Discovering Atmospheric Escape of the Unique Helium Tail in the HAT-P-67 Planetary System

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Helium Exospheres with HPF

We aim to understand how exoplanet atmospheres evolve across age, stellar irradiation environments, planet properties. The Helium Exospheres program with the Habitable Zone Planet Finder (HPF) spectrograph on the Hobby Eberly Telescope (HET) in West Texas has targeted 23 exoplanet systems over two years.

Here, we present a study of **HAT-P-67**, a type F subgiant hosting a low density planet with 0.3 $M_{Jupiter}$ and 2.1 $R_{Jupiter}$ on a close-in 4.8 day orbit. HAT-P-67b shows prominent in-transit absorption in the He 10830 Å triplet and infrared Ca II 8542 Å triplet across 20 nights of observations over the course of a year including in- and out-of-transit spectroscopy. As an extremely low-density object, we expect HAT-P-67b to lose its atmosphere rather rapidly for transiting an evolved host star.

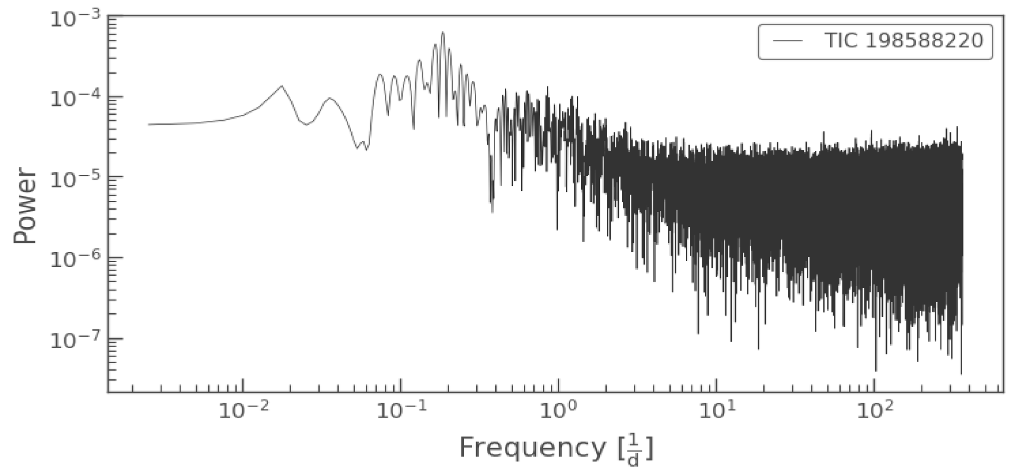
`µler`; a new Python tool for HPF, IGRINS, and Keck NIRSPEC

https://github.com/OttoStruve/muler/

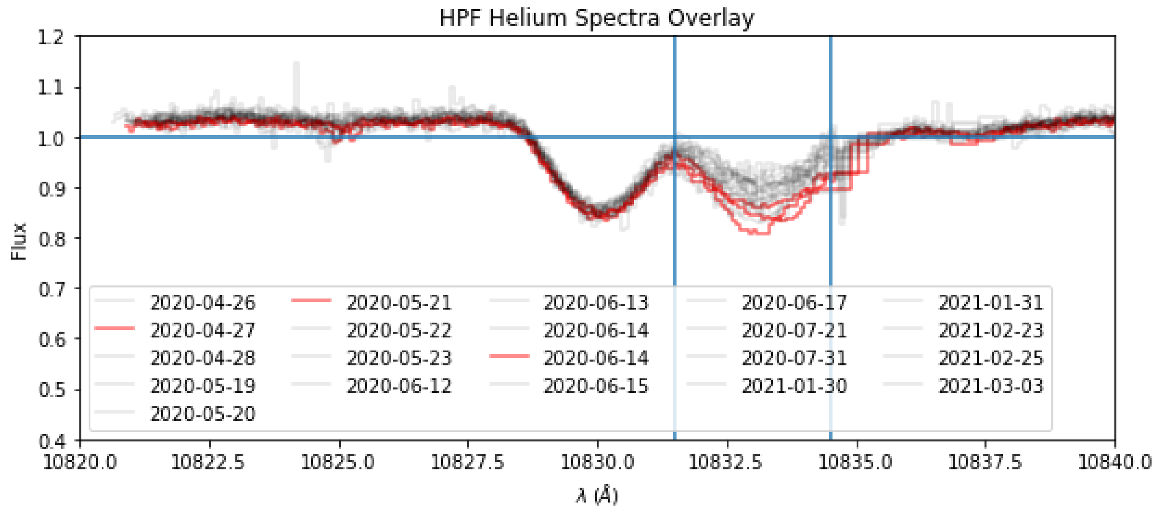
We used the open source Python tool `µler` to determine the equivalent width of the He and Ca II lines. `µler`, which conducts routine post processing on HPF Goldilocks spectra including sky subtraction, deblazing, masking telluric lines, and barycentric correction.

