UNIVERSIDAD AUTONOMA DE CHILE
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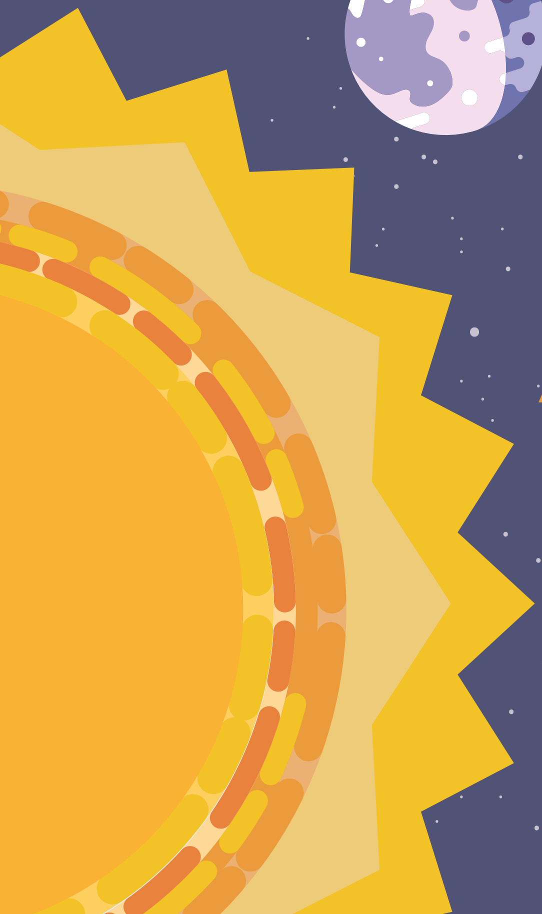
JUAN CARLOS BEAMIN

ILLUSTRATED ASTRONOMY

THE SUN
THE EARTH
THE MOON
ECLIPSES



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TRANSLATION: CATALINA LIMARÍ

ILLUSTRATED ASTRONOMY
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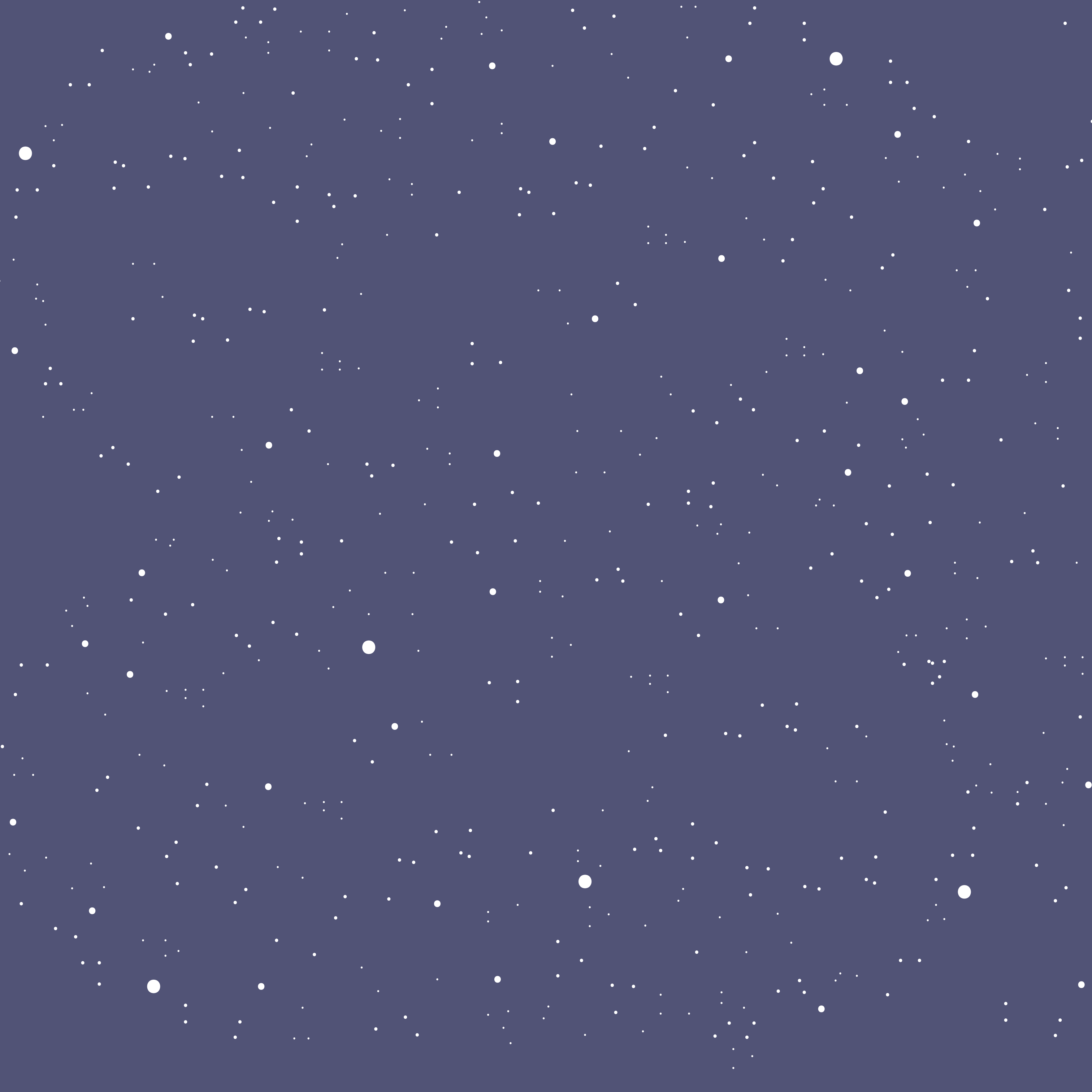
Universidad Autónoma de Chile

In honor of my father, Juan Carlos Beamin Anguita, who during the night, taught me to get amazed by stars, satellites, and the idea of creating new constellations. Without those contemplating hours, this book could not have been possible.



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HOW DID WE GET TO THIS DATE?
A very brief history of the Universe

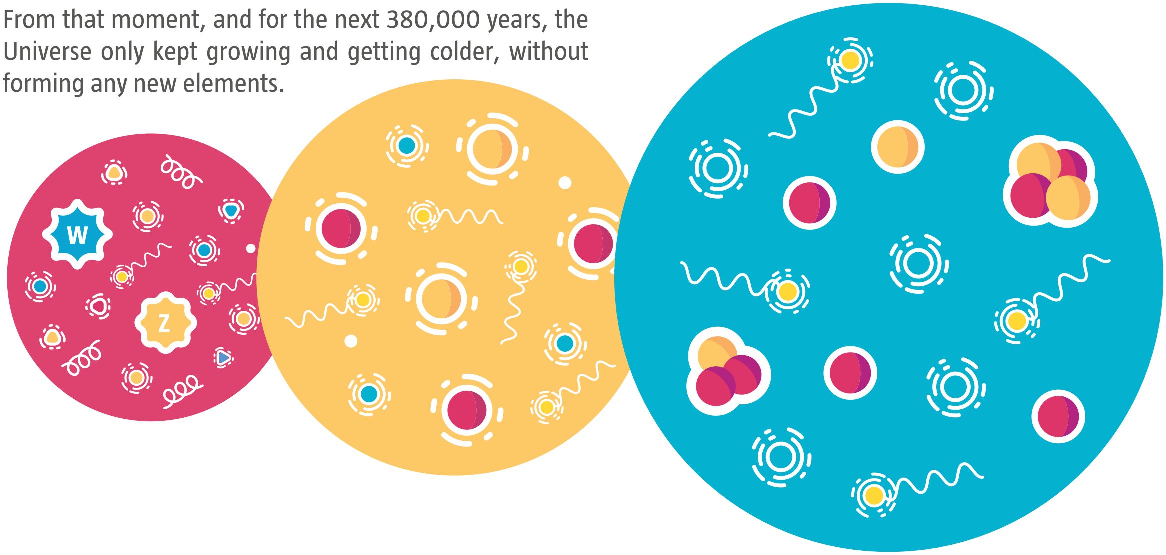
Our Universe was born about 13.7 billion years ago. During the first stages, there was no matter, neither atoms, and in a certain way, all the energy, gravitational and electrical forces were all together. Then, in a matter of seconds, the very first particles formed.

It is almost unlikely to believe that, at that very moment, all the matter of the Universe was made up of hydrogen (75 %), helium (25 %), and a pinch of lithium (less than 0.001 %)[1], and a temperature of hundreds of billions of Celsius degrees.

From that moment, and for the next 380,000 years, the Universe only kept growing and getting colder, without forming any new elements.

DID YOU KNOW THAT...

the antimatter is very alike to the ordinary matter? They have the same mass in general, but they differ in their electric charge signs. For instance, both an electron and a positron (or antielectron) have opposite electrical charges. When the matter and the antimatter bind together, they annihilate each other, generating a vast amount of energy.



On the early stages, the Universe was dominated by particles very different from what we know today.

During the first second, the antimatter and the matter annihilate each other. The creation and annihilation of both protons and neutrons cease.

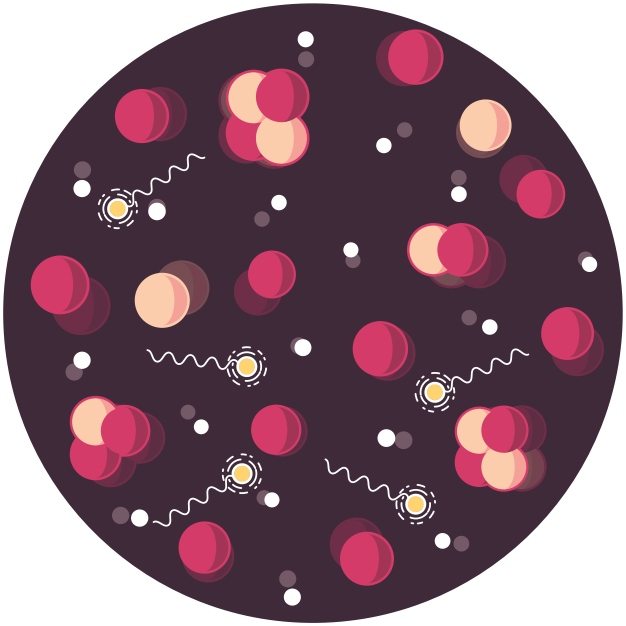
In this short time, protons and neutrons form nuclei based on other atoms, such as helium.

---

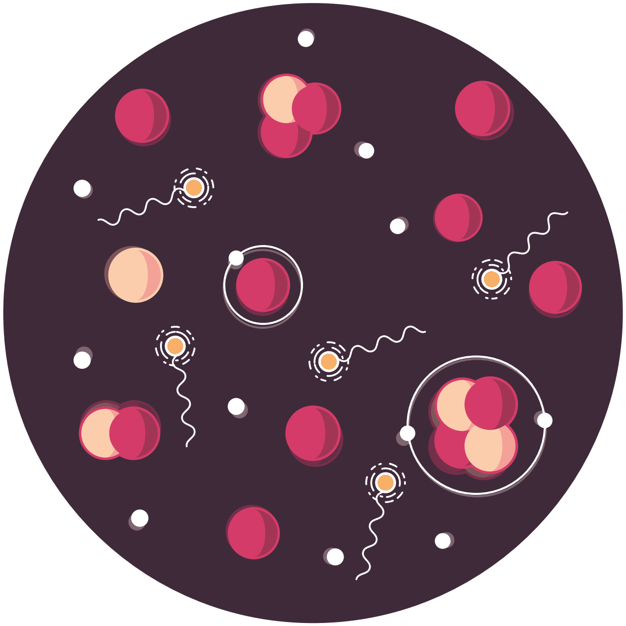
1 · A small amount of beryllium-7 was also formed, but since it was radioactive, it turned out to get discomposed into helium and lithium.

At first, the formed matter and light seemed trapped. The latter collided with the first one, being incapable of travel freely as it does now. The early cosmos was so dense and hot that electrons could not remain attached to the nuclei of the atoms. However, as the Universe continued to expand and the temperature cooled down (3,000 °C approximately), the electrons started to remain next to their nuclei, preventing the light from scattering. This stage is known as **Recombination or Surface of the Last Scattering** since the atoms merge and, from that very moment (380,000 years after the Big Bang), light can travel freely in the Universe.

The light we detect and see today thanks to the microwave telescopes, it has traveled 13.7 billion years, and it has "cooling down" with the Universe, reaching a temperature of only 2.7 K (-271 °C).

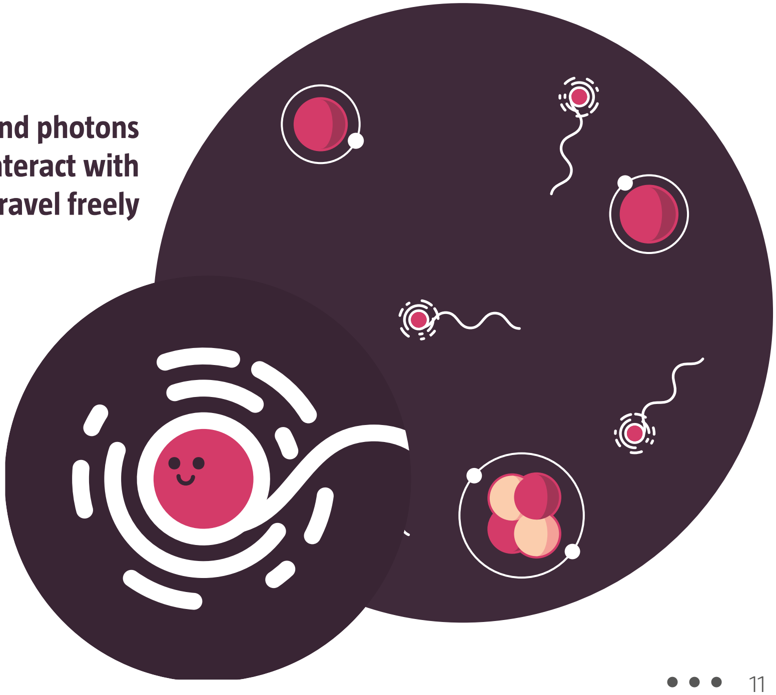


Electrons are not bound to the atomic nuclei, and photons collide continuously with electrons and ions.

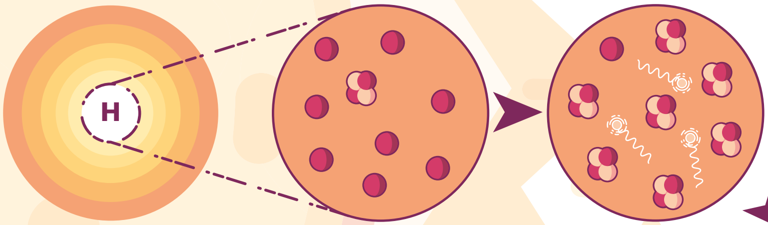


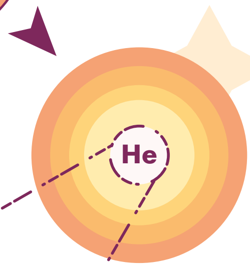
The Universe cools down. Electrons start to bind to the nuclei, and photons lose energy

The Universe is neutral, and photons don't have enough energy to interact with atoms. Photons can finally travel freely

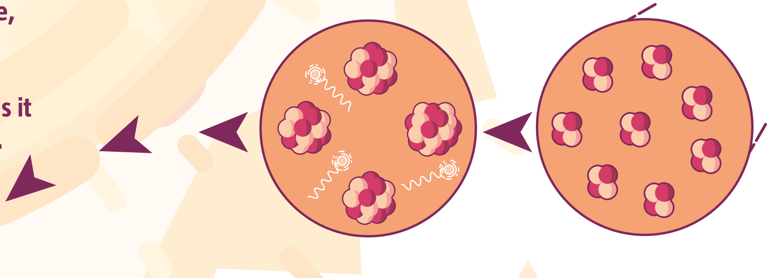


Within the nucleus, the hydrogen fuse, forming helium and releasing energy.

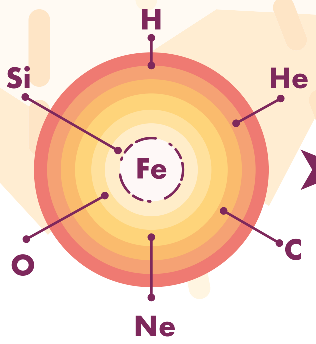


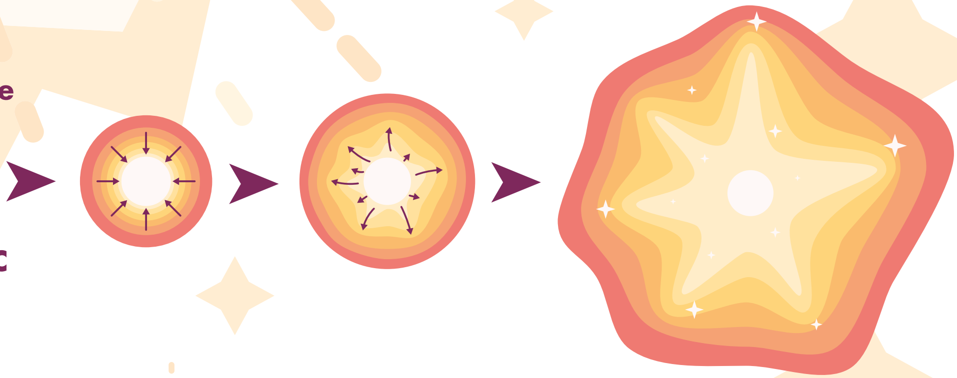


Helium can fuse within more prominent stars to create atoms such as carbon and oxygen.



Once helium comes to life, the fusion in the nucleus doesn't liberate energy anymore because it needs it to create other elements.





At this point, the star has layers dominated by different elements.

The lack of energy makes the star collapses over its nucleus and bounce over it. The crushing accelerates the reactions which liberate energy.

So, the energy produced during the crushing process makes the star explodes.

When light could finally escape, there were neither planets nor galaxies, and we had to wait other 200 million years before the first stars formed. During that time, the Universe was completely dark, just like a thick, darkened nocturne fog.

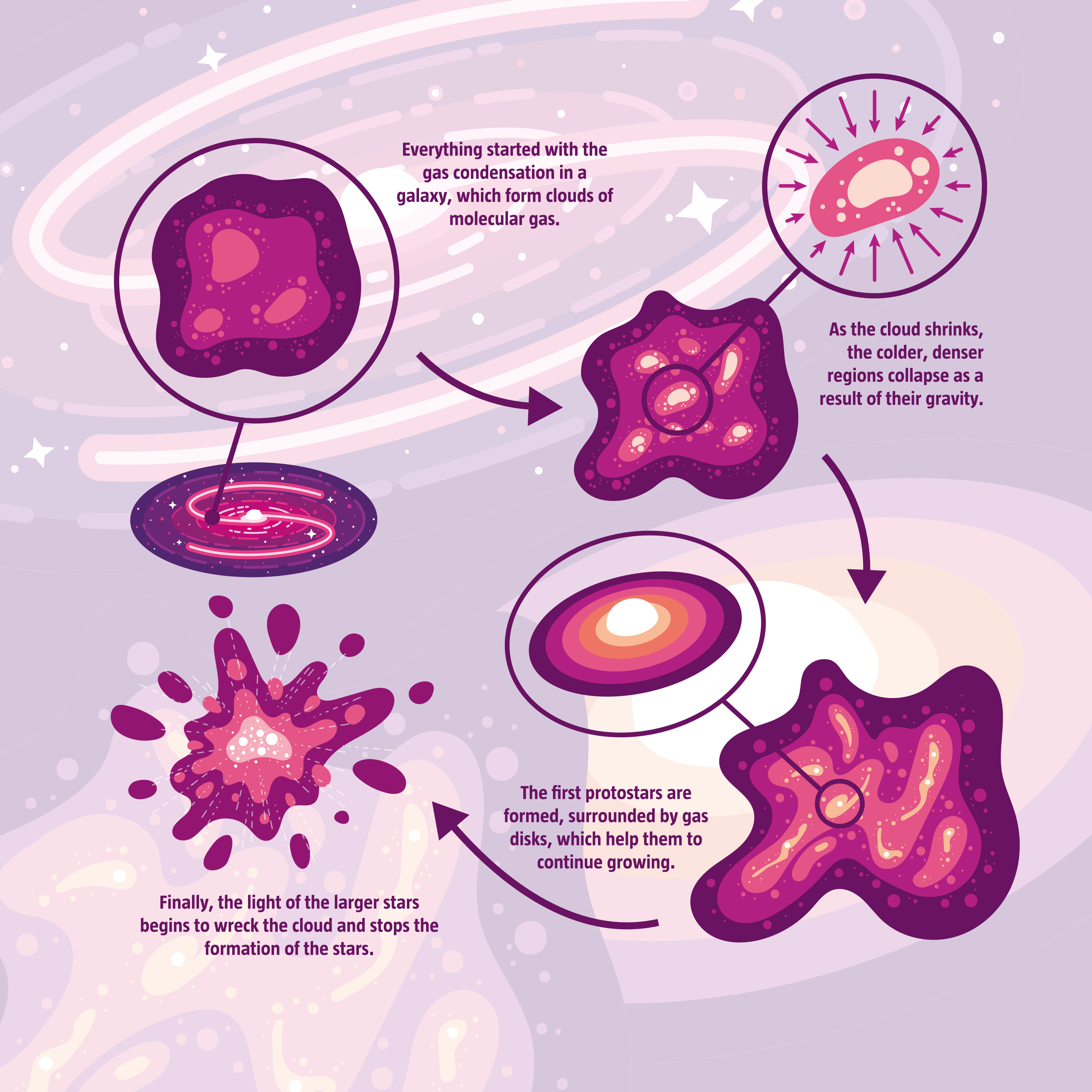
It is more than likely that the first formed stars were much hotter, larger, and brighter than our Sun. They needed fuel to shine, so they used both hydrogen and helium to do it. When they merged, they were creating new elements more complex, such as carbon, nitrogen, oxygen, and iron, at the same time when the Universe was releasing energy and light. These stars had very short lives, and when they died, they massively blew up, which is known as **supernovae**. Thus, they expelled to the cosmos the new materials they had formed, allowing the new generations of stars had access to tiny quantities of them.

