

Size and Scale of the Universe

(Teacher Guide)

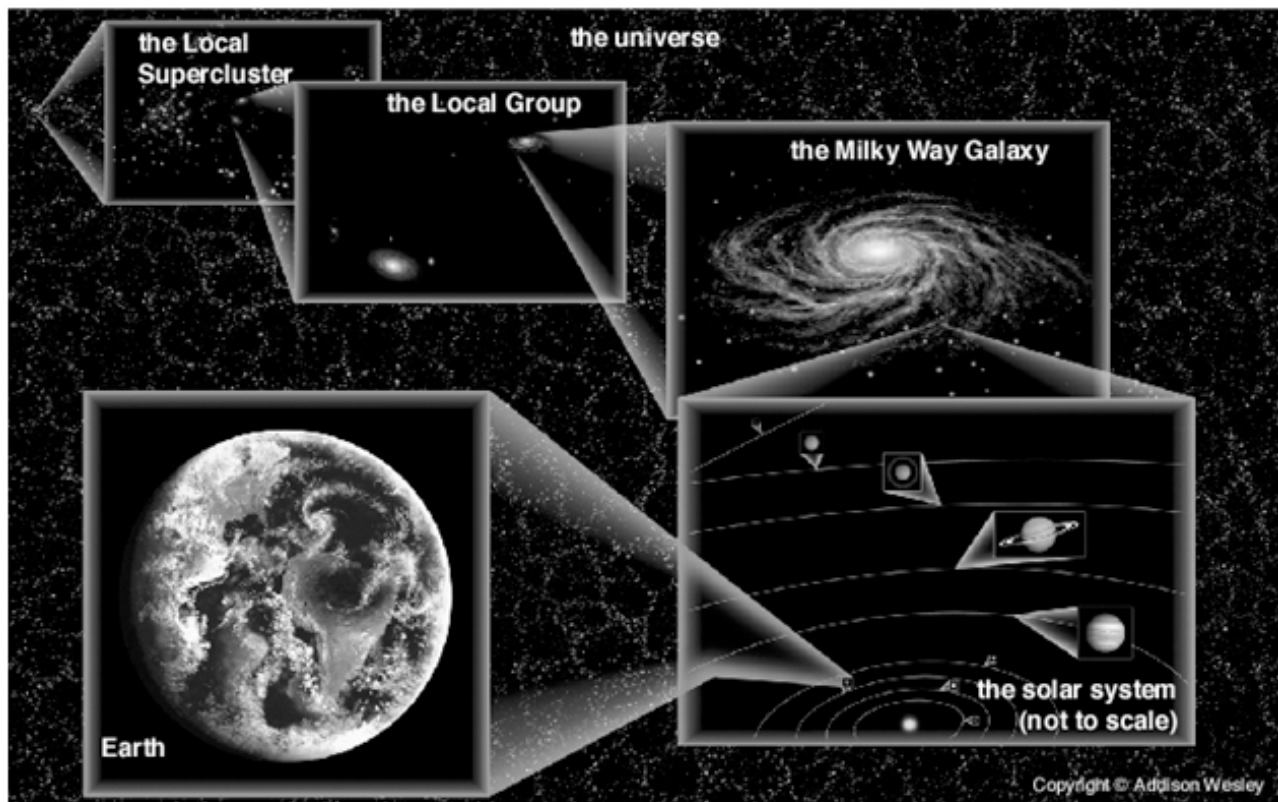


Image courtesy of The Cosmic Perspective by Bennet, Donahue, Schneider, & Voit; Addison Wesley; 2002

Overview:

The Universe is very, very big. But just how big it is and how we fit into the grand scheme can be quite difficult for a person to grasp. The distances and sizes are so far beyond our everyday experience.

Many activities have been created to help gain a sense of the scale of the Solar System by building scale models of it. Activities for scale models of the entire Universe are lacking, however, because of the sheer size of it. One cannot reasonably create a scale model of the Universe that includes all of its components—from people to superclusters—and simultaneously scales their distances and sizes.

