MICROSCOPE - Testing the Weak Equivalence Principle in Space

Meike List
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Universität Bremen*

*EXZELLENT.
Gewinnerin in der
Exzellenzinitiative

CENTER OF
APPLIED SPACE TECHNOLOGY
AND MICROGRAVITY

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Contents

- ✓ The MICROSCOPE mission
- ✓ Successful launch in April 2016...
- ✓ Orbit propagation and data analysis methods
- ✓ Summary and outlook

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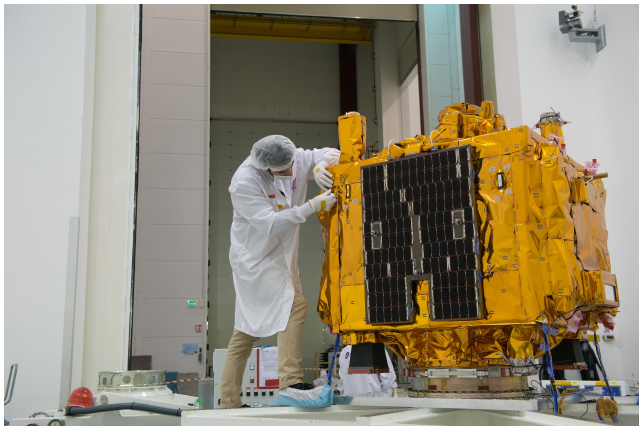
The MICROSCOPE mission

- Mission goal: Test of the Weak Equivalence Principle (WEP) with an accuracy of $\eta = 10^{-15}$
- Responsibilities: CNES (satellite) and ONERA (payload)

- Contributions and objectives of ZARM:
  - Free-fall tests of payload
  - On-demand tests during mission
  - First data evaluation as SWG member
  - Validation of the HPS
- Scheduled Launch date: **22.04.2016**



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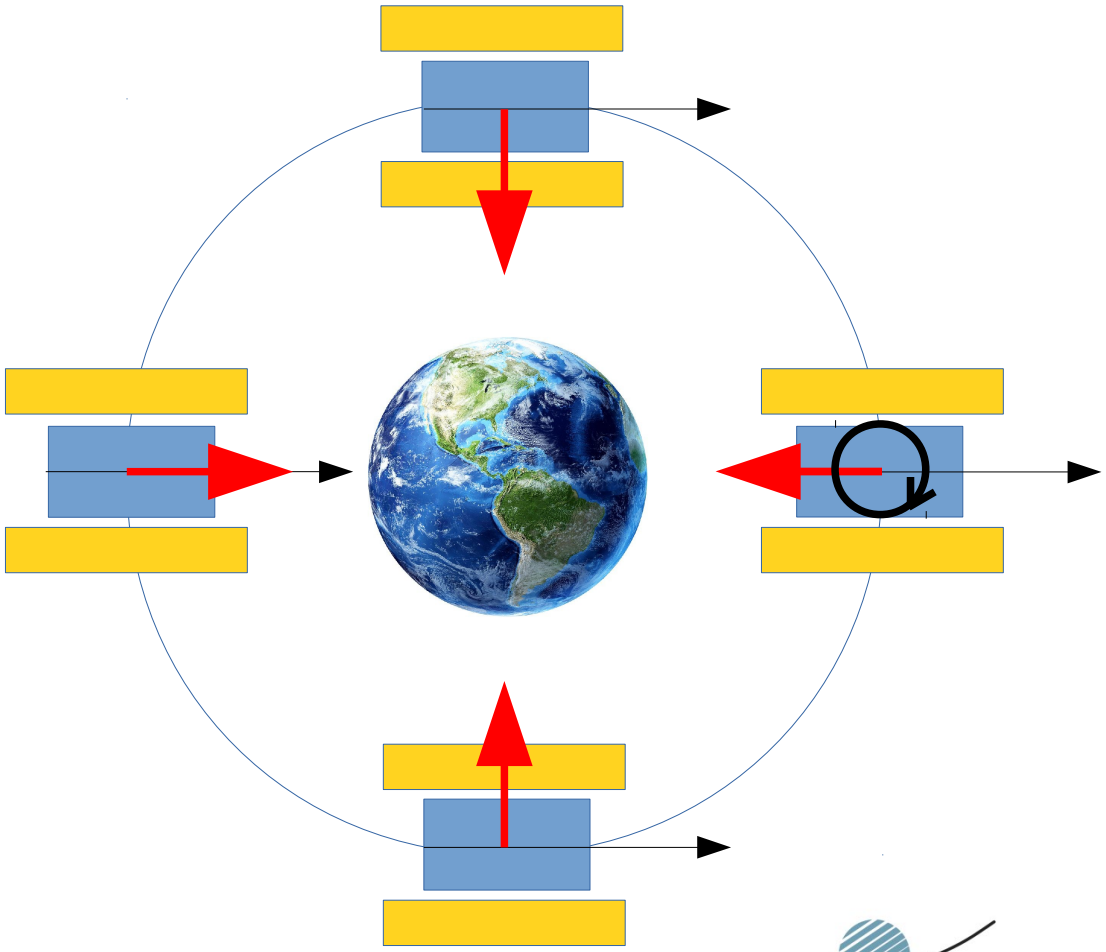
The MICROSCOPE mission

- Servo-controlled concentric masses in the same gravitational field
- Measurement of differential acceleration TM1/TM2
- Payload: T-SAGE
- AOCS: drag-free
- Inertial/spinning mode



Material TM 1 (Pt)

Material TM 2 (Ti)

Sensitive axis

Acceleration

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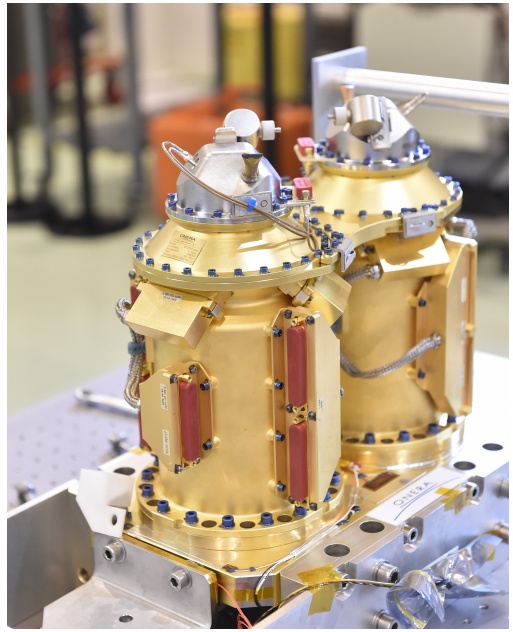
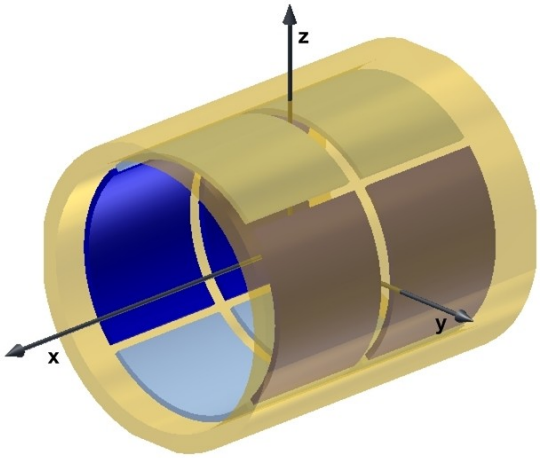
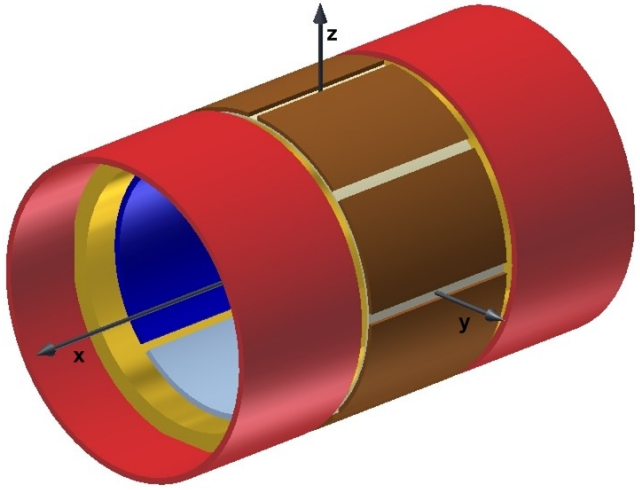
The MICROSCOPE mission – Payload T-SAGE

- Developed and built by ONERA
- Two differential accelerometers, each containing two test masses (Pt/Ti, Pt/Pt)
- Each test mass controlled via 18 electrodes
- Test mass production by PTB







