# Genesis Science Update

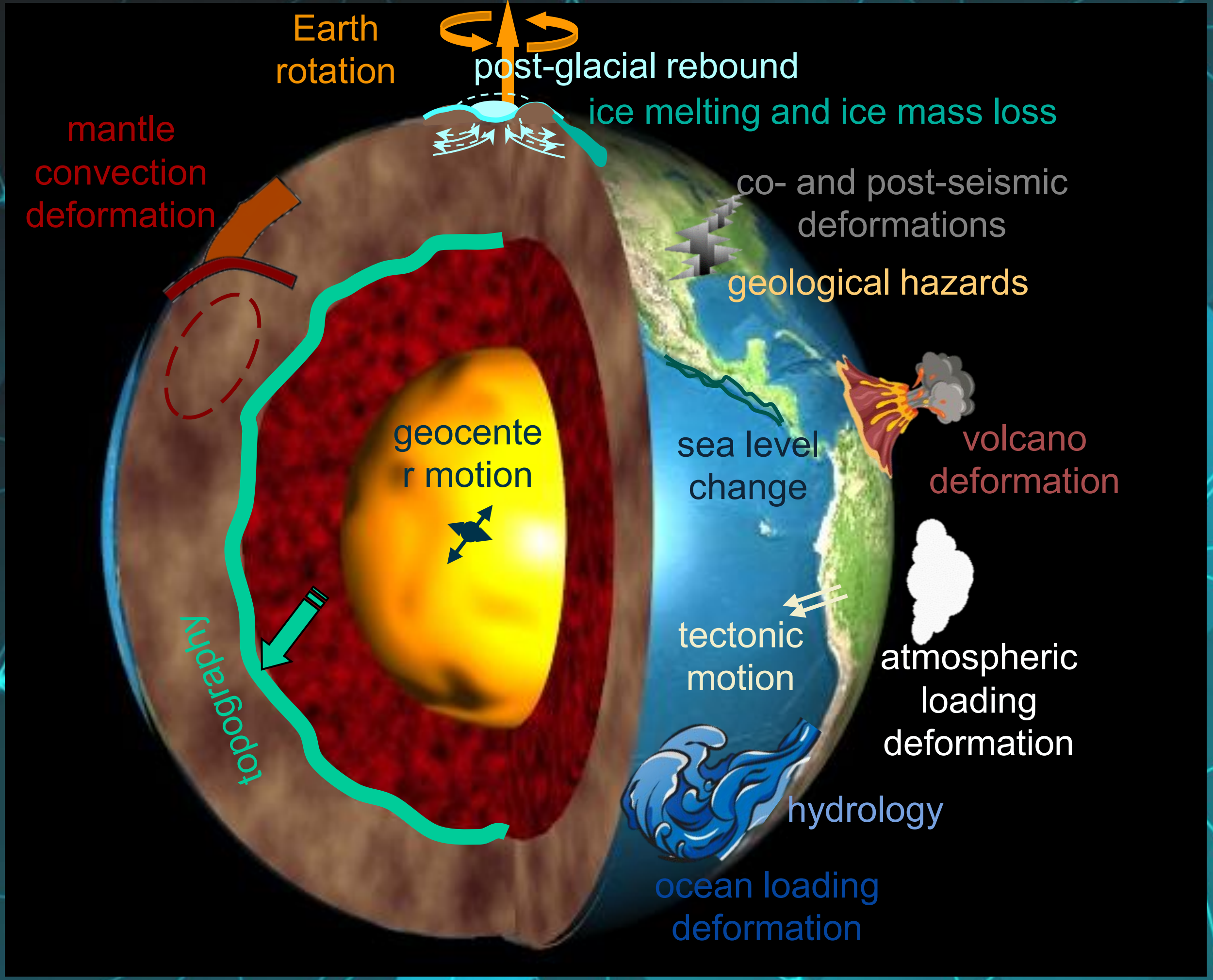
Özgür Karatekin, Francesco Vespe

FUTURE NAV esa.int/Applications/Navigation

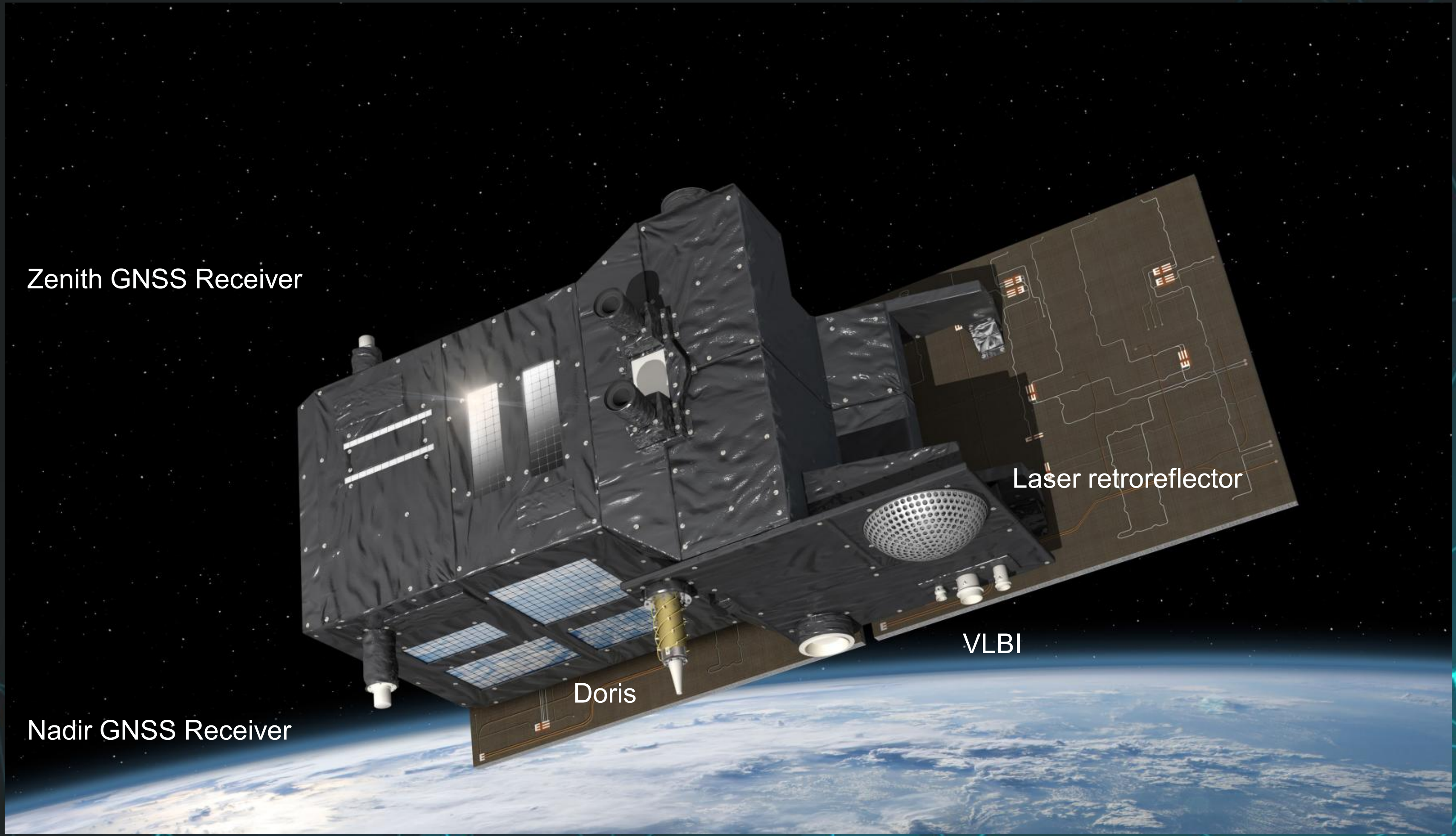
# International Terrestrial Reference Frame (ITRF) improvement

- The ITRF is defined through coordinates of tracking stations, accommodating motions of the Earth's deforming crust, caused  mainly by plate tectonics and post-glacial rebound

- Genesis will contribute to a highly improved International Terrestrial Reference Frame (ITRF) of Earth with a target accuracy of 1 mm and a long-term stability of 0.1 mm/year, providing a coordinate system for the most rigorous navigation applications on our planet.



# Space Ties




Genesis does not directly improve ITRF but identifies intra- and inter-technique systematics through combined POD  in mm scale—critical paradigm shift

Genesis's extreme accuracy is achieved by co-locating the four geodetic techniques onboard one well calibrated satellite that acts as a flying observatory.

# Genesis Mission: next steps after PDR

## Support of the Genesis Science Team during Phase C:

- Support detailed satellite & instrument design consolidation
- Support testing, verification and calibration strategy
- Support data type, volume and interface definition
- Contribute to end-to-end performance assessments
- Consolidate Genesis data processing concepts
- Contribute to system, instrument and technique operational concept
- Contribute to preliminary observation campaign definition and planning
- Consolidate service-specific interfaces for IGS, IDS, IVS, ILRS
- Prepare readiness of the services ground support infrastructure
- ➢ Manage and execute GSET activities

# Genesis Science Exploitation Working Groups

*All Working Groups exchange and interact with one another*

## WG1: ITRF & Combinations of Techniques

- **Focal point for ITRF and Combinations of Techniques** related topics
- **System Aspects**
- **Accuracy analysis** of the ITRF and the associated improvements, based on Genesis generated data
- **Quantify the impact of the mission performance** on the ITRF accuracy and stability
- **Interact** with the International Earth Rotation and Reference Service (IERS)

## WG2: GNSS

- **Focal point for GNSS** related topics
- Investigate what new or improved Position Navigation and Timing (PNT) products can be obtained with the improved knowledge of the ITRF and all the data products that will stem from the Genesis mission

## WG3: VLBI

- **Focal point for VLBI** related topics
- **Analyse & quantify the impact** of mission performance on the **Earth Orientation Parameters** (EOP) and **ties between ITRF and International Celestial Reference Frame** (ICRF)
- Coordinate, prepare and realise the required **VLBI campaigns**, including any required upgrades to infrastructure, data processing etc

