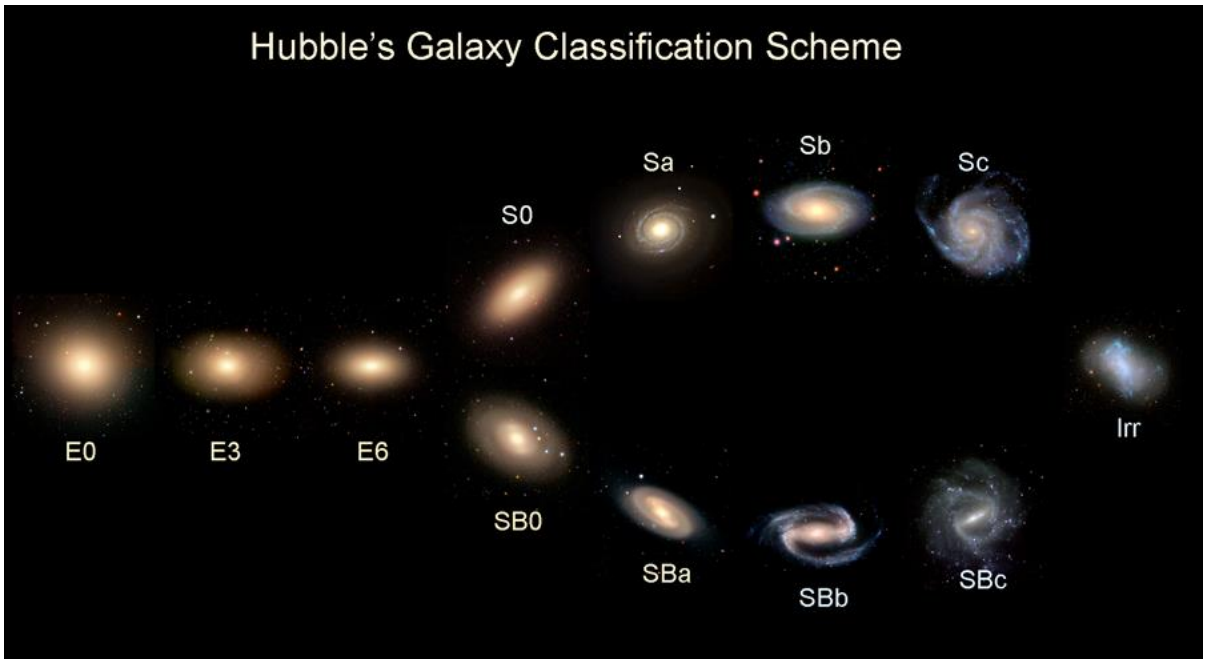
AS102 DAY LABORATORY EXERCISE:
Galaxy Classification

Goals:

- To learn about some of the properties of galaxies
- To classify galaxies according to their shapes
- To relate colors of galaxies to their classifications
- To associate classifications to the amount of star formation in a galaxy

Introduction

The roughly 2 trillion (2×10^{12}) galaxies in the part of the universe that we can see have a variety of shapes. Astronomers use a classification scheme that describes fairly well the characteristics of galaxies. Although some astronomers have proposed rather complicated schemes to describe details of the appearance of galaxies, an old scheme devised by Edwin Hubble suffices for many purposes. In this scheme, there are 3 basic types of galaxies: **elliptical, spiral,** and **irregular**. Note how the colors range from red to blue as one progresses to the right.



Elliptical galaxies ("E) range from circular (E0) to very elongated (E7). Spiral galaxies ("S") are classified according to how spread out their spiral "arms" are. S0 means arms so tight that one cannot separate them. (These are often called "lenticular" galaxies because they look like a convex lens when view edge-on.) Tightly spaced but discernable arms correspond to Sa galaxies; the loosest arms are in Sc galaxies. If there is a "bar" of stars through the center ("nucleus"), with the spiral arms emerging from the ends of the bar, the letter "B" (for "barred") is added after "S". The Milky Way, which contains about 100 billion stars, is an SBc galaxy. Galaxies without a regular pattern are simply called "irregulars" (Irr).

