Discovery of ancient stars on the stellar thin disk of the Milky Way

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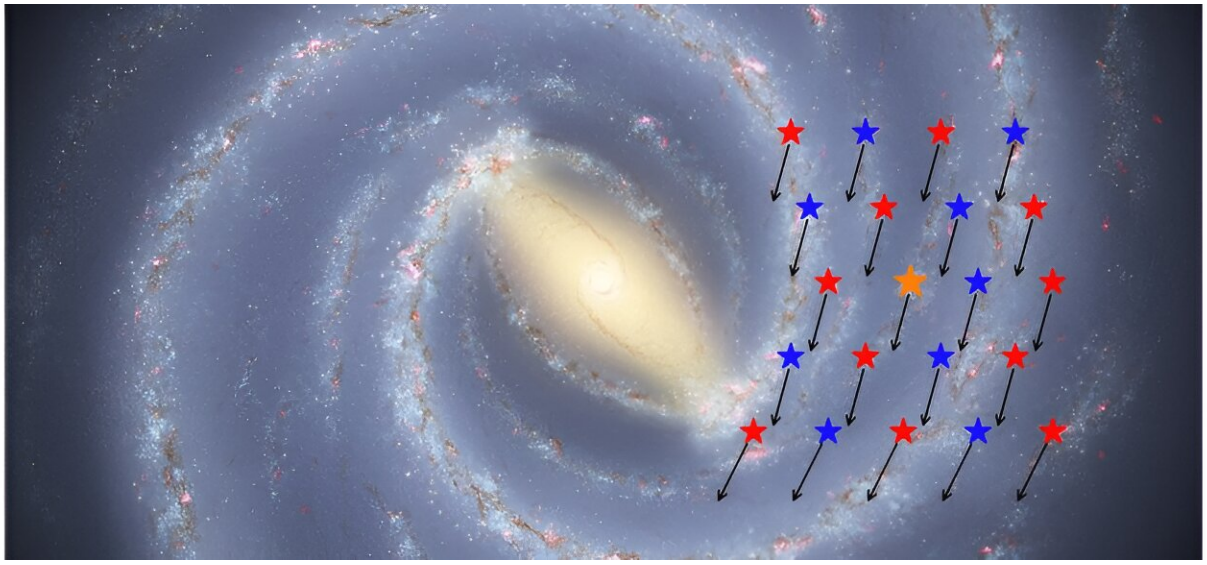

Rotational motion of young (blue) and old (red) stars similar to the Sun (orange). Credit: Background image by NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

A surprising discovery about the evolution of our galaxy using data from the Gaia mission found a large number of ancient stars on orbits similar to that of our sun. They formed the Milky Way's thin disk less than 1 billion years after the Big Bang, several billion years earlier than previously believed.

The Milky Way galaxy has a large halo, a central bulge and bar, a thick

disk and a thin disk. Most stars are located in the so-called thin disk of our Milky Way and follow an organized rotation around the galactic center. Middle-aged stars such as our 4.6-billion-year-old sun belong to the thin disk, which was generally thought to have started forming around 8 to 10 billion years ago.

Understanding how the Milky Way was formed is a major goal of galactic archaeology. To achieve this, detailed maps of the galaxy that show the ages, chemical compositions, and movements of stars are needed. These maps, known as chrono-chemo-kinematical maps, help to piece together the history of our galaxy. Creating these detailed maps is challenging because it requires large datasets of stars with accurately known ages.

One common approach to overcome this challenge is to study very metal-poor stars, which are old, to provide a window into the early Milky Way. Very metal-poor stars are known to be old because they were among the first stars to form when the universe was still largely composed of hydrogen and helium, before many of the heavier elements were created and distributed by successive generations of stars.

Using a data set from the European Space Agency (ESA) Gaia Mission, an international team led by astronomers from the Leibniz Institute for Astrophysics Potsdam (AIP) studied stars in the solar neighborhood, about 3,200 light years around the sun. They discovered a surprising number of very old stars in thin disk orbits; the majority of these are older than 10 billion years, some of them even older than 13 billion years.

These ancient stars show a wide range of metal compositions: some are very metal-poor (as expected), while others have twice the metal content of our much younger sun, indicating that a rapid metal enrichment took place in the early phase of the Milky Way's evolution.

"These ancient stars in the disk suggest that the formation of the Milky Way's thin disk began much earlier than previously believed, by about 4–5 billion years," explains Samir Nepal from AIP and first author of the study, which has been accepted for publication by *Astronomy and Astrophysics* and is available on the *arXiv* preprint server.

"This study also highlights that our galaxy had an intense star formation at early epochs leading to very fast metal enrichment in the inner regions and the formation of the disk. This discovery aligns the Milky Way's disk formation timeline with those of high-redshift galaxies observed by the James Webb Space Telescope (JWST) and Atacama Large Millimeter Array (ALMA) Radio Telescope.

"It indicates that cold disks can form and stabilize very early in the universe's history, providing new insights into the evolution of galaxies."

"Our study suggests that the thin disk of the Milky Way may have formed much earlier than we had thought, and that its formation is strongly related to the early chemical enrichment of the innermost regions of our galaxy," explains Cristina Chiappini. "The combination of data from different sources and the application of advanced machine learning techniques have enabled us to increase the number of stars with high quality stellar parameters, a key step to lead our team to these new insights."

The results were made possible by the third data release of the Gaia mission. The team analyzed the stellar parameters of more than 800,000 stars using a novel machine learning method that combines information from different types of data to provide improved stellar parameters with high precision. These precise measurements include gravity, temperature, metal content, distances, kinematics and the age of the stars.

In the future, a similar machine learning technique will be used to analyze millions of spectra, collected by the 4MIDABLE-LR survey with the 4-meter Multi-Object Spectroscopic Telescope (4MOST), starting operations in 2025.

More information: Samir Nepal et al, Discovery of the local counterpart of disc galaxies at z > 4: The oldest thin disc of the Milky Way using Gaia-RVS, *arXiv* (2024). DOI: 10.48550/arxiv.2402.00561

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