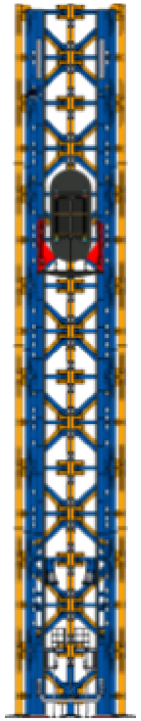
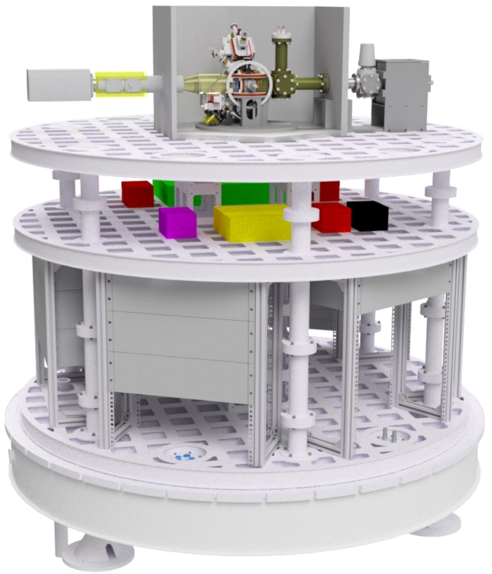
IQ

ITA

Institut für Transport- und Automatisierungstechnik

Prof. Dr.-Ing. Ludger Overmeyer





Quantum sensing in microgravity

Alexander Heidt

Wednesday, August 2, 2023

HITec Hannover Institute of Technology

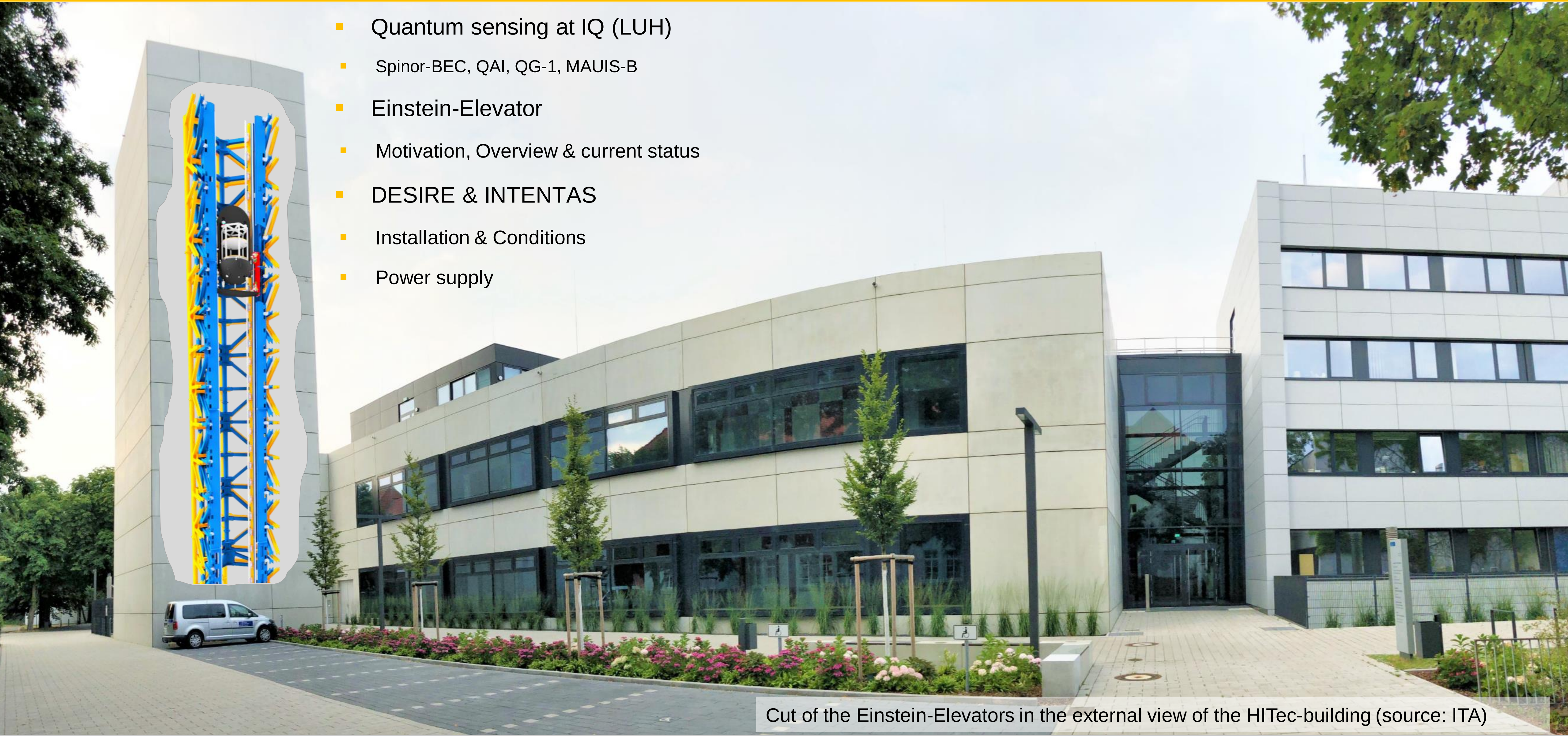
DLR

Leibniz Universität Hannover

Produktionstechnisches Zentrum Hannover

Agenda

- Quantum sensing at IQ (LUH)
  - Spinor-BEC, QAI, QG-1, MAUIS-B
- Einstein-Elevator
  - Motivation, Overview & current status
- DESIRE & INTENTAS
  - Installation & Conditions
  - Power supply

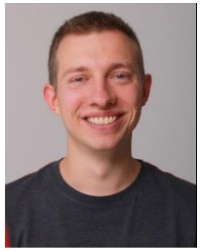


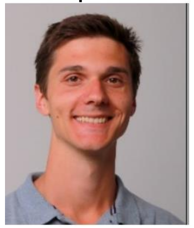
Cut of the Einstein-Elevators in the external view of the HITec-building (source: ITA)

probing the possibilities of employing entangled states in cold atom interferometry

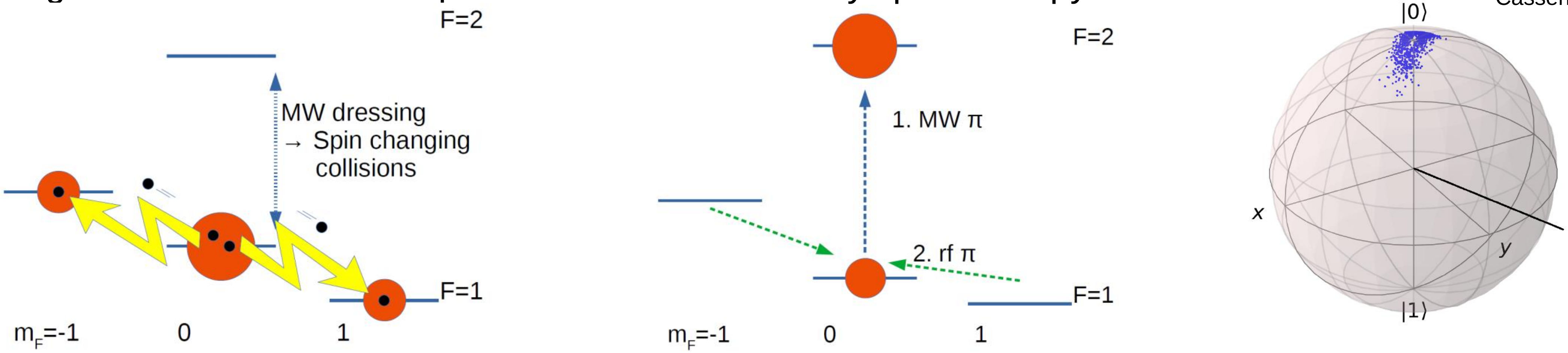
- Creating a BEC (→ 3D MOT → molasses cooling → evaporation → BEC)
- Spin dynamics change → entangled atoms
  - Start with Rb^{87}-BEC
  - Microwave (MW) dressing → decrease distance of F=1 and F=2 → Spin changing collisions
- Free fall and Delta Kick → prevent atoms from spreading
- Magnetic field-insensitive squeezed States → Ramsey spectroscopy


Carsten Klempt


Bernd Meyer-Hoppe


Christophe Cassens


Theo Sanchez



Spin changing collisions & MF-insensitive sqeezed state (source: LUH/ Christophe Cassens)

