NanoMagSat, a 16U Nanosatellite Constellation High-Precision Magnetic Project to Initiate Permanent low-cost Monitoring of the Earth's Magnetic Field and Ionospheric Environment

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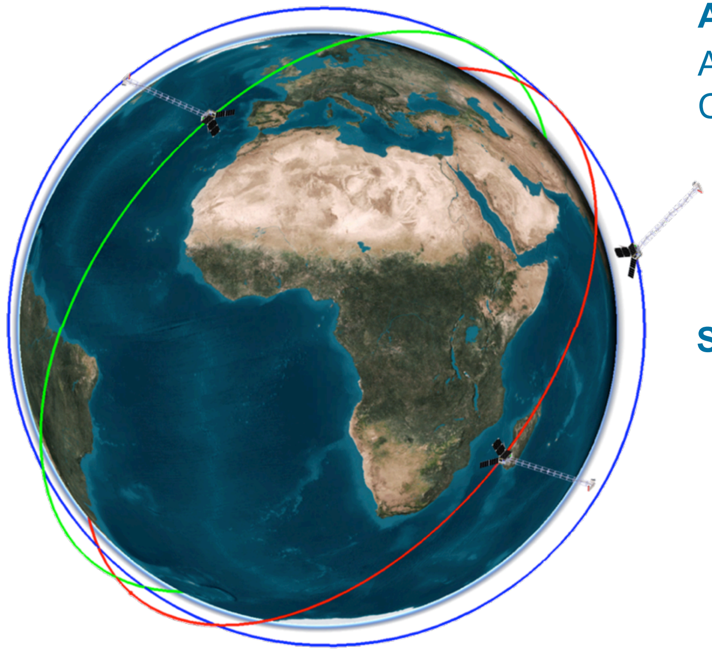
An optimal and scalable mission concept



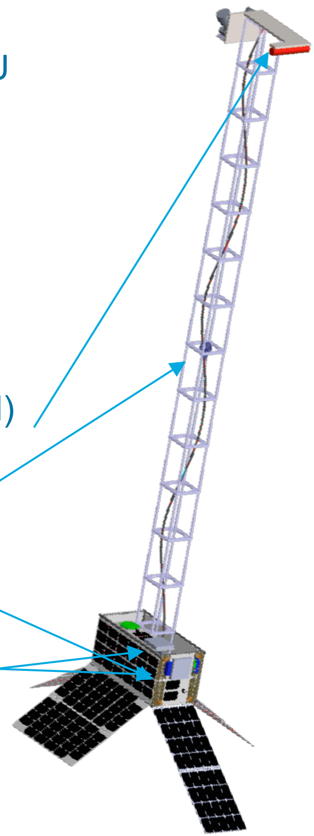
An innovative orbital configuration

A 3-year lifetime constellation composed of 3x16U Cubesats at 575 km initial altitude

- **1 satellite at 60° inclination**
- **1 satellite at 60° inclination offset by 90°-RAAN**
- **1 satellite in near-polar orbit**

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)

Producing magnetic and ionospheric environment data

1 Hz data synchronized to 1 ms

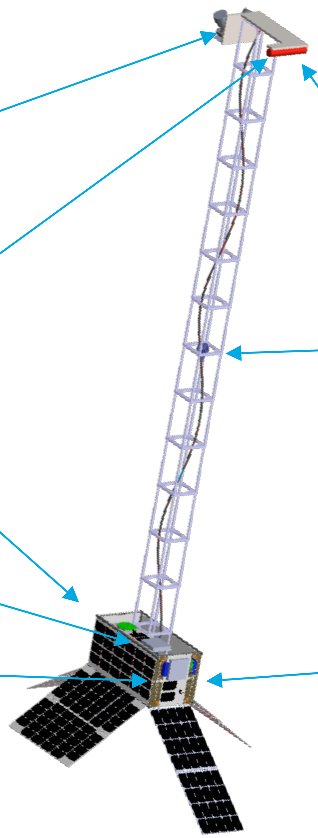
Attitude (STR) : σ < 5 arcseconds

B vector (MAM) : σ < 0.8 nT
B vector (NEC frame) : σ < 1 nT
B scalar (MAM) : σ < 0.2 nT

GNSS products (TEC, IP, SCI):
standard requirements

POD (r, θ, φ) within 8 m

Electron temperature (m-NLP)
(New !)



