CESAR Science Case

Exploring the Interstellar Medium

Studying the gas and dust between the stars

Teacher Guide

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Fast Facts

FAST FACTS

Age range: 16+

Type: Student activity

Complexity: Intermediate

Teacher preparation time: 1 hour

Lesson time required: 1 hour 15 minutes

Location: Indoors

Includes use of: Computers, internet, ESASky web application

Curriculum links

General

- Working scientifically.
- Use of ICT.

Physics

- Waves.
- Light waves. The electromagnetic spectrum.
- Reflection and refraction of light.
- Temperature. Blackbody radiation.

Space/Astronomy

- Research and exploration of the Universe.
- The evolution of stars.

Outline

These activities introduce the interstellar medium (ISM) using real astronomical observations from space missions and ground-based telescopes. Students will learn about the nature of the ISM, how it interacts with stars and how it can be detected. The activities deepen understanding of the properties of the electromagnetic spectrum (specifically visible and infrared) including the emission of light by objects according to their temperatures. .

Students should already know…

1. The concept of light as an electromagnetic wave.
2. About the reflection, absorption and scattering of light.
3. The concept of blackbody radiation.

Students will learn…

1. What the ISM is, and how astronomers study it.
2. The concepts of optical extinction and interstellar reddening.
3. About the emission of light by objects according to their temperature.
4. What information can be seen and extracted from an astronomical image.

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

Title	Activity	Outcomes	Requirements	Time
1. Infrared light	Students compare images of everyday objects taken with visible and infrared light and discuss about the origin of the infrared emission from those objects.	Students learn: • The properties of the electromagnetic spectrum. • The reasons to put telescopes in space. Students improve: • Their teamwork and communication skills. • Their ability to apply theoretical knowledge to real-life situations.	• Basic knowledge of the properties of waves. • Basic knowledge of the electromagnetic spectrum.	10 min
2. Getting familiar with ESASky	Students play with the tool to become familiar with it.	Students improve: • Their skills in the use of ICT.	None.	15 min
3. Empty or dark?	Students compare images of a dark cloud in different wavelength ranges and discuss the reason for the differences they find between them.	Students learn: • The properties of the electromagnetic spectrum. • The properties of interstellar dust. • About the emission of light by objects according to their temperature. • What information can be seen and extracted from an astronomical image. • About ESA missions. 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. • Their skills in the use of ICT.	• Completion of Activity 1.	20 min

Title	Activity	Outcomes	Requirements	Time
4. Hidden in the dust.	Students compare images of star clusters or associations in different wavelength ranges. They discuss the differences between images and how the presence of the ISM is affects observations.	Students learn: • The properties of the electromagnetic spectrum. • The properties of interstellar dust. • How the presence of dust affects the observation of stars (interstellar extinction and reddening). • What information can be seen and extracted from an astronomical image. 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. • Their skills in the use of ICT.	• Completion of Activity 3.	25 min

Title	Activity	Outcomes	Requirements	Time
5. Unveiling the Galactic Centre.	Students compare images of the centre of the Milky Way in different wavelength ranges and discuss the differences.	Students learn: • The properties of the electromagnetic spectrum. • The properties of interstellar dust. • How the presence of dust affects the observation of stars (interstellar extinction and reddening). • How astronomers use different types of light to study different objects or phenomena in the Universe. • What information can be seen and extracted from an astronomical image. 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. • Their skills in the use of ICT.	• Completion of Activity 5.	15 min

Introduction

The interstellar medium (ISM) is the matter filling the space between the stars, sometimes forming big clouds, or *nebulae*. It is very cold and much less dense than any vacuum created in a laboratory. Despite this very low density (1 atom/cm^3), the amount of matter that makes up the ISM adds up over the vast distances between stars.

About 99% of the ISM is gas, with about 90% of it in the form of hydrogen, 10% helium, and traces of other elements; the typical temperature of interstellar gas is around 10 K. The other 1% of the ISM is in the form of dust, mostly made of iron, silicates, carbon and dirty ice. Dust grains have typical sizes of a few hundred nanometres (similar to the wavelength of blue light), and typical temperatures of around 100 K.

Through this series of activities students study the ISM in various regions of the sky using real multi-wavelength images from observations by space missions and ground-based telescopes. Students can access the observations for themselves via the ESASky web application.

The study of the ISM is very important in Astronomy because its presence affects observations and may yield to erroneous interpretations if ignored. In particular, early attempts to determine the shape and size of our Galaxy were hampered by the fact that astronomers were not aware of the presence of the ISM until the middle of the 20th century. Furthermore, interstellar clouds serve as cradles for newly forming stars. At the end of their lives, stars return a fraction of their matter to the ISM, enriching it with elements heavier than hydrogen and helium.

