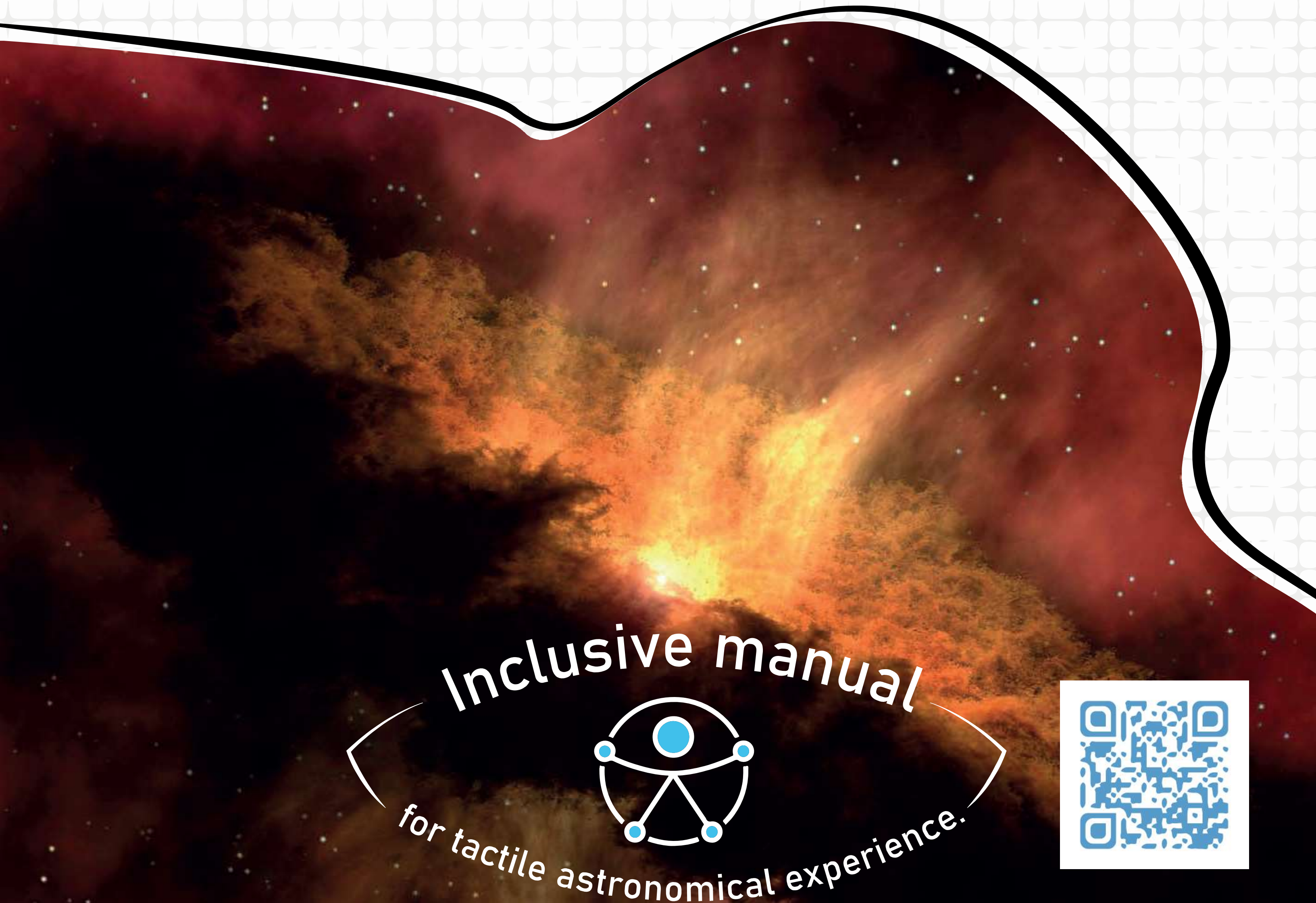
NPF
NÚCLEO MILENIO DE FORMACIÓN PLANETARIA

milenio
INICIATIVA CIENTÍFICA

PLANET FORMATION



Inclusive manual
for tactile astronomical experience.

TWO SCALES SOLAR SYSTEM

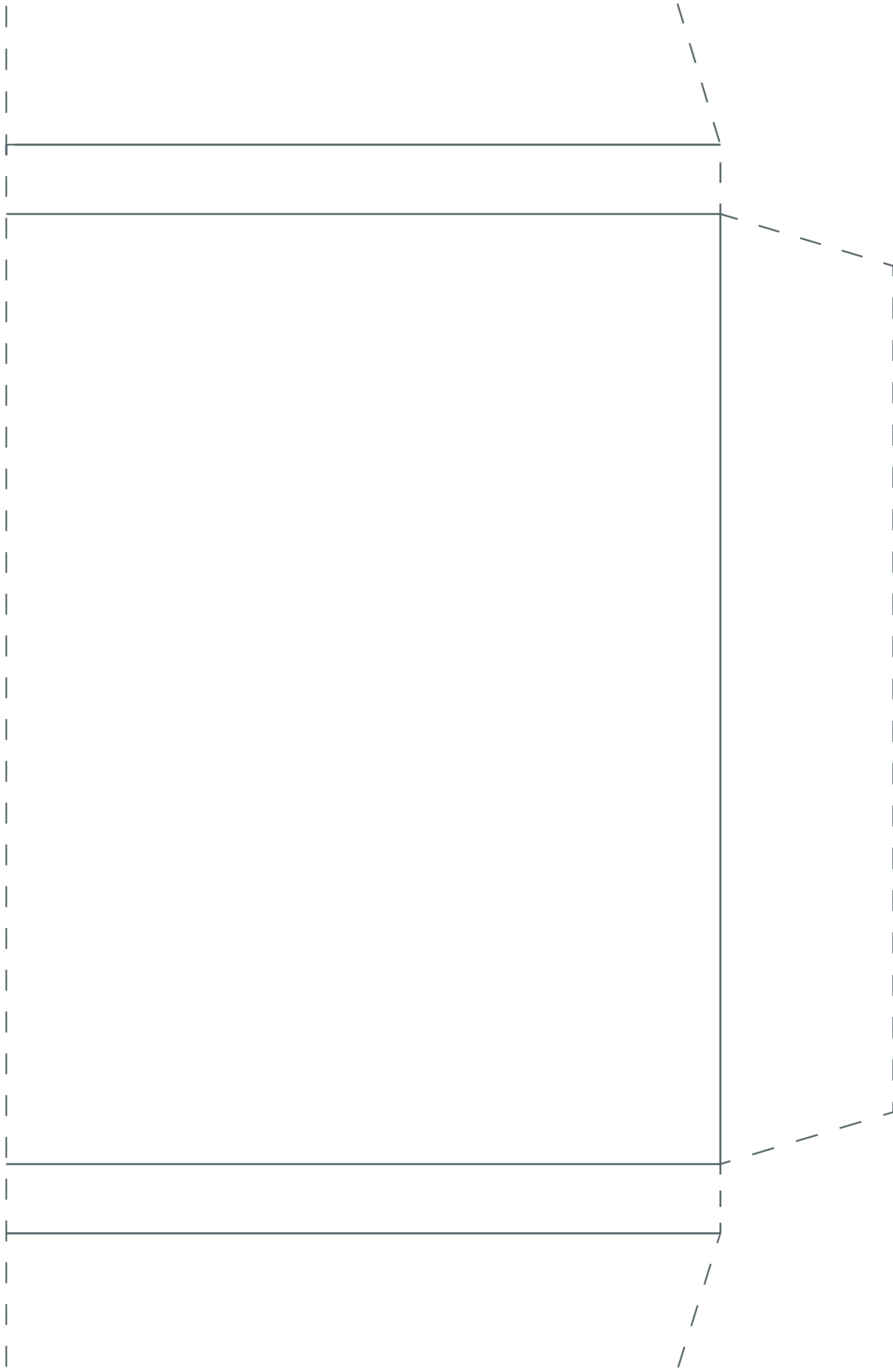
NÚCLEO DE ASTRONOMÍA udp
FACULTAD DE INGENIERÍA Y CIENCIAS

2

Assemble the pocket and glue it here by its tabs.

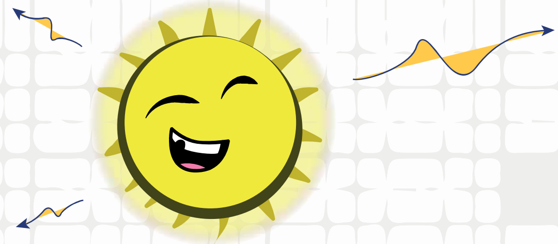
BEND

CUT



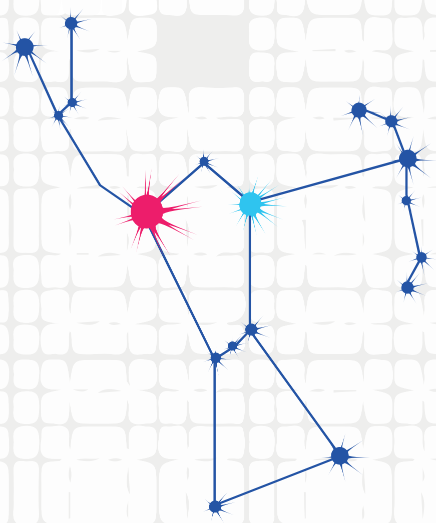
TEACHING IN MEMORY

Here we are the teachers who teach based on the Inclusive Planetary Training Manual.



LET'S TALK ABOUT YOUR EXPERIENCE

Figure 1: Teacher survey.



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milenio
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CEALIVI Quillota

DRA. AMELIA BAYO

Former Director of @NPF_CL
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WELCOME!

In my view, science outreach is a civic obligation of scientists and, fortunately, within the NPF many of us share that position. In particular, in astronomy we find ourselves in a somewhat "bipolar" situation since, although we are, humans, literally blind to most of the phenomena we study (e.g. the birth of planets) and we have to build detectors that allow us to analyze "that which our eyes do not see", we tend to share that information with the public based on images, leaving us de facto blind and/or low vision population out of the target audience...

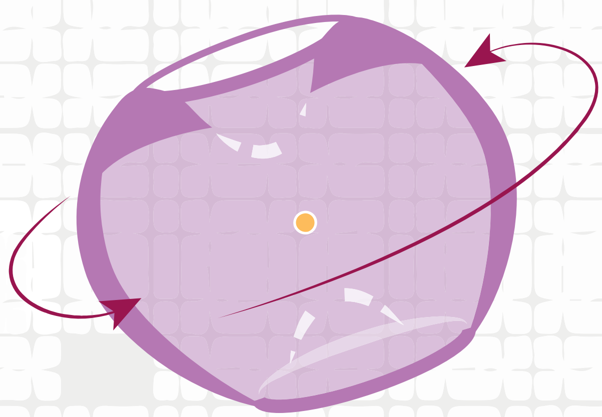


Figure 2: Envelope of dust and gas surrounding a star as young as a seed. It is surrounded by two arrows indicating rotational motion.

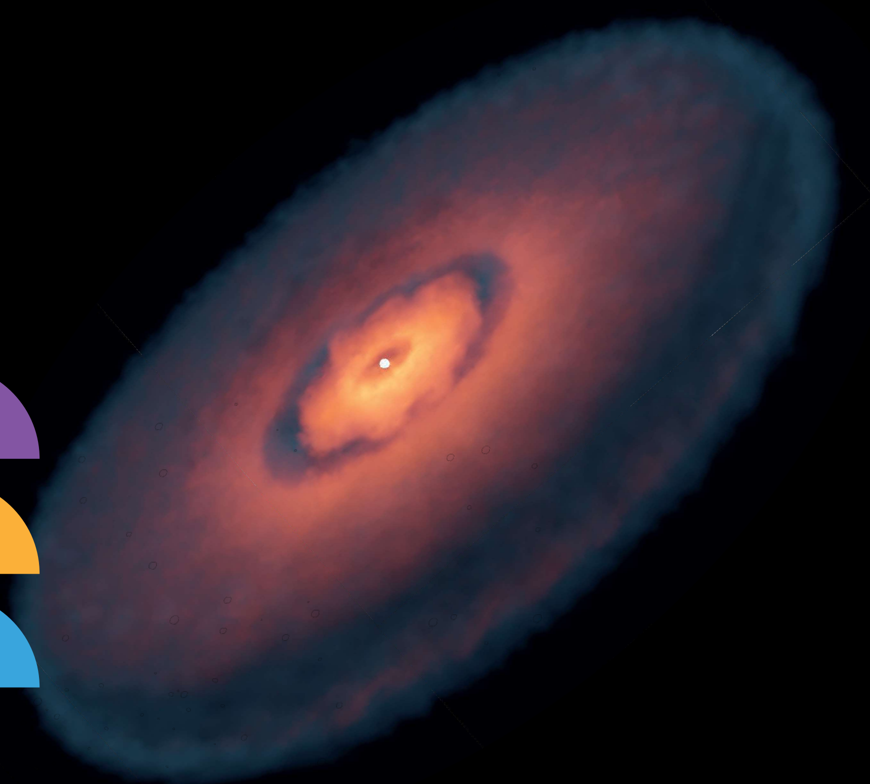
... With this model and its manual we want to highlight the fact that **by using multisensory material, we not only open the door of the "hard" and/or experimental sciences** to a group that we have ignored for too long and that can feel the most current discoveries as foreign, but **we significantly enrich the experience of those without vision problems** who can learn much more by receiving stimuli through their other senses.

Amelia
Valparaíso,
Chile.
2020

FOREWORD

Science is not only part of the lives of the women who developed this manual, but it is also part of the lives of the majority of female education professionals in Chile. 74% percent of Chilean teachers are women, which is why the handbook is written using the

FEMININE GRAMMATICAL GENDER.



COLOUR CODING

- Inclusion
- Basic education
- Secondary education

THE ROLE OF WOMEN IN ASTRONOMY

The depths of space have inspired the inexhaustible curiosity of women scientists, leaving **important legacies** that are little known. A clear example is that of the American astronomer **Annie Jump Cannon** , who developed a **method for classifying stars** that later evolved into the **Hertzprung-Russel**, recognising the two astronomers who refined this research rather than honouring its original author. We will see how this classification works on page 27.

Moreover, in the development of technology for astrophysics, women are creating ways everyday to **discover and document** the phenomena that occur millions of light years away from Earth. This is the case of **Wanda Díaz-Merced**, an astronomer who became blind during her undergraduate studies in physics. Wanda is currently developing the **sonification of a large dataset** for auditory analysis. The human ear can be an even finer sensor than sight, as the eyes are constantly saturated with colours, brightness and depth.

We invite you to experience planetary formation with Annie's curiosity, and not limited to the sense of sight as Wanda inspires us.

NÚCLEO MILENIO DE FORMACIÓN PLANETARIA

The NPF is a scientific and technological centre that seeks to understand the processes involved in planetary formation from three key points of view: theory, observations and the technological development of new observational infrastructure. Regarding the latter, the NPF, together with the Scientific and Technological Centre of Valparaiso, is collaborating with the Planet Formation Imager (PFI), an international consortium whose objective is to develop a new observatory that allows a clear image of the gravitational action radius of a planet similar to Jupiter at the time of its formation.

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CURRICULAR FOUNDATIONS

ASTRO·ACTIVITIES AND RESOURCES

1. PLANETARY FORMATION
2. SCIENTIFIC EXPERIMENT
3. ASTROPHYSICAL CONCEPTS
4. SOLAR SYSTEM AT TWO SCALES
5. PLANETRIVIA AND SURVEY

1.a. Tactile protoplanetary model
(available in .STL and other formats for 3D printing).
1.b. Braille planetary formation manual
(available in PDF, EPUB and audio).
2. Group activity guide.
3. Concepts manual
(available in PDF, EPUB and audio).
4. QR on page 1.
5. QRs on page 51.

