UCLouvain

GENESIS project: VLBI Antenna

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esa genesis

How the VLBI antenna looks like?

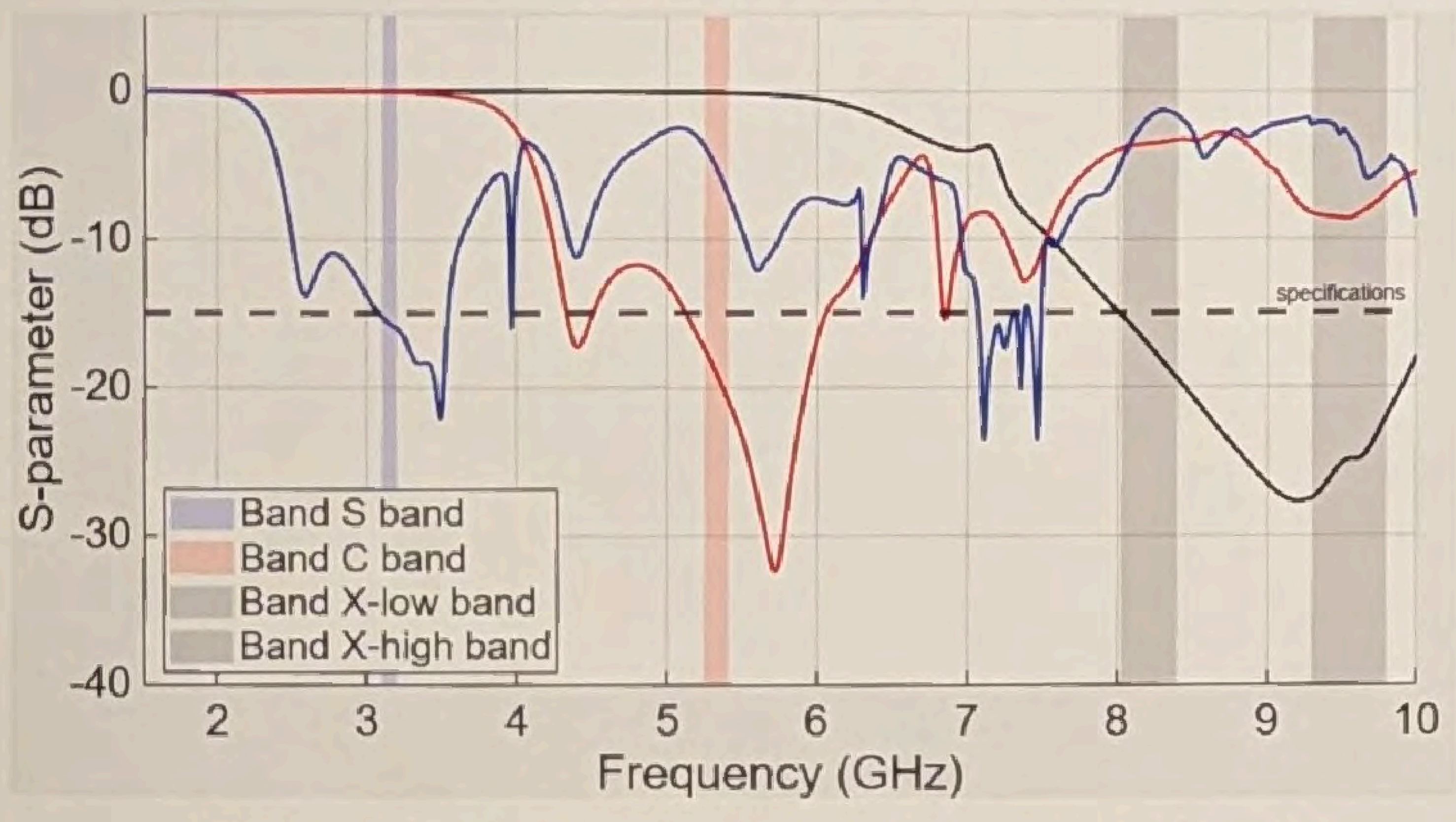
Three circularly polarized (CP) metallic cavity antennas operate in the four frequency bands. The antenna consists of an air-filled cylindrical metallic cavity, open at the top and short circuited at the bottom and is excited by a single L-shaped probe. The L-shaped probe simultaneously excites two orthogonal modes inside the cavity with equal amplitude and a 90° phase difference, generating left-hand circular polarization (LHCP) at the aperture [1].

Frequency bands and main requirement

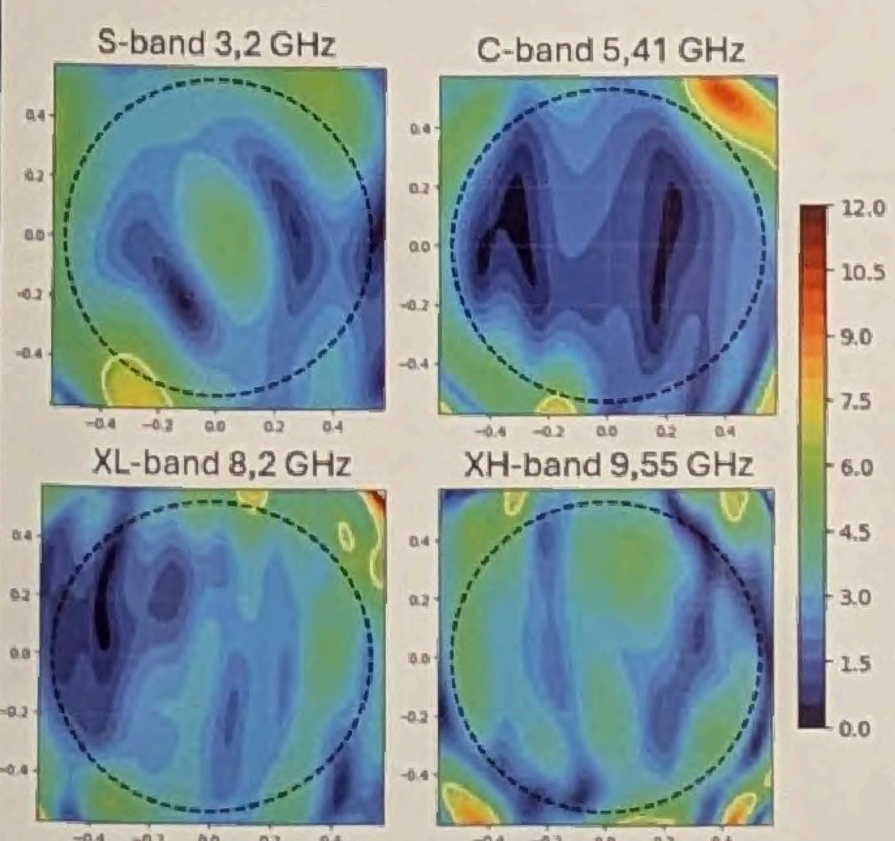
Frequency band	Start frequency [GHz]	End frequency [GHz]	Occupied bandwidth [MHz]
S band	3.1	3.3	200
C band	5.25	5.41	320
X-low band	8.025	8.4	375
X-high band	9.3	9.55	500

