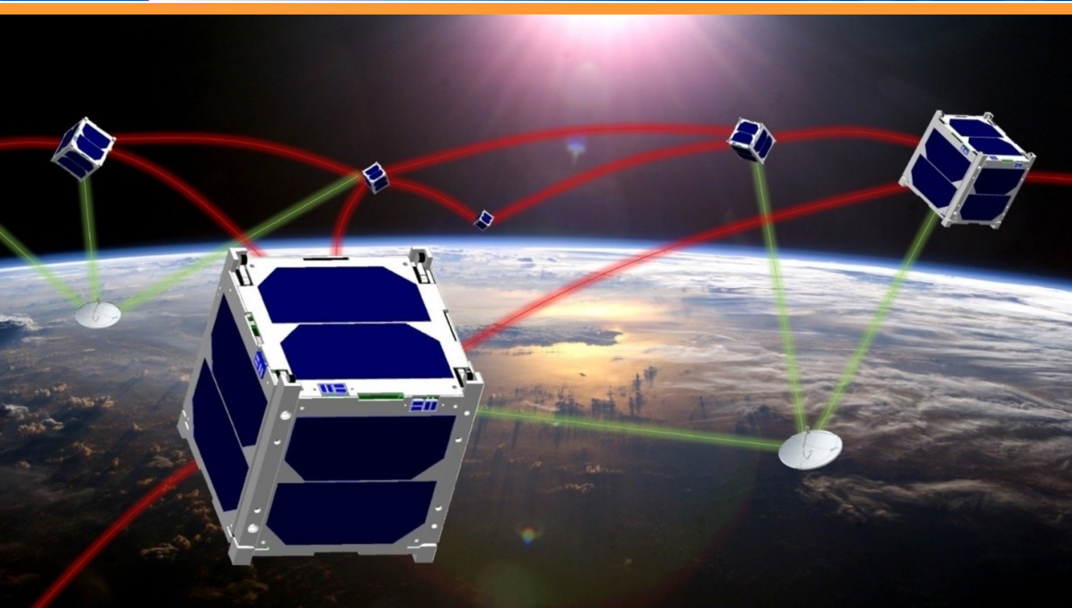

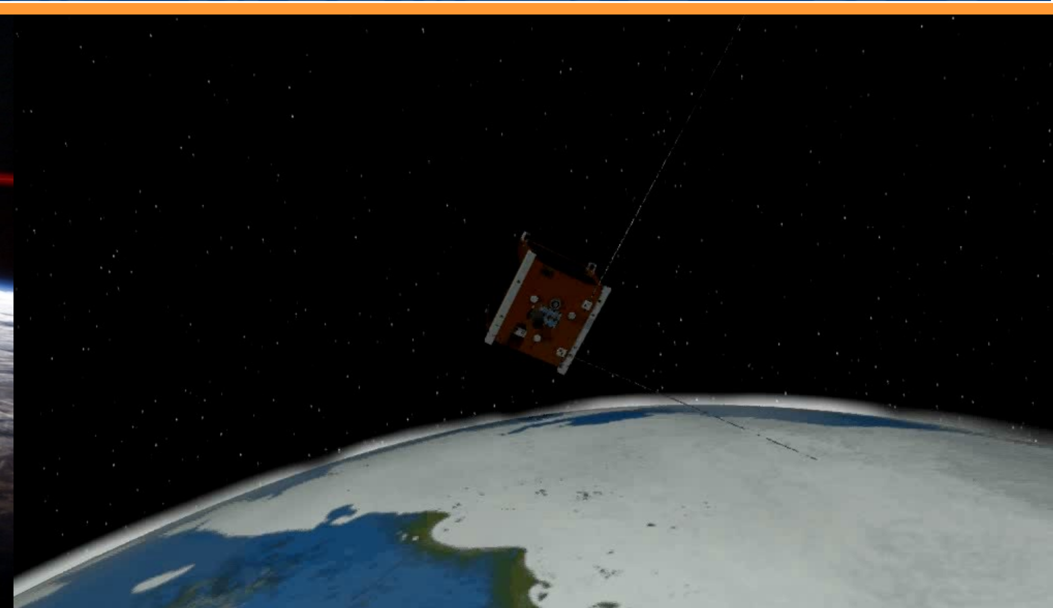

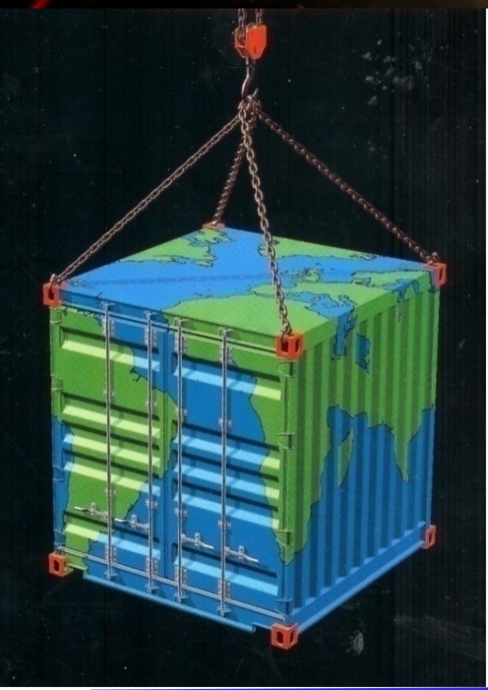

Small Satellites for Challenging Tasks in Earth Observation and Telecommunications

Prof. Dr.Klaus Schilling
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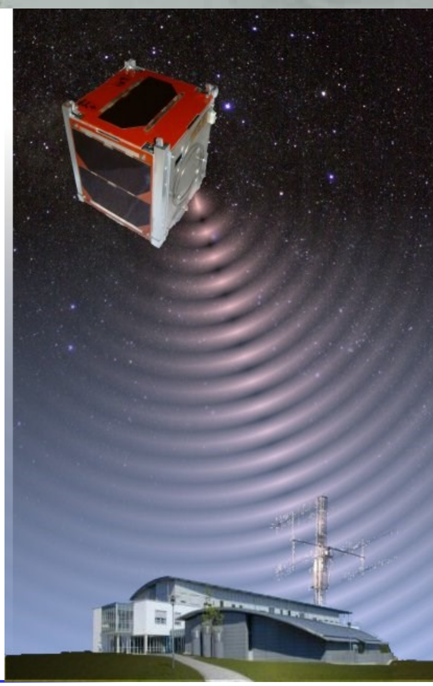
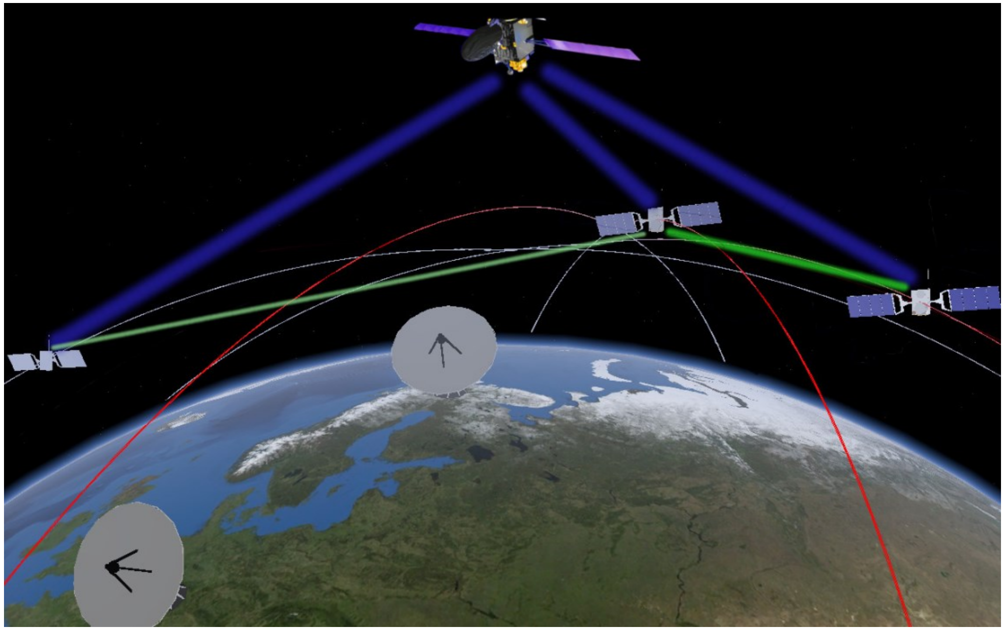


TNG BigTech Day

Munich, 3. June 2016

Commercial Perspectives for Small Satellites in Telecommunications



Two US-consortia are on the way to establish an innovative new communication infrastructure:

SpaceX Has Quietly Opened a New Office to Work on Internet-Providing Satellites

Written by JASON KOEBLER (/AUTHOR/JASONKOEBLER)

June 3, 2015 // 12:26 PM EST

SpaceX's new, Seattle-area satellite design office has quietly opened, and, presumably, early work has begun on Elon Musk's planned array of satellites (http://motherboard.vice.com/read/spacex-warns-paper-satellites-could-disrupt-its-space-internet-plan) that will be able to provide WiFi internet to any spot on Earth.

In January, Musk announced the plan (http://www.seattletimes.com/business/elon-musk-touts-launch-of-lsquospacex-seattlersquo/) to launch as many as 4,000 satellites into low-Earth orbit.

OneWeb and Airbus Space (USA) announced plans to launch a new satellite constellation to bring high-speed Internet to underserved areas around the World

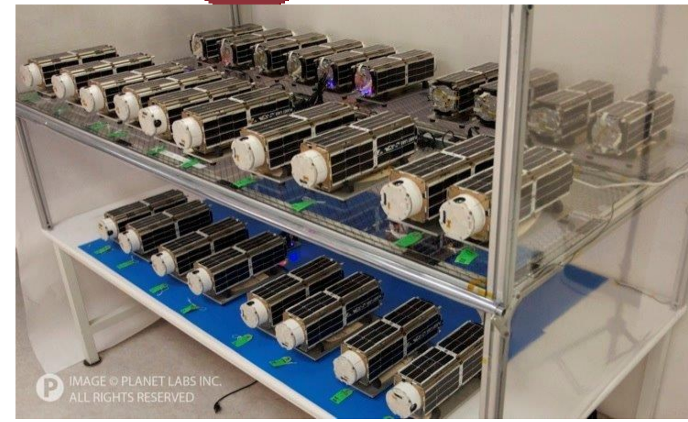
SpaceX (with 1 Billion $ invest by Google) **:** Plans for 4000 Satellites to provide Internet everywhere

CASIC addresses in China: with „Fortune Star“ similar aims

Commercial Perspectives: After *Constellations* subsequently *Formations* will be employed

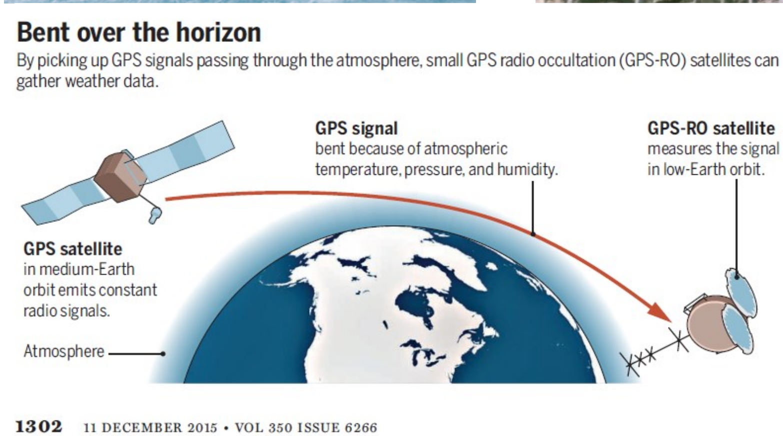
Commercial Perspectives for Small Satellites in Earth Observation

Planet Labs produces pico-satellites with dimension 30 cm x 10 cm x 10 cm for Earth observation with about 3 - 5 m resolution



2016: launch of about 100 Dove satellites flying in a constellation is planned

Picture taken by Dove pico-satellites



The companies **Spire** (San Francisco) and **PlanetiQ** (Boulder, Colorado) detect with a pico-satellite constellation atmospheric deviations of GPS-signals and infer weather characteristics (like temperature, pressure, humidity)

Dramatically growing interest in small satellites

ZENTRUM FÜR TELEMATIK E.V.

