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Gaps in Exoplanet Sizes Shift with Age

Twenty-six years ago, astronomers discovered the first planet orbiting a distant Sun-like star. Today thousands of exoplanets are known to inhabit our local swath of the Milky Way, and that deluge of data has inadvertently revealed a cosmic mystery: Planets just a bit larger than Earth appear to be relatively rare in the exoplanet canon.

A team has now used observations of hundreds of exoplanets to show that this planetary gap isn't static but instead evolves with planet age—younger planetary systems are more likely to be missing slightly smaller planets, and older systems are more apt to be without slightly larger planets. This evolution is consistent with the hypothesis that atmospheric loss—literally, a planet's atmosphere blowing away over time—is responsible for this so-called "radius valley," the researchers suggested.

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Changes with Age

In 2017, scientists reported the first confident detection of the radius valley (bit.ly/gap-radius). (Four years earlier, a different team had published a tentative detection; bit.ly/tentative-detection.) Defined as a relative paucity of exoplanets roughly 50%–100% larger than Earth, the radius valley is readily apparent when looking at histograms of planet size, said Julia Venturini, an astrophysicist at the International Space Science Institute in Bern, Switzerland, not involved in the new research. "There's a depletion of planets at about 1.7 Earth radii."

Trevor David, an astrophysicist at the Flatiron Institute in New York, and his colleagues were curious to know whether the location of the radius valley—that is, the planetary size range it encompasses—evolves with planet age. That's an important question, said David, because finding evolution in the radius valley could shed light on its cause or causes. It's been proposed that some planets lose their atmospheres over time, which causes them to change size. If the timescale over which the radius valley evolves matches the timescale of atmospheric loss, it might be possible to pin down that process as the explanation, said David.

In a new study published in the *Astronomical Journal,* the researchers analyzed planets originally discovered using the Kepler Space Telescope (bit.ly/exoplanet-size-distribution). They focused on a sample of roughly 1,400 planets whose host stars had been observed spectroscopically. Their first task was to determine the planets' ages, which they assessed indirectly by estimating the ages of their host stars. (Because it takes just a few million years for planets to form around a star, these objects, astronomically speaking, have very nearly the same ages.)

"There's a depletion of planets at about 1.7 Earth radii."

The team calculated planet ages ranging from about 500 million years to 12 billion years, but "age is one of those parameters that's very difficult to determine for most stars," David said. That's because estimates of stars' ages rely on theoretical models of how stars evolve, and those models aren't perfect when it comes to individual stars, he said. For that reason, the researchers decided to base most of their analyses on a coarse division of their sample into two age groups, one corresponding to stars younger than a few billion years and one encompassing stars older than about 2–3 billion years.

A Moving Valley

When David and his collaborators looked at the distribution of planet sizes in each group, they indeed found a shift in the radius valley: Planets within it tended to be about 5% smaller, on average, in younger planetary systems compared with older planetary systems. It wasn't wholly surprising to find this evolution, but it was unexpected that it persisted over such long timescales [billions of years], said David. "What was surprising was how long this evolution seems to be."

These findings are consistent with planets losing their atmospheres over time, David and his colleagues proposed. The idea is that most planets develop atmospheres early on but then lose them, effectively shrinking in size from just below Neptune's (roughly 4 times Earth's radius) to just above Earth's. "We're inferring that some sub-Neptunes are being converted to super-Earths through atmospheric loss," said David. As time goes on, larger planets lose their atmospheres, which explains the evolution of the radius valley, the researchers suggested.

Kicking Away Atmospheres

Atmospheric loss can occur via several mechanisms, scientists believe, but two in particular are believed to be relatively common. Both involve energy being transferred into a planet's atmosphere to the point that it can heat to thousands of degrees kelvin. That input of energy gives the atoms and molecules within an atmosphere a literal kick, and some of them, particularly lighter species like hydrogen, can escape.

"You can boil the atmosphere of a planet," said Akash Gupta, a planetary scientist at the University of California, Los Angeles not involved in the research.

In the first mechanism—photoevaporation—the energy is provided by X-ray and ultraviolet photons emitted by a planet's host star. In the second mechanism—core cooling—the source of the energy is the planet itself. An assembling planet is formed from successive collisions of rocky objects, and all of those collisions deposit energy into the forming planet. Over time, planets reradiate that energy, some of which makes its way into their atmospheres.

"Age is one of those parameters that's very difficult to determine for most stars."

Theoretical studies have predicted that photoevaporation functions over relatively short timescales—about 100 million years—while core cooling persists over billions of years. But concluding that core cooling is responsible for the evolution in the radius valley would be premature, said David, because some researchers have suggested that photoevaporation can also act over billions of years in some cases. It's hard to pinpoint which is more likely at play, said David. "We can't rule out either the photoevaporation or core-powered mass loss theories."

It's also a possibility that the radius valley arises because of how planets form, not how they evolve. In the future, David and his colleagues plan to study extremely young planets, those only about 10 million years old. These youngsters of the universe should preserve more information about their formation, the researchers hope.

By **Katherine Kornei** (@KatherineKornei), Science Writer

Chasing Magma Around Iceland's Reykjanes Peninsula

Icelandic Meteorological Office seismologist Kristín Jónsdóttir stands on solidified black basalt that glows red from erupting Fagradalsfjall volcano behind her. Credit: Kristín Jónsdóttir

In December 2019, Reykjanes Peninsula, which juts into the Atlantic Ocean southwest of Iceland's capital city of Reykjavík, began experiencing intense seismic swarms. Since then, scientists at the Icelandic Meteorological Office have been tracking and monitoring deformation of Earth's surface as magma intruded into the shallow crust. Three initial intrusions occurred near Mount Thorbjörn, just outside the town of Grindavík. A fourth slightly inflated the peninsula's westernmost tip, and a fifth leapfrogged back east, beyond Grindavík, to Krýsuvík, according to Sara Barsotti, an Italian volcanologist and coordinator for volcanic hazards at the Icelandic Meteorological Office.

More than a year after this unrest began, on 24 February 2021, a large earthquake measuring magnitude 5.7 jolted the peninsula between Keilir and Fagradalsfjall volcanoes, "marking a turning point," Barsotti said.

Soon thereafter, the Icelandic Meteorological Office's seismic network recorded more than 50,000 earthquakes on the peninsula. Using the monitoring tools at their disposal, scientists found a corridor of magma between Keilir and Fagradalsfjall, said Barsotti. This magma flowed underground for approximately 3 weeks, with earthquakes defining the edges of the subterranean chamber. Then both seismicity and deformation plummeted.

At that point, some scientists hypothesized that the intrusion would freeze within the crust, said Kristín Jónsdóttir, a seismologist at the Icelandic Meteorological Office. "Then," she said, "the eruption started."

Keeping Crowds Safe

On 19 March, lava began to erupt from the edge of the intrusion near Fagradalsfjall, and Icelanders flocked to the mountains above the fissure to picnic, play football, or simply