Session 3 – The Astronomer's Toolbox: Telescopes

General Description

Working in small groups (perhaps 2 or 3 students per group), students assemble a simple version of one of the astronomer's basic tools: the telescope. They experiment with their own telescopes and investigate their properties. Students then use postcard travel time to model the time it takes for information (traveling in the form of light) to reach us from distant astronomical objects.

Objectives

- To explore the function and principles of a basic refracting telescope.
- To ensure understanding that looking farther out in the Universe means looking back in time.

Concepts Addressed

- Magnification using lenses
- Light travel time

Materials

- 1 telescope kit per student (or for every 2–3 students, depending on availability) *
- Rulers, 1 per telescope kit
- Rubber bands, 1–2 per telescope kit
- White or light-colored tissue paper (like that used in gift wrapping), ½ to 1 sheet per telescope kit, as they tear easily
- At least 1 light source (all students must look at this, so more is nice) — options are:
  - 60-watt light clear bulb (so the filament can be seen) and 1 lamp base (such as a desk lamp without the shade) [OR]
  - Maglite-type flashlights with the upright "candle" setting, clear and no colors
- (Optional) 3″ square piece of paper, 1 per telescope kit
- Postcards and stamps — 1 set per student (*remember that a postcard requires less postage than a letter*)

* *Information about where to purchase this, along with the part number can be found in Appendix C.*

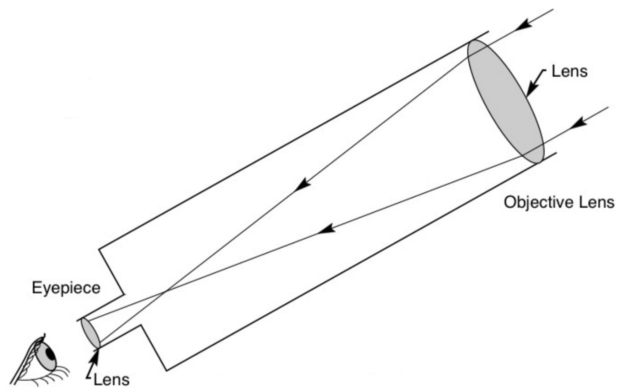
Other Requirements

- A room that can be darkened (by turning off lights and covering windows) with enough table or floor space for groups of students to spread out but work together.

Background

All telescopes are collectors of light. Some telescopes collect and focus light using a lens that light passes through. Such telescopes are called refractors. Other telescopes use a mirror from which light is reflected, and such telescopes are called reflectors. We use telescopes because they can collect much more light than our eyes can. About 400 years ago, Italian Galileo Galilei (1564-1642) was the first to design a telescope good enough to observe stars, planets and moons—and he was among the first to observe them systematically and record what he saw.

The original design Galileo came up with in 1609 is commonly called a Galilean telescope. This type of telescope uses two lenses to produce upright images. The objective, or front lens, of Galileo's telescope was only a few inches in diameter. Because of the shape of that lens, light falling on it is bent, which concentrates the light into a narrow beam. The light emerged through a second lens (eyepiece) and entered Galileo's eye. Because the diameter of the objective lens was much larger than the diameter of the pupil of Galileo's eye, the telescope collected much more light than his eye.



A simple ray tracing diagram of a very basic refracting telescope, much like Kepler's and the ones built by the students in this session.

Galileo's original telescope magnified images by three times—sufficient for those very early astronomical observations. He improved upon his original design, and his best telescope magnified objects by about 30 times. Using his telescope, Galileo observed the phases of Venus, craters on the Moon, four moons orbiting Jupiter, and sunspots on our Sun.

Johannes Kepler improved upon Galileo's design even further by changing around the types of lenses. The telescope he designed is called a Keplerian Telescope. His design allowed for a much wider field of view and greater eye relief, but the image for the viewer was inverted. However, since there is really no up or down in space, this does not pose any great disadvantage to observers.

We will build a basic refracting Keplerian telescope here, as shown in the diagram. This will not be a powerful telescope, but a simple model that students can easily build and use to explore their surroundings. Modern telescopes have bigger lenses and better optics. We can therefore see objects that are much further away.

