Long Ago and Far Away

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Introduction

Objects that are far away appear small, faint, and blurry. Astronomers want to see distant galaxies better because when we look at the distant universe, we see galaxies as they were a long time ago. Some of these young galaxies – the ones growing most rapidly – are "bursting" with rapidly forming new stars. Such "starbursts" generate huge amounts of stardust, which glows brilliantly in infrared light even while shrouding ordinary visible light. It is still a mystery why these infrared-bright young galaxies are growing so fast.

Activity Summary

You will learn how sizes and distances are related. Using images of nearby and distant galaxies, you will compare galaxies of different sizes both at the present day and when the universe was young. Based on what we know today, you will explore what future infrared telescopes might reveal about the young universe. This activity naturally follows "The Expanding Universe" but can also stand alone.

Materials: calculator, drawing supplies

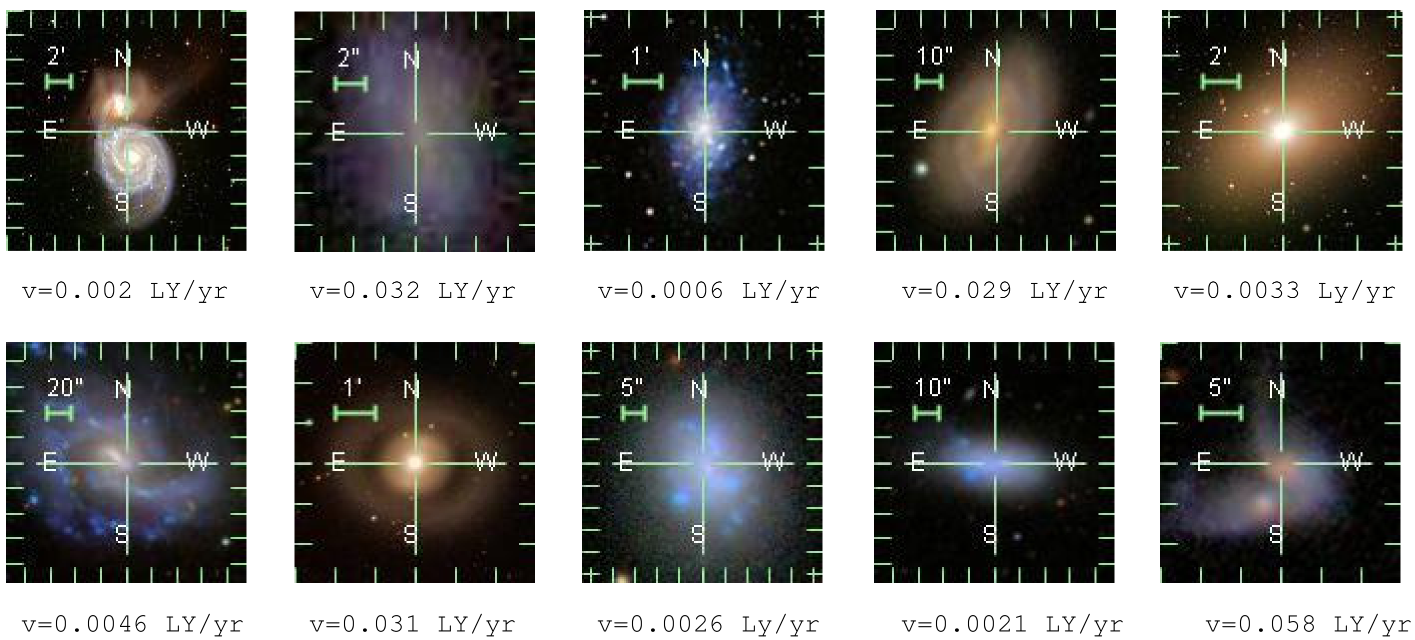


Figure 1: Image Source: Sloan Digital Sky Survey (Abazajian et al. 2004).

I. Small & close or big & far?

We often judge how far away things are by how big they appear. A "rule of thumb" is that if an object appears the same size as your thumb's width held at arm's length, then the object's distance from you is about 30 times its intrinsic size.

1. Try this experiment with another student. First, write down your partner's approximate head height (chin to forehead) in cm. Now, have your partner back away from you slowly. Tell your partner to stop when your thumb at arm's length just blocks out his or her head. How far away is your partner, using the rule of thumb?

Now walk toward your partner, counting the steps until you get there. Multiply the number of steps you take times the approximate length of your stride to get the distance. How does your answer compare with your estimate?

