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INSIDE EINSTEIN'S UNIVERSE

"Einstein's Lens" Scientist Presentation: Supplemental Demonstrations

http://www.universeforum.org/einstein/resource_lensing.htm

There are a number of hands-on demonstrations that can be used to further engage audiences in the ideas of gravitational lensing. The examples below are taken from the Universe Education Forum's "Journey to a Black Hole" demonstration manual, originally created for museum and planetarium educators. The full manual includes ten hands-on activities for bringing black hole science to public audiences.

http://www.universeforum.org/einstein/resouce_journeyblackhole.htm

In this document, we present two activities that address the effects of gravitational lensing. "Black Hole Lensing" uses an ordinary wine glass to create a model of a gravitational lens that your audience can look through. "How to Spot a Black Hole" uses magnetism to simulate the effect of gravity. By rolling a magnetic marble across a piece of foam board with a hidden "black hole," the path of the marble can be deflected, much like a photon of light is deflected by a gravitational lens. Note that this activity has several outcomes, and several accompanying visualizations, not all of which are directly related to the ideas presented in "Einstein's Lens."

http://www.universeforum.org/einstein/

We are always interested in how people are using these resources. You can contact the Universe Forum at einstein2005@cfa.harvard.edu or let us know about your presentation here: http://www.universeforum.org/eventreport.html

Thank you for your interest in the "Inside Einstein's Universe" program, and be sure to practice your demonstrations before presenting them to an audience!

Black Hole Lensing

What happens when a black hole crosses your field of view?

Supplies (Images are available in the Appendix, beginning on page 10):

- A large image with a distinctive shape (perhaps Albert Einstein) or even an actual person such as yourself or a volunteer
- Wine glass (glass is better than plastic) (See Appendix, Image 1)
- Protective gloves & goggles (See Appendix, Image 1)
- A fine file tool for cutting base off wine glass (See Appendix, Images 1 & 2)
- Volunteer(s)
- Optional: Video camera (camcorder or surveillance-type camera)

Procedure:

PREPARATION

1. Purchase a wine glass made of clear transparent glass, without any color tint or patterns on the glass. A thicker stem is preferred. See Image 1 in the Appendix. You will be able to create two lenses from each wine glass, using both the base and globe to produce the desired gravitational lens optical effects.

2. Put on protective gloves & goggles. You must **always** use protective gloves & safety glasses while handling, etching and breaking glass. **<u>Always!</u>**

The following steps will most likely produce some glass dust and shards. Take care to choose a safe work area and thoroughly clean up any glass shards.

3. Use the fine file tool to score the stem of the wine glass, just as it begins to widen into the stem. (More information about these tools can be found in Image 2 of the Appendix.) The location of this first score line should be just above the base as the glass begins to narrow into the slim stem. This is about 1 centimeter above the base, but use your best judgment, as the location of the score line is not too critical. See Images 1 and 3 in the Appendix. Follow this technique to etch a score line on the glass stem:

    a. Hold the wine glass by the globe firmly in one hand and the fine tool file in the other. See Image 4 in the Appendix.

    b. Score a single complete circle around the stem, making sure the beginning and ending of the etched line connect. Make only *<u>one etched line</u>* for each place you wish to break the glass, as several scores will produce multiple fractures and a poor break, if not a shattered glass!

   c. <u>Do not</u> score the glass at the second etching location yet. It is also important the single etched line's *<u>start and finish meet cleanly</u>* to produce a clean break in the glass.

   d. You may want to brace the wine glass globe against a table or other durable surface as you score the glass stem. Remember, you **<u>ARE</u>** wearing protective gloves and glasses!

