

## **"Comets as Messengers from the Early Solar System – Emerging Insights on Delivery of Water, Nitriles, and Organics to Earth"**

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The question of exogenous delivery of water and organics to Earth and other young planets is of critical importance for understanding the origin of Earth's volatiles, and for assessing the possible existence of exo-planets similar to Earth. Viewed from a cosmic perspective, Earth is a dry planet, yet its oceans are enriched in deuterium by a large factor relative to nebular hydrogen and analogous isotopic enrichments in atmospheric nitrogen and noble gases are also seen. Why is this so? What are the implications for Mars? For icy Worlds in our Planetary System? For the existence of Earth-like exoplanets?

An exogenous (vs. outgassed) origin for Earth's atmosphere is implied, and intense debate on the relative contributions of comets and asteroids continues – renewed by fresh models for dynamical transport in the protoplanetary disk, by revelations on the nature and diversity of volatile and rocky material within comets, and by the discovery of ocean-like water in a comet from the Kuiper Belt (cf., Mumma & Charnley 2011). Assessing the creation of conditions favorable to the emergence and sustenance of life depends critically on knowledge of the nature of the impacting bodies.

Active comets have long been grouped according to their orbital properties, and this has proven useful for identifying the reservoir from which a given comet emerged (OC, KB) (Levison 1996). However, it is now clear that icy bodies were scattered into each reservoir from a range of nebular distances, and the comet populations in today's reservoirs thus share origins that are (in part) common. Comets from the Oort Cloud and Kuiper Disk reservoirs should have diverse composition, resulting from strong gradients in temperature and chemistry in the proto-planetary disk, coupled with dynamical models of early radial transport and mixing with later dispersion of the final cometary nuclei into the long-term storage reservoirs. The inclusion of material from the natal interstellar cloud is probable, for comets formed in the outer solar system.

Being the least modified bodies in the Solar System, the composition of comets should provide useful tests of the current theories, and can establish observational constraints that future models must satisfy. For that reason, increasing emphasis has been placed on classifying comets according to the composition of native ices and dust (rather than orbital dynamics). The primary volatiles in comets (ices native to the nucleus) provide a preferred metric, and taxonomies based on them are now beginning to emerge [Mumma & Charnley 2011, Crovisier et al. 2009, DiSanti & Mumma 2008]. Similar compositional diversity is seen within bodies from each reservoir, but the number of

bodies so quantified is as yet too small to assess the fractional representation of the various chemical classes within each reservoir.

The measurement of other cosmic parameters such as the nuclear spin temperatures for H<sub>2</sub>O, NH<sub>3</sub>, and CH<sub>4</sub>, and of enrichment factors for isotopologues (D/H in water, methane, and hydrogen cyanide, <sup>14</sup>N/<sup>15</sup>N in CN and hydrogen cyanide) provide additional important tests of the nature and origin of cometary material. Surveys based on rocky materials are also underway, especially using the crystalline silicates as a signature of radial transport outward from the near-Solar region.

Much progress has occurred in the last decade, but challenges remain. I will provide an overview of these aspects, the present issues and new frontiers, along with emerging implications for the origin of Earth's water and prebiotic organics.

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