UNIT 2:

DISTANCES (1st part). GALAXIES

Author: Oswaldo González

Content revision and updating: Nayra Rodríguez

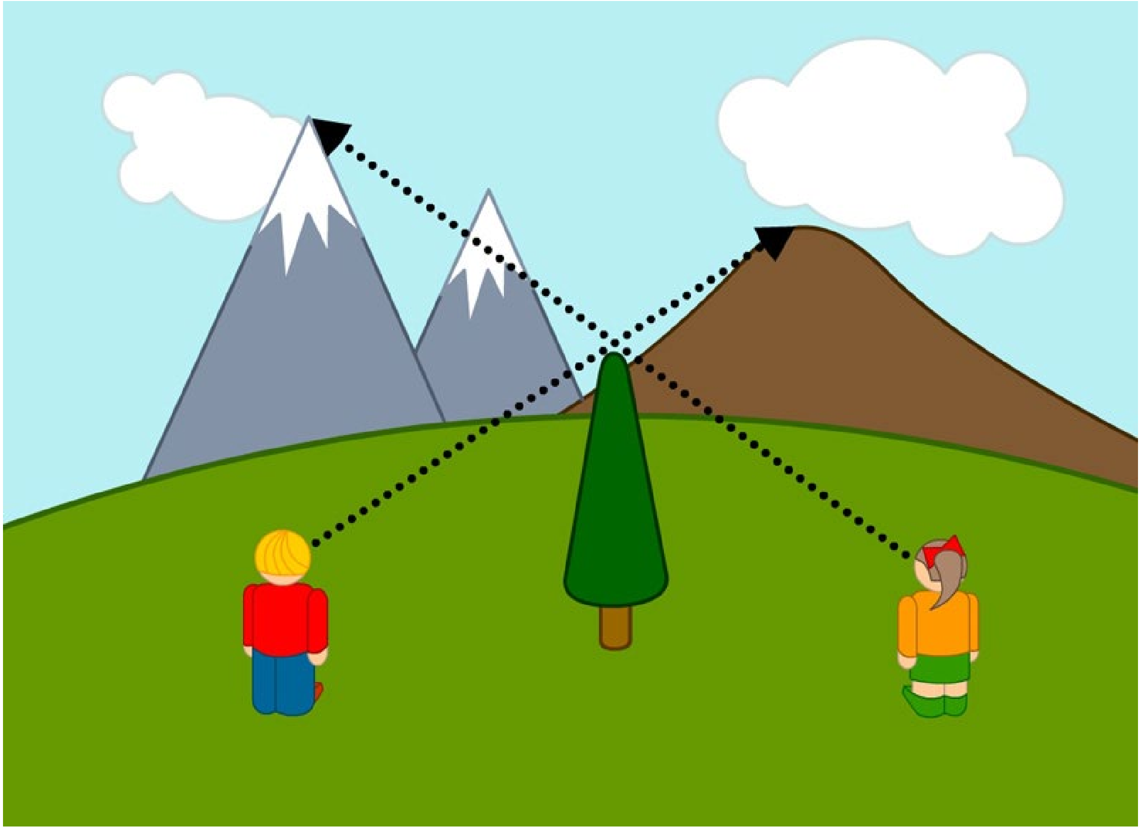
Scientific Advisor: Alfred Rosenberg

Ilustrations: Inés Bonet

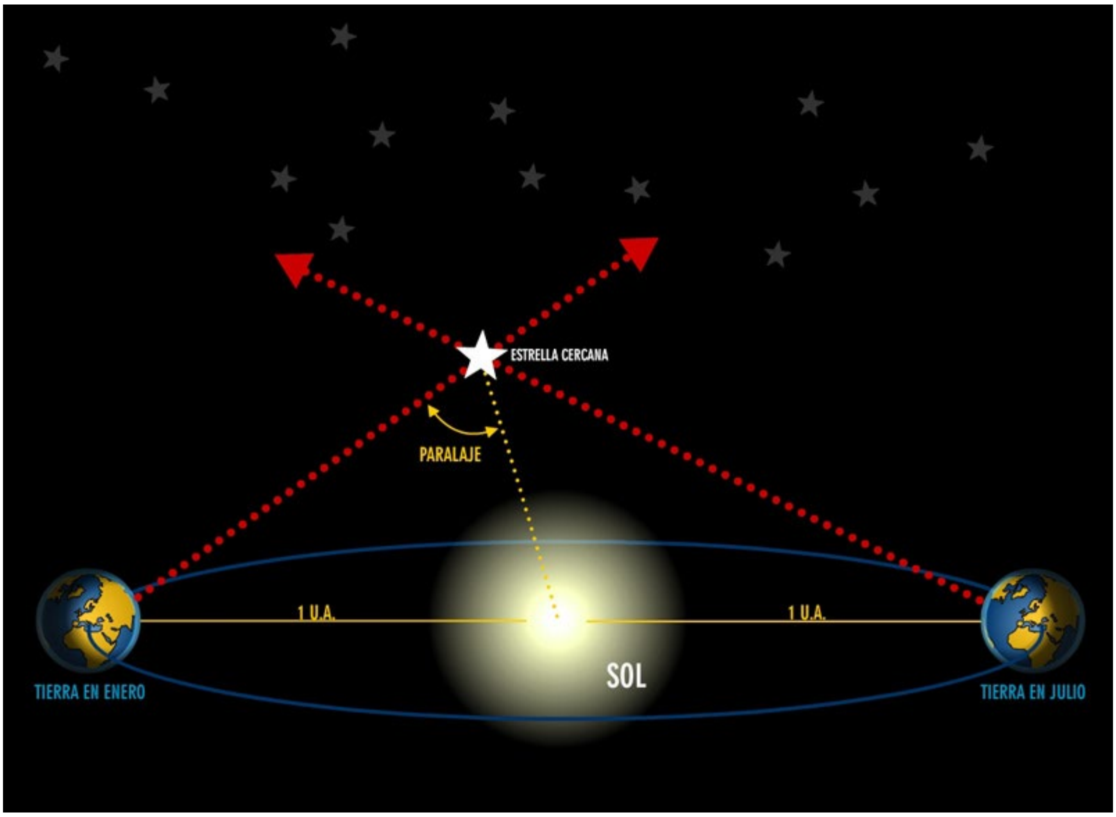
Measuring the distance to the stars

It´s complicated to determine the distance to a star because we cannot travel to it. These distances have to be measured indirectly, in the same way we measure the distance to objects that are on the other side of a gorge without having to go through it. This method is called parallax, and thanks to it we can estimate the distance in which close objects can be found. How does this method work? It´s very easy, reach out your arm and lift the thumb, now close one eye and see which objects are behind the finger, try again but now with the other eye closed and you will see that now behind the finger there are other objects. The method´s basis is in the distance between the eyes, that is, the distance or **baseline** between the two points from which we observe the finger and what there is behind it.

Thanks to years of experience, we have memorized that the greater or lesser angle at which we observe objects close to us, using the stereoscopic vision that having two eyes gives us, is inversely proportional to the distance that separates us from these objects. For example, if we bend our arm and look at the thumb alternately with each eye, we realize that the vision angle increases, however, it decreases as we move the finger away when we stretch the arm. In order to estimate the distance to a tree on the other side of a gorge, what we need to do is to observe it from two different positions, moving several meters. If we measure the angle that the tree forms from the two positions and we know the distance between such positions (baseline), we will obtain a triangle through which we can, by basic trigonometry, know the distance that separates us from the tree.



To find out the distance to a star, we have to use a very long baseline, for example, the Earth's orbit diameter. If we take a nearby star photograph and we wait 6 months to take another picture of the same star, the Earth will have moved half of its orbit, therefore, the distance between the two points where the photographs were taken is two Astronomical Units. An **Astronomical Unit** (*AU*) is the average distance between the Sun and Earth, i.e., if the Earth's orbit radius were circular, it would be nearly 150 million *km*. Through this way, we are observing the star position from two places that are about 300 million *km* far from each other. In the photos, we will detect that the stars are not exactly in the same position relative to the farthest stars, generally weaker. This apparent shift in the star position is called **parallax**. Parallax (α) is the object´s apparent change in position due to the change of the observer placement.



Measuring the very tiny α angle is very difficult. A nearby star has less than 1 *arcsecond* parallax and the most distant stars have increasingly smaller parallax.

