Space Time Telescopes: Hands-on Demonstrations

This set of six mini-demonstrations accompanies the Space Time Telescopes scientist presentation. One technical innovation from each telescope is highlighted. The presenter may well bring in more details about other aspects of a particular mission. It may also be good to have on hand flyers or information that goes into greater technical detail.

List of Demonstrations:

1. Hubble: Telescopes in Space (eyes above the atmosphere)
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Each demonstration write-up contains an overview, a list of supplies, a basic outline of the procedure, some key points for discussion, and a link where you can find more resources about the spacecraft. All demonstrations include a set-up using materials you may already have in your home or office.

Be sure to test the demonstrations on your own before trying them with an actual audience!!!

Download this document and the accompanying presentation at http://www.universeforum.org/einstein/

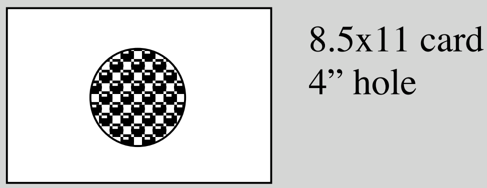
> Click on "Resources"→ "Educational Resources" → "Presentations for Scientists and Engineers" → "Space Time Telescopes"

If you have questions about these demonstrations or the accompanying presentation, please contact the NASA-Smithsonian Universe Education Forum at einstein2005@cfa.harvard.edu. You can also use this email address to tell us how your presentation went. Knowing how you use these materials will help us create more dynamic and useful presentations in the future. Be sure to let us know what questions you are asked; we use these queries to figure out which topics audiences find most interesting.

1. Hubble: Telescope in Space (eyes above the atmosphere)

Introduction: Astronomy from the ground is sometimes described as bird watching from the bottom of a swimming pool. Putting telescopes on high mountains (such as Hawaii) gets you above the densest and most turbulent part of the atmosphere, but to get a clear picture of the stars, you need to go all the way. The Hubble Space Telescope is in orbit 350 km above the Earth's surface, allowing it to use its optics to maximum effect.

Supplies: Budget set-up: sheets of letter sized card with 4-inch hole, bubble wrap.



Alternative set-up: Drainable fish tank, milk or cloudy/dirty water, eyedropper, picture of familiar object, TV or web camcorder with projection.

Demo version 1: Each audience member has a card with an aperture (4 inch hole). Covering the hole is a sheet of bubble wrap simulating the distortion of the atmosphere. Can we make out any detail of a picture on the far side of the room? What do we see? How could our view be improved? Move our detector (or eyes) in front of the bubble wrap.

Demo version 2: Predicting what's in the picture. There is a picture behind the fish tank, and in the fish tank is cloudy weather, representing the Earth's atmosphere. Our view through the telescope is simulated using a TV camera. Can you make out what the picture is? Now drain the fish tank–can you see the picture clearly now? We can't of course drain the atmosphere, but we can put our telescope above it.

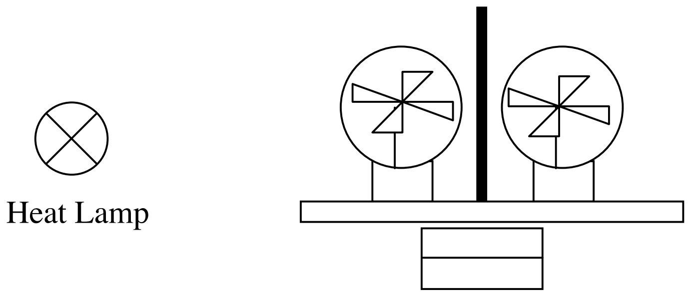
Discussion: Before you begin this demonstration you may wish to ask your audience why NASA puts telescopes in space. Science education research shows that a significant number of students (and adults!) think telescopes are in space “to get closer to the objects being looked at.” Pair this demonstration with a scaling activity and you will be well on your way to helping your audience build a better model of how we understand the universe we live in. (Examples of scaling activities, using cookies and CDs, can be found in the Universe Education Forum's “Journey To the Beginning of Time” demonstration, available in the Educational Resources section of the “Inside Einstein's Universe” web site. Also look for “The Incredible Two-Inch Universe.”)

To learn more about the Hubble Space Telescope, visit http://www.stsci.edu/hst/

2. WMAP: Radiometer (measuring heat)

Introduction: NASA's WMAP spacecraft measures the leftover heat from the Big Bang. In the 14 billion years since the Big Bang, the universe has cooled, although the glowing embers of that early universe still permeate all space as a "sea" of microwaves. By mapping the slight variations (1/10,000 of a degree) in the temperature of this radiation from one part of the sky to another give us huge amounts of information about the conditions in the early universe.

