Moon: Origin, alternative theories

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Definition

The Moon's origin and formation should be able to explain the current physical, dynamical, chemical, and internal thermal states. While the Giant Impactor Theory is the leading theory, we must also look into the earlier variations of lunar origins. This includes variants on three main possible scenarios: capture, rotational disruption, and co-accretion.

Capture

One particular idea was that the Moon was a strayed planetoid object, captured by Earth and circularized onto a stable orbit (Urey 1952; Mitler 1975). Most of these dynamical theories suggests a nebula that aids in the capture that has since dissipated (Gerstenkorn 1955). This nebula is likely to have vanished within ~1 – 10 Ma, this would not have been viable to physically capture, given the recognized current age of the Moon (Asphaug 2014). Asphaug (2014) states that instead a collision with Earth can decelerate a planetoid, to the point of capturing partial (or entirety) of it into orbit. A collision could have also led to the production of a swarm of captured planetesimals that would have eventually accreted into the Earth (Matsui and Abe 1986).

Öpik (1972) suggested that a proto-moon approached Earth in a nearly parabolic orbit (defining a Keplerian orbit very similar to the Earth's so that the Earth's relative velocities are very low when the proto-moon is further away). If this proto-moon passed us with a perigee within the Roche distance, then it would have broken up, where the inner half would be captured and the other portion "rejected". The captured pieces would then move in highly eccentric orbits, and then be rapidly circularized by mutual collisions into a ring. Mild inelastic collisions would then eventually make these pieces coalesce (Mitler 1975). Mitler (1975) states that this mechanism for partial capture does not depend on any dissipative process, such as the configuration of the Earth-proto-moon or loss of orbital angular momentum. Mitler (1975) suggests that if the proto-moon were already differentiated (including an iron core), then it would be simple to shed the core, leaving material low in iron to reaccumulate into a Moon.

Such advantages of having a capture-type mechanism for the origin of the Moon, as noted by Mitler (1975) were: (i) current hypotheses of planetary formation (Hallam and Marcus 1974); (ii) extensive cratering observed on the Moon, Mars, and Mercury; (iii) Age of the Moon being like that of Earth; and (iv) guarantees natural capture of material (or lack of certain materials, such as iron and siderophiles.

However, Singer (1968) concludes that one of the major objections to the capture theory was namely the dissipation in a relatively short period of time considering great amounts of rotational kinetic energy inside the Earth, and tidal disruption of the Moon.

Fission

Darwin (1879) proposed that the Moon originated from a rapidly rotating Earth and can be modified by substitution of excessive rotation rate and unstable spin during the formation of the Earth's core. The resulting instability would then "break" the Moon away. O'Keefe and Sullivan (1978) hypothesized that rapid differentiation changed Earth's moment of inertia, resulting in an ejected debris ring of silicates. Singer (1968) objects that under the fission theory the Moon would have formed initially in the equatorial plane of the Earth and that a multitude of moonlets would have formed within 10 Earth radii.

From Wise (1963), the hypothesis of rotational fission during the Earth-core formation can be visualized as a very rapidly spinning Earth whereon a small addition to centrifugal force by increased spin rate would free a partial amount of the equator from its gravitational attraction. The spin rate to account for the rigidity and shape of the body should occur with a period of rotation of ~2.65 hours (Jeans 1929). Assuming a proto-Earth of homogenous density, then settling, coalescing, compacting, or collapsing of the interior with time ould reduce the moment of inertia (Wise 1963). Conservation of angular momentum to a newly differentiated Earth would then increase the rotational speed (Wise 1963). From this, a possible sequence of shapes can be taken (see Wise 1963). At low spin rates, the Earth's shape starts as an oblate spheroid. With increasing spin rates, Jeans (1929) notes that the spheroid continues to flatten, whereupon unstable rotation begins. This transforms the oblate spheroid into an ellipsoid, revolving on its short axis. Finally with enough rotational acceleration, this shape would deform into a pear-shape, spinning with its long axis in the plane of rotation. The lunar embryo would be the "stem" oblate portion of the pear figure. This bulge would be composed primarily of Earth mantle material, with the outermost portion being primitive crustal components. Unstable rotation would cause the bulge to separate it from the proto-Earth. Both bodies would then reshape hydrostatically under their own gravitational forces to form the present Earth-Moon system (Wise 1963).

Impact-induced fission is a variant of this theory (Ćuk and Stewart 2012). This includes a sequence of processes: (i) spin-up of Earth nearing disruption; (ii) fission of Earth's mantle, triggered by smaller, energetic Theia-type planetoids; and (iii) orbital evolution of the Earth-Moon system to lose half of its angular momentum.

From Wise (1963), the fission theory provided some major points of lunar origin (at least in the 1960s), such as: (i) correctly predicting the direction of the Earth's rotation being the same direction as the Moon's; (ii) explain the relatively circular orbit of the Moon around the Earth; (iii) core-settling hypothesis predicts the observed specific gravity of the Moon; (iv) the same-facing position of the Moon due to the Moon accelerated out from the spinning proto-Earth; (v) explains the fundamental differences in the near versus far side of the Moon where the far side of the Moon would contain the remnants of lighter primitive Earth materials, whereas the nearside would be heavier mantle constituents; and (vi) the explanation of maximum moment of inertia along an axis pointing toward the Earth.

Although this theory solves the isotropic mystery by essentially homogenizing the reservoirs, this hypothesis conflicts with iron segregation that occurred in the Moon's early formation (Rudge et al. 2010). From Asphaug (2014), the Giant Impact Theory is considerably not that far removed from the concept of fission in that two-accreting planet-like objects going from high to low inertia as their cores merge, transferring angular momentum to form a debris disk to coalesce.

Co-accretion

This theory that Earth and the Moon co-accreted as a binary pair in the context of a solar nebula came about by Morishima and Watanabe (2001). In the plane of accretional and dynamical evolution of planet-satellite systems in a swarm of planetesimals on heliocentric orbits, a satellite with some initial value moves quickly toward the orbital radius, where accretion drag recompenses with tidal repulsion, and then grows toward equilibrium (Morishima and Watanabe 2001).

Morishima and Watanabe (2001) proposed two co-accretion origins for the Moon. The first scenario describes the Moon starting as a small embryo (10^{-2} M_M) and grew in a swarm of planetesimals with low velocity dispersion, so that large angular momentum was essentially supplied to planetary spinning. The rapid growth of the Earth (~10^6 years) was needed for the semimajor axis of the Moon to be kept so small that the Moon enlarged more rapidly under the benefit of "gravitational focusing" by the Earth. The second scenario describes that the Moon was formed by a giant impact occurring during Earth's accretion. This impact supplied enough angular momentum as large as that of the present Earth-Moon system. This particular scenario is then a basis for the current (and favored) Giant-Impactor Theory.

From Asphaug (2014), this co-accretion theory is not supported dynamically due to its dependence of a dynamic nebula and that W isotopes (and other chronometers; Touboul et al. 2007) have shown that the Moon must have formed at 4.5 Ga or later, long ahead of the proposed nebula dissipation. Co-formation, however, is somewhat consistent with the low-velocity collision that is required of the Giant-Impact Theory.

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