CESAR Science Case

The Secrets of Galaxies

How many types of galaxies are there?

Student Guide

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Background

A century ago, astronomers believed that our Galaxy, the Milky Way, was the entire Universe. In the 1910s and early 1920s there was much debate about whether the 'spiral nebulae' (spiral shaped, milky patches of light) that were seen scattered among the stars were outside the Milky Way or part of it. This was until work by Edwin Hubble (1889-1953) and Milton Humason (1891-1972) established that each of the spiral nebulae was actually a huge star system, called a *galaxy*. Hubble and Humason were able to measure the distance to some of these galaxies, proving that the Universe was much more vast than previously thought, and that our Galaxy is just one of billions of galaxies in the Universe.

In 1926, Edwin Hubble proposed a classification scheme based entirely on the visual appearance of a galaxy on a photographic plate. Hubble's system has three basic categories: elliptical, spiral, and irregular galaxies. The elliptical and spiral galaxies are subdivided further, this is known as the 'Hubble Tuning Fork' diagram, and is illustrated in Figure 1. Our galaxy, the Milky Way, is probably a barred spiral galaxy.

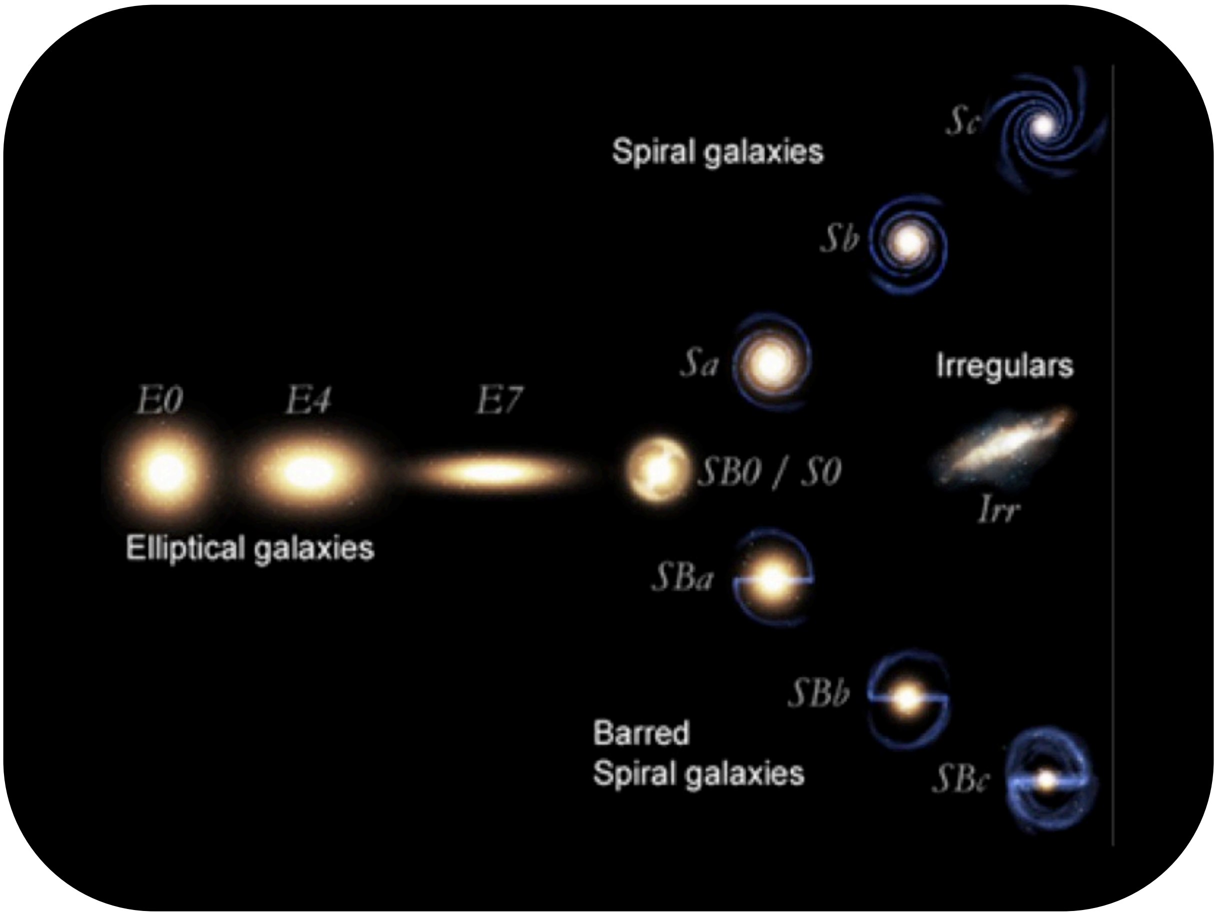
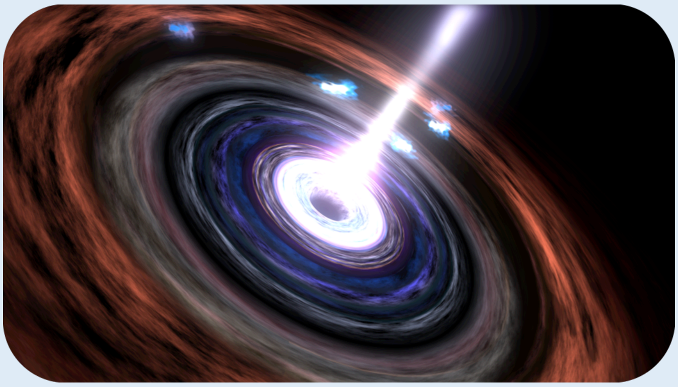


