Implications of localized time dilation

by David A. Seagraves

Abstract: The assumption that time dilation must be computed using velocities relative to the local Hubble Frame has important consequences for cosmology. Four such consequences are described: (1) the impact on redshift calculations, (2) an alternate explanation of the apparent accelerated rate of expansion of the universe, (3) a reinterpretation of the period of inflation following the Big Bang, and (4) reevaluation of the computation of time dilation experienced during space travel, such as that postulated in the Twins Paradox.

At every point is spacetime there exists an inertial frame moving with the Hubble Flow, i.e., whose 4-velocity is entirely in the temporal direction. This inertial frame may be identified by observing the distribution of speeds of distant objects in the universe (Kak, 2007) or the anisotropy of the CMB (Ellis, Maartens, & MacCallum, 2012, p. 21). I will refer to this inertial frame as the "Hubble Frame."

Recent research concludes that the time dilation experienced by a traveler at rest in an arbitrary inertial frame F, computed according to the Lorentz transform

$$t_0 = \frac{t_1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where t_1 is the time as measured in F by the traveler, and t_0 is the time as measured by a clock at rest in the Hubble Frame, must use the velocity v of F relative to the local Hubble Frame (Seagraves, 2023).

This simple conclusion resolves the clock paradox which has perplexed scientists (including Einstein, himself) since the advent of special relativity. At the same time, it has some far-reaching consequences which change forever the way we look at space and space travel:

Redshift calculations

There are seven factors that contribute to frequency shift of light from a remote source as measured from earth (the object) (Valente, 2018) (Bedran, 2002) (Davis & Scrimgeous, 2014):

1. Gravitational redshift at the source
2. Gravitational blueshift at the object (point of measurement)
3. Doppler effect due to expansion of the universe
4. Doppler effect due to peculiar velocity of the source
5. Doppler effect due to peculiar velocity of the object
6. Relativistic effect (time dilation) due to peculiar velocity of the source
7. Relativistic effect (time dilation) due to peculiar velocity of the object.

Frequently, redshift is used to determine the recessional velocity of the light source. To do so accurately, however, requires that we first account for the other six factors affecting the frequency shift.

The peculiar velocities of the source and object (#4, #5, #6, and #7) are measured relative to the local Hubble Frame at their respective locations. As noted above, time dilation, and its relativistic effect (#6 and #7), must be computed using peculiar velocities measured in this way. For the doppler effect (#4 and#5), only the radial component of these velocities (in the direction from source to object) is relevant. However, for the relativistic effect, the entire magnitude of the velocity must be used. It is easy to determine the peculiar velocity of the object, using the CMB dipole to determine the local Hubble Frame (Aurich & Reinhardt, 2021). It is more difficult to make this determination for the source. Similarly, it is relatively straightforward to determine the strength of the gravitational field, and therefore the gravitational blueshift at the object (#2). However, the gravitational strength at the source (#1) must be estimated based on the nature and composition of the source.

It is worth noting that the relativistic effect of time dilation is small at typical peculiar velocities in the universe. For example, for the Earth, assuming a peculiar velocity of approximately 360 k/s as measured relative to the CMB, the effect is in the 7th decimal place. At a peculiar velocity of 1000 k/s (rarely seen in the universe), the effect is in the 6^{th} decimal place. However, as measurements become more precise, these effects must be taken into account to get an accurate assessment of the distance to distant objects in the universe.

The Universe Tends Toward a State of Rest

An object or system moving at a constant velocity v relative to its origin, O, through idealized space (where the effect of gravity is negligible) will measure a monotonically decreasing velocity relative to the local Hubble Frame. This is a practical result of the expansion of space itself. Given the Hubble-Lemaitre law

$$v = H_0 d$$

there is, in every direction, a point P at rest in its Hubble Frame, at a distance

$$d = v/H_0$$

moving away from O at the velocity v. The traveling object will never approach P since their relative velocity is zero. Choose any inertial point P' between O and P, at rest in its local Hubble frame. P' will be moving away from P at a velocity v' < v due to the expansion of the universe. Our object will eventually reach P', but only when P' has moved to a distance d from P. At that time, our object will be moving at a velocity v – v' relative to the local Hubble frame, i.e., it has slowed down relative to its Hubble frame.

