SAMPLE

Worlds Beyond Earth: Earth's Moon Formation

The Giant Impact and the Birth of the Moon

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This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

The Moon is the only world humanity has visited, the anchor of our calendars and tides, the light of our nights, and the subject of this book's question: where did it come from? The answer turns out to be one of the most dramatic stories in planetary science. The gentle companion of our sky was born in violence: some 4.4 billion years ago, the young Earth was struck by a body the size of Mars, and from the incandescent debris of that collision, in a display no human ever witnessed, the Moon assembled itself in orbit.

The story of how we came to know this is itself an adventure of science. For most of recorded history the Moon's origin was a matter of myth; for most of the twentieth century it was an open contest of three unsatisfying theories; and in a single decade, the 1970s, the Apollo samples and a bold rethinking of the evidence collapsed the question into the giant-impact hypothesis that dominates today, refined by a half-century of simulation, sample analysis, and laser measurement.

The chapters ahead follow that story: the discovery of the theories and their failure, the physics of the collision and the disk of debris it left, the evidence written in isotopes and moonquakes, the modern models that keep refining the picture, the questions that remain open, and the fun, strange, and occasionally pseudoscientific byways of humanity's speculation about its companion. The book's subject is a single event, ancient beyond imagining; but its method is the whole of planetary science, doing what it does best: reading the survivors of a catastrophe to reconstruct the catastrophe itself.

One question governs everything ahead, and it is worth pinning down before the survey chapters begin. The moon in the reader's sky, the calendar-keeper, the tide-mover, the night's lamp, is one of the solar system's strangest objects: enormous for a satellite, Earth-like in its rocks yet dead, and, by the accepted account, born of a collision that would have melted both worlds. The reader is opening the book of the moon's origin, and the chapters that follow trace the argument from the first telescopes to the sample labs to the giant-impact theory, with the standing lesson that the moon's very existence, the thing the reader sees every clear night, is the evidence for the solar system's violent youth, and the moon is accordingly the sky's own scar.

Honesty also has its place at the start rather than at the end, so it belongs here. The giant-impact hypothesis is the leading theory, it explains the big facts, the moon's size, its dryness, its lack of iron core, and it has troubles, the oxygen fingerprints, the tilt questions, the refinements a generation of theorists is still arguing; the chapters ahead treat the theory as a work in

progress rather than a settled creed, since the honest answer to how the moon formed is a confident direction with unfinished corners, and the book's subject is accordingly the most human thing in science, a good theory, still being built.

Chapter 01: The Discovery of Earth's Moon Formation

A second hypothesis argued the Earth and the Moon formed together as a double system from the primordial accretion disk of the Solar System. Finally, a third hypothesis suggested that the Moon may have been a planetoid captured by Earth's gravity. The modern explanation for the origin of the Moon is usually the giant-impact hypothesis, which argues a Mars-sized body struck the young Earth and left a glowing ring of rubble that slowly gathered itself into one companion, the Moon.

The giant-impact hypothesis is currently the favored scientific hypothesis for the formation of the Moon. Multiple lines of evidence disprove that the Moon is hollow. One involves moment of inertia parameters; the other involves seismic observations. The moment of inertia parameters indicate that the core of the Moon is both dense and small, with the rest of the Moon consisting of material with nearly-constant density.

Little attention was paid to Professor Daly's challenge until a conference on satellites in 1974, during which the idea was reintroduced and later published and discussed in Icarus in 1975 by William K. Hartmann and Donald R. Davis. Their models suggested that, at the end of the planet formation period, several satellite-sized bodies had formed that could collide with the planets or be captured.

They proposed that one of these objects might have collided with Earth, ejecting refractory, volatile-poor dust that could coalesce to form the Moon. This collision could potentially explain the unique geological and geochemical properties of the Moon. A similar approach was taken by Canadian astronomer Alastair G. W. Cameron and American astronomer William R. Ward, who suggested that the Moon was formed by the tangential impact upon Earth of a body the size of Mars.

It is hypothesized that most of the outer silicates of the colliding body would be vaporized, whereas a metallic core would not. Hence, most of the collisional material sent into orbit would consist of silicates, leaving the coalescing Moon deficient in iron. The more volatile materials that were emitted during the collision probably would escape the Solar System, whereas silicates would tend to coalesce. Eighteen months prior to an October 1984 conference on lunar origins, William K.

