

Spreading of ice particles from Enceladus and accretion on the Saturn's main ring

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The formation age of Saturn's main rings remains an open question. Traditional hypotheses propose that the rings either co-accreted with Saturn itself or formed through impacts from external bodies during the Late Heavy Bombardment period. However, these scenarios face challenges in maintaining the long-term dynamical stability of the rings, as ring particles experience charging, sublimation due to solar insolation, and collisions or coalescence with other particles, all of which change their mass and dynamical state. More recently, an alternative hypothesis has been proposed, suggesting that the main rings originated from ice fragments generated by collisions between differentiated icy satellites or their tidal disruption. Spectroscopic observations by the Cassini spacecraft have revealed that ring particles consist primarily of water ice, with a small fraction of impurities. Based on these observations, several attempts have been made to estimate the rings' formation age. One such approach involves tracking the progressive contamination of ring particles due to the accretion of interplanetary material. In situ measurements by Cassini indicate that interplanetary material accumulates onto the rings at a flux of approximately 10^{-17} to 10^{-16} kg/m²/s. Assuming the rings were initially composed of pure water ice, estimation based on the observed impurity accumulation suggest that the rings formed between 100 million and 400 million years ago. However, several uncertainties remain in this estimation, one of which is the influence of Enceladus, a Saturnian icy moon. Enceladus continuously ejects water from its south polar region at a rate of 10 –100 kg/s, and a part of this water can diffuse into the surrounding space and potentially accrete onto ring particles. This process could result in a continuous coating of fresh water ice on the ring surfaces, making the rings appear spectroscopically younger than they actually are. Nevertheless, the diffusion process and the accretion rate onto the rings have not been quantitatively evaluated, leaving the extent of this effect uncertain.

In this study, we constructed a numerical model approximating the diffusion process of ice particles ejected from Enceladus using a random-walk approach. Enceladus orbits Saturn at approximately 4.0 Saturn radii with an orbital period of about 33 hours, ejecting water ice into space at a rate of 2 kg/s. We conducted a simulation tracking the diffusion of these ejected ice particles over a period of 1.65 million years. Our two-dimensional calculations revealed that the mean time for diffusing ice particles to reach the outer edge of the main rings, located at approximately 2.3 Saturn radii, was about 80,000 years. Furthermore, the temporal evolution of the number density distribution of ice particles as a function of distance from Saturn reached a steady state after approximately 1.32 million years (about 40,000 Enceladus orbital periods), resulting in a distribution similar to that of the E-ring particle reflectance. At this steady state, the accretion rate of ice particles onto the outer edge of the main rings was found to be 1.4×10^{-15} kg/m²/s. This rate is approximately ten times higher than the flux of interplanetary material responsible for ring contamination, suggesting that the accretion of ejected ice onto ring particles may dominate over the contamination process. Consequently, current age estimations based solely on contamination processes may significantly underestimate the true formation age of the rings. This finding implies that Saturn's rings could be substantially older than the currently estimated range of 100 million to 400 million years.

Keywords: Saturn ring, Enceladus, Random Walk