Figure 1: *The Hubble Tuning Fork. (Credit: NASA/ESA)*

Did you know?

Astronomers think that the centres of most galaxies harbour extremely massive black holes (even tens of billion times the mass of the Sun). Sometimes these black holes are extremely powerful, making the centres of those galaxies unusually bright. The black holes are continuously swallowing matter, and they can also expel part of the matter that falls onto them in the form of enormous jets. They are called *Active Galactic Nuclei (AGN)*.



An Active Galactic Nucleus (Credit: NASA)

While elliptical and irregular galaxies show very little structure, in spiral and barred spiral galaxies we can distinguish several parts (Figure 2): The central part is called the *bulge* ; it is spherical in normal spirals, while in barred spirals it appears elongated, with a *bar* connecting to the spiral arms. The bulge is surrounded by a flattened structure called the *disk*, which contains the *spiral arms*. Finally, the bulge and disk are surrounded by a spherical *halo*.

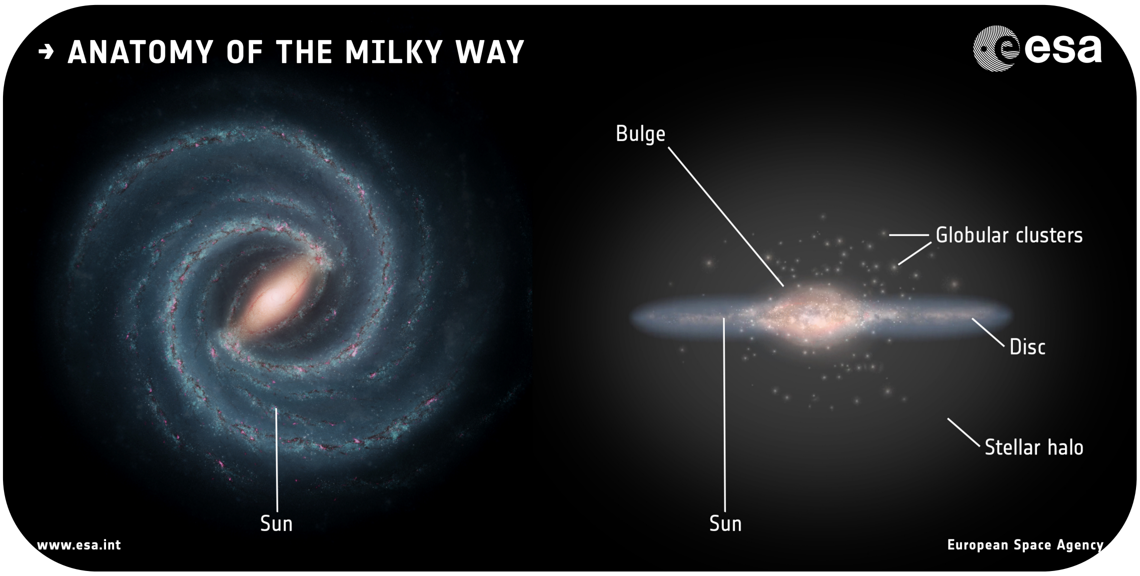


Figure 2: *Structure of a spiral galaxy, the Milky Way. (Credit: ESA)*

Investigating galaxies

Activity 1: What is a galaxy?

