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The Puzzle of Lunar Inclination

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Abstract

One long-standing issue with the giant impact model of lunar formation is the 5-degree inclination of the Moon. Multiple researchers, starting with Goldreich (1966), have reconstructed past tidal evolution of the Moon and consistently found that lunar inclination was about 12 degrees soon after lunar formation. While a second large impact on Earth could generate inclination, Canup (2004) has shown that such an impact is very unlikely to happen while the Moon's orbit is still coupled to Earth's equator.

Touma and Wisdom (1998) proposed an elegant solution involving several solar resonances entered in succession, but this model makes many contradictory demands on the tidal properties of Earth and the Moon. Ward and Canup (2000) propose that the lunar inclination arose from resonant interaction between the Moon and remnant circum-terrestrial ring. While physically plausible, this mechanism still needs to be tested using sophisticated numerical models.

We are currently exploring two new solutions to the problem of lunar inclination. First involves 3:1 mean-motion resonance between the Moon and a smaller Earth satellite. Unlike Canup et al. (1999) who did not model inclinations, we find that the evolving moons preferentially enter an inclination resonance, exciting inclinations of both objects. We find that a second moonlet of 0.1 lunar masses can induce a 10-degree lunar inclination through this mechanism. Further evolution converts this inclination into eccentricity, so our scenario needs interaction with additional debris or impactors to break the resonance and "freeze" the lunar inclination. The other possible solution involves an early resonance between free core nutation of Earth and the Moon, exciting lunar inclination and changing the obliquity and spin rate of early Earth. We will present numerical simulations for both of these scenarios and discuss arguments for and against each of them.

References

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