Pixel and Micro-lensing with NGST

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Abstract. Within 8 years, the current microlensing surveys of M 31 will provide several hundred events affecting unresolved stars. They will thus allow a statistical study of the dark matter in M 31's halo. The NGST will resolve these stars and constrain the mass of the corresponding lenses. In case of on-line alerts from ground-based observations, real-time NGST follow-up with high signal-to-noise ratio will provide further constraints on the lenses. In addition, high resolution observations with NGST will complement XMM and the previous optical data and thus enable a closer insight of X-ray binaries within M 31 to be obtained. The optimal instrumentation to achieve these scientific goals will be discussed. Last, the study of the dark matter encompassed in the galaxy clusters would be possible with high angular resolution observations on a large field camera and would open a new field of research. Presented at NGST Science and Technology Exposition at Hyannis – September 1999 – (PASP)

1. Introduction

Searching microlensing events towards neighbouring galaxies allows to probe the distribution of compact objects (also called MAssive Compact Halo Objects or Machos) along their lines of sight (Paczynski 1986, Griest 1991). The interpretation of the first results is still very preliminary and relies on a small number of events (Alcock et al. 1997a,b,c, Renault et al. 1997, Palanque-Delabrouille et al. 1998, Alard et al. 1997, Udalski et al. 1994, Derue et al. 1998). Enlarging this faint statistics and exploring new lines of sight will be key-points in the near future for drawing strong constraints on the dark haloes. The detection of microlensing events on unresolved stars, initiated by Crotts (1992) and Baillon et al. (1993), offers some new perspectives. Two independent methods, based on this principle, have been developed. On the one hand, monitoring the fluxes of all the pixels present on the images allows to achieve a good sensitivity to the possible variation of unresolved stars (Ansari et al., 1997; Melchior et al.
A systematic study of all the information present in the frames is thus possible, with in particular an estimation of the detection efficiencies. On the other hand, the image subtraction technique also allows the detection of variable objects (Crotts & Tomaney 1996), but has mainly been used so far to improve the photometry of microlensing events detected towards the Galactic Bulge and LMC (e.g. Alard 1999; Alcock et al. 1999).

Thus, when accounting for unresolved stars, the number of effectively monitored stars is significantly enlarged, lines of sight towards more distant target galaxies can be explored, and hence the number of potential target galaxies is increased by an order of magnitude. The efficacy of these approaches to detect luminosity variations with a high detection rate has been demonstrated. The flux of the unresolved star is by definition unknown: this prevents the definition of the Einstein ring crossing time (=intrinsic duration of the events) and the estimation of the lens mass. In this context, the NGST will open new opportunities. Here, we discuss a few of them with respect to the possible instrumentation of this telescope.

2. Towards M 31

The survey of M 31 undertaken at the Isaac Newton Telescope[^3] will detect a few hundred microlensing events[^4] if the dark haloes of M 31 and the Milky Way are filled with compact objects. In the following, we discuss how the NGST could improve our knowledge of the lenses and the dark component of the haloes.

2.1. Identification of unresolved stars for microlensing (Integral Field Spectrometer with R~1000)

Whereas spectroscopic identifications of unlensed (resolved) stars in the Galactic Bulge (e.g. Benetti et al. (1995)) are possible from the ground, the NGST will offer the possibility to perform a similar work in M 31 with unresolved stars. With a small field of view (10" × 10") in the optical and the near-infrared, the spectroscopy (R~1000) with high spatial resolution (0.1") would allow to further study microlensing candidates detected from ground-based telescopes, and in particular those affecting unresolved stars in M 31. The identification of those unresolved sources is very challenging with existing technology. For instance, the microlensing candidate detected by the AGAPE group (Ansari et al. 1999), at 41" from M 31’s centre, affects a star whose magnitude at rest is dimmer than 22 in R, and lies on a stellar background of magnitude 16 mag.arcsec^{-1}. In this case, 3D imaging from space will be possible and allows an identification and detailed study of the (unlensed) star.

The unresolved stars corresponding to the microlensing events detected during the on-going ground-based surveys towards M 31 (e.g. INT survey) could be resolved and further studied with 3D imaging. This would provide complementary informations and place some constraints on the lens mass. The typical

[^3]: see [http://www.ast.cam.ac.uk/~mike/casu/WFCsur/M31.html](http://www.ast.cam.ac.uk/~mike/casu/WFCsur/M31.html) and [http://www-star.qmw.ac.uk/AGAPE/](http://www-star.qmw.ac.uk/AGAPE/)

[^4]: This typically assumes a 5-year monitoring of M 31.
expected events will occur in an area with a surface magnitude of 22, and the NGST spectroscopy would easily detect stars down to magnitude 26. Moreover, spectroscopy in the near-infrared will be possible for the study of red giants.

