The Age Of The Universe

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Introduction

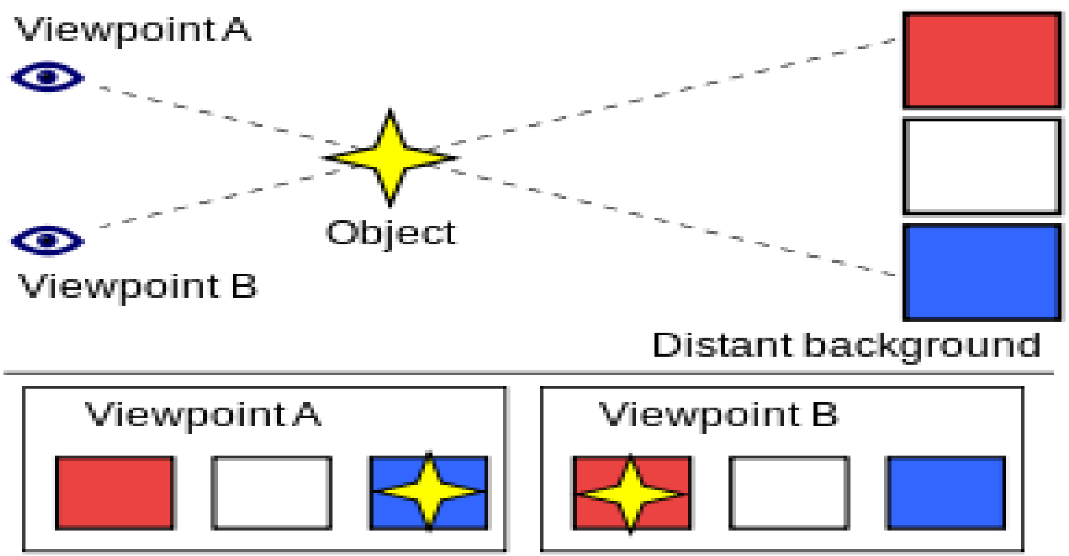
Ever since the first time one looks up at the profound and starry sky, there has dwelt a strong appetite of adventure over this vast but mystery universe on one's deepest mind. " Why the world has been made?" "What's the meaning of the Universe?" "What's the age of the Universe?" Those questions are the unfathomable nightmares that haunt ancient scientists and scholars every night, driving them to wake up and contempt while gazing the night sky. Fortunately, the latter question, "What's the age of the Universe", finally disclosed its mysterious veil and exposed the answer to humans in the 20th century. And it all occurred when Edwin Hubble[1] in 1929 observed that distant galaxies were all apparently moving away from us…….

Parallax

Before we get into how Edwin Hubble found the Universe is expanding, we first need to talk about the ways astronomers use to measure the distance of stars that are far away from us. One of the most widespread ways is by using the "Parallax". **The "Parallax" basically is the displacement or difference of the object viewed caused by the movement of the observer.** As the graph[2] shows below, although the object, the yellow star, is stationary during the moving of the viewpoint, it has different positions between the Viewpoint A and Viewpoint B. Generally, by applying the distance the

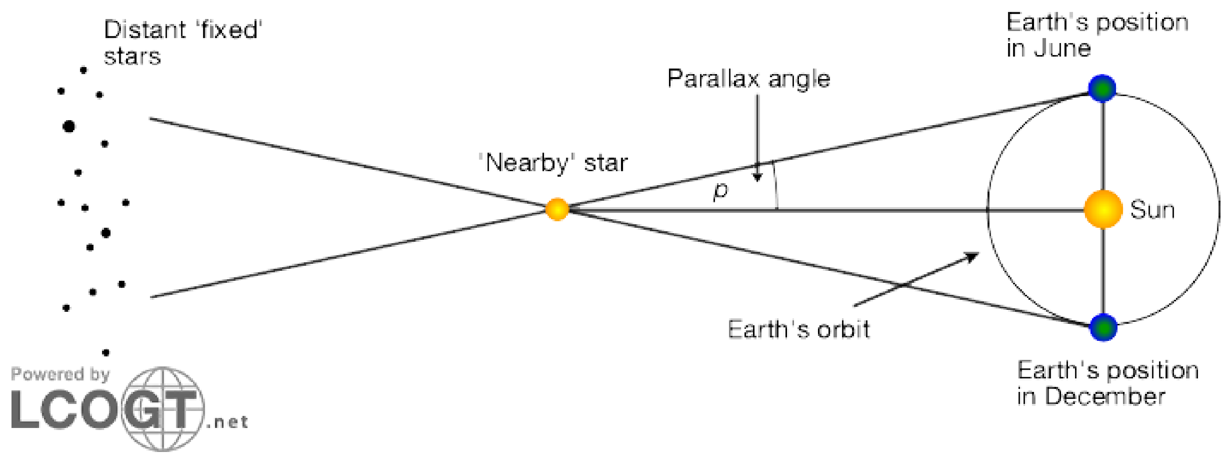
[1] Edwin Hubble was an American astronomer who played a crucial role in establishing the fields of extragalactic astronomy and observational cosmology
[2] Graph originated from google image

