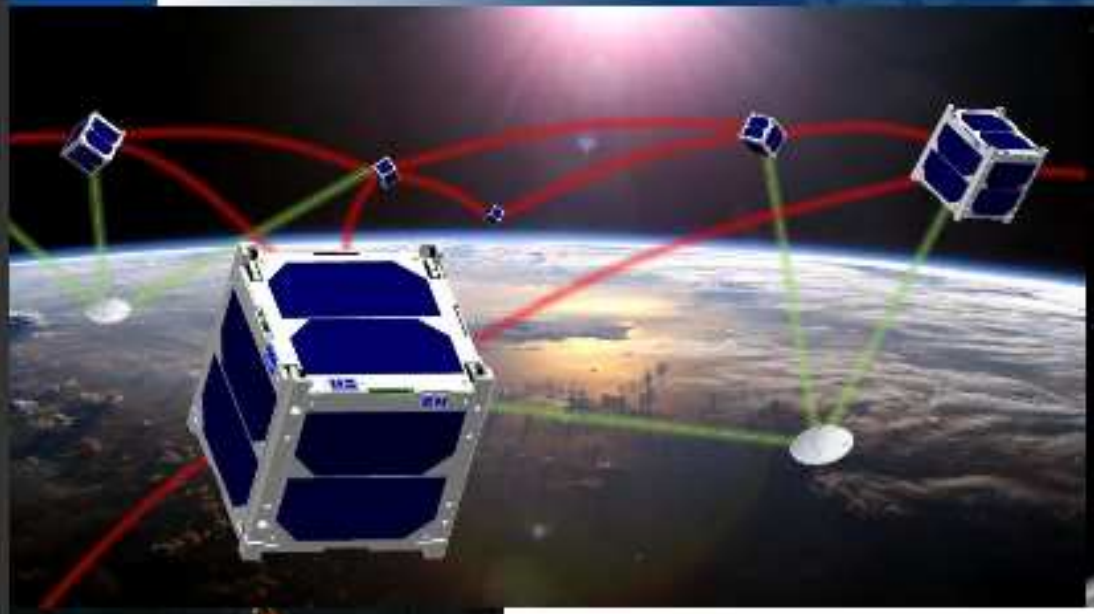
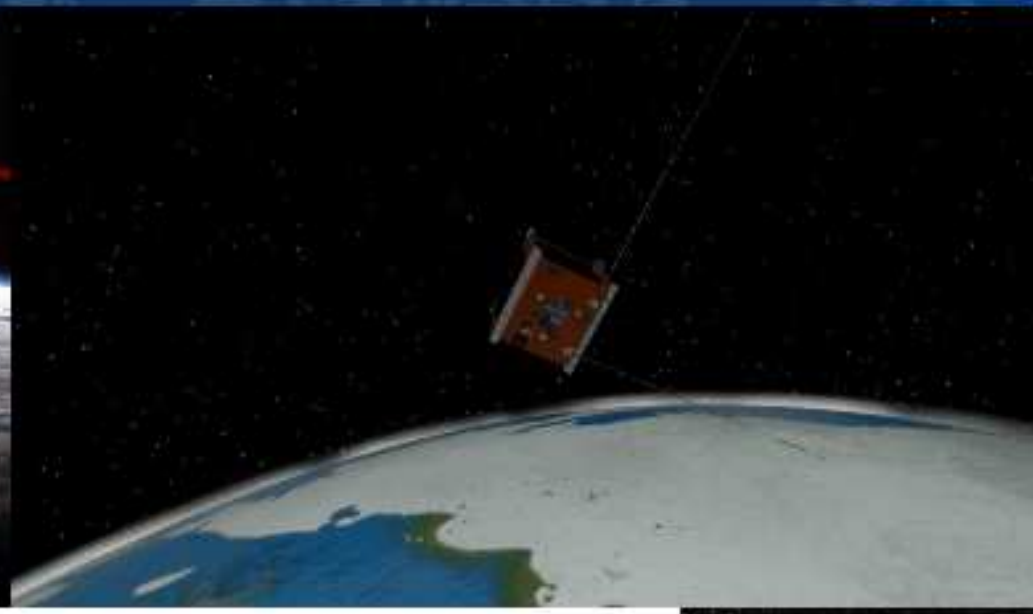
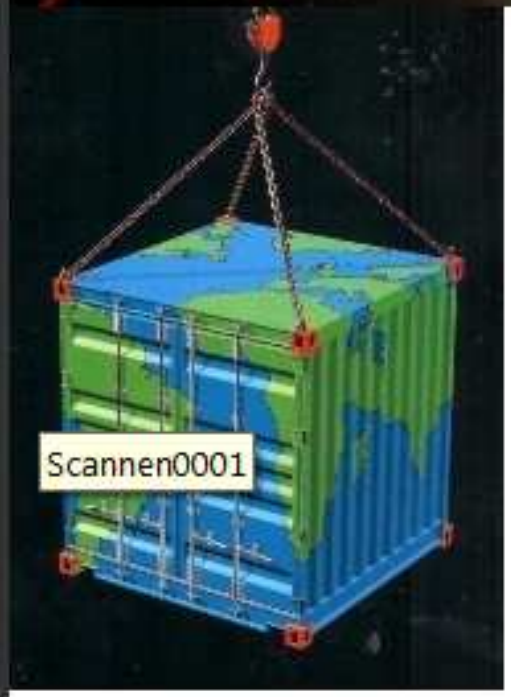


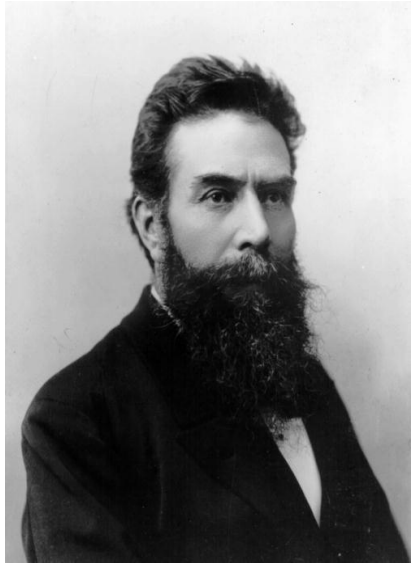




Pico-Satellites for Education and Research in Networked Space Systems

Klaus Schilling
Julius-Maximilians-University Würzburg
Am Hubland, D-97074 Würzburg, Germany
schi@informatik.uni-wuerzburg.de

IEEE Robotics and Automation Society (RAS) – Distinguished Lecturer Program
Egypt Chapter, New Cairo, October 11, 12



The University Würzburg

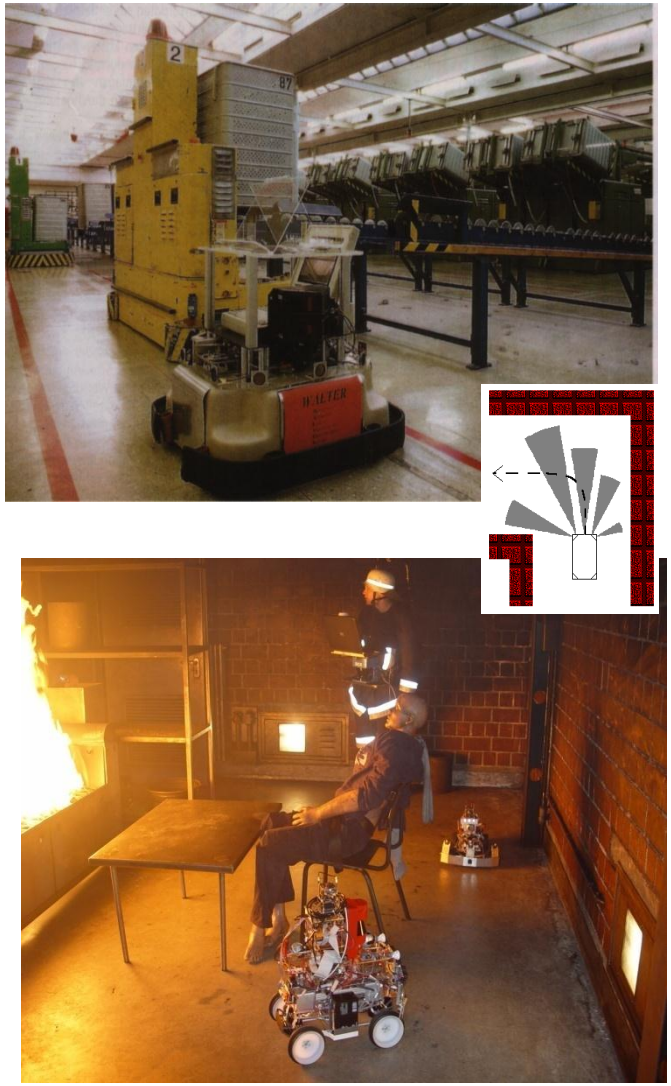
- was founded 1402
- was the place, where of Prof. Roentgen found the X-rays
- was the home of 14 Nobel prize winners
- is in the rankings among the top 10 German research unis
- hosts about 25 000 students in arts and sciences

Prof. Roentgen and his equipment

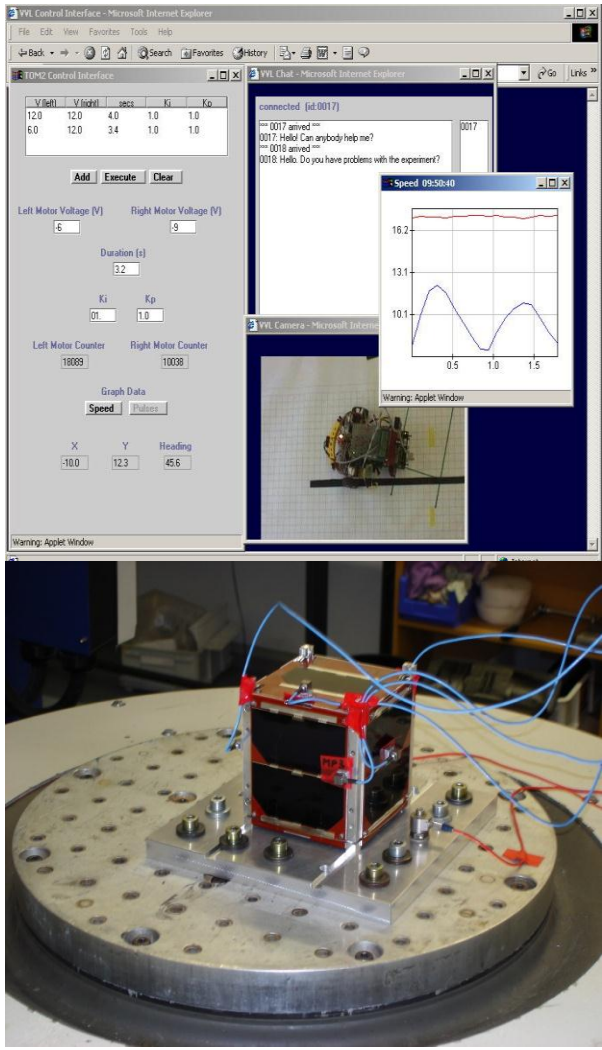
The Computer Science Institute

Space Exploration

Industry



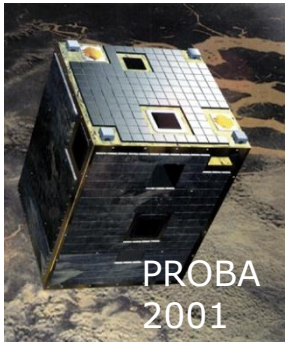
Education

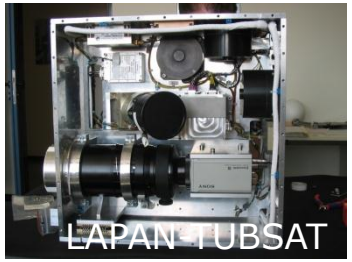


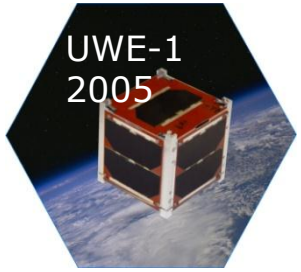
Research Areas at University Würzburg

Small Satellite Terminology

- Dramatic progress in miniaturisation technologies enables smaller satellites
- Advantages of small satellites: less expensive, more flexible, but limited capabilities



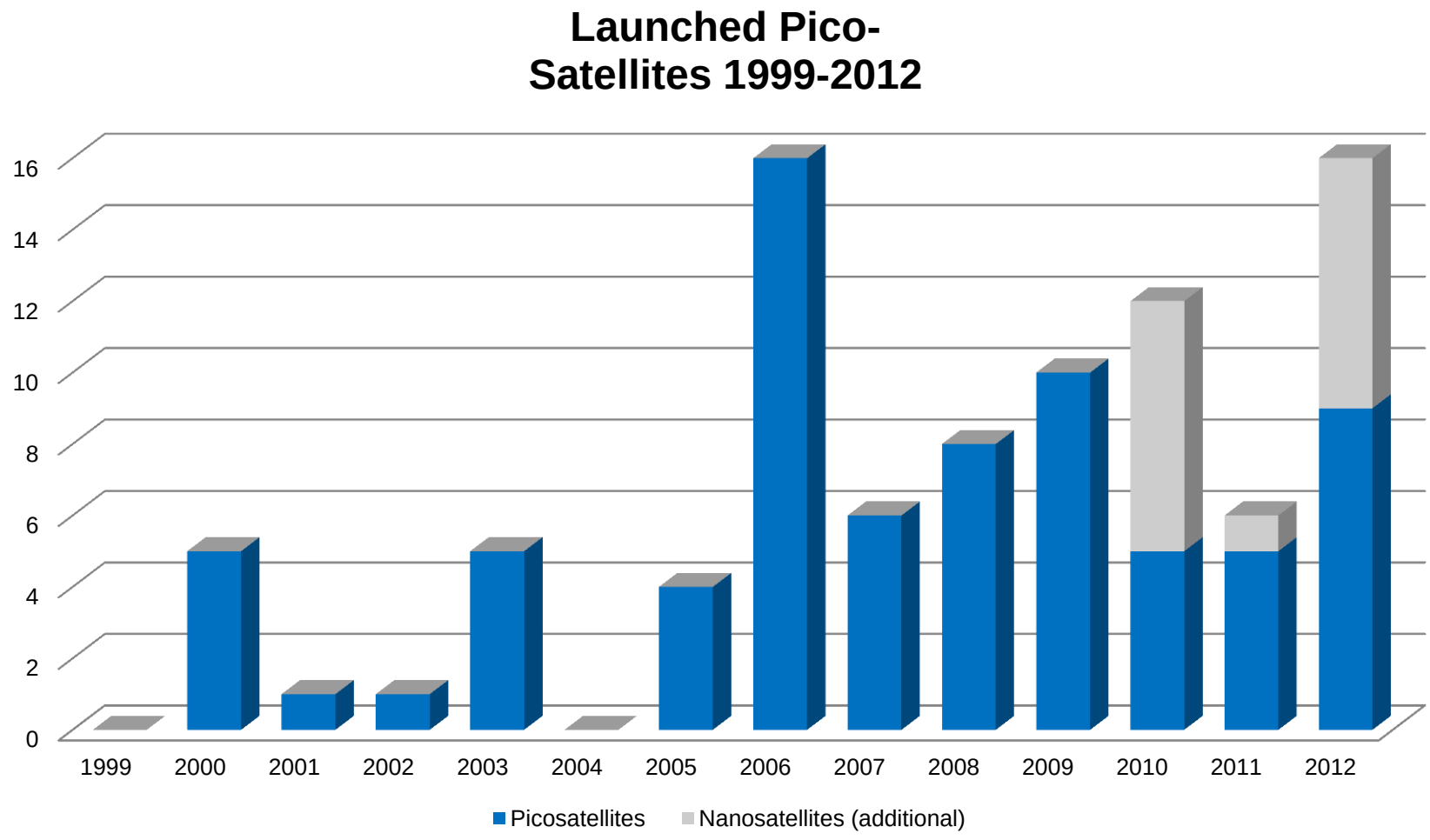




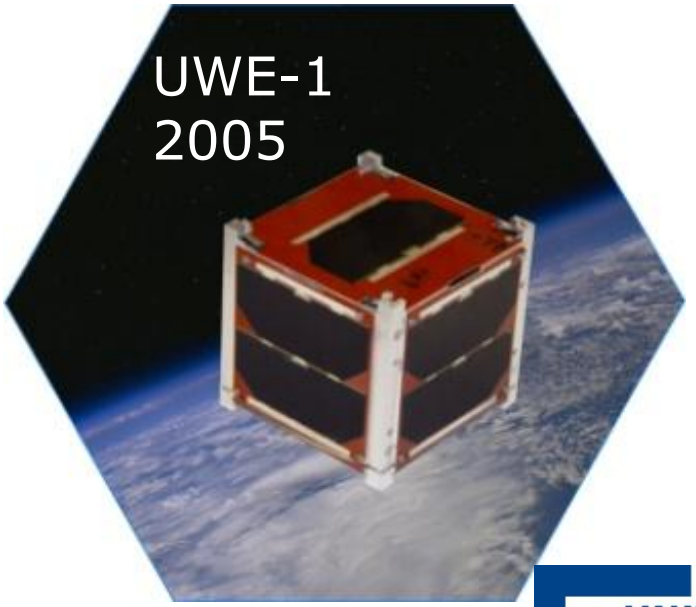
Typical Satellite	Mini-Satellite	Mikro-Satellite	Nano-Satellite	Pico-Satellite
(>500 kg)	(100 – 500 kg)	(50 – 100 kg)	(1-50 kg)	(~1 kg)

