UV Photolysis and Creation of Complex Organic Molecules in the Solar Nebula.

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Introduction: Studies of numerous carbonaceous chondrites have shown them to contain upwards of 70 different amino acids, many of which have no known terrestrial occurrence [1,2]. The origin of these molecules is unknown. Two proposed possibilities are that they are formed by Struck synthesis in ancient subsurface aquifers on asteroid parent bodies [2], or by accretion of material created in the ISM [3,4]. *We propose here a third mechanism, by which complex organic molecules can be created in the young solar system directly by irradiation from external O and B stars in dense star clusters.*

Organic molecules: Complex organic molecules can be created by a variety of processes, including thermochemistry, lightning, charged particle irradiation, and solar- and stellar-driven photochemistry. Photochemistry has usually been ignored because of the extreme line-of-sight optical depths within the protosolar nebula, effectively isolating photochemistry to occur only in the central 0.5 AU of the disk [5].

Numerous laboratory studies over the past decade have shown that UV light, when illuminating low-temperature mixtures of simples ices (H_2O, CH_3OH, HCN, NH_3) which are subsequently heated and hydrolyzed, creates complex organic molecules such as amino acids. The yield (molecules/photon) of this process is approximately 0.1% [4]. The process is robust under a variety of temperatures, pressures, irradiation levels, and initial ice mixtures.

Environment: The Sun and most nearby young stars probably formed in large, dense clusters of 100-10,000 stars. The young stars are exposed to the UV light of young O/B-type stars within ~1 pc. These massive stars create a UV radiation field of ~10^5-10^7 G_0, where G_0=1.6 10^{-3} is the current interstellar UV radiation field at the Earth. The energy is deposited equally to all regions of the disk. The UV from the young Sun itself is insignificant, because it is fainter than that from external stars, it drops off rapidly with distance, and it is extinguished by the disk's high radial line-of-sight optical depth.

Earlier studies of the energy budget of the young Solar System did not consider UV photolysis to be important, because the Sun is a weak source, and external UV sources were not included [5,6]. Subsequent studies have implied higher Solar UV fluxes, but these have not been included in nebular chemistry models [7,8]. Because the early Solar System contained great quantities of ice, and this is directly exposed to bright UV radiation from the external stars, photolysis on the surfaces of icy grains and/or planetesimals may have occurred in the young Solar System. The process would begin soon after the collapse of the pre-Solar nebula, and end after several Myr when O/B stars have turned off and/or the disk's optical depth has dropped so that it no longer intercepts UV photons.

Model: We developed a numerical model which simulates the exposure of the young Solar System disk to UV radiation. Icy surfaces in the exterior skin layer of the disk are exposed to UV photons. Grain growth is considered; once grains have grown large enough that the disk's optical depth drops below unity, exposure in that region is halted. Photo-evaporation [9] by the O/B stars removes gas but does not affect photolysis or ice grains > 5 um. We do not model specific chemical reactions, but use our model to predict the UV exposure of icy material in the disk as a function of time and location, for a variety of environmental and formation scenarios.

Results: We find that the energy of UV irradiation by external stars dominates all other energy sources considered in [5] and thus may play a substantial and unappreciated role in determining the Solar System's chemical and organic composition. The highest UV energy deposition per molecule is in the outer Solar System where the surface density is lowest and slow grain growth allows surface area to be exposed for long times. The total dose at 40 AU is ~4000 photons/molecule, which is sufficient to entirely photolyze the ices into complex organics assuming 0.1% efficiency and no loss processes. In the inner disk, the flux is sufficient by >5 orders of magnitude to create the entire organic inventory of Murchison of ~20 ppb. Thus, synthesis of meteoritic amino acids may not require warm asteroidal aquifers, nor creation of complex organics in the relatively cool, dark conditions of the ISM.

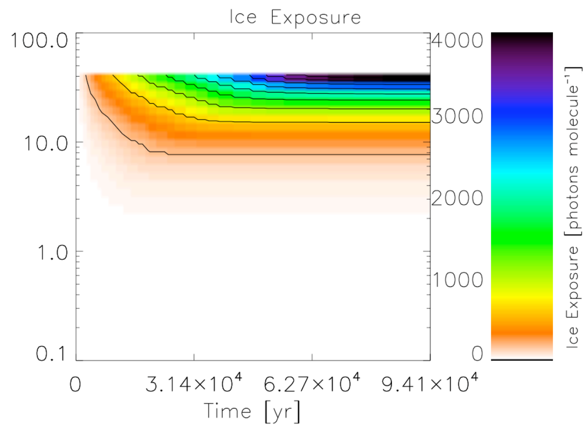

Figure 1: Exposure of ices in the proto-solar disk. Simulation runs for 10^5 years at a UV flux of 10^6 G_0. A standard Hayashi profile and disk of mass 0.015 M_{sol} is assumed. By the simulation end, ices in the outer solar system (>30 AU) have received a mean dose of ~4000 photons/molecule (5 10^5 eV/molecule). The contours flatten by the simulation end because rapid grain growth locks up exposed surface area into larger bodies.

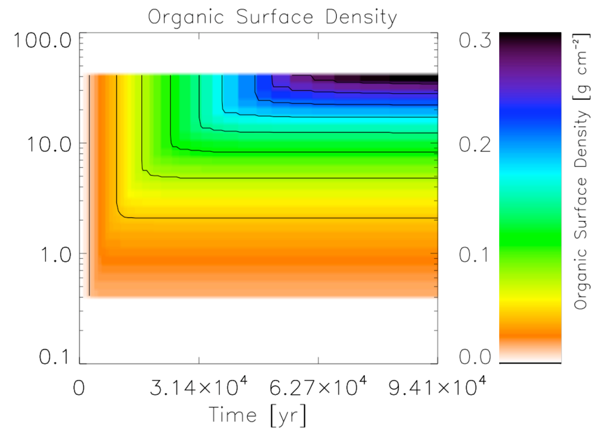

Figure 2: Model results for the organic surface density produced by UV photolysis, assuming a constant yield of 0.001 molecules/photon. Resulting photon density is highest at the outer edge, where grain growth and surface density are both low.

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