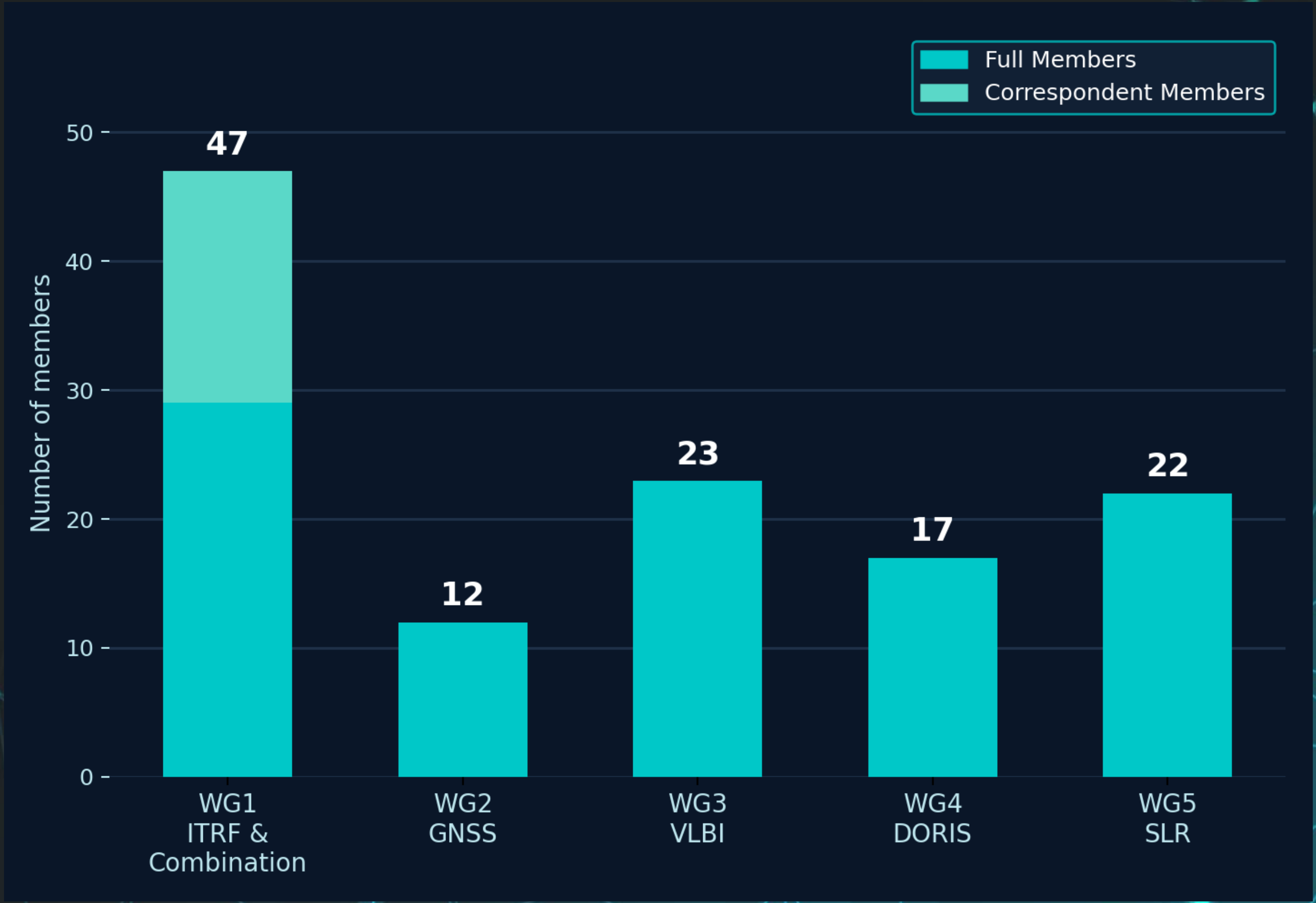
## WG4: DORIS

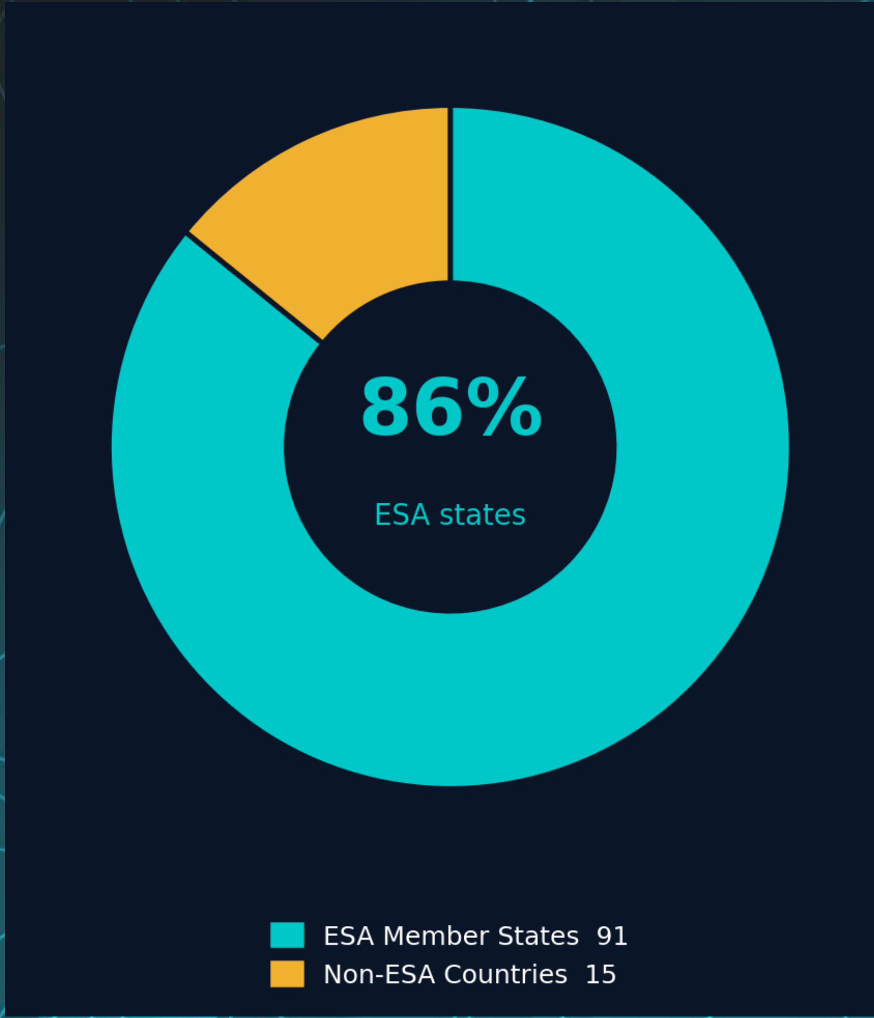
- **Focal point for DORIS** related topics
- **Improve the current measurements** of the ties between DORIS and the other geodetic technics

## WG5: SLR

- **Focal point for SLR** related topics
- Coordinate, prepare and realise the required **SLR campaigns**, including any required upgrades to infrastructure, data processing etc.

