THE HUBBLE SEQUENCE

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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 dues 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, both in professional astronomical research and in amateur astronomy.

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 some galaxies. We provide a list of galaxies you can easily locate in the Hubble Sequence.

2 Galaxies

Almost all the celestial objects we see by naked eye in the sky (like stars, nebulae, star clusters) belong to our galaxy. Outside our galaxy we can see only other galaxies, and exceptionally some supernovae or other violent explosions.

We know there are more than 100 billions of galaxies, like the ours, both smaller and larger. Galaxies are very bright objects, shining with 10^{11} stars, but because of their huge 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 Magellan Cloud. M31 is a giant spiral galaxy, similar to the Milky Way, located at 2.3 million of light-years from us. The Magellan Clouds, Andromeda and also the Milky Way belong to the same group, 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 center. 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.
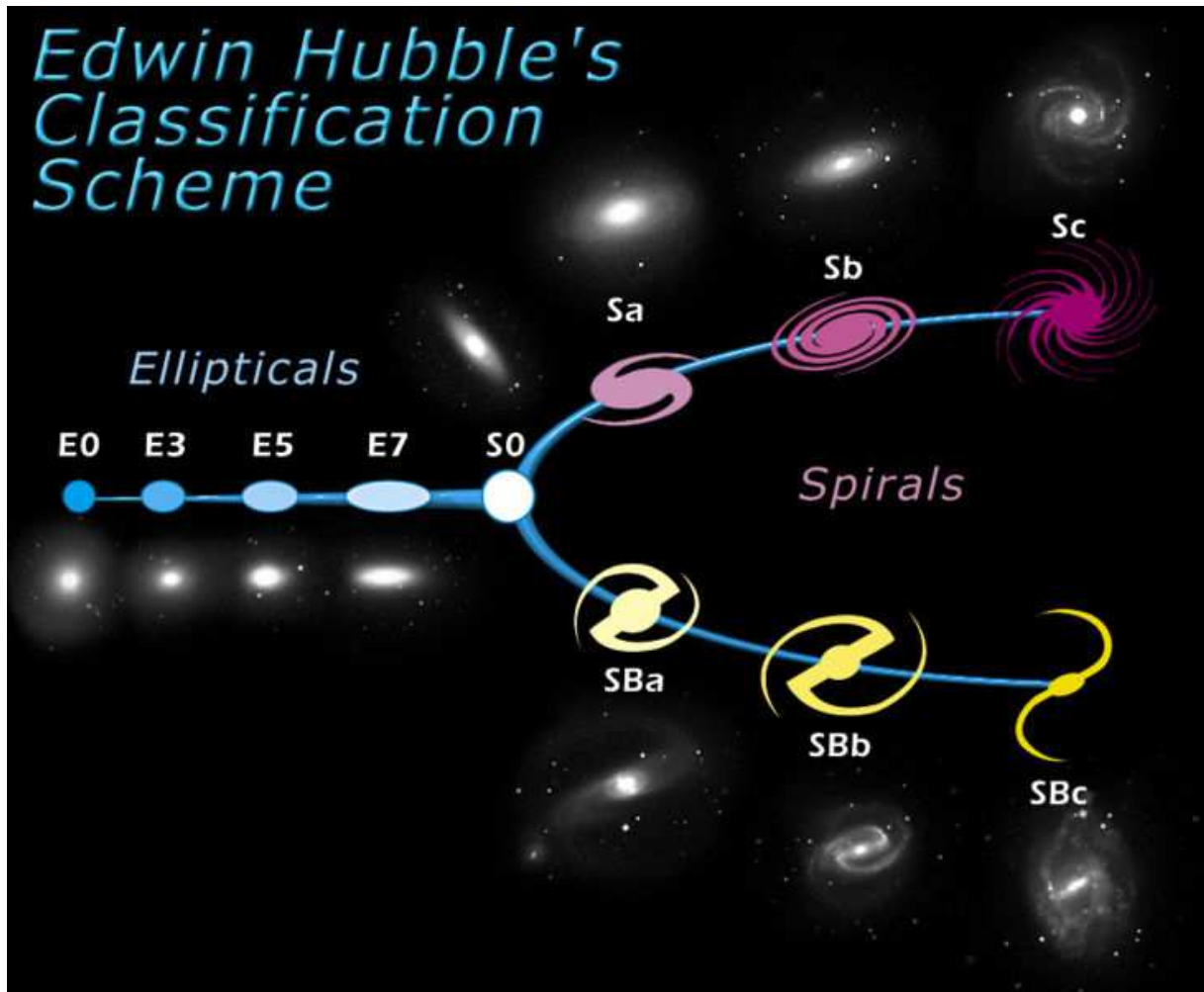
Figure 1: The Hubble Sequence: a morphological classification scheme for galaxies.

