Optics of Lunar Ranging Experiments

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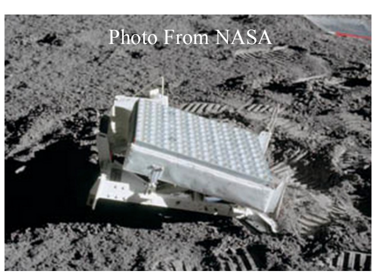
Background information:

My project came about as a result of a discussion our group had on February 12th about how one would figure out how long it took light to reach the moon and return back. We started by estimating the distance from the Earth and to the moon (about 3.8 $*10^8$ meters) and then multiplied this number by two in order to have a round trip. We then divided this number by the speed of light (about 3.0 $*10^8$) in order to find our answer of about 2.5 seconds. After finding this we then discussed about the physical properties of a laser if it was to be shined onto the moon. With a simple demonstration of shinning a laser beam across the room, we saw that the laser appeared clearer if it were closer. This is because the beam of light gets larger with distance; with more distance, the same photons need to be distributed over a larger area, thus light density decreases and the beam gets dimmer. This brought up the question of how big the laser beam would be if it were to be reflected onto the moon. My curiosity to answer questions like this one inspired me to research the Lunar Ranging Experiments.

Concept

The Apollo mission astronauts left behind small arrays of specialized optical devices called retro-reflectors when they visited the moon. The lunar retro reflectors are of the "corner-cube" type, which have prisms with three mutually orthogonal reflecting surfaces.

Retro reflectors are optical devices that return any incident light back in the direction from which it came. The concept of the design involves perpendicular mirrors arranged such as at the corner of a cube. The light sent to a retro reflector will bounce off each mirror in turn, with the net result being a precise 180° turn (not depending on the incident angle). If this angle is not 90 degrees and deviates by α, then it will cause the return beam to deviate by 2α.



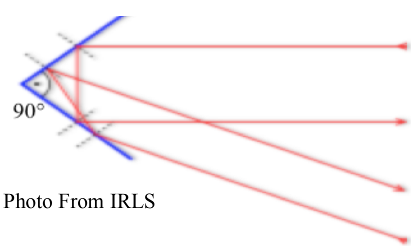


Photo From IRLS

Divergence of a laser beam is important to take into account for these experiments. The beam leaves the laser it starts as parallel, but then begins to spread out at a steadily increasing rate. The rate of spreading out eventually reaches a maximum value called the divergence angle, θ, given by the equation:

$$\theta\ [rad] = (2/\pi) * (\lambda\ [m] / 2\, w_0\ [m])$$

In this equation w_0 is the radius of the beam where it leaves the laser and λ is the wavelength of the laser. When we analyzed the equation as a group, we took a closer look at the units. It makes sense that the divergence angle, is in radians because the units from the wavelength and the radius of the beam cancel out. We also analyzed the hypothetical footprint on the moon if an average classroom laser was aimed at it. This laser beam would have a wavelength of 532nm and a radius of 1mm. From the equation above we find that the angle of divergence is:

$$\theta = (2/\pi) * (532\ e\text{-}9 / 2 * 1e\text{-}3) = 1.7 * 10^{\wedge}\text{-}4$$

This is then multiplied by the distance to the moon (3.844 *10^8 m), which gives us 61000 m.

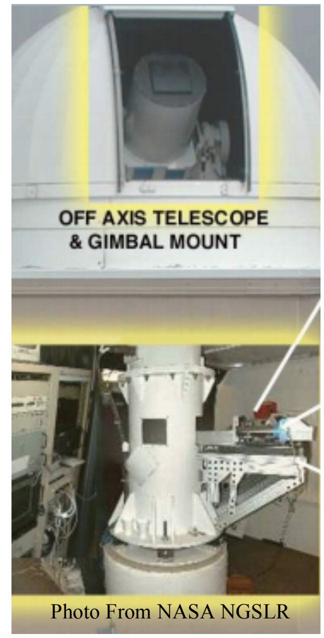


Photo From NASA NGSLR

The actual size of the footprint of the laser beam on the moon from the APOLLO experiment is about 1.8 km. However, it is important to note that in practice, the divergence of the laser beam to the moon is set by the atmospheric turbulence. This is because at the observatories a telescope is set out in front of the laser beam in order to control the divergence.

Experiment:

We tested a corner cube reflector at a distance of ~14 meters. The laser beam passed through a small hole in a sheet of paper, which allowed us to observe the reflected light. We estimated the beam spot size at the position of the retro reflector and after it was reflected back to its original source. The intensity of the HeNe laser is 1mW and its diameter is ~1 mm.

<u>Our results were as follows:</u>

Photo 1 shows laser beam right before it hits the retro reflector. The size of the laser pointer is about 1mm. When the laser beam size from the laser pointer and to the retro reflector: 1.5 cm (min) and 4.5 cm (max). There are min and a max measurement is because the laser beam had several layers of circles present on the paper, there was an intense center and a less intense outer layer.

Photos 2 and 3 show the laser beam hits the retro reflector. In photo 1, the retro reflector is centered while in photo 3 it is not (notice how it has two spots instead of 2).

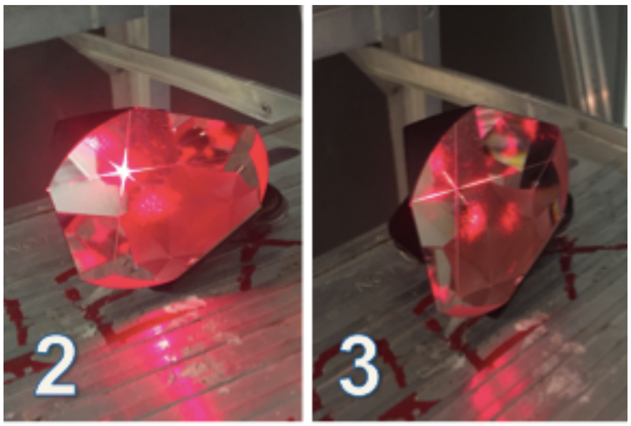
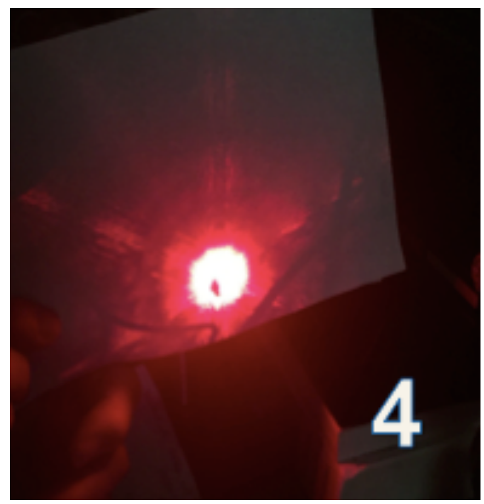


Photo 4 shows the laser beam when it is reflected back to its original source. Laser beam size from the laser pointer to the retro reflector and back to the laser pointer: 3.0 cm (min) and 8.7 cm (max).



Applications:

Corner cubes, such as the lunar retro reflectors have a variety of other applications, in
cluding land surveying, radar reflectors on boats, and reflectors on bicycle pedals. The lunar retro-reflectors have made it possible to monitor the distance to the moon to remarkable precision (centimeters) ever since, using intense pulsed laser beams, earth-based telescopes, and sensitive light detectors.