# Genesis Science Exploitation Working Groups




117 science members from 17 Countries regions

# Coordination Communications

- WG Meetings

    - WG1 Kick-off meeting  January 2025, total 3 meetings
    - WG2 Kick-off meeting July 2024, total 3 meetings.
    - WG3 Kick-off meeting July 2024, Monthly, total 15 meetings
    - WG4 Kick-ff meeting November 2024 total 3 meetings.
    - WG5 Started in summer 2024, total 4 meetings.

- Monthly meetings of GSET Management board

# GENESIS Objective: ITRF

## GSET WG 1

- **Combination of products**
- **Combination at the Observation Level including orbit combination (Space ties)**

**Ongoing work:**

- Development of concepts for the integration of Genesis observations into the TRF
- Process space geodetic techniques for TRF, CRF, and EOP utilizing satellites that support co-location
- Identify technique systematic errors/differences

- → Upgrade Software packages, Verify data formats
- → Combination of Genesis data with other satellites data
- → Consistent solutions of the four space geodetic techniques

→ Simulation of scenarios for optimal mission/ CONOPS

→ Getting ready to provide combined solutions; co-ordinated with IAG/IERS JWG 1.1.1

# ITRF Realisation Challenges

The orbit determination requirements at mm level

- Modelling of non-conservative forces
- Knowledge of the spacecraft orientation
- Estimation of the location of the centre of mass (COM)

Calibration of the Genesis Platform & Instruments (COM)

- Satellite CoM wrt. satellite mechanical reference frame
- Instrument reference point wrt. satellite mechanical reference frame
- Reference point stability wrt. environment, operations, lifetime…

→Sub-Working Group (WG1-S) on System Aspects

# Sub-Working Group (WG1-S) on System Aspects

**Support the spacecraft system-level design consolidation process up to CDR**

- Support detailed satellite design consolidation
- Support testing, verification and calibration strategy
- Collate information required for the scientific orbit determination process, in particular with respect to non-gravitational forces
- Develop, implement and validate scientific spacecraft dynamic model
- Contribute to system, operational concept

# Genesis Single Geodetic Techniques

- All 4 payloads moving forward in Phase C
- GSET WGs 2-5
  - revised the requirements, provided inputs & constraints
  - Will continue to support during Phase C:

Calibration of the Genesis Instruments

- Antenna PCO/PCV wrt. Instrument ref. point
- Antenna PCO/PCV stability wrt. environment, operation, lifetime

- Instrument design consolidation
- Prepare readiness of the services ground support infrastructure and Consolidate service-specific interfaces for IGS, IDS, IVS, ILRSP
- Data type, volume and interface definition
- E2E performance assessments
- Data processing
- Operational concept & Preliminary observation campaign definition

# GNSS activities and updates

## GSET WG 2

- WG2 discussion on maximizing the number of satellites tracked per epoch.
- From the experience with other LEO missions, calibration of the PCO and variations of antenna is a core issue for GNSS (including potential interferencies with other payload; nearfield effects, e.g., be the solar panel).

**Upcoming points for discussion:**

Simulations for an optimal GNSS tracking scenarios for best possible POD

Redundancy and risk mitigation for the GNSS equipment

Challenges in orbit modelling (shadowing effects etc.)

# VLBI activities and updates

GSET WG 3

esa

Implementing a new observing technique for satellites tracking  VLBI

- VLBI satellite tracking is is a novel technique that has never been realised for routine observations before
- VLBI transmitter is a novel instrument*
- Opportunity for Intercontinental Time/Freq transfer for the first time with VLBI technique

*→ Multiple aspects are yet to be investigated in order to make the Genesis VLBI observations reach their target accuracies.*

**Today, VLBI satellite observations only exist as test observations.  To further increase the achieved measurement precision by an order of magnitude (from current cm levels to mm precision)*

# VLBI activities and updates

**GSET WG 3**

- Natural signals from a black holes emit on wide spectrum; How does the signal aboard the satellite need to be generated? (Genesis sends in non-standard VGOS frequencies)
- Ground Station compatibility & IVS resources
- Multiple transmit antennas;  How to consider in data processing chain ?  PCO/PCV calibration.
- How can Genesis be effectively incorporated into geodetic observing and how many?
- Correlation and processing resources
- Tests including to already existing satellites, field tests, op
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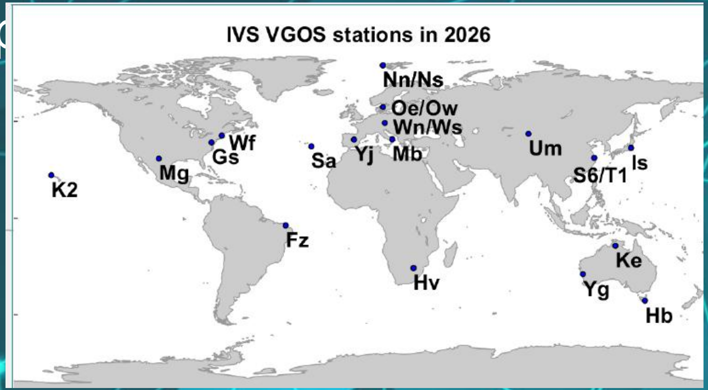


# VLBI activities and updates

WG-3 has seven work packages (WPs):

- • WP-1: frequencies, signals etc.
- • WP-2: ground station fidelity, etc.
- • WP-3: delay resolution and correlation, etc.
- • WP-4: scheduling
- • WP-5: end-to-end simulations
- • WP-6: test observations
- • WP-7: PRN-option

