# e.motion
# ein Vorschlag für eine zukünftige Satellitenmission zur Bestimmung des zeitvariablen Erdschwerefeldes

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# Outline of Talk

1. Introduction
2. Science Requirements
3. Mission Assumptions
4. Technology
5. Conclusions

# Introduction

1. ESA Call for Proposals for Earth Explorer Opportunity Mission EE-8 in October 2009.
2. Boundary Conditions:
   - Ceiling 100 M€ industrial costs for space and mission specific ground segment (excluding launcher, operations, generic ground segment, L2 processor, ESA internal costs).
   - Selection of up to 3 mission candidates. Then feasibility studies (Phase-A). Then review and selection by ESAC with support by the Agency. Following this the selected mission will enter implementation (Phase B/C/D/E).
   - Full Proposal was due on 1. June 2010: Content: Scientific objectives, requirements and justification, Mission assumptions and technical requirements.
3. European (+ Canadian) Consortium from Science & Industry submitted full proposal named e.motion (**E**arth System **M**ass Transp**O**r**T** Miss**ION**).
4. All together more than 30 proposals were submitted. Evaluation is ongoing and decision will be announced by end of November.

# Introduction

**Lead Proposer:**

- Johnny Johannessen, NERSC, Bergen, Norway

**Proposal Coordination & Preparation:**

- Isabelle Panet, Thomas Gruber

**Science Proposal Team:**

- Cryosphere: J. Bamber, M. Horwath, B. Legresy, M. van den Broeke.
- Geodesy: R. Biancale, F. Flechtner, J. Flury, P. Gegout, J. Huang, A. Jäggi, P. Knudsen, J. Kusche, F. Migliaccio, R. Pail, M. Sideris, N. Sneeuw, P. Visser.
- Geophysics: M. Diament, R. Sabadini, I. Sasgen, T. van Dam, B. Vermeersen.
- Hydrology: A. Güntner, G. Ramillien, H. Savenije.
- Oceanography: H. Dobslaw, C. Hughes, M.H. Rio , D. Stammer, M. Thomas, P. Woodworth
- Technology: K. Danzmann, G. Heinzel, B. Sheard, S. Vitale.

**Industrial Proposal Team:**

- SpaceTech GmbH Immenstaad (STI), Germany: Coordination & Preparation.
- Office National d'Études et de Recherches Aérospatiales (ONERA), France: Technical Proposal Preparation Accelerometer.
- Thales Alenia Space Italoia (TAS-I), Italy, Proposal Review.
- Astrium GmbH – Satellites (ASTRIUM), Germany, Proposal Review

# Science Requirements

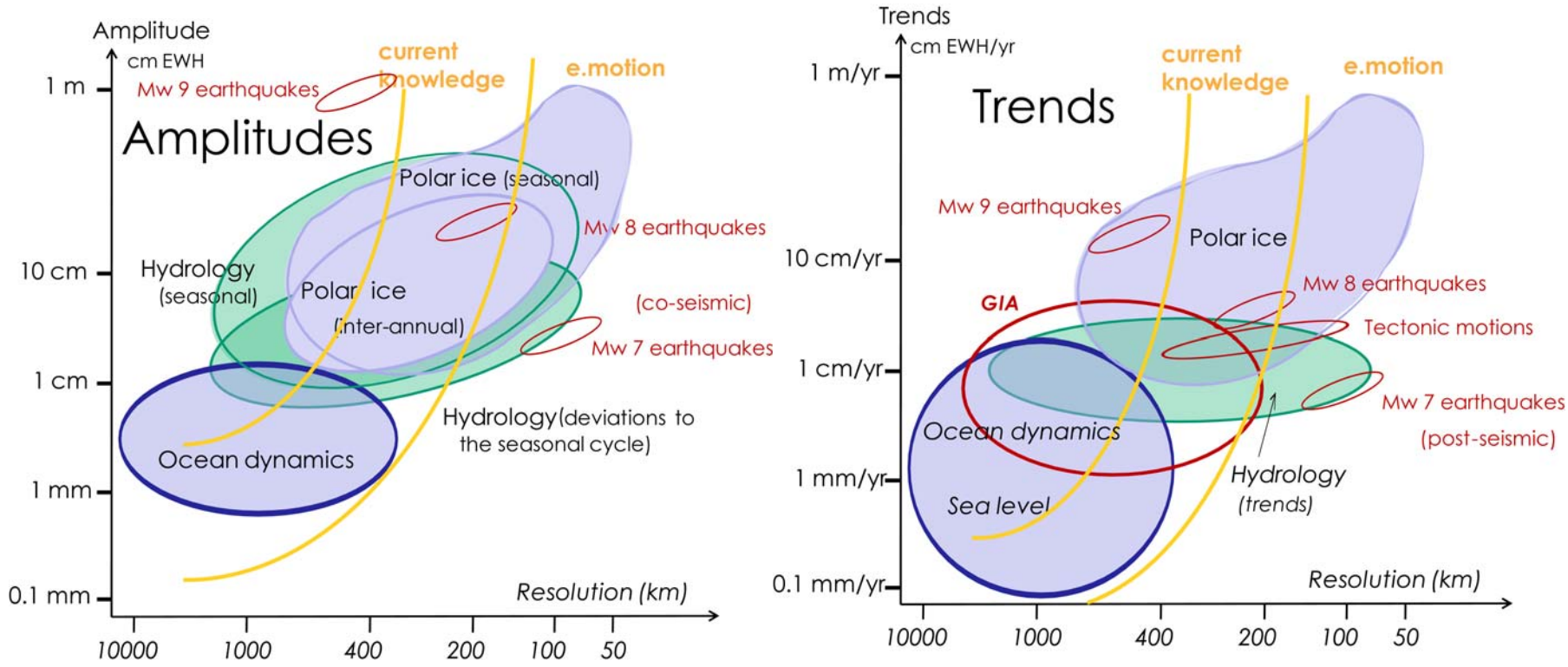
**Research objectives concerning three fields:**

