

Galaxy Classification and Evolution

Galaxy Morphologies

In order to study galaxies and their evolution in the universe, it is necessary 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. The most generally used classification scheme of galaxies is one proposed by Edwin Hubble in 1926. His classification is based entirely on the visual appearance of a galaxy on a photographic plate. Hubble's system lists three basic categories: elliptical galaxies, spiral galaxies, and irregular galaxies. The spirals are divided into two groups, normal and barred. The elliptical galaxies, and both normal and barred spiral galaxies, are subdivided further, as illustrated in the figure, and discussed below. This figure is called the "Hubble Tuning Fork".

The Hubble tuning fork is a classification based on the visual appearance of the galaxies. Originally, when Hubble proposed this classification, he had hoped that it might yield deep insights, just as in the case for classifying stars a century ago. This classification scheme was thought to represent an evolutionary scheme, where galaxies start off as elliptical galaxies, then rotate, flatten and spread out as they age. Unfortunately galaxies turned out to be more complex than stars, and while this classification scheme is still used today, it does not provide us with deeper insights into the nature of galaxies.

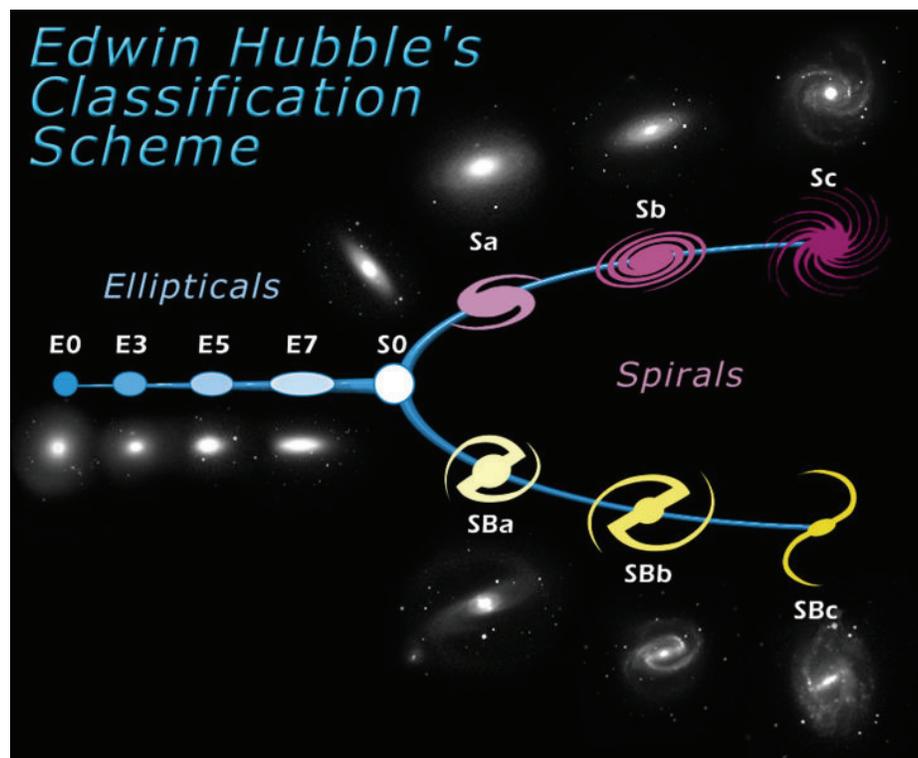


Image obtained from Wikipedia at http://en.wikipedia.org/wiki/Galaxy_morphological_classification

Part I – Classification

The **photocopies** of the galaxies are **not good enough to be classified**
You will need to access the images on the computer and look at some of the fine detail.

Open a Web page and click on
<http://cosmos.phy.tufts.edu/~zirbel/laboratories/galaxyimages/index.html>

You will see a list of galaxy images, click on each of them.

- a) Look at the classification on the front page. This image is called the Hubble Tuning Fork. In the “galaxyimages” directory on the Web double-click on the “classification” file. 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. Again, you need to 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.

