ORPHEUS

Team Orange

Mission Statement

"Study the internal magnetic field of the Earth's core on a global scale in order to better understand its fine structure dynamics"

WHY ORPHEUS?

- Long term solution for a long-term scientific goal
- Continuing the historical record for Earth's magnetic field
- An innovative formation enabling sophisticated measurements in an underexplored atmospheric region

Outline

SCIENCE CASE

MISSION PROFILE

SPACE SEGMENT

PROJECT ENVELOPE

Outline

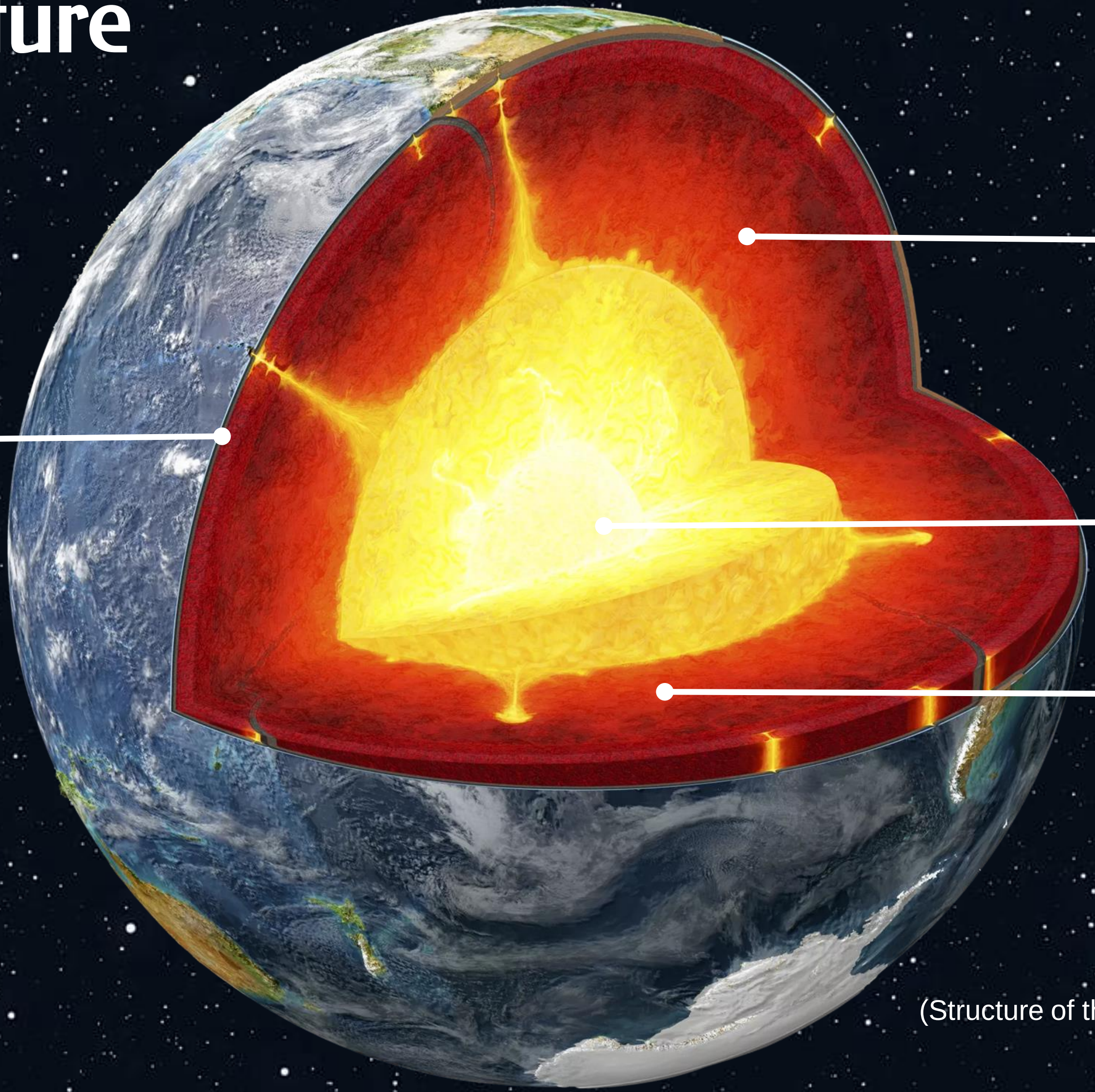
SCIENCE CASE → MISSION PROFILE → SPACE SEGMENT → PROJECT ENVELOPE

SPEAKER:
ELENA L. CONTRERAS

Importance of the Magnetic Field

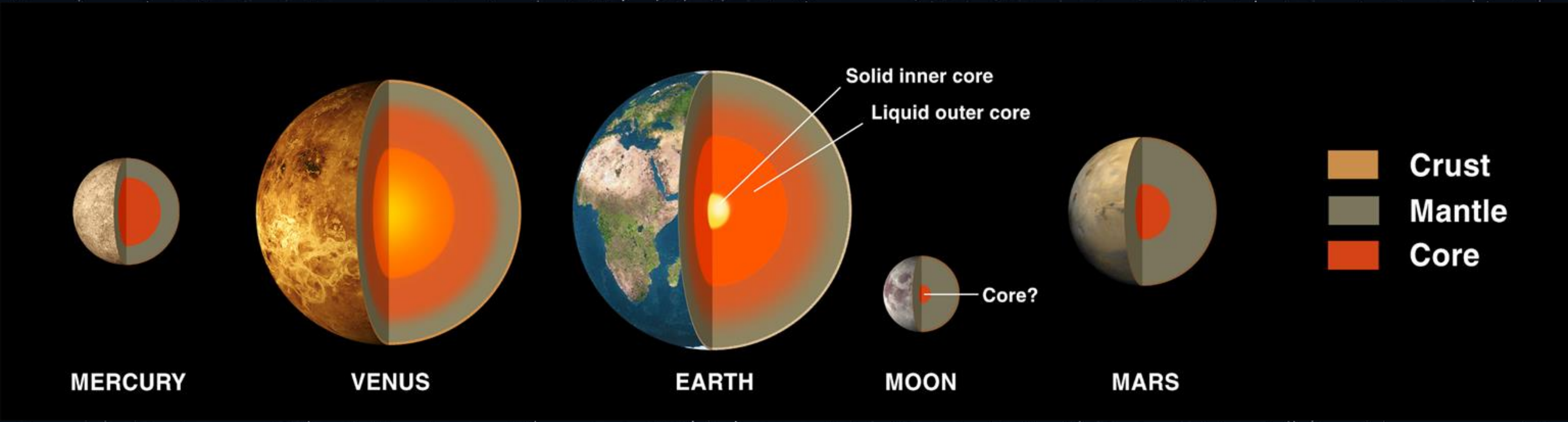
- Measurements of the core dynamics of Earth are imperative to understand the magnetic field of Earth
- Constant update of physical models
- The magnetic field is vital for life on Earth and modern society depends heavily on its stability

Earth's Structure



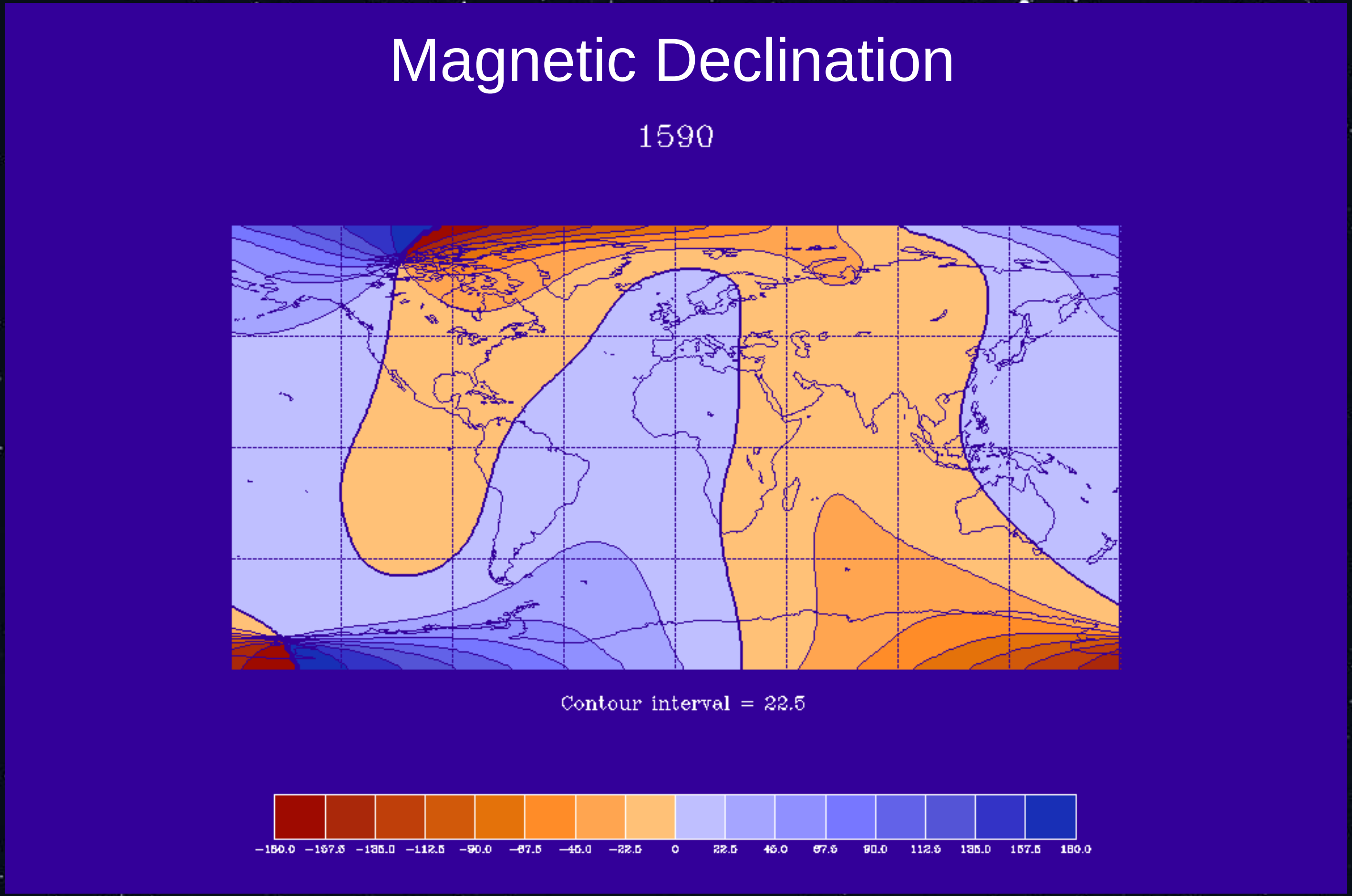
(Structure of the Earth (2019))

Geophysics of Other Planets



(ETH Zürich. Planetary Science (2019))

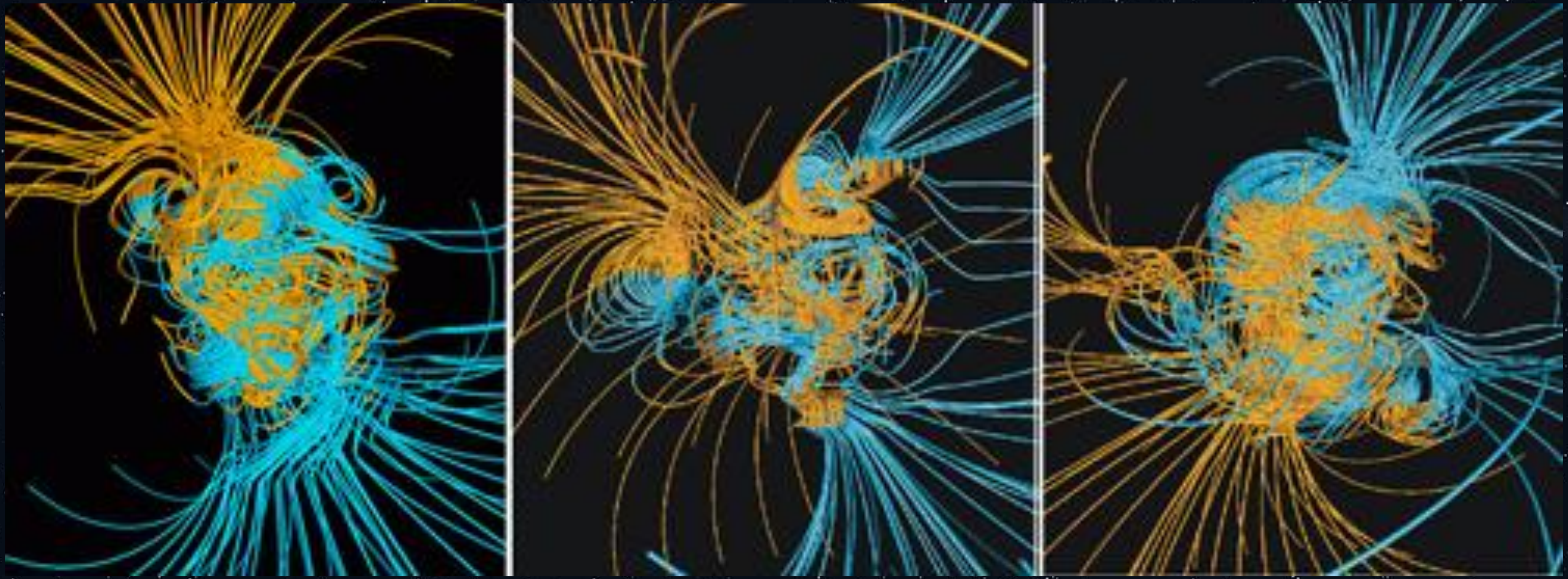
Time Varying Magnetic Field



- Time varying representation based on data from 1590-1990
- Earth’s magnetic field varies <u>over long timescales</u>

Courtesy of Andrew Jackson

Magnetic Field Polarity Reversal



Normal Field **Reversal Process** **Reversed Field**

A three-dimensional self-consistent computer simulation of a geomagnetic field reversal (Glatzmaier and Roberts. 1995)

Scientific Objectives

SO-1. Provide state of the art measurements of the fine structure and dynamics of the Earth's core (long time scale)

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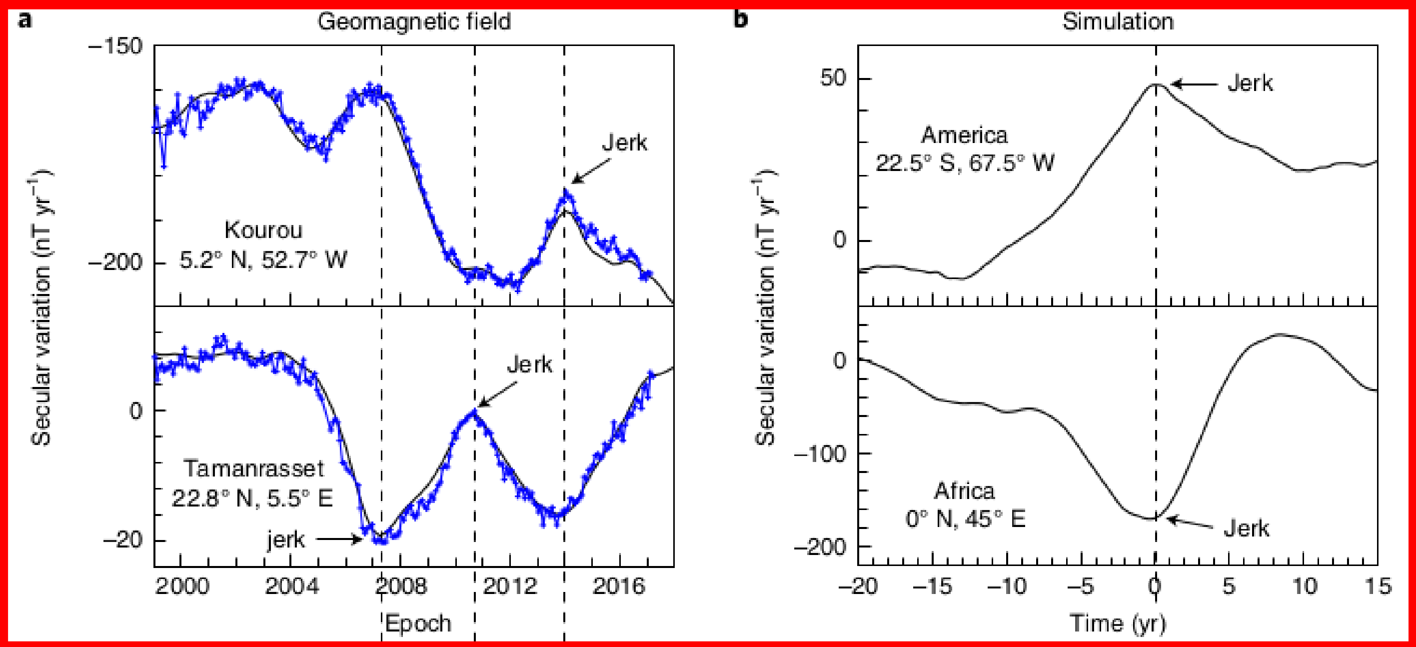
SO-3. Study the ionospheric current system contribution to the total magnetic field

SO-4. Characterize and link dynamic events of the geomagnetic field to core processes (shorter time scale)

Timescales

Months — Years — Decades — Centuries

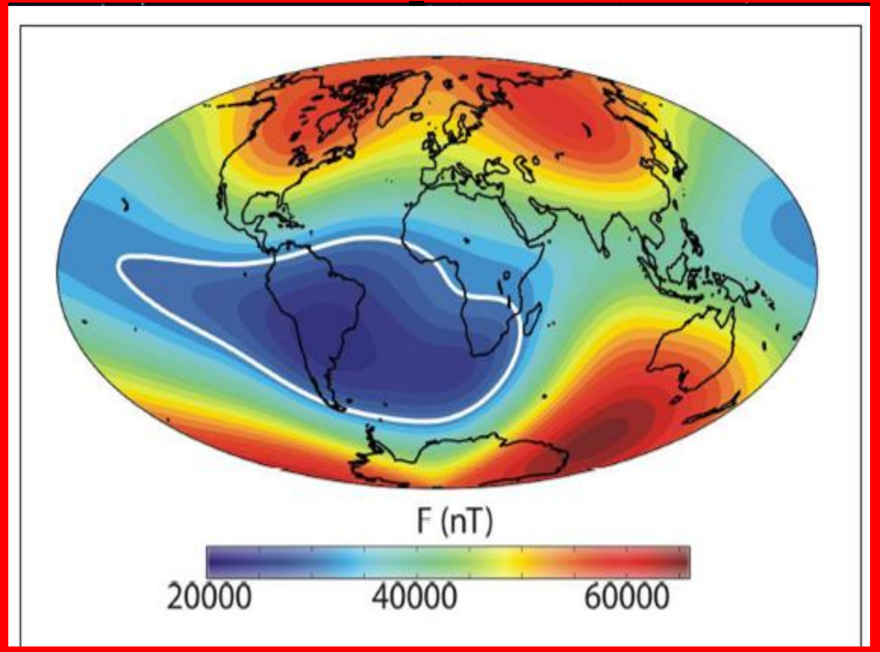
Geomagnetic Jerks



Observed and simulated geomagnetic jerks at Earth's surface.
Left: observed data. **Right:** model data

- (Aubert. C Finley. 2019)

South Atlantic Anomaly (SAA)



Intensity geomagnetic field map at 2015.0

(F. Javier Pavón-Carrasco and A. De Santis. 2016)

Scientific Requirements

SO-1.

SR-1. Measure all three components of the magnetic field vector

Scientific Requirements

SO-1.

SR-1.	Measure all three components of the magnetic field vector
SR-2.	Measure the magnetic field magnitude

Scientific Requirements

SO-1.

SR-1. Measure all three components of the magnetic field vector

SR-2. Measure the magnetic field magnitude

SR-3. Earth's magnetic field shall be continuously monitored

Scientific Requirements

SO-2.

SR-4. Remove contributions of non-core internal fields

Scientific Requirements

SO-2.

SR-4.	Remove contributions of non-core internal fields
SR-5.	Remove contributions from external fields

Scientific Requirements

SO-2.

SR-4.	Remove contributions of non-core internal fields
SR-5.	Remove contributions from external fields
SR-6.	Measurement duration of 25 years

Scientific Requirements

SO-3.

SR-7. Estimate the ionospheric current density

Scientific Requirements

SO-3.

SR-7. Estimate the ionospheric current density

SO-4.

SR-8. Global coverage

Scientific Requirements

SO-3.

SR-7. Estimate the ionospheric current density

SO-4.

SR-8. Global coverage

SR-9. Orbital revisit period shall be shorter than 2 weeks

So why do we need satellites?