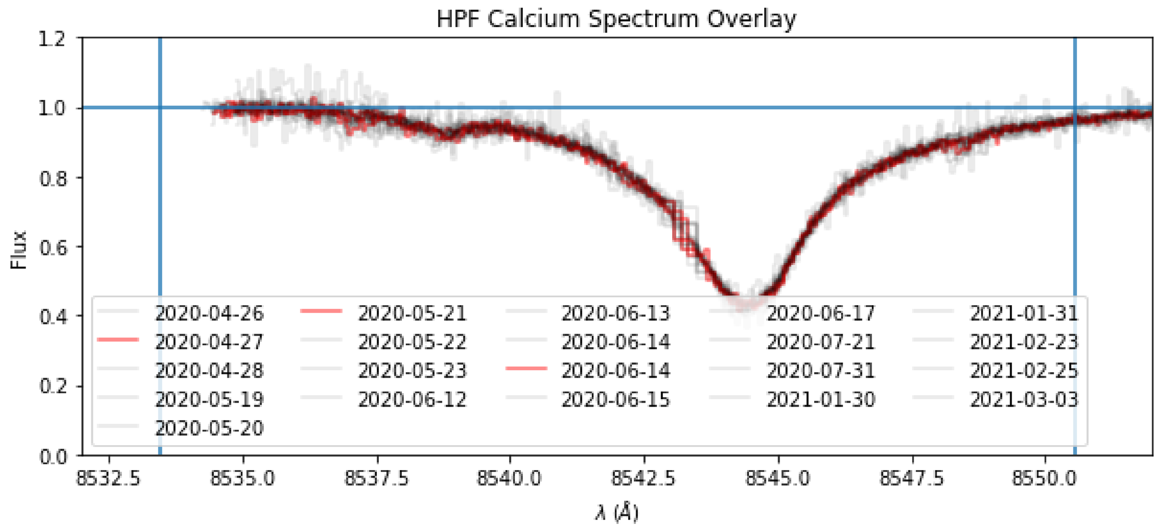
Rotational period of HAT-P-67

We created a periodogram of just the stellar signal and arrived at an estimate of several parameters for HAT-P-67b: the planetary period is 4.809 days, the original transit time is 1958.082 BTJD, and the planetary duration is 0.25 days. The resulting periodogram of just the stellar variation describes a rotational period of 5.417 days is shown in the bottom left.

