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P2_1 The Skywalker Twins Drift Apart

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Abstract

An investigation into the effect of relative velocity and gravitational time dilation on twins was performed. For twins travelling 0.28 and 7 days respectively, at slightly different relativistic speeds, respective time dilations of 62.6 days and 1.92 years were calculated. With one twin on the surface of a gas giant and the other one hundred times further away in orbit the total time needed to rectify this age gap using gravitational time dilation was 9.77×10^6 years, which was therefore unfeasible.

Introduction

The twin paradox states that twins travelling relativistically appear to age differently to one another due to time dilation [1]. In the 1980 film *Star Wars Episode V: The Empire Strikes Back*, twins Luke and Leia Skywalker travel very large distances at "lightspeed." This paper uses two scenarios to attempt to explore the theoretical effects of the twin paradox on the two protagonists.

In the first scenario, we consider the effects of time dilation while traveling at relativistic speeds. This phenomenon is known as relative velocity time dilation, which describes the bending of space-time due to differences in velocity. Consider a spacecraft moving at a uniform velocity and a stationary observer. If the observer were able to directly see a clock on board the spacecraft, the clock would appear to tick more slowly than a clock in the observer's reference frame. The magnitude of this effect is dictated by the Lorenz transformation. The dilation is given by

$$t_f = t_0/\sqrt{1 - v^2/c^2}, \qquad (1)$$

where t_f is the time dilation in the reference frame of the observer, t_0 is the proper time, v is the velocity of the moving spacecraft and c is the speed of light [2].

To examine relativistic time dilation we consider the separate journeys that both twins make to *Cloud City*. Leia travels from the neighbouring system of *Anoat*, while Luke travels from the much more distant planet *Dagobah*. Luke's journey was ~7 days travel in his own reference frame, which was estimated to be 25 times longer than Leia's, making her journey 0.28 days (6.72 hours) in her own reference frame. Additionally, as Leia travels in the *Millennium Falcon*, a much larger ship with more powerful engines than Luke's *X-Wing Starfighter*, it was assumed that it reaches a higher velocity of 0.99999c compared to the 0.99995c achieved by the *X-Wing*. Finally, it is assumed that both twins begin their journeys with the same age at the same proper time. Using equation (1) the time dilation that each twin observes on the other can be calculated.

In the second scenario gravitational time dilation is considered. *Cloud City*, a mining station, floats above the clouds of the planet *Bespin*, a gas giant very similar to Jupiter. As the planet is so massive, its gravitational potential causes gravitational time dilation, slowing time nearer to the surface [3]. This means that an observer at a distance far from the planet would see time pass more quickly than an observer on the surface. The gravitational time dilation is given by

$$t_0 = t_f\sqrt{1 - r_s/r}, \qquad (2)$$

where t_0 is the proper time, t_f is the time measured by an observer far away from the planet, r_s is the Schwarzschild radius of the planet and r is the observer's distance from the planet [4]. The Schwarzschild radius is the distance inside which light could not escape the gravitational pull of the planet if its entire mass was compressed inside it, and is given by

$$r_s = 2GM/c^2,$$

where G is the gravitational constant, M is the planet's mass and c is the speed of light. This can then be substituted into equation (2) to give

$$t_0 = t_f\sqrt{1 - 2GM/rc^2}. \quad (3)$$

This can be used to calculate the different time dilations for observers at different distances relative to the planet, which can then be compared to relativistic time dilations. We assume that the second scenario happens immediately following the first and that Leia remains on Cloud City on the edge of the planet. The planet is assumed to be similar to Jupiter with a mass of 1.898×10^{27} kg while Luke orbits the planet at a distance which is 100 times further away from the centre of mass.

Results

In scenario one, Leia's journey yields a time dilation of 62.6 days, which at a much faster speed means she is younger than Luke for the duration. However Luke's journey is much longer so over this period of time he ages slower than Leia, as she is stationary once she arrives at Cloud City. The time dilation Luke experiences whilst travelling is 700.8 days (1.92 years). Luke is therefore 638.2 days younger than Leia.

To compare the difference between relative velocity and gravitational time dilation we attempted to calculate the time Luke would have to orbit the gas giant in order to correct for the time dilation experienced in scenario one, and become the same age again. Using equation (3) the difference in time dilation experienced by Leia and Luke was calculated to be 1.96×10^{-7}seconds for every second of proper time. This results in time in Luke's reference frame ticking very slightly faster which means that for Luke to become the same age as Leia he would have to orbit for 9.77×10^{6} years.

Discussion

While it is not demonstrated in the film, the twins will actually have aged very differently due to their extensive travelling at speeds close to that of light. Despite Luke's journey being twenty five times longer than Leia's, the time dilation he experienced was only around ten times larger. This shows that miniscule changes in relativistic speeds have significant effects on the dilation observed.

An attempt was made to use gravitational time dilation as a tool to restore the difference between the ages of the twins. The results above indicate that this type of time dilation has a much less significant effect than velocity time dilation. Due to the length of time required to correct for the velocity time dilation, the gravitational dilation would be unfeasible to correct the age difference of the twins as they would need to be 9.77 million years old in proper time. Even at very large distances away from the gas giant, time does not pass considerably faster as the gravitational pull of the planet becomes negligible.

References

[1] J.D. Barrow and J. Levin, Phys. Rev. A **63** (2001)

[2] P.K. Hsiung, R.H. Thibadeau, C.B. Coxs and R.H.P. Dunn, Supercomputing '90 (1990)

[3] J. A. Auping, *Proceedings of the International Conference on Two Cosmological Models* (2012)

[4] http://www.sussex.ac.uk/Users/waa22/relativity/What_is_gravitational_time_dilation.html accessed 06/10/2014