Lenticular galaxies have a bulge and disk shape like the 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 the **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 $e = 1 - \frac{b}{a}$ for an ellipse with semi-major and semi-minor axes of lengths a and b respectively. Hence $n = 10 \cdot e = 10 \cdot (1 - \frac{b}{a})$ (fig. 2).

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 the true three dimensional shape (for example, a flattened, discus-shaped galaxy can appear almost round if viewed face-on or elliptical if viewed at an angle). The most flattened elliptical galaxies have ellipticity $e = 0.7$ (are classified E7).

At the right of the Hubble Sequence diagram there are two parallel branches including the **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 branch and are denoted by the letters SB. Both types of spirals are further subdivided according to the detailed appearance of their spiral
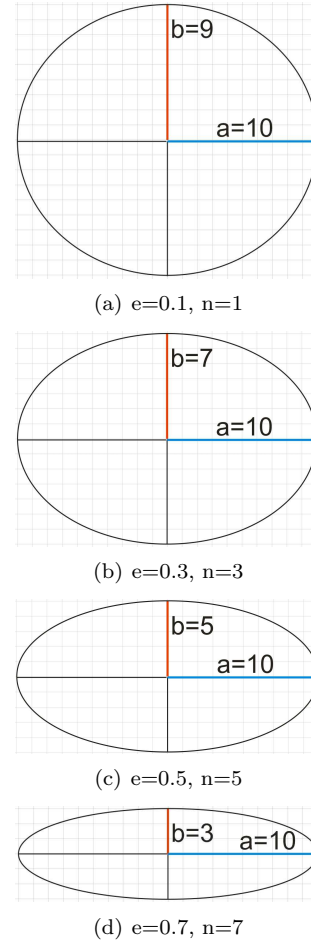

(a) e=0.1, n=1

(b) e=0.3, n=3

(c) e=0.5, n=5

(d) e=0.7, n=7

Figure 2: Examples of ellipses with different ellipticity.

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
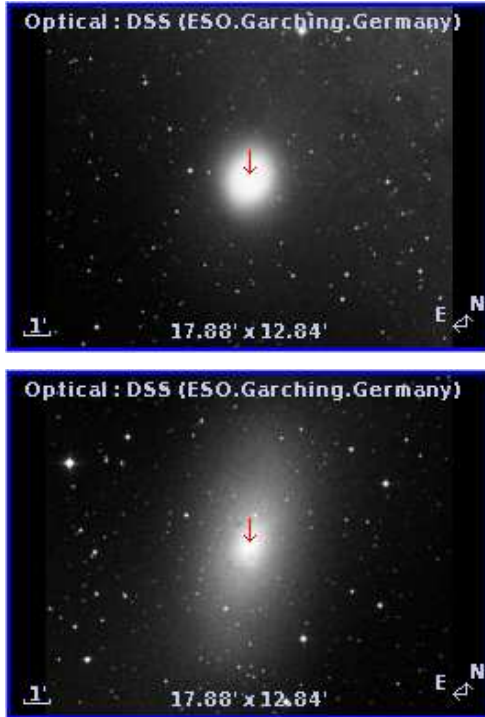
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Figure 3: The two elliptical galaxies M32 (E2, top) and M110 (E6, bottom).
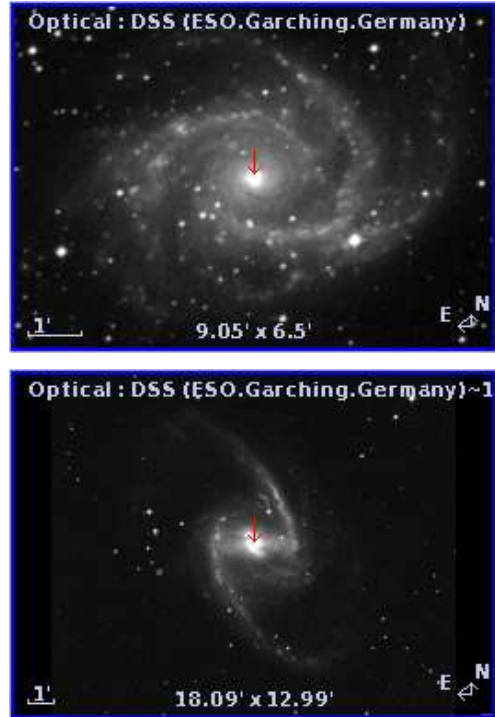
Figure 4: The two spiral galaxies NGC2997 (Sc, top) and NGC1365 (SBb, bottom).