2014 BREAKTHROUGH OF THE YEAR | RUNNERS-UP

High Scientific Profile

The journal "Science" selects every year the "Breakthroughs of the Year" and in addition also the 10 runner-ups for the most promising future scientific areas. Here the topic "Satellite formations" corresponds to two mentioned fields.

Two Earth-observing CubeSats (dark oblong objects) shoot from a satellite deployment device on the International Space Station.

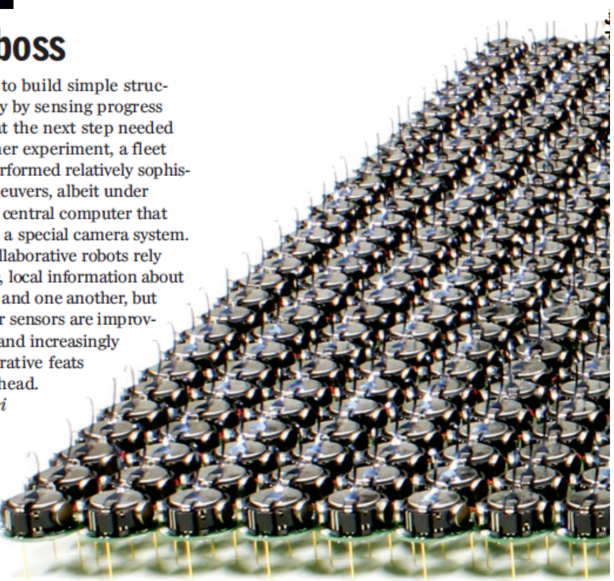
Cooperative 'bots' don't need a boss

Robots are getting better all the time at working with humans, but this year several teams demonstrated that these machines can also work together, without human supervision. At a time when roboticists are still struggling to improve how well individual robots sense their surroundings and respond to new situations, letting teams of robots execute their own missions may seem premature. But after years of work, researchers have come up with new software and interactive robots capable of cooperating on rudimentary tasks.

In one study, a thousand robots the size of U.S. quarter coins came together like a marching band to form squares, letters, and other 2D formations. The sheer scale required cheap, easy-to-run robots that could efficiently sense where other robots were. In another project, 10 quadcopters radioed their locations to one another and adjusted their paths to avoid collisions and fly in formation, creating a rotating circle. A third group of robots, inspired by termites, was programmed to build simple structures cooperatively by sensing progress and inferring what the next step needed to be. In yet another experiment, a fleet of robotic boats performed relatively sophisticated group maneuvers, albeit under the command of a central computer that tracked them with a special camera system.

So far, all the collaborative robots rely on relatively crude, local information about their environment and one another, but both they and their sensors are improving rapidly. More, and increasingly impressive, cooperative feats undoubtedly lie ahead.

–Elizabeth Pennisi



Small, disk-shaped robots that maneuver in formation are just one example of the year's progress in self-organizing machines.

The rise of the CubeSat

A decade ago, CubeSats were just educational tools, a way for university students to place a simple Sputnik in space. Now these 10-centimeter boxes, built with off-the-shelf technology and costing hundreds of thousands of dollars rather than hundreds of millions, have taken off. More than 75 were launched this year, a record. What's more, the little boxes are starting to do real science.

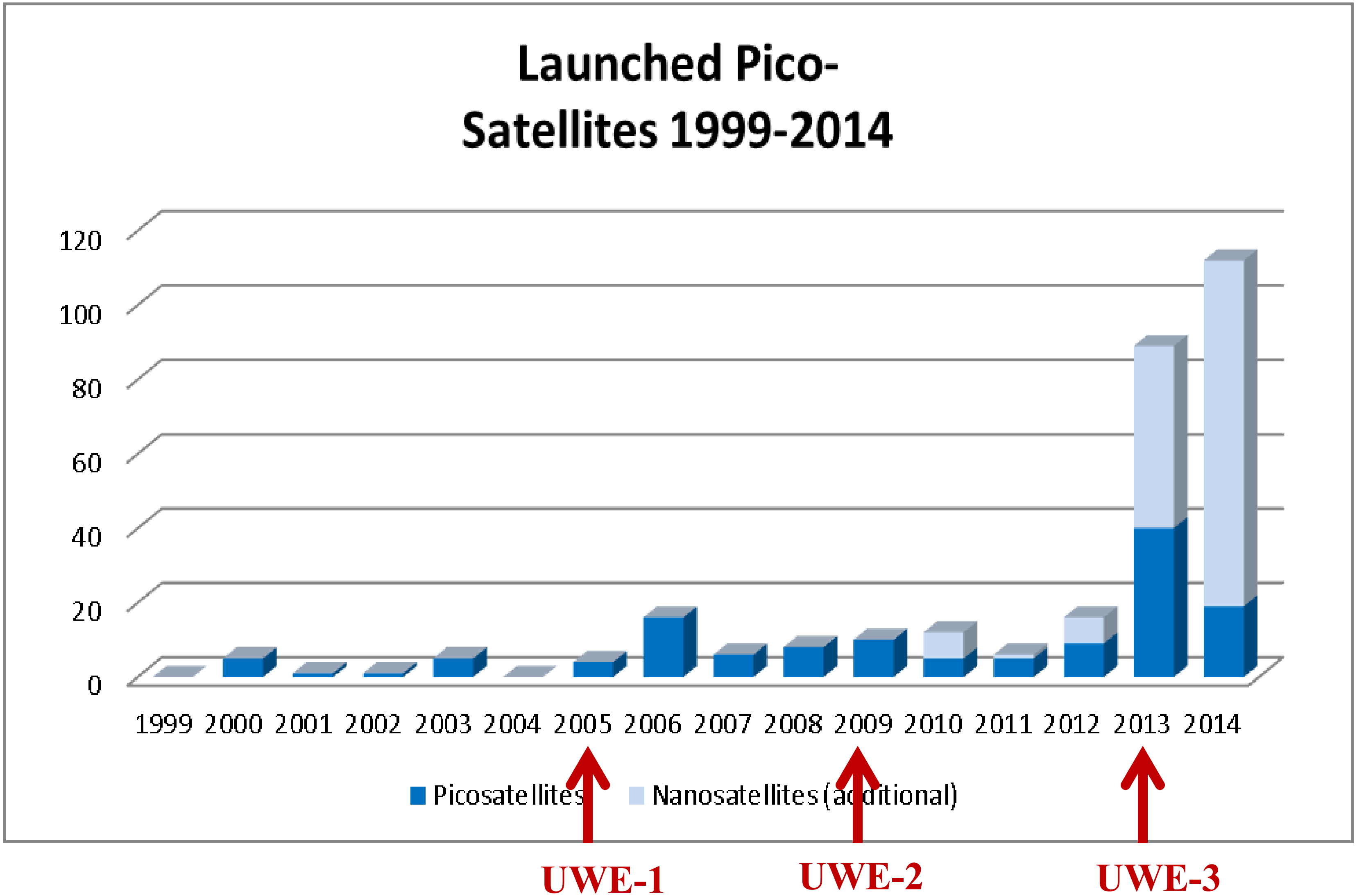
Increased and affordable access to space is driving much of the boom. CubeSats can hitch a ride on commercial or government rockets carrying bigger spacecraft, or they can be pushed out the door of the International Space Station. The rapid-fire launch rate is encouraging something never before seen in space: risk-taking. Designers can tolerate a failure or two and quickly get back in the game. As technology advances, they can also swap in better solar panels, batteries, or processors.

Private money has taken notice, funding companies such as Planet Labs, which is monitoring Earth with a swarm of perennially replaced CubeSats. Their small telescopes take pictures with relatively poor spatial resolution—a few meters—but at frequent intervals. Spy agencies may not be seduced, but Planet Labs' data are plenty useful for monitoring deforestation, urban development, and river changes.

Coming up next: CubeSats that talk to one another while taking measurements. Among other things, such CubeSat constellations will be able to cover more area, faster, or monitor Earth's surface in several wavelengths at once. If they work, CubeSats will have demonstrated not only that small is beautiful, but also that the whole is greater than the sum of its parts. *–Eric Hand*

IMAGES: (CLOCKWISE FROM TOP LEFT) NASA; SVEN LIDSTROM/ICECUBE/NSF; SYNTHORX, ADAPTED BY C. SMITH/SCIENCE

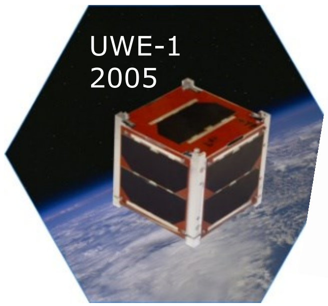
growing markets for very small satellites

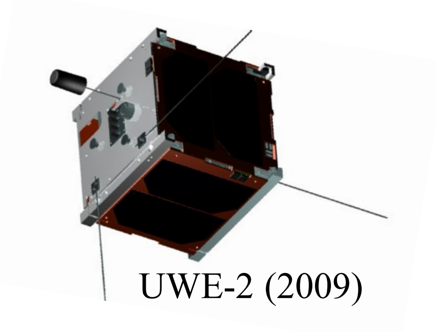


Worldwide launches of very small satellites, segmented into pico-satellites (mass ~ 1 kg) and nano-satellites (mass ~10 kg)

