# Zerodur based optical systems for precision measurements in space

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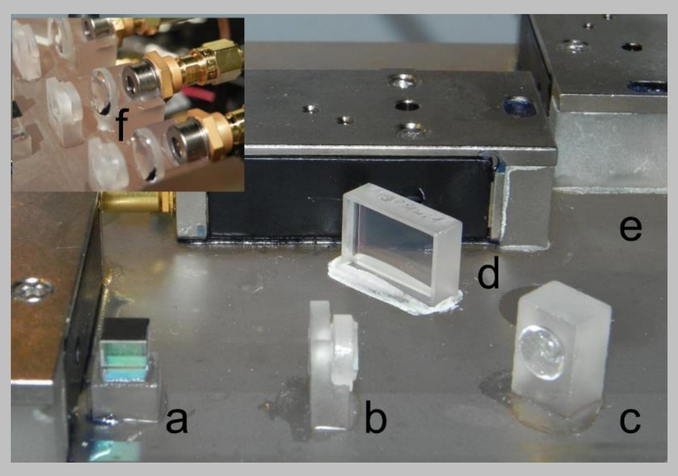
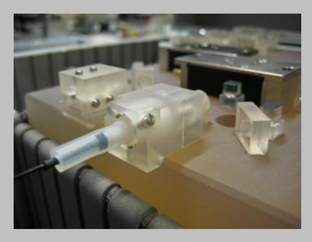
## Zerodur as material for optical benches

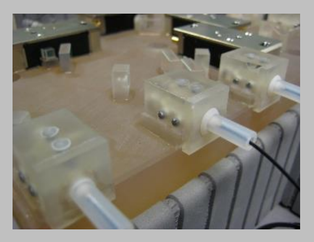
Space applications provide extended times of microgravity and thereby promise to improve the precision of interferometric measurements with matter waves. However, satellite environments or rocket launches pose stringent requirements on the employed components in terms of thermal and mechanical stress.

To pave the way for the next generation of quantum precision experiments in µg, we developed an optical bench technology based on Zerodur within the project "Lasus". The components and integrated systems benefit from the vanishing thermal expansion of Zerodur (<0.1 x $10^{-6}$ $K^{-1}$) and its mechanical robustness.

## Individual components

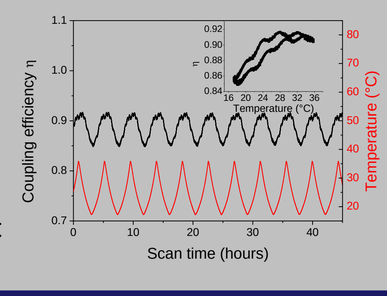


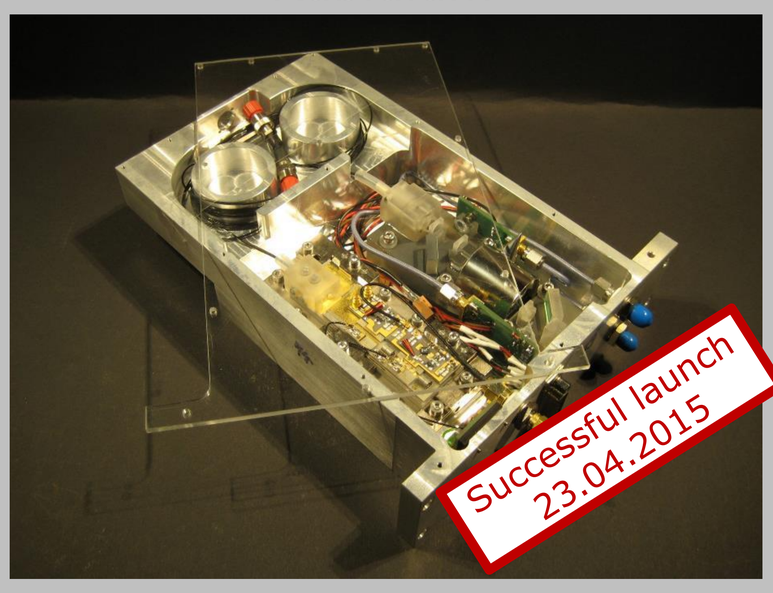


**Zerodur opto-mechanics:**

a. PBS mount
b. Rotation mount for wave-plates/polarizers
c. Adjustable mirror
d. Fixed mirror
e. AOM mount
f. Photodiode with lens mount

