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Article

Solving the Problems of Dark Energy and the Hubble Constant Using Corrected Hubble's Law

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Abstract: In 1929, E. Hubble discovered a correlation between the distance of galaxies from Earth and the redshift in the spectra of the galaxies. This redshift astronomers interpreted it as evidence that galaxies are moving away from the Earth, and that the Universe is expanding. In 1998, researchers from two independent projects concluded that the universe is expanding with acceleration under the influence of "dark energy", the nature of which is completely incomprehensible. Another problem is related to the Hubble constant (H). To date there are two leading approaches to determining H . One of them is based on measurements of the cosmic microwave background, the other is based on measuring the redshift of distant galaxies and then determining the distances to them by luminosity of variables (Cepheids) and exploding (supernovae) stars. The problem is that these methods give different values of the Hubble constant: according to the first method $H \approx 67$ (km/s)/Mpc, according to the other – $H \approx 73$ (km/s)/Mpc. The difference is 7–8%. Accordingly, the calculated radii of the observable universe differ. The reason for this discrepancy is unclear and constitutes the essence of the so-called cosmological crisis. In the presented article, we show that the original Hubble formula needs to be corrected and give the corrected formula (corrected Hubble's law), which is the key to solving these problems.

Keywords: Galaxies; redshift; Hubble's law; dark energy; Hubble constant

1. Introduction

At the beginning of the last century, astronomers discovered a redshift in the spectra of distant galaxies, i.e. a shift of spectral lines towards the red end of the spectrum. In other words, was detected a frequency difference $\Delta v = v_1 - v_2$, where v_1 is the frequency of light emitted by a cosmic source, v_2 is the frequency of light received on the Earth's surface.

In 1929, the US astronomer E. Hubble on the basis of observations discovered a linear relationship (later dubbed Hubble's law) between the relative redshift z in the spectra of the galaxies and distance r to them [1]:

$$cz = rH, \quad (1)$$

where c is the speed of light in a vacuum, H is the coefficient of proportionality called the Hubble constant.

It should be said that the distance that appears in Hubble's law is not directly measured. In reality we determine a object brightness, which provides information about its distance, and the redshift z .

Since astronomers determine the radius R of the observable universe (Metagalaxy) by the formula $R = c/H$, it turns out from equation (1) that the shift

$$z = rH/c = r/R. \quad (2)$$

Thus, from the Hubble's law implies that the visible light sources that have redshift $z > 1$ should be located outside the Metagalaxy, $r > R$.

Obviously, such an assumption is absurd, therefore, the distances can be directly determined from formula (1) only for relatively close objects with $z < 0.1$. Different methods are used to calculate distances at higher redshifts.

Recall that for determining distances to galaxies in astronomy is being used the method of "standard candles": the measurement of object (that has a known luminosity) which located within galaxy. The best type of standard candle for cosmological observations are Type Ia supernovae (SNe Ia).

In work [2] it is noted: "Deeper understanding of low-redshift supernovae greatly improved their cosmological utility. ... A more extensive database of carefully and uniformly observed SNe Ia was needed to refine the understanding of SN Ia light curves." Further: "A strong empirical understanding of SN Ia light curves has been garnered from intensive monitoring of SNe Ia at $z \leq 0.1$ through B and V passbands... We use this understanding to compare the light curves of the high-redshift and low-redshift samples at the same rest wavelength."

In 1998, two independent groups of researchers found that in distant galaxies, the distance to which it was determined from the redshift ($z = 0.16 \div 0.83$), supernovae Ia have brightness lower by 10÷15% than that they should be [3, 4].

In other words, it was found an apparent contradiction in the distance estimates by different methods: the distance to these galaxies, computed using the standard candles (supernovae Ia), was greater than the distance calculated by Hubble's law. The scientists concluded that the universe expands with acceleration under the influence of a mysterious "dark energy".

The nature of dark energy is completely incomprehensible and is the subject of speculation. Researchers discuss this problem from a variety of perspectives, trying to determine the properties of dark energy or finding alternative ways to explain the observational data [5-7].

Another problem is related to the Hubble constant.

To date there are two leading approaches to determining H . One of them is based on measurements of the cosmic microwave background (CMB or *cmb*), the other is based on measuring the redshift (r_s) of distant galaxies and then determining the distances to them by luminosity of variables (Cepheids) and exploding (supernovae) stars (such stars are crucial rungs on the "cosmic distance ladder").

Measurements by these methods give slightly different values of the Hubble constant. In particular, measurements of the microwave background (for example, made by the Planck Space Observatory) show a value of $H_{cmb} = 67 \div 68$ (km/s)/Mpc [8–10]. Measurements using calibrated distance ladder methods indicate on a value of $H_{rs} = 73 \div 74$ (km/s)/Mpc [11–13]. The difference is 7÷8%:

$$H_{rs}/H_{cmb} = 1.07 \div 1.08 = 1/(0.92 \div 0.935). \quad (3)$$

Since astronomers determine the radius (R) of the observable universe (Metagalaxy) by the formula $R = c/H$, accordingly, the calculated radii of the observable universe (Metagalaxy) differ at 7÷8%:

$$R_{cmb} = c/H_{cmb}, \quad R_{rs} = c/H_{rs}, \quad R_{cmb}/R_{rs} = 1.07 \div 1.08. \quad (4)$$

The reason for this discrepancy is unclear and is the subject of heated debate in the astronomical community.

