

CESAR Science Case

The Colours of Astronomy

Observing the visible and invisible Universe

Student Guide

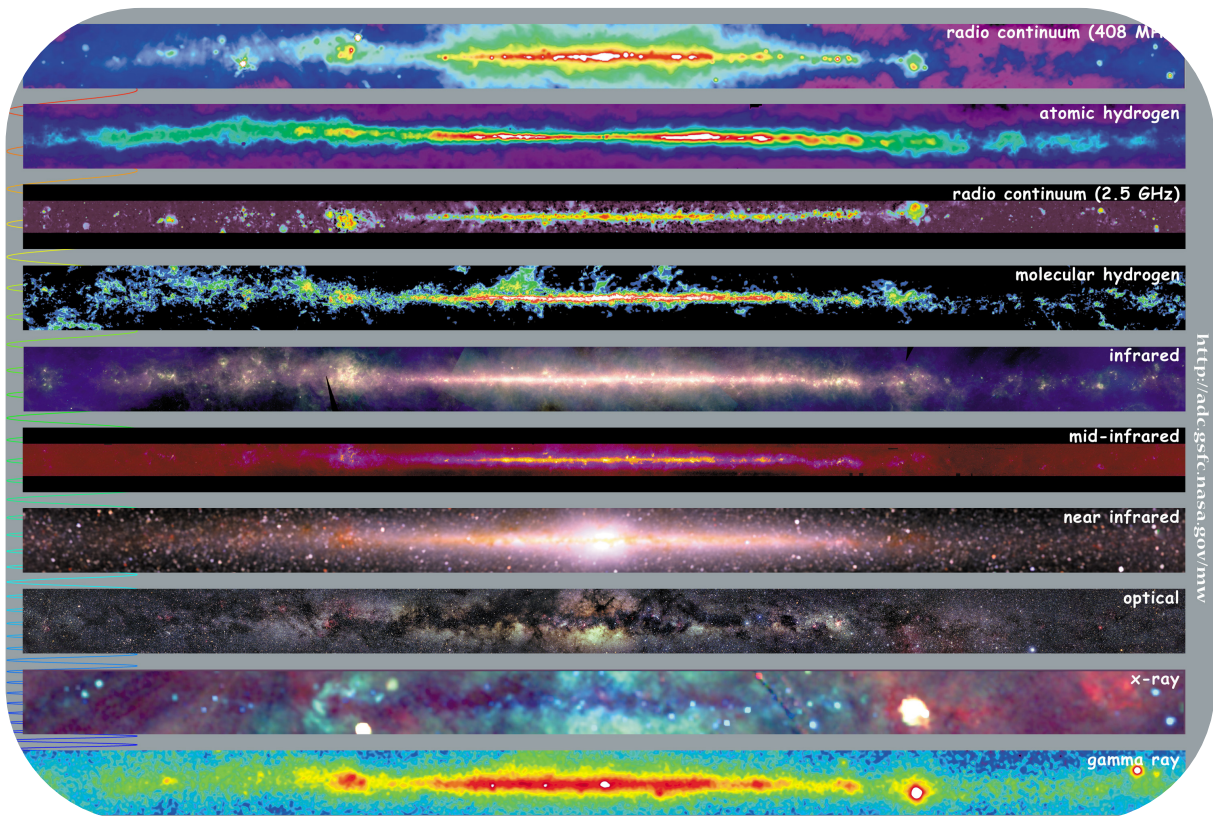


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Background

Visible and invisible light

We are all familiar with the colours of the rainbow, but light has many more colours –only our eyes cannot see them. Then, how do we know about them?

Physicists describe light as something called an *electromagnetic wave*, that is, the perturbation of an electromagnetic field that propagates in space, transporting some energy from one *source* (the object that emits light) to one *observer*. The number of times the wave repeats itself in a second is called the *frequency* of the wave, and it is inversely proportional to the *wavelength* or distance between two points in exactly the same state –in other words, the higher the frequency, the shorter the wavelength. The sample of all possible wavelengths (frequencies) of light makes up the so-called *electromagnetic spectrum* (Figure 1). Our eyes are adapted to detect only a small portion of this spectrum, and this portion is what we call “visible light”. Different wavelengths of visible light are perceived by our eyes as different colours. Gamma rays have the shortest wavelength, and radio waves the longest. Thus, the only difference between the colours of visible and invisible light is their wavelength (or frequency).

