ICE EVOLUTION DURING THE STAR FORMATION PROCESS: AN ICEAGE JWST STUDY OF CHAMAELEON I

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Abstract. Icy grain mantles are the main reservoir for volatile elements in star-forming regions. The IceAge* Early Release Science program on the James Webb Space Telescope proposes to trace the evolution of pristine and complex ice chemistry in Chamaeleon I - a representative low-mass star-forming region - through various stages of star formation from dense cloud to protoplanetary disk. Observations towards the dense cloud made in summer 2022 using the NIRCam, NIRSpec and MIRI instruments provided high spectral resolution (R $\sim$ 1500-3000) and sensitivity (S/N > 100) infrared spectra from 2.5 to 13 μm of two highly extincted background stars (A_V < 100).

Keywords: JWST, IR spectroscopy, star formation, molecular cloud

1 The IceAge Early Release Science program

The IceAge program McClure et al. (2017) is one of thirteen Early Release Science programs awarded Director's Discretionary observational time on the James Webb Space Telescope during the first six months of science operations. The IceAge program, led by PI Melissa McClure and co-PIs Adwin Boogert and Harold Linnartz, proposes to trace the evolution of pristine and complex ice chemistry in Chamaeleon I. This object was chosen as being a representative low-mass star-forming region containing – in close proximity – regions at various stages of star formation from dense cloud to protoplanetary disk. The program utilises the NIRCam, NIRSpec and MIRI instruments in a combination of imaging and spectral modes. The observed field of view in the Chamaeleon star forming region is shown in Fig. 1, a composite image obtained by combining NIRCam imaging filters.

2 First results from the IceAge program

The observations presented in this work were obtained in summer 2022 and are published in McClure et al. (2023). We summarise the results here. A combination of spectroscopy performed with the NIRCam, NIRSpec and MIRI instruments provided high spectral resolution (R $\sim$ 1500-3000) and sensitivity (S/N > 100) infrared spectra from 2.5 to 13 μm of two highly extincted background stars (A_V < 100).

In this talk, we presented the first results of the IceAge program: a complete ice inventory towards the observed lines of sight, including derived column densities for expected ice species as well as the first detection of several species along lines of sight in a quiescent cold core (McClure et al. 2023). In summary, ice features attributable to the major ice components H_2O, CO_2, CO, NH_3, CH_4 and CH_3OH were observed towards NIR 38 and J110621 (see Fig. 1), background stars with A_V estimated at 60 mag and 95 mag, respectively, from archival data. Weaker ice features attributed to $^{13}CO_2$, ^{13}CO, OCN^-, OCS, as well as functional groups of complex organic molecules, were detected in a dense cloud for the first time. Profiles of the deeper ice bands, for example the $^{12}CO_2$ ice profile, indicate that moderate growth of the icy grains has occurred compared to the grain size distribution expected in the diffuse interstellar medium. An initial estimation of column densities for the observed ice species allows a constraint to be placed on the bulk budget of S, with S-bearing ice accounting for around 1 % of total S, while confirming the budgets of icy C and O to be around 19 % and N to be $\sim$ 13 %. There is some indication that the formation of complex molecules may begin in the water-rich ice mantle, prior to CO freeze-out.

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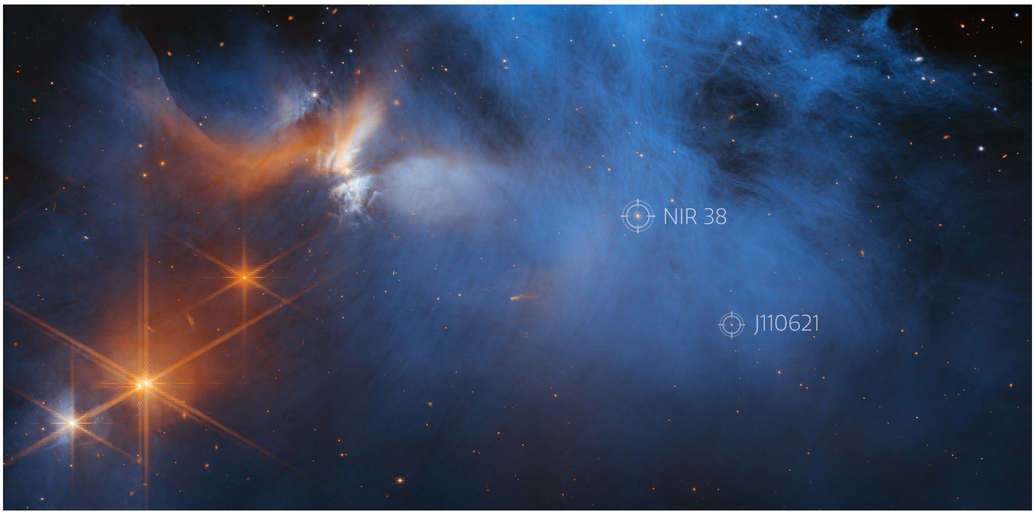

Fig. 1. Star-forming region Chamaeleon I, imaged by the JWST NIRCam instrument. The two highly extincted background stars targeted by the IceAge program are highlighted. This image was originally published in a press release on 23/01/23, available at: `https://esawebb.org/news/weic2303/`, to coincide with the publication of McClure et al. (2023). Image Credit: NASA, ESA, CSA, and M. Zamani (ESA/Webb); Science: M. K. McClure (Leiden Observatory), F. Sun (Steward Observatory), Z. Smith (Open University), and the IceAge ERS Team.

3 Conclusions and perspectives

This work presents the first results of the IceAge observational program targeting the Chamaeleon I star forming region. Since this talk, further results have been published, including NIRSpec observations of the class II edge-on protoplanetary disk HH 48 NE (Sturm et al. 2023). The perspectives for the rest of the IceAge program include mapping the spatial distribution of ices in the dense cloud down to $\sim$ 20-50 au to identify the onset of ice formation and determine the degree of chemical complexity achieved prior to star formation. Unravelling complex molecule formation and evolution during the star formation process requires the type of detailed, sensitive observations of interstellar ices now being performed with instruments on the JSWT. Ultimately, the IceAge program hopes to answer the question: how do complex organic molecules form in star-forming regions, and what are the chemical and physical processes responsible for this molecular complexity?

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