Main Specifications	
Parameter	Limit
Matching	-15 dB
Gain variation	< 3-5 dB
Polarization	Circular
Axial Ratio	< 10 dB
Mass	600 g (with margin)

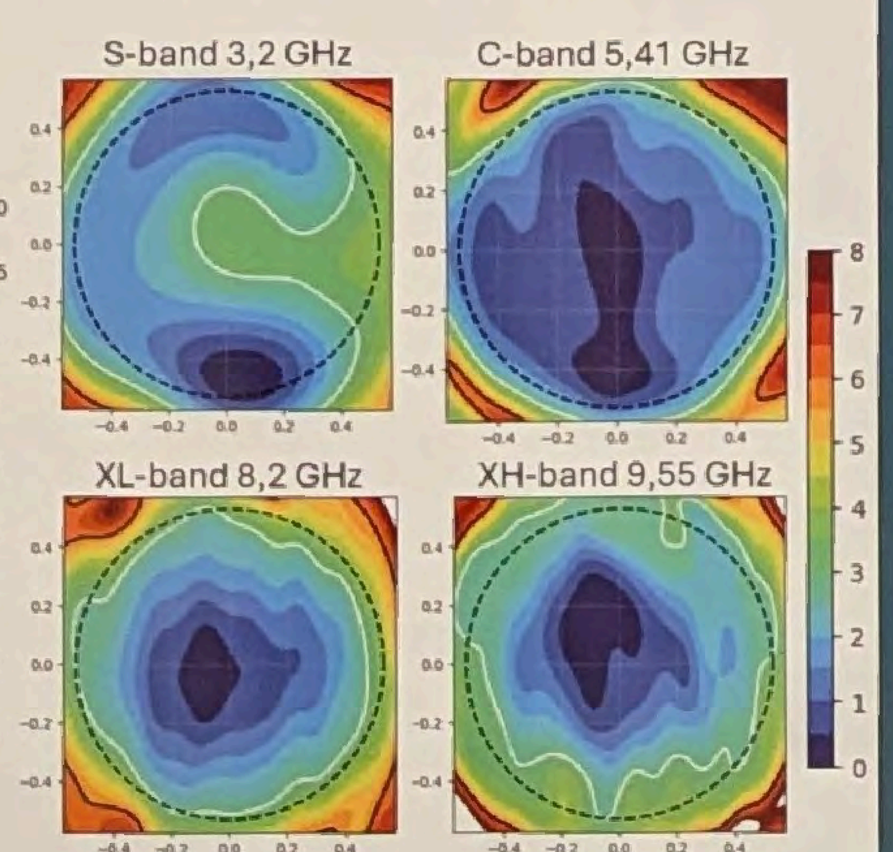
EM performances



Antenna impedance. (Dash line: The specification.)



Axial Ratio map for four frequency bands.



Gain Variation (GV) map for four frequency bands.

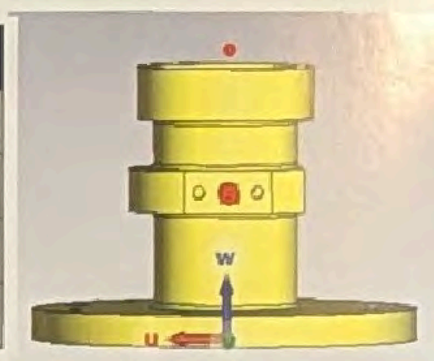
Area within the dash line: Field-of-View (FoV).
Area within the white line in the GV map: GV < 3dB.
We can see that the performance are all in compliance within the FoV.

[1] Longsheng Liu. "A wideband circularly polarized metallic antenna fed with an L-shape probe". In: *Microwave and Optical Technology Letters* 56.10 (2014), pp. 2398–2403.

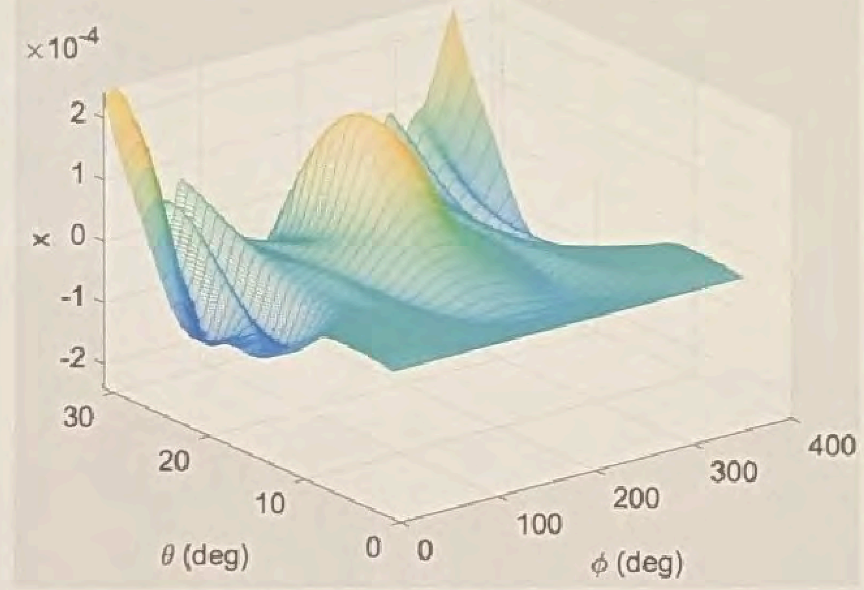
Phase center and Group Delay (GD)

The table below is the antenna Phase Center Offset (PCO) position on the central frequency of each band. The figure on the right contains the PCO coordinate system (UVW ⇔ XYZ) and the visual PCO location of the X-low band.

