Formation of super-Earths proven limited near metal-poor stars

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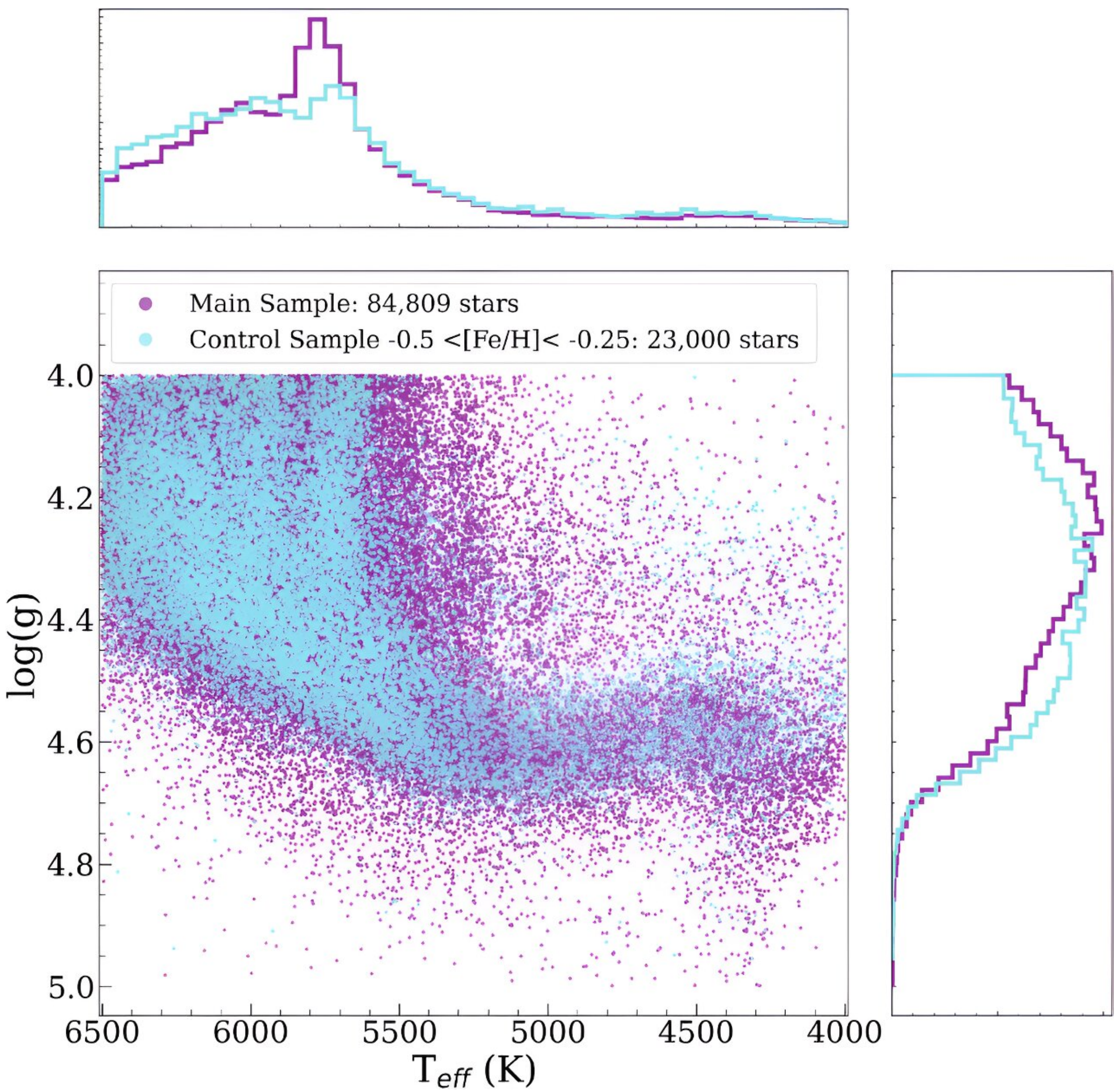

The stellar sample from TESS portrayed in the T_{eff} and log(g) plane. We show the main sample (−1 ≤ [Fe/H] ≤ −0.5) in purple, and the subsample (−0.5 The Astronomical Journal (2024). DOI: 10.3847/1538-3881/ad6570

In a new study, astronomers report novel evidence regarding the limits of planet formation, finding that after a certain point, planets larger than Earth have difficulty forming near low-metallicity stars.

