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Edwin Hubble and the Expansion of the Universe

Celso Luís Levada[1], Huemerson Maceti[1,2], Ivan José Lautenschleguer[1], Bruno Zaniboni Saggioro[1,2], Wadley Calegaro de Castro[1,2]
[1]*Science Teaching Group of the Hermínio Ometto Foundation – Brazil*
[2] *Science Teaching Group of the Colégio Puríssimo Coração de Maria – Brazil*
Corresponding Author: Celso Luís Levada

ABSTRACT: *On March 15, 2019, nine hundred years ago, Edwin Hubble(1), an American researcher, communicated to the scientific world the article entitled "A relation between distance and radial velocity among extra-galactic nebulae", published in the journal Proceedings of the National Academy of Sciences of the United States of America. At this time, the publication was widely criticized for not giving due recognition to the works of Slipher and Lemaitre. In the article, he determined the relationship between the recession velocity of the galaxies and their distance (V=Hd), which is known as the Hubble Law, and the proportionality constant H is called the Hubble constant. After the discovery of Hubble, Albert Einstein said he made a big mistake with the general idea that the universe was static.Nowadays, science books, encyclopedias, and most of the books on cosmology, attribute to Edwin Hubble the discovery of the expanding universe. In fact, the intellectual mentor of the attribution given to Hubble by the fact that the universe is expanding, was Einstein in 1930 when he uttered a series of lectures for astronomers in the United States. However, it would be more appropriate if we presented the expansion of the universe as a collective construction, in which Hubble played an important role, but was certainly not an isolated "discoverer".*

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I. INTRODUCTION

Edwin Powell Hubble(1) was born in Marshfield on November 20, 1889 and died in San Marino on September 28, 1953, and was one of the leading American astronomers. Famous for having discovered that the so-called nebulae were actually galaxies outside the Milky Way, and that they move away from each other at a rate proportional to the distance that separates them. Its name was given to the first space telescope, put into orbit in 1990, to study the space without the distortions caused by the atmosphere, that is in operation until the present day and its images can be visualized in real time through the NASA website.

In 1906, Edwin Hubble began(4) his studies in mathematics and astronomy at the University of Chicago, where he worked with Nobel laureate Robert Millikan as a laboratory assistant. After graduating, he began his law studies at the University of Oxford. One of Edwin Powell Hubble's main contributions to science was proof that there were other galaxies besides the Milky Way. At work, he presented data from 46 galaxies, with fairly reliable measurements of the distances of 20 galaxies. Almost all of the nearby galaxies except some very close ones and therefore subject to our gravitational field, would be moving away.

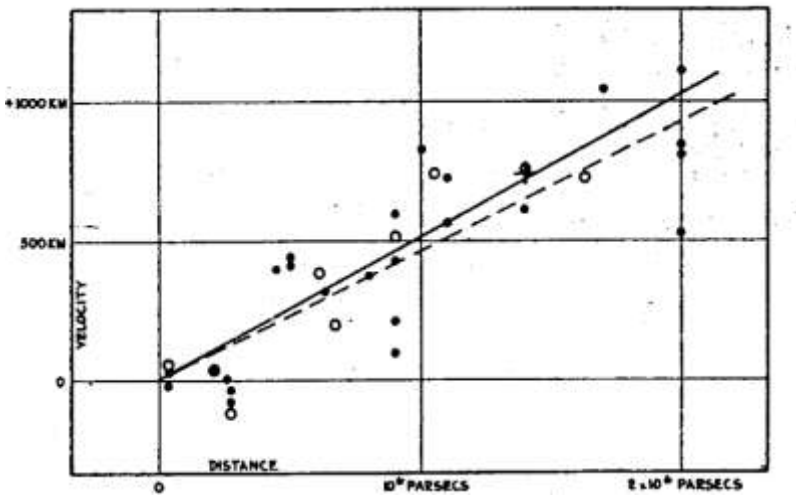

Figure 1: Graphic of the original Hubble article of 1929, showing how it was deduced the "Hubble Law".

