BECCAL – The Bose-Einstein Condensate and Cold Atom Laboratory

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Introduction

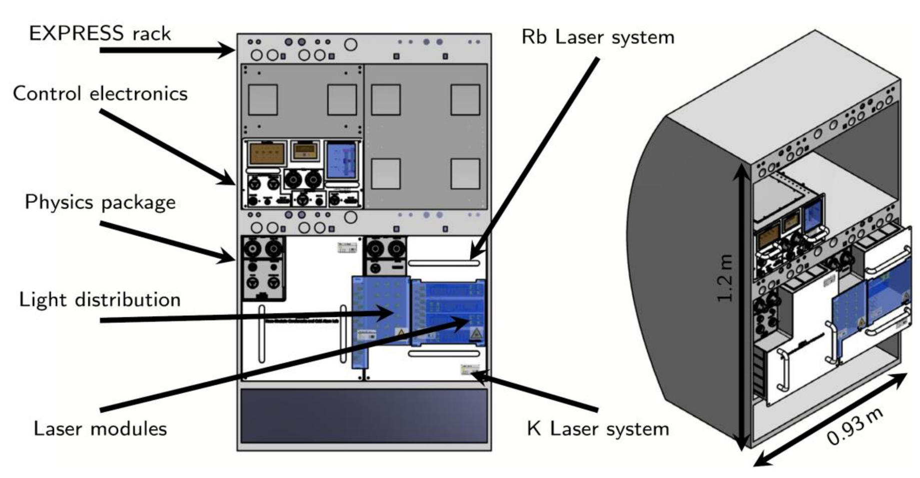
The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) will be a facility for conducting experiments with ultra-cold atoms and Bose-Einstein Condensates (BECs) aboard the International Space Station (ISS). BECCAL will enable fundamental research as well as the development of future quantum sensors based on matter-wave interferometry. The long term microgravity conditions on the ISS offer a unique environment for precision measurements.

BECCAL facility

Housed in an EXPRESS rack within Destiny module aboard the ISS.

Payload specification:
- Mass: 328 kg
- Power consumption: 1.3 kW
- Volume: 1x 66 l + 2x 164 l

Operation:
- Remote controlled from ground
- Persistent µg environment
- Multi-user, multi-purpose facility



CAD-drawing of BECCAL Facility in EXPRESS rack [2].

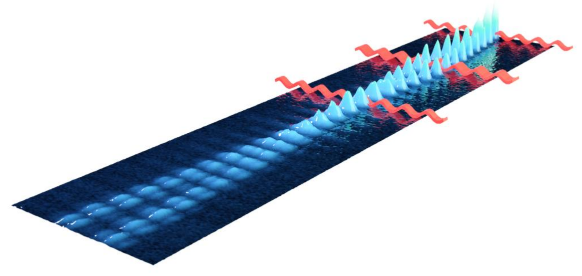
[2]

Quantum sensors

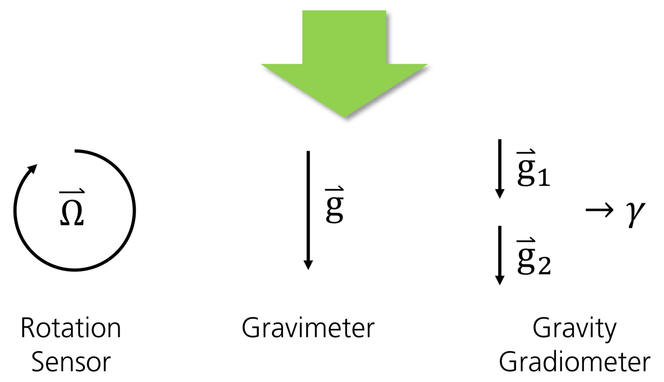
Matter-wave interferometry with neutral atoms.

Absolute measurement of:
- Rotation
- Acceleration

Applications:
- Fundamental tests (universality of free fall, …)
- Gravitational wave detection
- Navigation
- Earth observation



Mach-Zehnder like light-pulse atom interferometer [1].

