OBSERVATION OF MICROLENSING BY AN ASTROMETRIC SATELLITE

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ABSTRACT

The astrometric effect of microlensing will rarely reach a measurable size in observations by GAIA. It is, however, important to make a special effort to detect such rare effects, possibly hidden in the billions of measurements from the satellite, since information on the proper motion, distance and mass of deflecting dark bodies might be derived. The satellite would survey these elusive bodies in all directions in the Galaxy, not only in the directions of the LMC or the Galactic bulge where they have hitherto been discovered.

We discuss the possible photometric detection of microlensing events in GAIA observations and the subsequent analysis of the astrometric effect.It seems that measurement of distances, proper motions and masses of MACHOs might be possible. We also discuss the photometric detection of a MACHO passing the face of a star which could be used to determine the proper motion of the MACHO. The discussion concludes that such detections will be rare, but they seem frequent enough to warrant further consideration in connection with GAIA.

Key words: space astrometry; MACHO; microlensing; ROEMER; GAIA; photometry

1. MACHOs

The amplification of light from stars, sometimes called 'microlensing', was proposed by Paczynski (1986) as a means to detect MAssive Compact Halo Objects (MACHOs). This prediction of photometric lensing events in the light from stars in the large Magellanic Cloud (LMC) was confirmed by Alcock *et al.* (1993) and Aubourg *et al.* (1993) through their detection of three events, probably caused by MACHOs of about 0.1 solar masses as they passed within less than one milliarcsecond (mas) of the line-of-sight to a star. Nine lensing events in the light from stars in the Galactic bulge have been reported by Udalski *et al.* (1993, 1994) and Paczynski *et al.* (1994) with characteristic times $t_{\rm E}$ between 8.6 and 62 days.

The acronym MACHO has a very precise meaning, but it has become a misnomer since it is still attached to all objects discovered by observation of microlensing, even though many of these are ordinary low-mass dwarfs, according to Paczynski *et al.* (1994). This is the case for many MACHOs discovered in the direction of the Galactic bulge. MACHO is also the name of one of the collaborations searching for microlensing, i.e., Alcock *et al.*

2. MACHO PHOTOMETRY AND ASTROMETRY

The astrometric effect of microlensing should be considered simultaneously with the photometric effect of the same microlensing event. This was pointed out in a paper by Høg *et al.* (1995), hereafter called HNP. Three photometric observations were shown to be in principle sufficient to determine three parameters of a 'fly-by' event: The moment of closest encounter between the dark body and the line of sight to the star; the characteristic duration, $t_{\rm E}$, of the event; and the impact parameter, i.e., the ratio of the distance to the line of sight and the Einstein radius. When these three parameters are known it is in principle sufficient to obtain three one-dimensional astrometric observations of the same event in order to derive the proper motion, the distance and the mass, m, of the dark body. This assumes that the proper motion and the distance of the background star are accurately known, as can indeed be assumed. For the sake of redundancy and a better signal-to-noise ratio it is of course useful to have a much larger number of observations than just three photometric and three astrometric.

HNP predicts the size of the photometric and astrometric effects for the ROEMER satellite project proposed by Lindegren *et al.* (1993) and Høg & Lindegren (1994).

The photometric effect is more easily detected than the astrometric. HNP expects more than 300 light amplifications with a signal-to-noise ratio of at least 10 during a 5 year ROEMER mission. This expected number of significant amplifications depends on the total mass of the Galactic halo of dark bodies, but not on the distribution function of the masses of the individual dark bodies. If they all have masses of, e.g., $m = 1\ M_\odot$ these amplified photometric observations would belong to about 25 fly-by events. The dark body masses are, however, at present assumed to be about 0.1 $M_\odot$ which would mean that the 300 amplifications would be distributed on a larger number of events. The background stars are typically 16th magnitude at distances of 6 kpc. With GAIA, as described by Lindegren & Perryman (1994), the number of such amplifications will be at least an order of magnitude larger. Such photometric observations would be related to MACHOs much closer to the sun than MACHO observations so far and can therefore provide information on the local space density of MACHOs, and of the density in all directions from the sun.

The expected time scales of events are given in HNP-Table 1; e.g., for stars of $V = 16$ mag we get $t_{\rm E} = 8$ or 25 days if all halo dark bodies have the mass $m = 0.1$ or 1.0 $M_\odot$, respectively.