4. To detach the base from the stem of the wine glass, sharply tap the base against a hard surface, in one smooth yet firm motion*, <u>abruptly halting</u> the motion as the wine glass base hits the surface*. The base should strike the surface at an angle while the globe is protected in your gloved hand and the stem does not hit the surface. See Image 4 in the Appendix. The glass should break cleanly at the scored line. If not, repeat the motion again with slightly more force. If it still does not break cleanly, carefully etch a slightly deeper groove into the *<u>same</u> <u>score line</u>*, making sure NOT to etch any additional lines. Repeat the firm tapping motion with less force before proceeding to a more forceful tap. If the base breaks away from the stem but produces an attached shard to the base, firmly hold the base and tap the shard against a hard surface at an angle, which will likely break away at the scored line mark.

   Suggested appropriate hard surfaces to strike the glass against are a wooden table or bench top, a low pile carpet over concrete floor, a linoleum floor, etc. You want a hard surface that has a slight "give" in its firm surface.

5. File down any sharp glass edges at the break of the detached base. We want to eliminate any possibility of injury. This will yield a disk-shaped lens. See Image 5 in the Appendix for examples of finished disc gravitational lens.

6. To produce another gravitational lens from the leftover wine glass globe and remaining stem, repeat steps 3 through 5 with the following notes:

   a. Be very careful handling the end of the stem, as this is very sharp and can easily injury you.

   b. The approximate location of second score line is noted in Image 1 in the Appendix. The best position for the score line is very dependent on the type of wine glass you possess. How thick the glass is where the stem meets the globe and if you want to demonstrate more or less of lensing effect determines your choice. Most clear wine glass bases are quite similar, where as the globes vary greatly. We suggest you choose a score line that will result in more glass material in the globe lens than the base lens you just made, so show a stronger gravitational lens effect. See Image 5 in the Appendix for examples of different type globes.

c. Sharply strike the remaining stem and globe against a hard surface (AFTER you make the second scored line about the top of the stem, of course), you will very likely produce glass shards from the stem. Be aware of this. Thoroughly file down any sharp edges.

7. You have now made two gravitational lenses from one wine glass. Try creating another set from a different style or shaped wine glass. If not successful, try again with another wine glass. Always dispose of any glass material deemed a potential hazard.

SET UP

8. In the room where you plan to do the demonstration, post your background image on one of the far walls.

9. (Optional) If using a video camera, position the camera on a tripod and aim it at the background image or the position a person would stand to be imaged by the device.

10. (Optional) You may affix the base of the wine glass in front of the camera, with the cut end away from the camera.

ACTIVITY

11. Explain to your audience that a black hole distorts the view of space and time around it. (This is a very weird idea!)

12. If cut edge is not perfectly smooth, *FILE DOWN* these sharp edges *BEFORE* presenting to an audience. Otherwise, closely supervise the apparatus with protective gloves. Caution your volunteer(s) not to drop the breakable and fragile "black hole lens."

13. Invite your volunteer(s) to view the world through their "black hole lens" by looking at the background image through the base of the wine glass. Alternatively, view the background image with the video camera as you pass the "black hole lens" in front of camera's lens OR have someone walk through the location where the camera and "black hole lens" is focused on. What's the view?

14. Can you create an "Einstein ring"—a very thin ring around the center of the lens—by looking at the image through the lens and just the right angle?

Discussion:

Einstein predicted that the actual shape of space and time around a massive object is distorted by the object's gravity. Light from a distant object would travel in a straight path to the observer, but if that light happens to pass close to a massive object, the light would follow the curved, warped space around the massive giant. This gravitational lens effect allows these massive objects to act like lenses that focus and amplify the light from distant objects.

Arthur Eddington was first to observed a shift in a distant star's position as its light passed close to a massive object to the way to an observer. During a solar eclipse in 1919, Eddington measured how a star's position shifted when observed near the Sun as compared to when it was not. This measured deflection matched Einstein's predictions of how the Sun's gravity would distort space (and time).

What must the geometry of the observer, the gravitational lens and the distant object of interest be for this effect to be seen? How easy is it to move the observer? Or the gravitational lens to point at the object you want to observe?

