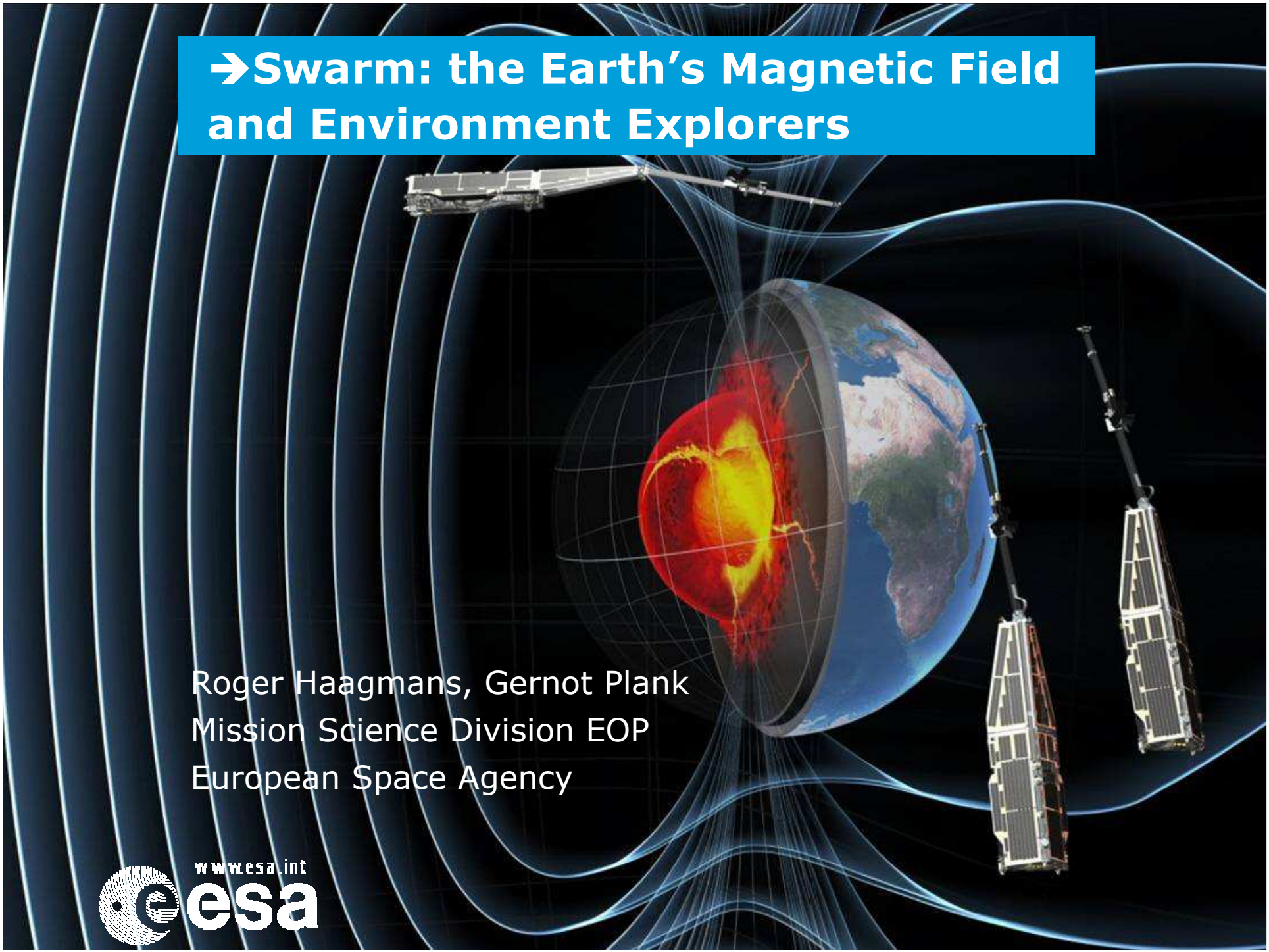
➔Swarm: the Earth's Magnetic Field and Environment Explorers

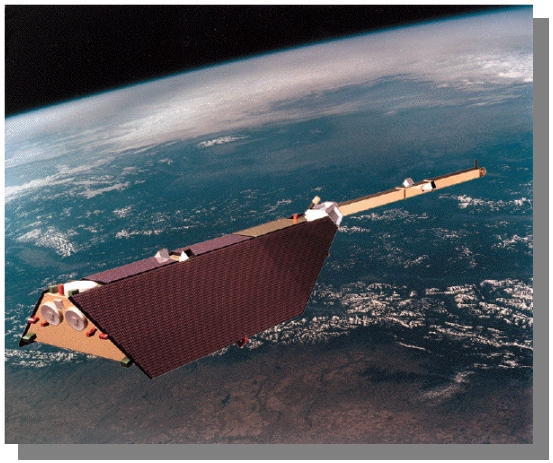


Roger Haagmans, Gernot Plank
Mission Science Division EOP
European Space Agency

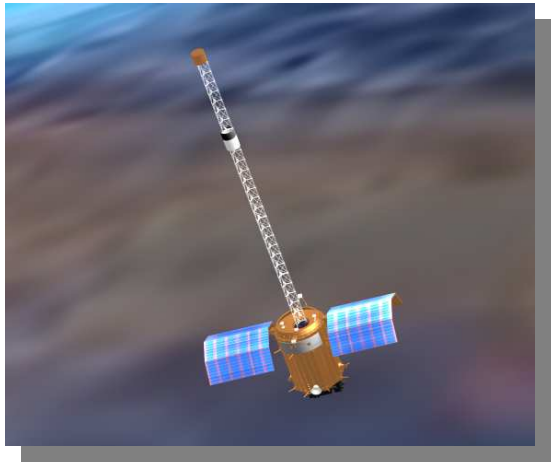
www.esa.int
esa

Results from the Decade of Geopotential Research …

ØRSTED [23/2/1999 -]

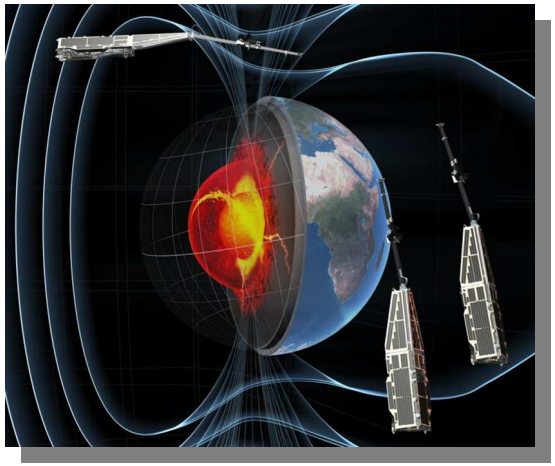


CHAMP [15/7/2000 -]



SAC-C [10/12/2000 -]

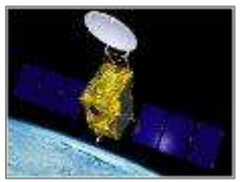
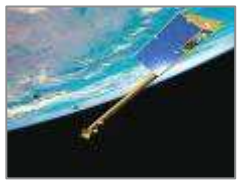
a very successful decade with a virtual constellation of national magnetic field missions to the ***near-future prospects*** of ……



