Ice on the Moon

No water was detected from the July 31 crash of Lunar Prospector into the Moon. More details are available in the October 13 NASA Press Release

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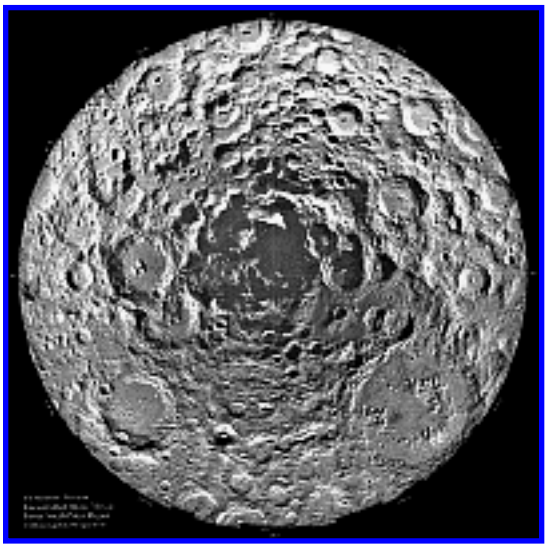
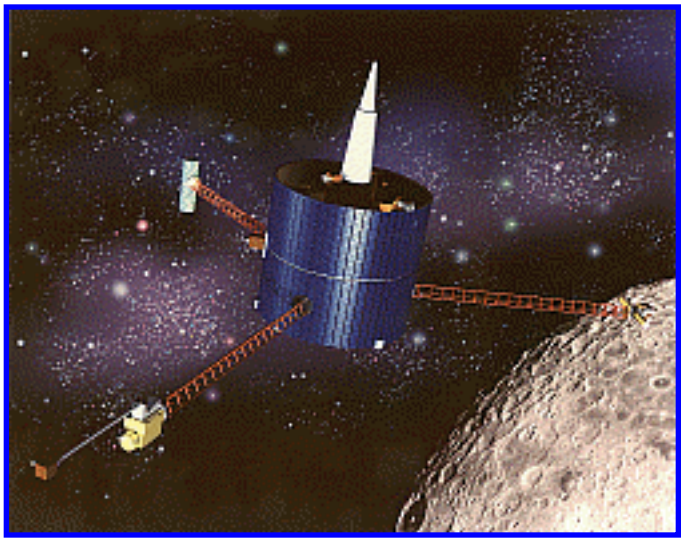


On 5 March 1998 it was announced that data returned by the Lunar Prospector spacecraft indicated that water ice is present at both the north and south lunar poles, in agreement with Clementine results for the south pole reported in November 1996. The ice originally appeared to be mixed in with the lunar regolith (surface rocks, soil, and dust) at low concentrations conservatively estimated at 0.3 to 1 percent. Subsequent data from Lunar Prospector taken over a longer period has indicated the possible presence of discrete, confined, near-pure water ice deposits buried beneath as much as 18 inches (40 centimeters) of dry regolith, with the water signature being stronger at the Moon's north pole than at the south (1). The ice was thought to be spread over 10,000 to 50,000 square km (3,600 to 18,000 square miles) of area near the north pole and 5,000 to 20,000 square km (1,800 to 7,200 square miles) around the south pole, but the latest results show the water may be more concentrated in localized areas (roughly 1850 square km, or 650 square miles, at each pole) rather than being spread out over these large regions. The estimated total mass of ice is 6 trillion kg (6.6 billion tons). Uncertainties in the models mean this estimate could be off considerably.

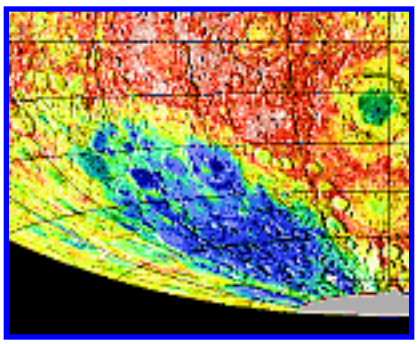
How was the ice detected?



The Lunar Prospector, a NASA Discovery mission, was launched into lunar orbit in January 1998. Included on Lunar Prospector is an experiment called the Neutron Spectrometer. This experiment is designed to detect minute amounts of water ice at a level of less than 0.01%. The instrument concentrated on areas near the lunar poles where it was thought these water ice deposits might be found. The Neutron Spectrometer looks for so-called "slow" (or thermal) and "intermediate" (or epithermal) neutrons which result from collisions of normal "fast" neutrons with hydrogen atoms. A significant amount of hydrogen would indicate the existence of water. The data show a distinctive 4.6 percent signature over the north polar region and a 3.0 percent signature over the south, a strong indication that water is present in both these areas. The instrument can detect water to a depth of about half a meter.

How can ice survive on the Moon?

The Moon has no atmosphere, any substance on the lunar surface is exposed directly to vacuum. For water ice, this means it will rapidly sublime directly into water vapor and escape into space, as the Moon's low gravity cannot hold gas for any appreciable time. Over the course of a lunar day (~29 Earth days), all regions of the Moon are exposed to sunlight, and the temperature on the Moon in direct sunlight reaches about 395 K (395 Kelvin, which is equal to about 250 degrees above zero F). So any ice exposed to sunlight for even a short time would be lost. The only possible way for ice to exist on the Moon would be in a permanently shadowed area.