Small satellites are complementary to classical satellites

Amount of launched Pico-Satellites



Pico-Satellites in Germany



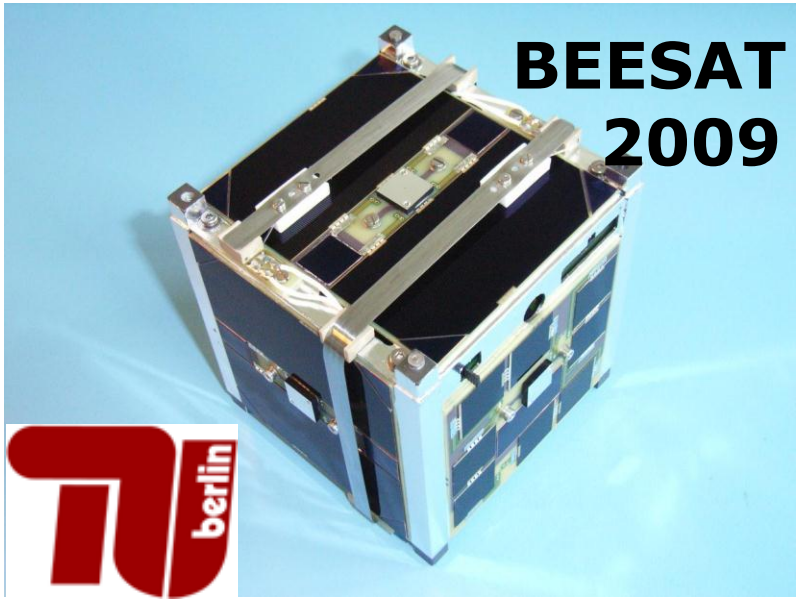
Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

FH AC
Hochschule Aachen

Objectives

Telecommunication tests:
Internet in Space

Technology demonstration AOCS:
magnetometer, magnetic coils, sun sensors



Objectives

- Internet in Space
- advanced attitude determination

Technology demonstration
reaction wheels

- **national program "pico-satellites for education " by DLR since 2007**
- **annual Pico-/Nano-Satellite national/European Workshop since 2007, alternating between Uni Würzburg and TU Berlin**
- **scientific perspective on very small satellite formation flying**
- **organisation of universities in national Pico-/Nano-Satellite Initiative**

Ongoing and future activities for European educational pico-satellite activities

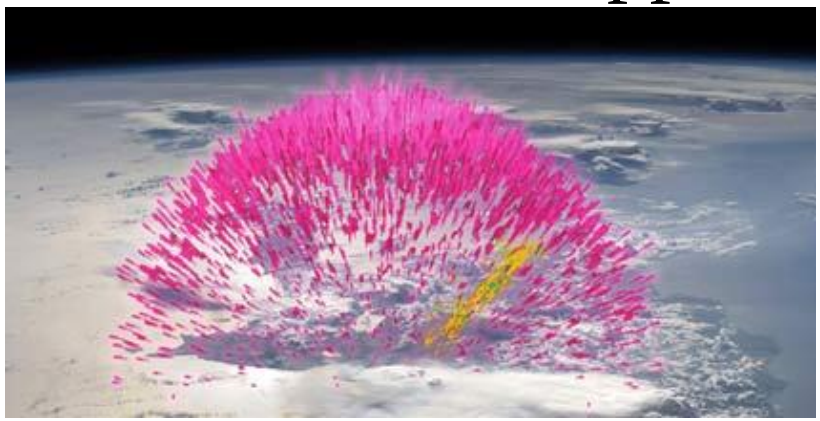
International network of ground stations for educational satellites endorsed by the International Space Education Board (ISEB), coordinated by ESA Educational Office

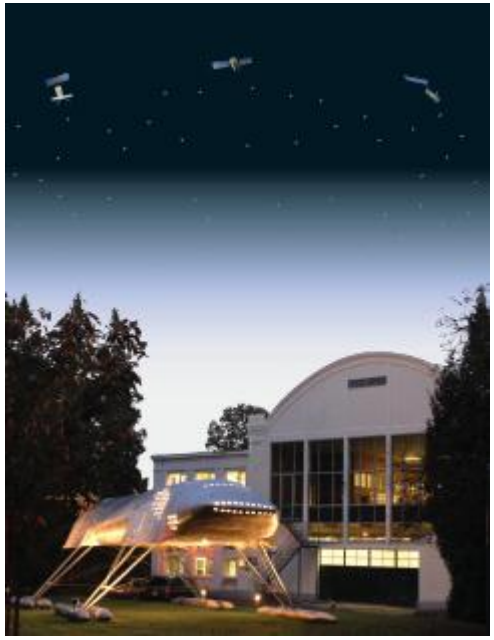
The VEGA Maiden flight carried 8 pico-satellites into orbit in February 2012, coordinated by ESA educational office

QB50: An European initiative started 2009 to build 50 CubeSats for

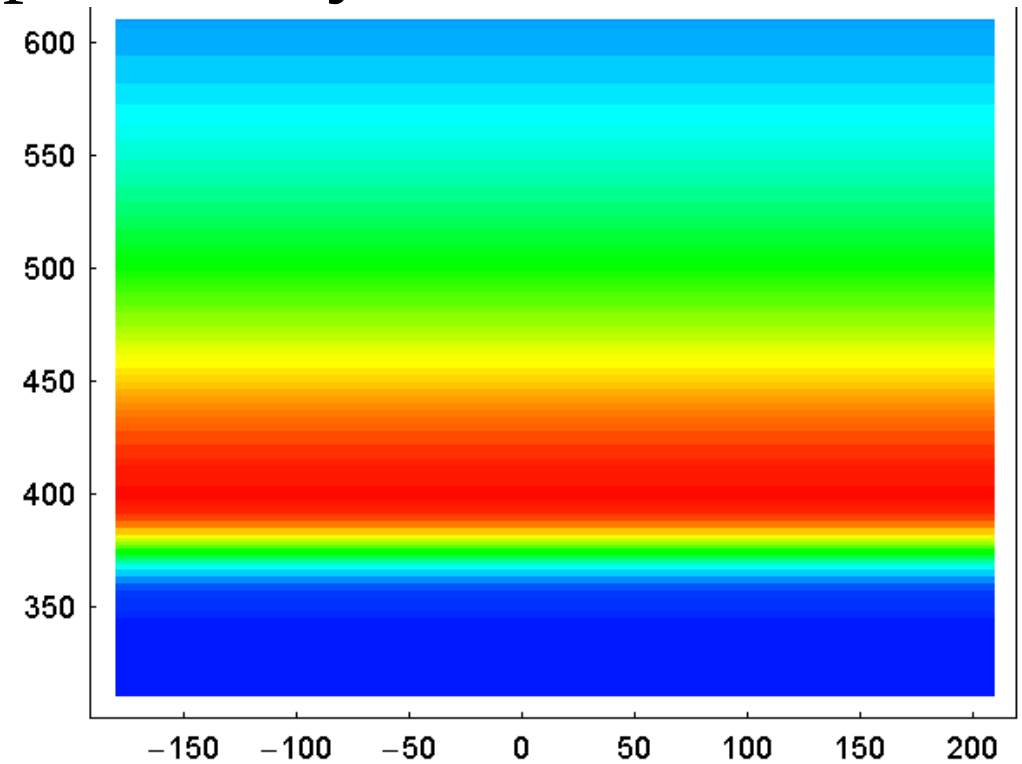
- in situ study of the temporal and spatial variations in the lower thermosphere at 90-300 km altitude,
- study of the re-entry process

Space Weather Applications for Characterization of the Upper Atmospheric Layers





Gamma ray emissions as potential reaction of anti-matter above lightning clouds detected (October 2010, FERMI)



mapping of ionospheric plasma structures and of irregularities

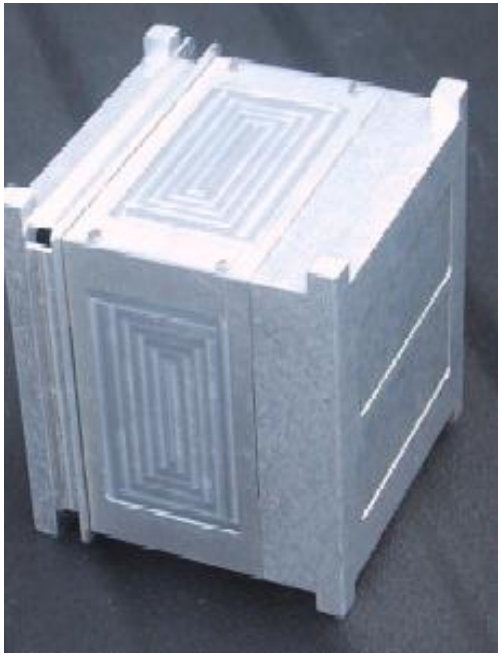
Exploration of the lower thermosphere (90-330 km) by in-situ measurements using small satellites (QB50-project)

CubeSat Experiments

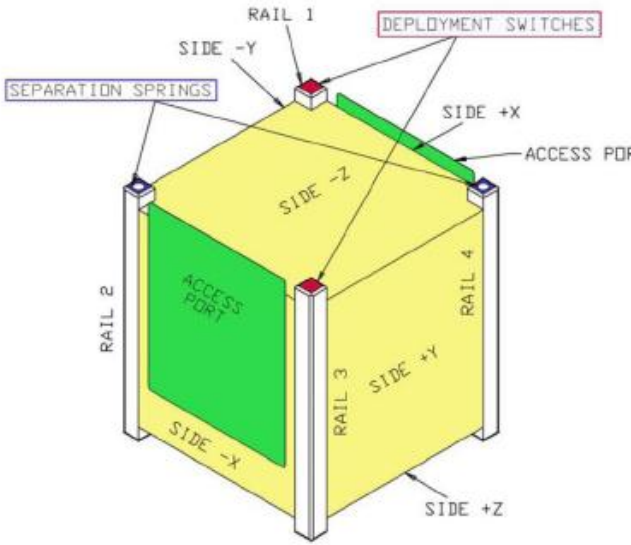
- E & M fields and waves
- Radio waves
  - VLF-UHF
  - microwave
- Plasma and particles
  - Electrostatic probes – mass & imaging spectrometers,
  - keV-MeV
- Photometers & imagers
  - near IR- UV
  - X & gamma rays

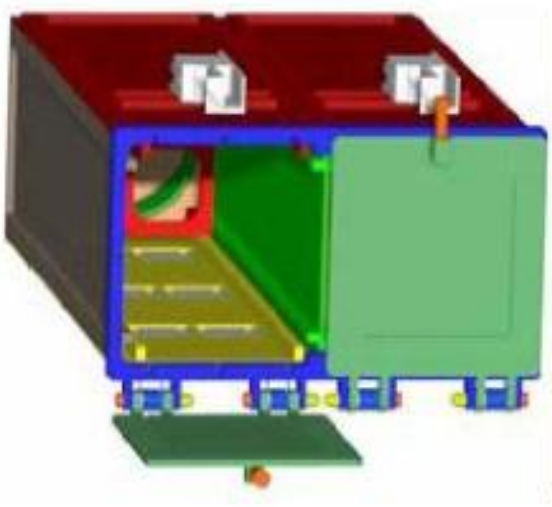
Plenary on Pico-Satellites at 60th International Astronautical Congress Daejeon (South Korea), 17.Oktober 2009

CubeSats

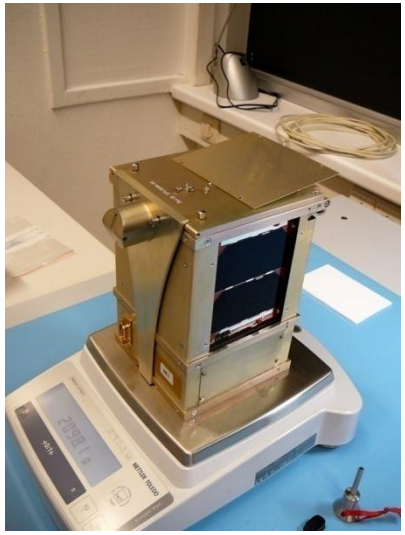


- A CubeSat is a cube-shaped spacecraft with side length of 10 cm and a mass of 1 kg.
- The structure is standardized for launcher adaptation.
- Students groups typically design in about 1 academic year the spacecraft.
- Interdisciplinary student teams have to analyse the orbit properties and related implications on different satellite subsystems, such as on board data handling, power, telecommunications, attitude determination and control, thermal control, structure.
- The complete satellite life cycle from feasibility analyses to design, implementation, launch, in orbit operations, data collection and interpretation is to be covered.





Standard P-Pod for 3 CubeSats



UWE-2 in the single launcher adapter of Astrofein

The standardized launcher adapter

Education on Building Satellites: first steps CanSats

Studenten learn to build from components
powerful measurement systems

CanSat - in a can are to be placed sensors in order to characterize the atmosphere

CanSats for preparation to finally build satellites

SpaceMaster is supported by scholarships within the "ERASMUS MUNDUS"-Program of the EU for European elite-curriculla. It is offered at University Würzburg in cooperation between Computer Science and Physics/Astronomy, and by the partner universities

- Luleå University of Technology, Sweden
- Cranfield University, United Kingdom
- Czech Technical University, Czech Republic
- Helsinki University of Technology, Finland
- Université Paul Sabatier Toulouse III France

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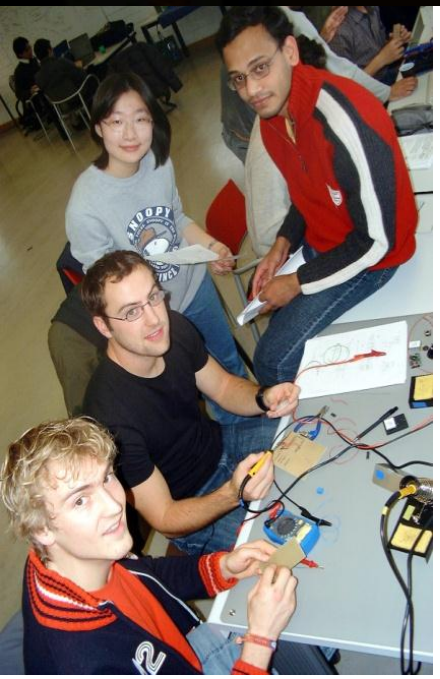
Education: SpaceMaster

SpaceMaster

Joint European Master in Space Science and Technology

Education and Culture

Erasmus Mundus



University partners outside the EU :

Stanford University, USA
Utah State University, USA
University of Tokyo, Japan
University of Toronto. Kanada
Shanghai Jiao Tong Uni, China

Recent awards of Würzburg students

- ZARM Award 2006
- First price in Student Contest at International Astronautical Conference 2006 Valencia
- Award of the British Interplanetary Society
- IABG-Award 2008 for Oliver Kurz
- Silver medal at Student Contest of International Astronautical Conference 2008 Glasgow

International students :

~ 25 from outside EU
~ 15 Europeans outside Germany
~ 10 German students

UWE Roadmap

University ***W***ürzburg's ***E***xperimental satellites)

UWE X Formation Flying Mission

- **Formation Control**
- **Higher Data Rates**
- **Ad-Hoc Networks**
- **Relative Navigation**
- **…**

