General relativity and navigation: we do not get lost thanks to Einstein

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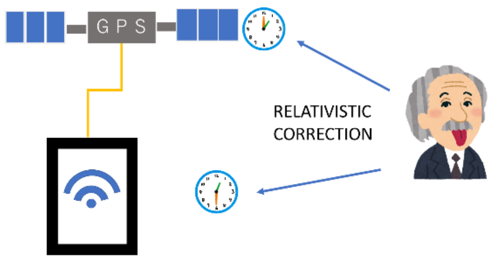
What do you think about when you hear the words “theory of relativity”? You may find it difficult, and it may not seem useful in our daily life. However, your life is supported by the applications of theory of relativity.

The origin of the theory was to explain problems in physics [1]. Without theory of special relativity, electromagnetic law changes when observed from moving person. They also failed to explain the experimental result that the speed of light never changes between observers moving different speeds. Albert Einstein, a German physicist, first solved this problem in 1905. He introduced a special treatment of space and time, and that solved these problems. In this theory, there are two main principles; (i) light speed is constant (ii) physics is same when no external force is acting. Ten years after that, he then made a general relativity. This theory has two main concepts; (i) laws of physics same in any reference frame (ii) in a small region we can think an inertial frame in which gravitational force equal to zero. These theories have changed physics drastically. For example, the concept of “time” had changed. Special treatment of space and time in special relativity revealed that time passes slower for moving objects than for stational objects, when observed from a stopping observer. Similar thing occurs when thinking about general relativistic effect. Gravitational potential changes the speed of time. When thinking about moving object in the universe, we often need to consider relativistic effect because velocity is fast or gravitational force is strong.

With relativistic theory, we can explain many phenomena. You may have heard one of them, “black hole.” Black hole is a region with extraordinarily strong gravity.

Anything, even light, cannot escape from the region. Black holes are of interest even today to understand the evolution of galaxies [2], and other cosmological problems. When black holes (or other massive objects) move, we can observe gravitational wave, which is also predicted in the theory of relativity. Another example of general relativistic effect is Mercury's perihelion. Planets are revolving around the sun in an elliptical orbit. Perihelion is a point at which a planet gets closer to the sun. Planetary orbits are not stable but changing with time due to other planets' gravity and other forces. We can calculate the effect of each planet on the perihelion shift. However, observed Mercury's perihelion shift was different from the sum of evaluated effects due to other planets. After general relativity is suggested, astronomers thought the theory would help precise calculations of perihelion shift, and it actually worked. Another example is Poynting-Robertson effect [3, 4]. Particles in the solar system absorb and re-emit radiation. Particles are moving around the sun, and the velocity of this movement cause the relativistic effect acting like a drag force. This effect is important in planetary rings. Jupiter rings evolve faster under the influence of the Poynting-Robertson effect. Particles are released from rings in about 100-10000 years, and this lifetime is noticeably shorter than Jupiter's age. Therefore, there need to be something like satellites that supply ring particles continuously and efficiently. As you can see from these examples, theory of relativity is necessary to understand astronomical phenomena accurately and that is why astronomers are interested in relativistic effect.

How can general relativity support our daily lives? One example is GNSS, Global Navigation Satellite System. GPS is the most famous one included in GNSS. You can find your position in the maps in your smartphones thanks to GNSS. These systems calculate your position by calculating the distances between us and GNSS satellites. To calculate the distances, in principle, they just calculate the product of light speed and the time consumed to reach to the device [5]. So how can this calculation be affected by relativistic theory? The key points are



gravity and velocity. The Earth's gravity is almost constant on the surface. However, at high altitudes, the gravitational force is smaller than on land. Therefore, gravitational force on the orbit of GPS satellite is smaller than that on land. According to general relativity, time goes faster when gravity is small. Also, when seen from the GNSS devices, the satellites are moving with nonzero velocity. According to special relativity, the time of moving object passes slower than stopping object. To summarize, relativistic effect causes the difference of time between the devices and the satellites. This difference of time (or the difference of "clocks") can cause error in calculation of the time consumed to reach to the device, causing the error of evaluation of distance between the satellites and devices. This error finally results in the error of evaluated position. Therefore, to precisely point out where we are, we need to add correction due to the relativistic effects. Without the correction, error in evaluating your position can even amounts to a few kilometers. GNSS with 1 km error is obviously no use. Without theory of relativity, you cannot point out where you are, and perhaps, you will get lost. This application of theory of relativity is not likely to be intended at first, but scientists' or engineers' inspiration make such applications possible. Both the research in basic science and inspirations in engineering are necessary to make our life better and you can be a part of such researchers by studying basic science .

I have not used any assistive tools to write this essay. I used Microsoft editor for spell check and errata of grammatical mistakes.

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