Latest publication: Dynamical low-noise microwave source for cold-atom experiments by Fabian Anders, DOI:10.1063/5.0160367

Rapid generation and number-resolved detection of spinor rubidium Bose-Einstein condensates

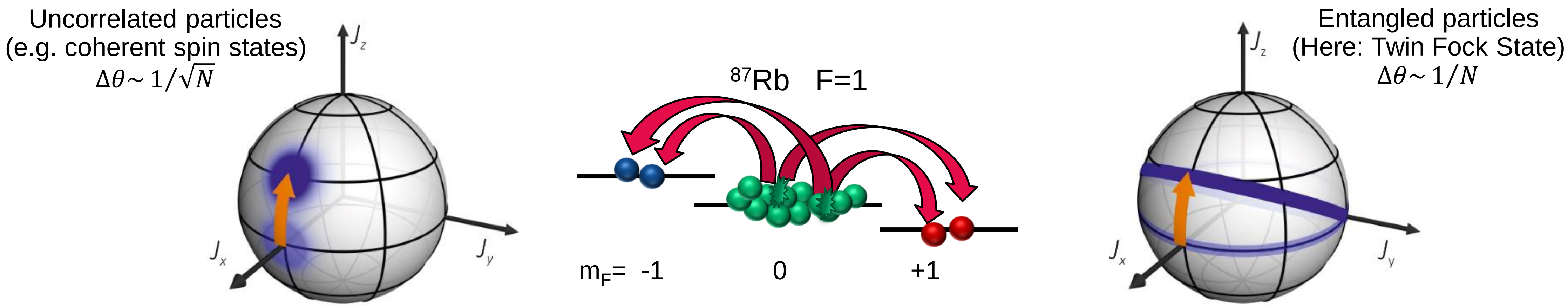
- Similar procedure like Spinor-BEC but with better technologies and performance → more precise & options to operate
- Their interests:
  - Preparation of entangled states
  - Employing those states for enhanced measurement precision → count single Atom-pairs

Martin Quensen

Mareike Hetzel

Carsten Klempt

→ INTENTAS motivated by these projects



Entaglement of atoms and Twin Fock State (source: LUH/Mareike Hetzel)

Latest publication: Rapid generation and number-resolved detection of spinor rubidium Bose-Einstein condensates by Cebrail Pür, DOI:10.1103/PhysRevA.107.033303

Quantum sensing at LUH – QG-1 - Group Prof. Ernst Rasel
Quantum Gravimeter

IQ

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Measure gravity with a Mach-Zehnder-Interferometer

- Applications:
  - Map local mass distribution
  - Study mass transport
  - Verify dynamic earth models
- Goals: No drift & No offset after transport
- Advantage: Absorption-imaging to detect Atom clouds in 3D

PhD students

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Nina Heine

Post Docs

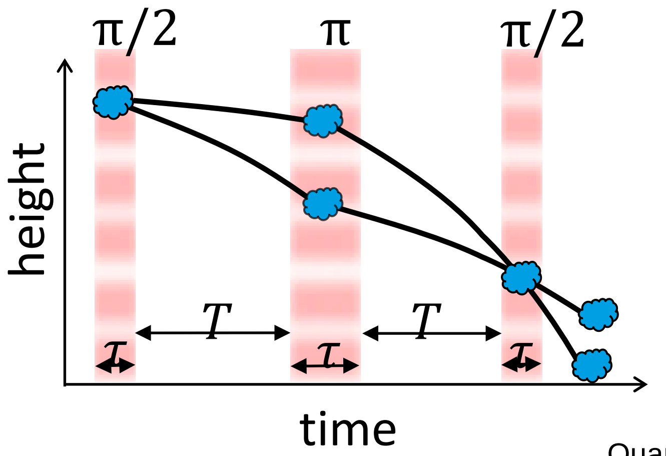
Christian Schubert

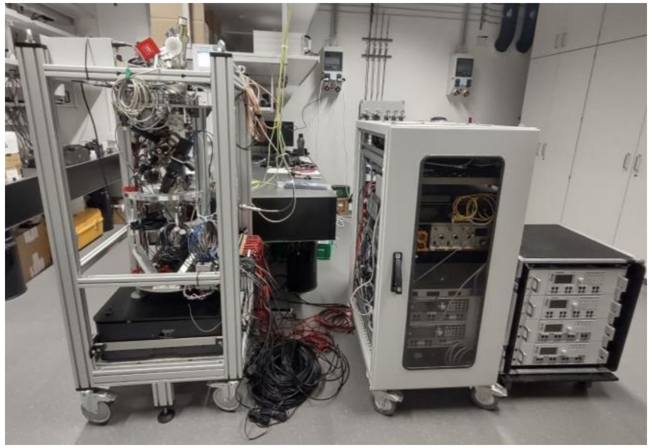
Waldemar Herr

Principal Investigators

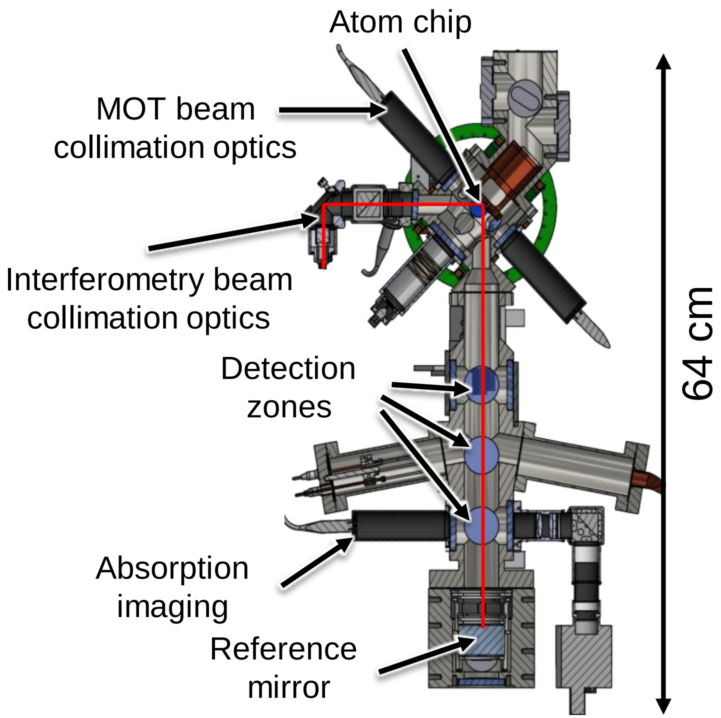
Ernst M. Rasel

Jürgen Müller ife





Quantum Gravimeter QG-1 (source: LUH/Pablo Nuñez von Voigt)



Latest publication: A transportable quantum gravimeter employing delta-kick collimated Bose-Einstein condensates by N. Heine et al., Eur. Phys. J. D, 74 (2020), doi.org/10.1140/epjd/e2020-10120-x

mat

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Test Equivalence principle at low scale in space

- Atom interferometry with two Atom species: RB^{87} and K^{41}
- Creating BEC`s for both species
- Raman double-diffraction enhanced beam splitters
- Measuring phase → acceleration of both species

→ DESIRE motivated by MAIUS projects


Ernst M. Rasel


Baptist Piest

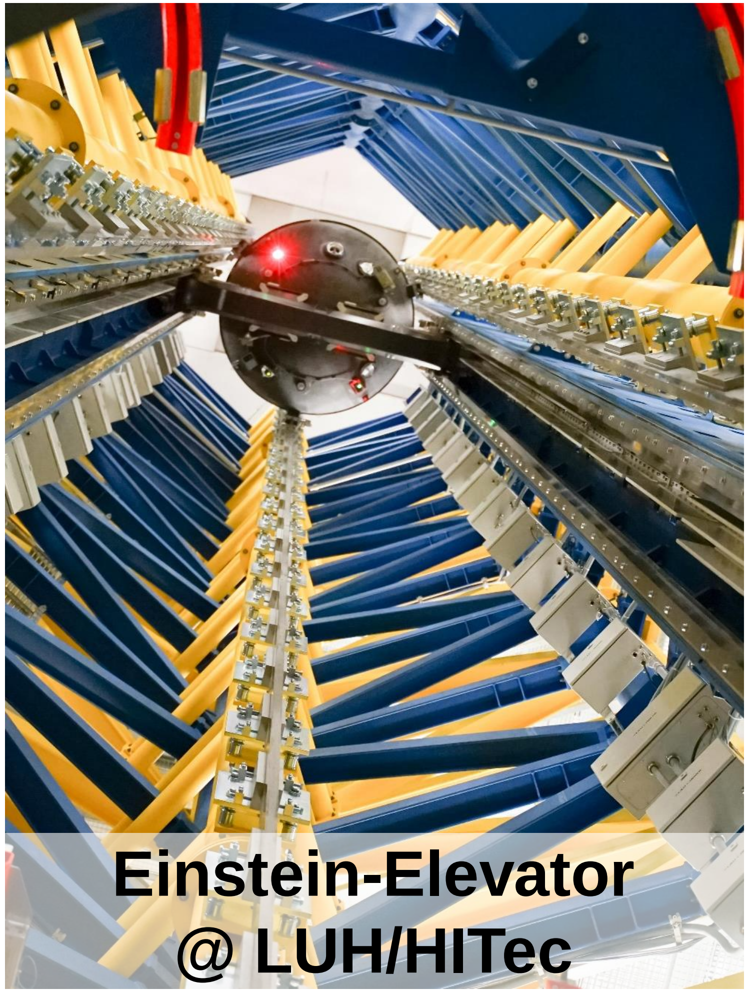

Thijs Wendrich


Jonas Böhm


Priyanka Guggilam

Einstein-Elevator - Motivation for a µg to 5g Facility

What is the Einstein-Elevator?



