# HOW TO MEASURE COSMIC DISTANCES ? (Part 1)

**The first step** did the great Greek astronomer **Erathostenes** 230 B.C. (about 300 years after the Buddha lived): He heard, that at a certain day at a certain place in the south of Egypt (in Syene), the sun shines into a very deep shaft of a well and lights the bottom completely centred. He knew that this never could happen in Alexandria in the north of Egypt because the sun never shines exactly vertically there. He and other scientists knew from different observations, that the Earth must be a sphere (ball). He recognized, that there is a excellent possibility to measure the Earths circumference and to calculate the Earth‘s diameter:

**Figure 1** (see separate sheet)

In many years of measuring, he and his crew found the distance between Alexandria and Syene to be 800 km.
The full circle is parted in 360°. The 7.2° Erathostenes measured at a tower in Alexandria, takes place 50 times in the full circle. So the whole circumference must be 50 x 800 km = **40‘000 km**.

The diameter of a circle is 3.14 times shorter than its circumference. (This number is called $\pi$ = 3.14159...)

So he found, that the Earth is a ball with a diameter of 40‘000 km divided by 3.14 = **12‘732 km.**

**The second step** has been done by observing a moon eclipse: The astronomers knew, that the moon runs around the Earth in about 29 days and they concluded, that every hour it moves forward for about its own diameter. By observing a well centred moon eclipse they saw, that the moon was for about 4 hours in the Earths shadow. And as they assumed the sun to be far away and for this reason the Earths shadow is about a cylinder, they concluded, that the moon must be 4 times smaller than the Earth. That means **3183 km**.

**Figure 2** (see separate sheet)

They measured **0.5°** from one edge of the moon to the other.
Trigonometry told the astronomers, that the distance from the Earth to the moon has to be **364‘735 km**.

But even without any higher mathematics we can say, that the moon runs around the Earth in 29 x 24 = 696 hours (about 700 hours). In every hour it runs 3183 km. So, it runs a total distance of 2‘194‘488 km on its way around the Earth. The diameter is 3.14 times smaller. That means 698‘500 km.
So the distance between the Earth and the moon is again about 350‘000 km.
A flash of light needs about 1.25 seconds to reach the moon, and the same does a radio signal. So, a dialog with an astronaut on the moon is a bit strange and sounds funny.

**The third step** was to measure the distance between the Earth and the sun. The first idea to do this, came from the Greek scientist Aristarchos (he lived even before Erathostenes). He said, that at half-moon the angle between moon and sun should be less than 90° and he tried to measure this angle:

**Figure 3** (see separate sheet)

The problem was to find out the time when the moon is exactly half, because the line of the shadow on the moon is not so clearly definable. He measured an angle of 87° (much too small, as we know today; it should be 89.86°). So he calculated the distance between Earth and sun to be only about 20 times farther than the distance to the moon, which was much too short, but the method was principally correct.
Today better measurements provide the distance to the sun to be 400 times longer than the distance between Earth and moon. And so it is about **150‘000‘000 km**. This result has first been found by observing a transit of the inner planet Venus in front of the sun. An event that only happens very rarely. Today the distance to the sun has been measured very exactly by satellites with geometrical methods.
A flash of light needs about 8,33 minutes to reach the sun. And on the other hand, the light of the sun needs 8.33 minutes to reach the Earth.

**The fourth step** based on the well known fact, that at a sun eclipse the moon covers the sun quite exactly.

**Figure 4** (see separate sheet)

We know from the second step, that the distance from the Earth to the moon is about 110 times longer than the moons diameter. The same relation must so be valid for distance and diameter of the sun as well.
That means, that the sun is 110 times smaller than the distance between the Earth and the sun, and this is **1‘400‘000 km**.
A flash of light needs about 4.5 seconds from one edge of the sun to the other.

With this knowledge and a bit of trigonometry the old Greek scientists also found out the distances to the planets Mercury and Venus, the two planets on inner orbits around the sun.

