

## Teacher's guide

### CESAR Science Case - Exploring the Interstellar Medium

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- **Material that is necessary during the laboratory**
  - CESAR Booklet
  - CESAR List of Regions (.txt file)
  - CESAR Student's guide
  - Computer with an Internet browser
  - Paper, pencil or pen

## Introduction

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This Science Case provides an introduction to the interstellar medium (ISM) based on real multi-wavelength observations with space missions. It discusses concepts such as the nature of the ISM, its interaction with stars and how it can be detected, as well as several different types of nebulae (dark, emission and reflection).

During the activity, students make use of *ESASky*<sup>1</sup>, a portal for exploration and retrieval of space astronomical data, to visualise different regions of the sky and explore how the interstellar medium is affecting astronomical observations. Students can load different sky maps to see how different sky regions and astronomical objects look like when they are observed at different wavelength ranges, and discuss how the presence of the ISM is affecting these observations.

The activity can be used as an illustration of the main properties of the ISM, after they have been introduced to the students in a previous class session, or through the CESAR booklet; or to encourage students to discover the properties of the ISM on their own prior to their discussion in class.

## Learning Outcomes

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By the end of this laboratory, students will be able to:

1. Explain the main properties of the interstellar medium.
2. Explain how the interstellar medium affects optical observations of the stars (extinction and reddening).
3. Explain the difference between a reflection and an emission nebula, and what creates them.
4. Explain how astronomers study the interstellar medium.

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<sup>1</sup> <http://sky.esa.int>

## Laboratory Execution

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Students work in pairs or small groups (not more than 3-4 people) with one computer per group. It is important that they take some time to get familiar with the application before starting working with it. The provided *Beginners' Guide* may be useful for that.

To begin the exploration, students have to upload the .txt file with the list of regions to *ESASky*. This is done by clicking on the *Upload target list* button in the top left menu. The list of objects will be displayed. To navigate through it, click on the objects names, or use the video style buttons below the list. In doing so, the displayed sky map will move to the selected object. It is possible to adjust the zoom level with the mouse, the laptop trackpad, or using the '+' and '-' buttons on the right. To visualise a different sky map, click on the *Skies* button in the top left menu and select among the different maps available. It is recommended to create a stack of the three maps that are compared through the activity (Optical – DSS2 color; Near-infrared – 2MASS color; Far-infrared – Herschel-PACS-RBG) in order to switch easily from one to another.

Students are asked to compare how each of the regions in the list looks like in the optical (visible), near-infrared and far-infrared, looking for hints for the presence of ISM and discussing the origin of the differences between the maps. Finally, they have to summarize their conclusions on how the ISM affects the observation of stars, and how it is possible to study the properties of the ISM itself.

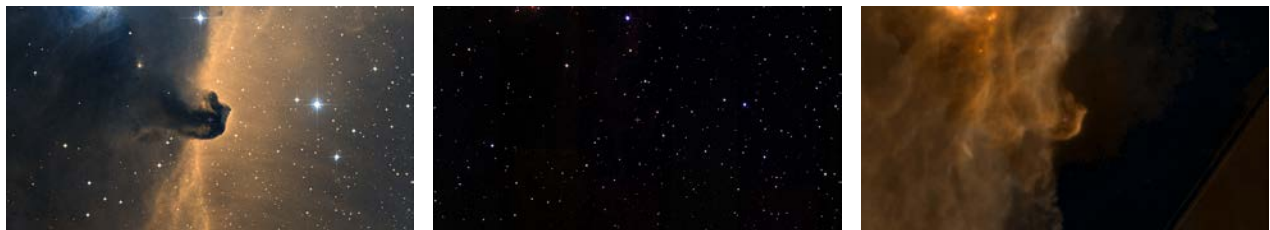
It may be necessary to point out to students that not all images have the same resolution; as a general rule, resolution is best in the optical and worst in radio and gamma rays. For this reason, some details visible in the optical images may not be appreciated in the infrared images.