## ESA GSET WG-3 (VLBI)

### WG-3 participants:

Simone Bernhart – BKG/MPIfR, DEU; Johannes Böhm – TU Vienna, AUT; Patrick Charlot – CNRS Bordeaux, FRA; Christophe Craeye – UCL, BEL; Thibault Deleu – RoB, BEL; Pablo de Vicente – IGN, ESP; Claudia Flohrer – BKG, DEU; Susana Garcia-Espada – Kartverket, NOR; Luciano Garramone – ASI, ITA; Jakob Gruber – BEV Wien, AUT; Rüdiger Haas – Chalmers, SWE; Robert Heinkelmann – GFZ, DEU; Masafumi Ishigaki – GSI, JAP; Lucia McCallum – UTas Hobart, AUS; Alexander Neidhardt – TU München, DEU; Axel Nothnagel – TU Vienna, AUT; Almine Özyildirim – RoB, BEL; Christian Plötz – BKG, DEU; Chet Ruszczyk – MIT Haystack, USA; Matthias Schartner – ETH Zürich, CHE; Harald Schuh – GFZ Potsdam, DEU; Gino Tuccari – INAF & MPIfR, ITA/DEU; Rimsky Wolfs – Chalmers, SWE; Ex-officio (ESA GSET coordinator & co-coordinator) Özgur Karatekin – RoB, BEL; Francesco Vespe – ASI, ITA; ESA: Sara Bruni – ESOC, DEU; Gaia Fusco – ESTEC, NLD; Erik Schönemann – ESOC, DEU; Pierre Waller – ESTEC, NDL; Frank Zimmermann – ESOC, DEU

### Working group meetings:

- Online WG meetings every 4–6 weeks
- 2024: 5 WG meetings; 2025: 9 WG meetings; 2026: so far 1 WG meeting

### Work packages:

WG-3 has seven work packages (WPs):

- WP-1: frequencies, signals etc.
- WP-2: ground station fidelity, etc.
- WP-3: delay resolution and correlation, etc.
- WP-4: scheduling
- WP-5: end-to-end simulations
- WP-6: test observations
- WP-7: PRN-option


### WP-1: some examples

The Genesis VLBI signals will be transmitted in four VGOS-compatible frequency bands. These are 3.1–3.3, 5.25–5.57, 8–8.4, and 9.3–9.8 GHz. Table 1 presents the proposed frequency setup for VGOS observations of Genesis with 5-8-8-8 channels of 32 MHz each in the four bands, spreading in total 6624 MHz. Figure 1 depicts the corresponding delay resolution function.

**Table 1**: Proposed frequency setup for VGOS observations of Genesis.

| Band-A | | Band-B | | Band-C | | Band-D | |
|---|---|---|---|---|---|---|---|
| start 3110 (MHz) | stop 3290 (MHz) | start 5260 (MHz) | stop 5560 (MHz) | start 8010 (MHz) | stop 8390 (MHz) | start 9350 (MHz) | stop 9750 (MHz) |
| 3096,4 | 3128,4 | 5272,4 | 5304,4 | 8024,4 | 8056,4 | 9368,4 | 9400,4 |
| 3128,4 | 3160,4 | 5304,4 | 5336,4 | 8056,4 | 8088,4 | 9400,4 | 9432,4 |
| 3160,4 | 3192,4 | 5336,4 | 5368,4 | 8184,4 | 8216,4 | 9432,4 | 9464,4 |
| 3192,4 | 3224,4 | 5400,4 | 5432,4 | 8216,4 | 8248,4 | 9528,4 | 9560,4 |
| 3224,4 | 3256,4 | 5432,4 | 5464,4 | 8248,4 | 8280,4 | 9624,4 | 9656,4 |
| 3256,4 | 3288,4 | 5464,4 | 5496,4 | 8280,4 | 8312,4 | 9656,4 | 9688,4 |
| 3288,4 | 3320,4 | 5496,4 | 5528,4 | 8312,4 | 8344,4 | 9688,4 | 9720,4 |
| 3320,4 | 3352,4 | 5528,4 | 5560,4 | 8344,4 | 8376,4 | 9720,4 | 9752,4 |
| 5 | | 8 | | 8 | | 8 | |

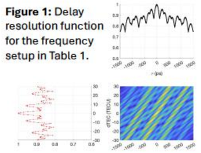


**Figure 1:** Delay resolution function for the frequency setup in Table 1.

The Genesis signal will be LHCP. The signal strength on the earth surface shall not exceed 20 Jy and be tuneable. Figure 2 depicts the proposed tuning scheme with 15 steps of 1 dB. Due to the close distance to the earth surface, the Genesis signals will experience geometry-dependent free-space loss effects. Figure 3 visualizes the geometry where the free-space loss difference between a station in nadir direction and a station at the edge of illumination is 4.5 dB.

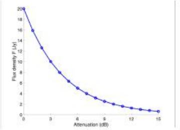


**Figure 2:** Tunable signals strength.

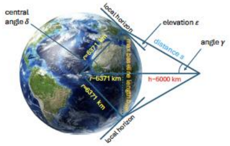



**Figure 3:** Genesis observation geometry.

### WP-2: some examples

Genesis will pass over a VGOS station within 68 minutes from horizon to horizon. For a VGOS antenna of 13 m diameter, Genesis will pass through the telescope beam within 6 s (Fig. 4). Continuous tracking is therefore necessary. A standardized command for satellite tracking will be implemented in the VLBI field system. The radio frequency environment at the VGOS stations needs to be studied. Figure 5 depicts the example of station ONSA13NE.