2 kHz data synchronized to 1 μs

B scalar (MAM)

Noise below 1 pT/√Hz over DC-800 Hz

B vector (HFM)
B vector (NEC frame)

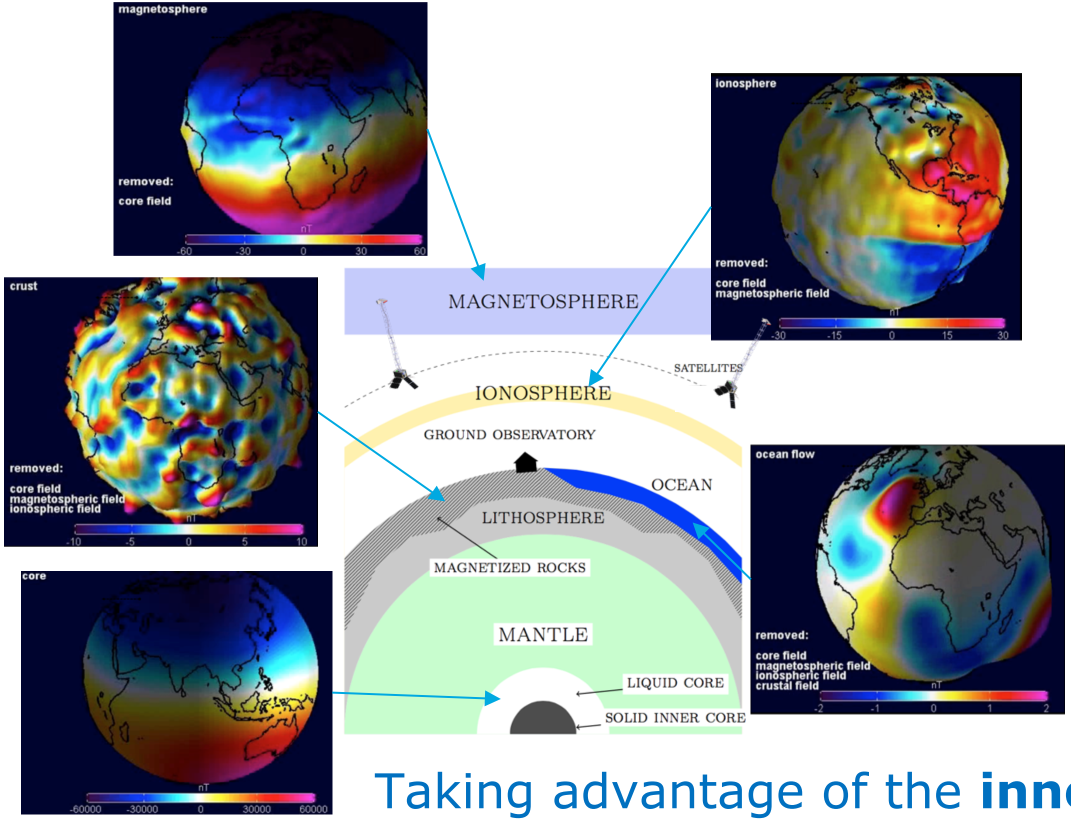
Noise below 1 pT/√Hz over 10-800 Hz

Electron density (m-NLP)