Light from astronomical objects gives us most of the information we have about them, since we can't go to them. Although light travels very quickly, it is not instantaneous. For example, it takes light 8 minutes to reach us from the Sun, 4 years from the next nearest star, and 13 billion years from the most distant objects. As a result, we can only get information about these objects as they were when they sent out their light, not as they are right now.

Session Overview

After a short introduction from the leader, groups of students assemble a simple telescope, learn to focus light through it, and practice using it. Throughout this activity, the leader provides direction and roams among students — to provide advice for assembly and offer questions that encourage students to think analytically about their own telescope's performance. Students then mail postcards to themselves, to simulate light's travel from distant astronomical objects.

Preparation

- Leaders may want to review this website to learn about telescopes: http://www.amnh.org/education/resources/moveable_astro/telescopes.php
- This activity is much easier for the leader if they have assembled one kit and tried the activities in advance.
- Put appropriate stamps on each of the postcards.
- In order to save time during assembly, leaders may choose to do step number 4 of the telescope assembly in advance (drawing a scale on the smaller tube). This is optional.

Activity

I. Discussion (5-10 minutes)

Ask students if they know what a telescope is. What does it do? A telescope is a tool that we can use to look at the sky. It makes things that are very far away appear closer so that we can study the objects in detail.

The telescope has been around for almost 400 years now. An Italian astronomer named Galileo Galilei is associated with the telescope. Galileo did not invent the telescope, but he was the first to design one that was good enough to observe stars, planets and moons — and he was among the first to make such observations. He built a very simple telescope using a wooden tube and two lenses.

Copy the diagram that is shown in the background section onto the blackboard or whiteboard or a large sheet of paper in the room. This is actually a model of a Keplerian telescope as discussed in the background section. Briefly explain how this simple telescope works.

Tell students they will now build and use a simple refracting telescope.

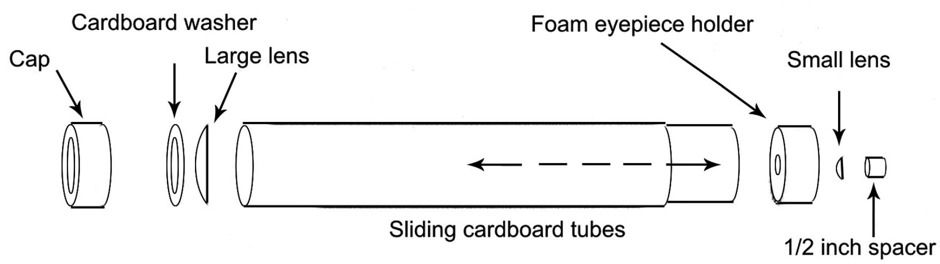
II. Building and using the telescope (~20 minutes)

(Adapted from the Learning Technologies, Inc. (now Science First) Refracting Telescope Kit)

Check our online resources for a video about building this telescope.

Throughout this process, circulate among students to advise them on assembly and give them questions for thought. They will need to take turns with their team members for the experiments after assembly.

1. Students can work alone or in teams of 2 or 3, depending on the number of kits available, and a telescope kit with a diagram of the components is distributed to each team. Students should take every item out of the kit (some pieces may be inside of others) and examine the parts they have been provided.



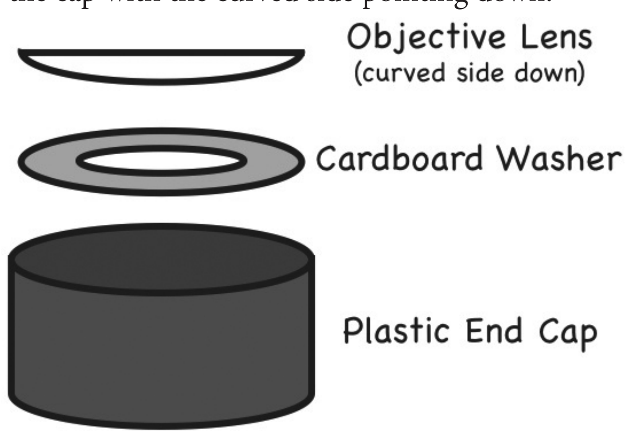
Overall view of kit's pieces and assembly.