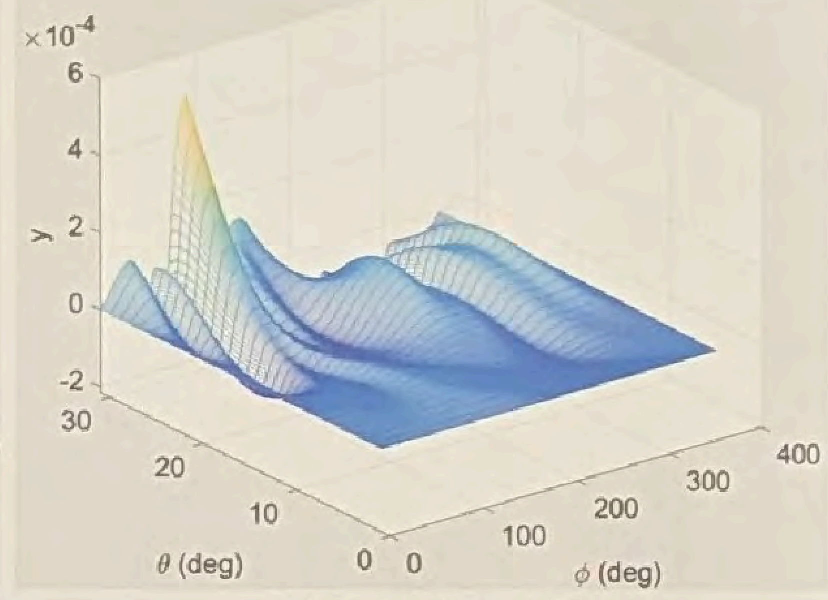
Phase center offset (PCO)	VLBI Antenna			
Central Frequency (GHz)	S band	C band	X-low band	X-high band
X coordinate (mm)	-2.8	-0.2	-0.9	-0.2
Y coordinate (mm)	-0.5	0.3	0.0	0.2
Z coordinate (mm)	59.7	79.5	55.8	54.3



Phase Center Variation (PCV) plot at X-low band 8.2GHz. (Unit: meter)

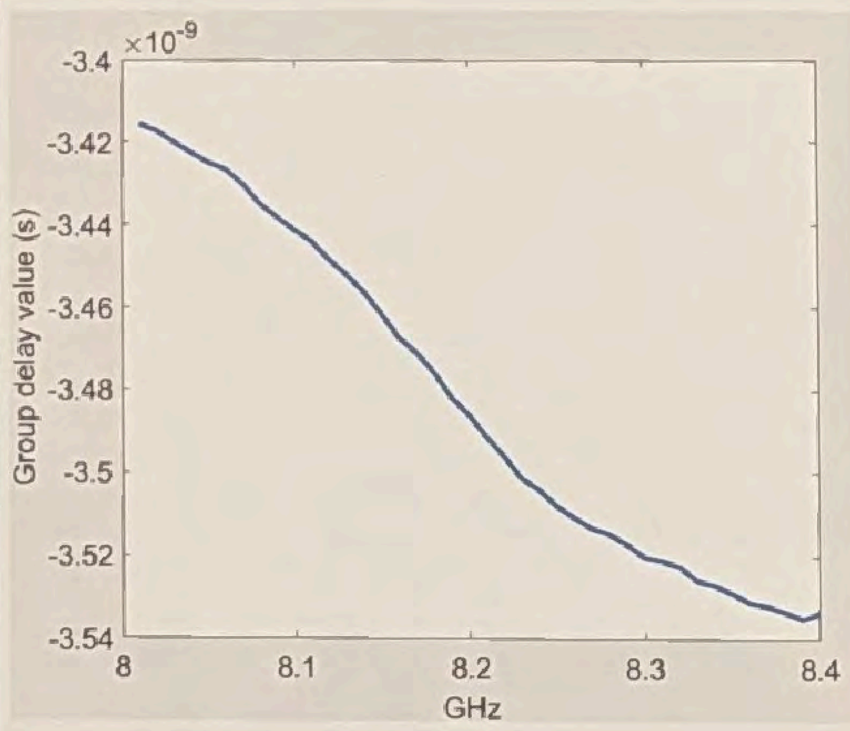


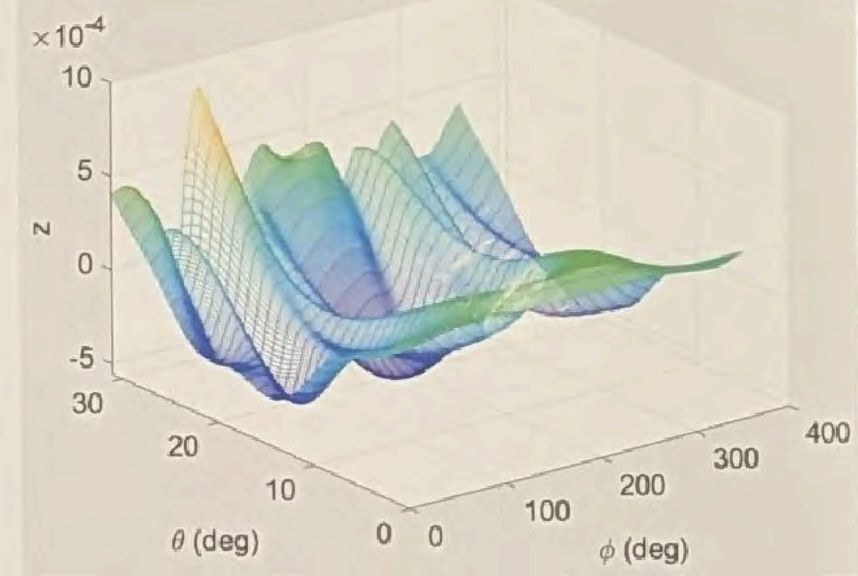
(a) In X direction.



