Testing the Equivalence Principle - MICROSCOPE Colloquium III - 3-4 Nov 2014 Palaiseau (France)

Space environment simulations and free fall tests for MICROSCOPE

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Universität Bremen*

*EXZELLENT.
Gewinnerin in der Exzellenzinitiative

CENTER OF APPLIED SPACE TECHNOLOGY AND MICROGRAVITY

ZARM

Outline

- The MICROSCOPE-team at ZARM
- Free fall tests
  - ZARM catapult facility
  - MICROSCOPE payload tests
- Space environment simulation
  - High Performance Satellite Dynamics Simulator (HPS)
  - MICROSCOPE Orbit and attitude simulation

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Cooperation

- **CNES**
  Yves André,
  A. Robert et al.
- **ONERA**
  P. Touboul,
  M. Rodrigues et al.
- **OCA**
  G. Metris et al.
- **ZARM**
  C. Lämmerzahl,
  H. Selig et al.
- **PTB**
  F. Löffler,
  D. Hagedorn et al.

The MICROSCOPE-Team at ZARM

- ZARM is member of the Microscope SWG and SPG
- Co-I: Claus Lämmerzahl
- Project members: **- Free fall tests**

Hanns Selig
Andreas Gierse
Marcus Stadtlander

- Modelling and mission simulation

Stefanie Bremer
Meike List
Benny Rievers
Hanns Selig

funded by DLR Agency & DFG

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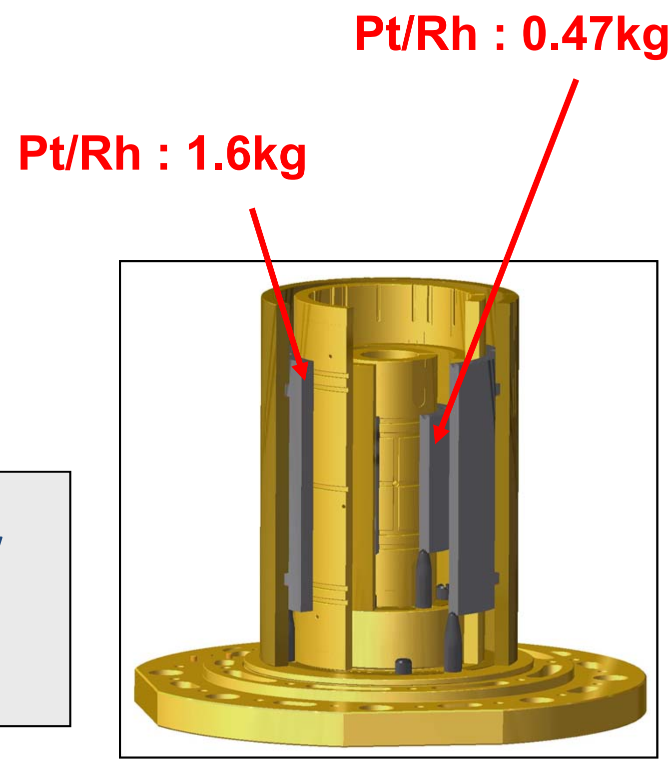
ONERA ULTRA SENSITIVE ACCELEROMETER - Testability on ground

Ultra sensitive accelerometers are optimised for the in orbit environment

⇒ operate within ranges up to 10^{-6} ms^{-2}

⇒ Reach performances of 10^{-12} ms^{-2}/sqrtHz: heavy test masses



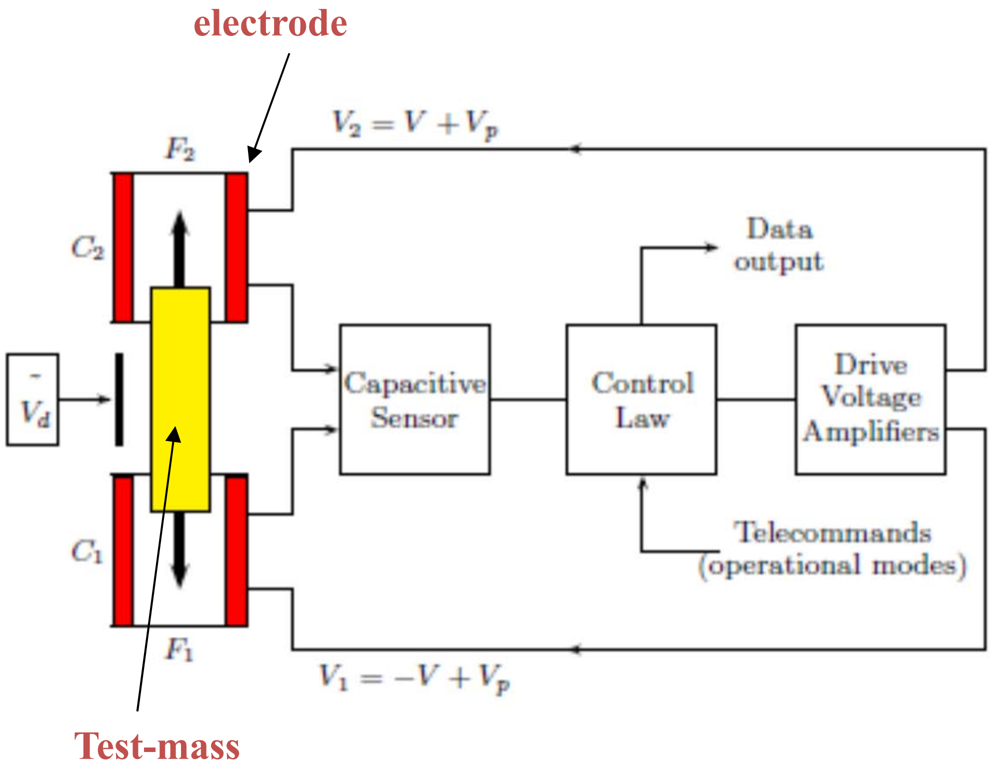
Their testability on ground requires creating a low gravity environment to verify their functionalities and partially their performances

⇓

Free fall tests are the only way to obtain such a microgravity environment that represent space conditions.

MICROSCOPE payload (Onera)

T-SAGE (Twin Space Accelerometer for Gravity Experiments)



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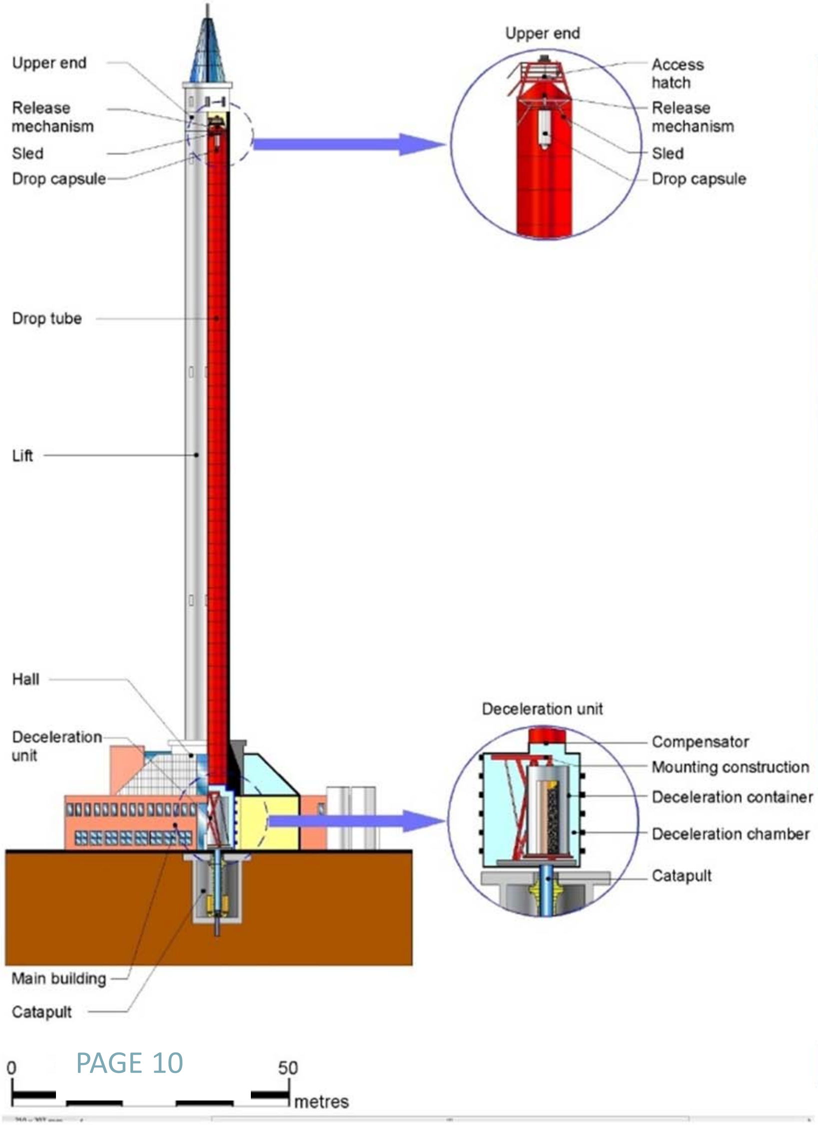
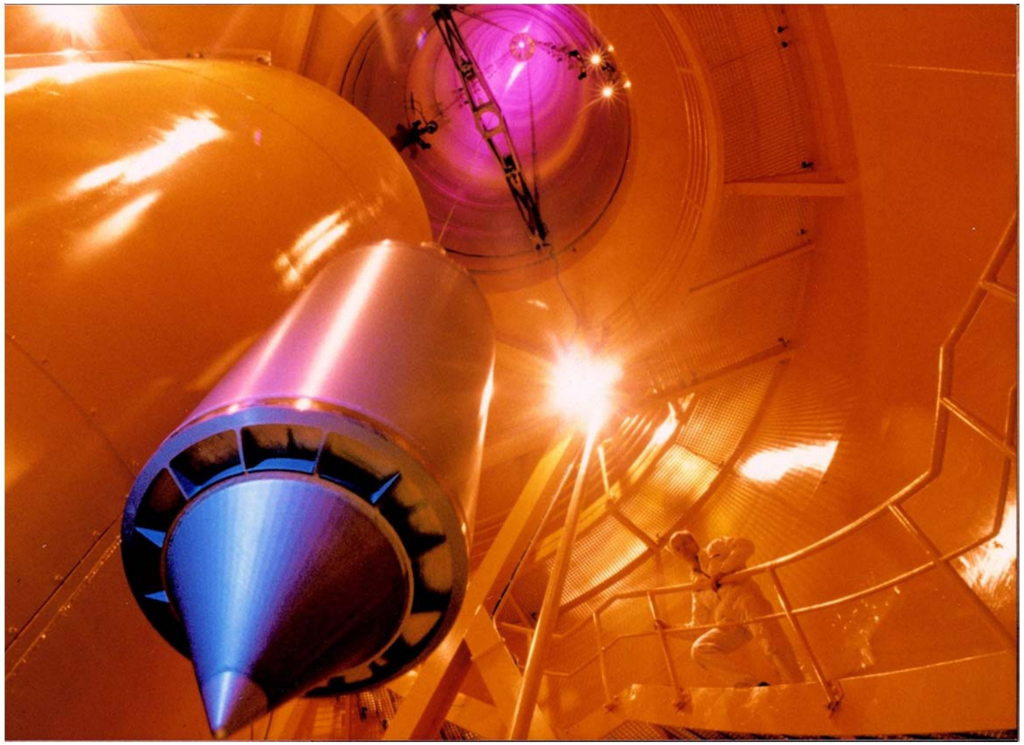
Free fall tests