Swarm [end 1st half 2011 - 2015]

ESA's Living Planet Programme

Earth Explorer
Research driven

- Core Missions
  - 
    GOCE
    March 17th 2009
  - 
    ADM-Aeolus
    2011
  - 
    EarthCARE
    2013
- Opportunity Missions
  - 
    CryoSat 2
    2009
  - 
    SMOS
    2009
  - 
    Swarm
    2011

Earth Watch
Operational Service driven

- Operational Meteorology
  - **Meteosat**
  - **MSG**
  - **EPS (MetOp)**
  - **MTG**
  - **Post EPS**
- GMES
  - **Sentinel 1**
  - **Sentinel 2**
  - **Sentinel 3**
  - **Sentinel 4**
  - **Sentinel 5**

www.esa.int/livingplanet

BIOMASS
CoReH2O
PREMIER

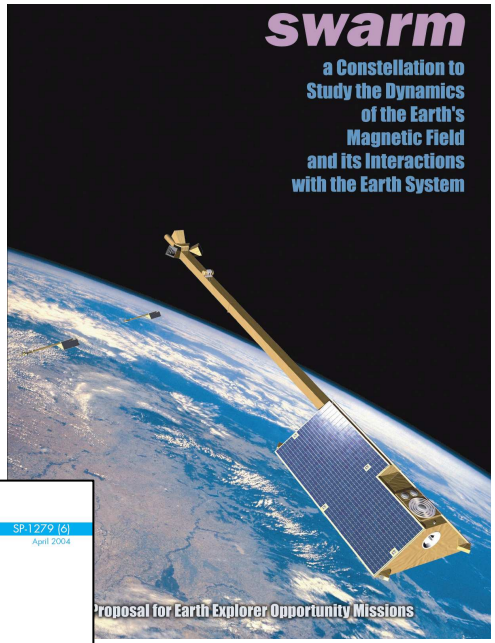
+ 3 Candidate Core Explorers

? **Earth Explorer 7**
2016

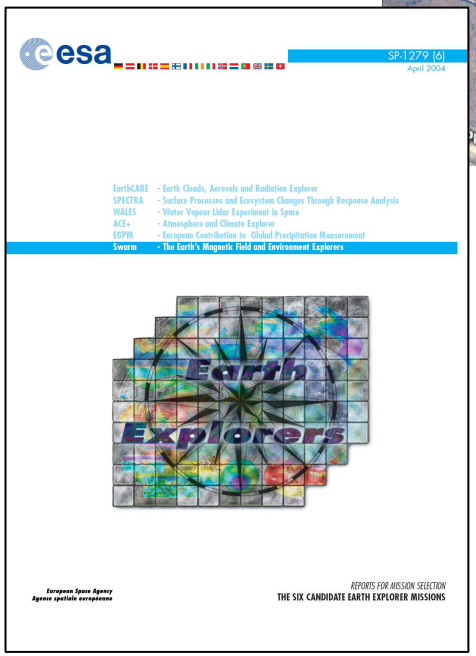
Swarm Background

- Lead proposers and team:
  - Eigil Friis-Christensen DNSC, Denmark
  - Hermann Lühr GFZ-Potsdam, Germany
  - Gauthier Hulot IPGP, France
  - team of 27 institutes worldwide

- selected for full implementation at User Consultation Meeting, Frascati, 2004
  - Phase A 2003/2004
  - Phase B 2005/2007
  - Phase C/D 2007 – …
  - Fifth Earth Explorer Mission
  - Constellation of 3 satellites
  - Launch mid-2011
  - www.esa.int/esaLP/LPswarm.html