**Figure 5** (see separate sheet)

They measured the angle between the inner planet and the sun at a time, when the planet seemed to be most far away from the sun.

For **Mercury** this is 23°.

For Mercury we find:

150 Mio. x sin 23° = **58 Mio. km**

*or 8.3 L.M. x sin 23° =* ***3.2 Light minutes***

For **Venus** this is 46°.

For Venus we find:

150 Mio. x sin 46° = **108 Mio. km**

*or 8.3 L.M. x sin 46° =* ***6.0 Light minutes***

## HOW TO MEASURE COSMIC DISTANCES ? (Part 2)

In Part 1 of this essay we saw, that 2250 years ago Greek scientists had a correct image of our nearer surrounding in the cosmos. They were able to "measure" the distances from the Earth to the moon, to the sun and to the planets Mercury and Venus and they knew the diameters of the Earth, the moon and the sun. Even if not all their measured values were very accurate, they have been thinking very successfully of a physical order in the cosmos, apart from religious dogmas, and myths. But all this knowledge has been forgotten for 1800 years, during the time of the Roman Empire and the time we call the Middle-Age in western history. Fortunately Arab scientists were interested in Greek sciences, yet they did not add great new theories, but perfected some of them. When the Muslim culture arrived in Europe after 650 A.C., more and more of the Greek knowledge began to influence the European way of thinking. But it took another hundreds of years till 1550 A.C. European scientists (Nicola Copernicus was the first) ventured to say, that the Earth is not the centre of the universe, and at the end no centre can be defined. The Christian church had forbidden theories like this by death for more than thousand years.

It was the German mathematician **Johannes Kepler**, who found in a lifelong work, that all planets rotate around the sun in elliptic orbits and not in precise circles. He also found a very important relation between their times of revolution and their distances to the sun. It says:
***The distance to the sun powered with 3 divided by the time of revolution powered with two makes the same number for all planets in our solar system.***

In mathematic terms: $r^3 \div T^2$ = constant

**r** means the distance from the sun to the planet
**T** means the time of one revolution of the planet

For easier computing we set the distance r from the Earth to the sun as a new unit, and we call it

**Astronomical Unit [AU].** ***1 AU = 150 Million km*** For **T** we use the **year** as a unit.

So Johannes Kepler's constant number is simply **1**.

Now, if we want to know, how far away Jupiter is from the sun (Jupiter is the biggest gas giant in our planetary system), we only need to know how many years Jupiter needs to come back to the same place in the sky after a full orbit. He needs about 12 years.
So, we calculate his distance to the sun with: r = cubic root out of 12 square = 5.2 AU = 780 Million km.
That means, Jupiter is a little bit more than five times farther away from the sun than the Earth.
And a flash of light or a radio signal needs 43 Minutes to reach Jupiter. So it is not very comfortable to talk with an astronaut on Jupiter by handy.

With Keplers formula it is easy to find the distances of all solids orbiting around the sun: Planets, asteroids, comets and smaller particles from ice and stone.

By the way: The diameters of the planets could only be found after the development of telescopes was perfected, and that was about 100 years later.

**So since 300 years the scientists know size and distance of every orbiting solid in our system.**

A flash of light from the border of our solar system needs about one week to reach us.
Remember: From the moon it needs a bit more than one Second, and the moon is 360'000 km away from us. This is about 150 times from Mundgod to Lhasa.

The question arises, what is outside our solar system?
It took another 150 years of research to find out, that there is a gigantic almost empty room. Our star neighbours are enormously far away from us. It takes years for a flash of light to reach us.
Imagine: Our neighbour star could actually have exploded years ago, and we would not notice it.

It results: **The farther we look, the further we look back in time (into the past).**

But how did the astronomers find out this?

