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Analysis and Research on the Expansion of the Universe and the Calculation of the Distance to Distant Galaxies Based on Doppler's Law

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Abstract: As a basic physical law widely used in various wave phenomena, Doppler's law is often used in the study of the emission distance of light waves in the universe and the movement speed of celestial bodies, and has been frequently mentioned and used in the development of physics and cosmology in recent years. This paper mainly reviews how Doppler's law is applied to the absorption lines (Franhofer lines) of different elements and uses this to explain the appearance and role of redshift and blueshift, and then deduce the fact that the universe is expanding based on the redshift, and use data analysis to calculate the distance between distant galaxies on this basis. Finally, through the movement phenomenon between different galaxies in the universe due to the expansion of the universe, the relative motion of the galaxies moving away from each other and the increasing actual distance between them are determined, providing a simple basis for astronomical calculations. This paper finds that the redshift phenomenon caused by the Doppler effect can deduce the state of motion of the universe that is constantly expanding, and can help calculate the relative distance between stars.

Keywords: Doppler's Law, Fraunhofer Line, Redshift, Cosmic expansion, Galactic distance

1. Introduction

From a macroscopic perspective of the entire Milky Way and even the universe, tens of thousands of galaxies and the stars and planets they contain are constantly undergoing complex relative motion and light wave transmission. Among them, their relative motion changes and actual distances are important astronomical research data and are required by various astronomical and cosmological experiments and observations. The use of the Doppler effect in stellar spectra to observe and study the movement of stellar bodies can be traced back to 1868, when William Huggins observed the tiny movement of the Sirius spectrum line due to the Doppler effect. After that, in the 1920s, Edwin Hubble, based on the improvement of the redshift and blueshift theories, proposed that the recession speed of galaxies is proportional to the distance (Hubble's law) through the collected data and observations of the Mount Wilson Observatory, which served as direct evidence that the universe is expanding. In 1990, the launch of the Hubble Space Telescope made the redshift measurements received by humans more accurate, and the actual values of galaxies and celestial bodies at farther distances could be observed and calculated. Although the fact that the universe is expanding has become a fact recognized by the scientific community, there are still

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disagreements about the measurement of the Hubble constant, especially the Hubble tension problem, which leads to great inconsistencies in the actual distances measured using different methods. This difference may come from some systematic errors that have been ignored by researchers. Therefore, it is necessary to re-explain the fact that the universe is expanding from the simple Doppler effect, and to re-examine and analyze the calculation and relationship of redshift measurement for the distance between stars. This paper will use the method of literature analysis and review, through the relationship between Doppler's law and redshift combined with the changes of Fraunhofer lines in the spectrum, to calculate the redshift value and prove that the universe is expanding while verifying the calculation method of the relative distance of stars. This process can simply and effectively summarize and summarize the theoretical basis of the expansion of the universe and the main methods of measuring the distance between celestial bodies, and can provide a novel perspective in understanding the origin and development of the universe.

2. Reasoning and analysis of the relationship between Doppler's law and redshift

2.1. Relationship between Fraunhofer lines and wavelength of light dispersion

Fraunhofer lines are a series of dark lines in the solar spectrum. They were first discovered by British chemist William Hyde Wollaston in 1802 in an improved dispersion experimental spectrum. The solar dispersion spectrum is an optical spectrum similar to the distribution of rainbow colors observed by physicist Newton in the 17th century in a basic optical experiment by decomposing sunlight through a prism. This is also an early basic study of the dispersion phenomenon of light [1]. In 1814, German physicist Joseph von Fraunhofer further improved the prism and slit device of the new spectrum measurement instrument, which improved the resolution of the solar spectrum to a certain extent and further discovered more and clearer dark lines in the solar spectrum. In subsequent experiments, Fraunhofer successively recorded and observed the spectra of several other stars and found that the positions of dark lines in the spectra of different stars were also different. From this, he concluded that these dark lines were controlled by the stellar light source itself [2]. In 1859, German physicist Gustav Kirchhoff and chemist Robert Bunsen discovered that the dark lines in the spectrum were related to the elemental composition through the study of bright lines produced by the combustion of different elements. These dark lines were the absorption lines of the elements [3]. Therefore, through the specific dark line position of each element in the spectrum, as long as the light can be received, the corresponding elemental composition can be obtained. This dark stripe in the spectrum that can be used to determine the elements contained in the luminous celestial body is called Fraunhofer line.

