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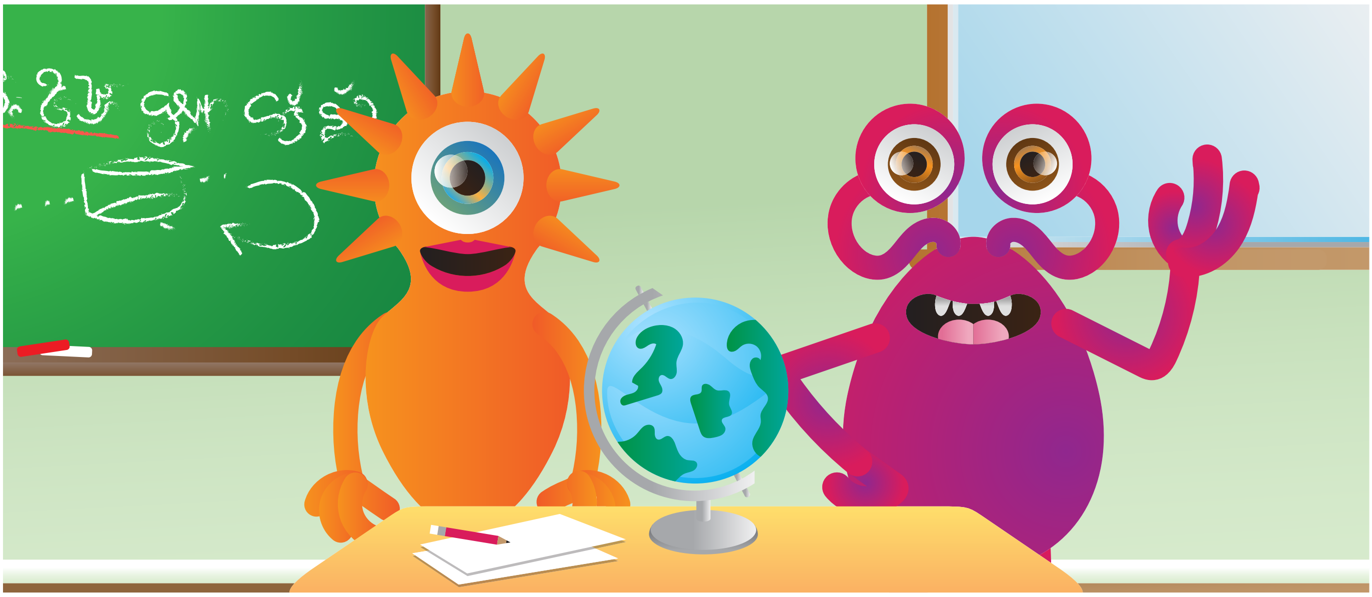

ARE THERE OTHER EARTHS OUT THERE? ASTRONOMERS' FIRST CLUES TO AN ANSWER DATE BACK 100 YEARS

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Of all the questions that science might hope to answer, few excite people more than "is there life on worlds other than our Earth, and, if so, do any alien creatures possess intelligence similar to that of human beings?" But how can we find rocky Earth-like worlds that orbit around stars other than our Sun? Remarkably, the first astronomical evidence that such worlds exist dates back 100 years! This evidence involved observation of something called a "white dwarf" star, which is the type of star that our Sun will become five billion years from now. Studies of white dwarf stars have shown that rocky worlds with compositions similar to that of Earth are common throughout our Milky Way galaxy. Thus, future prospects are bright for finding rocky planets suitable for hosting life.

Of all the questions that science might hope to answer, few excite people more than "is there life on worlds other than our Earth, and, if so, do any alien creatures possess intelligence similar to that of human beings?" The possible existence of other life in the Universe is one reason why I became fascinated by astronomy when I was only 8 or 9 years old. Like many kids, I was educated by trips to my local planetarium (in New York City) and enthralled by science fiction on TV and in the movies. I can still remember my heroes Flash Gordon and Doctor Zharkov battling Ming the Merciless on Ming's home planet Mongo.

Now 60 years later, I have spent almost my entire career as an astronomer investigating phenomena that relate to the question of life in the Universe. My recent research focus has been on the origin and evolution of planetary systems, including our own solar system, which is the planetary system that we are most familiar with. Most astronomers expect that life can only originate on a planet, perhaps a planet with size, composition (meaning the materials that it is made of), and temperature similar to that of Earth. Earth, Venus, Mars, and Mercury are called "rocky" planets, because they are made up almost entirely of solid material and possess very little gaseous material (such as the gases found in our atmosphere).