The idea to measure the distances to far away stars is very old. Maybe even the Greek astronomers knew the method. But using it, they could not be successful, because their observing instrumentation was not precise enough at all. Even at the time of Kepler (1800 years later) the astronomers missed to be successful. And here is why:

**Figure 6** (see separate sheet)

On its orbit around the sun, the Earth runs a diameter of 300 Million kilometres in half a year. During this time a near star shifts a little bit compared with other stars farther away. The nearer the star the bigger the angle of vision of this shifting.

A simple calculation gives us the distance to this star:
Distance = 150‘000‘000 km x 360° / 2Pi / Angle of vision

For example:

| | | | |
|---|---|---|---|
| An angle of vision of 1° | corresponds to a distance of | 8.6 billion km | = 8 light hours |
| An angle of vision of 1' | corresponds to a distance of | 516 billion km | = 20 light days |
| An angle of vision of 1" | corresponds to a distance of | 31 thousand billions km | = 3.3 light years |

Note: An angle of 1° ("1 degree") means the full circle divided by 360
An angle of 1' ("1 minute") means 1 degree divided by 60
An angle of 1" ("1 second") means 1 minute divided by 60 or 1 degree divided by 3600.

Note: For easier computing, the astronomers defined a new scale for long distances:
**The Parsec [pc]**. One Parsec [1 pc] corresponds to the distance from which the radius of Earth's orbit around the sun can be seen under a angle of vision of 1" (Sec.) (= 1 / 3600 of a degree).

Since about 150 years astronomers are able to measure angles of visions of less than 0.1 ". And so they found out, that our next star neighbour ("Alpha-Centauri") is about 4.3 light years (1.3 Parsec) away from us. And "Sirius", the brightest star in our whole sky is 8.6 light years (2.6 Parsec) away.
Today's modern telescopes are able to measure angles down to 1 / 1000 of a second and so they achieve geometrically measured distances of more than 3000 light years. Thousands of stars can be measured in this way. But this geometrical method is limited, because we have no larger base than the Earth's orbit around the sun. In the future the astronomers will surely be able to measure even smaller angles, but real cosmic distances such as the diameter of our galaxy or, even much farther, to other spirals like the andromeda galaxy or, again much farther, to galaxy clusters like the Virgo cluster, will never be measured with a geometrical method.

But as soon as photographical techniques had been invented about 150 years ago, the astronomers found other possibilities to roughly estimate these huge distances by astrophysical methods like the behaviour of some special stars like Cepheids, novas and supernovas.

In 1912 Miss Henrietta Leavitt measured and compared ten thousands of photographic sheet of our night sky, which Mr. Pickering produced with a ten meters long and one meter thick telescope. Miss Leavitt discovered, that some stars vary their brightness periodically. She called them Cepheids, because o-Cephey was the first discovered star with this behaviour. Some Cepheids oscillated fast (one full cycle in a few hours), others very slowly (one cycle in weeks). And she found out, that big (bright) Cepheids oscillated slowly and small (weak) Cepheids were fast. And so she could define a table to describe the relationship between the absolute brightness of a Cepheid-star and its period of oscillation.

## HOW TO MEASURE COSMIC DISTANCES ? (Part 3)

In Part 2 of this essay we saw, that with geometrical methods ("parallax methods") the astronomers of the 19th century were able to measure distances of a few hundred light years. But they also saw that this method has its limits, because by measuring smaller and smaller angles the errors grow bigger and bigger. Nevertheless the method showed that the **visible brightness** of stars does not say anything about their distance from us, because the **absolute brightness** varies very much from star to star. There are big bright stars and there are small weak stars and a bright star far away seems to have the same brightness as a small one close to us.
Looking up to the sky at night time one could think that the brighter a star, the closer to us it is, but this three-dimensional feeling is completely misleading.

However the astronomers made themself a picture of our cosmic surrounding. The big telescopes showed more and more stars, where the former small telescopes only showed nebulas. They said that most probably our solar system is embedded in a huge spiral system of stars and dark clouds which we can see as the Milky Way in clear dark nights. But still the distances were very vague and unknown.