## Object Discussion

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### Horsehead Nebula

*The Horsehead Nebula is a dark nebula making part of the much larger Orion Molecular Cloud Complex. First inspect the visual image: Why is it dark? Then load the near-infrared and the far-infrared maps. What do you see in each of them? Why?*



**Figure 1:** 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

This object 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. The nebula looks dark because the dust within it is opaque to visible light; this is so because the size of the dust grains is similar to optical (visible) wavelengths, and therefore, photons in this range get absorbed by the dust. In the near-infrared, wavelengths are slightly longer than visible and the photons can get through the dust, allowing us to see the stars within and behind the nebula. That’s why the near-infrared images show much more stars than the optical images, while the nebula itself is hardly visible.

Observations of this nebula also put the students’ knowledge 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 images we can see the nebula again, this time as an emitting object.

### Cygnus OB2

*Cygnus OB2 is an association of young massive stars. Look at the visual image: Can you see any evidences of the presence of ISM here? How would check this?*



**Figure 2:** Images of Cygnus OB-2 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

This region is used to discuss some less evident effects of the ISM on the observation of stars, namely light extinction and reddening. Stars look reddish in the optical image, suggesting that, either they are very cold, or something is scattering the blue light coming from them, allowing mostly red light to get through. If this second possibility is true, the stars should in reality be bluer, but also brighter than they appear because of this loss of light.

To check if there is some interstellar medium affecting our view of these stars, we can compare the optical image with the infrared images. The near-infrared image shows a large number of stars not visible in the optical; they are either very cold, or hidden in the optical image somehow. The far-infrared image reveals all the dust that populates this region.

## W40

*Check the optical image first. Do you see any evidences of the presence of ISM in this region? Now inspect it in the near-infrared. What is hidden within the dust?*



**Figure 3:** Images of W-40 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

This is a great example of the hidden treasures of the Cosmos. In the optical, only a few dispersed, reddish stars are seen. The image does show some traces of reddish dust as well. Both pieces of information together already suggest a large amount of extinction and reddening in this area.

When we observe the same region in the near-infrared, a rich star cluster is revealed. The far-infrared image provides a much better idea of the amount of dust in this region.

## NGC 1333 (Perseus Molecular Cloud)

*A mere 1,000 light-years distant, the NGC 1333 region lies on the edge of the large Perseus Molecular Cloud. How does this cloud look like in the optical and infrared? What type of stars do you see? How is the presence of these stars affecting the cloud?*



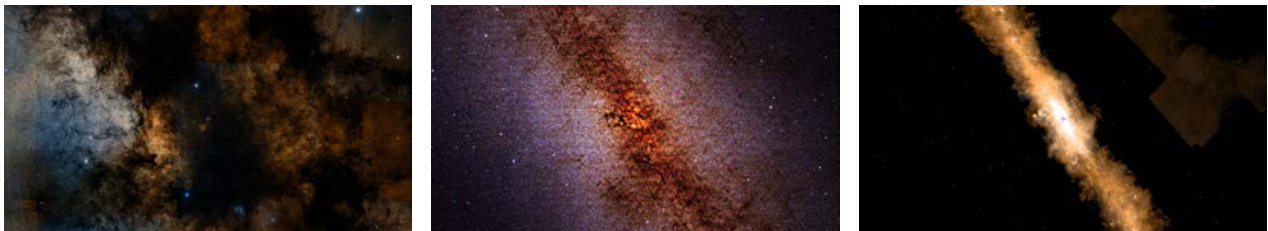
**Figure 4:** Images of the Perseus Molecular Cloud in the optical (DSS-2, left), near-infrared (2MASS, centre) and far-infrared (Herschel-PACS, right), taken with the Snapshot functionality of ESASky. **Credit:** ESA/CDS

This region is used to discuss the different types of nebulae: emission and reflection. The two of them are visible in the optical image (with a field of view of about 14'), and are easily identified by their colors. As their name indicates, reflection nebulae reflect or scatter the light of stars located behind or within them; since blue light is more scattered than red light, they look bluish. Emission nebulae are hydrogen clouds ionized by the light from the stars within them; as the electrons are re-captured, they emit their characteristic reddish glow (due to one very prominent transition in the hydrogen atom). It is important for students to notice that, a star must be very hot in order to emit photons energetic enough to ionize a cloud.