ZARM Catapult system





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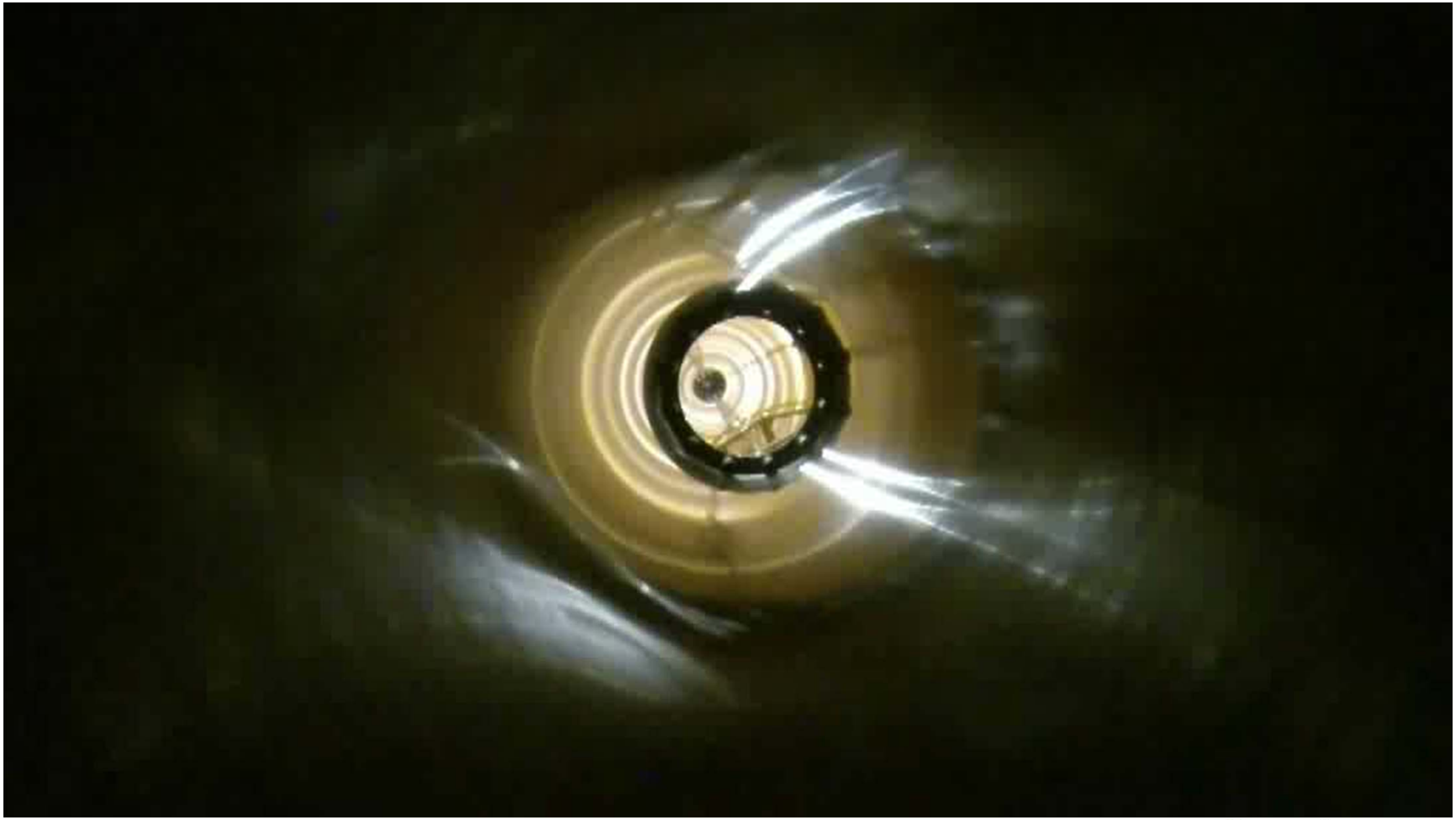
Free fall tests – ZARM Catapult



Free fall tests – ZARM Catapult

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MICROSCOPE DEVELOPMENT

- PRE QUALIFICATION TEST
  => Several drops in order to adjust the parameters to control the Proof Masses for all axis in the drop tower condition

- REFERENCE DROP

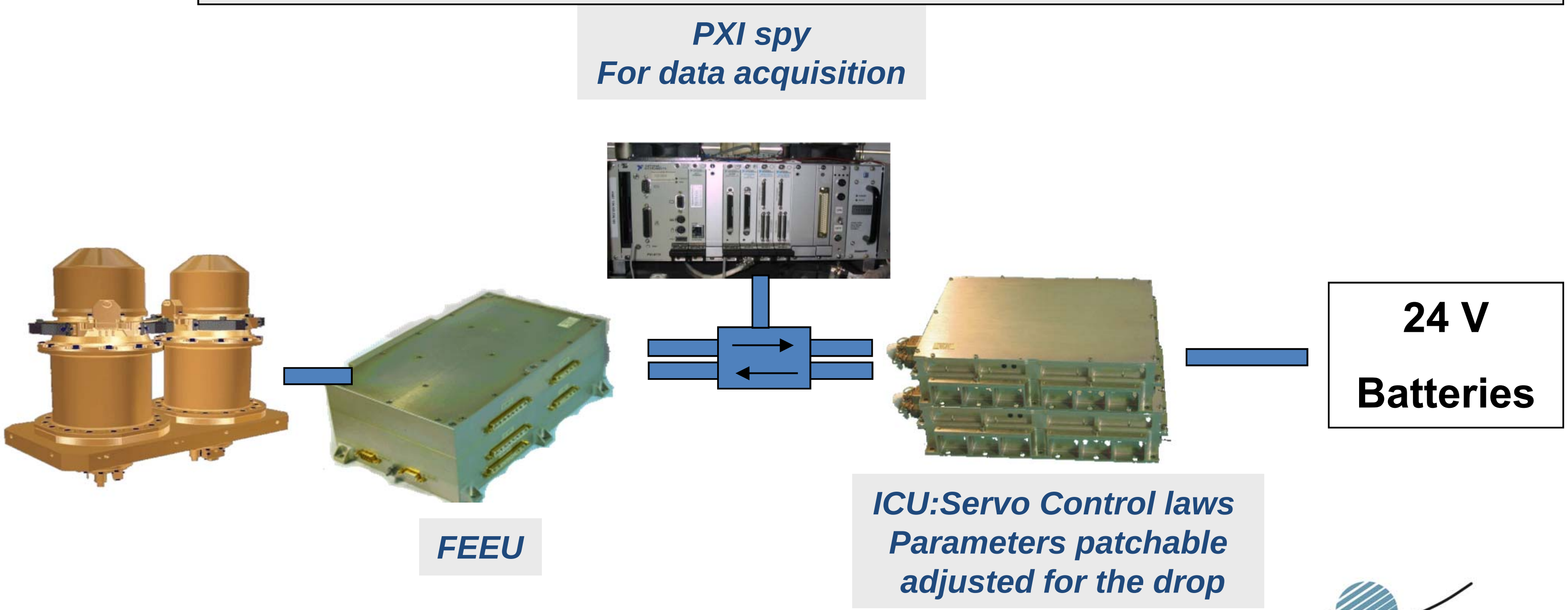
- ENVIRONMENTAL TEST
  - Vibration test
  - Thermal vacuum
  - Shock