- Mass variations in the global water cycle,
- Mass variations within the solid Earth, and
- Precise gravity reference for geodesy and Earth observation

**Specifically, the science requirements for e.motion are:**

- To recover temporal gravity and mass variations in the Earth system with a spatial resolution of 200 km or better, with global coverage;
- To recover small amplitude mass variations with 10 times increased sensitivity compared to current knowledge;
- To resolve mass variations at seasonal to decadal time scales, by extending the existing record of satellite data by a time series of 7 years or more with enhanced quality, with a temporal resolution of 1 month or better.

# Science Requirements

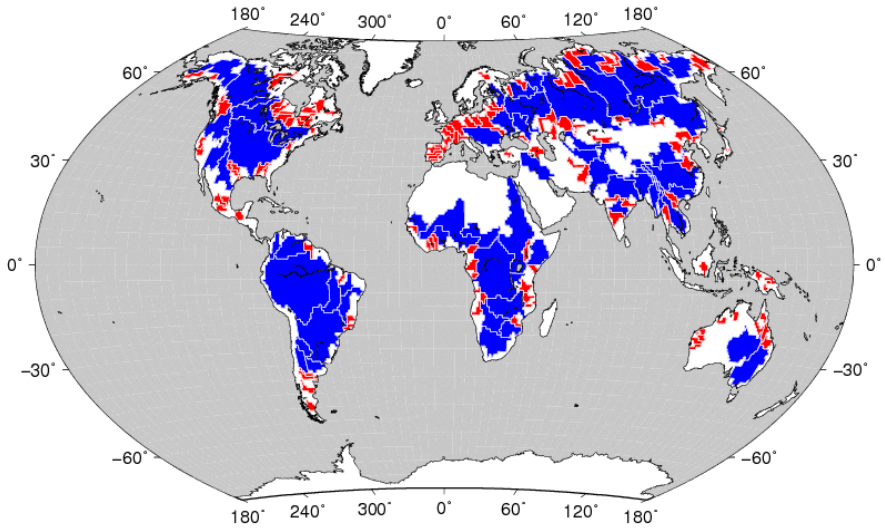



Signal amplitudes of mass variations in EWH as a function of spatial resolution, together with present-day and e.motion performance and resolution. Solid Earth mass variations are converted to EWH. Contributions from seasonal to interannual variations (left panel), and contributions from long-term trends (right panel).

1 cm EWH in a spherical cap of radius 2000 km (800 km, 400 km, 200 km, 100 km respectively) maps to a 0.5 mm amplitude geoid variation (0.3 mm, 0.15 mm, 0.08 mm, 0.04 mm resp.).

