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COMPUTE BEFORE FLIGHT

HOW THE VIRTUAL ENGINE CAN ADVANCE AERONAUTICS RESEARCH

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WITHIN A FRACTION OF A SECOND

Achieving improved positioning and timing with an iodine clock, a frequency comb and a laser terminal

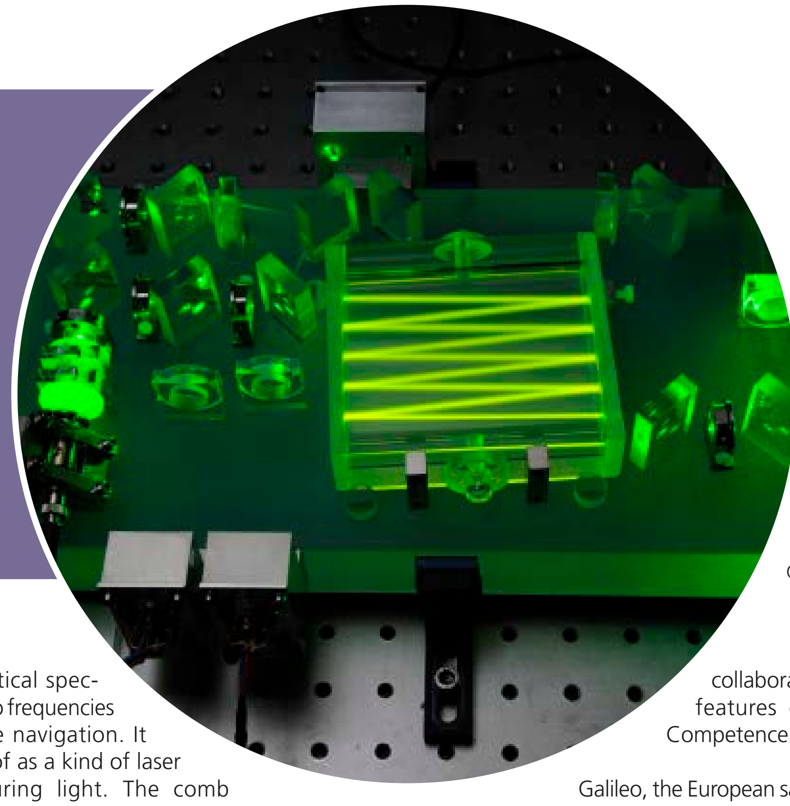
by Katja Lenz

For thousands of years, people have been inventing better time-measuring devices. Yet mechanical clocks, which include wristwatches and pocket watches, are still inaccurate by one second a day. For quartz clocks, which use an electronic oscillator regulated by a quartz crystal, this reduces to one second a year. Atomic clocks, however, lose about one second every million years. These are based on the vibrational frequency of certain atoms. In the case of laser-optical clocks, it takes a billion years for it to be maybe one second off. It is hard to imagine more accuracy than that. This type of optical clock – more precisely an iodine-based atomic clock – is the focus of the Compasso project, which aims to make the Galileo system more precise than ever before.

But what do clocks have to do with navigation? "Clocks are a key technology in any satellite navigation system," says Stefan Schlüter, Compasso Project Manager at DLR's Galileo Competence Center. Satellites are constantly sending out signals that allow the recipients to determine their location. The more precisely the signal propagation time between the transmitter and receiver can be determined, the more exact the positioning. In addition to optical clocks, researchers at the newly founded Galileo Competence Center at the DLR site in Oberpfaffenhofen are also working on a frequency comb and a terminal that can be used by future generations of Galileo satellites.

How does an optical clock work?

Generally speaking, a clock consists of a pendulum that oscillates as regularly as possible, together with a counter that records these oscillations. The faster the oscillation, the finer the time measurement. In optical clocks, an atom serves as the 'pendulum'. "The atom emits at a defined wavelength in the optical frequency range – in visible light, in other words," says Stefan Schlüter. "In the Compasso project, this atom is molecular iodine with a wavelength of 532 nanometres." Light with this wavelength is green. The frequency comb acts as the interface between the optical spectrum and the radio frequencies used for satellite navigation. It can be thought of as a kind of laser ruler for measuring light. The comb consists of around 100,000 to 1,000,000 narrow-band laser frequencies. The combination of a frequency comb with an optical clock is necessary because the clocks oscillate extremely rapidly, and no other electronic devices are capable of counting these oscillations. The frequency comb converts their output so that the clocks can be used in combination with conventional systems.