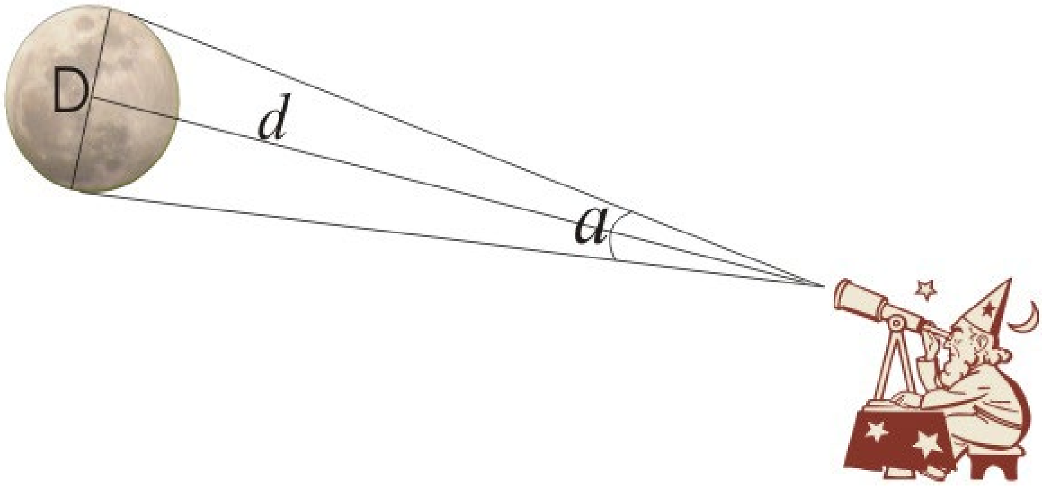
The stars distances are so huge that it's not convenient to measure it in astronomical units. When we measure the parallax distances is convenient to use the distance unit called ***parsec***, that is equivalent to 206,265 *AU* (On the next page you will find more information of this number). In other words, one *parsec* is the distance from which we would see the Earth´s orbit radius with an apparent size of 1″. Due to the limited telescopes accuracy, this system is only useful to calculate stars distances over 30 *parsecs* far from us.

Another often used distance unit is the ***light-year***, which is the distance that light travels in one year, a very large unit, especially when we think that light moves in the vacuum space at a speed of almost 300,000 *km* per second. A light-year is equivalent to 63,240 *AU* and one *parsec* is 3.26 *light-years*.

The small angles approximation

In Unit 1 we had a first contact with angle measurement which, in astronomy, is the way used to calculate sizes and distances. In this unit we will go deeper into this tool.

The **linear diameter** (*D*) of an object (e.g. a planet) is the length of the straight line between two opposite ends of it passing through its center and, as a rule, measured in meters or kilometers. The **angular diameter** (*a*) is the angle between two lines drawn from the same ends and converging in our eye. Logically, the further away an object is, the lower its angular diameter is.



The relationship between the angular diameter (*a*) and the linear diameter (*D*) with the distance to object (*d*) is in the small angle approximation:

$$D = d\,\frac{a}{206{,}265} \qquad Eq.(1)$$

The number 206,265 is a constant that serves to obtain the angular diameter (*a*) in *arcseconds*. Of course, both *D* and *d* must be expressed in the same unit length: meters, kilometers, light-years, etc.

Let's see a couple of examples. Imagine that we see a person located 1 *km* away with an angular diameter of 6 *arcminutes*. If we apply the formula for small angles, we can determine its linear size, i.e., its height. First, we must express 6 *arcminutes* in *arcseconds*, and as we have seen that 1 *arcminute* contains 60 *arcseconds*, the 6' are equivalent to 360''. As *D* and *d* have to be in the same units, we´ll use the meter, then we can locate the person 1,000 meters away from us (1 *km*). If we take these values into the equation, we get the height of the person:

$$D = 1.000\,\frac{360}{206{,}265} = 1{,}74\,m$$

Let's see another example: let´s use the formula to calculate the size of a planet. When Saturn is 1,380 million *km* away from Earth, it´s shown to us through the telescope with a size of 18″. If we use the formula, we can find its linear diameter:

$$D = 1{,}380\ 10^{6}\,\frac{18}{206.265} = 120.427\ km.$$

On a dark night, a light band across the sky can be seen with the naked eye. It´s our own galaxy, the Milky Way, which means *road made of milk*. Nowadays we call Milky Way to a group of two hundred billion stars, including our Sun, which rotate together in a giant whirlpool with gas and dust. There are billions of systems like the Milky Way spreaded through the universe. We call them **galaxies**.

