A NEW ICE AGE: TRACING FROZEN MOLECULAR CHEMISTRY FROM CLOUDS TO EXOPLANETS WITH JWST.

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Volatile elements, like C, H, O, N, and S, are critical to the detectability of planetary atmospheres and the origins of life as we know it. These elements are mostly carried by icy dust grains that may have been transferred to Earth from the cold outer regions of the Solar protoplanetary disk. A substantial fraction of this ice is thought to have originated in the Sun's natal molecular cloud; however, the total amount and variety of ices inherited this way is an open question. Additionally, the chemical complexity achieved by the ices is unclear; interstellar complex organic molecules (COMs, $>$6 atoms, including C) are seen in the gas phase of dense clouds and in cometary ices, but whether they form as ices or not is hotly debated. These questions are critical to understanding planetary habitability and the rise of life, and they could allow us to use the atmospheric composition of giant planets to trace their formation zones in protoplanetary disks.

Infrared spectroscopy of clouds, protostars, and protoplanetary disks with JWST allows us to answer these questions. In this talk we present some first results from the ERS program Ice Age[1] showcasing the exquisite data quality from JWST[2]. These observations reveal the diversity of icy chemistry found in dark regions of molecular clouds and the distribution of ice and gas in protostars and disks. The ice profiles seen at high resolution allow us to probe the icy grains' size and chemical pathways by which ices form. We find evidence for early formation of methanol and COMs in the polar, H_2O ice-rich phase, prior to full CO freeze-out. We show some initial results for how the ice has evolved after during infall to the comet-forming regions of the protoplanetary disk, and why interpreting JWST ice absorption spectra correctly without radiative transfer modeling is difficult. We end with a discussion of the implications of these results for exoplanetary atmospheric compositions and planet formation.

[1] http://jwst-iceage.org

[2] https://ui.adsabs.harvard.edu/abs/2023NatAs...7..431M/abstract, M.K. McClure, W. Rocha, K. Pontoppidan, N. Crouzet, et al., An Ice Age JWST inventory of dense molecular cloud ices, Nature Astronomy, Volume 7, p. 431-443 (2023).

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