TEACHING OBJECTIVES:

6° Básico

CN06 OA 10 | CN06 OA 12

7° Básico

CN07 OA 08 | CN07 OAA G | CN07 OAA H

8° Básico

CN08 OA 11 | CN08 OA 13

1° - 2° Medio

CN1M OA 09 | CN1M OA 16 | CN1M OA 14 | CN2M OA 14

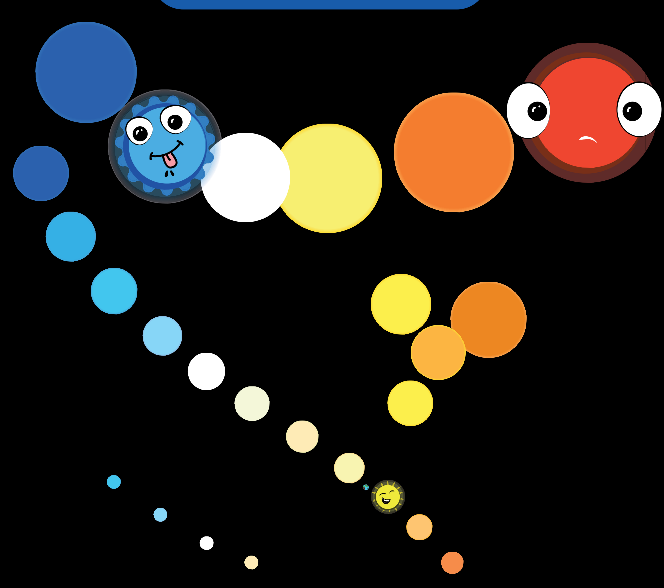
LEARNING OBJECTIVES:

CN07 OAH a

CN08 OAH a

CN07 OAH f

CN08 OAH f

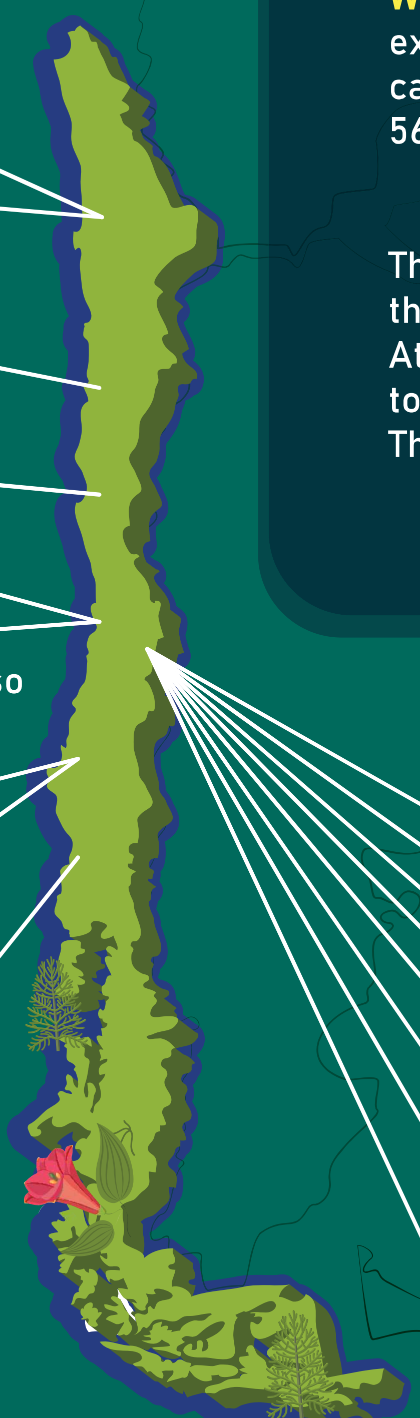


ASTRONOMY IN CHILE

Figure 3: Universities with professional female astronomers.

In 2015 Chile was recognised as the **Astronomy Capital of the World**, as it has 31% of the existing astronomical observing capacity, and is expected to have 56% by 2030.

This scientific area was driven by the large telescopes in the Atacama Desert, with mirrors up to **8 metres in diameter!** That's the VLT.

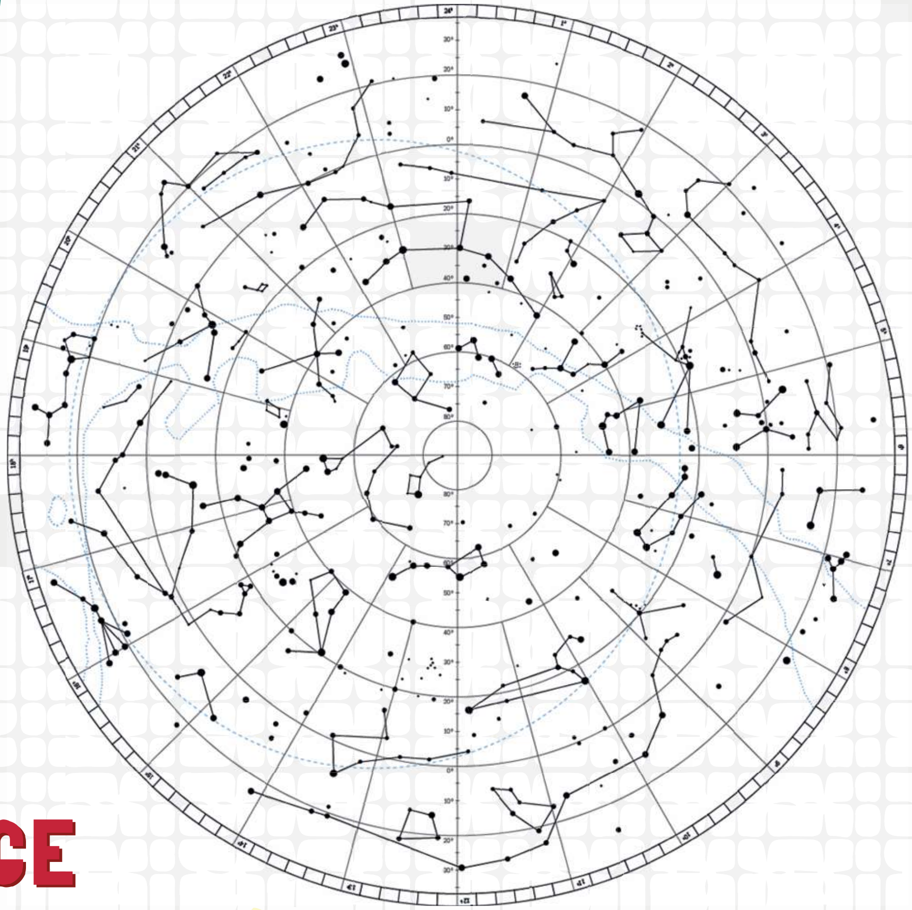


Fuente: SOCHIAS (APRIL 2019)

Much of the light received from the universe is not perceptible to our eyes because it has very long or very short wavelengths. **To compensate for this bias there are astronomical instruments that complement our eyes to reveal the invisible.** In many of the activities in this manual we will let our eyes rest.

CARTA CELESTE

Figure 4: Projection of the celestial sphere on a plane.



What does light tell us in astronomy?

Is that message universally accessible?

THE CHALLENGE OF INCLUSION

The term inclusion can be confusing, and everyone is likely to have a different interpretation. To get the best performance according to the learner's ability, the key is **to streamline teaching strategies, improving flexibility to adapt the medium of message delivery.**

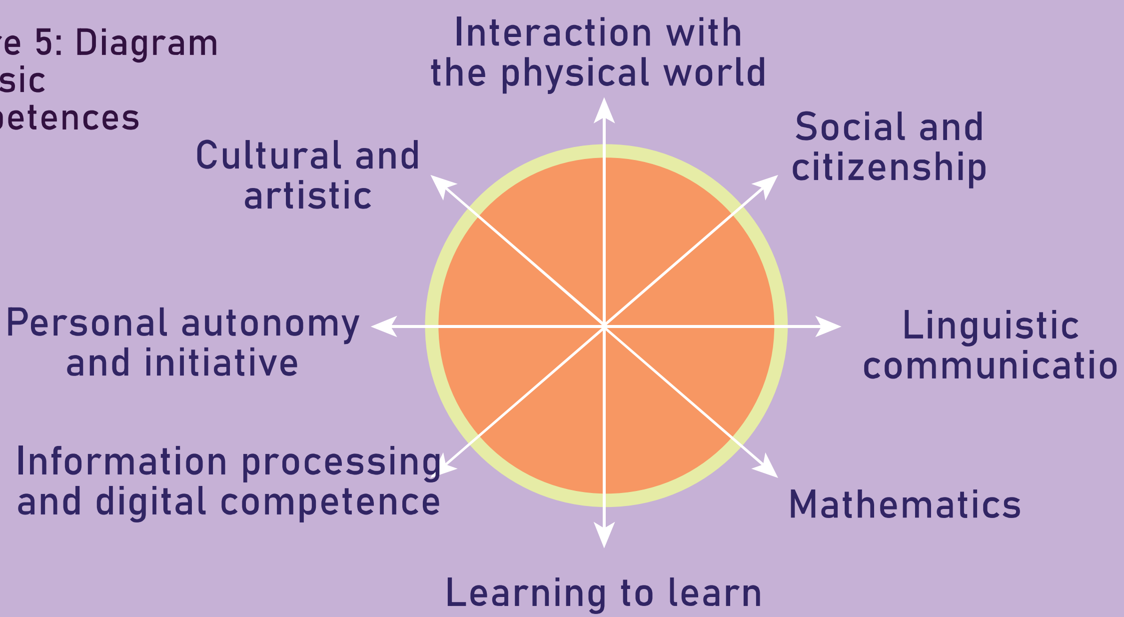
"Transcendence means going beyond the immediate situation or need that motivated the intervention. It does not only refer to a generalisation to other areas. It means that every situation produced in an intervention is useful for other situations (cause-effect)".

Quote from Theory of Cognitive Structural Modifiability and the mediating role, Reuven Feuerstein.

EIGHT CORE COMPETENCES

The neuropsychologist Howard Gardner in 1983 divided a person's intelligences into eight parts, creating the **Theory of Multiple Intelligences.** This proposes that each individual has abilities, and/or subsequently develops a particular type of intelligence that will allow him or her to make original contributions and learn in different ways in the context of cooperative learning.

Figure 5: Diagram of basic competences



A decade ago, the European Union and the Organisation for Economic Co-operation and Development were inspired by the eight intelligences to create the **eight basic competences**, which are skills necessary for an agile learner in the socio-cultural and digital environment, who develops reasoning and empathy.

Following the United Nations Sustainable Development Goal #4, let us seek to ensure inclusive, equitable and quality education for all, and promote lifelong learning opportunities.

4 EDUCACIÓN DE CALIDAD

ICT (information and communication technology) resources offer the possibility of streamlining skills.

Responsible use of the Internet brings us into a communicative society, with free information about what is happening both in our world as well as in distant galaxies. The pedagogical value of ICTs must be assessed by you, always planning for an objective of understanding.

Which competencies do you use on a daily basis?

In which competences are you most agile?

What do you think about the use of ICT in the classroom?

Neural plasticity is the capacity of our brain to learn and adapt to new habits...

... and it is around the ages of 6 and 7 when this characteristic works intensely, to the extent that there are visuospatial and motor stimuli in our environment (Rosselli, 2015).

Seek to stimulate the student multi-sensorially. Allow her to explore metacognition.

Invite her to ask questions and reflect together on how her thoughts changed during the activity.

GOAL

Guiding the scientific experience of planetary formation through strategies that generate expectations, surprise, and develop an intuition about the fascinating universe. We will use the eight intelligences to make autonomous, reliable, didactic and equitable knowledge.

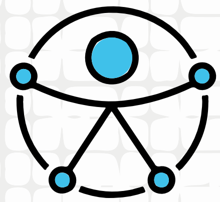
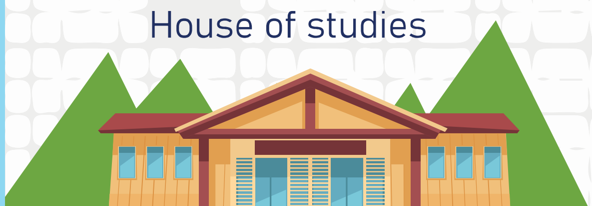


Figure 6: International symbol for accessibility.

Table 1: Comparison of education strategies.

Agent	Integrator	Inclusive
Professor 	Creates separate activities, is a provider of information	She is a guide to learning, transferring control to the students
 Students with disabilities (EeSD) and without them.	They reproduce activities, they have a static learner role.	Decision makers, with a dynamic role.
 Space	It is modified when someone needs it.	It is an environment free of sensorial noise.
House of studies 	It has only one interaction (in the room during the class).	It creates a bond of trust that allows you to learn from the EeSD.
Learning design 	It focuses on adaptations for the student.	It focuses on valuing diversity in the classroom.

This manual is full of complementary links, and the activities focus on **Socratic Teaching**, where the Socratic questioner will seek to ask questions rather than give answers, to be that inner voice that guides the student's critical thinking.

Our invitation is for you to explore the internet, be amazed and bring technology to the students with genuine motivation.

THE SOCRATIC QUESTIONER CAN...

Make assumptions:	**What if...?**
Ask questions to explore reasons and evidence	**How can I be sure of what you are saying?**
Ask about views and perspectives	**Could you explain why this is necessary or beneficial and who it benefits?**
Asking to test implications and consequences	**What then?**
Asking about questions	**Why do you think I asked that question?**

Periodically summarise what has and has not been questioned and resolved.

Involve as many students as possible in the discussion.

Be curious too, discover the links and learn new ways of learning, close to the technology.

If you have taught a person with a disability you may have felt anxious, **remember that it is important to maintain an atmosphere of respect and attention**, especially to the needs of the learner.

Remember that **tyour actions will be a model** for the behaviour of colleagues and the public. Below you will find **recommendations for interacting in inclusion (National Aeronautics and Space Administration, NASA, 2008).**

> **"The child is made of a hundred,**
> **the child has a hundred languages**
> **a hundred hands, a hundred thoughts**
> **a hundred ways of thinking**
> **of playing and speaking**
> **a hundred always a hundred".**
>
> **Extract from**
> **The hundred languages of the child,**
> **Loris Malaguzzi.**

HOW TO TEACH NATURALLY?

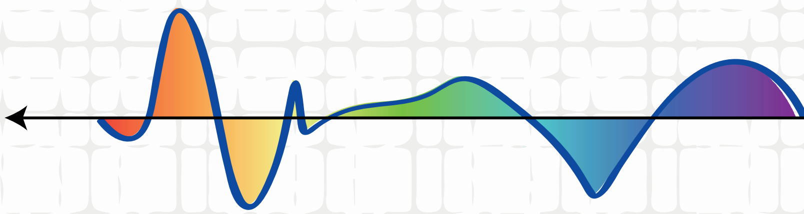
A **Adapt to their time**
We all want to be treated with dignity and respect, give yourself the time you need to listen with real interest.

B **Adjust to her**
Ask how to help and follow her instructions, there is no need to insist.

D **Don't use intermediaries**
Address the person directly, if she doesn't understand you, she will seek your help or that of someone she trusts, so that you can repeat it.

E **Organise in advance**
Make the material available in advance. Plan for alternative formats in case someone needs it.

Below you will find a spectrum of common disability situations. Keep them in mind when teaching.



SPECTRUM OF DISABILITIES

1

BLINDNESS OR LOW VISION

A **Light sensitivity is gradual,** be flexible in adjusting the amount of ambient light and brightness.

B Look for ways to isolate **ambient noise.** Sounds outside the activity distract the participants as well as the presenters.

C Make **digital content available in accessible formats** and look for tactile alternatives as a complement.

.

D Seek and provide students with **kinaesthetic stimuli** that concretise the addressed concept, identifying shapes, textures, sensations, tastes and/or sounds.

E **Remember to say goodbye.** Announce when you leave the group or the venue. No one wants to talk alone

F USE **UNIVERSAL DESIGN**

ALTERNATIVE TEXT

For images or graphics, add ***alternative text***, that describes in detail what is being represented. Try to complement with tactile resources.

VECTORS

Thickness of 2pt

MACROTYPE

Aa2020

Letter size 48pt

HIGH CONTRAST COLOURS

2 DEAFNESS OR HEARING IMPAIRMENT

A In communication it is useful, but not essential, to be able to use **sign language.** If you don't know sign language, don't be nervous and spend more time than usual understanding what the person needs. Also, look for communication alternatives such as drawing or writing.

