L16 Moon's impact origin < planetesimals common in the early solar system >

In his 1799 four-volume treatise *Mecanique celeste*, he declared that the universe was stable and fully predictable. Laplace later wrote, "[with] all the forces by which nature is animated ... nothing [is] uncertain, and the future as the past would be present to [our] eyes." When queried by Napoleon Bonaparte on the absence of any reference to God in his treatise, Laplace replied [as a put-down of Newton], "Sire, I have no need of that hypothesis." —**Neil deGrasse Tyson**, 1995.[1]

In 1759 a comet previously seen in 1607 and 1682 returned, just as Edmund Halley [1656-1742] had predicted in his calculations based on Newton's gravitational theory. The comet's return removed any doubt about whether Newton's conclusions about the motions of the planets, and hence of objects in space, were correct.
—Scott Huler, *de-fin-ing the wind*, 2004.[2]

Pierre Simon Laplace (a marquis who survived the French Revolution) in 1799 proposed that the solar system (Sun, planets, moons, asteroids, and comets that are gravitationally bound to each other) evolved from a rotating nebula of gas and dust. And evidence is, out of such seven stars a year are born in our Galaxy,[3] but how specific bodies such as Earth and Moon formed remains an open question. Constraints on speculation, and new challenges for explanation, are from analyses of Earth rocks, *Apollo*-returned lunar rocks, and meteorites, and from space probe revelations of the variety of other solar system bodies and ranges of their environments.[4]

Long sung of in mythologies, *Moon*, called *Luna* by the Romans, *Selene* or *Artemis* by the Greeks, inspires explanations that now answer mundane questions as: When did Earth and Moon become a closely bound system? Why is lunar volcanic-rock devoid of included water whereas similar igneous rocks of Earth's crust contain hydrated minerals? Why in comparison to the other solar system stony planetary bodies is 150 km of Moon's mantle base partly molten and its iron-rich core so tiny (solid inner, diam. 240 km, molten outer 90 km thick)?[5] Some answers can be found in a review in *Destiny or Chance: Our Solar System and Its Place in the Cosmos*, 1998, by Stuart Ross Taylor.[6]

Two gravitationally bound bodies orbit a common center of gravity (barycenter). This will be closest to one of the bodies unless both have exactly the same mass. If the barycenter lies nearer one of the bodies, that heavier body is called the *primary* and the other (lighter) body is a *satellite* to it. The solar system's barycenter is interior to Sun. For a planetary system with moons, the barycenter is in the "planet"—a body, not a star, spherical by its own gravitation—and when outside two such spherical bodies, call it a *binary planet* suggest A. Stern and J. Mitton, in *Pluto and Charon*, 1999.[7]

Earth and Moon have long been strongly gravitationally bound. In 1963, J. W. Wells discovered that Paleozoic corals contain more diurnal (L. *diurnus*, daily) growth bands per yearly growth band than do modern corals, suggesting more days per year in the Paleozoic. (The shell carbonate of corals is mostly precipitated by the symbiotic algae—zooxanthellae—living in the coral, and their day and night activities differ.) The energy of ocean tides (which the rotating Earth drags and keeps to 10º ahead of Moon's orbital position) is dissipated (mostly) in shallow coastal seas and in deep water where there is roughness as on oceanic-ridge rises. This energy (less frictional heat generated) is transferred to orbiting Moon. As a result Moon's recession from Earth is presently 3.8 cm a year (as measured to Laser Ranging Retro-Reflectors left there by *Apollo 11, 14* and *15* astronauts).[8] The need for accuracy ties time-keeping not to astronomical phenomena such as Earth's rotation and the motion of the planets but since 1967 to Coordinated Universal Time (UTC—a compromise acronym for use in all languages) which is International Atomic Time (*Temps Atomique International*, or TAI) offset by an integral number of seconds. Earth's rotation is known thereby to be slowing down currently by 1 hour every 1000 years ("leap seconds" are added to UTC at the end of either June or December when the discrepancy of Earth's rotation with TAI is 0.9 seconds).[9]

Uniformitarianism actualistically would have Moon closer to Earth, receding faster, and revolving more rapidly in the Silurian. Corroborating this, growth increments in fossils, such as Phanerozoic solitary corals and clams record about 400 days in the Devonian year and 420 days in the Silurian year. Studies of rhythmic banding in stromatolites and in rhythmite sediments, find at 541 Ma (end of the Precambrian) 450 days per year and 19 ½ hours per day, and at 2 Ga, when Earth spun over twice as fast as now, about 800 days per year and 11 hours a day (***Figure L16.1***, p. 681).