(b) In Y direction.

The figure below is Group Delay plot at boresight over frequency on X-low band.





(c) In Z direction.

	Average	Maximum
Group delay variation (GDV) for all frequency bands	0.11ns	< 0.3ns

Mechanical and thermal stability

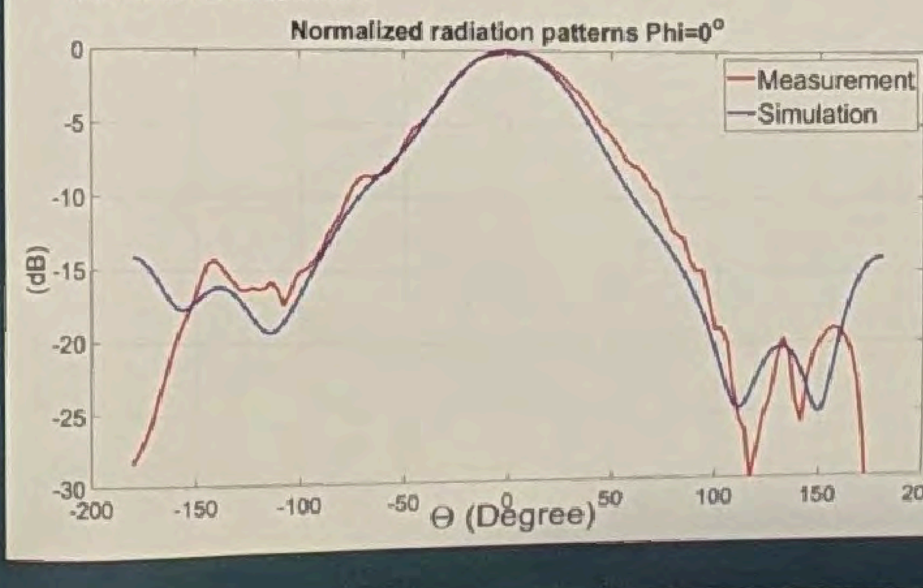
The structural stability of the VLBI antenna is verified through mechanical analyses.
The comparison table on the right is to show the antenna thermal stability between +105 °C/-100 °C and reference room temperature.

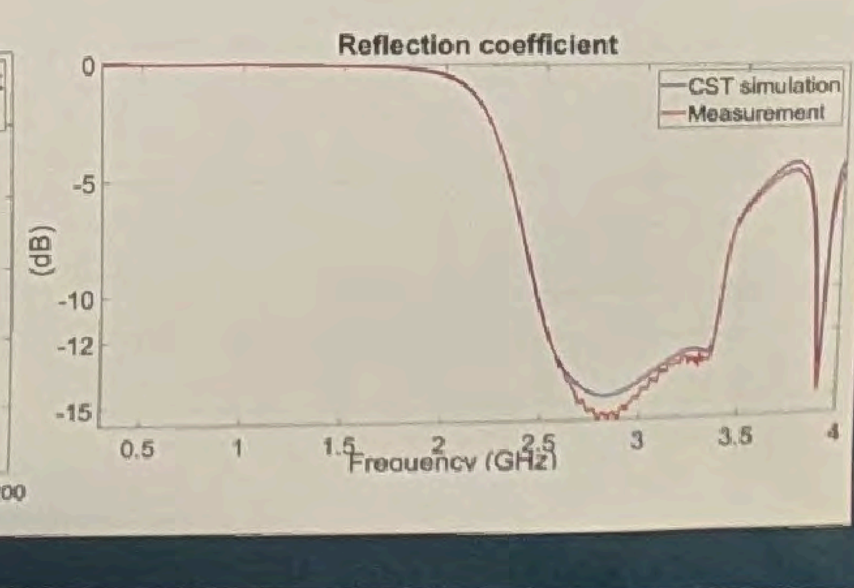
Mechanical analysis	Compliance
Static	✓
Quasi-static	✓
Random vibration	✓
Sinusoidal vibration	✓
Shock	✓
Linear Acceleration	✓
Angular Acceleration	✓
Angular Rate	✓
Depressurization	✓

	Comparison between +105 °C/-100 °C with reference room temperature(+20°C)	
	Average change	Maximum change
Antenna deformation	0.16mm	0.3mm
Antenna performance (Impedance, AR, GV)	0.1dB	0.3dB
PCO	0.2mm in Z position. Less than 0.1mm in X and Y position.	0.6mm in Z position. Less than 0.1mm in X and Y positions.
GD and GDV	Less than 0.01ns	less than 0.02ns

First prototype fabrication and measurement

The first measurement results show a good agreement with the simulations.





GENESIS

GENESIS-D: a geodetic project by German organizations to support ESA's Genesis mission

Heinkelmann[1] R., Schuh[2] H., Thaller[3] D., Bloßfeld[4] M., Glaser[5] S., Schreiner[1] P., Flohrer[3] C., Seitz[4] M., Männel[1] B., Flechtner[1] F., Jeon[1] S., Balidakis[3] K., Weinem[3] L., Yeskali[1] Y., Baumgartner[4] M., Zeitlhöfler[4] J., Seitz[4] F.