B Instead of repeating, explain in different ways using **intuitive non-verbal** language if you do not speak sign language.

C Do not turn your back when communicating to ensure access to body language and **lip-reading.**

3 ATTENTION DEFICIT HYPERACTIVITY DISORDER (ADHD)

A Be **clear and direct** with the person, be patient and order the ideas to be transmitted. To do this

B **use structures** that indicate the steps to be taken

C Ask **key questions** during the activity to check understanding. Repeat if necessary.

D Use **visual aids** to accompany verbal and/or written instructions. Also add **mnemonic clues** to retain conceptual content.

E Validate **fatigue** as part of learning.

F Set **goals** for self-management of time in the activities.

C Have a **peer tutor** to document the learning process.

4 ORTHOPAEDIC/ MOTOR DISABILITIES

A Clear the path of obstacles and provide assistance with luggage, cane or other support equipment.

B Offer her a placement close to the teacher or a peer tutor.

C Inform her about safety protocols in the event of an evacuation.

D When in conversation, be at her eye level, and if she is in a wheelchair, find a chair yourself.

E Ask if it is possible for her to make notes, if not, offer her some means of recording the activity.

5 AUSTISTIC SPECTRUM

A Be direct, specific, patient and clear in communication, she may have difficulty maintaining eye contact or may not interpret non-verbal cues (such as facial expressions or emphatic tones).

B Pay attention to signs of sound, tactile, colour or light sensitivity. Understand that the person may be occasionally attracted to an object or topic of discussion.

C They are often shy, distant, and talk quietly to themselves - don't take this as an offence.

6 SPEECH AND COMMUNICATION DISORDERS

A Don't pretend you understood if her speech is incomprehensible to you. Ask her to **repeat it for you**

B **Be patient** with speed if the person uses sound aids.

C Reply when she finishes the message unless she will not be offended if you **reply sooner.**

7 COGNITIVE DISABILITIES

A **Communicate directly** using short sentences and simple vocabulary. Respect processing times in the student and repeat the instruction if necessary.

B Look for different ways to achieve understanding. If the student did not understand verbally, you can show pictures, videos, audios, and/or **alternative communication** systems.

C Consider scaling the proposed activity to **various levels of complexity** and abstraction, in order to achieve in-depth learning.

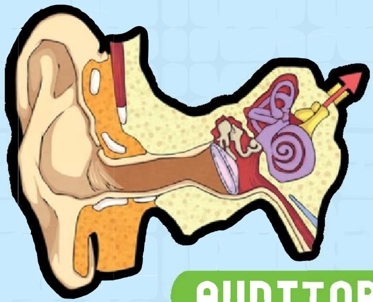
D When giving feedback, motivate to create from a different perspective and give your **constructive recommendation** Always practice this.

E **Strengthen the functions** of execution, planning, control, self-regulation, inhibition and/or self-evaluation.

F

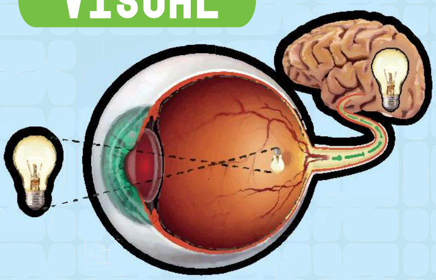
Occupy and observe all perceptual channels

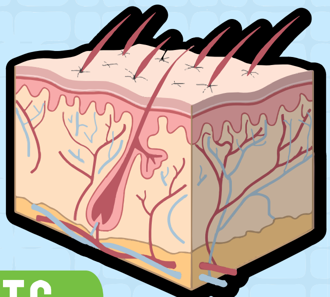
of the student's



AUDITORY

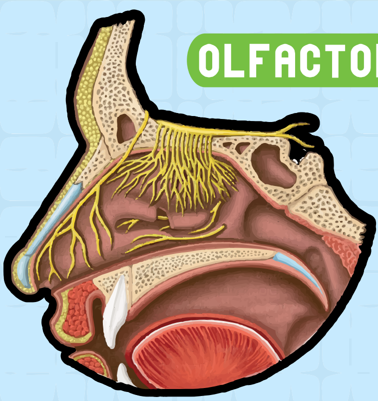
VISUAL



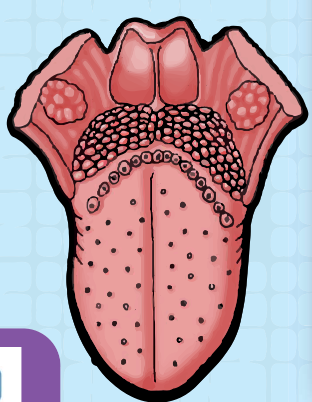


HAPTIC

OLFACTORY



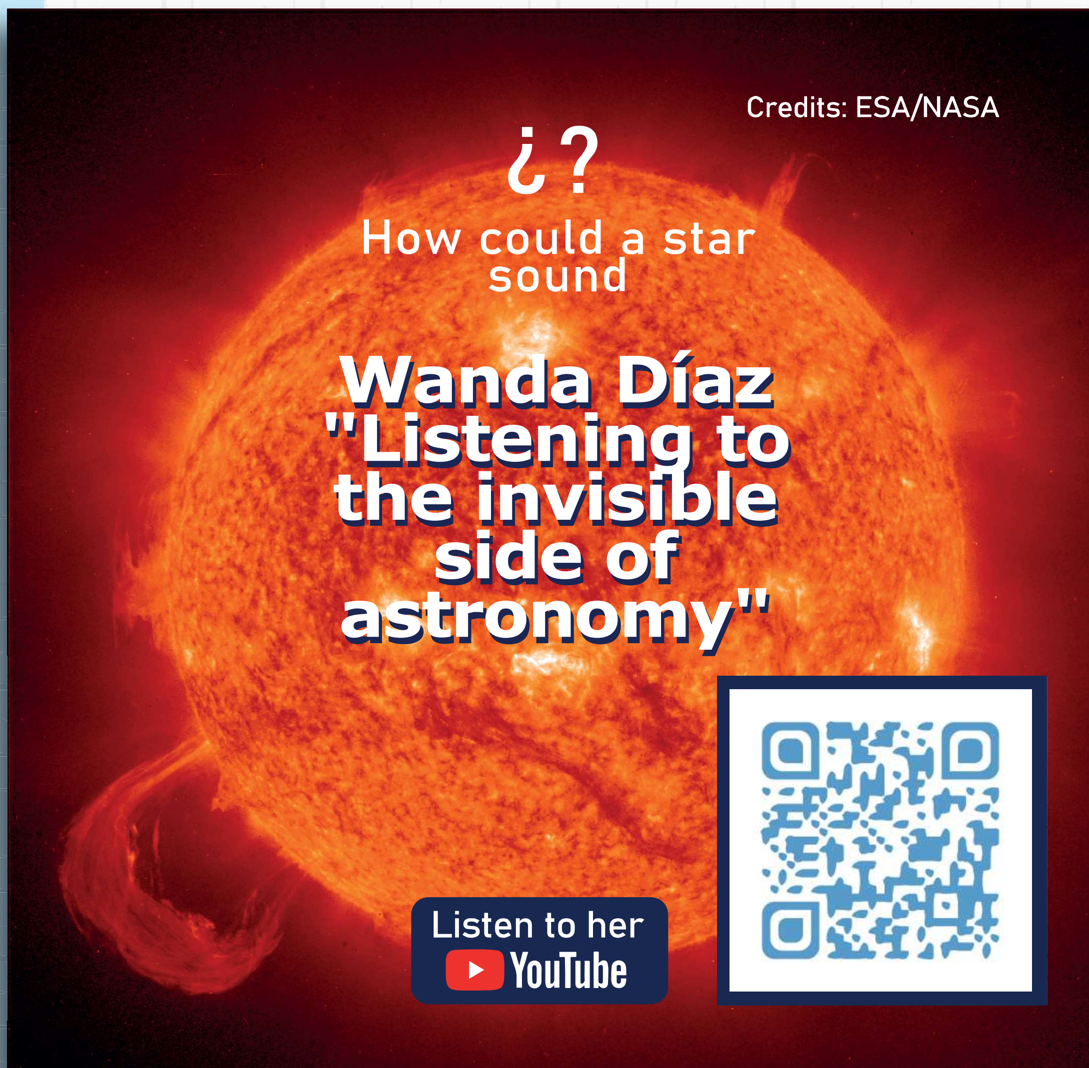
GUSTATIVE



It is possible to train skill in each perception, and we can also experience several of them together. The latter process is called

Perceptual Synaesthesiat

in which the brain can hallucinate blue smells, or touch sweet tastes. It seems that brain structures are more interconnected than perceptual channels.



Mix up the activities and adapt to the learners.

To be successful you will need to keep in mind:

ENVIRONMENTAL VARIABLES

that you can regulate and actively intervene to build a more inclusive classroom.

THE EIGHT

core competences for teaching.

THE ACCESSIBILITY

of the content. It allows for collaborative, motivating, and hands-on teaching (constructivist learning). Facilitate access to the internet when necessary.

EVALUATE YOUR CLASSROOM EXPERIENCE

- Among teachers, do you share your successful strategies for inclusion?
- During the activity, what else can you keep in mind about students with disabilities?
- Do you know about technological aids?

Visit the website of the Spanish National Organisation for the Blind ONCE to find out which activities improve inclusion in education, within the family, and in society.

COMPREHENSION GOALS

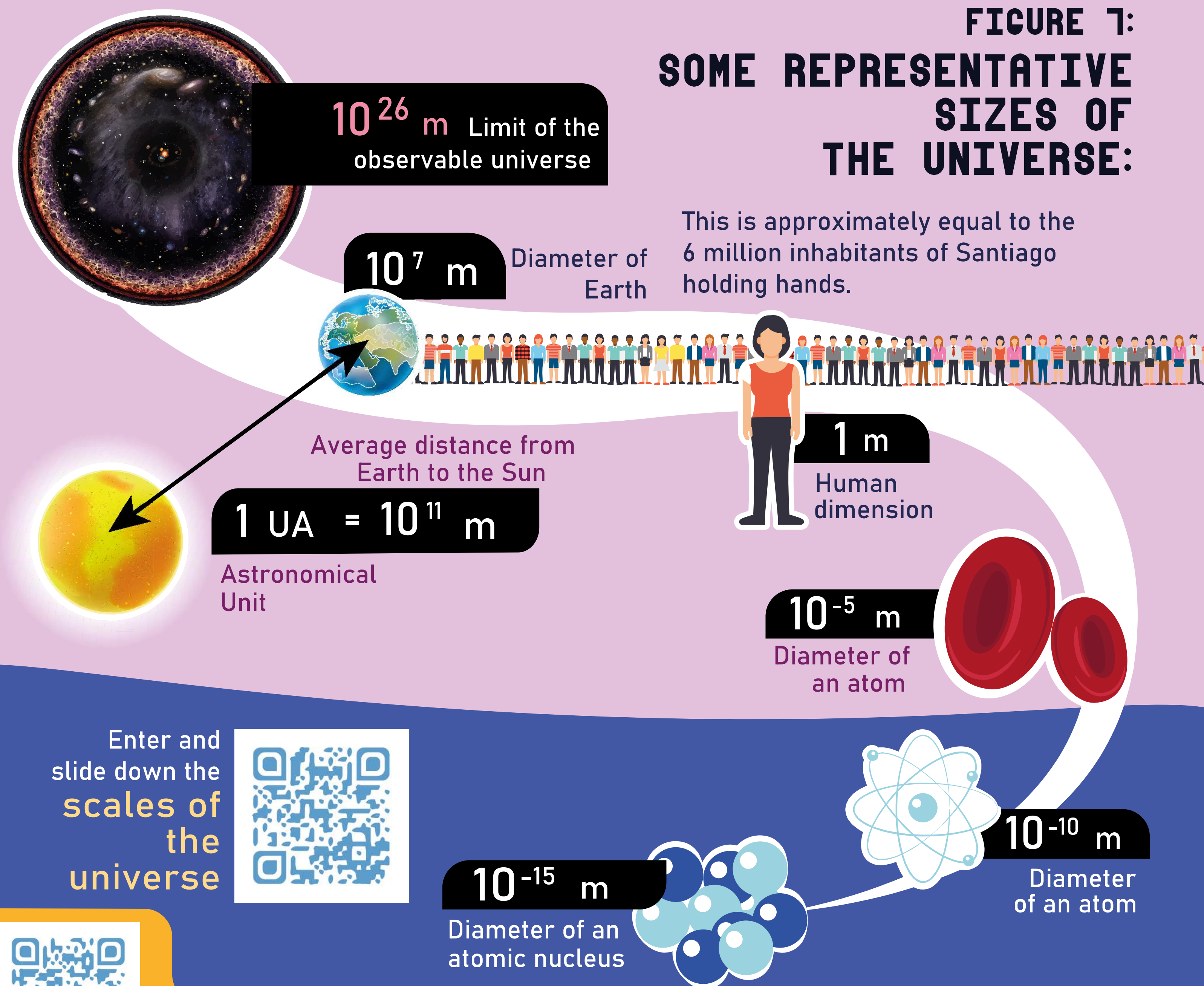
SCALES What are the scales of size and time involved in astronomical phenomena and the methods astronomers use to measure them?

ELEMENTS How planets form and what environmental factors are necessary for this to happen

EVOLUTION What is the life cycle of a star, what are its stages?

ESTIMATES How to calculate the diameter of the star while standing on a planet in its system?

FIGURE 7: SOME REPRESENTATIVE SIZES OF THE UNIVERSE:



Enter and slide down the **scales of the universe**

TIME BEGINS
0 MILLION YEARS (MYR)

How does a galaxy rotate? How does an asteroid differ from a comet? Under what conditions can life form on a planet?
These questions are raised by teams of people who are interested in astronomy. The NPF is formed by people with different professions and occupations.

Astronomy
Bachelor of Science in Physical Sciences
Mechanical Engineering
Industrial Design
Science Journalism
Product Design
Electronic Engineering

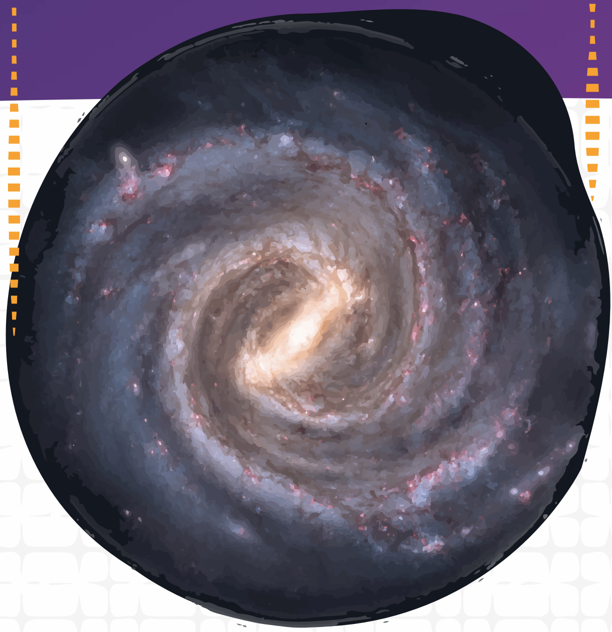
We all support each other collaboratively as we work, pointing telescopes at the sky and developing innovations that advance astronomical and astrophysical science.

Write down your name, and following your own skills, choose your role in the activities. Now let's run the time machine, **travelling at impossibly high speeds, to learn about the formation of stars and their planets.** The machine is noisy, so you must be quiet when a partner speaks or asks questions.

1. Choose your role
2. What interests you about this role?
3. What would you like to research in astronomy?

GALAXIES

Figure 8:
100,000 light years (lyr) in diameter.



Stars are not randomly distributed across the sky. On a large scale, they cluster together in giant families **due to the attractive nature of the force of gravity** (the same force that pulls objects down to Earth), forming small luminous clumps in the night sky. **These families, if they are large enough, are called galaxies.** It should be noted that, for example, globular clusters containing a large number of stars are NOT galaxies.

