THE BREMEN DROP TOWER

AT A GLANCE

ZARM FAB mbH, 2018
Bremen, Germany

Dr. Thorben Könemann
ZARM Drop Tower Operation and Service Company
WWW.ZARM.UNI-BREMEN.DE

Universität Bremen

CENTER OF
APPLIED SPACE TECHNOLOGY
AND MICROGRAVITY

ZARM

Free Hanseatic City of Bremen

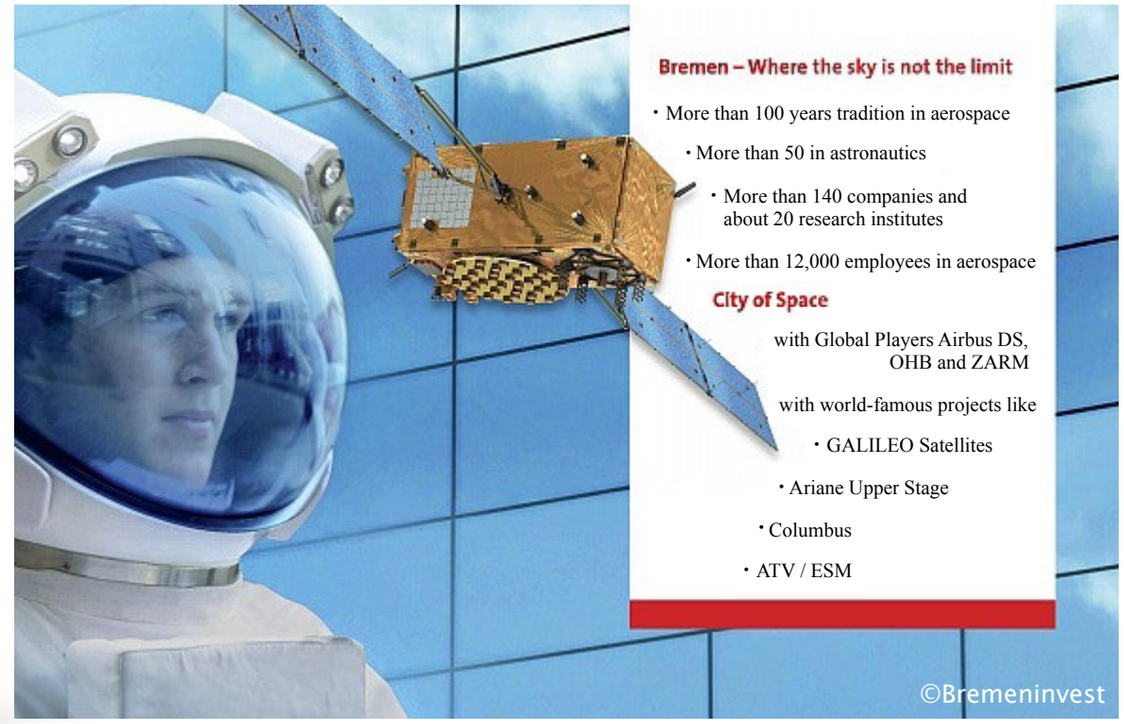
- A Historic Place - Worth to Visit

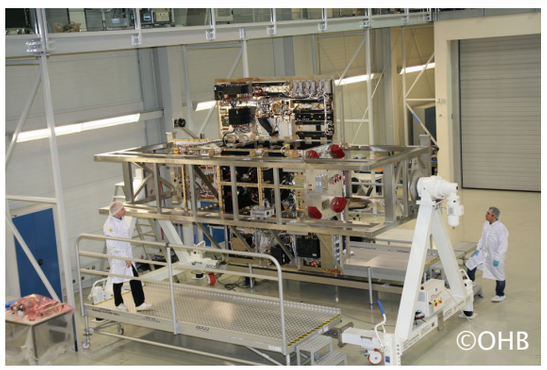
The Bremen Town Musicians

Bremen - City of Space

Space Research Institutes:
DLR - Institute of Space Systems
ZARM - University of Bremen

- One of Europe's largest Aerospace Location



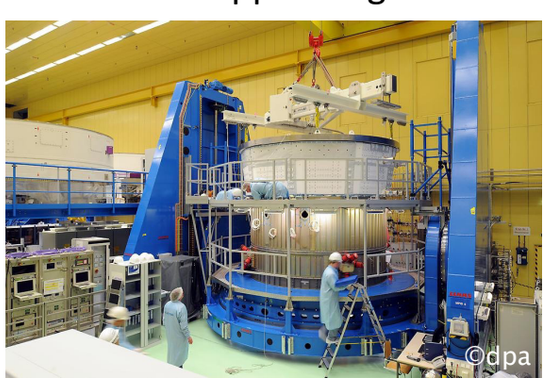


- Galileo Satellites

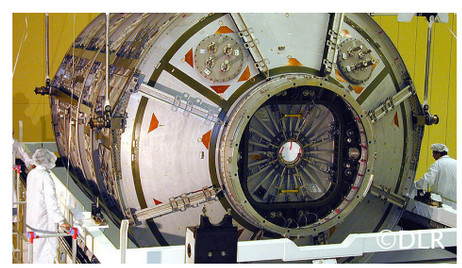
OHB

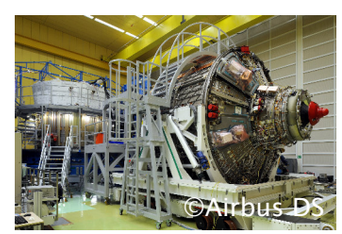
AIRBUS DEFENCE & SPACE

- Ariane Upper Stage



- Columbus - ISS Module





- ATV (Automated Transfer Vehicle) - ISS Support

- ESM (European Service Module) - Orion Support

ZARM

Content

- Overview - ZARM
- Suborbital Platforms
- The Bremen Drop Tower
- Drop Tower Experiments
- Future Drop Tower System

ZARM's Organization Structure

founded in 1985

ZARM - Center of Applied Space Technology and Microgravity

c/o Universität Bremen
Am Fallturm 2, 28359 Bremen, Germany
www.zarm.uni-bremen.de

ZARM - University of Bremen

Research Institute - Faculty 04 Production Engineering

Prof. Dr. Marc Avila
(Executive Director)

Prof. Dr. Marc Avila
(Director Fluid Dynamics)

Prof. Dr. Claus Lämmerzahl
(Director Space Science)

Prof. Dr. Claus Braxmaier
(Director Space Technology)

ZARM FAB mbH

ZARM Drop Tower Operation and Service Company

Prof. Dr. Marc Avila
Peter von Kampen
(Executive Board)

Christian Eigenbrod
Dr.-Ing. Thorben Könemann
Ulrich Kaczmarczik
(Scientific / Technical Management)

ZARM Technik AG

Supplier of Attitude Control Equipment for Satellites

Holger W. Oelze
(Chief Executive Officer)

Peter von Kampen
(Chief Financial Officer)

Marco R. Fuchs
(Chairman of Supervisory Board)

- Research / Teaching
- Technical Support
- Space Hardware

ZARM's Organization Structure

founded in 1985

ZARM - Center of Applied Space Technology and Microgravity

c/o Universität Bremen
Am Fallturm 2, 28359 Bremen, Germany
www.zarm.uni-bremen.de

ZARM - University of Bremen

Research Institute - Faculty 04 Production Engineering

Prof. Dr. Marc Avila
(Executive Director)

Prof. Dr. Marc Avila
(Director Fluid Dynamics)

Prof. Dr. Claus Lämmerzahl
(Director Space Science)

Prof. Dr. Claus Braxmaier
(Director Space Technology)

- Research / Teaching

ZARM FAB mbH

ZARM Drop Tower Operation and Service Company

Prof. Dr. Marc Avila
Peter von Kampen
(Executive Board)

Christian Eigenbrod
Dr.-Ing. Thorben Könemann
Ulrich Kaczmarczik
(Scientific / Technical Management)

- Technical Support

ZARM Technik AG

Supplier of Attitude Control Equipment for Satellites

Holger W. Oelze
(Chief Executive Officer)

Peter von Kampen
(Chief Financial Officer)

Marco R. Fuchs
(Chairman of Supervisory Board)

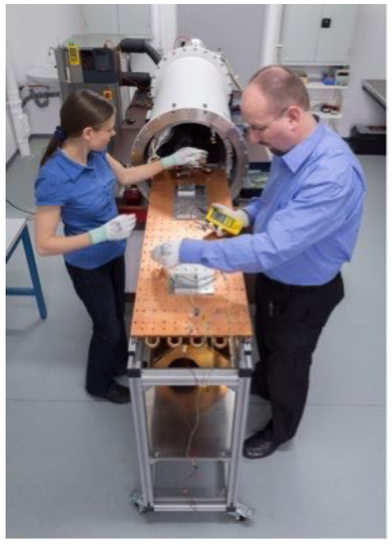
- Space Hardware

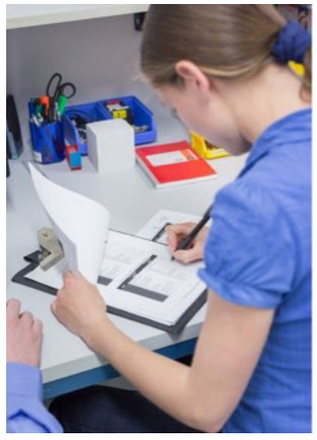
ZARM TEST CENTER - we.know.how.

know-how, reliability, flexibility, customer-focused solutions

- Convenient Combination of ZARM's Test Labs
  - Aerospace Qualification and Test Services under one roof
    - VIBRATION TEST LAB - LONG STROKE SHAKER (35.6 kN)

    - THERMAL VACUUM LAB - LARGE-/MEDIUM-/SMALL-SIZED TVCs + TCC

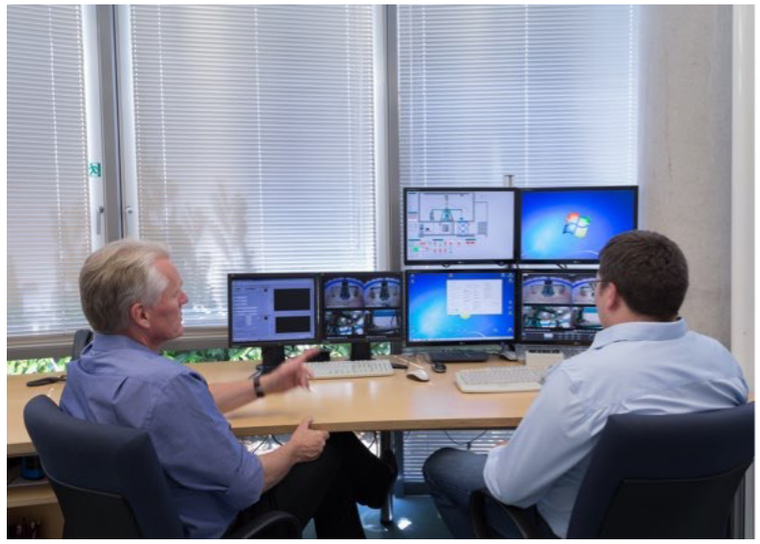




ZARM TEST CENTER - we.know.how.

know-how, reliability, flexibility, customer-focused solutions

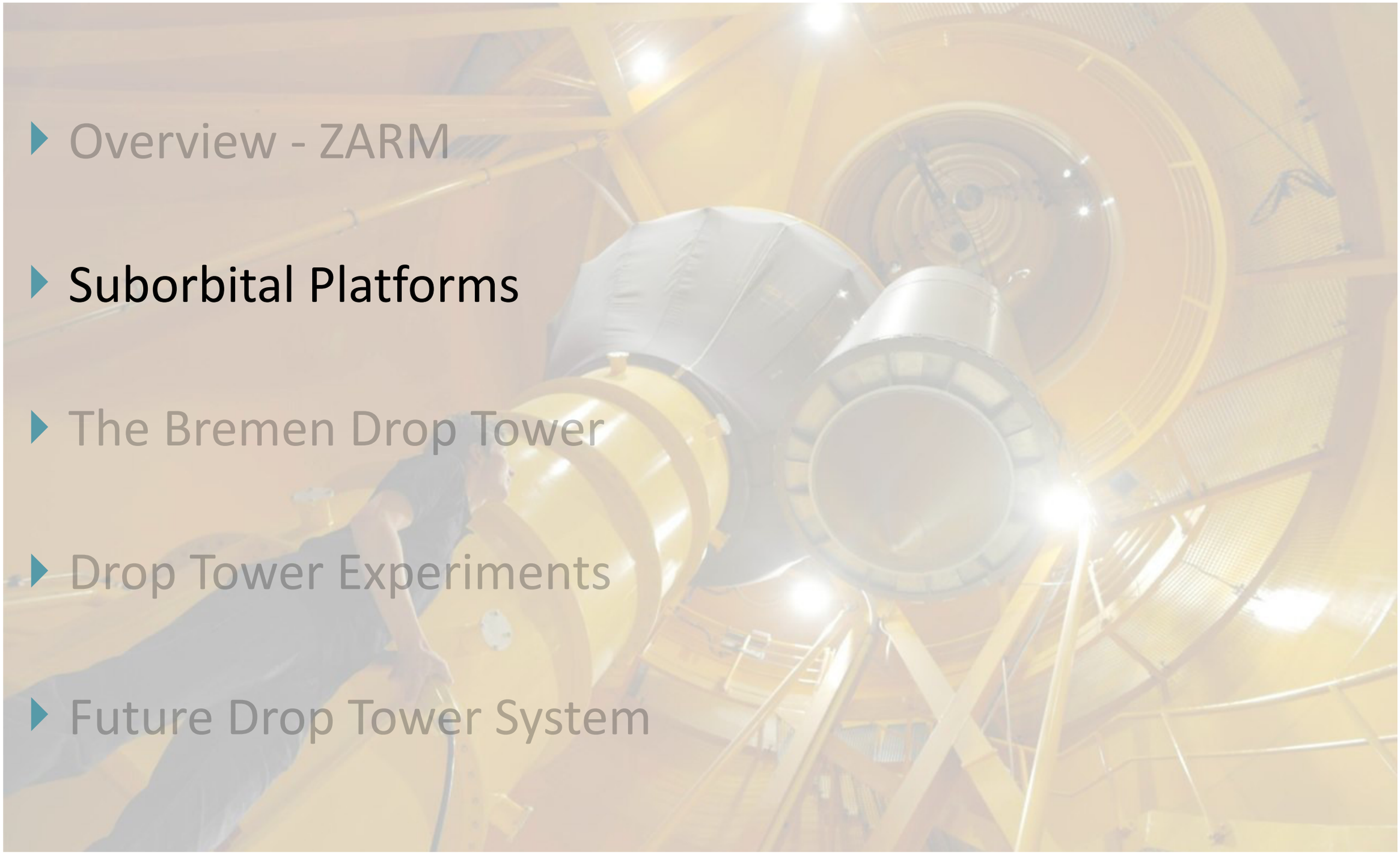
- Convenient Combination of ZARM's Test Labs
  - Aerospace Qualification and Test Services under one roof
    - 30g CENTRIFUGE - EUROPE's LARGEST HYPER-GRAVITY FACILITY



- ZARM TEST CENTER - Team

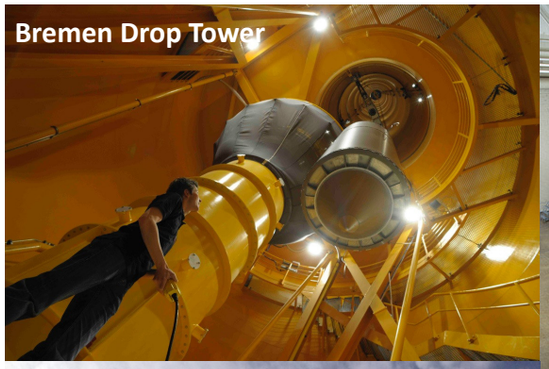
- ELECTRICAL TEST SERVICES
  (in cooperation with Aircraft Elektro/Elektronik System GmbH)
- VARIETY OF TEST STANDARDS: RTCA DO-160, MIL-STD-810,…

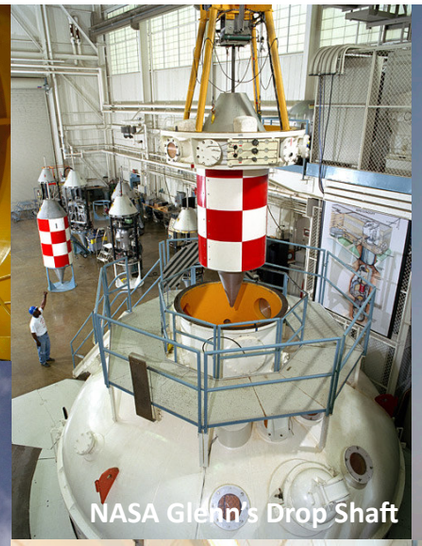
Content

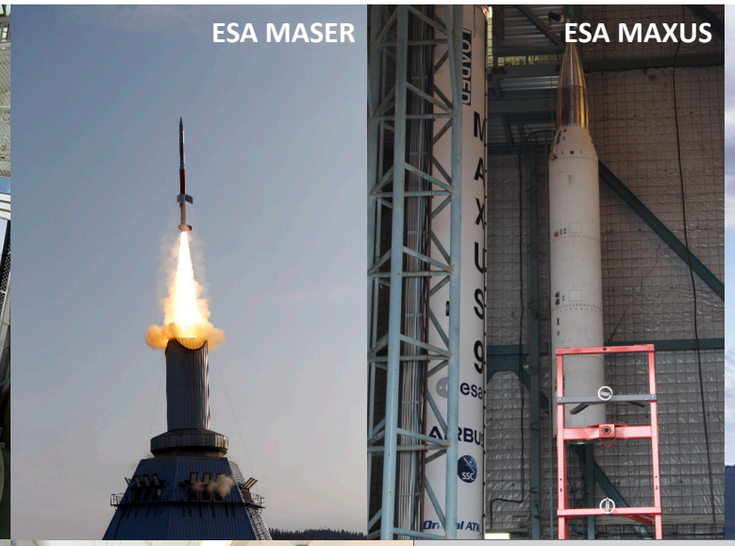


- Overview - ZARM
- Suborbital Platforms
- The Bremen Drop Tower
- Drop Tower Experiments
- Future Drop Tower System

