Apollo-era lunar seismic data yields new lunar core model

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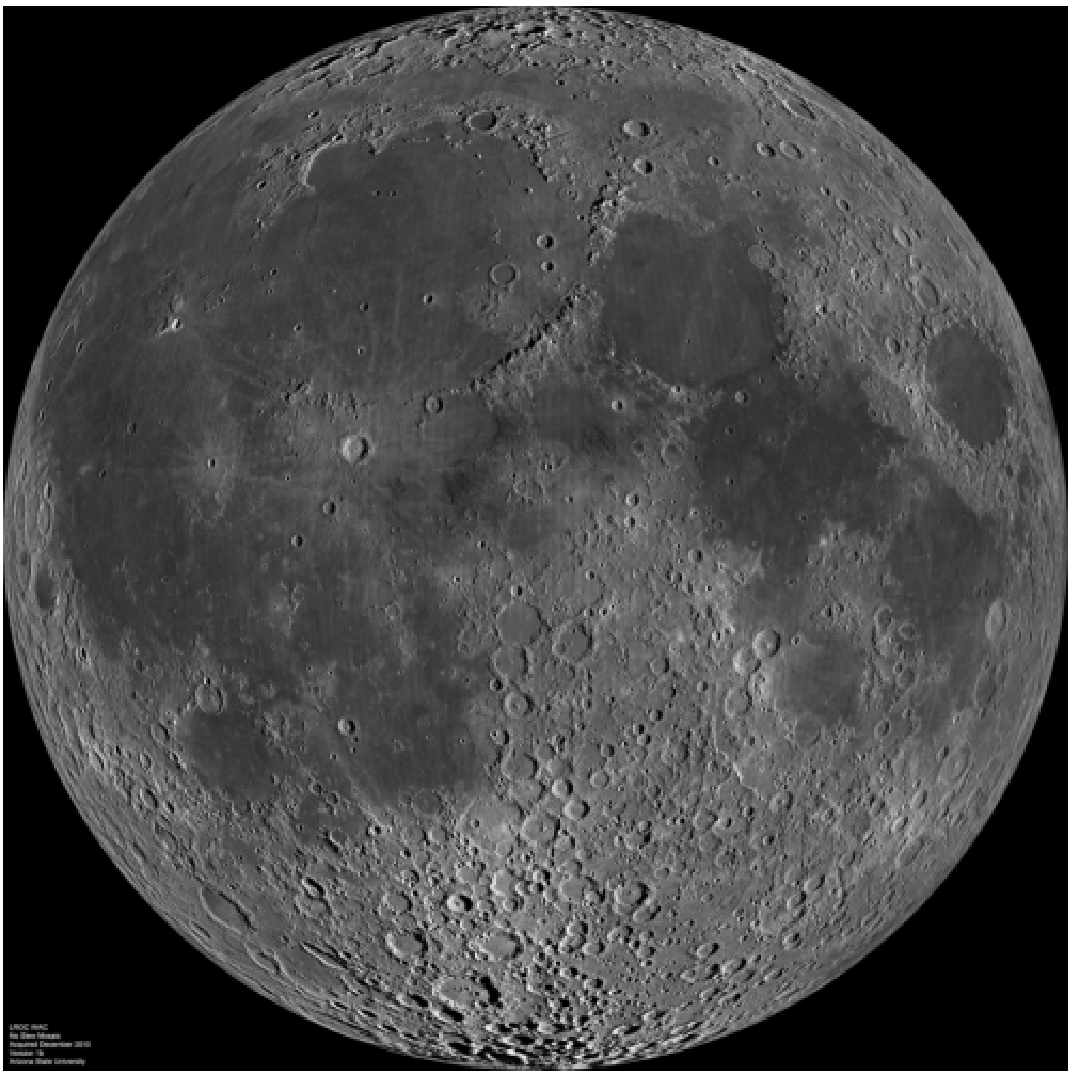

This is a composite image of the lunar nearside taken by the Lunar Reconnaissance Orbiter in June 2009, note the presence of dark areas of maria on this side of the moon. Credit: NASA

(Phys.org)—Like the solar system's telluric planets, including Earth itself, the moon's internal structure is composed of geoochemically distinct mantle, crust and core layers. The core is mostly iron; much of our understanding of its composition is derived from seismic data provided by the Apollo Lunar Surface Experiments Package.

At the massive pressures of Earth's core, iron exists in a hexagonal closed packed phase (HCP), as the pressures are likely to be stable across temperature and pressure conditions. However, in less massive bodies such as the moon, Mercury and Mars, researchers believe that iron exhibits a face-centered cubic crystalline structure (FCC).

