Attempted Detection of Weather Patterns on HAT-P-7b

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1. Introduction – Kepler Data

HAT-P-7b is an extrasolar planet that was observed by the Kepler satellite from 2009. Kepler, launched in March 2009, was designed to find and characterise Earth-size planets in or around the habitable zones of their host stars.

Despite its primary objective, some of the exoplanets observed by Kepler were Hot Jupiters; these are Jupiter-sized objects that have migrated to a position very close to their parent stars. As a result, they have extremely short periods, much shorter than that of the Earth. HAT-P-7b is one of these.

The prime mission ceased in 2013 due to a giro failure, making way for the new shorter-duration K2 surveys. This left 18 quarters of data available for the majority of planets observed.

Kepler data is stored in the Mikulski Archive for Space Telescopes (MAST). Light curves for the observed exoplanets are available in FITS format and can be downloaded in bulk as a .tar file[1].

Weather is a key aspect of understanding exoplanets, and conditions upon them. The quarterly data for HAT-P-7b was used to investigate a new technique for inferring the presence of weather patterns.

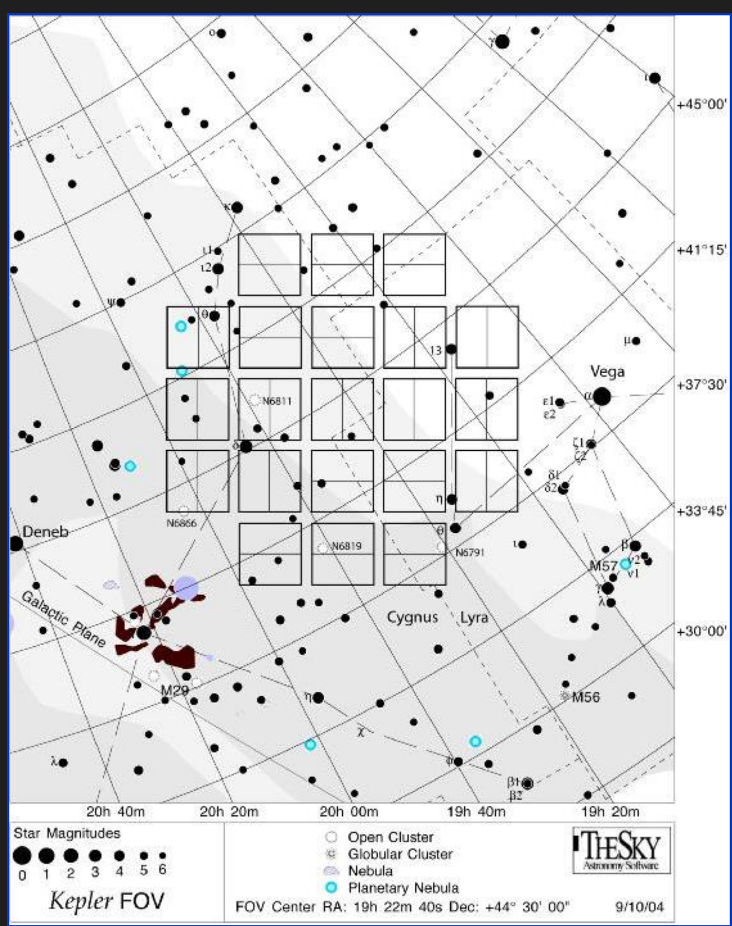


Figure 1 The Kepler satellite's field of view. HAT-P-7b is located at $19^h 28^m 59^s$, +47° 58′ 10″ (RA, Dec).