observer traveled and the angle[3] of the object changed, one can precisely estimate how far the object is.



The “parallax” is usually used to measure the distance of stars nearby. As the Earth is orbiting around the sun, in people’s eyes the stars nearby will appear to move in another direction and against the background because of the parallax. Therefore, Astronomers can record the position of the star once, and six months later measure the change of the position of that star. By doing so, astronomers can use the angle it changed and the distance the Earth traveled to measure the distance.[4]

[3] The changing angle of the object in observer’s eyes is actually the changing angle of observer’s movement relative to the object
[4] Information referenced from LCOGT.net



Here in the graph, the distance from the Earth to the Sun is declared to be one astronomical unit(1 AU in calculation). Therefore, we can easily find the relations between the Parallax angle and the distance to star by using the trigonometric rules[5]:

tan P = 1 AU/ D (*D represents the distance to the star)

It can even be simpler. As x is approaching 0, tanx = x and $\sec^2 x = 1$(derivatives)[6]. (*lim x → 0 tanx/x = 1) In other words, as x is approaching 0, the function of f(x) = tanx is coinciding with the function of f(x) = x. And because the angle here measured is so small that we can directly switch the f(x) = tanx to f(x) = x. Therefore,

P = 1/D

-> D = 1/P

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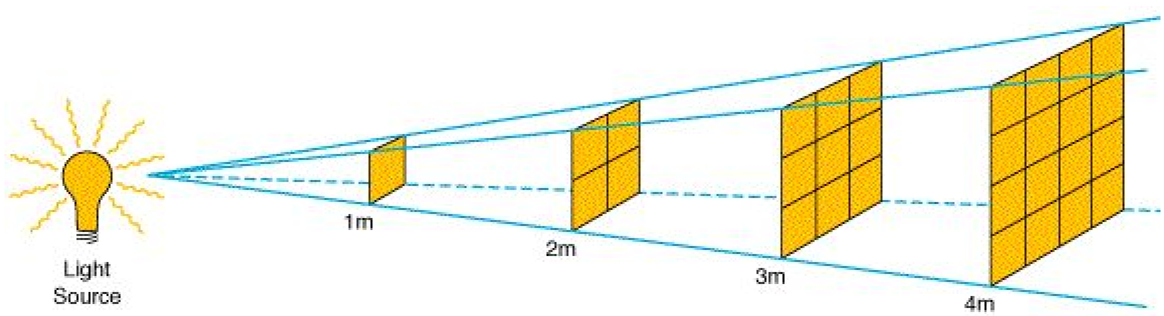
[5] tanx is the opposite divided by the adjacent. Here 1 AU is right the opposite and the distance to star is right the adjacent

[6] take the derivatives of both sides, we find two sides still equal

The distance D is measured in parsecs and the parallax angle P is measured in arcseconds. (*60 arcseconds=1 arcminute, 60 arcminute=1 degree, 1 parsec=3.26 ly) By applying the equation “D = 1/P”, we can easily estimate the distance of stars nearby.