This activity attempts to overcome that difficulty by examining the Universe at different realms. First, we start with Earth and zoom out to the Sun and then the Solar System. We continue zooming out from the Solar System, to galaxies, all the way out to the observable Universe. Each step of the way, we use the room we are in to represent a realm of the Universe and then look for common materials that can represent the astronomical objects within each realm, all to scale.

Grade Level:

This lesson is intended for grades 8-12, but can be adapted down for lower grade levels as well.

Standards Correlation: See Appendix A for California, Texas, NSES, and AAAS alignment

Objectives:

- To learn about the structures of the various realms of the Universe
- To gain a sense of relative scales of the various realms of the Universe
- (Optional) To learn the various methods astronomers use to determine distances

Time:

Between 60-120 minutes:

- 60 minute option: you can speed through everything in 60 minutes by not having the students write anything down (no student worksheets), skimming over the new concepts and vocabulary, and not showing slides 16-22 (this approach is best if you are solely looking for the immediate “WOW!” effect)
- 120 minute option: this is recommended for most classes because it allows time for the students to digest and synthesize the new concepts and vocabulary. Experience shows that students are highly engaged with this topic and typically want more time to ask questions and let the concepts “sink in”. The mid-way break point typically occurs several slides into the ‘Explore and Explain’ section (somewhere around slide #10 ‘The Solar Neighborhood’).

Materials:

For the whole class:

- Accompanying Powerpoint (or PDF) presentation titled ‘Size and Scale of the Universe’
- Projector and screen for showing the Powerpoint
- A Globe (optional)

For each group of students:

- Grains of salt (<0.5mm diameter)
- Peppercorn or small bead or BB (~5mm diameter)
- Small Button (~8mm diameter)
- Large Button (~1.25 cm diameter)
- Grapefruit or Wiffle Ball (~9cm)
- CD or Roll of Masking Tape or Large Cookie (~10 to~12cm diameter)
- Small paper plate (~15cm diameter)
- Large Pizza Box or Circular Piece of Paper (~50cm in diameter)
- Anything else that is approximately the same size as any of these objects

Grading:

Please refer the 'Evaluate' section at the end of this Teacher Guide

Getting Ready:

Gather the materials listed above and separate them into piles for each group (1-4 students per group). Each pile should contain one or more of each of the objects listed (feel free to use objects that are not listed here, especially if they are the appropriate sizes).

Ideally this activity should be conducted in a room that is approximately 10 meters by 10 meters, but it is definitely not crucial. The activity involves students imagining that the room they are in represents a certain realm (e.g. Solar System, Galaxy, Supercluster, etc..) and then guessing the relative size of the smaller realms inside of it. The instructions and answers provided in these instructions assume that the room is 10m x 10m. If you do not have access to a room of this size there are two options:

- 1) *(recommended)* Mention to the students that they should assume (envision) a room that is 10m x 10m. Give them something to reference that is approximately 10 meters long (the short end of a doubles tennis court is 11m, the average school bus is about 11m). Remind them throughout the activity that the answers are for a 10m x 10m room.
 - 2) Use the accompanying excel file to calculate the answers (and object sizes) based on your actual room size. *Note: this will also change the objects and materials that you will need to provide as the 'answers'.*
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Procedure:

Engage:

Begin with a globe, and point out the location of the classroom allowing students to gain some sense of the size of Earth in relation to the places they are familiar with (e.g., it takes five hours to fly 3,000 miles, or forty hours to circle the Earth).

- 1) Show slide #2: 'What is your cosmic address?'

Tell the students: "Suppose you had an alien friend who lived across the universe, billions of light years away. And suppose they wanted to mail you a letter through some sort of intergalactic postman. What address would you give them?"

Have the students brainstorm with their neighbor what their “mailing address” in the Universe is. The “mailing address” should contain one line for each realm and should start small and move out, beginning with:

- Street
- City
- State
- Country
- Continent
- Hemisphere
- Planet

...but then the students should keep going further out and brainstorm what other lines (realms) should be added (e.g. third planet from the Sun, Solar System, Spiral Arm, Milky Way Galaxy, Galaxy Cluster, etc..)

Request responses from students and write them on the board (or type them into the powerpoint) until all are listed.

