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The strange star discovered by Planet Hunters

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A very ordinary, isolated star varies by 20% in brightness on time scales from a day to a century. No one has yet proposed a convincing explanation.

The star KIC 8462852 is reasonably advertised as the most mysterious star in our galaxy. It is by almost all measures a perfectly ordinary F2 main-sequence star, which is to say that it is middle-aged and stable. At a temperature of 6750 K, it's a bit hotter than our sun, and at 1.43 solar masses, it's a bit more massive too. Until 2015 the star was unnoticed in the wing of the constellation Cygnus (the Swan), though at a distance of about 1500 light-years and an optical magnitude of about 12, the star is visible with a small telescope. When it was noticed, it created quite a splash.

Discovery

Launched by NASA in 2009, the *Kepler* spacecraft was fitted with a telescope trained on 115 square degrees of sky on the border between Cygnus and Lyra (the Lyre). For 3.5 years, the telescope continuously monitored some 145 000 stars in the region, obtaining 1-minute and 30-minute exposures. The primary mission was to look for the slight dimmings of light caused by transits—that is, the passing of an orbiting planet in front of a star.

To help pull out transits, Debra Fischer of Yale University launched a popular citizen science program called Planet Hunters, which enabled the public to examine the *Kepler* brightness records. In 2015, Planet Hunter volunteers noted that a star named KIC 8462852 in the Kepler Input Catalog had deep brightness dips lasting about a day. Those dips cannot be from planet transits because they are not periodic and because their depth would require a transiting body 70% as large as our sun. As shown in the figure, the dips have complex and unique structures.

Later that year Tabetha "Tabby" Boyajian (now at Louisiana State University) and colleagues put together an impressive collection of *Kepler* data, follow-up observations, and calculations. Their paper, which appeared on the arXiv preprint server in September 2015, was titled "Planet Hunters X. KIC 8462852—Where's The Flux?" The star's catalog number is awkward, so Boyajian provided the nickname "the WTF star" to describe the flux lost during the dips. Another widely known meaning for the abbreviation is also perfect. In popular accounts, the WTF star is also called "Tabby's star," and "Boyajian's star," perhaps its ultimate name.

With the appearance of Boyajian and company's paper, the mystery of the brightness drops and speculations as to its mechanism hit the public. The interest created by the paper has been overwhelming and long-lasting.

Gradual dimming over the years

Boyajian's star is utterly ordinary, yet it shows unique dips. Astrophysicists know that isolated F2 main-sequence stars supposedly cannot dip in brightness by 20% on time scales less than many millions of years. We have been accurately watching the myriad of other middle-temperature, isolated main-sequence stars on daily to yearly to century-long time scales, and essentially none have a variability of more than a percent or so.

Admittedly, some very rare stars share traits with KIC 8462852. Examples include the so-called hot R Coronae Borealis stars, the recurrent nova U Scorpii late in its most recent eruption, and some just-formed young stars with thick accretion disks. In all cases known and imagined, the peculiar stars are easily recognizable, usually because they are anomalously bright at IR wavelengths due to absorption and reemission by surrounding material. The kicker is that Boyajian's star certainly does not have an excess of IR light. Again, where's the flux?

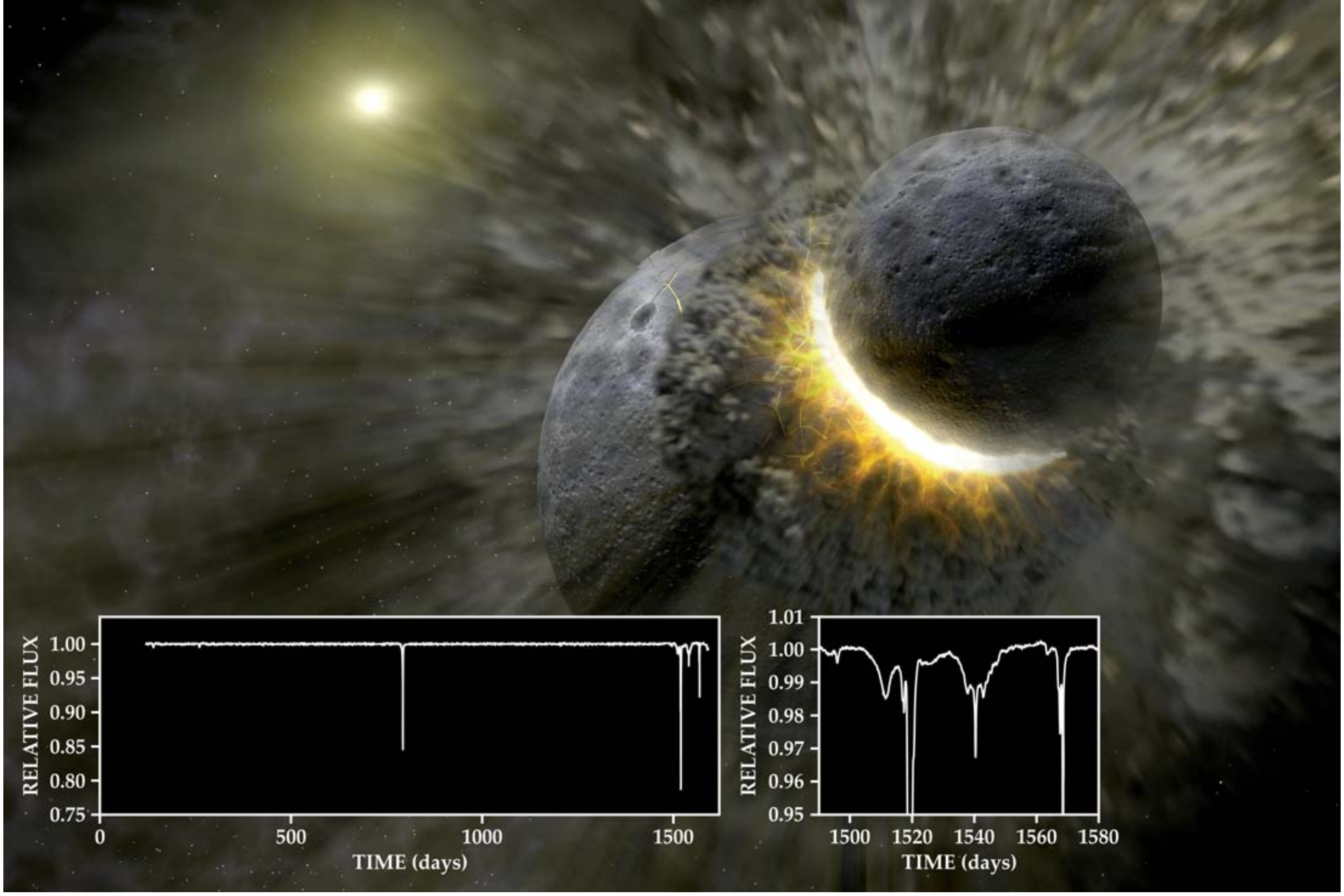
To measure the brightness history of Boyajian's star over the past century, I examined 1338 sky photos taken between 1890 and 1989, now stored at Harvard University. I found that over that period, the star faded irregularly and lost 19% in brightness. A subsequent analysis of the *Kepler* data by other researchers showed that the star faded by 0.9% in 1000 days during 2009–11 and then faded by an additional 2% during the next 200 days.