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

But temperature is not the only phenomenon that can produce light. For example, electrons moving in a magnetic field will emit light in radio frequencies; this is called *synchrotron radiation*, and is an example of *non-thermal emission*.

Observing invisible light

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 rest of the electromagnetic spectrum is blocked by the atmosphere –luckily, as it could be very harmful to us. The bar at the top of Figure 1 provides information on whether the atmosphere is transparent (white), opaque (black) or partially opaque (grey) to light of a given wavelength.

Most stars are relatively bright in the visible, but other objects and phenomena in the cosmos emit light in wavelengths other than visible (see Table 1 for some examples). To study them, astronomers use telescopes that are able to see those types of light our eyes cannot. Such telescopes must be placed in space, where the atmosphere is no longer a problem. This way, astronomical objects can be observed across the whole spectrum, and we can get the full picture of what is happening in them.

Another reason to send telescopes to space, even if they detect a type of light observable from Earth, is prevent distortions in the images caused by the atmosphere. By getting rid of the atmosphere, the quality of the images and the amount of detail we see in them are improved.

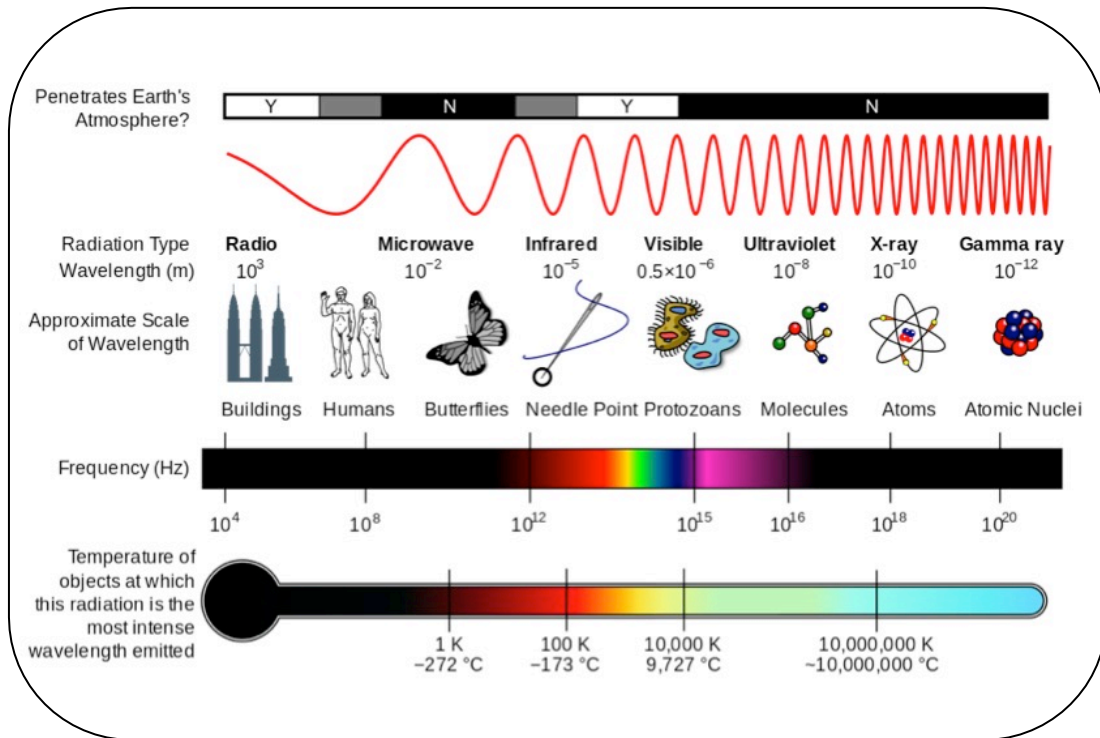


Figure 1: Properties of the electromagnetic spectrum. (Credit: Wikimedia Commons)