The detection of microlensing from a scanning astrometric satellite is characterized by an uneven distribution in time of the observations, due to the strict scanning law. This is very different from the rather uniform distribution of ground based MACHO observations. A discussion of this subject is given in HNP, but it can be said that the uneven distribution offers advantages and disadvantages; many possible time scales will be sampled, but the sampling will be incomplete.

The astrometric measurements with ROEMER and GAIA are one-dimensional, as assumed above. HNP shows that a satellite giving astrometric observational errors 20 times smaller than ROEMER—and those of GAIA will be even smaller than that—would give a significant determination of the proper motion of a MACHO of $m = 1\ M_\odot$ passing close to a 16 mag star. Proper motion and distance give the tangential velocity, and thus a clue to the space velocity, otherwise inferred only from models of the halo.

HNP considered the prospects for astrometric observations of MACHOs to be meagre. But the paper was written in May 1994, and since then the prospects for space astrometry have improved drastically through new technical ideas and owing to initiatives by the European Space Agency.

3. CROSSING THE FACE OF A STAR

If a MACHO passes over the face of the star it is lensing, then one can measure the MACHO's proper motion, as discussed by Gould (1994) and Nemiroff & Wickramasinghe (1994). When the MACHO passes in front of the stellar disk the shape of the photometric curve differs from what it would be with a point-like source star; the peak is flattened. Observation of a single event of the kind will give an upper limit for the MACHO's proper motion, relative to that of the star, if one assumes that the MACHO crossed centrally over the stellar disk of known angular diameter. Thus, a statistical analysis of several events is required. The unknown angle between the directions of the two proper motions also gives an uncertainty in the interpretation, but this is probably small since MACHOs are expected to have much higher space velocities than the source stars.

For a Galactic halo MACHO of 0.1 $M_\odot$ the Einstein radius is 0.2 mas when observed at a source of $V = 16$ mag, according to HNP-Table 1. A typical source star at the median distance 6 kpc has the radius $2R_\odot \sim 0.002$ mas. Therefore a fraction of $0.002/0.2 = 1$ percent of the photometric events would contain a stellar disk crossing. The crossing of the stellar diameter at a velocity of 200 km/s takes about 4 hours. To make a clear measurement one should probably sample the light curve of order 10 times as the MACHO passes the stellar diameter. This implies a desirable sampling interval of $\Delta t \simeq 0.4$ hours. If GAIA rotates with 120 arcsec/s the observations by the three directions of view will be spaced at about 1 hour intervals, and some 12 such observations by incoherent imaging would be obtained before the band of scan of 1.6 degrees width has moved away from the star. This seems realistic enough to warrant further consideration in connection with GAIA, in view of the importance of improving our knowledge of the dark Galactic halo.

REFERENCES

Alcock, C. *et al.* 1993, Nature 365, 621 (MACHO collaboration)

Aubourg, E. *et al.* 1993, Nature 365, 623 (EROS collaboration)

Gould, A. 1994, ApJ 421, L71

Høg, E., Lindegren, L. 1994, ROEMER satellite project: The first high-accuracy survey of faint stars. In: *Galactic and Solar System Optical Astrometry*, by L. V. Morrison & G. Gilmore (Eds.), 246-252, Cambridge University Press.

Høg E., Novikov I.D., Polnarev A.G. 1995, MACHO photometry and astrometry, Astron. Astrophys. 294, 287.

Lindegren L. (ed.) 1993, *ROEMER: Proposal for the Third Medium Size ESA Mission (M3)*, Lund.

Lindegren L., Perryman M.A.C. 1994, GAIA: Global Astrometric Interferometer for Astrophysics, in *Supplementary Information Submitted to the Horizon 2000+ Survey Committee*, 52pp.

Nemiroff, R.J., Wickramasinghe, W.A.D.T. 1994, ApJ 424, L21

Paczynski, B. 1986, ApJ 304, 1

Paczynski, B., Stanek, K.Z., Udalski, A. 1994, ApJ 438, L113 (OGLE collaboration)

Udalski, A., Szymanski, M., Kaluzny, J. *et al.* 1993, Acta Astronomica 43, 289

Udalski, A., Szymanski, M., Kaluzny, J. *et al.* 1994, ApJ 426, L69