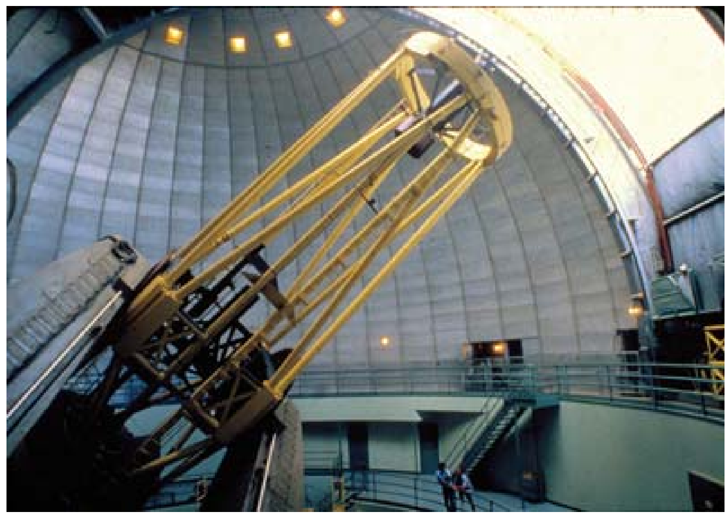
Hi Mike,

In response to your request, here is the story of the Lunar Laser Ranging experiment as I recall and like to tell it.

The Lunar Ranging RetroReflector (LRRR) project was one of the two major science experiments placed on the Moon by Apollo 11 astronauts. Physicists Caroll Alley (U. of Maryland) and James Faller (Wesleyan) were PIs. The plan was to use the 3m reflector to fire brief (some nanoseconds in length) but intense pulses of light at a reflector placed on the moon, then precisely time the arrival of the return pulse back at the telescope about 2.5 seconds later. Each pulse would allow measurement of the distance to the moon to within a few meters. Repeated pulses would allow increased precision of measurement, and were expected to result in a night-to-night distance to the moon accurate to a few centimeters. The primary goal was to investigate fundamental aspects of gravitation.



Anticipating the Apollo 11 Mission in 1969, NASA gave us $75,000 to dig a pit below the coude slitroom. Into that pit we installed the two most powerful lasers anyone in the world would admit to having, mounted on brand new Bridgeport mills. From the lasers mounted on optical benches on the mill tables in the pit below the telescope, the light pulses went up through holes in the floor of the slitroom, bounced off of large mirrors (still in the slitroom mounted on rails) which sent the light up the polar axle and then through the telescope, which was thus used in reverse as a giant laser gun.

We were issued unbelievably dense safety glasses, darker than typical welding glasses, in case we had to go out on the dome floor during laser firing. After a couple of tries on test nights we found no one could see anything through them, and everyone stopped using them. We were quite cautious about going onto the dome floor, however.

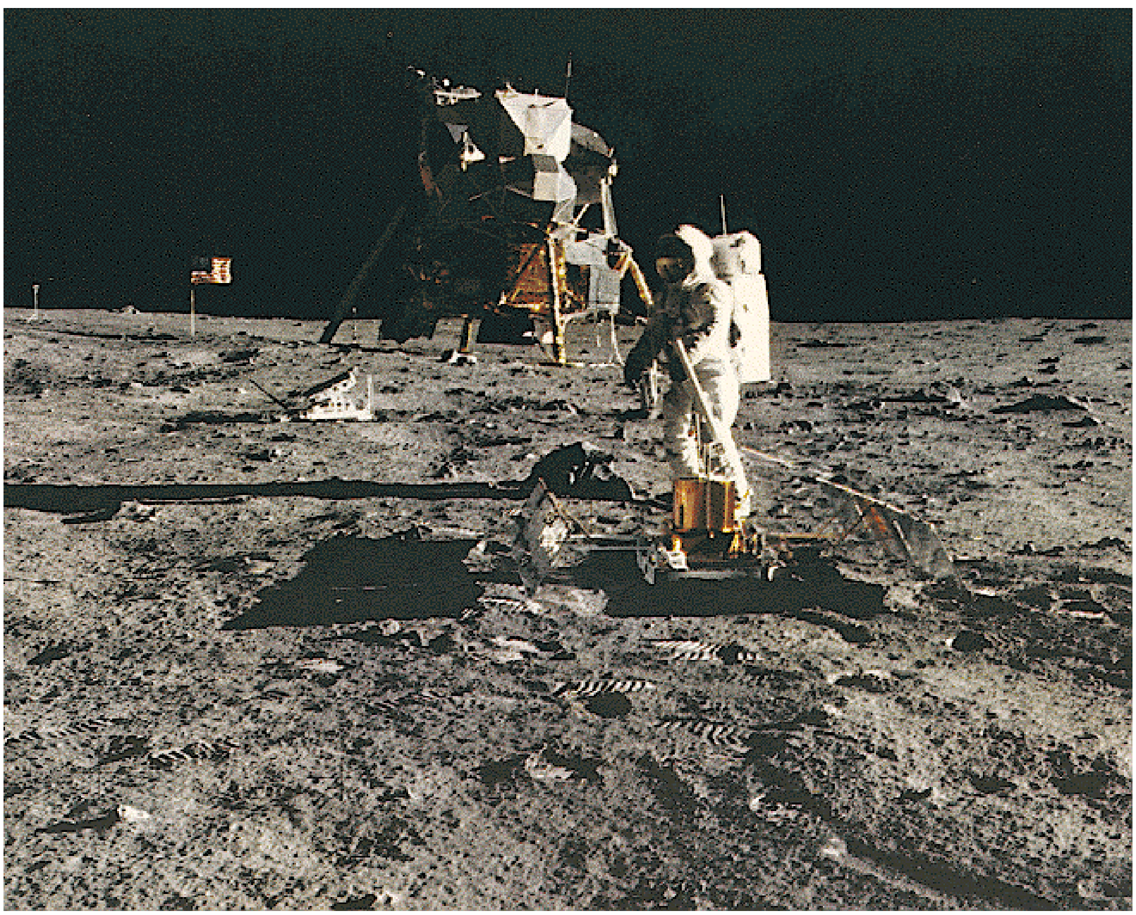
Channel 9 (PBS) and Channel 7 (ABC) both had news crews at the telescope for that first moon landing event in July 1969. The idea was to broadcast this exciting big-time Bay Area science effort to the local citizens as it happened. Fortunately, I think we were so overshadowed by lunar events that evening that nothing was ever broadcast from Lick.