UNIVERSE IN EXPANSION

Telescopic observations[2] of distant galaxies indicate that the Universe is expanding, that is, the distances between galaxies are increasing with time. The fact that the Universe is expanding is established for the reason that it is possible to measure the relative velocities of spacing or approaching the galaxies through the Doppler shift of the light they emit. From the observation of the distant galaxies, we realize that they are moving away from us.

In view of this, from the 1930s the dominant interpretation was that Hubble's work provided evidence that the universe is expanding. However, the idea that the universe is expanding actually began in 1914, when Slipher demonstrated the displacement of light from various nebulae to red and this result can be interpreted as if these nebulae were moving away from us due to the Doppler Effect.

After that, other scientists[2] set out to study the equations of Einstein's theory of general relativity in order to study the mathematical behavior of the evolution of the universe. Such equations could only present two possibilities for solution: the universe should be expanding or contracting. Einstein was very intrigued by these possibilities, for he and most of the astronomers believed in a static universe. In view of this, Einstein had introduced a constant into his equations, the famous cosmological constant, which functioned as a force of repulsion to compensate for the force of gravitational attraction resulting in a static universe. He was heavily criticized by some scientists who said he was "forcing" the equations to a desired result. Time passed and it was only between 1925 and 1927 that George H. Lemaître, a Belgian physicist and mathematician, recreated the model of the expanding universe using the equations of general relativity.

Lemaitre[2] believed that the red shift of the light emitted by the galaxies corresponded to the fact that these galaxies are moving away from each other and, in addition, the predicted displacement would be proportional to the distance, as in the Hubble Law. Lemaître published the article in the prestigious English scientific journal MNRAS (Monthly News of the Royal Society of Astronomy). After the publication of this article, the theory of universe expansion finally began to take credit.

WHAT IS THE AGE OF THE UNIVERSE?

One can estimate[3] the maximum age of the universe, t_0, by calculating the time that distant galaxies, moving at the same speed as today, spent to get where they are, assuming zero dark energy. Hubble law, which relates the recession velocity of galaxies, V, to the distances between them, d, is given by equation (1)

$$V = H_o . d, \quad (1)$$

Where

$$V = \frac{d}{t_0} = \frac{1}{t_0} . d \quad (2)$$

By comparing equations (1) and (2), one obtains

$$t_0 = \frac{1}{H_0} \quad (3)$$

In this case, t_0 is the time elapsed since the moment the galaxies were all together until the present time. We may also think that it is the time in which the galaxies would have taken to reach the distances that are today

if they had moved all the time with the speed that they have today. In other words, t_0 is the age of the universe at a given constant expansion rate (H_0). Therefore, by measuring the Hubble constant we can estimate the age of the universe. The most current value of the Hubble constant is $H_0 = 71.3 \pm 2.0$ km/s/Mpc. Using equation (3), it can be concluded that the age of the universe would be

$$t_0 = \frac{1Mpc}{72\ km/s}$$

By considering that 1 Mpc ≈ 3.1 x 10^{19} km and 1 year = 3.15 x 10^7 s, one obtains that to ≈ 13.8billion years.

RED SHIFT MEASURES

The Doppler Effect[4] is a phenomenon observed in the waves when emitted or reflected by an object that is in movement with respect to the observer. If a sound source and a receiver are moving relative to one another, the received frequency is not the same frequency as the source. If they are approaching, the frequency received is greater than the frequency of the source; if they are moving away, the frequency received is less than the frequency of the source. A typical example is the ambulance siren: the sound you hear when you are away from and near the receiver is different. In this case, the wave propagates in a medium. This phenomenon can also be seen in electromagnetic waves, which do not necessarily need a medium to propagate. Equation (4) represents the Doppler effect of light:

$f' = f.\ (v \pm u'' / v \pm u')$,(4)

where f represents the frequency emitted by the source, f'symbolizes the frequency realized by the receiver, v denotes the speed of the wave, u" represents the speed of the receiver and u' symbolizes the speed of the source.

