The Solar Neighbourhood XI: The trigonometric parallax of SCR 1845–6357

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ABSTRACT

We present a trigonometric parallax for the nearby star SCR1845–6357, an extremely red high proper motion object discovered by Hambly et al. (2004) and identified via accurate photoelectric photometry and spectroscopy to be an M8.5 dwarf with a photometric parallax of 4.6 ± 0.8 pc by Henry et al. (2004). Using methods similar to those described in Deacon & Hambly (2001) we have derived a full astrometric solution from SuperCOSMOS scans of eight survey and non–survey Schmidt photographs held in the United Kingdom Schmidt Telescope Unit plate library. We calculate the trigonometric parallax to be \( \pi = 282 \pm 23 \) mas yielding a distance of 3.5 ± 0.3 pc which implies an absolute \( K_s \) magnitude of 10.79. This distance calculation places SCR1845–6357 as the 16th closest stellar system to the Sun.

Subject headings: stars: distances—low-mass, brown dwarfs—late-type—Galaxy: solar neighborhood

1. Introduction

There has been a recent flurry of discoveries of stars within the local solar neighbourhood. Some have been discovered as companions to well–known nearby stars (eg. \( \epsilon \) Indi B/C; see McCaughrean et al. 2004 and references therein) while others are entirely new systems (eg. Teegarden et al. 2003). The RECONS group (Research Consortium on Nearby Stars) has sought to identify and study all systems within 10pc of the Sun. Previous papers of this series have used a variety of photometric and spectroscopic techniques to identify and study samples of nearby stars and describe discovery of companions to known nearby stars and identification of entirely new systems. Most recently, a new initiative (Hambly et al. 2004) identified five nearby high proper motion stars, two of which have initial photometric parallaxes within the RECONS horizon. The nearest of these, SCR1845–6357, (hereafter the target) was shown subsequently to have a photometric parallax of 4.6 ± 0.8 pc (Henry et al. 2004). Photometric data for the target are reproduced in Table 1. These show that the object is very red; Henry et al. (2004) classified the target as an M8.5 dwarf.
2. Observational data and reduction

Luckily there is a wealth of astrometric data available for this object, partly because it lies in the overlap region between the standard Schmidt photographic survey fields, and partly because non–survey programmes have fortuitously observed the field containing the target frequently and over a long time baseline. The target was identified on two United Kingdom Schmidt Telescope (UKST) R survey plates and one European Southern Observatory (ESO) survey R plate. These had already been scanned as part of the SuperCOSMOS Sky Survey (Hambly et al. (2001a) and references therein). In addition six UKST non-survey R photographs from the UKST Plate Library were selected for their image quality and useful parallax factors, and were scanned especially for this study using SuperCOSMOS. Hence a total of nine Schmidt photographs were used, details of these are shown in Table 2. These also provide a nine year baseline, ideal for measuring an accurate proper motion.

Each plate was scanned individually on SuperCOSMOS and processed using standard methods (Hambly et al. (2001a) and references therein). Global astrometric plate solutions result in systematic errors of order $\sim 0.2$ arcsec in absolute positions. Hence it is necessary to correct for these; a local linear plate model with respect to the array of mean positions from all measures was employed for this purpose. A sample of circular, single, stellar images which are not affected by proximity to bright stars were selected as local astrometric reference stars. These reference stars were used to fit linear models for each of the plates with respect to the array of mean reference star positions. The residual errors from the reference stars after these models are applied give an indication as to the astrometric quality of each plate; as a result of this test, one of the non–survey plates was excluded from the rest of the study owing to poor astrometric quality (see Table 2).

It is also important that the maximum distance of reference stars from the target is carefully chosen. Too small a distance and the number of reference stars will be too few, too large and non–linear plate effects may leave systematic errors in the linear fit (indicated by an increase the RMS error). In order to choose the maximum reference star distance correctly several different selections were made and the average RMS errors (the mean of all the errors from all the plates) from the local linear plate fit were noted along with the number of reference stars. The results are shown in Table 3. We chose the maximum extent available (20 arcminutes) from the area in

Table 1: Photometric data on SCR1845–6357. JHK magnitudes are taken from the Two Micron All Sky Survey, V, R and I measurements are from Henry et al. 2004. Note that the $B_J$ measurement comes from a plate where the target image is deblended and hence may not be as accurate as the other measurements.

| $B_J$ | $R_{59}$ | $I_N$ | $J$ | $H$ | $K_s$ | V | $R_C$ | $I_C$ |
|-------|----------|-------|-----|-----|-------|---|-------|-------|
| 19.05 | 16.33    | 12.53 | 9.54 | 8.97 | 8.51  | 17.40 | 15.00 | 12.47 |
common between both plates as there is no indication of an increase in systematic errors up to this value.

