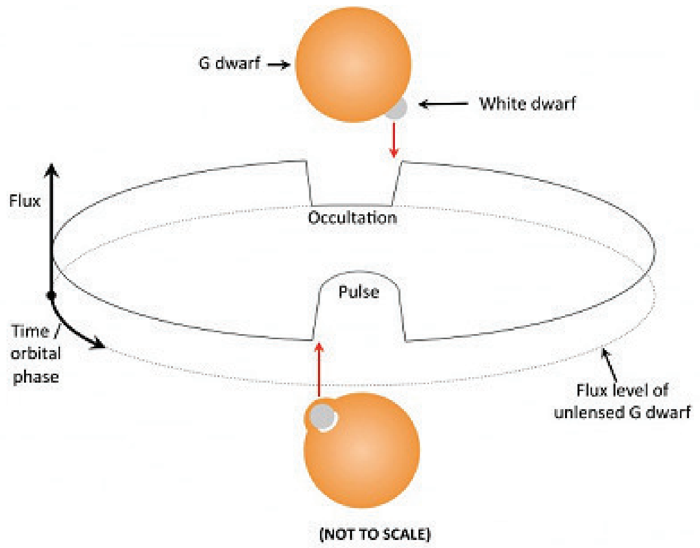
KOI-3278: A self-lensing binary star system

More than 40% of stars are in pairs that orbit around each other, called binary star systems. KOI-3278 is a pair of stars consisting of a white dwarf and a main sequence G-star with an orbital period of 88.18 days. This system produces the first ever case of periodic microlensing signal, based on data collected by NASA's Kepler planet-hunting space observatory. Previously theorized, around forty years ago, this phenomenon has never actually been observed directly until now.

A team of astronomers – lead by Ethan Kruse and Eric Agol - at the University of Washington in Seattle has discovered the very first known instance of a self-lensing binary-star system. A self-lensing effect is based on Einstein's theory of relativity: light does not have mass, but it is subject to gravity, so it is bended when passing a massive object.

The term “self-lensing binary” refers to a binary star system that is edge-on to the line of sight and in which one star causes a brightening of its companion – due to gravitational magnification, or “microlensing” – as it passes in front of the companion’s disk.

KOI-3278 is also one example of an eclipsing Sirius-like system – a binary composed of a non-interacting white dwarf and a Sun-like (hotter) main-sequence star. The system is located in the constellation Lyra, and has been known for some time as a good candidate to host an extrasolar planet, as it had previously been identified to dim periodically. The latest study (Kruse & Agol, 2014) has revealed the companion is a white dwarf star, not a planet.



When the white dwarf eclipses its companion, its gravity magnifies the light, making the star appear very slightly brighter. Credit: Eric Agol / Ethan Kruse.

http://www.astro.washington.edu/users/eakruse

The primary star is very similar to the Sun. Scientists used the MCMC (*Markov Chain Monte Carlo*) analysis and stellar models to constrain the mass of the white dwarf to be ~63% solar (Kruse & Agol, 2014). When a WD is in a binary system, it magnifies its companion's light, causing a pulse – it gets briefly brighter instead of dimmer, like in a normal eclipse. To get a pulse instead of an eclipse, the alignment and orbit has to be very unique. The lensing effect allows the mass of the white dwarf to be estimated, which helps scientists to understand how similar binary systems may have evolved.

