CESAR Science Case

The Secrets of Galaxies

How many types of galaxies are there?

Teacher Guide

Table of Contents

Fast Facts

FAST FACTS

Age range: 14-18 years old

Type: Student activity

Complexity: Medium

Teacher preparation time: 30-45 minutes

Lesson time required: 1 hour 30 minutes

Location: Indoors

Includes use of: Computers, internet, ESASky web application

Curriculum relevance

General

- Working scientifically.
- Use of ICT.

Physics

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

Space/Astronomy

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

Outline

In these activities, students learn about the Hubble Tuning Fork and classify a list of galaxies according to their shapes. They then study other differences between the types of galaxies, such as their star, gas and dust content and their appearance when observed in different parts of the electromagnetic spectrum. As an extension, students apply their knowledge to assess whether the Hubble Tuning Fork could represent an evolutionary sequence for galaxies.

Students should already know…

1. How astronomers use different types of light to study different objects or phenomena in the Universe.
2. The concept of blackbody radiation.
3. The very basic ideas of stellar evolution.
4. The concept of a galaxy.

Students will learn…

1. How astronomers classify galaxies according to their shape and contents.
2. The basic properties of the different types of galaxies.
3. 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 evaluation 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. What is a galaxy?	Students discuss what a galaxy is and how they could investigate how many different types of galaxies exist.	Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills.	None.	10-15 min
2. Getting familiar with ESASky	Students play with the application to get familiar with it.	Students improve: • Their skills in the use of ICT.	None.	15 min
3. Classifying galaxies	Students classify galaxies according to the Hubble Tuning Fork.	Students learn: • How astronomers classify galaxies according to their shapes. • The basic properties of the different types of galaxies. Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills. • Their evaluation skills. • Their ability to apply theoretical knowledge to real-life situations. • Their skills in the use of ICT.	• Completion of Activity 1.	15 min

Title	Activity	Outcomes	Requirements	Time
4. The colours of galaxies	Students inspect the images of galaxies in the visible and study the relationship between the shape and the colours of galaxies.	Students learn: • How astronomers classify galaxies according to their shape and contents. • The basic properties of the different types of galaxies. • 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. • Basic knowledge of stellar evolution and how the colour of a (massive) star relates to its age.	20 min

Title	Activity	Outcomes	Requirements	Time
5. Galaxies in different light	Students compare images of different galaxies in the visible, infrared and X-rays, and hypothesise on the reasons for the differences they observe.	Students learn: • How astronomers classify galaxies according to their shape and contents. • The basic properties of the different types of galaxies. • 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 4. • Knowledge of the electromagnetic spectrum. • Knowledge of blackbody radiation. • Basic knowledge of stellar evolution.	30 min
6. Evolution of galaxies	Students discuss if the Hubble Tuning Fork diagram could represent the evolution of galaxies.	Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills. • Their evaluation skills. • Their ability to apply theoretical knowledge to real-life situations.	• Completion of Activity 4. • Basic knowledge of stellar evolution.	10 min

Introduction: A universe of galaxies

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 these activities students use the ESASky web application to explore real multi-wavelength observations of galaxies from space missions and ground-based telescopes.

Background

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.