2. They should take both lenses and look through them (from both sides) at posters on the walls, printed words, etc.

   What do they notice? Do the two lenses behave differently?

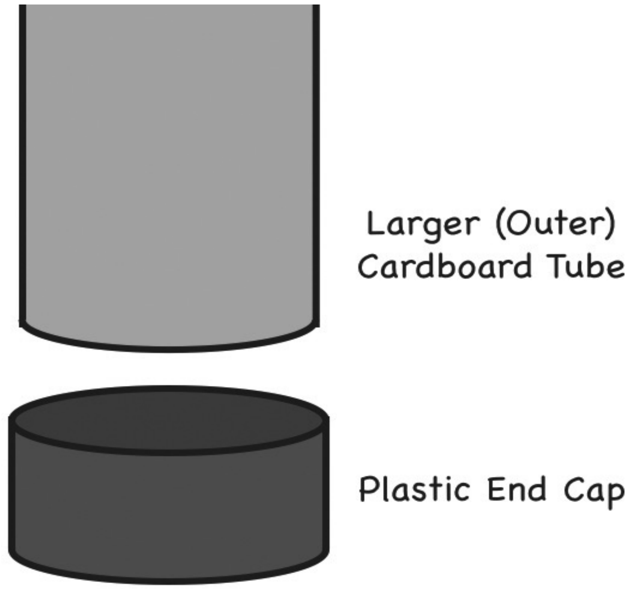
   Explain that the larger lens is the objective and the smaller is the eyepiece and refer to the general telescope diagram.

3. Lead the students step-by-step through the process of building the telescope. For the first step, lay the cap down on the table or desk with the open end up. Place the cardboard washer (disk with hole) into the cap. Holding it carefully by the edges, place the larger (objective) lens into the cap with the curved side pointing down.



Assembly of the objective end of the telescope.

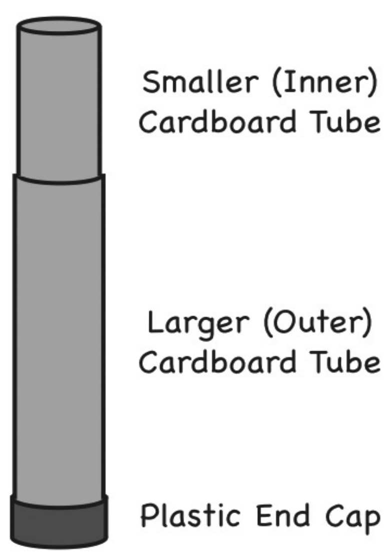
Take the two tubes apart. Insert the end of the larger of the two sliding cardboard tubes into the cap.



Attaching the objective end to the telescope.

4. To make it easier to focus the telescope, it is useful to draw a scale on the smaller tube. Using a ruler, and starting from the eyepiece end, mark each inch on the outside of the smaller tube. The first mark (label it "1") should go one inch from that end, and the second mark ("2") two inches from the end, etc. Students should be able to mark up through "11," because the tube is 12 inches long and "12" would be on the objective end.

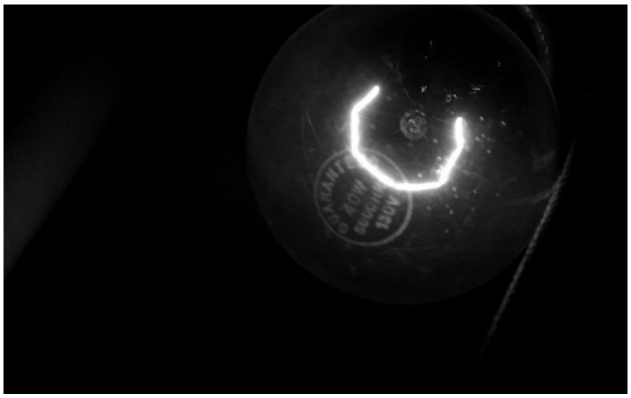
5. Fit the smaller tube back into the larger tube, but leave a little bit sticking out. Instead of inserting the second lens, place a piece of tissue paper over the eyepiece end and secure it tautly with a rubber band.