2.2. Derivation of the red-blue shift of Fraunhofer lines in the spectrum combined with Doppler's law

Doppler's law is a physical formula for studying the change in frequency and wavelength and is widely used in optical and astronomical research. When the light source moves away from or towards the observer, the frequency and wavelength of the light wave will change to a certain extent. Assuming that the observer is stationary, the relationship between the frequency and wavelength of the light wave is as follows:

When the relative motion is away from each other:

$$\lambda' = \lambda\left(1 + \frac{v}{c}\right) \tag{1}$$

$$f' = \frac{f}{1+\frac{v}{c}} \tag{2}$$

When the relative motion is close:

$$\lambda' = \lambda\left(1 - \frac{v}{c}\right) \tag{3}$$

$$f' = \frac{f}{1-\frac{v}{c}} \tag{4}$$

Where λ' and f' represent the wavelength and frequency received by the observer (the Earth when observing light waves emitted by other celestial bodies), λ and f are the original wavelength and frequency of the emitted light waves. c generally represents the speed of light in the universe, and v is the speed of the light source moving along the line of sight.

The above formula can be used to derive the relationship that when the light source moves away from the observer, the wavelength of the light is stretched and the frequency is reduced. On the contrary, when the light source moves closer to the observer, the wavelength of the light is compressed and the frequency is increased. Combined with the research on the combustion of different elements, it has been determined that Fraunhofer lines are absorption lines of an element, and the relative position of the dark line (Fraunhofer line) of each element is fixed in the spectrum. However, when the light source moves away from or closer to the observer (the earth), the wavelength and frequency of the observed light wave will also change to a certain extent according to the Doppler law formula. Therefore, the spectrum will also change to a certain extent due to the change in wavelength and frequency. This phenomenon causes the Fraunhofer lines fixed in the spectrum to shift to a certain extent. The Doppler frequency shift generated by this spectrum is reflected in the shift of the Fraunhofer lines as the spectral lines move toward the red end when the light source moves away from the observer. When the light source moves closer to the observer, the spectral lines move toward the blue end [4]. Therefore, the phenomenon that the Fraunhofer lines move toward the red end when the light source moves away from the observer is called redshift. The phenomenon that the light source approaches the observer, and the Fraunhofer lines move toward the blue end is called blueshift.

3. The derivation and analysis of the relationship between redshift and the continuous expansion of the universe

3.1. Changes in redshift values in the spectrum and calculation model

As described above, when the spectral line shifts to the red end or blue end due to the relative motion between stars, the newly generated element emission line or absorption line will produce a change from the fixed value of the element in the initial light source spectrum. Based on this change, the redshift value caused by the relative motion of the star can be calculated in combination with formula (5).

$$z = \frac{\lambda_{obe}-\lambda_{emit}}{\lambda_{emit}} \tag{5}$$

From formula (5), we can see that z represents the change in the observed wavelength and the emission wavelength, that is, the redshift value. It is also a parameter that describes the movement of the spectrum line in the astronomical spectrum toward the long-wave direction. During the calculation process, if the value of z is a positive number, it represents a redshift phenomenon. On the contrary, if the value of z is a negative number, it represents a blueshift phenomenon. In the formula, λ_{obs} represents the observed wavelength, that is, the wavelength actually measured in the astronomical spectrum. And λ_{emit} represents the emission wavelength of the light source, that is, the

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theoretical wavelength of the spectrum line in a static state (the original wavelength of the light source).

In general, when calculating λ, the difference data generated by the position of the emission line after the element is moved and the original position of the emission line of the element are used for comparison and calculation.

3.2. Linear relationship between recession velocity and relative distance derived from redshift value

After finding the relative redshift value of the celestial body to be measured or observed, the recession velocity experienced by the light source star can be obtained through this difference [5].

$$v = c \cdot \frac{(z+1)^2 - 1}{(z+1)^2 + 1} \tag{6}$$

In equation (6) about the recession velocity, v represents the speed of the celestial body moving away from the observer (the Earth), that is, the recession velocity. c represents the speed of light(c $\approx 3 \times 10^8$ m/sc$\approx 3 \times 10^8$ m/s), and combined with the known redshift value z obtained above, the complete redshift velocity relationship based on the relativistic Doppler effect can be obtained.