source: Leibniz Universität Hannover/Marie-Luise Kolb

- Active drop tower
- Vertical parabolic flight
- Microgravity, partial gravity
- Low residual acc.
- High repetition rate
- Large and heavy experimental setups
- Build since 2011
- First flight in 2019
- Part of the HITec research infrastructure (LUH)

Head of new research group

Dr.-Ing. Christoph Lotz

What is its use?

<u>Mechanical engineering</u>

- Production technologies under space (gravity) conditions
- Material science
- Technique demonstrations
- …

<u>Physics</u>

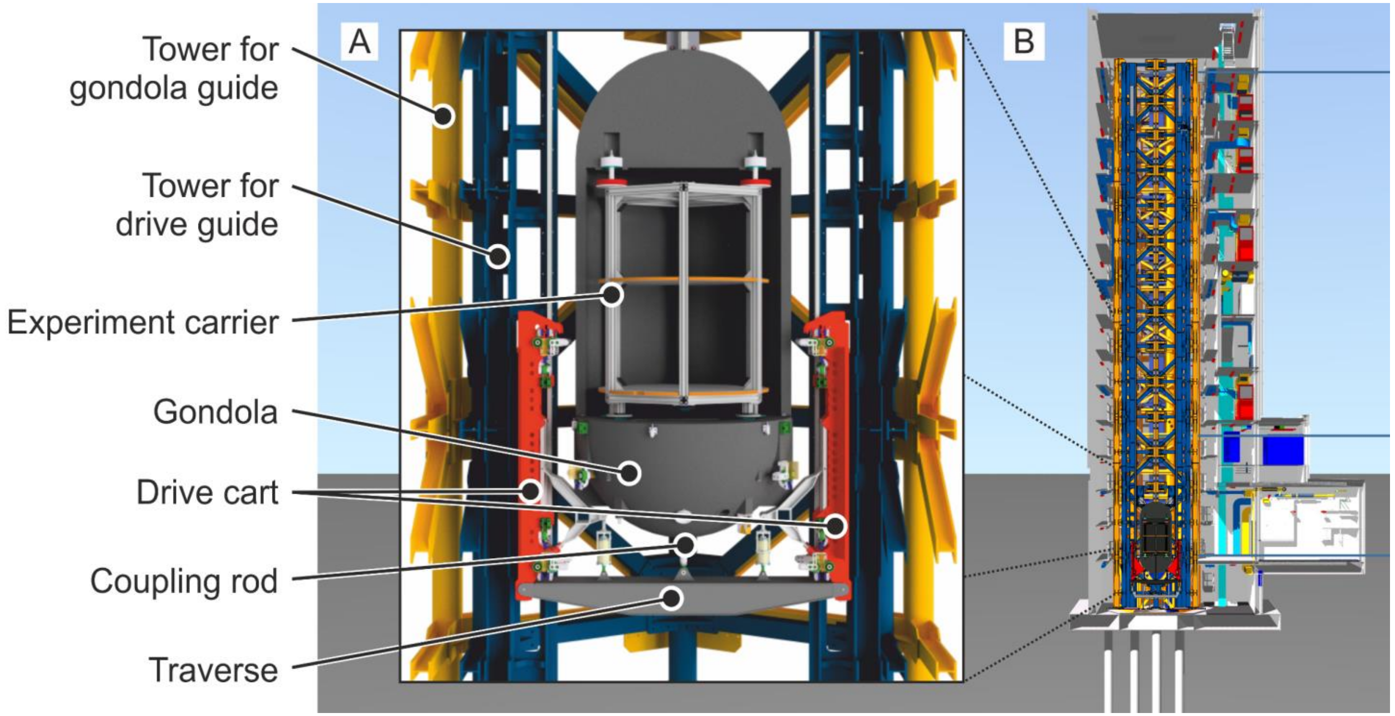
- BEC in microgravity
- Atom interferometry in space
- …

<u>External</u>

- Plasma physics
- Testing sensor concepts
- …

Einstein-Elevator - Overview

Active "drop tower" for experiments in µ*g* to 5*g* regime with a high repetition rate



Duration in Microgravity: 4 s

Repetition Rate: 100 (up to 300)/day

Residual **Acceleration:** 10^{-6} *g*

Payload: 1,000 kg

Carrier **Dimensions:** Ø1.7 m, 2 m

Drive System: linear synchronous Motor

Max./var. Acceleration: <5 *g*

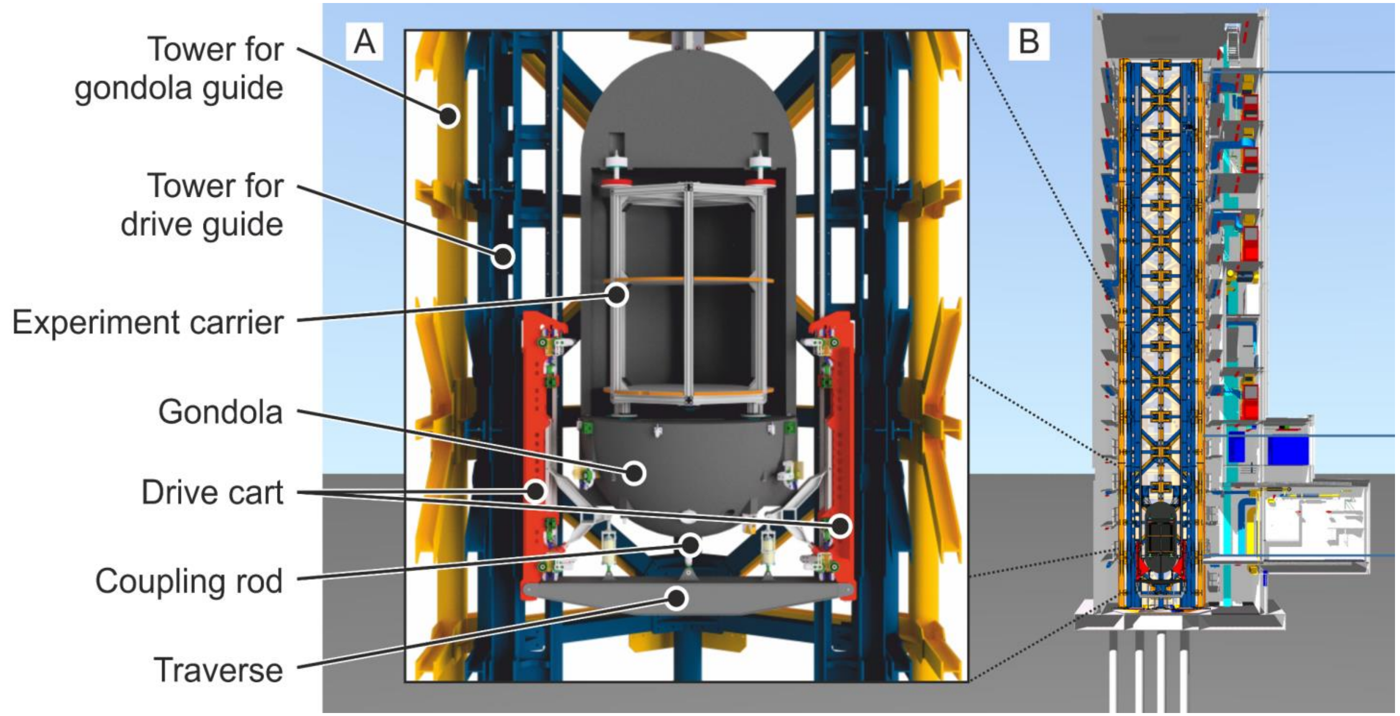
Electrical Peak Power: 4.8 MW

Supporting structure height: 37 m

Left (1): Space Shuttle Atlantis during STS-132 (source: By NASA/Crew of STS-132, http://spaceflight.nasa.gov/gallery/images/shuttle/sts-132/hires/s132e012208.jpg) **(2):** Full moon as seen from Earth's Northern Hemisphere (source: Von I, Luc Viatour, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1254946), **(3):** Mars in natural colour in 2007 (source: By ESA - European Space Agency & Max-Planck Institute for Solar System Research for OSIRIS, http://www.esa.int/spaceimages/Images/2007/02/True-colour_image_of_Mars_seen_by_OSIRIS), **(4):** Launching of a rocket for manned spaceflight with Arianespace's Ariane 5: 4.55 *g* just before first-stage cutoff (source: http://www.arianespace.com/wp-content/uploads/2011/07/Ariane5_Users-Manual_October2016.pdf),

