JD14

Formation of Cometary Material

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https://doi.org/10.1017/S1539299600016336 Published online by Cambridge University Press

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

Apparent Inconsistencies in the Formation of Cometary Matter

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Abstract. The Joint Discussion (JD14) is intended to focus attention on several apparent inconsistencies found in comet observations when compared with observations of collapsing interstellar clouds, star-forming regions, and models of the solar nebula. The JD is not intended to resolve these problems, for that a one-day discussion is too short. It rather is intended to draw attention to the inconsistencies to be discussed and resolved in future workshops.

1. Enumeration of Some Inconsistencies

Observations of comets reveal information about the structure and composition of their nuclei. They in turn, provide clues about the thermodynamic conditions and composition of the solar nebula in the region where comet nuclei formed. Most neutral molecular species identified in comets, coming directly from comet nuclei, have also been identified in the gas phase in the interstellar medium (ISM). However, the relative abundances of ice species are the important quantities that should be compared, not the gaseous species. Abundances of species in the ISM vary with location and abundances in the coma of a comet are not necessarily the same as the abundances of ices in the nucleus (Huebner & Benkhoff 1999).

The D/H ratios in molecules have been measured in a few Oort-cloud comets (Halley, Hale-Bopp, Hyakutake). They are consistent with values expected from interstellar chemistry. This suggests that if interstellar molecules were incorporated in comet nuclei, they were not chemically transformed in the solar nebula accretion shock in the region where these nuclei formed. The question arises if the accretion shock was absent or too weak in the region where comets formed, or can the same molecules found in the ISM reform in the solar nebula? No reliable measurements of the D/H ratio exist for Kuiper-belt comets. A key question concerns the abundances of various ices on interstellar grains.

The hydrogen ortho-to-para ratio in cometary H_2O and NH_2 suggest that comet nuclei formed at low temperatures [1P/Halley at $\sim$ 50 K: Mumma, Weaver, & Larson 1987; C/1999 S4 (LINEAR) at $\sim$ 28 K: Kawakita et al. 2001]. CO has been detected in many comets, but N_2, CH_4, and Ar are found only in trace amounts. Yet, CO is less volatile than N_2 and more volatile than CH_4 and Ar.

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Evidence for amorphous water ice in comets is circumstantial. It is based on models for the release of gases trapped in amorphous water ice to explain the heliocentric distance dependence of some observed gaseous species abundances in comet comae. However, it is thought that amorphous water ice cannot form in the solar nebula (SN) even though temperatures are low enough. The condensation rate in the SN is too slow so that H_2O molecules have time to reorient themselves to form crystalline ice (Kouchi et al. 1994). Thus, the question arises about additional evidence for amorphous vs. crystalline water ice in collapsing clouds, ISM, and Comets.

The discovery of large, highly saturated complex molecules of biological importance in collapsing clouds and the ISM is increasing. There are still many unidentified spectral lines in comet comae. Do some of them belong to complex molecules? How complex can we expect molecules to be in comets? Can complex molecules form in the SN?

Detection of crystalline silicate grains in comet comae indicates that some dust has been exposed to temperatures of about 900 K. One theory suggests that turbulent mixing and heating of dust in the inner solar nebula followed by transport into the comet-forming zone may be responsible for crystallization. However, this also requires heating the gas that entrains and transports the dust. Heating the gas would change its interstellar composition. Are comet coma observations consistent with such high-temperature exposures? What evidence exists for amorphous and crystalline silicates in collapsing clouds, the ISM, dark interstellar clouds (DISCs), and comets? Are there alternative mechanisms for formation of crystalline silicate grains?

Silicates and GEMS (submicron-sized glassy silicates) bear evidence of exposure to large doses of ionizing radiation. They appear to be similar to the inferred properties of interstellar grains. Can these properties also be acquired in the SN?

Recently it has been pointed out that the composition of comet nuclei is not consistent with the solar composition of icy planetesimals (SCIPs) responsible for the formation of Jupiter (Owen & Encrenaz 2003). Has the composition of comet nuclei changed over time? Is the composition of Kuiper-belt comets different from Oort-cloud comets? From the formation of comet nuclei, what inherent differences can we expect in structure and composition of Kuiper belt comets vs. Oort cloud comets (other than cosmic ray effects)? Did SCIPs that formed the core of Jupiter possibly come from a companion cloud to the SN? Was such a companion cloud too small to form a star but cold and dense enough to form comet nuclei that have a different composition? Can we find such comets?

Models of collapsing clouds and of star-forming regions are used as analogs of the SN. In such models, the physics (e. g., turbulence and shocks) and chemistry are not separable. How can SN models be constraint by observations of comets? What are the extent, strength, and effect of the accretion shock in the SN? How does it influence the gas and dust composition of the SN? How strong are the effects of the SN accretion shock on gas and dust in the comet-forming region?

Laboratory work relevant to the above topics is very important but can be difficult: Higher densities must be assumed in the laboratory to account for time-compression. The interstellar radiation field varies with location. Physical effects such as turbulence are difficult to simulate. Relative abundances are difficult to determine because they depend on properties of various species and their state variables such as gases or ices.

2. Prospects for the Resolution of the Inconsistencies

This Joint Discussion is intended to focus attention on the conflicting evidence of survival of the low-temperature interstellar molecules in the SN in spite of the accretion shock, the detection of crystalline features in cometary dust, and on observations, models, and laboratory experiments that help to clarify the issues at hand. The following presentations were made in the Joint Discussion to focus attention on these challenging issues.

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