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Water delivery to dry protoplanets by hit-and-run collisions

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Abstract. Final water inventories of newly formed terrestrial planets are shaped by their collision history. A setting where volatiles are transported from beyond the snowline to habitable-zone planets suggests collisions of very dry with water-rich bodies. By means of smooth particle hydrodynamics (SPH) simulations we study water delivery in scenarios where a dry target is hit by a water-rich projectile, focusing on hit-and-run encounters with two large surviving bodies, which probably comprise about half of all similar-sized collisions (Genda *et al.* 2017).

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1. Methods

We base our analysis in this work on existing collision simulations from Burger *et al.* (2018) and re-examine these data under the aspect of a dry target being hit by a water-rich projectile. The scenarios comprise differentiated, self-gravitating, embryo-sized bodies, consisting of an iron core, a silicate mantle, and a water(ice) shell. For details about the SPH code and the material model we refer the reader to Schäfer *et al.* (2016) and Burger *et al.* (2018). Projectile and target have equal initial compositions, 25% iron, 65% silicates and a 10% water mass fraction (wmf). This allows us to track individual contributions from the projectile/target, by tracking the respective SPH particles' origin. For the results presented here we assume a dry target body by tracing only the projectile's water. The differences to a simulation with a really dry target are small (Burger *et al.* 2018), and should be negligible for the global quantities we are interested in.

2. Results and discussion

Post-collision wmf of the initially dry target are plotted in Fig. 1 for various parameter combinations (impact velocity $v/v_{\rm esc}$, impact angle α, $\gamma = M_{\rm proj}/M_{\rm targ}$). Typical hit-and-run collisions (top panels) are compared to head-on collisions (bottom panels). Along with that the water accretion efficiency is illustrated, here defined simply as $\xi_{\rm w} = M_{\rm w,tf}/M_{\rm w,p}$ with water mass on the target fragment and the projectile (see also Burger & Schäfer 2017). We abandon the usual notion of the projectile being the smaller body and switch to a one-body perspective, with an always dry target being hit by a (possibly even more massive) water-rich projectile. In our low-velocity hit-and-run scenarios ($v/v_{\rm esc} = 1.5$, $\alpha = 45°$ in Fig. 1) the target's post-collision wmf is strongly increasing with γ, and this trend continues even for projectiles considerably larger than the target. This behavior is qualitatively different for higher impact velocities ($v/v_{\rm esc} = \{2.5, 3.5\}$, $\alpha = 45°$), where the wmf accreted by the target increases with γ and peaks at mass ratios of roughly 1:1, before

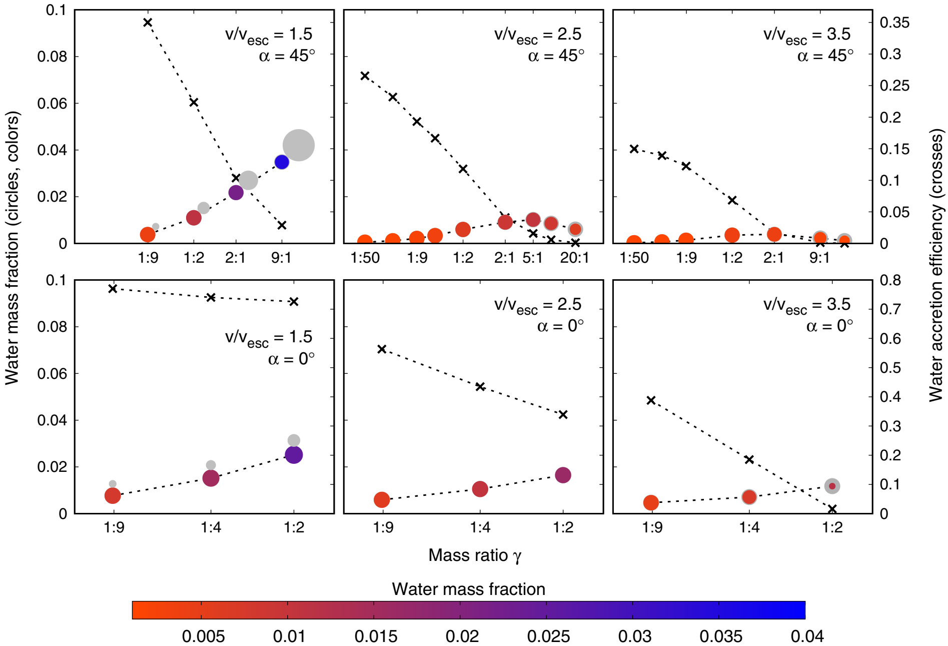

Figure 1. Dry targets being hit by water-rich projectiles (wmf = 0.1), for hit-and-run (top row) and head-on collisions (bottom row). Post-collision wmf are plotted on the left y-axes and color-coded. Water accretion efficiencies ξ_w are plotted on the right y-axes. Grey circles indicate either pre-collision sizes ($\propto$ mass$^{1/3}$), or the projectile body (impacting from the top).

decreasing again, despite the potentially huge water supply in larger projectiles. The water accretion efficiency ξ_w – the fraction of projectile water accreted by the target – is a decreasing function of γ for all scenarios in Fig. 1, and is generally high for small projectile bodies (small γ), but tends to be very low for larger impact velocities and/or mass ratios, indicating that only very little water is transferred to the target.

From the point of view of individual hit-and-run encounters the most water can be delivered to dry target bodies with either low impact velocities, or mass ratios approaching 1:1 for higher v/v_{esc}. However, planet formation is a chaotic process and planets grow from a stochastic history of successive collisions. Therefore it will be rather the (average) water accretion efficiency that determines how much water a growing planet can accrete from the limited amount of water-rich material scattered into its feeding zone. Our results show that this figure is considerably higher for smaller hit-and-run projectiles compared to larger ones, and yet significantly higher for head-on collisions, with water retention up to 80%, compared to at most 35% in our hit-and-run scenarios. It is important to emphasize however, that this does not include the further fate of the (potentially still very water-rich) projectile, after a hit-and-run encounter, therefore it is crucial to consider and track *both* hit-and-run fragments and their volatile inventories.

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