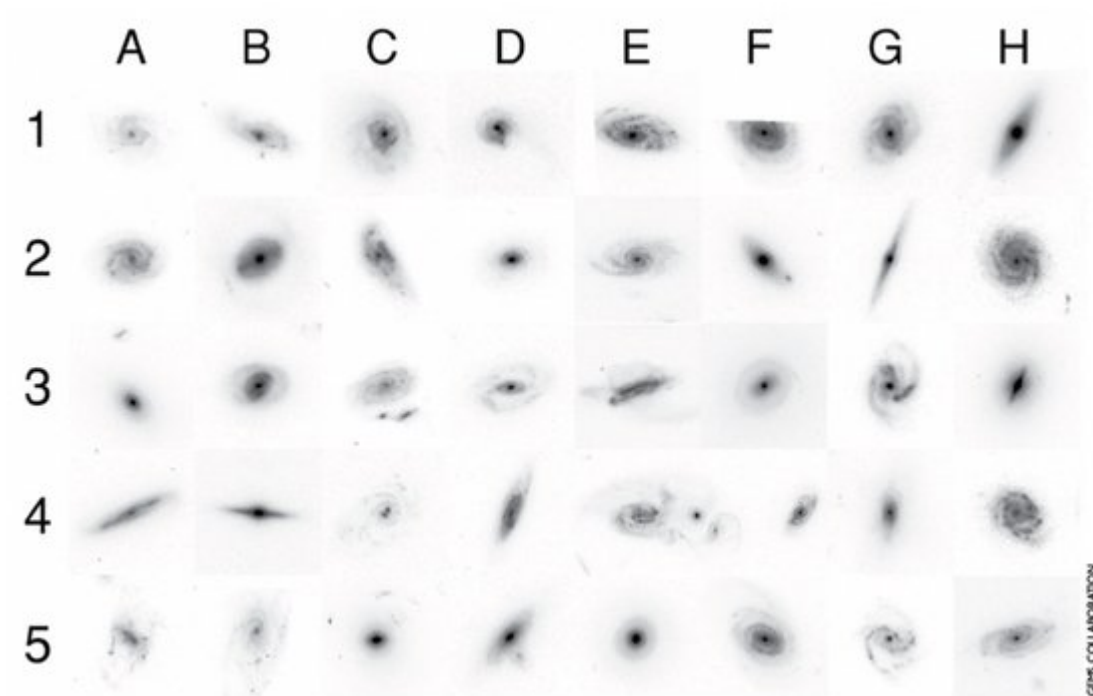




Coma Cluster of Galaxies

Learn the basics of galaxy classification and grouping, using actual Hubble Space Telescope images.

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KEYWORDS

Galaxy, Coma Cluster



CATEGORY

Astrometry and celestial mechanics, Galaxies



LOCATION

Small Indoor Setting (e.g. classroom)



AGE

16+



LEVEL

University



TIME

1h



GROUP

Group



SUPERVISED

No



COST

Low Cost



SKILLS

Planning and carrying out investigations, Analysing and interpreting data, Constructing explanations, Communicating information



TYPE OF LEARNING

Guided-discovery learning



GOALS

- Students will learn the basics of galaxy classification by making use of real astronomical data from the Hubble Space Telescope. Classification is a scientific practice important in many different fields of science; by simplifying a diversity of objects into a smaller number of categories, it becomes easier to see what characteristics are shared by many objects, and study these properties of representative objects, rather than each object individually.
- Students will discover a "morphology-density effect" and then make hypotheses about the causes of this effect.



LEARNING OBJECTIVES

- Students will be able to classify different galaxy types based on astronomical images.
- Students will explain the importance of classifying objects.
- Students will propose ideas for why galaxies might have different shapes.
- Students will practice asking questions and planning investigations.

