Distance variation in accelerating frames and its potential role in Hubble expansion

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Abstract

We refer to distance variation as the change in Lorentz contracted apparent distance of a body in motion relative to an observer, due to a change in the velocity of the observer. We show that distance variation can have a large contribution in the apparent velocities of distant bodies. We propose that this needs to be included in cosmological models. We also show that it can potentially explain some observed cosmological peculiarities.

Distance variation defined

We refer to distance variation as the change in Lorentz contracted apparent distance of a body in motion relative to an observer, due to a change in the velocity of the observer.

Proper distance defined

Let us formally define the proper distance to a point from an observer, at any time, as being equal to the apparent distance of that point if the observer were to instantaneously adopt the frame of the point.

In other words, the proper distance to a point from an observer in relative motion, is equal to the apparent distance of the point if the observer were to instantaneously accelerate to the velocity of the point, so that the point comes to rest in the frame of the observer.

Apparent distance

The apparent distance, $p(t)$, of a body at proper distance $P(t)$, moving with velocity v relative to an observer, will be,

$$p(t) = P(t)\sqrt{1 - \frac{v^2}{c^2}}$$

Apparent velocity of a body from an accelerating observer

Let us try to find out the apparent velocity of a body, at proper distance $P(t)$, moving with velocity $v(t)$ relative to an accelerating observer. Suppose, for the sake of simplicity that the remote body is not accelerating.

At time $t = 0$ in the frame of the observer, the apparent distance of the body, $p(0)$, is,

$$p(0) = P(0)\sqrt{1 - \frac{v(0)^2}{c^2}} \approx P(0)\left(1 - \frac{v(0)^2}{2c^2}\right)$$

At time $t = dt$ in the frame of the observer, the apparent distance of the body, $p(dt)$, is,

$$p(dt) = P(0)\sqrt{1 - \frac{v(dt)^2}{c^2}} + v\,dt \;\approx\; P(0)\left(1 - \frac{v(dt)^2}{2c^2}\right) + v\,dt$$

where v is just the average relative velocity in the time interval dt.

Note that the error in the above approximations is less than 10% even for relative velocities as high as 75% of the speed of light. Hence, this approximation is quite valid for almost all of the macro objects in the Universe. Truly enormous forces would be needed to accelerate macro bodies to any significant percent of the speed of light, and even though the Universe is not shorn of enormous forces, we have not yet observed such forces or velocities with any appreciable degree of confidence. We do observe apparent velocities that are much higher, even many times the speed of light, but as we shall see, such apparent velocities are easily possible even without enormous forces or large relative velocities.

Therefore, considering the above approximations to be valid, we get,

$$dp(0) = p(dt) - p(0) = \frac{P(0)}{2c^2}\left(v(0)^2 - v(dt)^2\right) + v\,dt$$

Knowing that $v(0) + v(dt) = 2v$,

$$\frac{dp}{dt}(0) = \frac{P(0)}{2c^2}\left(\frac{v(0) - v(dt)}{dt}\right)(2v) + v$$

Simplifying,

$$\frac{dp}{dt}(0) = \frac{P(0)}{c^2}\left(-\frac{dv}{dt}(0)\right)(v) + v$$

Further simplifying and generalizing,

$$\frac{dp}{dt}(t) = v(t)\left(1 - \frac{P(t)}{c^2}\frac{dv}{dt}(t)\right) = v(t)\left(1 - \frac{\gamma(t)\,p(t)}{c^2}\frac{dv}{dt}(t)\right) \qquad (1)$$

where $\gamma(t)$ is the Lorentz factor.

Apparent Velocity of distant accelerating bodies

For distant bodies, when $p(t)$ is sufficiently large, the first term on the right hand side of equation (1) can become negligible as compared to the second term.

Therefore, for distant bodies,

$$\frac{dp}{dt}(t) = -P(t)\frac{v(t)}{c^2}\frac{dv}{dt}(t) = -\gamma(t)\,p(t)\frac{v(t)}{c^2}\frac{dv}{dt}(t) \qquad (2)$$

We propose that this apparent velocity of distant bodies due to variation in their Lorentz distance contraction, as observed from an accelerating Earth, should be incorporated into existing cosmological models.

As we shall see, equation (2) potentially explains some of the peculiarities and anomalies of existing cosmological observations.

Hubble expansion of the Universe

Interestingly, equation (2) shows that the apparent velocity $\frac{dp}{dt}(t)$ of distant bodies is proportional to their apparent distance $p(t)$ when observed from an accelerating Earth, which is exactly what is observed as a consequence of the Hubble's Law.

