THE HUBBLE SEQUENCE

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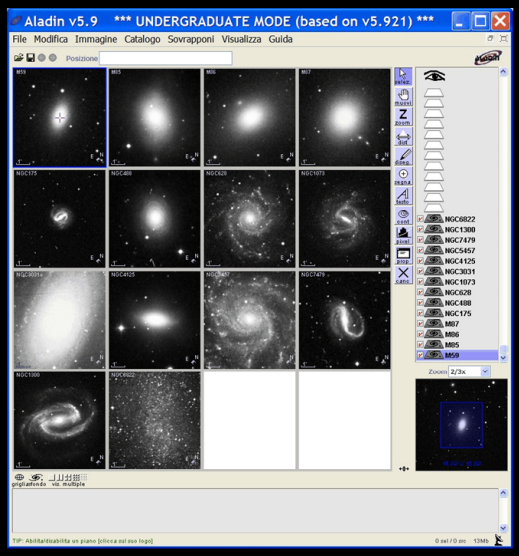
This use case explores the morphology of galaxies and their classification according to the Hubble Sequence.

Galaxies are fundamental building blocks of the Universe. The galaxies, like we see them on images, have many shapes, sometime simple and sometime complicated: there are elliptical galaxies, spirals, barred spirals, lenticulars and irregulars.

Aladin displays the images of galaxies taken by the biggest telescopes of the world. It allows also the visualization of more galaxies in the same time, in order to facilitate their comparison.



By the comparison of the 14 galaxies proposed in this exercise it is possible to build the Hubble Sequence, a morphological scheme for the classification of galaxies created by Edwin Hubble in 1936. Actually the Hubble Sequence is the most used way to classify galaxies, both in professional astronomical research and by the amateur astronomers.

1 Introduction

Galaxies are fundamental building blocks of the Universe. They allow us to trace the matter distribution on the largest scales. The shapes of galaxies as we see them, show a variety of different shapes, from simple to very complex ones. Shapes of galaxies are due to how they have formed and how they will evolve.
The Hubble Sequence is a morphological classification scheme for galaxies invented by Edwin Hubble in 1936. Hubble's scheme divides regular galaxies into three broad classes: ellipticals, lenticulars and spirals, based on their visual appearance (originally recorded on photographic plates). A fourth class contains galaxies with an irregular appearance.
Today, the Hubble Sequence is the most commonly used system for classifying galaxies.
Today we also known that the Hubble Sequence does not correspond to an evolutionary sequence of a galaxy during different phases of its life. The Sequence however maintains its importance.
In this tutorial we describe the Hubble Sequence and then how to classify them. We also provide a list of galaxies you can easily place in the Hubble Sequence.

2 Galaxies

Almost all the celestial objects we see by naked eye in the sky (e.g. stars, nebulae, star clusters) belong to our galaxy. Outside our galaxy we can see only other galaxies, and exceptionally supernovae or other violent explosions.
We know there are more than 100 billions galaxies, like the our, both smaller and larger than our Milky Way. Galaxies are very bright objects, shining with 10^{11} stars but, because of their large distances from us, we can see only three of them by naked eye: the two Magellanic Clouds (Large and Small) and Andromeda (M31). The Magellanic Clouds are irregular galaxies, described for the first time by Magellan in 1519 A.D.
They are visible in the southern hemisphere; recently, in 1987 A.D., a supernova was observed in the Large Magellanic Cloud. This supernova is very important because a supernova explosion in a nearby galaxy, or in our Milky Way, is a rare event that occurs once every 400 years.
M31 is a giant spiral galaxy, similar to the Milky Way, located at 2.3 million light-years from us. The Magellanic Clouds, Andromeda, the Milky Way and other N smaller galaxies belong to the same physical group of galaxies, gravitationally bound, called the Local Group.
Galaxies have several shapes: there are ellipticals, spirals, barred spirals, lenticulars and irregulars.
Elliptical galaxies have a spherical or ellipsoidal shape, with a variable flattening. They appear like wads with luminosity decreasing uniformly with the distance from the centre.
Spiral galaxies are similar to the Milky Way: they show a bright central nucleus from which two spiral arms depart.
Barred spiral galaxies differ from the ordinary spiral galaxies because their arms do not depart directly from the nucleus but from a bar-like feature. Recent observations seem to indicate that also the Milky Way could be a barred spiral.
Lenticular galaxies have a bulge and disk shape like spirals, but the bulge dominates the shape of the galaxy and the disk has only dust without spiral arms or bright stars.
Irregulars galaxies have an irregular and uneven shape and usually have small mass and luminosity.