1 σ <1% for $n_e > 10^{10}$ m^{-3}

1 σ <10% for $10^9 < n_e < 10^{10}$ m^{-3}

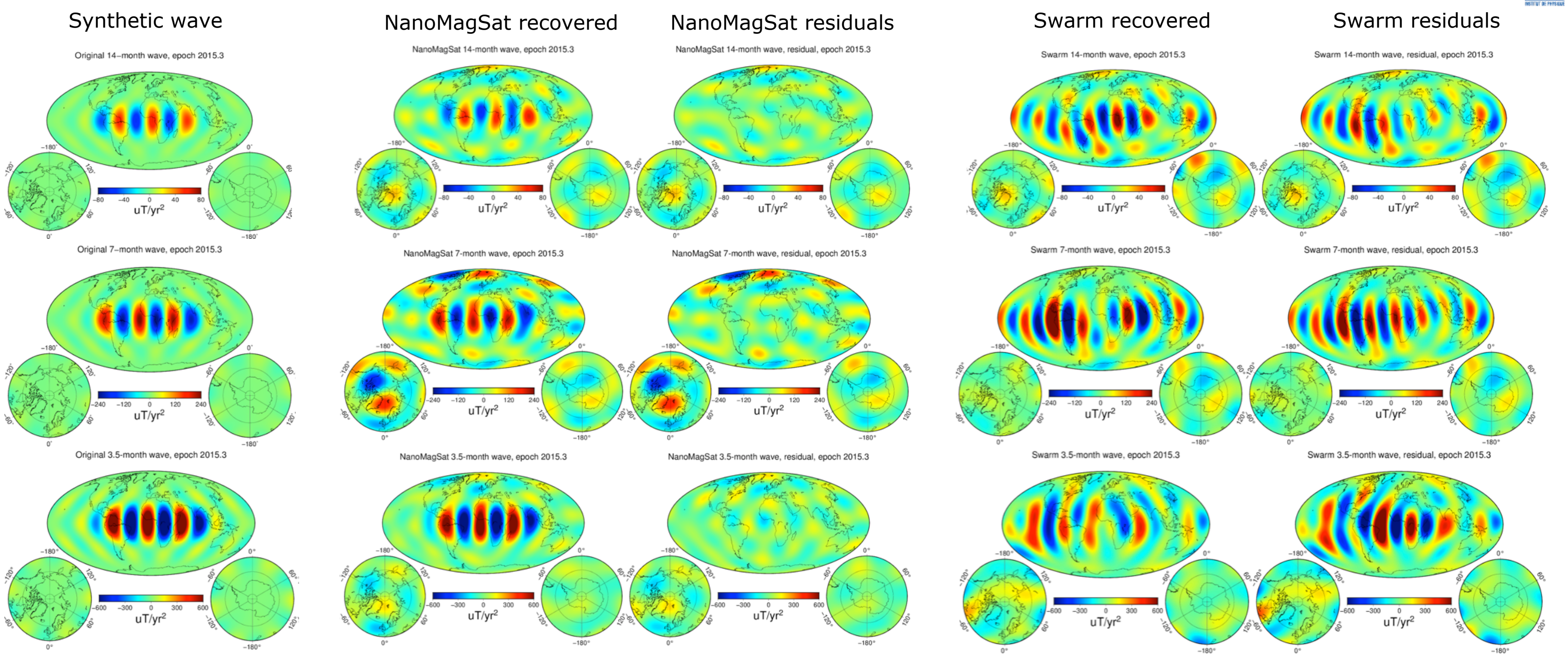
First family of objectives: Earth’s magnetic field



- 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 the **innovative constellation**

Recovering fast core waves (E2E simulations)