Background

In first approximation, the light emission of stars and other astronomical objects follows a blackbody curve (Figure 1). Hence, according to Wien's law, the temperature of an object determines the wavelength at which the emission of light reaches its maximum:

$$\lambda_{max} = \frac{b}{T} \tag{1}$$

This means that astronomical objects are most easily detected in the region of the electromagnetic spectrum corresponding to the maximum of a blackbody curve of the same temperature. In the case of stars, this range spans from part of the ultraviolet through the visible to the near-infrared. But because of the low temperatures of the ISM components, they can usually be detected only at wavelengths much longer than visible. Dust, with typical temperatures around 100 K, is best studied in the far-infrared, while gas, which can be as cool as 10 K, needs to be observed at radio wavelengths.

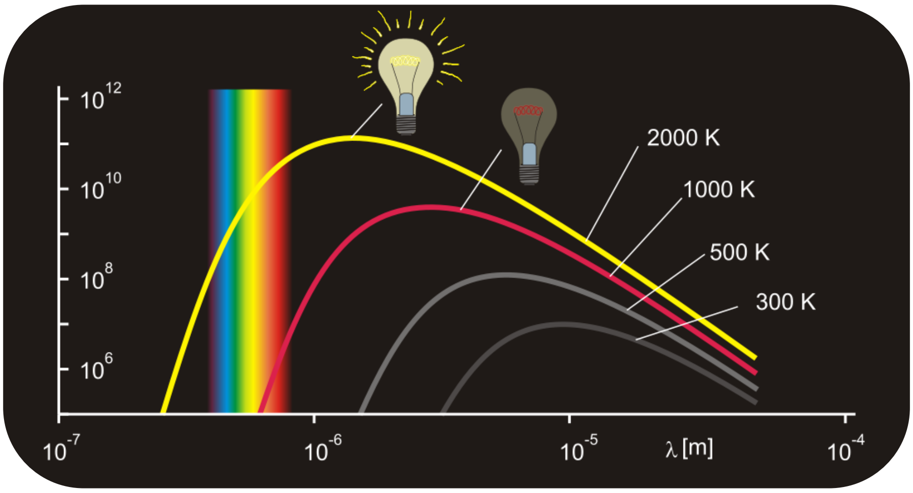

Figure 1: *Blackbody curves of different temperatures. (Credit: Wikimedia Commons)*

The ISM can be studied at visible wavelengths due to its interaction with light from stars. Even though it makes up only a small fraction of the ISM, the effect of dust is easy to see in visible light images. 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, whose longer wavelengths are not absorbed or scattered by the dust grains, all the stars hidden within and behind the dust are revealed.

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. These two phenomena are known as *interstellar reddening* and *optical extinction*, respectively (Figure 2). They 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.

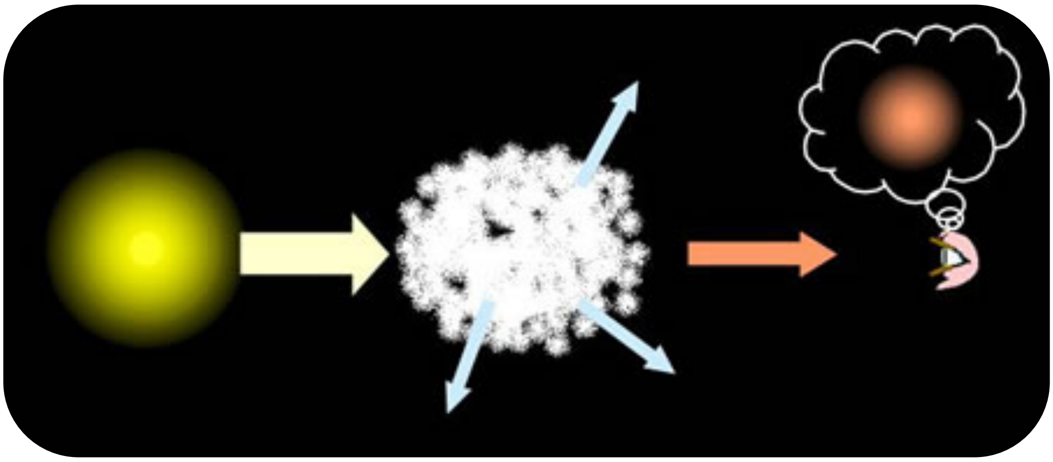

Figure 2: *Effects of the ISM: A star behind it will look redder and fainter than it really is. (Credit: COSMOS, the SAO Encyclopedia of Astronomy)*

Activity 1: Infrared light

This activity builds students understanding of infrared light by introducing them to the discovery of infrared and asking them to make a comparison between visible and infrared images of familiar objects. The concept that all objects emit light because of their temperature is also discussed.

