NanoMagSat, an ESA Scout LEO nanosatellite constellation to investigate Earth's magnetic field and ionospheric environment

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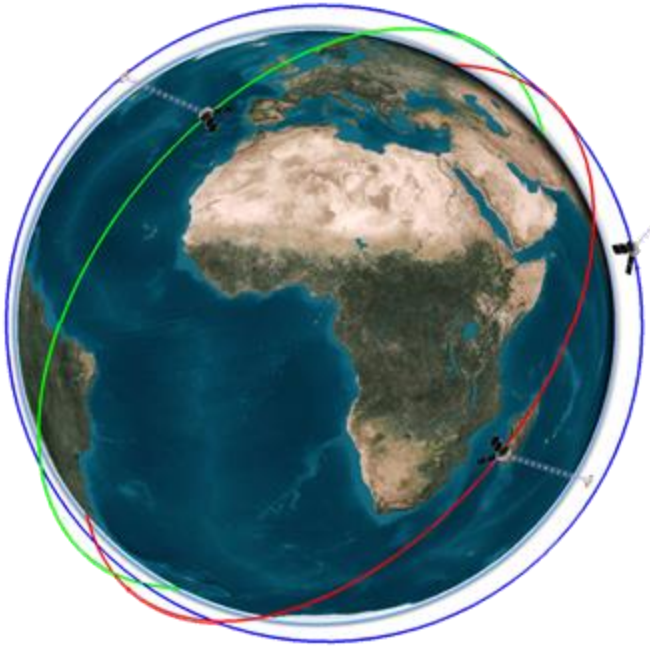
Swarm 10 years Anniversary Science Conference

Copenhagen, Denmark, 10/04/2024

NanoMagSat mission concept



Innovative orbital configuration

A 3-year minimum (targeting 5+ years) lifetime constellation composed of 3x16U Cubesats at around 550 km initial altitude

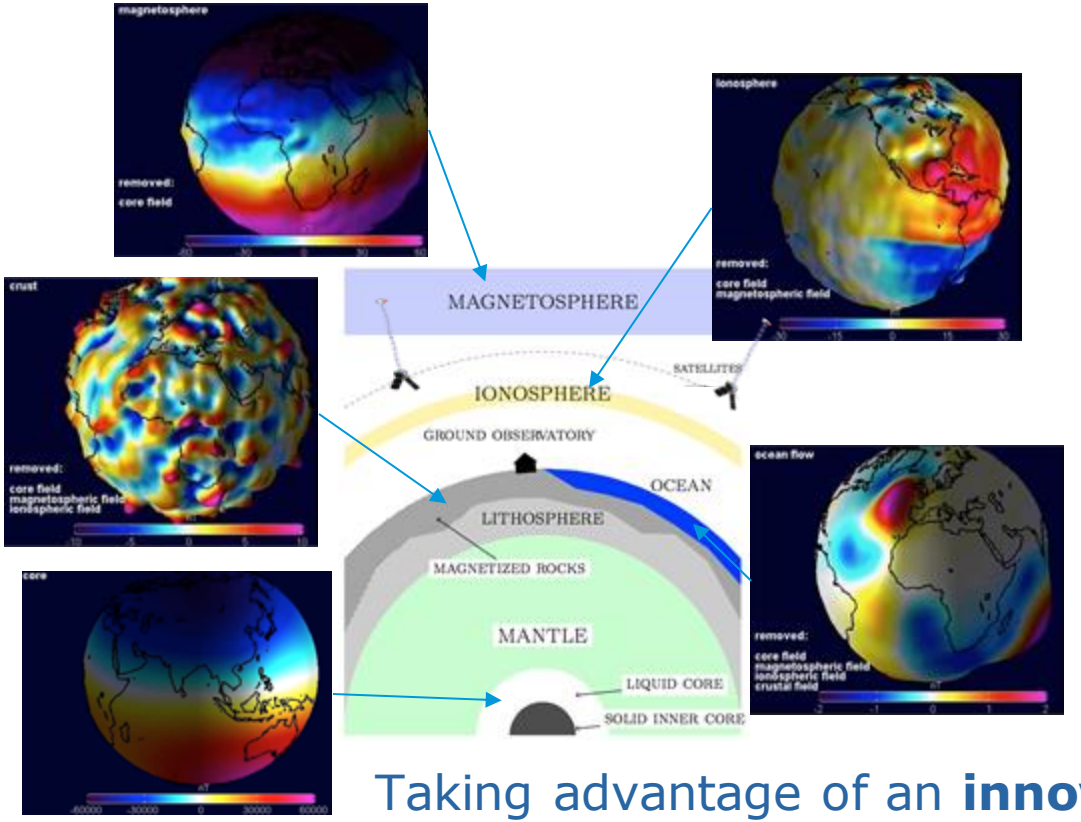
- **1 satellite at 60° inclination**
- **1 satellite at 60° inclination offset by 90°-RAAN**
- **1 satellite in near-polar orbit (phased w/r to Swarm)**

State of the art compact payloads

- A **Miniaturized Absolute Magnetometer** (MAM) with a set of **two Star Cameras** (STR)
- A **High Frequency Magnetometer** (HFM)
- A **multi-Needle Langmuir Probe** (m-NLP)
- 2 **dual-frequency GNSS**

Initiating a **low-cost scalable collaborative constellation solution for very long-term observations** (extending to space the Intermagnet network of magnetic observatories)