3 The Hubble Sequence

Figure 1 represents the Hubble Sequence, a morphological classification scheme for galaxies.

On the left are ellipticals (fig. 3). Elliptical galaxies have smooth, featureless light distribution and appear as ellipses in photographic images. They are indicated with the letter E, followed by an integer number *n* representing their degree of ellipticity on the sky. By convention, *n* is ten times the ellipticity of the galaxy, rounded to the nearest integer number.
The ellipticity is defined as $e = 1 - b/a$ for an ellipse with semi-major and semi-minor axes of lengths *a* and *b* respectively. Hence $n = 10 \cdot e = 10 \cdot (1 - b/a)$ (fig. 2).

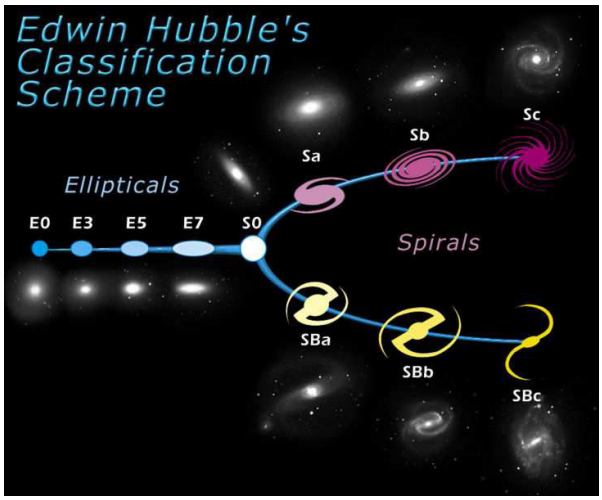


Fig. 1: The Hubble Sequence: a morphological classification scheme for galaxies.

The ellipticity increases from left to right on the Hubble Sequence diagram, with near-circular (E0) galaxies situated at the very left of the diagram. It is important to note that the ellipticity of a galaxy on the sky is only indirectly related to its three dimensional shape (for example, a flattened, disl shaped galaxy can appear almost round if viewed face-on or elliptical if viewed at an angle). The most flattened elliptical galaxies have ellipticity $e = 0.7$ (classified E7).
The right of the Hubble Sequence diagram consists of two parallel branches for spiral (fig. 4) galaxies. A spiral galaxy consists of a flattened disk with a (usually two-armed) spiral structure, and a central concentration of stars known as the bulge.

Roughly half of all spirals have a bar-like structure extending from the central bulge, with the spiral arm beginning at the end of the bar. In the Hubble Sequence, regular spirals occupy the upper branch and are denoted by the letter S, while barred spirals occupy the lower