2013 UWE-4

- **Position Control**

2013 UWE-3

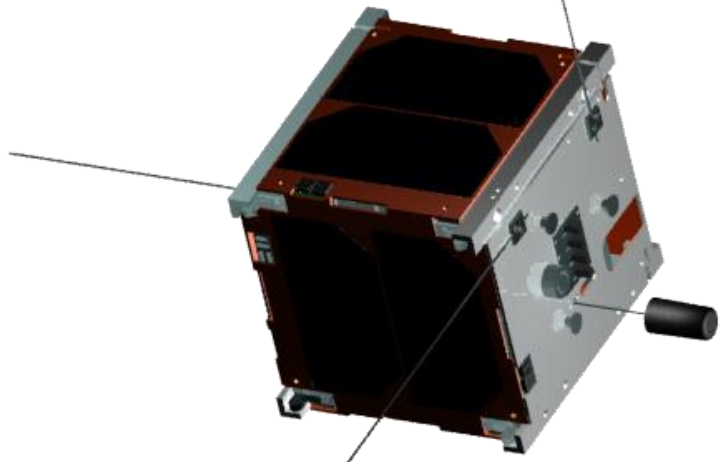
- **Attitude Control**

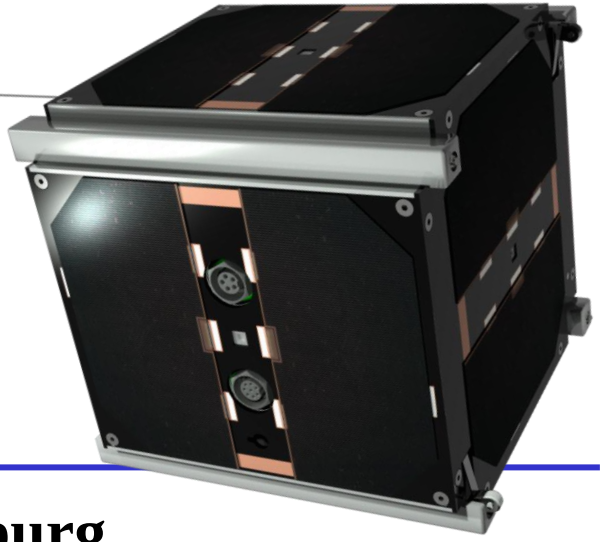
2009 UWE-2

- **Attitude- and Orbit Determination**

2005 UWE-1

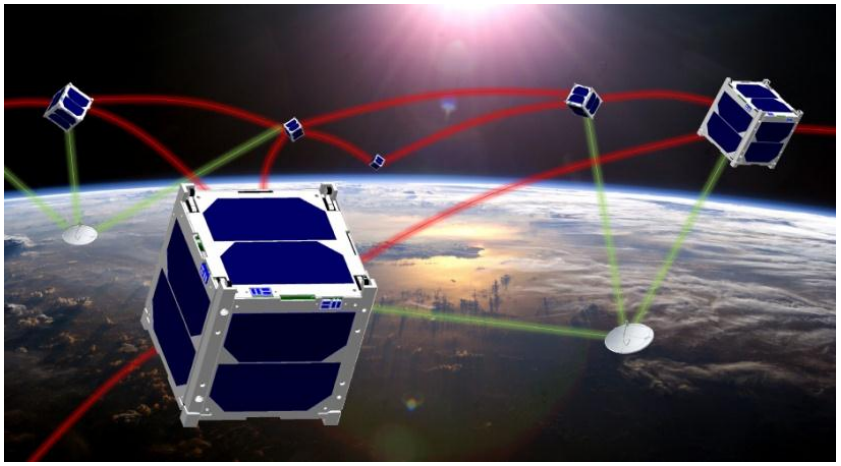
- **Telecommunication**



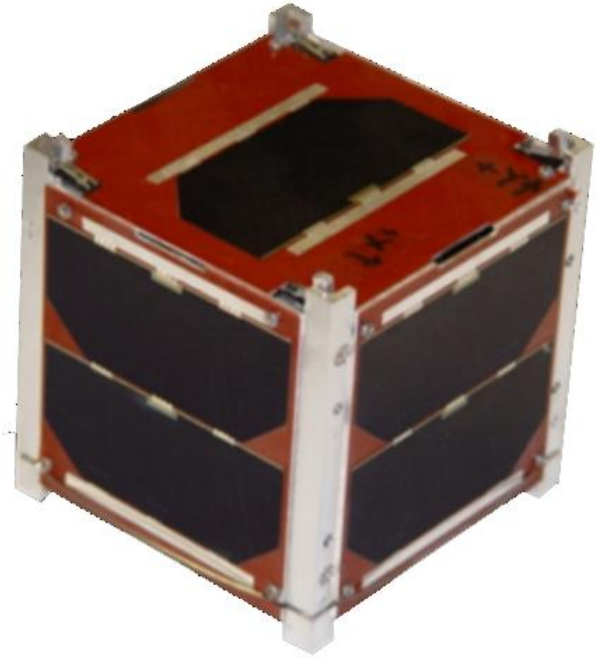


Distributed satellite systems require coordination of

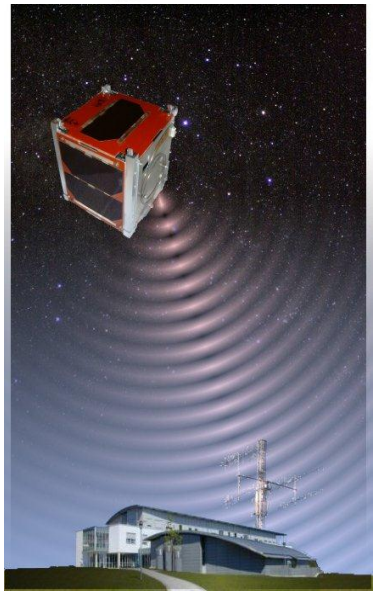
- orbits at different altitudes,
- optimal control strategies for position and attitude pointing of the specific system components,
- activities for heterogeneous sensors,
- flow of information and its storage.



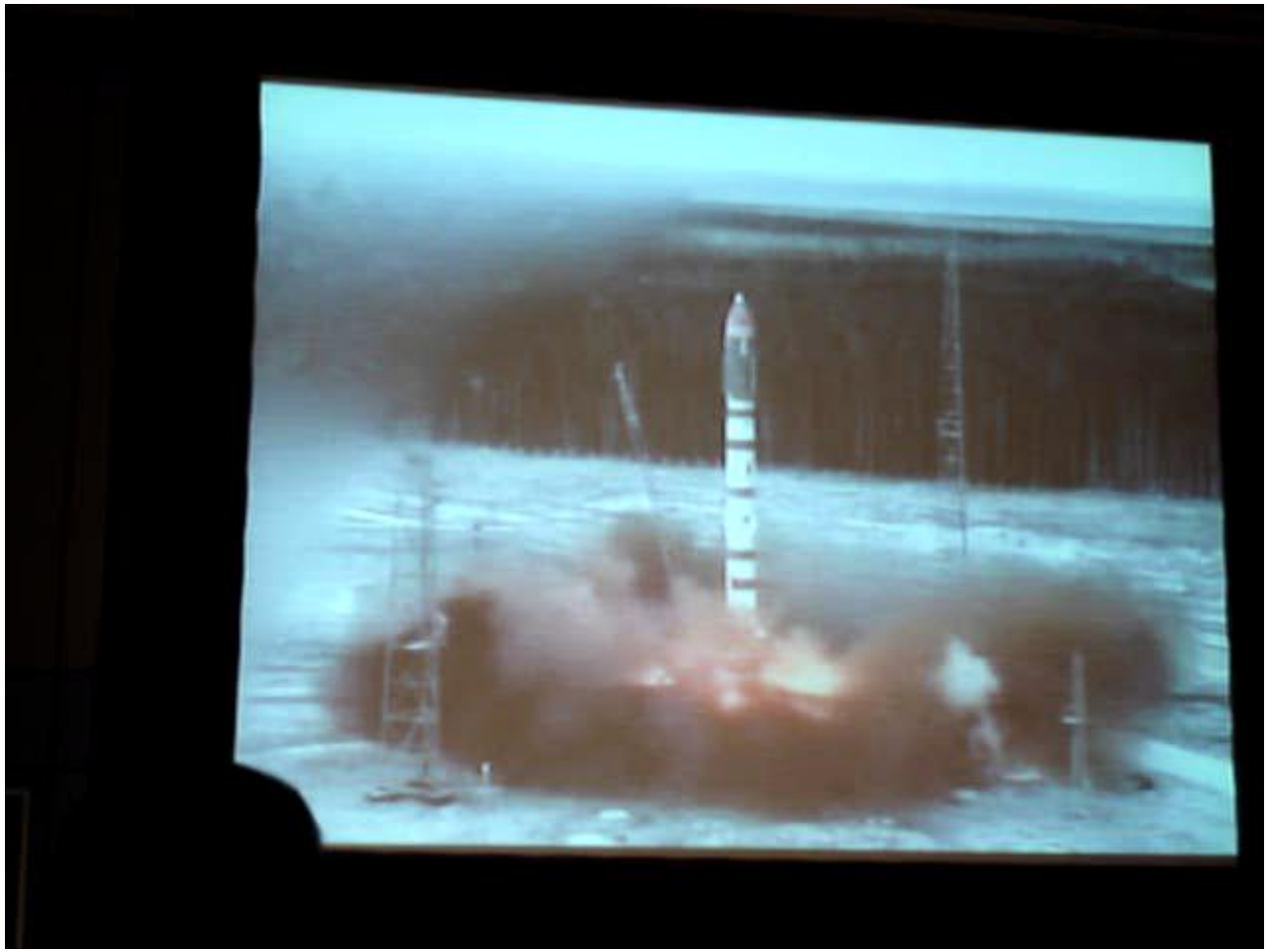
UWE-1 Objectives



- Adaptation of parameters in internet protocols for the telecommunication link to delays and disturbances, typical for space environments
- Technology Development Tests
  - Demonstration of modern miniaturization techniques to implement of fully functional satellite at a mass below 1 kg
  - Use of micro-Linux as on-board operating system
  - Test of highly efficient, triple-junction GaAs solar cells, manufactured in Europe, in space environment
  - Integration of the ground control station into a international network of CubeSat ground stations via Internet



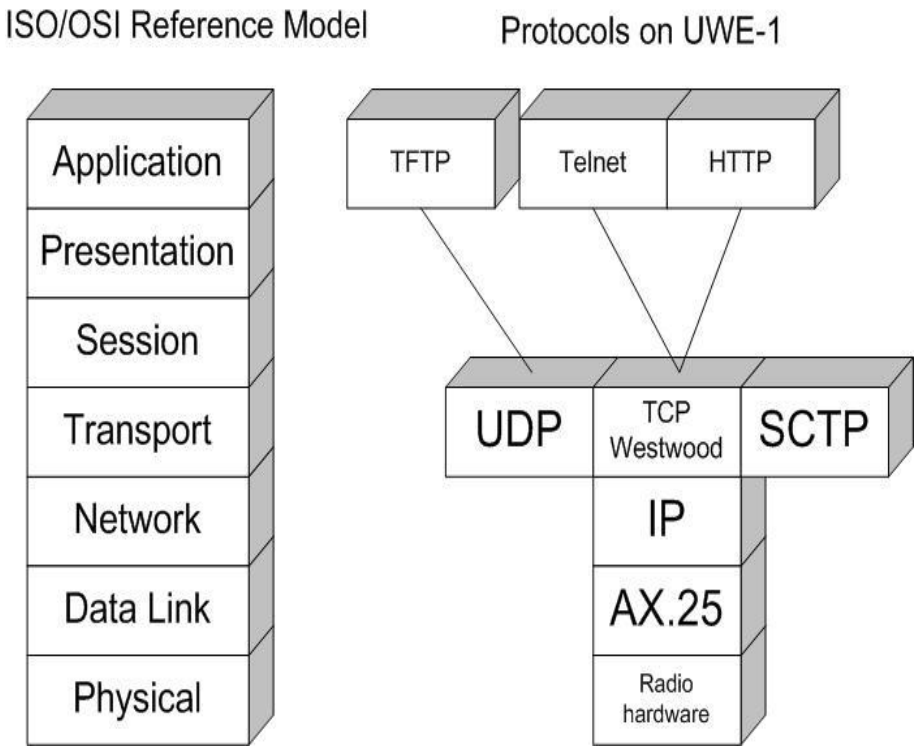
UWE-1: University Würzburg's Experimental Satellite with only 1 kg mass, launched on 27. 10. 2005 , 8:52



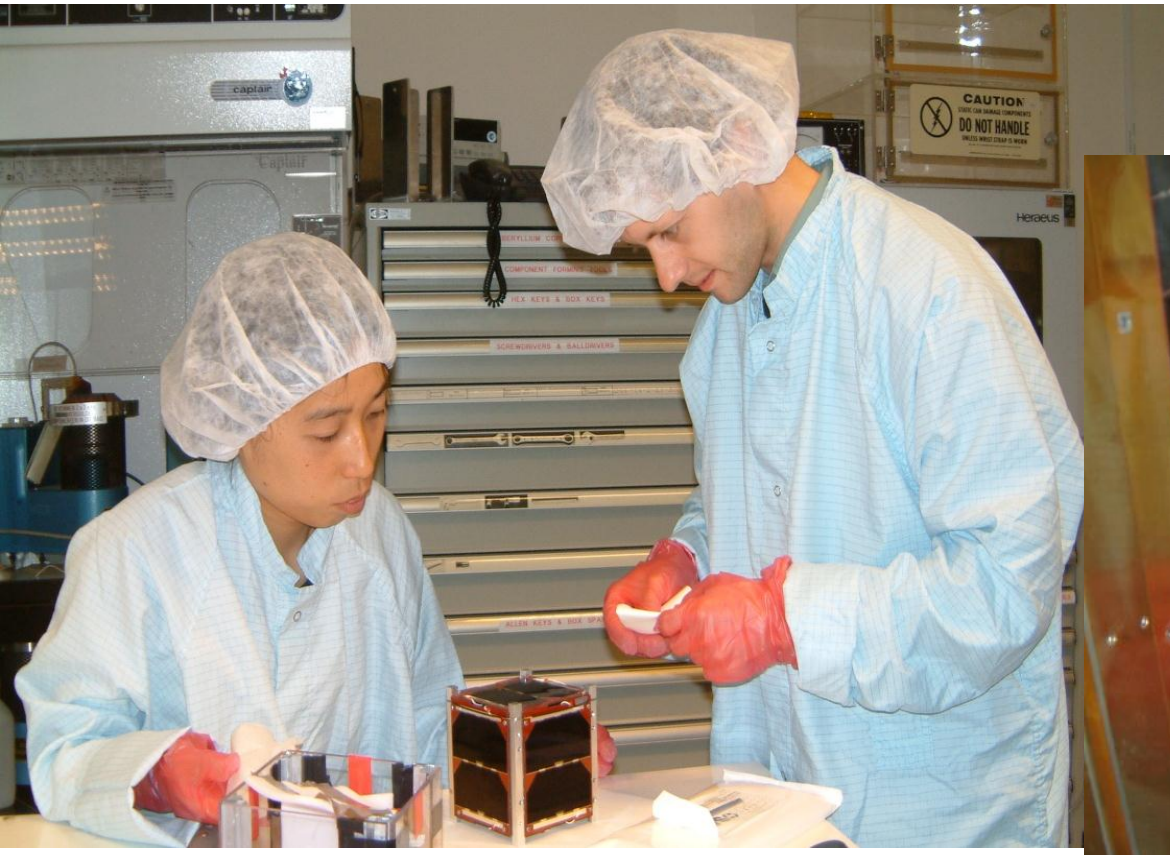
UWE-1 Experiments

The main experiments were related to cross layer optimizations between AX.25 and higher protocol layers (i.e. IP) and to application layer protocols like HTTP and TFTP.

The specific implementation of ISO/OSI reference model layers on-board of UWE-1. Here for comparison reasons several transport layer alternatives were realized.



