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Asteroid-Comet continuum: no doubt but many questions

M.A. Barucci(1), and P. Michel(2)

(1), LESIA, Observatoire de Paris, PSL Research University, CNRS, Univ. Paris Diderot, Sorbonne Paris Cité, UPMC Univ. Paris 06, Sorbonne Universités, 92195 Meudon, France (antonella.barucci@obspm.fr) (2), Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, CS 34229, 06304 Nice Cedex 4, France

Abstract

Recent discoveries about comets and asteroids from ground-based observations as well as results from space missions (Stardust, Rosetta, DAWN, Hayabusa2, OSIRIS-REx) indicate that the frontier between the population of asteroids and the population of comets is not as sharped as previously thought, on the sole basis of their physical properties. They rather indicate that the distinction between the two populations is more subtle and goes through a continuum.

1. Introduction

In the 1970s, several authors suggested that inactive comets were classified asteroids by mistake, and started to call them dormant or extinct comets. The first evidence was the comet 107/P Wilson Harrington previously known as asteroid (4515) Wilson-Harrington. These dormant comets can be found in both comet-like and asteroid-like orbits. In 2008, DeMeo et al. [1] stated that about 8-10% of NEOs could be dormant or extinct comets. In fact, asteroids with C-P-B-D- types are very similar to comets, but also similar to Hilda and Trojan asteroids.

With the first discoveries of active asteroids also called main belt comets [2], which already shows the issue to discriminate between the two populations, the interest of these transition objects increased rapidly, particularly connected to the identification of the presence of ice in the "warm" inner solar system.

Dark primitive asteroids and comets form a continuum sample of material covering now different regions of the solar system, but these different locations may have a common origin and may just be the signature of some solar system instabilities and planet migrations in the past [4]. The continuum between asteroids and comets is in line with the mixing occurred during the different phases of the solar system, but also with the transport of solid particles in the protoplanetary disk [3]. Moreover extrasolar planetary systems clearly demonstrate that giant, gaseous planets can move from their more distant formation regions to very close to the central star [4]. Such observations have led to increasingly sophisticated modelling resulting in predictions for our own solar system, with Jupiter penetrating deep into the inner solar system, bringing in the inner solar system bodies formed well beyond the orbits of the most distant planet [5] and mixing them with those formed at closer distances. As a result, the physical properties of the whole small body population, from asteroids to comets, can only form a continuum.

2. Space missions

Starting from data analysis of dust samples of comet Wild2 returned by Stardust, the presence of high-temperature minerals (forsterite and CAIs), that formed in the hottest regions of the solar nebula, provided evidence of extensive radial mixing at early stages of the solar nebula [6]. New analysis of the returned sample [7] suggests that the micron-sized rocky crystalline contents of that comet formed in different inner solar system environments, concluding that highly diverse materials incorporated into the comet were transported and mixed over great distances.

The Rosetta ESA mission on the comet 67P/Churyumov-Gerasimenko revealed a dehydrated comet with particle emission having dust-to-gas ratio of about 4-5 and grains rich of refractory organic matter ([8] for review). The COSIMA mass spectrometer detected the presence of solid organic matter analogous to the insoluble organic matter found in carbonaceous chondrite minerals [9]. The numerous results from Rosetta suggest that 67P accreted in a region of the proto-solar nebula drier than where CI chondrites have formed.

The presence of hydroxyl (OH)-rich materials was proposed a long time ago on the surface of (1) Ceres, but the detection of water vapor was finally reported by Herschel around the dwarf planet [10] and the presence of water ice was firmly confirmed by the remote observations of the Dawn mission [11].

More recently the two sample return missions Hayabusa2 from JAXA and OSIRIS-REx from NASA that visit the asteroids Ryugu and Bennu, respectively, gave a large quantity of data on two primitive asteroids. The preliminary spectral data indicate that both asteroids have hydrated minerals on their surface but with a different abundance. The NIRS3 spectrometer on board Nof Hayabusa2 [12] detected on Ryugu's surface a weak band at 2.72 μm indicating the presence of OH-bearing minerals associated to Mg-rich phyllosilicates [12]. The Visible and near-infrared spectrometer OVIRS on board OSIRIS-REx detected all around the surface of Bennu a much deeper and large band at 2.74 μm typical of hydrated phyllosilicates [13].

The discovery of particle plumes erupting from Bennu [14, 15] by OSIRIS-REx can be interpreted as the first close-up observations of an active asteroid by a space mission, which is particularly exciting and raises many questions among scientists.

3. Conclusion

Thanks to improvements in ground-based observations and associated more sophisticated data analysis as well as recent space missions, the number of objects exhibiting physical properties in both the asteroid and comet populations has grown substantially in recent years and will grow in the future. The associated discoveries lead us to reconsider the traditional distinction between asteroids and comets and rather consider these two kinds of bodies as forming a continuum. The large-scale mixing in the early solar system seems to be a major phenomenon that can explain the absence of sharp frontier between the two populations. Different scenarios exist to explain this mixing, and what this continuum really means remains unclear. The isotopic composition of various elements, the nature of the organics and the mineralogy of the rocky elements in these early solar system bodies are necessary data to clarify these issues and to obtain information on the great variety of processes that took place during the solar system history.

By returning primitive materials from the two primitive asteroids Ryugu and Bennu, Hayabusa2 and OSIRIS-REx will offer the possibility of distinguishing between effects of solar-nebula processing and effects of alteration from asteroidal parent-body processing. The sample analysis will also permit determination of the abundance of a number of short-lived radionuclides present at the time of formation of a variety of early solar-nebula components offering a clear insight into the timing of the formation of these components and determining their clear origin.

We predict that many more objects in the middle of this continuum between asteroids and comets could be present among the near-Earth asteroids.

All these new and future findings can only be achieved by sample return missions, which will allow us to better characterize this continuum, the diversity of its components and to possibly reveal exciting new insights about our solar system history.

Acknowledgments

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