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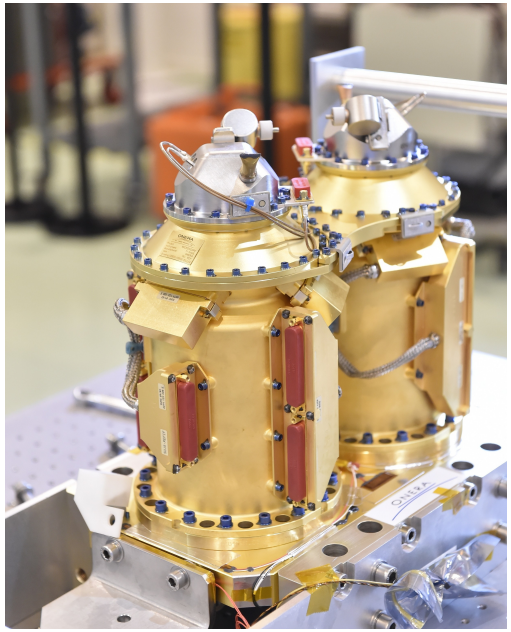

$$\vec{a}_{mes,k} = \vec{B}_{0,k} + \mathbf{M}_k \cdot \vec{a}_{app,k} + \vec{a}_{mes,quad,k} + \vec{a}_{n,k}$$

$\vec{B}_{0,k}$ Instrument bias, constant offsets

$\mathbf{M}_k$ Sensibility matrix (scale factor, coupling, alignement errors)

$$\vec{a}_{app,k} = \frac{1}{m_{tm,k}} \left[K_k \cdot \vec{r}_{sens\,k,tm\,k} + D_k \cdot \dot{\vec{r}}_{sens\,k,tm\,k} \right] + \ddot{\vec{r}}_{sens\,k,tm\,k} - \vec{a}_{gg,k} + \vec{a}_{sat} - \vec{a}_{rot,k}$$

$\vec{a}_{mes,quad,k}$ Non-linear term of 2nd order

$\vec{a}_{n,k}$ Instrument noise

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Successful launch in April 2016…

Soyuz (http://www.arianespace.com/mission-updates/?taxonomy%5Bmission-update-category%5D=soyuz) Apr 20, 2016

Soyuz meets its multi-satellite payload for Friday's Arianespace launch

The integration of Flight VS14's "upper composite" began with its transfer to the launch pad (at left). It was then raised to the upper level of the mobile gantry for installation atop the Soyuz launcher (photos center, and right).

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Successful launch in April 2016…

Sovuz (http://www.arianespace.com/mission-updates/?taxonomy%5Bmission-update-category%5D=sovuz) Apr 21, 2016

Arianespace's Soyuz is a "go" for liftoff with a multi-mission satellite payload

Arianespace's third mission of 2016 – and the first this year with its Soyuz launcher – is a "go" for liftoff from the Spaceport in French Guiana on Friday evening to deploy a five-satellite European payload.

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Sovuz (http://www.arianespace.com/mission-updates/?taxonomy%5Bmission-update-category%5D=sovuz) Apr 22, 2016

Weather postponement for Arianespace's Flight VS14 Soyuz mission

Arianespace's Soyuz mission with five European satellites has been postponed for 24 hours due to unfavorable weather observed above the Guiana Space Center, as well as the forecast for liftoff time this evening.

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Sovuz (http://www.arianespace.com/mission-updates/?taxonomy%5Bmission-update-category%5D=sovuz) Apr 24, 2016

The next Arianespace Soyuz mission is set for April 24

Arianespace has decided to restart the launch chronology for Soyuz Flight VS14, as the weather conditions over Europe's Spaceport in French Guiana are now favorable.

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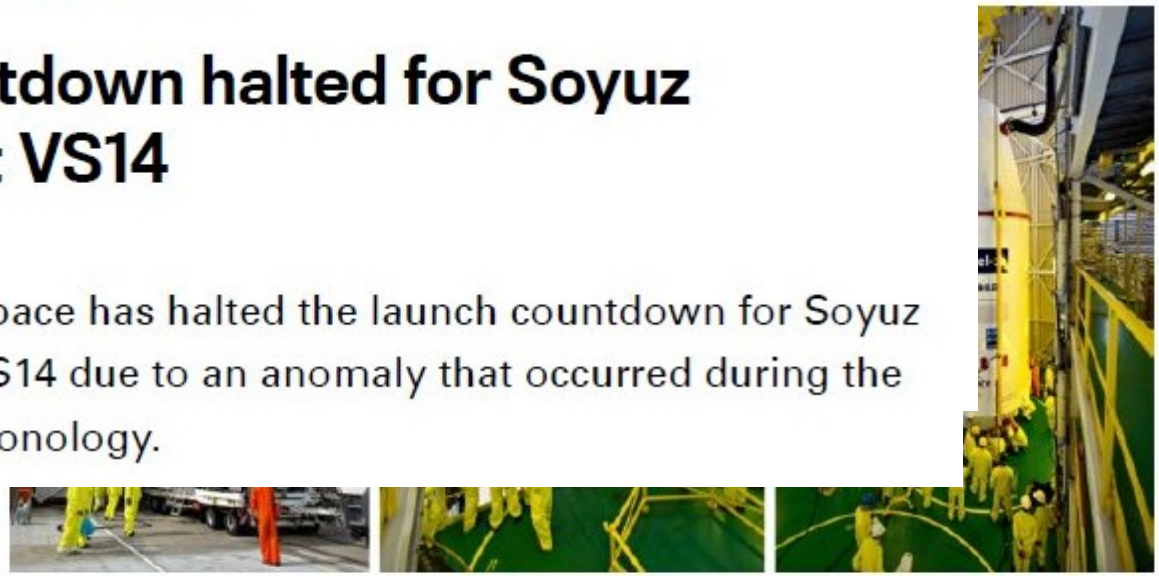
Sovuz (http://www.arianespace.com/mission-updates/?taxonomy%5Bmission-update-category%5D=sovuz) Apr 24, 2016

Countdown halted for Soyuz Flight VS14

Arianespace has halted the launch countdown for Soyuz Flight VS14 due to an anomaly that occurred during the final chronology.



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Sovuz (http://www.arianespace.com/mission-updates/?taxonomy%5Bmission-update-category%5D=sovuz) Apr 24, 2016

Soyuz Flight VS14: Liftoff is targeted for April 25

Replacement operations are underway for the inertial unit of Soyuz Flight VS14 that was affected by an outage, and a new technical review will be occur tomorrow at H0-5h.

The integration of Flight VS14's "upper composite" began with its transfer to the launch pad (at left). It was then raised to the upper level of the mobile gantry for installation atop the Soyuz launcher (photos center, and right).

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Successful launch in April 2016…

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Launch chronology resumes for a planned April 25 liftoff of Arianespace's Soyuz Flight VS14

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Arianespace has decided to resume the launch chronology for Soyuz Flight VS14 following the successful completion of operations to replace the launcher's inertial system that experienced a technical fault and associated checks.

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Successful launch in April 2016…

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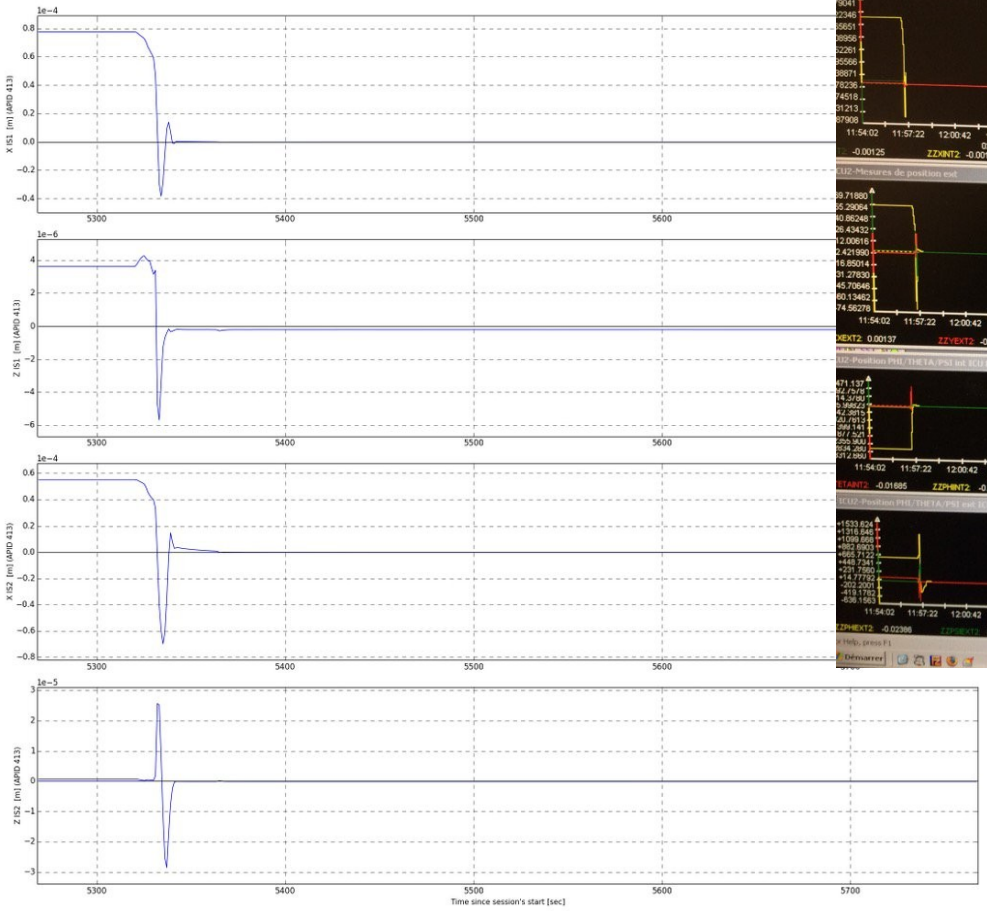

