A New Source of Drift for Geostationary Satellites

By Avi Loeb on July 6, 2024


Earth. (Image credit: NASA)

At an altitude close to 35,786 kilometers above the equator, a satellite circling the Earth moves at a speed of 3.07 kilometers per second and completes an orbit around the Earth in exactly one sidereal day. This means that such a satellite would appear motionless to an observer on the ground, making it geostationary, if it follows the direction of Earth's rotation. For that reason, communication, weather or navigation satellites are often placed in geostationary orbits.

The gravitational tides induced by the Moon and the Sun as well as the gravitational correction from the equatorial bulge induced by Earth's rotation, generate precession of the orbital plane of geostationary satellites, with a period of 53 years and an initial rate of inclination change by about 0.85 degrees per year. This amounts to 1.63 times the angular diameter of the Moon every year. To correct for this drift, station-keeping maneuvers by thrusters are needed with a velocity kick of about 50 meters per second every year.

Today, I realized that there is another source for a minor correction that was not appreciated before. A new Nature paper suggests that the core of the Earth follows a 70-year cycle during which its rotation is slowing down and speeding up. By conservation of total angular momentum, this generates a counter-cycle in the Earth's mantle and crust surrounding the core.

The inner core of the Earth is a solid, crystalized iron sphere of 70% the size of the Moon. It floats about 5,150 kilometers under our feet in a sea of liquid iron, nickel and other metals known as the outer core. The central temperature of Earth is about 5,700 degrees Kelvin, similar to the surface temperature of the Sun.

The new study shows that the inner core began to slow down around the year 2010, moving slower than the Earth's surface. This conclusion is based on data concerning the arrival times of seismic waves from 121 earthquakes in the South Sandwich Islands between 1991 and 2023 obtained by seismographs in Canada and Alaska, as well as shock waves data from Soviet nuclear tests conducted between 1971 and 1974.

The resulting drift in the rotation of the mantle translates to about a millisecond in the duration of a day over a period of several decades. Given the velocity of geostationary satellites, this change in the rotation period of the Earth's crust generates a slip by a meter per decade for a fixed point on Earth's surface relative to a geostationary satellite in an orbit designed based on the assumption of a constant rotation period of Earth.

This drift is much smaller than other known effects that are routinely corrected for by station-keeping maneuvers. However, it could potentially be searched for in positioning data on geostationary satellites as a new way to measure changes in the rotation period of Earth's inner core.

One can imagine a more direct, but less practical, way to probe the Earth's core. If Earth were to trap a primordial black hole with the mass of a kilometer-size asteroid, the event horizon of the black hole would be of the scale of an atomic nucleus and so it could travel back and forth through Earth's inner core with negligible dynamical friction. Scientists could then use the seismic signal from this motion to map the internal structure of the Earth, as the black hole completes a full trip from one side of the Earth to the opposite side and back every 84 minutes.

In the absence of an ideal probe of this type, it is tempting to imagine digging a tunnel with an average length of 12,742-kilometer through Earth's center. Such a tunnel would have allowed us to reach the other side of Earth in 42 minutes by free-fall. This brings three benefits. First, a straight line is the shortest path to the other side, with a length equal to the Earth's diameter instead of (pi/2)=1.57 times this diameter as needed for an international flight around the Earth. Second, the journey's duration of 42 minutes is shorter than with any other transportation vehicle at our disposal. And third, free fall is powered by gravity and does not require any fuel. The first 21 minutes of the journey will involve acceleration, followed by 21 minutes of deceleration after crossing Earth's center, all the way to a full stop on the other side. There is no better green-energy solution to travel around the globe. Unfortunately, no construction material would withstand the heat from the core at 5700 degrees, and the changing rotation of the inner core would twist the shape of such a tunnel as if it were chewing gum on a spinning wheel.

A less futuristic concept for travel is a space elevator. Here, a cable fixed to the equator and reaching out to pace has a counterweight at its upper end, which could keep its center of mass at the altitude of a geostationary orbit. In that arrangement, the cable would be kept upright by the upward centrifugal force induced by the rotation and an elevator can carry cargos up and down the cable. The main challenge for realizing this concept involves the required material strength of the cable, which cannot be met by known materials.

If humans ever inhabit smaller objects in space, like asteroids or moons, the same physical principles could be employed by space engineers to construct tunnels or space elevators on these platforms. Unlike the legal system, which varies geographically among different nations, the laws of physics are universal and cannot be broken. Imagining new applications of these laws is what makes us, fragile creatures born on a tiny rock left over from the formation of the Sun, so powerful. As Albert Einstein noted: "imagination embraces the entire world, stimulating progress, giving birth to evolution."

ABOUT THE AUTHOR

Credit: Chris Michel (October 4, 2023)

Avi Loeb is the head of the Galileo Project, founding director of Harvard University's - Black Hole Initiative, director of the Institute for Theory and Computation at the Harvard-Smithsonian Center for Astrophysics, and the former chair of the astronomy department at Harvard University (2011-2020). He is a former member of the President's Council of Advisors on Science and Technology and a former chair of the Board on Physics and Astronomy of the National Academies. He is the bestselling author of "*Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*" and a co-author of the textbook "*Life in the Cosmos*", both published in 2021. His new book, titled "*Interstellar*", was published in August 2023.