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The Moon at its Core

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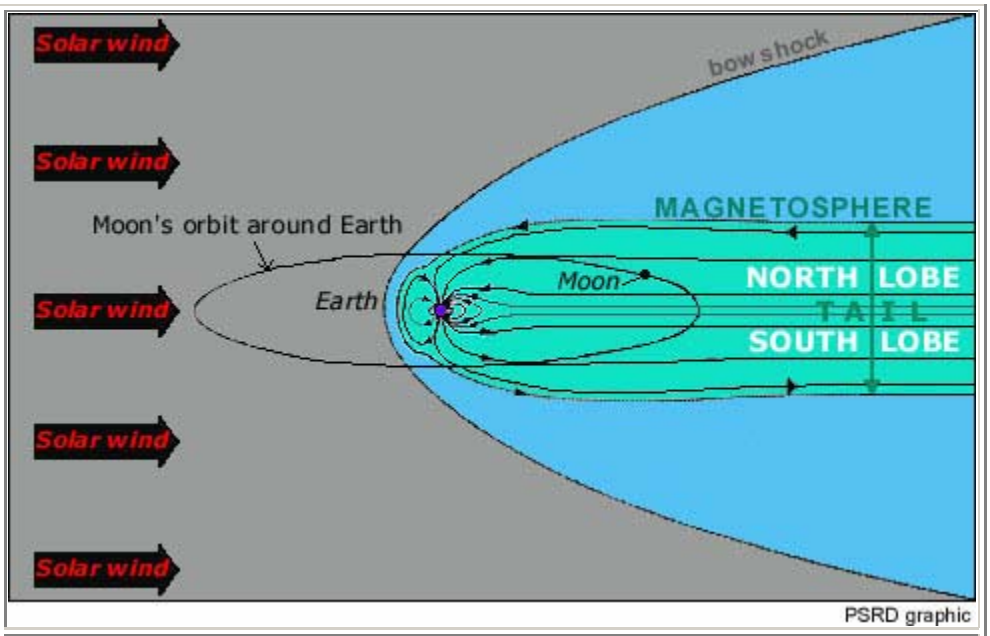
Ever since Apollo astronauts picked up rock samples and started to collect geophysical data from the Moon, evidence has been growing for a small lunar core. The most recent news comes from the Lunar Prospector magnetometer team of Lon Hood (University of Arizona), David Mitchell and Robert Lin (University of California, Berkeley), Mario Acuna (NASA Goddard Space Flight Center), and Alan Binder (Lunar Research Institute). Using the spacecraft's on-board instruments, they measured Earth's magnetic field paying particular attention to the slight alterations caused by the Moon. The data were collected in April 1998 while the Moon swung through the north tail lobe of Earth's magnetosphere. The spacecraft magnetometer detected changes in Earth's magnetic field thus giving the researchers the information they needed to estimate the size of the Moon's core. That size came out to be very small. Hood and his collaborators report a lunar core radius of only 340 km ± 90 km. For an iron-rich composition, a core of this size represents merely 1 to 3% of the Moon's total mass. In contrast, Earth's core is about 33% of our planet's total mass. This new evidence for a small lunar core strengthens the popular giant impact hypothesis which says that the Moon formed from hot, rocky debris after a Mars-sized object smashed into the early Earth. Down to its very core, the Moon has a unique history in our Solar System.

Reference:

Hood, L. L., D. L. Mitchell, R. P. Lin, M. H. Acuna, A. B. Binder, 1999, Initial Measurements of the Lunar Induced Magnetic Dipole Moment Using Lunar Prospector Magnetometer Data, *Geophysical Research Letters,* vol. 26, no. 15, p. 2327-2330.

