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# Dusty phenomena in vicinity of exoplanets

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## Abstract

The gradient analysis of pre- and post-transit parts of Kepler's light-curves reveals hitherto unknown photometric phenomena apparently from exoplanetary associated dust. In addition to dust tails of decaying planets, there are various manifestations of circumplanetary halos as well as pre-transit obscuring matter. Such phenomena appear a valuable source of information about dusty exoplanetary plasmas and winds.

## 1. Introduction

Hitherto the out-transit parts of light-curves (LCs) were studied only for the search of cumulative effect of exomoons [1]. For the first time we analyze individual cases of transit-vicinities. These regions are of interest regarding possible manifestations of near-by exoplanetary dust structures. They could be generated by e.g., moonlet erosion, volcanoes of Io-type satellites as well as eroding dusty atmospheres.

## 2. The gradient method

We use publically available *Kepler* long-cadence LCs [2] after Pre-search Data Conditioning (PDCSAP flux or $F_{PDC}$ hereinafter) [3]. To remove the residual instrumental drifts as well as the stellar variability at timescales longer than the transit duration, we approximate the normalized light-curve $F_{PDC}(t_k)/\langle F_{PDC}(t_k)\rangle$, which covers a time interval $\pm 10\Delta t_{tr}$ centered at the transit, with a 6$^{th}$-order polynomial $F_b(t_k)$. Here $t_k$ is the flux measurement time, and $\Delta t_{tr}$ is the transit duration. After the iterative exclusion of outliers, we use $F_b(t_k)$ as a reference level to find the flux decrease during the transit: $\Delta F_k = [F_{PDC}(t_k)/\langle F_{PDC}(t_k)\rangle] - F_b(t_k)$, used in further analysis. To detect the dust extinction, the linear gradients $G_{1,2} \equiv \partial(\Delta F)/\partial(\delta t)$ were found for folded LC in the time intervals $-\tau_{max} < \delta t < -\tau_{min}$ and $\tau_{min} < \delta t < \tau_{max}$ before ingress and after egress, respectively. Here $\delta t$ is the time counted from the nearest transit border, calculated with cumulative transit parameters (reference time, period, duration) from [2]. The interval borders $\tau_{min}$ and $\tau_{max}$ were varied between 0.01 days (half-period of the flux counting/smoothing) and 0.16 days corresponding to the planetocentric distances from ~2 to ~17 typical radii $R_p$ of hot-jupiters.

## 3. Results

Our data set includes long-cadence LCs of transits of 183 Kepler's objects with maximal signal-to-noise ratio, mainly from the list in [4]. Figure 1 presents the results obtained in the distant regions with $\tau_{min}$=0.03 days and $\tau_{max}$=0.16 days.

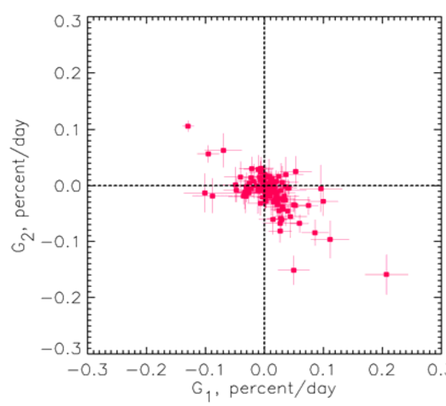


**Figure 1**: Diagram of gradients $G_2$ (post-egress) vs. $G_1$ (pre-ingress) in the distant regions ($\tau_{min}$=0.03 and $\tau_{max}$=0.16 days) for 117 exoplanets with errors below 0.05 percent/day.

One can see in Figure 1 the excess abundance of estimates in the ($G_1$>0, $G_2$<0) quadrant, supposing the forward-scattering by micron dust. Atmospheric aerosols could give the increase of the flux only by $\delta(\Delta F_k) \leq 32.5$ ppm for ~1μm particles (Table 2 in [5]) on the phase-angle scale 20$^o$ (Eq.2 in [6]) corresponding to the time-scale $\tau_s \approx (20^o/360^o) P_{tr}$ for the transit period $P_{tr}$. Taking the typical $P_{tr} \approx 10$ days, one can estimate $\tau_s \sim 0.6$ days and $|G_{1,2}| \sim \delta(\Delta F_k)/\tau_s < 0.005$ percent/day. This atmospheric contribution is negligible in comparison with observable gradients $|G_{1,2}| > 0.5$ percent/day, supporting the dust interpretation. The cases from ($G_1<0$, $G_2>0$) quadrant correspond the flux obscuration by large (>>1μm) particles.

Closer to planets (for $\tau_{min}=0.01$ and $\tau_{max}=0.05$ days) the analogous $G_2$ vs. $G_1$ diagram in Figure 2 demonstrates different distributions.

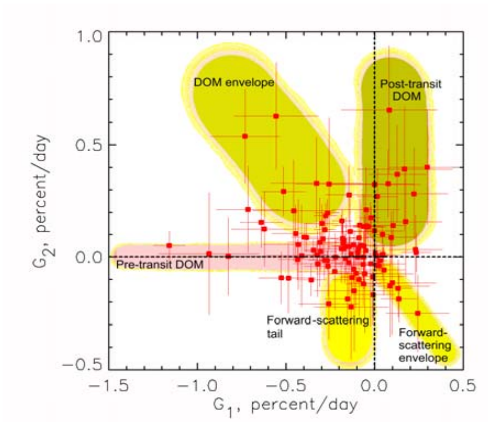


**Figure 2**: Diagram of gradients $G_2$ (post-egress) vs. $G_1$ (pre-ingress) in the closer to planet regions ($\tau_{min}=0.01$ and $\tau_{max}=0.05$ days) for 130 exoplanets with errors under 0.3 percent/day. The supposed domains with labelled interpretations are marked by colours.

One can see in Figure 2 a shift of the main cluster of estimates toward negative $G_1$. This shift means pre-transit manifestations of the dust obscuring matter (DOM; rose-colour domain). Example of such events are shown in Figure 3.

## 4. Summary and Conclusions

Since the found out-of-transit photometric peculiarities show clear patterns (Fig. 1-3) in the transit-related time-scale ($\delta t$), they are related to planet, being apparently of dust origin. This is a new aspect of hot-jupiters' transits and physics.

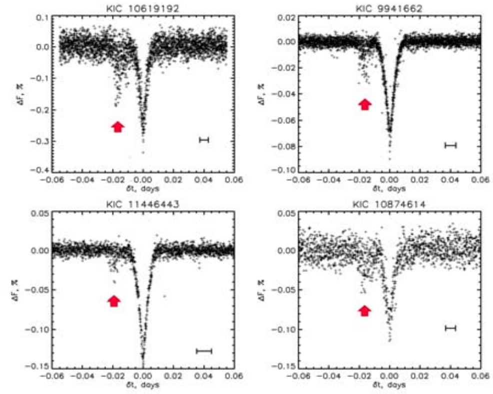


**Figure 3**: Examples of the pre-transit, with DOM (arrowed), and post-transit parts of LC. The bars correspond to the planet's radius ingress-time.

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