Such fading is in theory impossible for isolated main-sequence stars, and nothing like it has ever been seen in other stars of that type. Occam's razor suggests that both dipping and dimming are aspects of a single mechanism that yields variability on a continuum of time scales ranging from a day to a century.

Catch me if you can

The lack of excess IR flux from Boyajian's star means that KIC 8462852 does not have any dust clouds, close companion stars, accretion disks, or anything strange. So what's going on? Many speculations posit that something passing between the star and Earth dims the light briefly. A typical scenario is that a recent collision between two rocky planets or asteroids orbiting the star creates an expanding dusty debris cloud that happens to orbit in a way that briefly hides the star (see the figure). Or maybe the culprit is a swarm of dozens of supercomets whose joint tail hides the star for a day.

Those ideas all have problems with the physics details, although maybe they can be overcome with specific parameter



CURVE AND COLLISION. The plots show features of the *Kepler* light curve for Boyajian's star, KIC 8462852 (adapted from the Boyajian et al. arXiv preprint cited in the text). The brightness histories are plotted as flux in units of the average flux for the star versus time in days after the *Kepler* launch. As the left plot shows, the brightness is generally constant, but several evident dips have amazed and confounded astrophysicists. Near day 800, a week-long dip drops the brightness by as much as 16%, mostly over a period of a day or so. Day 1520 presents a 21% brightness drop associated with a complex structure from days 1505 to 1570, as shown in the right plot. The background rendition (courtesy of NASA) illustrates one idea for explaining the day-scale dimming of Boyajian's star: A recently suffered collision between two rocky planets in the star system creates an expanding debris cloud that for a day orbits in front of the star. Such must be an incredibly rare event and it doesn't account for the star's *two* deep dips and its century-long dimming. And where is the expected IR radiation from all that warm dust?

choices. The lack of IR excess is a quick killer to most realizations, although it is possible to push to extremes in which the IR light is minimized.

It could be that Boyajian's star is transited by an interstellar dust cloud perhaps halfway between Earth and the star. That scenario invokes its own special pleading: The dust cloud is a peculiar one with a carefully crafted profile of clumps. Such fine tuning illustrates the extremes to which astrophysicists have been pushed in seeking explanations that are not ruled out.

The best way to solve the dip-causing mechanism is to catch it in the act. A comparison of photometric colors and spectra from dipped to nondipped states should clarify the physics. For example, if a dust cloud is involved, the colors will redden during the dip in a characteristic manner. If the cloud has gases, then spectral absorption-line depths for hydrogen, sodium, and calcium should change. If the transiting body is optically thick, as a planet is, then the color and spectrum will not change. If the star itself changes—for example, because of some huge star spot—then the spectral lines will exhibit distinct variations.

Unfortunately, astrophysicists cannot predict when the uncommon dips in Boyajian's star will occur, so the only solution is to monitor the star hourly, around the clock. Then, when a dip is seen to start, the world's telescopes can be alerted to take intensive observations. In general, telescopes cannot accommodate such a long continuous watch, but one telescope system, the Las Cumbres Observatory (LCO), with its worldwide array of robotically controlled telescopes, has that capability.

To get money for the purchase of LCO time to monitor the star, Boyajian launched a Kickstarter program in the spring of 2016. The appeal was a success and the money is now in hand to fund more than a year's worth of telescope time. Crowdfunding for astrophysics is new. It is possible only for a project with high public interest and is the only practical funding mode for solving the puzzle of KIC 8462852. To date, several months of wonderful, high-precision LCO data show no dips. But any night now, Boyajian's star might go into a dip and reveal the mechanism behind its mysterious dimming.

Additional resources

▶ T. S. Boyajian et al., "Planet Hunters IX. KIC 8462852—Where's the flux?," *Mon. Not. R. Astron. Soc.* **457**, 3988 (2016).
▶ J. T. Wright, S. Sigurdsson, "Families of plausible solutions to the puzzle of Boyajian's star," *Astrophys. J. Lett.* **829**, L3 (2016).
▶ B. T. Montet, J. D. Simon, "KIC 8462852 faded throughout the *Kepler* mission," *Astrophys. J. Lett.* **830**, L39 (2016).