To be clear, this is no claim of complete explanation of Hubble expansion. Indeed, with no knowledge of $\gamma(t)$, $v(t)$, and $\frac{dv}{dt}(t)$, such a claim would be unsound.

Even so, it is illuminating to note that the Hubble expansion (where apparent velocity of distant galaxies is proportional to their distance from us), which has absolutely no explanation in classical physics, can be potentially explained as a result of variation in Lorentz distance contraction.

Decelerating expansion and no need for Dark Energy?

For the purposes of gaining more insight about the implications of equation (2), let us assume that the observed Hubble expansion of the Universe is explained primarily by that equation. If that were so, what does the equation signify?

We know that the apparent velocity of distant galaxies, $\frac{dp}{dt}(t)$, is observed to be positive, if we assume the positive direction to be radially outwards from the Earth. The Lorentz factor, $\gamma(t)$, is positive by definition. The apparent distance $p(t)$ is also positive since the bodies lie radially outward from the Earth. This means that, for $\frac{dp}{dt}(t)$ to be positive as observed, the directions of $v(t)$ and $\frac{dv}{dt}(t)$ should be opposite of each other. That is, one of them should point radially outwards, and the other radially inwards.

In other words, either the distant galaxies should be approaching us and slowing down or they should be receding from us and slowing down. The second scenario, namely that the galaxies are receding from us but slowing down, is much more probable since it is consistent with other models as well.

However, interestingly, note that equation (2) shows that even if the rate of expansion of the Universe is decelerating, that is, even if $\frac{dv}{dt}(t)$ is negative, the Universe can appear to be expanding as per the Hubble's law, that is, $\frac{dp}{dt}(t) \propto p(t)$ can be true because of variability of distance contraction from an accelerating Earth.

Furthermore, since a decelerating expansion can also appear like the Hubble expansion according to equation (2), it shows that invoking the dark energy hypothesis may not be necessary to explain the observed rate of expansion of the Universe.

The confidence in the dark energy hypothesis is primarily borne out of the significant difference between the observed rate of expansion and the expected rate of expansion in the absence of dark energy [1]. This is because the expected rate of expansion in the absence of dark energy is thought to be decelerating [1]. Therefore, the observed anomalous acceleration, even though deviating only very slightly from Hubble expansion, exhibits statistically significant deviation from the predicted decelerating expansion, thus forcing the hypothesization of dark energy.

However, equation (2) shows that even a decelerating expansion of the Universe can appear to be non-decelerating, thus suggesting a potential hypothesis, independent of dark energy. With equation (2) easily explaining a Hubble expansion, the statistical deviation of observed anomalous acceleration is significantly reduced.

Furthermore, recent research has shown that the evidence for accelerating expansion of the Universe may be statistically much less significant than previously thought. Sarkar et al., making use of a vastly increased data set — a catalogue of 740 Type Ia supernovae, more than ten times the original sample size — have found that the data is consistent with a constant rate of expansion, rather than an accelerating one [2].

Apparent velocities greater than the speed of light

A peculiar observation in cosmology is that distant galaxies appear to be moving faster than the speed of light, the furthest ones are many times faster. This is traditionally explained by invoking the dichotomy between expansion *of* space-time versus expansion *in* space-time. It is explained that since the apparent velocity of distant galaxies is the result of expansion of space-time rather than motion through space-time, the laws of relativity are not violated even if those galaxies appear to be moving many times faster than the speed of light.

However, there is no experimental equivalent of this expansion of space-time. Nor has it ever been directly observed to any degree of confidence. Furthermore, it gives rise to the paradox that if the space-time is indeed expanding, the measuring scales must also expand in the same proportion and therefore, the expansion of space-time should not be observable. It must be noted here that existing cosmological models do explain this paradox in different ways and we do not claim to offer any evidence to prefer any explanation over the others.

Interestingly, this phenomenon of apparent velocity being faster than the speed of light is easily explained by equation (2). If we assume that the Hubble expansion of the Universe is primarily explained by equation (2), the apparent velocity of distant objects is predominantly a result of variation in their distance contraction, and not actual relative motion through space-time. Therefore, for sufficiently large $p(t)$, the apparent velocity $\frac{dp}{dt}(t)$ can be greater than speed of light without violating the laws of relativity.

References

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2. J. T. Nielsen, A. Guffanti & S. Sarkar*, Marginal evidence for cosmic acceleration from Type Ia supernovae*, Scientific Reports, **6**, Article number: 35596 (2016)