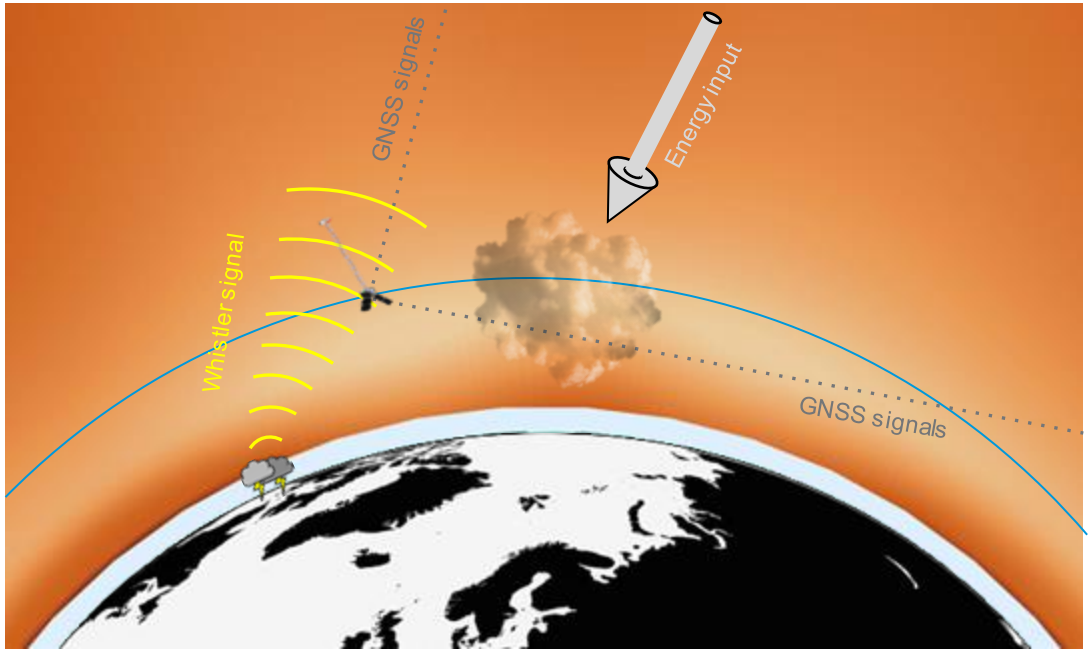
First family of objectives: Earth's magnetic field



- Targeting **recovery of fast planetary changes** in **core**, **ionospheric** and **magnetospheric** fields, also improving **recovery of crustal** and **oceanic** signals
- To investigate **fast core dynamics, solar-terrestrial interactions, crust and deep Earth properties** and possible signatures of climate change

Taking advantage of an **innovative constellation**

Second family of objectives: Ionospheric environment



- Targeting **ionospheric plasma density dynamics**
- Combining standard **GNSS techniques**
- With **new ways of sensing the ionosphere below the satellites** (using whilsters, e.g., Jenner et al. in session 4) **and monitoring in situ meter to km scale dynamics and energy input**
- To investigate **Space weather** phenomena that affect radio and GNSS signals, and improve **science and operational ionospheric models**

Taking advantage of an **innovative compact payload**

Specifics of ESA Scout Missions

- Scout missions are implemented as **service contracts**
- The **NanoMagSat consortium** is contractually **committed to design, build, launch, operate the mission up to phase E1** (Commissioning), and **be ready for phase E2** (Exploitation)
- ESA is buying the service, the **output** of which **is Level 0/1/2 data products, with Level 2 data to be made available to the Science (and broader) community, through a user interface** operated by the **Payload Data Ground Segment** (equivalent to Swarm PDGS).
- Note that in the Scout framework, **NanoMagSat Level 2 data are equivalent to Level 1b Swarm data,** e.g. for the magnetic data:

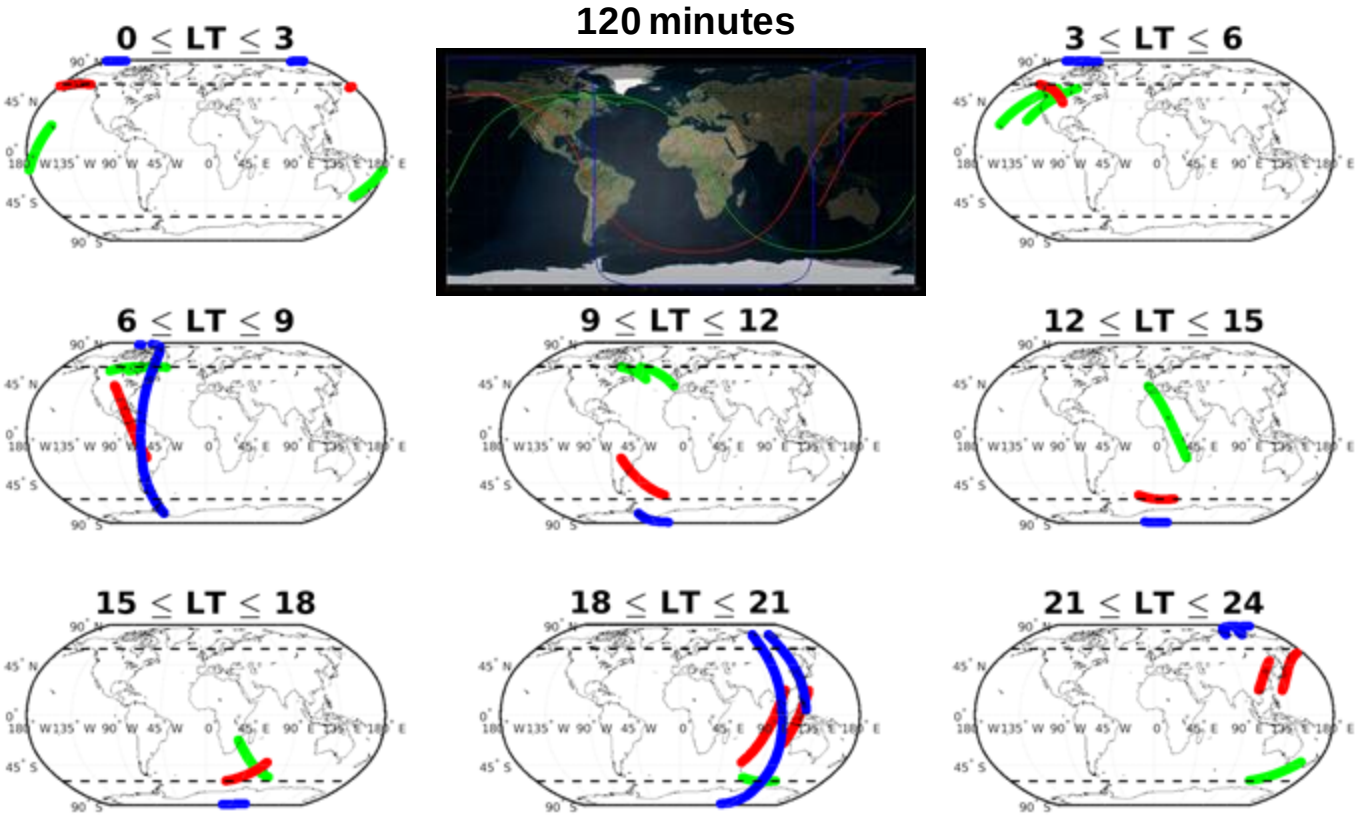
"Geophysical measurements at the satellite location, corrected for platform perturbations and in both the instrument reference frame and the North East Center (NEC) frame (for vector data), time-referenced and annotated with ancillary information"

- **All software and Level 0/1/2 data produced are also to be transferred to ESA**

