Detection with PLATO of atmospheric lensing effects during planets transit

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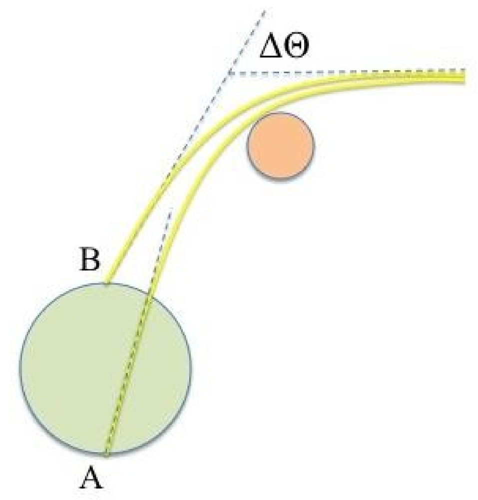
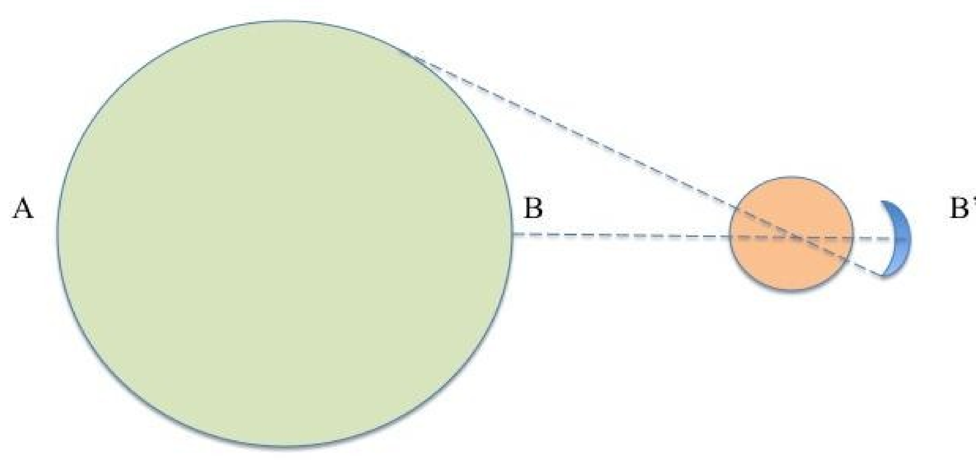
Abstract. The light curve observed during the transit of a planet in front of a star provides valuable information on the physical parameters of the planet, as long as the curve is modeled with enough accuracy. In this poster we present some curves based on the model presented recently by Sidis & Sari (2010), where the refraction of the star light from the planetary atmosphere is taken into account. In particular we discuss how the level of noise required for the PLATO mission limits the capability to distinguish features in the light curve as a function of the parameters of the star and of the planet.

1. During a transit, the disc of a planet is seen projected onto the surface of its star; as a consequence the stellar light curve shows an eclipse of amplitude, at most $(R_p/R_x)^2$, where R_p and R_x are the radii of the planet and of the star, respectively. This result assumes that the planet is nothing but a solid disc that transits in front of the star and does not take into account the limb darkening of the star.

Actually, planets may have an atmosphere which refracts the stellar radiation causing a lensing effect as shown in the following figures (adapted from Sidis & Sari 2010)



Refraction of the stellar light caused by the planet's atmosphere. The angular shift ΔΘ scales as square root of the impact parameter: light coming from A is more deflected than the light coming from B.



The effect of the lensing is to produce a secondary image of the star whose size increases as the planet is seen approaching the star's surface. Points A and B corresponds to the points in the above figure. This secondary image produces an increment of the observed flux named S' in the following text.

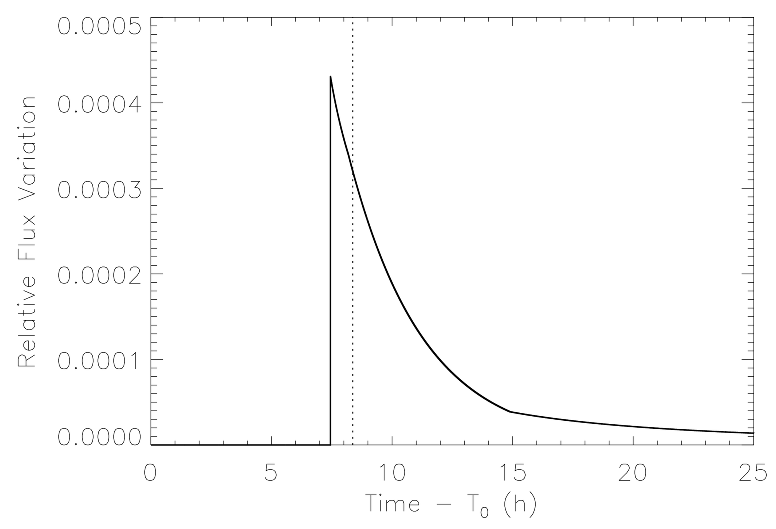
2. Sidis & Sari (2010) derived some analytical formulae for specific moments of the transit, ie far away and very close to the star's surface.