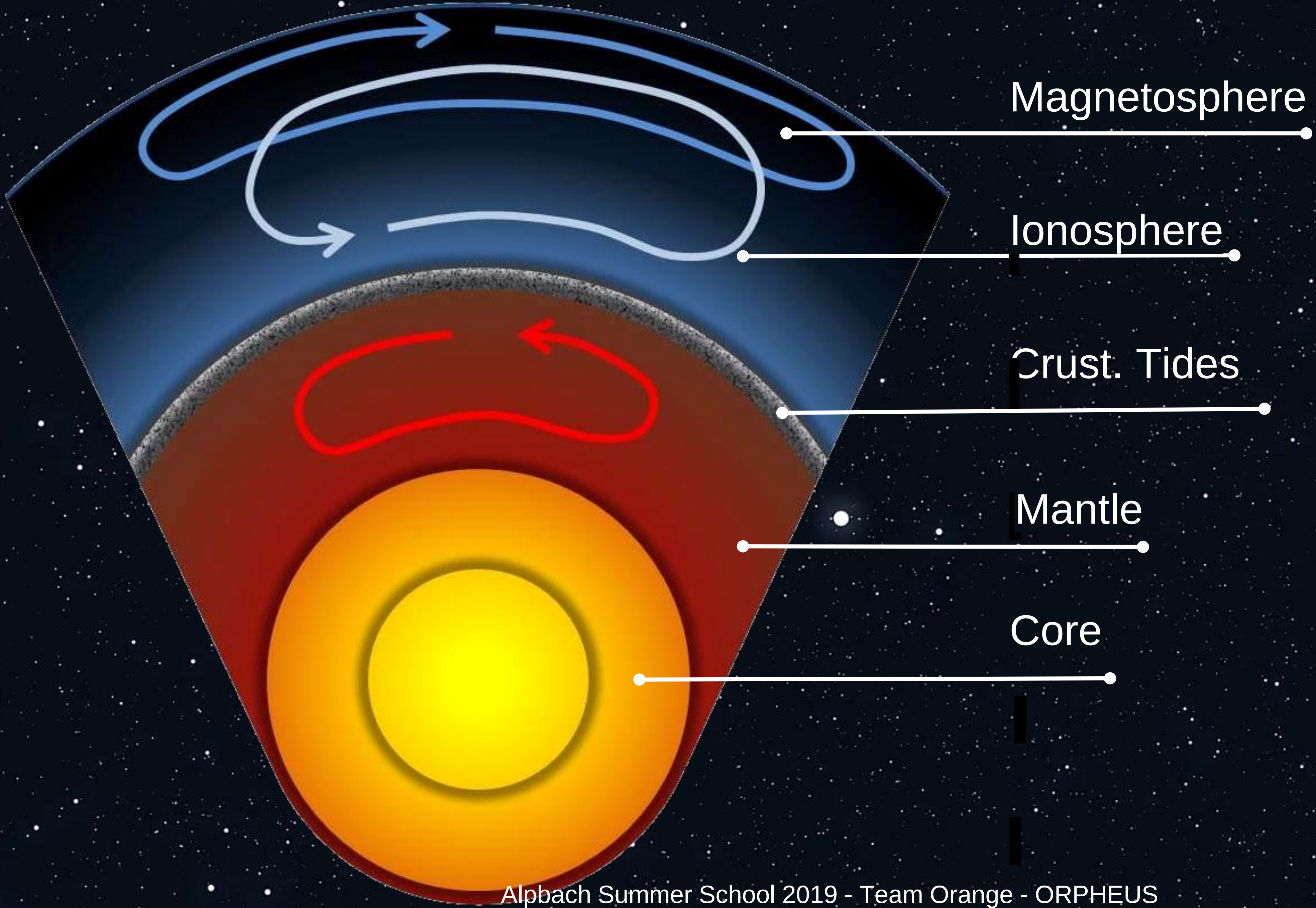
GLOBAL COVERAGE

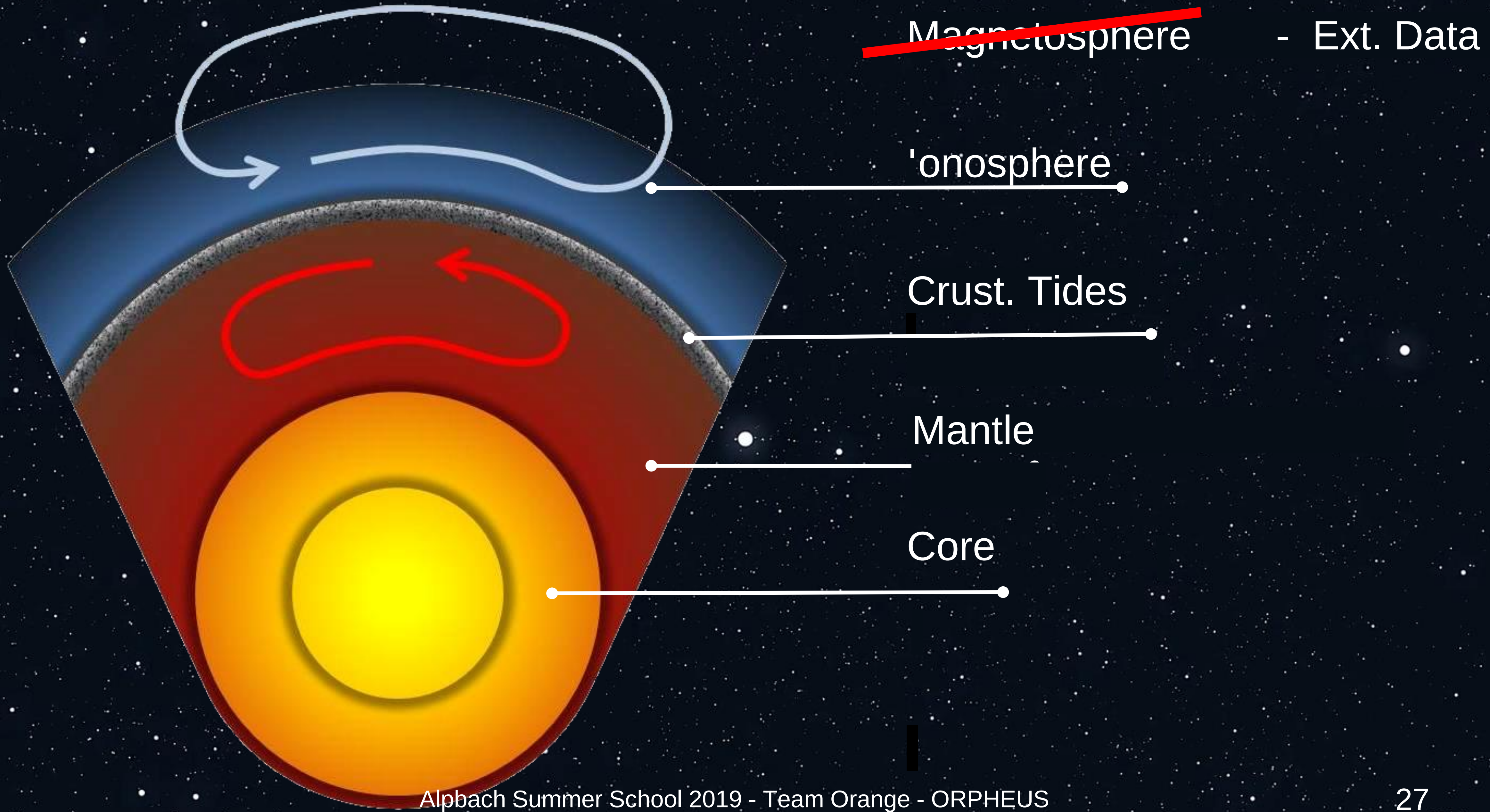
71% of EARTH'S SURFACE IS WATER

ALTITUDE

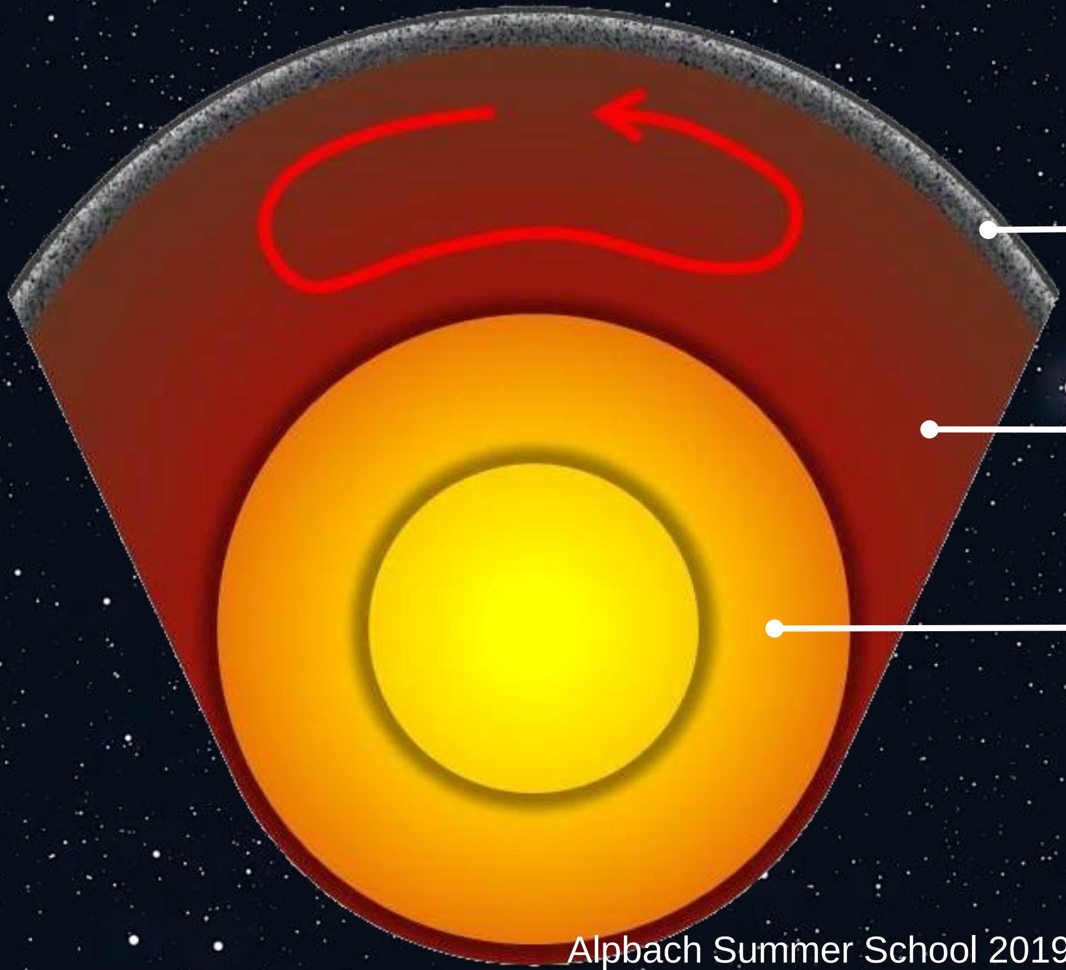
> 400km

CRUSTAL MAGNETIC FIELDS & ONE OF THE MAJOR CURRENT SYSTEMS


Magnetosphere
Ionosphere
Crust. Tides
Mantle
Core



Magnetosphere
- Ext. Data
'onosphere
Crust. Tides
Mantle
Core



~~Magnetosphere~~ - Ext. Data

~~Ionosphere~~ - Measure

Crust. Tides

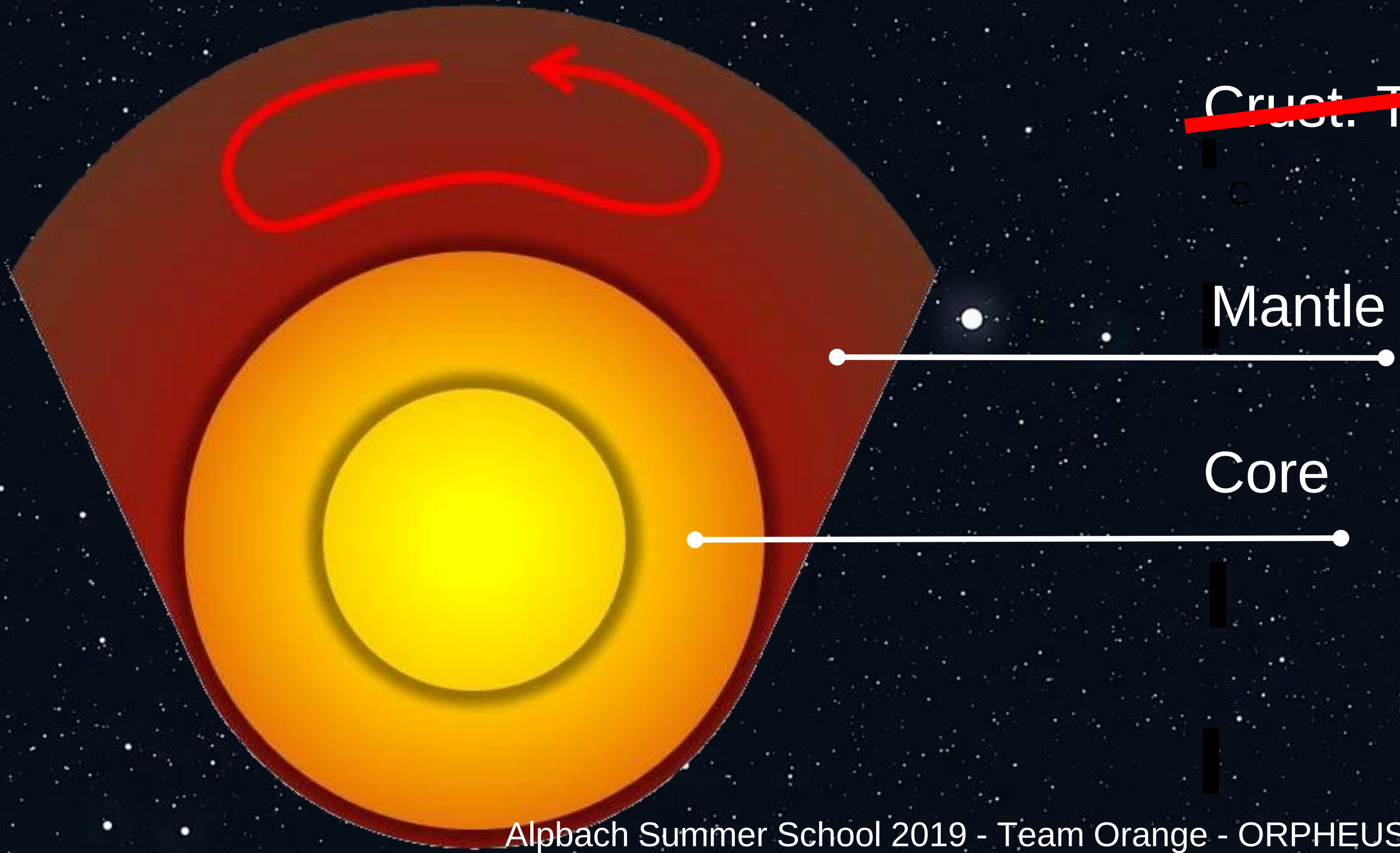
Mantle

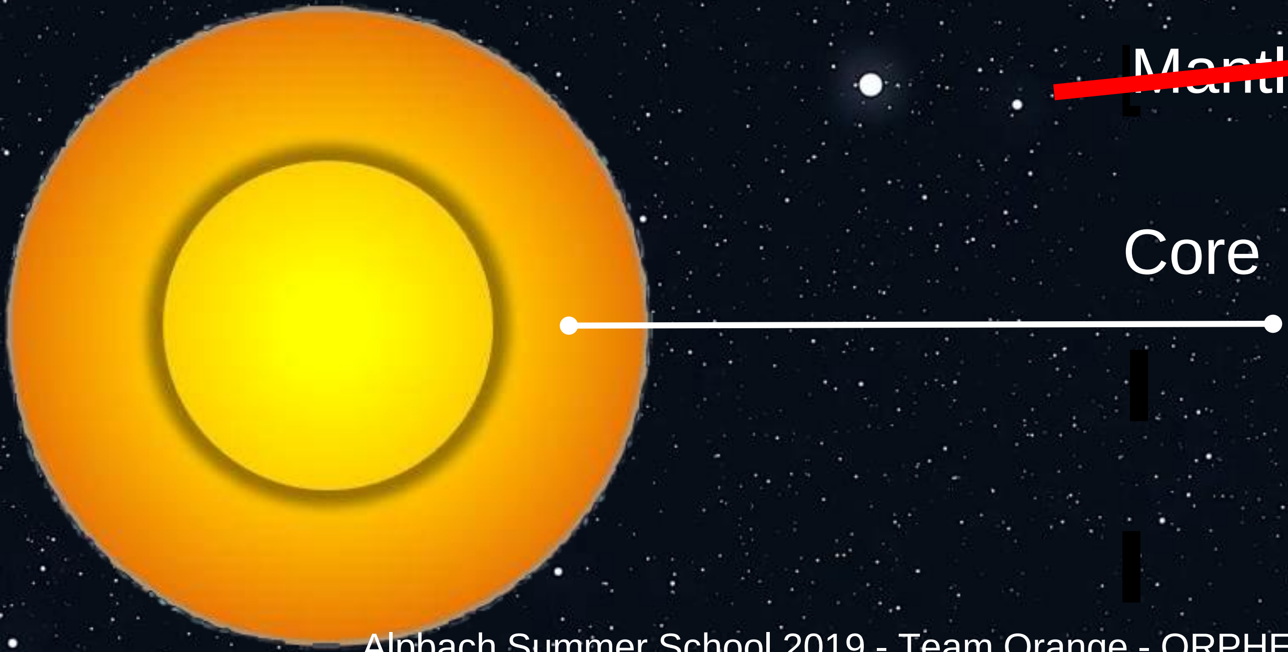
Core

~~Magnetosphere~~ - Ext. Data

~~Ionosphere~~ - Measure

~~Crust: Tides~~ - Ext. Data





~~Magnetosphere~~ - Ext. Data

~~Ionosphere~~ - Measure

~~Crust. Tides~~ - Ext. Data

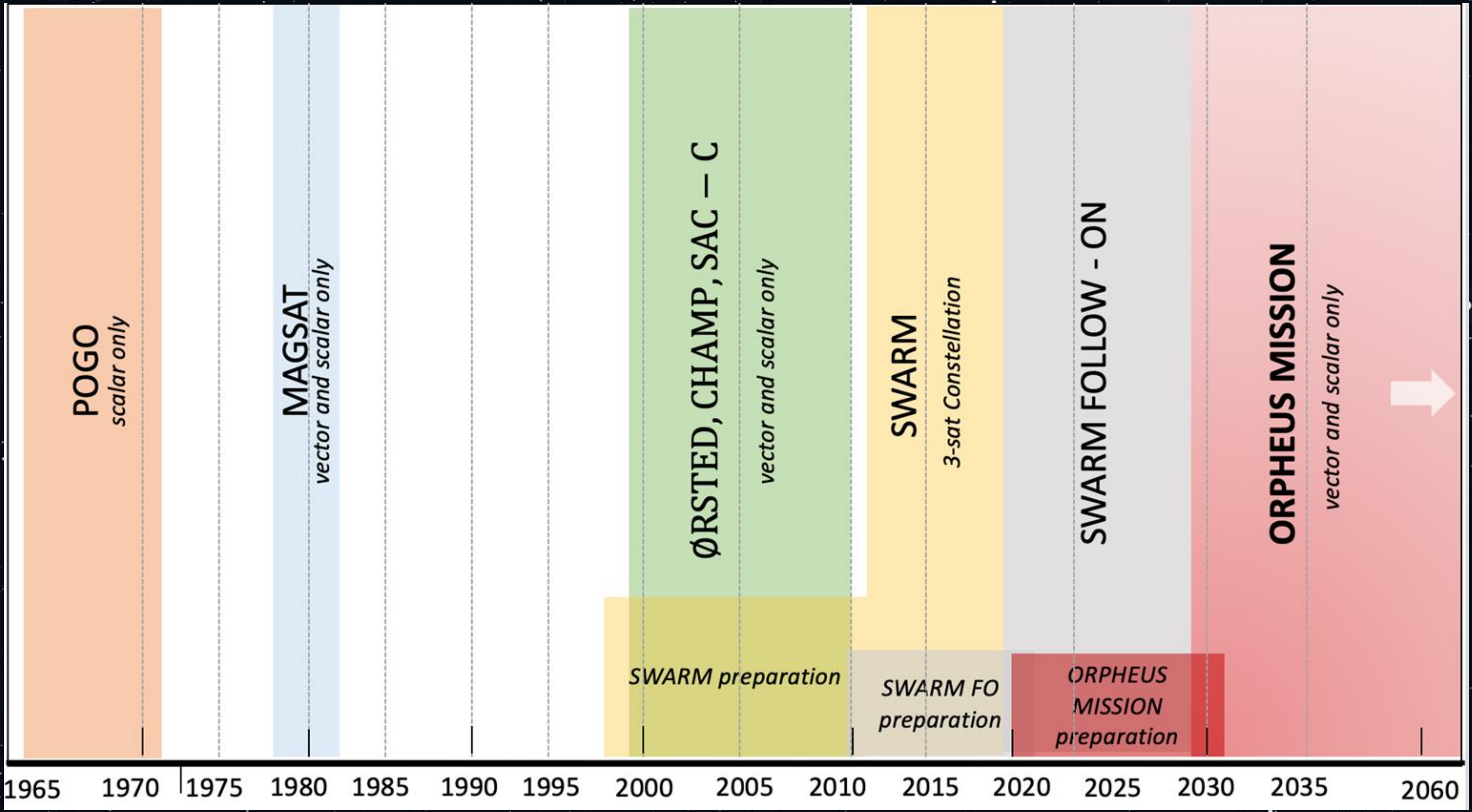
~~Mantle~~ - 1 Hz

Core

Mission Drivers

- Measure all three components of the magnetic field vector
- Measure the magnetic field magnitude
- Determine the magnetic field gradients
- Estimate the ionospheric current density close to the satellite

Past. Present & Future Missions



Historical Missions

Previous missions have used the following constraints to study the core dynamics:

- < 70 DEGREES
- GEOMAGNETIC STORM QUIET TIME
- NIGHT TIME DATA

We intend to estimate **ionospheric currents** for the purpose of using day time data

Historical Missions

Previous missions have used the following constraints to study the core dynamics:

- < 70 DEGREES
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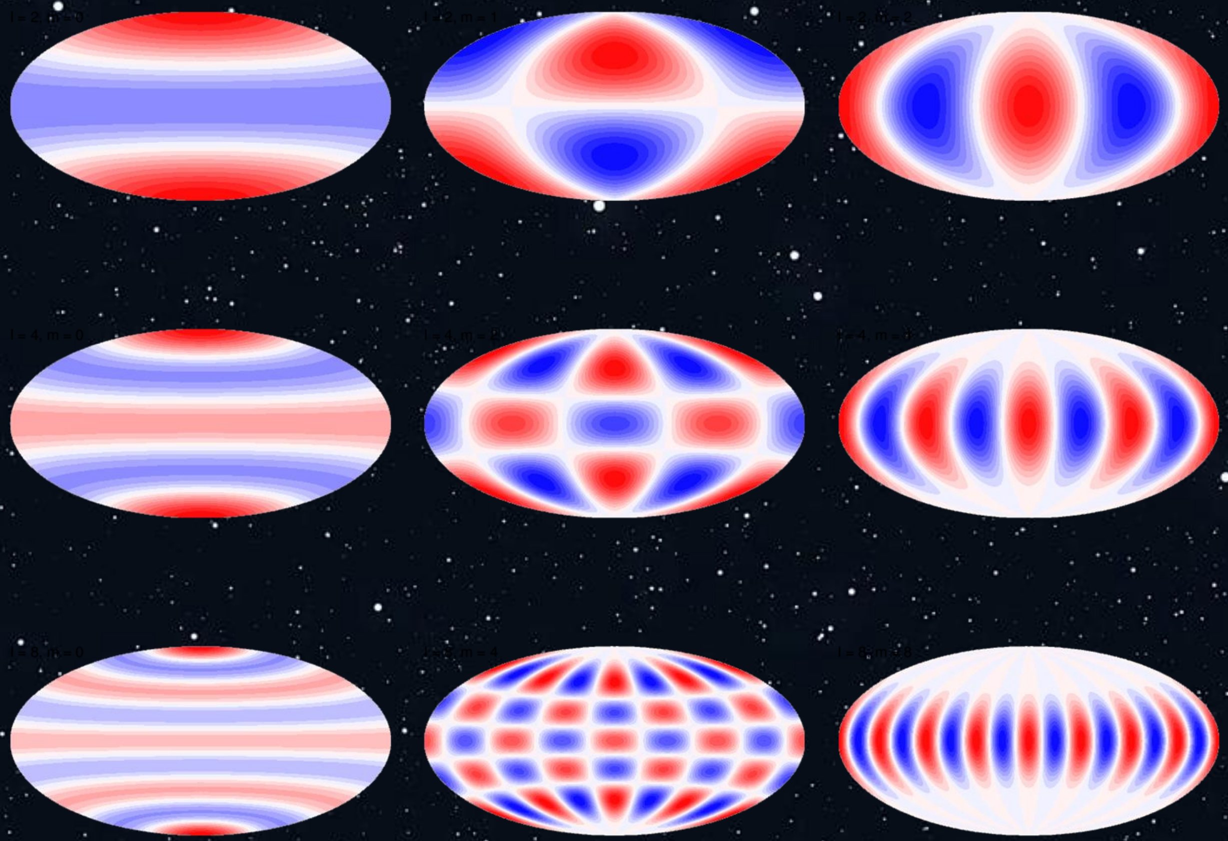
We intend to estimate **ionospheric currents** for the purpose of using day time data

Spherical Harmonics



(University of Texas. Teaching: Spherical Harmonics (2019))

- Earth’s magnetic field can be described in terms of a spherical harmonic series expansion.