2. Methodology and Data Reduction

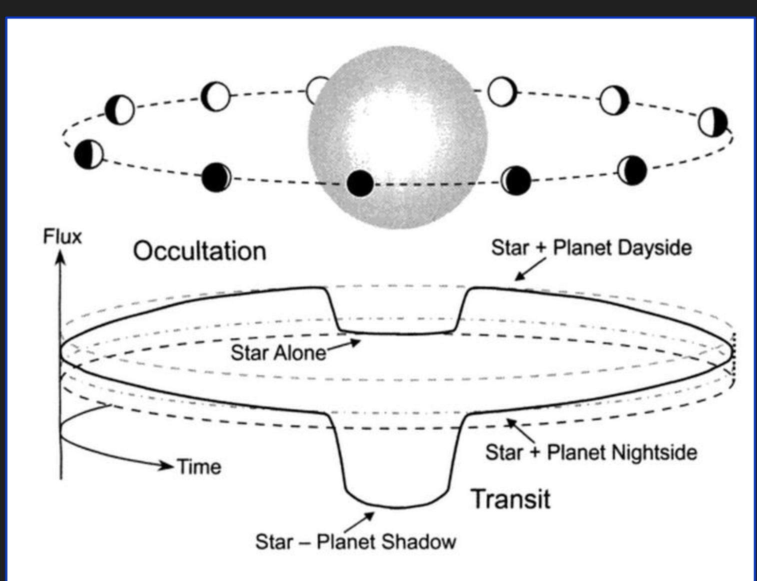


Figure 2 The shape of the phase curve at various phases of the planetary orbit about its parent star.

Figure 2[2] shows an example of an exo-planetary phase curve, complete with a secondary eclipse. This occurs when the planet moves behind its host star, and results from the loss of reflected light from the planet's surface[2]. Phenomena such as cloud cover will affect the amount of reflected light; the shape of the phase curve should vary over time if weather is present. Hence, light curves for the planet in question had to be phase-folded in order to attempt to observe this effect.

Long cadence light curves for HAT-P-7b were retrieved from MAST's database. The following steps were taken:

- The quarterly light curves were de-trended using PyKE[3].
- Unwanted sections of the data were removed.
- The resulting 'cleaned' light curves were phase-folded; the overall phase curve is displayed in Figure 3.
- A sinusoidal model was fitted to the curves; the parameters were plotted against time.

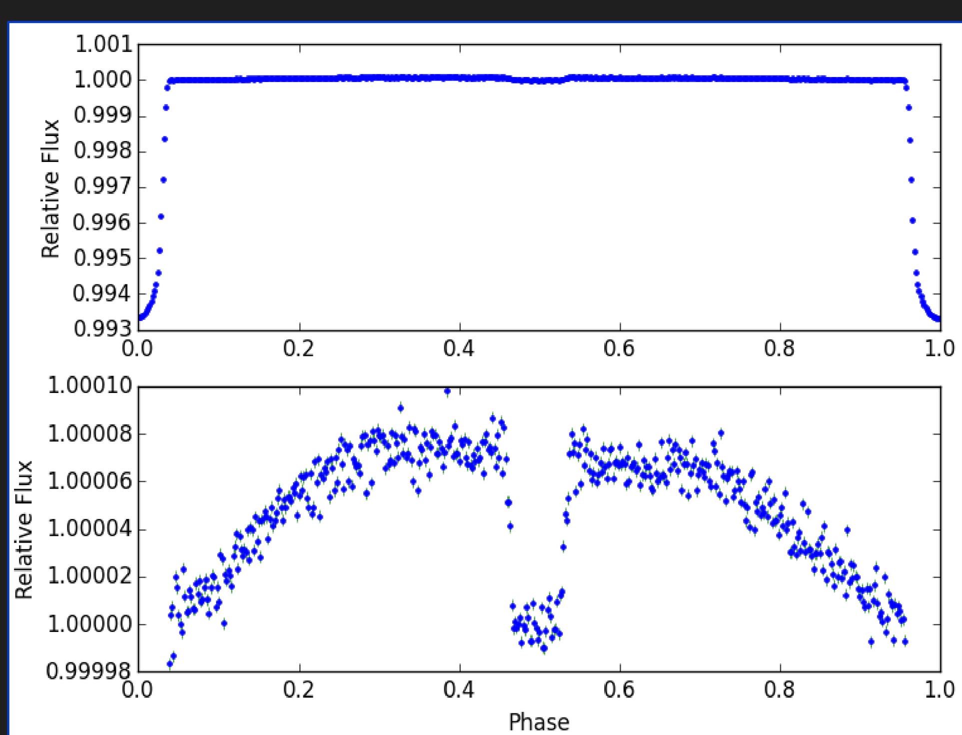


Figure 3 The phase curve for HAT-P-7b, with a subplot zoomed in to display the secondary eclipse. All 18 quarters of data have been phase-folded; the data were split into 500 bins.