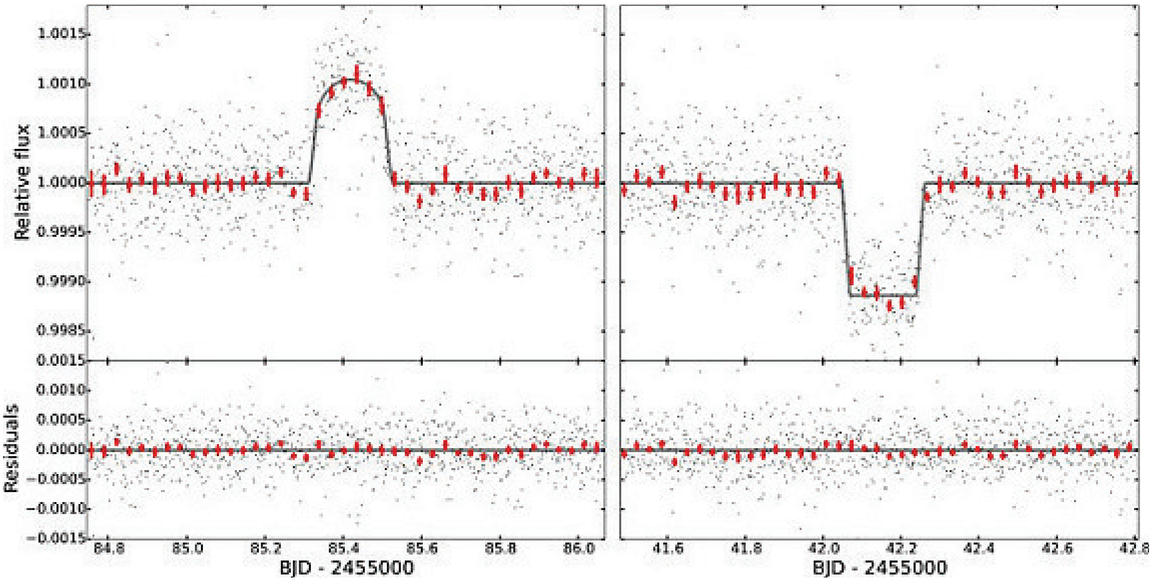
The magnification effect combined with the dimming provides a way of very accurate measures of the mass and radius of the white dwarf companion, which would be hard to achieve otherwise. White dwarfs are the burnt-out cores of former Sun-like stars, which fuse helium into heavier elements.

A Horseshoe Einstein Ring from Hubble. Pictured above, the gravity of a luminous red galaxy (LRG) has gravitationally distorted the light from a much more distant blue galaxy. More typically, such light bending results in two discernible images of the distant galaxy, but here the lens alignment is so precise that the background galaxy is distorted into a horseshoe -- a nearly complete ring. Credit: ESA/Hubble & NASA

Albert Einstein first proposed a phenomenon called gravitational lensing in 1915. This effect was experimentally confirmed long ago and is now a standard method of surveying galaxies and clusters. It is the focusing of light from more distant objects by a massive body, often producing multiple images. The first observational test of the theory was lensing of starlight during a total solar eclipse in 1919, when Arthur Stanley Eddington measured the deflection of starlight from stars in Hyades around the momentarily hidden Sun. A good historical overview of the experiment, written by Karl S. Kruszelnicki, can be found at *http://www.abc.net.au/science/articles/2001/11/05/94876.htm*

Most of the gravitational lenses in the past have been discovered accidentally. A search for gravitational lenses in the northern hemisphere (Cosmic Lens All Sky Survey, CLASS), done in radio frequencies using the Very Large Array (VLA) in New Mexico, led to the discovery of 22 new lensing extragalactic systems.

In the beginning of 1970's astrophysicists predicted that a similar lensing effect may occur in binary systems, but on a much smaller scale (Maeder, 1973). Maeder predicted that binary star systems in which one star is a compact object – a white dwarf, neutron star, or black hole – could cause periodic magnification of its companion star's light (instead of the standard eclipses), if the orbit happened to be viewed edge-on. A special case of microlensing is self-lensing, which occurs when both the foreground and background objects are part of the same binary system, which exactly is the case with KOI-3278.



Detrended and folded Kepler photometry of KOI-3278 presented as black points (all pulses and occultations have been aligned), overplotted with the best-fit model (gray line) for the microlensing pulse (left) and occultation (right). Red error bars show the mean of the folded data over a 45-min time scale. Bottom graphs show the residuals of the data with the best-fit model subtracted. BJD, barycentric Julian date. Image and description are taken from (Kruse & Agol, 2014).

For exoplanets, the effect of self-lensing is far too small to be seen. The problem is that in most binaries, the eclipse blocks far more light than the microlensing amplifies, meaning astronomers can't measure the effect of general relativity. In the KOI-3278 binary system, microlensing from the white dwarf boosts the light of its G-dwarf companion by only 0.1 percent (Kruse & Agol, 2014). What is extremely important, researchers could determine the WD mass and even its radius, which is about 1.1 percent of the Sun.

Those readers, who possess a good math background, may find a list of several important papers below, which present a theoretical basis of self-lensing in binary systems. KOI-2378 is the first system of that type discovered yet, and the Kepler space observatory, though its mission is completed, produced a huge volume of data to be analyzed. So new discoveries are waiting in line.

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