Analysis and Comparison of Cosmic Distance-Measuring Scenarios

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Abstract. As a matter of fact, astronomical research relies heavily on Earth-star distance measurement. With this in mind, it is crucial to develop accurate detection approaches with high precision facility. On this basis, this study introduced four commonly used measuring methods. The trigonometric parallax, in which triangulation is used to calculate the distance. The spectroscopic parallax, determining the distance of stars through spectrum analysis, and the comparison between a star's luminosity and apparent brightness. The variable stars measurement, in which the variable stars are set as standard distances to determine nearby stars' distance. The main-sequence fitting method uses theoretical models to determine the distance of stars in star clusters. While the first two methods are more likely to be precise, the last two are able to measure the distance of further stars. To gain more accuracy, more research about the cosmic background and theoretical models needs to be done. Overall, these results shed light on guiding further exploration of distance measurement.

Keywords: Astronomy, astrophysics, measurement.

1. Introduction

The history of astronomy is evolutionary [1]. Innovations in technologies and methods are both required for development and further findings. The methods of measurement of stars' distance are a part of various grand innovations and they proved to be delicate and convenient. The measurement of stars is essential in astronomy. It can help determine stars' position, motion, and cosmic composition. Accurate measurements of stars can lead to excellent scientific findings. In addition, Earth is the only currently known planet that has the necessary conditions like water and oxygen to hold an ecosystem. As humans develop, increasing demands of resources are formed, which continues to strengthen people's will to find exoplanets to live on or to take necessary resources from. The only feature that enables researchers to find and locate in other solar systems than ours is stars, since they would emit light. Therefore, locating stars is currently the only way to find exoplanets.

Moreover, forming an understanding of the universe, including its origin and formation, also requires the innovation of techniques to measure the distance of stars. From these results, information about the great expansion such as the redshift can be analyzed. Since the closest star from us is 4 light years away, one cannot directly use physical measurement to evaluate stars' distance, nor can one uses sound or light location to find out their position. Astronomers have identified other ways, which make use of star-emitted light and gravitation, to testify a possible range of results of stars' distance. Throughout history, different techniques have been developed to serve for distance measuring in cosmic background. One will choose some typically used methods and make a comparison between them. This would enable us to know more about distance measuring and make further improvements on the techniques, which would be beneficial for star-positing related topics to develop. The most commonly used method is the triangulation measurement, also called the trigonometry parallax. It is typically used to decide nearby stars that can be observed through a telescope clearly. Triangulation is a technique to determine the distance of a star from its angular position measured on two positions on the Earth on which the sun is the middle point [1-4].

Spectroscopic parallax uses star's appeared brightness to determine the distance of stars that are far away from Earth. In this method, the star's spectrum is analyzed to determine its luminosity and compared with its apparent brightness. By finding out how much the light intensity decreases during the distance, the length of the distance can be analyzed. Other techniques include using electronic

images to determine a star's distance through stars' color and light intensity [2]. Inside electronic images, those fainter stars are often compared with the stars whose distance is already known. From their difference in color, which represents the wavelength of light, and light intensity, which is influenced by the distance it traveled and the cosmic environment, one can evaluate the difference between their distance from the Earth and the standard stars' distance. Therefore, their position and distance from the Earth can be evaluated. Usually, the standard stars are variable stars, for which distance is relatively easier to measure due to their special properties. Directly observed colors are also used for determining the distance of stars, usually in clusters. Stars' colors are related to their groups and ages. Therefore, stars of different colors in a cluster are put into a color-magnitude diagram, which will be compared with a main theoretical sequence of the expected position of stars of different masses and ages. The best match sequence can be used as an evaluation of the star cluster's distance [3].

This study will further discuss the background information, development, and application of the four methods. A comparison will be made to generally analyze these methods. By outlining the strengths and weaknesses and reflecting upon the whole path of their development, a clearer state of the development of stellar measurement can be reached and this would be helpful for further studies.