Suborbital Science and Technology - Platforms


Bremen Drop Tower


NASA Glenn's Drop Shaft


ESA MASER

ESA MAXUS


NASA / SSC Balloons


Beijing Drop Tower

DLR TEXUS


ISRO RH-200


JAXA SS-520

Novespace

Zero Gravity Corporation


REXUS


BEXUS

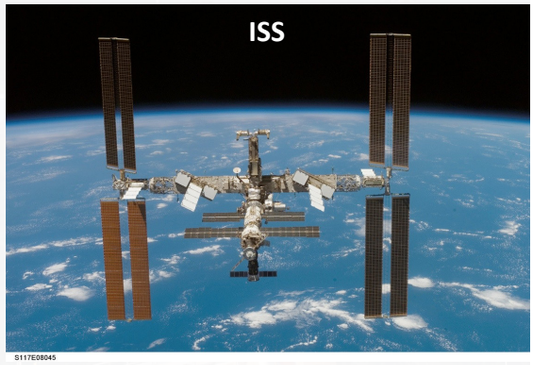
ZARM

Suborbital Science and Technology - Platforms

- Stepping Stones into Space - Microgravity Research

bottom-up approach

TO SPACE



- breadboards for space missions
- breadboards for sounding rockets

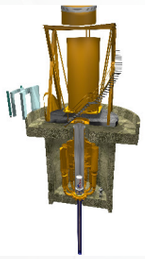
ZARM

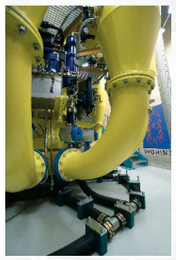
Suborbital Science and Technology - Platforms

- Drop Towers / Drop Shafts

- drop towers
  - max. 9.3 s µg -

catapult





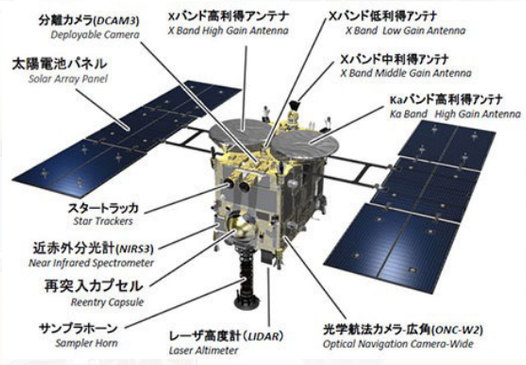
Benefits:

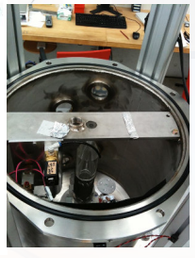
- **highest quality of weightlessness**
- **high payload masses**
- **daily available / easy hardware access**

Science and Technology:

- **combustion**
- **fundamental physics**
- **fluid dynamics**
- **astrophysics**
- **material sciences**
- **biology / chemistry**
- **technology tests**

- Hayabusa-2 mission preparation





(tests: sampler horn, MINERVA-II, MASCOT)

Suborbital Science and Technology - Platforms

- Parabolic Flights

Science and Technology:

- human physiology
- biology
- astrophysics
- fluid dynamics
- material sciences
- combustion
- fundamental physics
- technology tests / training

- Ballistocardiography in microgravity

- parabolic flights
  - 20 till 30 s µg -

Benefits:

- µg effects on human physiology
- astronaut training
- high payload masses
- direct hardware access

Suborbital Science and Technology - Platforms

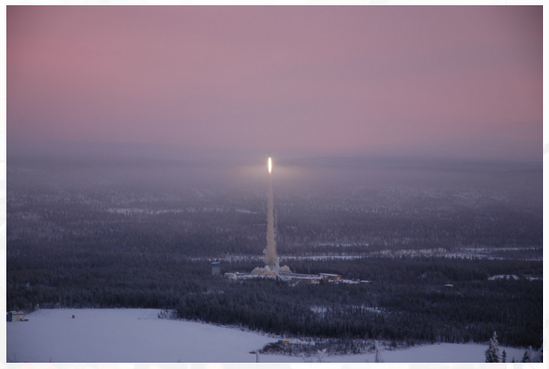
- Sounding Rockets

Benefits:

- high-quality weightlessness
- long microgravity duration
- high TRL (1. space experiment)

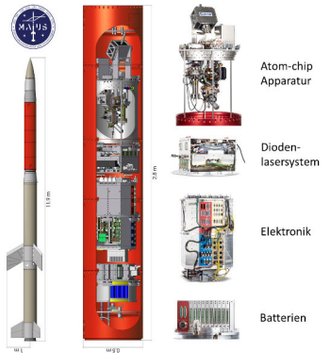
Science and Technology:

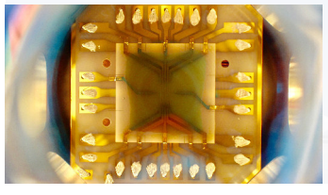
- material sciences
- biology
- fluid dynamics
- combustion
- fundamental physics
- astrophysics
- technology tests



- quantum systems (first BEC in space)

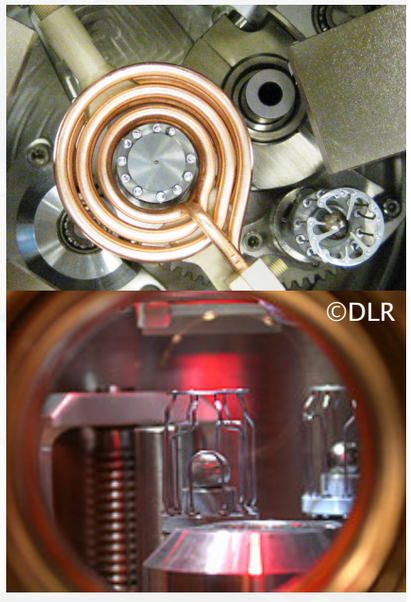
MAIUS





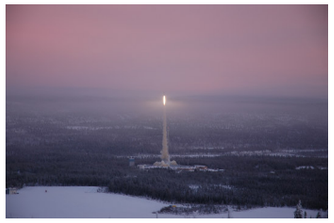
- sounding rockets
  - 6 / 13 min µg -

- metallic melts (EML)



Overview





Microgravity Platforms	Drop Towers / Drop Shafts	Parabolic Flights	Sounding Rockets	Reentry Capsules	International Space Station
time of weightlessness	9.3 s (Bremen Drop Tower) 5.2 s (NASA Glenn Shaft) 3.6 s (Beijing Drop Tower)	20 s (Airbus A310 ZERO-G)	13 min (MAXUS) 6 min (TEXUS / MASER) 2 min (REXUS)	2 - 4 weeks (FOTON / BION)	months (depending on astronaut working times)
quality of weightlessness	10^{-6} g (Bremen Drop Tower) 10^{-5} g (others)	10^{-2} g	10^{-5} g (others) 10^{-3} g (REXUS)	10^{-5} g	10^{-4} g
reduced gravity option	-	23 s / 30 s (Moon / Mars)	-	-	-
experiment series	daily	up to 2 per year	up to 2 per year	1 per > 2 years	1 per several years
experiment repetition rates	up to 3 per day	3 flights with 31 parabolas	1 flight continuously	1 flight continuously	1 flight continuously
hardware access	very high	high	medium	low	very low
operation costs	low	medium	high	high	very high

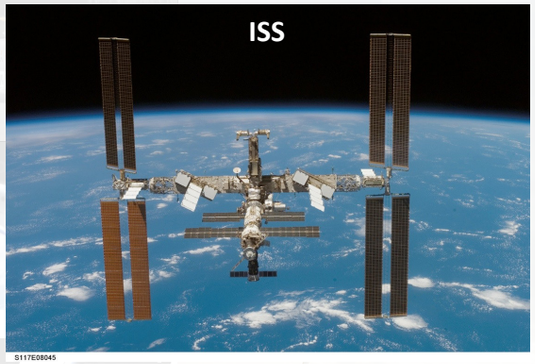
Suborbital Science and Technology - Platforms

Suborbital Science and Technology - Platforms

- Synergy Effects - Sounding Rockets - Standardization

bottom-up approach

TO SPACE



- breadboards for space missions
- breadboards for sounding rockets

Suborbital Science and Technology - Platforms

- Extended µg Research Opportunities - Human Physiology / Astronaut Training

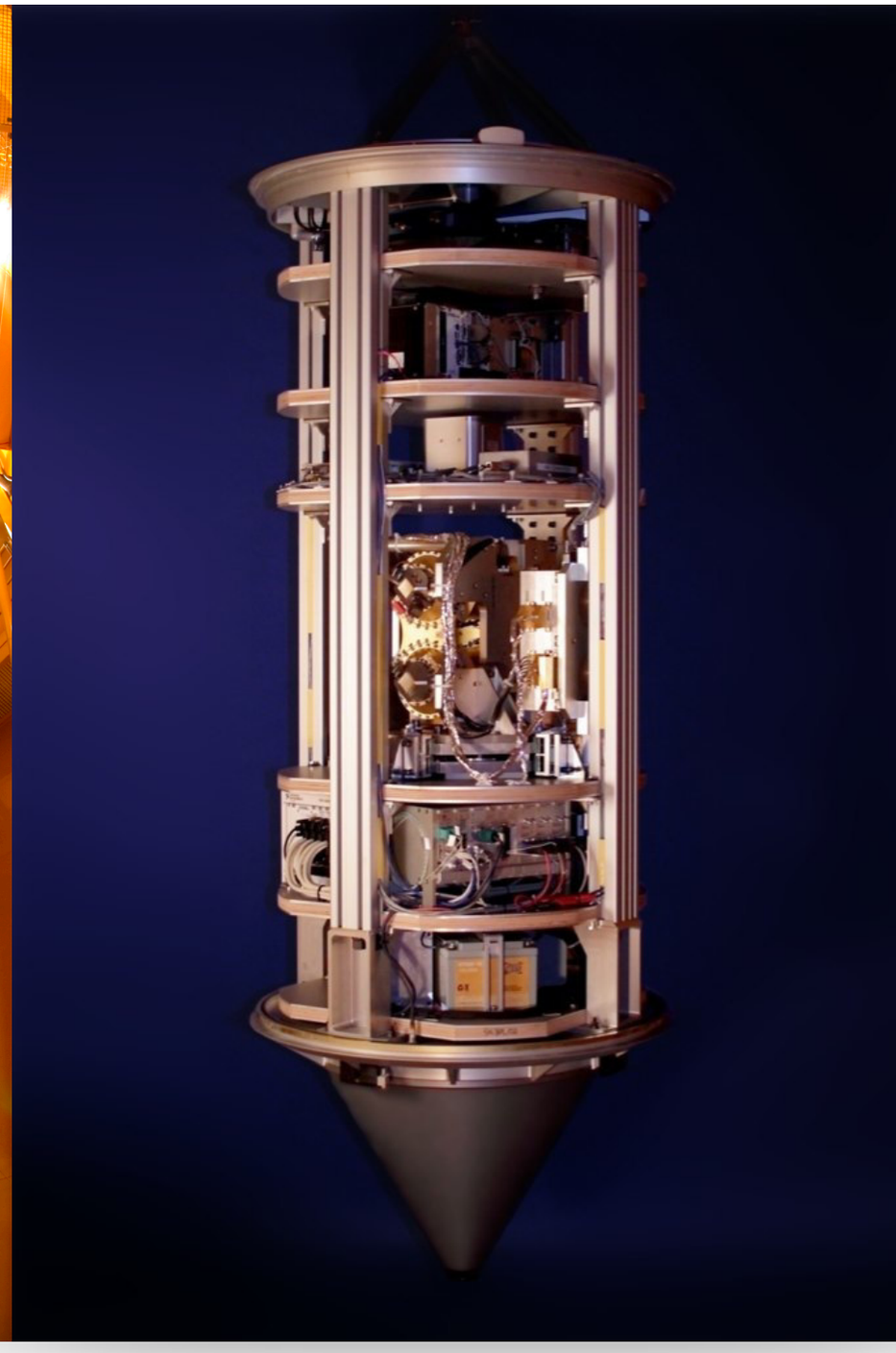
- suborbital flights
  - 3 min µg -

- parabolic flights
  - 20 till 30 s µg -

Content

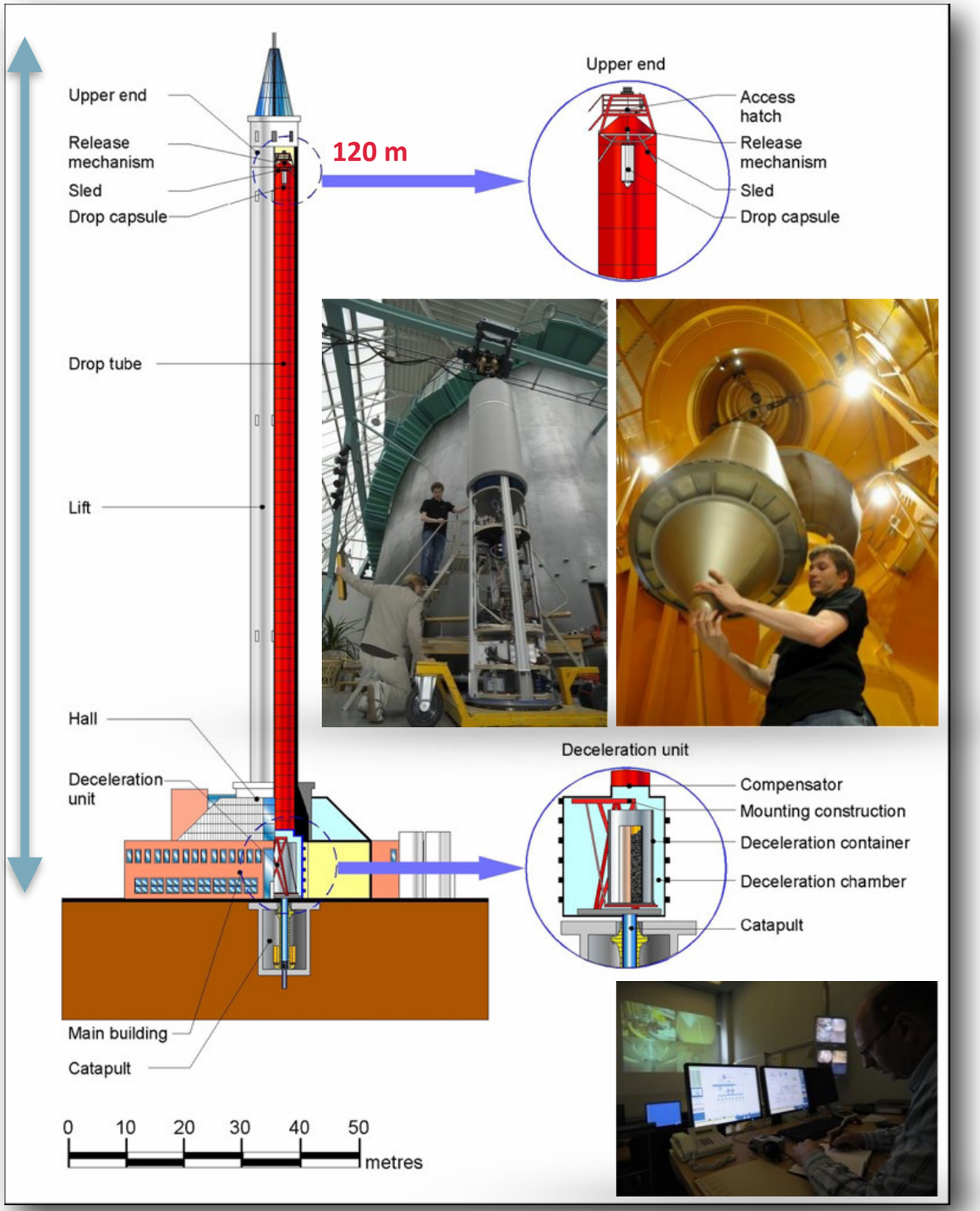
- Overview - ZARM
- Suborbital Platforms
- The Bremen Drop Tower
- Drop Tower Experiments
- Future Drop Tower System

The Bremen Drop Tower - Introduction



The Bremen Drop Tower - Introduction

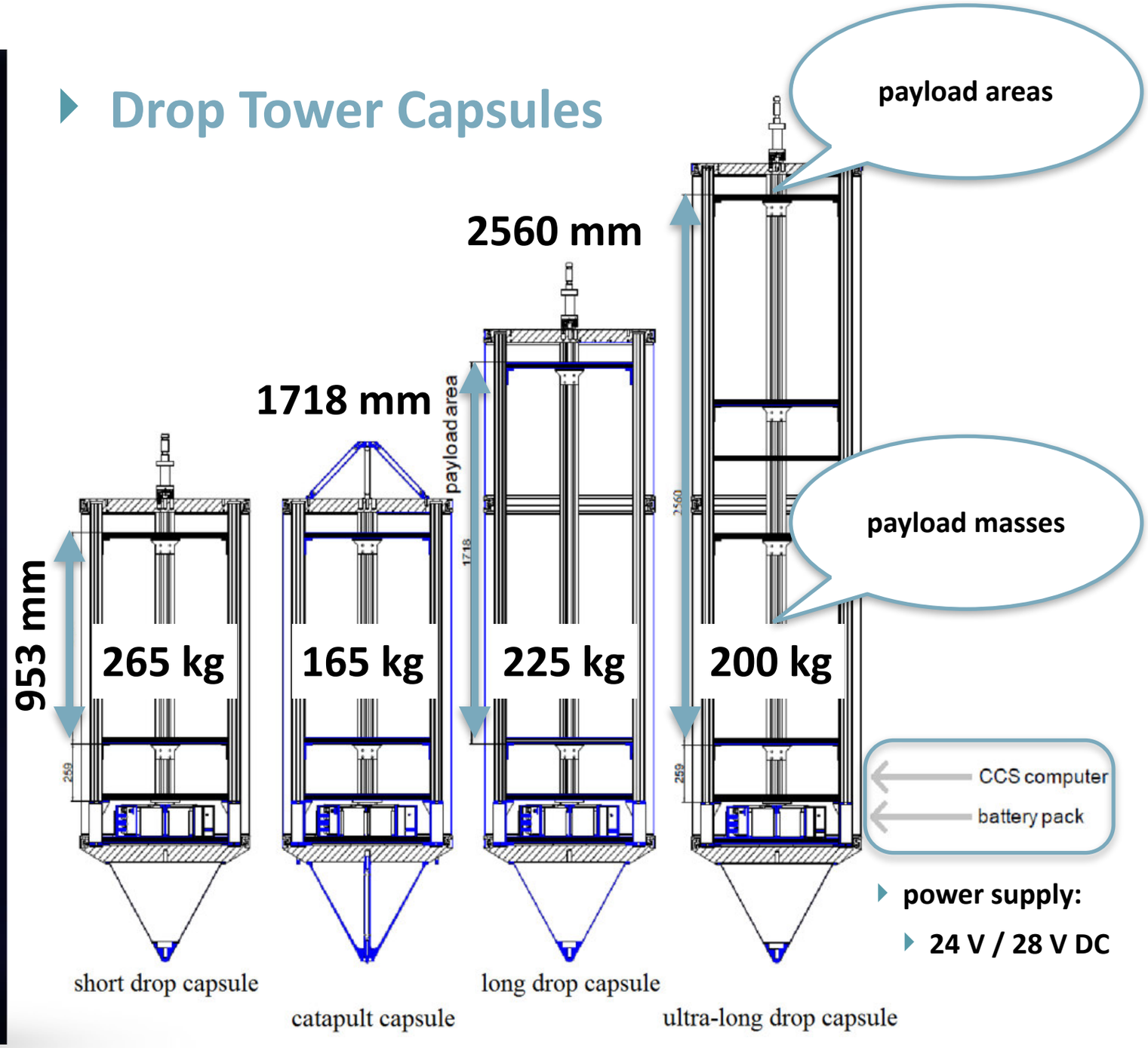
operation started in 1990



- drop mode:
  - 4.74 s in weightlessness
  - highest quality - 10^{-6} g (µg)
  - decelerations of up to 50 g
- catapult mode:
  - worldwide unique system
  - 9.3 s in weightlessness
  - highest quality - 10^{-6} g (µg)
  - accelerations of up to 30 g
  - decelerations of up to 50 g
- daily operations (up to 3 times)
- on-site technical support