- VERIFICATION DROP

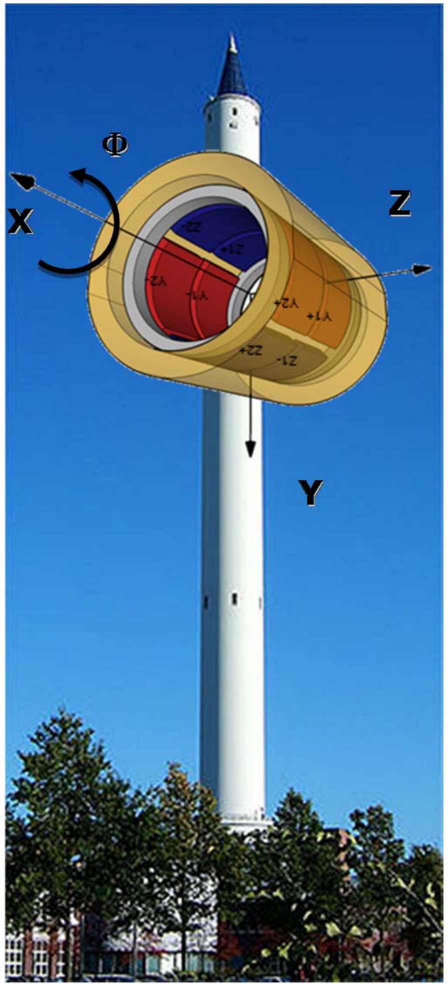
DROP TEST CONFIGURATION

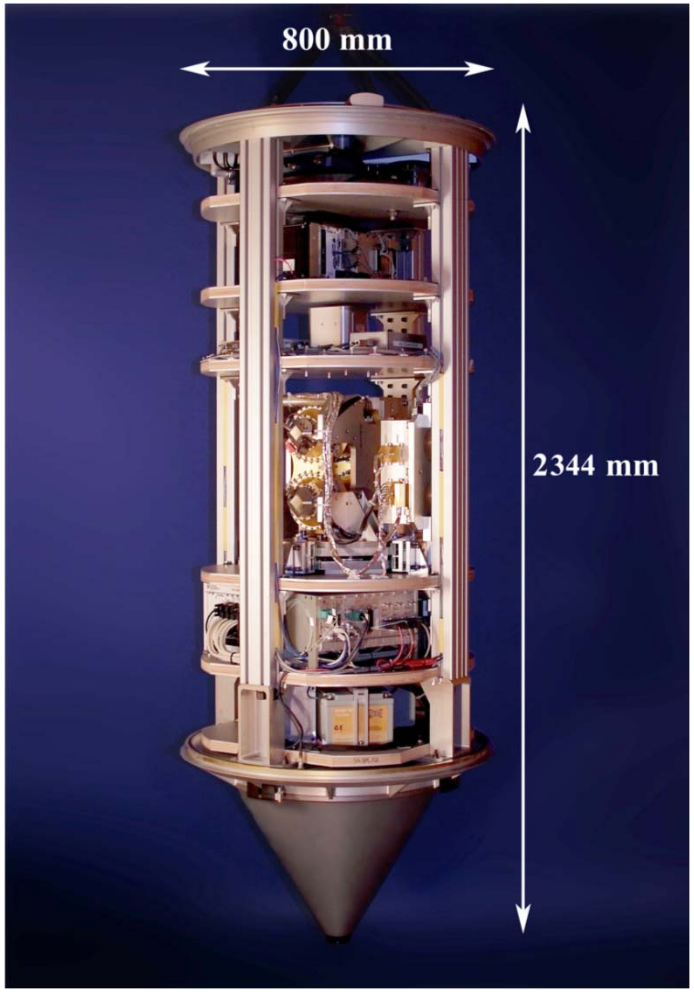
- **Data acquisition**

  Data, sampled at 1kHz, are acquired by the ICU from the FEEU via one bi-directional RS422 link at 1.25Mbaud. A spy line has been implemented from this link to an acquisition and storage system in order to collect data during the drop.



Capsule integration: Drop in Y direction





- Optimisation of the capsule balance is a key point in the experiment preparation

=> part of the residual atmospheric drag can be transferred from the fall axis to axis of the horizontal plane.

Perturbation minimization

- Vibration damping
- No moving parts
- No “rotating” harddiscs
- Switch off on board computer fans

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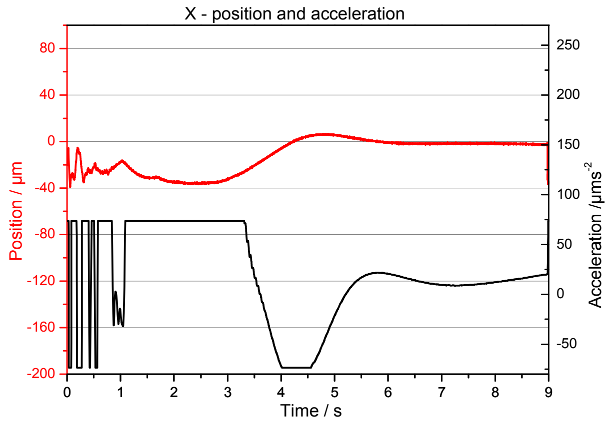
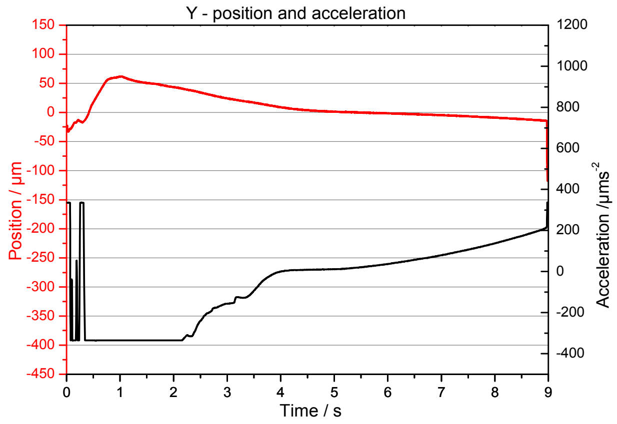
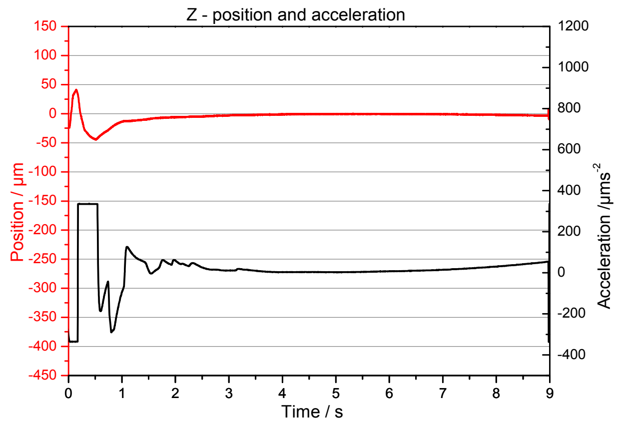
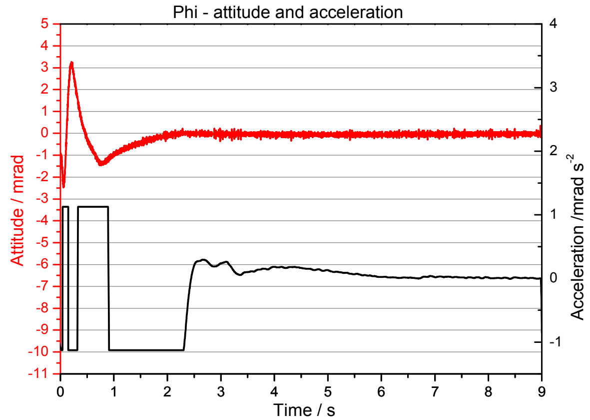
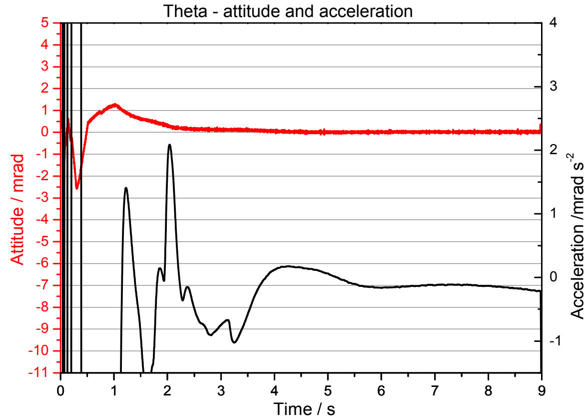
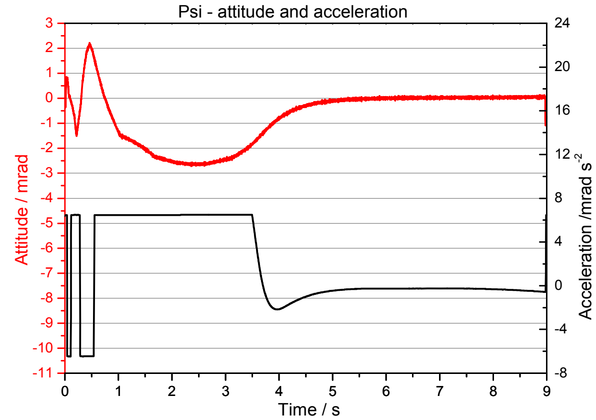

X - position and acceleration
Position / µm
Acceleration /µms-2
Time / s

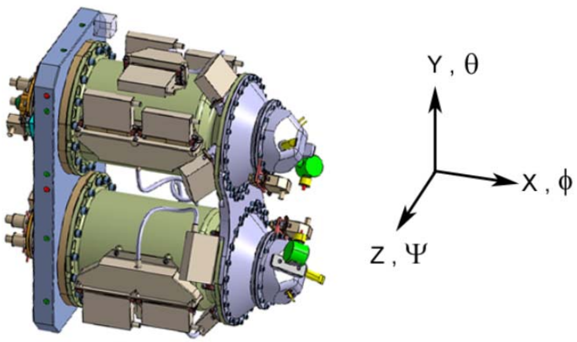

Y - position and acceleration
Position / µm
Acceleration /µms-2
Time / s


Z - position and acceleration
Position / µm
Acceleration /µms-2
Time / s


Phi - attitude and acceleration
Attitude / mrad
Acceleration /mrad s-2
Time / s


Theta - attitude and acceleration
Attitude / mrad
Acceleration /mrad s-2
Time / s


Psi - attitude and acceleration
Attitude / mrad
Acceleration /mrad s-2
Time / s


Y , θ
X , ϕ
Z , Ψ

Conclusion for the MICROSCOPE mission

The free fall tests have demonstrated the function of the instrument by confirming good operations of the twelve electrostatic digital loops in micro gravity and the good reliability and robustness of the configuration.

