An unlikely survivor: A low-density, hot Neptune orbiting a red giant star

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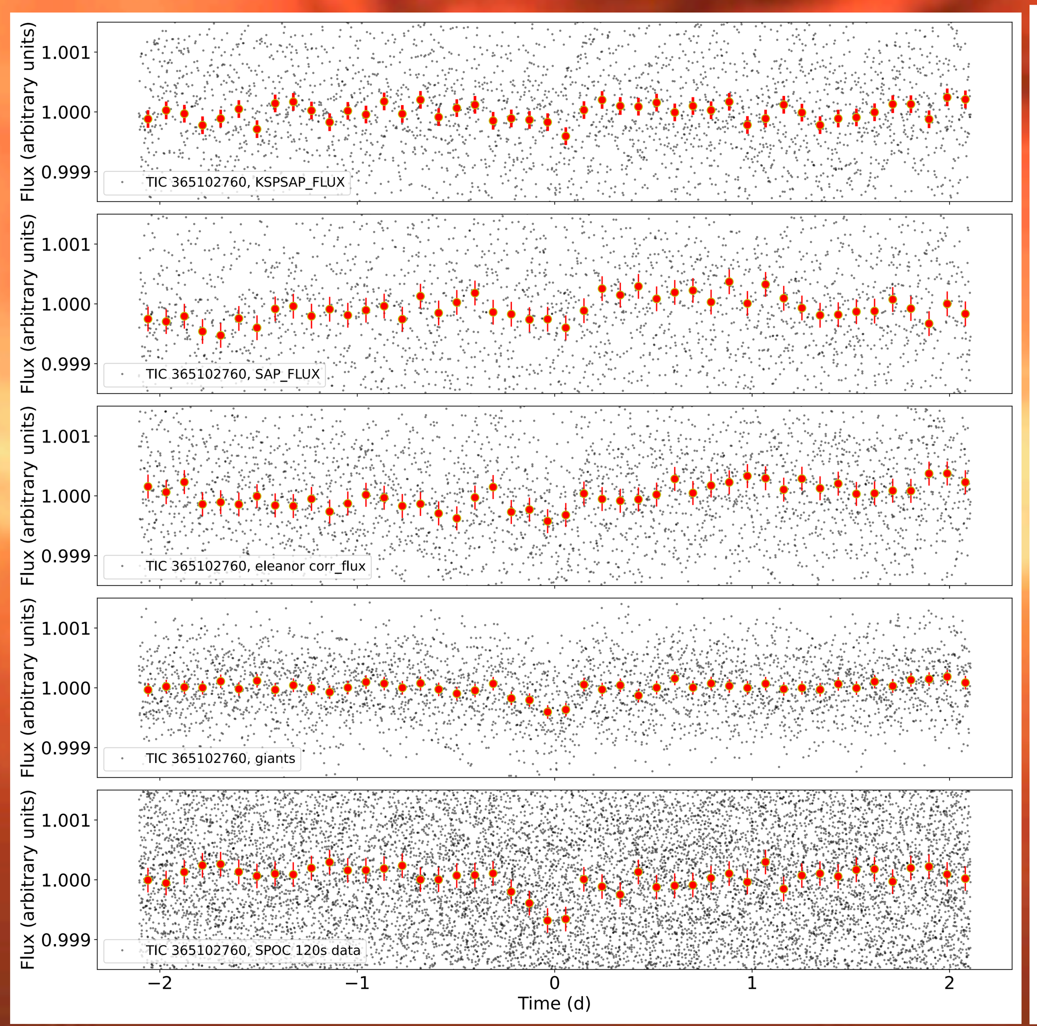
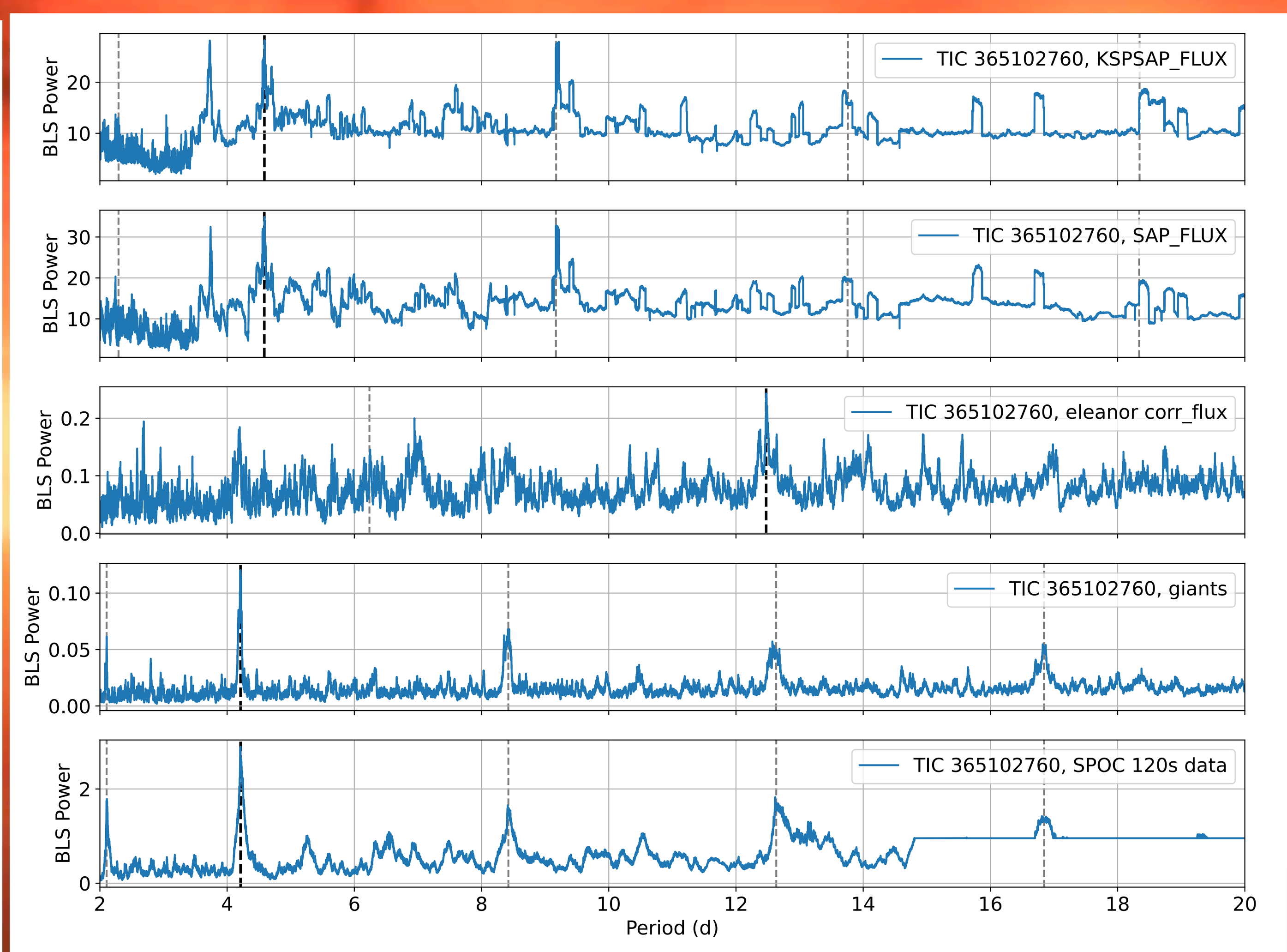
Key Points

