EROS 2 HIGH PROPER MOTION SEARCH FOR WHITE AND BROWN DWARFS

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In 1996 EROS 2 started surveying 350 square degrees to look for nearby white dwarfs and brown dwarfs by proper motion, using its two-colour wide-field imager. We report here the preliminary analysis of the first 140 square degrees for which we possess two epochs. We expected around ten M_V=16.5–17 halo objects and found none. However one nearby, probably disk, brown dwarf was discovered.

1 Introduction

The most common solutions to the Galactic dark matter problem add to the thin and thick disks and bulge/spheroid of the Galaxy a massive dark halo or a so called maximum disk. If baryonic, dark matter would likely be formed by stellar remnants or sub-stellar objects.

Many observing programs tried to detect or constrain the shape and nature of the Galactic dark matter. Microlensing experiments (Afonso *et al*[4]) have provided around 15 microlensing candidates towards the Magellanic Clouds, the standard interpretation of which being that they belong to the Galactic halo, with favored mean mass between 0.1 and 1 $M_\odot$, forming around 50% of a *standard* halo of mass 4.10^{11} $M_\odot$ within a sphere of radius 50 kpc. However, this mass measurement is strongly model dependent. Deep searches using pencil beam WFPC images have also put strong limits to the contribution of brown dwarfs brighter than M_I = 15 mag (less than 6% at 95% C.L.) and by white dwarfs brighter than M_V = 16.9 mag and redder than V-I = 1.7 mag (less than 33% at 95% C.L.) (see Flynn *et al*[6]).

The direct search for faint, nearby white and brown dwarfs is an important step for further understanding of the mass contribution of faint baryonic compact objects. Here we present the preliminary results of a search for nearby white and brown dwarfs by proper motion. The use of the EROS 2 wide-field imager provides the necessary solide angle, in two bands, with time sampling optimized for fast, halo stars; we shall present the reduction procedure and conclude with the current preliminary results corresponding to the first two years of data (two epochs with a one year baseline).

*EROS 2 COLLABORATION.

2 The EROS 2 proper motion survey

2.1 Instrument characteristics

The EROS 2 two colour wide-field imager is made of two identical $8k \times 4k$ CCD mosaics. It is mounted at the Cassegrain focus of the 1-m Ritchey-Chretien Marly telescope. The passbands are large, as defined by the dichroic beam splitter used to divide the flux. The *visible* band is centred on the Johnson V filter, while the *red* one is centred on the Cousins I filter, with sensitivity up to 1 micron. Calibration (Bauer et al[2]) is still preliminary and standard magnitudes given below are indicative. The present analysis used seven CCDs ($0.81\,^{\circ 2}$) in the red passband and eight CCDs ($0.87\,^{\circ 2}$, due to cosmetic defects) in the visible band. The pixel size is 0".6.

2.2 Observing Strategy

EROS 2 operates its dedicated telescope on a full-time basis. Observations for the proper motion survey are conducted one to two hours per dark night, within 90 minutes from the meridian to minimise atmospheric refraction. Images are shared with the EROS Supernovae detection program [9], so that fields were selected within those of the Las Campanas redshift survey, at declination $-40\,^{\circ}, -45\,^{\circ}$ near the South Galactic Pole ($144\,^{\circ 2}$), and at $\delta = 0\,^{\circ}, -6\,^{\circ}, -12\,^{\circ}$ in the Northern Hemisphere ($219\,^{\circ 2}$). Each year every field is observed twice if possible (50% of all fields) or more. To date $296\,^{\circ 2}$ have been surveyed twice in 1996, 1997 or 1998. Observations for a third epoch started in August 1998, but are not included in the present analysis. The experiment is expected to last until 2002, so that eventually 3 to 5 epochs will be available.

2.3 Creation of the proper motion catalogue

The reduction software for source detection, classification and catalogue matching was written in the framework of the EROS PEIDA package[1]. The data are processed by chunks of $(11\ \text{arcmin})^2$. The precision for the larger fluxes could be improved by a more sophisticaded PSF model than the Gaussian function we used, but as errors are dominated by the photon noise for low fluxes, as can be seen in Figure 2, that would not improve the astrometry for most of the volume. A rough star/galaxy classification is performed to limit galaxy contamination, with such cuts that few stars are misclassified.