These ideas are explored in more depth in the scientist presentation "Einstein's Lens," available at http://www.universeforum.org/einstein/resource_lensing.htm. This presentation includes an image of the 1919 *New York Times* headline!

Accompanying Visual Resources:

Gravitational Lensing Simulation
http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/01/video/a
Short animation shows the gravity of a massive foreground object warping space. The light of background galaxies is bent as it passes the gravitational lens making the galaxies appear distorted and brighter. Credit: STScI, NASA

Baltimore's Inner Harbor Seen Through a Gravitational Lens
http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/01/video/b
Simulation of a gravitational lens moving across the Baltimore city skyline. The lens is produced by a compact and massive object, which bends space around it. This distorts light coming from any object behind the lens. The simulation shows how the lens distorts the background buildings. Credit: Frank Summers (STScI, NASA)

Image of Smithsonian Castle Seen Through a Gravitational Lens
http://cfa-www.harvard.edu/~bmcleod/castle.html

Image of how the Smithsonian Castle might look if a black hole with the mass of Saturn appeared in the middle of the National Mall. The effect is caused when a massive gravitational force bends light. Credit: Brian McLeod, SAO

Image of Abell 2218, A Galaxy Cluster Lens
http://hubblesite.org/newscenter/newsdesk/archive/releases/2000/07/image/b
The massive galaxy cluster Abell 2218 is so compact that its gravity bends and focuses light from galaxies behind it. Acting as a telescope, Abell 2218 distorts these background galaxies into long faint arcs, allowed astronomers to detect the most distant galaxy yet measured. This young, still-maturing galaxy is faintly visible to the lower right of the cluster core. Credit: Andrew Fruchter (STScI) et al., HST, NASA.

Image of Abell 1689, A Galaxy Cluster Lens
http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/01/
The galaxy cluster Abell 1689 is one of the most massive objects in our universe. As predicted by Einstein's theory of gravity, the collective mass of this cluster is warping space, causing light from galaxies behind to bend, producing the faint bluish arcs visible in this image. This effect is a product of the combined mass of the galaxies and the dark matter in this cluster. Credit: NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA

Create your own Gravitational Lens with your image processor!
http://leo.astronomy.cz/grlens/grl0.html
Image processing software can be expanded by use of plug-in filters to create your own gravitational lens effects on any image. Provided by Leos Ondra, with assistance from the Filter Factory plug-in by Joseph Ternasky and Dave Corboy.

Black Hole Hide and Seek

How can you stay safe in a universe filled with black holes?

Adapted from Astronomical Society of the Pacific/Night Sky Network's "Black Hole Survival Guide" activity kit

http://www.astrosociety.org/education/nsn/nsnpress.html
http://nightsky.jpl.nasa.gov/

Supplies:

- 2 sheets of foam board, roughly 11" x 17" (alternative: use black signboard, e.g. Coroplast®)
- 1 strong, small cylindrical magnet (e.g. AmazingMagnets.com: Item # T250B)
- A magnetic marble (e.g. School-Tech.com: Item #12610W2)
- (Optional) Towel or tray

Procedure:

PREPARATION

1. Bore or cut several holes in one of your sheets of foam board, with the same diameter as the cylindrical magnet. The magnet should fit snuggly into the hole but can be held in place with tape if necessary.

2. Place the magnet in one of the holes. The other holes allow you a variety of locations for the black hole.

3. Cover the foam board (and the magnet) with the second piece of foam board, so that the surface of space appears uniform.

4. Use the towel or a tray underneath the demo to keep the marbles from rolling away!

ACTIVITY

5. Ask your audience if they are worried that a black hole might "eat" them. Assure them that this is a common concern for many people, but nothing to worry about.

6. Remind them that a black hole's gravity is just like that of anything else in the universe—dependent on mass and distance from the object. Black holes are very massive, so their gravitational fields are very strong, but you still need to get very close (hundreds or thousands of miles) to suffer any severe effects.

