Program 2: Making YOUR Observations

First airs live, March 14, 1996, 13:00-14:00 Eastern

"Making YOUR Observations" will climax with a live "First Look" at the original astronomical data acquired as a result of the *Passport to Knowledge* observations. Planet Advocates Heidi Hammel, Marc Buie and participating K-12 students will see, at exactly the same moment, what we've collectively discovered about Neptune and Pluto, during a live uplink from the Space Telescope Science Institute, in Baltimore, Maryland (STScI). ("First Look" is what astronomers call their initial glimpse of new data: during the comet Shoemaker-Levy 9 collision with Jupiter, "First Look" was welcomed with whoops of delight and celebratory toasts, as we'll see during this program.)

There'll be another, equally unique "First Look" as—for the first time ever—live cameras are welcomed into the Space Telescope Operations Control Center at NASA's Goddard Space Flight Center. Though there's no live camera currently up in orbit to show us HST from outside, we'll see exactly where HST is at that precise moment, and exactly what HST is seeing. Via our live cameras, students will come as close, virtually, to HST as any human on Earth can ever be. Students will look over controllers' shoulders and see what happens as the telescope slews to acquire new guide stars, or "dumps" its data from the on-board tape recorder. If there is a spacecraft "Health and Safety" emergency, however, we will be unceremoniously booted out of the Mission Operations Room!

Videotaped sequences will show the wide variety of people it takes to operate HST, from astronomers and astronauts, to engineers, computer programmers, communications specialists, mathematicians, graphic artists, technical writers… secretaries. Footage from across America and around the world will show the diverse places, far from STScI and GSFC, where HST work is performed, and the processes which are involved. Students will see what HST has contributed to our understanding of the solar system, and will appreciate that while spacecraft missions have returned stunning, high resolution images of nearly all our local planets (except Pluto), HST provides ongoing coverage, functioning as a kind of "interplanetary weather satellite" for our cosmic neighborhood.

Heidi Hammel and Marc Buie will review what we know about Neptune and Pluto, what they hope the new images might reveal, and describe the hard work they'll be facing in the coming five weeks, to prepare the brand-new data for the April 23rd telecast. Students will find out how they also can work on the data, using custom software and lessons plans provided over the Internet by *Passport to Knowledge* and others. "Mrs. Jupiter," Planet Advocate Reta Beebe, shares images from the "bonus" orbit observing Jupiter which she's contributing to the project, and we see how researchers use the huge STScI data archive to compare and contrast past pictures to help make sense of new information.

The program will also provide an e-mail address where questions can be sent during the live broadcast, providing information about how to participate using e-mail or the World Wide Web. Students will meet some of the men and women on the Hubble team who've volunteered to write *Field Journals* and who'll be responding to student questions on-line as part of *Researcher Q&A*.

In addition to live uplinks from STScI and GSFC, students from Washington state will participate via satellite and interactive video: some of them played a role in the "Great Planet Debate" and will now witness results of the decision they helped make. In another first for *Passport to Knowledge*, students at the European Space Agency's ECF (European Coordinating Facility) in Garching, near Munich, Germany, will interact via videoconferencing. (ESA built the FOC, or Faint Object Camera, which will be used to image Pluto.) We expect e-mail input directly from schools in Brazil, some in Manaus in the Amazon rainforest, who will be watching the programs live via USIA's Worldnet.

Tony Roman, Program Coordinator, STScI

My job is to help astronomers specify all the technical details necessary to conduct observations with the Hubble Space Telescope… then to take that and process it so that the observation eventually becomes something that the computers on board the telescope can understand and perform. Sometimes when you work with these difficult observations it can be a significant challenge to get them to work, and sometimes when you are caught up in all these details, you kind of forget that what you're really doing is working on putting together observations for one of the most powerful observatories the human race has ever built…when the data comes back at last I feel pretty excited and pretty proud to have been a part of that.

I was interested in astronomy since I was a small child, I guess, and I studied physics in college, and mathematics. Those are very important backgrounds for astronomy… I became interested in astronomy through my father, an engineer who worked on the Pioneer and Viking missions. Even though he wasn't an astronomer, he was working on those missions. And even though, at the time, I didn't really understand what he did, just the fact that that's what he was doing got me interested. Also, a more specific example, was that Carl Sagan had a television show on PBS called Cosmos *that I found very inspirational.*

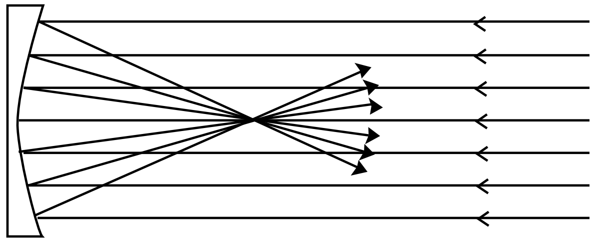
Activity 2A: Using a Concave Mirror to focus Radiation

Objective

Students will demonstrate the ability to explain how different forms of electromagnetic radiation can be focused using a concave mirror, and how HST's mirror functions.

Engage

Ask students why we use telescopes to study the universe. Answers may center on the power of various telescopes and their ability to show distant objects close up. Tell students that while telescopes do give us visually magnified images of distant objects, this isn't really their main function. (General background on the electromagnetic spectrum, as well as several hands-on activities, may be found in the *Live from the Stratosphere* Teacher's Guide, or in NASA's *Space Based Astronomy*, co-packaged with this *LHST* Guide.)