Elliptical galaxies have a wide range of sizes, from "giant" to "dwarf." The largest ellipticals, which can contain more than 100 trillion (10^{14}) stars, are found at or near the centers of clusters of galaxies. Astronomers have concluded that these have grown so large over billions of years by merging with other galaxies in their cluster. Spiral galaxies have a smaller range of masses and sizes, with the 100 billion stars in the Milky Way being somewhat above the average. The Milky Way is the 2nd largest galaxy in our Local Group of about 40 galaxies. The largest, the Andromeda Galaxy (catalog name M31), has about 2 times the number of stars as the Milky Way.

The center of a galaxy, its **nucleus**, contain a super-massive black hole with mass between 100,000 and 10 billion times the mass of the Sun, but with a size comparable to the orbits of planets in our Solar System. The nucleus also contains, on larger scales, one or more dense clusters of stars, which makes the nucleus brighter than the outer regions of the galaxy.

Most elliptical galaxies have red colors, indicating that they no longer have active star formation, so that most of the blue stars, whose lifetimes are relatively short, have died. S0 galaxies are also mostly red, while the spiral arms of Sa, SBa, Sb, SBb, and especially Sc, SBc galaxies have blue colors, as do most irregular galaxies. Some elliptical galaxies have regions of active star formation if a spiral or irregular galaxy is currently (as we see it) merging with it. During and after such a merging event, stars and gas clouds can fall into the super-massive black hole at the center of the galaxy. The infalling matter forms an accretion disk, which is very hot (roughly 100,000 K) within a few Schwarzschild radii of the black hole and radiates visible and UV light with an extremely high luminosity. Such an "active galactic nucleus" (AGN) can outshine the rest of the galaxy. The most luminous AGNs, called "quasars," can be so bright that it is extremely difficult even to detect the surrounding galaxy of stars because the contrast can be greater than the dynamic range (ratio of brightest to faintest detectable light) of the image.

Exercise in Classification of Galaxies in the GEMS Survey

A group of astronomers used very long-exposure images made with the Hubble Space Telescope to study galaxies within a small area on the sky. On the following 5 pages you will find the images of the brightest 125 of these galaxies. **Use the classification system on page 1 and the information in the previous paragraph to classify each of these galaxies as one of the following**:

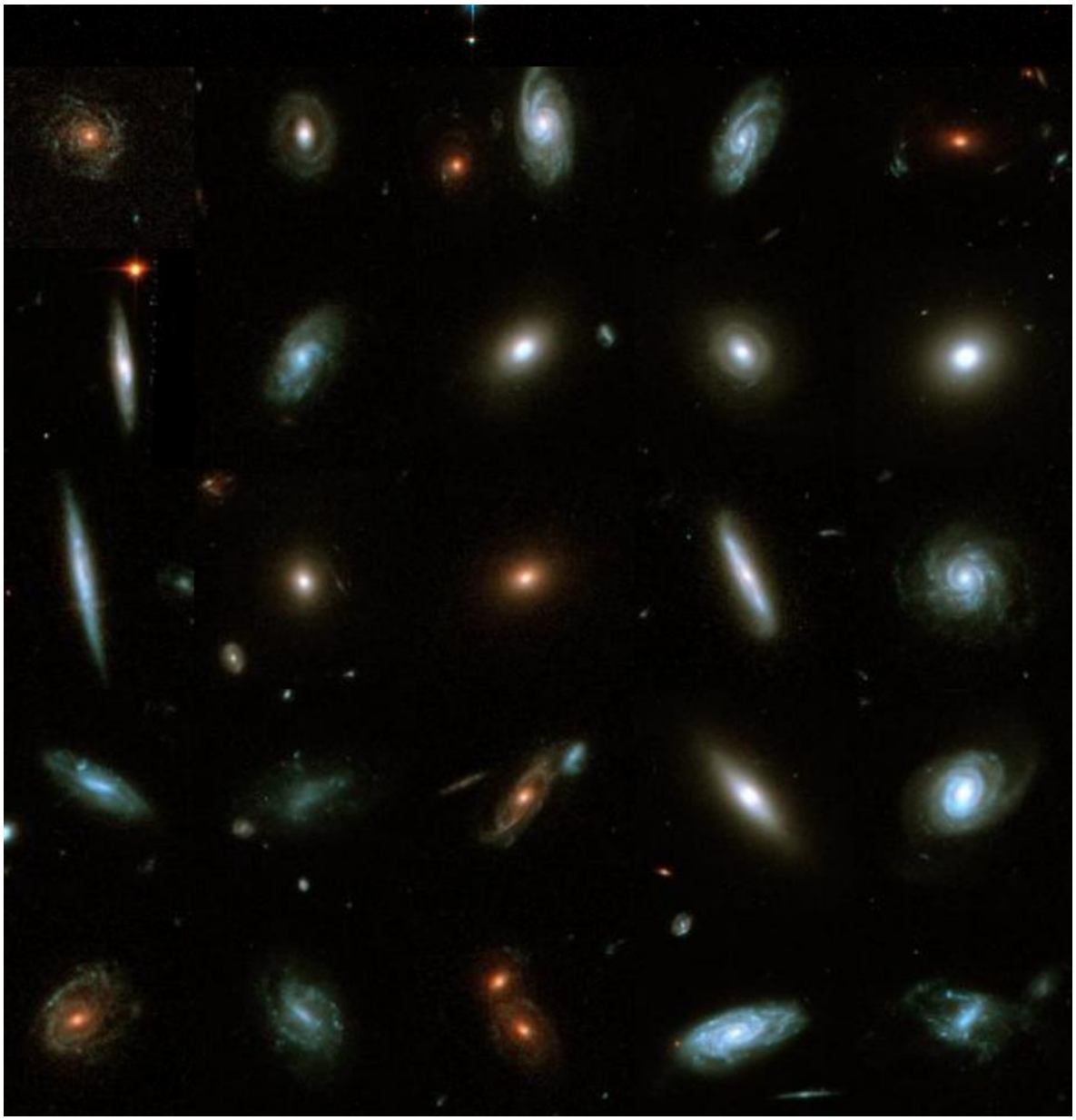
E0, E1, E2, E3, E4, E5, E6, E7, S0, Sa, SBa, Sb, SBb, Sc, SBc, Irr, M (for "merger"), and AGN.

The galaxies are numbered 1 – 125. **Ignore any small galaxies that are near the larger ones. There are likely to be some cases where the classification is uncertain. In that case, put a question mark (?) after your suggested classification**.

A merger can be identified by distortions in the shape of a spiral or elliptical galaxy, two or more bright nuclei, or a dark area cause by dust in an elliptical galaxy. An AGN has an extremely bright nucleus.

By inspecting the image of each galaxy, determine its dominant color as R (red) or B (blue). For the spiral galaxies, the color should correspond to the spiral arms, not the central region.

Write your classification and color determination for each galaxy in the spaces provided on each page. Then answer the questions on the last page.



