Introduction: Our own Milky Way galaxy contains over 200 billion stars. Yet it is just one of hundreds of billions of galaxies in the visible universe. Hundreds of billions! That’s 100,000,000,000 galaxies! So how do these galaxies form? Do they change and evolve? Are the galaxies of the past different than the galaxies of the present? How so? Why? These are all questions that today’s astronomers are asking. In this computer-based activity you will use the same basic techniques astronomers use to answer these questions.

In 2003 the Hubble Space Telescope pointed its gaze at a piece of the sky about the size of the full moon. Within that tiny patch of sky it saw about 8,500 galaxies. These HST images have all been compiled online into the Galaxies and Cosmos Explorer Tool (GCET). Using data gathered from other ground-based telescopes, GCET can also tell us how old each of these galaxies is, giving us the ability to scientifically examine galaxies of the past. In this activity you will learn to use GCET to see if the types of galaxies that used to dominate the early universe are still common in the recent universe.

Learning to use the Galaxies and Cosmos Explorer Tool:

1) Open your web browser, make sure pop-ups are enabled, and go to this URL:
   [http://www.as.utexas.edu/gcet/](http://www.as.utexas.edu/gcet/)

2) * Click on the link that says- “Start your Exploration!”  (see arrow in image on right)

3) The next page will show a close-up image of the mosaic of 78 tiles (63 around the edge and 15 in the middle).

   When you click on any tile, it will take you to larger image of that tile.

   * Go ahead and click on Tile # 54…

4) The image you see on this screen was taken with the Hubble Space Telescope. Almost every little smudgy dot is an entire galaxy! We’ll zoom in on them in just a second, but first…
* Click on the link- “Click here for corresponding C-17 ground image” to see what the same patch of sky would look like to a telescope on Earth. Keep your mouse on that same spot and you can flip the images back and forth quickly.

The difference in resolution is amazing, huh? That’s because the air in Earth’s atmosphere blurs astronomical images taken from the ground. Space telescopes like the Hubble show us much sharper details. Hubble gets even better than this!

* When the Hubble image is showing on your screen, click anywhere in the picture.

5) Now you are seeing an even closer view of tile 54. At first you only see the upper left corner of the tile, use the scroll bars at the bottom and right hand sides of your browser to see the rest of the image.

(Again, most of the objects are individual galaxies. The few dots with ‘crosshairs’ sticking out of them are foreground stars.)

At the top of the screen are the words: “Highlight Galaxies | Zoom In | Reset | Zoom Out”. Click on or wave your cursor over each one to see how it affects the image. The ‘Highlight Galaxies’ option shows which galaxies have more information available, a ‘Galaxy ID’ window will pop up when you move your cursor over one of the little yellow boxes, you’ll learn more about that in a second…

Hold the cursor over ‘Zoom In’ and go as far as you’d like, you can then scroll around the image to find a galaxy you want to see up close. (You can also use the arrow keys on the keyboard).

Even without the galaxies highlighted, you may have already noticed as you moved your cursor over the image that every so often a ‘Galaxy ID’ box appears. This happens every time you cross over a galaxy that GCET has more information about.

* Zoom out and click on the biggest blue spiral galaxy in the upper left portion of the tile.
6) A separate window will pop up, ignore it for now, move it to the side but don’t close it.

Your screen should look something like this. Focus on the bigger window for now…

There is a lot of information on this page, here’s how it is broken down:

A) Identification info for this galaxy:
   - its ID number (7146)
   - the tile where it is found (54)
   - its sky location in Right Ascension & Declination (53.00, -27.64)

B) The two images show the galaxy in two different wavelengths of light (the HST looked at every galaxy with two different wavelength filters). We call these smaller close-up images ‘Postage Stamps’.

***  
\( z \) is the galaxy’s **redshift** (0.2400)  ***

\( \lambda \) is the symbol for wavelength (*the rest-frame wavelength has been red-shifted to become the observed wavelength - ask your teacher if you don’t remember why the observed wavelength and rest-frame wavelength are different*). The colors written in parenthesis below each image (Violet/Blue & Orange/Red) tell you the wavelength of the light that was originally emitted (the Rest-frame wavelength). In this example, the left image shows hot young blue stars in the galaxy and the right image shows the cooler old red stars.

C) This graph will show you the Lookback Time (i.e. ‘Light Travel Time’: how long it took the light from the galaxy to travel across space to get to us) as well as the Age of the Universe when that light was emitted.