Here we will give a solution to both mentioned problems.

2. Corrected Hubble's law

First of all, it should be noted that there are two relative magnitudes of redshift,

$$\Delta v/v_1 = (v_1 - v_2)/v_1 = 1 - v_2/v_1 \quad (5)$$

and

$$z = \Delta v/v_2 = (v_1 - v_2)/v_2 = v_1/v_2 - 1, \quad (6)$$

between which there is a simple connection:

$$\Delta v/v_1 = z/(z+1). \quad (7)$$

From equation (5) follows that the unit (the number 1) is the limit of the relative redshift $\Delta v/v_1$:

$$\lim \Delta v/v_1 = 1. \quad (8)$$

In addition, the distance r to the radiation source cannot exceed the radius R of the observable universe, therefore

$$\lim r/R = 1. \quad (9)$$

Hence, we get a corrected formula (corrected Hubble's law):

$$\Delta v/v_1 = z/(z+1) = rH/c = r/R \quad (10)$$

or

$$cz/(z+1) = rH. \quad (11)$$

Obviously, this formula is applicable for any z .

Now it is clear that the original Hubble formula (1) needs to be corrected, but Hubble and other astronomers did not know this, because at the beginning of the last century only relatively close galaxies with very small redshift, namely $z < 0.005$, were known. For such small offsets, the value of $z \approx z/(z+1)$ or $z \approx \Delta v/v_1$, i.e. the relative redshift magnitudes, z and $\Delta v/v_1$, are approximately equal to each other.

For example, if $z = 0.005$ then the value $\Delta v/v_1 = z/(z+1) = 0.005/1.005 = 0.004975... \approx 0.005$.

However, even for small offsets, the distances calculated using the original Hubble formula (1) and the corrected formula (11) will differ.

For comparison we will carry out the calculations.

- 1) $z = 0.005$: according to formula (2) the ratio $r/R = 0.005$, and according to formula (10) the ratio $r/R = z/(z+1) = 0.005/1.005 = 0.004975$, i.e. the distance to an emitting object is less by $0.005/0.004975 = 1.005$ times (by 0.5%);
- 2) $z = 0.01$: from (2) $r/R = 0.01$, from (10) $r/R = (0.01/1.01) = 0.0099$, i.e. the distance is less by $0.01/0.0099 = 1.01$ times (by 1%);
- 3) $z = 0.05$: from (2) $r/R = 0.05$, from (10) $r/R = (0.05/1.05) = 0.04761$, i.e. the distance is less by $0.05/0.04761 = 1.05$ times (by 5%);
- 4) $z = 0.1$: from (2) $r/R = 0.1$, from (10) $r/R = (0.1/1.1) = 0.0909$, i.e. the distance is less by $0.1/0.0909 = 1.1$ times (by 10%);
- 5) $z = 0.16$: from (2) $r/R = 0.16$, from (10) $r/R = z/(z+1) = 0.16/1.16 = 0.1379$, i.e. the distance is less by $0.16/0.1379 = 1.16$ times (by 16%);
- 6) $z = 0.2$: from (2) $r/R = 0.2$, from (10) $r/R = z/(z+1) = 0.2/1.2 = 0.166$, i.e. the distance is less by $0.2/0.166 = 1.2$ times (by 20%).

Thus, when using the original Hubble formula, the calculated distances are overestimated.

3. Determination of the Hubble constant

Equation (10) can be written as:

$$z/(z+1) = rH_{rs}/c = r/R_{rs}. \quad (12)$$

Here it is necessary to pay attention to the following circumstance.

As the distance r to the emitting objects increases, the redshift z increases and it becomes increasingly difficult to fix it. Currently, is known the object (probably, galaxy) HD1 that has the largest measured value $z \approx 13$ [14].

Consequently, for the most distant visible objects located on the edge of the Metagalaxy, the redshift z tends to its limit $z_{\max} = \lim z$. Taking into account equation (3), we come to the conclusion that the number z_{\max} should lie in the interval $13 \div 14.5$, because in this case

$$z_{\max}/(z_{\max} + 1) = 0.92 \div 0.935 = 1/(1.07 \div 1.08). \quad (13)$$

Thus, formula (12) in the limiting case has the form:

$$z_{\max}/(z_{\max} + 1) = 0.92 \div 0.935 = r_{\max}H_{rs}/c = r_{\max}/R_{rs}, \quad (14)$$

where r_{\max} is the maximum distance at which the radiation source can be observed.

Now we will move on to the method based on measurements of the cosmic microwave background.