The primary purpose of this article is to describe how astronomers can now, for the very first time, measure the composition of the building blocks of rocky worlds that orbit stars other than our Sun. If these compositions are found to be similar to that of Earth, then it is reasonable to conclude that such worlds might harbor alien life forms, perhaps life not too different than Earth life.

When I was young, before we knew of the existence of any planets other than those in our solar system, astronomers would discuss techniques that could be used to find "extrasolar" planets, meaning planets that orbit around stars other than our Sun. One obvious technique for the discovery of **extrasolar planets** is called "direct imaging" where one can see and take a picture of a planet that orbits around another star, much as one can see Venus and Jupiter in the night sky and, with the right equipment, take pictures of these planets (see Figure 1). When it is not possible to take a direct picture of an extrasolar planet, astronomers can instead use other techniques that can reveal the existence of a planet by the planet's effect on the star that it orbits. For example, if a planet happens to pass in front of its star as seen with a telescope on Earth, then the planet will block a little of the starlight and this dimming can be measured. In our own solar system on rare occasions, as seen from Earth, Venus passes in front of the Sun. Two such occasions occurred in 2004 and 2012 and were witnessed by millions of people with the aid of solar telescopes (see Figure 2).

EXTRASOLAR PLANET

All planets that orbit around stars that are not our Sun are called extrasolar planets.

The best technique now available to astronomers to reveal the compositions of extrasolar rocky worlds is not one of these older classical techniques but something new. This new technique, which came as a complete surprise to all astronomers, will be described in this article. By analyzing the light from a star, we are able to learn more about what that star is made up of and if there are planets around it. Perhaps most surprising of all, 100 years ago, before astronomers understood how to properly interpret the starlight, this technique produced the very first evidence [1] of the existence of an extrasolar planetary

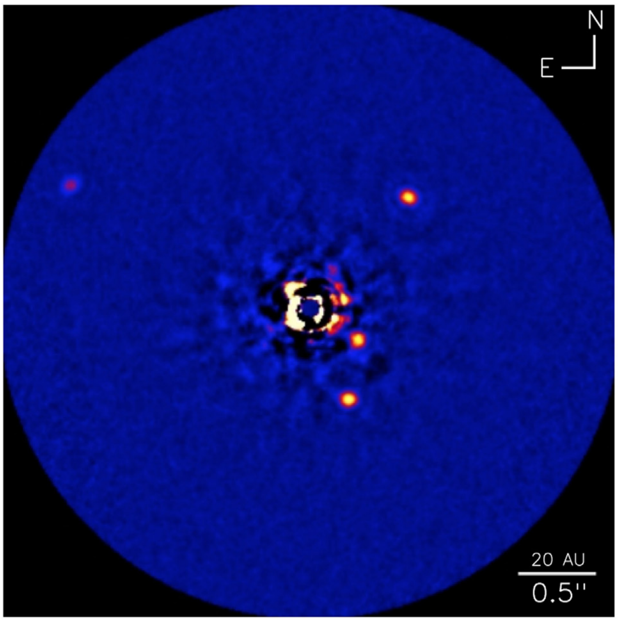

FIGURE 1

FIGURE 1

An image of the bright star HR 8799 along with its four known giant planets – the planets are the three bright spots seen to the right of and above and below the star plus the fainter point of light seen in the upper left-hand corner. The star is actually much much brighter than the planets, but, in this picture, most of the starlight has been blocked by a mask that was purposely placed in front of the star. Because this blockage is not perfect, residual starlight is seen near the center of the picture "peeking" out from around the edges of the mask. HR 8799 and its 4 planets – all more massive than the planet Jupiter – are located about 130 light years from Earth. (Credit: National Research Council of Canada, C. Marois, and Keck Observatory).

system – around a star called "van Maanen 2" (named after the astronomer who discovered it). It took astronomers nearly 100 years before they knew enough about astronomy and this technique to understand the evidence and realize that van Maanen 2 is orbited by a planetary system [2].

