ASTROPHYSICS

A centennial gift from Einstein

Deflection of a distant star's light provides a solution to the puzzling mass of a nearby white dwarf star

By **T. D. Oswalt**

The 1919 detection of the apparent displacement of background stars near the edge of the eclipsed Sun's disk provided one of the first convincing proofs of Einstein's theory of general relativity (*1*, *2*). Almost 100 years later, Sahu *et al.* report on page 1046 of this issue the first measurement of the gravitational deflection of starlight by a star other than the Sun (*3*). Using the superior angular resolution of the Hubble Space Telescope (HST), they measured shifts in the apparent position of a distant background star as a nearby dense stellar remnant called a white dwarf passed almost in front of it in 2014. Because of the relative distances involved, the deflections they observed were about 1000 times smaller than those seen in 1919, but also in agreement with general relativity theory.

A ray of light from a background source passing by a foreground object is bent toward the line of sight by an amount that depends on how close they line up in the sky, the mass of the foreground object, and the relative distances between each object and the earthbound observer (see the figure, top). Because all rays passing the foreground object at the same radial distance from the background object are deflected by the same amount, this creates an "Einstein Ring" around the foreground object that brightens the combined light seen by the observer. If the two objects are not exactly lined up, this ring is asymmetrical, and the background object appears to be displaced. Einstein envisioned such events in a 1936 paper published in *Science* (*4*), but he felt it extremely unlikely that any two stars in the sky would ever line up so precisely that such an event would be observed.

Because the foreground star observed by Sahu *et al.* was about 400 times brighter than the background star, the brightening of their combined light was far too small to be detectable even with Hubble. However, the apparent displacement in the background star's position, so-called "astrometric lensing," was measurable (see the figure, bottom). The more nearly the two objects align, the more an apparent displacement occurs in the direction away from the foreground star. In the case of the nearby white dwarf, Stein 2051 B, this caused the faint background star to appear to trace out a small ellipse as the white dwarf passed by.

A white dwarf star is the collapsed remnant of a star that has completed its hydrogen-burning life cycle. At least 97% of the stars in the sky, including the Sun, will become or already are white dwarfs (*5*). Because they are the fossils of all prior generations of stars, white dwarfs are key to sorting out the history and evolution of galaxies such as our own.

The single most important property of a white dwarf star is its mass. The mass of Stein 2051 B has been a source of controversy for over 100 years. It has a very distant companion star (not involved in the lensing event) whose purported orbital motion implies a much lower mass for the white dwarf than normal, which, if true, implies an unusual composition.

Here lies the importance of Sahu *et al.*'s project. Their astrometric lensing measurements show convincingly that Stein 2051 B is not an exotic "iron core" white dwarf but a rather typical one, with a carbon-oxygen core and a normal mass and radius, thus resolving the long-standing debate over its nature. Their results agree very well with Chandrasekhar's 1930 Nobel-Prize–winning theoretical relation between a white dwarf's mass and radius (*6*). Even today, this relation is very poorly constrained by only three other nearby white dwarfs, all of which are in wide binary systems where masses were obtained from the stars' orbital motion. Now, a completely independent verification of Chandrasekhar's relation has been achieved from astrometric lensing.

The astrometric lensing approach used by Sahu *et al.* can be used equally well for any other nearby stars that happen to pass in front of background stars. In the coming era of truly massive sky surveys such as the Large Synoptic Survey Telescope (*7*), astronomers are bound to observe other similar events, despite their rarity. ■

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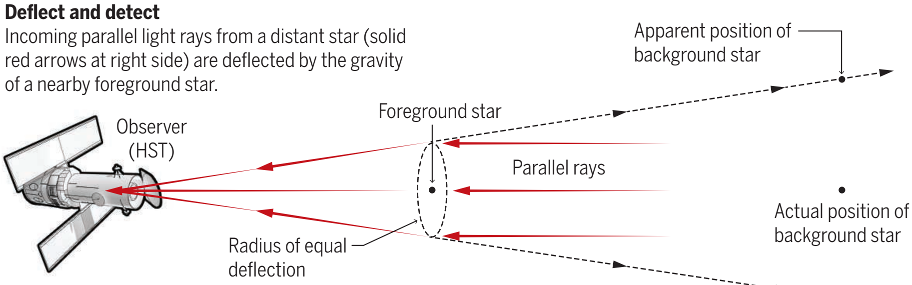
10.1126/science.aan2996

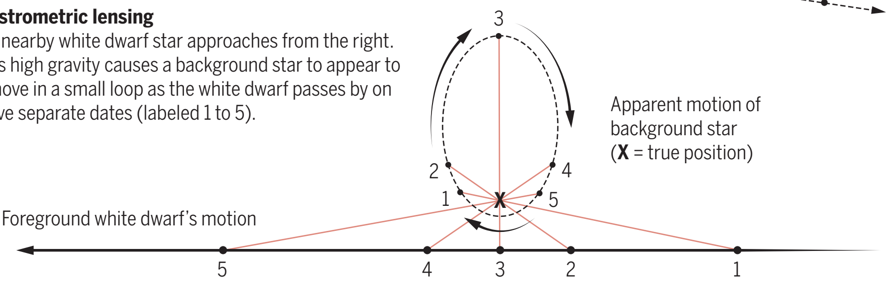
Weighing a star with light

As a dense stellar remnant called a white dwarf nearly passes in front of it, the white dwarf's gravity deflects a distant background star's light. If the alignment is perfect, the background star appears as an "Einstein Ring"; if it is not, one side of the ring is brighter and the background star's position appears to shift.

Deflect and detect
Incoming parallel light rays from a distant star (solid red arrows at right side) are deflected by the gravity of a nearby foreground star.



Astrometric lensing
A nearby white dwarf star approaches from the right. Its high gravity causes a background star to appear to move in a small loop as the white dwarf passes by on five separate dates (labeled 1 to 5).



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Science

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Science **356** (6342), 1015.
DOI: 10.1126/science.aan2996originally published online June 7, 2017