It would seem that objects caught in a gravitational field might escape this trend. However, this is not the case. Such objects travel a world line that describes an ellipse in 3 dimensions, and a spiral in space-time. The velocity of the orbiting object relative to the local Hubble Frame along the vector from the system's center of gravity to the object is

$$\Delta v = H_0 d$$

where H_0 is the present Hubble Constant and d is the current distance from the center of gravity to the object. But H_0, being the inverse of τ_0, the Hubble time, is decreasing over time. Therefore, Δv is also decreasing. The velocity v of the object relative to the local Hubble Frame is the vector sum of the object's orbital velocity and Δv. Since the orbital velocity, on the average, is constant, v is also decreasing over time.

The ramification of this is that velocity relative to the Hubble Frame of all objects and systems moving throughout the universe is monotonically decreasing. On a grand scale, this means that the universe tends toward a state of rest! More importantly, it means that objects in the early universe had a higher peculiar velocity than at present. In fact, the peculiar velocity of all objects in the early universe would have been exceptionally high. All of this is simply a result of the observed expansion of the universe.

An alternate explanation for the apparent acceleration of the expansion of the universe

An important consequence of this realization is that objects in the early universe experienced greater time dilation than at present due to their higher peculiar velocities. Thus, light from the earliest eras (and further from earth) experience a greater relativistic redshift than light from recent events. This offers an alternate, simpler explanation for the increased redshift observed in more distant objects (Soter & Tyson, 2001, p. 132), and the excessive luminosity distances observed in high-z Supernova Ia observations (Riess & al., 1998). This explanation obviates the need to posit an accelerating rate of expansion of the universe (Soter & Tyson, 2001, p. 112), and a hypothetical force to make it happen, or cosmological constant to balance the Einstein Field Equations (Riess & al., 1998). Occam's razor favors this simpler explanation.

Inflation

Immediately after the Big Bang, as energy diverted stochastically into other dimensions (than time), time dilation caused powerful gravitational forces which resulted in the acceleration of existing matter to high velocities, resulting in even more time dilation. Extreme time dilation, when viewed through the lens of our own reckoning of time, appears as a period of rapid inflation, since the expansion of the universe continued unabated, while time slowed way down. Thus, the period of inflation may alternatively be viewed as a period of excessive time dilation.

Twin "paradox" revisited

As a result of the above argument, it will be seen that the typical method of computing time dilation experienced by the traveling twin is incorrect, since it assumes the time dilation is relative to the velocity of the Hubble Frame at the point of origin throughout the journey, and generally ignores the expansion of the universe during the journey. Computations taking these factors into account show that the effect is only significant for long journeys at a significant proportion of the speed of light. For example, for a 1000 light year journey at 0.5 times the speed of light, the classic computation yields a wait of 4000 years for the stay-at-home twin, while the traveler will experience an elapsed time of 3464 years, 37 days, 2 hours, 45.5 minutes. Taking account of the expansion of the universe adds .0004338 light years and 6 hours, 15.75 minutes to the time measured by the stay-at-home twin. Finally, accounting for the local nature of time dilation adds another 44 minutes to the time measured by the traveler. Similar results are obtained for a velocity of 0.9c. These results were obtained through digital integration using Python code.

$$t_t = \int_{s=0}^{s=S} \sqrt{1-v^2}\,dt$$

where v is the velocity relative to the local Hubble Frame, s is a monotonically increasing function of time (t), and S is the accumulated distance travelled accounting for the expansion of the universe, assuming the destination is 1000 light years away at the start of the journey. It is further assumed that the initial velocity of the return journey is the same as the starting velocity, but in the opposite direction, and relative to the destination.

The tables below summarize these differences for a hypothetical journey of 1,000 light years at 50% and 90% of the speed of light:

1,000ly at 0.5c	Distance Travelled	Earth Time	Traveler Time
Classic Computation	2,000ly	4,000y	3,464y 37d 2h 45.5m
Accounting for Expanding Universe	2,000.0004ly	4,000y 0d 7h 37m	3,464y 37d 9h 21.25m
Accounting for the local Hubble Frame	2,000.0004ly	4,000y 0d 7h 37m	3,464y 37d 10h 5.25m

1,000ly at 0.9c	Distance Travelled	Earth Time	Traveler Time
Classic Computation	2,000ly	2,222y 81d 4h 0m	968y 235d 7h 8.5m
Accounting for Expanding Universe	2,000.0002ly	2,222y 81d 6h 21.1m	968y 235d 8h 10.1m
Accounting for the local Hubble Frame	2,000.0002ly	2,222y 81d 6h 21.1m	968y 235d 9h 37.5m

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