3. Results

Once the process described in Section 2 was carried out, plate-to-plate systematic errors were eliminated, the relative astrometric quality of each plate with respect to the mean positional measures was determined and it was possible to apply a full weighted astrometric fit to the target and reference stars. Equations 1 and 2 show the astrometric models for Right Ascension and Declination respectively (where \( f_\alpha \) and \( f_\delta \) are the parallax factors in Right Ascension and Declination):

\[
\alpha = \alpha_o + \mu_\alpha t + \pi f_\alpha; \\
\delta = \delta_o + \mu_\delta t + \pi f_\delta. 
\]

The error-weighted design matrix formed from these equations was solved via Singular Value Decomposition to yield a least-squares fit; we employed numerical routines from the SLALIB positional astronomy library (Wallace 1998). The results for the target (along with \( \chi^2_\nu \), ie. \( \chi^2 \) normalised per degree of freedom) are shown in Table 4. The total proper motion is 2.64 ± 0.0082 arcseconds/year with a position angle of 74.9 degrees, these compare with the values of 2.56 ± 0.013 arcseconds/year and 74.8 degrees quoted in Hambly et al. (2004). The proper motion measurements differ but this may be due to systematic errors in either measurement or because Hambly et al. (2004) did not include a parallax in their astrometric solution. The trigonometric parallax was found to be \( \pi = 282\pm23 \) milliarcseconds. Figure 1 shows the deviation in position of the target from it’s proper motion. Figure 2 shows the parallax ellipse traced out by the target star.

As a test of the astrometry, each reference star was also run through the same astrometric model fitting procedure and the proper motions and parallaxes of the reference stars were found. These are plotted in Figure 3 along with the target. It is clear that the target is well separated from the mass of reference stars. In general the reference stars have proper motions and parallaxes consistent with zero (and a mean value of \( \chi^2_\nu \sim 0.72 \) indicating good model fits) and hence are good reference stars. To further investigate the reference star distances, and for the purposes of correcting the measured (ie. relative) parallax to an absolute parallax, the mean B–R\(_{59}\) and R\(_{59}\) for the reference stars were found. The mean B–R\(_{59}\) calculation was then used to find that the mean spectral type (assuming they are dwarfs) for the reference stars is G5 (Zombeck 1990). From this the mean expected absolute R\(_{59}\) magnitude (Zombeck 1990) can be deduced which combined with the mean R\(_{59}\) magnitude yields the mean expected distance of the reference stars. The mean expected trigonometric parallax of the reference stars was thus found to be \( \pi = 0.7 \) mas. This is clearly insignificant compared to the formal error on our parallax for the target, so we made no correction from relative to absolute parallax.

To further test that the method used was sound, 100 sets of simulated data were created. Each had the same astrometric parameters as the target and each data point was given a random
Table 2: Schmidt photographs used in this study; relative astrometric quality is indicated by the \( \sigma_x \) and \( \sigma_y \) values (see text). One plate was excluded due to poor astrometric quality.

| Plate No. | Date (ddmmyy) | LST | Zenith Angle | Emulsion | Filter | Exp. (min) | \( \sigma_x \) (mas) | \( \sigma_y \) (mas) | Material |
|-----------|---------------|-----|--------------|----------|---------|------------|------------------|------------------|---------|
| ESOR6887  | 30/04/87      | 1713 | 37.7°        | IIIaF    | RG630   | 120        | 46               | 64               | Glass copy of ESO survey plate |
| OR13751   | 20/06/90      | 1843 | 32.7°        | IIIaF    | OG590   | 60         | 41               | 42               | Original non-survey plate |
| OR14370   | 16/06/91      | 1831 | 32.8°        | IIIaF    | OG590   | 55         | 40               | 39               | Original non-survey plate |
| OR15689   | 12/08/93      | 1746 | 34.0°        | IIIaF    | OG590   | 55         | 40               | 42               | Original survey plate |
| OR16753   | 28/08/95      | 1850 | 32.7°        | IIIaF    | OG590   | 80         | 46               | 44               | Original survey plate |
| OR17012   | 24/03/96      | 1648 | 37.5°        | 4415     | OG590   | 15         | 48               | 49               | Original non-survey film |
| OR17038   | 15/04/96      | 1757 | 33.6°        | 4415     | OG590   | 15         | 53               | 56               | Original non-survey film |
| OR17256   | 15/09/96      | 1838 | 32.7°        | 4415     | OG590   | 15         | 55               | 64               | Original non-survey film |

| Plate Not Used |
|----------------|
| R 5991         | 16/05/80 | 2032 | 36.7° | IIIaF | RG630 | 150 | 107 | 92 | Original non-survey plate |

Table 3: Selecting the optimum maximum distance of reference stars from the target. Note the number of reference stars does not increase as the square of the maximum radius due to plate boundary cutoffs.

