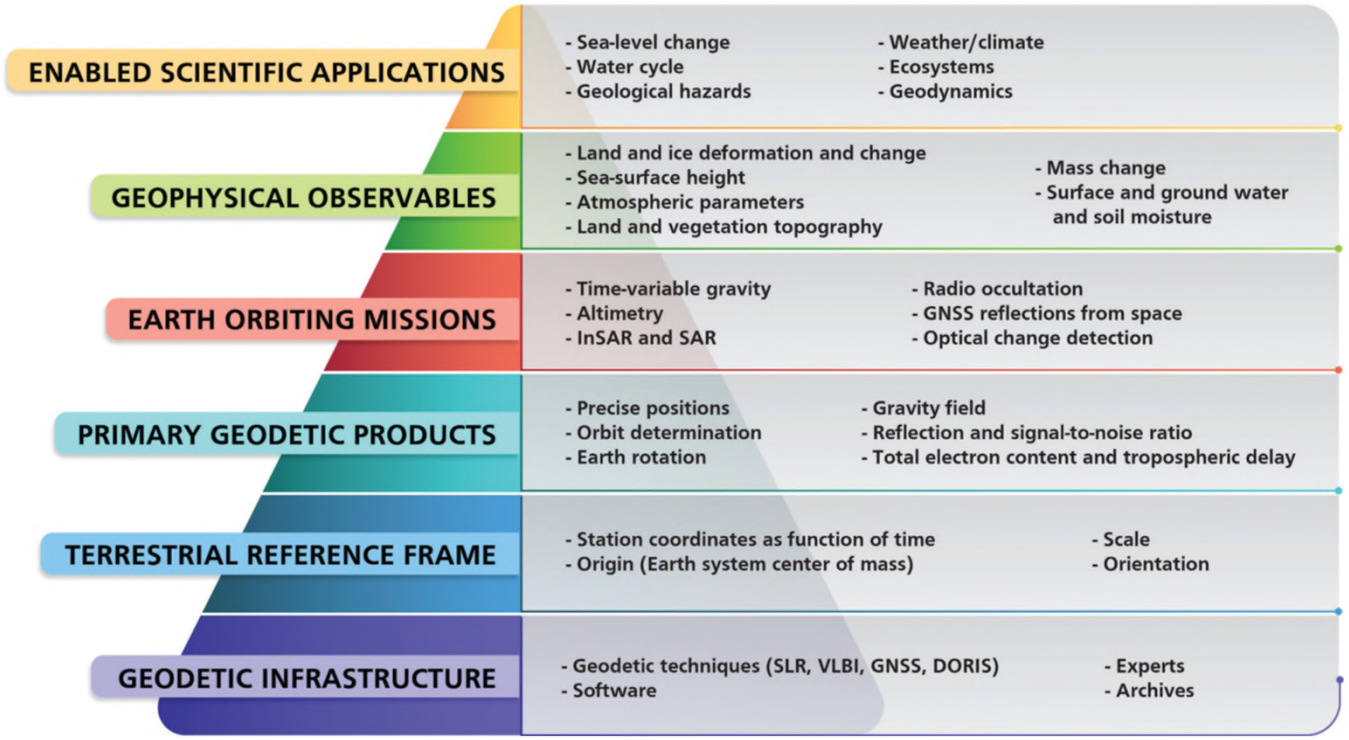
- $\Rightarrow$ VLBI to Galileo satellites



Why should we observe satellites with VLBI radio telescopes?

- Realising ties on-board a satellite in addition to local ties on the ground
- Improvement of the terrestrial reference frame

