KIC12557548b: exo-planet with a comet like tail

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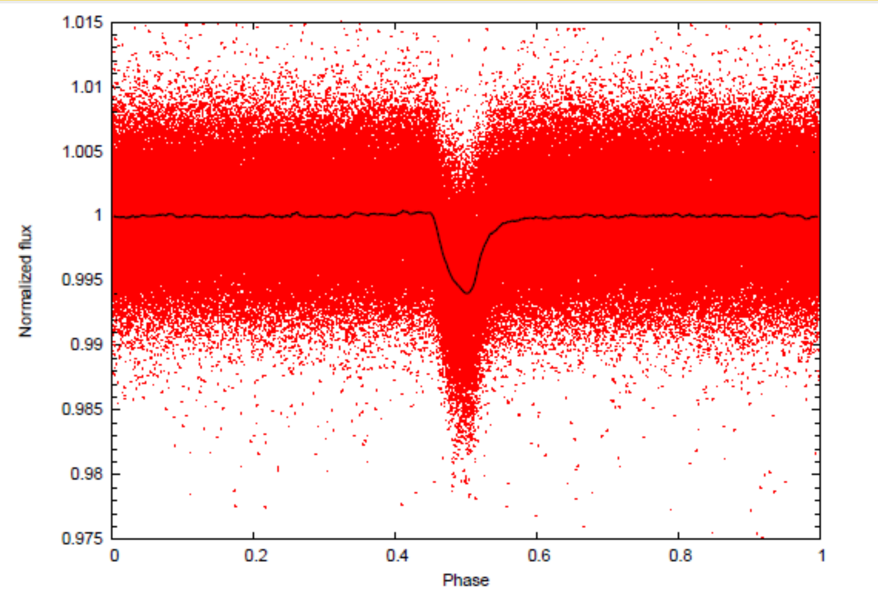
Abstract

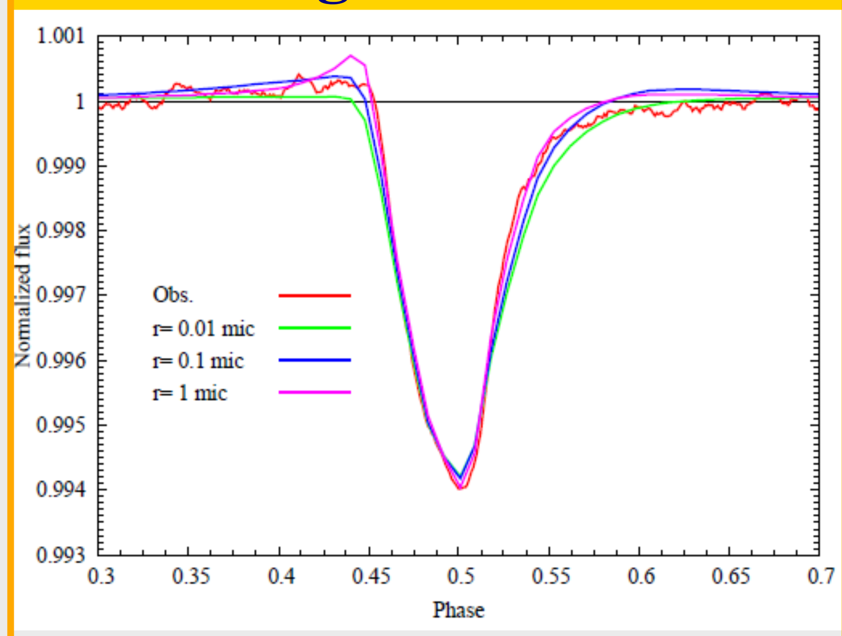
An object with a very peculiar light-curve was discovered recently using Kepler data (Rappaport et al. 2012). Authors argue that this object may be a transiting disintegrating extrasolar planet with a comet-like dusty tail. Here, we reanalyse and model the light-curve with the code SHELLSPEC (Budaj & Richards 2004). Mie absorption and scattering on spherical dust grains with realistic dust opacities and phase functions and finite radius of the source of the scattered light are taken into account. Light-curve has a prominent pre-transit brightening and a less prominent post-transit brightening. Both are caused by the forward scattering and are a strong function of the particle size. This feature enabled us to estimate a typical particle size (radius) in the dust tail of about 0.1-1 micron. However, there is an indication that the particle size decreases along the tail. Dust density is a steep decreasing function of the distance from the planet which indicates a significant tail destruction caused by the star-planet interaction. Possible combinations of dust properties are tabulated.We reveal interesting periodic long term evolution of the tail on the time scale of about 1.3 years and also argue that the 'planet' does not show uniform behaviour but may have at least two constituents. This exoplanet's tail evolution may find an analogy in the comet tail disconnection events caused by the magnetic/coronal activity of the Sun while the light-curve with pre-transit brightening is analogous to the light-curve of ε Aur and AZ Cas with mid-eclipse brightening and forward scattering plays a significant role in such eclipsing systems.