Galaxy numbers

1 – 5

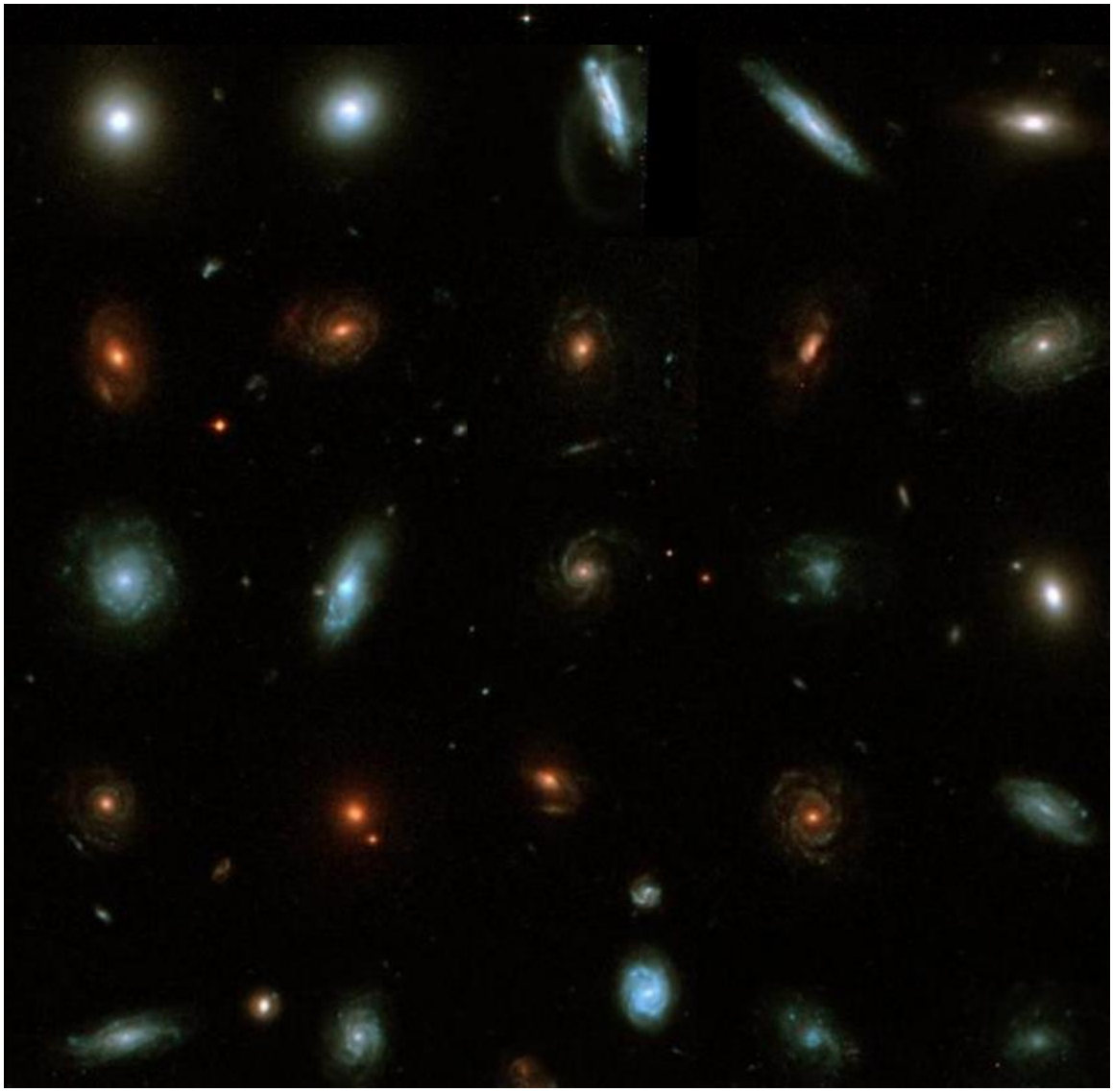
6 – 10

11 – 15

16 – 20

21 – 25

	Classification	Color
1.	_____	_____
2.	_____	_____
3.	_____	_____
4.	_____	_____
5.	_____	_____
6.	_____	_____
7.	_____	_____
8.	_____	_____
9.	_____	_____
10.	_____	_____
11.	_____	_____
12.	_____	_____
13.	_____	_____
14.	_____	_____
15.	_____	_____
16.	_____	_____
17.	_____	_____
18.	_____	_____
19.	_____	_____
20.	_____	_____
21.	_____	_____
22.	_____	_____
23.	_____	_____
24.	_____	_____
25.	_____	_____