2) Show slide #3: (table with ‘Realm’ and ‘Guesses’ on top)

Explain that there are many different ways to divide up the realms of the Universe, but that most astronomers typically think in terms of the ones listed here in the left column. Mention that these realms will be defined and explained in more detail later into the activity.

- 3) **Distribute the materials** to each group. Point out that they are provided as scale models to represent relative sizes.
- 4) Tell students that the smallest object – the grain of salt – will be our model of the Earth.
- 5) Now that they know the size of the Earth, ask students to work with their neighbor to figure out which objects could represent each realm of the Universe going out (i.e., each subsequent line on the “mailing address”). Have them refer to the realms listed on the powerpoint slide (#3). **Point out that they are not constrained by the objects provided to them. They can suggest larger objects or larger examples if they think it is necessary.**
- 6) Ask the students what object (or larger example) they chose to represent each realm. Write their answers on the board (or type them into the powerpoint). Review

their guesses and ask for their reasoning. Laugh condescendingly at their puny guesses.

- 7) Show slide #4 (table that is filled in - with 'Realm', 'Actual Size'... on top)
Give them time to absorb what is being shown, explain that the last column has the correct answers to the previous challenge. If time allows, reveal each row one by one.
- 8) Show slide #5: Realms of the Universe and continue to the next section.

Explore and Explain:

Pass out the Student Activity Worksheets (one per student).

1. Sun and Earth:

- Show Slide #6: Earth -Discuss the talking points on the side.
- Show Slide #7: Sun -Discuss the talking points on the side.
- Show Slide #8: Sun & Earth -Discuss talking points on the side.

Ask the students to imagine that the Sun is the size of the classroom, and then have them hold up an object representing how large Earth would be.

**Note: Remind the students to assume a large classroom (10 meters square – or 10 meters in diameter):*

Size and Scale of the Universe (Student Worksheet)

As we move from one realm of the Universe to the next, look at the materials in front of you and pick the one that best represents the size of the previous (smaller) realm when the current (larger) realm is represented by the classroom.

Throughout this activity, make your guesses as if you're in a large classroom (10 x 10 meters – or 10 meters in diameter):

1. Sun and Earth: Imagine that the Sun is the size of the classroom...

- a) Which object best represents how large would **Earth** be at the same scale?

Guess:

Actual (given by the teacher):

I. Show your math to see if you get a similar answer:

$$\frac{\text{Room's diameter (10 m)}}{\text{Sun's diameter (1,390,000 km)}} = \frac{\text{Answer (in meters)}}{\text{Earth's diameter (12,700 km)}}$$

2. Solar System: Now imagine that the Solar System out to the boundary between the Solar Wind and interstellar space (200 AU diameter) is the size of the classroom.

- a) Compared to the size of the room, how large would the **Sun** be? Which object best represents this?

Guess:

Actual:

(a) How large would the **Earth** be?

1a) Answer: A grapefruit or Wiffle Ball (9.14 cm diameter)

Have the students show their math on their worksheets for Question I (*they can/should use a calculator*).

2. Solar System:

- Show Slide #9: The Solar System

-Discuss talking points on the side.

Ask the students to now imagine that the Solar System out to the boundary between the Solar Wind and interstellar space (200 AU diameter) is the size of the classroom.

(a) How large would the **Sun** be?

2a) Answer: A grain of salt (0.46 mm diameter)

(b) How large would **Earth's orbit** around it be?

2b) Answer: A CD, or a bit smaller like a roll of masking tape (10 cm diameter)

(c) How big would **Earth** be?

2c) Answer: Microscopic bacteria (4 microns [4×10^{-6} meters])

b) Which object is closest in size and shape to **Earth's orbit** compared to the size of the room?

Guess:

Actual:

c) What object best represents **Earth** on this scale?

Guess:

Actual:

II. What is an AU?

3. Solar Neighborhood: Zoom out to make the Sun's Neighborhood (40 light-year diameter) the size of the classroom.

a) Which object best represents the **Solar System** at this scale?

Guess:

Actual:

III. What is a light-year?

4. Galaxy: Zoom out to make the Milky Way Galaxy (100,000 light-years diameter) the size of the classroom.

a) Which object best represents the **Solar Neighborhood** at this scale?