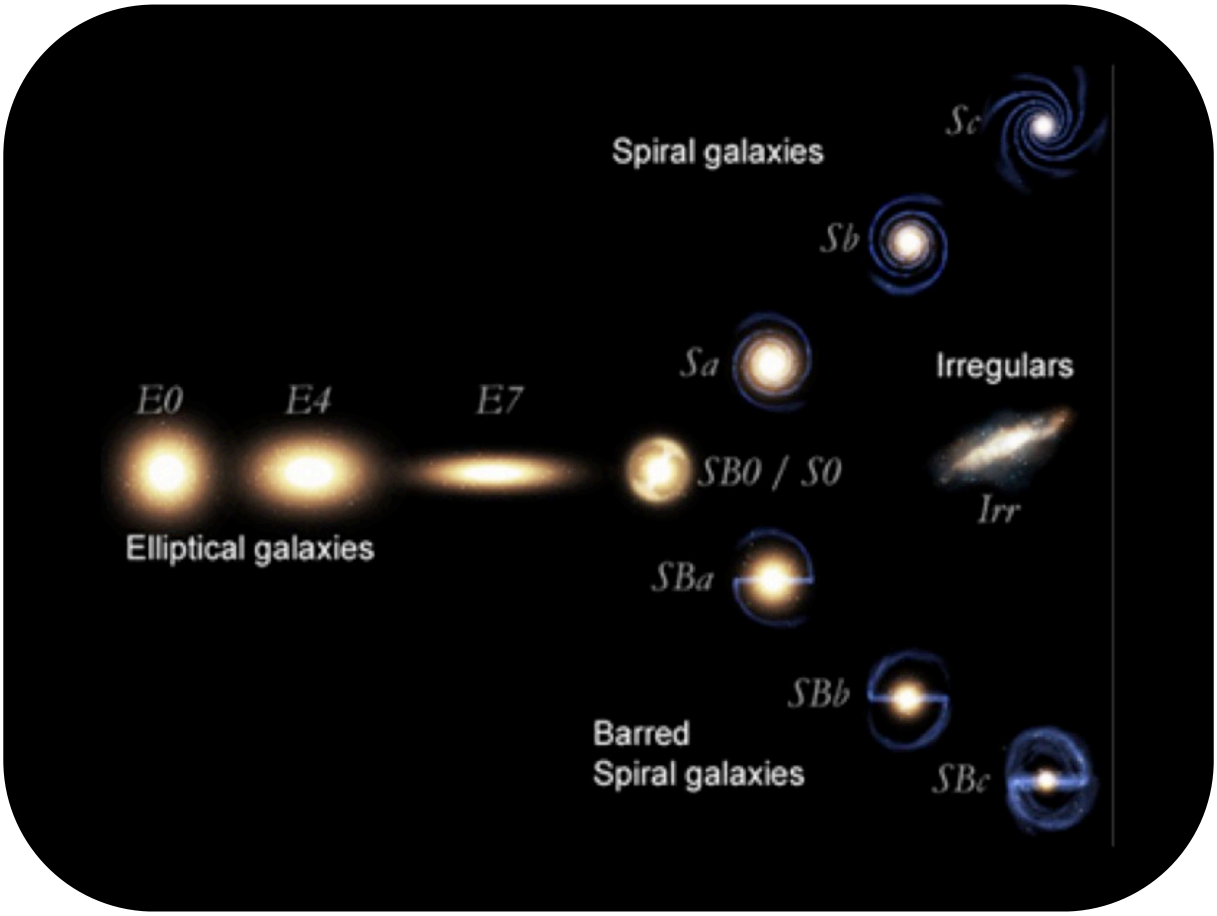

Figure 1: *The Hubble Tuning Fork. (Credit: NASA/ESA)*

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.*

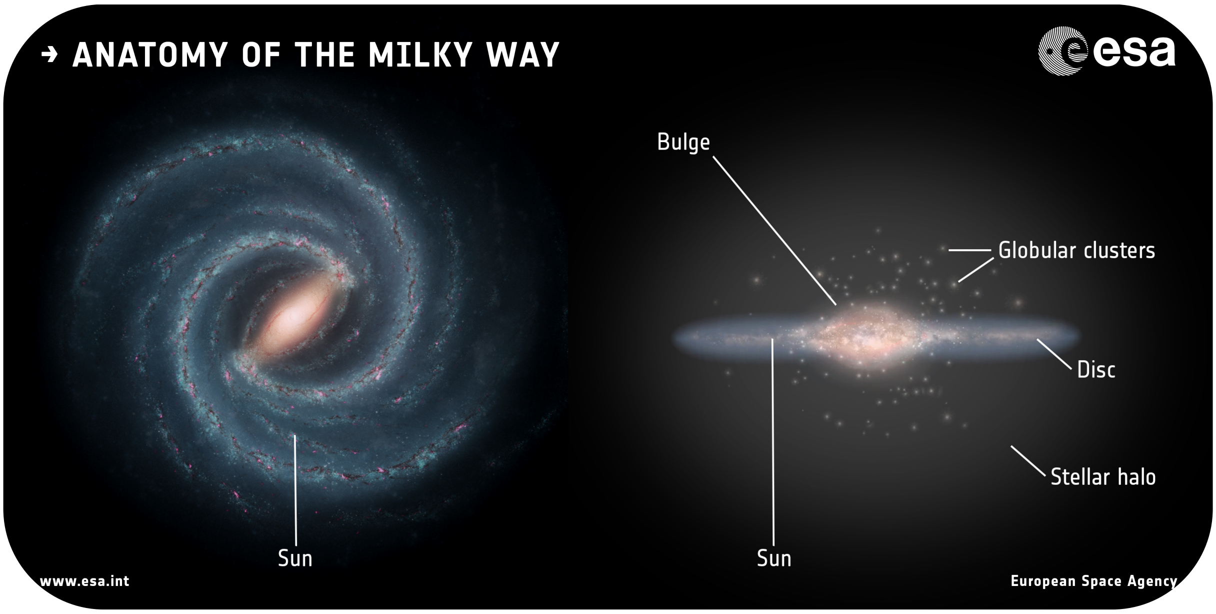

Figure 2: *Structure of a spiral galaxy, the Milky Way. (Credit: ESA)*

How astronomers study galaxies

Astronomers soon discovered that the shape of a galaxy is related to other 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.