- Students will discuss the ideas that there are physically different environments throughout the universe that galaxies live in, that galaxies interact, and that there is a relationship between environment and galaxy morphology (called the "morphology-density effect").
 - Students will make hypotheses about the cause of the morphology-density effect.
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BACKGROUND

Galaxy Classification:

Astronomers classify galaxies based on their appearance into three main classes: elliptical, spiral, and irregular galaxies. Edwin Hubble first came up with this classification scheme. Hubble originally thought that the 'tuning fork' sequence represented the evolutionary progression of galaxies. This concept turned out to be wrong, but astronomers still use these general categories and labels to describe galaxies.

The Main Galaxy Types:

Elliptical (E), Lenticular (S0), Barred Lenticular (SB0), Spiral (S), Barred Spiral (SB) and Irregular (IR). In detailed on the activity description section.

An additional type of galaxy category:

Interacting: Consists of two or more galaxies that are so close together that they are affecting each other's shape.

Data provided in this activity:

The data used in this activity is Hubble Space Telescope data of the Coma Cluster of galaxies. It was taken in 2006 using the Advanced Camera for Surveys (ACS) instrument on the Hubble Space Telescope.

Galaxy Environments:

Galaxies are found throughout the universe, and live in a variety of environments. Galaxies can be found in clusters, groups, or in isolation.

Groups:

Sometimes galaxies are found in smaller numbers called groups, with just a handful of galaxies being members of the group. The Local Group contains our Milky Way galaxy, and our next door neighbours the Magellanic Clouds and the Andromeda galaxy, along with a few dozen smaller galaxies.

Field:

At other times, galaxies can be isolated and be far from another in the field. These are called field galaxies.

Clusters:

A galaxy cluster is a large structure in the universe consisting of hundreds or thousands of galaxies that are gravitationally bound together. The large number of

galaxies in a cluster are all packed close together, such as in the Coma Cluster. Clusters make some of the largest, and densest structures in the universe. Clusters, groups, and some isolated galaxies can all be part of even larger structures called superclusters; at the largest scales in the visible universe, superclusters are gathered into filaments and walls surrounding vast voids. This structure is often referred to as the 'cosmic web'.



FULL DESCRIPTION

Students will first investigate images of 40 galaxies to become familiar with how galaxies appear and are shaped differently. They will come up with their own classification scheme for galaxies, and then explore how astronomers actually classify galaxies into four main groups.

Step 1

Tell students: Above diagram shows a mosaic of 40 galaxies. These images were taken with the Hubble Space Telescope and show the variety of shapes that galaxies can have. When astronomer Edwin Hubble first started studying these various types of galaxies in the 1920s, he developed a way to organize and categorize them. He created a classification scheme in which he grouped similar galaxies together.

Your job is to do the same thing. In the following chart, invent your own galaxy types and provide a description of these galaxy types and three examples for each one. Fill in the following table.

Galaxy Type (name)	Galaxy Type (drawing)	Defining Characteristics (write a short description, provide enough detail so that anyone could use your scheme)	Three Examples (give 3 grid coordinates)
1			
2			
3			
4			

Step 2

Discussion:

Ask students to share their classification schemes with each other. Suggested points of discussion:

- What are significant similarities between schemes?
- Significant differences?
- Arguments about how to classify particular galaxies?
- Why did students decide to design their schemes the way they did?
- What are other completely different types of schemes you could devise, e.g., if you had different data on the same galaxies?
- Why is it important (or not) to classify objects we discover?
- Might classification schemes be changed over time?

These discussion points can be re-visited later in the activity as well.

(Presumably at least some students will come up with classification schemes based on shape---but if they do not, after discussing their schemes, encourage them to come up with other schemes that are based on shape.)

Prompt students to make observations and ask questions based on their analysis of the image so far, discuss them in groups, and write them down. The goal is for them to ask, "Why do different galaxies have different shapes?" Then, prompt students to discuss and write down questions and ideas about why galaxies might have different shapes---for example

- Did the galaxies form in different shapes, or did they all form in the same shapes and then evolve into different shapes?
- What different histories could different galaxies have (especially, that could affect their shapes)? (encourage students towards the idea of galaxies interacting with each other)
- Could the evolution of galaxy shape be due to internal processes or driven by external processes? (e.g., something that happens to all galaxies over time no matter what, or something driven by an interaction with another galaxy)
- Could the shapes be related to the size of the galaxy when it forms?
- Are the shapes we observe transient or long-lasting?

