Measuring the universe with cosmic “ruler”

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Have you ever wondered how the universe started and how it will end? Have you ever wondered how the universe will look like billions of years later? There were many attempts to answer these questions, however, we are still very far from fully understanding the nature of our universe.

25 years ago, observations have shown that our current universe is in a phase where the expansion speed grows faster over time (a so-called accelerated expansion). It is known that for this acceleration to occur, our universe needs to be dominated by an energy source that exerts negative pressure. This mysterious energy source dominating our current universe is called “the dark-energy”. The dark-energy domination epoch is estimated to have started around several billion years ago, quite a “recent” feature compared to the full history of cosmological expansion, and its effect on the cosmological evolution will grow larger and larger in the later epoch. Therefore, understanding the nature of dark energy is necessary to predict how our universe will look in the future.

Because the nature of dark energy is tightly connected with the evolution of the universe, astronomers have made efforts to constrain the nature of dark energy by measuring the expansion of our observable universe. So, how do we measure the expansion history of the universe? The basic idea is to use two observational quantities: “redshift” and “light travel distance”.

Imagine observing some far away light source. It can be anything including stars, galaxies, and supernovae. When light travel through expanding universe, its wavelength will be stretched along with the background. Therefore, by observing how much the wavelength was stretched, we can measure how much the universe expanded. This elongation of wavelength due to cosmic expansion is called the “redshift”. The other quantity “light travel distance” is the distance light traveled from emission to observation. The most common way to observe distances is to measure the apparent size or luminosity of a light source with a known size or luminosity. Because the apparent size (luminosity) decreases by the distance squared, we can estimate the light travel distance. You can imagine how the light travel distance changes depending on the expansion model through this simple exercise.

1. Set the initial distance between the light source and the observer as 10cm. Divide the distance into 10 pieces. (1cm per segment)
2. Set the final distance as 20cm, meaning each segment will be 2cm long.
3. Assume that light can travel 1cm per second.

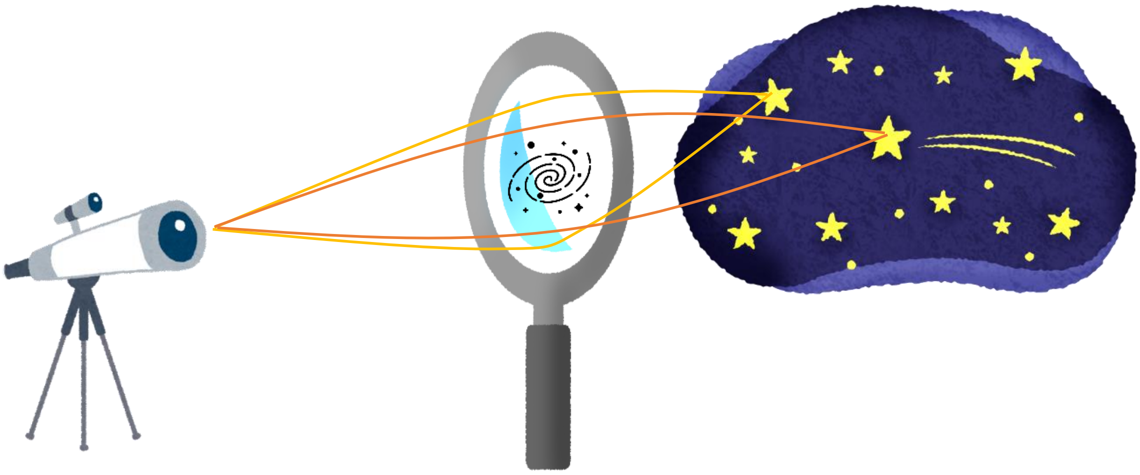
First, think of a model when the distance expanded to 20cm in the first second and kept constant for the rest of the time. After the first second, the light will be passing through the first segment. The distance to the observer is 18 to 19cm, so the total light travel distance will be 19 to 20cm. Next, let’s think of a model in which the distance expanded to 20cm after 9 seconds. In this case, light has already passed the 9th segment and there is only 1 segment left. Therefore, the total light travel distance will be 10 to 11cm. Generally, if the universe has an accelerated expansion, light will have traveled a considerable distance before the expansion, resulting in a shorter light travel distance.

Now that we learned how to measure the cosmological expansion, however, here comes the trick. Assuming the standard expansion model, the observational results of nearby light sources and faraway light sources do not match, leaving room for other models to come in.

A recently discovered method using "gravitational lensing" may be a breakthrough in constraining the expansion model. Gravitational lensing is a phenomenon where the optical path of light passing through massive objects, such as galaxy clusters (thousands of galaxies in a gravitational bond), gets bent by the strong gravitational field. How can we measure distances using this phenomenon? Imagine a light stream passing through an optical lens. You can easily imagine that the refraction angle depends on the distance between the light source and the lens. If there are two or more light sources, we can calculate the distance ratio using the refraction angle, even if we don't know the lens's optical properties. Following similar steps for gravitational lensing, we can measure the distance between the light source and the gravitational lens [1].

The thing so special about this method is that one can measure "remote" distances between faraway objects separately from the nearby universe. Remember that other methods always measured the distance between the light source and the observer. Thich means that, when we try to measure the distance from a faraway object, the light travel distance is always subject to the expansion of the nearby universe. By measuring the "remote" distance, it is expected that we can get a better insight into the cause of the discrepancy between nearby and faraway light sources [2].

For centuries, humans have always wanted to understand the universe, and even today, I believe that understanding how the universe and how it ends is an object of interest. Dark energy is the dominant energy of the universe, and its effect on the evolution of the universe will get larger in later epochs. Depending on the nature of dark energy, the universe may experience a rapid death where every matter and even space-time itself gets torn apart by accelerated expansion, while other scenarios predict a rather moderate doomsday in which the universe will become a cold, empty space with nothing in the observable area [3]. Right now, we do not know what our universe will look like in its latest days, and measurement using gravitational lensing may be an important milestone for predicting the future universe.



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Reference

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Used Grammarly to check grammatical errors.