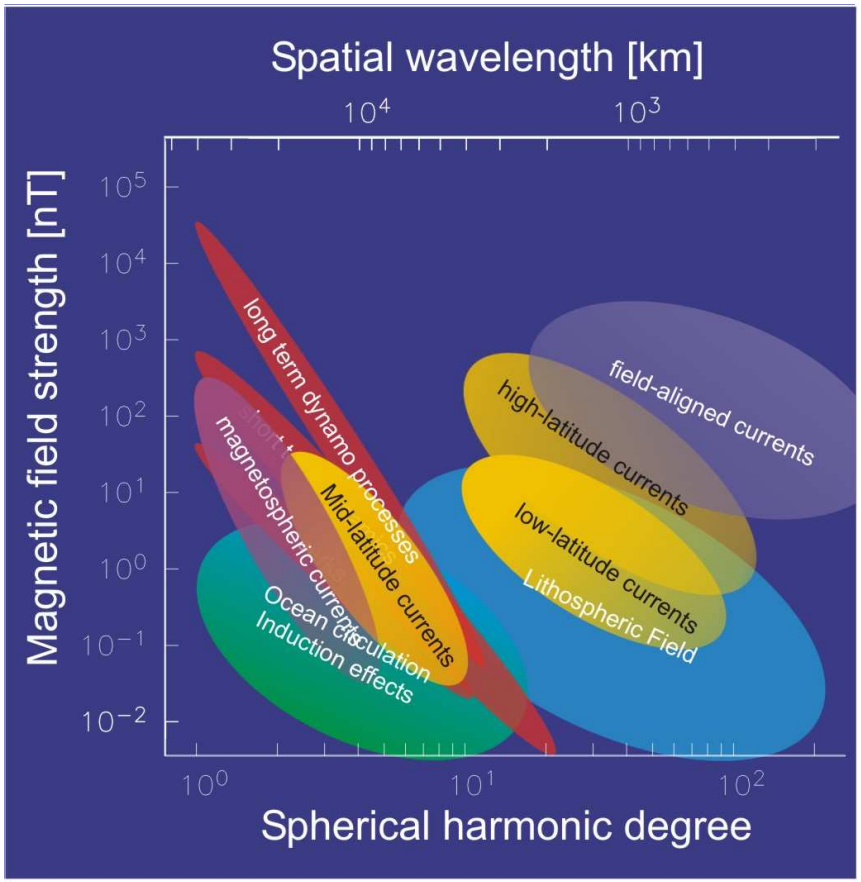


2002 Proposal to ESA



2004 Report for Mission Selection

Magnetic Field Contributions



$10R_E$

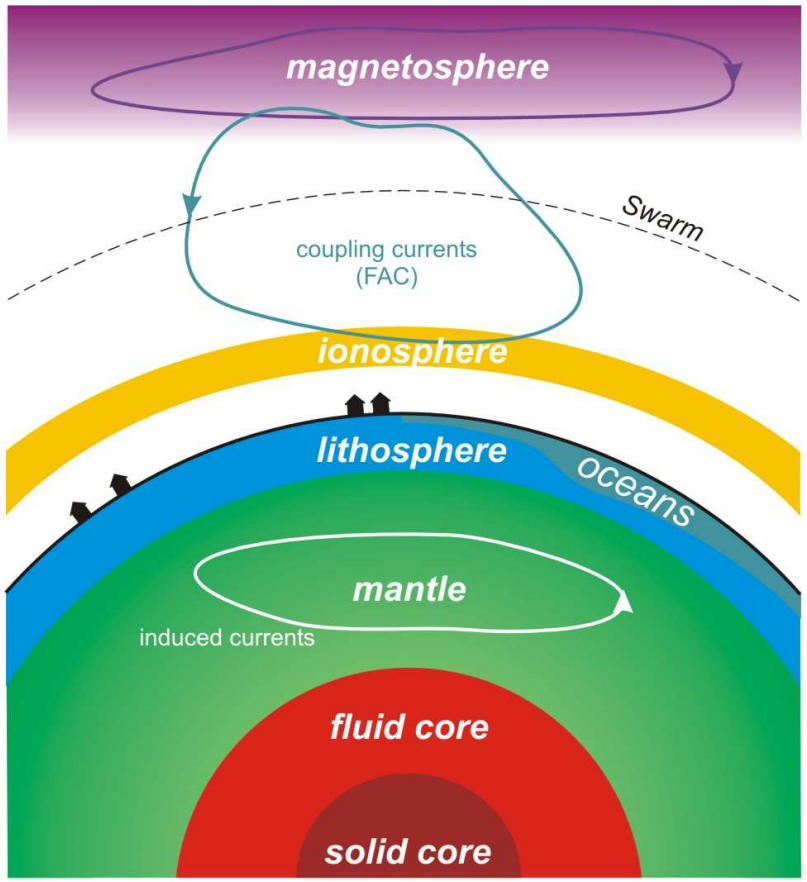
R_E + 450km

R_E + 110km

R_E

3485km

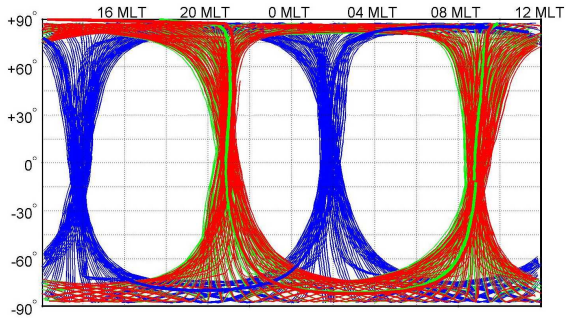
1233km

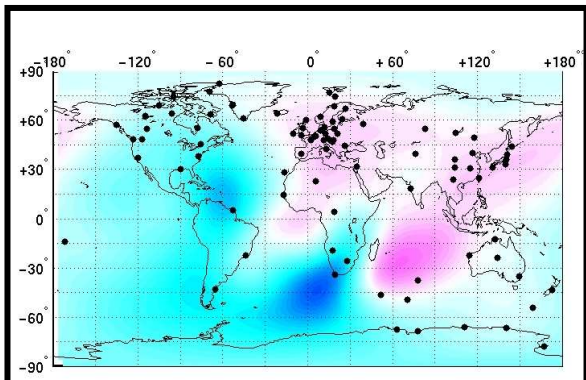


R_E = Earth radius ~ 6371km

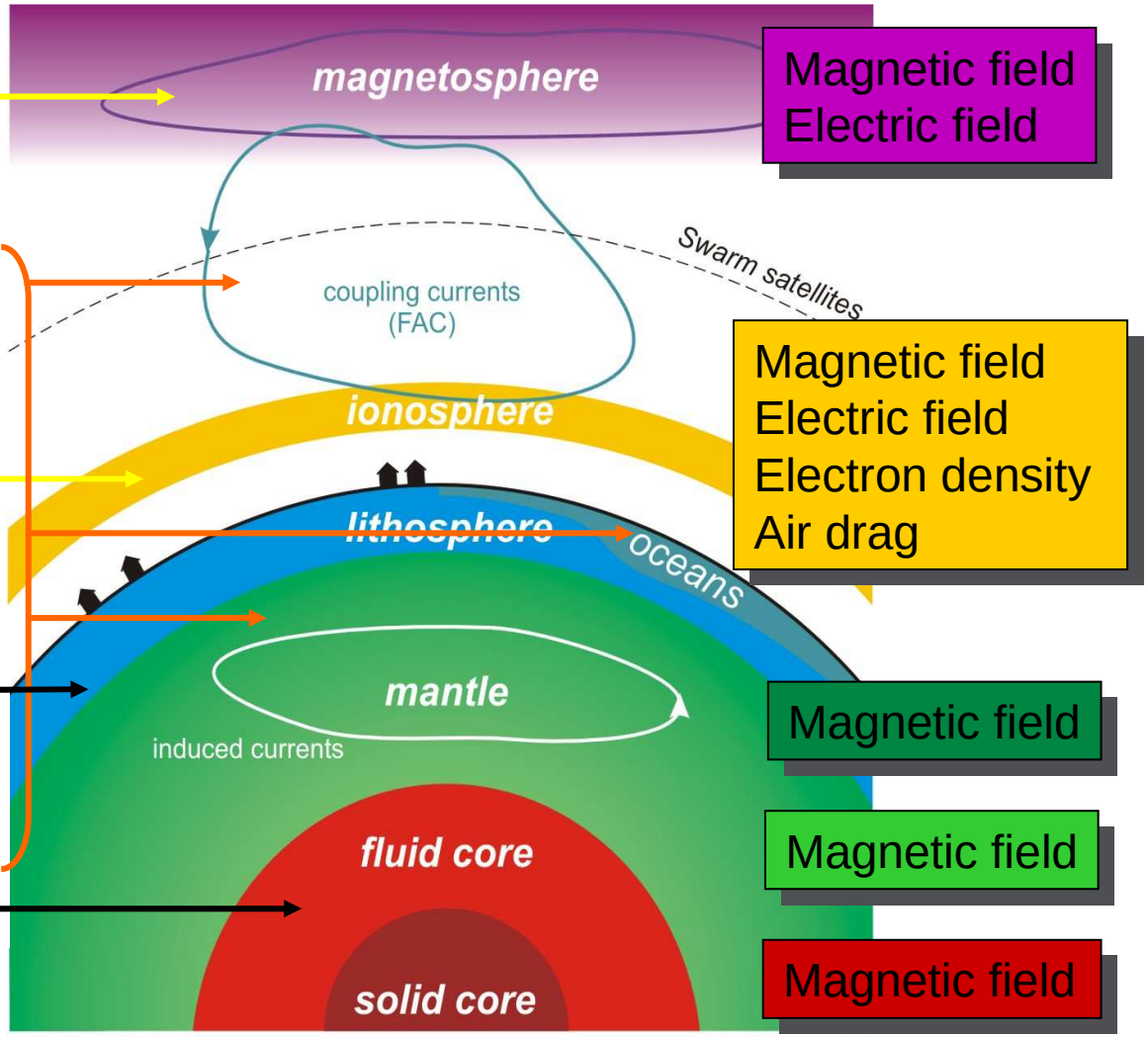
Sampling, aliasing and observations

Sun- driven





Earth-fixed



Magnetic field
Electric field

Magnetic field
Electric field
Electron density
Air drag

Magnetic field

Magnetic field

Magnetic field

Mission Requirements