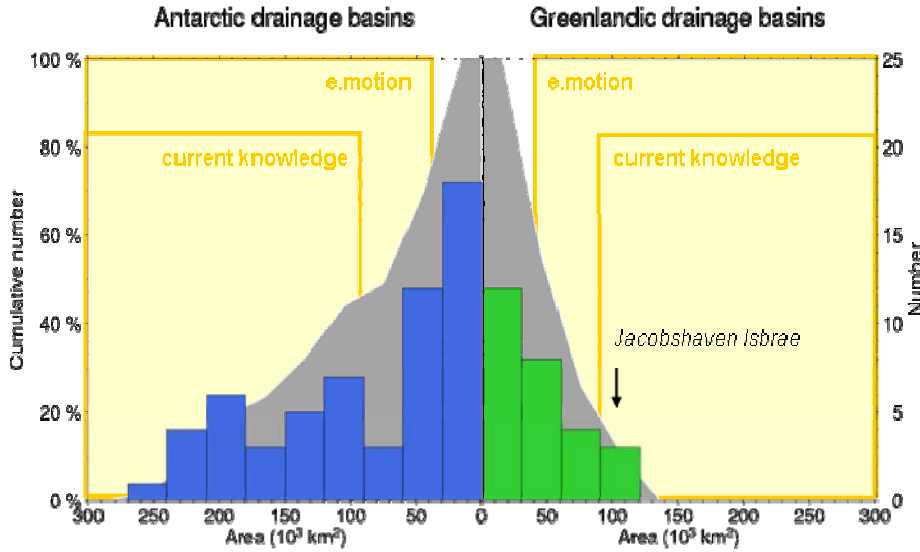
# Science Requirements

## Hydrology




River drainage basins with a size between 40000 km$^2$ and 200000 km$^2$ (red) which will be resolved by e.motion, as well as basins larger than 200000 km$^2$ (blue) which corresponds to the present day resolution.
Source: Oki, T. & Sud, Y.1998, Earth Interactions; Rodell, M. and Famiglietti, J., 1999, Wat. Res. Research.

## Continental Ice




Distribution of areas of continental hydrology drainage basins. Lines indicate recovery improvement of e.motion with regard to current knowledge. Grey area indicates the cumulative number of basins.
Source: Oki & Sud,1998, Earth Interactions.

# Mission Assumptions

**Selected Orbit Configuration:**

Near polar orbit; Mission duration > 7 years

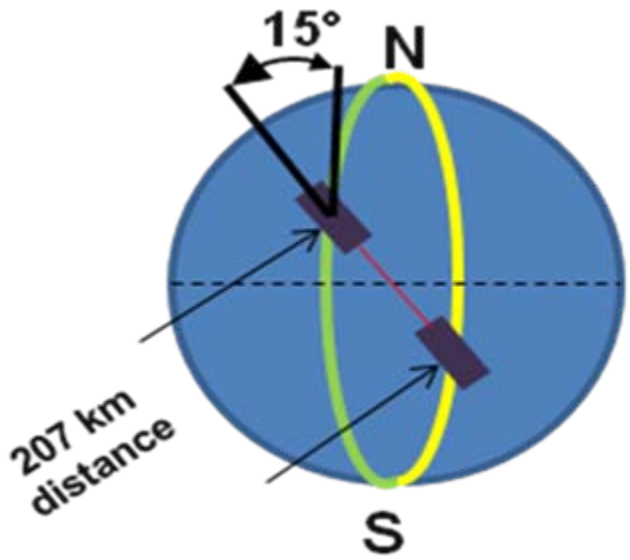
Nominal orbit height of 373km (a slightly higher orbit as fallback option).

Repeat period of 28.92 days, equatorial inter-track distance ca. 44 km.

Sub-cycle of approximately 10 days can be implemented.

**SST-ll Configuration:**

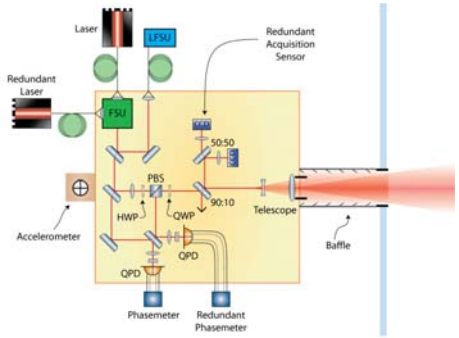
- For polar or near-polar orbits (both satellites in the same orbital plane) observations are mostly taken in North-South (or vice-versa) direction. This results in reduced cross-track resolution and North-South stripes.
- Therefore for e.motion a pendulum orbit is foreseen. Orbital planes of lead and trail satellites are rotated relatively to each other (change of right ascension of ascending node). Observations with a maximum tilt of about 15° at the equator are taken, leading to multi-directional observations.

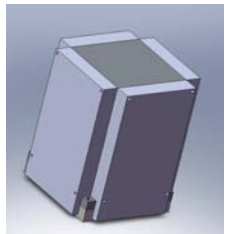


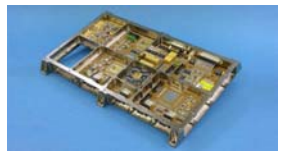
# Mission Assumptions

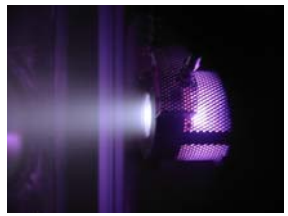
**Key Elements:**

- The inter-satellite ranges and range-rates have to be observed with very high accuracy. For e.motion it is foreseen to use a laser interferometer system with a wavelength of 1 µm in order to observe ranges with an accuracy level of some 10's of nanometer.
- Accelerations originated from non-gravitational forces have to be observed within a dedicated measurement range with a high-sensitive accelerometer. We seek for a resolution on the level of $10^{-11}$ to $10^{-12}$ m/s$^2$ with drag compensation and 3 high sensitive axes.
- The geo-location of the satellite has to be observed by a GNSS space receiver delivering ultimate accuracy.
- In order to implement an efficient pendulum orbit, both satellites have to be oriented with high accuracy against each other enabling high precision inter-satellite measurements. For this purpose also the attitude of the satellites has to be observed / reconstructed with very high accuracy.







