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News Release

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Pinpointing the orientation of the Earth's axis using the world's most stable ring laser

First ever direct measurement of the Earth's rotation

A group with researchers at the Technical University of Munich (TUM) are the first to plot changes in the Earth's axis through laboratory measurements. To do this, they constructed the world's most stable ring laser in an underground lab and used it to determine changes in the Earth's rotation. Previously, scientists were only able to track shifts in the polar axis indirectly by monitoring fixed objects in space. Capturing the tilt of the Earth's axis and its rotational velocity is crucial for precise positional information on Earth – and thus for the accurate functioning of modern navigation systems, for instance. The scientists' work has been recognized an Exceptional Research Spotlight by the American Physical Society.

The Earth wobbles. Like a spinning top touched in mid-spin, its rotational axis fluctuates in relation to space. This is partly caused by gravitation from the sun and the moon. At the same time, the Earth's rotational axis constantly changes relative to the Earth's surface. On the one hand, this is caused by variation in atmospheric pressure, ocean loading and wind. These elements combine in an effect known as the Chandler wobble to create polar motion. Named after the scientist who discovered it, this phenomenon has a period of around 435 days. On the other hand, an event known as the "annual wobble" causes the rotational axis to move over a period of a year. This is due to the Earth's elliptical orbit around the sun. These two effects cause the Earth's axis to migrate irregularly along a circular path with a radius of up to six meters.

Capturing these movements is crucial to create a reliable coordinate system that can feed navigation systems or project trajectory paths in space travel. "Locating a point to the exact centimeter for global positioning is an extremely dynamic process – after all, at our latitude, we are moving at around 350 meters to the east per second," explains Prof. Karl Ulrich Schreiber who directed the project in TUM's Research Section Satellite Geodesy. The orientation of the Earth's axis relative to space and its rotational velocity are currently established in a complicated process that involves 30 radio telescopes around the globe. Every Monday and Thursday, eight to twelve of these telescopes alternately measure the direction between Earth and specific quasars. Scientists assume that these galaxy nuclei never change their position and can therefore be used as reference points. The geodetic observatory Wettzell, which is run by TUM and Germany's Federal Agency for Cartography (BKG), is also part of this process.

In the mid-1990s, scientists of TUM and BKG joined forces with researchers at New Zealand's University of Canterbury to develop a simpler method that would be capable of continuously tracking the Chandler wobble and annual wobble. "We also wanted to develop an alternative that would enable us to eliminate any systematic errors," continues Schreiber. "After all, there was always a possibility that the reference points in space were not actually stationary." The scientists had the idea of building a ring laser similar to ones used in aircraft guidance systems – only millions of times more exact. "At

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the time, we were almost laughed off. Hardly anyone thought that our project was feasible," says Schreiber.

Yet at the end of the 1990s, work on the world's most stable ring laser got underway at the Wettzell observatory. The installation comprises two counter-rotating laser beams that travel around a square path with mirrors in the corners, which form a closed beam path (hence the name *ring* laser). When the assembly rotates, the co-rotating light has farther to travel than the counter-rotating light. The beams adjust their wavelengths, causing the optical frequency to change. The scientists can use this difference to calculate the rotational velocity the instrumentation experiences. In Wettzell, it is the Earth that rotates, not the ring laser. To ensure that only the Earth's rotation influences the laser beams, the four-by-four-meter assembly is anchored in a solid concrete pillar, which extends six meters down into the solid rock of the Earth's crust.

The Earth's rotation affects light in different ways, depending on the laser's location. "If we were at one of the poles, the Earth and the laser's rotational axes would be in complete synch and their rotational velocity would map 1:1," details Schreiber. "At the equator, however, the light beam wouldn't even notice that the Earth is turning." The scientists therefore have to factor in the position of the Wettzell laser at the 49th degree of latitude. Any change in the Earth's rotational axis is reflected in the indicators for rotational velocity. The light's behavior therefore reveals shifts in the Earth's axis.

"The principle is simple," adds Schreiber. "The biggest challenge was ensuring that the laser remains stable enough for us to measure the weak geophysical signal without interference – especially over a period of several months." In other words, the scientists had to eliminate any changes in frequency that do not come from the Earth's rotation. These include environmental factors such as atmospheric pressure and temperature. They relied predominantly on a ceramic glass plate and a pressurized cabin to achieve this. The researchers mounted the ring laser on a nine-ton Zerodur base plate, also using Zerodur for the supporting beams. They chose Zerodur as it is extremely resistant to changes in temperature. The installation is housed in a pressurized cabin, which registers changes in atmospheric pressure and temperature (12 degrees) and automatically compensates for these. The scientists sunk the lab five meters below ground level to keep these kinds of ambient influences to a minimum. It is insulated from above with layers of Styrodur and clay, and topped by a four-meter high mound of Earth. Scientists have to pass through a twenty-meter tunnel with five cold storage doors and a lock to get to the laser.

Under these conditions, the researchers have succeeded in corroborating the Chandler and annual wobble measurements based on the data captured by radio telescopes. They now aim to make the apparatus more accurate, enabling them to determine changes in the Earth's rotational axis over a single day. The scientists also plan to make the ring laser capable of continuous operation so that it can run for a period of years without any deviations. "In simple terms," concludes Schreiber, "in future, we want to be able to just pop down into the basement and find out how fast the Earth is accurately turning right now."

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