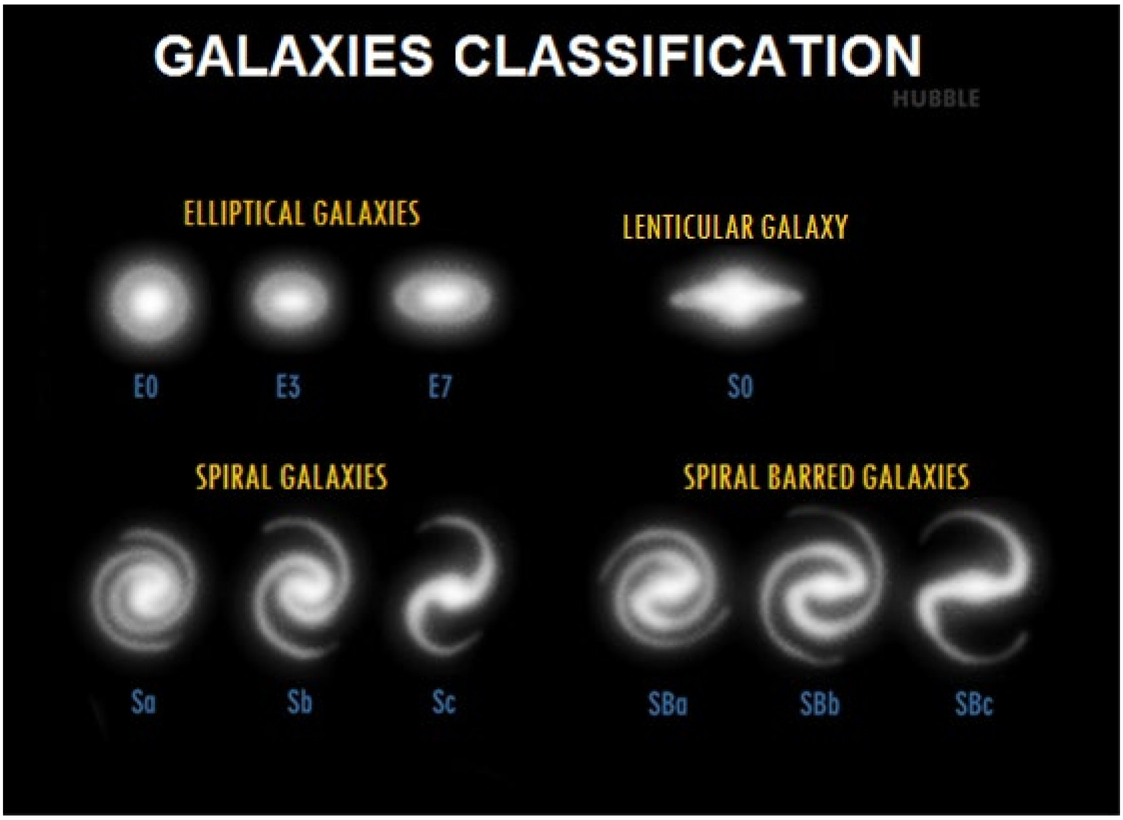
Actually, all celestial objects that we see with our naked eyes are our galaxy members, although there are three exceptions: two small irregular galaxies that we can observe from the southern hemisphere, called Magellanic Clouds; and Andromeda galaxy, that is seen with naked eye as a faint light patch, very similar to our galaxy, in the Andromeda constellation.

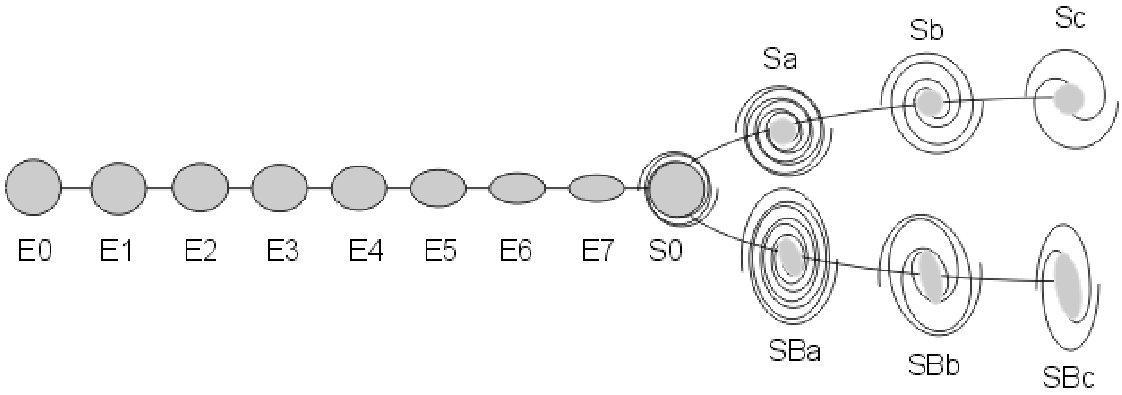
Being immersed within our galaxy, we can´t see it as a whole as we see other galaxies, or observe much of it due to dust and gas clouds that hides the light. We can only take photos just over 10% of our galaxy, but it is enough to know the size and shape it has. The Milky Way is disc-shaped and the Sun (and therefore also the Earth) is located approximately midway between the center and the disc end, inside one of the spiral arms it forms.

