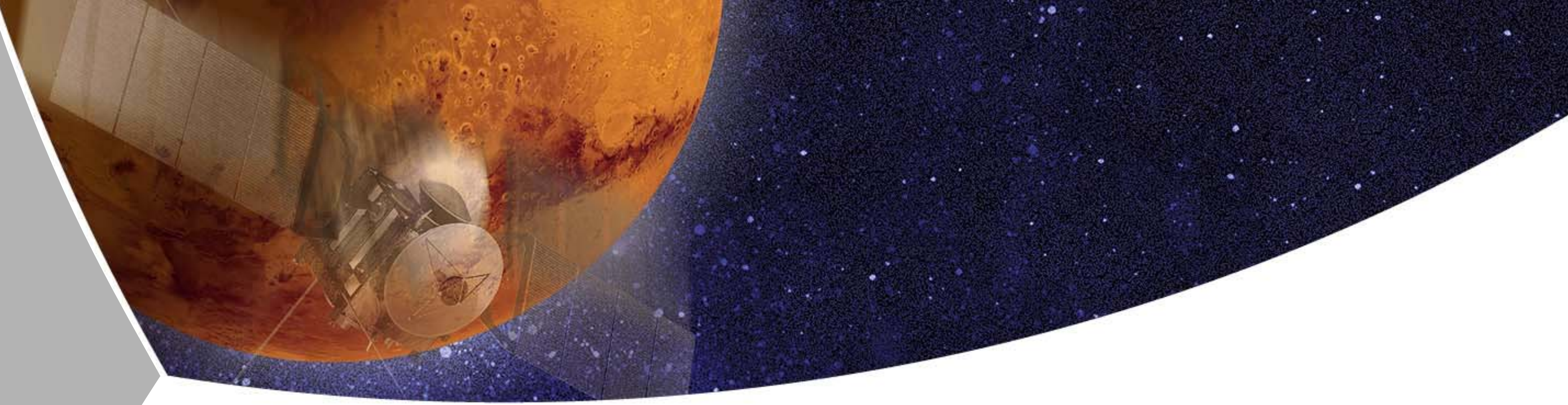


The DLR-Institute of Space Systems (DLR-RY) and Fundamental Physics

Hansjörg Dittus

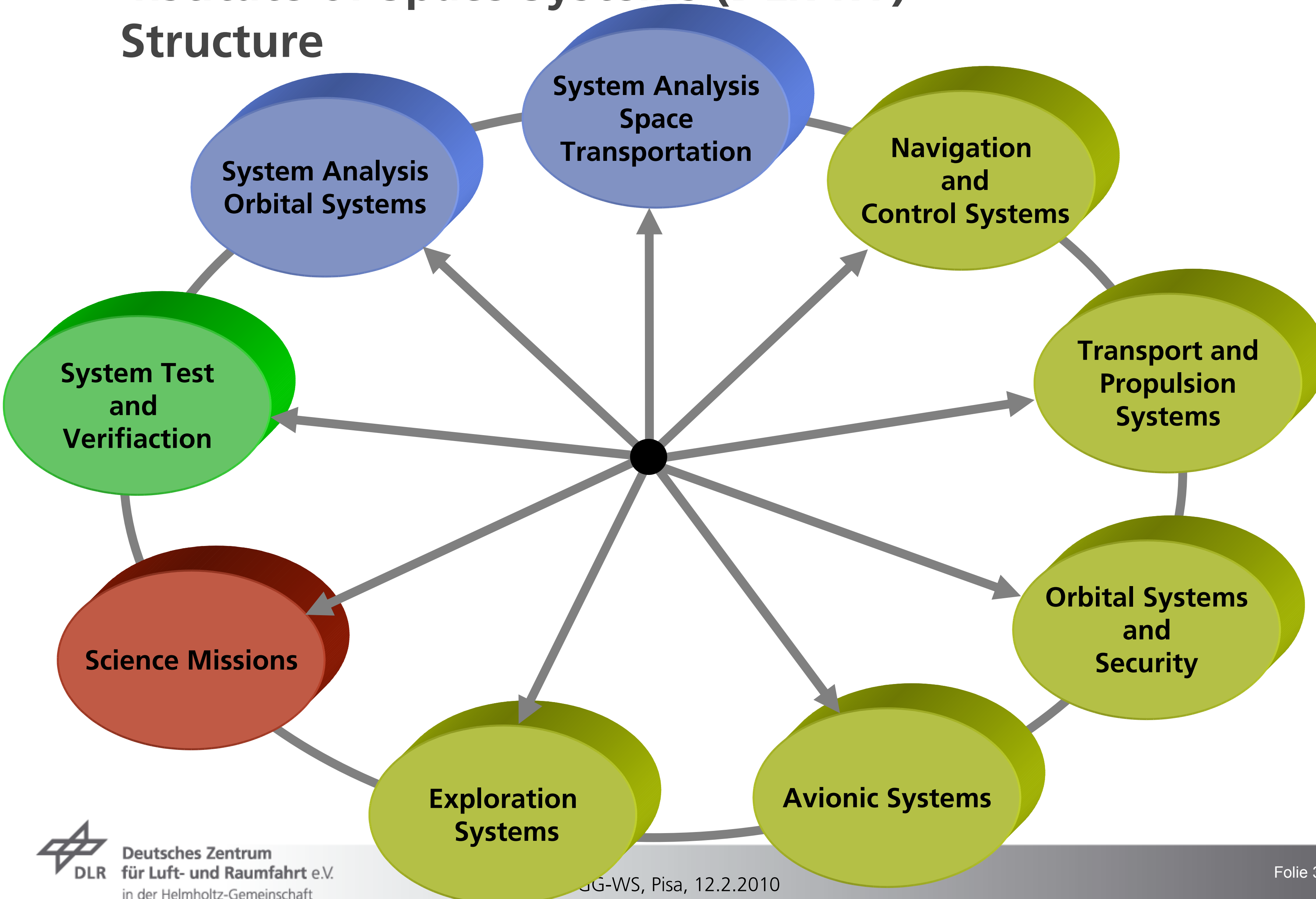
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Institute of Space Systems
Mission

…………

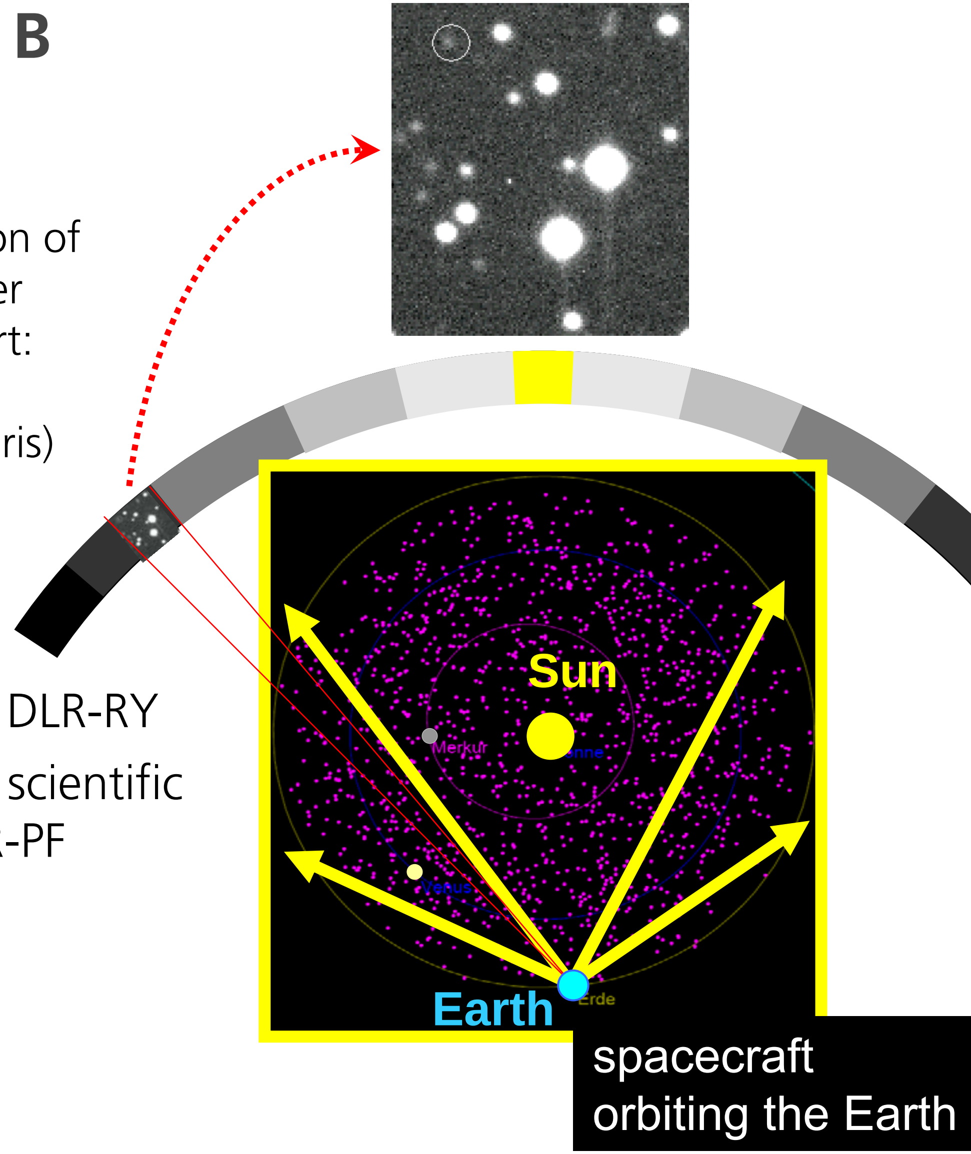
……The Institute develops concepts for innovative space missions on high national and international standard. Space based applications needed for scienctific, commercial and security-relevant purposes will be developed and carried out in cooperative projects with other research institutions and industry……………

Institute of Space Systems (DLR-RY) Structure



AsteroidFinder / Start Phase B

Mission statement:
TheAsteroidFinder Mission observes the population of Near Earth Objects (NEOs), in particular IEOs (Inner Earth Objects / Interior to Earth's orbit objects) wrt:
- Number of objects
- Orbit distribution and orbit parameters (ephemeris)
- Scale distribution



- System Lead, Institute of Space Systems, DLR-RY
- Instrument development (telescope) and scientific lead, Institute of Planetary Research, DLR-PF
- 6 more DLR Institutes contributing: RM, RB, DFD, FA, ME, SC
- Scheduled launch: 2012

AsteoridFinder

Sun shield

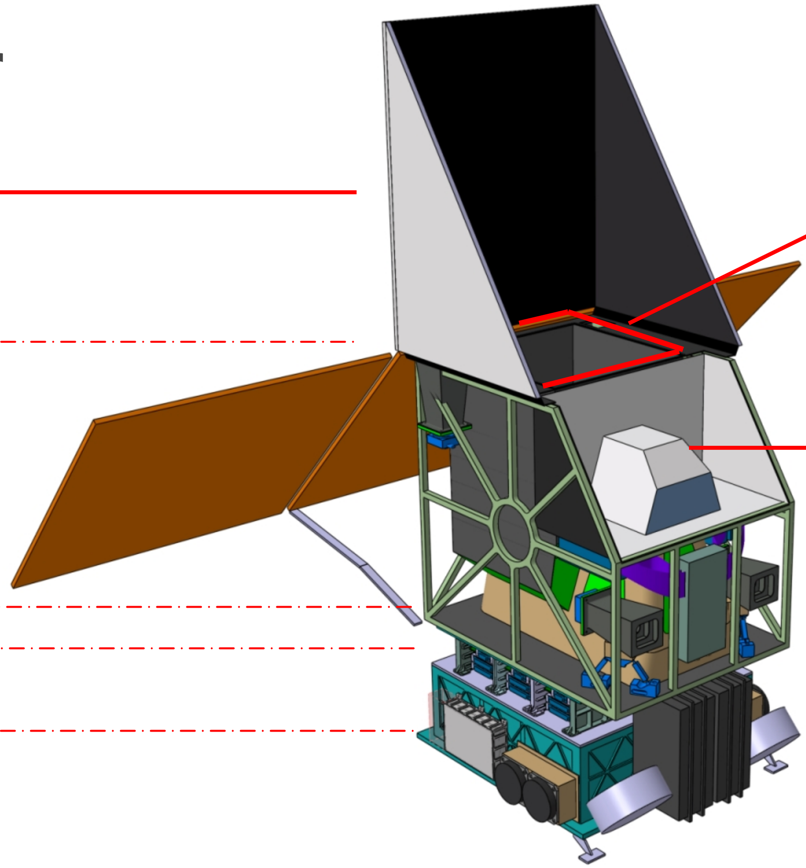
Telescope apertur

Payload segment

Radiator
(Sensor)