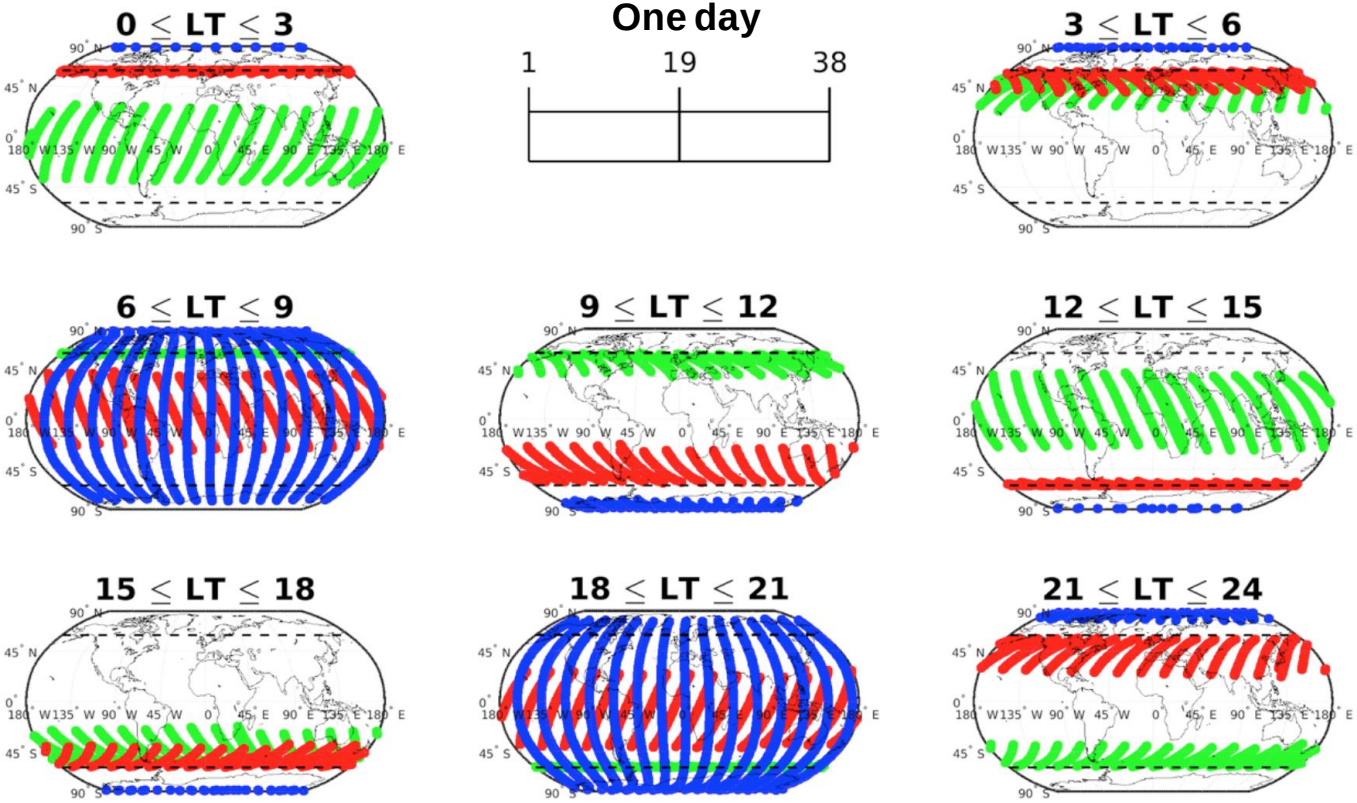
NanoMagSat constellation requirements

- **For low-medium latitude regions (< 60°)**, the **geographic and LST coverage** shall meet the following requirement:
  - Assuming a spatial-LST mesh of cells of size ±6° long., lat. X ±1.5h LST, all these cells shall have been **visited within a time of less than 3 months**.
  - As a **target**, all LT below 60° should be visited within a time **of less than 2 months**.
- **For high latitude regions (> 60°)**, the **geographic and LST coverage** shall meet the following requirement:
  - Assuming a spatial-LST mesh of cells of size (±6° long., lat. X ±1.5h LST), all these cells shall have been visited up to at least 85° latitude within a period of **less than 6 months** (**target of less than 5 months** to avoid phasing with seasons).
  - **If any Swarm satellite is still in operation** at time of launch of the NanoMagSat satellite covering this requirement, target should be revised to ensure **joint Swarm/NanoMagSat coverage within a period of less than 4 months** (ideally 3 months).

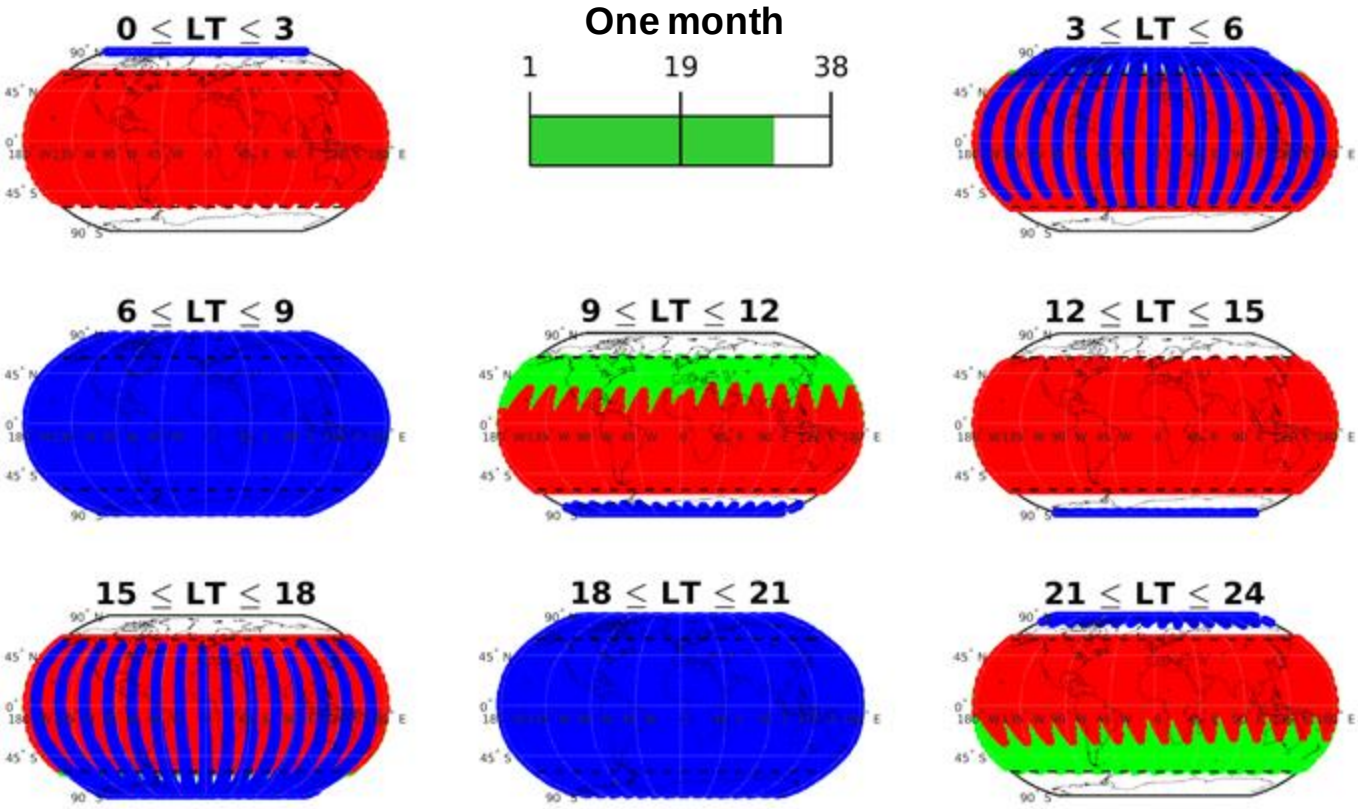
NanoMagSat Geographic/Local Time coverage