The Student Guide begins by describing Herschel's experiment that yielded to the discovery of infrared light. Time and resources permitting, it may be interesting to carry out this experiment in the lab. An example of the procedure to perform the experiment can be found in the Links section.

Students are asked to study some visible and infrared images of the same objects (Figure 3) and answer questions to test their understanding of them. Alternatively, if possible, students could take their own images of everyday objects (ice cubes, pencils, classmates, and more) with an infrared camera, and use them to answer the questions, instead of the images in their guide. To support this activity students are also provided with an image summarising the properties of the electromagnetic spectrum (Figure 1 of the Student Guide) and a table indicating the temperature ranges corresponding to the near, mid and far-infrared spectral regions.

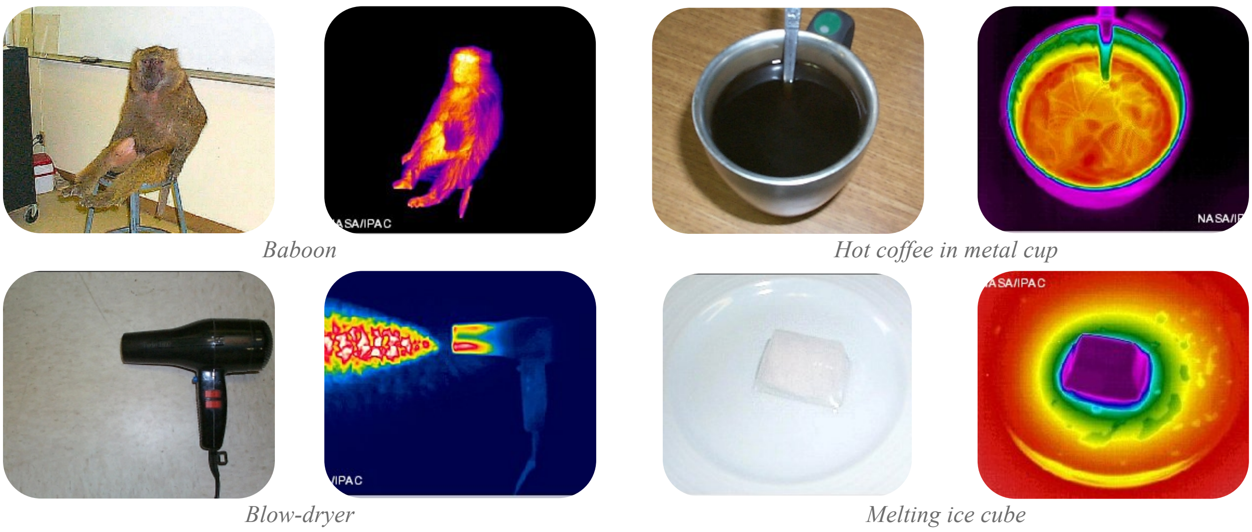

Figure 3: *Everyday things observed in visible (left) and infrared light (right)*
(Credit: coolcosmos.ipac.caltech.edu)
[NOTE: this is Figure 4 in the Student Guide].

Answers to the questions in the Student Guide

1. Look at the pairs of images in Figure 3. Each pair shows the same image, one taken in visible light and other taken in infrared light.

   a. In what sense are the two images in each pair similar? In what sense are they different?

   Some obvious things students may point out are that the shapes of the objects are similar (so most things are still recognisable in the infrared images), but the colours are different. Some details (e.g. the baboon's facial features) are only seen in the visible light images, while others (most prominently, the hot air ejected by the blow dryer) are only seen in the infrared.

b. In the visible light images, do we see the light emitted by the objects? If not, why can we see them? Is it the same for the infrared images?

Students should be aware that these objects do not emit visible light, and that our eyes (and the camera) see them because they reflect light. On the contrary, in the infrared, the objects are detected because of the infrared light they are emitting.

It may be necessary to explain to students that the colours in the infrared images are artificial, and are just a convenient code to show the intensity of the light emission. For example, hot coffee is displayed in yellow and red, but the colder metal cup is shown in magenta, and the even colder table surface, in black. On the contrary, the ice cube is displayed in magenta because it is colder than the plate that it is on, which looks red in the image. Students might notice how the temperature of melt water increases as it flows away from the ice cube.