Little by little, the dark Universe started to light up. After two hundred million years, the first galaxies showed up, and from then on, a new transformation began: the large amount of light that stars produce makes electrons split up inside hydrogen atoms, so the Universe is ionized again (as in the beginning), and that's how it is up to date.

Going forward in time, the Universe continues to expand; new galaxies and stars are formed, some of them explode as supernovae and inject some other materials into the Universe; galaxies merge with each other, grow, and trigger the formation of new stars. That's how the **Milky Way**, our Galaxy, arouse, which due to its shape is classified as a spiral type.

Even though it is impossible to define an exact age for our Galaxy, we can say that it is almost as old as the Universe itself. Some of the star groups orbiting the Milky Way (known as globular clusters) are nearly 12.5 billion years old.

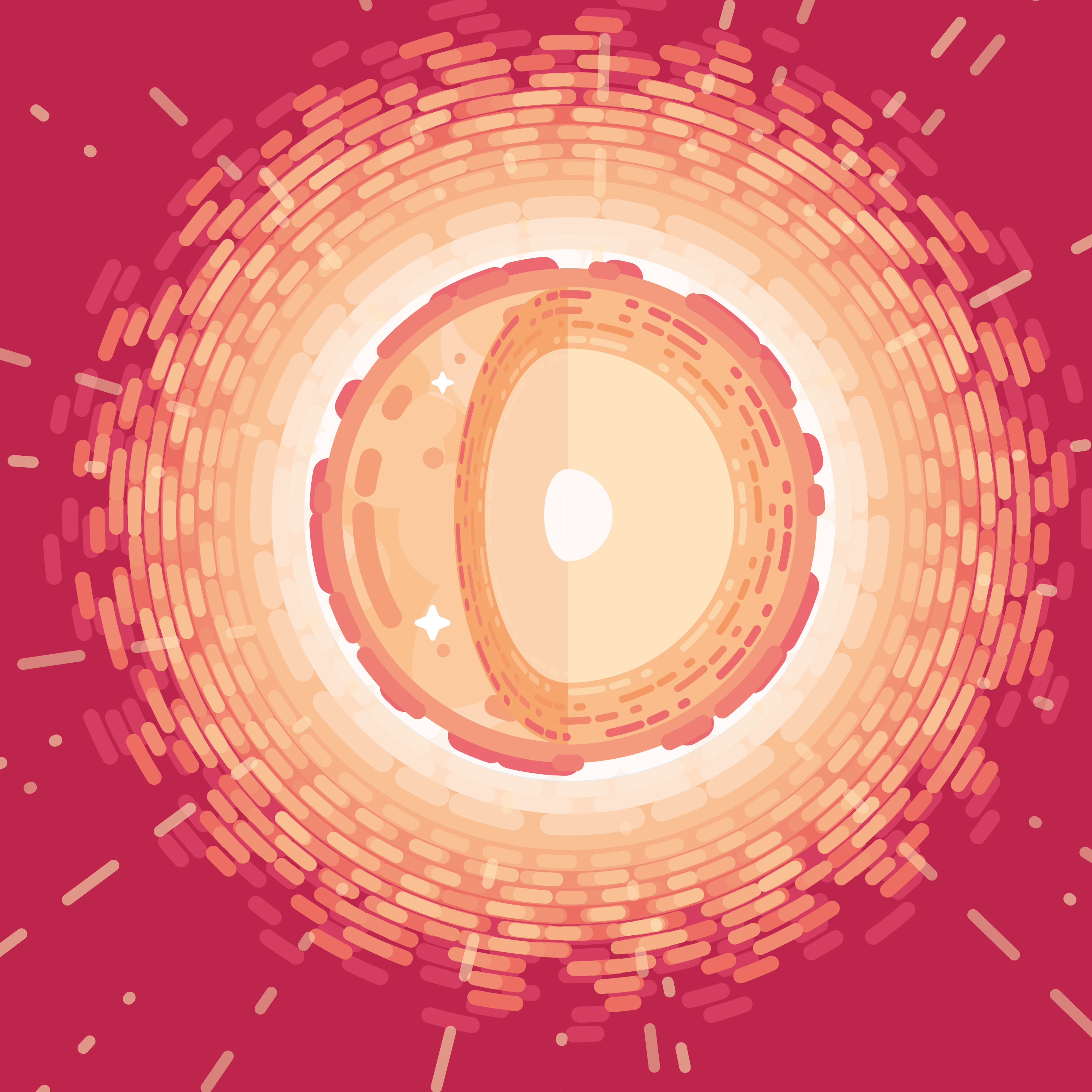
About 4.5 billion years ago, a great cloud of gas and dust, located at one of the spiral arms of the Milky Way, started to shrink and got divided into smaller and denser clouds. In so doing, hundreds or even thousands of stars of different sizes were formed. Among them is the Sun, that since then is orbiting around the center of the Galaxy, apart from other hotter stars and many other tinnier and colder ones.


Everything started with the gas condensation in a galaxy, which form clouds of molecular gas.
As the cloud shrinks, the colder, denser regions collapse as a result of their gravity.
The first protostars are formed, surrounded by gas disks, which help them to continue growing.
Finally, the light of the larger stars begins to wreck the cloud and stops the formation of the stars.

The Sun is part of the more than 200 billion stars that make up the Milky Way. It orbits around 25,000 light-years[2] away from the galactic center, and it travels at a speed of 200km/s. Completing a single orbit (cosmic year), it takes 250 million Earth years.

2 · A **light-year** is the distance that light takes during a year traveling in the vacuum, which is the equivalent to 9,461,000,000,000 (or 9.5 trillion approximately). It is important to remember that a light-year is a measurement of distance and not time.

When the Sun was forming from its cloud, shrinking to be the size it is today, a minor part of this cloud created a disk around the Sun. Such disk originated all the planets in the solar system, from Mercury to Neptune. Every single one of them took remains of the material existing from the Big Bang, or that was once inside a star, and after thousands of millions of years, they condensed into a planet. Also, comets, asteroids, and the rest of the objects that we can find in the Solar System were formed, such as dwarf planets, where Pluto is the most known. Out of the eight planets that the Solar System has, in the third one closest to the Sun, life developed. In the beginning, 3 billion years ago, there were only bacteria, but this was increasing in time and diversifying. And today, as human beings, we can do research and understand how did we get here and amaze at everything that exists.



I

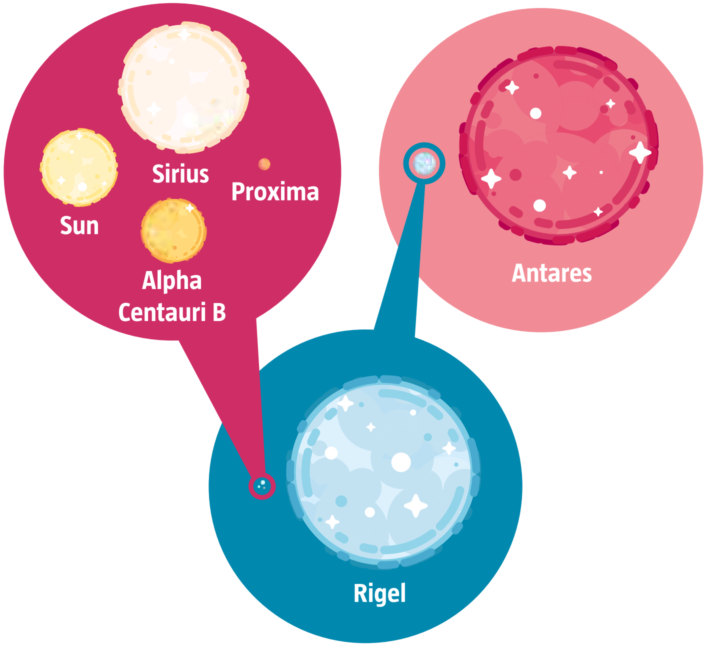
THE SUN

THE BRIGHTNESS OF STARS

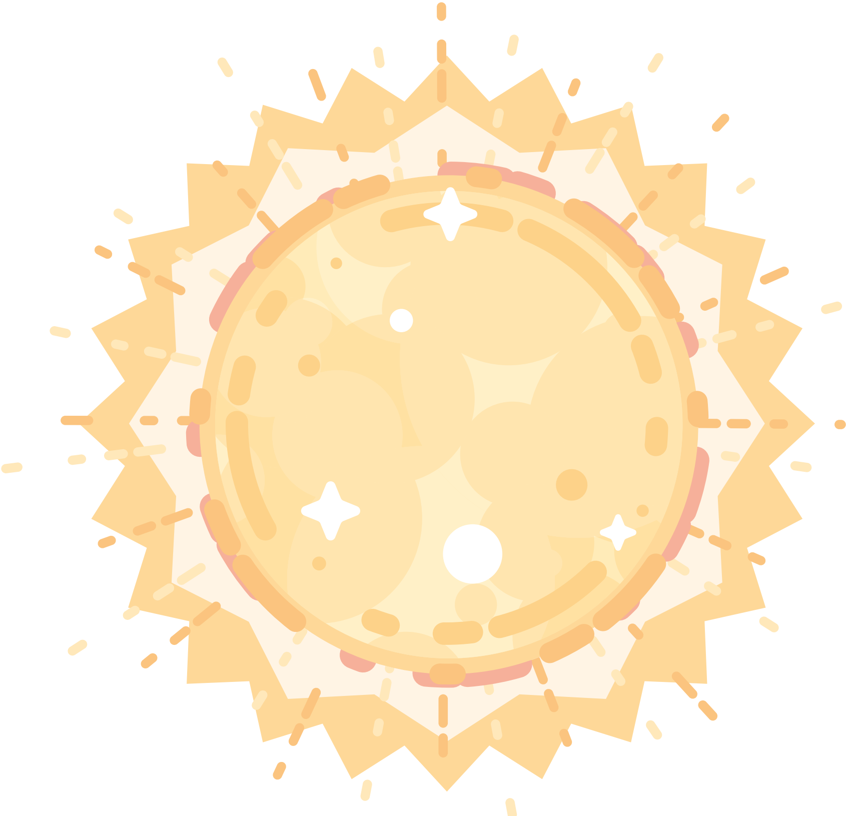
The Sun is the nearest star to us, and its luminosity makes it special from the rest. We can see its intense brightness since it is "very close" to us, merely to 150 million kilometers away, whereas the next closest star is no less than 39,762,576,000,000 kilometers away (39 trillion kilometers). Two thousand times farther!

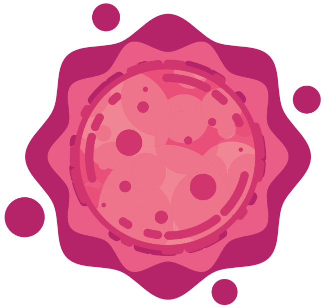
Most of the stars in the Universe are, in fact, smaller and brighter than our Sun. Nevertheless, it is surprising that most of the ones we can see at night are actually, larger, hotter, and brighter. It seems contradictory, but let's imagine that we can see a light bulb or a streetlight shining from a distance. A match, however, requires to be relatively closer to see if it is lit.

Let's review a real example. The nearest star is **Proxima**, located at the **Constellation Centaurus**. It is part of a triple-star system, where the main one is **Alpha Centauri A**, following by **Alpha Centauri B**, and then **Alpha Centauri C** or Proxima. Of those three stars, the first two are visible to the naked eye, even though they seem to be only one because they are very close, and we need a telescope to watch them separately. Alpha Centauri A is similar to the Sun in terms of size, age, temperature, and brightness, being one of the most luminous stars in the southern hemisphere sky. Although it is slightly closer, Proxima has just under one-eighth of the Sun's mass, and the surface temperature at almost 2800 °C (in contrast to the Sun that is over 5400 °C), which means that its brightness is less than the hundredth part of the Sun's shine. That is why we cannot see it without help, even though it is very near.



Up here it would be valid to ask: **Why all stars are different?** Every single one of them owes all their features properties, such as color, brightness, and size to its mass and to their age. Although indeed, the chemical composition does matter, it is a secondary factor. For instance, the Sun has a mass of 1,988,000,000,000,000,000,000,000,000,000 kg (1,988x10^{30} kg), the so-called **solar mass ($M_{\odot}$)**, and we designate a number to the stars in comparison with that value. Then, Proxima has a mass of 0.123 solar masses.





A solar mass is equal to 1.99 x 10^{30} kg; a solar radius is equivalent to 700,000 km, and the Sun brightness is 3.8 x 10^{26} W. The Earth could consume between 1,500 and 40,000 Exajoules from the radiation the Sun emits, whereas the whole humanity consumption of one year rise to 600 Exajoules.

In the following table, you can see some examples of stars and their masses, sizes (radius), and brightness or luminosity.

Star	Mass	Radius	Distance [light years]	Luminosity or brightness
Alpha Centauri A	1.1 $M_\odot$	1.22 $R_\odot$	4.3	1.52 $L_\odot$
Alpha Centauri B	0.907 $M_\odot$	0.86 $R_\odot$	4.3	0.5 $L_\odot$
Proxima (Alpha Cen. C)	0.122 $M_\odot$	0.15 $R_\odot$	4.24	0.0017 $L_\odot$
Sirius	2.06 $M_\odot$	1.7 $R_\odot$	8.6	25.4 $L_\odot$
Aldebaran	1.16 $M_\odot$	44 $R_\odot$	65.3	518 $L_\odot$
Canopus	8 $M_\odot$	71 $R_\odot$	310	10,700 $L_\odot$
Antares	12 $M_\odot$	680 $R_\odot$	550	97,700 $L_\odot$
Rigel	23 $M_\odot$	79 $R_\odot$	860	120,000 $L_\odot$

In astronomy, this symbol $\odot$ represents the Sun

DID YOU KNOW THAT...

...if the light could travel at infinite speed or if the Universe were endless, the night sky would be crystal clear since we would see stars in every direction? However, as the Universe has a starting point, and the speed of light is finite, our sky looks dark.

Read more about "Olbers' paradox." on this link: https://en.wikipedia.org/wiki/Olbers%27_paradox

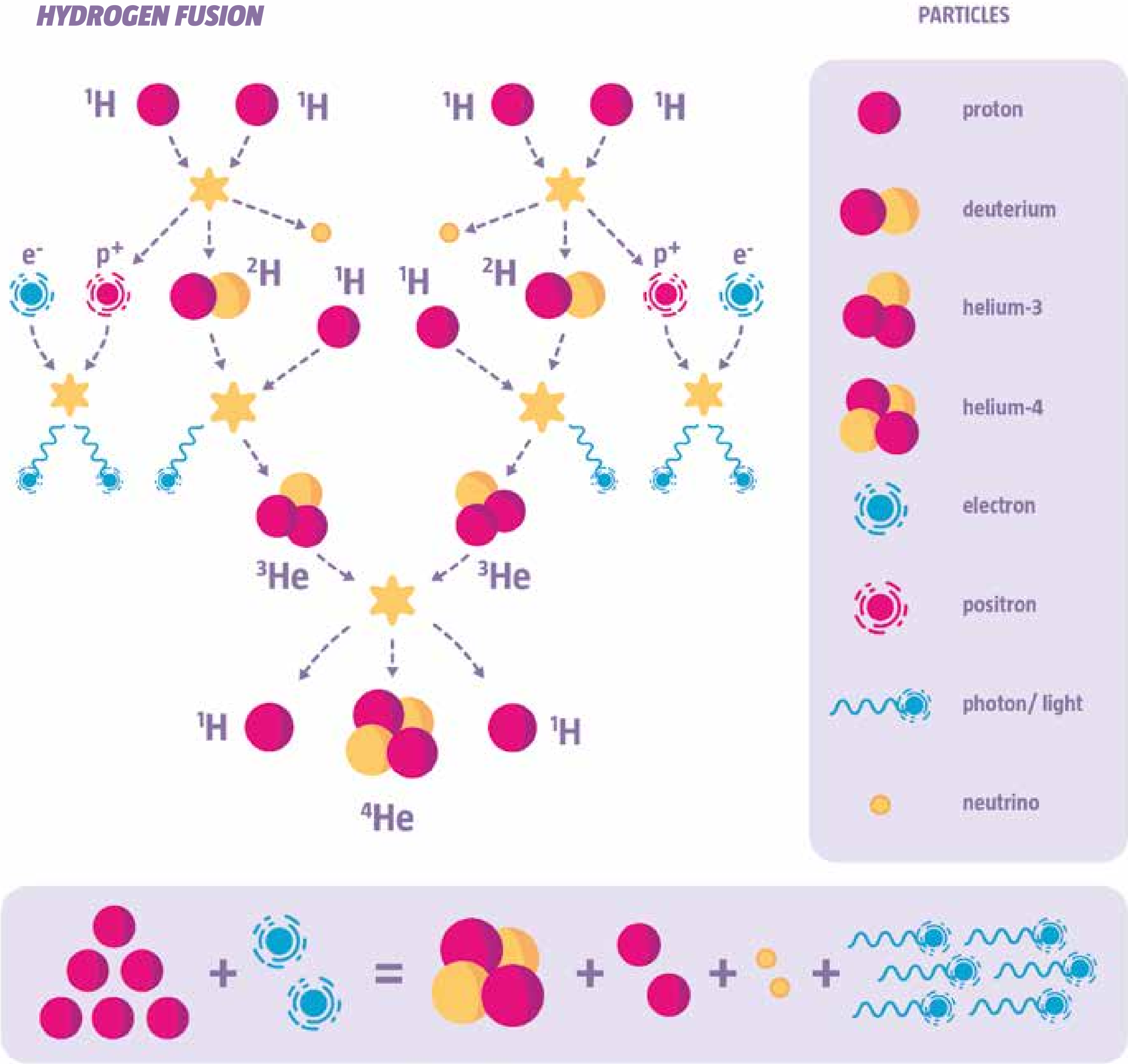
WHERE DO STARS GET THEIR ENERGY FROM?

To turn on a light, a telephone or a computer, to move a car, to warm ourselves in winter and refresh in summer, to walk, or even read these lines, we need energy. So, where does this energy come from? There are different sources. We can burn some fuel to warm up or move, or take advantage of the wind or the falling water on a waterfall to turn it into kinetic energy useful for other purposes. We can also take the solar light and turn it into chemical energy, keep it within batteries, and then use them to run our electronic devices. Even plants can transform solar light, air, water, and minerals into sugars to generate energy through other chemical processes, but how is the energy that comes from the Sun produced?

The Sun is mainly made up of hydrogen and helium, the most lightweight and common elements in the whole Universe, besides small quantities of chemical components such as carbon, nitrogen, oxygen, iron, sodium, calcium, and magnesium, among others.

In contrast to the Earth conditions, the Sun possess an enormous gravity due to its gigantic mass, which makes its core particularly hot. Also, it is very dense. There is an immense pressure and, under these extreme conditions, a phenomenon known as **nuclear fusion** occurs. Nuclear fusion is the process in which small and lightweight atoms, such as hydrogen, come together to create larger and heavier ones such as helium. In fact, it is needed four hydrogen atoms to fuse into one helium, but the process is much more complicated than just put atoms together.

HYDROGEN FUSION



Chemical's Reactions summary

What does this have to do with generating energy? If we put on a balance four hydrogen atoms and one helium atom, we see that the mass of the hydrogen atoms is slightly larger than the helium in 0.7 % or so. This means that **during the fusion process of hydrogen atoms, part of the mass is lost!**

DID YOU KNOW THAT...

...the core of the Sun can reach 15 million Celsius degrees, and its pressure is 200 billion times higher than the atmospheric pressure on Earth? Only under these conditions, the fusion of lightweight elements can occur, transforming them into heavier ones.

If you had heard that "the mass can neither be created nor destroyed" then, what happened with the mass loss on the fusion process? In this case, **the energy is the one which transforms**, and the mass is only a type of energy, such as light and heat. The famous formulae $E=mc^2$, which reads "energy = mass times the speed of light squared," precisely stands for this: if the mass of something is multiplied by the speed of light squared, it is obtained its rest energy.

If we want to or could transform 1 kg stone into energy, we would have to do it this way:
$E= mc^2$
Where c = 300 000 000 $[m \cdot s^{-1}]$ (the speed of light in vacuum)
m = 1 kg
$E= 1 \times (300\ 000\ 000)^2\ [Kg \cdot m^2 \cdot s^{-2}]$
$E= 9 \times 10^{16}$ [Joules]

This energy is tremendous, similar to the total energy released by an earthquake magnitude 9.1 or half of the energy of the most powerful nuclear weapon ever detonated in human history: The Tsar Bomba.

The Sun has a luminosity of 3.8×10^{26} J/s. If we divide this value by the speed of light squared, we obtain the mass that the Sun turns into energy at every second. It is more than four million tons of matter. Fortunately, as our star has so much mass, we can say that it can withstand those levels of energy production for at least 4.5 billion years more.

If it has lived that amount of years already, we might say that it is in the middle of its age as it is estimated that it will live about 9 or 10 billion years.

DID YOU KNOW THAT...

...the energy that the Sun produces takes at least 100,000 years to come out of it and reaches the Earth in only eight minutes?

DID YOU KNOW THAT...