Astronomers also know that all stars form from clouds of gas and dust, and that blue giant stars are young and massive, while red giants and supergiants are old stars that are 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 4. On the other hand, young, low-mass stars – the so-called *red and yellow dwarfs* – are quite dim, contributing very little to the overall light emission of a galaxy.

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 depending on their temperature and the phenomena that are going on in them. Table 1, provides you with 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 1 lists the temperature range of astronomical sources within a galaxy for each portion of the electromagnetic spectrum, as well as some examples of these sources.

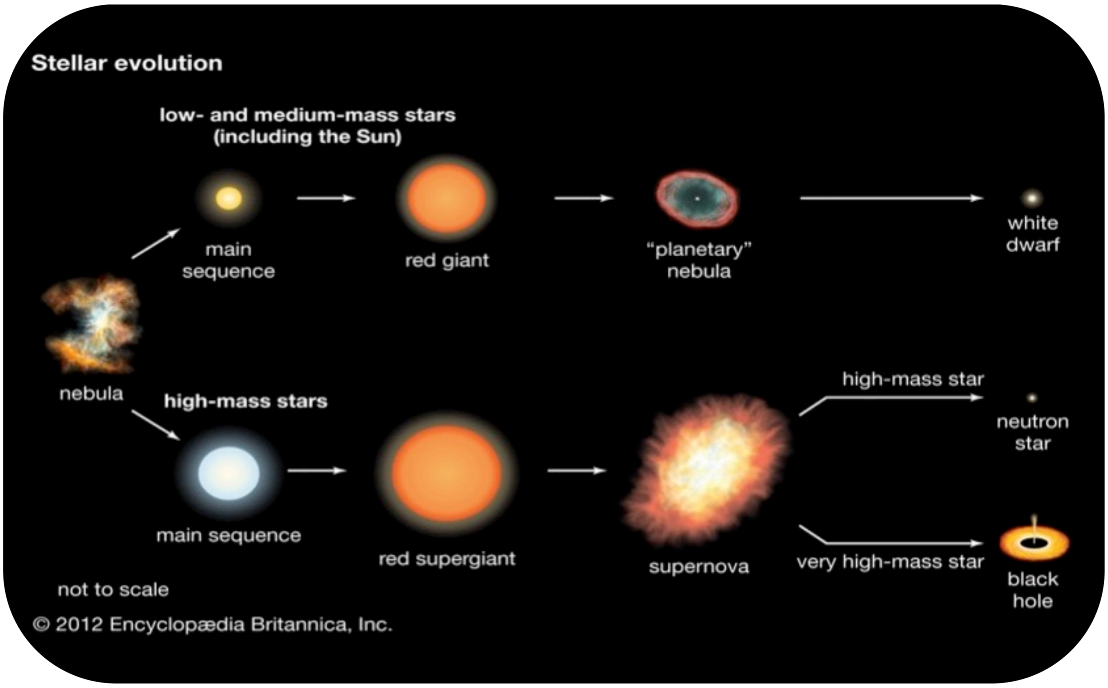

Figure 4: *A star's evolution in time depends on its mass. (Credit: Encyclopaedia Britannica)*

Table 1: *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!*

Activity 1: What is a galaxy?

This activity provides an introduction to the topic of galaxies by establishing students' current knowledge.

The Student Guide asks students to write down what they already know about galaxies and what they want to learn. To help students begin this task they could be asked the following questions

- *What is a galaxy?*
- *What galaxy are we in?*
- *How many galaxies do you think there are in the Universe?*
- *Are all these galaxies the same? How would you find out what types of galaxies exist?*
- *Do galaxies only contain stars? How would you investigate the contents of a galaxy?*

Alternatively, students could be given the questions to research at home, in preparation for the following activities.

Activity 2: Getting familiar with ESASky (Optional)

This activity will enable students using ESASky for the first time to become familiar with this online application. If they have used ESASky before, this Activity can 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 instructions and the list of astronomical objects to explore 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.

