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Why are the James Webb Space Telescope's data so surprising?

abstract:

The implications of recent astronomical observations made by the James Webb Space Telescope (JWST) and compares them with those from the Hubble Space Telescope. Specifically, it discusses the discovery of galaxies such as GN-z11 and JADES-GS-z13-0, which appear to have formed at very early stages of the universe, challenging previous assumptions about galaxy formation and the age of the universe. The author uses a thought experiment involving relativistic speeds and redshift calculations to question the current estimates of the universe's age, suggesting that the universe might be older than widely accepted. The piece critically examines the methodologies used in determining the age of distant galaxies and the universe, proposing that new data from JWST could necessitate a revision of cosmological models.

In 2016, the Hubble Space Telescope discovered the galaxy GN-z11, for which the redshift is 11.1[1], indicating that it is visible from a time when the Universe was about 400 million years old. (It seems like a very short time for a galaxy to form.) However, the Webb Space Telescope has discovered even more distant galaxies. One of them is the galaxy JADES-GS-z13-0, which has a redshift of 13.2[2]. It is estimated to be visible from a time when the Universe was about 300 million years old. Both of these galaxies are relatively well-formed, suggesting that their formation began even earlier. It's hard to imagine how such large galaxies could have formed in such a young Universe, so let's try to verify the abovementioned estimates of the age of the Universe at the moments when these galaxies are visible. To do this, let's conduct a thought experiment.

To begin with, we will conduct this experiment on a very small scale. (In our immediate surroundings, we have well-understood laws of physics, so there will be no problem in drawing accurate conclusions.) Let's assume that we have a rifle from which we can fire a spherical bullet at relativistic speeds ranging from, for example, $\boldsymbol{0.1c}$ to $\boldsymbol{0.999c}$ (speed can be varied by using explosive charges of different masses). We also have a high-speed camera capable of taking rapid, high-speed, and sharply focused images to capture the bullet in flight. The camera has a clock that measures time with great precision (e.g., $0.01[ns]$). The clock's time is displayed on each captured image. The clock starts measuring time from zero the moment the bullet exits the rifle's barrel. The camera lens is positioned near the muzzle of the barrel. We estimate the distance traveled by the bullet based on its angular diameter visible in the captured photographs. We assume that the bullets emit light at a specific frequency, allowing us to determine their velocity based on the redshift of this frequency. We assume that the experiment is conducted in a vacuum (e.g., in outer space), and the fired bullets move at a constant velocity.

Let's analyze this experiment in a flat, Cartesian, two-dimensional coordinate system related to a stationary camera, where the horizontal axis (denoted as $\boldsymbol{T}$) represents time. Meanwhile, on the ordinate axis (denoted as $\boldsymbol{R}$), we will depict the distance $\boldsymbol{r}$ traveled by the bullet. To ensure clarity in the graphs we will plot on this coordinate system, we assume that the speed of light is equal to 1. Therefore, the velocity of massive objects $\boldsymbol{v}$ is dimensionless and confined to the right-open interval $\langle 0\,,1)$. In that case, if we scale the $\boldsymbol{T}$ axis in nanoseconds $[\boldsymbol{ns}]$, we must scale the $\boldsymbol{R}$ axis in light-nanoseconds, where one light-nanosecond is approximately equal to $0.33564[m]$. In such a coordinate system, the ray of light is inclined at a 45° angle relative to the $\boldsymbol{T}$ axis, and time and space share the same measurement.[3]

After these initial clarifications, let's proceed with the previously designed thought experiment. We are, therefore, firing a bullet from our rifle that is moving at a relativistic speed. First, we determine the redshift z of the light emitted by this bullet to calculate its velocity based on the Doppler effect for light. For a velocity directed along the line of observation, the following relationship applies:

$$z + 1 = \sqrt{\frac{1+v}{1-v}} \tag{1}$$

where the velocity of separation is positive and the velocity of approach is negative.

From equation (1), we will obtain the velocity v as a function of the redshift z:

$$v = \frac{(z+1)^2 - 1}{(z+1)^2 + 1} \tag{2}$$

In Figure 1 below, we have presented a schematic representation of our thought experiment in a two-dimensional Cartesian coordinate system with axes T and R. The blue line represents the worldline of the fired bullet, while the T axis is the worldline of the camera (the observer's worldline). We assume that after a time t_2 from firing the bullet, we take its photograph. The photograph of the bullet depicts its position when it was at point A_1. Now, based on the measured redshift displacement z and the time t_2, we determine the position r_1 and the proper time t_p of the bullet. We calculate the velocity v of the bullet using equation (2).

