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The POINT-AGAPE survey: 4 high signal-to-noise ratio microlensing candidates detected towards M31

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The POINT-AGAPE survey... $S. Paulin-Henrikssonetal.$

We have carried out a survey of the Andromeda galaxy for unresolved microlensing (pixel lensing). We present a subset of four short timescale, high signal-to-noise microlensing candidates found by imposing severe selection criteria: the source flux variation exceeds the flux of an $R = 21$ magnitude star and the full width at half maximum timescale is less than 25 days. Remarkably, in three out of four cases, we have been able to measure or strongly constrain the Einstein crossing time of the event. One event, which lies projected on the M31 bulge, is almost certainly due to a stellar lens in the bulge of M31. The other three candidates can be explained either by stars in M31 and M32 or by MACHOs.

Galaxy: halo – M31: halo – lensing – dark matter

Introduction sec:intro

The galactic dark matter may be partly composed of compact objects (e.g., faint stars, brown dwarfs, Jupiters) that reside in halos and are popularly called MACHOs ("MAssive Compact Halo Objects"). Microlensing surveys towards M31 crotts92,baillon93 have the potential to resolve the puzzling question raised by searches toward the Magellanic Clouds: the optical depth $\tau \sim 10^{-7}$ measured by MACHO macho is too large by a factor 5 to be accounted for by known populations of stars and too small by the same factor to account for the dark matter, while the mass scale inferred for the lenses $M \sim 0.4\,M_\odot$ is in the mid-range of normal stars. EROS eros obtained upper limits that are consistent with the MACHO results.

Since M31 is 15 times more distant than the Magellanic Clouds, the stars are about 200 times fainter and more densely packed on the sky. Even with new techniques that are required to monitor flux changes of unresolved stars in the face of seeing variations cro96,ans97,ans99, the low signal-to-noise ratio (S/N) engenders a whole range of problems. First, the detection efficiency is reduced. Second, there is a degeneracy between the Einstein crossing time, the impact parameter and the source flux gould96. Third, some variable stars can not be easily distinguished from microlensing events and so will contaminate the signal. We elaborate on each of these points as follows:

The POINT-AGAPE collaboration is carrying out a pixel-lensing survey of M31 using the Wide Field Camera (WFC) on the 2.5 m Isaac Newton Telescope (INT). We monitor two fields, each of $\sim 0.3\,\mathrm{deg}^2$, located North and South of the M31 centre. After a brief description of the observations and data analysis in Section sec:obsdata, we present four events with high S/N and short durations in Section sec:candidates, for which microlensing is by far the most plausible interpretation.

Observations and Data Analysis sec:obsdata The analysed data are from 143 nights between August 1999 and January 2001. The observations are made in three bands close to Sloan g', r', i'. The exposure times are typically between 5 and 10 minutes per night, field and filter. Because the total allocated time per night is usually less than one hour, observations are not perfomed in all filters each night. Moreover, the observations are strongly clustered in time because the WFC was not always mounted on the telescope.

The data reduction is described in detail by Paulin-Henriksson (2002) and is similar to the method given in previous papers ans97,gold,calchi02. After bias subtraction and flat-fielding, each image is geometrically and photometrically aligned relative to reference images (one per CCD), which are chosen to have long exposure times, typical seeing between 1.″3 and 1.″6, and little contamination from the Moon. To remove the correlations with seeing variations, we first compute lightcurves on 7-pixels square “superpixels”. We then apply an empirical correction on the flux of the superpixels, called “seeing stabilisation”. This is described briefly in Section sec:stabsee and will be discussed in more detail in a forthcoming paper. The conversion to Johnson/Cousins (V, R, I) is made by using the photometry standards of Haiman et al. (1994). The detection of events is made in the r' band, which offers the best compromise between sampling and sky background. Other bands are then used to test the achromaticity of candidates. A bump is defined by at least three consecutive r' data points rising above the baseline by at least 3σ. In this way, we detect about 80 000 variable objects. As a preliminary selection, we keep a subsample of the brightest 10%. More precisely, we demand $R(\Delta F) < 21$, where $R(\Delta F)$ is the (Cousins) magnitude of the flux difference between the baseline flux and the maximally magnified flux during the event. Note that for small impact parameters, such as applies for the four candidates presented below, $R(\Delta F)$ is similar to the magnitude of the event at maximum magnification. Selection of the microlensing candidates among the remaining events is described in Section sec:selection.

Seeing stabilisation sec:stabsee For very crowded fields like ours, and in the absence of resolved stars, the difference between an image and its own median comes from star density fluctuations. This difference is fully correlated from image to image. The correlation, shown in figure fig:cigare, is figure center ! file=cigarepts.eps,scale=0.4,clip= Correlation between $\Phi_i^I - \widetilde{\Phi}_i^I$ and $\Phi_i^{ref} - \widetilde{\Phi}_i^{ref}$ for a seeing difference between image I and the reference image: $\Delta seeing \sim 0.4''$ and (7×7) superpixels. fig:cigare