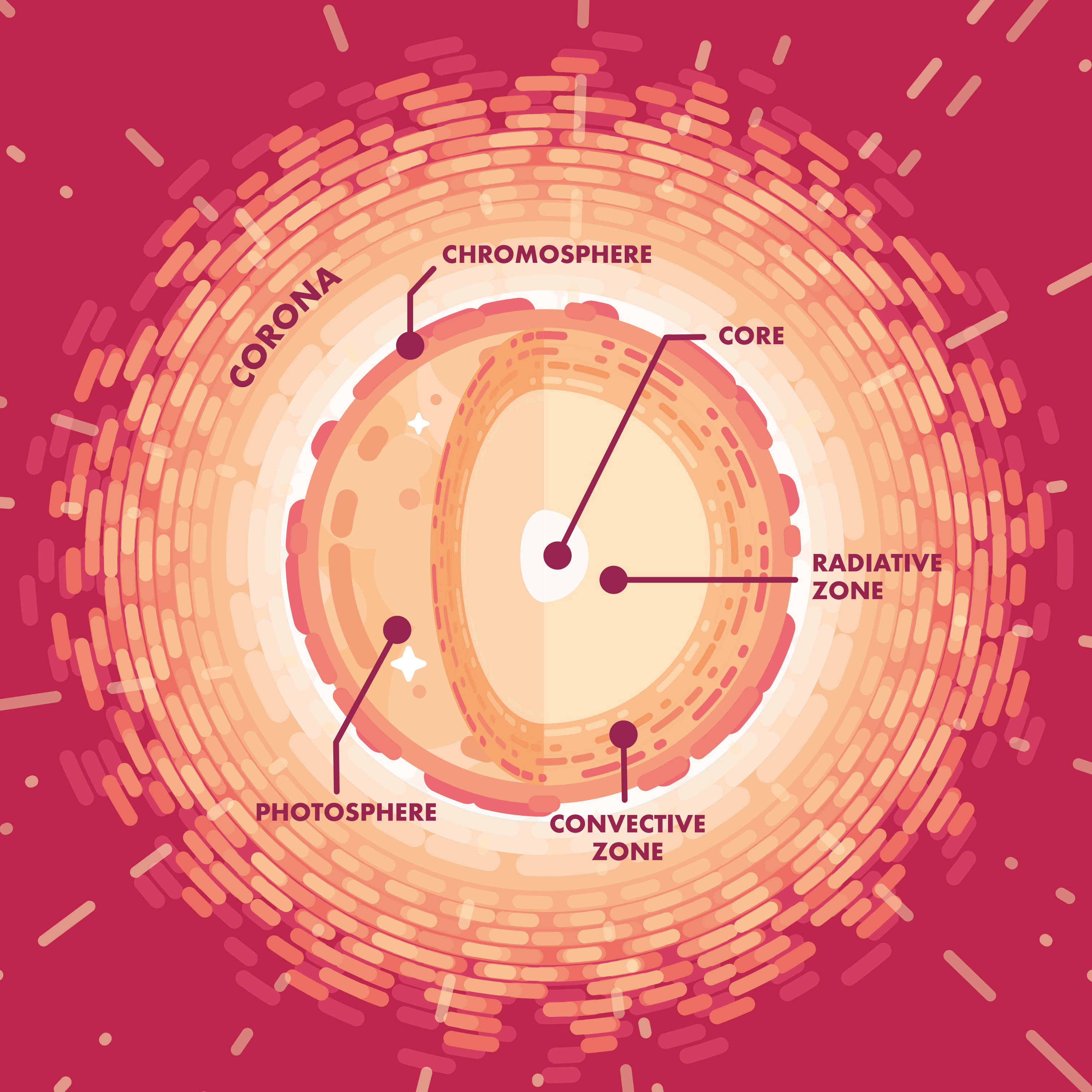
at every second, the Sun produces more energy than all humanity has spent in its history?

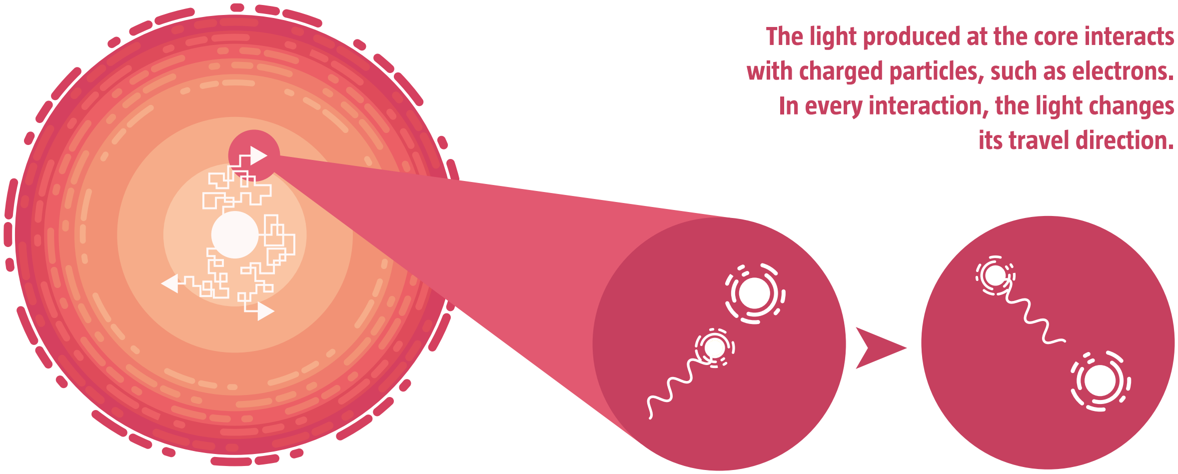
THE SUN STRUCTURE, OR WHAT IS IT BETWEEN THE SUN'S CORE AND WHAT WE SEE?

The star has six main layers:

THE CORE

Where its energy is produced. It is the innermost part and is up to 20 % or 25 % of its total radius, which means if the Sun has a radius of 700,000 km, the core from the center goes between 150 and 200,000 km. In this place, a significant quantity of helium builds up at every moment.


CHROMOSPHERE
CORONA
CORE
RADIATIVE ZONE
PHOTOSPHERE
CONVECTIVE ZONE

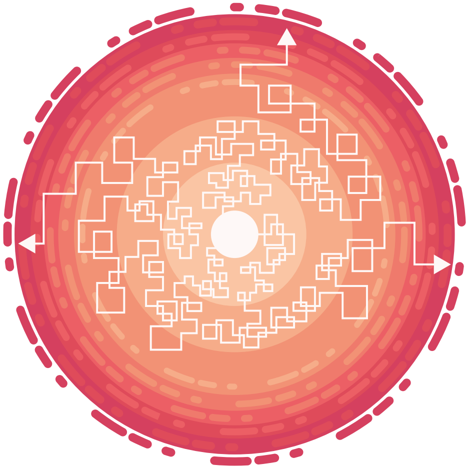


The light produced at the core interacts with charged particles, such as electrons. In every interaction, the light changes its travel direction.

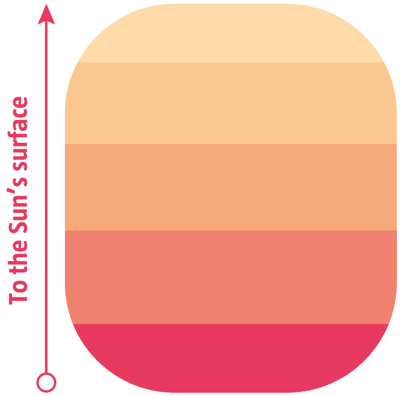
RADIATIVE ZONE

The radiative zone is the second layer, where the energy produced in the core travels to almost 70 % of the Sun size, which means, between 200,000 and 500,000 km through the physics process of radiation. In this region, the temperature decreases dramatically, from 7 million degrees to 2 million degrees when it hits the transition zone called Tachocline, to then move to the third layer.

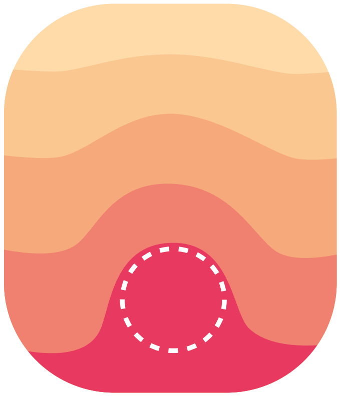
It is believed that in this transition layer is where the Sun rotation changes from a rigid rotation, such an "iron" sphere, to rotate differentially. Like when we shake a ball with liquid in, and we observe the ball spin faster than the liquid inside. Apparently, this would produce the magnetic field of the Sun.



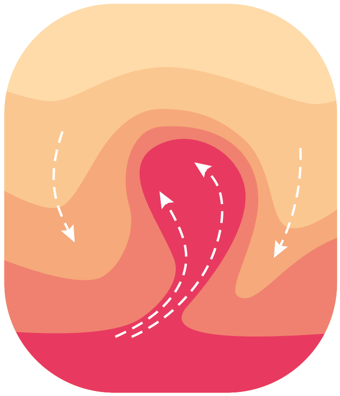
The interactions occur so often that the light energy takes thousands of years to escape from the Sun.



From the core of the Sun upward to the surface, both temperature and density decrease



The inner core of the Sun is chaotic, and sometimes, little bubbles of low density are formed there, trying to pop up



If the bubble stays hotter than its surroundings will continue to rise

CONVECTIVE ZONE

The convective layer ranges from 500,000 km to almost its visible surface. Here, energy does not travel by radiation, but by convection. The cooling-down process happens differently from the previous layer because the Sun's material moves as heat "bubbles" (**convective cells**) —which comes from the Tachocline and expand, making them "float" or moving upwards — carrying this innermost part heat to the outermost ones. Through the movement of this material (plasma state), the temperature cools down from about 2,000,000 °C in the Tachocline to 6000 °C in the photosphere, which is the following layer.

This is called convection, and it releases the energy faster than the radiation in the inner core of a star.

DID YOU KNOW THAT...

...the movement of material in the solar surface produces the so-called Granulation and Supergranulation?

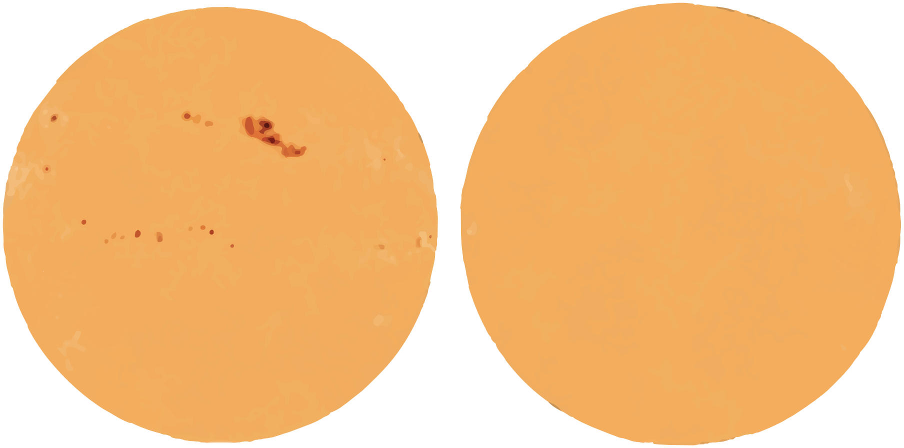
PHOTOSPHERE

The photosphere is the visible layer of the Sun. When we talk about the temperature of a star, we generally refer to the photosphere's temperature, and the light of the mentioned layer is also useful to do chemical analysis of the stars. In the case of the Sun, the photosphere's temperature goes from 4,200 °C to 5,700 °C.

On this layer, we can see different phenomena such as sunspots, which are regions of reduced temperatures caused by local magnetic fields that inhibit the escape of hot material from the innermost layers. These spots appear and then disappear as it is related to a solar cycle of eleven years in which the Sun changes its global magnetic field, which means that the north pole turns into the south pole, and vice-versa. Like so, if in one year we see many sunspots, after five or six years we will see just a few.

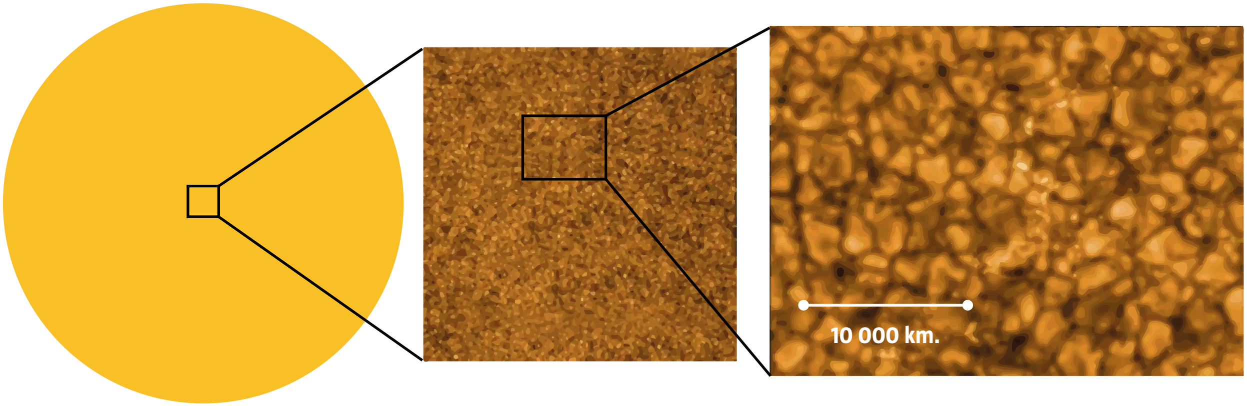
A small telescope with a suitable solar filter can help to observe these sunspots.

Solar telescopes are specially designed to observe the solar surface with higher contrast. We can obtain high-resolution images of solar flares, sunspots, spicules, and granulation with a particular filter called H-alpha filter (Hα).



Sun images during periods of higher and lower activity in the photosphere.

Another visible feature of the photosphere is **granulation**, which owes its name to the "granulate" or "granules" appearance that hot plasma takes when it rises from the convective zone and gets colder when it reaches the photosphere. This plasma has a hot core, but its edges are colder, which creates this granulated shape on the surface. The granules have an average size of 1,500 km and dissipate after 10 or 20 minutes, approximately. Granulation is a constant motion, and it can only be seen observing the Sun through a telescope with special filters.



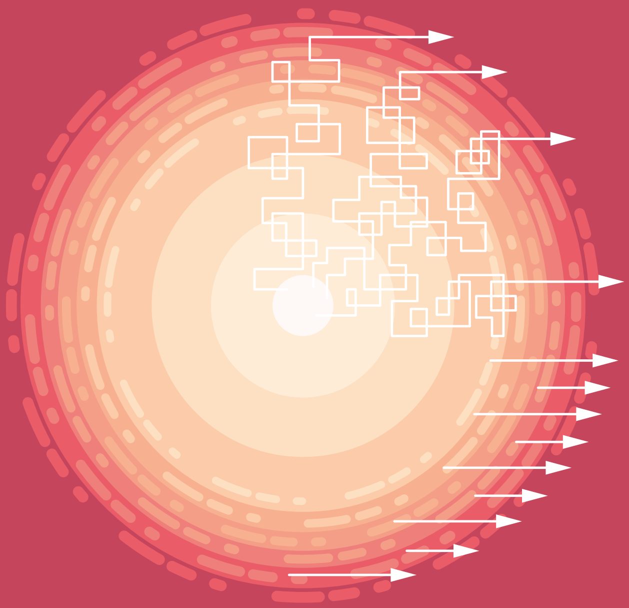
The Sun's diameter is 1.4 million km.

The granulation of the Sun can be seen as small imperfections or temperature differences on the surface. To have a general idea of the convective cells' size, on average, they are slightly smaller than Brazil. In other words, in every "grain", you can place Argentina, Colombia, Perú, Bolivia, and Chile.

Finally, another feature of this layer is the darkening towards the edges, also known as **limb darkening**, where the Sun's center appears brighter that the edges.

Why does this happen? When we look at the center of the solar circle, we can see more in-depth, and the light comes straight to us, crossing fewer layers of its atmosphere. On the contrary, if we look at the edges and we want to observe the same depth as if we look at the center, the light would have to go through more layers of the solar atmosphere. So, by observing the edges of the Sun, we can see colder, outer layers, that's why it looks slightly darker.

Something similar can be observed in the Earth's atmosphere. The stars in the sky look clearer and static when we look up, whereas if we look to the horizon, they look blurred and blinking because the stars above cross fewer atmospheric layers to approach us.



Nearby the center of the star, a part of the light we observe is in the depths of it, where the temperature is higher, which means more light.

On the contrary, the light we observe near to the edge of a star is produced closer to its surface, where the temperature is colder.

CHROMOSPHERE

Is the next-to-last solar layer and is characterized by its reddish color visible during a total solar eclipse or using a solar telescope specially designed for this kind of observations (a telescope with an alpha -Hα hydrogen filter). On this layer, way less dense than the previous ones, it can be observed phenomena such as spicules, which are plasma jets moving at 20 km/s from the photosphere to outer space. Spicules can happen anywhere in the solar sphere, and last around 15 minutes.

Unlike the rest of the Sun, it is observed that on this layer, as it moves away from the center, the temperature increases from 4,200 °C in the outer part of the photosphere to about 25,000 °C, 2,000 km in the "upper" part.

A definitive explanation of what causes a temperature inversion is still under discussion, although the local magnetic field is likely to undergo some variations, known as magnetic reconnection. That is how the energy of the magnetic field turns into motion and heat, which increases the temperature on this layer.

CORONA

The corona is the outermost layer of the Sun. It extends a few million kilometers into outer space but is not that dense, just like a billion times less than the photosphere. On the other hand, its temperature is way hotter, hitting temperatures between 1 million and 3 million Celsius. This layer is visible during a solar eclipse or using coronagraphs designed to observe it. It is worth mentioning that it is probably one of the most breathtaking and iconic views of a total solar eclipse. The corona does not have a well-defined, symmetrical shape, and it depends on the solar magnetic cycle.

What is the solar magnetic cycle?

The Sun, like the Earth, has two magnetic poles: the north pole and the south pole. Every eleven years, these poles turn upside-down, and the one in the north moves to the south, which is known as the magnetic cycle. This situation generates changes in the emitted Sun's radiation (less than 0,1 %) as well as in the plasma amount ejected from its surface. During the maximum magnetic activity of the Sun, most sunspots, solar flares, and others are observed in the photosphere.

Studying these changes is essential since they cause effects on space and Earth, mainly on an atmospheric level, producing auroras and, in the case of stronger events, they can even affect satellites orbiting around our planet.

The solar corona behavior is still not known precisely and is one of the biggest open questions on solar physics. Nevertheless, the Parker Solar Probe, launched in 2018 by NASA, may provide more information about its origin.

Doubtlessly, the Sun is the star that has received the most attention over human history, and its significance has been recognized in all cultures. We are going in-depth on this topic later in chapter VI about the ancient worldview of eclipses.

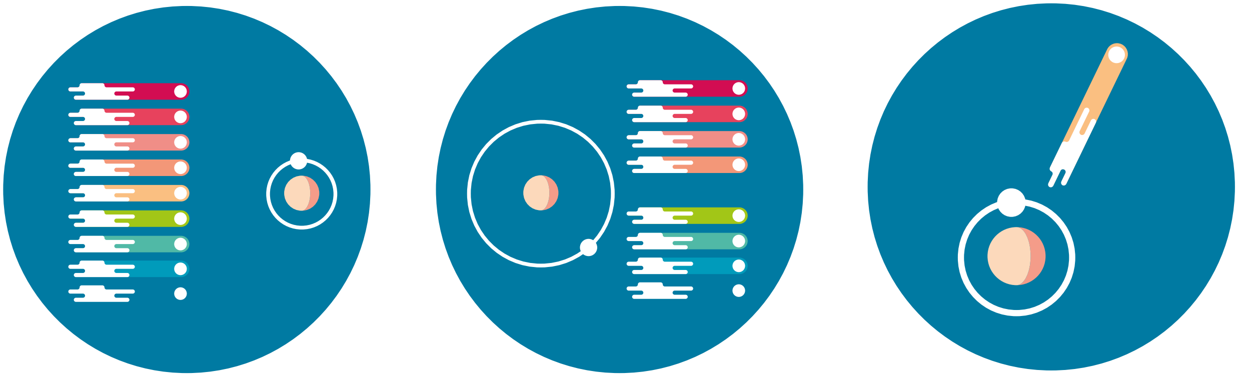
Solar corona during a total eclipse of the Sun. Behind the moon's shadow, redlined, we can see the solar flares, typical phenomena of the chromosphere.

STARS ARE MADE UP OF ATOMS BUT HOW TO KNOW WHICH ATOMS ARE IN EVERY SINGLE ONE OF THEM?

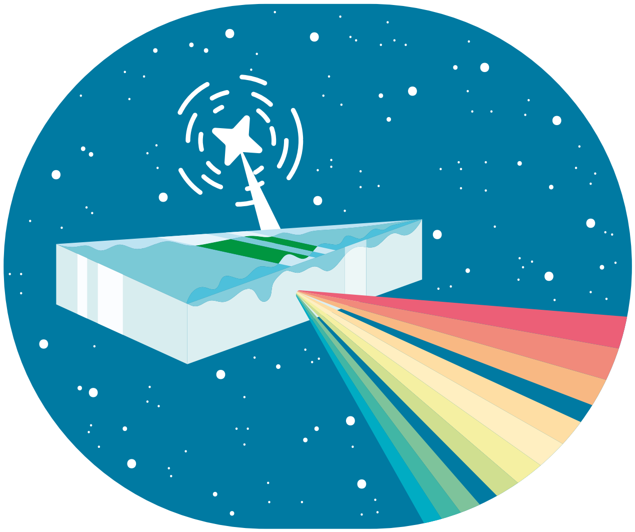
Astronomers research the material that stars are made up of. To do so, they can only see the light they emit. Fortunately, the light produced at the center of the stars pass through their atmosphere and approach us, acting just like the light we produce on Earth. Also, their atoms behave the same way in the star as in the laboratory, which means that first, we study the kind of light atoms produce on Earth, and the colors they emit, and also how bright is every color.