The Sun and 200 billion other stars make up the Milky Way. Galaxies with whimsical shapes of discs, spirals and spheres have been observed, but... What does ours, the Milky Way, look like?

THE MILKY

Figure 9: Diagram of the Milky Way with 5 arms

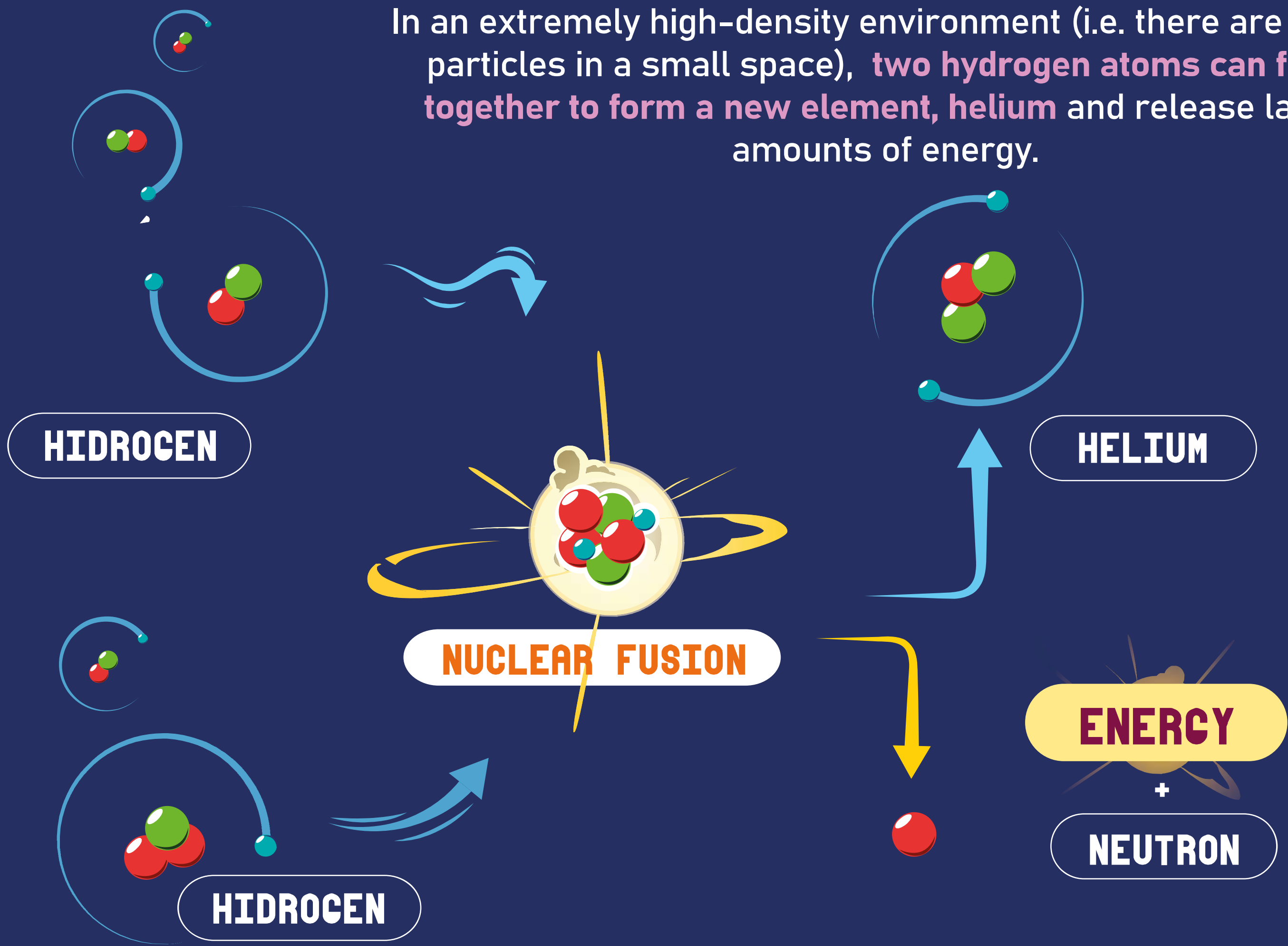
In the Milky Way galaxy there are currently 5 defined arms (although this is still a matter of debate), these arms are large, bright, nebulous areas where there is a large amount of gas and dust with enough material to form thousands and millions of new stars (protostars).

Remember that our sun is "old" now counting about 4.5 billion years.

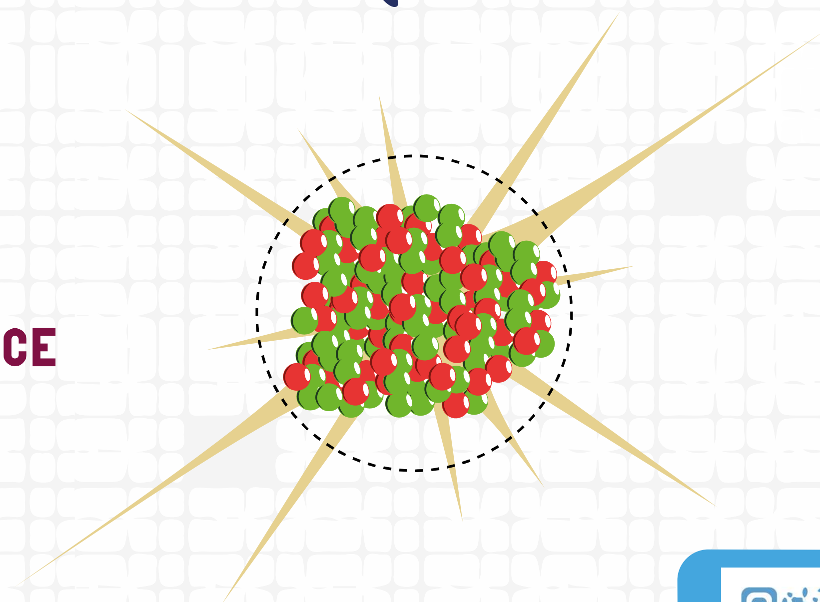
THE ENERGY OF THE STARS

In an extremely high-density environment (i.e. there are many particles in a small space), **two hydrogen atoms can fuse together to form a new element, helium** and release large amounts of energy.

Figure 10: Schematic of the nuclear fusion



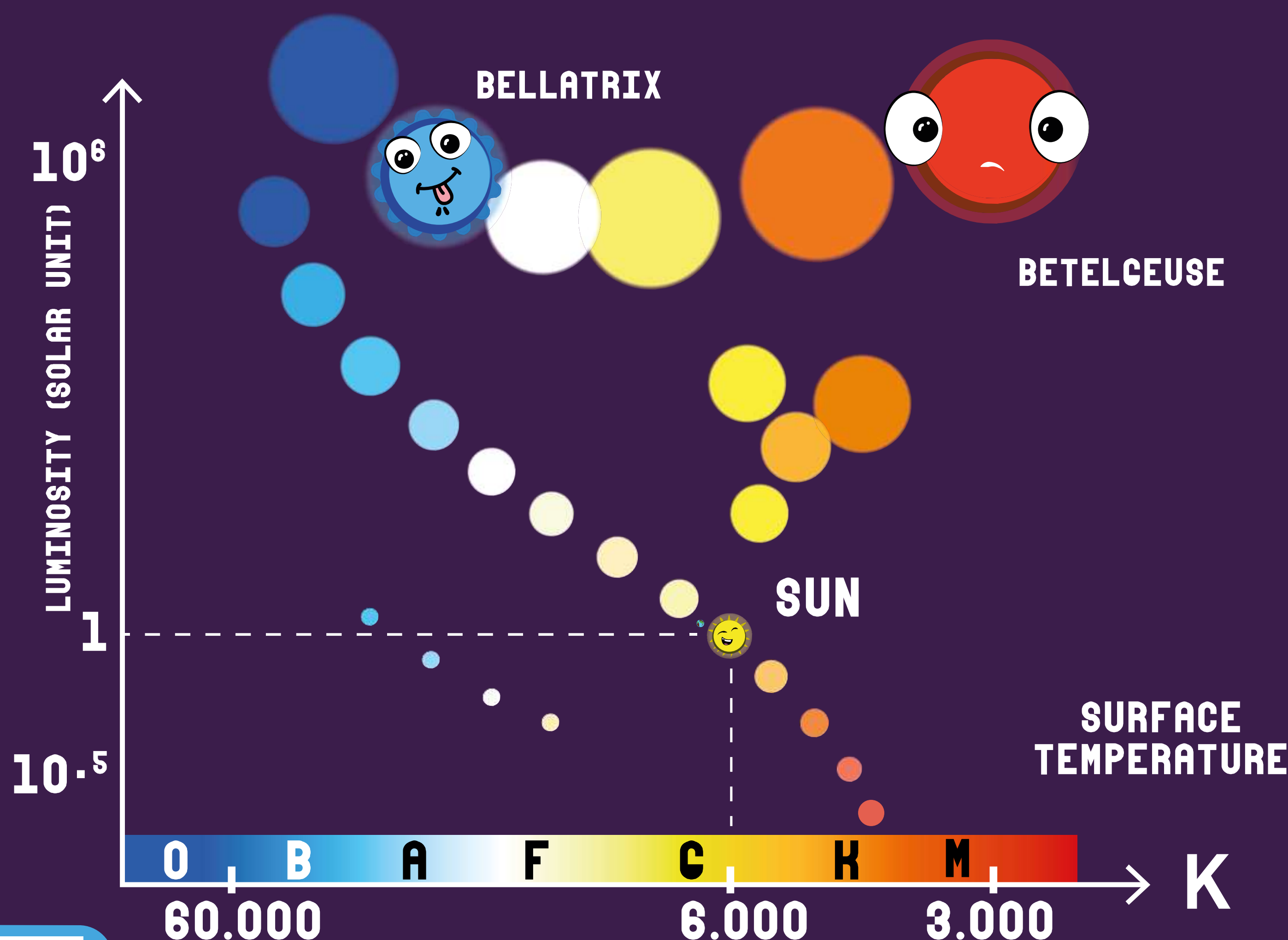
At the centre of a star, where the density is very high due to the effect of gravity, a **(STRONG NUCLEAR) FORCE** comes into action that is so powerful that it allows nuclear fusion processes.



STELLAR EVOLUTION

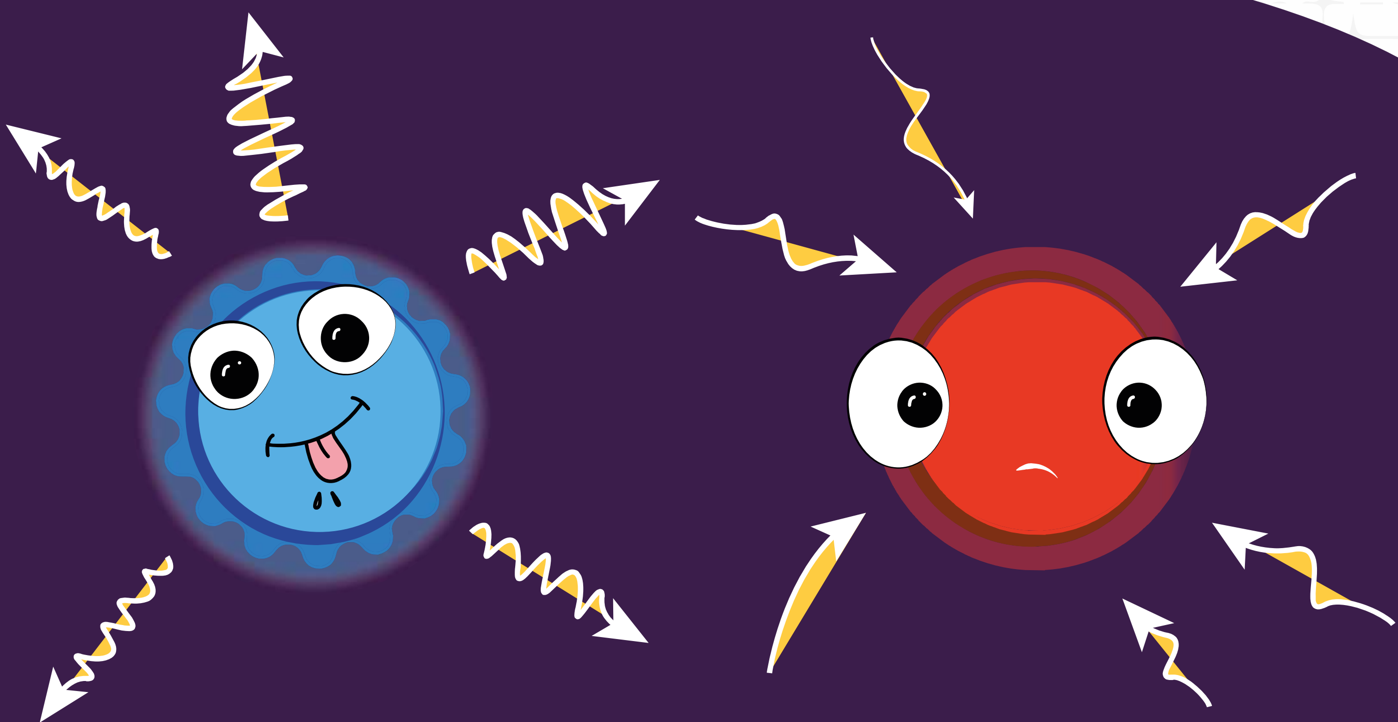
In 1910 astronomers **Ejnar Hertzsprung y Henry Norris Russell** arranged stars according to their brightness and temperature, placing them on a **graph that allows us to infer the age, temperature, luminosity and estimated size** of the observed star. They also showed that in this diagram, the stars follow well-defined sequences that allow us to know their past and also predict their future.

FIGURE 11: HERTZPRUN -RUSSEL DIAGRAM



The temperature of a star cannot be measured directly (in contrast to yours with a thermometer), but its **surface temperature** can be estimated from its colour.

Equipped with a **spectrograph** you can break down **the light from a star into the colours of the rainbow** and measure which of these is more intense.



Hotter stars will be predominantly bluer because they shine brighter at shorter wavelengths.

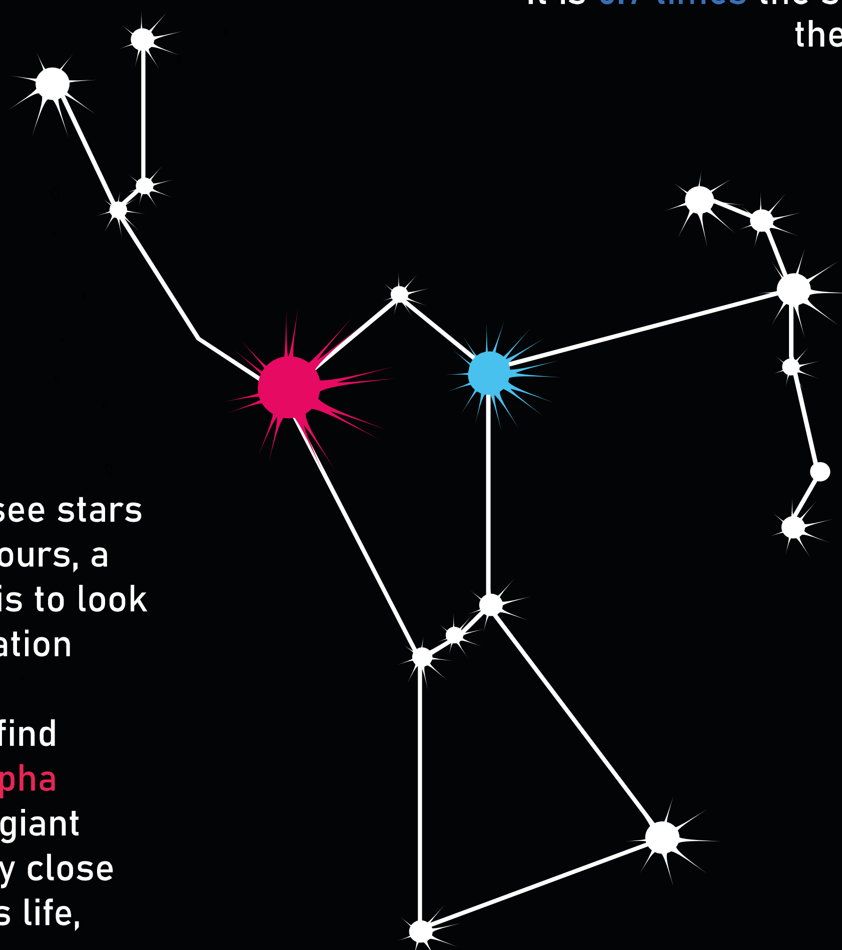
Cooler stars will appear redder as they shine brighter at longer wavelengths.