At the centre of the Hubble Sequence, where the two spiral arms meet the elliptical branch, lies an intermediate class of galaxies known as **lenticulars** (fig. 5) and indicated by 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.

Figure 5: The lenticular (S0) galaxy NGC5866

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

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Figure 6: The irregular galaxy NGC1427A

from astronomical catalogues, and to interactively access related data and information.

Aladin is developed and maintained by the Centre de Donnes 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   The 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 configuration modification.

Click on the presentation window of Aladin, a blank window appears. Here we can load our astronomical images. Before to do this switch to multi view mode, in order to visualize all the galaxies in the same time. Click on the multi view 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).
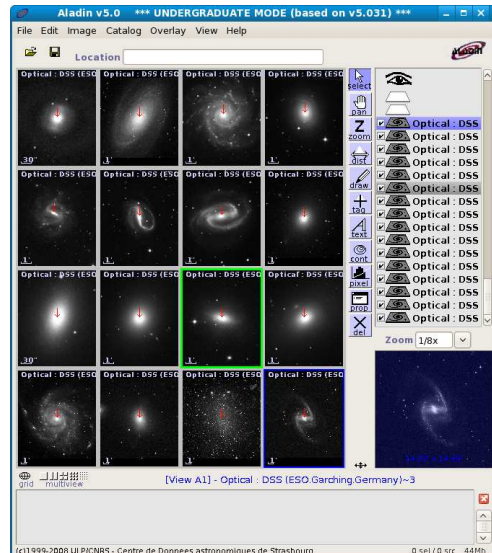

Figure 7: The 14 galaxies to classify loaded in Aladin.

Now we have loaded all the galaxies in Aladin and we can start to classify them. To zoom on a galaxy use the button "zoom", on the right of the multi vision 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.

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.

Figure 8: The *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 center 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.

Figure 9: Data access panels of VirGO.

LEARNING LEVELS

▷ 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				

Table 1: Table to classifying galaxies between ellipticals, spirals, lenticulars and irregulars.

▷ Level 2

- Requires level 1;

- classify galaxies according to the Hubble Sequence.

Activity: Classify the galaxies in each column of table 1 according to the Hubble Sequence. In the following tables (table 2 for ellipticals, table 3 for spirals, table 4 for barred spirals and table 5 for lenticulars and irregulars) insert in the first column the name of the galaxy and then a cross in the correct cell according to your classification.

ELLIPTICAL GALAXY	E0	E1	E2	E3	E4	E5	E6	E7

Table 2: Classification of elliptical galaxies according to the Hubble Sequence.

SPIRAL GALAXY	Sa	Sb	Sc

Table 3: Classification of spiral galaxies according to the Hubble Sequence.

BARRED SPIRAL GALAXY	SBa	SBb	SBc

Table 4: Classification of barred spiral galaxies according to the Hubble Sequence.

OTHER GALAXY	Lenticular	Irregular

Table 5: Classification of lenticular and irregular galaxies according to the Hubble Sequence.

