Questions About Lunar Origin. Fred S. Singer

In 1975 William K. Hartmann and Donald R. Davis 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 may have collided with the Earth, ejecting refractory, volatile-poor dust that could coalesce to form the Moon. This collision could help explain the unique geological properties of the Moon.

The impact hypothesis was devised mainly to circumvent what was thought to be a low probability of lunar capture. (Yet, strangely, capture appears to be the preferred hypothesis for the origin of the outer moons of Jupiter and some other planetary satellites.) But the impact hypothesis has similar probability problems that are hardly ever mentioned -- in addition to more fundamental problems, all of which can be overcome only with various *ad hoc* assumptions.

The impact hypothesis (Hartmann; Benz, Cameron, Melosh; Canup, Asphaug) of lunar origin seems to have found general acceptance – in spite of the fact that its probability is low and the physics of the lunar formation is not readily transparent, being obscured by a complicated computer program. Nevertheless, one can raise certain questions that an impact process should answer:

1. For what range of impact parameters a is there an appreciable chance of forming the Moon? If a is close to the Earth radius R, then the impact is only glancing and the process becomes operationally indistinguishable from "capture"; if $a \ll R$, then the probability of forming a Moon from Earth material appears low (as evident from arguments of angular momentum conservation).

2. Therefore how many Mars-like bodies must impact in order to have a reasonable chance to produce the present Moon? And why is impact origin more probable than capture? Also: If there are so many bodies available, why didn't it happen on Venus or Mars?

3. At what stage of terrestrial accretion does the hypothetical impact occur? Early or late? Different papers give different answers.

4. What is the mass of the impactor? Twice lunar or more like that of Mars? Different papers give different answers.

5. In the calculation, what is the assumed pre-impact spin of the Earth? The initial papers on impact formation of the Moon did not consider a pre-impact rotation of the Earth. What restraints are there on the pre-impact angular momentum? E.g., could a retrograde impact produce the Moon? Or: How to be sure that the total angular momentum matches the present value of the Earth-Moon system? How does the Earth spin angular momentum vector change during and following the impact? What fraction of the total angular momentum is taken up by the debris emanating from the impact? What fraction is carried away by the escaping debris?

6. What happens to the splashed-out material from the impact; how many particles escape and how many return on ballistic orbits? Whence comes the angular momentum for a bound lunar orbit? How and where does "captured" material assemble and what exactly is the initial lunar orbit?

7. At what Earth distance does the Moon assemble? At Roche limit or at ~ 10 Earth radii? Different papers give different answers.

8. If assembly proceeds into an equatorial orbit, as one might expect, how does one account for the present lunar orbit without any *ad hoc* assumptions? [cf. Goldreich (1966) argument]

9. If the initial Moon orbit is retrograde, or within the synchronous orbit limit of the spinning Earth, will not the Moon spiral in and thus not survive?

10. Just what is the dynamics of assembly from a ring in the presence of tidal perturbations? Responding to the most massive agglomeration of material, the Earth's tidal bulge would drive it outward and at the same time despin the Earth – thereby increasing the synchronous orbit radius; this would drive smaller agglomerations (now within the synchronous limit) into inward-spiraling orbits -- thus preventing a complete assembly. Has this feature been taken into account?

11. Similarly, if subsequent to the formation of the Moon, the Earth's spin is changed by another large impact that puts the lunar orbit within the synchronous limit, what happens then to the probability of lunar survival? How do later impacts affect the total angular momentum.

[One cannot discern answers to these questions from existing publications. For example, the Canup papers do not indicate how the spin period of the Earth changes over time; nor do they show the tidal distortion. There is also the Roche limit problem and others that I have not mentioned.]

12. In addition to the dynamical problems just discussed, how does the impact hypothesis deal with chemical (Saal 2007) and geological (Borg 2011) findings? Initially, the impact hypothesis was supported by the similarity of lunar chemistry with that of the Earth's mantle. Recent publications show also the existence of water and other volatiles in lunar rocks and raise questions of their survival at the high temperatures generated by the impact.

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