CESAR Scientific Challenge

Revealing the mysteries of the Universe

(Observing visible and invisible light)

Teacher Guide

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Didactics

Learning objectives

Figure I: *The considered top 10 skills in the 2020. (Credits: Rethinking).*

The CESAR Team generates activities for students to develop the considered top 10 skills in the 2020, where problem solving requires critical thinking and creativity. Our proposal is to execute these activities in teams. Students will find the environment where to develop their communication skills, managing different opinions and approaches, and making use of their emotional intelligence.

The CESAR scientific challenges aim to follow the thinking skills order established by the Bloom's taxonomy diagram, from a low order thinking skills (**remembering, understanding)** to a high order thinking skills (**evaluating, creating**), passing through mid-order thinking skills (**applying** methods and concepts for **analyzing** events).

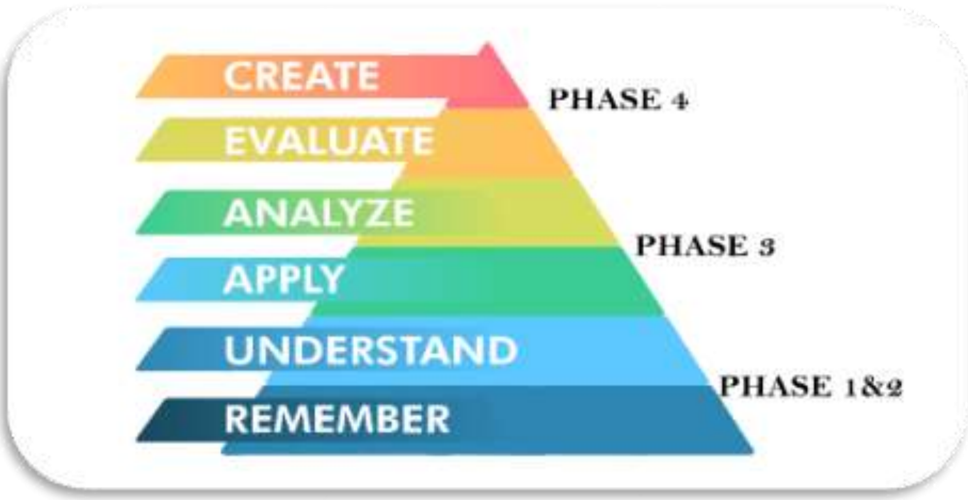

Figure II: *Bloom's Taxonomy diagram. (Credits:* https://medium.com/@ryan.ubc.edtech/*)*

Teaching Techniques:

In order to achieve the previously mentioned Learning Objectives, the CESAR Team recommends the use of some techniques like, ***flipped-classroom, solution of daily life problems (using the scientific method) and collaborative work.***

In this activity students will make use of the *flipped classroom* for Phases 0 and 1 to get ready for the problems solution of their Challenge during Phase 3. Phase 2 is optional and consist on a video call with us. In Phase 4, each team will evaluate their Experience and share it with the Scientific Community (their class/center and us, the CESAR Team). All phases are recommended to be executed as collaborative work (using **forum and blogs)**. Here we detail the process:

- **Your Scientific Challenge:** We introduce the Challenge to students and ask for their support
- **Phase 0: Putting things into context**
  - The role of the **European Space Agency** their center in Spain (European Space and Astronomy Centre, ESAC) as well as the CESAR Team. (in videos)
  - **Nowadays role models** for students to build the **Teams for their Challenge**. We recommend that Teams are formed by 4-6 people, each one of them with well-defined tasks. When possible, try to balance them in gender and diversity of capabilities.
- **Phase 1 and Phase 2:** ***remembering and understanding*** using different sources:
  - **Phase 1**: scholar cv material & new concepts (videos, documents, games)
  - **Phase 2 (optional)**: learn from an expert
    - For the teachers: talks provided by experts on the topic in previous CESAR teacher workshops.
    - For the classroom: A video call with the CESAR Team to solve doubts that may have appeared until the moment in what students have just learnt. At this stage, students had already become "experts" on the topic of the Challenge .
- **Phase 3:** ***applying*** the already known concepts following a methodology (procedures) for ***analyzing*** *data* and *solving daily life problems* (their Scientific Challenge).
- **Phase 4:**
  - ***evaluating*** their learning process during the Challenge (self and co-evaluation)
  - ***creating*** a final product to show to the Community (class/school/us) their learning process. With this you could participate in the CESAR Scientific Challenge contest.

As Figure III shows, the CESAR Scientific Challenges should execute all mentioned Phases. Phase 0 and 1, are the roots for all the Scientific Experiences, always to be done in the classroom/home. Phase 2 (video call executed from the classroom to us) is optional.

Depending on the type of Phase 3, there are various CESAR Experience Types:

- **Type I: Space Science Experience(s) @ESAC**: At ESAC, (as always in the past), completely run by the CESAR Team. Total duration 1.5 hours, with 45 minutes for the Activity and another 45 minutes the tour around the ESA spacecraft models.

1. **Type II : On-line Space Science Experience(s)**: In the classroom/home, (Type I but completely guided by the teacher). Total duration 1h (MIXED when combined with Type I/III)
2. **Type III: On-line Research Project**: In the classroom/home, completely guided by the teacher. Total duration several days. (Type II but executing more or all the Activities of the Guide).

Phase 4 is always executed in the classroom/home to evaluate the learning process per Team as a whole.

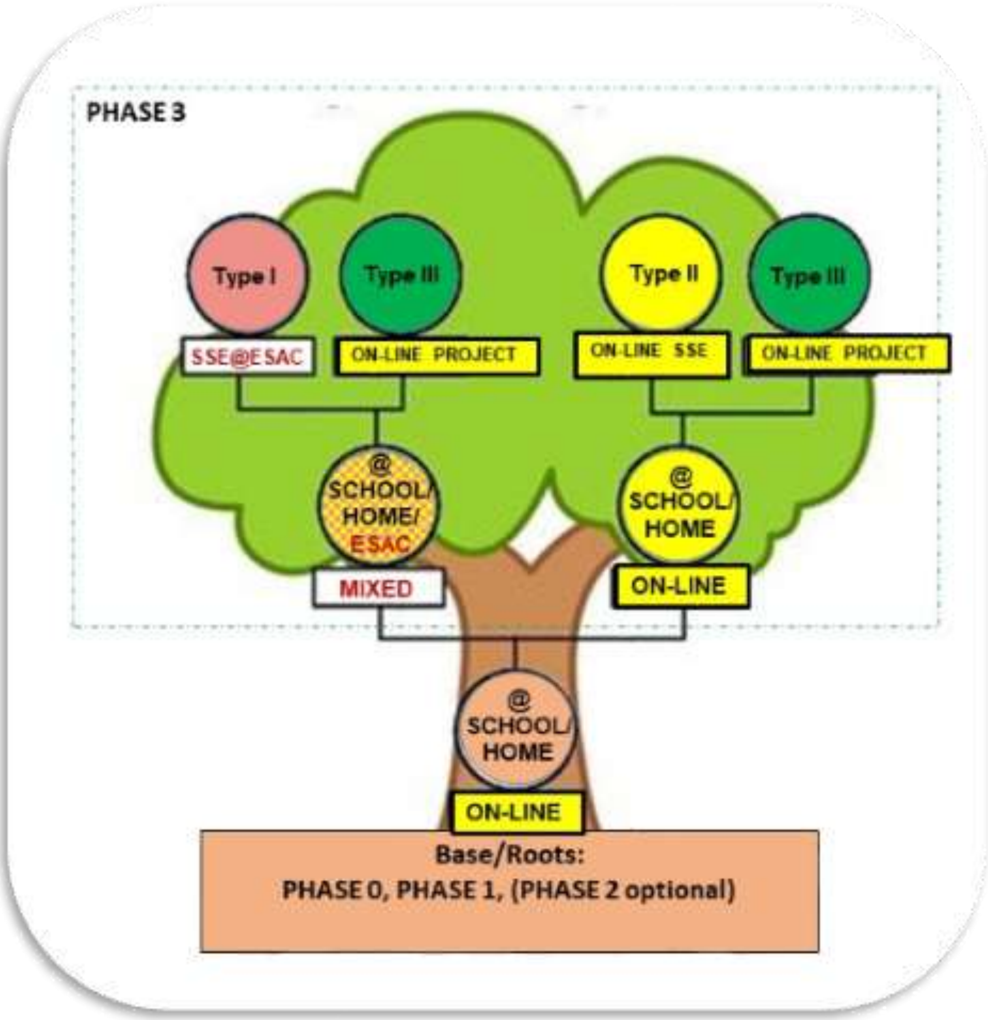

Figure III: Decision tree of the CESAR Experiences according to Phase 3 (Tipo I @ESAC, Tipo II y III, on-line) .In yellow are indicated those paths that can be run completely on-line.(Credits:teacherspayteachers.com)

Teachers are the best ones in assessing the Type of Experience (Challenge) for their classroom and school year conditions. **Per each Type of Experience we propose you different Adventures. The teacher decides if each Team in the class execute an Adventure and once finish they put them in common or whether all the Teams execute the same Adventure(s) at the time (see Tables I, II and III).** Teachers can also decide whether they want to execute some Activities on-line, and when it became feasible, to ask for the already well known an SSE @ESAC (Type I), for the same Challenge but different Adventure or another Challenge (see Figure III).

The CESAR Team recommends you to follow the phases in order (for an optimum learning process) and do not start one before closing the previous one. The Table Summary of Activities" will mention when the execution of a previous Activity is required. The CESAR Team can be contacted once in phase 2 (with the class) and in phase 3 (only for the teacher). For that, dedicated slots of 30 minutes are scheduled.

For the Scientific Challenge, the Fast Facts section provides the information regarding the school curriculum and the contents of each of the Activities (by Phase) can be found in the Table "Summary of Activities". The flavors of Adventures, per each Type of Scientific Experience are in Tables I, III and III.

Table I: Space Science Experience @ESAC (SSE @ESAC):

Phase	0	1	2	3	4	Minimum duration
Activities (Adventure 1)	videos	1,3, 4,6.1,7	9*	10.1,10.2,11	14	3,15 h
Activities (Adventure 2)	videos	1,3, 4,6.1,7	9*	10.1, 11.2	14	3,10 h
Activities (Adventure 3)	videos	1,3, 4,6.2,7	9*	10.1,11.2	14	3,10h
Activities (Adventure 4)	videos	1,3, 4,6.3,7	9*	10.1, 11.2	14	3,10h
Activities (Adventure 5)	videos	1,3, 4,6,7	9*	10.1, 10.3, 11.2	14	3,15h
Activities (Adventure 6)	videos	1,3, 4,6.1,7	9*	10.1,10.4,(11.1,11.2,11.3,11.4), 12	14	3,45h
Activities (Adventure 7)	videos	1,3, 4,6.1,7	9*	10.1,10.4, 10.5,	14	3,30h

Table II: On-line Space Science Experience (On-line SSE):

Phase	0	1	2	3	4	Minimum duration
Activities (Adventure 1)	videos	1,3, 4,6.1,7	9*	10.1,10.2,11	14	3,15 h
Activities (Adventure 2)	videos	1,3, 4,6.1,7	9*	10.1, 11.2	14	3,10 h
Activities (Adventure 3)	videos	1,3, 4,6.2,7	9*	10.1, 11.2	14	3,10h
Activities (Adventure 4)	videos	1,3, 4,6.3,7	9*	10.1, 11.2	14	3,10h
Activities (Adventure 5)	videos	1,3, 4,6,7	9*	10.1, 10.3, 11.2	14	3,15h

Table III: Research Project: All Activities

Phase	0	1	2	3	4	Minimum duration
Activities	all	all	9*	All	all	4,30 h

(*) optional activity, only if concepts of Phase 1 are not clear – check yourself in Activity 8

REALLY IMPORTANT

- ✓ As a teacher, **register as part of the CESAR Community** [here](#) (If you approach us for the first time, it may take some time – a non-automatic process -, but you will not regret ;o))
- ✓ **Once you have been confirmed as part of the CESAR Community** ask for the CESAR Scientific Experiences to live with your class **and you will be guided in the process:**
  - Click here to request an on-line experience – Type II & III
  - Click here to request a combined experience - Type I (Only for schools in the Comunidad de Madrid and close cities)
- ✓ **Guides are very long (many possible tools) to build your Experience but also very flexible**

It is your time! Choose your Adventure!

Fast Facts:

Age range: 14-18

Type: Scientific challenge for students

Complexity: Medium

Teacher preparation time: (1 -2) hours

Lesson time required: (1 -3) hours, depending on the activities selected by the teacher to be executed.

Location: Indoors

Includes use of: Computers, internet

Curriculum relevance

General

- Working scientifically.
- Use of ICT.

Physics

- Waves.
- Light waves. The electromagnetic spectrum.
- Temperature. Blackbody radiation.

Space/Astronomy

- Research and exploration of the Universe.
- The evolution of stars.
- Stars, star clusters, interstellar medium, galaxies.

To know more...

- CESAR Booklets:
  - "The electromagnetic spectrum"
  - "Interstellar medium"
  - "Stellar evolution"
  - "Galaxies"

Outline

In this scientific challenge, students will learn about various astronomical objects, from "small" scales, like stars, to galaxies, passing through cluster of stars and interstellar medium.

From the color of the stars, students will estimate temperatures, by comparing them with a set of bulbs of well-known temperature values. Using simulators, students will understand at what wavelength (color) the peak of the black body distribution falls as well as possible evolutionary stages of the star, depending on their location in the Herztsprung- Rusell diagram.

Key for this scientific challenge is the inspection of astronomical objects in those regions of the electromagnetic spectrum for which there are available data from the European Space Agency scientific missions using ESASky.

Analyzing ESASky images in different wavelengths, students will discover the distribution of star populations in close galaxies, the population of stars in distant galaxies, as well as the effects of molecular clouds.

Students should already know (Phase 1, Activity 1)

- The concept and basic properties of waves.
- The concept of light as an electromagnetic wave.
- The concept of blackbody radiation.

Students will learn...

- The different phenomena responsible for the emission of light by astronomical objects.
- How astronomers use different types of light to study different objects or phenomena in the Universe.
- The reasons for sending telescopes to space.
- What information can be seen and extracted from an astronomical image.
- Some basic ideas about a variety of astronomical objects.

Students will improve...

- Their understanding of scientific thinking.
- Their strategies of working scientifically.
- Their teamwork and communication skills.
- Their ability to apply theoretical knowledge to real-life situations.
- Their skills in the use of ICT.

Summary of Activities

Phase	Activity	Material	Results	Requirements	Time
Phase 0	• Putting things into context	VIDEOS: a) This is ESA b) ESAC: ESA's A window on the Universe c) Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura	Students will get familiar with • ESA • ESAC • The CESAR Team	None	10-20 min
Phase 1	1. Refresh concepts	VIDEOS: a) Temperature and heat (TED-ED) b) Energy (TED-ED) c) The light (kurzgesagt) d) Wave-particle theory (TED-ED) e) Waves behaviour (transmission, absorption, reflection, refraction, diffraction and scattering) f) How glasses help us see? (TED-ED) g) Life, Energy & ATP (kurzgesagt)	Students refresh: • The concept of heat and temperature. • The concept of energy. • The electromagnetic spectrum • Light as a wave and as a particle • Differences between reflection & refraction • Lenses & mirrors	None	30 min
Phase 1	2. Compare sound and light waves	Activity 2		None	5 min

Phase	Activity	Material	Results	Requirements	Time
Phase 1	3. Light in everyday life		Students learn: • The different type of light existing in their normal life and their use. • The properties of light (electromagnetic spectrum). Students improve: • Their teamwork and communication skills. • Their ability to apply theoretical knowledge to real-life situations.	Necessary to have executed Activity 1 and recommended Activity 2.	15 min
Phase 1	4. The electromagnetic spectrum	PDFs: a) Introduction b) The electromagnetic spectrum (CESAR booklet) c) A brief history of infrared astronomy d) Blackbody radiation VIDEOS: e) Light waves, visible and invisible (TED-ED) f) Electromagnetic radiation & pollution (kurzgesagt) g) Radiation (TED-ED)	Students learn: • The properties of the electromagnetic spectrum. Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their ability to apply theoretical knowledge to real-life situations.	Necessary to have executed Activity 1 and recommended Activity 2 and 3.	30 min

Phase	Activity	Material	Results	Requirements	Time
Phase 1	5. The path of the light in its way to generate the astronomical data	VIDEOS: a) Eye vs. Camera (TED-ED) b) How do we study the stars? (TED-ED) c) Gravitational waves detectors (TED-ED) Simulator: d) Telescope simulator e) Spectrometer simulator	Students learn: • What information can be seen and extracted from an astronomical image. • How their cell phone camera works • How a spectrometer works. Build your own spectrometer. • How a telescope works		

Phase 1	6. Astronomical objects in a nutshell • Stars and star clusters. • Interstellar medium • Galaxies	VIDEOS: a) How do we study the stars? (TED) b) How small are we in the scale of the Universe? (TED-ED) c) How do we measure distance in space? (TED) d) How to find a star cluster? (ESA/GAIA) e) Stellar evolution f) Limits of humanity (square space) g) Stars & red dwarfs (kurzgesagt) h) Stars & white dwarfs (kurzgesagt) i) Stars & neutron stars (kurzgesagt) j) Stars & blackholes (kurzgesagt) Poster: k) Stellar evolution (Chandra) PDFs: l) Stellar evolution (CESAR booklet) m) Interstellar medium (CESAR booklet) n) Galaxies (CESAR booklet)	Students learn: • Some basic ideas about a variety of astronomical objects. • The different phenomena responsible for the emission of light by astronomical objects (i.e.: a real case: the Crab Nebula) Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills. • Their ability to apply theoretical knowledge to real-life situations. a) Their skills in the use of ICT.	Necessary to have executed Activity 1.	30

Phase	Activity	Material	Results	Requirements	Time
Phase 1	7. The exploration of the Universe by the European Space Agency.	POSTER: a) ESA's fleet of cosmic observers b) ESA's fleet across the spectrum VIDEOS c) Science@ESA: *The full spectrum* d) What gravitational waves are? e) Science@ESA: *The untamed, violent universe* f) Science@ESA: *Exploring the infrared universe* 3D MODELS: g) ESA scientific fleet	Students learn: • The types and purpose of ground-based and space telescopes. • About European Space Agency scientific missions. Students improve: • Their understanding of scientific and critical thinking. • Their strategies of working scientifically. • The need of collaborations and teamwork.	Necessary to have executed Activity 1 and 4.	15
	8. What have you learn so far?	Mentimeters The light Astronomical Objects ESASky			
Phase 2	9. Ask for a video-call with the CESAR Team if needed	a) http://cesar.esa.int/index.php?Section=Scientific_Cases&Id=22&ChangeLang=en	Teachers will have state-of-the-art information about the astronomical topics from the • CESAR teacher workshop session • Teachers and students will have the chance of having a video call with the CESAR Team	Necessary to have executed Activities 1, 4 and 5.	30-40 min

Phase	Activity	Material	Results	Requirements	Time
Phase 3	10. Exploring the Universe through the ESA's window 10.1. Getting familiar with ESASky 10.2. Staring at the stars through ESASky 10.3. A tour around the various types of astronomical objects with ESASky (Target lists) 10.4. Multi-wavelength studies using ESASky 10.5. Analysing the effects of Interstellar medium with ESASky	a) ESASky Web & videos: b) General documentation (ESASky tutorial) c) How to upload a target list ESASky tutorial) d) How to visualize different wavelengths with ESASky?(ESASky tutorial) e) Crab Nebula: The Multiwavelegth Structure of a Pulsar Wind Nebula	Students learn: • The different phenomena responsible for the emission of light by astronomical objects. • How astronomers use different types of light to study different objects or phenomena in the Universe. • Some basic ideas about a variety of astronomical objects Students improve: • Their skills in the use of ICT. • Their understanding of user-friendly databases. • Their library of images about celestial objects by navigating through the ESA scientific archives. • Their understanding of the need of working in multi-wavelength ranges.	Necessary to have executed Activities 1, 4 and 5.	15 min
Phase 3	11. Revealing the secrets of your favourite celestial object. 11.1. The Crab 11.2. NGC 3766 11.3. The Horsehead nebula. 11.4. The Whirlpool galaxy		Students improve: • Their skills in the use of ICT. • Their capability to execute a complete analysis of a region • Their understanding of the need of working in multi-wavelength ranges.		30 min

Phase	Activity	Material	Results	Requirements	Time
Phase 3	12. Access the scientific data in ESASky. 12.1. Direct access to the ESA astronomical images 12.2. Direct access to the ESA astronomical spectra 12.3. catalogues and databases through ESASky. 12.4. Direct access to catalogues and databases in ESASky. 12.5. Analysing scientific information of the Orion constellation with ESASky 12.6. Downloading catalogues through ESASky and handling them.		Students will check whether they have had a meaningful learning process Students improve their team work and communication skills.	Necessary to have completed Activities 1, 7 and 8.	20 min – 2h
Phase 3	13. Other CESAR resources	Monographs and other activities for the students	More fun in the exploration of the Universe		30min-2h
Phase 4	14. Evaluate yourself	Fill in this questionnaire	Students improve: • Their evaluation skills Students complete a meaningful learning process	Necessary to have completed Activities 1, 7, 8 and 10.	45min

Phase	Activity	Material	Results	Requirements	Time
Phase 4	15. Present your results	Open format (ppt, YouTube, Word)	Students improve: • Their application of theoretical concepts to real life situations. Their teamwork and communication skills.	Necessary to have completed Activities 1, 7, 8 and 10.	45min

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Your Scientific Challenge

Revealing the invisible

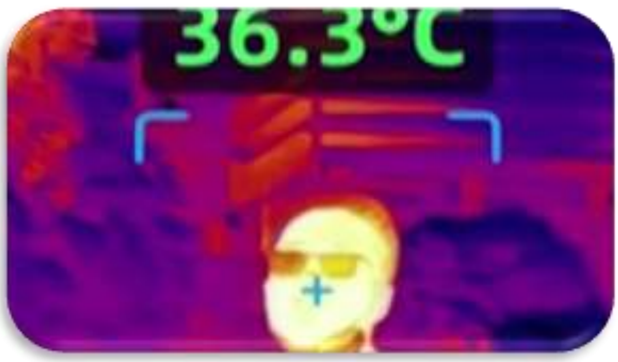
Not only are superheroes able to see the invisible, but also the state-of-the-art technology on board the European Space Agency scientific missions, that fly over the Earth's atmosphere to reveal the invisible and bring this information back home. Are you ready to discover the hidden Universe? **Guess which is the superpower and the name of the ESA mission that uses it.**

What is its superpower?