(1) GFZ Helmholtz Centre for Geosciences (4) TUM (3) BKG Wir geben Orientierung. (5) UNIVERSITÄT BONN (2) Technische Universität Berlin

ESA's Genesis Satellite Mission

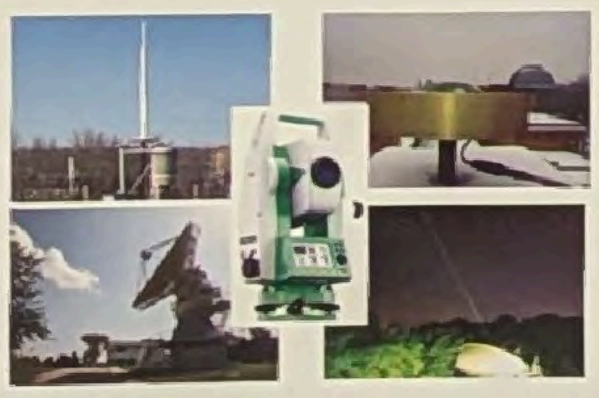
- For the first time a **MEO co-location satellite** (altitude ≈ 6000 km, i ≈ 95°) with the four space geodetic techniques GNSS, SLR, DORIS, and VLBI on board that contribute to the ITRF.
- The application of phase center to center of mass tie vectors allows for the combined orbit determination, presenting an innovative four-technique **Space Tie** for the ITRF computation.
- The active **VLBI transmitter** on board the satellite is a novelty for the geodetic community.
- The **time and frequency** on board the satellite will be delivered centrally, a novelty for the DORIS payload.

Credit: © ESA-D. Ducros

Genesis mission patch
Credit: © ESA

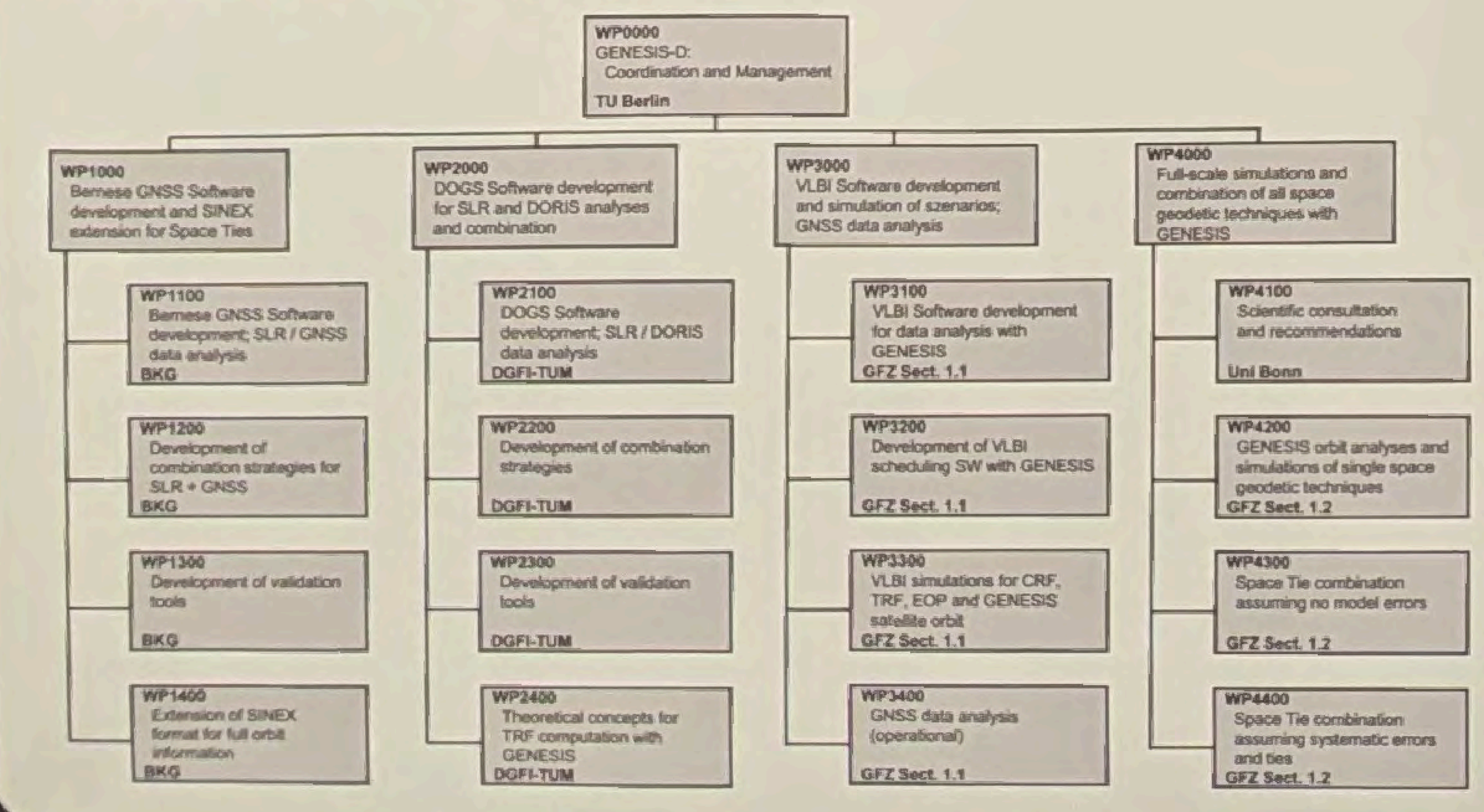
GENESIS-D Project Objectives

- Establish a **scientific network** of researchers capable of **simulating, analyzing and combining** the **four space geodetic techniques** that contribute to the **generation of highly precise terrestrial reference frames**.
- Investigate aspects of **satellite scheduling** of VLBI and SLR observations.
- **Develop the software** of the project partners to handle Genesis data.
- Test the combined orbit determination for Genesis with **simulated data** and with **real data** from other satellites, such as Sentinel-6A (ESA).



The **Space Tie** allows for testing local ties and it will provide a unique option for identifying systematic errors across the four space geodetic techniques.

GENESIS-D Work Package Structure



Genesis: community-based scientific exploitation

- ESA proposed to deliver the data relevant for the scientific exploitation as **open access** to the geodetic community.
- The coordination of the scientific part of the mission is organized by ESA through the interface between ESA and the scientific community, that is the **Genesis Scientific Exploitation Team** (GSET).
- With that, the success and the exploitation of the mission depend on the activity of the geodetic community, in particular of the IAG Technique Services: **IGS, ILRS, IDS, and IVS**.

IVS ILRS IDS IGS INTERNATIONAL GNSS SERVICE

GENESIS-D: German contribution to Genesis

- The scientific contributions of German organizations to the success of this mission are bundled in project GENESIS-D.

- Funding is provided by the German Space Agency at DLR (acknowledgement).

