FRAUNHOFER INSTITUTE FOR APPLIED OPTICS AND PRECISION ENGINEERING IOF

PRESS RELEASE

Measuring gravitational waves with glass

Fraunhofer IOF researchers develop highly sensitive glass sensors for the Einstein Telescope

Jena (Germany)

From 2035, the Einstein Telescope will be able to study gravitational waves with unprecedented accuracy. For the telescope, researchers from Jena have manufactured highly sensitive sensors made entirely of glass for the first time.

Gravitational waves are distortions of space-time caused by extreme astrophysical events, such as the collision of black holes. These waves propagate at the speed of light and carry valuable information about such events through the universe. In future, the Einstein Telescope will measure these waves with unprecedented precision, making it a world-leading instrument for detecting gravitational waves

In order to minimize the impact of noise on the measurements, the telescope is to be built up to 300 metres underground. But even there, there are still mechanical vibrations, caused for example by distant earthquakes or road traffic above ground. Highly sensitive vibration sensors will measure these remaining vibrations.

Researchers from the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena have developed and built these vibration sensors for the Einstein Telescope in collaboration with the Max Planck Institute for Gravitational Physics, Hanover (Albert Einstein Institute AEI).

Resonator for vibration sensors made entirely of silica glass for the first time

"Such a vibration sensor consists of two core components: a movable resonator and a laser that reads the movement of the resonator," explains Dr. Pascal Birckigt, the responsible sub-project manager at Fraunhofer IOF in Jena. The resonator was built in Jena and the laser was added in Hanover. "The mechanical resonator is the part of the sensor that converts the vibrations from the environment into a measurable movement, similar to a tuning fork."

Researchers at Fraunhofer IOF have created something that has never been seen before: a filigree mechanical resonator made of pure silica glass (>99.8% SiO_2). It combines a low natural frequency of 15 Hertz with a high-quality factor (>100,000) and a compact size of just five centimeters in diameter.

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"In future, the vibration sensors will be placed in the immediate vicinity of the approximately 200-kilogram mirrors in the Einstein Telescope's gravitational wave detectors," Birckigt continues. There will be three sensors per mirror. "Thanks to our resonators, the sensitivity of the sensors will be so high that they will be able to make the water waves of the Atlantic Ocean, which is prospectively 200 kilometers away from the telescope's location, clearly visible as peaks in the seismic spectra."

Complex sensor requirements: glass is the solution

The fact that the resonators are made entirely of glass is due to the complex requirements for the sensor: "There is very little space available for the sensors in the Einstein Telescope," explains Birckigt. "At the same time, the sensors have to be particularly powerful." Only with glass as a material could the requirements for compactness and low natural frequency be combined with high sensitivity. The reason for this is the so-called leaf springs inside the resonator.

The leaf springs are the heart of the resonator. They enable its low natural frequency, that is, the frequency at which the system begins to react to vibrations. This is necessary because the Einstein Telescope wants to measure low-frequency waves in the range between 3 and 30 Hertz. "There are two technical options to make this possible," explains Birckigt. "Either a large test mass is installed inside the resonator, which reacts to the external vibrations, or long, elastically deformable bending beams, known as leaf springs, are attached to the test mass

A large test mass is not possible due to the required compactness of the sensor. So the only solution was to use leaf springs, which the researchers made from glass: "Glass is a material characterized by its particularly high rigidity," explains Birckigt. "It shows practically no plastic deformation. It is therefore possible to produce paper-thin leaf springs from glass." In this case, paper-thin means that a single spring is 0.1 millimetres thick, seven centimetres long and weighs just 34 milligrams. A total of six such springs hold the three-gram test mass stably and aligned inside the resonator.

Special bonding process for manufacturing the glass resonator

The production of such a delicate yet powerful resonator is a complex process. It includes milling and polishing work as well as laser processing methods. Furthermore, a special plasma-activated bonding process is used to create a bond at atomic level between the glass surfaces of the resonator. "From now on, the two individual parts form a monolithic, that is permanent, unit," explains Birckigt, who was specifically responsible for the bonding processes for the production of the glass component in the project. "This makes the resonator extremely stable and precise." The researchers at Fraunhofer IOF want to further develop this special method of joining glass without any additional intermediate layer in the future. Their aim is to create even more complex, three-dimensional structures.