What is the name of this ESA mission?

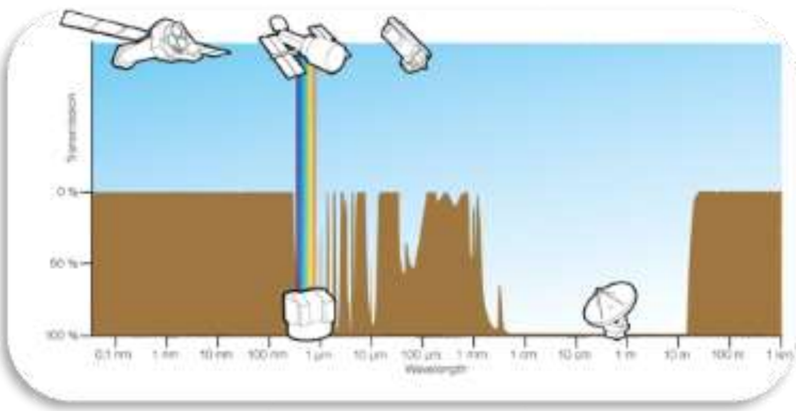
X-ray vision

XMM-Newton



Able to measure the body temperature

Herschel



Phase 0

In order to put into context, we recommend students to watch these **videos:**

- This is ESA (10 min)
- ESAC: ESA's A window on the Universe (3 min)
- Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura (15 min)
- Here there is another complementary set of videos.

We recommend to **work in teams**, of (4-6) people, with a clear role in their team, assigned per profession. Students will fill Table 1 for the coming Challenge with a name for their Team and the name of the team members after having agreed among themselves on their role in the team.

Challenge ID			**Team number (1-6):**	
Names				
Profession	**Mathematician/ Software engineer**	**Astrophysics**	**Engineer**	**Biologist**
Roles	Lead the correctness of the calculations	Lead the use of the virtual telescope ESASky and the understanding of their celestial objects.	In charge of finding the optimum strategy agreed among the team members and its correct execution.	Lead the more detailed research about the scientific understanding of the energetic processes and composition of the celestial objects.
Reference **(female)**	Katherine Johnson 	Vera Rubin 	Samantha Cristoforetti 	Marie Curie 
(male)	Steve Wozniak 	Matt Taylor 	Pedro Duque 	Albert Einstein 

Table 0: *Write down the Identification of your Challenge (an unique number), the Number of your Team (1-6) and the name of the team members, one of them with a clear role (and assigned tasks), all needed.*

Note: The documentation makes use of the International System of Units.

Phase 1

Activity 1: Refreshing concepts

Students should refresh concepts before starting with the Scientific Challenge. The teacher decides which is the best way for doing so with their class. We offer a set of links that may be fun to do so. Enjoy them!

Temperature and heat	**Energy**	**The light Wave-particle theory**
Waves behaviour (transmission, absorption, reflection, refraction, diffraction and scattering)	**How do glasses help us see?**	**Life, Energy & ATP**

Table 1: *Concepts to refresh before starting the Scientific Challenge, according to the scholar curricula.*

Activity 2: Compare waves of sound and light

Students are expected to compare the waves of sound and light

Characteristics	Sound	Light
Wave	Yes	Yes
Particle	No	Yes
Does it need a medium to travel?	Yes	No
Speed	~ 300 (343,2) m/s	Medium dependent In the vacuum ~ 300 000 000 m/s
Example	Thunder	Lightning

Table 2: *Comparison of sound and light waves.*

Activity 3: Light in everyday life

In this activity, students have to think about **what light is** and types (colors or wavelength). Students might need to do some research to answer the questions.

1. How would you explain what light is?

> Students should answer that light is a wave. More advanced students should answer that light is both a wave and a particle.

2. What types of light do you know about? Can you see all of them? How? Do you know about any animal that can see more colors (light) than humans?

> All age groups should be able to understand that the different colors are the way our eyes interpret different wavelengths of light, and that the difference with other types of light is simply that they are wavelengths that human eyes cannot detect.

3. What is radiation? Is all radiation harmful?

Although students have probably heard the term "radiation" before, they may not be able to provide an accurate definition for it, as energy is transferred without contact between source and receptor. The teacher can provide examples (e.g. heating radiators) to help students understand that radiation does not always imply harm to living things.

4. How do we use invisible light (all types of lights of Table 4 but visible light) in everyday life?

Types of light	**Sources and devices**	**Uses**
Gamma-rays	Radioactive materials	Radiotherapy (medicine)
X-rays	Radiography machine Airport security scanner (for things)	Radiography (medicine) Seeing content of luggage bags
Ultraviolet	Sun tanning bed	Getting tanned UV-therapy (medicine) Detecting forged bank notes
Optical (Visible)	Sun Light bulbs	Seeing things
Infrared	Living things Radiator Remote control device	Heating (Short-range) communications
Microwaves	Microwave oven Mobile phone Wi-Fi	Cooking Communications
Radio	Radio and TV station Radar	Communications Radar detection

Table 3: *Types of light, sources, devices and their uses.*

Activity 4: The electromagnetic spectrum

Activity 4.1: The colors of the stars

Have you ever looked at the night sky and seen stars with different colors? If not, we recommend you to do it.

1. Write in the box: What colors do you see in the five stars identified in Figure 5? What do you think the colors of the stars mean?

When looking at the sky in the night some stars look redder, others yellowish or whiter and some bluer. Depending on their properties, such as their superficial temperature, distance to us, … we see one or other color.

Stars can be compared with bulbs, where colors are related to temperatures (Figure 4).

Figure 4: *Colours of bulbs as a function of their temperature. (Credit: https://rec-line.com/blog)*

2. Have a look at the constellation of Orion and guess the temperatures of the stars:

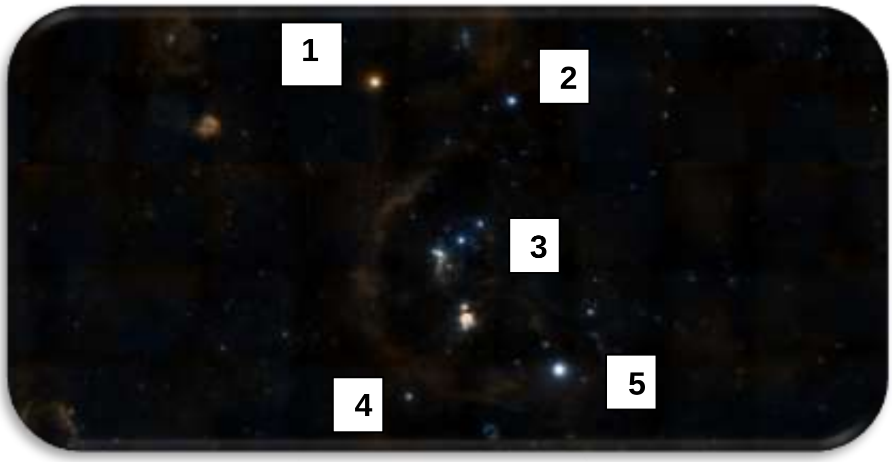


Figure 5: *Orion constellation. (Credit: ESA/CESAR)*

3. Fill in Table 5 with the information requested for each of the five stars identified in Figure 5, in the Orion constellation:

- Column 1: Star number as identified in Figure 5.
- Column 2: Link to *Wikipedia* where this star is described
- Column 3: Distance to the Earth (data obtained from *Wikipedia*)
- Column 4: The colour of the star (your perception by looking at Figure 5)
- Column 5: Star superficial temperature (your guess by checking Figures 5 and 4).

Star number [from Figure 5])	Star name [from Wikipedia]	Distance (light years,ly) [from Wikipedia]	Star colour [from Figure 5]	Star temperature (in Kelvin, K) [comparing Figures 4 and 5]
1	**Betelgeuse** (alpha Ori)	700 ly[1]	reddish	~ 3 500 K
2	**Bellatrix** (gamma Ori)	240 ly	bluish	> 10 000 K
3	**Mintaka** (delta Ori)	915 ly	bluish	> 10 000 K
4	**Rigel** (beta Ori)	860 ly	whitish - bluish	(6 000 -10 000) K
5	**Saiph** (kappa Orionis)	650 ly	whitish - bluish	~5 000 K

Table 4: *Identification of the color and temperature of the main stars in the Orion constellation*

Activity 4.2: Visible and invisible light

We are all familiar with the colors of the rainbow, but how can we measure the invisible colors?

Figure 6: *Rainbow. (Credit: National Geographic)*

William Herschel did so, and discovered the **infrared light** by putting a thermometer outside the reddish part of the visible light, as shown in Figure 7.

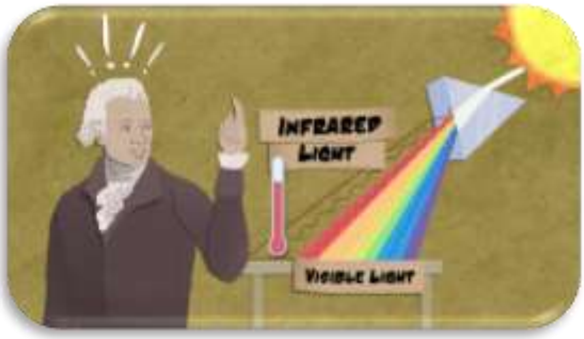
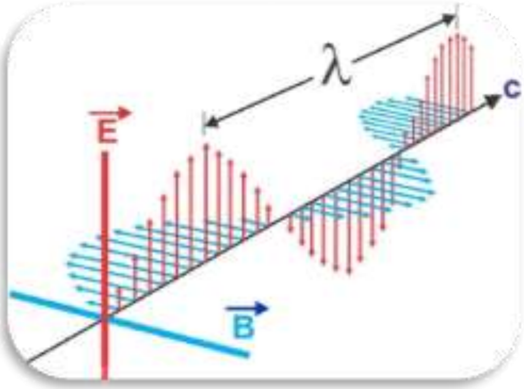


Figure 7: *Cartoon of the Herschel experiment. (Credit: www.emaze.com)*

[1] Ly stands for the unit of length light-year, used to measure astronomical distances (9.46x 10^{12} km). We see that the various stars in a constellation are not at the same distance !!

Physicists describe light as an electro-magnetic wave, that is, the perturbation of an electro-magnetic field (field composes by an electric field, *E*, and a magnetic field, *B*).

Figure 8: Representation of an electromagnetic field. (Credit: https://www.highfidelitycables.com/technology/



The separation between two consecutive peaks of the wave (or distance between two points in exactly the same state) is called **wavelength (λ)**, and the number of times the wave repeats itself in a second is called the **frequency of the wave (f)**. **Wavelength and Frequency are inversely proportional**. In other words, the higher the frequency, the shorter the wavelength.

The **electromagnetic spectrum** is represented in Figure 9 as a sample of wavelengths of light. It can also be determined by frequencies, colors, temperatures or energies. The electromagnetic radiation is **divided into visible and invisible light** (radio, microwave, infrared, ultraviolet, X-rays and gamma-rays).

Our eyes are adapted to detect only a small portion of this spectrum, and this portion is what we call "**visible light**". The only difference between the colors of visible and invisible light is their wavelength (or frequency). Gamma rays have the shortest wavelength, and radio waves the longest.

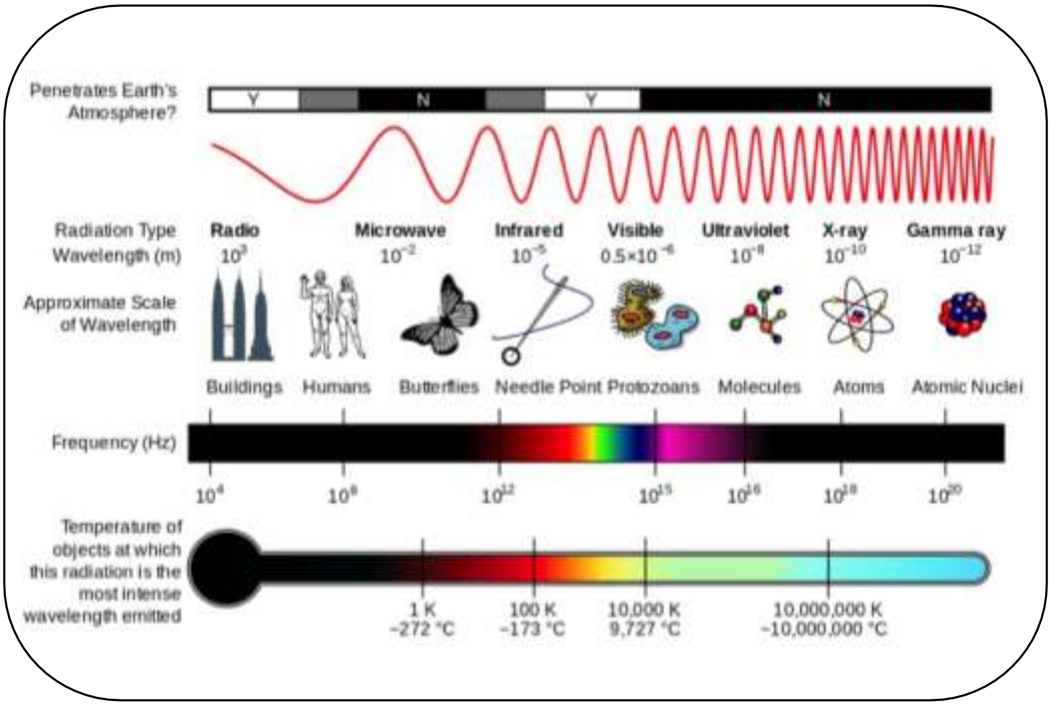


***Figure 9:** Properties of the electromagnetic spectrum. (Credit: Wikimedia Commons)*

Activity 4.2.1: The blackbody concept

The wavelength (and frequency) of light is related to the temperature and energy of the source. As a matter of fact, all objects emit light because they all have a temperature above absolute zero. This is called **thermal emission or blackbody emission**. However, depending on the actual value of that temperature, most of the light will be emitted in a different wavelength range.

The blackbody distribution of a source can be characterized by:

- the **peak intensity** of the emitted energy (E) (or of the spectral power density)
- the peak center (measured in wavelength or in color)
- the Thermal emission of a blackbody[2] is $\boldsymbol{E = \sigma T^4} = \sigma\left(\frac{b}{\lambda_{peak}}\right)^4$ where σ is the Boltzmann's constant, T is the effective temperature (T_{eff}) and b the Wien's displacement constant.

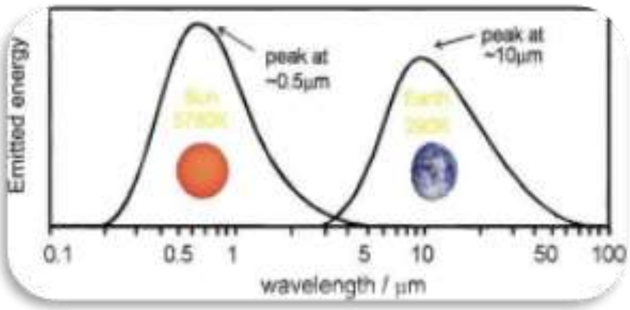


Figure 10: *Examples of Sun (left curve) and Earth (right curve) black bodies. (Credit: Wikimedia Commons)*

This is why most everyday objects (like tables, cats, or ice cubes) do not seem to be emitting light, but they are in a color that our eyes cannot detect. We see those objects thanks to the light they reflect, not the one they emit.

Activity 4.2.2: Blackbody distribution simulator

To better understand the relationship between the blackbody distribution and the star temperature, play with the black body simulator and complete Table 6:

1. Go to this link: https://phet.colorado.edu/en/simulation/blackbody-spectrum
2. Figure 11 shows a thermometer on the right side of the simulator. Four marks indicate the temperature of some objects (a) the Earth, b) a visible light bulb, c) the Sun (the disk of the Sun), d) the star Sirius A).
3. Write down the information requested in Table 6 (extracted from this simulator)

Source	Sirius A	Sun	Light Bulb	The Earth
Maximum Intensity (peak) of the black body distribution (MW/m²/microns)	1000	80	3.5	3×10^{-5}
Position of the peak of the blackbody distribution (characterizes the object colour)	10 microns (ultraviolet)	0.5 microns (blue/green)	0.7 microns (red)	10 microns (mid-infrared)
Blackbody temperature	10 050 K	6 000 K	3 050 K	300 K

Table 5: *Maximum intensity, peak position (in wavelength) and color and temperature of the blackbody distribution for the list of sources available in the blackbody simulator.*

[2] combining Stefan-Boltzmann Law and Wien's Law ,

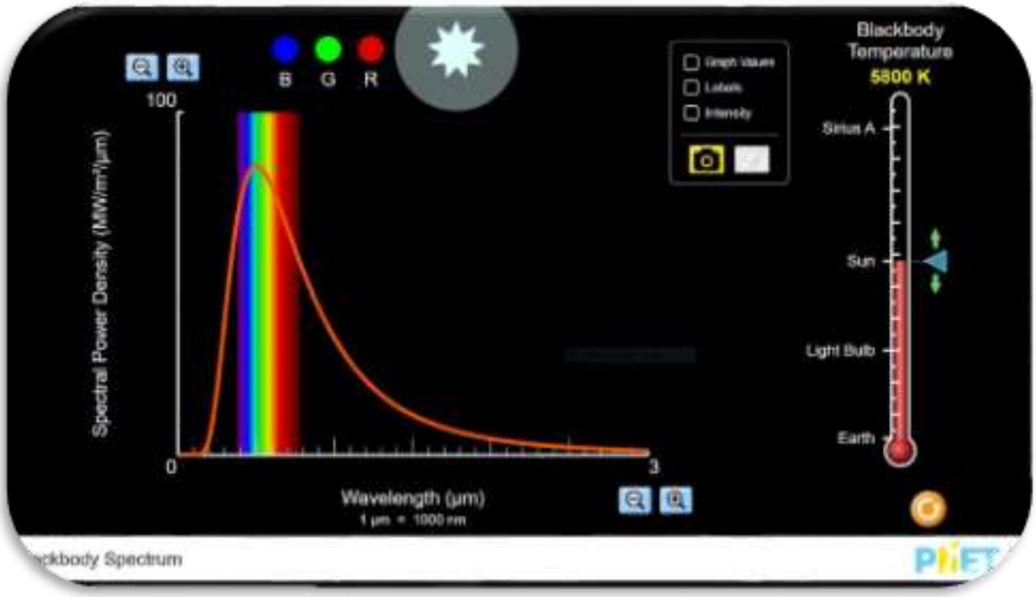


Figure 11: Blackbody simulator. (Credit: [https://phet.colorado.edu)](https://phet.colorado.edu)

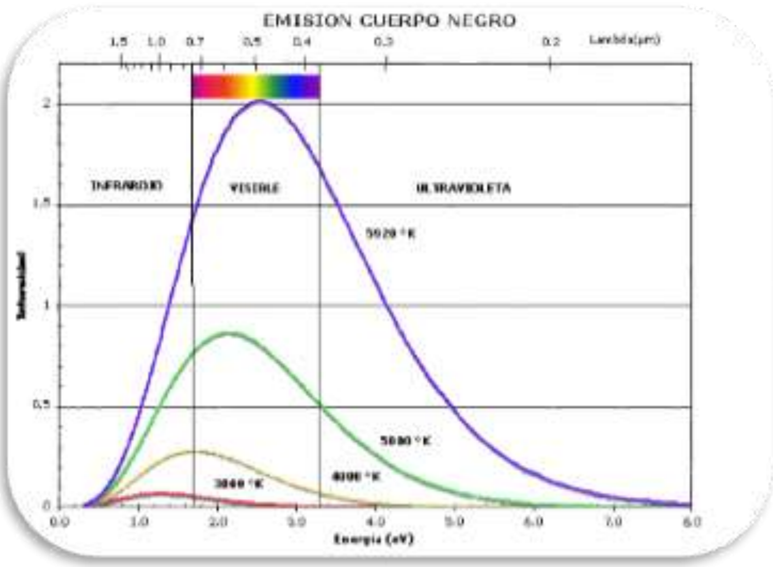


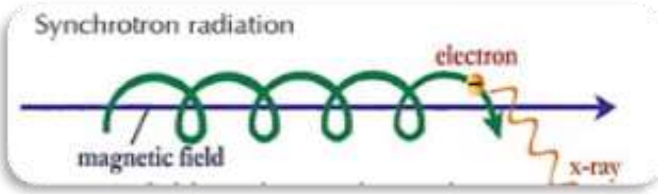
Figure 12 shows that the visible light covers the wavelength range of (0.7, 0.4) microns, with different peak positions for the colors from violet to red.

