# Report on the TLCM-analysis of the CHEOPS simulated data on WASP-18b

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## 1. Introduction

The data analyzed here were synthetic data, produced by CHEOPSIM and distributed by A. Collier-Cameron via an e-mail we obtain 4th December, 2017. Following his advices, we used only the events which had an event-flag 0 or 100 and we skipped all other data.

First, we concentrated onto one transit event of WASP-18b (data-file: DP-056 763 5415, visit 1**, Alexis please check it!!!)**. The data looked like as it is shown in Figure 1.

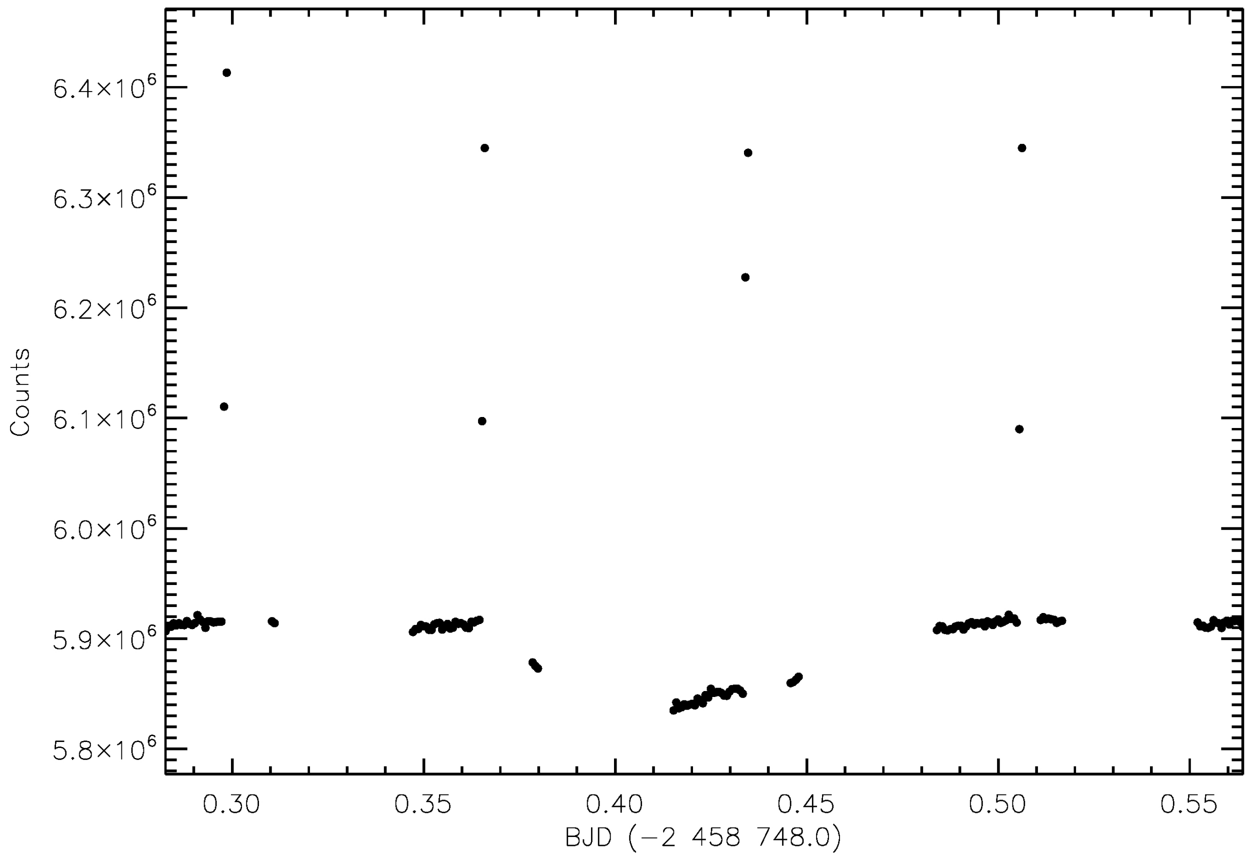


**Figure 1.** The light curve of WASP-18b as the outcome of CHEOPSIM (time vs flux). Time is in days and flux is in counts. Only those data points are shown in this figure which have an event flag of 0 or 100 as was adviced by A. Collier-Cameron.