The bigger the star, the faster it will consume material, and the shorter its lifetime will be. When it finishes consuming hydrogen, more complicated processes will begin that will mark the beginning of the end of the stars' lives.

This ending will be very different depending on how massive the star was when it formed.

ORION CONSTELLATION

In the same constellation we can also see the blue giant Bellatrix (Gamma Orionis), one of the hottest stars that can be seen with the naked eye, with a surface temperature of 21.500K. It is 5.7 times the size of the Sun.



If you want to see stars of different colours, a good example is to look at the constellation Orion.
There you will find Betelgeuse (Alpha Orionis), a red giant star that is very close to the end of its life, with a surface temperature of 3.500 K, and 84 times the size of the Sun

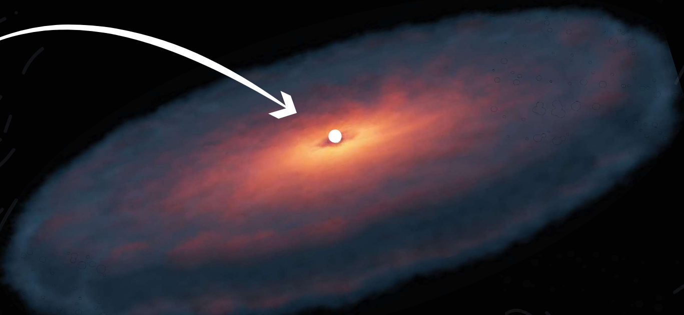
PLANET FORMATION: STAGES

PRE-STELLAR ENVELOPE

A cloud of dust and gas with sizes around 20000 au and temperatures below 20K.

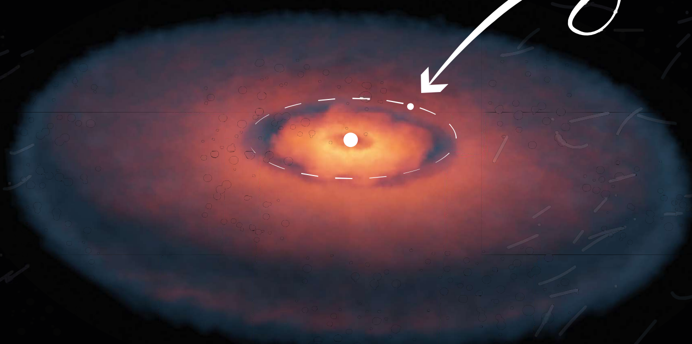
PROTO-STAR

A contracting cloud of gas and dust, due to the effect of its own gravity, which will eventually form a star. During this process, due to the effect of its high rotation, the cloud shrinks, forming a disc around a super-dense centre.



PROTO-PLANET

A small accumulation of dust, rocks and gas with its own gravity, which feeds on the material in the disc, sweeping everything in its path (or orbit) until it forms a planet (giant if it accumulated gas).



DEBRIS DISC

A disc surrounding an already formed star composed of the debris from the formation of giant planets, from which rocky planets such as Earth will form.

The mass of many celestial bodies is measured relative to the mass of the Sun: $M_\odot$.

These rotating discs typically have masses between

$0.01 - 0.1\ M_\odot$

and are made up of 99% gas and 1% dust

Remember to have blindfolds or masks available so that we can all experience the multi-sensory activities without being biased by sight.

TACTILE ACTIVITY

In this activity we will learn how the disc of gas and dust is initially transformed by **the gravity** and **radiation pressure of its central star**, and later by the birth of a planet.

Have you ever walked through the fog?

You would experience something similar walking through the gas and dust disc in the early stages of the model.

You already feel the three-phase model in your hands, and by playing with it and feeling its textures we can put together a representation of what is happening somewhere in a distant part of the galaxy where a new planetary system is forming.

PHASE 1: YOUNG DISC
1 · 2 MILLION YEARS

The first stage of the star formation processes, which we call **PHASE 0** in Figure 12 and not included in this model, begins with the collapse of the nebula, which rotates and flattens to form a protoplanetary disc (**PHASE 1** in the model) around a protostar.
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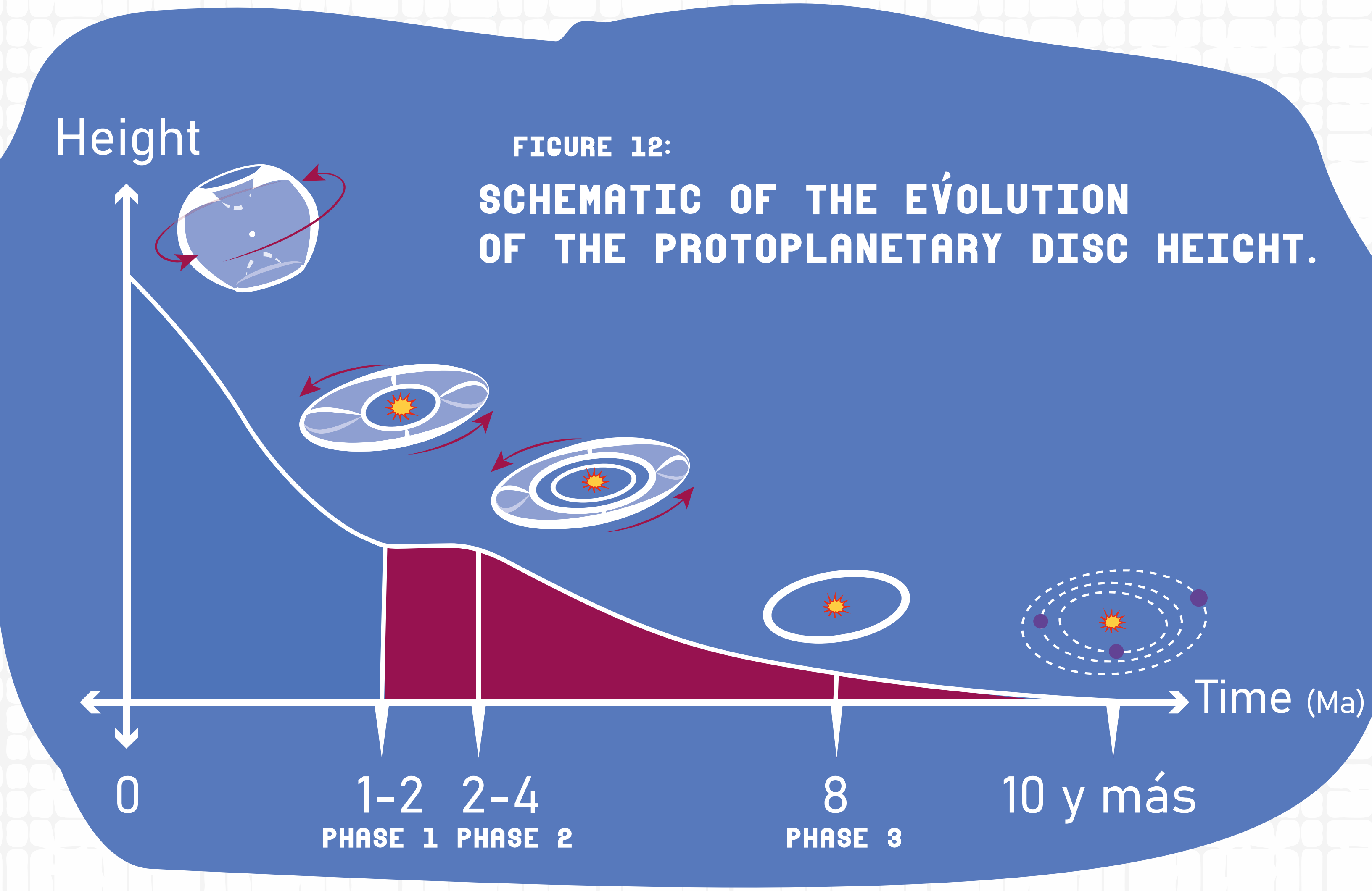
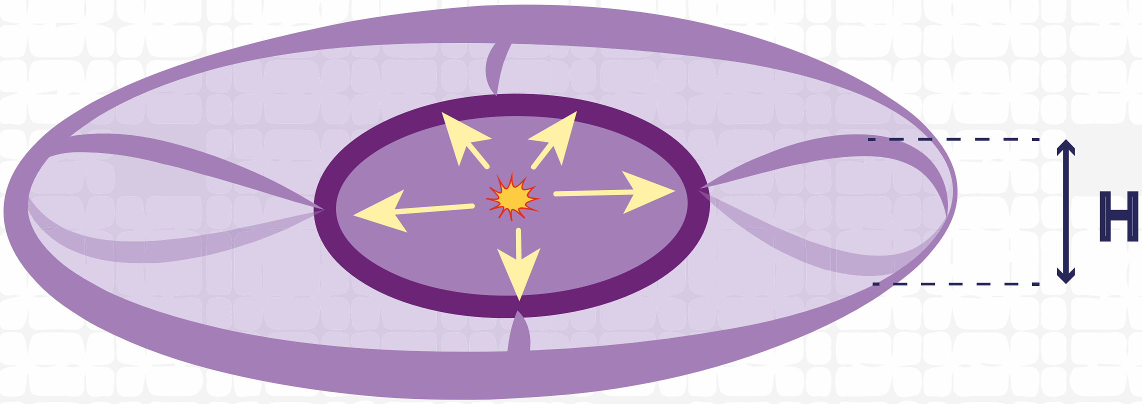


Protoplanetary discs are the environment where planets, asteroids and comets form on a scale of several million years (Myr).

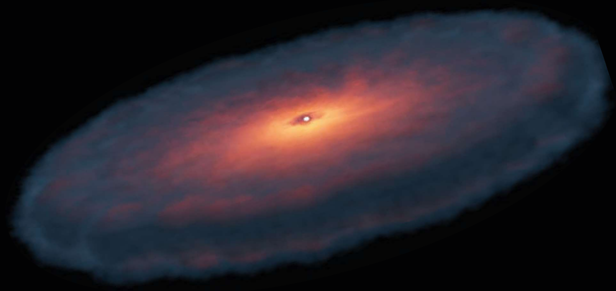
Its shape will mutate as the star evolves, decreasing in height and depleting its material as it ages.

PHASE 1 in the model refers to the time scale where two main components can be seen, **the star in the centre, radiating**, **and the flared disc with a higher altitude towards the outer regions of the system.**



ICE LINES

The radial distances at which different gases (H2O, CO, etc.) condense on dust grains are called "ice lines". These are analogous to the line between vegetation (green) and snow (white) seen on snow-capped mountains in winter. **Inside these lines rocky planets will form and outside gaseous planets will form.**



The protostar will illuminate and heat the atmosphere in the disc it has formed around itself, but if we cut across this disc (Figure 13) we see that towards the mid-plane on the vertical axis the temperature is decreasing.

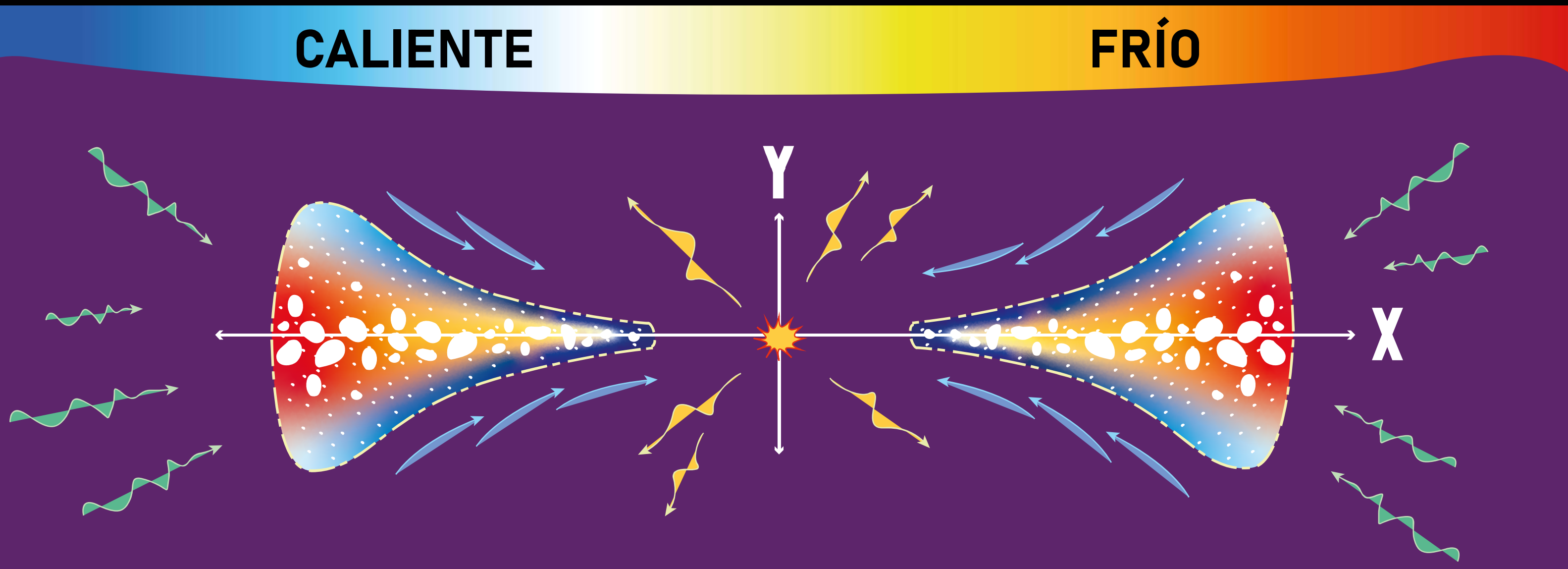


Figure 13: Schematic of motions, temperatures and particle size distributions in a cross-section of the protoplanetary disc.

Does it strike you that the blue represents hot spots?

Also following this cross section, the different components of the disc behave differently: the larger dust particles (> 1 mm) decouple from the gas, populating the regions closer to the midplane, while the smaller ones will continue to move following the gas, which is strongly influenced by stellar radiation.

TABLE 2

DISC TEMPERATURE MOVEMENTS

3.000 K ← → 10 K

Dust (microns) + gas	Pebbles (centimetres and metres)	Planetesimals (kilometres)

MOVIMIENTOS

Stellar winds and radiation pressure	Stellar consumption of the disc material	External radiation (other stars, ...)

The stars are so dispersed and distant from each other that the temperature in **interstellar space** is quite low, **about 20 degrees above absolute 0.**

0° ABSOLUTE

-273.15 °C

HOW DOES A STAR GROW? ¿?

Accretion is the process by which (according to different mechanisms) the star captures material from the disc.