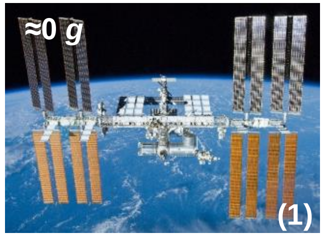
Einstein-Elevator - Overview

Active “drop tower” for experiments in µ*g* to 5*g* regime with a high repetition rate

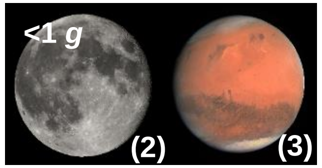


Concept of Einstein-Elevator (source: ITA)

Trajectory Profiles



Space flight gravity
e.g. ISS (center of mass): ≈ 0 *g*



Hypo-gravity:
Surface gravity
Moon: 0.165 *g*
Mars: 0.376 *g*

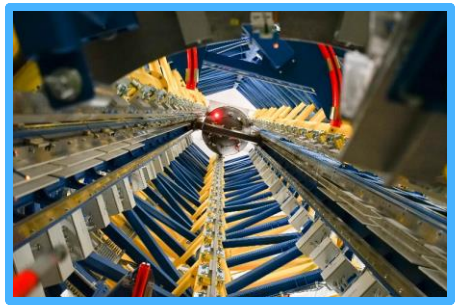
Hyper-gravity:
Manned spaceflight
Ariane 5: 4.55 *g*
Soyuz: 4.30 *g*

Left (1): Space Shuttle Atlantis during STS-132 (source: By NASA/Crew of STS-132, http://spaceflight.nasa.gov/gallery/images/shuttle/sts-132/hires/s132e012208.jpg) **(2):** Full moon as seen from Earth's Northern Hemisphere (source: Von I, Luc Viatour, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1254946), **(3):** Mars in natural colour in 2007 (source: By ESA - European Space Agency & Max-Planck Institute for Solar System Research for OSIRIS, http://www.esa.int/spaceinimages/Images/2007/02/True-colour_image_of_Mars_seen_by_OSIRIS), **(4):** Launching of a rocket for manned spaceflight with Arianespace’s Ariane 5: 4.55 *g* just before first-stage cutoff (source: http://www.arianespace.com/wp-content/uploads/2011/07/Ariane5_Users-Manual_October2016.pdf),

Einstein-Elevator - Overview – Test sequence

1. Preparation of the experiments in the preparation area
2. Integration of the carrier in the Einstein-Elevator
3. Closing the gondola and starting the control system
4. Experiment execution

The control of the system and the experiments are performed from the control room



Einstein-Elevator - Current status

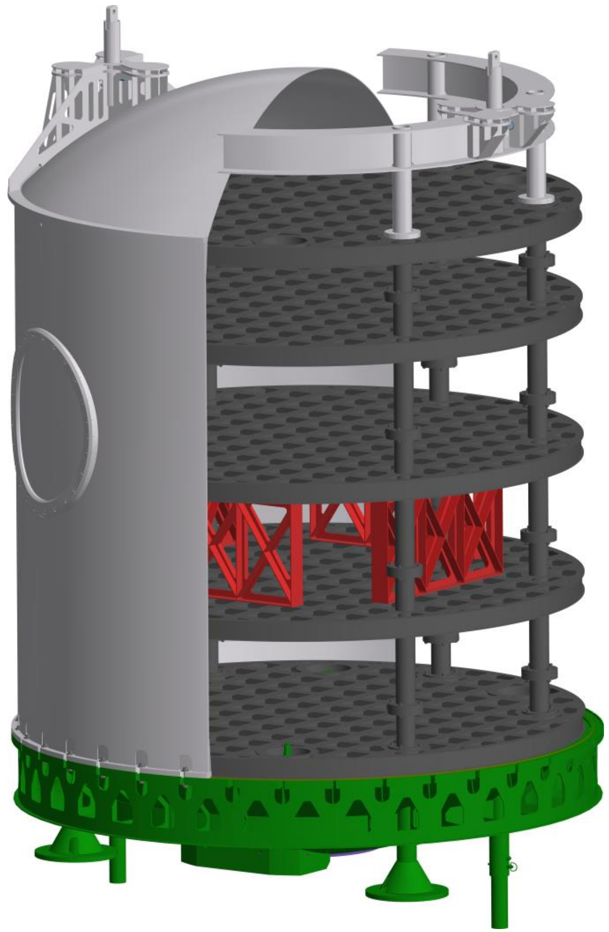
Carrier technical data

- → Payload size: **Ø1.7 m, height 2 m, max. weight 1,000 kg***

- → **Pressure-tight shell** encapsulate experiment to gondola vacuum
- → Carrier **can also be used without shell** and only with one floor, side structures and a support ring on the top

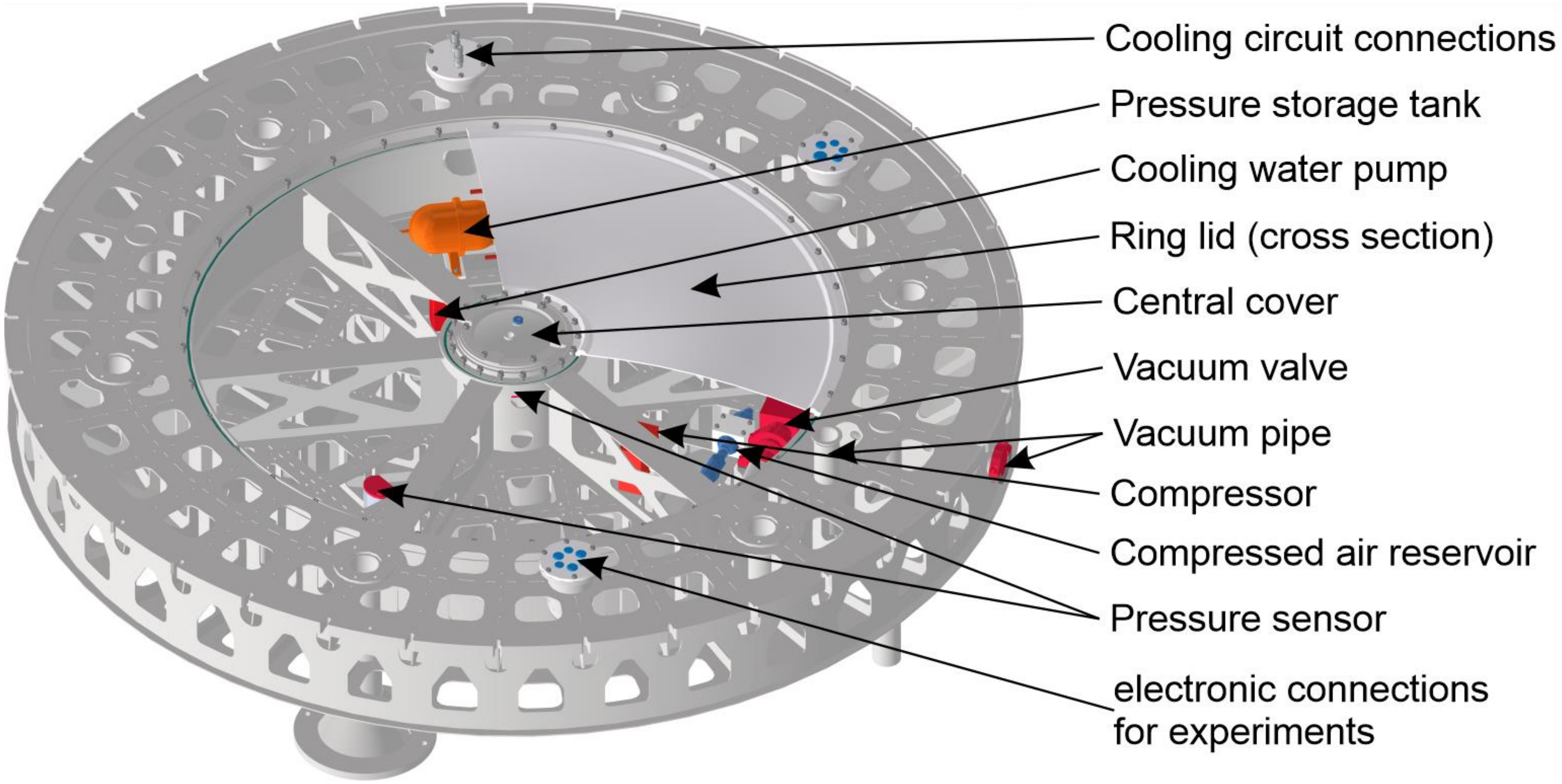
- → **Power supply** → see following slides (INTENTAS & DESIRE example)
- → **Cooling water circuit with up to 1 kW**
- → **Different camera types available:** High speed camera, thermal camera, hyperspectral camera and webcams

