One in ten stars ate a Jupiter-sized planet, suggests paper

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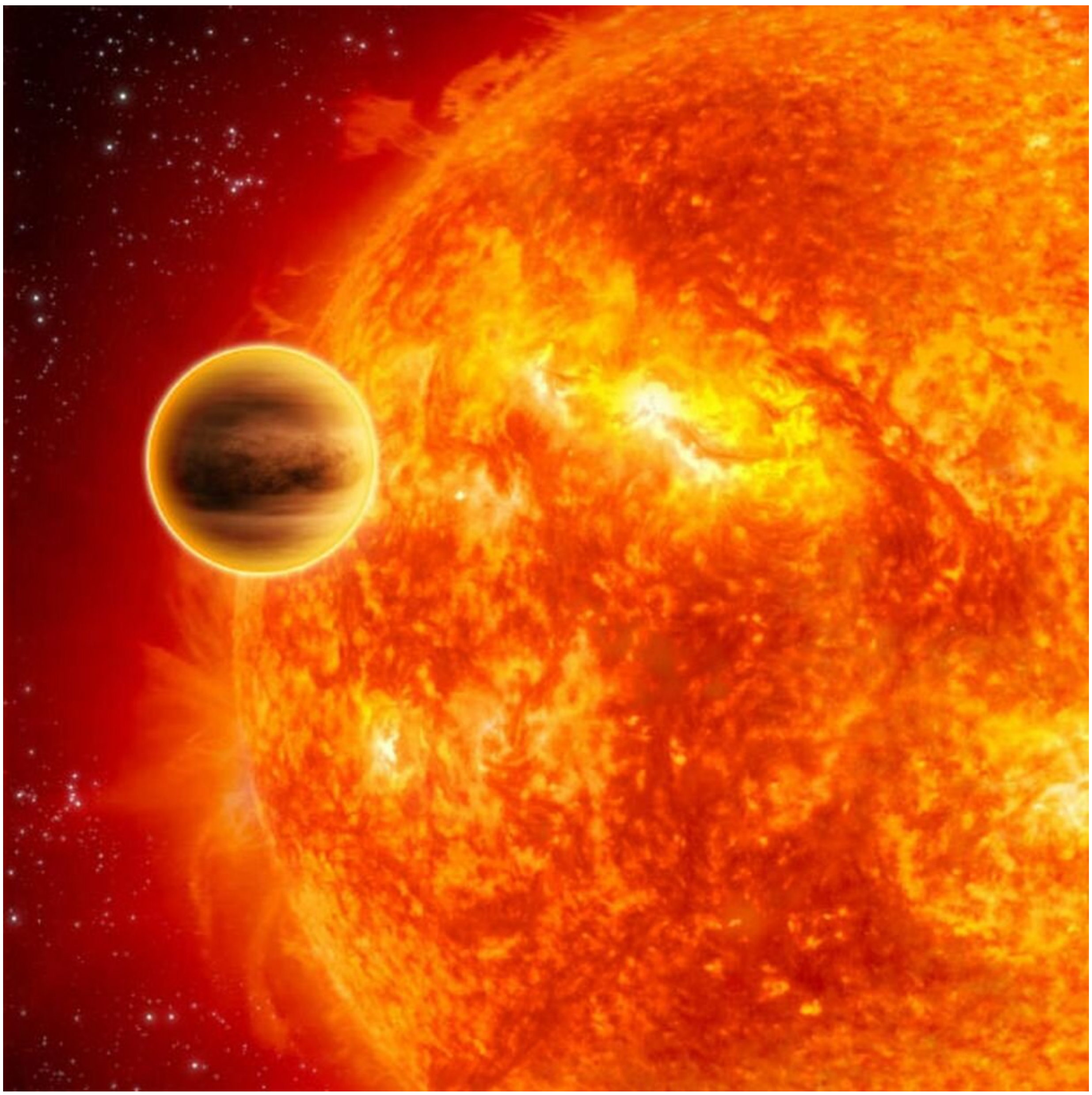


This illustration shows a Jupiter-mass exoplanet getting perilously close to its star. Eventually, the star will engulf the planet, something that happens in many stars' lives as they leave the main sequence. Credit: C. Carreau / ESA

In space, cataclysmic events happen to stars all the time. Some explode as supernovae, some get torn apart by black holes, and some suffer other fates. But when it comes to planets, stars turn the tables. Then it's the stars who get to inflict destruction.

