SLOTT-AGAPE Project

V. BOZZA, S. CALCHI NOVATI, M. CAPACCIOLI, S. CAPOZZIELLO, V. CARDONE, G. COVONE, F. DE PAOLIS, R. DE RITIS, G. INGROSSO, G. IOVANE, G. LAMBIASE, A.A. MARINO, G. MARMO, I. MUSELLA, E. PIEDIPALUMBO, S. PEZZUTO, M. RONCADELLI, C. RUBANO, G. SCARPETTA, P. SCUDELLARO, F. STRAFELLA

1 Universita' di Lecce, Italy
2 Universita' Federico II, Napoli, Italy
3 Universita' di Salerno, Italy
4 INFN, Pavia, Italy
5 Osservatorio Astronomico di Capodimonte, Napoli, Italy

ABSTRACT: SLOTT-AGAPE (Systematic Lensing Observation at Toppo Telescope - Andromeda Gravitational Amplification Pixel Lensing Experiment) is a new collaboration project among international partners from England, France, Germany, Italy and Switzerland that intends to perform microlensing observation by using M31 as target. The MACHOs search is made thanks to the pixel lensing technique.

1. Introduction

In recent years, much attention was centered on the possibility that dark matter, and in particular its baryonic side, consists of astrophysical objects, generically termed as "Massive Astrophysical Compact Halo Objects" (MACHOs) with mass $10^{-8} M_\odot < M < 10^{-2} M_\odot$. Direct searches of these objects can, at best, reach the solar neighborhood. In order to detect them further out, it was proposed by Paczynski (1986) to search for dark objects by gravitational microlensing [1].

Microlensing is an application of General Relativity effect of gravitational lensing where the separation between the produced images is too small to be appreciated ($\delta \theta \leq 10^{-3}$ arcsec); nevertheless – owing to the motion of the lens – it produces a time–dependent light amplification of the source which is observable. In fact, when a compact object passes nearby the line of sight of a background star, the luminosity of this star increases giving rise to a characteristic luminosity curve (see Fig.1).

The galactic structure is not very well understood due to the ignorance of the effective content of dark matter and its actual distribution, so the first goal is to perform a map of the MACHOs’ dark matter distribution both in the galactic disk through microlensing observations towards the galactic bulge and the spiral arms (Sagittarius, γScuti, βScuti)

* Italian Component.
1 Of course, observations towards the galactic bulge are not easy from the Northern Hemisphere, but possible.
and in the galactic haloes of the Milky Way, M31, M33 and dwarf galaxies.

Until now a lot of microlensing events have been detected towards the galactic bulge and the LMC [2][3]. These results have allowed to better understand the galactic structure. For example it has been recently suggested that the bulge has not a simple spherical symmetry but it has also a barred structure [4]. Microlensing searches by MACHO and EROS groups, looking for the magnification of LMC stars by MACHOs, have now been underway for several years. The very low microlensing probability requires several millions stars to be daily monitored, in order to observe significant luminosity increases. Some events have been reported, but less than expected in the standard halo model. Other experiments (DUO and OGLE), as well as MACHO itself, are monitoring stars of the Galactic bulge in order to look for microlensing by stars in the Galactic disk and in the bulge itself. These appear to find more events than expected [5].

The AGAPE and Columbia-Vatican (VATT) collaborations look for microlensing in the direction of the M31 galaxy. This could yield very useful information on the haloes of both our own Galaxy and M31. A pilot observation at Pic-du-Midi Observatory by AGAPE has given promising results [6].

Our project is to extend observations towards all the visible targets from the Potenza Toppo Observatory in order to detect a larger amount of microlensing events.

Fig. 1. Characteristic luminosity curve and related impact parameter.

