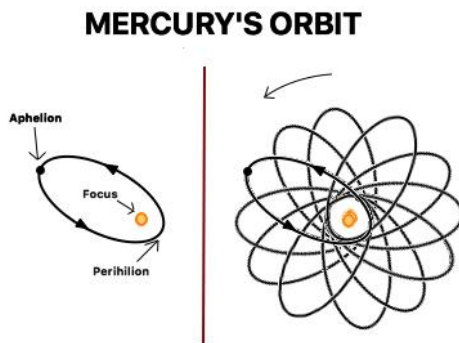


The story of Mercury and Vulcan, as told by Einstein

By C. Pantelidou (ICCUB)

The movement of all celestial bodies must follow Kepler's laws of planetary motion, which are nothing more than manifestations of Newton's law of gravity. In particular, the first of Kepler's laws loosely goes as follows: in a two-body system, the object with the smallest mass moves around the heavier one in an elliptical orbit, with the second object being at a point called the *focus* of the ellipse. Applying this rule to our solar system, we deduce that all planets follow elliptical orbits around the Sun; it's just that some are more elliptic than others. For example, the orbit of our planet has a degree of non-circularity, called *eccentricity*, of about 2% while the planet Mercury has eccentricity of 20% resulting in a cigar-like orbit. It should be emphasized that in these orbits, the focal point, or equivalently the location of the Sun, is not at the center of the ellipse, but rather shifted to one of its sides. Thus, in a full orbit, each planet passes through two special points: the perihelion, the point closest to the sun, and the aphelion, the point farthest from the sun.



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However, what I have described above applies solely when one considers only two bodies at a time. If one wants to account for the whole solar system at once, then the above needs to be corrected by taking into consideration the small effects that each planet induces on the nearby ones. This can slightly change the eccentricity of the orbit as well as make it slowly rotate around the sun.

The rotation of the orbit of Mercury was measured by timing the *transits* of the planet across the sun as observed by terrestrial observers. The Mercury transit, first observed in 1631 by Gassendi, is a phenomenon that occurs approximately 13 times every century during which the planet of Mercury is aligned in between the Sun and the Earth and thus, one can see Mercury as a small black dot on the solar disk. The transit can be observed either in May or November, with the November ones being slightly more frequent. This can be explained by the fact that the November transit, unlike the May one, happens close to the aphelion of the Mercury orbit where the planet moves slower. For exactly the same reason, the November transit lasts longer, and since the aphelion is closer to the Earth, the black dot on the sun is bigger.

By analyzing all the data collected from observations between 1679 and 1848, Le Verrier showed in 1859 that the orbit of Mercury rotates with a rate of approximately 574 arcsecs per century. And it was then when the puzzle arose: all the corrections due to the other planets could only account for 531 arcsecs per century, leaving a deficit of 43 arcsec. One of the explanations proposed at the time was that there exists another planet, called Vulcan, that lives very close to Mercury (so that it does not alter the orbits of the other planets) and slightly perturbs its orbit. For years and years, astronomers searched for Vulcan but with no success.

It was only in 1916 when Einstein's theory of General Relativity (GR) correctly accounted for this deficit, supporting the idea that Vulcan does not exist. According to GR, you can think of space as a water bed and each star as a ball resting on the water bed's surface forcing it to curve depending on how heavy it is. If one now throws a marble –a planet- in the vicinity of the ball –the Sun-, the marble will start rotating around the ball and, generically, after a few loops it will fall in the well. It is only when the marble is rolled with just the right velocity that it's orbit will be stable. And this is exactly the case for our solar system. All of the planets rotate with just the right speed for their distance from the Sun: the closer the planet is, the faster it has to rotate in order to not fall into the Sun. Now, let's focus on Mercury. As said above its orbit is very eccentric, causing the perihelion to be very close to the Sun. At this point, Mercury senses an even stronger curvature or equivalently, as said by Einstein himself, Mercury "feels" like there is an extra mass pulling it inwards. This extra pull kicks the orbit a bit, making it slowly rotate around the sun. Going back to the marble analogy, imagine you slightly kick the marble inwards, but not enough for it to fall all the way in. The marble will stabilize but in an orbit that is slightly different than the path it would have followed if you hadn't interfered. This is exactly what happens to the orbit of mercury.

The most recent Mercury transit occurred on May 9th, 2016, and was embraced with particular excitement. This is both because it is a rare astronomical phenomenon but also because of its historical value as the first experimental test of General Relativity, which the latter passed with flying colours in 1916! Since then, GR has passed a series of non-trivial checks, with the ultimate one being the direct observations of gravitational waves (GWs). GWs are nothing more than ripples of space-time itself - or, given our analogy above, ripples on the water bed's surface- that were predicted by Einstein in 1916 and observed by the LIGO collaboration in September 2015. However, it was the Mercury transit that gave the first hint in favour of GR and guided us through all these years in further exploring and understanding Einstein's theory of General Relativity.