Elektronic segment

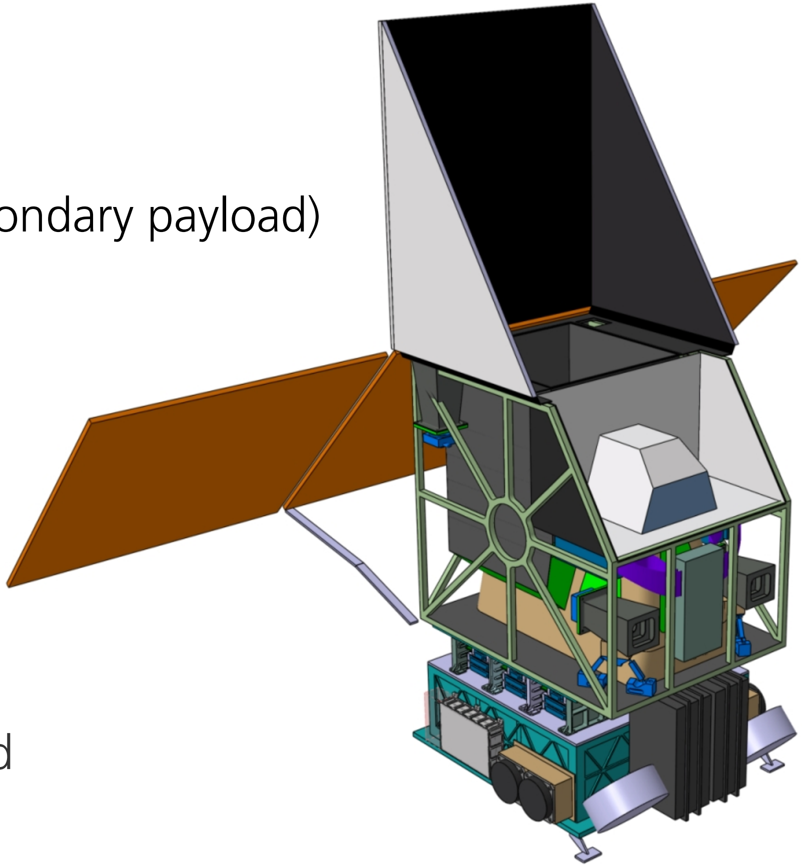
Service segment
(Batteries, Reaction wheels, Antennas)



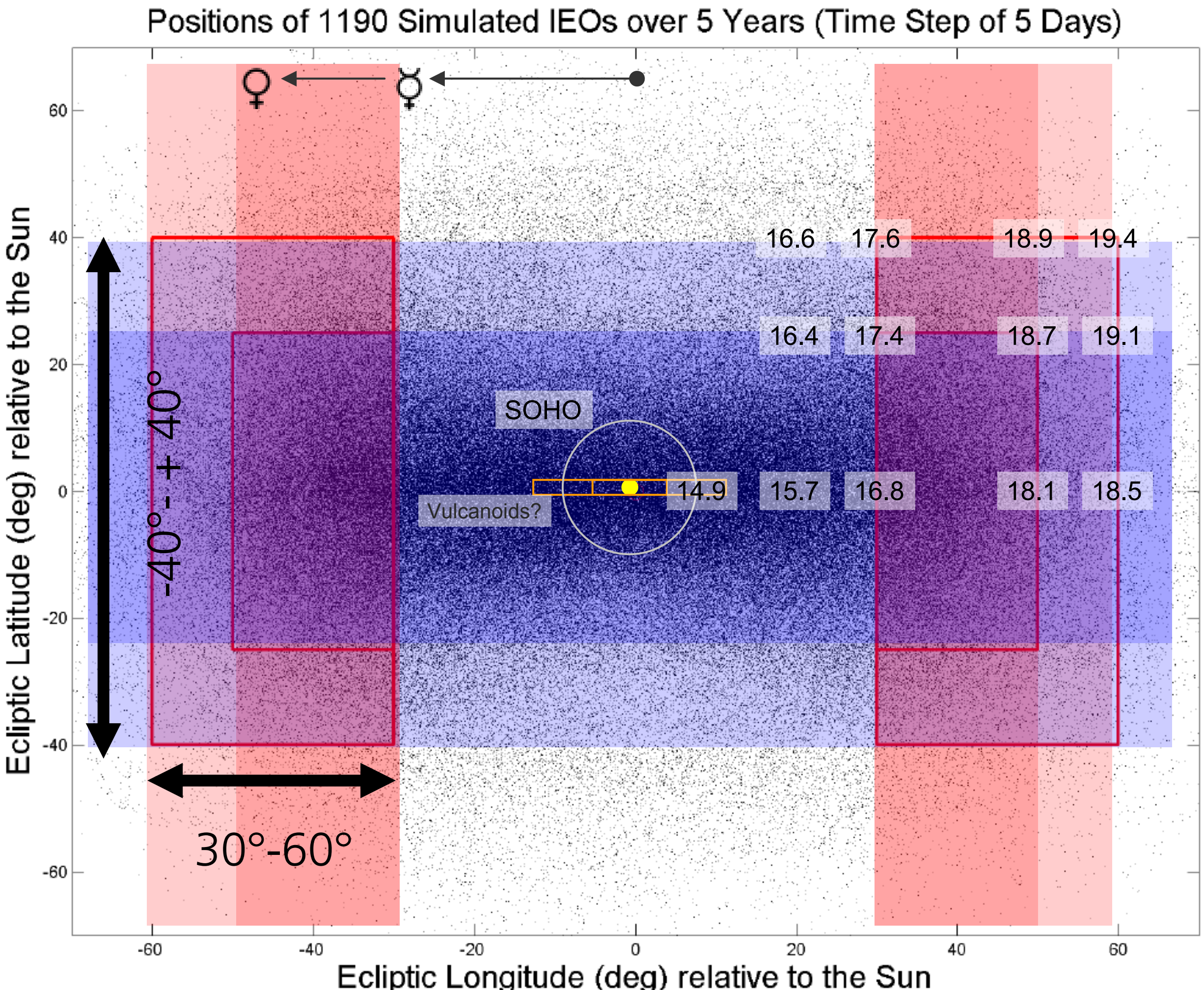
- SSO (600 – 800 km), LTAN 06:00

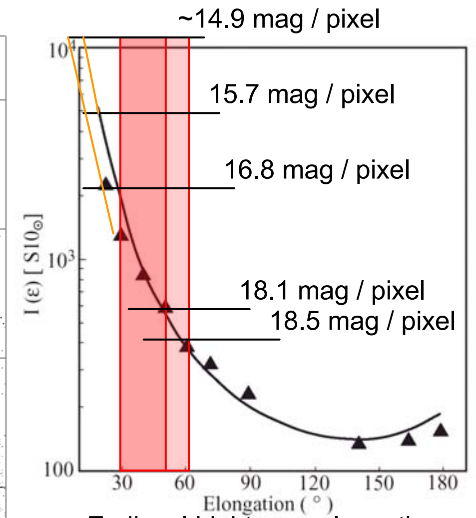
AsteroidFinder Satellite

- Basis: satellite platform: compact S/C bus:
  - 150 – 200 kg
  - To be launched as „piggy-back“ (secondary payload)
  - in a Low-Earth-Orbit (LEO)
  - 3 axes stabilised attitude
  - no thrusters
  - unregulated voltage: 18-24V
    power supply 285 W
  - Kcommunication:
    S-band (omni-direktional) and X-band
  - Passive thermal control system

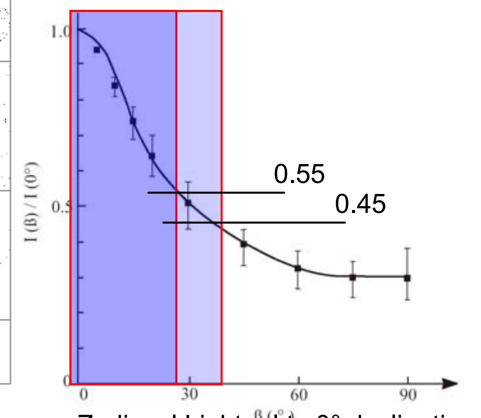


Zodiacal and stray light





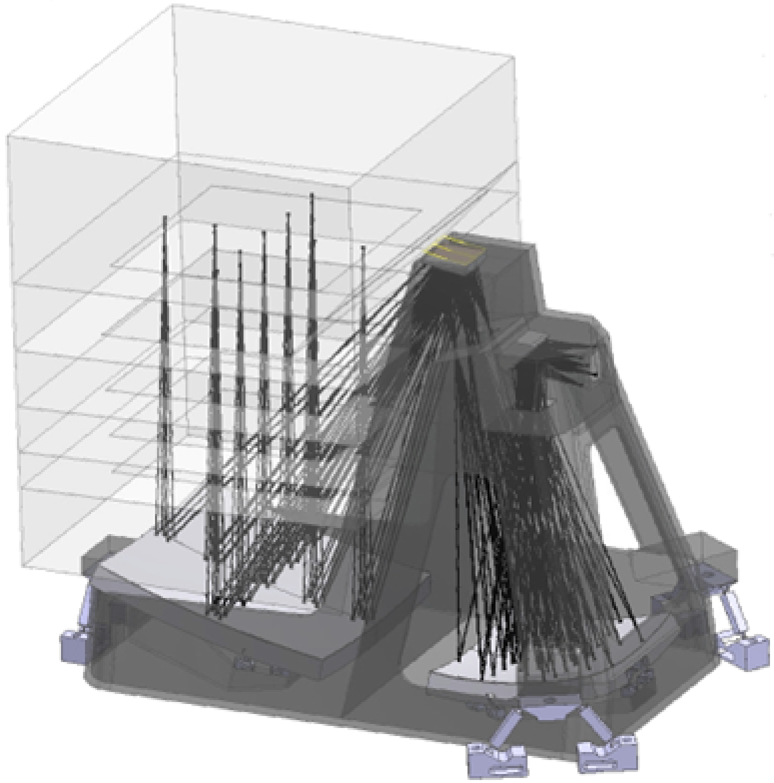
Zodiacal Light over elongation



Zodiacal Light rel.to 0° declination

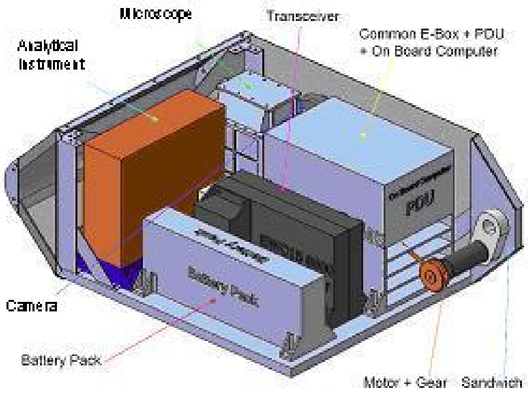
Instrument-Anforderungen und Möglichkeiten

- Images: 5 s^{-1} (frames per second) (~200 ms exposure time)
- Stacking of up to 300 frames within 60 s by means of guide stars .
- Requirement: V_{lim} > 18,5 mag:
  - No sunlight into the telescope
  - No remittance from earth (albedo) into the telescope
- CCD temperature (on focal plane): < -80 °C
  - No sunlight on radiator
  - No earth infrared on radiator
- **BUT**:
  Sufficient sunlight on solar panels for energy supply – needs optimum pointing to the sun