2. If the objects in Figure 3 emit mostly infrared light, do they have higher or lower temperatures than objects that emit mostly visible light? Use Figure 1 to justify your answer.

   With the help of Figure 1 in their guides, students should realise that infrared light has longer wavelengths than visible light, and that these wavelengths correspond to lower temperatures. Therefore, the objects in Figure 3 emit mostly infrared light because of their low temperatures. It may be interesting to remark how even things like ice cubes that are very cold (in our everyday experience) emit light.

3. For humans, normal body temperature is around 36 °C. Based on Table 1, in which region of the infrared do humans emit most light? Explain your answer. (Remember that 0 K = -273 °C)

   Students should make the conversion 36 + 273 = 309 K and note that this temperature corresponds to the mid-infrared range.

Activity 2: Getting familiar with ESASky (Optional)

This activity will enable students using *ESASky* for the first time to become familiar with the online application. If they have used *ESASky* before, this step may be skipped, and students can proceed to Activity 3.

To access *ESASky*, go to: http://sky.esa.int

For this activity, Explorer Mode is used. This mode is set by default on tablets and mobile phones, but not on laptops and desktop computers. If necessary, the mode can be selected in the welcome dialogue window, or with the switch on the top bar.

Students should work in pairs or small groups with one computer or tablet per group. Using the guidelines and object list provided in the Student Guide, they should practice the following:

- Panning and zooming around the sky.
- Moving from one object to another using the search box.
- Viewing the sky in different wavelengths.

Table 2: Sky regions to explore

Object	Description
Horsehead Nebula	The Horsehead Nebula is a dark nebula that makes up part of the much larger Orion Molecular Cloud Complex. First look at the visible (optical) image: Why is it dark? Then load the near-infrared and the far-infrared maps. Are they different? Why? What do you see in each of them?
Cygnus OB2	Cygnus OB2 is an association of young massive stars (hot, blue and bright). Look at the visible (optical) image. What colour are the stars that you see? Now switch to the near-infrared, what are the differences between this image and the visible image? Can you see any evidence that the ISM is present here? How would check this?
W40	Compare this region of massive star formation with the previous region, Cygnus OB2. Check the visible (optical) image first. Do you see any evidence that the ISM is present in W40? Now inspect it in the near-infrared. What is hidden within the dust?
Sgr A*	This is the region in the centre of our Galaxy. Until the middle of the last century, this region was completely unknown to astronomers. To find out why, load the visible (optical) map, and zoom out until the field-of-view is about 12° (the size is indicated in the upper part of the screen). What does this region look like in the optical? Why was the Galactic Centre so difficult to observe? What do you expect to find if you observe it in the near and far-infrared?

Activity 3: Empty or dark?

In this activity, students explore one of the most striking manifestations of the ISM: dark clouds. They study images of the Horsehead Nebula in the optical (visible light), near-infrared and far-infrared (Figure 4) and discuss the differences between them, as well as the reasons for these differences.

To begin their exploration, students need to create a stack of maps following the instructions in their guides, and load the list of regions they will study in this and the following activities, available in the application as a predefined target list with the name "CESAR ISM". The list of regions and their descriptions are summarised in Table 2. The first object in the list is the Horsehead Nebula (Figure 4). This nebula is used to exemplify one of the most common ways the interstellar medium shows itself in optical observations – by obscuring or blocking the light from the stars.

Figure 4: *Images of the Horsehead Nebula in the optical (DSS-2, left), near-infrared (2MASS, centre) and far-infrared (Herschel-PACS, right), taken with the Snapshot functionality of ESASky. (Credit: ESA/CDS)*

About the images

When comparing images taken in different wavelength ranges, it is important to point out to students that the colours are not real, and that the objects would not look like they do in the images if we were to see them with our own eyes. One reason for this is that our eyes are not capable of seeing light other than visible (optical). The images have been produced by combining black-and-white images taken in particular filters, and they have been artificially coloured to make the objects' features easier to distinguish. Usually, blue indicates the shortest wavelength and red the longest.

Students may also note the differences in resolution (amount of detail) among images. Generally, resolution is best in the optical (visible-light) images and worst in both extremes of the spectrum; this is due to limitations of the telescopes and instrumentation.

Answers to the questions in the Student Guide

5. Go to the first object in the list, the Horsehead Nebula. Look at the visible ("optical/DSS2") image (the name of the displayed map is shown above the Skies button in the top-left corner). Why are there no stars visible in the nebula? Provide a possible explanation in the box below.