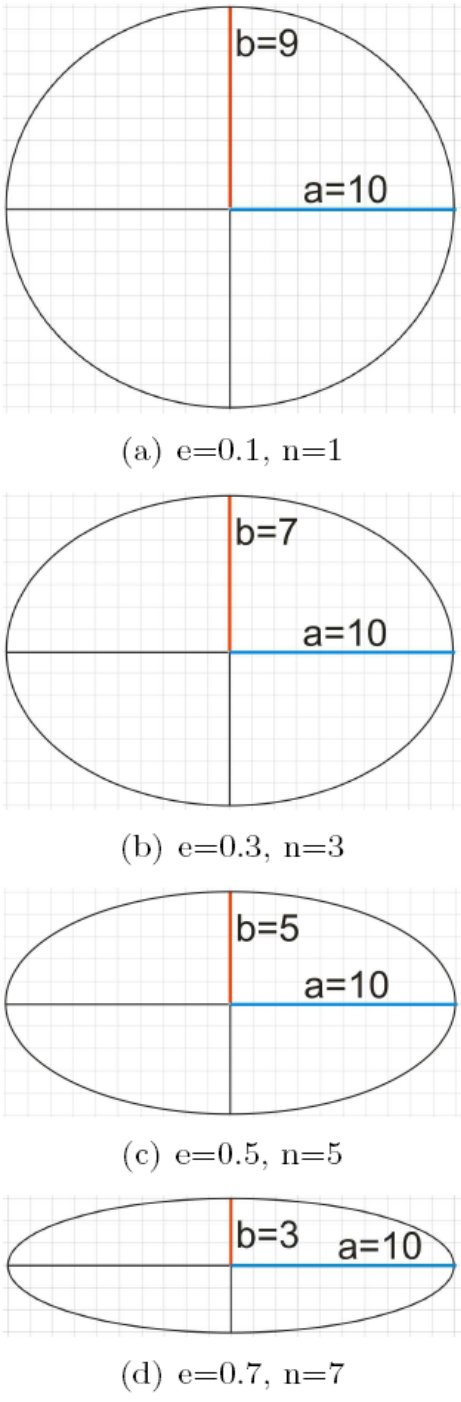


Fig. 2: Examples of ellipses with different ellipticity.

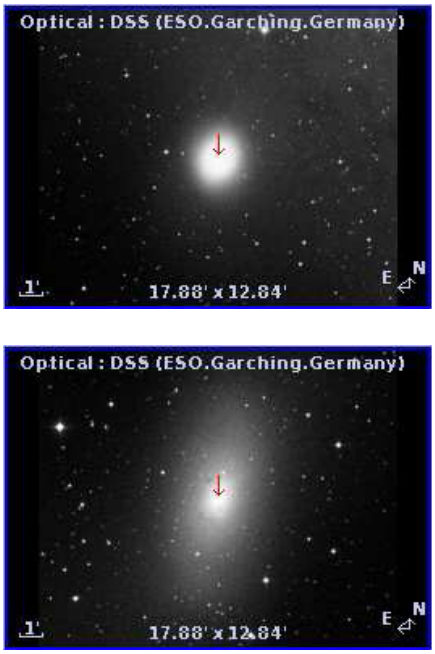


Fig. 3: Elliptical galaxies M32 (E2, top) and M110 (E6, bottom).

branch and are denoted by the letters SB. Both types of spirals are further subdivided according to the detailed appearance of their spiral structures. Membership of one of these subdivisions is indicated by adding a lower-case letter to the morphological type, as follows:

- Sa (SBa) - tightly-wound, smooth arms; large, bright central bulge;
- Sb (SBb) - less tightly-wound spiral arms than Sa (SBa); somewhat fainter bulge;
- Sc (SBc) - loosely wound spiral arms, clearly resolved into individual stellar clusters and nebulae; smaller, fainter bulge.

At the centre of the Hubble Sequence, where the two spiral arms meet the branch of ellipticals, lies an intermediate class of galaxies known as lenticulars (fig. 5) and indicated by the symbol S0. These galaxies consist of a bright central bulge, similar in appearance to an elliptical galaxy, surrounded by an extended, disk-like structure. Unlike spiral galaxies, the disks of lenticular galaxies have no visible spiral structure nor bright stars. The bulge component is often the dominant source of light in a lenticular galaxy. Face-on lenticulars are difficult to distinguish from ellipticals of type E0, making the classification of many such galaxies uncertain. When viewed edge-on, prominent dust-lanes are sometimes visible in absorption against the light of stars in the disk.
Galaxies that do not fit into the Hubble Sequence, because they have no regular structure (either disk-like or ellipsoidal), are called irregular (fig. 6) galaxies.

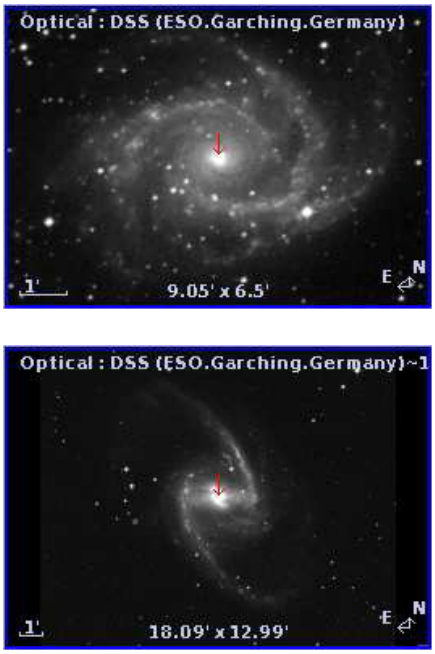


Fig. 4: Spiral galaxies NGC2997 (Sc, top) and NGC1365 (SBb, bottom).