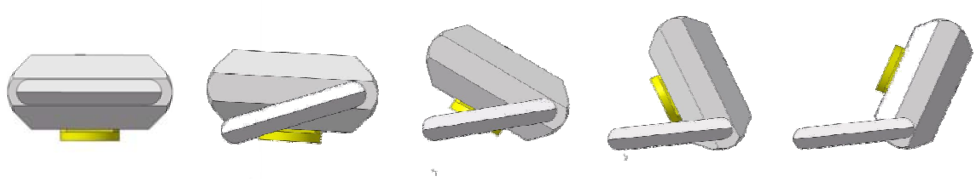
MASCOT (Marco Polo Surface Scout) Hayabusa 2

- Small MASCOT Lander for:
  - Hayabusa 2 (JAXA)
    - Launch: 2014
    - Asteorid target: 1999JU3
    - Lander touch-down: 2018
  - Marco Polo NEO Sample Return Mission (ESA/Cosmic Vision - Launch: 2018/2019)
- Lander mass: 20 kg
- French contribution: power and communication subsystems
- Lander able to adjust itself:
  - Guarantee of measuring position & mobility on the NEO surface (‚hopping')
- Total mass of experimental equipment: 3 kg
  - → 3 science instruments



Experimental devices

1. Wide angel camera (topography & geology of the landing terrains)
2. Mikroscope + IR spectrometer (mineralogy in µm-range)
3. Analyt. instrument (chemical composition) **or** Radiotomographer (innere structur)



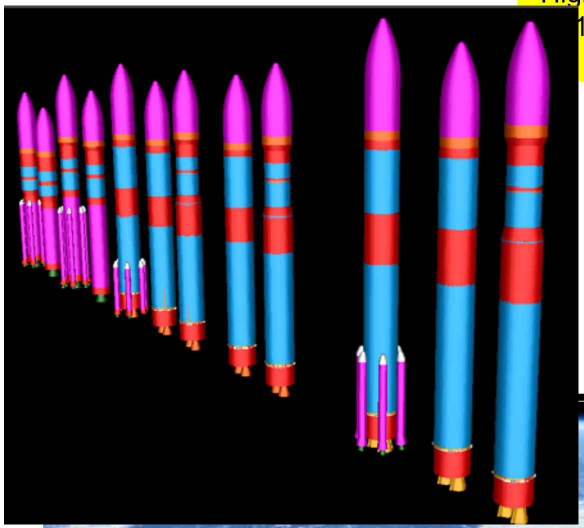
System Analysis
Space Transportation

Running projects

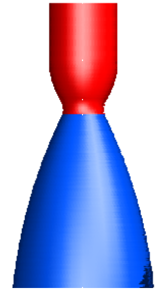
- Lead of Study „Bemannter Europäischer Raumtransport“ BERT (Manned European Space Transportation)
- ELV-system design in cooperation with EADS Astrium and MT-Aerospace / nationale studies WOTAN and VENUS
- SpaceLiner (in 2009 EU-Project FAST20XX)
- Mikro-Launcher design and in cooperation with CNES within the Aldébaran Programme
- Systems analyses of propulsion engine, e.g. ceramic engine
- EU-Hypersonic projekts LAPCAT, ATLLAS ...

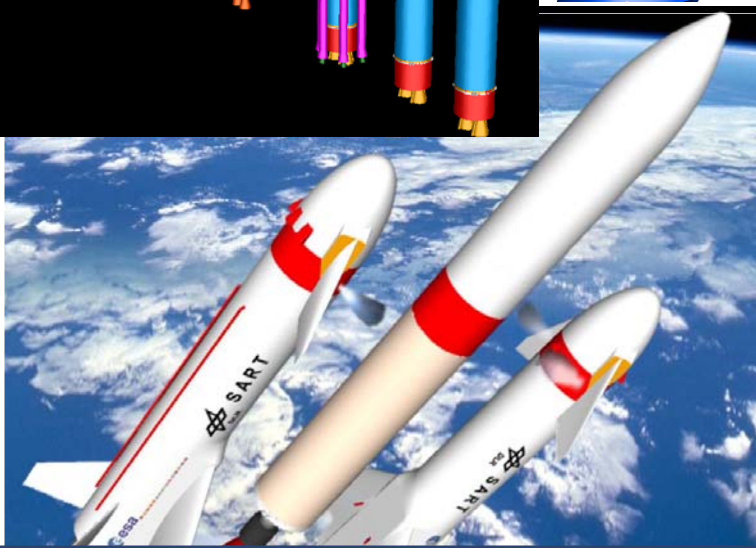
Facility:

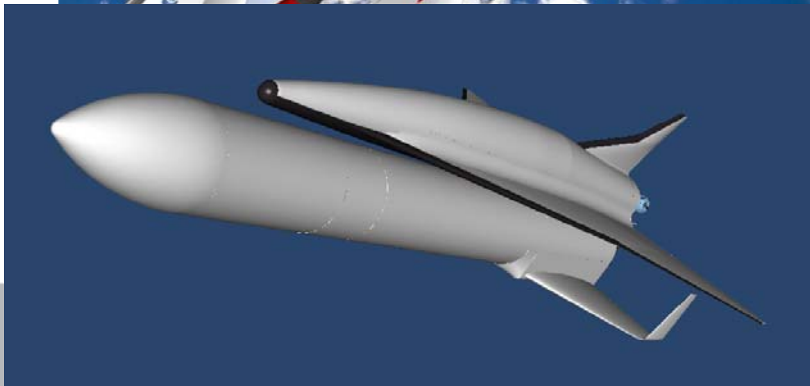
- Support for the Concurrent Engineering Facility



High heat-transfer 110 MW) thrust chamber

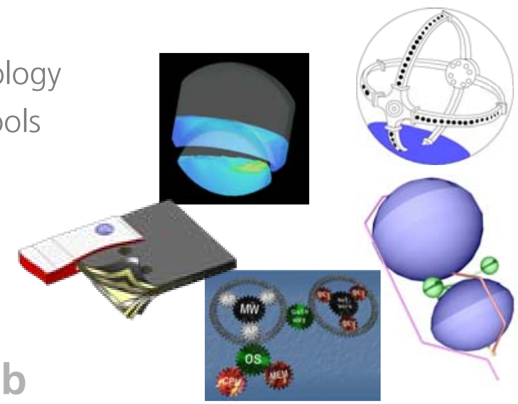




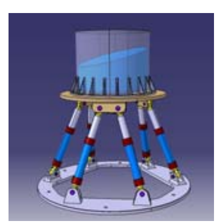


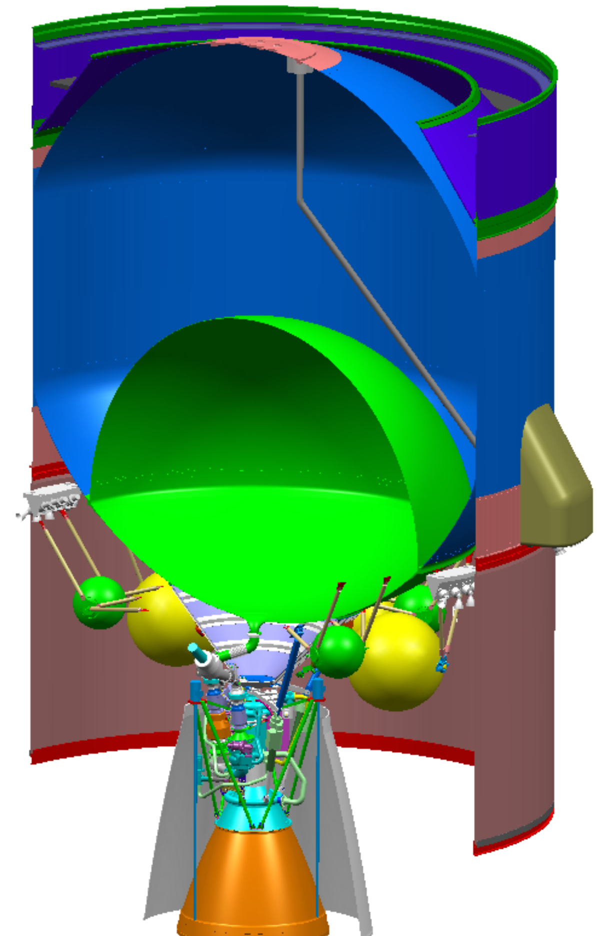
German Upper Stage Research Cooperation

- **Research Cooperation Upper Stage**
  - In cooperation with German launcher industry EADS- Astrium, MT Aerospace, University of Bremen ZARM and 4 DLR-Institutes
  - Term of 3 years
  - Focus: Re-ignitable cryogenic upper stage, 5 Technology-Roadmaps:
    - Propellant Management Technology
    - Further Development of CFD-Tools
    - Simulation Feeding System
    - Composite Fibre Technology
    - Avionics Technology

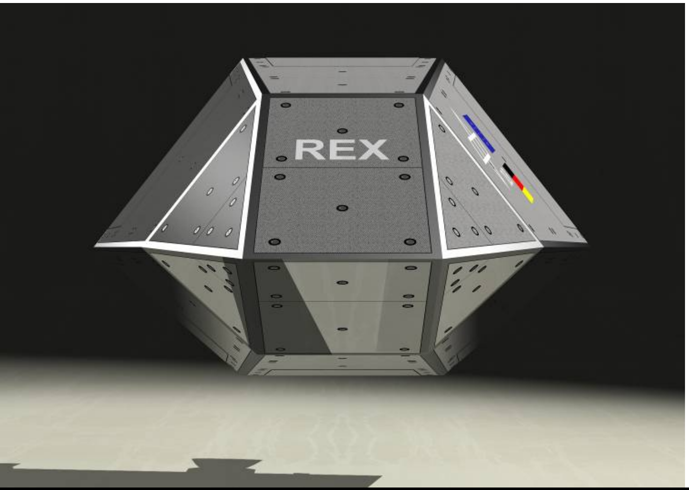


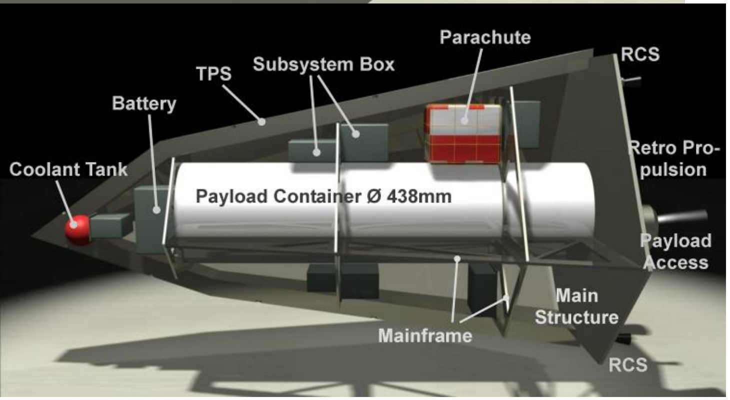
- **Testfacility in Bremen: Cryolab**
  - Cryogenics LH2, LOX (50l), LN2 (1000l)
  - Vacuum chamber
  - Sloshing table
  - Functional in 2012





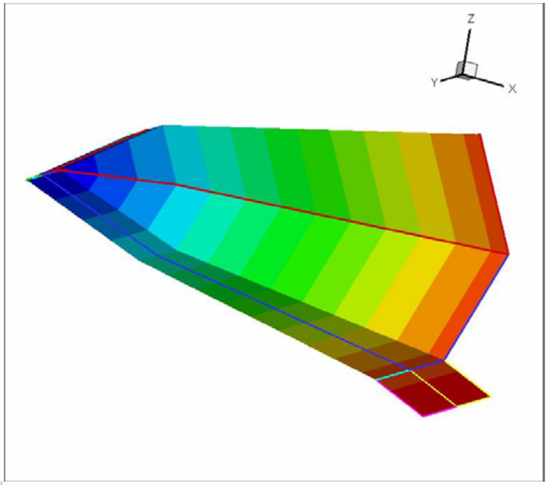
Re-entry Systems:

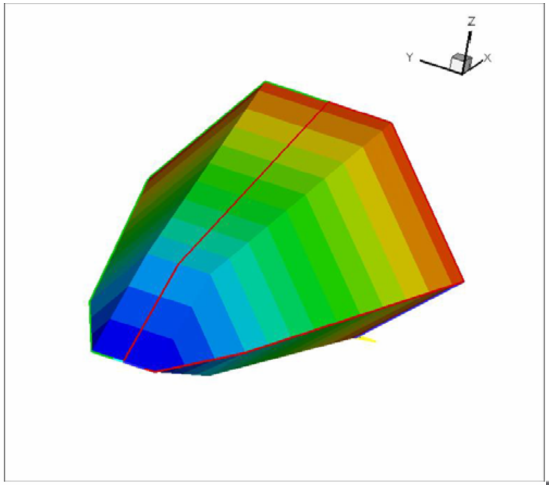




REX- Free Flyer

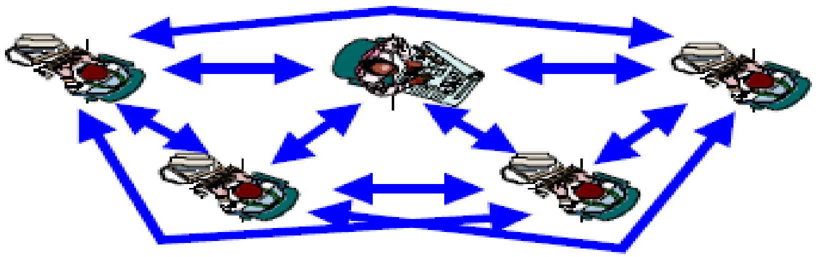
- Orbital system for re-entry and re-use
- Platform for experikments under weightlessness
- Highly variable experimental time (hours to weeks)
- Excellent µg-quality (~$10^{-6}g$)
- Platform for the development of innovative re-entry technology
- Re-enty control
- Landing control
- Variable size and weight
- Open for different launchers



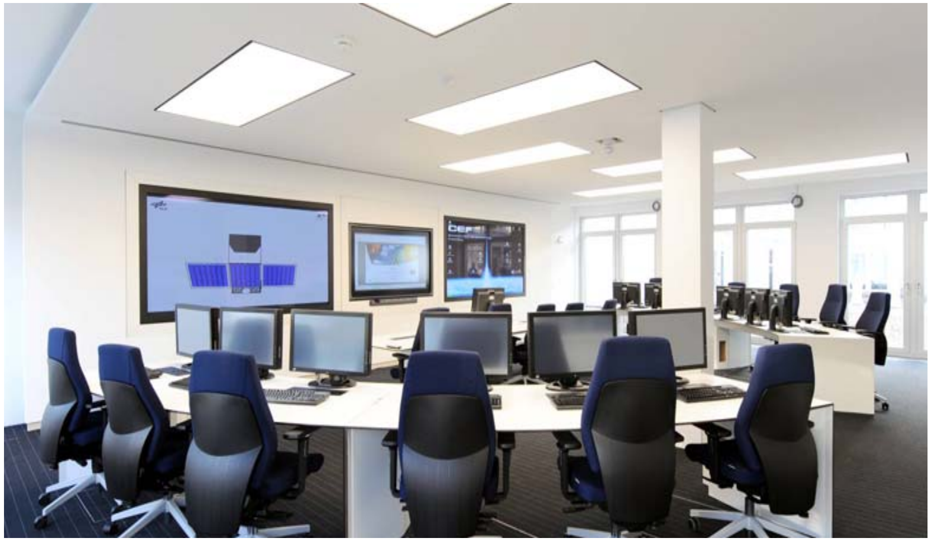


DLR - Concurrent Engineering Facility

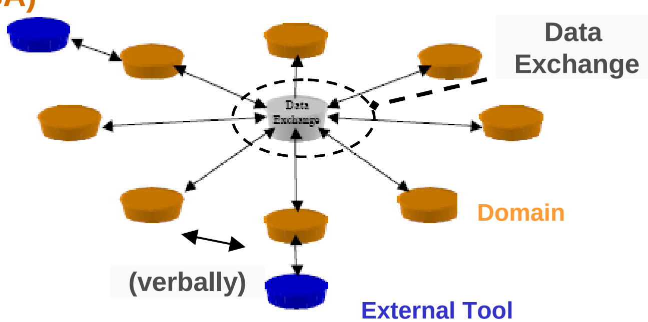
Concurrent Engineering (CE):



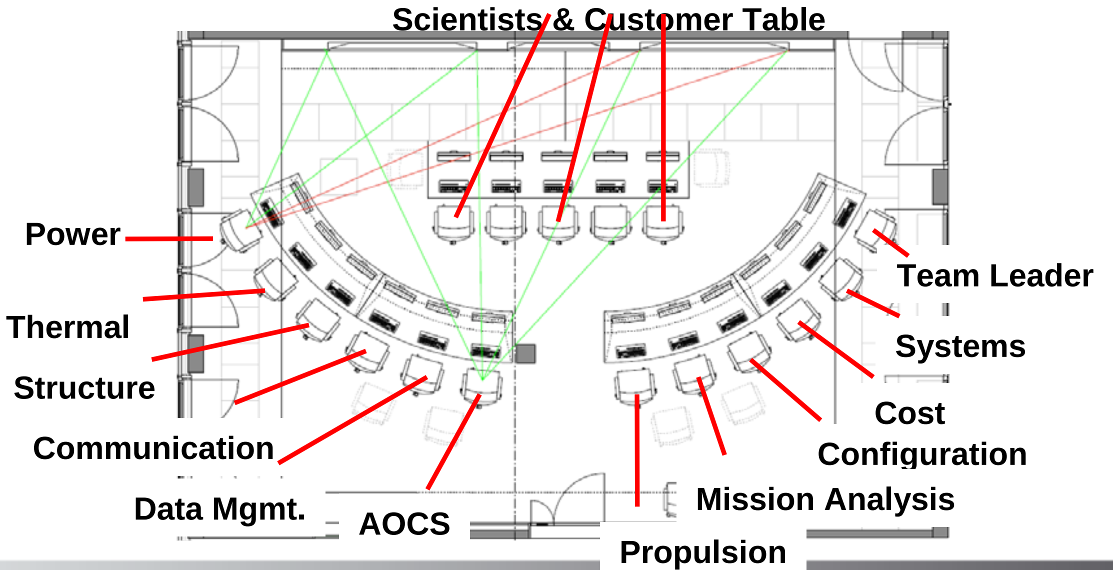
Sketch: ESA



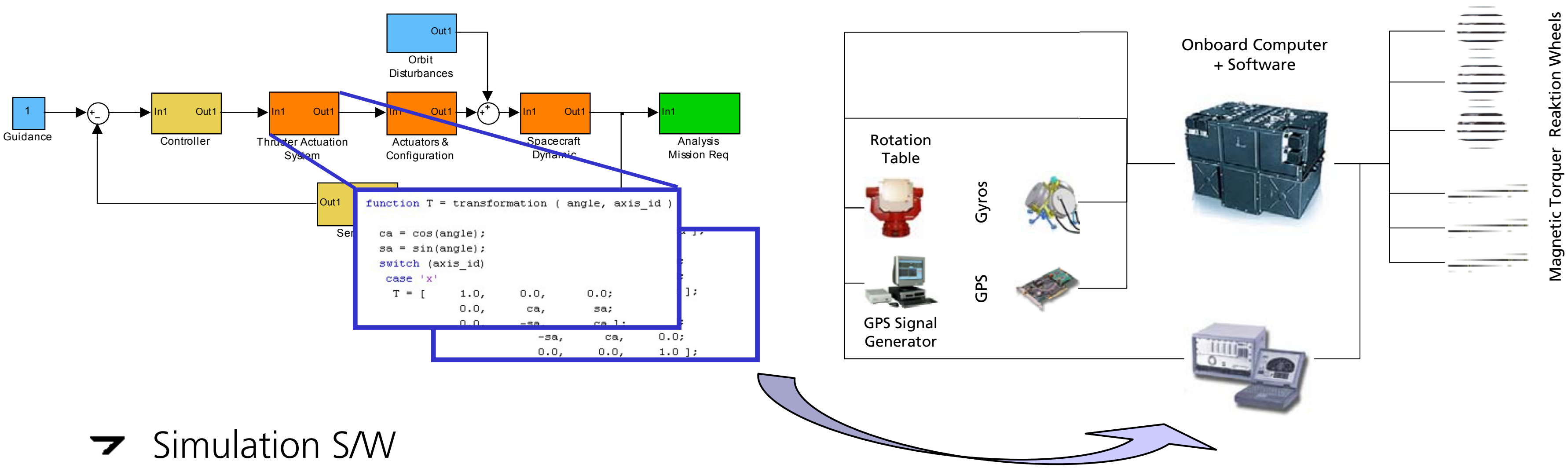
Pre. S/W-Tool: Integrated Design Model (ESA)



Sketch: ESA



Tools for AOCS/GNC Development

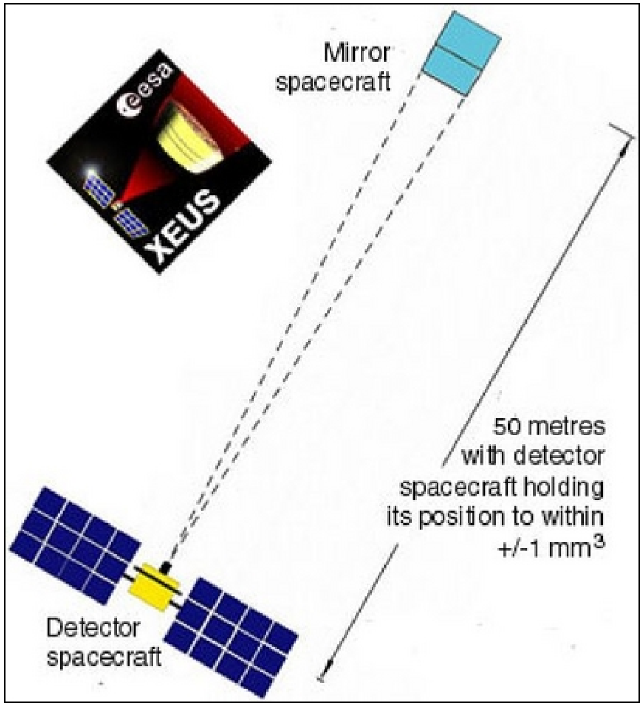


- Simulation S/W
  - Precise modelling
  - Validation with flight data
- Hardware-in-the-Loop-Testbed
  - Modular structure
  - Applicable for different missions
- Tests facilities for AOCS components