The catalogues of the two epochs are then geometrically aligned using a linear transformation between the 40 brightest stars. Linear transformations are good enough over such a small sky area. Then the whole catalogues

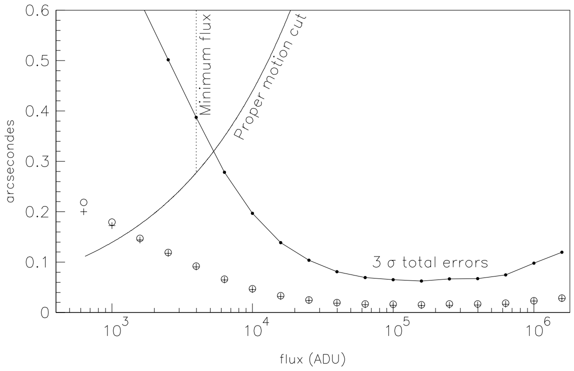

Figure 1. Standard astrometric errors along α versus red (crosses) and visible (circles) EROS flux. 3σ total error in the visible band is shown by the plain line with crosses; the proper motion cut, by the plain line.

are matched, requiring that the matched stars have a compatible brightness, within a search radius of 9 arcsec, to be compared with the mean distance between two stars, 1 arcmin.

From the displacement between the star positions, we derive the total astrometric error. The results are shown in Figure 1. It appears that the precision saturates at 0.04 pixel or 25 mas for the larger fluxes, corresponding to a 20σ detection of a 250 km/s halo star at 100pc from the Sun. The errors increase with decreasing flux in agreement with the photon noise model, showing that the astrometric measurement procedure does not add significant errors.

3 Selection of the candidates

3.1 Single colour selection procedure

In the current analysis we try to select any candidate to form significant part of the dark matter, hence we impose a minimum proper motion according to the star relative magnitude, so that we get all stars faster than 100 km/s and fainter than $M_V = 16.7^m$, $M_I = 15.9^m$. If we do that using either the visible or the red images, many spurious candidates are selected close to the detection limit, and they will have to be eliminated by the third epoch images.

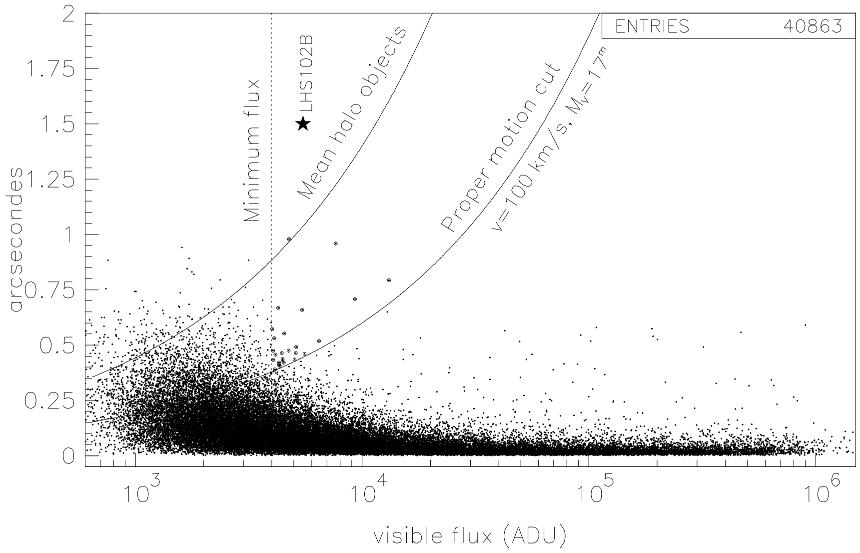

Figure 2. Distance of association versus the visible flux. Only 5% of objects are shown. The flux cut is represented by the dotted vertical line; the proper motion cut, by the plain oblique line. the mean position of a typical 250 km/s, M_V=17 halo object, by the dashed line. The brown dwarf we discovered is represented by a star.

3.2 Current selection procedure

As we now possess only two epochs, we eliminate the spurious candidates by imposing selection in both bands. This reduces the searched volume for brown dwarfs, hardly detected in the visible band, but not much for the coolest white dwarfs, which are expected to be bluer [3,8].

