The Icy Chemical Origin and Evolution from Embedded Protostars to Disks

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In recent years, the common detection of gas-phase complex organic molecules (COMs) suggests extensive chemical reactions have already taken place in the early phase of star formation. However, while some protostars have abundant gas-phase COMs, many protostars still show no sign of COM emission. This contrast of their gas-phase chemical signatures begs the question: Does the diverse gas-phase chemistry represent distinctively different chemical evolution? Ice not only represents the more pristine chemistry with minimum contamination from gas-phase reactions but also enables major formation pathways of COMs. While ALMA provides sub-100 au resolution, a resolution necessary to resolve sites of planet formation, to characterize gaseous COMs in nearby embedded protostars, measurements of chemical composition in ices had been limited by low-resolution and limited sensitivity spectroscopy until JWST. Thus, it is imperative to probe both gas and ice chemistry related to COMs, which can only be achieved with both ALMA and JWST. In this talk, I will highlight the latest JWST results on ice chemistry and the characterization of complex ice species in comparison with those detected in the gas phase by ALMA. Particularly, I will present the results from the CORINOS program, which aims to delineate the origin of COM diversity in the gas phase. We detect likely features of icy COMs regardless of the presence of gaseous COMs. I will discuss the challenges and our approach to isolating blended ice features. Moreover, I will present the ice characterization of SO2, CH4, and possible COM identifications in the CORINOS protostars as well as a full ice inventory (Figure 1; Gross et al. 2026). Finally, I will highlight the perspectives of ice characterization in the JWST era and the synergy with sub-mm/mm molecular spectroscopy in the gas phase.