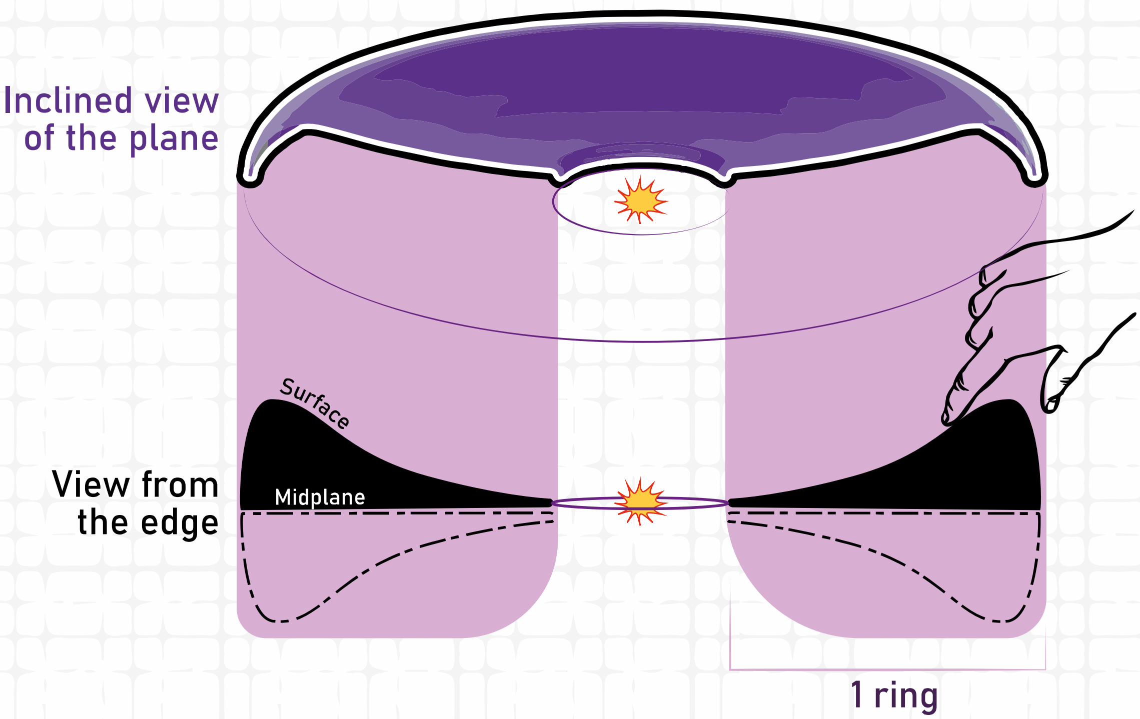
Against this gain, solar winds and radiation pressure stand in the way, in Phase 1 there is still significant accretion.

Material that is not consumed or ejected by the star will continue to revolve around it, fuelling the formation of planets.

PAY ATTENTION TO YOUR HANDS

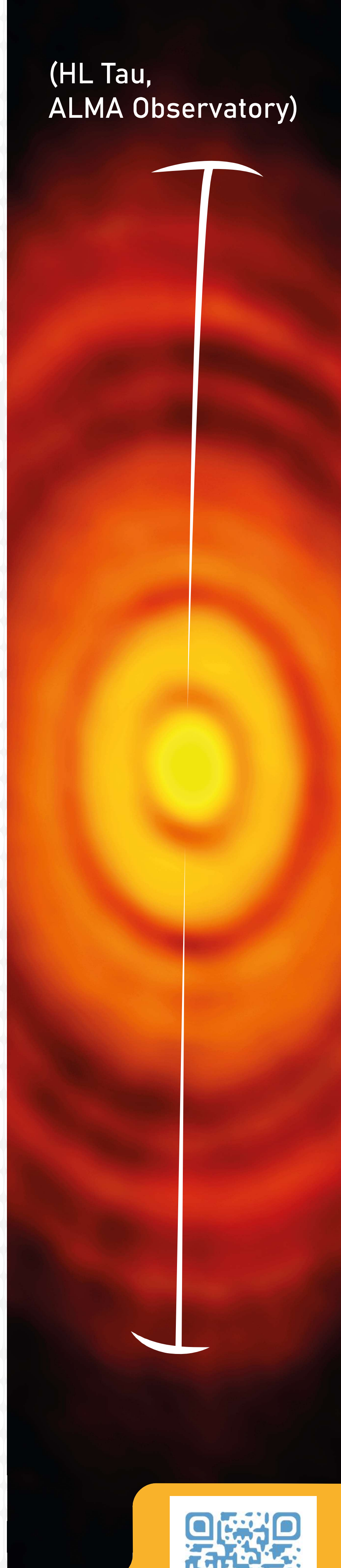
Ask the student to explore Phase 1 of the model with her fingertips and palms, using one or both hands. The rotation of the disc, the texture and the different heights will shed light on the shape and movement of the disc material.

Above the disc we are feeling a gaseous cloud mixed with almost imperceptible particulate grains, and homogeneous. The prototype grows in height as we move away from the centre. The thickness is directly related to the presence of gas.



In the model, the size of the star is artificially increased with respect to the size of the disc.

If the disc were on the same scale, it would be 10 metres in diameter.



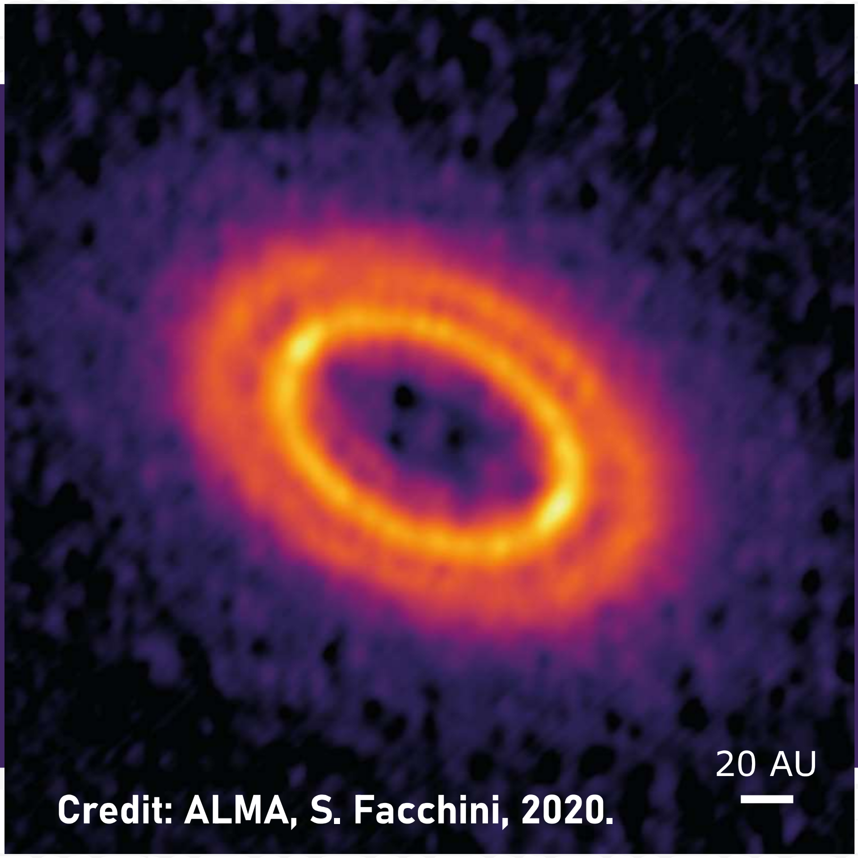
PHASE 2: DISC STRUCTURES AND PLANETARY FORMATION

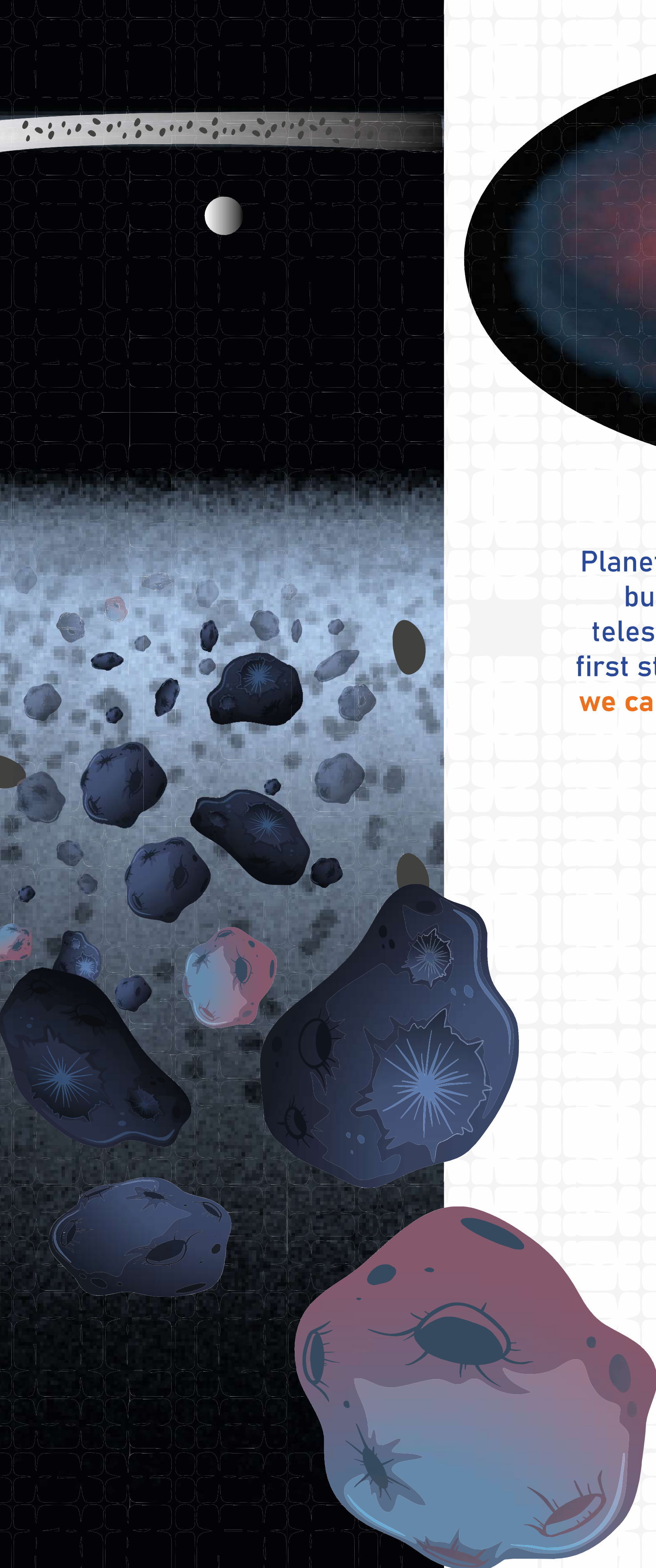
2 · 8 MILLION YEARS

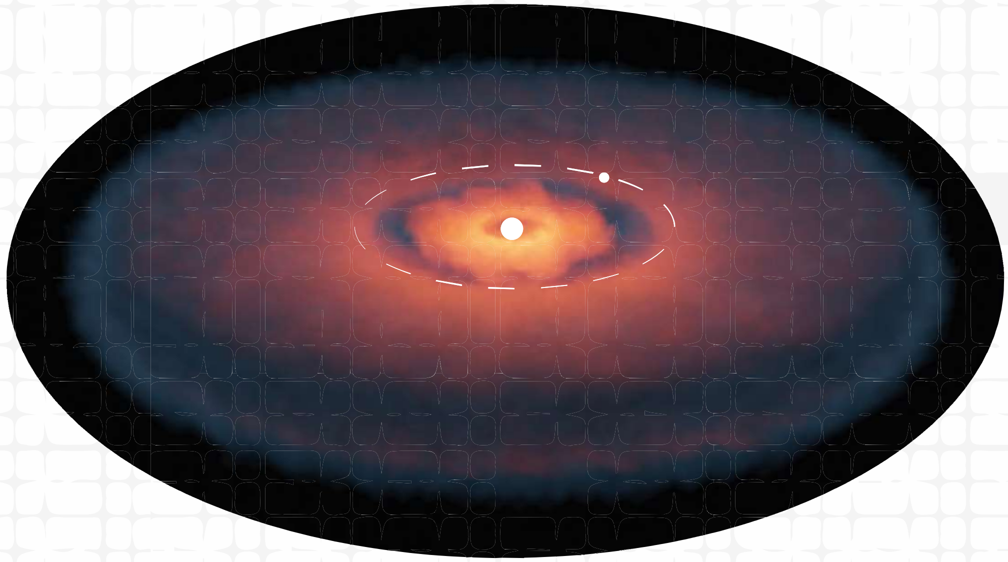
The star has already consumed all the nearby material, its X-ray and ultraviolet radiation has created a vacuum that separates it from the disc.

Many of the photons emitted by the star will have a low probability of travelling further, as they will be absorbed and/or scattered into the surrounding medium with lower energy. On the other hand, those that are emitted perpendicular to the disc will be able to travel further, even as far as our telescopes, and can be detected.

Figure 14:
LkCa 15 is a young star analogous to our Sun, which has an inner cavity devoid of dust and where the first interactions between a young giant planet and the disc may be evident.







Planet formation is already taking place, but with today's technology (radio telescopes) we cannot yet observe the first stages (protoplanets) in detail. **What we can see are the gaps produced in the disc.**

As the protoplanets move in their orbits within the disc, they will become increasingly massive as they capture some of the surrounding material. **The increase in their mass will, in turn, imply an increase in their gravitational power.** That is to say, the more mass they capture, the more they will be able to capture much more.