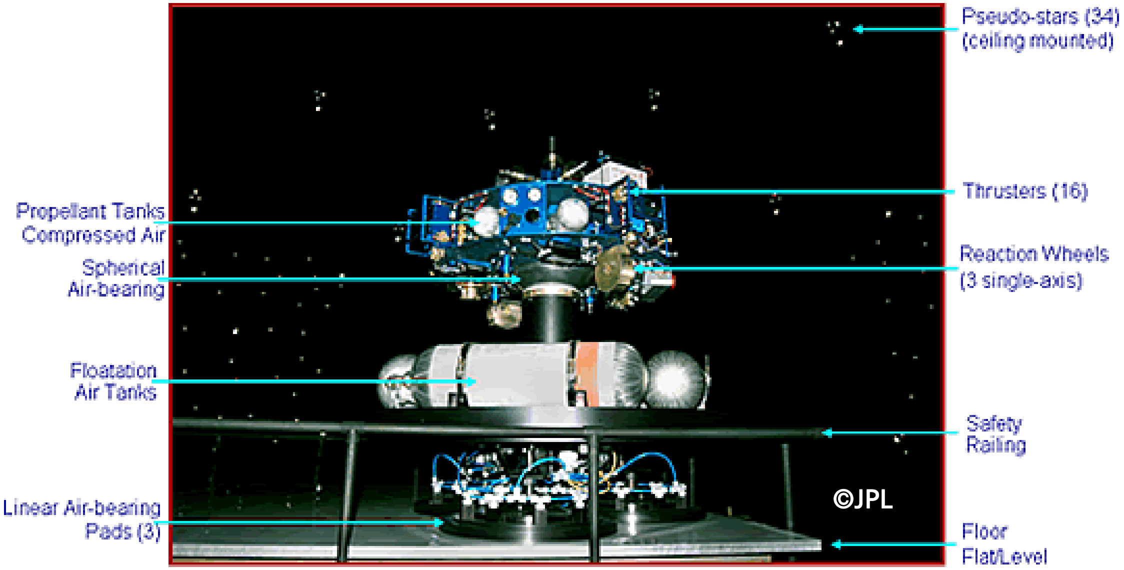
GPS-Simulator

3-Axis Rotation Table

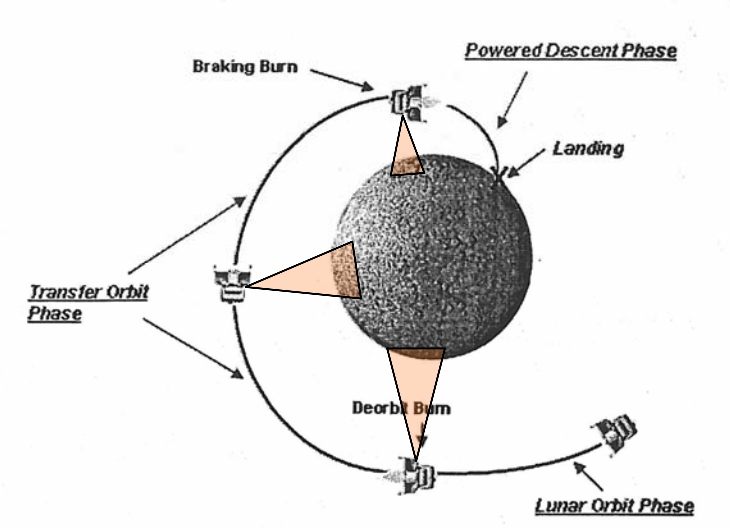
Highly Precise Formation flight

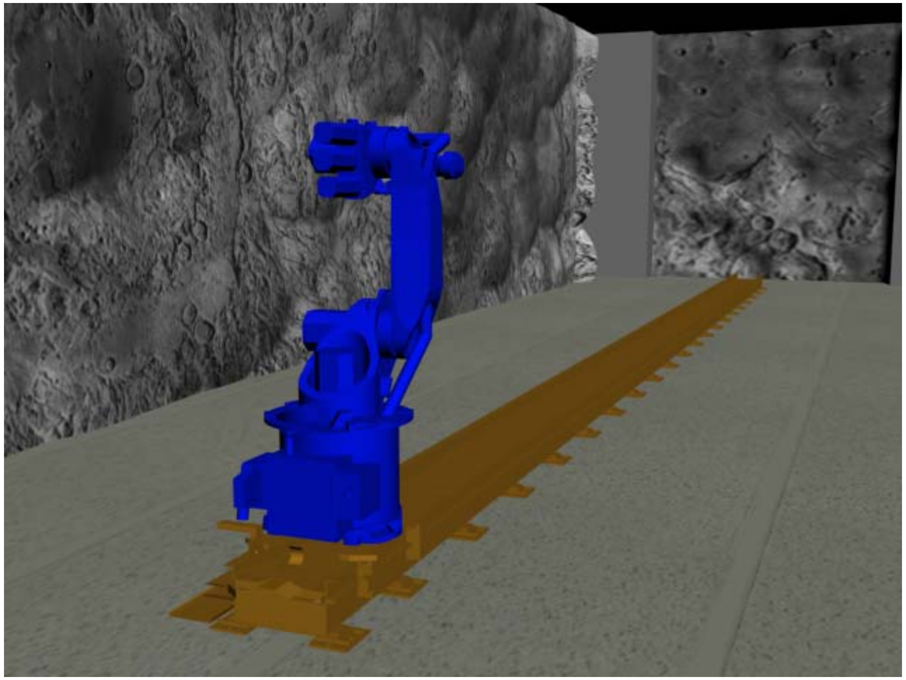


- Motivation: Virtual structures (e.g. XEUS)
- Technologies:
  - Guidance and Control
  - Sensors and actuators
- Development of test facilities



Autonomous Navigation for Exploration Missions

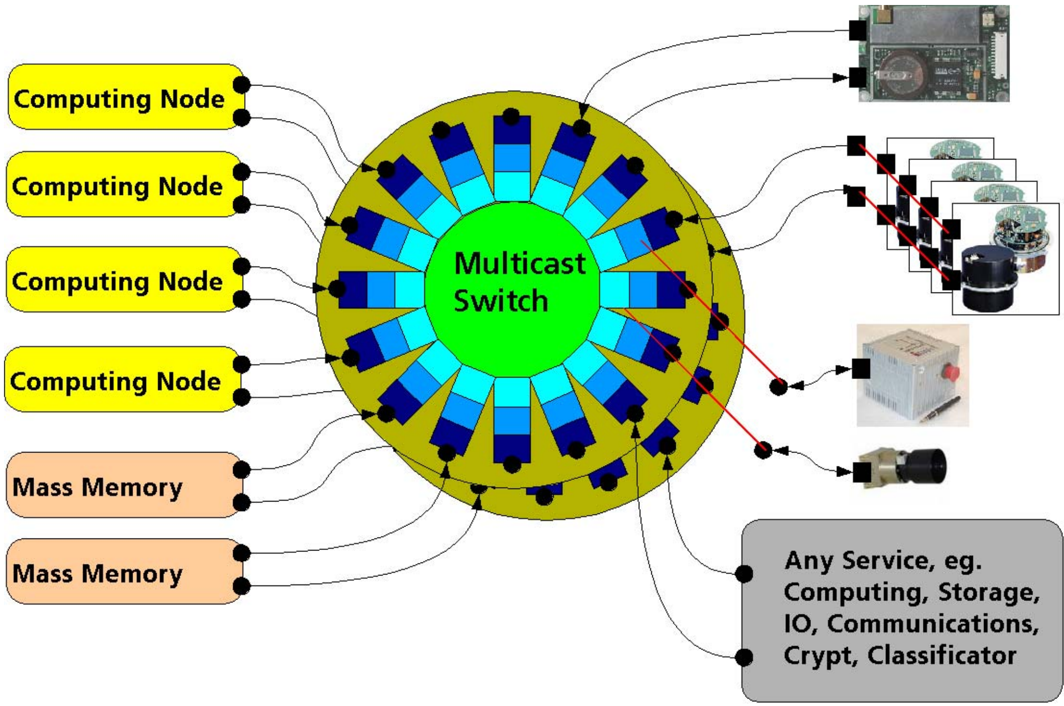




- Motivation:
  - Precise and soft landing
  - Autonomous orbit control
- Technologis:
  - Terrain basede navigation
  - Hazard avoidance

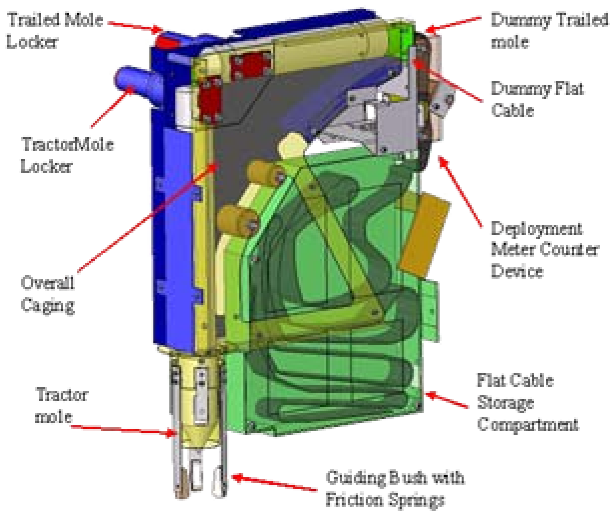
System Technology
Central avionics

- Data management for space systems: satellites, launchers
- Design: board computer and software
- Highest reliability
- Innovative concept: Network-Centric
- Cooperationen:
  STI Spacetec,
  Astrium
  IHP
  Astrofein Technik (TET)
  Kayser Threde (TET)
  DLR: OS & SISTEC

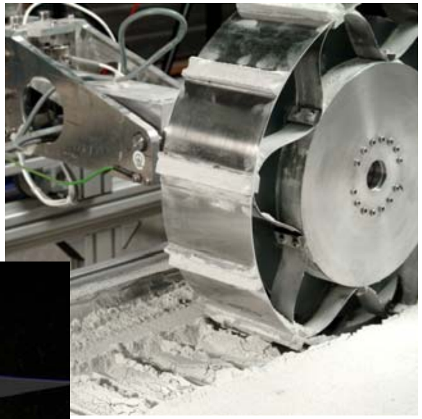


Space Technology: Exploration Systems

- **Projects**
  - ExoMars-Instrument HP³
  - Wheel development for ExoMars-Rover
- **Studies**
  - Cost-utilization-analysis of in-situ missios vs. sample return
  - Moon lander mission LAPIS
  - Geophysical instrument package for Titan lander on TSSM
  - Contribution to NEXT Lunar Lander Phase A (ESA)
  - Contribution to Marco Polo Stuy (‚Cosmic Vision') (ESA)
  - Marco Polo Lander ‚MASCOT'
  - Contribution to ‚Landing System' Study (ESA, with Alenia, Astrium)
- **Contribution to HGF-Alliance „Planetary Development and Life"**
- **Running mission contributions:**
  - Mars Exploration Rover (NASA)
  - Rosetta (ESA)



HP³



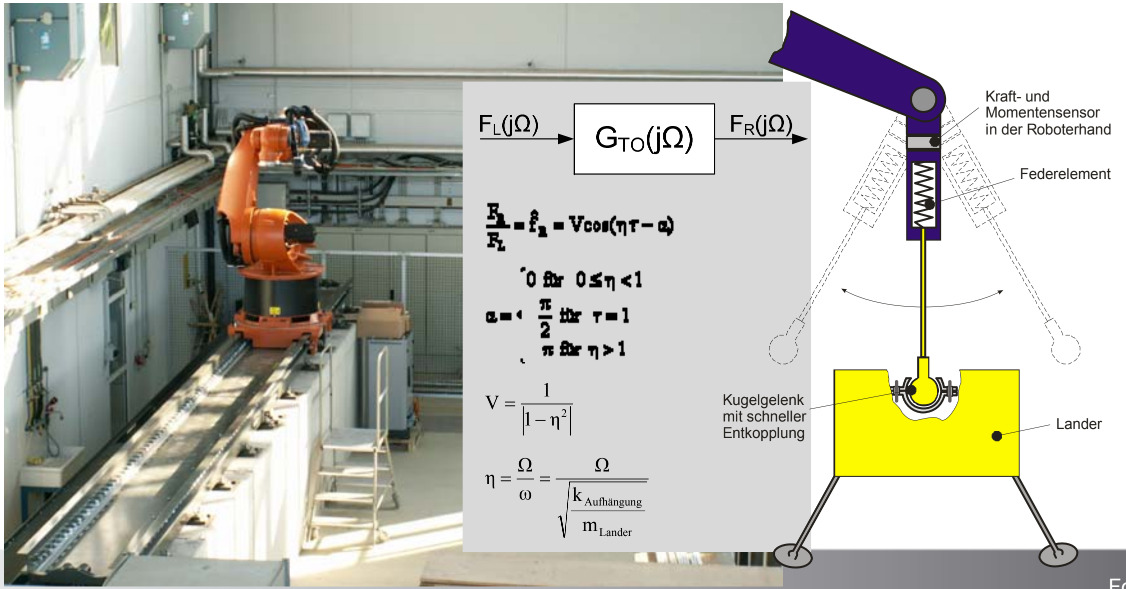
ExoMars-Rad

Space Technology: Exploration Systems

Facilities

Centre for planetary landing Bremen

- Simulator LAMA for
  - Landing dynamics
  - Rover mobility
  - Cooperation with
    - Astrium
    - DLR-FA
- Planet simulation chamber