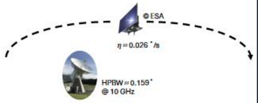



**Figure 4:** Schematic of a Genesis overpass.

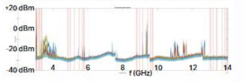



**Figure 5:** Radio frequency environment at VGOS station ONSA13NE.

### WP-3: some examples:

There will be three VLBI transmit antennas, one each for S-band, C-band, and X-band signals (see Tab.1). The antennas will have individual phase center offsets (PCOs) w.r.t. the satellite's center of mass (COM), as well as individual phase center variations (PCVs). These effects, as well as satellite attitude, will affect the interferometric phase measurements and need to be corrected in the VLBI processing chain. It is suggested to do this before fringe fitting.

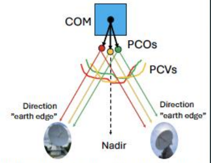



**Figure 5:** Schematic of VLBI transmit antennas, COM, PCO and PCV.

### WP-4: some examples

The possibility to observe the Genesis satellite depends on geometry, i.e. the VGOS ground station network and the satellite orbit. Figure 6 depicts an example satellite orbit and how many stations can see the satellite simultaneously. Eq. 1 describes the necessary observing time $T$ for a pair of VGOS stations to achieve a particular signal-to-noise ratio ($SNR$). Here, $SEFD_i$ and $S_i$ are the stations sensitivities and signal flux densities, respectively, while $BW$ is the observed bandwidth, $bits$ describes the sampling, and $\eta$ is the correlator efficiency.

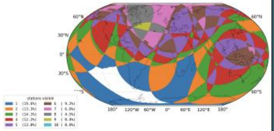


**Figure 6:** Example of Genesis visibility in the VGOS network (reference: M. Schartner, ETH).

$$T = \frac{1}{2 \cdot BW \cdot bits} \cdot \left(\frac{SNR}{\eta}\right)^2 \cdot \frac{SEFD_1}{S_1} \cdot \frac{SEFD_2}{S_2} \quad (1)$$

### WP-5: some examples

A number of end-to-end simulations were performed and published already, see Table 2. The most important outcomes are that (a) Genesis observations can be integrated into IVS observations without influencing the IVS products negatively (b) orbit determination is possible (c) station position repeatabilities are achievable in the mm-range.

**Table 2:** Examples of end-to-end simulations.

| |
|---|
| Klopotek G, Hobiger T, Haas R, Otsubo T (2020). **Geodetic VLBI for precise orbit determination of Earth satellites: a simulation study.** In: *Journal of Geodesy* (Vol. 94, Issue 6). https://doi.org/10.1007/s00190-020-01381-9 |
| Schunck D, McCallum L, Molera Calvés G (2024). **On the Integration of VLBI Observations to GENESIS into Global VGOS Operations.** In: Remote Sensing (Vol. 16, Issue 17, p. 3234). MDPI AG. https://doi.org/10.3390/rs16173234 |
| Schunck D, McCallum L, Molera Calvés G (2024). **Practical Considerations of VLBI Observations to the GENESIS Mission.** In: IAG Symposia. Springer Berlin Heidelberg. https://doi.org/10.1007/1345_2024_245 |
| Wolf H, Kern L M, Steinmetz S, Böhm J (2025). **Impact of the Inclination of Genesis on the VLBI Terrestrial Reference Frame.** In: *Proc. EVGA2025*, https://doi.org/10.5281/zenodo.18088484 |
| Sert H, Schartner M, Haas R, Karatekin Ö (2025). **SNR simulations for Genesis VT observations.** In: *Proc. EVGA2025*, https://doi.org/10.5281/zenodo.18088484 |

### WP-6: some examples

First test observations using the proposed Genesis frequency setup (Tab. 1) were performed successfully in July 2025. A set of natural radio sources was observed, and examples of fringe plots are depicted in Fig. 7. A 24 h observation session with a global VGOS network is planned for spring 2026.

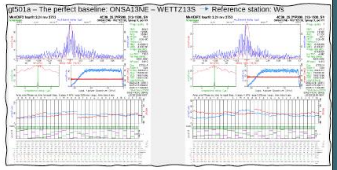



**Figure 7:** Fringe plots of the first test observations using the proposed Genesis frequency setup (Tab. 1).

### WP-7: some examples

The wide bandwidth available with Genesis raised the idea to also have the possibility of sending a pseudo range noise (PRN) code in at least two of the Genesis bands. This could allow one-way ranging measurements with about 15–20 times higher precision than today's GNSS. These could be of interest for time and frequency transfer over long distances. Further work on this interesting topic is ongoing.

### Conclusions and outlook:

ESA GSET WG-3 (VLBI) is working hard to understand all aspects of future VLBI observations using Genesis signals. The WG works tightly with ESA and gives advice and recommendations. The overriding goal is to be well prepared and to able to incorporate Genesis observations smoothly into IVS operations, as well as to prepare for combination with the other space geodetic techniques onboard Genesis.

# DORIS Activities & Updates

GSET WG 4

- Upgrade DORIS processing software to integrate future Genesis data
- Inventory of IDS analysis centres ready to ingest Genesis DORIS observations

- USO thermal sensitivity:
- Beacon tracking strategy
- Antenna phase centre calibration
- Beacon frequency monitoring

- Sub-WG on USO thermal impact / Clock tie experiment*
- Simulations on beacon obs. and tracking strategies

- DORIS integration into multi-technique combination strategies (Coordinated with WG1
  - Improve ties between DORIS and other techniques — contribute to multi-technique combination at observation level
  - Sentinel-6A multi-technique solutions (DORIS + GNSS + SLR)

*connecting DORIS and GNSS REGINA receivers to same clock at time beacon sites (Hartebeesthoek, Kourou, Papeete, Toulouse, Terre Adélie)