Activity 3: Classifying galaxies

In this activity, students use *ESASky*, to view different galaxies and classify them according to their shapes. Students will study each of the galaxies from a list in the optical *Digital Sky Survey 2* (DSS2) map[1], and provide a classification for it based on the Hubble Tuning Fork diagram (Figure 1).

Detailed instructions for this activity are given in the Student Guide.

Following the instructions in their Guide students first have to load a list of the galaxies they will need to study to *ESASky*, available in the application as a predefined target list with the name "CESAR Galaxies". The names of the galaxies in the list, along with a description of each, are given in Table 2. The galaxies themselves are shown in Figure 5.

As students view the galaxies in the list they should compare their appearance with the different types in the Hubble Tuning Fork diagram and assign each galaxy a type. The official classification is given in Table 3.

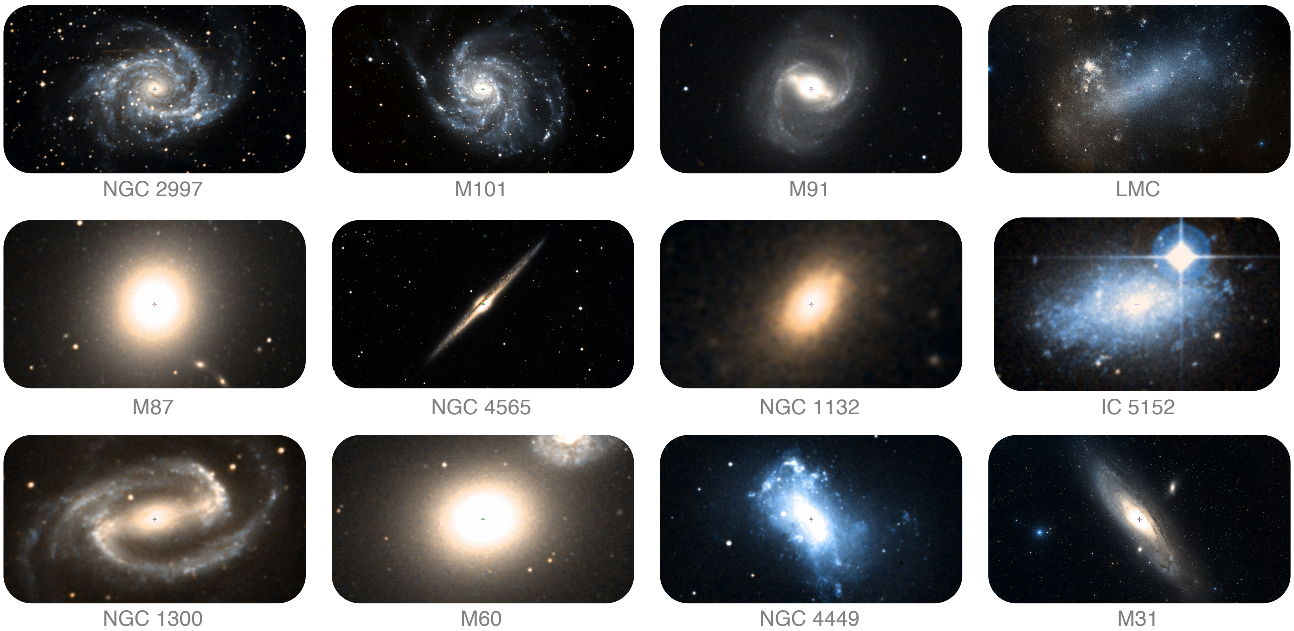

Figure 5: *The galaxy gallery, as observed in visible light by the Digital Sky Survey (DSS2). Credit: ESA/ESDC*

[1] For all information on the data that are visualised in the activity, we refer to the *ESASky* documentation pages and links therein: https://www.cosmos.esa.int/web/esdc/esasky-skies

Table 2: *List of galaxies with their descriptions.*

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 putative 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 (780 kiloparsecs) 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.