Said otherwise: The tidal bulge that Moon creates in Earth's oceans and rock, kept forward by Earth's faster rotation than Moon orbits, pulls on that causing body by its gravitation. So Moon has speeded up in its orbit and is now farther away from Earth than it was. The efficiency of energy transfer from Earth to Moon is relatable to the tidal amplitude and mass of the layers deformed. This is greatest for the oceans (and insignificant for relatively light air and relatively more rigid rock) and becomes large where the wave of the ocean tide surges against continental margins.

Tidal records show that Earth and Moon have orbited a common barycenter for at least the last 2 Gy. Calculations show that Moon's presence gives Earth a rotational stability of tilt, to within 3º, that it otherwise would not possess. Moon's tilt too is kept to within 1.5º. Going back in time, Moon and Earth would have been ever closer. Just how close, is hard to estimate—but not within the Roche limit of roughly 3 Earth radii (18,500 km). The Roche limit (named to honor Edouard Roche who in 1848 calculated it for Saturn) is the distance inside of which a liquid (molten) satellite will disintegrate from the effect of the tidal tensional forces between it and the planet it revolves about. (For Saturn it is roughly 1.5 Saturn radii which is to the outer edge of that planet's main rings).[10]

Any system with more than two bodies, as is so of the solar system, is by nature chaotic.[11] Newton thought God was needed to keep the solar system from going awry. Laplace found otherwise. The possibility is for gravitational bindings and breakaways. Of the inner planets, Mars probably captured its two satellites, Phobos and Deimos. Did Earth likewise capture its satellite Moon (first argued for by T. J. J. See)? If it did, the tidal evidence recorded by fossils puts the time of capture to before 2 Ga. Further, *Apollo*-returned lunar rocks have no record of having been subjected to the sort of extreme deformation that capture would have entailed. Nor have the mare-basalt filled planetesimal craters and older terrae craters been deformed in a way that would indicate subsequent capture. If capture occurred, it would have been before 4.5 Ga. And did it? Many moons ago, Irwin Shapiro, noting the extreme improbability of such an event (for Earth is truly a tiny target in a vast and nigh empty, as seen today, solar system) joked that any sighting of Moon must be "observational error."

Concede as unlikely an early orbital capture, although this has occurred for small bodies such as Mars' moons Demos and Phoebus. Then a posture to lessen the improbability of the association of Earth and Moon forming soon after Earth's origin can be a capture mechanism for Earth's moon, Moon, 1) that involves an extreme form of air breaking as NASA scientists have successfully used to put satellites into orbit about planets. In air breaking, a space probe that otherwise would pass on by, is passed through the outer fringes of the planet's atmosphere to slow it enough for it to go into orbit about the planet. 2) a similar, although more dramatic, scenario proposed by William K. Hartmann and Donald R. Davis in 1975 involves a planetesimal (which in 1976 Alastair G. W. Cameron (1925-2005)[12] and William R. Ward independently calculated would be Mars-sized given the angular momentum of the Earth-Moon system)[13] in an oblique bodily collision with Earth (Reginald A. Daly in 1946 had proposed such a mechanism; but maverick for an early solar system falsely thought to have been as empty of planetismals as today).[14] Computer modeling shows that a few hours after such a collision, the impact debris of both the impactor, named *Theia*, and part of Earth's mantle would spread out in space as a turbulently mixed vapor.[15] Within 24 hours, the part of this ejection that stays in orbit beyond the Roche limit about Earth, would clump by gravitational attraction between its parts and become our Moon. This collision hypothesis (recounted in *The Big Splat*, 2003, by Dana Mackenzie)[16] is made reasonable by noting the variety of rotation energy and axial inclination of bodies in the solar system. That is, the process had numerous opportunities to operate before 4.5 Ga, at the magnitude invoked, in a then planetesimal-crowded solar system.

A Mars-sized impactor would create a shock wave that propagates through Earth and cause at locations far from the impact site, a sudden outward-directed surface velocity. For this, G. Q. Chen and T. J. Ahrens in 1997 calculated a velocity of 8 km/s and a loss then of "almost all [the] atmosphere." In 2003, H. Genda and Y. Icarus Abe found for a velocity of 6 km/s and, in their model, 30% of the atmosphere is lost and some of the impactor's atmosphere would have been captured.

