Moving Clocks and Special Relativity Rest Reference Frames

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Abstract

Einstein's special relativity theory predicts that time will go slower on moving clocks than stationary clocks. Without an absolute rest reference frame, how do we know which clock is moving and which is stationary? Although there is no absolute rest reference frame there are some practical rest reference frames. When the appropriate rest reference frame is chosen, clocks moving with respect to that rest reference pass time slower than those at rest in that reference frame.

Background

There has been some confusion concerning Einstein's (1905) special relativity theory (SRT). It appears to come about because there is no absolute rest frame of reference. All measurements are made relative to the observer. Additionally, whether an observer is moving or stationary with respect to another observer, he/she will have no concept that time is other than moving at his/her normal experience of time. To all observers, each accurate clock will still pass time at sixty billion (6×10^{10}) nanoseconds for each minute of their local time. How can moving observers tell who is moving the fastest and hence whose time is going the slowest? This presentation shows how that question is easily answered.

Practical Rest Reference Frames

There is no absolute rest reference frame. All motion is relative. Most people are familiar with ground as their normal rest reference frame. A fixed position on it considered to be "at rest". Everything else is seen as moving relative to that "fixed" position. It is not fixed. Earth's daily rotational velocity is ≈ $0.46\cos\theta$ km/sec, where θ is the latitude. When compared to regarding Earth's centre as a fixed rest reference frame, that corresponds to a difference of ≈ $1.5 \times 10^{-6}\cos\theta.c$, where c is the speed of light in vacuum. Under Einstein's SRT corrections, this gives time intervals

$$\Delta t' = \Delta t \Big/ \sqrt{1 - v^2/c^2} \qquad (1$$

where $\Delta t'$ is the time interval on the moving clock, Δt is the time interval on the stationary clock and v is the velocity of the moving clock relative to the stationary clock. There is a maximum time difference of ≈ 2×10^{-12} between clocks on Earth from equator to poles.

That gives two rest reference frames, Earth's rotating surface and its centre of mass. Earth centric time is the same as time at the poles. With those rest reference frames in mind, consider two highly accurate clocks at rest with respect to each other. They will keep the same time. One set of clocks, A, are placed in rocket payloads and launched into Earth orbit. The others set, clocks B, remain on Earth. That clearly defines which clocks are moving with respect to the other in both Earth's surface and centric reference frames. In the case of the Global Positioning System (GPS) satellites, clocks A orbit Earth at a speed of ≈ 3.5 km/sec or ≈ 1.1 x 10^{-5}.c. Clocks A run slower than the ground based clocks, B, by about 7 microsecond per day. That has been measured and clearly indicates the "travelling" clocks, A, have a slower time than the "stationary" clocks, B. Those corrections are taken into consideration for the accuracy of GPS navigation (Ashby 2002). Earth centric and Earth surface reference frames are adjusted by the cosθ latitude term.

Earth's orbital speed about the sun is ≈ 29.8 km/sec, or ≈ 10^{-4}.c. It is here that care needs to be taken in selecting the correct rest reference frame. Earth's orbital speed about the sun does not need to be considered in calculations of the time difference between Earth and its orbiting satellites because it is their relative speed differences that matter. However he sun's centre does provide a very convenient rest reference frame.

Consider two accurate clocks, D and E. Clock D is sent into space to remain in stationary orbit around the sun. It would require acceleration in the retrograde Earth orbit direction to a velocity of ≈ 29.8 km/sec. It could be held in position by solar sails. It would appear to Earth based observers as being accelerated and therefore be considered as the moving clock. When Earth returned to its position the following year, the Earth bound clock, E, would show the time slower by ≈ 0.32 sec. In that situation, Earth is the moving object, even though clock D was accelerated. That is the situation in which the correct rest reference frame is the sun's centre.

Along the same lines, consider a third clock F, with the same accuracy as D and E, sent into double retrograde orbit to travel at 29.8 km/sec in the opposite direction, as illustrated in figure 1. The arrows indicate their direction of rotation around the sun. A and C both show clocks E and F both moving at the same speed in the same direction at different positions in their orbit. B and D show that three months later, they will be travelling in opposite directions at a relative speed of 59.6 km/sec.