The Bremen Drop Tower - Equipment

- Drop Tower Capsules



- power supply:
  - 24 V / 28 V DC

The Bremen Drop Tower - Operation

The Bremen Drop Tower - Operation

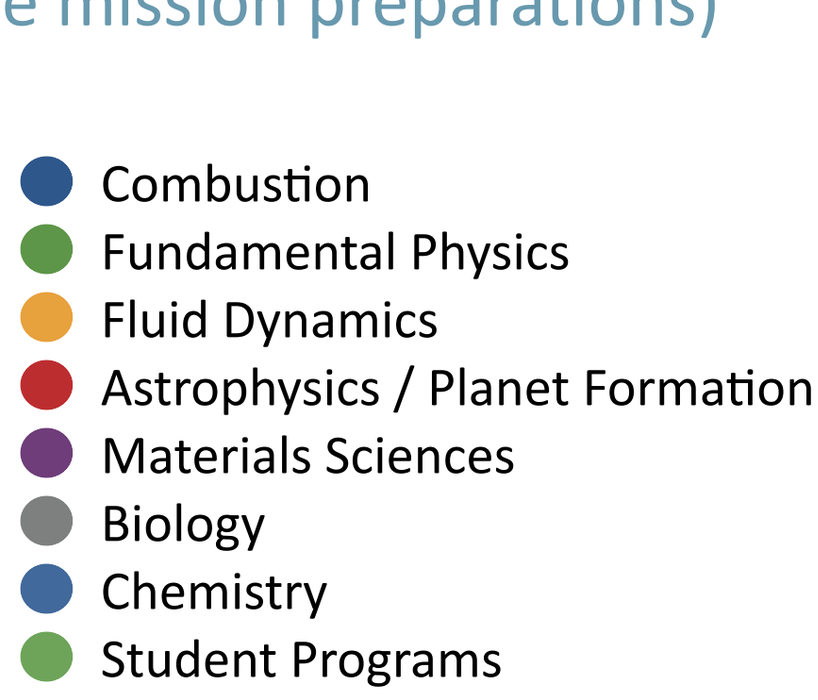
ZENTRUM FÜR
ANGEWANDTE RAUMFAHRTTECHNOLOGIE
UND MIKROGRAVITATION

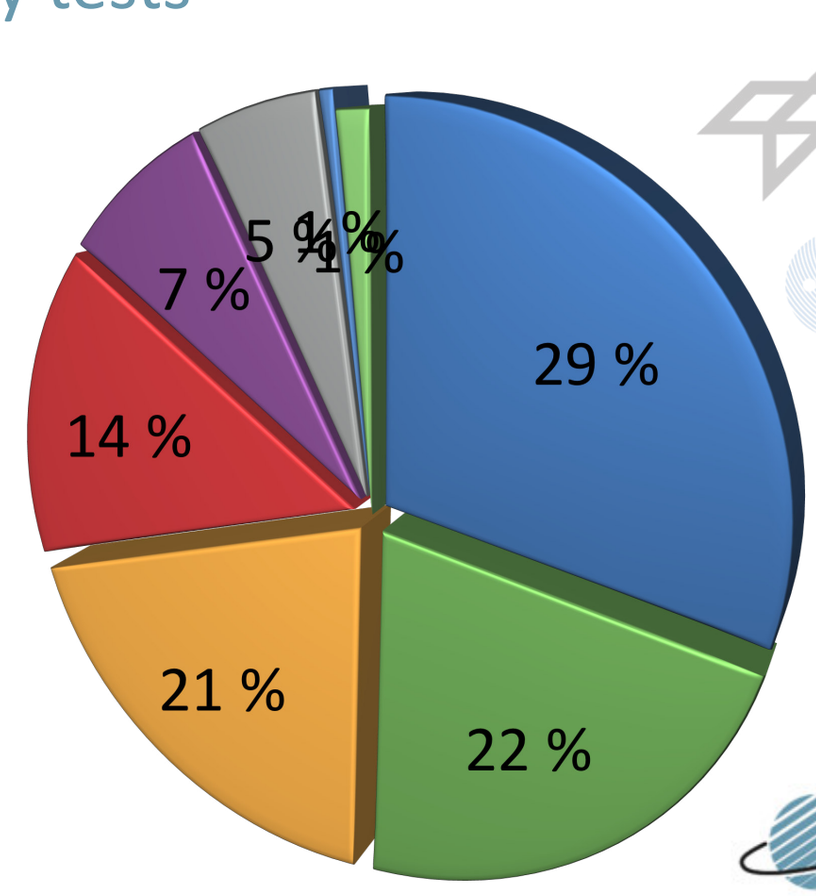
ZARM

ZARM

The Bremen Drop Tower - Facts and Figures

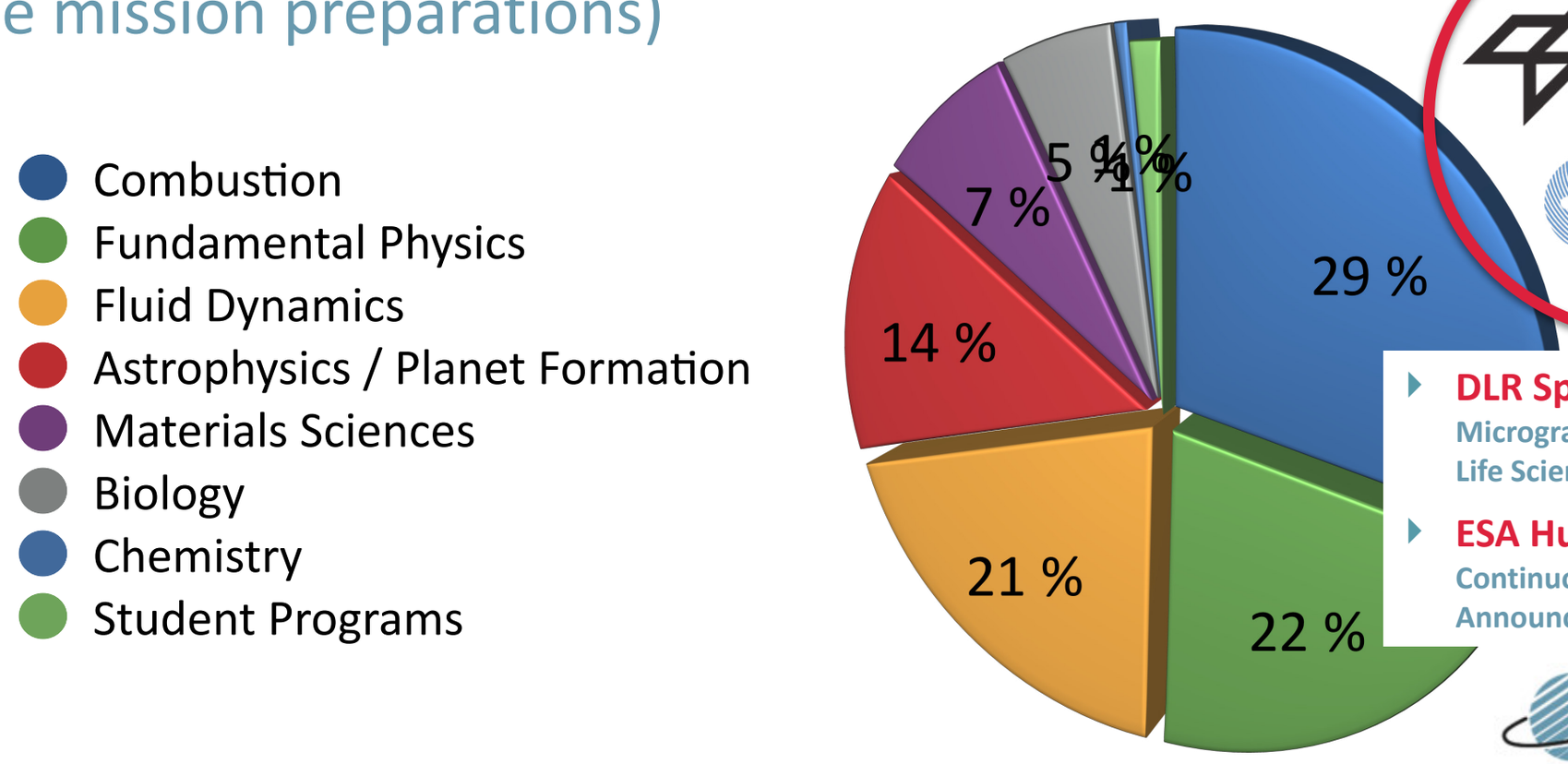
- Since the Start of Operation in 1990
  - over 8300 drops / catapult launches have been conducted
  - more than 200 different experiment types have been integrated
  - within international collaborations from over 40 countries
- Research Fields of Drop Tower Experiments
  - fundamental research / technology tests (space mission preparations)





The Bremen Drop Tower - Facts and Figures

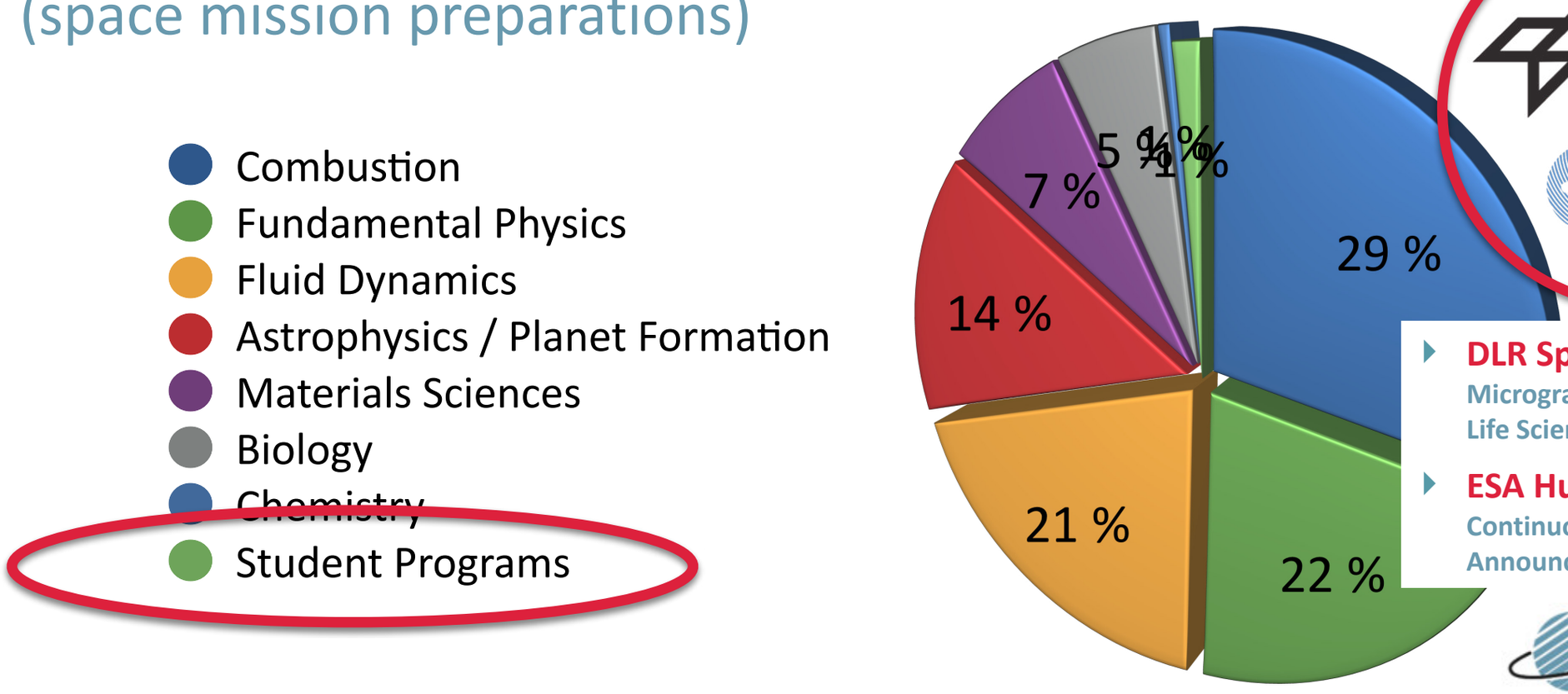
- Since the Start of Operation in 1990
  - over 8300 drops / catapult launches have been conducted
  - more than 200 different experiment types have been integrated
  - within international collaborations from over 40 countries
- Research Fields of Drop Tower Experiments
  - fundamental research / technology tests (space mission preparations)



- **DLR Space Administration:** Microgravity Research and Life Sciences Program
- **ESA Human Spaceflight:** Continuously Open Research Announcement (CORA)

The Bremen Drop Tower - Facts and Figures

- Since the Start of Operation in 1990
  - over 8300 drops / catapult launches have been conducted
  - more than 200 different experiment types have been integrated
  - within international collaborations from over 40 countries
- Research Fields of Drop Tower Experiments
  - fundamental research / technology tests (space mission preparations)



- **DLR Space Administration:** Microgravity Research and Life Sciences Program
- **ESA Human Spaceflight:** Continuously Open Research Announcement (CORA)

Student Programs at ZARM

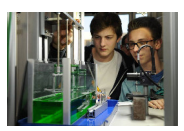
Support of Young Scientists

ZARM - Center of Applied Space Technology and Microgravity

c/o Universität Bremen
Am Fallturm 2, 28359 Bremen, Germany
www.zarm.uni-bremen.de

ZARM

DroPS - ZARM -



Drop Tower Project for School Students

- DLR_School_Lab -

DropTES - UNOOSA -

Drop Tower Experiment Series

UNITED NATIONS
Office for Outer Space Affairs

DLR

- Bremen Drop Tower

Drop Your Thesis! - ESA Education Office -

Drop Tower Experiment Series

drop your thesis!

esa

- Bremen Drop Tower

REXUS / BEXUS - DLR / SNSB -

Sounding Rocket and Ballon Experiment Series

DLR

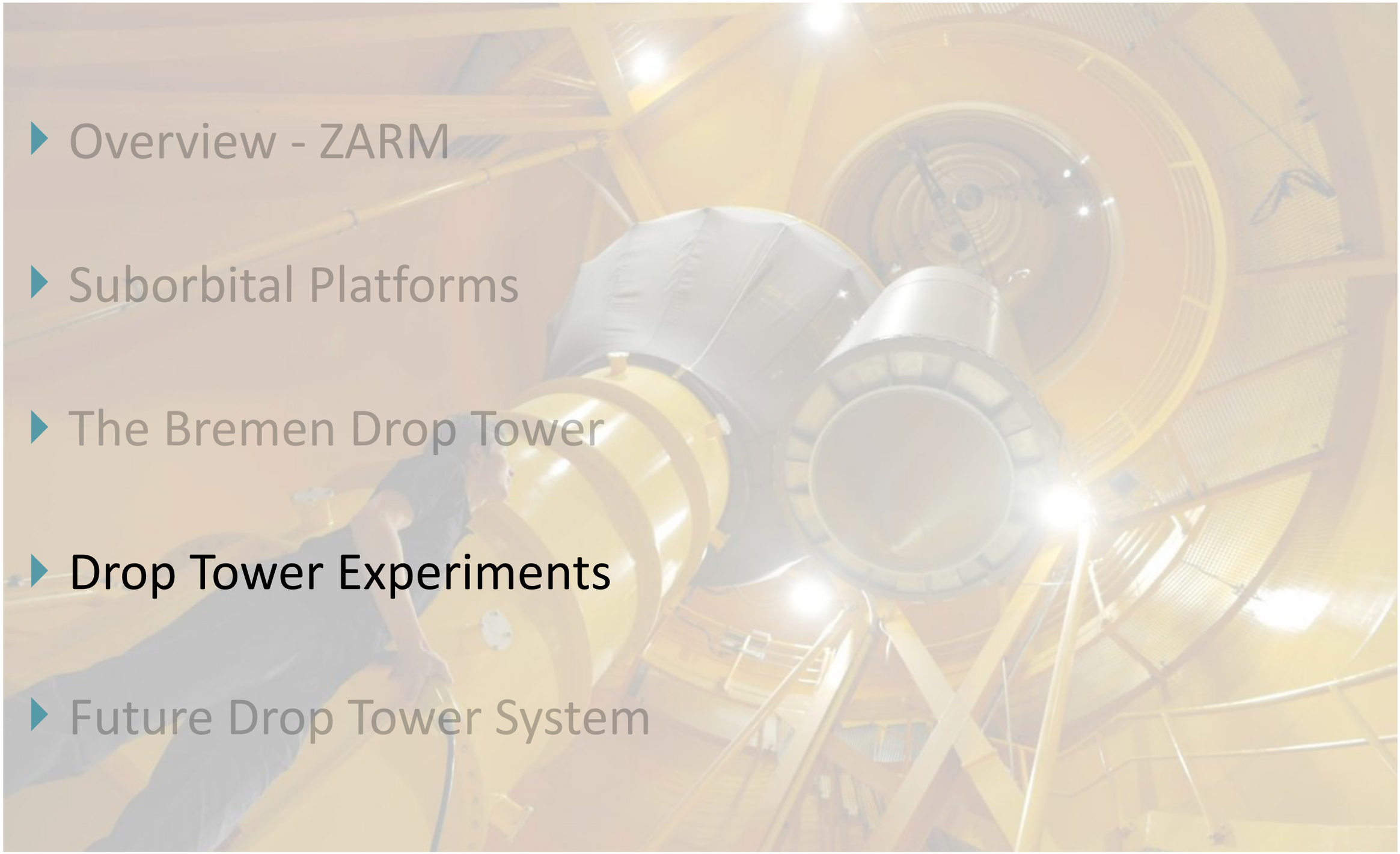
RYMDSTYRELSEN
Swedish National Space Board

- Esrange Space Center Kiruna, Sweden

Förderverein ZARM e.V.

