The secrets of galaxies

Teacher's Guide – Advanced Level

CESAR's Science Case

Introduction

This Science Case provides an introduction to galaxies based on real multi-wavelength observations with space missions and ground-based telescopes. It discusses concepts such as the Hubble Tuning Fork and the morphological classification of galaxies, the stellar and ISM content of the different types of galaxies, and galaxy interaction and evolution. The activity is designed to encourage students to discover the properties of galaxies on their own.

During the activity, students make use of *ESASky*[1], a portal for exploration and retrieval of space astronomical data, to visualise different galaxies and classify them according to their shapes and optical colours. Students can load different sky maps to see how the galaxies look like when they are observed at different wavelength ranges, and discuss how the presence of the ISM is affecting these observations.

Learning outcomes

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

1. Explain how astronomers classify galaxies according to their shapes and contents.
2. Explain the properties of the different types of galaxies.
3. Explain the very basic ideas of galaxy interaction and evolution.
4. Extract information from an astronomical image.

[1] http://sky.esa.int

Material

This Science Case requires the following material:

- The student's guide
- CESAR Booklet
- Computer with web browser and internet connection[2]
- List of regions (.txt file)
- Paper and pen

The relevant chapters from the Booklet are **"The Electromagnetic Spectrum",** the **"Stellar Evolution"** and the **"Interstellar Medium".** Students need to be familiar with the concepts discussed in all three chapters to successfully complete the activity. The ideas developed in the activity are presented in the chapter **"Galaxies"**, but it is our recommendation that students are introduced to them through the activity itself, and that this chapter is read *a posteriori* to fix the concepts.

If the students are not familiar with *ESASky*, we recommend devoting some time to explore the tool using the guide *ESASky for beginners*.

The teacher will need a computer and a projector or digital board to demonstrate the use of the tool, and for the activity extension.

Background

This activity is conceived as a guided investigation encouraging students to discover the properties of galaxies by themselves, prior to their discussion in class.

For this purpose, it is important that **students are familiar with the properties of stars and of the interstellar medium**. In particular, they must understand that young, massive stars display blue colours, while evolved stars look yellowish or reddish. They must also understand the relation between the ISM and young stars. The rest of concepts are discussed with them as they proceed through the activity.

Alternatively, the activity may also be used as an illustration of galaxy properties, after they have been introduced to the students in a previous class session.

[2] Since currently there is no mobile version of the application available, the use of iPads and tablets is not recommended.

Activity Execution

Students’ tasks

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 galaxies to *ESASky*. This is done by clicking on the *Upload target list* button in the left menu. Select the .txt file in the file browser, and the list of objects will be displayed. To navigate through it, click on the objects names; in doing so, the displayed sky map will move to the selected object (the whole gallery is shown in Figure 1). 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.