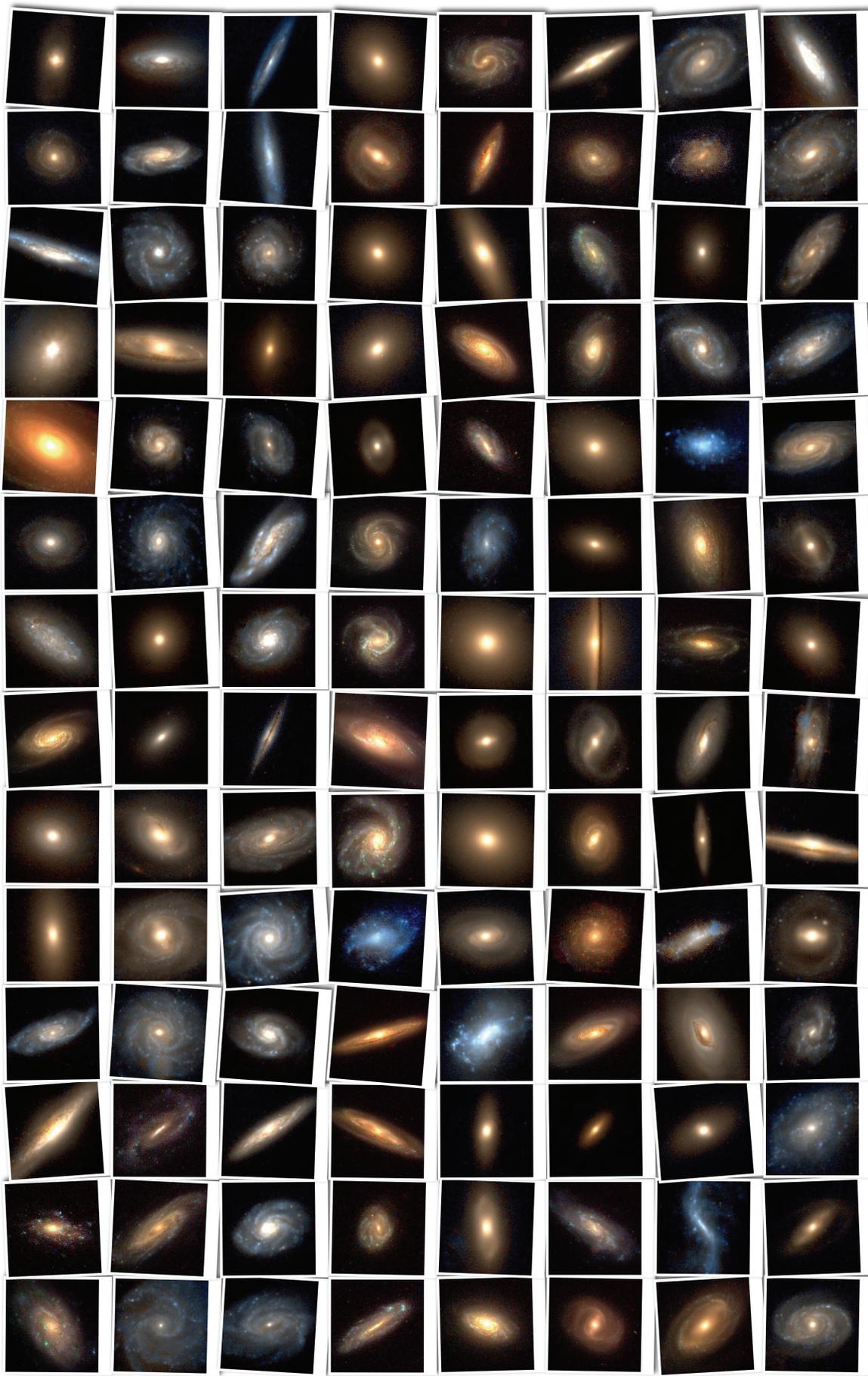
Note: You can try to do a fast job and classify the galaxy thumbnails on the photocopies – but please do look at the larger galaxy images on your computer. You will find that the additional detail does often result in different classifications.

The Classification Scheme

Read the Pre-Lab again; Look at the Hubble Tuning Fork; Compare to the Examples

- **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.

Gallery of Galaxy Morphologies



Created by Zolt Frei and James E. Gunn Copyright © 1999 Princeton University Press

Images taken from <http://www.astro.princeton.edu/~frei/catalog.htm>.

Click on http://www.astro.princeton.edu/~frei/Geat.htm/cat_ims.htm to see enlarged images of individual galaxies.

Table 1: Galaxies to be classified

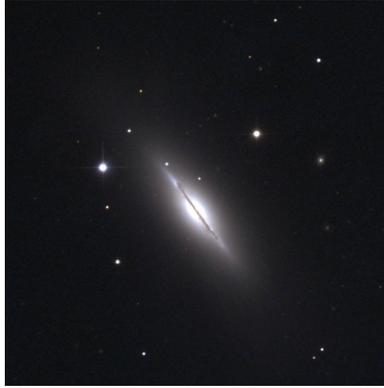
Images obtained from http://www.noao.edu/image_gallery/ and <http://www.aao.gov.au/images/>

Name	Type	Comments
M101		
M102		
M104		
M110		
M32		
M33		
M49		
M51		
M59		
M61		
M64		
M74		
M77		
M104		
LMC		
M81		
M84		
M85		
M87		
M95		
M88		
M89		
M94		
NGC2147		
NGC2644		
NGC2685		
NGC3077		
NGC3718		
NGC4565		
NGC4651		
NGC470		
NGC5364		
NGC5383		
NGC55		
NGC6946		