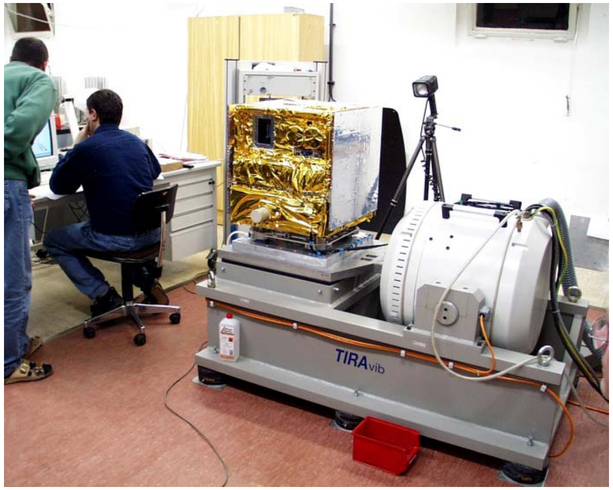


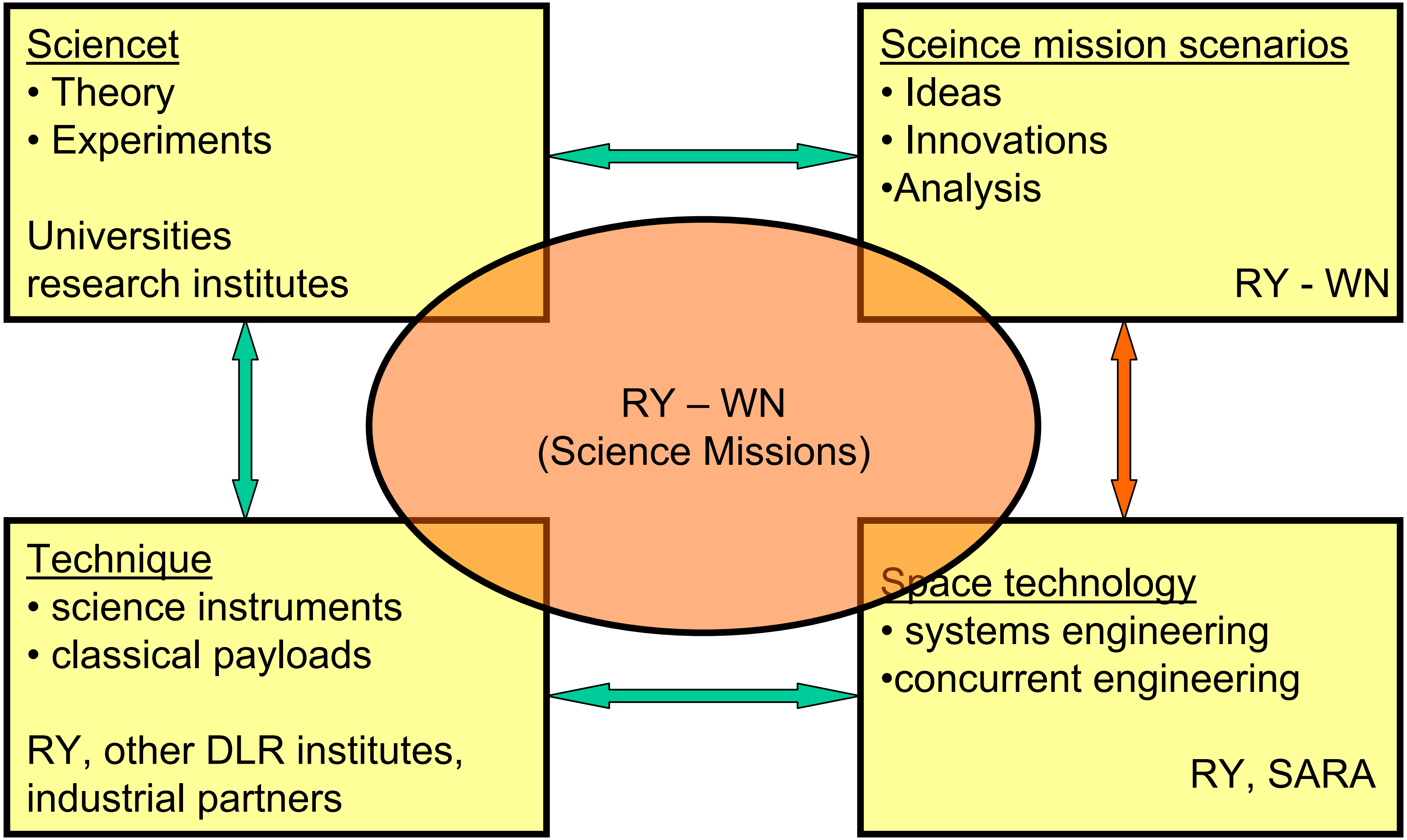
System Test and Verification

Location: Berlin-Adlershof

Facilities

- Simulation- and Test facilities for
  - Space environment, vacuum
  - Sun
  - Radiation
- Mechanischal load
  - Shaker
  - shock
  - centrifuge
- Thermal-vacuum (climate)
- EMC-Lab



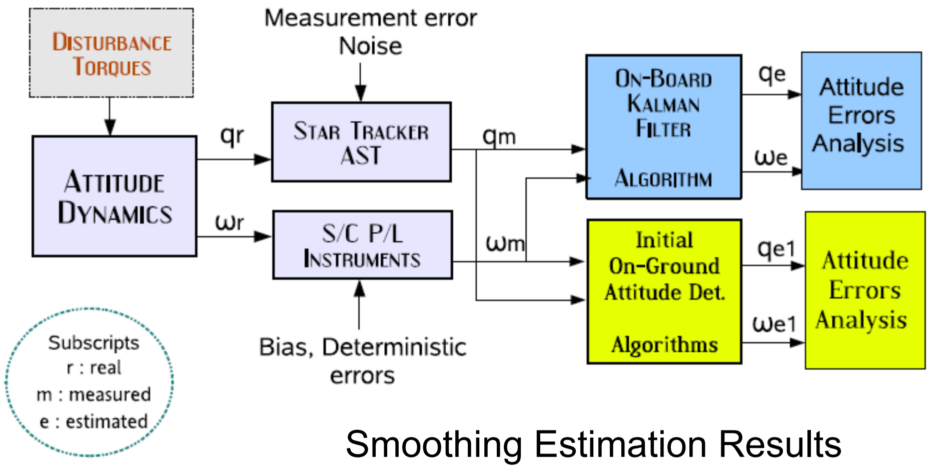

Sciencet
• Theory
• Experiments
Universities
research institutes
Sceince mission scenarios
• Ideas
• Innovations
•Analysis
RY - WN
RY – WN
(Science Missions)
Technique
• science instruments
• classical payloads
RY, other DLR institutes,
industrial partners
Space technology
• systems engineering
•concurrent engineering
RY, SARA

Fundamental Physics Interests

- MICROSCOPE (Co-I)
- Inertial sensors
- S/C dynamics – „science craft“
- S/C precision AOCS
- Precision thrusters (laser ablative thrusters)
- Quantum Optics in space
  - Quantum sensors / space atom interferometer (SAI)
  - Space clocks
  - Optical links / time links
- Thermal Modelling
- Space Time Anisotropy
- Problems in deep space: communication, energy, propulsion

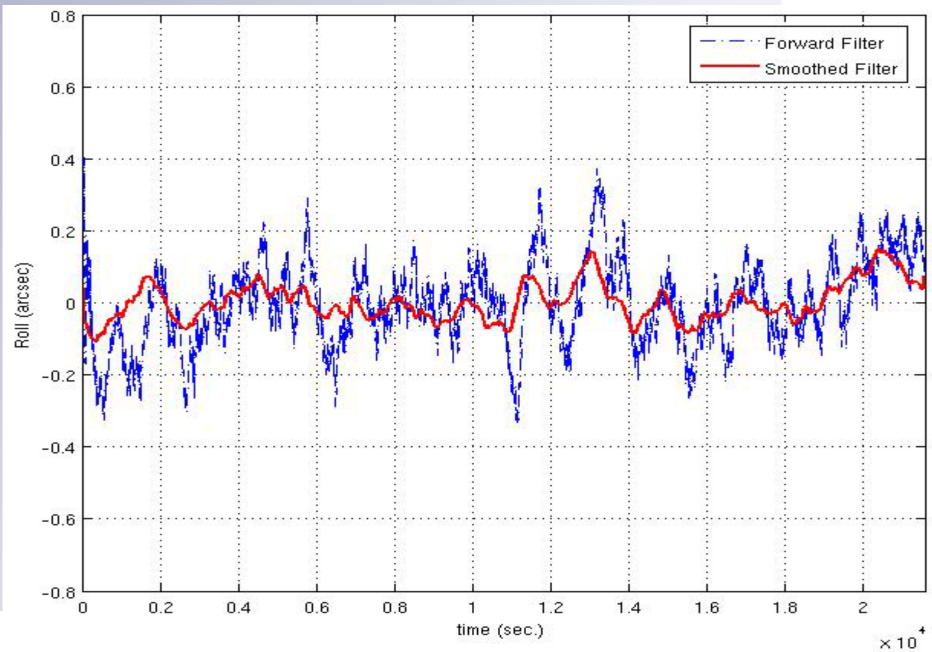
Challenge: S/C dynamics

- Study of appropriate attitude reconstruction method
    - Kalman filter, batch filter, …
- Development of attitude estimation procedure
- Integration into Core Processes
- Physical attitude dynamics modelling
- Identification of satellite dynamics parameters



Smoothing Estimation Results

(*Theil et al*)



S/C Simulator Objectives

- Provide comprehensive simulation of the real system including science signal and error sources
- Provide simulation environment for control system performance validation
- Generate data needed to test data reduction methods
- Provide capability for identification of the satellite and instrument

Simulator Core Features

- Simulation of full satellite and test mass/experiment dynamics in six degrees of freedom by numerical integration of the equations of motion
- Multi-body system: e.g. STEP setup: satellite + 8 test masses → calculation of 117 states
- Consideration of linear and nonlinear coupling forces and torques between satellite and test masses/experiment as well as between test masses/experimental bodies
- Modelling of cross-coupling interaction
- Earth gravity model up to 360th degree and order,

  influence of Sun, Moon and planets can be included
- Gravity-gradient forces and torques
- 5th order Runge-Kutta numerical integration, Bulirsch-Stoehr, Euler-Cauchy

Several error sources are considered in the model:

+ misalignment and attitude errors

+ coupling biases

+ displacement errors

Force & Torque Modeling (1/2)

- **Modeling of forces and torques acting on the satellite and test masses because of:**
  - Gravitation and Gravity Gradients
  - Control (forces and torques applied by the control system)
  - Interaction with the upper layers of the Earth atmosphere
  - Electromagnetic radiation
    - heat, radio communication emission
    - Absorption and reflection of radiation incident (Sun, Albedo, etc.)
  - Interaction with the magnetic field
  - Interaction (coupling) between satellite and experiment
    - From sensor and actuation systems
    - Gravitational coupling

Force & Torque Modeling (2/2)

- **Modeling approaches:**
  1. Utilization **AND extension** of standard models
  2. Derivation of parametric models from detailed FEM analysis of specific effects

- **Standard models used:**
  - International Geomagnetic Reference Field (IGRF, IAGA)
  - Earth Gravity Model (GRACE-based)
  - Mass Spectrometer Incoherent Scatter Model (MSIS, NRL)
    - Short-term variations of Earth atmospheric density (analysis of CHAMP mission data)