Table 1: Examples of astronomical sources emitting in each range of the electromagnetic spectrum. *

Type of radiation	Temperature	Energy	Typical sources
Gamma-rays	$>10^8$ K	$> 2 \times 10^{-14}$ J	Matter falling into black holes
X-rays	10^6 - 10^8 K	2×10^{-17} - 2×10^{-14} J	Gas in clusters of galaxies Hot gas clouds in supernova remnants Stellar coronae Neutron stars
Ultraviolet	10^4 - 10^6 K	5×10^{-19} - 2×10^{-17} J	Hot gas clouds in supernova remnants Very hot stars
Visible	10^3 - 10^4 K	3×10^{-19} - 5×10^{-19} J	Stars Hot clouds of gas
Infrared	10 - 10^3 K	2×10^{-22} - 3×10^{-19} J	Very cool stars Planets
Infrared	10 - 10^3 K	2×10^{-22} - 3×10^{-19} J	Cool clouds of dust
Microwave and radio	<10 K	$< 2 \times 10^{-22}$ J	Cool clouds of gas The Cosmic Microwave Background (CMB) Electrons moving in magnetic fields

*Adapted from: NASA/Imagine the Universe!

The Universe in full colour

Activity 1: Light in everyday life

Before starting your investigation, take a few minutes to reflect about what you know about light, and about the difference between visible and invisible light.

1. Can you think of everyday sources that emit visible and invisible light? What is this light telling us about those objects? Do you know some devices using different types of light? What is this light useful for in each case? Enter some examples in the table below:

Table A

Type of light	Sources	Uses
Gamma-rays		
X-rays		
Ultraviolet		
Optical (Visible)		
Infrared		
Microwave		
Radio		

2. Which types of light can be especially harmful to humans and other living beings on Earth? What can be the reason? (Hint: Use Table 1 and Figure 1.)

3. What type of light is emitted by a radiography machine, a mobile phone, and a TV remote control? If you had missed any of these devices, note them now in the table above.

4. Have a look at Table 1 and note the relation between the type of light and the wavelength, frequency and energy carried by the electromagnetic wave. What device emits the least energetic radiation: a radiography machine, a mobile phone, or a TV remote control? Explain your answer.

Activity 2: Getting familiar with ESASky (optional)

In the next activities, you will use *ESASky*, a portal for exploration and retrieval of space astronomical data, to see how different astronomical objects have been observed by different telescopes. If you had not worked with it before, take a few minutes to get familiar with the tool.

1. Load *ESASky* in your browser by entering:

<http://sky.esa.int>

2. Select “Explorer” mode.
3. When loading the application, it will display an astronomical object and a pop-up window with a brief description of it. Note that this image is actually a map of the whole sky: You can zoom in and out the object, and pan to move to other regions of the sky.
4. To view a particular astronomical object, enter its name in the search field on the top-right corner, and your target will be displayed. Table 2 suggests you some of the favourite objects of the *ESASky* team, for you to enjoy.

Table 2: *Some of our favourite astronomical objects.*

Object	Description
M51 (Whirlpool Galaxy)	Spiral galaxy interacting with the NGC 5195 galaxy, a traditional target for first-light observations of space telescopes.
M16 (Eagle Nebula)	Star forming region containing the iconic “Pillars of creation” imaged by the Hubble Space Telescope with its WFPC2 camera.
M13 (Hercules Globular Cluster)	A favourite globular cluster among amateur astronomers.
Sgr A*	The centre of our Galaxy, the Milky Way. Have a look at it in different wavelength ranges!
SN 1006	Another supernova remnant. It looks spectacular in X-rays!
M82 (Cigar Galaxy)	A starburst galaxy, looking very different in optical and X-rays.
Cheshire Cat	Gravitational lensing makes this cat (actually a galaxy group) smile in the HST images.
Ring Nebula	A famous planetary nebula, looking great in some of the infrared maps.
Centaurus A	A radio galaxy hosting a powerful supermassive black hole in its centre.