Sensor free fall test and qualification at ZARM is meanwhile a well established procedure.

The facility is also used for the test and qualification of the Grace-FO payload. The first campaign started in Sept. 2014.

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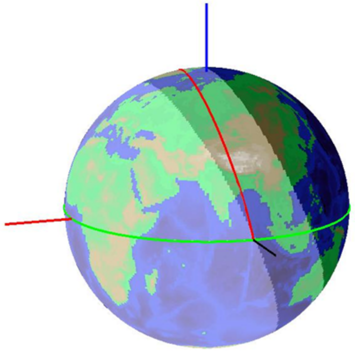
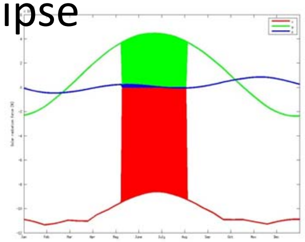
Simulating a space mission

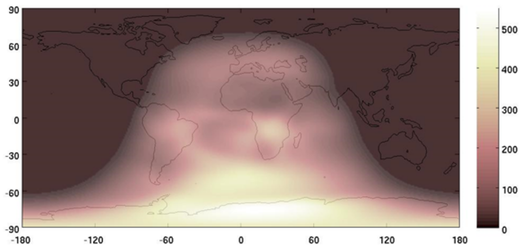
Orbit dynamics

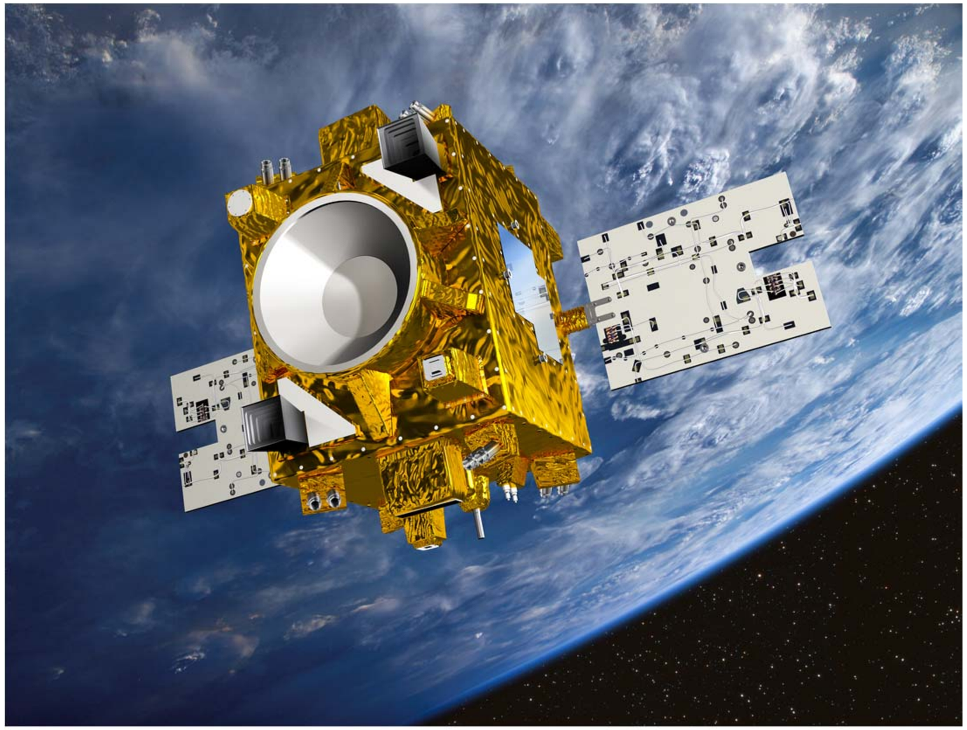


Solar radiation pressure including eclipse



Albedo





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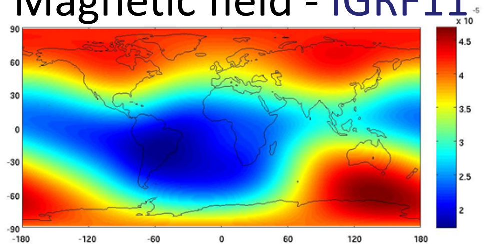
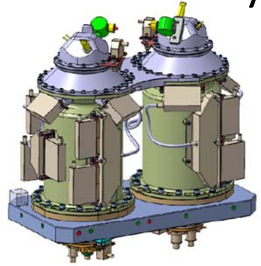
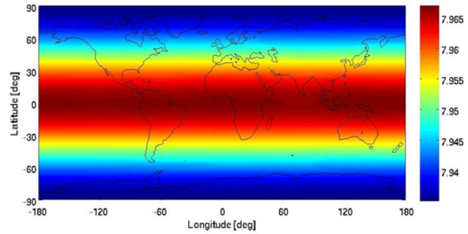
Magnetic field - IGRF11



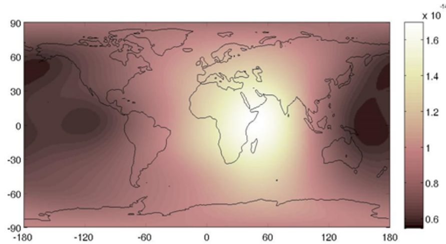
Special requirement for MICROSCOPE:
Test mass dynamics



Gravity field



Atmospheric drag



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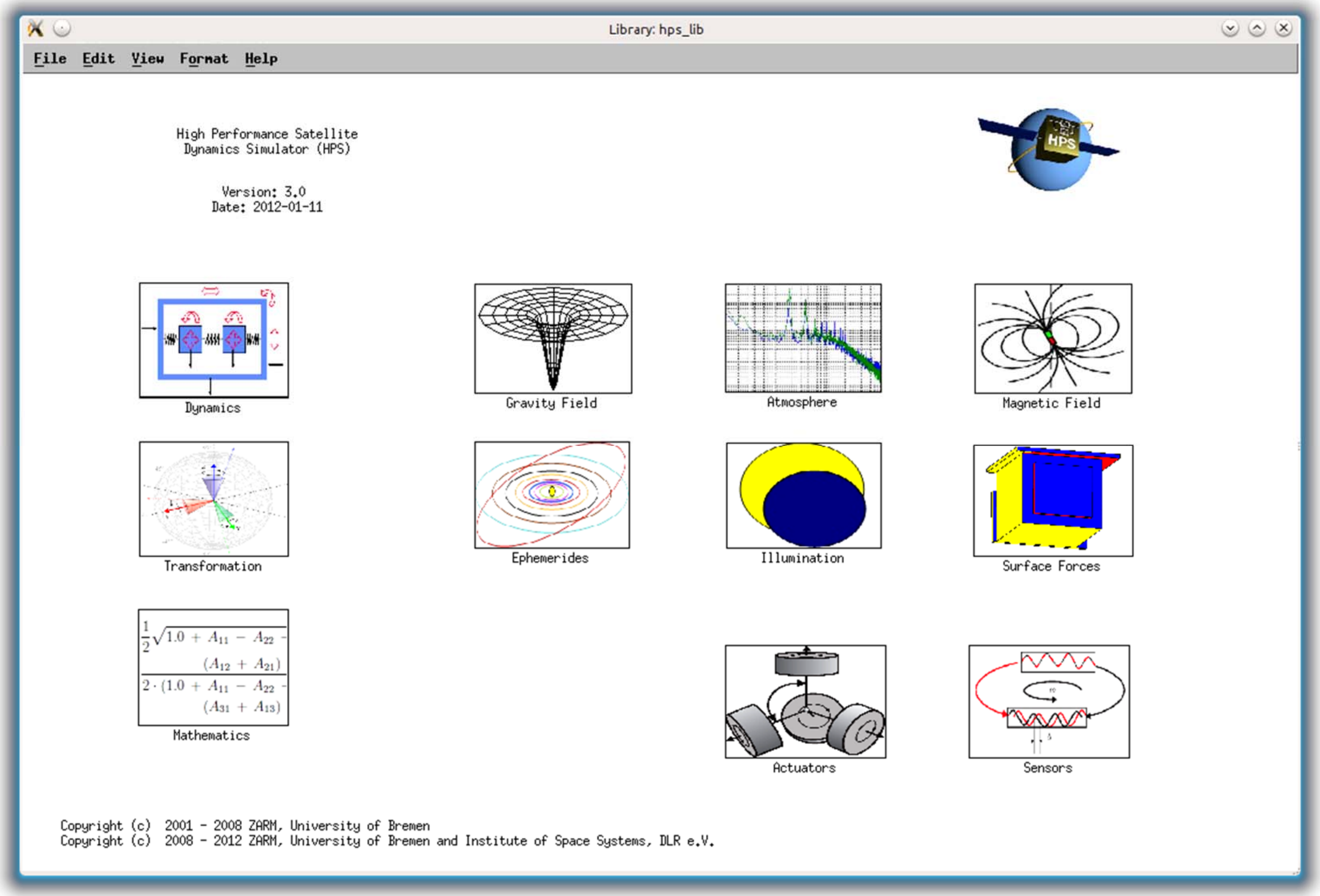
High Performance Satellite Dynamics Simulator