7. Bring out your foam board apparatus and explain that there is a black hole hidden somewhere in this piece of space. Because black holes are "invisible," we cannot see it with our eyes. Instead, we are going to look for it using "gravity."

8. Invite a volunteer to come up and hand her one of the magnetic marbles.

9. Explain to your audience that this marble represents a piece of matter in space. This piece of matter will begin to orbit the black hole if it gets close enough to the black hole. Your volunteer's job is to send the matter on a journey through space to find the black hole.

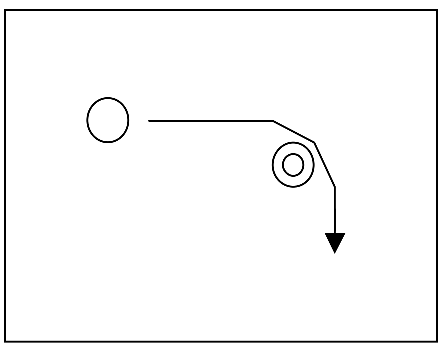
10. Have the volunteer roll the marble slowly across the cardboard.

11. If the marble rolls over the hidden magnet, its path will change; if its path does not change, it has not been affected by the black hole's "gravity."

12. Repeat this activity until the volunteer "discovers" the black hole.

13. If you like, repeat the entire activity with the marble in a different hole.

Illustration of effect:



Discussion:

In this activity, the magnetic force is being used to simulate the force of gravity, and it is very important to emphasize that **magnetism is *not* gravity**. One major difference is that gravity is always attractive, whereas magnetism can attract and repel. Gravity is also a much weaker force, and only becomes noticeable when dealing with massive (planet-sized or bigger) objects. We are therefore using magnetism as a model for gravity when the marbles attract each other. (Interestingly, the force acting between the Sun and the planets was initially attributed to magnetism by the great astronomer and mathematician Johannes Kepler in the early 17^{th} century.)

Depending on how close (and how fast) the marbles encounter the hidden magnet, visitors will notice different outcomes:

Outcome A – If the marble passes by the magnet at a great distance, we notice no deflection. Both the magnetic and gravitational fields decrease with distance. When far away from the magnet, our marble is still under the influence of the magnetic force, but it is too weak for us to notice. Similarly with black holes, we need to get very close to notice their presence.

Outcome B – Some marbles will roll by the black hole but their path will be deflected. The passing object is traveling at greater than the escape velocity of the black hole at that distance, but we still detect the black hole through the deflection. If the magnetic marble is representing a photon of light, rather than a planet or star, this result models gravitational lensing.

Outcome C – Some marbles will be captured by the black hole's gravity and end up in orbit. This models how stars and gas can be captured by the black hole's gravity. We see this scenario in the accompanying visualization (see below). Notice how close an encounter you needed for such an outcome.

Accompanying Visual Resources:

Gravitational Lensing Videos from the Space Telescope Science Institute
http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/01/video/

Animation of a Star Ripped Apart by a Giant Black Hole
http://chandra.harvard.edu/resources/animations/blackholes.html
This animation shows what happens to a star that drifts too close to a giant black hole. At this very close distance, the star is subjected to the tidal forces caused by the black hole's gravity. The star is ripped apart by these forces and part of it is drawn into orbit around the black hole. The part that does not get drawn into orbit continues its journey through space.

Stars in the Galactic Center
http://www.mpe.mpg.de/ir/GC/
This animation shows the orbits of stars very close to the center of our galaxy over a period of 14 years: from 1992 through 2004 and projected to 2006 (watch the counter in the upper left corner). The red cross in the center marks the location of the invisible giant black hole in the center of our galaxy. See how fast the stars are moving as they pass by the central black hole. Credit: Max-Planck-Institut für extraterrestrische Physik