Explore / Explain

Explain that astronomers learn about objects in space by studying and analyzing the radiation that comes to us from these objects. The more radiation an astronomer can collect from an object, the more he or she can learn about that object because radiation is the carrier of information. So, really, astronomers are not as interested in the power of a telescope as in how much visible light and other radiation the telescope can collect and concentrate for study. This amount is usually far greater than can be achieved with the human eye alone. In this Activity, students will be able to calculate how much more radiation the HST can concentrate for study than can their own unaided eyes. They will see how a concave mirror, like that in the HST, focuses or concentrates radiation.

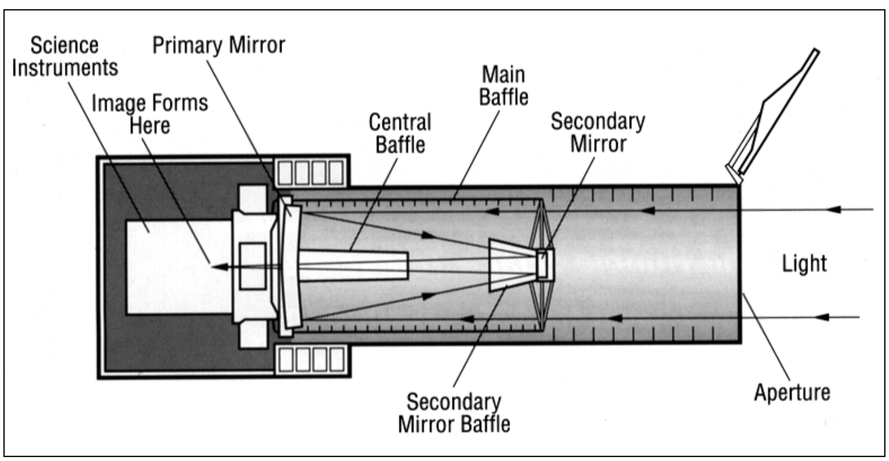
Materials

For use in demonstrations by the teacher:

- concave mirror (such as is used for shaving or applying make-up, or as can be purchased from a supply company e.g., Edmund Scientific Catalog #S52,016 [$26.00] or #S42,427 [$9.95]).
- candle or other small, bright light source
- thermometer and/or the heat-sensitive paper co-packaged with this Guide
- source of UltraViolet radiation (a UV lamp such as Edmund Scientific Catalog # S35,485 [$36.95] or #S34,501 [$32.95]) (Middle and elementary schools may find they can borrow this from their high school.)
- piece of tracing paper or wax paper
- electric space heater
- small jar of fluorescent luminous paint (such as Edmund Scientific Catalog #S31,806 [$10.95] or as is available in some art supply stores.) or the UV-sensitive beads co-packaged with this Guide

For each team of students

- cup of paper circles (the stuff you usually throw away after making holes with a 3 ring binder punch)
- a circle of dark construction paper, 6 inches in diameter



Procedure

Sketch on the chalkboard how a concave mirror focuses radiation using a simple ray tracing diagram, as shown above. Explain that the HST's primary mirror is curved like the drawing on the board (see cutaway HST diagram to left), and like the demonstration mirror you have acquired for this activity.

Proceed with one or more of the demonstrations on the following page.

1 Focusing Visible Light

Darken the classroom as much as possible. Light the candle or other small, bright source of light and place it several feet away from the mirror. Hold the mirror in one hand and the piece of tracing or wax paper in the other. Adjust the position of the mirror and paper until the candle flame or other light source is focused on the paper for the class to see.

2 Focusing Infrared Radiation

For this demonstration, the classroom can be fully lit. Explain that concave mirrors such as this one, and that on the HST, are also capable of focusing infrared (IR or heat) radiation from objects on Earth and in space, just as they do visible light. At this point produce a safe and handy source of infrared radiation such as an electric heater. Since infrared radiation is invisible to the unaided eye, challenge the students to suggest ways that you can know whether or not the mirror is indeed focusing this radiation from the heater. If a student suggests using the thermometer or heat-sensitive paper, let them go ahead and do the demo for you! If not, produce an answer by holding up the thermometer. Note the general temperature in the room. Then place the heater several feet away from the mirror at the same spot where you had placed the candle in the last demonstration and turn the heater on. After a few minutes, hold the mirror in one hand and the thermometer in the other. Place the thermometer at the same point where you placed the paper in the last demonstration. (Hint: as preparation you may want to have a C-clamp or other stand so that you can precisely mark the place to hold your detector in this and the following demonstration.) Have one or two students read off the temperature. It will rise as the mirror focuses the heater's otherwise invisible infrared radiation at this point in space. To parallel the first demonstration more precisely, use the heat-sensitive paper: it will turn white where the mirror focuses the IR radiation, and then turn colored once more when removed.

3. Focusing Ultraviolet Radiation

Explain that concave mirrors such as the one on the HST are also capable of focusing ultraviolet radiation from objects on Earth and in space. Hold up the ultraviolet lamp for the class to see, plus the UV-sensitive beads or the jar of fluorescent luminescent paint and a small piece of plain paper. Explain that the paint and/or beads contain special chemicals that glow or change color when exposed to ultraviolet radiation. Apply the paint to the paper.

This time, darken the classroom as much as possible, if you use the paint rather than the beads. Turn on the UV lamp and place it in the same position as the candle and heater in the previous demonstrations. Hold the mirror in one hand and place the beads or painted piece of paper at the same place where you placed the tracing or wax paper. Students will begin to observe the beads change color or the paint glow from the concentrated UV radiation. Removing the beads or paper from the focus of the mirror will cause the glow to become reduced or to cease.

Activity 2B; Hubble: A Very Big Eye in the Sky

Objective

Students will first estimate and then calculate the amount of light which can be gathered by HST's main mirror, and then compare and contrast this with the light-gathering power of the human eye.

