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September 30, 2022

The Honda Prize 2022 Dr. Hidetoshi Katori, Professor, the Graduate School of Engineering, The University of Tokyo

―Invention of an optical lattice clock that only loses one second in 30 billion years

The Honda Foundation, the public interest incorporated foundation established by Soichiro Honda and his younger brother Benjiro and currently led by President Hiroto Ishida, is pleased to announce that the Honda Prize 2022 will be awarded to Dr. Hidetoshi Katori, Professor, the Graduate School of Engineering, The University of Tokyo (Chief Scientist and Team Leader, RIKEN) for his invention an optical lattice clock that is 1,000 times more precise than conventional atomic clocks.

The Honda Prize, established in 1980 and awarded annually, is an international award that recognizes the work of individuals or groups generating new knowledge that will drive the next generation from the standpoint of ecotechnology.[*1] Dr. Katori invented in 2001 a novel optical atomic clock that uses a large number of atoms trapped in an optical lattice to provide an ultra-high precision time and frequency standard. In contrast to the cesium atomic clocks[*2] that keep the International Atomic Time with an accuracy of about 15 digits[*3], the optical atomic clocks are expected to allow 18-digit precision by employing optical transitions that have tens of thousand times higher frequency than microwave frequency. At this precision, it takes 30 billion years to lose one second.

This precision enables relativistic geodesy capable of measuring a height difference of one centimeter on Earth based on the relativistic effect that time flows slowly for a strong gravitational field. For example, relativistic geodesy may be applied to disaster prevention, such as detecting the rise of volcanic magma by clocks set on the mountain. The high-precision clocks will open up new measurement technologies and research fields.

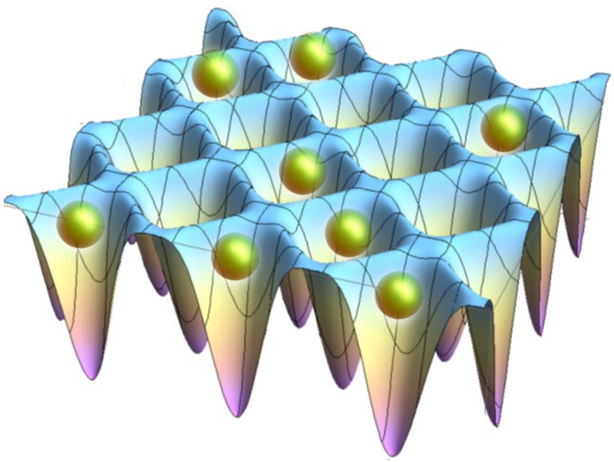
The origin of ecotechnology is in Soichiro Honda's words, "Make people happy with technology." The improvement in accuracy of one second is expected to have an immeasurable impact on mankind. The Prize will be awarded to Dr. Katori for this groundbreaking invention, which is worthy of the highest recognition.

<Research on the optical lattice clock by Dr. Katori>

The importance of precision time measurement is growing ever greater in modern society each year. It forms an infrastructure vital to all social activities, including the Global Navigation Satellite System (GNSS) with atomic clocks on board, timestamps used in e-commerce, and precision measurements employed in cutting-edge science and technology.

At present, the definition of "one second" in the International System of Units (SI) is based on the unperturbed ground-state hyperfine transition frequency of the cesium 133 atom. International Atomic Time based on the cesium atomic clocks (with a microwave frequency of approx. 9.2 GHz) has an accuracy of about 15 digits. However, the optical atomic clock that uses optical transitions with a higher than microwave frequency holds the potential to create atomic clocks with higher precision. The most promising candidate for an optical atomic clock has been considered to be a clock based on a singly trapped ion in which the transition frequency of a single ion, cooled to ultracold temperature and trapped between electrodes, is repeatedly measured over a million times to achieve 18-digit precision. As each measurement takes one second, a million seconds (10 days) of averaging time is required.

Instead of averaging one million seconds, Dr. Katori conceived of an optical lattice clock to dramatically reduce the averaging time by measuring many atoms at a time. Atoms are trapped in an optical lattice created by the standing wave of light*4 to reduce the Doppler effect caused by the atomic motion. At the same time, the quantum noise is reduced by averaging the signal from many trapped atoms. He proposed and demonstrated that the optical lattice does not affect the eigenfrequency of the atoms by tuning the laser to the magic wavelength*5 to create the lattice.



Schematic representation of an optical lattice
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Such high-precision atomic clocks have been mainly studied in the laboratory, as they are consisted of many components and are sensitive to environmental conditions. The research team led by Dr. Katori conducted an experiment to compare two downsized optical lattice clocks—one installed on the observation deck and the other on the ground floor of Tokyo SkyTree, which is a broadcasting tower in Tokyo. In April 2020, the team published a paper reporting that the clock on the deck ticked faster by 4/1,000,000,000 of a second per day than the clock on the ground. This triggered a huge response from around the world, as the experiment verified Einstein's general theory of relativity with a precision comparable to that of spaceborne experiments using rockets and satellites, despite a height difference of only 450 meters. This demonstration was the first step toward relativistic geodesy employing high-precision atomic clocks.