3. Results and Analyses

A program was constructed using Python to plot the phase curves for small blocks of the overall data set. It then plots different parameters from the model fit against time to investigate variation in the curves.

1. The user can input the size of the blocks they wish to take.
2. Block by block, the program iterates through the entire light curve for HAT-P-7b.
3. Every phase curve is fitted with the same sinusoidal model.
4. The curves are displayed as shown in Figure 4. The user can then decide if the quality of the fit is sufficient.
5. Parameters for each fit are stored for further analysis.

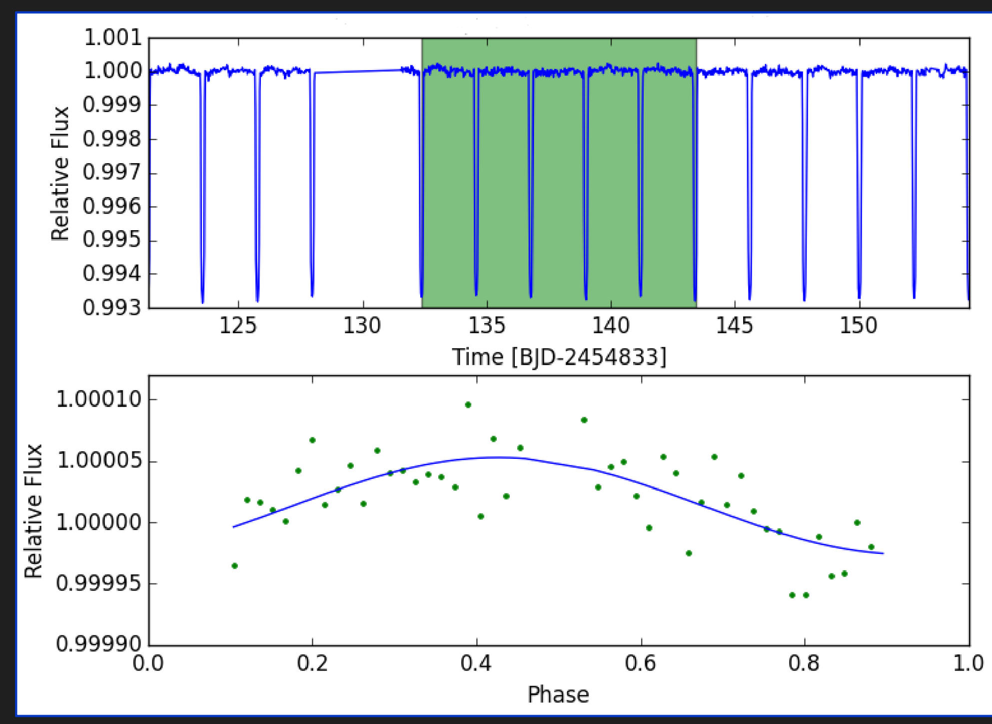


Figure 4 The user is able to see the block of the light curve in question (top) and its corresponding phase curve (bottom).

The program was run for numerous block sizes. It was found that blocks of five periods yielded the best results; these were small enough to gain an idea of periodicity, yet large enough to keep uncertainties reasonably low. For each block size, the amplitudes and phases of the model fits were plotted against time. For the case of five period blocks, amplitudes vary between $(6\pm6)\times10^{-6}$ and $(6.6\pm0.5)\times10^{-5}$, whilst the phases range from (3.7±0.3) to (6.1±0.3). The errors in the average amplitude and phase are given by $\pm(6\times10^{-7})$ and ±0.02 respectively. As these errors are much smaller than the variation in each parameter, we can say with confidence that there is variation in the phase curves for HAT-P-7b over time, implying that a weather-like influence exists.

