Climates of Distant Terrestrial Worlds

Wednesday, November 27, 2019
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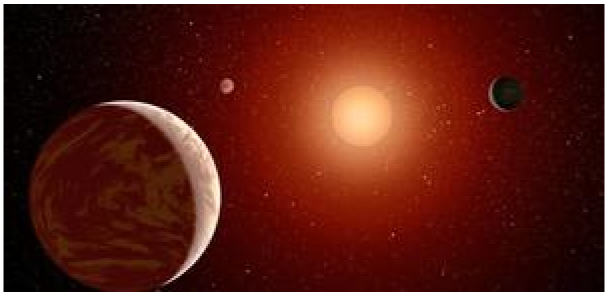

Artist’s illustration of an M-dwarf star surrounded by three planets.

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NASA/JPL-Caltech

Radiation In, Radiation Out

The climate for a planet like Earth is largely set by the delicate balance between incoming radiation from the planet’s star, and outgoing radiation in the form of heat emitted into space. The amount of energy absorbed, reflected, and emitted by a planet’s surface and atmosphere dictate how this balance plays out.

Diagram describing the annual mean energy budget for a planet orbiting a G dwarf star.

Click to enlarge. [Adapted from Shields et al. 2019]

The pathways that govern this *global energy budget* for our own planet have been worked out through many decades of modeling and analysis of observations — to the point where we can identify sources of imbalance in the Earth's system, like those currently caused by anthropogenic CO_2 emissions.

But these climate models don't apply directly to other planets, because the factors that determine a planet's global energy budget all depend on the wavelength distribution of incoming light. Since stars of different temperatures emit varying amounts of radiation at different wavelengths, models that describe the energy budget for a planet around a Sun-like G dwarf won't accurately describe a planet around a cooler M dwarf or hotter F dwarf.

So how *do* the climates of distant, Earth-like worlds change when orbiting a different type of host star? A team of scientists led by Aomawa Shields (University of California, Irvine) has now used detailed 3D global climate models to find out.

A Difference of Hosts

Shields and collaborators' models of terrestrial planets take into account details like the interaction between the incoming host star's radiation and gases like CO_2 and H_2O in the planet's atmosphere, as well as with icy and snowy surfaces on the ground.

Plot of the global mean surface temperature as a function of the amount of incoming stellar radiation at the top of the planet's atmosphere, shown for a planet orbiting an F dwarf (blue triangles), a G dwarf (black plus symobls), and an M dwarf (red x symbols). [Adapted from Shields et al. 2019]

The authors show that M-dwarf planets absorb more of their hosts' radiation, both in their atmospheres and their surfaces, whereas F-dwarf planets absorb less. As a result, a planet can have a climate similar to that of modern-day Earth if it’s receiving current solar amounts of incoming radiation from a G-dwarf star — but to achieve the same climate around an M-dwarf star, it would need to receive 12% less incoming radiation. Around an F-dwarf star, it would need to receive 8% more.

What about rotation? The above models assumed that the planets all had 24-hour rotation rates, but Shields and collaborators also test how this compares to a tidally locked planet that always shows the same face to its host. For an M-dwarf host, a tidally locked planet has lower minimum and maximum dayside temperatures when compared with a planet with a 24-hour rotation period; the average dayside temperature is around 37 K colder on the tidally locked planet.

As we continue to discover more planets around a variety of stars, a constant question is whether these distant worlds have the potential to support life. Understanding how these planets’ global climates are shaped by their host stars is an important part of this exploration!

Citation

“Energy Budgets for Terrestrial Extrasolar Planets,” Aomawa L. Shields et al 2019 *ApJL* 884 L2. doi:10.3847/2041-8213/ab44ce

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In the Media
Physics & Astronomy
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