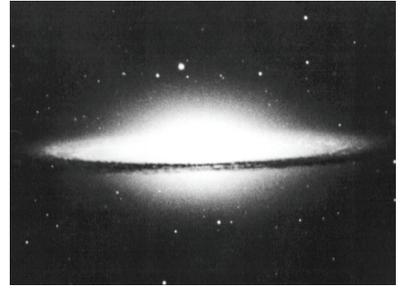
Galaxies to be classified



M101



M102



M104



M110



M32



M33



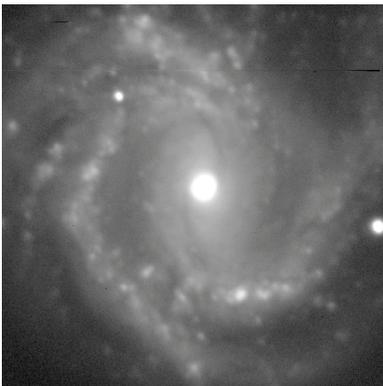
M49



M51



M59



M61



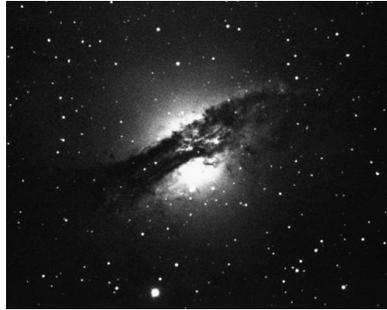
M64 / Black-Eye Galaxy



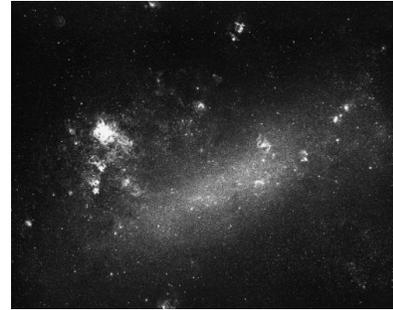
M74



M77



M104 / Cygnus A



LMC



Local Group Galaxy



M81



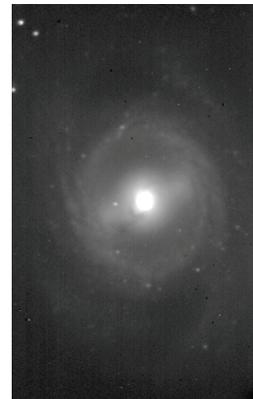
M84



M85



M87



M95



M88



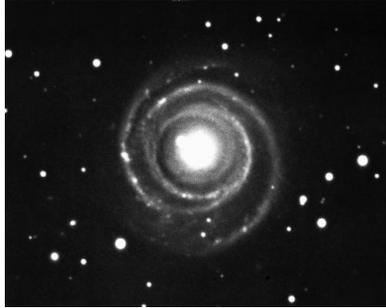
M89



M94



NGC2147



NGC2644



NGC2685



NGC3077



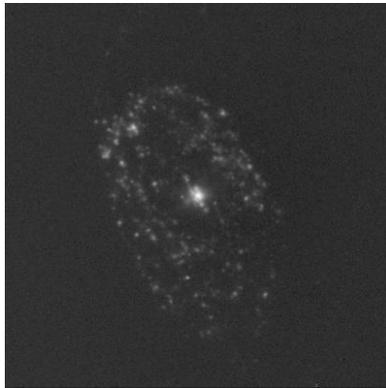
NGC3718



NGC4565



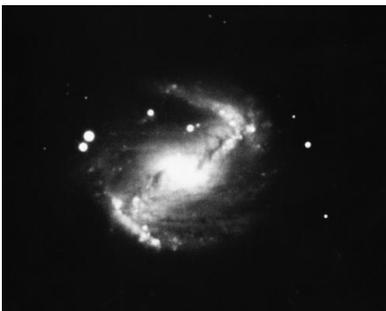
NGC4651



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!
Images are obtained from the Anglo Australian Observatory at <http://www.aao.gov.au/images/>
and from the Space Telescope Institute http://heritage.stsci.edu/gallery/gallery_category.html.

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!)