Kepler observations



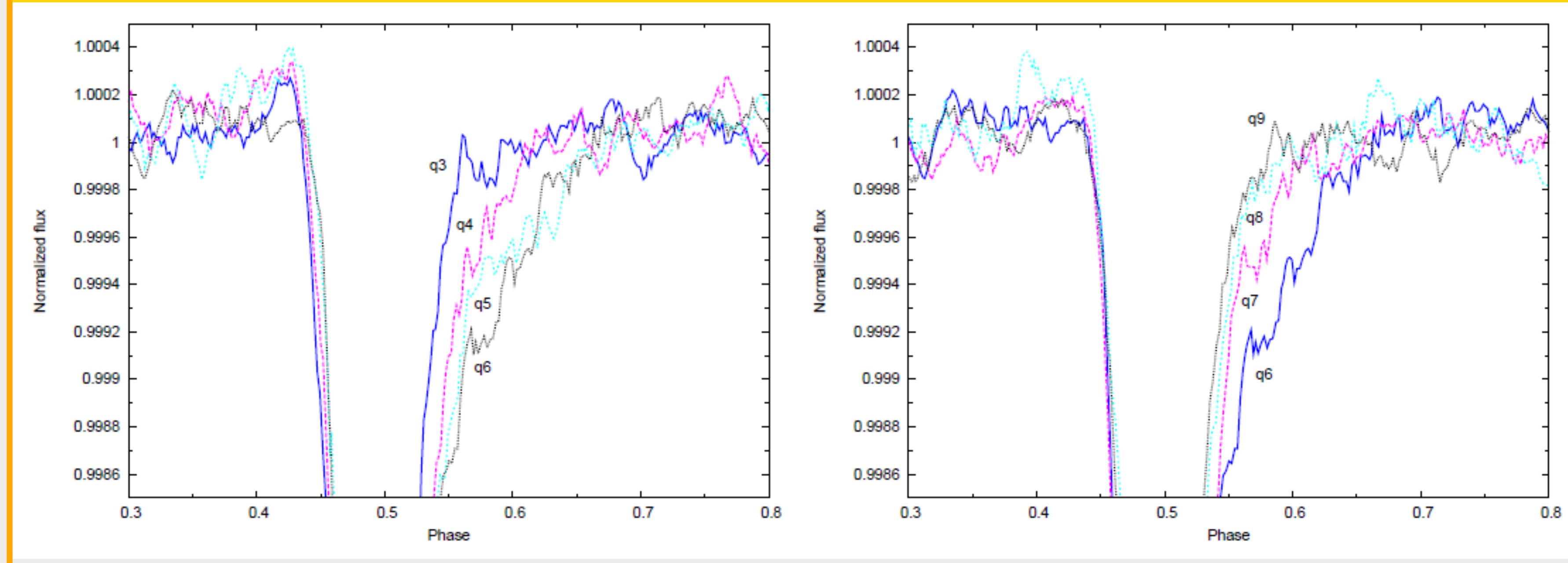
Kepler short cadence observations (red dots) (Borucki et al. 2011), averaged light-curve (line). Transit depth can change from one transit to the other.