- Retrieval of the magnetic field data

Satellite Configuration

- SWARM retrieves core field up to order m = 18
- ORPHEUS sensitive to core field order m = 25

→ Satellite separation of 7 ± 0.5° horizontally

= 860 ± 60 km separation

Satellite Configuration

- Current density at 700 km estimation from SWARM data

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$$

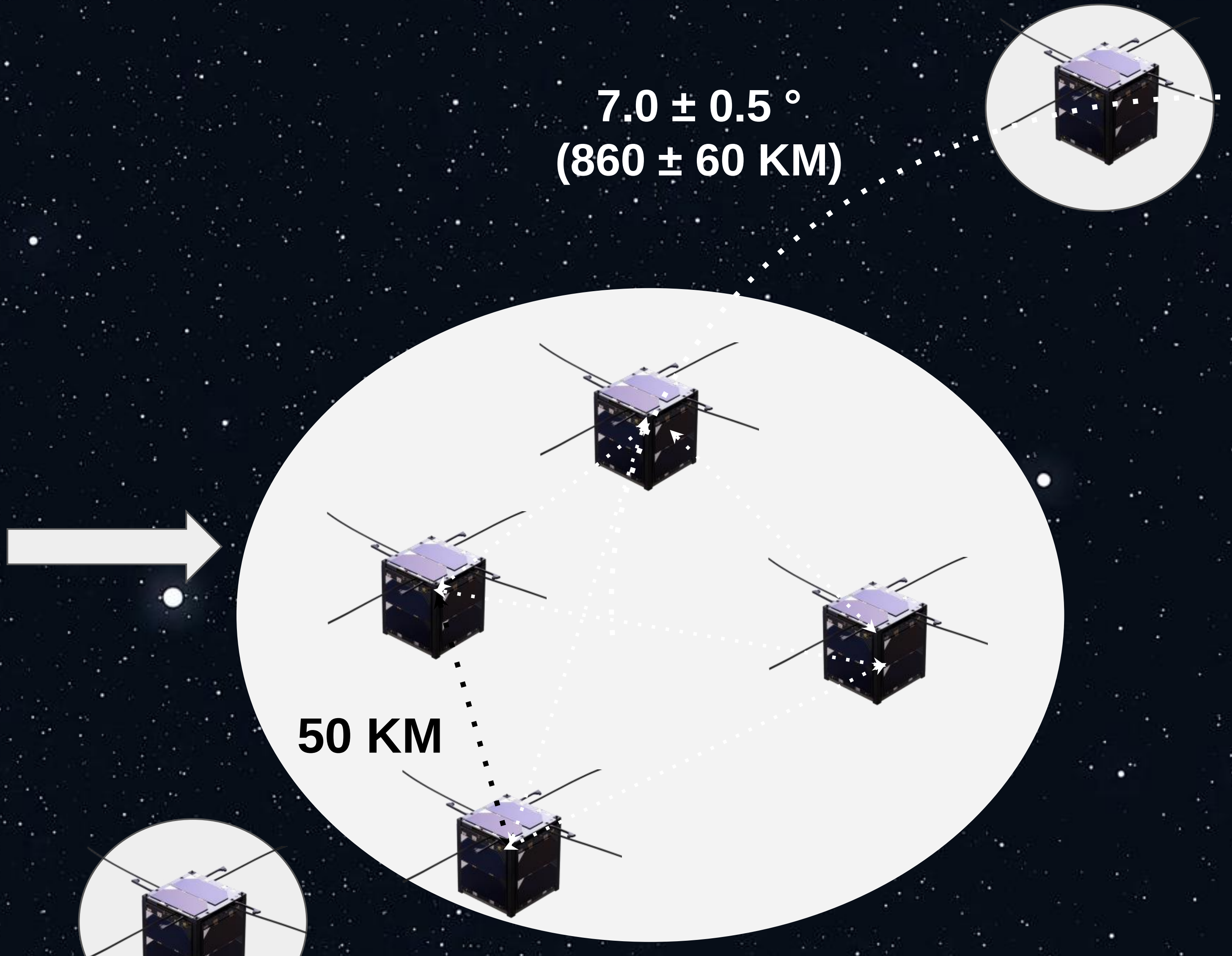
$$\mathbf{L} \approx \frac{\delta \mathbf{B}}{\mu_0 \mathbf{J}}$$

- From ionospheric current density: 20 - 100 km

→ satellite separation of 50 km for good signal-to-noise ratio

Satellite Configuration

TOTAL OF 5 + 1 SATELLITES



FORMATION

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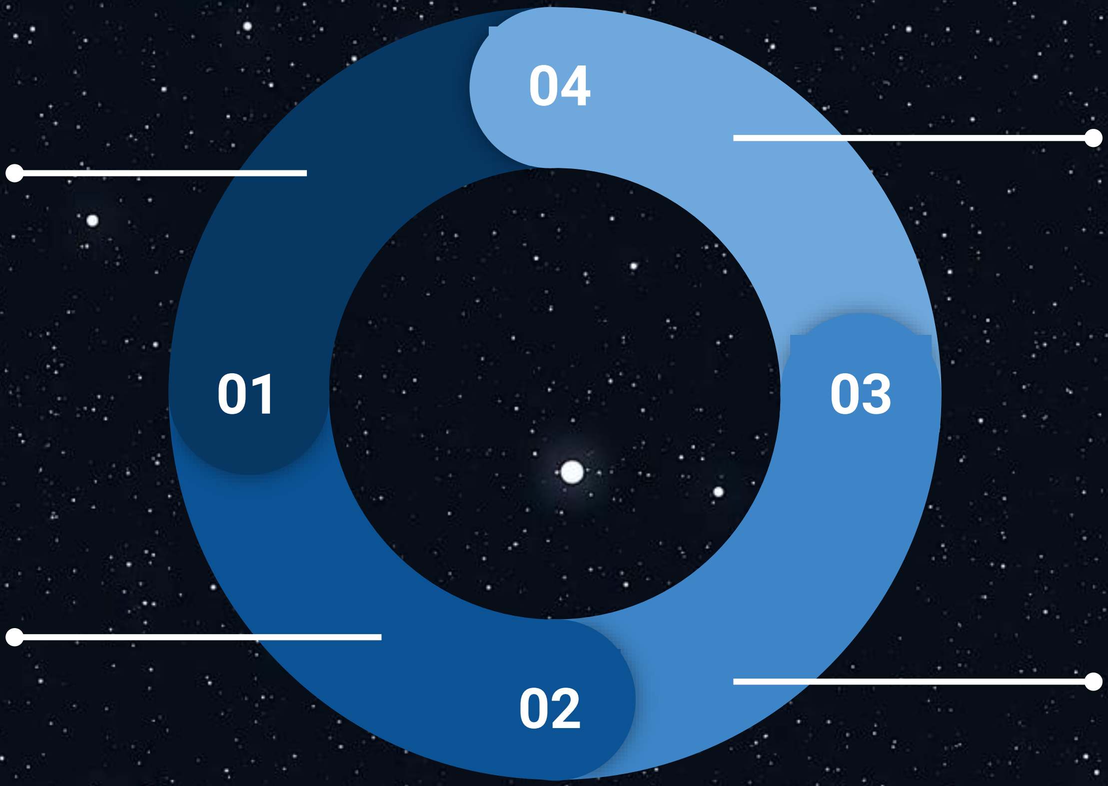
SPEAKER:
TRYM ERIK NIELSEN

Mission Profile



SYSTEM DRIVERS

MISSION REQUIREMENTS

ORBIT & LAUNCH SELECTION

MISSION PHASE & TIMELINE

System Drivers

01	ORBITAL CHARACTERISTICS	• Coverage • Lifetime • Radiation density
02	CONSTELLATION CHARACTERISTICS	• Quality of measurements • Formation stability
03	INSTRUMENT HOSTING	• Size • Magnetic cleanliness • Mechanical & thermal needs

Tradeoffs

1. FORMATION TYPE
2. ORBIT HEIGHT
3. ORBIT INCLINATION
4. LAUNCHER

Tradeoffs

1 FORMATION TYPE

0%	TETRAHEDRAL
0%	CARTWHEEL
0%	HELIX
0%	HELIX WITH CHASER

Selection Criteria:

- ❑ Magnetic field accuracy
- ❑ Formation stability
- ❑ Active control
- ❑ Delta V budget for injection
- ❑ Total orbital lifetime

Tradeoffs

1 FORMATION TYPE

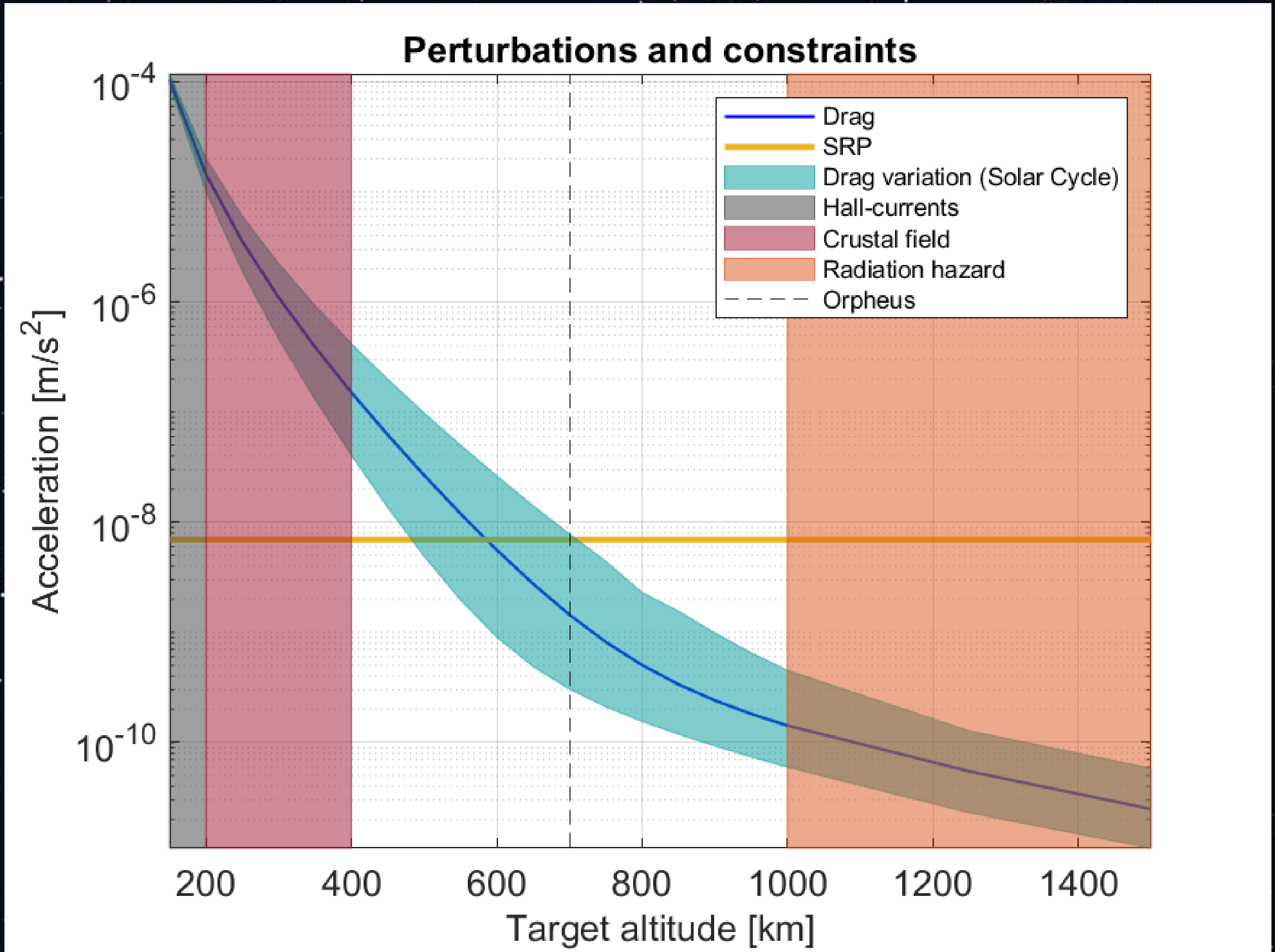
50%	TETRAHEDRAL
75%	CARTWHEEL
75%	HELIX
40%	HELIX WITH CHASER

Selection Criteria:

- ❑ Magnetic field accuracy
- ❑ Formation stability
- ❑ Active control
- ❑ Delta V budget for Injection
- ❑ Total orbital lifetime

Tradeoffs

2 ORBIT HEIGHT



Tradeoffs

ORBIT INCLINATION

3

0%	Sun Synchronous orbit
0%	Polar
0%	Near Polar at 95°
0%	Near Polar at 70°

Selection Criteria:

- ❑ Global earth coverage
- ❑ Ground station coverage
- ❑ Variation of local time
- ❑ Perturbation strength
- ❑ Frequency of launches
- ❑ Revisit period

Tradeoffs

3 ORBIT INCLINATION

60%	Sun Synchronous orbit
80%	Polar
90%	**Near Polar at 95°**
70%	Near Polar at 70°

Selection Criteria:

- ❑ Global earth coverage
- ❑ Ground station coverage
- ❑ Variation of local time
- ❑ Perturbation strength
- ❑ Frequency of launches
- ❑ Revisit period

Tradeoffs

4 LAUNCHER

0%	VEGA SSMS
0%	ROCKET CRAFTERS
0%	SPACEX SMALL SATs
0%	ROCKET LAB

Selection Criteria:

- ❑ Orbital inclination
- ❑ Flexibility
- ❑ Reliability
- ❑ Cost
- ❑ Altitude

Tradeoffs

4 LAUNCHER

35% VEGA SSMS

85% **ROCKET CRAFTERS**

50% SPACEX SMALL SATs

25% ROCKET LAB

Selection Criteria:

- ❑ Orbital inclination
- ❑ Flexibility
- ❑ Reliability
- ❑ Cost
- ❑ Altitude

ORPHEUS FINALIZED CONFIGURATION

1. CARTWHEEL HELIX
2. ORBIT HEIGHT = 700KM
3. ORBIT INCLINATION= 95 degrees
4. LAUNCHER - ROCKET CRAFTERS

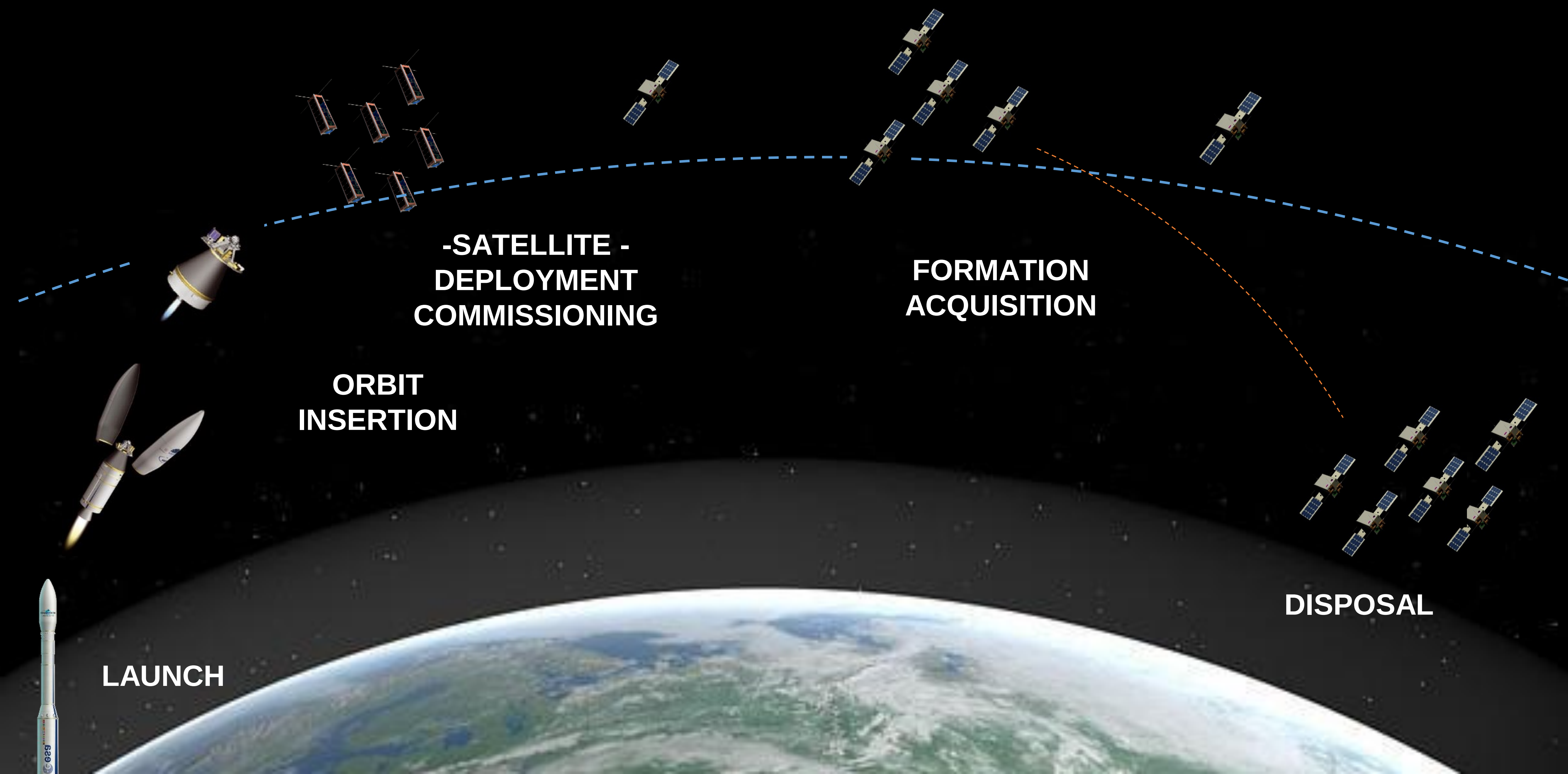
Mission Profile Overview

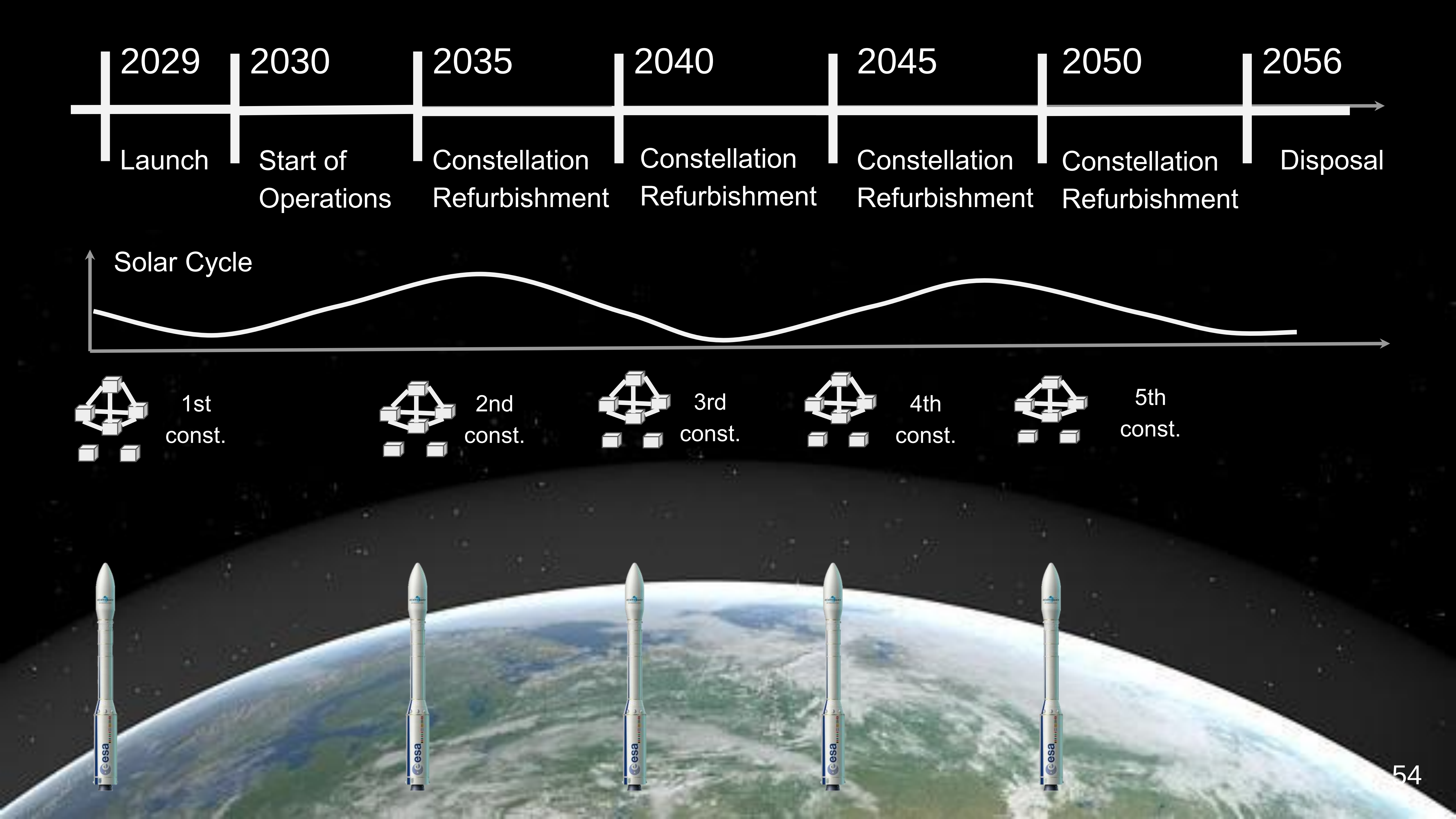
MISSION	TARGET ORBIT	FORMATION	ORBIT DETERMINATION
30 SATELLITES	700 KM ORBIT	6 SATELLITES	GPS BASED
SIZE: 12U (3X2X2) 25 years lifetime	95 DEGREE INCLINATION	CARTWHEEL HELIX 5 years lifetime	ACCURACY: 1cm approx.