Application potential for space and semiconductor manufacturing

In the future, the new glass resonators can be used wherever systems need to be monitored with a number of compact acceleration or position sensors. In addition to gravitational wave research, this is the case with satellites, for example, for determining their orbits, measuring the earth's surface or inertial navigation. The resonators can also be used to improve the measurement accuracy of atomic interferometers and in EUV lithography systems for processing semiconductors.

Commissioning of the Einstein Telescope planned from 2035

The Einstein Telescope has been under continuous development since 2008. It is a highly sensitive gravitational wave detector, now in its third generation, with up to 10 times greater sensitivity than current detectors. According to the current schedule, construction is set to begin in 2028. The telescope is expected to begin its observations in 2035. According to current planning, the locations under consideration for the telescope are the Meuse-Rhine Euroregion in the border triangle of Germany, Belgium and the Netherlands, the Sos Enattos location in Sardinia, and the Bautzen-Kamenz-Hoyerswerda location in Lusatia.

The sensors were developed by researchers from Jena and Hanover as part of the "Glass Technologies for the Einstein Telescope" (GT4ET) project.

Fraunhofer IOF presents technologies at the "Space Day" on March 28

On March 28, the institute will provide information about the sensors for the Einstein Telescope and other technology highlights by Fraunhofer IOF in the field of space and space research with a public exhibition and lecture program as part of the Federal Action Day ("Tag der Raumfahrt").

Details can be found here: https://s.fhg.de/TdR-2025-en

Correction note (March 19, 2025):

The original version of this press release dated, March 11, 2025 included an incorrect sentence. It stated: "According to current plans, the Euregio Meuse-Rhine in the border region of Germany, Belgium and the Netherlands will be the location for the telescope." No decision has yet been made regarding the final location. Accordingly, this sentence has been corrected as follows: "According to current planning, the locations under consideration for the telescope are the Meuse-Rhine Euroregion in the border triangle of Germany, Belgium and the Netherlands, the Sos Enattos location in Sardinia, and the Bautzen-Kamenz-Hoyerswerda location in Lusatia." According to the current status, construction is scheduled to begin in 2028.

About Fraunhofer IOF

The Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena conducts application-oriented research in the field of photonics and develops innovative optical systems for controlling light - from its generation and manipulation to its application. The institute's range of services covers the entire photonic process chain from opto-mechanical and opto-electronic system design to the production of customer-specific solutions and prototypes. At Fraunhofer IOF, about 500 employees work on the annual research volume of 40 million euros.

For more information about Fraunhofer IOF, please visit:
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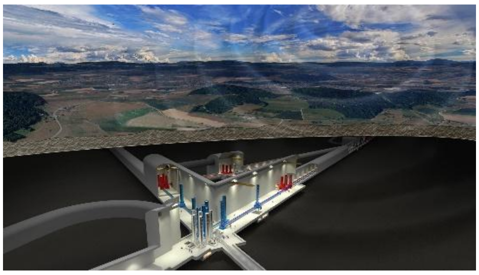
Press images

The following images can be downloaded from Fraunhofer IOF press area at https://www.iof.fraunhofer.de/de/presse-medien/pressemitteilungen.html.



Visualization of the planned Einstein Telescope. © Marco Kraan / Nikhef

Visualization: Gravitational waves are distortions of space-time caused, for example, by the collision of black holes. © Fraunhofer IOF

Researchers from Jena have manufactured highly sensitive resonators made entirely of glass for the vibration sensors of the Einstein Telescope. © Fraunhofer IOF

The monolithic glass resonator with paper-thin leaf springs is manufactured using a special joining process. © Fraunhofer IOF

The glass sensor as a drawing: Blue are the leaf springs, green is the test mass, gray is the outer frame, yellow is a mirror coating. © Fraunhofer IOF