Journal of Theoretics
Guest Commentary
Volume 6-1, Feb-March 2004

The Origin of Our Moon

Lance May
lanceimay@hotmail.com

Probably in no branch of the sciences is there such misuse of the term theory as in astronomy. This misuse finds its way into science magazines, TV and radio broadcasts, science news web sites, and even encyclopedias. Many of the conjectures about the solar system's formation are bantered as theories when they really are insufficiently scrutinized hypotheses. I think the Big Bang has adequate evidence to be labeled rightly as a theory, and that our solar system having formed out of a condensing cloud of interstellar gas that swirled increasingly faster as it condensed is also an acceptable theory. Why? Partly because of data obtained by direct observation of our universe provided by ground based observatories and space deployed observational devices like the Hubble Space Telescope coupled with mathematically solid theoretical mechanical models. In other words, we seem to have a pretty secure grip on the big picture, but the details are still fuzzy. We do not seem to have a firm grip on the details of our own solar system's formation (a lot can happen in some 5 billion years). If we can get some direct observational evidence of other solar system's planets and their satellites forming (and we will) coupled with what we have gathered from our solar system exploration then we will be in a position to make comprehensive and specific theories instead of shaky hypotheses. In this paper I want to look at various popular hypotheses of the Moon's formation and in particular the newest Collision Theory in an attempt to point out what I think are its possible shortcomings.

Prior to the 1970s, there were three main theories regarding the origin of the Moon (Encarta, 2001). The first involved a fission event, in which the Moon broke off from a rapidly spinning Earth. The second theory, a co-formation theory proposed that the Earth and Moon formed contemporaneously as a gravitationally bound pair. The third theory suggested that the Moon formed as an independent planetary body that was later "captured" by the Earth during a close pass. Supposedly each theory had deficiencies; for example, it was proclaimed difficult in both the capture and co-formation models to account for the lack of a large lunar iron core, because both predicted that the Moon formed from the same mix of materials as the terrestrial planets, which typically contain a more substantial abundance of iron. I can't help but object to this on the basis that Mars, although somewhat farther from the sun, is considered a terrestrial planet with a mean density of only 3.95×10^3 kg m^{-3} compared to the Moon's mean density of 3.34×10^3 kg m^{-3}. Neither body has a large iron core and consequently little or no magnetic field (Nicolson, 1977, p.135, 142). What this data implies to me is that the Moon cannot be completely excluded from being a small terrestrial planet just on the basis of lacking a metal core.

