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Cometary dust, present understanding and open questions after the Rosetta mission

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Abstract

In-situ observation of several comets by spacecraft, the collection and delivery to Earth of dust from a cometary coma, remote sensing of comets, and comparison with the properties of interplanetary dust, some of which is cometary, collected at Earth, have provided many new insights to the composition and structure of cometary dust. These investigations have raised new, more detailed questions, suggesting future directions for comet research.

1. Introduction

Our present understanding of cometary dust has significantly progressed in the last years. It was mostly derived from the results of ten flyby missions to comets, e.g., Giotto, Vega, Stardust (with samples collected in 81P/Wild 2 coma), Deep Impact, and of the 26-months long Rosetta rendezvous mission with comet 67P/Churyumov-Gerasimenko (thereafter 67P). Numerous remote observations and technical achievements, together with elaborate theoretical studies, laboratory experiments and analytical capabilities, made such missions possible and contributed to the interpretation of their results.

Our purpose is to summarize our understanding on cometary dust, as given in [1], and to update it as much as possible.

2. Cometary dust Present understanding

It is now recognized that, at least for Jupiter Family Comets (JFCs) such as 67P, the relative proportion of minerals and organics within the dust is quite comparable, and that the refractory-organic phase appears to be dominated by organics of high molecular-mass [e.g., 2, 3]. The elementary composition of the particles for 67P is chondritic for most major elements (within a factor of 3), except for C and N, which are enriched with respect to the chondritic value [3]. It is also understood that dust particles within such comets are built up of aggregates of sub-micrometer grains, with morphologies of the particles ranging from extremely porous particles to almost compact ones; their hierarchical structure has been imaged during the Rosetta mission [e.g., 4, 5, 6].

Such properties suggest that cometary dust particles consist of material from the outer regions of the Solar System, mixed with material reprocessed in the inner protosolar nebula and transported to the outer regions. The existence of both fractal and more compact aggregates is consistent with dust growth starting by low-velocity hierarchical accretion forming low-porosity fractal particles, followed by a compaction phase creating aggregates with a range of higher densities. The preserved fractal particles are quite likely the most pristine solid matter available from the early stages of the Solar System formation [7].

It may be added that cometary dust particles, mainly subjected to gravitational and radiative forces, progressively become parts of the interplanetary dust cloud. Recent independent studies indicate that most interplanetary dust particles reaching the Earth could originate from JFCs [e.g., 8]. They might have delivered a huge amount of complex organics to the Earth, during the heavy bombardment epoch.

3. Cometary dust
Some open questions

As anticipated by Mike A'Hearn in 2017, "As we have dramatically increased our knowledge, we have also opened up many new questions" [9]. The results already obtained about composition and physical properties of dust in comets are indeed opening new questions.

1. Does the (elementary and isotopic) composition of the dust vary between comets?
2. Is the composition of the dust released by the nucleus representative of the bulk composition of the dust in its interior, or has it been reprocessed? At which scale are organic and mineral phases mixed in dust? How is ice mixed with the mineral and organic components? Is the organic refractory component totally or only partly of pre-solar, i.e., interstellar origin?
3. What are the smallest grains or monomers building cometary dust aggregates? What are their individual properties? Are they of interstellar origin, or did they form within the early Solar System?
4. Were dust particles revealed from studies within 67P's coma altered during the formation and evolution of the nucleus? Or during the processes leading to dust ejection from the nucleus? Or during the collection on-board Rosetta?
5. While clear similarities appear between cometary dust and CP-IDPs (Chondritic Porous Interplanetary Dust Particles collected in the Earth's stratosphere) [10] or even UCAMMs (Ultra Carbonaceous Antarctica Micro-Meteorites) [11], could further developments in collection and analyses of such particles provide more information on various types of comets and main-belt primitive objects?

4. Perspectives

Missions Hayabusa 2 and OSIRIS-REx to primitive main belt asteroids should soon offer the opportunity to compare cometary dust to primitive asteroid material, a study that will further advance our understanding of the early Solar System. The Lucy mission to Jupiter Trojans could later provide links between comets and other primitive objects. Meanwhile, some of the above-mentioned open questions could hopefully be solved by further studies of the enormous amount of data provided by Rosetta and comparisons with interplanetary dust particles collected at Earth.

Further progress requires sophisticated cross-platform analysis combining more insight into past space missions, elaborate remote observations of comets from Earth and near-Earth based telescopes, as well as improved numerical and experimental simulations. The development of the technological steps allowing sample returns of fragile cometary material in a not too distant future would be of major importance. NASA has preselected in late 2017 two proposals as possible New Frontiers 4 missions. One of them (CAESAR) would return a sample from 67. A final selection between the two missions is expected in 2019, for a launch sometime in 2025.

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