The moons of Jupiter, Saturn, Uranus and Neptune number 57. Some of the smaller stony ones, could be captured asteroids such as the outer 4 of Jupiter but not, as evidenced by their compositions, its 4 Galilean satellites (Io, Europa, Ganymede and Callisto) and its other 9 inner moons (known from Voyager 1 and 2 photographs taken in 1979). These, in their variety and order present an analogue of the solar system planets. As an historical note: The "Galillean satellites" were first seen by Galileo. an hour after sunset on January 7, 1610, through a spyglass (eyepiece—a strong ocular concave lens, and at far end—a large weak objective convex lens) that he had made with a twenty-fold magnification. (In October, or November,1609, Galileo had used this spyglass to view Moon[17] but in this Thomas Harriet had scooped him by using a six-fold magnifying spyglass in August 1609.)[18] The changing positions of the four new "stars" near Jupiter (Kepler suggest he use the word satellite—Gk. *Satellos* meaning *attendant*—which is now applied) on successive nights gave Galileo proof of the Copernican system, and allowed him, although later proclaiming for the doctrinally correct stationary Earth,[19] the reported luxury of muttering on his death bed: "*Eppur' si mouve* (And yet it moves)." In 1611, Cardinal Boronius had commented wryly (or dismissively?) "The Bible tells us how to go to Heaven, not how the heavens go" (often wrongly attributed either to Galileo—who in 1613 did allude to the (late) Vatican librarians's aphorism when considering the possibility that "the sun stood still in the midst of heaven [Josh, 10:13]," or to Newton).

Uranus (the planet; not the orifice that forthright pronunciation humorously yields and which led newscasters to develop a mangled pronunciation during the *Voyage*r flyby) and Neptune are similar in size and have small orbital inclinations. Respectively, they have days of 17 and 16 hours and equatorial inclinations of 98° and 30°. The collision of an Earth-mass body with Uranus could account for the differences along with its five planetary moons. Asteroid-like Pluto (Planet X of yore)[20] has a large icy companion Charon (discovered in 1978) that is most easily explained as the result of planetesimal collision. The Pluto-Charon binary planet (center of mass between them from Pluto is 185% the radius of Pluto) is debatably best considered to be a member of the a second—beyond Neptune—asteroid-belt called the *Kuiper* belt after Gerard Kuiper[21] although priority should go to Kenneth Essex Edgeworth (1880-1972) who proposed the same in 1943,[22] and now a certainty with the discovery of TNOs (trans-Neptune objects) as icy Quaoar (diameter ~1250 km) found in 2002 by Chad Trujillo and Mike Brown and the centaur (outer-planet orbit crossing icy asteroid) Chiron (pronounced *KEYE ron*) found in 1977 by Charles Thomas Kowal.[23] A TNO larger than Pluto, is two mooned (Nix and Hydra) Eris (nicknamed "Xena" after a TV show's warrior princess) that some hail as the 10th (or 12th, counting Charon and spherical asteroid Ceres) planet.[24] But the IAU decided 24 August 2006: A *planet* must be heavy enough to clear other objects from its path as so of the classical planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, & Neptune.[25] Pluto and Eris, heavy enough to have near-circular orbits, are *plutinoids* (IAU ruling, June, 2008).[26]

A steady accretion model of the dust and gas of a primordial nebula is inadequate to account for chaotic formation process that the variety of the solar system bodies and their rotations record.

Nebula gas and dust, between condensed bodies, was swept away (by sunlight pressure and solar wind) within a few million years of Sun becoming radiant. Before that happened, the inner solar system was swarming, as is likely the norm for stars rich in heavy elements,[27] with planetesimals and the outer planets were already large and accumulating ices and Jupiter and Saturn were sufficiently massive to have gathered upon their cores enough nebula gas to be "gas giants."

The solar system planets (single and binary) and moons (some with atmospheres and planetary processes), were formed by 4.55 Ga, either by capture of the bodies left over after major accretion and collisions, or by accretion in the gaseous disks thrown out from the planets by collisions. Likely, 50 million years suffices for stony planets to form from repeated collisions of rocky bodies of a few meters or kilometers in size. These accreted perhaps within a million years of when the gas and dust of the originating nebula had become gravitationally bound and collisions were quotidian.[28] ❑