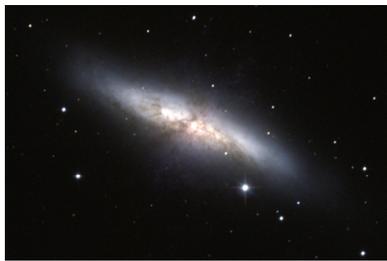
NGC2997



M101



NGC1313



M82



M87



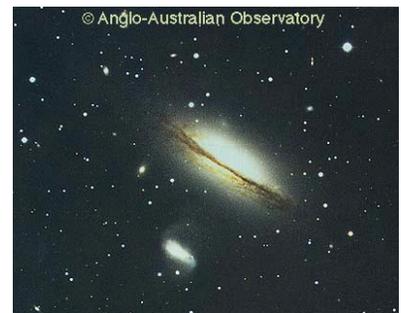
NGC4565



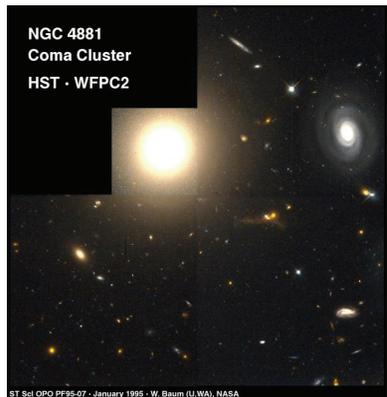
NGC22



NGC6745



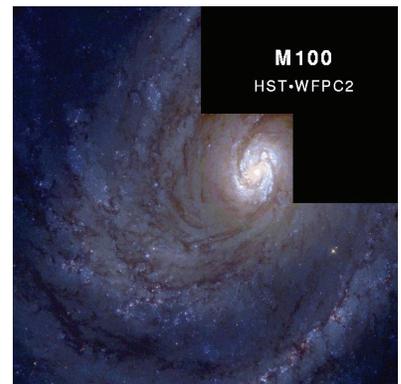
NGC5364



NGC4881



NGC55



M100

Part III – Galaxy Environments

Galaxies, like stars, exist in clusters. It is now known that the Milky Way is part of a local cluster of about 30 galaxies called the Local Group. The Local Group lies on the outskirts of a much larger cluster called the Local Supercluster. A nearby cluster, the Virgo cluster of galaxies, is prominent in the sky because of its relative nearness. It lies in the Virgo and Coma Berenices constellations, at a distance of about 65 million light-years, and contains many bright objects, some with Messier numbers and hundreds with NGC (New General Catalogue) numbers. High quality astro-photographs of this Virgo Cluster show thousands of individual galaxies that are ideal for studying the various types of galaxies. There are several advantages of studying clusters of galaxies; the members of clusters are all at about the same distance, so relative luminosities and diameters can be easily compared for the cluster members. Examples of galaxies in collision can also often be found in galaxy clusters.