   The nebula looks dark because it is opaque to visible light (left panel of Figure 4). This is because the dust grains are similar in size to the wavelengths of visible light, and therefore, absorb and scatter photons from this portion of the electromagnetic spectrum.

6. Dust grains only absorb and scatter light whose wavelength is similar to their size; longer or shorter wavelengths are not affected and simply pass through the dust. Taking into account that the typical size of an interstellar dust grain is just a fraction of a micron (10^{-6} m), which wavelengths of light will be absorbed and scattered? Use Figure 1 to find out the answer to this question.

   The size of the dust grains is similar to optical (visible) wavelengths. Therefore, the dust absorbs and scatters photons of these wavelengths. Longer and shorter wavelengths (infrared or ultraviolet light) are not affected.

7. Look at the image of the Horsehead Nebula taken by the near-infrared telescope ("near-infrared/2MASS"). Compare this image to the optical image and explain how and why they are different.

   In the near-infrared image (central panel of Figure 4), the nebula is not seen. Instead, the space occupied by the dark horsehead shape is filled with stars. The reason is that near-infrared wavelengths, being slightly longer than visible, can get through the dust, allowing us to see within and through the cloud.

8. Taking into account that the typical temperature of interstellar dust is about 100 K, or -173 ºC, which of the three images in your stack tells you more about the properties of the ISM itself, and why? Figure 1 and Table 1 can help you find the answer to this question.

   This question puts the students' understanding of the properties of blackbody radiation to test. Assuming that the nebula emits as a blackbody, because of its temperature (about 100 K), it is expected that most of its light will be emitted at far-infrared wavelengths (which are very long).

Indeed, in the far-infrared image (right panel of Figure 4) we can see the nebula again, this time as an emitting object.

9. Interstellar gas is even colder than dust, with typical temperatures of about 10 K, or -263 °C. According to Figure 1, which type of telescope would you need to observe this gas directly?

   Using Figure 1 in their guides as a reference, students should note that bodies with a temperature as low as 10 K emit mostly in the radio domain.

Activity 4: Hidden in the dust

In this next activity, students will explore two more regions of the sky, Cygnus OB2 and W40. They will use ESASky to discover some of the less evident effects of the ISM on the observation of stars, such as, optical extinction and ISM reddening.

Students begin by examining the optical images to see how the stars in the field of view appear to be different to what is expected based what is known about their properties. They then study the near and far-infrared images of the same regions to find out how the presence of dust is affecting the optical view of each.

To help students with their analysis, information is provided about the process that creates a blue sky and a red sunset on Earth. Students should use this as an analogy to explain what is happening in the two regions, taking into account that dust particles act in a similar way to gas molecules in the Earth's atmosphere.

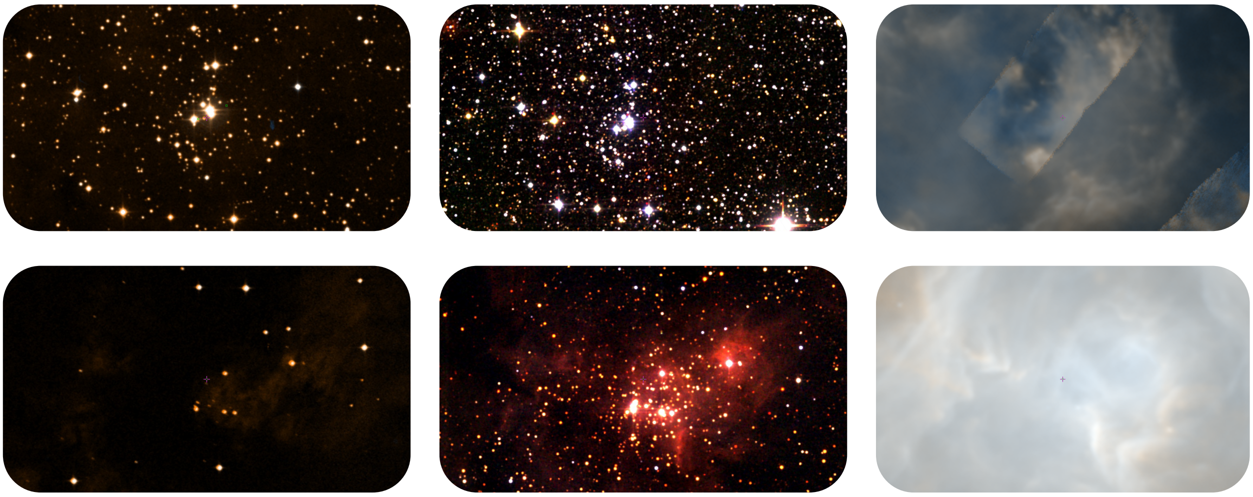

Figure 5: *Images of Cygnus OB2 (top) and W40 (bottom) in the optical (DSS-2, left), near-infrared (2MASS, centre) and far-infrared (Herschel-PACS, right), taken with the Snapshot functionality of ESASky. (Credit: ESA/CDS)*

Answers to the questions in the Student Guide

1. Have a look at Cygnus OB2 in the visible ("optical/DSS2") map.

   a. Do you see many stars in this image? What do they look like?

