Questions about Lunar Origin S. Fred Singer <singer@sepp.org>

Introduction: 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 (Singer 1968, 1986). (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.

Another advantage of 'impact' over 'capture' was thought to be the chemical composition of the Moon, which resembles that of the Earth' mantle. But recent findings show substantial and unexplained differences.

12 Questions: 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*<<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. 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?

4. 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?

Plus 8 more qestions

Conclusion: We will discuss how to decide on which lunar origin hypothesis is more probable. Capture or Impact.

References: Singer, S.F. *Geophys. J. Royal Astron. Soc*. 15, 205-226, 1968; "Origin of the Moon by Capture" in *The Moon* (W. Hartmann et al., ed.) LPI, Houston, 1986. pp, 471-485.
Canup, R.M. and E. Asphaug 2001. *Nature*, **412**, 708-712
Canup, R. M. 2004. *Icarus* **168** (2): 433
Borg, L. et al. 2011. *Nature* **477,** 70–72
Saal, A. E. 2008. *Nature* **454**, 192-195