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Scientists Chip Away at Mysteries of the Moon

By [KENNETH CHANG](#)

The Moon is slightly squashed, as if someone had held it at the poles between thumb and forefinger and squeezed, flattening it around its equatorial midsection. That is not surprising. The Moon spins, and the outward centrifugal force should indeed have generated a bulge as the molten magma of a young moon cooled to solid rock eons ago.

But as far back as 1799, the mathematician Pierre-Simon Laplace noticed a back-and-forth wobbling because of the Moon's deformed shape. Although the flattening was slight — the Moon's width, 2,159 miles, is about 2.5 miles greater than its pole-to-pole height — it was still greater than would be expected for its current rotation period of 27 days 7 hours 43 minutes and 11.5 seconds.

“The puzzle had been the Moon was too flat,” said Maria T. Zuber, a professor of geophysics and planetary sciences at the [Massachusetts Institute of Technology](#).

Space probes of the 1960's and 1970's found a second deformity of the Moon: it is slightly elongated along the Moon-Earth axis. That is, if the Moon were sliced in half along its equator, the cross-section would not be a circle, but more like a football, with one of the narrow ends pointing toward Earth.

But no one could come up with a completely convincing explanation for the Moon's current shape. That is not its only mystery. Another is why its near side, which always faces Earth, is so different in material and appearance from the far side. The Moon's origin still holds some uncertainties, although many scientists believe that it formed out of the debris when a Mars-size object struck Earth 4.5 billion years ago.

“Quite a lot of the darned thing is still quite mysterious,” said Kimmo Innanen, a professor of astronomy at York University in Toronto.

In the current issue of Science, Dr. Zuber, with Jack Wisdom and Ian Garrick-Bethell, say they have [a possible answer to the problem of the Moon's shape](#). Actually, they say they have several.

What Laplace did not know is that the Moon is moving away from Earth and slowing down. Years of bouncing laser beams off mirrors left on the lunar surface by the Apollo astronauts show that each year the Moon is another 1.5 inches farther from Earth.

The Moon now orbits in what astronomers call a 1:1 resonance with Earth, its orbital period equal to its rotation time so that the same side of the Moon always faces Earth.

Thus, in the past, the Moon was much closer and took less time to orbit. With the 1:1 resonance, the Moon spun faster as well, possibly explaining the bulge. But those calculations did not come with the correct answer for observed distortion along the Moon-Earth axis. “They ought to be self-consistent,” Dr. Zuber said.

One suggestion has been that the Moon by chance cooled into this somewhat odd configuration. Other solid planets like Earth are not exactly in their predicted shape either.

The M.I.T. scientists, however, say the observed distortions are larger than would be expected for chance.

Instead, they suggest that in the Moon’s early history, it traveled in an elliptical rather than a circular orbit and that it was in a 3:2 resonance, spinning three times for every two orbits.

It would have been in this resonance for only a few hundred million years at most, the scientists said, before tidal forces slowed its spin and it fell into the current 1:1 circular resonance.

Their calculations show that such an orbit would provide the necessary forces to produce the Moon’s shape. “There’s a 200-year-old problem, and we’ve got the first solution that works,” Dr. Zuber said.

They also found that orbits with higher resonances, like two spins for every orbit, could produce the same lunar shape. “It’s a bunch of families of solutions,” Dr. Zuber said.

In [an accompanying commentary](#) in Science, Dr. Innanen described the proposed solution as “ingenious.”

But Peter M. Goldreich, an emeritus professor of astrophysics and planetary physics at the [California Institute of Technology](#), said the M.I.T. team did not explain how the Moon was caught in the 3:2 resonance. “That is a real weakness,” he said.

While an elliptical orbit and a 3:2 resonance may explain the shape, they would not explain the disparities between the Moon’s sides. The crust on the near side is much thinner, with vast plains of dark basalt, called maria (pronounced MAH-ree-uh), that erupted long ago. The crust of the far side is thicker, with many more craters; there are few maria.

Partly because of the denser basalt of the mare, the Moon’s center of mass is not at the center, but shifted by more than a mile. But how that shift occurred is unknown.

“That would be a good research project,” Dr. Innanen said.

Many of the mysteries depend on a better understanding of the Moon’s early history. Under the prevailing theory that the Moon formed after something the size of Mars slammed into Earth, scientists believe that the Moon initially orbited very close, perhaps just 16,000 miles from Earth (compared with roughly 238,000 miles today) before moving outward.

David J. Stevenson, a professor of planetary science at Caltech, said the evidence for the collision theory

was solid. Then he stopped. He said instead, “The argument against the alternatives is strong.”

In the past, scientists have suggested that the Moon is somehow captured gravitationally or that it formed out of material spun off from the Earth. The mysteries have persisted because little new data have been collected.

In the three decades since the Apollo Moon landings, [NASA](#) has sent only one probe, a bargain-basement one, to the Moon, the [Lunar Prospector](#) that orbited it in 1998 and 1999.

NASA’s push to send astronauts back has led to robotic missions as well, including the [Lunar Reconnaissance Orbiter](#), scheduled for launching in 2008. India, Japan and China are also planning robotic missions.

And that, scientists say, could lead to a scientific renaissance in the study of the Moon.

“Talk to me in five years,” Dr. Zuber said.

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