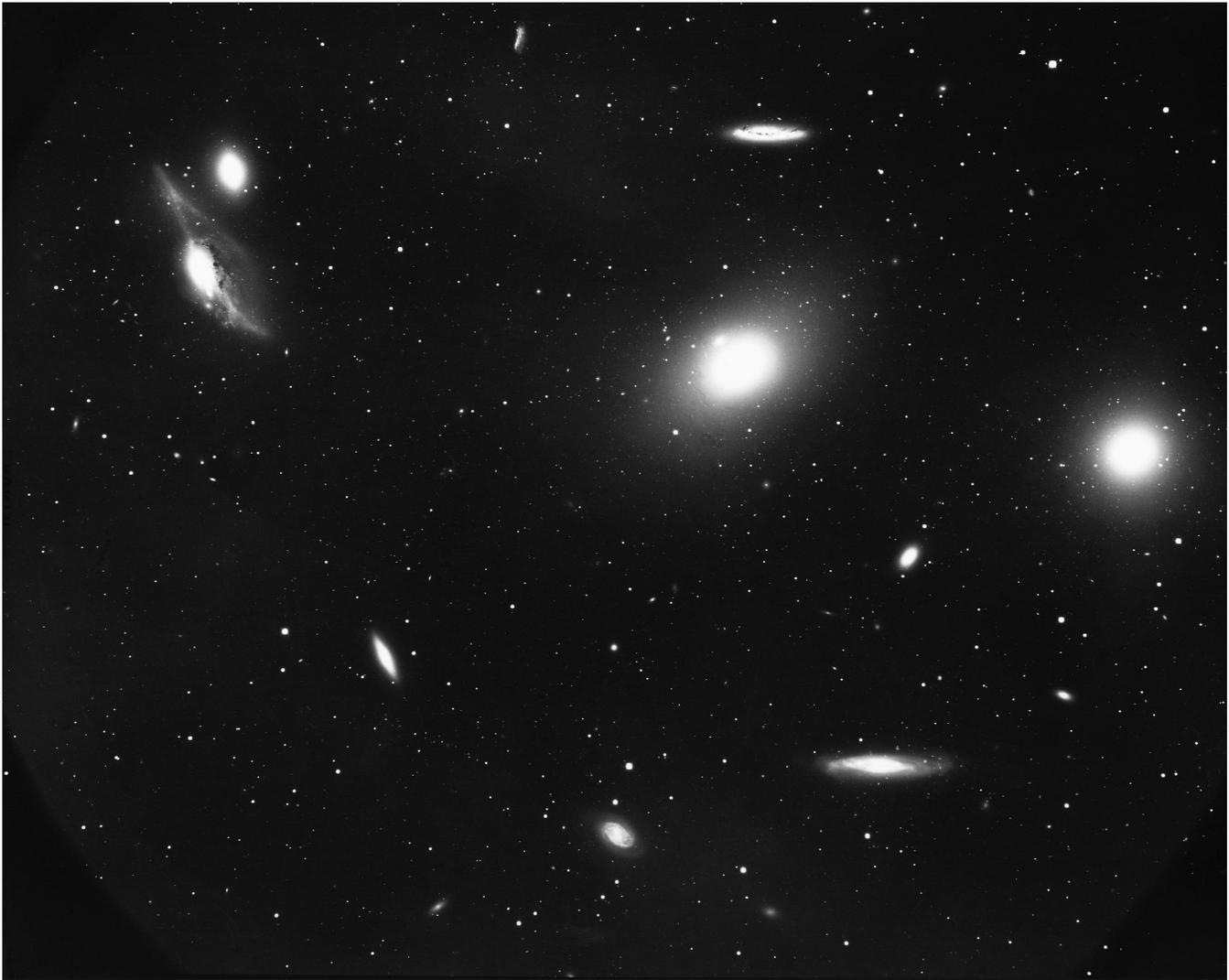


Image from http://www.noao.edu/image_gallery/galaxies.html

There are differences among clusters, and the proportion of Spiral and Elliptical galaxies depends on the galaxy environment. The Morphologies of the Galaxies turns out to depend on the environment of galaxies. This suggests that the neighbors of galaxies are somehow responsible for the final shapes of the galaxies. If we can understand exactly “how” the environment affects the evolution of galaxies, we might be able to figure out how galaxies have formed during the early stages of the universe.

Galaxies in Different Environments

Look at the Hercules and Coma Clusters and classify the galaxies roughly according to Elliptical, Spiral, and Irregular. Let's do a rough classification first. Put the pictures of the Coma and the Hercules cluster in front of you (even the bad photocopies might be good enough for this). The scales and the exposure times of those pictures are slightly different, but that's not so important for now.

- a) What are the dominant types of galaxies in the Coma Cluster? _____
- b) What are the dominant types of galaxies in the Hercules Cluster? _____
- c) Using the magnified pictures on the computer, please classify ~30 galaxies and count the number of galaxies in each category. (You might like to use color pens marking the galaxies you already classified as E, S, or Irr). Fill out the table below.

	Elliptical	Spiral	Irregular	Total Number
Coma				
Hercules				

- d) Determine the percentage fractions of Elliptical, Spiral, and Irregular.

$$\text{percentage fraction} = \frac{\# \text{ of ellipticals}}{\text{total \# of galaxies}} \times 100$$

	Density	Elliptical	Spiral	Irregular
Coma	very dense			
Hercules	not so dense			
Poor groups	few galaxies	25%	70%	5%

- e) How does the proportion of Elliptical and Spiral Galaxies depend on the density of the Environment?

- f) As the universe ages, galaxies gravitate toward each other, in other words, clusters tend to get denser. What impact could such an evolution have on the morphologies of the galaxies?