Light-curve



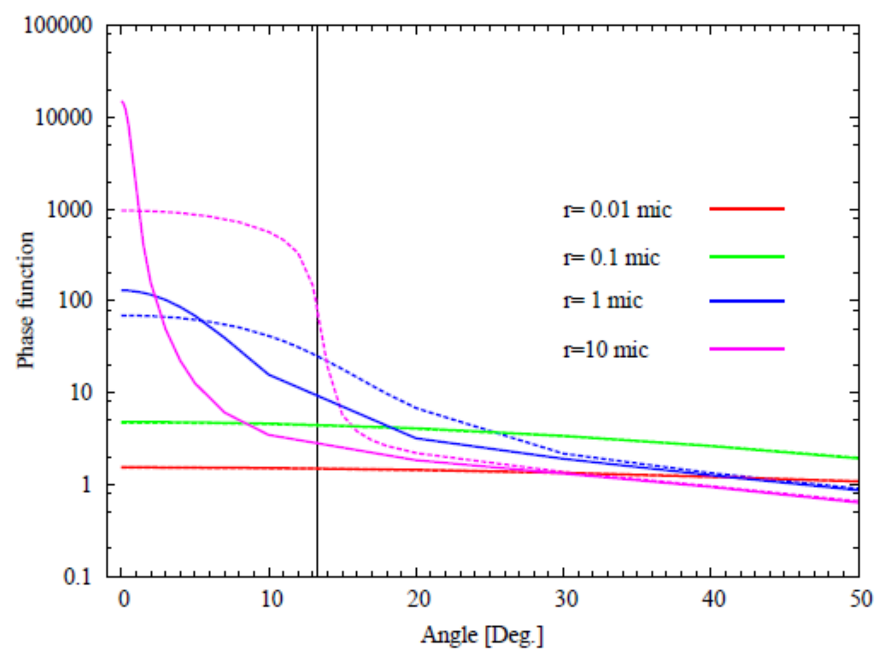
Light-curve is asymmetric with long egress what indicates the presence of a comet-like tail. Dust particles of different size (green, blue, purple) can reproduce the observations (red). Dust density in the tail rapidly decreases.

Evolution of the comet-like tail



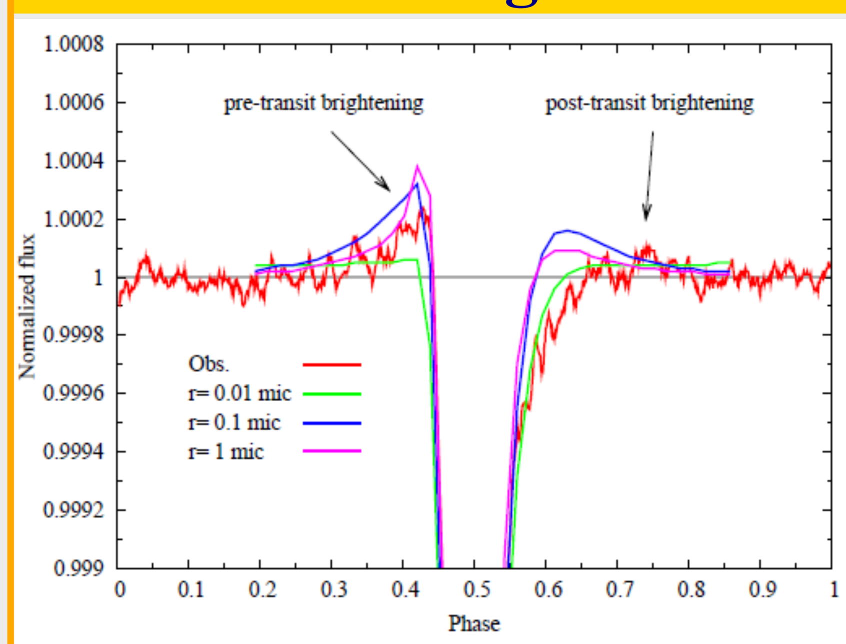
There is a progressive strengthening of the tail during Kepler quarters 3-6 and diminishing during quarters 6-9. The process is periodic with the period of about 1.3 yr. One can speculate that it may be due to the magnetic/coronal activity of the star or presence of an additional planet in the system. Planet may have a sort of 'coma' responsible for the transit core (changes on the timescale of the orbital period, 0.6535521 day) and 'tail' responsible for the egress (changes on the timescale of 1 yr).

