M A G M A - C

Magnetic Mantle Constellation

"A 3D-Picture of our Earth's Mantle"

Team Blue

Team Blue - Alpbach Summer School 2019

Fanny Boutier, Daithí Byrne, Daniele Calvi, Sreemoyee Chakraborty, Marie Fayolle, Fabian Mueller, Samuel Ocaña Losada, Lidia Luque, Tatu Peltola, Jesus Vilaboa Perez, Alice Praet, Wolfgang Senoner, Jan Snizek, Panagiotis Trifa, Sebastian Zieba

Tutors: Jerome Loicq, Adriana Elizabeth Nuncio Quiroz

Speakers

Science Case

Marie Fayolle

Payload

Jesús Vilaboa Pérez

Mission Profile

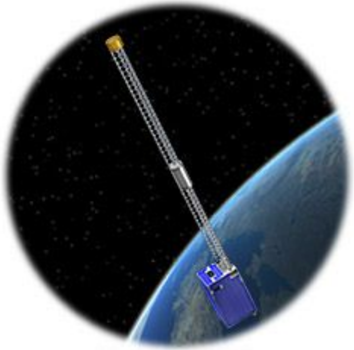
Samuel Ocaña Losada

Spacecraft Design

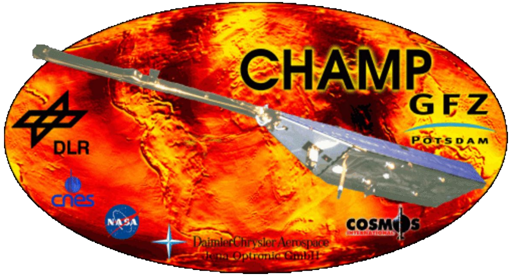
Fanny Boutier

Science Case

Past magnetic field missions



Ørsted (1999-2013)

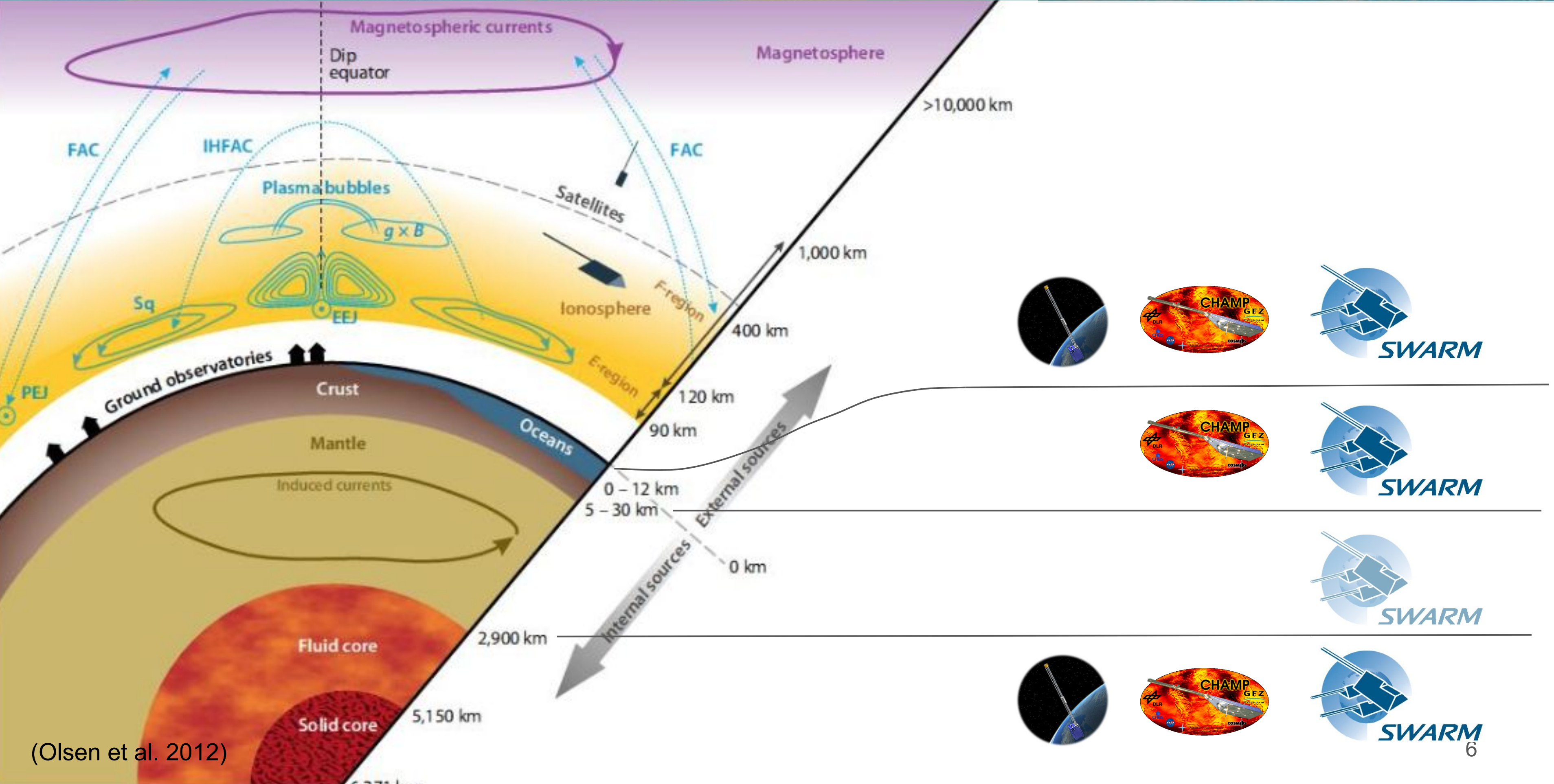


CHAMP (2000-2010)

SWARM

SWARM (2013-)

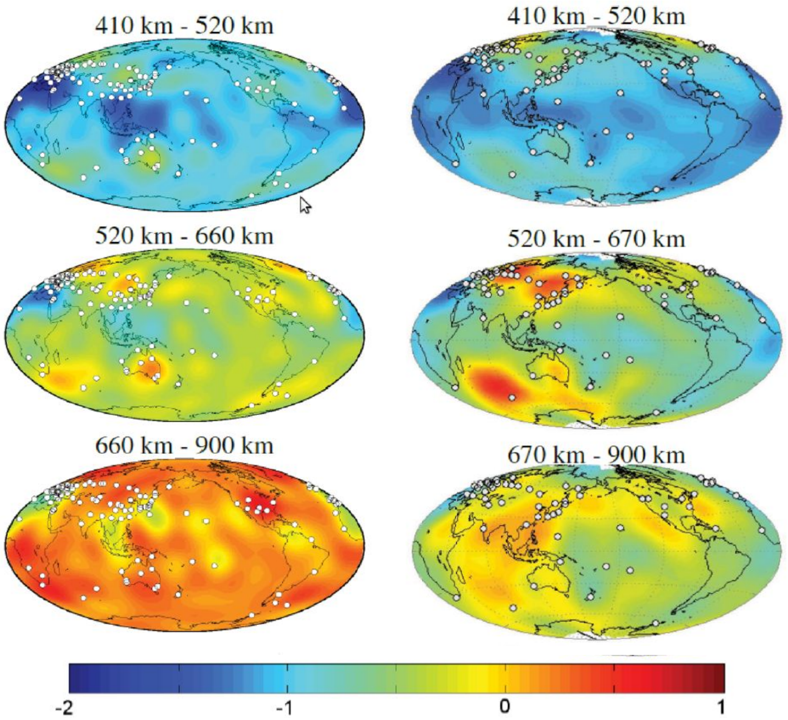
Earth's Magnetic Field

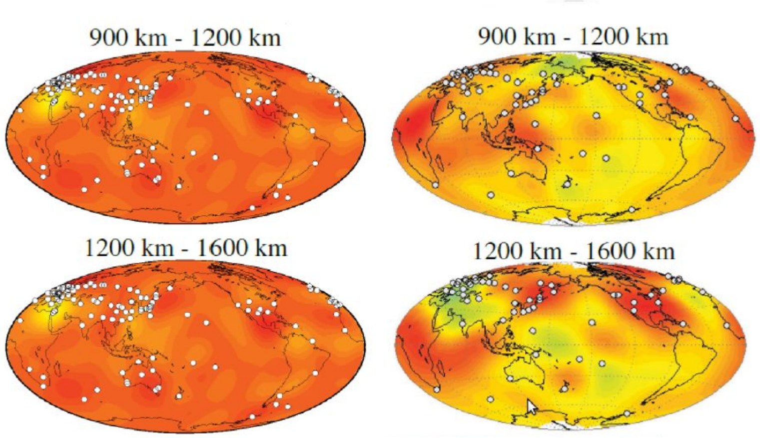


(Olsen et al. 2012)

State of the art: 3D conductivity profile

Ground-based measurements





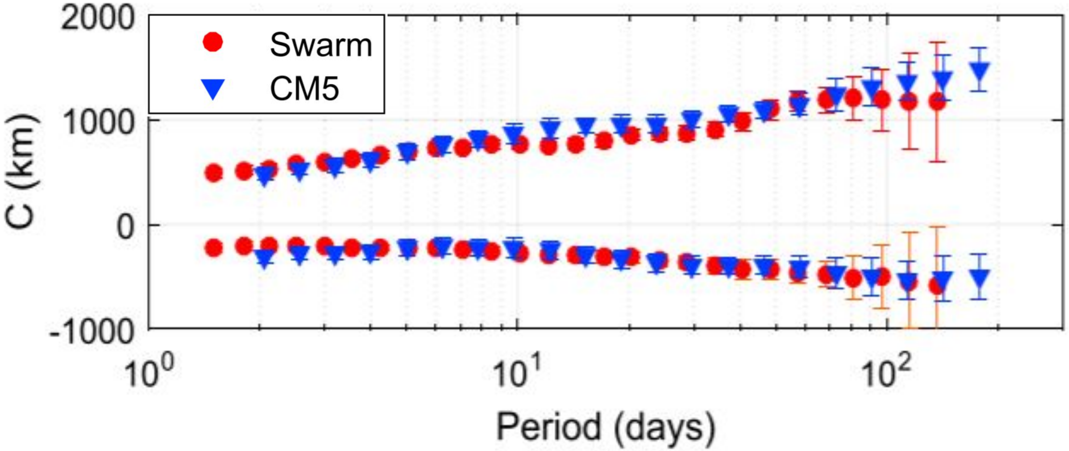
(Semenov et al., 2012) log(σ)

Models diverge rapidly with increasing depth

State of the art: 1D conductivity profile

Space-based data

C-response

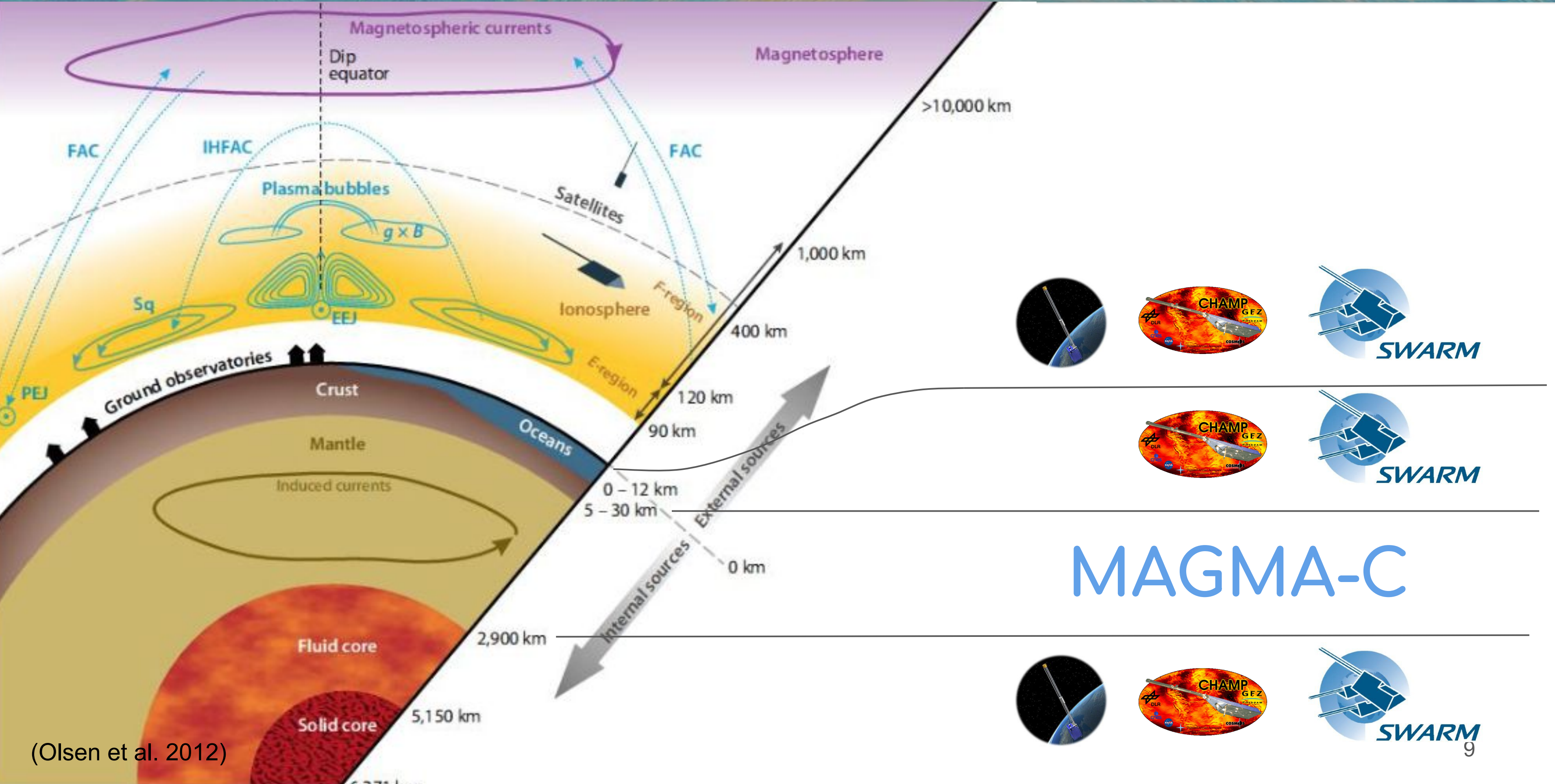


(Adapted from Grayver et al., 2017)

- Some disagreement in 1D model
- Large uncertainties at lower end of depth measurement

No 3D model

The Earth's Magnetic Field



(Olsen et al. 2012)

Feasibility

3D conductivity map

from

Global mapping of the magnetic field
with high **temporal resolution**

↓

Requires the use of many satellites

now feasible due to

- Miniaturisation of instruments
- Technological maturity of small satellite constellations

Mission Statement

Measure the total magnetic field at ionospheric altitudes
with high spatial and temporal resolution to
isolate the magnetic field due to induced currents in the mantle.

Provide unprecedented **3D conductivity profile**
of the Earth's mantle.

Mapping of the **water content** and **temperature** in the mantle
will advance knowledge of mantle structure and dynamics.

Science Objectives

Main objective

To establish a 3D conductivity profile of the mantle from the induced magnetic field due to magnetospheric and ocean currents.

Specific objectives

Map the water content in the mantle	Create a 3D temperature profile of the mantle

Byproduct

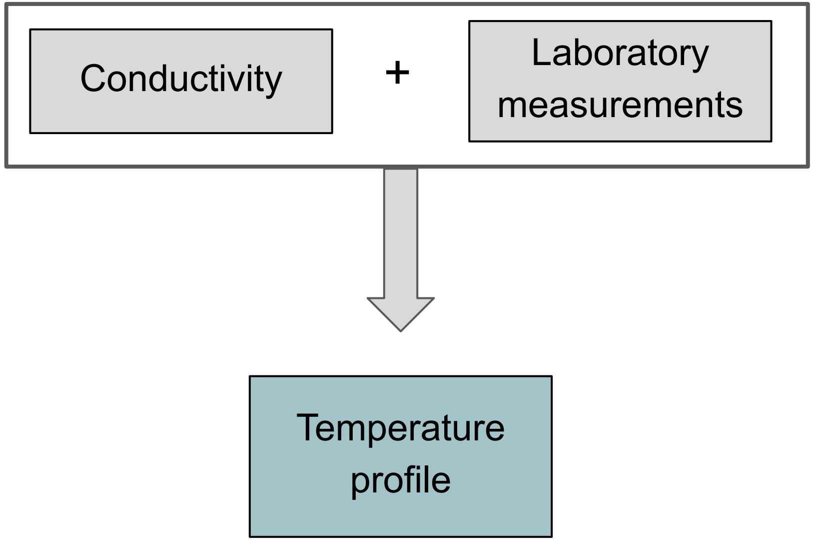
Improve the existing model for the ionospheric currents

Specific Objectives: Temperature profile

Create a 3D temperature profile of the mantle

Important input in models of mantle structure and convection

Conductivity interpreted in terms of **temperature** variations by making **assumptions on the composition** (Civet et al., 2015)



*assumes known composition

Specific Objectives: Mantle water content

Map the water content in the mantle

Conductivity varies two orders of magnitude for expected ranges of **water content** (Karato, 2011)

"One of the more important influences on Earth's **structure** and **dynamics.**"

- Main driver of **plate tectonics**
  ➡ Insights into other planets
- Slows **seismic waves**
  ➡ Improve earthquake modelling

(Hirschmann et al., 2012)

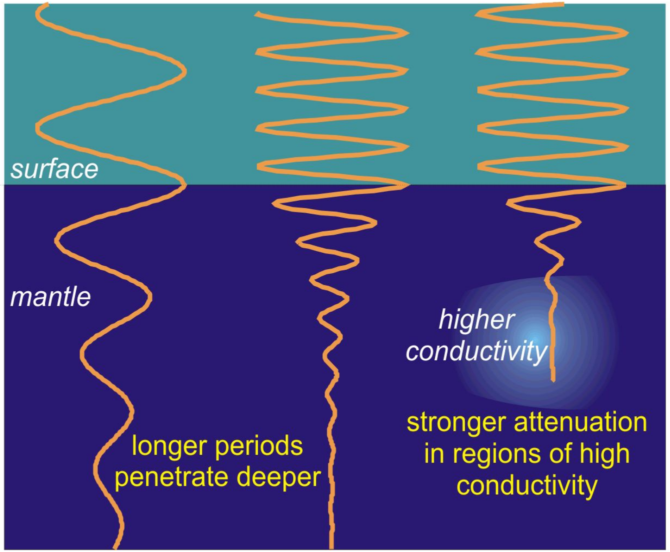
Model of Venus (ESA)

Measurement strategy

Induced magnetic field in the mantle due to other magnetic field sources

Skin effect:
Inducing magnetic field variations with **lower frequencies** generate **deeper currents** in the mantle.