Coma Cluster

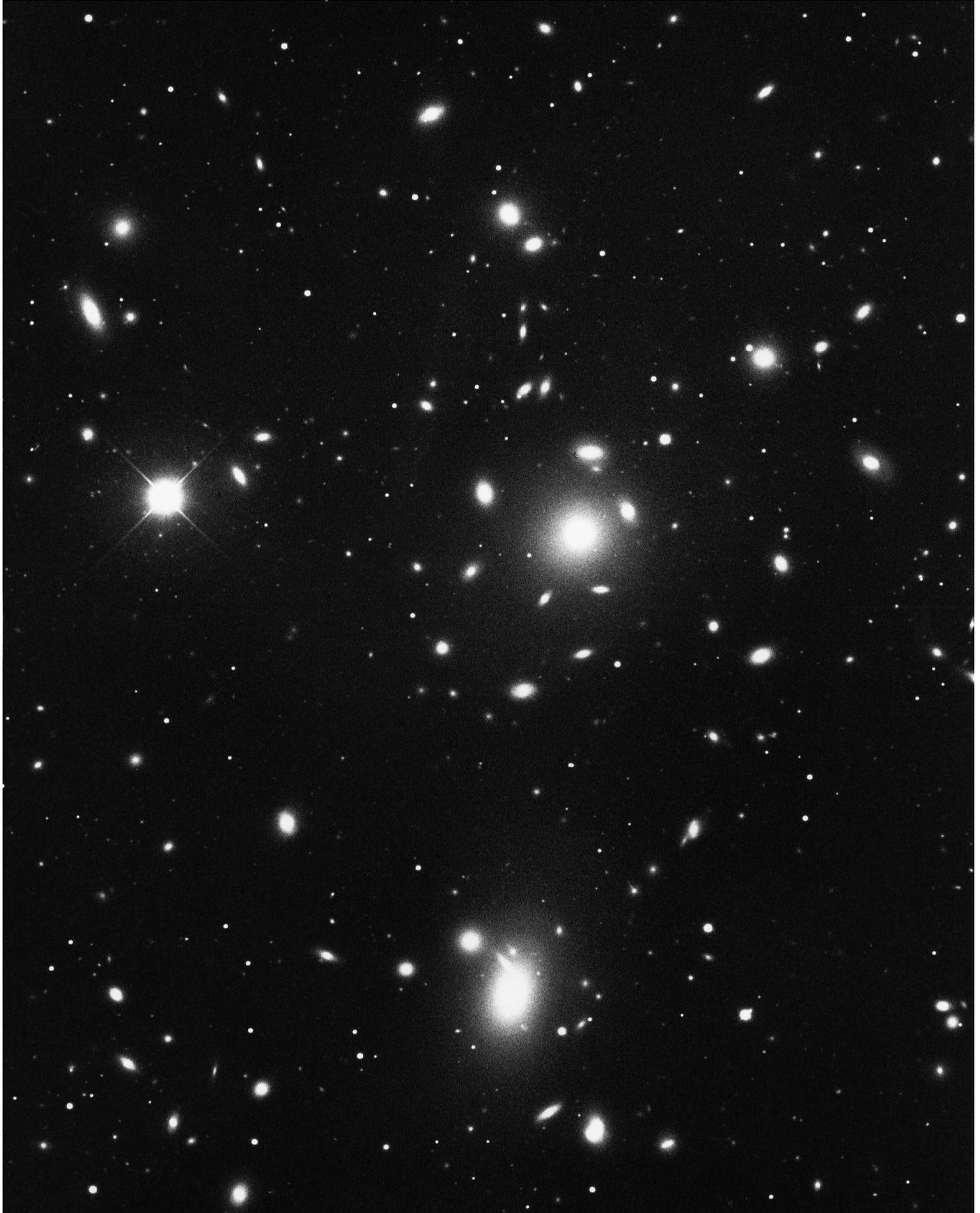


Image from http://www.noao.edu/image_gallery/galaxies.html

Hercules Cluster

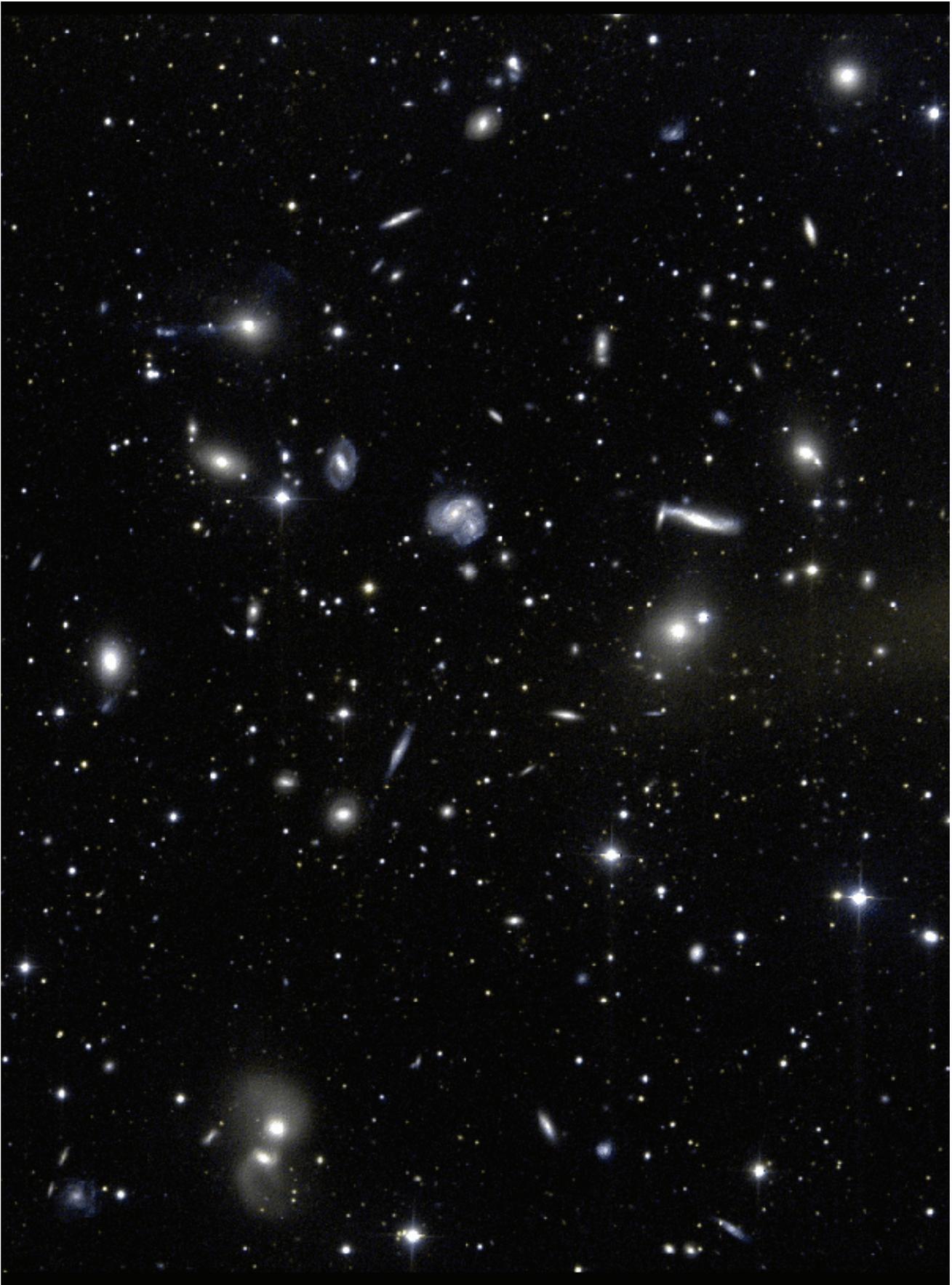


Image from http://www.noao.edu/image_gallery/galaxies.html

Part IV – Galaxy Evolution

a) Look at the Hubble Deep Field. These are galaxies at the edge of the universe. Since light from them takes a long time to reach us, most of those galaxies are intrinsically young. Take a part of that