Table 3: Official classification of the selected galaxies

Type	Galaxies
Spirals	NGC 2997, M101, M31
Barred spirals	M91, NGC 1300, NGC 4565
Ellipticals	M87, NGC 1132, M60
Irregulars	LMC, NGC 4449, IC 5152

Answers to questions in the student guide

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

It is interesting to discuss these classifications with the students. For example:

- Is the Large Magellanic Cloud (LMC) really an irregular galaxy or, as some astronomers claim, a barred spiral?
- If M31 is a spiral, why does it look so elongated in comparison to the others? The reason is perspective: We are seeing this galaxy slightly inclined, while other spiral galaxies are seen from above.
- Do all groups agree on the classification of NGC 4565? It is a barred spiral galaxy, but the disk is seen edge-on, so the spiral arms cannot be seen, however we do see a dark band that indicates the presence of this disk (this band is caused by the dust in the spiral arms blocking visible light). Students can look at Figure 2, which shows an impression of the Milky Way as seen from above and edge-on. Astronomers can tell that there is a bar because the central bulge is elongated.

Students should reflect on the difficulty of determining the real shape of a galaxy when there is no way to observe them from different perspectives, and how classification is not always clear-cut and requires some consensus. To solve these types of discrepancies, astronomers make further observations to get more detailed views of the galaxy features, or to see what the galaxy looks like in wavelengths other than visible. This enables them to learn more about the contents and shape of the galaxy.

Make sure that students know the official classification of each galaxy, so that they can proceed to the next activities.

Activity 4: The colours of galaxies

During this activity students will use the official classification of the galaxies studied in Activity 3 to determine the general properties of the different types of galaxies. Students will base their investigation on the optical colours of the galaxies as seen in the images in ESASky and will need to apply some basic knowledge of the properties of stars.

Only the most massive and luminous stars contribute significantly to the luminosity of a galaxy. Therefore students can assume that blue stars = young stars and red stars = old stars, even though young, low-mass stars are red and not blue. Some students may argue that elliptical galaxies and bulges of spiral galaxies look yellowish or whitish, rather than reddish. If this point is brought up, explain that those regions contain stars of many different ages, but the lack of blue stars is telling us that those stars are, in any case, older than in the blue regions of the galaxy.

Answers to questions in Student Guide

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

   As a general rule, elliptical galaxies are yellowish, while spirals and irregulars look more blue. However, students may point out some exceptions: NGC 4565 does not look blue, but it must be noted that we only see the edge of the disk of this galaxy (as a dark ridge due to the dust blocking visible light), where most of the blue stars are seen in other spiral galaxies.

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.)

   This observation suggests that the stars that are contained in each region are different. The spiral arms look blue because they contain many young stars (and young, massive stars are blue), while the bulges look yellowish because they are rich in evolved stars (that look more red).

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

   The bulges of spiral galaxies are similar to elliptical galaxies in shape and colour. This suggests that their stellar content is similar (evolved stars).

Activity 5: Galaxies in different light

This activity introduces students to what galaxies look like when observed at wavelengths other than visible. They compare the similarities and difference between images of the same galaxy in different types of light, X-ray, infrared, and submillimetre (short radio waves). Then they consider how this supports their conclusions on the properties of galaxies made using the optical (visible light) images in Activity 4.

To complete this activity students must be familiar with the basic properties of the electromagnetic spectrum, and in particular, the different types of light that exist, the definition of wavelength/frequency and their relationship with energy and temperature (blackbody radiation).

Students must also have some basic knowledge of stellar evolution. In particular, they need to know that stars form from clouds of cold gas and dust, and be able to make the association between the location of such clouds within a galaxy and the location of young stars. They can check this by looking at observations made of the galaxy in infrared and radio, because at these wavelengths, the emission of a galaxy is dominated by the dust and gas within it, respectively. This is because of the cool temperatures of these components.

Students must also know that massive stars end their lives as supernovae, leaving behind neutron stars or black holes (depending on their mass); both types of objects are associated with X-ray sources observed at the centres of supernova remnant clouds. Thus, observing in X-rays, students should be able to make the connection between the location of X-ray sources and that of the old stars detected in visible light.

A summary of the properties of the electromagnetic spectrum, including a summary table with examples of sources emitting in each type of light is provided in Table 1 (also in the Student Guide). To guide the students' investigation, a number of questions are proposed in the Students' Guide.

About the images

When comparing images taken in different wavelengths, it may be necessary to point out to students that not all of them 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 seen in the infrared images.

It may also be necessary to remind students that the colours of the astronomical images in light other than visible do not resemble what our eyes would see - because our eyes do not see infrared light or X-rays. The colours used are just a convenient code to represent different frequencies (or energies) in that particular domain.

Answers to questions in Student Guide

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.

   Since we have just seen that spiral galaxies contain many young stars, while elliptical galaxies don't, we expect that spirals are also rich in clouds gas and dust, and that ellipticals contain very few such clouds.