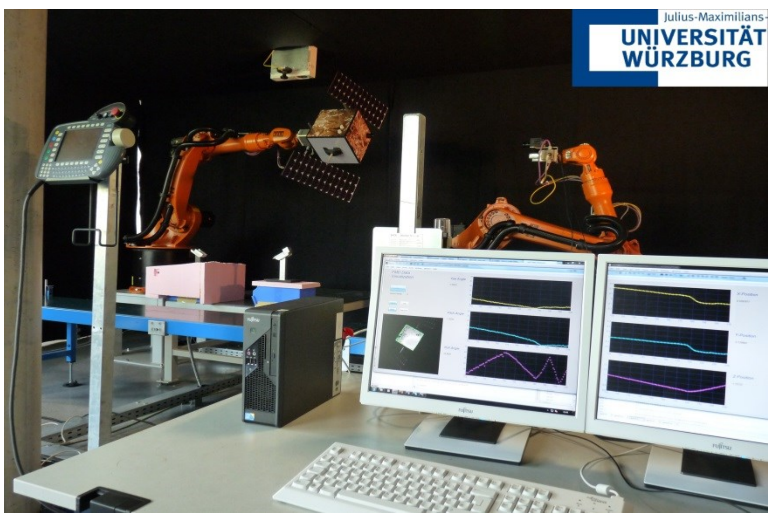
Research in Robotics and Spacecraft System Design

Highlights Spacecrafts

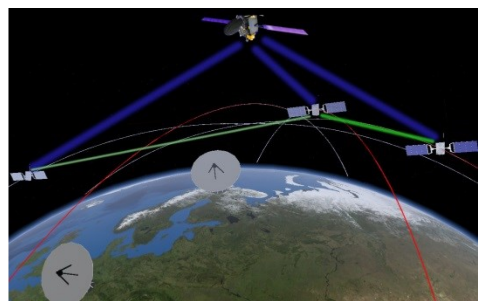




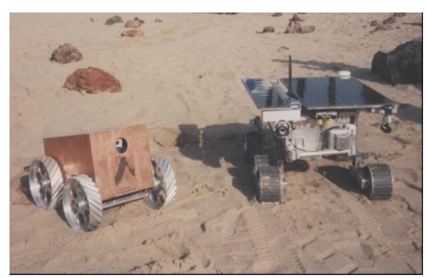
UWE: ***U***niversity ***W***ürzburg's ***E***xperimental satellites



Rendezvous & Docking for space debris removal



Satellite formations



Mars Rover MIDD

Awards

STANFORD AERONAUTICS & ASTRONAUTICS

Consulting Prof. Stanford University 2002-2006

International Academy of Astronautics 2010

European Research Council

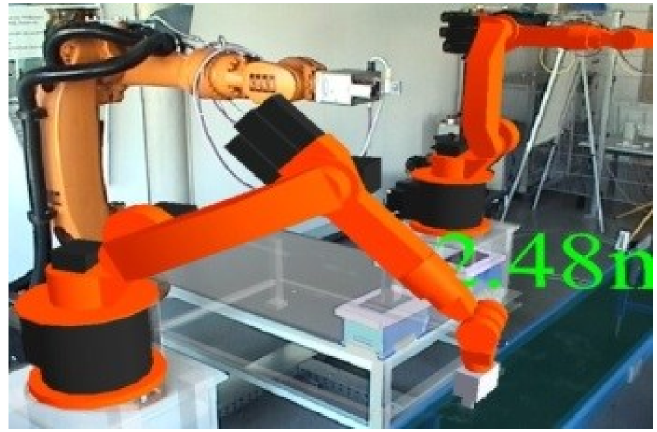
ERC Advanced Grant 2012

1.Price IAC student con-test 2013

Research in Robotics and Spacecraft System Design

Highlights Manipulators/Control/Medical Robotics

Motion compensation for radiation therapy (BFS)



Augmented Reality for intuitive operations

Tele-Medicine for Dialysis and COPD (BMBF cluster of excellence „Medical Valley“)

Robot support in carrying heavy parts in industrial production

Awards

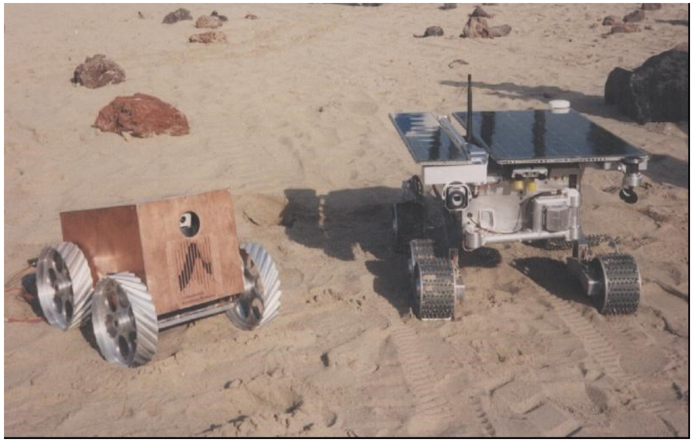
Walter-Reis-Award for Innovation in Robotics 2012 (medical robotics)

International Federation of Automatic Control

Outstanding Service Award 2014

Research in Robotics and Spacecraft System Design

Highlights Robotic Vehicles



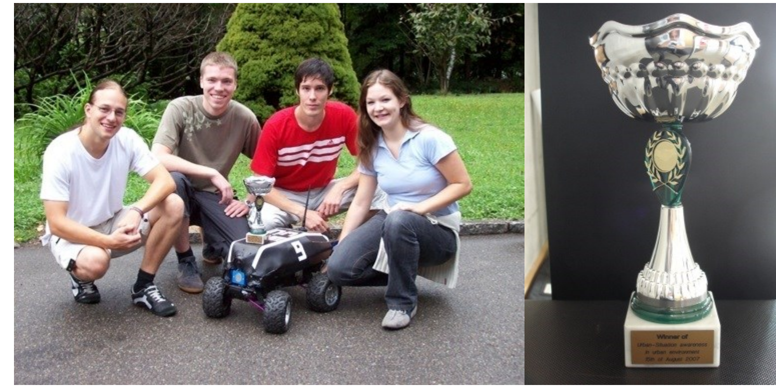
Mars Rover MIDD (ESA)

surveillance: MobRob

Industrial logistics:
ReTraRo (EU)

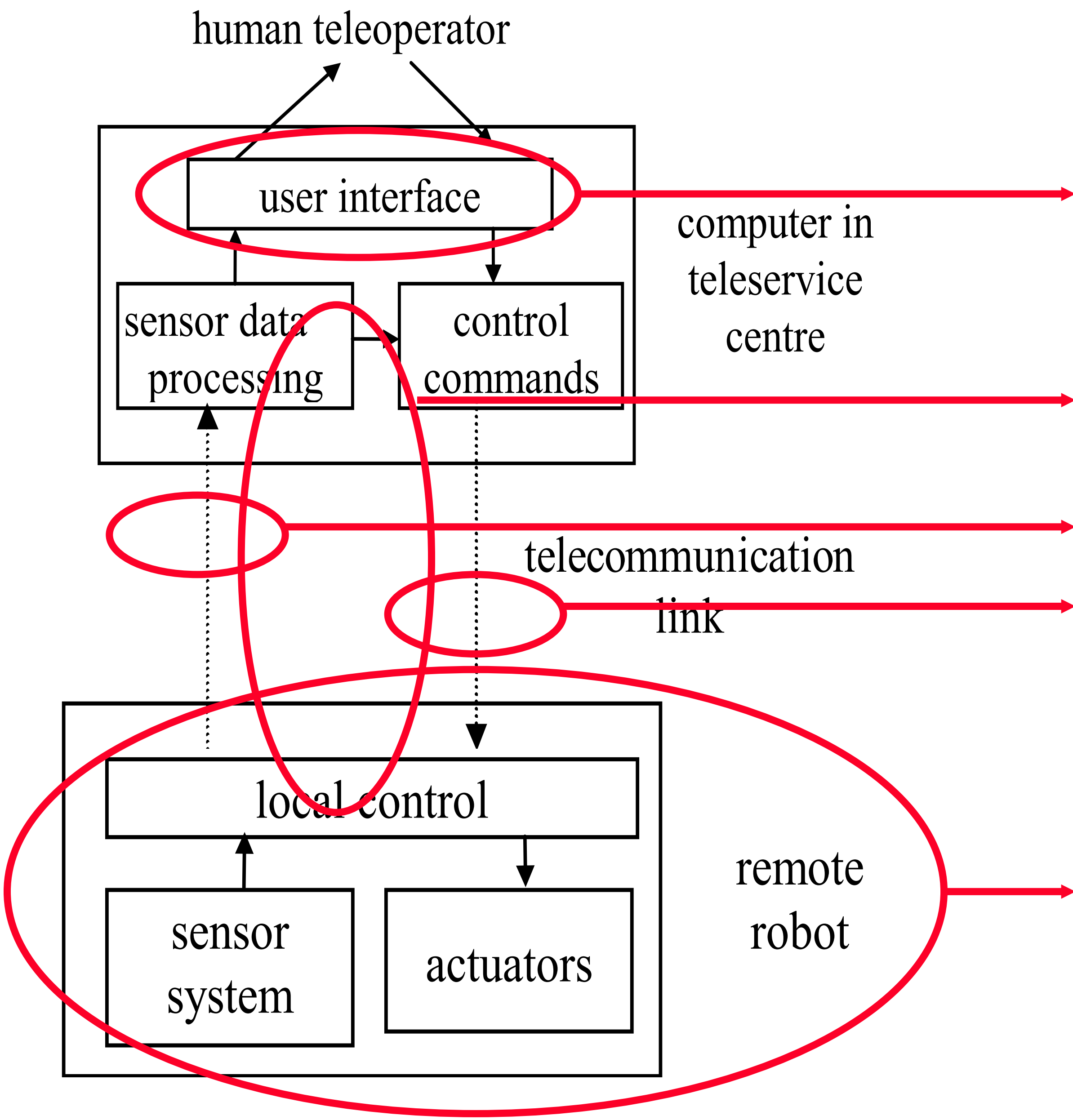
Mobility for senior
people: Fit4Age (BFS)

Awards



1.Price European Land
Robotics trial ELROB 2007

Walter-Reis-Award in
Service Robotics 2008



Research Areas

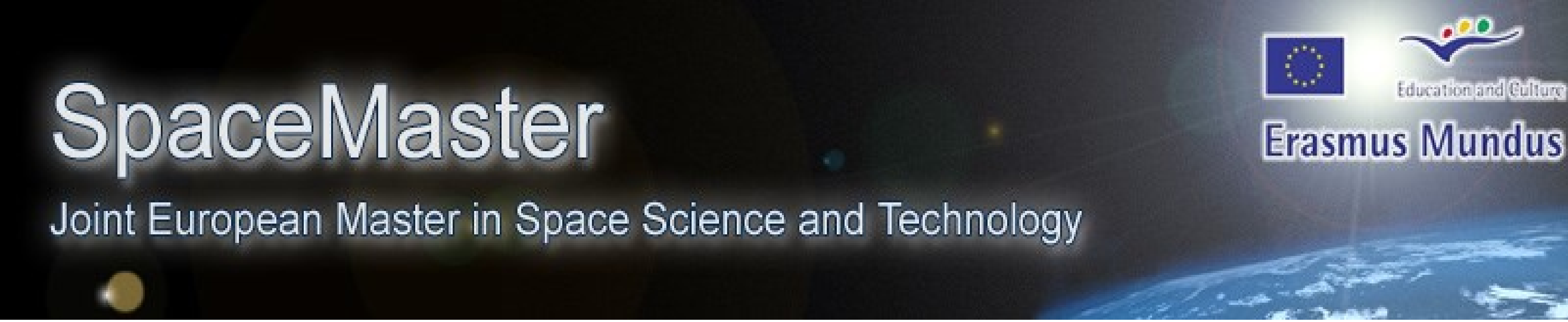
- haptic user interfaces
- virtual / augmented reality