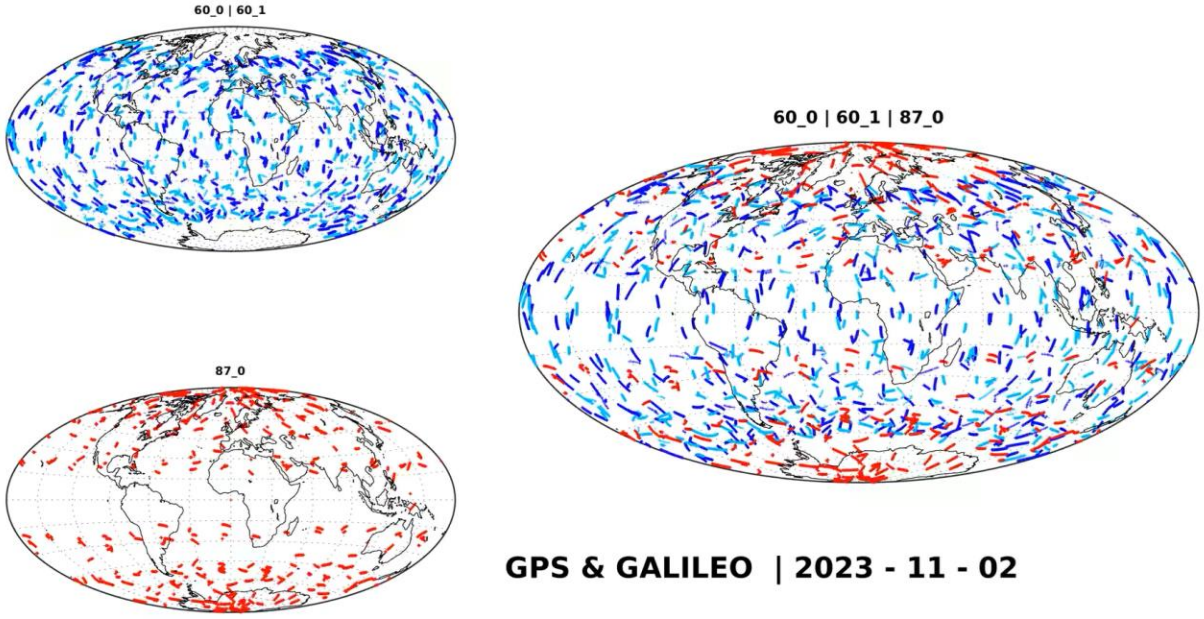
NanoMagSat Geographic/Local Time coverage



NanoMagSat Geographic/Local Time coverage



Very favorable Radio Occultation configuration



- Shown are day-by-day occultation tangent points with GPS and Galileo satellites, starting at altitudes of 90 km (up to NanoMagSat satellites), when traces are less than 1000 km long (i.e. sampling the ionosphere close to the NanoMagSat satellites).
- 60° inclined orbits (close to the 55°/ 56° GPS/Galileo inclined orbits) are very favorable.

NanoMagSat Level 2 data requirements

1 Hz product synchronized to 1 ms

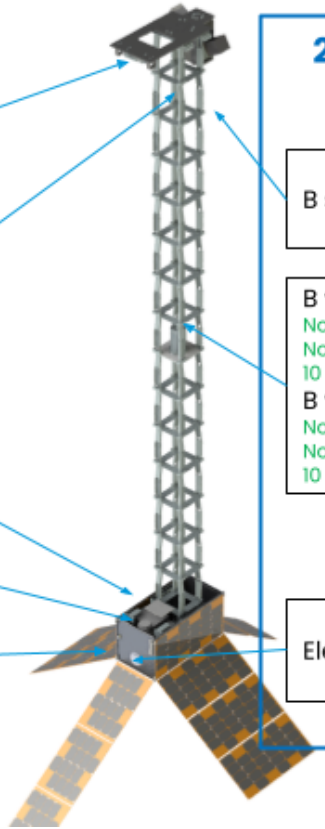
Attitude (STR) : σ < 12 arcsecond (one STR)

B vector (MAM frame) : σ < 0.6 nT
B vector (NEC frame) : σ < 3 nT if only one STR is not binded, else σ < 1.4 nT
B scalar : σ < 1nT (targeting 0.2 nT)

GNSS products (for TEC, IP, SCI): heritage requirements

POD (r, θ, φ) within 2 m (radius) 10 m (else), timestamped within 0.1 ms

Electron density & temperature (m-NLP):
Ne: σ <10^8 m^{-3} Te: σ <500 K (targeting 200K)



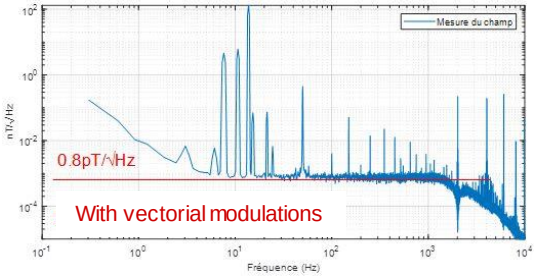
2 kHz product synchronized to 0.1 ms

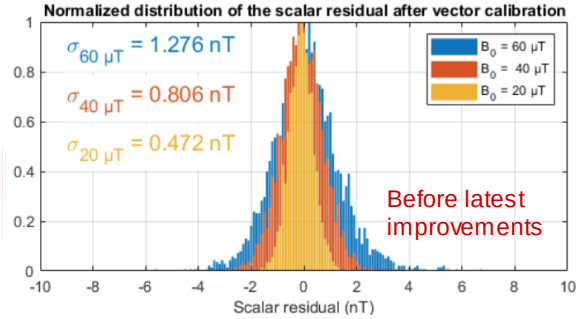
B scalar (MAM): Noise below 1 pT/√Hz over 20-800 Hz