▷ Level 3

- Includes levels 1 and 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!
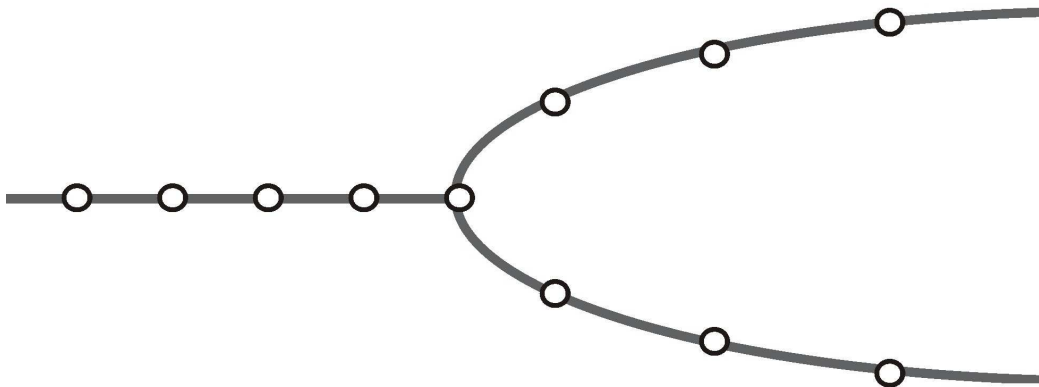

Figure 10: Empty Hubble Sequence where to place our galaxies.

SOLUTIONS

▷ **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

Table 6: Table to classifying galaxies between ellipticals, spirals, lenticulars and irregulars.

▷ **Level 2**

- Includes level 1;

- classify galaxies according to the Hubble Sequence.

Activity: Classify the galaxies in each column of table 6 according to the Hubble Sequence. In the following tables (table 7 for ellipticals, table 8 for spirals, table 9 for barred spirals and table 10 for lenticulars and irregulars) insert in the first column the name of the galaxy and then a cross in the correct cell according to your classification.

ELLIPTICAL GALAXY	E0	E1	E2	E3	E4	E5	E6	E7
M59						X		
M86				X				
M87		X						
NGC4125							X	

Table 7: Classification of elliptical galaxies according to the Hubble Sequence.

SPIRAL GALAXY	Sa	Sb	Sc
NGC488	X		
NGC628			X
NGC3031		X	
NGC5457			X

Table 8: Classification of the spiral galaxies according to the Hubble Sequence.

BARRED SPIRAL GALAXY	SBa	SBb	SBc
NGC175	X		
NGC1073			X
NGC1300		X	
NGC7479			X

Table 9: Classification of barred spiral galaxies according to the Hubble Sequence.

OTHER GALAXY	Lenticular	Irregular
M85	X	
NGC6822		X

Table 10: Classification of lenticular and irregular galaxies according to the Hubble Sequence.

▷ Level 3

- Requires levels 1 and 2;

- place galaxies in the diagram of the Hubble Sequence.

Activity: Fill the empty Hubble Sequence diagram (fig. 11) 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!
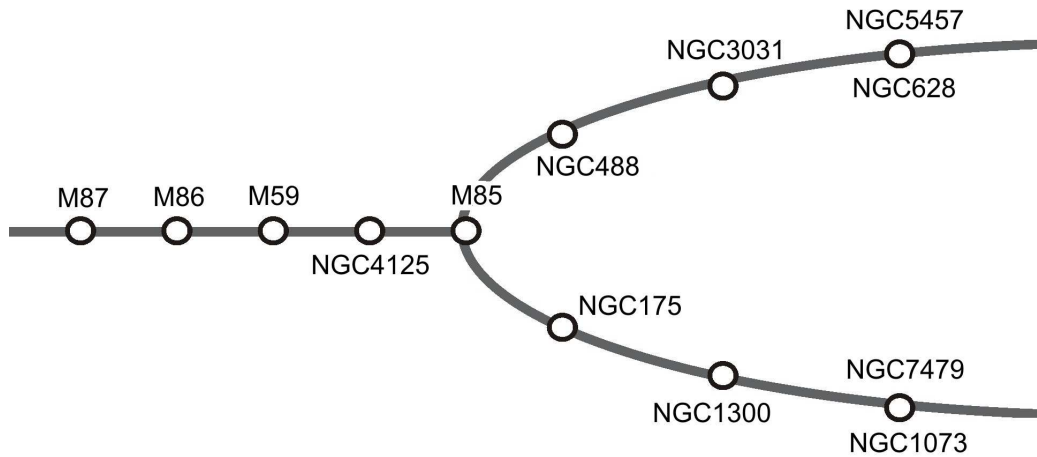

Figure 11: Empty Hubble Sequence where to place our galaxies.