- → **Multiple sensors recording experiment environment** acceleration (3 axis, diff. measuring ranges), magnetic field (3 axis), pressure (inside and outside the carrier), multiple temperatures sensors, humidity,…
- → **Interfaces for experiment control** or **experiments directly linked to the control room**
- → **Telemetry with direct data link** to the user terminals in the control room


Carrier System SN1 (source: LUH/Richard Sperling)

Einstein-Elevator - Current status

- 6 areas within different sensor etc.

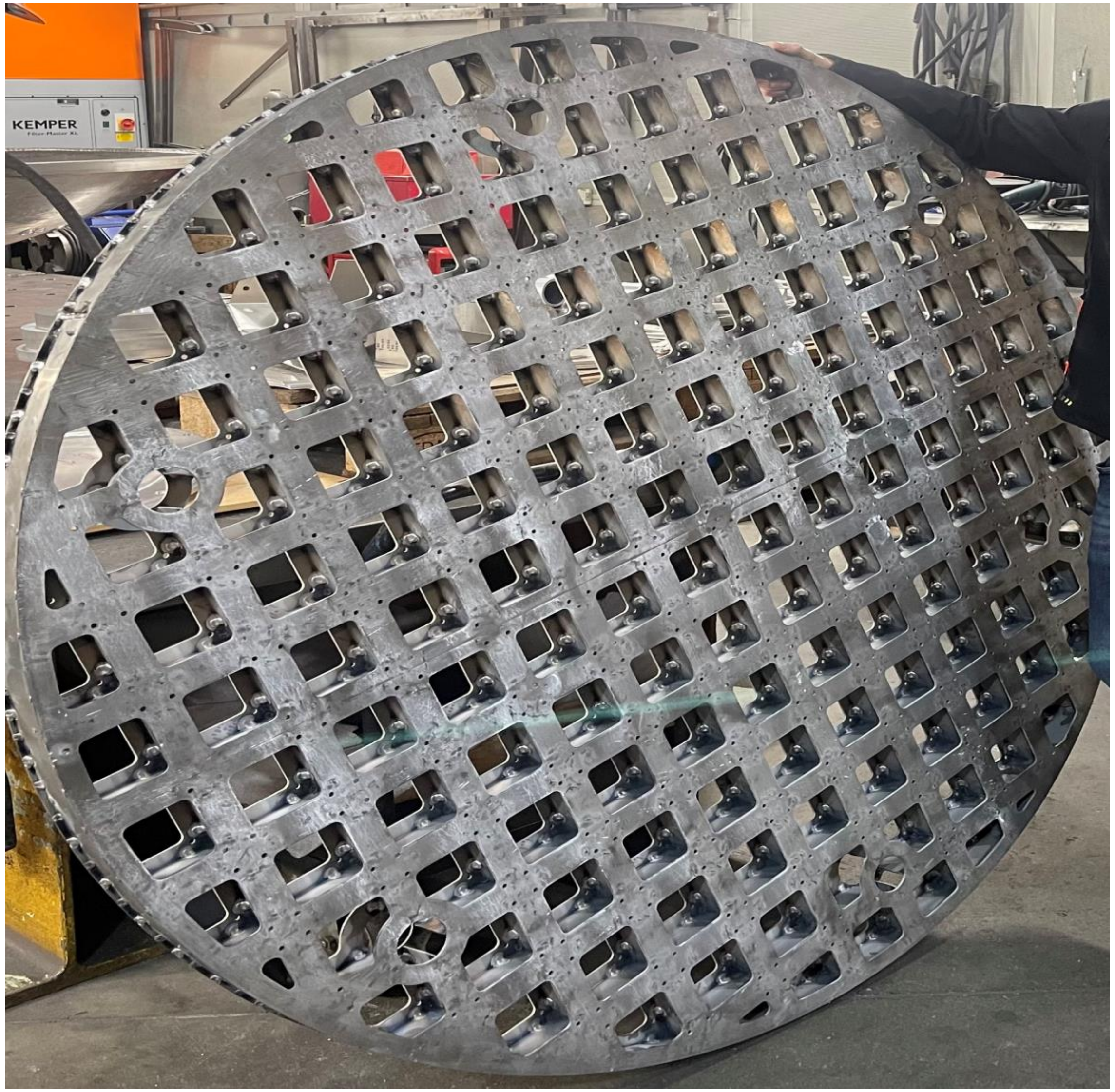


Carrier System SN1 (source: LUH/Richard Sperling)

Einstein-Elevator - Current status

Eilhauer status:

- Pressure hull ready
- Lowest carrier is nearly finished:
  - Leakage checks
- They started with the other levels

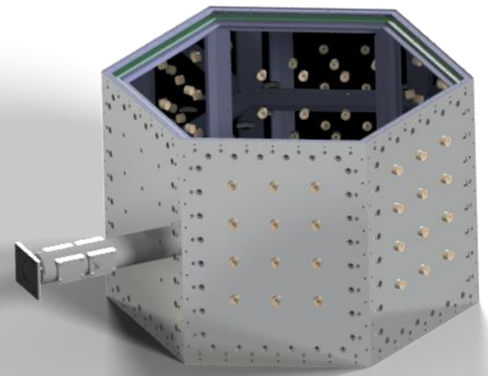


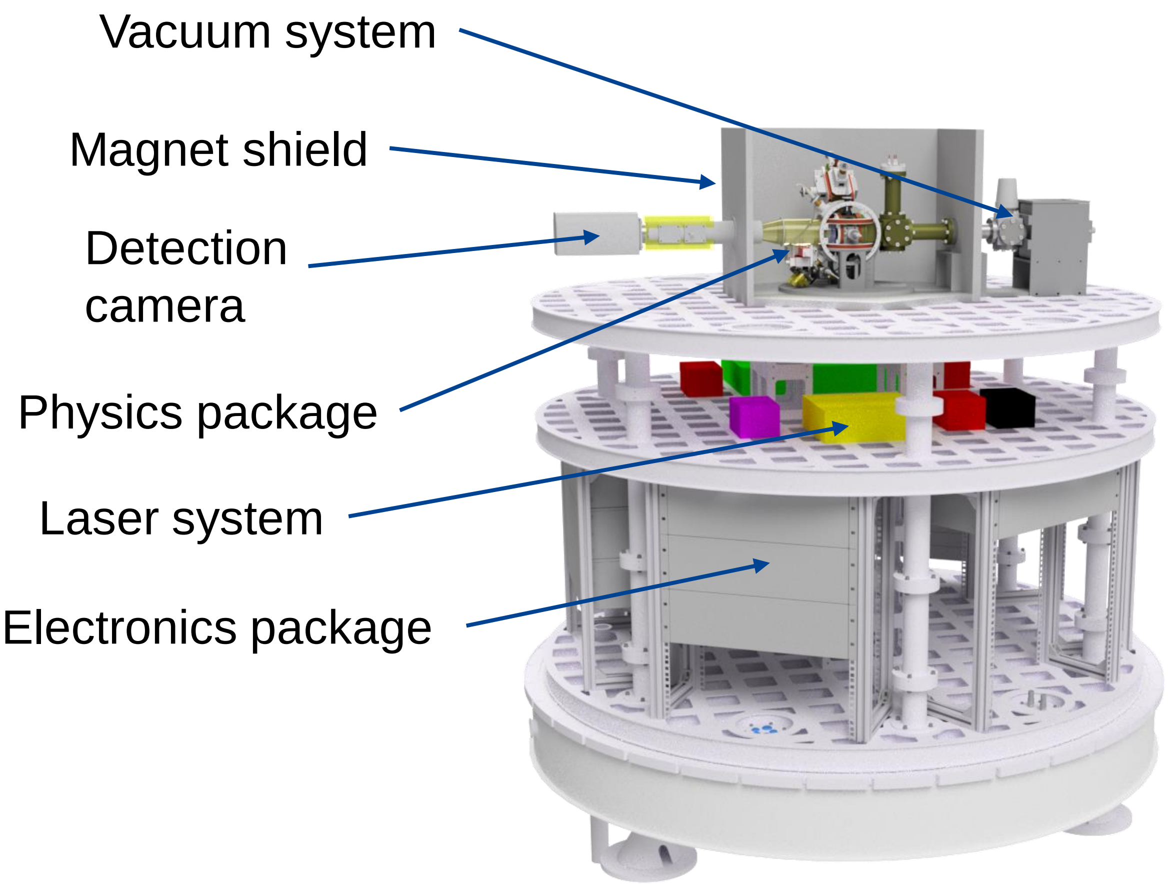
Carrier System SN1 (source: LUH/Richard Sperling)