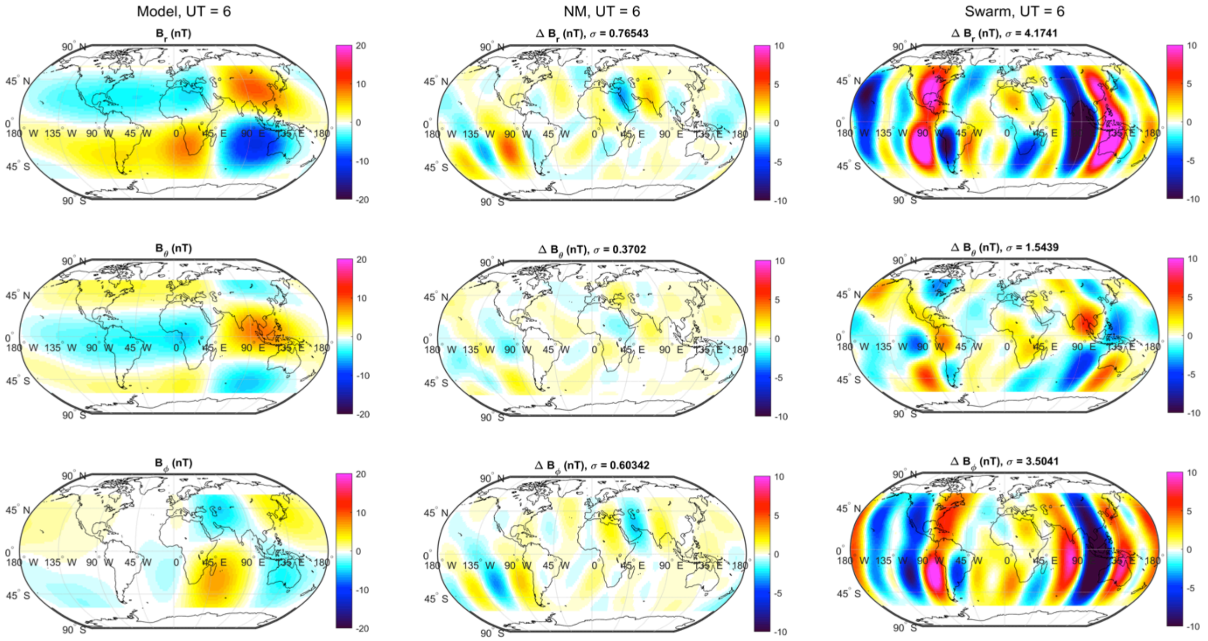


Core waves with 14 (top), 7 (middle) and 3.5 (bottom) months periods can be recovered by NanoMagSat and not by Swarm

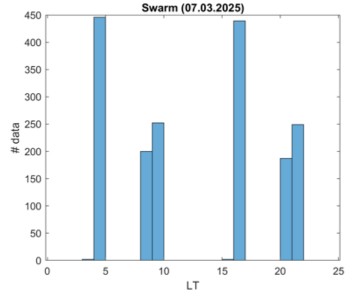
Recovering the daily Ionospheric Field (SQF) (E2E simulations)

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

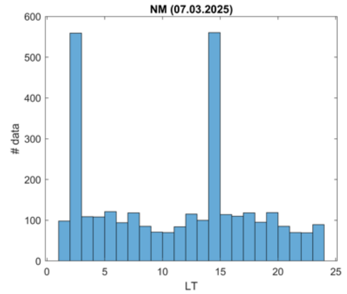
Synthetic SQF | NanoMagSat residuals | Swarm residuals