Based on Figure 1, we have:

$$r_1 = t_2 - t_1 \ ; \qquad t_1 = \frac{r_1}{v}$$

$$r_1 = t_2 - \frac{r_1}{v} \ ; \qquad r_1 v + r_1 = t_2 v$$

$$r_1 = t_2 \frac{v}{1+v} \tag{3}$$

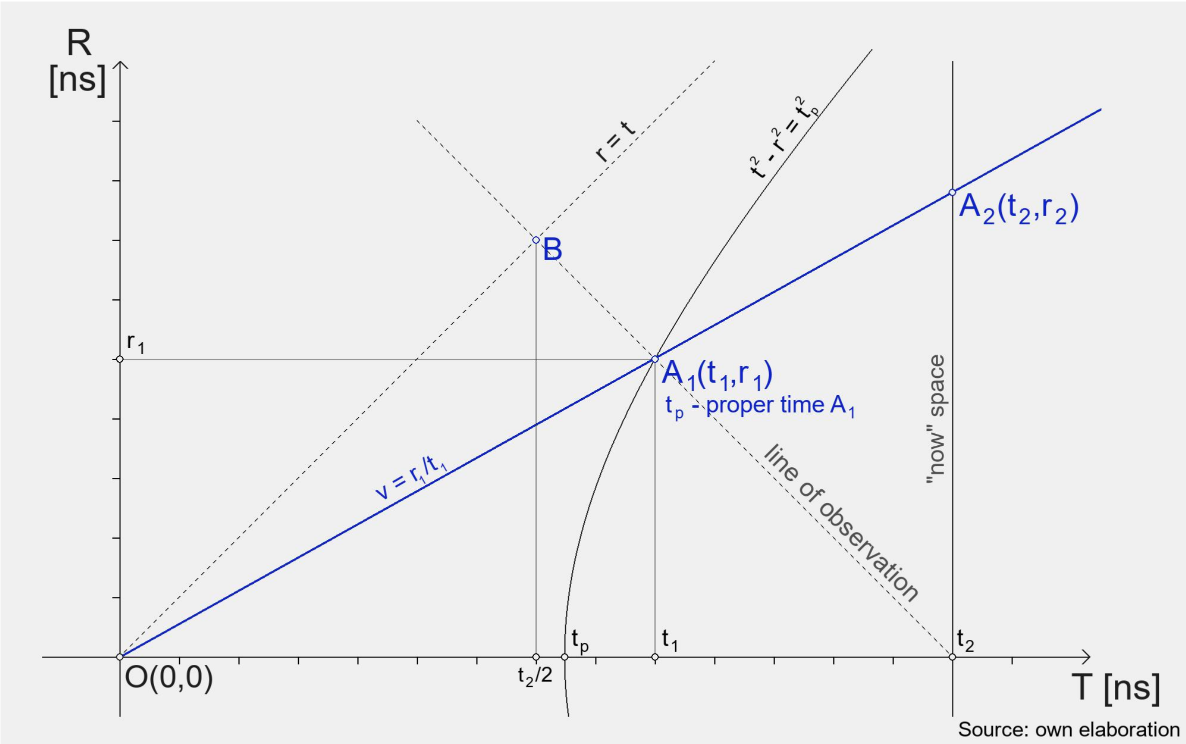

Figure 1

From equation (3), we can also express the relationship between velocity $\boldsymbol{v}$ and distance $\boldsymbol{r_1}$:

$$\boldsymbol{v = \frac{r_1}{t_2 - r_1}} \tag{4}$$

When we substitute the expression from equation (2) for $\boldsymbol{v}$ into equation (3), we obtain:

$$\boldsymbol{r_1 = \frac{t_2}{2}\left[1 - \frac{1}{(z+1)^2}\right]} \tag{5}$$

To calculate the proper time $\boldsymbol{t_p}$ of the bullet at point $\boldsymbol{A_1}$, we will use the Lorentz transformation formula for time:

$$\boldsymbol{t_p = \frac{t_1 - v r_1}{\sqrt{1 - v^2}}} \tag{6}$$

We substitute $\boldsymbol{t_1}$ with $\boldsymbol{t_2 - r_1}$ and $\boldsymbol{r_1}$ with the expression from equation (3):

$$\boldsymbol{t_p = \frac{t_2 - r_1 - v r_1}{\sqrt{1 - v^2}} = \frac{t_2 - r_1(1+v)}{\sqrt{1 - v^2}}}$$

$$t_p = \frac{t_2 - t_2 \frac{v}{1+v}(1+v)}{\sqrt{1-v^2}}$$

$$t_p = t_2 \frac{1-v}{\sqrt{1-v^2}} = t_2 \frac{1-v}{\sqrt{(1-v)(1+v)}}$$

$$t_p = t_2 \sqrt{\frac{1-v}{1+v}} \tag{7}$$

On Figure 1, there is also depicted a hyperbola given by the equation:

$$t^2 - r^2 = t_p^2 \tag{8}$$

This hyperbola represents the locus of points where bullets fired at different velocities have the same proper time t_p counted from the moment the bullet leaves the end of the barrel.