   Cygnus OB2 stands out as a rich association of reddish stars in the optical map (upper left panel of Figure 5). The stars tend to be concentrated toward the centre of the cluster, where the brightest stars are seen.

   b. The stars in Cygnus OB2 are known to be hot, massive and blue. Do the stars in the optical image look like this? If not, what could be the reason? (Hint: See Figure 2)

   The stars in the image look red rather than blue. Since we are told that these stars are actually hot and blue, this colour cannot be due to their temperature. Something is scattering and absorbing the blue light coming from them, allowing mostly red light to get through; that something must be interstellar dust, as depicted in Figure 2 (this is the same figure as in the Student Guide). If this is the case, the stars should also be brighter than they appear because of this loss of light.

2. Now study Cygnus OB2 in the near-infrared map ("near-infrared/2MASS").

   a. Does this image look different to the optical image? Describe the differences you see.

   The 2MASS near-infrared map (upper central panel of Figure 5) shows a large number of stars that are not visible in the optical, making the association look even more populated. Students may also point out that, while all stars have similar colours in the optical, they show a variety of colours in the near-infrared. Students may need to be reminded that the colours in the near-infrared image are artificial and by no means similar to what our eyes would see, as we cannot detect infrared light. The colours used simply indicate differences in temperature (differences in the slope of the blackbody curve at these wavelengths).

   b. Why are some stars in the near-infrared image not seen in the optical image? Load the far-infrared map to find the answer to this question.

   Some stars are not seen in the optical image because they are hidden in the dust. The reason is that dust particles absorb and scatter visible light. Near-infrared light is not absorbed or scattered because of its longer wavelength (only light of a similar wavelength to the size of the dust grains is absorbed and scattered).

   A look at the far-infrared map (upper right panel of Figure 5) will confirm this, revealing a dusty cloud in the location of the stellar association. Even though the dust does not form a clear dark nebula in the optical image, as in the case of the Horsehead Nebula, it is affecting the way we observe Cygnus OB2 in this range. The cloud is emitting far-infrared light because of its very low temperature.

3. Now go to the next region, W40, and compare the images of this cluster in the three wavelength ranges.

   a. Describe the differences between the images and explain the reasons for them. (Hint: You can compare this situation with the effect of the Earth's atmosphere.)

In the optical image (lower left panel of Figure 5), only a few dispersed stars are seen; in contrast, the near-infrared image unveils a very rich star cluster. The fact that all those stars are hidden in the optical image, together with the reddish colour of the few stars that are visible, again suggests the presence of interstellar dust. In fact, the optical image also shows some traces of a reddish cloud.

The differences between the optical and the near-infrared images (lower left and central panel of Figure 5, respectively) are explained by the differences in wavelength. In the optical, the light from the stars is absorbed and scattered by the dust particles, making those stars invisible. Since (as it happens in the Earth's atmosphere) blue light is absorbed and scattered more than red light, the few stars we can see look redder (and fainter) than they actually are (as it happens with the Sun at sunset). On the other hand, near-infrared light, having longer wavelengths than visible light, is not absorbed or scattered by the dust, allowing us to see the stars hidden within it.

The presence of dust is confirmed by the far-infrared image (lower right panel of Figure 5), which reveals a bright cloud in the location of W40. We do not see stars in this image, because at these long wavelengths, we are detecting the light emitted by objects colder than the coolest stars.

   b. How would the optical image of W40 change if there were no interstellar dust? Would the stars be brighter or dimmer? Would their colour change? Explain your answers.

If there were no dust, the optical image of W40 would be very similar to the image in the near-infrared, showing a rich cluster of stars. The stars that we already see would appear brighter and bluer, because there would be nothing to absorb and scatter the blue light.

4. What are the names of the two effects of interstellar dust you observed in these two regions? Provide a definition for each of them.

These regions are typical examples of interstellar reddening and optical extinction.