# Mission Assumptions

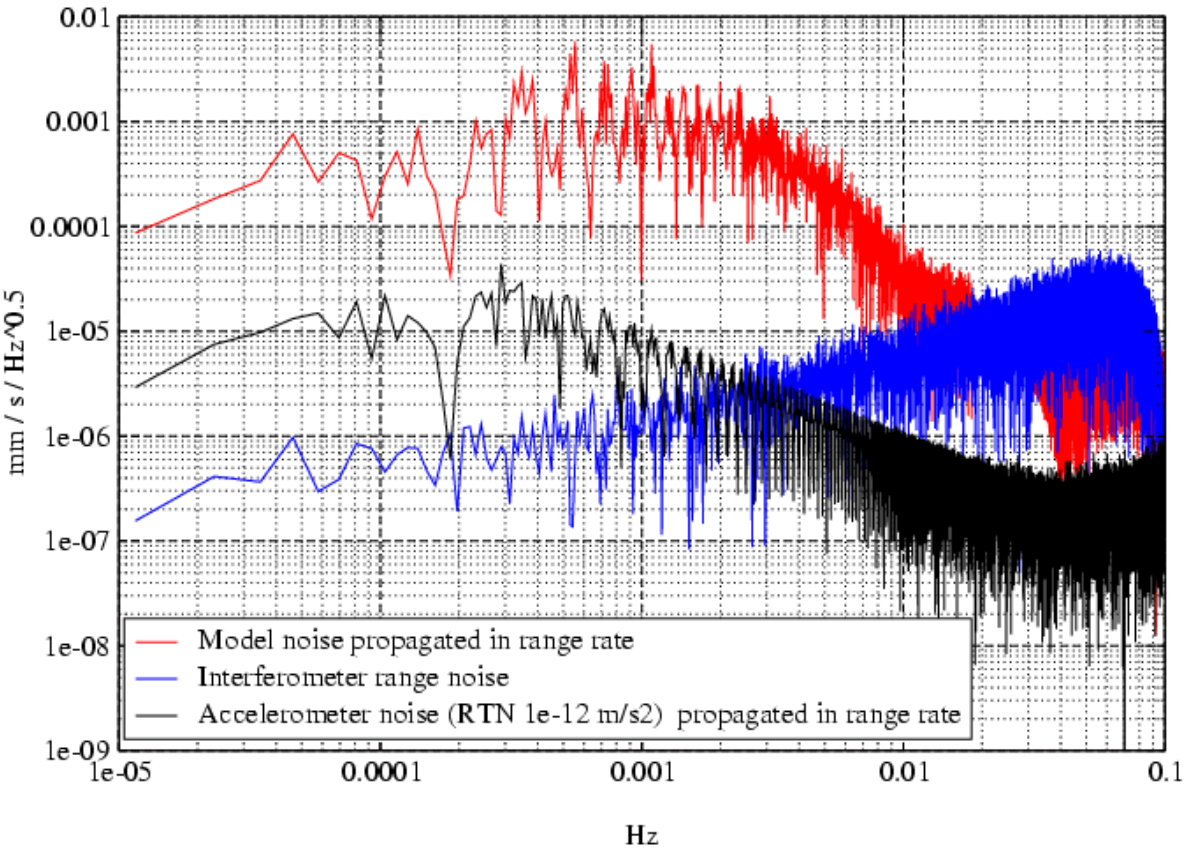
**Closed-Loop (Numerical) Simulation:**

Instrument noise:

- Laser interferometer coloured noise 50 nm/√Hz (white noise level),
- Accelerometer coloured noise of $1 \cdot 10^{-12}$ m/s$^2$√Hz (white noise level).