Expanding red giant stars consume and destroy planets that get too close, and a new study takes a deeper look at the process of stellar engulfment.

Stars like our sun will eventually become red giants. Through nuclear fusion, they convert mass into energy ($E=mc^2$, right?) Over their lifetimes, they shed so much mass as energy that they eventually expand and turn red. For planets that are too close to these swollen spheres, it spells the end. They're eventually engulfed and completely destroyed.

A lot of research has delved into the planetary engulfment process, and a new study calculated one in ten evolved stars in the Milky Way will swallow Jupiter-mass planets.

The study is titled "Giant planet engulfment by evolved giant stars: light curves, asteroseismology, and survivability." The first author is Christopher O'Connor. O'Connor is a Ph.D. student at the Department of Astronomy at Cornell University. The study has not been peer-reviewed yet and is available on the *arXiv* server.

The study focuses on two types of evolved stars that are closely related: red giant branch (RGB) stars and asymptotic giant branch (AGB) stars. The two are similar, and in fact, RGB stars can become AGB stars. The term evolved star is descriptive enough to cover both, and in this work, the important thing is that RGB stars and AGB stars have both left the main sequence.

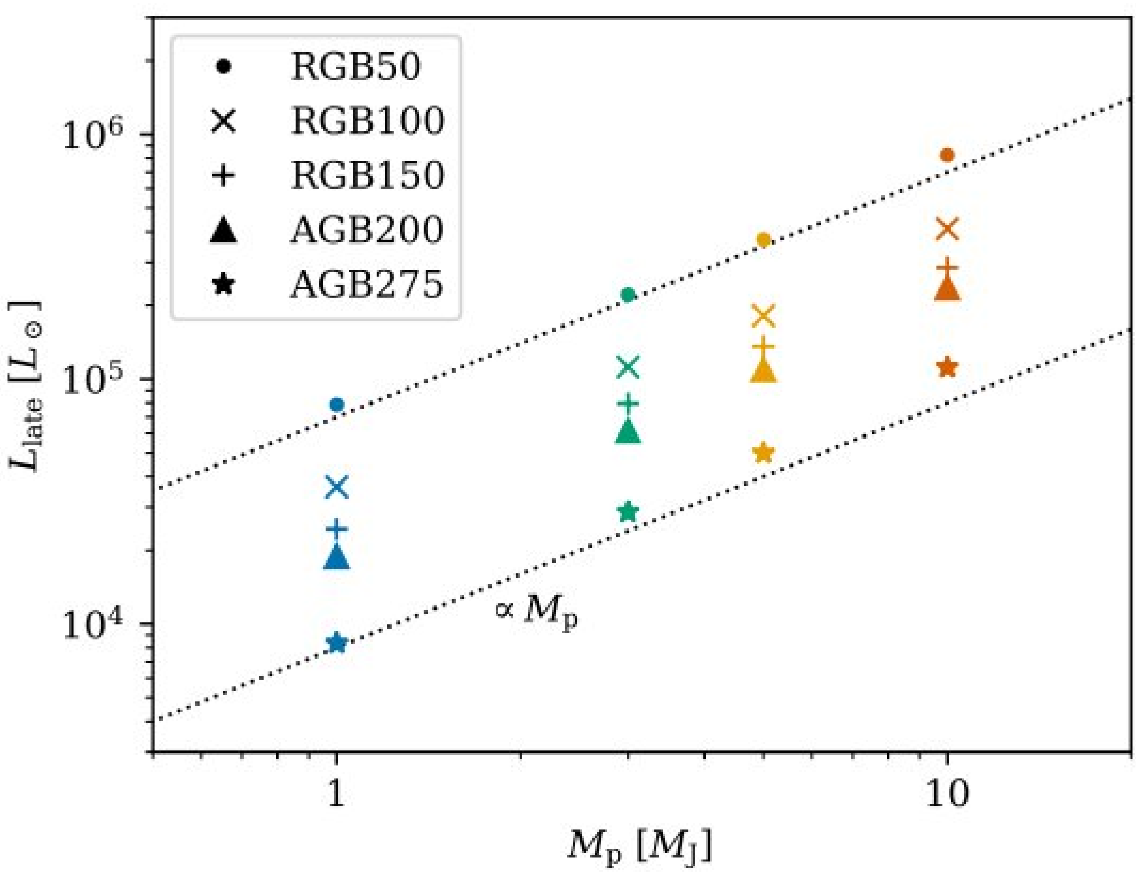
As these evolved stars lose mass, they expand, and at this stage, any planets in close proximity are in peril. The star's convective envelope swells and ensnares the planet. This creates drag, which causes the planet to spiral inward toward the star. Astronomers know this, and in this work, the authors examined the frequency of these events and how the stars respond.