We had what I believe was the first civilian-use low-light-level vidicon camera, which had just been declassified by the Defense Department and been mounted on the 3m only a couple of weeks before. We had used it successfully for a few practice nights when it had delivered excellent images, and all seemed in order.

I had just been promoted out of my initial job as night assistant, but was there nevertheless as Joe Wampler's hand-picked telescope operator for this special occasion. Thus I was at the center of the first difficulty, which was that we could not find the moon with the world's second largest telescope! In those days the Astronomical Almanac included geocentric lunar coordinates for every hour during the year. When I set to the coordinates given for the nearest hour (usually plenty good enough to find the moon), nothing was there. Over the next 30 or 40 minutes I repeatedly and frantically interpolated coordinates to the nearest 5 minutes, checked to be sure I really had the current Almanac and not last year's, made sure I had the correct time and tried again -- but still couldn't find the moon. This was deeply humiliating with the TV geeks just out in the hall, and Louis Alvarez sitting there being very polite. Finally someone shouted "There it is!" It appeared as the most delicate spiderweb tracery of just the brightest highlights, still barely perceptible. We had started to set to it in very early twilight with this new camera which we had previously used only at night. The contrast of a bright moon on a bright sky was not as expected. We could find the moon after all, and in fact we must have been on it 100 times already that evening. Whew!

We took a break to watch Neil Armstrong's historic first step event on TV, a thrill shared by all present.

After the PR opportunity, the astronauts began to place science experiments out on the moon's surface. The first such experiment was our retroreflector, an array of 100 beautiful corner cube prisms, cut so as to return any inbound light exactly back to the source.

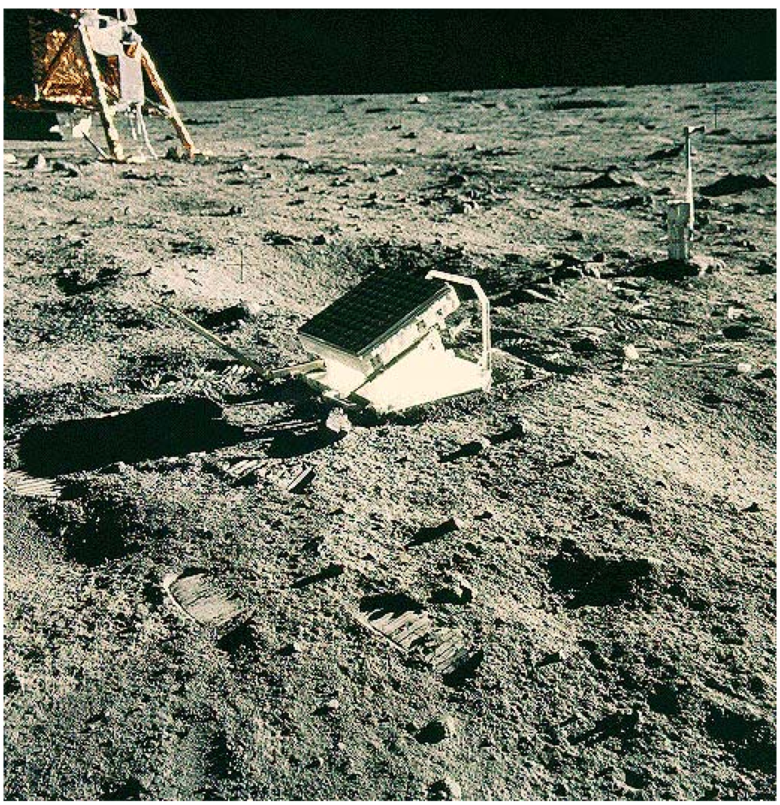


The Retroreflector array is seen here about 1/3 from the left edge of this photo, between the flag and Lunar Expedition Module. The astronaut in the foreground is now placing a seismograph on the lunar surface.

