

# GCET Teacher's Guide

(The Galaxies and Cosmos Explorer Tool- [www.as.utexas.edu/gcet](http://www.as.utexas.edu/gcet) )  
(Using older versions of Microsoft Excel)

## Introduction

This computer-based activity is focused on galactic astronomy, specifically learning how to classify different galaxy types and investigating how galaxies might evolve over the age of the Universe. The activity uses a new online tool called the 'Galaxies and Cosmos Explorer Tool' (GCET) that contains thousands of galaxy images taken with the Hubble Space Telescope (HST). Students follow a worksheet guide to learn how to use GCET, and then use the images and data provided in GCET to:

- (1) determine galaxy types (morphology) in two wavelength bands
- (2) measure the relative diameters of galaxies
- (3) measure galaxy ages in terms of lookback time
- (4) collect a class sample of many analyzed galaxies, plot the data in a chart using Excel, and interpret the results to learn about galaxy evolution

## Materials and Preparation

This activity requires a computer lab.

**The teacher** will need:

- 1) **This teacher guide**
- 2) **A computer**
- 3) **A projector** connected to the computer and **a screen**

**Each student** will need:

- 1) **A student guide worksheet**
- 2) **A computer** - each student computer requires the following:

Javascript must be enabled

Pop-up blocker must be turned off

Flash plug-in must be installed

*\*Mozilla Firefox is the best browser to use. Internet Explorer has been known to not properly run the programs.*

**Before introducing GCET in class**, familiarize yourself with it and go through the student worksheet to make sure that all steps work correctly (e.g., pop-up windows work). The **Help** menu at the top of the main GCET page ([www.as.utexas.edu/gcet](http://www.as.utexas.edu/gcet)) has step-by-step instructions to get started. You may want to pick out a few interesting objects to show the students when you demo GCET in class.

## Pre-requisites

Students should already be familiar with the following concepts:

**Galaxy types (morphology)**: spiral, barred spiral, elliptical, irregular

**Multi-wavelength astronomy as it relates to galaxies**: the various parts of galaxies that can be seen by looking at their light in many different wavelengths

**Basic properties of stars and their colors**: blue stars are hot, bright, and young, while red stars are cool, dim, and often old. Students should also be familiar with how this corresponds to color features in galaxies (e.g., blue spiral arms contain new hot bright stars).

**Arcseconds as a measurement of size:** astronomers often measure a galaxy by its apparent angular size (how much space it takes up in the celestial sphere) as opposed to its actual physical size (which is harder to measure).

**Distance in space vs. lookback time:** because light has a speed limit, the farther out in space we look the farther back in time we see.

**Cosmological redshift:** the redshift of a galaxy tells us both its age and distance.

**Observed wavelength vs. rest-frame wavelength:** because of redshifting, the light from a galaxy we observe is not the same wavelength as the light that was originally emitted.

## Introducing GCET

To introduce GCET, do a quick demo in front of the class. Make sure to explain that the images were taken as part of a survey with the Hubble Space Telescope in two filters of light (one bluer and one redder). Click and zoom in on a few tiles to show the students just how many objects there are to explore. Click on a few interesting objects (e.g., different types of galaxies) and show the students what type of information is available for each galaxy: the galaxy ID, the wavelength of the image, and the redshift of the galaxy.

## GCET Student Worksheet

Next, the students should work through the GCET student worksheet. This activity will familiarize them with all of the features of GCET and will walk them through the steps of classifying the morphology of a galaxy, measuring its size (major axis) and age, and recording that information in the Analysis pop-up window. *This will take approximately 45-50 minutes.*

Here are some **important concepts and definitions** that you might want to discuss with the students as they work through the steps in the worksheet:

**Step 3:** A “tile” refers to an image from one pointing of the Hubble. Each of these images or tiles are woven together to make the full mosaic and cover the whole field of view.

**Step 4:** In this step, students compare a Hubble image with the same piece of sky as imaged with a ground-based telescope. They should notice how much sharper the Hubble image looks. It is important to point out that the difference in resolution is not because the Hubble is more powerful or that it is in space and therefore closer to the astronomical objects (a common misconception)! In fact, the difference in distance between a telescope on the Earth’s surface and one in an orbit around Earth, compared to the distances to the galaxies is absolutely negligible. The huge advantage of putting a telescope in space is that it does not have to look through the atmosphere, which causes the blurring and smearing seen in the ground-based image.

**Step 5:** Students will notice that some objects in the image are galaxies, and that others are stars. All of the stars we see in these images are stars in our own galaxy, the Milky Way. Because other galaxies are so far away, it is next to impossible to see individual stars in them (except for the very nearest galaxies). Because we live in the disk of our galaxy, when we look out into space, we have to look through some stars in our galaxy, and these are the “foreground” stars seen in some of the images.

