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# Analysis of KOI 2700b: the second exoplanet with a comet-like dusty tail

## An improved tail model

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**Abstract.** The *Kepler* object KOI 2700b was discovered recently as the second exoplanet with a comet-like dusty tail. Previously, we aimed at verifying the disintegrating-planet scenario of KOI 2700b by modeling its light curve and to put constraints on various tail and planet properties, as was done in the case of KIC 12557548b. Here, we describe an improved tail model with five free parameters and its application in the case of $\gamma$-alumina 1 micron grains.

**Key words:** planets and satellites: general – planet-star interactions – scattering

## 1. Introduction

The *Kepler* object KOI 2700b (KIC 8639908b) was discovered by Rappaport et al. (2014) as the second exoplanet with a comet-like dusty tail. It exhibits a distinctly asymmetric transit profile, likely indicative of the emission of dusty effluents and reminiscent of KIC 12557548b (Kepler 1520b), the first exoplanet with a comet-like dusty tail (Rappaport et al., 2012). Garai (2018) aimed at verifying the disintegrating-planet scenario of KOI 2700b by modeling its light curve and to put constraints on various tail and planet properties, as was done in the case of KIC 12557548b (Budaj, 2013). Here, we describe an improved tail model and its application.

## 2. Data analysis

We used the phase-folded and binned transit light curve of KOI 2700b, presented by Garai (2018), and we also adopted the analysis procedure from this work, but with an improvement. Four free parameters were originally adjusted simultaneously during the fitting procedure – the orbital inclination angle $i$ [deg], the dust density at the beginning of the ring $\rho(0)$ [g.cm$^{-3}$], the planet to star radius ratio $R_\mathrm{p}/R_\mathrm{s}$, and the density exponent $A2$. One more free parameter – the transit midpoint phase shift of the synthetic light curve with respect to the observed light curve ($\Delta\varphi_0$) – was adjusted only before the modeling process and then was kept fixed to its best value. This parameter reflects the unknown mid-transit time of the planet. Garai (2018) describes that every synthetic light curve was shifted in phase by $\Delta\varphi_0 = -0.235$. The advantage of this treatment is that it saves computing time; on the other hand, one cannot exclude the possibility that uncertainties on the resulting parameters are underestimated.

In our analysis procedure we used the transit midpoint phase shift of the synthetic light curve with respect to the observed light curve as a next free parameter. We prepared a parameter range and stepping for $\Delta\varphi_0$ similarly, as it was described in the case of other free parameters by Garai (2018). During the first iteration we used the range of $[-0.215, -0.255]$ and the stepping of 0.005. During the next iteration we reduced the range of the parameter $\Delta\varphi_0$ and at the same time we used finer stepping in the parameter range. We selected the best value of the parameter $\Delta\varphi_0$, found in the previous iteration, as a midpoint ($\tilde{x}$) of the new parameter range. As the second iteration we used the parameter range of $\tilde{x}_{\Delta}\varphi_0 \pm 0.008$ and stepping of 0.002. During the last (third) iteration we similarly applied the parameter range and stepping of $\tilde{x}_{\Delta}\varphi_0 \pm 0.004$ and 0.001, respectively. Other parameters were applied during this analysis procedure as it was described by Garai (2018). A formal, quantitative goodness-of-fit was measured via determination of reduced $\chi^2$ ($\chi^2_{\rm red}$). The best fit corresponds to the minimum value of $\chi^2_{\rm red}$. To derive uncertainties on the resulting parameters we applied Monte Carlo simulations as it was described by Garai (2018).

To save the computing time, we applied our improved tail model in the case of $\gamma$-alumina 1 micron grains only. In this case, we can compare only the results for $\gamma$-alumina 1 micron grains, i.e. results, obtained via the original four-free-parameter model with our results, obtained via the five-free-parameter model.

## 3. Results and Conclusions

Applying $\gamma$-alumina 1 micron grains, Garai (2018) obtained the following fitted parameters. The orbital inclination angle $i = 87 \pm 0.6$ [deg], the dust density at the beginning of the ring $\rho(0) = 0.2190 \pm 0.0005$ $(\times 10^{-15})$ [g.cm$^{-3}$], the planet to star radius ratio $R_{\rm p}/R_{\rm s} = 0.007 \pm 0.006$, and the density exponent $A2 = -8.0 \pm 0.2$. In this case the reduced $\chi^2$ was $\chi^2_{\rm red} = 1.093$.

Applying our five-free-parameter model, we obtained the following fitted parameters. The orbital inclination angle $i = 87 \pm 0.7$ [deg], the dust density at the beginning of the ring $\rho(0) = 0.2185 \pm 0.0008$ $(\times 10^{-15})$ [g.cm$^{-3}$], the planet to star radius ratio $R_{\rm p}/R_{\rm s} = 0.007 \pm 0.005$, the density exponent $A2 = -8.0 \pm 0.2$ and the transit midpoint phase shift of the synthetic light curve with respect to the observed light curve $\Delta\varphi_0 = -0.237 \pm 0.003$. In this case the reduced $\chi^2$ was $\chi^2_{\rm red} = 1.109$.

The fitted parameters and their uncertainties are comparatively summarised in Tab. 1. We can see that the fitted parameters and their uncertainties are very similar in both cases. The reduced $\chi^2$ values are also comparable. This means

**Table 1.** Comparison of the fitted parameters and their uncertainties. *This parameter was fixed to its best value.

| Parameter | Garai (2018) | This work |
|---|---|---|
| $i$ [deg] | $87 \pm 0.6$ | $87 \pm 0.7$ |
| $\rho(0)$ $(\times 10^{-15})$ [g.cm$^{-3}$] | $0.2190 \pm 0.0005$ | $0.2185 \pm 0.0008$ |
| $R_\mathrm{p}/R_\mathrm{s}$ | $0.007 \pm 0.006$ | $0.007 \pm 0.005$ |
| $A2$ | $-8.0 \pm 0.2$ | $-8.0 \pm 0.2$ |
| $\Delta\varphi_0$ | $-0.235^*$ | $-0.237 \pm 0.003$ |

that to include the parameter $\Delta\varphi_0$ into the model as a next free parameter is not necessary. On the other hand, we have to note that we applied the improved tail model only in one case from 15 (Garai, 2018). The full comparison can change this conclusion, but this needs a lot of computing time.

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