Primeval Planet: Oldest Known World Conjures Prospect of Ancient Life

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Astronomers have discovered the oldest known planet, a primeval world 12.7 billion years old that will force them to reconsider how and when planets form. The discovery raises the prospect that life may have begun far sooner than most scientists ever imagined.

A leading planet-formation expert not involved in the work called the discovery mind-boggling.

The ancient world is well more than twice the age of Earth and all other known planets. It is nearly as old as the universe itself. And it has had an incredibly wild ride through time.

The world formed when the universe was just a billion years old, researchers said at a NASA press conference today. It began its travels around a fairly normal star much like our Sun. The next 10 billion years were fairly routine.

Then the planet was booted from its stellar orbit and captured by the gravity of another star that was well into its death throes.

That's where astronomers found the planet, in a controversial search that began a decade ago.

An early Earth?

The planet is at least as big as Jupiter and almost surely gaseous. It would not harbor life as we know it.

And because it orbits a dying star, any other planets in the system would not receive the sort of life-giving heat and light provided by the Sun.

But since the object's initial eons were spent around Sun-like star, astronomers said it's possible it had a neighbor somewhat like Earth, a place where life might have found opportunity at a time when the Sun wasn't even a glimmer in eyes of the cosmos.

Steinn Sigurdsson, a Penn State University researcher who led the work, said the Jupiter-like planet formed in a nearly circular orbit, somewhere between two and eight times as far from a star as Earth is from the Sun. That orbit would have been favorable to the development of an Earth-like planet, a so-called "terrestrial."

"This [orbit] is wide enough that a terrestrial planet could have comfortably fit in the habitable zone -- if [the terrestrial] formed in the first place," Sigurdsson told *SPACE.com*. "It certainly makes it more likely that planets capable of hosting life could have formed earlier than hitherto thought. Possibly much earlier and much more commonly."

Any Earth-like planet that might have developed inside the orbit of the gas giant -- and there is no evidence that one did -- would have been destroyed during a later bout with gravitational chaos.

The planet's chaotic history

The planet was forged from gas around a newborn yellowish star in an ancient "globular" star cluster called M4, 7,200 light-years away and within our Milky Way Galaxy. Its existence was first suspected in 1992.

Recent Hubble Space Telescope observations allowed Sigurdsson and his colleagues to devise a remarkable tale of the planet's presumed journey.

About two or three billion years ago, as the yellow star and its planet were plunging into the crowded core of M4, they passed near a collapsed, dense and dying neutron star, an object that resulted from some previous explosion of a very massive star.

The neutron star had an orbiting companion star. The gravitational tug-of-war that ensued booted the neutron star's companion into space. But the neutron star, a weighty competitor, captured the yellow sun-like star and its planet.

The sun-like star aged, bloating into a red giant (our Sun will do the same one day). The red giant's gas flowed onto the neutron star, energizing it. The neutron star spun faster. Today, it rotates on its axis 100 times every second and is known as a pulsar.

Meanwhile, the red giant's fuel was exhausted and it turned into a cool, fairly dim white dwarf.

The newfound planet now orbits both the white dwarf and the neutron star.

"We probably would never have found this planet if it had just stayed with its original star," Sigurdsson said. "Its history put it in the right place; the interactions helped us see it."

End to controversy

Researchers discovered the pulsar, named PSR B1620-26, and its companion white dwarf star in the late 1980s. The planet was first suspected in 1992, but some astronomers thought the data showed a third, distant orbiting star, rather than a close-in planet.

"By 1999 we knew the object was low-mass, with a significant probability it was a planet," Sigurdsson said.

Ending a decade of controversy, the new Hubble observations of the neutron star's white dwarf companion, and how the objects wobble in space due to the gravitational tugs, allowed Sigurdsson's team measure the trajectory and mass of the suspected planet. They confirmed that it is indeed not large enough to be anything else. The data, along with knowledge of the stars' ages, also allowed them to trace the planet's remarkable history.

The planet has not been seen or imaged directly, so final proof of its existence awaits further study.

It is estimated to be 2.5 times the mass of Jupiter. Its heft might equal Jupiter's, Sigurdsson said, and it is definitely no lighter. There's a slight chance it is a few times Jupiter's mass.

The planet's orbit is about 100 years long. It goes around the two old stars at a distance that is most likely similar to Uranus' distance from the Sun.

At 7,200 light-years from Earth, it is not just the oldest known planet but also the farthest.

The results will be detailed tomorrow in the journal *Science*.

Mind-boggling

The planet exists in an unlikely place. Astronomers assumed the gravitational interactions in a globular cluster -- M4 contains 100,000 tightly packed stars -- would rip planetary systems apart.

"This is tremendously encouraging that planets are probably abundant in globular star clusters," said study team member Harvey Richer of the University of British Columbia.

But its the objects apparent history that has astronomers reeling.

"The fact that this system managed to form a gas-giant planet 12.7 billion years ago certainly boggles the minds of those of us who are used to having a hard time going back just 4.5 billion years in time," said Alan Boss, a leading planet-formation theorist at the Carnegie Institution of Washington.