Fig. 5: Lenticular galaxy (S0) NGC5866.

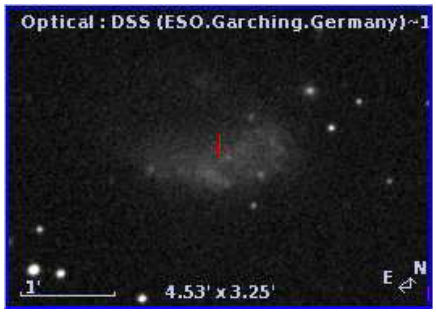


Fig. 6: Irregular galaxy NGC1427A.

4 Aladin

Aladin is an interactive software sky atlas for the visualization of digitized images of any part of the sky. Within Aladin it is possible to superimpose entries from astronomical catalogues, and to interactively access related data and information.
Aladin is developed and maintained by the Centre de Donnèes astronomiques de Strasbourg (CDS). Aladin can be downloaded from http://aladin.u-strasbg.fr.
In what follows we use the standalone version of Aladin in *undergraduate* configuration. The *undergraduate* Aladin extension has been developed in the framework of the EuroVO-AIDA European project.

5 VirGO

VirGO is a Visual Browser for the ESO Science Archive Facility developed by the VO Systems Department. It is a plug-in for the popular open source software Stellarium with added capabilities for browsing professional astronomical data.
VirGO gives astronomers the possibility to easily select data from millions of observations in a new visual and intuitive way. Its main feature is to perform real-time access and graphical display of a large number of observations by showing instrumental footprints and image previews, and to allow their selection and filtering for subsequent retrieval.
It superimposes DSS background images and allows to view the sky in a real life mode as seen by the observer.
Virgo is downloadable from http://archive.eso.org/cms/tools/documentation/visual-archive-browser.

6 Classification

We provide a list of 14 galaxies you have to classify according to the Hubble Sequence. The galaxies are: M59, M85, M86, M87, NGC0175, NGC0488, NGC0628, NGC1073, NGC1300, NGC3031, NGC4125, NGC5457, NGC7479, NGC6822.
Open Aladin and switch to the “undergraduate" mode from the menu
edit -> user preferences -> profile -> undergraduate.
Restart Aladin to validate the new configuration.
Click on the presentation window of Aladin, a blank window appears. Here we can load our astronomical images. Before doing this, switch to multiview mode, in order to visualize all the galaxies at the same time. Click on the multiview button in the bottom left corner of Aladin (first button from the right). The window splits into 16 parts: we will load a different galaxy in each one.
Click on the first sub-window, then move to the “command" field and enter the name of the first galaxy. After a few seconds the image of the galaxy appears. Click on the second sub-window and load the second galaxy. Repeat the same steps for all the 14 galaxies (fig. 7).
Now we have loaded all the galaxies in Aladin and we can start classifying them. To zoom on a galaxy use the button “zoom", on the right of the multivision panel, and click on the image you want to zoom.
Alternatively you can use the F7/F8 keys. You can use the button “pan" and drag and drop the image to move the image if it is larger than its windows.

