Beyond solar system

Spheres of incandescent gas

Everybody knows the stars. Even in the skies above our cities, where there is so much light interference from other sources, we can spot some of them. And probably we are able to distinguish them by their color and brightness. In fact there are many kinds of stars and in order to include them all in a single category, something must be said about their intrinsic proprieties.

Stars are gigantic balls of incandescent gas suspended that have their own light. This is not exactly the definition we will find on any Italian vocabulary, but probably it helps us to focus on the real nature of these small bright spots that have always fascinated human beings.

As we said stars are gigantic spheres of incandescent gasses.

In fact all stars are spheroid or semispheric because of gravity forces. All matter found in the universe generates a force of attraction simply because of its mass. If the distribution of matter is uniform, such as for example in a cloud of gas, around the gravity center the mass tends to accumulate in an identical way from every direction, thus forming spheroid shaped celestial bodies. However, because gravity is a weak force, we only see its effects when masses are very large. This is why stars have very large masses. The sun's diameter is 1,4 million km long, 100 times more than the earth's. But the sun is an average star. Star diameters range from a few hundredths to hundreds of times the solar one.

Yet even star dimensions, no matter how large, are small compared to the distances between them. Proxima Centauri, the closest star to our Solar System, is 250 thousand times farther from Earth than the sun. Even at a speed of 300 thousand kilometers per second, Proxima's light takes four years to reach us.

Now we know that stars are enormous spheres scatterred in the empty parts of interstellar space. What are they made of? We haven't spoken yet about their composition. Stars are made of high temperature gasses. Even though there are many kinds of stars, by analyzing the light that they emit, we know that they are composed mainly of hydrogen (70%) and helium (less than 30%), the most simple and abundant substances in the Universe, in addition to minimal percentages of more complex elements such as, for instance, carbon, oxygen, nitrogen and metal.

Stellar gas has a very high temperature. The sun's surface is around 6000 degrees, but some stars can be almost ten times hotter. All bodies surrounded by a cooler environment tend to release their inner energy irradiating it in the form of light and heat. This is why stars emit light; the hotter they are the brighter they shine. The power released by the sun as light and heat is equal to ten thousand billion atomic bombs the size of the one dropped on Nagasaki. And there are stars that are one million times brighter than the sun!

But this is not all. Stars have colors. For instance, if you observe Orion's big constellation on a winter night, you can notice the left shoulder of the hunter is distinctly red, while the right foot is definitely blue. A star's color gives astronomers precious information on the energy with which most of its radiation is released. Since the way that a star emits light depends solely on its surface temperature, thus color becomes and indicator of its temperature. Hotter stars whose surface can reach 40 thousand degrees emit a blue light, while the coldest ones, reaching "only" 2000 – 3000 degrees release red radiation. The sun at 6000 degrees is yellow. Therefore we have proceed to create a star classification based on this characteristic which includes all the main groups O, B, A, F, G, K, M from the hotter to the colder ones.

Spheres suspended

Let's go back to the initial definition that we have given of a star.

First of all let us stop and think: have we ever seen a gas take on a definite shape, such as a sphere, without beong enclosed in a container? The answer obviously is no, because gasses tend to spread and occupy all the available space. Then how can it be that the gasses of the stars are somehow confined and don't dispel into space? The explanation can be found once again in gas behavior: when compressed, a gas warms becomes warmer. Stars have a hydrostatic equilibrium thanks to the balance between two equal forces pulling in opposite directions: gravity, that tends to make matter collapse inwards toward the center, and pressure caused by the expansion of the hot gas, pulling outwards Astronomers estimate that temperatures at the center of the sun reach 15 million degrees Celsius and that density is about a dozen times the one of lead. Nevertheless the center of the sun is still gaseous because gas at such high temperatures is in a particular state called plasma where electrons and nuclei, are no longer bound by their classical atomic structure so they generate clouds of free-floating electrically charged particles; in this state, matter is highly compressible thus remaining in a gaseous state.

This eternal clash between forces lasts throughout the star’s long life. Star longevity has been one of the main problems for astrophysics to solve in the past. Stars in fact appear eternal and immutable compared to our life time. Let’s take the sun for instance: because Earth cannot exist without its star , we know that the sun is at least as old as our Planet which is about 4,5 billion years old. And this is not all: terrestrial fossil discoveries let us know that during all this time, the sun has continued to shine more or less as it does nowadays. The age problem is strictly related to the production system of the energy released. In fact, this energy could come solely from gravity: as the sun contracts it heats up and becomes brighter. Estimates on the gravitational energy available to fuel the process prove, however, that the sun cannot survive beyond thirty million years. Therefore there must be an alternative energy source to fuel the longevity that we have observed.

Spheres that shine

To discover the system which is able to heat so much gas and for such a long time we have to dive into the microscopic world of atomic nuclei. Atoms have a precise structure: they have a nucleus formed by particles called protons and neutrons, around which orbits a cloud of smaller particles called electrons. We are in the extremely small world: take a millimeter, divide it by a million and then again by ten and we will have the size of an atom. Generally atoms are stable, but particular pressure, density and temperature conditions, can cause a reaction which will transform the atoms of a certain element into atoms of another element. Any alchemist’s dream!