Recall that there is the following relationship between the speed of light c , the wavelength λ and the frequency ν :

$$c = \lambda\nu = \lambda\omega, \quad (15)$$

where $\lambda = \lambda/2\pi$ is the reduced wavelength value, $\omega = 2\pi\nu$ is the cyclic frequency.

To eliminate confusion, it is necessary to establish that λ is the wavelength, and λ is the *radius* of the wave. When electromagnetic waves propagate, the wavelength and its radius increase, and the frequency, on the contrary, decreases. Therefore, the maximum radius of the wave λ_{\max} corresponds to the minimum cyclic frequency ω_0 :

$$c = \lambda_{\max}\omega_0. \quad (16)$$

If we compare this formula with expression of

$$c = R_{cmb}H_{cmb}, \quad (17)$$

then it is obvious that the largest wave radius λ_{\max} is equal to the Metagalaxy radius R_{cmb} , $\lambda_{\max} = R_{cmb}$, and the Hubble constant H_{cmb} is the smallest cyclic frequency of electromagnetic waves ω_0 , $H_{cmb} = \omega_0$.

Therefore, we can write:

$$c = \lambda_{\max}H_{cmb} \quad (18)$$

or

$$1 = \lambda_{\max}H_{cmb}/c = \lambda_{\max}/R_{cmb}. \quad (19)$$

Now we will rewrite the formula (14) in a short form:

$$0.92 \div 0.935 = r_{\max}H_{rs}/c = r_{\max}/R_{rs}. \quad (20)$$

From equations (19) and (20) follows the relationship between the values of the Hubble constant calculated by two different methods:

$$1/(0.92 \div 0.935) = H_{rs}/H_{cmb} = R_{cmb}/R_{rs} = 1.07 \div 1.08 \quad (21)$$

Or

$$H_{cmb}/H_{rs} = 0.92 \div 0.935. \quad (22)$$

3. Conclusions

1. Direct determination of distances using the original Hubble formula (1) is possible only for relatively close objects with $z < 0.1$. This is a significant shortcoming of this formula, so it needs to be corrected. We obtained the corrected equation (11) which is applicable for any z and determined in comparison that when using formula (1), the distances are overestimated. In our opinion, this circumstance is the reason for the discrepancy discovered in 1998 in the estimates of distances by various methods. Therefore, the modern scale of cosmic distances, based on redshifts, is not accurate.

Thus, the statement about the accelerated expansion of the universe under the influence of mysterious dark energy seems to be erroneous. In fact, apparently, the distances to distant space objects are incorrectly determined by redshift!

2. Today there are two main methods for determining the Hubble constant and they are used different equations.

A method that based on measurements of the cosmic microwave background, is used the equation which relates the speed of light, wavelength and frequency: $c = \lambda\nu = \lambda\omega$. We noted that it is convenient to call the quantity $\lambda = \lambda/2\pi$ the radius of an electromagnetic wave. Besides, we have determined that the Hubble constant H_{cmb} is the smallest cyclic frequency of electromagnetic waves ω_0 . Therefore, as equation (19) shows, the largest wave radius λ_{max} is equal to the Metagalaxy radius R_{cmb} : $\lambda_{max}H_{cmb}/c = \lambda_{max}/R_{cmb} = 1$.

A method using measurements of the redshift (i.e., Hubble's law), as it turns out, must take into account the existence the limit value of z : $\lim z = 13\div 14.5$. Therefore, as equation (14) shows, the maximum distance to the visible radiation source r_{max} is less than the Metagalaxy radius R_{rs} by 7÷8%: $r_{max}H_{rs}/c = r_{max}/R_{rs} = 0.92\div 0.935$.

However, until now this fact has not been known, so in calculations using calibrated distance ladder methods the astronomers get an overestimated (on 7÷8%) value of the Hubble constant $H_{rs} = H_{cmb}/(0.92\div 0.935) = 73\div 74$ km/(s Mpc) and, accordingly, an underestimated (on 7÷8%) value of the Metagalaxy radius $R_{rs} = (0.92\div 0.935)R_{cmb}$.

Recognition of existence of the maximum redshift $z_{max} = 13\div 14.5$ requires an automatic reduction of the Hubble constant in the redshift law: $H_{rs} = (0.92\div 0.935) \times (73\div 74)$ km/(s Mpc). The result is the same values of H and R for both methods:

$$H_{rs} = H_{cmb} = H = 67\div 68 \text{ km/(s Mpc)}, \quad (23)$$

$$R_{rs} = R_{cmb} = R = c/H. \quad (24)$$

Thus, in our opinion, the problem of the cosmological crisis has been solved and it remains only to clarify the value of the Hubble constant.

Footnote: Section 2 as a separate article "New formula of cosmological redshift (corrected Hubble's law)" is registered as an object of copyright in the Intellectual Property Office of Kyrgyzstan (Kyrgyzpatent) 11 November 2021 (Certificate № 4558).

Competing Interests: The author declare no competing interests.

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