Figure 12: Blackbody distribution for the visible light. (Credit: https://losmundosdebrana.com/)

Note: Temperature is not the only phenomenon that can produce light. For example, **electrons moving in a magnetic field will emit non-thermal emissions** (see Figure 13).

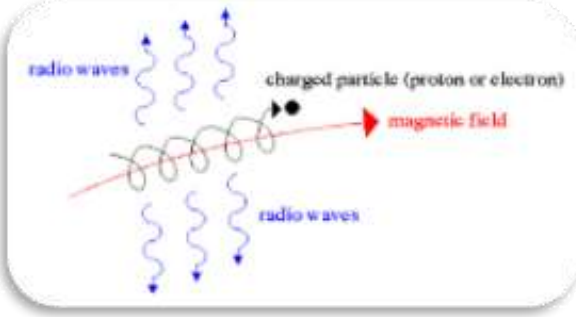
- When electrons move at low speed compared to the speed of light (non-relativistic[3] velocities) they emit **cyclotron radiation**.
- When electrons move at a speed which is a percentage of the speed of light (relativistic velocities) they emit **synchrotron radiation**.

[3] Relativistic speed



X-ray and gamma ray emission

The Crab (pulsar). (Credit: ESA/NASA Hubble)



Radio emission

M87 galaxy. (Credit: ESA/NASA Hubble)

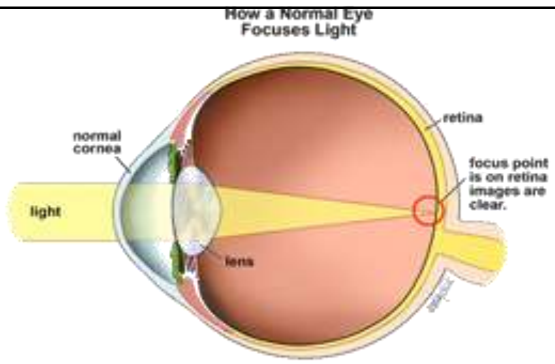
Figure 13: *Examples of non-thermal emission. (Credit: ESA/NASA Hubble)*

Synchrotron radiation is very common in astrophysics when material is ejected at relativistic velocities around black holes, pulsars and active galaxies.

Activity 5: The path of light in its way to generate astronomical data.

Astronomical data is the end-up product of the light of the celestial objects collected by the collectors (telescopes), after passing through various instruments (selected depending on their scientific goal) which are located at the focal plane (of the telescope). Photons (the particles of light) from the celestial objects impact at the end of their trip on the detectors ([semiconductor material]) of those instruments, creating photo-electron events. These photoelectrons are moved to a storage area and dumped into the astronomical data (images and spectra) properly stored and organized in the giant scientific archives (such as those of the European Space Agency, ESASKy).

Activity 5.1: Astronomical collectors



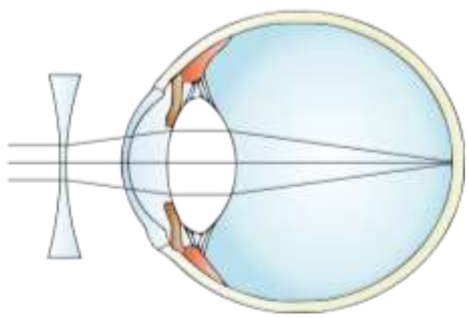


Figure 14*: Representation of the path of light inside a naked-eye (left) and with an external lens. (Credit: Wikipedia)*

Optics and lenses are essential in our daily life as for us to see our eyes are indeed using both!

Lenses are optical instruments that change the direction of light, by refraction. It is the fact that light goes through a curved, or inclined, optical medium what makes the focus change. We may differentiate between:

- **Converging lenses:** they converge light rays and focus them at one point.
- **Diverging lenses:** they diverge light, so the light rays are dispersed.

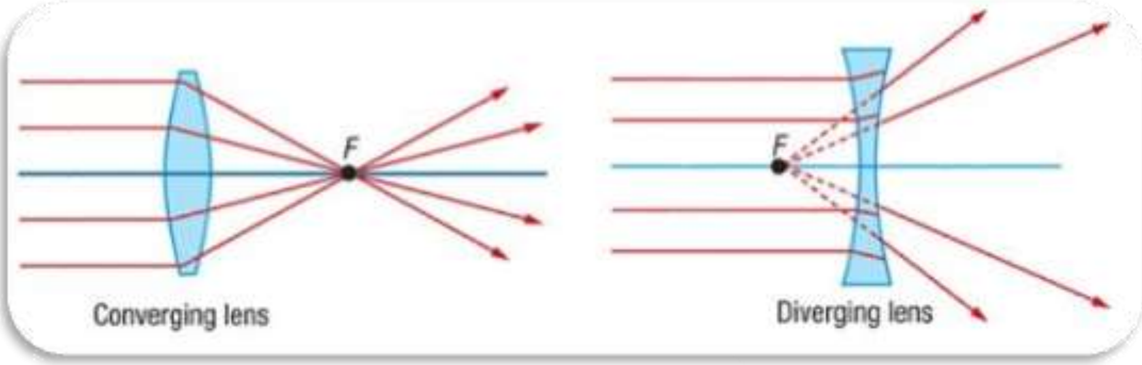


Figure 15: *Light diagram of a converging and diverging lens. (Credit: pinterest.com)*

Some **telescopes (refractor type)** use a system of lenses and the bending of light going through them operates, as well as our eyes, glasses and microscopes. **Professional ground-based telescopes and space missions** (i.e., [ESA missions]) **use mirrors (reflector type),** allowing them to be much lighter (and preventing [chromatic aberration] correction). Figure 16 shows the different light paths for a refractor and a reflector telescope.

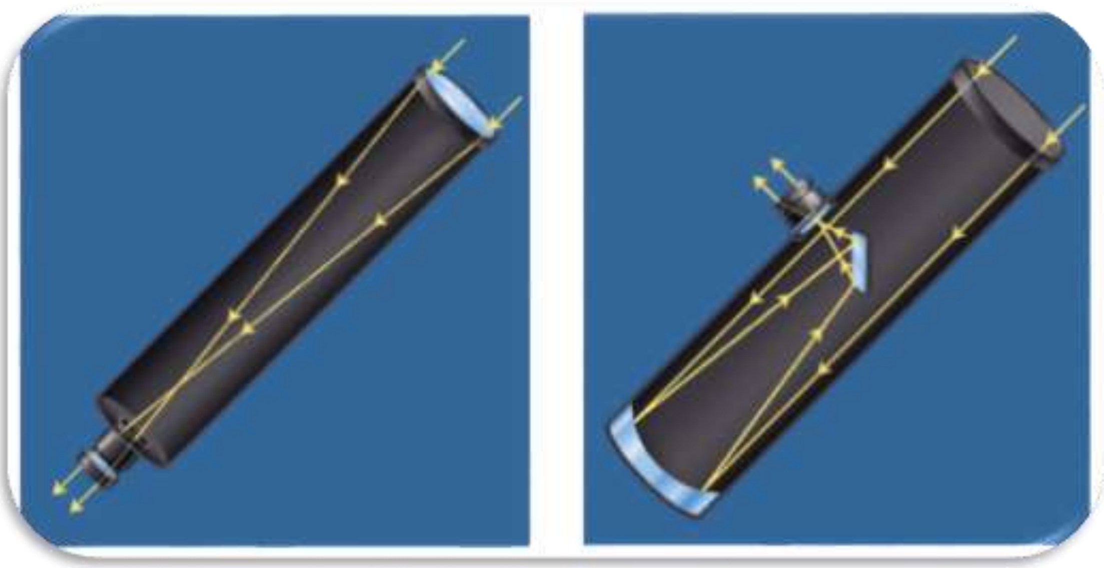


Figure 16: *Path of light through a refractor (left) and a reflector telescope (right). (Credit: https:/www.chegg.com)*

Our eyes are adapted to visible light because that is the light from the Sun that reaches the Earth's surface. Most of the light in the electromagnetic spectrum, **outside the visible light that we can call invisible light**, which is partly blocked by the atmosphere, luckily for us, as it could be very harmful to us. Figure 17 shows open windows and barriers to the light coming from the Universe to the Earth's surface.

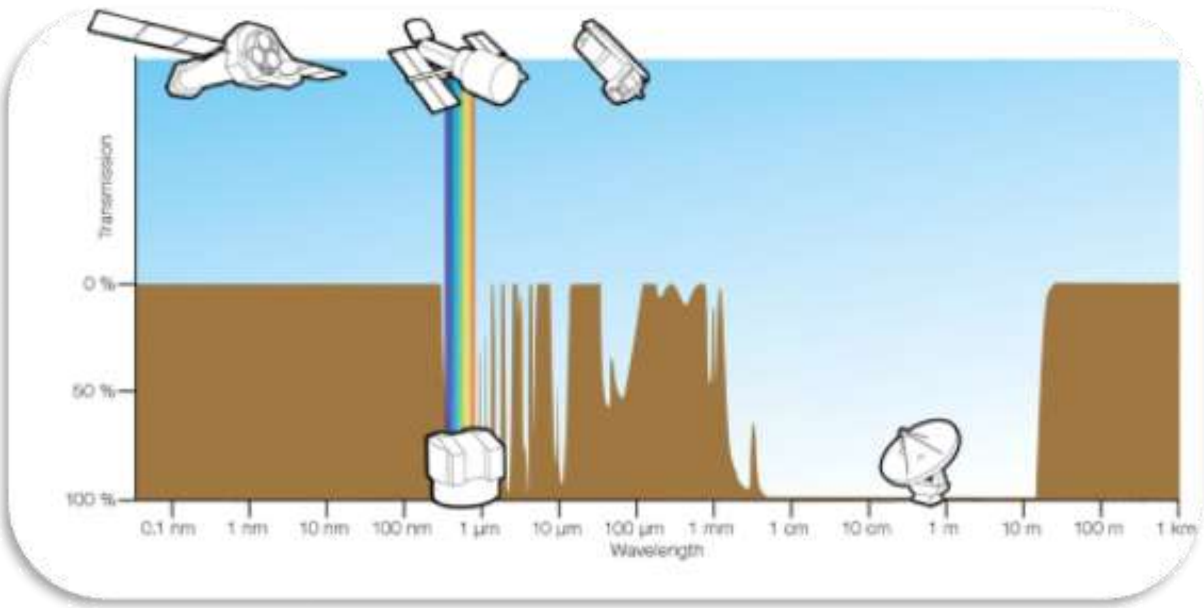


Figure 17: *Transmission windows of the atmosphere. (Credit: https://gisgeography.com/atmospheric-window/)*

For this reason, astronomers need to observe the Universe (at those particular wavelengths) with telescopes on board space missions. Observable light from the Earth could also be observed from space to prevent distortions in the images caused by the atmosphere, improving the quality and the detail in the astronomical data.

- Write here what you learnt about astronomical collectors (types)

Activity 5.2: Astronomical Detectors

Apart from the naked eye, we use cameras, such as those in our cell phones, that kept in memory the data registered by their detectors. Detectors work based on the photoelectric effect (left image in Figure 18), that consist on the activation of the electron from a material when a photon (the particle of light) hits on its surface. This effect takes place place on each pixel of the camera or resolution element.

Figure 18: *(left) Simplified version of the photoelectric effect, (right) Cell phone camera. (Credit: Wikipedia)*

Detectors used in professional astronomy and imaging, based on the photoelectric effect, are Charge-coupled device (or CCDs).

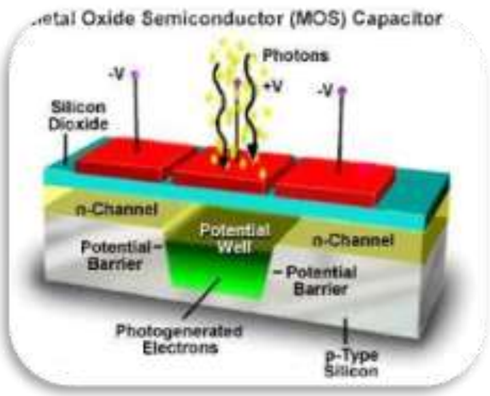


Figure 19: *Simplified 3D version of a CCD. (Credit: https://www.pinterest.ph/pin/414401603183351217/*

CCD cameras convert a light signal into an electric signal when a photon hits the camera (covered with a semiconductor material, such as silicon) and transfers its energy to an electron (called photoelectron). This given energy allows the electron to jump the energetic gap (from Si *n* to Si *p*).

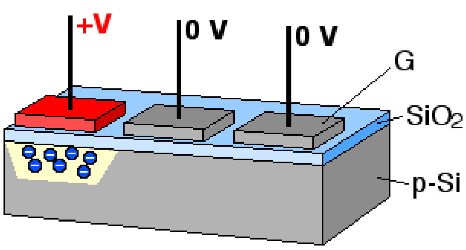


Figure 20: *CCD transference of charge packets to the read-out area. (Credit: Wikipedia)*

The photoelectrons (charged particles at the Si *p* edge) are collected in packets and shifted, by an electric current, to one edge of the detector called *read-out area*, as shown in this animation.

An analogue-to-digital converter (ADC) turns each pixel's value into a digital value (in binary form).

Most modern sensors are CMOS type, which are an improved version of CCDs (use several transistors to amplify each pixel, use color filters and move the charge using more traditional wires).

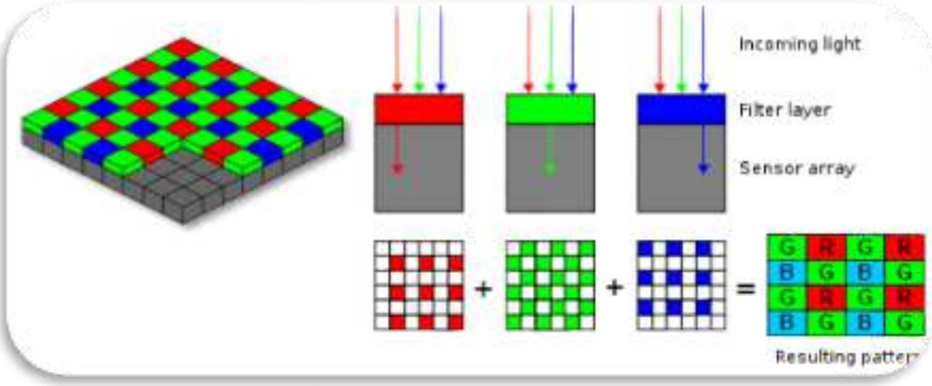
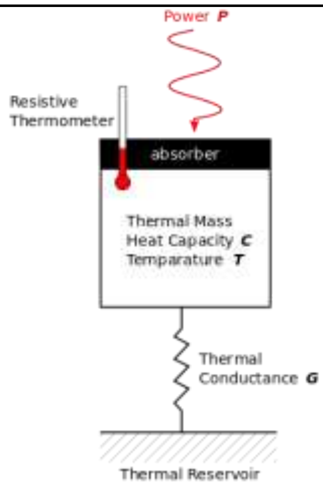
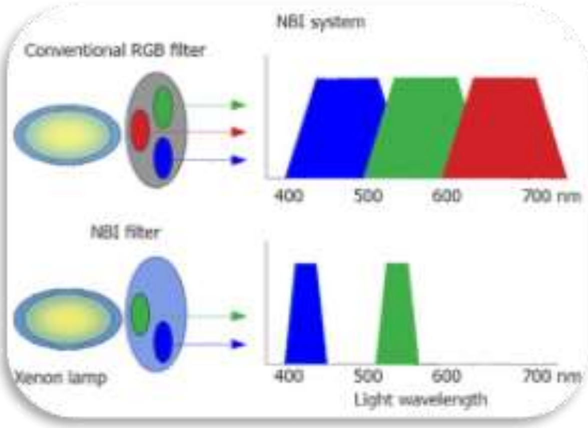


__Figure 21:__ CMOS detectors. (Credit: https://www.einfochips.com/)

To learn more about the differences between these two technologies, which are quite similar, watch this video.

Some missions, such as the far-infrared ESA scientific mission, Herschel, brought on board bolometers, instead of CCD cameras.

<u>Bolometers:</u> Devices capable of measuring the power of the incident light by measuring the heating of the material with a temperature-dependent electrical resistance.	**Filter wheel:** A wheel with several optical filters in it. An optical filter is a device that transmits light at a specific wavelength range. These filters can be broad-band and narrow-band effective.
 *__Figure 22a:__ Conceptual scheme of a bolometer. (Credit: Wikipedia)*	 *__Figure 22 b:__ Broad and narrow-band filters. (Credit: World J Gastroenterol)*

- What have you learnt from the detectors?

Astronomical data is the end-up product of the light emitted by astronomical objects
After passing through the telescopes and instruments and hitting their detectors. In general terms, astronomers use two main types of data for their scientific analysis: **images** (output from cameras) and **spectra** (output from spectrometers).

Photometry:

The technique of measuring the amount of photons emitted by the source (brightness) and their spatial distribution (levels) for astronomical objects, in **images**.

This measure can be done in a single point or several points in time. This second option is the technique used to detect flux variations in time (if any) and the plot (flux, time) is called *light curve*.

Exoplanets may be detected this way using the method of *transits.* If the planet is big enough and is in the light of sight between the observer and the star, we could detect variations in the amount of light when the planet is in front, at a side and behind its star (Figure 23c)

Spectroscopy:

The technique of identifying the chemical elements of an emitting source by the code bar that transitions generate in the **spectra**.

Gratings and prisms are the elements used to separate (disperse) light in colors (wavelengths or frequencies).

If we find dark lines in the spectrum (absorption lines) is because photons from the emitting source were absorbed by a coldest gas in its way, and those lines give us the code bar of that cold gas (Figure 23e).

If we detect bright lines in the spectrum is because we can see photons of an excited gas coming down to a lower energetic level and emitting light (Figure 23f)

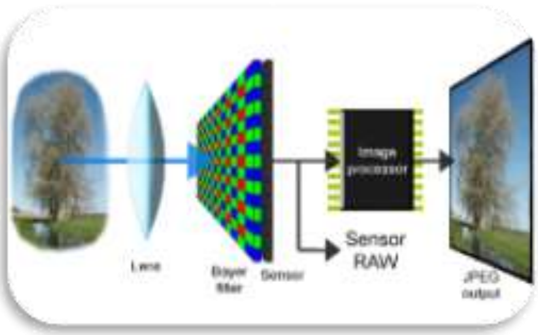


***Figure 23a**: Representation of a camera. (Credit: WordPress)*

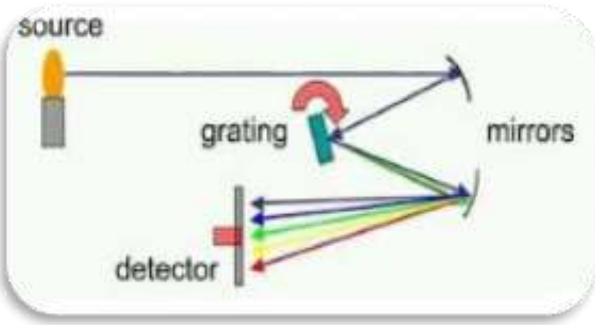


***Figure 23d**: Representation of a spectrometer. (Credit: scholar of chemical engineer)*

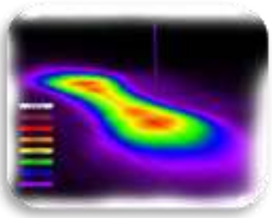


***Figure 23b:** Intensity level lines (or flux lines). (Credit: wikipedia)*

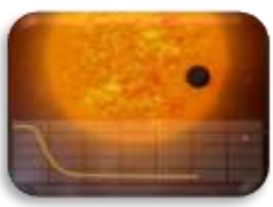


***Figure 23c:** Light curve for the detection of exoplanes by the CHEOPS satellite . (Credit: ESA)*

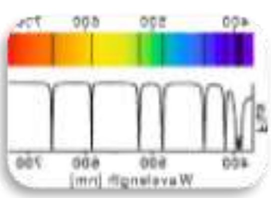


***Figure 23e:** Atomic spectra with absorption lines (Credit: UCLA)*

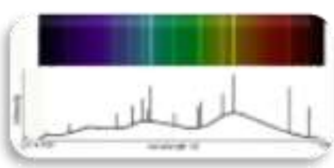


***Figure 23f:** Atomic spectra with emission lines. (Credit: Universe today).*

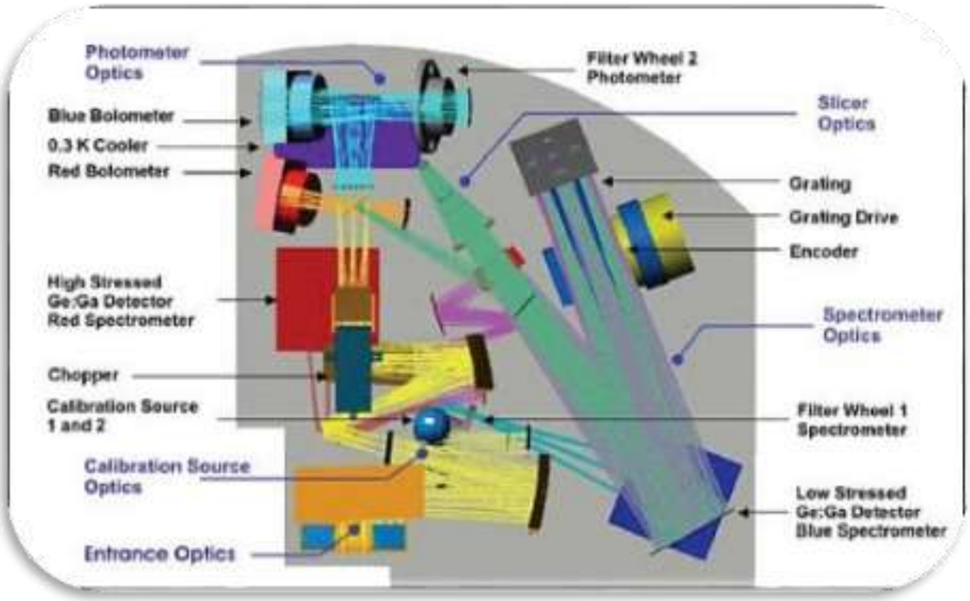


Figure 24: *Optical light path of the ESA Herschel mission for the PACS instrument. (Credit: ESA/MPE)*

The astronomical data collected by the instruments need to be calibrated, using well-known targets and/or internal sources to the instruments for it, to transform their values into understandable physical units (i.e., from the International System of Units). These astronomical data tend to be stored in FITS format (that in English stands for Flexible Image Transport System).

