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In ancient stellar nurseries, some stars are born of fluffy clouds

Observations of the Small Magellanic Cloud: insights into star formation in early-universe-like environments

Fukuoka, Japan—How are stars born, and has it always been this way?

Stars form in regions of space known as stellar nurseries, where high concentrations of gas and dust coalesce to form a baby star. Also called molecular clouds, these regions of space can be massive, spanning hundreds of light-years and forming thousands of stars. And while we know much about the life cycle of a star thanks to advances in technology and observational tools, precise details remain obscure. For example, did stars form this way in the early universe?

Publishing in *The Astrophysical Journal*, researchers from Kyushu University, in collaboration with Osaka Metropolitan University, have found that in the early universe, some stars may have formed in “fluffy” molecular clouds. The results were obtained from observations of the Small Magellanic Cloud and may provide a new perspective on star formation throughout the history of the universe.

In our Milky Way galaxy, the molecular clouds that facilitate star formation have an elongated “filamentary” structure about 0.3 light-years wide. Astronomers believe that our Solar System was formed in the same way, where a large filamentary molecular cloud broke apart to form a stellar egg, also called a molecular cloud core. Over hundreds of thousands of years, gravity would attract gases and matter into the cores to create a star.

“Even today our understanding of star formation is still developing, comprehending how stars formed in the earlier universe is even more challenging,” explains Kazuki Tokuda, a Post-doctoral Fellow at Kyushu University’s Faculty of Science and first author of the study. “The early universe was quite different from today, mostly populated by hydrogen and helium. Heavier elements formed later in high-mass stars. We can’t go back in time to study star formation in the early universe, but we can observe parts of the universe with environments similar to the early universe.”

The team set their sights on the Small Magellanic Cloud (SMC), a dwarf galaxy near the Milky Way about 20,000 light-years from Earth. The SMC contains only about one-fifth of the heavy elements of the Milky Way, making it very close to the cosmic environment of the early universe, about 10 billion years ago. However, the spatial resolution for observing the molecular clouds in the SMC was often insufficient, and it was unclear whether the same filamentary structure could be seen at all.

Fortunately, the ALMA radio telescope in Chile was powerful enough to capture higher-resolution images of the SMC and determine the presence or absence of filamentary molecular clouds.

“In total, we collected and analyzed data from 17 molecular clouds. Each of these molecular clouds had growing baby stars 20 times the mass of our Sun,” continues Tokuda. “We found that about 60% of the molecular clouds we observed had a filamentary structure with a width of about 0.3 light-years, but the remaining 40% had a ‘fluffy’ shape. Furthermore, the temperature inside the filamentary molecular clouds was higher than that of the fluffy molecular clouds."

This temperature difference between filamentary and fluffy clouds is likely due to how long ago the cloud was formed. Initially, all clouds were filamentary with high temperatures due to the clouds colliding with each other. When the temperature is high, the turbulence in the molecular cloud is weak. But as the temperature of the cloud drops, the kinetic energy of the incoming gas causes more turbulence and smoothens the filamentary structure, resulting in the fluffy cloud.

If the molecular cloud retains its filamentary shape, it is more likely to break up along its long "string" and form many stars like our Sun, a low-mass star with planetary systems. On the other hand, if the filamentary structure cannot be maintained, it may be difficult for such stars to emerge.

"This study indicates that the environment, such as an adequate supply of heavy elements, is crucial for maintaining a filamentary structure and may play an important role in the formation of planetary systems," concludes Tokuda. "In the future, it will be important to compare our results with observations of molecular clouds in heavy-element-rich environments, including the Milky Way galaxy. Such studies should provide new insights into the formation and temporal evolution of molecular clouds and the universe."

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For more information about this research, see "ALMA 0.1 pc View of Molecular Clouds Associated with High-Mass Protostellar Systems in the Small Magellanic Cloud: Are Low-Metallicity Clouds Filamentary or Not?" Kazuki Tokuda, Yuri Kunitoshi, Sarolta Zahorecz, Kei E. I. Tanaka, Itsuki Murakoso, Naoto Harada, Masato I. N. Kobayashi, Tsuyoshi Inoue, Marta Sewilo, Ayu Konishi, Takashi Shimonishi, Yichen Zhang, Yasuo Fukui, Akiko Kawamura, Toshikazu Onishi, and, Masahiro N. Machida *The Astrophysical Journal*
https://doi.org/10.3847/1538-4357/ada5f8

About Kyushu University
Founded in 1911, Kyushu University is one of Japan's leading research-oriented institutes of higher education, consistently ranking as one of the top ten Japanese universities in the Times Higher Education World University Rankings and the QS World Rankings. The university is one of the seven national universities in Japan, located in Fukuoka, on the island of Kyushu—the most southwestern of Japan's four main islands with a population and land size slightly larger than Belgium. Kyushu U's multiple campuses—home to around 19,000 students and 8000 faculty and staff—are located around Fukuoka City, a coastal metropolis that is frequently ranked among the world's most livable cities and historically known as Japan's gateway to Asia. Through its VISION 2030, Kyushu U will "drive social change with integrative knowledge." By fusing the spectrum of knowledge, from the humanities and arts to engineering and medical sciences, Kyushu U will strengthen its research in the key areas of decarbonization, medicine and health, and environment and food, to tackle society's most pressing issues.