- The shallow, long-duration transit signal of this planet could **initially be found only with the `giants` FFI pipeline**, but has now been confirmed with a high-cadence, `SPOC` light curve detection and ground-based RV followup.
- With a mass of 19.2 +/- 4.2 Earth masses and 6.2 +/- 0.8 Earth radii, this is the **first hot Neptune found around an evolved star**.
- ***The planet is predicted to have lost ~65% of its mass to atmospheric mass loss, which should have stripped its atmosphere entirely, unless the star was unusually inactive, or the planet experienced late-stage migration and/or re-inflation.***

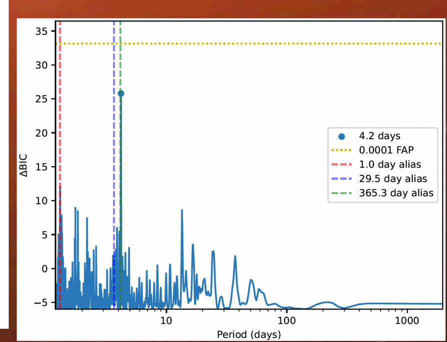
A needle in the haystack

A targeted visual search for giant planets transiting giant stars with the `giants` pipeline (Saunders+ 2022) revealed a shallow (~400 ppm), long-duration (~9 hr) transit signal at a 4.2 day period. This signal was not found by other pipelines until 120-second cadence TESS data was available and a `SPOC` light curve was produced.