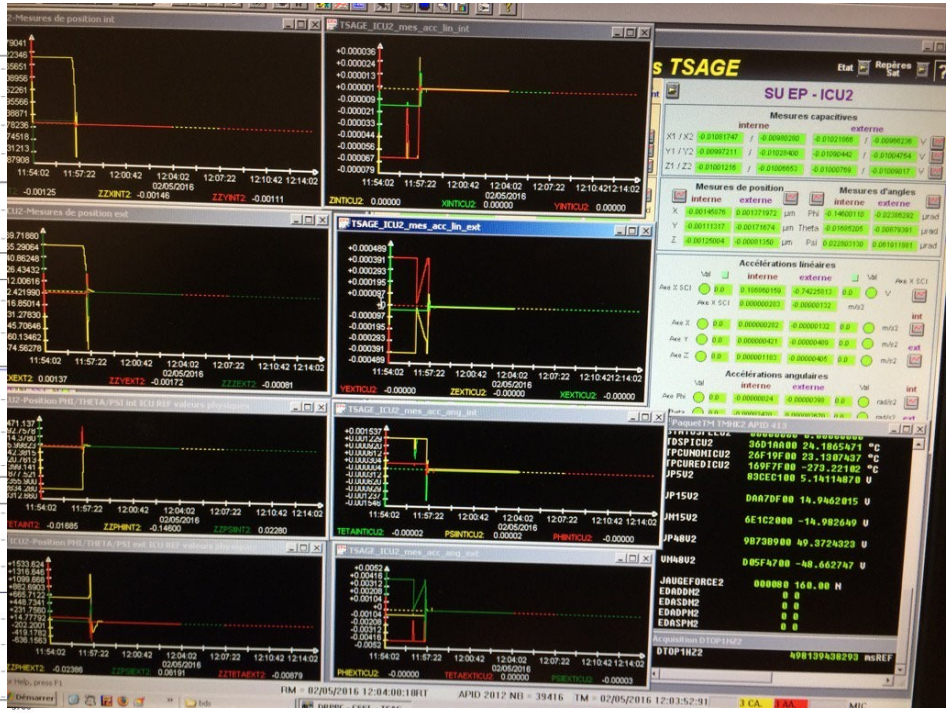

May 2nd 2016:
“The test masses have been released and servo looped!!!! Great all green“

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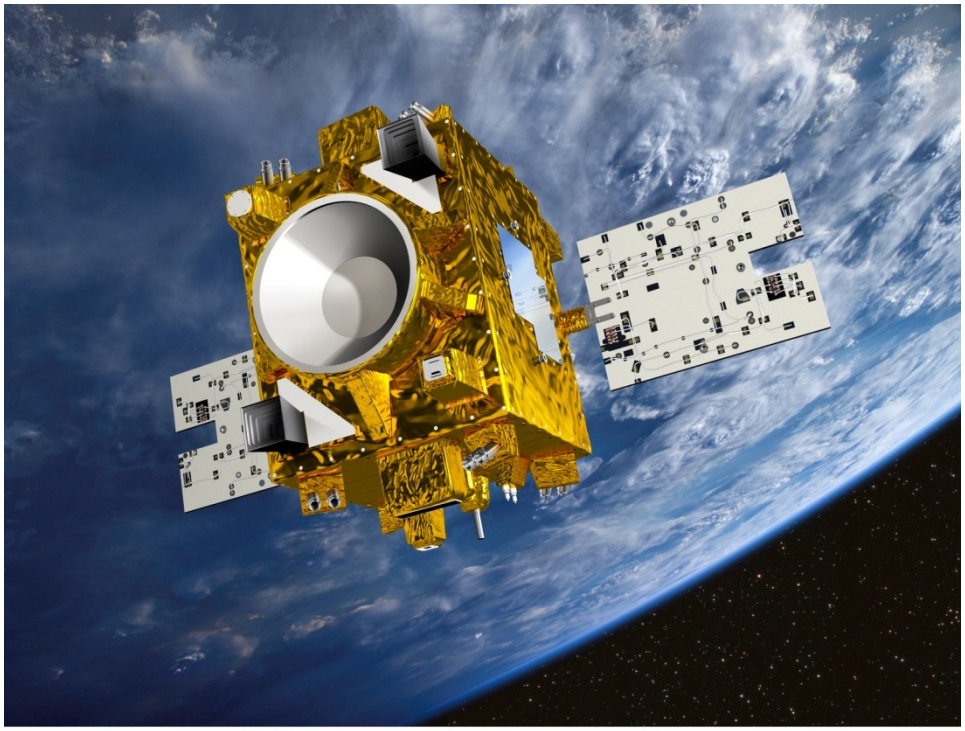

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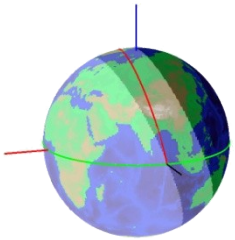
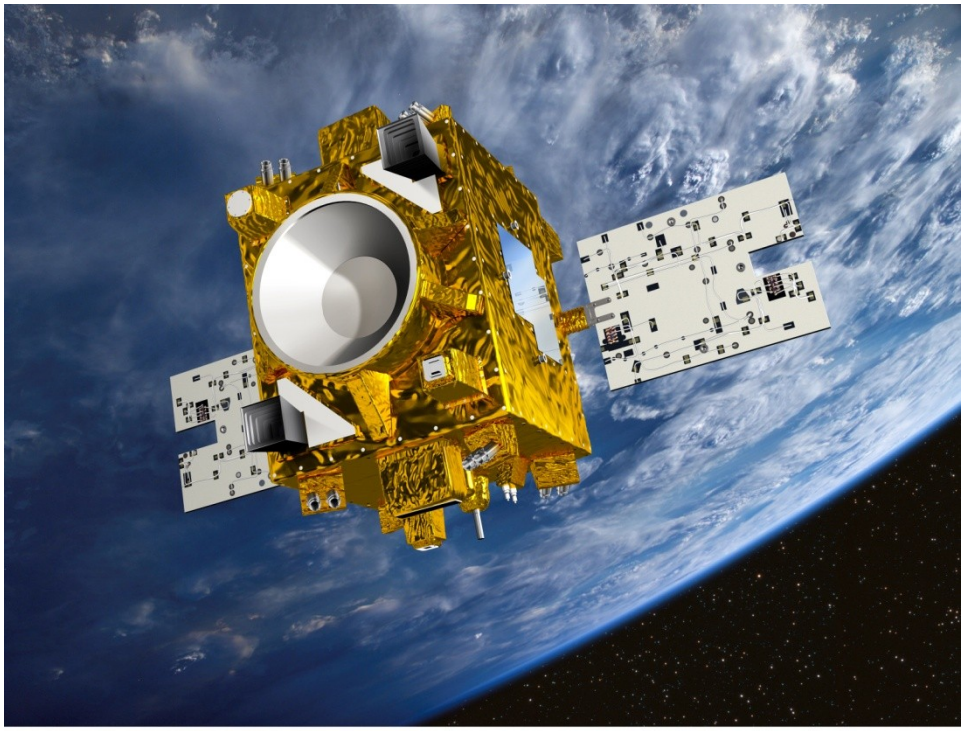
Orbit propagation…

