Laboratory demonstration of cryogenic-specific reddish coloration with cryoplasma

*Noritaka Sakakibara[1], Yu Yu Phua[1], Tsuyohito Ito[1], Kazuo Terashima[1]

1. The University of Tokyo

Reddish coloration and color diversity among icy bodies in the outer solar system are one of the important characteristics for understanding the environment and history of the solar system. Ultra-red objects only occur far from the Sun such as some Trans-Neptunian objects and Centaurs, whereas the reddish coloration is absent among cometary nuclei and dead comets closer to the Sun lack (Luu & Jewitt 1996; Sheppard 2010). The reddish color has been attributed to refractory tholin-type materials (Cruikshank et al. 2005). However, because the tholin-type materials are very stable even when warmed to room temperature, the origin of color distribution in the cryogenic world remains debatable (Dalle Ore et al. 2011). In this presentation, we will provide experimental demonstration of reddish coloration that is stable only at cryogenic temperatures.

The reddish coloration was produced on methanol- and water-containing ice irradiated with 3% nitrogen-containing helium cryoplasma at 85 K. Cryoplasma is non-equilibrium plasma source whose gas temperature can be controlled continuously at wide range of cryogenic temperatures below room temperature (Stauss et al. 2018), which enables coexistence of plasma with ice without melting (Sakakirbara & Terashima 2017; Sakakibara et al. 2019). The reddish color faded and disappeared at 120–150 K as the ice was heated. This behavior is distinct from well-known refractory organic tholins that are stable even when heated to room temperature. By temperature programmed desorption analysis and LC-MS/MS analysis of the residue at room temperature, the reddish material was suggested to be nitrogen-containing organic compounds.

The temperature dependence of reddish coloration under cryogenic conditions could add on a new explanation for the absence of ultra-red coloration closer to the Sun in the outer solar system; the cryogenic-specific reddish materials sublimate or convert to other colorless compounds at higher cryogenic temperatures, as an icy body travels from the Trans-Neptunian region to the inner solar system. Our result implies that a reddish material specific to cryogenic environments might be a promising clue for the investigation of color diversity and formation mechanism of the outer solar system. Moreover, cryoplasma was expected as a novel modern technology for accelerating the investigation of chemistry and materials science in cryogenic space environments including the outer solar system.

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Keywords: cryoplasma, reddish coloration, outer solar system, ice, color diversity, astrochemistry