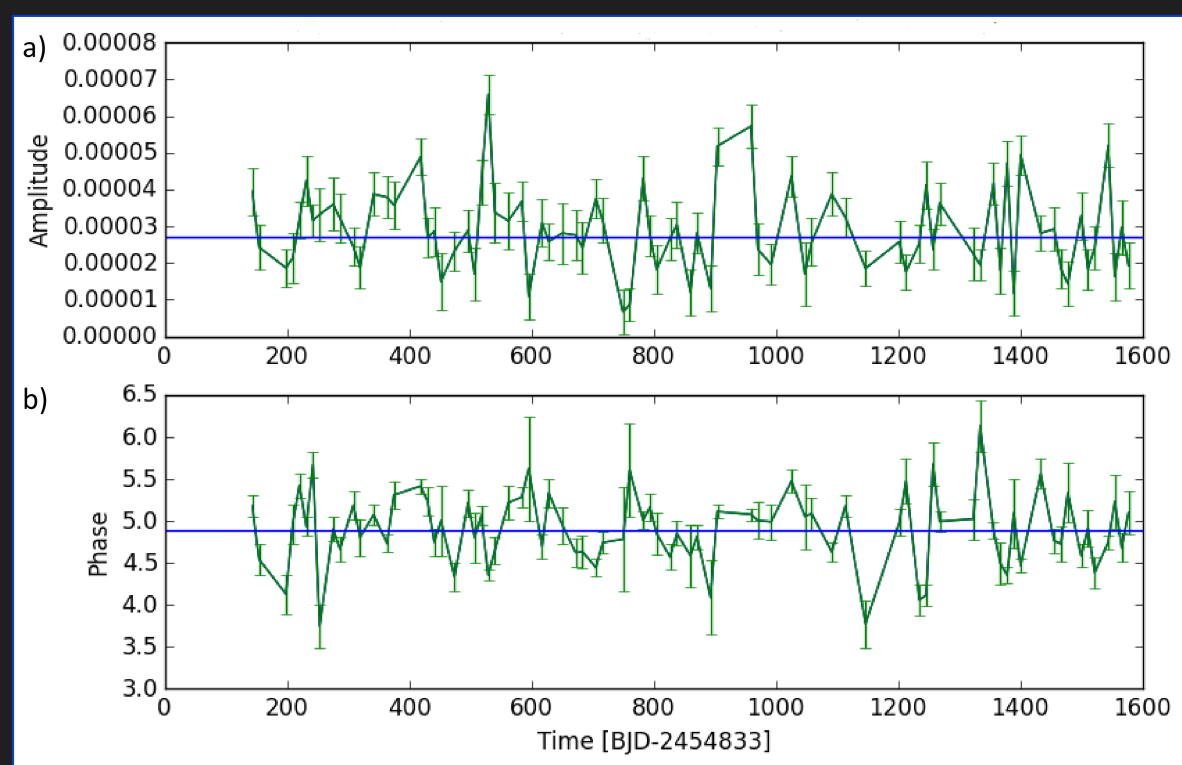


Figure 5 a) The variation in the amplitude of the model fit over time for a block size of five periods. The average amplitude, taken from the fit of the overall phase curve, is shown by the blue line.
b) The variation in the phase of the model fit through time, again for a block size of five periods. The phase for the fit of the overall phase curve is shown by the blue line.
Errors were found using the covariance matrices of the fits.

4. Conclusions and Further Work

The phase curves for HAT-P-7b were found to vary significantly over time. In theory, this could imply the presence of changing weather upon the exoplanetary surface, although more work must be done to say this with any confidence. Extensions of the project include:

- Repeating the above for other Hot Jupiters, a prime candidate being the planet KOI-13b (right).
- Testing for periodicity in the variations by conducting a periodogram.

