Galaxy Classification and Evolution

The word “galaxy,” having been used in English since the fourteenth century, is as old as this language. Galaxy was derived from the French, Greek, and Latin words for milk. To pre-industrial people, lacking bright lights, the Milky Way, a band of diffuse light stretching across the dark sky, would have been as familiar as the planets and the Moon. This band of stars completely encircles Earth. It is the disk of our Galaxy seen from the inside (but not the center). With unaided eyes one other galaxy can be seen in the northern sky, the Andromeda nebulae, as it was called before its true nature was known. It is a faint fuzzy patch in the region of the sky containing the stars of the constellation Andromeda. Two galaxies, the Large and Small Magellanic Clouds, can be seen with unaided eyes in the southern sky from south of about 10 degrees north latitude. The Magellanic Clouds were described by sailors from Magellan's voyage, and are now known to be small irregular galaxies, that orbit the Milky Way. Our Sun and all of the individual stars that can be seen with unaided eyes from Earth are part of the Milky Way.

Immanuel Kant (1724-1804) speculated that the faint patches of light, which improved telescopes revealed in large numbers, were "...island universes - in other words, Milky Ways..." Astronomers of the eighteenth century identified celestial objects as being either stellar or non-stellar, with the second category including gaseous nebulae, planetary nebulae, hazy star clusters, and faint lens-shaped formations. If these objects were nearby, with distances comparable to those of observable stars, they would have to be luminous clouds of gas within our Galaxy. If they were very remote, far beyond the foreground stars of the Galaxy, they would be systems containing billions of stars. Kant's speculation was rejected for over 150 years. Edwin Hubble published a paper in 1929, "A Spiral Nebula as a Stellar System," which showed that the fuzzy patch in the constellation Andromeda is a system of numerous individual stars, star clusters, and dust clouds. The Andromeda galaxy, as it is now known, is 2 million light-years away, and is the nearest spiral galaxy to the Milky Way. Hubble also proposed a classification scheme based entirely on the visual appearance of a galaxy on a photographic plate. His system has three basic categories: elliptical, spiral, and irregular galaxies. The elliptical and spiral galaxies are subdivided further, as illustrated below. This is known as the “Hubble Tuning Fork.”
Describing Galaxy Morphologies

(a) Spiral Galaxies

Spiral galaxies are associated in the public's mind with galaxies because their curving arms and dust clouds make spectacular pictures. Photographs of the Andromeda, the Whirlpool, and the Sombrero galaxies are often reproduced because of their beauty. The arms form a disk that extends out from a central or nuclear bulge of stars, often called the nucleus, which is brightest at its center. The arms require longer exposures as seen in astrophotography, which usually causes the nucleus to be overexposed. In spiral galaxies, the disk and central nucleus of a spiral galaxy is enclosed in a larger spherical halo, which includes many globular clusters of stars. The halo is surrounded by a dark corona with a radius of several times the radius of the disk. The corona is the location of the hypothetical dark mass. The disks of spiral galaxies are filled with clouds of dust and gas.

Spiral galaxies are classified by the shape of their nuclei and their arms. Spirals with arms that appear tightly wound are classified as Sa galaxies, while those with more loosely wound arms are Sc galaxies. Sb’s are between these classes. Spirals with loosely wound arms also have smaller central bulges.

The arms in barred spirals originate at the ends of a bar running through the galaxy's nucleus. Some barred spirals have tightly wound arms, while other barred spirals have loosely wound arms, which are classified into SBa, SBB, and SBC categories.
(b) Elliptical Galaxies

Ellipticals are galaxies whose images have elliptical outlines, without spiral arms, and often appear rather smooth and featureless. Ellipticals vary in shape from spherical to flat, lens-shaped formations. Hubble identified these galaxies with the letter E and classified them according to their elliptical shape using numbers from zero through seven. Spherical galaxies are classified as E0, almost spherical as E1, and galaxies with maximum elongation as E7. Elliptical galaxies contain relatively little dust and gas. Some giant ellipticals contain as many as a hundred times more stars than our Galaxy. M87 is an example of such a giant galaxy. Dwarf ellipticals are the most numerous type of galaxy, and typically contain only a few million stars. Since the formation of new stars occurs in regions which contain dust and gas, elliptical galaxies are composed primarily of old stars.

(c) Lenticular Galaxies

Still another class of galaxies intermediate between the elliptical and spiral galaxies are the SO galaxies. Superficially, they appear like ellipticals, but they contain too much dust to be ellipticals, yet are too smooth to be spirals. Some show faint disks. The range of galaxies that exist seem to form a continuous sequence of galaxy types between the ellipticals and the spirals.

(d) Irregular and Peculiar Galaxies

Irregular galaxies lack the organized appearance found in ellipticals and spirals.
Part I — Classification

Please click on
http://cosmos.phy.tufts.edu/~zirbel/laboratories/galaxyimages/

The first step prior to studying galaxies and their evolution is to categorize them by some method. A classification scheme generally must satisfy two criteria to be successful: It should act as a shorthand means of identification of the object, and it should provide some insight to understanding the object. We still use the classification scheme proposed by Edwin Hubble in 1926. His classification is based on the visual appearance of a galaxy on a photographic plate.

a) On the next page you will see some galaxies that have been classified according this scheme.

b) Classify all galaxies (e.g. S0, Sc, SBa, E0, E4 etc; just Elliptical or Spiral in not enough). Write the classification into Table 1. Please look at the pictures on the computer (to see sufficient detail); the thumbnails on the next pages are for orientation only. Write a short comment of how you arrived at each classification.