INTENTAS – Installation

Motivation: Realization of a compact source of entangled atoms for space applications → surpassing the standard quantum limit (SQL)

- Electronics package – using supercapacitors (first level)
- Laser system and (later) vacuum system (second level)
- Physics package etc. (third level):
  - Spin dynamics change → entangled atoms
  - Vacuum chamber (up to 10^{-11} mbar)
  - Detection: highspeed camera with a quantum efficiency of 95%
  - Magnet-shied: Aim shielding factor : 10.000 → down to 10 nT

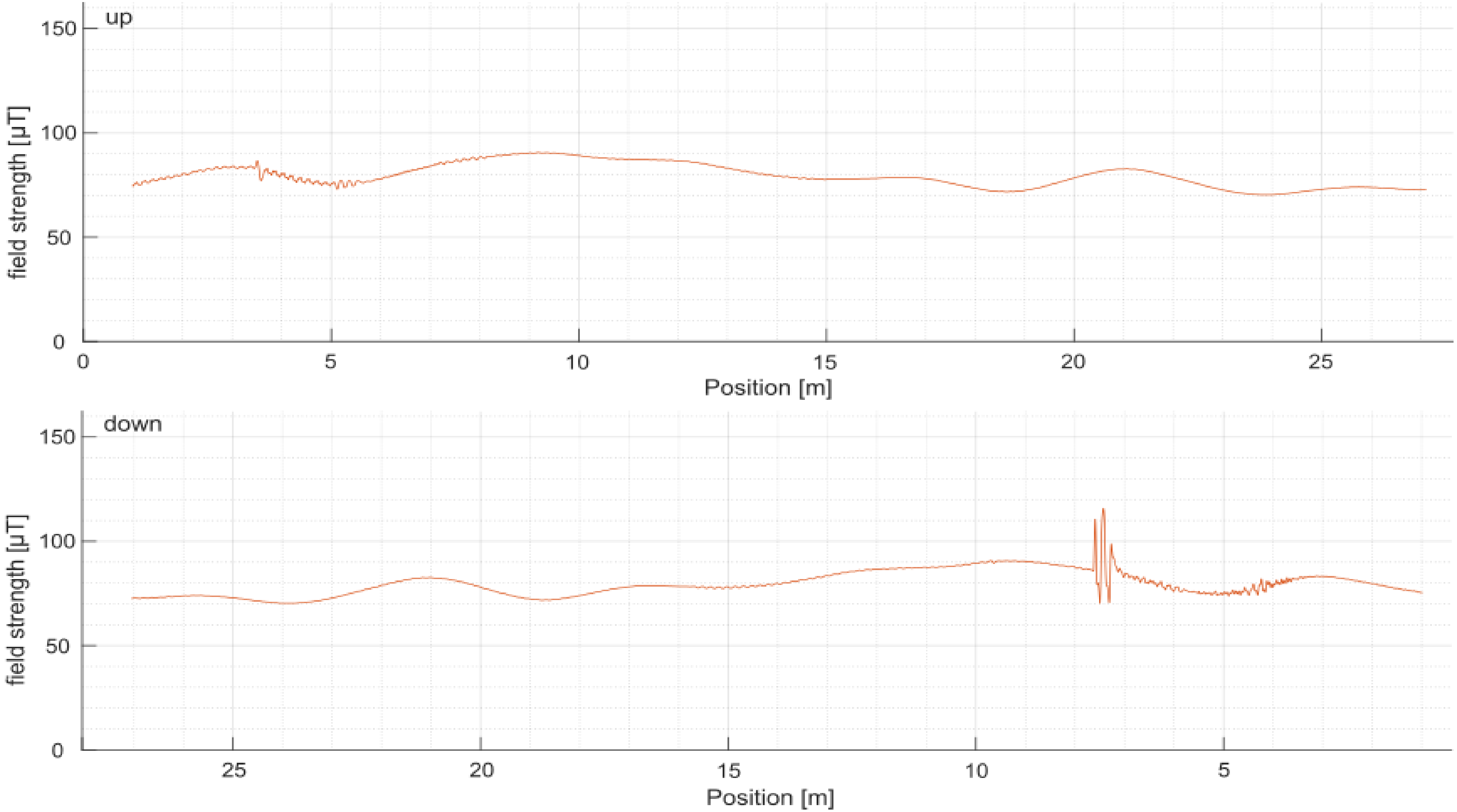




INTENTAS - Magnetic field in the EE

Field strength:

75 ± 10 µT



DESIRE – Installation

Motivation: Search for dark energy – chameleon fields: low mass density → acceleration

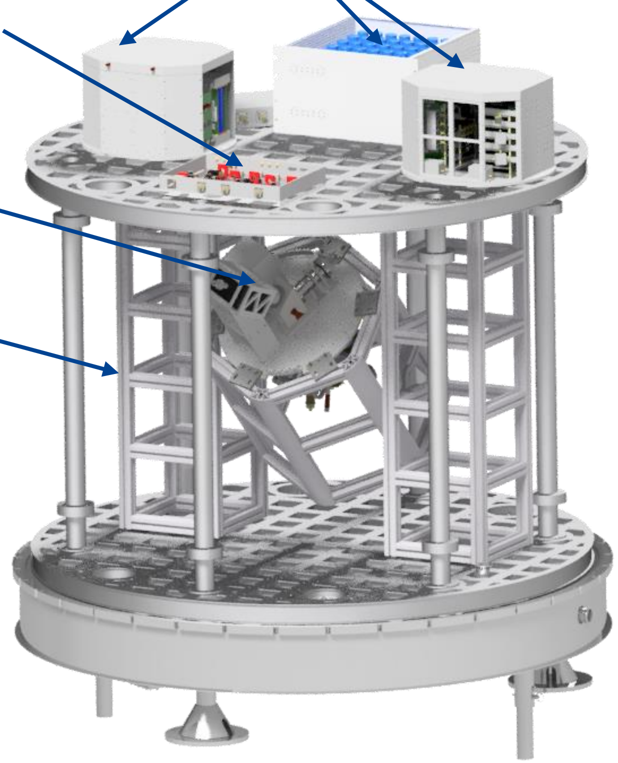
- Idea based on a paper by S. Chiow
  (Multiloop atom interferometer measurements of chameleon dark energy in microgravity. Chiow, Yu, PRD **97**, 044043 (2018))
- Test mass generated a periodic chameleon/acceleration signal
- Microgravity used for longer interaction time
- Test mass in use (Center of mass in EE important):
  - Critical rotation rate: 3 mrad/s
  - COM around Test mass

