MEGA, a Wide-Field Survey of Microlensing in M31

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1. Introduction

Microlensing has become an interesting probe of dark matter in our Galaxy. Recent microlensing surveys have indicated that approximately one-half of the matter in the Galactic halo may be dark objects with masses comparable to those of stars, but have not revealed what these objects might be. We have detailed how microlensing internal to M31 (Crotts 1992, Gyuk and Crotts 2000) might be used to test such results and show better how the microlensing matter is distributed in space and as a function of mass. A survey of small fields in M31 has revealed several such candidate events, at roughly the predicted rate (Crotts & Tomaney 1996). We discuss below what efforts have been required to further verify the microlensing nature of these events.

Many papers have predicted the lensing optical depth $\tau$ in M31, which should approach $\tau \approx 10^{-5}$, over an order of magnitude greater than towards the LMC, but none of these works study the variation in halo lensing optical depth over the face of M31. Since M31 is distinct from the Galaxy in the many sightlines for microlensing that it presents to an observer at Earth, the variation of $\tau$ depending on the spatial distribution of lensing objects should be explored.

2. Testing Candidate Microlensing Events

Originally, Crotts & Tomaney (1996) identified six events from the 1995 observing season in M31 (using the Vatican Advanced Technology 1.8-meter telescope on Mt. Graham, Arizona) over $\sim 60$d covering a $120$ arcmin$^2$ field. These events were characterized by full-width half-maximum timescales of $10d < t_{\text{fwhm}} < 50d$. The longer end of this range is troublesome, because it coincides with the range of pulsewidths seen in miras and other longterm red variables. In fact, a mira lightcurve, resembling a symmetric sawtooth in magnitude, with peak-to-valley amplitudes of about $5^{\text{mag}}$ in the $R$ band, appears similar to the lightcurve of a simple (point-mass, point-source) microlensing event during its maximum amplification. Furthermore, if the period of a mira is about $2$ yr, one must monitor for two M31 seasons past (or preceding) the peak in the light curve in order to detect
another peak, since proximate peaks occur when M31 is not easily observable. The peak of such a mira has $t_{\text{FWHM}} \approx 40\text{d}$, which would correspond to lensing masses $m \approx 0.5M_\odot - 1M_\odot$ for typical lensing geometries in our survey region. Hence mira-like variables are troublesome contributors to a potential false event rate, and require multiple seasons of observations in order to be eliminated.

We have performed two tests of these six original candidates: 1) constructing well-sampled lightcurves over the M31 seasons of the three subsequent years (through 1998), and 2) obtaining HST WFPC2 snapshot observations of these sources in order to determine if their colors are consistent with mira-like variables. (The latter test is impossible from the ground, since crowding does not allow one to resolve typical sources in average seeing conditions, however, variable sources are made to appear isolated from one another by virtue of image subtraction e.g. Tomaney & Crotts [1996]). The result of these two event filters is to eliminate three of the six events, with the remainder firmly inconsistent with mira-like variables. For the remaining events, now that we have measured their baseline magnitudes from WFPC2 images, we can calculate a more accurate peak amplification (assuming that the lensing mass rests as close as possible along the sightline to the core of M31). These persist in mass estimates for the lensing masses in the range $0.3M_\odot \lesssim m \lesssim 1M_\odot$, with two events possible arising from stars in M31’s bulge, but one almost certainly not a bulge lens, given its source position 2.5 kpc out into the disk.

3. Possible Results from a Larger Survey

Given the robust nature of at least some of the candidate microlensing events seen in the small area survey discussed above, it is worthwhile considering the possible outcome of a larger, wide-angle survey, especially considering the advent of CCD imagers covering large fractions of a square degree.

We present here representative results simulating a survey in which roughly one-half square degree is imaged for six hours every three nights on a two-meter telescope, in 1-arcsec seeing, requiring each event to be sampled at least twice at the $4\sigma$ level. The halo fraction, halo flattening ($q$) and core radius ($r_c$) are allowed to vary between models, and then a maximum likelihood calculation is performed to yield resulting values for these parameters.

Our calculations show that this larger survey might easily observe $\sim 100$ such events per M31 observing season, which would allow the shape of the microlensing halo of M31 to be mapped. Since most masses reside near where the sightline passes the center of the galaxy, at a known source-lens distance, this survey would also allow a more exact determination of the masses doing the lensing. Selected fields in M31 might also serve as an independent sightline through the halo of our Galaxy. The preliminary epochs for a large survey in M31, over one-half square degree, have already been obtained, initiating the project MEGA: Microlensing Exploration of the Galaxy and Andromeda.

All models produce $\gtrsim 100$ events per season. Our ability to measure $r_c$ and $q$ depend on the true value of $r_c$, with small values providing greater $\tau$ in the galaxy’s center, where more sources exist. After three seasons, $r_c$ can be measured to within $\sim 1.5 \text{kpc}$ ($1\sigma$), and $q$ to $\sim 0.1$ (for $r_c < 5$ kpc), or $\sim 2.5 \text{kpc}$ and $\sim 0.2$, respectively for $r_c > 10$ kpc. With $q$ and $r_c$ well-constrained, the
Figure 1. An 80×40 arcmin$^2$ plot of M31’s center (major axis of M31 is horizontal, minor axis vertical) showing contours of the predicted event rate for bulge and halo microlensing in M31. The highest contour is for 50 events yr$^{-1}$ arcmin$^{-1}$ (near the center), with lower contours at 20, 10, 5, 2, 1, 0.5, 0.2 (dotted), 0.1 and 0.05 events y$^{-1}$ arcmin$^{-1}$. This reasonable model, for an unflattened halo with a 5 kpc core radius, predicts over 100 detections during an M31 observing season.

data allow a superior estimate of lens mass distribution. This many events can result from a campaign using existing wide-field CCD arrays on two-meter+ class telescopes. We have initiated this effort (MEGA) by establishing long baselines eliminating long-period variables, having obtained several epochs of such data in 1997 and 1998, and having begun more intensive observations in 1999 to detect microlensing events across much of M31 over the course of several seasons.

References

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Figure 2. The same region as in Fig. 1, but for contours of lensing optical depth (halo only) for two models of the spatial distribution of halo microlensing masses. The top panel corresponds to an unflattened model with 1.5 kpc core radius, and, on the bottom, a 3.3-to-1 flattening and a 10 kpc core radius. The dotted contours (just below center in each panel) correspond to $2 \times 10^{-6}$, increasing towards the top (far side of disk) to over $6 \times 10^{-6}$ in the top panel and $3.5 \times 10^{-6}$ in the bottom. In addition to the halo contribution, the central 10 arcmin diameter contains a $\tau \lesssim 5 \times 10^{-6}$ bulge signal (represented in Fig. 1), a uniform $\tau \lesssim 10^{-6}$ due to the Galaxy, and a much smaller contribution from M31 disk-disk lensing.