**Step 6:**

**B)** Some students may notice that the spiral galaxies look somewhat different in the two filters of light. They may look much smoother in the redder filter (F850LP) and more patchy in the blue filter (F606W). You can remind them that the blue filter is detecting light from the clusters of

hot, young stars in the galaxy. Also the blue light is more easily absorbed by dust in the galaxy, so the galaxy looks more patchy and knotty in blue light. The red filter is detecting light from cooler stars. These stars are distributed more evenly in the disk, and the red light is not as easily absorbed by dust, making the red image look smoother.

C) You may want to review the concept of lookback time with the students. Because light travels at a constant speed, it takes a long time for light from very distant galaxies to reach us. Therefore, when we look at very distant objects, we are seeing them as they were a very long time ago – the light that they emitted billions of years ago is just reaching us now. The farther away a galaxy is, the farther back in time we are looking.

## Student Quiz

After the students have completed the worksheet, administer the quiz to test their skills at using GCET.

### Teacher Guide Answers to Student Quiz

This first **scavenger hunt** section does not need to be graded. Questions #1-4 can be graded, with each blank counting 10%.

1) ID# 3962  
Lookback time = 8.378 bil yrs

2) C  
A  
E  
F  
D  
B

3) The spiral galaxy is CLOSER to us

4) 13.7 billion years  
(the age of the universe)

### Using GCET – Student Quiz

Scavenger Hunt: Find three galaxies in GCET that fit each of the following characteristics:

<u>Galaxy Characteristic</u>	<u>Three Galaxies that Qualify</u> (Write down each Galaxy Id#)		
Spiral Galaxy	_____	_____	_____
Elliptical Galaxy	_____	_____	_____
Galaxy with a redshift (z) less than 0.150 <i>(Hint: these are very close, blue and bright)</i>	_____	_____	_____
Galaxy with a redshift (z) greater than 1.00 <i>(Hint: these are very distant, red and faint)</i>	_____	_____	_____

1) Go to tile# 24 - somewhere in the upper right quadrant is a barred spiral galaxy with a very high redshift of  $z = 1.1250$ .

What is the galaxy Id#? \_\_\_\_\_

How old is the light coming from this galaxy (its look back time)? \_\_\_\_\_

2) Go to tile# 34 – near the upper left portion of the tile you'll see an area that looks like this →  
(without the letters of course)



Match the objects in this area with the most accurate description (write in the letter):

- \_\_\_\_\_ A star that is in the foreground (inside our own Milky Way galaxy)
- \_\_\_\_\_ An obvious elliptical galaxy
- \_\_\_\_\_ A faint spiral galaxy with a redshift of  $z = 0.789$
- \_\_\_\_\_ A galaxy that could either be an irregular or a barred spiral (not enough detail to know)
- \_\_\_\_\_ An obvious bright spiral galaxy
- \_\_\_\_\_ A galaxy that could be spiral, elliptical, or irregular (not enough detail to know)

3) Go to tile# 30 – there are two bright elliptical galaxies on the left side of the tile (ID #s 4537 & 4489) and there is also a bright spiral galaxy near the bottom of the tile (ID# 4446). Is the spiral galaxy closer to us or further away than the two ellipticals?

4) Measure the age of any galaxy, look at the 'Analysis' pop-up window – Add the number for 'Age of the Universe' to the number for 'Look back time'. What do you get for the sum?

# GCET Activity – Exploring Galaxy Evolution Over Cosmic Time

## Goals:

Now that the students have completed the student worksheet and quiz (*about 45-50 minutes*), introduce part two of the GCET activity. In the thousands of galaxies imaged by Hubble available in GCET, there are galaxies of all types, at many different distances, and therefore of many different ages. The availability of this large amount of data is a goldmine for astronomers who want to piece together how galaxies change and evolve over time.

The goal in this activity is to do just that, by having the class analyze a large sample of galaxies (several hundred if possible) to see whether the properties of galaxies change as we look back in time. You will plot the percentages of different types of galaxies as a function of lookback time. This plot will help you answer the questions: Do galaxies stay the same or do they change and evolve as the Universe ages? Do the galaxies in the distant past look the same as galaxies of the present day? If they are different - how so? Also, you will discuss what types of problems astronomers can encounter when they try to analyze galaxies.

## Student instructions:

(1) The students should use the skills that they learned from the student worksheet to pick galaxies from the HST tiles and record for each galaxy

- a) the galaxy size (major axis) in both filters
- b) the galaxy type (S, SB, E, I) in both filters
- c) the lookback time of the galaxy

for a sample of 30-50 galaxies per student. The number of galaxies per student can be adjusted depending on the time available. You may consider assigning each student their own tile to measure. For best results, the total number of galaxies classified by the whole class put together should be several hundred.

