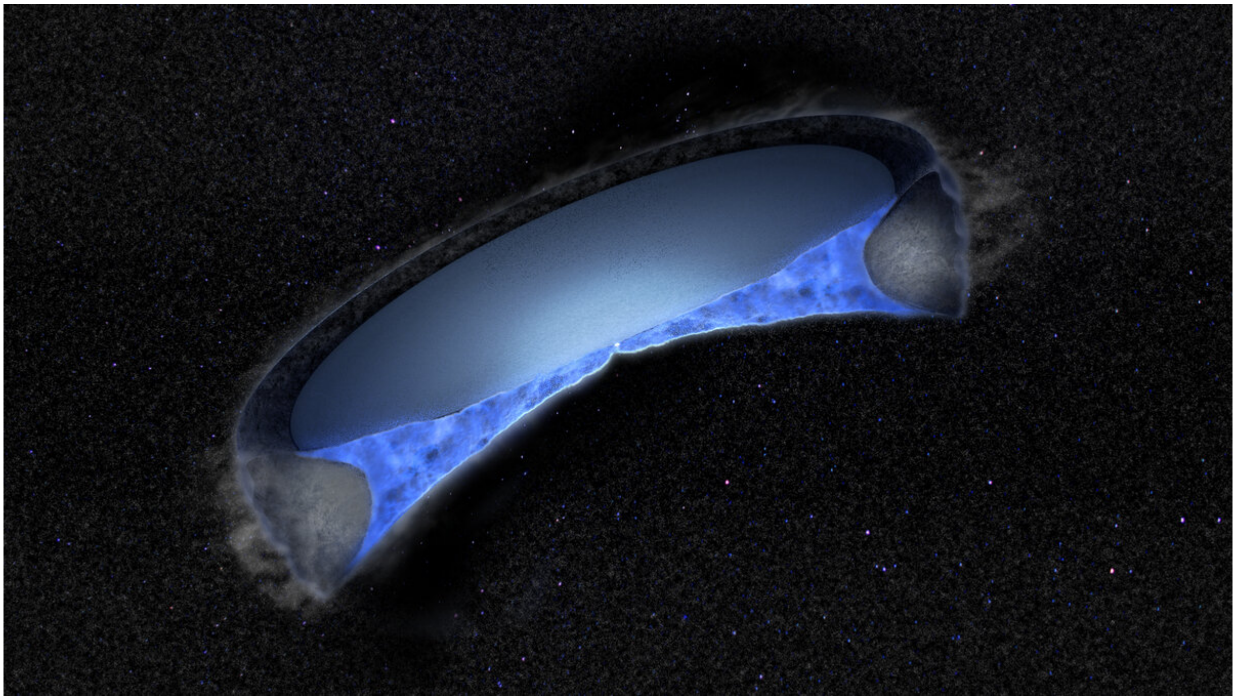
Tracing the history of water in planet formation back to the interstellar medium

March 8 2023, by Amy C. Oliver



V883 Ori is a unique protostar whose temperature is just hot enough that the water in its circumstellar disk has turned to gas, making it possible for radio astronomers to trace the water's origins. New observations with the Atacama Large Millimeter/submillimeter Array (ALMA) have provided the first confirmation that the water in our Solar System may come from the same place as the water in disks surrounding protostars elsewhere in the Universe: the interstellar medium. Credit: ALMA (ESO/NAOJ/NRAO), B. Saxton (NRAO/AUI/NSF)

Scientists studying a nearby protostar have detected the presence of water in its circumstellar disk. The new observations made with the Atacama Large Millimeter/submillimeter Array (ALMA) mark the first detection of water being inherited into a protoplanetary disk without significant changes to its composition. These results further suggest that the water in our solar system formed billions of years before the sun. The new observations are published today in *Nature*.

V883 Orionis is a protostar located roughly 1,305 light-years from Earth in the constellation Orion. The new observations of this protostar have helped scientists to find a probable link between the water in the interstellar medium and the water in our solar system by confirming they have similar composition.

"We can think of the path of water through the universe as a trail. We know what the endpoints look like, which are water on planets and in comets, but we wanted to trace that trail back to the origins of water," said John Tobin, an astronomer at the National Science Foundation's National Radio Astronomy Observatory (NRAO) and the lead author on the new paper.

"Before now, we could link the Earth to comets, and protostars to the interstellar medium, but we couldn't link protostars to comets. V883 Ori has changed that, and proven the water molecules in that system and in our solar system have a similar ratio of deuterium and hydrogen."

Observing water in the circumstellar disks around protostars is difficult because in most systems water is present in the form of ice. When scientists observe protostars they're looking for the water snow line or ice line, which is the place where water transitions from predominantly ice to gas, which radio astronomy can observe in detail.