Procedure Divide the students into teams. Give each team the disk of dark paper 6 inches in diameter and a cup with the white paper circles made by a 3 ring hole punch. Explain that the white circles are about the size of the pupil of the eye. Ask the students to spread the white circles out onto the dark circle and estimate how many white circles cover the dark circle, with no overlap of white circles but as little dark material as possible showing through. Tell them to make their best estimate. When the team are through, write down their answers and ask the class to compute the average. Explain that the HST's main mirror has about 248 times more area than do their 6 inch paper disks. Have them multiply the average they calculated by 248 for their answer.

Finally have them calculate the answer directly by using the formula for the area of a circle:

$A = \pi r^2$, where $\pi = 3.1416$ and r = the radius of the circle. (The relevant HST dimensions appear on the student worksheet.)

Expand

Discuss the reason for different answers to the above question using the two techniques. Which is more accurate? Also have students research and discuss what types of information might be learned about the planets by studying them in the infrared and the ultraviolet as well as in visible light.

Activity 2B: Hubble: A Very Big Eye in the Sky

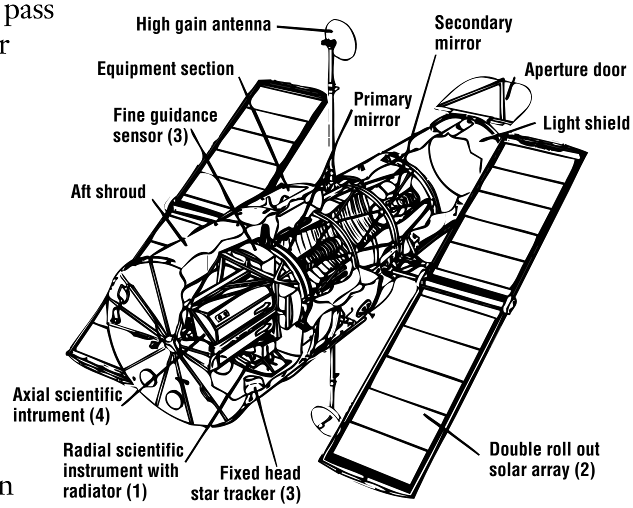
With our eyes alone, we can only see things down to a certain level of faintness at night or in a darkened room. We are limited by the amount of light that can pass through the pupils of our eyes which rarely widen to more than 0.25 inches across.

Telescopes allow us to see fainter objects because a telescope takes all the light that falls on its main lens or mirror and focuses, or concentrates, it down into a narrow beam that can usually pass through the pupil of the eye. Thus if an astronomer looks out at night with a telescope like the HST which has a mirror some 94.5 inches across, he or she is looking out on the universe with the equivalent of eyes that are 94.5 inches across! No wonder we can see more with telescopes.

How much bigger is the HST's main mirror than the human eye? Well, it's 94.5 inches divided by 0.25 inches, or 378 times the diameter of your pupil! But the true ability of the eye or a telescope to gather light depends on the **area** of its lens or mirror, not its diameter.

So how much more light does the HST focus than your eye? Let's use two methods to find out.

Cutaway diagram of the Hubble Space Telescope



Method #1: Estimation Using a Physical Model

Your teacher will distribute dark circles and cups with small white circles, which are about the size of the pupil of your eye. Carefully spread out the small white circles on the dark circle. How many does it take to completely cover the dark circle? Try to have as little overlap and as little dark material showing through as possible.

Write your estimate here. ________

Write the average estimate of all the teams in your class here. ________

The HST's main mirror has an area about 248 times greater than your dark circle. So how many little white circles would it take to cover the entire main mirror of the HST? ________

This is an estimate of how much more light falls on the HST than on your pupil, and so approximately how much more light the HST can focus.

Method #2: Direct Calculation

The amount of light a mirror or lens focuses depends upon its area. The area of a circle is given by the formula: $A = \pi r^2$, where $\pi = 3.1416$ and r is the radius of the lens or mirror, that is its diameter divided by 2.

How much more light does the HST focus than the lens in your eye? That's the same as asking how much greater is the area of the HST's main mirror than the area of the pupil of your eye. First, calculate the area of the HST's main mirror (All the information you need is contained in the Introduction to this Activity, at the top of the page.) Write your answer here ________

Next, calculate the area of the pupil of your eye. Write your answer here. ______ Finally, calculate how many times bigger the first area is than the second. Write your answer here ___

Compare your answers using method #1 and #2. Which do you think is more accurate? ________ Why? ______________________

Activity 2C: Observing "Moving Targets" with the HST

Objective

Students will demonstrate the ability to plan Hubble observations by plotting planetary positions at 3 specific dates on a sky-chart, determining a safety zone for HST, and verifying the accuracy of their results.

Engage

Point out to the students that most of the objects that astronomers look at in the sky are very faint and that, accordingly, most of the HST's instruments are very, very sensitive to light. Ask them to think about objects which HST cannot look at because they are so bright that they would blind and ruin the instruments. (The obvious answer is the Sun—but in fact the moon is also too bright). Tell them that for safety reasons the HST is usually not pointed within about 45 degrees of the Sun. (Note: A fist held at arm's length is about 10 degrees across.)

Explore / Explain

Tell the students that in this activity they are going to serve in the important role of Mission Planners for the HST (STScI calls such specialists "Program Coordinators," one of whom is Tony Roman, who'll appear on camera in Program 2, and whose comments may be found on p. 18 in this Guide.) For three different dates, students will determine which planets are safe for the HST to observe and which are not. As noted in the sidebar (p. 17), explain to the students that the planets and the Sun appear to move continuously relative to the "fixed" stars and so their changing positions need to be constantly tracked. Even though the planets of our solar system are close by, and relatively bright, they're literally "moving targets" and sometimes quite difficult to observe.