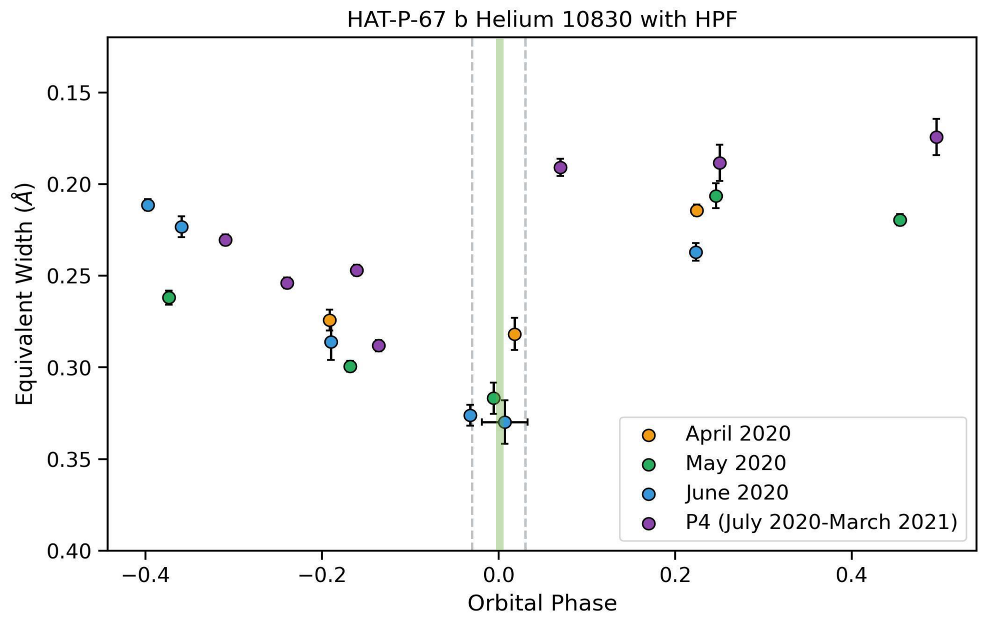


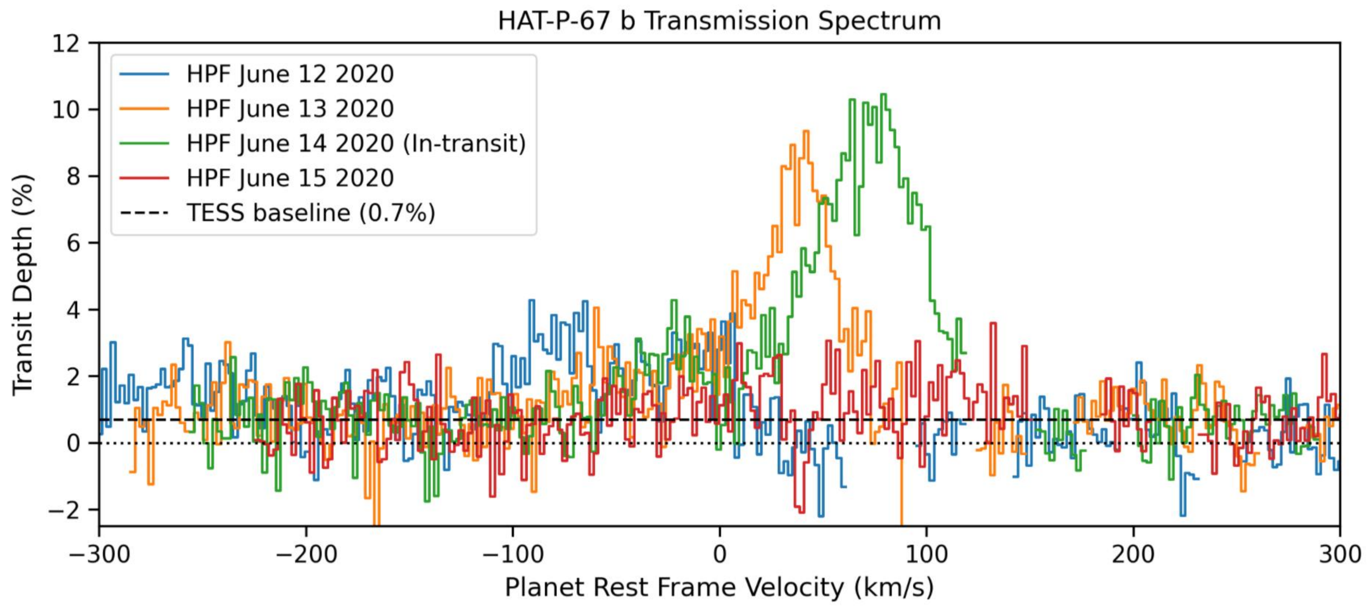
Detection of He 10830 Å in the atmosphere