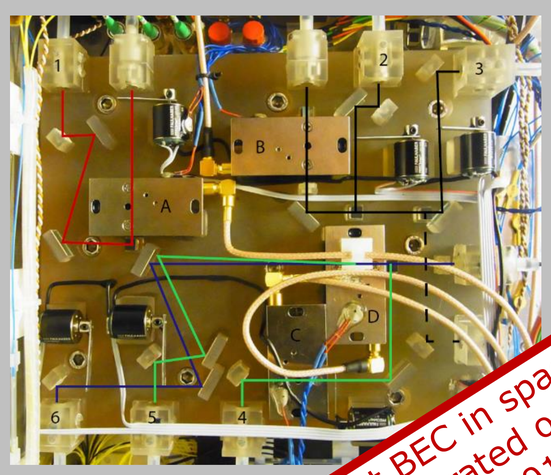



## Optical frequency reference for space applications: Rubidium



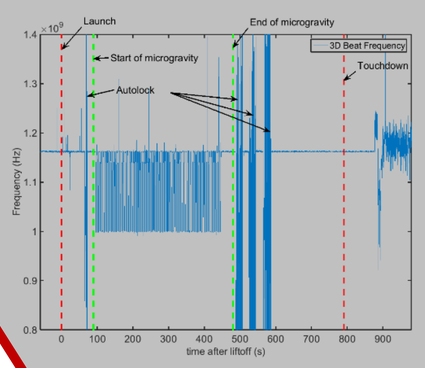

- Part of the FOKUS missions on TEXUS 51 and 53
- Micro-integrated DFB-Laser which was fiber coupled using a Zerodur fiber-coupler
- Spectroscopy unit on a Zerodur optical bench (footprint: 100x40 mm²) capable of stabilizing a Laser's frequency via FMS onto an atomic transition of Rb

## Optical system for the BEC and atom interferometry experiment MAIUS-1

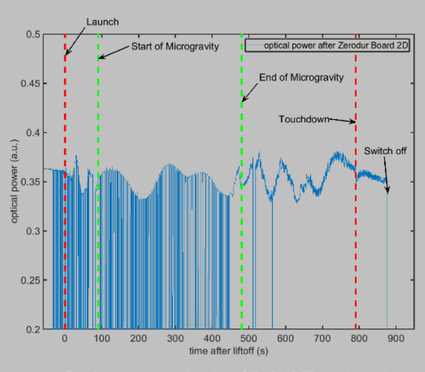



V = (27x34x23) cm³, m = 27 kg

First BEC in space generated on 23.01.2017



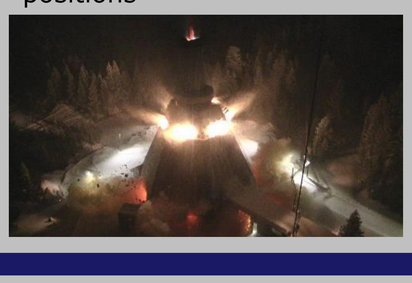

3D Beat Frequency during the MAIUS-1 flight



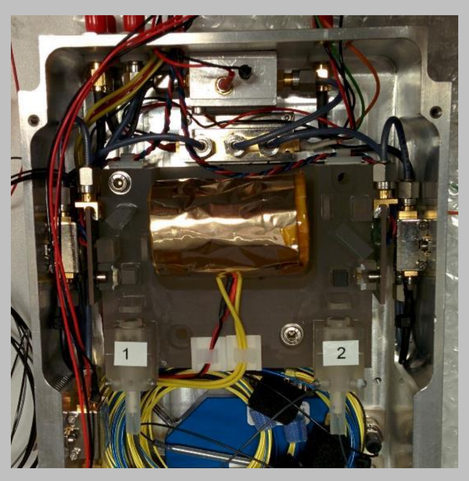

Optical power in the 2D-MOT during the MAIUS-1 flight

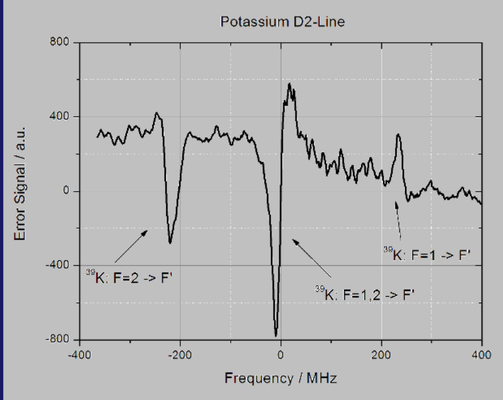
Switching and Spectroscopy modules providing the full functionality for a proof-of-principle Rb atom interferometer on a sounding rocket:

- 4 fibers for 2D+ MOT operation
- 4 fibers for 3D MOT operation
- 2 fibers for Bragg diffraction
- 1 fiber for absorption detection
- Autonomous Frequency stabilization within <10GHz of atomic transition
- Switching times <10µs
- Intensity tunable by AOMs
- Monitoring of optical intensities and system temperatures at several positions



## Optical frequency reference for space applications: Potassium

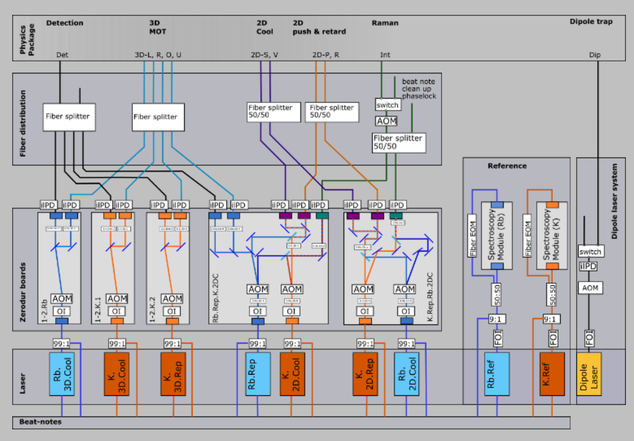


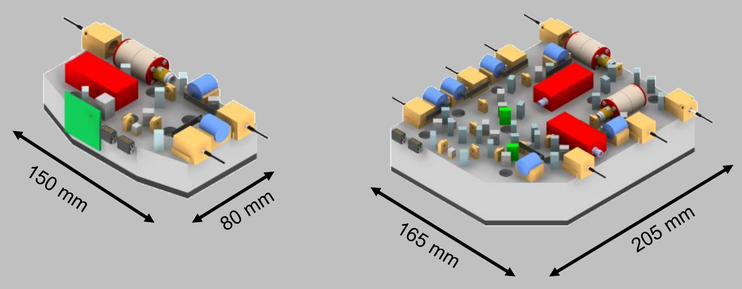

- Developed within the KALEXUS-project
- Footprint: 100x85mm²
- Doppler-free error signal generation for two separate micro-integrated ECDLs at 767nm
- Heating of spectroscopy cell to compensate for low vapor pressure
- Fully redundant design via two separated light paths
- Part of the TEXUS 53 campaign

Successful launch 23.01.2016

## Next generation modules for the dual species atom interferometer mission MAIUS-2/3



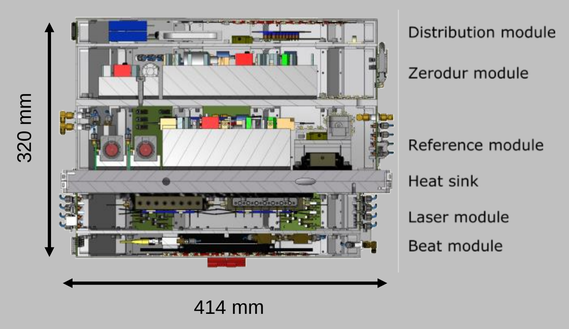

Scheme of the Laser System for the MAIUS-2/3 missions




Design of two of the five switching boards for MAIUS-2/3

Optical system for switching, distribution and frequency stabilization for a dual species atom interferometer on a sounding rocket:

- Modular approach to meet the even more stringent volume and weight constraints than in MAIUS-1
- Additional implementation of free space optical isolators
- Two spectroscopy modules which generate FMS- as well as MTS-signals for frequency stabilization to Rb as well as K
- 5 modules for switching, pulse generation and intensity control for cooling, trapping and atom interferometry of Rb and K
- Fiber based distribution for the beams to the physics package and for the frequency offset stabilization

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