Materials (for each Mission Planning Team)

- copy of the HST "Zone of Solar Avoidance" disk (p. 23)
- Coordinate Tables for the Sun and planets for 3 dates (to right)
- 9 different colored marking pens
- scissors, pins or pushpins
- 3 copies of the Star Chart (p. 23)

Procedure Divide the students into Mission Planner Teams. Distribute materials to each Team. Ask them to make a color key for their own reference, and assign a different colored making pen to the Sun and each of the eight planets other than Earth. Point out the dates on the three separate Coordinate Tables and have them mark each of their three Sky Charts with one of the dates.

Illustrate how to plot a position on the first Sky Chart (March 14, 1996) using the Sun as an example. Have them mark their March 14 , 1996 chart making a small dot with the appropriate colored marking pen for the Sun. Then have them continue to plot and mark the positions of the planets on the same Chart. Have them proceed to the other two Charts and sets of coordinate data. Discuss how the position of the Sun and various planets has changed from one chart to the next.

Next, ask them to cut out their HST "Zone of Solar Avoidance" disk. Explain that this disk is designed to help them determine which planets are too close to the Sun to be safely observed with the HST. Make as many copies (or transparencies) as needed and give one to each team. Then, for each of the three Sky Charts, have the students carefully pin the center of the disk on the Sun. All planets lying within the disk are too close to the Sun to observe safely. For each Chart, have them complete the list on their Worksheets of which planets are safe, and which are not safe, to observe for the date of the Chart.

Expand

Ask students to research thoroughly the changing positions of planets to see if there's a planet which can **never** be observed with the HST.

TABLE 1 March 14, 1996

OBJECT	R.A.	Dec.
Sun	23.6 hrs.	2.5 deg.
Mercury	22.9 hrs	–9.5 deg
Venus	2.4 hrs.	16.2 deg
Mars	23.5 hrs	–4.2 deg
Jupiter	19.0 hrs	–22.6 deg
Saturn	23.9 hrs	–3.0 deg
Uranus	20.4 hrs	–19.9 deg
Neptune	20.0 hrs	–20.3 deg
Pluto	16.3 hrs	–7.8 deg

TABLE 2 January 15, 1997

OBJECT	R.A.	Dec.
Sun	19.9 hrs	–21.0 deg
Mercury	18.3 hrs	–20.9 deg
Venus	18.5 hrs	–23.1 deg
Mars	12.3 hrs	1.3 deg
Jupiter	20.1 hrs	–20.8 deg
Saturn	00.2 hrs	–1.3 deg
Uranus	20.4 hrs	–19.8 deg
Neptune	20.0 hrs	–20.3 deg
Pluto	16.3 hrs	–8.7 deg

TABLE 3 March 14, 1997

OBJECT	R.A.	Dec.
Sun	23.6 hrs	–2.5 deg
Mercury	23.8 hrs	–2.9 deg
Venus	23.3 hrs	–5.9 deg
Mars	12.0 hrs	4.2 deg
Jupiter	20.9 hrs	–17.8 deg
Saturn	00.5 hrs	1.2 deg
Uranus	20.6 hrs	–19.0 deg
Neptune	20.1 hrs	–19.9 deg
Pluto	16.4 hrs	8.7 deg

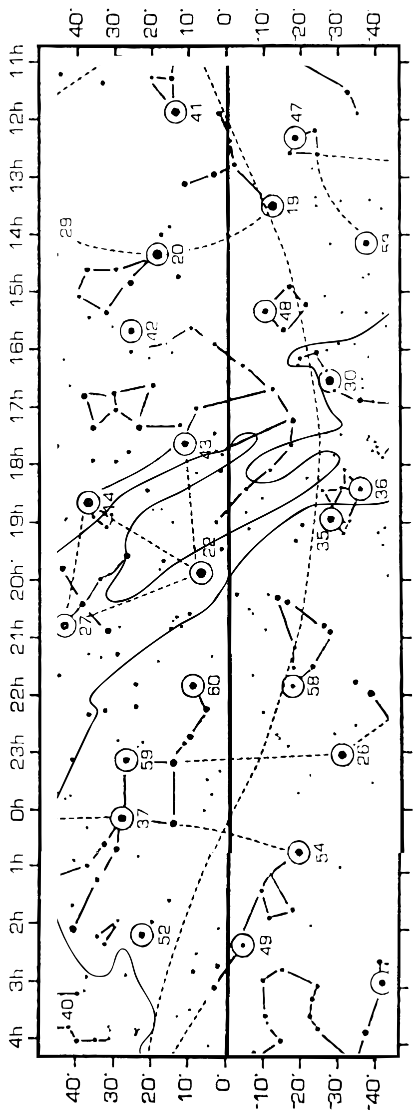
Activity 2C: Observing "Moving Targets" with the HST

In this Activity you and your team are going to become Mission Planners for the Hubble Space Telescope. Astronomers cannot just look at any planet with the HST, anytime they wish. This is because planets change position in the sky relative to the Sun, and the HST's instruments are so sensitive they are usually not pointed within about 45 degrees of the Sun. Sometimes, the planets wander too close to be observed safely. Your job will be to figure out for the astronomers, for three different dates, which planets can and cannot be observed with the HST.

Your teacher will pass out Sky Maps and Tables of positions for the Sun and the planets on three different dates. As instructed, plot the position of all these celestial objects on the appropriate Star Charts. Use the HST Zone of Solar Avoidance disk to determine which planets are safe to view and which are not for each of the dates in question. Once you have plotted all your data, fill the appropriate spaces in the Table below with the words SAFE or UNSAFE

PLANET	March 14, 1996	January 15, 1997	March 14, 1997
Mercury			
Venus			
Mars			
Jupiter			
Saturn			
Uranus			
Neptune			
Pluto			

Star Chart



Then answer the following questions.