**2. Data analysis**

We excluded all data points which had a flux over 6 million counts because they can be identified as clear outliers in Figure 1. Then we estimated the median level and the standard deviation of he data points which were obtained before 2 458 748.35 BJD or after 2 458 748.47 because these parts of the data looked like out-of-transit part by visual inspection of Figure 1. Then all data points were normalized by this median and we set a uniform uncertainty for every data points taken the previously determined standard deviations of the out-of eclipse part of the light curve.

We used TLCM (Transit and Light Curve Modeller). The following model was fitted:

Model = Transit model + flux shift + red noise model + Fourier-components.

The 'Transit model' was based on the model of Mandel & Agol (2002). The flux shift was constant in time and the aim of its usage was to correct any constant flux shift due to the normalization. (We need out-of-transit flux 1.0 in the normalized light curve to be able to fit a Mandel-Agol model.) The red-noise model was a wavelet model based on Carter and Winn 2009. Finally, The Fourier-components were:

$$Fourier\ components = \Sigma_{i=1}^{4} a_i \cos\left(2\pi RA/360\,deg\right) + b_i \cos\left(2\pi RA/360\,deg\right) \qquad (1)$$

where RA was the so-called 'roll angle' of the satellite. This was known froma  separate file for every moment where we had an observation. The whole model was fitted simultaneously. For the optimization we used a genetic algorithm (GA), and the results obtained by GA were refined by simulated annealing (quite similar to MCMC, the only difference is that the 'temperature' of the MCMC chain is continuously decreased). The error bars were estimated by bootstrap-analysis.

Since the ingress and the egrees are not defined by this one visit, we fixed the scaled semi-major axis (a/R_s) and the period value. Their values were taken from Southworth et al. (2009). We found a strange, approximately 0.47 part of the period shift in the transit time relative to the ephemeris given by exoplanet.eu or by Southworth et al. (2009).

Our free parameters were:

- the epoch (E)
- the white and red noise scatters ($\sigma_w$, $\sigma_r$)
- flux shift ($p_0$)
- $k = R_{planet}/R_{star}$ , planet-to-star radius ratio
- impact parameter
- the eight Fourier-coefficients (cf. Eq. 1),

in total 14 parameters.

Circular orbit was assumed and we used a fixed $u_{plus} = u_a + u_b = 0.7, u_{minus} = u_a - u_b = 0.1$ fixed limb darkening for the quadratic law.

**3. Results**

The best light curve fit is shown in Figure 2 and the results are summarized in Table 1.

**Figure 2.** The light curve fit of one transit of WASP-18b. Black points are the simulated data. Red curve represent a transit light curve without the Fourier-components and without red noise. The gray curve is actually the fit (cf. Eq. 1) which contains the Fourier-components (i.e. dependence on the roll angle) and the red noise fit.