→ Isolate induced fields at a given **frequency** gives the magnetic field at a certain **depth**.



(Haagmans et al., 2015)

Measurement strategy - inducing sources

We measure the total magnetic field

$$\vec{B}_{\text{measured}} = \vec{B}_{\text{core}} + \vec{B}_{\text{crust}} + \vec{B}_{\text{tides}} + \vec{B}_{\text{magnetosphere}} + \vec{B}_{\text{ionosphere}} + \vec{B}_{\text{mantle}}$$

Induced field

Which sources could be used to extract the induced field in the mantle?

Tidal field

Internal field
Period precisely known: T = 12.42 hours

→ **Induced and inducing fields can be separated**

BUT depth of 10 - 300 km only

Magnetospheric field

External field
Highly time-varying signals

→ **Induced and inducing fields can be separated**

Ionospheric field

Internal field
Strong dayside/nightside variations

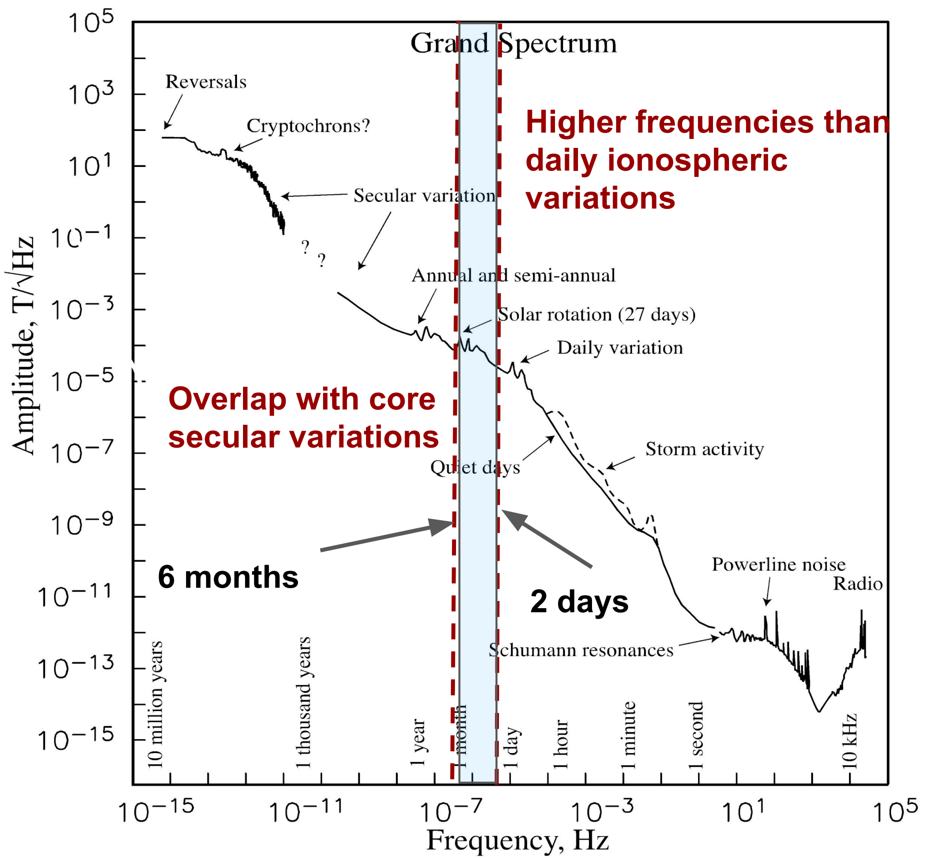
→ **Induced and inducing fields cannot be separated**

Measurement strategy - inducing sources

Frequency range of the inducing field used to get the mantle field

	Period	Depth (skin effect)
Magnetosphere (ring current)	2 days - 6 months	≈ 400 - 1600 km
Oceanic tides	12.42 h	10 - 300 km

Adapted from Kuvshinov, n.d.



(Kwisanga, 2017)

Measurement strategy - inducing sources

CONTRIBUTIONS TO BE REMOVED

Core field

Year to decade variations

Crustal field

Static field

Ionospheric field

Strong daily variations
T = 24, 12, 8, 6 hours…

Longest period signals

The inducing and induced parts cannot be separated.

Cannot use T > 1 year signals (overlap with secular variations)

Cannot use T < 1 day signals to derive the induced currents

INDUCING FIELDS USED TO GET THE MANTLE FIELD

Tidal field

T = 12.42 hours

Very precisely known period

Magnetospheric field

Irregular, non-periodic signals, varying on short timescales

Separation of the magnetic field

CONTRIBUTIONS TO BE REMOVED

Core field

Year to decade variations

Crustal field

Static field

Ionospheric field

Strong daily variations
T = 24, 12, 8, 6 hours...

T = 24, 12, 8, 6 hours signals have to be removed

8 local times evenly distributed (3 hours separation)

INDUCING FIELDS USED TO GET THE MANTLE FIELD

Tidal field

T = 12.42 hours

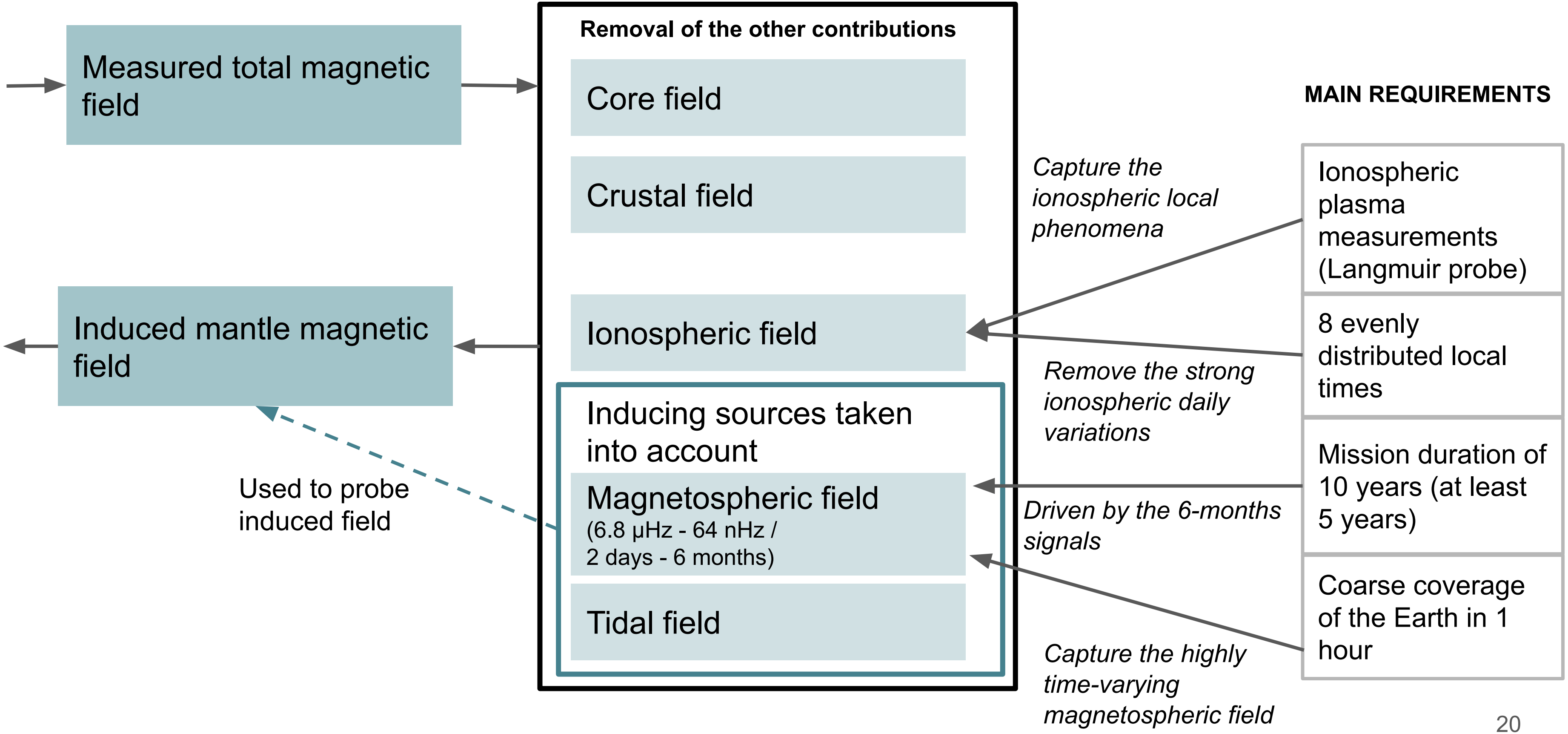
Magnetospheric field

Irregular, non-periodic signals, varying on short timescales

1 hour mapping of Earth with large space scales
(few thousands kilometers)

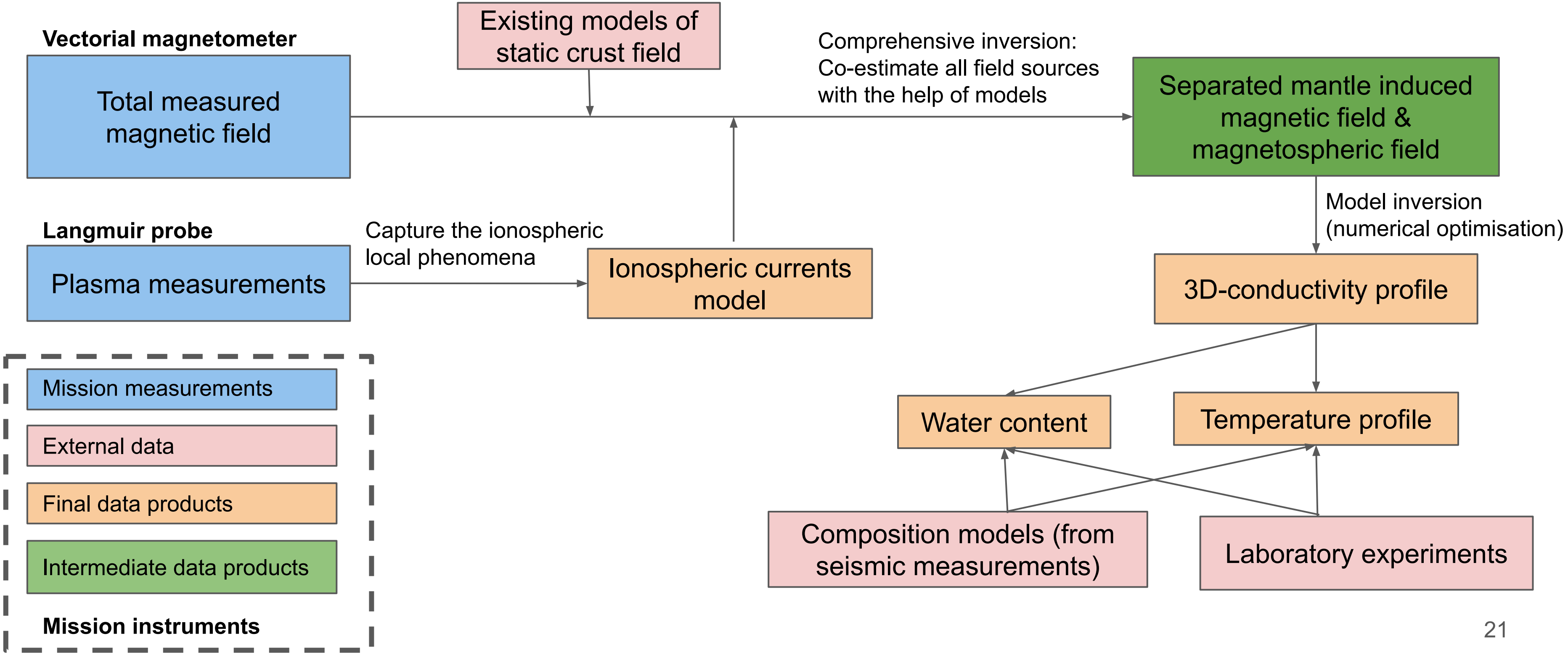
Better spatial resolution over 1 day
(few hundreds kilometers)

Summary of the measurement strategy



Data products

From magnetic field to data products



Scientific Payload

Scientific Payload

Objectives		Instruments
Measurement of the **magnetic field**	→	Magnetometers
Induced electrical current caused by **local variations** in the ionosphere	→	Electron density sensors

Scientific Payload - Requirements

<table>
<tr><th>Instrument</th><th>Measurement requirements</th></tr>
<tr><td>Vector Field Magnetometer (VFM)</td><td rowspan="2">Range of strength of the magnetic field:
± 25000 nT to ± 60000 nT
Noise density in the range of pT/√Hz</td></tr>
<tr><td>Absolute Scalar Magnetometer (ASM)</td></tr>
<tr><td>Star trackers (to have VFM precision measurements)</td><td>1 nT → Accuracy: 0.001 deg</td></tr>
<tr><td>Electron density sensors (Langmuir probe)</td><td>Range of the ionosphere storms:
100 Hz - 3 kHz</td></tr>
</table>

Vector Field Magnetometer (VFM)

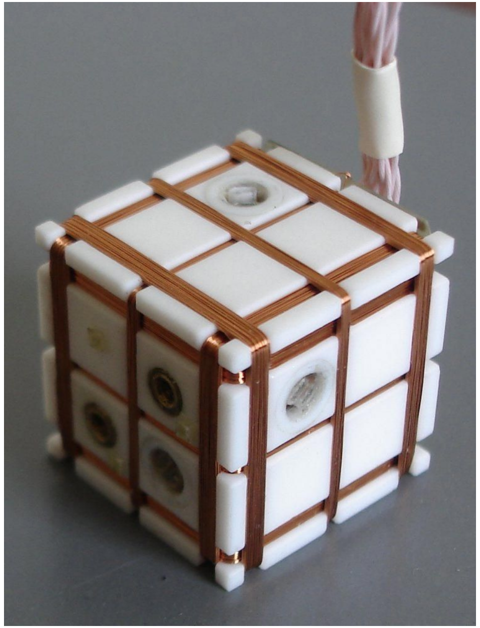
Capability of the instrument:

VFM gives information about the value of each of the components of the magnetic field.

Characteristics of the instrument:

Why it is good: improves the range of the Themis VFM (only ± 25000 nT).

- **Range: ± 65000 nT**
- **Noise density (1 Hz): 25 pT/√Hz**
- Mass: 25 g sensor, 40 g electronic
- Size sensor: 20 x 20 x 21 mm
- Size electronics: 65 x 65 x 10 mm
- Power consumption: < 0.4 W
- Maximum sample rate: 250 Hz
- **TRL 6** (No flight heritage) year 2019



Reference: Miniaturised fluxgate sensor LEMI-020. Lemi LLC sensors. Lviv Centre of institute for space research.

Why is the instrument needed?

To measure the magnetic field vector in order to have the information needed for the science objective.

Attitude Determination: Star Trackers

Capability of the instrument:

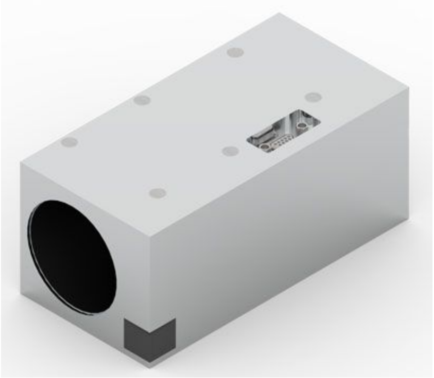
Star tracker for precise attitude determination.

Characteristics of the instrument:

Number of star trackers: three in order to avoid the sun blinding effect

Location: in the same optical bench that the VFM

- Mass: 250 g
- Size: 45 x 50 x 95 mm
- Power consumption: nominal < 1 W
- **Accuracy: 2 arc seconds → 0.0005°**
- Design: lens and electronics are radiation shielded
- **TRL 6** (No flight heritage) year 2019



Reference: KU Leuven Star Tracker. CubeSat Shop KU Leuven Star Tracker for nanosatellites.

Why needed?