For instance, if the gas of an element is heated, the brightness of its color is always the same. So, thanks to the laws of quantum physics, we can precisely calculate how much energy that brightness means. Atoms can emit or absorb light only on those specific colors.

Astronomers, on their behalf, scatter the light coming from the stars (leaving it as a rainbow), and they observe which colors are NOT there. Later, using spectroscopy, which is a technique used in every natural science, they compare the colors missing with the ones that atoms emit.



The light of the stars interacts with electrons within atoms. Photons with the exact energy are absorbed and drive electrons to higher energy levels. If the electron drops to a less energetic level, it emits a photon but not necessarily in the first direction.



Analyzing the light of the stars, we observe fewer photons with specific energy, which provides information about atoms in their atmosphere.

Review questions

1 · Why does the Sun shine?

2 · What makes the stars different from one another?

3 · How is the Sun inside and how do we know that?

4 · How is energy transferred from the Sun to Earth?

5 · Which layer of the Sun is visible during an eclipse?

DID YOU KNOW THAT...

...the Sun contains 99,9 % of the Solar System's mass?

In other words, if we gather all the planets and their moons, and asteroids, and comets, they become just a thousandth part of the Solar mass.

DID YOU KNOW THAT...

...the Solar System travels to 220 km/s around the Milky Way's center and, besides its high speed, it takes 220 million years to orbit once around the Galaxy?

This period is called a galactic year or cosmic year.

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SUMMARY SELF-TEST

In the next link https://tinyurl.com/y356z72x or QR code you can find Sun pictures taken in different days and the date they were shot. *

And by using them:

1 · Calculate the rotation speed of the Sun.

2 · About what speed (in km/h), something on the Sun surface would move (at its Equator)?

3 · Compare that speed to the one we experience on the Earth's surface.

· Have in mind that the radius of the Sun is 700,000 km.

If you don't know how to start, we give you the following clues:

CLUE 1: You can calculate the motion of every spot using the grid in the QR code downloaded. To do so, follow the motion of every spot and calculate how many degrees does the spot move per day.

CLUE 2: If you have already calculated the angular distance per day, you can calculate how much it will take to complete the 360° of the solar sphere.

CLUE 3: Everything can be simplified with a higher margin of error. You can get the highest values of the day in which a spot appears and how long it takes to disappear. As it traveled halfway through the Sun (the part we can see), the total travel time has to be twice.

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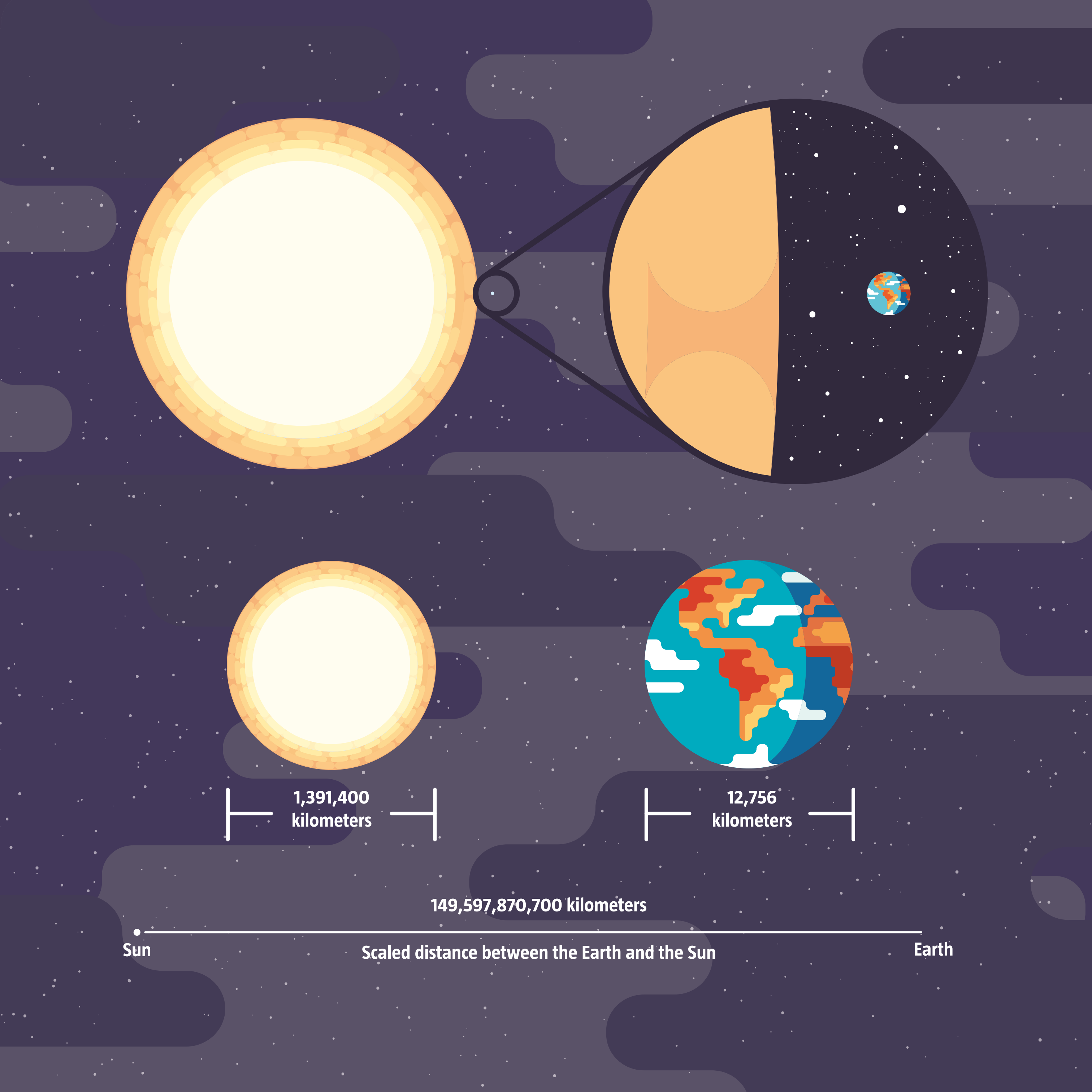
* · The images of this exercise were taken from https://sohowww.nascom.nasa.gov/classroom/docs/Spotexerweb.pdf where you can find the complete exercise.

II

THE EARTH

The Earth is the third planet in the Solar System counting from the Sun. It is the largest planet among the rocky ones (Mercury, Venus, and Mars), but smaller than gas giants (Jupiter, Saturn, Uranus, and Neptune) and it is located about 150 million kilometers from the Sun. This enormous distance means that the light coming from the Sun doesn't reach the Earth immediately, but takes around eight minutes, even though light is the fastest thing that exists! Since it travels to almost 300,000 kilometers per second.

If, for any reason, the Sun disappeared or stopped shinning, we would take eight minutes to know it, and the Earth would keep orbiting along that time to continue then traveling in a straight line into space at 30 km/s since the Sun would exert no force upon it.

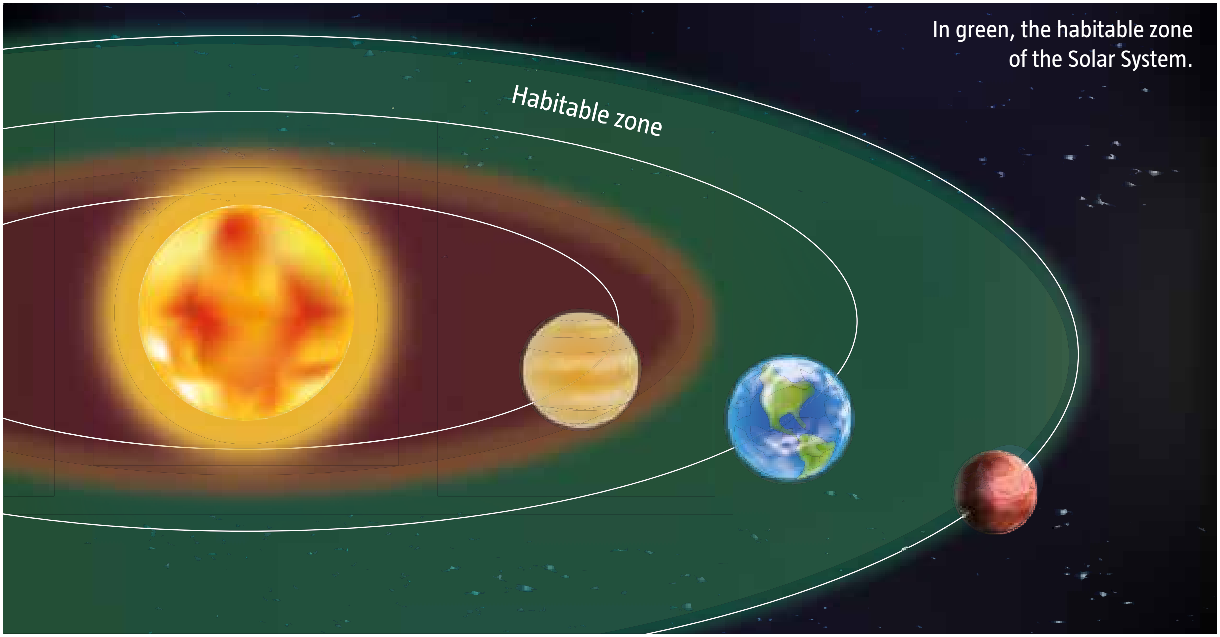

1,391,400
kilometers
12,756
kilometers
149,597,870,700 kilometers
Sun
Scaled distance between the Earth and the Sun
Earth

On the one hand, this enormous distance is something great because if the Earth were closer, the amount of light and energy that it would receive would be much higher. Therefore, the temperature would increase, putting the development of life in danger. On the other hand, if we were further, it would be the opposite: the lack of energy and low temperatures would make the living existence on our planet difficult.

Another interesting feature is that Earth's orbit is almost circular (is indeed an ellipse), and that makes our radiation levels neither lower nor higher. An eccentric orbit would cause us to get very close to the Sun in a short time, but in that period, life would experience significant changes: it would be fire everywhere and a lot of UV radiation which would kill bacteria, causing damage to the living creatures here on the Earth surface. The rest of the time, we would be far from the Sun, which would bring a brief ice age every year, and by the freeze of everything and the lack of both energy and light, it would be significantly hard to survive.

The term "habitable zone" or "circumstellar habitable zone" was created to describe a place as the one the Earth has in space, which means, in a stable, almost circular orbit at the exact distance of its star. This term refers to the space region around a star, where the temperature of an object or planet is between 0 °C and 100 °C, and water in liquid state is possible under normal pressure conditions.

Venus and Mars are in the inner and outer bounds of the habitable zone. However, it is needed much more than the right temperature to the existence of life. Next, we are discussing four essential conditions for habitability on Earth.



In green, the habitable zone of the Solar System.

PRESENCE OF LIQUID WATER

More than 70 % of the terrestrial surface is covered in water. In fact, the Earth is the only planet in the Solar System that has the three phases of water on its surface (solid, liquid, and gas).

Some of the properties that make water an essential element for life development on Earth are: it is an excellent solvent, it provides suitable conditions to many chemical reactions, and it allows the transfer of substances between cells and their environment. Also, the heat capacity of water -that is the amount of energy required to increase one Celsius degree- is very high, which means that in comparison with other elements such as rocks or metal, water takes more time to heat, remaining the surface temperature of the planet stable with slight variations between day and night.

ATMOSPHERE

A thin layer of air surrounds the Earth that we denominate the atmosphere as a whole, which protects us from the Sun's UV radiation and from particles such as cosmic rays, and it also provides us oxygen to breathe. However, the current atmosphere has changed dramatically along time. Probably, the first layer of the atmosphere lasted a short time. It was mainly hydrogen and helium (yes, the same element which the Sun is made of), but being so light, and the Earth being a relatively small and low-mass planet, these elements "evaporated" and were released to space. Then, after the constant volcanic activity, the second atmosphere formed, mainly made up of methane, ammonia, water vapor, nitrogen, monoxide, and also carbon dioxide.

In that environment is where life begins. The first living organisms (bacteria) used solar light and these atmosphere elements to produce energy. They generated large quantities of free oxygen. Finally, as time goes by, these bacteria ended up changing the conditions of this layer, and today we have an atmosphere consisting of nitrogen (N_2) and oxygen (O_2), and other gases such as carbon dioxide, argon, neon, helium, and ozone.

It is interesting to note that though the atmosphere has changed over the last million years, life has remained as a constant, so the restrictions to its existence are not limited to an exact atmosphere like the one we have today.

Outer view of Earth

MAGNETIC FIELD

The magnetic field is a force field. The Earth has a great magnetic field that seems to be related to the terrestrial core composition, a core of molten iron. This magnetic field acts like a protective shield, deflecting the high-speed particles coming from the Sun.

All of this is beneficial to us because without this magnetic field life on Earth would be exposed to a constant charged particles rain, such as electrons (particles or beta radiation), protons, and helium cores (alpha particles), among others, putting its existence at risk.

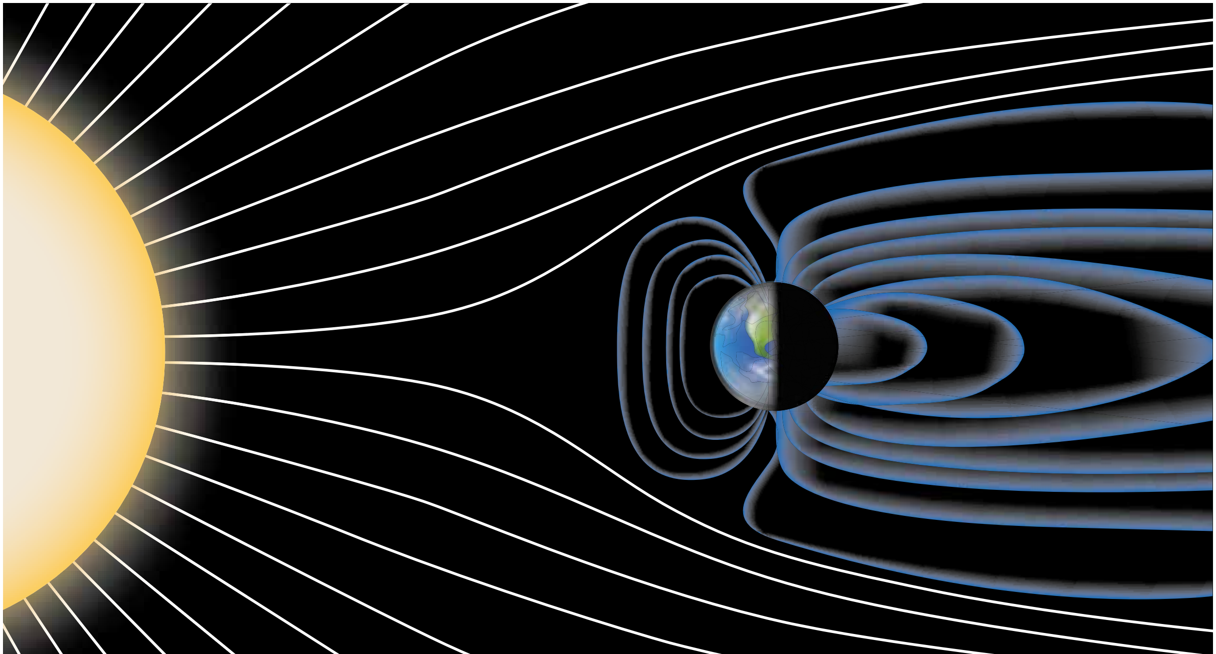
Once particles are deflected, they speed up and enter the Earth through the polar regions, producing the most breathtaking wonder ever: The Polar Aurora (aurora borealis in the Northern Hemisphere, and aurora australis in the Southern Hemisphere).

DID YOU KNOW THAT...

...Earth's magnetic field, as the Earth itself, also has poles, but the magnetic north pole is, in fact, near to the geographic south pole and so?

In fact, if we drew a straight line between the southern and the northern pole, it would not pass through the Earth's center since its terrestrial magnetic field is not perfectly symmetrical.

Earth magnetic field



DID YOU KNOW THAT...

...polar auroras happen when the terrestrial magnetic field deflects the electrically charged particles coming from the Sun, and when they come closer to Earth, they accelerate by electromagnetic force and not by gravity?

Once they reach the Earth, they emit different colors due to their interaction with the atmospheric gases. Yellow and green are the result of the reaction of the particles to the oxygen, while red, violet, and blue are for reactions to the nitrogen.

Photograph: National Geographic. Mads Pete Iversen/Epson international PANO awards 2018

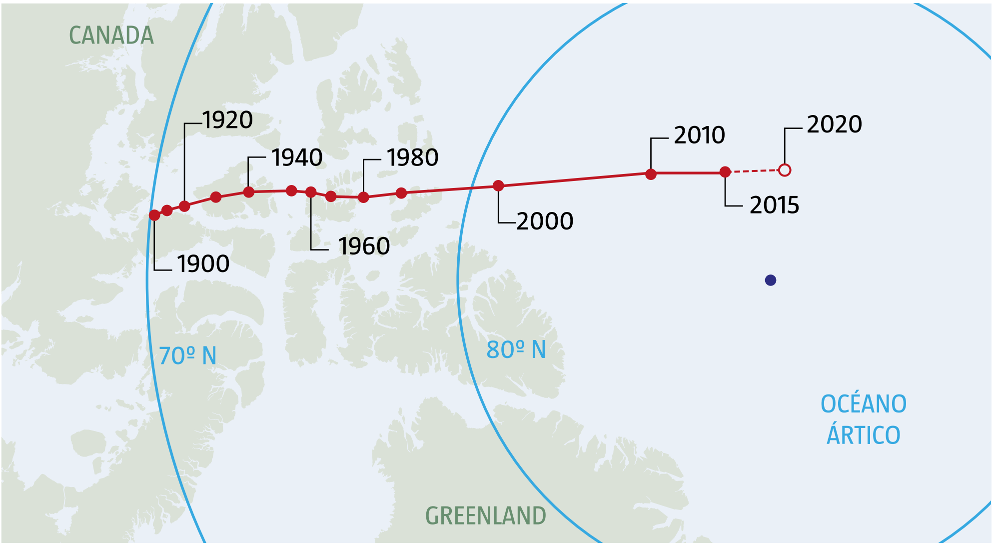
Both magnetic and Earth's geographic poles are not aligned. The first ones actually change in time, which means that our compasses show where is the north or the south with a slight difference as the years pass by.

In the following figure, we can see how the northern magnetic pole has been moving in time. It seems that the mentioned changes happen due to the movement variation of the outer core, but that is research in progress.

Lastly, throughout Earth's history, the magnetic poles have turned upside down multiple times, and we know it thanks to the rocks found in the mid-ocean ridges, structures in the sea bottom formed by magma material which elements are sensitive to magnetic fields (such as iron, for instance).

These particles and the terrestrial field of that moment line up and then get solidified, making impossible to change their position again.

On these rocks, we have found orientation changes; that's why we know the magnetic field have been upside-down and passed through constant changes.



The magnetic north pole changes its exact position in time. Currently, it is nearby Canada and is moving to the Siberian land, located in Russia. Over the last 30 years, the geographic position of the magnetic pole north has changed more than in the previous 90 years.

THE MOON

The Moon is primarily responsible for the Earth's almost constant axis of rotation, preventing dramatic changes in the axial tilt. It is essential to mention that thanks to this obliquity of 23,5°, we experience the four seasons. Without it, we could experience times where we would receive sunlight only on one Earth side, producing an overheat, whereas the other half would freeze; or extreme seasons of both winter and summer in different locations.

Even though, as human beings, we have lived on this planet for thousands of years, yet there are many things we don't understand completely. For example, though the Earth is almost a perfect sphere, slightly flatten on its poles, we still have to discover why the south pole is a little bit bulkier than the north pole.

Besides, Earth has different shapes on its surface. The largest mountain is Mount Everest, standing about 8,848 meters above sea level, located in Nepal. On the other side, the Mariana Trench, with a depth of 11,034 meters, which is the deepest trench in the world. In spite of these extreme examples, which seems to be so high or so deep for us, if we could compare Earth at a scale of a billiard ball, Earth would be much more even than the surface of a brand-new ball.

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SHORT MATH EXERCISE

How could you verify if the Earth is much more even than a billiard ball?

Consider these numbers:

· The Earth has a diameter of 12,730 km, and a billiard ball 5.715 cm.

· The highest roughness allowed in a billiard ball is 0.0127 cm.

Now, compare the "roughness" equivalence of the Mariana Trench or the Mount Everest.

(Clue: you can use the "rule of three")

The inner part of the Earth is hard to explore. One may think that the best way to know what it is inside is to dig a hole and take samples, but that is not only difficult to do but also extremely expensive.

An alternative way to study the inner part of our planet is to see how does the energy transfer from the rocks. The Earth is very active in tectonic terms. Earthquakes and volcanic eruptions happen since the plates are periodically moving, and the energy that this movement produces travel across the rocks. The displacement speed, such as the loss of the mentioned energy, it depends on the kind of rock and its density. How can we measure these waves?

There are some instruments called seismometers. We are able to study the inner part of our planet at scattering around some of them.

The deepest place the human being has ever dug is the Kola Superdeep Borehole, located in Russia that reaches about 12,262 meters of depth, and it was built for research purposes.

Even so, in spite of its dimensions, it hasn't been able to cross completely the first layer of the Earth's crust, which is just 35 km of thickness.

DID YOU KNOW THAT...

...the spatial mission InSight landed on Mars on November, 26th in 2018, and its target is observing the insides of the planet? To do so, it is digging a couple of centimeters, and it is placing a seismometer that helps to understand better the Martian crust, mantle, and core, and how heat escapes onto its surface.

Based on these discoveries, we hope to understand better how rocky planets evolve.

LAYERS OF EARTH

Thanks to researches that the Danish seismologist Inge Lehmann carried out is that today we know our planet has a core, and it can be divided into two parts: inner and **outer core**.