While students are thinking of these kinds of ideas, encourage students to discuss how they could investigate the answers to these questions. (Perhaps some students will think of the idea that interactions with other galaxies could be important, and that looking at regions where there are many galaxies so many interactions take place might be a way of investigating this. Whether they come up with this idea or not, this previous discussion will help them to be in a better position to think through this idea later in the activity.)

Step 3

Tell students: Astronomers have developed their own classification scheme for galaxies, based on the galaxy shape (often called "morphology"). The definitions of the main galaxy types which astronomers use are listed below. Using these definitions, place the 12 galaxies shown in the above figure into their commonly-used categories. Fill in the table below.

- **Elliptical (E)** : galaxy with a spherical or elliptical shape (like an American football); it has no flat disc or spiral arms.
- **Lenticular (SO)** : galaxy with a smooth, flat disk shape without spiral structure; often hard to distinguish from ellipticals.
- **Barred Lenticular (SB0)** : same as above, but with an elongated (barred) nucleus (galaxy centre).
- **Spiral (S)** : galaxy with a flat disk shape, with notable spiral patterns in the outer disk; also contains a large bright central bulge.
- **Barred Spiral (SB)** : A special type of spiral characterised by an elongated nucleus with the spiral arms springing from the ends of the bar.
- **Irregular (IR)** : an oddly shaped galaxy that doesn't fit into any other category.

Morphology Image Numbers (3 each)

E/SO/SB0

S

SB

IR

Note: The smallest galaxies are often called dwarf galaxies (No. 5 and No. 7 are dwarf galaxies). These contain only a few billion stars — a small number compared to the Milky Way's 200 billion. The largest ellipticals contain several trillion stars.

Discuss: How does the classification scheme used by astronomers compare with the classification schemes designed by members of the class?

Step 4

Tell students: Use the image below and guidelines to help decide how to identify and count the galaxies.

Guidelines:

- **I) Ellipticals or Lenticulars:** it can be hard to tell these apart. If you know it's either an E or SO / SB0, it is okay to guess between these two.
- **II) Spirals and Barred Spirals:** it can be hard to tell these apart. If you know it's either an S or SB, it is okay to guess between these two.
- **III) Irregular galaxy.**
- **IV) Uncertain:** an edge-on view of a galaxy that could possibly be an SO, SBO, S, SB, or IR. There are too many possibilities, so do not count these.
- **Star)** any object that has 'crosshairs' sticking out of it is a foreground star in the Milky Way galaxy, so do not count these.
- **?)** Don't count small, faint objects like these that are too hard to classify.

Step 5

Download the images "Galaxies Cards" A-D to count the types of galaxies seen in each image. Count the number of galaxies of each morphological type and write down the number in the correct spot in the table.

Galaxy Card E SO /SB0 S SB IR/INT

A
B
C
D

Step 6

Tell students: Galaxies are found throughout the universe, from our next door neighbours — the Magellanic Clouds and Andromeda — all the way out to the visible universe 13 billion light years away. Galaxies live in a variety of environments. Sometimes large numbers of them are packed close together in clusters, such as the Coma Cluster; sometimes they gather in smaller numbers called groups, like the Local Group that contains the Milky Way; and sometimes they are isolated far from one another in the field. The table below shows the different properties for the different types of galaxy environments.

Galaxy Cluster	Large and dense	50 to thousands	3 2 to 10 Mpc	10^{14} to 10^{15} solar masses
Galaxy Group	Small and dense	less than 50	6 1 to 2 Mpc	10^{13} solar masses
The Field	Large and deserted	very few	0 Voids, can be larger than 100 Mpc	$< 10^{10}$

In the previous step, Galaxy Cards images A and C show the dense central core of the Coma Cluster, and images B and D show galaxies out in the field. (NB Astronomers sometimes use the term "field" to mean the area outside galaxy clusters.) Fill in the table below using the numbers you wrote down in the table from step 5 of the activity.