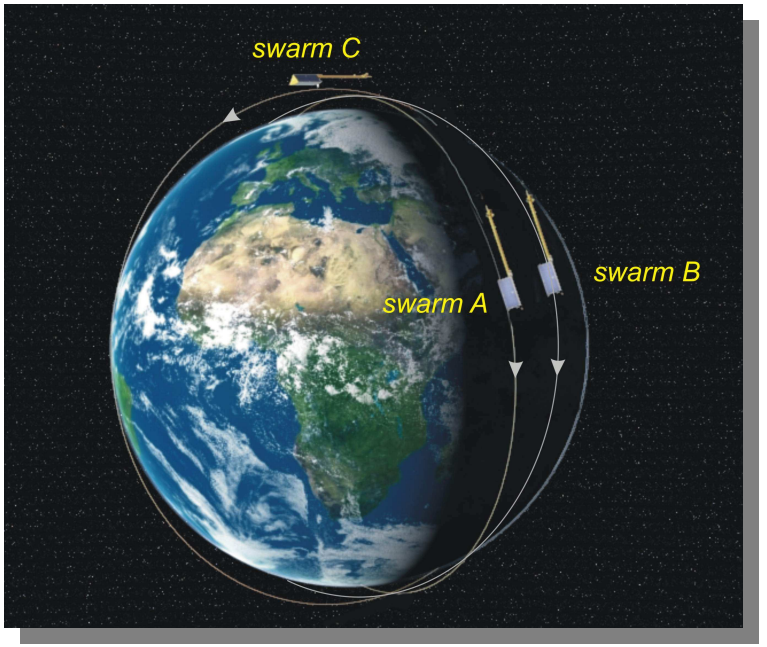
Single satellite

- Magnetic field magnitude and vector components
- Electric field vector components
- Electron density, Ion/Electron Temp.
- Air drag
- Position, attitude and time

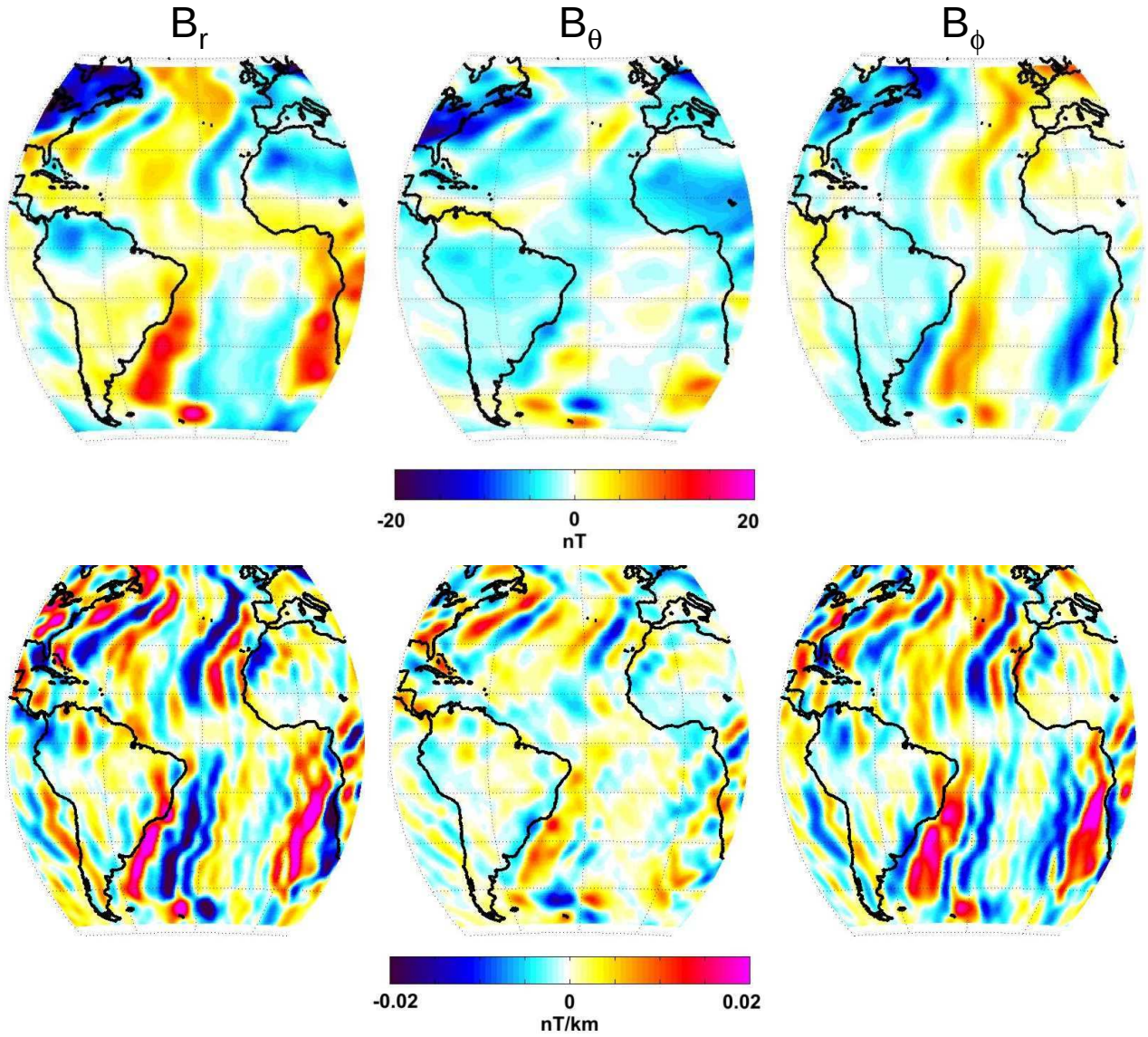
accurate enough at satellite altitude to measure the most demanding signals at finest spatial and fastest required temporal sampling

Constellation

- 3 satellites:
  - 2 side-by-side in low orbit
  - 1 in higher orbit
- three orbital planes with two different near-polar inclinations
- Near polar orbits for global coverage