ZARM

Content

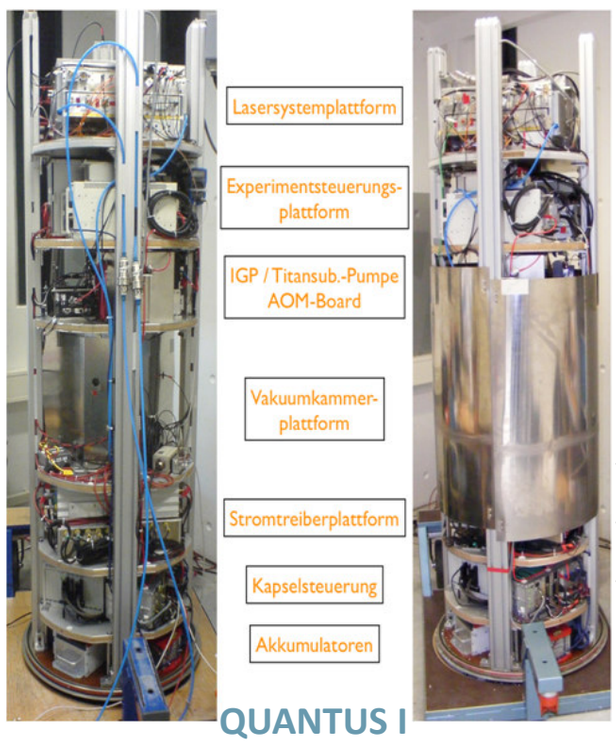


- Overview - ZARM
- Suborbital Platforms
- The Bremen Drop Tower
- Drop Tower Experiments
- Future Drop Tower System

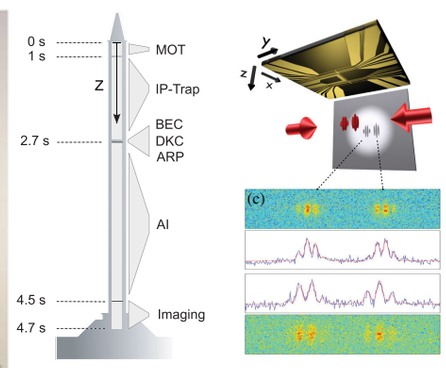
Fundamental Physics - QUANTUS I / II

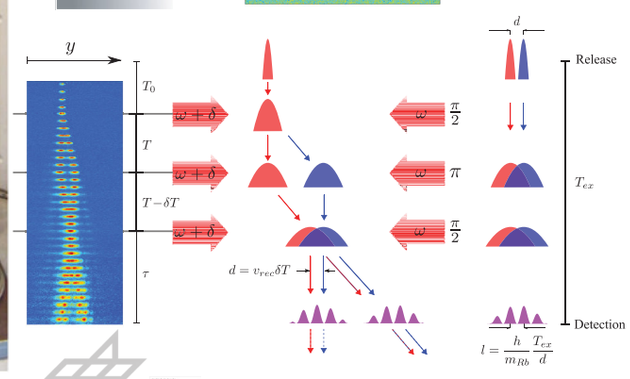
- Ultracold Macroscopic Quantum Systems in Weightlessness - Drop Tower Experiments
  - supported by DLR Space Administration
    - QUANTUS - Collaboration / U Hanover, Berlin, Bremen, Hamburg, etc.
  - Realization of first Bose-Einstein Condensates, Atom Interferometers (QUANTUS I), Dual-Spezies Atom Interferometers (QUANTUS II) in µg
    - transportable high-precision quantum sensors

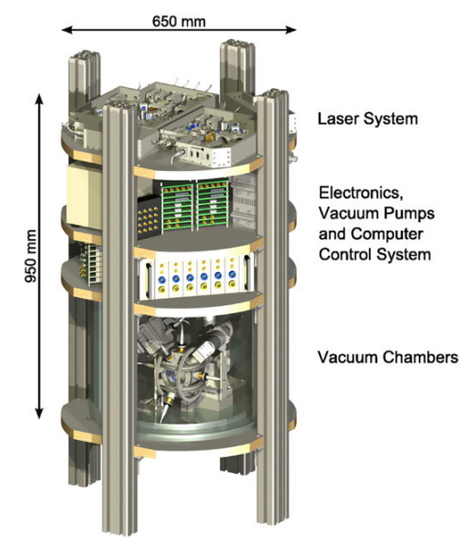
Related Publications:
- T. van Zoest et al., Science 328 (2010)
- H. Müntinga et al., Phys. Rev. Lett. 110 (2013)
- J. Rudolph et al., New J. Phys. 17 (2015)



QUANTUS I







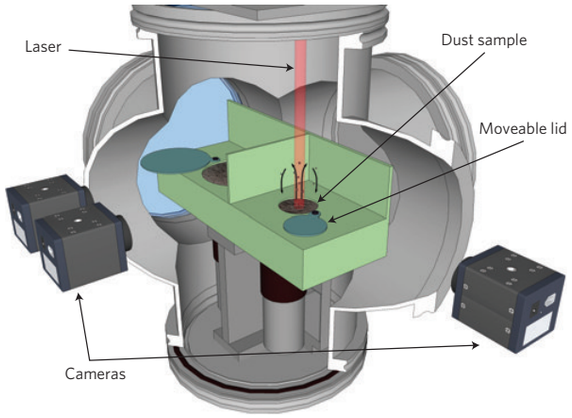
QUANTUS II
- Catapult Experiment -

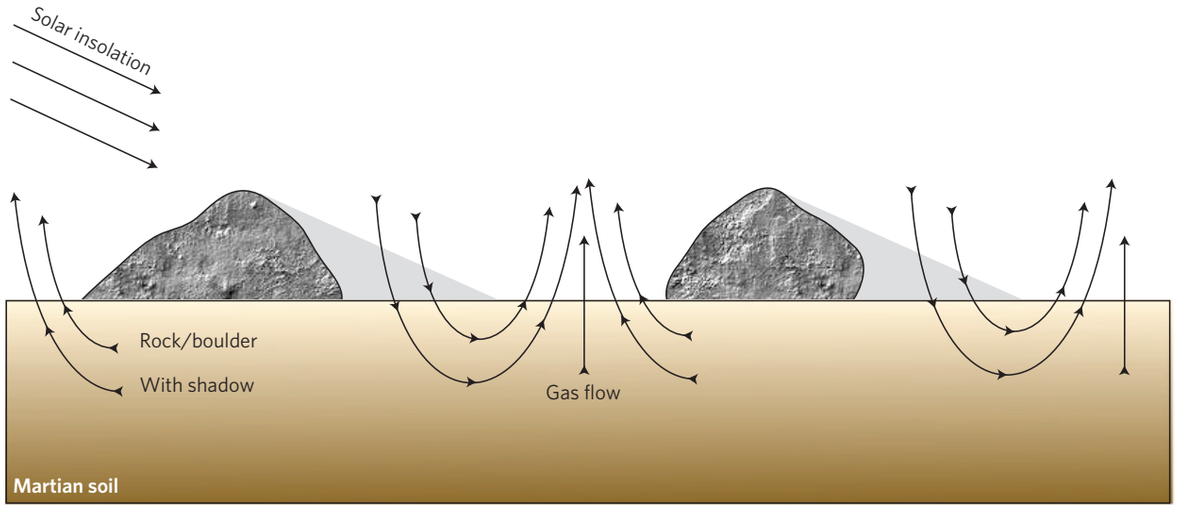
MAIUS - Sounding Rocket Experiment, 2017

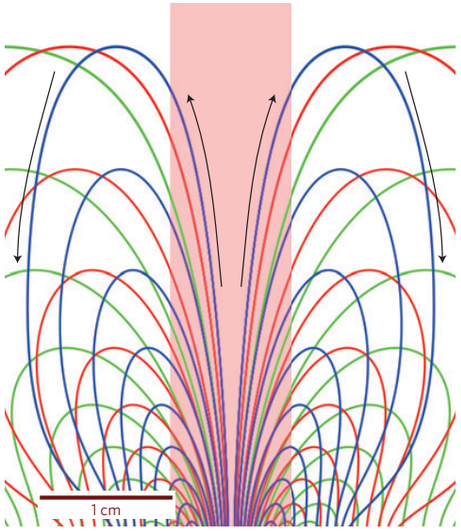
BECCAL - ISS Experiment, 2021

Astrophysics - EULE

- Experimental Investigation of Light-Induced Eruptions in Microgravity - Drop Tower Experiments
  - supported by DLR Space Administration
    - Experimental Astrophysics Group, University of Duisburg-Essen
  - Natural Transport Mechanism of Dust on Mars
    - The Martian Soil as a Planetary Gas Pump
      C. de Beule et al., Nature Physics, 10 (2014)





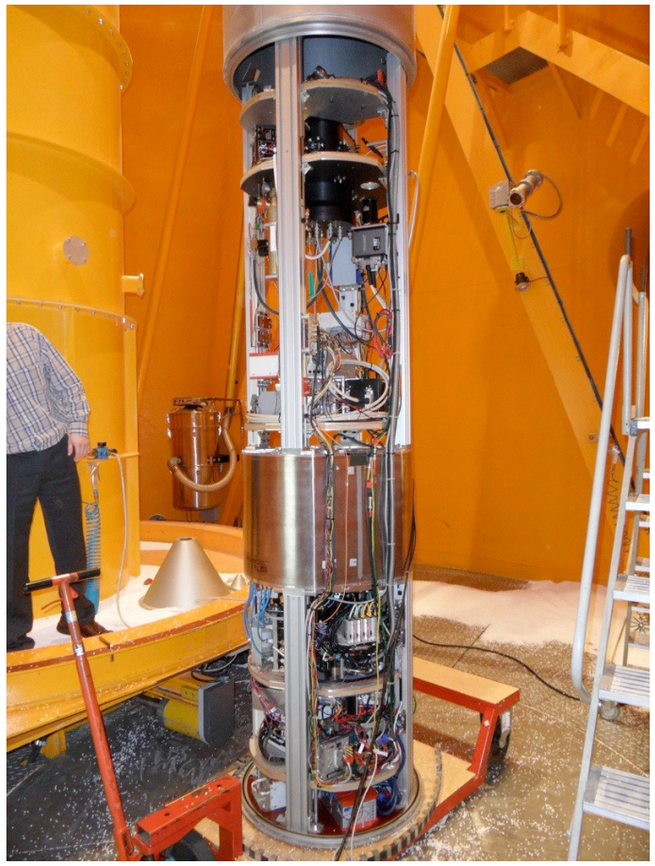


EULE
- Catapult Experiment -

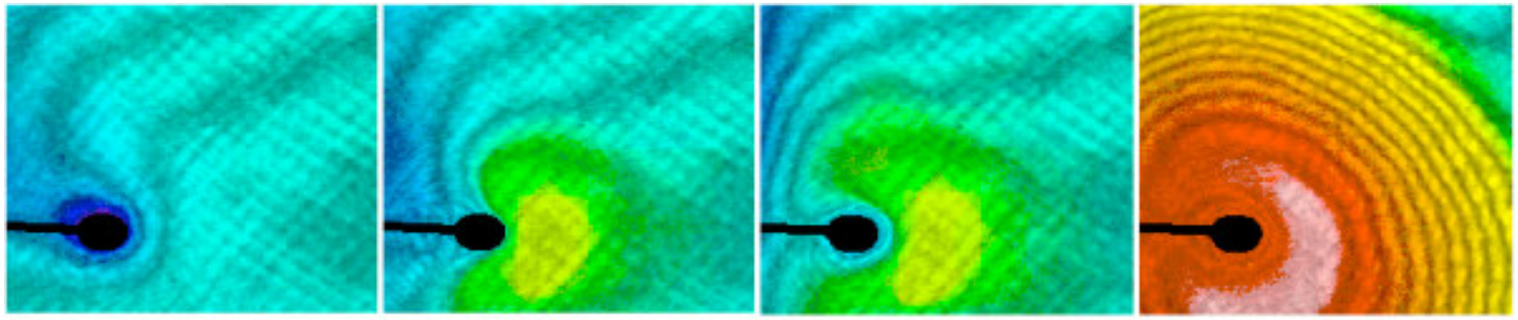
Combustion - DDI-ADL

- Investigation of Droplet-Droplet Interaction utilizing the Advanced Disc Laser - Drop Tower Experiments
  - supported by DLR Space Administration
    - Combustion Engineering Group, ZARM - University of Bremen
  - Lowering the Emissivity of harmful Nitric Oxides
    - for future gas-turbines of the aero-propulsion type and electric power generators
    - experimental data for numerical simulations

Ultra-Long Drop Capsule



Laser-Induced Fluorescence Spectroscopy (ADL)



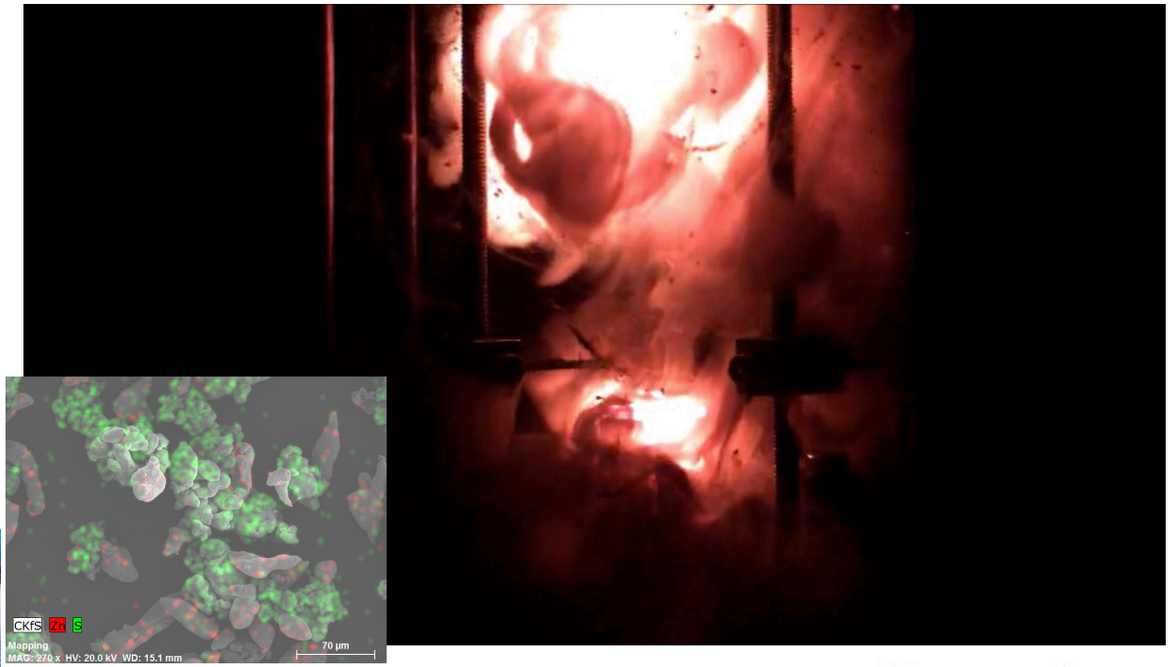
Droplet vaporization | Cool-flame ignition | Cool-flame burning | Hot ignition

Materials Sciences - diZplay

- Advanced Processing of Zinc Sulfide (ZnS) Materials to be Implemented into Displays - Drop Tower Experiments
  - supported by DLR Space Administration, INNOspace Initiative
    - Materials Sciences Group, ZARM - University of Bremen
  - New Energy Efficient Light Emitting Devices (Electroluminescence)

Screen Technology	Power Requirements	Robustness	Production Cost
Liquid-crystal displays (LCD) cathode fluorescent lamp (CCFL) backlight	High	Low	Low
Liquid-crystal displays (LCD) light-emitting diode (LED) backlight	High	Low	Low
Organic light-emitting diode (OLED)	High	Low	Moderate
Plasma Screen	Very High	High	Very High
Liquid-crystal displays (LCD) electroluminescent (EL) backlight	Very Low	High	Low

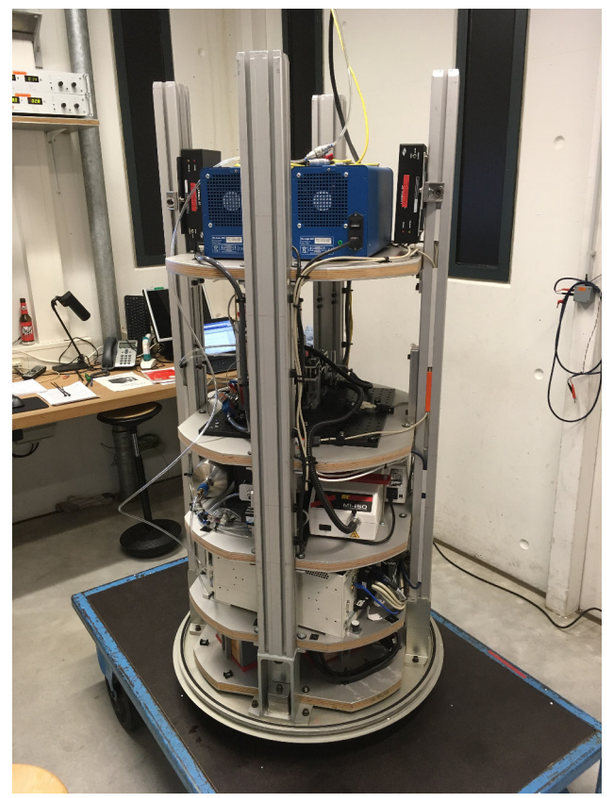
- Self-Propagating High-Temperature Synthesis (SHS) - Methode in µg