* **Click on the** Measure Age **button in the corner of the graph**  
   *(the separate window may pop up again, ignore it for now, don’t close it)*

Notice the new line that appears on the graph. The point where the line touches the left side of the graph tells you the Age of the Universe when the light left the galaxy (between 10 and 12 Gyr [billion years]). The point where it crosses the Lookback time curve tells you how long ago the light was emitted (between 2 and 4 Gyr ago).
* Now go back to the separate pop-up window that says ‘Analysis’

7) The pop-up window will look like this →

This window contains a lot of the same information that you’ve already seen in the other window (section I). And when you just clicked on the “Measure Age” button it automatically filled section III (i.e. 10.696 Gyr and 3.004 Gyr)

But now you get to add in some of your own information in sections II and IV (you won’t use section V for this project)…

What type of galaxy were we just looking at? Was it a Spiral? A Barred Spiral? An Elliptical? An Irregular? If you said ‘Spiral’ you are correct! This is the galaxy’s morphological type (section IV).

* Type ‘Spiral’ into both boxes in section IV
(The galaxy type almost always looks the same in both filters)

…Now what about section II?

You could guess how many arcseconds across the galaxy is (there is a scale above the images), but there is a much more accurate way…

* Leave the ‘Analysis’ window open, go back to the other window…
…now you should be looking at the main window again…

8) Look at the area in between the two galaxy images. Do you see where it has two grey boxes (‘Circle’ and ‘Line’)? These are two tools that both do the same basic thing. They each allow you to accurately measure the angular size of the galaxy.

* Click on the Circle box (a little red circle will appear on the left image),
* Move the cursor to the inside of the circle,
* Click and drag the circle to the middle of the galaxy,
* Push the up and down arrows on your keyboard to change the size of the circle (you will see the Diameter number changing in the blue box).
* Try to encircle the whole galaxy without including too much black space around it (the diameter will probably be somewhere around 5 [arcseconds]).
* Click the grey box that says ‘Record Measurement’ (Do you see anything new in the pop-up window?)

9) Now let’s try the ‘Line’ tool. It makes the same type of measurement as the circle, it’s really just another option available for you to use…

* Click on the Line box (two little red squares connected by a dashed line will appear in the left image),
* Click on one of the red squares and drag it all the way over to the righthand image (Filter F850LP),
* Click the other red square and drag it over the righthand image as well,
* Move the two squares so that they are on opposite sides of the galaxy with the dotted line, going through the center of the galaxy (the line length will probably be about 4.5),
* Click the grey box the says ‘Record Measurement’
10) Look back at the pop-up window. Every box should now be filled except for the ‘Comments’ box (which you will not use for this activity).

**Congratulations! You have just analyzed your first galaxy in GCET!**

Now that you’ve learned all you need to know, let’s practice on another galaxy…

- 1- Close the pop-up window – Do Not Save it!
- 2- Click the link at the bottom of the main window ‘To choose another galaxy click here’
- 3- Go to Tile # 37
- 4- Toggle between the ground image and the Hubble image
- 5- Click on the Hubble image
- 6- Scroll to the right and click on the blue barred-spiral galaxy in the upper right portion of the image (the biggest galaxy in the upper right corner (Galaxy ID: 5322)
- 7- Measure the size of the galaxy in each image using either the circle tool OR the line tool, whichever tool you prefer – is does not matter which one you use - they both do the same thing (and don’t waste time trying to make a perfect measurement, just make an estimate)
- 8- Click the ‘Measure Age’ button to record the age and look back time information
- 9- Type in what type of galaxy you are looking at, but…

  ***Very important! …From now on use the following initials for typing in the galaxy type:

  **S** – for a spiral galaxy  
  **SB** – for a barred spiral galaxy  
  **E** – for an elliptical galaxy  
  **I** – for an irregular galaxy

  ***It is very important that you use these exact capitalized letters***

- 10- Compare your results with the image on the next page…
Compare your pop-up window to this one:

* Your major axis measurements do not need to be the same as what you see here...
You might have much larger or smaller numbers if you thought the edge of the galaxy was further out or in.

**FOR MOST ACTIVITIES, IT IS NOT IMPORTANT TO BE PRECISE WHEN MEASURING THE SIZE OF THE GALAXY.**

How did you do?

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You are now finished with the GCET training. **DON'T SAVE THIS WINDOW! - CLOSE IT AND GO BACK TO THE MAIN WINDOW TO BEGIN THE NEXT SECTION.**
### Using GCET – Student Quiz

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

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

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? _____________________________________