Magnetic Field Gradient at 400 km altitude

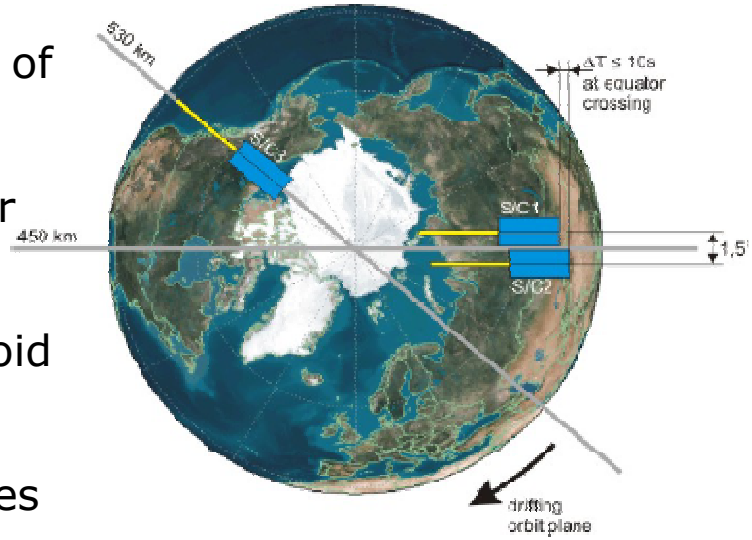


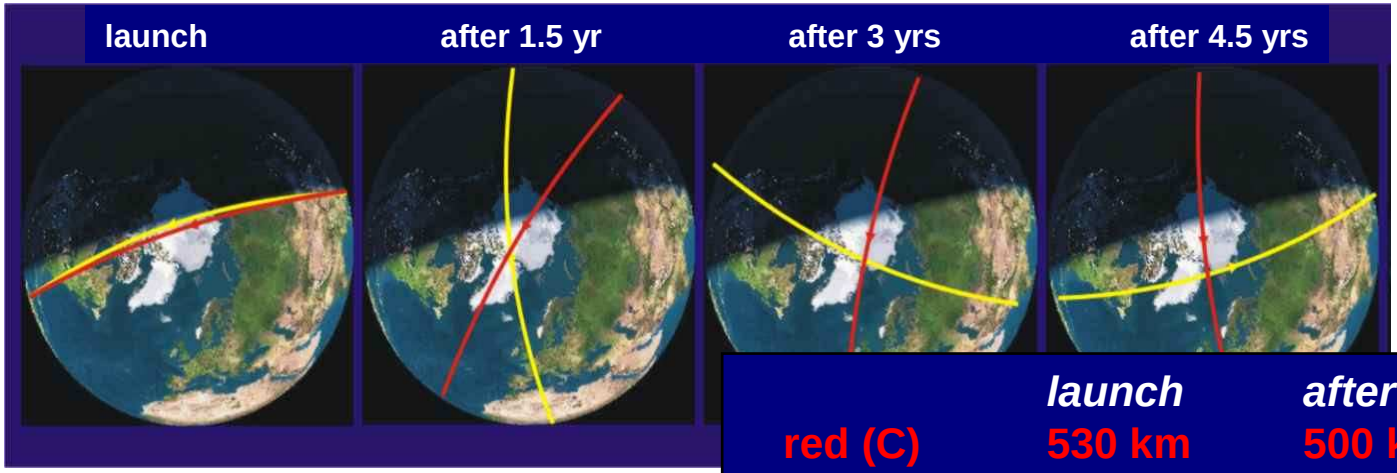
Magnetic field

East-West Gradient of Magnetic field

Swarm Optimised Constellation

- 4 years operational phase
- Low altitude down to 300km (or lower) and pair of satellites for "zoom" on crustal signal
- Altitude difference: higher (app. 530km) & lower satellites (app. 490km)
- 24 hours LT coverage within 7-10 months to avoid seasonal or yearly periods (near polar)
- Inclination difference: drift between orbital planes towards 9 hours LT





	launch	*after 4.5 years*
red (C)	530 km	500 km
yellow (A,B)	490 km	300 km

Swarm scientific objectives

Objectives: the Earth

- Studies of core dynamics, geodynamo processes, and core-mantle interaction,
- Mapping of the lithospheric magnetisation and its geological interpretation,
- Determination of the 3-D electrical conductivity of the mantle,
- Identifying the ocean circulation by its magnetic signature

Unique view "inside" the Earth from space for core, mantle & crust

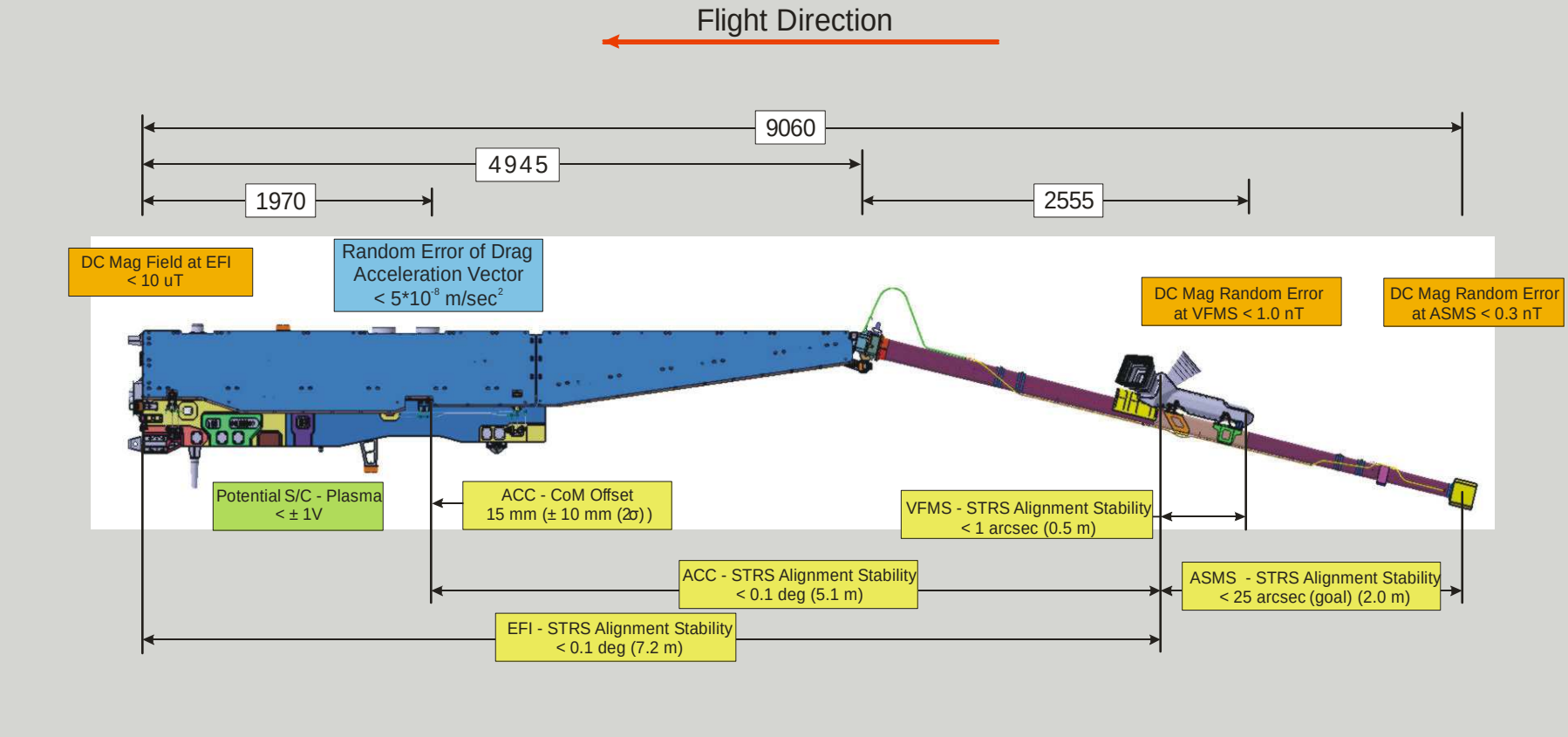
correction

Objectives: near-Earth EM Environment

- Investigation of electric currents flowing in the magnetosphere and ionosphere,
- Quantifying the magnetic forcing of the upper atmosphere