Boss, who was not involved in the discovery, said the tortured history of the system implies there is no life there now. And back when it formed, there would have been less rock -- the stuff of a terrestrial planet -- because heavier elements form with subsequent generations of stars.

But there would have been some rock, and Boss agrees that the discovery suggests life might have had a chance.

"If there were gas giants around at 12.7 billion years ago, I would think that there could be a few terrestrial-like planets too," Boss said in an e-mail interview. "Presumably some of them [would have] experienced a more gentle history than this poor world, and so some might have experienced some sort of flirtation with life, if not something much more serious."

Fresh view of planet formation

More certain, Boss said, is that the primeval planet supports his own radical model of planet formation.

Building on the controversial work of others, Boss last year proposed that all the giant planets in our solar system formed via direct collapse of material in a disk of leftover stuff that circled the newborn star.

The model, "wild" even by Boss' reckoning, is called "disk instability."

The standard model of planet formation -- which all experts agree no longer explains all of reality -- held that gas giant planets formed after a rocky core larger than Earth had first assembled. The massive rocky core then attracted lots of gas.

But this so-called "core accretion" model takes considerable time, and there has to be a lot of rocky material available.

The newfound planet may have formed too quickly for core accretion to be responsible.

Boss points out that the early universe was composed mostly of gas. Stars in the M4 cluster have just $1/20^{th}$ the amount of rocky or metal material that exists in the Sun, he said. That implies a slow rate of growth for a rocky core and probably the lack of sufficient mass to build a Jupiter-like planet through core accretion.

"Disk instability would seem to be the only hope in a system composed almost entirely of hydrogen and helium," he said.

Earth-sized pulsar planets, too

The newfound planet is not the first found orbiting a pulsar.

Another trio of planets -- all about the size of Earth -- orbit the pulsar PSR 1257+12. They were confirmed to exist just two months ago and, prior to that, their presence had long been suspect.

The Earth-sized pulsar planets, found by Alex Wolszczan (also of Penn State), are a different breed, however. They probably formed *after* the stellar explosion that created the dying star they go around, Boss said. So they are almost surely devoid of life and never could have supported any.

The International Astronomical Union lists Wolszczan's worlds in its catalogue of extrasolar planets. But other planet hunters choose not to list them, partly because their formation and environment is so different, and partly because they are not considered habitable and so are not as important in the search for life.

The newfound pulsar planet, having presumably formed around a normal star, is unlikely to be ignored. Its discovery brings the total of known extrasolar planets, counting Wolszczan's, to 121.

The Life and Times of the Newfound Planet

This account of the pulsar planet was provided by the Space Telescope Science Institute, which operates the Hubble Space Telescope for NASA and the European Space Agency:

Long before our Sun and Earth existed, or even the Milky Way galaxy, as we know it today, a planet formed around a sun-like star in one of the earliest homesteaders of our corner of the universe, a globular star cluster.

This planet, a few times more massive than Jupiter has survived the harsh conditions of a globular cluster, a gravitational collision with a binary system, and the death of its progenitor star.

The planet resembled Jupiter in several ways: its mass was only a few times that of Jupiter and its orbit was similar, somewhere between 250 and 750 million miles from its sun. The star and planet orbited untouched for almost 10 billion years as they fell into the dense heart of the cluster, where stars are so crowded together they are a fraction of a light-year apart. Like strolling into a crowded marketplace, this star system would not be independent for long without "bumping" into something.

As it passed by a binary system containing an old neutron star and a white dwarf, gravitational forces pulled the two systems together into a web of tangled orbits. Soon, the small-mass white dwarf was booted out of its original position and thrown into space by the more massive progenitor star. Meanwhile, the planet was thrown into a circumbinary orbit, a large orbit around both its original star and the neutron star.

The new system of the planet, its sun, and the neutron star recoiled from the ejected white dwarf, in much the same way a cannon jumps backwards when it fires a cannon ball. This gravitational recoil sent the new binary system out of the globular cluster's core into a less dense region of the cluster, reducing its chance for another such stellar interaction.

At its new position in the cluster, the planet slowly traced out a wide orbit around the neutron star and its progenitor star at a distance of approximately 2 billion miles, which is similar to Uranus's orbit around our Sun. From this vantage point the planet witnessed the death of its progenitor star over the course of the next billion years. The sun-like star aged into a red giant and poured matter onto the neutron star. The neutron star's acquisition of mass caused it to rotate faster and faster on its axis, eventually spinning up into a pulsar. Now the neutron star makes almost 100 rotations per second on its axis (that's 10 times faster than a humming bird flaps its wings!)

Once all the excess gas left the star, it became a small, bright, helium-core white dwarf. All the while, the planet continued on its sweeping orbit. This is the state, established less than one billion years ago, in which astronomers discovered the planet.

So, how could researchers tell that this planet had survived such dynamic cosmic forces, or existed at all? Using Hubble data, scientists used the white dwarf's color and temperature to determine its age and mass, which they compared to the wobble of the neutron star. In addition, radio studies of the pulsar revealed irregularities in its signal that could not be caused solely by its white dwarf companion star.