Brightness

However, although using parallax to measure distance is extremely convenient that it only requires the data of angle for calculation, the “parallax” can merely be applied for stars within hundreds of parsec. Fortunately, scientist and astronomers later discovered another way of measuring distance by using the brightness of stars. At that time scientists realized that there are two kinds of brightness, “the flux and the luminosity”. **The Flux is the energy of light output observed in the Earth, while the Luminosity is the actual energy of light output.**

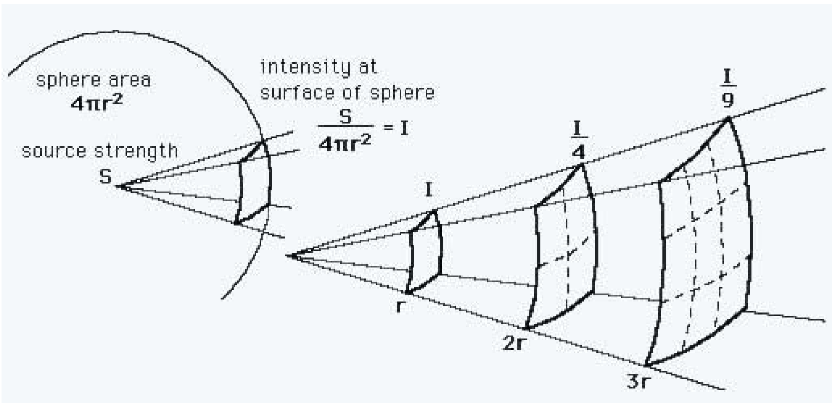


As one can see through the above picture, the luminosity is the energy of light in the light source, while the flux is the energy of light in the yellow panel[7]. Moreover, scientists even found the relations among flux, luminosity and distance, that:

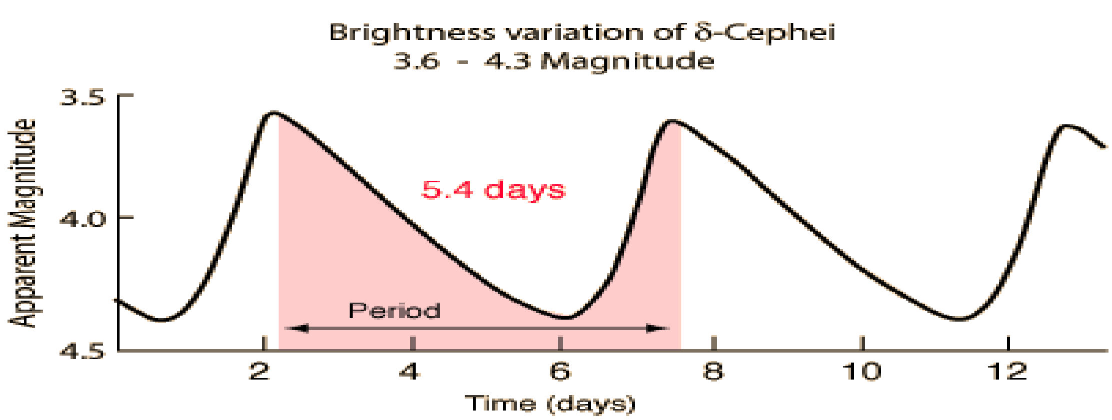
[7] As the area geometrically increases, the light also geometrically decreases so as to be distributed evenly to the area