To derive equation (8), we will substitute v in equation (6) with the expression $\frac{r_1}{t_1}$:

$$t_p = \frac{t_1 - \frac{r_1^2}{t_1}}{\sqrt{1 - \left(\frac{r_1}{t_1}\right)^2}}$$

Then we multiply both the numerator and denominator by t_1:

$$t_p = \frac{t_1^2 - r_1^2}{\sqrt{t_1^2 - r_1^2}} = \sqrt{t_1^2 - r_1^2}$$

$$t_p^2 = t_1^2 - r_1^2 \tag{9}$$

Therefore, equation (8) is correct.

Now, we will express the proper time of the bullet t_p in terms of the redshift. For this purpose, in equation (7), we will substitute the expression from equation (2) for v:

$$t_p = t_2 \sqrt{\frac{1 - \frac{(z+1)^2-1}{(z+1)^2+1}}{1 + \frac{(z+1)^2-1}{(z+1)^2+1}}} = t_2 \sqrt{\frac{2}{2(z+1)^2}}$$

$$\boldsymbol{t_p = t_2 \frac{1}{z+1}} \tag{10}$$

The coordinate system from Figure 1 is scaled in nanoseconds $[ns]$. However, there's nothing preventing us from scaling it in seconds, years, or even billions of years. In that case, this thought experiment schematic can be applied to analyze the Universe. Point $\boldsymbol{O}$ would represent the location of the Big Bang, time $\boldsymbol{t_2}$ would be the age of the Universe, and point $\boldsymbol{B}$ on the line of observation would be the edge of the observable Universe. Currently, it is accepted that the distance to the edge of the observable Universe is about 14 billion light-years. Therefore, the age of the Universe $\boldsymbol{t_2}$, as indicated in Figure 1, would be approximately 28 billion years.

Now, using the model presented above and assuming that the Universe is 28 billion years old, let's determine, based on equation (10), how old the Universe was when galaxies GN-z11 and JADES-GS-z13-0 were observed by our telescopes. For these galaxies, proper time $\boldsymbol{t_w}$ is equal to the distance, measured in billion years, from point $\boldsymbol{O}$ in their own reference frames, which was their actual age of the Universe, just as time $\boldsymbol{t_2}$ is the current age of the Universe for us. (Hyperbola (8) is the locus of points where objects that started from the origin $\boldsymbol{O}$ with different velocities at the same time have the same proper time $\boldsymbol{t_w}$).

For the GN-z11 galaxy (z = 11.1), the age of the Universe during the period when it is observed by us, according to formula (10), was:

$$\boldsymbol{t_p = 28 \frac{1}{11.1+1} = 2.31 \, billion \; years}$$

Meanwhile, for the JADES-GS-z13-0 galaxy (z = 13.2), the age of the Universe was:

$$\boldsymbol{t_p = 28 \frac{1}{13.2+1} = 1.97 \, billion \; years}$$

However, if we were to assume that the Universe is approximately 14 billion years old, then the calculated values above should be reduced by half, which still results in values approximately three times larger than what is currently accepted.

Let's also pay attention to formula (4). If we apply this formula to the Universe, $\boldsymbol{t_2}$ will have dimensions [billion years], $\boldsymbol{r_1}$ - [billion light-years], and the velocity will be dimensionless in the range $\langle 0, 1)$. From formula (4), as well as from formula (3), it is clear that there is no linear relationship between velocity $\boldsymbol{v}$ and distance $\boldsymbol{r_1}$ as defined in Hubble's law. **Hence, cosmologists may face difficulties in determining the Hubble constant because such a linear relationship exists in the "now" space (see point $\boldsymbol{A_2}$ in Figure 1), while observations of the Universe are made along the observation line where formulas (3) and (4) apply**.

References

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1. „Hubble Team Breaks Cosmic Distance Record". NASA. 3 March 2016. Retrieved 10 March 2016.
2. Cesari, Thaddeus (9 December 2022). „NASA's Webb Reaches New Milestone in Quest for Distant Galaxies". Retrieved 9 December 2022.
3. Tadeusz Pastuszek. „The New Applications of Special Theory of Relativity". Abacus Publishing House, Bielsko-Biała 2023.