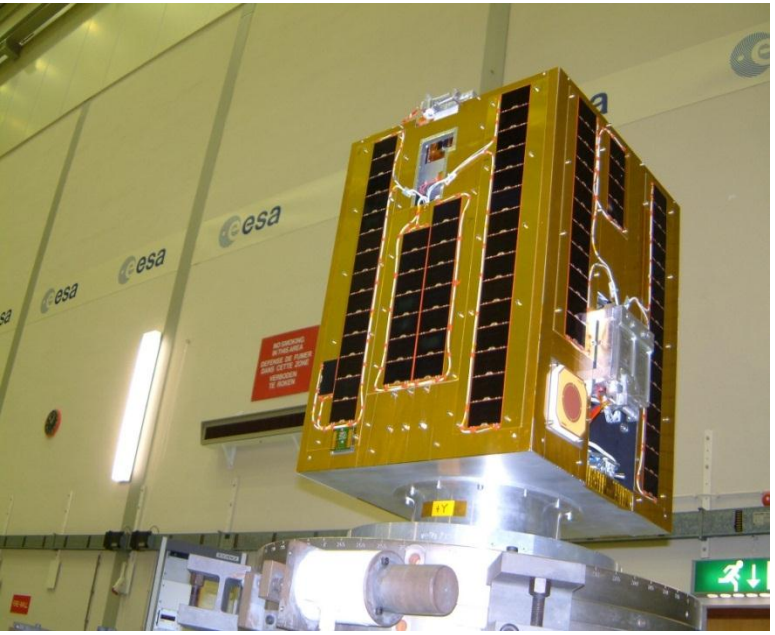
The two system engineers
(from Japan, Romania)
during final integration



Integration into
the adapter
31.5.2005

UWE-1 in spring 2005

The other passengers for ESA

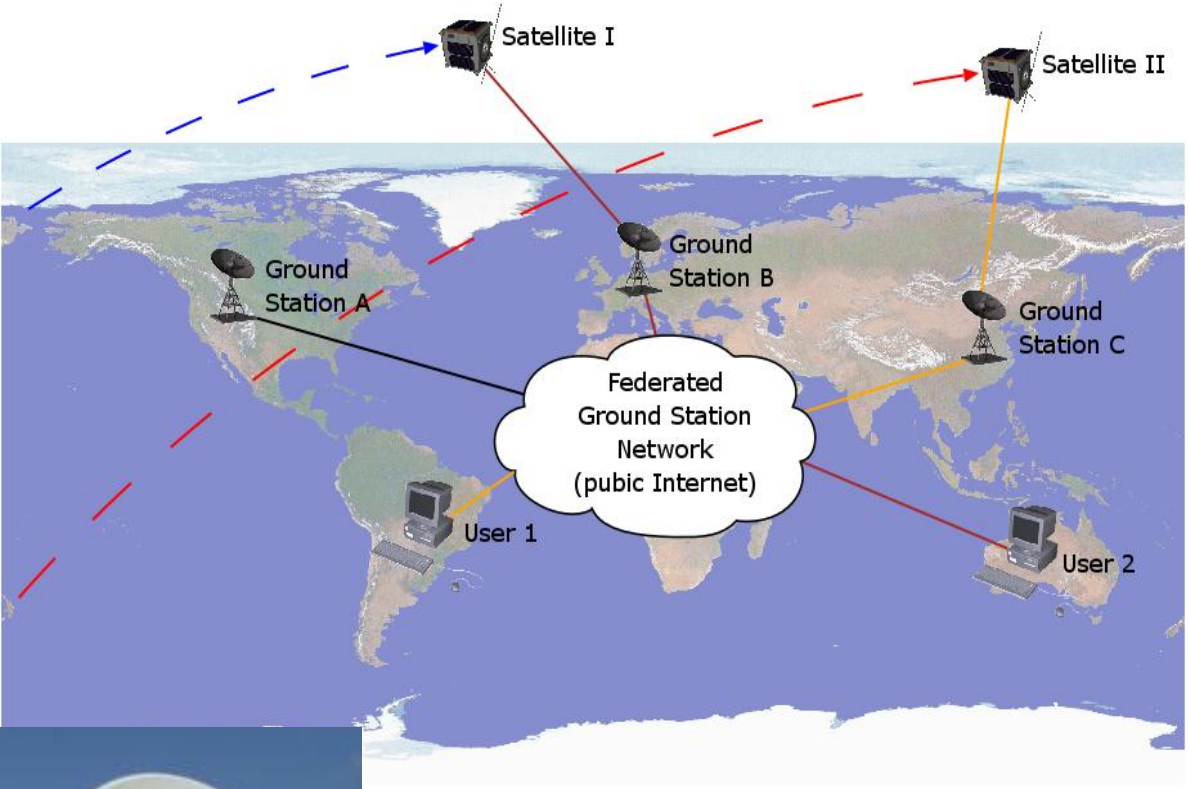


SSETI – a 80 kg satellite built by 23 groups of european students

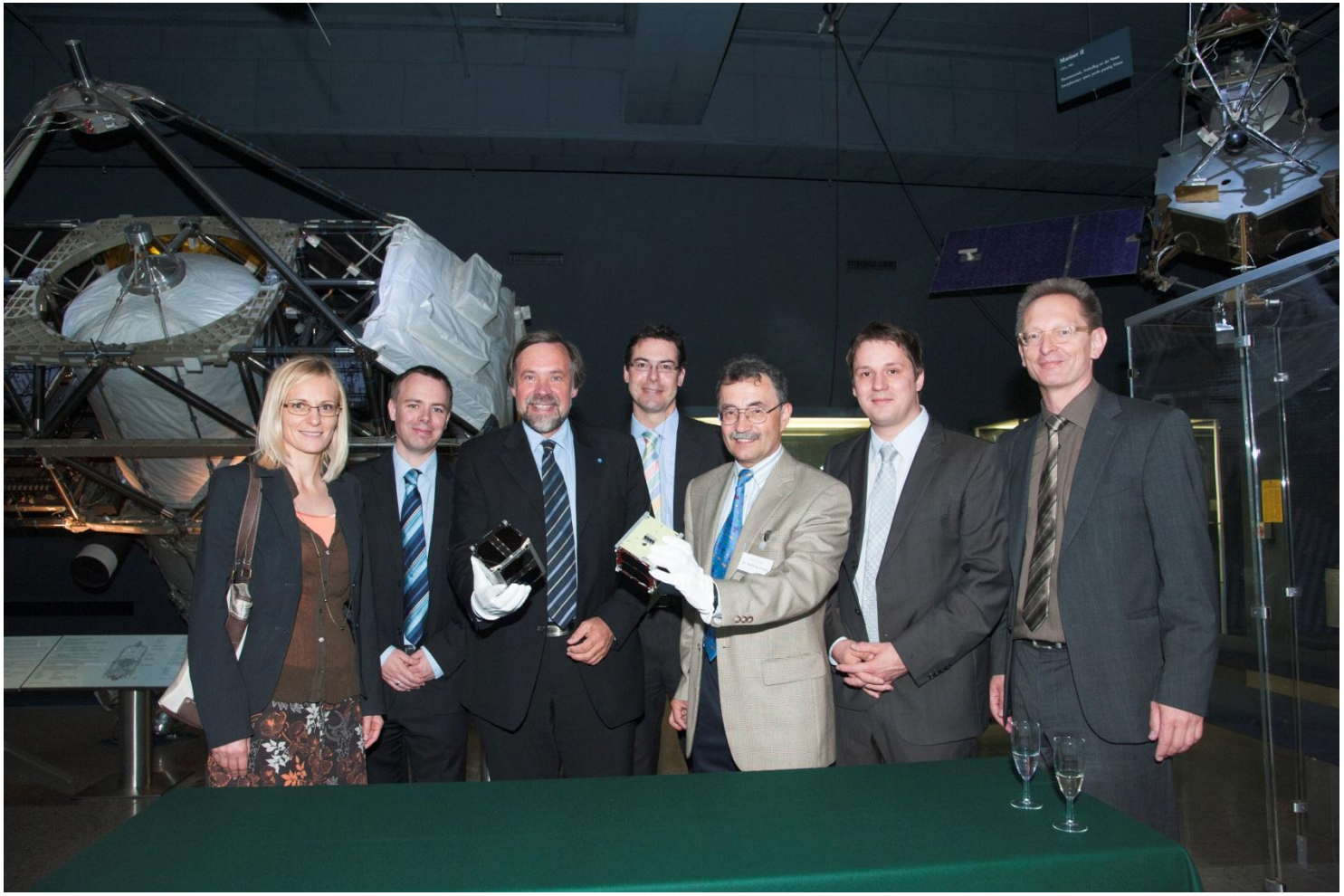
N-Cube 2 from Norway

Xi-V from Japan

Satellites sharing the launch on 27.10.2005



Contributions to world wide networks of ground control stations



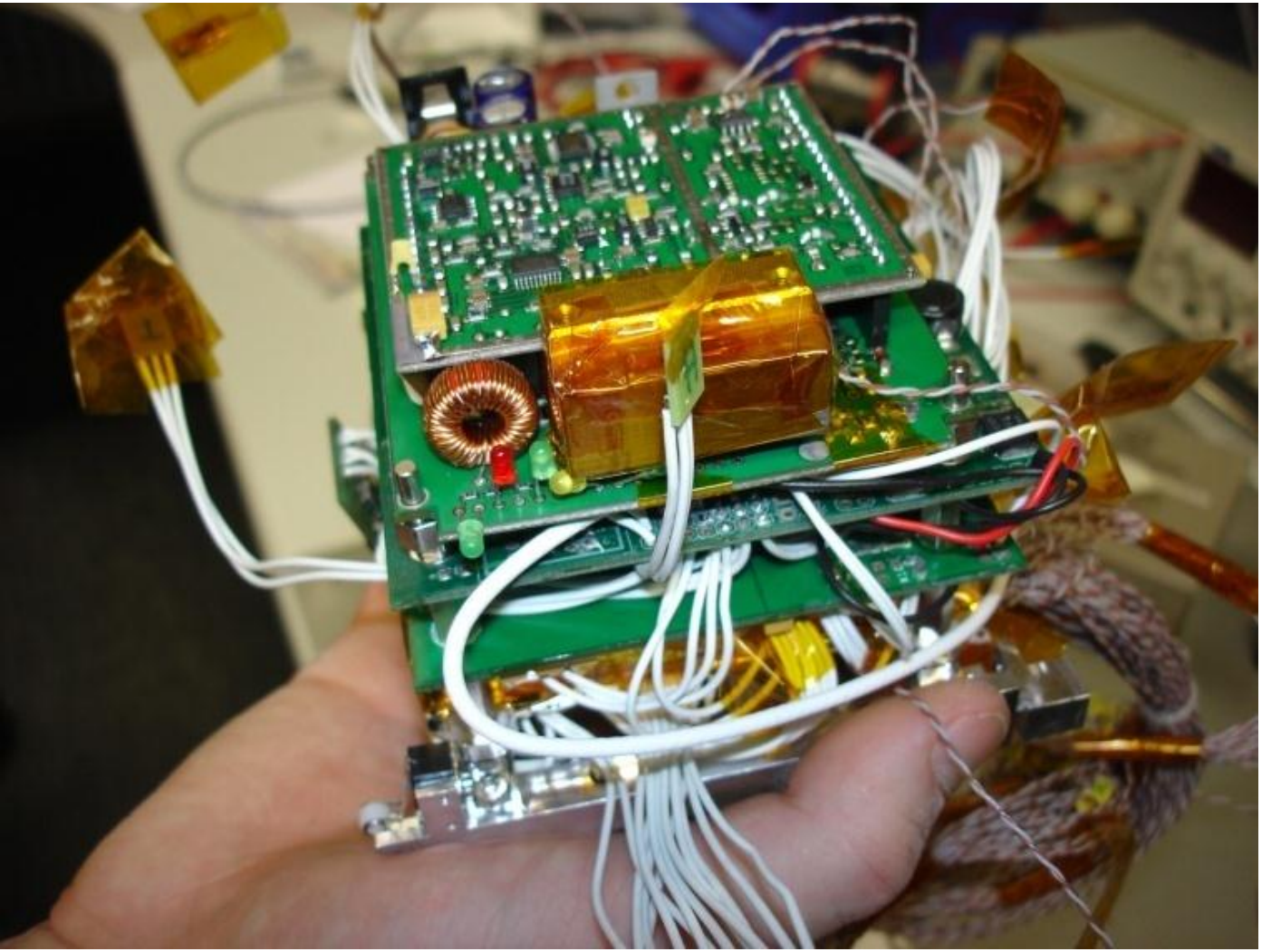
UWE-1 was the first German Pico-Satellite and is now on display as technology demonstrator at the Deutsche Museum (Munich)

UWE-2

Scientific objectives

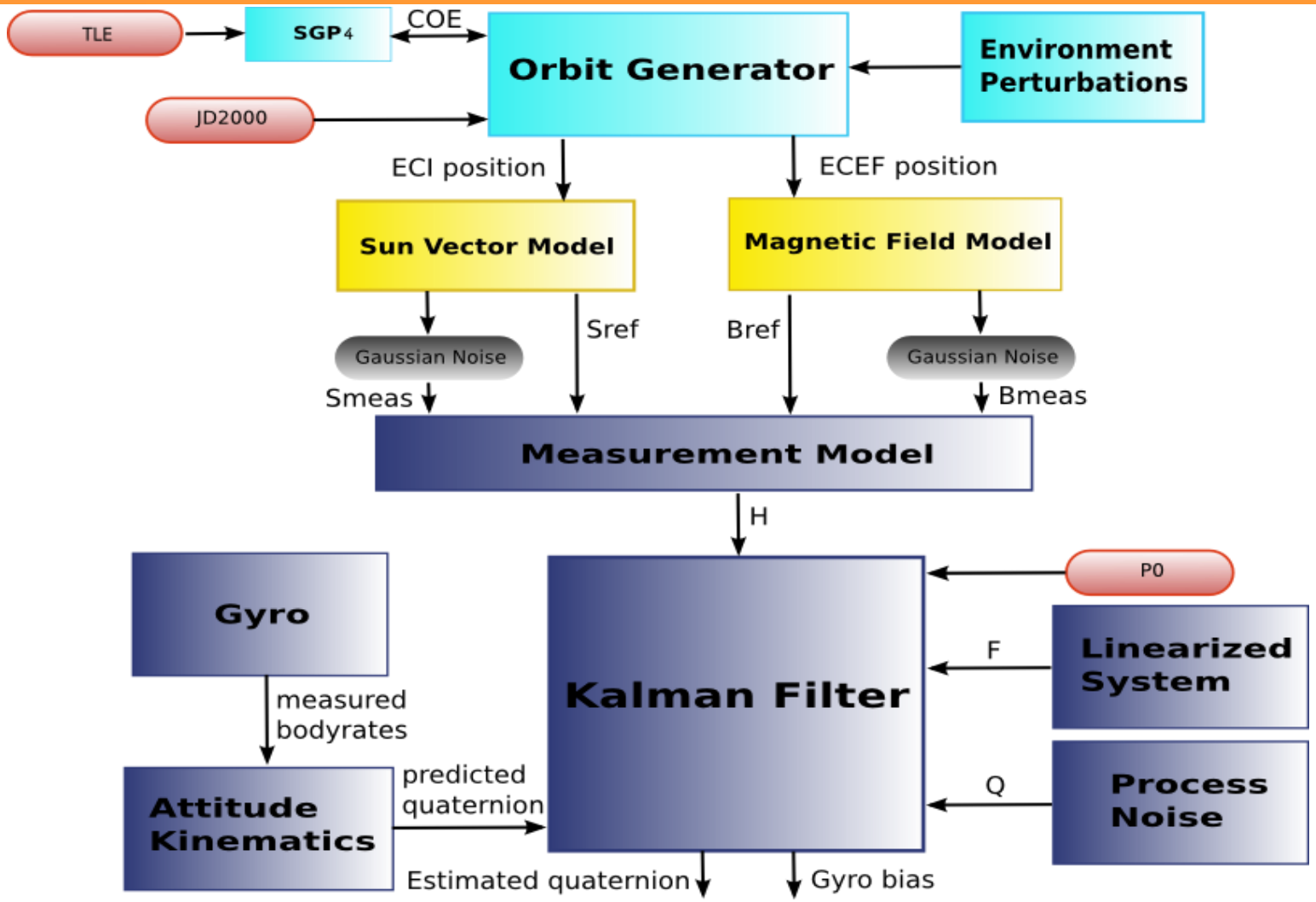
- Precise attitude determination by using GPS, MEMS inertial sensors, magnetic field and sun sensors
- Continuation of telecommunication experiments related to IP in space

Succesful launch: 23.9.2009 with indian PSLV-launcher



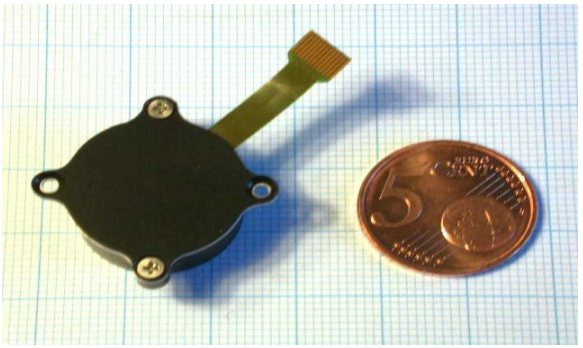
The UWE-2 boards:

- Telecommunication (UHF / VHF)
- Energy storage and distribution
- Data processing (H8, µLinux)
- GPS receiver



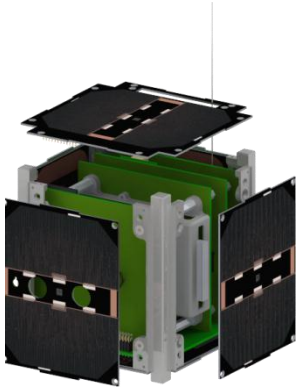
Functional block diagram of the UWE-2 attitude determination software, designed to provide the inputs for control actions in formation flying

UWE-3 addresses attitude control



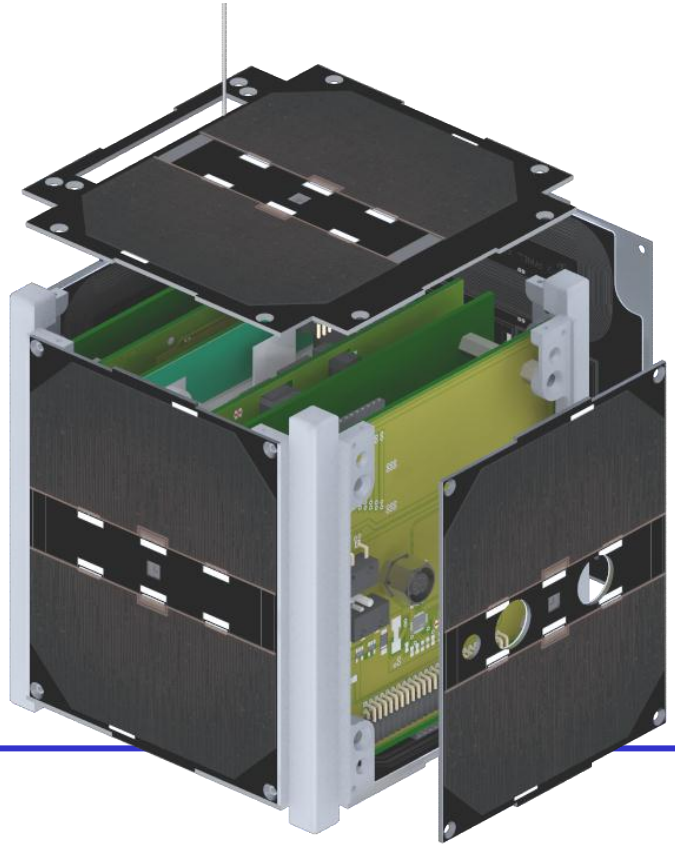
Micro wheel from Astrofein

Modular satellite design



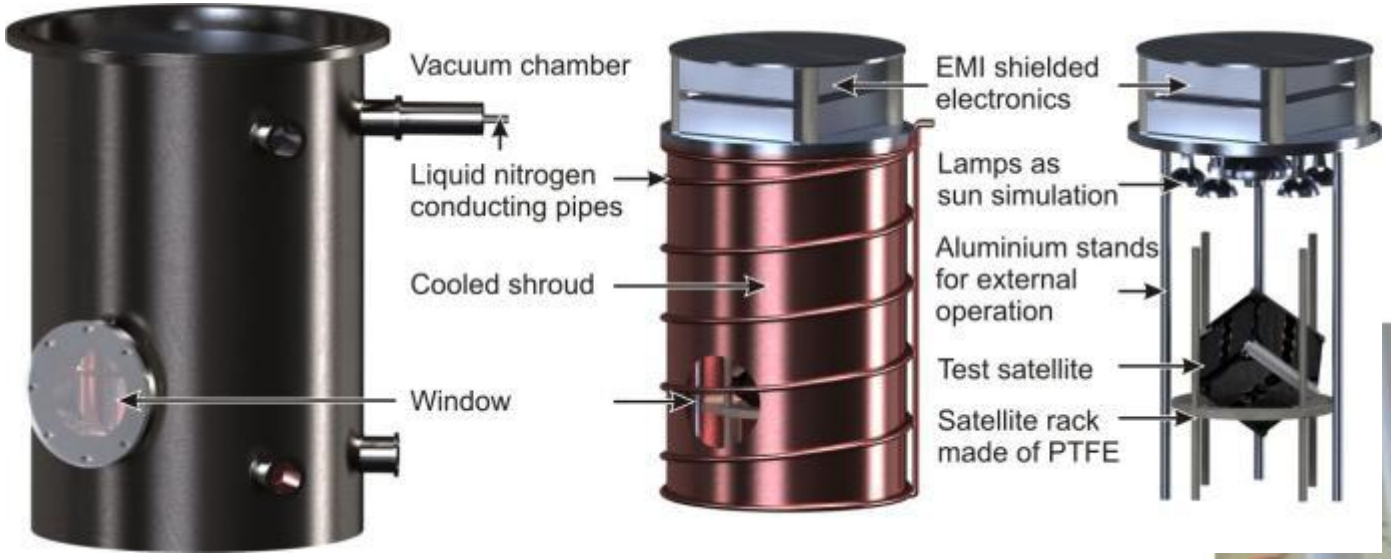
UWE-3 Bus Design

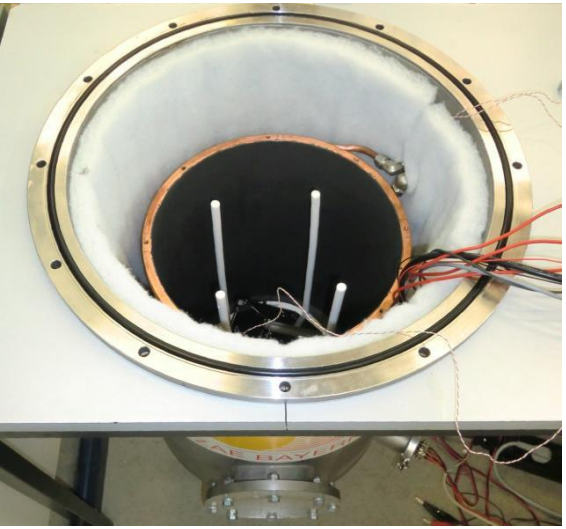
- Miniaturized flexible and modular structure
  - lighter, more space, easier manufacturing
  - modularity and flexibility accelerates development, integration, test, maintenance, replacements and extensions



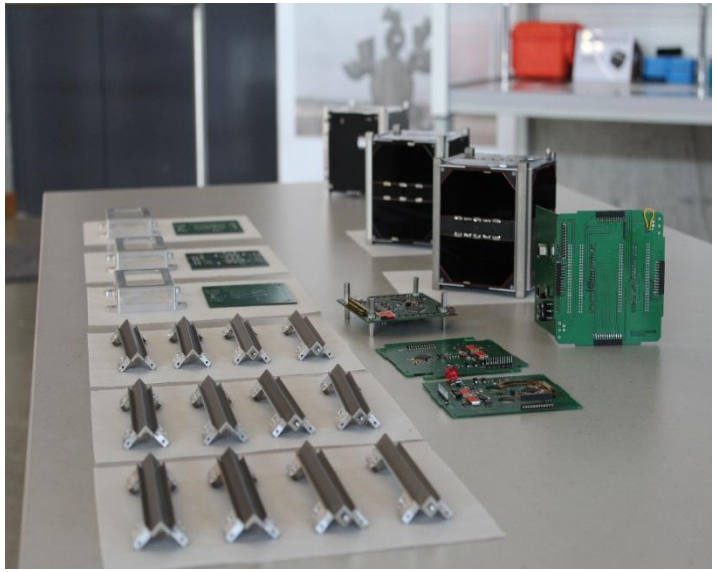
- Decoupling of mechanical and electronics structure
  - Protect interior from thermal hazards
  - provide comfortable access to all subsystems in a functional configuration, even after integration
  - easy assembly and disassembly

Thermal Vacuum Tests



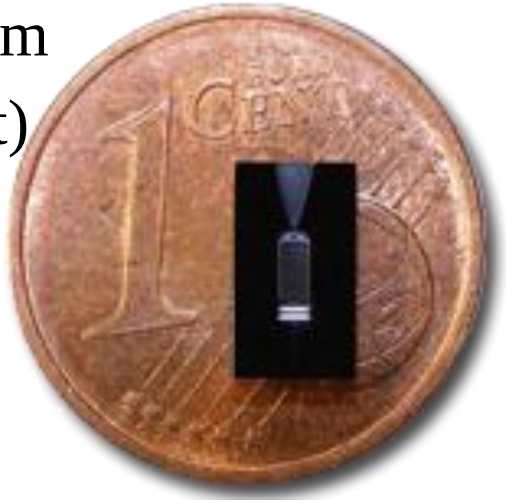


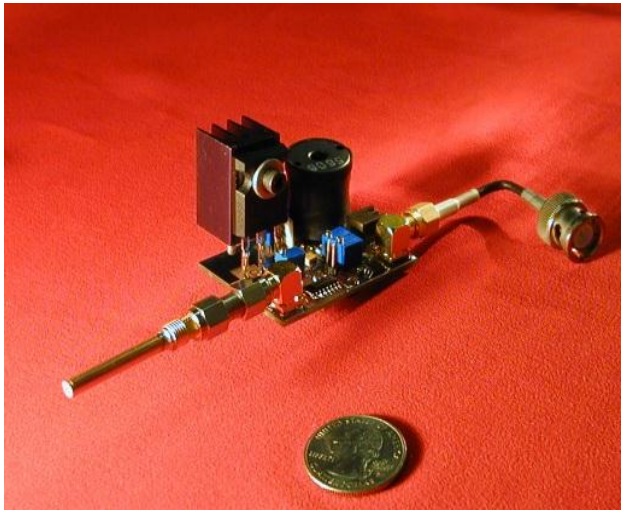
UWE-4 in preparation, emphasis on orbit control



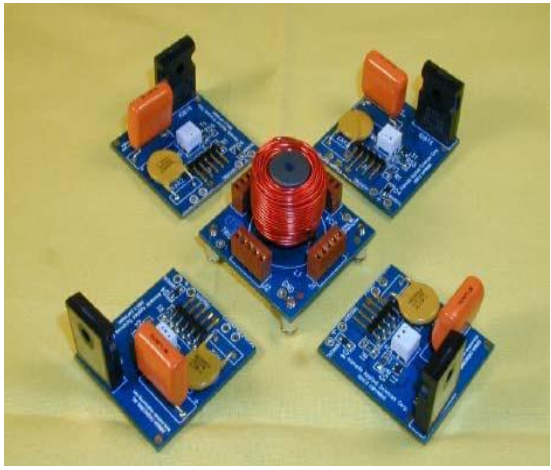
Current preparation of UWE-3 and -4 engineering and flight models

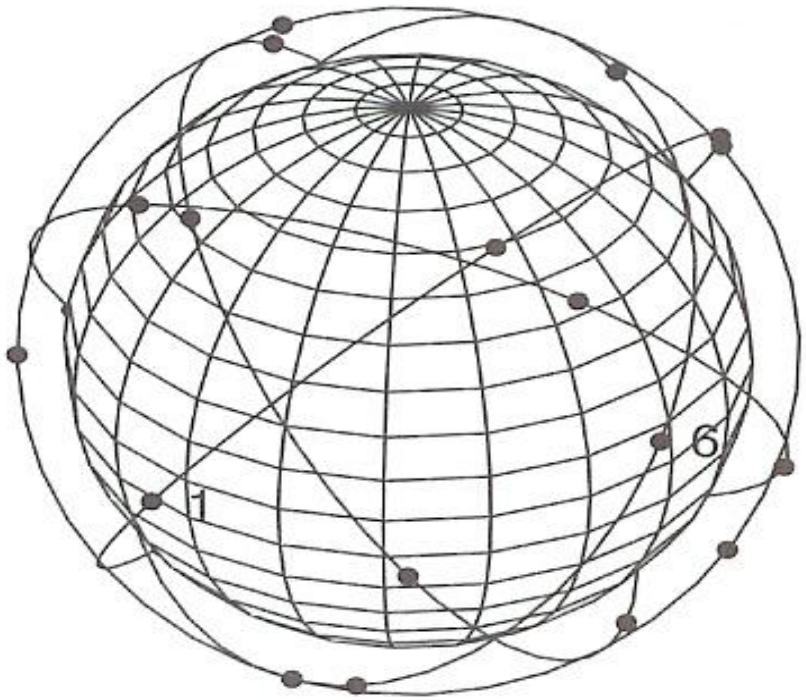
micro propulsion system (EU FP7 development)

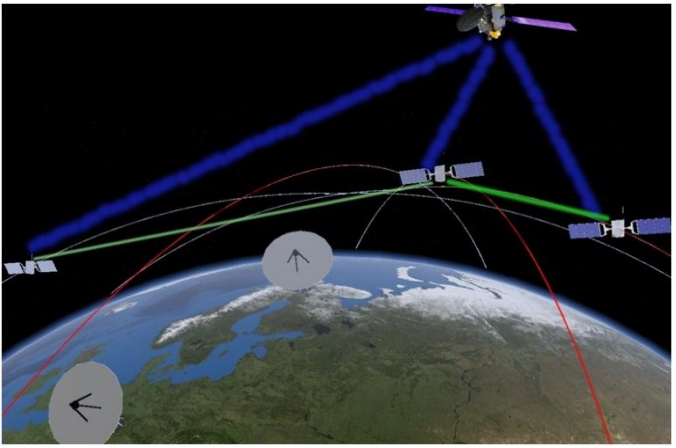




Vacuum arc thruster propulsion system (Uni BW)