Coma Cluster

Morphology→	E Ellipticals	SO & SBO Lenticulars	S & SB (sum both together) Regular and Barred Spirals	Total (E+SO+SBO+S+SB)
Image A				
Image C				
Sum Total From A + C	(e)	(f)	(g)	(h)

The Field

Morphology→	E Ellipticals	SO & SBO Lenticulars	S & SB (sum both together) Regular and Barred Spirals	Total (E+SO+SBO+S+SB)
Image B				
Image D				
Sum Total From B + D	(i)	(j)	(k)	(m)

Step 7

Ask students to think about and discuss in groups: What trends do you notice from the data you've analysed above? Do you notice anything about where different types of galaxies tend to be found? (Extra prompt: Do you tend to see more spirals in the dense cluster or in the field? What about ellipticals?) _ Students should notice that spiral galaxies are more common in the field, and ellipticals are more common in dense clusters._ Follow-up question: Does that seem surprising? The goal here is to get students to ask "Why does the number of spiral galaxies (or elliptical galaxies) depend on where the galaxy is located?"

Ask students to discuss and write down ideas for why galaxy type seems to be affected by where the galaxy is located. Ask students how they could investigate their ideas: What predictions would their ideas make? What additional observations or information would they want to have? How could they quantify this trend using the data?

Step 8

The following steps tell how students can investigate this trend, first by quantifying it, and then by reading more information about how galaxies form and evolve. You can tell them exactly what to do as below.---Better yet, have them discuss in groups how they could investigate their question, starting with how to quantify the trend and then determine the procedure *themselves* for making the calculations below.

Using a calculator, find the percentages of each galaxy type in the cluster versus the field (Ignore IRs and INTs). Use your numbers from the table above to calculate the percentages and fill in each of these blanks below:

In the Cluster: % of Ellipticals (e / h) = __ __ %

% of Lenticulars (f / h) = __ __ %

% of Spirals (g / h) = __ __ %

In the Field: % of Ellipticals (i / m) = __ __ %

% of Lenticulars (j / m) = __ __ %

% of Spirals (k / m) = __ __ %

Question: Where did you find a higher percentage of spirals - in the Cluster or in the Field? Answer: _ _ _ _ _

Tell students: The percentages that you just found tell us which types of galaxies are common in the Coma Cluster versus which types are common in the field. Astronomers have done this same experiment on hundreds of thousands of galaxies in the nearby universe, and discovered that the following percentages are pretty typical:

- In dense clusters, 40% of the galaxies are ellipticals, 50% are lenticulars, and 10% are spirals.
- In the field, 10% of the galaxies are ellipticals, 10% are lenticulars, and 80% are spirals.

When galaxies are found very close together there are more ellipticals and lenticulars. When galaxies are far apart there are more spirals. Astronomers call this the "morphology-density effect." This term basically means that in crowded galaxy neighbourhoods, like clusters, there are different types of galaxies than are found in open areas, like the field.

Step 9

Students should by now (from Step 7) have asked the question, "Why do we see more elliptical and lenticular galaxies in clusters and more spirals in the field?" (This question can also be phrased, "Why do we observe the morphology-density effect?") They should also have had the idea that interactions could be involved, and maybe even the idea that more interactions take place in denser environments, like the center of a cluster.

Below is information that can be used to answer this question. You can give students this text to read, then ask them to discuss and write down an explanation for this effect; or you can continue to prompt students to brainstorm and discuss ideas for possible explanations, then potentially have them do research in textbooks / on the internet on their own or in groups, and then have them share their explanations with each other.

Explanation:

Many galaxies contain what astronomers call "gas," which generally means hydrogen gas, sometimes mixed with the gases of other elements, and sometimes mixed also with dust. Gas clouds can collapse by gravity, which leads to the formation of stars. Astronomers have observed many spiral galaxies (S and SB) and find that most of these galaxies contain a lot of gas, and are currently forming lots of new stars. Elliptical and lenticular galaxies (E, SO, and SBO) are gas-poor and are not making many new stars.