On a solar centric rest frame, both are travelling at the same speed. To the solar centric rest reference, clock D, they will both loose 0.32 seconds per orbit. How would time on F vary from the perspective of a clock E on Earth.

Before that is answered, it is best to consider the more general case of two local stars each with orbiting planets. The positions of the stars in our local region of the galaxy remain approximately fixed with respect to each other, even though they have a galaxy rotation speed of over 220 km/sec, ≈ 7 x 10^{-4} c, with respect to the galaxy's centre (Liu, 2018). That means the sun's rest reference frame, sometimes referred as its inertial reference frame, sets a good rest reference frame for all motions with respect to it. That includes interstellar

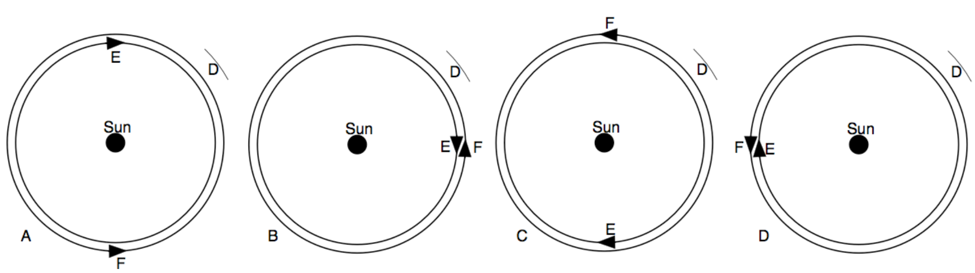

Figure 1 Schematic illustration of three clocks around the sun. D is docked on a solar sail in stationary orbit around the sun. E is on Earth moving around the sun. F is flying in retrograde orbit, the opposite direction to and same speed as Earth.

travelers originating from star systems within a radius of a few thousand light years (at least 2,000 parsec). The only difference would be the speed of their planet's orbit around its star. That is approximately 10^{-4}.c for Earth and a similar speed for the other planet. That could give the initial speed rest reference difference of ≈ 2 x 10^{-4}.c. That gives a "fuzzy" time accuracy of ≈ 4 x 10^{-8}, in which their respective on board clocks may differ.

Consider a situation in the far distant future. An intrepid traveler from a planet around another star approaches an Earth based interstellar traveler. Both travelers would have their stellar centers with identical rest reference frame times. Their planetary origin could give them rest reference frame time differences of up to ≈ 4 x 10^{-8}. Beyond that small difference, both would know who was traveling the faster. That would be irrespective of the method of determining their relative speeds.

Sidereal time, the time measured with respect to the "fixed stars", provides a practical rest reference time frame against which all extra terrestrial activities can be calculated. That includes intra and extra solar system activities. Most Earth based activities can use Earth's centre as a fixed rest reference frame. Their most obvious use is in accurate international timing and global positioning systems.

Now to the situation of the accurate clock F accelerated to double retrograde Earth orbit. Clock D is held in a fixed position by solar sails or some other mechanism. Clock F is in retrograde Earth orbit, also at 29.8 km/sec. That is an extra terrestrial activity that requires a solar centric reference frame. If clocks E and F were in constant communication with each other, clock E would see clock F's time varying because of the time delay of transmission of signals between the two, the Doppler effect of their relative speeds and the relativistic corrections. They combine to give a "fuzzy" time zone around the sun, somewhat similar to the situation between travelers from distant stars.

A fourth rest reference frame is the centre of the Milky Way Galaxy. Compared to that reference frame, the local region of our galaxy is moving at about 220 km/sec, 7 x 10^{-4}.c around that centre. For travellers originating from beyond ≈ 2,000 parsec in a radial direction, a slight additional correction may be required to compensate for their changed rest reference time associated with their rotational speed.

There is a fifth rest reference frame. The Milky Way Galaxy is moving towards the Norma cluster of galaxies and the Great Attractor at over 600 km/sec, 2 x 10^{-3}.c (Stavely-Smith 2016). Intergalactic travellers rest reference frame may require a larger correction to compensate for their changed initial velocity.