They describe a sun-like star as a star with 1 to 2 solar masses. About 10% of these stars will engulf a planet between 1 to 10 Jupiter masses. For these mass relationships, the in-spiral will take between 10 and 100 years or between 100 and 1000 orbits.

To determine these ranges and how the star responds, the researchers used an open-source astronomy software tool called MESA (Modules for Experiments in Stellar Astrophysics.) "We use the Modules for Experiments in Stellar Astrophysics (MESA) software instrument to track the stellar response to the energy deposition while simultaneously evolving the planetary orbit," they explain. MESA revealed how the different evolved stars responded to engulfing planets with different masses.

While many astrophysical events play out over thousands, millions, or even hundreds of millions of years, planetary engulfment is a much quicker process. But before the planet and star come into contact, two things draw them together: stellar expansion and orbital decay. This is the first phase of the engulfment, where tidal friction causes the planet's orbital decay. The authors explain that the tidal friction is "most likely due to turbulent dissipation in the star's convective envelope." At this point in the process, drag from the stellar corona and the stellar wind are minimal.

Once the star and planet start to come into contact with one another, things change. Tidal friction takes a back seat to drag forces. The authors call this the "grazing" phase. "The 'grazing' hydrodynamical interaction of the star and planet is complex and three-dimensional," they write. The complexities in the grazing phase can include phenomena like the expulsion of matter from the star and optical and X-ray transients triggered by shocks. But this study leaves those phenomena aside for now. "We focus on the later 'inspiral' phase of engulfment, when the planet is completely immersed in the envelope," they write.



This figure from the paper shows heat deposited in stars in the later inspiral phase. The RGBs and AGBs in the legend are modelled host stars with different masses. The x-axis shows planetary mass, and the y-axis shows the amount of heat deposited. Clearly, the more massive the planet, the more heat is deposited. Credit: O'Connor et al. 2023