MISSION PHASES - SINGLE CONSTELLATION

- Launch
- Orbit insertion
- Commissioning
- Science operations
- Orbit maintenance
- Constellation handover
- Disposal
- Data analysis

MISSION PHASES - SINGLE CONSTELLATION

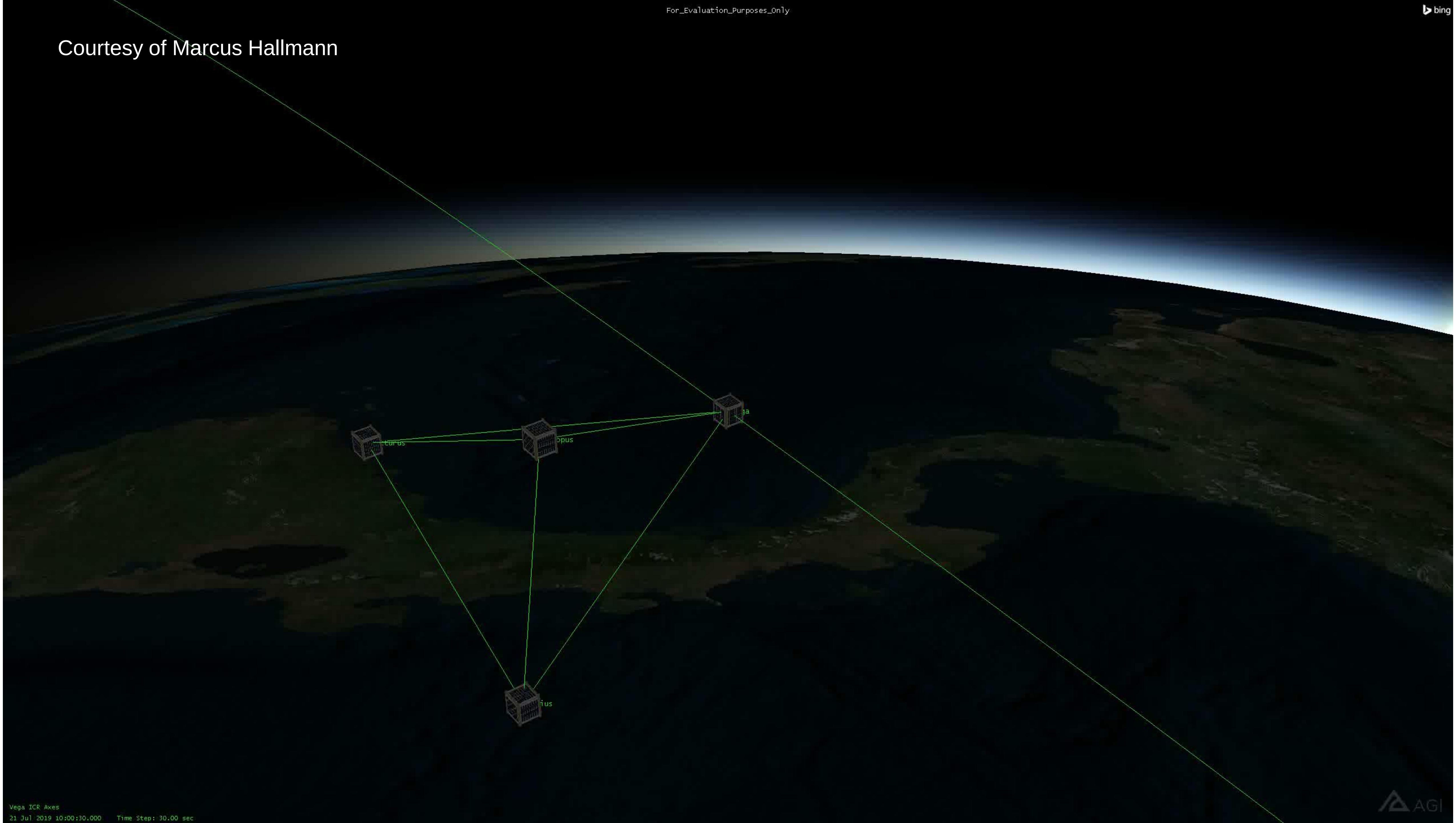



2029
Launch
2030
Start of Operations
2035
Constellation Refurbishment
2040
Constellation Refurbishment
2045
Constellation Refurbishment
2050
Constellation Refurbishment
2056
Disposal
Solar Cycle
1st const.
2nd const.
3rd const.
4th const.
5th const.
esa

Spacecraft Deployment and Constellation Formation

1. 6 SATELLITES SINGLE DEDICATED LAUNCHER
2. REDUCE MEAN ECCENTRICITY OF ALL SATELLITES
3. TEMPORARY INCLINATION CHANGES TO CREATE RAAN DRIFT
4. INTRODUCE OFFSETS TO ARGUMENT OF PERIGEE
5. FINALIZE ORBIT BY PERFORMING PHASE MANEUVERS
6. **ACQUISITION DELTA V = 68 m/s**

Courtesy of Marcus Hallmann



Delta V Budget

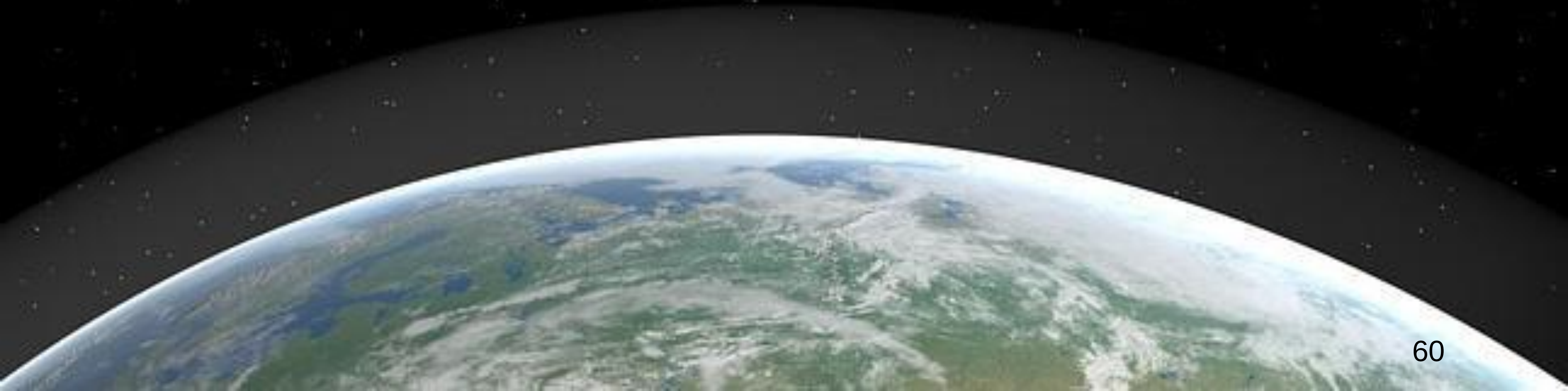
	Delta V (m/s)	Fuel Mass (grams)
Injection	54-68 (per satellite)	1188.77
Collision Avoidance	~1	~17.48
Formation + station keeping	~40 (per satellite per year)	~3500
Deorbit	~51.33 (per satellite)	~897.35
Total	**~320.33 m/s (5 year lifetime)**	**~5600**

Launch & Transfer

Requirements and Constraints	
No of spacecraft per launch	6 satellites (12U each) -> 72U
Satellite mass	20kg per satellite
Satellite dimensions	30 cm x 20 cm x 20 cm per satellite
Mission orbit	e≈0 a=700km i=95°
Mission timeline	25 years
Minimum vibration	31.5 Hz
Launcher C3	-0.00051234

Mission Profile Advantages

- Schedule flexibility in handover between deployments
- Incorporation of lessons learned in subsequent deployments
- Cost savings in mass production of identical spacecraft



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SPEAKER:
ALEXANDER PUTZ

Scientific Payload Identification

STATE OF THE ART MAGNETOMETERS

ACCURATE VECTOR & SCALAR MEASUREMENTS OF THE GEOMAGNETIC FIELD

VECTOR FIELD MAGNETOMETERS

ACCURATE DETERMINATION OF ATTITUDE & MECHANICAL STABILITY

PAYLOAD

SUITABLE MASS & VOLUME FOR A MICRO-/CUBESAT

MAGNETIC CLEANLINESS & PHYSICAL ISOLATION

ALLOWS FOR MORE ACCURATE READINGS

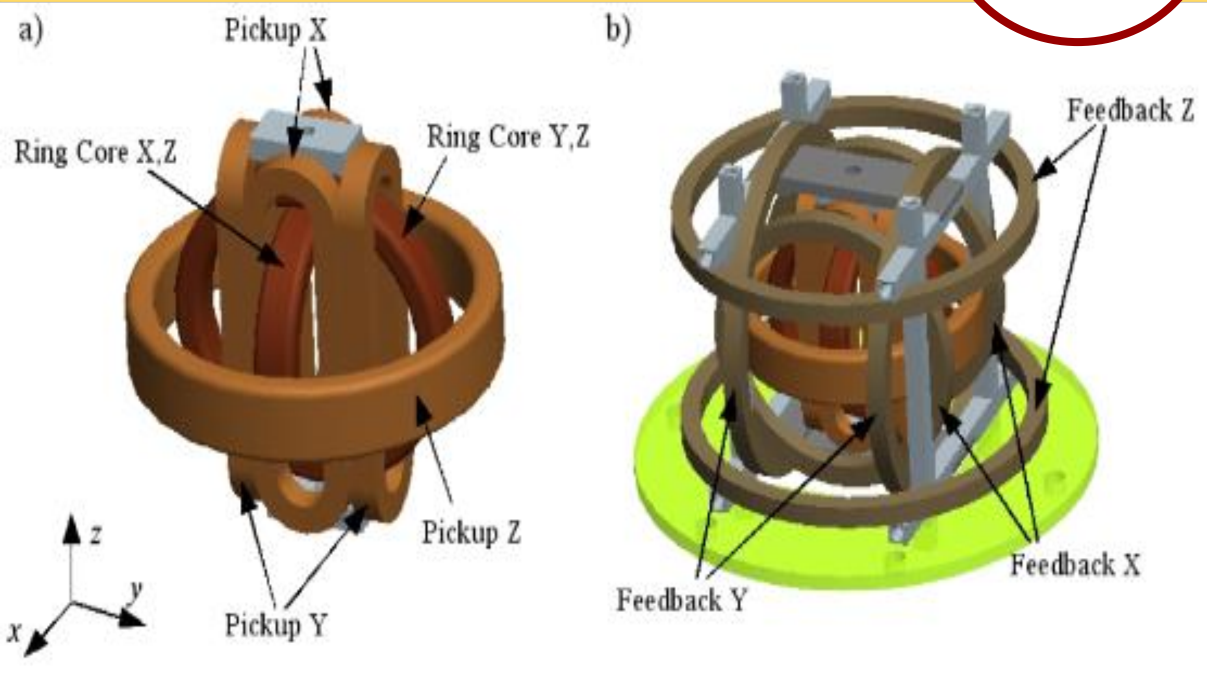
Payload Requirements

ID number	Short Descriptive Text	Source of Requirement	Object text
INSTR-01	Scalar magnetometers accuracy	SO-02	The scalar magnetometers shall measure the magnitude of magnetic field with an accuracy of 0.3nT.
INSTR-02	Measuring vector field	SO-01	Spacecraft shall use an instrument capable of measuring magnetic vector field.
INSTR-03	Vector magnetometers accuracy	SO-01	The vector magnetometers shall measure all three components of the magnetic field vector with an accuracy of 1 nT.
INSTR-04	Attitude accuracy	SO-01	Spacecraft shall be able to determine its attitude with an accuracy of 0.1 degree to precisely determine magnetic vector field.
INSTR-05	VFM and star trackers alignment	SO-02	Vector field magnetometer and star trackers responsible for determining the VFM attitude shall be aligned to 1 arcsec.
INSTR-06	EM interferences level	SO-01	Electromagnetic interferences measured by magnetometers shall be lower than 1nT.

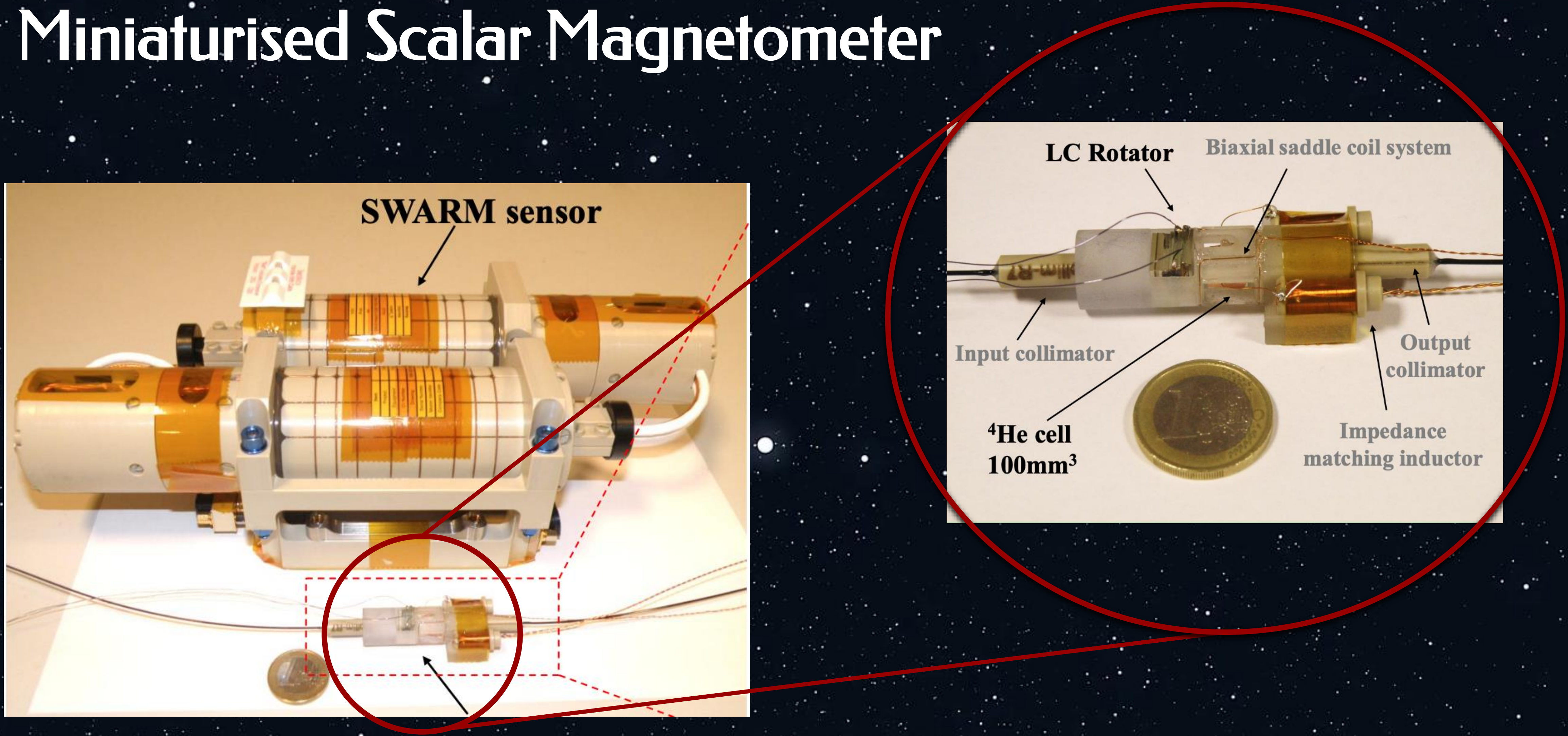
Miniaturised Vector Field Magnetometer

TRL 9

Vector Field Magnetometer Performance
Miniaturized fluxgate sensor
Used in conjunction with star trackers (precise attitude measurement)
Achievable **1nT** absolute accuracy w/ independant sensor calibration
Resolution: 3 pT (24bit) Noise: 10 pT/√Hz

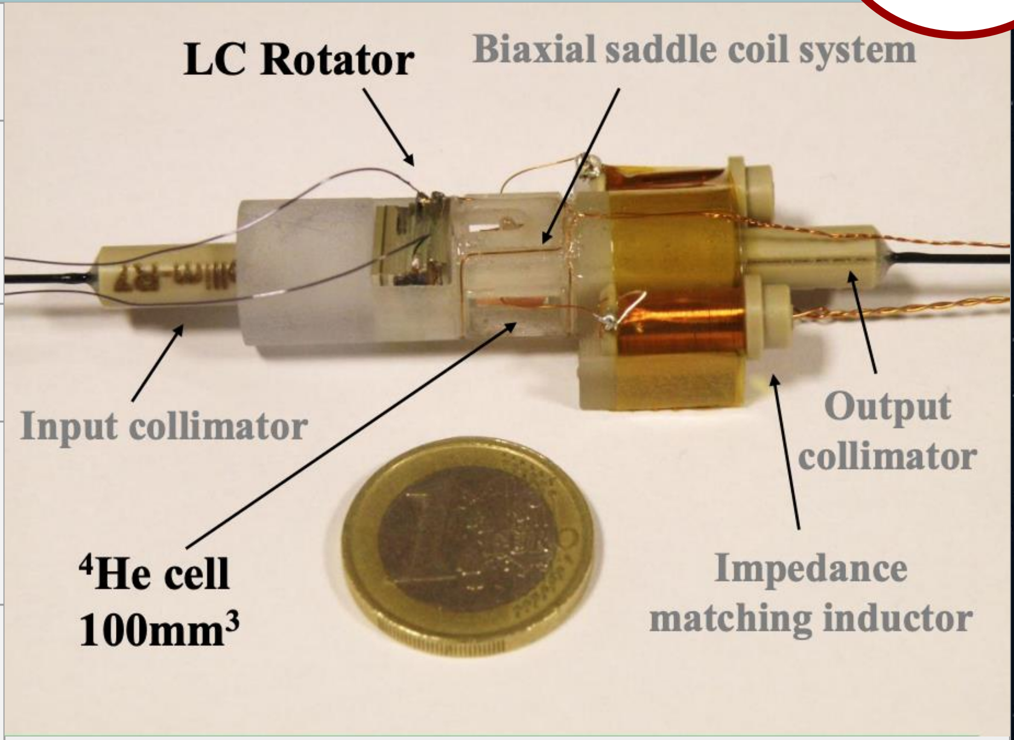


Miniaturised Scalar Magnetometer



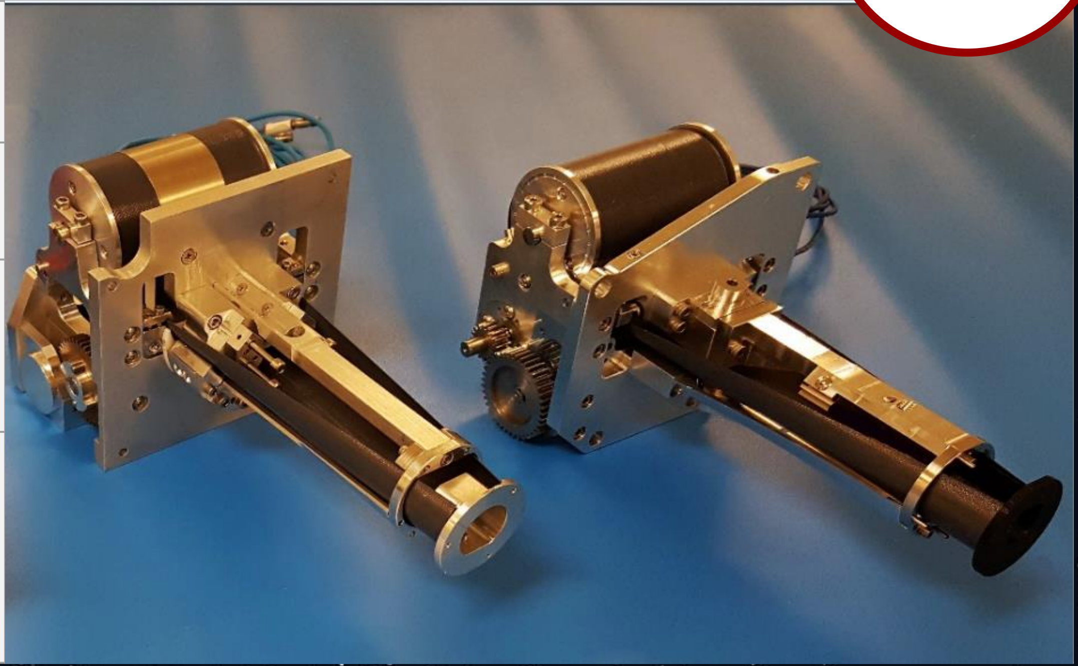
Miniaturised Scalar Magnetometer

TRL 4

Scalar Magnetometer Performance	
Optically pumped He magnetometer	
Miniaturization of SWARM Isotropic Helium-4 Atomic Scale magnetometer	
Volume **two orders** of magnitude smaller than SWARM	
High **accuracy** and **stability** to calibrate against the vector field magnetometer	
Sensitivity: 10 pT/√Hz Bandwidth: DC to 100 Hz	

Magnetometer Boom

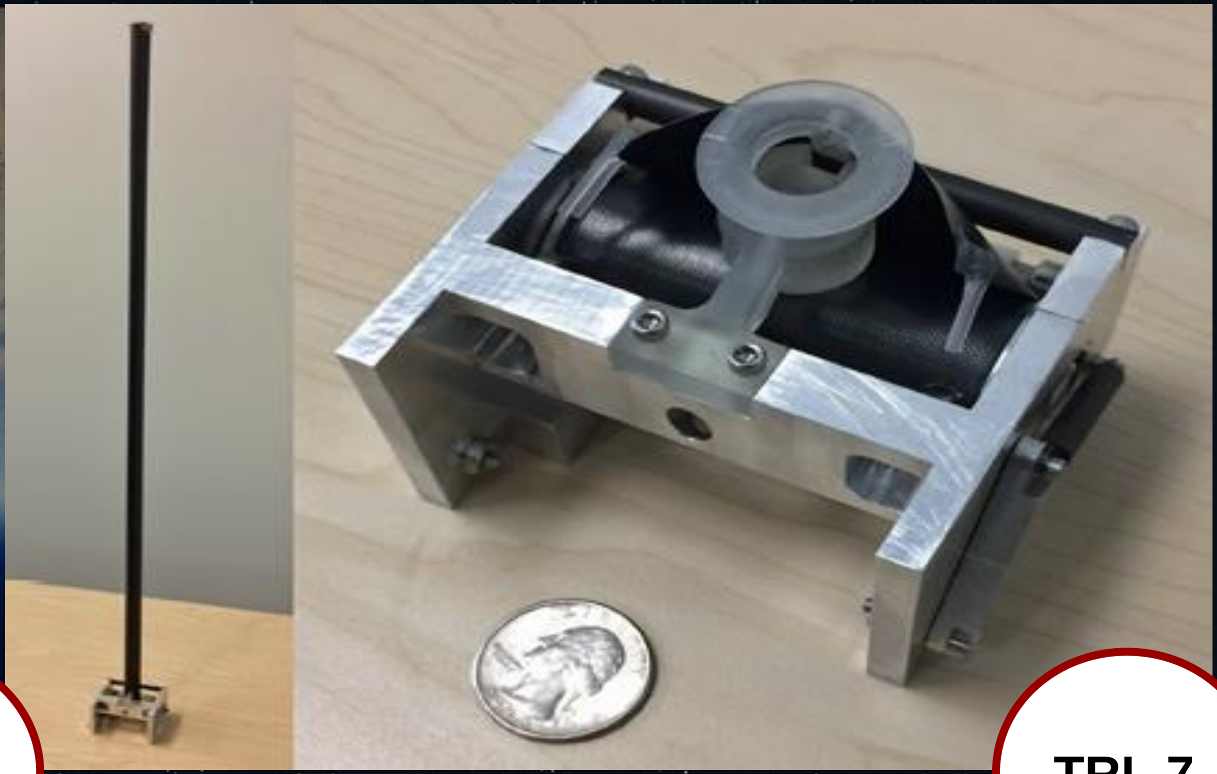
TRL 6

Boom Performance	
Vector field magnetometer is placed on a **<u>deployable 1.2 meter boom</u>** with two star trackers	
Scalar magnetometer is placed on a **<u>separate 1.2m boom</u>**	
Magnetic cleanliness programme and data cleaning allow for for further improvements and can compensate for a **shorter boom**	
Expecting to require a **<u>dedicated development programme</u>** to adapt boom for our specific usage needs	

Magnetometer Boom

Oxford Space Systems-Astrotube Boom (1.5m)

TRL 9



Roccor- Cubesat ROC Boom (1.5m)