The telescope, almost fully assembled.

6. Place the light source on a table. Students stand in a circle at a distance of 3 steps from the light. Darken the rest of the lights in the room and have students aim the objective lens end of the tube at the light.

7. Students should look at (not through) the tissue paper, with the telescope roughly a foot away from their eyes. They should slide the smaller tube in and out of the large tube until they can see a clear focused image of the incandescent filament (the wires in the middle of the bulb) on the tissue paper. This will not be a dot, but rather a sharp image of squiggly lines. Once they can see this, they should record the position of the smaller tube by making a clear mark on it, such as an X.



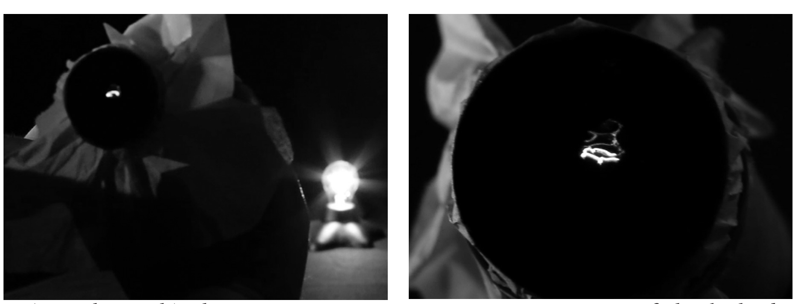
Light bulb filament. Image courtesy and copyright Alexander Lingo.

Instead of a lamp, a Maglite-type flashlight in upright "candle" mode can be used for the focusing. Here, the focus is reached when the spot of light is the smallest, and as crisp and clear as possible.

8. Students should then move as far as they can away from the light and repeat the experiment. When they get a focused image they should check the position of the smaller tube. Ask them to predict answers to the following questions:

– *In this position, is the telescope longer or shorter than when you were closer to the light?* (Answer for leaders: it will be shorter.)

– *If you wanted to get a clear image of a very distant object, would the telescope length have to be longer or shorter?* (Answer for leaders: it will be shorter still.)

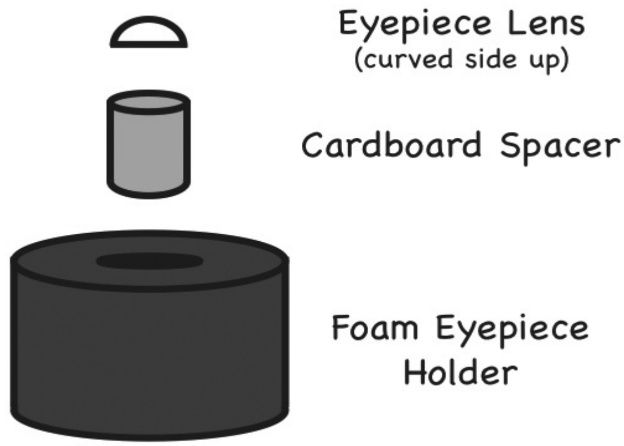


Looking at (not through) the tissue paper, you can see an image of the light bulb filament.

9. If possible, ask students to aim the telescope at a distant object through a window. Now ask them if their prediction was correct.

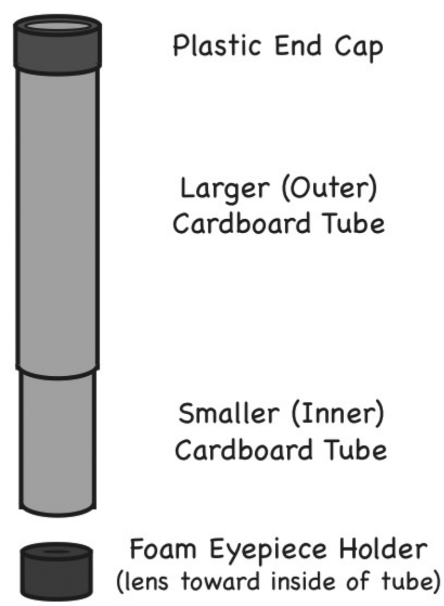
Warn students not to look at the Sun with their telescopes! Permanent eye damage can result.