Fundamental element for the Vector Field Magnetometer to improve the quality and precision of the measurements.

Absolute Scalar Magnetometer (ASM)

Capability of the instrument:

provides absolute measurements of the magnetic field strength.

Characteristics of the instrument:

Miniature atomic scalar magnetometer → rubidium isotope ^{87}Rb.

- Range: tested at ± 71428 nT

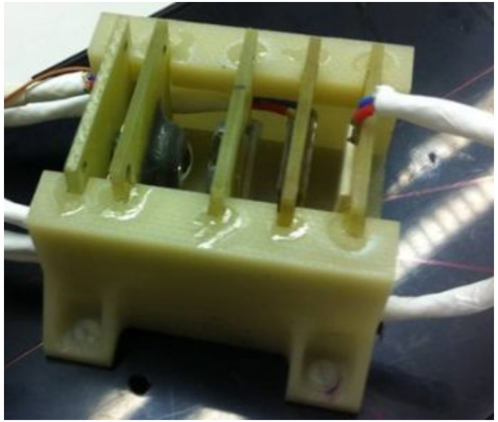
- Noise density (1 Hz) → < 15 pT/√Hz

- Mass (sensor + electronics): 500 g

- Size (sensor + electronics): 20 mm - 30 mm

- Power consumption: < 1 W

- **TRL 6** (No flight heritage) year 2016



Reference: Haje Korth, et al. Miniature atomic scalar magnetometer for space based on the rubidium isotope ^{87}Rb

Why we need the instrument:

- To reduce the offset problem due to manufacturing/behavioral errors.
- For the in-flight calibration of the VFM (Vector Field Magnetometer).

Compatibility magnetometers

Problem to solve:

- Cross-talk during the measurements between the vector field and scalar magnetometer

Solution:

- **Two booms** configuration. One boom for each magnetometer
- **Magnetic cleanliness** program: on ground (flat sat) + in flight

Other options:

- Use instead of a scalar magnetometer an **external field** to calibrate → similar to the BepiColombo mission
- An ASM dual mode (burst/vectorial) → similar to MagSat: but 10x noise compared to fluxgate

Electron density sensor - Langmuir probe

Capability of instrument:

Provides measurements of the **electron density**, **electron temperature** and electric potential.

Characteristics of the instrument:

Design: 2 probe configuration.

- Mass (of each probe): 100 g
- Size (of each probe): 52 mm x 10 mm
- Power (of each probe): 0.25 W
- Relative error in electron density ≈ 10%
- **Low pass filter: 4 kHz**
- **High pass filter: 10 Hz**
- **TRL 9** (flight heritage in the mission Astrid 2)

Reference: B. Holback, et al.
LINDA – the Astrid-2 Langmuir probe instrument.
European Geophysical Society

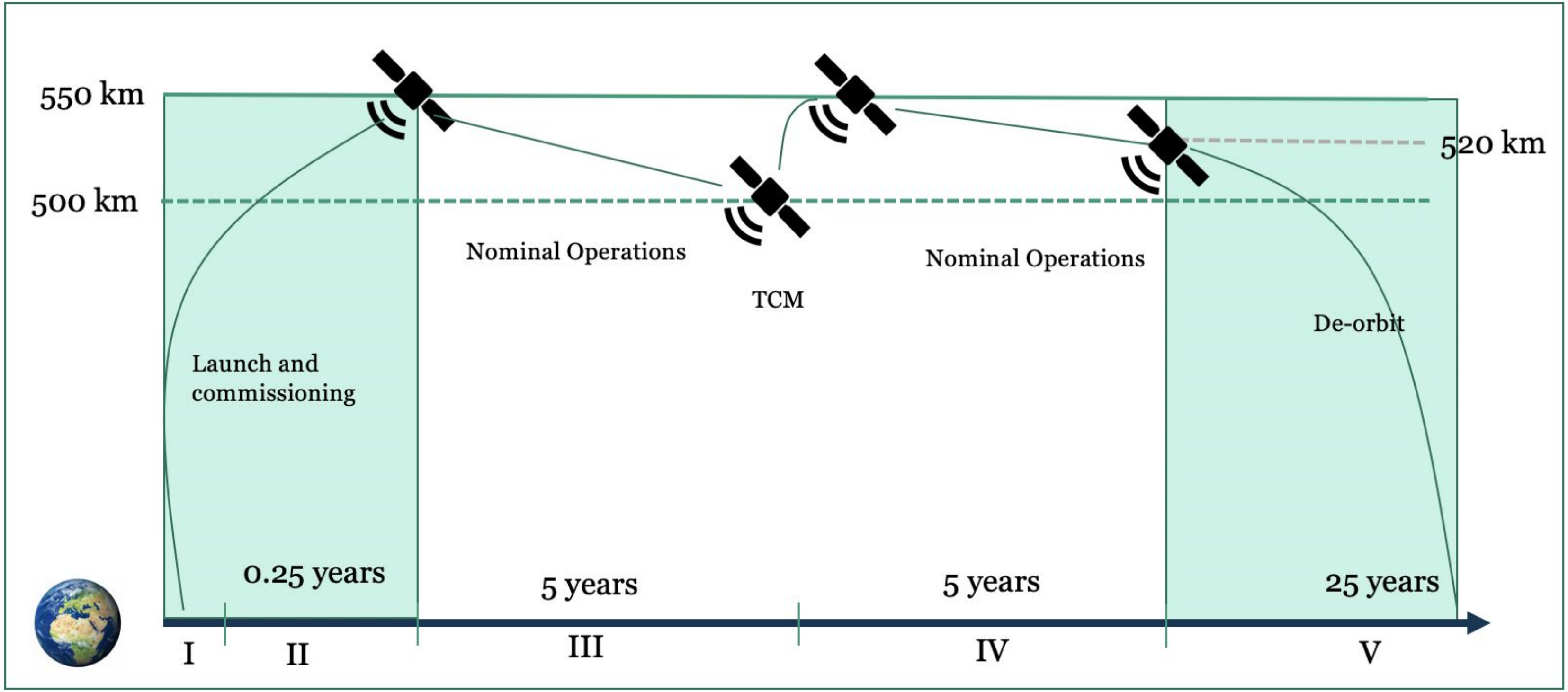
Why we need the instrument:
To measure the local storms and the plasma bubbles to be later subtracted from the magnetometer data.

Scientific Payload & Requirements

Instrument	Scientific requirements	Instrumental requirements
Vector Field Magnetometer (VFM)	Range of strength of the magnetic field: ± 25000 nT to ± 60000 nT Noise density in the range of pT/√Hz	Range of the instrument: ± 65000 nT Noise density: 25 pT/√Hz
Absolute Scalar Magnetometer (ASM)		Range of the instrument: ± 71428 nT Noise density: 15 pT/√Hz
Star trackers (to have VFM precision measurements)	Accuracy: 1 nT → 0.001 deg	Accuracy: 2 arc seconds → 0.0005 deg
Electron density sensors (Langmuir probe)	Range of the ionosphere storms: 100 Hz - 3 kHz	Range of the instrument: 10 Hz to 4 kHz

Mission Profile

Overall Mission Profile



Mission profile - Orbital planes

1. Measure ionospheric currents (reducing drag effect) >> Altitude of 550 km

Mission profile - Orbital planes

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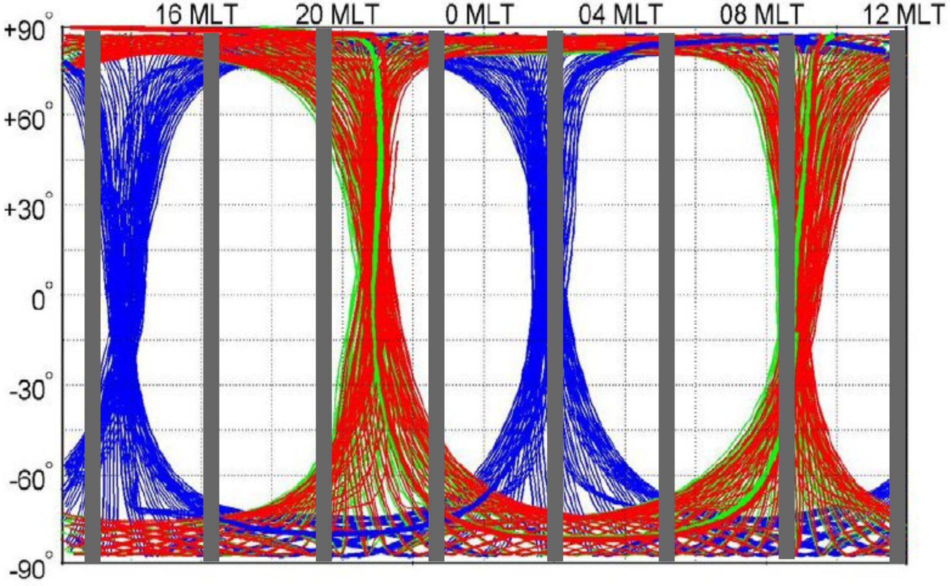
2. Coverage of 8 local times



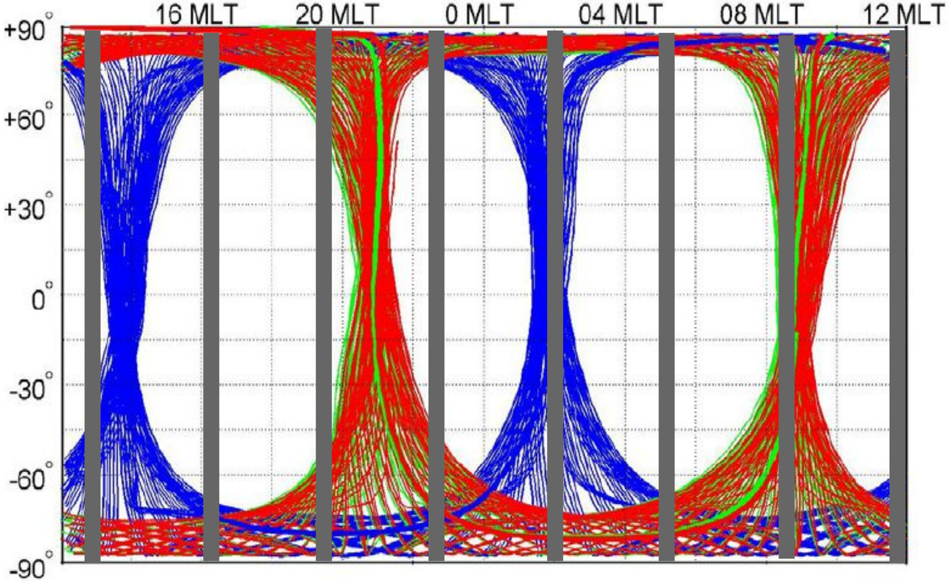
8 local times compared to SWARM's 4 local times

Mission profile - Orbital planes

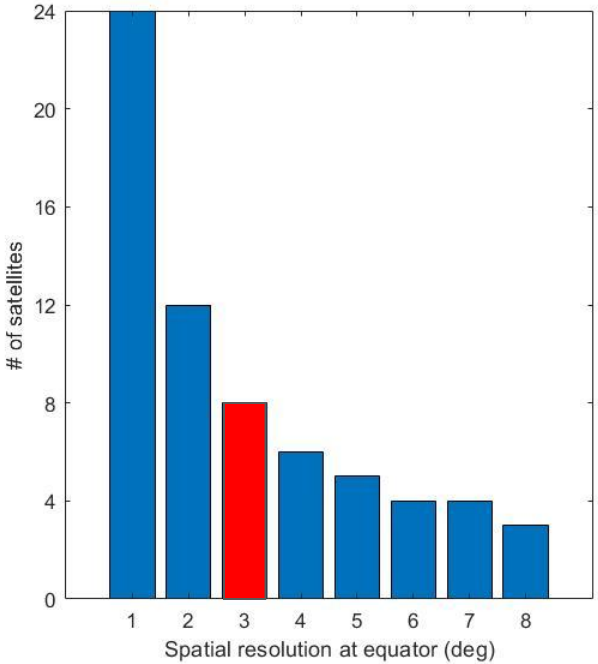
1. Measure ionospheric currents (reducing drag effect) >> Altitude of 550 km