Orbit dynamics





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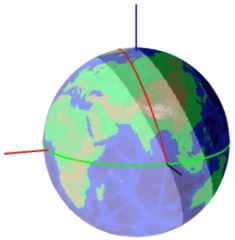
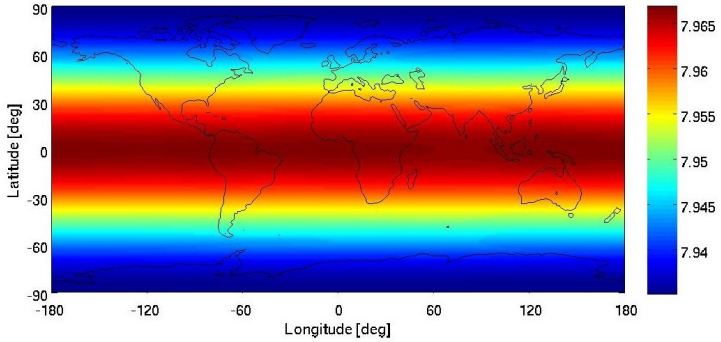
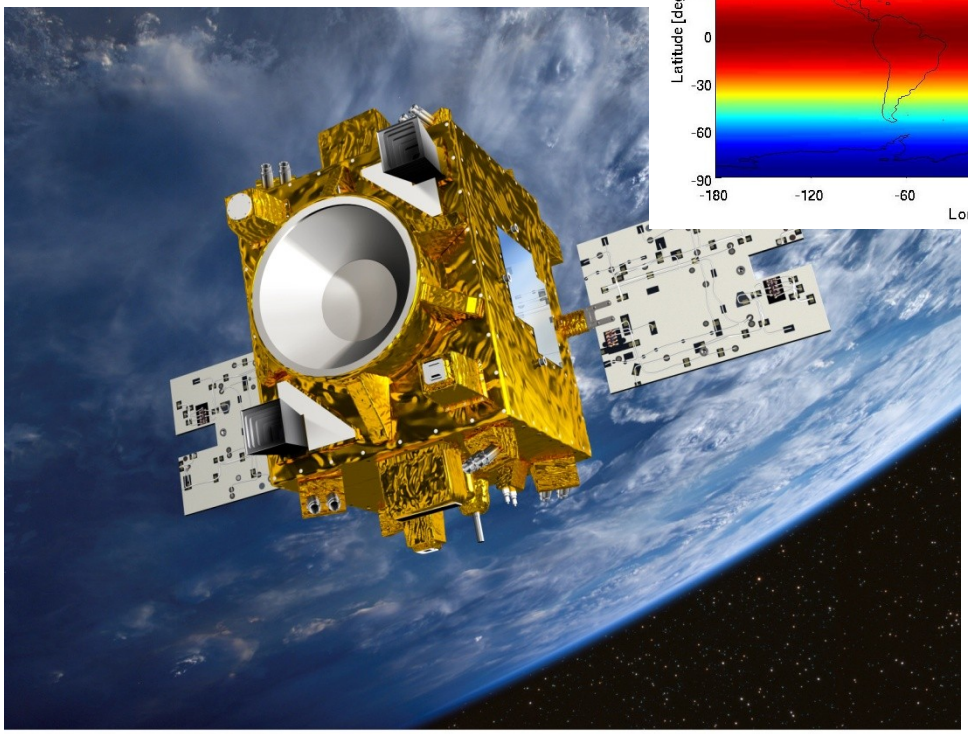


Gravitational field





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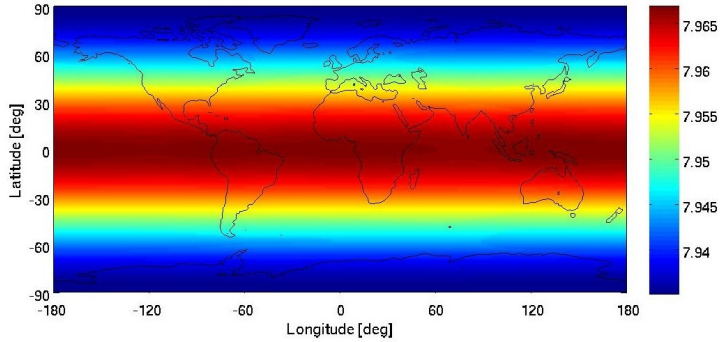
Orbit propagation…

Gravitational field



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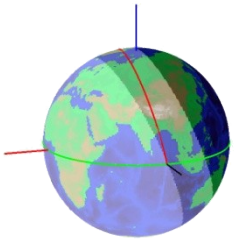

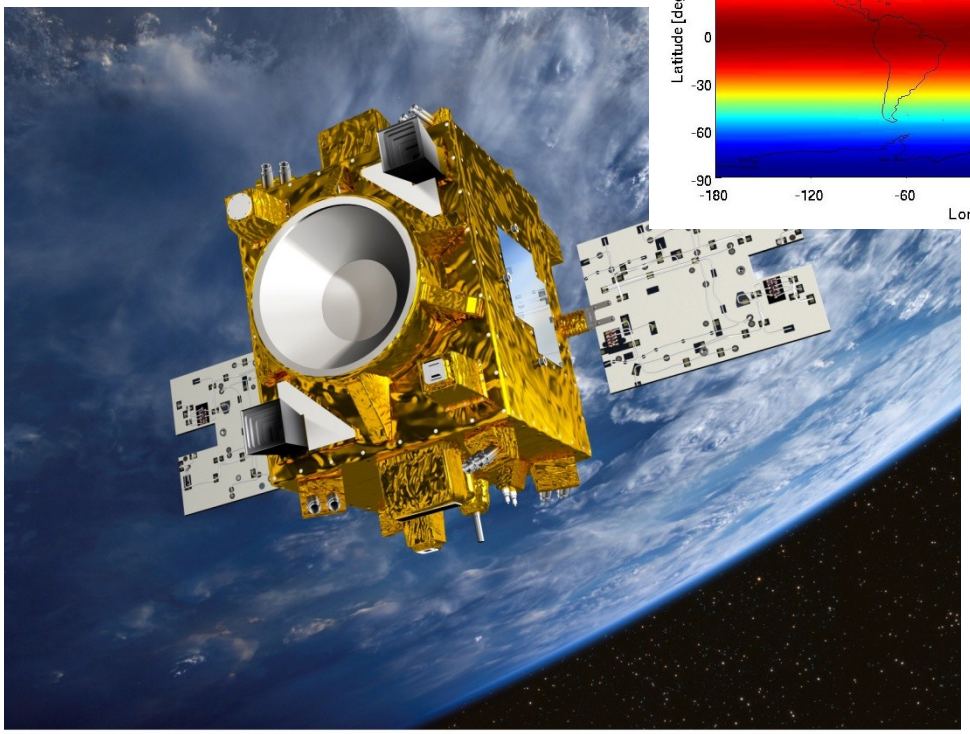

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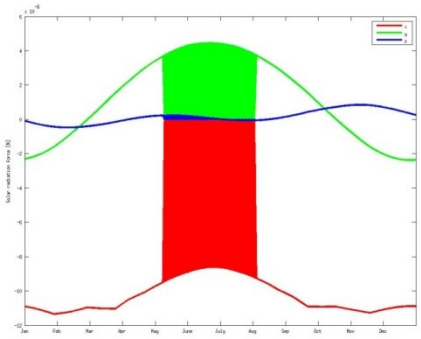
Solar radiation pressure and eclipse



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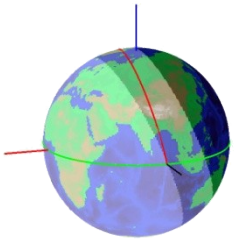
Orbit propagation…

Orbit dynamics



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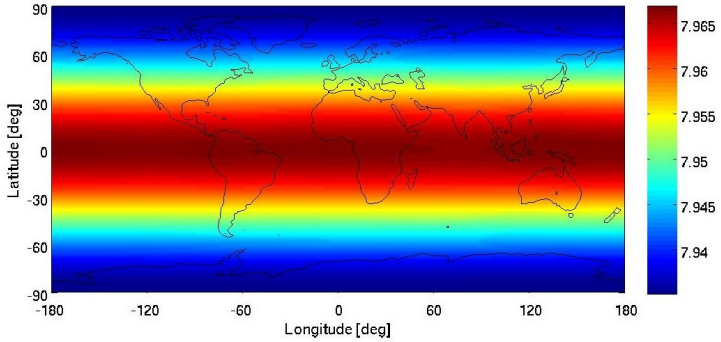