| Maximum distance from target (Arcminutes) | Average RMS error (mas) | Number of reference stars |
|------------------------------------------|------------------------|---------------------------|
| 20                                       | 56                     | 108                       |
| 18                                       | 56                     | 108                       |
| 16                                       | 56                     | 98                        |
| 14                                       | 58                     | 77                        |
| 12                                       | 59                     | 56                        |
| 10                                       | 58                     | 41                        |
Fig. 1.— The deviation from the proper motion in (a) RA and (b) Dec versus time. The line shown
Fig. 2.— The parallax ellipse traced out by the target, the dotted lines represent one sigma upper and lower limits on the parallax.
Gaussian error calculated from the RMS error estimates of the particular plate. These were then run through the astrometric solution fitting program. No significant offsets were found and the error on the parallax calculated from the scatter of the simulated data solutions was in good agreement to that predicted by the astrometric solution.

Finally, we examined differential colour refraction (DCR) effects between the reference stars and the target. In Figure 4 we show model predictions for the coefficient of refraction, $R$, for stars of various synthetic photographic colour. We used methods described in Hambly et al. (2001b) and references therein; we additionally used the flux calibrated spectrum of SCR1845–6357 presented in Henry et al. (2004) to compute $R_{59}$ and synthetic ($R_{59}–I_{N}$) for the extremely red target. The reference stars are taken as an ensemble of points that typically have ($R_{59}–I_{N}$) ~ 0.5, whereas the target has ($R_{59}–I_{N}$)=3.6 computed from the spectrum, and 3.75 from the photographic photometry listed in Table 1 (these colours are consistent within the photographic photometric errors of ~ 0.1 mas for $R_{59}–I_{N}$). These colours indicate a difference in refraction coefficient of $\Delta R$ ~ 35 mas at airmass of 1.5 (Figure 4). This difference changes negligibly with airmass, i.e. recomputations at 1.0 and 2.0 airmasses show a zero point shift in the locus of Figure 4, but no significant change in the Delta R value for the two colors. However the quantity of most relevance is of course how this differential refraction coefficient translates into image displacement at the different hour angles and zenith distances of the observations in Table 2. Typically, the DCR shift for RA is ±5 mas and for Dec is ±1.5 mas; the largest change between any two observations is 10 mas for RA and 3 mas for Dec because all of the plates used are within 2 hours of the meridian, so DCR is minimal. Hence, we feel justified in neglecting these corrections in our astrometric model since the positional uncertainties dominate systematic effects due to DCR.

Table 4: The full astrometric solution for SCR1845–6357, note the $\chi^2$ indicating a good fit to the model.

| Parameter      | Fitted Value | Error | Units |
|----------------|--------------|-------|-------|
| RA on 01/01/2000 | 18$^h$45$^m$05$^s$.2008 | 0.0407 as | —     |
| Dec on 01/01/2000 | −63$^\circ$57′47″.355  | 0.0435 as | —     |
| $\mu_\alpha \cos \delta$ | 2.5495       | 0.0055 as/yr |       |
| $\mu_\delta$      | 0.6874       | 0.0061 as/yr |       |
| $\pi$              | 282          | 23     | mas   |
| $\chi^2_\nu$      | 0.49         | —      | —     |
Fig. 3.— Comparing the fitted parallax and proper motions for the reference stars with SCR1845–6357.
Fig. 4.— Computational models (after Hambly et al. 2001b and references therein) for the coefficient of refraction $R$ at an airmass of 1.5 as a function of synthetic photographic (R–I) colour. Data are from a spectrophotometric atlas except for the point at (R–I, R) = (3.6, 60.05) where we have used the spectrum for SCR1845–6357 presented in Henry et al. (2004). The solid line is a polynomial fit to the data points.
4. Discussion

The calculated trigonomteric parallax for the target gives a distance of $3.5\pm0.3$ pc. Consulting the RECONS list of nearby stars\(^1\) we find that this makes SCR1845–6357 the 16th nearest stellar system to the Sun. The upper and lower one sigma error boundaries would make it the 23rd and 10th nearest stellar system respectively. We note that the RECONS photometric parallax is $4.6\pm0.8$ pc (Henry et al. 2004) hence our new trigonometric parallax puts this object $2.8\sigma$ nearer than was first estimated. Hambly et al. (2004) estimated the distance to be $3.5\pm0.7$ pc; we expect the true distance of the target to be between the estimate given here and that of Henry et al. (2004).

5. Conclusion

We have measured the trigonometric parallax of SCR1845–6357 and found it to be the 16th nearest stellar system to the Sun. This demonstrates that the wealth of astrometric information on the many plates taken over the past 50 years can yield new insight into the nearby star population and, in particular, permit the determination of valuable trigonometric parallaxes.

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