In 1976 and 1977, two groups proposed a new theory for lunar origin that in the last decade after refinements through computer simulations has gained more and more acceptance: The Giant Impact Theory (Halliday et al., 1999). The idea was that an off-center impact of a roughly Mars-sized body with early Earth could provide Earth with its high initial spin, needed to explain the current system's angular momentum, and eject enough debris into orbit to form the Moon. If the ejected material came primarily from the mantles of the Earth and the impactor, the lack of a sizeable lunar core was easily explained, and the energy of the impact could account for the extra heating of lunar material required by lunar volatile depletions (Alper, 1994). Other huge impacts have been proposed to account for various anomalies in the solar system. According to Alastair Cameron at the Harvard-Smithsonian Center for Astrophysics, the pronounced tilt of Uranus is probably the result of one or more blows from an object as large as Earth (Apler, 1994). Just one of my problems with these “theories” is the repeated mention of trying to explain our Earth’s unusual tilt and supposedly fast rotation as the result of a massive collision. A glance around our solar system should shed serious doubt on collisions explaining tilt or rotational characteristics. Take the already mentioned Uranus lying on its side tipped 98 degrees relative to its orbital plane around the sun as an extreme example of tilt. Uranus has 18 confirmed moons, 16 of which revolve around its equator (Encarta, 2001). Sure it’s conceivable that it got knocked over by some outlandishly huge collision but how the heck do you explain almost all of its moons tipping with it? Interestingly enough R.M. Canup has tackled this problem with computer simulations also and shown that up to 5 of the outer moons of Uranus can be accounted for from a massive collision (Canup, 2000). Even though that seems pretty impressive, it leaves me wondering about the other 11 moons that are orbiting in the sky around the equator of Uranus. When I look at the configuration of Uranus and its moons I can’t see how any collision between solid bodies could account for all of this equatorial uniformity. It leaves me wondering why I should accept a hypothesis that explains that the Earth’s tilt is the result of a giant collision resulting in a moon that doesn’t rotate around its equator. Next let’s take a look at the rotational velocity of Earth as being unusual at close to 24 hours. Is it? I don’t think so. Mars rotates on its axis in 24.6 Earth hours, Jupiter in 9.8 hours (that’s angular momentum!), Saturn in 10.66 hours, Uranus 17.24 hours, and Neptune 16 hours (Encarta, 2001). My opinion is, anyone that believes (without a detailed model) these comparable or faster than Earth rotational rates are the result of single big hits or repeated little ones should stick to buying lottery tickets! I think that there had to be a fundamental process during the contraction of the original solar nebula that imparted spin to all the forming planets, which then most certainly were modified later due to gravitational interactions and sizeable collisions, and that eventually we will work out these details. The real odd duck that might qualify for a single big hit that totally changed its tilt and rotation would be Venus. Maybe such a big hit left it more or less upside down relative to the rest of the planets with an amazing retrograde rotation time of 243 Earth days. The gratifying rub here is that it doesn’t even have a trace of a moon to show for such a horrific past collision! Maybe our moon is the progeny of some kind of a romantic relationship between Earth, and The Goddess of Love; after all there is that strange coincidence of Venus having almost a perfect rotational resonance with Earth's orbital period.

For about 10 years, the giant impact theory was heavily criticized. The idea that the Moon was the result of a particular large impact event was considered "too arbitrary", and did not fit in well with the existing view of a gradually evolving planet formation process. In 1984, a conference devoted to lunar origin prompted some critical comparison of the existing theories. Somehow the giant impact theory emerged from this conference with nearly consensus support, promoted by new models of planet formation that suggested large impacts might indeed be common events in the end stages of terrestrial planet formation. Such models demonstrated that the relatively quiet stage of planetary growth continued only until young planets grew to sizes ranging from lunar to Mars-sized, and that the final stages of growth were characterized by collisions among tens to hundreds of these large, planet-sized bodies (Canup, 1999). In the course of the many impacts apparently required to yield the final four terrestrial planets, it seemed reasonable that one of the impacts would be of the type required to yield the Moon. Here again my common sense question is, where is everybody? If there were tens to hundreds of planet sized bodies needed to form the terrestrial planets as R.M Canup has suggested, where are they today? Apparently they're not obeying Newton's Law's and staying around the neighborhood. I'm sensing a missing mass factor here. What I'm asking is, with all due respect, shouldn't there be more of these bodies still floating nearby? To me it seems reasonable to ask, is there a tiny bit of evidence left over, besides the Moon, from all this activity; even a ring of debris or fine dust that we could get a sample of? There is no doubt about collisions of a somewhat smaller variety; one only needs to look at pictures of many of the airless bodies in the solar system to verify this, or better yet look through a backyard telescope at our Moon's surface. What I'm skeptical of is the concept of these giant planet sized collisions being common.

For obvious reasons the impact of a Mars or larger-sized body with Earth cannot be reproduced experimentally. To be pragmatic researchers must rely on computer simulations that can be compared with experimental results at small sizes and then extrapolated to larger scales. And so scientists have used these tools to join the Space Age with the Information Age. An SPH simulation of a potential moon-forming impact requires months of computational time on a single workstation (Canup, 1999). So where are we today, using this sophisticated programming? Well as it stands today planetary scientists are definitely leaning toward the Moon's origin as the end result of a glancing collision of Earth. One class of simulated impacts that characteristically places sufficient amounts of material into orbit around Earth involves bodies with three times the mass of Mars and more than twice our current system's angular momentum. These impacts yield an Earth with a moon of the correct size, but leave the system spinning too rapidly (Canup, 1999). From the basic laws of physics, it is known that the angular momentum of the Earth-Moon system has been very nearly conserved over the age of the solar system (Zeilik, 1982, p.177). Consequently, for these extremely high angular momentum impacts, one must fabricate some mechanism to significantly slow the Earth's spin after the Moon-forming event, such as perhaps a second massive impact, and to me we are starting to build even shakier hypotheses on more implausible and questionable premises.

