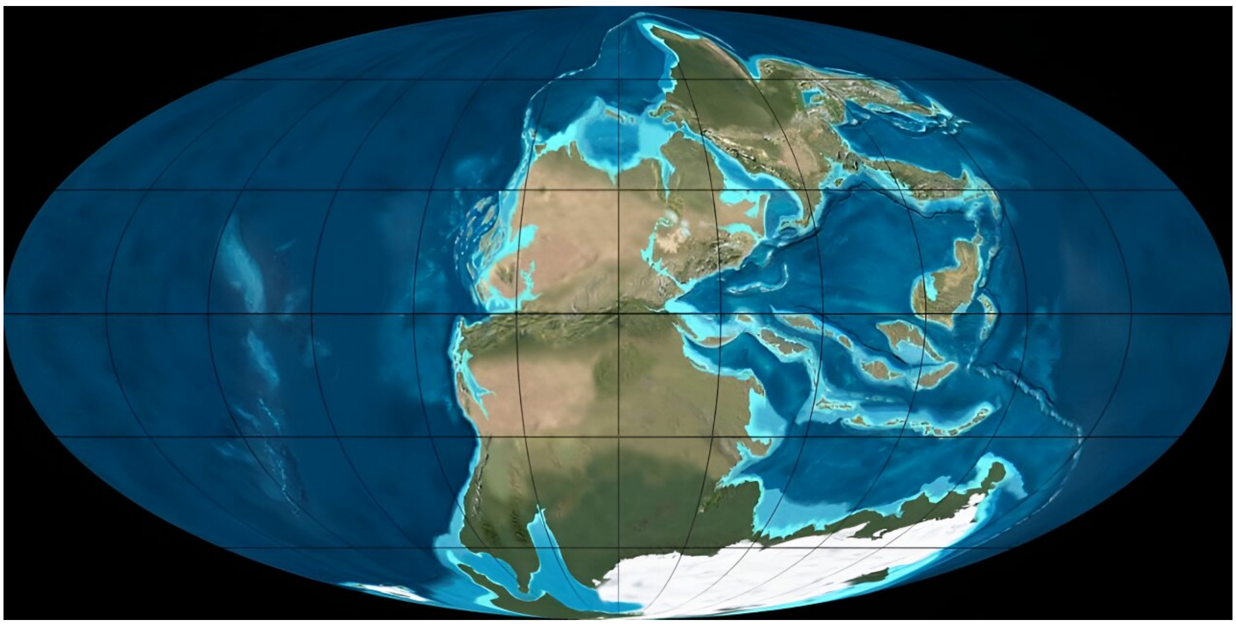
When did the first exocontinents appear in the universe?

September 20 2023, by Evan Gough



Continents might be necessary for life, especially complex life. This image shows super-continent Pangaea during the Permian period (300–250 million years ago). Credit: NAU Geology/Ron Blakey

On Earth, continents are likely necessary to support life. Continents "float" on top of the Earth's viscous mantle, and heat from the planet's core keeps the mantle from solidifying and locking the continents into place.

The core is hot because of the presence of radioactive elements that came from neutron star collisions. It should be possible to calculate when the first continents formed in the universe.

So that's what one researcher did.

Jane Greaves is an astronomy professor in the School of Physics and Astronomy at Cardiff University in Wales. Her work focuses on planet formation and habitability. Her new research is published in *Research Notes of the AAS*. Its title is a simple question: "When were the First Exocontinents?"

Greaves' work is aimed at making the search for habitable worlds more effective. If continents and the plate tectonics that allow for them are critical for life, then narrowing down the likely locations of rocky planets can make the search for habitable worlds more effective.

First of all, why are continents and plate tectonics important?

Plate tectonics may not be entirely necessary for life. But they play an important role by moderating Earth's temperature. They allow heat to vent from the core, and too much heat in the core would inhibit Earth's protective magnetosphere. They also help keep Earth in the so-called Goldilocks zone. However, some research shows that plate tectonics weren't very active billions of years ago when life first appeared. So they may not be necessary for life to begin, but for life to persist and evolve into more complex creatures like humans, they're likely necessary.

