World of Relativity explored by optical lattice clocks

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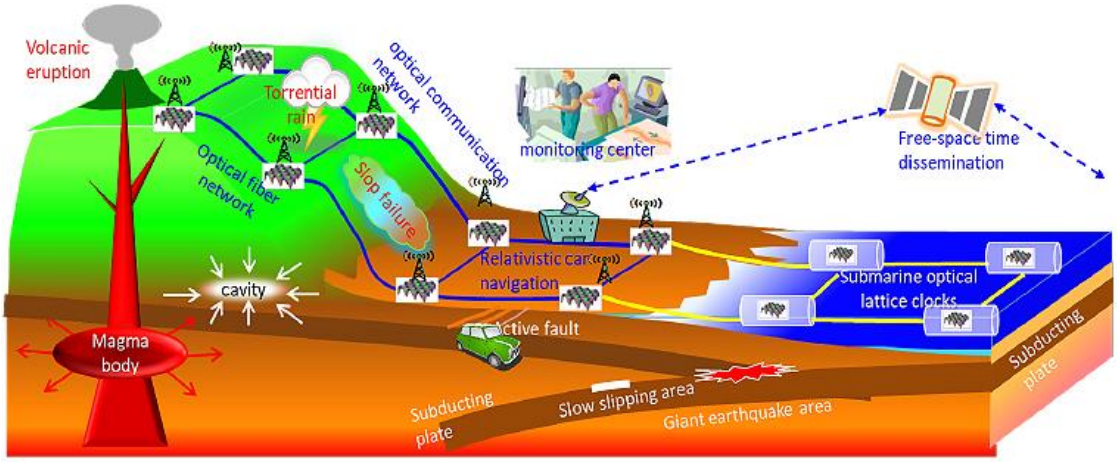

Optical lattice clocks network

Linked to the image: http://www.katori-project.t.u-tokyo.ac.jp/outline.html

Today, we cannot even walk around the city without Google Maps. The reason why we can always know our location with an error of only a few meters is that satellites are equipped with a very accurate clock called an atomic clock. The clock is defined by the current definition of a second and is off by only one second in 30 million years. An atomic clock may seem far removed from our everyday lives, but even without being aware of it, we humans depend on this ultimate precision in our daily lives. So, is there a clock with better accuracy? How does it benefit society?

The world's most accurate clock was invented by a Japanese researcher. The clock is called an optical lattice clock, which deviates by only one second in 30 billion years. Since the universe is said to be 13.8 billion years old, this clock would be off by less than one second even if it circled the universe twice from its creation to the present. The optical lattice clock is currently being studied in nearly 20 countries and is a strong candidate for the next generation definition of a second.

So, what can we do with optical lattice clocks that will make GPS even better? It can do even more than that. According to Einstein's famous theory of relativity, time moves differently in places with different gravitational forces. The way time flows between twins on the first and second floors of a building is also strictly different, with the person on the first floor getting a little younger. But the difference is too small to feel the effect of relativity in everyday life. However, with an optical lattice clock, this effect will occur on a human scale. With an optical lattice clock, a centimeter difference in height will cause the clock to go out of balance due to the difference in gravity.

By using an odd clock that is too accurate to be thrown off by changes in gravity, it is possible to see changes in gravity that are invisible to the eye.

Some examples of applications are presented below. The first is earthquake prediction. Have you ever heard of slow-slip phenomena? These are ground vibrations with periods ranging from less than one second to several months and have been pointed out to be related to large earthquakes. Recently, slow-slip phenomena have been observed intermittently in the Nankai region, and various opinions about the Nankai earthquake have been expressed. The optical grating clock can detect the types of ground changes caused by this slow-slip phenomena that are difficult to detect with existing technology[1]. Japan is an earthquake-prone country that needs to take national measures against earthquakes, and we expect that demand for optical grating clocks will increase as a powerful tool in this framework.

Next is the prediction of volcanic eruptions. During a volcanic eruption, magma moves significantly underground. Magma is generally very heavy, and its movement causes a change in gravity. It is thought that optical lattice clocks can detect such gravity changes occurring underground.

Finally, there is the use of optical lattice clocks in space. In addition to the ordinary matter as we know it, dark matter and dark energy are believed to exist in the universe, but their nature is still largely unknown. Dark matter is invisible to the eye and cannot be detected by many measurement methods, but since it affects gravity, it is hoped that gravitational changes caused by the presence of dark matter can be detected by an optical lattice clock placed in space[2].

In the 20th century, the two great theories, quantum mechanics and relativity, emerged. Humanity has benefited from quantum mechanics in everything around us, including the invention of the LED. In the 21st century, what will revolutionize human life is the theory of relativity. Optical lattice clocks bring the effects of relativity, which until now have only been considered on the cosmic scale, to the human scale. What will the relativistic worldview depicted by optical grating clocks deployed in various locations reveal to us? And what new and exciting things will emerge from it?

The optical lattice clock was born in Japan and is currently being developed one by one in laboratories, but its development is progressing day by day under competition in many countries. The iPhone was born 15 years ago when no one even thought of a smartphone and has evolved into the thin, large, and highly functional device that it is today. History has proven that if demand is stimulated and capital is invested, even dream-like devices can be realized. Let's work together in the industry, academia, government, and the world to further develop the optical lattice clock, a magical machine that will transport us to a new world and create a more wonderful world.

1. Tanaka. Y, *et al*, Exploring potential applications of optical lattice clocks in a plate subduction zone, Journal of Geodesy **95** 93 (2021).
2. Gulielmo M. Tino, *et al*, SAGE: A proposal for a space atomic gravity explorer, Eur,

Phys, J. D **73** 228 (2019).