2. Astronomers often solve a similar but opposite problem: they use the distance and apparent size of an object to estimate its intrinsic size. You can do this in two steps.

- ❑The recession speed v is known for the galaxies on the first page. Compute the first galaxy's distance from us using the Hubble law, $v = H_o*d$, writing your answer next to the galaxy. Here H_o is the Hubble constant you found earlier in the Expanding Universe activity, $H_o \cong 7 \times 10^{-11}$ 1/yr. Hint: rewrite the Hubble law to find d in terms of v and H_o.

- ❑Roughly estimate the angular size of the same galaxy, using the scale bar provided. Convert your answer to radians (note " = arcseconds and ' = arcminutes, 1 radian = 206265 arcseconds, and 1 degree = 60' = 3600"). Record your answer by the galaxy.

- ❑Compute the intrinsic size of the galaxy using the small angle formula (intrinsic size = angle in radians x distance; see Appendix). Confirm the answer with your teacher, who will then give you the distances, angular sizes, and intrinsic sizes for the other galaxies on page one. Write the numbers by each galaxy.

- ❑Now rank the galaxies from largest to smallest. What differences do you see? Are any related to intrinsic size?

II. The telescope as a time machine

Light travels very fast, but not infinitely fast. For example, it takes light from the Sun about 8 minutes to reach Earth. So a telescope is like a time machine – objects appear as they were when the light we see left them, not as they are right now. When we look at the distant universe, we see galaxies at an early stage of their lives.

1. Recall that the light year (LY) is a unit of distance equal to how far light can travel in one year. For each galaxy on page one, use the results from part I to determine how long ago the light reaching Earth left that galaxy. Explain. Hint: you don't need math!

2. The galaxy on page one with recession velocity 0.0046 LY/yr is a spiral galaxy like our home galaxy, the Milky Way. Suppose that a clone of planet Earth began to form in that distant galaxy at the same time as our own Earth started forming in the Milky Way. If there were dinosaurs on that clone Earth living at the same time as the dinosaurs on our Earth, are we seeing that galaxy as it was in the age of the dinosaurs? Explain. Hint: dinosaurs became extinct on Earth about 65 million years ago.

3. Astronomers use the telescope as a time machine to see how galaxies have evolved over cosmic time. But galaxies evolve slowly over *billions* of years, not millions. All of the galaxies on the first page are considered "modern" from this point of view. The most rapid phase of galaxy growth via starbursts was in the first 5 billion years of the life of the universe. Recall that the age of the universe is estimated at around 14 billion years. How far away must we look to see galaxies in this early starburst phase?

III. Fighting faint and blurry

The Spitzer Space Telescope is currently the most sensitive infrared telescope in astronomy. Figure 2 shows distant galaxies as seen by Spitzer in infrared light and by the Hubble Space Telescope (HST) in visible light. HST makes distant galaxies look almost nearby! But some infrared-bright galaxies are hard to see in the HST image, because dust obscures visible light. Conversely, Spitzer cannot resolve the structure of distant galaxies like HST can. Future infrared telescopes will dramatically increase our knowledge of distant, dusty young starburst galaxies, by allowing us to see faint infrared-emitting objects at the same level of detail that HST provides in visible light.

1.The galaxy (or merging pair) on page 1 with recession velocity 0.058 LY/yr is a rare example of a fairly nearby "ultraluminous infrared galaxy," which is experiencing a starburst as intense as those seen in young, distant galaxies. Using the ratio of this galaxy's actual distance to the distance you worked out in Part II-#3, estimate the angular size of this galaxy if it were observed at a distance corresponding to 5 billion years after the Big Bang. (The small angle formula breaks down for large cosmological distances, but just assume it works approximately.) Spitzer can resolve details as small as a few arcseconds. If this ultraluminous infrared galaxy were observed in the distant, 5 billion-year-old universe, would Spitzer recognize the galaxy as two merging objects?

2. Figure 3 shows some distant ultraluminous infrared galaxies that are bright enough for HST to see in visible light. Crudely estimate their angular sizes (long dimension) knowing that each box is 7.5" wide. These galaxies' irregular shapes may be a clue that galaxy collisions create the huge starbursts in these young, rapidly growing systems. However, small galaxies in our cosmic backyard can also appear knotty, e.g., the v = 0.0026 LY/yr example in Figure 1, perhaps due to rapid gas flows onto these systems that fuel multiple bursts of star formation. If the galaxies in Figure 3 were at the distance of the v = 0.0026 LY/yr galaxy, they would appear 17 times larger in angular size than they do in Figure 3. About how much larger are they than the v = 0.0026 LY/yr galaxy? Where do they fit in the size ranking of Figure 1? Does this result favor either scenario, mergers or gas flows? Explain.