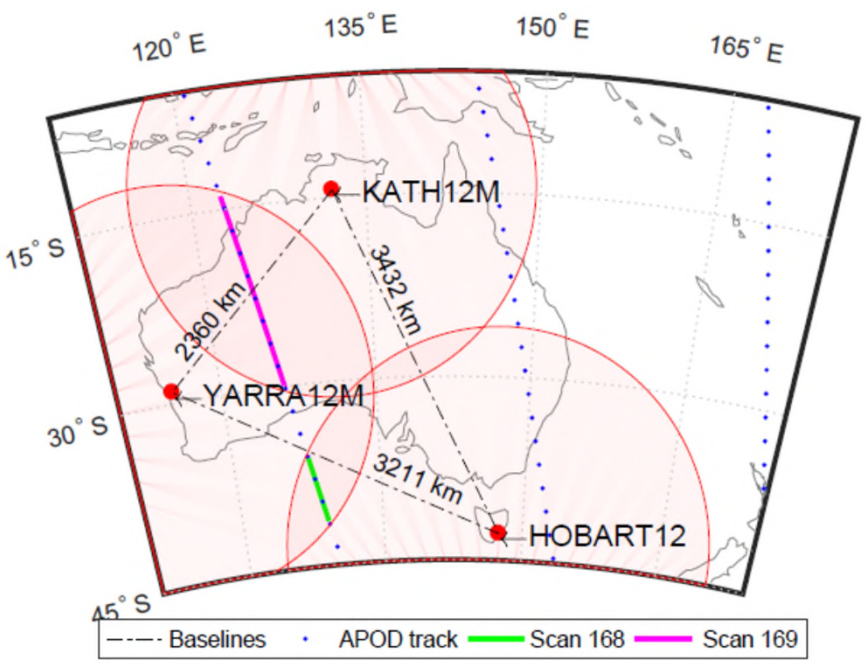
- ⇒ VLBI observations to Genesis

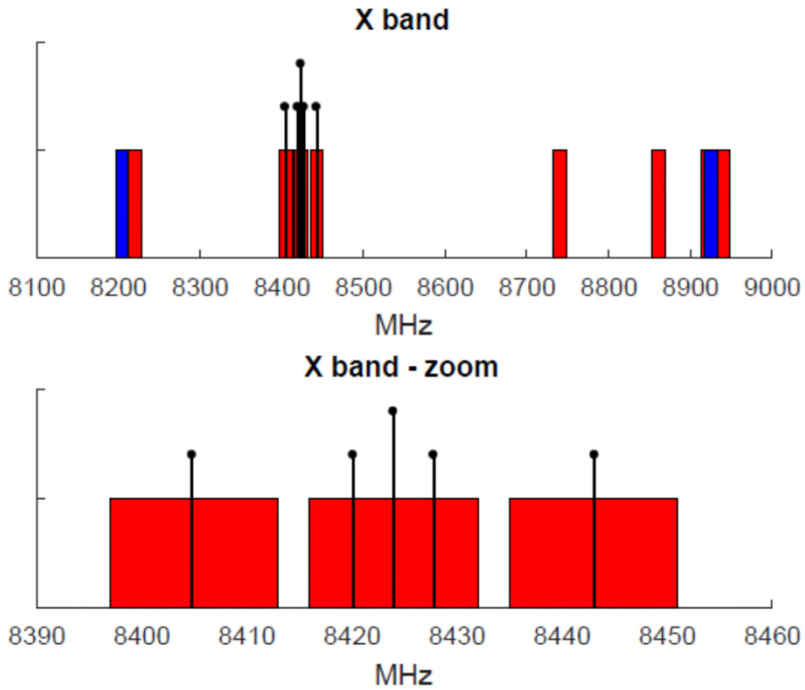


National Academy of Sciences, 2020

Past achievements with real observations

- L-band GNSS satellite signals: E.g., Tornatore et al. (2014), Kodet et al. (2014), Haas et al. (2014, 2019)
- GNSS satellites at L1 with Australian baseline Hobart-Ceduna (Plank et al., 2017)
- APOD-A with Australian network (Hellerschmied et al., 2018)





Past achievements with real observations

- OCEL observations to DOR tones from the Chang‘e-3 lander on the Moon
  - postion accuracy at the level of several meters

Comments on the elements in the VLBI processing chain (1/2)

- Scheduling
  - Good progress, e.g. with VieSched++ (Schartner and Böhm, 2019)
- Data transfer
  - Feasible, since real-time is not the goal currently
- Analysis
  - Near-field delay models available
  - Software packages under development (Bernese, C5++, VieVS, ...)

Comments on the elements in the VLBI processing chain (2/2) – lessons learned

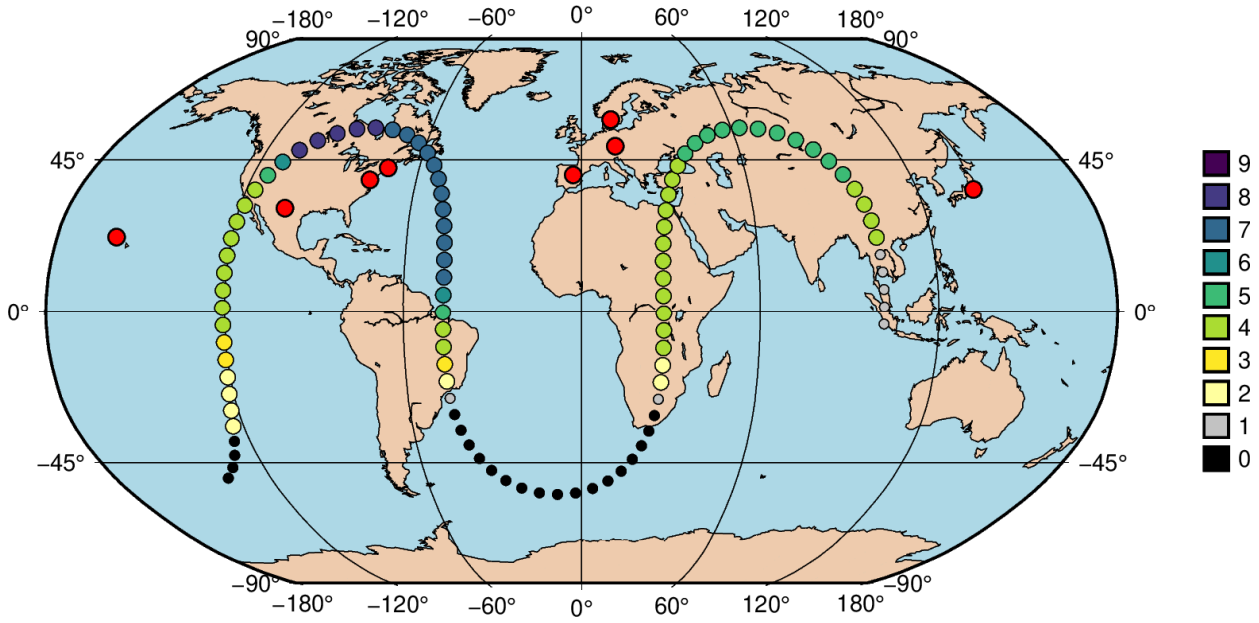
- Observation
  - Tracking of low satellites tricky
  - Limited possibilities because of receiving systems versus existing signals
  - VLBI needs X/S band or VGOS frequency range
- Correlation and fringe-fitting
  - Tricky because of frequency setup, e.g., for DOR tones
  - Bandwidth of several hundred MHz needed
  - No experience with modulated signals for ranging