Forward scattering



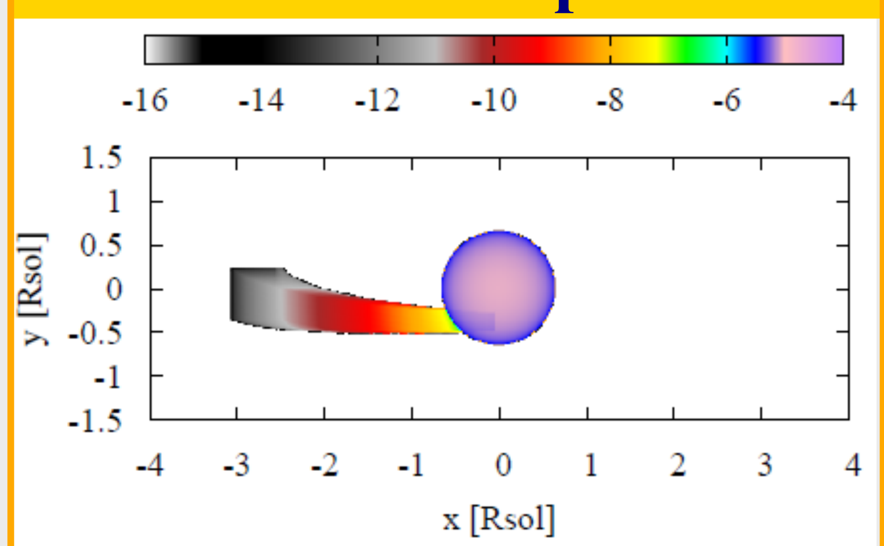
Scattering on dust is not isotropic. It is characterized by the phase function and depends on the particle size. Notice strong forward scattering peak for larger particles.
Solid line - point source, dashed – finite dimension of the source of light, vertical line – radius of the star. This is the reason of the pre-transit brightening and mid-eclipse brightening in some eclipsing systems (see also Brogi et al. 2012.)

Detail of the light-curve



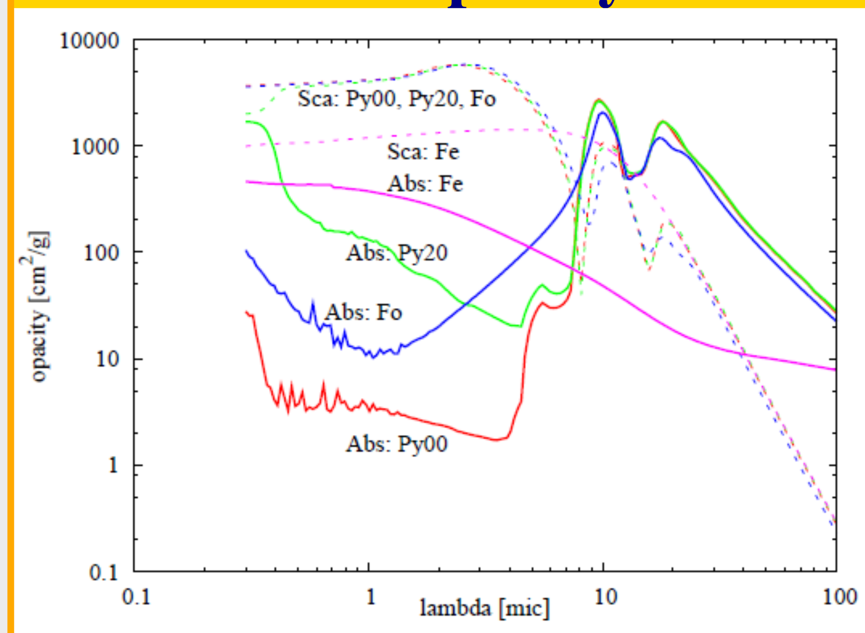
There is a pre-transit brightening (and less pronounced post-transit brightening) which is sensitive to the particle size. Particles in the comet-like tail have typical radius of about 0.1-1 micron.