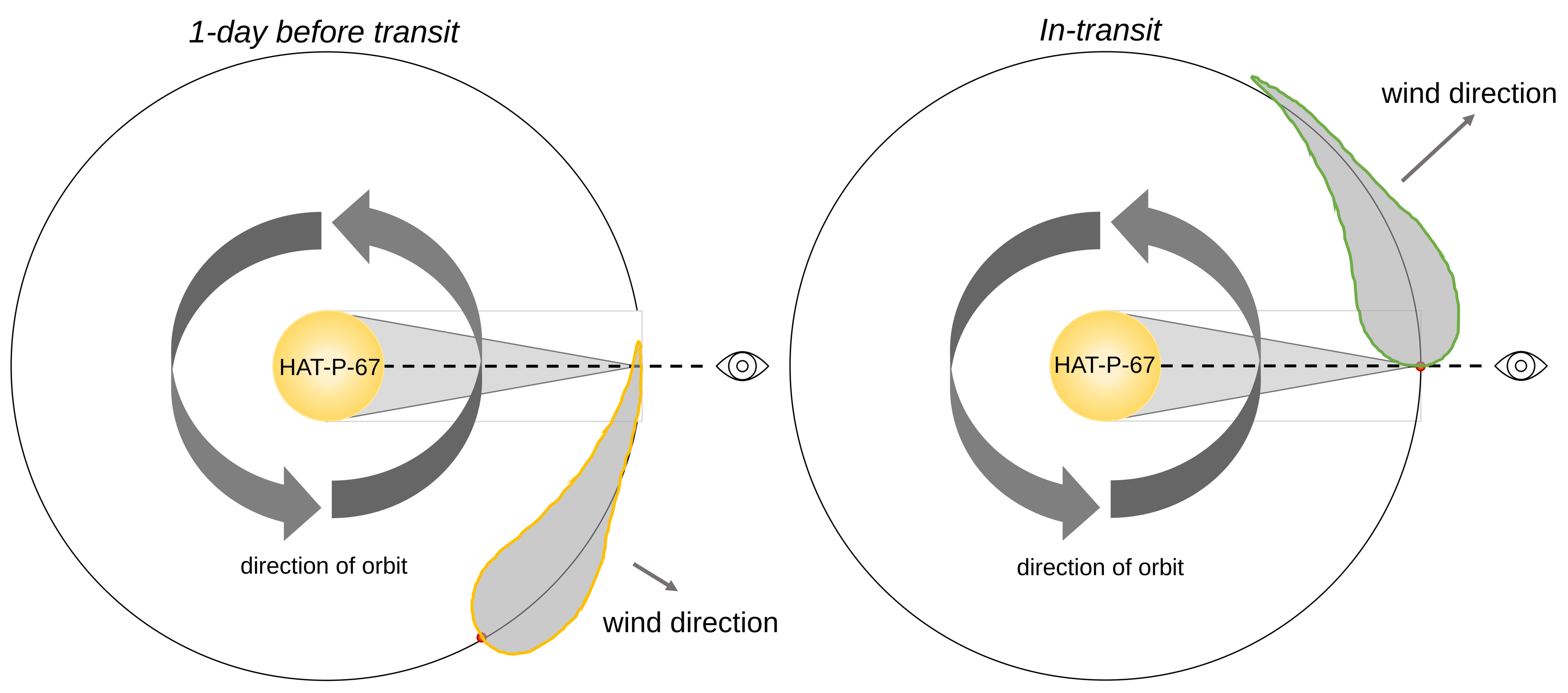
We aim to analyze the in-transit He 10830 Å and infrared Ca II 8542 Å absorption of HAT-P-67b. In order to differentiate if the change in equivalent width is due to the planet or host star we must observe the chromospheric lines. He 10830 Å and infrared Ca II 8542 Å are both chromospheric lines and the calcium infrared triplet serves as the best simultaneous indicator for stellar variability. The plots above display the equivalent width of each night via the method using `µler` with a 5% error bar and the contemporaneous Transiting Exoplanet Survey Satellite (TESS) lightcurves from sectors 24 and 26. The planet shows prominent in-transit absorption in the He 10830 Å across 20 visits over the course of a year including in- and out-of-transit spectroscopy. We observe that the helium line depth changes by 5-10% when the planet is in-transit.