Activity 6: Astronomical objects in a nutshell

In this section, we are going to make **an easy tour from stars, like our Sun, to clusters of (gravitationally bended) galaxies** (Figure 25).

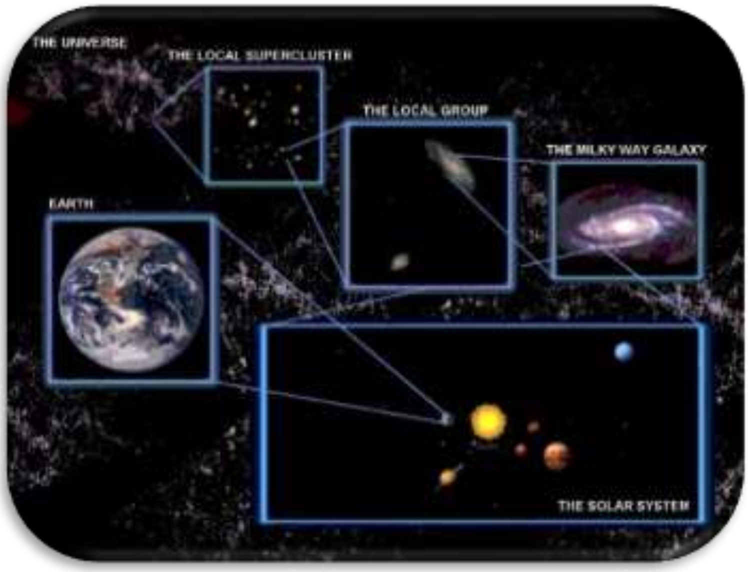


Figure 25: *Scales of the Universe. (Credit: National Geographic)*

For an overview of different types of objects in the Universe we recommend you to execute Activity 9.3, that walk through the targets lists of astronomical objects, selected by the ESASKy Team.

Activity 6.1: Stars

Stars, like our Sun, are big balls of gas in the state of plasma. They are joined by gravitational forces capable to generate high temperatures in their center (millions of kelvin) that trigger nuclear reactions. This way the pulling forces (gravity) and the pushing forces (gas pressure) get balance in the star.

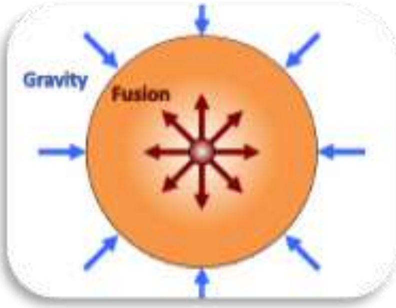


Figure 26: *Balance of forces at the time a star gets born (Credit: http://large.stanford.edu)*

At the beginning deuterium starts to get burnt, but it is not until hydrogen is converted into helium when we consider that **a star is born**.

[Activity 6.1.1](#). explains a bit more in detail the star formation process and [Activity 6.1.2](#) the stellar evolution processes.

To get familiar with the different sizes of the stars you can watch this [video](#).

Activity 6.1.1: From the molecular clouds to stars

Figure 27 shows the star formation process:

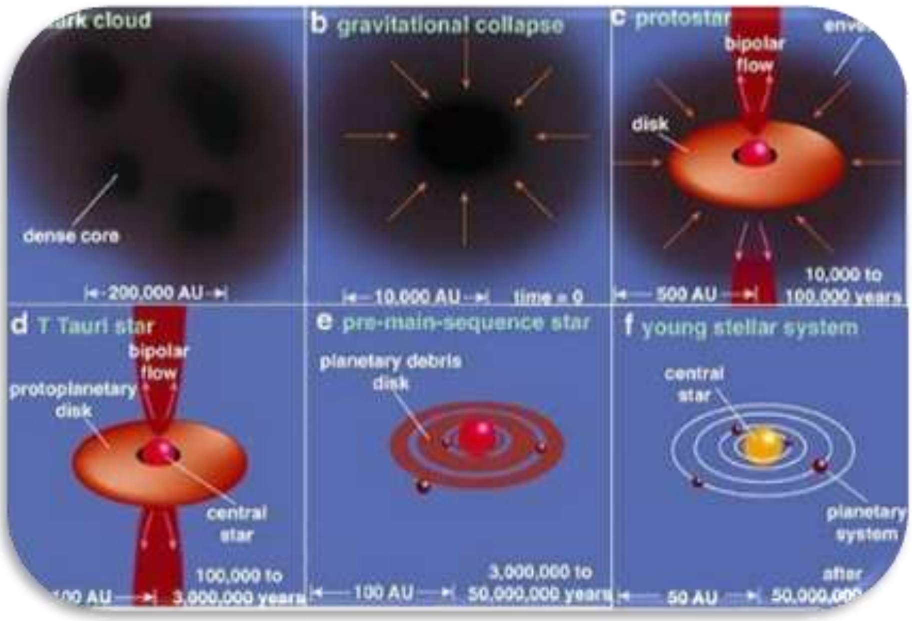


Figure 27: *Star formation process. (Credit: SPITZER)*

The star formation theory of Sir James Jeans proposed that cold and dense **molecular clouds,** in hydrostatic equilibrium, could collapse by gravitational forces, breaking them into smaller fragments (*"clumps")* close to the stellar mass (Figure 27a).

Each of these clumps keeps collapsing to a denser and hotter core, called **protostars** (Figures 27b to 27c). The protostar keeps accreting material from the surrounding molecular. By conservation of the angular momentum, the accreted material spirals in towards the protostar forming a **disk,** perpendicular to the direction of rotation.

Figure 27c shows that the accreted material falls from the envelope onto the disk and from there is accreted to the protostar. Part of this material is released as bipolar jets that are detected in X-rays (close to the center) and radio wavelengths (at further distances).

When the center of system is hot enough **nuclear reactions trigger**. The gas pressure prevents further material to be accreted by the star and the disk stars to be dispersed (Figur e 27d).

A protostar becomes a star when hydrogen is burnt in its nucleus. Planets are part of the star formation process (Figure 27e and 27f) as a final product of the evolution of protoplanetary disks into planetary system.

The ESA/NASA Herschel satellite revealed **filamentary structures in molecular clouds,** caused by variable densities of gas and dust, at short and long scales. These structures are thought to be formed by a combination of shock compression (collisions between material, maybe caused by a supernova explosion in the area) and self-gravity. The bright areas in Figure 28, shows **star formation regions,** where the material is denser and hotter.

Figure 28: *Herschel Eagle's Nebula. (Credits: ESA/Herschel/PACS,SPIRE/Hi_CAL Project. Acknowledgement: G.Li Causi, IAPS/INAF)*

Activity 6.1.2: The evolution of the stars

Stars, as humans, pass through different phases during their lifetime (Figure 29).

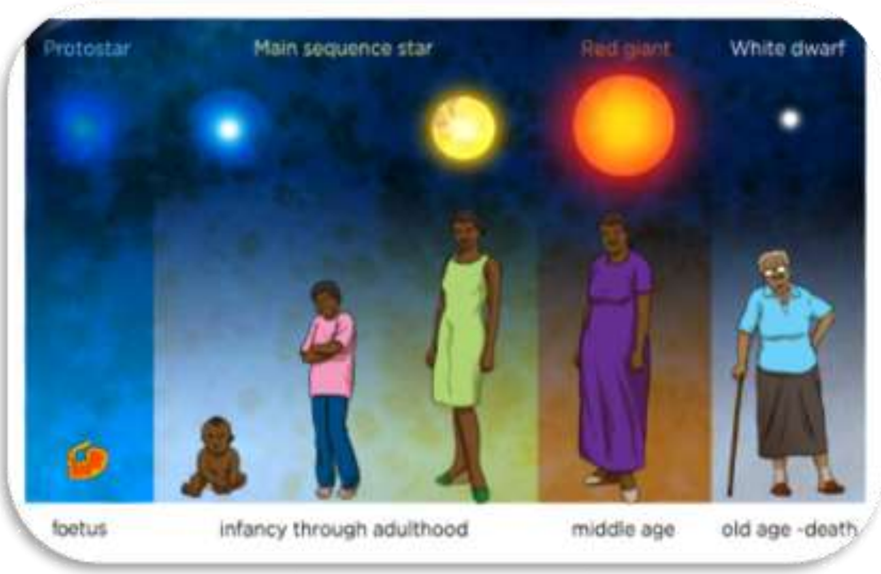


***Figure 29**: Life cycle of a star. (Credit: https://www.siyavula.com/)*

These phases and how much they last depend on the mass when the star was formed (called **initial mass**). Stars will burn hydrogen in their nuclei (obtaining helium) during their **main sequence phase**. When stars run out of hydrogen in their center, the gas pressure is not able to compensate the gravitational force anymore and the star starts to collapse and the external shells that fall onto the compacted nucleus bounce and get expanded. It is at this moment when the star abandon the main sequence phase to be in the **red giant phase**. The collapse of the nucleus increase its temperature, triggering new nuclear reactions.

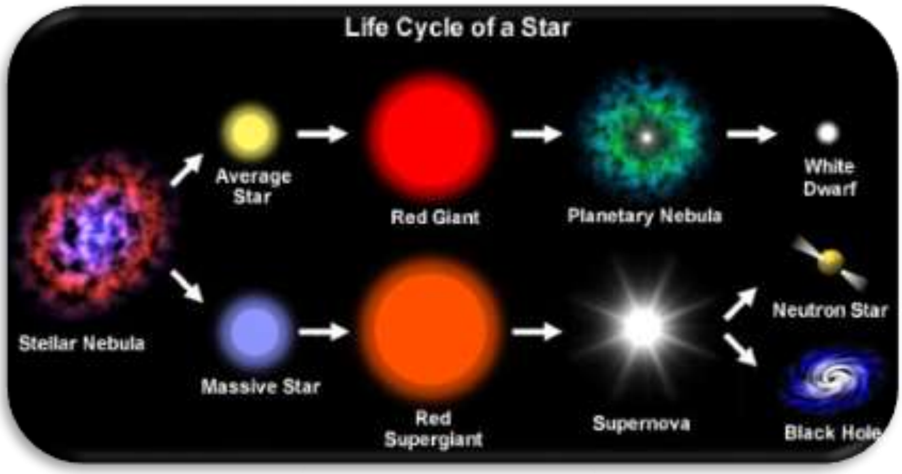


***Figure 30**: Life cycle of a star as a function of their mass (Credit: www.schoolsobservatory.)*

Low-mass stars keep having nuclear reactions until their whole nucleus is transformed into carbon. (these stars do not have enough mass to raise the temperature of its centre and start the ignition of carbon. The external shells of the star will escape to the medium and form, what it is called, **a planetary nebula** and the dense center will get colder and convert it into a **white dwarf** and later on a black dwarf.

Medium and high-mass stars are able to increase the temperature of their nuclei and continue having nuclear reactions further that carbon. These stars also get expanded as they evolve to **red** or **blue supergiant**, as a function of their mass. They will end up their life with very violent processes, called **supernova**, becoming their centers a **neutron star** or a **black hole**, depending as well on their remaining mass.

In general terms, it is said, that when **a star is not able to burn nuclear reactions in its nucleus, it is the end of their life**. The greater the initial mass of a star the faster the fuel in the nucleus is burnt, lasting high-mass stars over ~ 100 000 years versus the ~1000 000 000 years for low-mass stars. **Stars are classified by age in Populations**. The youngest are *Population I* and the eldest, Population III (in line with *the third age for senior people*).

Hertzsprung-Russel Diagram:

Astronomers use the **Hertzsprung-Russel diagram** to identify the life cycle of stars. The most common representation of this diagram compare the amount of light emitted by the object (luminosity[4]) versus the temperature of the star (in kelvin).

In a nutshell, stars can pass through main five evolutionary stage, well identified on the H-R diagram (Figure 31). Here we mention them:

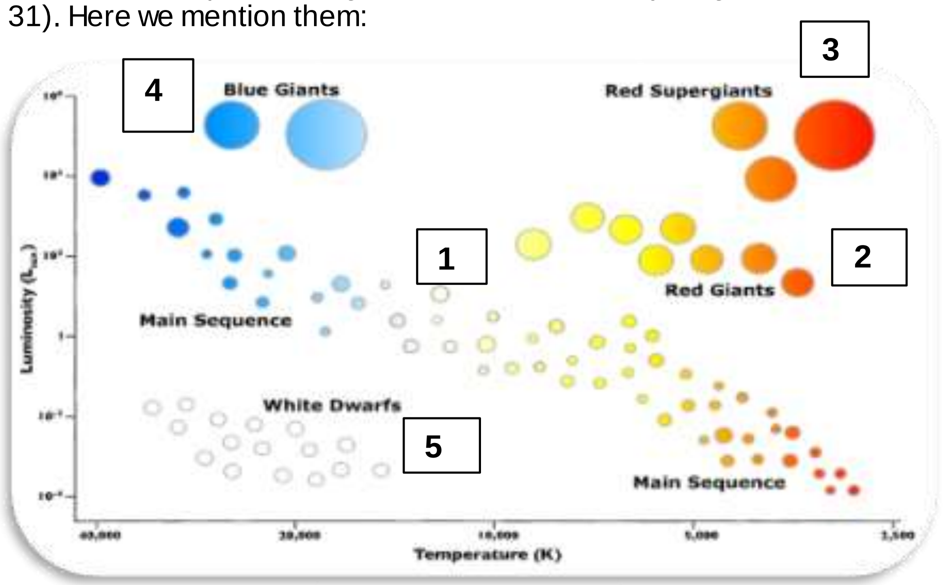


Figure 31: *Hertzsprung-Russell Diagram. (Credits: https://hrdiagram.weebly.com)*

1. **Main sequence:** More stable phase of stars during their lifetime
2. **Red giants:** evolved low-mass stars
3. **Red super giants**: evolved intermediate-mass stars
4. **Blue giants:** massive stars
5. **White dwarfs:** dead Earth-sized stars.

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[4] https://en.wikipedia.org/wiki/Luminosity

Activity 6.1.2.1:

Let's play with the simulator star in a box to better understand the life of stars.

1. Watch this video tutorial to see how to use the simulator and the information displayed.

2. Fill in the value **initial mass** in region 1 of Figure 32. (Remember that the key parameter in the evolution of a star is its initial mass).

3. **Observe the variation of the following parameters** through the lifetime of the star (that you have given an initial mass) in Figure 32:
   - **Age** (indicated in region 2).
   - **Star phase** (indicated in region 3)
   - **Size, Temperature, Brightness**, **Main sequence time**, **Mass left** (indicated in region 4)

4. Check the variation of some properties of the star during their life (in region 5 of Figure 32).

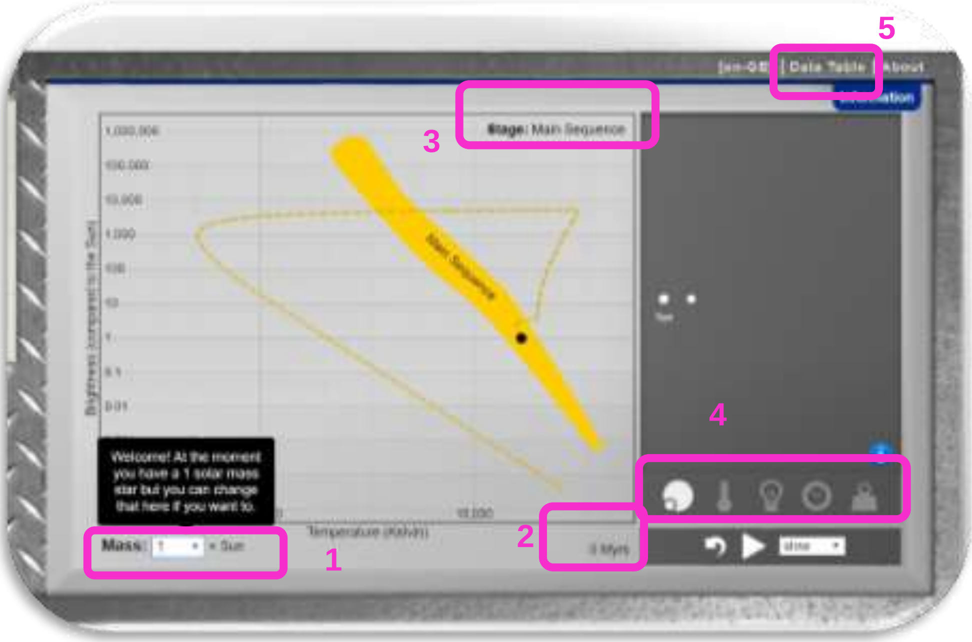

Figure 32: Star in a box. (Credit: Las Cumbres Observatory)

5. Fill in your findings in Table 7.1 for a star of 1 solar mass

Star phase	Radius (in solar radius)	Temperature (K)	Age (billion years)
Main-sequence	1.7	~ 6 000	~ 9 000
Red giant	200	~ 5 600	9 000 + 1 000
White dwarf	0.01	Cooling	A very long time

Table 7.1 Properties of the evolutionary phases of a star with an initial mass of 1 solar mass.

6. Fill in your findings in Table 7.2 for a star of 20 solar masses

Star phase	Radius (in solar radius)	Temperature (K)	Age (million years)
Main-sequence	15.6	~ 34 000	~ 9
Red supergiant	1500	~ 27 000	~ 9 + 1
Neutron star	< 0.01	Cool down from a temperature of 2 000 000	A very long time

__Table 7.2__ Properties of the evolutionary phases of a star with an initial mass of 20 solar masses.

7. Fill in Table 7.3 for a star with an initial mass of 30 solar masses. Tip: Read the information in the Data Table for the Normal option.

Star phase	Size (sun radius)	Temperature (K)	Age (million years)
Main-sequence	22.18	38 690	5.95
Red Giant	114.88	28 022	0.52
Blue Giant	1.04	126 911	0.18
Black hole	<< 0.01	<< 1	A very long time

__Table 7.3__ Properties of the evolutionary phases of a star with an initial mass of 30 solar masses.

8. **(Optional activity for Phase 4):** Record a basic video explaining the evolutionary process of a star with an initial mass of 30 solar masses. Tip: You may use Screencastify, Windows cast, OBS Project, YouTube video, others …

If we would have selected in the application “star in a box” the option “Advanced”, the information in Tables 7.1 and 7.2 will become the one shown in Figure 33. There we see that stars pass through various intermediate phases from the Main-Sequence to the Red giant, such as **Hertz sprung Gap, Red Giant Branch, Core Helium Burning, Asymptotic Giant Branch, Thermally-pulsing Asymptotic Giant Branch**, as shown in the Tables of Figure 33.

This is a summary of the star that is currently selected. Mass: **20 M☉**

Stage	Radius (R☉)	Luminosity (L☉)	Temperature (K)	Duration (Myrs)
Main Sequence	15.56	111686.32	34056	8.82
Hertzsprung Gap	249.52	121870.89	27046	0.02
Core Helium Burning	1222.08	149245.07	6668	0.98
Asymptotic Giant Branch	1507.30	191029.31	3256	0.02
Neutron Star	< 0.01	0.00	Cool down from 2123244	A very long time

Download data as CSV

This is a summary of the star that is currently selected. Mass: **1 M☉**.

Stage	Radius (R☉)	Luminosity (L☉)	Temperature (K)	Duration (Myrs)
Main Sequence	1.69	2.82	6005	8992.81
Hertzsprung Gap	2.40	3.25	5635	478.60
Red Giant Branch	159.51	2622.41	5027	609.15
Core Helium Burning	21.67	149.21	4916	124.60
Asymptotic Giant Branch	200.26	3910.21	4320	4.60
Thermally-pulsing Asymptotic Giant Branch	0.02	742.34	3232	0.50
Carbon/Oxygen White Dwarf	0.01	<< 0.01	Cooling	A very long time

Figure 33: *Data Tables for an initial mass of 1 and 20 solar masses. (Credit: star in a box).*

Activity 6.1.3: Clusters of stars:

Stars gravitationally bound are called **clusters of stars**. **Open clusters** are loose aggregates of young stars (~ 100 mega-years), while **globular clusters** are denser aggregates of redder older stars (~10 giga-years). Figure 37 shows in our galaxy, the distribution of younger stars (Population I) and elder stars (Population III).