TRL 7

Star Tracker

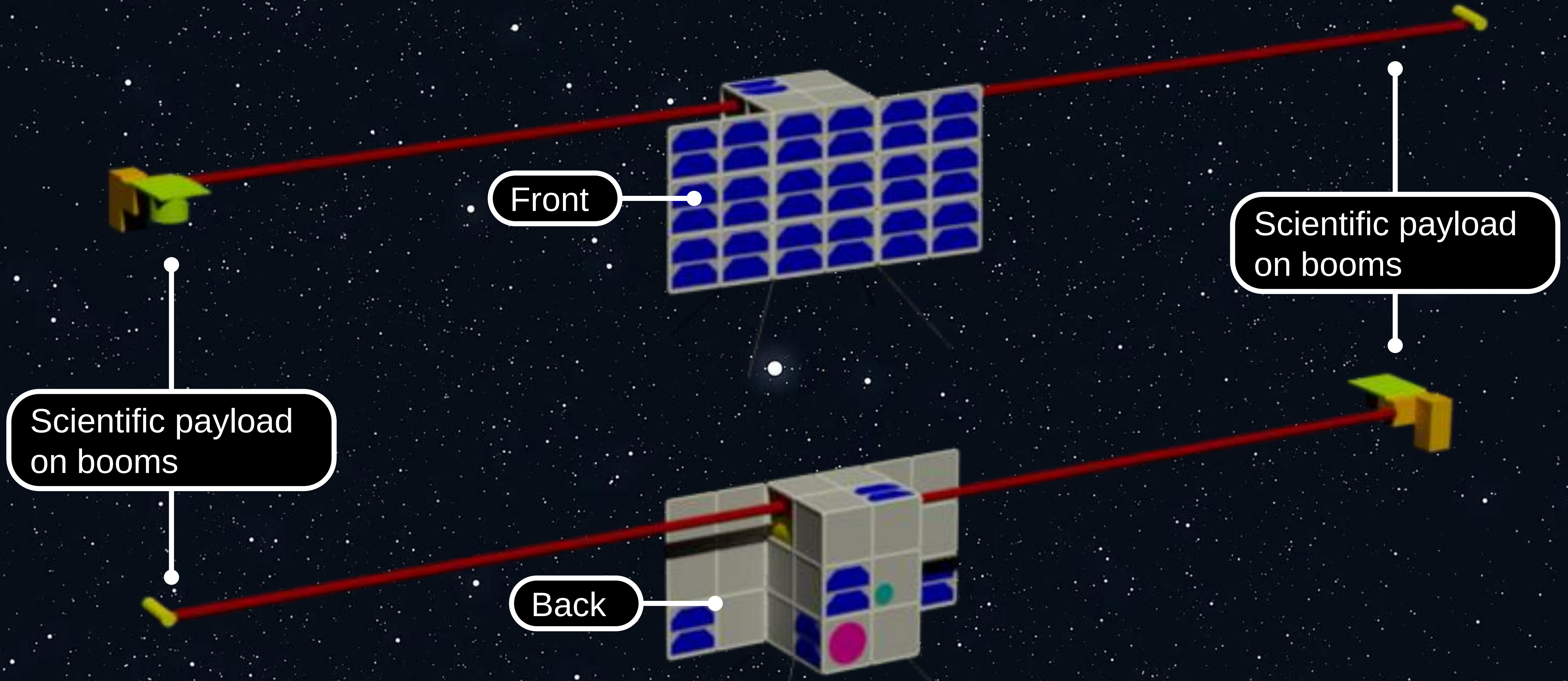
TRL 9

Star Tracker Performance	
CubeSat compatible star trackers are used for **precise attitude determination**	
The star trackers are arranged with the **boresights at 90°** from each other to improve the accuracy	
Accuracy: 6 arcsec Dimensions: 30x30x38mm	

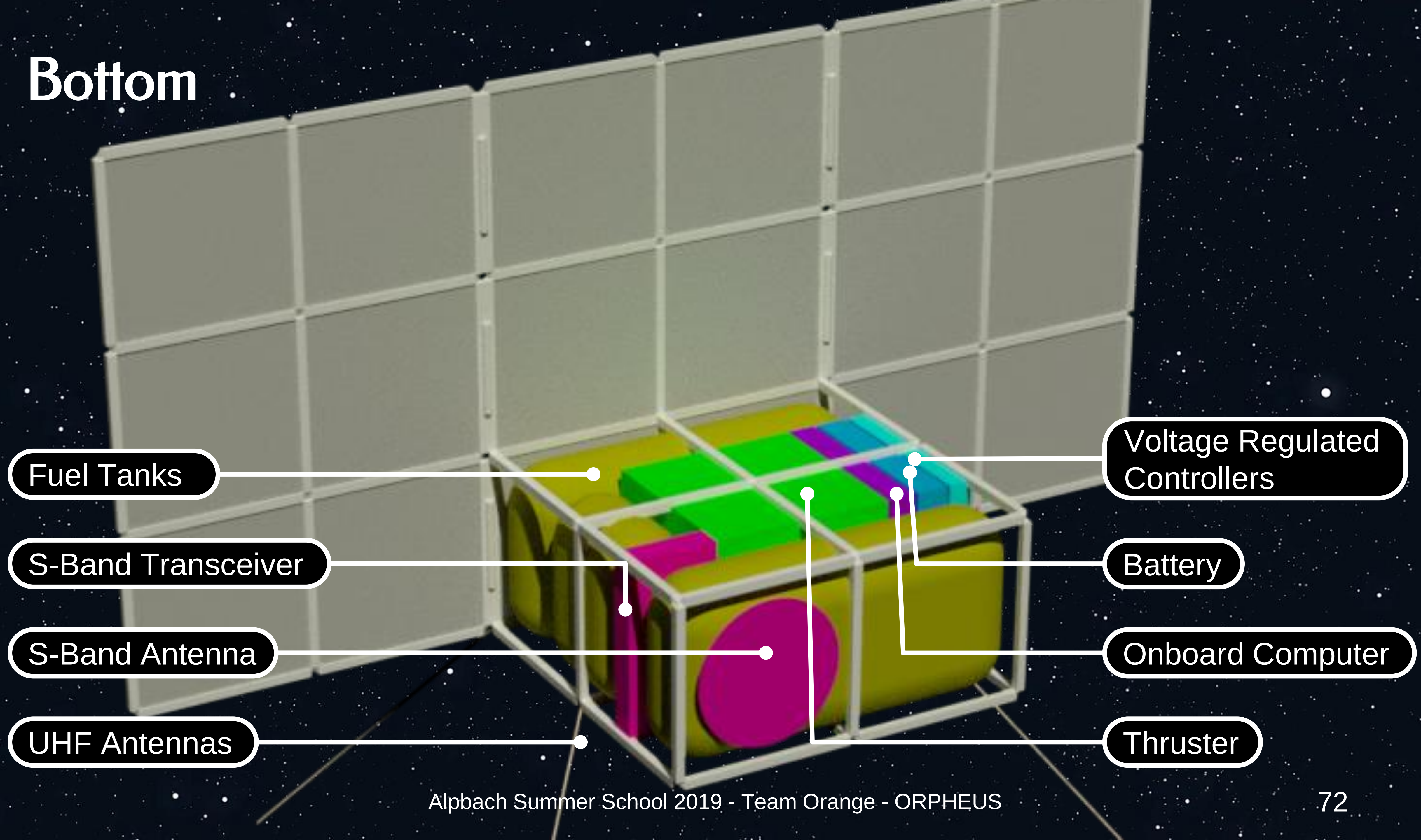
Overview of Subsystems

- Structure
- Power
- Propulsion
- ADCS
- Thermal
- Communications
- Ground Segment

Spacecraft Design & Configuration

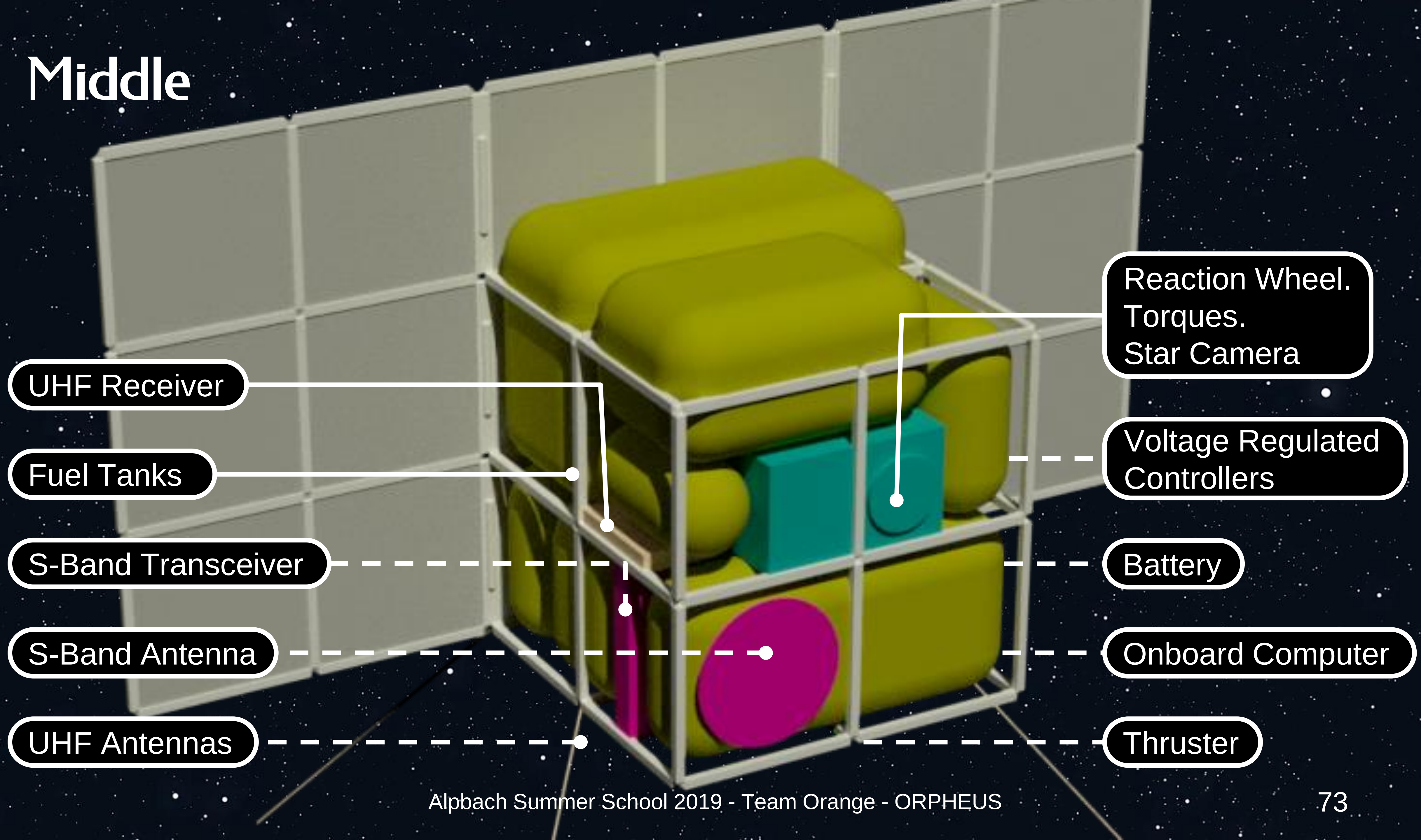


Bottom

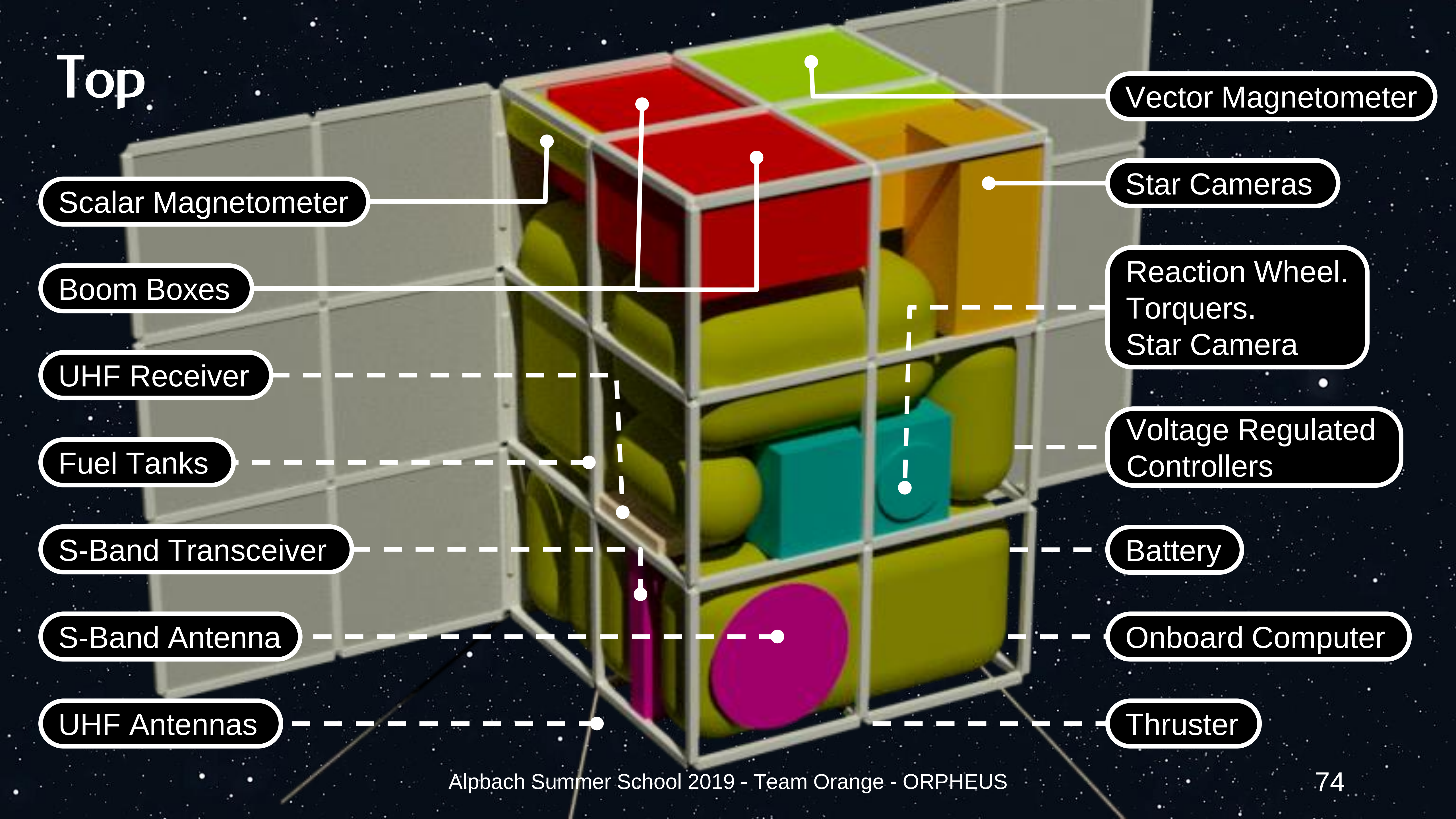


Fuel Tanks
S-Band Transceiver
S-Band Antenna
UHF Antennas
Voltage Regulated Controllers
Battery
Onboard Computer
Thruster

Middle

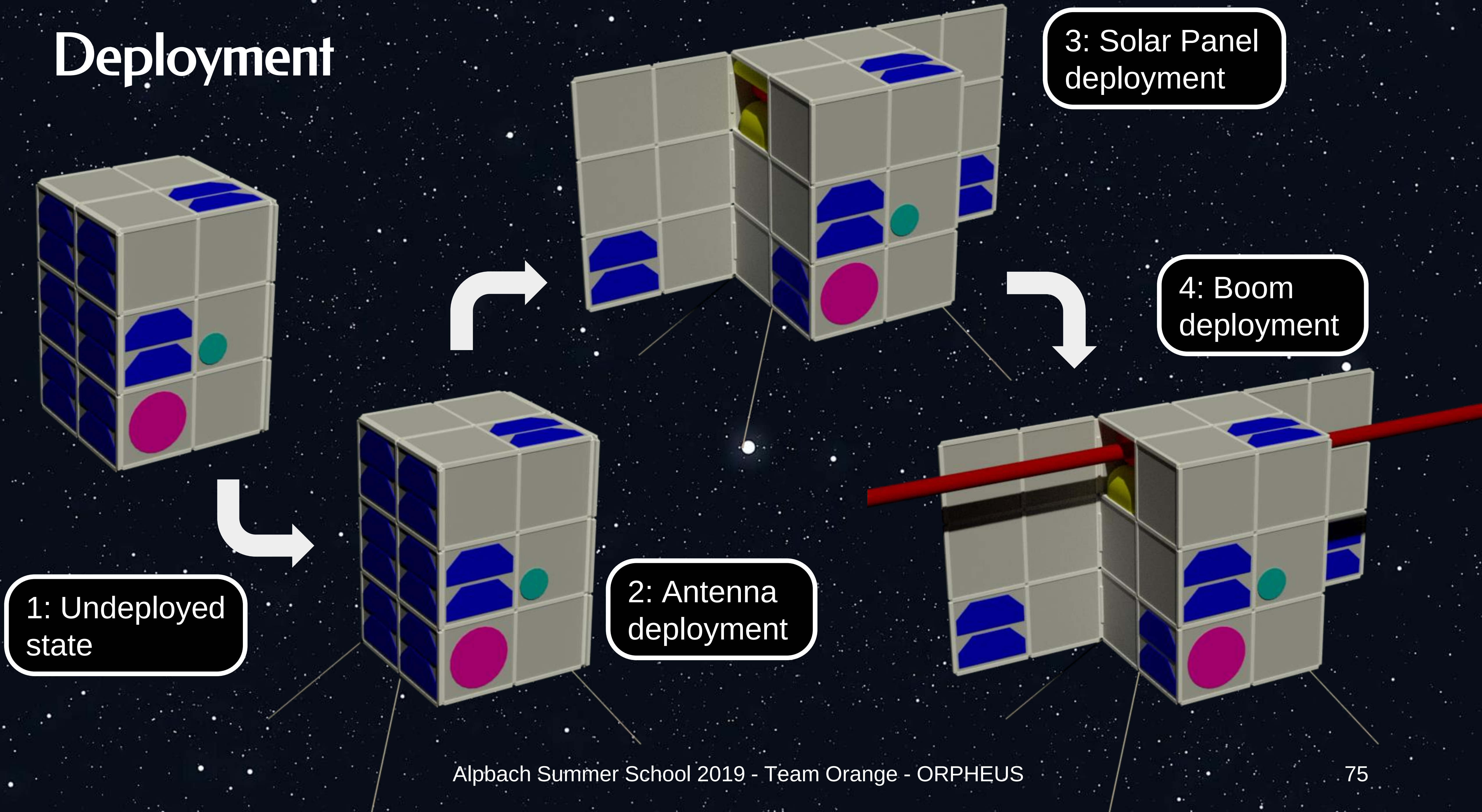

UHF Receiver
Fuel Tanks
S-Band Transceiver
S-Band Antenna
UHF Antennas
Reaction Wheel.
Torques.
Star Camera
Voltage Regulated
Controllers
Battery
Onboard Computer
Thruster

Top

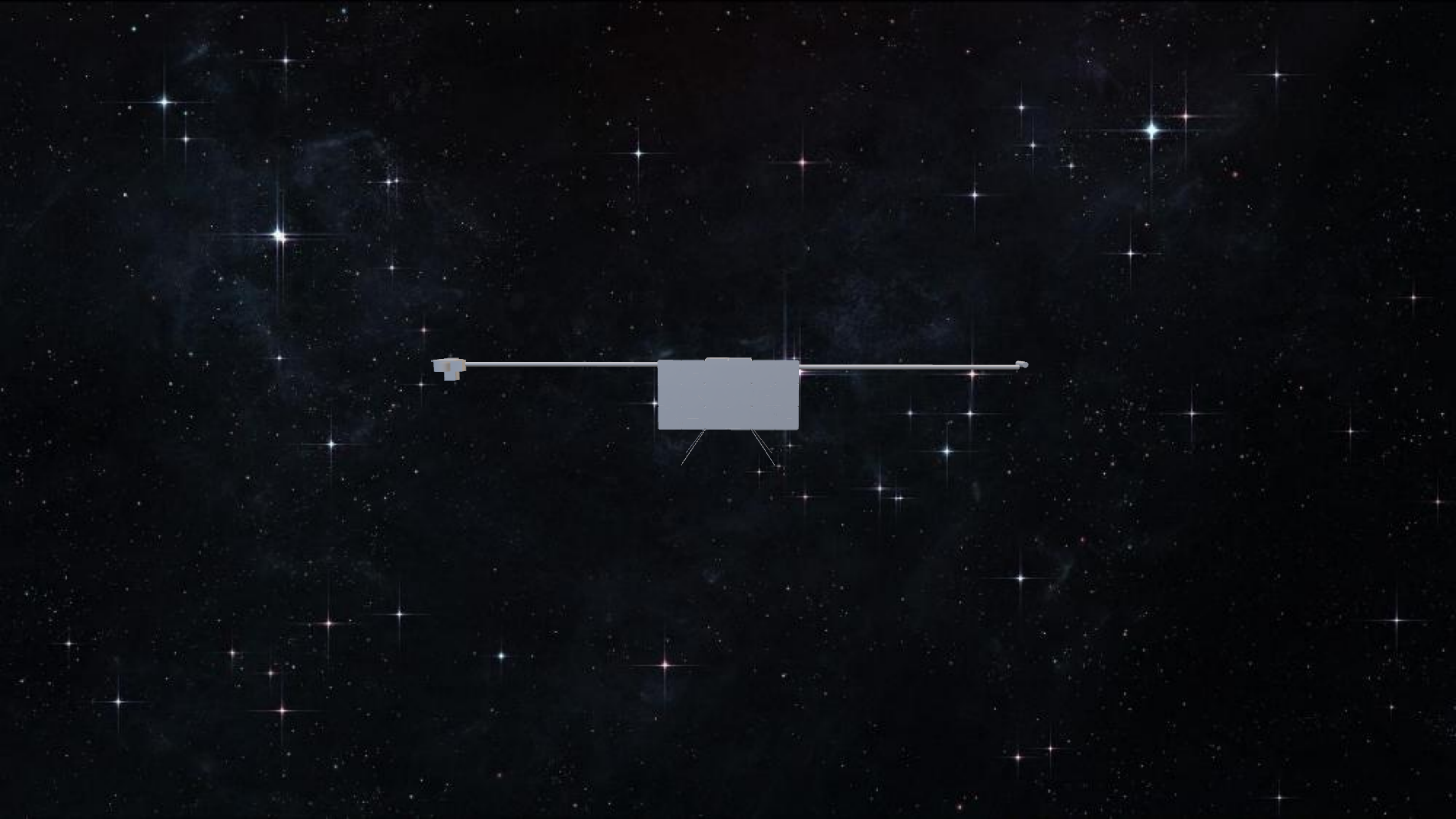


Vector Magnetometer
Scalar Magnetometer
Star Cameras
Boom Boxes
Reaction Wheel.
Torquers.
Star Camera
UHF Receiver
Voltage Regulated
Controllers
Fuel Tanks
S-Band Transceiver
Battery
S-Band Antenna
Onboard Computer
UHF Antennas
Thruster

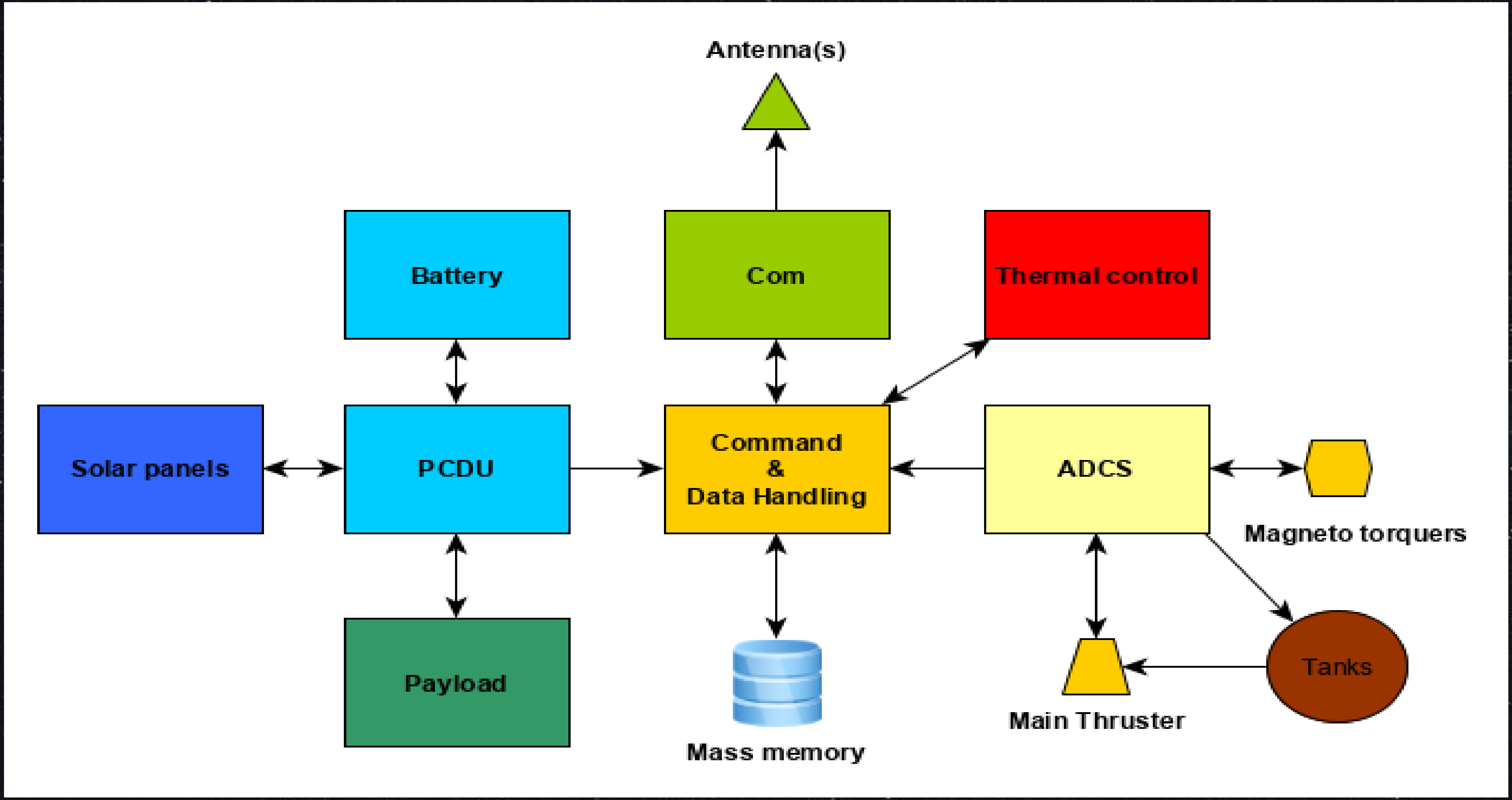
Deployment



1: Undeployed state
2: Antenna deployment
3: Solar Panel deployment
4: Boom deployment