Galaxy numbers

26 – 30

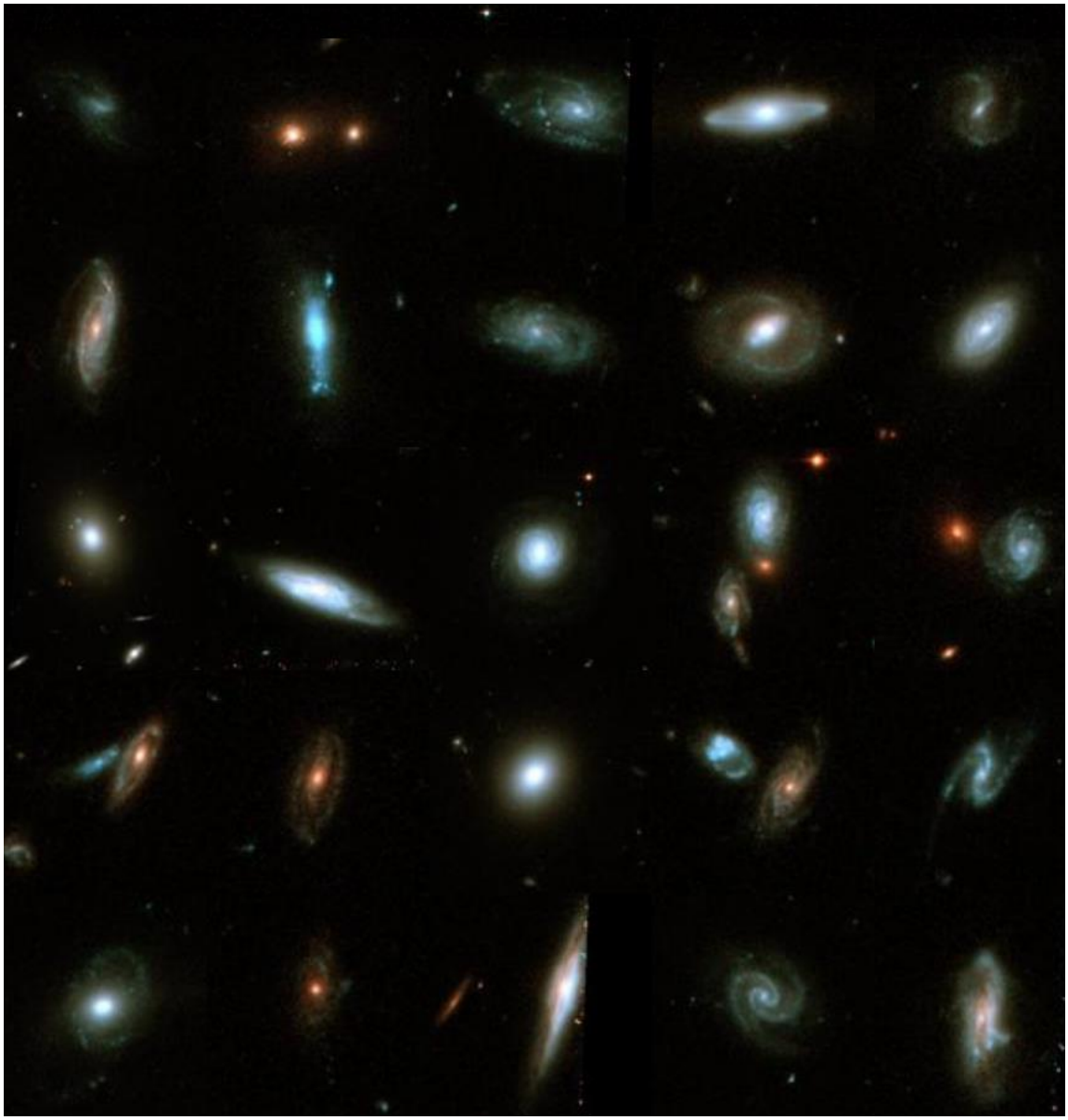
31 – 35

36 – 40

41 – 45

46 – 50

	Classification	Color
26.	_____	_____
27.	_____	_____
28.	_____	_____
29.	_____	_____
30.	_____	_____
31.	_____	_____
32.	_____	_____
33.	_____	_____
34.	_____	_____
35.	_____	_____
36.	_____	_____
37.	_____	_____
38.	_____	_____
39.	_____	_____
40.	_____	_____
41.	_____	_____
42.	_____	_____
43.	_____	_____
44.	_____	_____
45.	_____	_____
46.	_____	_____
47.	_____	_____
48.	_____	_____
49.	_____	_____
50.	_____	_____



