Teacher's guide

CESAR Science Case – The secrets of galaxies

- **Material that is necessary during the laboratory**

  - CESAR Booklet
  - CESAR List of Galaxies (.txt file)
  - CESAR Student's guide
  - Computer with an Internet browser
  - Paper, pencil or pen

Introduction

This Science Case provides an introduction to galaxies based on real multi-wavelength observations with space missions. It discusses concepts such as the Hubble Tuning Fork and the morphological classification of galaxies, 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 laboratory, 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.

Before starting this activity, students must be familiar with the properties of stars and of the interstellar medium, as well as have some basic concepts of stellar evolution. In particular, they must understand that young, massive stars display blue colors, while evolved stars look yellowish or reddish. They must also understand the relation between the ISM and young stars.

Learning Outcomes

By the end of this laboratory, 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

Laboratory Execution

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. They can use the attached *Beginners' Guide* to that purpose.

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 top left menu. The list of objects will be displayed (the whole gallery is shown in Figure 1). 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.

Students are asked to inspect each of the galaxies from the list in the optical DSS2 map, and to provide a classification for it based on the Hubble Tuning Fork. 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 representation of the way galaxies evolve. Their answers are written in a worksheet that can be collected for assessment.

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 infrared images.

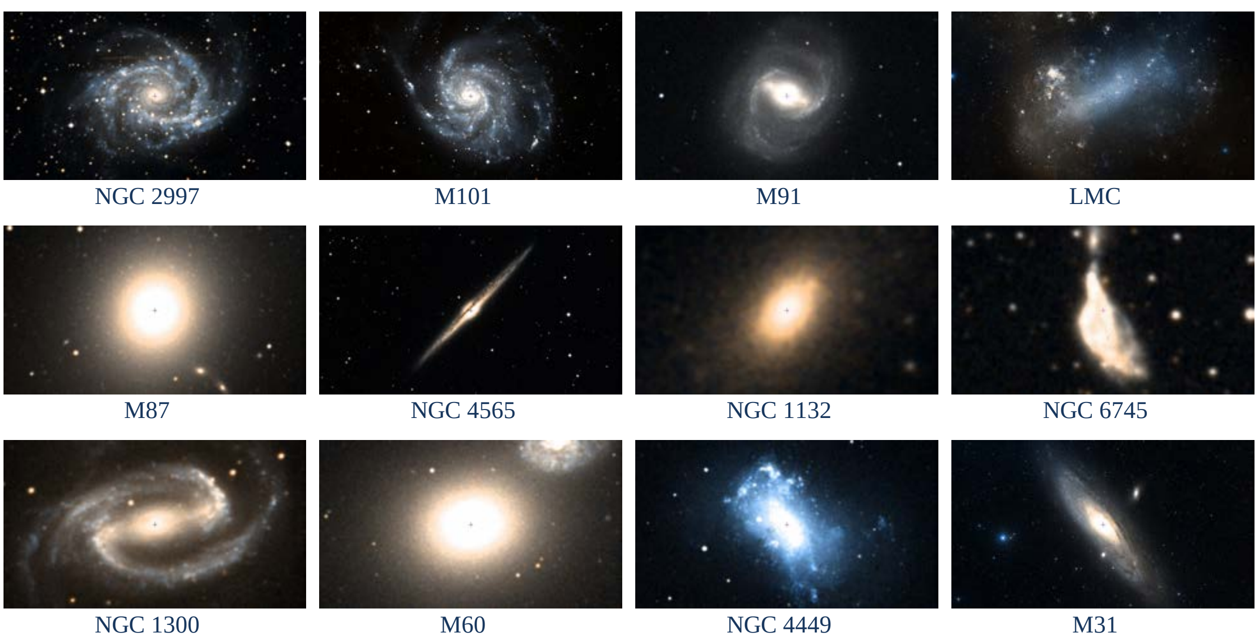

Figure 1: *The galaxy gallery, observed in visible light (DSS2).* ***Credit:*** *ESA/ESDC*

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 1 for further discussion.[2]

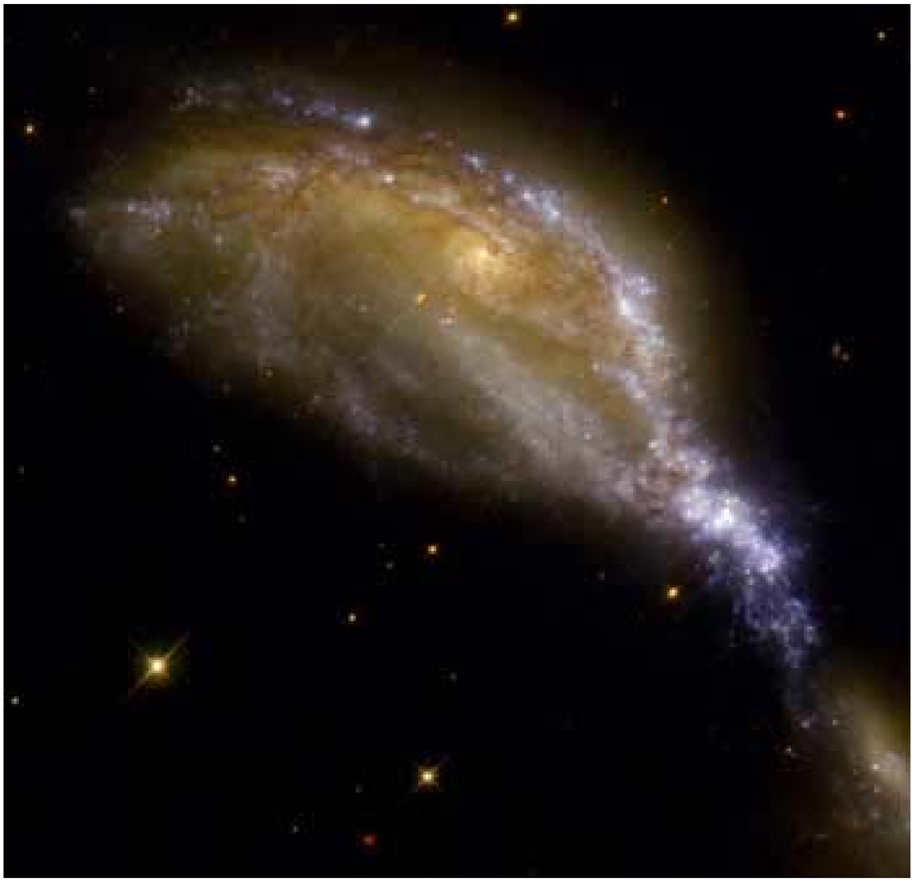

Figure 2: *A high-resolution image of galaxy NGC 6745 taken with the Hubble Space Telescope.*
Credit: *NASA/ESA*

Assessment

Assessment of the learning outcomes can be performed by classroom observations during the group work and in the final class discussion, through the completed worksheets and/or with the attached quiz.

[2] 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 students. For example, do they all agree on the classification of NGC 4565? How do astronomers know that it is a spiral? (The disk is seen edge-on, with the dust within it blocking the light.) And that there is a bar? (The elongation of the bulge suggests it.) Is the LMC really an irregular galaxy or, as some astronomers claim, a barred spiral?

This exercise will 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.

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 colors of the bulge and the colors 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 color. This suggests that their stellar content is similar (evolved stars).

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?

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 the optical DSS2 images with the Herschel PACS and/or SPIRE images to see how the infrared and submillimetre 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 submillimetre.

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, 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 of 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.