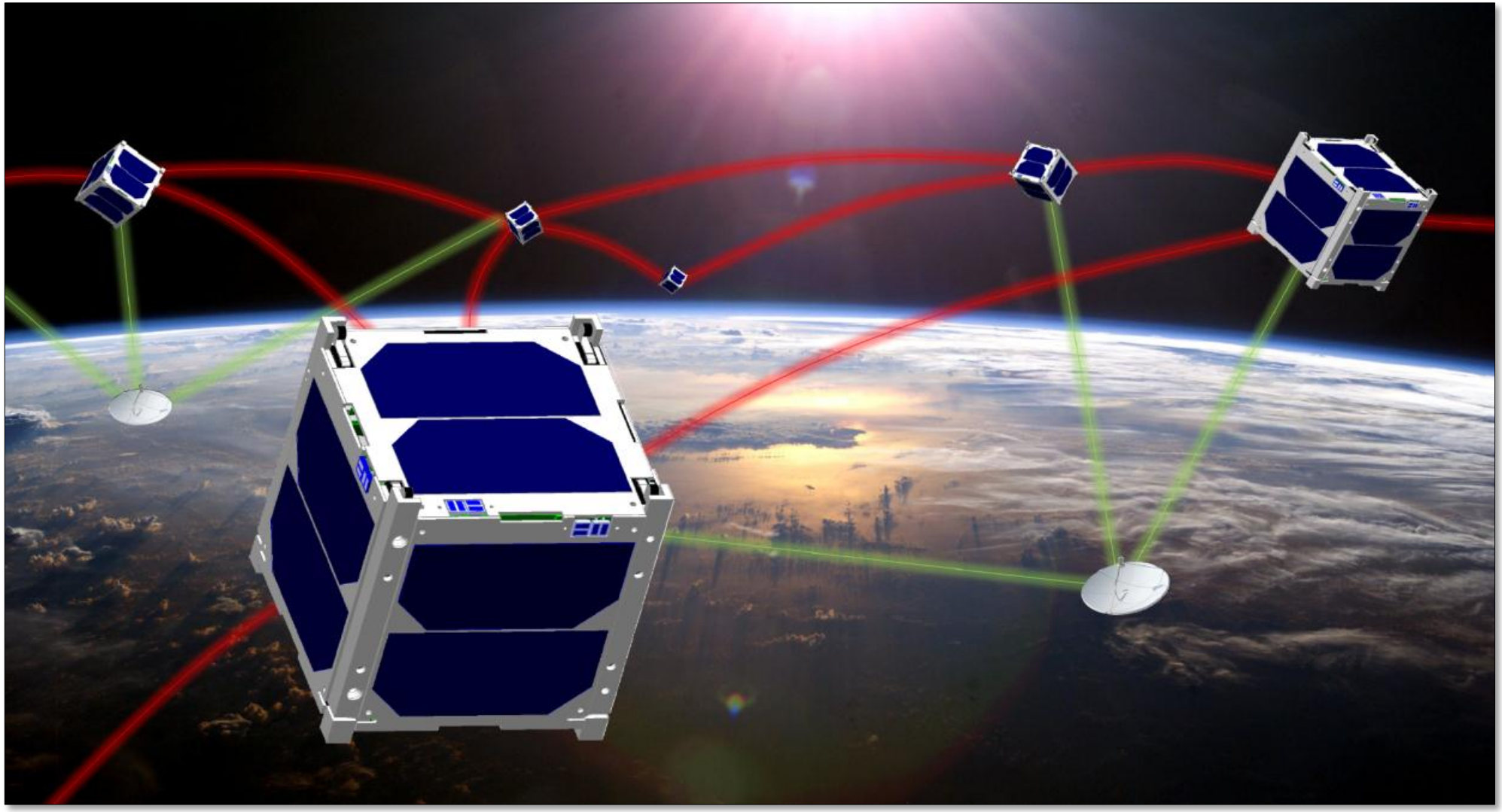






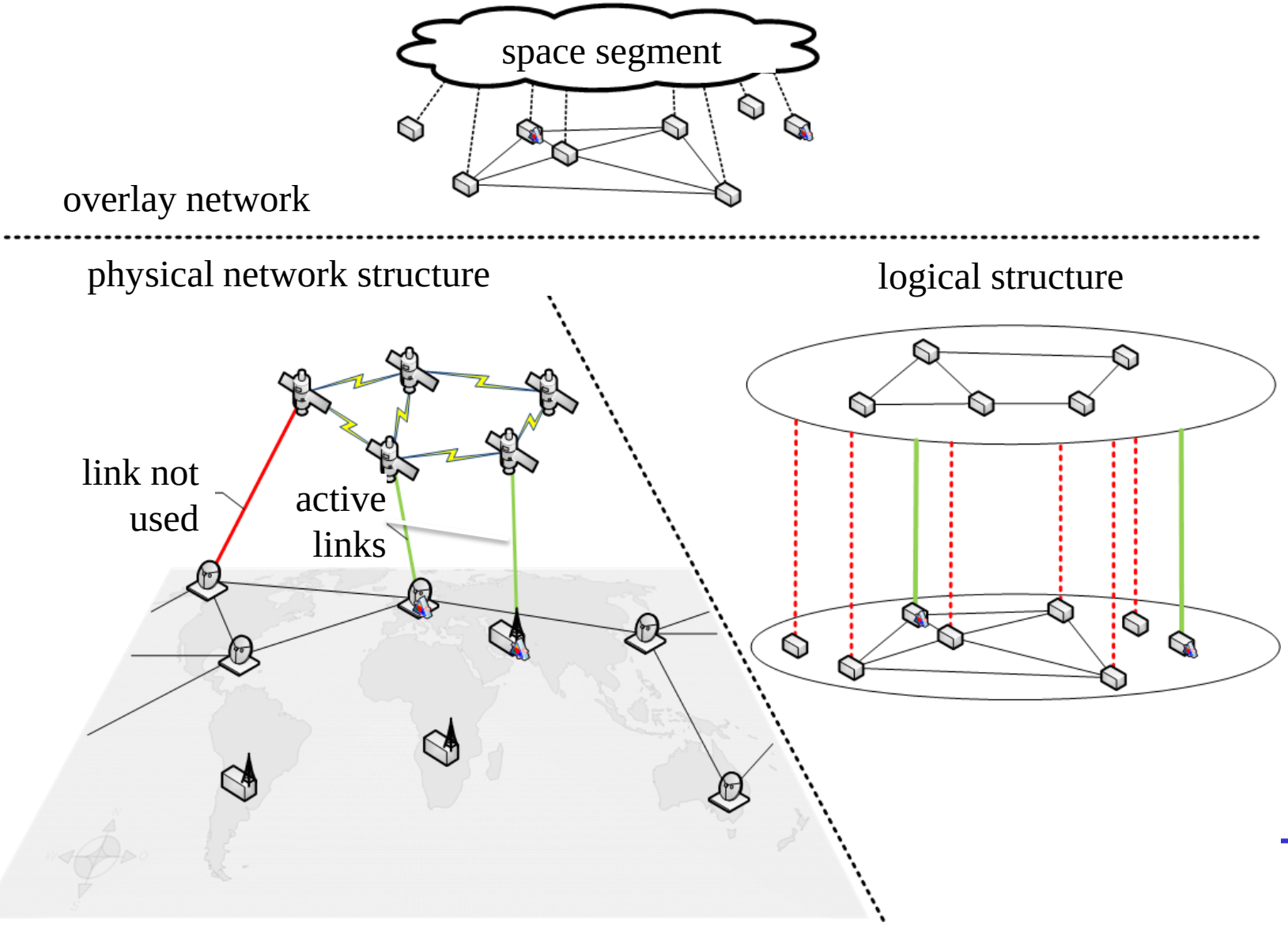
- Temporal and spatial coverage requirements
- Minimization of the amount of necessary satellites by selecting appropriate orbit constellations
- A frequently used class is the Walker Delta pattern for a continuous coverage of the Earth's surface by a minimum number of spacecraft.

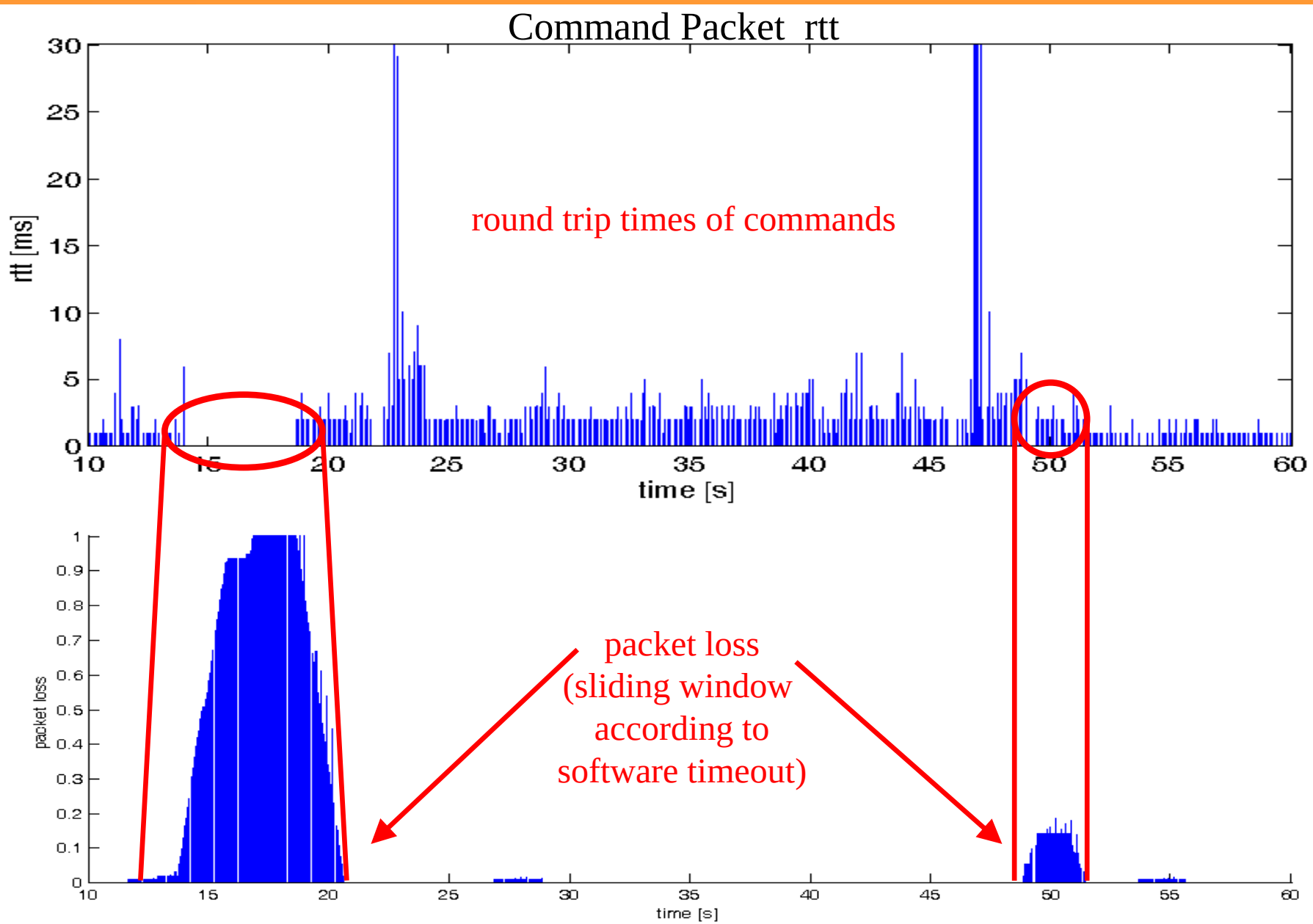
Mobile Ad-Hoc-Networks in Orbit



Telecommunications for swarms of satellites

Physical network structure and logical structure in a satellite based overlay network

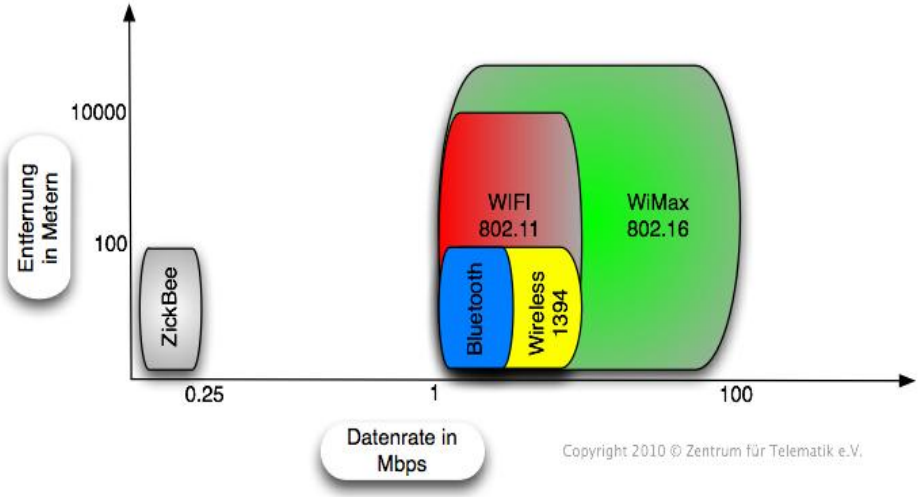




Terrestrial MaNet-telecommunication for swarms

Intersatellite communications: Protocols

- Netzwork protocols affect the quality of data transfer
- IEEE 802 standards can be adapted for ISLs
- standards differ according to range, frquency and data rates



	Kommunikationstechnologien / Protokolle						
Name	802.11..	802.11a	802.15...	802.16..	802.16e	AX.25	CCSDS Proximity 1
Reichweite	0.1 - 10 km	< 120 m	<100m	< 70 km	<70 km		1m-100,000 km
Reichw. erweiterbar?	ja	N/A	N/A	N/A	N/A	N/A	ja
Frequenz	2,4 / 5 GHz	5.2-5.8 GHz	868/915 MHz/2,45 GHz	0.7 - 66 GHz	1,25-20 GHz	N/A	~400 MHz/~26 GHz
Datenrate	< 54 Mbit/s	<54 Mbit/s	< 54 Mbps	< 100 Mbit/s	5 -10 Mbps	2.4/9.6 kbps	2kbps - 2Mbps
Modulation		OFDM			SOFDMA		
Ad-Hoc-Fähigkeit		ja			ja	nein	ja
Weltalltauglich		ja	ja		ja	ja	ja

Orbit Drift Analysis for the September 2009 Launch of UWE-2, BeeSat, ITUSat1, Swisscube

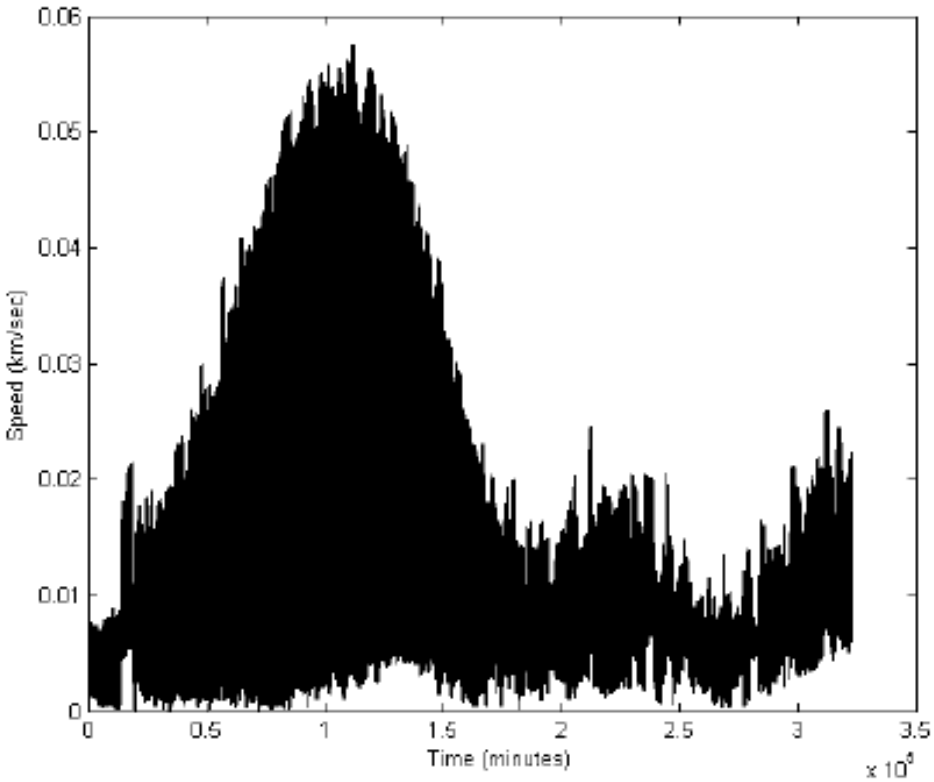


Figure 4: Relative speed between ITUpSat1 and BeeSat

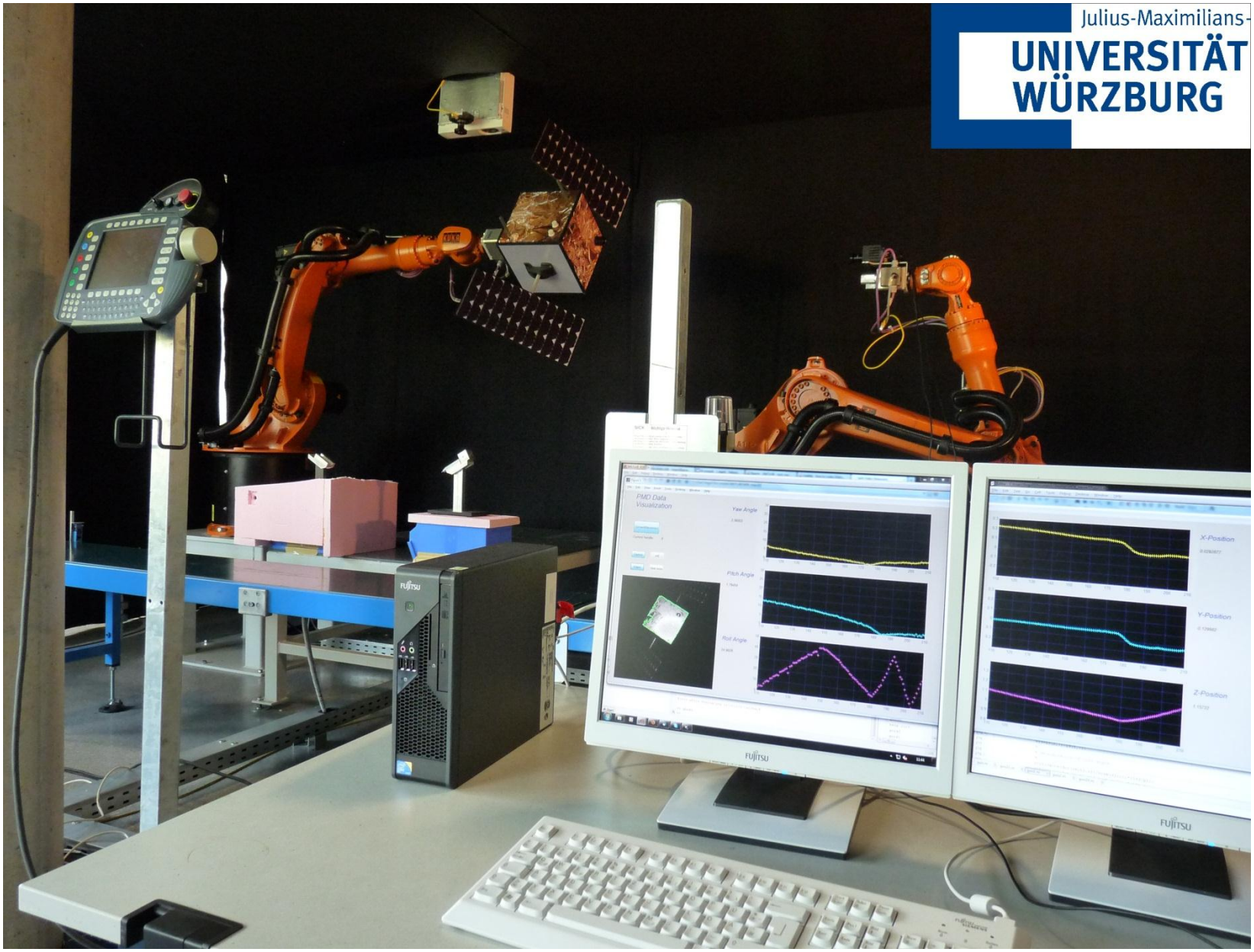
Relative distances after one year

Satellite pair	Relative Distance (km)
ITUpSat1 ↔ SwissCube	21.623
SwissCube ↔ UWE-2	35.095
UWE-2 ↔ ITUpSat1	56.714