Similar to living creatures, stars are born, they age, and then they die. Our Sun is now in its middle age. It has existed for about 4.6 billion years and, according to calculations based on physics, it will live for about an equal length of time before it becomes what is called a "white dwarf" star. Today, the Sun contains a mass about 300,000 times greater than that of our Earth and a diameter – the length of a line that passes through the center of any planet or star and extends all the way from one side to the other – about 100 times greater than that of Earth. After the Sun has become a white dwarf, it will still have about 1/2 of its current mass but it will be tiny, only the size of Earth (that is why such stars are called "dwarf" stars). Because white dwarfs are about the size of Earth but have more than 100,000 times more mass, they are incredibly dense with enormously strong gravitational forces – if you now weigh 100 pounds, on a typical white dwarf you would weigh more than 10,000,000 pounds. The vast majority of stars in our Milky Way galaxy will spend their old ages as **white dwarf stars**. Van Maanan 2 is a white dwarf star.

WHITE DWARF STAR

A star that is about the size of Earth and thus much smaller than normal stars such as our Sun. Almost all normal stars eventually become white dwarfs; in the case of the Sun, this will happen about five billion years from now.

Gravity is one of the basic forces in nature. All objects in our solar system – the Sun, the planets, and the asteroids – feel the gravitational force (pull) of all the other objects in the system. If a white dwarf star is orbited by planets and by smaller objects similar to the asteroids in our solar system, then it is possible that the gravitational pull of a planet could change the orbit of an asteroid such that the asteroid gets very close to the white dwarf. Because of its strong gravity, the white dwarf will tear apart the asteroid into lots of little

FIGURE 2

The Sun as the planet Venus passed in front of it as seen from Haleakala, Hawaii in 2012. Venus is the dark circular spot seen above the center of the Sun's disk. Other, less prominent, features that are visible are associated with sunspots and regions of enhanced high-energy solar activity. [Photograph by Ron Dantowitz (Clay Center Observatory) and Jay Pasachoff (Williams College – Hopkins Observatory)].

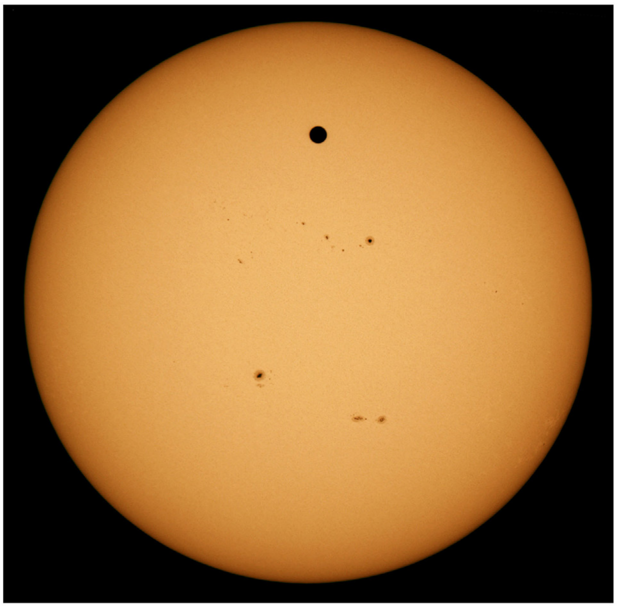

FIGURE 2

chucks of rocky debris. This debris will first go into orbit around the white dwarf forming a ring-like structure, similar to the rings around Saturn (see Figure 3). After a while, the orbiting debris will fall onto the white dwarf star.

Everything we have ever seen in nature is built out of 92 unique atomic building blocks called the chemical elements. An element is identified and named depending on the size of its atomic core, called the nucleus. Hydrogen is the simplest and lightest element, whereas uranium is the heaviest element found to occur naturally in nature. Using an instrument called a **spectrometer** that breaks white light up into the colors of the rainbow, astronomers can determine which elements make up the rocky debris that originates in asteroids that have fallen onto the white dwarf. Thus, it is possible to figure out the chemical composition of the rocky objects that orbit around white dwarf stars. Planetary scientists believe that the rocky planets Mercury, Venus, Earth, and Mars in our own solar system were built up, 4.6 billion years ago, from accumulation of huge numbers of smaller objects similar to the asteroids that now orbit the Sun between Mars and Jupiter. We now have direct samples of these asteroids in the form of **meteorites** that fall to Earth; meteorites are little pieces broken off from asteroids that suffered collisions long ago.

SPECTROMETER

an instrument that separates light into various colors of the rainbow. Each color corresponds to a different wavelength of light and, since each element emits and absorbs light only at certain wavelengths characteristic of that element, the spectrometer can identify which elements are present in the material responsible for the light.

METEORITE

a stony or metallic object from outer space that survives passage through the atmosphere and hits Earth's land or water surface. Meteorites have their origin in collisions between asteroids.