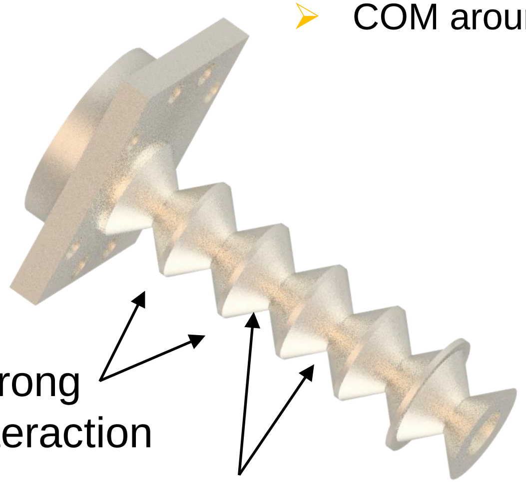
Electronics

Laser system

Experimental chamber with test mass

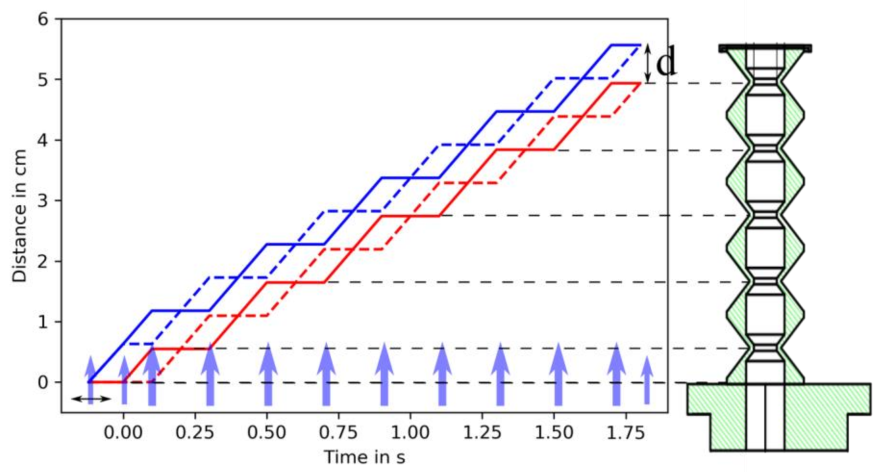
Experiment support structure





Strong interaction

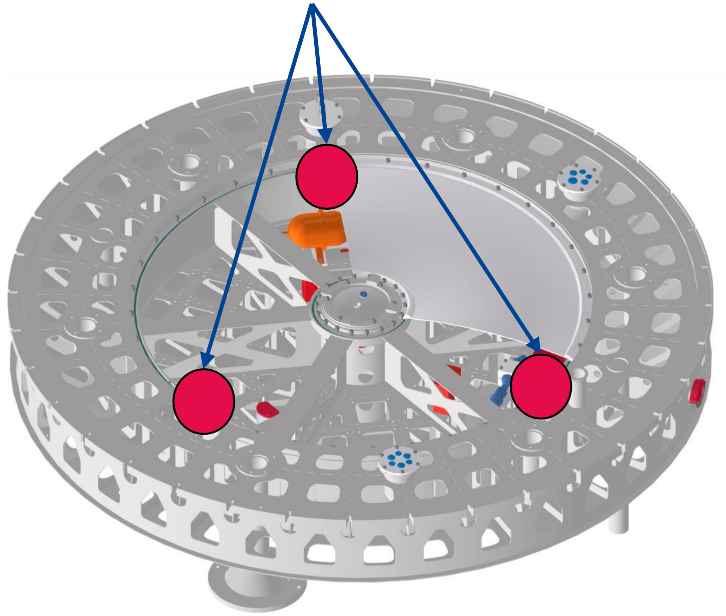
Weak interaction

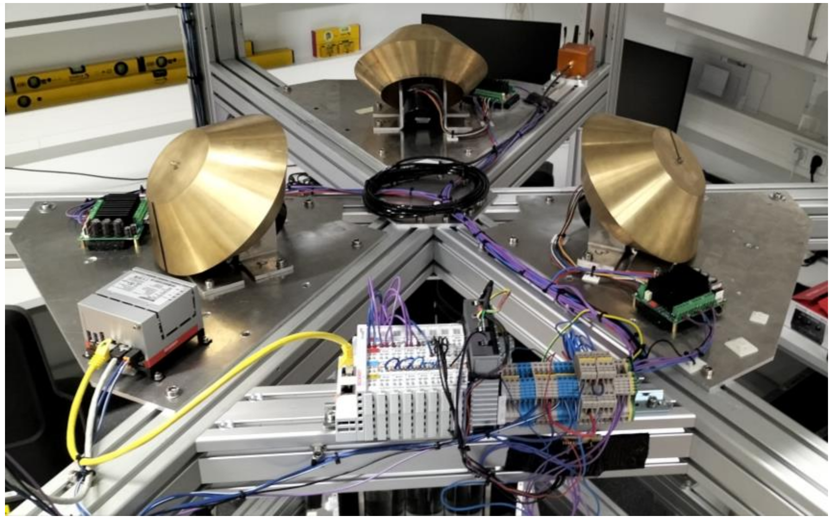


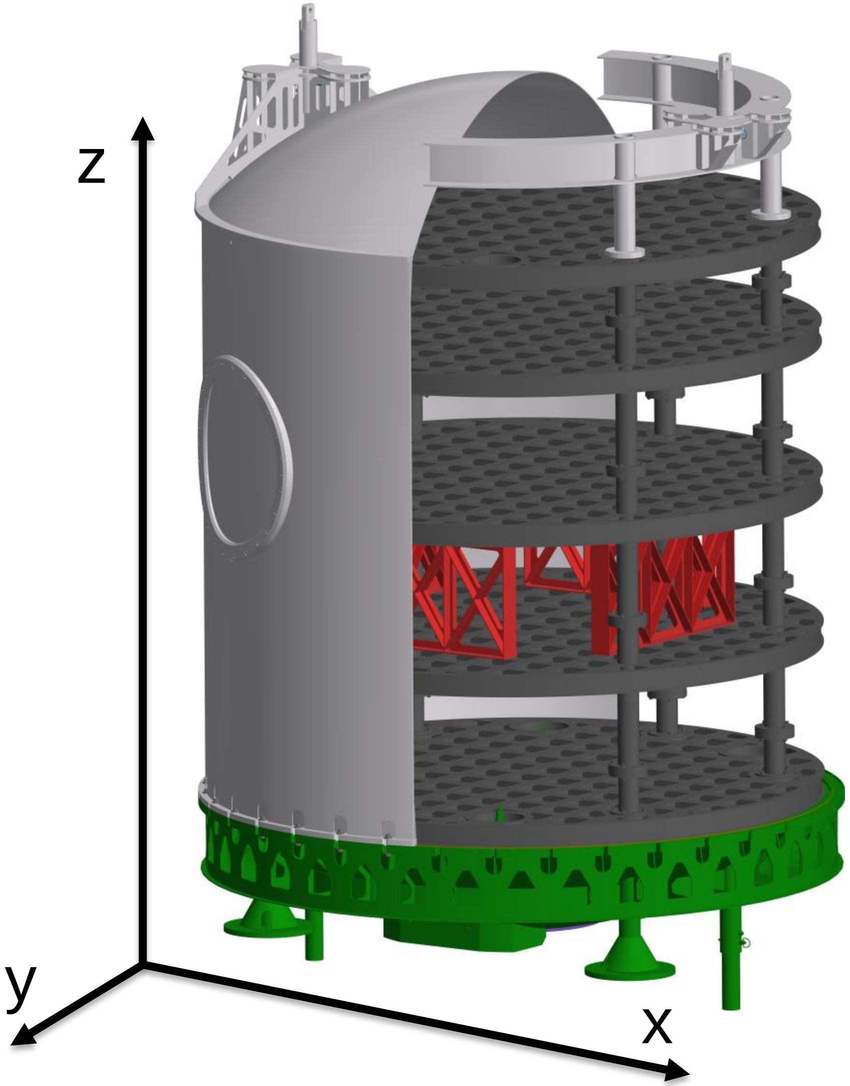
DESIRE - Rotation and acceleration

- Rotation around z-axis: 5,6 ± 1,4 mrad/s
- Rotation around x-axis: 1,9 ± 1,6 mrad/s
- Rotation around y-axis: 4,7 ± 2,3 mrad/s
- Superposition (real rotation): 8,5 ± 2 mrad/s