The breakthrough arrived with the discovery of **Henrietta Leavitt** in 1912: Some stars (**Cepheids**) have a periodically variable brightness and the brighter such a Cepheid is, the slower is its period.

The astronomers now had a **new "ruler" for measuring the universe**: Measuring the period of the changing brightness told them how bright the star is really (the absolute brightness); and measuring the visible brightness told them how much of the star's light arrives on Earth. Comparing absolute and visible brightness gives them the distance of the star.

It was the famous astronomer **Edwin Hubble** who discovered 1923 the first Cepheid in the well known "cloud" called Andromeda Nebula, which in dark nights can be seen by the naked eye. He proved that this "nebula" was far beyond the Milky Way, namely about a million light years away from us. And he showed that this Andromeda Nebula in reality is a complete galaxy like our Milky-Way-Galaxy. Today's improved measurements give a distance of 2.25 million light years. The Andromeda Galaxy is our neighbour galaxy and is a spiral of stars and dark material clouds like the Milky Way but is about two times bigger.

The growing telescopes in the first half of the 20th century showed even more and more of similar spirals and other shapes of star-systems in the space and there distances could be estimated up to 20 million light years with the methods of the Cepheids. But in even farther systems the Cepheids could no longer be observed. For measuring these distances the astronomers needed an new "ruler". They found it by observing a certain special type of very bright star explosions (Type II - Supernovae), that occur from time to time and are bright enough to be photographed by the biggest telescopes even in galaxies more than 100 Million light years away. Of course this and other similar methods are not very reliable any more. But together with lots of other observations and physical and chemical calculations the cosmic distances could be estimated better and better.

As the astronomers now new the approximate distances of thousands and thousands of galaxies and they measured the colours of there light, they found out, that the farther a galaxy is, the more the light of its spectrum is shifted to red and they called this phenomena the **Red Shift**. They explained this red shift with the well known Doppler Effect as it can be easily observed acoustically when a fast driving car passes us using its horn. First the tone is high (short waves) and after passing us its low (long waves).
Like acoustic waves, light-waves are shorter when the sender is moving towards us and longer when the sender is moving away from us. And because long light-waves look red for the human's eye, we call it Red Shift.
So, after measuring hundreds of Red Shifts, it seemed that **the farther the distance to a far away galaxy, the faster it is moving away from us**. This lead **George Lemaître** and many other scientists to the conclusion that about 13 Billion years ago all galaxies have been very close together and that at the beginning of all, there must have been a very small cosmos (some said even, it has been a single point, a so called Singularity) that contained all material of all stars and galaxies. A scientific journalist called it **"The Big Bang"**.

In 1929 Edwin Hubble showed that there is a direct relation between a galaxy's distance and its Red Shift. For measuring the biggest distances in the cosmos an astronomer now just has to measure the Red Shift in the spectrum of an unknown galaxy, and he can easily calculate its distance.

After all, the Red Shift phenomena is again a new "ruler" for measuring distances, and this "ruler" works up to **billions of light years**, till to the border of the visible world.