Model of the planet



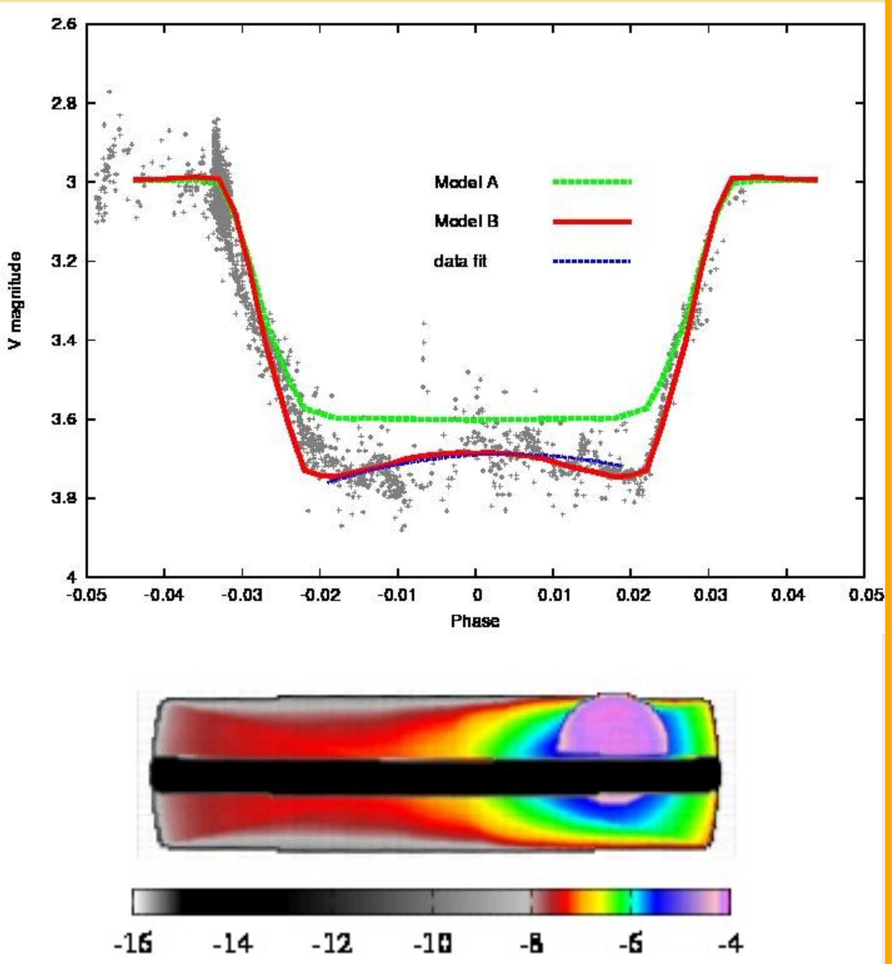
2D image (log of intensity [erg/cm2/s/Hz]) of the planet with a comet-like tail. Intensity of the tail gets fainter rapidly due to the decrease in the dust density and forward scattering. Notice also optically thin absorption on the limb darkened stellar disk.