Cluster of stars (Figure 34) are formed **from the same parent molecular cloud,** having the stars in it a similar range of ages, chemical composition and distance to us. Therefore, they are excellent locations where to study star formation, being the initial mass of their stars the main difference among them.

Figure 34: *Star cluster Westerlund 2. (Credit: NASA/ESA, the Hubble Heritage Team (STScI/AURA), A. Nota (ESA/STScI), and the Westerlund 2 Science Team)*

Watch this ESA Gaia video and tell us: How to find a star cluster?

> This video talks about the discovery of cluster of stars "Gaia 1" by the ESA/Gaia satellite. This cluster is located at a distant galaxy at 15 000 light-years from us. As this distant galaxy is in the visual direction of Sirio it was not possible to detect it from Earth. The method used by the ESA mission to detect it was the same as the one performed by the XVIII astronomers (the Herschel siblings) by counting stars in several regions of the sky, but this time with the use of computers. There may be up to 1 billion of solar stars in this cluster.

- Execute Activity 9.2 to inspect real scientific data of stars collected by the ESA space missions.
- For more detailed information, read the CESAR monograph about "stellar evolution".

Activity 6.2: Interstellar Medium (ISM)

Among stars there is a diffuse matter, called **interstellar matter (ISM). It consists of gas (99%) and dust (1%)**, mostly found in the form of clouds or nebulae (plural of nebula).

About 75% of the interstellar gas is in the form of hydrogen, and nearly all the remaining 25% as helium. This gas is extremely cold (~ 10 K)[5] and diluted, about 1 atom per cubic centimeter (for comparison, the air we breathe has a density of about 30 000 000 000 000 000 000 molecules per cubic centimeter). However, despite this very low density, the amount of matter adds up over the vast distances between two stars.

Interstellar dust is not like the dust you might find under your bed. It **consists mainly of silicates, iron, carbon and dirty ice.** Dust particles are irregularly shaped and very small, just a fraction of a micron across (similar to the wavelength of blue light), and have typical **temperatures of around 100 K**.

Activity 6.2.1: Effects of interstellar matter

The ISM can be studied at visible wavelengths due to its interaction with light from stars. This is because the typical size of dust grains (in the order of a fraction of a micron) is very similar to visible wavelengths, in particular, blue and violet light. Therefore, **dust grains are capable of absorbing and scattering visible light, making a region of the sky appear empty**. If the same region is observed in near-infrared light, their wavelengths are longer than dust grains sizes, and all the stars hidden within and behind the dust are revealed.

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[5] The ISM may contain hydrogen in atomic, molecular and ionized states depending on the processes taking place in molecular clouds, taking into account the combination of gravity forces, magnetic fields, turbulences, thermodynamics and stellar feedback. Depending on these processes t temperature may vary between 10 K -10^8 K

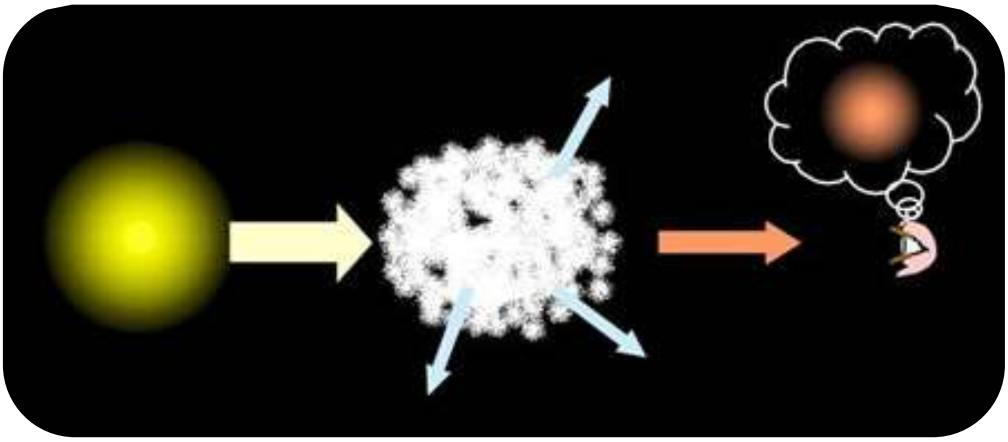


Figure 35: Effects of the ISM: A star behind it will look redder and fainter than it really is. (Credit: COSMOS, the SAO Encyclopaedia of Astronomy)

Often this absorption and scattering is not complete, and some stars are still visible in optical images. However, since blue light is absorbed and scattered more than red light, those **stars will appear redder and fainter than they really are**, being the blue light absorbed and re-emitted at longer wavelengths (redder colors).

These two phenomena shown in Figure 35, are known as ***interstellar reddening* and *optical extinction***, respectively, and have important consequences on the measurements made by astronomers; neglecting them will yield to wrong estimations of the star's properties and of its distance.

- Check whether you have understood what you have just read in this section.

Interstellar Medium is:

- 99 % of gas, being composed by a 75% of hydrogen and a 25% of helium
- 1 % is dust, whose temperature is around …100…K
- Dust grains are made by silicates and ices
- The size of the dust grains that affects the (Tip: check Figure 7 for support)
  - visible light, is 0.5 x 10^{-6} meters
  - ultraviolet light, is ~10^{-8} meters
- The effect of interstellar medium in the images can be
  - reflecting the light from close stars in the cloud in the visible
  - blocking the light in the visible
  - obtaining fainter (called optical extinction)
  - obtaining redder colors in the images (called interstellar reddening)

- Execute Activity 9.5 to analyses the interstellar medium effects with real scientific data of the ESA space missions (in ESASky).
- For more detailed, we recommend you to read the CESAR monograph about "interstellar medium"

Activity 6.3: Galaxies

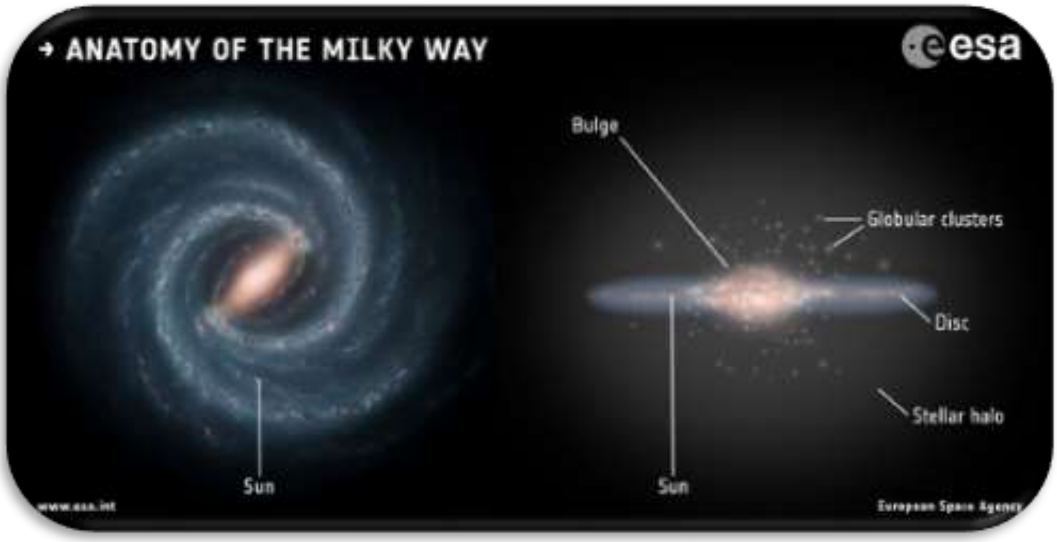


Figure 36: *Anatomy of the Milky Way. (Credit: ESA/Gaia)*

Stars and clouds bounded gravitationally form **galaxies.** Figure 36 shows the anatomy of our galaxy, the Milky Way, a spiral galaxy. Our galaxy contains a central part called **bulge,** a **disk,** and a less dense bubble called **halo**. It also has a bar in the disk (spiral barred galaxies). Not all the galaxies have these zones. If you want to know more about galaxies we invite you to visit [the CESAR booklet about galaxies.]()

Figure 37 shows an example of how stars get distributed in our galaxy by age, being Population III the elder stars and Population I the youngest.

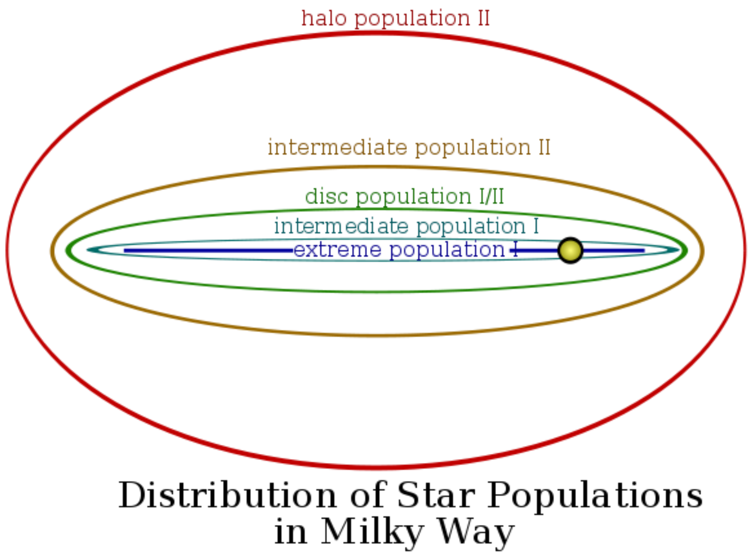


Figure 37: *Distribution of the stars by Population (age) in our Galaxy. (Credit: www.quora.com)*

Blue stars are young and massive while red stars can be young low-mass stars or old stars (as we saw in Activity 6.1.2).

As only the most massive and luminous stars contribute significantly to the luminosity of a galaxy, we can say that in a galaxy reddish parts are old stars and bluer parts are hot gas from young stars. Young stars tend to be around the disk and older stars in the halos. Bulges of spiral galaxies look yellowish or whitish, rather than reddish because they contain stars of many different ages.

In the 1920s, Edwin Hubble classified galaxies by their morphology as elliptical, lenticular and spiral. Nowadays (Figure 38), astronomers **classify galaxies as elliptical, spiral (with/out bars) and irregular.**

Note 1: Galaxies tend to contain a **supermassive black hole in their center, most of them in active stage**.

Note 2: The first evidence of the existence of dark matter was found by Vera Rubin at the end of 1970s, when detected that stars at the edges of the Andromeda galaxy rotated at a similar speed to stars in other parts of the galaxy, what was against Newton's laws. For that reason, she achieved the conclusions that halos in galaxies could be 10 times wider than what we see from the input light, **being halos dark matter containers. This video is very interesting to understand how the discovery of the dark matter, by Vera Rubin, took place.**

Figure 38: *Types of galaxies, characterized by their shape in visible light. (Credit: ESA/NASA Hubble)*

- Execute Activity 10.4 to analyses real scientific data of galaxies collected by the ESA space missions (in ESASKy).

Activity 7: The exploration of the Universe by the European Space Agency

The European Space Agency has a fleet of scientific missions observing the with satellites that carry on-board cameras, spectrometers and detectors, as mentioned in Activity 5.

1. Have a look to the ESA scientific fleet of cosmic observers (Figure 39) and fill in Table 8 with the name of the space mission able to observe light at that “type of color” or wavelength.

Type of light	ESA missions
(soft) X-rays	XMM-Newton
Ultraviolet	XMM-Newton
Optical (Visible)	Gaia, Hubble, Cheops
Near-Infrared (short infrared waves)	JWST, Euclid
Far-Infrared (long infrared waves)	Herschel
Submillimetre (short microwaves)	Planck

Table 8: *Types of light observed by the various ESA space missions.*

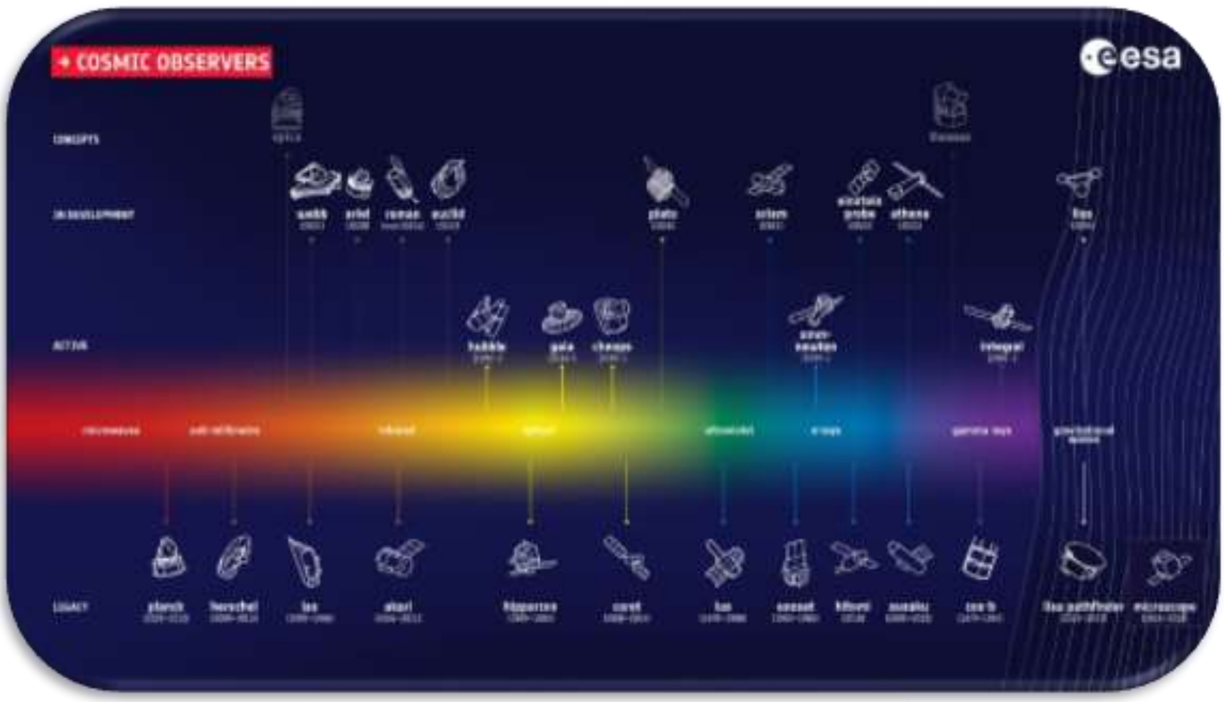


***Figure 39**: ESA's scifleet of cosmic observers. (Credit: ESA)*

The astronomical data collected by the European Space Agency space missions are cleaned-up and calibrated by the “pipelines”, ready to be used and to analyses their data in the ESA scientific archives of ESAC (European Science and Astronomy Centre, Villanueva de la Cañada, Madrid, Spain), Figure 40.

Through ESASky not only the ESA scientific data are provided but also data from ground-based telescopes and other space missions that collaborate with ESA, as well as access to astronomical catalogues and databases commonly used by astronomers.

Figure 40: *ESAC mission planning room. (Credit: ESA)*

The ESASky Team that belongs to the ESDC Team, with base in ESAC, has designed this portal not only as a consistent and rigorous access to astronomers but also as an spectacular window for those educators that are interested in knowing in a simple and attractive way the Universe, as it is explained in the Activity 9.

Activity 8: What have you learnt so far

Check what have you learnt until now with this questionnaire

Phase 2

How to proceed in this Phase depends on the results obtained in the latest Activity of Phase 1 (questionnaire).

- **Case 1:** Your students replied quite well to the quizz
  ➔ **Go to PHASE 3**

- **Case 2:** Your students did not reply very well to the quizz or they have many questions related to the topic of the Scientific Challenge
  ➔ **Review PHASE 1** (see below) **using this extra material**

http://cesar.esa.int/index.php?Section=Scientific_Cases&Id=22&ChangeLang=en	
• Expert talks given at CESAR Teacher workshops (pdf and/or videos) • ESA dedicated videos • CESAR Monographics (booklets) • Simulators/websites	

➔ **Go to PHASE 3**

- **Case 3:** You can not make it alone and you need interaction with the CESAR Team

Activity 9: Ask for a videocall with the CESAR Team if needed

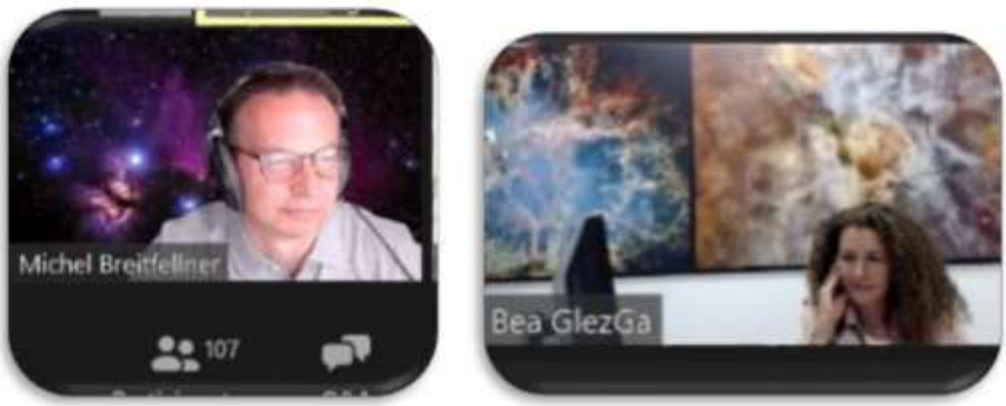


Figure 41: *Image of the CESAR Team making a video call (Credits: ESA)*

Note: Per scientific challenge you have the opportunity to ask for 30 min video calls

- with your class (in PHASE 2) to clarify concepts
- teachers only (in PHASE 3) in case you are stuck with software/answers

Phase 3

Activity 10: Exploring the Universe through ESASky Virtual Telescope

ESASky is a scientific discovery portal that allows easy access to the entire sky as observed by the European Space Agency's scientific missions. The different functionalities available in ESASky are explained through its help in this link.

Activity 10.1: Getting familiar with ESASky

ESASky is a science driven discovery portal providing full access to the entire sky as observed with Space astronomy mission. All ESASky help tutorials are available on this link.

Figure 42a: *ESASky portal selecting Explorer mode. (Credit: ESASky)*

1. Click on this link to go into *ESASky* in your browser. Choose the option "**Explorer**" (that is the simplest way to get familiar with ESASky).
2. If you want **to search for a specific object** (i.e., Crab Nebula) type its name at the searching box that is located at the top-right area of the portal, as shown in Figure 42b. (Note: It is necessary to write the name of the object in English and/or in a particular format, to be recognized by astronomical databases).

Figure 42b: *ESASky results of the Crab Nebula. (Credit: ESASky)*

Activity 10.2: Staring at the stars through ESASky.

In Activity 4.1, students filled in Table 5 with the information of five stars in the Orion constellation, identified in Figure 5. Comparing the color of the stars with those of bulbs with well-known temperatures, students were able to guess the temperature of those. If you have not executed this Activity yet, we recommend you to do so before continuing.

What type of stars were redder and what type of stars bluer? Tip: Check Figure 43 to explain your answer.

Bluer stars are those with their blackbody peak at shorter wavelengths than redder stars. Blue stars are hotter (with effective temperatures, ~ 20 000 K) and more massive stars (initial mass > 8 solar masses). This evolve faster and more violently than less massive stars, burning their fuel in their nuclei faster.

Extra info: Massive stars leave the main sequence after $10^{7\text{-}8}$ years and become blue giants, later on exploding as supernovae. The core of the star will end up as a pulsar or a black hole. Low-mass stars leave the main sequence after $10^{10\text{-}11}$ years to become red giants (or supergiants). The external shells are released to the interstellar medium as planetary nebula and its core will get colder and denser in the form of a white dwarf.

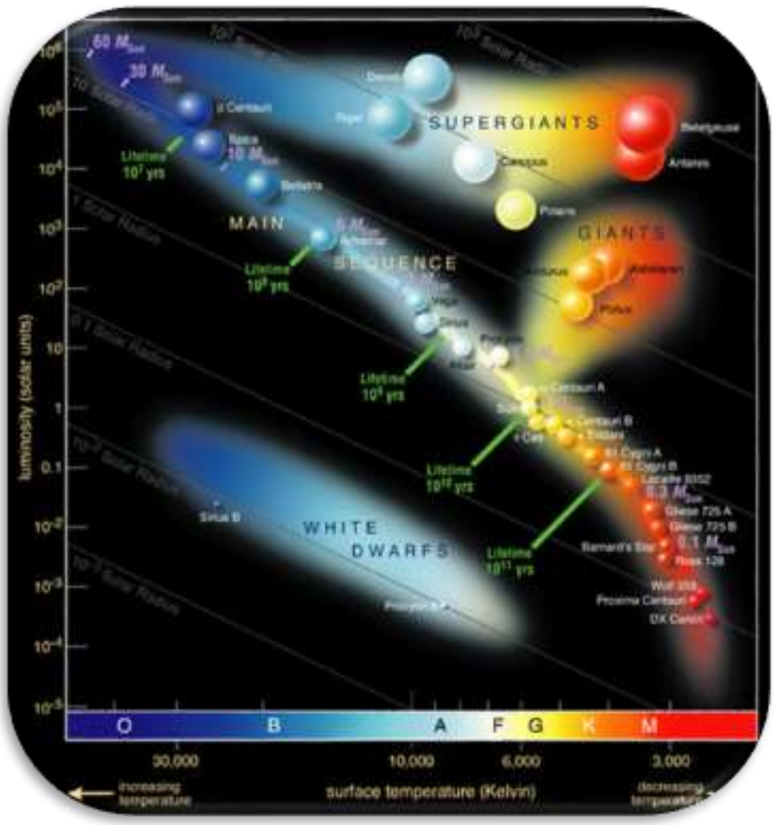


Figure 43: *The H-R diagram. (Credit: ESO)*

Activity 10.2.1: Getting familiar with an H-R diagram

- Get the information, for a sample of stars, from the H-R diagram of Figure 43 and fill in Table 9.

