Organic molecules at 0.2 solar metallicity

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Properties of complex organic molecules in metal-poor environments will be crucial information for understanding organic chemistry in high-redshift galaxies where the metallicity was significantly lower than the present solar neighborhood. The Small Magellanic Cloud (SMC) is a nearby star-forming dwarf galaxy, whose metallicity is lower than typical Galactic values by a factor of ~5. Here we present observational and theoretical studies on the formation of complex organic molecules in the metal-poor environment of the SMC.

First, we report the results of sub-parsec scale submillimeter observations towards a high-mass young stellar object in the SMC with the Atacama Large Millimeter/submillimeter Array (Shimonishi et al. 2018, submitted). As a result of observations, we for the first time detected a complex organic molecule, methanol (CH_3OH), in the SMC. Besides CH_3OH lines, we also detect the dust continuum as well as emission lines of CS, $C^{33}S$, H_2CS, SO, SO_2, $H^{13}CO^+$, $H^{13}CN$, SiO, and tentatively HDS from the observed region. The target infrared point source is spatially resolved into two dense molecular cloud cores; one is associated with an embedded high-mass young stellar object, another is not associated with an infrared source but shows rich molecular lines including those from CH_3OH. The first detection of CH_3OH in the SMC has a strong impact on our understanding of the formation of complex organic molecules in metal-poor environments. The gas temperature is estimated to be ~10 K based on the rotation analysis of CH_3OH lines, suggesting that non-thermal desorption would contribute to the production of gas-phase CH_3OH in this source. The fractional abundance of CH_3OH gas in the observed dense core is estimated to be (0.5-2) x 10^{-8}, which is comparable with those of similar Galactic cold sources despite a factor of five lower metallicity in the SMC. This would indicate an enhanced production or an inhibited destruction of gas-phase CH_3OH in the present SMC source as compared to Galactic counterparts.

Next, we report the results of numerical simulation on gas-ice chemistry dedicated to the galactic environment of the SMC. Using the physical conditions constrained by the ALMA observations, the abundances of the detected molecular species are well reproduced by the astrochemical simulation. However, to achieve this, we need to assume (i) a higher elemental abundance of sulfur compared to the standard sulfur-depleted abundance model of the SMC, (ii) reactive desorption of grain surface species with a probability of ~1%, and (iii) a sufficiently low dust temperature (<15 K). The requirement (i) implies that gas-phase elemental sulfur is less depleted into dust in the metal-poor environment of the SMC compared to Galactic dark clouds. The requirement (ii) indicates that, by taking into account reactive desorption, observed and model-predicted molecular abundances show good agreement without incorporating energetic desorption processes such as shock sputtering. The requirement (iii) indicates that a cold and well-shielded region is necessary for the production of the observed amount of CH_3OH gas in the SMC, and such a source is actually found by our observations in the metal-poor environment.

Although it is still unclear if the observed source represents common characteristics of cold and dense molecular clouds in the SMC, this work provides observational evidence that an organic molecule like CH_3OH, which are largely formed on grain surfaces, can be produced even in a significantly lower metallicity environment compared to the solar neighborhood.