1. What can you say about the position of the Sun on March 14, 1996 and March 14, 1997. _________ Why? _________

   ____

2. Which two planets appear close to the Sun on all three dates? ______________________________

   Why do you think so? ______________________

3. The dashed line in your Charts shows the path of the Sun among the stars as seen from Earth (known as the "ecliptic"). All the planets (except Pluto) lie very close to this line. Why? (Hint: It has to do with the shape of the solar system)

   ____

Activity 2D: Bouncing Data around the World

Objective

Students will demonstrate the communications path between a distant planet and an observer on Earth, with data transmitted via HST, communications satellites and ground stations.

Engage

Ask students to relate how a letter, sent from far away, gets to their house. Have them brainstorm a list of places the letter may have passed through—including the Internet—what kinds of vehicles may have been used to carry it, how long it took to travel to its destination, etc.

Explore / Explain

Explain that scientists need to send instructions up to HST as it orbits the Earth as well as receive data back from it. This activity will help students better understand the communications path between a scientist such as our Planet Advocates, and they themselves as *LHST* "virtual co-investigators," and the Hubble Space Telescope, showing how data are sent and received.

Materials A minimum of eight students is necessary for this activity

- one 6" or 8" ball (slightly deflated)
- tennis ball (optional)
- Set of 8 signs mounted on cardboard and string that students can wear around their necks. Signs should read: Planet (Neptune or Pluto?), HST, TDRS, (Tracking & Data Relay Satellite) White Sands, DOMSAT, (domestic satellite) Goddard (or GSFC), STScI, P.I. (Principal Investigator)
- clear space enough for the demo (20' x 20' at least)—a gym is ideal. Everyone must be free to move—no tables or chairs in the way.
- overhead transparency of the HST satellite data flow (see inside back cover)

Procedure Show students the overhead transparency of the HST satellite data flow. Explain the diagram, following the data path as shown. Explain that the HST receives, stores, and later relays data that is detected by the telescope.

Explain that TDRS is operated by NASA and communicates with the ground station at White Sands, New Mexico. TDRS is in a geosynchronous orbit, meaning it is synchronized with the Earth's rotation ("geo" meaning Earth). TDRS is approximately 26,000 miles from the center of the Earth (all geosynchronous satellites are positioned at this distance. Their period of revolution is the same as the time it takes for the Earth to rotate once around its axis). (NASA actually operates two geostationary satellites for HST, TDRS East and TDRS West, but only one TDRS communicates with HST at a time.)

Earth Locations

Four students are placed back to back in the center of the room forming a circle that will represent the Earth. (This is done for ease of the demonstration although in reality, all of the ground stations are on the continental United States and therefore the satellites would actually only send signals to a portion of the Earth rather than to the whole globe.)

Each of the four students is given a sign to wear—in consecutive order from left to right: P.I., STScI, Goddard, White Sands. This may sound complex, but just look at the diagram looking down on Earth's north pole locations and with an arrow specifying rotation (see inside back cover) and all will become clear!

Adapted with permission from *NASA's EUVE Satellite Data Flow* by Marlene Wilson and Dennis Biroscak, with contributions from Bill Hammerman and Dan Reimer Thanks Marlene and everyone!
http://sdp1.cea.berkeley.edu:80/Education/dataflow/

Satellite Locations

- TDRS: one student is placed at the edge of the room exactly opposite White Sands, NM, and wears the sign TDRS.
- DOMSAT: another student wearing DOMSAT is placed just as far away from the Earth as TDRS, but is positioned between White Sands and Goddard. Explain that DOMSAT is another geosynchronous used by NASA which also relays TV programs and other communications.

At this point, you could start the Earth rotating SLOWLY and let the geosynchronous satellites move sideways to try to keep up with the Earth. They have to remain over the same spot on the Earth. You could also wait until everyone gets assigned a position before you start the rotation.

- HST: another student is given the HST sign to wear. Explain that HST is only 380 miles above the Earth. Position this student very close to the Earth. HST travels around the Earth approximately 15 times for every once that the Earth turns (15 times per day), so it moves around the Earth much faster than the rate at which the Earth rotates.
- PLANET: from a corner of the room or anywhere well outside of the outer satellites, a student is positioned with the PLANET sign.

The student is given the small, slightly-deflated ball that will representing star light. For the purposes of this demonstration the PLANET does not move, so the student stands still.

The path of data from the planet to the P.I. is as follows: Planet, HST, TDRS, White Sands, DOMSAT, Goddard, STScI, P.I.

Motion in Space

Make sure students understand the difference between rotation and revolution. Within the revolution category are two subcategories, geosynchronous (or geostationary) revolution and non-geosynchronous revolution. For this demonstration, the only satellite that is non-geosynchronous is the HST. At this point, you may want to do a small "sub-demo" by having one student stand at the center of the room representing Earth, who will then rotate while one person on the outside (a satellite) follows the face of the "Earth." Students will clearly see that the Earth needs to rotate very slowly to allow time for the satellite to follow (around the circumference of the room).

Then start the motion in space with everyone except the PLANET as described above. Now call out the path as the students throw the ball. Have them call out who they are as the ball is caught by each.

- The Planet throws the ball (planetary image) to HST.
- HST sends the ball to TDRS.
- TDRS sends the ball to White Sands.
- White Sands sends the ball up to DOMSAT located between White Sands and Goddard.
- DOMSAT sends the ball to Goddard.
- Goddard "hands" the ball to STScI (since the data are transported through ground-based phone lines at this point).
- Finally, the ball (planetary image) is handed from STScI to the P.I. (Surprisingly enough, this is usually done via FEDEX!)