(2) For each galaxy, after the student has entered the information in the Analysis pop-up window, they should click **Save** at the bottom of the window to save their data before moving on to the next galaxy. The page will refresh and they will be able to analyze more galaxies by clicking the **Browse** button.

*\*\*\*Be sure to remind the students to **CLICK ‘SAVE’ FIRST, THEN ‘BROWSE’** (otherwise the data will be lost)\*\*\**

(3) When the student has recorded the properties for their target number of galaxies, they should click on the blue **Download** button on the bottom of the Analysis pop-up window. This will save their galaxy data as an Excel file, typically to the Desktop of the computer.

(4) Instruct the students to open their Excel file and make sure that everything they recorded has been uploaded to the Excel spreadsheet correctly. They should now rename the Excel spreadsheet with their name and save it.

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## Compiling and organizing student data:

This part can be done either outside of the classroom or in front of the class, depending on your preference and time constraints...

*Note: These instructions are for the older versions of Excel (version 11 or older, found in Microsoft Office packages older than 2007). Instructions for newer versions of Microsoft Excel (version 12, found in Microsoft Office 2007 or newer) can be found online at <http://www.as.utexas.edu/gcet/teachers.html>*

(1) Gather the students' saved Excel files and copy/paste all of the data into one spreadsheet (hint: it may be easier to download all of the student files onto one USB flash drive). Name this consolidated spreadsheet **GCETdataClean.xls** \*\*\*It is important that you use this exact filename\*\*\*

(2) Remove the second row (if it is blank). To do this, click on the '2' in the far left column to highlight the entire row, then in the Excel menu on top click on **Edit > Delete**.

	D	E	F	G	H	I	J
1	Title	RA	Dec	Redshift z	Rest Frame	Rest Frame	Major axis
2							
3		Sz03:3h 33m 4s -27deg 47'		0.574	3758	5783	1.71
4		Sz03:3h 33m 3s -27deg 47'		0.733	3413	5253	1.2
5		Sz03:3h 33m 3s -27deg 47'		0.418	4171	6420	3.48
6		Sz03:3h 32m 59 -27deg 47'		0.11	5329	8201	4.05
7	4656 s9z31A	GEMSz03:3h 32m 58 -27deg 47'		1.247	2632	4051	1.05
8	4661 s9z31A	GEMSz03:3h 32m 58 -27deg 47'		0.152	5135	7902	2.4
9	4659 s9z31A	GEMSz03:3h 32m 55 -27deg 47'		0.149	5148	7923	1.8
10	4645 s9z31A	GEMSz03:3h 33m 3s -27deg 47'		0.651	3583	5514	3.96
11	4644 s9z31A	GEMSz03:3h 33m 1s -27deg 47'		0.95	3033	4688	0.45
12	4642 s9z31A	GEMSz03:3h 32m 59 -27deg 47'		0.836	3222	4958	2.88
13	4648 s9z31A	GEMSz03:3h 32m 59 -27deg 47'		1.055	2878	4430	1.65
14	4646 s9z31A	GEMSz03:3h 32m 58 -27deg 47'		0.071	5523	8500	0.6
15	4651 s9z31A	GEMSz03:3h 32m 55 -27deg 47'		0.055	5607	8628	2.85
16	4652 s9z31A	GEMSz03:3h 32m 54 -27deg 47'		0.389	4258	6554	3.51
17	4639 s9z31A	GEMSz03:3h 32m 58 -27deg 48'		0.727	3425	5271	1.95

(3) **Make sure the GCETdataClean.xls is already open** on your desktop and **then double-click on the DataFormatter.xls** file to start running the program. Excel may pop up a security warning asking if you want to allow the program to run. If this happens, click "Enable Macros" in the security pop up window. It will automatically start organizing the data in your spreadsheet. The program will appear to do some strange things with your Excel files and may take several minutes to complete. *(If the program does not work or crashes, make sure that you have your data spreadsheet open, and that you have named it GCETdataClean.xls).* When the program is done running, it will have transferred the data points into a new Excel sheet with an easy-to-read table off to the right that looks something like this:

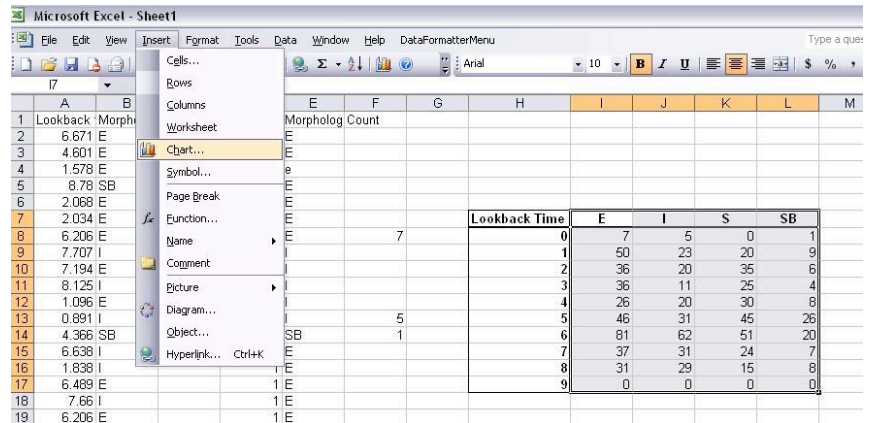
Lookback Time	E	I	S	SB
0	7	5	0	1
1	50	23	20	9
2	36	20	35	6
3	36	11	25	4
4	26	20	30	8
5	46	31	45	26
6	81	62	51	20
7	37	31	24	7
8	31	29	15	8
9	0	0	0	0

This new table shows how many galaxies of a specific morphological type there are in each lookback time bin. The '0' row represents how many galaxies of each type have a lookback time between 0 and 1 billion years (Gyr), the '1' row is for lookback times between 1 and 2 Gyr, '2' for between 2 and 3 Gyr, etc...

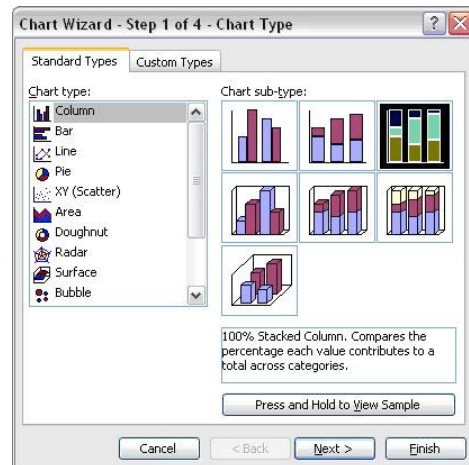
(4) Now you will make a chart of the data. In the spreadsheet where the new table is displayed:

a) Highlight the whole table excluding the first column.

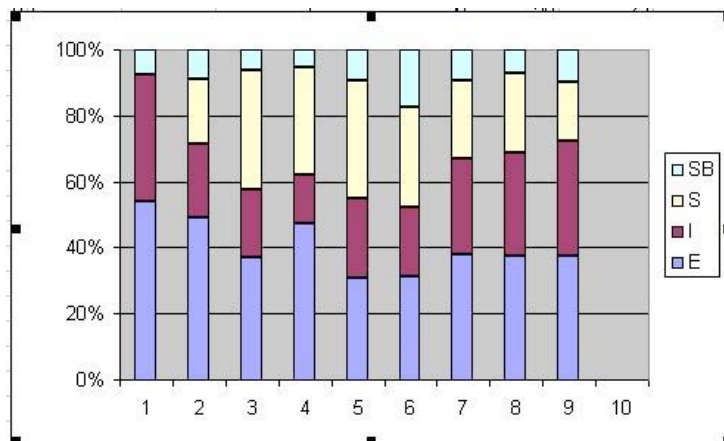
b) In the Excel menu at the top of the window, click on **Insert > Chart**



c) The chart menu window will pop up. Select chart type “**Column**” in the list on the left. In the same window, select the picture of the **100% Stacked Column** chart (the third chart picture in the first row). Click “Finish.”



(5) You should end up with a chart that looks very roughly like this, although, since your class data is different, you will have different proportions of galaxy types.



If you know how to do so, you can add the following labels to the chart:

Chart title: **Galaxy Morphology Over Cosmic Time**

[X axis] Horizontal (category) axis: **Lookback Time (Gyr)**

[Y axis] Vertical (value) axis: **[%] Galaxy Type**

Note that the x-axis values in this chart are different than in the original table (in Step 3). Here in the chart, the '1' column represents all galaxies with lookback times of 0 to 1 billion years (Gyr), the '2' column represents lookback times between 1 and 2 Gyr, '3' is between 2 and 3 Gyr, etc... The last '10' is often blank because there are very few galaxies in the GCET database with a lookback time over 9 Gyr.

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### **Interpreting and discussing the results:**

Once the plot is made, you can guide the students through interpreting the results. Here are some questions/discussion points and things to keep in mind.