- distributed systems

- sensor data processing
- data reduction / compression

- control with delays

- autonomy / adaptive systems
- intelligent sensors
- sensor data fusion
- robust systems
- cooperating robots



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

www.spacemaster.eu
spacemaster.uni-wuerzburg.de

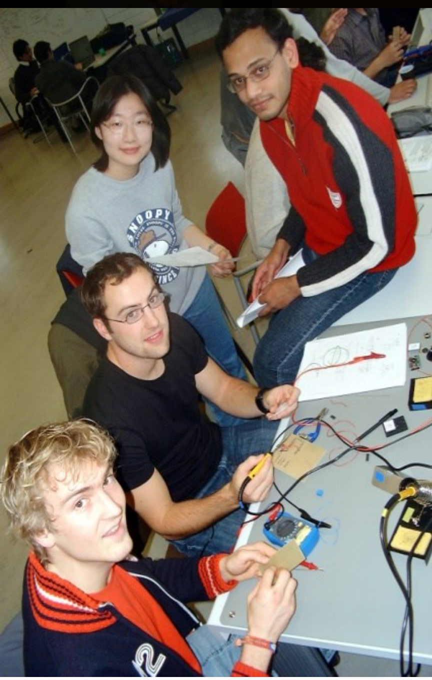
Education: SpaceMaster

SpaceMaster

Joint European Master in Space Science and Technology

Erasmus Mundus

Education and Culture



University partner s outside the EU :
Stanford University, USA
University of Tokyo, Japan
University of Toronto. Kanada
Shanghai Jiao Tong Uni, China

Recent awards of Würzburg students

- ZARM Award 2006
- 1st price in Student Contest at Internat. Astronautical Conference 2006 Valenci
- Award of the British Interplanetary Soc.
- IABG-Award 2008 for Oliver Kurz
- Silver medal at Student Contest IAC 2008 Glasgow
- Rotary Award 2011
- Gold medal at IAC 2013 in Beijing
- 2013 Amelia Earhart Fellowship from Zonta
- 2015 1st price IAA Earth observation

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

International Education

Research emphasis: Autonomous adaptive systems, advanced controls, sensor systems, communication, networked distributed multi-vehicle systems

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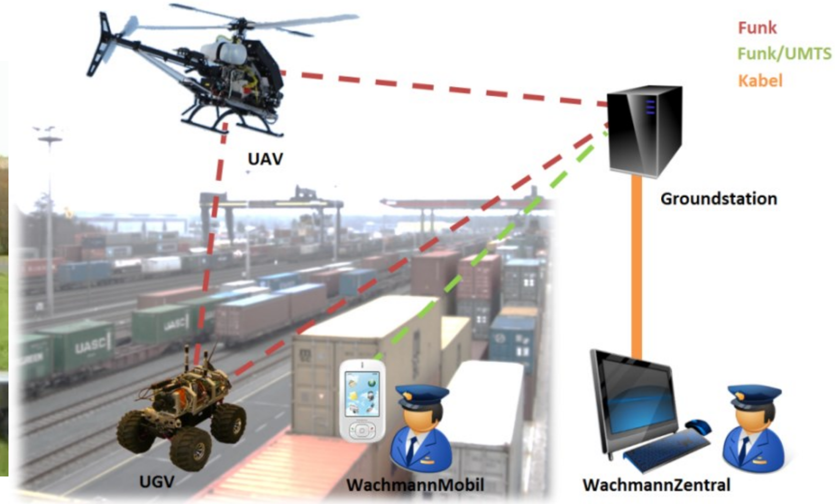
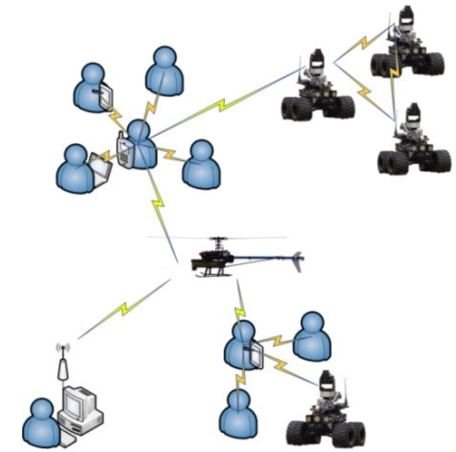
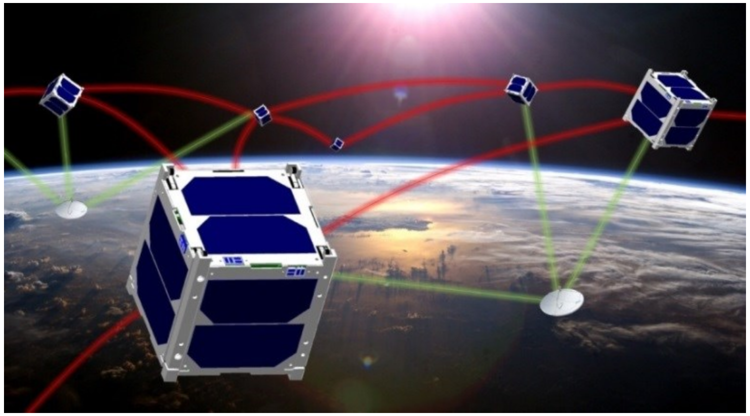


Cooperating ground and air vehicles for monitoring of storage areas



Remote control via communication links by suitable protocols

Control of multi-vehicle systems



Networked distributed systems of very small satellites

Precision tracking of mobile vehicles

ZfT /Uni Würzburg: Roadmap for distributed networked pico-satellite systems

ZENTRUM FÜR TELEMATIK E.V.

(UWE = ***U***niversity ***W***ürzburg's ***E***xperimental satellites)

2017/18 NetSat-1 to NetSat-4 Formation Flying Mission

- **Distributed Computing Capabilities**
- **Formation Control**
- **DTNs, MANets**
- **…**

2017 TIM, TOM

- Relative Navigation

2016 /17 UWE-4

- Position Control

2013 UWE-3

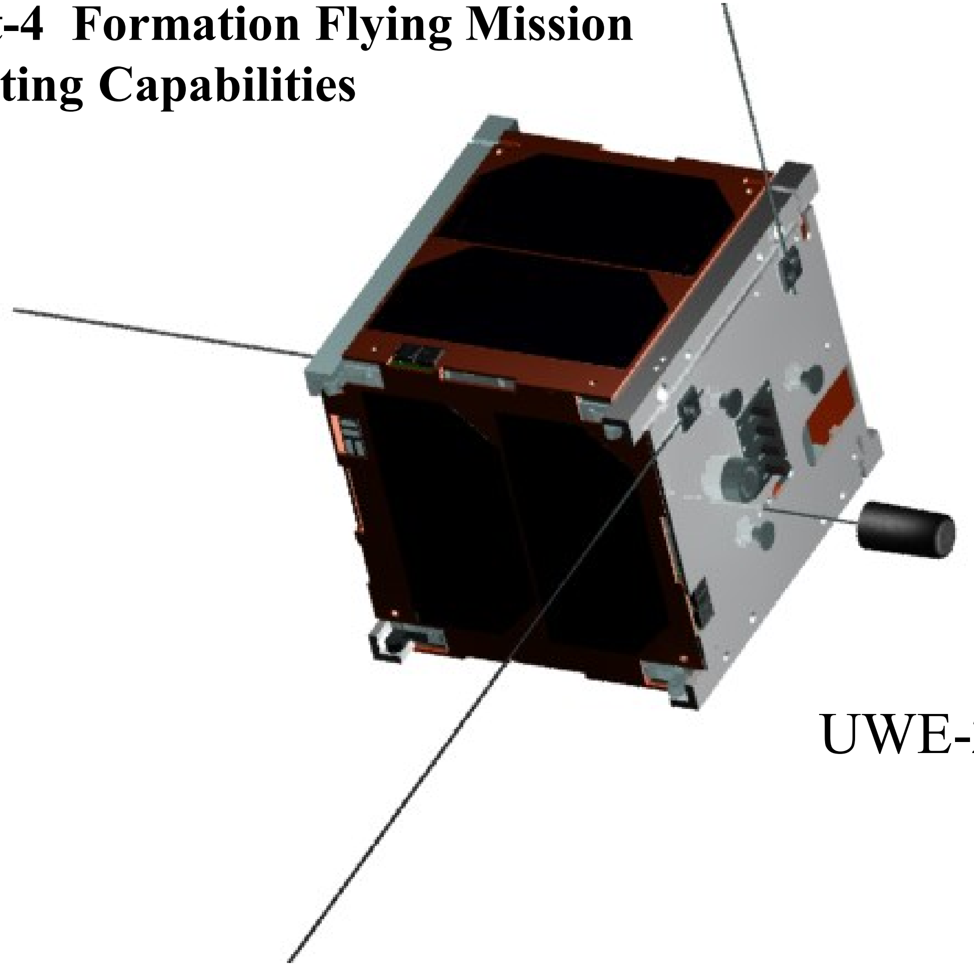
- Attitude Control

2009 UWE-2

- Attitude- and Orbit Determination

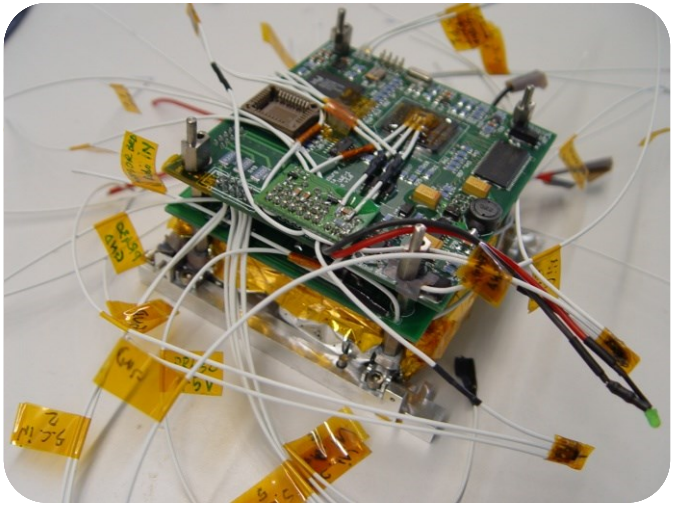
2005 UWE-1

- Telecommunication "Internet in Space"