In particular, when the planet is very close to the surface of the star the observed flux is enhanced by a factor

$$\frac{S'}{S}=\frac{R_p H}{R_x^2}\ln\left(\frac{2}{X-1+R_p/R_x}\right) \qquad (1)$$

where S is the flux emerging from the star and X the distance, normalized to the stellar radius, between the centres of the star and of the planet. H is the height scale of the planet's atmosphere.

In the figure below, the light curve at the exit of the eclipse is shown for the particular case of $R_x=8R_p$ and $R_p=100H$, as adopted in Sidis & Sari's paper: the enhancement is clearly visible (the dotted line is explained in the next box)



3. The peak in the light curve described in Equation (1) is for X=1

$$\frac{S'}{S}=\frac{2}{e}\frac{H}{R_x} \qquad (2)$$

In the table on the right the values for S'/S are reported for the planets of the solar system: Radii and H are taken from Scharf (2009)

Planet	Radius (Km)	H (Km)	S'/S (10^{-6})
Venus	6051	16	1.09
Earth	6378	8.5	0.60
Mars	3397	18	0.76
Jupiter	71492	18	7.90
Saturn	60268	35	14.70
Uranus	25559	20	4.22
Neptune	24764	19	3.92

The requirement on the noise for PLATO is 27 ppm in one hour; this translates in a noise of 6.61×10^{-5} in 600 seconds which is larger than any S'/S in the table.

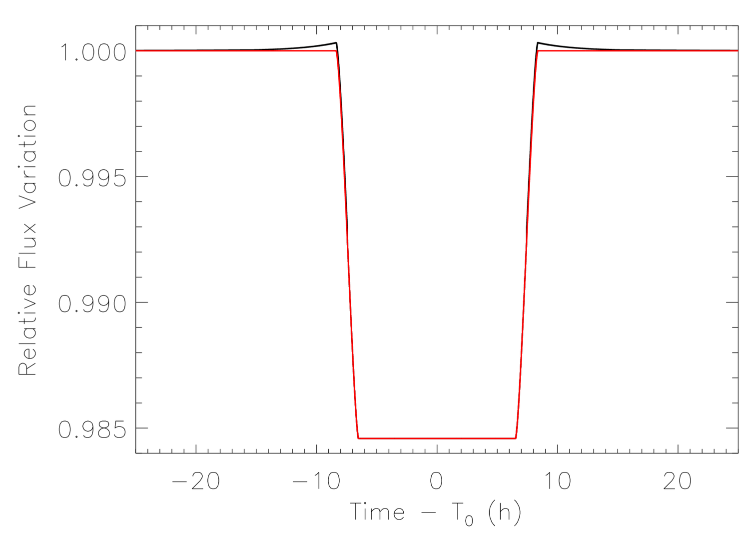
Equation (2) has a maximum for a ratio R_p/R_x = 2/e ~ 0.74 which gives

$$\frac{S'}{S}=\frac{R_p H}{R_x^2}\ln\left(\frac{2}{R_p/R_x}\right) \qquad (3)$$

For a star like the Sun the largest enhancement corresponds to R_p~$7R_J$; inverting Equation (3) we can find H such that S'/S is at least equal to the SNR: H ~ 62 Km. These values show that the effects of the atmospheric lensing are not visible with PLATO for a planetary system like ours.

Moreover, when X=1 the transit has already begun so that the net effect (eclipse + lensing) in the light curve is actually smaller than that given in Equation (2) and the maximum does not occur for X=1. For the previous figure, the maximum is indeed observed when X= 1 + R_p/R_x (the dotted line in the previous figure).

The light curve with both effects is shown below in red color; the black line is the curve with lensing only.