4 Current expectations and results

4.1 The detection efficiency

The efficiency calculation is of prime importance for such a survey, and it can be relatively safely determined with this CCD reduction procedure, by Monte–Carlo techniques. Inefficiency is due to non–detection of the object on one of

Table 1. Number of expected objects for a *standard* halo of $0.01 M_\odot/pc^3$ local density, in the present survey.

Type of objects	V-I$\sim$1 white dwarfs		Brown dwarfs	
	M_V=16.7	M_V=17.7	M_I=15.9	M_I=16.4
Number of objects	10	3	5	3

the images, poor astrometry, wrong classification or mismatching. Effects of the pointing errors and failure of the geometric alignement can be measured directly and are included in the value of the surveyed area. We then measured the matching and selection efficiency, calculated by simulated displacement of a random real star on every quarter of CCD, for different displacement radius and magnitude. Efficiency varies between 80 and 85% for large fluxes down to 10σ above background and then drops, for any halo-type proper motion up to 8"/yr.

4.2 Sensitivity of the survey to halo white dwarfs

In the present analysis, the useable area for which we possess correct images for both epochs and both colours is 1,200 (20 min)^2 CCDs, or 140 $^{\circ 2}$. Taking into account the efficiencies indicated above, we calculate the number of expected stars, in the hypothesis that the halo is filled with white/brown dwarfs of a certain magnitude and colour. The results are presented in Table 1.

4.3 Present detections

Among a thousand of stars selected in one single colour, six were selected in both colours: four had with incompatible visible and red proper motions; one was rejected by eye examination (apparent binary). The remaining, very red, candidate was confirmed with a third epoch image in May 1998, and its DENIS infrared colours[5] proved very interesting: I-K=5.6, I-J=4.7, I=17. It happens to be the previously undetected companion to LHS102, whose proper motion (82 ± 6 km/s) and distance (9.6 ± 1.2 pc) are known[12]. It was later observed at Keck and confirmed by spectroscopy as a L–class, lithium depleted brown dwarf. Further information on this star can be found in Goldman *et al*[7] and Martin *et al*[11].

5 Conclusion

The EROS 2 proper motion program is now in its productive stage with data from two epochs reduced, and a third epoch being imaged. The present analysis restricted to fast and faint stars expects about ten M_V=17.2 halo white dwarfs to be detected for a halo filled with such those objects. With no halo object detected, we confirm the results of recent different detection programs[10], according to which hydrogen white dwarfs younger than $\sim$14 Gyr cannot form the full halo.

Within a few months, using third epoch images and relaxed cuts, the program should be sensitive to tens of halo white or brown dwarfs, putting definitive constraints on these types of objects in the local Dark matter budget. It will also be sensitive to faint disk objects, similar to the brown dwarf already detected, and help define the luminosity function of faint stars in the solar neighbourhood as well as their intrinsic characteristics.

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References

1. R. Ansari *et al.*, A&A **314**, 94 (1996)
2. F. Bauer *et al*, *in Proceedings of the "Optical Detectors for Astronomy" workshop*, ESO (1997).
3. P. Bergeron *et al*, ApJ Suppl. Ser. **108**, 339 (1997).
   Ed. T.R. Bedding, A.J. Booth and J.Davis (Kluwer; Dordrecht) (1997).
4. C.Afonso *et al*, ApJ **199**, L12 (1998).
5. G.Simon, E.Clerc, X.Delfosse, private communication (1998).
6. C. Flynn *et al*, ApJ Letters **466**, L55 (1996).
7. B.Goldman *et al*, to be submitted to A&A (1998).
8. B.M.S. Hansen, Nature **394**, 860 (1998).
9. D. Hardin, report DAPNIA-SPP to appear; The Messenger **88**, 26 (1997).
10. C.Lidman *et al*, submitted to MNRAS (1998).
11. E.Martin *et al*, to be submitted (1998).
12. W.F. van Altena, J.T. Lee, E.D. Hoffleit, The General Catalogue of Trigonometric Stellar Parallaxes, Fourth Edition, Yale University Observatory, 1995.