Swarm LT coverage



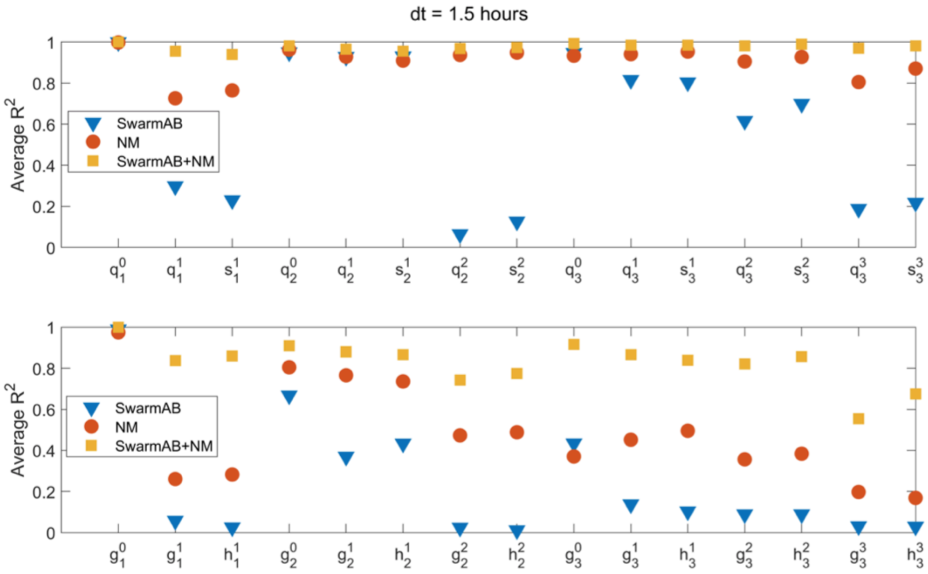
NanoMagSat LT coverage

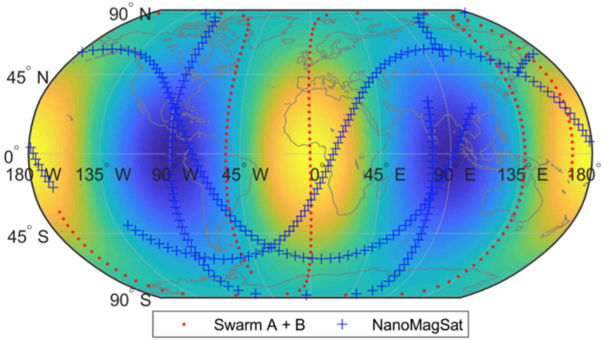


Daily models can also be recovered by NanoMagSat and not by Swarm, thanks to the much better LT coverage

Recovering the Magnetospheric Field (E2E simulations)

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



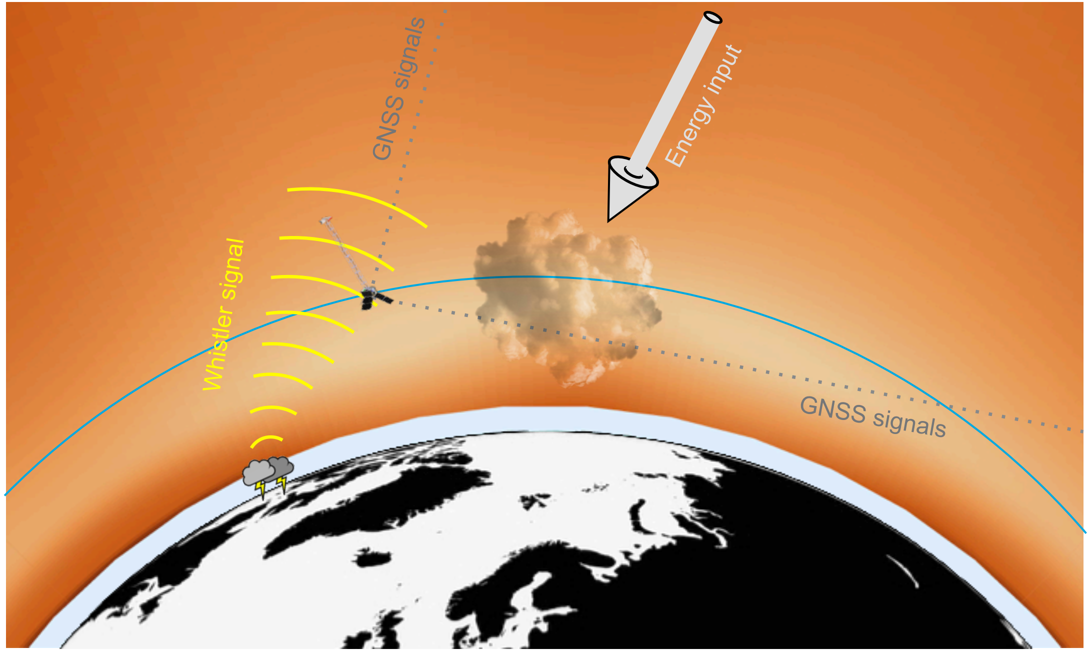


Sectorial Spherical Harmonic basis function $P_2^2(cos\theta)cos\,(im\phi)$ corresponding to the q_2^2 coefficient plotted along with the satellite orbits during 12:00 – 13:30 on 01.12.2023.