Supplies: 2 radiometers mounted on a turntable (Lazy Susan) with a board between them. Heat source (heat lamp or window with bright sunshine)



Demo: Because astronomers are interested in temperature variation, WMAP uses two radiometers to calculate the difference in temperature between two regions of sky. As the spacecraft rotates, the two radiometers are exposed to different regions of sky, eventually completing a full-sky difference map of the temperature of the universe. Here two blade radiometers sit on a turntable. Due to the heat lamp, one side of the "sky" is slightly warmer than the other. As the radiometers are exposed to the lamp, they spin faster.

Discussion: An important first thing to note is that in this simple model, the heat lamp is not representing the Big Bang, but simply providing an obvious temperature difference to see how the radiometers respond. One of the biggest misconceptions, held by students and adults alike, is that the Big Bang happened in a particular point in space, or "over in that direction." The Big Bang occurred everywhere in space, just as light is striking these radiometers from every direction in the room (though thanks to the heat lamp, not uniformly). This demonstration illustrates the technology, not the scientific result.

This demonstration illustrates how the WMAP spacecraft measures temperature variations in the early universe. Because matter in the early universe was hot, it radiated. It is this light from the early hot universe that is detected by the radiometers onboard WMAP. By measuring variations in the intensity of the light, astronomers infer a variation in temperature (and by extension, density) in the early universe. The variations in temperature are actually tiny, no more than a few ten thousandth of a degree, but even this subtle variation is all that is needed to provide the seeds of future galaxies, stars and planets. How can we picture this miniscule variation? Imagine our blade radiometers set up in a pure white, uniform room, with identical looking floor, ceiling and walls. Yet, in certain orientations, one blade spins just a little faster than the other.

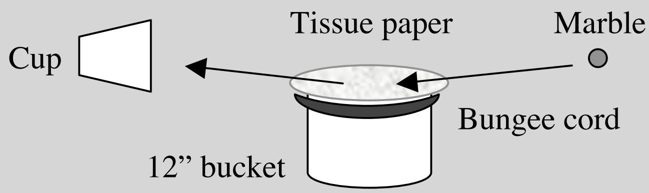
To learn more about WMAP, visit http://wmap.gsfc.nasa.gov/

3. Chandra: Grazing Incidence (tissue paper stopping a stone)

Introduction: Focusing X-rays is not easy. They will happily travel straight through a normal telescope mirror. But if you catch them at a shallow enough angle, they can be reflected. Chandra's mirrors are almost cylindrical. X-rays that enter Chandra's aperture are traveling almost parallel to the surface of its mirror. Almost, but not quite. Like stones skipping off a pond, they strike that mirror at a grazing angle, and are reflected and focused onto the telescope's detector.

Supplies: tissue paper, bucket (~12" diameter recommended), bungee cord or rubber band, marbles, cup, stepstool or chair

X-ray Set Up:



Demo: It would be nice to have a pond at our disposal, but chances are this presentation will be done indoors! Instead, we use a sheet of tissue paper to represent the mirror, and a cup to represent the telescope's detector. Using the bungee cord, attach the tissue paper to the edges of the bucket so that it lies taut and flat across the opening. The presenter, standing on the stepstool high above the bucket, sends a marble, representing the x-ray, towards the tissue paper at a right angle, making a nice hole right through the paper! Return to the ground to cast your second marble at a very shallow angle. When this second marble is cast, it should skim the surface of the paper, glancing off the paper, and bouncing into the cup! (Be sure to practice dropping and skimming your x-rays before your presentation.)

Discussion: Because x-rays are so energetic, they would travel straight through your average telescope mirror. In order to collect x-rays, they must be focused at very shallow angles, such as skipping rocks on a pond. Try this demonstration as a game. Players get points for every x-ray they collect. If they can get the x-ray to bounce off the mirror into the cup, they are in luck; otherwise their light will travel straight through the mirror and be lost forever! (This game may also work with round pieces of candy similar in weight to marbles, but such "edible x-rays" have not yet been tested.)