Plate tectonics might not be necessary for life to get started on a planet. But tectonics and continents are likely for life to persist and evolve in complexity. Credit: University of Rochester illustration / Michael Osadciw

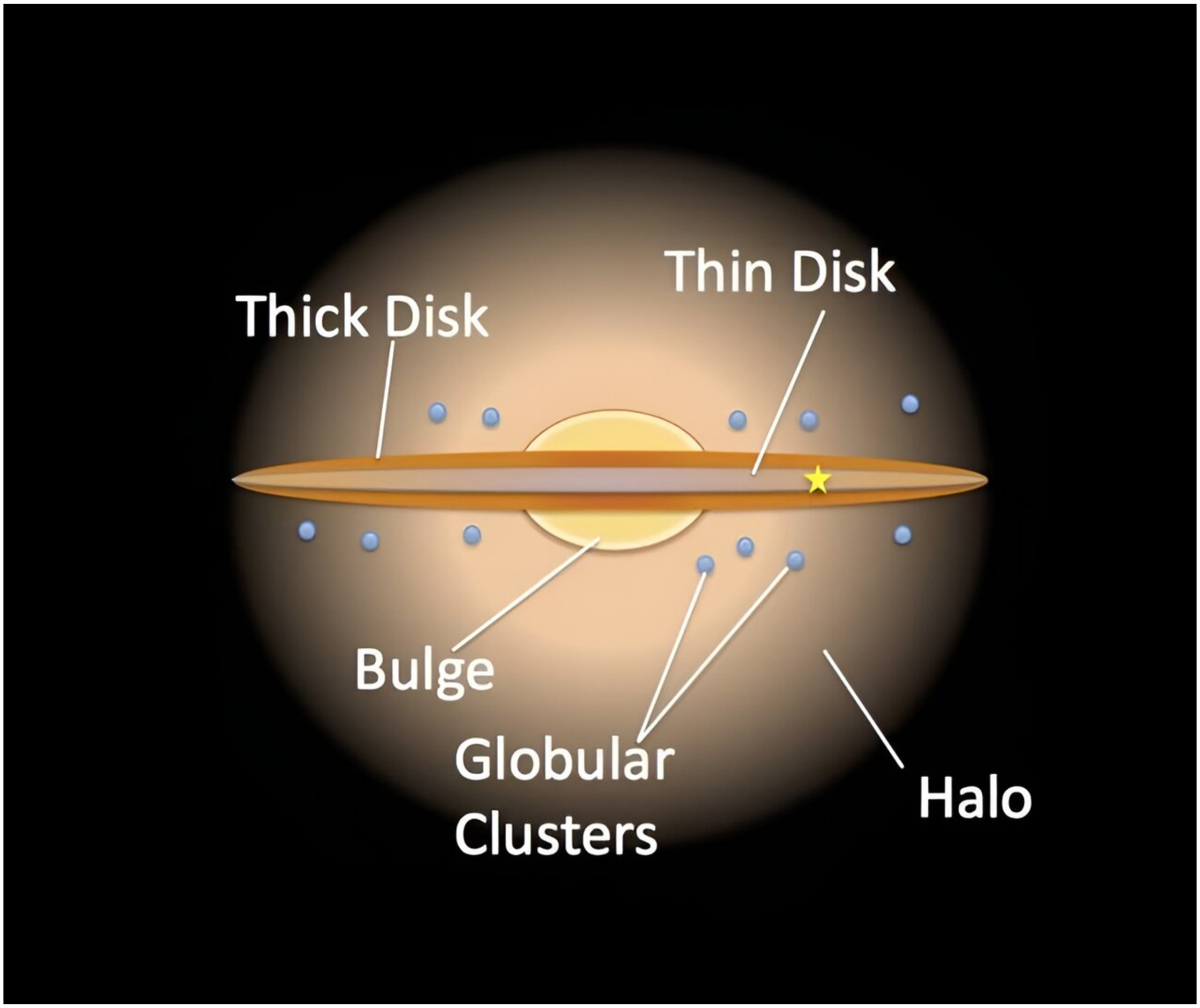
So the search for life and habitable planets should be biased towards rocky planets with plate tectonics. What we really want to find are planets with continents. Planets with continents can support more biomass for longer time periods than planets without, and plate tectonics create continents.