Guess:

Actual:

Give the students time to answer Question II ("What is an AU?"). The answer is on slide #8 'Earth & Sun'(and at the end of this teacher guide).

3. Solar Neighborhood:

- Show Slide #10: The Solar Neighborhood -Discuss talking points on the side.

Ask the students to zoom out and now imagine that the Sun's Neighborhood (40 light-year diameter) is the size of the classroom.

(a) How large would the **Solar System** be?

3a) Answer: A grain of salt (0.8 mm diameter)

Give the students time to answer Question III ("What is a light-year?"). The answer is on the current slide #10 'The Solar Neighborhood' (and at the end of this teacher guide).

4. Milky Way:

- Show Slide #11: The Milky Way Galaxy -Discuss talking points on the side.

Ask the students to zoom out and now imagine that the Milky Way Galaxy (100,000 light-years diameter) is the size of the classroom.

(a) How large would the **Solar Neighborhood** be?

4a) Answer: A peppercorn or bead (4 mm diameter)

5. Local Group:

- Show Slide #12: The Local Group -Discuss talking points on the side.

5. Local Group: Zoom out to make the Local Group of galaxies (6.5 Million light-years diameter) the size of the classroom.

a) Which object best represents the **Milky Way Galaxy** at this scale?

Guess:

Actual:

IV...Show your math to see if you get a similar answer:

Hint: The Milky Way Galaxy is 100,000 light-years across.

6. Local Supercluster: Zoom out to make the Local Supercluster of galaxies (130 Million light-years diameter) the size of the classroom. How large is the Local Group? How big is the Milky Way?

a) Which object best represents the **Local Group** at this scale?

Guess:

Actual:

b) What object best represents the size of the **Milky Way** at this scale?

Guess:

Actual:

7. Universe: Zoom out to make the entire observable Universe (91 Billion light-years diameter) the size of the classroom. How big is the Local Supercluster? How big is the Local Group?

a) Which object best represents the **Local Supercluster** at this scale?

Guess:

Actual:

(a) How big is the **Local Supercluster**?

7a) Answer: A large button (1.4 cm diameter)

(b) How big would the **Local Group** be?

7b) Answer: A grain of salt (0.7 mm diameter)

Elaborate: (optional)

Showing Slide #s 16-22 which cover how astronomers know and understand these distances.

- Show Slide #16: So How Do We Know These Distances?
- Show Slide #17: The Standard Rulers -Discuss talking points on the side.
- Show Slide #18: Parallax -Discuss talking points on the side.
- Show Slide #19: The Standard Candles -Discuss talking points on the side.
- Show Slide #20: Cepheid Variable Stars -Discuss talking points on the side.
- Show Slide #21: Supernovae (Type 1a) -Discuss talking points on the side.
- Show Slide #22: The Cosmic Ladder -Discuss talking points on the side.

Evaluate:

There are 5 boxes on the Student Worksheet where students are asked to answer questions as they go through the activity – these are the questions that can be graded.

The other questions (about guessing which object represents each realm) are not meant to be graded.

The recommended breakdown for weighting each question is:

- Question I = 15%
- Question II = 15%
- Question III = 15%
- Question IV = 15%
- Question V = 40%

Grading Rubric:

Question I = 15% (“*Show your math to see if you get a similar answer*”):

- Full credit (15%) - the student shows the proper mathematical steps to reach the correct answer (0.0913669 meters or 9.14cm)
- Partial credit (10%) – the student shows the proper mathematical steps but reaches the wrong answer
- Partial credit (5%) – the student shows the wrong mathematical steps and reaches the correct answer
- No credit (0%) – the student shows the wrong mathematical steps and reaches the wrong answer

Question II =15% (“*What is an AU?*”):

- Full credit (15%) – the student covers all 3 of the following main points:
 1. Stands for Astronomical Unit
 2. Is the average distance between the Earth and the Sun
 3. Is about 150 kilometers (or 93 million miles)
- Partial credit (10%) – the student covers 2 of the 3 main points
- Partial credit (5%) – the student covers 1 of the 3 main points
- No credit (0%) – the student covers 0 of the 3 main points