Galaxy numbers

51 – 55

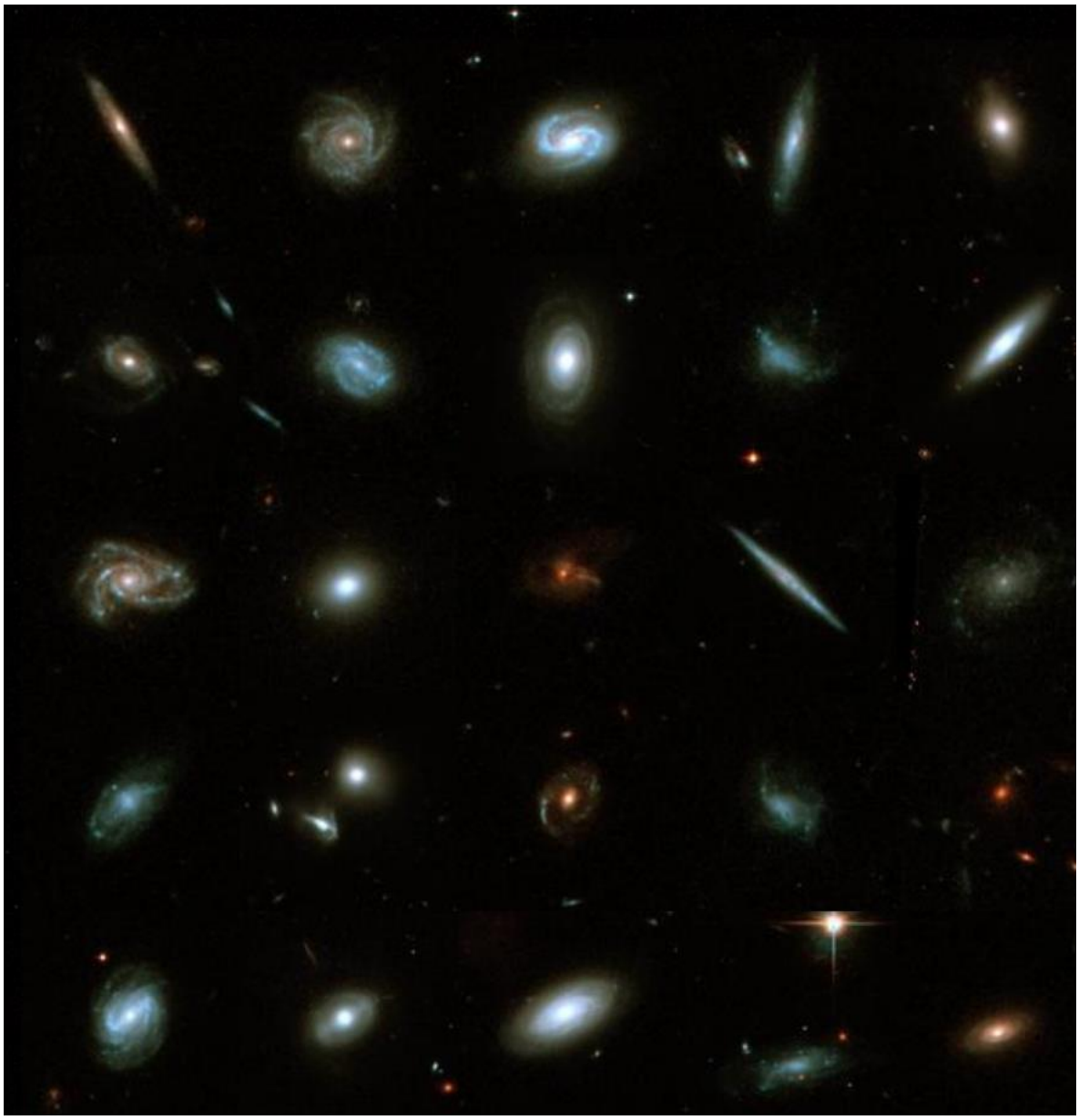
56 – 60

61 – 65

66 – 70

71 – 75

	Classification	Color
51.	_____	_____
52.	_____	_____
53.	_____	_____
54.	_____	_____
55.	_____	_____
56.	_____	_____
57.	_____	_____
58.	_____	_____
59.	_____	_____
60.	_____	_____
61.	_____	_____
62.	_____	_____
63.	_____	_____
64.	_____	_____
65.	_____	_____
66.	_____	_____
67.	_____	_____
68.	_____	_____
69.	_____	_____
70.	_____	_____
71.	_____	_____
72.	_____	_____
73.	_____	_____
74.	_____	_____
75.	_____	_____