Reaves found a way to trace which planets might have continents, by tracing which planets might have plate tectonics. A lot of it comes down to heat. If the core of a rocky planet produces enough heat, then there are likely active plate tectonics, and we know why Earth's core produces heat.

The core contains the radioactive isotopes ^{238}Uranium, ^{232}Thorium, and ^{40}Potassium. Over geological timescales, these elements decay into other elements and produce heat. These elements don't just appear by happenstance. They're formed in neutron stars and in supernova explosions.

There's an enormous amount of detail in all of this, and one study can't corral it all. Greaves' work is a wider view attempt at understanding it. "Here I present an exploratory method, for hypothetical Earth-like planets of stars whose photospheric abundances allow some inference of planetary radiogenic heating," she writes.

The link between stars and the planets that form around them plays a role in this. Planets form from the solar nebula, the same material that a star forms from. So the abundance of different chemical elements in a star is reflected in planets that form around them.



An artist's impression of the Milky Way shows the thick and thin discs. Thin disk stars are younger and have higher metallicity than the older, metal-poor stars in the thick disk. Credit: NASA/JPL Caltech/R.Hurt/SSC

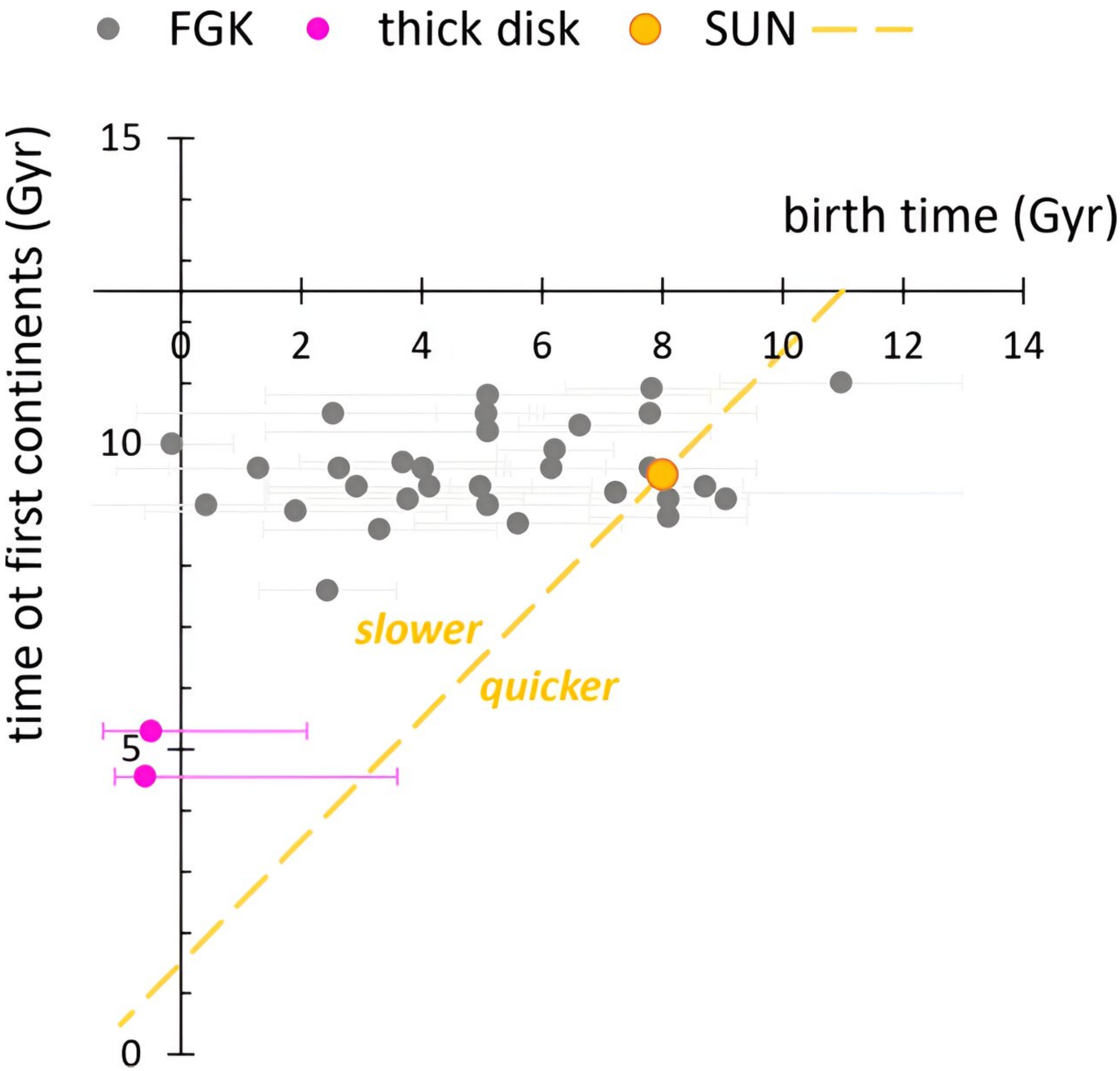
Greaves took data from previous studies about stellar abundances of different elements and then combined them with the ages of the stars from Gaia. She looked at two separate populations of stars for accuracy: thin-disk stars and thick-disk stars. Thin disk stars are typically younger and have higher metallicity, while thick disk stars are older and metal-poor.