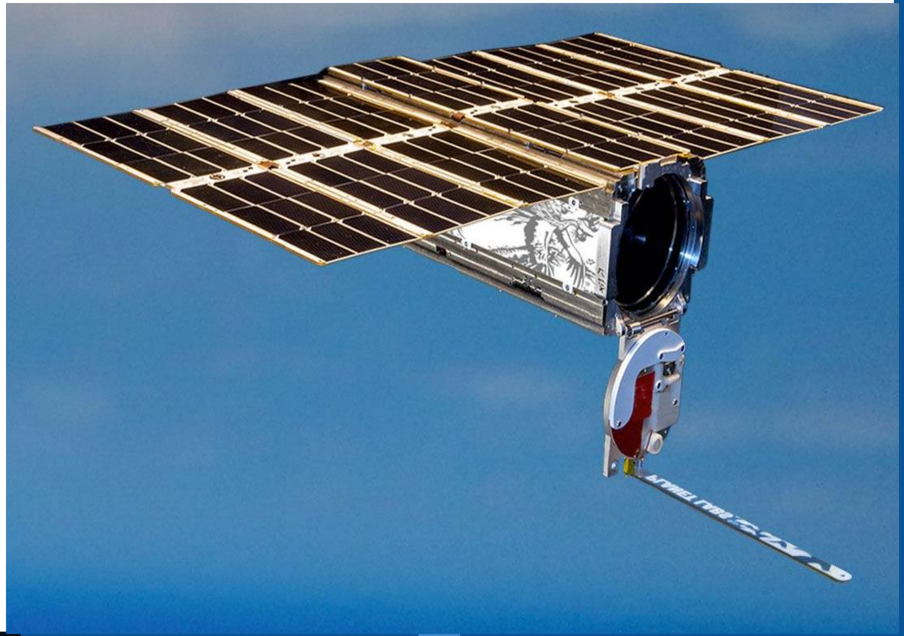
System - Overview



System - Power Budget

Power Usage [W]								
Operational mode	ADCS	Electrical	P/L (Science)	Propulsion	Telecomms	Thermal Control System	TOTAL	Total w/ margin
Safe mode	2.03	2.95	0	0	6.05	0.15	11.18	12.66
Commissioning	3.38	13.95	0	0	6.05	0.15	23.53	26.93
Science	3.30	13.95	2.8	0	0	0.15	20.20	23.26
Orbital maintenance	3.30	13.95	0	5	0	0.15	22.40	25.68
Telecom	1.43	13.95	0	0	6.05	0.15	21.58	24.59
Science + heating	3.30	2.95	2.8	0	0	10	19.05	21.93
Margin for subsystem	20%	15%	10%	10%	10%	15%	20%	

System - Power



Active attitude control provides a stable sun-facing spacecraft panel (0.18 m²) generating 51 W of usable electrical power.

- Battery size 40 Wh
- Power Control Unit
- Voltage regulated buses

System - Propulsion

SELECTED SYSTEM:

5.6 kg propellant based on
~12.08 kg ceiling for total satellite dry mass

Tank volume sizing:
~ 0.69 m^3
~ 0.32 MPa

TRL 6

Propulsion systems considered:

- Resistojet
- **Cold gas**
- Electrospray

TRL 9

Drivers:

- Total delta-v
- Magnetic cleanliness
- Total burntime over 5 years
- Propellant mass

System- Attitude Determination & Control

DESIGN DRIVERS

- Solar Incidence & Power Budget
- Orbit Maintenance & Formation Keeping
- Structural Vibrations (Boom)
- Magnetic Cleanliness (Science Operations)

System- Attitude Determination & Control

OPERATIONAL MODES

Telecommunications
- ❑ Ground station communication
- ❑ Active transceivers and deactivated magnetometers.

Acquisition & Safe
- ❑ After deployment/failure of a subsystem.
- ❑ Coarse Sun pointing.

Science & Heating
- ❑ Notably significant low temperatures
- ❑ Additional heating for key subsystems

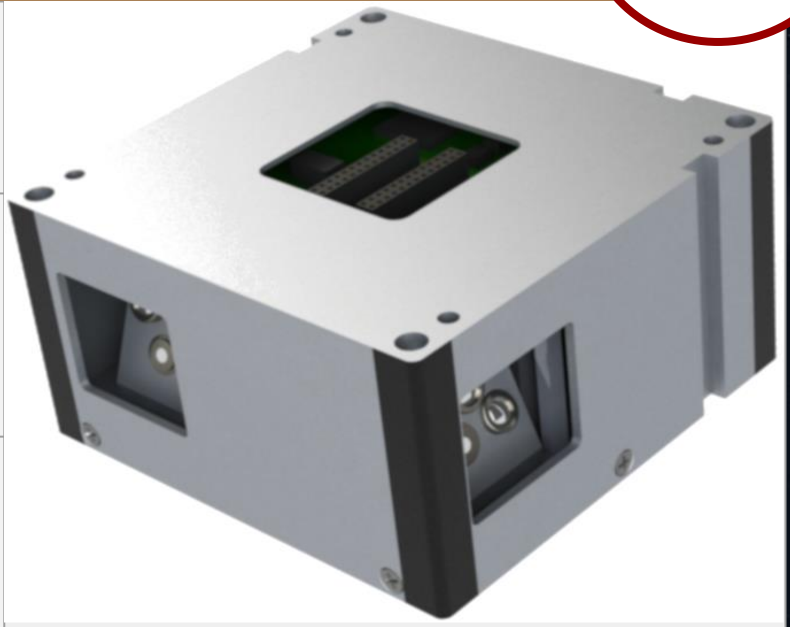
Commissioning
- ❑ Solar panels & booms deployment with instruments' calibration.
- ❑ Fine Sun pointing.

Orbital Control
- ❑ Orbit acquisition & formation keeping.
- ❑ Inertial stabilisation for propulsion.

Science
- ❑ Magnetometer data acquisition.
- ❑ Fine attitude knowledge required.

System- Attitude Determination & Control

TRL 9

ADACS Control Board	
Attitude determination: ➔2 Sun sensors (Coarse pointing + Safe mode) ➔2 Star trackers (Fine pointing)	
3-axis attitude control: ➔4 Reaction wheels (Redundancy) ➔4 Magnetorquers - Desaturation of wheels - Detumbling & safe mode	
Desaturation ➔ **~ 2 days (duration** < 1 min) ➔ Coordination with science operations for reduced impact	MAI-400 Maryland Aerospace. Inc

Thermal Control Analysis

Identify hardware temperature limit

+

Single node analysis made for worst case scenarios for a 700 km orbit.

+

Worst Case Scenario

Hot conditions ~308K

Cold conditions ~242K

=

Spacecraft will need heating system and extra insulation for critical subsystems

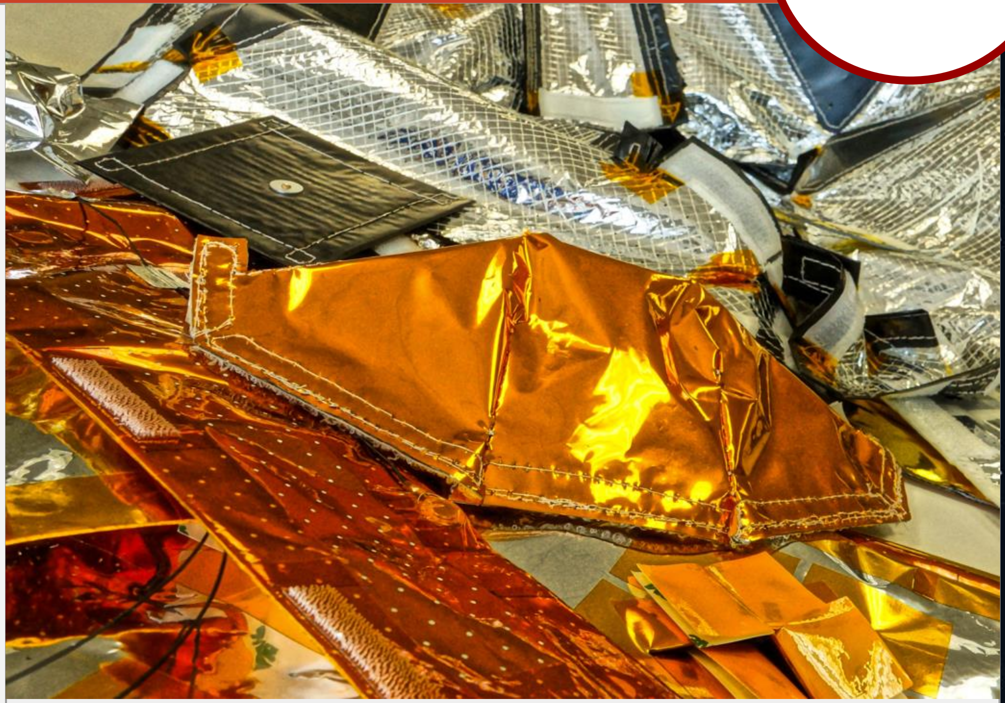
Spacecraft Operating Temperature Ranges/Limits	
Nominal operations	+20 to +40 °C
Worst case envelope	0 to +50 °C

System - Thermal Control

Thermal Control Procedures

TRL 8/9

- ➔ Active attitude control ensures a ***"cold side"*** of the spacecraft
- ➔ A radiative surface for thermal control is not needed
- ➔ **Electrical heaters** are included for emergency heating in case of safe-mode
- ➔ Monitoring temperatures of critical components using **temperature sensors**
- ➔ Extra **MultiLayer Insulation (MLI)** will be included for the battery, onboard computer, electronics and propellant tank.



Communications - Overview

DATA PRODUCTION

On-board storage (4GB) is not a limiting factor

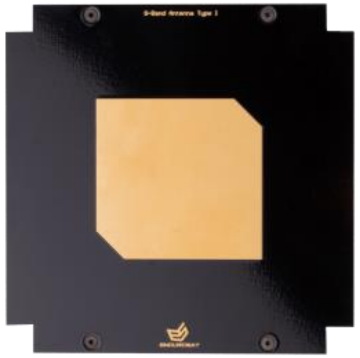
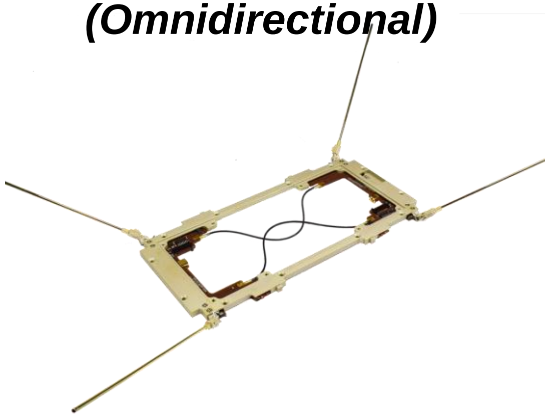
Scientific payload: 128 bit/s @ 1Hz
TT&C: 60bit/s 10Hz for sensors & 1 Hz GPS

23 Mbit /satellite/day
140 Mbit /constellation/day

3 years until storage saturation

20% MARGIN

Communications- Link Budget

	S-BAND *(Half)* 	ULTRA HIGH-FREQUENCY *(Omnidirectional)* 
UPLINK	❑ Eb/En around **38.5 dB** ❑ Data Rate up to **50kb/s**	❑ Eb/En around **35.3 dB** ❑ Data Rate up to **2.4kb/s**
DOWNLINK	❑ Final Eb/En around **46.5 dB** ❑ Data Rate up to **1Mb/s**	❑ Final Eb/En around **15.8 dB** ❑ Data Rate up to **24Kb/s**

Communications - Ground Segment

AUGMENTED NETWORK
1 South Point
2 Santiago
3 Troll
4 Svalbard
5 Dongara

2 BACKUP-KIR_2

- ❑ Existing Ground link to ESOC
- ❑ 10 Usable passes/Day >11 min

4 PRIMARY-ESOC-1

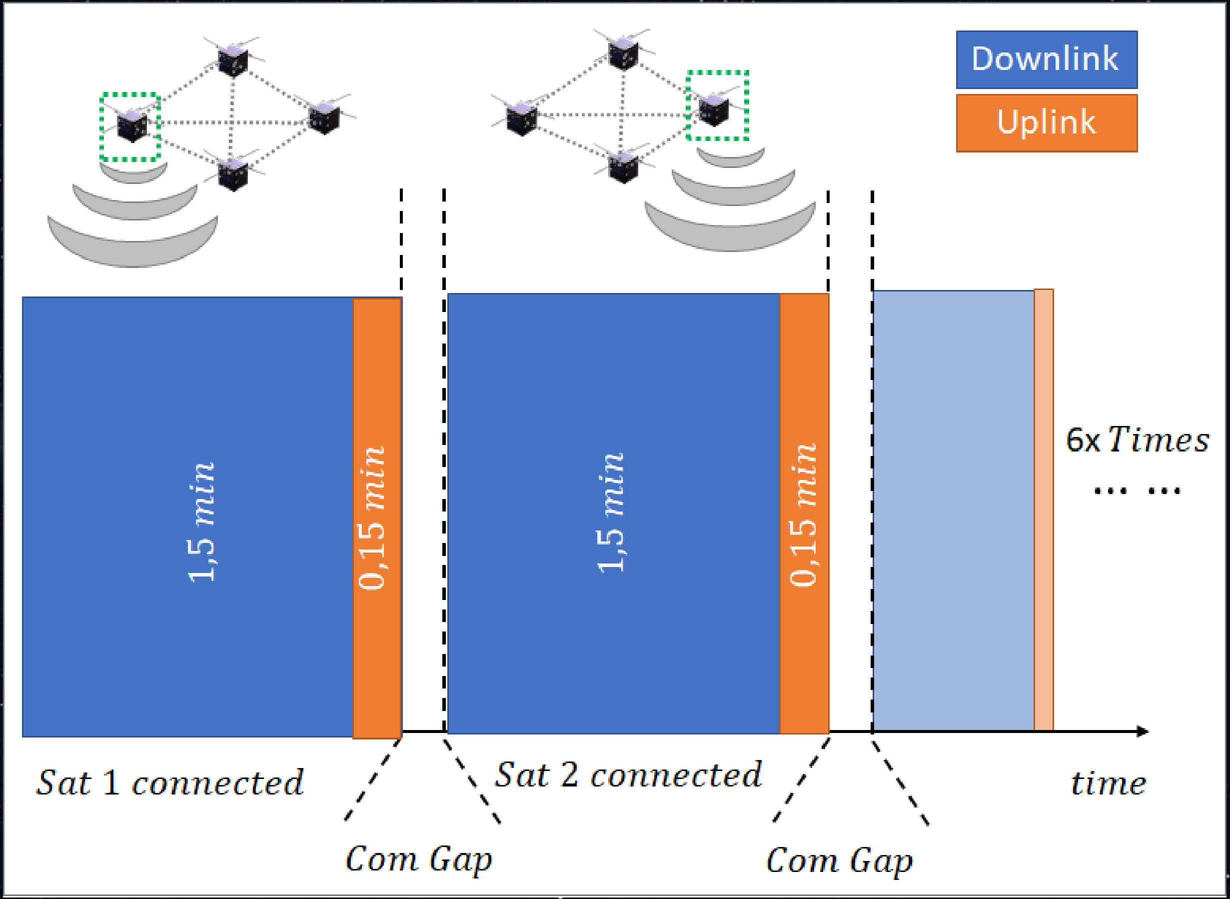
- ❑ Specially designed for small sat missions
- ❑ Control center integrated
- ❑ 4 Usable passes/Day >12 min
- ❑ Existing Ground link to KIR_2

CONTROL CENTRE-ESOC

Communications - Ground station transit timeline

Single pass Uplink & Downlink

S-Band telecom link		Margin
Revisit time (days)	4	
Downlink S Band (Min)	7.0	20%
Uplink S Band (Min)	1.7	20%
Com Gap	0.03	20%
Time/const (min)	**8.8**	**20%**



Outline

SCIENCE CASE

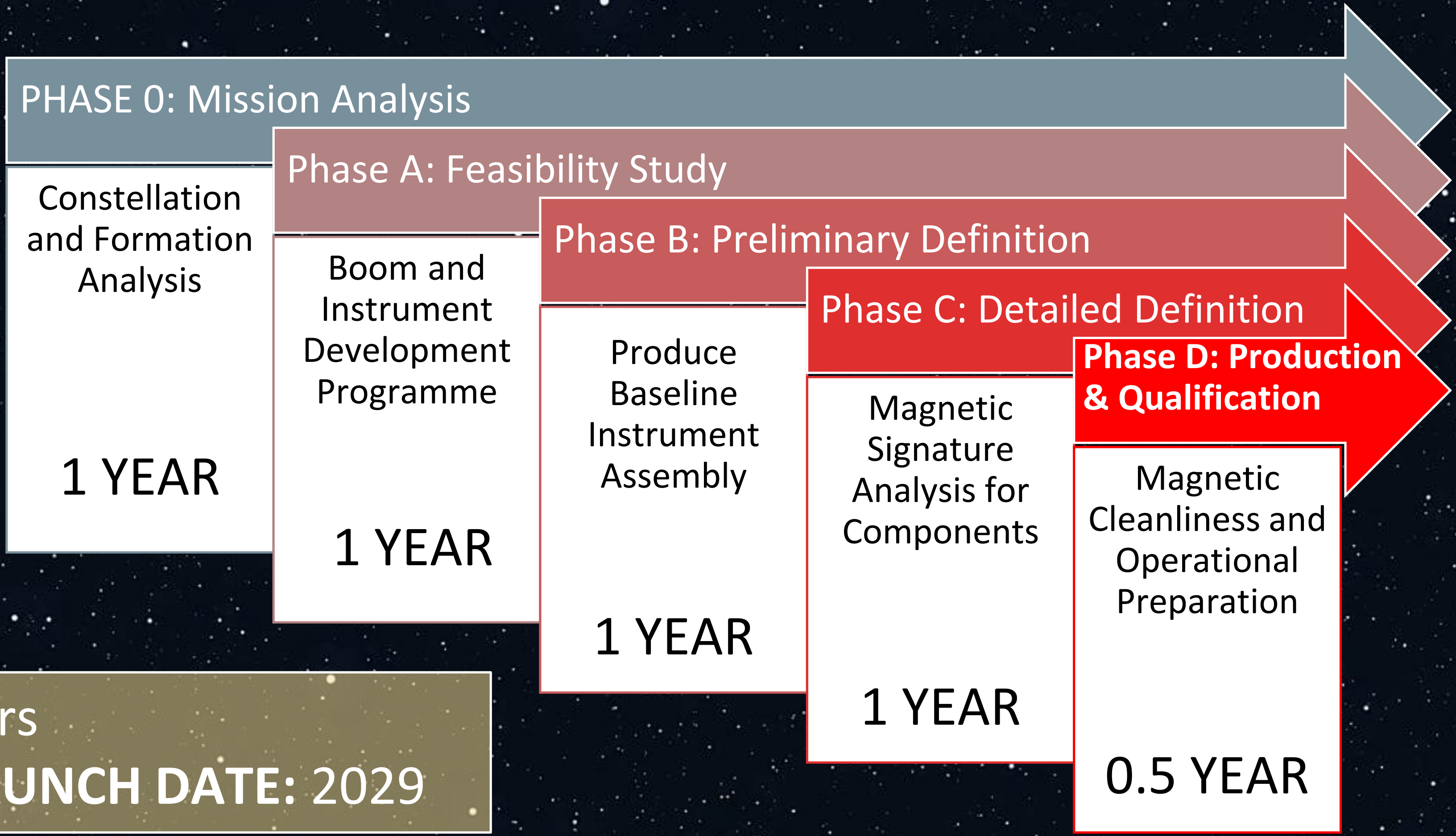
MISSION PROFILE

SPACE SEGMENT

PROJECT ENVELOPE

SPEAKER:
ILHAM SAID

Development Schedule for Orpheus



TOTAL: 4.5 years
> EXPECTED LAUNCH DATE: 2029

Risk Assessment

Risk	Call Sign	Mission Risk	Likelihood	Impact	Mitigation
Schedule	SCH-1	Failure to keep launch schedule due to launcher unavailability	3	3	Allow for sufficient launcher development time and overlap between constellation deployments
Schedule	SCH-2	Low TRL boom concept causes delay of schedule	2	3	Allow for sufficient development time when selecting boom provider
Payload	PAY-1	Structural / deployment failure of boom	2	4	Constellation approach allows for degraded performance when one or two satellites are compromised
Spacecraft	SPC-1	Being unable to communicate with spacecraft	2	5	Test campaign and backup communication scheme
Spacecraft	SPC-2	Failure to meet Cubesat launch standards results in delayed launch and additional dispenser and component costs	1	4	Conformance to Cubesat standards is to be paramount at every stage of the design process
Cost	CST-1	COTS parts no longer available for later satellite generations	2	2	Adherence to Cubesat standards will increase likelihood of compatibility with functionally equivalent successor components
Mission	MSN-1	Faster than anticipated degradation of formation degrades data and shortens spacecraft lifetime due to propellant consumption	2	3	Allow for schedule flexibility for early replacement of constellation

Risk Assessment

Likelihood	Trivial	Trivial	Significant	Major	Catastrophic
Very Likely					
Likely					
Quite Possible			SCH-1		
Possible		CST-1	SCH-2 MSN-1	PAY - 1	SPC-1
Not Like				SPC-2	

Impact

Cost Breakdown Estimation

COST BREAKDOWN ESTIMATION				
SPACECRAFT ELEMENTS	Price per Spacecraft	Recuring Spacecraft	NRE +5 RS/C	
	Million €			
Structure	0,60	0,48	3,00	TOTALS
Thermal Control	0,28	0,22	1,40	
ADCS	1,20	0,96	6,00	
Electrical Power supply	0,50	0,40	2,50	
Propulsion(Reaction Control)	0,15	0,12	0,75	
Telemetry Tracking and Command	0,60	0,48	3,00	
CD&H	0,75	0,60	3,75	
Payload	1,20	0,96	6,00	
IA&T	0,20	0,16	1,00	
Engineering, Software	0,50	0,40	2,50	
TOTAL	5,98	4,78	29,90	149,5
Total S/C including payload+20% Margin				179,4
Program management	3 person for 5 years 1.5 for 20 years			9,0
Mission Operation (incl GS)	1 h GS per day+1 person			10,0
Science Operation(incl archiving)	3 persons for 5 and 1.5 for 20 years			9,0
Launch	5.4/launch-for 200 Kg total launch mass			27,0
Contigency (20%)				46,9
TOTAL COST				281,3

Contribution per ESA Member State Citizen
0.54 €

Descoping Options

- Reducing number of satellites per formation by 1
  (still be able to gather data with the help of existing models)
- Reduce handover between launches / accept gaps in data to extend mission duration without compromising long-term goals
- Cut down total mission duration would save on cost
  (manufacturing and operation)
- Cut down to one boom with a single magnetometer in vector / scalar mode

Outreach - Education!