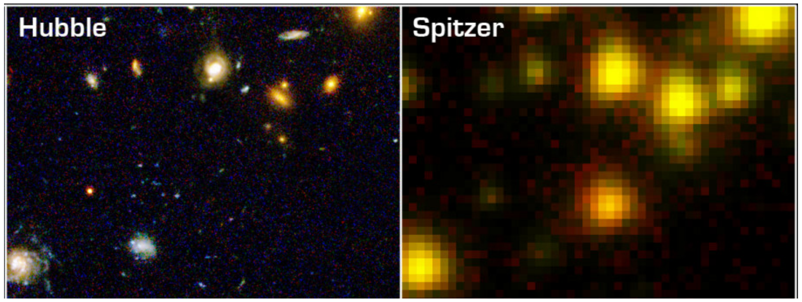


Figure 2: Image Source: NASA/JPL-Caltech (Koekemoer/Dickinson)

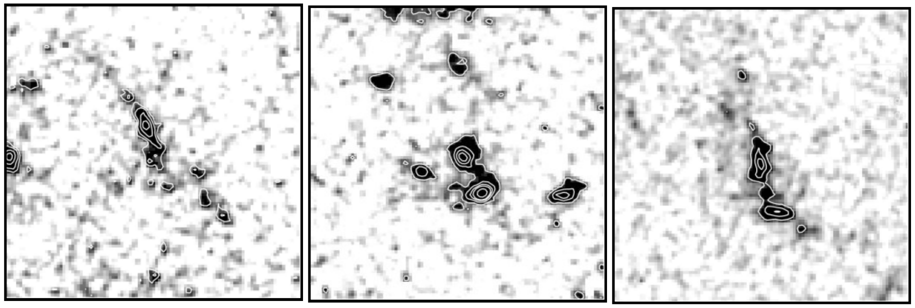


Figure 3: HST images of distant ultraluminous infrared galaxies (source: S. Chapman). We are seeing them as they were about 10 billion years ago.

3. Future infrared telescopes will help to answer whether galaxy mergers or rapid gas inflows lie at the heart of early galaxy growth. For now, it's fun to imagine what we might see. Using the comparison of visible and infrared images in Figure 5 (for nearby galaxies), plus the visible images in Figure 3 (for distant ultraluminous infrared galaxies), draw pictures of what you think we might see when we can obtain detailed infrared images of distant ultraluminous infrared galaxies. Here's how one artist envisions what we can't see in three of Spitzer's infrared sources (as observed, left, and with imagination added, right).

Figure 4: Images (real & artistic) from Spitzer Science Center

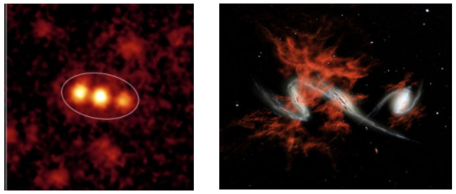
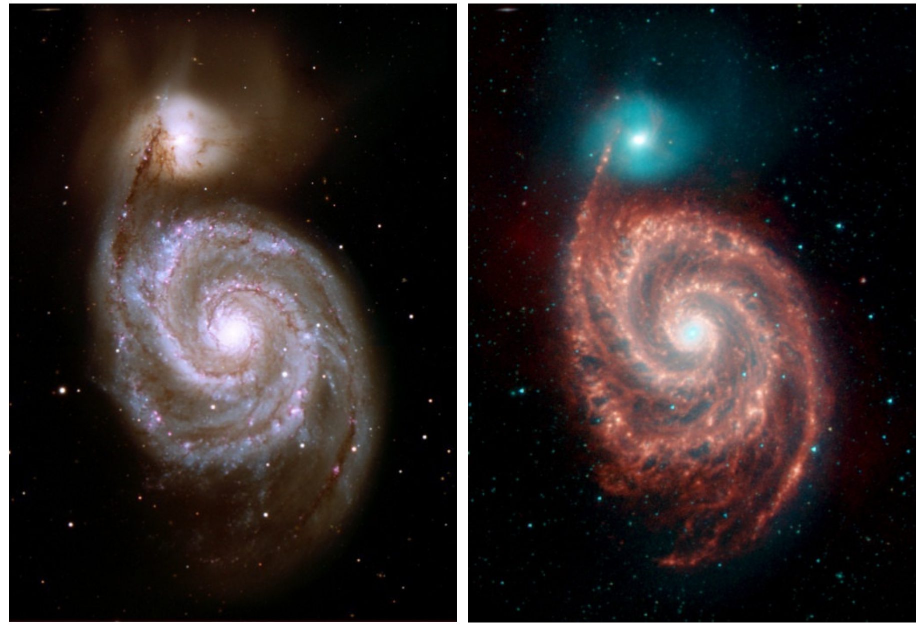