Magnetometer Data from an Orbiting Spacecraft

The magnetometer onboard Lunar Prospector was designed to measure the magnetic field surrounding the spacecraft as it orbited the Moon. In order to eliminate the possibility that the instrument would detect magnetic fields generated by the spacecraft's own electronics, the magnetometer was mounted on a boom 2.6 meters away from the drum-shaped craft. The magnetometer was used by researchers to figure out the magnetic field generated deep inside the Moon itself. In April of 1998, the Moon spent 2 days moving through the near-vacuum environment of the relatively strong and steady magnetic field of the north tail lobe of Earth's magnetosphere (see schematic diagram below). Lunar Prospector was positioned perfectly to detect disturbances in Earth's magnetic field caused by the presence of the Moon, and estimate the magnetic field induced in the Moon.



This sketch shows Earth's magnetosphere, the region (in green) dominated by Earth's magnetic field. Lines of force are drawn as though produced by a giant bar magnet inside the center of the planet. Arrows on the lines point in the direction of the magnetic force. The area shaded blue is the magnetosheath, the area between the magnetosphere and the bow shock. The long, stretched-out tail of the magnetosphere extends downstream in the solar wind and away from the Sun, which is off the left side of the diagram. The Moon's orbit intersects Earth's magnetic tail and is shown here in the north tail lobe.

While the Moon and orbiting spacecraft were passing through the north tail lobe, Hood and his colleagues used 21 orbits of Lunar Prospector magnetometer data to estimate the magnetic field induced in the Moon. Their calculations yield an amplitude of $-2.4 \pm 1.6 \times 10^{22}$ Gauss-cm^3 per Gauss of applied field. Such a negative value, in general, is attributed to electrical currents flowing through the Moon's interior that create magnetic fields oriented opposite to the Earth's magnetic field. If this negative value is a result of a highly electrically conducting, iron-rich, lunar core, then it corresponds to a lunar core radius of 340 ± 90 km - representing only 1 to 3% of the total mass of the Moon.

Why a Small Lunar Core is Interesting

The size and electrical conductivity of the lunar core is directly related to the formation of the Moon, its magnetic history, and ultimately, its relationship to Earth. These three issues are briefly considered below.

FORMATION

Earth rocks and Moon rocks have similar compositions so it's natural to conclude that they share a common origin. But, if Earth and Moon had simply formed together from the same material, then we'd expect their cores to be proportionately similar. They're not. The lunar core is, by latest accounts, 1 to 3% of the total mass, but Earth's core is 33% of the total mass. The Moon's core is, in fact, proportionately smaller than the cores of any of the inner planets in the Solar System. There are many more arguments pointing to another origin for the Moon, as explained so eloquently by the giant impact hypothesis. For a complete discussion see **PSRD** article: Origin of the Earth and Moon. Ultimately, a small lunar core strengthens the giant impact hypothesis and

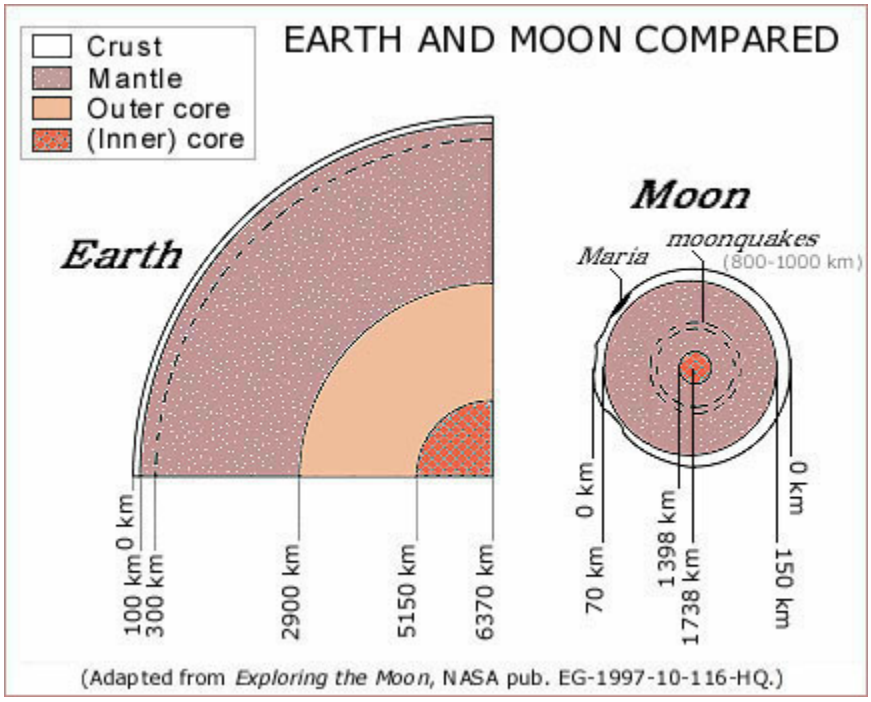
suggests that the Moon's origin is unique.