The first one is solid. It has a temperature around 5,400 °C, similar to the solar surface's, and is primarily made up of iron and nickel, while the outer core is made up of molten metal, and apparently rotates differently from the outer layers, which makes it responsible for the Earth's magnetic field.

Then, looking from inside out is the **mantle**, a layer where most of the Earth's mass is concentrated (about 67 %) and corresponds to 84 % of its total volume. In there, the most considerable part of both seismic and volcanic activity happens. In some cases, during the collision of plates, an element of the material in the upper mantle and the oceanic crust raise, allowing us to have access to rocks that belong to the mantle. These places, which are crucial to understanding the composition of the upper Earth's mantle, are called ophiolites. We have one in Chile, and its location is in Patagonia, specifically at the Taitao Peninsula.

Finally, the outermost layer is known as **the crust**. It is very thin. It measures between 5 and 7 km deep, and all human and animal activities developed on it.

The most of the rocks, part of the Earth's crust, are about 100 million years old, but it has been found some minerals 4,000 million years old, which would show that the Earth has a rigid crust almost since its formation.

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AT-HOME EXPERIMENT

How do compasses work?

Doing this short experiment, you will be able to see how a magnetic field interacts with metal particles.

MATERIALS:

· 1 magnet
· Steel powder (you can get it from a ball of steel wool)
· 1 bowl (plastic or glass)
· 1 liter of water

STEP BY STEP

1 · Scrape the steel wool and save the powder you get.

2 · Then, pour down the water in the bowl, and let the steel powder falls.

3 · See that the powder stays mostly on the top of the water (at least the tiny little pieces), and they are randomly spread.

4 · Now, pass the magnet slowly over the water without touching the steel powder.

What differences do you see with what was before the magnet passed?

The minuscule metal particles aligned because the metal dust interacts with the magnetic field that the magnet produces.

That is the basis of how a compass works: a small metal needle is aligned with the Earth's magnetic field. The compasses stop working when a magnet passes near them since the magnet distorts the magnetic field its needle perceives.

Review questions

1 · Since the Earth was formed, its atmosphere has gone through great changes, what is that for?

2 · Can you mention and describe at least two effects the Moon produces on Earth?

3 · How can we know what is in Earth's core?

4 · Why Earth does have a magnetic field?

5 · What is the habitable zone or the circumstellar habitable zone?

THE MOON

The Moon, that large object that we can see in the sky both at daytime and nighttime, is a natural satellite of the Earth. Its surface, with such areas of different shapes and various shadows, pop up immediately, and it has inspired practically all cultures, including artists, priests, warriors, and lovers. The Moon is, comparatively, the biggest natural satellite in the Solar System (if we measure its size in respect of the planet that orbits). In the Solar System, the only satellites which are larger than the Moon, in absolute terms, are Ganymede, Calisto and Europa in Jupiter, Titan in Saturn, and Triton in Neptune.

The Moon's surface is covered in craters but, how were they created? Since its formation, different sizes of rocks have attacked the Moon, as the Earth and the rest of the planets have[6]. When these rocks collide with the surface at high speed, they melt the rock, turning it into some kind of lava; once the molten rock cools down, it leaves a region darker, quite flatter than its surroundings. These areas are called maria, whereas the neighboring space, lighter in color, is called plateau or ground.

During these collisions, large amounts of gases were released, but the Moon was not able to hold them back due to its low mass, and therefore, it doesn't have an atmosphere.

Due to these impacts on the solid rock of the Moon, broken stones called regolith accumulated there. In the case of the Earth, the regolith exists mainly in tropical regions, but its origin is different from the Moon's. Here, 1% of this material comes from meteorites, and it is thought that comes from the bombardment and accumulation of meteorites of different sizes. This regolith may vary its thickness between 2 to 20 meters, so every time a mission land on the Moon, it leaves a record of that event. Even though the Moon is covered in this dust, most of its surface (under this layer) has basalt, a volcanic rock, or, in this case, from a lunar core rock that resurfaced after meteors impacts.

The Moon, unlike stars like the Sun, but like the planets, doesn't emit light itself but reflects the light that comes from the Sun, which happens due to the lack of mass to produce energy in its core.

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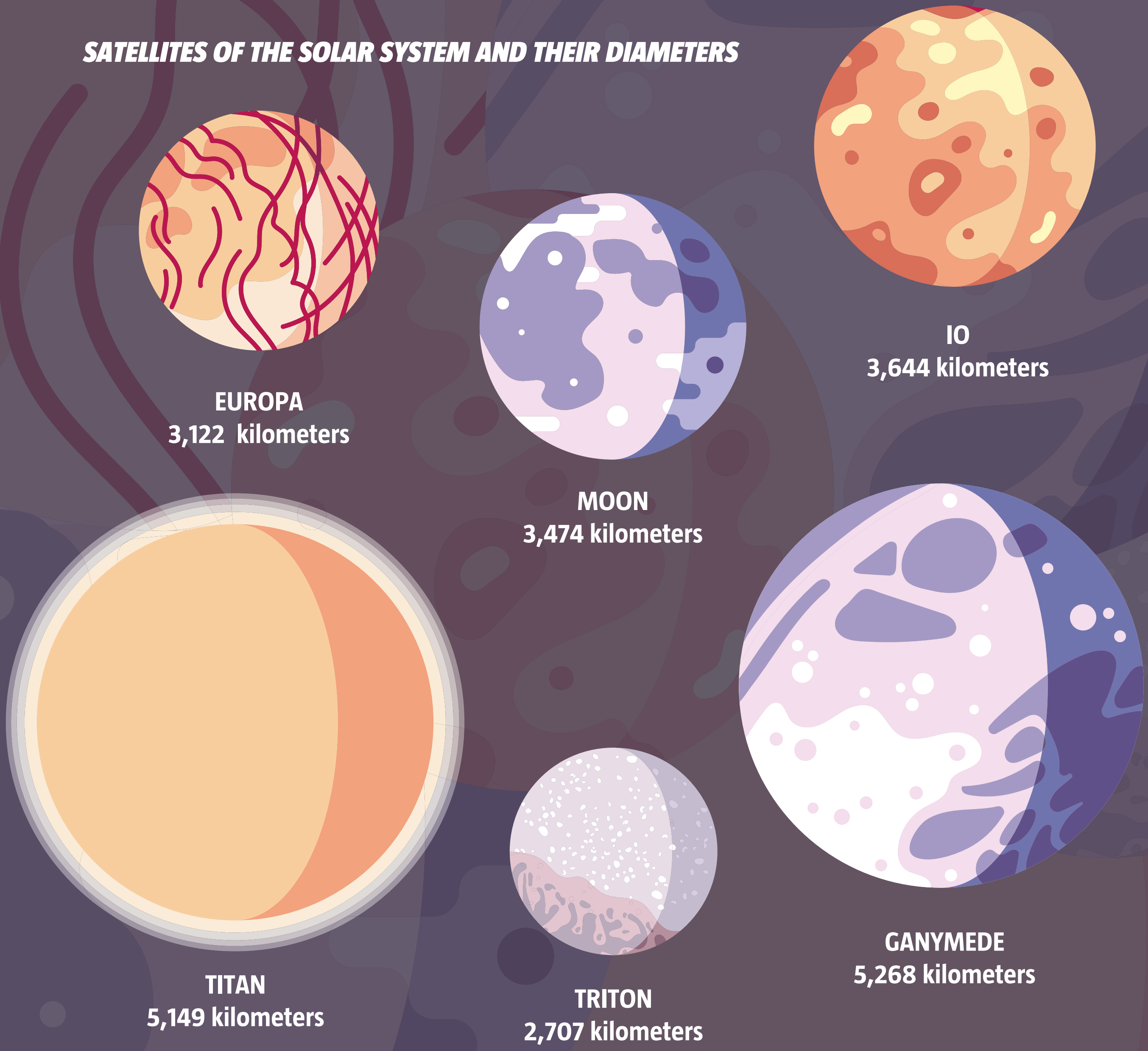
6 · We can see some craters on Earth. However, vulcanism, water (rain, rivers, glaciations), and wind have been in charge of erasing the majority of the craters, especially the smaller and older ones.

SATELLITES OF THE SOLAR SYSTEM AND THEIR DIAMETERS



AT-HOME EXPERIMENT

How are craters formed?

You are going to see the differences between the impacts and recognize which ones were bigger meteors or where did they come from to create the many craters of the Moon.

Materials:

- 1 plastic bowl
- 1 strainer
- 3 kilos of flour
- 1 cup of chocolate powder
- You can find some other colored powder if you want

Step by step:

- Pour the 3 kg of powder into the bowl. Get at least 5 cm of thickness
- Powder the chocolate over with a strainer
- Throw different stones but in different sizes and with different speeds and angles.
- Look at the results and compare them with real images of Moon's craters.
- You can try the experiment more times and add powders of different colors besides the chocolate.

This small rocky world, which tells us a story full of impacts, orbits the Earth in 27.32 days. It is called the **sidereal period**. As the Earth revolves around the Sun, the time between two identical lunar phases is known as the **synodic period**, and it lasts 29.53 days.

Perhaps, you may notice the shape or shapes of the Moon that we see are always the same way. That is because the Moon always shows the same face to Earth, so we always see the same half of it.

When a celestial object is showing the same face to another is called **synchronous rotation**, which means that its rotational and orbital periods are the same. In the case of the Earth with the Sun, it doesn't happen because the Earth rotates 365.25 times per orbit.

The fact that we always see the same face of the Moon made us jump into the conclusion that it has a dark side. There is indeed a side we can't see from Earth, but that doesn't mean that it doesn't get any light and it is always dark because of the Sun lights up every inch of the Moon in different moments of the lunar phase. For instance, during the New Moon phase, the Sun is entirely lightning up the side that we can't see.

The Moon and its craters


Fases de la Luna

The ancient Greeks were right when they thought that the Moon phases could be explained through its relative motion around the Earth and that it is much closer than the Sun. The reason why we can see some brightness, even in those parts where the Sun can't light directly, is because of the sunlight reflection on the Earth's surface.

DID YOU KNOW THAT...

...we can see more than one face of the Moon?

In fact, we can see about 59 % of the Moon from Earth thanks to a phenomenon called libration. Libration is an oscillation of the Moon in relation to Earth, and it happens for three reasons: libration in longitude (results from the eccentricity of the lunar orbit); libration in latitude (results from a slight inclination of the rotation axis regarding its orbit with Earth); and diurnal libration, which is a consequence of the Earth's rotation. So, if we see the Moon at breaking dawn, midday, or twilight, we have different perspectives of it, its position in the sky, and its size.

DID YOU KNOW THAT...

...as the Earth reflects the Sunlight onto the Moon's surface, some astronomers have observed the dark side of it using terrestrial telescopes?

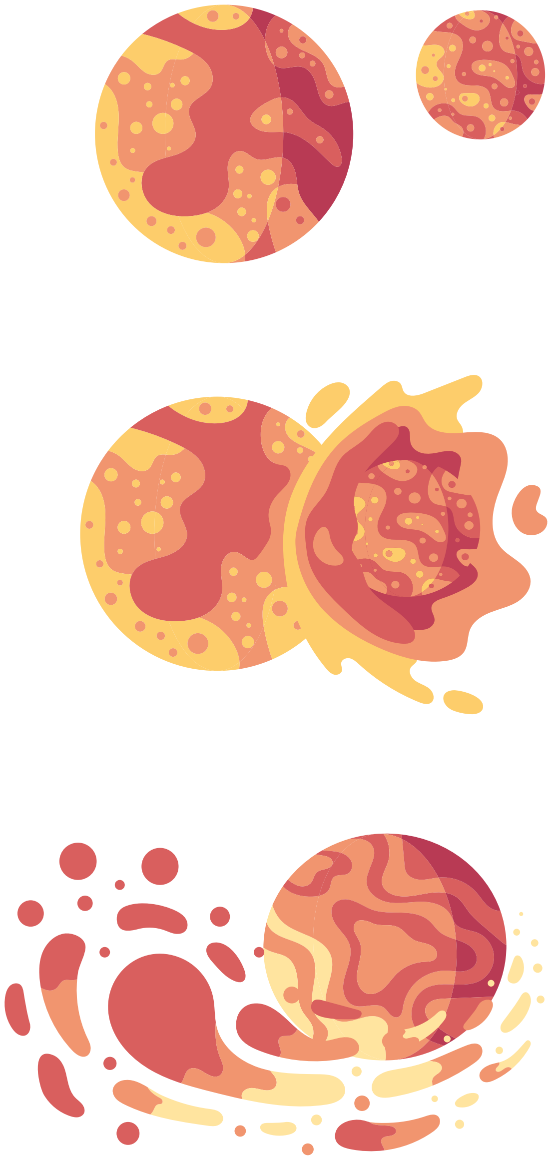
How does this work?

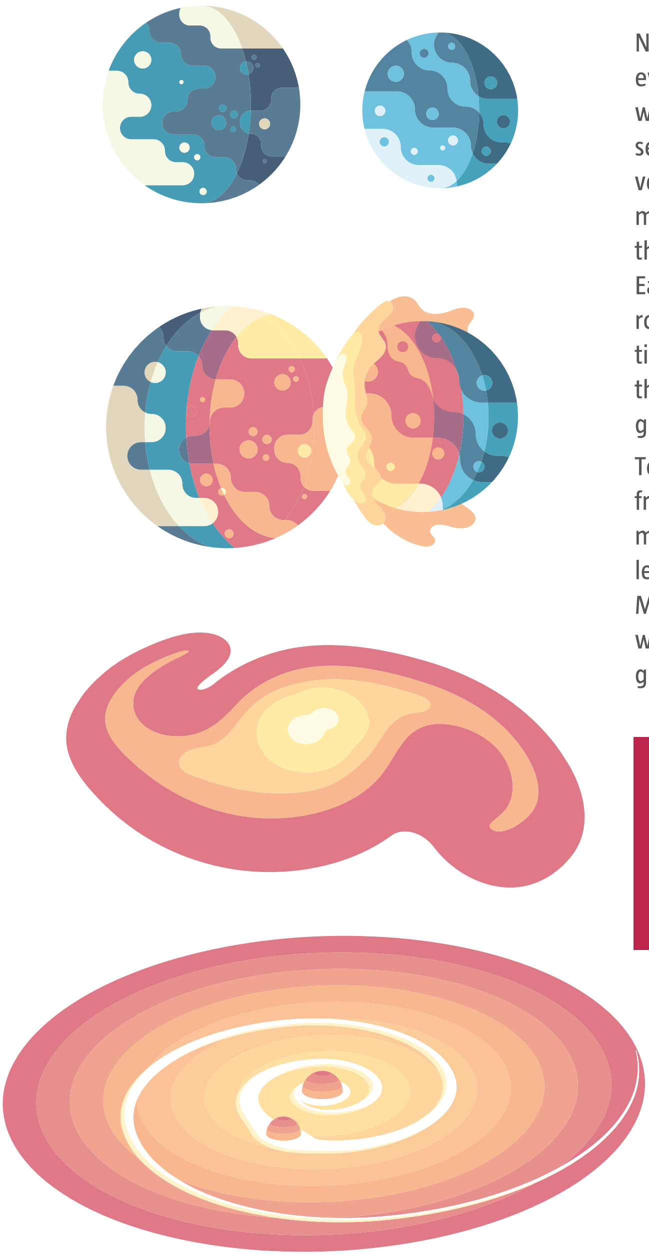
The Sunlight reflects itself on Earth, and gently lights up the dark side of the Moon. Such light has the characteristics, or chemical fingertips of the terrestrial atmosphere tattooed, allowing us to observe the Earth as if it were an exoplanet.

The origin of the Moon is still under scientific discussion.

The most frequent explanation involves an early catastrophic impact, when the Solar System was still in formation, about 4,5 billion years.

This “traditional theory” implies that a Mars-sized object called Theia, just like the Greek goddess -mother of Selene, goddess of the Moon- collided with young Earth (or at least 90 % of it), and this caused a considerable impact that melted and vaporized Theia, creating a significant damage on Earth. Part of the material coming from Theia stayed on Earth, and another part was lost to space and were accumulated, only by gravity, to create what we know today as the Moon. This theory offers reasonable explanations to understand some of the properties we see both in our planet and in the Moon, like its distance, circular orbit, and the fact that its rotation is in sync with its orbit rotation (and that is why it shows us the same face). However, considering the new analysis of lunar rocks brought by the Apollo mission, which shows that these rocks have an Earth-alike composition and that Theia having the same composition of former Earth is lower to 1 %, other theories have come up. One of them suggests that, if there were two planets, five times bigger than Mars each, would form a disk when they collide, so the formation of the Earth and Moon can be explained, and, in this case, both would share the same composition indeed. However, the last word has not been said yet, so it is essential to keep exploring our natural satellite.





Now, apart from the theory about the Moon's formation, every one of them agrees on something: in the past, it was closer to Earth, and it is a phenomenon we can observe today. At the moment it was formed, the Moon was very close to us, around 25,000 kilometers away, which means, less than a tenth portion of the current distance, this situation caused massive tides, and distortions on Earth's surface, producing at the same time the slower rotation of Earth. The energy that our planet lost by rotating so slow transferred to the Moon's orbit and caused the Moon to move away, and consequently, to move slightly slower.

Today, our satellite moves away about four centimeters from us every year. Such is the case that in 100 years more, the day would last two thousandths of a second less, which means that in the not-too-distant future, the Moon is going to look smaller than we see it today, tides won't change so much as they do currently, and the day is going to have more than 24 hours.

If the Moon produces a tidal force on Earth, does the Earth also cause a tidal force on the Moon?

The answer is yes, it does. The difference is that the Moon's surface is solid, so the deformation is much lower, whereas the liquid water is easily deformable.

However, among all the things that stand out of the Moon, the most important one occurred in the late '60s. The Apollo 11 mission landed on July 20th in 1969, and it turned the Moon into the first place outside the Earth in where humanity could put a foot on the ground. The astronauts, Neil Armstrong and Buzz Aldrin, were less than two hours on this surface, in the area called "mare tranquillitatis" ("sea of tranquility"). There, they installed some mirrors, still in use today to measure the exact distance to the Moon, they took walks, did some experiments, and gathered samples. They brought around 22 kg in stones! The third astronaut, who could not get off since someone had to fly the spaceship to come back to Earth, was Michael Collins.

That was the first time out of the six missions of the Apollo program that carry astronauts who landed successfully on the Moon between 1969 and 1972. The achievement obtained by the different spatial agencies, particularly from the United States and the former Soviet Union, marked a milestone in human history, such was the case that it had been mentioned on multiple occasions that today we are living in the Spatial Era or Spatial Age.

DID YOU KNOW THAT...

...the Lunar Orbiter Reconnaissance, a survey for lunar exploration, could record in a video the traces left by Apollo 11, 12, 14, 15, 16, and 17, besides capturing images from other satellites such as Chang'e 3 from China?

You can watch the rest of the descent stage of Apollo 11, 12, and 14, the footprints or traces of the Apollo 14's astronauts, and the vehicle that Apollo 17 left, besides the many instruments used in the mentioned missions.

Watch the video, following https://moon.nasa.gov/resources/128/lro-explores-the-apollo-11-landing-site/ or scan the following QR code with your phone.

In different regions of the Moon, Apollo's missions left a few instruments to study the inner core of this satellite, and to measure seismic movements in three dimensions. The so-called moonquakes are very mild and, even though near three thousand movements per year are registered, none of them exceed the 2nd grade in the Richter scale. They are very shallow and occur mainly due to temperature variations, the landing of spatial missions sent from Earth, or the hit of meteorites.

Another aspect that stands out of the Moon is its minimal core, compared with the rest of the rocky bodies in the Solar System. According to the last seismic measurements, its composition is mainly made up of partly molten iron.

The exploration of this satellite will keep providing data about its evolution and formation. It is also possible that the Moon is used as a basis to launch future exploration missions of the Solar System or as a host of future telescopes generations which can work together with some observatories on Earth.

DID YOU KNOW THAT...

...the Moon would be an ideal place to install a telescope due to its lack of atmosphere, and for that reason, it could be observed with a quality impossible to reach from Earth? Also, it could be observed during most of the lunar day since the sunlight doesn't scatter, leaving skies in total darkness both at day and at night.

IV

ECLIPSES

Eclipses are spectacular astronomical events. Not only amaze us with an intense color variation of the Moon or, even more astonishing, change into full darkness during a few minutes in broad daylight, but also, we can see in real-time the stars motion when, for instance, the Moon stands between the Sun and us, or when the Earth stands between the Sun and the Moon.

In general terms, there are two types of eclipses: Moon eclipses and Sun eclipses[7].

There are three types of Sun eclipses, and they distinguish from one another depending on the occultation type of the Moon and the Sun.

Total eclipses: refers to when the Moon blocks the Sun entirely during the full eclipse.

Annular eclipses: refers to when the Moon is farther from the Earth, and its shape doesn't block the Sun completely, leaving a Sun ring around the Moon.

Hybrid eclipses: refers to when the Moon is just in the distance where it can completely block the Sun, however, as it moves forward, it moves slightly away from the Earth, and stop eclipsing the Sun, becoming into an annular eclipse. It can start either as an annular eclipse, and then moving a little to become in a total eclipse.

HOW DO ECLIPSES OCCUR?