GENESIS-D: contributions of the Project Group to WGs

		ESA GSET WG					IAG, IERS & GGOS
		WG-1 ITRF & Combination	WG-2 GNSS	WG-3 VLBI	WG-4 DORIS	WG-5 SLR	Joint WG 1.1.1 GENESIS
Harald Schuh	TU Berlin			x			
Robert Heinkelmann	GFZ	x		x			x
Benjamin Männel	GFZ	x	Co-Chair				x
Patrick Schreiner	GFZ	x			x		x
Florian Seitz	DGFI-TUM	Co-Chair					x
Manuela Seitz	DGFI-TUM	x					x
Mathis Bloßfeld	DGFI-TUM	x				x	x
Daniela Thaller	BKG	x					x
Claudia Flohrer	BKG	x		x			x
Susanne Glaser	Uni Bonn	x					x

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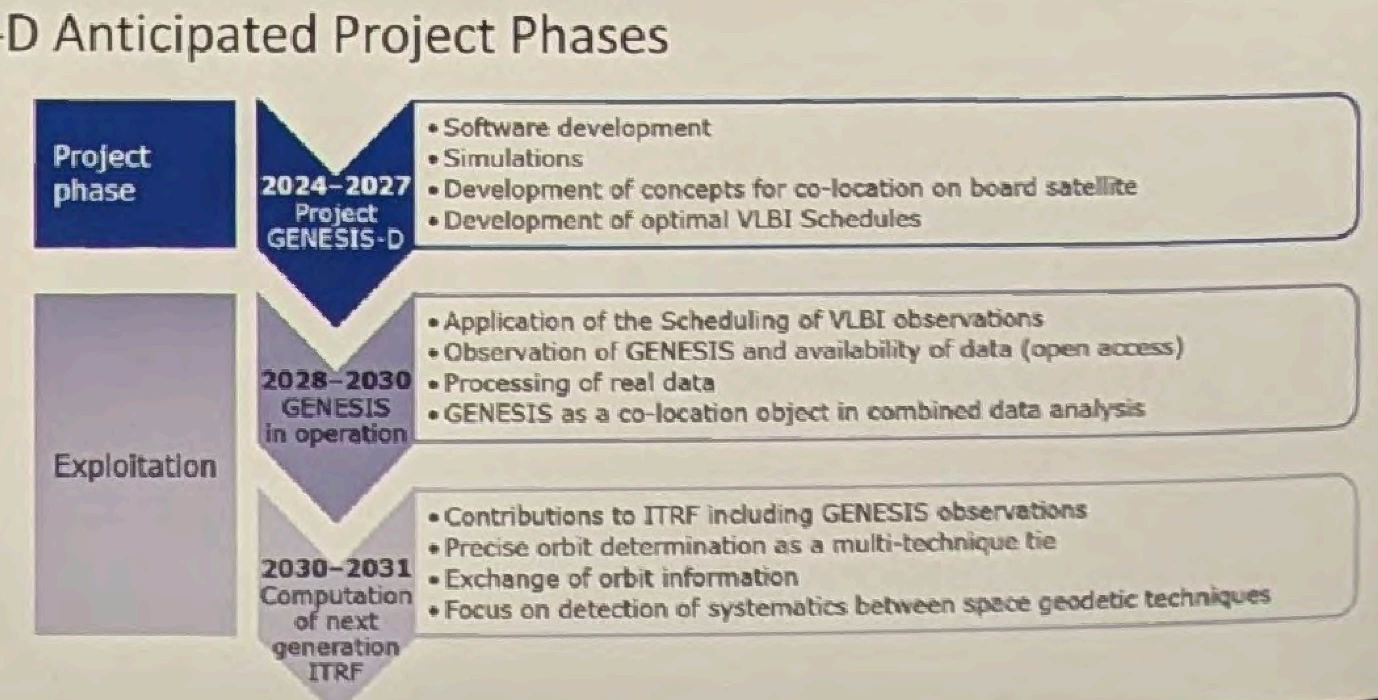
International Association of GEODESY

International Earth Rotation and Reference Systems Service

GGOS Global Geodetic Observing System

Genesis-D Anticipated Project Phases



Combining Geodetic Techniques at the Observation Level: Challenges and New Perspective for the Terrestrial Reference Frame

Paul Ries,[1,a] Bruce Haines,[1] Willy Bertiger,[1] Shailen Desai,[1] Michael Heflin,[1] Da Kuang,[1] Charles Naudet,[1] Athina Peidou[1]

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Observation Level Frames

Each of the four space geodetic techniques (GNSS, DORIS, VLBI, SLR) contributes with various strengths to a global terrestrial reference frame (TRF). The current International Terrestrial Reference Frame (ITRF) and those preceding it have combined station position and Earth orientation from each of the four techniques processed separately. Since such information is typically stored in a SINEX file, we refer to this form of reference frame as a combination-at-SINEX-level frame, where the four techniques are processed independently, then their outputs are later combined.

Recently, JPL has begun exploring reference frames which process measurements at the observation level from all four techniques concurrently (Haines et al., 2024), resulting naturally in the combination of the four techniques. We refer to this as a combination-at-observation-level frame.

Space Ties

In typical TRF solutions, techniques are tied together using surveyed site ties between different ground sites (e.g. between an SLR telescope and a nearby GNSS receiver). Measuring such ties is challenging. In our research, we use spacecraft which provide ties of opportunity with precisely measured installation of instruments from multiple geodetic techniques.

By using Jason-2 and -3 and the GRACE missions we can tie together GNSS and SLR without using ground ties. Our most recent development is using Jason-2 to add DORIS to the solution with space ties.