**Erathostenes measures the Earth's diameter in 235 B.C.**

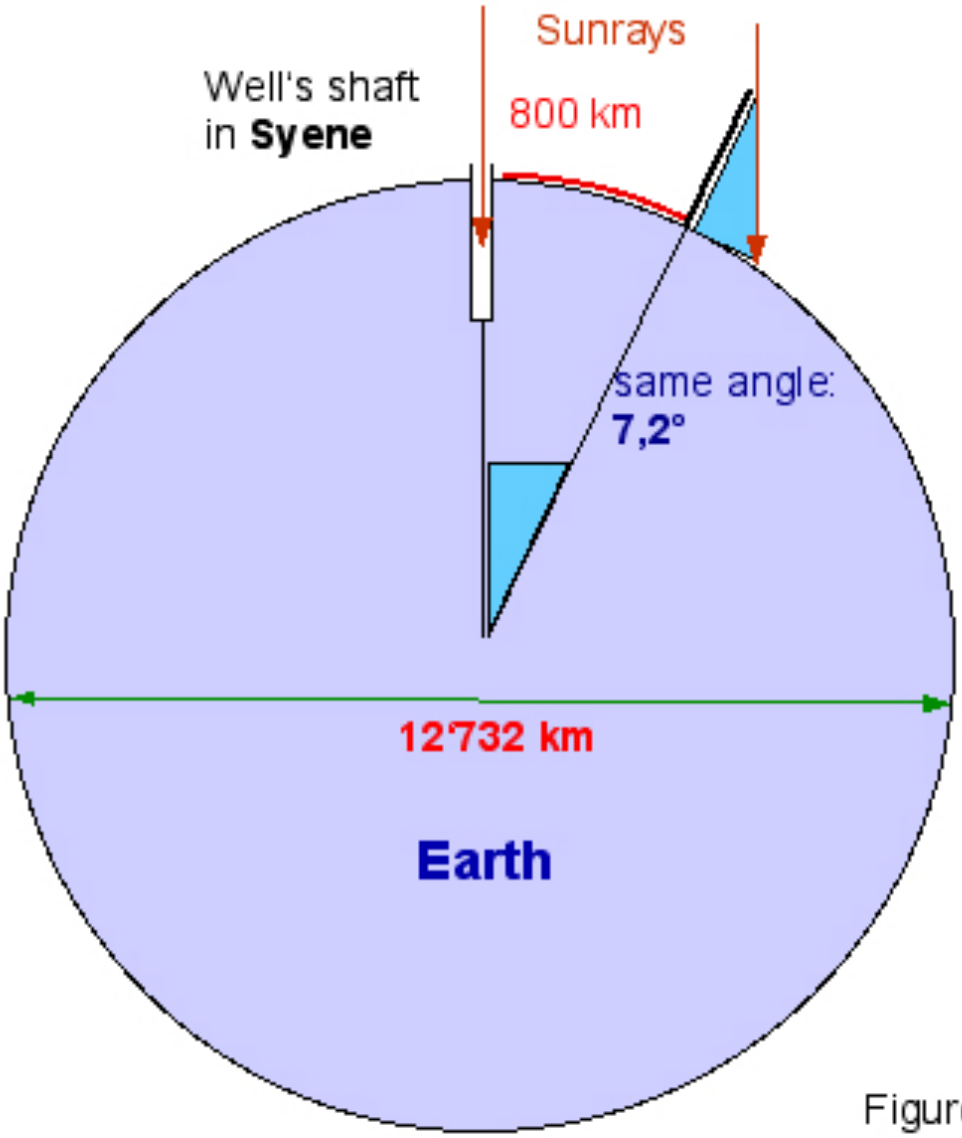
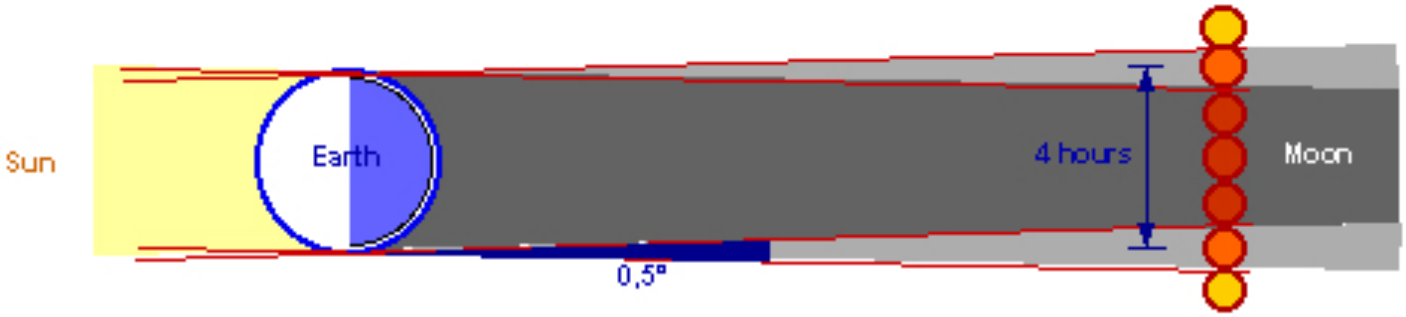



