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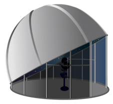
The Academy provides students with a motivational venue for learning about science through research or outreach oriented projects based on instruction in earth science, astronomy and space science.



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Moon Parallax Project

by Jeff Adkins, Rob Sparks, Chris Moore, Chris Guarini, and Kelli Hover

Note: This version is substantially revised from the original document posted here.

Abstract:

Using simultaneous photography, the parallax of the moon was determined through digital image analysis. Using the parallax angle the distance to the moon was computed to be 236,000 miles from the observers, which is very nearly the correct value.

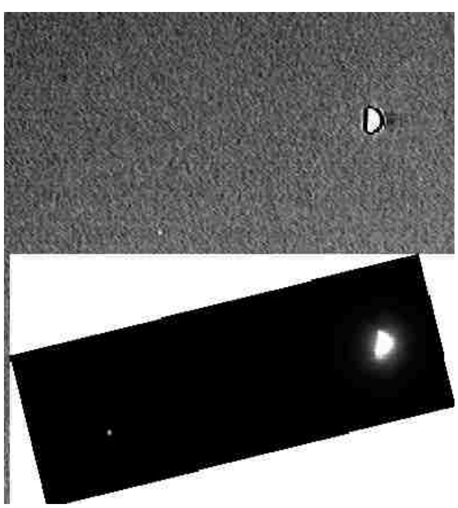
Procedure:

Based on a prediction made by Kelli Hover using Starry Night, we planned to observe the moon and Jupiter simultaneously when they would be relatively near each other. On the evening of Wednesday, May 26, we photographed the moon simultaneously from Antioch, California and Racine, Wisconsin. Jeff Adkins took the Antioch picture, while Rob Sparks of Racine, Wisconsin took the other picture. Many thanks to Rob for assisting us with short notice.

The photos were taken precisely at 8:30 Pacific, 10:30 Central time. Time was established using "atomic clocks" synchronized with the official time signal from WWV.

The moon was near the planet Jupiter. In order to establish the plate scale of the photos, we also photographed a nearby object of known size and distance using the exact same zoom setting. This can be used to determine the number of pixels per degree in each photo. The scales are not identical.

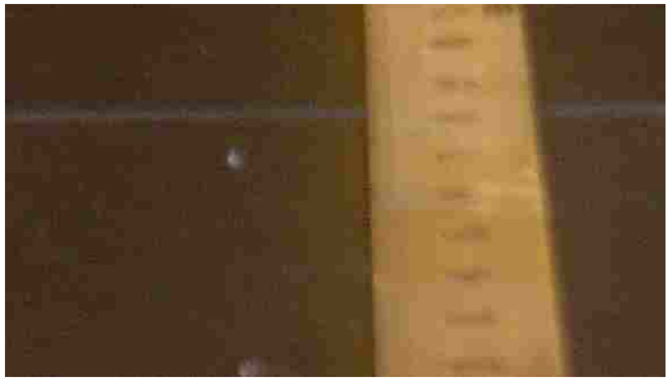
Due to the different observer locations, the moon appeared to be in two different positions. The position shift is called the parallax. The amount of shift measured as an angle is called the parallax angle.



These pictures show the approximate effect. The scale of the pictures has been adjusted to be approximately the same. You can clearly see that distance between the moon and Jupiter is larger for Racine (bottom) than it was for Antioch (top) even though the pictures were taken simultaneously. This picture's scale is not precisely to the correct scale and should not be used for measurement. The original pictures should be used for that. (See further down the page)

Data and Calculations

Presented below are the original photos from Racine. The first shows the moon and Jupiter together. The second shows a 12 inch ruler exactly 2 meters from the camera, using the same exact zoom setting.



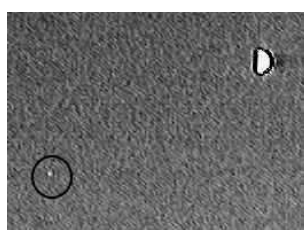
The images are presented full size because the scaling requires the original scale, although the images have been compressed by the JPEG conversion. (We have the originals if you would like to see them.)

Using the photo of the ruler, we determined the plate scale of the camera Rob Sparks used. At a distance of 2 meters, a 12 inch ruler subtends an angle of 8.66520 degrees (determined using tangent equation). Using NIH Image, we measured the number of pixels for the length of the ruler, which turned out to be 1051 pixels, establishing a plate scale for the camera of 121 pixels per degree.

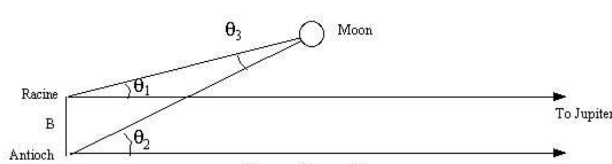
Then, the picture of the moon and Jupiter was measured using the same software, and the center-to-center distance was determined to be 833 pixels, corresponding to 6.867 degrees of separation.

The second image is a 3.50 inch circular disc exactly 15.0 inches from the camera, taken with exactly the same zoom. At this distance the disc subtended an angle of 13.13407 degrees. Image software used by Chris Guarini and Chris Moore determined the diameter of the disc to be 370 pixels, yielding a plate scale of 28.1711 pixels per degree.