10. Turn on the lights. The room should be well-illuminated for the next part. Students should remove the tissue paper and get ready to insert the eyepiece. Lay the foam eyepiece holder on the table with one end of the hole pointing up. Push the half-inch spacer all the way down into the foam eyepiece holder so that it is flush with the table. Using a piece of cloth or tissue to protect the lens from fingerprints, push the smaller lens (eyepiece) into the foam eyepiece holder with the curved side facing up.



Assembly of the eyepiece end of the telescope.

Now pick up your two tubes and push the end of the smaller sliding cardboard tube down over the top of the foam eyepiece holder (see diagram). The telescope is now complete!



Attaching the eyepiece end to the telescope

Students can now look at "distant" objects, through the window or at the opposite end of the room. If the telescope is shaky or hard to aim, encourage students to devise a means of bracing or supporting their telescopes. It may be helpful to put up eye charts, or other images and text on the wall to give the students something particular to focus on for indoor observation.

After a few minutes, ask students what they noticed. They probably saw that the image was upside-down!

What else did they notice? Things should look closer, they should also be able to see details on objects that are already close…

Did anything surprise them?

11. **Optional Extension**: Cut a circle out of the 3″ square piece of paper that is a little smaller than the diameter of the objective lens, and discard the circle. Tape the paper with the hole over the objective lens and see what happens. The field of view does not get smaller, but it does get dimmer, because the light-gathering area of the lens/telescope got smaller. The larger the area, the more light you can collect, so you can see dim objects (objects that are further away). This is why astronomers want to build big telescopes!

III. Postcard activity (~10 minutes)

1. Tell students that astronomers use light to study the Universe since it is not possible to travel to the stars and galaxies. But light takes time to travel! (Students may not know this or even understand this concept.) Email and text messaging, which we tend to think of as instantaneous, are in fact slower than the speed of light — that's how fast light travels! But as fast as it is, it still takes time. Even the time between when you flip a light switch and when the light comes on is not instantaneous. Explain that we will now do an activity to understand this concept of travel time.

2. Pass out postcards, and have students work individually or in the same teams to figure out and write down the address of the program location. For example:

   Irene Smith
   Afterschool Program
   100 Main Street
   Washington, DC 20001

   Ask them to write down the date and a sentence or two that says what they are doing or did today. "I'm writing this note for the postcard activity today" works — or anything they have done that day that is unique to that date and time. They can write drafts of their sentences on separate paper first, if desired. Have them read their notes aloud.

3. Have students guess when the postcards will arrive if they are mailed today — 1 day? 2 days? Later than that?

Ask them if their postcards will tell them what they are doing at the time that they read it when it arrives. Or at the time they wrote it?

The answer is that it will tell them what they were doing when they wrote it, a day or two before they read it.

Ask for examples from students about what might change in their lives between today and when they will receive the postcard — they might get a haircut, get a new toy, go visit a friend's house, watch a TV show, etc.

4. Explain the analogy with the postcard:

    The postcard's travel is like light traveling from very far away in the Universe, from a distant star or galaxy. That light gives us most of the information we have about these distant objects, since we can't go there.

    Light does not travel instantaneously — it is very fast, but it does have a speed limit. It takes time to travel, just like your postcards: 8 minutes for light from the Sun to reach us, 4 years from the next nearest star, and 13 **billion** years from the most distant objects.

    Here are some examples of light travel time:

    - Moon to Earth: 1.3 seconds
    - Sun to Earth: 8 minutes
    - Mars to Earth: 12 minutes
    - Jupiter to Earth: 35 minutes
    - Pluto to Earth: 5.5 hours
    - Nearest star to the Sun: 4.3 years

5. You can either ask the students to mail the postcards themselves or you can collect the postcards from your students and mail them. Tell them that you will discuss what they wrote in the postcard when they receive it. Hold a follow-up discussion on this topic 2–3 days after this session when the postcards are delivered back to the program location to re-iterate the point that it takes time for objects and information to travel and get to places. That includes even light and the information it carries about the Universe.