Another goal is to search for planets or binary lensing events for which a very accurate photometry is required. Toppo Telescope has the right features to contribute substantially to this aim. This fact will also allow us to investigate in detail the initial stellar mass function as well as the presence of planets (both Jupiter-like and Earth-like) [7].
2. Gravitational lensing

The light deflection due to a gravitational field (in weak field approximation and geometrical optics approximation) is described by lens equation

\[
\eta = \frac{D_s}{D_d} \xi - D_{ds} \hat{\alpha}(\xi),
\]

with

\[
\hat{\alpha}(\xi) = \int d^2\xi' \frac{4G \Sigma(\xi')}{c^2} \frac{\xi - \xi'}{|\xi - \xi'|}
\]

and \(D\) is euclidean distance on galactic scale, while angular diameter distance on extragalactic scale.

The Schwarschild one is the simplest lens system, made of a point-like deflector. In this case, the deflection angle is:

\[
\hat{\alpha} = \frac{4GM}{c^2 b},
\]

where \(M\) is the deflector mass and \(b\) the impact parameter.

3. Pixel Lensing

In a dense field, many stars contribute to any pixel of the CCD camera at the focal point of the telescope. If an unresolved star is sufficiently magnified, the increase of the light flux can be measured on the pixel. Therefore, instead of monitoring individual stars, we follow the luminous intensity of the pixels. Then all stars in the field, and not the only few resolved ones, are candidates for a microlensing event; so the event rate is potentially much larger. Of course, only the brightest stars will be amplified enough to become detectable above the fluctuations of the background, unless the amplification is very high and this occurs very seldom. In a galaxy like M31, however, this is compensated by the very high density of stars.

The first step for the analysis of light curves is to define the baseline or the background flux \(\phi_{\text{background}}\). This is done by taking the minimum of a sliding average on 10 consecutive points. One can define the beginning of a "bump" if 3 consecutive points lie \(3\sigma\) above \(\phi_{\text{background}}\) and the end when 2 consecutive points fall below \(3\sigma\). The second step is to select microlensing candidates by light curves with only one bump and not more. The third step is to fit a high amplification degenerate Paczynski curve to the mono-bumps. The amplification is then well approximated by

\[
A(t) - 1 \approx \frac{1}{u(t)} \quad \text{with} \quad u(t) = \sqrt{\left(\frac{t - t_0}{t_e}\right)^2 + u_0^2},
\]

where the Einstein time is \(t_e = R_e/V_\perp\), the ratio of the Einstein radius to the transverse velocity of the lens.

In Fig.2 we find a typical light curve obtained with AGAPE method.

\[\text{2 A significative variation of luminosity on an opportune group of pixels connected with the dimension of the average PSF.}\]
4. Conclusion

The achievement could allow us to obtain:

a) the first large microlensing survey performed in the Northern Hemisphere for spiral arms observations and marginally for the bulge by taking into account the geographic position, the new generation optics and device at the Toppo telescope;
b) a detailed survey on other galaxies besides the Galaxy (first of all M31);
c) the capability of detecting planets (both Jupiter-like and Earth-like);
d) the participation in the follow-up observations of microlensing events which will be announced by programs like the Global Microlensing Alert Network (GMAN) or Planet Collaboration;
e) the possibility to use larger or spacecraft telescopes as HST to resolve interesting pixels obtaining more astrophysical information on the amplified objects.

An on-line selection and a quasi-on-line analysis could be made to perform the last point [8].

References

[1] B. Paczynski, ApJ, 304, 1, 1986.
[2] Alcock Ch. et al., ApJ, 486, 697, 1997. Alcock Ch. et al., ApJ, 479, 119, 1997.
[3] Renault et al., A&A, 324, 69, 1997.
[4] Dwek E. et al., ApJ, 445, 716, 1995.
[5] Udalski A. et al., Acta Astronomica, 47, 319, 1994.
[6] Ansari R. et al., A&A, 324, 843, 1997.
[7] Covone G., de Ritis R. and Marino A.A., astro-ph/9903287 Bozza V., astro-ph/9904297, 1999.
[8] Capozziello S. and G.Iovane, AstroTech Journal, Vol.2, n.1, 1999