picture and count the number of Elliptical, Spiral, and Irregular galaxies. Determine the PERCENTAGES of Elliptical, Spiral, and Irregular galaxies and complete the table below.

		% Elliptical	% Spiral	% Irregular
Nearby Galaxies; Observed Today	Coma			
	Hercules			
	Poor Groups	25%	70%	5%
Distant Galaxies	Field Galaxies in the HDF			

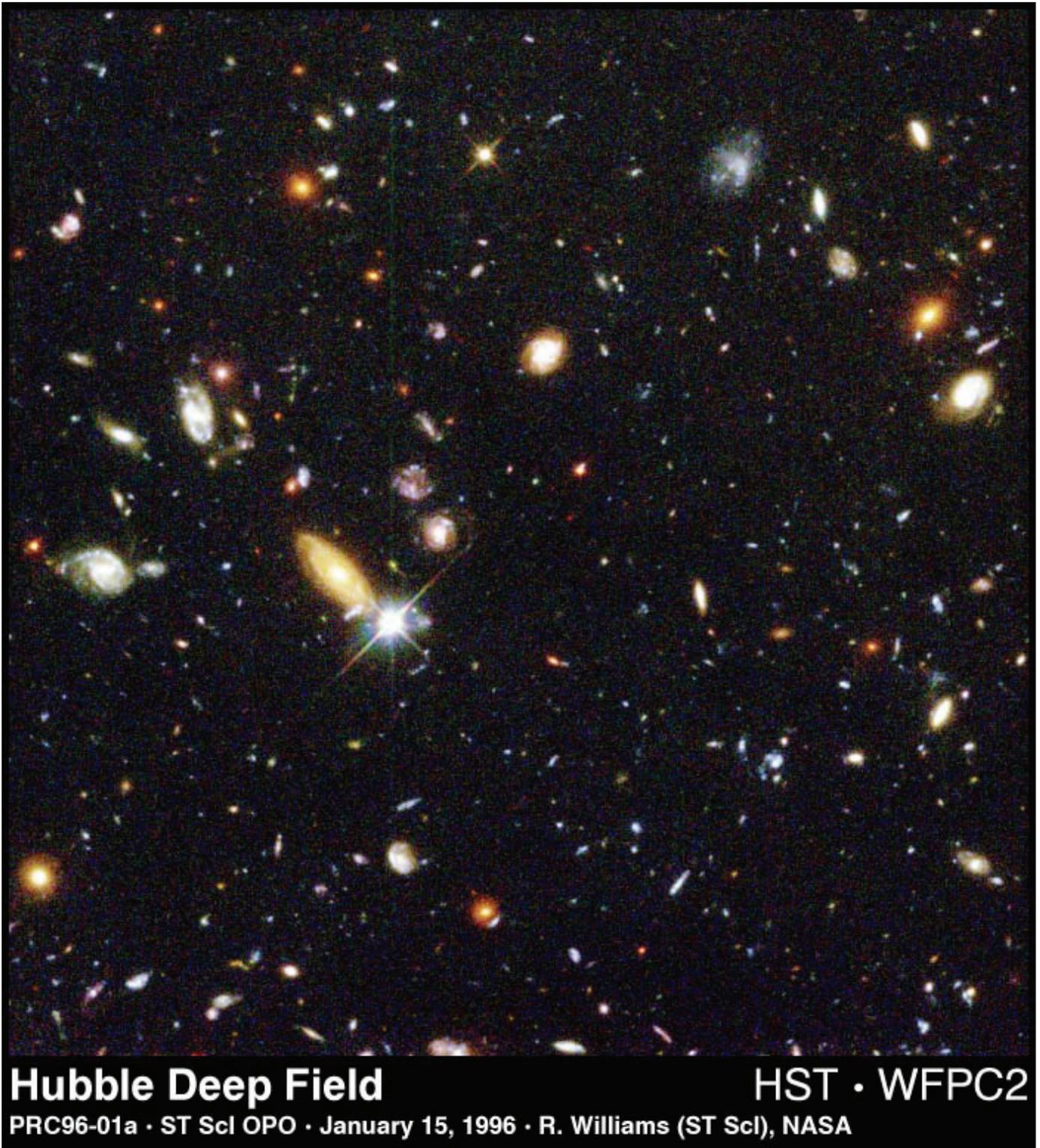
b) How are today’s “field galaxies and galaxies in poor groups” different from distant ones?