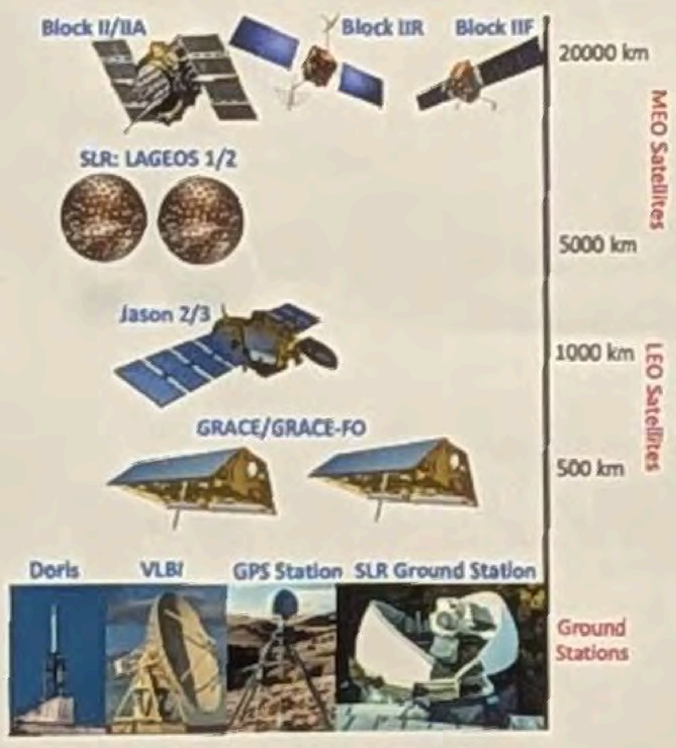

Figure 1. Illustration of ground, LEO, and MEO platforms used in observation-level TRF

Spacecraft	GNSS	SLR	VLBI	DORIS	Years
Jason-2	X	X		X	2008-2019
Jason-3	X	X		X	2016-
GRACE-A/B	X	X			2002-2017
GRACE-C/D	X	X			2018-
Sentinel-6A	X	X		X	2021-
Sentinel-6B	X	X		X	2025-
SWOT	X	X		X	2023-
GRITSS	*X*	*X*	*X*		*2026-*
GENESIS	*X*	*X*	*X*	*X*	*2028-*

Table 1. Satellites available to provide space ties. So far, we have used Jason-2, Jason-3, and the GRACE missions as ties of opportunity. GENESIS will provide the first opportunity to tie together all 4 techniques

3-technique reference frame at measurement level

Time Span: 2010.0 – 2022.6
Arc length: 3.25 d
Number of GPS stations per solution: 45
Superset of nearly 550 stations.

- GNSS (388)
- SLR (47)
- VLBI

Haines et al., 2024

Linear and annual motions for:

- 210 GNSS sites
- 27 SLR observatories
- 17 VLBI stations

Derived GPS-SLR ties

- Test vs surveyed values
- Mean E, N, V accuracy: 3, 5, 5 mm

Figure 2. Plot of velocity field (plate motion) from 3-technique reference frame.

Recent work: adding DORIS to make 4-technique frame

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

- One space tie: Jason-2
- ~47 ground stations per day
- Data weight: 0.5 mm / s
- 3.25d arcs spanning 04/2019 – 07/2019
- Station positions 100m apriori – all techniques