NanoMagSat does much better than Swarm, at recovering the field up to SH degree 3 with 1.5 h resolution thanks to the "criss-crossing" of 60° inclined orbits.

Combining NanoMagSat with Swarm would also be very beneficial, illustrating the potential complementarity of the two constellations.

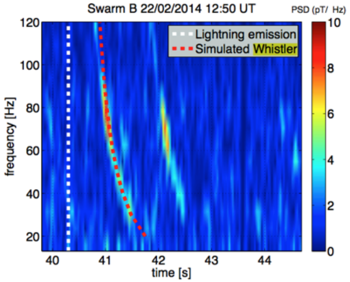
Second family of objectives: Ionospheric environment

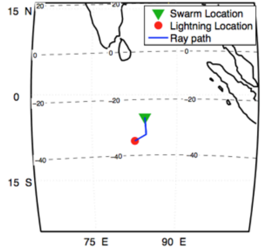


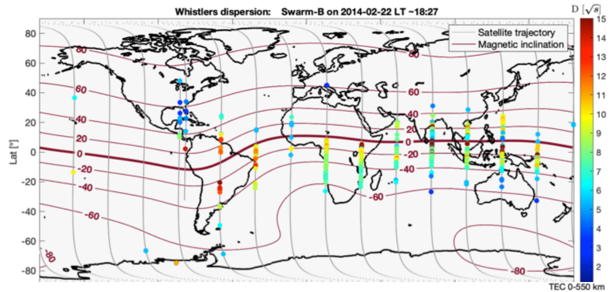
- Targeting **ionospheric plasma density dynamics**
- Combining standard GNSS techniques
- With **new ways of sensing the ionosphere below the satellites and monitoring in situ meter to km scale dynamics and energy input**
- To investigate **Space weather** phenomena that affect radio and GNSS signals, and improve **science and operational ionospheric models**

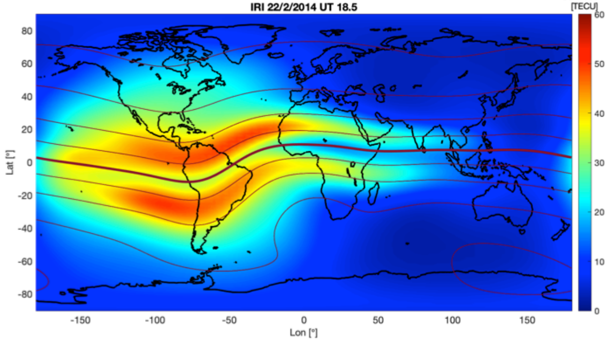
Taking advantage of an **innovative compact payload**