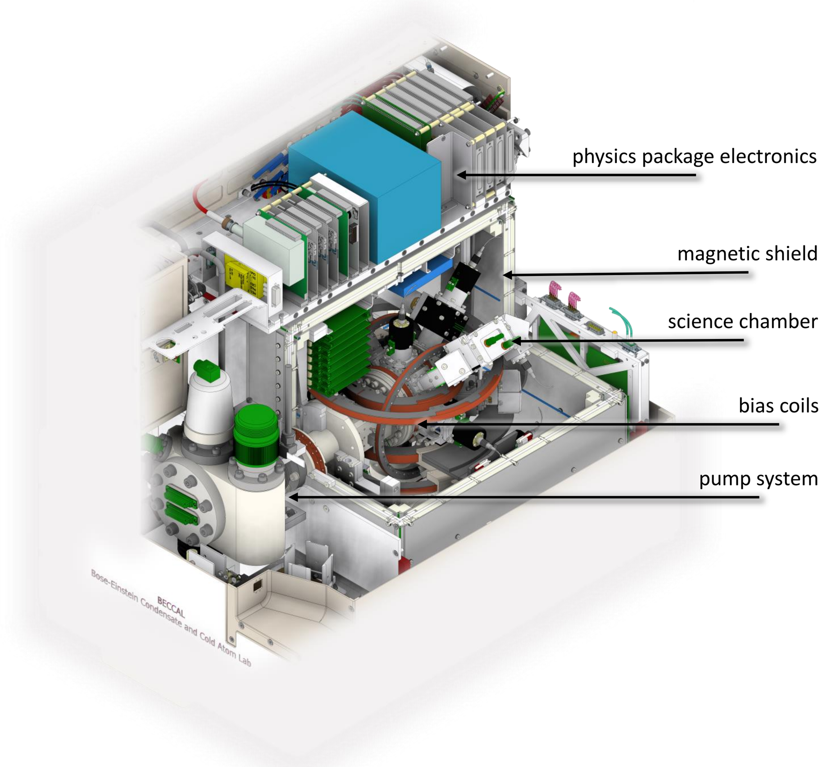


[1]

Physics Package locker

Includes:
- Physics Package electronics
- Ultra-high vacuum system
- Magnetic shielding
- Interfaces to other lockers

Ultra-high vacuum system:
- Pump system
- 2D⁺-MOT preparation chamber
- Science chamber with atom chip



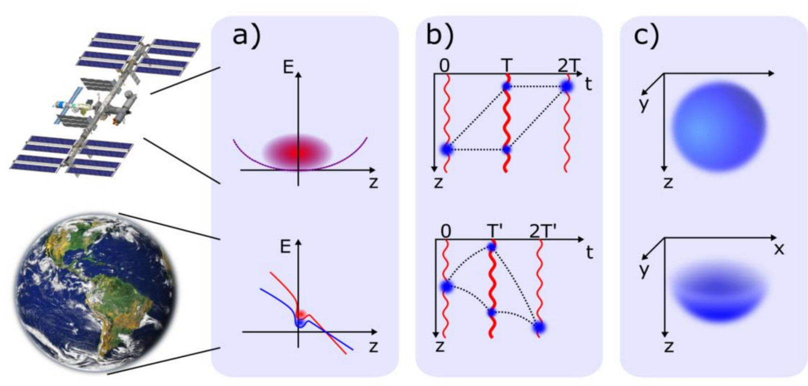
[2]

Space-borne quantum sensors

Unique environment for experiments.

Features:
- Optimised overlap of different species (a)
- Avoids gravitational sag (a, c)
- Extends free-fall times (b)

Applications:
- Testing universality of free fall
- Inertial measurements
- Geodesy
- Gravitational wave detection



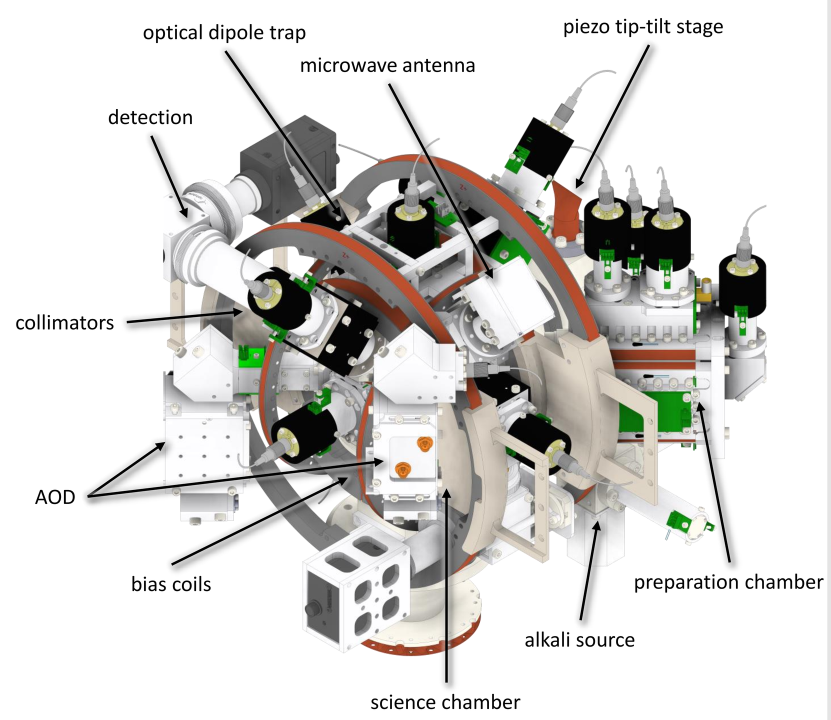
Advantages of space-borne quantum sensor compared to earth-bound systems [2].