5. To see how the objects look like as observed by different missions in different types of light, you have to open the ‘Manage Skies’ menu by clicking on the colourful button on the top-left corner of the application (Figure 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.
6. Check if your favourite astronomical object has been observed in wavelengths other than visible light (called ‘optical’ by astronomers), and by which missions or surveys. Note that most maps display many blank regions, as most missions and surveys have not covered the whole sky, but only selected regions.

When you feel confident working with *ESASky*, move to the next step.

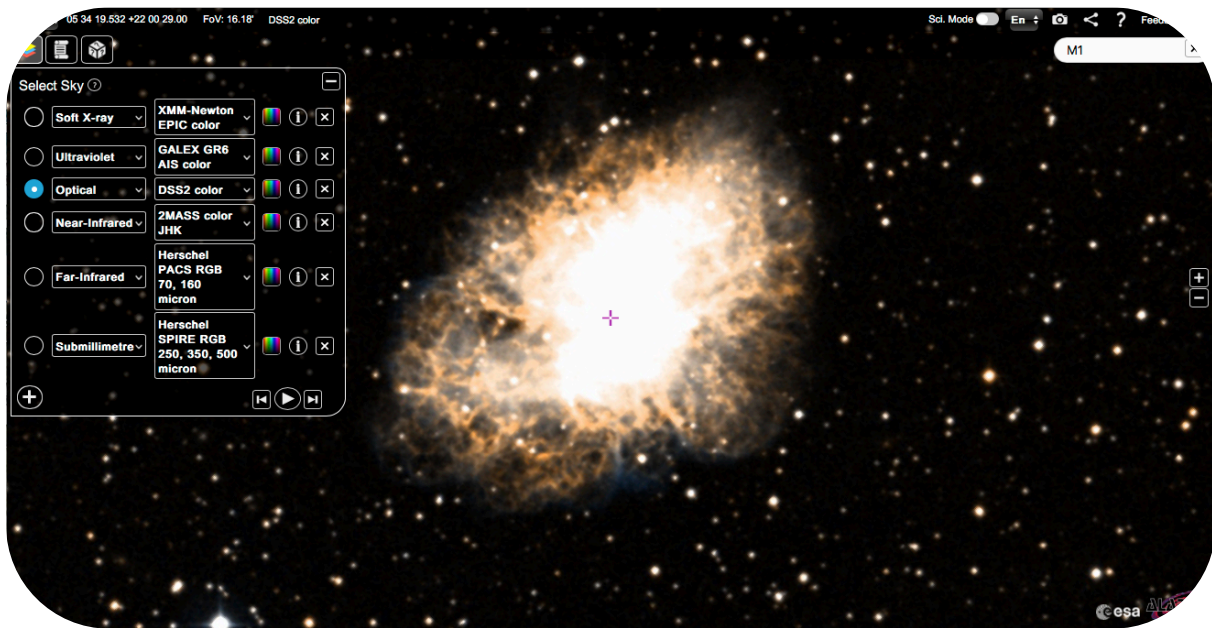


Figure 2: ESASky displaying the Crab Nebula in visible light and its Skies menu opened, showing a stack of maps. (Credit: ESA/ESDC)

Activity 3: Observing all types of light

You will begin your exploration by learning about the different telescopes that have observed the sky in different types of light –different frequencies (or wavelengths). In this activity, you will limit your study to just one object: the Crab Nebula (M1), a cloud formed by the remains of an aged star that exploded as a supernova nearly 2,000 years ago.

1. In *ESASky*, make sure that the optical ‘DSS2 color’ map is displayed. The name of the displayed map is shown above the Skies button on the top-left corner. If the ‘DSS2 color’ map is not displayed, click on the Skies button and select it in the menu.
2. Type the name of the Crab Nebula (also called ‘M1’ or ‘Crab’) in the search box, and play with the zoom buttons if necessary to get the full image of it (Figure 2).
3. To see how the Crab Nebula was observed by different telescopes, create a stack of maps similar to the one shown in Figure 2, covering the electromagnetic spectrum from soft X-rays (low-frequency X-rays) to submillimetre (very short microwaves). To do so, click on the “+” sign as many times as needed and select different wavelength ranges in the left drop-down menus, until you have all of them.
4. For each wavelength range, select a map from a telescope that has observed the Crab Nebula in the right drop-down menus (in most cases, the default one will do, but feel free to pick another map if you prefer).