Figure 1

HOW TO MEASURE COSMIC DISTANCES: The Figures to the Text.




**Measuring roughly the moon's diameter at moon eclipse.**
Done by former scientists than Erathotenes.

Figure 2

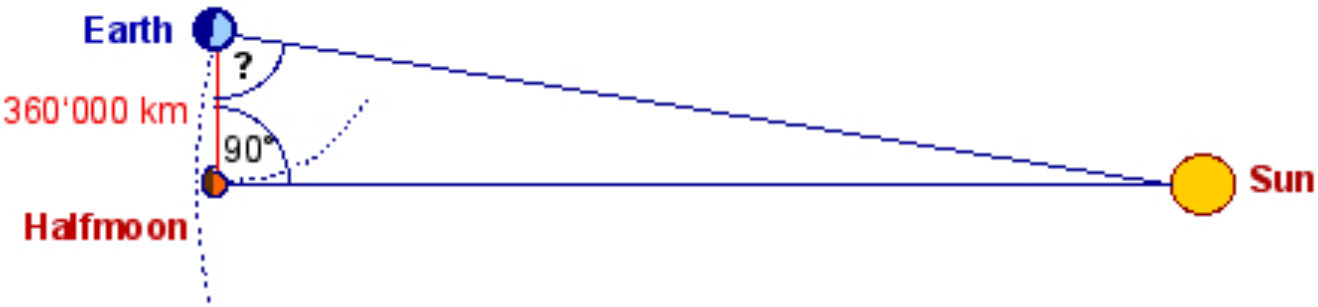



Figure 3

**Aristarchus tries to measure the distance to the sun with a correct method but too poor instruments.**

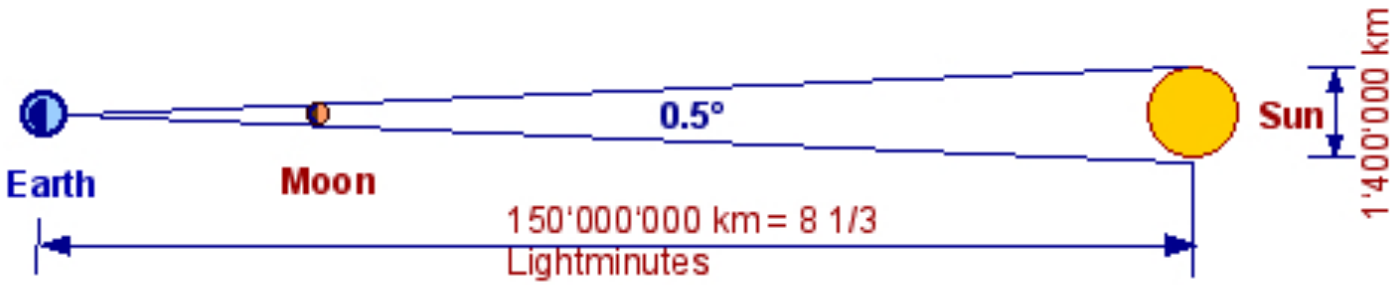



Figure 4

**Calculating the sun's diameter with the help of a total sun eclipse.**
Knowing the moon's diameter and the distance between Eart and moon.