# SLR Activities & Updates

GSET WG 5

**ILRS Analysis Standing Committee (ASC) established special WG for TRF+EOP products from non-spherical Sat obs.**

- Assess ILRS data format / sharing
- Observation strategy:
  - full arc vs. interleaving,
  - passes/NPs per station,
  - coordination with VLBI/DORIS at multi-technique observatories
- Data analysis: combination with other ILRS satellites; SLR-only and inter-technique solutions
- LRR calibration (CoP) to (CoM

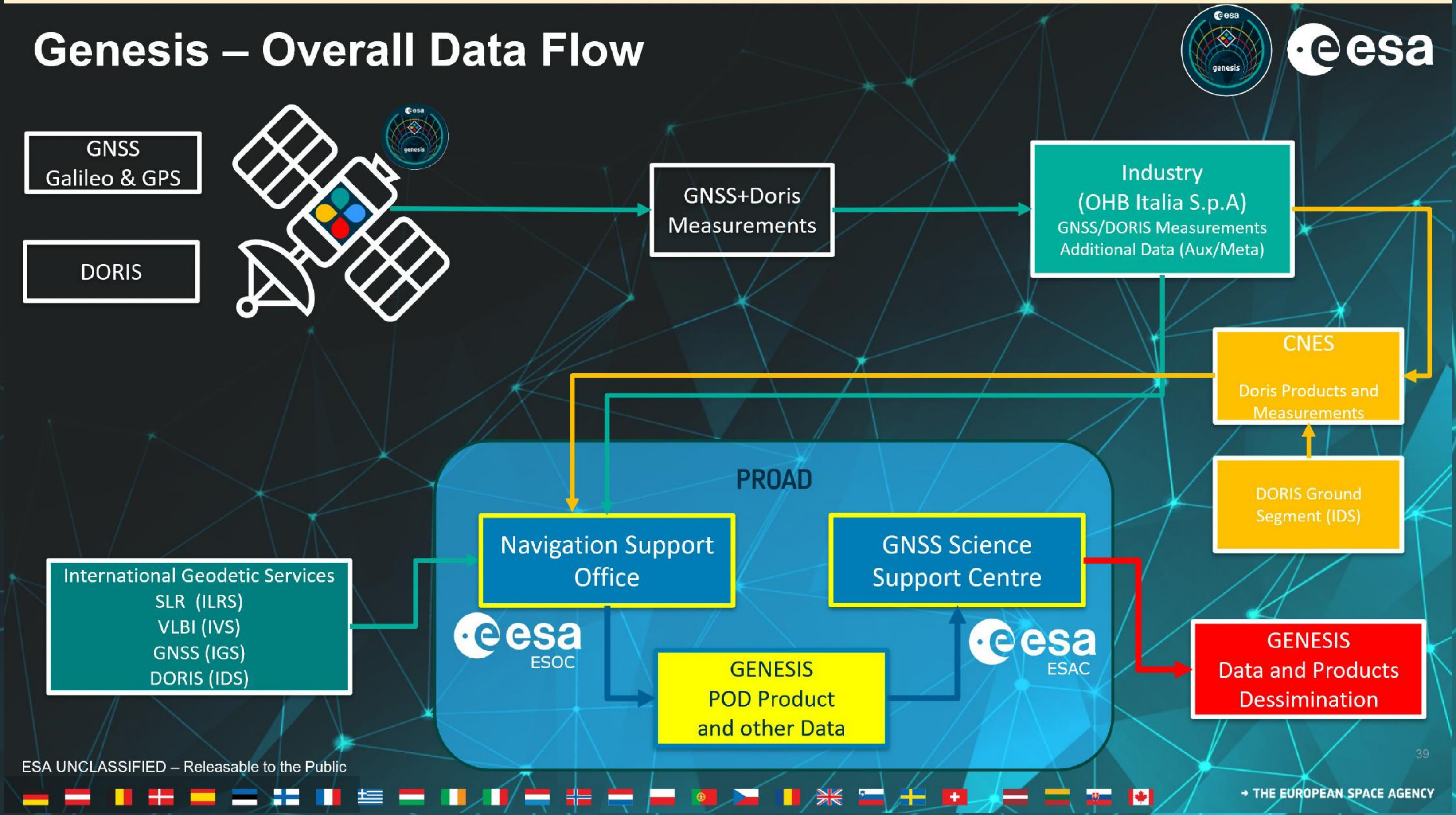
- IAG Services coordination: Genesis already triggered cross-service dialogue (e.g. SINEX format upgrade for orbit combination)
- Simulation studies ongoing: ,Wroclaw, CNES,… FESG-TUM and DGFI-TUM developing NEQ-level combination
  - refined non-conservative force models and Genesis metadata
  - Coordinate with WG1 on inter-technique combination strategies and required ITRF-level products

# Consolidated service-specific interfaces

- ILRS Analysis Standing Committee (ASC) established special WG for TRF+EOP products from non-spherical satellite observations (Dec 2025)
- IDS analysis centers assessment  to ingest Genesis DORIS observations
- IVS Working Group on Satellite Observations with VLBI (WG7)
- IAG/IERS/GGOS JWG 1.1.1JWG aims at maximizing the utilization of the mission's capabilities.