Appendix: Pictures of Black Hole Lensing Equipment

Image 1: Materials for creating a gravitational lens out of a wine glass

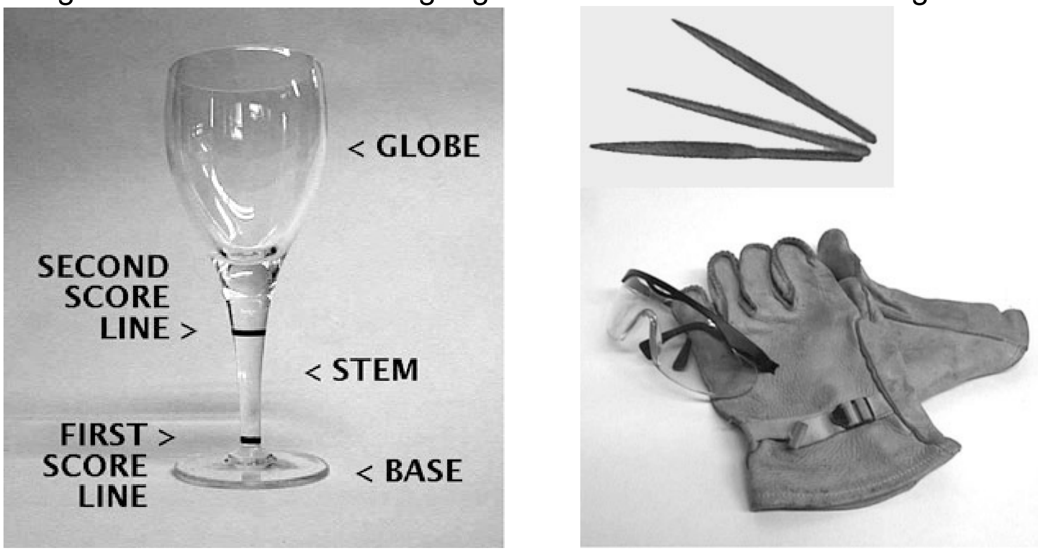
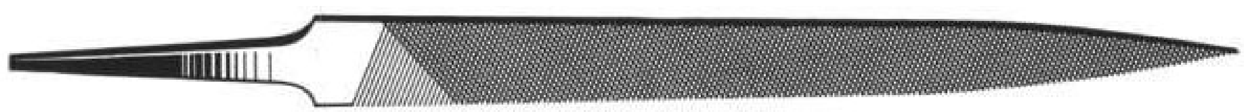


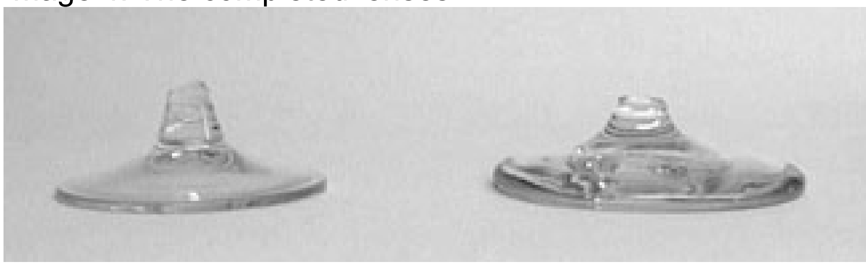
Image 2: Fine file tool for etching the base of glass:



The fine tool file for etching the glass can be a simple mill flat, square, taper, three-square or even a half-round file, as long as the file has an edge and cuts a fine line pattern. These fine finishing files made of carbon steel are also called Swiss-pattern files. Fine tool files produce very precise etched marks that score glass well. A coarse and random etched pattern is not desired and will produce a poor break in the glass. If you possess a non-round diamond file, use that tool instead, especially if you will be making numerous gravitational lenses. Diamond files are quite expense and are not necessary for making a few etches in glass, as fine carbon steel files work well.

Image 3: Removing the stem from the wine glass

Image 4: The completed lenses



The globe on the right will show stronger lensing effects than the left globe.

Image 6: A view through the lens

Note the distortion of red EXIT sign around the curve of the glass.