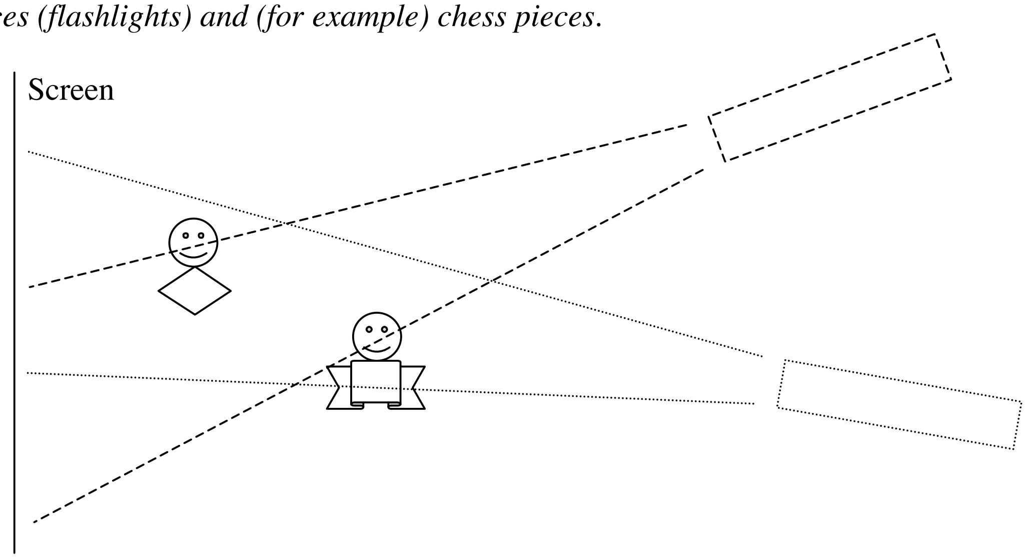
You can also use this demonstration as a jumping off point for talking about x-ray astronomy—x-ray light provides very different information than the light our eyes (and the Hubble Space Telescope) can detect, so it is with x-ray technology that we are able to gain a clearer picture of the high-energy universe. Try showing your audience pictures of active galaxies or other dramatic phenomenon as seen in both visible and x-ray light. Examples include the Crab Nebula and Centaurus A images that appear in the Space Time Telescopes presentation.

To learn more about Chandra, visit http://chandra.harvard.edu/

4. Swift: Aperture Masks (using shadows to predict position)

Introduction: Gamma ray light cannot be focused – the photons just shoot right through anything (almost anything) in their path. If there is a flash of gamma rays in the sky, how can we tell which direction it came from? Swift makes use of shadows to pinpoint position. Part of the telescope's detector is covered with a random pattern of lead tiles. Lead is a material that gamma rays struggle to get through. If a gamma ray strikes a lead tile, it does not reach the detector (use OHP template). If the gamma ray's path avoids the lead tile, Swift will detect the gamma ray. How does this aperture mask allow us to measure position?

Supplies: Two volunteers, 3 bright directional light sources, or one mobile (theatre spot light), white screen. *Budget set- up: This could also be done on a desktop scale with smaller light sources (flashlights) and (for example) chess pieces.*



Demo: We are using people as the lead masks. The white screen is the detector. We have three sources of gamma rays (three supernovae) in different parts of the sky (the spot lights). Their light is approaching the detector from three different angles. Depending upon which source lights up, the shadows from the two lead masks (or volunteers) will be in different positions on the detector (screen). Can your audience figure out where the light is coming from by looking at the shadows on the screen?

Discussion: In this model, our light source can shine for as long a time period as we want. The technical challenge the Swift telescope faces is in observing gamma-ray BURSTS—quick flashes of high-energy gamma-ray light. Swift must react very quickly to record a single burst and pinpoint its location, based on the light shadow. If it is lucky enough to catch one of these flashes, it then must then relay the location of the flash to other telescopes on Earth and in space so that those telescopes can observe the aftermath of the burst. Try this demonstration by flashing your light source very rapidly. (One of those phosphor screens and flashguns would be perfect for this!)

To learn more about Swift, visit http://swift.gsfc.nasa.gov/

5. Gravity Probe-B: Gyroscopes (which way are you pointing?)

Introduction: An amazing property of nature is that anything spinning on an axis will try to keep that axis pointing in the same direction (angular momentum). Whether it is a spinning top, gyroscope, planet (Earth always points to Polaris), or a bicycle wheel, to push or pull your spinning object out of alignment requires a bit of force—even more if it's a planet! GP-B uses its incredibly engineered gyroscopes to know exactly which direction the spacecraft is pointed. It uses this precise pointing accuracy to detect the twisting of the space it is moving in.