In this activity, you are going to learn about galaxies. But what is a galaxy? How would you explain it to somebody that knows nothing about them? How many galaxies are there in the Universe? Do you think that all these galaxies are the same? If not, how are they different?

Discuss these questions with your partner or group. You can use the space below to list all you know about galaxies, and what you would like to know:

What we know about galaxies:	**What we'd like to know about galaxies:**

Activity 2: Getting familiar with ESASky (optional)

In this Science Case, you will use *ESASky*, a web application to explore real images of galaxies to study their properties.. If you have 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 entire sky: You can zoom in and out the object, and pan to move to other regions of the sky.

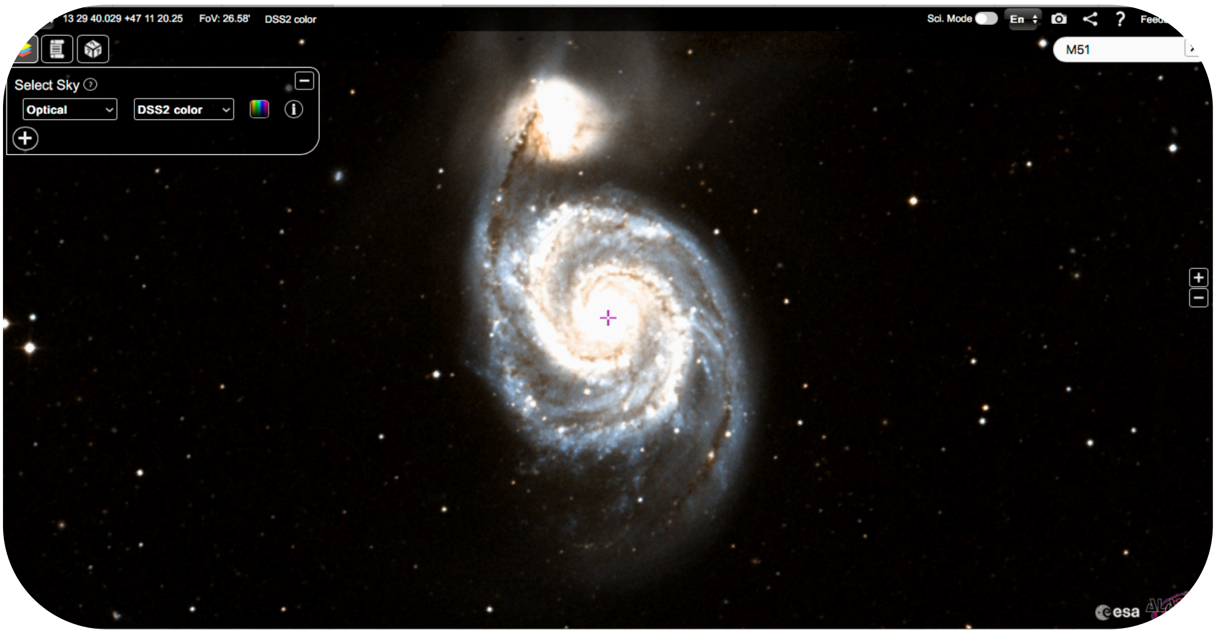


Figure 3: *The ESASky interface. (Credit: ESA/ESDC)*

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 1 suggests some of the favourite objects of the *ESASky* team, for you to enjoy.

5. To see how the objects look 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 3). 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.

Table 1: *Some of the ESASky team's favourite astronomical objects.*

Object	Description
M51 (Whirpool Galaxy)	Spiral galaxy interacting with the NGC 5195 galaxy, a traditional target for first-light observations of space telescopes.
M1 (Crab Nebula)	Remnant of a supernova observed by Chinese astronomers in 1054.
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.
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.