Variations: Data Drop-out

When someone drops the ball, it can be considered data "drop-out" and the ball goes back to the planet again. Explain that a data drop-out can occur at any point in the communication path.

Commanding the HST

Another ball (tennis ball) could be used to represent a command from the P.I. to HST. The path of the command is the same but in the opposite direction (P.I., STScI, Goddard, DOMSAT, White Sands, TDRS and HST). For more of a challenge, this can be done simultaneously with the incoming data from the planet, as in real life.

After the physical demonstration is complete, have students diagram the activity, labeling all the locations, and using arrows to indicate the flow of data, as if from a perspective out in space. [Younger students might be given a copy of the diagram used to introduce the activity (remove arrows and labels before copying) on which to draw the path.] Illustrations and diagrams should be added to their HST portfolios. Your students might also enjoy working collaboratively to produce a hall display or large mural showing the datapath.

Expand

Calculate the total time it takes light to travel the satellite pathway from our target planets via HST to Goddard. (Hint: remember the formula: Distance = Speed x Time.) What else do you need to know? Speed of Light = 186,000 miles per second. What about the number of miles between Earth, the various satellites, and the planets? The necessary information is all provided above and in Activity 1C—but students will have to apply some geometry to figure things out! Watch on-line and on camera for more *Challenge Questions*.

Hubble as a Weather Satellite for Our Solar System

Earth has been called an "incredible weather machine." Orbiting satellites hourly scan the planet from pole to pole, tracking storms, recording temperatures and moisture levels, and helping meteorologists make better weather forecasts. Can you think of a satellite that's regularly used to study weather on other planets? It's the Hubble Space Telescope, often doing as much meteorology as astronomy—scanning our celestial neighbors and revealing amazing worlds of weather clear across the solar system.

Mars has a thin atmosphere of carbon dioxide that keeps the planet drier than the Sahara and far colder, on average, than Antarctica. Hubble has shown us that the planet's temperature is now, on average, some 20 degrees less than that recorded by the Viking spacecraft in the 1970s, a significant and puzzling change.

At the edge of the solar system, orbits tiny Pluto. Like Neptune's moon, Triton, Pluto may have a thin nitrogen atmosphere that sometimes propels frosts and fogs across its icy landscape, and at other times freezes in place as Pluto's "seasons" change. Only closer study will reveal Pluto's climate and weather.

Between Mars and Pluto are Jupiter, Saturn, Uranus and Neptune, giant worlds whose faces are but the tops of enormous, turbulent atmospheres, thousands of miles deep. Here weather is driven not by the Sun but by heat rising from within. Soaring air currents couple with the planets' rapid rotation rates to produce jet streams that can race at over 1,000 miles per hour and produce storms larger than the entire Earth.

When astronomers speak about the atmospheres of the other planets, you'll hear them talk of winds, temperatures and atmospheric pressures. Much of the vocabulary of interplanetary weather will sound familiar to you and your students from tv weather reports, but the scale will be very different. After all, we're talking about other worlds, giant, strange and fascinating. Using the Hubble Space Telescope to study our planetary neighbors, scientists are studying weather on a cosmic scale, with many more examples than were available before the Space Age. In the process, they are trying not only to understand weather on each individual planet but also the similarities and differences between these worlds, and what they mean for Earth, now and in the future.

Activity 2E: Pictures from Outer Space

Objective

Students will simulate the interrelated processes by which spacecraft computers encode pictures of a planet, and computers on Earth later decode digitized data and transform it back into an image of the planet.

Engage

Ask students to think about the last time they or one of their family members took pictures with their still camera. Ask them how they think the image of the real world got from inside their camera into their hands as finished prints. (The answer is, of course, a physical thing called film which, after being exposed to light, is removed from the camera, chemically processed at the photo shop and returned as prints or slides). Ask them how they think we get pictures from the HST and other spacecraft? Early satellites did indeed parachute film packs back to Earth, but that's not the way it's done today. And astronauts aren't always popping up to change the film, so how does it work?

Materials (for each team)

- photocopy of the grid to the right
- set of 4 paper sheets of differing shades of black to white (black, dark gray, light gray, white)
- glue, scissors, four paper cups (to hold sets of paper squares)

Explore / Explain

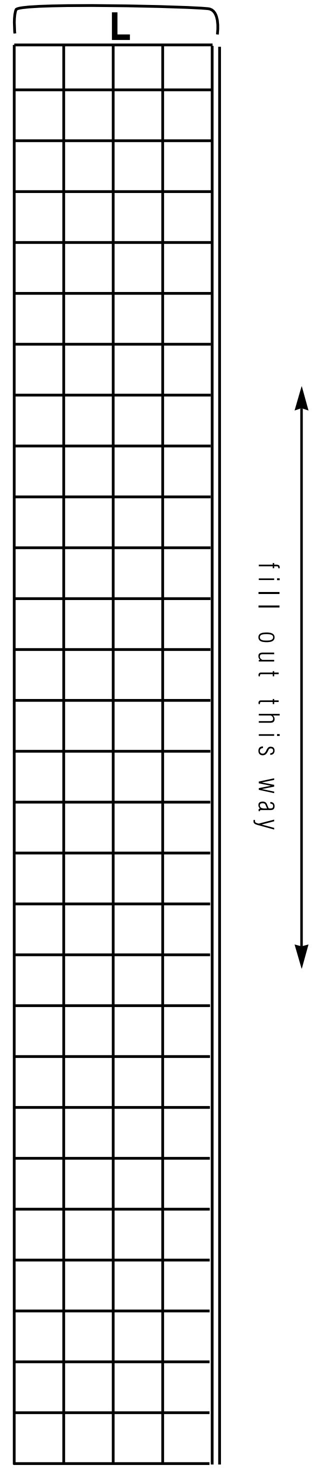
Have the students examine a TV or computer screen with a magnifying glass. Ask them to describe what they see. They'll note the picture is actually made up of little dots (called pixels, or picture elements.) Explain that the HST and other spacecraft actually send images to Earth by radio as a long string of numbers which tell the location and brightness of each pixel in the image. Then computers put all the pixels together like a great cosmic jigsaw puzzle. Explain that in this Activity, they are going to take the place of NASA computers and convert a string of coded data from a spacecraft back into the image of an actual object in space.