The Clementine imaging experiment showed that such permanently shadowed areas do exist in the bottom of deep craters near the Moon's south pole. In fact, it appears that approximately 6000 to 15,000 square kilometers (2300 to 5800 square miles) of area around the south pole is permanently shadowed. The permanently shadowed area near the north pole appears on Clementine images to be considerably less, but the Lunar Prospector results show a much larger water-bearing area at the north pole. Much of the area around the south pole is within the South Pole-Aitken Basin (shown at left in blue on a lunar topography image), a giant impact crater 2500 km (1550 miles) in diameter and 12 km deep at its lowest point. Many smaller craters exist on the floor of this basin. Since they are down in this basin, the floors of many of these craters are never exposed to sunlight. Within these craters the temperatures would never rise above about 100 K (280 degrees below zero F) (2). Any water ice at the bottom of the crater could probably exist for billions of years at these temperatures.

Where did the ice come from?

The Moon's surface is continuously bombarded by meteorites and micrometeorites. Many, if not most, of these impactors contain water ice, and the lunar craters show that many of these were very large objects. Any ice which survived impact would be scattered over the lunar surface. Most would be quickly vaporized by sunlight and lost to space, but some would end up inside the permanently shadowed craters, either by directly entering the crater or migrating over the surface as randomly moving individual molecules which would reach the craters and freeze there. Once inside the crater, the ice would be relatively stable, so over time the ice would collect in these "cold traps", and be buried to some extent by meteoritic gardening. Such a possibility was suggested as early as 1961 (3). However, loss of ice due to photodissociation, solar wind sputtering, and micrometeoroid gardening is not well quantified (4).

Is there any other evidence for ice?

In a Science magazine article (5) on 29 November 1996, it was announced that interpretation of data from a Clementine spacecraft experiment suggested the possibility of ice on the surface of the Moon. The ice was believed to be in the bottom of a permanently shadowed crater near the Moon's south pole (at the center of the Clementine mosaic shown at the top of the page). It was also thought likely that other frozen volatiles, such as methane, were in the deposit. The deposit was estimated to be approximately 60,000 to 120,000 cubic meters in volume. This would be comparable to a small lake in size, four football fields in surface area and 16 feet deep. This estimate was very uncertain, however, due to the nature of the data.

One of the problems in studying a permanently shadowed area is that no pictures can be obtained. The Clementine spacecraft searched for the ice using an investigation known as the Bistatic Radar Experiment. Basically, this experiment consisted of having the Clementine spacecraft transmit an S-band radio signal through its high gain antenna towards a lunar target. The signals reflected off the Moon and were received by a 70 meter Deep Space Network (DSN) antenna on the Earth. Frozen volatiles such as water ice are much more reflective to S-band radio waves than lunar rocks. Radio waves also have different characteristics when reflected off ice than off silicate rock. An analysis of the signals returned from orbit 234 showed reflection characteristics suggestive of water ice for the permanently shadowed areas near the south pole. Reflections from regions which are not permanently shadowed do not show these characteristics. It is possible that other scattering mechanisms could be responsible for this result, but the interpretation of the radio returns and the fact that they are associated only with the permanently shadowed regions seem to indicate that water ice is the most likely possibility. However, Arecibo radio telescope studies using the same radio frequency as Clementine showed similar reflection patterns from areas which are not permanently shadowed. These reflections have been interpreted as being due to

rough surfaces, and it was suggested that the Clementine results may have been due to roughness, rather than water ice, as well.

Bistatic Radar Experiment Parameters
9-10 April 1994
Transmission: S-Band 2.273 GHz (13.19 cm wavelength)
Polarization: Right Circular (RCP)
Signal Power: 6 Watts
Axial Tilt: 4.5 to 5.5 degrees (Moon to Earth)
Orbits Used: 234 and 235

Why is ice on the Moon important?

The ice could represent relatively pristine cometary or asteroid material which has existed on the Moon for millions or billions of years. A robotic sample return mission could bring ice back to Earth for study, perhaps followed by a human mission for more detailed sampling. The simple fact that the ice is there will help scientists constrain models of impacts on the lunar surface and the effects of meteorite gardening, photodissociation, and solar wind sputtering on the Moon. Beyond the scientifically intriguing aspects, deposits of ice on the Moon would have many practical aspects for future manned lunar exploration. There is no other source of water on the Moon, and shipping water to the Moon for use by humans would be extremely expensive ($2,000 to $20,000 per kg). The lunar water could also serve as a source of oxygen, another vital material not readily found on the Moon, and hydrogen, which could be used as rocket fuel. Paul Spudis, one of the scientists who took part in the Clementine study, referred to the lunar ice deposit as possibly "the most valuable piece of real estate in the solar system". It appears that in addition to the permanently shadowed areas there are some higher areas such as crater rims which are permanently exposed to sunlight and could serve as a source of power for future missions.

References

1) Fluxes of fast and epithermal neutrons from Lunar Prospector: Evidence for water ice at the lunar poles, Feldman et al., Science, v. 281, p. 1496, 1998
2) Stability of polar frosts in spherical bowl-shaped craters on the Moon, Mercury, and Mars, Ingersoll et al., Icarus, v. 100, p. 40, 1992
3) The behavior of volatiles on the lunar surface, Watson et al., Journal of Geophysical Research, v. 66, p. 3033, 1961
4) Ice in the lunar polar regions, Arnold, Journal of Geophysical Research, v. 84, p. 5659, 1979
5) The Clementine bistatic radar experiment, Nozette et al., Science, v. 274, p. 1495, 1996

NASA Press Release (13 October 1999) - on results of Lunar Prospector crash impact on the Moon

NASA Press Release (3 September 1998) - announcing enhanced estimate of quantity of water on the Moon

NASA Press Release (5 March 1998) - announcing the detection of ice on the Moon

Cornell Press Release (3 June 1999) - radar provides 3-D views of lunar poles

Lunar Prospector

Neutron Spectrometer Experiment

Clementine

Clementine Bistatic Radar Experiment

Ice at the South Pole of the Moon - Lunar and Planetary Institute

Ice on the Bone Dry Moon - Paul Spudis

Moon Home Page

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