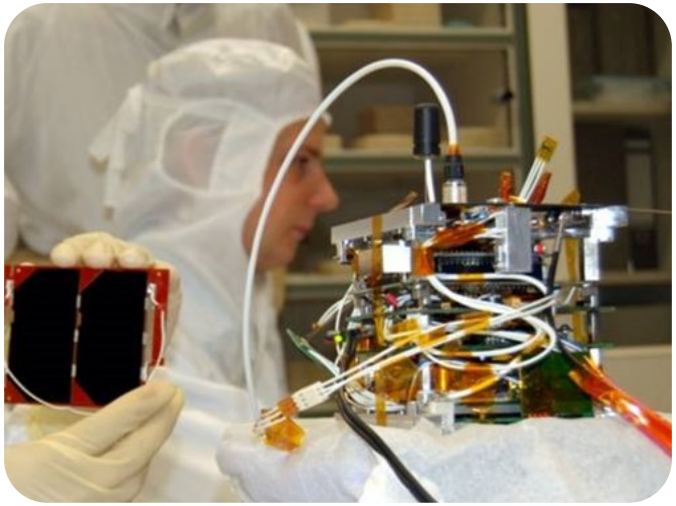


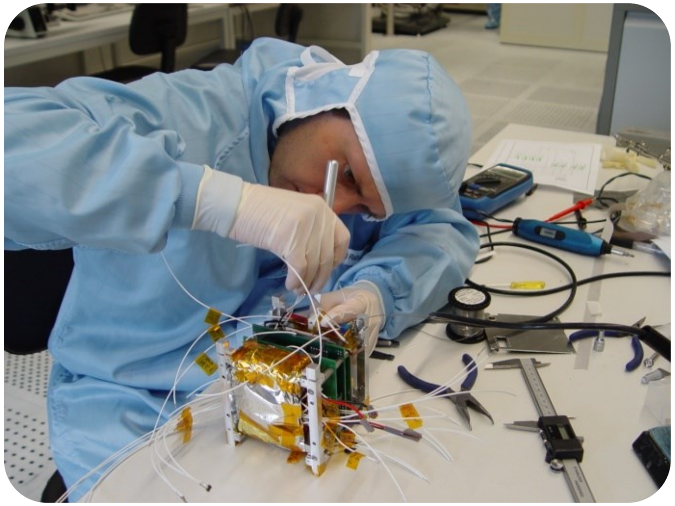
UWE-2

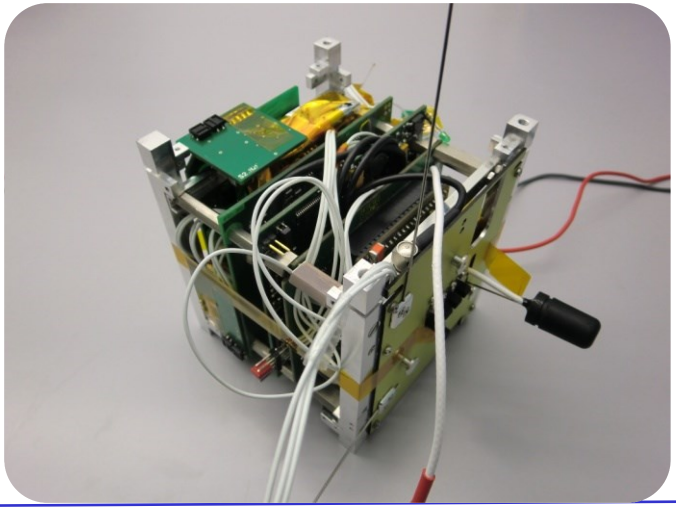
UWE-1: 2005



UWE-2: 2009



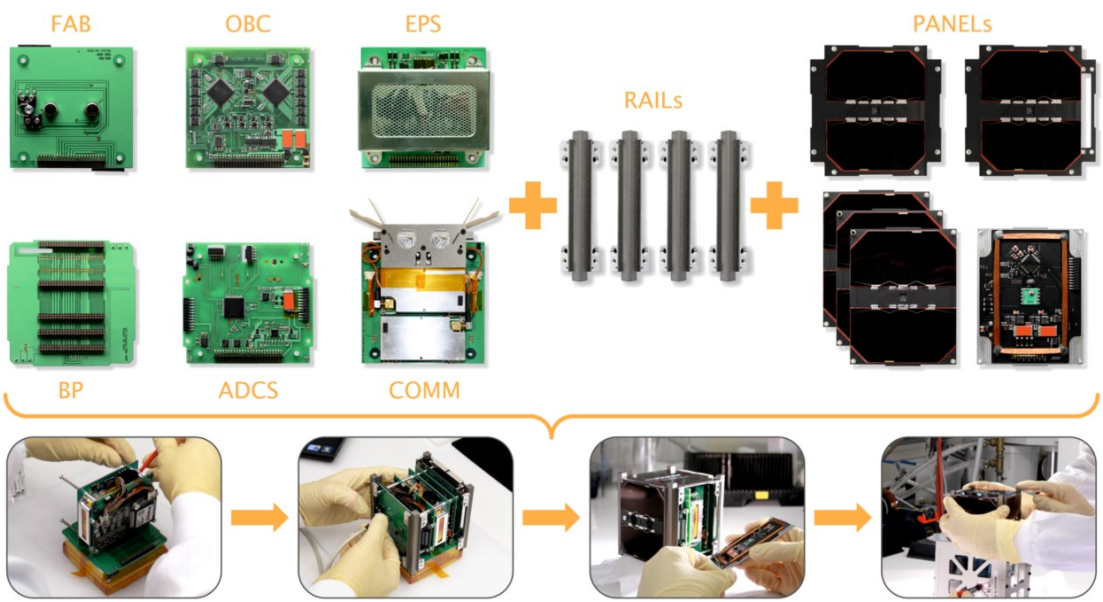


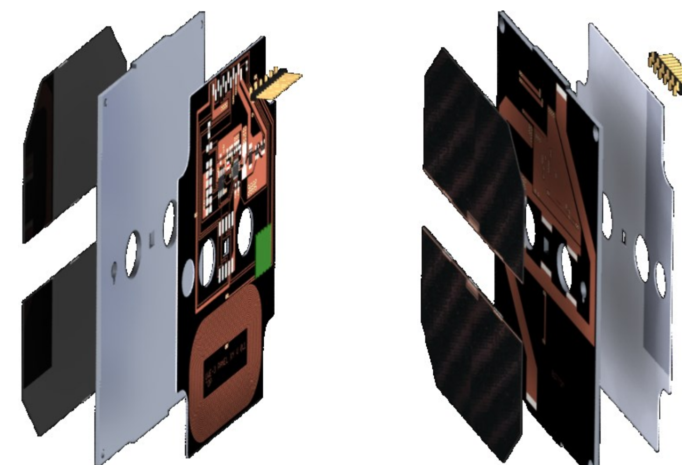


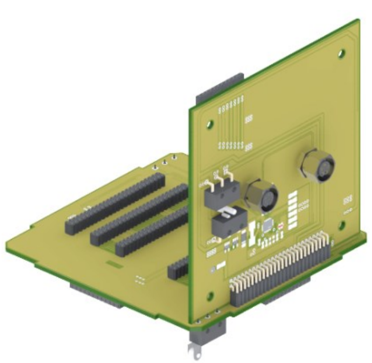
First Pico-Satellites

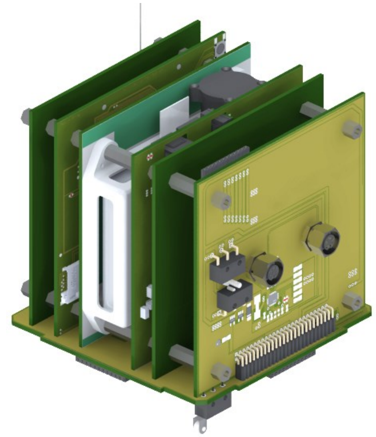
Technology Progress:

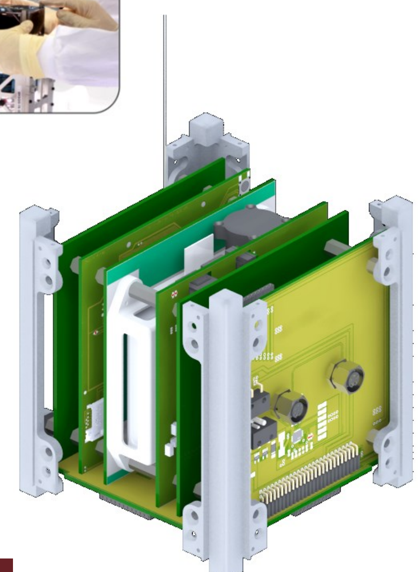
Standardization of electrical IF,
Modular and Flexible Satellite System Design

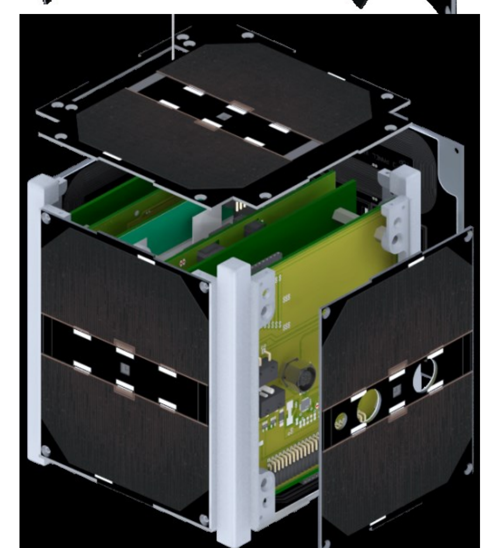








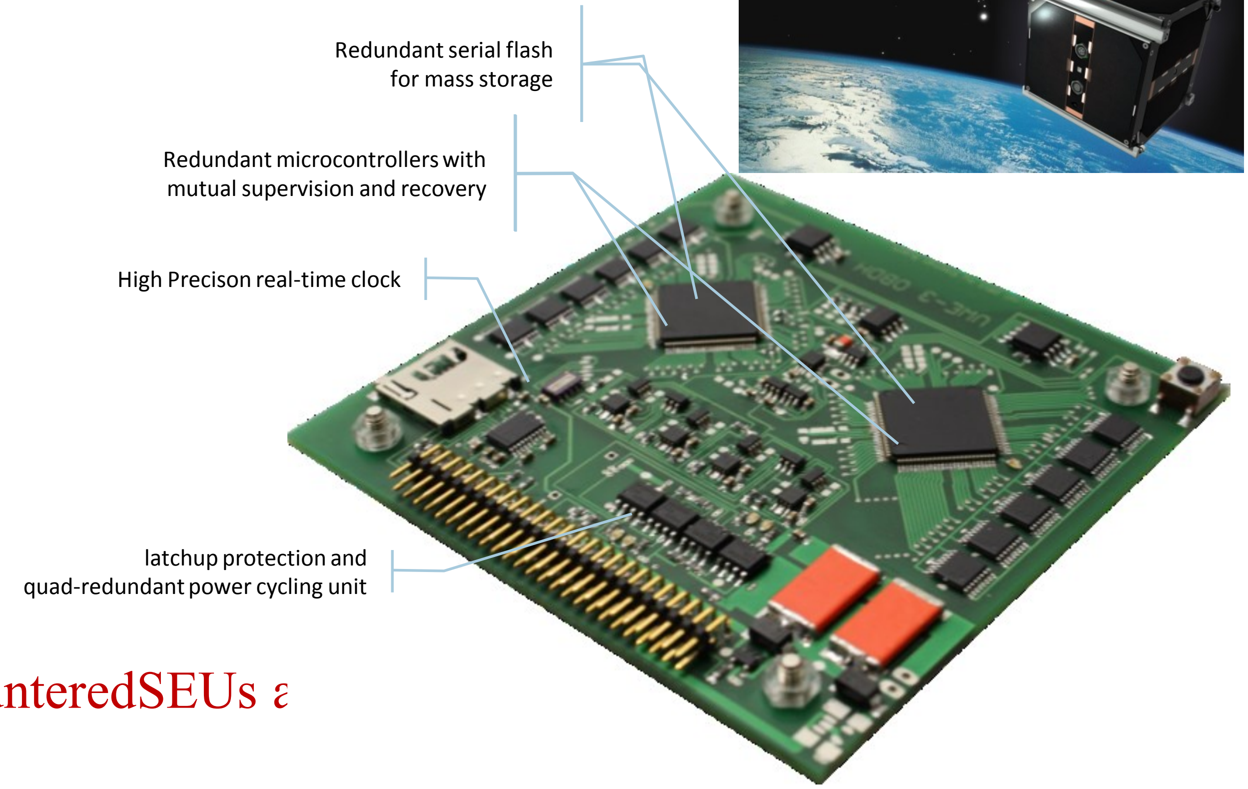




Technology Challenge: Reliable Robust Pico-Satellites

Reliable Data Handling by Commercial Low Power On Board Microprocessors Using Radiation Shielding by Software