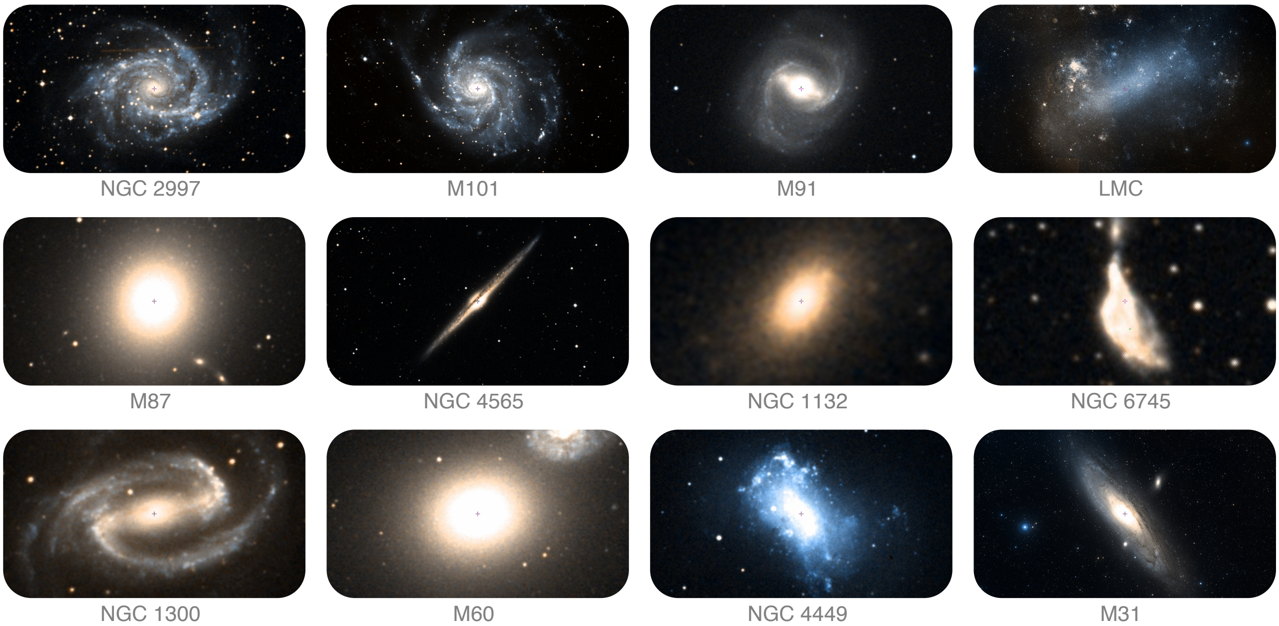

Figure 1: *The galaxy gallery, observed in visible light (DSS2). Credit: ESA/ESDC*

Students are asked to inspect each of the galaxies from the list in the optical DSS2 map,[3] and to provide a classification for it based on the Hubble Tuning Fork (they will need to play with the zoom levels to see all the details). Then, they must extract some conclusions on the general properties of the different types of galaxies, and discuss whether the Hubble Tuning Fork is likely to be a

[3] 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

representation of the way that galaxies evolve. To guide the investigation, a list of questions is provided in the attached worksheet, which can be collected for assessment. The key to this worksheet is provided below.

Extension

The last exercise in the worksheet discusses the properties of NGC 6745, and can serve as an introduction to the topic of interacting galaxies. After hypothesizing on what is causing the peculiar shape of this galaxy, students are given the HST press release image shown in Figure 2 for further discussion.[4] This image is also available in the attached .pptx file to be projected on the classroom screen or board.

