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A concurrent comet and TNO formation scenario

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For decades, comet scientists have debated whether comet nuclei are primordial rubble piles, formed at their current sizes through gentle accretion in the Solar Nebula, or if they are collisional rubble piles formed in the aftermath of violent collisions between larger parent bodies. The Rosetta mission to comet 67P/Churyumov-Gerasimenko and the Stardust sample-return mission to comet 81P/Wild 2, combined with observations by Cassini or from ground of irregular giant planet satellites captured from the primordial disk, have provided a variety of physical, mineralogical and chemical information that allow us to revisit the problem of comet formation with greater confidence than previously.

The emerging picture is that thermal processing due to short–lived radionuclides, combined with collisional processing during accretion in the primordial disk, is expected to create a population of medium–sized bodies that are comparably dense, compacted, strong, heavily depleted in supervolatiles and that have experienced extensive aqueous alteration due to the presence of liquid water. Irregular satellites Phoebe and Himalia are potential representatives of this population. Collisional rubble piles inherit these properties from their parents. Contrarily, comet nuclei have low density, high porosity, weak strength, are rich in supervolatiles, and do not display convincing evidence of in situ aqueous alteration. Therefore, comet nuclei do not resemble collisional rubble piles, but display all properties expected for primordial rubble piles.

We outline a comet formation scenario that starts in the Solar Nebula and ends in the primordial disk, that reproduces these observed properties, and additionally explains the presence of extensive layering on 67P/Churyumov–Gerasimenko (as well as on 9P/Tempel 1 observed by Deep Impact), its bi–lobed shape, the extremely slow growth of comet nuclei as evidenced by recent radiometric dating, and the low collision probability that allows primordial nuclei to survive the age of the Solar System.

We argue that TNOs formed due to streaming instabilities at sizes below ~ 400 km and that ~ 350 of these grew slowly in a low–mass primordial disk to the size of Triton, Pluto, and Eris, causing little viscous stirring during growth. We thus propose a dynamically cold primordial disk, that prevented medium–sized TNOs from breaking into collisional rubble piles, and allowed for the survival of primordial rubble–pile comets. We argue that comets formed by hierarchical agglomeration out of material that remained after TNO formation, and that this slow growth was a necessity in order to avoid thermal processing by short–lived radionuclides (that would have led to aqueous alteration and loss of supervolatiles), and that allowed comet nuclei to incorporate ~ 3 Myr old material from the inner Solar System.

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