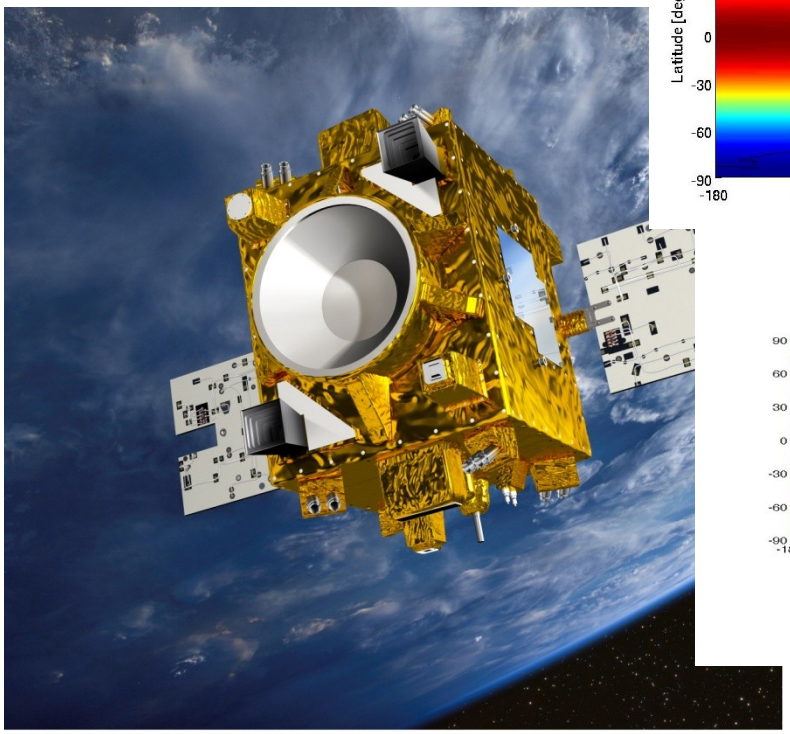

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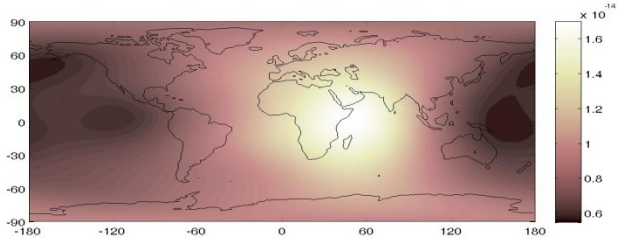
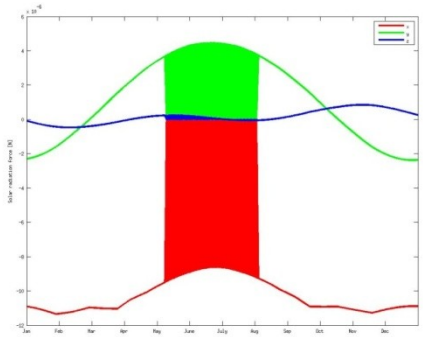
Atmosphere



Solar radiation pressure and eclipse



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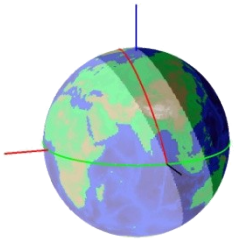
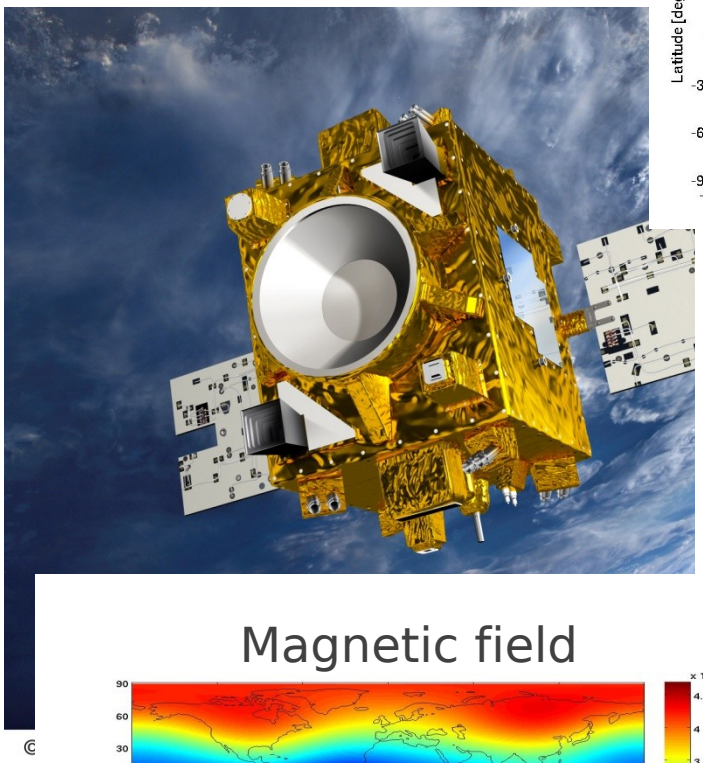
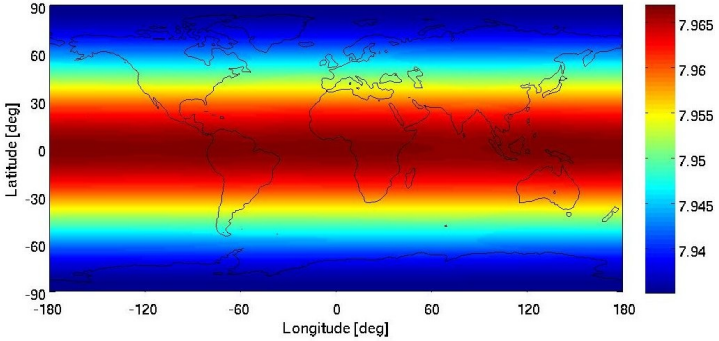
Orbit propagation…

Orbit dynamics





Gravitational field



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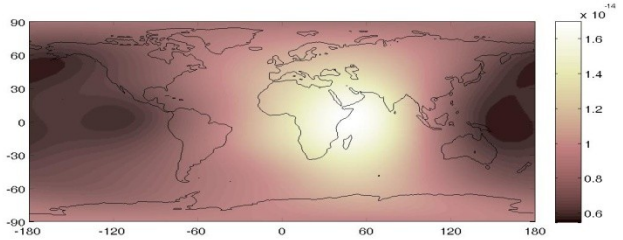

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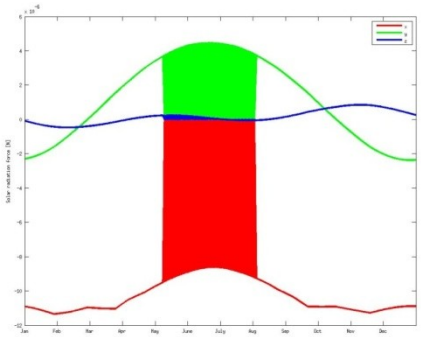
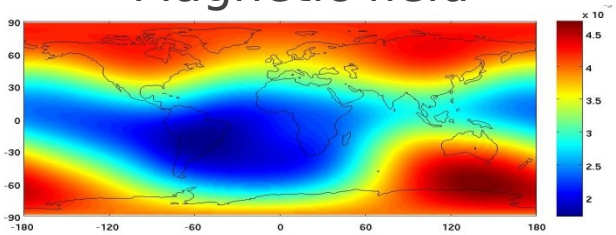


Magnetic field



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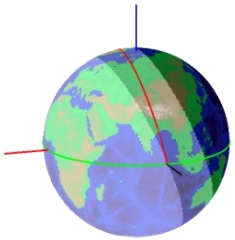
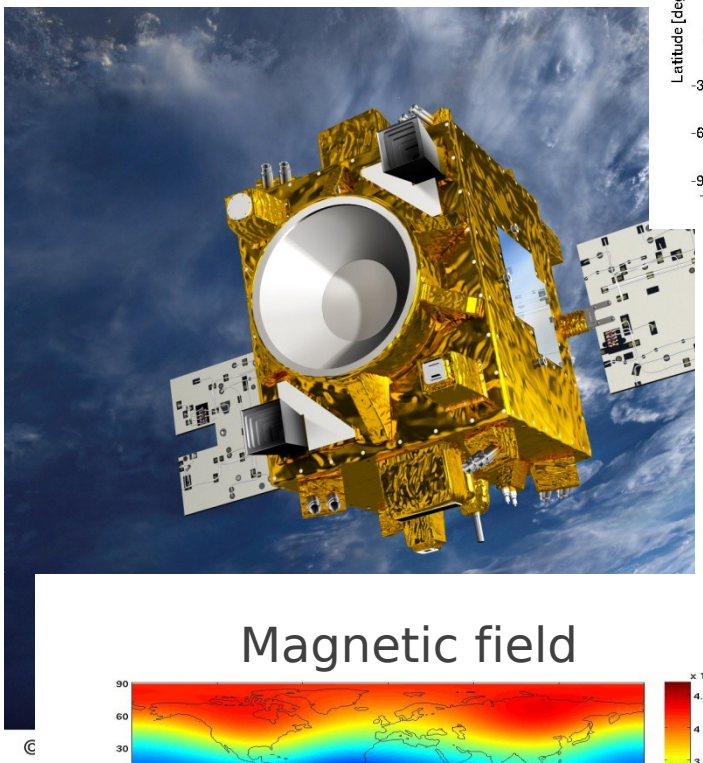
Orbit propagation…