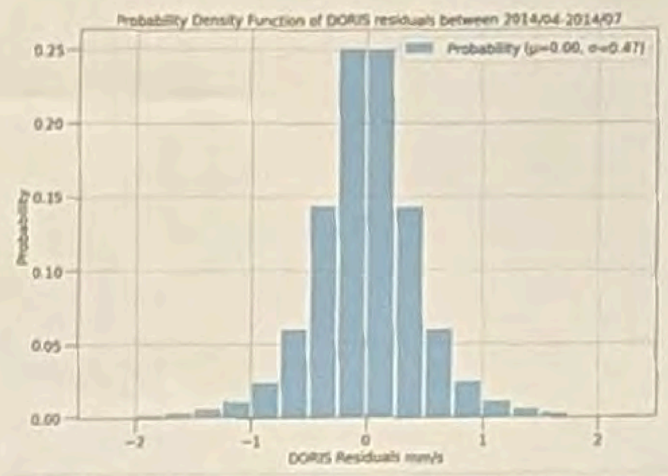

Figure 3. Histogram of all DORIS residuals for 3-month experiment

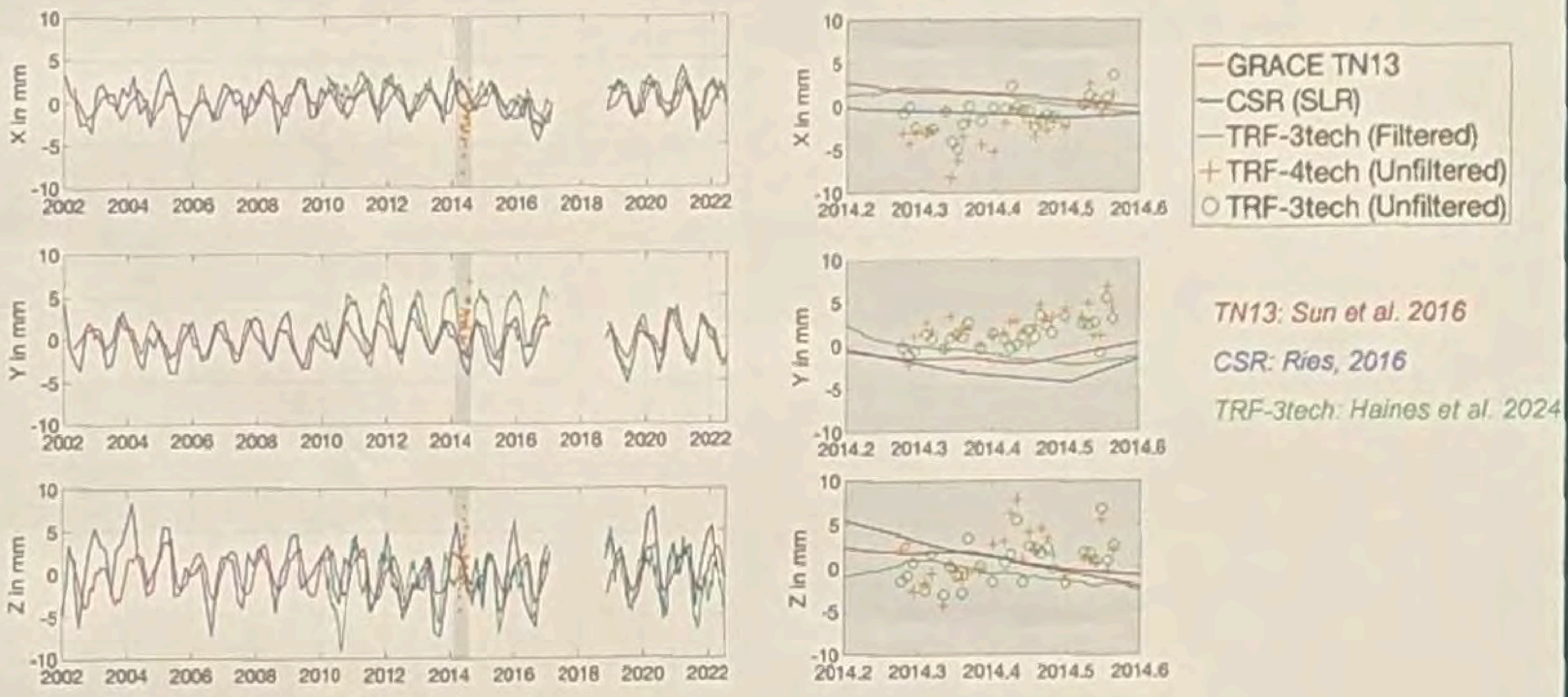

Figure 4. Comparison of Geocenter motion from several different time series

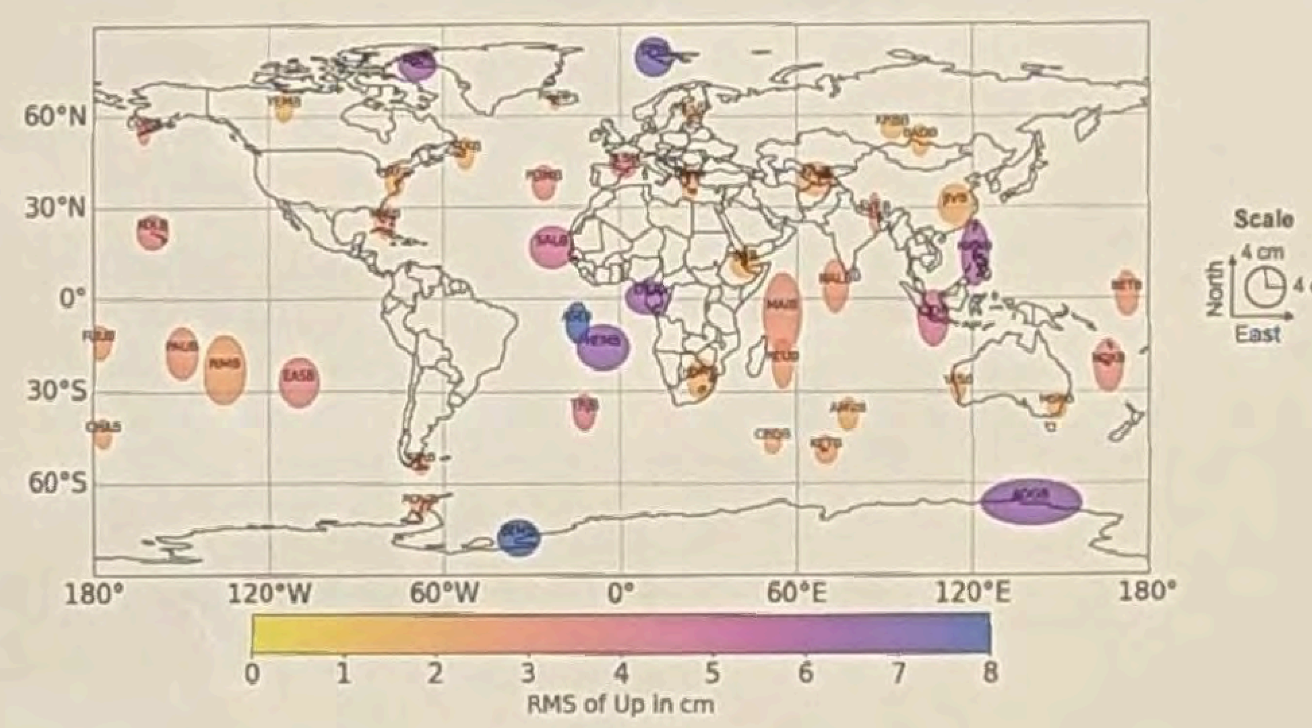

Figure 5. DORIS station repeatability demarcated by ellipse for E and N and shading for V

4-technique results

- Consistent geocenter results with unfiltered 3-technique time series
- DORIS station positions reproduced at ~4 cm in horizontal

Challenges with existing opportunistic ties

- Adding ability to process multiple clocks for existing DORIS platforms
- Adding all necessary calibrations (e.g. SLR biases, VLBI antenna offset correction)
- Coping with the lack of a space tie for VLBI (requires ground ties)
- Preprocessing of diverse away of file formats
- Acquiring all necessary data for LEOs (RINEX, SRP modeling, attitude model/attitude quaternions)
- Tuning the relative weighting of diverse observation types from different techniques with markedly dissimilar data abundance (e.g., GPS vs VLBI).
- Establishing best practices for troposphere ties at collocated sites.
- Screening bad data, especially for VLBI (new to GipsyX).

Future work

- Add additional LEOs with DORIS
- Add additional SLR-only platforms (LARES 1 + 2)
- Extend 4-technique from 2010 to present (vs 3-month test)
- Convert output to SINEX files
- Process GENESIS

Acknowledgements and References

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Haines, B., Bertiger, W., Desai, S., Ellmer, M., Heflin, M., Kuang, D., Lanyi, G., Naudet, C., Peidou, A., Ries, P., Sibois, A., Wu, X. (2024) A Global Combination of Geodetic Techniques at the Observation Level: New Perspectives on the Terrestrial Reference Frame. *Journal Of Geophysical Research*. doi.org/10.1029/2024JB029527

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Sun Y., Riva R., Ditmar P., 2016. Optimizing estimates of annual variations and trends in geocenter motion and J2 from a combination of GRACE data and geophysical models, *J. Geophys. Res.*, 121(11), 8352–8370.. 10.1002/2016JB013073