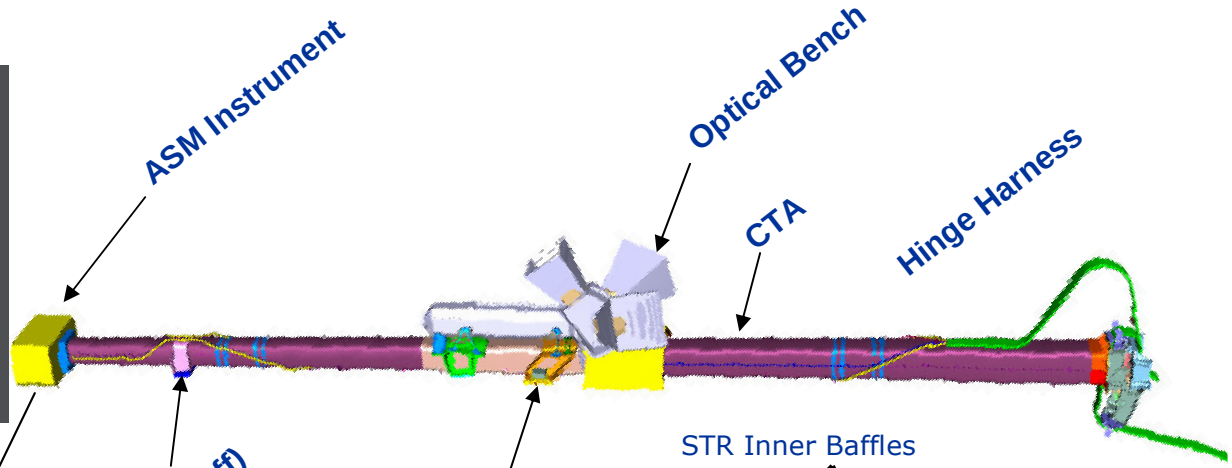
Sun's influence within Earth system

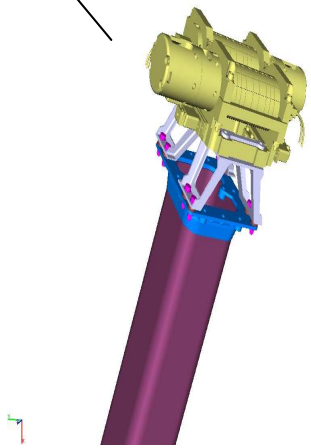
Configuration & Performance Requirements

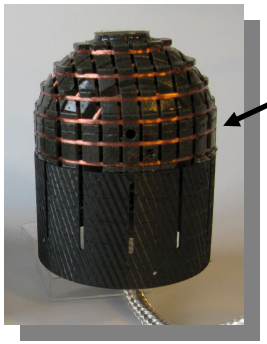


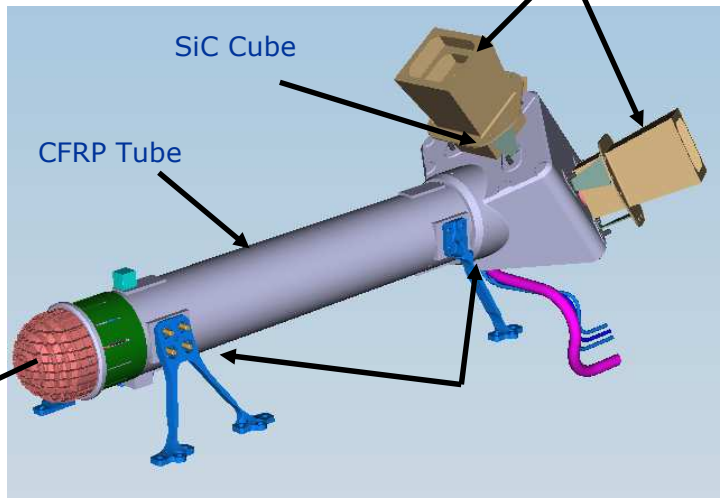
500kg incl. 99kg fuel; ~1.0 m² cross section 4 years lifetime

Instrument Accommodation: ASM & VFM/STR





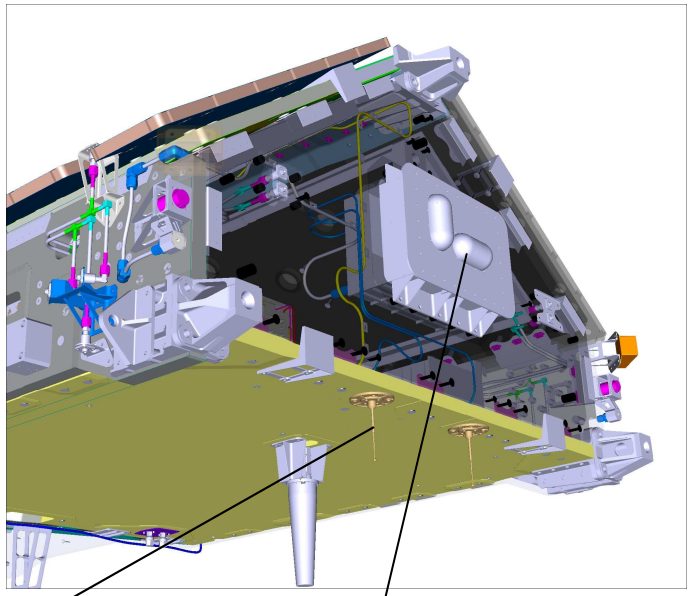


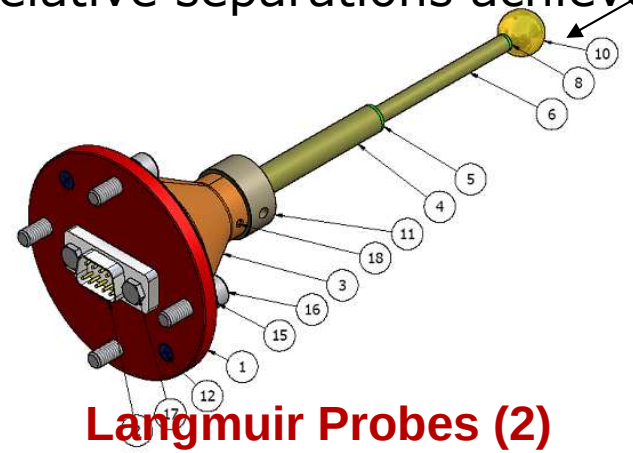


Excluding Thermal Cover

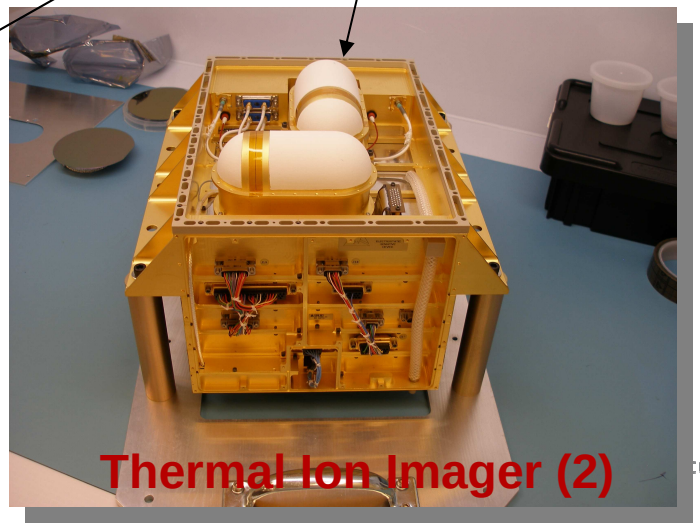
Instrument Accommodation: EFI

- EFI located on Ram panel
  - Electronics thermal control by radiation to internal environment
  - Sensors clear Fields of View and orientated in flight direction
- Langmuir Probes on Nadir
  - Relative separations achieved





