Webb Unveils the Dark Side of Pre-stellar Ice Chemistry

The discovery of diverse ices in the darkest, coldest regions of a molecular cloud measured to date has been announced by an international team of astronomers using the NASA/ESA/CSA James Webb Space Telescope. This result allows astronomers to examine the simple icy molecules that will be incorporated into future exoplanets, while opening a new window on the origin of more complex molecules that are the first step in the creation of the building blocks of life. Researchers at the Universities of Copenhagen and Aarhus made important contributions to this work.

If you want to build a habitable planet, ices are a vital ingredient as they are the main carriers of several key light elements — namely carbon, hydrogen, oxygen, nitrogen, and sulphur. These elements are important ingredients in both planetary atmospheres and molecules like sugars, alcohols, and simple amino acids. In our Solar System, it is thought they were delivered to Earth's surface by impacts with icy comets or asteroids. Furthermore, astronomers believe such ices were most likely already present in the dark cloud of cold dust and gas that would eventually collapse to make the Solar System. In these regions of space, icy dust grains provide a unique setting for atoms and molecules to meet, which can trigger chemical reactions that form very common substances like water. Detailed laboratory studies have further shown that some simple prebiotic molecules can form under these icy conditions.

Now an in-depth inventory of the deepest, coldest ices measured to date in a molecular cloud **[1]** has been announced by an international team of astronomers using the NASA/ESA/CSA James Webb Space Telescope in an article in Nature Astronomy and an accompanying press-release. In addition to simple ices like water, the team was able to identify frozen forms of a wide range of molecules including carbon dioxide, ammonia, methane, methanol and even signs of more complex prebiotic species. This is the most comprehensive census to date of the icy ingredients available to make future generations of stars and planets, before they are heated during the formation of young stars. These icy grains grow in size as they are funnelled into the protoplanetary discs of gas and dust around these young stars, essentially allowing astronomers to study all the potential icy molecules that will be incorporated into future exoplanets.

"*Our results provide insights into the initial, dark chemistry stage of the formation of ice on the interstellar dust grains that will grow into the centimetre-sized pebbles from which planets form in discs,*" said Melissa McClure, an astronomer at Leiden Observatory and a member of the Danish Center for Interstellar Catalysis, who is the principal investigator of the observing program and lead author of the paper describing this result. "*These observations open a new window on the formation pathways for the simple and complex molecules that are needed to make the building blocks of life.*"

The ices were detected and measured by studying how starlight from beyond the molecular cloud was absorbed by icy molecules at specific infrared wavelengths visible to Webb. This process leaves behind chemical fingerprints known as absorption spectra which can be compared with laboratory data to identify which ices are present in the molecular cloud. In this study, the team targeted ices buried in a particularly cold, dense, and difficult to investigate region of the Chameleon I molecular cloud, a region roughly 500 light-years from Earth which is currently in the process of forming dozens of young stars.

"*We simply couldn't have observed these ices without Webb,*" elaborated Klaus Pontoppidan, JWST Project Scientist at the Space Telescope Science Institute, who was involved in this research. "*The ices show up as dips against a continuum of background starlight. In regions that are this cold and dense, much of the light from the background star is blocked and Webb's exquisite sensitivity was necessary to detect the starlight and therefore identify the ices in the molecular cloud.*"

Researchers in Denmark at the Universities of Aarhus and Copenhagen played an important role in this work. Funded by The Danish National Research Foundation (DNRF), the Center for Interstellar Catalysis (InterCat) at Aarhus University performed laboratory experiments to explore pathways that lead to the formation of the ice molecules observed by JWST on interstellar dust grains. "*Webb's observations of ices in pre-stellar cores bring us one step closer to pinpoint the origin of the molecular building blocks of life in space*," explained Sergio Ioppolo, associate professor at InterCat. "*This work confirms that interstellar nanoscale dust grains act as catalysts for the formation of complex molecules from the very dilute atomic and molecular gas of the interstellar medium.*" At the Niels Bohr Institute at University of Copenhagen a group led by Jes Jørgensen and Lars Kristensen contributed observations of the Chameleon region at longer wavelengths than observable by Webb. "*Using observations for example from the Atacama Large Millimeter/submillimeter Array (ALMA) it is possible for us to directly observe the dust grains themselves as well as measure light emitted from the molecules when they are present as gas*" explained Lars Kristensen, associate professor at the Niels Bohr Institute. Using the combined data provide a unique insight into the complex interplay between gas, ice and dust in regions where stars and planets form according to Jes Jørgensen, professor at the Niels Bohr Institute: "*We can thereby provide maps of where the molecules are present in the region both before and after they have been frozen out on the grains and follow their paths from the cold molecular clouds to emerging protoplanetary systems around young stars.*"

The Ice Age team have already planned further observations using both Webb and other telescopes. "*These observations together with further laboratory studies will tell us which mixture of ices — and therefore which elements — can eventually be delivered to the surfaces of terrestrial exoplanets or incorporated into the atmospheres of giant gas or ice planets.*" concludes McClure.

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Notes

[1] A molecular cloud is a vast interstellar cloud of gas and dust in which molecules can form, such as molecular hydrogen, carbon monoxide, carbon dioxide, and water. Cold, dense clumps in molecular clouds with higher densities than their surroundings can be the sites of star formation if these clumps collapse to form protostars.

More information

Webb is the largest, most powerful telescope ever launched into space. Under an international collaboration agreement, ESA provided the telescope's launch service, using the Ariane 5 launch vehicle. Working with partners, ESA was responsible for the development and qualification of Ariane 5 adaptations for the Webb mission and for the procurement of the launch service by Arianespace. ESA also provided the workhorse spectrograph NIRSpec and 50% of the mid-infrared instrument MIRI, which was designed and built by a consortium of nationally funded European Institutes (The MIRI European Consortium) in partnership with JPL and the University of Arizona.

This research forms part of the Ice Age project, one of Webb's 13 Early Release Science' programs. These observations are designed to showcase Webb's observing capabilities and allow the astronomical community to learn how to get the best from its instruments.

Webb is an international partnership between NASA, ESA and the Canadian Space Agency (CSA).

[Image Description: A large, dark cloud is contained within the frame. In its top half it is textured like smoke and has wispy gaps, while at the bottom and at the sides it fades gradually out of view. On the left are several orange stars: three each with six large spikes, and one behind the cloud which colours it pale blue and orange. Many tiny stars are visible, and the background is black. Two stars are denoted with white text]

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 Ice Age ERS Team.

Links

- ESA press release
- ESA Webb Seeing Farther Interactive Brochure
- Early Release Science Program 1309: *IceAge: Chemical Evolution of Ices during Star Formation*
- Release on STScI website

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