THE PATHS OF ICE GRAINS IN THE SOLAR NEBULA: IRRADIATION AND THE FORMATION OF ORGANICS

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Introduction: Organic compounds have been found in a number of meteorites, leading many to suggest that Earth's prebiotic material was delivered through the accretion of cometary and chondritic-like planetesimals. While formation of organic molecules during aqueous alteration of a parent body can occur [1], the D/H ratios in these compounds have led many to investigate a low temperature origin [2]. Among the favored pathways is the UV irradiation of ice-mantled grains, where photons break up molecules in solid grains, leaving behind reactive ions and radicals, which form more complex species. Most studies have considered an interstellar setting for such reactions [e.g. 3, 4]. Here we explore whether ice-mantled grains in the outer solar nebula could have absorbed enough UV photons to contribute significantly to the organic inventory of the Solar System.

Model: We have developed a particle-tracking model that calculates vertical and radial paths of dust particles through a diffusive protoplanetary disk [5, 6]. This allows us to determine the amount of time that particles spend at different locations throughout an evolving disk. By assuming an incident flux of UV radiation on the disk, we can then determine the flux wherever the particles reside and determine an irradiation history (number of incident UV photons) for each particle.

Results: We tracked the motions of 5000 ice grains released from the midplane of a disk where temperatures were <50 K—low enough for molecular species like H_2O, CO_2, NH_3, and CH_3OH to be frozen onto grain surfaces—for a period of 10^6 years. We find that, because the UV flux is rapidly attenuated through the disk as small dust particles readily absorb the incident radiation, ices only see significant fluences of UV photons when lofted to high altitudes in the disk. Thus only small, <10 μm grains, are exposed to large fluences of UV photons. However, in many cases, these fluences can be large enough to lead to the production of significant amounts of organic molecules.

Discussion: Throop (2011) [7] suggested organics could have been produced in the outer solar nebula if the Sun formed in an Orion-like setting, such that a nearby massive star would have irradiated the disk at $10^6\times$ the current interstellar UV flux (G_0). In that model, UV photons were assumed to be evenly distributed among all ice particles at a given location in the disk, and as such, high UV fluxes were necessary to produce high yields of organics. We find that turbulence would have lofted small grains to high altitudes, exposing many to enough UV radiation that significant organic synthesis could have occurred, even at low incident UV fluxes ($<10^3\,G_0$), such as those expected for a young star irradiating its own disk or one in a small cluster. This suggests organic synthesis can occur in most protoplanetary disks, meaning organic compounds should be commonly found in young planetary systems.

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