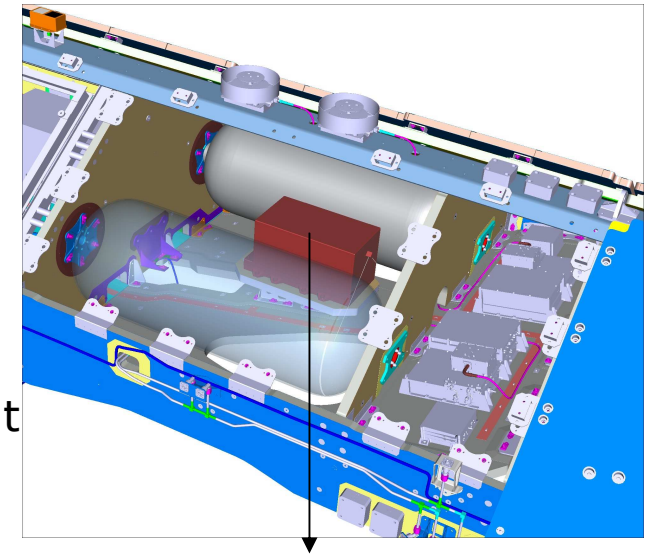
Langmuir Probes (2)

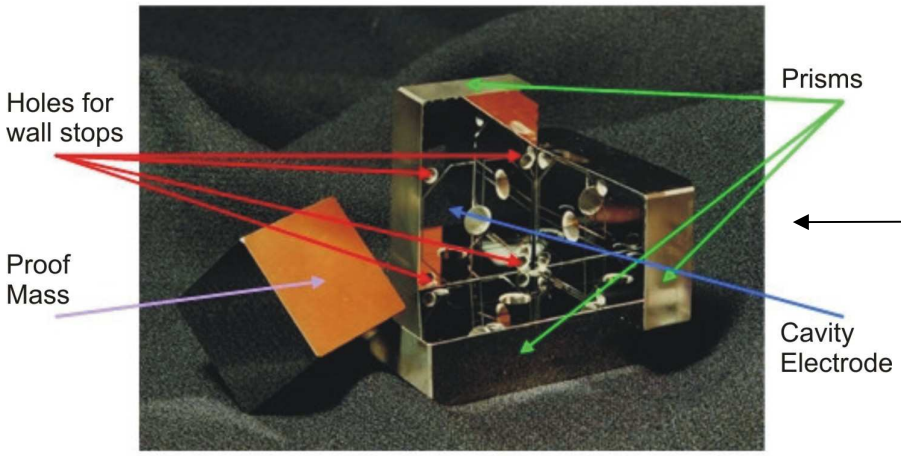


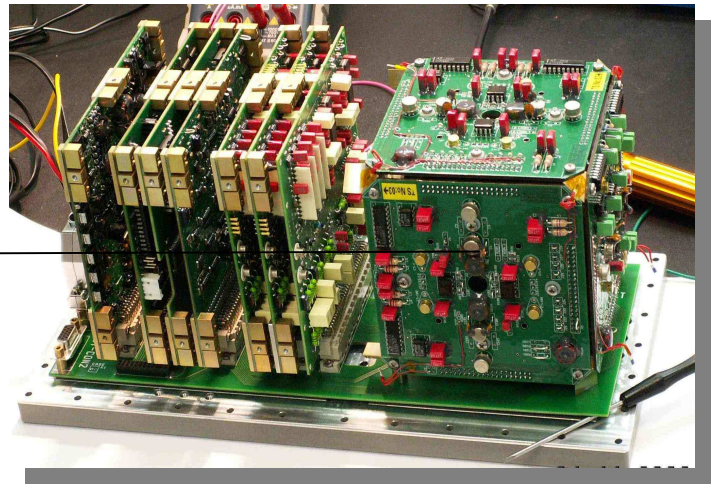
Thermal Ion Imager (2)

Instrument Accommodation: ACC

- Accelerometer
  - Aligned to satellite CoG through lifetime
    - Located between fuel tanks
    - Replaceable platform for late adjustment
    - Satellite balance masses to adjust CoG
  - Alignment cube sightlines through Tank cut-out
  - Thermo-elastic stable structure