F = L/(4π*d^2)   *L: luminosity, d: distance, F: flux

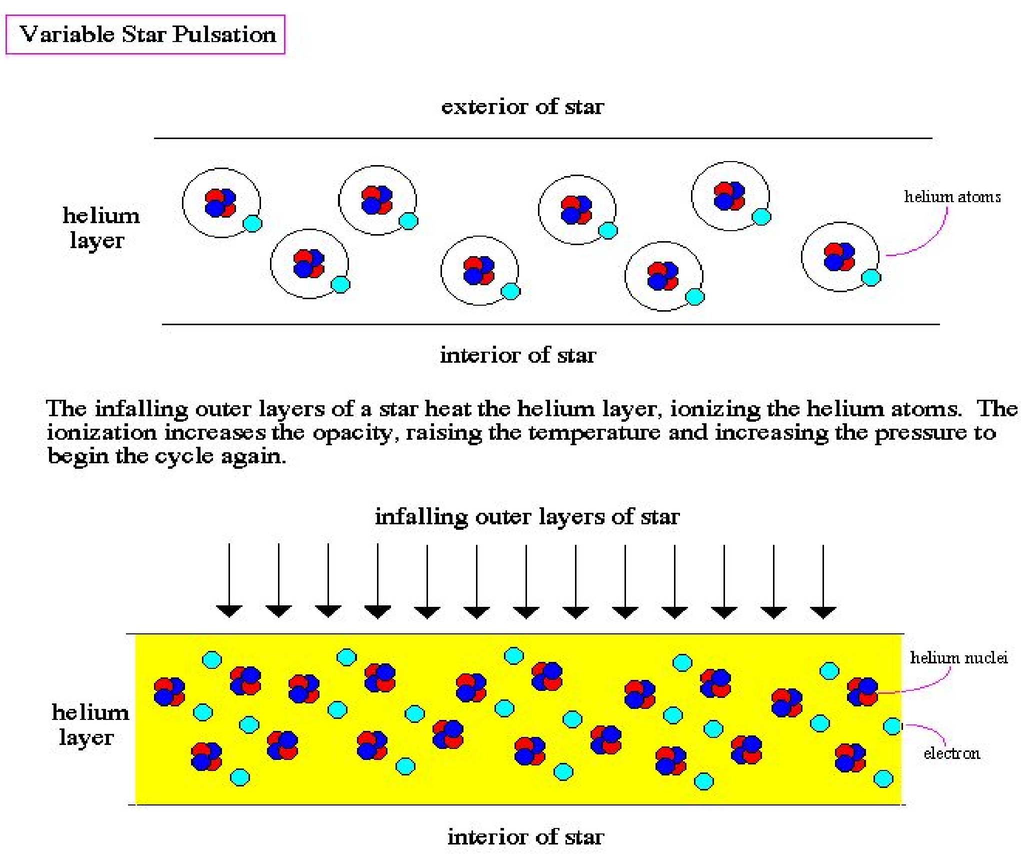
The following picture also explains how this equation comes out.



Therefore, if one can find both the luminosity of a star and the flux we observe in the Earth, we can calculate the distance to that star. But, how can we find the actual luminosity of a star that is millions of light years far away from us? Scientists here use an unusual kind of star called “Cepheid variable star” to find the luminosity. **The Cepheid variable is a special type of star that pulsates radially, changing both diameter, temperature, and brightness with a stable period.** Here the graph shows a typical Cepheid variable star. As you can see, its brightness varies with a stable period of 5.4 days.