Using the sun as a baseline, astronomers can measure when a star formed by determining its metallicity, or the level of heavy elements present within it. Metal-rich stars or nebulas formed relatively recently, while metal-poor objects were likely present during the early universe.

Previous studies found a weak connection between metallicity rates and planet formation, noting that as a star's metallicity goes down, so, too, does planet formation for certain planet populations, like sub-Saturns or sub-Neptunes.

Yet this work is the first to observe that under current theories, the formation of super-Earths near metal-poor stars becomes significantly more difficult, suggesting a strict cut-off for the conditions needed for one to form, said lead author Kiersten Boley, who recently received a Ph.D. in astronomy at The Ohio State University.

"When stars cycle through life, they enrich the surrounding space until you have enough metals or iron to form planets," said Boley. "But even for stars with lower metallicities, it was widely thought that the number of planets it could form would never reach zero."

Other studies posited that planet formation in the Milky Way should begin when stars fall between negative 2.5 to negative 0.5 metallicity, but until now, that theory was left unproven.

To test this prediction, the team developed and then searched a catalog of 10,000 of the most metal-poor stars observed by NASA's Transiting Exoplanet Survey Satellite (TESS) mission. If correct, extrapolating known trends to search for small, short-period planets around one region of 85,000 metal-poor stars would have led them to discover about 68 super-Earths.

Surprisingly, researchers in this work detected none, said Boley. "We essentially found a cliff where we expected to see a slow or a gradual slope that keeps going," she said. "The expected occurrence rates do not match up at all."

The study was published in *The Astronomical Journal.*

This cliff, which provides scientists with a time frame during which metallicity was too low for planets to form, extends to about half the age of the universe, meaning that super-Earths did not form early in its history.

"Seven billion years ago is probably the sweet spot where we begin to see a decent bit of super-Earth formation," Boley said.

Moreover, as the majority of stars formed before that era have low metallicities and would have needed to wait until the Milky Way had been enriched by generations of dying stars to create the right conditions for planet formation, the results successfully propose an upper limit on the number and distribution of small planets in our galaxy.

"In a similar stellar type as our sample, we now know not to expect planet formation to be abundant once you pass a negative 0.5 metallicity region," said Boley. "That's kind of striking because we actually have data to show that now."

What's also striking is the study's implications for those searching for life beyond Earth, as having a more precise grasp on the intricacies of planet formation can supply scientists with detailed knowledge about where in the universe life might have flourished.

"You don't want to search areas where life wouldn't be conducive or in areas where you don't even think you're going to find a planet," Boley said. "There's just a plethora of questions that you can ask if you know these things."

Such inquiries could include determining if these exoplanets hold water, the size of their core, and if they've developed a strong magnetic field, all conditions conducive for generating life.

To apply their work to other types of planet formation processes, the team will likely need to study different types of super-Earths for longer periods than they can today. Fortunately, future observations could be attained with the help of upcoming projects like NASA's Nancy Grace Roman Space Telescope and the European Space Agency's PLATO mission, both of which will widen the search for terrestrial planets in habitable zones like our own.

"Those instruments will be really vital in terms of figuring out how many planets are out there and getting as many follow-up observations as we can," said Boley.

Other co-authors include Ji Wang from Ohio State; Jessie Christiansen, Philip Hopkins and Jon Zink from The California Institute of Technology; Kevin Hardegree-Ullman and Galen Bergsten from The University of Arizona; Eve Lee from McGill University; Rachel Fernandes from The Pennsylvania State University; and Sakhee Bhure from the University of Southern Queensland.

More information: Kiersten M. Boley et al, The First Evidence of a Host Star Metallicity Cutoff in the Formation of Super-Earth Planets, *The Astronomical Journal* (2024). DOI: 10.3847/1538-3881/ad6570

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