Main-sequence stars	**Red & blue Giants/Supergiant stars**
Star: **Altair** Colour: White Temperature: 8 500 K Luminosity: 10 $L_\odot$ Spectral Type[6]: A7 V	Star: **Arcturus** Colour: Orange Temperature: 4 500 K Luminosity: 4×10^2 $L_\odot$ Spectral Type: K1.5 III
Star: **Bellatrix** Colour: Blueish Temperature: 20 000 K Luminosity: 6×10^3 $L_\odot$ Spectral Type: B2 III	Star: **Betelgeuse** Colour: Red Temperature: 3 500 K Luminosity: 2×10^5 $L_\odot$ Spectral Type: M2 Iab
Star: **Spica** Colour: Blue Temperature: 25 000 K Luminosity: 10^4 $L_\odot$ Spectral Type: B1	Star: **Rigel** Colour: White-blue Temperature: 10 000 K Luminosity: 10^5 $L_\odot$ Spectral Type: B8 Ia

Table 9: *Selection of stars labelled in Figure 43*

- Why do you think that Arcturus may have a higher luminosity if its temperature is smaller than the one from Altair?

> Because the giant stars are bigger in size (surface) than main sequence stars and their radioactive power (in the complete surface) is higher.

[6] Spectral type is the classification of the stars based on the characteristics of their spectra.

Activity 10.2.2: Staring at the stars of an H-R diagram through ESASky

- **Search in ESASky for the selection of the objects** of Table 9 and fill in Table 10 with a snapshot (and their url in ESASky) of their appearance in the visible range, as shown in ESASky.

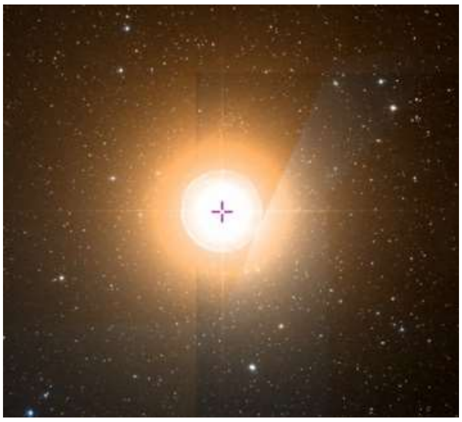
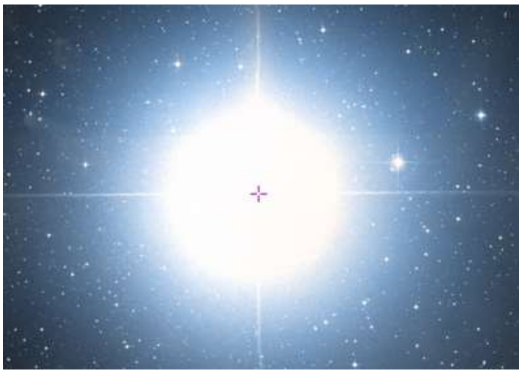
Main-sequence stars	Red & blue Giants/Supergiant stars
Altair 	Arcturus 
Bellatrix 	Betelgeuse 
Spica (Alfa Virginis) 	Rigel (beta Orionis) 

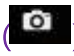
***Table 10:** Visible images of a sample of stars in different evolutionary stages from ESASky.*

Activity 10.3: Tour around various astronomical objects with ESASky (Target lists)

The ESASky Team made available ***target lists,*** accessible through the icon of the Pergamum (see Figure 44) which are lists of astronomical objects of the same type.

Figure 44: *ESASky target lists. (Credit: ESASky)*

1. Complete Table 11 for a **target** selected object per **target list** is
    1. Write a Description of the target (Tip 1: given by ESASky)
    2. Add a snapshot and the link to the target in ESASky

Tip 2: click on this icon () to make a snapshot of your field of view in ESASky.

Tip 3: click on this icon () to obtain a shareable link of your field of view in ESASky.

Target description	ESASky image (in the visible)
Target list: Star formation regions **Target:** Orion Nebula **Description:** The **Orion Nebula** (also known as **Messier 42**, **M42**, or **NGC 1976**) is a diffuse nebula situated in the Milky Way, being south of Orion's Belt in the constellation of Orion.[b] It is one of the brightest nebulae, and is visible to the naked eye in the night sky. M42 is located at a distance of 1,344 ± 20 light years[3][6] and is the closest region of massive star formation to the Earth. The M42 nebula is estimated to be 24 light years across. It has a mass of about 2,000 times that of the Sun. Older texts frequently refer to the Orion Nebula as the **Great Nebula** in Orion or the **Great Orion Nebula**.[7]. (Wikipedia)	 Image in ESASky

Target list: Bright nebulae **Target:** Eagle Nebula **Description:** The **Eagle Nebula** (catalogued as **Messier 16** or **M16**, and as **NGC 6611**, and also known as the **Star Queen Nebula** and **The Spire**) is a young open cluster of stars in the constellation Serpens, discovered by Jean-Philippe de Cheseaux in 1745–46. Both the "Eagle" and the "Star Queen" refer to visual impressions of the dark silhouette near the centre of the nebula,[3][4] an area made famous as the "Pillars of Creation" imaged by the Hubble Space Telescope. The nebula contains several active star-forming gas and dust regions, including the aforementioned Pillars of Creation. (Wikipedia)	 Image in ESASky
Target list: Dark nebulae **Target:** Cocoon Nebula **Description: IC 5146** (also **Caldwell 19**, **Sh 2-125**, and the **Cocoon Nebula**) is a reflection[2]/emission[3] nebula and Caldwell object in the constellation Cygnus. The NGC description refers to IC 5146 as a cluster of 9.5 mag stars involved in a bright and dark nebula. The cluster is also known as Collinder 470.[4] It shines at magnitude +10.0[5]/+9.3[3]/+7.2.[6] Its celestial coordinates are RA 21^{h} 53.5^{m}, dec +47° 16′. It is located near the naked-eye star Pi Cygni, the open cluster NGC 7209 in Lacerta, and the bright open cluster M39.[2][5] The cluster is about 4,000 ly away, and the central star that lights it formed about 100,000 years ago;[7] the nebula is about 12 arcmins across, which is equivalent to a span of 15 light years.[6]. (Wikipedia)	 Image in ESASky
Target list: Supernova remnants **Target:** Cygnus Loop **Description:** The Cygnus Loop is a large supernova remnant in the constellation Cygnus, located about 1 500 light years from the Earth. It measures nearly 3 degrees across (about 6 full moons). Some arcs of the loop, known collectively as the Veil Nebula or Cirrus Nebula, are seen in visible light. The complete loop is revealed in radio, infrared and X-ray images. (ESASky)	 Image in ESASky

Target list: Supermassive black hole **Target:** Sombrero Galaxy **Description:** The **Sombrero Galaxy** (also known as **Messier Object 104**, **M104** or **NGC 4594**) is a lenticular galaxy in the constellation Virgo found 9.55 mega parsecs (31.1 million light-years)] from the Earth. The galaxy has a diameter of approximately 15 kilo parsecs (49,000 light-years),[5] 30% the size of the Milky Way. It has a bright nucleus, an unusually large central bulge, and a prominent dust lane in its inclined disk. The dark dust lane and the bulge give this galaxy the appearance of a sombrero hat. Astronomers initially thought that the halo was small and light, indicative of a spiral galaxy, but the Spitzer Space Telescope found that the dust ring around the Sombrero Galaxy is larger and more massive than previously thought, indicative of a giant elliptical galaxy. (Wikipedia)	 Image in ESASky
Target list: Brown dwarfs **Target:** Teide 1 **Description:** **Teide 1** was the first brown dwarf to be verified, in 1995, discovered by a Spanish Team led by Dr. Rafael Rebolo and Dra. Zapatero Osorio. It is located in the Pleiades open star cluster, approximately 400 light-years (120 pc) from the Earth. This object is more massive than a planet (57 ± 15 M_J),[5] but less massive than a star (0.0544 M_{Sun}). The radius of the brown dwarf is four times that of Jupiter. Its surface temperature is 2,600 ± 150 K,[5] which is about half that of the Sun. Its luminosity is 0.08–0.05% of that of the Sun.[4] Its age is only 120 million years compared to the Sun's age of 4.68 billion years. (Wikipedia)	 Image in ESASky

Target list: Brown dwarfs in multiple systems **Target:** Gliese 229 **Description: Gliese 229** (also written as **Gl 229** or **GJ 229**) is a binary system composed of red dwarf and brown dwarf about 19 light years away in the constellation Lepus. Primary component has 58% of the mass of the Sun,[7] 69% of the Sun's radius,[8] and a very low projected rotation velocity of 1 km/s at the stellar equator. (Wikipedia)	 Image in ESASky
Target list: Closest exoplanetary systems **Target:** Próxima Centauri b **Description:** Proxima Centauri b (also called Proxima b[5][6] or Alpha Centauri Cb) is an exoplanet orbiting in the habitable zone of the red dwarf star Proxima Centauri, which is the closest star to the Sun and part of a triple star system.[7][8] It is located approximately 4.2 light-years (4.0×10^{13} km) from the Earth in the constellation of Centaurus, making it the closest known exoplanet to the Solar System (Wikipedia).	 Image in ESASky
Target list: Open clusters **Target:** The Pleiades **Description:** The **Pleiades**, also known as the **Seven Sisters** and **Messier 45**, are an open star cluster containing middle-aged, hot B-type stars in the north-west of the constellation Taurus. It is among the star clusters nearest to the Earth and is the cluster most obvious to the naked eye in the night sky (Wikipedia).	 Image in ESASky

<table>
<tr><td>Target list: Globular clusters

Target: Messier 13

Description: Messier 13 is a globular cluster of stars approximately 22 800 light-years away in the constellation of Hercules and is composed of several hundred thousand stars. Best seen in the optical SDSS9 sky (ESASky)</td><td>
Image in ESASky</td></tr>
<tr><td>Target list: Spiral galaxies

Target: M31

Description: The Andromeda Galaxy, M31, is a spiral galaxy approximately 2.5 million light-years away in the constellation Andromeda. Being approximately 220 000 light years across, it is the largest galaxy of the Local Group, which includes the Milky Way, the Triangulum Galaxy and about 44 other smaller galaxies. Best seen in the optical SDSS9 sky (ESASky)</td><td>
Image in ESASky</td></tr>
<tr><td>Target list: Peculiar galaxies

Target: NGC 523

Description: NGC 523, also known as Arp 158, is a peculiar galaxy located in the constellation of Andromeda. The observations suggest that the peculiarities result from a close encounter by two dwarf galaxies, with tidal interaction responsible for the formation of the galactic bridge and tails. (ESASky)</td><td>
Image in ESASky</td></tr>
</table>

Target list: **Interacting galaxies** **Target:** Arp 240 **Description:** Arp 240 is a pair of interacting spiral galaxy located in the constellation Virgo. The two galaxies are listed together as Arp 240 in the Atlas of Peculiar Galaxies.[4] The galaxy on the right is known as NGC 5257, while the galaxy on the left is known as NGC 5258. Both galaxies are distorted by the gravitational interaction, and both are connected by a tidal bridge, as can be seen in images of these galaxies. (Wikipedia)	 Image in ESASky
Target list: Galaxy clusters **Target:** Abell 2218 **Description:** **Abell 2218** is a cluster of galaxies about 2 billion light-years away in the constellation Draco. **Acting as a powerful lens,** it magnifies and distorts all galaxies lying behind the cluster core into long arcs. The lensed galaxies are all stretched along the cluster's center and some of them are multiply imaged. Those multiple images usually appear as a pair of images with a third — generally fainter — counter image, as is the case for the very distant object. The lensed galaxies are particularly numerous, as we are looking in between two mass clumps, in a saddle region where the magnification is quite large.	 Image in ESASky

Table 11: *Targets lists available in ESASky.(Credit: ESASky)*

Activity 10.4: Multi-wavelength studies using ESASky

The colors of astronomical images like the ones in ESASky are not real. Remember that our eyes cannot see infrared or ultraviolet colors! In fact, **telescopes register only black-and-white images.**

Those images can then be artificially colored and combined to create the beautiful color pictures we all admire. Usually, the image observed in the shortest wavelength is colored in blue, in the longest wavelength in red and another in the range in between in green. By mixing these three colors, all the rest can be produced, as shown in Figure 45.

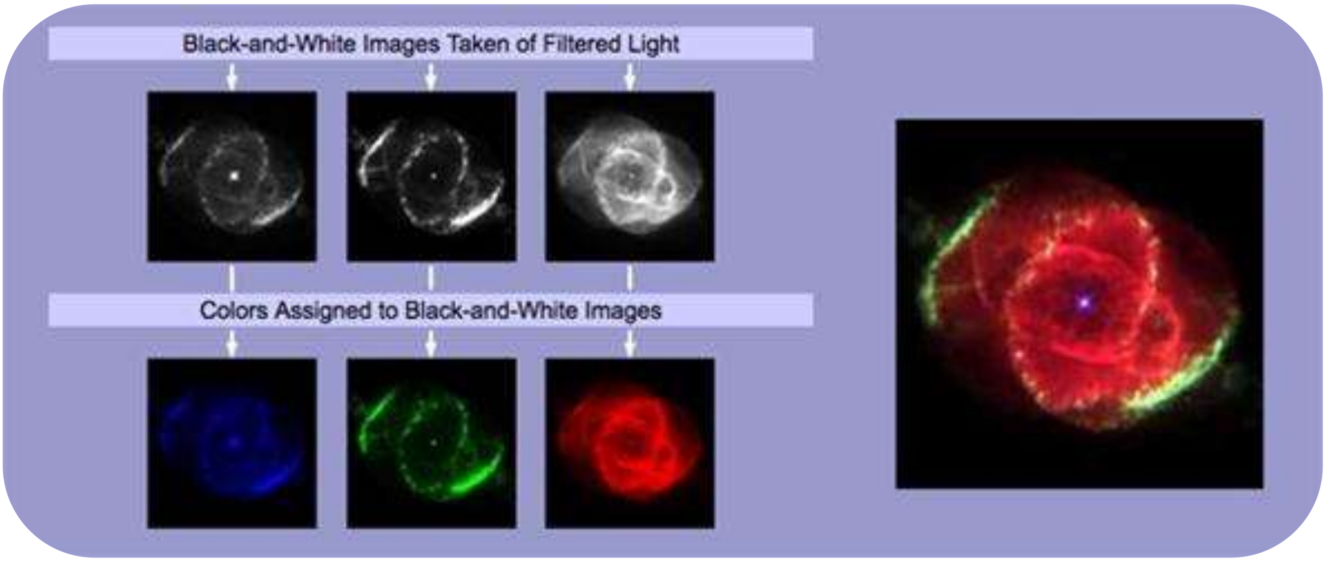


Figure 45: *How to create a coloured astronomical image. (Credit: astronomy.wonderhowto.com)*

In ESASky, images are associated to a filter or a wavelength. To study an object in multi-wavelength range we will load a set of images (collected by different instruments and/or collectors) and inspect them. Check this video tutorial to see how to load 'skies' in ESASky

1. **To open the various images**, click on the colourful button at the top-left corner 'Manage Skies'
2. **To select an all-sky map,** choose the wavelength region in the left drop-down menu, and then browse the available skies in the second menu.
3. **Click on the "+" sign** as many times as needed and select different wavelength ranges

Note 1: Even when most of the targets (celestial objects) have been observed by various missions, and ESASky serves you them, not all of them have been observed in the whole spectral range.

Note 2: The resolution (minimum element able to be resolved in an image/spectrum) depends on the mission (collector), the instrument and the detector, as well as the wavelength range where the astronomical data were collected.

Activity 10.5: Analyzing the effects of Interstellar **Matter** through ESASky

Activity 10.5.1: Effects of Interstellar Matter in bright nebulae

1. In ESASky go to Target lists (check Activity 10.3), in particular to Bright nebulae Target list
2. Search for the target *"Bubble Nebula"*
3. Load a set of skies (as explained in Activity 10.4) to analyses this region for those wavelengths.
4. Fill in Table 12 with your findings in regions Near-infrared, Visible and X-rays with:
   - a snapshot of the target in each spectral region
   - a description of what you see.

Near-IR	Visible	X-rays
		
In near-infrared we do see neither the bubble nor the majority of the heated nebula. Instead we can see the field of stars hidden by the nebula itself.	The material ejected from a central hot massive star, interacting with the interstellar medium (surrounding of the star) in the shape of a bubble. The nebula surrounding the hot star is heated by this and it glows. This is an HII region.	In X-rays, only the remaining central core of the hot massive star is detected and not the external shell ejected.

Table 12: *Inspection of the Bubble Nebula in various filters using ESASky*

Activity 10.5.2: Effects of Interstellar Matter in dark nebulae

1. In ESASky go to Target lists (check Activity 10.3), in particular to Dark nebulae Target list
2. Search for the target *"Snake Nebula"* 10
3. Load a set of skies (as explained in Activity 9.4) to analyse this region for the wavelengths
4. Fill in Table 13 with your finding in regions Far-infrared, Mid-infrared and Visible.
   4.1. A snapshot of the target in each spectral region
   4.2. A description of what you see.

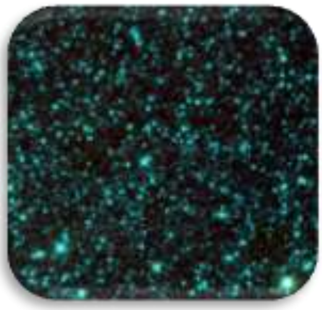
Far-infrared	**Mid-infrared**	**Visible**
		
We see a cloudy pattern due to the emission of the cold gas at far-infrared.	We see the field of view plenty of stars emitting at long wavelengths. Most probably because the light of the stars is absorbed by the cloud and re-emitted at longer wavelengths (interstellar reddening and optical extinction effects mentioned in Activity 6.2.1)	We see a dark pattern with the shape of a snake, that gives the name to the nebula. The light from that region is blocked to us because the size of the dust grains has the same length as the visible wavelength (~0.5 x 10^{-6} metres, check Figure 7).

Table 13: *Inspection of the Snake Nebula in various filters using ESASky*

Activity 11: Revealing the secrets of your favorite celestial object.

For this Activity, students should pick up one of the following objects and start their investigation following steps of the procedure in Activity 10.1 (Crab Nebula), Activity 10.2 (NGC 3766), Activity 10.3 (Horsehead nebula) or Activity 10.4 (The Whirlpool galaxy)

Object	Description	Activity
The Crab Nebula (M1) 	It is a cloud formed by the remains of an aged star that exploded as a supernova nearly 2000 years ago. Read more here	Activity 11.1
NGC 3766 	**NGC 3766** is an open star cluster in the southern constellation Centaurus. It contains more than 100 stars relatively young (blue) and two red supergiant stars Read more here	Activity 11.2
The Horsehead nebula 	It is a small dark nebula in the constellation Orion. It is one of the most identifiable nebulae because of its resemblance to a horse's head. Read more here.	Activity 11.3
The Whirlpool galaxy 	It is an interacting grand-design spiral galaxy with an active galactic nucleus. It was the first galaxy to be classified as a spiral galaxy. Read more here	Activity 11.4

Table 14: *Types of objects to be selected as part of this Activity, from left to right, the Crab, the Horsehead nebula and the whirlpool galaxy. (Credit: ESASky)*

Procedure:

1. Type the name of *your object* in the search box, as shown in Figure 42 (at Activity 10.2)
2. Play with the zoom buttons if necessary to view the full image.
3. Create a stack of coloured map images, using the option "Manage Skies", as shown in Figure 45, covering the electromagnetic spectrum from soft X-rays (low-frequency X-rays) to submillimetre (very short microwaves).
4. Now observe *your object* in all wavelength ranges. How do the images change as you move through the spectrum?

5. Take a snapshot of every image using the camera button. You can paste the images into the table on the next page.
6. Next to each image in the table, describe what you can see. Pay attention to the **shape** and **size** of the object in each image. Where is, the bright source seen in the X-ray image located in the rest of images?