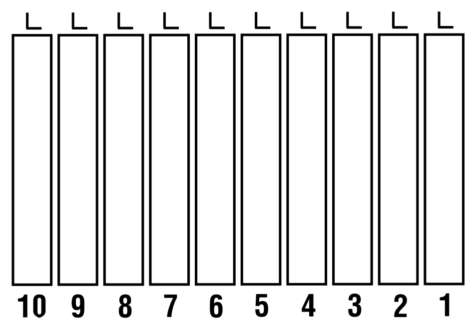
Procedure Begin by dividing the class up into ten Data Analysis Teams (and since this is a space-related project, you can call them DAT's. All space agencies love acronyms.) Give each DAT a copy of one of the coded lists of numbers (their "data stream") from your Master Code List. Also provide a copy of the grid to the right.

Tell them:

1. their grid provides the framework for one portion, strip or slice of the picture to be deciphered from space
2. the numbers in their data stream represent information on the brightness of the 1120 image pixels that they will be responsible for putting in place
3. the order of the pixels in their data stream is a clue to the order in which their pixels are to be arranged in their portion of the final image

Instruct them to place the grid horizontally on their desk tops (with the "L" mark on the left) and begin to encode the image by placing the first number in their data stream in the uppermost left box in their image grid. (Here they are doing, in a greatly simplified way, what the CCD detectors on board a spacecraft do when they observe a target.) Then place the second number in the data stream in the box on the same line immediately to the right, the third number in the next box, etc. When the first line is complete, tell them to begin filling in the second line of the grid, again from left to right, and continuing until their entire grid is filled in. Then one member of the team should re-read the numbers as the others check for accuracy.





Final image is constructed with strips in this orientation

When all teams have completed this task, pass out a set of paper sheets to each team. Explain that the shades of brightness and darkness correspond to the numbers sent down by the spacecraft with 0 representing pure white, 1 light gray, 2 dark gray and 3 representing black. Tell them to carefully cut the pieces of paper into small squares each the size of one of the grid boxes and to group each different color into a different pile. (An alternative is to use a paper-cutter, carefully, to mass produce squares in advance, then distribute them in paper cups) Have students glue an appropriately shaded square over each correspondingly-numbered grid box. Be sure to have one member of the DAT time how long the process takes to code their grids.

When all the DATs are finished, assemble all the pieces of the image to create the full image (as shown below left) on a larger piece of paper or card.

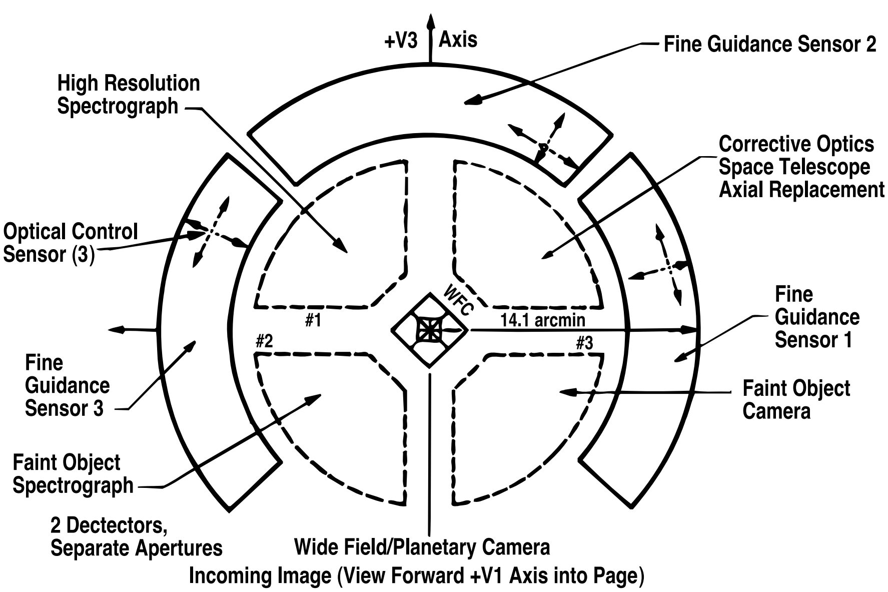
As the image comes together, challenge them to identify it, giving clues as you go. When completed, tell them the significance of Jupiter's Great Red Spot, and show them the actual image from Voyager 2 for comparison (to be seen in Program 1, "The Great Planet Debate" and on the HST lithographs co-packaged with this Guide).

Engage

Relate the coarsely-detailed (or "low resolution") image the students assembled to an actual image from the HST, as on the enclosed lithographs. These images clearly have more detail because they contain many more pixels in the same space and incorporate many more shades of gray between white and black. In short, it contains much more (picture and computer) information.