Thus, by comparing the elements that compose Mars, Earth, the Moon, and asteroids in our solar system with the composition of the debris seen in the atmospheres of many white dwarf stars, astronomers can now answer the question: "are rocky worlds that orbit around stars other than our Sun similar in composition to our Earth or are the compositions very different?" If the compositions are very similar or very different, then this might be important evidence for (or against) the possibility of life on those rocky extrasolar planets.

FIGURE 3

An artist's conception of part of a planetary system in orbit around a white dwarf star (the white spot at the center of the red ring). In the foreground, we see some rocky asteroids. If the orbit of such an asteroid is sufficiently altered by the gravity of a planet, then the asteroid may pass so close to the white dwarf as to be torn apart into little chunks of rock that orbit close to the star. The red ring represents the rocky debris that remains of former asteroids that have already been broken apart by the strong gravity of the white dwarf.

FIGURE 3

The four most abundant elements in planet Earth are iron, magnesium, oxygen, and silicon. By using spectroscopes to study, the atmospheres of the white dwarfs astronomers have found that these four elements also dominate the composition of rocky extrasolar planets [3]. Thus, astronomers can say for the first time ever, and with good confidence, that the white dwarf studies demonstrate that the composition of most rocky worlds that orbit around stars is similar to the overall composition of Earth. As mentioned above, this conclusion brings us a step closer to the possibility that alien forms of life may exist on other worlds. More detailed understanding will require additional future studies, most probably using telescopes located in interplanetary space.

The elements that make up Earth are not all mixed together equally throughout our planet. Instead, most of the iron in the Earth is deep in its center, called the core; the mantle, which sits on top of the core, is rich in magnesium; and the outer layer, called the crust, is rich in silicon and aluminum. Planets and large asteroids that have different compositions at different depths are called "differentiated."

From spectrometer measurements of the composition of the debris in some white dwarf atmospheres, it is possible to figure out some details about the structure of the rocky objects that used to orbit about the star. For example, the material in the atmosphere of one white dwarf (named NLTT 43806 because it is a star that is described in the catalog called the NLTT catalog which was compiled by astronomer Willem Luyten in the middle of the twentieth century) is especially rich in aluminum, but contains relatively little iron. We can compare the amounts of nine elements in the atmosphere of NLTT 43806 with their amounts in objects in our solar system, including meteorites, parts of the Earth, and the moon's surface. In this way, astronomers figured out that the elements seen in NLTT 43806 have a composition similar to a mix of the material found in Earth's crust and upper mantle [4]. This result could be interpreted to mean that a differentiated extrasolar planet, with a crust, a mantle, and a core, used to or still does orbit around NLTT 43806.

If this planet suffered a violent, but not head-on collision with another planet, then the collision could have stripped off some of the outer layers of the differentiated planet. If the rocky debris from this collision subsequently fell onto NLTT 43806, then that could explain the ratios of the elements now measured in the atmosphere of this white dwarf.

Returning to van Maanen's discovery 100 years ago, now, after all these years, we finally understand that the elements iron, magnesium, and calcium that his spectrometer detected in van Maanen 2 must have come from one or more busted up rocky asteroids or planets that previously orbited this white dwarf star. Recent studies of white dwarfs such as NLTT 43806 demonstrate that astronomers have come a long way – in just the past 10 years or so – in our understanding of rocky extrasolar worlds. We now know that the composition of most such worlds is similar to that of Earth and that they also have differentiated structures. The next steps for astronomers will be to determine if any of these planets harbor alien life forms.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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LAPWAI HIGH SCHOOL, 14–17 YEARS OLD

Lapwai High School, age 14–17: Lapwai High School is located near the Nez Perce Reservation in Lapwai, ID. This review was conducted by nine Nez Perce students of Tami Church's mathematics class, the first-ever American Indian student reviewers for Frontiers for Young Minds.

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Benjamin Zuckerman is a Professor in the Physics and Astronomy department at UCLA. He received undergraduate and graduate degrees from MIT and Harvard. His major scientific interests are the birth and death of stars and planetary systems. He has maintained a continuing interest in the question of life, especially intelligent life, in the Universe. He has co-edited six books including "Extraterrestrials, Where Are They?" Cambridge University Press 1995, "The Origin and Evolution of the Universe" Jones & Bartlett 1996, and "Human Population and the Environmental Crisis" Jones & Bartlett 1995. *ben@astro.ucla.edu