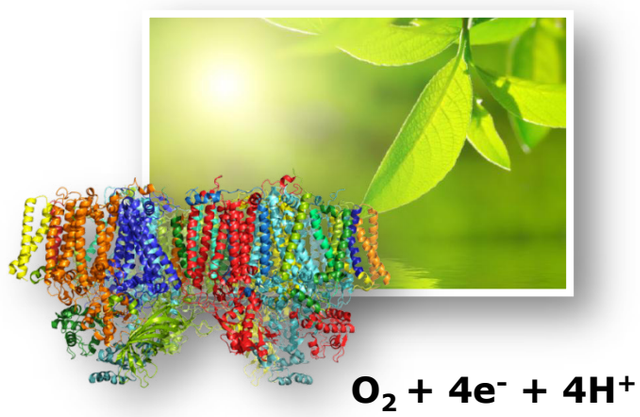


Chemistry - PhotoEChem

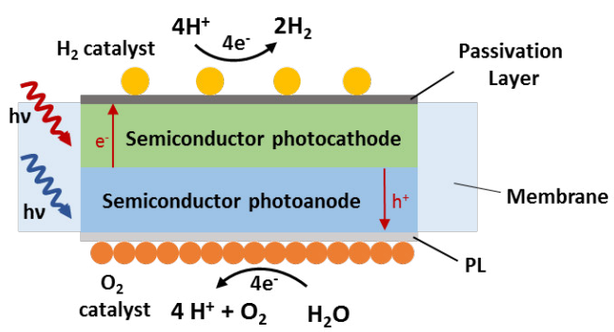
- Photoelectrochemical Water Splitting and Hydrogen Generation in µg Environments - Drop Tower Experiments
  - supported by ESA Human Spaceflight and Exploration
    - European Space Agency, Advanced Concepts Team, ESTEC
  - Realization of an Efficient Artificial Photosynthesis in Space
    - for future life support systems on space missions or in habitats (Moon / Mars) - Oxygen / Hydrogen

K. Brinkert et al., Nature Comm. 9, (2018)





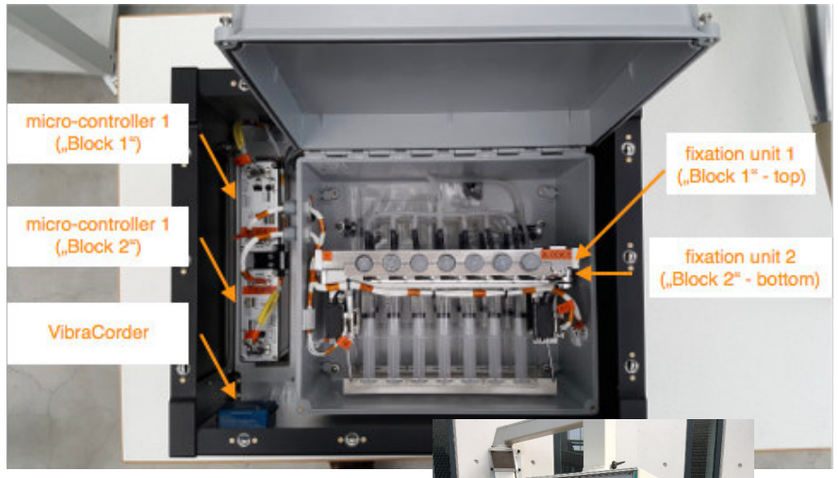
From the Nature…

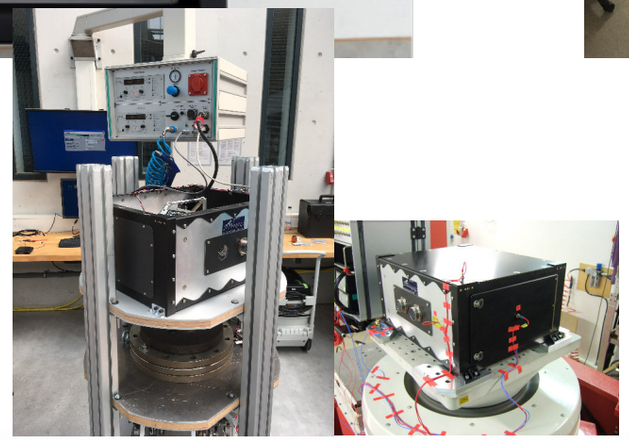


… to an Art

Biology - Daphnia (Mission Preparation)

- Investigation of the Impact of Microgravity on Gene Expression and the Cytoskeleton in Daphnia (Water Fleas) - Drop Tower Experiments / Suborbital Flight Experiment
  - supported by DLR Space Administration
    - Animal Ecology I, University of Bayreuth
  - Daphnia as a Model Organism Candidate for Space Missions





Experiment Preparation
(Bremen Drop Tower + ZARM Test Center)

launched
on April 29, 2018

„New Shepard"

approx. 100 km

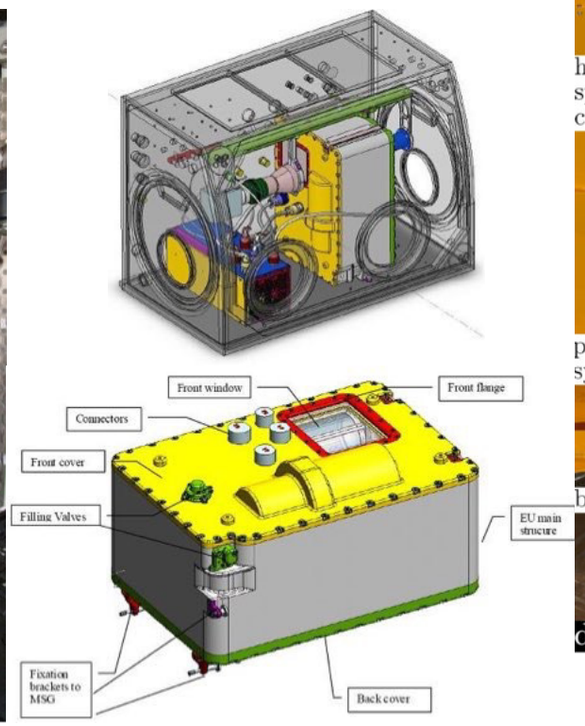
Fluid Dynamics - CCF (Mission Preparation)

- Capillary Channel Flow - Experiment onboard ISS
  - US - German Partnership ISS Mission by NASA / DLR
    - ZARM - University of Bremen / Portland State University
  - Mission Overview (launched in April 2010 / installed in Dec. 2010 / re-installed in Sep. 2011 - EU#1 and EU#2 with different geometries)
    - investigation of capillary flows in the absence of gravity
    - finding new ways to move liquids in space

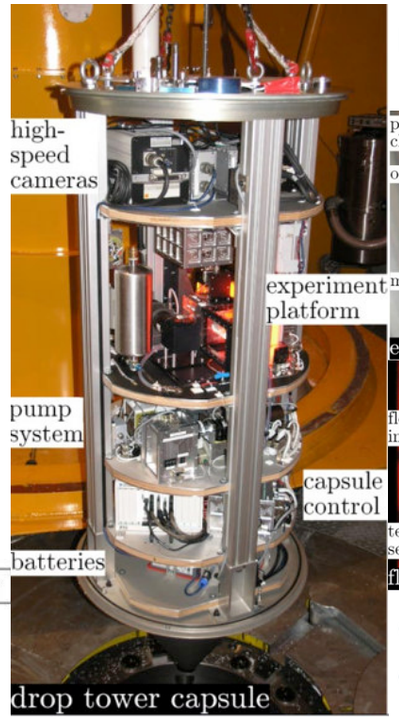
Parabolic Flight Missions

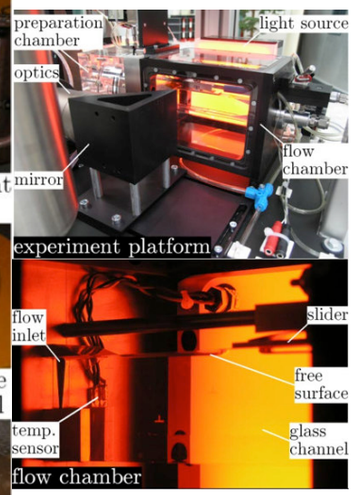
Sounding Rocket Missions:
- CCF on TEXUS 37 (2000)
- CCF on TEXUS 41 (2004)
- CCF on TEXUS 42 (2005)

NASA



Drop Tower Experiments

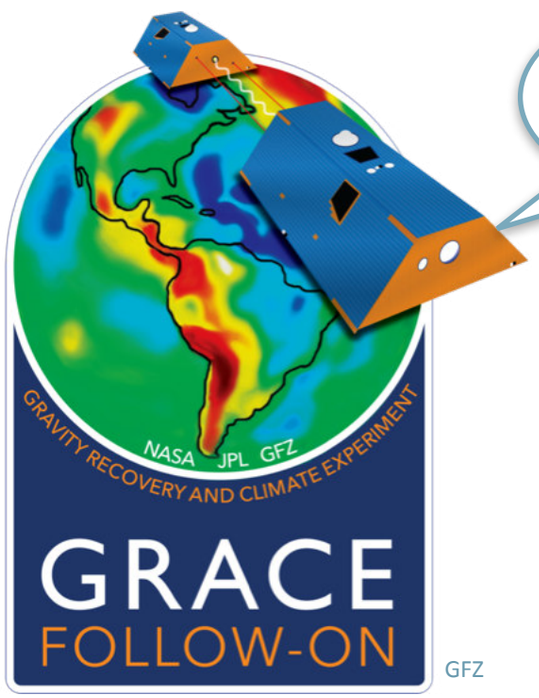




e.g. Microgravity Tests of Channel Geometries

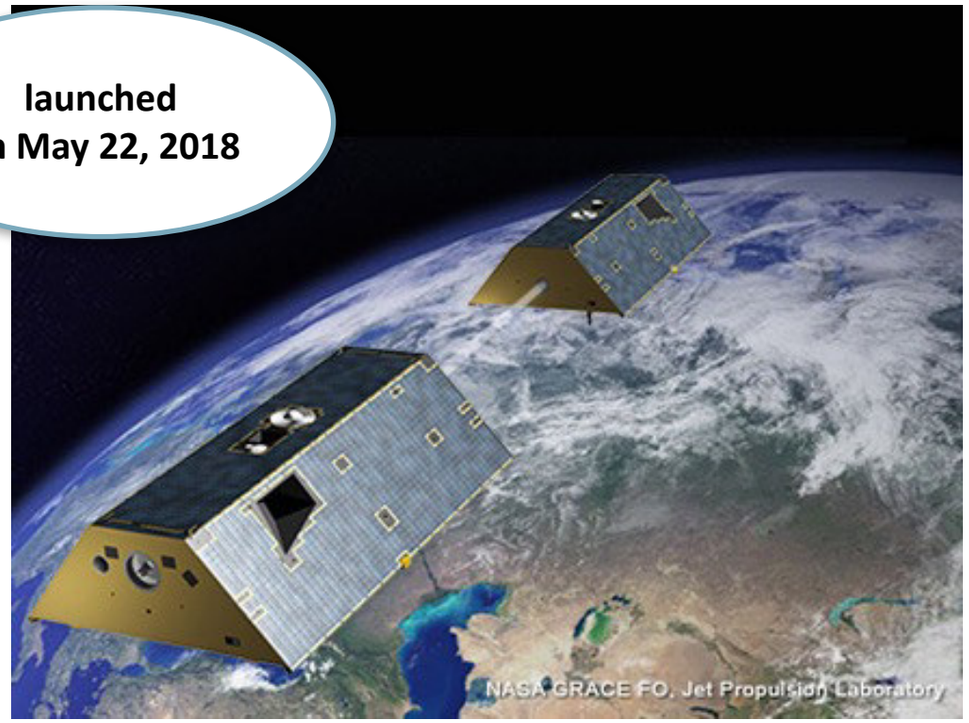
Preparation of Space Missions - GRACE-FO

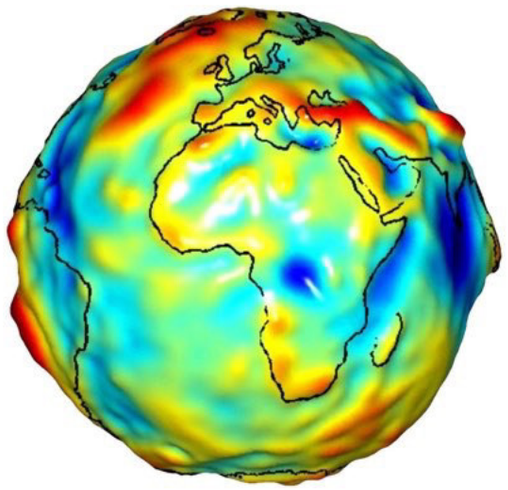
- Gravity Recovery and Climate Experiment Follow-On
  - US - German Partnership Satellite Mission by
    - NASA/JPL and the German Research Center for Geosciences (GFZ) (Center for Space Research (CSR) / University of Texas, DLR, …)
  - Mission Overview (Successor of GRACE - launched in March 2002)
    - measuring variations in gravity over Earth's surface
    - generating a new map of the gravity field every 30 days



GFZ

launched
on May 22, 2018

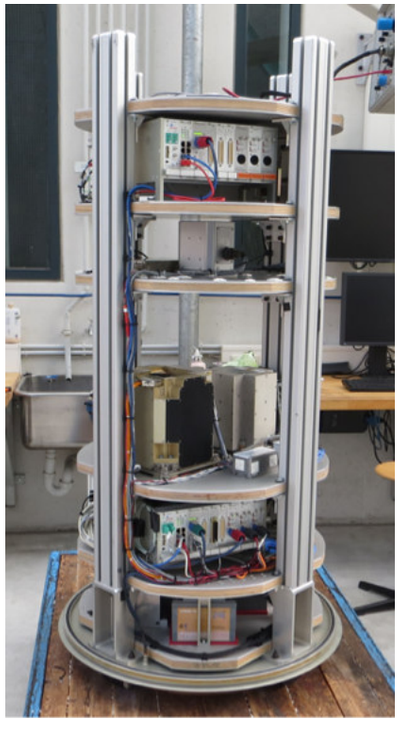


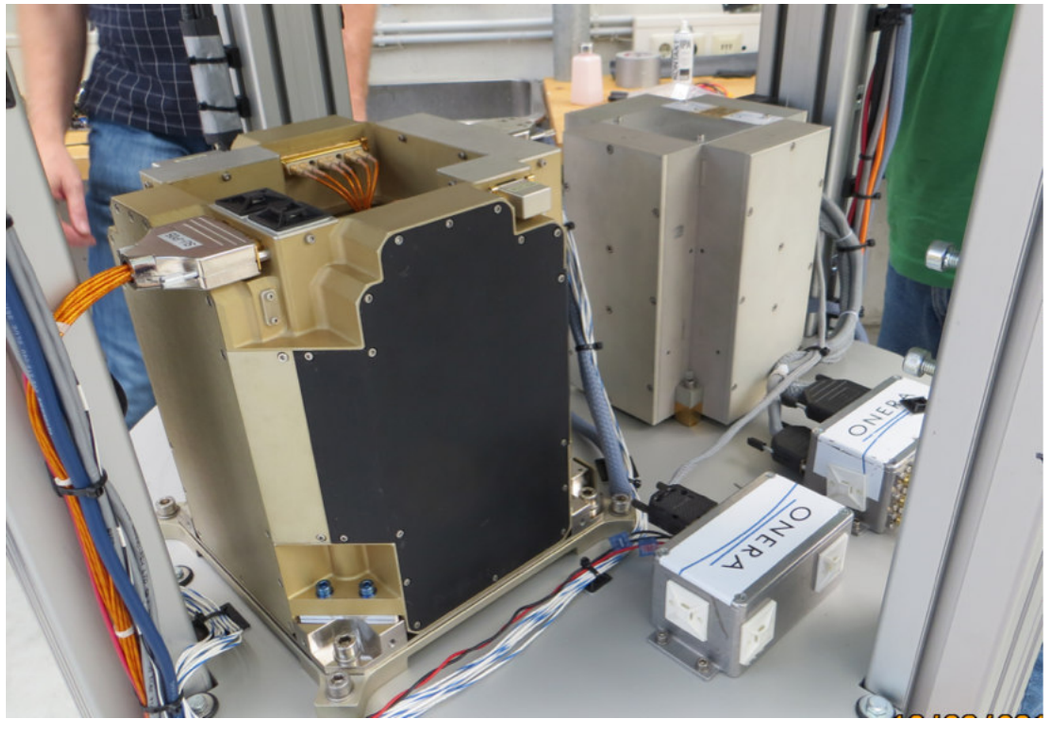


NASA GRACE, Jet Propulsion Laboratory

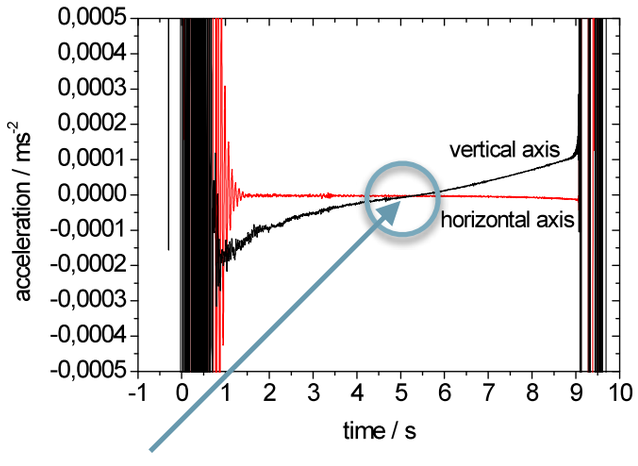
Preparation of Space Missions - GRACE-FO

- Gravity Recovery and Climate Experiment Follow-On
  - Mission Preparation at the Bremen Drop Tower
    - GRACE-FO - scientific instrument: accelerometers by ONERA (Office national d'études et de recherches aérospatiales)
    - performance tests of the accelerometers (EM, FM, SM) in µg with ZARM's catapult system as part of the qualification process
    - determining bias values for the test mass positioning