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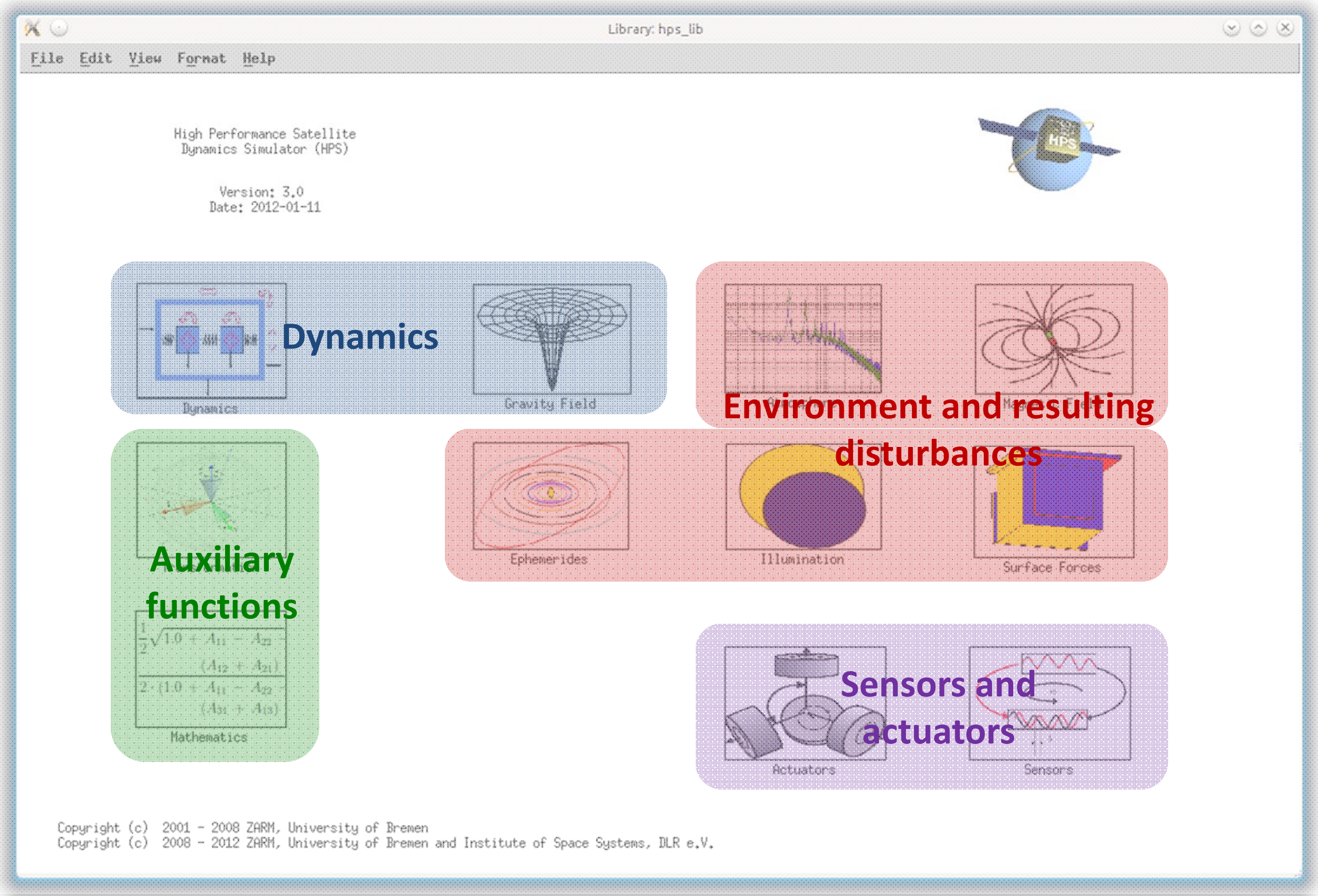
High Performance Satellite Dynamics Simulator



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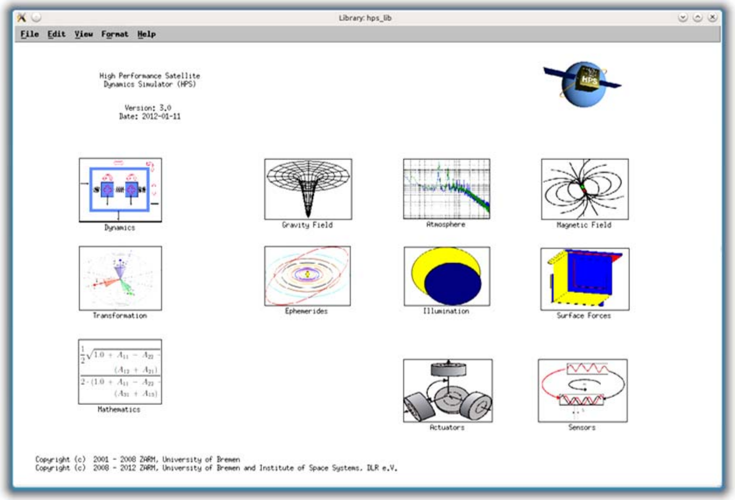
High Performance Satellite Dynamics Simulator

Two major applications for MICROSCOPE:

- Utilising the HPS in order to characterise the mission environment → Preparation of the data analysis
- Validation of the formulation and simulation of the test mass dynamics



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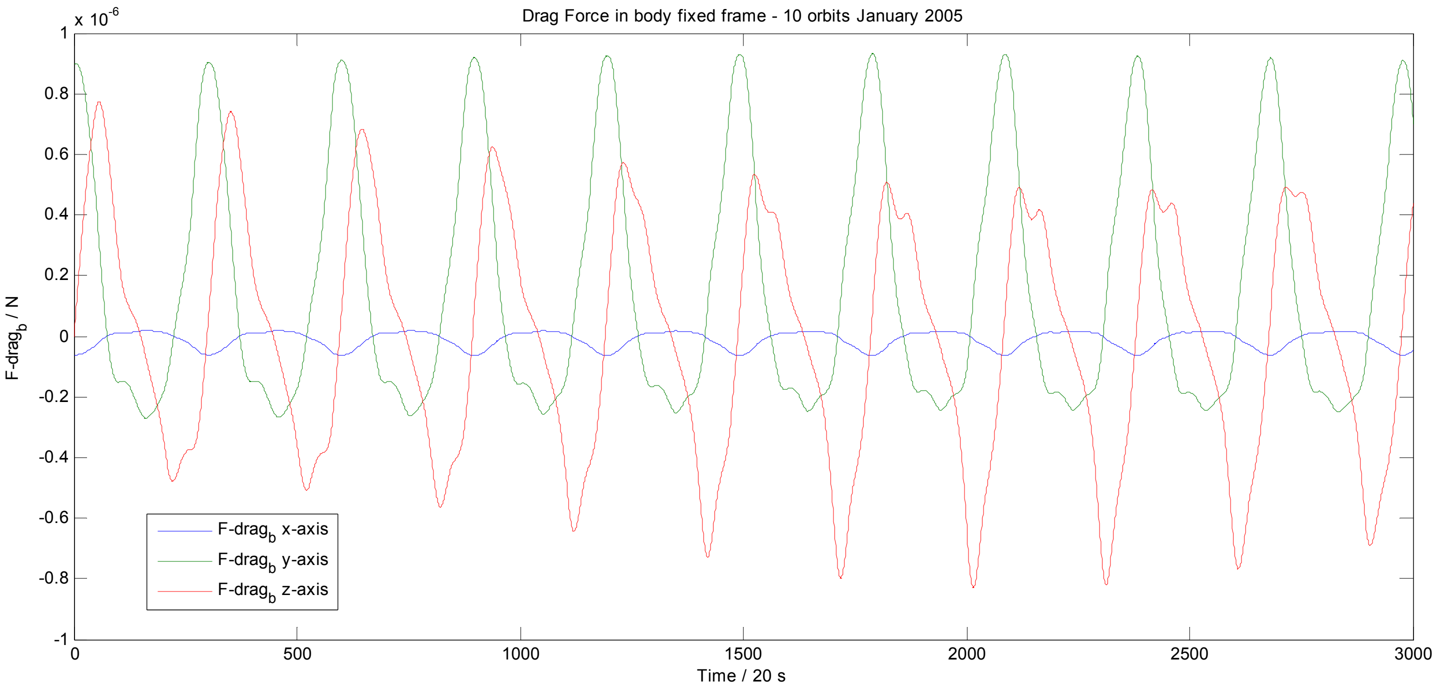
Example: Simulation of atmospheric drag force