(See Activity 3A page 30 for how black and white data becomes a color image.) Have the students compare the number of pixels and shades of gray in their image and one from the HST, using the information given in their Worksheets. Finally, ask them to calculate how much longer it would have taken them to assemble the real image at the rate they worked.

How HST's Instruments Share the Telescope's Focal Plane & Incoming Electromagnetic Radiation



From pixels to pictures

The Hubble Space Telescope and other spacecraft, including weather satellites, take pictures using video technology and devices known as charge coupled devices, or CCDs for short. Like a picture on a TV set or computer screen, each image is made up of thousands of tiny dots or picture elements ("pixels"). The pictures are not sent down to the ground as hard copy. Instead, the photons of light reflected off an object are collected by the sensitive CCDs, and recorded and analyzed pixel by pixel. Then, the information on the location of each pixel within the picture and the brightness of that particular pixel is radioed down to Earth. Computers convert this information back into light and dark spots and place these pixels in their correct positions, so that a complete picture is re-constituted by computer. Prints and slides can then be made. This is the process you and your students will see happening for images of Jupiter, Neptune and Pluto during the videos, and you'll be able to follow the Planet Advocates' image processing work on-line, during the hectic weeks between the live broadcasts.

Another key thing to appreciate is that the HST and other spacecraft take their images in black and white. Yet we see beautiful spacecraft images in full color, such as the M-16/Eagle Nebula picture co-packaged with this Guide. How is this possible? To make a color image of an object, the spacecraft takes several black and white images, each through a different colored filter. By carefully examining how bright different parts of the object look through the different filters, scientists using computers can figure out the true appearance of the object, and so re-create a realistic color image.

Activity 2E: Pictures from Outer Space

You and your Team of Data Analysts are going to take the place of NASA computers and decipher an image beamed down from space. (This is an actual image, created in 1979 even though it's been simplified for this activity.) Your team will be responsible for putting together part of the overall picture. Your teacher will pass out a special grid and a stream of numbers sent down by the spacecraft. Encode the grids with the numbers as instructed by the teacher. As you begin, notice what time it is and write the time here. _______

You'll receive several sheets of paper, 4 colors ranging from pure white to pure black. Carefully cut them into squares the size of the grid boxes and attach the correct squares to the grid as explained by your teacher.

When you are done, your team will have completed one portion of the image. Again, note the time here. __________ Now, answer the next five questions and when you're finished tell your teacher that your grid is complete. What was the total amount of time it took your team to complete its assignment? _________

How many pixels were there in your team's grid? _______

How many teams are there in your class? _________

How many total pixels are there in the overall image put together by the class? _________

Now your teacher will collect all the completed portions of the image and put them together so you can see what the spacecraft was seeing.

Finally, consider the following: The total number of pixels in the image that your class assembled was 1,120. Each pixel had one of four numbers assigned to it , designating one of four shades of gray, white and black. That means it took 1,120 x 4, or 4,480 pieces of information to make this picture.

That may seem like a lot but an image of Jupiter from the HST's Wide Field Camera would use about 640,000 pixels, each of which can have any one of 2,048 different shades of gray. That makes for a much clearer, smoother picture but it takes much more information to create it. How many pieces of information would it take to make such an image? _________

Based on how long your DAT took to assemble your part of the image, (put together 4,480 pieces of picture information) calculate how long it would take your team to assemble one entire HST image of Jupiter. Write your answer: _______

NASA computers take less than 5 minutes for the same task. Can you see why NASA likes to use computers?

DATA STREAM for *"Pictures from Outer Space"*

Team #1

0000	0001	1100	1100	0112	1112	3333
0000	0100	1211	1110	0120	2233	3333
0001	0010	1221	1111	1120	2333	3333
0001	0000	1122	1111	1122	2333	3333

Team #2

0011	1000	0022	1101	1122	2323	3333
0112	2100	1022	1101	1111	2223	3333
0122	2210	0102	2211	1111	2223	3333
0121	2222	0101	1111	2111	2122	3333

Team #3

1211	1112	2111	2211	2110	2212	2333
1211	1111	2211	1221	1101	2212	2333
1210	2211	2221	1222	1111	1122	2333
1210	2222	2221	2122	1111	1112	2333

Team #4

0210	2222	2222	1112	1222	1121	2233
0120	1122	3222	2111	2211	2121	2233
0021	1222	3322	3211	2100	1211	2233
0021	1223	3332	3212	1000	0121	2223

Team #5

1012	1112	3332	3212	2000	0021	1223
1012	1112	3333	2312	2000	0012	2223
2111	2121	2333	2322	2100	0002	1223
2111	2111	2333	3332	2210	0001	2223

Team #6

0210	1211	2233	3332	1221	0001	2313
0220	0221	1222	2232	1222	1001	2333
0211	0022	2222	2332	1212	2222	2233
1012	1002	2222	3232	1222	2222	2223

Team #7

2001	2101	2233	3332	1221	1122	2332
2300	1210	1123	3332	0122	1211	2332
3210	0012	2223	2332	0112	1212	2333
3221	1100	1222	1221	0011	1122	2333

Team #8

3222	2221	0123	1222	1011	2222	2333
3321	2212	1001	0112	1011	2232	2333
3321	1221	1000	0111	1001	1222	3233
3331	0122	2110	2111	1000	1212	1323

Team #9

3331	0122	2111	2121	1100	1122	1333
0001	0120	0000	2111	1100	1122	1333
3332	0120	0000	1210	2100	1122	2232
3332	1100	0010	1111	2100	1121	2332

Team #10

2323	2100	0011	1222	1110	0122	2222
2323	2110	0111	1122	2221	0112	2222
2332	2122	2211	1112	2121	0112	1222
2332	2111	1011	1122	2222	0112	2222