Monitoring the ionosphere below NanoMagSat

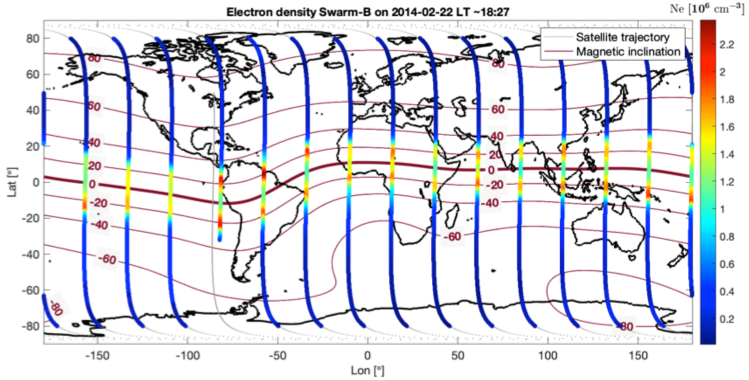








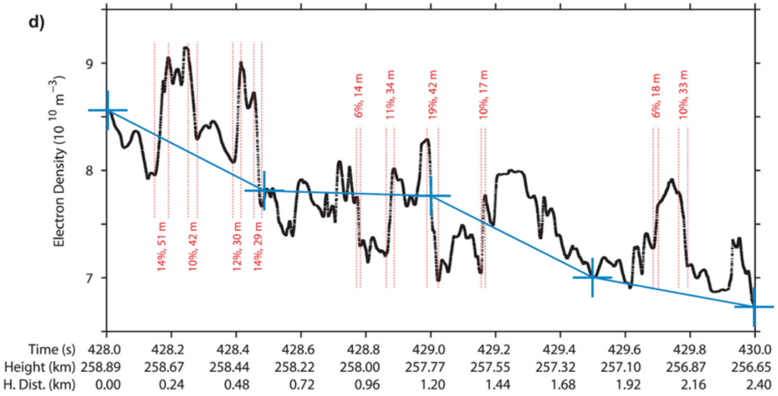
Principle illustrated using Swarm B ASM (250 Hz magnetic scalar Burst mode, left) and 1 Hz Langmuir Probe data (below) on 22/02/2014



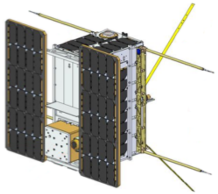
IRI model prediction on 22/02/14

- **Take advantage of ELF Whistlers produced by lightning, detected by the MAM (scalar) and HFM (vector) magnetometers (2 kHz)**
- These propagate through the ionosphere with a dispersion that **allows sensing the ionospheric plasma below the satellites**
- **Complementing local m-NLP measurements**
- **Providing information in regions not covered by ionosonde or GNSS techniques**
- **Also allowing investigations of whistlers in general**

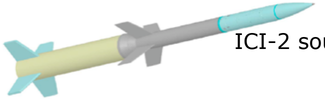
Investigating in-situ small scale plasma variability



Moen, J., et al. (2008), doi:10.1029/2012GL051407



NorSat-1 nano-satellite

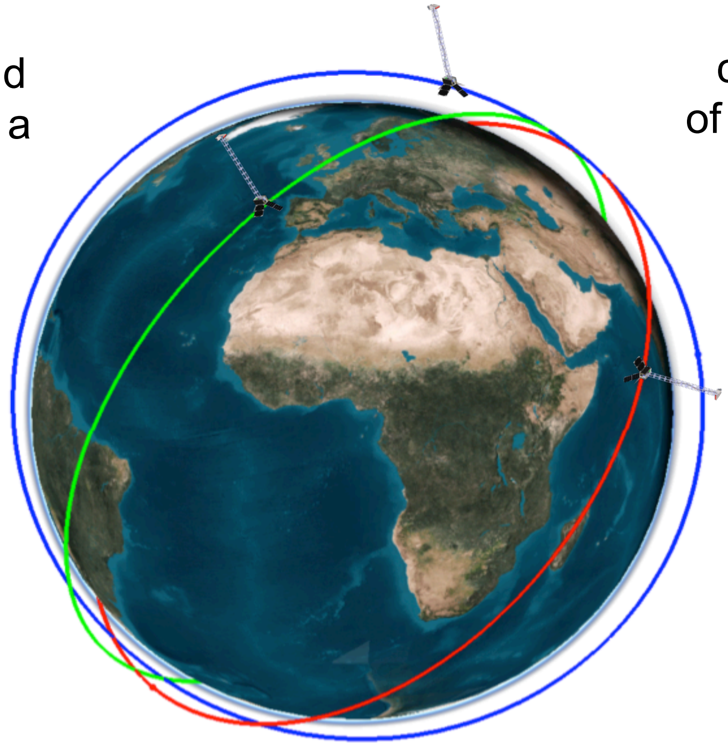


ICI-2 sounding Rocket

- **First joint measurements of electron density and magnetic signals at high frequencies** (2 kHz)
- **to access meter to km scale plasma variability and associated electrical currents**
- using a **multi-Needle Langmuir Probe** (m-NLP), only flown so far on sounding rockets and the NorSat-1 nano-satellite, and the **High Frequency Magnetometer** (HFM), which NorSat-1 fails to have