5. Complete the table below with information about the stack of maps you created for the Crab Nebula. You can find the name of the telescope that made the observations by clicking on the ‘i’ icon on the right of the drop-down menu (the name is under “Mission”). Use the information at the top of Figure 1 to decide if the telescopes in your stack are likely to be ground-based or spaced-based.

Table B

Type of light	Telescopes	Ground or space?
(soft) X-rays		
Ultraviolet		
Optical (Visible)		
Near-Infrared (short infrared waves)		
Far-Infrared (long infrared waves)		
Submillimetre (short microwaves)		

6. Explain how you decided if a telescope was ground-based or space-based:

7. Now observe the Crab Nebula in all wavelength ranges. How do the images change as you move through the spectrum?
 - a. Take a snapshot of every image using the camera button. You can paste the images in the table in the next page.
 - b. 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?
 - c. 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. Taking this into account, and using the information Table 1, can you think of an explanation of the changes you see in the images? Write your hypotheses next to each image in the table. Bear in mind that the wavelength of light can be related to the temperature or the energy of the source.

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

Did you know?

The colours of astronomical images like the ones you will use in these activities are not real. Remember that our eyes cannot see infrared or ultraviolet colours! As a matter of fact, telescopes register only black-and-white images. Those images can then be artificially coloured and combined to create the beautiful colour pictures we all admire. Usually, the image observed in the shortest wavelength is coloured blue, and the image in the longest wavelength is coloured red. If a third image is available, taken in a wavelength between the two, it is assigned the colour green. By mixing these three colours, all the rest can be produced.

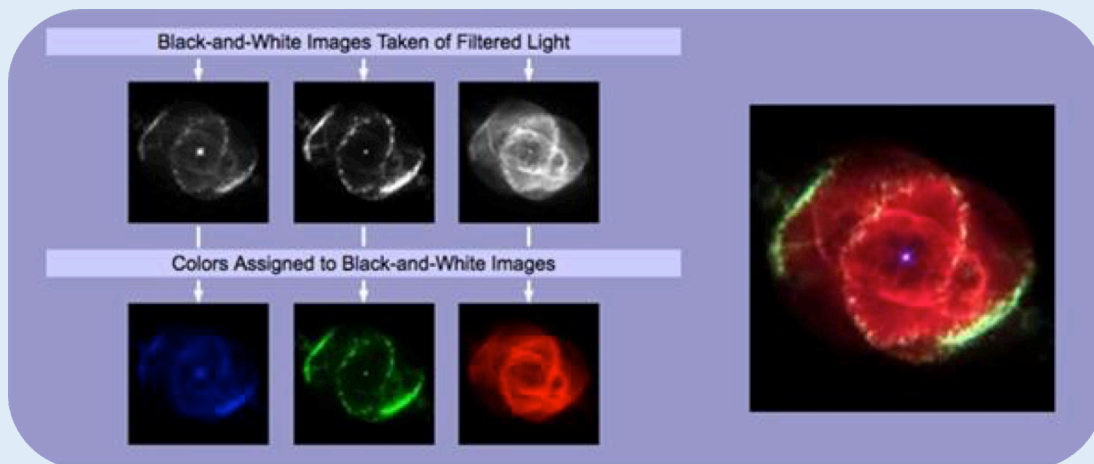


Figure 4: How to create a coloured astronomical image. (Credit: astronomy.wonderhowto.com)

Table C

Object: Crab Nebula (M1)			
Type of light	Image	Description	Explanation
(soft) X-rays			
Ultraviolet			
Optical (Visible)			
Near-Infrared			
Far-Infrared			
Submillimetre (short microwaves)			

Activity 4: The multi-coloured Universe

You are now going to repeat the investigation with different types of astronomical objects. To do so, you will have to upload the list of objects to *ESASky*.

