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On a radiolytic origin of red organics at the surface of the Arrokoth Trans-Neptunian Object

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The classical Kuiper Belt Object (KBO) Arrokoth was surveyed by the New Horizons spacecraft on 1st January 2019, revealing a small bilobed object with a red surface, whose spectral slope lies in the average of the whole KBOs population. This red color has been assigned to reddish organic materials, either inherited from the protosolar disk during accretion, or formed through radiolytic processes in the surface due to exposure to solar or interstellar photons, Solar Wind, Solar Energetic Particles or Galactic Cosmic Rays. We report here a study investigating the radiolytic scenario, based on numerical calculations and experimental simulations run with swift heavy ions (74.8 MeV $^{136}Xe^{19+}$ and 33.06 MeV $^{58}Ni^{9+}$), and low-energy 105 keV $^{18}O^{6+}$ ions on CH_3OH ice, the only molecule identified at Arrokoth's surface. Chemistry within the subsurface is essentially controlled by Galactic Cosmic rays (H and He), which penetrate deep down to several tens of meters and deliver an electronic dose higher than 1 eV.atom^{-1} in the first meter. Experimental simulations show that irradiating methanol ice with a dose consistent with that in planetary conditions, results in the formation of reddish organic materials made of aliphatic, conjugated and unconjugated olefinic, acetylinic, carbonyl and hydroxyl groups. A similarity with irradiated simple polymers (e.g. polyethyleneglycol) and materials formed through cold plasma experiments (tholins) is observed. There is little dependence with the nature and energy of the ion. The residue recovered at room temperature was analyzed with High Resolution Mass Spectrometry (Orbitrap), revealing a complex composition with around 6596 chemical formulas and likely several tens of thousands of molecules. Altogether, these analyses support active polymerization mechanisms similar to those observed in irradiated polymers, as bond-breaking, cross-linking or formation of olefinic bonds through recombination of radicals in adjacent carbon atoms. Considering both sputtering and radiolysis, as well as material ablation due to dust bombardment reported in literature, a scenario is taking shape as the production of reddish organics deep in the subsurface, and the settling of an organic crust at the top surface through volatiles removal. The presence of methanol and absence of water, inconsistent with sputtering fractionation, remains unexplained.