NanoMagSat in summary

A nanosatellite constellation to investigate Earth's magnetic field and ionospheric environment in a unique way.

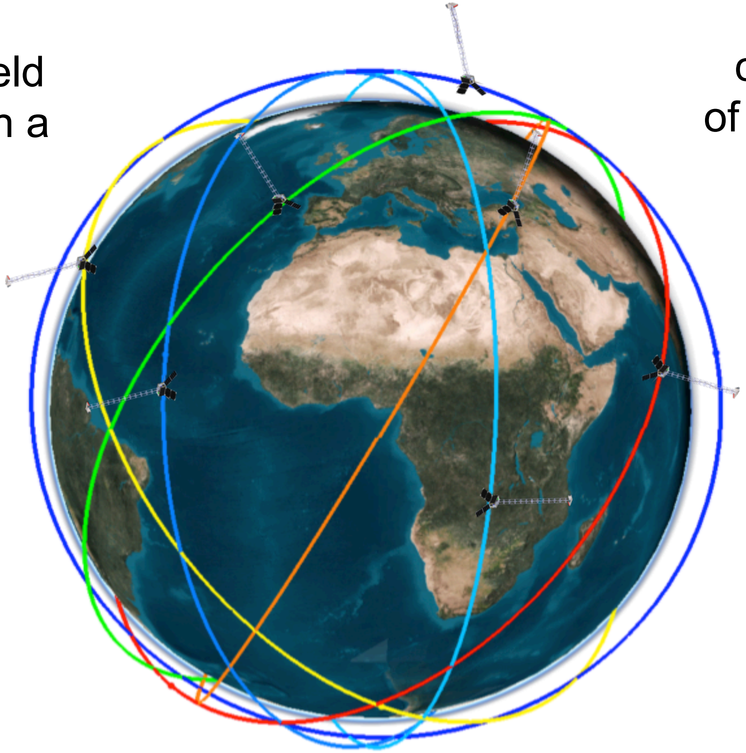


A mission ensuring continuity in the monitoring of Earth's magnetic field and ionospheric environment.

NanoMagSat in summary

A nanosatellite constellation to investigate Earth's magnetic field and ionospheric environment in a unique way.

A mission ensuring continuity in the monitoring of Earth's magnetic field and ionospheric environment.



A stepping stone for a space network of observatories with international scalability.

NanoMagSat programmatic history and status

- **August 2019: Submitted** to the **ESA Scout call**
- **November 2019: Selected** as one of four missions **to undergo a consolidation study**
- **January to August 2020: Consolidation study** carried out
- **November 2020**: **Science very well evaluated by ACEO** (Advisory Committee for Earth Observation of ESA), but **ESA recommended further maturation of key technologies** before moving to implementation
- **February 2021:** ESA (through **PBEO,** Program Board of Earth Observation) gave the **green light to proceed with Risk Retirement Activities** (RRA).
- **Currently: Consortium** (Open Cosmos, CEA-Leti, IPGP, Univ. of Oslo) **in dialogue phase with ESA**
- **Second Quarter of 2021**: **ESA industrial Policy Committee** (IPC) **to approve**
- **September 2021: KO of RRA**

-> NanoMagSat moving forward towards implementation

-> Teams and institutions from over 16 countries expressed interest and support

-> Science consolidation activities (expanding science team and scope of mission, consultation of user community, running more E2E simulations) to **move forward in parallel to RRA.**

-> Do not hesitate to contact us: gh@ipgp.fr