Instructions for the NASA Lunar Parallax Challenge

The size of the universe has been the subject of great scientific campaigns for thousands of years. Distances to the sun, moon, planets, and stars were debated heavily up until recent times. Even before the invention of the telescope, astronomers had a powerful tool at their disposal for deriving distances within the solar system. This tool was geometry.

Armed with geometry as well as planer and spherical trigonometry, around 190 BC, the Greek astronomer, Hipparchus knew that the position of the moon appeared to change against the background of the heavens depending on ones location on Earth. This effect is called lunar parallax. Hipparchus assumed that the sun was at an infinite distance. He then observed the solar eclipse of March 14, 190, which was total in his birth place of Nicaea. Hipparchus watched as the moon covered the sun. He combined his observations with observations of the eclipse from Alexandria, approximately 9 degrees of latitude south where the moon was reported to cover 80% of the sun's disk. From this information, he concluded that the moon was between 71 and 81 Earth radii from the Earth. This is close to the modern values of 56.9 and 63.6 Earth radii. Hipparchus later calculated values of 62 – 72 Earth radii for the distance to the moon. Claudius Ptolomy (100-178 AD) and others followed, measuring lunar parallax to derive the distance to the moon achieving more and more accurate results. For the August 1 solar eclipse, you will replicate these historic observations and find the distance to the moon for yourself.

Tools:
Telescope or projection device
Solar Filter for telescope
Camera
Watch
Computer

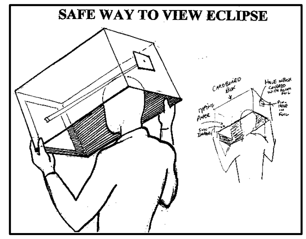
Step 1 Observing the eclipse

Method 1

You will need either a telescope or a solar projection device. If you are using a telescope, almost any telescope on a steady mount will do. High magnification is not necessary. A magnification of 20-30 power should be sufficient. Most importantly, the telescope's field of view (and the camera's field of view) should easily accommodate the full dimensions of the eclipse. A solar filter for the front end of the telescope will allow you to view the eclipse safely. **ONLY** during totality can the filter be taken off and the sun observed directly. A camera – digital or film will be needed to photograph the eclipse. If a film camera is used, you will need to digitize the final image.

Method 2

Using any variety of solar projection devices such as a pin hole camera, binocular projection, or commercially sold “Sun Spotter” or “Solar Viewer”, project an image of the eclipsed sun onto a piece of paper. Try to make sure the paper is perpendicular to the image. You can then take a picture of the projected eclipse image with a digital or film camera.



Method 3

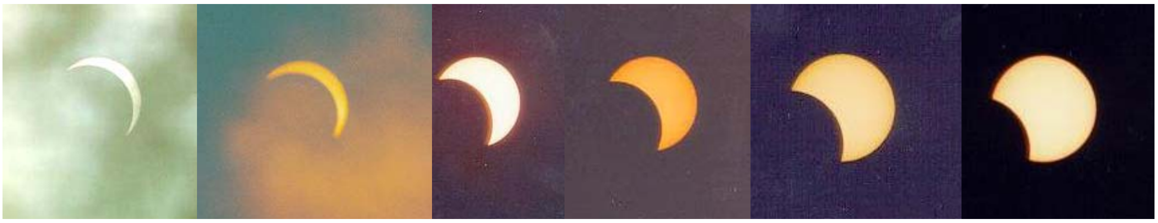
In some cases, a good camera with 10-15 X zoom (**and solar filter**) could be mounted on a stable tripod eliminating the need for a traditional telescope. In this case, the zoom lens substitutes for the telescope and you can take the picture of the eclipsing sun directly.