The iodine-based frequency reference, in which a hyperfine line of iodine molecules is measured with a laser, can make the clocks of the Galileo satellites more precise. The frequency reference is being developed at the DLR Institute of Quantum Technologies under the leadership of Prof. Braxmaier and Dr Schuldt, whose many years of research in the field of quantum-optical scientific space missions led, among other things, to the Compasso mission concept.

The optical iodine clock has been developed by the DLR Institute of Quantum Technologies, and the frequency comb by its industry partner Menlo Systems. The laser terminal is manufactured by Tesat. Other DLR institutes are also involved. The laser terminal makes it possible to transmit the signal generated by the frequency comb and the time data to the ground, while at the same time providing highly accurate distance measurements. The focus on technology transfer and the close collaboration between research and industry are key features of the work conducted by the Galileo Competence Center.

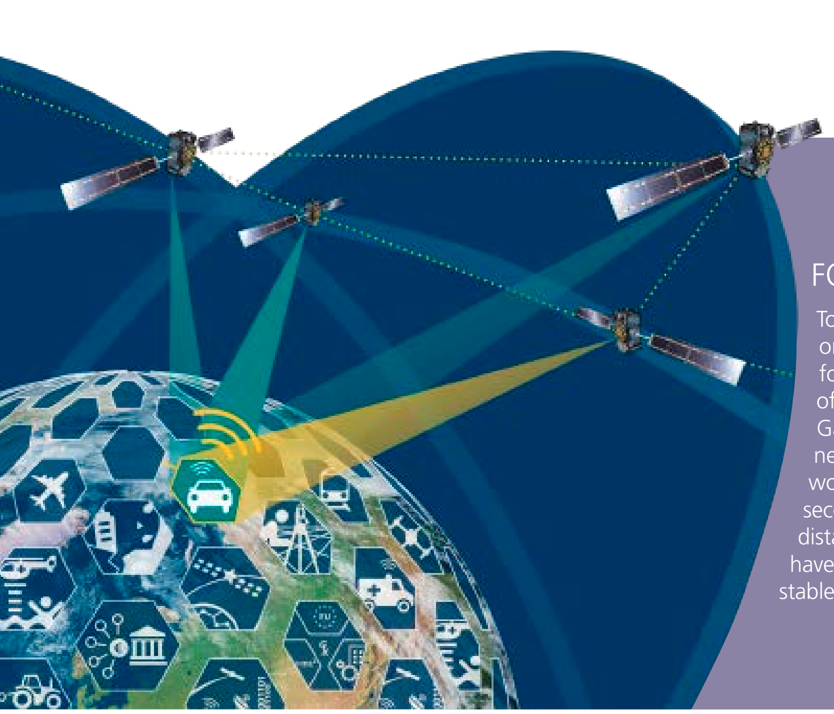
Galileo, the European satellite navigation system, has been in operation since 2016 and is still undergoing improvements. In a few years, 30 satellites will be orbiting the Earth at an altitude of 23,222 kilometres. Galileo is already highly accurate. "In comparison, however, the new technologies offer up to 10 times more accuracy and also more rapid position determination, ideally down to the centimetre range. In addition, the resilience and autonomy of the system would increase," explains Schlüter. This would be precise enough to show which lane a car was travelling in, and its distance from other vehicles. Accuracy is also important for satellite-based Earth observation, as time-series measurements can be used to detect changes on Earth's surface, such as water levels or glacial melting. It is also relevant to financial markets and energy supply – areas that do not require position determination but do require highly precise timing information. The smaller the subdivision of seconds, the more actions can be performed with an exact time stamp.

Compasso is expected to be operated from the Columbus Control Centre from 2025

THE GALILEO COMPETENCE CENTER

The Galileo Competence Center at the DLR site in Oberpfaffenhofen is working on the best navigation technologies that deliver the greatest benefits. It was founded in 2019 and officially opened in October 2021. Users, ground facilities and satellites are all given equal consideration here. The goal is to implement sustainable concepts and technologies for the European satellite navigation system and to contribute to the further development of Galileo. Some 40 personnel currently work for the Galileo Competence Center, and it is constantly expanding; it is expected to have 150 researchers by 2024.