Another class of simulated impacts that have paraded forth onto the pages of astronomy literature that could produce an appropriately sized moon yields the correct total angular momentum, but results in an Earth that is only 60 percent of its current mass (Canup, 1999). This scenario obviously also has some bugs. Another problem with any collision hypothesis is if the Earth continued to accumulate solar-orbiting material in large amounts after the Moon was formed, it would be expected that the Moon also would be collecting such material and have become equally contaminated with iron-rich material. The Moon is definitely lacking in iron rich compounds (Spudis, 1999, p.137). So the bottom line is researchers have not yet produced a set of simulated impact conditions that yields the Earth-Moon system in its current configuration. "In spite of a growing consensus, some workers still dislike the entire Giant Impact Theory on both dynamical and geochemical grounds", says Alex Halliday and Michael Drake (Halliday et al., 1999). All I can say to this is thank goodness for small favors! I'm ashamed that even the highly technical journal *Science* doesn't criticize using the word theory instead of hypothesis. In a breath of fresh air, The New Solar System states, "The advent of the giant-impact *hypothesis* (italics mine) has not solved the problem of lunar origin." (Spudis, 1999, p, 138)

Another item Canup brought up was how Dr. William Ward allegedly proved in 1974 that were it not for the Moon, the influence of the giant planets in our system would cause Earth's obliquity -- the angle between the Earth's equator and the plane of its orbit, whose current value is 23.5 degrees -- to vary wildly with values as extreme as 0 to 80 degrees. And that "such variation would probably cause extreme climatic changes that would render the planet uninhabitable"(Canup, 1999) Well I have a lot trouble accepting this concept because Mars without a big moon doesn't have this problem in any extreme and it's closer to the gas giants than Earth is. If this collision hypothesis turns out to be completely correct (exercise for an open mind) and I live to see it rise to the level of the respect of a theory then one thing is for sure: I'll know planets like Earth with an accompanying moon are darned scarce in the cosmos. Intelligent life must only happen once in a Blue, Blue Moon.

In one of his books of collected essays Isaac Asimov made an elaborate, and I thought, strong case for the Moon being a double planet (Asimov, 1975 pp.129-142). The appealing thing to me was how he demonstrated that the Moon orbits the sun very near the plane of the solar equator just like the rest of the planets except Pluto, and that in doing so is unique to of all our solar system's moons in as much that its orbit is always concave toward the sun, where as all the other satellites without exception fall away from the Sun through part of their orbits, caught as they are by the superior pull of their primary. So for me, I'm going to stick with this older version of the Moon's origin over the Giant Impact "Theory" based on my previous objections. I think the formation of a solar system's bodies probably involves some extremely complex and subtle processes that are yet to be discovered. Simply put, we don't know enough yet, or in other words there probably are many considerations that just haven't been factored in to account for specific chemical compositions that conflict with the hypothesis of the Earth and Moon forming from the same planetesimal pool, and if they did form from the same general planetesimal pool then Earth's tilt may well be the result of yet to be discovered tilting factors that resulted in the anomalous axial tilts found elsewhere in the solar system. My prediction is that as time passes and we get a better look at other nearby star systems with upcoming space telescopes that there will be occasional double-planets found with properties similar to our Earth- Moon system, and planetary scientists will concede that they are not the result of improbable giant collisions. At that point mark my words, an updated computer simulation will be run that shows just how they form via evolution from a double planet scenario.

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