Step 2 Photographing the Eclipse

You will need to photograph the eclipse through the telescope, projection device or with your tripod mounted camera. For information on photographing solar eclipses, go to http://eclipse.gsfc.nasa.gov/SEhelp/SEphoto.html . For this experiment, you will be taking images at 10 minute intervals based on UT. You will take images on the hour and at 10 minute intervals thereafter (e.g. 10:00, 10:10, 10:20,…) between 8:08:07 UT and 12:38:28 UT. This will help to ensure that we compare “apples to apples” when looking at two images of the eclipse from different locations. Remember that the Earth (at the equator) rotates at about 1,000 miles per hour which is equivalent to 15 degrees per minute or 1 degree every four seconds. By comparing pictures taken at as close to the same time as possible, we are minimizing the error that results from the Earth’s rotation. Of course, there will be some error. Our goal is to get as close to the correct distance as possible. Umbral and Penumbra contacts are as follows:

Time (UT)	Event
08:04:06	P1 Penumbra
09:21:07	U1 Umbra
09:24:10	U2 Umbra
11:18:30	U3 Umbra
11:21:28	U4 Umbra
12:38:28	P4 Penumbra

Note the time the photograph was taken and convert to UT. Try to take as many images as possible that show the sun in some phase of being eclipsed. If using film, digitize your film picture or if using a digital camera, just download your digital picture and put your now digital images on your computer. You can now work with the image if needed using image processing software to adjust size, contrast, etc. Once you have completed this task, you might end up with pictures like the six images below taken of the 1999 eclipse just north of Paris, France.



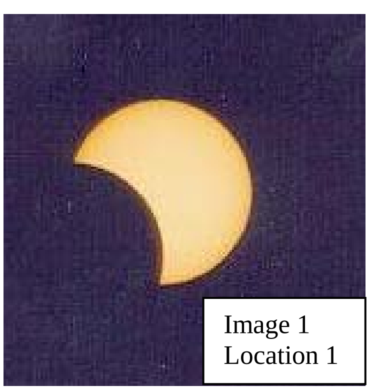
In each image, the moon is covering a different part of the sun. In this case, the eclipse was total in Soissons, France where these pictures were taken although clouds obscured the eclipse during totality☹.

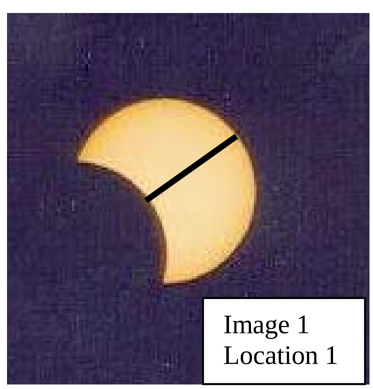
For the Lunar Parallax Challenge, please email your pictures of the eclipse to Louis.A.Mayo@nasa.gov making sure to include your name, the time of the observation (in UT) and the latitude (hrs/min/sec) and longitude (deg/min/sec) of your location. We will upload your pictures with this identifying information. Your eclipse images will be added to images from other eclipse watchers around the world thus building a database from which our parallax calculations can be made.

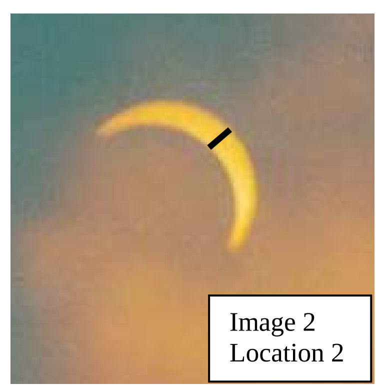
Step 3 Analyzing the eclipse

To derive a distance to the moon, you will need to measure the angular displacement of two images of the eclipse taken at the same time and (preferably) close to the same line of longitude. You will be taking and labeling images of the eclipse from your location and adding them to images taken by other amateur astronomers from different locations around the world. With these images, you will be able to perform some simple geometry to derive a distance to the moon.

First, you would like to find the apparent angular displacement of the moon silhouetted against the disk of the sun for two locations on Earth. This can be done most easily on the computer. For each picture, try to draw a line that represents the maximum distance between the moon's limb and the sun's limb (see below). For different times and locations on the Earth, the moon will appear to cover a different percentage of the sun.







This difference is due to parallax. On August 1, the sun will subtend an anglular diameter of 31.5' (31.5 arc minutes) or roughly ½ degree. Measure the lengths of the two lines you have drawn as above and ratio them with the actual solar angular diameter. This will give you two angles. Subtract the smaller angle from the longer one to get the angular displacement of the moon against the sun or lunar parralax angle.