Her results show that the appearance of continents on Earth represents the median value.

Earth's plate tectonics began about 3 billion years ago, or about 9.5 billion years since the beginning of the universe. In Greaves' sample, the first continents appeared 2 billion years before Earth's on thin disk stars. The thick disk stars in her work produced rocky planets with continents that appeared even earlier: about 4 to 5 billion years before Earth's.

She also found that on most planets, continents will form more slowly than on Earth. Planets need the right amount of heat to form continents, and too much heat is adverse.

Greaves also found a correlation between continents and the Fe/H ratio in stars. "There is an overall trend versus stellar iron content, with continents appearing earlier at lower [Fe/H]," she writes.



This figure from the study presents some of Greaves' results. Grey dots represent types F, G, and K stars. Our sun is a G-type star, and F and K stars are similar enough to be grouped together in this work. The pink dots represent the two thick-disk stars in the study, and the orange dot is our sun, for reference. The yellow dashed line divides planets where continents form either more slowly or more quickly than on Earth. The axes cross at 12.5 billion years, the current age of the universe. Image Credit: Jane S. Greaves, *Research Notes of the AAS* (2023). DOI: 10.3847/2515-5172/acf91a

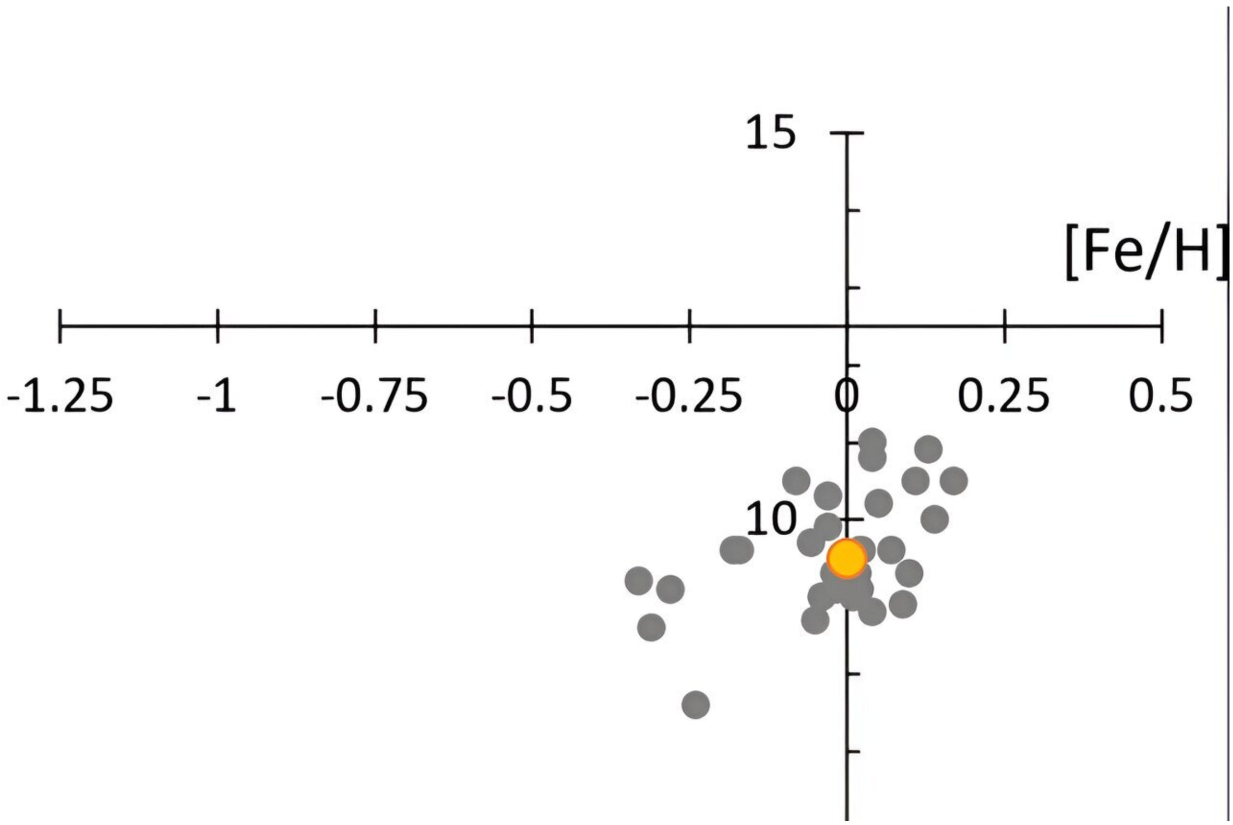
Greaves writes that stars with lower metallicity than our sun might be a good place to search for habitable exoplanets with continents. "Systems with sub-solar metallicity seem particularly interesting," she writes. In her sample, all of those planets formed continents more quickly than Earth, so advanced life is more likely there. Maybe even more advanced than us.

The thick disk stars are also intriguing since they clearly developed continents quickly. "The example thick disk systems are especially far ahead, meriting more investigation," she writes, adding that out of all the stars that we know that have exoplanets, only 7% are thick disk stars.