#### ***(1) What does the plot show us?***

Ask the students to explain what they are seeing in the graph. They should start by looking at the axes. The x-axis shows lookback time in billions of years (Gyr) in 1 Gyr bins. The y-axis shows the percent of each galaxy type (SB, S, I, E) in each Gyr bin of time. Ask the students to point to the side of the x-axis where the most evolved galaxies are found. What about the youngest? How about the ones that are farthest away? Closest to us? (The last bins – 8 and 9 Gyr – are the most distant galaxies and therefore the youngest. The first bins – 1 and 2 Gyr - are the closest galaxies and these are also the most evolved.)

#### ***(2) Looking at the most distant (youngest) galaxies, what type of galaxy is most common?***

The students should look at the last two bins in their graph (8 or 9 Gyr) and pick out the most common type of galaxy in those bins.

#### ***(3) Looking at the closest (most evolved) galaxies, what type of galaxy is most common?***

The students should look at the first two bins in their graph (1 or 2 Gyr) and pick out the most common type of galaxy. Can they see any pattern from large to small lookback times?

#### ***(4) What if there is no pattern?***

Ask the students to think about why they may not see any sort of pattern in the chart. The true reason for this is most likely small number statistics and the small volume sampled. In other words, 50 to several hundred galaxies are not enough to show a representative picture of how galaxies evolve over such a large chunk of the age of the universe. This is why several thousand (or more) galaxies are necessary in real astronomical studies to have conclusive results.

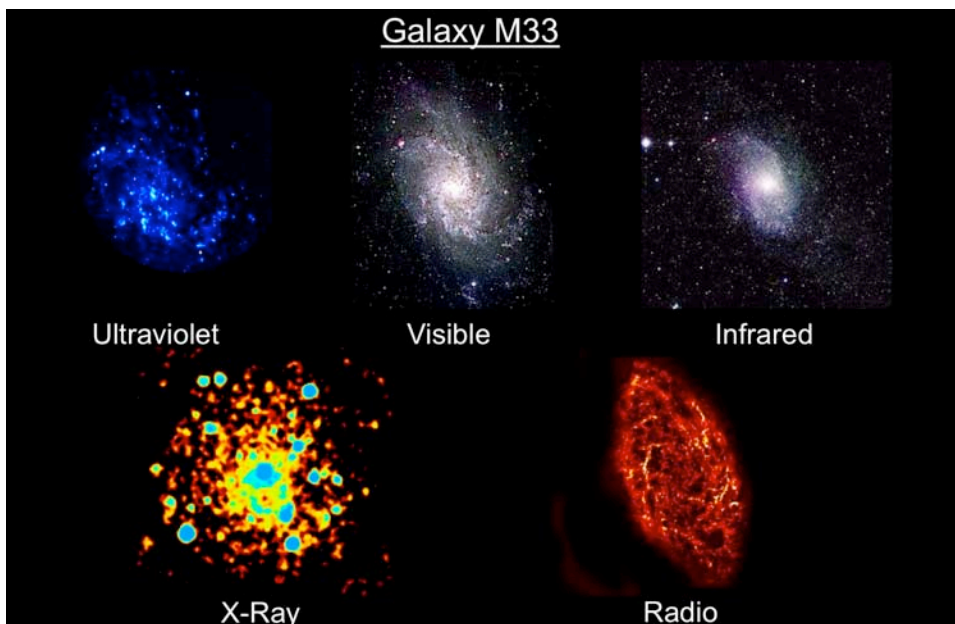
#### ***(5) Compare to what astronomers actually observe in large surveys.***

The students can compare their class plot with the example shown on the next page. This chart shows an example of what astronomers observed in one large survey with Hubble. Remember that no survey can see every galaxy, especially out to very large distances (lookback times). The mix of galaxies seen in a particular survey will depend on how faint the survey can see, and therefore different surveys may get different results. Scientists keep this in mind when

interpreting the results. These sources of error and bias are called “selection effects” and are discussed more extensively below.

In the nearby universe, (lookback times of 1 or 2 Gyr), it is easy to see galaxies even down to very faint magnitudes. So for small lookback times, the proportions of the different galaxy types are pretty well established: 20% of galaxies are ellipticals/lenticulars, and 80% are spirals and irregulars. (*Lenticular (S0) galaxies are a type of galaxy that is disk-shaped but without obvious spiral structure; they are inherently difficult to distinguish from ellipticals*). Out of the spiral galaxies, we know that approximately 50% are barred at small lookback times. But the results at larger lookback times become more uncertain. The main factor that influences the results from surveys of distant galaxies is selection effects. Selection effects must be taken into account before astronomers can draw conclusions from their results. **There are several major selection effects:**