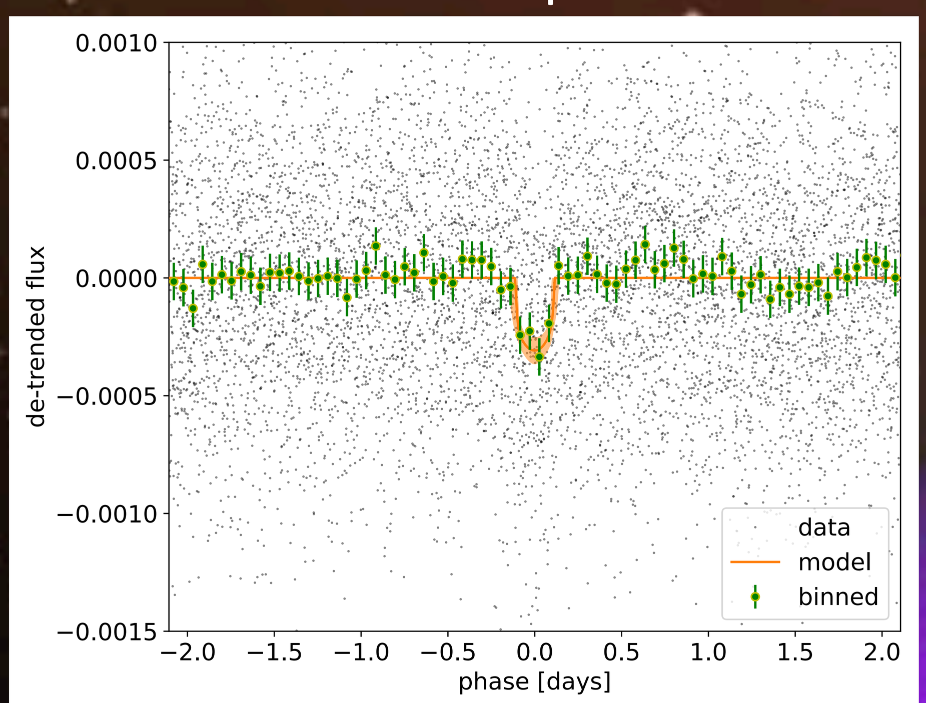


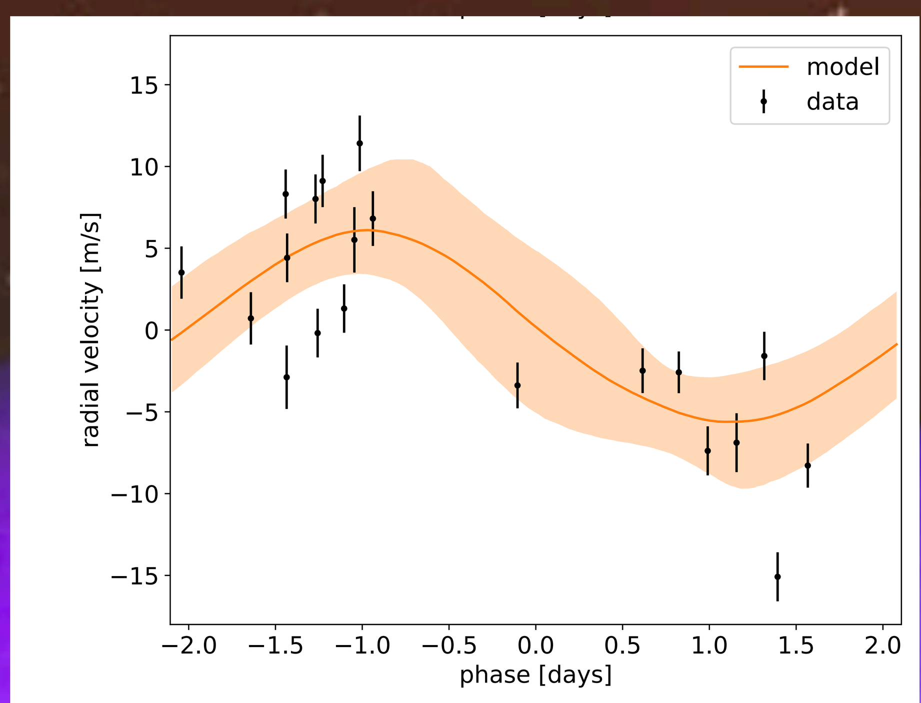
Subsequent Keck/HIRES RV followup detected a signal at the same period and phase as `giants` and `SPOC`.