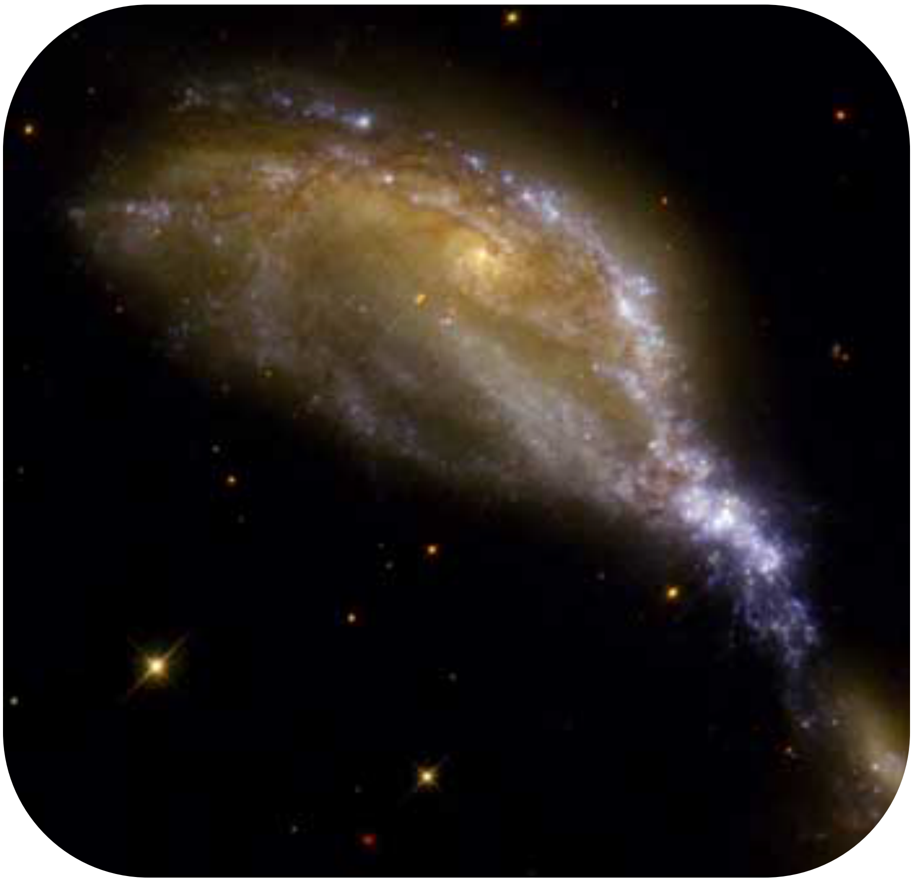

Figure 2: *A high-resolution image of galaxy NGC 6745 taken with the Hubble Space Telescope. Credit: NASA/ESA*

[4] http://heritage.stsci.edu/2000/34/supplemental.html

Student Worksheet (with key)

1. *Classify the galaxies in the list according to the Hubble scheme:*

Hubble type	Galaxies
Spirals	NGC 2997, M101, M31
Barred spirals	M91, NGC 1300, NGC 4565
Ellipticals	M87, NGC 1132, M60
Irregulars	LMC, NGC 4449, NGC 6745

It is interesting to discuss these classifications with the students. For example, is the LMC really an irregular galaxy or, as some astronomers claim, a barred spiral? If M31 is a spiral, why it looks so elongated in comparison to the others? The reason is perspective: We are seeing this galaxy slightly inclined, while the other two are seen pole-on.

And do students agree on the classification of NGC 4565? How do astronomers know that it is a spiral? In this case, the disk is seen edge-on, so we cannot see the spiral arms, but 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). And how can astronomers tell that there is a bar? The reason is that the elongation of the bulge suggests it.

This exercise should make students reflect about 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. It must be stressed that astronomers use many other sources of information, in addition to visible-light images, to make their classification, and that what we do here is a simplification of a very complicated task.

2. *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 bluish. However, students may point out some exceptions: NGC 4565 does not look bluish, but it must be noted that we only see the edge of the disk for 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. NGC 6745 was classified as an irregular galaxy, but does not look very blue in the DSS2 image.

3. 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. (Note 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 reddish).

4. 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).

Depending on the knowledge of stellar evolution of the students, we can ask them about a way to test that these regions are indeed rich in evolved stars. Massive stars end up their lives as Type II 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. We can then tell them to check what M60 –an elliptical galaxy– and M31 –a spiral galaxy– look like in X-rays by loading the 'XMM-EPIC color' map: While M60 has quite a similar appearance in the X-ray image, in the case of M31, we see a concentration of X-ray sources in the area corresponding to the central part of the galaxy in the optical image.

5. Do you expect spiral galaxies to be rich in gas and dust? And elliptical galaxies? Where do you expect most of this dust to be located? How would you check this using the tool?

Because spiral galaxies contain many young, massive stars, they must be rich in gas and dust, as this is the material needed to form these stars. Since the young stars are mainly seen in the spiral arms, we expect most of the gas and dust to be located there. We can check this by observing in infrared and radio, because at these wavelengths, the emission of a galaxy must be dominated by the dust and gas within it, respectively. Students can be invited to compare M91 and M31 in the optical DSS2 images with their counterparts in the 'Herschel PACS RGB' and/or 'Herschel SPIRE RGB' images to see how the infrared and sub-millimetre images reproduce the spiral pattern.

On the other hand, as elliptical galaxies only contain old stars, they must have very little gas and dust. This implies that they are not very bright in the infrared and sub-millimetre. An example students can check is M60: While the neighbouring spiral galaxy NGC 4647 is clearly visible in the PACS and SPIRE maps, M60 does not stand out above the background noise in those 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 appreciated in the X-ray or 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 –as our eyes do not see infrared light or X-rays–, but they are just a convenient code to represent different frequencies (or energies) in that particular domain.

6. 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 collision and 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.