- The farther away the galaxy is, the fainter it *appears* to us. Therefore, when we are looking at the farthest galaxies, we only see the very brightest ones, because the rest are just too faint to see. Generally, elliptical galaxies are much brighter than spirals and irregulars. Because of this, we will tend to see an artificially higher proportion of ellipticals to spirals and irregulars at higher lookback times. For nearby galaxies however, we can see both the faint and the bright. This effect might bias our results when comparing the proportions of ellipticals to spirals at low and high lookback times.
- The farther away the galaxy is, the less detail we can see. The farthest galaxies just look like smudges even though they may really be spirals with a lot of spiral structure or irregular galaxies. The students may even have classified some of these galaxies as ellipticals. For example, astronomers are now trying to determine whether barred spiral galaxies were just as common in the past. What does the plot on the next page? Can we tell whether this trend is real?
- Another very important effect comes from redshifting. Remember that the farther away a galaxy is, the more stretched out (redshifted) its light gets as it travels to us. Because of this, we preferentially see the light from younger and younger (bluer) stars as we look at more distant galaxies. This can drastically change the appearance of a galaxy, even making some distant spiral and irregular galaxies look like ellipticals. For example, look at the images of the same galaxy, M33, at different wavelengths:

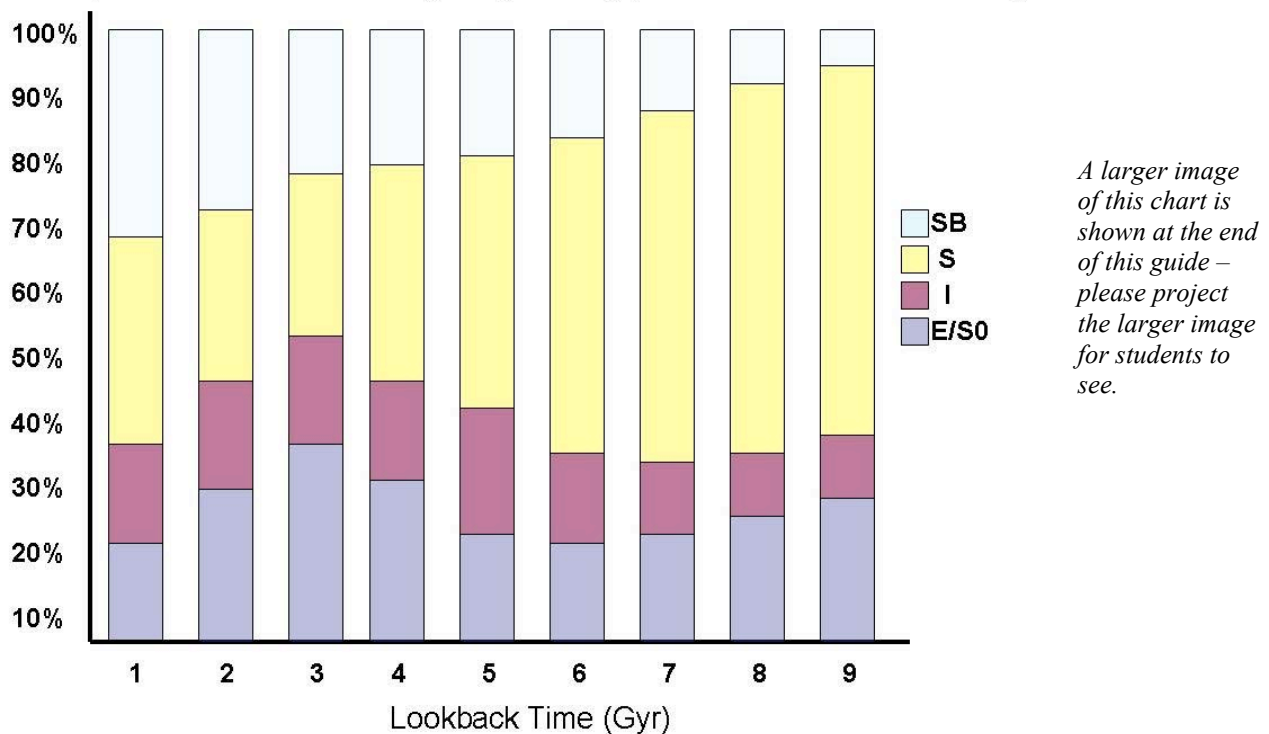


*A larger version of this image is shown at the end of this guide –please project the larger image for students to see.*

- Another source of error may be that the plot is made by combining classifications from many different classifiers. Even if everyone is really careful during classification, there are still subjective differences in the galaxy classifications from person to person when the galaxy type is not obvious. For example, what one person calls a spiral, another might call an irregular. Real astronomers deal with this problem too. To try to account for this source of error, it is common practice to have several astronomers classify the same set of galaxies and then measure the difference in their classifications.

