Signatures of rotating binaries in micro-lensing experiments

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In the last decades the gravitational micro-lensing technique, initially developed to search for Massive Compact halo objects (MACHOs) in the Galactic halo and in the Galactic disk has been widely used to infer the presence of exo-planets[1] orbiting around the main lensing stars. Indeed, the presence of a planet around its hosting star forms a binary lens that can micro-lens a background source, inducing non-negligible deviations with respect to the usual symmetric Paczyński light curve. In particular, the light-curve analysis of highly magnified events is sensitive to the presence of lens companions when the binary components are separated by a distance of the order of the Einstein radius $R_{\rm E}$ associated to the whole lens system. In general, such signatures are characterized by short duration deviations lasting from a few hours to a few days (depending on the parameters of the binary lens system). As a matter of fact, the micro-lensing technique is so sensitive that it allows to detect exo-planets in a rather large range of masses, spanning from Jupiter-like planets down to few Earth-mass objects.

The main reason for considering binary events is that the best fit procedure to a micro-lensing light curve may allow, in principle, to derive the parameters (the projected lens separation b and the mass ratio q) of the lens system. Typically, a static binary lens is considered and this implies the minimization of a functional depending on seven free parameters. These are, in addition to b and q, the time t_0 of closest approach to the lens system, the impact parameter u_0 (in units of the Einstein radius), the Einstein time of the event T_E, the angle θ that the background source trajectory forms with respect to the binary lens separation, and the source radius ρ_*. Considering in the fit procedure the orbital motion of the lens system is extremely time consuming since a good modeling of such motion would imply six additional parameters, i.e. the semi-major axis a, the orbit eccentricity e, the time of passage at periastron t_p, the angle i between the normal to lens orbital plane and the line of sight, the orientation ϕ_a of the orbital plane in the sky, and the orbiting versus (either clockwise or counter-clockwise). For the determination of the lens parameters one should also include the relative lens-source parallax π_E due to Earth motion around the Sun which involves two more parameters. As a result of the large number of parameters involved[2], when a best fit procedure is attempted, some tricks are required in order to make the fit converging to reliable results.

In this work, we considered binary systems with orbital parameters for which the resulting micro-lensing light curve is very close to a Paczyński curve (i.e. a planetary case). Indeed, one expects that the presence of planets rotating around the hosting star should cause, most often, only small perturbations to the Paczyński light curve associated to the equivalent single lens event. We consider two cases: 1) the binary system orbital period P is lower than the typical Einstein time T_E of the event, and 2) P is comparable or larger than T_E. In the latter case, we required that the light curve is long enough to contain at least three full cycles. We showed that an accurate timing analysis of the residuals (calculated with respect to the Paczyński model) is sufficient to infer P.

We tested different methods to extract the period. All the algorithms give consistent results, but here we prefer to present those obtained via the classical Lomb-Scargle method (the generalized version did not improved the period detection) because its statistical behaviour is well known and the technique can be easily implemented.

The method requires to specify the minimum (ν_{min}) and maximum (ν_{max}) frequencies to be searched for in the input signal, together with the frequency step $\Delta\nu$. We chose to set these parameters depending on the *observational* data set, i.e. $\nu_{min} = 1/(3T_{obs})$, $\nu_{max} = 1/(2\delta t)$, oversampling by a factor 10, being T_{obs} the duration of the ob-

[1]At the time of writing, the number of exo-planets detected via the micro-lensing method is 24 (see e.g. the extra-solar planet encyclopedia available at `http://exoplanet.eu/`).

[2]Note that in the most general case one should also consider the baseline magnitude and the blending parameter.

servation and δt the associated time step. Note that by using the minimum frequency ν_{min} we are implicitly requiring to have at least three full cycles per observational window.

The blind application of the Lomb-Scargle method to the residual light curves resulted in the detection of the simulated periodicity. Note that the Lomb-Scargle periodogram (as well as the other period search algorithms) does not give exactly the simulated period since the frequency of the periodic signal is affected by the relative source-lens motion. Indeed, the central part of the residual light curve has spurious peaks that disturb the timing analysis since they introduce additional power at frequencies different from the fundamental one, i.e $\nu = 2\pi/P_{Sim}$.

We have found that the best results in the period search are obtained by removing a central region in the residual curve, around the event peak. Without this cut, the Lomb-Scargle periodogram may return other peaks in addition to that corresponding to the simulated periodicity. It is remarkable that, in all the cases we have considered, it is sufficient to remove a very small region around the event peak with size of the order of a fraction of the orbital period P_{Sim} in order to get always the true periodicity (indicated as P_{Est}).

We have also considered a rotating (stellar) binary with orbital parameters $a = 0.23$, $q = 0.8$, $e = 0$, and $i = \phi_a = 0^0$ rotating with a period $P_{Sim} \simeq 0.33T_E$. Since the system is face-on and the eccentricity is null, the projected distance does not change during the micro-lensing event, thus implying that the caustics simply rotate without any deformation. This particular geometry appears in the periodogram as a peak always at half of the simulated period as a consequence of the North-South symmetry in the caustic plane. We simulated a binary lens event with the same orbital parameters but with $P_{Sim} \simeq 2T_E$ and an observational window of $\simeq 6T_E$. In spite of the fact that there are only a few full cycles in the lightcurve, the periodogram gives again half of the expected period.

We have also considered real event OGLE-2011-BLG-1127 / MOA-2011-BLG-322 observed during 2011 towards the Galactic Bulge and possibly due to a binary lens. By using the publicly available OGLE data (http://ogle.astrouw.edu.pl/) we have fitted the data with a simple Paczyński model and analyzed the residuals by using either the generalized Lomb-Scargle and the discrete fast Fourier transform techniques (DFFT treated via the CLEAN algorithm). These are the best-performing period search methods for this kind of data. Both techniques return the presence of a period at about $\simeq 12$ days [3].

It seems that this periodic feature is remarkably stable since it always appears when a time resolved periodogram is performed, i.e. when the period search algorithm is applied on different parts of the residual light curve, provided that each part contains a sufficiently large number of cycles. It is therefore possible that the periodicity at $\simeq 12$ days is associated to an intrinsic variability of the source star as if it is in a binary system or intrinsically variable [1] or contaminated by a close variable star. Note also that some period search techniques, such as the cleaned DFFT and the generalized Lomb-Scargle periodogram, give significant power also at $\simeq 4$ days and $\simeq 30$ days. Since we test trial periods in a given range, it is possible to evaluate the significance of each feature compared to the power at all other frequencies. Hence, we evaluate the false alarm probability and obtained the significance levels at 68%, 90%, and 99%, respectively. We noted that the periods at $\simeq 4$ days and $\simeq 30$ days are not significant while the 12 day periodicity is likely to be true. As a matter of fact, we note that the light curve of the event OGLE-2011-BLG-1127 shows an oscillation around the best fit (static) model, as it is apparent in Fig. 1 of Shvartzvald et al. [2], with a time scale of $\simeq 15$ days. If the bump-like structure observed $\simeq 50$ days after the event peak is really present along the whole light curve then our analysis is returning a periodicity related to the source or to the binary lens motion.

This report is based on the paper by Nucita et al. [3] to which we refer for more details.

REFERENCES

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[3] Here we note that the region around the event peak has not been removed since already poor of data.