The first hot Neptune with an evolved host

Using `exoplanet` (Foreman-Mackey+ 2018), we modeled the available data for this system to determine the planet mass and radius.

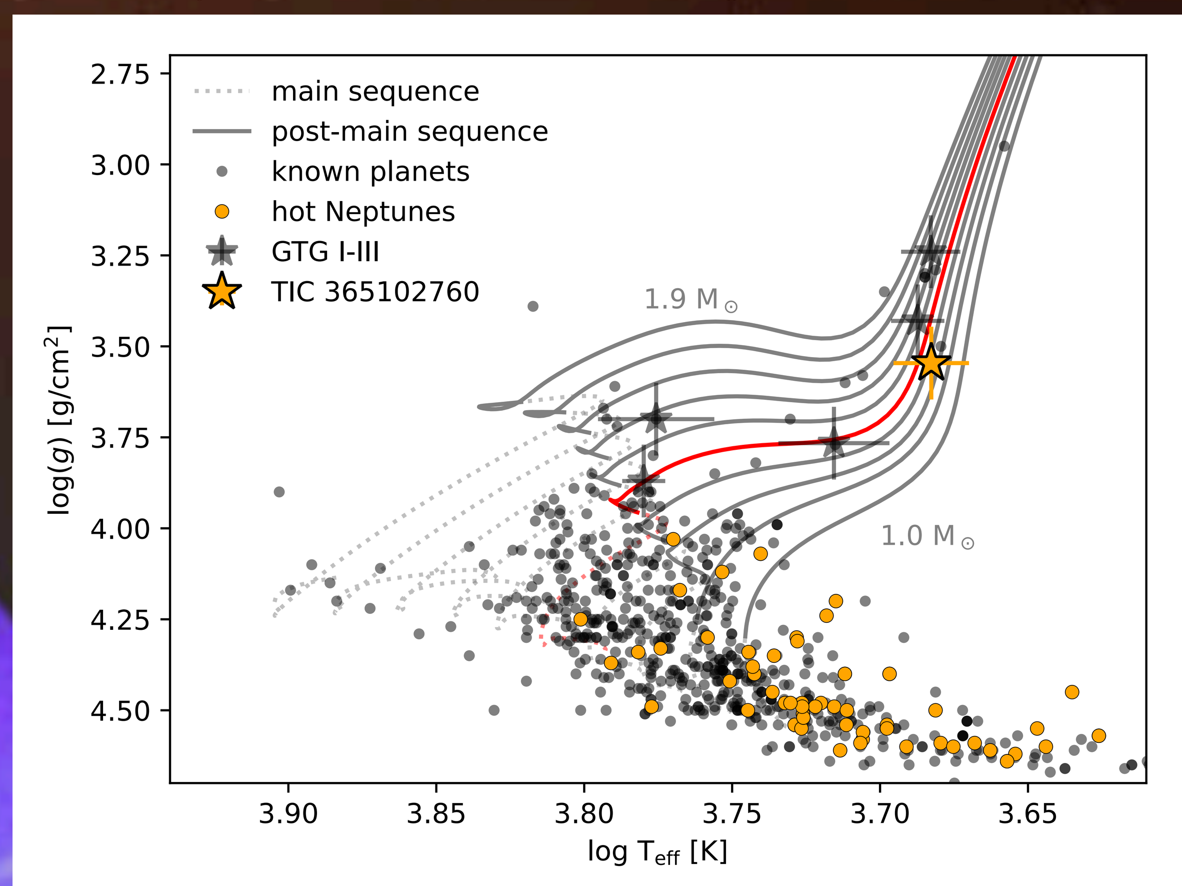




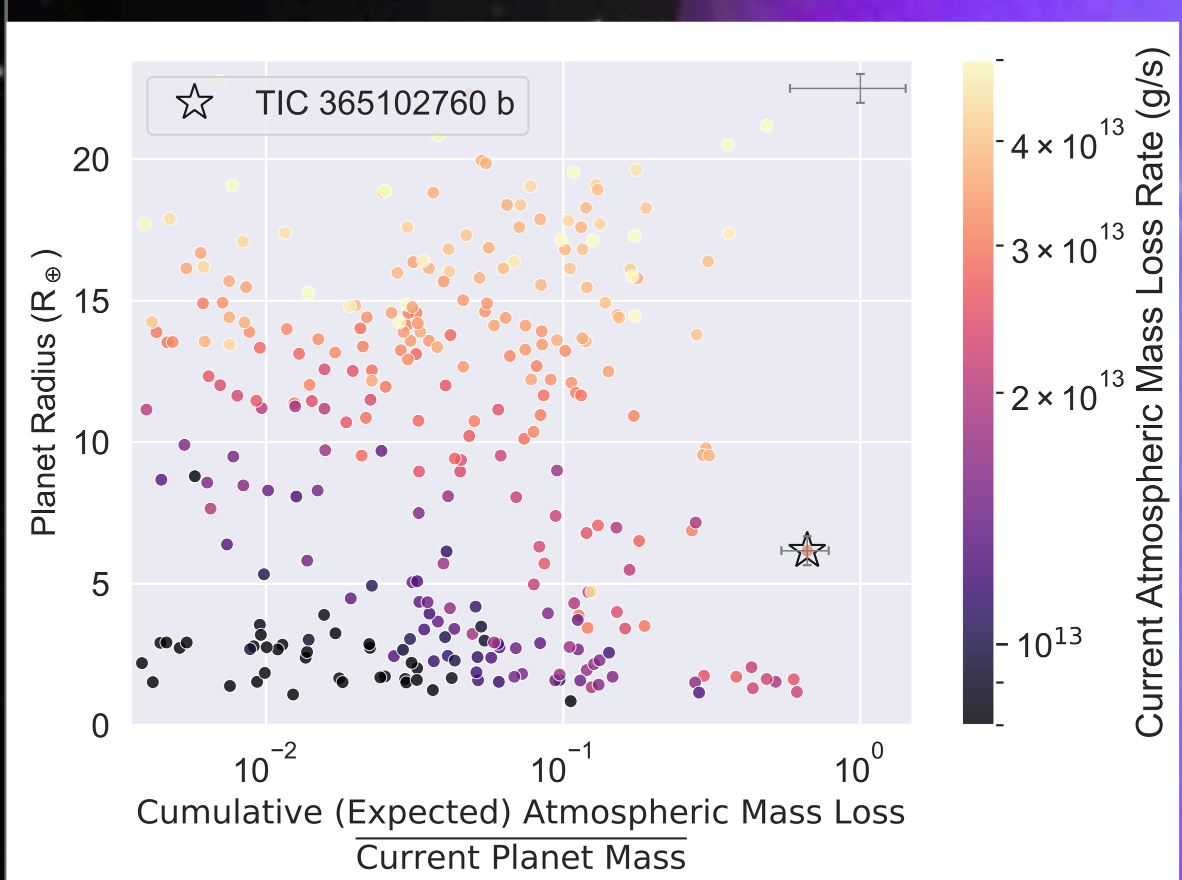
R_p = 6.21 +/- 0.76 R_{Earth}

M_p = 19.2 +/- 4.2 M_{Earth}

Taking stellar parameters into account, we found that this is the first well-characterized hot Neptune known orbiting an evolved star.

