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The Asteroid–Comet Continuum: Evidence from Extraterrestrial Samples

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Abstract

We will argue that comets and dark asteroids form a continuum sampled by a diversity of extraterrestrial matter, namely carbonaceous chondrites, micrometeorites and comet Wild 2 dust collected by the Stardust spacecraft. The comet-asteroid continuum arises from intense transport of chondritic components (CAIs, chondrules) and small bodies at different epochs of the Solar System evolution. The observational differences between comets and dark asteroids are due to a different environment/history, but not to a difference of nature.

1. Introduction

Identifying the parent-bodies of primitive meteorites and micrometeorites has long been one of the major goals of cosmochemistry. Because most extraterrestrial samples were not subjected to planetary processes such as differentiation, they are thought to originate from small bodies, namely comets or asteroids. This quest has always been intimately linked to the preconception that comets and asteroids are two radically different kinds of bodies, and that the former are more primitive than the latter. Recent data, and especially the analysis of dust samples from comet Wild 2 brought back on Earth by the Stardust spacecraft, have however jeopardized that view and have opened new perspectives on the nature of comets and their link to asteroids.

2. Evidence from the orbit of the Orgueil meteorite

The orbit of the Orgueil (CI) meteorite was calculated using numerous visual observations communicated shortly after its fall (May 14, 1864) to the main mineralogist of the time, Auguste Daubrée. Taking into consideration 13 visual observations, [1] suggested that the orbit of the Orgueil meteorite (aphelion $Q > 5.2$ AU and inclination $i \sim 0°$) was more compatible with that of a JFC than with that of an asteroid or an Oort-cloud comet. Clearly, given the nature of the input data (150-year-old visual observations), this conclusion is more a best informed guess rather than a certainty. It however led [1] to speculate the existence of a continuum between asteroids and comets given the similarity between Orgueil and other carbonaceous chondrites (belonging to the CM and CR groups), allegedly coming from dark asteroids [2].

3. Evidence from Stardust samples

The Stardust mission brought back to Earth several hundreds of micrograms of dust collected in the coma of the JFC comet Wild 2 in an aerogel collector [3]. Individual grains with sizes up to 40 μm were found. CAIs and chondrules similar to those found in carbonaceous chondrites were discovered. In addition to a similar mineralogy to their counterparts in carbonaceous chondrites, it turned out they have the same oxygen isotopic composition [4, 5]. A copper sulfide, cubanite, was also found within Wild 2 samples. This type of sulfide was previously reported in CI chondrites such as Orgueil. The best match of olivine and low-Ca pyroxene compositions is to CI chondrites [6]. Only a handful of presolar grains were found. The structure of cometary organic matter is reminiscent of that found in carbonaceous chondrites; it enrichments in deuterium are comparable to those observed in carbonaceous chondrites.

Four important conclusions emerged from these surprising results. 1) Cometary solids were processed in the solar protoplanetary disk; 2) Cometary solids are not unmodified pristine interstellar matter; 3) Given that CAIs are thought to have formed close to the Sun, solid transport between the inner solar system and the outer solar system (where comets formed) was efficient; 4) The differences between cometary solids and carbonaceous chondrites is comparable to the differences among the different groups of carbonaceous chondrites.

4. Additional evidence

Recent study of mm-sized xenoliths in meteorites have shown that they are made of a matter similar to the hydrated carbonaceous chondrites CI, CM and CR [7]. Because independent dynamical studies to be a mixture between asteroidal and cometary dust trapped in the H parent-body [8], it implies that there is a continuum between dark asteroids and comets. A similar argument holds for 100 µm-sized micrometeorites recovered from Antarctica which are related to CM chondrites [9], and which sample preferentially cometary bodies [10].

Small bodies on asteroidal orbits have been shown to exhibit a cometary-like activity [11], and water ice has been detected at the surface of some asteroids [12]. Because water ice is not stable at such heliocentric distances, it implies that this ice has been recently exposed, probably by a collision, and that probably many more dark asteroids are ice-rich. If dark asteroids are ice-rich rocky objects, it is difficult to tell the difference with comets, which are dust-rich ice objects.

The hydrogen isotopic composition of a JFC has recently been shown to be identical to that of CM, CI and CR carbonaceous chondrites [13], strengthening the link between comets and carbonaceous chondrites.

5. Why a continuum ?

The idea of a continuum between comets and asteroids is totally in line with our recent understanding of Solar System formation and evolution. Solid particles which make up asteroid and comets have been shown to be intensely transported all over the protoplanetary disk during the first million years of the Solar System [14]. Not only mixing between constituents occurred during the Solar System phases, but small bodies were also transported on large heliocentric distances. Bodies formed beyond Jupiter are now found embedded in the asteroid belt [15].

6. Conclusions

It is not to say that comets and dark asteroids are totally alike. There is obviously an observational difference. We would however argue that there is no difference in nature between the two types of objects. The observational differences (in spectra, albedo etc…) arise from a different history and the different environments which they endured during the last 4.5 Gyr.

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