Orbit dynamics





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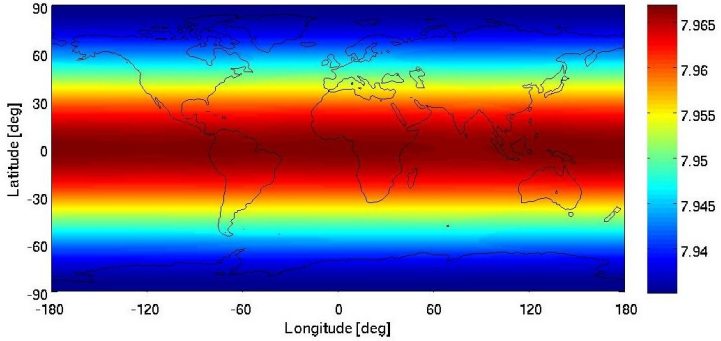

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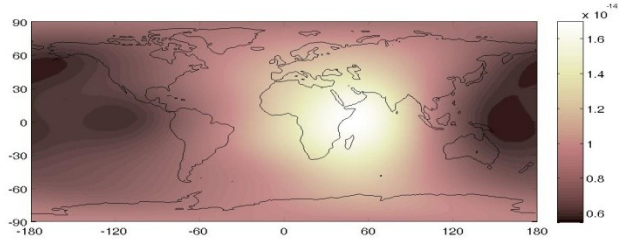

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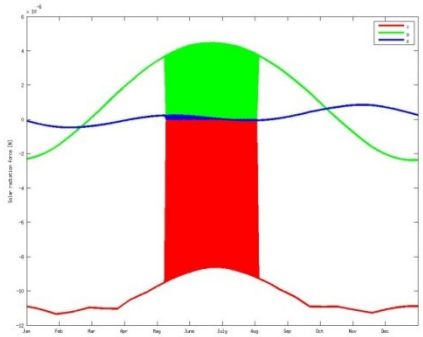

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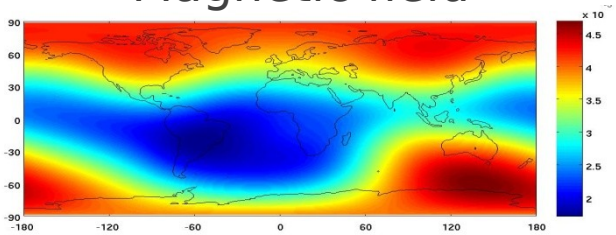

- ✓ Albedo radiation
- ✓ Earth infrared radiation
- ✓ Space debris
- ✓ Ephemerides
- ✓ …

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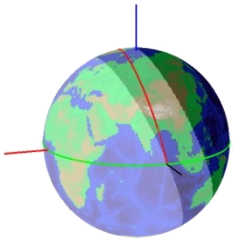
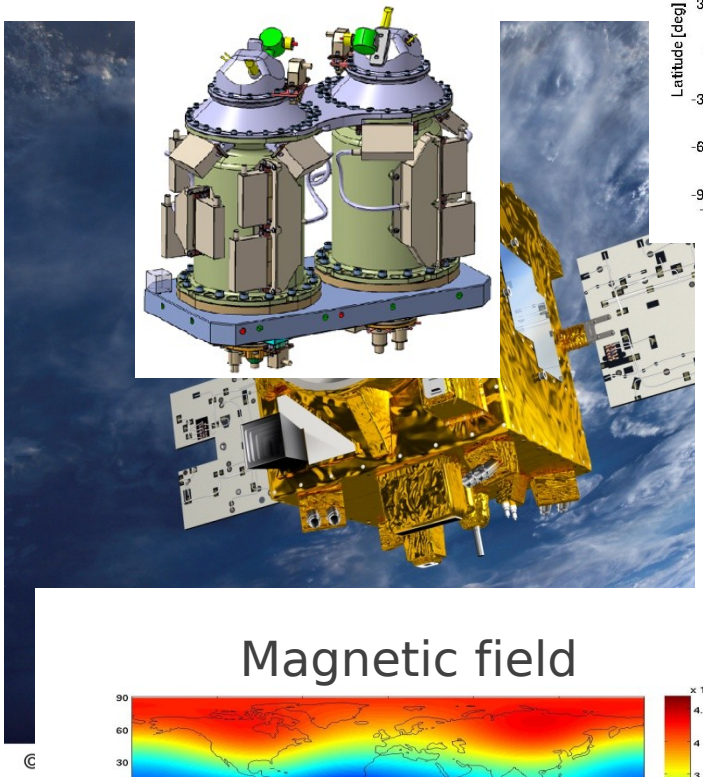
Orbit propagation…

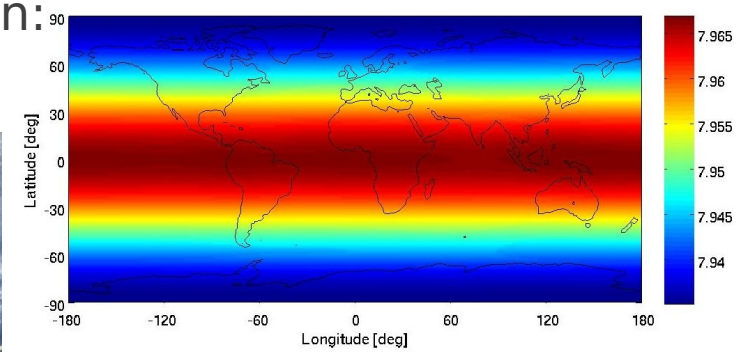
Orbit dynamics



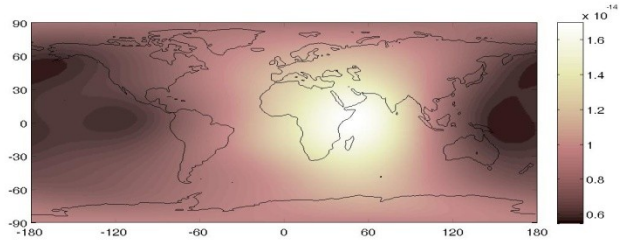
Special requirement of mission:
Payload



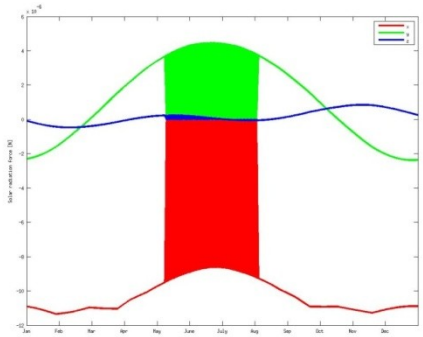
Gravitational field



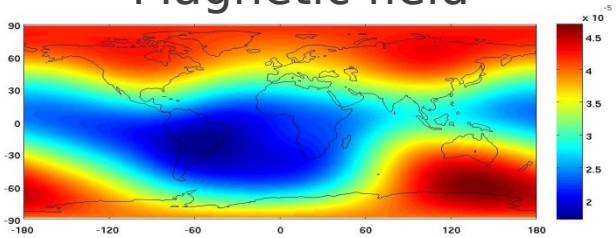
Atmosphere



Solar radiation pressure and eclipse



Magnetic field



- ✓ Albedo radiation
- ✓ Earth infrared radiation
- ✓ Space debris
- ✓ Ephemerides
- ✓ …