B vector (HFM frame):
Noise below 1 pT/√Hz over 20-800 Hz
Noise decreasing from 2.7 nT/√Hz at 1 Hz to 85 pT/√Hz at 10 Hz to 30 pT/√Hz at 20 Hz
B vector (NEC frame):
Noise below 1 pT/√Hz over 20-800 Hz,
Noise decreasing from 2.7 nT/√Hz at 1 Hz to 85 pT/√Hz at 10 Hz to 30 pT/√Hz at 20 Hz

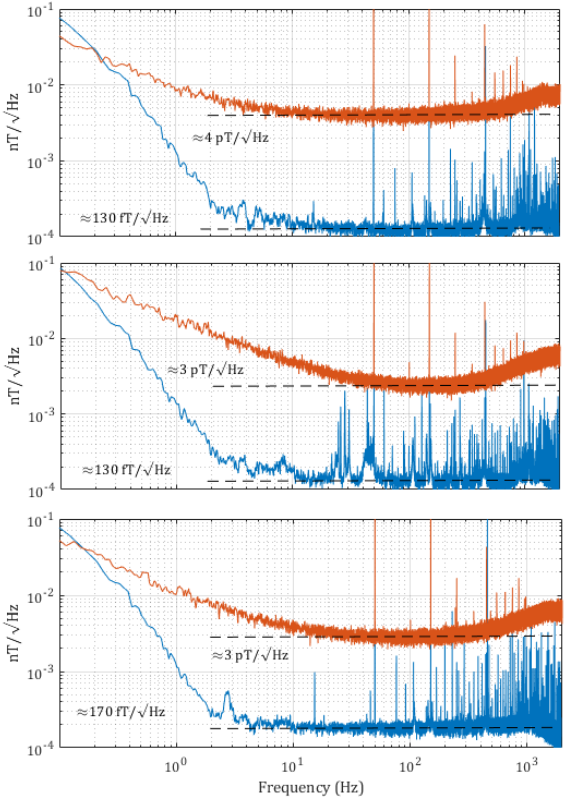
Electron density (m-NLP): σ <10^8 m^{-3}

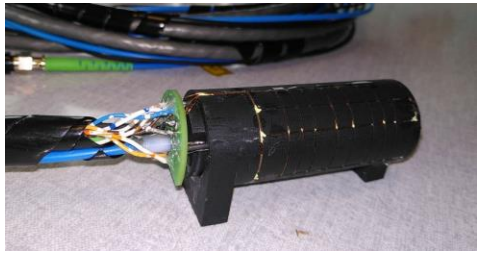
MAM and HFM instruments





HFM versus Bartington Fluxgate

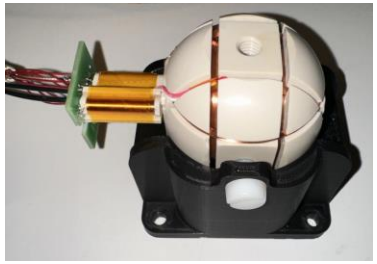




MAM ^{4}He magnetometer

- Absolute scalar field (2kHz)
- Self-calibrated vector field 1 Hz

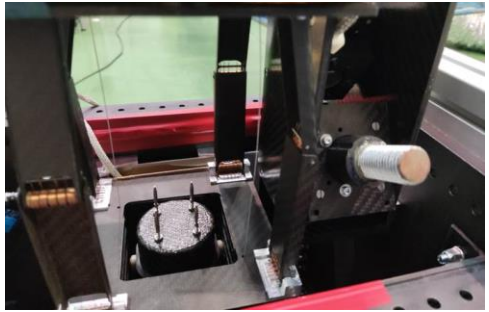
MAM/HFM DPU



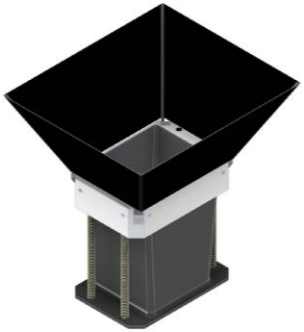
HFM ^{4}He zero-field magnetometer

- Vector field (2kHz)

Star Trackers (STR)