Students can switch between the images to see how the differences between the nebulae nearly disappear when they are observed in infrared light.

### Sgr A\*

*This is the region in the centre of our Galaxy (you will need to zoom out to a field of at least 12 degrees to fully appreciate it). How does this region look like in the optical? Make a guess: What do you expect to find if you observe it in the near and far-infrared?*



**Figure 5:** 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

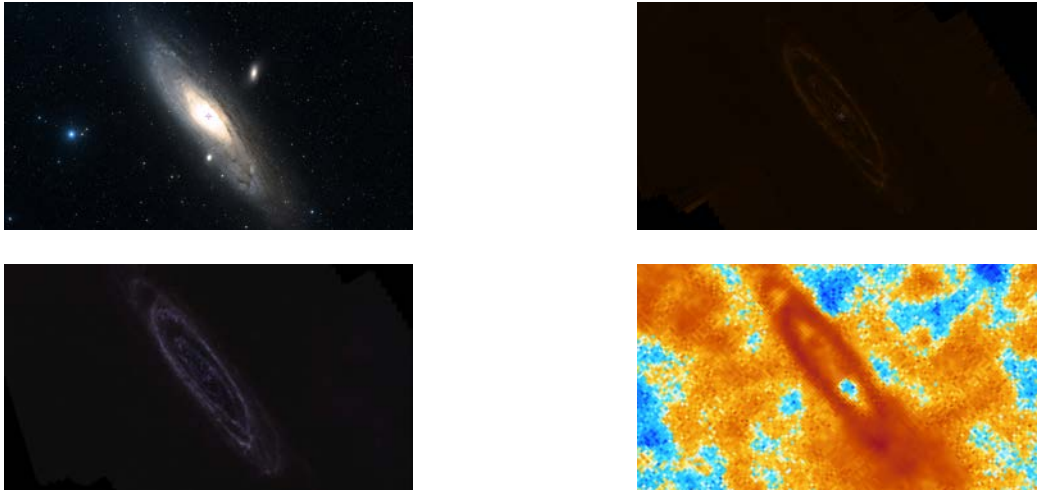
To fully appreciate that this is the Galactic Centre, students will have to zoom out to a field of view size of about 12 degrees. With this perspective, they can fully appreciate in the optical image how the central area looks much darker than the surroundings. They are now asked to apply the knowledge they have acquired in the previous steps of the activity, making a prediction on how this region will look like in the near and far-infrared. They can then switch to the corresponding images to check if they were right.

Because near-infrared light can get through the dust, in this image many more stars are revealed, so closely packed together that it is difficult to separate one from another. The far-infrared image confirms the large amount of the dust in this part of the Galaxy.

When discussing this region, it is interesting to comment how the fact that the Galactic Centre is hidden behind so much dust hampered early attempts to map the Milky Way.

## M31

*M31, the Andromeda Galaxy, is one of the nearest galaxies and the one of the largest member of the Local Group of galaxies, together with our own Galaxy, the Milky Way. Compare the observations of this galaxy in the optical and infrared. Do you think M31 is rich in gas and dust? Where is this ISM mostly located within the galaxy?*



**Figure 6:** Images of M31, the Andromeda Galaxy, in the optical (DSS-2, top left), far-infrared (Herschel-PACS, top right), submillimetre (Herschel-SPIRE, bottom left) and radio (Planck, bottom right). The images were taken with the Snapshot functionality of ESASky. **Credit:** ESA/CDS

This is an example of how the ISM is distributed in spiral galaxies. Again, students are asked to apply the acquired knowledge and hypothesise about the composition of M31. Then, they can switch to longer wavelengths to see how the spiral arms are nicely reproduced in the far-infrared observations, thus showing that they are rich in ISM. It is suggested that they check the sub-millimetre and radio to see how this is true to both dust and gas.