Dust opacity



Opacity of various dust species: Fo-forsterite, Py00-pyroxene with 0% iron, Py20-pyroxene with 20% of iron, Fe-pure iron, Sca (dashed)-scattering, Abs (solid)-absorption. Multi-wavelength transit observations might distinguish between the species.

ε Aur



Top: light-curve, bottom: 2D intensity image of ε Aur.
ε Aur is a bright eclipsing binary star which consists of F0I supergiant or post-AGB star and an unknown secondary object with a dark dusty disk. Orbital period is 27 yr. During the eclipse we observe shallow mid-eclipse brightening (Budaj 2011). It is due to the flared disk geometry and forward scattering. AZ Cas, another long period eclipsing binary, also has a shallow mid -eclipse brightening (Galan et al. 2012). It is very interesting that such seemingly different objects show similar effects which gives stronger footing to the model.

Conclusions

- Improved orbital period of the planet is 0.6535521(15) days.
- There is not significant long term period variability.
- A periodic tail evolution was revealed with the period of about 1.3 yr.
- Pre-transit brightening in the light-curve was confirmed. There is also an indication of the post-transit brightening. Both are caused by the forward scattering.
- Light-curve modelling enabled us to estimate the particle size (0.1-1 micron), inclination (82 deg) , dust region with the shape of the ring, and other dust properties which are given in the Table 1.
- Dust density profile along the tail is a steep decreasing function $\rho \sim \rho(0)e^{x*A2}$ where A2=-20 which indicates significant dust destruction caused by the planet-star interaction.
- Simultaneous multi-wavelength transit observations in the optical and IR regions may put more stringent constraints on the chemical composition and particle size.
- Planet has at least two components one which is responsible for the transit core ('coma') and the other responsible for the egress ('tail') which are variable on different timescales.
- This planet's light-curve with pre-transit brightening is analogous to light-curves of some interacting binaries with mid-eclipse brightening, particularly ε Aur and AZ Cas, and forward scattering plays an important role in such eclipsing systems. The evolution of the planet's tail may be connected with the magnetic/coronal activity of the star, magnetic activity of the planet or presence of an additional planet in the system.

Table 1. Some combinations of the physical properties of the dust that satisfy the observed depth of the transit.

	Pyroxene		Enstatite		Forsterite		Iron	
A2	ρ	τ	ρ	τ	ρ	τ	ρ	τ
				0.01 micron				
-10	42	0.066	110	0.064	90	0.064	0.75	0.066
-15	54	0.081	150	0.082	120	0.080	0.99	0.082
-20	66	0.095	178	0.094	145	0.094	1.20	0.096
-25	79	0.110	215	0.11	177	0.11	1.45	0.11
				0.1 micron				
-10	0.26	0.075	0.30	0.073	0.26	0.072	0.33	0.069
-15	0.33	0.091	0.38	0.086	0.33	0.086	0.42	0.082
-20	0.41	0.110	0.46	0.10	0.40	0.10	0.50	0.095
-25	0.49	0.120	0.56	0.12	0.49	0.12	0.60	0.11
				1 micron				
-10	3.0	0.14	3.0	0.13	3.0	0.13	7.1	0.12
-15	3.8	0.17	3.8	0.15	3.8	0.15	8.6	0.13
-20	4.6	0.19	4.6	0.18	4.6	0.18	10.8	0.16
-25	5.6	0.23	5.6	0.21	5.6	0.21	13.0	0.19

Notes. The columns are: density exponent *A2*, dust density $\rho(0)$ at the edge of ring in $\times 10^{-15}$ g cm^{-3}, and maximum optical depth τ for pyroxene with 20% of iron, enstatite, forsterite, **iron**. The three blocks are for various dust particle radii: 0.01, 0.1, 1 micron. Model assumes that the geometrical cross-section of the ring is 0.01 and 0.09 $R_\odot^2$ at the beginning and the end of the ring, respectively.

Acknowledgements

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