Collisional dust fragmentation near nuclear surface within cometary jets

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Previous studies of dust and grain fragmentation within cometary comae have focused on dust fragmentation schemes far from the nucleus [1–4]. In this work, we explore how to quantitatively constrain dust fragmentation mechanisms near the nuclear surface, and show that dust fragmentation within dust jets of Comet 9P/Tempel 1 is dominated by collisions. The dust jets on Tempel 1 that originate from a long scarp [5] obey power-law radiance profiles [6], which is the function describing the radiance (a proxy for dust) along the centerline of a dust jet as a function of height above the surface. The exponent of these power-law radiance profiles within the first kilometer of the surface is greater than -1, indicative of dust fragmentation. We constructed a one-dimensional numerical model of a cometary dust jet, which incorporates two end-member dust fragmentation schemes: binary fission and grain shedding [1]. In binary fission, an initial dust grain continually splits into two equal size pieces after a specified period of time (τ_s), whereas, in grain shedding, an initial dust grain continually loses a thin layer (ΔR) of fundamentally small grains from its surface. We model dust as spherical grains that conserve volume during fragmentation, with an initially uniform diameter of up to 5 cm. We model these two schemes without assuming a driving mechanism. Rather, we constrain their fundamental splitting parameters to generate power-law radiance profiles. We formulate the binary fission splitting time ($\tau_{s(R)}$) and the grain shedding thickness of the shed layer ($\Delta R_{(R)}$) as functions of the size of the dust grain (R). This generates power-law radiance profiles when the split time has the functional dependence $\tau_{s(R)} \propto R^{-2}$ or when the depth of the shed layer has the functional dependence on the powers of the radius of the grain of $\Delta R_{(R)} \propto R^2$ and higher. We then incorporate a power-law size-frequency distribution of initial grain sizes into our model and find that $\Delta R_{(R)} \propto R$ is additionally able to create power-law radiance profiles. For a thermal fragmentation mechanism, thermal skin depth considerations suggest that the splitting time in binary fission should have the dependence of $\tau_{s(R)} \propto R^2$, whereas the thickness of the shed layer ΔR in grain shedding should remain constant or grow with time, rather than decrease with time as the grain loses mass. Therefore, these functional dependencies of the fundamental splitting parameters are inconsistent with the thermal fragmentation mechanisms suspected to act on dust grains further away from the nucleus such as volatile sublimation [2] and sintering [4]. Our best fit to the most prominent Tempel 1 scarp jet [5,6] is a binary splitting mechanism where $\tau_{s(R)} R^2 =$ const. (see Figure). This dependence of dust fragmentation upon the surface area of the dust grain suggests that dust fragmentation near the origin of Tempel 1's scarp jets is dominated by collisions, consistent with observed radiances. The low collisional speeds in this region are consistent with weak, fractal-like dust-grain structures.

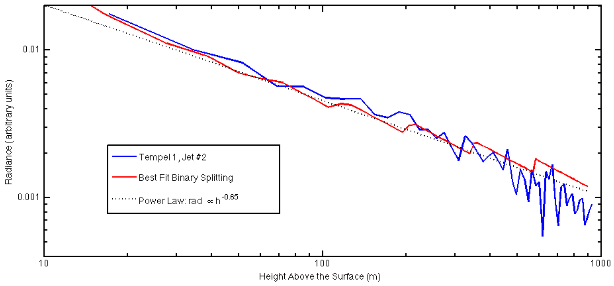

Figure: Plot of the radiance profile of Jet 2 on Comet 9P/Tempel 1 [5], along with our best-fit simulation and the power law that both radiance profiles follow. Our best-fit simulation follows binary splitting fragmentation with $\tau_{s(R)} \propto R^{-2}$, which is consistent with collisional fragmentation.

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