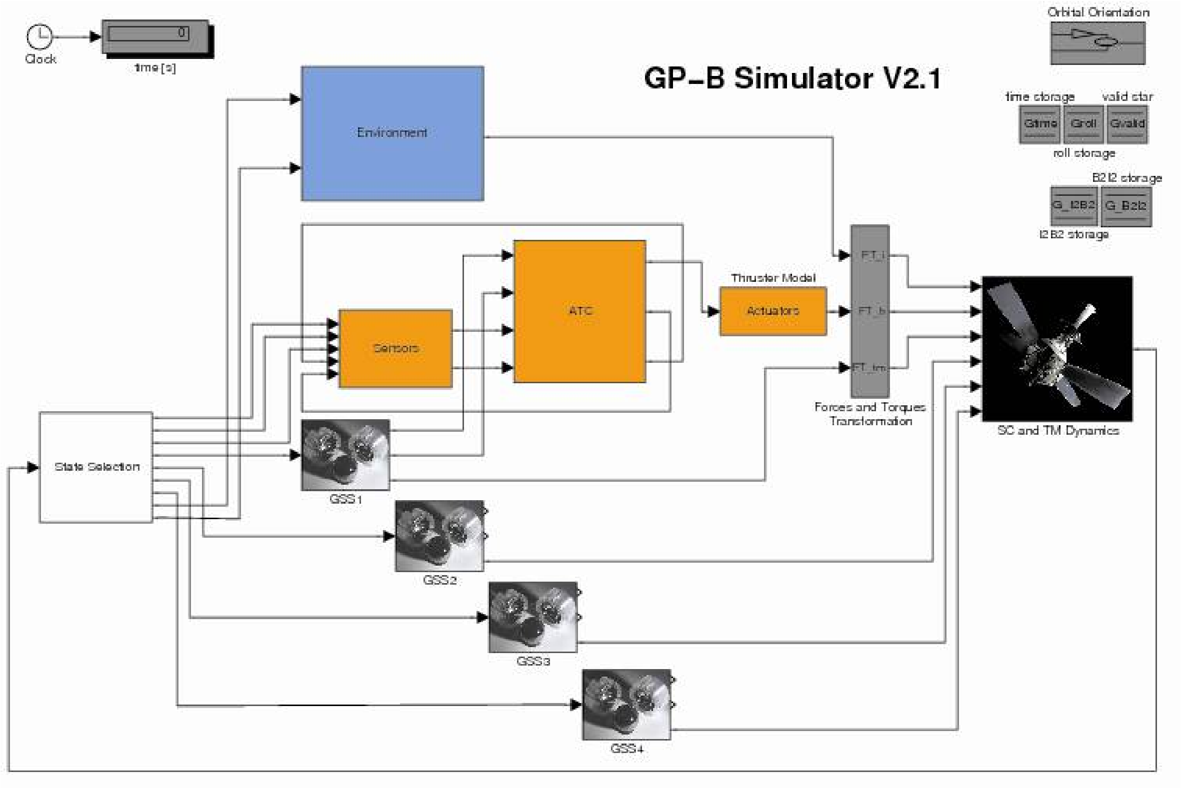
Verification of Simulator

- Comparison to analytical solution of simplified system
  - Simplified model renders ODE in Mathieu-Form
  - Verification by comparison of stability boundaries
- Comparison to Hill's Equation
  - Analytical description of uncoupled relative movement
- Comparison to other orbit propagators
- Verification of uncoupled attitude motion
- Test of dynamic coupling between satellite and test masses
- Verification with flight data (Gravity Probe B)

Simulator Architecture

- User interface in Matlab/Simulink
  - Simulator for each mission is assembled from modules.
  - Modular design makes it easy to include new subsystems
  - Software and hardware in the loop capabilities

Application example: verification with GP-B

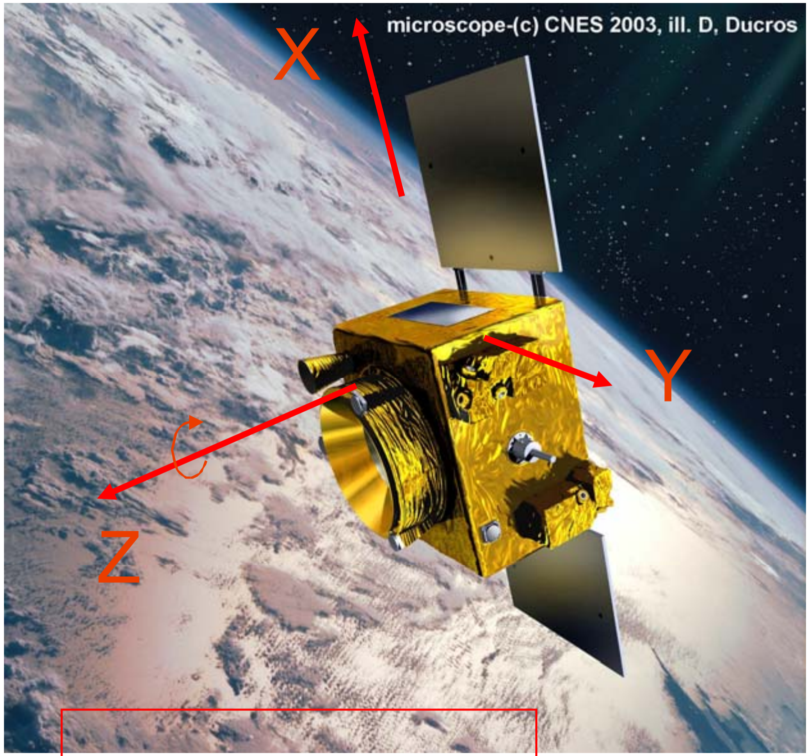


MICROSCOPE

**Micro-satellite
à Trainée Componsée pour
l´Observation du Principe
d´Equivalence**

Mission Parameter:

- Sun synchronous Orbit: 660 km
- Orbit-Excentricity : < 5 · 10^{-3}
- Spin-Rate: variabel for modulation, der Orbit-Frequenz
- Signal frequency: $(\pi + 1/2)\ f_{orb}$ und $(\pi + 3/2)\ f_{orb}$
- Missions duration: 6 to 12 months
- Satellite mass: < 120 kg
- CNES-Project (with contributions from DLR and ESA)



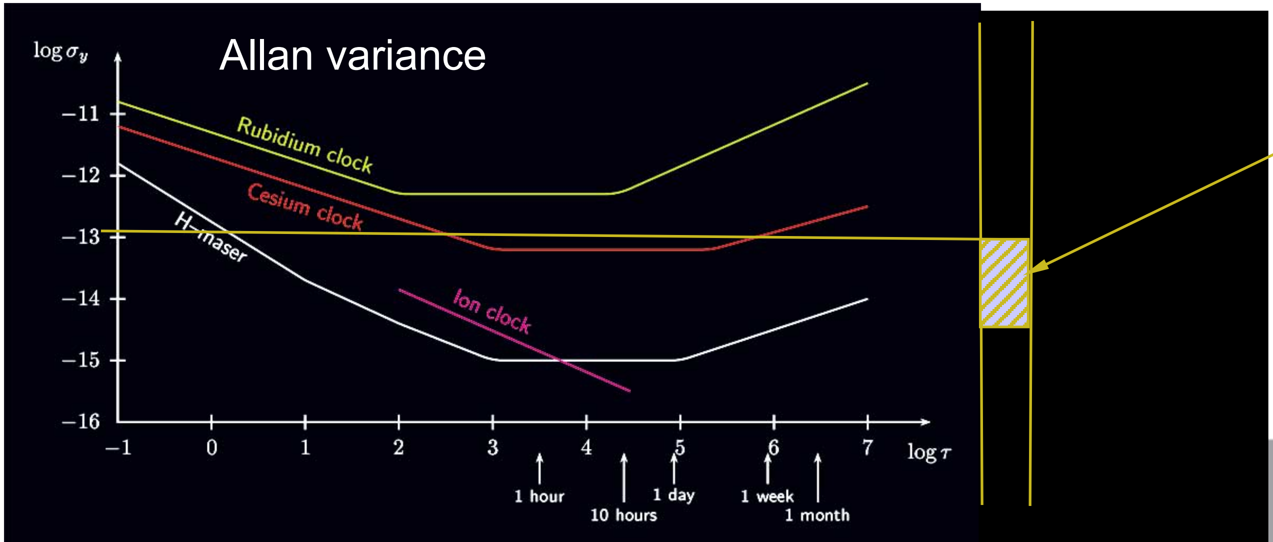
x-axis: sensitive axis
z-axis: satllite spin axis

Problem: Clocks to explore space-time

- Redundant measurements
  - Measuring acceleration of S/C on geodesic via ranging and Doppler tracking
  - Measuring redshift of clocks on-board S/C for example Pioneer Anomaly

$$\frac{\Delta \nu}{\nu} = \frac{1}{c^2} \int_{20\,AU}^{90\,AU} a_{PA}\, dx \approx 10^{-13}$$

  Clock exploration does not depend on geodesic motion, independent from non-gravitational acceleration
  - Cock exploration is cumulative
  - Clocks automatically isolate the pure gravity sector
  - Clocks represent an absolute DC-accelerometer

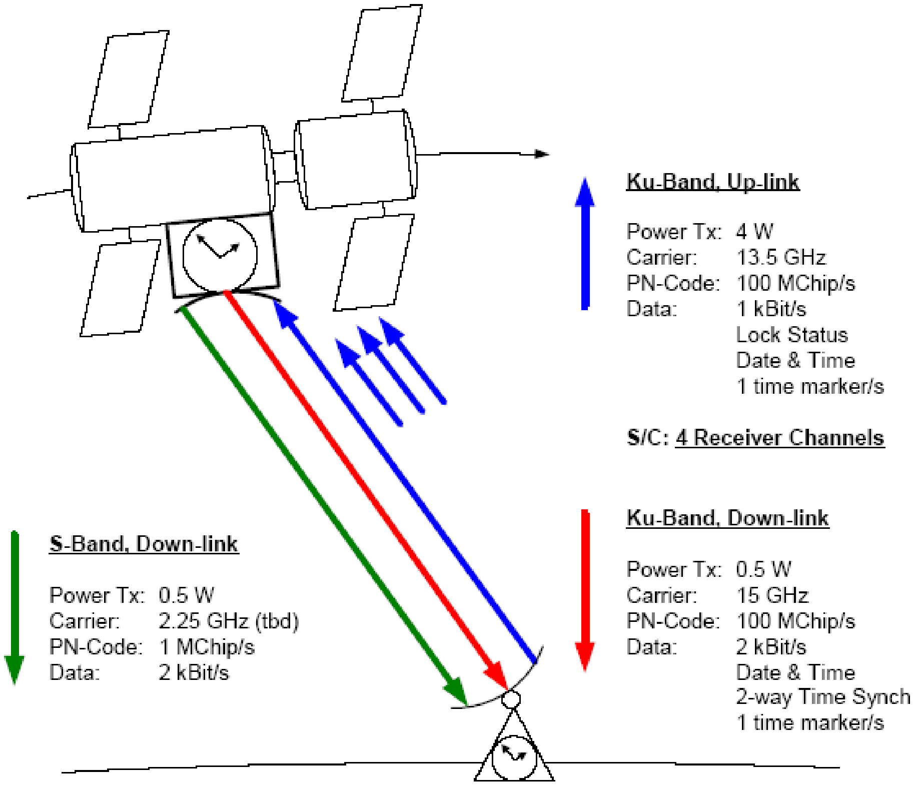


requirement for deep space missions

Challenge:
long term stability

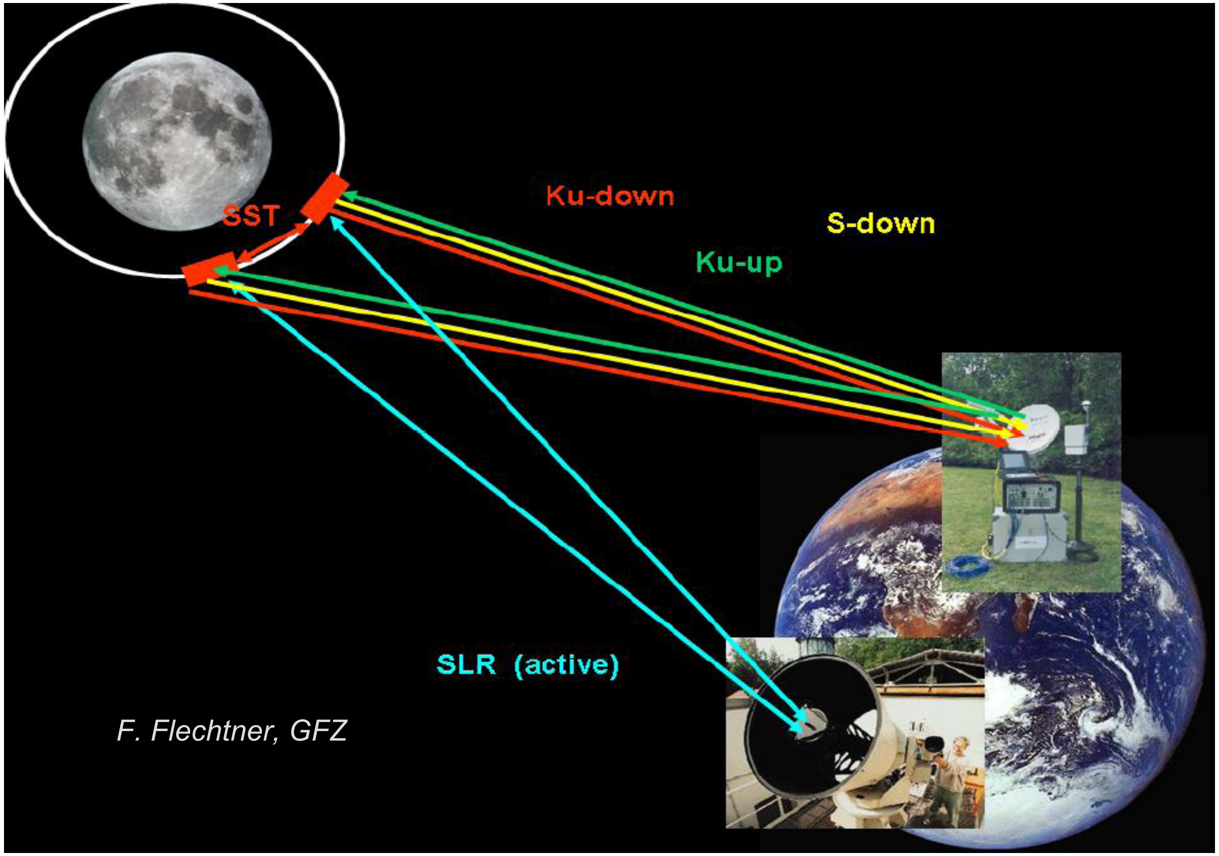
Problem: Time transfer (MWL)

