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Simulations of vaporization of Earth-like planets tell planet-hunters what to look for in atmospheres of super-Earths

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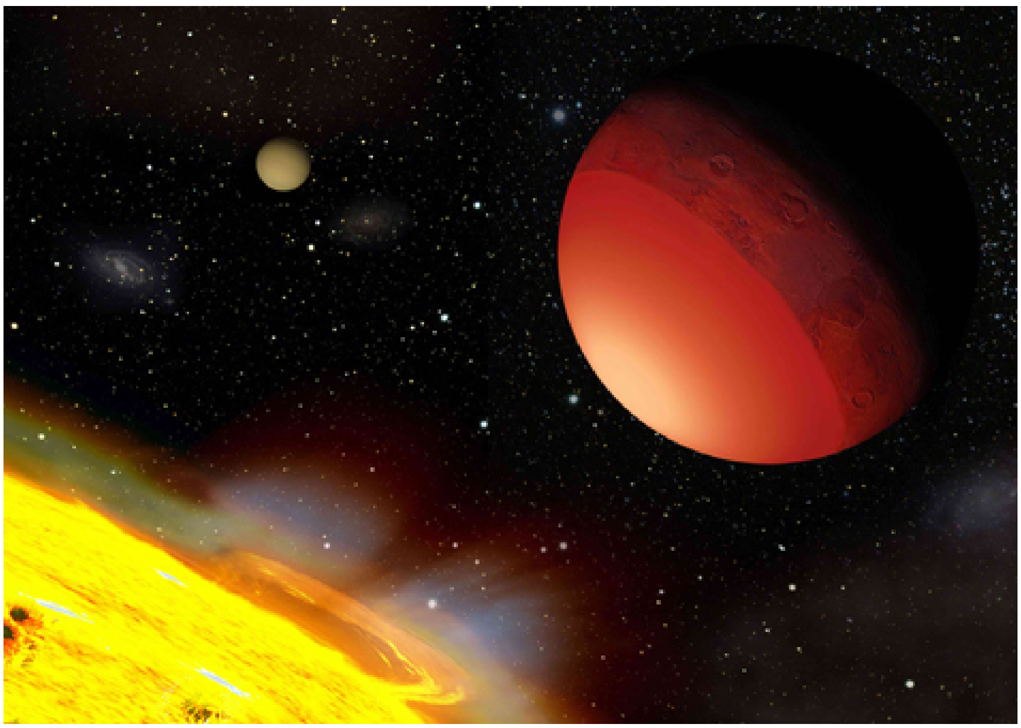

Scientists at Washington University have simulated the atmospheres of hot Earth-like planets, such as CoRoT-7b, shown here in an artist's conception. CoRoT-7b orbits so close to its star that its starward side is an ocean of molten rock. By looking for atmospheres like those generated by the simulations, astronomers should be able to identify Earth-like exoplanets. (A. LEGER ET AL./ICARUS)

(Phys.org) -- In science fiction novels, evil overlords and hostile aliens often threaten to vaporize the Earth. At the beginning of *The Hitchhikers Guide to the Galaxy*, the officiously bureaucratic aliens called Vogons, authors of the third-worst poetry in the universe, actually follow through on the threat, destroying the Earth to make way for a hyperspatial express route.

"We scientists are not content just to talk about vaporizing the Earth," says Bruce Fegley, professor of earth and planetary sciences at Washington University in St. Louis, tongue firmly in cheek. "We want to understand exactly what it would be like if it happened."

And in fact Fegley, PhD, and his colleagues Katharina Lodders, PhD, a research professor of earth and planetary sciences who is currently on assignment at the National Science Foundation, and Laura Schaefer, currently a graduate student at Harvard University, have vaporized the Earth — if only by simulation, that is mathematically and inside a computer.

They weren't just practicing their evil overlord skills. By baking model Earths, they are trying to figure out what astronomers should see when they look at the atmospheres of super-Earths in a bid to learn the planets' compositions.

Super-earths are planets outside our solar system (exoplanets) that are more massive than Earth but less massive than Neptune and made of rock instead of gas. Because of the techniques used to find them, most of the detected super-Earths are those which orbit close to their stars —within rock-melting distance.

Their NSF- and NASA-funded research, described in the August 10 issue of *The Astrophysical Journal*, show that Earth-like planets as hot as these exoplanets would have atmospheres composed mostly of steam and carbon dioxide, with smaller amounts of other gases that could be used to distinguish one planetary composition from another.

