Debris from Borealis Basin Formation as the Primary Impactor Population of Late Heavy Bombardment.
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Introduction: Here we investigate a novel Giant Impact Debris (GID) hypothesis to explain a number of observations regarding a period of early solar system history known as the Late Heavy Bombardment (LHB). In the GID hypothesis, the early impact histories of the Moon and Mars are dominated by debris left over from two giant impacts: The Moon-formation impact [1,2], and the formation of the crustal dichotomy on Mars (Borealis Basin) [3,4].

The Moon-formation impact has been constrained to have occurred within the first ~100 My of solar system history [5,6]. Debris left over from the Moon-formation impact would be substantial, but would clear out rapidly and preferentially impact the Earth-Moon system. This debris would therefore produce an Early Heavy Bombardment (EHB), possibly associated with the pre-Nectarian of the lunar cratering record. The timing of the Borealis Basin formation on Mars is not well constrained, other than the obvious fact that it predates all other northern hemisphere basins. Borealis Basin impact debris, though smaller than Moon-formation debris, could preferentially become trapped in a quasi-stable region currently occupied by the so-called Hungaria asteroids, which are not only dynamically distinct, but also compositionally distinct, including a prevailing number of E-type asteroids that are believed to be the source of the unusual, highly reduced enstatite achondrites (aubrites), and possibly the mesosiderites [7].

The dynamical decay lifetime of the Hungaria region is long, having a half life of ~600 My [7,8]. Therefore, it is plausible that Borealis Basin debris trapped in the Hungaria asteroid region could be responsible for the late lunar basins, such as Imbrium and Orientale, which are the most stringent constraints on the timing and existence of the LHB.

Our model makes several testable predictions, and naturally explains several observations that are difficult to reconcile under giant planet instability models, such as the Nice Model, which is the currently most-favored hypotheses for the cause of the LHB [8,9].

Challenges of the Giant Planet Instability Hypothesis for the LHB: Currently, many researchers have adopted a model for the LHB in which late-migrating giant planets destabilized reservoirs of small bodies [9-12] This model has many unresolved challenges [13]. In particular, giant planet instability models, such as the so-called Nice Model, [9,14,15] predict that a large fraction of the LHB-era impactors were comets from a massive icy planetesimal disk beyond Neptune. This is difficult to reconcile with geochemical constraints [16] as well as the size-frequency distribution of the impactors. The currently-favored version of the Nice Model, the so-called Jumping Jupiter model [17], predicts a substantially reduced fraction of destabilized Main Belt and extended inner Main Belt (E-Belt) asteroids to the total lunar impact record [8], compared with the "classical" Nice Model, which predicted roughly equal fractions of asteroidal and cometary impactors [9].

Giant planet instability models for the LHB predict that the impactors sourced from both the Main Belt (and E-Belt) and proto-Kuiper Belt would reach the terrestrial planets in a size-independent way. This was in fact used as evidence for an instability model, due to the close correlation between the derived impactor size-frequency distribution of ancient heavily cratered terrains and the Main Asteroid Belt [11]. However, there is a substantial disconnect between the density of ~100 km craters and the >300 km basins relative to the Main Asteroid Belt [18, 19]. The Main Asteroid Belt is far more abundant in >70 km objects than the putative lunar highlands impactors [19]. Because the abundance of large objects appears to be a primordial feature of both the Main Belt and the Kuiper belt [20, 21], the lack of this feature in the ancient lunar highlands bombardment population suggests that they did not come from either of these reservoirs.

Many authors have also reported evidence of impact "spikes" in the early bombardment record of the Moon and Mars based on counts of craters on top of basins (large craters) [22-24]. However, under a giant planet instability model, in which impactors are delivered to the inner solar system in a size-independent way, such spikes should not be observable. The existence of such spikes indicates either size-dependent preservation [25], or a mass-dependence on the impactor delivery timescale.

Promise of the Giant Impact Debris Hypothesis for the EHB/LHB: The GID hypothesis resolves the issue of cometary impactors by not requiring them. In this model, all impactors are sourced locally from rocky inner-solar system material. The impactor SFD of both the Moon formation debris (EHB) and the Borealis debris (LHB) would lack the excess of large bodies that are present in the "planetesimal" remnants (the Main Belt and Kuiper Belt). Collisional evolution of these debris remnants would produce a similar SFD for the <10 km objects as observed in the Main Belt [26, 27]. The relative flux of the impactor populations onto the respective planets would be far different than in the giant planet instability models. The EHB impactors would favor the Moon over Mars by as much as a factor of 10, while the LHB impactors would favor the Mars by a factor of ~10-100. This could explain why the pre-Nectarian on the Moon (EHB) includes ~2/3 of all lunar basins, while the equivalent period on Mars, the pre-Noachian, contains proportionally many fewer basins [28].

The timing of the LHB would suggest that the Borealis Basin impact occurred relatively late, coinciding with the start of the Nectarian at 4.1-4.2 Gy [7]. This is well within the plausible timescale of the loss of a "fifth" terrestrial planet under the Planet V hypothesis [29].

References:

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