ASTRONOMERS SPY MOST DISTANT STAR

This image shows the the distant galaxy cluster MACS J1149.5+223. After being magnified some 2,000 times via gravitational microlensing, the star LS1 appeared within a galaxy in this cluster.

Astronomers call it a Lensed Star because gravitational microlensing magnified its light some 2,000 times. Astronomers said on April 2, 2018, that they used the Hubble Space Telescope to find the most distant star yet. This star is at least 100 times farther away than the next individual star ever seen, except for supernova explosions. Normally, when we talk about objects at this very great distance – in this case, seen at a time only 4.4 billion years after the Big Bang – we're talking about supernova explosions, or other very, very bright objects or events in the universe, perhaps galaxies containing of billions of stars, or galaxy clusters, or energetic processes going on within galaxies. But this discovery is of a single star. It's a hot blue star – called Lensed Star 1, or LS1, by astronomers – whose light was magnified some 2,000 times via a technique called gravitational microlensing. The scientists said in a statement that the discovery provides new insight into the formation and evolution of stars in the early universe, the constituents of galaxy clusters and also on the nature of dark matter.

As so often happens in astronomy, the astronomers were looking at something else – a supernova explosion in the galaxy cluster MACS J1149.5-223 – when they found this very distant star in April 2016. They happened to spot the hot blue star – brightened due to magnification by the lensing technique – in the same galaxy that hosted the supernova.

Patrick Kelly of the University of Minnesota, Jose Diego of Instituto de Física de Cantabria in Spain, and **Steven Rodney** of the University of South Carolina led the discovery team. Their statement explained:

> *The light from LS1 was magnified not only by the huge total mass of the galaxy cluster, but also by another compact object of about three times the mass of the sun within the galaxy cluster itself. This effect is known as gravitational microlensing …*

The discovery of LS1 allows astronomers to gather new insights into the constituents of the galaxy cluster. They know that the microlensing was caused by either a star, a neutron star, or a stellar-mass black hole.

LS1 therefore allows astronomers to study neutron stars and black holes, which are otherwise invisible, and they can estimate how many of these dark objects exist within this galaxy cluster.

What's more, the star is enabling astronomers to gain insights about dark matter, a mysterious unseen substance thought to constitute a substantial fraction of the total matter in our universe. Kelly said:

> *If dark matter is at least partially made up of comparatively low-mass black holes, as it was recently proposed, we should be able to see this in the light curve of LS1.*

So far, these astronomers said, their observations don't favour the possibility that a high fraction of dark matter is made of low-mass black holes. But they said they're looking forward to using the gravitational microlensing technique to probe for more individual stars in the distant, and young, universe.

While astronomers routinely study galaxies much farther away, they're visible only because they glow with the brightness of billions of stars. And a supernova, often brighter than the galaxy in which it sits, also can be visible across the entire universe. Beyond a distance of about 100 million light years, however, the stars in these galaxies are impossible to make out individually.

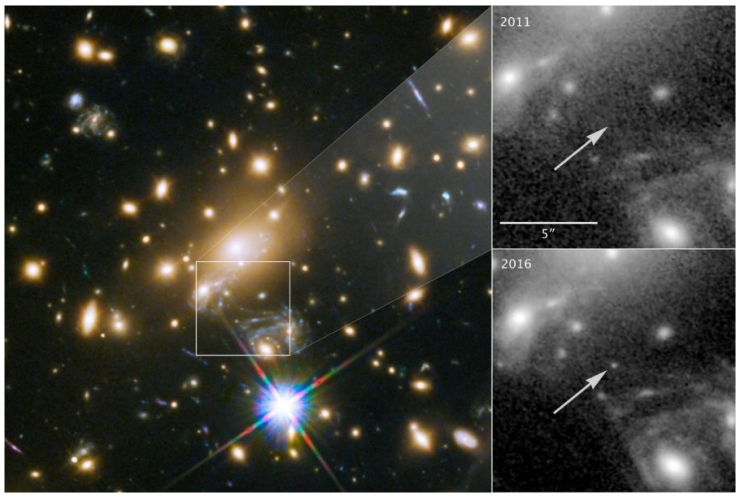
But a phenomenon called gravitational lensing -- the bending of light by massive galaxy clusters in

the line of sight -- can magnify the distant universe and make dim, far away objects visible. Typically, lensing magnifies galaxies by up to 50 times, but in this case, the star was magnified more than 2,000 times. It was discovered in NASA Hubble Space Telescope images taken in late April of 2016 and as recently as April 2017.