The core of a star is a gigantic nuclear reactor where simple atoms melt and create more complex atoms. Most of a star’s existence is sustained by the fusion of hydrogen nuclei into helium nuclei. The energy produced by the reaction heats the gas which expands, thus opposing gravitational collapse, and then reaches the surface from where it scatters in space in the form of light and heat. Right at this very moment within the sun’s core 4 million tons of hydrogen are being burned per second; this impressing rhythm has remained the same for the past 5 billion years and will remain unchanged for the another 5.

When the main gas heating fuel runs out, the precious balance between forces that keep a star alive are lost. In the difficult search for a new stability, the star evolves, beginning fusion processes of heavier elements, such as carbon. Then, from the core of a star like the sun, the enormous quantity of energy produced rises to the surface over millions of years. As it travels through thick layers of dense gas, this radiation interacts with gas atoms along the way and is degraded, somewhat like what happens to the kinetic energy in a billiard ball when it collides with another one. On its way, this energy will also pass through a turbulent gas layer where gas columns, rather like huge escalators, carry it up to the surface where it is released into space where it will travel until it reaches us.

Star groups: reality or fiction?

Constellations are groups of stars which form certain familiar shapes in the sky. Nevertheless, the celestial sphere is simply a two-dimensional projection of the universe that surrounds us centred on our planet. Thus when considering the third dimension, which is depth, stars belonging to the same constellation are not bound together in any way, in fact, they are often considerably far from one another. Therefore the belief that certain constellations may influence people's lives is apparently groundless.

Yet this doesn't mean that stars live alone, on the contrary. Often stars form complex systems with two, three or more components bound together by their mutual gravitational attraction.

The most common configuration are double stars, which are pairs of stars that orbit around a single centre of gravity. In

particularly tight systems, the two components can exchange masses, sometimes consistently. In fact, the gravitation force of the most dense and compact star draws in matter from the more expanded mate, even if their masses should be the same size.
In addition to doubles, one can find multiple systems and real masses, groups of stars bound together by gravity. The latter are divided into two families: open masses and globular ones. The first ones are made up by a number of newly formed stars ranging from ten to a thousand and are all gathered in an area with an approximately ten light year diameter. The open masses are in fact proof of the stars' young age because they tend to be born in clusters within our galaxy's disk. Within scale times of two to three billion years open masses will break up: gravitational interactions act as slingshots and end up expelling all the massed stars. Numerous open masses are sufficiently close for us to see them with the naked eye: the brightest one of them all is the one of the Seven Sisters in the Taurus constellation, only 425 light years away from Earth.
Globular masses instead are totally different. They are more unusual than the open ones, they can be made up of over a million of stars gathered in no more than about one hundred light years: they are so dense that they can survive much longer against gravitation attacks which instead break up all the young open masses. In fact globular masses are made of very old stars, that were born when the galaxy was still being formed, and they are spread in a spherical halo around the centre. Scientists study them just because they can foster secrets on the formation of the Milky Way itself.

The distance problem

One of the principal problems in astronomy is the measurement of stellar distance. We have already seen that all objects are "squashed" on a spherical projection, known as celestial sphere, at the centre of which we have Earth. A lack of depth obviously brings to misled calculations of luminosity and distances among the objects. The sun for instance is a medium sized object, yet because it is also the star which is closer to us, it seems larger and brighter than many other stars that, even if they are much brighter, they seem smaller and weaker because of the distance.
There are many ways to calculate the distance between the stars; one of these goes by the yearly parallax. The parallax is the apparent movement of an object compared to its background, when looked at from two different points. The farther an object is, the smaller and less noticeable its movement will be when increasing the distance between the two points of observation. Since the stars are so distant, in order to be able to notice the parallax, they are watched every six months, that is when Earth is at two opposite ends of its orbit around the sun. Thus the yearly parallax method. By measuring the angle of this movement and knowing the radius of earth's orbit, we can calculate the distance between us and the object with a simple trigonometry formula: D = Rearth : tgangle expressed in parsec. Parsec is the unit of measurement used by astronomers for distances in the Universe; the name stands for the abbreviation of "second parallax" which is the distance from which one can see the radius of earth's orbit under an angle of 1 arcsecond. 1 parsec is the equivalent of 3.26 light years. In the past years we have been able to calculate with remarkable accuracy the distance of most of the closest stars with the parallax method thanks to the Hypparcos satellite.
Nevertheless one is easily inclined to think that the validity of this method is limited to stars near us; in the case of very distant stars the parallax angle becomes so small that it cannot be measured so we have to turn to indirect measuring methods. For instance, one can take into consideration some variable stars, whose variability is linked to their intrinsic luminosity. By measuring their apparent luminosity, meaning the one that we measure from Earth, it is possible to calculate their distance.
Several objects belong to this class of candle samples, the best known are the Cepheid, luminous stars that can be seen also in other galaxies beyond the Milky Way. The measuring precision of these stars allowed the Astronomer Edwin Hubble to measure the distance of the closest galaxies and discover their recession, paving the way to modern cosmology and the Big Bang theory. Today we are able to evaluate, even if not with perfect accuracy, galactic distances of hundreds of millions, and even billions, of light years.