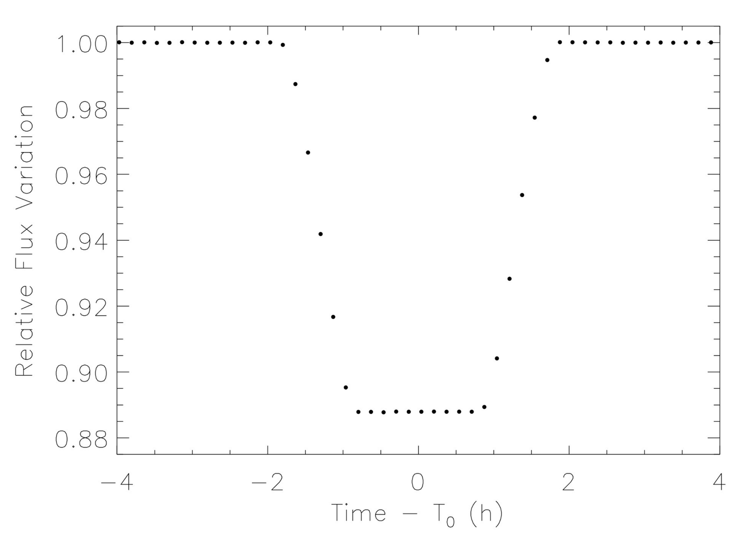


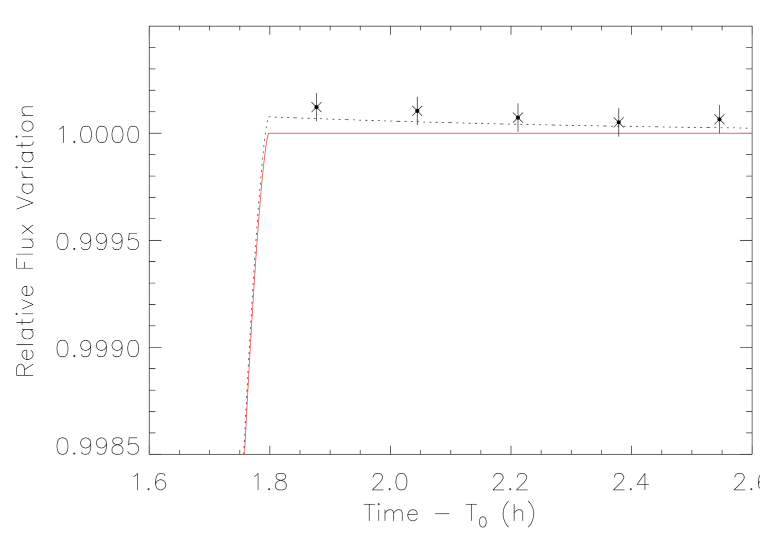
4. To increase the ratio S'/S in Equation (3) we need a star with a small radius: the smallest observed R_x in a planetary system detected up to now with a transit is $R_x=0.21R_{sun}$ (from http://exoplanet.eu). In such a system the largest S'/S (lensing only) for a given H is observed for a planet with R_p~$1.5R_J$.

For instance, for H = 20 Km the enhancement in the light curve is as high as 1×10^{-4}, visible with PLATO.

As an example we show the light curve of the transit of a planet with radius $R_p=0.7\ R_J$, R_x = 0.21 R_{sun} (~M6), H = 35 Km for an inclination angle of ~90°. The first figure shows the complete transit; the second figure is an enlargement to emphasize the difference between the two curves when lensing is not taken into account: the two curves differ more than the noise.

The curves have been obtained first by simulating the transit with a high sampling time: then the points have been averaged over 25 seconds and a Gaussian noise with $\sigma=3.24\times10^{-4}$ (which corresponds to a noise of 27×10^{-6} in one hour scaled to 25 seconds) has been added. On board these data are accumulated and averaged every 600 seconds, so that the 25 seconds data points have been averaged 24 by 24 and the noise has been scaled as σ/√24.





Conclusion

The lensing effect allows to derive the height scale of the atmosphere of a planet transiting in front of its star: the refraction of the light rays inside the planet's atmosphere causes an enhancement of the observed flux just before and during the initial phase of the transit.
For the parameters typical of our solar system this effect is small compared to the S/N required for the PLATO mission; but can be observed in giant planets (with a size comparable to the radius of Jupiter), having a height scales of few tens of kilometers (~30 Km), orbiting around late type stars (~M6).

References

Sidis, O. & Sari, R., 2010, ApJ, 720, 904
Scharf, C.S., 2009, Extrasolar Planets and Astrobiology, University Science Books