- Miniaturization leads to higher susceptibility to space radiation environment
- Only commercial of the shelf electronics was used
- Fault detection, identification and recovery by software and simple watch-dog function

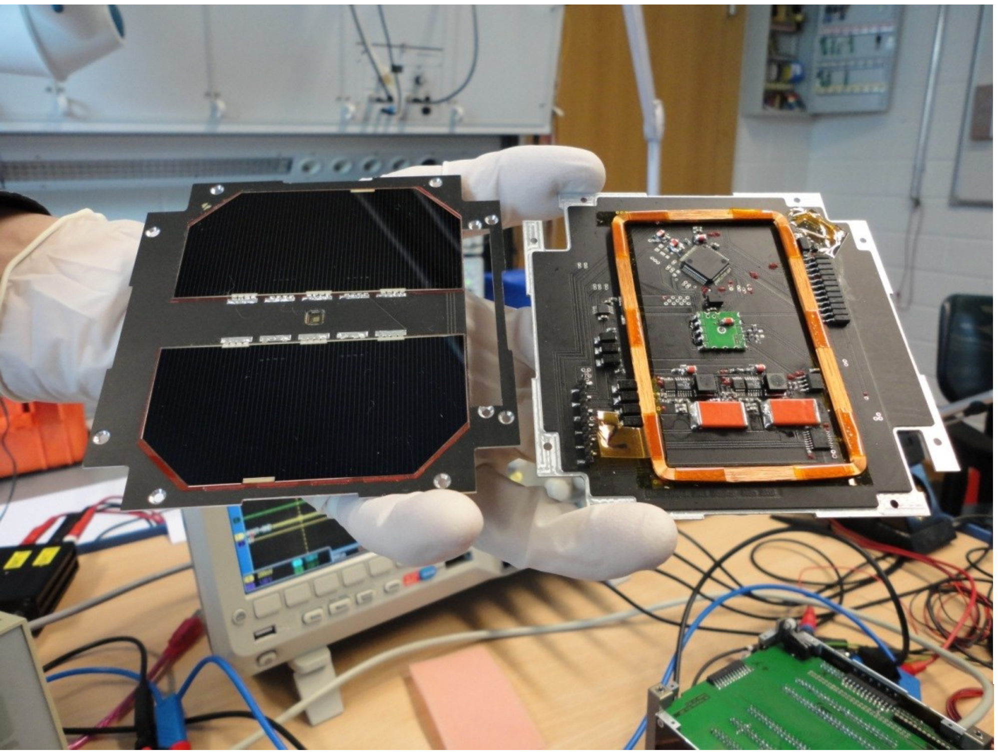


Despite significant radiation encountered, UWE-3 runs now since launch for more than 2.5 years without any interruption, despite encounteredSEUs a

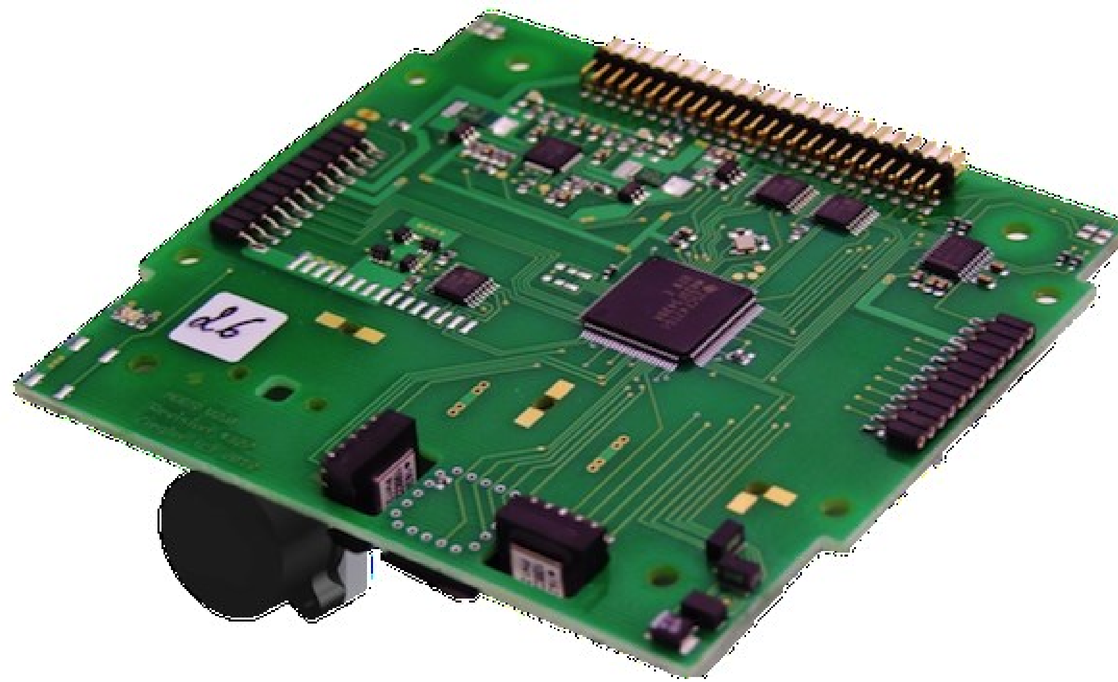
Future developments address provision of distributed computational resources integrated on different spacecrafts of a formation

Technology Challenge:

Attitude Determination and Control System



Integrated magnetic torquer, Sun sensor and magnetometer on the backside of each solar array panel

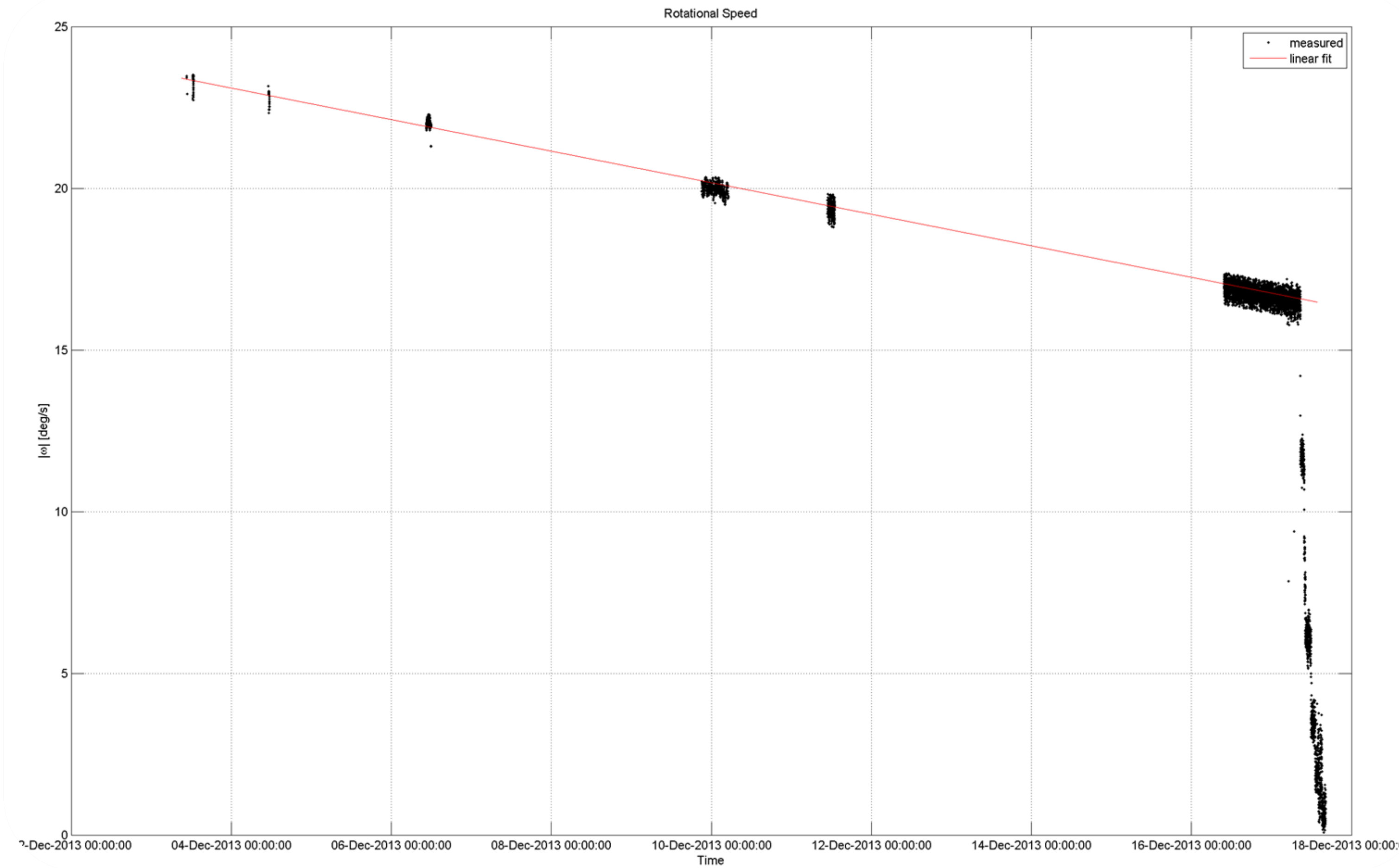


Miniature reaction wheel combined with low power ADCS control board

Detumbling after Deployment

Tumbling rates > 23 deg/s

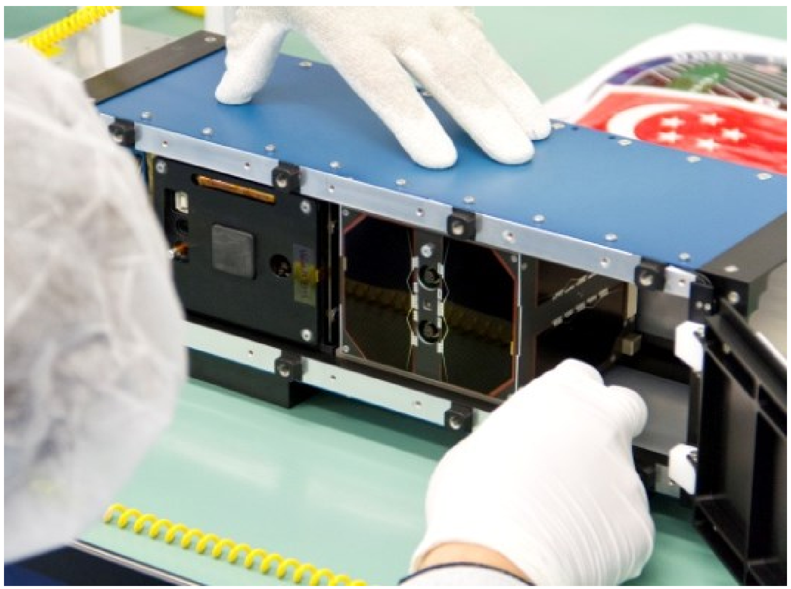
Natural decay of 0.5 deg/s/day



UWE-3 stopped tumbling after 7 min of activity by the Magnetic Torquers

Technology Challenge: Attitude and Orbit Control for Pico-Satellites

Launch by Dnepr-rocket on 21.11.2013



Integration von UWE-3 in den Raketenadapter

The Dnepr-rocket launch carried 32 satellites into a sun-synchronous orbit in an altitude of 700 km