2.2. Identification of unresolved stars for Low Mass X-ray Binaries (Integral Field Spectrometer with R~200)

These microlensing surveys will also achieve a good sensitivity to cataclysmic variables. XMM, due to be launched in 15 December 1999, will observe M 31. The cross-identification with the microlensing surveys will provide the first optical counter-parts of LMXB. The NGST will be complementary to these two observing modes, and in particular, be able to identify the optical counter-parts of LMXB when quiescent (mag~28-30). In fact, the optical to near-infrared spectrum could be studied, and thus allow an unprecedented study of these systems in M 31.

2.3. Real-time follow-up of ground-based observations (Integral Field Spectrometer with R~200-2000)

Whereas spectroscopy of on-going microlensing events towards the Galactic bulge has been performed (e.g. see the remarkable work of Lennon et al. (1996)), a similar work, but for extragalactic stars, will be possible with the NGST. If ground-based microlensing surveys towards galaxies like M 31 are still going-on in 2007, high S/N follow-up observations based on an alert system would be possible with 3D imaging. Possible deviations from the point source/point lens approximations could be studied in external galaxies like M 31: (1) chromatic and spectroscopic signatures as suggested by Valls-Gabaud (1998) (and references therein) for the study of stellar structure; (2) planets orbiting around a star in M 31 (e.g. di Stefano 1999); (3) binary lenses (e.g. Gaudi & Gould 1999).

2.4. New survey of M 31 in the near-infrared (Wide Field Imager – multi-band filter mode)

Depending on the results of the current ground-based surveys, monitoring a large field of view (5’×5’) in M 31 with a resolution better than 0.03” would allow a complementary study. A sensitivity to different (dimmer) stars could be achieved, and in addition to the optical, the near-infrared wavelength range (1-2µm) could also be investigated. Also the constant seeing, which would characterise such data, would be a major advantage. A multi-band follow-up will allow an unprecedented analysis of microlensing events, with in particular a determination of the lens mass, completely independent from the ground-based optical observations. Moreover, a close insight into extragalactic dim stars will be possible for the first time.

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5see [http://astro.estec.esa.nl/XMM/xmm_top.html](http://astro.estec.esa.nl/XMM/xmm_top.html) and [http://xmmssc-www.star.le.ac.uk/](http://xmmssc-www.star.le.ac.uk/) and [http://www-star.qmw.ac.uk/AGAPE/xpage1.html](http://www-star.qmw.ac.uk/AGAPE/xpage1.html)
3. Towards other galaxies

A near-infrared survey, with high spatial resolution (0.03") combined with a large field of view (5'×5'), will allow to probe more distant galaxies, and thus a larger number of lines of sight can be explored. In particular, M 87 (at ≃17 Mpc) will be seen from space (with a constant seeing ≃ 0.03") with the same observing conditions as M 31 (at 0.7 Mpc) with ground-based observations (with a mean seeing ≃ 1.5"). A space-based monitoring of galaxies at the distance of M 87 with an 8-meter telescope will require 5-min exposures. In first approximation, if M 31 was at the same distance as M 87, we could typically expect of order of 50 microlensing events over a 6 months observing period. As studied by Gould (1995), additional events could be expected if intra-cluster MACHOs constitute a significant fraction of the dark matter of the Virgo cluster. An ambitious programme monitoring 10-20 galaxies would perform an unprecedented cartography of dark haloes.

Real-time follow-up of such microlensing events with 10 mas resolution would achieve a high signal-to-noise ratio and to constrain the lens mass.

4. Conclusions

The NGST equipped with an Integral Field Spectrometer (R~200-2000) and with a multi-band filter mode on a Wide Field Imager, characterised by a good spatial sampling, would first allow for the first time the study of extragalactic dim stars thanks to the magnification detected with ground-based observations. With a wide spectral range (from optical to near-infrared), the NGST would be unique to break the degeneracy of the parameters of each lens-source system as it could resolve the stars. Hence, the mass function of the lenses detected in M 31 could be determined, and a better understanding of the dark matter content of dark haloes achieved. Exotic events in M 31 could be studied with an unprecedented sensitivity and would further help to constrain the lens population. In addition, this would offer the unique opportunity to detection of extragalactic planets (see Rhie et al. (1999) for the possible detection of the first planet in the Galactic Bulge).

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