It is worth noting that when the redshift value z is less than 1, formula (6) can be simplified to formula (7)

$$v \approx c \cdot z \tag{7}$$

This formula is applicable to most cases with low redshift values, but when the redshift value z is greater than or equal to 1, the full relativistic formula is required for calculation.

After obtaining the required recession velocity, the actual distance of some celestial bodies from the earth can be calculated through a series of methods such as Cepheid variable star return distance measurement [6]. From this, we can observe and conclude that in a coordinate system with the recession velocity in the vertical direction and the actual distance in the horizontal direction, the horizontal and vertical coordinates show a linear relationship of positive proportion.

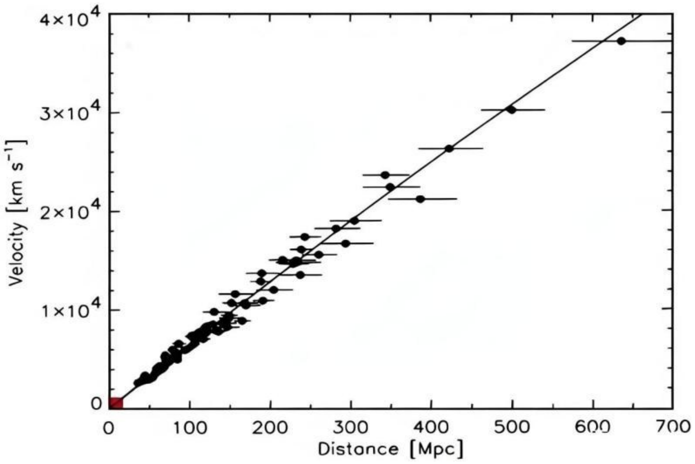

Figure 1: The coordinates of the speed and distance of some celestial objects in the universe relative to the Earth

The linear relationship between the recession velocity and the relative distance shown in Figure 1 is the basic theory of Hubble's law. Assuming the recession velocity is v and the relative distance is d, we can get formula (8)

$$v = H_0 \cdot d \tag{8}$$

The resulting invariant constant H0 is defined as the Hubble constant.

Through the derivation and variation of the above formula, we can finally draw the conclusion that the larger the relative redshift value between the star and the observer (the Earth), the greater the relative distance between the two.

3.3. Cosmic motion state and calculation method of distance between celestial bodies

According to the derivation of Hubble's law above, after determining the linear relationship between the recession velocity and the relative distance, a proportional relationship between them can be obtained. That is to say, the farther the star is from the observer (the earth), the faster its relative recession (moving away) velocity will be. In this case, the most natural and reasonable inference is that the entire universe is constantly expanding [7]. An image assumption is that if the universe is imagined as a two-dimensional plane, the universe can be regarded as a rubber band. After uniform force stretching occurs, each point on the rubber band will move away from other points, and the speed of moving away is proportional to the distance between the two points.

Therefore, under the premise of determining the basic structure model, when calculating the relative distance, the specific distance data that needs to be observed and used can be obtained through redshift measurement (5) and Hubble's law (8).

4. Conclusion

This paper mainly derives and studies how to discover and define redshift and blueshift through the spectral shift caused by Doppler's law, and proves the phenomenon of the universe's expansion and the relative distance between different stars by calculating the redshift value. Under the derivation of this article, the calculation methods of a series of data such as redshift value, recession velocity and relative distance are explained, and it is proved that the motion state of the universe is expanding. It should be noted that the derivation and calculation process of the article does not fully consider the situation of relativity or ultra-high speed. If you encounter these situations in the calculation or observation process, please discuss them in detail in conjunction with other articles. In addition, in the process of finding linear relationships, a large amount of real data is not combined for effective data comparison. If a more accurate derivation of a specific linear relationship is required, the latest astronomical data needs to be combined for calculation, drawing and analysis. In addition, dark energy, radiation energy, cosmic curvature and other factors that affect the expansion of the universe can also be combined with the laws of the cosmic motion phenomenon in this article. In addition, the different Hubble constants generated by the Hubble tension problem can also be explored in conjunction with the calculation of relative distance. It can be foreseen that the discussion on cosmic movement and relative distance will be continuously improved and advanced as various specific situations are gradually considered and referenced.

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