Now refer to figure A below. Once you have measured the lunar parallax angle** ("a" in the diagram), you need to estimate the distance between the two observers. The actual diatance you measure will be the distance along the Earth's spherical surface. Since we are doing these calculations in planer geometry, your derived distance between the two observers will be a little bigger than a straight line between them. This is another source of error but for our purposes, this should work fine. If you know the latitude and longitude, you can get the distance between any two points on Earth by going to:

http://www.nhc.noaa.gov/gccalc.shtml

Now, refering to the diagram, we know d (the distance between the two observers) and a (the parallax angle)**. Take out your trusty calculator and perform the following calculation:

$D = (d/2) / \tan(a/2)$

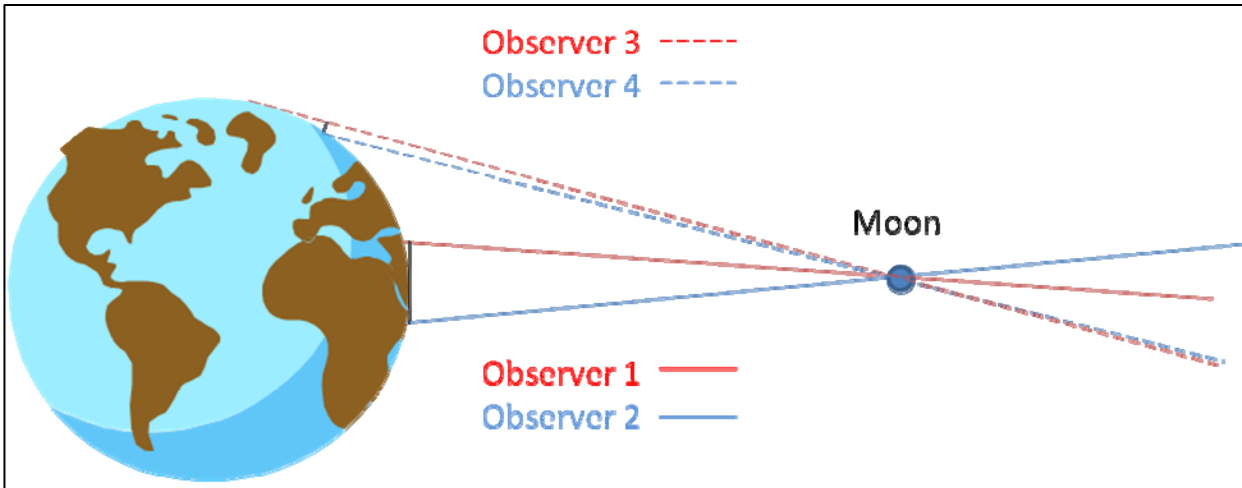
Where D = the distance to the moon in what ever units you used to measure the distance between the two observers. We suggest you use km to keep things uniform. Want to avoid all that cumbersome math? Go to http://www.1728.com/angsize.htm for an angular size calculator.