Galaxies that are very close to each other, such as those in clusters, often undergo many violent interactions with each other. When a gas-rich spiral galaxy interacts with another galaxy, it tends to quickly use up most of its gas to make new stars, leaving little gas behind. Galaxy-galaxy interactions often change gas-rich galaxies into gas-poor galaxies. Many lenticular galaxies are the remains of old spirals that have lost their gas, and many elliptical galaxies are the remains of several spiral galaxies that have collided.

Galaxy clusters are usually filled with a lot of extremely hot gas that is spread between galaxies throughout the cluster. However, there is no hot gas like this out in the field. When the radiation from this hot gas hits a spiral galaxy, it strips the spiral galaxy of its much cooler gas in a process called "ram-pressure stripping." This process quickly converts a gas-rich spiral galaxy into a gas-poor lenticular galaxy. Spiral galaxies have a hard time surviving in the superheated gas environment.

As you see, galaxies change and evolve over time, and galaxies we observe in the nearby universe today have had a very long history already.



EVALUATION

The teacher could discuss the answers with students, encouraging them to share their calculated values of the different types of galaxies found in both the field and the cluster as well as their answer to the final question about the morphology-density effect.

Student understanding can be assessed by discussion as detailed throughout the activity and by collecting scripts to mark. As these activities assess student understanding, additional evaluation tasks are unnecessary. Suggested grading is detailed below.

Suggested Grading

- Table 1: 5 points - students provide clear explanations of the classification scheme they create
- Table 2: 2 points each - Answers (E/SO/SB0 - 2, 6, 9), (S - 1, 8, 12), (SB - 3, 4, 10), (IR - 5, 7, 11)
- Tables 3, 4 and 5 (counting galaxies): not graded - based on student's subjective interpretation.
- Table 6 and Calculations: 30 points - Graded for completion, not accuracy. Students will get different numbers, but math should be correct. Answers for percentages are typically in the following range: (Cluster: E 50%, L 30%, S 20%) (Field: E 20%, L 10%, S 70%). Students usually find a higher percentage of spirals in the field.

Hypothesis Question: 30 points - Student's hypothesis should mention the effects of interactions and ram-pressure stripping in changing past gas-rich spirals into current gas-poor ellipticals and lenticulars in clusters.



CURRICULUM

Country | Standard | Lesson --- | --- | --- | --- USA | Next Generation Science Standards | Content Standard in 9-12 Science as Inquiry (Abilities necessary to do scientific inquiry, Understanding about scientific inquiry) USA | Next Generation Science Standards | Content Standard in 9-12 Earth and Space Science (Origin and evolution of the universe)

Country | Level | Subject | Exam Board | Section --- | --- | --- | --- UK | GCSE | Physics | AQA Science A | Not in current curriculum
UK | GCSE | Physics | Edexcel | P1.3: 2, 7 UK | GCSE | Physics | OCR A | P7.3.12 UK | GCSE | Physics | OCR B | P2f UK | GCSE | Physics | WJEC | Not in current curriculum UK | GCSE | Astrophysics | Edexcel | Unit 1.4: 2a, 2d UK | A level | Physics | AQA | Not in current curriculum UK | A level | Physics | Edexcel | Not in current curriculum UK | A level | Physics | OCR A | 5.5.1a UK | A level | Physics | OCR B | Not in current curriculum UK | A level | Physics | WJEC | Not in current curriculum UK | KS3 | Physics | - | Space Physics: Other Galaxies



ADDITIONAL INFORMATION



CONCLUSION

Students identify the galaxies by making calculations, working through the worksheets and drawing a hypothesis about the morphology-density effect.

CITATION

Finkelstein, K., , *Coma Cluster of Galaxies*, [astroEDU, 1410](#) [doi:10.11588/astroedu.2014.2.81340](#)

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