## Extension

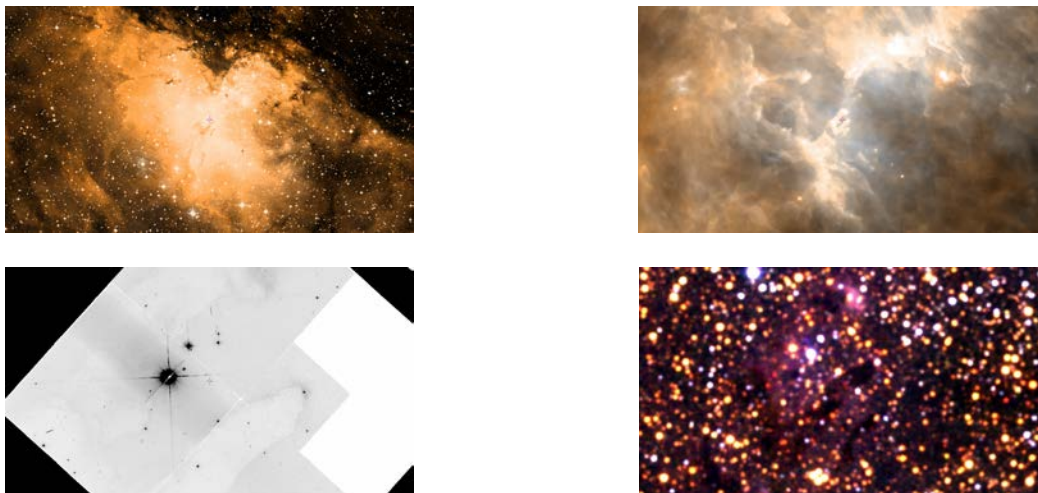
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At the end of the activity, it may be interesting to discuss the relation between the ISM and the origin of stars. This can serve as introduction to the topic of star formation. A good way to do this is to display M16, the Eagle Nebula, which became very popular after the publication of the famous ‘pillars of creation’ HST image. Unfortunately, the HST maps available in *ESASky* do not match the spectacular nature of the (highly processed) press release images. However, the DSS2 optical map is well fitted to the purposes of the suggested demonstration.

M16 is a nice example of the interaction between a cloud and the newly formed stars within it: The cloud is being carved by the light from the young, hot stars, creating a spectacular emission nebula. The ‘pillars’ are

denser cloud areas being compressed by the surrounding radiation, and this compression in turn triggers the formation of more stars.

Display M16 by entering the name in the search box. Adjust the zoom to show the cavity and the well-known ‘pillars of creation’, and ask the students to hypothesise about the way the cloud is interacting with the stars within it, what is causing the pillars’ shape, and what may be happening within them. Then zoom into the pillars and switch to the 2MASS map to show them the new-born stars within the pillars. The far-infrared and/or sub-millimetre images can be used to show how the central area is more devoid of dust by effect of the photo-evaporation, giving the region the shape of a giant bubble.