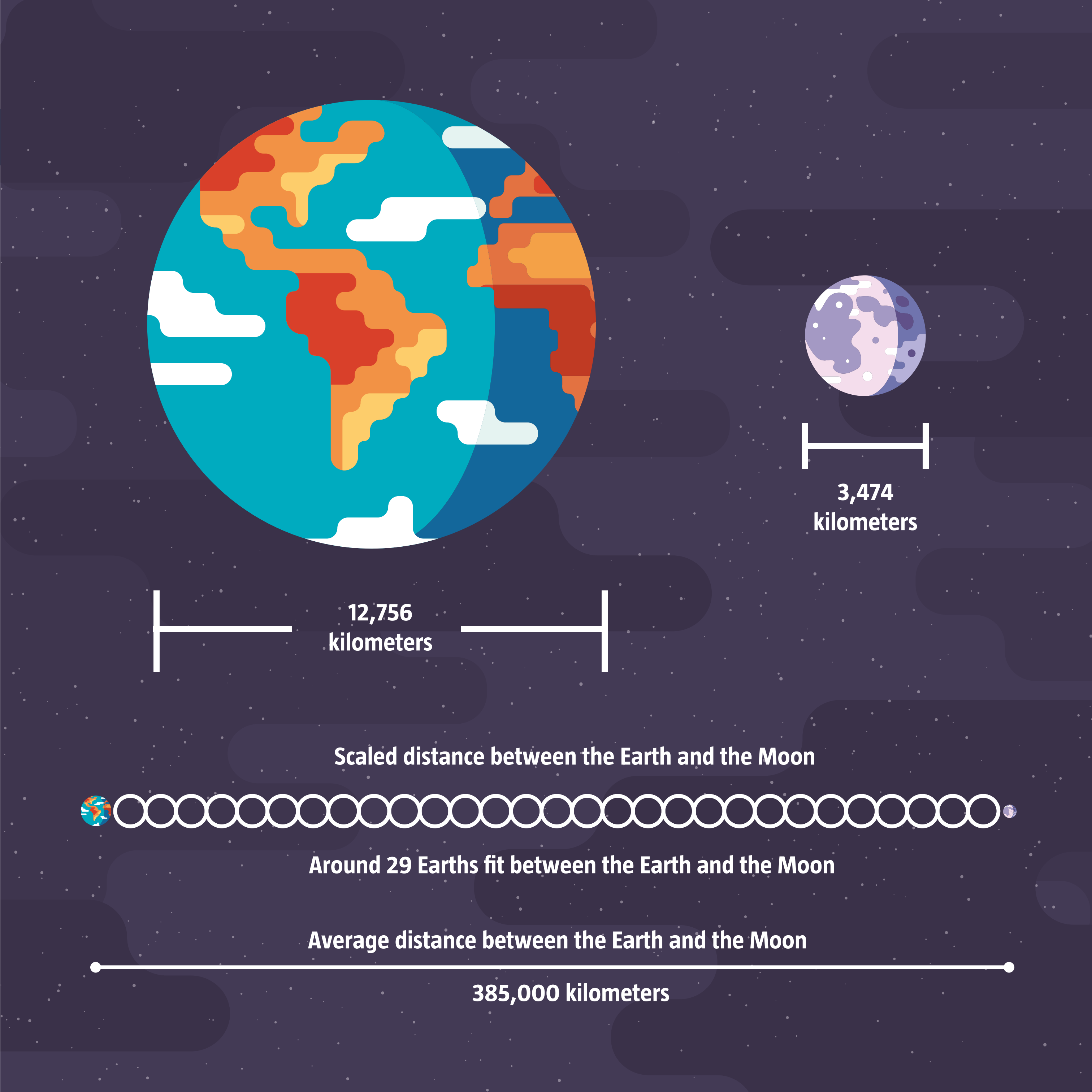
Both solar and lunar eclipses occur when the Sun, the Earth, and the Moon are in the same line. We talk about lunar eclipses when the Earth gets on the way of the sunlight, darkening the Moon completely. In the case of solar eclipses, the Moon is the one who gets on the way of the solar light before reaching the Earth.

A Moon eclipse is visible from anywhere on the terrestrial globe that is on the same side as the Moon, whereas a solar eclipse is only visible from a small part of the Earth since our planet is larger than the Moon, so that it can hide the sunlight from the whole surface. In the case of the Moon, since it is smaller in size, it blocks the sunlight entirely in a very vast region of the Earth, and partially in a broader region (which we called as a partial eclipse of the Sun).

The lunar eclipses always occur in Full Moon, whereas solar eclipses occur in New Moon because only in that position they are entirely in line.

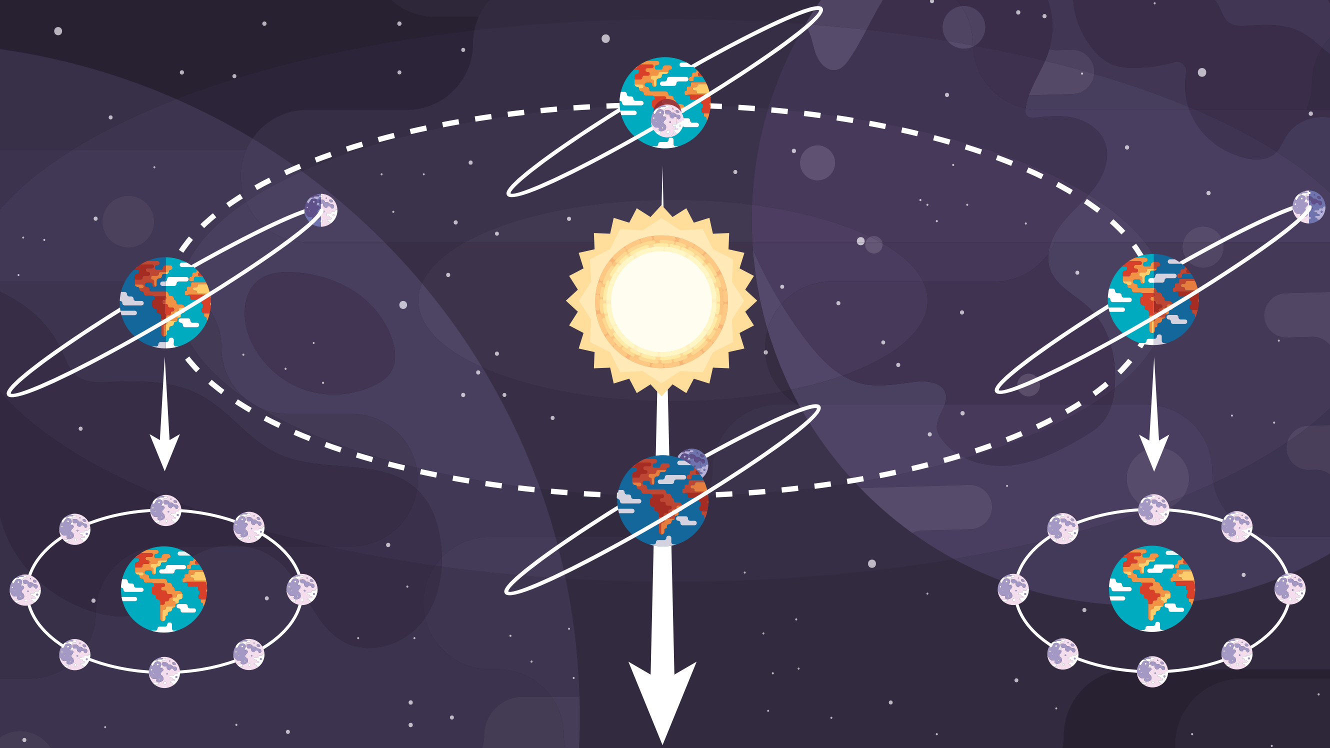
To understand this better, let's review the following figures:

7· Technically, there is a third type which involves two stars. We will discuss it in chapter V.


12,756 kilometers
3,474 kilometers
Scaled distance between the Earth and the Moon
Around 29 Earths fit between the Earth and the Moon
Average distance between the Earth and the Moon
385,000 kilometers

For a solar or lunar eclipse to occur, the Moon and the Sun have to be almost perfectly aligned.

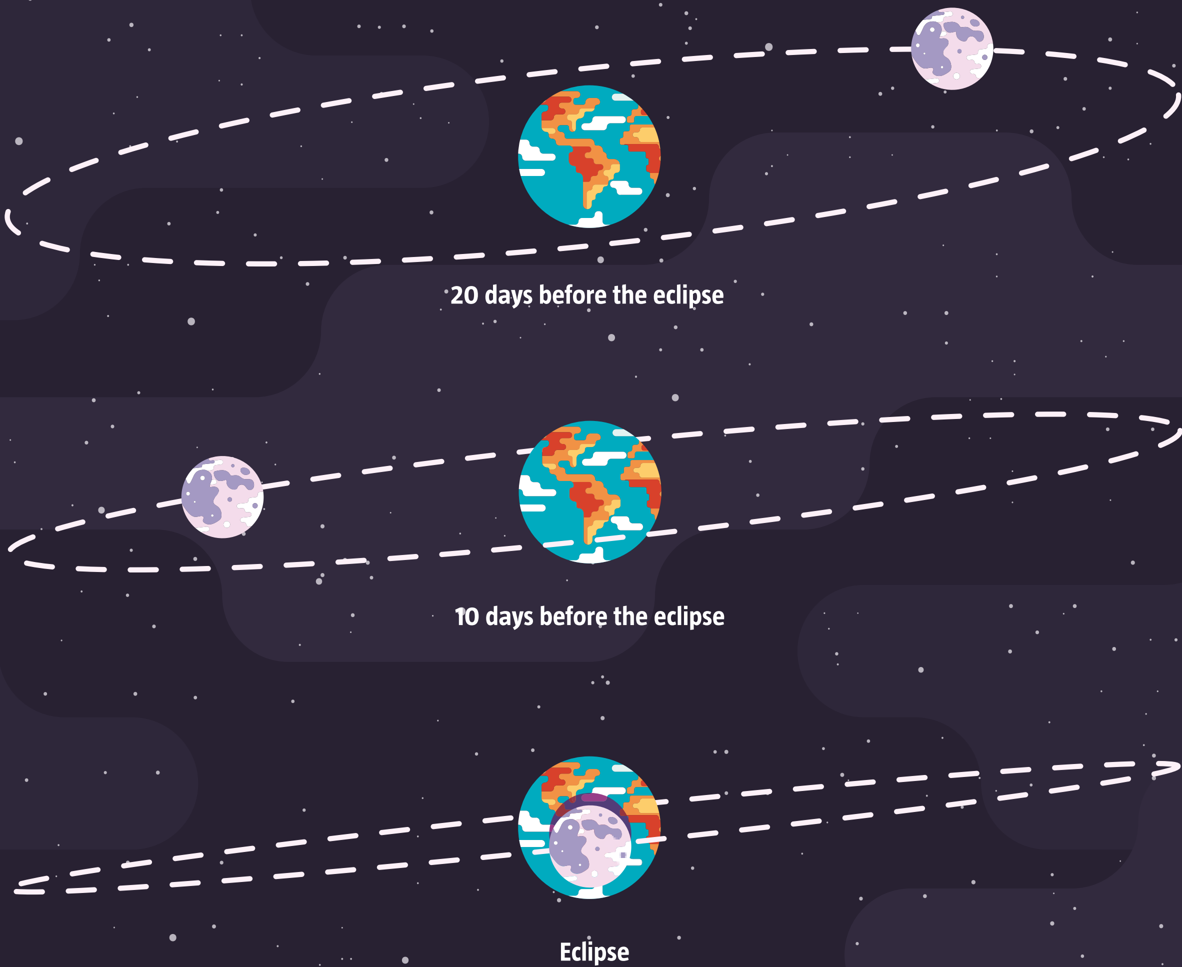
Due to the Moon's orbit surrounding the Earth and its remoteness, these conditions only occur every six months or so.

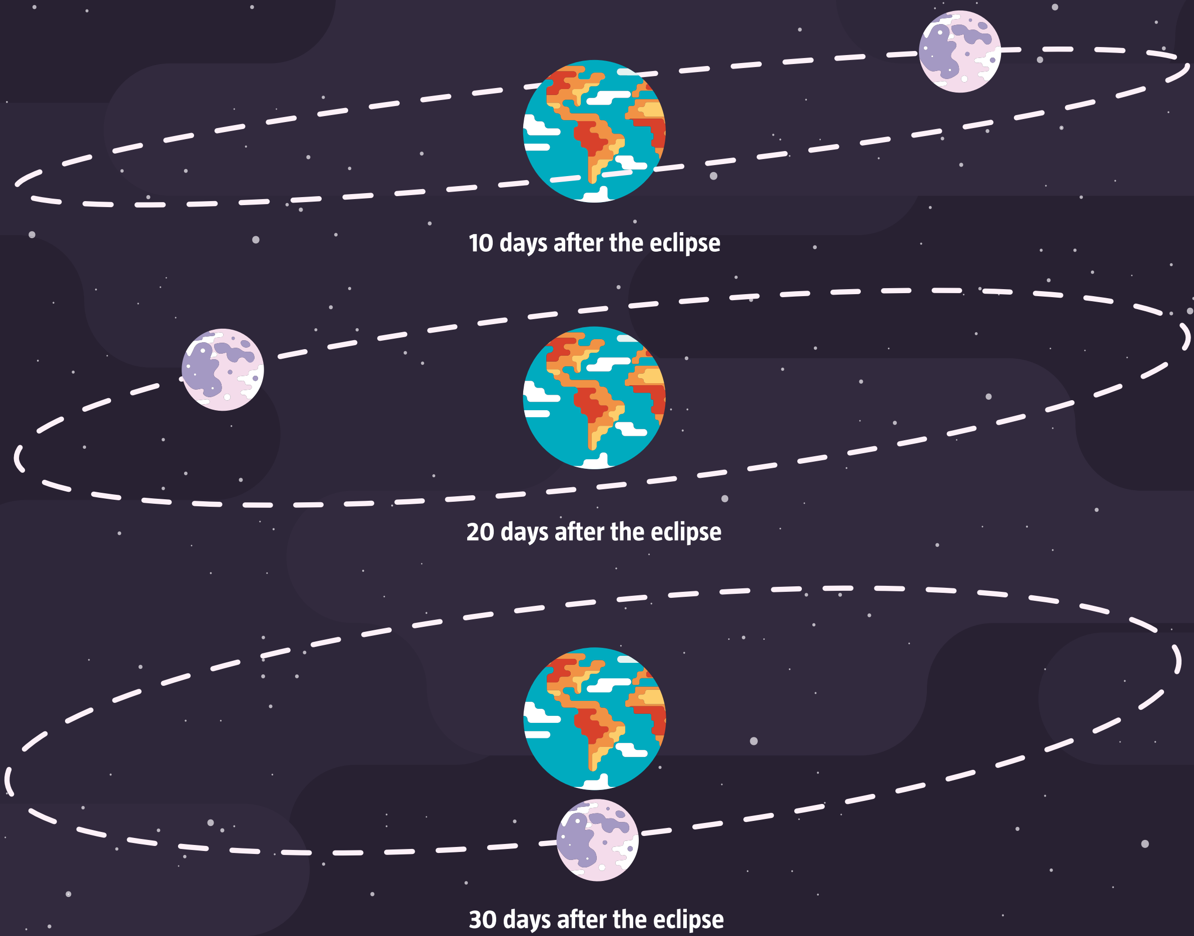


From the Sun’s perspective, the Moon revolves around the Earth without crossing its ways most of the year.

In two regions of the Earth’s orbit, on the opposite side of each other, the Moon’s orbit crosses between our planet
and the sunlight.

It takes about 29 days for the Moon to orbit the Earth. That is enough time for our satellite, after a lunar cycle, not to be able to cast a shadow on the Earth again, and therefore there is no new eclipse.





In the following picture, we see as the Earth or the Moon block the sunlight, respectively.

According to what is observed and reviewed in chapter III on this book, every 29.53 days, a New Moon or Full Moon happens. But, why eclipses do not happen every time this occurs? Because Earth is revolving around the Sun in a plane (called ecliptic), and the Moon is orbiting the Earth in another plane, slightly leaned in comparison to the first one. Both planes are only 5° apart. It seems to be a mild inclination, however, it is enough for the shadows of the Moon or Earth to fall out of the other object.

Today, we can predict eclipses in advance thanks to accurate calculations, using math formulae, and what we know about physics. In contrast, in the past, some civilizations could predict eclipses identifying different patterns in the lunar motions fruit of their acute observation power and their accurate notes about past events.

Around the 4th century BC, the wiser Chaldean astronomers/astrologists of the new Babylon identified what Greeks later would call saros, which was related to the period of 223 moons, in other words, 18 years, 11 days, and 8 hours. These wise people noticed that every time a saros happened, the position of the Sun, Earth, and Moon were alike and, therefore, the same series of eclipses repeated, but these would not be in the same place as Earth since the cycle doesn't have whole numbers of days, but it has eight more hours. Within those eight hours, the Earth has rotated one-third (eight hours on the twenty-four a day has), and therefore the eclipse occurs in one-third of Earth towards the west. For instance, if today an eclipse in Concepción, Chile, occurs, in one saros should be in New Zeeland.

Based on this, one would expect that every three saros (something like 54 years) a new solar eclipse would happen in the same region. However, it is not entirely correct due to small differences, and other celestial motions related. In fact, on average, a region of the Earth experiences a total eclipse of Sun every three hundred years.

Nowadays, we know much better about the physics laws of celestial bodies, and the motions of the planets and their satellites are calculated precisely.

The Sun gravity forces, the eight planets and their satellites, asteroids, and dwarf planets are included to make more accurate calculations. Also, tidal effects, Earth distribution mass (which is not perfectly homogenous), and the terrestrial motions and precession and nutation, among others, are included in the motion calculations.

DID YOU KNOW THAT...

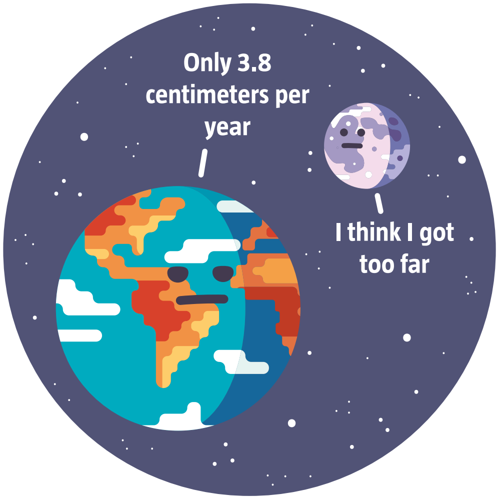
the duration of an eclipse depends on Earth's position compared to the Sun, on Moon's in respect of the Earth, and on what Earth's region is shade? Theoretically, the longer solar eclipse could last 7 minutes and 32 seconds. So far, the longest ever registered was on July, 15th of 743 B.C., and lasted 7 minutes, 28 seconds.

On July, 16th of 2186, it is expected a total solar eclipse will pass over Venezuela, lasting 7 minutes, 29 seconds, becoming the longest eclipse since 4000 B.C., and it will be until the year 6000 A.D., at least.

THE FUTURE OF ECLIPSES

Both the Earth and the Moon attract one another. However, this attraction has not been constant since both formed, and the distance between them has continually changed. Actually, as we saw in chapter III, the Moon moves away four centimeters per year from Earth, which confirms that in the distant past, the Moon was much closer to Earth, and in the future, it will be much further.

What are the consequences of this? In a distant future, we no longer can be witnesses of total solar eclipses since the Moon, even in its closest-to-the-Earth position, it won't be able to block the Sun completely, and there will be only annular or partial eclipses.



Million years later

5,000 million years later

NUTATION AND PRECESSION MOTIONS

Precession is a terrestrial motion that occurs because Earth is not a perfect homogenous sphere, so as a result, the rotation axis changes over time. To imagine this movement, watch a whistling top spin. It could be expected only to spin, but in reality, the whistling top, besides spinning, its rotation axis is in a circular motion, like a nodding kind of thing, and that motion is exactly what happens to Earth. If we were able to go through it with a gigantic pencil, which could draw a line in the sky, we would see a circle, and the process of drawing that line would take around 26,000 years.

This phenomenon (known as "axial precession") was described by the great Greek astronomer and mathematician, Hipparcos, in the 2nd century B.C., who was based on observations that Babylonian astronomers and astrologists carried out. Hipparcos realized that the position of the stars during equinoxes was slightly different from the ones observed by astronomers in the past, and he calculated that it should move 1° per century (the value given today is 1.38° per century). In the 4th century A.D., this phenomenon was also explained by the astronomer Yu-Xi from the Jin dynasty, in China. In spite of these insights, the answer to why precession occurred remained unknown, and only because of the studies of celestial mechanics by Isaac Newton, it could be understood fully: the precession refers to the forces that the Sun and the Moon cause on Earth, and to Earth being a non-perfect spheroid.

On the other side is nutation, which is a motion overlapping precession. It happens mainly for a gravitational attraction that Earth feels towards the Moon and Sun[8] *and, mainly, due to its 5° inclination of the plane in which the Moon orbits the Earth regarding the plane where the Earth orbits the Sun.*

To sum up, these two motions are caused by the rotation of the Earth on its axis and its non-perfect sphere shape. In this motion, the Moon creates a small extra distortion because it is not aligned correctly with Earth's orbit.