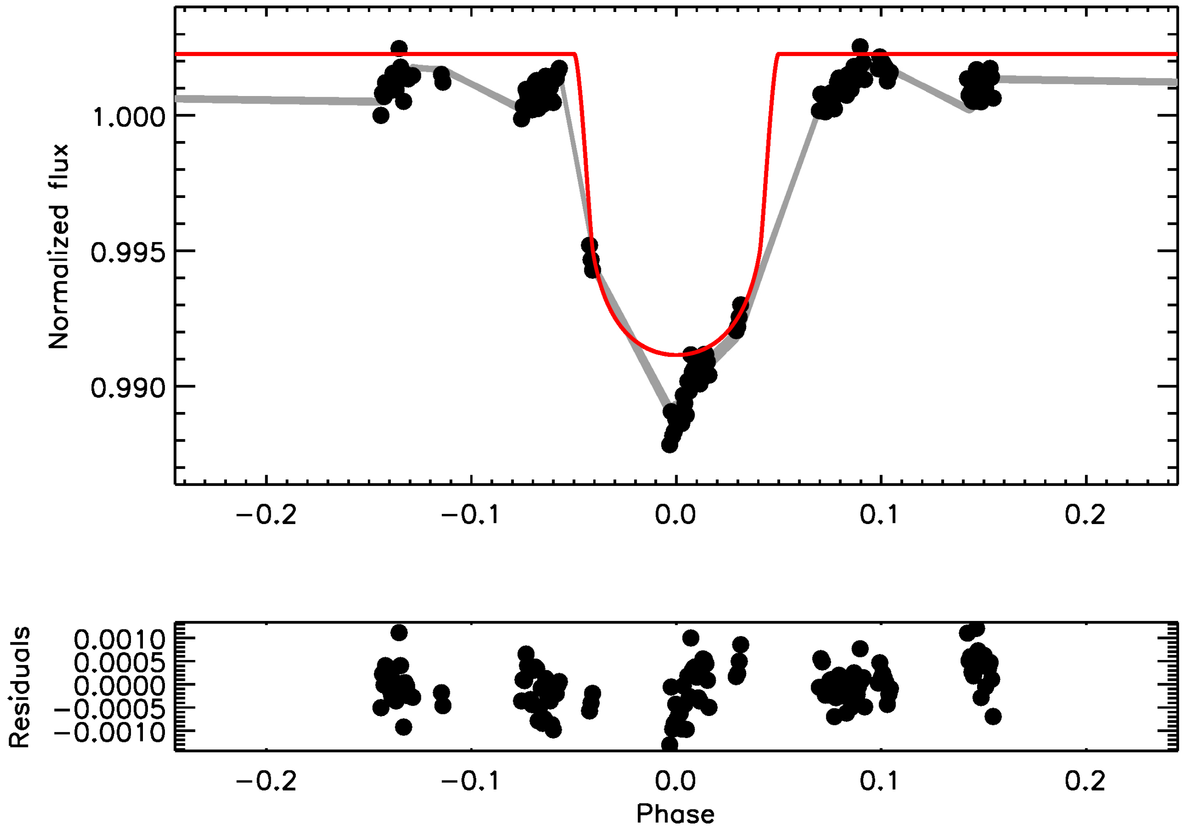


**Table 1.**
Results of the fit of one transit of WASP-18b.

| Parameter | Value | ±1σ | Southworth et al. (2009) |
|---|---|---|---|
| Semi-major axis (in stellar radii): | 3.54484 | fixed | |
| Planet-to-star radius ratio : | 0.0954 | 0.0003 | 0.09636 ± 0.00057 |
| Inclination: | 88.197 | 0.008 | 85.96 ± 1.70 |
| Impact parameter: | 0.112 | 0.001 | |
| Pri. Limb-darkening coefficient (u+): | 0.7 | fixed | |
| Pri. Limb-darkening coefficient (u-): | 0.1 | fixed | |
| Epoch (BJD): | 54221.91796875 | <0.0001 | |
| Period (d): | 0.94145182 | fixed | |
| Red Noise factor | 0.00024472518 | 1.9777930e-05 | |
| Sigma_white_noise | 0.0019301213 | 1.9115978e-05 | |
| $p_0$ | 0.0022624261 | 9.3299896e-06 | |
| $a_1$ | 0.0011282504 | 1.0081916e-05 | |
| $a_2$ | -0.00056514033 | 9.8116579e-06 | |
| $a_3$ | -0.0010453451 | 9.8047894e-06 | |
| $a_4$ | -0.00028994467 | 1.0172706e-05 | |
| $b_1$ | 0.0010884858 | 1.0041171e-05 | |
| $b_2$ | 0.0016553754 | 1.0068587e-05 | |
| $b_3$ | 0.00025475537 | 9.7593147e-06 | |
| $b_4$ | -0.00027551680 | 9.7117299e-06 | |

R_planet = 1.1346378 +/- 0.036459727 R_jup


References: [1] Carter, J. A., & Winn, J. N. 2009, ApJ 704, 51
[2] Mandel, K. & Agol, E., 2002, ApJ 580, L171
[3] Southorth, J. et al. 2009, ApJ 707, 167