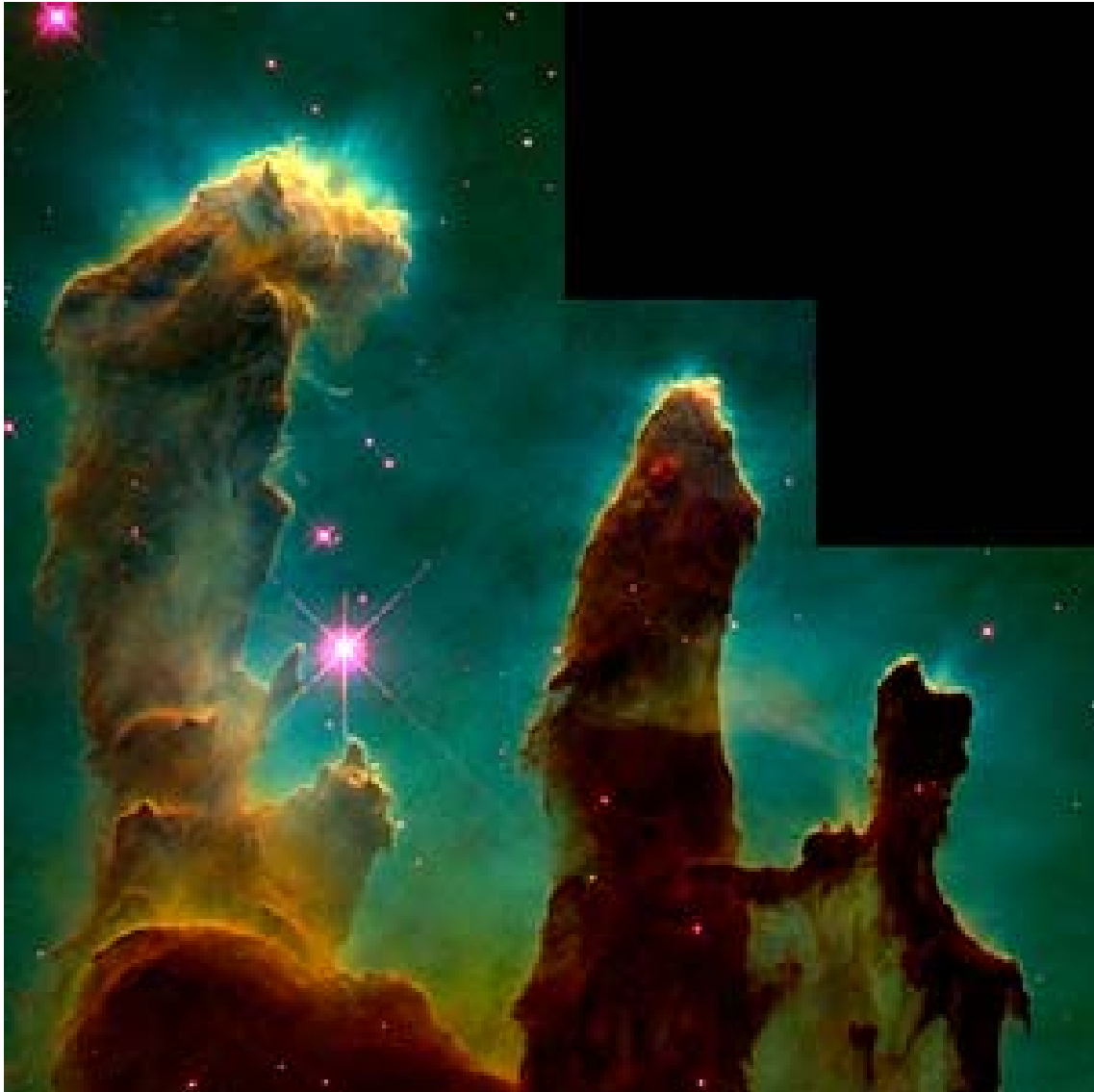
**Figure 7:** Images of M16, the Eagle Nebula, in the optical (DSS-2, top left) and far-infrared (Herschel-PACS, top right), and details on the Pillars of Creation as observed in the, bottom left) and near-infrared (2MASS, bottom right). The images were taken with the Snapshot functionality of ESASky. **Credit:** ESA/NASA/CDS

To conclude, switch to the HST WFPC2 map to show them a higher-resolution (B/W) image of the pillars, and/or show students the famous HST image. The HST-WFPC2 map displays the images that were combined to create the iconic colorful image (it may be necessary to zoom into the pillars area to fully appreciate it).

## Assessment

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Assessment of the learning outcomes can be performed by classroom observations during the group work and in the final class discussion, by asking students in each group to write down and turn in a final report summarising their conclusions, and/or with the attached quiz.



*Figure 7: HST iconic high-resolution image of the Pillars of Creation in M16. Credit: ESA/NASA*