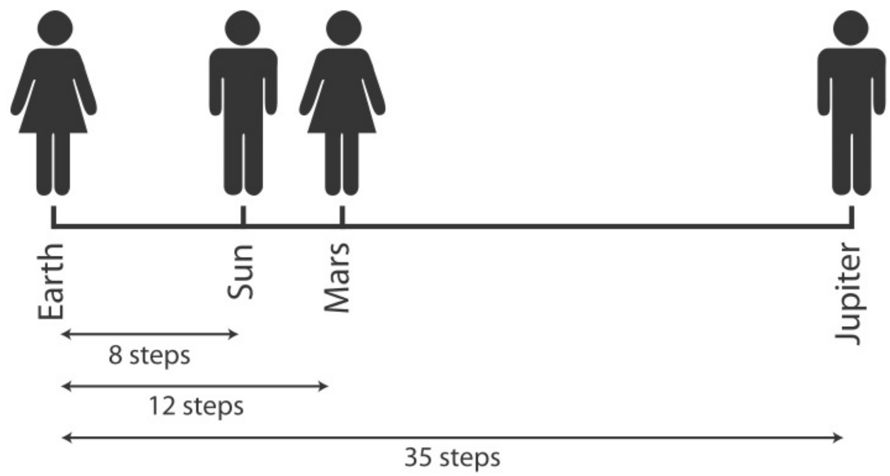
6. Remind students to think about their postcards, and have them offer their thoughts.

    Tell them that from the Sun, we receive information "written in light" 8 minutes ago. Ask them if something were to happen on the Sun right now, when would we actually find out about it? Answer – only after 8 minutes have passed because it will take that much time for the light that carries this information to reach us on Earth. The light is a kind of "time capsule." It tells us what was happening with these objects when the light left them. We don't know what's happening there right now.

IV. Light travel time kinesthetic (15 minutes)

Check our online resources for a video about facilitating this activity.

1. You can ask the students to role play this to truly understand the concept. Ask for 7 volunteers. 4 of them will represent objects in the Universe — the Earth, our Sun, Mars, and Jupiter. The student representing the Earth will stand at one end of the room or a hallway, and those representing the Sun, Mars, and Jupiter should line up at increasing distances from Earth. Each footstep will represent the distance light travels in 1 minute. So the Sun should be 8 steps away from the Earth, Mars 12 steps away, and Jupiter should be 35 steps away.



Students in position for light travel role-playing activity.

[If you wish to carry this further, you can have another student representing Pluto standing out in the corridor to represent that it is very far away. 5.5 hours represents 330 steps, which may not be possible to do! Exact scale representation does not matter as we are focusing on the underlying concept of travel time.]

The other 3 students will represent a light ray traveling from each of the non-Earth objects – each of these students should stand beside the object they are associated with. The student representing Earth should have his/her back to those representing the other objects. Alternatively, a blindfold could be used to accomplish this goal. Either way, this emphasizes that the only information the Earth will receive will be what the light brings to it.

2. Now have the student representing the Sun touch his/her head or perform some other action. The student representing the light ray emitted by the Sun will now face away from the Sun (so that s/he cannot see what else the Sun might do) and take 8 steps to the Earth and tell the Earth that the Sun has just touched its head. The light ray carries the information to the Earth. To make this point even clearer, the student representing the light ray from the Sun can keep performing the Sun's actions all the way to the student representing the Earth.

In the meantime, the Sun might have done something else – like put on a hat – but the light will not know this and cannot tell the Earth about what happened after it left. If you would like, you can have another volunteer play the part of a second light ray to leave the Sun after the first carrying new information to the student representing the Earth.

3. Next, the student representing Mars can perform another action – say bend down and touch his/her toes. The student representing the light from Mars will now face away from Mars and take 12 steps away from Mars towards the Earth and tell the Earth that Mars just bent down and touched its toes. Again, Mars might have done something else as soon as the ray of light left it and the light would not know about this action, since the light's back was turned. Once again, you may have another student play the part of a second light ray to illustrate this point.