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

Activity 3: Classifying galaxies

Your task is to classify a sample of galaxies according to the Hubble Tuning Fork diagram shown in Figure 1. To do so, you need to load the list of galaxies on *ESASky*:

1. Hubble observed in visible light, so make sure that the optical 'DSS2 color' map is displayed. The name of the displayed map is shown on the top bar. If the DSS2 color map is not displayed, click on the Skies button and select it in the menu.

2. Load the galaxy list. 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 Galaxies". Click on this name, and the list of objects will be displayed as shown in Figure 4.

3. You can move to any galaxy 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 all the galaxies and their descriptions are given in Table 2. You can also move through the list using the video-style buttons.

Figure 4: The Target List functionality of ESASky. The list of galaxies is loaded, and a description of the displayed object (which is highlighted) appears in a pop-up window. (Credit: ESA/ESDC)

4. Inspect each galaxy and classify it according to the Hubble Tuning Fork diagram (Figure 1):

Hubble type	Galaxies
Spirals	
Barred spirals	
Ellipticals	
Irregulars	

5. Compare your classifications with those from the other groups and discuss any differences.

After you have discussed your classification, your teacher will tell you the 'official' classification – that is, the type assigned to each galaxy by astronomers based on their current knowledge of the objects. You will need this information to continue your investigation.

Table 2: *List of galaxies.*

Galaxy	Description
NGC 2997	NGC 2997 is located approximately 25 million light-years away, in the constellation Antlia.
M101	M101, also known as the Pinwheel Galaxy, is a spiral galaxy approximately 21 million light-years away in the constellation Ursa Major.
M91	M91 lies approximately 63 million light-years away in the Coma Berenices constellation. It is part of the Virgo Cluster of galaxies.
LMC	The Large Magellanic Cloud (LMC) is the largest satellite galaxy of the Milky Way, and the fourth largest galaxy in the Local Group. At a distance of about 163 000 light-years, the LMC is the third-closest galaxy to the Milky Way, after the Sagittarius Dwarf and the Canis Major Dwarf Galaxy
M87	M87, located near the centre of the Virgo Cluster, is one of the most massive galaxies in the Local Universe.
NGC 4565	NGC 4565, also known as the Needle Galaxy for its narrow profile, is located about 30 to 50 million light-years away, in the constellation Coma Berenices.
NGC 1132	NGC 1132 is located approximately 320 light-years away, in the constellation Eridanus.
IC 5152	IC 5152 is a dwarf galaxy in the Local Group, the group of galaxies our Milky Way belongs to.
NGC 1300	NGC 1300 is located approximately 61 million light-years away, in the constellation Eridanus. The galaxy is about 110 000 light-years across (about 2/3 the size of the Milky Way). It is a member of the Eridanus Cluster, a cluster of 200 galaxies.
M60	M60, also known as NGC 4649, is located approximately 55 million light-years away in the constellation Virgo. Together with NGC 4647, it is part of a pair of galaxies known as Arp 116.
NGC 4449	NGC 4449 is a galaxy in the constellation Canes Venatici. It is located about 12 million light-years away, part of the M94 Group (the Canes Venatici I Group), a galaxy group relatively close to the Local Group containing the Milky Way.
M31	The Andromeda Galaxy, M31, is located about 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.

Activity 4: The colours of galaxies

Now that you know the type of each galaxy, go through the list again to investigate the properties of the different types of galaxies. Let's begin with the most obvious property, apart from their shape –their colours.

The shape of a galaxy is related to properties such as its colour (in visible light), which in turn depends on the type of stars it contains. But because galaxies are so far away, it is not possible, in most cases, to see the individual stars that form them. What we see is the combined light from all those stars. Essentially, it is the light from the brightest and biggest stars within a galaxy – the *giants* and *supergiants* – that are responsible for the colours observed.