2. Coverage of 8 local times

3. ≈ 300 km spatial resolution after 1 day

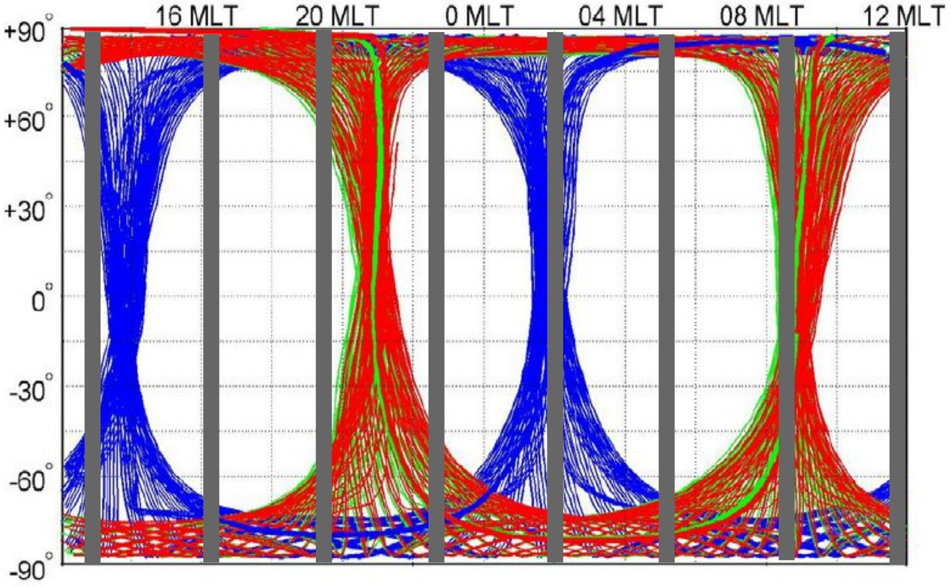


8 local times compared to SWARM's 4 local times

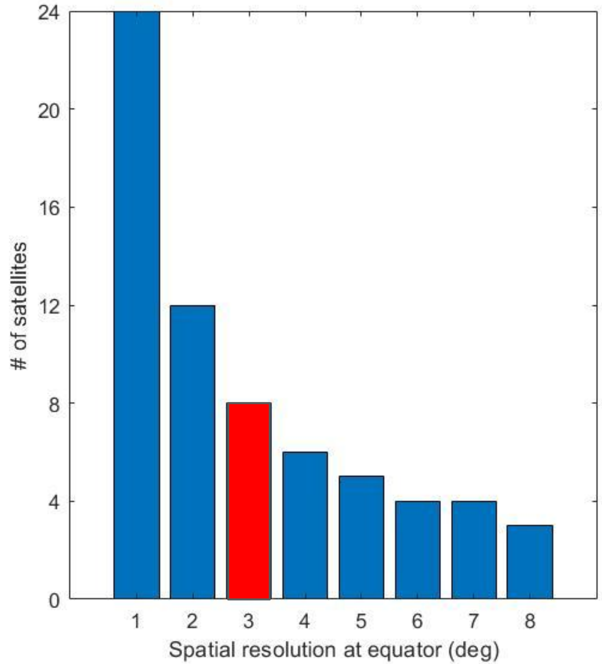


Mission profile - Orbital planes

Constellation of 8 satellites → divided into 4 orbital planes

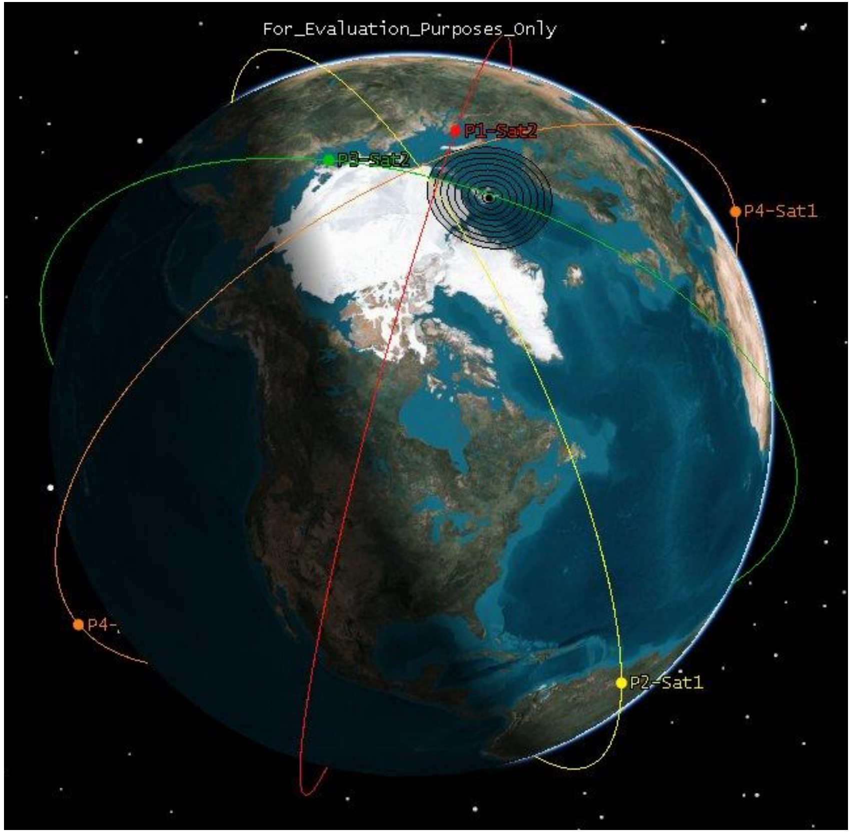


8 local times compared to SWARM's 4 local times

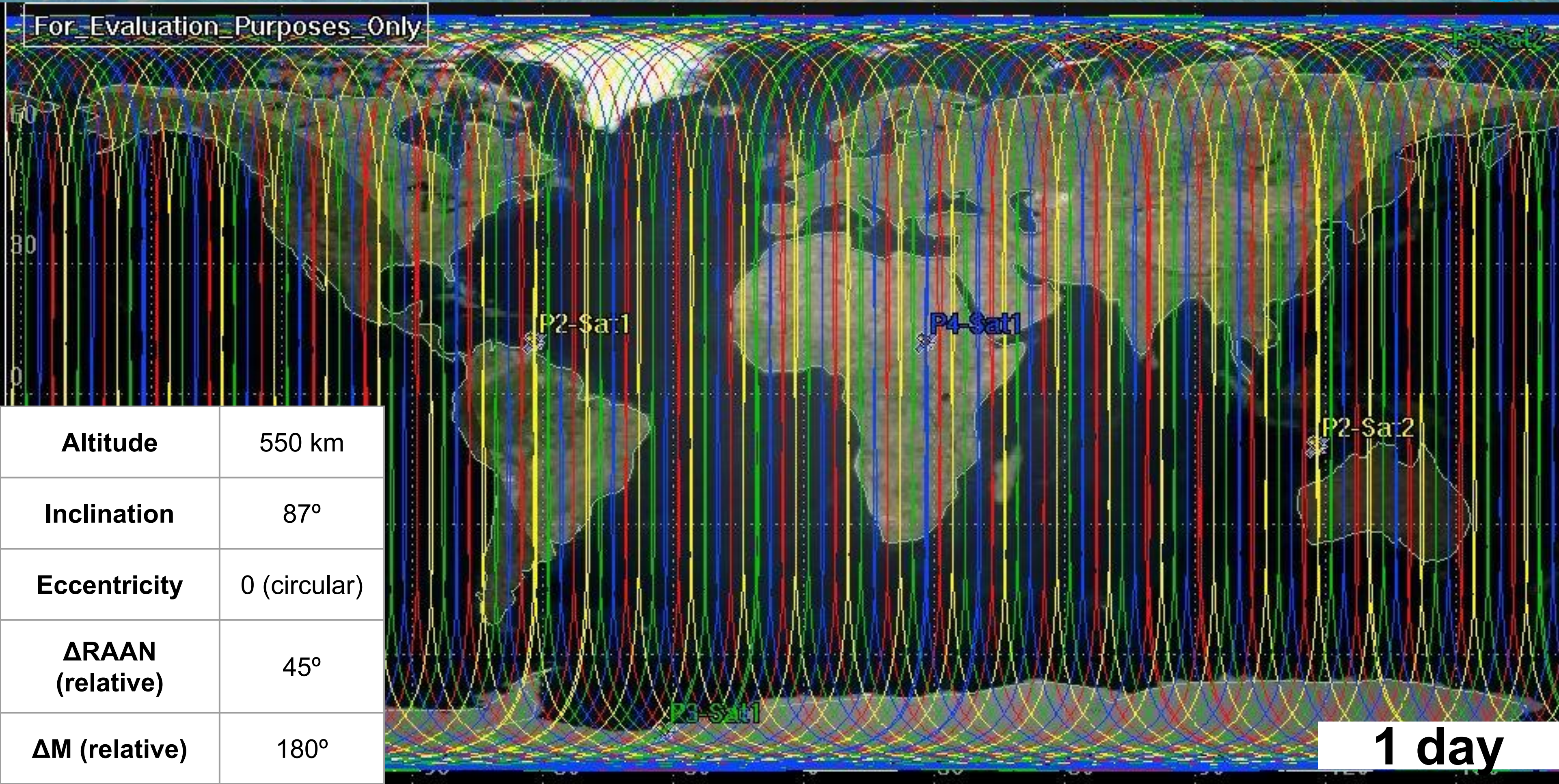


Mission profile - Orbits

Altitude	550 km
Inclination	87º
Eccentricity	0 (circular)
ΔRAAN (relative)	45º
ΔM (relative)	180º

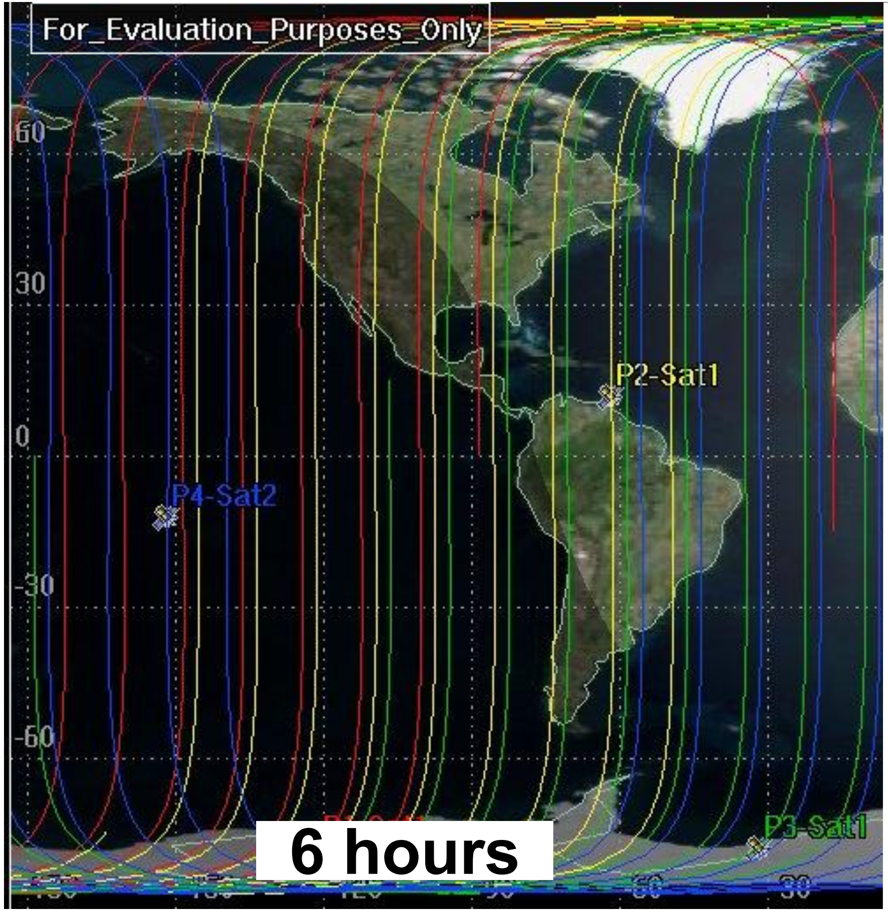


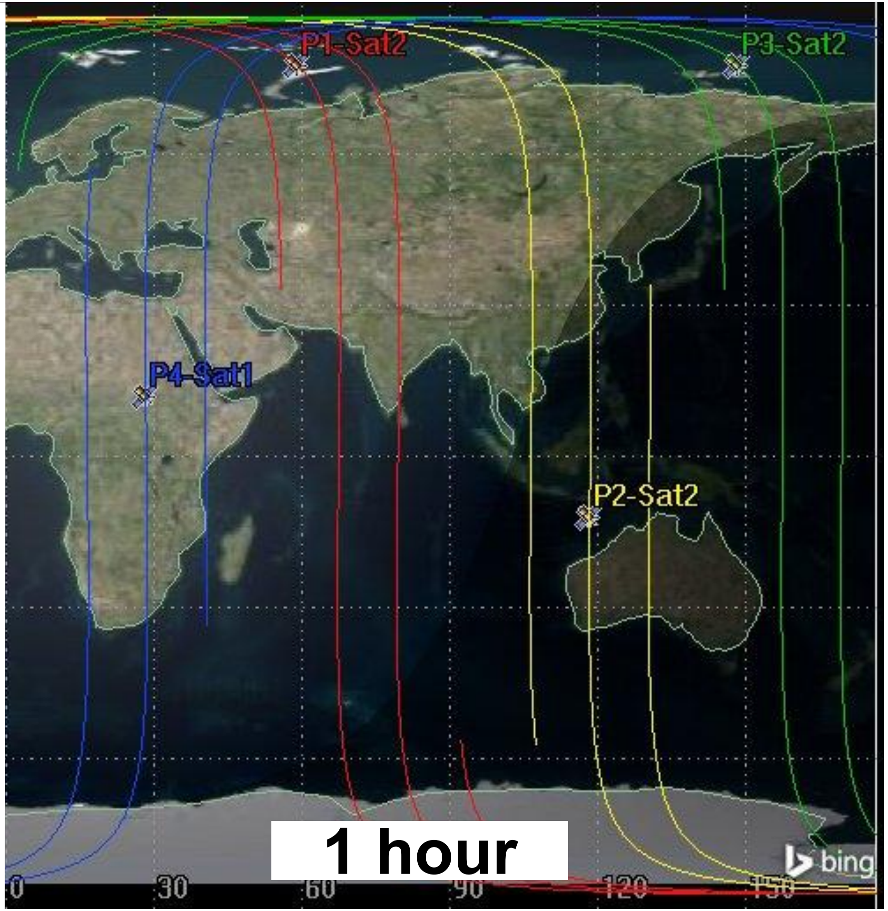
Mission profile - Ground Tracks



Altitude	550 km
Inclination	87º
Eccentricity	0 (circular)
ΔRAAN (relative)	45º
ΔM (relative)	180º

Mission profile - Temporal Resolution





Mission profile - Launcher

Initial configuration:

2 orbital planes separated 90º in RAAN

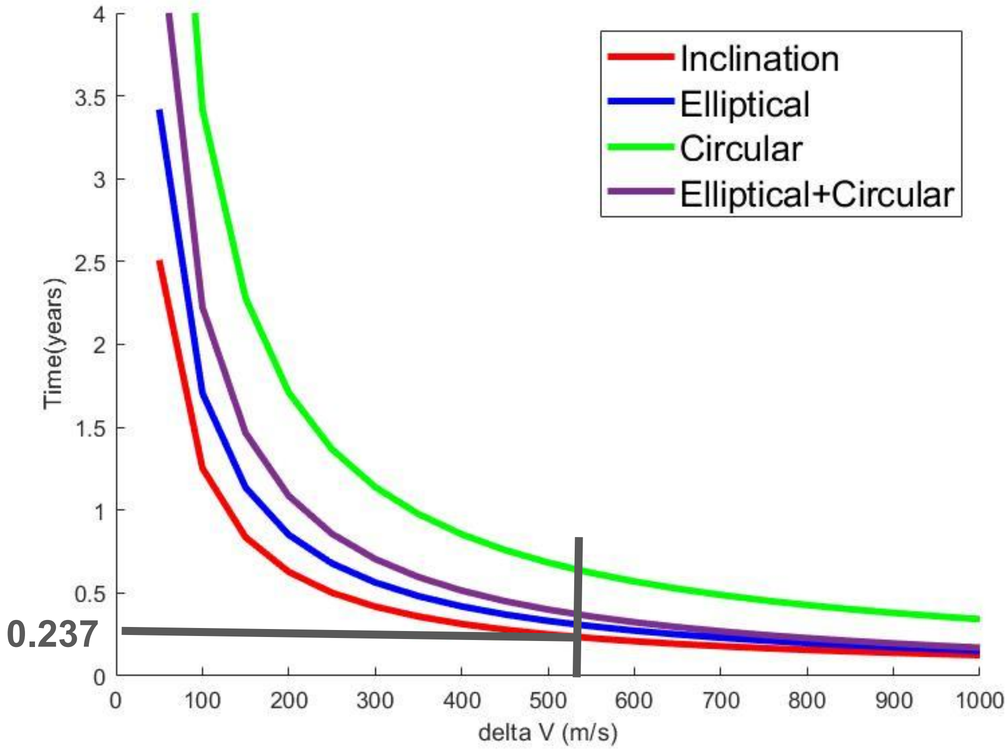
RAAN change

Use of J2 perturbation for RAAN drift of the planes

Inclination change: 2º

Phasing

180º over 2 days



Mission profile - Transfer

Initial configuration:

2 orbital planes separated 90º in RAAN

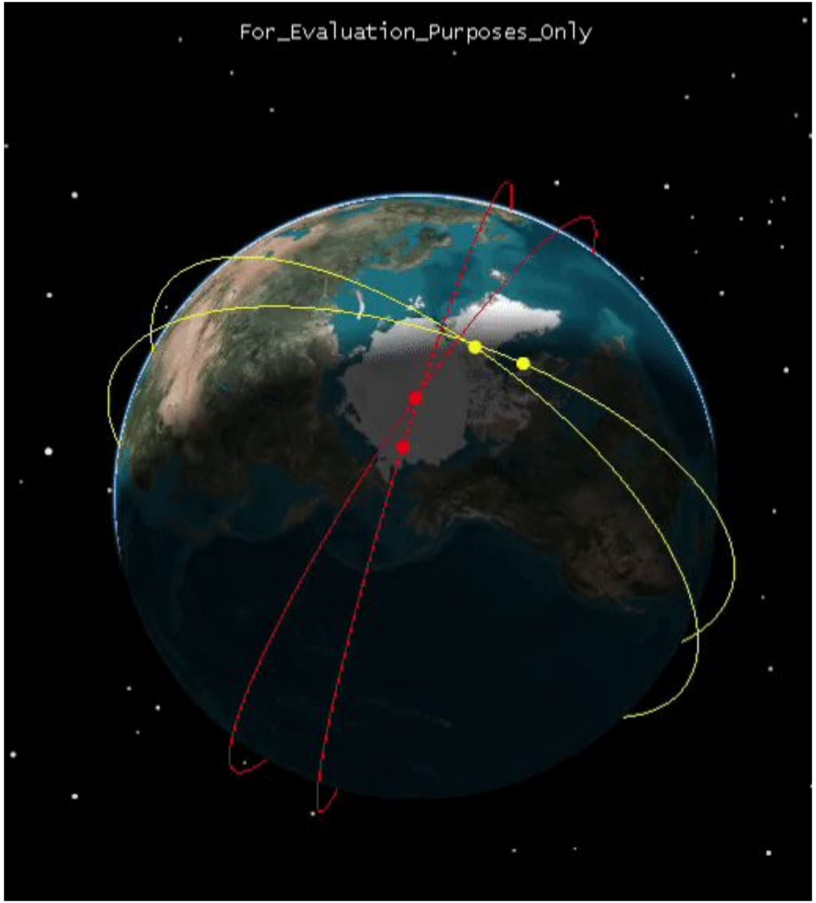
RAAN change

Use of J2 perturbation for RAAN drift of the planes

Inclination change: 2º

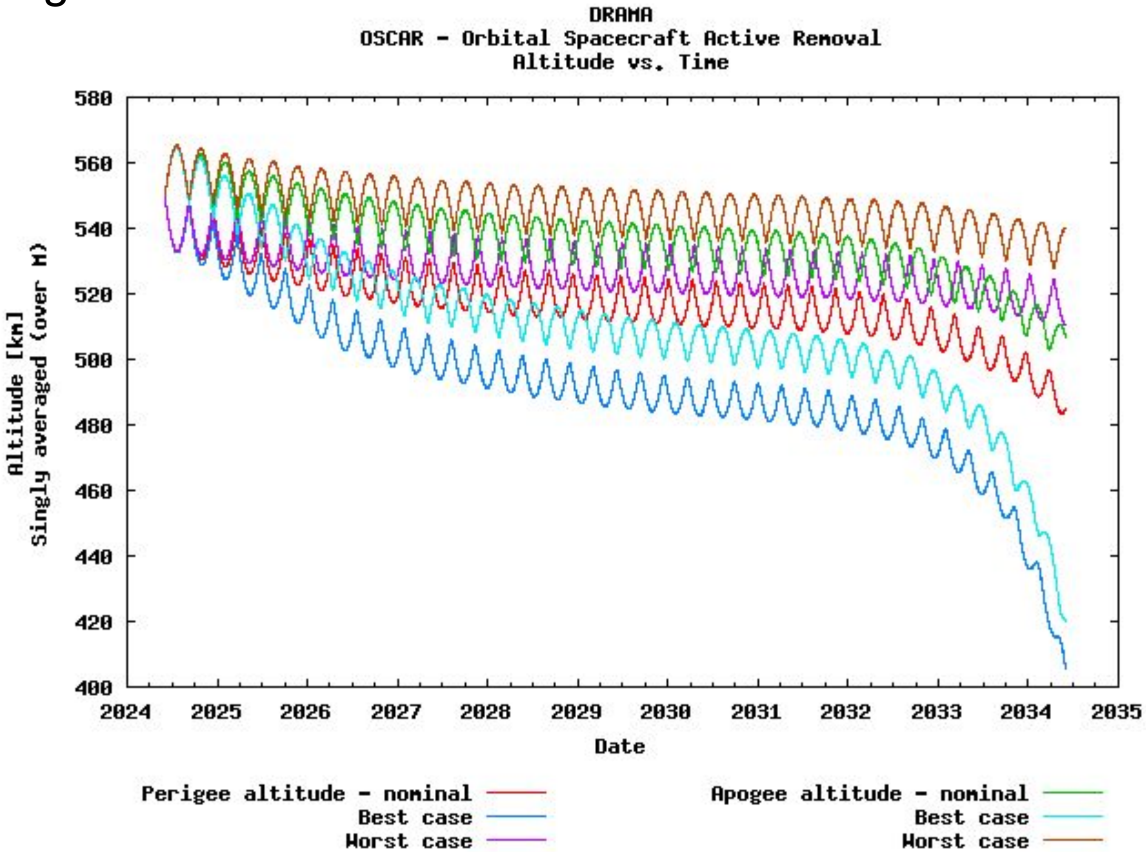
Phasing

180º over 2 days



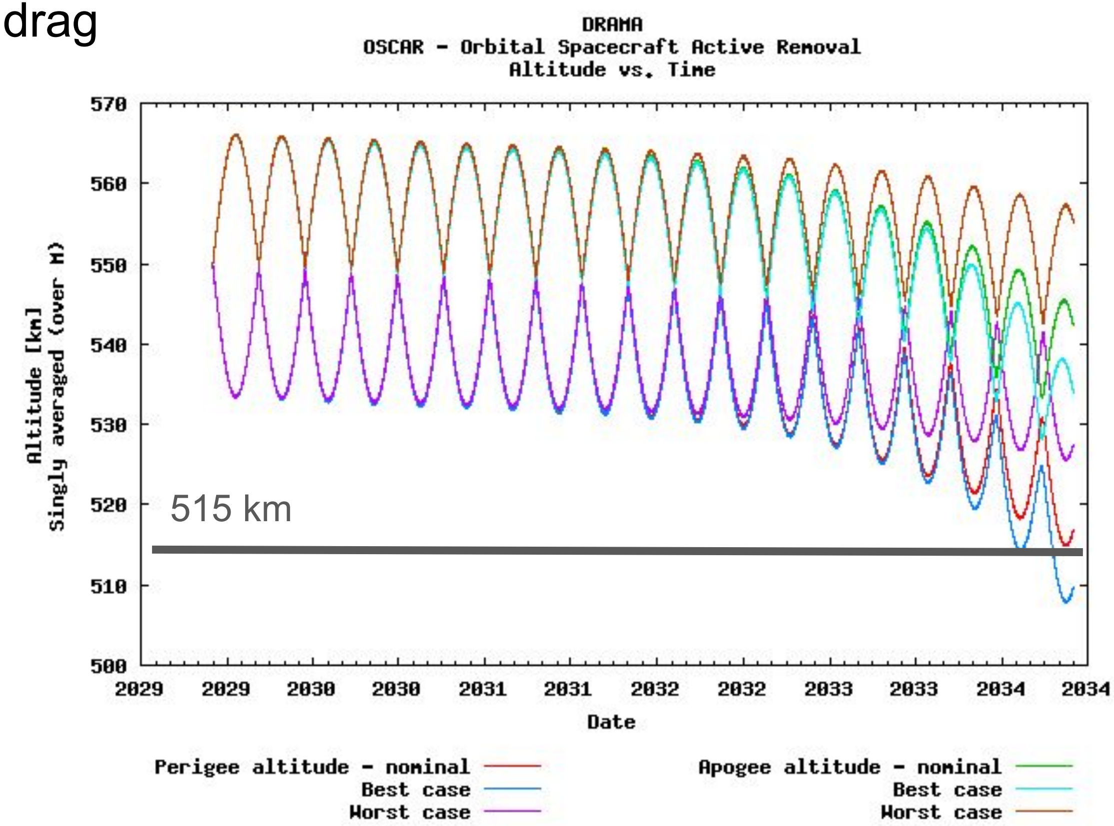
Mission profile - Environment

Atmospheric drag



Mission profile - Environment

Atmospheric drag



Delta-v Budget

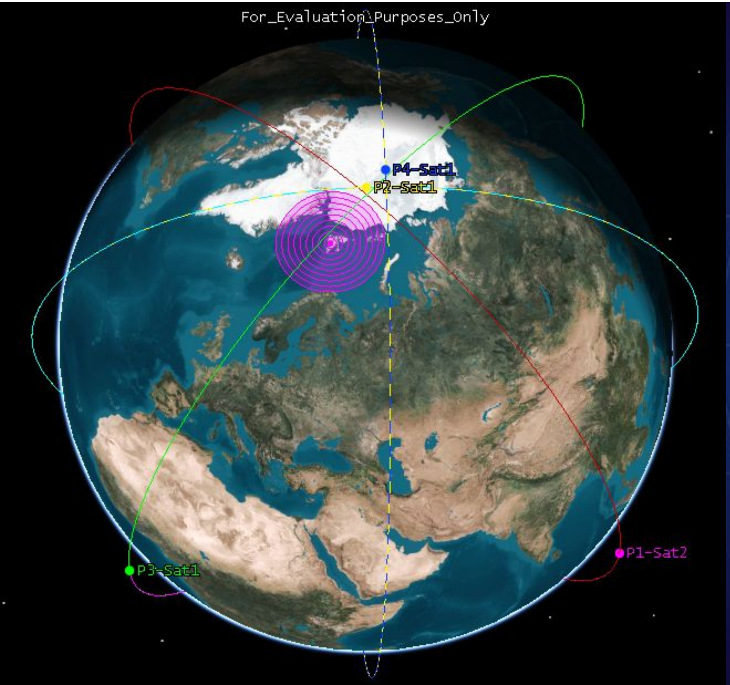
Maneuver	ΔV (m/s)
Transfer	530
Phasing (2 day)	84
Orbit maint.	27.5
Attitude control	Reaction Wheels + Magnetorquers
De-orbit	None
Margin (10%)	64.15
Total:	**705.65**
Propellant mass:	**10.03 kg**

Ground stations and downlink

Main station: Svalbard (Min. coverage: 540.850 s / Max. Coverage: 695.511 s)

Download: Every 8 days (Science) / Every day (Housekeeping)

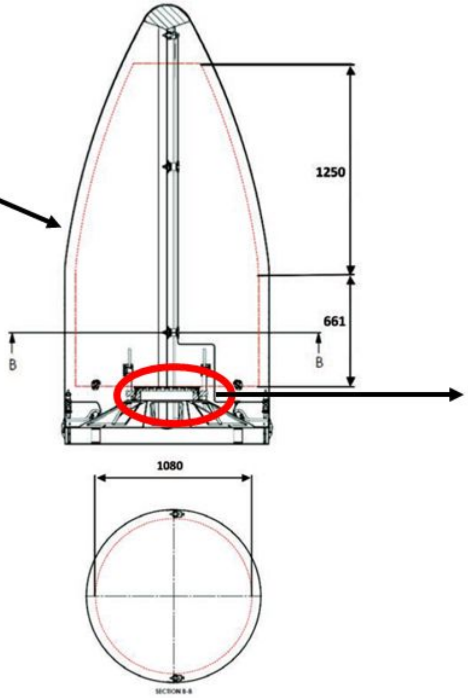
Maneuvers: Pair of ground stations at the equator



Launcher - Spacecraft Interface

Electron Launch Vehicle

Usable Volume for a Main Passenger Mission



Customized Multiple Spacecraft Separation System

Carrying Structure
[RUAG Space 2019]

Payload Plate configurations **can be customized** to accept single or **multiple satellites**, independent of whether they are CubeSat or **microsatellite** form factors.

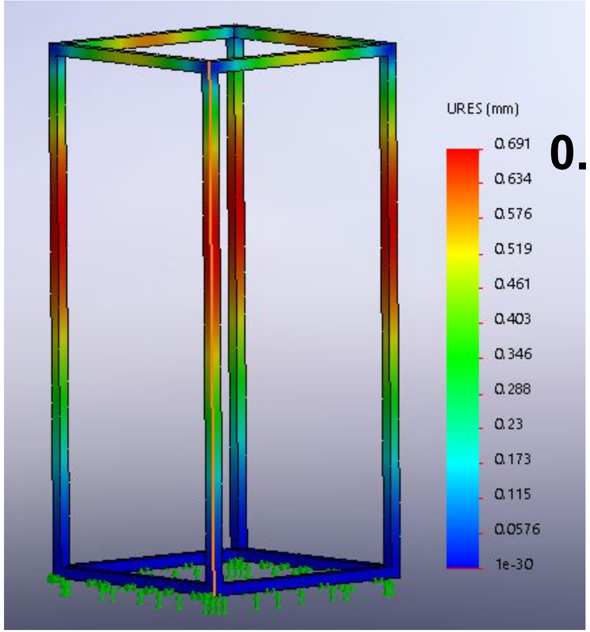
PAYLOAD
Nominal Payload: 150 kg (to 500 km SSO)
Payload diameter: 1.08 m **Payload height:** 1.91 m

Launch environment

Simulation for Quasi-Static Loads*:
Most Severe Combinations of Static and Dynamic Accelerations

- Shock Loads
- Acoustic Loads
- Radio frequency
- Random vibration
- Venting

Linear static analysis of the frame



0.691 mm

Displacement distribution

*data from: https://www.rocketlabusa.com/assets/Uploads/Rocket-Lab-Payload-Users-Guide-6.4.pdf

Spacecraft Design

Key Spacecraft Design Drivers

Goal: 10-year mission

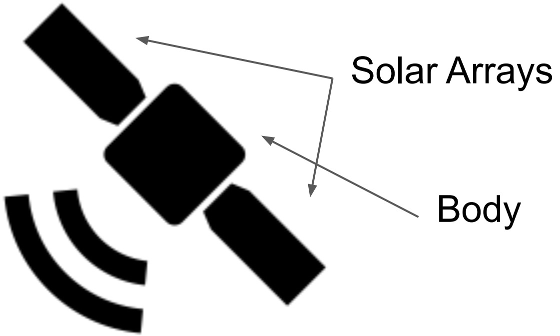
Control **drag** of the spacecraft by reducing the **ballistic coefficient** (BC)

$$BC = \frac{m}{C_D A_n} \left(\frac{\text{kg}}{\text{m}^2}\right)$$

- Maximize the mass
- Reducing the cross section

A_n →

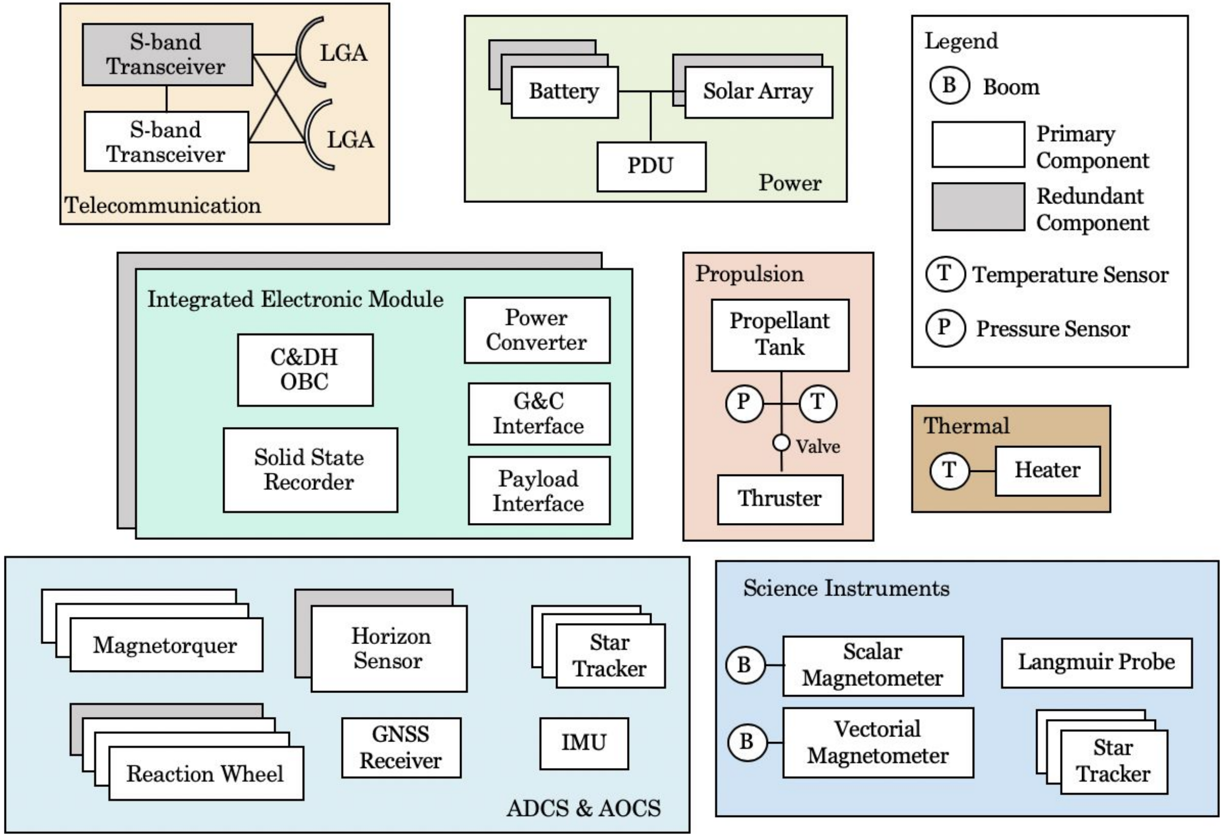
- Sizing of the S/C subsystems
- Solar array positioning and size



Requirements

Objective	Device	Requirements
Determination of orbital position	GPS receiver and GPS antenna	Position accuracy: 10 m
Attitude determination of the satellite	Gyroscopes and Inertial Measurement Unit (IMU)	Accuracy: 1 deg
Attitude control of the satellite	Reaction wheels and magnetorquers	NADIR pointing
Orbit keeping	22N HPGP Thruster	Δv = 613 m/s

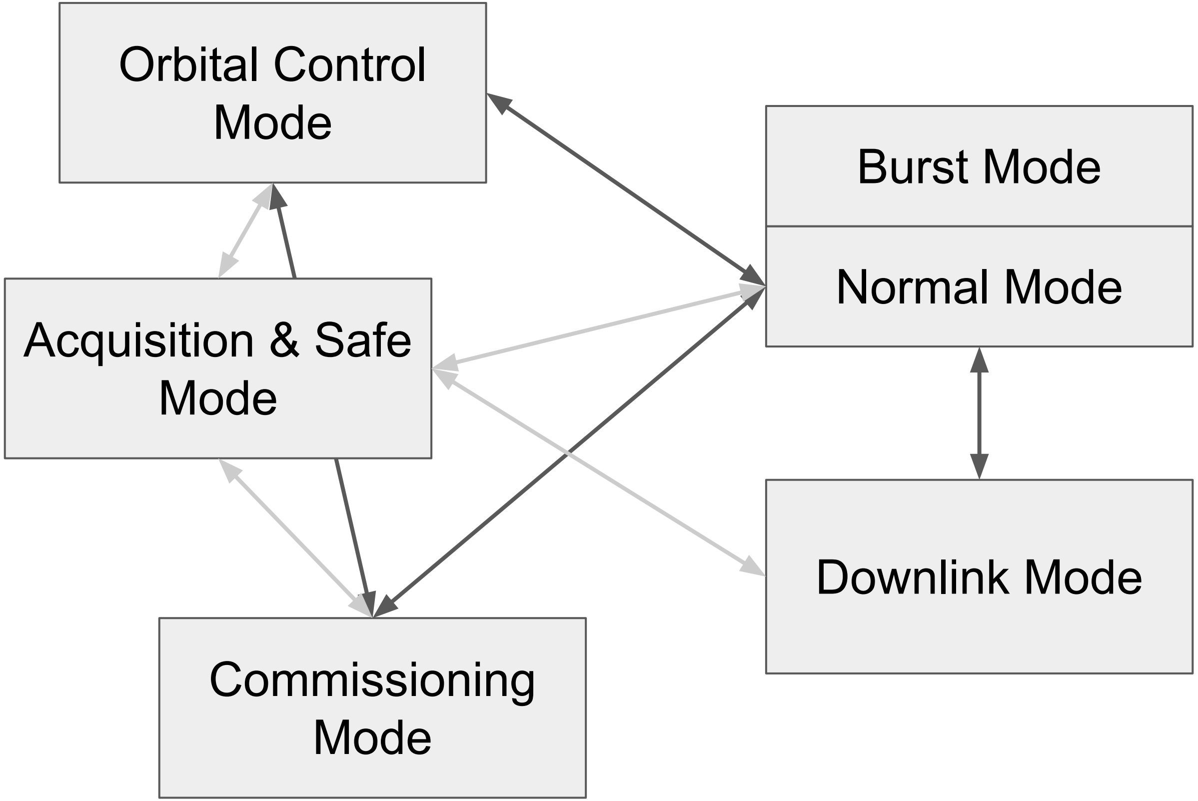
Preliminary spacecraft design



Mass Budget - *current best estimates*

Mass Budget			
Subsystem	Mass	Contingency	Total Mass
Science Instruments	2.55 kg	20 %	3.06 kg
Telecommunication	0.81 kg	20 %	0.97 kg
Propulsion	1.9 kg	20 %	2.28 kg
C&DH	2 kg	20 %	2.4 kg
ADCS	3.2 kg	20 %	3.84 kg
Structure	7.25 kg	20 %	8.7 kg
Power	5.5 kg	20 %	6.6 kg
Total Dry Mass	23.21 kg	20 %	29 kg
Harness	1.84 kg	20 %	2.2 kg
Propellant	10 kg	20 %	12 kg
Total	35 kg	20 %	42 kg