However, a new analysis of the Apollo seismic data by a collaborative of researchers reveals that the seismic velocities suggested for the moon's inner core are well below that of FCC-phase iron. They developed a dataset that provides strong constraints to existing seismic models of the moon and of small telluric planets allowing a direct compositional and velocity model of the moon's core. They have published their results in the *Proceedings of the National Academy of Sciences*.

Similar structures, varying conditions

That the solar system's planetary bodies have similar compositions is unsurprising; however, differences in the bulk masses of planets and planetary satellites imply different pressure (P) and temperature (T) conditions at their cores. These variables produce liquid versus solid core differences as well as the varying crystalline structures of solid-phase cores.

Although the Earth and the moon are the only bodies for which real seismic data exists, scientists believe that the lower T and P levels of bodies such as Mercury and Mars result in solid, mostly FCC-phase iron cores.

The Apollo program returned core-reflection seismic data from the moon indicating the existence of a liquid outer core and a solid inner core. A determination of the precise structure and chemical composition of the moon's core is essential for the constraint of lunar origin models, including the possibility that the moon once had an active dynamo.

Reanalyzing the data

To explore the Apollo data and set new constraints on its interpretation, the researchers carried out density and sound velocity measurements on body-centered cubic (BCC) and FCC iron at high pressure and temperature using X-ray scattering combined with X-ray diffraction measurements. This technique is useful for measurements on metallic samples compressed in a diamond anvil cell and, recently, for measurements under high P-T conditions.

According to these measurements, the compressional sound velocity of FCC-phase iron is about 400 m/s lower than that of BCC-phase iron at the same density. The most significant finding from these results is that the Vp value proposed for the lunar core based on the Apollo seismic diagrams is significantly below the value for FCC iron.

The researchers further studied the possibility of iron alloyed with nickel and other elements; its incorporation at 22 atomic percent increased density at the same pressure but did not change the compressional sound velocity of the material. Thus, the researchers conclude that the sound velocity proposed for the inner core is incompatible with a core of pure solid iron or any plausible iron alloys.

The researchers propose that the current most plausible structure of the moon's core comprises a pure iron solid inner core with a liquid iron/iron-sulphur outer core. "The temperatures characteristic of the moon's interior point to the Fe-FeS system as the most probable explanation for a liquid iron alloy stable at the thermodynamic conditions of the moon's core. To have a solid inner core, pure Fe has to be the solid phase coexisting with Fe-FeS melt at the liquidus," they write.

Pointing out that the temperature of the core provides further constraints, the researchers observe that the presence of partial melting at the bottom of the mantle means that temperatures at the core-mantle boundary must be 1,650° K. Furthermore, for the iron inner core to be at equilibrium with the outer liquidus, the sulphur content has to be below 37 atomic percent. These results are also consistent with an extinct lunar dynamo.

Taking the mineral physical constraints into consideration, they provide an estimate of the sizes of the inner and outer lunar cores. From the data, the researchers obtain an inner core with a radius of ~245 to 250 kilometers and an outer core of ~85 to 80 kilometers in thickness. The results can also be extrapolated to the conditions of telluric planetary cores of Mars size which may one day be compared to actual seismic data from Mars, and the researchers note the applicability of their conclusions to other small telluric bodies.

More information: "Toward a mineral physics reference model for the Moon's core." *PNAS* 2015 ; published ahead of print March 16, 2015, DOI: 10.1073/pnas.1417490112

Abstract
The physical properties of iron (Fe) at high pressure and high temperature are crucial for understanding the chemical composition, evolution, and dynamics of planetary interiors. Indeed, the inner structures of the telluric planets all share a similar layered nature: a central metallic core composed mostly of iron, surrounded by a silicate mantle, and a thin, chemically differentiated crust. To date, most studies of iron have focused on the hexagonal closed packed (hcp, or ε) phase,

as ε-Fe is likely stable across the pressure and temperature conditions of Earth's core. However, at the more moderate pressures characteristic of the cores of smaller planetary bodies, such as the Moon, Mercury, or Mars, iron takes on a face-centered cubic (fcc, or γ) structure. Here we present compressional and shear wave sound velocity and density measurements of γ-Fe at high pressures and high temperatures, which are needed to develop accurate seismic models of planetary interiors. Our results indicate that the seismic velocities proposed for the Moon's inner core by a recent reanalysis of Apollo seismic data are well below those of γ-Fe. Our dataset thus provides strong constraints to seismic models of the lunar core and cores of small telluric planets. This allows us to propose a direct compositional and velocity model for the Moon's core.

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