All motion caused by those sources does not induce any change in the relative positions of the stars in our local stellar rest reference frame. The movement they cause has no effect on the local stellar rest reference frame.

Reciprocity

That raises the question: "Is there reciprocity between moving and stationary clocks?" As mentioned above, it has been measured that clocks in satellites orbiting Earth run slower than those stationary on it. Other observations of time slowing down can be found in the cosmic ray showers. Muons have a half life of about 2 microsecond (μS). That is time for most them to travel only about 0.5 to 2 km. They are generated by cosmic rays in our upper atmosphere and detected many tens of km lower. That can only happen if their time reference frame slows down at their high velocity and the apparent distance they travel is shortened. Additionally, Einstein's SRT corrections must be used to get accurate travel of particles in particle accelerators.

The answer no! There is no reciprocity between a clock moving in the stellar rest reference frame and one fixed in that rest reference frame. That frame extends for thousands of light years in all directions around us. A stationary clock will “tick by” at its constant rest reference frame rate. The moving clock will “tick by” at a slower rate compared to the stationary clock’s time rate. When the moving clock is returned to the stationary clock’s position, the travelled clock will show a time delay with respect to the stationary clock. However that does require the correct rest or inertial reference frame to be chosen.

Cosmic rays provide the best evidence there is no reciprocity. They have energies in the GeV range, giving them velocities approaching c. Local observer speeds are significantly less than c. Cosmic ray protons have higher mass than terrestrial protons. The SRT mass correction $m_v = m_0 \big/ \sqrt{1 - v^2/c^2}$ indicates cosmic ray particles are the faster travelers, not Earth. There is no confusion about whether it is the cosmic rays or Earth that is travelling the fastest.

The use of the solar centric rest frame takes care of which twin moves and will age less in the so-called “Twin Paradox”. There is no reciprocity. The twin moving the fastest with respect to the solar rest reference frame will age less than the twin remaining at rest with respect the same frame. An example of choosing the wrong rest reference frame is the use of an Earth rest reference frame and accelerating one twin in retrograde Earth orbit to remain stationary in the sun’s rest reference frame and use Earth as the rest reference frame.

Complexity?

The problems associated with the current understandings of special relativity are that Einstein’s mathematics was so complex that many people do not have the opportunity to study it in sufficient depth to understand it. Derivations of SRT corrections need not be much more complex than Pythagoras’ theorem with the constant speed of light making up the hypotenuse (Robinson 2019), Robinson (2020). When that is understood the complexities that lead to misunderstandings disappear. It shows that the SRT corrections are an inherent property of every moving particle. Although there is no absolute rest reference frame in space, there are three fixed rest reference frames as mentioned above. Choosing motions against the appropriate reference frame determines which observer is moving and which is stationary. Choosing the wrong frame could result in confusion.

Many people have expressed concerns about the confusion and complexity associated with Einstein’s special and general relativity theories. In this presentation I am discussing only his special relativity theory. When the appropriate rest reference frames are chosen, as mentioned above, Einstein’s SRT corrections are accurate for all circumstances. Those who choose to believe it is complex and reciprocity applies haven’t gone into the topic in the detail required to fully understand it.

Summary and Conclusions

Moving clocks running slower than stationary clocks has been experimentally verified for decades. It is hoped the above gives readers a better understanding of time dilation predicted by Einstein’s special relativity theory and observed experimentally. Einstein’s special relativity theory is a simple, non-confusing topic when either its origins are understood (Robinson, 2019, 2020) or the correct rest reference frame is used.

There is no reciprocity. The key is in choosing the correct rest or inertial reference frame. For convenience, most Earth bound motions such as satellites orbiting it, can use Earth's centre as a rest reference frame. For extra terrestrial observations, reference to the sun's rest or inertial reference frame is required. The positions and speeds of stars within a few thousand light years (≈ 2,000 parsecs) from Earth are fixed. Irrespective of their speed, interstellar travelers will know which one is travelling the faster and therefore which clock is going slower.

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