Operation Modes



Power Budget - *current best estimates*

Power Budget for each operating mode					
Subsystem	**Safe Mode**	**Orbital Control Mode**	**Normal / Burst Mode**	**Commissioning Mode**	**Downlink Mode**
Science Instruments	-	-	4.5 W	-	-
Telecommunication	2 W	2 W	2 W	2 W	8 W
Propulsion	-	8 W	-	-	-
C&DH	5 W	5 W	5 W	5 W	5 W
ADCS	-	30.5 W	30.5 W	30.5 W	30.5 W
Structure	-	-	-	10 W	-
Battery	-	-	25 W	-	-
Subtotal	7 W	45.5 W	67 W	47.5 W	43.5 W
Margin	20 %	20 %	20 %	20 %	20 %
Total	**8.4 W**	**54.6 W**	**80.4** W	**57 W**	**52.2 W**

Sizing the solar arrays and batteries

Assumptions for the sizing

- RW will not be switched on all the time
- Eclipse time worst case consideration
- Regulation Type → Peak Power Tracking
- Mission lifetime → 10 years

	Daylight	Eclipse
Power (W)	80.4	23
Time (min)	60	36
Efficiency (Regulation)	0.8	0.6

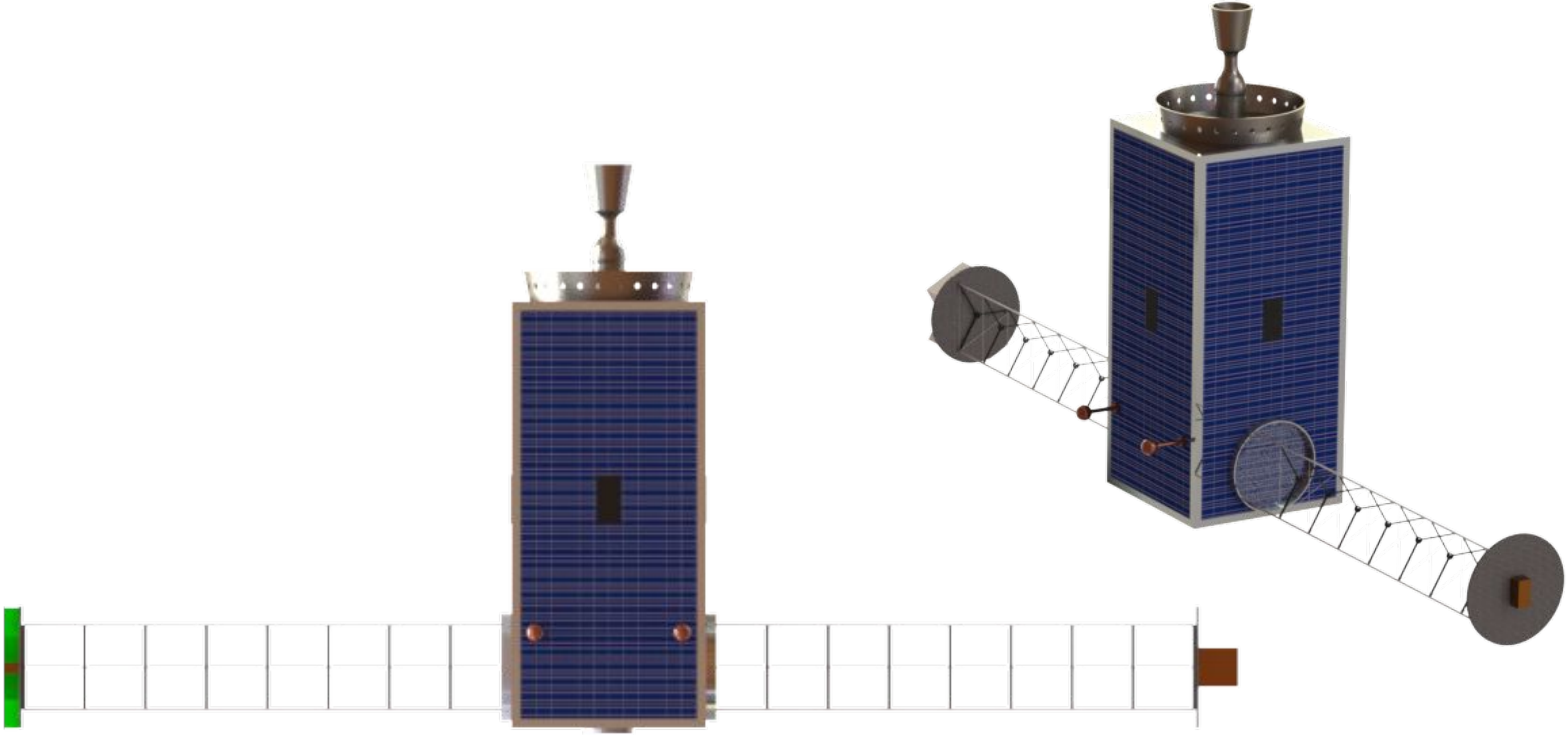
Results

- **Batteries**:
  - DoD = 15%
  - Capacity = 93 Wh
- **Solar Cells:**
  - Power Required → 80.4 W
  - EOL power capability → 114 W/m^2
  - **Area = 0.85 m^2**

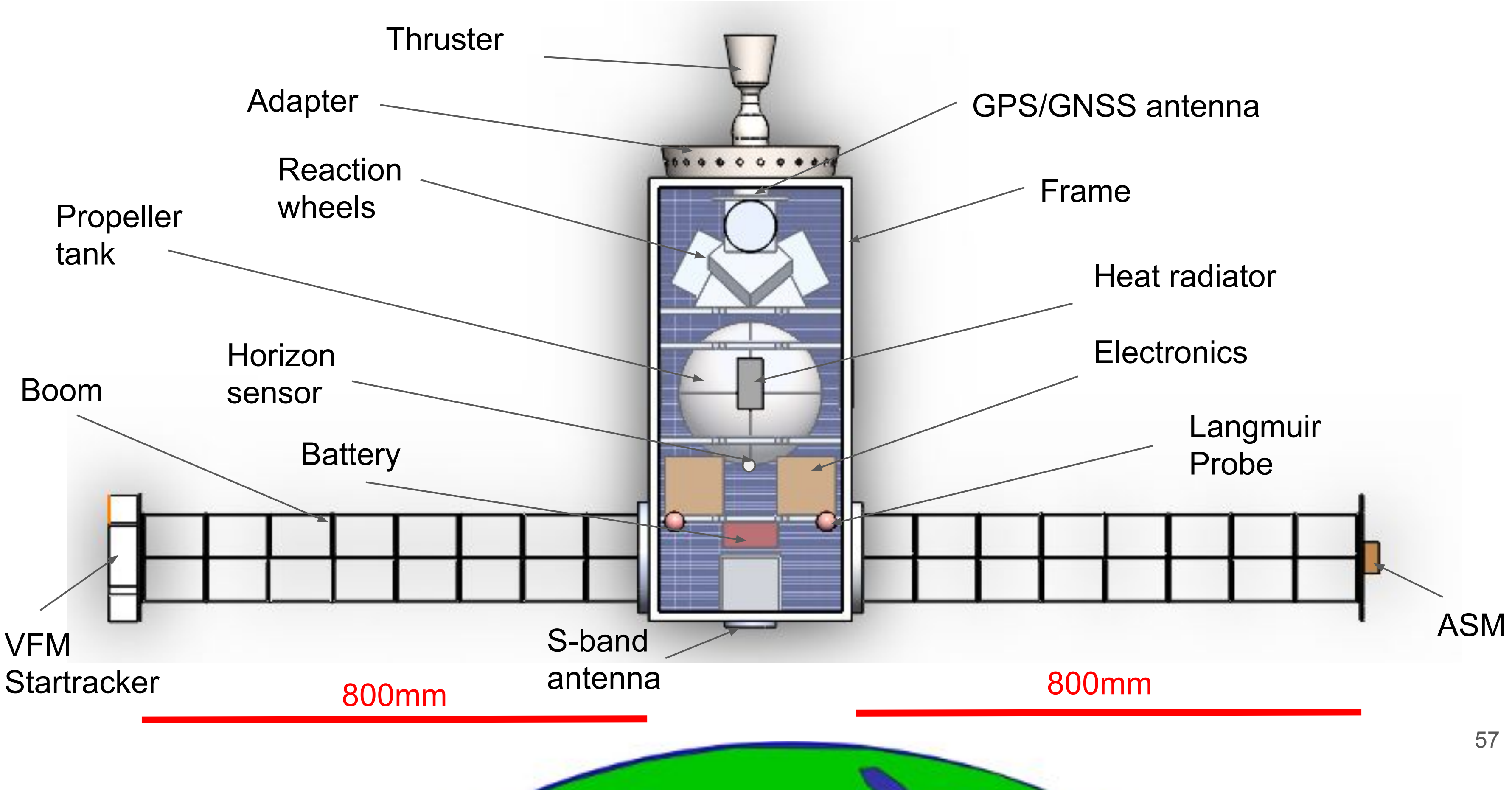
Solution

- 2 packs of batteries (8 cells for each pack and capacity of 77 Wh)
- Solar Array on all S/C faces (except nadir & thruster face)

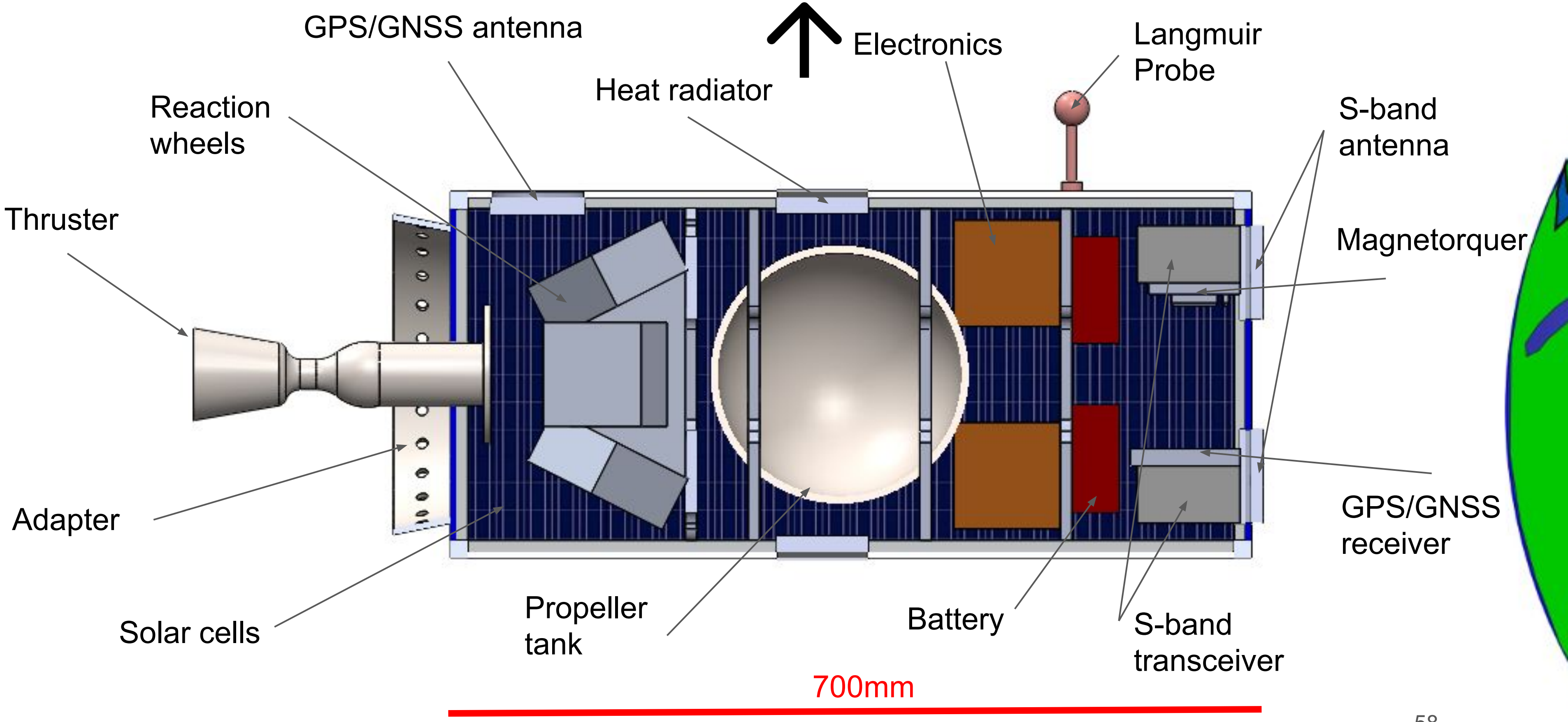
Spacecraft - 3D Model



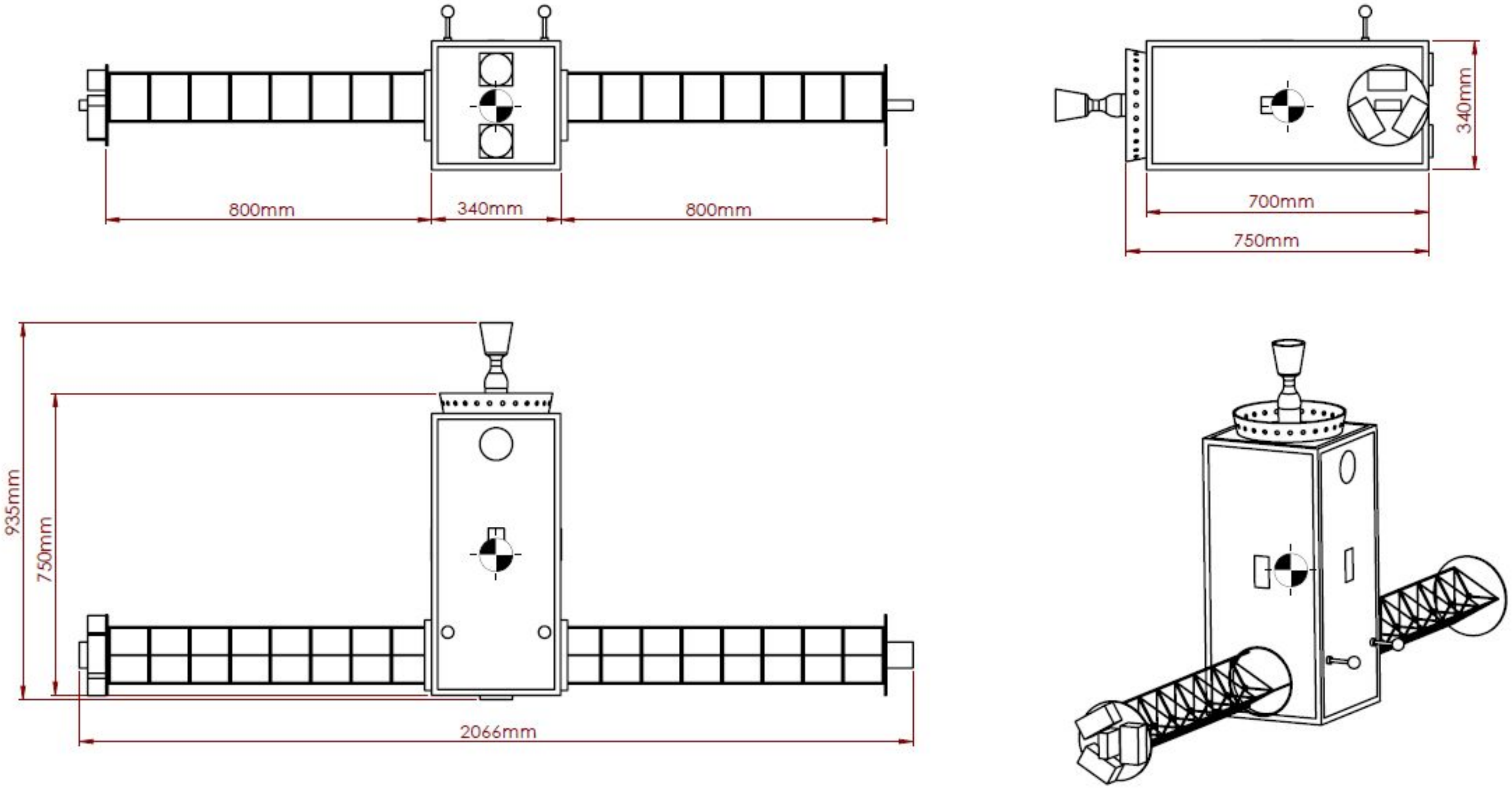
Spacecraft - Configuration



Spacecraft - Configuration



Spacecraft - Mechanical Drawing



Stabilization and orientation

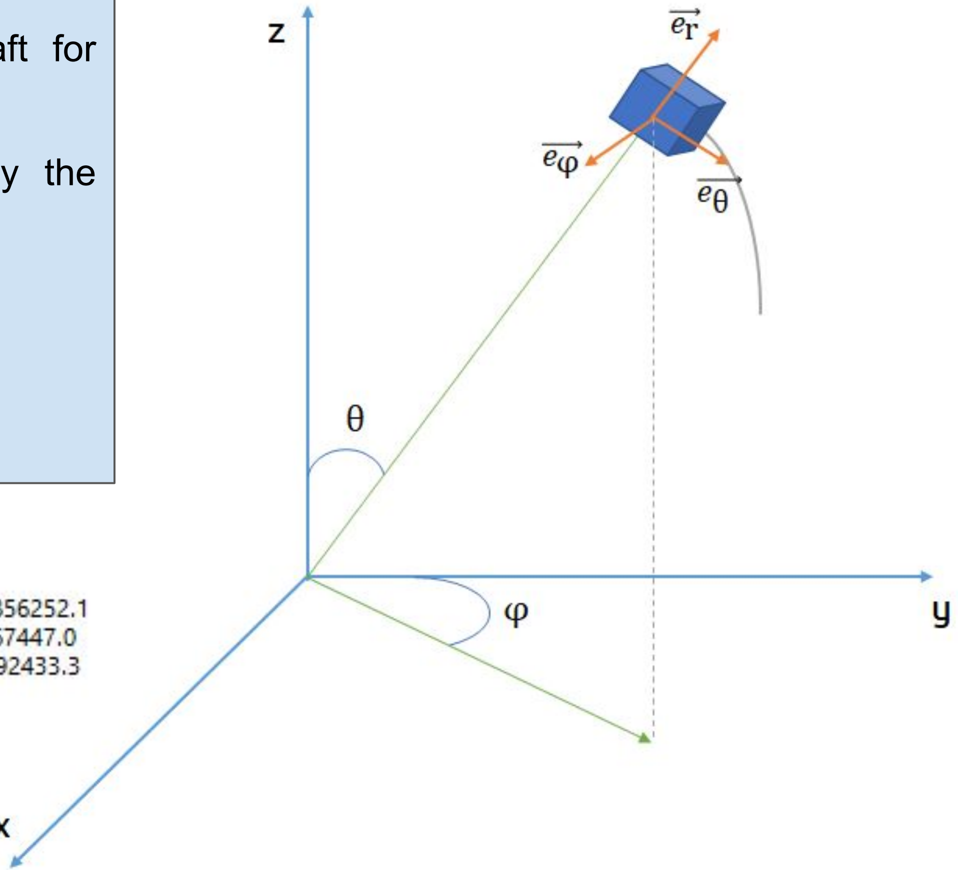
Using the moment of inertia of spacecraft for stabilization in **NADIR pointing**.