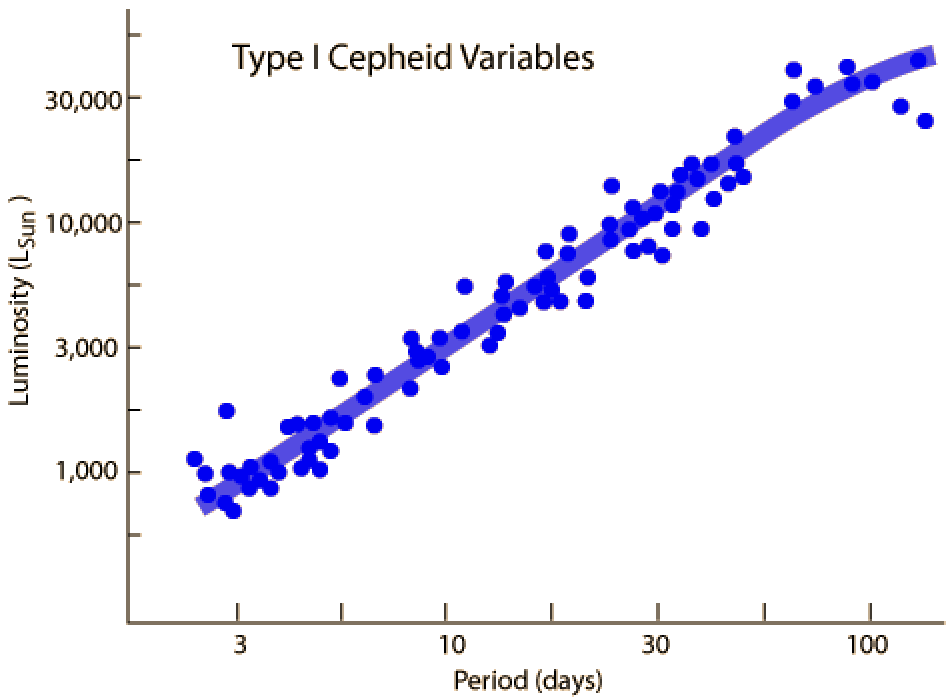


The reason why those stars behave like this is also extremely simple. Most of those stars[8] are fully filled with helium atoms in the exterior layer. When the temperature is extremely high, the helium atoms tend to lose all the electrons and make the outside layer exceedingly opaque that the energy of light cannot pass through and the star becomes dim. When the temperature becomes higher and higher, the star itself is also growing bigger. Therefore, the exterior layer becomes more transparent that the energy of light can traverse and the temperature is also going down, making the star shrinking again. The whole star is getting brighter and cooler until it shrinks to a certain degree that light again cannot pass through. It forms a circle, exactly like the picture below reveals.



[8] Generally, they are up to 30,000 times as luminous as the sun and about 5 to 20 times more massive

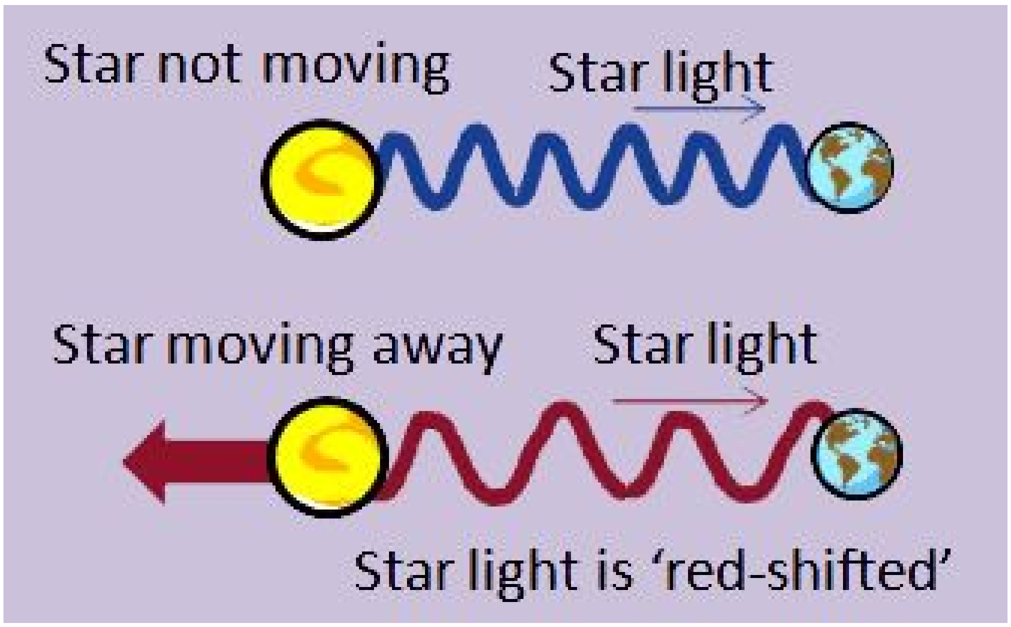
When the scientists put the period of Cepheid variable star and the flux of those stars together, they surprisingly found they two form a straight line, “that a star with a higher luminosity has a longer period”. Therefore, if we can use parallax to find one star in the line with a certain period has what luminosity, we can figure out all the actual brightness of the stars in that straight line according to the period they have.



As a consequence, if we find the actual brightness through the way of Cepheid variable stars, we then can calculate the distance to those stars.

Expanding Velocity

We have already talked about the ways astronomers use to measure the distance to remote galaxies and stars. Now let’s move to the page how scientists calculate the relative velocity of a distant object. We know Edwin Hubble has discovered distant galaxies are moving away. But how did he realize this truth and how did he calculate the velocity of those galaxies? Here he used a point called “redshift”. **The redshift is the displacement of spectral lines to longer wavelengths due to the stretching of light.** Right as the picture below shows, because the star is moving away from us, when the light reaches the Earth, the light itself is also being stretched to spectral lines with longer wavelengths[9]. By calculating how long the wavelengths are stretched, scientists can figure out the relative velocity of the stars.



