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Does Hyperion Carry an Interstellar Heritage of Organics and Ice?

Y. J. Pendleton (1), D. P. Cruikshank (2), J. B. Dalton (3)
(1) NASA Lunar Science Institute, NASA Ames Res. Center, California, USA (yvonne.pendleton@nasa.gov / FAX +1 650 604 6779) (2) NASA Ames Res. Center, California, USA, (3) Jet Propulsion Lab., California, USA

Abstract

Recent discoveries support the contention that materials from the Solar System's nascent molecular cloud and materials lightly processed in the solar nebula are preserved in some objects now accessible to closer study. Saturn's satellite Hyperion may be a special case of a large, unmelted planetesimal that is primarily made of H_2O, and probably CO_2 ice, laced with hydrocarbon-bearing dust and small amounts of other volatile molecules. We discuss the analysis of Cassini VIMS observations of Hyperion in this context.

1. Introduction

Several Solar System objects that can now be studied in detail appear to preserve compositional traces of various early stages in the processing and agglomeration of solar nebula materials to form planetesimals. Some asteroids inside Jupiter's orbit appear to have retained a fraction of their original inventories of H_2O and organic molecular material, although their bulk composition is silicate-rich. Objects having very low (≤ 1 g/cm^3) densities, including some comets and TNOs, and Saturn's satellite Hyperion, either accreted as porous planetesimals or have lost the more volatile ices from their interiors since accretion.

2. Recent Discoveries and the Nature of Hyperion

Recent discoveries support the contention that materials from the Solar System's nascent molecular cloud and materials lightly processed in the solar nebula are preserved in some objects now accessible to closer study. Some of those discoveries are:

1. Native (parent) CO_2 ice in comets C/2007 N3 (Lulin) [15], 103P/Hartley [9], and others
2. Organic materials, interstellar dust particles, and refractory minerals comingled in *Stardust* samples from comet P/Wild 2 [19]
3. Aromatic and aliphatic hydrocarbons on Saturn icy satellites Iapetus, Phoebe, and Hyperion [5,8]
4. CO_2 complexed with other materials (e.g., H_2O ice) on several of Saturn's satellites [6]
5. H_2O ice and complex organic refractory material on main-belt asteroids 24 Themis [1,18] and 65 Cybele [14]
6. Red colors of TNOs suggestive of complex organic material mixed with, or masking surface ices [e.g., 7]

Hyperion may be a special case of a large, unmelted planetesimal that is primarily made of H_2O, and probably CO_2 ice, laced with hydrocarbon-bearing dust and small amounts of other, unidentified volatile molecules [8]. With a bulk density of <0.6 g/cm^3 and an effective diameter of ~180 km, Hyperion's surface morphology, and perhaps its shape, indicates that is has been modified by a combination of impacts and sublimation [20,4,11,8]. Sublimation depressions often have accumulations of dark material on their floors, while lumps of the same or similar dark material lay at random places in the surrounding icy landscape. Hartmann [10] and subsequent authors have described this process of vertical segregation of dust and ice by sublimation on icy bodies in the outer Solar System. A study of Cassini data for Hyperion, including images with spatial resolution ~40-80 meters and VIMS compositional maps with resolution ~1-4 km, establishes local and regional trends in the distribution of H_2O, CO_2, aliphatic and aromatic hydrocarbons, and adsorbed H_2. Complexed (wavelength-shifted) CO_2 and adsorbed H_2 are concentrated in the dark floor deposits, while the hydrocarbons appear to be broadly distributed within the moderate-albedo (~0.6) icy terrain. H_2 is viewed as a photoproduct of H_2O ice, while CO_2 may be formed locally from H_2O ice and carbon from carbonaceous grains, or may represent trapped molecules leaching out from the interior. The long-term loss of CO_2 (which is unstable as a surface ice at Hyperion's heliocentric distance) from the interior may contribute to Hyperion's low bulk density.

The material from which Hyperion formed is expected to be some combination of native interstellar ices and solid organic matter, plus an unknown fraction of the same material processed in the solar nebula. The dominant form of carbon in interstellar ice depends primarily on competition between CO hydrogenation ($CO + H \rightarrow CHO$), and CO oxidation ($CO + O \rightarrow CO_2$) on grain surfaces [21]. The HCO radical produced in the first reaction readily undergoes further reactions to the organic molecules H_2CO, CH_3OH, and others. The second reaction produces CO_2, in which the carbon is sequestered in a tightly bound molecule that tends to inhibit further chemical changes. The apparent high abundance of CO_2 in the composition of Hyperion, and the absence of H_2CO and CH_3OH, thus discriminates between two paths of chemical evolution of the materials from which it accreted.

In addition to ices, interstellar dust carries hydrogenated amorphous carbon [16] and relatively refractory polycyclic aromatic hydrocarbons (PAHs); together these are the dominant carriers of carbon. In the solar nebula, PAHs were destroyed inward of ~2 AU [13]; aliphatic hydrocarbons are less stable than PAHs, and are more readily destroyed. The presence of both aromatic and aliphatic hydrocarbons in the ice of Hyperion supports the view that it accreted from outer solar nebula materials. The low-albedo dust interspersed in the ices consists of these relatively small hydrocarbons plus other macromolecular carbonaceous material consisting of the more refractory kerogen-like organic solids. These astronomical kerogens are thought to be produced in interstellar space by the irradiation of ices on carbon and silicate grains, some of which are incorporated into the solar nebula during accretion. Outside the terrestrial planet formation zone the kerogens are preserved [2], and together with silicates constitute the refractory part of the feedstock of comets, carbonaceous meteorites, and icy bodies. Several of these bodies are now recognized as planetary satellites. The astronomical kerogen bears a structural and optical similarity to some tholins (also characterized as carbon nitrides) synthesized in the laboratory, and have pronounced colors ranging from brown to red [e.g., 12,17] Tholins impart the generally reddish colors to many outer Solar System bodies [e.g., 3], but when exposed to the space environment these materials become blacker and more neutral in color as they become dehydrogenated and undergo increasing graphitization.

The organic molecules and low-albedo dust found in Hyperion's ices may represent original interstellar material that was largely unaltered in the solar nebula. As the ices evaporate and leave concentrations of the carbonaceous dust exposed to the space environment, dehydrogenation drives the dust to neutral-colored and spectroscopically featureless graphite.

Acknowledgements

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