One of its main tasks is the technical implementation and demonstration of future-proof concepts and technologies. The scientific basis for these is provided by DLR institutes and facilities with which the Galileo Competence Center works closely. It is thus able to draw upon well-founded scientific and technical expertise and years of experience with the requirements of various user groups. Another focus is the use and promotion of quantum technologies. With its expertise, the Center is intended to serve as a point of contact between policy makers, researchers, industry, the European Commission and other partners.



FOUR SATELLITES FOR ONE POSITION

To determine a position, the distance from the satellites to a receiver on Earth must be determined. This is derived from the time it takes for the signal from the satellite to reach the receiver. The positions of the satellites are known, but since the clocks of the user and the Galileo system are not synchronised, at least four satellites are needed to determine the absolute position. Satellite clocks have to work with extreme precision; a timing inaccuracy of just one millisecond results in an error of 300 kilometres on Earth – roughly the distance between Cologne and Bremen. The more satellites that can have their data received and work together, the more accurate and stable the position determination on Earth.

Test phase on the ISS 'research balcony'

Before they can be incorporated into satellites, these technologies need to be proven, first in a laboratory on Earth, and then on the International Space Station (ISS). The Galileo Competence Center is responsible for this. Together with industry, it is advancing the new technologies developed by DLR institutes so that they can be used for Galileo satellites and ground systems. The optical clock, frequency comb and laser terminal are expected to fly to the ISS on board a space transporter in 2025. When they arrive, they will be integrated onto the Bartolomeo platform – a balcony-like structure attached to the exterior of the European Columbus Module on the ISS. The platform offers five square metres of space for research in the space environment. The Compasso components will remain there for one and a half years, before returning to Earth for analysis.

How can precision benefit satellite navigation?

Compasso uses new quantum optical technologies. Compared with conventional systems, these developments promise greater precision and reliability, and will allow more application areas to be addressed. "The transport sector is no longer conceivable without global satellite navigation signals," says Schlüter. "This ranges from individual journeys, to rail, shipping and air transport, and all the way through to automated driving." Rail traffic collisions could be avoided by highly accurate positioning in rail transport. Shipping could optimise coastal and port navigation using these means, while maritime rescue operations would also benefit from more reliable positioning. In air transport, it would make precision landings possible even in the event of poor visibility. For agriculture, meanwhile, better navigation could lead to the more resource-efficient use of fertilisers and fuel.

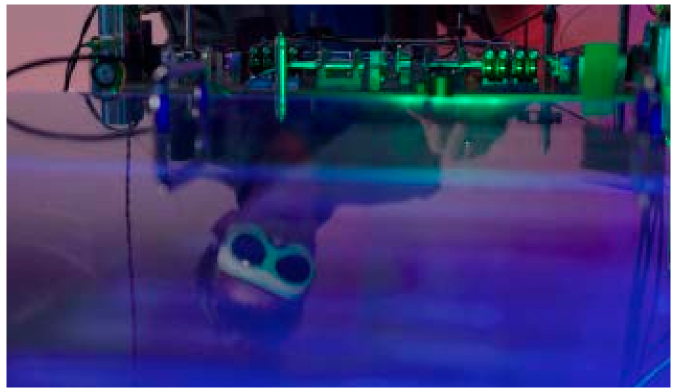
The name 'Compasso' comes from the first commercial scientific instrument developed by Italian astronomer Galileo Galilei (1564 to 1642) – a geometric and military 'compass'. This resembled a proportional compass – made up of a pair of rulers – and is considered to be a precursor of the slide rule. It could also be used to measure distances on nautical charts. In Galileo Galilei's day, navigation was still hampered by a great deal of uncertainty. But that is history; these days, navigation is determined based on tiny fractions of a second using highly accurate clocks.

Katja Lenz is a Media Relations editor at DLR.