7. Discuss your hypotheses with other groups. Do you all agree on the reasons for the differences between the images?

Activity 11.1: Revealing the secrets of the Crab Nebula

Object: Crab Nebula (M1)			
Type of light	**Image**	**Description**	**Explanation**
(soft) X-rays (XMM-Newton EPIC colour)	 ESASky image	The image shows a bright source located in the center of the nebula that is seen in images at other wavelengths.	There must be a bright X-ray source at the centre of the nebula. Concretely, the emission comes from high-energy particles moving around the central neutron star, but this cannot be appreciated in the image due to its low resolution.
Ultraviolet (XMM-Newton UV colour)	 ESASky image	This image is similar in shape and configuration to those in the visible and infrared. We see the cloud shape, but not many details may be guessed due to the relatively low resolution.	The cloud gas is being heated by the central source and the energy from the explosion. That is why it glows, emitting ultraviolet light.
Optical (Visible)* (DSS2 colour)	 ESASky image	This image shows the cloud. Not much detail is appreciated in the central part, as the image is overexposed. Some filaments are observed at the edges.	As with the ultraviolet image, the gas is heated up and glowing in visible light. The filaments are the result of the explosion that blasted the star's outer layers into space.

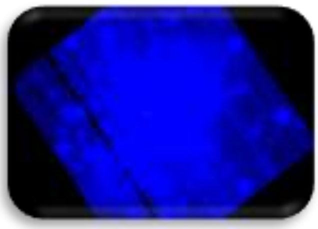
Near-Infrared* (2MASS colour JHK)	 ESASky image	This image looks similar to the optical one. However, when comparing star patterns in both images, the pattern appears further away from the diffuse emission in the visible image. We also see a higher number of stars.	Because near-infrared light has slightly longer wavelengths than visible light, they are not blocked as much by the dust in the cloud, allowing us to see stars that are too faint in the optical image. The hot gas is not so bright in this image, making the cloud emission less extended.
Far-Infrared (Herschel/PACS RGB 70, 160 micron)	 ESASky image	The cloud and the expanding filaments are also clearly seen in this wavelength range.	What we see here is the thermal emission from interstellar dust, that is, the light emitted by the dust due to its temperature. Hence, we can tell that the cloud not only contains gas, but also dust, and that this dust closely follows the patterns of hot gas seen in shorter-wavelength images.
Submillimetre (short microwaves) (Herschel/SPIRE RGX 250, 360, 500 micron)	 ESASky image	Although the resolution is much worse, the cloud shape and some of its structure can be recognised in this image.	Supernova remnants like the Crab Nebula emit radio waves because of high-energy electrons fast moving in a magnetic field.

Table 15: *Analysis of various skies for the Crab. (Credits: ESA)*

Remarks:

At the centre of the Crab Nebula, astronomers have discovered a neutron star that was once the core of the dead star that went supernova. It is a very small, massive, and hot object, with a very strong magnetic field. It also spins very fast, emitting regular pulses of light like a lighthouse.
Activity 10.2: Revealing the secrets of the open cluster NGC 3766

Activity 11.2: Revealing the secrets of the open cluster NGC 3766

Object: Pearl Cluster (NGC 3766)			
Type of light	**Image**	**Description**	**Explanation**
(soft) X-rays (XMM-Newton EPIC colour)	 ESASky image	In this image, we can identify many stars in the cluster as weak X-ray sources.	The detection of these stars in X-rays confirms that these stars are very hot and/or have strong coronal activity.
Ultraviolet (XMM-Newton UV colour)	 ESASky image	We can recognise the cluster from the visible image in this ultraviolet image. However, the image is less clear due to the impossibility of separating the stars in the central part of the cluster, both because of the low resolution and because of the brightness of the stars that saturate this central part.	This image confirms that most stars in the cluster are very hot, and thus prominent ultraviolet sources.
Optical (Visible)* (DSS2 colour)	 ESASky image	This image shows a rich cluster of blue stars of different brightness. A couple of more red stars are also visible; they look similarly bright to some of the blue stars in the cluster.	This observation indicates that most stars in the cluster are hot and blue, but two of them are red and cold.

Near-Infrared* (2MASS colour JHK)	 ESASky image	In this image, two stars are clearly brighter than the rest. Their location coincides with that of the red stars in the visible image.	The fact that these two stars stand out so clearly in the near-infrared confirms that they must be cold and red: they are brighter in near-infrared wavelengths than in the visible, contrary to the hot and blue stars.
Far-Infrared (Herschel/PACS 70, 160 micron)	 ESASky image	We do not see the cluster in this image, just some emission of infrared light all over the region.	This image is simply telling us that there is some dust between the stars and us, but the cluster is not associated with any nebula.
Submillimetre (short microwaves) (Herschel/SPIRE RGB 250, 350,500 micron)	 ESASky image	As in the far-infrared image, the cluster is not seen in this image, just some cloudy emission.	Similarly, to the far-infrared image, all that we can tell from this image is that some interstellar gas is present.

Table 16: *Analysis of various skies for NGC 3766 (Credits: ESA)*

Remarks:

- Students could compare the Pearl Cluster with NGC 4372 and discuss the differences in the stellar content of both types of clusters.
  - Students could also compare both clusters with the Iris and Bubble nebula and discuss the differences in the stars they contain and their content in gas and dust. If wished, this comparison could serve as a transition to the topic of stellar evolution

Activity 11.3: Revealing the secrets of the Horsehead Nebula

Object: Horsehead Nebula			
Type of light	**Image**	**Description**	**Explanation**
(soft) X-rays (XMM-Newton EPIC colour)	 ESASky image	The display shows that the centre of the region has not been observed with XMM-Newton, but some part at the top left and at the bottom right. We see points in blue and in green.	There are not observations collected for the centre of this region available in ESASky. The sources are most probably dead stars, as supernova remnants or pulsars with jets (material ejected and accelerated by magnetic fields). The bluer the colour the higher the temperature.
Ultraviolet (XMM-Newton UV colour)	 ESASky image	The display shows that the centre of the region has not been observed, but some part at the top left and at the bottom right. There are two squares with a bluer light and some features (as lines or patches).	There are not observations collected by XMM-Newton for the centre of this region. The background of the images shows a diffuse emission, such as a heated nebula. There are some patterns (lines) in the images generated by bright objects (in & out) of the field of view that saturate the image.
Optical (Visible)* (DSS2 colour)	 ESASky image	This image shows the cloud and in it the horsehead in dark. The cloud is blocking the light from behind. There are four big stars in the field of view and plenty of little stars all around.	As with the ultraviolet image, the nebula (made of cold gas and dust) is heated up and glowing in visible light. The bright stars are blue massive stars and they are closer. The shape of the horse is visible due to the light from background stars is blocked by the material of the nebula. The reason is that the wavelength of the light has the same size as the dust grains in the nebula.

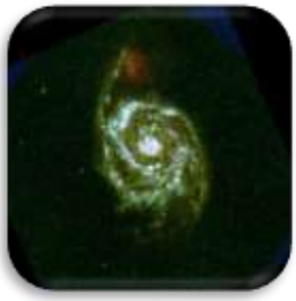
Near-Infrared* (2MASS colour JHK)	 ESASky image	This image looks similar to the optical one. However, when comparing star patterns in both images, the pattern appears further away from the diffuse emission in the near-infrared image. We also see a higher number of stars.	Because near-infrared light has slightly longer wavelengths than visible light, they are not blocked as much by the dust in the cloud, allowing us to see stars that are too faint in the optical image. The hot gas is not so bright in this image, making the cloud emission less extended.
Far-Infrared (Herschel/PACS 70, 160 micron)	 ESASky image	The cloud and the expanding filaments are also clearly seen in this wavelength range. There are some patches where there are no data and others where images from several observations are overlapped.	What we see here is the thermal emission from interstellar dust, that is, the light emitted by the dust due to its temperature. Hence, we can tell that the cloud not only contains gas, but also dust.
Submillimetre (short microwaves) (Herschel/SPIRE RGB 250, 350,500 micron)	 ESASky image	Although the resolution is much worse, the cloud shape and some of its structure can be recognised in this image.	High-energy electrons fast moving in a magnetic field.

Table 17: *Analysis of various skies for the HorseHead Nebula. (Credits: ESA)*

Remarks:

- Students should keep in mind that in the wavelength ranges where stars are particularly prominent (ultraviolet, visible and near-infrared); the light from bright, massive stars dominates the emission, even though those stars cannot be resolved individually.
- Although it is not strictly necessary to talk about the evolutionary stage of the different stellar populations, students may be encouraged to make the connection between the optical colours of the stars and their age based on their location within the galaxy.
- We have not added gamma, hard X-ray and radio images because the resolution is so low.

Activity 11.4: Revealing the secrets of the Whirlpool galaxy

Object: Whirlpool galaxy (M51a or NGC 5194)			
Type of light	**Image**	**Description**	**Explanation**
(soft) X-rays (XMM-Newton EPIC colour)	 ESASky image	The image shows two big sources, a yellow source at the centre of the image and a green one at the top region. Other smaller sources in blue, yellow and orange as well. They seem to show well located areas with different temperatures. We do not see many sources in its background.	The yellow source represents the nucleus of the galaxy. In the centre, redder areas represent older stars and bluer dots hotter stars. In green we see its companion galaxy NGC 5195.
Ultraviolet (XMM-Newton UV colour)	 ESASky image	The image shows very well defined spiral arms of the galaxy. At the top part, there is an extended region in red. There are no many sources in the background.	Because the young massive and hot stars are formed in the spiral arms of galaxies we see there the gas heated at ultraviolet temperatures. The companion galaxy, in red is not emitting much in ultraviolet, telling us that it does not contain many young stars.
Optical (Visible)* (DSS2 colour)	 ESASky image	In this image we see a similar structure to the ultraviolet image but the arms are denser and less defined at the internal arms of the galaxy and at the companion galaxy. Bright and dark areas are well defined within the arms. There are quite some stars in the background.	Light in the visible corresponds mainly to stars in the main sequence. This galaxy is therefore a spiral galaxy with a high-rate of star formation. The dark areas correspond to colder regions of dust.

Near-Infrared* (2MASS colour JHK)	 ESASky image	We see a similar pattern to the optical one but with less arms. The companion galaxy is as bright as the nucleus of M51 indicating stars of similar age (old). There are quite some stars in the background.	In the near infrared, we see the gas heated by low-mass young stars and red giants.
Far-Infrared (Herschel/PACS 70, 160 micron)	 ESASky image	We see a pattern similar to the visible and ultraviolet structure.	What we see here is the thermal emission from interstellar dust, that is, the light emitted by the dust due to its temperature. Hence, we can tell that the cloud not only contains gas, but also dust.
Submillimetre (short microwaves) (Herschel/SPIRE RGB 250, 350,500 micron)	 ESASky image	Although the resolution is much worse, the cloud shape and some of its structure can be recognised in this image.	Same as for the far-infrared, dust at colder temperatures distributed in the shape of the galaxy arms.

Table 18: *Analysis of various skies for the Whirlpool galaxy. (Credit: ESA)*

Remarks:

- As only the most massive and luminous stars contribute significantly to the luminosity of a galaxy, we can say that in a galaxy reddish parts are old stars and bluer parts are hot gas from young stars.
- Bulges of spiral galaxies look yellowish or whitish, rather than reddish because they contain stars of many different ages.
- Young stars are formed at the arms of the spiral galaxies, close to their disk and older stars tend to be in the halo.

Activity 12: Analyze your favorite piece of sky with ESASky

Activity 12.1: Access to the scientific archives of astronomical images for your piece of sky

Select in ESASky **the ¨Scientific Mode¨** (see Figure 46) and access various scientific archives that contain astronomical images (mainly from the ESA missions). **These images can be downloaded and analyzed with various software afterwards.**

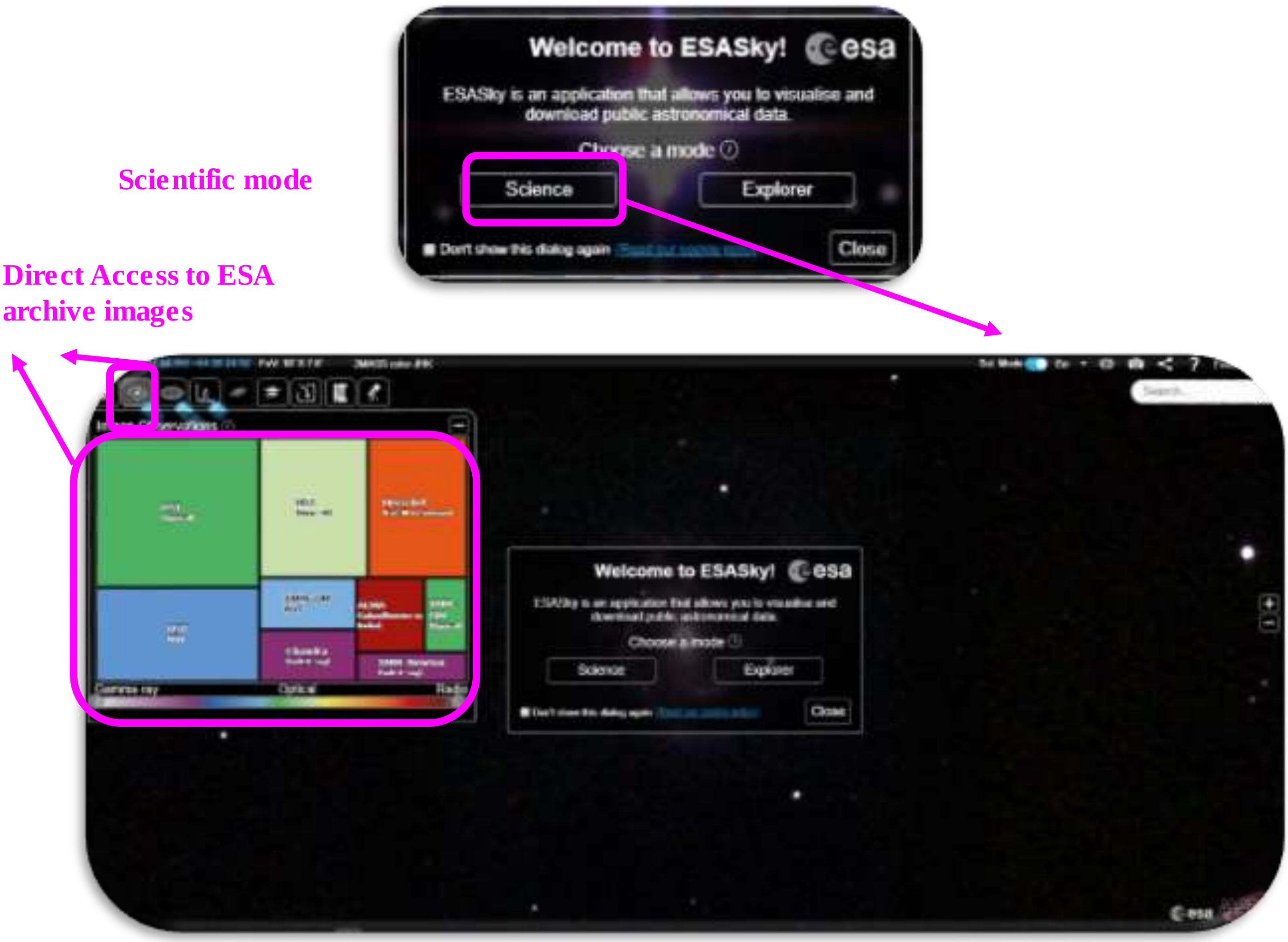


Figure 46: Access to ESASky spectral data for the Orion constellation. (Credits: ESA/CESAR)

- The whole procedure to do that and how to treat them to open them in Salsa J in **this video.**

Activity 12.2: Direct access to the ESA spectral data in the ESA archives (ESASky)

Select in ESASky **the ¨Scientific Mode¨** (see Figure 47).

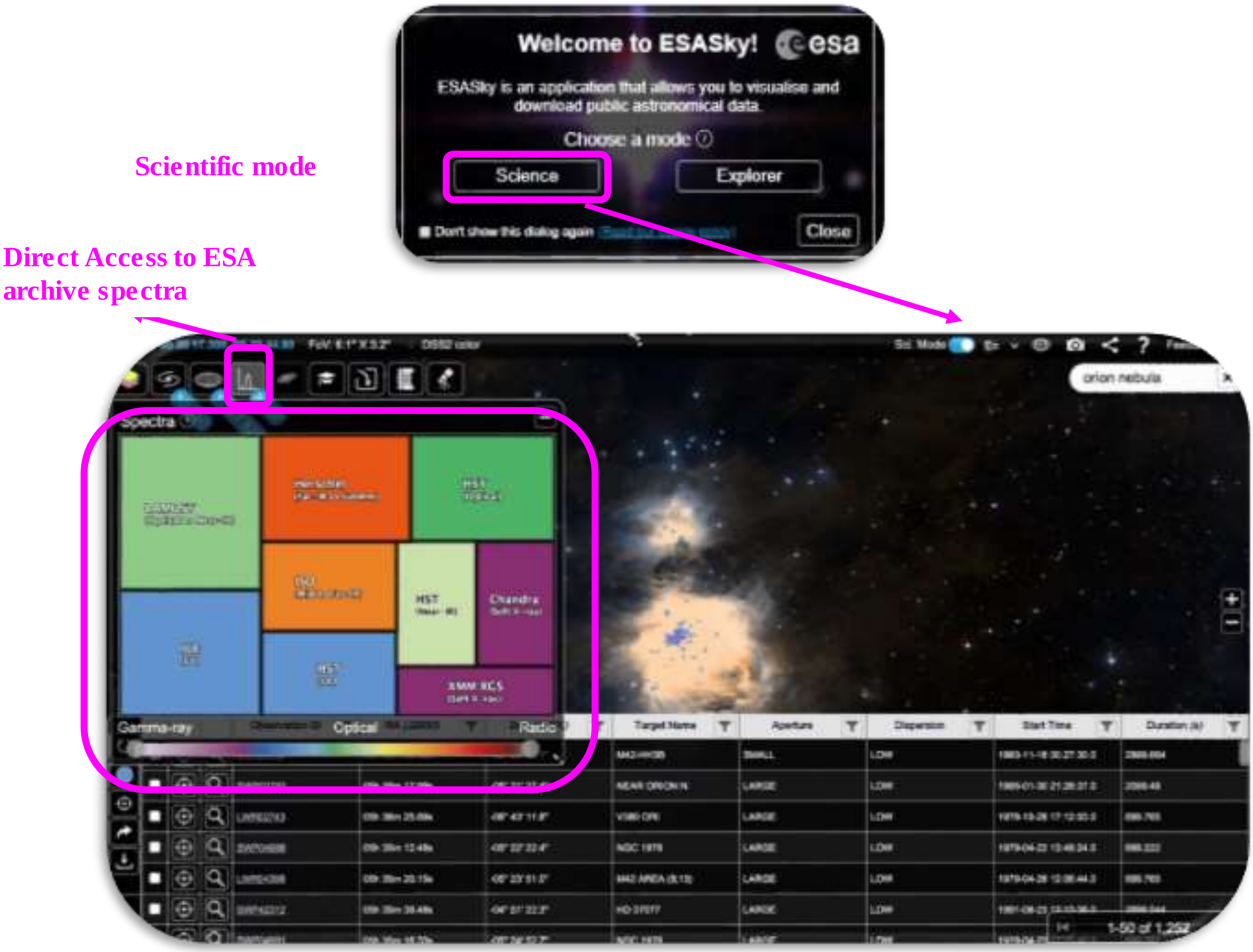
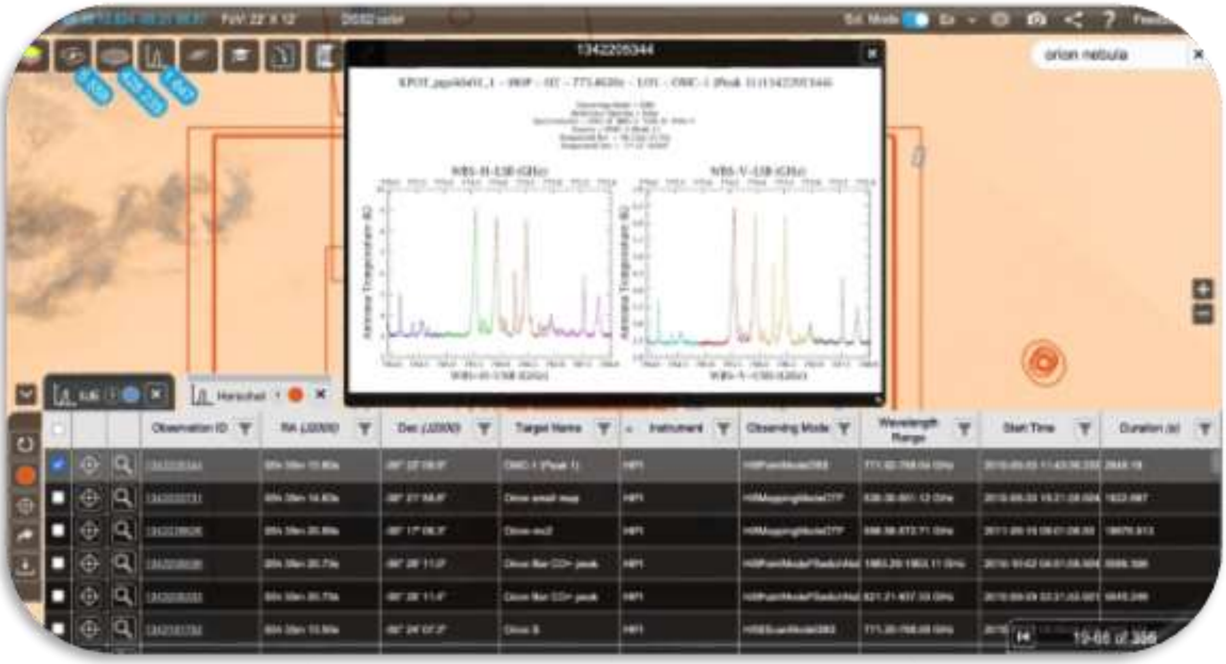


Figure 47: Access to ESASky spectral data for the Orion constellation. (Credits: ESA/CESAR)

Figure 48 shows observations of the Orion constellation taken by the ESA/Herschel satellite, that observed the Universe in the far-IR range. These data were particularly collected by the HIFI instrument and is currently available in the ESA/Herschel science archive (and accessible via ESASky), without artefacts and with understandable physical units (what we call "calibrated data"). Data treatment was automatically done by an expert software (pipeline[7]), run in powerful machines at ESAC (configured as grid of parallel machines) and their quality control, manually inspected by a

[7] https://en.wikipedia.org/wiki/Pipeline_(computing)

team of scientist, also at ESAC, to assess possible issues that may have an impact in their scientific analysis and publication.