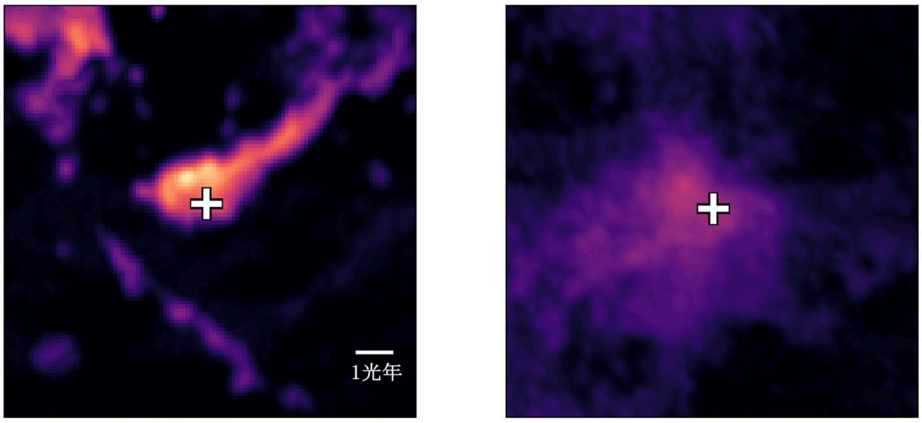

Fig. 1. Example of a filamentary (left) and fluffy (right) molecular cloud in the Small Magellanic Cloud captured by the ALMA telescope. The radio waves emitted by carbon monoxide molecules are shown in color. The brighter the color, the stronger the radio emission. The crosses in the middle indicate the presence of giant baby stars. The left figure shows a molecular cloud with a filamentary structure, and the right figure shows an example of a molecular cloud with a fluffy shape. Scale bar: one light-year. (ALMA (ESO/NAOJ/NRAO), Tokuda et al.).

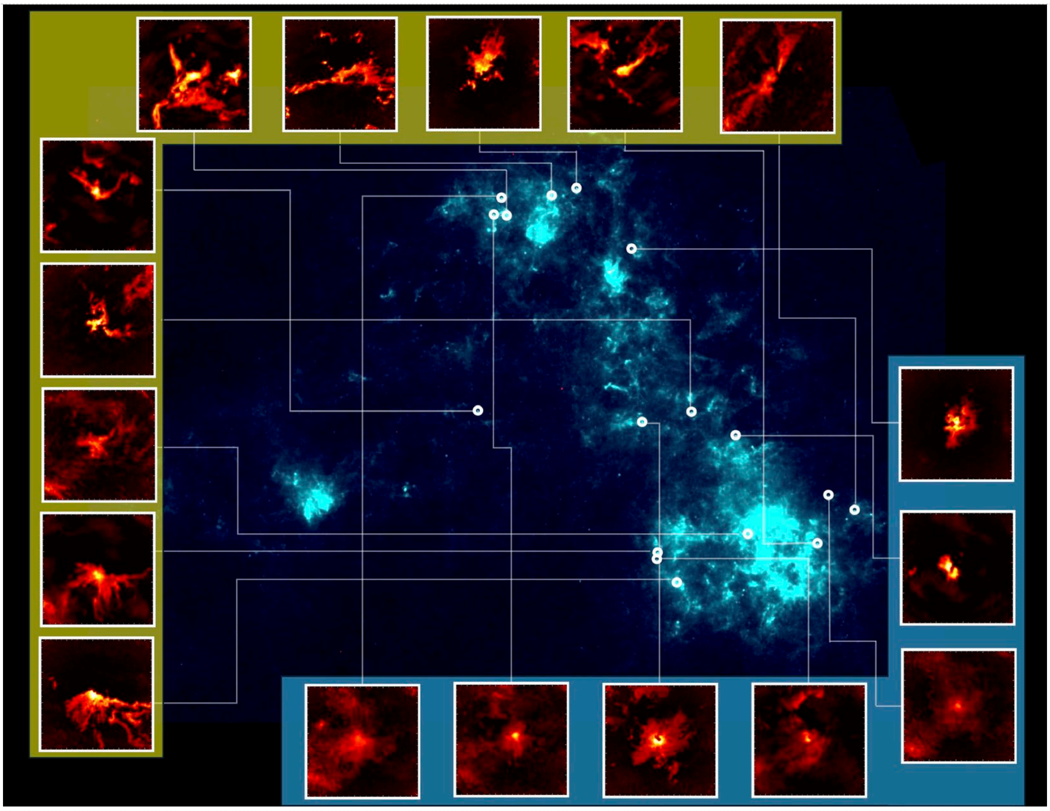

Fig. 2. Molecular clouds in the Small Magellanic Cloud. A far infrared image of the Small Magellanic Cloud as observed by the European Space Agency's (ESA) Herschel Space Observatory. Circles indicate the positions observed by the ALMA telescope, with the corresponding enlarged image of the observed molecular cloud from radio waves emitted by carbon monoxide. The enlarged pictures framed in yellow indicate filamentary structures. The pictures in the blue frame indicate fluffy shapes. (ALMA (ESO/NAOJ/NRAO), Tokuda et al., ESA/Herschel)

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