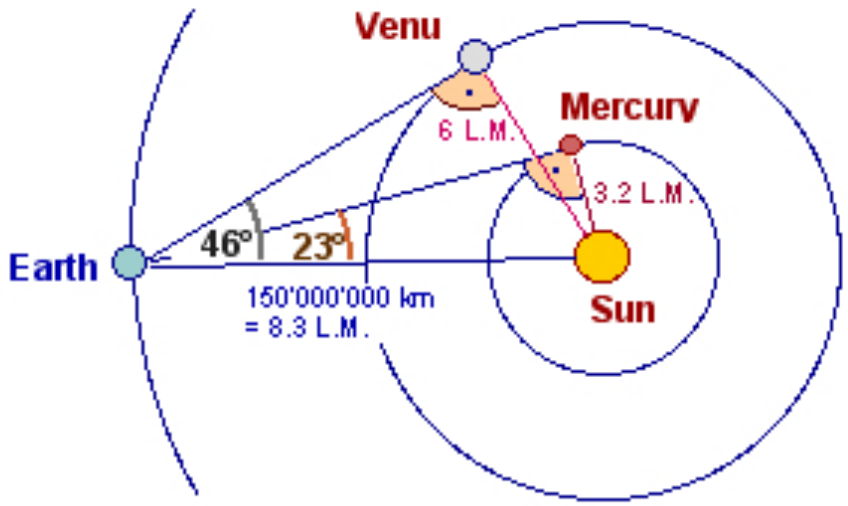



Figure 5

**The Old Greek measured the maximum angels between the sun and Venus and between the sun and Mercury and calculated the distances to Venus and Mercury.**

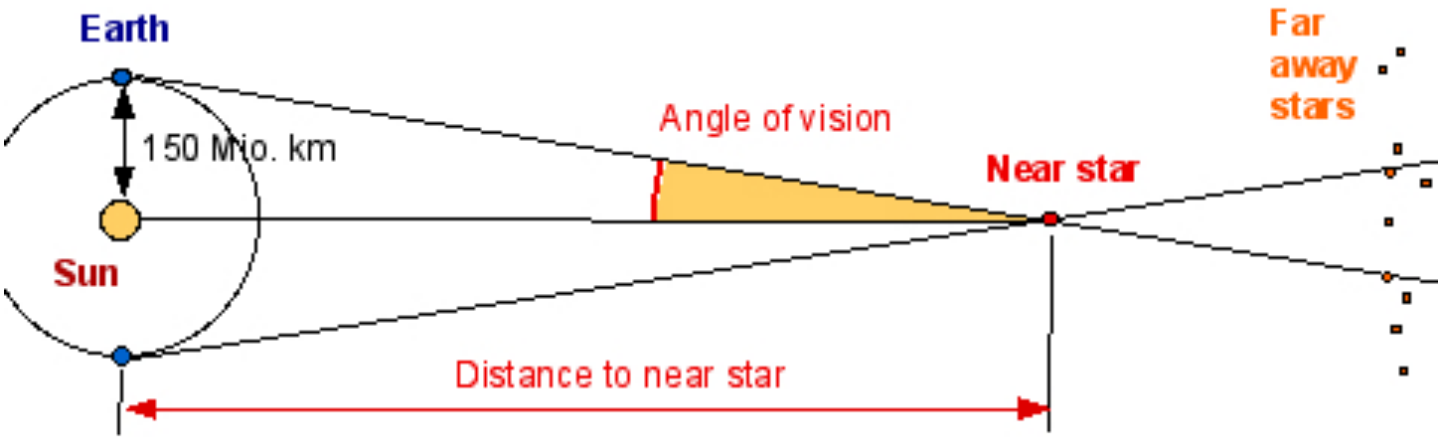



Figure 6

**Even the Old Greek tried to measure the distance to the stars with the method of parallax, but faild because parallax angles are to small to be measured without advanced telescopes.**