2. Trigonometric Parallax

The triangulation measurement of stars is to determine the distance of a star through its change of angular position in earth-based observation after half a year. It can also be called the trigonometric parallax. Usually, the position of a nearby star is measured from two points that are on opposite sides of the Earth's orbit around the sun. The two times will commonly be 6 months apart. By examining the angular displacement θ and using the already known information, the radius r of Earth's orbit, a triangulation model is formed. A simplified model can be seen in Fig. 1. Therefore, the distance s between the Earth and the planet can be calculated by:

$$s = \frac{r}{\sin\left(\frac{1}{2}\theta\right)} \tag{1}$$

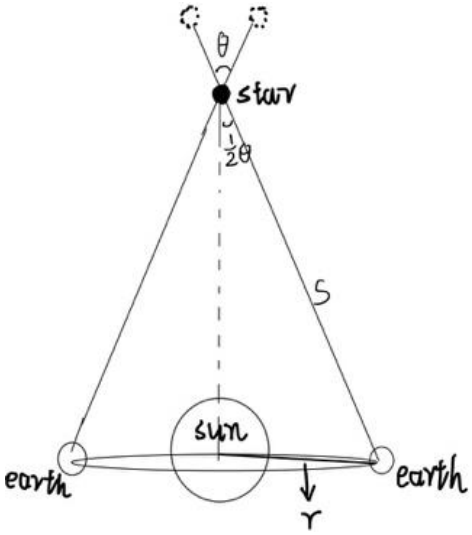


Figure 1. A sketch of the triangulation model

Triangulation measure is the simplest way to determine the distance of stars. Only trigonometric function is used in the formula. Therefore, it is a common way to measure the nearest stars to the Earth. Nevertheless, though convenience and simplicity, a lack of accuracy also exists. For the stars to be observed, although they are relatively the nearest ones, they are still lightyears away. Thus, completely trusting the angular displacement θ of the telescope to fully represent the parallax angle

would result in a lack of accuracy. Since r and s are long, the small inaccuracy of the angle might result in greater imprecision.

3. Spectroscopic Parallax

The spectroscopic parallax is a method to compare the luminosity of the star with its apparent brightness. Through the amount of decreasing brightness, the distance between the star and the Earth can be evaluated. It was first proposed by W.S. Adams in 1916 [4]. As Hearnshaw has said in his review [5], a spectrum is a one-dimensional image of light, in which light of different wavelengths is dispersed consecutively. The concept of "spectrum" was first created by Newton's experiment of dispersing the sunlight through a triangular prism. The best-known example of an emission spectrum is in an experiment in the 19th century, which is the spectrum of a candle flame. In that case, the spectrum is discrete. In the mid-nineteenth century, the spectroscope was developed, and later multiple objective prisms were used, which together gave the possibility for high-resolution spectrums of stars to be formed. The study of stellar spectroscopy was pushed forward by Lewis Rutherfurd, who observed many stars through spectroscopes and categorized them into three types due to the difference in their spectrum. Through the spectrum of stars, their chemical composition, temperature, and size can be determined, and an evaluation of their luminosity, which measures the total energy it emits, can be made. The stars' apparent brightness on the telescope usually would be much less than their actual brightness, since during light transmission in space the light intensity would decrease. If one obtains to know the difference between the representation of stars' original brightness, their luminosity and their apparent brightness observed through a normal telescope, one could determine the distance the light traveled from the star to the Earth by the energy cost of light. Spectroscopic parallax enables astronomers to measure the distance to stars that are too far to be measured by triangulation measurement. However, the uncertainty in the determination of stars' luminosity due to the imprecision of their spectrum and the effect of cosmic dust and gravitational waves on the light during the transmission of light will influence the accuracy of this method. Fig. 2 shows the difference between continuous and discrete spectrums [6].

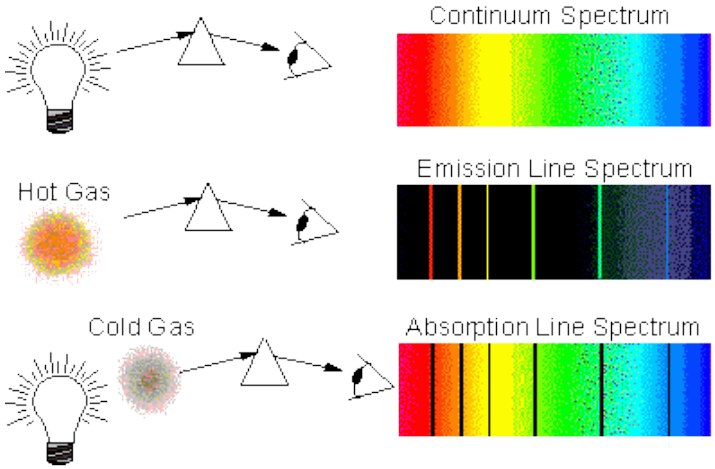


Figure 2. A sketch of spectra differences.

