55.4: Rotation Rate

As mentioned earlier, shifts in the distribution of the Earth's mass due to earthquakes, tsunamis, or even dams cause small changes in the Earth's moment of inertia, that are reflected in tiny changes in the Earth's rotation rate. There are also seasonal variations: ice melts in one hemisphere or the other depending on the season, which also causes small changes in the mass distribution.

Superimposed on the smaller effects is a long-term slowing of the Earth's rotation due to tidal drag. As the Moon pulls on the Earth's oceans, there is a friction force created that tends to slow the Earth's rotation over long time scales. From the beginning of the Paleozoic era (about 542 million years ago) to the present, the length of the day (LOD) has been found to be $[4,5,16]$

$$\mathrm{LOD}=24.00-4.98\tau \tag{55.4.1}$$

where LOD is the length of the day in hours, and τ is the time in billions of years ago (Ga). (Prior to the beginning of the Paleozoic era, the slowing of the Earth's rotation was thought to have been at a slower rate than this $4.98\,\mathrm{hr}/\mathrm{Gyr}$ rate.) Using this formula, the day length at the beginning of the Age of Dinosaurs (the Mesozoic era, about 250 million years ago) was only about 22 hours 45 minutes, or an hour and 15 minutes shorter than it is today.

This slowing of the Earth's rotation continues today, and is the source of some difficulty in timekeeping. We keep time by very precise atomic clocks, but at the same time we would like to keep our clocks in synchronization with the Earth's rotation. In fact, for historical reasons, the SI second as defined by atomic clocks corresponds to the length of the day as it was around 1820. Since the Earth's rotation has slowed since then, it means atomic clocks are running fast compared to the Earth rotation. To accommodate this, we from time to time insert leap seconds into our civil time scale (called Coordinated Universal Time, or UTC). A leap second inserts an extra second at the end of a day (generally a June 30 or December 31), so that clocks just before midnight read: 23:59:58, 23:59:59, 23:59:60,00:00:00. This has the effect of setting the clock back one second to keep it in synchronization with the Earth's rotation.

The Earth's moment of inertia is roughly constant, so as the Earth's rate of rotation ω decreases, its angular momentum $L=I\omega$ must also decrease. But angular momentum is conserved; where does the angular momentum go? It turns out that it is transferred to the Moon, in the form of increased orbital angular momentum. As the Earth's rotation slows, the Moon recedes away from the Earth to conserve angular momentum. This lunar recession has been confirmed using Earth-based lasers and retroreflectors left on the lunar surface by the Apollo astronauts: the Moon is currently receding from the Earth at a rate of about 4 cm per year. This recession should continue until the Earth becomes tidally locked to the Moon the same way the Moon is now tidally locked to the Earth: not only will the Moon always present the same face to the Earth, but the Earth will always present the same face to the Moon. At that point, the Moon will appear stationary in the sky, and from some parts of the Earth will never be visible.

However, it's not likely that this tidal locking of the Earth to the Moon will ever happen. Calculations show that it would not occur for another 50 billion years [1]; in about 5 billion years the Sun will reach its red giant stage, and may expand enough to consume both the Earth and the Moon.

[1] For comparison, the current age of the Universe is 13.7 billion years.