H. Selig et al., Microgravity Sci. Technol. (2010)



turning point of catapult capsule

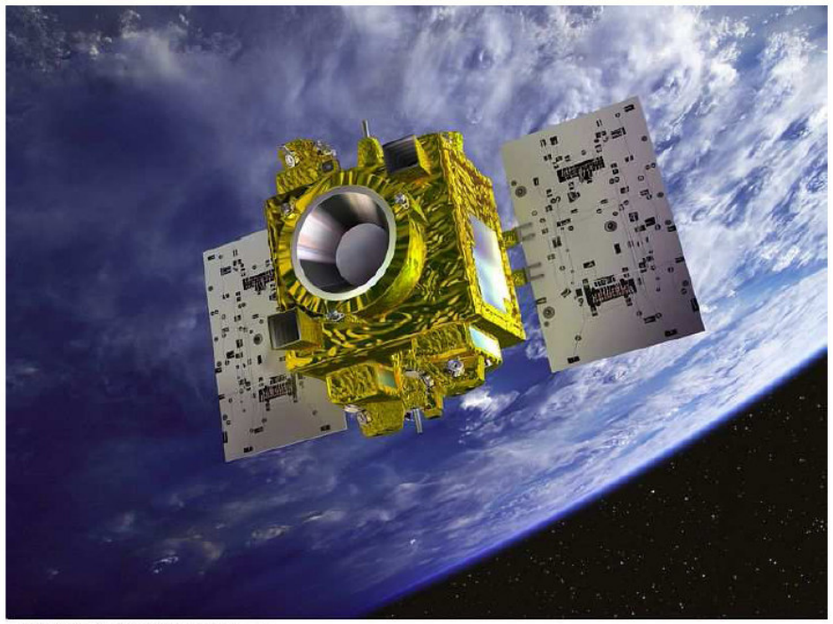
- v = 0 / a = 0

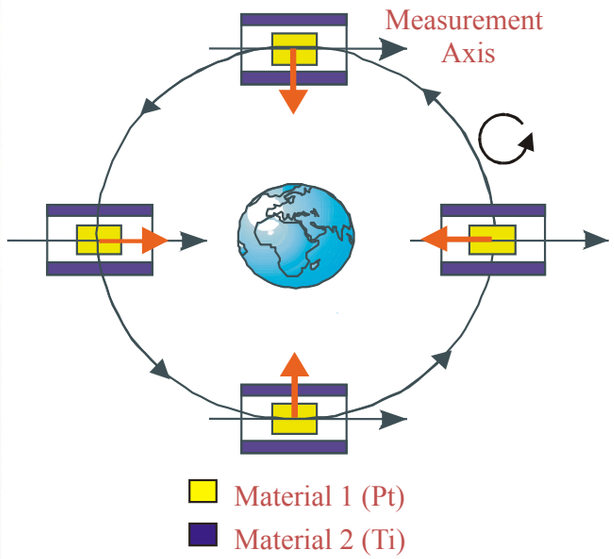
Preparation of Space Missions - MICROSCOPE

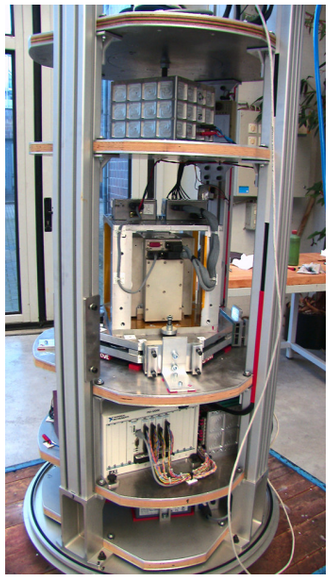
- Gravity-Research Micro-Satellite Mission
  (Micro-Satellite à traînée Compensée pour l'Observation du Principe d'Equivalence)
  - French Satellite Mission by CNES / in Cooperation with ESA
    - in Cooperation with ONERA, the Observatoire de la Côte d'Azur (OCA), ZARM, and the National Metrology Institute of Germany (PTB)
  - Mission Overview (launched in April 2016)
    - testing the Weak Equivalence Principle down to an accuracy of 10^{-15}

First Results - P. Touboul et al., Phys. Rev. Lett. 119, 231101 (2017)

CNES


© CNES - Avril 2009/Illust. D. Ducros





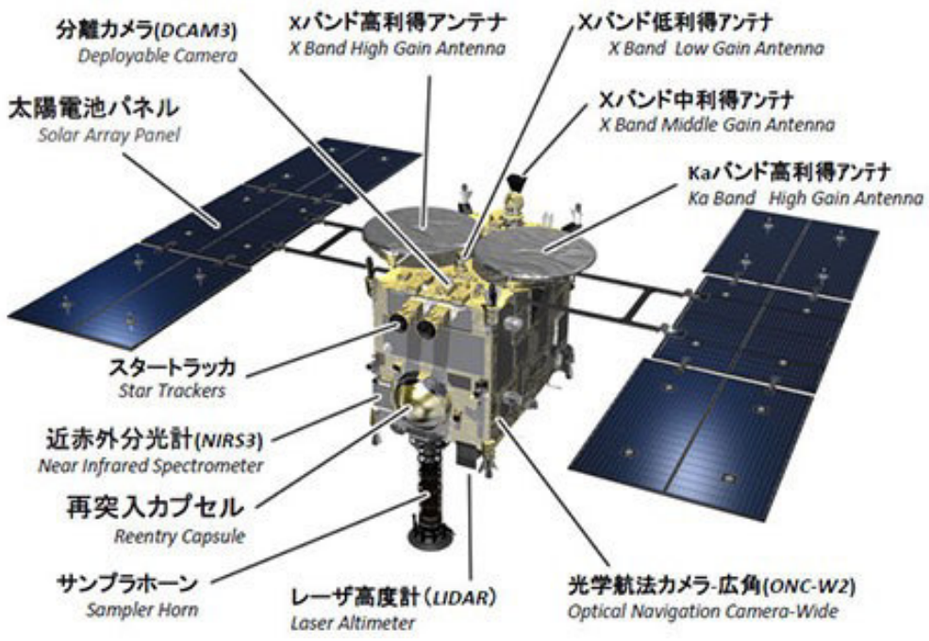
ZARM

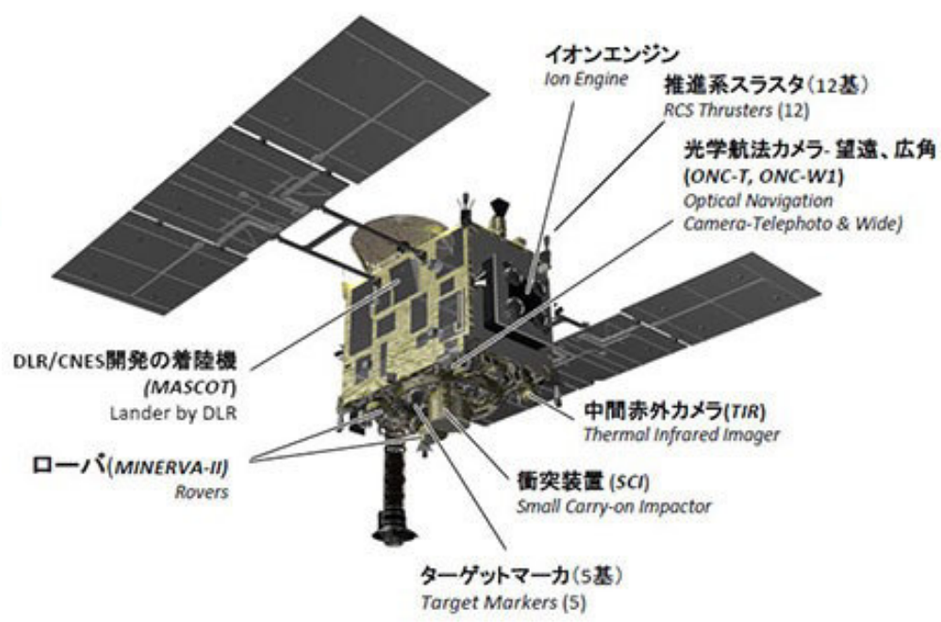
Preparation of Space Missions - Hayabusa 2

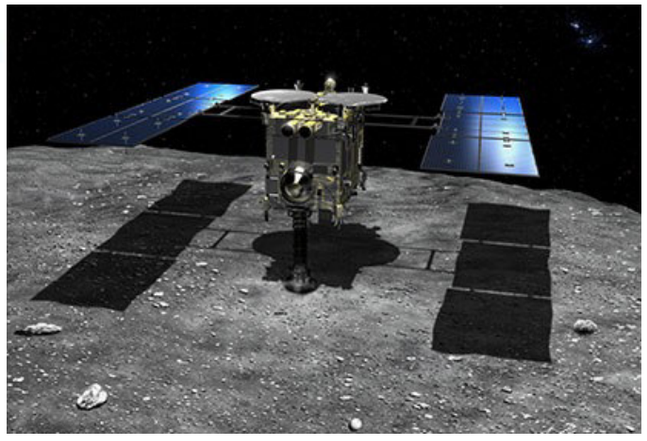
Peregrine Falcon

- Asteroid Explorer Mission (Target: Asteroid Ryugu)
  - Japanese Satellite Mission by JAXA
    - in Cooperation with DLR and CNES (MASCOT - Lander)
  - Mission Overview (Successor of Hayabusa - launched in May 2003 / landed on Asteroid Itokawa in Nov. 2005 / returned in June 2010)
    - studying the origin and evolution of the solar system as well as materials for life (launched 2014 / landing 2018 / return 2020)

first return of asteroidal material back to Earth





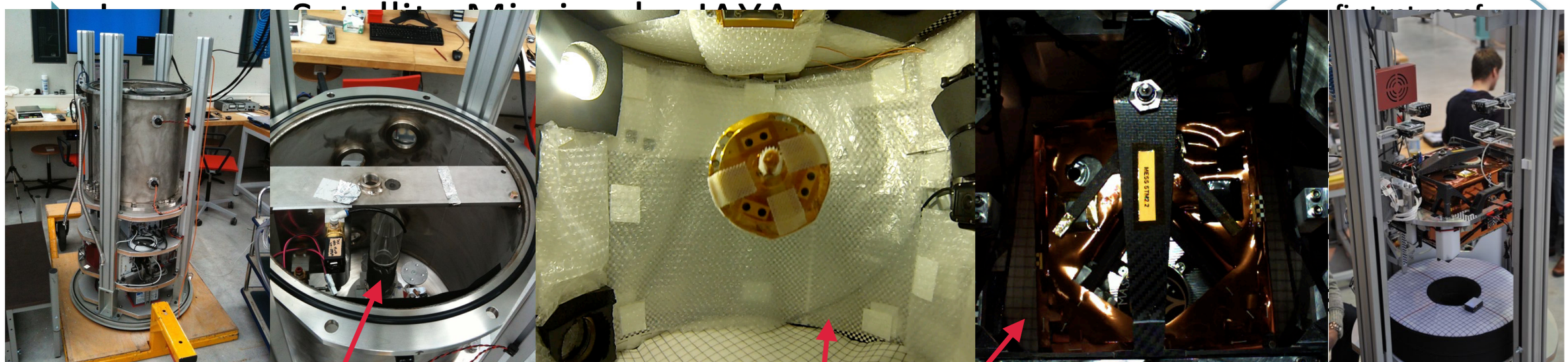


JAXA

Preparation of Space Missions - Hayabusa 2

Peregrine Falcon

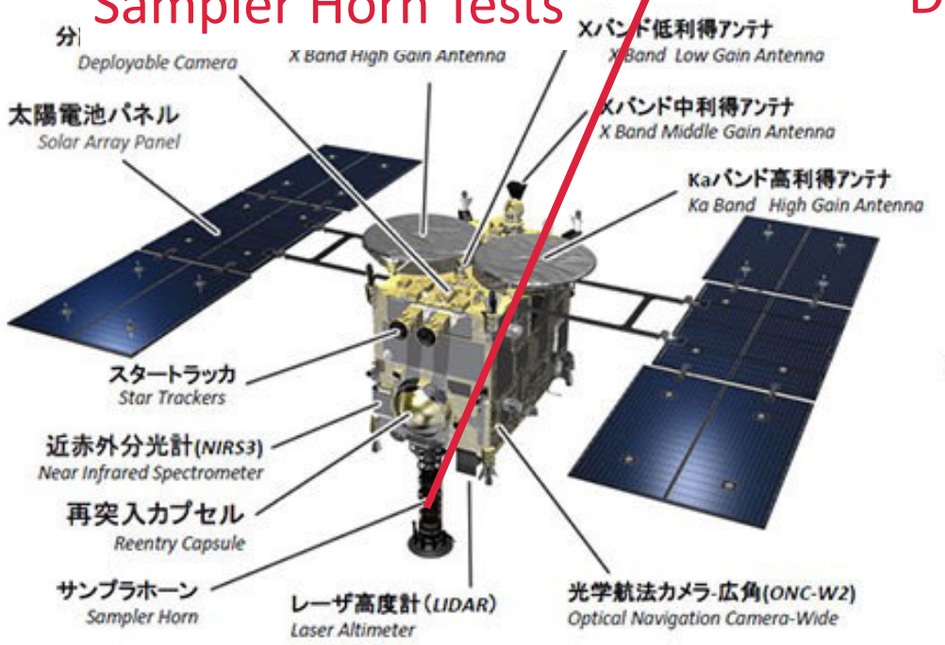
- Asteroid Explorer Mission (Target: Asteroid Ryugu)

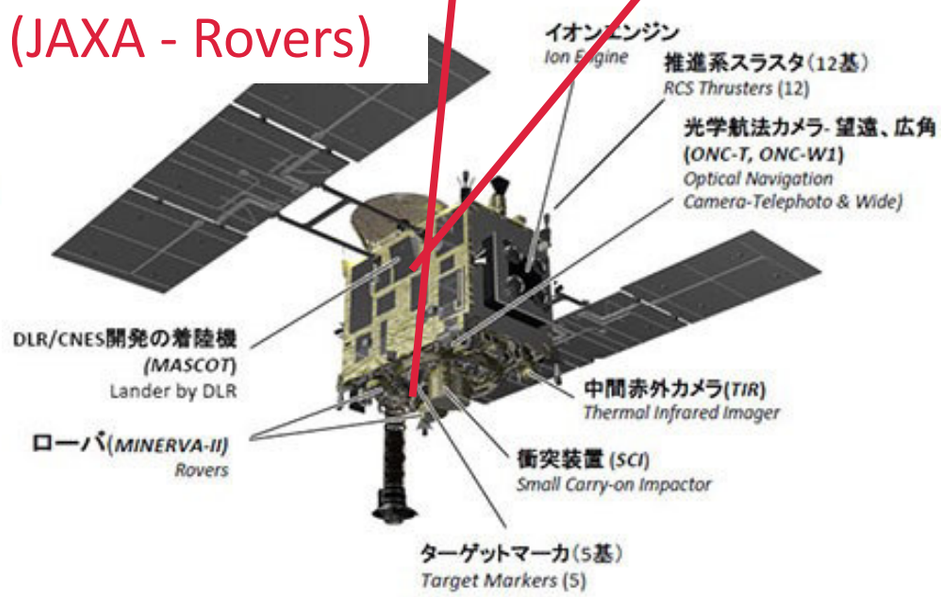


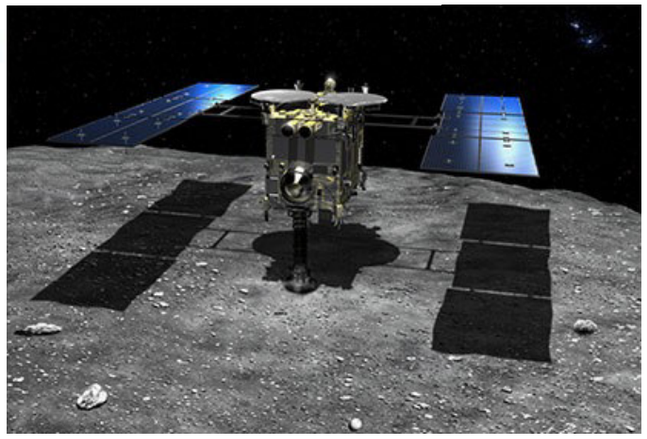
Sampler Horn Tests

Deployment Tests (JAXA - Rovers)

Separation Tests (DLR - Lander)