4. Variable Stars Measurement

In this method, the distances of stars that are too distant from Earth to be measured by the triangulation measurement and the spectroscopic parallax are determined by comparing their brightness and color to the stars for which distances are already known and evaluating the differences. The known stars are often variable stars. Variable stars are defined as being able to have a sizable amplitude and a certain amount of regularity in light variation. Two types of variable stars are mainly used as standard stars to determine the distance of other stars, the Cepheids and the RR Lyrae stars.

The two kind of pulsating stars are highly distributed in the Milky Way. Though there are variations, a basic similar pattern of the periodic variation of brightness can be observed and analyzed. That is, among the whole category of Cepheids, the luminosity of one of them is proportional to its period of brightness variation. For RR Lyrae stars, there is also the same pattern. Ledoux et al, in the book Variable Stars, have made a combination of the period-luminosity relation for RR Lyrae stars and Cepheids analyzed by scholars (seen from Fig. 3) [7].

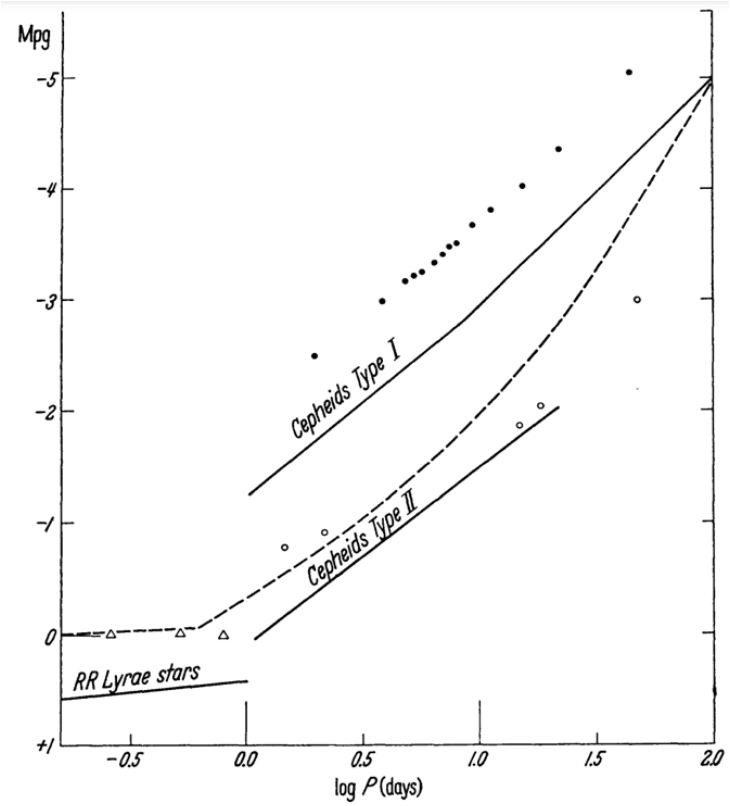


Figure 3. The magnitude of luminosity as a function of period.

Therefore, by measuring the period of the variable stars and determining its luminosity, then comparing the luminosity with its apparent brightness, the distance of the variable stars can be determined and so do the nearby stars. While paving an effective and efficient way for the distance of far-away stars that cannot be directly measured to be known, the method also has some limitations. The luminosity-period relationship of variable stars is not in exact precision, making the random error of this method large. In addition, for places where the Cepheids and RR Lyrae Stars are faintly distributed or hard to observe, such as the Andromeda nebula, it would be hard for this method to carry out.

5. Main-Sequence Fitting

The Main sequence fitting method is typically used to measure the distance of stars in a star cluster, which is a group of stars born together and share similar chemical composition. The stars are put into a color-magnitude diagram, and a theory model of stars, that contains the distance of different kinds of stars, which is the most similar to the diagram, will be found and used as the determination of the distance of this cluster.

The light emitted from the star is a representation of its chemical composition, temperature, and size, which is why different stars have different light colors. A main theoretical sequence is a model of the expected distribution of stars of different mass and age properties on a color-magnitude diagram. The analysis of the theoretical models includes their properties and position. After observation, the stars in a cluster are sorted into a color-magnitude diagram, which will be then compared with the

main theoretical sequences. By finding the best-matched theoretical sequence, the distances between the stars in the cluster and Earth are determined.