Dr. Katori is presently working on the further downsizing of the optical lattice clock. While the SkyTree clock has a volume of approximately 1,000 liters, a smaller machine with a volume of 1/5 is underdevelopment. When continuous and stable operation of such downsized clocks becomes possible, a network of optical lattice clocks can be realized by installing them in various locations. The clock network will not only provide time reference with a precision far higher than GNSS but also will be able to detect spacetime curved by gravity, thus allowing precision monitoring and investigation of the environment on the earth's surface, as well as the oceans, climate, and crustal movements. For example, real-time monitoring of crustal movements may be used to study precursors of earthquakes.

*1 Ecotechnology: a neologism combining imaging of the natural world (ecology), including civilization as a whole, and technology. Advocated by the Honda Foundation in 1979, it seeks new technological concepts required by human society to further the coexistence of people and technology.

*2 Cesium atomic clock: an atomic clock that uses the cesium 133 atom. Atomic clocks rely on the property of atoms to emit and absorb electromagnetic waves with a certain frequency. The duration for the electromagnetic waves to oscillate 9,192,631,770 times, which is generated by cesium transition, defines one second and is used to keep the International Atomic Time, since the 13th General Conference of Weights and Measures in 1967. The accuracy of the cesium clock corresponds to a loss of 1 second in 60 million years.

*3 International Atomic Time accuracy of about 15 digits: accurate enough to measure with a fractional accuracy with one part in 10^{15}.

*4 Standing waves: frequency waves with a fixed amplitude distribution in space.

*5 Magic wavelength: the wavelength where the polarizabilities of two electronic states used for the clock transition become equal. Because the polarizability of the atomic state depends on the electronic state, the light shift likewise differs with the electronic state. This results in a change in the resonant frequency of atoms trapped in the optical lattice. However, the optical lattice created with a laser tuned to the magic wavelength equalizes the polarizability for the two states and does not affect the resonant frequency of trapped atoms.

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Dr. Hidetoshi Katori

- Professor, Department of Applied Physics,
  Graduate School of Engineering, The University of Tokyo
- Chief Scientist, Quantum Metrology Laboratory /
  Team Leader, Space-Time Engineering Research Team,
  RIKEN Center for Advanced Photonics (RAP), RIKEN
- Program Manager, JST-MIRAI Program,
  Japan Science and Technology Agency

Born

September 27, 1964, Japan

Education and Qualifications

1988	B. Eng. in Applied Physics, Faculty of Engineering, The University of Tokyo
1990	M. Eng. in Applied Physics, Graduate School of Engineering, The University of Tokyo
1994	D. Eng. in Applied Physics, Graduate School of Engineering, The University of Tokyo

Scientific Positions

1991	Research Associate, Department of Applied Physics, Faculty of Engineering, The University of Tokyo
1994	Guest Scientist, Max Planck Institute for Quantum Optics, Garching, Germany
1997	Group Leader, ERATO Gonokami Cooperative Excitation Project, Japan Science and Technology Corporation
1999	Associate Professor, Engineering Research Institute, Faculty of Engineering, The University of Tokyo
2005	Associate Professor, Department of Applied Physics, Graduate School of Engineering, The University of Tokyo Principal Investigator, CREST, Japan Science and Technology Agency
2010～present	Professor, Department of Applied Physics, Graduate School of Engineering, The University of Tokyo
2010～2016	Research Director, ERATO Katori Innovative Space-Time Project, Japan Science and Technology Agency
2011～present	Chief Scientist, Quantum Metrology Laboratory, RIKEN
2014～present	Team Leader, Space-Time Engineering Research Team, RIKEN Center for Advanced Photonics (RAP), RIKEN
2014～2022	Distinguished Guest Professor, University of Tübingen
2018～present	Program Manager, Space-time information platform with a cloud of optical lattice clocks, JST-Mirai Program, Japan Science and Technology Agency

Awards

2001 Marubun Research Award

2005 The European Frequency and Time Award
The 1st JSPS (Japan Society for the Promotion of Science) Prize
Julius Springer Prize for Applied Physics

2006 Marubun Special Science Award
The 20th IBM Japan Science Prize

2008 Rabi Award

2010 The 42nd Ichimura Academic Award, Special Prize

2011 The 12th Optics and Quantum Electronics Achievement Prize (Hiroshi Takuma Award)
The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Prizes for Science and Technology, Research Category
The Philipp Franz von Siebold Prize

2012 Asahi Prize 2011

2013 The 53rd Toray Science and Technology Prize
The 54th Fujihara Award
Nishina Memorial Prize

2014 Medal with Purple Ribbon

2015 Japan Academy Prize

2016 JSAP (The Japan Society of Applied Physics) Outstanding Achievement Award 2015

2017 Leo Esaki Prize

2020 The 90th Anniversary Special Award from the Hattori Foundation
The Micius Quantum Prize 2020

2022 Breakthrough Prize in Fundamental Physics

Academic Society

The Physical Society of Japan, The Japan Society of Applied Physics, The Laser Society of Japan, American Physical Society, The Engineering Academy of Japan