Supplies: Bicycle wheel gyroscope, swivel chair, two ropes tied to chair. Budget set-up: any toy gyroscope or top could make the point.

Demo: The GP-B spacecraft is represented by a volunteer sitting in a swivel chair holding a spinning bicycle wheel gyro. The twisting of space is represented by two other volunteers tugging at the chair to make it rotate. The person in the chair will turn, but the spinning gyro will attempt to retain its original direction—the volunteer will feel the gyro resisting the change.

Discussion: Gravity Probe-B is a very sophisticated detector that uses four carefully designed gyroscopes. The four gyroscopes are aligned to point at a distant star as the spacecraft orbits Earth 400 miles above its surface. Each gyroscope in and of itself is a near-perfect sphere, rendering its interaction with its surroundings virtually nonexistent. Each gyroscope is housed within a quartz "shell," lined with carefully-tuned detectors that will be able to sense miniscule changes in the gyroscope's orientation. These detectors will be sensitive enough to detect a tilt in spin axis ~ 2 ten-millionths of a degree—equivalent to measuring Lincoln's head on a penny from 3,000 miles away or the width of a human hair from 25 miles!

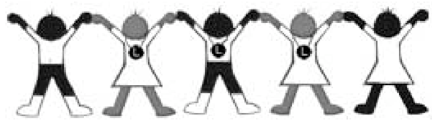
Because our planet Earth is a mass in space, it has an effect on the spacetime around it. Gravity Probe-B is measuring how Earth is warping this surrounding spacetime, and also how the Earth's rotation drags spacetime around with it. These effects, though small for the Earth, have major implications for the nature of matter and the structure of our universe. Because these effects are predicted in Einstein's equations of gravity, Gravity Probe-B is often said to be "testing Einstein's universe."

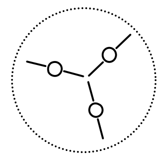
To learn more about Gravity Probe-B, visit http://einstein.stanford.edu/

6. LISA: Stretching Space (kinesthetic gravitational waves)

Introduction: LISA is a sophisticated interferometer that measures a path length to the accuracy of the width of an atom. However, LISA is basically measuring distance, or separation, and that separation changes because passing gravitational waves stretch and squeeze the space between LISA's components.

Supplies: At least 5 volunteers, 3 CD medallions with LISA probe pictures

Model 1: 

Model 2: 

Top view: A circle of volunteers around a star of 3 volunteers, wearing the CD medallion.

Demo Version 1: Here we will model kinesthetically and in one dimension a gravitational wave traveling through space. People will represent the fabric of space, and three CDs around three of the volunteer's necks represent the LISA probes in space. The five volunteers line up hand in hand. The presenter (gently) pushes the person at one end, sending a compression wave down the line. (Volunteers should "go with the flow," not resisting the wave when it arrives and gently passing it along to the next person in line. They are allowed to, and will probably need to, move their feet as the wave passes "through" them.) As the wave passes through the space occupied by the LISA probes, the audience should notice that the probes move closer, then further apart. A key observation is that all three probes do not move at the same time—there is a delayed reaction, as each probe "waits" to experience the compression in its surrounding space.

Demo Version 2: Place three volunteer "sensors" in the middle, touching hands to make a three-pointed star. The rest of the group forms a circle around the star, such that the "sensors" can each reach with their other hand to touch a part of person in the outer circle. Have the sensors close their eyes as the rest of the group quietly sends a wave in one direction around the circle. Each sensor says "mark!" to indicate when he or she senses the wave. Based on how the three sensors felt the wave they can determine the direction of travel. Reverse the direction around the circle and sensors detect it differently. Try varying the speed of the wave and the sensors will be able to indicate whether the wave was traveling fast or slow. Although gravitational waves do not actually move in a circle, this model allows your audience to see how the three sensors work together to gather information about direction and speed.

Discussion: In the first model it is easy for the audience to see what happens to the probes as gravitational waves move through the surrounding space—the distances between the probes increase or decrease by a few inches depending on what is happening to the space around them. In reality, the effect of a gravitational wave motion is incredibly small—a mere atom's width, even over millions of miles. (The three probes will fly in formation, at the corners of a triangle 3 million miles per side.) If you ask your volunteers to stand as still as they possibly can, they are still moving 10 thousand times as much than LISA probes do when a gravitational wave travels through the surrounding space!

To learn more about LISA, visit http://lisa.jpl.nasa.gov/