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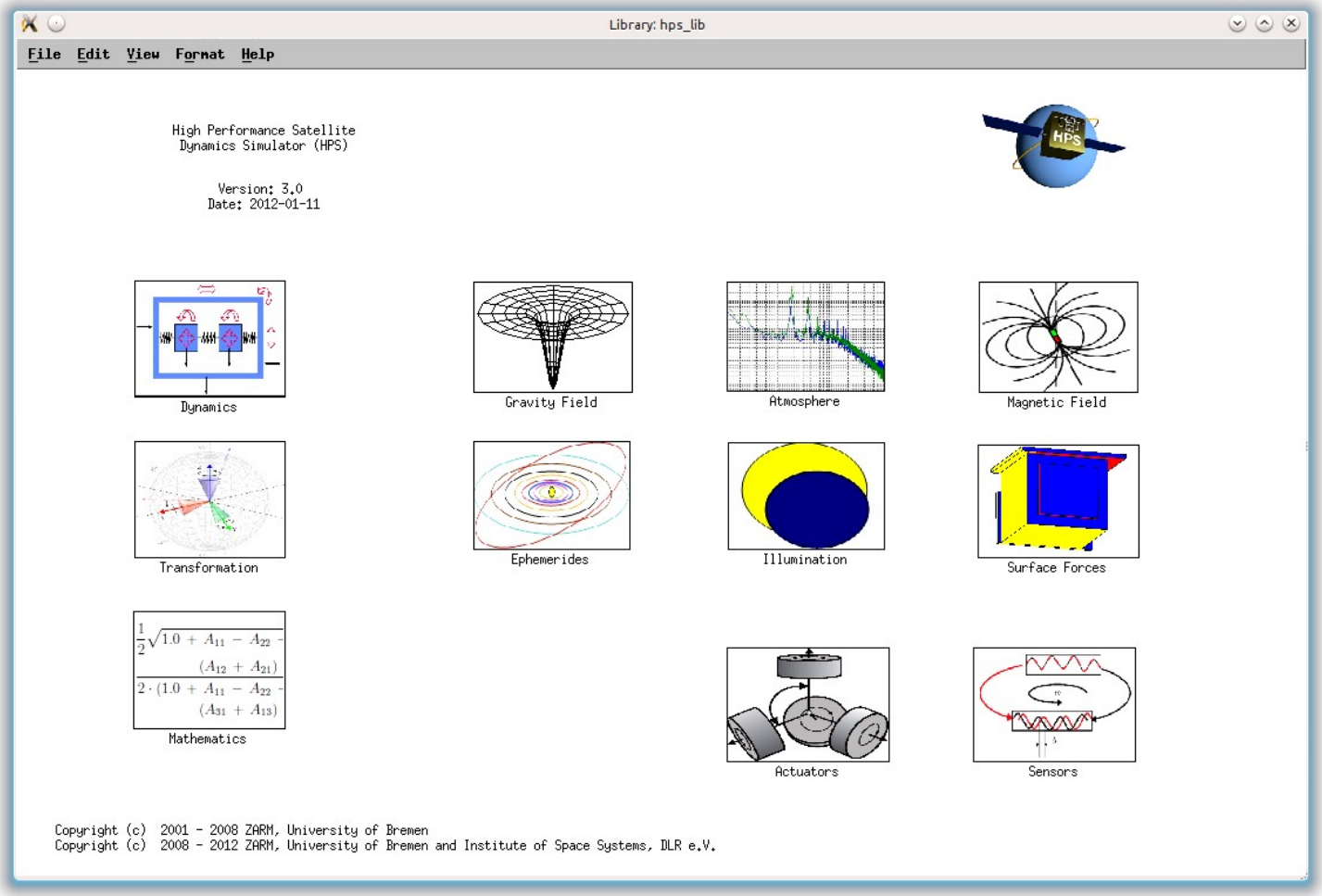
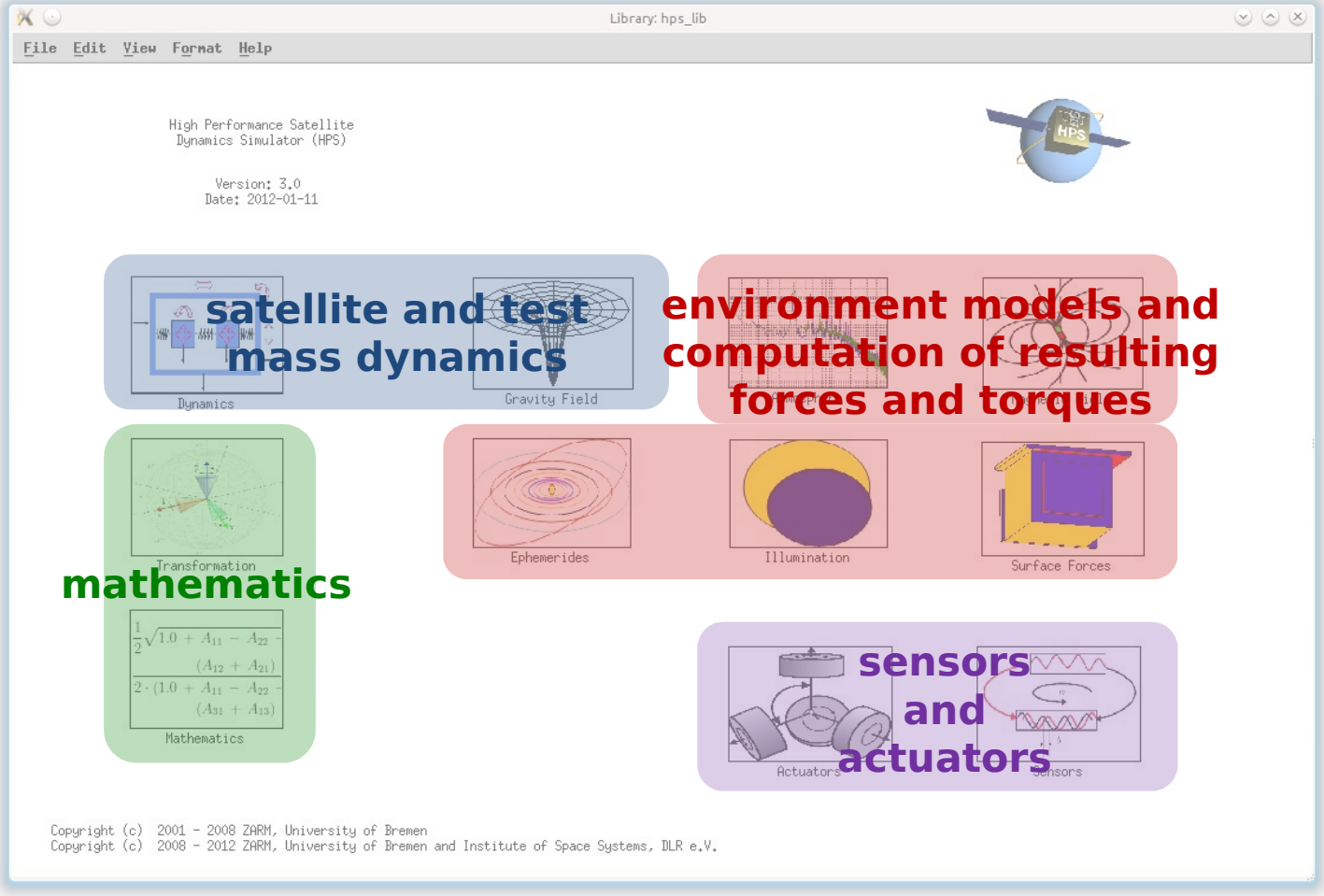
Orbit propagation…



Orbit propagation...



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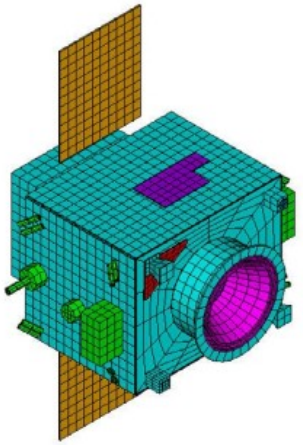
Orbit propagation…

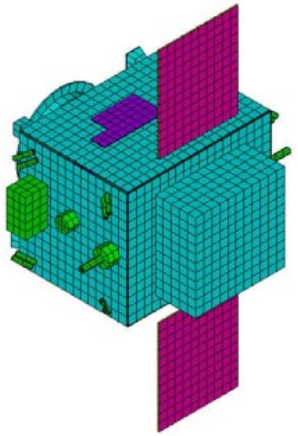
- Computation of the resulting disturbance forces and torques due to Solar radiation Pressure (SRP) based on the detailed geometry model of the satellite

$$\vec{F}_{\mathrm{SRP}} = \sum_i \vec{F}_i$$

$$\vec{F}_i = \int d\vec{F}_{\mathrm{total}}$$

$$= -P \int \left[(1-\gamma_S)\, \vec{e}_{\mathrm{Sun}} + 2 \left(\gamma_S \cos(\theta) + \frac{1}{3}\gamma_D \right) \vec{e}_N \right] \cos(\theta) dA$$