Model of HAT-P-67 Planetary System with Escaping Atmosphere

Top-down view, to scale



We depict the transit of HAT-P-67b 1-day before transit and the day of transit in the schematics below. The orbital phase versus equivalent width plot shown above illustrates that helium absorption during transit is asymmetrical. As a result, we mold the shape of the helium exosphere to mimic the irregular absorption with constraints on the velocity and length. The *HAT-P-67b Transmission Spectrum* plot indicates the direction of the gas on different days in the planet's orbit.

Fate of the exosphere

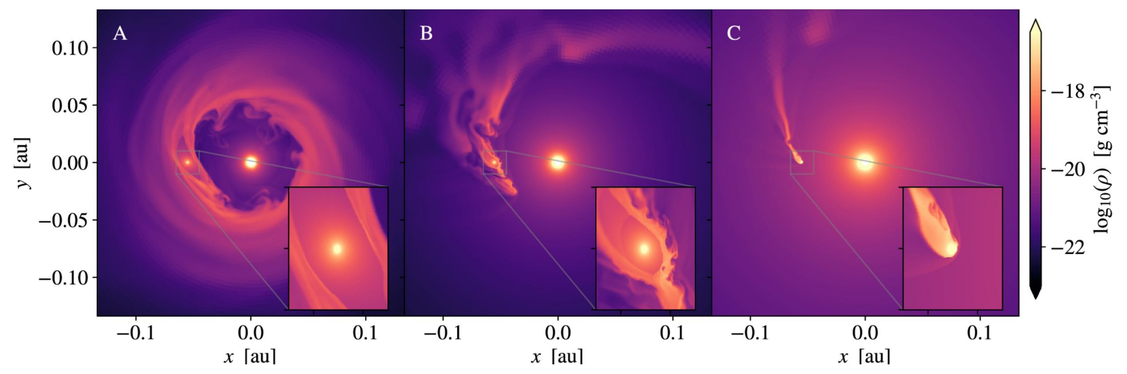
What is the planet's mass loss rate?

Parker wind models, such as those implemented in the Python tool `p-winds`, are incapable of accurately measuring mass loss rates for systems as extreme as HAT-P-67. Instead, we must constrain the mass loss rate to the mass of the planet over the course of the age of the universe. The resulting value is 2.045 $* 10^{12}$ g/s, which is equivalent to 13,660 blue whales every second!

Where does the mass go?

Scenario One: Towards the Star
The first scenario is where the mass from the exosphere falls onto the surface of the star. The TESS lightkurve for this system exhibits a reoccurring 0.2% increase in the flux that is not attributable to the planet's transit. Assuming that this modulation is due to a hot spot on the stellar surface, we conclude that gravitational potential energy alone is not sufficient to increase the flux by such an amount. Larger mass loss rates could cause brighter hotspots, but this would cause the planet to disappear entirely over its lifetime, which is unphysical.

Scenario Two: Away from the Star
The second situation involves the mass being pushed away from the star. We can refer to the schematic below from the paper *Stellar Wind Confinement of Evaporating Exoplanet Atmospheres and Its Signatures in 1083 nm* Observations by MacLeod et al. The figure shows hydrodynamic winds from model exoplanets interacting with stellar winds and mass loss rates of varying magnitude. While our model more closely resembles cases B, the leading tail as seen in the insert is much less dramatic than the one pictured in the model of the HAT-P-67 planetary system.



References

[1] Gully-Santiago et al., submitted
[2] MacLeod et al., 2022, ApJ, 926, 226
[3] Mahadevan et al., 2012, 2014
[4] Zhou et al., 2017, AJ, 153, 211