DLR INSTITUTES AND FACILITIES INVOLVED IN THE COMPASSO PROJECT

- Galileo Competence Center
- Institute of Communications and Navigation
- Institute of Quantum Technologies
- Institute for Software Technology
- Space Operations and Astronaut Training
- Institute of Space Systems
- Institute of Optical Sensor Systems

Compasso project leader Stefan Schlüter checks the signals from the frequency comb



The iodine clock was developed by the Institute of Quantum Technologies. The technology is now being prepared for space with the Galileo Competence Center.

YOUR QUESTIONS ANSWERED

Our researchers answer questions from the community

Asking questions is key to improving your understanding of how and why things work as they do. Particularly in science, an inquiring approach is indispensable for addressing and better understanding complex topics. We regularly receive questions about a wide range of scientific subjects on our social media channels, by letter or by email. If you too have a question you would like to ask, please contact us at magazin@dlr.de.

Question from Tobias H. via email

I'm a commuter and interested in vehicles with alternative propulsion systems for environmental reasons. DLR's SLRV would be a realistic alternative to my current car. Does DLR have any concrete plans to offer the SLRV as a production car for private sale?

The Safe Light Regional Vehicle (SLRV) is a small vehicle powered by a fuel cell propulsion system. It has a sandwich panel chassis, so the car body weighs only 90 kilograms, and it is fuelled by hydrogen. Although it has already been driven on test tracks, it is a research prototype. In other words, DLR will use it for research, for its own projects and together with partners from industry and other scientific institutions. Before a vehicle like the SLRV could find its way onto the road, some further development and corresponding investment would have to happen – in terms of safety for road approval, design, equipment, storage compartments and full-body cladding for protection against moisture. Since DLR is a research institution that is largely publicly funded, we develop technologies up to the prototype phase. If there is interest, development for the market and series production is then the task of companies. Here, DLR can advise, support and license certain technologies or approaches, for example.

Michael Kriescher works in Vehicle Architectures and Lightweight Design Concepts at the DLR Institute of Vehicle Concepts

Question from Andrej D. via email

I recently saw the film 'Don't Look Up' in which an asteroid destroys Earth. Since then, I have kept revisiting this scenario. Could it actually happen that an asteroid will pose a serious threat to our planet in the near future?

You can sleep soundly! The probability of something happening to us in our lifetime as a result of an asteroid impact is almost zero.

Of the slightly more than one million asteroids known today, almost all orbit the Sun between Mars and Jupiter. Of those that have a diameter of more than 100 metres, about 27,000 follow orbits that also take them into the inner Solar System and, in some cases, they cross Earth's orbit. These Earth orbit crossers – we refer to them as Near Earth Objects (NEOs) – are observed very closely by telescope to keep track of their precise trajectories. None of them are currently expected to collide with Earth this century. However, some of them, and this is also correct, will come close to Earth in the coming decades: These are the 'potentially hazardous asteroids' that pass Earth at a distance of less than seven and a half million kilometres. Even this group, about a fifth of the known NEOs, does not contain an asteroid that will hit Earth. The flyby distances are usually at least several tens of thousands of kilometres, and most are further away than the Moon (400,000 kilometres). We do not really know how the orbits of these asteroids will change as they fly close to Earth – that is, whether they will come closer to it at their next encounter or whether they will move further away.

Bodies smaller than 100 metres are not all known; these too can cause considerable damage. Examples are the 60-metre asteroid that destroyed forests in the Tunguska region of Siberia over an area the size of Berlin in 1908, or as recently as 2013, the 20-metre asteroid that exploded at an altitude of 30 kilometres above the city of Chelyabinsk in Western Siberia, causing thousands of windowpanes in the city of millions to shatter (but without any fatalities). According to our current knowledge, events like Tunguska happen once or twice per century.

Ulrich Köhler is responsible for public relations at the DLR Institute of Planetary Research

Cover image
Engines are the heart of aircraft propulsion systems. At DLR, they are put through their paces – digitally on a computer and in real life on test rigs such as the Multistage Two Shaft Compressor Test Facility (M2VP) at the Institute of Propulsion Technology in Cologne. As in many areas, the importance of simulations is also increasing in research. In aviation, for example, DLR researchers are developing a platform on which they are testing new concepts and ideas for virtual engines.

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