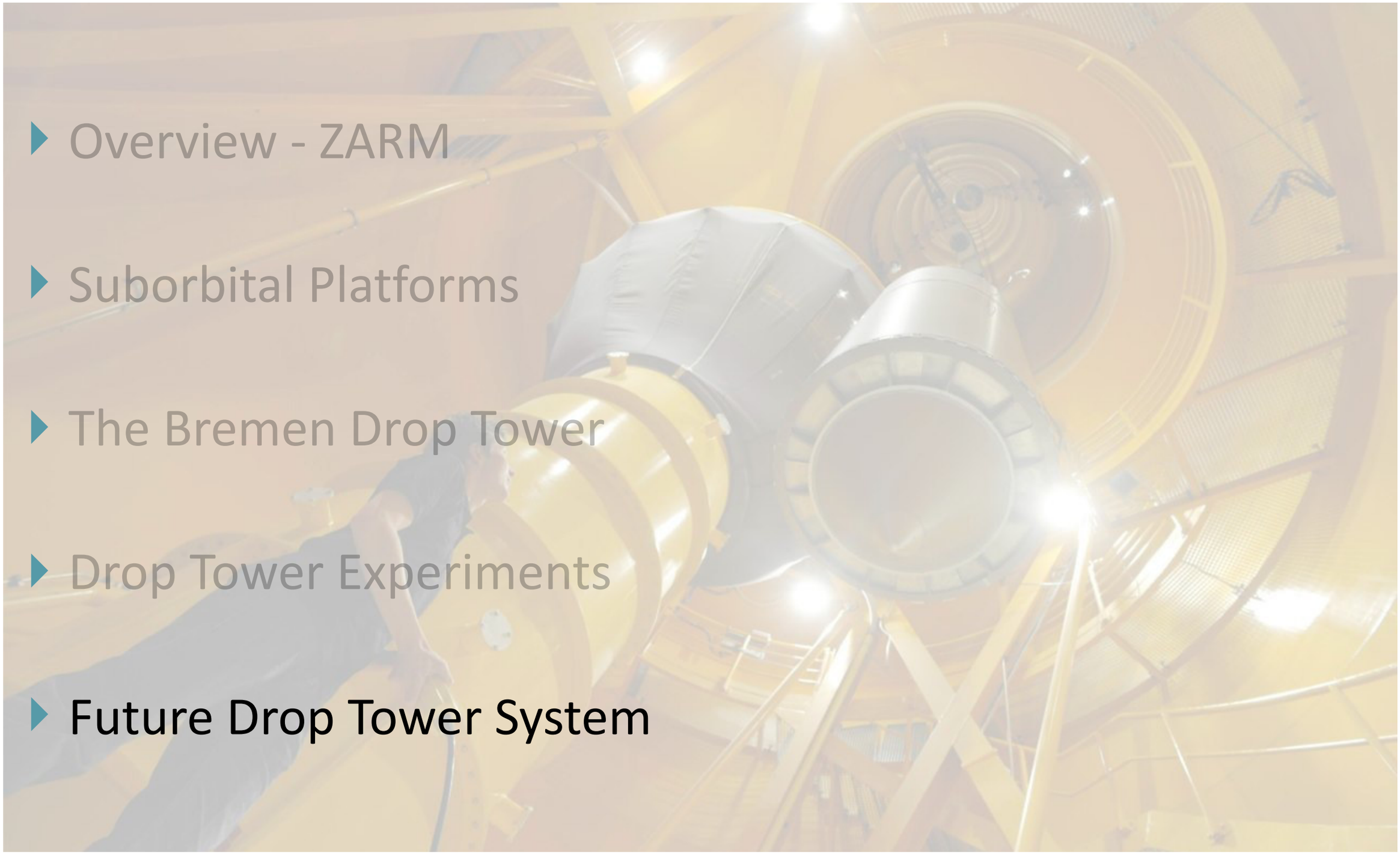






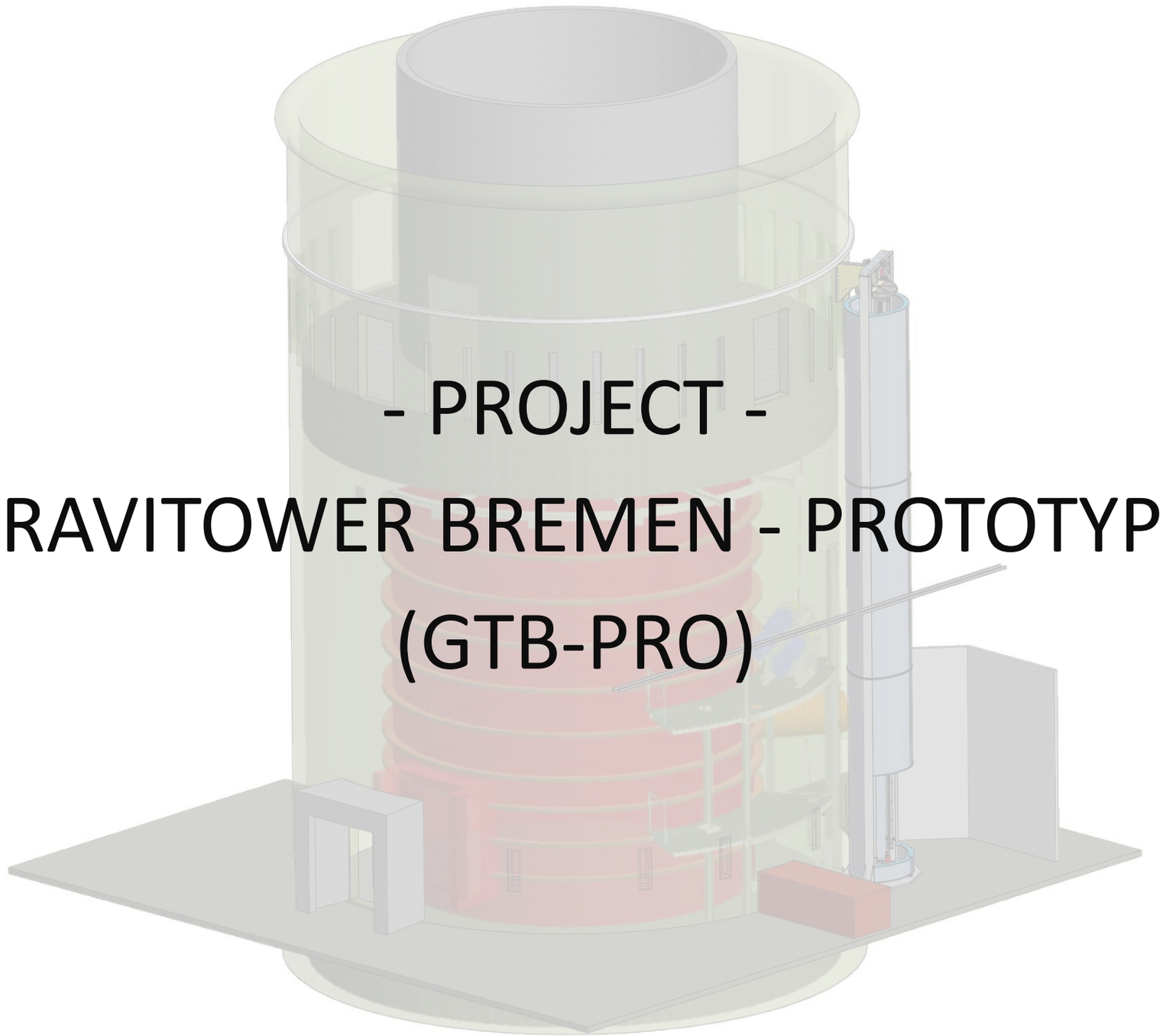
JAXA

Content



- Overview - ZARM
- Suborbital Platforms
- The Bremen Drop Tower
- Drop Tower Experiments
- Future Drop Tower System

FUTURE DROP TOWER SYSTEM



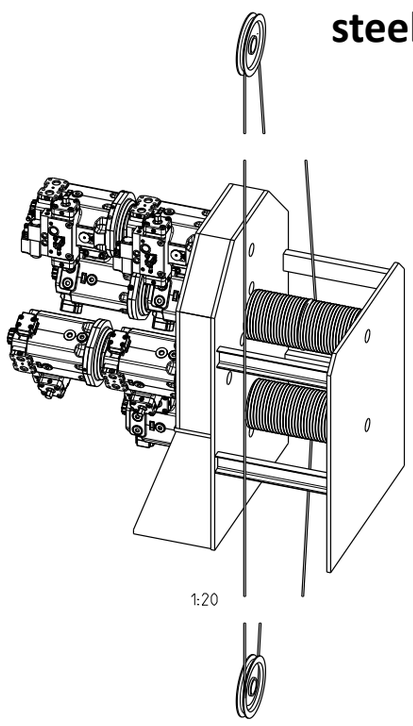
- PROJECT -

GRAVITOWER BREMEN - PROTOTYPE

(GTB-PRO)

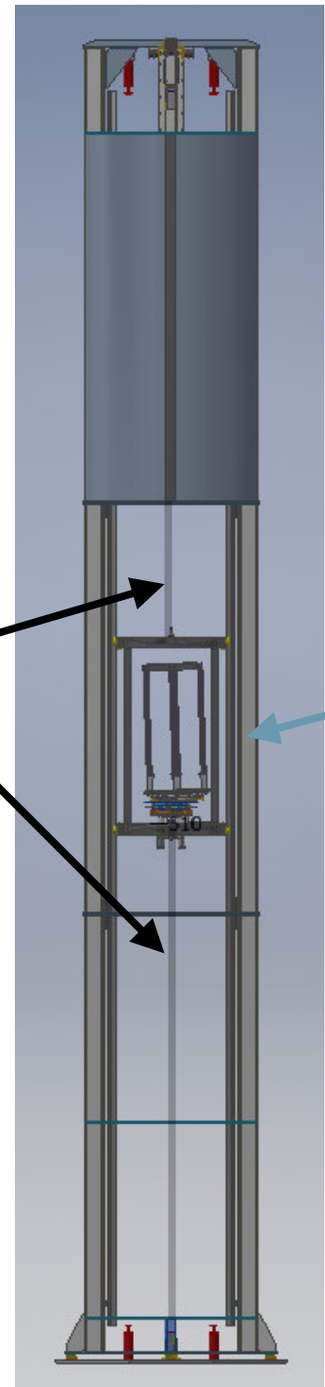
GraviTower Bremen - Prototype

- over 100 µg-experiments per day
- „elevator system“
- without limiting factor - vacuum (capsule-in-capsule drop tower)
- active rope drive system (commercial hydraulic winches)



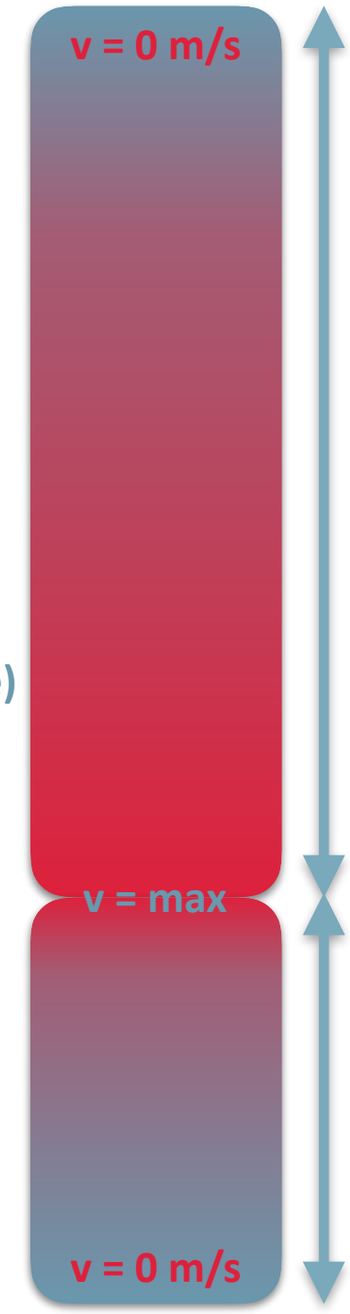
hydraulic winches

steel ropes



railing system

slider / drag shield incl. free-flyer (capsule-in-capsule)

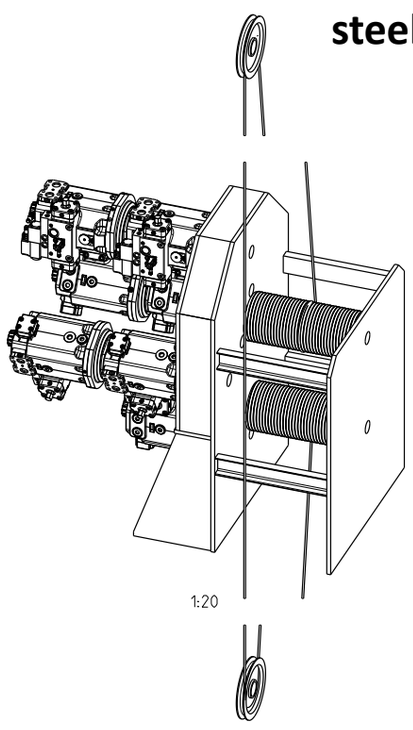


free-flyer phases

- free fall phase
- release / capture
- acc. / dec. phase

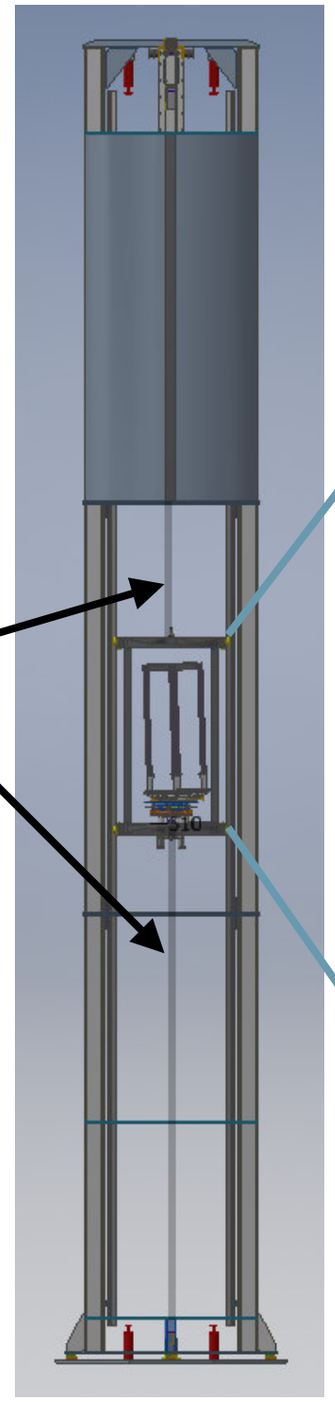
GraviTower Bremen - Prototype

- over 100 µg-experiments per day
- „elevator system“
- without limiting factor - vacuum (capsule-in-capsule drop tower)
- active rope drive system (commercial hydraulic winches)

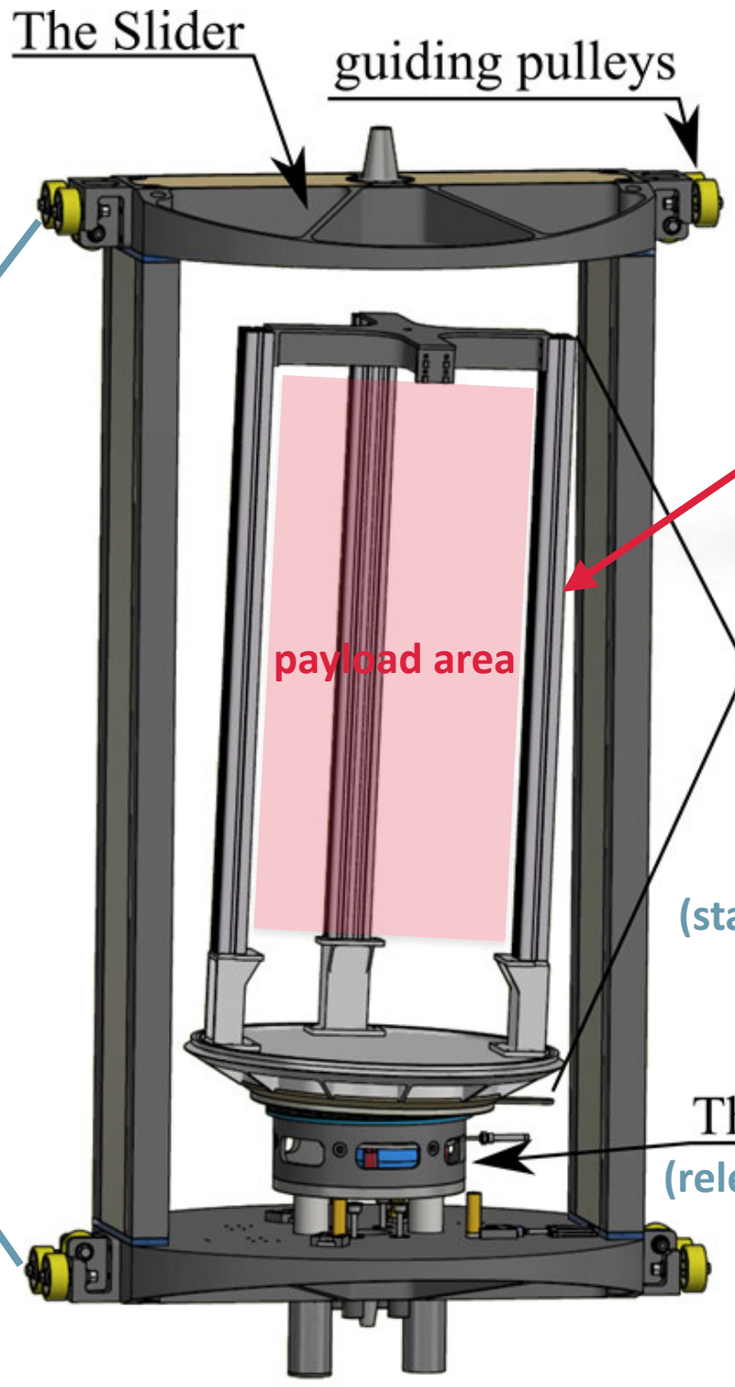


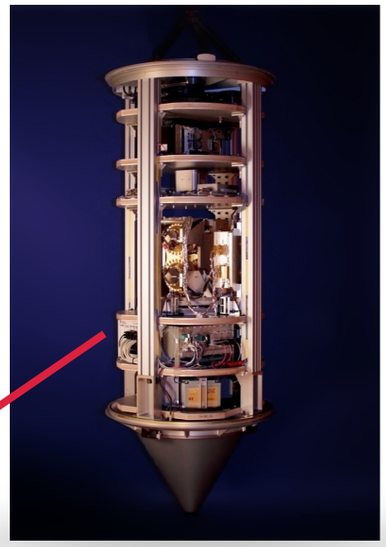
hydraulic winches

steel ropes



railing system





The Free-Flyer
shown with:
maximum tilt
maximum translation

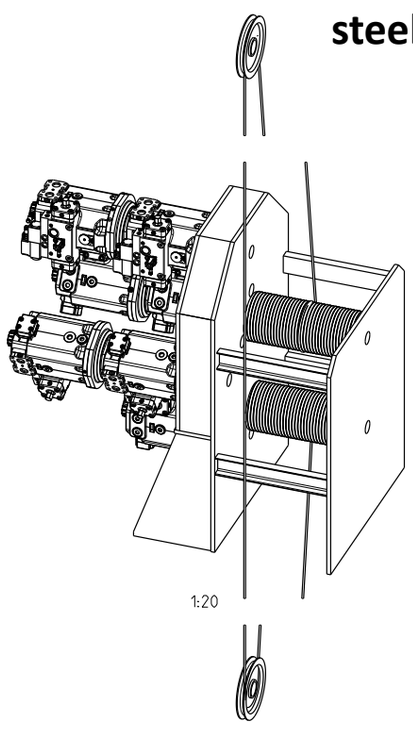
(standard catapult capsule / short drop capsule)

The RCM
(releasing-caging mechanism)

slider / drag shield

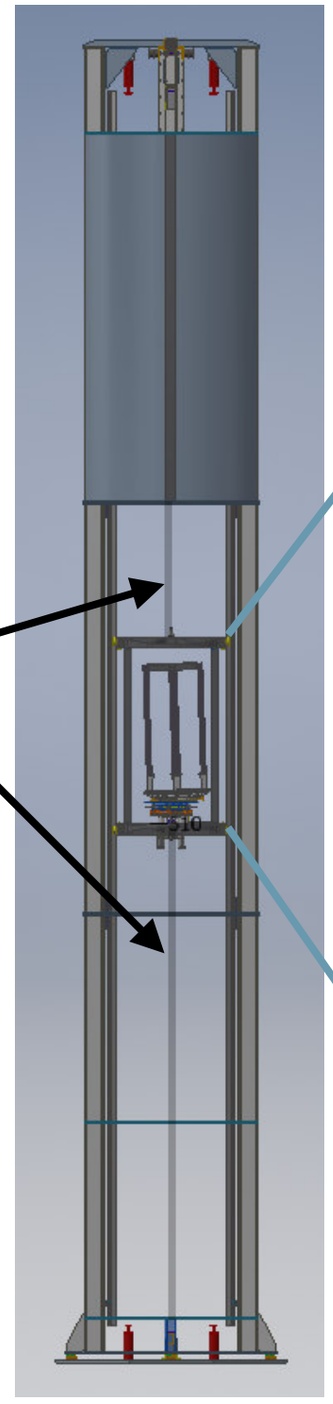
GraviTower Bremen - Prototype

- over 100 µg-experiments per day
- „elevator system“
- without limiting factor - vacuum (capsule-in-capsule drop tower)
- active rope drive system (commercial hydraulic winches)