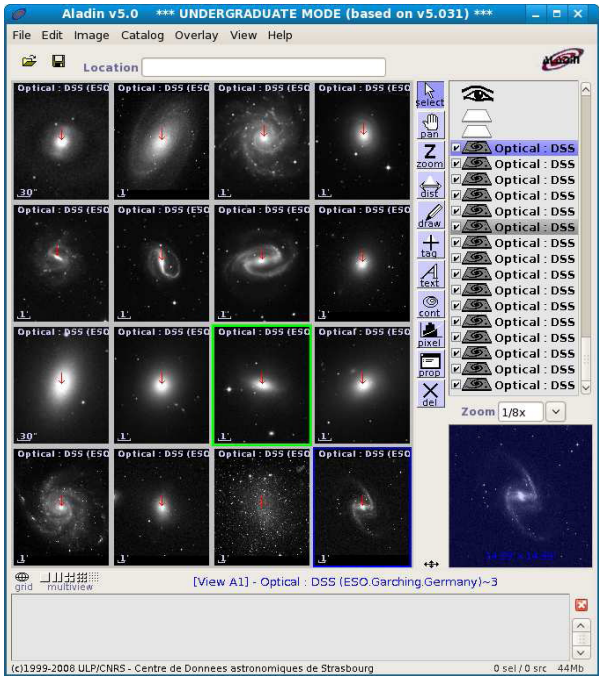


Fig. 7: The 14 galaxies loaded in the Aladin window.

7 Locate galaxies in the sky with VirGO

VirGO is a plug-in for the software Stellarium with added capabilities for browsing professional astronomical data. Open VirGO, you see the same screen as Stellarium, with some windows to access astronomical data. From the *Sky and viewing option window* (fig. 8), in the lower left menu, you can set up coordinates grid, equator and meridian lines, constellation lines and other settings.

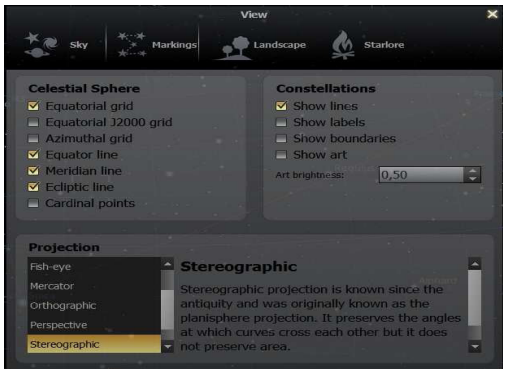


Fig. 8: *Sky and viewing option window* of VirGO.

In the data access panels (fig. 9) select the panel *target* and enter the name of the first galaxy. Click *search* and look at the constellation in the centre of Stellarium: the galaxy belong to it. Zoom in (mouse wheel or pag up/down keys) up to see the galaxy in the sky and wait for the real sky images to be loaded.
Click on the galaxy: in the upper left angle of Stellarium you have information about its name, magnitude, coordinates and size.
Search the others galaxies and enjoy looking at their position in the sky.

Fig. 9: Windows for data access in VirGO.

The astronomer's opinion

The Hubble Sequence does not correspond to an evolutionary sequence of a galaxy during its life: galaxies do not originate ellipticals and them become spirals and irregulars.
Theoretically, we think that galaxies form in large halos of matter whom nature still remains unknown (dark matter).
The gas stored in these halos looses energy and collapses towards the center. The conservation of angular momentum creates a disk structure like that observed in spiral galaxies (e.g. our Milky Way). We think that elliptical galaxies and spheroidal structures, observed at the center of spiral galaxies, originate from interaction or merging between galaxies.
Such phenomena are frequent and commonly observed. They occur when galaxies are close enough to feel the reciprocal gravitational field. The force acting between the two galaxies aims at warping and eventually breaking up them. This can originate, depending on the velocity and orbit of the galaxies, a really fusion process that distributes stars in a spherical structure. The gas compression, during the fusion process, can cause new star formation.

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EXERCISES

Learning level 1

- Visualize some galaxies through apposite tools (Aladin and VirGO);
- distinguish galaxies according to their shape (elliptical, spiral, other);
- fill a simple classification table.

Activity: Divide the 14 galaxies between ellipticals, spirals, barred spirals, lenticulars and irregulars. For each galaxy, check with an X the correct column according to your classification.

Galaxy	Elliptical	Spiral	Barred Spiral	Other
M59				
M85				
M86				
M87				
NGC175				
NGC488				
NGC628				
NGC1073				
NGC1300				
NGC3031				
NGC4125				
NGC5457				
NGC7479				
NGC6822				

Learning level 2 (requires level 1)

- Classify galaxies according to the Hubble Sequence.

Activity: Classify the galaxies in each column of previous exercise table according to the Hubble Sequence. In the following tables insert in the first column the name of the galaxy and then a cross in the correct cell according to your classification.