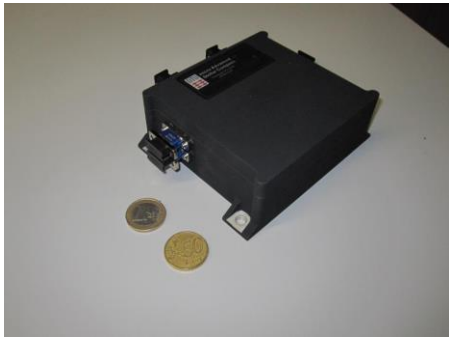


Optical bench accommodation



Deployable baffle

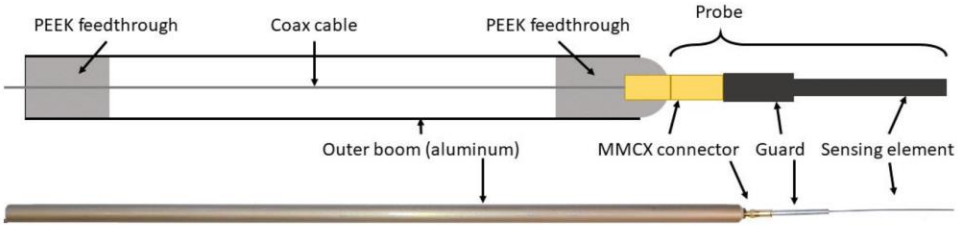
Optical Head

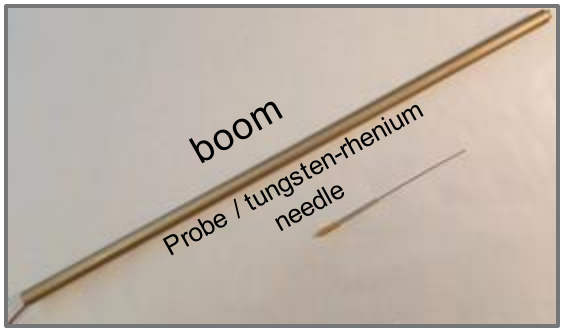


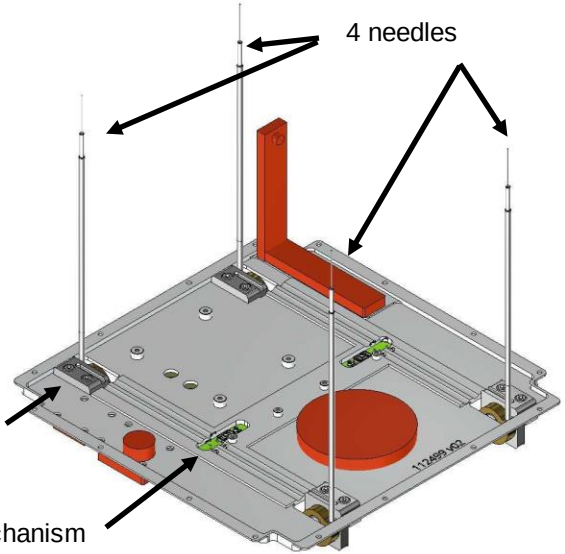
Data Processing Unit

- **Two STRs (~ 110° to 120° inter-boresight angle, looking "sideways")**
- **Magnetically clean**
- **Deployable baffles, fitting within optical bench allocated volume**

Multi-Needle Langmuir Probe (m-NLP)





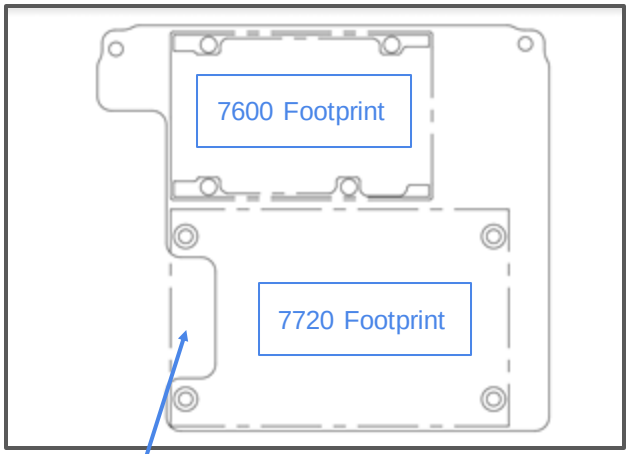


- **Validation of proof of concept done in space thanks to BRIK-II**
- **Change of probe material (aluminium for boom, tungsten-rhenium for needle) to avoid magnetic signature tested and OK**
- **Can be accommodated on satellite body**
- **Requirements for 2kHz Ne (and 1 Hz Te) can be met (simultaneous fixed bias / sweep mode)**

UiO : University of Oslo

GNSS receivers/antennas (subject to update)

- POD/TEC receiver: NovAtel 7600
  - ✓ Multiple frequencies (GPS/Galileo)
  - ✓ Single Antenna (top side)
- Occultation receiver: NovAtel 7720
  - ✓ Multiple frequencies (GPS/Galileo)
  - ✓ Dual Antenna input (front and rear)
  - ✓ High sampling rate (up to 100 Hz)
- Both receivers magnetically OK
- Antennas : Tallysman TW3972E
  - ✓ Magnetic signature tested
  - ✓ Requires adapting metallic cover