Our Galaxy, the Milky Way. Author: O. González

Galaxy Classification

In 1936 the astronomer Edwin Hubble devised a fairly simple system to classify the countless galaxies he observed with professional telescopes. Hubble arranged galaxies in a diagram (called Hubble sequence or Hubble tuning fork) according to their shape, i.e., according to their visual morphology. The galaxies can be divided into ellipticals, spirals, lenticulars and irregular galaxies.





Approximately 70% of all galaxies in our nearby universe are **elliptical**. Its appearance is circular or elliptical and no trace of gas, dust, or hot bright stars can be seen. It does not have a spiral structure neither. Elliptical galaxies in the Hubble classification are denoted by the letter *E* followed by a number from 0 to 7, indicating the apparent aspect of the galaxy. Circular appearance galaxies are classified as *E0*. The more elliptical galaxy is like, the greater the number they have.


Example of an elliptical galaxy

Although they only represent 30% of all nearby galaxies, the **spiral galaxies**, are the most striking ones. They are easily distinguished by the presence of a **disc-shaped** component containing gas, dust and stars (many of them hot and bright). In addition, they have another component in its center, very bright and composed by stars, known as **bulge**. Spiral galaxies are called this way because they have spirals structures extending from the central bulge, where gas, dust and young stars are concentrated forming what we call **spiral arms**. It is easy to identify a spiral galaxy with a face-on persepctive, when we can see its spiral arms. Nevertheless, the dust is more visible on the galaxies which can be observed by its sideway, because we will notice dark bands throughout the disc that correspond to the zones where the dust is. Spiral galaxies are so bright that they are easily seen from very long distances.

Among spiral galaxies, which are identified with the letter *S* in the Hubble classification, we mainly distinguish three types:

- Lenticular galaxies: those without spiral arms. They are represented as *S0*.
- Regular spirals galaxies: They have spiral arms that come from the galaxy´s center where new stars are made. They are represented as *Sa-c*, where the lowercases show the opening level arm. *Sa* are galaxies that show more closed arms, almost completely closed; *Sb*, represent more opened ones like our galaxy or Andromeda; *Sc* are the ones with completely open arms.


Example of a regular spiral galaxy

- Barred spiral galaxies: They have a bar-liked star central group, which comes from the bugle. They are represented by the letters *SBa-c*, and like the previous types, the lowercases show how open the spiral arms are. In this case the spiral arms come from the bars ends not from the galaxy bugle like in the previous case.


Barred spiral galaxy example

Finally, the irregular galaxies are those that don´t fit in other Hubble classifications. Their appearance is chaotic and lot of gas and dust is mixed with young and old stars. Apparently, they don't have bulge, arms or spirals. Some of those irregular galaxies are small spiral galaxies that have been distorted by another neighbor galaxy crash or closeness. Magellanic Clouds, easily visible from the south hemisphere are a good example.


Magellanic Clouds taken from Australia. Credits: Chris Schur. NASA Images

For more information, visit our website: **www.iac.es/peter**

Nayra Rodríguez Eugenio (peter@iac.es)
Unidad de Comunicación y Cultura Científica
Instituto de Astrofísica de Canarias
Calle Vía Láctea s/n
38205 La Laguna
Santa Cruz de Tenerife
España

This didactic unit has been funded by:

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
INSTITUTO DE ASTROFÍSICA DE CANARIAS · IAC
LIVERPOOL JOHN MOORES UNIVERSITY