[2]

Physics Package / vacuum system

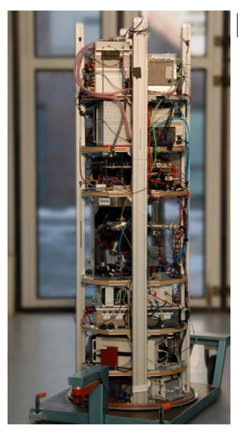
Features:
- Rubidium & Potassium atoms
- Rapid BEC production
- Magnetic traps
- RF & MW fields
- Atom interferometry
- Rotation compensation
- Optical dipole traps at 764 nm & 1064 nm

Testbed for future quantum sensors in space.



[2]

Microgravity and space heritage



[3]

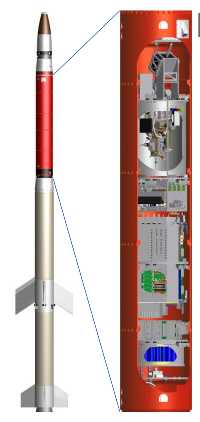
QUANTUS-1

Drop tower capsule:
- >400 drops
- BEC-flux: 10^4 atoms/10 s
- Interferometer: 2T=675 ms
- 1st BEC in µg

[4]

QUANTUS-2

Drop tower capsule:
- >370 drops, 9x catapulted
- BEC-flux: 10^5 atoms/s
- Delta-kick collimation in µg
- U_{kin} = 38 pK



[5]

MAIUS-A

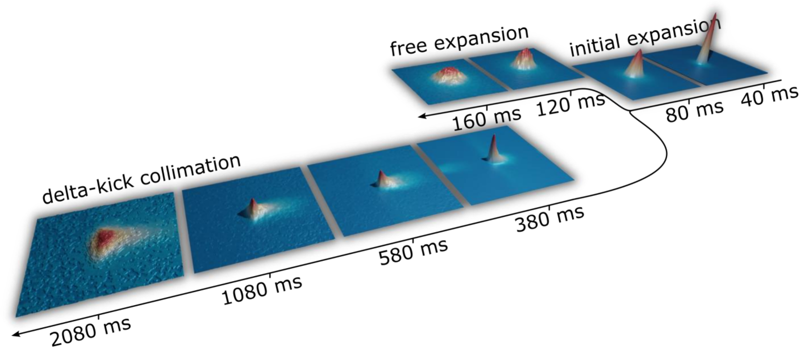
Sounding rocket:
- 6 min in space
- 1st BEC in space
- 1st atom interferometer in space

[3 – 11]

Conclusion

BECCAL features:
- Rubidium & Potassium atoms
- Magnetic & optical traps
- Atom interferometry
- Total time of flight up to 10 s

Ideas for experiments in BECCAL:
- Matter-wave collimation
- Core-shell / bubble trap geometries
- Matter-wave interferometry (accelerometer, multi-loop, etc.)
- Dual-species atom-optics experiments



Absorption images of free-falling, delta-kick collimated BECs in microgravity with U_{kin} = 38 pK obtained with QUANTUS-2 [4].

[2,4]

References:

[1] image by: H. Ahlers, CC BY 4.0, creativecommons.org/licenses/by/4.0
[2] Frye et al., EPJ Quantum Technology **8**, 1 (2021), images under CC BY 4.0, creativecommons.org/licenses/by/4.0
[3] H. Müntinga, PhD thesis (2019)
[4] image by: C. Deppner, CC BY 4.0, creativecommons.org/licenses/by/4.0
[5] M. Lachmann, PhD thesis (2020), image under CC BY 3.0 DE - http://creativecommons.org/licenses/by/3.0/de/
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DLR