SOME NEARBY PROTO-PROTOPLANETARY DISCS

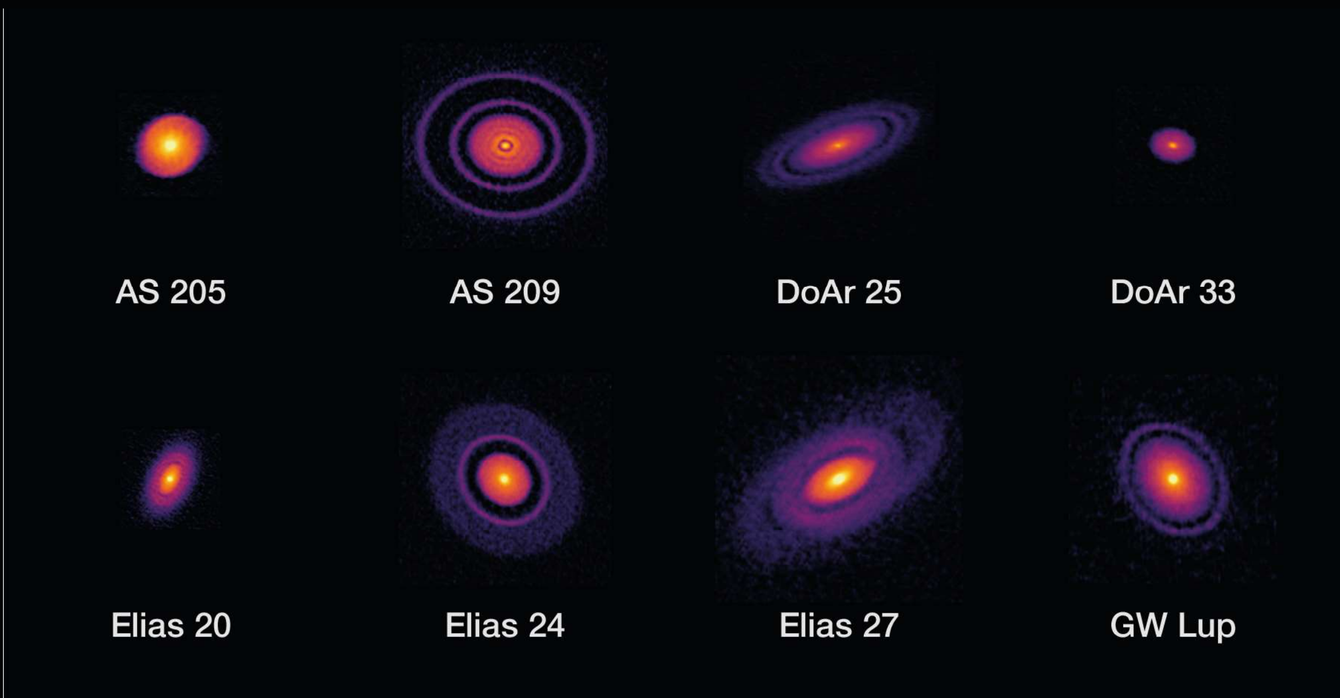


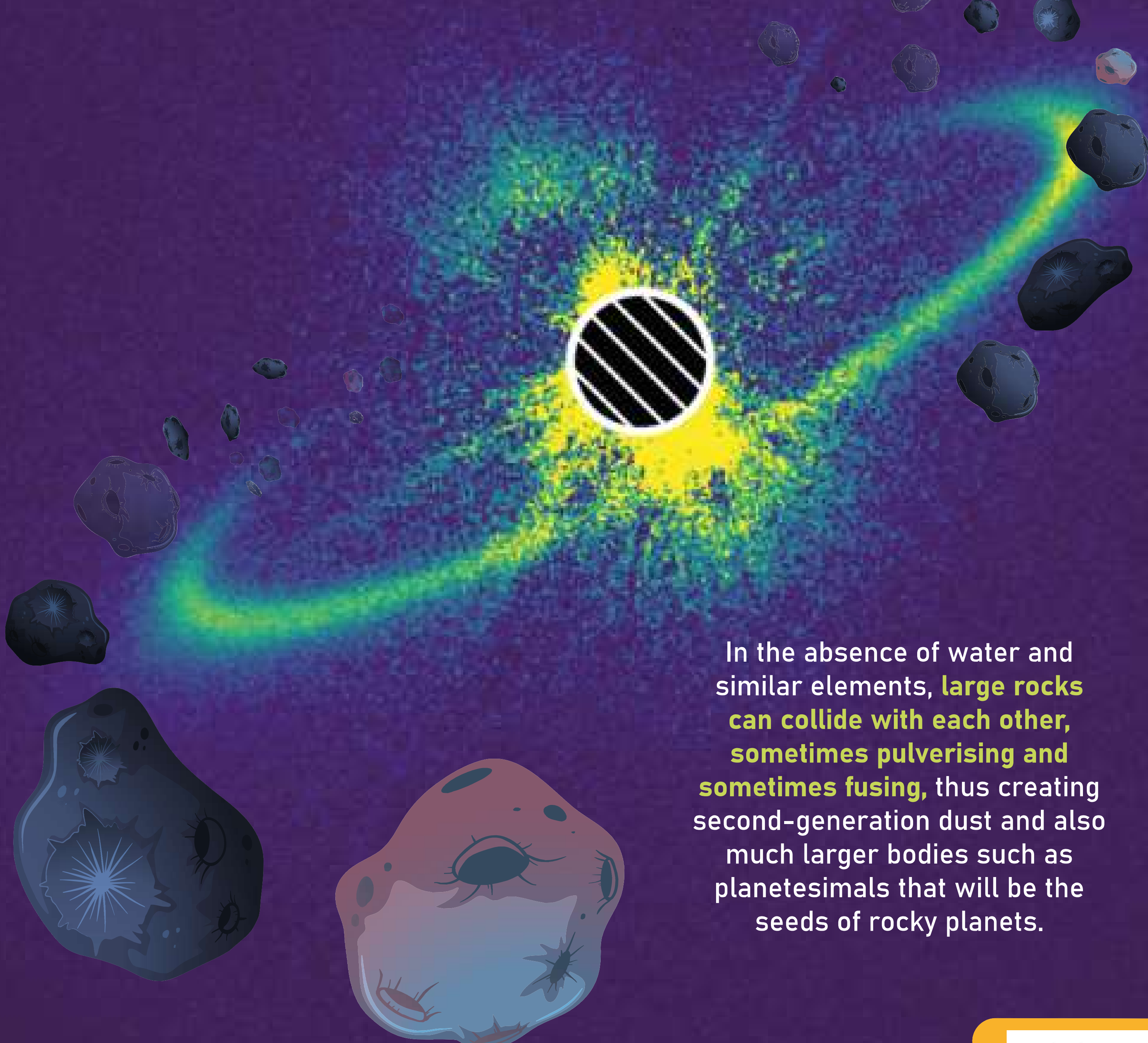
Figure 15: Protoplanetary discs. DSHARP project (S. Andrews et al.; N. Lira, ALMA (ESO/NAOJ/NRAO))

Figure 16: Decomposing the light from these objects (spectroscopy) reveals the interaction of the stellar radiation with the gas and dust molecules in the disc.

As each molecule and chemical element has a unique spectroscopic fingerprint, it is possible to infer the composition of the disc.

Figure adapted from Kamp et al, 2017.

As the star is the main source of energy, the regions of the disc closest or most exposed to it will have much higher temperatures than those farther away or less exposed (inner disc). **In low-temperature regions, molecules of water and other materials condense on the small dust grains and act as a natural glue between them,** favouring the formation and growth of planetesimals.

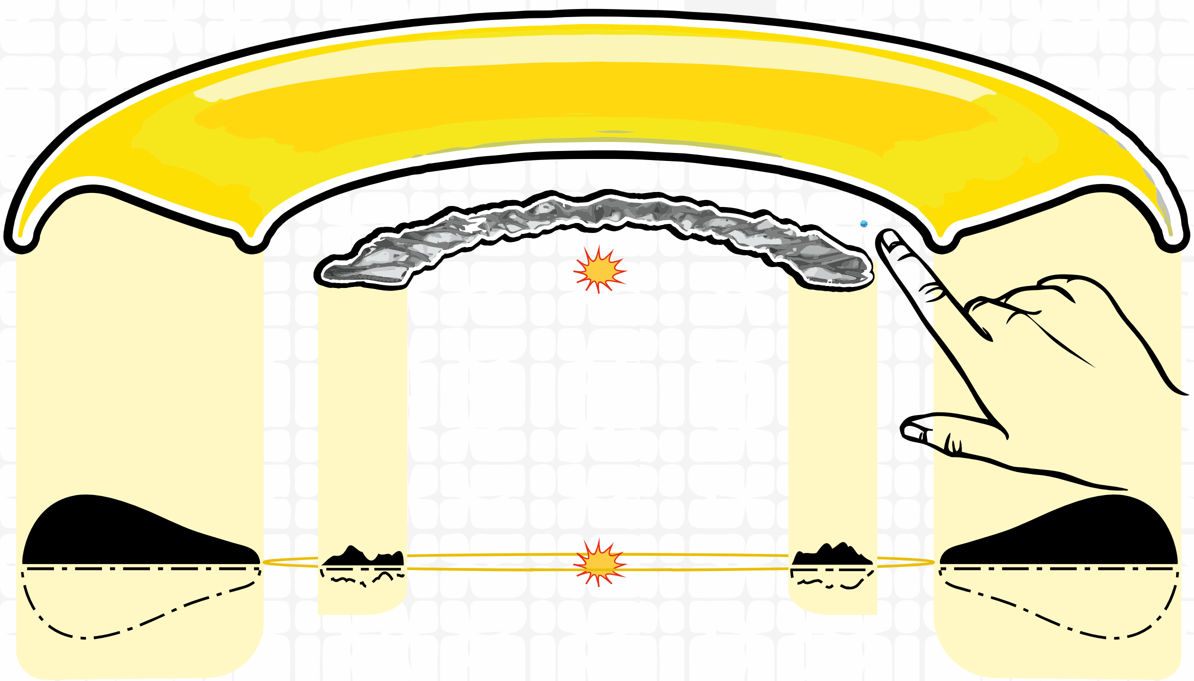


In the absence of water and similar elements, **large rocks can collide with each other, sometimes pulverising and sometimes fusing,** thus creating second-generation dust and also much larger bodies such as planetesimals that will be the seeds of rocky planets.

PAY ATTENTION TO YOUR HANDS

Lift the Phase 1 layer to reveal Phase 2.

In a cosmic blink of an eye (~one million years) new structures have been created. We are feeling a central ring, but there are also cases where spiral arms form (which this model does not show). Around the star, there is still a void that is now even larger. If we continue to explore outwards, the height of the disc increases, but to a lesser extent than in Phase 1. What has happened to the large mass of gas?



Let's feel the ring again and try to identify the planet in formation that is responsible for opening that gap in the disc.

In the model, the size of the protoplanet is also artificially enlarged so that we can feel it. In this case, if the disc were on the same scale, it would be 100 metres across.

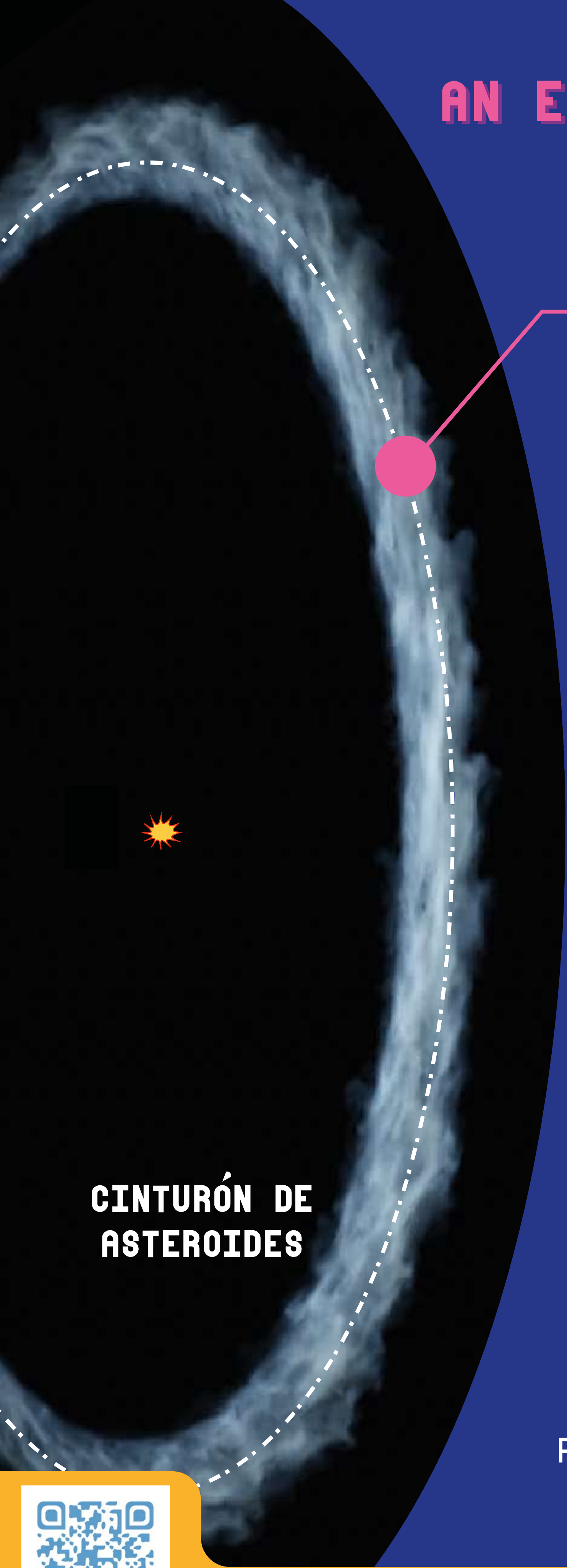
PHASE 3: DEBRIS DISCS

> 8 MILLION YEARS

This is the evolutionary moment where the transformation of the disc slows down because there is no gaseous material left. Some of the original material was accreted by the star, some by the forming planets, and some was expelled from the system.

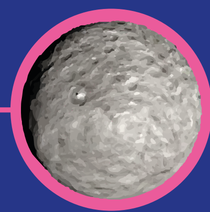
Phases 1 and 2 gave rise to arms and rings populated by planetesimals, giant planets, etc. Collisions and/or interactions between these elements repopulate the disc with small dust grains (second generation), favour the transport of ices from the outer parts towards the star (exo-comets), and provide the right conditions for the formation of rocky planets.

FIGURE 17: ORBITS OF ASTEROIDS AND COMETS



AN ENORMOUS ASTEROID

CERES



MOON

In 1801, the Italian Giuseppe Piazzi observed the largest asteroid ever found: Ceres. This object is located in the main asteroid belt, between the orbits of Mars and Jupiter.

Its size: 1/4 of the Moon	**Its mass:** 1/3 of the total mass of the belt

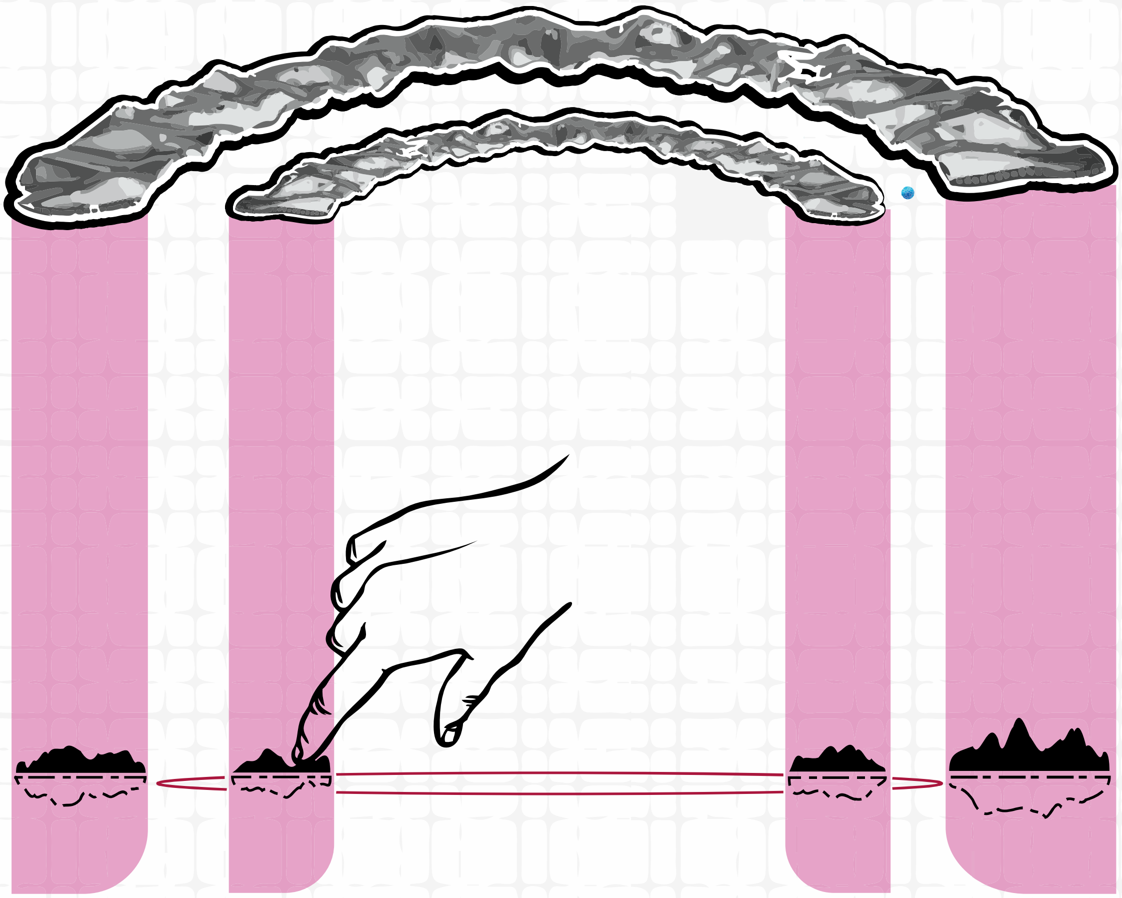
Ceres cannot be classified as a minor body, because it is the most massive of all observed asteroids, but neither can it be classified as a planet, because it is not the dominant body in its orbit. In 2006 the International Astronomical Union created a new classification: **Dwarf Planet.** Something similar happened with Pluto.

PAY ATTENTION TO YOUR HANDS

Lift the outer layer of Phase 2.

Feel that there are striking changes in the outer disc. The gas has dissipated leaving only rocky debris and dust.

This debris lies icy and distant from the star in a second debris belt.



The surviving bodies are now stable and remind us a little of our own solar system.

In the centre is the star, further out is an asteroid belt that marks the border between the realm of the small planets and that of the giants.

Below is the giant planet that formed in Phase 2. In the outermost part of the system a second belt can be seen, which would be the analogue of the Kuiper belt of our Solar System.