c) Look at the elliptical galaxies in the HDF. Do those Ellipticals look any different from elliptical galaxies seen today? What can you infer about the ages of those galaxies?

d) Which types of galaxies have evolved most? Justify your argument.

e) Comment on the overall evolution of galaxies in the universe, and the role of the environment.

The Hubble Deep Field



Hubble Deep Field

HST · WFPC2

PRC96-01a · ST ScI OPO · January 15, 1996 · R. Williams (ST ScI), NASA

This is a picture of the Hubble Deep Field (HDF) at <http://www.stsci.edu/ftp/science/hdf/hdf.html>. It was taken with the Hubble Space Telescope for 15 consecutive days. It is the deepest image taken of the sky (apart from the Hubble Deep Field South). You virtually see galaxies at the edge of the universe (and everything else in between). This is a picture of the most distant galaxies we have seen to date.

Lab Report

1) Objective of the Lab.

2) Describe the *Classification* Scheme you used in Part I.

3) Summarize the results from Part II. **Critically** discuss this *Classification* Scheme. Is it a useful scheme? Why / why not? Invent an **alternate** classification scheme. In what sense does your scheme do a better job than the Hubble scheme? **Explain.**

- 4) **SUMMARIZE** the results from Part III and IV Table. Copy the numbers from the first and second tables in part III into the table below. Also copy the numbers from the first table in Part IV into the bottom row.

	Ellipticals		Spirals		Irregulars	
	#	%	#	%	#	%
Coma						
Hercules						
Poor Groups	---	25%	---	70%	---	5%
HDF						

Use Words to summarize the results from the above Table.

- 5) **ANALYZE** your results and think about the significance of the numbers you just summarized. Now let's assume you misclassified some galaxies. Two of the elliptical galaxies in Coma are in fact Spirals, two of the Spirals in Hercules are Ellipticals, and two of the Irregulars in the HDF are spirals. Insert the new numbers into the table below and calculate the percentages.

	Ellipticals		Spirals		Irregulars	
	#	%	#	%	#	%
Coma						
Hercules						
Poor Groups	---	25%	---	70%	---	5%
HDF						

Compare the results from the two above tables. How different are the numbers in the second table? How do they affect what you said in the previous point?

6) **EXPLAIN** what the results from points 4 and 5 tell you about how galaxies evolve and how this evolution depends of the environments of galaxies.

7) Because Lenticular Galaxies (the S0's) are often misclassified as Ellipticals, they were not included in Parts III and IV. Below is a Table including these Galaxies. Comment on how this would refine the conclusions you reached in point 6.

	Elliptical	Lenticular	Spiral	Irregular
Coma	40 %	48 %	10 %	2 %
Hercules	20 %	44 %	32 %	4 %
Poor Groups	10 %	30 %	55 %	5 %
Galaxies in HDF	30 %	20 %	30 %	20 %

8) **For Extra Credit** suggest **mechanisms** that may make galaxies evolve. Mention these mechanisms might change the galaxy morphologies (for example, galaxies may collide and merge, but there are also many other ways in which galaxies may change).