- Interstellar reddening: More blue light is absorbed and scattered than red light, therefore we mainly detect red light from these stars. Consequently, they look redder than they actually are.
- Optical extinction: The dust absorbs and scatters light, therefore stars appear fainter than they should just by the effect of distance.

5. Which region do you think contains more dust, Cygnus OB2 or W40? Explain your answer.

W40 seems to contain more dust than Cygnus OB2. It looks brighter in the far-infrared image, and even though it is as rich a cluster as Cygnus OB2 when observed in the near-infrared, it seems to contain much fewer stars in the optical image.

6. A light source looks dimmer the further away it is. Imagine that an astronomer is trying to measure the distance to the stars in these clusters based on their brightness in visible light images. If the astronomer did not know about the ISM, how would this affect their measurements? Would the estimated distances be bigger or smaller than the real ones? Explain your answer.

   Since the presence of the ISM makes stars look dimmer, this effect adds to that of distance. Hence, if the effect of optical extinction by dust grains is not taken into account, stars will seem to be further away than they actually are. Therefore, the astronomer will overestimate their distances.

Activity 5: Unveiling the Galactic Centre

The last activity discusses the presence of the ISM toward the centre of our Galaxy. Students will apply the knowledge they have acquired in the previous activities, by making a prediction about how this region will look in near and far-infrared light. After that, they examine a popular model of the Milky Way proposed at the beginning of the 20th Century and consider why, at that time, it was so difficult to study the centre of the Milky Way.

This activity also illustrates how scientific knowledge changes as new discoveries are made – in this case, how the discovery of the ISM allowed astronomers to understand that their picture of our Galaxy was incorrect. It can be used as an introduction to the topic of galactic structure, or to encourage students to speculate what is hidden behind so much dust in the centre of our Galaxy.

Following the instructions in their guides, students study the final object in their list, Sagittarius A (Sgr A). Students will have to zoom out to a field of view size of about 12 degrees to appreciate that the last region in the list is the Galactic Centre. With this perspective, they can clearly see the Milky Way as an elongated structure across the field of view (Figure 6); this structure is actually the Galactic Disk.

If necessary, students can do some background research to help them find the answers to the questions in the Student Guide.

Answers to the questions in the Student Guide

1. Load the optical map (DSS2), switch to the last object in the list Sgr A* (a powerful radio source near the Galactic Centre), and zoom out until the field-of-view is about 12º (the size is indicated in the upper part of the screen). Why was the Galactic Centre so difficult to observe in visible light?

   With a field of view size of about 12 degrees, students can clearly see the Galactic Disk and that the central area looks much darker than the surroundings (left panel of Figure 6). Based on the concepts discussed in the previous activities, they should be able to explain that the centre of our Galaxy is rich in interstellar dust, and that this dust is preventing us from seeing the centre itself.

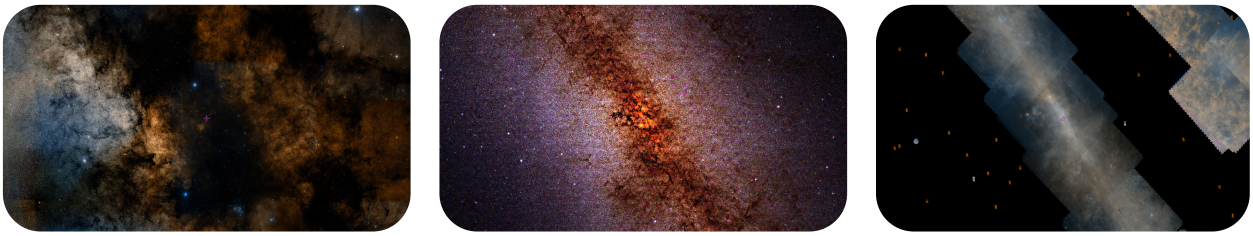

Figure 6: *Images of the Galactic Centre in the optical (DSS-2, left), near-infrared (2MASS, centre) and far-infrared (Herschel-PACS, right), taken with the Snapshot functionality of ESASky. (Credit: ESA/CDS)*

Students should conclude that early attempts to map the Milky Way were hampered because the Galactic Centre is hidden behind a huge amount of dust.

2. Which type of light would you use to see the stars near the Galactic Centre? Explain your answer.

Near-infrared light is the most appropriate to see through the dust and study the stars near the Galactic Centre, because its longer wavelengths are not blocked by the dust grains.