NADIR provide us with direct pointing by the smallest area of the spacecraft to the Earth:

- Better efficiency of solar cells
- Smaller power consumption
- Patch antenna orientation

Moments of inertia: (kilograms * square millimeters)
Taken at the output coordinate system.

Ixx = 5734785.7	Ixy = 1902650.3	Ixz = -1856252.1
Iyx = 1902650.3	Iyy = 10232918.5	Iyz = -867447.0
Izx = -1856252.1	Izy = -867447.0	Izz = 6792433.3



Platform ADCS & AOCS

Objective	Device	Mass	Power
Determination of orbital position	GPS receiver	110 g	1 W
	Patch antenna (for the GPS)	80 g	80 mW
Attitude determination of the satellite	2 x Earth horizon	33 g (in total)	0.132 W (in total)
	inertial measurement unit	16 g	0.35 W
Attitude control of the satellite	4 x reaction wheel	940 g (in total)	8 W (in total)
	3 x magnetorquer	120 g (in total)	0.8 W (in total)

Data Budget - *current best estimates*

Normal Mode
From science requirements we need **1 Hz sampling** from each of our science instruments.

Burst Mode
To adapt our constellation to future scientific needs, the acquisition rate can be tuned up to **250 Hz**.

Data Budget for each operating mode					
Type of Data	Safe Mode	Orbital Control Mode	Normal / Burst Mode	Commissioning Mode	Downlink Mode
Science Instruments	-	-	0.1 to 7.6 kbits/s	-	-
Housekeeping	-	10 kbits/s	10 kbits/s	10 kbits/s	10 kbits/s
Downlink duration	-	4.85 min	4.8 to 8.45 min	4.85 min	4.85 min

Data downlink strategy

Normal mode

- **Daily downlink**: housekeeping data
- **Weekly downlink**: scientific data

Burst mode

Weekly downlink of both science and housekeeping data

Thermal Subsystem

Classic LEO Case

From our system:

- Worst Hot Case: Burst mode
  - Power dissipation: 30 W
- Worst Cold Case: Safe mode
  - Power dissipation: 8.5 W

Heat source	Hot Case	Cold Case
Electronics (W)	30	8.5
IR earth (W/m^2)	258	216
Albedo (W/m^2)	466.62	0
Sun (W/m^2)	1368	0

Temperature equilibrium:

$T_{min, eq}$	$T_{max, eq}$
-53.4°C	55.5°C

T_{min} operative = - 30°C

T_{max} operative = 40°C

Solution for our system:

- Heaters for critical component:
  - Pack battery (heater integrated in the COTS equipment)
  - Propulsion system
- Area > 0.02 m^2 of Radiator (≈ 4.8 W)

Programmatics

Risk Analysis

Severity	A	B	C	D	E
5		Scientific sensors Telecommunication			
4	Launch stage On-board Computer	Power system			
3		Boom deployment	AOCS		
2			Propulsion		
1			Orbit insertion		
	Likelihood				

Estimated Mission schedule

Mission Schedule MAGMA-C						
Phase 0	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
2019	***2020***	***2021***	***2022***	***2023***	***2024***	***2035*** ***2060***
6 Months	*12 months*	*12 months*	*18 months (Phase C/D)*	*18 months (Phase C/D)*	10 years	Estimated end
Feasability study →	*Preliminary Mission studies* →	*Detailed Definition studies* →	*Design, Development* →	*Testing, evaluation* →	*Launch, Deployment* →	*Disposal*

Technology Readiness Level

Component	TRL
Boom	9
S-band antenna	9
Langmuir probe	9
Thruster	9
Reaction wheels	9

Component	TRL
Solar panels	9
Battery	9
Scalar sensor	6
Startrackers	6
Vector sensor	6

Cost

Analysis Approach: back-of-the-envelope calculations taking into account development, testing etc.

Component	Cost [M€]	Notes
Satellites Launcher Ground Segment Project Team	80 10 25 35	Per unit: 10 M€ (x8) 2 Launchers with max. 4 satellites each 2.3M€ per year & 10.5 years Commissioning & operations
Total	150	-
Incl. 20% margin	180	-

Comparable to similar missions like NASA CYGNSS Mission (same number of satellites, mass per satellite and mission lifetime)

Outreach

- Social Media:

- School / Educational Events
- Mission Explanation Video/Animation

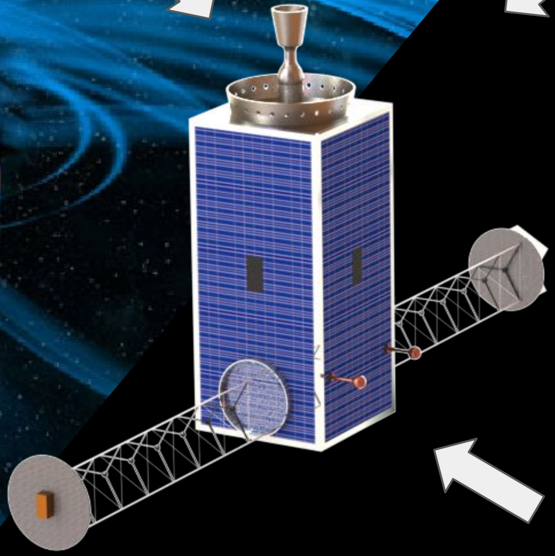
Conclusion

Unprecedented Science

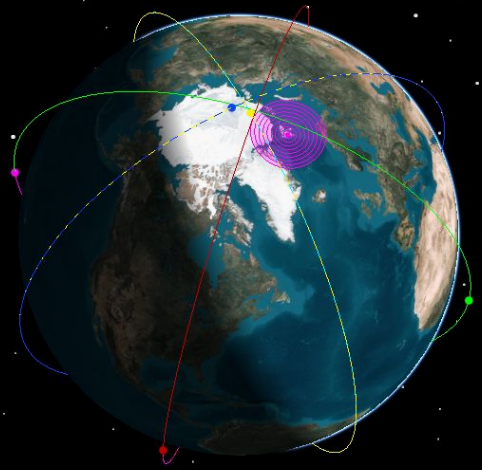
Ionosphere:
improve existing models

First mantle 3D
conductivity mapping

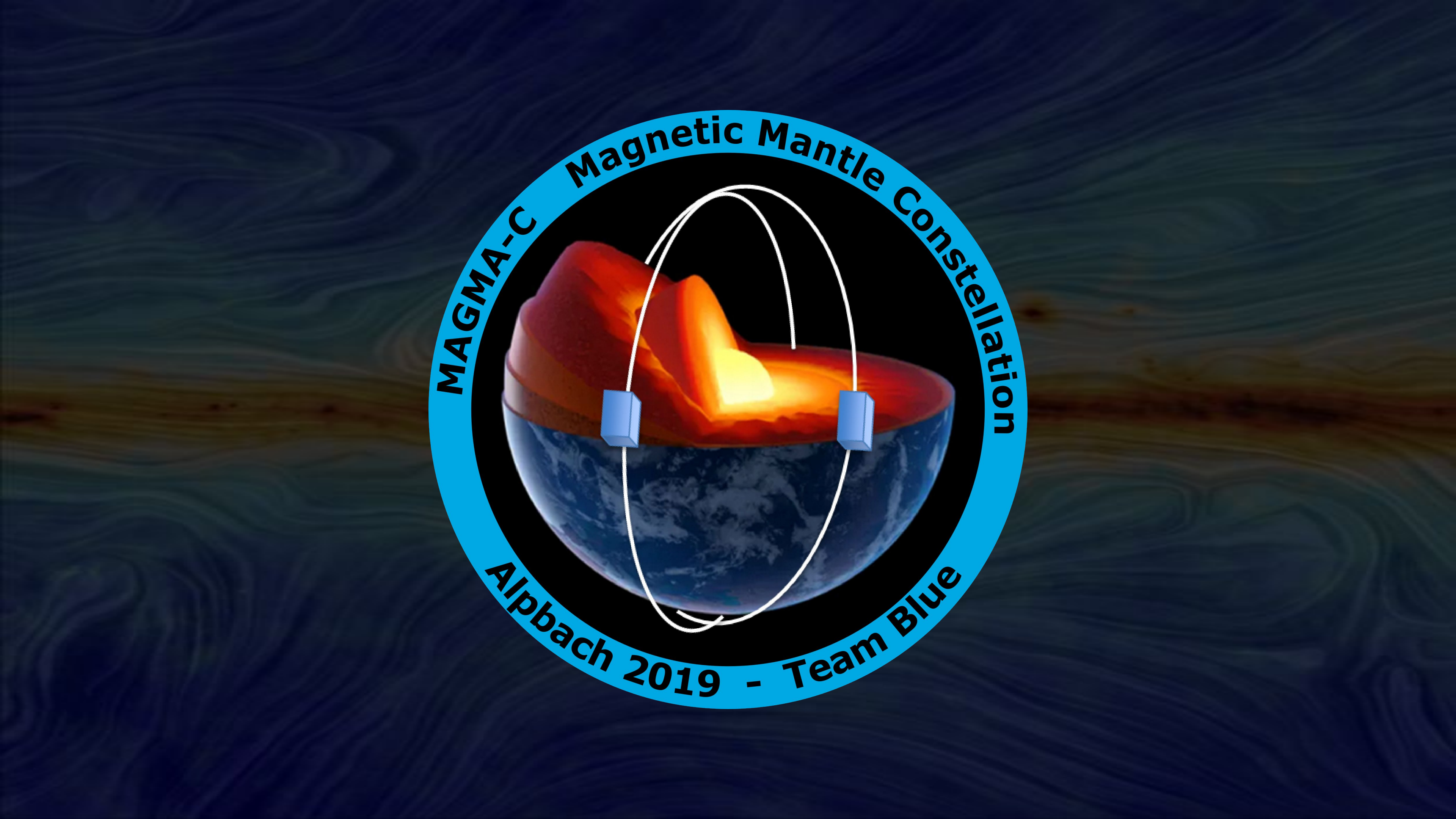
Mantle water content
→ insight to other planets
→ earthquake modelling



8 Satellites for high **spatial** and **temporal** resolution



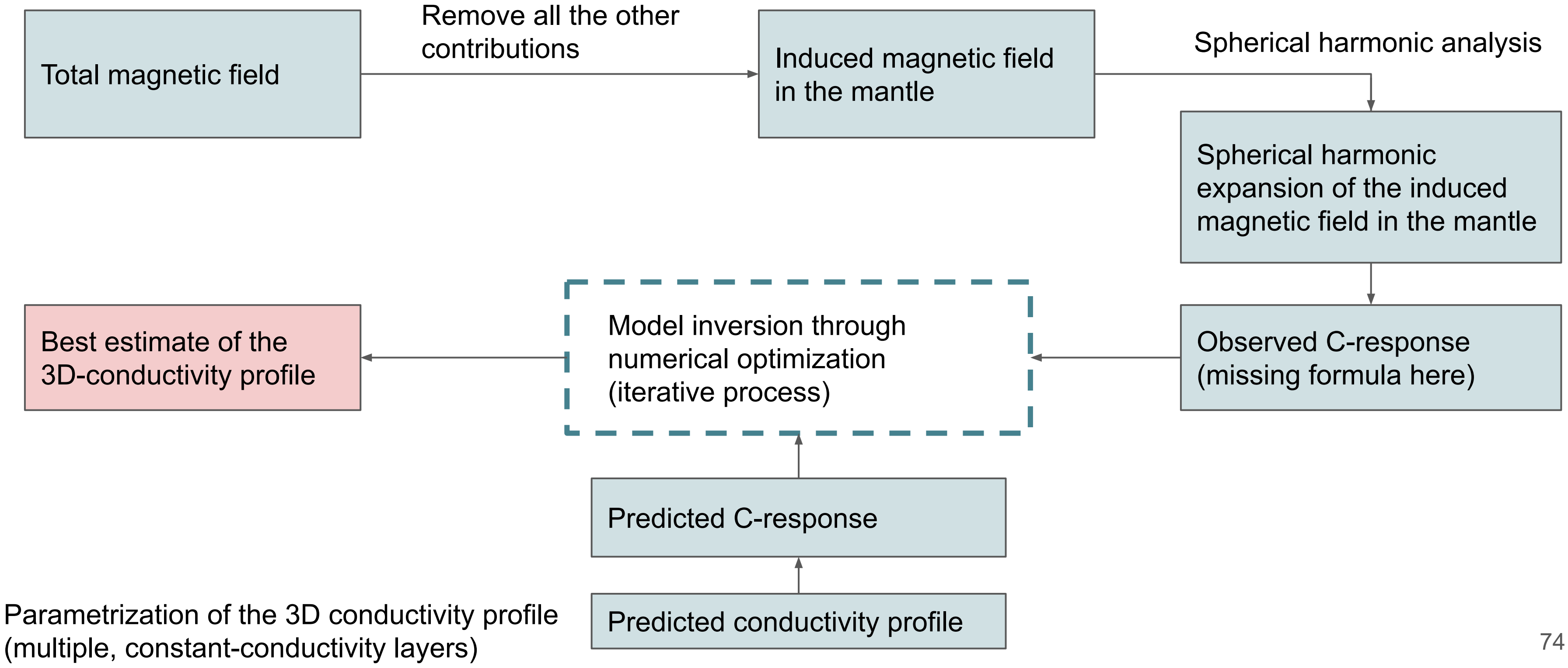
Feasible & Low-cost mission
COTS components: Low Risk
Only 2 Launches - 8 Local times