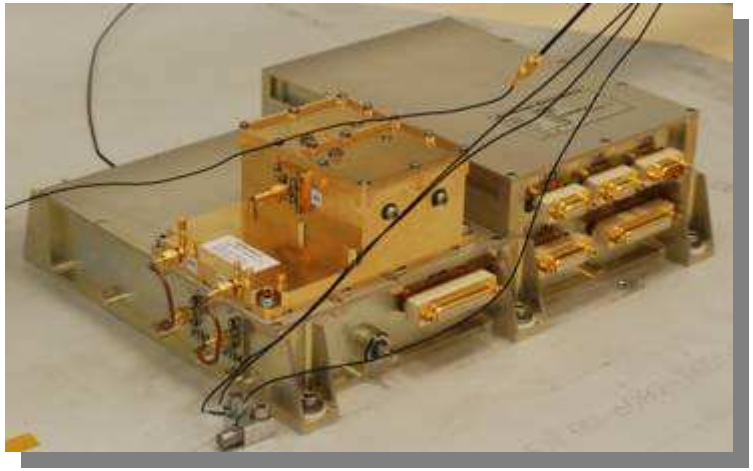


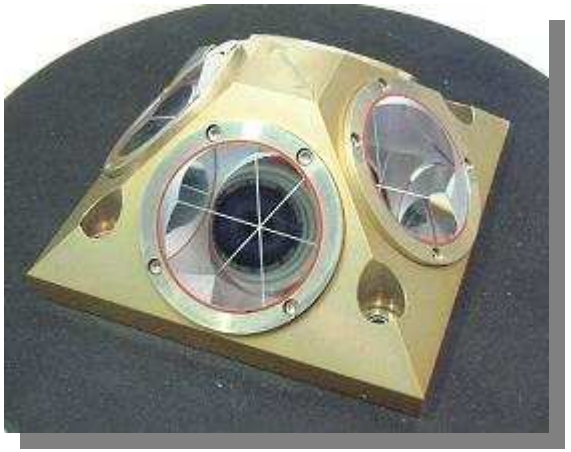




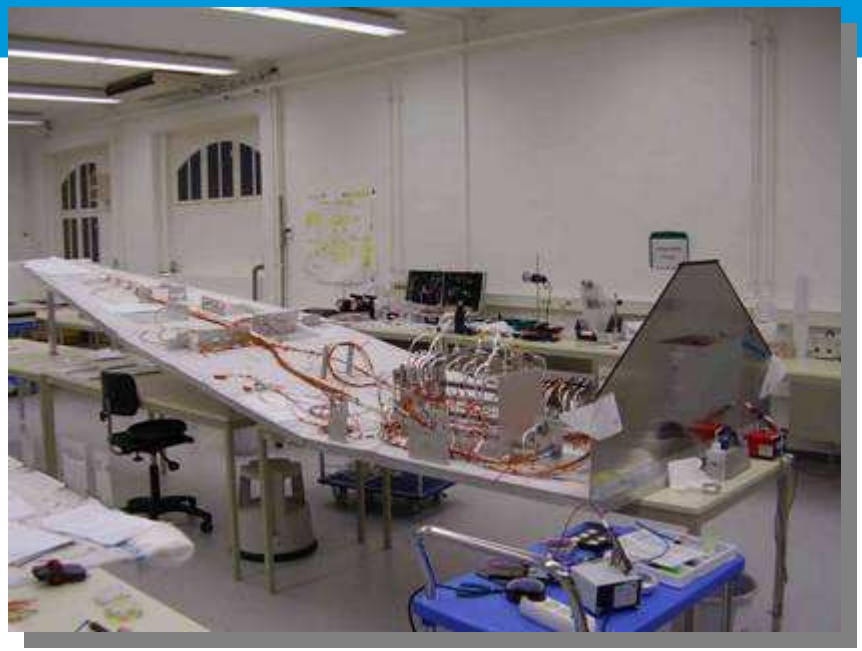
Instrument Accomodation: GPSR & LRR

- GPS electronics inside body
- GPS antennae on Zenith side of body
- LRR on Nadir side of body





Swarm Hardware



Swarm STM

Swarm Data Hierarchy

Level 0	**Raw measurements and housekeeping data** (from instruments and spacecraft)
Level 1b	**Calibrated and validated instrument data**, including Magnetic field magnitude Magnetic field vector Ion drift velocity vector Electric field vector Plasma density Ion and electron temperature Acceleration vector, linear and rotational Position, velocity and attitude of spacecraft
Level 2	**Validated scientific data and models**, including Magnetic field models (internal and external), & info on currents. Accelerometer data (incl. calibration parameters) Air density and winds

Studies until today

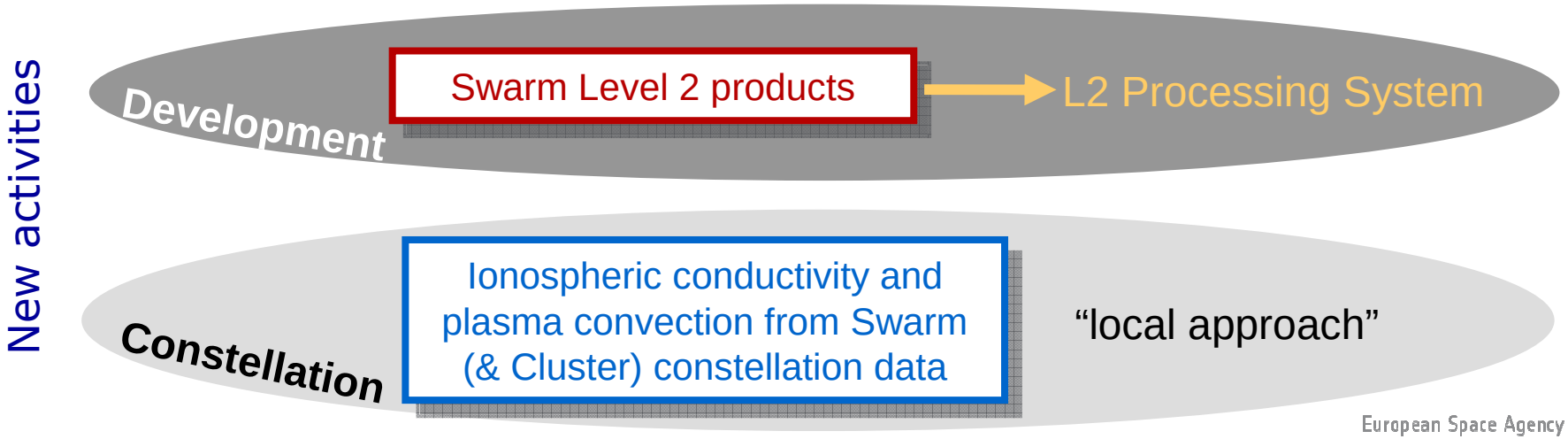
Issue	Activity	Result	
"optimised constellation for magnetic field estimation"			
"Ideal" Constellation and Mission Impact	Closed loop simulation: recovery of models related to primary objectives	3 satellites concept as baseline	✓
Improved Comprehensive magnetic field Inversion Analysis	Higher data sampling rate in measurement frame, lower pair "gradients", multi-satellite alignment	Gradients & multi-satellite alignment improve models	✓
"constellation and multi-instrument analysis for currents estimation"			
Impact of joint use electric and magnetic field data	Coupled model simulation: check different current regimes & develop approaches for analysis (high-latitudes)	FAC estimation Horizontal currents Activity Indices	✓
Ionospheric current quantification and modelling for improved magnetic and electric field analysis.	CTIP model for multi-instrument observation simulation and comparison (CHAMP). In addition TEC from GNSS and plasma buble methods defined.	Single satellite current procedure TEC & buble procedure	✓

Studies until today

Issue	Activity	Result	
"3D-Mantle Conductivity"			
Retrieving 3D Mantle conductivity from Swarm	Development and testing of different approaches for estimating 3D Mantle conductivity	Independent methods developed and tested on simulated data	✓
Benchmarking 1D and 3D Mantle conductivity methods for Level 2	Testing and validating 1D and 3D methods in controlled experiments	Error assessment of methods for simulated test cases	✓
""Drag, air density and wind incl. link to magnetic field"			
Accelerometer necessary for air drag product ?	Air drag from single satellite precise orbit analysis against accelerometer data	Complementary information	✓
Air density models derived from multi-satellite drag observations.	Air density & wind estimation procedures improved for CHAMP and GRACE and simulations done for Swarm. Compared to models and correlated with magnetic field signatures.	Existing procedures improved. Error assessment performed	✓

Studies until today and future activities

Issue	Activity	Result	
	"miscellaneous"		
Quantify role of ocean circulation on performance	Forward modelling ocean circulation model effects on satellite data	Impact demonstrated	✓
Preparation of possible Swarm Level 2 data processing.	Potential Level 2 products and processing chains defined	Starting point for developing Level 2	✓



Science Community Involvement

- First international Science Meeting (Nantes, May 2006) Left
- Second International Science Meeting (Potsdam, June 2009) Right

- Special Issue of Earth, Planets and Space on Swarm Vol. 58 (No. 4), pp. 349-496, 2006
  http://www.terrapub.co.jp/journals/EPS/toc/5804.html

- Info and study reports etc.:
  http://www.esa.int/esaLP/LPswarm.html

UK Science Community Involvement

- Large(st) national user community in ESA member states
- UK community expertise available for all aspects of the mission
- UK teams involvement:
  - early proposal writing
  - Mission Advisory Group
  - various ESA studies
  - participation in ESA Swarm International Science meetings
- Excellent potential for supporting geophysical product validation and data exploitation for the Swarm mission

Thanks: EADS/Astrium, DTU Space, Leti, CNES, UoC, IRF, COMDEV, CSA, VZLU for material used in this presentation

Cluster and Swarm: Opportunities for a better understanding of the Earth System?