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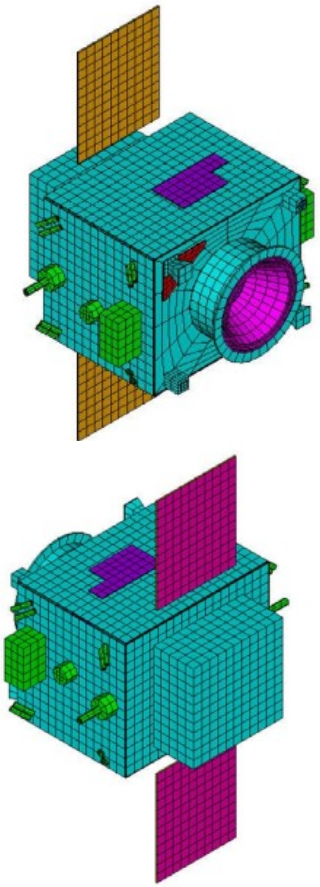
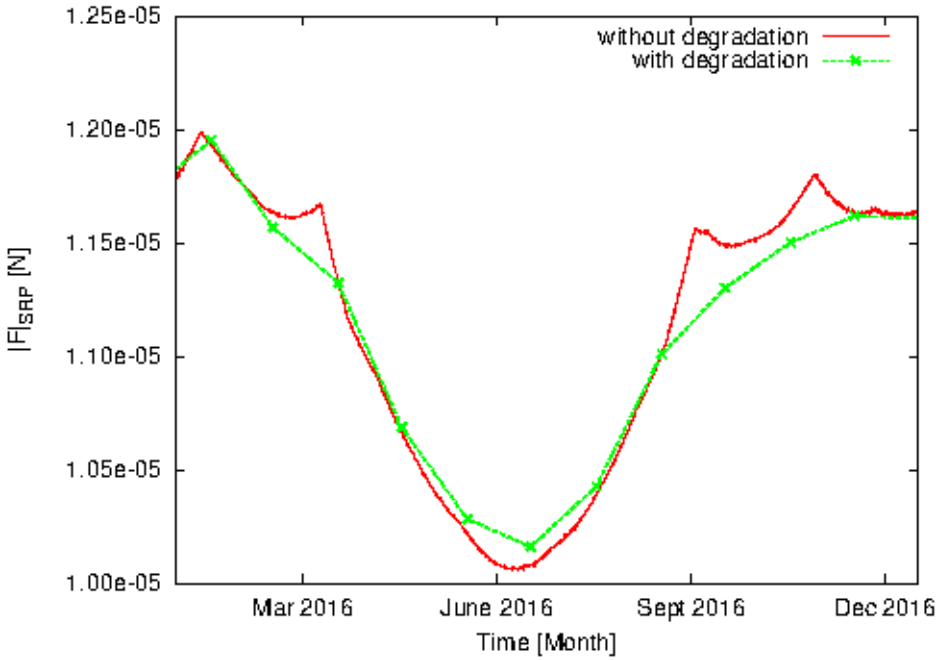
Orbit propagation...





$$\vec{F}_{\mathrm{SRP}} = \sum_i \vec{F}_i$$

Geometry

$$\vec{F}_i = \int d\vec{F}_{\mathrm{total}} = -P \int \left[(1 - \gamma_S)\vec{e}_{\mathrm{Sun}} + 2\left(\gamma_S \cos(\theta) + \frac{1}{3}\gamma_D\right)\vec{e}_N \right] \cos(\theta) dA$$

Material degradation (BOL ←→ EOL)

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Orbit propagation…

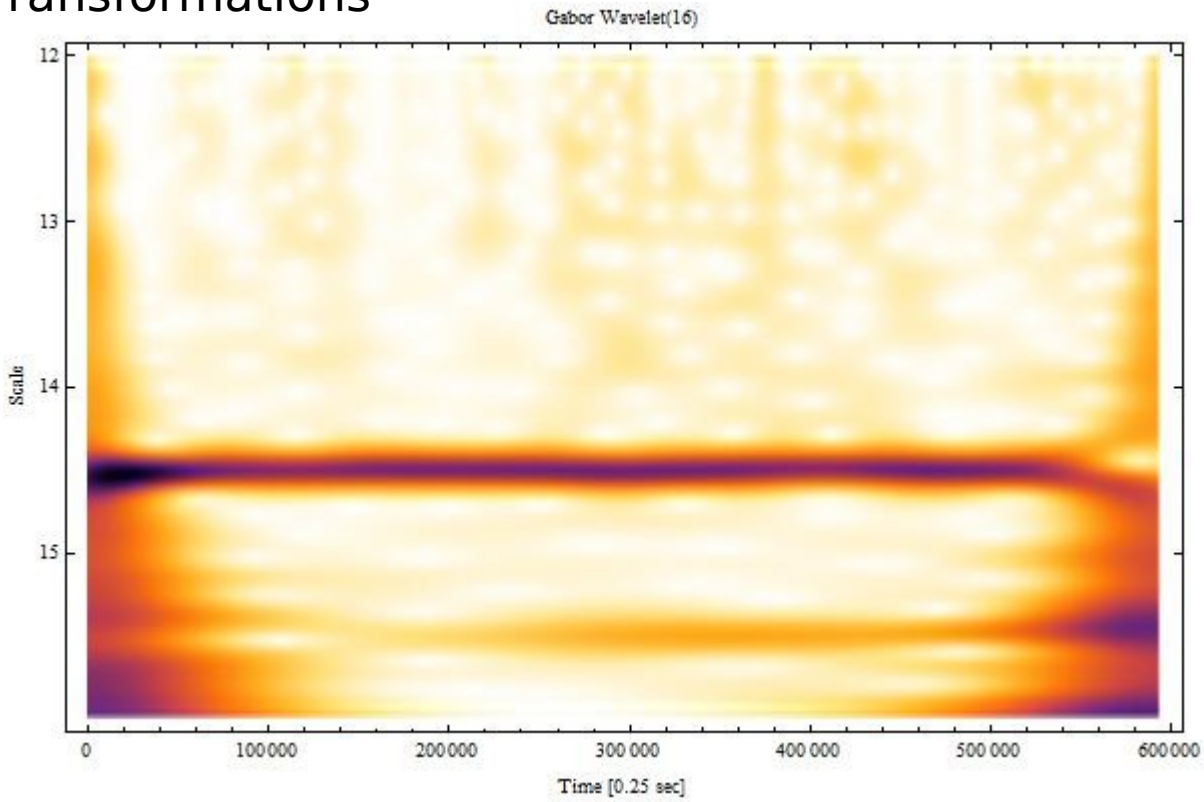
- ✓ Central task for developing mission analysis tools

- ✓ Satellite motion in the non-spherically symmetric gravitational field of the Earth (zonal and tesseral variations), Earth oblateness
  → non-spherically symmetric Earth gravitational field results in "gravitational disturbances" of the pure Keplerian orbit

- ✓ "Non-gravitational disturbances" have a large effect on satellite motion and its attitude, e.g.
  → Solar Radiation Pressure (SRP)
  "Modelling of solar radiation pressure effects: Parameter analysis for the MICROSCOPE mission", M. List, S. Bremer, B. Rievers, H. Selig, International Journal of Aerospace Engineering, Volume 2015, Article ID 928206 (2015).
  → Thermal Radiation Pressure (TRP)
  "Advanced Thermal Radiation Pressure modeling and its benefits for the MICROSCOPE mission", B. Rievers, M. List and S. Bremer, Proceedings of AIAA/AAS spaceflight mechanics meeting (2016).

… and data analysis methods

- Identification of temporal (non-stationary) disturbances by using Wavelet Transformations



- Time segments of the signal that are disturbed at the WEP-frequency can be excluded from the final analysis

Contents

- ✓ The MICROSCOPE mission
- ✓ Successful launch in April 2016...
- ✓ Orbit propagation and data analysis methods
- ✓ **Summary and outlook**

Summary and outlook

- ✓ MICROSCOPE was succesfully sent to orbit, all systems are subject to fixed calibration procedures
- ✓ After (i) the calibration and after (ii) the eclipse phase (eclipse phase ends in August 2016) the collection of science data will start (science data will be recorded for ca. 5300 orbits over 1 year + ???)
- ✓ Data processing and analysis procedures have been developed and installed within the Science Working Group (CNES, ONERA, OCA, ZARM)
- ✓ First results will be published as soon as possible!!!

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Thank you for your attention.

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DLR Deutsches Zentrum für Luft- und Raumfahrt

DFG Deutsche Forschungsgemeinschaft

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