4. Lastly, the student representing Jupiter should carry out an action, like jumping in place. The student representing the light from Jupiter will now face away from Jupiter and take 35 steps to the Earth. S/he will now tell the Earth that Jupiter has jumped in place, but again, Jupiter might have done something else, like sit down. The light will once again not know this and can only tell the Earth what it knew when it left Jupiter.

   These are very simplistic models to show that it takes time for light to travel and it can only carry the information about the object when it left. But it should help to emphasize that we cannot receive information instantaneously and it takes time for any information to be transmitted to us via light.

Suggestions for Running this Session

- Students should slide the telescope tube slowly, as it's much easier to focus. If their hands shake, they should find a way to brace the telescope, or rest it on something for additional stability.

- You may wish to set up some indoor viewing options - an eye chart or other printed text posted on a distant wall is useful for checking out how these work (and seeing that the image is inverted). An astronomical poster on the wall can also mimic the night sky for viewing. If you want to take the telescopes outside during the day, they can be used to view trees or other natural features, but remind students to never, ever point them at the Sun.

- Think about what you want students to do with their team telescopes at the end of the activity — if they worked alone, they can take their telescope home. If they worked in groups, perhaps they can take turns taking them home? Take them outside during free periods to look at objects? If they take it home, suggest that they look at the moon with their telescope. Alternately, you can keep the kits for re-use with a later group.

- **Galileoscopes**

  The Galileoscope is a high-quality, low-cost telescope kit developed for the International Year of Astronomy, celebrated in 2009 to mark 400 years of the telescope. This 50-mm (2-inch) diameter, 25- to 50-power achromatic refractor telescope is a better telescope than the ones we use in this session, although it more expensive. It is also not as easy to assemble as the telescopes we suggest using.

  If you are interested in providing your students with an observing experience (for example a star party or a family night), we suggest you purchase 1-2 telescopes for your site. For more information and to order these "Galileoscopes", please visit https://www.galileoscope.org/

Emphasize that students should never look at the Sun with their telescope!

Misconceptions

- The two lenses used in this telescope create an inverted image. This is not a problem in astronomy (which way is up in space?), but it makes it difficult to read a street sign, for example. Don't worry, this is not a sign that you put it together incorrectly.

- We do not have the ability to travel anywhere close to light speed. Our fastest spacecraft can go a little over 48,000 kilometers per hour (30,000 miles per hour), while the speed of light is over 1 billion kilometers per hour (670 million miles per hour)!

- There may be potential confusion between telescopes and microscopes. Students may not understand the difference between the two, since both allow us to see things that we would otherwise not be able to see. The basic difference is that telescopes look at distant objects, while microscopes look at very small objects.

Useful websites for background or activity extension

- **Telescopes from the Ground Up**
  Information on the history of telescopes, different kinds of telescopes, and basic explanations of light, color, and optics
  http://amazing-space.stsci.edu/resources/explorations/groundup/

- **Science@NASA**
  Simple explanation of how telescopes work, their history, and why astronomers need more than one kind
  http://science.nasa.gov/newhome/headlines/features/ast20apr99_1.htm

- ***Scope It Out!* Game**
  A flash game explanation of how telescopes work, and the James Webb Space Telescope in

particular
http://www.jwst.nasa.gov/scope.html

- ***Sky & Telescope* magazine**
  All about tools for sky-gazing
  http://skytonight.com/letsgo/toolsforstargazing

- **Meade Instruments Corporation**
  Relatively simple explanations of how telescopes, and a range of telescope accessories, work.
  http://www.meade.com/support/telewrk.html

- **NASA's *Universe Education Forum***
  How big is our Universe? Take this journey through space and time
  http://www.cfa.harvard.edu/seuforum/howfar/index.html

- **The Galileoscope**
  The Galileoscope is a high-quality, low-cost telescope kit developed for the International Year of Astronomy. This easy-to-assemble, 50-mm (2-inch) diameter, 25- to 50-power achromatic refractor telescope is a better telescope than the ones we use in this session, though it is also a bit more expensive.
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