UWE-3-Launch

Advanced Manufacturing of "Industry 4.0" at Specific Example of Small Satellite System

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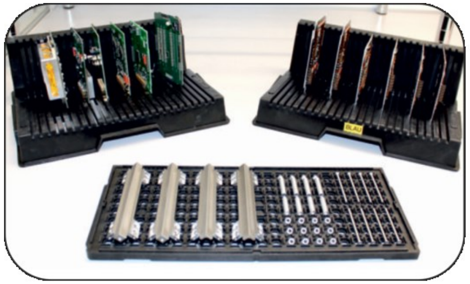
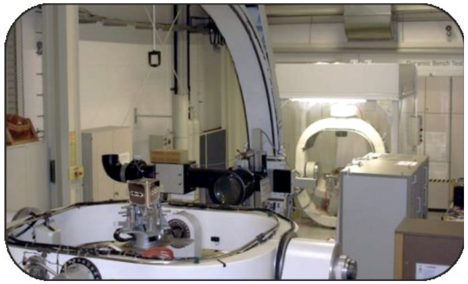


modular satellite bus architecture to support flexible integration an production

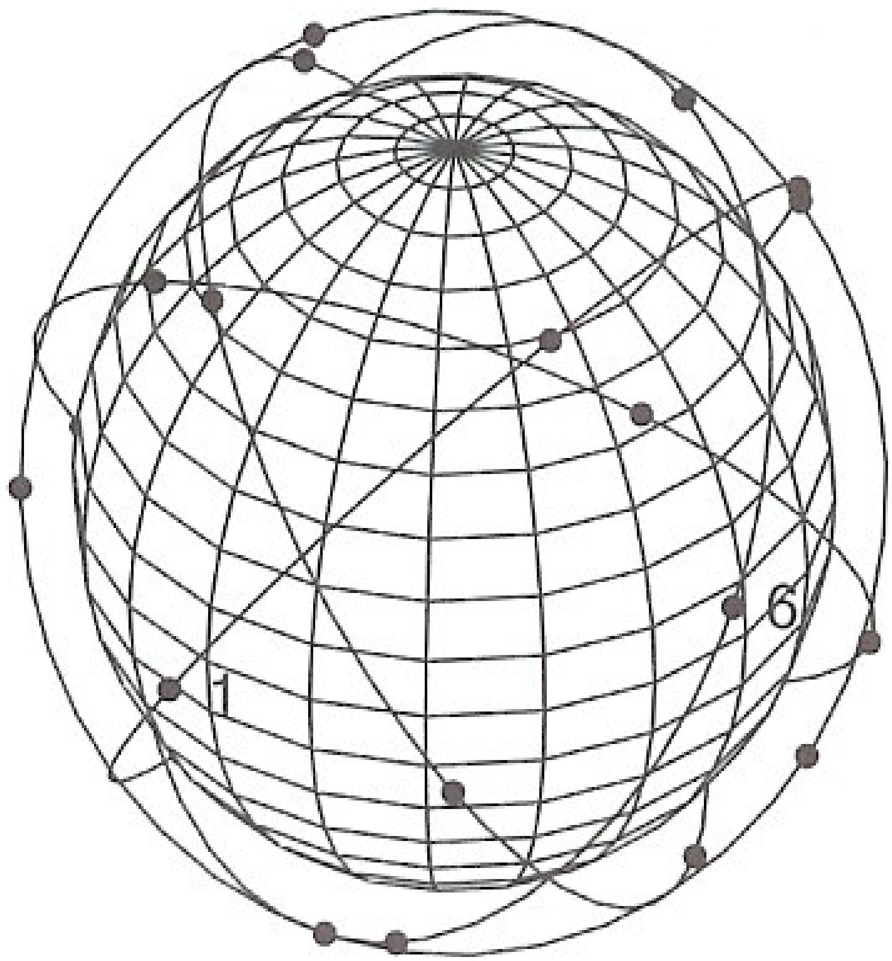
close worker / robot cooperation for efficient satellite system integration

Specific advantages include
- high flexibility to variations of standard product
- fast integration of modular components
- respecting high quality requirements

flexible flow of materials between integration and testing areas by transport robots



automated tests for functionality and performance of the satellite



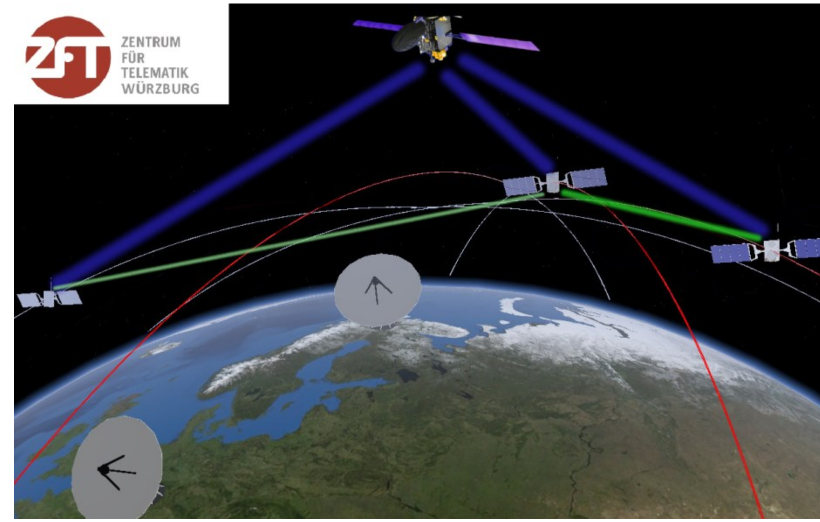
Surface Coverage by Formations

- improved temporal and spatial coverage
- robust system performance in case of defects
- Minimization of the amount of necessary satellites by selecting appropriate orbit constellations
- A frequently used class is the Walker Delta pattern constellation for a continuous coverage of the Earth’s surface by a minimum number of spacecraft.

NetSat Objectives

ZENTRUM FÜR TELEMATIK E.V.

- Realization of distributed, cooperating multi-satellite systems using autonomous formation control for optimization of observation periods
- 4 small satellites in order to establish a three-dimensional formation
- The satellites will be separated by relative distances between 50 - 10 km during nominal operations.
- The first objective is to maintain the formation configuration autonomously with the implemented actuators
- At the end of the operational phase risky, near range formations will be realized with distances between 20 – 40 m.

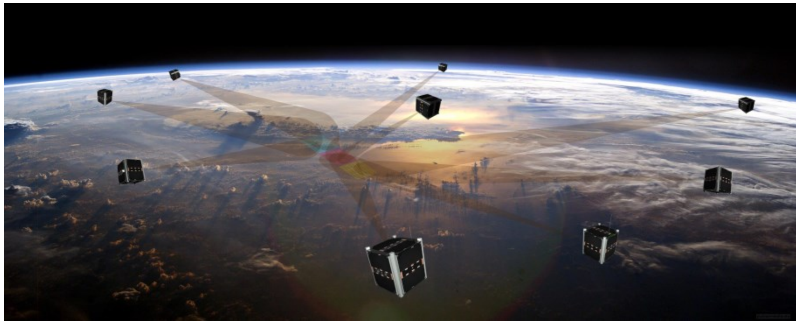


erc
European Research Council

Research supported by a ERC Advanced Grant

Distributed Networked Pico-Satellite Formations

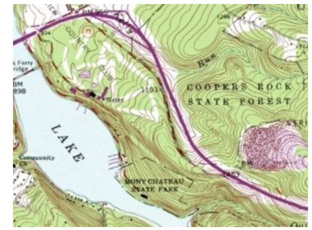
- formation control
  - model reference based adaptive control for attitude and orbit control by reaction wheels, magnetic torquers, electric propulsion



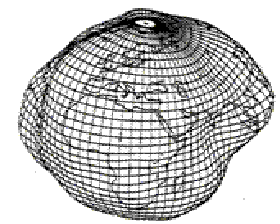
  - Relative attitude and position determination within the formation, based on data exchange and data fusion
- autonomous, networked satellite control
  - Reliable data exchange between the satellites by mobile DTNs and ad-hoc networks to adapt to changing communication topologies and interruptions
  - Networked control of the satellite formation, combination of supervisory control from ground with autonomous reactions
- small satellite in-orbit demonstration
  - Implementation of a demonstrator mission based on 4 pico-satellites
  - navigation sensor system, in particular for relative distances & orientations

Problem areas benefitting from satellite formations and photogrammetric observations

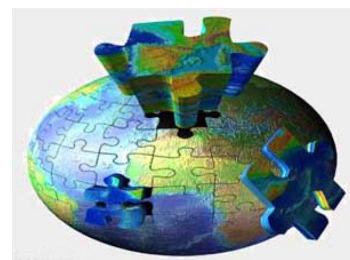
- Cartography and topography
  - Road maps
  - Air navigation maps



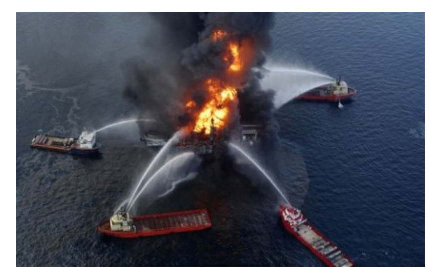
- Geodesy
  - 3D profile of the Earth
  - Spatial position and size of large constructions