➢ Reaction wheels with servo motor

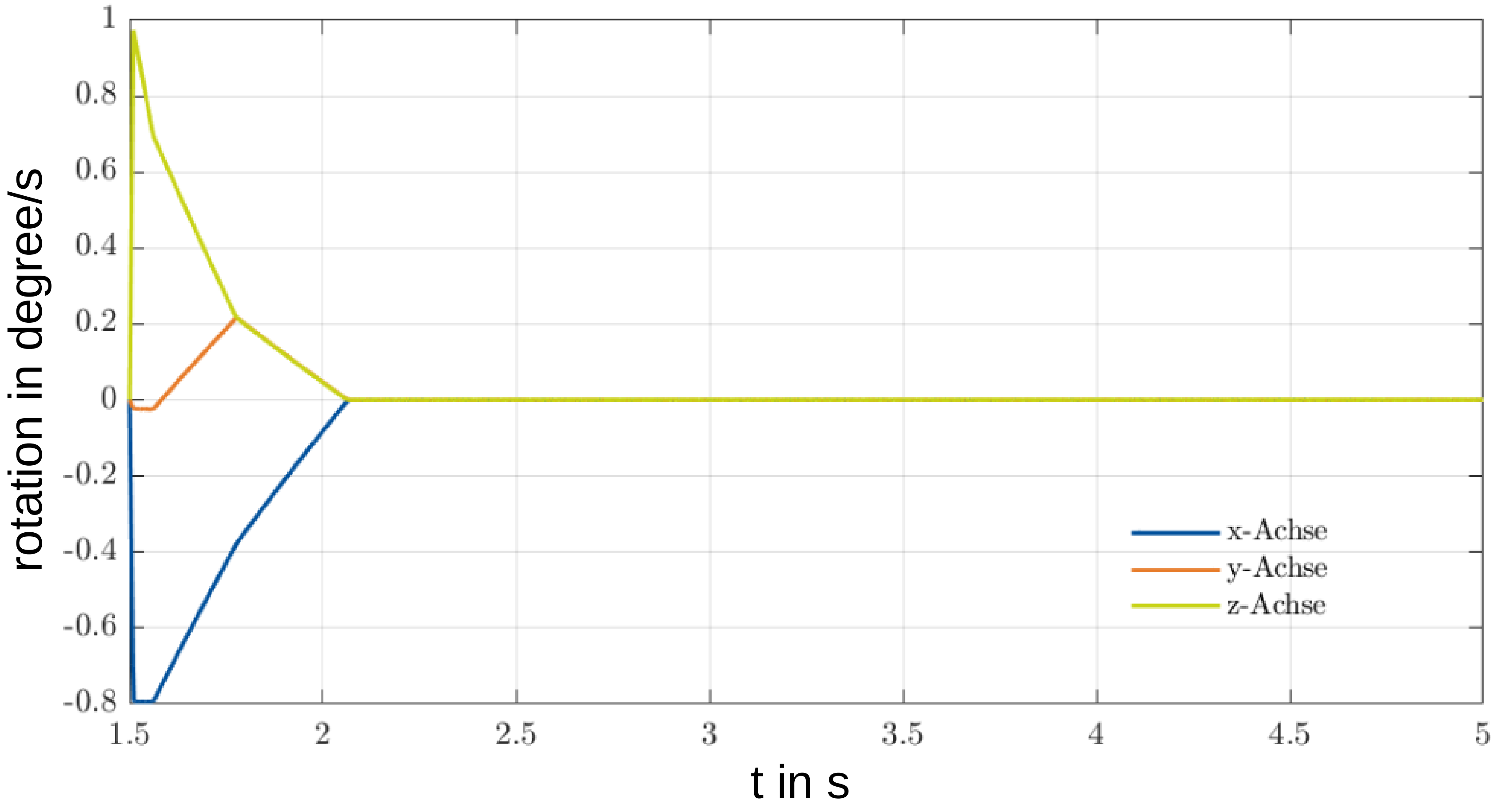






DESIRE - Rotation and acceleration

- Rotation improvement down to 17 µrad/s (sensor resolution)
- Tests are still on going
- Planned to teach the reaction wheels:
  - rotation impulse before start → increase flight time with minimized carrier rotation
  - Center of Mass (COM) stability



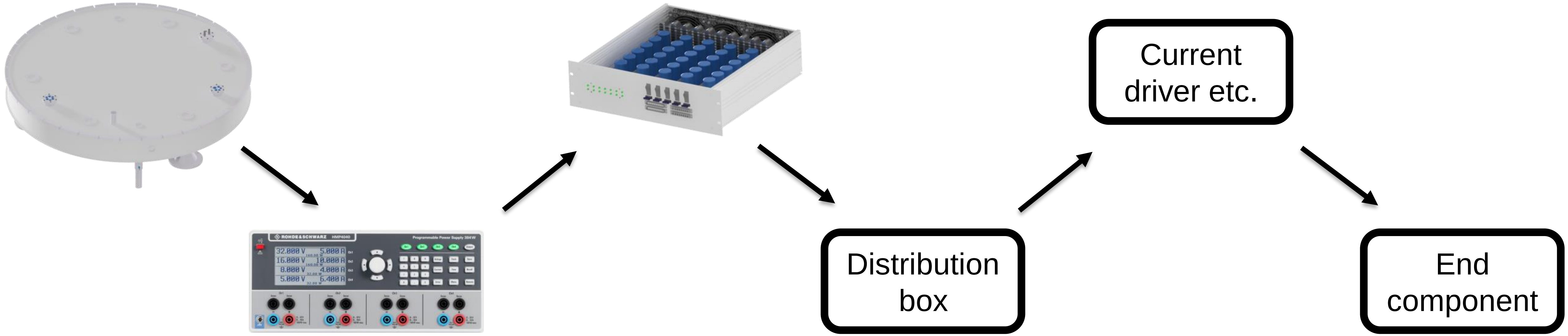
Power supply (INTENTAS & DESIRE example)

Charge and Supply Overview

- Einstein-Elevator Pins used for R&S HMP4040 Power supply

➢ During flight: (24 V/ 16 A, 5V, 3.3V, AC-DC converter: 230 V/), on ground: (230 V/ 16 A, etc.)

- Charge supercapacitors by R&S HMP4040
- R&S HMP4040 off during flight → supercapacitors provides power
- Distribution box with switches → controlling/switching the connected components on and off
- Voltage ruler → current driver etc. → end component



Outlook

- Finish Rotation Tests including COM stability
- Prepare the new carrier:
  - Test the microgravity quality → residual acc. 10^{-6} g
  - Test vacuum for acoustic decoupling
  - Test Power supply possibilities including TTL
- Integrate projects → first flights

DESIRE-Team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Sukhjovan Gill


Bentley Turner

INTENTAS-Team


Carsten Klempt


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Alexander Fieguth


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Thank you for your attention!

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German Aerospace Centre

Leibniz Forschungs-Schule
QUEST - Leibniz Research School

Institute of Transport and Automation Technology

Institute of Quantum Optics

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Institut für Transport- und Automatisierungstechnik

Thank you for your attention!

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Publications (extract):

Lotz, C.; Hsg: Overmeyer, L. (2022): Untersuchungen zu Einflussfaktoren auf die Qualität von Experimenten unter Mikrogravitation im Einstein-Elevator, Gottfried Wilhelm Leibniz Universität Hannover, Diss., xvii, 222 S., **DOI: 10.15488/11713**, 2022.

Reitz, B.; **Lotz, C.**; Gerdes, N.; Linke, S.; Olsen, E.; Pflieger, K.; Sohrt, S.; Ernst, M.; Taschner, P.; Neumann, J.; Stoll, E.; Overmeyer, L. (2021): Additive Manufacturing Under Lunar Gravity and Microgravity, *Microgravity Science and Technology*, Vol. 33, Nr. 25, **DOI: 10.1007/s12217-021-09878-4**, 2021.

Neumann, J.; Ernst, M.; Taschner, P.; Gerdes, N.; Stapperfens, S.; Linke, S.; **Lotz, C.;** Koch, J.; Wessels, P.; Stoll, E.; Overmeyer, L. (2021): The MOONRISE: payload for mobile selective laser melting of lunar regolith, *Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020*, 118526T (11 June 2021); **DOI: 10.1117/12.2600322**, 2021.

Lotz, C.; Gerdes, N.; Sperling, R.; Lazar, S.; Linke, S.; Neumann, J.; Stoll, E.; Ertmer, W.; Overmeyer, L. (2020): Tests of additive manufacturing and other processes under space gravity conditions in the Einstein-Elevator, *Logistics Journal*, Vol. 2020, S. 1–12, **DOI: 10.2195/lj_Proc_lotz_de_201310_01**, 2020.

Lotz, C.; Wessarges, Y.; Hermsdorf, J.; Ertmer, W.; Overmeyer, L. (2018): Novel active driven drop tower facility for microgravity experiments investigating production technologies on the example of substrate-free additive manufacturing, *Advances in Space Research*, Available online: 31 January 2018, ISSN 0273-1177, **DOI: 10.1016/j.asr.2018.01.010**, 2018.

Lotz, C.; Froböse, T.; Wanner, A.; Overmeyer, L.; Ertmer, W. (2017): Einstein-Elevator: A New Facility for Research from µg to 5g, *Gravitational and Space Research*, Vol. 5, No. 2, ISSN 2332-7774, **DOI: 10.2478/gsr-2017-0007**, 2017.

A complete list of publications can be found here:
https://www.ita.uni-hannover.de/en/institute/team/christoph-lotz/list-of-publications/

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