Comparison of Ranging Technologies

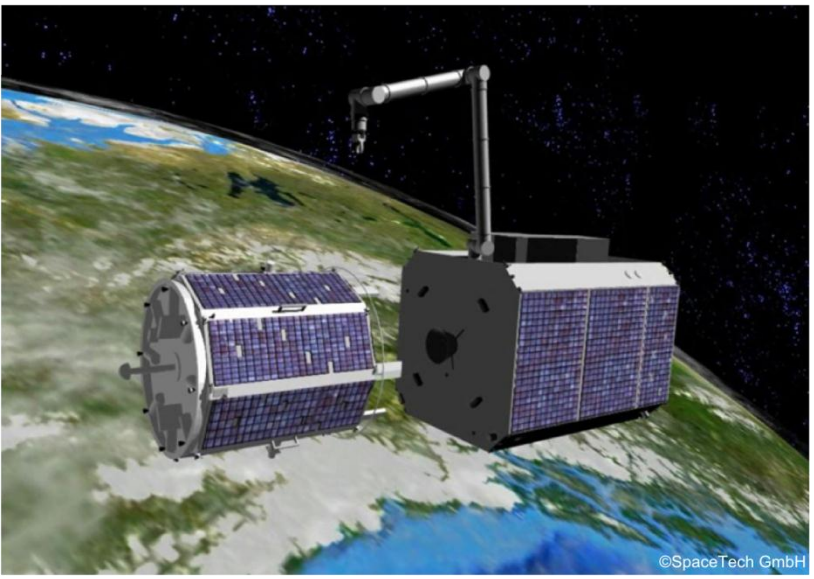
	cost	weight & power	range	reliability	accuracy	flexibility
NORAD-RADAR + TLE	++	++	++	-	- -	- -
laser technologies	- -	- -	+	o	++	-
binocular cameras	+	+	- -	-	-	+
3D time-of-flight cameras	o	+	-	+	+	++
GNSS	++	+	++	+	+	+
radio based ranging	++	++	+	+	o	++

++ : very good / o: indifferent / - -: very bad



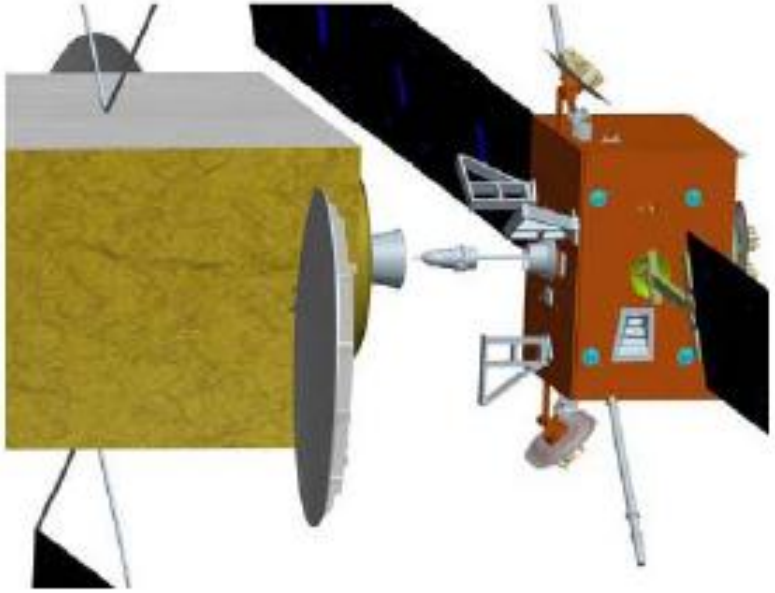
Near range dynamics test facility based on two robotic manipulators to simulate a relative motion, picturing a satellite (on left arm) by a PMD camera (right

Rendez-vous and docking for in-orbit servicing



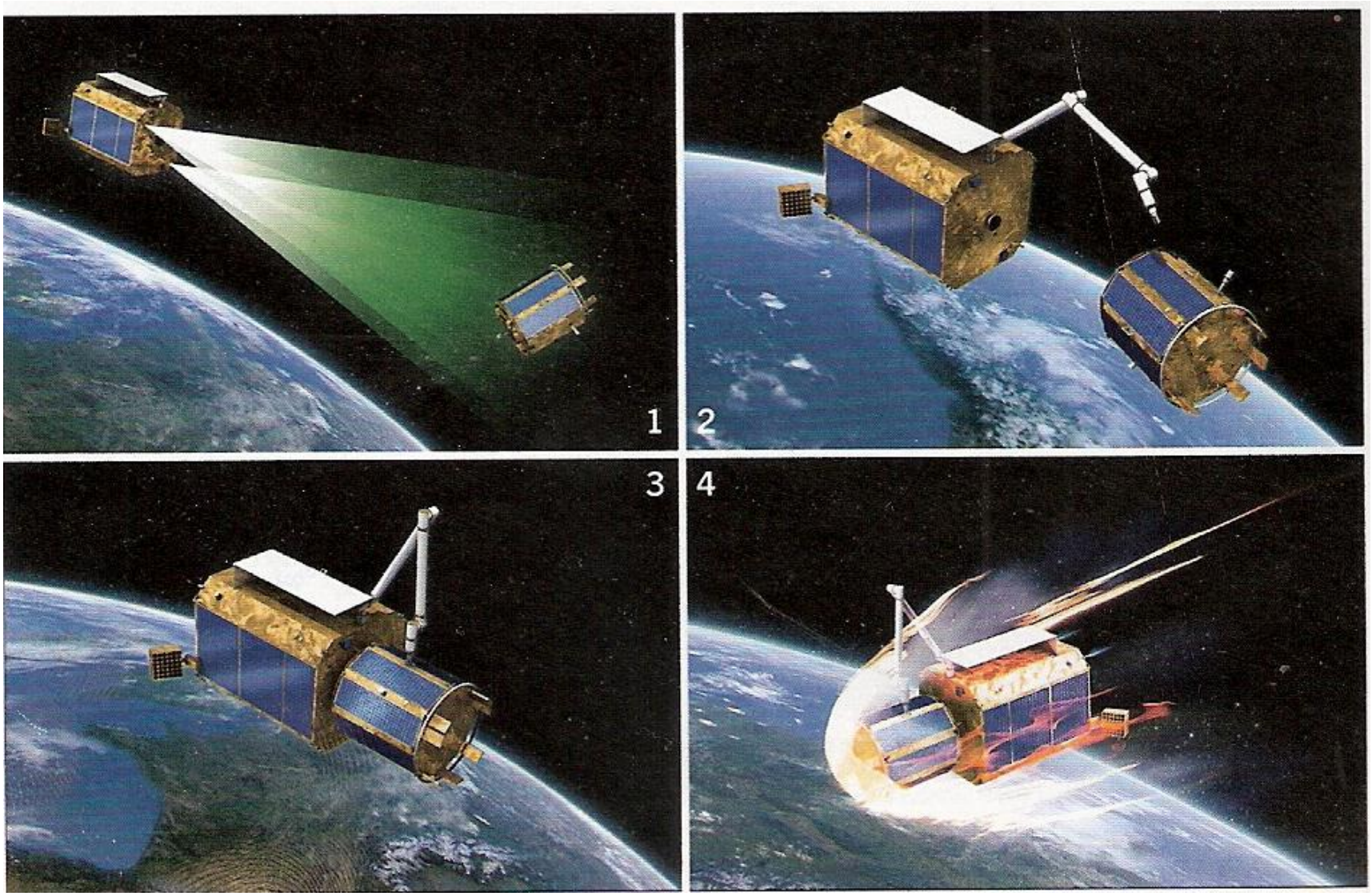
Example mission DEOS

Example mission Smart-Olev

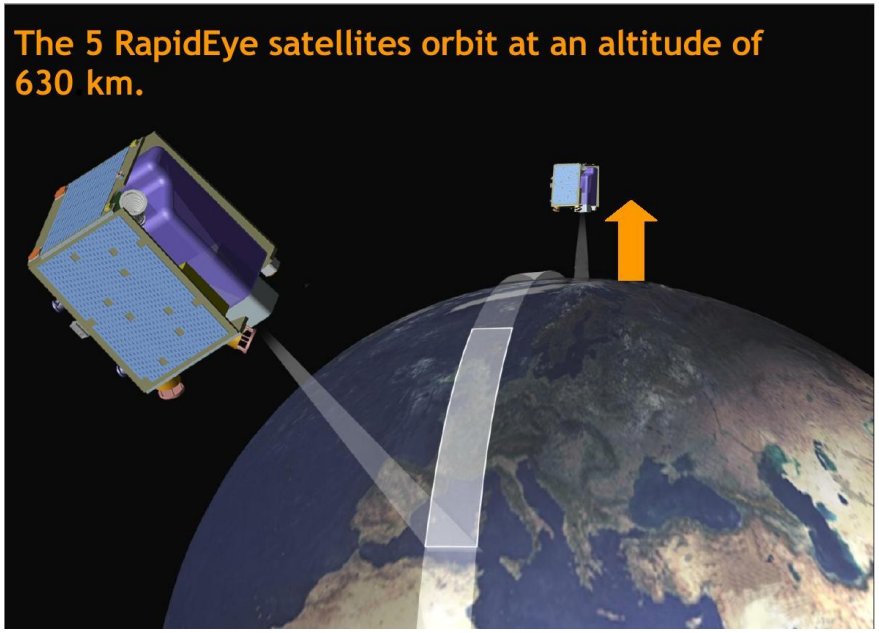


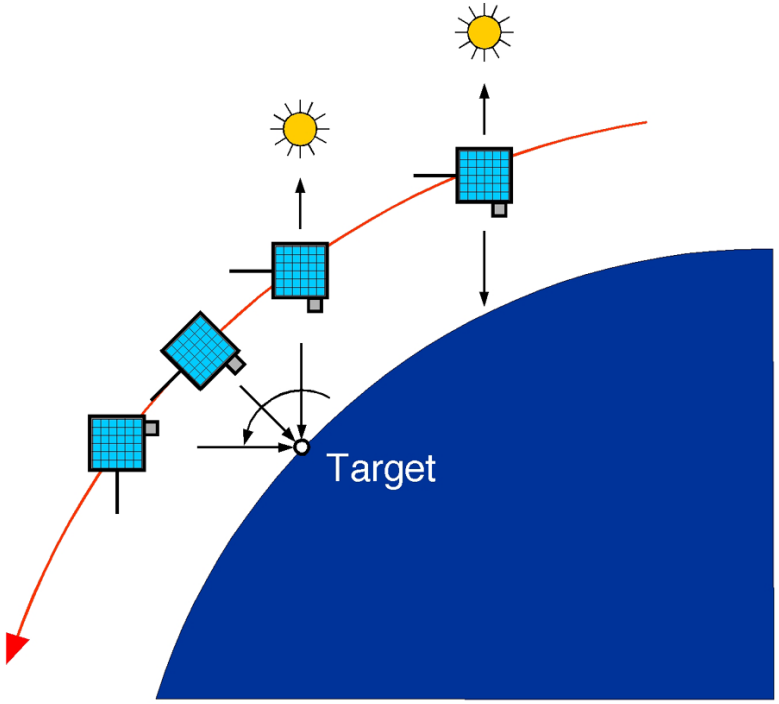
New challenges for rendez-vous and docking to non-cooperative objects in order to place non-operable satellites to graveyard orbit

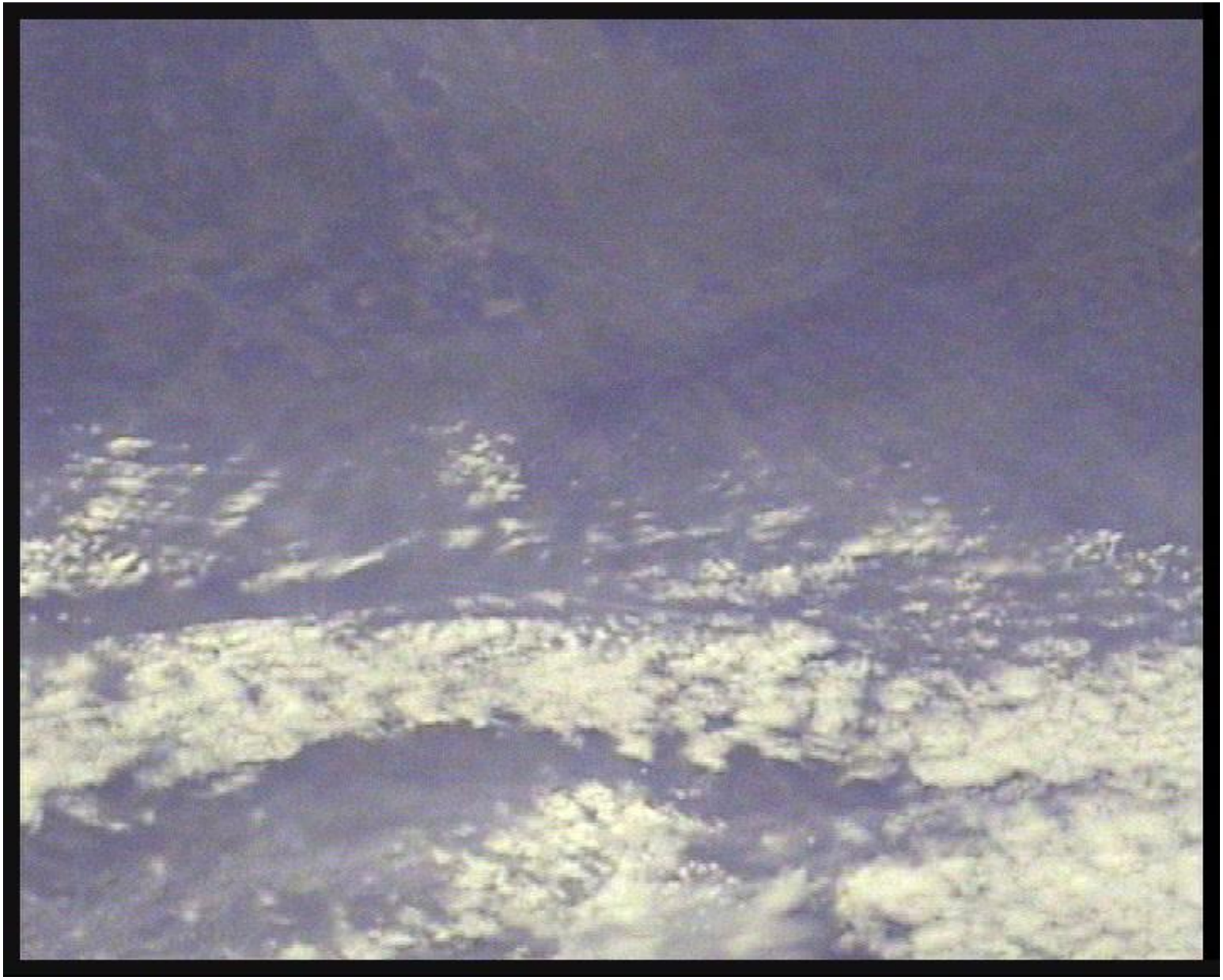
Pico-Satellites for Education and Research