In calculation, scientists generally use “Z” to express how the light is redshifted, that:

Z = redshift = $(\lambda-\lambda 0)/\lambda$ * λ: the wavelength observed which is already redshifted

$\lambda 0$: the original and expected wavelength that we know in the lab

[9] Red has relatively longer wavelength in the visible light, while blue has relatively shorter one

Moreover, scientists even discovered an equation to express the relations between the velocity and the redshift, that:

$Z = V/C$ *C: light speed   V: the speed of object

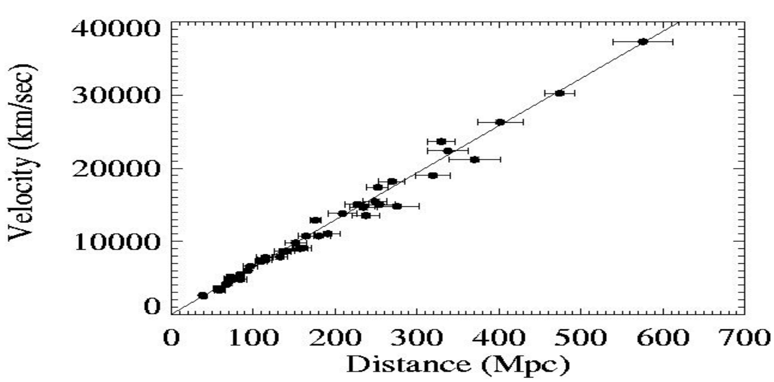
-> $(\lambda-\lambda 0)/\lambda = V/C$ *switching Z to $(\lambda-\lambda 0)/\lambda$

-> $V = (\lambda-\lambda 0)/\lambda * C$ *multiplied by C

Therefore, if one can find the λ absorption in telescope and calculate the λ0 in the lab, he can directly calculate the velocity of that object by the equation above.

Hubble Constant

After Edwin Hubble in 1929 observed that distant galaxies were all apparently moving away from us, scientists then used the three ways above to measure the distance to remote galaxies and the velocity, trying to find out the relation between distance and expanding velocity. Surprisingly, they found the distance and velocity are almost proportional, that when they put the stars on the chart, it is exactly a straight line like the graph below.



Scientists assumed that the relations between distance and velocity forms an exact linear equation, with the hubble constant H as the ratio, that:

$V = D * H$ (H is the Hubble Constant, which is about 73.8 km/sec/Mpc *Mpc is a million parsecs)

Moreover, scientists discovered that, since at the beginning of the universe all the matter is in the singularity and the distance is all 0, the distance today we have to other stars is actually the time(also the age of the Universe) times the expanding velocity[10]. In another word, it is:

$D = V * t$ (where the t is the age of Universe, and the velocity is the changing expanding velocity, but we just pretend that the velocity is not changing for avoiding the advanced calculation of Calculus)

Therefore, by rearranging both the equations, we can get:

$t = 1/H$ * the H is the Hubble constant, and the t is the age of the Universe

H, as we know, is 73.8 km/sec/Mpc. So 1/H is right 1,000,000 parsec/73.8 km seconds, which is 1,000,000 * 3.086 * 10^13 km/73.8km seconds, which is approximately

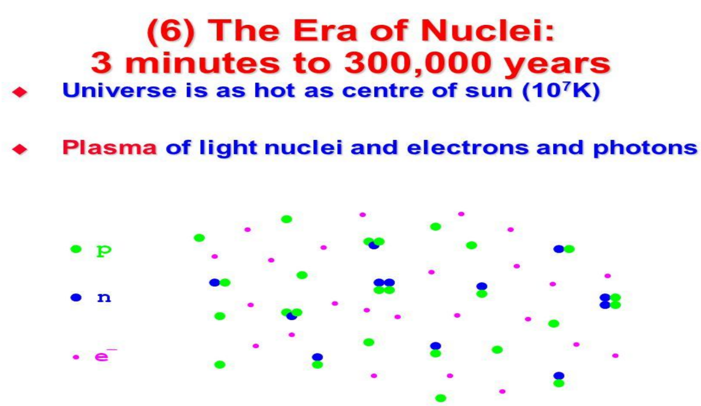
[10] If the theory of Big Bang is true, and there really exists a start point of universe

4.18 * 10^17 seconds. If we convert it to years by dividing 3600, 24 and 365, we find it is right 1.32 * 10^10 years, about 13.2 billion years.