All stars form from clouds of gas and dust (nebulae). Blue giant stars are young and massive, while red giants and supergiants are old stars approaching the end of their lives. Depending on the mass of these old stars, their lives could end as a white dwarf, or a supernova explosion leaving behind a neutron star or a black hole, as shown in Figure 5. Young, low-mass stars –*red and yellow dwarfs* – are quite dim and contribute very little to the overall light emission of a galaxy.

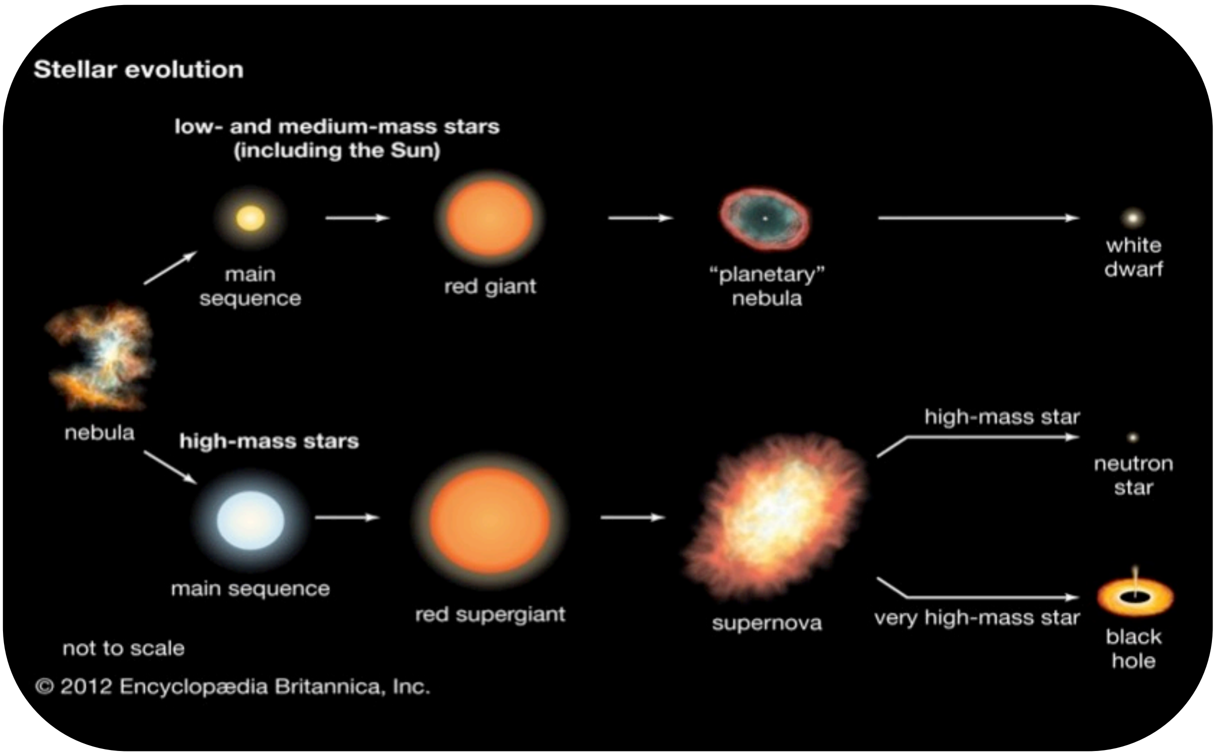


Figure 5: *A star's evolution in time depends on its mass. (Credit: Encyclopaedia Britannica)*

1. In *ESASky*, go through the list of galaxies again. Do the colours of galaxies seem related to their shapes? Explain.

2. Look at the spiral galaxies. Why are the colours of the bulge (central part) and the colours of the spiral arms so different? Suggest an explanation. (Remember that only the most luminous stars are observable at these large distances)

3. Compare the bulges of spiral galaxies to elliptical galaxies. In what sense are they similar?

Activity 5: Galaxies in different light

You now know the types of stars that the different types of galaxies contain, let's go one step further and investigate other contents of the galaxies.

Galaxies do not only contain stars. However, in order to study other types of astronomical objects inside a galaxy, astronomers need to observe it in other types of light that are invisible to our eyes. This is because the astronomical objects inside a galaxy emit light of different wavelengths (different colours) depending on their temperature and the phenomena that are going on in them. In Table 3, you have a list of the temperatures of sources within a galaxy emitting in the different colours of the electromagnetic spectrum, as well as some examples of these sources.