Galaxy numbers

76 – 80

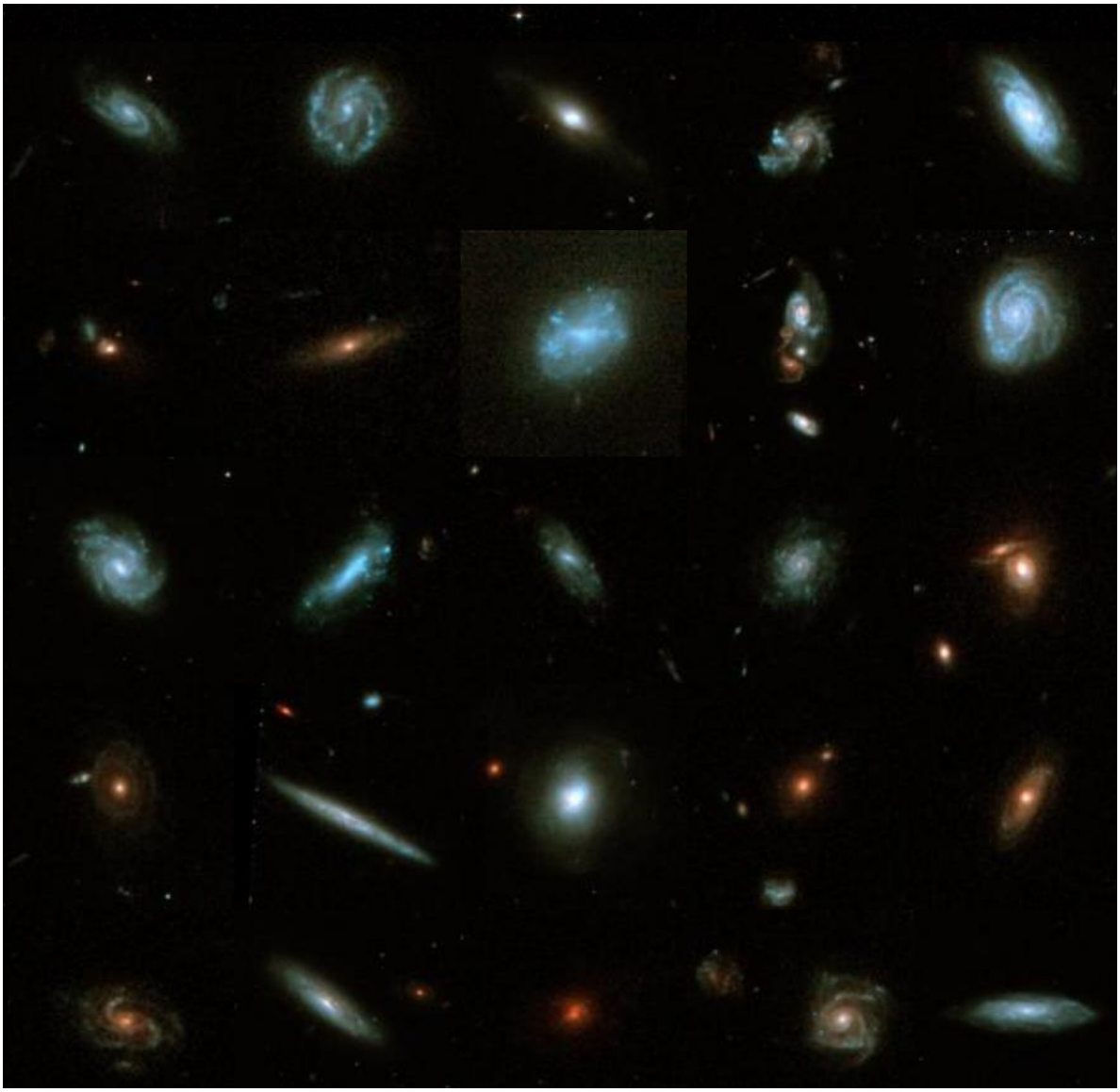
81 – 85

86 – 90

91 – 95

96 – 100

	Classification	Color
76.	_____	_____
77.	_____	_____
78.	_____	_____
79.	_____	_____
80.	_____	_____
81.	_____	_____
82.	_____	_____
83.	_____	_____
84.	_____	_____
85.	_____	_____
86.	_____	_____
87.	_____	_____
88.	_____	_____
89.	_____	_____
90.	_____	_____
91.	_____	_____
92.	_____	_____
93.	_____	_____
94.	_____	_____
95.	_____	_____
96.	_____	_____
97.	_____	_____
98.	_____	_____
99.	_____	_____
100.	_____	_____



Galaxy numbers

101 – 105

106 – 110

111 – 115

116 – 120

121 – 125

	Classification	Color
101.	_____	_____
102.	_____	_____
103.	_____	_____
104.	_____	_____
105.	_____	_____
106.	_____	_____
107.	_____	_____
108.	_____	_____
109.	_____	_____
110.	_____	_____
111.	_____	_____
112.	_____	_____
113.	_____	_____
114.	_____	_____
115.	_____	_____
116.	_____	_____
117.	_____	_____
118.	_____	_____
119.	_____	_____
120.	_____	_____
121.	_____	_____
122.	_____	_____
123.	_____	_____
124.	_____	_____
125.	_____	_____

Your name:

Summary Questions

1. How many elliptical, spiral, and irregular galaxies, mergers, and AGNs did you classify?

E: _____ S: _____ Irr: _____ Mergers: _____ AGNs: _____

Divide each number by 125 total galaxies and multiply the result by 100% to determine the percent of galaxies in each class:

E: _____ S: _____ Irr: _____ Mergers: _____ AGNs: _____

2. Do the colors of the different types of galaxies correspond to the expectations discussed in the Introduction and the figure on page 1? (Answer only for elliptical, spiral, and irregular galaxies.)

Based on your answer, do any of the elliptical galaxies that you classified appear to have active star formation? If so, indicate their numbers:

Do any of the spiral (not including S0) or irregular galaxies appear <u>not</u> to be actively forming stars? If so, indicate their numbers:

3. Are the central regions of spiral galaxies similar in shape and color to elliptical galaxies? If so, this suggests that the population of stars (in terms of whether they are all old or there is active star formation) is similar. Draw a conclusion from this comparison: Can spiral galaxies be described as the combination of an elliptical galaxy plus a disk with spiral arms?

4. Astronomers have found that the mass of the black hole at the center of a galaxy is proportional to the mass of its elliptical part. (For elliptical galaxies, this is the entire galaxy, for spirals it is the central elliptical region.) Based on the diagram on page 1, what types of galaxies would you then expect to have the most massive central black holes?

Give 5 galaxy numbers from the 125 galaxies that you have classified where you would predict the most massive central black holes:

_____ _____ _____ _____ _____