2. Based on the information provided in Table 1, what type of light would you use to study the gas and dust within a galaxy?

   According to Table 1, dust is best observed in the infrared, and cold gas in radio.

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

   If gas and dust clouds are associated with young stars, we expect to find such clouds in the same location within a galaxy where we observe those stars – namely the spiral arms of the galaxy.

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

   M91 and M31 are both spiral galaxies. Their images in the optical and their counterparts in the infrared and submillimetre all reproduce the spiral pattern. This confirms that those regions of the galaxies are rich in dust and cold gas, as well as in young stars.

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?

   While the spiral arms are clearly visible in optical and infrared, in X-rays what we see is a roughly spherical clump of sources. The location of these sources corresponds to that of the bulge of the galaxy in the optical image. Since, according to Table 1 in the Student's Guide, the most prominent X-ray sources are supernova remnants, neutron stars and black holes, which are the end products of the lives of massive stars, this observation is a further hint that the bulge of this galaxy is rich in old stars.

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

   M60 is an elliptical galaxy. In the X-ray image and in the optical image, it has quite a similar appearance; this confirms that this galaxy is rich in old stars. However, if we observe M60 in the infrared, we see barely anything more than noise, while the neighbouring galaxy NGC 4647 is clearly visible. This means that M60 contains barely any dust, in agreement with the fact that it does not have many young stars.

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?

   The infrared image shows this galaxy as a very elongated shape, just like a needle. This confirms that we are seeing the edge of a flattened structure – the disk. In X-rays, we see a clump of sources in the central part, which looks spherical in the optical image – this corresponds to the bulge of the galaxy.

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

Elliptical galaxies contain mostly old stars and no cold gas and dust, while spiral galaxies contain many young stars and cold gas and dust in their spiral arms, but not in their bulges, which look very similar to elliptical galaxies. Since stars form from clouds of cold gas and dust, it immediately follows that spiral galaxies will be forming stars in their spiral arms, while very little star formation, if any, must be taking place in elliptical galaxies.

Extension activity: Evolution of galaxies

In this extension activity students examine whether the Hubble Tuning Fork can represent an evolutionary sequence for galaxies. Here, students must apply their acquired knowledge of the properties of galaxies to decide if it seems likely that elliptical galaxies evolve into spirals and, finally, irregular galaxies. This activity could be used as a transition to the topic of galaxy formation and evolution.

Answers to questions in Student Guide

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. Based on what you have been discussing, do you think that this hypothesis is plausible? Explain your answer.

If elliptical galaxies have only relatively old stars, and little gas and dust, while spirals contain both old and young stars, and are rich in gas and dust, it seems unlikely that ellipticals evolve into spirals. It looks more probable that it was the other way round: that spiral galaxies (and at least some irregulars) evolve into elliptical galaxies somehow.

As a matter of fact, the current picture of galaxy formation is much more complicated than that. Astronomers currently think that galaxies were initially small and irregular, and evolved through collisions, merging into larger structures. The giant ellipticals we see in the centre of many galaxy clusters would be the last step in this process, having originated from the merging of many smaller galaxies.

Links

Other related Science Cases

- *The Colours of Astronomy:* http://cesar.esa.int/index.php?Section=The_colours_of_the_astronomy
- *Exploring the Interstellar Medium:* http://cesar.esa.int/index.php?Section=Exploring_the_Interstellar_Medium

Galaxies

- CESAR Booklet: *Galaxies* http://cesar.esa.int/upload/201801/galaxies_booklet.pdf
- Galaxies and the expanding universe: http://sci.esa.int/education/36827-galaxies-and-the-expanding-universe/
- The *Galaxy Zoo* project: https://www.galaxyzoo.org
- Edwin Hubble: http://www.esa.int/About_Us/Welcome_to_ESA/ESA_history/Edwin_Hubble_The_man_who_discovered_the_Cosmos

Stars

- CESAR Booklet: *Stellar evolution*
- Stellar processes and evolution: http://sci.esa.int/education/36828-stellar-processes-and-evolution/

The electromagnetic spectrum and ESA missions

- CESAR Booklet: *The electromagnetic spectrum* http://cesar.esa.int/upload/201711/electromagnetic_spectrum_booklet_wboxes.pdf
- Science@ESA: *The full spectrum* (video) http://sci.esa.int/education/44685-science-esa-episode-1-the-full-spectrum/
- 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/

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://youtu.be/zkJkhSDr0nQ