Elliptical	E1	E2	E3	E4	E5	E6	E7

Spiral	Sa	Sb	Sc

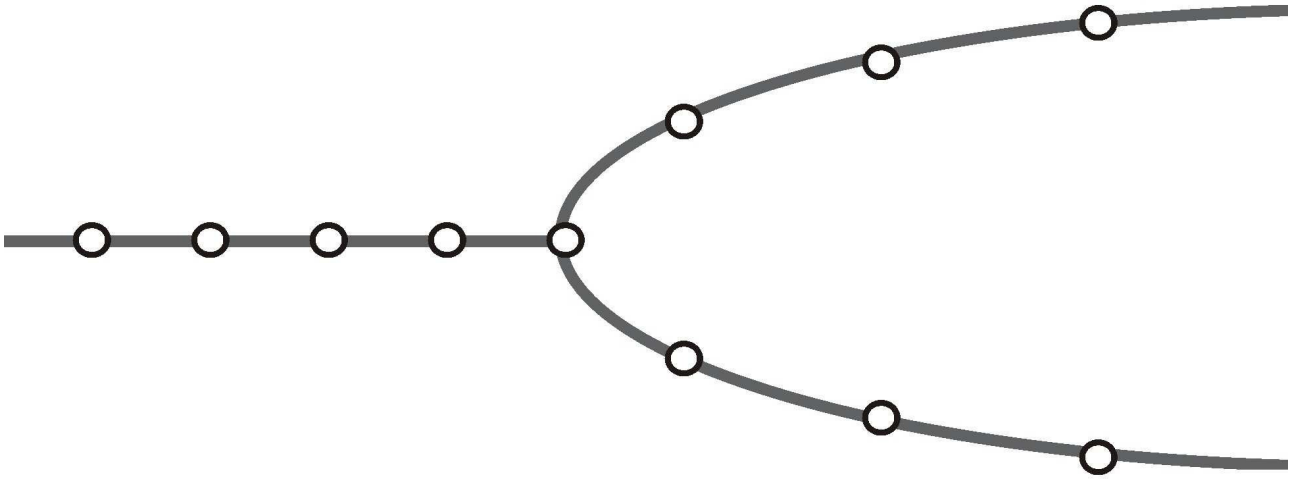
Barred Spiral	SBa	SBb	SBc

Other galaxies	Lenticulars	Irregular

Learning level 3 (requires levels 1 e 2)

- Use diagrams like the Hubble one to classify galaxies.

Activity: Fill the empty Hubble Sequence diagram with the names of the 14 galaxies just classified. Put each galaxy on its point in the diagram. Note that one galaxy will not enter the diagram!



SOLUTIONS

Learning level 1

- Visualize some galaxies through apposite tools (Aladin and VirGO);
- distinguish galaxies according to their shape (elliptical, spiral, other);
- fill a simple classification table.

Activity: Divide the 14 galaxies between ellipticals, spirals, barred spirals, lenticulars and irregulars. For each galaxy, check with an X the correct column according to your classification.

Galaxy	Elliptical	Spiral	Barred Spiral	Other
M59	X			
M85				X
M86	X			
M87	X			
NGC175			X	
NGC488		X		
NGC628		X		
NGC1073			X	
NGC1300			X	
NGC3031		X		
NGC4125	X			
NGC5457		X		
NGC7479			X	
NGC6822				X

Learning level 2 (requires level 1)

- Classify galaxies according to the Hubble Sequence.

Activity: Classify the galaxies in each column of previous exercise table according to the Hubble Sequence. In the following tables insert in the first column the name of the galaxy and then a cross in the correct cell according to your classification.

Elliptical	E1	E2	E3	E4	E5	E6	E7
M59					X		
M86			X				
M87		X					
NGC4125						X	

Spiral	Sa	Sb	Sc
NGC488	X		
NGC628			X
NGC3031		X	
NGC5457			X

Barred Spiral	SBa	SBb	SBc
NGC175	X		
NGC1073			X
NGC1300		X	
NGC7479			X

Other galaxies	Lenticular	Irregular
M85	X	
NGC6822		X

Learning level 3 (requires levels 1 e 2)

- Use diagrams like the Hubble one to classify galaxies.

Activity: Fill the empty Hubble Sequence diagram (fig. 10) with the names of the 14 galaxies just classified. Put each galaxy on its point in the diagram. Note that one galaxy will not enter the diagram!