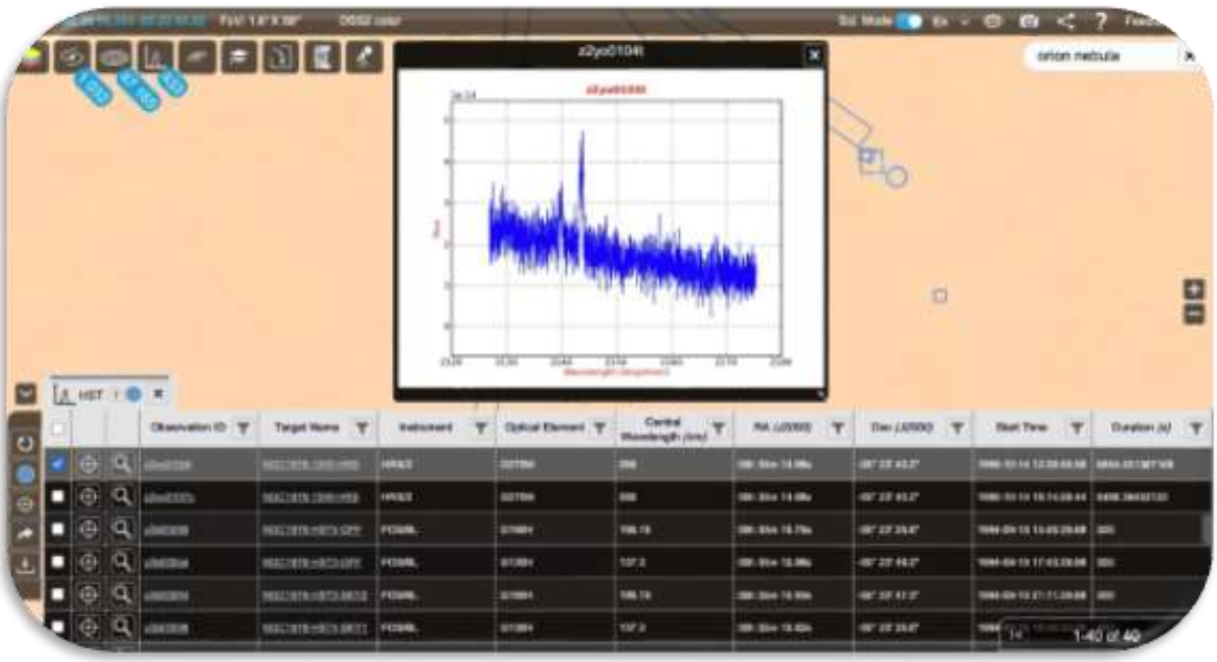


Figure 48: *Access to ESASky spectral data for the Orion constellation. (Credits: ESA/CESAR), top image shows Herschel/HIFI data and bottom image HST data, both ESA/NASA space missions.*

Activity 12.3: Direct access to the catalogues and databases in the ESA archives (ESASky)

ESASky does not only contain scientific data **but also the link to scientific catalogues and databases of the celestial objects in the image displayed by ESASky, if you select the ¨Scientific Mode¨** (see Figure 49).

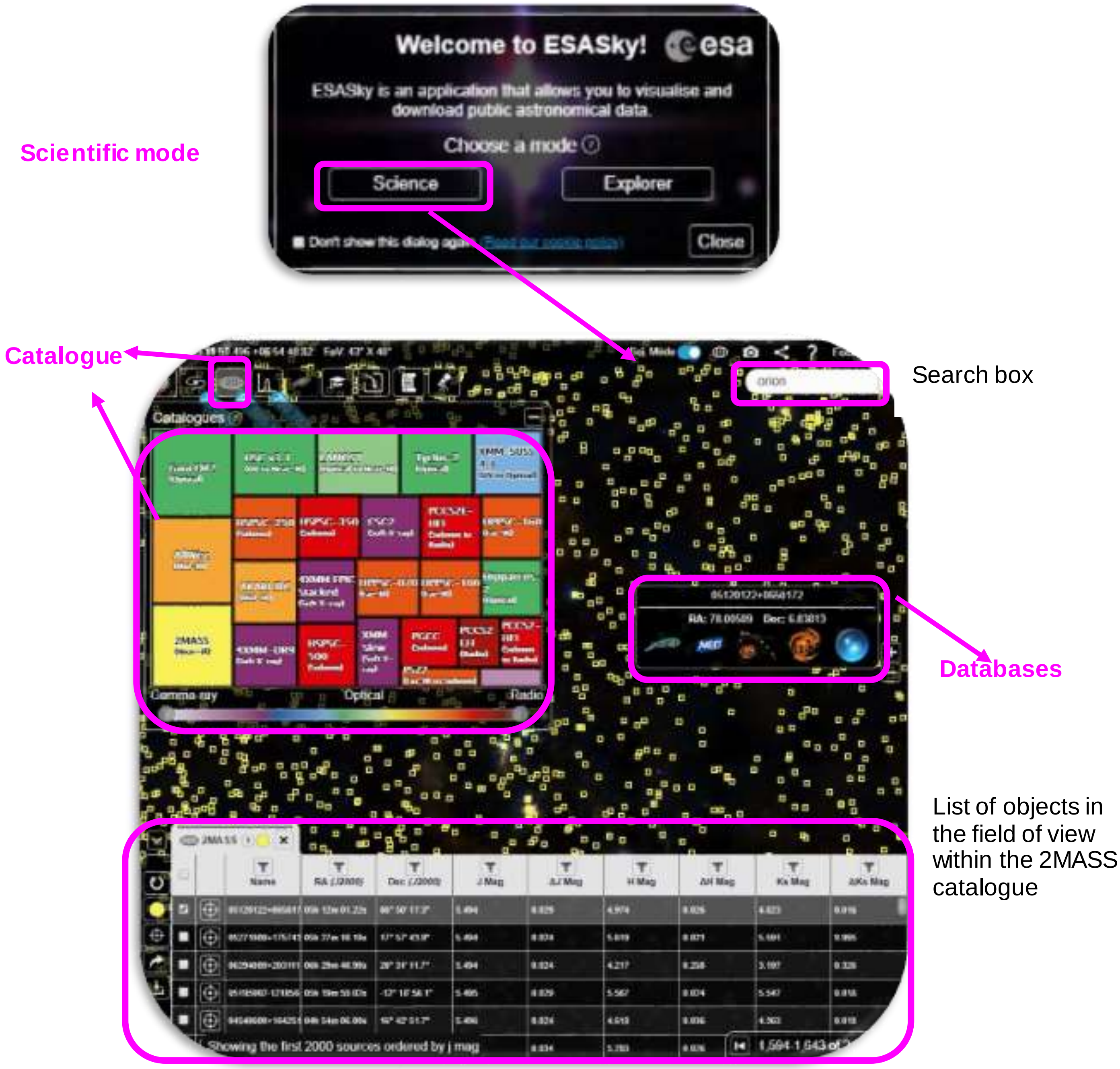


Figure 49: *Access to the ESASky catalogues and databases for M51. (Credit: ESA/ESDC)*

- **Databases** is a wide term that consider compilations of basic data, atlas, cross-identifications, biography and measurements for astronomical objects among others. Examples of widely used astronomical databases are Aladin, Simbad, Vizier, NED and CDS.

- **Catalogues** are compilations of lists of objects, identified and published in Databases. Per object there is an entry in a table, with their properties derived from the data, such as coordinates, magnitudes, temperature, type of object, chemical composition among others. Some examples are the 2MASS and the Herschel-PACS-pointsource catalogues, generated from the sources detected in their data. (Note: The Vizier database contains all the individual published catalogues).

Activity 12.4: Analyzing scientific information of the Orion constellation with ESASky

We are going to analyse in ESASky the five stars identified in the Activity 4.1. This time you will access as a scientist (selecting the ***ESASky in Science Mode***) to the Two Micron All Sky Survey (2MASS) and Vizier catalogues and to the astronomical databases Simbad and Aladin Lite.

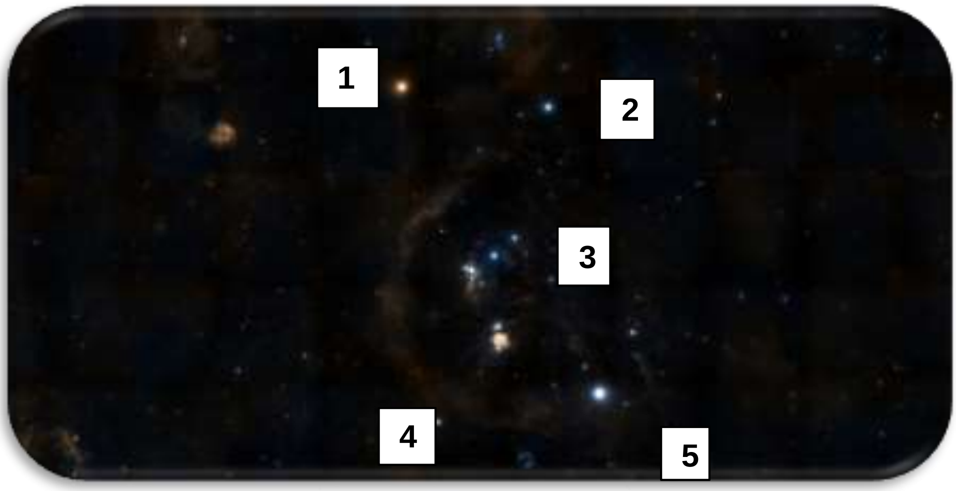


Figure 50: *Repetition of Figure 5, Orion constellation. (Credit: ESASky)*

Fill in Table 19 with the information from ESASky for each of the five stars identified in Figure 50 (one entry per star) following this procedure:

1. Access to ESASky in this link

2. Type in the **searching box** Orion" or "M42"

3. Press this icon to performing a increase your field of view (performing a zoom out) until you see in the centre of your screen the five stars indicated in Figure 50. (Note: you can have a straight access to the configuration of the image in this link).

4. Make sure you have selected the **Science Mode in ESASky**, otherwise activate it.

5. **The values in the first column of Table 19** correspond to the numbers assigned to the stars in Figure 50.

6. **We want to access to the 2 MASS catalogue and overlap the list of objects corresponding to our piece of sky on top of our image.** For this we should access to the icon of catalogues, at the top left panel and click in the yellow square identified as 2MASS (Near-IR), as Figure 49 shows.

7. **To fill in columns 2 to 6 of Table 19,** we **need to identify** what **objects in the catalogue 2MASS** (small yellow square in Figures 49-51) **correspond with the location of stars 1 to 5 of Figure 50.**

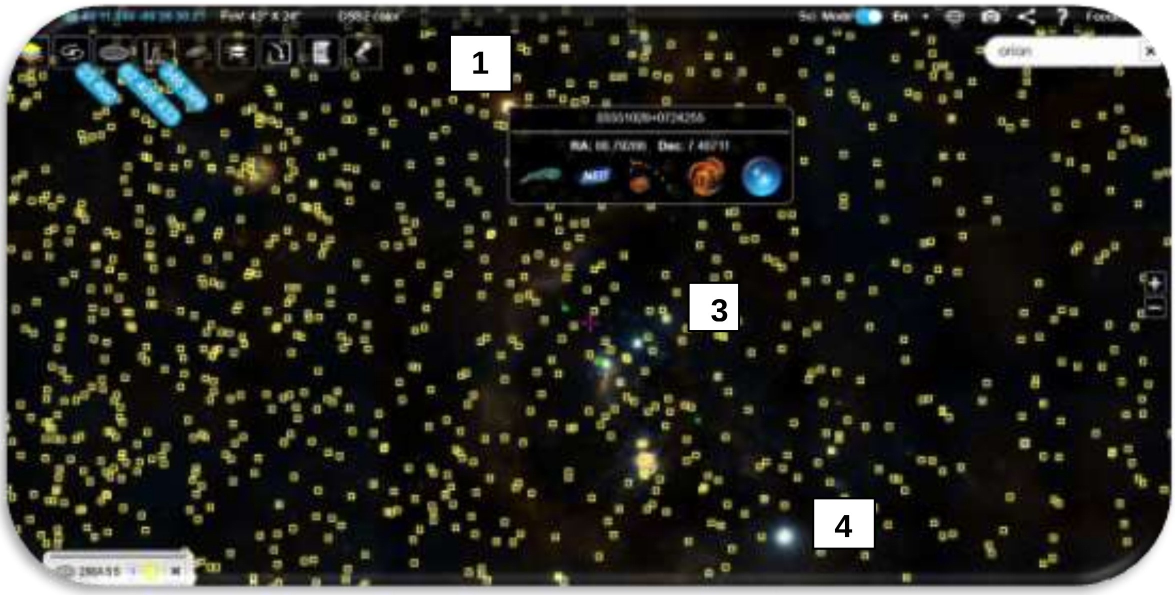


Figure 51: *List of objects from the 2MASS catalogue plotted on top of the ESASKy visible image of the [Sloan Digital Sky Survey](#) (DSS9) of Orion constellation. (Credits: ESA/CESAR)*

8. **For each one of them, one at the time, put the mouse on top of your star (yellow square) and right click. This will display the access to catalogues** and databases in ESASKy, (Simbad, Vizier and Aladin Lite), as shown in Figures 51 and 52.

Figure 52: Direct access to the databases for the example 05120122+0650172 (Simbad, Vizier and Aladin Lite). (Credits: ESASky).

9. **Check this video to see how to populate the columns of Table 19. We also explain it in the steps 9.1 to 9.4.**

9.1. To fill in the column **"Name of the star",** we will access to the **Simbad database and copy the name assigned to the star in it.**

9.2. **To fill in the column "Blackbody distribution** (Figures 10, 11 and 12) we will access to the Vizier database and will select a field of view of 2 arc seconds (2") around our star minimize the contamination of the flux distribution for other surrounding targets.

Note: The blackbody distribution is generated as a collection of flux measurements performed on the data of several telescopes/instruments/filters for a particular object or region. Their values have been extracted from individual catalogues stored in the database of catalogues, Vizier.

9.3. The value of the **effective temperature**, derived by the fit of the flux distribution to a blackbody.

This video shows a case when the **effective temperature is not accessible,** because is a variable/double star. Otherwise, the effective temperature will be part of the parameters in Vizier defining the object.

9.4. The image and its link to that image for a field of view of **2◦x2◦** could be **obtained Aladin Lite or ESASky.**

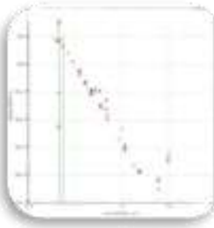
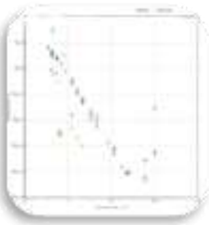
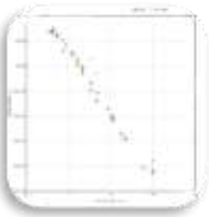
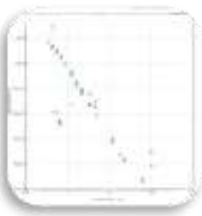
Star number	Star name [Simbad DB]	Basic description [Simbad DB]	Blackbody distribution [Vizier DB]	Teff [Vizier DB]	Image [Aladin DB]
1	* alf Ori	Red supergiant star	 1.26 microns	3540 K	 1.85◦ x 1.85◦ FoV
2	*gam Ori	Variable star	 < 0.3 microns	21 700 K	 1.85◦ x 1.85◦ FoV
3	* del Ori	Eclipsing binary of Algol type	 < 0.3 microns	n/a ~20 000 K	 1.85◦ x 1.85◦ FoV
4	Beta Ori	Blue supergiant star	 < 0.3 microns	12 100 K	 2.05◦ x 2.05◦ FoV
5	Kap Ori	Blue supergiant star	 < 0.3 microns	23 170 K	 1.6◦x1.6◦ FoV

Table 19: *Analysis of the main Orion Nebula stars using databases and catalogues. (Credits: ESA/CESAR)*

Remarks:

- Delta Ori is a multiple star, therefore the effective temperature derived from the blackbody distribution does not have sense

- Kapa Ori looks a bit reddish in the image, however when checking its flux distribution in the 2MASS catalogue the blackbody peak is at low wavelength, therefore high frequencies (energies). The effective temperature derived from the blackbody distribution is around 23 000 K.

Activity 12.5: Downloading catalogues though ESASky and handling them.

- To download the targets in your ESASky image from a selected catalogue, you just need to access to this **video.**
- To plot the information from the downloaded catalogues you may use plot in a google excel sheet as shown in this video

Activity 13: Other CESAR monographs

- For a 14+ year-old students we recommend **to read the CESAR booklets:**
  - The evolution of the stars
  - Galaxies
  - The interstellar medium
  - The electromagnetic spectrum

Phase 4

Congratulations!
You have completed your Science Challenge!
Tell us your story!

Stop to think about the Experience with your Team and teacher and complete these Activities.

Activity 14: Auto y co-evaluation

- **Teams:** Fill in this questionnaire so that you can check what you have learned in the Challenge.
- **With your teacher:** Give us your feedback

IMPORTANT NOTES

- Teachers will make sure that each Team performs the evaluations (quizzes)

Activity 15: Present your results

Students will have to create a final product (an A0 poster in pdf format, using power point, for example) showing what they have learned in the different phases of the Scientific Challenge.

This poster is the ticket to participate in the CESAR international adventure competition.

IMPORTANT NOTES:

- It would be very interesting if you could present it to your schoolmates on a certain date, simulating a congress of scientists.
- Any document involving photos of your students can be published on the CESAR website or social networks. Therefore, please only attach those images for which you have explicit permission for publication, intellectual property and image. The CESAR Team is not responsible for their intellectual property and image.

Congratulations teacher!
Thanks to your dedication your class will receive a CESAR Team Super Diploma

Links

Astronomical objects

- Stellar processes and evolution: http://sci.esa.int/education/36828-stellar-processes-and-evolution/
- Galaxies and the expanding universe: http://sci.esa.int/education/36827-galaxies-and-the-expanding-universe/

The electromagnetic spectrum and ESA missions

- *A brief history of infrared astronomy:* http://sci.esa.int/herschel/59550-a-brief-history-of-infrared-astronomy/
- Science@ESA: *The full spectrum* (video) http://sci.esa.int/education/44685-science-esa-episode-1-the-full-spectrum/
- Science@ESA: *The untamed, violent universe* (video) http://sci.esa.int/education/45421-science-esa-episode-5-the-untamed-violent-universe/
- Science@ESA: *Exploring the infrared universe* (video) http://sci.esa.int/education/44698-science-esa-episode-3-exploring-the-infrared-universe/
- Blackbody radiation: http://sci.esa.int/education/48986-blackbody-radiation/
- Science in School: *More than meets the eye: the electromagnetic spectrum* http://www.scienceinschool.org/2011/issue20/em
- Science in School: *More than meets the eye: the exotic, high-energy Universe* http://www.scienceinschool.org/2012/issue24/em
- Science in School: *More than meets the eye: unravelling the cosmos at the highest energies* http://www.scienceinschool.org/2011/issue21/em
- Science in School: *More than meets the eye: the cold and the distant Universe* http://www.scienceinschool.org/content/more-meets-eye-cold-and-distant-universe

ESASky

- General documentation: https://www.cosmos.esa.int/web/esdc/esasky-how-to
- *How to upload a target list* (video): https://www.youtube.com/watch?v=M-aJn5TTd50
- *How to explore multi-wavelength skies* (video): https://www.youtube.com/watch?v=zkJkhSDr0nQ

Credits:

Material prepared to be executed on-line, based on previous activities developed by the ESASky Team in collaboration with CESAR and Planeta Ciencias in collaboration with CESAR, under the initiative and coordination of the European Space Agency within the framework of the CESAR programme. The CESAR Team counted with the support of the Young Graduate Trainee (YGT) Programme. And special mention to the comments from Dr. Benjamín Montesinos-Comino

Initial versions:
http://cesar.esa.int/index.php?Section=SSE_The_Color_of_the_Stars
http://cesar.esa.int/index.php?Section=SSE_The_Secrets_of_the_galaxies
http://cesar.esa.int/index.php?Section=SSE_Estudio_a_traves_del_espectro_portada
http://cesar.esa.int/index.php?Section=SSE_The_Hertzsprung_Russel_Diagram
http://cesar.esa.int/index.php?Section=SSE_Composicion_de_las_estrellas_portada
http://cesar.esa.int/index.php?Section=The_colours_of_the_astronomy