The WUSTL team is collaborating with Dr. Mark Marley's research group at the NASA Ames Research Center to convert the gas abundances they have calculated into synthetic spectra the planet hunters can compare to spectra they measure.

Motivated by degeneracy

Under favorable circumstances planet hunting techniques allow astronomers not just to find exoplanets but also to measure their average density.

The average density together with theoretical models lets the astronomers figure out the bulk chemical composition of gas giants, but in the case of rocky planets the possible variety of rocky ingredients can often add up several different ways to the same average density.

This is an outcome scientists, who would prefer one answer per question, call degeneracy.

If a planet passes in front of its star, so that astronomers can observe the light from the star filtered by the planet's atmosphere, they can determine the composition of the planet's atmosphere, which allows them to distinguish about alternative bulk planetary compositions.

"It's not crazy that astronomers can do this and more people are looking at the atmospheres of these transiting exoplanets," Fegley says. "Right now, there are eight transiting exoplanets where astronomers have done some atmospheric measurements and more will probably be reported in the near future."

"We modeled the atmospheres of hot super-Earths because that's what astronomers are finding and we wanted to predict what they should be looking for when they look at the atmospheres to decipher the nature of the planet," Fegley says.

Two model Earths

Even though the planets are called super-Earths, Fegley says, the term is a reference to their mass and makes no claim about their composition, much less their habitability. But, he says, you start with what you know.

The team ran calculations on two types of pseudo-Earths, one with a composition like that of the Earth's continental crust and the other, called the BSE (bulk silicate Earth), with a composition like the Earth's before the continental crust formed, which is the composition of the silicate portion of the primitive Earth before the crust formed.

The difference between the two models, says Fegley, is water. The Earth's continental crust is dominated by granite, but you need water to make granite. If you don't have water, you end up with a basaltic crust like Venus. Both crusts are mostly silicon and oxygen, but a basaltic crust is richer in elements such as iron and magnesium.

Fegley is quick to admit the Earth's continental crust is not a perfect analog for lifeless planets because it has been modified by the presence of life over the past four billion years, which both oxidized the crust and also led to production of vast reservoirs of reduced carbon, for example in the form of coal, natural gas, and oil.

Raining acid and rock

The super-Earths the team used as references are thought to have surface temperatures ranging from about 270 to 1700 degrees Celsius (C), which is about 520 to 3,090 degrees F. The Earth, in contrast, has a global average surface temperature of about 15 degrees C (59 degrees F) and the oven in your kitchen goes up to about 450 Fahrenheit.

Using thermodynamic equilibrium calculations, the team determined which elements and compounds would be gaseous at these alien temperatures.

"The vapor pressure of the liquid rock increases as you heat it, just as the vapor pressure of water increases as you bring a pot to boil," Fegley says. "Ultimately this puts all the constituents of the rock into the atmosphere."

The continental crust melts at about 940 C (1,720 F), Fegley says, and the bulk silicate Earth at roughly 1730 C (3,145 F). There are also gases released from the rock as it heats up and melts.

Their calculations showed that the atmospheres of both model Earths would be dominated over a wide temperature range by steam (from vaporizing water and hydrated minerals) and carbon dioxide (from vaporizing carbonate rocks).

The major difference between the models is that the BSE atmosphere is more reducing, meaning that it contains gases that would oxidize if oxygen were present. At temperatures below about 730 C (1,346 F) the BSE atmosphere, for example, contains methane and ammonia.

That's interesting, Fegley says, because methane and ammonia, when sparked by lighting, combine to form amino acids, as they did in the classic Miller-Urey experiment on the origin of life.

At temperatures above about 730 C, sulfur dioxide would enter the atmosphere, Fegley says. "Then the exoplanet's atmosphere would be like Venus's, but with steam," Fegley says.

The gas most characteristic of hot rocks, however, is silicon monoxide, which would be found in the atmospheres of both types of planets at temperatures of 1,430 C (2,600 F) or higher.

This leads to amusing possibility that as frontal systems moved through this exotic atmosphere, the silicon monoxide and other rock-forming elements might condense and rain out as pebbles.

Asked whether his team ever cranked the temperature high enough to vaporize the entire Earth, not just the crust and the mantle, Fegley admits that they did.

"You're left with a big ball of steaming gas that's knocking you on the head with pebbles and droplets of liquid iron," he says. "But we didn't put that into the paper because the exoplanets the astronomers are finding are only partially vaporized," he says.

Provided by Washington University School of Medicine in St. Louis

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