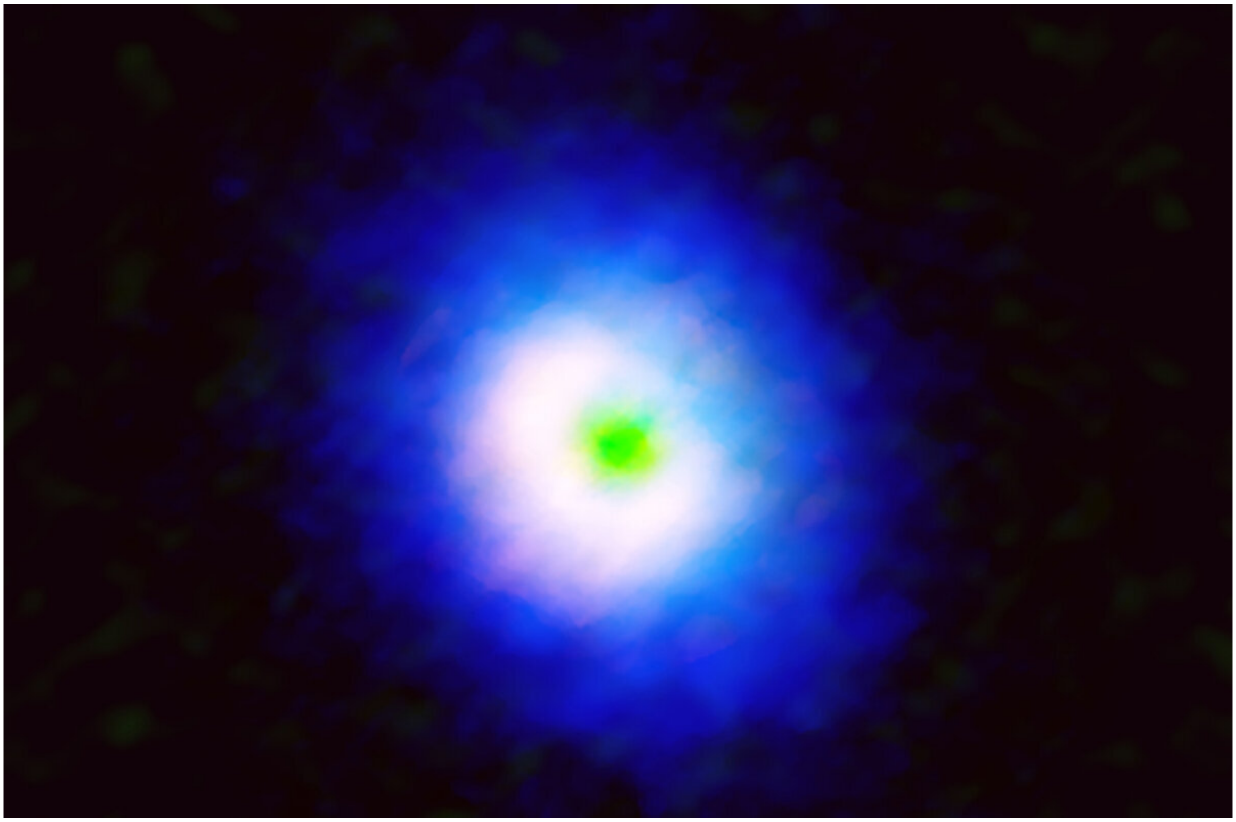
"If the snow line is located too close to the star, there isn't enough gaseous water to be easily detectable and the dusty disk may block out a lot of the water emission. But if the snow line is located further from the star, there is sufficient gaseous water to be detectable, and that's the case with V883 Ori," said Tobin, who added that the unique state of the protostar is what made this project possible.

V883 Ori's disk is quite massive and is just hot enough that the water in it has turned from ice to gas. That makes this protostar an ideal target for studying the growth and evolution of solar systems at radio wavelengths.

"This observation highlights the superb capabilities of the ALMA instrument in helping astronomers study something vitally important for life on Earth: water," said Joe Pesce, NSF Program Officer for ALMA. "An understanding of the underlying processes important for us on Earth, seen in more distant regions of the galaxy, also benefits our knowledge of how nature works in general, and the processes that had to occur for our solar system to develop into what we know today."

To connect the water in V883 Ori's protoplanetary disk to that in our own solar system, the team measured its composition using ALMA's highly sensitive Band 5 (1.6mm) and Band 6 (1.3mm) receivers and found that it remains relatively unchanged between each stage of solar system formation: protostar, protoplanetary disk, and comets.

"This means that the water in our solar system was formed long before the sun, planets, and comets formed. We already knew that there is plenty of water ice in the interstellar medium. Our results show that this water got directly incorporated into the solar system during its formation," said Merel van 't 'Hoff, an astronomer at the University of Michigan and a co-author of the paper. "This is exciting as it suggests that other planetary systems should have received large amounts of water too."