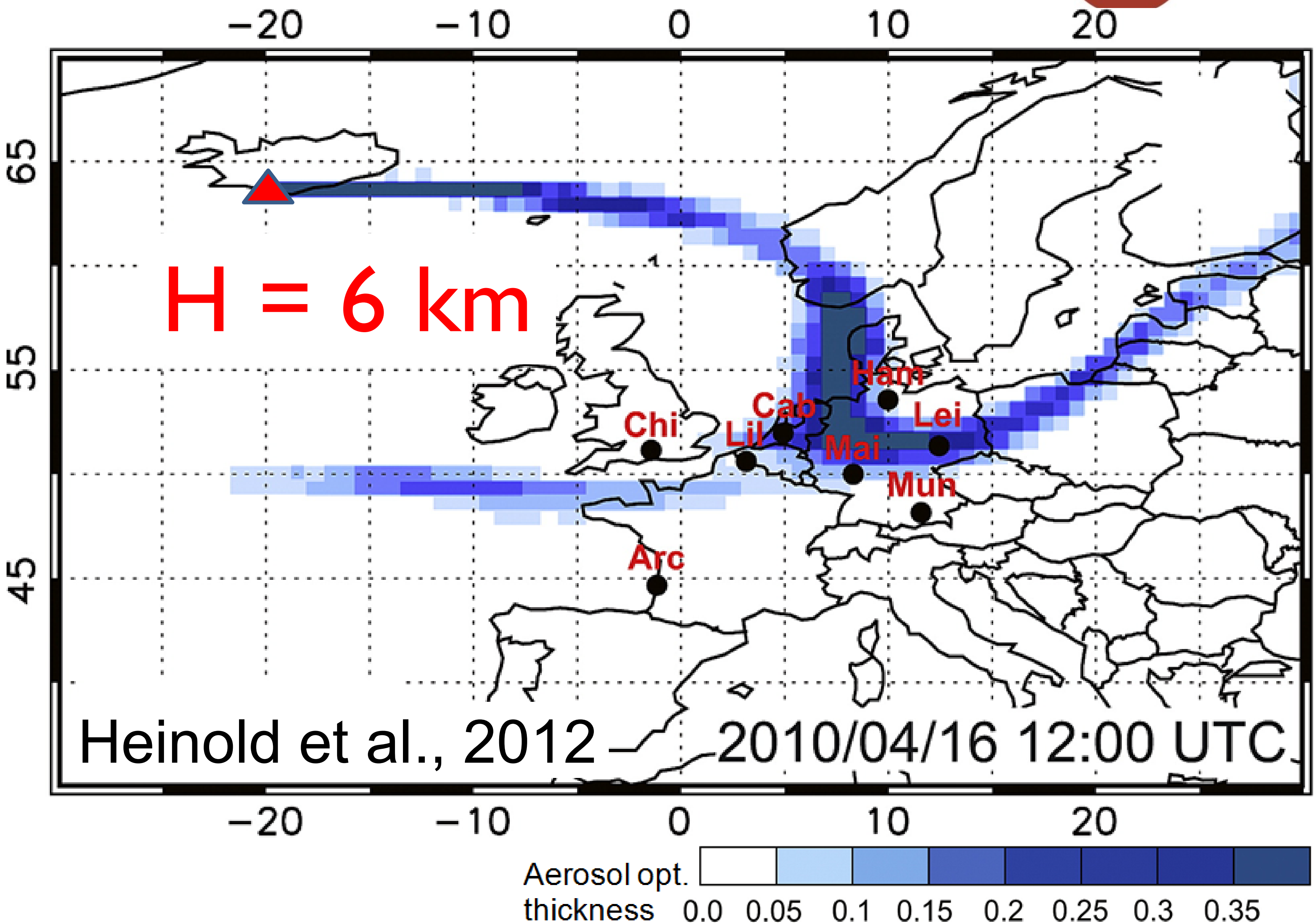
- Geology and volcanology
  - Mineral exploration
  - Prediction of eruptions



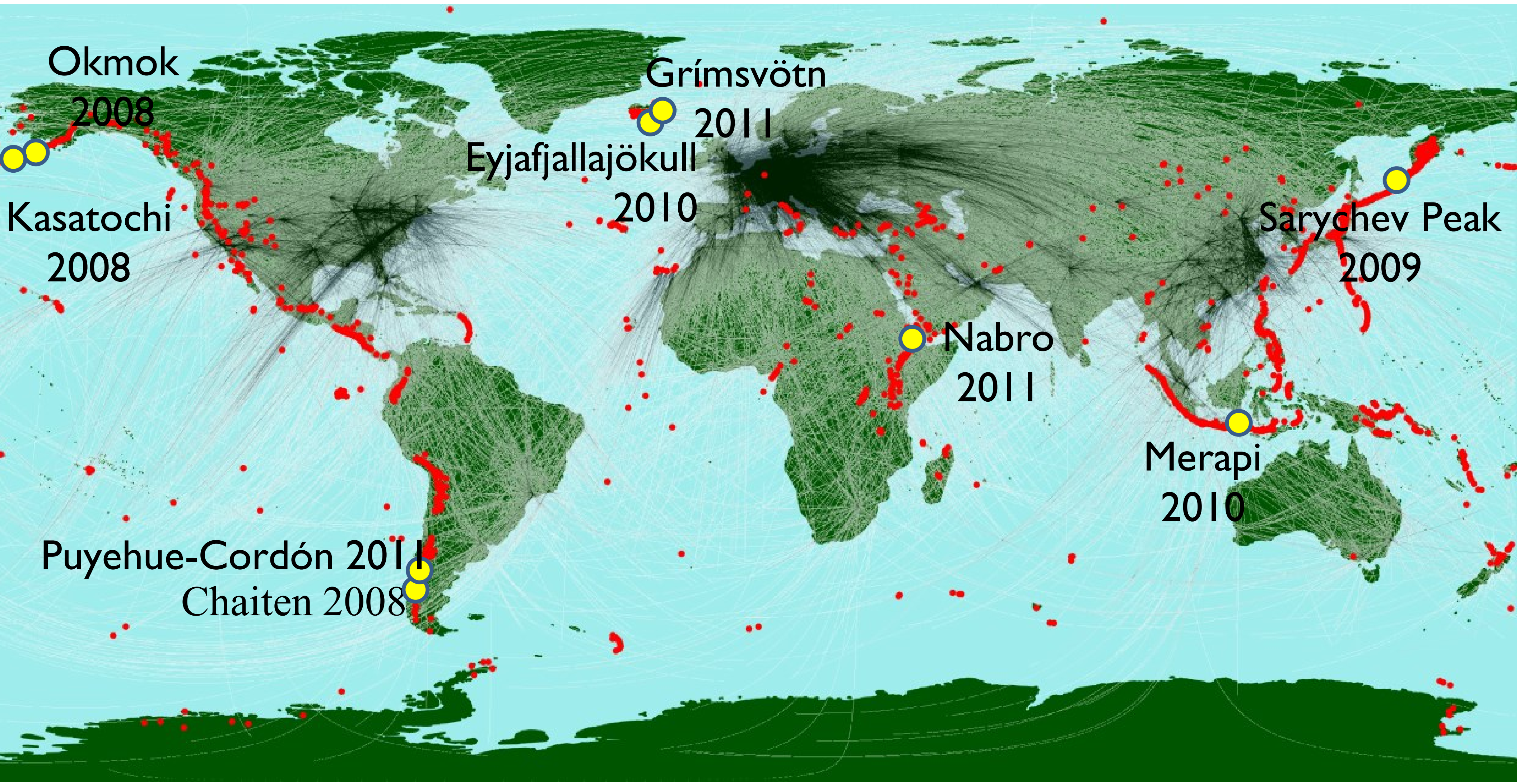
- Natural and industrial disasters
  - Disaster prevention
  - Monitoring



Model of 2010 Eyjafjallajökull Eruption



Major Eruptions in Last Years



• Active volcanoes in last 10,000 years

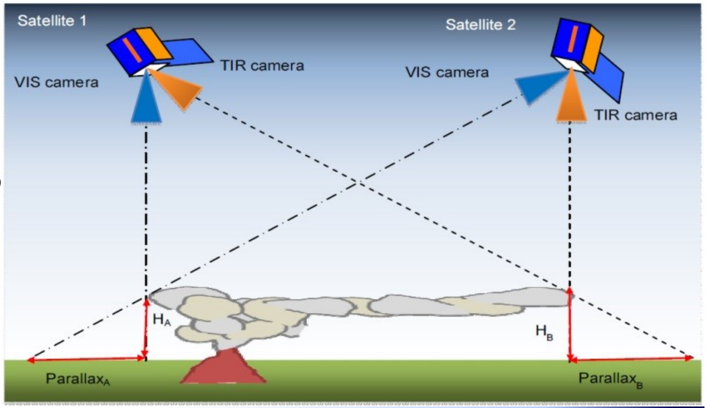
Denisty of airlane routes

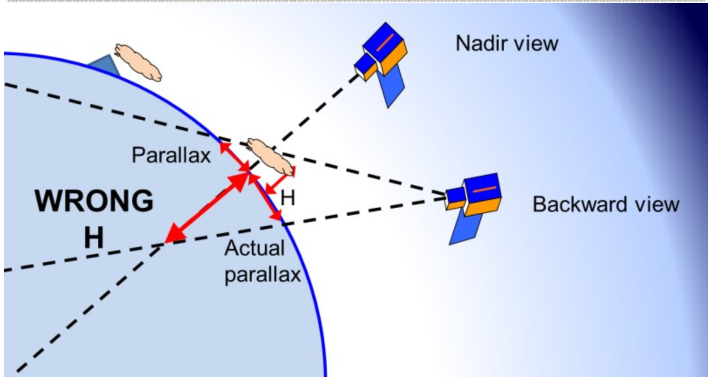
Mission Objectives

Photogrammetric Ash Cloud Observations by Small Satellite Formations

ZENTRUM FÜR TELEMATIK E.V.

- Estimate cloud spatial distribution and its temporal evolution;
- Estimate cloud top height with an accuracy comparable to lidar for all visible layers (200 m);
- Increase the temporal resolution of the observations to at least once per day (lidar only in nadir, every 16 days);
- Simultaneously capture high-resolution images of the same target area in the visible (VIS) range from at least two viewpoints (mandatory);
- Autonomously detect and track an ash cloud within a specified region of interest (mandatory). Note: this could potentially be achieved with an extra thermal infrared (TIR) sensor (optional);
- Adapt the observation baseline to different operation and observation scenarios (optional).





Klemen Zakšek: 1st price at Mission Idea Contest: Clouds Height Mission

Preparations for Würzburg's Multi Satellite Simulation Environment

Turntables providing high precision and high dynamics capabilities

Wirtschaftsministerin Ilse Aigner (Mitte) lässt sich von Klaus Schilling (li./Zentrum für Telematik) im TGZ eine Testvorrichtung für Satelliten erklären. Rechts Landtagspräsidentin Barbara Stamm, hinten TGZ-Geschäftsführer Alexander Zöller. FOTO: THERESA MÜLLER

Conclusions

Technology achievements in the field of very small satellites (at 1 kg level)

- modular, flexible design with standardized interfaces via backplane
- suitable attitude determination and control capabilities
- robust miniaturized on-board data handling system
- orbit control capabilities are foreseen

Networked satellite systems offer efficient approaches

- for high spatial and temporal resolution of observation data
- for cooperatively solving complex tasks and faster completion by parallelisation
- for higher fault tolerance and robustness of the overall system
- for scalability (according to application needs further satellites can be added)

Interesting application fields concern **optical multi-perspective** observations and **gradiometry** missions

There are excellent opportunities for cooperations in international partnership