Dust as a Key to Understanding the Molecular Evolution of the Low-Metallicity Universe

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Understanding the chemistry of the interstellar medium in environments with low dust abundance (i.e., low metallicity) is essential for unveiling the physical and chemical processes that occurred in the early Galactic environment or in high-redshift galaxies, where the metallicity was significantly lower compared to the present-day solar neighborhood. Over the past decade, there has been significant progress in astrochemical studies of interstellar molecules in low-metallicity star-forming regions, such as those in the Large and Small Magellanic Clouds (LMC/SMC), other dwarf galaxies in the Local Group, and the outskirts of our Galaxy (see Shimonishi 2025, IAU Proc., in press; arXiv:2411.04451, and references therein).

Observations with single-dish telescopes have revealed enhanced photochemistry in low-metallicity molecular clouds, likely due to reduced shielding of the interstellar radiation field in such environments. Infrared telescopes have unveiled the chemical compositions of ices in deeply embedded protostars in the LMC and SMC. These ice compositions cannot be explained solely by differences in elemental abundances; instead, grain surface chemistry under relatively warmer conditions—compared to solar-metallicity clouds—must be considered. Observations with ALMA have detected a variety of molecular species, including complex organic molecules (COMs), toward dense and high-temperature protostellar envelopes in low-metallicity environments. Interestingly, the abundance of organic molecules exhibits substantial source-to-source variation: in some cases, it aligns with a metallicity-scaled abundance relative to Galactic counterparts, while in others, it is markedly lower than what would be expected from metallicity differences alone. The origin of this chemical diversity among low-metallicity protostellar sources remains under debate, but it may be linked to grain surface chemistry, as most COMs are thought to form as ices during the early stages of star formation.

These observations suggest that dust grains are crucial for understanding the molecular complexity of the metal-poor universe. This presentation will summarize recent advances in the observation of interstellar molecules in low-metallicity environments, from molecular-cloud scales (~1–10 pc) to protostellar-core scales (<0.1 pc). I will then discuss the key processes that govern molecular evolution in low-metallicity star-forming regions.