The upcoming Habitable Worlds Observatory is years away from launch, and there's time for the scientific community to sort out its search criteria and what makes the best targets. "Habitable Worlds Observatory has only 46 FGK stars in its top-tier target list," she writes. But 15 of them are in her results. If her work is correct, "…there could be two systems in this sample alone with biospheres more advanced than here on Earth."

Greaves concludes that the outlook for finding habitable planets with long-lived continents is good. "The outlook seems very promising for finding rocky exoplanets with continents, given that nearby sun-like stars have already produced a few candidate hosts," she writes.

The next step is to investigate the stellar abundances of the thorium and potassium isotopes that cause radiogenic heating. Doing that "…could help to uncover more old systems where life on land could pre-date that on Earth."



This figure from the study shows the age of the universe on the x-axis and the Fe/H, a broad measure of stellar metallicity, on the y-axis. The grey dots are F, G, and K-type stars, and the pink dots are the thick-disk stars, which are clear outliers to the rest. Credit: Jane S. Greaves, *Research Notes of the AAS* (2023). DOI: 10.3847/2515-5172/acf91a

Some elements are geophysically critical, especially the radiogenic heat-producing ones like U, Th and K. When you add in Fe, this group of elements is critical to a planet's core size, gravity, and it's internal temperature. A planet's internal temperature is critical, not only because it governs the life-supporting magnetosphere, but also because it helps create the conditions for plate tectonics and continents.

Previous research shows a higher likelihood of Earth-like planets with continents earlier in galactic history and a drop-off as the galaxy evolves. But we've still got a lot to learn about exoplanets, habitability, radiogenic heating, continents and plate tectonics, and a hundred other things.

We can't say for sure where we'll find life or in what geophysical environments. All we can do is take note of Earth, keep building more powerful telescopes, and be patient.

More information: Jane S. Greaves, When were the First Exocontinents?, *Research Notes of the AAS* (2023). DOI: 10.3847/2515-5172/acf91a

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