1. Make sure that the optical 'DSS2 color' map is displayed. The name of the displayed map is shown above the Skies button on the top-left corner. If the DSS2 color map is not displayed, click on the Skies button and select it in the menu.
2. Load the list of objects to explore. To do so, click on the Parchment button on the left-hand side, and then on 'Select target list'. Scroll down the list names until you find "CESAR Colours". Click on this name, and the list of objects will be displayed as shown in Figure 3. Note that the first object is the Crab Nebula that you have just studied.
3. You can move to any object in the list by clicking on its name. The application will automatically load the image of it, and a pop-up window will provide a brief description of the object. The names of the objects and their descriptions are also presented in Table 3. You can also move through the list using the video-style buttons.

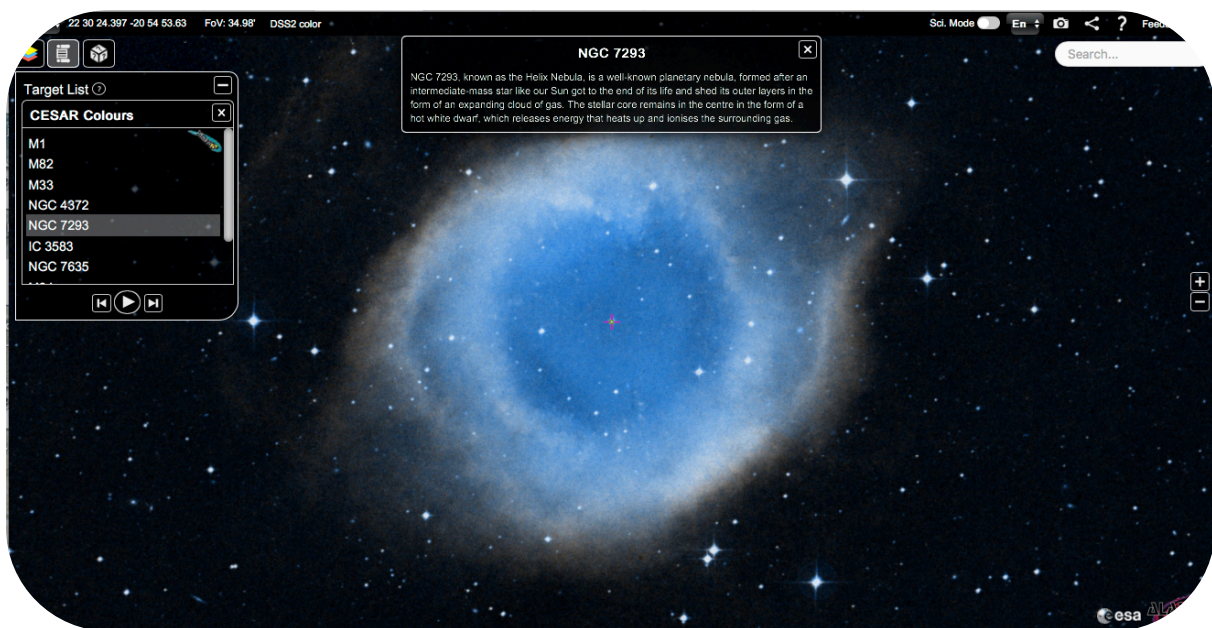


Figure 3: The Target List functionality of *ESASky*. The list of objects is loaded, and a description of the displayed object (which is highlighted) appears in a pop-up window. (Credit: ESA/ESDC)

4. Explore the objects in the list. Which object (or objects) looks similar in all images across the spectrum? Which object (or objects) shows the biggest differences? (Note that some objects may not have been observed by all telescopes.)

Table 3: Astronomical objects to explore.