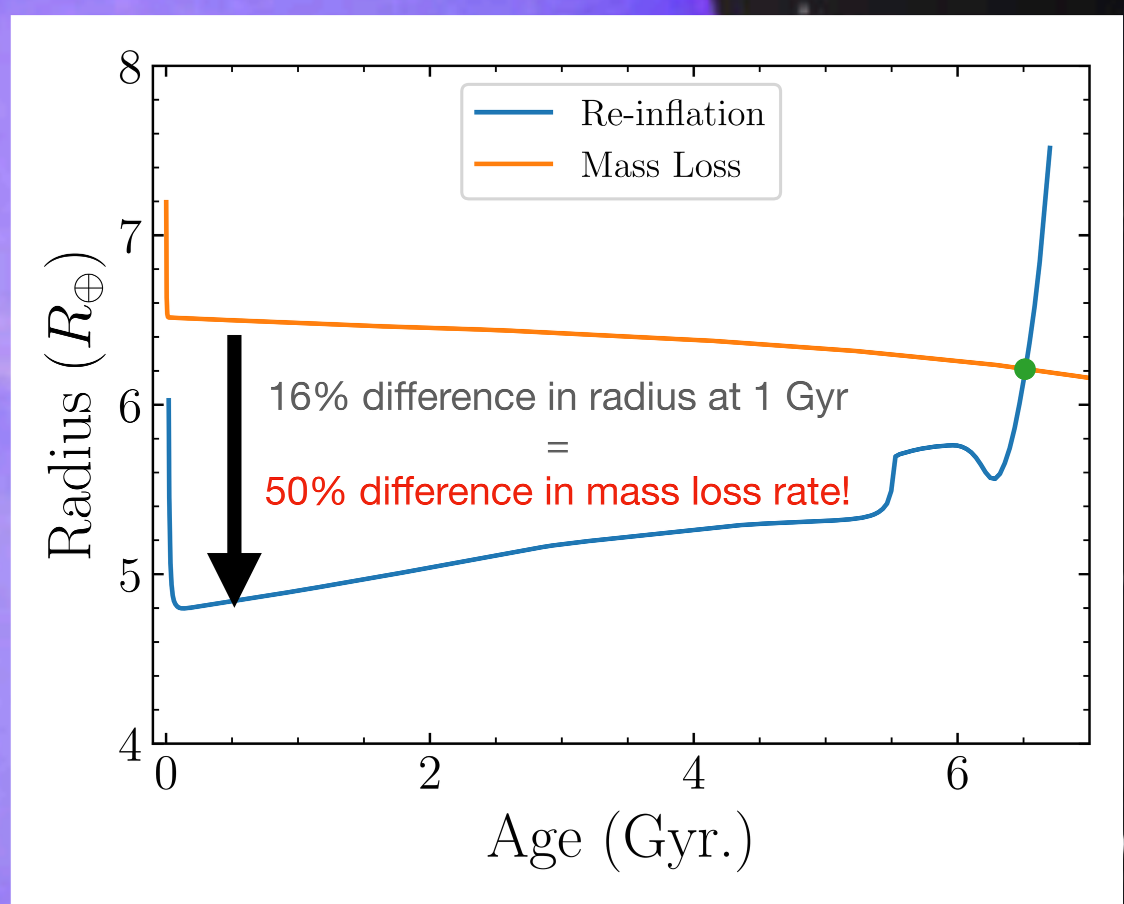


An atmosphere saved by re-inflation?



Integrating the XUV flux expected for this and all other well-characterized planets with ages, we determine the cumulative expected atmospheric mass loss as a fraction of total planet mass. This planet is expected to have lost **65%** of its mass, more than any other gaseous planet, despite models suggesting the atmosphere is only 20-30% of the planet mass (Lopez & Fortney 2014, Chen & Rogers 2016).

How did this planet retain its atmosphere?



Atmospheric mass loss depends on the planet density (Watson+ 1981):

$$\dot{M} = \frac{\epsilon \pi R_{XUV}^2 F_{XUV}}{K G M_p / R_p}$$

Thus, if the planet's density was higher in the past, it can retain significantly more atmosphere. A 16% reduction in early planet radius results in a 50% reduction in atmospheric mass loss, allowing this planet to survive.

Link to arXiv: https://arxiv.org/abs/2303.06728 (or use QR code above!)

References

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2. Foreman-Mackey, D., Luger, R., Agol, E., Barclay, T., Bouma, L, et al. "exoplanet: Gradient-based probabilistic inference for exoplanet data and other astronomical time series," JOSS, 2021.
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