** Technically, the angle of parallax is ½ the angle that you measure or, in this case (a/2).

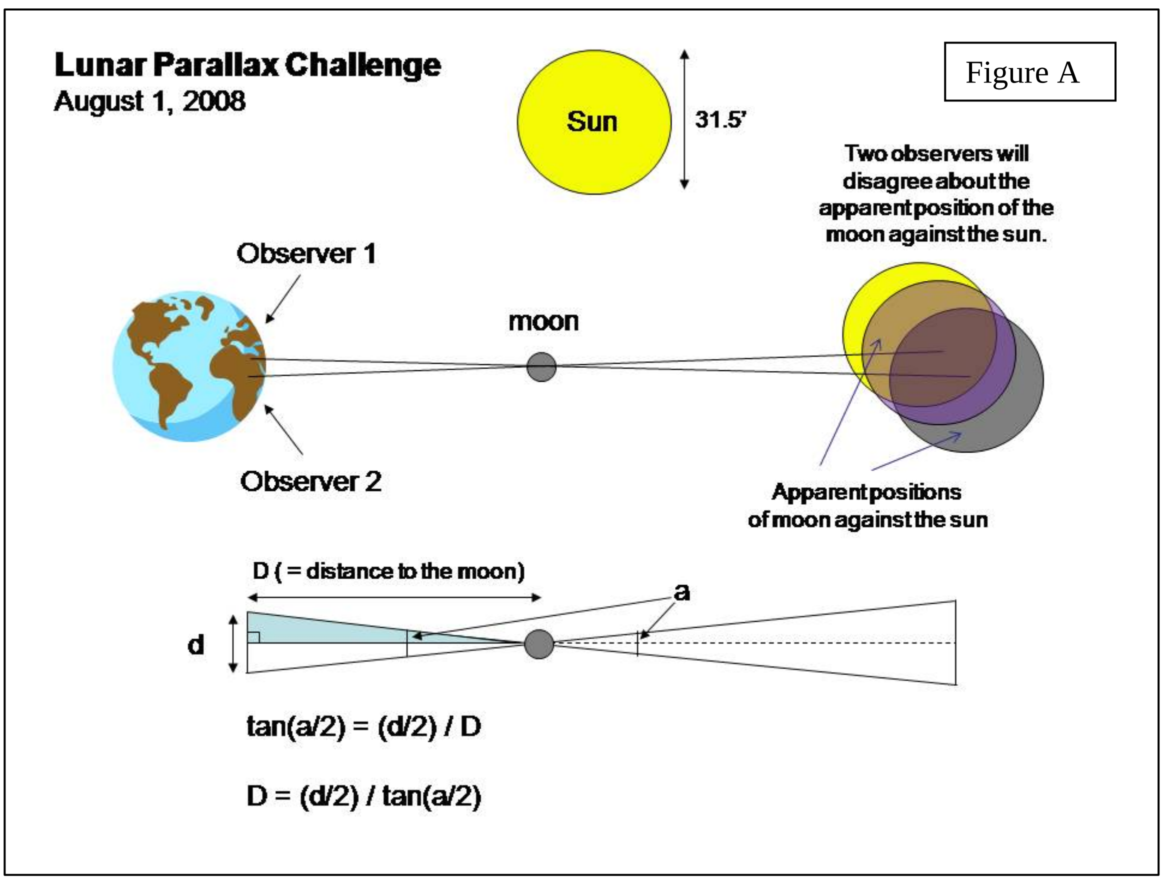
Sources of error

There are a few sources of error that will bias your results. The first is time. For two observers near the meridian, each minute of difference between the times their observations were taken means that 15 degrees is added to the apparent angular difference . This is not precisely true since the Earth's curve means that some of the motion of the Earth goes into the surface of the Earth moving toward or away from the moon, but it is true to first order.

Space is a second source of error. As in the above example, a one minute difference in time means that the Earth's surface has moved about 17 miles, thus increasing or decreasing the baseline of your right triangle. Ideally, you would like to select two observations (images) of the eclipse taken at the same time AND along the same line of longitude. Around solar noon, it is not quite as critical that the two images be on the same line of longitude, but as you progress toward lower solar angles, the distance along the Earth's surface between any two observers will begin to be significantly greater than the actual angle of parallax causing the derived distance of the moon to be too large. This effect is minimized when the two observers are along the same line of longitude. The following figure illustrates this effect.



Observers 1 (red) and 2 (blue observe the eclipse very near local solar noon. Their measured distance between them is very close to the angle of parallax. Observers 3 and 4, imaging the eclipse very near the horizon will measure an artificially large baseline for the parallax angle.



Another source of error is the curvature of the Earth. When you measure the distance between two points on the Earth's surface, you are measuring along an arc. What you want is the distance along the linear chord that connects these two end points of the arc.

Imagine for a moment that the two points you have selected are the north and south poles. These two locations are 1/2 of the circumference of the Earth apart. The polar radius of the Earth is 6,357km so the polar circumference is 2pr or 39,942km and 1/2 that is 19,971km. But the length of the chord stretched between the poles is only 2r or 12,714km - a difference of 7,257km !! Of course, the smaller the distance between the two observers, the smaller the difference between the length's of the arc and chord. To calculate the length of a chord given the radius of the circle and the length of an arc on that circle, you can go to:
http://www.handymath.com/cgi-bin/arc18.cgi?submit=Entry.