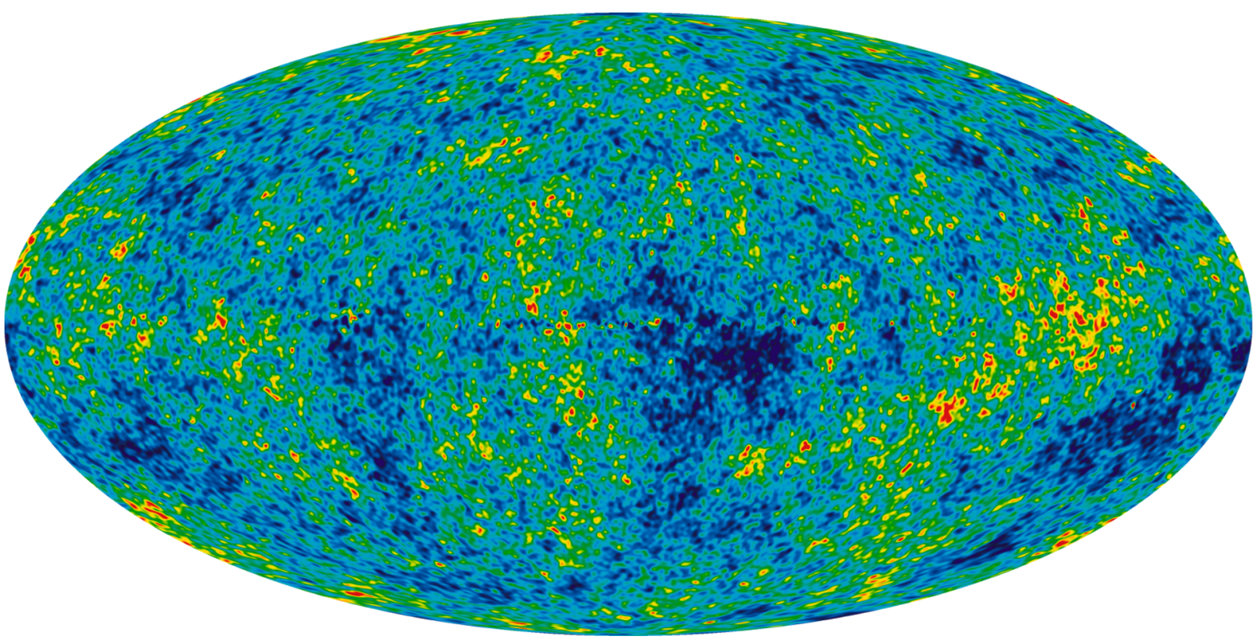
Therefore, as the calculation shows, the age of the Universe is **13.2 billion** years, which is really close to its real number of 13.8 billion years.

Cosmic Microwave Background

There are many ways to demonstrate the theory of Big Bang, and one of the most famous ones is the “Cosmic Microwave Background”, CMB as the abbreviation. **The Cosmic MIcrowave Background is the electromagnetic radiation left over from the Era of Nuclei in Big Bang cosmology.** As we know, the early time of the Universe can be divided into different stages according to the basic composition of the Universe. Before 380,000 years, the whole universe is tremendously dense and hot that all the atoms were forced to ionize and therefore made the space too opaque for light to pass through. As the graph shows, all the space is completely filled with plasma that does not allow the photons to be transmitted.



However, after 380,000 years, the Universe is growing big enough for the photons to pass on and the information to transmit. As a consequence, if the Big Bang really exists and the Universe really has experienced these different stages, there should be microwaves issued right after the 380,000 years that we can observe today from all directions. **Those microwaves, which has traveled about 13.8 billion years and just reached the Earth right now, should be detected by humans from all directions if the theory of Big Bang is really true.** And luckily, we did detect those microwaves in the late 1960s. Below is right the picture of the cosmic microwave background.



The detection of the Cosmic Microwave is a powerful evidence to the theory of Big Bang. The landmark discovery of CMB eventually consolidated the Hubble’s estimation of the age of Universe, also prevailing the theory of Big Bang both in the academic and the public in the late 1960s.

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