# Examining Einstein—precise experiments using lasers in space

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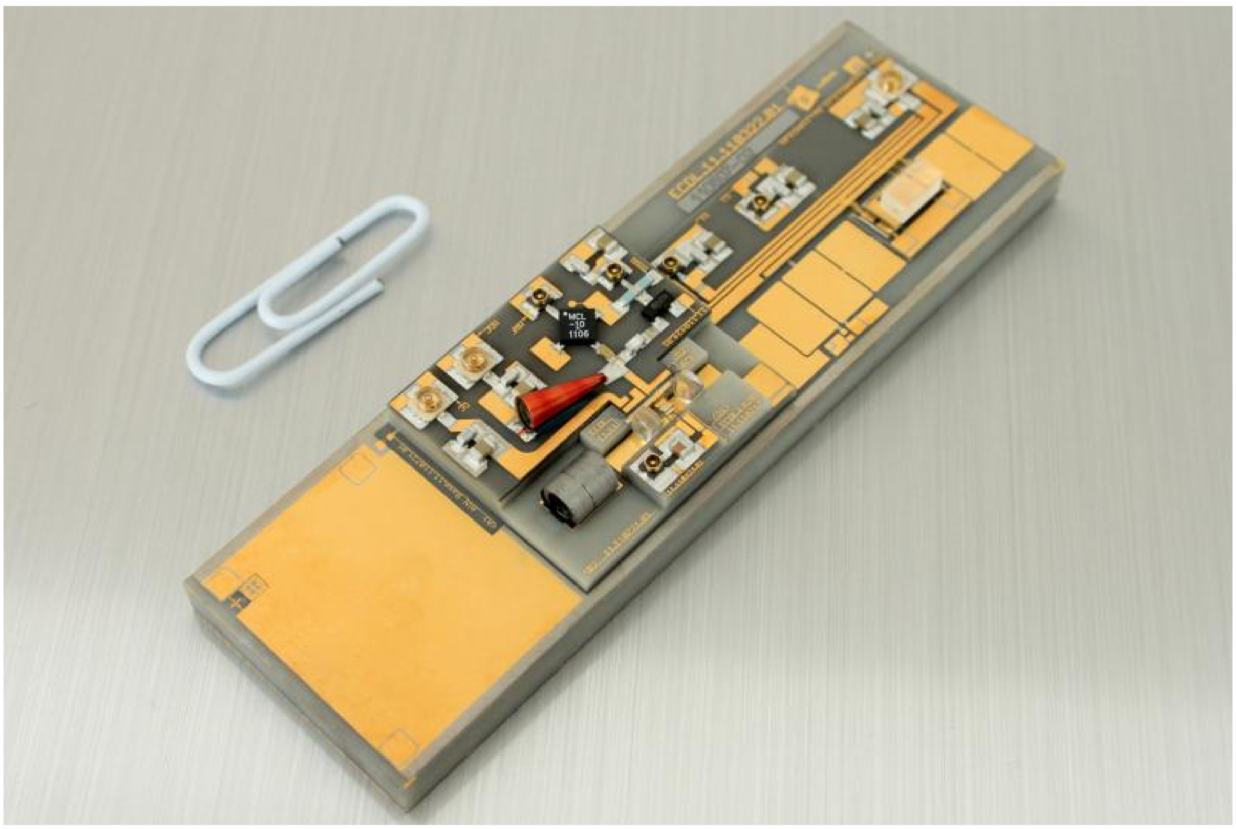

Micro-integrated Extended Cavity Diode Laser (ECDL) for laser spectroscopy of rubidium atoms in space. This module has been used on April 23 for tests on board the FOKUS research rocket aiming to demonstrate whether there really are no differences in how clocks run differently under space conditions like Einstein claimed. Credit: FBH/P.Immerz

Tests carried out in zero-gravity on board the FOKUS research rocket. Successful demonstration of technology for the QUANTUS mission.