MAGNETIC HISTORY

The Moon, as any conductor, has electrical currents induced in its interior when it is exposed to an external magnetic field change. These currents result in a lunar induced magnetic field. This does not require the Moon to be capable of generating its own magnetic field. In fact, the Moon today does not have an internally-produced magnetic field the way the Earth does. But lunar rock samples show a remnant magnetism which suggests that three to four billion years ago, the lunar core was producing its own magnetic field. The question lingers: what shut off the Moon's magnetic field? The best guess is that the core, like the rest of the Moon, cooled enough to cause the core to solidfy, at least partway. The magnetic field would have shut down when the flow of molten metal in the core ceased.

RELATIONSHIP TO EARTH

The diagram below depicts what we know about the interiors of the Moon and Earth. The drastic differences in total size and in the total amount of metallic core in each is a manifestation of the origin of the Earth-Moon system. When the giant impact happened, Earth's iron core had already formed. The impactor itself also had an iron core which melted on impact and was added to Earth's core. Some of the debris from the rocky mantles of both Earth and the impactor was ejected into orbit, forming the much smaller Moon. Because so little metallic iron was blown out to orbit, the Moon ended up with a tiny core.



(Adapted from *Exploring the Moon*, NASA pub. EG-1997-10-116-HQ.)

A related origin and partnership in space affect both the Moon and Earth. The more we understand the Moon, inside out, the more we understand our own planet. We also look to the Moon as a new place for people to live and work, as well as a place to mine natural resources to support future human space activities farther away.

Sizing the Lunar Core: In Search of Conclusive Evidence

The deployment of new seismometers on the Moon is anticipated early in the next decade. The Japanese mission, LUNAR-A, is currently scheduled for launch in 2003. It will carry a mapping camera and two surface penetrators equipped with seismometers. Each 13-kilogram, missle-shaped penetrator has been designed to withstand an impact force of 10,000 G (10,000 times the force of gravity at Earth's surface) and is expected to pierce one to three meters into the surface. According to the mission profile, one penetrator will hit the

equatorial near side (in the vicinity of the Apollo 12 and 14 landing sites) and the other one is targeted at the equatorial far side. Key questions about the Moon, including its internal structure, origin, and relation to Earth, are being addressed now and will usher us into the 21st century.

Additional Resources

Hood, L. L., D. L. Mitchell, R. P. Lin, M. H. Acuna, A. B. Binder, 1999, Initial Measurements of the Lunar Induced Magnetic Dipole Moment Using Lunar Prospector Magnetometer Data, *Geophysical Research Letters,* vol. 26, no. 15, p. 2327-2330.

Lunar Prospector homepage from the NASA Ames Research Center.

Taylor, G. J. "Origin of the Earth and Moon." Dec 1998. <http://www.psrd.hawaii.edu/Dec98/OriginEarthMoon.html>

The Apollo Manned Space Program, from the Smithsonian Air and Space Museum.

The Exploration of Earth's Magnetosphere from NASA Goddard Space Flight Center.

The Origin of the Moon website at the Planetary Science Research Institute.

Plasma, Plasma, Everywhere story on the plasmasphere surrounding Earth from NASA Space Science News.

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