- Earth observation with small satellites
  - Several satellites enable improved temporal and spatial coverage
  - Interactive attitude pointing enables more extended observation of interesting areas



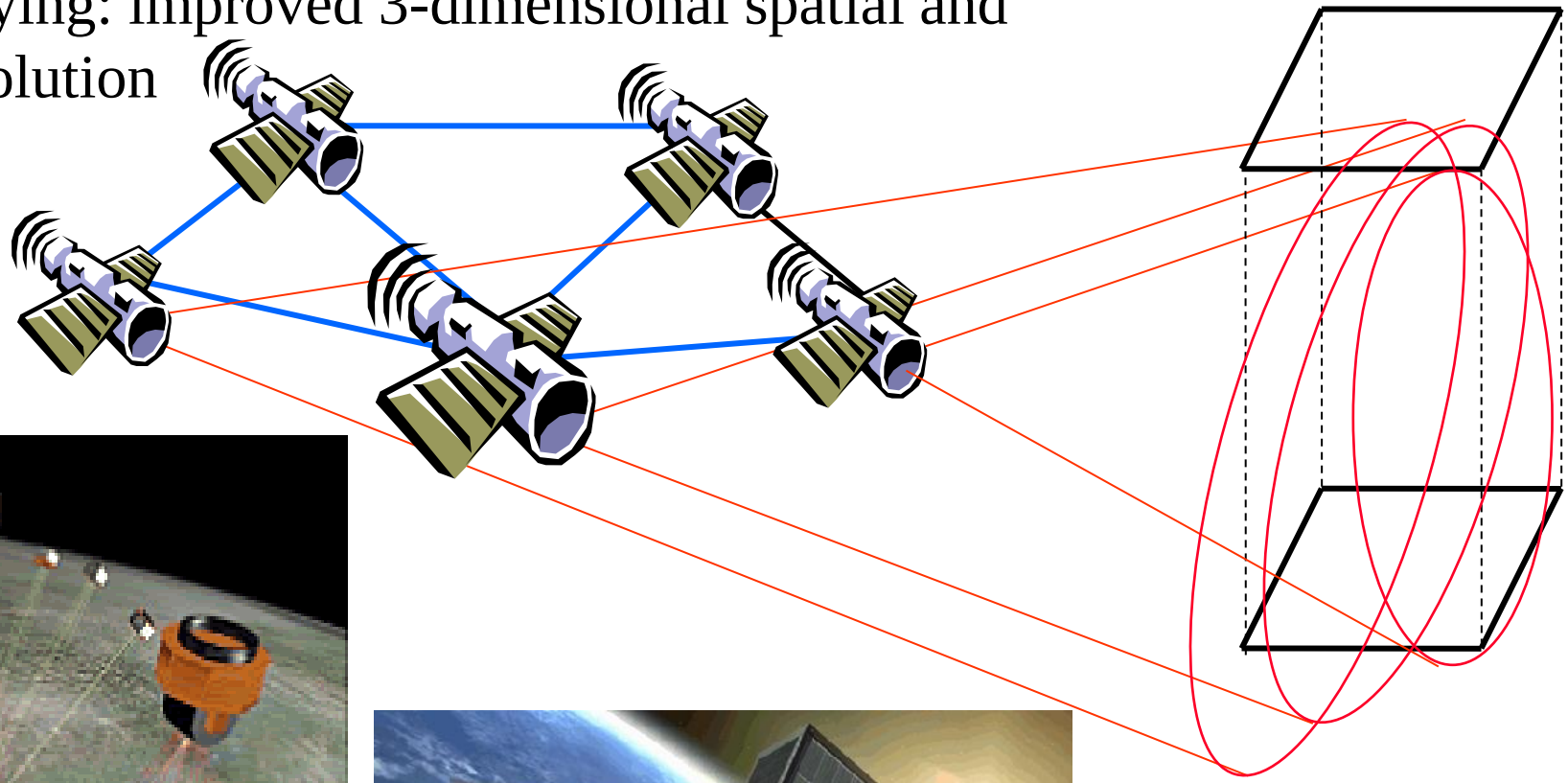


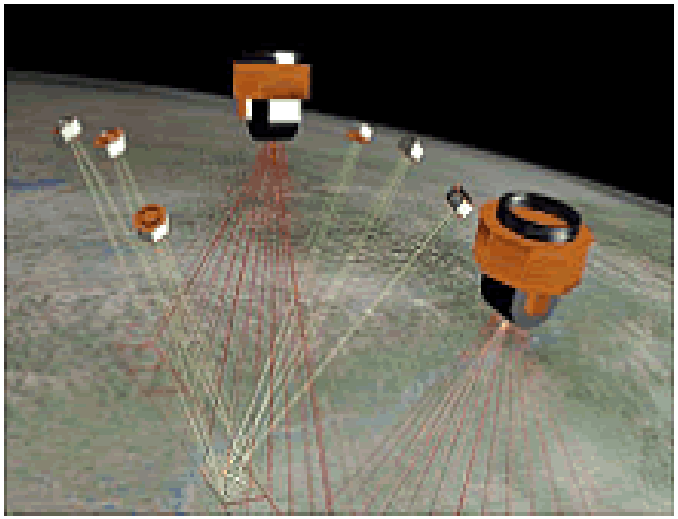


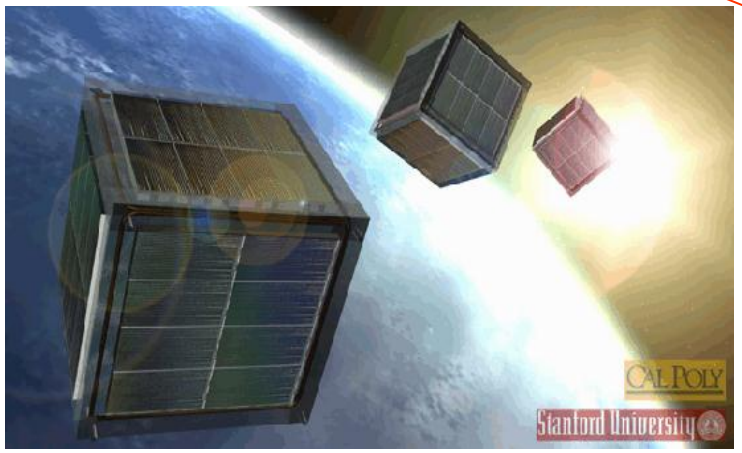
LAPAN-TUBSAT
Video courtesy of Prof. Renner TU Berlin

Science: Interactive Earth observation (Frankfurt airport)

Formation flying: improved 3-dimensional spatial and temporal resolution

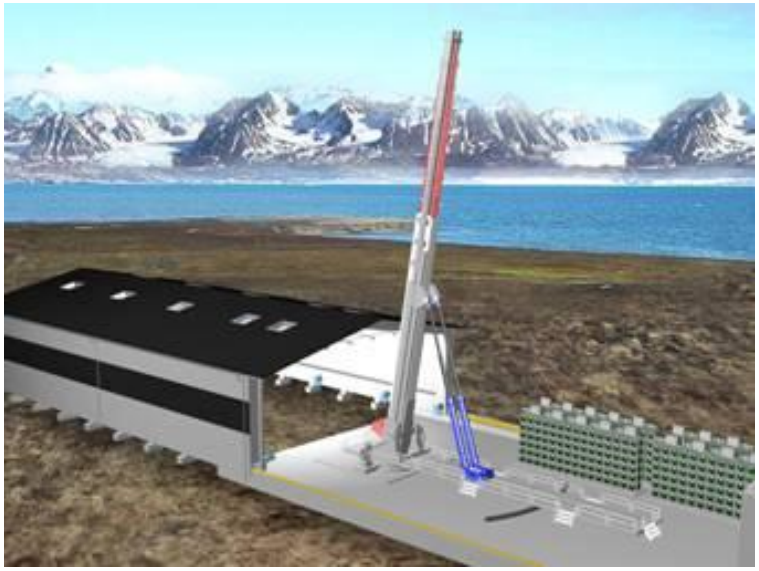






Innovative Launch Concepts for Pico-Satellites

Approach 1: EM-Launch to Space

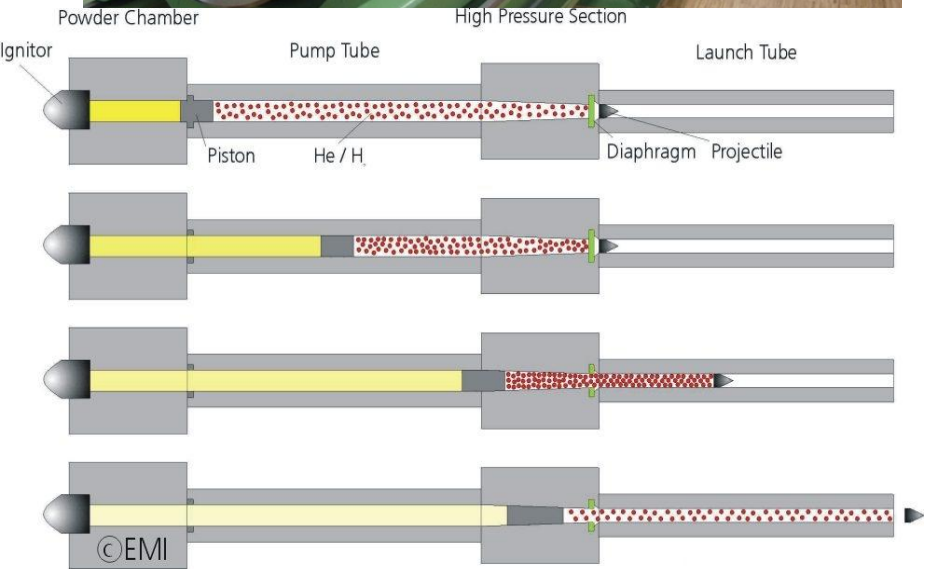


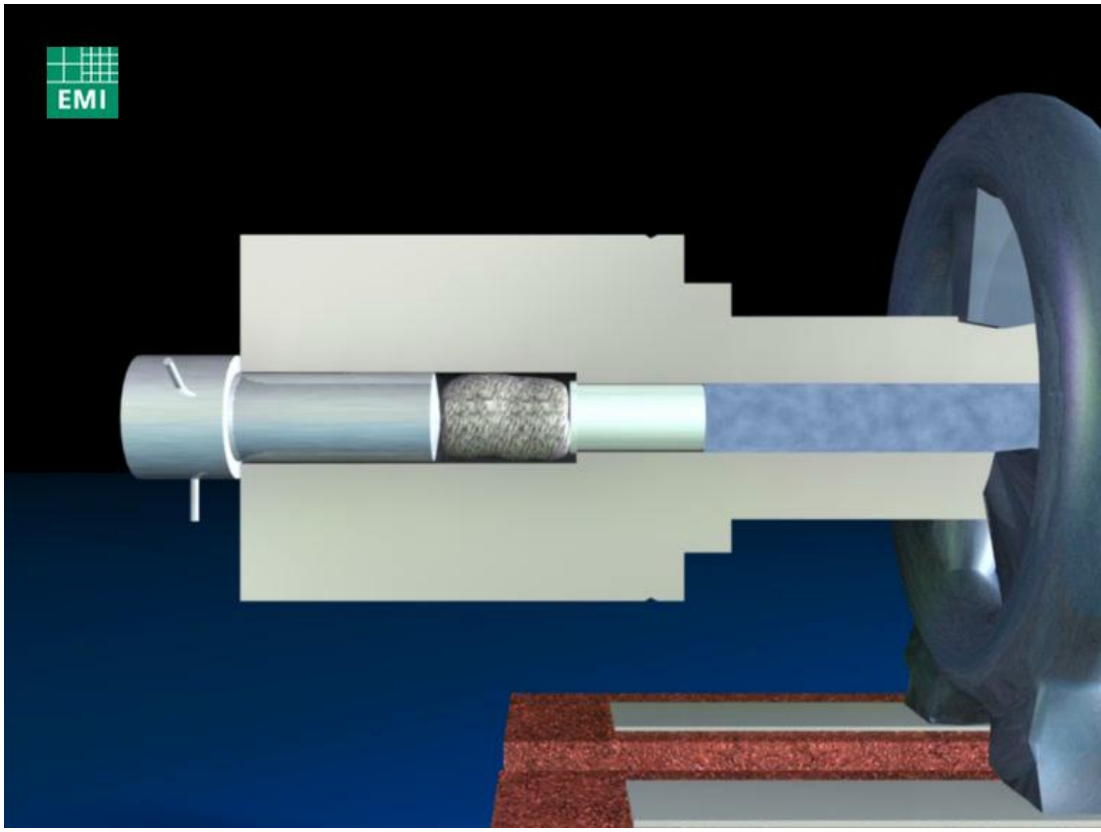
- Advantages
  - high exit velocity
  - moderate acceleration levels
- Restrictions
  - high electrical power needs
  - huge R&D efforts still needed
  - high static infrastructure demands

Approach 2: Gun-Launch to Space

- Advantages
  - most technologies are available
  - mobile capabilities
- Restrictions
  - limited exit velocity

Gun launches of small satellites





Quelle: Fraunhofer EMI, Freiburg

Alternative launcher principles: light gas guns

Conclusions

Paradigm shift from traditional large spacecrafts with multiple payloads to decentralized, distributed small satellite offering challenges for research and education, but also great opportunities for cooperation.

Research perspective

Networked satellite systems offer efficient approaches

- for exploiting parallel activities for faster mission completion
- for cooperatively solving complex tasks
- for higher fault tolerance and robustness of the overall system
- for scalability: according to application needs satellites can be added
- for high spatial and temporal resolution of observation data

- Appropriate interdisciplinary integration of control, graph theory, path planning, communication, localization and tracking
- Combinations of satellite systems, composed of few large and many small satellites will provide the required data quality, as well as flexibility and robustness.

Conclusions for Educational Aspects

Small Satellites relate to

- Exciting areas to attract students to science and engineering
- A huge global need for Aerospace engineers (20 000 engineers just for retirement replacements for next 10 years in Germany alone)
- Feasible implementation durations compliant to study plans (about 1 year)
- Excellent field to practice system design approaches
- Huge demand for innovative technology development
- Efficient approach for innovative technology testing in space by frequent small satellite in-orbit demonstration
- Attractive area for University / Industry cooperation
- Good field for national and international university cooperation

Essential to establish a continuous , sustainable satellite program to attract students, to establish international university and industry cooperation.

Offers for cooperations

- In the IEEE lecture program (we are grateful for the travel grant for this lecture)
- Intensive classes on small spacecraft design (Turin,Samara, Barcelona, Monastir, Sfax, Istanbul, Dos Campos, Stanford University, University of Ohio, …)
- Emphasis on formations in Earth observation and telecommunications
- Networked ground stations
- Cooperation in small satellite design
- Networked distributed satellite projects (QB 50, HUMSAT, …)
- Pico- and Nano-Satellite conference (alternating in Berlin and in Würzburg, already 7 conferences, > 100 participants)

Contact: schi@informatik.uni-wuerzburg.de

IFAC ACA 2013 Symposium on Automatic Control in Aerospace

19th IFAC Symposium on Automatic Control in Aerospace

September 2-6, 2013
Würzburg, Germany

www7.informatik.uni-wuerzburg.de/aca2013

International Federation of Automatic Control

IFAC

Schedule

- Submission of draft papers: January 31, 2013
- Notification of acceptance: April 30, 2013
- Submission of full paper: May 31, 2013
- Symposium: September 2-6, 2013

Keynote Address

The space pioneers Prof. Dr. Eveline Gottzein (formerly EADS/Astrium) and Wolfgang Wummer (formerly ESOC) will report first hand from the exciting starting phase of EuropeanSpace activities and about the foundation of the IFAC TC on Aerospace.

Conference Location

The IFAC symposium will be held at the Informatics building, Turing-Hörsaal, located at Hubland campus of University of Würzburg and can be quickly be reached by public transport from the city center.

Thanks to the complete team

Further Information: www.telematik-zentrum.de
www7.informatik.uni-wuerzburg.de