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The Formation of Super-Earths and Mini-Neptunes with Giant Impacts

The majority of discovered exoplanetary systems harbour a new class of planets, bodies typically several times more massive than Earth but orbiting their host stars well inside the orbit of Mercury. The origin of these close-in super-Earths and mini-Neptunes is a major unanswered question in planet formation. Unlike Earth, whose atmosphere contains $<10^{-6}$ its total mass, a large fraction of close-in planets have significant gaseous envelopes, containing 1−10% or more of their total mass. It has been proposed that these close-in planets formed in situ either by delivery of 50−100M_E of rocky material to the inner disc, or in a disc enhanced relative to the MMSN. In both cases, final assembly of the planets occurs by giant impacts (GIs). Here we test the viability of these scenarios. We show that atmospheres accreted by isolation masses are small (10^{-3}–10^{-2} the core mass) and that atmospheric mass-loss during GIs is significant, with typical post-GI atmospheres that are 8×10^{-4} the core mass. Such values are consistent with terrestrial planet atmospheres but more than an order of magnitude below atmospheric masses of 1−10% inferred for many close-in exoplanets. In the most optimistic scenario with no core luminosity, post-GI envelope accretion from a depleted gas disc yields atmospheric masses that are several per cent the core mass. If the gravitational potential energy due to the last mass doubling of the planet by GIs is released over the disc dissipation time-scale as core luminosity, then envelope masses are reduced by about an order of magnitude. Finally we show that radial drift time-scales due to gas drag for many isolation masses are shorter than typical disc lifetimes. Given these challenges, we conclude that most observed close-in planets with envelopes larger than several per cent likely formed at larger separations from their host stars.