"You can see individual galaxies out there, but this star is at least 100 times farther away than the next individual star we can study, except for supernova explosions," said former UC Berkeley postdoctoral scholar Patrick Kelly, now on the faculty at the University of Minnesota, Twin Cities. Kelly is first author of a paper about the discovery appearing online this week in advance of publication in the journal Nature Astronomy.

The discovery of the star, which astronomers often refer to as Icarus rather than by its formal name, MACS J1149 Lensed Star 1 (LS1), kicks off a new technique for astronomers to study individual stars in galaxies formed during the earliest days of the universe. These observations can provide a rare look at how stars evolve, especially the most luminous ones.

"For the first time ever we're seeing an individual normal star -- not a supernova, not a gamma ray burst, but a single stable star -- at a distance of nine billion light years," said **Alex Filippenko**, a professor of astronomy at UC Berkeley and one of many co-authors of the report. "These lenses are amazing cosmic telescopes."



Icarus, whose official name is MACS J1149+2223 Lensed Star 1, is the farthest individual star ever seen. It is only visible because it is being magnified by the gravity of a massive galaxy cluster, located about 5 billion light-years from Earth. Called MACS J1149+2223, this cluster, shown at left, sits between the Earth and the galaxy that contains the distant star. The team had been using Hubble to monitor a supernova in the far-off spiral galaxy when, in 2016, they spotted a point of light near the supernova that began to brighten. Even though the object subsequently became three times brighter in one month, the colors of the light coming from the object did not change. Analysis of these colors showed it was a blue supergiant star in the background galaxy whose magnification grew for several weeks due to an intervening object, probably a star, in the galaxy cluster. The panels at the right show the view in 2011, without Icarus visible, compared with the star's brightening in 2016.

The astronomy team also used Icarus to test and reject one theory of dark matter -- that it consists of numerous primordial black holes lurking inside galaxy clusters -- and to probe the make-up of normal matter and dark matter in the galaxy cluster.

EINSTEIN RING

Kelly noticed the star while monitoring a supernova he had discovered in 2014 while using Hubble to peer through a gravitational lens in the constellation Leo. That supernova, dubbed SN Refsdal in honour of the late Norwegian astrophysicist **Sjur Refsdal**, a pioneer of gravitational lensing studies, was split into four images by the lens, a massive galaxy cluster called MACS J1149+2223, located about 5 billion light years from Earth.

Suspecting that Icarus might be more highly magnified than SN Refsdal, Kelly and his team analyzed the colours of the light coming from it and discovered it was a single star, a blue supergiant. This B-type star is much larger, more massive, hotter and possibly hundreds of thousands of times intrinsically brighter than our Sun, though still much too far away to see without the amplification of gravitational lensing.

By modelling the lens, they concluded that the tremendous apparent brightening of Icarus was probably caused by a unique effect of gravitational lensing. In fact, if the alignment was perfect, that single star within the cluster turned the light from the distant star into an "Einstein ring": a halo of light created when light from the distant star bends around all sides of the lensing star. The ring is too small to discern from this distance, but the effect made the star easily visible by magnifying its apparent brightness.

Kelly saw a second star in the Hubble image, which could either be a mirror image of Icarus, or a different star being gravitationally lensed.

"There are alignments like this all over the place as background stars or stars in lensing galaxies move around, offering the possibility of studying very distant stars dating from the early universe, just as we have been using gravitational lensing to study distant galaxies," Filippenko said. "For this type of research, nature has provided us with a larger telescope than we can ever possibly build!"

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