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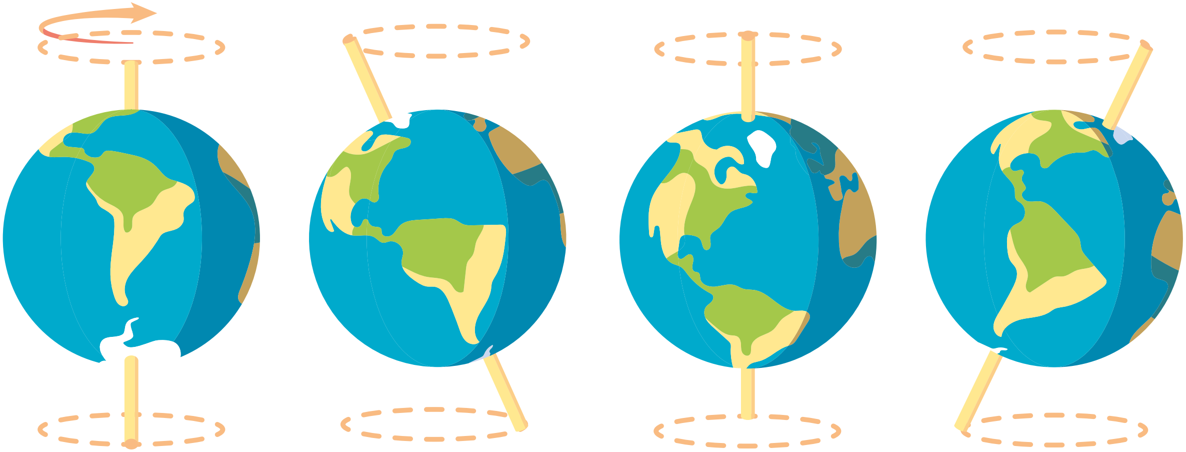
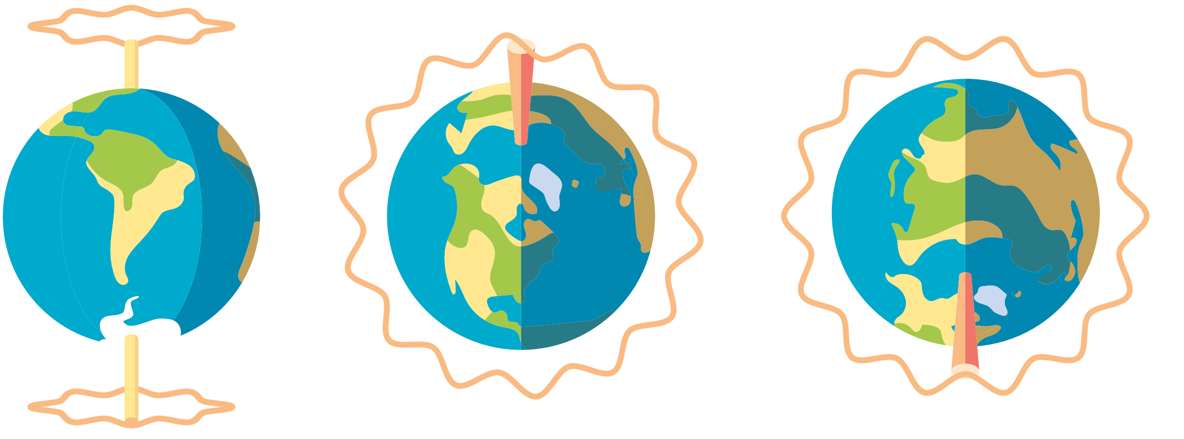
8 · **Planets also help in changing and add little tiny perturbations to nutation that would be created only by the Moon and the Sun.**

Precession



Nutation



Something else about tides

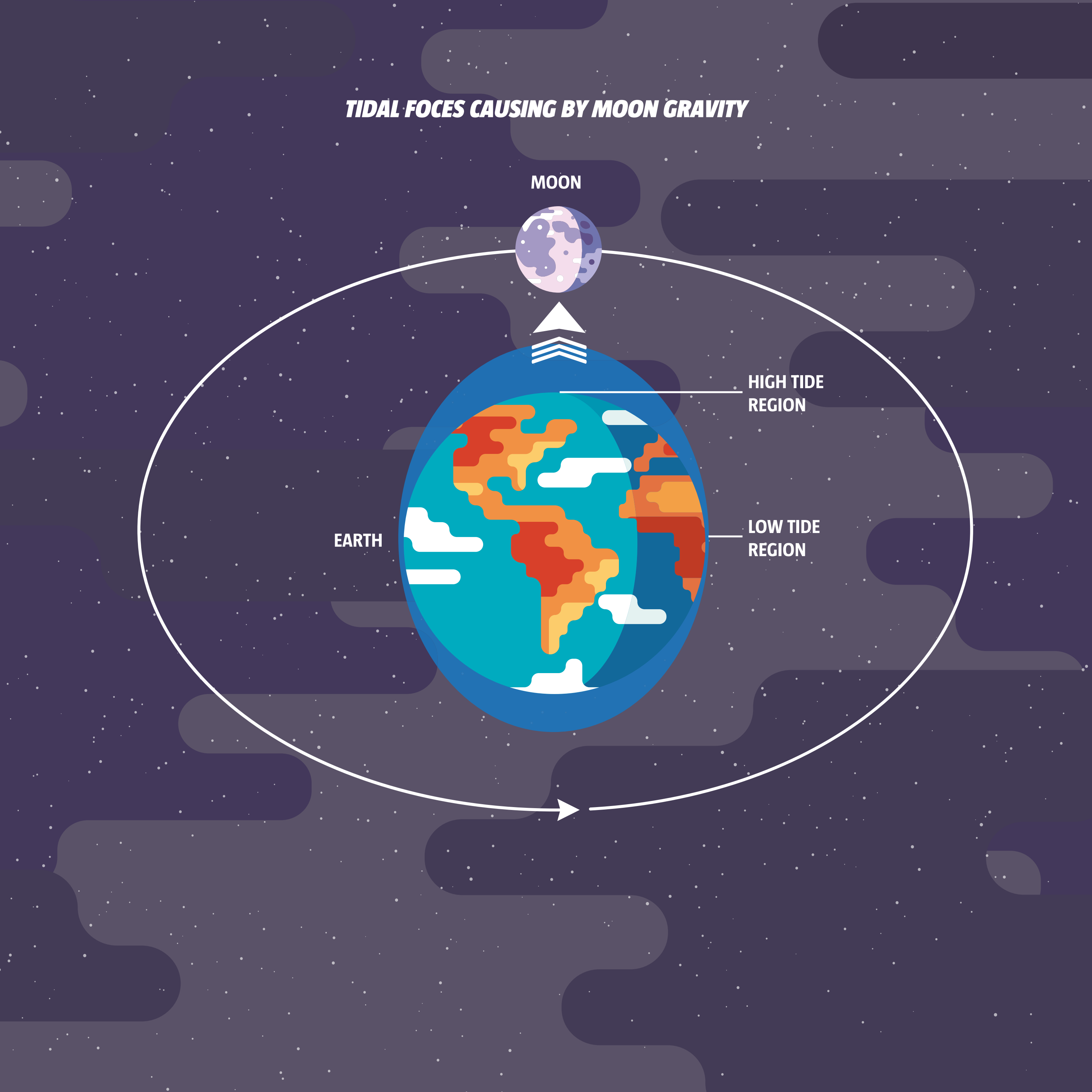
There is a force known as the tidal force, and it occurs since the gravity force gets weaker while things are separated by greater distances. This difference in the distance also makes a difference in the gravitational attraction among two points, making the closer region higher and the opposite region lower. That is the reason why the tidal force "faint" too fast, but is stronger when the distance between the involved bodies is short.

For instance, in the case of the Earth and the Moon, we say that its distance is, on average, 384,000 km. However, that is measured from the Earth's core to the Moon's core. If we measure from the surface (without counting the distance between the center and the last mentioned), the Moon is 6700 km closer, whereas who is on the other side of the Moon is 6700 km further regarding the center of the Earth.

As we have seen, both gravity and tidal force decrease according to the distance. For example, if we increase the distance between two objects twice, the gravity force slows down four times, rather the tidal force does the eighth part. If we increase the distance five times between these objects, gravity decreases 25 times, but the tidal force does 125 times!

Then, we can confirm that the gravity force drops with the distance squared, whereas the tidal force does with the distance cubed. For that reason, the region of the Earth that is straight towards the Moon is under more attraction, the regions in the middle are under a "neutral" force, and the further region is under less attraction. For that very reason, high tides occur in the region that directly faces the Moon and, in the opposite-in-diameter part.

It is essential to have in mind that the tidal force is related to gravity, and it is a consequence of gravity acting on sized objects.


TIDAL FOCES CAUSING BY MOON GRAVITY
MOON
HIGH TIDE
REGION
EARTH
LOW TIDE
REGION

EXERCISES FOR ASTRONOMY AND MATHS ENTHUSIASTS

1 · The Moon and the Sun seem to be the same size, that is the reason why total and annular eclipses happen. If both Sun and Moon's sizes are known, can we know at which distance is each from the Earth?

2 · At what distance must be the Moon from the Earth for a total and an annular eclipse to occur? Does it depend on Earth-Sun distance?

Answers

The Earth is an elliptical (almost circular) orbit around the Sun, just like the Moon around the Earth. The maximum and minimum distances from the Earth to the Sun are 147 and 152 million kilometers, respectively, and the Sun has a diameter of 1,391,400 km.

For the Moon, the minimum and maximum distances to the Earth are 356,500 and 406,700 km, and it has a diameter of 3474.2 km.

With these numbers, we can calculate the angular sizes (the apparent size we see in the sky measured in grades) using the following math relation:

Angular size = tangent (diameter / distance)

If we replace the values mentioned above, we find that the angular sizes are: -Maximum size of the Sun (when it is closer) = 32.54 minutes of an arch (0.54°).

Minimum size of the Sun (when it is further) = 31.47 minutes of an arch (0.52°).

Maximum size of the Moon = 33.50 minutes of arch (0.56°).

Minimum size of the Moon = 29.37 minutes of arch (0.49°).

We can see that if the Moon is at a minimum distance from the Earth, it doesn't matter at what distance is the Earth from the Sun if the conditions form an eclipse are given, the total eclipse is seen. Whereas if the Moon is at its furthest distance from the Earth, a total eclipse would never happen, only annular (and partial), no matter the distance Earth-Sun.

For any other middle point, it is necessary to analyze in detail the relative distances of the three bodies.

3 · How much longer will it take to stop producing eclipses?
In order to never experience an eclipse again, we have to imagine ourselves in the worst possible scenario. Even when the Moon is the closest to Earth, and the Earth the farthest from the Sun, the Moon looks smaller than the Sun.

Let's suppose that both of them don't change their sizes, that the orbit of the Earth remains constant, and the Moon is the only one moving away.

In this case, the minimum size of the Sun is 31.47 minutes of arc, and to have no more eclipses the rule is that the Moon, in its maximum size, must be lower than that.

Then: Angular size = 31.47 = 0.54° =
tangent (diameter / distance).

So, how do we know what size the Moon is (diameter)?

At this distance, the Moon won't be able to eclipse the

$$\text{Arctangent } (0.54°) = \frac{3474.2 \text{ km}}{\text{distance}}$$

$$0.0091 = \frac{3474.2 \text{ km}}{\text{distance}}$$

$$0.0091 = \frac{3474.2 \text{ km}}{\text{distance}} = 379.530 \text{ km}$$

Sun completely!

If we suppose that the Moon will keep moving away 3.8 cm per year as it does today, it would have to pass 715 million years to experience no more a total eclipse of the Sun. It will be right, even when the Moon is to the closest distance to Earth, and the Earth to the furthest distance from the Sun (that is, the Moon being the largest ever possible, and the Sun the tiniest ever possible).

Although, in fact, the process is a little more complicated because as the Moon moves away from the Earth, the tides are slightly weaker, and, as a result, the Moon moves slower away, which would increase the time we have to keep observing total eclipses. However, in that timescale, the Sun would not be the same size, actually, it would grow a little bit, accelerating the effect that the Moon produces when moves away. As a consequence, the change of the Sun size would accelerate the process to leave us without total eclipses in about 500 million years more.

V

OTHER TYPES OF ECLIPSES: TRANSITS AND OCCULTATIONS

We have already said that there are other types of eclipses not related to the Moon and the Sun, but distant stars.

50 % of the stars are binary systems or more stars included.

The Sun, however, doesn't have a stellar neighbor, but only planets. The binary stars can have different separations or orbits, and these are oriented randomly in the sky. Since there are many stars in our Galaxy, some binary stars orbit a plane very aligned with the Earth, so then, in a particular region of its orbit, a star passes in front of the other, blocking the brightness of the one in the back. These double stars are classified as **eclipsing binary stars**. A historical example is the star Algol, the second brighter star of the Perseus constellation, which name comes from the Arabic, and it means possessed star (from Ras Al-gul). When the Arabic astronomers saw the periodical change in the star brightness due to its eclipses, they understood that it was because of devilish powers given their world view of an immutable sky[9].

9 · Paradoxically, western astronomers, with a similar vision of the sky, observed changes in brightness in the star Mira (not due to eclipses but to changes in its temperature and size). The name Mira comes from Latin, and it means wonderful. A curious difference in the way both cultures perceived and called an astronomical phenomenon.


BRIGHTNESS OBSERVED
FROM EARTH

The importance of eclipsing binary stars is when they are studied in detail; they allow us, for example, to calculate the radius of the stars and their brightness and, combining other special measurement instruments, we can measure their masses. All of this to understand better how they are formed and evolve.

DID YOU KNOW THAT...

...multiple systems with more than three stars are less common, but instead exist two systems of seven stars? They are Nu Scorpii and Ar Cassiopeiae.

in spite of the eclipses of distant stars, there are two phenomena similar to an eclipse: **occultations and transits**.

OCCULTATIONS

In our Solar System, besides the planets, there are thousands of asteroids, comets, and distant objects beyond the orbit of Neptune called **trans Neptunians objects**.

The best example and largest one of these objects are Pluto and its moons but there are many others in what is known as the Kuiper Belt.

On some occasions, these objects pass between a distant star and us and block the light of the star.

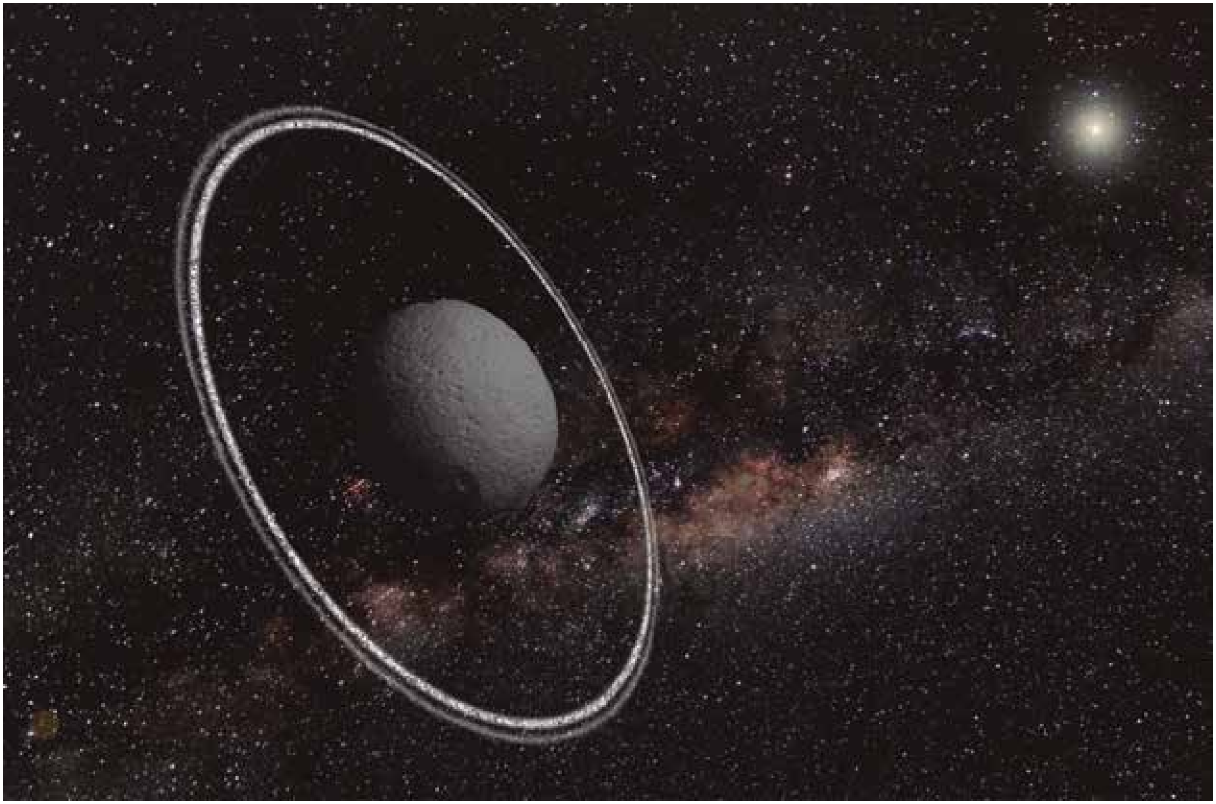
This phenomenon is called **occultation**, and it is the best way to study the Trans-Neptunian object's shape that is hiding the starlight. In the case of planets, it has no advantages to carry a more extensive study since they are a lot, and we can measure their sizes using telescopes and probes, whereas for small bodies, such as some asteroids or trans-Neptunian objects from the Kuiper belt, is very useful.

To study the trans-Neptunian objects, we have to know very well its orbits, this is the only way we have to predict when they are going to pass between us and a star. With the calculations made, we are going to determine from which parts of the Earth they can be observed (as they are small, the occultation is not visible from every part of the Earth). Generally, when this phenomenon is recognized, an astronomical alarm is set for observatories and amateur observers to follow the event.

Having said that, as the object is small, the observations carried out in different regions of the Earth have different perspectives and the duration of the occultation changes depending on our point of view. To better describe the shape of the object and its size, we get all observations together, including the position of observers, and we analyze the process case by case.

It seems to be easy at first. However, we have to consider that occultations last only a few minutes or even seconds, so there are needed telescopes with cameras set up to take many images in a short period.

Among the most exciting findings achieved due to the observations of these occultations, it stands out the discovery of **binary trans-Neptunian objects** or **asteroids with rings**. A mini version of Saturn!



Chariklo representation, asteroid-like object which is also known as Centaurus. Illustration by Lucie Maquet.

TRANSITS

The eight planets of the Solar System orbit around the Sun practically in the same plane, with a few differences between them, orbiting in the same direction. Also, out of the eight planets, six of them rotate on its axis in the same direction of its orbit (Venus and Uranus are the exceptions). All of this would make sense if the planets were formed in a protoplanetary disk 4,500 million years ago.

The Moon is "almost" aligned in this same plane, but there is a minor inclination of only 5° regarding the plane where the Earth transit the Sun (called ecliptic). It may seem not much, but it is enough so that instead of having a solar and lunar eclipse every month, we have a total solar eclipse every eighteen months on average, as we have already seen.

There are times when Venus or Mercury pass in front of the Sun, and we can see it with the right telescopes. They can't eclipse the Sun entirely due to the considerable distance that separates the Earth from these two planets, blocking a small part of the sunlight, which are called **transits**.

The outer planets (from the Earth outwards), which means, Mars, Jupiter, Saturn, Uranus, and Neptune, are never between the Earth and the Sun, so they never produce a transit.

There are also other very interesting transits. Today, we know that it is very usual that stars have planets, which are known as exoplanets or extrasolar planets.

Such is the case that there should be more planets than stars in our galaxy.

The same as eclipsing binary stars, some of these exoplanetary systems may have an orbit aligned with the Earth. In these cases, planets partially block the light coming from the orbiting star. Unlike binary stars, in which the change in the light we receive is profound, in the case of planetary transits, the variations can be one hundredth if it is a planet like Jupiter and a few millionths in the case of a planet like Earth.

Even though it is not an easy thing to perceive, since we are talking about detecting a firefly next to a stadium spotlight located hundreds of kilometers away, we can do it thanks to telescopes and cameras specially designed to measure these changes in brightness. Actually, most of the planets have been found by this technique, either from telescopes on Earth or space ones.

The Kepler space telescope, which is currently on the TESS mission and, in the near future the PLATO mission, have been and will be responsible for discovering new planets, such as the Earth, orbiting other stars, and bringing humanity one step closer to the search for another possible Earth where life may exist because, despite the progress achieved, the most crucial question remains unanswered: Is there life beyond our planet?

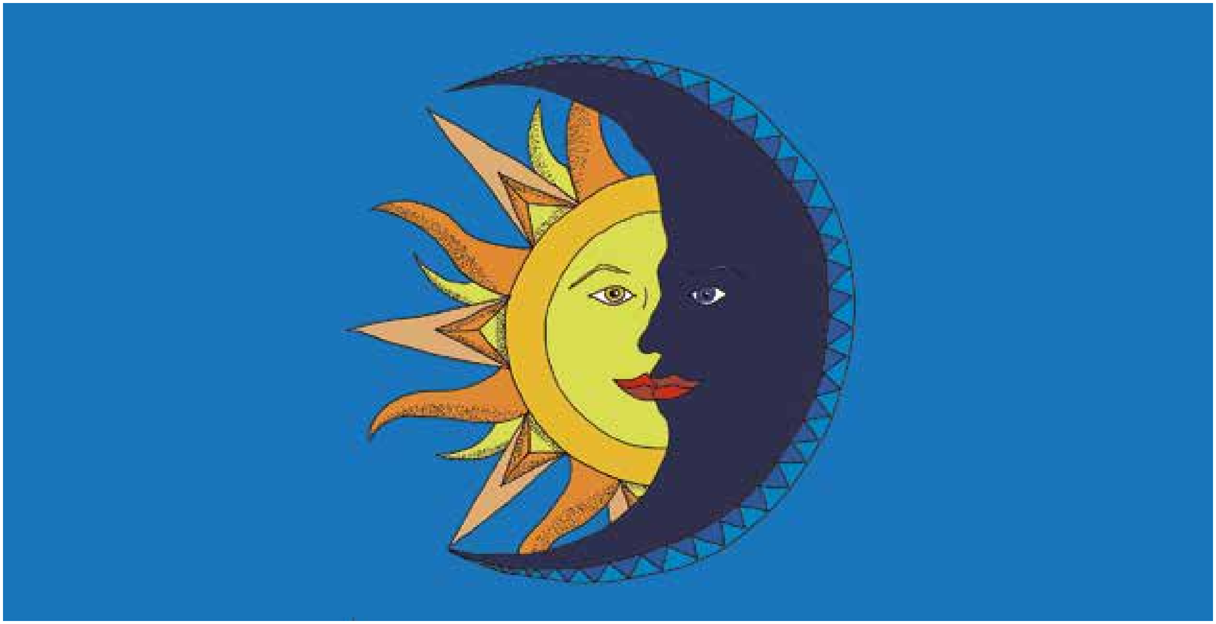
VI

ECLIPSES FROM DIFFERENT WORLD VIEWS

From Earth, we have a privileged view of the Moon.