This method could help determine the positions of faint and distant stars. It is also effective in determining the properties of the star cluster and therefore further cosmos star compositions. On the other hand, the theoretical sequences might not always be matched to the real observations, which would lead to errors on the distance determination. Fig. 4 and Fig. 5 show the modeled sequence of two clusters of stars, the Pleiades and the Globular Clusters. [8]

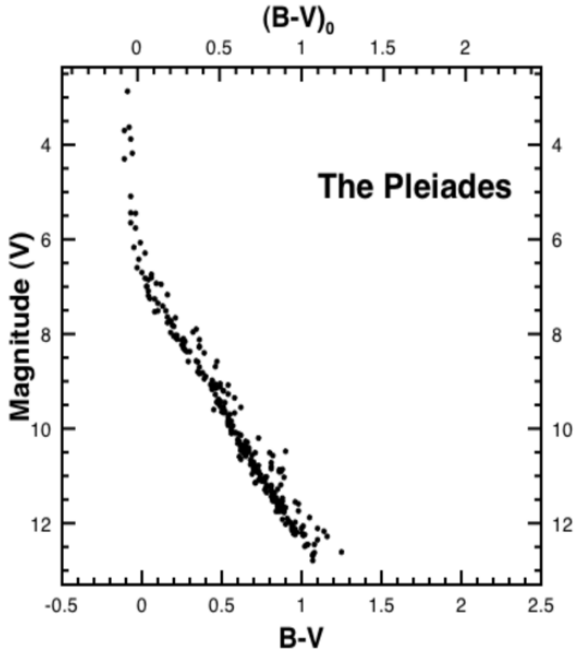


Figure 4. Modeled sequence of the Pleiades and the Globular Clusters

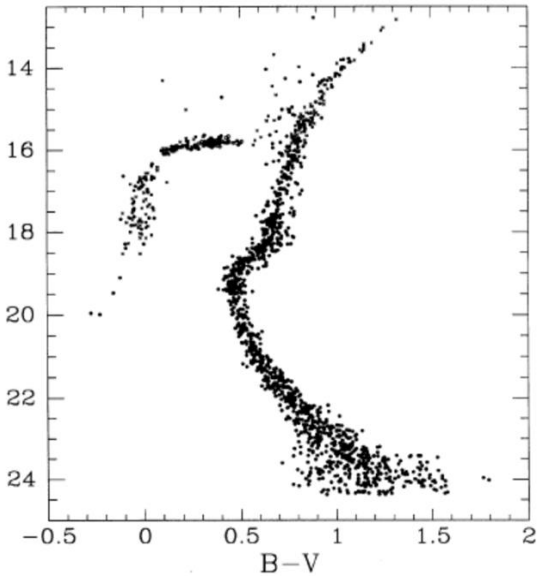


Figure 5. Modeled sequence of the Globular Clusters.

6. Comparison and Discussion

Four methods of determining Earth-star distance are introduced, including the trigonometric parallax, the spectroscopic parallax, the variable stars measurement, and the main-sequence fitting method. While triangulation and spectroscopy only focus on the collection and analysis of observed data, the comparison of the measured star toward variable stars and toward theoretical sequences also depends on the comparison between known information and new data [8-10].

The trigonometric parallax has a complete theoretical model and is simple to carry out, but a long time scale would be required since the two observations need to be half a year away. The imprecision of the measurement of the angular displacement would lead to systematic errors. The measure of the spectrum is more precise and is available to further stars. However, the spectrum might be vague and the cosmic environment impacts the result a lot. Meanwhile, since there will not be informational errors in these two methods, they can be seen as relatively accurate measurements. When it comes to the variable stars measurement, it is a great substitute for spectroscopy for the distant stars. In the meantime, the magnitude-period relationship of variable stars is still in debate, and the distribution of variable stars has not covered all the interstellar space, creating inconvenience. The Main-Sequence Fitting method targets clusters of stars. However, using theoretical models to describe real observations is risky. The precision and completion of different main sequences can lead to more precision, but still, errors would exist. Therefore, these two methods to determine distant stars have less possibility to be precise but a wider distance measuring range than the parallax. The innovation and continuous correction of theoretical models would be required to increase the accuracy of them.

7. Conclusion

Measuring Earth-star distance is vital in cosmology. This study introduces the commonly used methods, including the trigonometric parallax, spectroscopic parallax, variable stars measurement and MS fitting. While the first two methods focus on nearer stars and are likely to reach a higher accuracy level, the other two methods, limited by the need to use existing models to help with the far distance of stars, have risks for the possible difference between the theory models and the actual interstellar environment and telescope observation. Therefore, more understanding of the composition and matter distribution of the cosmic environment and continuous advancement of the theoretical models are needed for the precision to improve.

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