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P2_2 Voyager 1: 43 Years Young

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Abstract

Special relativity can measurably dilate time for objects which are in gravitational fields or are moving at high speeds. Here we investigate the effects relativity has on the age and passing of time on the Voyager 1 spacecraft. The time dilation experienced due to the speed of the spacecraft was calculated as 50 ms/yr and compared with the time dilation due to gravity at Earth's surface of 22 ms/yr. The net dilation for Voyager 1 was therefore calculated as 1.23 s.

Introduction

Relativistic effects are rarely considered in daily life as most of us do not travel anywhere near the speed of light. However, in space there is a lot of room for acceleration without air resistance or other limiting factors experienced on Earth. Spacecraft travel at high speeds in order to cross the vast distances of space in as little time as possible but currently still take many years to reach their destinations. As we make faster and faster spacecraft, relativistic effects will increase and potentially become significant. In this paper, we investigate the effects of time dilation on the Voyager 1 spacecraft, currently travelling at ~ 17 km/s [1] out of our solar system, and compare it to the passage of time at Earth, which is also dilated by its gravitational field.

Theory

Time dilation occurs between an observer in an inertial frame and an object/person moving relative to them. It can be calculated from the Lorentz transformations [2].

$$\Delta t' = \gamma \Delta t \tag{1}$$

where,

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{2}$$

Equation (1) tells us how long it takes for a period of time to pass for observers in another reference frame. In this scenario, the equation is used to calculate how much time has passed for the Voyager craft, $\Delta t'$, compared with the time that has passed for a stationary observer, Δt. The speed of light is represented by c and velocity is represented by v.

The second equation used is derived from general relativity, specifically the Schwarzschild metric, which describes space-time in the vicinity of a non-rotating massive sphere. This equation is used to calculate the time dilation for observers inside the gravitational influence of a planet, in this case Earth.

$$t_0 = t_f \sqrt{1 - \frac{2GM}{rc^2}} \tag{3}$$

Here, M is the mass of earth, r is the separation from the centre of the earth, and c and G have their usual meanings. For simplicity, the Earth is assumed to be non-rotating which allows equation (3) to be used. Here, t_0, represents the proper time between events for an observer close to the massive sphere (Earth in this case), and t_f represents the coordinate time between events for an observer at an infinite distance where a clock would tick one second per second of coordinate time.

To calculate the time dilation of the Voyager 1 spacecraft and compare it to that in Earth's gravity, equations (1) and (3) can be combined [3] to create a new gamma factor γ' shown in equation (4):

$$\gamma' = \frac{\sqrt{1-\frac{v^2}{c^2}}}{\sqrt{1-\frac{2GM}{rc^2}}} \tag{4}$$

This γ' combines the time dilation effects of gravity and velocity across reference frames so that both influences can be accounted for when calculating time dilation for Voyager 1.

Results and Discussion

Using equations (1) and (2), we calculated that a stationary observer would see Voyager 1's time passing at a rate of 0.9999999984 seconds per second locally. This means that, as Voyager 1 is not moving at a significant fraction of c, the dilation is almost insignificantly small, losing only 2.2 s over 43 years at a rate of $\sim$ 0.05 s/yr.

The effects of time dilation due to Earth's gravity were calculated with equation (3) (using Earth's radius and mass [4]) and we found that for every second passing on Earth, we would only measure 0.9999999993 seconds passing out in deep space where the gravity is insignificant. If Voyager 1 was far away from Earth and stationary relative to Earth, over the 43 years since launch we would measure it as $\sim$ 0.95 seconds younger than at Earth. This is a smaller difference in time period when compared with the dilation caused by Earth due to the relatively small mass of our planet. This number would however be slightly inaccurate as it is the time passing at a theoretically infinite distance from Earth where its gravitational field has no effect. For the purposes of this paper we take the difference to be negligible.

The combined γ' factor works out to be 0.9999999991 for Earth and Voyager meaning for every second Earth experiences, Voyager experiences 0.9999999991 seconds. This period of time is larger than when compared with the stationary observer as the effect of Earth's gravity slows down time also.

Conclusion

Since its launch, Voyager 1 has aged 2.2 seconds less than a stationary observer on Earth. In this same time, the Earth has aged 0.95 seconds less than a point in the universe under no influence of gravity. However when compared to each other, Voyager experiences time the slowest, only experiencing 1.23 s fewer over 43 years of Earth time. This shows that effects due to Earth's gravity and the speeds our spacecraft travel do not have significant relativistic consequences and therefore shouldn't cause any problems. In order to make time dilation a significant factor, we would need to launch spacecraft at much higher speeds or live within a gravitational field similar to that produced by a black hole.

References

[1] `https://voyager.jpl.nasa.gov/mission/status/` [Accessed 27 October 2020]

[2] Tipler P. A., Mosca, G., 2008. Time Dilation. In: Physics for Scientists and Engineers: Sixth Edition. New York: W. H. Freeman and Company, p. R-5.

[3] A.Conte, *Combination of time dilation and gravitational time dilation* (2020)

[4] `https://en.wikipedia.org/wiki/Earth` [Accessed 27 October 2020]