Albert Einstein tells us that clocks run slower the deeper they are in the gravitational potential well of a mass – the closer they are to a heavenly body, for example. This effect is described by General Relativity Theory as the gravitational red shift – it is detectable in spectral lines that shift toward the red end of the spectrum. General Relativity Theory also predicts that the rates of all clocks are equally influenced by gravitation independent of how these clocks are physically or technically constructed. However, more recent theories of gravitation allow for the possibility that the type of clock indeed influences the degree of gravitational red shift.

To test this theory-about-a-theory, project FOKUS funded by the German Aerospace Centre (DLR) today launched a high-altitude research rocket to send various types of clocks into space and back again. This is where the most suitable experimental conditions are found because of the large gradient in the gravitational potential (gravity varies there a lot). This permits testing whether there really are differences in how clocks run – and in the end, also whether one of the newer theories of gravity provides a more exact description than Einstein did. The first experiments in space have now been successfully carried out. A team of scien-tists launched an extremely stable quartz oscillator into space that ticks like a modern wrist-watch – but at a very high frequency – together with a complete laser system for purposes of comparison. The centerpiece of the laser system is a micro-integrated semiconductor mod-ule that was developed and tested by the Ferdinand-Braun-Institut, Leibniz-Institut für Höch-stfrequenztechnik (FBH) in Berlin. The integration of entire laser system took place at Hum-boldt-Universität zu Berlin (HU Berlin). The frequency of the semiconductor laser was stabi-lized by locking it to a specific electron transition of a rubidium atom in an advanced module developed by Universität Hamburg. These rubidium atoms in conjunction with the lasers pro-vide an "optical atomic clock" that works according to a different physical principle that the quartz clock and "ticks" about ten million times faster than the quartz unit. To compare how the two clocks run, the company leading the project, Menlo Systems, is employing an optical frequency comb they developed.

Zero-gravity on board the FOKUS research rocket. Credit: Photo Astrium

The scientists demonstrated with the tests for the first time that these types of "optical atomic clocks" and the laser systems required for them can be employed in space for testing gravita-tional red shift and other precision measurements. The demanding demonstration of the technology also allowed them to lay the technical foundations for examining Einstein's equiv-alence principle using potassium and rubidium atomic interferometers under the MAIUS pro-ject. MAIUS is part of the QUANTUS mission funded by DLR in which new technologies in-volving quantum physics will be developed for cooling, entangling, and manipulating atoms. It should also advance miniaturizing the laser modules and testing a fully automated quantum sensor in space. The long-term objective in this case is to examine Einstein's equivalence principle by which the acceleration of a body by a gravitational field is independent of the nature of the body – i. e. all objects subjected to the same gravity "fall at the same speed".

## Compact and extremely robust diode laser modules for space from FBH

Countless drop-tower experiments at the Center of Applied Space Technology and Micro-gravity (ZARM), University of Bremen were used to prepare for the sophistiacted experiment in space. The laser module was built at the Ferdinand-Braun-Institut through the Joint Lab Laser Metrology together with the Optical Metrology research group at HU Berlin. The Joint Lab has been investigating and developing ultra-precise and extremely compact semiconductor laser modules for use in space for some time.

Their centerpiece is a DFB (distributed feedback) laser that emits light in an extremely narrow wavelength or frequency region. This narrow spectral band characteristic is one of the main requirements for the laser module needed for spectroscopy of the rubidium atoms and the associated precision measurements. With the help of a unique hybrid micro-integration technique, the diode laser chip is assem-bled together with electronic and optical components into an exceedingly compact, space-certified package. The palm-sized modules absolutely have to operate flawlessly under the extremely harsh conditions of space. They are subjected to heavy mechanical loading during liftoff when the acceleration rises to eight times' that of Earth's gravity.

"Our integration tech-niques can even withstand up to 30-times' Earth's gravity," says Dr. Andreas Wicht, head of the Laser Metrology Group at FBH, who views his group as well-prepared for future chal-lenges. "In addition, we are working on even narrower bandwidth lasers with a hybrid inte-grated optical amplifier that is highly suited to even more complex experiments." FBH is ex-panding its know-how in both the area of precision optical and spectroscopic measurements. These represent some of the most precise and exact measurement techniques of our time and will open up further applications.

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