Looking at the chart below, we see that the fraction of spirals first decreases then increases as you go to larger and larger lookback times. The fraction of ellipticals also starts to increase past the lookback time of 6 Gyr. It is difficult to say whether this increase of ellipticals is real, or whether it is caused by selection effects. In addition, the more distant the galaxy, the fuzzier it looks in images, and therefore the harder it is to see detailed structure like a bar. Looking at the fraction of barred spirals with lookback time, we can see that it appears to decrease dramatically as you look deeper into the past. It is not possible at this stage to say how much of this decrease is real or how much is caused by selection effects. The fraction of irregular galaxies appears to stay mostly constant. However, irregulars are the faintest of all galaxy types, so this class should be the most affected by selection effects.

#### Example of results from one galaxy survey (based on selection effects)

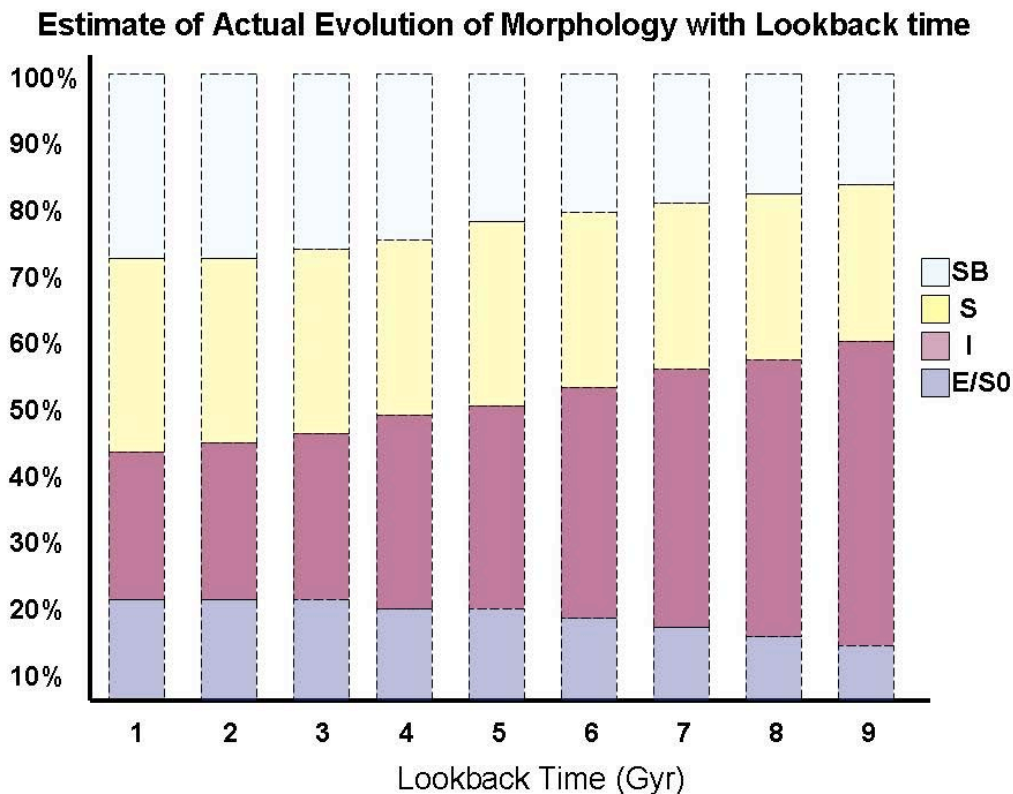


#### (6) So then how do galaxy morphologies ACTUALLY evolve out to lookback time of 9Gyr?

Based on the discussion of selection effects above, and the graph of actual observational results, ask the students to draw a graph of what we might see if we could see every galaxy without

selection effects all the way out to lookback time of 9Gyr. The students can then compare their estimate to what scientists think actually happens, shown in the chart below.

If selection effects make it so difficult to tell which trends are real, how do astronomers have an idea of how galaxy types actually evolve out to very large distances? Astronomers don't yet know the whole story, but they use a combination of observational results and computer models to make an educated guess. For example, looking at the chart on the previous page (the observed results) tells us that the fraction of spirals does not decrease dramatically at large lookback times, even though it is harder to see these fainter galaxies. Computer models confirm this and tell us that the fraction of irregulars actually increases at larger lookback times. Models also tell us that the fraction of elliptical galaxies probably also decreases as you look farther back in time. Below is shown a picture of what the chart would probably look like if we could see every galaxy no matter what the distance (i.e., without selection effects). Ask the students to compare the differences between this and what is actually observed. The most striking difference is what happens to the irregular galaxies. Notice that the fraction of these galaxies goes up dramatically with lookback time. At what lookback time do the two charts really start to differ? Ask them to explain how the differences come from selection effects.