It seemed then as if we were all set, but we still needed to know exactly where on the moon the astronauts were. As the laser beam diameter at the moon was only about two miles, we had to be able to point fairly accurately. The lunar module, under manual control in order to avoid some rough terrain, had not been landed exactly where planned. The astronauts soon determined their precise location on the moon and radioed that information to Mission Control in Houston. Later that evening, Joe Wampler spoke with Mission Control to obtain the coordinates for the actual landing site. I was sitting next to him as he stood at the night assistant's desk in the 3m control room, upon which he had a large scale moon map spread out. I heard Joe repeat back the coordinates three times in order to be absolutely certain he had them correct. Then, with the spot carefully marked on the map, we pointed the telescope to that exact lunar location and started firing a laser at it - scientific history in the making!

We blasted away all night but detected no return signal whatsoever. Things got pretty subdued later in the evening as it became apparent we had a problem.

This problem was identified the next day when someone called Houston again to verify the lunar coordinates, which turned out to be 00°41′15″N, 23°26′00″W. Despite the fact that Joe had repeated every number three separate times, they were still wrong. The person he had spoken with in Houston that first night had a deep Texas accent, and although the last two digits in the N-S coordinate group were 15, through the thick Texan drawl Joe had consistently heard "fifty" rather than "fifteen", so we had not been pointed at the correct spot on the first night.



The Retroreflector is an array of 100 corner-cube prisms, each 3.8cm in diameter. It is still in service.

We started the second night with confidence but still obtained no return signal, and the same was true for a couple more nights. Nothing. Yet, very careful checks appeared to verify that everything was functioning as expected; laser power, optical alignments, location on the moon, atmospheric clarity, photon detectors, timing electronics … everything looked good.

We were only searching for the reflected pulse within a small time window, because the belief was that the distance was already known to within 500m. My recollection is that we had only 2 kilobytes of memory in which to store the return pulse. That 2k of memory was cost-limited, and in the late 1960s it represented approximately a $10,000 expense to the project (about $65,000 in current dollars)! But it should have been enough to ensure the return pulse was detected within the few millionths of a second time window during which that return pulse was expected. After all, the Solar System experts from the Jet Propulsion Laboratory had provided an ephemeris for the anticipated separations between the 3m telescope and the retroreflector on the moon which included the carefully calculated influences of every known variable.

Finally Lloyd Robinson suggested that, despite our assurance that we were looking for the return pulse at the right time, since we were unable to pinpoint any other source of difficulty we should try moving the small window of time within which we were looking for a return signal. That idea soon produced a result, and we were able to center up on a good signal with the expected strength, and began to accumulate data.

It remained to explain the unexpected discrepancy in timing. Every detail of the experiment was examined carefully. It took weeks to finally locate the source of the error within the computer program JPL had used to generate the expected timing for the return signal. They quite reasonably had assumed that Lick Observatory (LO) was where the American Ephemeris and Nautical Almanac (predecessor of the Astronomical Almanac) said it was, which in turn and equally reasonably listed the observatory location as given by the U.S. Coast and Geodetic Survey (USCGS). USCGS thought LO was where their Lick Observatory benchmark was placed. Their benchmark was in the parking lot west of the Main Building, 1700 feet from the 3m telescope.

Thus, the first result of this very sophisticated Lunar Laser Ranging Experiment was to accurately measure the distance between the 3m telescope and the Main Building parking lot - via a retroreflector on the moon!

The first scientific paper which resulted from this experiment improved the previous best measurements of distance to the Moon by a factor of 100. This activity is still being conducted from McDonald Observatory. Using the much shorter laser pulses and faster electronics now feasible, distances to the Moon are routinely measured to within about one centimeter per night!

Rem
Somewhere over Texas
1 May 2007

Refs:

1. "Laser Beam Directed at the Lunar Retro-Reflector Array: Observations of the First Returns", Faller, J. et al., Science, New Series, Vol. 166, No. 3901, (Oct 3, 1969), pp 99-102.
2. "Laser Ranging Retro-Reflector: Continuing Measurements and Expected Results", Alley, C.O. et al., Science, New Series, Vol. 167, No. 3918, The Moon Issue, (Jan 30, 1970), pp. 458-460.