Table 3: *Examples of astronomical sources emitting in each range of the electromagnetic spectrum.**

Type of radiation	Temperature	Typical sources
Gamma-rays	$>10^8$ K	Matter falling into black holes
X-rays	10^6-10^8 K	Supernova remnants Stellar coronae
Ultraviolet	10^4-10^6 K	Supernova remnants Very hot stars
Visible	10^3-10^4 K	Stars Hot planets
Infrared	10-10^3 K	Very cool stars Planets Cool clouds of dust
Radio	<10 K	Cool clouds of gas Electrons moving in magnetic fields

****Adapted from:*** *NASA/Imagine the Universe!*

1. Stars form from clouds of cold gas and dust that collapse due to their own gravity; therefore, very young stars are usually observed near such clouds. After what you have deduced from the colours of galaxies, do you expect spiral galaxies to be rich in gas and dust? And elliptical galaxies? Explain your answer.

2. Based on the information provided in Table 3, what type of light would you use to study the gas and dust within a galaxy?

3. Where do you expect to find most of this cold gas and dust within a spiral galaxy? Make a hypothesis:

4. You can check your hypothesis by comparing images of galaxies at different wavelengths. To ease the comparison between different skies, you can create a stack of maps as the one shown in Figure 6. To do so, click on the "+" sign and selecting the following maps in the drop-down menus:

   - Soft X-ray: XMM-Newton EPIC color
   - Optical: DSS2 color
   - Far-infrared: Herschel PACS RGB 70, 160 micron
   - Submillimetre: Herschel SPIRE RGB 250, 350, 500 micron

   You can move from one map to another manually or with the video-style buttons. Clicking on the "Play" button will switch from one map to the next automatically every few seconds.