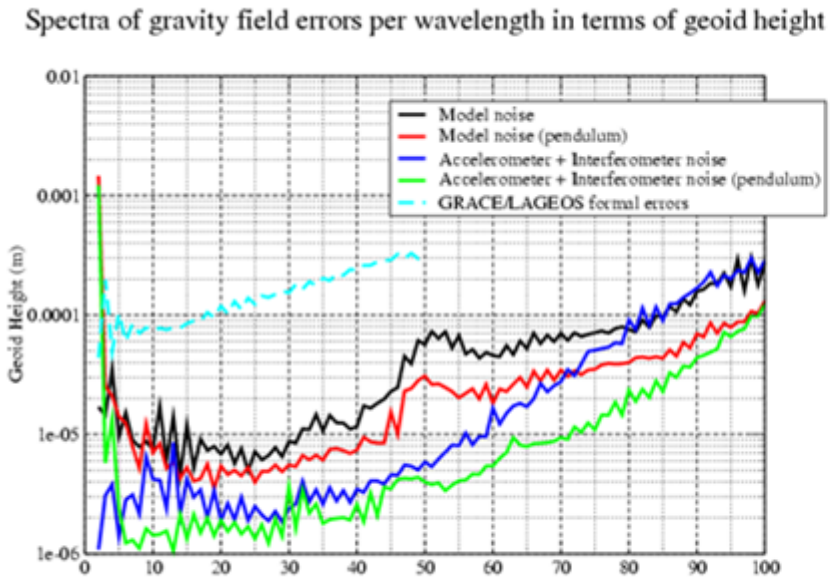
Background model noise:

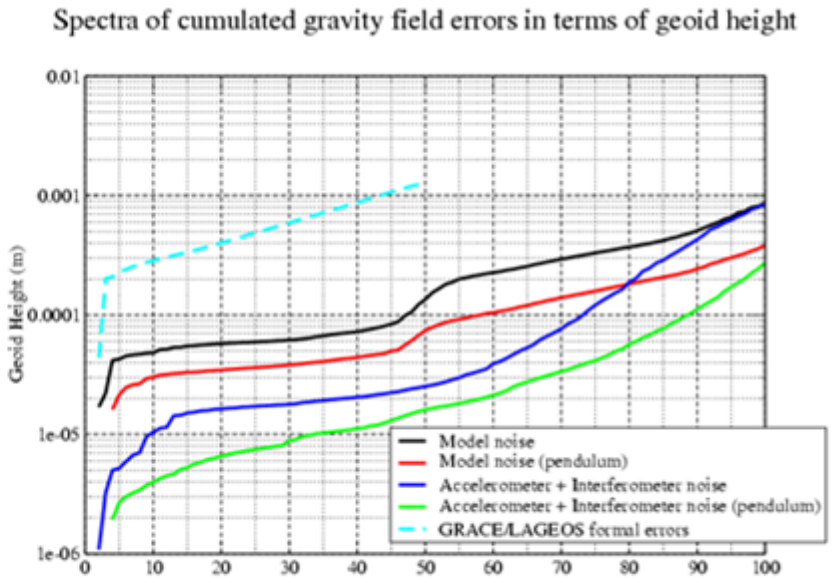
- Differences between nominal and reference models and scaling factor applied (0.1).