Object	Description
M1	The Crab Nebula is the remnant of a supernova observed by Chinese astronomers in 1054. A star much more massive than our Sun exploded at the end of its life, creating a cloud of dust and hot gas that is expanding into space. In the centre of the cloud, astronomers have discovered a neutron star that was once the core of the star. This is a very hot, small, and massive object, with a very strong magnetic field. It also spins very fast, emitting regular pulses of light like a lighthouse.
M82	Messier 82, also known as the Cigar Galaxy, is a so-called ‘starburst galaxy’. These galaxies are forming stars at a much higher rate than normal galaxies; astronomers think this is a consequence of the interaction with another galaxy (in the case of M82, the neighbouring galaxy M81). The starburst region of M82, located in its centre, is 100 times brighter than the centre of our Milky Way galaxy, thanks to the high number of young, bright and hot massive stars it contains. Because these stars live fast and end their lives as supernovae, in M82, one such event happens every ten years.
M33	M33, the Triangulum Galaxy, is the third largest member of the Local Group of galaxies, after the Milky Way and the Andromeda galaxy: It has a diameter of about 60,000 light years, roughly 40% of the Milky Way. M33 is a spiral galaxy, meaning that the central spherical region of the galaxy is surrounded by a disk of cold gas and dust, which moves around the galactic centre forming the spiral arms. M33 contains two different populations of stars: The stars in the central region, or bulge, are relatively old, while the stars in the spiral arms are quite young, and new stars are continuously forming in this part of the galaxy.
NGC 4372	NGC 4372 is a globular cluster, that is, a spherical collection of stars very tightly bound by gravity. The density of stars increases as we move toward the centre of the cluster. NGC 4372 is part of the halo of our Galaxy, orbiting the galactic centre. Globular clusters like this one contain considerably more stars, and much older (thus brighter and cooler), than the less dense open clusters found in the Milky Way disk, and very little interstellar gas and dust.
NGC 7293	NGC 7293, known as the Helix Nebula, is a well-known planetary nebula, formed after an intermediate-mass star like our Sun got to the end of its life and shed its outer layers in the form of an expanding cloud of gas. The stellar core remains in the centre in the form of a hot white dwarf, which releases energy that heats up and ionises the surrounding gas.
IC 3583	IC 3583 is an irregular galaxy, that is, a galaxy with no distinct shape. It has a bar of stars running through its centre, suggesting it was once a spiral galaxy that got disrupted in a collision with its neighbour, galaxy Messier 90.
NGC 7635	NGC 7635, the Bubble Nebula, is a so-called emission nebula, a cloud of gas that is being heated up by a hot, massive star, causing it to glow and expand.
M84	Messier 84 is an elliptical galaxy belonging to the Virgo Cluster of Galaxies. This type of galaxy contains mostly aged stars, some of them ending their lives as supernovae, and little cold gas and dust.
NGC 7023	The Iris Nebula, NGC 7023, is a bright reflection nebula, that is, a cloud of interstellar dust that is reflecting the light of a nearby star. Contrary to an emission nebula, in this case the star is not hot enough to make the cloud glow in visible light.
NGC 3766	The Pearl Cluster, NGC 3766, is an open star cluster, that is, a group of stars that formed from the same interstellar cloud and have roughly the same age. This type of star cluster has no clear shape, and its members are only loosely bound by gravity, getting dispersed in the Galaxy as time goes by. NGC 3766 contains more than 130 known stars, most of them hot and blue, although two red supergiants (cool and red) are also part of the cluster.

5. Pick an object in the list. Based on the description provided in the screen (and in Table 3), and with the help of the information in Table 1, complete the table in the next page for this object as you did for the Crab Nebula. (If the object has not been observed in a given wavelength range, leave that row of the table blank.)
6. If you have time, repeat the process with more objects from the list. You can print (or copy) the table in the next page as many times as you need.

Activity 5: All the colours of...

After you have inspected the objects in the list, choose your favourite one and do some research to check if your guesses were correct, and to learn more about it. For example: How did this object form? What will its fate be? How do astronomers know this from the properties of the object? What questions about this object are still unanswered?

Later, you can present your findings to the rest of the class.

Table D

Object:			
Type of light	Image	Description	Explanation
soft X-rays			
Ultraviolet			
Optical (Visible)			
Near-Infrared			
Far-Infrared			
Submillimetre (short microwaves)			