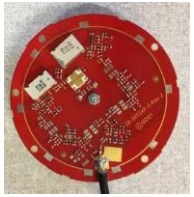
Bottom view

Top view

GNSS Receiver Motherboard

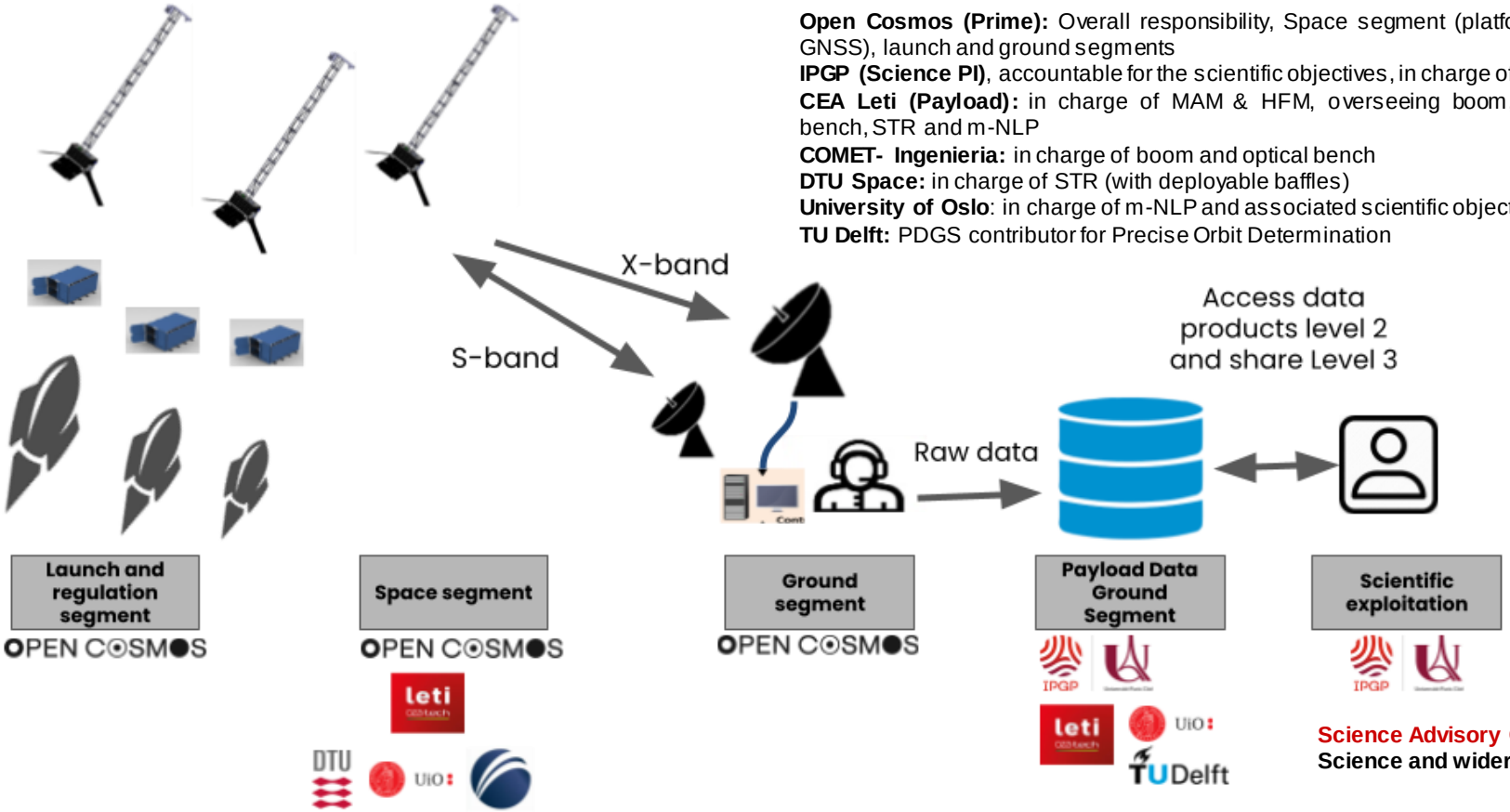
cover

Without cover



OPEN COSMOS

Mission architecture



Open Cosmos (Prime): Overall responsibility, Space segment (platform and GNSS), launch and ground segments
IPGP (Science PI), accountable for the scientific objectives, in charge of PDGS
CEA Leti (Payload): in charge of MAM & HFM, overseeing boom, optical bench, STR and m-NLP
COMET- Ingenieria: in charge of boom and optical bench
DTU Space: in charge of STR (with deployable baffles)
University of Oslo: in charge of m-NLP and associated scientific objectives
TU Delft: PDGS contributor for Precise Orbit Determination

Science Advisory Group (SAG)
Science and wider community

Next steps

Overall programmatic schedule:

- **ESA is commited to go fast**
- **Pre-ATP (Authorization to Proceed) to de-risk activities on the critical path**
- **Full proposal to be submitted by Q2 2024**
- **Full contract (up to phase E1) to be signed and KO end of the year (by November 2024)**
- **(First) launch planned for end of 2027**

Science preparation side:

- **Setting up of a Science Advisory Group (evolution of current informal Science Team)**
  - **SAG membership to be provided as part of the proposal**
  - **Support Letter and CV to be provided at proposal submission (end of May)**
  - **Possible additions/adjustments can be made at contract signature (November)**
- **Progress Scientific Readiness Level**

Role of Science *Advisory* Group

- **Provide *independent* scientific advice, expertise, and feedback on:**
  - **mission concept and requirements**
  - **mission performance assessment**
- **Check and endorse the Mission Requirements Document (for end of May):**
  - **This includes ownership of the mission objectives and requirements (observation, measurement, and data product requirements/specifications, as well as data quality requirements) which shall address the scientific needs of the community.**
  - **The SAG shall also provide advice on (geophysical) processing and validation of the mission products.**
- **Check, contribute to and endorse the Science Plan (derived from the Scientific File provided in the earlier selection phases), a first version of which is to be provided for end of May, and which shall provide guidance on further scientific support activities, including any campaigns, data exploitation and impact studies.**
- **Monitor the strategy and progress in terms of rising SRL levels (SAG SRL readiness endorsement)**
- **Engage with and provide an interface to the science and user communities, and promote the mission (e.g., through presentations, publications, outreach, etc.)**

NanoMagSat SAG organisation and call

- SAG composition (large enough, small enough)
  - **International** (including beyond ESA member states)
  - Chaired by **Mission PI**, seconded by a **secretary**
  - Assisted by an **ESA member** (appointed by ESA)
  - **May include members of the current NanoMagSat "core science team"**, who contributed to initial E2E Level 3 product recovery studies
  - **Shall also involve external experts** that can steer the science, develop a scientific roadmap (Science Plan), and provide *critical* assessments
- SAG working means
  - **Budget** available **for meetings, publications, etc.**
  - But **membership and work based on a voluntary basis**

➢ I will shortly (before end of April) come back to prospective members

➢ **You are anyway encouraged to volunteer ASAP (with a letter of motivation to gh@ipgp.fr)**