Dust evolution in the protoplanetary disk around TW Hya

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Understanding how dust grows in protoplanetary disks is crucial for understanding how planet formation begins. Theoretically, how far dust growth can proceed is highly uncertain because the stickiness of dust aggregates is largely unconstrained. Previous models assumed that water ice is sticky and facilitates dust growth in the outer part of protoplanetary disks. However, it is now under debate whether water ice grains are really sticky at low temperatures (Gundlach et al. 2018; Musiolik & Wurm 2019). It is also possible that some nonsticky materials like CO_2 ice cover the grains and prevent their collisional growth (Musiolik et al. 2016). Elucidating whether dust grains in the outer regions of disks are sticky or not is particularly important for understanding how icy planets and small solid bodies like comets form.

In this study, we derive constraints on the stickiness of icy aggregates from observations of the protoplanetary disk around TW Hya. TW Hya is a relatively old T Tauri star surrounded by a massive protoplanetary disk. Recently, high-resolution observations with the Atacama Large Millimeter/submillimeter Array (ALMA) revealed that the dusty disk has circular gaps at 25 au and 41 au (Andrews et al. 2016; Tsukagoshi et al. 2016). Based on the scenario that the gaps are created by two sub-Neptune-sized planets, we simulate how dust aggregates grow and radially drift in the gapped disk assuming that the aggregates fragment upon collisions at velocities above a given threshold. We find that the fragmentation threshold of as low as 0.5 m s^{-1} gives the best match to the ALMA observations. Higher fragmentation thresholds lead to significant dust accumulation at the outer edges of the planetary gaps and to dust depletion interior to the 25 au gap, both inconsistent with the observational appearance of the TW Hya disk. The derived fragmentation threshold is considerably lower than previously anticipated for aggregates made of 0.1 μm-sized water ice grains ($\approx$ 80 m s^{-1}; Wada et al., 2013). Possible explanations for this include (1) water ice grains are indeed not as sticky as previously thought, (2) the icy grains are larger than 10 μm, and (3) the grains are covered by nonsticky CO_2 ice.