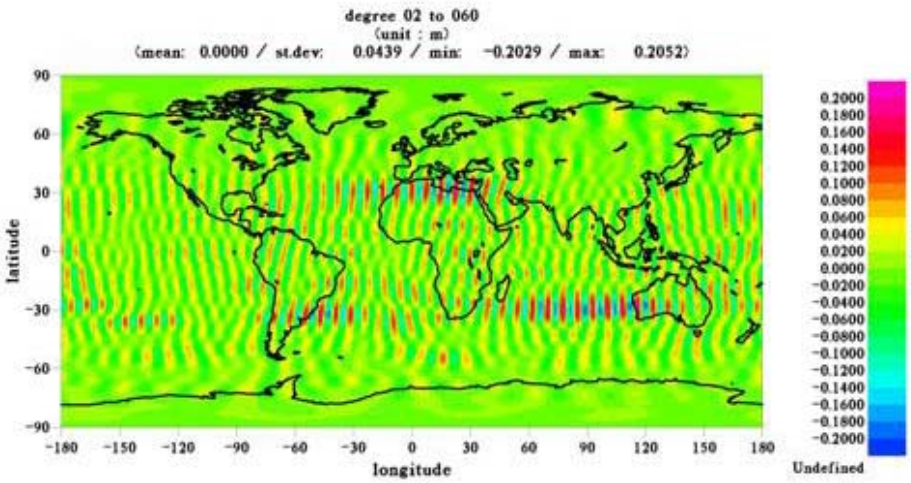


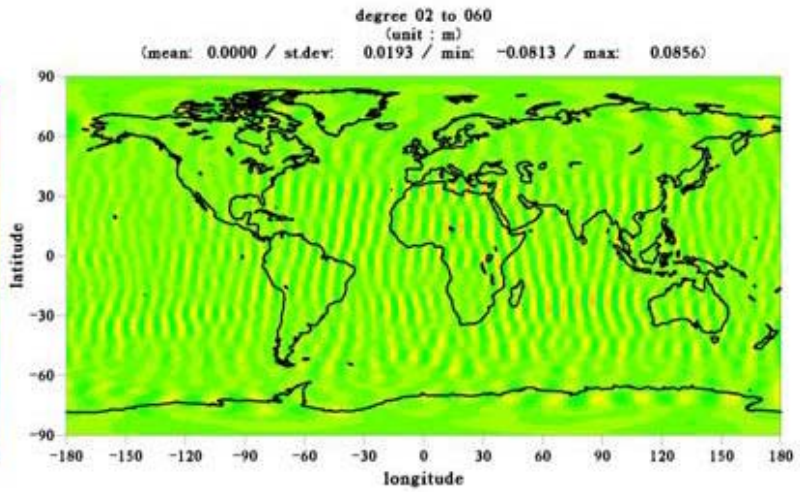
# Mission Assumptions

## Closed-Loop (Numerical) Simulation:



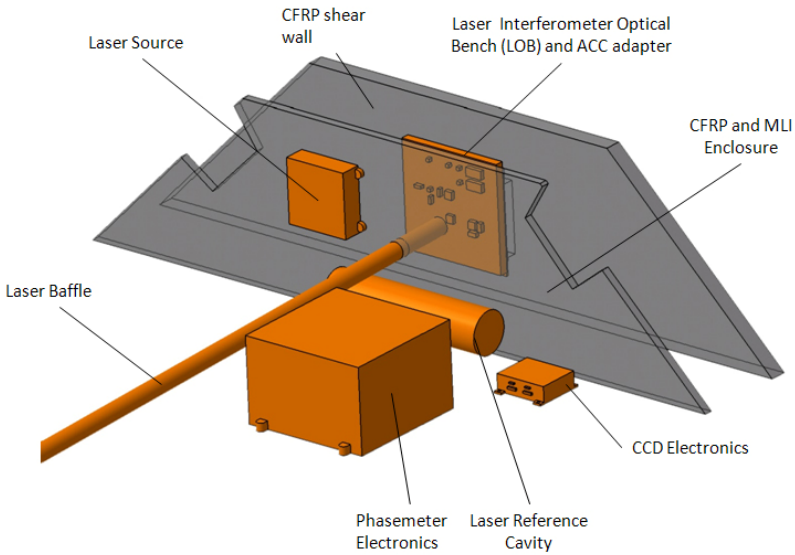



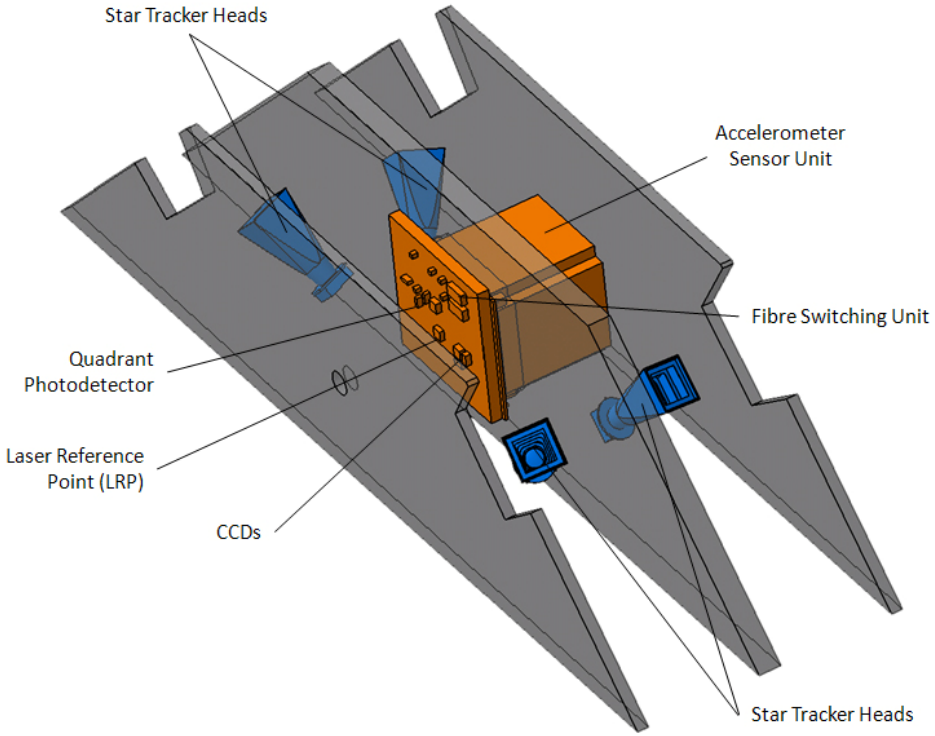
# Technology

## Space Segment:

Elements of laser interferometer

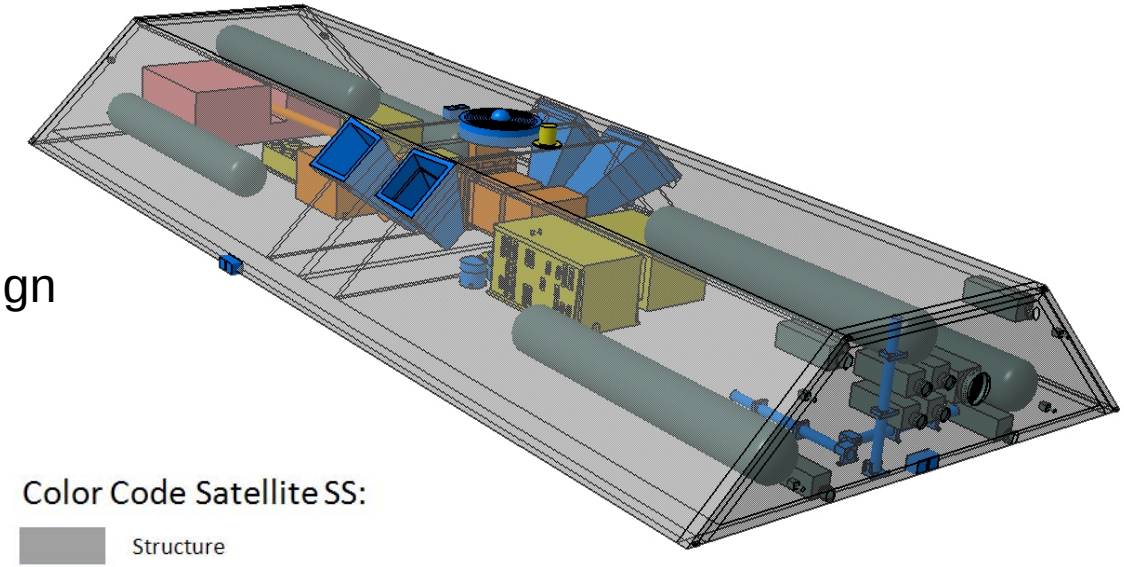



Dissipating elements inside laser Interferometer / ACC thermal enclosure

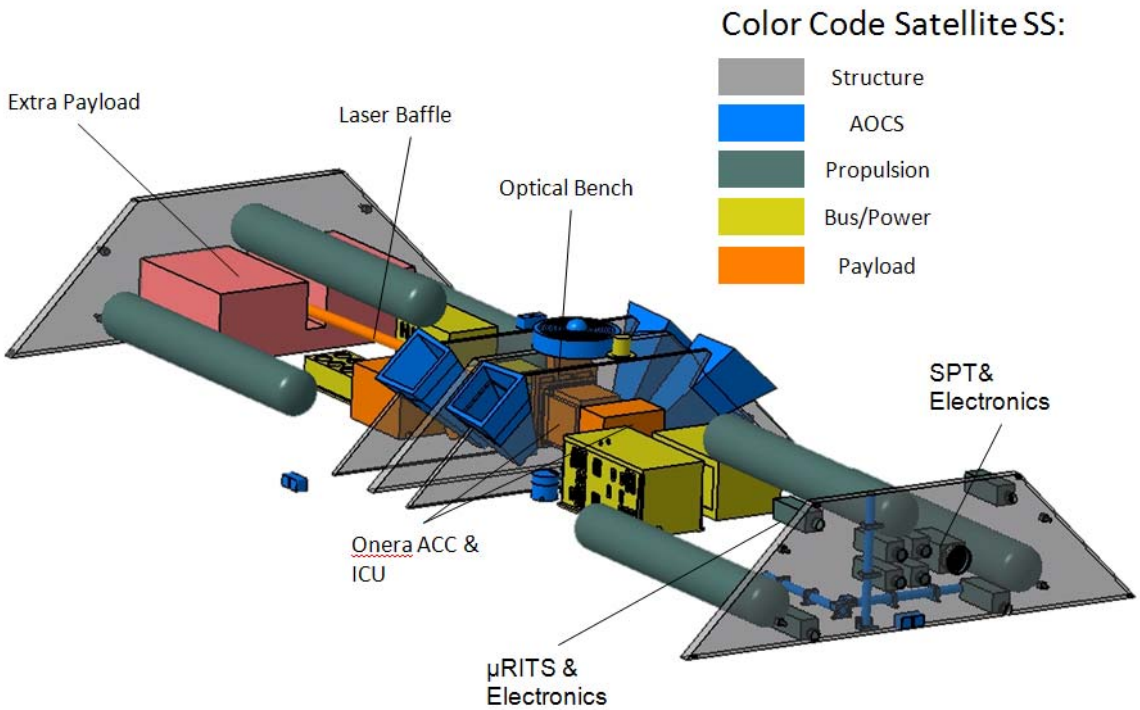


# Technology

## Space Segment:



Satellite Accomodation & Design



# Technology

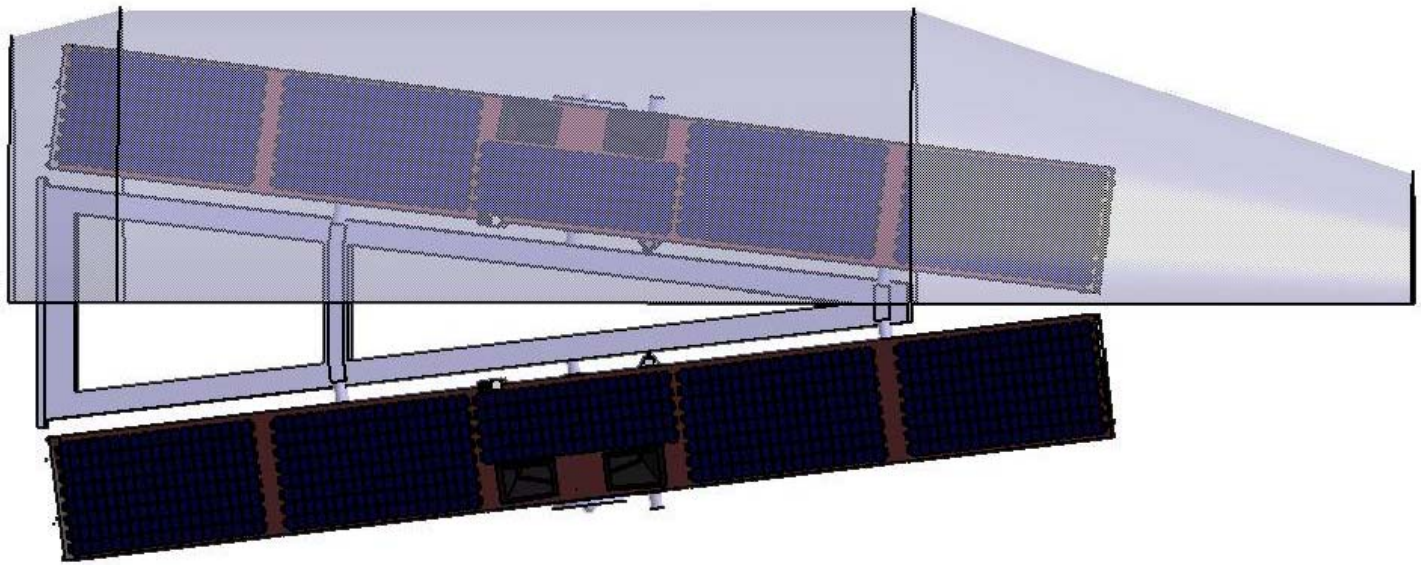
**Propulsion System:**

- Besides magnet torquers, the propulsion system provides all actuators needed to support precise attitude control (5 arcsec range) as well as drag compensation.