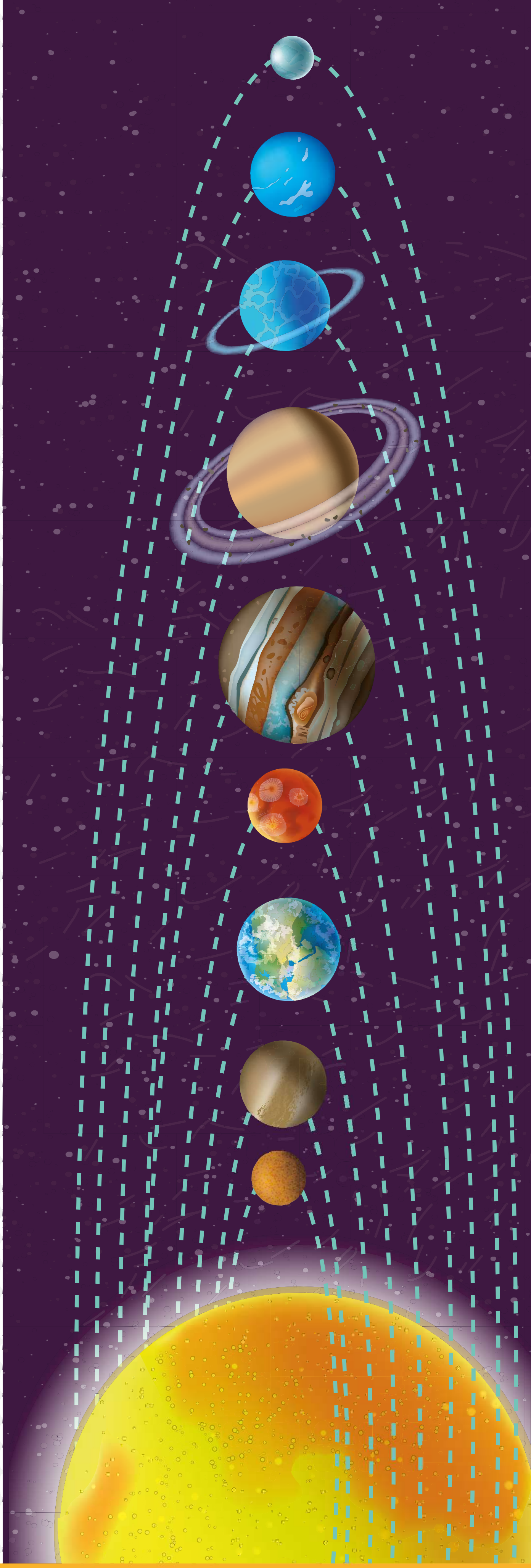
SOLAR SYSTEM ACTIVITY AT TWO SCALES

Link on Page 1.

Our friends at AstroUDP invite us to use **touch rather than sight**. Our Sun has already dispersed its infantile envelope of dust and gas, now we are left with the planets and planetesimals that we see with binoculars and telescopes.

This second model is designed for the visually impaired, and **is on two scales**: one for the **sizes of the planets and the Sun relative to each other** and another, 1000 times smaller, **for the distance between them**. Have several blindfolds.

How big would the Solar System be if the Moon were a pixel? Discover the large void left by our Sun when the system stabilised.



SCIENTIFIC EXPERIMENT

How big is the Sun?

Now the team (in their roles) will be able to calculate the diameter of a star from their planet

MATERIALS

You will need a sunny day

A tape measure

A sheet of paper

A sharp object

PROCEDURE

Drill a small hole in the centre of the sheet, the hole represents our Sun.

Place the sheet under daylight.

When the sunlight passes through the small hole, the projected silhouette of the Sun will light up on the ground. This point represents the Earth.

Measure the distance from the ground to the sheet, and the diameter of the circular silhouette on the ground.

Look up the distance between the Earth and the Sun on the internet.

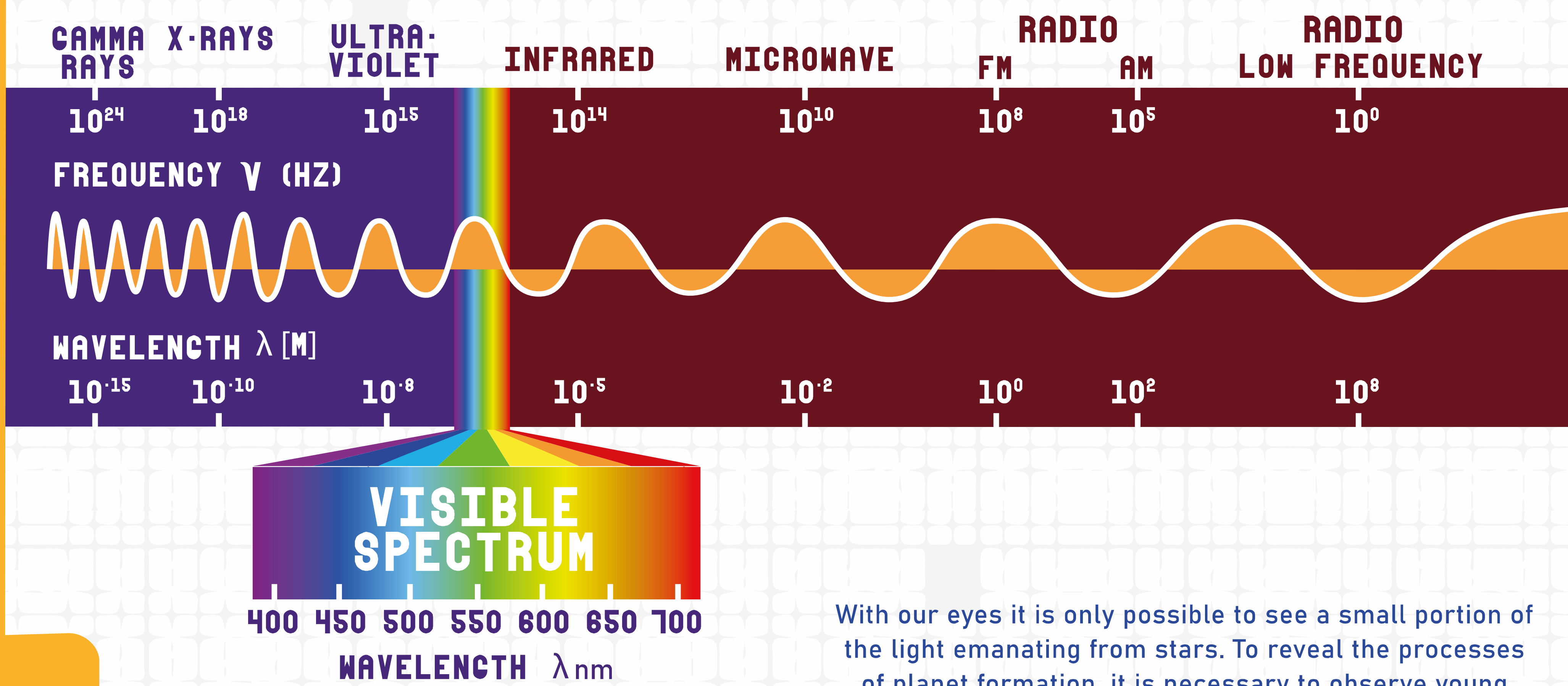
Apply the rule of three (Thales' theorem) with the measured distance, the value of the shadow, and the distance to the Sun to find its real diameter.

When the Sun evolves in the next 4.5 billion years...

Will we be the same distance away as we are today?

What colour will the Sun and the Earth be?

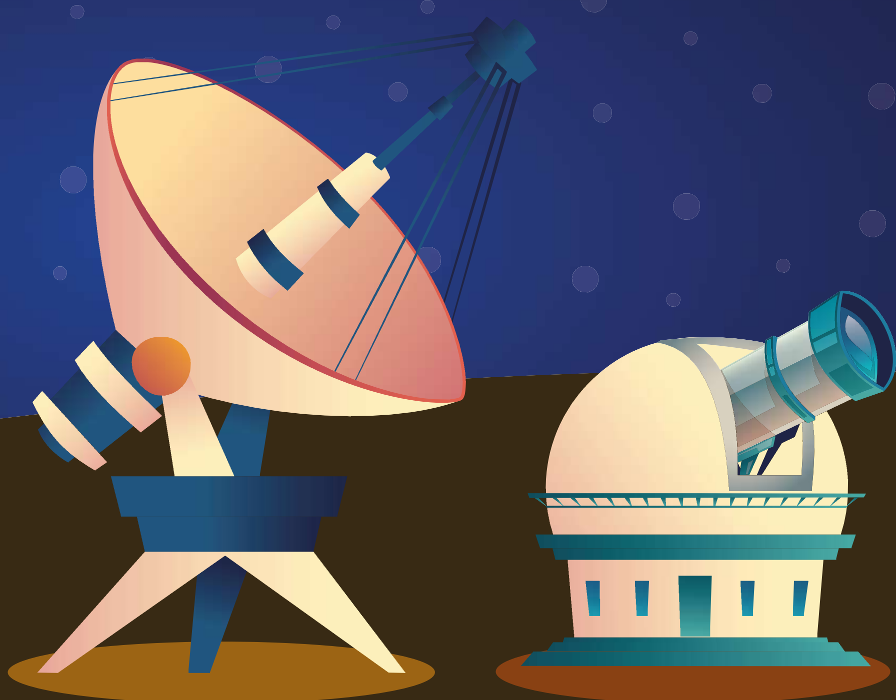
FIGURE 18: ELECTROMAGNETIC SPECTRUM



MEASURING TOOLS

With our eyes it is only possible to see a small portion of the light emanating from stars. To reveal the processes of planet formation, it is necessary to observe young stars at longer wavelengths, from the infrared towards the right of the diagram. By interacting so weakly with the gas and dust surrounding the star, this type of light can emerge from the interiors of these systems carrying information about what is happening there.

A **domestic optical telescope** works thanks to a set of lenses and/or mirrors that can capture a portion of the light emitted by celestial objects and direct it through the small opening of your eye (the pupil) to form an image on your retina. In the retina **there are light receptors that are sensitive to the colours red, green and blue, which are part of the visible range of light.**

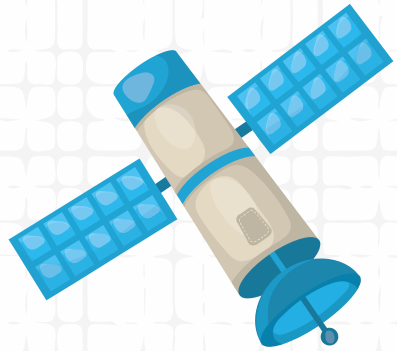


A radio telescope uses one or more antennas that pick up the radio waves emitted by celestial objects.

This information is analysed by computers and can be encoded into images seen by our eyes.

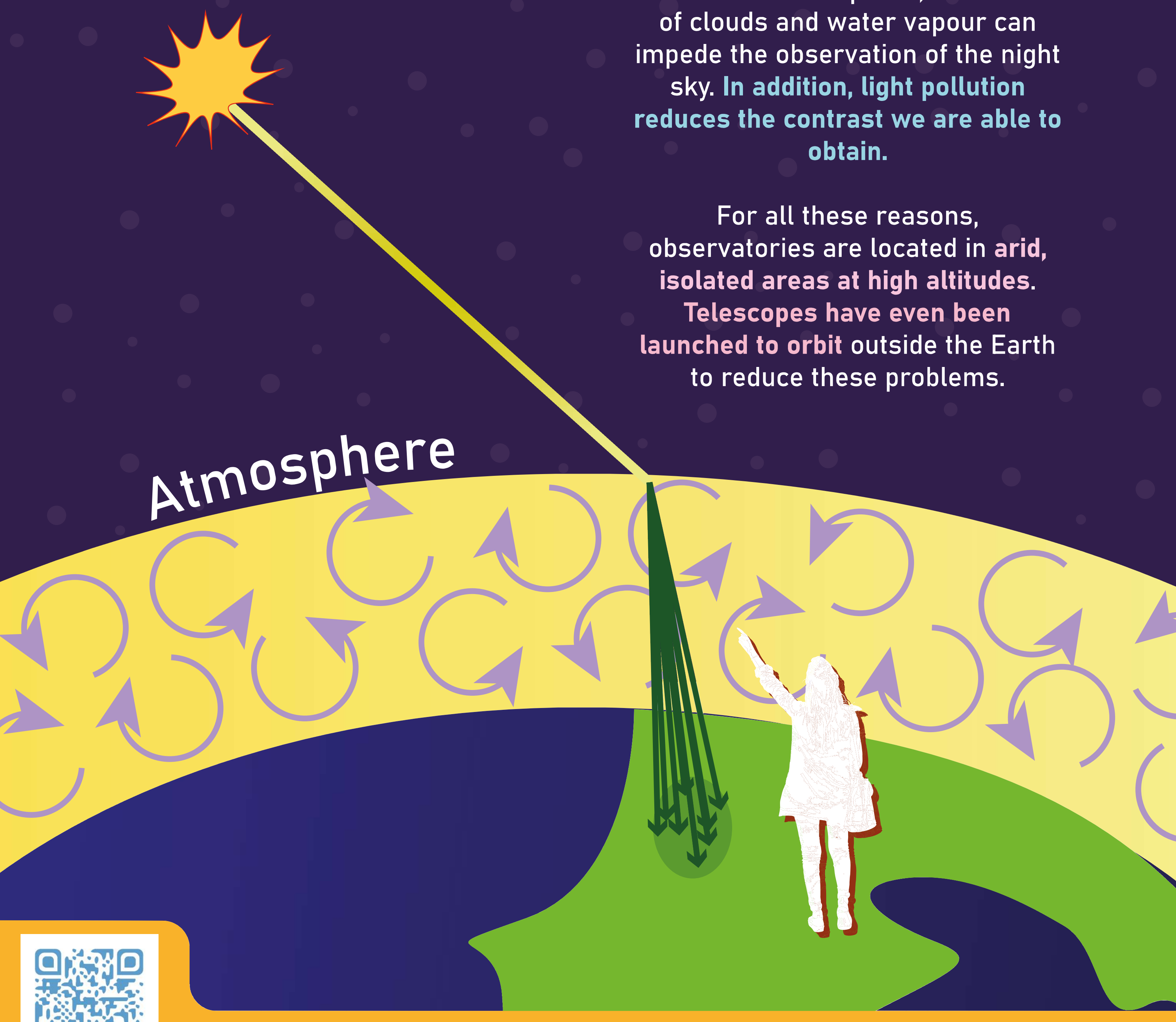
The most advanced observatories, such as ALMA, work by combining the information obtained by dozens of antennas separated by large distances to achieve a level of detail similar to the best infrared telescopes.

A challenge for observing in the visual and infrared range from Earth is that our atmosphere interferes with the light coming from celestial objects, distorting it, and thus worsening the sharpness of the images obtained.



Also in our atmosphere, the effects of clouds and water vapour can impede the observation of the night sky. **In addition, light pollution reduces the contrast we are able to obtain.**

For all these reasons, observatories are located in **arid, isolated areas at high altitudes**. **Telescopes have even been launched to orbit** outside the Earth to reduce these problems.



PlaneTrivia

To accompany the end of the activity, scan the following codes to enter the Planetrivia: a series of quizzes to test your astronomical knowledge.

Planet formation

The life of the stars

General astronomical concepts

Overview of the Solar System

RESOURCES IN ENGLISH

Beuther H., et al. (2014), “Protostars and Planets VI”, University of Arizona.

Schulz, Norbert S., (2012), “The Formation and Early Evolution of Stars), Springer, p. 121-138.

Dmitry A. Semenov, ”Accretion disk around young stars: the cradles of planet formation”.

RESOURCES IN SPANISH

Census of astronomers - SOCHIAS

Universal Design for Learning DUA - Dualetic

Core competencies - Juan López

The 100 languages of the child - Loris Malaguzzi

Socratic Questions - Eduteka

Rosselli Monica, (2015), "Neuropsychological development of visuospatial and visoconstructional skills", Journal Neuropsychology, Neuropsychiatry and Neurosciences, 15(1), p.(175-200).

Routines of thought - A. Hidalgo Cortés

Suggestions for making accessible material - Universidad Técnica Federico Santa María.

Theory of Multiple Intelligences - Howard Gardner

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