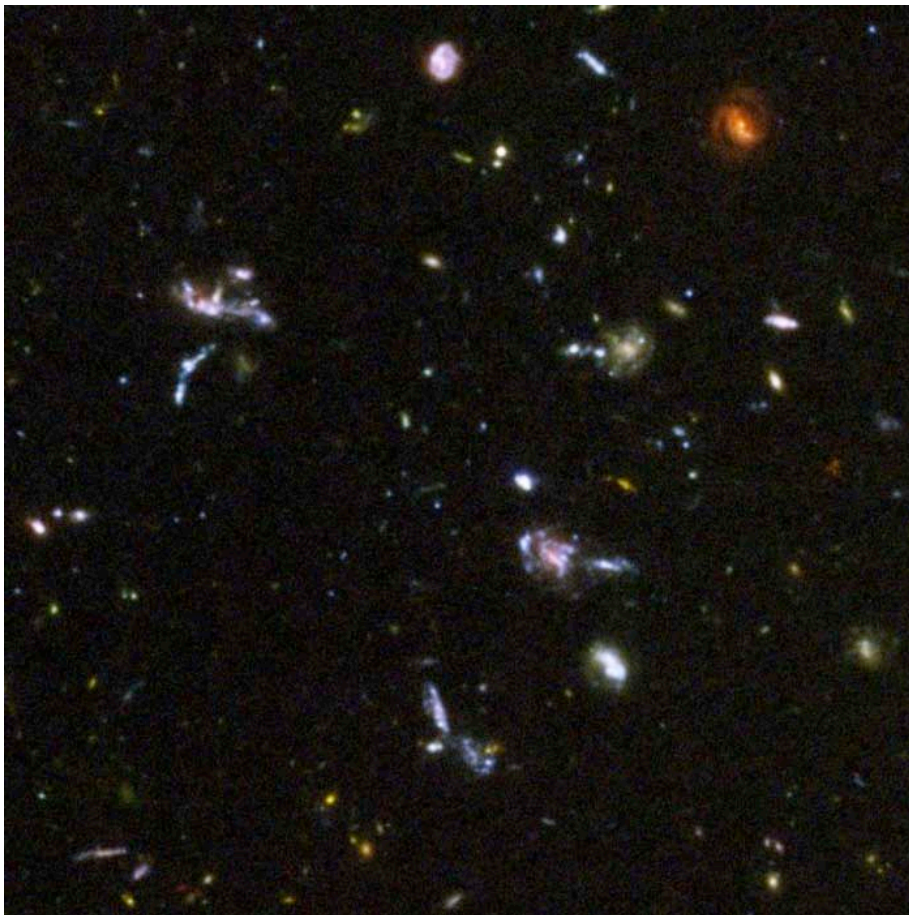
**(7) What happens beyond lookback times of 9 Gyr?**

At a lookback time of 9 Gyr, the universe was only about 30% of its present age. Remind the students that when they look at their graph of galaxy morphologies as a function of lookback time, they are looking at how galaxies evolve as they age. Some of them might make the connection that when galaxies were younger (large lookback time), more of them look like irregulars. There are two reasons for this: (1) the fraction of irregulars was actually larger in the past, and (2) some galaxies that look like irregulars are actually galaxy mergers. Large galaxies,

like the ones we see today, were built up out of smaller, irregular galaxies, through galaxy mergers. In fact, beyond lookback time of 9 Gyr was epoch in the universe when galaxies were actively forming and assuming their present-day appearance. Galaxy collisions were much more common at lookback times greater than 9 Gyr (however some still happen today). The students may have come across snapshots of some of these galaxy mergers in the HST tiles (below is one example of a galaxy merger in its early stages from tile 57), and some they may have classified as irregulars.



And here are a couple snapshots of very distant galaxies (many at lookback times greater than 9 Gyr) from the Hubble Ultra Deep Field. Notice that most galaxies look like irregulars. Can you spot some galaxy mergers?



*Larger versions of these images are shown at the end of this guide –please project the larger image for students to see.*



**(8) *Points to take away: summary and conclusion.***

Learning about galaxy evolution is a complex problem, and it is currently a very active area of astronomical research. This activity is an example of the types of studies that astronomers are currently doing. As you saw firsthand, the Hubble telescope has allowed us to see billions of distant galaxies and probe the epochs when galaxies were very young and first forming. However, we still have to deal with selection effects as we survey these distant galaxies. The next generation of space telescopes, like the James Webb Space Telescope (JWST), will greatly advance our knowledge of galaxy evolution, because it will help alleviate some of the selection effects that come from dimming, loss of resolution, and redshifting. Therefore, the next generation of astronomers will be better able to test their predictions on how galaxies have actually evolved throughout the age of the universe.