Highlights of Astronomy, Vol. 13
International Astronomical Union, 2003
O. Engvold, ed.

Material Processing of Interstellar Dust in Comets

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Abstract. To better understand the processing of pristine materials in comets, we compare the composition of cometary and interstellar dust. We suggest that the deficit of N in comet dust bears evidence for the processing of the organic refractory mantle of pre-solar interstellar dust, unless it arises from the protosolar disk chemistry. The amorphous silicate core, in contrast, seems to be protected against processing due to the presence of the organic refractory mantle.

1. Introduction

The processing of pre-solar interstellar materials incorporated into comet nuclei is a key parameter for understanding the formation and evolution of comets. Here we compare the element composition of cometary and interstellar dust to seek evidence for material processing.

2. Composition of Pristine Materials

Cometary dust: The elemental composition of dust from comet Halley was measured in situ aboard VeGa-1, VeGa-2, and Giotto (Kissel et al. 1986a, 1986b). Kissel & Krueger (1987) claimed that the data are better interpreted by the predominance of silicate-core, organic-mantle grains, similar to the pre-solar interstellar dust model (see Greenberg 1998). Jessberger, Christoforidis, & Kissel (1988) found that comet dust is a mixture of refractory organics, called CHON, and Mg-rich silicates, deriving the elemental abundances of Halley's dust from the most reliable data (see Fig. 1a). Laboratory analysis of interplanetary dust particles (IDPs), collected in the stratosphere, would provide detailed composition of comet dust. Cluster IDPs are likely of cometary origin because of their pristine nature inferred from enhanced D/H ratios (Messenger 2000). These cometary IDPs contain sub-micron glass with embedded metal and sulfides (GEMS) within a matrix of amorphous carbonaceous material (Bradley 1994). GEMS may be pre-solar interstellar silicates preserved in comets and the amorphous carbonaceous material seems to be transformed from pre-solar interstellar organics that carry the high D/H ratio (Keller, Messenger, & Bradley 2000). The bulk compositions of 3 GEMS measured by Bradley (1994) and 5 GEMS by Bradley & Ireland (1996) are averaged to determine the elemental abundances of GEMS (see Fig. 1b).

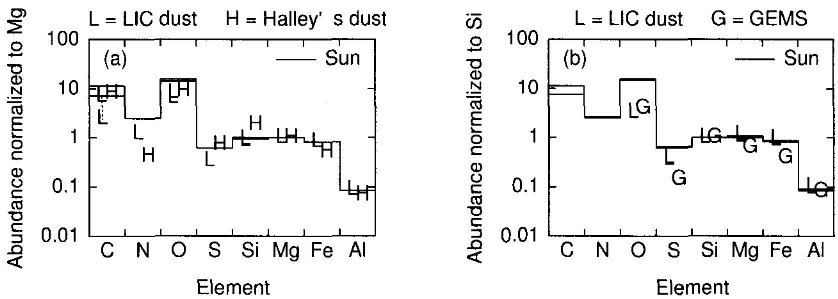

Figure 1. Elemental abundances of solar photosphere, (a) dust in the Local Interstellar Cloud (LIC) and dust in Comet Halley, normalized to Mg, and (b) silicate component in the LIC dust and glass with embedded metal and sulfides (GEMS) in interplanetary dust particles, normalized to Si.

Interstellar dust: We assume that siliceous and carbonaceous materials in present-day interstellar dust provide a reference composition of pre-solar interstellar dust. The solar system currently lies inside the Local Interstellar Cloud (LIC) filled mainly with warm partially ionized hydrogen atoms (Linsky et al. 1993; Lallement et al. 1995). Measurements of UV absorption lines through the LIC by Hubble Space Telescope gives the elemental abundances of LIC gas (Kimura, Mann, & Jessberger 2003b). The elemental abundances of LIC dust are derived from comparison between the gas-phase abundances and the solar photospheric abundances (Kimura, Mann, & Jessberger 2003c). The similarity in the compositions between LIC and Halley's dust justifies our assumption mentioned above (see Fig. 1a). This similarity also allows us to stoichiometrically assign the elements to $MgAl_2O_4$, FeNi, Mg_2SiO_4, $MgSiO_3$, FeS, and CHON, based on our best knowledge of possible major compositions for comet dust. Further information on the composition of LIC dust comes from analysis of impact data measured in situ by Ulysses (Mann & Kimura 2000, 2001). The data on the velocity and mass of LIC dust places constraints on acting forces that depend on the dust composition (Mann 1996; Landgraf et al. 1999). Solar radiation pressure on LIC dust estimated from the data suggest that the LIC contains aggregate particles consisting of silicate-core, organic-mantle, and submicron grains (Kimura et al. 2003c).

3. Results and Discussion

Organic refractory mantle: Figure 1a shows that comet dust contains only 1/3 of N compared to interstellar dust despite the similarity in the overall composition. The N depletion in comet dust might be related to gas-grain chemistry in the comet-forming regions of the solar nebula (Charnley & Rodgers 2002). Alternately, it may indicate the processing that transformed organic refractory into amorphous carbonaceous material, the amount of which depends on the degree of processing. In fact, light scattering properties of comet dust are well explained if 2/3 of carbonaceous materials is in the form of amorphous carbon and 1/3 in the form of organic refractory (Kimura, Kolokolova, & Mann 2003a).

https://doi.org/10.1017/S1539299600016373 Published online by Cambridge University Press

This supports the idea that the organic refractory mantles of comet dust are partially processed into amorphous carbon, but this issue requires further studies.

Amorphous silicate core: Figure 1b shows the similarity in the composition between GEMS and the silicate component of interstellar dust except for S, which is more than a factor of two depleted in GEMS. The S abundance in the silicate component of interstellar dust would be lowered if the majority of S is contained in the organic refractory. However, the correlation of S and Fe in dust from Comet Halley and the similarity of the S abundances in Halley's and LIC dust do not support this idea (see Jessberger et al. 1988). The S depletion in GEMS may be better explained by the partial loss of S due to atmospheric-entry heating (Greshake et al. 1998). If this is the case, there is no evidence for processing of the amorphous silicate core of pre-solar interstellar dust after its incorporation in comets. This possibly indicates that the core has been protected from alteration by its organic refractory mantle.

Acknowledgments. We would like to thank Elmar K. Jessberger and Iris Weber for useful discussions. This research is supported by the German Aerospace Center *DLR* (Deutschen Zentrum für Luft- und Raumfahrt) under the projects "Kosmischer Staub: Der Kreislauf interstellarer und interplanetarer Materie" (RD-RX-50 OO 0101-ZA) and "Mikro-Impakte" (RD-RX-50 OO 0203).

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