Magnetometers are a common payload on student payloads ESA Education programs (CanSat. REXUS/BEXUS. Student Cubesats).

- Students can compare data with ORPHEUS
- ORPHEUS experts can serve as mentors
- Promising students can intern with the ORPHEUS science and mission operations team

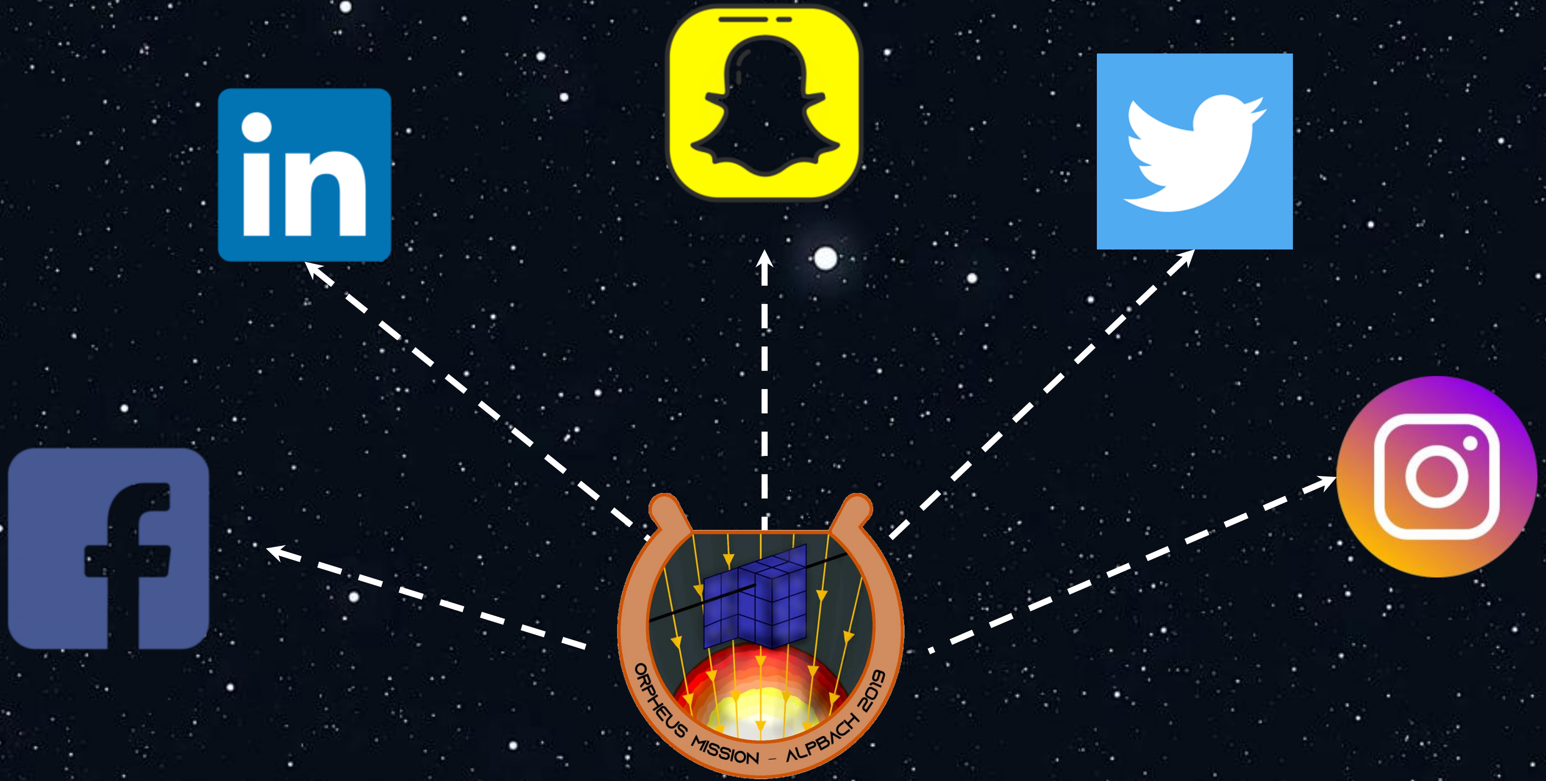
Outreach - Education!

Orienteering competitions organized on university campuses with prominent geomagnetic research to shine a light on recent developments

Outreach - Social Media!

esa
European Space Agency

Social media presence for general public with emphasis on citizen science (we all live in the magnetic field. let's go out and measure it!)



Summary

- Scientists have told us: “We want Swarm to continue!”
- Engineers responded: “We can make it cheaper, longer and better!”

Orpheus is the solution:

“Magnetic measurements in an orbit formation designed to focus on the Earth’s core. This will enable for sophisticated measurements in an all-new region. with a mission configuration to deliver continuous world class data for years to come” - ORPHEUS 2019

Special Thanks!

To our tutors. lecturers. organizers. and the whole summer school for this fabulous learning opportunity and for all the new knowledge. techniques. and friendships we’ve gained along the way.

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BACKUP-SLIDES

Backup Slide-Past Missions

Ørsted:

- 1 satellite
- mapping of internal and external field

Swarm:

- 3 satellites
- mapping of internal and external field

Backup Slide - Power Subsystem

- Deployable solar panels provide 18U of surface area. which translates into ~0.134 m² of solar panel area (40mm x 80mm panels)
- Assuming a solar constant of 1361 W/m² and a high-TRL multijunction solar panel efficiency of 30 %. we obtain 52.25 W
- Considering a degradation of 0.5 % per year. the available power at the end-of-life is 51 W
- Source: https://sst-soa.arc.nasa.gov/03-power

Backup Slide - Power Subsystem

- Eclipses up to 35 minutes on our 99 minute period will require a battery of size 40 Wh to account for a worst-case power consumption of 32 W. assuming a 50% depth-of-discharge as best practice
- Source: https://sst-soa.arc.nasa.gov/03-power

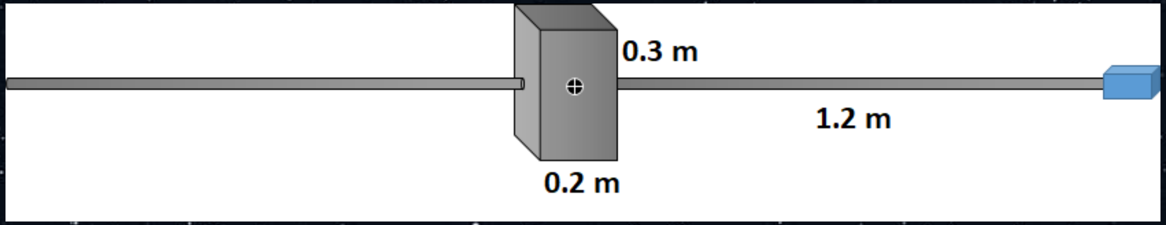
Backup Slide - Power ADCS subsystem

Perturbations	Type	Maximum torque	with 20% margin
Drag	Variable*	[2] 5.46 x 10^{-8} Nm	**6.55 x 10^{-8} Nm**
Gravity gradient	Cyclic*	[1] 3.45 x 10^{-6} Nm	**4.14 x 10^{-6} Nm**
Solar pressure*	Secular*	[2] 4.37 x 10^{-8} Nm	**5.36 x 10^{-8} Nm**

*Sun pointing (x-axis)

[1] Assuming uniform density for 12U cuboid + 2 booms + optical payload. I = [2.163. 0.195. 0.120] kg/m^2

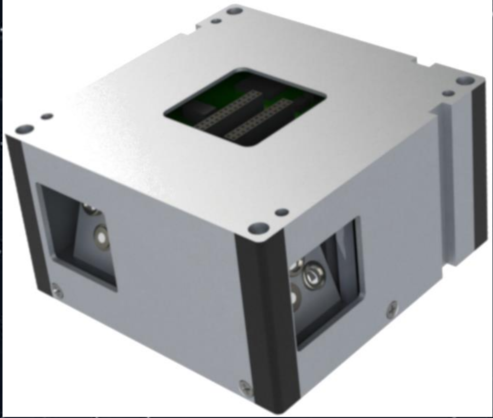
[2] Assuming center of gravity to center of pressure (SRP & Drag) distance ~ 10 cm



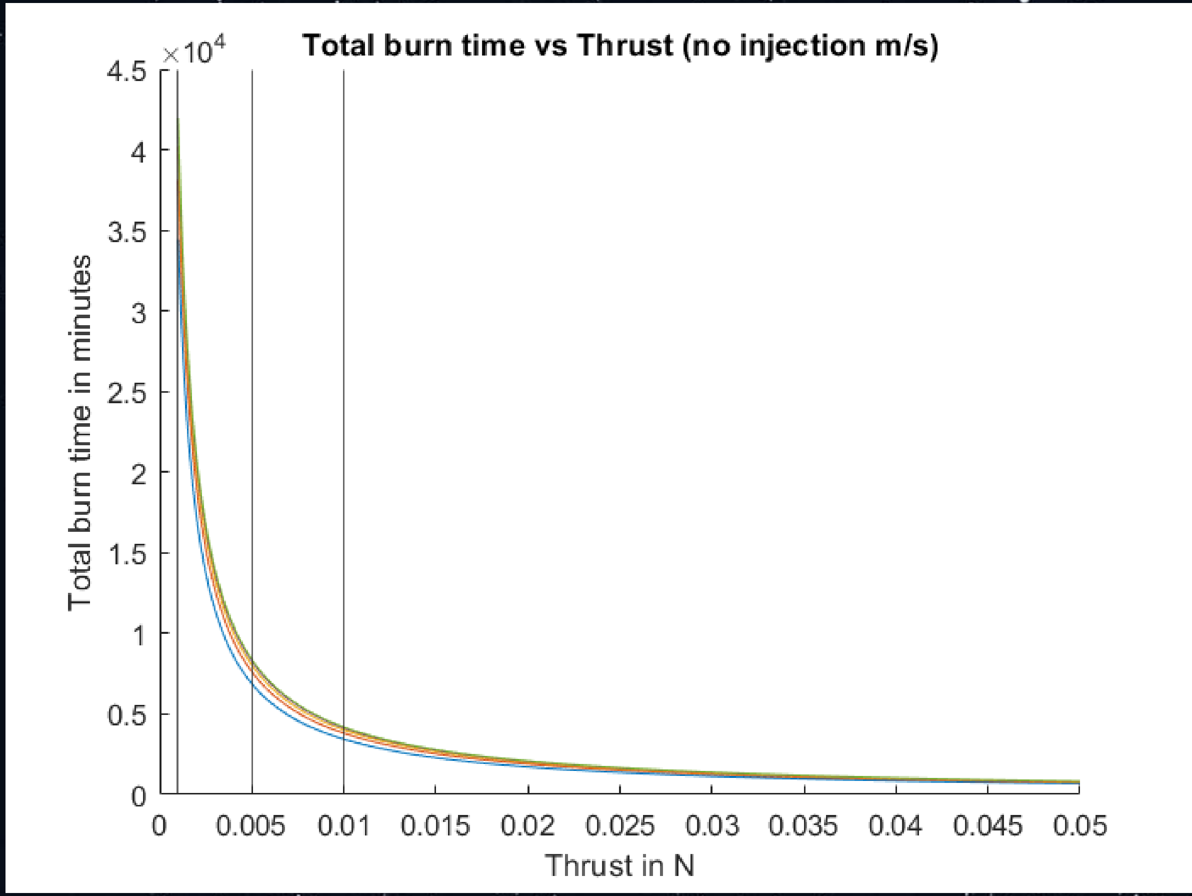
Backup Slide - Power ADCS subsystem

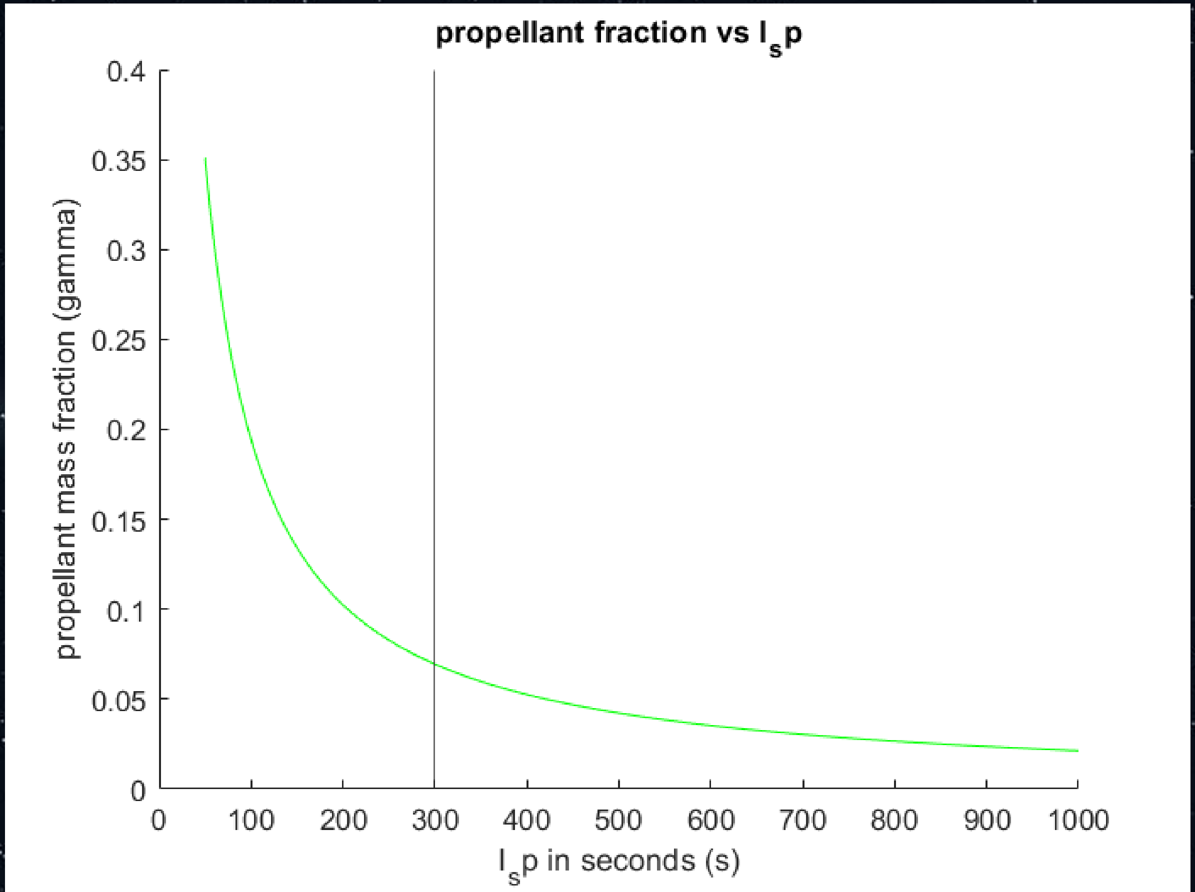
Momentum storage	11.076 mNms
Maximum Torque	0.635 mNm
Magnetic dipole moment	0.108 Am^2 (0.15 @72% Duty Cycle)
*Integrated ADACS Stock #: MAI-400-31130200 Maryland Aerospace. Inc.	

ΔT between desaturations*	~ 40 hours (24h target for operations)
Desat. time	~ 10 sec
* Including allocated 4 mNms momentum storage for GG compensation and slew manoeuvering.	

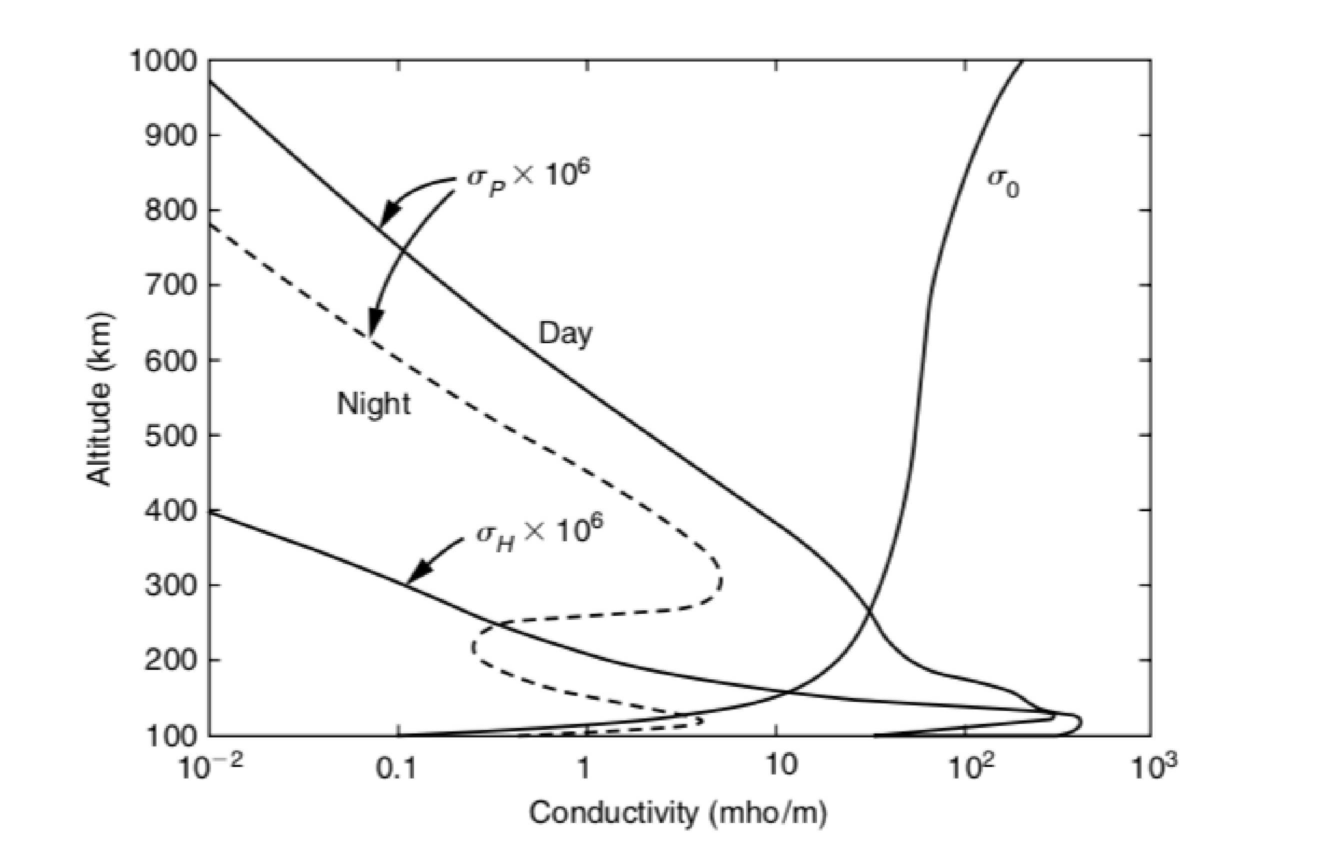


Backup slide - propulsion





Backup Slide - Hall Current



With courtesy of M. Kelly

- Pedersen and Birkeland currents are still contributing however
- Hall currents are of minor importance

Backup Slide - Spherical Harmonics 1

- Spherical harmonics are a series of special functions defined on the surface of a sphere
- Solution to the Laplace equation:

$\nabla \times \boldsymbol{B} = 0 \rightarrow \boldsymbol{B} = -\nabla U$,

where U is the scalar potential.

$\nabla \cdot \boldsymbol{B} = 0 \rightarrow \nabla^2 U = 0$ (Laplace equation)

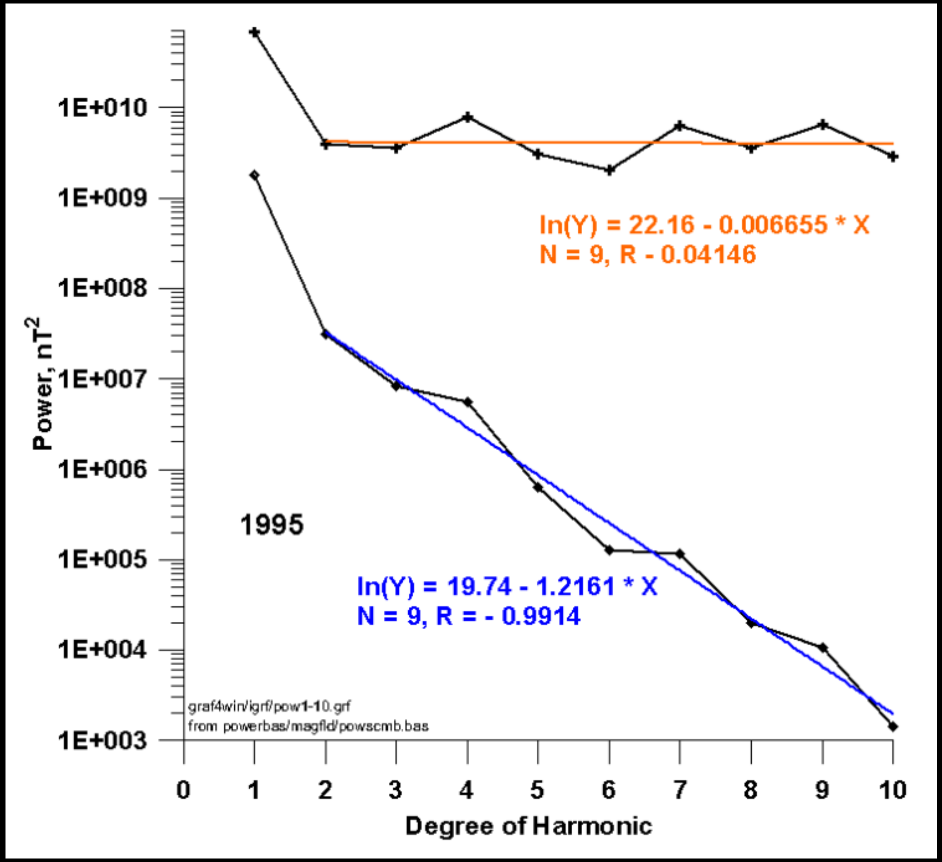
There are two types of solutions:

- potential U_i due to sources internal to the Earth $(r < R_E)$

- potential U_e due to sources external to the Earth $(r > R_E)$

such that $U = U_i + U_e$.

