Search for exoplanets in M31 by pixel-lensing and the PA-99-N2 event revisited

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1. Search for exoplanets in M31 with pixel-lensing

Gravitational microlensing technique initially developed to search for MACHOs in the Galactic halo can be used to infer the presence of exoplanets around lens stars [1,2]. Indeed, the planet orbiting the primary lens star may induce significant perturbations to the standard (single lens) Paczyński like microlensing light curve [3,4]. Until now, 10 exoplanets have been detected towards the Galactic bulge (see http://exoplanet.eu) by microlensing and the least massive planets have masses of about 3, 5 and 13 $M_\oplus$. The planet orbital separations are in the range 2–5 AU (about the Einstein ring radius). Microlensing technique complements planet detections by other methods, that are more sensitive to large planet masses (Jupiter-like planets) at small orbital distances. Microlensing may also give the opportunity to detect planets lying in other galaxies (the closest to us being M31) [5–8].

We have used a Monte Carlo (MC) approach to investigate which is the best observational strategy based on ground-based telescopes to detect exoplanets in M31 [9]. Assuming that each lens star in M31 is hosting a planet, we simulate binary microlensing light curves (see also [10,11]) and explore the multi-dimensional space of the parameters for both the lensing and planetary systems. We assume a regular sampling of the light-curves, telescopes of different diameters and typical observational conditions. Since in pixel-lensing towards M31 the bulk of the source stars are expected to be red giant (with large radii), we take into account the source finiteness by averaging the planetary magnification numerically evaluated by solving the binary lens equation [12,13]) on the source size. Planetary perturbations in light curves occur when the source star trajectory in the lens-plane (the plane orthogonal to the line of sight to the M31 star source, passing at the lens position) crosses and/or passes near caustics. This is the caustic set of the source positions at which the magnification is infinite in the ideal case of a point source. Clearly for realistic sources of finite size the magnification gets still large, but finite. Light curves that show detectable deviations with respect to the Paczyński shape are selected by using the method of residuals. The MC approach allows to characterize the sample of events for which the planet detections are more likely to be observed.

We find two classes of events (indicated by I and II). Events of the I class have short time durations and larger flux variations. In these events planetary deviations are caused by the source trajectory crossing the central caustic region, close to the primary lens star. Events of the II class, have longer durations and smaller flux variations. Planetary perturbations in these cases are caused by the intersection of the source trajectory with the planetary caustics and may also appear at times far from the maximum magnification time.

We estimate the typical duration of a single planetary feature to be of about one day. However, the number of significant planetary deviations and consequently the overall time scale of the perturbations increases (up to a few days) by increasing the source size. Therefore for pixel-lensing searches towards M31 only few exposures per day could be enough to detect planetary features in light curves.

Pixel-lensing technique favours the detection of large mass planets ($M_{\rm P} \simeq 2\ M_{\rm J}$), even if planets with mass less than 20 $M_\oplus$ could be detected, although with small probability, by using large telescopes with a sufficient photometric stability. The probability of planet detection is maximised when the planet-to-star separation $d_{\rm P}$ is inside the so called "lensing zone", which is the range of star-to-planet separation $0.6 < d_{\rm P}/R_{\rm E} < 1.6$ [14].

We also verify that the overall probability to find pixel-lensing events with detectable planetary deviations is, however, very small: less than 3% for a large (with diameter $D = 8$ m) telescope and decreases rapidly for smaller telescopes. Since, perhaps, the assumption that all stars have planets is too optimistic, more realistically one should further divide these values by at least a factor of two.

2. Analysis of the PA-99-N2 event case

As a test case for exoplanetary searches in M31, we have reconsidered the POINT-AGAPE event PA-99-N2 [15], which had already been probed to show an anomaly with respect to the Paczyǹski shape compatible with a binary lens [16]. According to this analysis this binary system has a small mass ratio and this makes at least plausible that the lens companion is indeed an exoplanet.

We had analysed this event within the framework of our simulation scheme, showing that its (microlensing and planetary) parameters nicely fall in the expected range for II class events [9]. First, starting from the observational data (courtesy of the POINT-AGAPE collaboration), we test the robustness of the binary-lens best fit solution. Second, because the event in question has an extreme brightness ($R_{\rm max} \simeq 19$ mag) and a particularly long duration ($t_{1/2} \simeq 24$ day), we address the question of the efficiency for finding binary-like deviations for such bright and long duration events.

As a first step, we have revisited the issue of the single lens versus binary lens solution, finding that the latter is indeed robust against the introduction of a gaussian noise along the observed data. In particular, by allowing to the best fit parameters to vary, we find a) that the observed light curve cannot be obtained by any single lens model with random noise and b) the best single lens fit is much worst than any of the binary lens models.

As a second step, we have carried out a specific MC simulation that allowed us to show that for this kind of events (we fix the single lens parameters $R_{\rm max}$ and $t_{1/2}$ to those of PA-99-N2 and we let vary the binary ones) the chance of finding exoplanetary deviations is indeed greatly enhanced (up to 27% for the planetary mass range $1-10M_{\rm J}$) with respect to events without any constraint on $R_{\rm max}$ and $t_{1/2}$, and possible even for an observational set up as that of the POINT-AGAPE observations.

Whatever the case for PA-99-N2 event, our analysis confirms that looking for exoplanets in M31 with pixel-lensing, at least in the Jupiter mass range, is already reachable with present technology. Clearly, an efficient strategy of search, as towards the Galactic bulge, is mandatory: a wide field survey, to collect a large enough number of pixel-lensing candidates, endowed with an early warning system to trigger subsequent follow up observations, possibly with a network of telescopes around the world (for which also telescopes with small field of view could be usefully employed). In our opinion, the reward of such a project would be substantial: going from the settling of the question of the MACHO fraction in M31 halo, to important information on the stellar mass function and the detection of exoplanets, besides other information on the M31 structure and content of variable stars.

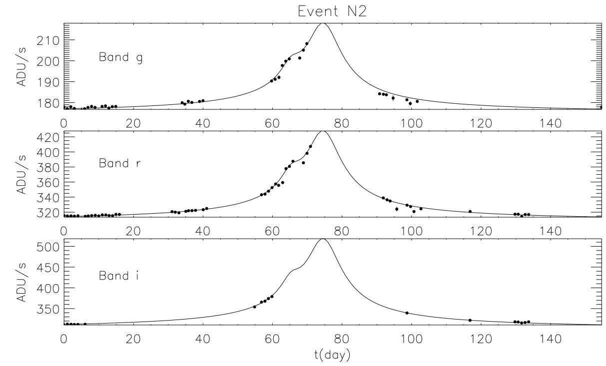

Figure 1. The binary light curves corresponding to the binary best fit for g, r and i bands.

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