Note: You can try to do a fast job and classify the galaxy thumbnails on the photocopies – but please do look at the larger galaxy images on your computer. You will find that the additional detail does often result in different classifications.

The Classification Scheme in Brief

- **Spirals** have a bulge and a disk with a spiral structure. A big bulge with tightly wound arms corresponds to a Sa; a small bulge with loosely wound arms is an Sc – pay attention to the length and tightness of the spiral arms and to the relative size of the bulge. Sometimes you might even be able to determine intermediate cases; for example an Sbc is intermediate between an Sb and Sc. If there is a bar, you might have an SBb, or an SBC. Do not confuse spiral arms with tidal arms (a gravitational influence of a close neighbor).

- **Elliptical** galaxies tend to be smooth and regular. Ellipticals do not have a disk or a bulge, only a spheroidal component. Their shape somewhat resemble that of a “fuzzy football”. The flattest Ellipticals are classified as E7, round ones as E0. In some cases you might see a rather broad dust patch orbiting the galaxy (as in the case of Cygnus A). These dust patches look very different from signatures of dust seen in the arms of spiral galaxies.

- **Lenticular** galaxies (denoted S0) are often confused with elliptical galaxies, however they are rather different. They look as smooth and regular as Ellipticals, however they have a disk and a bulge (Ellipticals do not have a disk). They are basically spiral galaxies with NO arms.

- **Irregular** galaxies do not have a well-defined shape and are not as symmetrical or regular like Ellipticals or Spirals. Some galaxies may have a rather weird structure – these can be classified as “peculiar” or Irr II.
**Table 1: Galaxies to be classified**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Comments of unusual morphologies; e.g., E3, but with dust ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>M101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC2147</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC2644</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC2685</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC3077</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC3718</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC4565</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC4651</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC470</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC5364</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC5383</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC6946</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Galaxies to be classified

M101
M102
M104
M110
M32
M33
M49
M51
M59
M61
M64 / Black-Eye Galaxy
M74
M77

M104 / Cygnus A

LMC

Local Group Galaxy

M81

M84

M85

M87

M95

M88

M89

M94
NGC2147  NGC2644  NGC2685
NGC3077  NGC3718  NGC4565
NGC4651  NGC470   NGC5364
NGC5383  NGC55    NGC6946
Part II: The Colors of Galaxies

Look at the Pictures on the next page AND at the pictures in color on the Computer!

a) Do the colors of galaxies seem related to their shapes? Explain.

b) Suggest an explanation for the colors of Spiral, Elliptical and Irregular galaxies. In particular, comment on the amount of gas and dust and the stellar populations of those galaxies.

c) Compare the bulge of Spiral galaxies to elliptical galaxies. In what sense are they similar?

d) Look at M101, NGC2997 and M100. Why are the colors of the bulge and the colors of the spiral arms so different? Suggest an explanation.

e) Look at NGC55: Some parts of the spiral arms have a reddish glow. What is that? NGC2997 is also a spiral galaxy, but not much of this pink light is visible. Why not?

f) NGC6745 is interacting with another galaxy that is located at the bottom right of that picture. Comment on the overall colors of NGC6745. How much gas and dust do you think this galaxy has relative to NGC22? What are the blue patches? Why aren’t any other parts of that galaxy so blue?
Galaxies in Color (look at the **COLOR** pictures!)

NGC2997

M101

NGC1313

M82

M87

NGC4565

NGC22

NGC6745

NGC5364

NGC4881

NGC55

M100
Part III — Analyzing the Hubble Tuning Fork

a) Describe how the properties of galaxies change along the Hubble sequence (from left to right).

   (i) For spirals: disk/bulge ratio

   (ii) For ellipticals: the ellipticity

   (iii) For spirals: tightness and length of the arms

   (iv) Amount dust (as inferred from the presence of dark clouds and/or reddening and extinction)

   (v) Amount gas (as inferred from the presence of HII regions)

   (vi) Overall galaxy colors

   (vii) Dominant spectral types

   (viii) Time since the last star formation episode
b) **Explain** how (iv) to (viii) are correlated.

-----------------------------

-----------------------------

-----------------------------

-----------------------------

-----------------------------

-----------------------------

c) Originally, when Hubble proposed this classification, he had hoped that it might yield deep insights – just as in the case for classifying stars. He hoped this scheme would represent an evolutionary scheme, where galaxies start off as elliptical galaxies, then rotate, flatten and spread out as they age.

**Critically** comment on Hubble’s proposal that his classification represents an evolutionary scheme.

-----------------------------

-----------------------------

-----------------------------

-----------------------------

-----------------------------

-----------------------------

d) Invent an **alternate** classification scheme. In what sense does your scheme do a better job than the Hubble scheme? **Explain.**

-----------------------------

-----------------------------

-----------------------------

-----------------------------

-----------------------------

-----------------------------