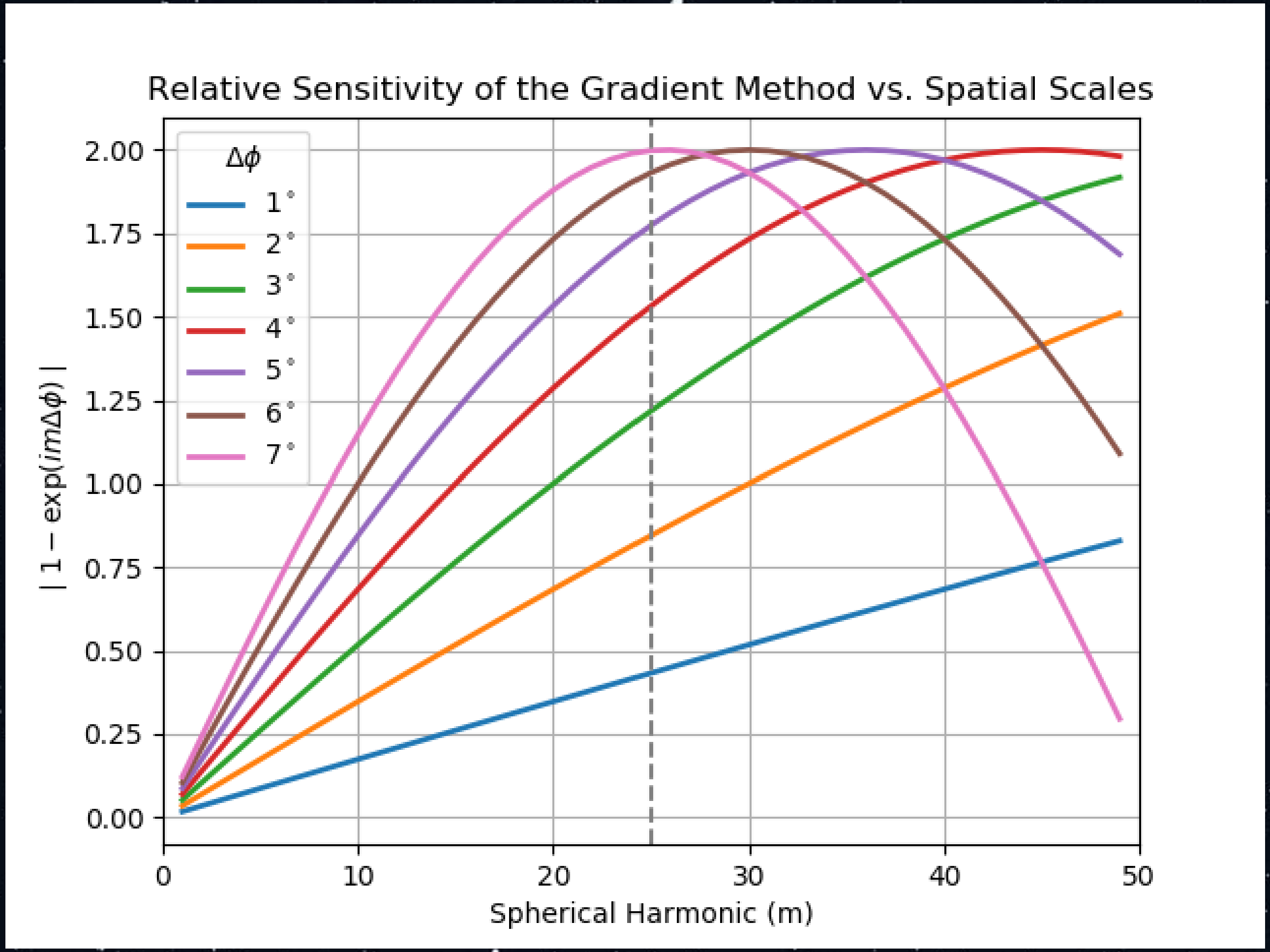
Backup Slide - Spherical Harmonics 2



- Power of Earth’s 1995 field as a function of harmonic degree. shown for surface field (blue) and CMB field (orange)

With courtesy of C. Harrison

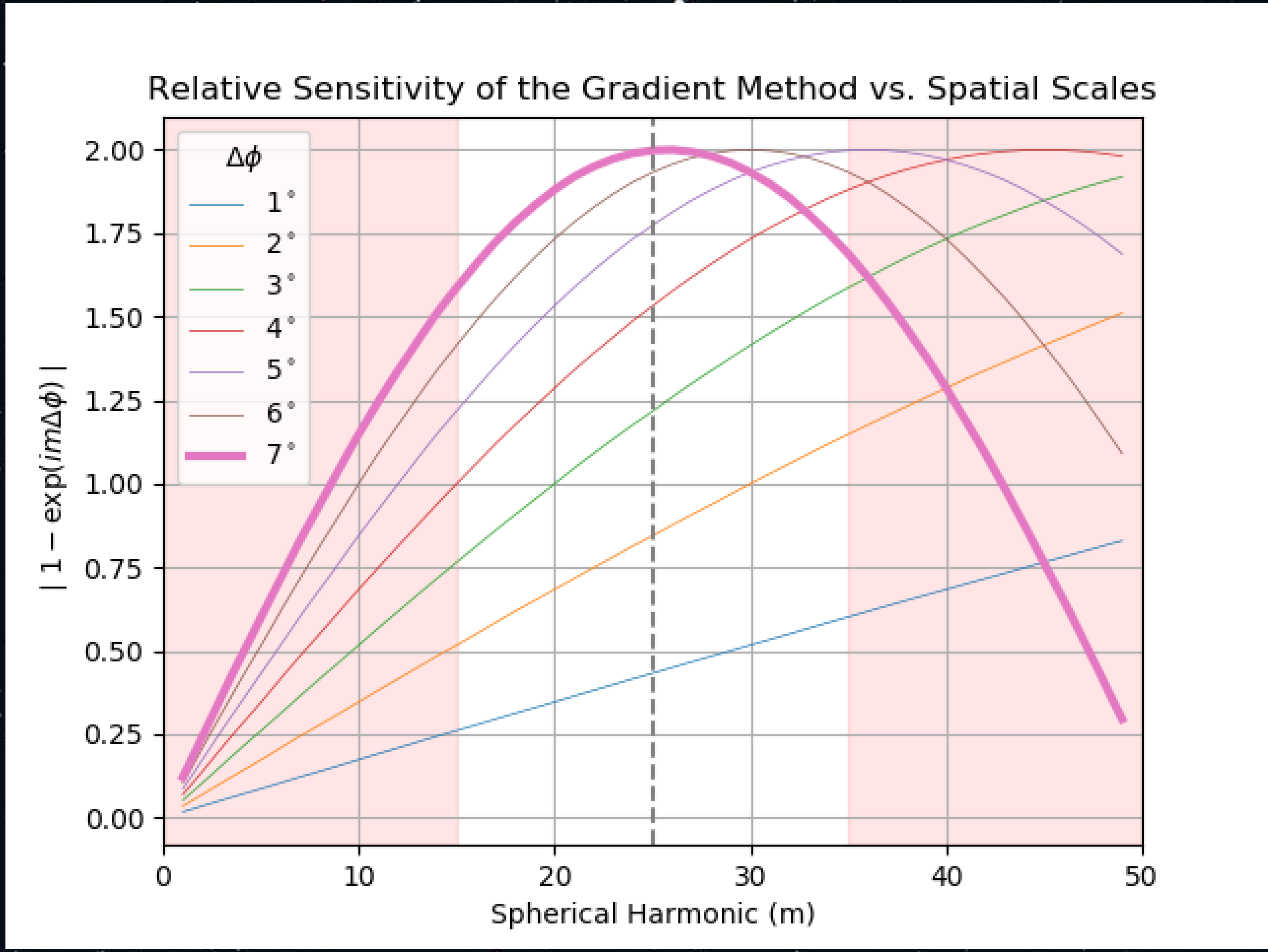
Backup Slides - Spherical Harmonics 3



Measure core dynamics to degree m = 25

→ Satellite separation of 7° horizontally

Backup Slides - Spherical Harmonics 4



Measure core dynamics to degree m = 25

→ Satellite separation of 7° horizontally

= 860 km (time separation ~2 min)

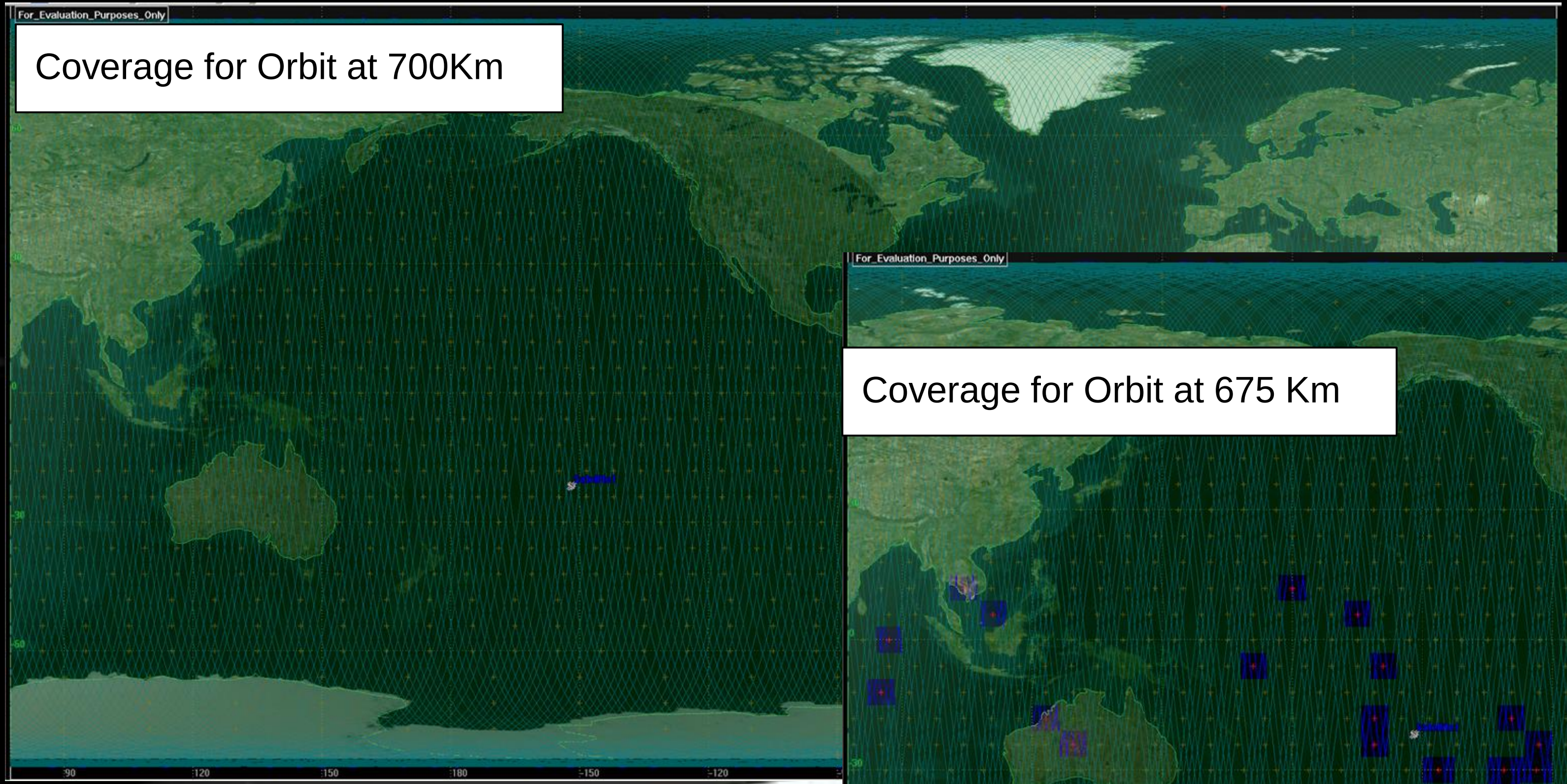
Backup Slide - Mass Budget

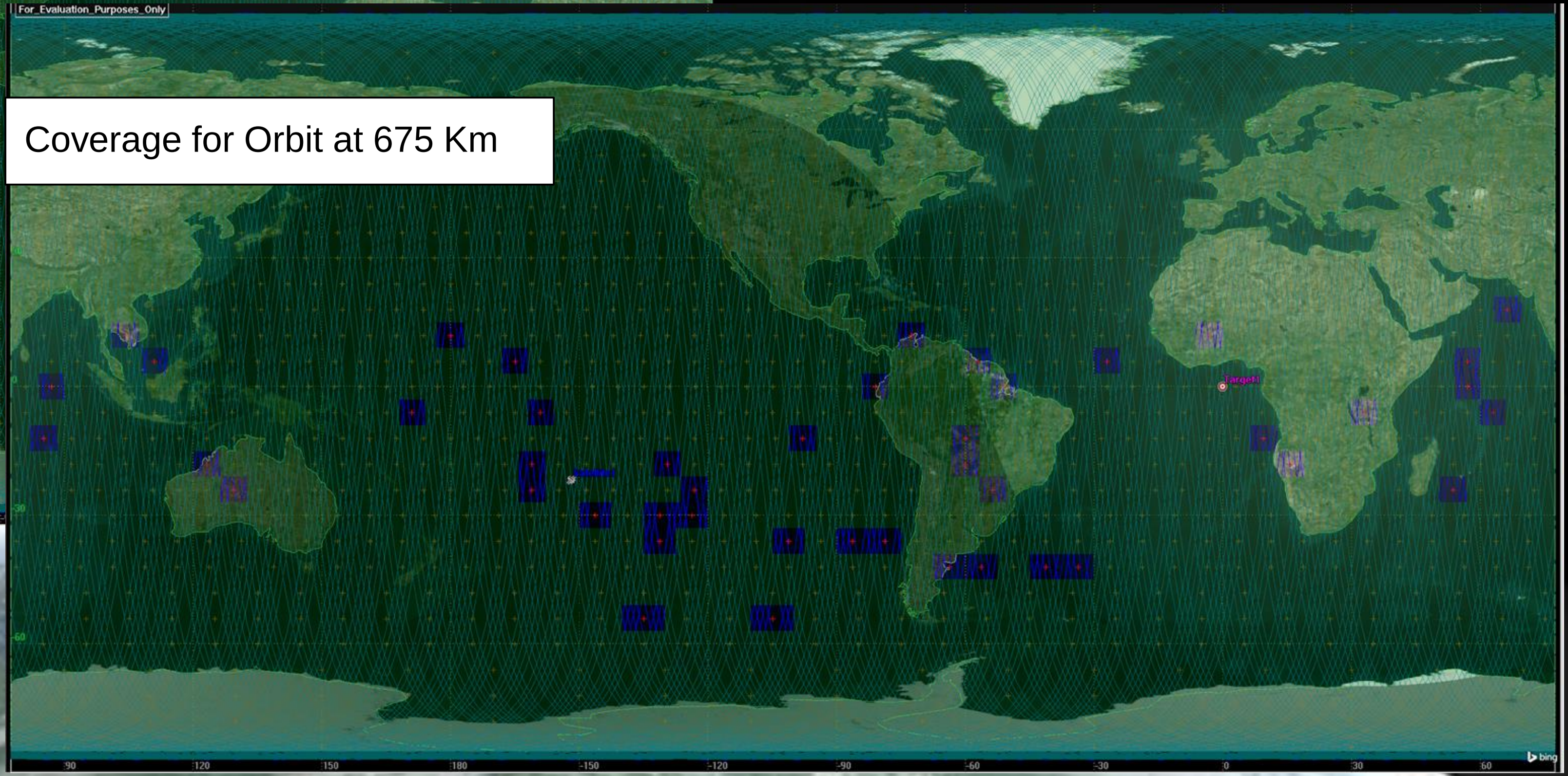
Subsystem	Element	Units	Mass (kg)	Total Mass (kg)	Margin	Final Mass (kg)
ADCS	Magnetorquer	4	0,176	0,464	5%	0,487
	On-board computer	1	0,010			
	Reaction wheel	4	0,192			
	Star tracker	2	0,080			
	Sun sensor	2	0,006			
Electrical	Battery	1	0,335	1,545	5%	1,622
	PCU	1	0,074			
	Solar cell	40	0,792			
	Voltage regulated buses	NA	0,344			
Payload	Boom	2	2, 000	2,675	20%	3,210
	Scalar Magnetometer	1	0,300			
	VFM	1	0,375			
Propulsion	Propellant	1	1,244	7,500	15%	8,395
	Tank	1	0,456			
	Thruster	1	5,600			
Structure	Frame	1	2,000	2,000	20%	2,400
Telecommunications	S-BAND Antenna	1	0,064	0,253	10%	0,278
	S-BAND Transceiver	1	0,075			
	UHF Antenna	1	0,090			
	UHF Transceiver	1	0,024			
Thermal	Heater	1	0,005	0,257	10%	0,283
	MLI	NA	0,153			
	Temperature sensors	2	0,080			
	Thermistors	2	0,024			
Total Mass	16,80 kg					
System margin	20%					
Final mass	20,16 kg					

Backup Slide - TRL

Subsystem	Element	TRL
ADCS	Magnetorquer	7
	On-board computer	9
	Reaction wheel	9
	Star tracker	9
	Sun sensor	9
Eletrical	Battery	9
	PCU	7
	Solar cell	9
	Voltage regulated buses	9
Payload	Boom	6
	Scalar Magnetometer	4
	VFM	9
Propulsion	Propellant	9
	Tank	6
	Thruster	9
Structure	Frame	7
Telecommunications	S-BAND Antenna	9
	S-BAND Transciever	7
	UHF Antenna	7
	UHF Transceiver	7
Thermal	Heater	9
	MLI	7
	Temperature sensors	8
	Thermistors	8

Orbit -Backup Slide



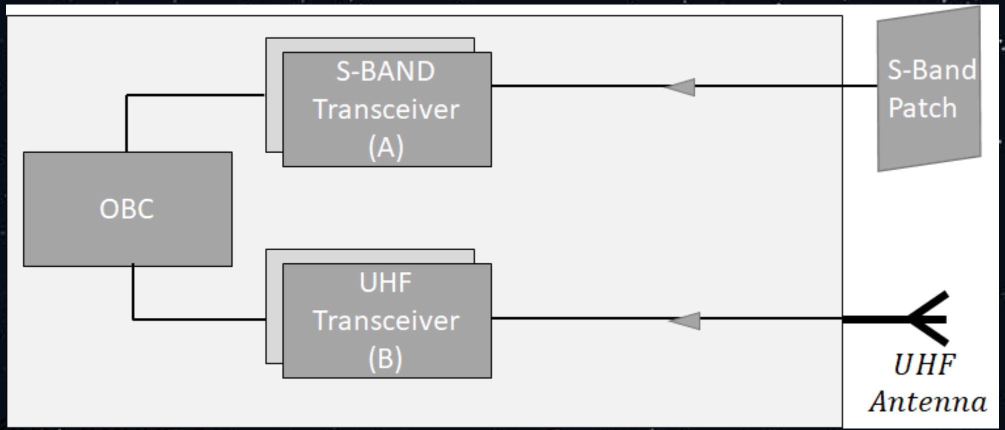


Communications - Backup Slide

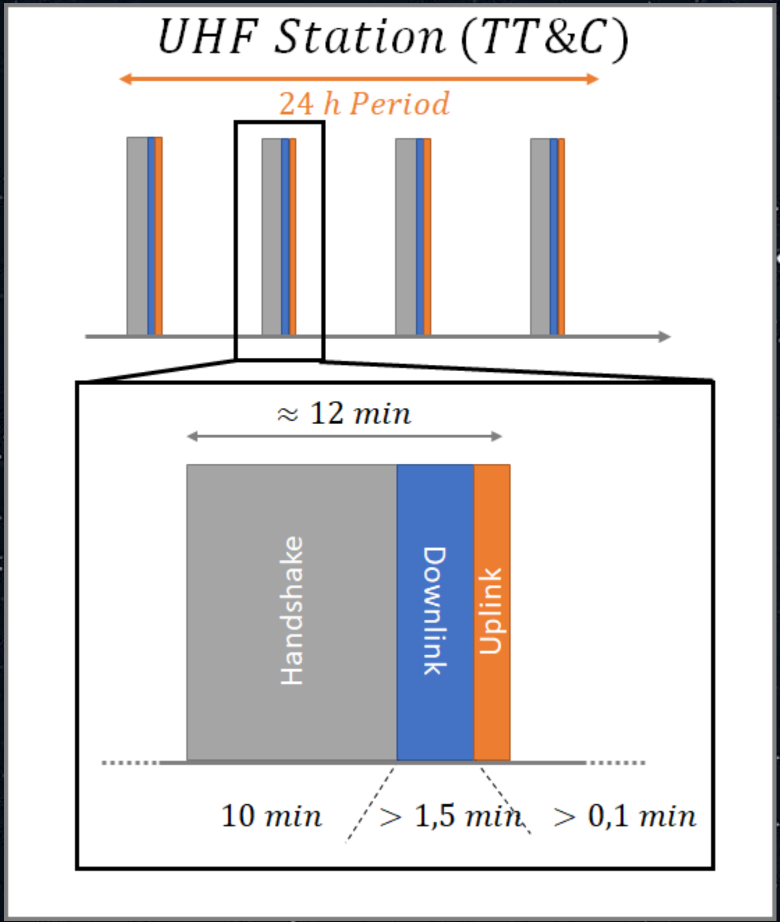
Data Production

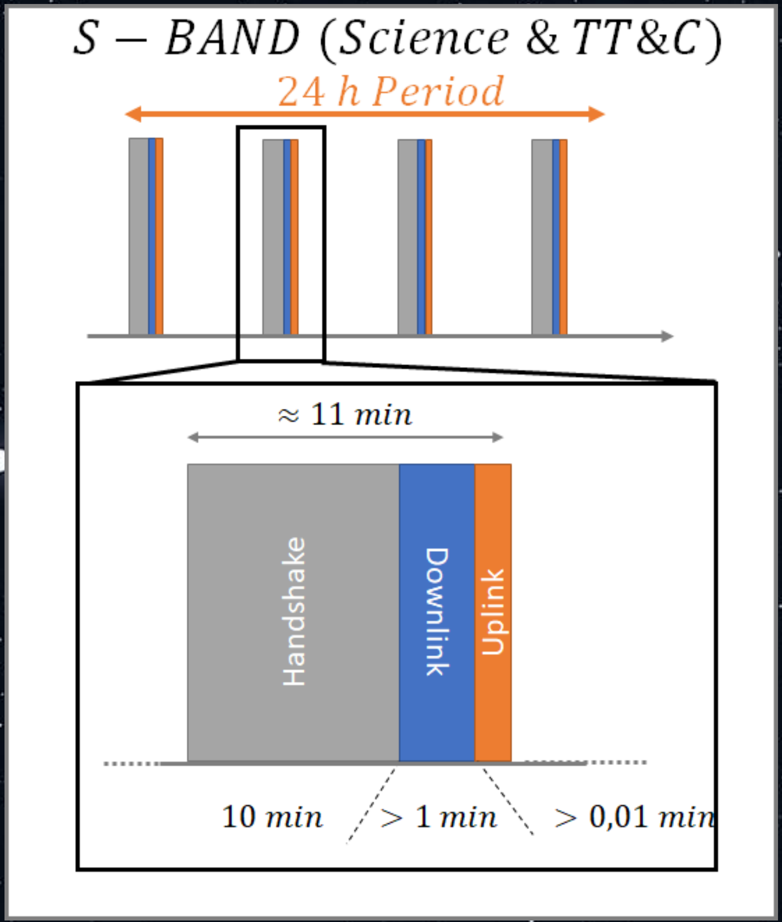
Data Generation	Packet Size	Mes Rate (Hz)
Scalar Mag. 1 (bit/s)	32	1
Mag. 2 (bit/s)	96	1
TT&C (bit/s)	60	1
Total (bit/s)	225.6	20% Margin

Data Output		Margin
Mbit/Day/Sat	23	20%
Mbit/Day Const	117	
Days to Mem Sat	1140	20%



Communications (Backup Configuration)





Spacecraft Operational Modes- Back-up

- Measurements require magnetic cleanliness; not possible during:
  - orbit maintenance (monthly)
  - reaction wheel desaturation (weekly)

- All measurement downtimes will be coordinated with the PI and scientific planning team to minimize impact on long-term science goals
  - e.g.. reaction wheel desaturation over poles