The next images are from Antioch. This is a screen capture from an analog video camera, unlike the digital image captured in Racine. The image quality isn't nearly as good, but it should be "good enough." The first shows the moon and Jupiter. Jupiter is circled because the image is grainy. The center to center distance of the moon and Jupiter was determined to be 184 pixels which corresponds to an angle of 6.531 degrees. This is significantly different than the separation angle of the two objects as seen in Racine.

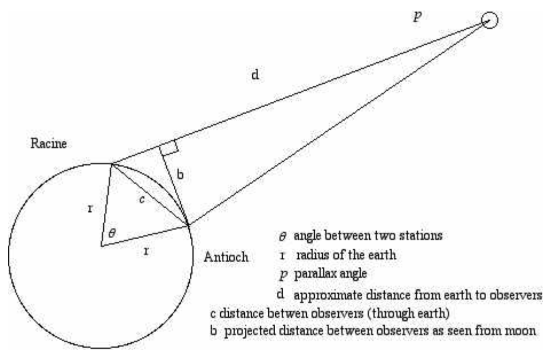


This diagram shows why the parallax angle is the difference between the two observed angles. Using the values above, the **parallax angle between the two is the difference between these angles or 0.33685 degrees.**



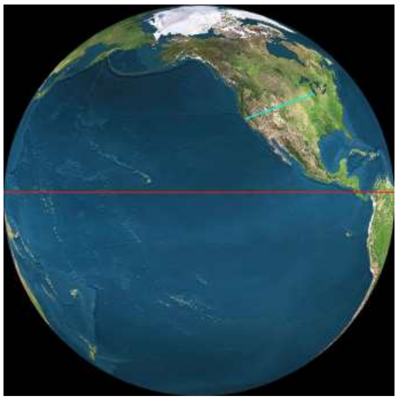
$$\theta_3 = \theta_2 - \theta_1$$

A complicating factor is that the line of sight from Racine and Antioch to Jupiter is not perpendicular to the line connecting the cities, because the earth is round. It is possible to calculate the distance between the cities by projecting the line between them onto a plane perpendicular to the line of sight, but to keep the technique approachable for high school students we used a method based on the approach used by a different group that did this same project in Europe (Backhaus, 2001).



The problem we need to solve is that the baseline between the observing stations is not c, because that is tilted with respect to the line of sight as shown in this diagram. The baseline distance is, rather, "b". Calculating b is tricky, but can be done simply by allowing a computer projection to assist us.

Using the earth-moon simulator (Walker, 2004) we created an image of the earth *as seen from the moon* at the same time the photos were taken from the earth. Then using image analysis techniques on the artificial image, we were able to determine the apparent separation of the observing stations as seen from the moon's perspective, which yields b in the diagram above. The picture shown is a greatly reduced quality image. The red line represents the diameter of the earth and the teale colored line is the distance between Racine and Antioch ("b").



Using this image to determine b, we set up a simple proportion using the following numbers and formula:

b/pixels of teale line = diameter of earth/pixels of red line

teale line = 179 pixels

red line = 1022 pixels

diameter of earth = 2 x 6378 kilometers

Plugging in the values to the right we determined the baseline b is 2234 kilometers or 1388 miles. This makes sense because the surface distance between Racine and Antioch is 1811 miles (Kindred, 2004) and our projected distance should be smaller.

Now we have all the pieces necessary to determine the distance to the moon.

Given the baseline b = 1388 miles, and the parallax angle 0.33685 degrees, the tangent equation can be used to determine the distance using

tangent (parallax) = b/d

or

d = b /tangent (parallax)

yielding **d = 236,000 miles.**

The accepted value is 239,000 miles. Since we are measuring the distance to the observers, there is an additional distance which must be added in to reach the center of the earth. Figuring out the correction is left as an exercise for the reader (and next year's students!)

Extensions

This paper will be presented at the National Convention of the American Association of Physics Teachers in Sacramento in August 2004. At this meeting, we will invite participants to join a mailing list which will be used by a student in the next year to recreate the experiment on a larger scale with more students. You can request to be put on the mailing list by sending email to astronomyteacher "at" mac.com.

References (posted June 2004)

Backhaus, Dr. Udo. (2000) "Internet Project: Simultaneously Photographing the Moon and Determining its Distance." <<http://didaktik.physik.uni-essen.de/~backhaus/moonproject.htm>>

Kindred, David. (1998, public domain perl script). <<http://www.indo.com/distance/>> Based on the `geod' program, which is part of the `PROJ' system available from the U.S. Geological Survey at ftp://kai.er.usgs.gov/pub/.

Lawrence, Pete. (2003) "Lunar Parallax Demonstration Project." <<http://homepage.ntlworld.com/p.lawrence1/lunar_parallax.html>>

Walker, John. (2004, web based simulator) Earth and Moon Viewer. <<http://www.fourmilab.ch/earthview/vplanet.html>>

The Mars Global Surveyor photo analysis was performed on a Macintosh computer using the public domain NIH Image program (developed at the U.S. National Institutes of Health and available on the Internet at http://rsb.info.nih.gov/nih-image/).

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