NRLMSIS-00 Atmosphere density model

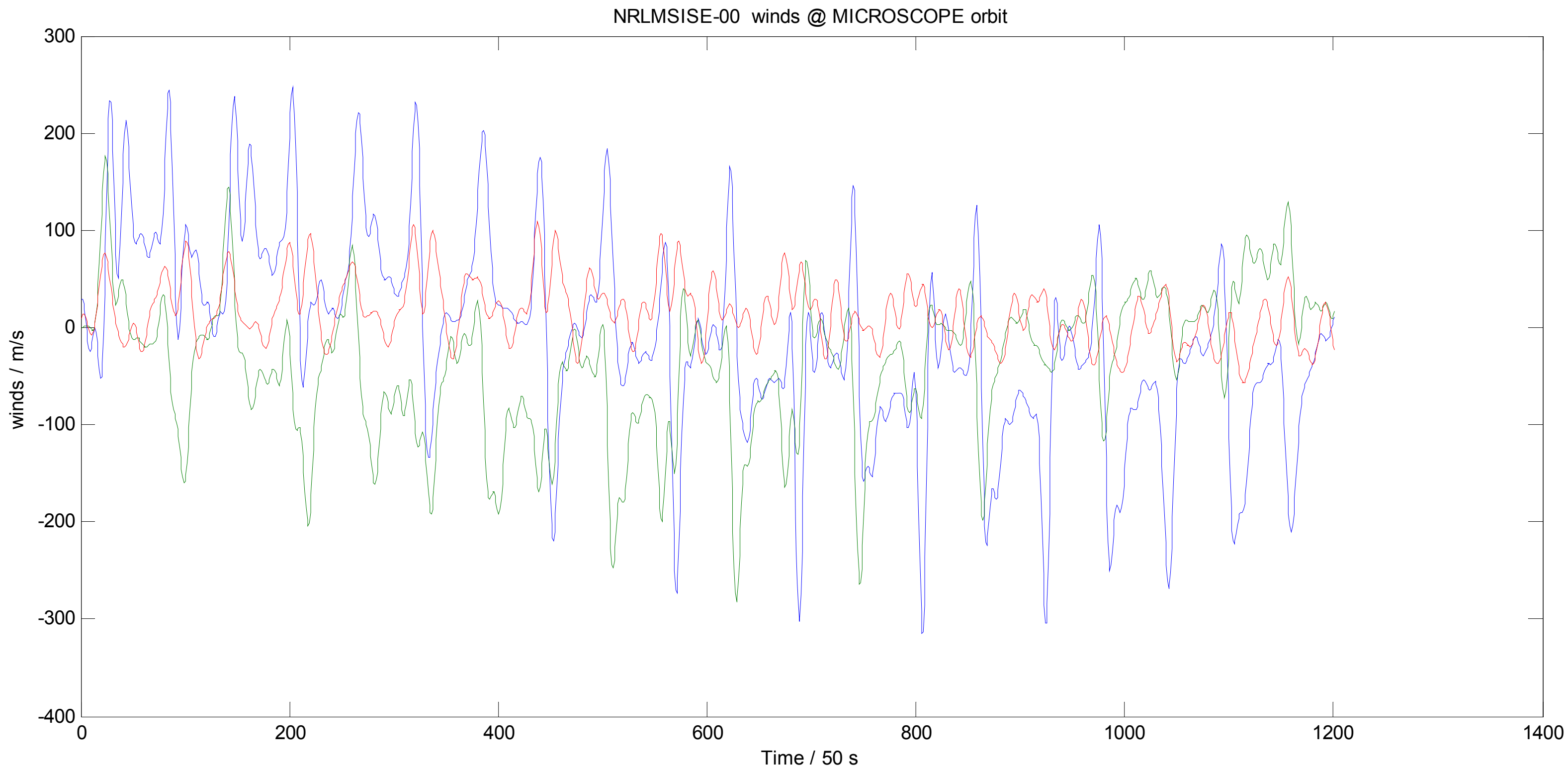
Drag force @ MICROSCOPE orbit (10 orbits) body fixed frame



Example: Simulation of atmospheric drag force

NRLMSIS-00 Atmosphere density model

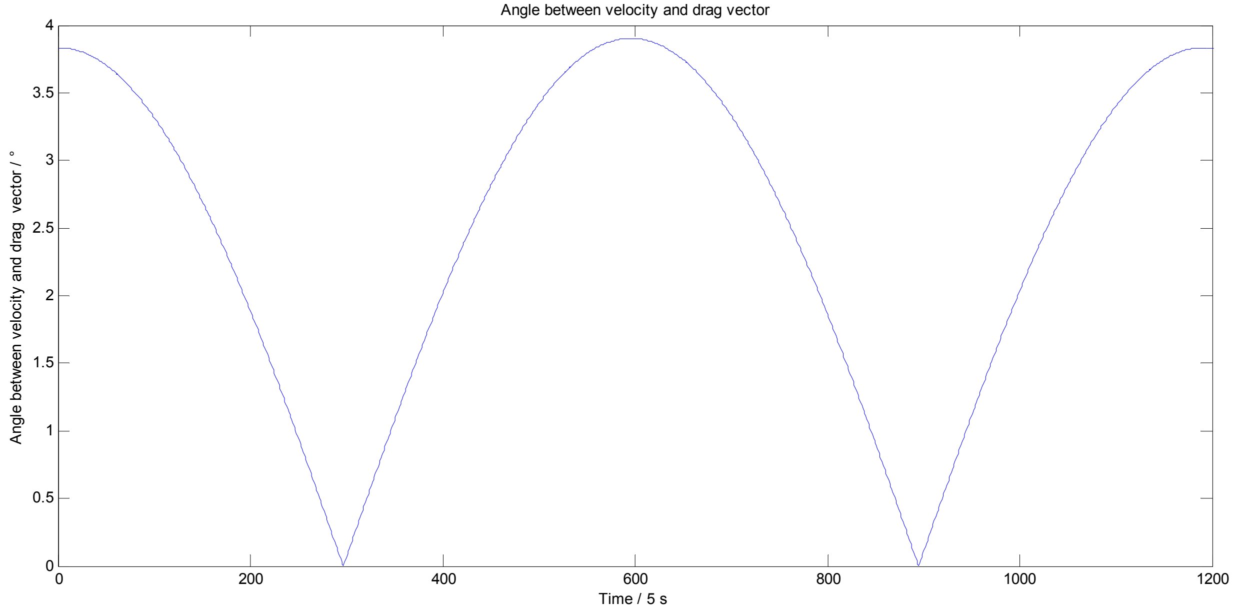
winds @ MICROSCOPE orbit (10 orbits)

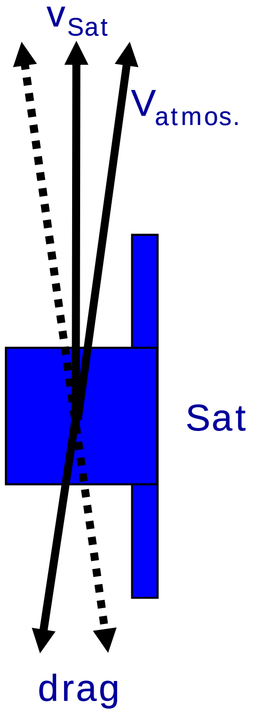


Example: Simulation of atmospheric drag force

Angle between velocity and drag vector due to co-rotating atmosphere

max. 3.9° @ 0° latitude





Angle between velocity and drag vector due to winds:

max. 2.35° => worst case: 3.9° + 2.35° = 6.25°

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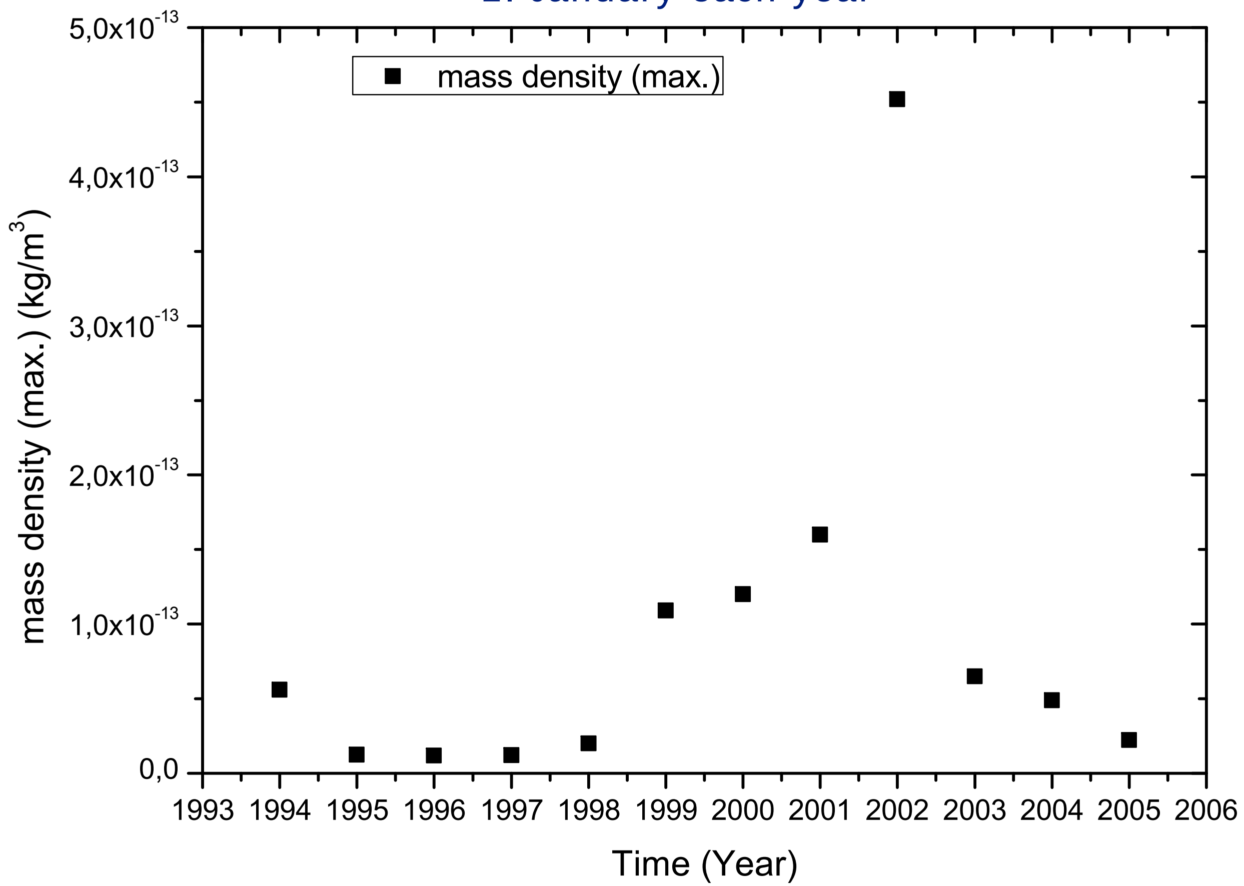
Example: Simulation of atmospheric drag force