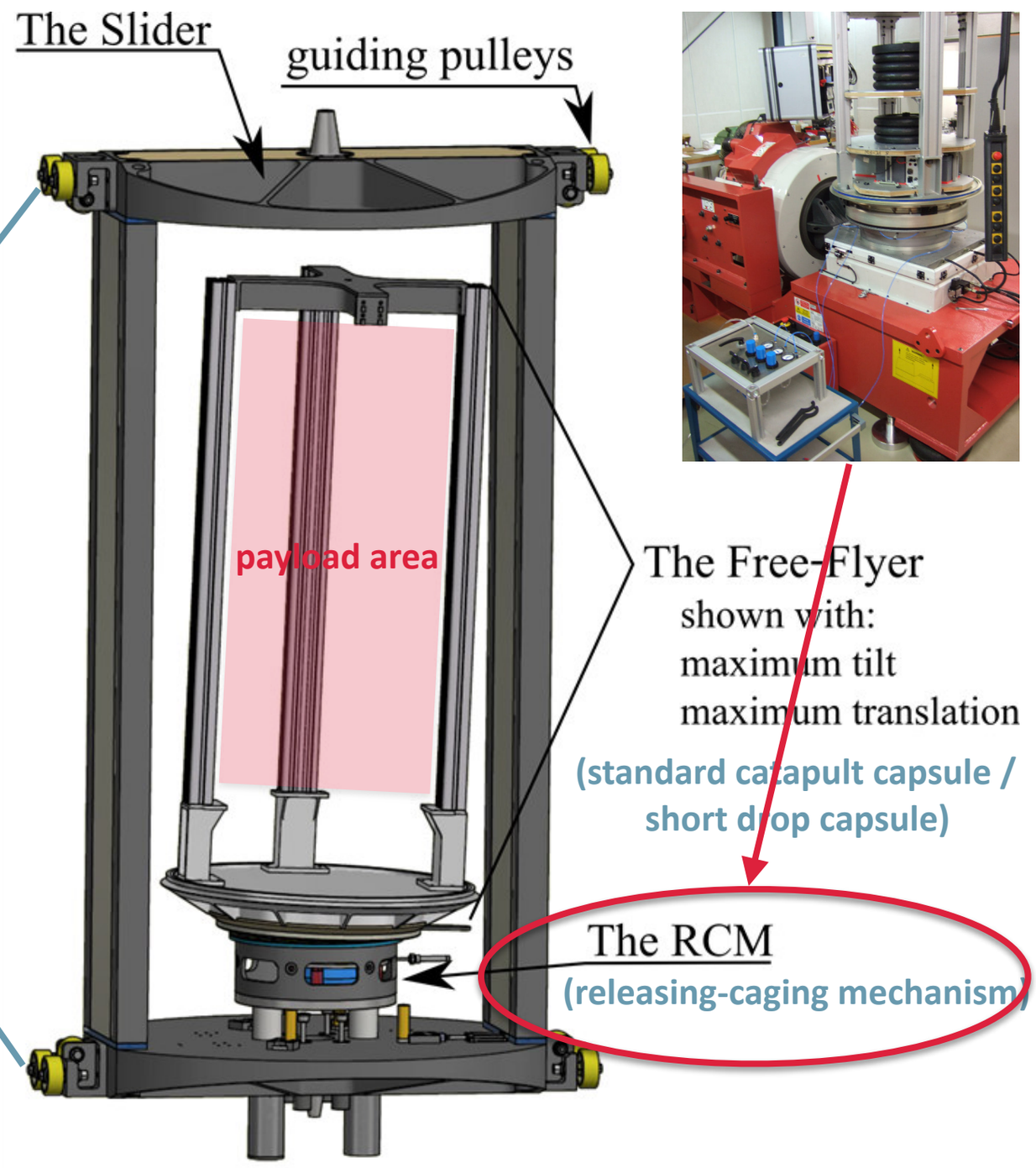


hydraulic winches

steel ropes

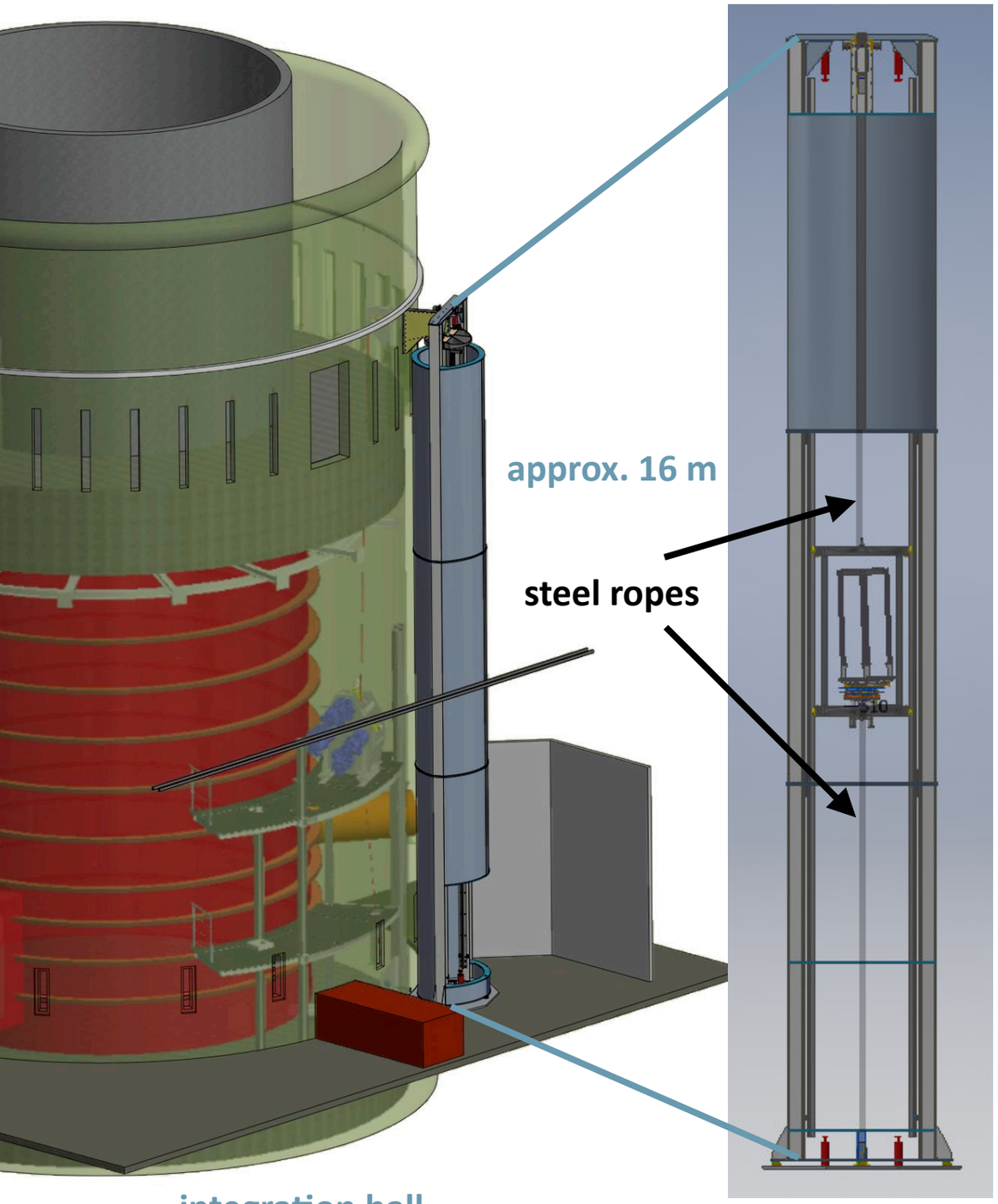


railing system



slider / drag shield

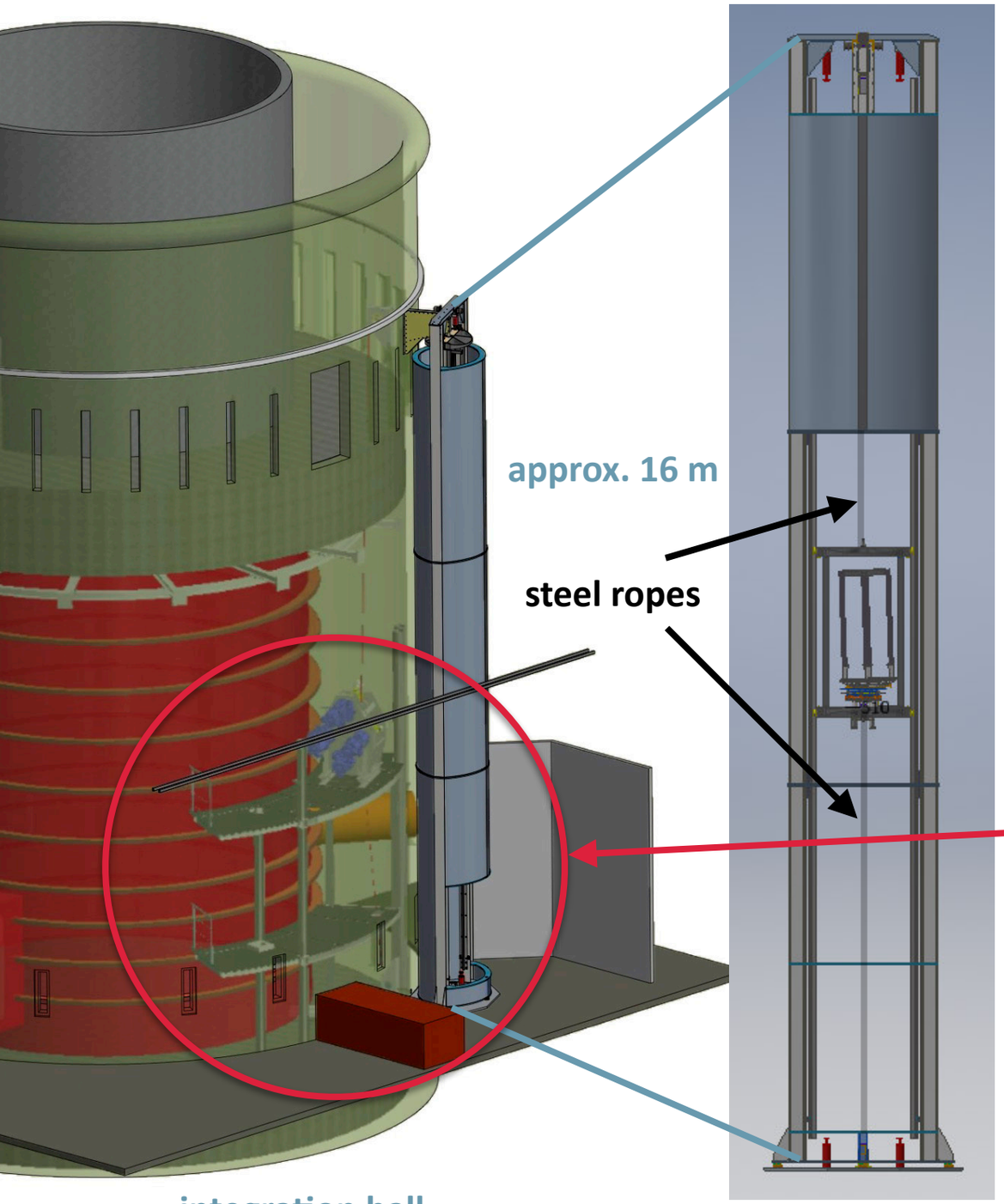
GraviTower Bremen - Prototype

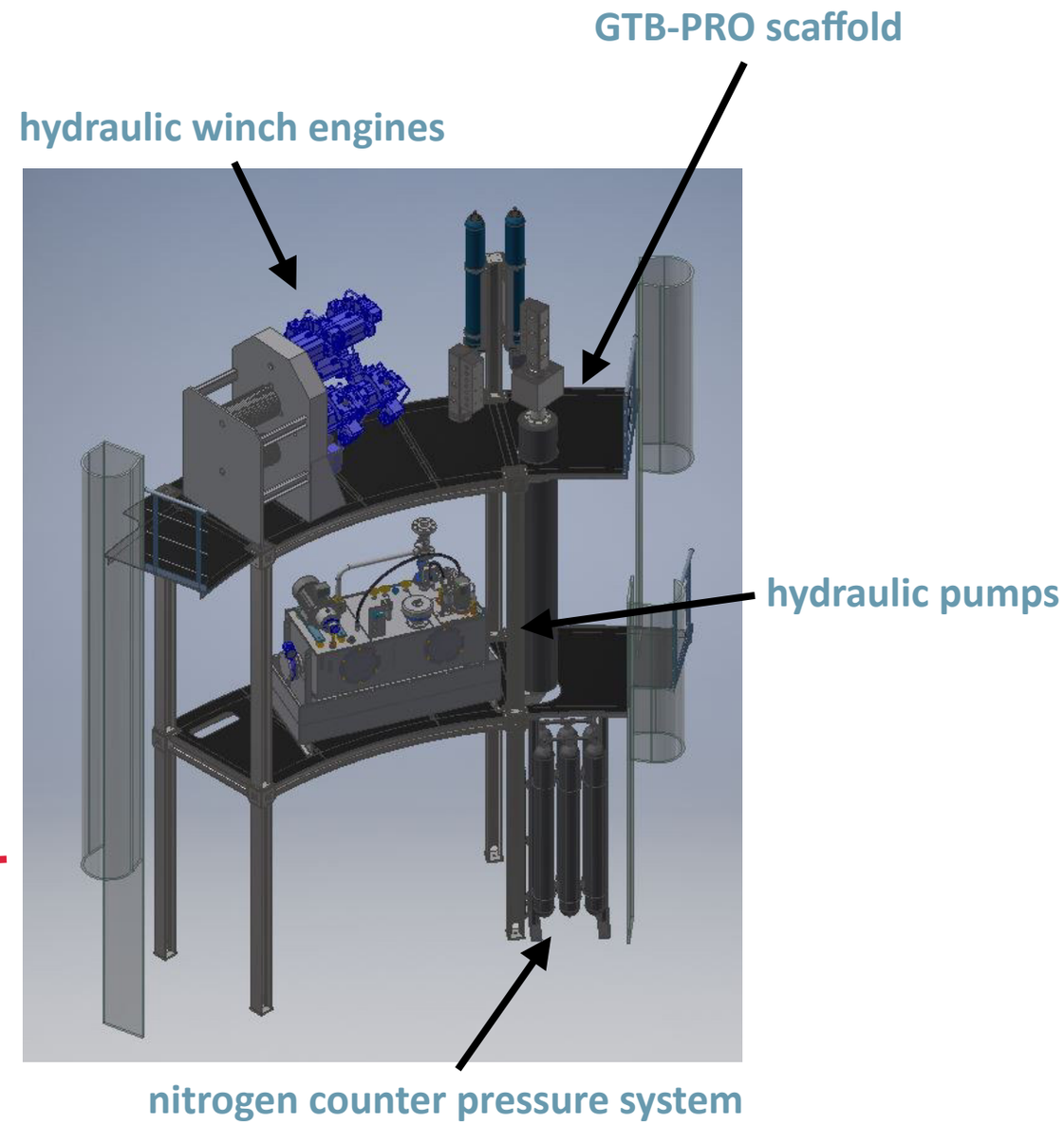


integration hall
- Bremen Drop Tower -

railing system

GraviTower Bremen - Prototype





GraviTower Bremen - Prototype

experiment repetition rates	**over 100 experiments per day (maximal 12 launches per hour)**
acceleration / deceleration	**only 4 g**
microgravity duration	**2.5 s (first stage of development)**
microgravity quality	**< 10^{-4} *g* *(first approximation)***
experiment accommodation	**standard catapult / short drop capsule (synergy effects)**
additional microgravity options	**drop: 4.7 s / catapult launch: 9.3 s (Bremen Drop Tower)**

- target: approx. 8.0 s in microgravity (new tower -> GTB)

THANK YOU VERY MUCH FOR YOUR ATTENTION

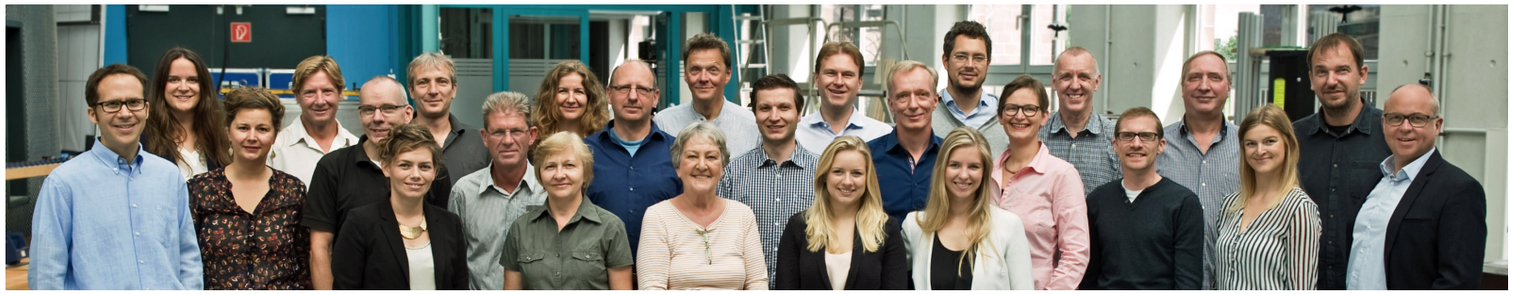
ACKNOWLEDGEMENTS

UNITED NATIONS
Office for Outer Space Affairs

DLR

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

esa



ZARM FAB MBH **WWW.ZARM.UNI-BREMEN.DE**

Universität Bremen

CENTER OF
APPLIED SPACE TECHNOLOGY
AND MICROGRAVITY

ZARM