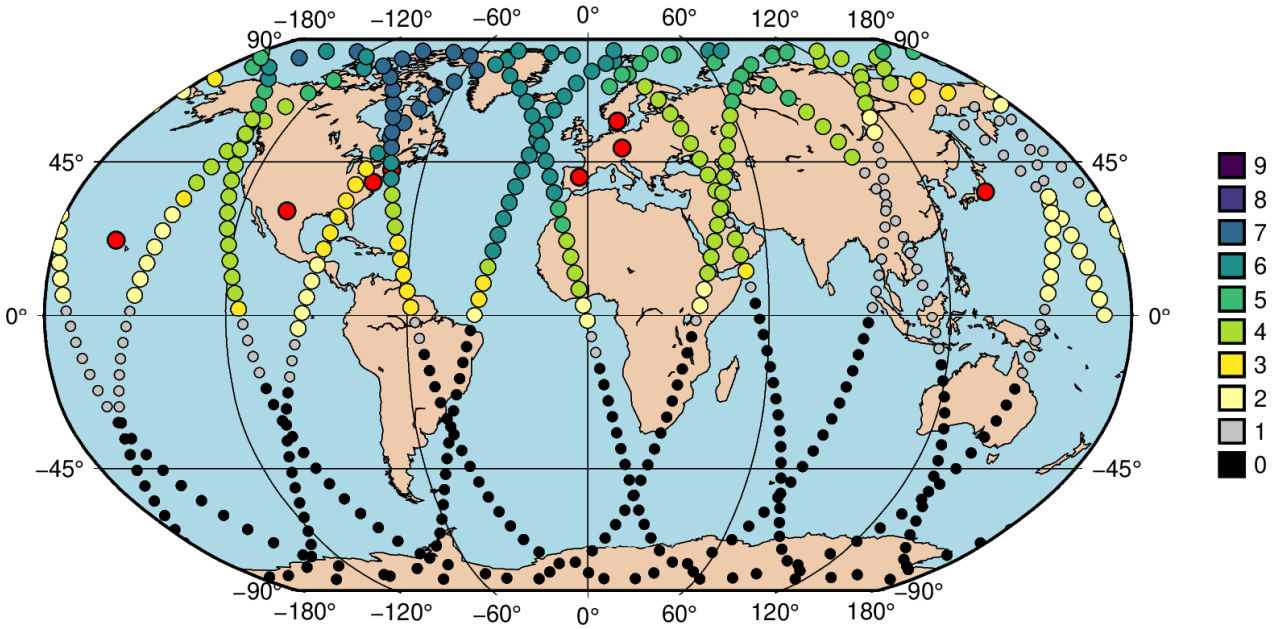
Past achievements with simulations of VLBI observations to

- GNSS satellites Plank et al. (2014, 2015), Schunck et. al (2022), Sert et al. (2022)
- Co-location satellite by Anderson et al. (2018)
- MEOs by Klopotek et al. (2020)
- ...

Visibilities for Galileo and Genesis

- One day for one Galileo and the Genesis (6000 km) satellite with 8 stations





Orbit precision based on DOP values

Orbit precision based on Monte Carlo simulations

- Kinematic positions versus Orbit elements
- Deficiencies with longer arcs because of troposphere

Station coordinates and frame ties

Do we need modulated signals for ranging?

- Would allow direct ranging (time of flight, ToF) measurements between Genesis and VLBI telescope
- Satellite clocks on Genesis known with high accuracy (from estimation)
- This time information will then be known at the VLBI telescope if the path in the latter is well calibrated
  - Corrections at the hydrogen masers will be available
  - Currently, VLBI refers the time to the clock at Kokee (Hawaii)
- Allows the positioning of the satellite in the orbit with good accuracy
  - 1 μs mean 7 mm @ 7 km/s

Conclusions