- MWL (Microwave link to ISS) devel from PRARE for time transfer between and ground
- Frequency comparison on the 10^{-16} level (230 fs per pass, 5 ps per orbit)
- 2 symmetric 1-way links carrying continous pseudo-noise coded signals
- High Ku-band chip rate (100 MChi in order to increase resolution and sup potential multipath
- 1 W power (S and Ku-band)
- Although not planned: ranging would be possible with λ/1,000 = 24 μm accuracy.



Direct application

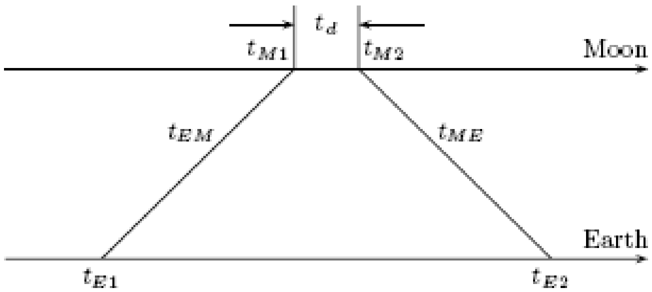
- e.g. lunar gravity field exploration
- a path to relativisitc geodesy



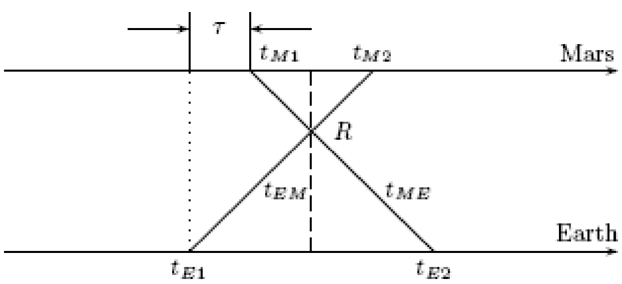
Future: Optical links

- Optical transponders (on-board lasers, telescopes, timing receiver)
- Demonstrated over 0.17 AU (24 million km) with Messenger S/C and Mars Global Surveyor S/C (1-way)
- Nd:YAG laser, pulse rate 8 Hz
- Needs atmospheric correction: calibration can be done by ranging to near earth objects (e.g. LAGEOS) from differnt stations

	Messenger S/C	MOLA on Mars Global Surveyor S/C (1-way only)
range	$2.4 \cdot 10^7$ km	$8 \cdot 10^7$ km
pulsewidth	10 ns (up), 6 ns (down)	5 ns
pulse energy	16 mJ (up), 20 mJ (down)	150 mJ
repetition rate	240 Hz (up), 8 Hz (down)	56 Hz
laser power	3.84 W (up), 0.16 W (down)	8.4 W
beam divergence	60 µrad (up), 100 µrad (down)	50 µrad
receive area	0.042 m^2(up), 1.003 m^2 (down)	0.196 m^2



Echo transponder for
e.g. lunar laser ranging
Time delay must be known



Asynchronous transponder for
satellite laser ranging
Repetition rate must be known

John J. Degnan, in Lasers, Clocks, and Drag Free…

QUANTUS Collaboration

Quantum sensors

Based on:

(1) Ultra-precise optical metrology
$\delta\nu/\nu < 10^{-17}$ in the optical frequency domain

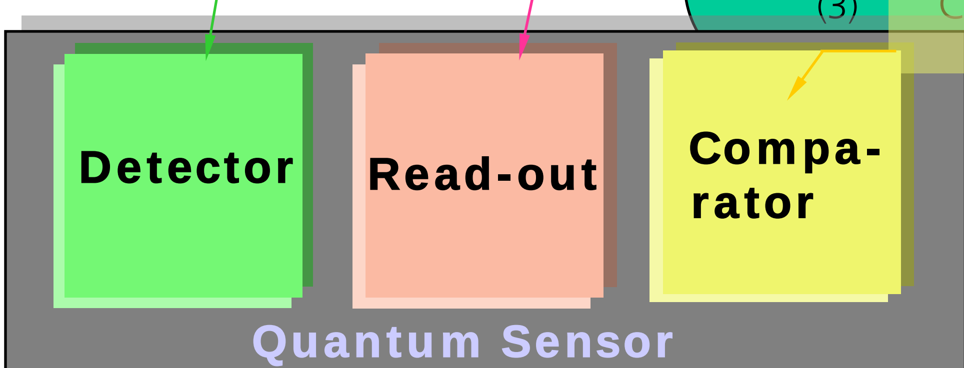
(2) Phase-sensitive atom interferometry
$\delta E/E < 10^{-19}$
due to the sub-microscopic quantum mechanical structure

Needs experimental competence in:

(1) Processing ultra-cold atomic ensembles:
- „classical" laser cooled ensembles: ~ 1 μK
- Bose-Einstein Condensates (BEC): < 50 nK
- ultra-cold molecules

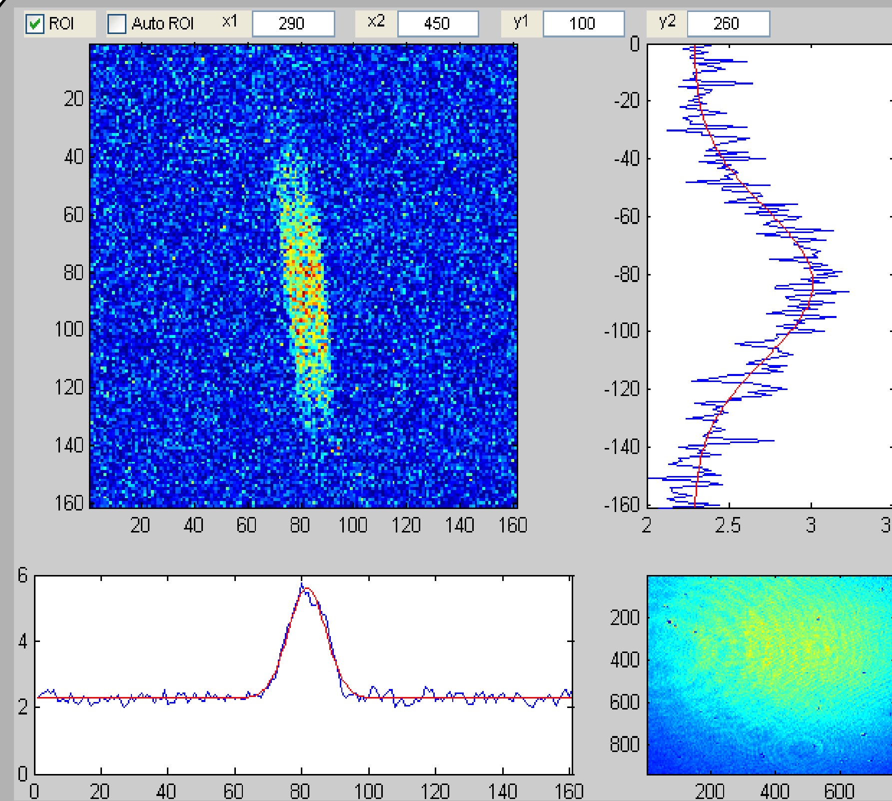
(2) Measuring the phase highly precise:
- highly stable, phase-locked EM-oscialltors (RF-, THz-, optical)

(3) Calibrating oscillators:
- frequency comb



Long evolution time in µg

- BEC-TOF: 700 ms
  (meanwhile 850 ms)
- Thermal background disappeared
- Ca. 9,000 atoms
- Large extension: ca. 0.5 mm



Outlook (Experiments)

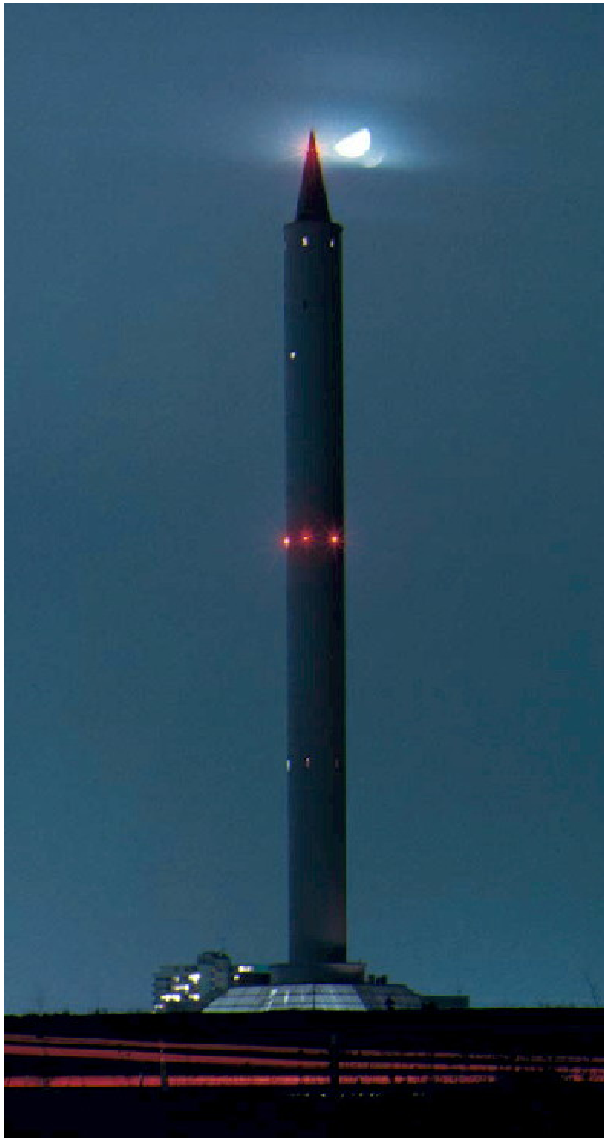
- Test of the Equivalence Principle with quantum objects

  - Freely falling quantum probes / distinct atomic species

  - CAPRICE experiment within QUEST-Programme (Quantum Engineering and Space-Time Research)

  - *M. Kasevich* et al. (2007):
    - Atom interferometer height: ca. 10 m
    - Wavepackage separation: > 10 cm
    - statistical accuracy: $\delta g/g < 10^{-15}$
    - systematic uncertainty: $\delta g/g < 10^{-16}$

quest



Summary: DLR-RY competences

- System apporach: AsteoridFinder: DLR compact satellit „Sciencecraft"
- Cooperation with other DLR space related institutes for planetary research, GSOC/operations, robotics /mechatronics, communication / navigation, technical physics, light structure mechanics, construction, and S/W development
- System competence at RY:
  - Lander (ES)
  - AOCS / precision attitude control (NR)
  - S/C dynamic simulation
  - avionics
  - satellite construction (OR)
  - System analysis (SA)
  - Mission analysis / concurrent engineering (OR / SA)
  - Thermal analysis (SK / OR)
  - Test and verification (SK)