MAGMA-C
Magnetic Mantle Constellation
Alpbach 2019 - Team Blue

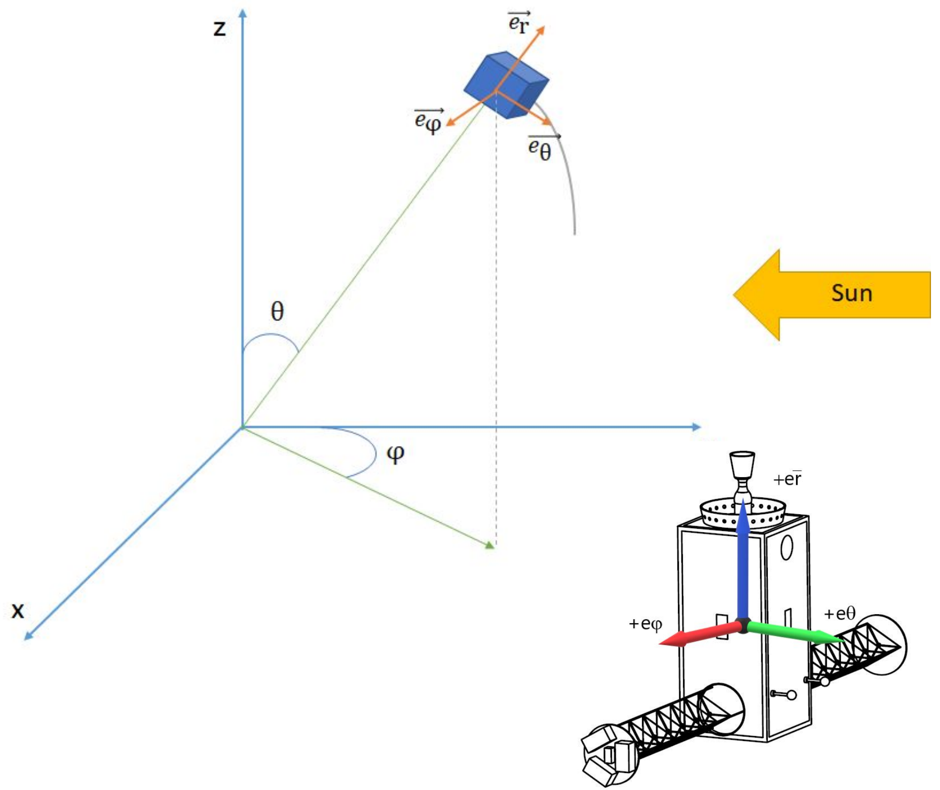
Backup Slides

Backup: Data products

From magnetic field to 3D conductivity profile



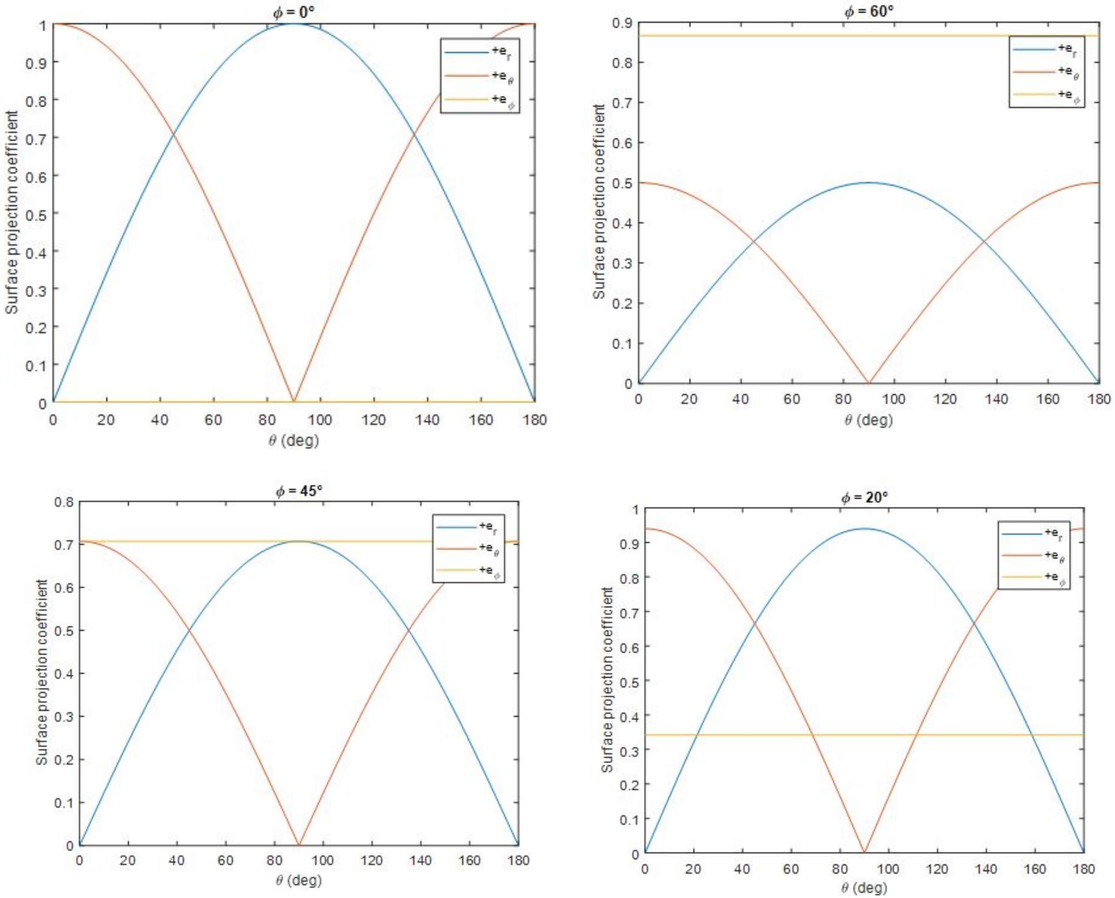
EPS: BOL power capability (1/3)



Assumptions

- Reference Frame:
  - Φ =Longitude of the orbit respect to y axis
  - Θ = Angular position of the S/C
- Sun vector // y axis
- Eclipse is not considered
- S/C in nadir pointing
- Name of the faces considered:
  - e_θ= face with normal $\vec{e_\theta}$
  - e_r = face with normal $\vec{e_r}$
  - e_φ= face with normal $\vec{e_\varphi}$

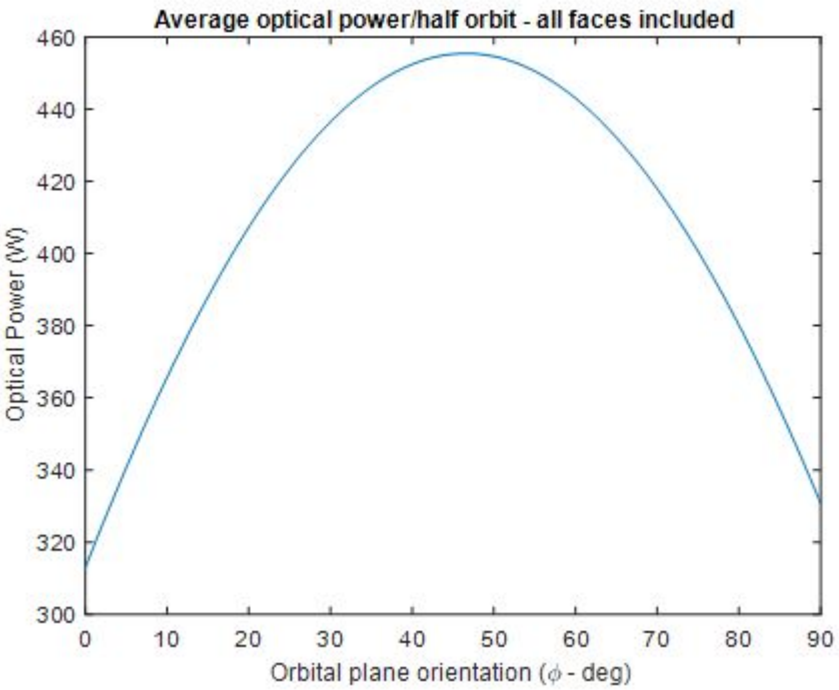
EPS: BOL power capability (2/3)



If $\vec{s}$ is the versor of the Solar vector, the "surface projection coefficient" is:

$$\vec{e_i} \cdot \vec{s}$$

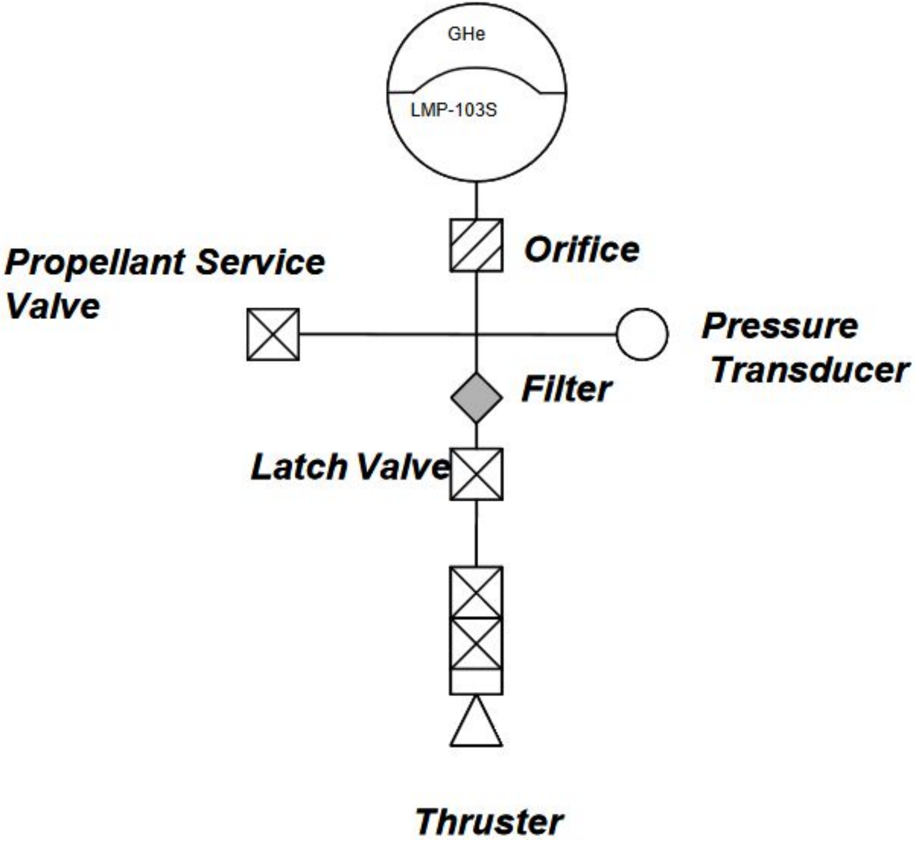
EPS: BOL power capability (3/3)



With the surface projection aera, it is possible to compute the Power

$$\frac{P_{BOL}}{I_d} = P_s\left(\vec{e_i} \cdot \vec{s}\right) A_i$$

Backup: Propulsion System



- Blow-down pressure system
- LMP-103S
- 22 N
- TRL 5/6

Backup: Communication and down/up link

S-band receiver

mass 0.325 kg,

maximum output RF power 2 W

power consumption 8 W, 2 W when receiving only

Temperature rate from -40 to 50 Celsius

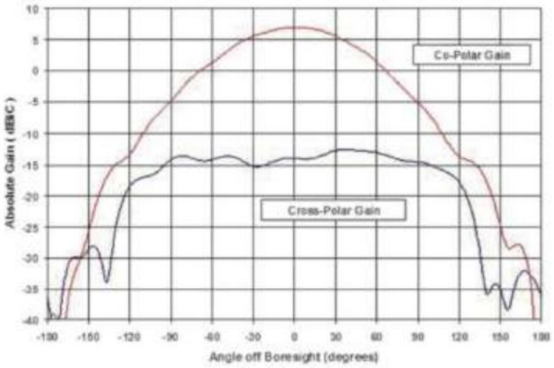
Antenna

temperature range from -105 to 105 Celsius

gain at boresight 6 dB, 0 dB at 60 degrees, and -5 at 90 degrees.

Why needed:

- To maintain housekeeping and down/up link of data



https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5054816/

Backup: Orbit determination - GNSS

Capability of the device:

Accurate determination of orbital position and times of the satellites.

<u>GPS receiver:</u>

-Mass: < 110 g. Size: 96 mm x 96 mm x 15 mm

-Power: 1 W

-GPS frequency: L1 (1575.42 MHz). Single frequency

-TRL 9 → 15 different mission since 2017

<u>Patch antenna:</u>

Mass: <80 g. Size: 54 mm x 54 mm x 14.1 mm

Power: < 80 mW

TRL 9 → 15 different mission since 2017

Reference: NewSpace Systems (NSS) GPS Receiver and Patch antenna for small satellites.

Backup: Attitude determination

Capability of the device:

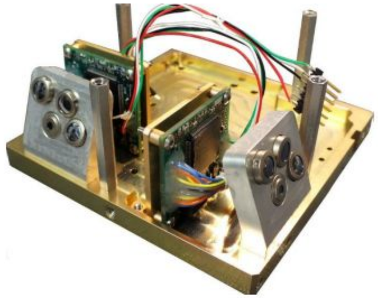
Earth sensor: view the Earth, Space, and Earth limb and measure the dip angle with respect to the horizon

Inertial Measurement Unit: for redundancy of the Earth sensor

Characteristics of the instrument:

Two Earth sensor:
Mass: 33 g for both sensors
Size: 43 x 32 x 32 mm
Power: 0.132 W

Inertial Measurement Unit
Mass: 16 g
Size: 23 x 23 x 23 mm
Power: 0.225 W



Reference: MAI-SES Earth Sensor. Maryland Aerospace.

Backup: Attitude control

Capability of the device:

Reaction wheel
provides high torque and momentum storage capability

Magnetorquer
system for attitude control, detumbling, and stabilization built from electromagnetic coils

Characteristics of the instrument:

Reaction wheel Four reaction wheel Pyramid configuration
Mass: 940 g
Size: 95 x 95 x 95 mm
Power: 2 W per wheel

3 x Magnetorquer:
Mass: 30 g
Size: 70 x 15 x 13 mm
Power: 0.2 mW

Reference 1: GOMSPACE NanoTorque GSW-600, four reaction wheel.
Reference 2: NewSpace Magnetorquer NCTR-M002.

Backup: Thruster

ECAPS by Bradford - Solna, Sweden - Heerle, The Netherlands - San Jose, California U.S.A. - Luxembourg

Bradford ECAPS's **22N HPGP Thruster** is designed for attitude, trajectory and orbit control

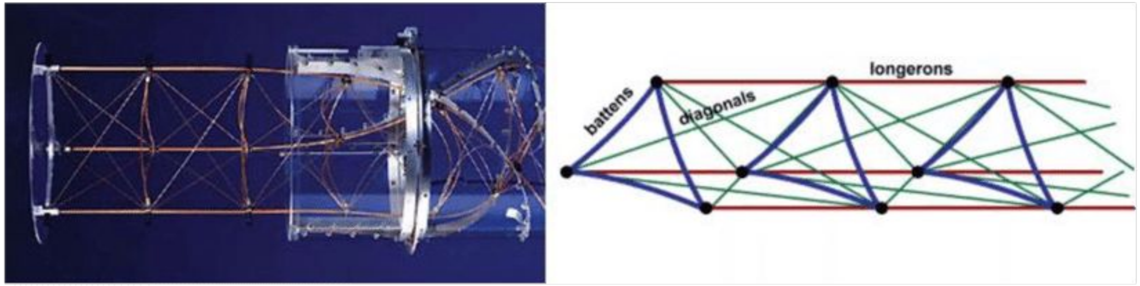
Thruster Type	HPGP
Propellant	LMP-103S
Thrust Class	22 N
Thrust Range	5.5 - 22 N

Nozzle Expansion Ratio	150:1
Steady State ISP (vacuum) Typical	2385 - 2500 Ns/Kg (243 -255 s)
Density Impulse (vacuum)	2957 - 3100 Ns/L
Minimum Impulse Bit	≤0.44 Ns
Overall Length	260 mm
Mass	1.1 kg

Backup: Boom

- Extremely mass efficient (<35 g/m)
- Magnetically clean
- Compact mast stowage (2% of deployed length typical; <0.7% for lightweight variants)
- Tailorable for stiffness, strength, stability and/or low mass
- High reliability, heritage deployment system

Program	Customer	Launch Date	Length each (m)	Diameter (in)	EI (lb*in2)
SAFE	Lockheed/ NASA	3-Feb-84	32	14.4	1.79E+06
Galileo	JPL	18-Oct-89	3.5	12.5	1.34E+07
Galileo	Univ. of Iowa/JPL	18-Oct-89	6.45	12.5	1.34E+07
LACE	NRL	14-Feb-90	44.5	10	4.97E+06
UARS	GE Astro	15-Sep-91	4.9	12.5	1.41E+07
EUVE	Fairchild Space	7-Jun-92	1.6	17.64	5.01E+07
GGS WIND	Martin Marietta	1-Nov-94	12.4	12.5	1.34E+07
GGS POLAR	Martin Marietta	24-Feb-96	6.2	12.5	1.34E+07
Mars Pathfinder	JPL	4-Dec-96	0.8	7.2	1.79E+06
Cassini	JPL	15-Oct-97	4.8	12.5	1.75E+07
Lunar Prospector	Lockheed Martin	7-Jan-98	2.6	8	2.20E+06
EOS-AM (Terra)	Lockheed Martin	18-Dec-99	9	13.75	1.34E+07
MIDEX IMAGE	U. Mass Lowell	25-Mar-00	9.9	7.2	9.00E+05
Classified	Lockheed Martin	1-Jun-03			
GOES N/O/P	Boeing	4-Mar-10	8.4	10	6.39E+06
Orbcomm	Argon ST	14-Jul-14	8	10	
DSX Z-Axis	AFRL	delivered	8	10	4.97E+06
DSX Y-Axis	JPL / AFRL	delivered	40	9.5	2.40E+06
LADO	N-G/NASA/SIDO	delivered	8	16.67	4.45E+07
Triana/ DSCOVR	Northrop Grumman	delivered	3.5	10	4.97E+06
Mars Polar Lander	NASA JPL	21-Jun-05	0.8	7.2	1.80E+06
MMS	LASP	delivered	12	10.24	4.56E+06
GEMS	NASA-GSFC	cancelled	3.8	34	2.72E+08
GOES R/S/T/U	Lockheed Martin	delivered	8.5	12.5	1.34E+07



Reference: Northrop Grumman Corporation.

Backup: Thermal Ranges - subsystems

Temperature Ranges for each operating mode										
Subsystem	Safe Mode		Orbital Control Mode		Normal / Burst Mode		Commissioning Mode		Downlink Mode	
Science Instruments	-	-	-	-	-40 °C	60 °C	-	-	-	-
Telecommunication	-40 °C	50 °C	-40 °C	50 °C	-40 °C	50 °C	-40 °C	50 °C	-40 °C	50 °C
Propulsion	-	-	-	-	-40 °C	60 °C	-	-	-	-
C&DH	-30 °C	60 °C	-30 °C	60 °C	-30 °C	60 °C	-30 °C	60 °C	-30 °C	60 °C
ADCS	-	-	-40 °C	40 °C	-40 °C	40 °C	-40 °C	40 °C	-40 °C	40 °C
Battery	-40 °C	85 °C	-40 °C	85 °C	-40 °C	85 °C	-40 °C	85 °C	-40 °C	85 °C