Question III =15% (“*What is a light-year?*”):

- Full credit (15%) – the student covers all 3 of the following main points:
 1. Is the distance that light travels in one year
 2. Is about 10 trillion kilometers (or 63,000 AU)
 3. The student does not refer to it as a unit of time
- Partial credit (10%) – the student covers 2 of the 3 main points
- Partial credit (5%) – the student covers 1 of the 3 main points
- No credit (0%) – the student covers 0 of the 3 main points

Question IV =15% (“*Show your math to see if you get a similar answer*”):

- Full credit (15%) - the student shows the proper mathematical steps to reach the correct answer (0.1538461 meters or 15.4cm)
- Partial credit (10%) – the student shows the proper mathematical steps but reaches the wrong answer
- Partial credit (5%) – the student shows the wrong mathematical steps and reaches the correct answer
- No credit (0%) – the student shows the wrong mathematical steps and reaches the wrong answer

Question V =40% (“*Write one paragraph describing how your perspective and understanding of the Universe have changed after participating in this activity*”):

- (0-40%) Up to the teacher’s discretion to determine the level of thought and effort put into answering the question.

Appendix A: Standards Correlation

California State Science Content Standards:

Grades 9-12: Earth Sciences, Earth's Place in the Universe

1. Astronomy and planetary exploration reveal the solar system's structure, scale, and change over time. As a basis for understanding this concept:
 - d. Students know the evidence indicating that the planets are much closer to Earth than the stars are.
2. Earth-based and space-based astronomy reveal the structure, scale, and changes in stars, galaxies, and the universe over time. As a basis for understanding this concept:
 - a. Students know the solar system is located in an outer edge of the Milky Way galaxy, which spans 100,000 light years.
 - b. Students know galaxies are made of billions of stars and comprise most of the visible mass of the universe.

Grade 8: Earth in the Solar System (Earth Sciences)

4. The structure and composition of the universe can be learned from studying stars and galaxies and their evolution. As a basis for understanding this concept:
 - a. Students know galaxies are clusters of billions of stars and may have different shapes.
 - b. Students know the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.
 - c. Students know how to use astronomical units and light years as measures of distances between the Sun, stars, and Earth.

Texas Essential Knowledge and Skills (TEKS):

Grade 9-12 Astronomy Course:

- 112.33(c)-6: Science concepts. The student knows our place in space. The student is expected to:
- (A) compare and contrast the scale, size, and distance of the Sun, Earth, and Moon system using data and modeling.
 - (B) compare and contrast the scale, size, and distance of objects in the solar system such as the Sun and planets using data and modeling.
 - (C) examine the scale, size, and distance of the stars, Milky Way, and other galaxies through the use of data and modeling.
 - (D) relate apparent versus absolute magnitude to the distances of celestial objects.
 - (E) demonstrate the use of units of measurement in astronomy, including Astronomical Units and light years.

112.33(c)-12: Science concepts. The student knows the variety and properties of galaxies. The student is expected to:

- (B) recognize the type, structure, and components of our Milky Way galaxy and location of our solar system within it.

Grade 8 Science:

- 112.20(b)-8: Earth and space: The student knows characteristics of the universe. The student is expected to:
- (A) describe components of the universe, including stars, nebulae, and galaxies, and use models such as the Hertzsprung-Russell diagram for classification.
 - (B) recognize that the Sun is a medium-sized star near the edge of a disc-shaped galaxy of stars and that the Sun is many thousands of times closer to Earth than any other star.
 - (D) model and describe how light years are used to measure distances and sizes in the universe.

National Science Education Standards (NSES):

Grades 9-12: Earth and Space Science (Content Standard D):

The Origin and Evolution of the Universe

Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass in the universe.

Grades 5-8: Earth and Space Science (Content Standard D):

Earth in the Solar System

The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.

AAAS Benchmarks for Science Literacy:

Grades 6-8: 4. The Physical Setting, A. The Universe:

- The sun is a medium-sized star located near the edge of a disc-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night. 4A/M1a
- The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot. 4A/M1bc
- The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years. 4A/M2abc
- Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were that long ago in the past. 4A/M2de