In this way, it can be seen that when a star or galaxy is moving towards us, the wavelengths of the light they emit are shifted to the blue side of the spectrum, where the frequency value is greater. Such a phenomenon is called the deviation to the blue. If a star or galaxy is moving away, the wavelengths of the light they emit are shifted to the red of the spectrum, where the frequency value is smaller. This is referred to as the redshift. This phenomenon, the displacement of wavelengths due to the relative movement of objects, is known as the Doppler Effect. All light from the stars and galaxies that reaches the Earth is shifted to the red, meaning stars and galaxies are moving away from us.

Astronomers[4] can measure exactly what the red shift or blue shift of a galaxy by observing its spectrum. A spectrum represents the different wavelengths that an object emits. Spectra of stars and galaxies usually exhibit a series of maximum and minimum points called "spectral lines". These lines always appear on the same wavelengths, making them good red shift or blue shift indicators. If astronomers, by observing a galaxy, notice that a spectral line has a wavelength greater than it would be on Earth, they will conclude that the galaxy has been shifted to the red and is moving away from us. If they observe that a spectral line has a wavelength smaller than it would be on Earth, they will conclude that the galaxy has been shifted to the blue and is approaching us.Each spectrum is placed in a computer program that automatically determines the correct shift. For example:

$\lambda = (1+z)\ \lambda_0$,(5)

Which means that a galaxy with red shift z is moving away from us with velocity $v = c \cdot z$.

CONTROVERSIES

To make this subject even more controversial[2], it was discovered in 1998 that the expansion of the universe occurs in an accelerated manner, which was of great astonishment to the scientific community, since the theoretical prediction was that the rate of expansion of the universe would decrease with the over time, and it was from this that the idea of the existence of a strange energy that accelerates this expansion that is called dark energy arose. This discovery was made by two groups of American astronomers who measured distances using explosions of certain types of supernovae. The theoretical model predicted that the rate of expansion near our galaxy would be less than at great distances, with the universe expanding indefinitely or not, for when we look at great distances in the universe, we see the past (this is due to the fact that light to have a finite velocity) and therefore at great distances (past), it should be expanding more rapidly than in our vicinity (present).

The only way to explain this accelerated expansion[5] would be to admit the existence of a kind of repulsive force, contrary to the force of gravitational attraction, which was termed dark energy, and this equates to reintroducing Einstein's cosmological constant into the general relativity equations. To this day one does not know what dark energy really is, being a matter of extreme complexity and it will probably take some time for it to be fully explained. After discovering the expansion of the universe, Einstein considered the introduction of the cosmological constant into his equations as the greatest scientific error in his life. Ironically, however, this might not have been a mistake, for the most likely quantity to explain dark energy would be the cosmological

constant introduced by Albert Einstein in 1917, that is, it would represent a kind of situation where the universe would be forever accelerated.

II. DISCUSSION

To admit that Hubble "discovered" the expanding universe is a dubious statement. It is usually said that a scientific discovery occurred when the scientist, through observation or experimentation, encounters a new phenomenon in nature that was previously unknown. Thus it cannot be said that Hubble was the only "discoverer of the Law that bears his name" and not even the first. When Hubble found the linear relationship between the redshift and the distances of the galaxies, he did not discover the expansion of the universe. The construction of the theory of the universe in expansion had several collaborators[(2)], was a process that lasted some years, involving both theoretical aspects, as experimental ones. So we cannot even say that Hubble created the idea of the expanding universe. The concept of an expanding universe, with which we are familiar today, was introduced independently by the Russian scientist Alexander Friedmann and the Belgian cosmologist Georges Lemaître, from their solutions to Einstein's theory of general relativity equations applied to cosmic fluid.

THEBIG BANG

The Big Bang term was coined by Fred Hoyle[(5)] during a radio broadcast in 1949. Hoyle proposed an alternative cosmological model called "Stationary State Theory," and decided to create a pejorative term for the expanding universe model. A few years ago Hoyle explicitly denied this and said it was "just an impressive term to highlight the difference between the two models." Hoyle also helped, years later, in understanding the stellar nucleosynthesis, the nuclear pathway associated with building some heavier elements to the lightest ones.