Putting this information together, researchers obtained a tilt for the white dwarf's orbit, after which they could infer the tilt of the third orbiting body. From there, astronomers were able to determine the mass of the third body, which is too small to be a brown dwarf or a low-mass star; thus, the planet revealed itself through its subtle tug on the system. "We probably would never have found this planet if it had just stayed with its original star," remarked Steinn Sigurdsson of Pennsylvania State University. "Its history put it in the right place; the interactions helped us see it."

Furthermore, the planet's orbit and place in the globular cluster give us clues to its past. For the proposed scenario to be plausible, the white dwarf must have lost its gaseous envelope after it and the planet joined the neutron star; therefore, the white dwarf should be young, bright, and low mass, which evidence suggests is the case. In addition, the planet's presence in a wide near-circular orbit reveals that the mass transfer from the progenitor star, now the white dwarf, to the neutron star, spinning up into a pulsar, did occur after the planet was in an orbit around the pair.

The wide orbit also makes the planet more vulnerable to the gravitational forces of nearby stars, in which case the planet's continuing presence suggests the system has been in the lower-density portion of the cluster since its current configuration was established. Because such a system would return to the cluster's core on a time scale of a billion years and we know that the system has not yet returned, we can establish the time scale for the current configuration, the tumultuous series of events leading to the present, and an age for the planet.

This planet's tale also gives astronomers an idea of where planets may reside and how many could exist. The planet was born before many heavier elements existed in space, such as oxygen, carbon and silicon. It's birth in such an element-poor globular cluster like M4 may imply that planets are more common in such environments than once thought.

"This is a big hint that there are more out there," said Sigurdsson. "There are 100 pulsars like [the one this planet orbits] out there, this one was just extremely well researched."

Having theorized the planet's existence 10 years ago, Sigurdsson says the discovery of this planet means that we must "overcome theoretical prejudices" and "suggests we should make more of an effort to look for [such planets]." Coming in at 13 billion years old, this planet also makes a case for planet formation occurring earlier and more abundantly than previously thought.

Timeline of the Discovery

Provided by the Space Telescope Science Institute:

1987

A British team finds pulsar, PSR B1620-26, in the core of M4, a globular cluster about 7,000 light-years away. It is suspected to be part of a binary system, with the companion a white dwarf star. But the team has to wait half the white dwarf's orbit time (200 days) to confirm it.

1988

The team publishes the discovery paper. Since it is one of the first of its kind to be discovered, the pulsar sparks many follow-up papers describing how the neutron star became a pulsar and explaining the white dwarf's origins.

1990-92

Using pulsar timing, three groups find an anomaly in the pulsar's signal indicating it is being gravitationally pulled by one or more unseen objects.

1992

At a conference, Don Backer of UC Berkeley presents a paper contending that the anomaly discovered using pulsar timing is a third object in the system. At the same conference, Steinn Sigurdsson proposes that "it might be possible to see planets "stolen" from their parent stars by pulsars."

1993

In just one year, four papers are published discussing possible explanations for the anomaly in the system. Theories for the object's celestial designation range from a black hole to a Saturn-like planet. Debates run high as this list of third-body candidates grows.

At this time Sigurdsson presents his paper on the anomaly in which he rejects several different models to predict the exchange interaction scenario. Shortly afterward, scientists rule out the possibility of a black hole. This implies that it is a half solar mass star or a Jupiter-sized planet.

Even more papers are now published, most concerning the orbits of the system's objects. Within the current scope of knowledge about the system, the white dwarf's orbit should be perfectly circular, but turns out to be slightly elliptical, like Earth's orbit, which is a great surprise. In addition, the eccentricity of the third object, predicted to be quite large, is instead rather small. Because of such ongoing uncertainties, many new explanations for the system arise, including reformed theories about the evolution of the system after it settled into its current configuration.

1995-96

Multiple parties begin to look for a proposed third star in the system. One team claims to have found it, but it is discovered instead to be a nearby star that is not actually in the system. Following that close call, new theories about the possibilities of a faint cold star or a white dwarf arise.

1999

After more than 10 years of perplexity over this system, a paper is published analyzing a decade's worth of data concerning this system. The system is subsequently observed in radio wavelengths, but scientists still possess no complete answer because there is no data about the system's tilt. An unknown inclination gives researchers a wide range of possibilities.

Later, however, individual probabilities are calculated for different solutions. Researchers find there to be a low chance that the third body is a star; rather, they find a higher probability of the object being a low-mass object, like a Jupiter-mass planet or brown dwarf.

2000

A student’s theory paper suggests a mechanism for the planet being in the system. This is a well-known effect to explain the squished orbit of the white dwarf, but researchers had yet to apply it to this situation.

2000-present

Hubble data sets, one taken starting in 1995 and another recent one, are compared to distinguish the movement of the white dwarf within the cluster. After a long wait, scientists are now able to determine the white dwarf’s true mass, inclination, time of formation, and the age of the system.

This new data boosts enormously the probability of the object being a planet. Determination of the planet’s inclination is now possible, because all three components are not coplanar.

From this calculation, the team is able to find the mass of the planet.