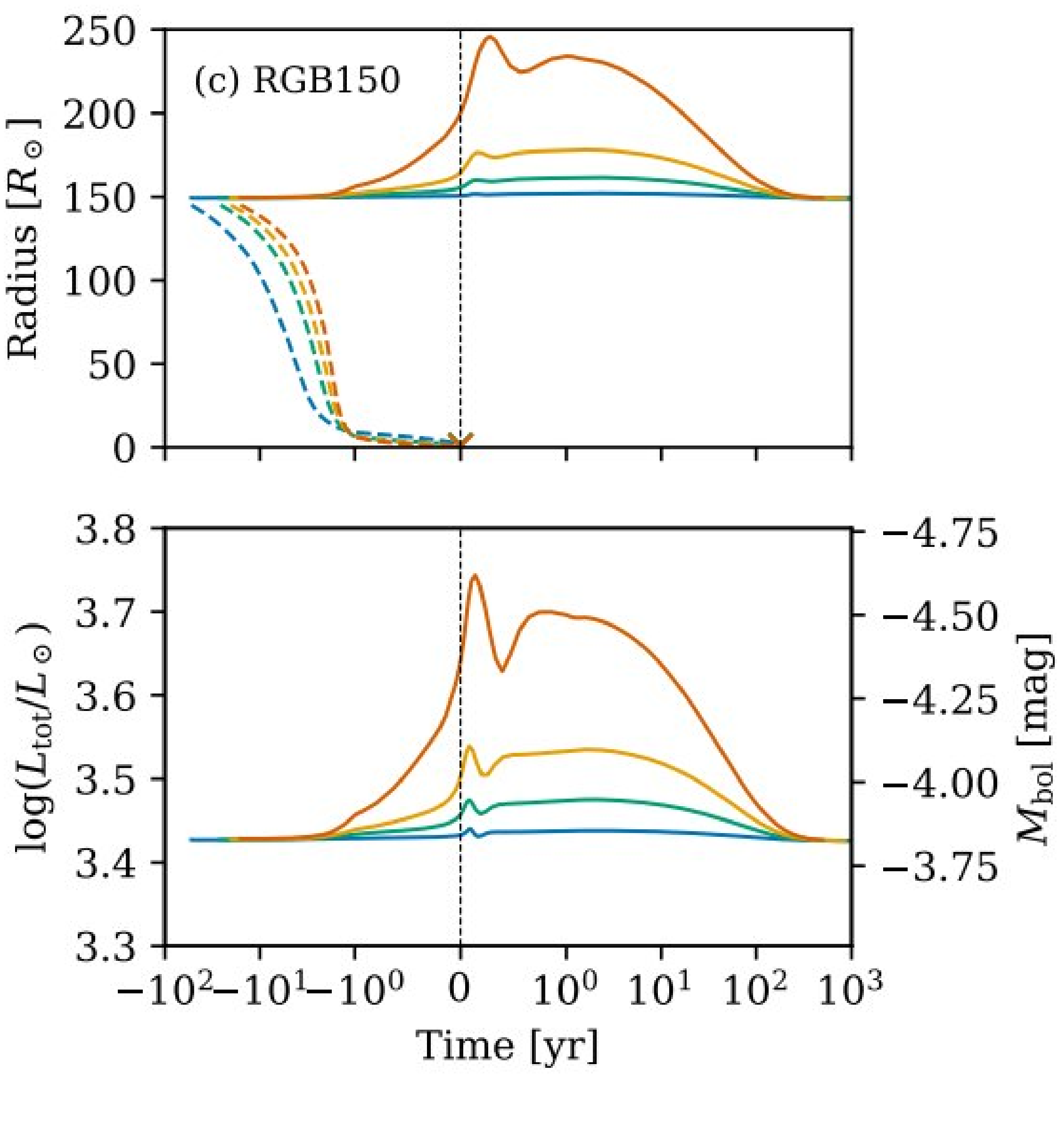
When a planet is in the inspiral phase, it deposits heat into the star. The latter part of this phase is called the late inspiral phase, and the heat added to the star during this phase is largely responsible for the star's response. The mass of the planet is a determining factor in how much heat is deposited.

The engulfments cause the stellar envelope to expand and contract, though not monotonically. A given mass shell can expand and contract multiple times during the event. The researchers say the planet can be visualized as a local heat source in the shell, and the source is moving toward the star's center. This movement, and other properties of the star, create varied expansions and contractions.

This research agrees with previous research showing that planet engulfment leads to optical and infrared bursts in luminosity. The power and duration of these bursts are largely determined by the mass of the planet and the star, though other factors like rotation can come into play. The researchers found that for all RGB stars, and for AGB stars engulfing planets up to five Jupiter masses, the star brightens considerably in only a few years.

The researchers' overall results show that for both types of evolved stars engulfing a planet on the low side of the range, up to three Jupiter masses, the changes to the stellar structure are mild to moderate. The star's brightness rises by up to one magnitude in only a few years. Brighter stars can experience a double peak.

For stars in the later stages of the AGB, the engulfed planet can create a major disturbance in the star's outer layers. It can trigger supersonic expansion of the star's outer layers. In this case, the stars can resemble Luminous Red Novae (LRN) as they produce bright, red, dusty eruptions.



This figure from the study shows the changes in radius and magnitude for one of the host stars modelled in the study. The top panel shows how a star can expand

and contract multiple times during engulfment. The bottom panel shows how the star's magnitude changes. Credit: O'Connor et al. 2023

Regardless of the type of star, the mass of the planet, and how the star responds to the engulfment, the planet's fate is always the same: tidal disruption.

This study has limited applicability to our solar system. Our sun will become a red giant in a few billion years, but unless something extremely disruptive happens before then, Jupiter is out of reach. Instead, the inner rocky planets face engulfment.

This study is based on simulations rather than observations, but the simulations could help astronomers identify the real thing when it happens. Engulfments are transient events, and some existing and future telescopes and observatories focus entirely on transients and time-domain astronomy. When the Vera Rubin Observatory comes online around August 2024, it'll spot a multitude of transient events, some of which will be evolved stars engulfing Jupiter-mass planets.

The results of this study could help spot them.

More information: Christopher E. O'Connor et al, Giant planet engulfment by evolved giant stars: light curves, asteroseismology, and survivability, *arXiv* (2023). DOI: 10.48550/arxiv.2304.09882

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