Students could be asked to make a prediction about what this region would look like in the near and far-infrared before viewing the Galactic Centre in the corresponding maps. Because near-infrared light can get through the dust, the 2MASS map (central panel of Figure 6) reveals many more stars that are so closely packed together it is difficult to separate one from another. The far-infrared image (right panel of Figure 6) confirms the large amount of the dust in this part of the Galaxy.

3. Is there any evidence that the ISM is present in the visible (optical/DSS2) image?

Students can point out the following evidence:

- Dark areas due to dust blocking visible light.
- Reddened stars when zooming into the central area.

In 1922 Dutch astronomer, Jacobus Kapteyn, proposed that the Milky Way had a lens-shaped structure with a diameter of 30 000 light years. In his model, the Sun was positioned relatively close to the centre of the Milky Way, at a distance of 2000 light years. Kapteyn also proposed that the density of stars decreased with distance from the Galactic Centre (Figure 6). He got these figures from star counting in all directions in the sky, and taking into account that stars look dimmer when they are further away.

We now know that Kapteyn's model is not correct. The Milky Way has a diameter of at least 100 000 light years, and that the Sun is actually quite far from the centre, at a distance of about 26 500 light years.

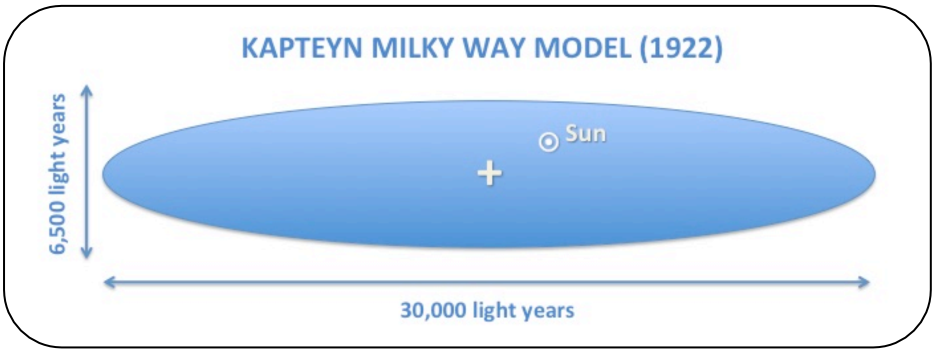

Figure 7: *Kapteyn's Galaxy model (Credit: CESAR)*
[NOTE: This is Figure 6 in the Student Guide]

4. Explain how the presence of the interstellar medium, unknown at the time, affected Kapteyn's measurements:

   The most obvious consequence of the presence of the ISM is that Kapteyn could not see the centre of the Milky Way, erroneously thinking that there were very few stars in that area. This affected his star counts and his estimation of the density of stars.

   Given that the ISM everywhere, Kapteyn's star counts were actually wrong in all directions. Because the amount of interstellar dust along the line-of-sight adds up, it prevented him seeing far beyond the Solar Neighbourhood, and his measured numbers of stars were decreasing with distance. All this led him to think that our Galaxy was much smaller than it really is, and that the Sun was near the centre.

Links

Other related Science Cases

- *The Colours of Astronomy:* http://cesar.esa.int/index.php?Section=The_colours_of_the_astronomy
- *The Secrets of Galaxies:* http://cesar.esa.int/index.php?Section=The_Secrets_of_Galaxies

Interstellar medium

For students:

- CESAR Booklet: *The Interstellar Medium:* http://cesar.esa.int/upload/201801/ism_booklet.pdf
- *Ask an Astronomer! What's between the stars?* (video): http://www.spitzer.caltech.edu/video-audio/161-ask2008-006-What-s-Between-the-Stars-

For teachers:

- *The Interstellar Medium, an online tutorial:* http://www-ssg.sr.unh.edu/ism/what1.html

Infrared light and ESA missions

- ESA's fleet across the spectrum (poster): http://sci.esa.int/education/59465-esa-fleet-across-the-spectrum-poster/

For students:

- CESAR Booklet: *The electromagnetic spectrum* http://cesar.esa.int/upload/201711/electromagnetic_spectrum_booklet_wboxes.pdf
- TED-ED: *Light waves, visible and invisible* https://ed.ted.com/lessons/light-waves-visible-and-invisible-lucianne-walkowicz

For teachers:

- *A brief history of infrared astronomy:* http://sci.esa.int/herschel/59550-a-brief-history-of-infrared-astronomy/
- Herschel's experiment for the classroom: http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment.html
- 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 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 use ESASky in Explorer Mode* (video): https://youtu.be/m14JlkqdiUE
- *How to explore multi-wavelength skies* (video): https://www.youtube.com/watch?v=zkJkhSDr0nQ