Hartmann, Roger Phillips, and Jeff Taylor challenged fellow lunar scientists: "You have eighteen months. Go back to your Apollo data, go back to your

computer, and do whatever you have to, but make up your mind. Don't come to our conference unless you have something to say about the Moon's birth." At the 1984 conference at Kona, Hawaii, the giant-impact hypothesis emerged as the most favored hypothesis.

Before the conference, there were partisans of the three "traditional" theories, plus a few people who were starting to take the giant impact seriously, and there was a huge apathetic middle who didn't think the debate would ever be resolved. Afterward, there were essentially only two groups: the giant impact camp and the agnostics. The name of the hypothesised protoplanet is derived from the mythical Greek titan Theia, who gave birth to the Moon goddess Selene.

This designation was proposed initially by the English geochemist Alex N. Halliday in 2000 and has become accepted in the scientific community. According to modern theories of planet formation, Theia was part of a population of Mars-sized bodies that existed in the Solar System 4.5 billion years ago. Theia is hypothesized to have orbited in the L4 or L5 configuration presented by the Earth-Sun system, where it would tend to remain.

One of the attractive features of the giant-impact hypothesis is that the formation of the Moon and Earth align; during the course of its formation, Earth is thought to have experienced dozens of collisions with planet-sized bodies. The Moon-forming collision would have been only one such "giant impact" but certainly the last significant impactor event. The Late Heavy Bombardment by much smaller asteroids may have occurred later - approximately 3.9 billion years ago.

Astronomers think the collision between Earth and Theia happened at about 4.4 to 4.45 billion years ago (bya); about 0.1 billion years after the Solar System began to form. In astronomical terms, the impact would have been of moderate velocity. Theia is thought to have struck Earth at an oblique angle when Earth was nearly fully formed.

Other mechanisms that have been suggested at various times for the Moon's origin are that the Moon was spun off from Earth's molten surface by centrifugal force; that it was formed elsewhere and was subsequently captured by Earth's gravitational field; or that Earth and the Moon formed at the same time and place from the same accretion disk.

Another hypothesis attributes the formation of the Moon to the impact of a large asteroid with Earth much later than previously thought, creating the satellite primarily from debris from Earth. In this hypothesis, the formation of the Moon occurs 60-140 million years after the formation of the Solar System

(as compared to hypothesized Theia impact at 4.527 +/- 0.010 billion years).

The asteroid impact in this scenario would have created a magma ocean on Earth and the proto-Moon with both bodies sharing a common plasma metal vapor atmosphere. The shared metal vapor bridge would have allowed material from Earth and the proto-Moon to exchange and equilibrate into a more common composition. Yet another hypothesis proposes that the Moon and Earth formed together, not from the collision of once-distant bodies. This model, published in 2012 by Robin M.

Canup, suggests that the Moon and Earth formed from a massive collision of two planetary bodies, each larger than Mars, which then re-collided to form what is now called Earth. After the re-collision, Earth was surrounded by a disk of material which accreted to form the Moon.

The discovery story closes with one receipt worth itemizing in full: the Apollo samples, the theory's evidence locker. The returned samples settled the moon's basic chemistry at a stroke, its rocks matched the Earth's in the fingerprint elements and matched no expected foreign source, a result that killed the capture theory and starved the sister theory; the samples carry the final authority, that the moon is the only other world whose surface material sits in terrestrial laboratories by the hundreds of kilograms, and the formation debate is accordingly the best-evidenced argument in planetary science, conducted with rocks rather than photographs.

The theory's public acceptance arrived a decade after its revival, at the 1984 conference in Kona, Hawaii, convened to settle the Moon's origin once and for all. The specialists who gathered there, presented with the isotope evidence and the first serious collision simulations, left with the giant impact as their working consensus, and the proceedings volume that followed marked, in retrospect, the closing of the old three-theory era. The word consensus deserves a caution: the conference did not crown a finished answer, it set the terms of an argument that the following four decades have refined, and every model since has been an effort to save the Kona verdict from its own loose ends.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.