For ages, in the sky, we only contemplated clouds, auroras, the Moon, the Sun, and six planets: Earth, Mercury, Venus, Mars, Jupiter, and Saturn. We also saw the "fixed" stars, once in a while the appearance of shooting stars, comets, and "new" stars or novas, and also supernovae that after a long sudden glow, vanished forever. Almost every change occurring in the sky was perceived as problematics or bad omens, especially in the case of wonders involving the Moon and the Sun, mainly the eclipses.

There are stories and myths about eclipses in almost every culture and in the five continents. Through these narratives, we can notice both cultural and social differences. However, before questioning such beliefs, let's remember what the Sun and the Moon represent. The Sun gives us its energy and heat and, therefore, is essential in every aspect of life. For thousands of years, its position regarding the stars was observed to seed and harvest. The Moon, on the other hand, illuminates at night, and it is appreciated on its brighter stages in scorching places because it helps to carry out farming and livestock activities at night, avoiding the heat during the day. With this in mind, many nations reverenced these celestial objects, even as the most important among gods in some cultures. Thanks to the observation of repeated phenomena, they tried to give answers based on their experiences or knowledge. Today, we do something similar since we try to explain observed phenomena through physics laws and math.



ASIA

In ancient Babylon (Iraq today), astrologists[10] achieved an extensive astronomical knowledge and a predictive ability about eclipses. For them, these events came along with misfortune, in particular, the death of the king or his family. In the aim to prevent the Monarch from dying because of this phenomenon, he and his heirs were hidden. In his substitution, other people who would receive the royal treatments took his place, but, in return, they had to sacrifice their lives after the eclipse in order to avoid the destiny of the Monarch and his family. Nowadays, it would not be a work that so many people were willing to do.

In Hinduism, we find two types of demigods, suras and asuras. It is said that in the beginning, suras used to rule the Universe, but they were cursed after Indra (king of the skies) insulted Durvasa, the great sage. This situation caused asuras to take control over the battle "between the good and the evil." Then, in the attempt to recover their power, suras consulted the god Vishnu, who recommended to obtain the elixir of immortality located in the bottom of the ocean of milk. However, they had to join forces with asuras to get it. They agreed, tempted by the lust of immortality, even though both of them planned to use it for their own benefits. They had to fight against the snake's king to get the desired nectar, whom they bent together, and the elixir of immortality came along to the surface.

Asuras took the elixir first, and fled, then suras once more asked for help to Vishnu. As a response, the god took the shape of Mohini, a beautiful woman, and fooled the asuras to take the beverage, so then she can divide it. A bit tipsies, asuras gave up and didn't peep a word while they were aligned in different lines and see Mohini pour the elixir into the mouth of the suras. One of the asuras, called Svarbhanu, realized and moved to the other cue to receive the immortality; the Sun and the Moon noticed about this and warned Mohini, but it was already too late, Mohini had already given him the beverage. Quickly, Vishnu grabbed his sword (chakra) and cut his head off before he had the chance to swallow the drink, but as the head had already had contact with the nectar of immortality, he lived without his body, and was known as Rahu, while his body is known as Ketu. It is believed that Rahu stayed living in the ascendant node of the Moon, and Ketu in the descendant.

That's why when an eclipse occurs; it is said that Rahu eats or devours the Sun or the Moon, but since he doesn't have a body, he comes out again. This action would be an act of revenge for advertising Vishnu of his intentions.

10 · Unlike astronomy, which studies the behavior and functioning of the stars regarding provable physics theories and laws, astrology gives explanations of the motions and events based on the gods' plans or supernatural forces.

In Vietnam, it is believed that a frog or toad devour the Sun, whereas, in China, the eclipses' explanation is related to a dragon who gobbles down the Sun. Interestingly, the word to eclipse in Chinese is Shih, which literally means, eat.

In ancient China, a tradition lasted two millenniums, which lay in throw fired arrows to chase away the Moon, afraid of the Sun would never shine again. In fact, in the XIX century, Chinese sailors were seen shooting cannons to the eclipse hoping for avoiding the dragon (Moon) eats the Sun.

EUROPE

In the Nordic tradition, eclipses are a result of a fight between two wolves in the sky, called Skoll and Hati, who are always chasing the Moon and the Sun.

When they are caught, the darkness comes, and the red color, seen over the Moon during a lunar eclipse, would be blood splatters that cover it because Skoll has already bitten him.

In Germany, female and male roles assigned to the Moon and the Sun are different, although the reason for this is not very clear. The myth reads that during the day, the lazy, cold Moon (male) ignore the hot Sun (female), except for the fleeting moment of passion during the eclipse of Sun. After a minor fight, the Sun comes back to shine.

AFRICA

It is believed that in some western regions in Africa, the Sun (male) and the Moon (female) have a romantic relationship, and during the eclipses, they turn off the lights to have more intimacy.

Furthermore, the inhabitants of the Batammariba region (Togo and Benin) believe that during eclipses, the Moon and the Sun are involved in a fight, and people urge both to stop fighting. Part of that consists of setting the example. That’s why during the eclipses, people make peace or different conflicts between families or other kinds of problems are solved, even those issues that could have been dragged along for years.

In ancient Egypt it was believed that pharaohs were direct descendants of the god Sun and, consequently, their representatives on Earth. During a solar eclipse, the pharaoh walked around the main temple of Osiris until the event ended. The idea behind this was that the Sun should have move continuously, and when it started to get dark, its human representative should have done whatever in its power to regulate the motions in the sky. This ritual is also present in Chinese culture, where the emperor or ruler also was a Sun descendant, walking outside the temple.

NORTH AND SOUTH AMERICA

Among the diverse stories, we find Incas, who used to think that a jaguar, who devoured the Moon and covered it in blood, caused eclipses. Once the process finished, the animal came back down to Earth to keep eating. To avoid this attack, Incas reunited together, they were very loud and punched the animals, mainly dogs, to make them howl, so the jaguar got scared to then leave them alone.

In a tribe from northern California, the U.S, called Hupa, they believed that the Moon had many wives and animals as pets, including snakes and mountain lions.

If the Moon didn't bring enough food, its pets would attack and hurt the Moon, which explained its reddish color, typical of a lunar eclipse. Then, its wives arrived, who fixed the Moon. The eclipse ended with them cleaning its blood.

On the other hand, the Eskimos believed that during eclipses, the Sun and the Moon had a kind of disease, resulting in their blinking light. They protected and warmed themselves to not infect from the stars, and they also covered the valuable things to carefully not spread out the supposed illness.

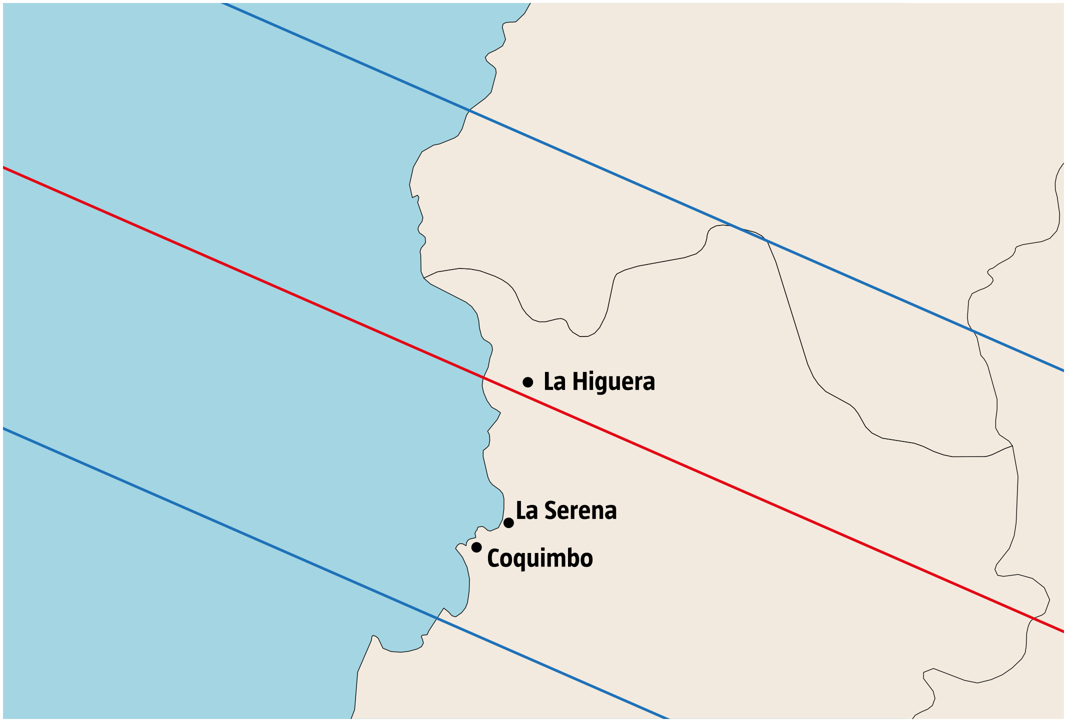
In the case of the pre-Columbian cultures from the south of Latin America, Chile and Argentina today, we found the Mapuches. According to these people, the physical Sun and the spiritual self always go together; in fact, it plays a crucial role in prayers. Regarding the eclipses, they called them malonji ta Antü (they came to block the Sun), and see them as lousy omen since they consider this as the defeat of the Sun at hands of the darkness. Considering this, people who live eclipses offer prayers dedicated to the Sun through songs, asking if it can back to life to light up the world again and don't leave them.

In general, myths and beliefs have something in common in different parts of the world: they cause fear due to the sudden change of the most visible celestial bodies, those which affects the most in our lives, but also there are very noticeable changes you can tell by the environment and the threating dangers.

Even today that we know the Moon is a great rock and the Sun a giant ball of plasma, some people decide not coming out of their houses and not watch the eclipse just for fear. Other urban myths state that eclipses are dangerous for pregnant women sitting outdoor during the eclipse, or it is even more dangerous to look at the Sun during the eclipse instead at any other time. Even when there are no reasons to justify these superstitions, they are the beliefs passed down from generation after generation.

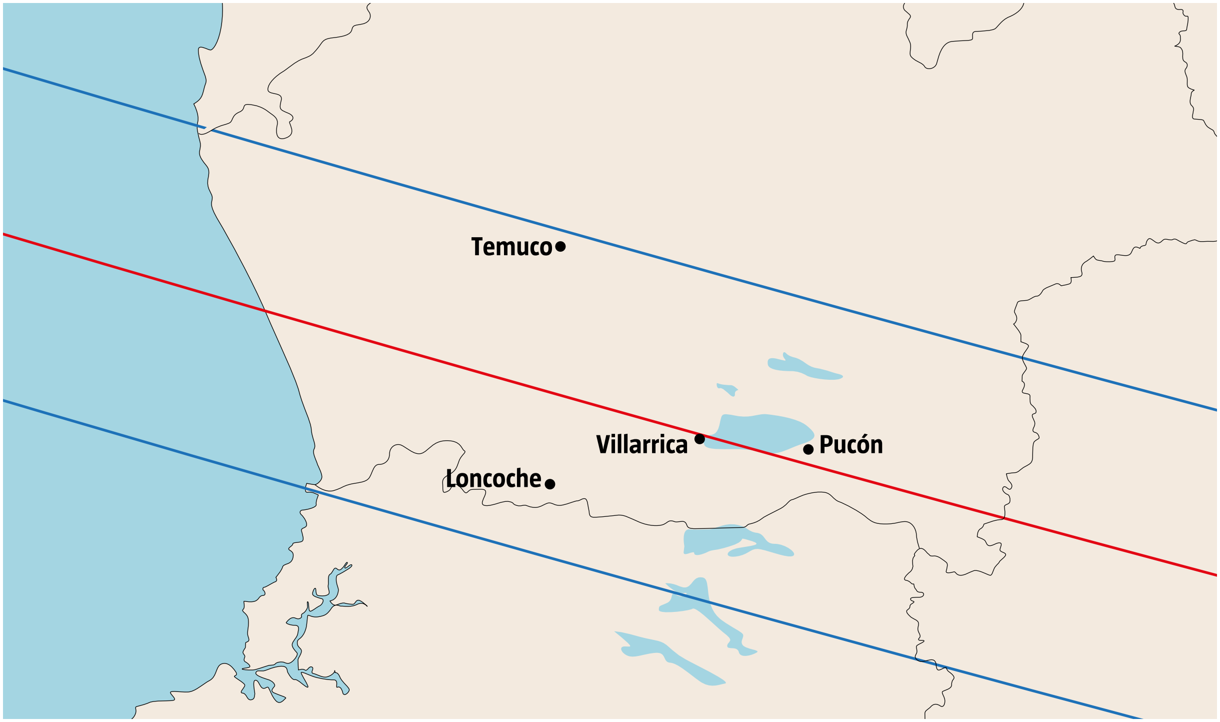
VII ECLIPSES IN CHILE 2019 AND 2020

Chile and Argentina are going to witness two total eclipses of the Sun during 2019 and 2020. In the maps below, you can see the exact point where this wonder will be visible. The red line traces the central and long-lasting path. The blue lines trace the bounds from where the total eclipse happens. Out of that region, you can only see a partial solar eclipse.



In the region of Coquimbo, the last total eclipse of the Sun was seen in 1893, 126 years ago, whereas La Araucanía has waited since 1467 to witness this phenomenon again.

In the case of Chile, the last total solar eclipse was on Easter Island in 2010. Now, after the eclipses of this year (2019, Coquimbo) and the two coming (2020, La Araucanía, and 2021, Chilean Antarctic), we have to wait until 2048 where we will be witnesses of another total solar eclipse in the region of Aysén.



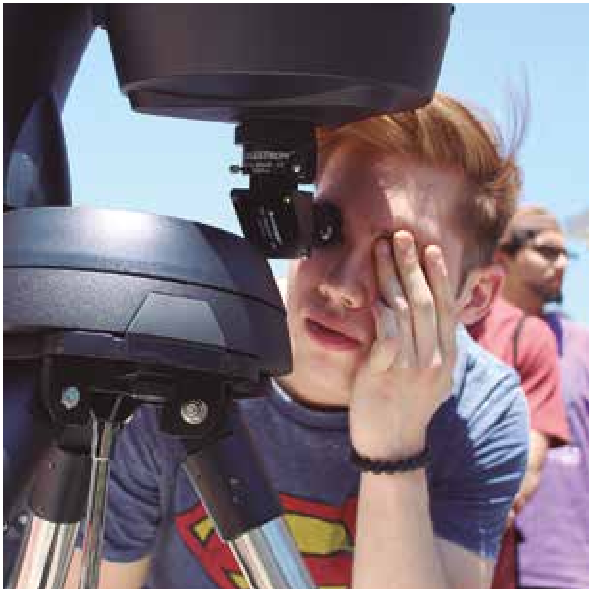
VIII WATCHING ECLIPSES SAFELY

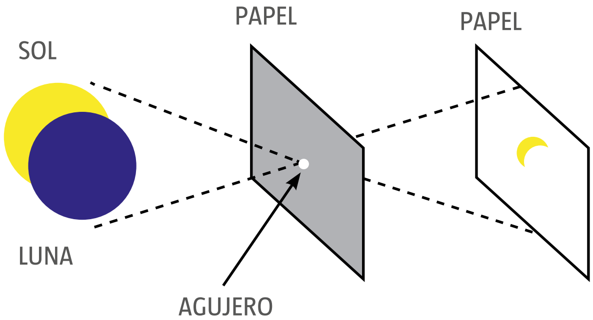
There is no need to use safety measures to watch a lunar eclipse so that this section focuses on solar eclipses.

Watch directly at the Sun is harmful to our sight. The brightness is so intense that our retina can be irreversibly damaged. So, if we want to watch the Sun directly, we must do it using the right implements. Then, during the total solar eclipse, it is not necessary to use any protection, you can watch directly without glasses and is NOT harmful, but before the totality and right after, we should protect ourselves.

WATCHING THE SUN INDIRECTLY

The safest way to watch the Sun is by watching it indirectly. To do so, you can take any paper sheet and cut a tiny hole (of 0.5 mm, for example). Then, point to the Sun and see how the light goes through the hole, projecting onto another surface, which can be another paper, a wall, the ground, etcetera. The closer, the smaller is seen, but intense. If you put the paper away, it is blurrier but bigger.





WATCHING THE SUN DIRECTLY (AND SAFELY)

There are different ways to watch the Sun directly, with or without zoom. In the case of no using zoom, we can get glasses specially designed for it. It is imperative to have certified glasses to avoid retina damages; you must ensure the glasses block the 99,999 % of the solar light.

If you decide to watch the Sun with zoom, you can do it using binoculars or telescopes well equipped with filters specially designed to watch the Sun. There are two types of filters:

1 · "Gray" filters or neutral density filters, which block all the light equally and create a sight of the Sun as seen with glasses. You can see the Sun a bit bigger, and perhaps you distinguish its solar spots.

2 · Narrowband filters, particularly hydrogen-alpha filter, which block all the light except a very particular reddish color that allows the solar chromosphere, solar spots, eruptions or solar flares, and granulation to stand out. The telescopes full equipped with these filters are suitable to watch the Sun all the time, but they are not a great advantage during an eclipse.

At the same time, but irresponsibly, is has been suggested to use CD, X-ray photographies, smoked glasses, sunglasses, polarized glasses, the old diskettes inner disk, ribbon cassettes, aluminum foil, among others. The truth is that none of these elements are suitable to watch direct and safely the Sun since the amount of light passing through them can damage the sight beyond repair.

DO NOT USE

· CD

· X-RAY PHOTOGRAPHIES

· SMOKED GLASSES

· SUN GLASSES

· POLARIZED GLASSES

· OLD DISKETTES INNER DISK

· CASSETTES RIBBON

·ALUMINUM FOIL

Watching a total eclipse of the Sun is an unforgettable experience. As we reviewed in the preceding section, these are relatively common phenomena in the world. However, they can't always be seen from any city since, sometimes, they happen in the poles or the middle of the ocean. That's why when it is visible on solid ground, thousands of people travel to watch them.

VISIBLE ECLIPSES FROM CHILE IN THE 21ST CENTURY		
Date	**Region**	**Total time**
July 11th, 2010	Valparaiso (Easter Island) and Magallanes and the Chilean Antarctic	5 min 20 s
July 2nd, 2019	Coquimbo and Atacama	4 min 32 s
December 14th, 2020	La Araucania and Los Rios	2 min 10 s
December 4th, 2021	Magallanes and the Chilean Antarctic	1 min 54 s
December 5th, 2048	Aysén del General Carlos Ibáñez del Campo and Los Lagos	3 min 28 s
August 12nd, 2064	Valparaiso, Metropolitan Region, and Libertador Bernardo O'Higgins	4 min 28 s
August 3rd, 2073	Magallanes and the Chilean Antarctic	2 min 29 s
January 16th, 2075	Coquimbo	2 min 42 s

*The eclipses on April, 20th of 2023 and November, 14th of 2031 are hybrid, which means that from some places will be a total eclipse, while in others annular.

*Data obtained from https://eclipse.gsfc.nasa.gov/solar.html

DATES AND PLACES OF THE NEXT TOTAL SOLAR ECLIPSES UNTIL 2040		
Eclipse date	**Place**	**Total time**
July 2nd, 2019	Chile and Argentina	4 min 33s
December 14th, 2020	Chile and Argentina	2 min 10s
December 4th, 2021	Antarctic	1 min 54s
April 20th, 2023 *	Indonesia, Australia, Papua New Guinea	1 min 16s
April 8th, 2024	Mexico, EEUU, Canada	4 min 28s
August 12th, 2026	Artic, Greenland, Iceland, Spain	2 min 18s
August 2nd, 2027	Morocco, Spain, Algeria, Lybia, Egypt, Saudi Arabia, Yemen, Somalia	6 min 23s
July 22nd, 2028	Australia, New Zeeland	5 min 10s
November 25th, 2030	Botswana, South Africa, Australia	3 min 44s
November 14th, 2031*	Panama	1 min 08s
March 30th, 2033	Russia, Alaska	2 min 37s
March 20th, 2034	Nigeria, Cameroon, Chad, Sudan, Egypt, Saudi Arabia, Iran, Afghanistan, Pakistan, India, China	4 min 09s
September 2nd, 2035	China, Korea, Japan	2 min 54s
July 13th, 2037	Australia, New Zeland	3 min 58s
December 26th, 2038	Australia, New Zeeland	2 min 18s
December 15th, 2039	Antarctic	1 min 51s

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Lastly, I'm forever thankful for these four people that move me every day: my wife Lilian, my son Dante, mi mother Karin, and my sister Valeska. Their affection and support are more valuable than anything the world can offer.

Chile is the astronomy world's capital. The world's most state-of-the-art observatories survey the southern sky to find new distant galaxies and planets, and to contribute with hints to answer questions such as where do we come from, where do we go or if there is life in some other places in the Universe.
Responding to the citizen interest on this subject, the Science Communication Center of Universidad Autónoma de Chile provide to the community a book in which some details about some of the most relevant stars, such as the Sun, the Earth, and the Moon are addressed accurately, stressing one of the most exciting, fascinating wonders that involve these three celestial bodies: Eclipses.
Illustrated Astronomy was written by the Ph.D. in Astrophysics and science communicator, Juan Carlos Beamin, and had the illustrations of the artist/astronomer, José Utreras, who gave life to this book with his colors, which main goal, in particular, is transforming astronomy the science behind our Sun, Moon and Earth, in a collective good and at everyone's fingertips. Illustrated Astronomy is part of the collection called Aprende Conciencia, and it can be freely downloaded from the site web ciencias.uautonoma.cl.

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