- The propulsion system consists of a combination of linear and non-linear cold gas thrusters, as well as Electric Propulsion thrusters (µRIT and SPT) (RIT=Radio Frequency Ion Thrusters, SPT=Stationary Plasma Thrusters).
- All thrusters are operated with Xenon, which is stored in six tanks distributed over the spacecraft. Through a propulsion manifold the tanks for the operation of the thrusters are selected. Each thruster can be operated using gas from each tank.

# Technology

**Launcher:**

- VEGA has been selected as primary launch vehicle.
- The present VEGA specification has been used to derive mass and volume constraints for the two e.motion S/C and their common dispenser.
- DNEPR is proposed as fallback launcher offering more volume and lift off mass. The flight sequence of the launch will be a direct injection



# Conclusions

- A full proposal for a satellite-to-satellite tracking mission based on laser interferometry has been prepared and submitted by a European (+Canadian) consortium in response to ESA‘s Earth Explorer 8 call (e.motion).
- Science mission goal is monthly 1 mm geoid (10 cm EWH) for 200 km spatial resolution enabling observation of about 70% to 80% of time variable gravity signal amplitudes in all domains.
- e.motion is planned as a SST laser interferometer polar pendulum mission, with a 3-D accelerometer of the GOCE class, a basic drag compensation and a sophisticated attitude and orbit control system based on electric propulsion. Potential launch date is 2018.
- Technology readiness for the laser interferometer and the propulsion system is expected to be reached after phase A. Fallback options were defined (orbit height, propulsion).
- Mission selection to be proposed for phase A is ongoing (up to 3 will be selected). Decision will be announced by the end of November.