NRLMSIS-00 Atmosphere density model – MICROSCOPE orbit solar cycle effect

1. January each year



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MICROSCOPE orbit simulation

- Simulation setup:
  - Sun-synchronous orbit with ascending node at 18h local time
  - Altitude of 700 km
  - Inclination of 98.248°
  - Simulation of long-term measurement sessions (120 orbits, no spinning)

- Investigation of orbit accuracy:
  - Example: Selection of gravity field model

→ Trade-off between accuracy and time consumption

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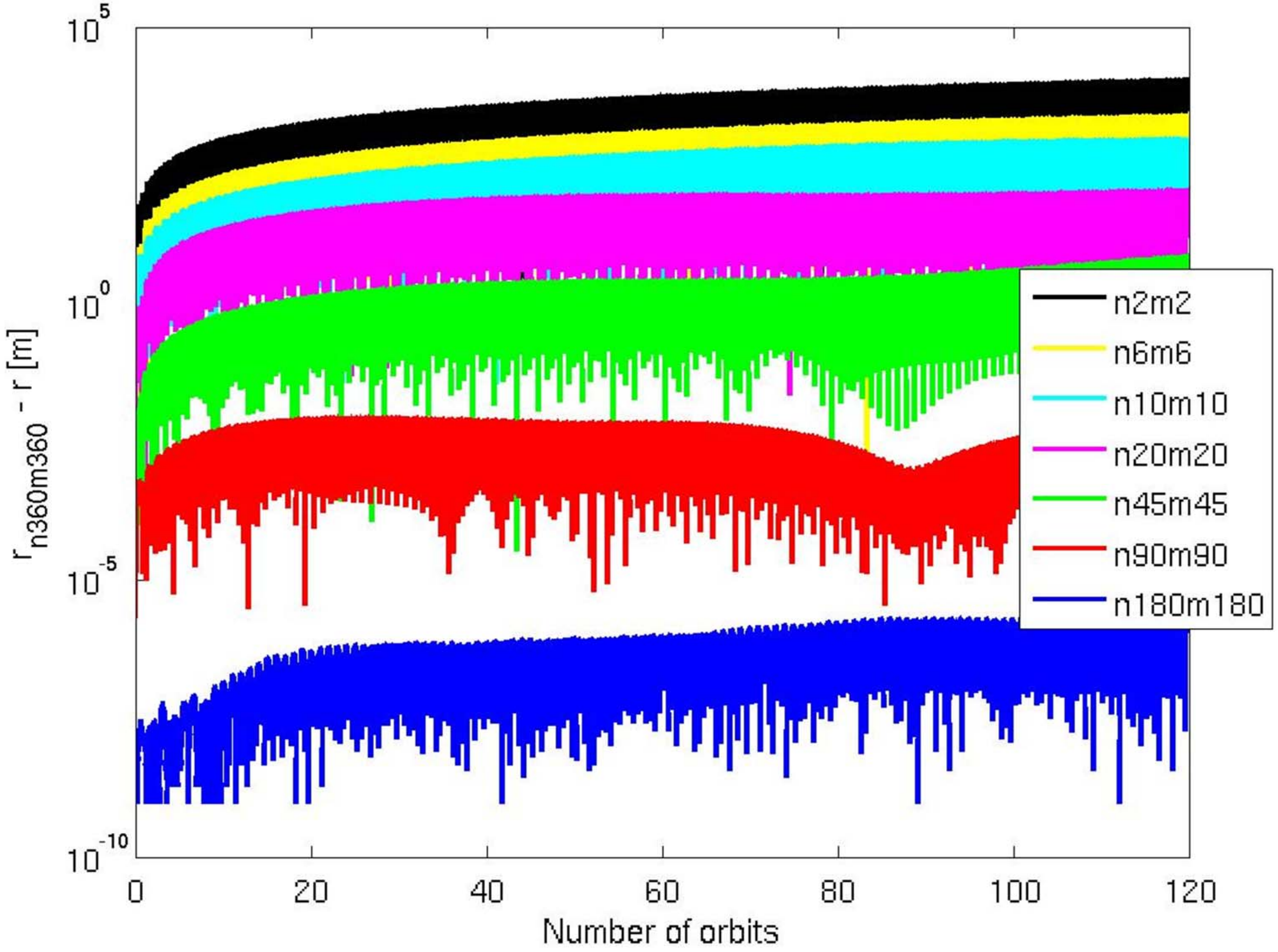
Variation of gravity field model



EGM2008 with n = m = 360 is taken as reference (simulation time 2 h)

Compromise: n = m = 45, deviation of about 10 m, simulation time 2 min)

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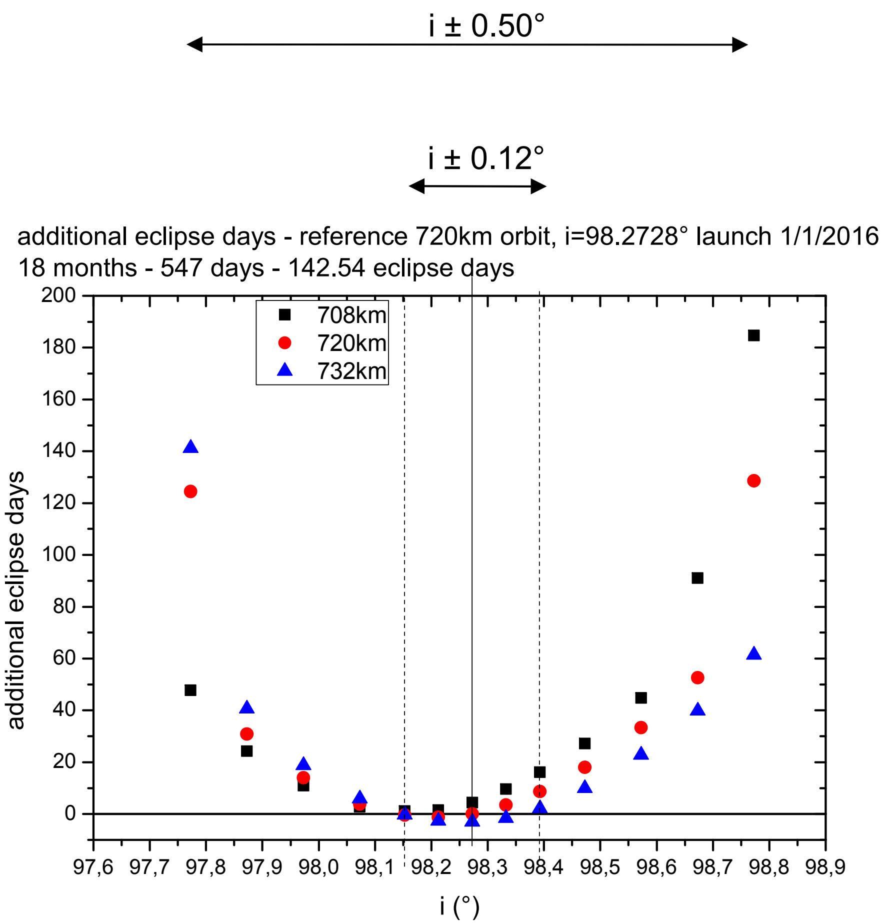
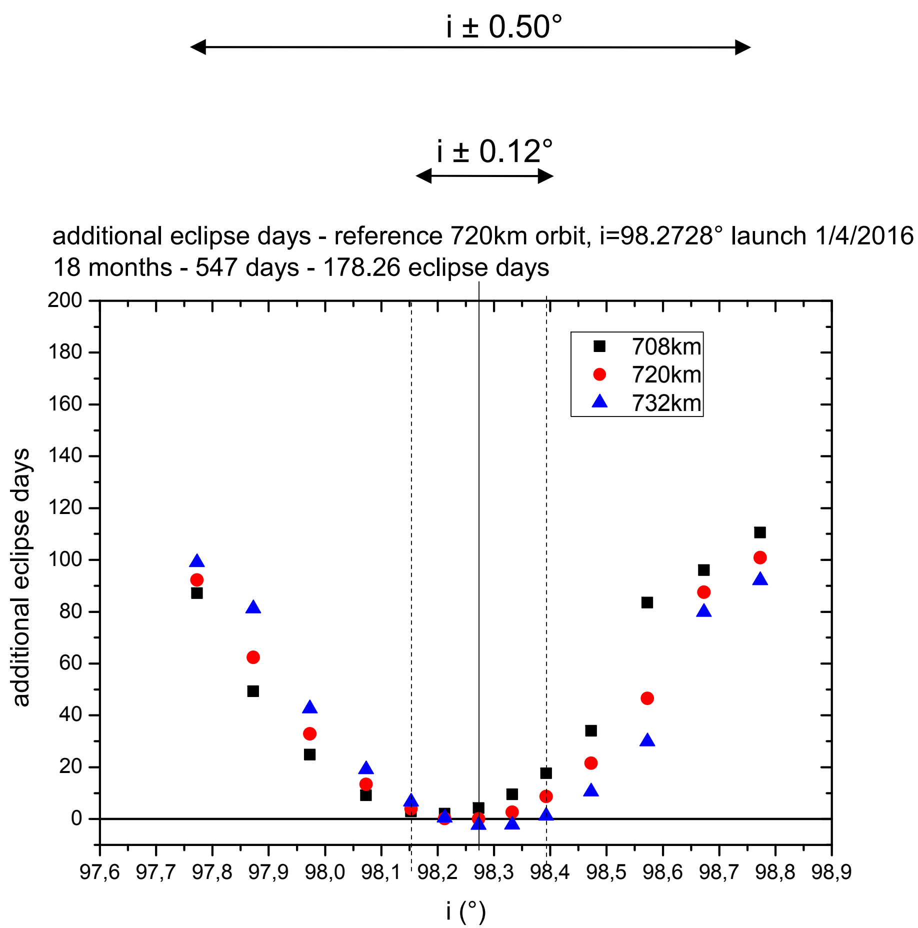
Variation of orbit parameters – eclipse phases