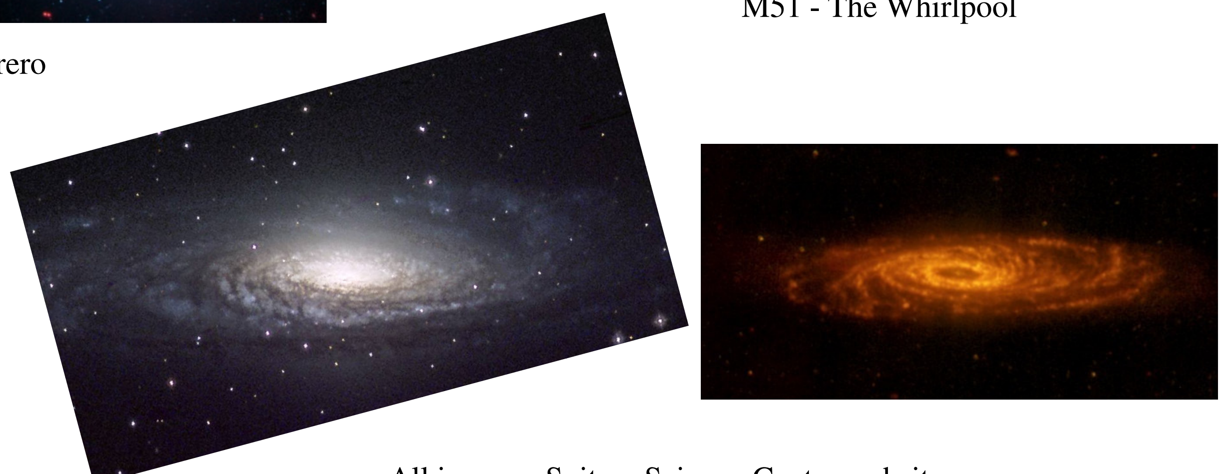
Figure 5: Comparison
visible (left) and mid-far infrared (right) images of nearby galaxies

NGC 4038 and 4039: Interacting Antennae

M104 - The Sombrero



M51 - The Whirlpool

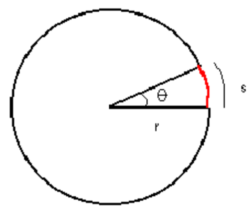


Optical image of NGC 7331 is rotated so that the galaxy is viewed in same aspect.

All images: Spitzer Science Center website

Appendix: The small angle equation

The small angle equation relates the size of an object to its distance and angular size. It comes from considering a circle of radius **r**. The circumference **c** is the distance around the circle, and c=2π **r**. Consider the length of arc marked **s** and the subtended angle Θ.



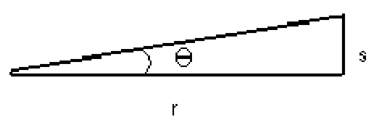
The ratio:

$$\frac{\text{length of } s}{\text{distance around whole circle}} = \frac{\text{angle subtended by } s}{\text{angle around whole circle}}$$

Reduces to:

$$\frac{s}{2\pi r} = \frac{\theta}{360^\circ}$$

The wedge of the circle is just like a small triangle.



Since 2 π = 360°, the small angle equation is s/r = Θ where the angle Θ is expressed in radians.

For students with a knowledge of trig, another way to approach the problem is to note that the sine of an angle equals the side opposite the angle divided by the hypotenuse. The hypotenuse here is the radius. For very small angles, sin Θ = tan Θ = Θ (in radians). (You can confirm this in a spreadsheet.)

Science Standards

National Science Education Standards

Grade 9-12 content standard -

- Abilities necessary to do scientific inquiry
- Forces and motions
- The origin and evolution of the universe

Texas Essential Knowledge and Skills

Astronomy

(5) Science concepts. The student knows the scientific theories of the evolution of the universe. The student is expected to

(A) research and analyze scientific empirical data on the estimated age of the universe;

(B) research and describe the historical development of the Big Bang Theory