Probing asteroids with remote sensing and sample return

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1. Asteroid relevance

The origin of the solar system is one of the fundamental questions that we seek to understand, and tells us not only about the birth of our own Sun and the planet that is our home, but also informs us of some of the key processes at the heart of the very development of Life on Earth itself. Two of the key ingredients for Life may have been delivered to Earth after the main formation event, with the delivery of water and complex organic molecules by asteroids and/or comets. However, questions remain unanswered as to how the Earth acquired so much water, having formed from a hot, dry part of the disk of gas and dust from which the solar system formed.

Small bodies, as primitive leftover building blocks of the solar system formation process, offer clues to the chemical mixture from which the planets formed some 4.6 billion years ago. In addition, they retain material that predates the solar system and contains evidence for interstellar processes and its original formation in late-type stars. Current exobiological scenarios for the origin of Life on Earth invoke an exogenous delivery of organic matter: primitive bodies could have brought these complex organic molecules capable of triggering the pre-biotic synthesis of biochemical compounds on the early Earth. It has been proposed that carbonaceous chondrite matter (in the form of planetesimals down to cosmic dust) could have imported vast amounts of complex organic molecules capable of triggering the prebiotic synthesis of biochemical compounds [1].

For these reasons, asteroids and comets have been targets of interest for missions for over three decades.

2. Presence of water

Small bodies may have been the principal contributors of the water and organic material on Earth. Pioneer works [2, 3, 4] found that about 60 % of the C-class asteroids, at heliocentric distances between 2.5 and 3.5 AU, have undergone some kind of aqueous alteration process. Aqueous alteration is a low-temperature chemical alteration of compounds by liquid water which acts as a solvent and produces secondary minerals such as phyllosilicates, sulphates, oxides, carbonates, and hydroxides. It also plays a major role in the modification and synthesis of organics. Several transitions are only possible in the presence of liquid water on the surface of the object. Related spectral features, found on several meteorites and asteroids, indicate that liquid water was present on their surface during some previous epoch. Moreover, water ice and organics were recently observed on the surface of three asteroids of the C-complex, (24) Themis, (65) Cybele [5, 6] and (1) Ceres by DAWN mission [7].

It remains unclear from where the water for the Earth's oceans came. Models of the early solar system indicate that accretion at 1 AU and the energy released during this process would have led to a body poor in water. Comets are a major available source of water in the solar system, but the D/H ratio of water measured in a number of comets is in general much higher (by a factor of 2-3) than that of the Earth's oceans [8]. The mean D/H ratio of carbonaceous chondrites appears to be much closer to that of the oceans – and therefore primitive asteroids originally from the main belt may be considered as the potential delivery mechanism for the abundance of water now present on the Earth that is so essential for all life.

3. Present and future small body exploration

The outstanding success of the Rosetta mission highlights the importance of studying primitive minor bodies. The Rosetta mission provided unique new insight into the nature of comet 67P/ Churyumov-Gerasimenko, but the instruments aboard Rosetta and Philae were not able to define the organic material present on its surface. In fact, the type and quality of information that can be obtained from a rendezvous and remote landing mission is always heavily compromised by the resource limitation of instruments carried by spacecraft.

Fly-bys provided the first close-up views of these objects and led to major advances in our knowledge of their physical properties and evolution. However, remote sensing gives only limited information on their composition, and even in-situ measurements that could be made by a lander are limited by the resources available. Only a mission returning a sample of primitive material will be able to answer the fundamental questions and in fact all the major space agencies are planning sample return missions with the two missions recently launched by JAXA, Hayabusa2 to the C-type asteroid Ryugu and by NASA, OSIRIS-REx to the B-type asteroid Bennu. Space missions of sample return from primitive near Earth asteroids (as

OSIRIS-Rex and Hayabusa-2) will provide insight to the abundance and isotopic signatures of water on asteroids.

Only in the laboratory can instruments with the necessary precision and sensitivity be applied to individual components of the complex mixture of materials that forms an asteroid regolith, to determine their precise chemical and isotopic composition. Such measurements are vital for revealing the evidence of stellar, interstellar medium, pre-solar nebula and parent body processes that are retained in primitive asteroidal material, unaltered by atmospheric entry or terrestrial contamination. It is no surprise therefore that sample return missions are considered a priority by a number of the leading space agencies.

Asteroids could even one day be a vast new source of scarce and precious material if the financial and technological obstacles can be overcome and discussions start to learn how to mine them. Asteroids are lumps of metals, rock and water. The numerous number of asteroids start to be considered by space industries as possible source of water as it is a critical life-support item for a spacefaring civilization. Moreover water can provide with its constituent hydrogen and oxygen in-situ sources for rocket fuel.

4. References

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Short Summary

The relevance of asteroid for the origin of the solar system and the condition of Life apparition on Earth, as well as the state of the art of asteroid exploration are presented.