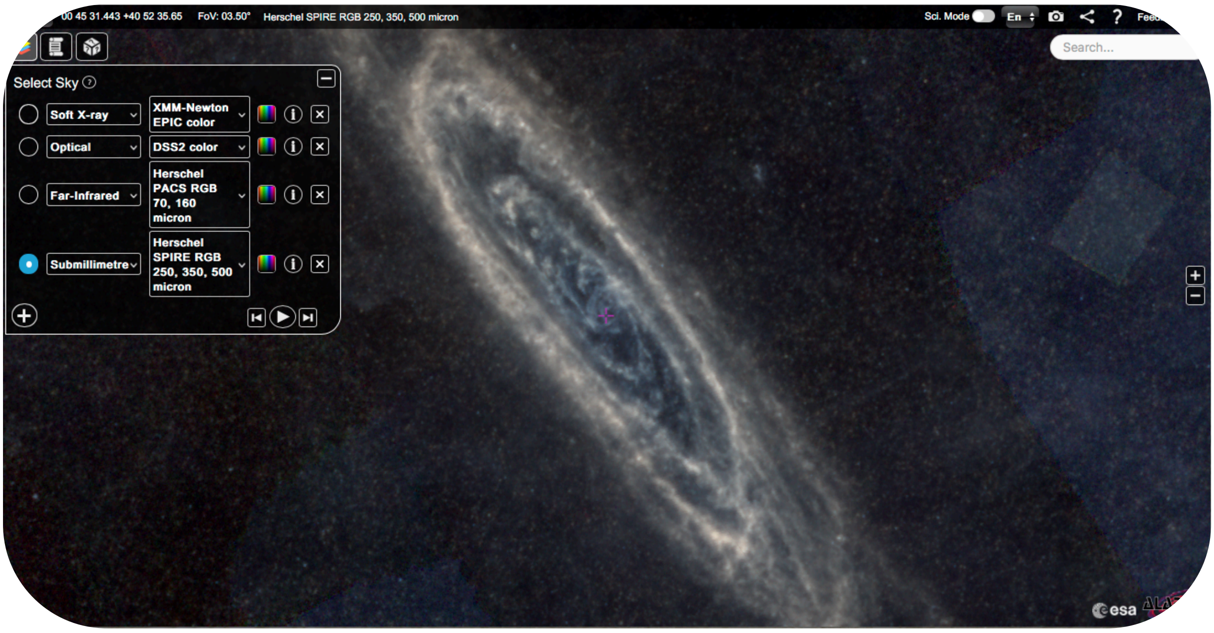


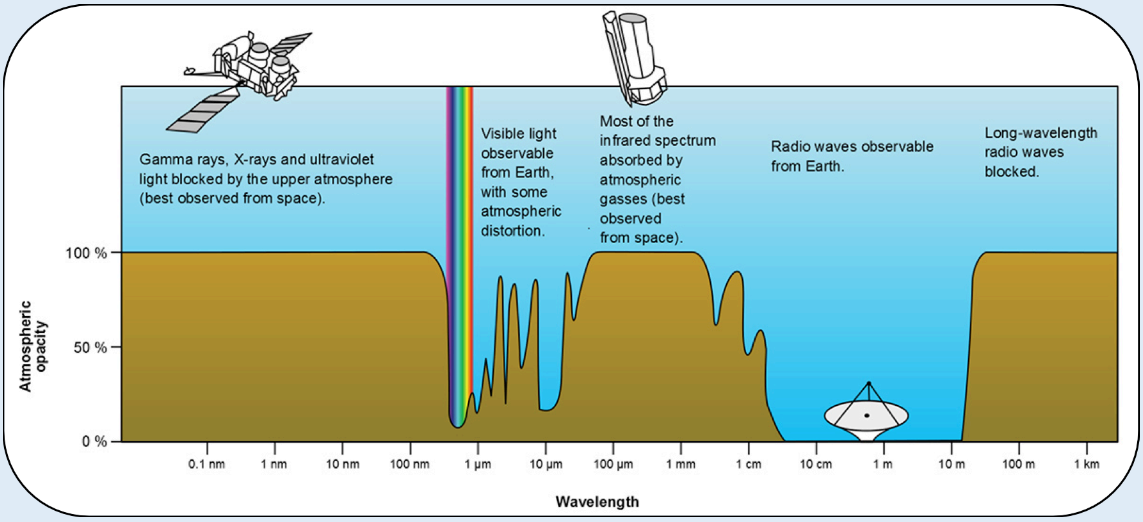
Figure 6: *ESASky with its Skies menu opened, showing a stack of maps. (Credit: ESA/ESDC)*

5. Once you have created your stack of maps, compare the images of galaxies M31 and M91 in the optical (visible) with those in the far-infrared and submillimetre (very short radio waves). What do these galaxies look like in the different types of light? What is the reason?

6. Compare the appearance of galaxy M31 in soft X-rays with the images in the optical and far-infrared. Why does it look so different?

Did you know?

The Earth's atmosphere is opaque to most types of light; only visible light and part of the infrared and radio light from astronomical sources reach the ground. This is good for humans, because gamma rays, X-rays and ultraviolet light are very harmful to us. But it is not so good for astronomers, because they miss a lot of information about the Universe.



Most invisible light is blocked by the atmosphere (Credit: NASA)

To be able to observe astronomical objects emitting light that is blocked by the atmosphere, scientists send telescopes to space. In these activities, you are working with observations performed with two space telescopes of the European Space Agency (ESA) covering different parts of the electromagnetic spectrum: XMM-Newton (X-rays) and Herschel (infrared), which complement the observations in visible light carried out from the ground.

7. Compare the appearance of galaxy M60 in soft X-rays, optical and far-infrared. What are the reasons for the differences you see?

8. NGC 4565 was classified as a spiral galaxy seen edge-on. What does this galaxy look like in far-infrared light? And in X-rays? How do these observations confirm that NGC 4565 is a spiral galaxy?

9. Which galaxies are forming stars, and which are not? Explain your answer.

Extension activity: Evolution of galaxies

Hubble thought that his tuning fork diagram displayed an evolutionary sequence for galaxies. According to his hypothesis, galaxies would initially have a spherical shape, and would flatten and develop their spiral arms with time, until they become very disrupted and irregular.

Taking into account what you have learned about the content of the different types of galaxies, do you think that this hypothesis is plausible? Explain your answer.

If you want to learn more, you can now do some research on how galaxies actually evolve.