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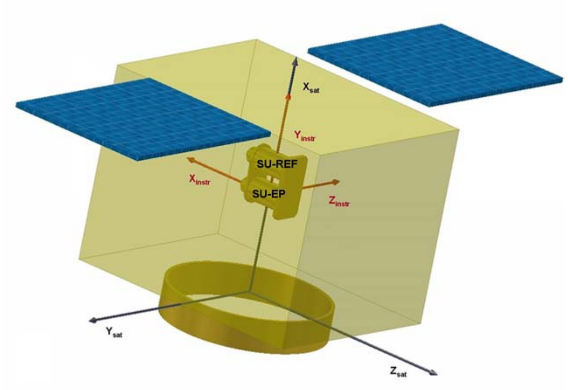
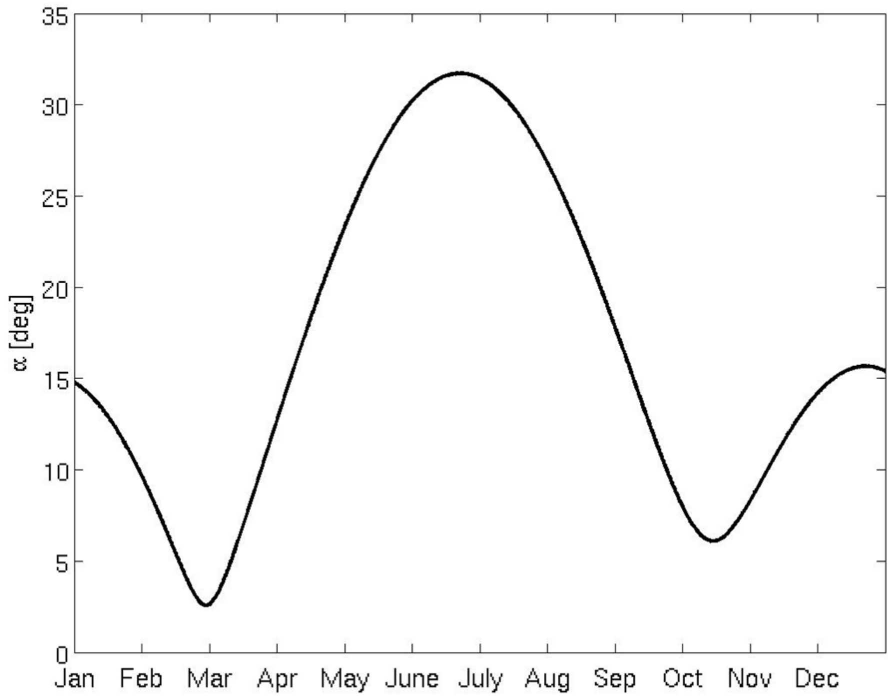
Attitude simulation

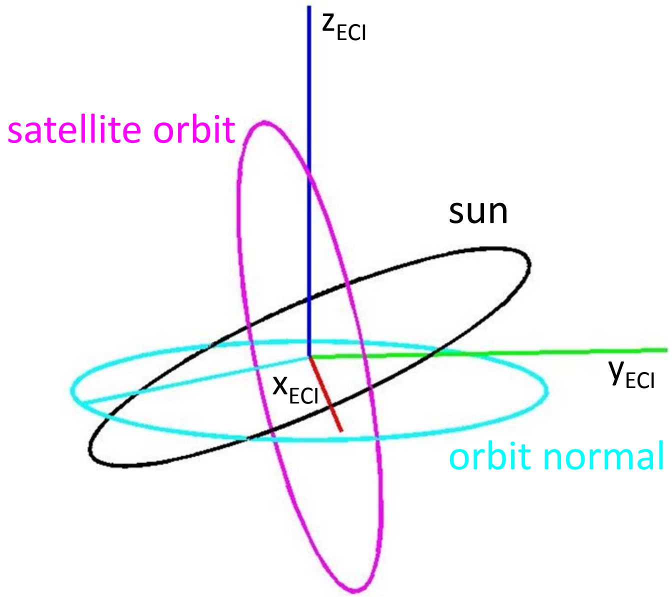
- X_{sat} is aligned with the orbit normal
- Z_{sat} is aligned with the vector to the satellite's starting point which is placed in the equatorial plane
- Y_{sat} is given as cross product of X_{sat} and Z_{sat}



The MICROSCOPE mission design envisages that X_{sat} is always aligned with the orbit normal.

Angle between vector to the sun and orbit normal





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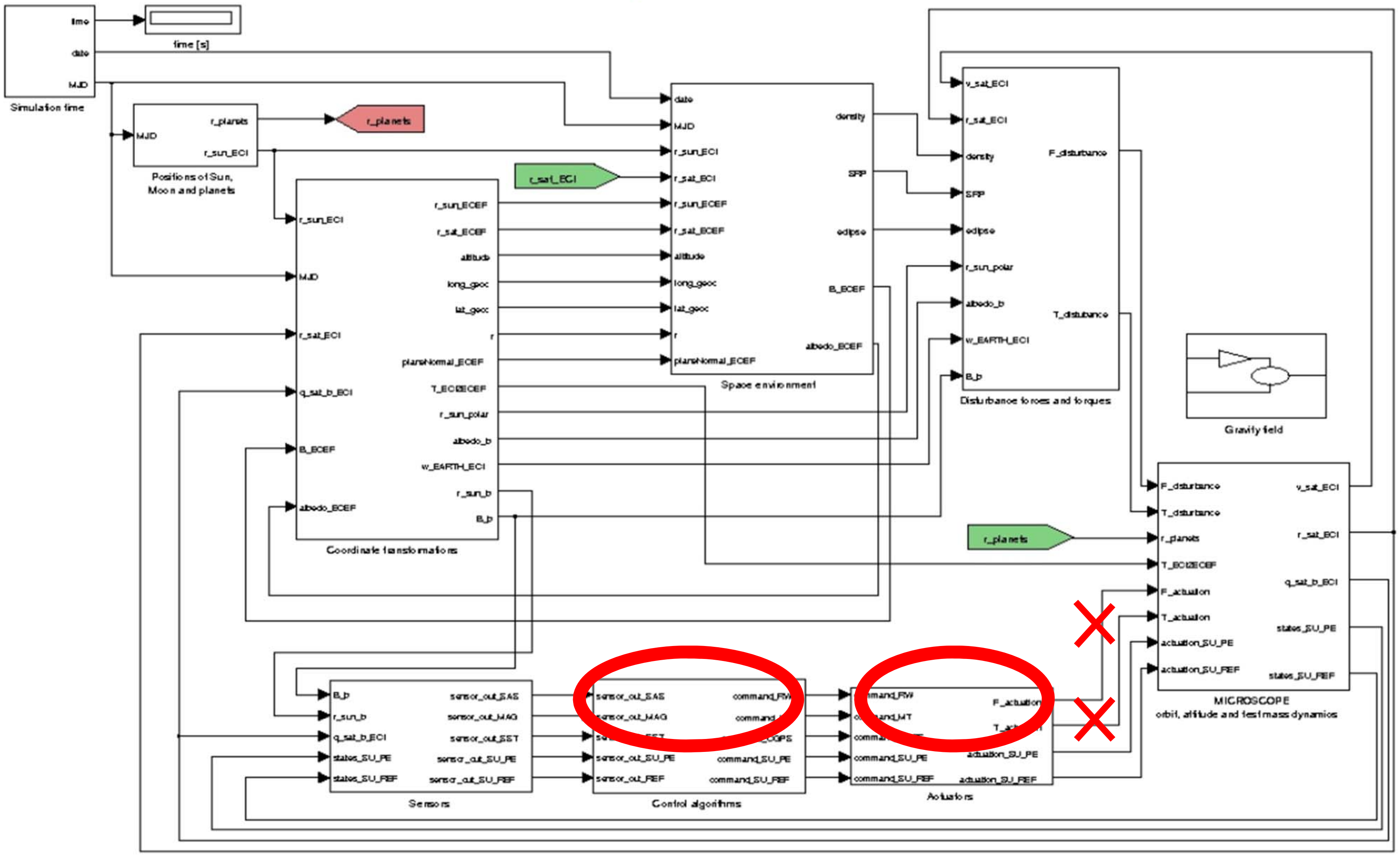
Microscope Simulator



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Outlook

- Closed loop simulation (including DFACS)
  - Additional models needed:
    - Drag free controller model
    - Thruster (CGT) model
- Generation of simulated mission data (calibration and science sessions)

  for the mission data processing and analysis preparation
- Contribution to the preliminary and final mission data analysis

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Summary

- Simulations of space missions require a variety of models
- High Performance Satellite Dynamics Simulator offers possibility to account for multibody dynamics simulations
- Simulations are always a trade-off between accuracy and simulation time
- Each simulation has to be optimised to the current requirements
- Full closed loop simulations can be performed as soon as additional needed models (DFACS) are implemented in the HPS tool

Thank you for your attention.

Supported by:

Federal Ministry
of Economics
and Technology

on the basis of a decision
by the German Bundestag

This work is supported by the German
Space Agency of DLR with funds of the
BMWi (FKZ 50 OY 1305)
& The German Research Foundation DFG.

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