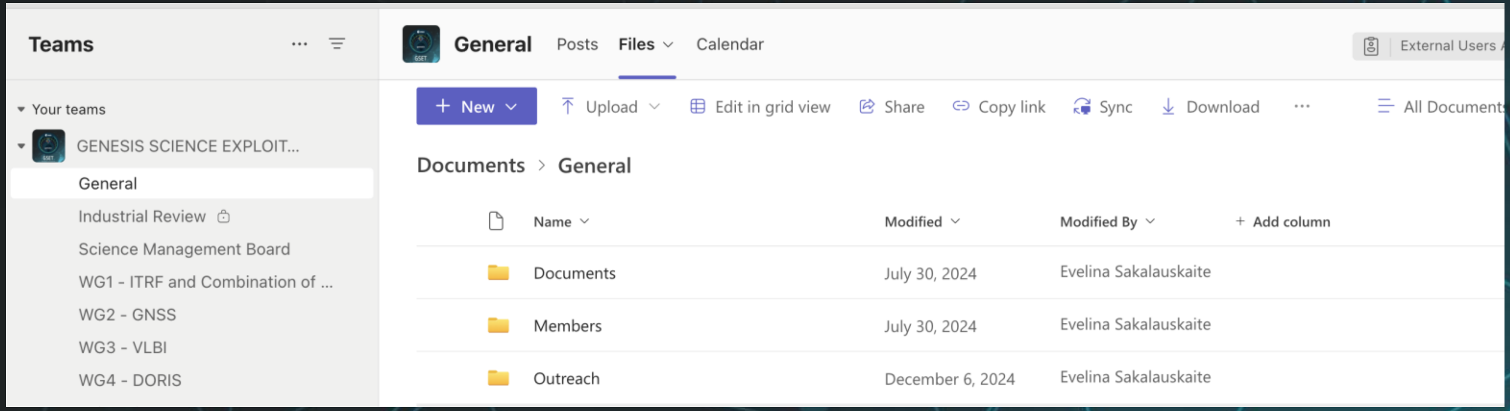
# PROAD Overall Data Flow

In the context of the ESA Genesis Mission, all agreed Genesis mission data and products, including Navigation Support Office generated POD products, will be accessible to the global scientific community via The PROcessing, Archiving and Dissemination Centre (PROAD), consisting of the ESA Navigation Support Office facilities in Darmstadt (Germany) for the processing part, and the ESA GNSS Science Support Centre (GSSC) in Madrid (Spain) for the archiving and distribution part,



# TEAMS

- Genesis Science Exploitation Team has been created on Teams
- All members should have received notification from Microsoft Teams




Shared environment for collaboration

- WG Objectives, progress tracking
- WG and Science team meetings notes, presentations, participants list,
- Documents (Technical notes,. Publications, ...)
- Announcements
- Any comments or suggestions for its structure, are welcome

# PUBLICATIONS

All GENESIS Science Exploitation Team members are encouraged to publish scientific data resulting from GENESIS mission data

To structure the process for publications, detailed rules will be established and coordinated with the Working Groups

This publication policy will continue to apply for two years after the end of the GENESIS mission (nominal or, as the case may be, extended)

# Publications

- Topics of papers are to be proposed by GSET Members.
- The papers on mission will be coordinated by the Science Management Board
- When information about the performance of the spacecraft/mission is included in the publication, the ESA mission shall be asked to review the related content of the paper and its prior approval must be obtained.
- **Annual Genesis workshops** are organized to share results of the respective analysis across the various domains and coordinate the work
- Several Genesis focused **presentations and sessions** at International meetings such as; Genesis Session at COSPAR, presentations at EGU on Mission and GSET activities, Scientific and Fundamental Aspects of GNSS. 10th International Colloquium
- **A special issue** in Peer reviewed journal will be organized for Genesis

# A new Initiative 🌱 : Genesis Young Scientists Group

Engaging early-career scientists now ensures continuity from pre-launch through full science exploitation.

*Building the next generation of space geodesists*

1 **Strengthen mission long-term legacy**

GENESIS science exploitation runs through 2031+

2 **Build next-gen space geodesists**

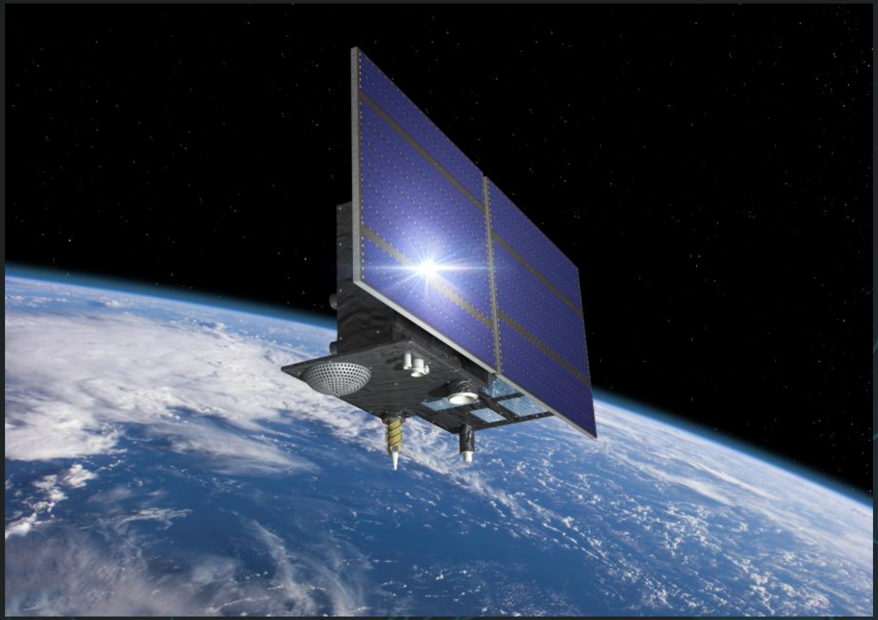
PhD students & researchers within 5 yrs of PhD

3 **Increase diversity & fresh perspectives**

Broaden participation across all 5 Working Groups

4 **Foster cross-WG connections**

Liaison roles, dedicated sessions, mentoring



# Thank you for your attention

On behalf of Genesis Science Exploitation Team (GSET)

**Özgür Karatekin**, Royal Observatory of Belgium

**Francesco Vespe**, ASI Direzione Ingegneria e Tecnologie