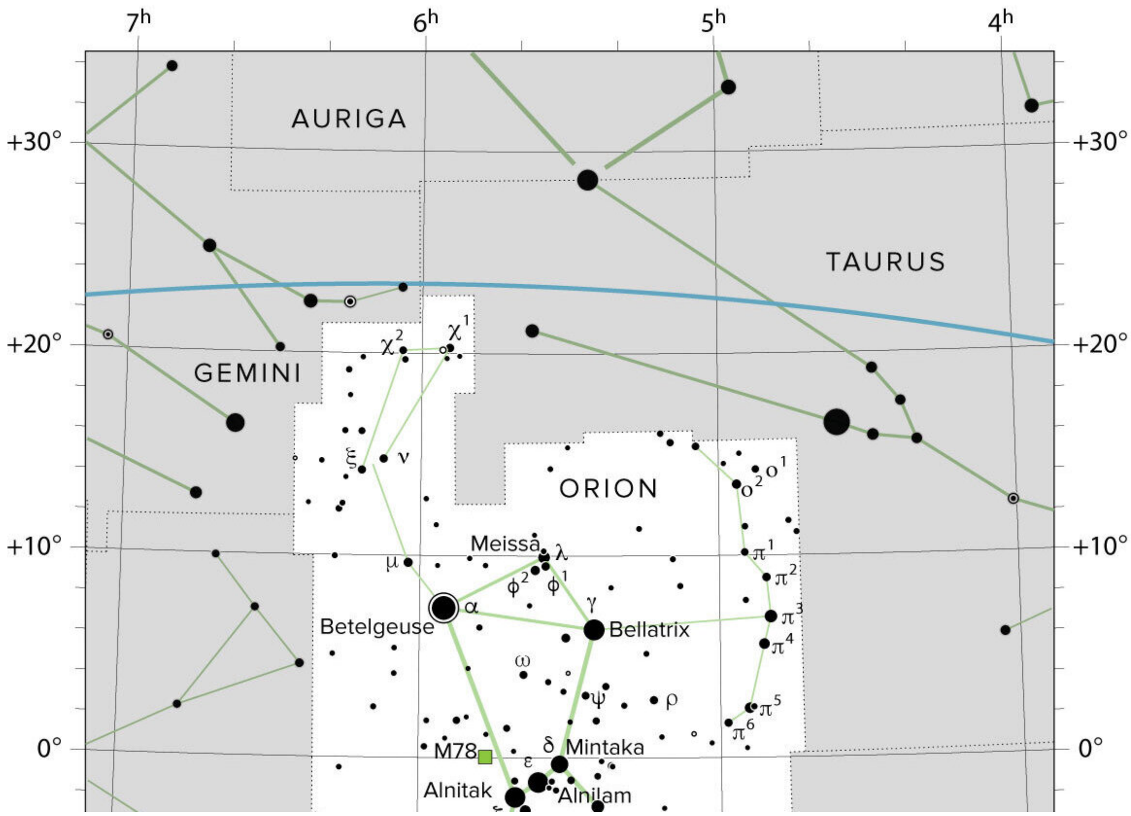


While searching for the origins of water in our Solar System, scientists homed in on V883 Orionis, a unique protostar located 1,305 light-years away from Earth. Unlike with other protostars, the circumstellar disk surrounding V883 Ori is just hot enough that the water in it has transformed from ice into gas, making it possible for scientists to study its composition using radio telescopes like those at the Atacama Large Millimeter/submillimeter Array (ALMA). Radio observations of the protostar revealed water (orange), a dust continuum (green), and molecular gas (blue) which suggests that the water on this protostar is extremely similar to the water on objects in our own Solar System, and may have similar origins. Credit: ALMA (ESO/NAOJ/NRAO), J. Tobin, B. Saxton (NRAO/AUI/NSF)

Clarifying the role of water in the development of comets and planetesimals is critical to building an understanding of how our own solar system developed. Although the sun is believed to have formed in a dense cluster of stars and V883 Ori is relatively isolated with no nearby stars, the two share one critical thing in common: they were both formed in giant molecular clouds.

"It is known that the bulk of the water in the interstellar medium forms as ice on the surfaces of tiny dust grains in the clouds. When these clouds collapse under their own gravity and form young stars, the water ends up in the disks around them. Eventually, the disks evolve and the icy dust grains coagulate to form a new solar system with planets and comets," said Margot Leemker, an astronomer at Leiden University and a co-author of the paper.

"We have shown that water that is produced in the clouds follows this trail virtually unchanged. So, by looking at the water in the V883 Ori disk, we essentially look back in time and see how our own solar system looked when it was much younger."



V883 Orionis is a protostar located roughly 1,305 light-years from Earth in the constellation Orion. Credit: IAU/Sky & Telescope

Tobin added, "Until now, the chain of water in the development of our solar system was broken. V883 Ori is the missing link in this case, and we now have an unbroken chain in the lineage of water from comets and protostars to the interstellar medium."

More information: John Tobin, Deuterium-enriched water ties planet-forming disks to comets and protostars, *Nature* (2023). DOI: 10.1038/s41586-022-05676-z.
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