After the discovery of cosmic background radiation associated with microwaves in 1964, and especially when their spectrum was schematized by a blackbody curve, many scientists were reasonably convinced by the evidence that some of the scenarios proposed by the Big Bang theory must have occurred. The importance of the discovery[(6)] of cosmic background radiation consists in the fact that it represents a "fossil" of a time when the universe was very new, being the most evidence of the existence of the Big Bang. This radiation comes from the dissociation of its interaction with matter (the so-called recombination period).

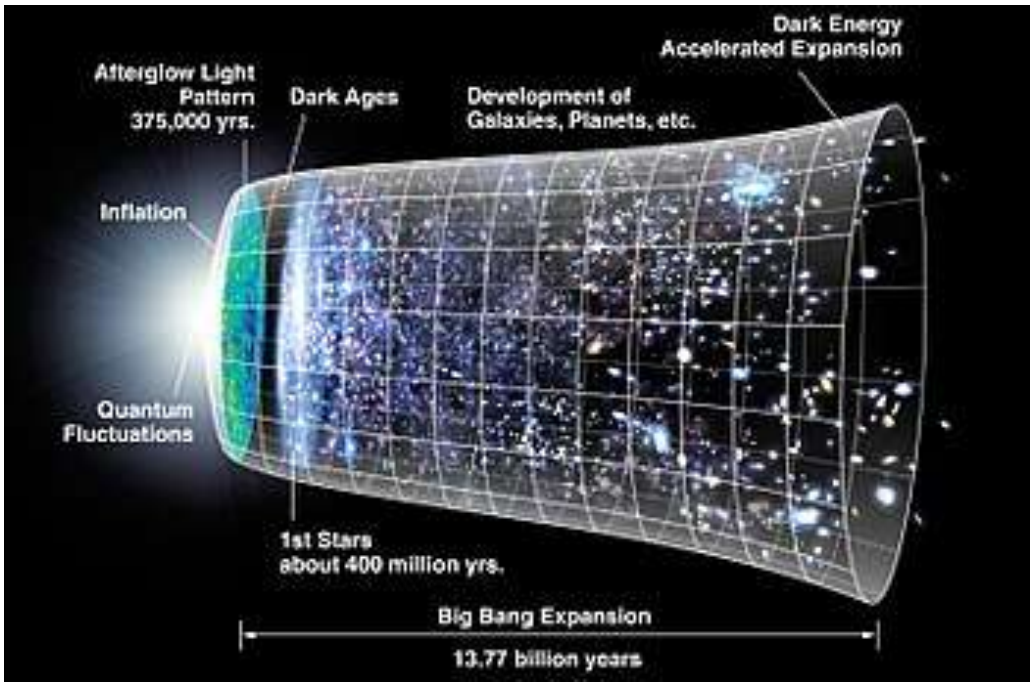

Figure 2: Artistic concept of the expansion of the Universe, where space (including hypothetical unobservable parts of the Universe) is represented in every moment, in circular sections. The scheme is decorated with WMAP satellite images.

FINAL CONSIDERATIONS

As it can be seen, the theory of the expansion of the universe had a great evolution, since it began with only a few speculations and was being perfected over the years. Hubble is taken as the protagonist[(2)] of this story, and of course he played a key role in this by showing that the greater the distance from a galaxy, the greater its speed

will be, but as it was reported, he did not really believe that his law could show that the universe is expanding, being very careful about it and he preferred not to give physical interpretations to the result obtained.
The both discovery of the universe in accelerated expansion and the mysterious dark energy have left physicists and astronomers with no satisfactory explanation until the present moment. The theory of universe expansion is one of the pillars of the Big Bang theory, which opens the way to many considerations that still need to be clarified, in addition to making possible an estimate of the age of the universe in approximately 14 billion years.

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