7. Have a closer look at galaxy NGC 6745.

a. What may be the cause of its peculiar shape?

This galaxy looks elongated toward a second, smaller galaxy close to it. This shape suggests that there is a connexion between the two galaxies –maybe they are colliding, or have just collided and are now moving away from each other. This could have caused NGC 6745 to lose its original shape.

b. Inspect the high-resolution image of this galaxy. Comment on the colours of NGC 6745. What are the blue patches? Why aren't any other parts of that galaxy so blue?

In this image, most of NGC 6745 looks yellowish, while the area connecting this galaxy with the interacting galaxy at the bottom right looks bluish. Again, as this blue colour is caused by young, massive stars, this suggests that star formation is mainly taking place in that part of the galaxy.

c. Provide a hypothesis that explains what is happening in this galaxy, taking into account its shape and colours.

NGC 6745 is likely to have had a collision with the smaller galaxy, and its shape suggests the path followed by this second galaxy during the encounter. It seems that the interaction has disrupted the former spiral arms of NGC 6745, and that gas, dust and stars have been pulled after the second galaxy. Because the blue patches in NGC 6745 must be regions of ongoing star formation, their location suggests that the interaction with the second galaxy is what is triggering star formation in that area: probably the gas was compressed by the passing of the second galaxy, beginning the collapse.

Assessment

There are different ways the activity may be assessed: Directly through the students' worksheets, by direct observation of the discussion in class, or by asking students to write down a brief report summarising their conclusions on the properties of galaxies. They can use the *ESASky* snapshot functionality to take images of the galaxies to attach to their reports.

A further possibility, once all relevant concepts have been extensively discussed in class, is to use the provided quiz.

Quiz (with key)

1. The Hubble Tuning Fork Diagram of galaxies is useful for:

- ☐ **X** Summarising galaxy classification by shape
- ☐ Illustrating possible paths of galaxy evolution.
- ☐ Organising galaxies by size and age.
- ☐ Describing galaxies by size and chemical composition.

2. What type of galaxy has a disk and a central bulge?

- ☐ Elliptical.
- ☐ **X** Spiral.
- ☐ Irregular.
- ☐ All types of galaxies.

3. Which of the following statements about elliptical galaxies is false?

- ☐ They contain mostly old stars.
- ☐ They have no distinct nucleus.
- ☐ They can be giant or dwarf.
- ☐ **X** They are rich in clouds of gas.

4. The bulge of an ordinary spiral galaxy is similar in characteristics to:

- ☐ **X** An elliptical galaxy.
- ☐ An irregular galaxy.
- ☐ Both elliptical and irregular galaxies.
- ☐ Nothing.

5. Where do you expect to find a lot of gas and dust within a galaxy?

- ☐ Anywhere.
- ☐ Where the old stars are, because they explode as supernovae and create clouds.
- ☐ **X** Where the young stars are, because they form from clouds of gas and dust.
- ☐ Where there are no stars at all.

6. What type of galaxy is the Milky Way?

- ☐ Elliptical.
- ☐ Spiral.
- ☐ Irregular.
- ☐ **X** Barred spiral.

7. The biggest and intrinsically brightest galaxies in the Universe are member of which group?

- ☐ Spirals.
- ☐ Irregulars.
- ☐ **X** Ellipticals.
- ☐ Barred spirals.

8. Current galaxies formed:

- ☐ **X** By merging of smaller fragments.
- ☐ By splitting of larger galaxies.
- ☐ By collapse of gas clouds.
- ☐ In the Big Bang.

9. Very detailed observations of distant galaxies show that:

- ☐ There were once many more ellipticals in clusters than we now see.
- ☐ **X** There were once many more spirals in clusters than we now see.
- ☐ There were once many more giant galaxies than we now see.
- ☐ Galaxies in clusters have always been as we see them now.

10. What happens to stars when two galaxies collide?

- ☐ They often collide.
- ☐ They do not collide, because stars do not gravitationally interact with each other.
- ☐ **X** They do not usually collide, because the typical distance between stars is very large compared to their sizes.
- ☐ The black hole in the centre of one galaxy swallows up all the stars from the other.