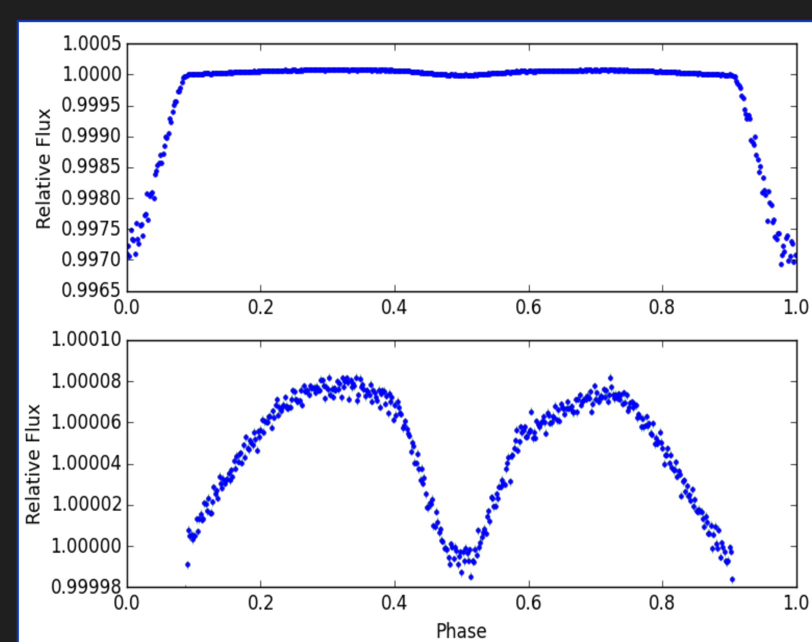
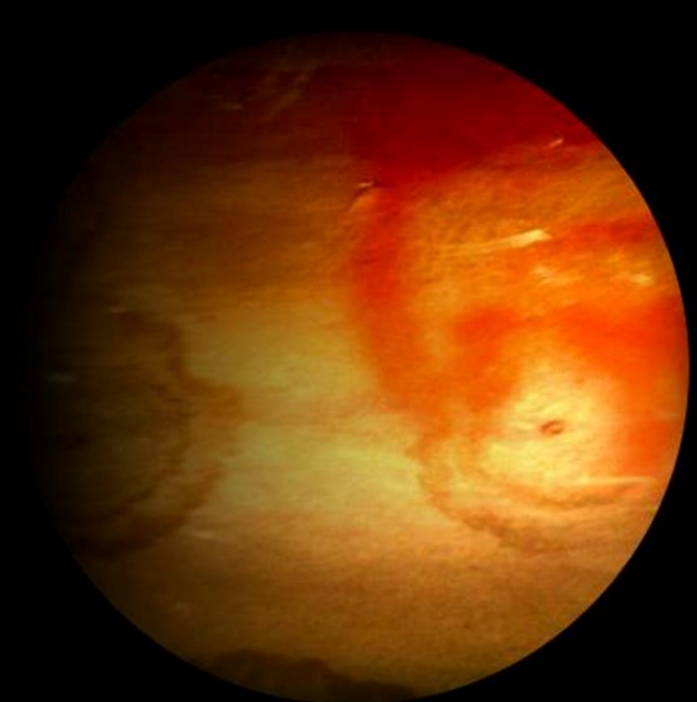


Figure 6 The well-defined secondary eclipse for KOI-13b; its strength makes it a good candidate for the presented technique.



HAT-P-7b[4]

Period	(2.204737±0.000017)days
Mass	$(1.776\pm0.077)M_J$
RA	$19^h 28^m 59^s$
Dec	47°58′10″
Inclination	(83.111±0.030)°
Eq. Temp.	(2733±21)K
Transit dur.	(0.1685±0.0110)days

References

[1] S. E. Thompson et al. 2014, *Kepler Archive Manual* (STScI KDMC-10008-005)
[2] M. Perryman, *The Exoplanet Handbook* (Cambridge University Press, Cambridge, 2011)
[3] M. Still, *Contributed Software – PyKE*, http://keplergo.arc.nasa.gov/PyKE.shtml (2013)
[4] B. M. Morris et al. 2013, ApJ 764 L22 (arXiv:1301.4503)

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