SESSION D

ASTROMETRY WITH LARGE TELESCOPES

PROPER MOTION AND PARALLAX PROGRAMMES FOR LARGE TELESCOPES

(Invited Paper)

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Abstract. Proper motion work at the present time relies on the availability of plates taken in the past, for which the magnitude limit is generally not fainter than about $m_{pg} = 16$, apart from Luyten's survey with the Palomar Schmidt. It is very important for future studies to fainter magnitudes in, for example, star clusters, that sufficient time is made available on large telescopes so that plates can be taken now. Consideration should also be given to an extension of proper motion work in Selected Areas.

Ideally, trigonometric parallax observations are best carried out on a dedicated telescope, such as the USNO 61-in. reflector, with a large amount of time available; but if sufficient observational material is to be obtained on faint stars, time must also be taken on other medium sized and large reflectors. With the severe limitation of time available on these telescopes, the criteria for selection of stars for such programmes become of prime importance. Large Schmidt telescopes, with fast automatic plate measurement, may possibly be used for surveys of nearby stars, unbiased by any kinematic or photometric selection effects.

1. Introduction

The large output of astrometric data during the first decades of this century, notably the photographic positional catalogues and parallax work on long focus refractors, has provided a reservoir of information for objects brighter than about the twelfth magnitude. Much of these data were collected without a specific astrophysical motivation, but they have nevertheless proved invaluable in subsequent researches. Nowadays however the astrometrist is at somewhat of a disadvantage; with the increase in the number of large telescopes now available, the interest in astrophysics is shifting towards fainter apparent magnitudes for which there are as yet little astrometric data.

Astrometrists must also use these larger telescopes to obtain their raw material, but, while the technique of obtaining good plates is relatively simple, they must have a sufficient lapse of time for measuring a parallax and even longer for precise proper motion. It is therefore important that good observational programmes be planned now and plates taken as soon as possible.

Astrometry itself has been responsible for the discovery of many interesting objects, primarily through proper motion surveys, but as these surveys go to fainter and fainter magnitudes, such as the current survey by Luyten with the 48-in. Schmidt, the problem of obtaining precise parallax and proper motion data becomes more acute.

In the present context I shall define 'large' to mean an aperture of about 48 in. or greater. Considerable experience has already been gained with astrometric work on telescopes in this category. Strand (1962) has discussed the parallax work by van Maanen with the 60-in. and 100-in. reflectors on Mount Wilson. At Herstmonceux we have also used 60-in. Cassegrain plates successfully for proper motions in some cluster fields (e.g. Murray *et al.*, 1965; Cannon and Lloyd, 1970) and I have also used

Gliese, Murray, and Tucker, 'New Problems in Astrometry', 151–158.

old 60-in. Newtonian photometric plates on Selected Areas (Murray and Sanduleak, 1972) in spite of the comatic images. Furthermore, an investigation of the astrometric performance of the 98-in. Isaac Newton Telescope with the Wynne four element prime focus corrector, has shown that precise work is possible with this instrument (Murray, 1971). The 48-in. Palomar Schmidt has also been shown to be capable of good astrometry. In addition to the blink survey, Luyten (1963) has used plates from this telescope for measuring a parallax. He has also reported satisfactory positional measurements over the whole area of a 14 in. sq plate (Luyten and La Bonte, 1972) in a southern field using SAO catalogue positions for reference stars and, likewise at Herstmonceux a positional investigation has been carried out on a northern field over a 10 in. sq plate taken with the same telescope, using AGK3 stars as references (Parkes and Penston, 1973). In both these investigations the major contribution to the errors is from the catalogue positions, but the actual errors ($0\overset{''}{.}6$ for the SAO field and $0\overset{''}{.}36$ for the AGK3 field) are reasonable, bearing in mind the likely random errors in the star places and the accidental errors of measurement.

My own feeling is that, given good plates taken with whatever optical system, the information is there, and it is up to the ingenuity of the astrometrist, aided by the computer and measuring machine to extract the information from the plates.

2. Trigonometric Parallaxes

A major advance in the astrometric study of stars fainter than about twelfth magnitude has been brought about through the operation of the USNO 61-in. astrometric reflector at Flagstaff. In a paper presented at the symposium associated with the dedication of that telescope, Worley (1966) summarized the state of parallax work at that time; in particular, parallaxes had then been measured for fewer than 100 stars in the northern sky fainter than $m_v = 13$. Since then the situation has changed dramatically; out of the two hundred stars for which parallaxes from 61-in. reflector observations have been published (Riddle, 1970; Routly, 1972), 75% are fainter than $m_v = 13$, but only four are fainter than $m_v = 16$. Also, van Altena (1971) has published a few results from the new Yerkes programme for stars of thirteenth and fourteenth magnitude.

At Herstmonceux we are making a small contribution to this problem with a programme of some 20 faint stars between photographic magnitudes 16 and 18.5, which we are observing at the prime focus of the Isaac Newton Telescope. However, this telescope is used for many other purposes and my group gets, on the average, an allocation of just over three full nights per month, not all of which are clear, for this and other astrometric programmes. In our case it is therefore very important to choose the programme carefully to avoid wasting time on small parallaxes. For the current programme the selection has been mostly on proper motion criteria, but I am not too sure, even at these faint magnitudes, that this was the wisest course.

It is very well known that, at least at brighter magnitudes, selection by proper motion introduces a bias in favour of high velocity stars with small parallaxes. This is

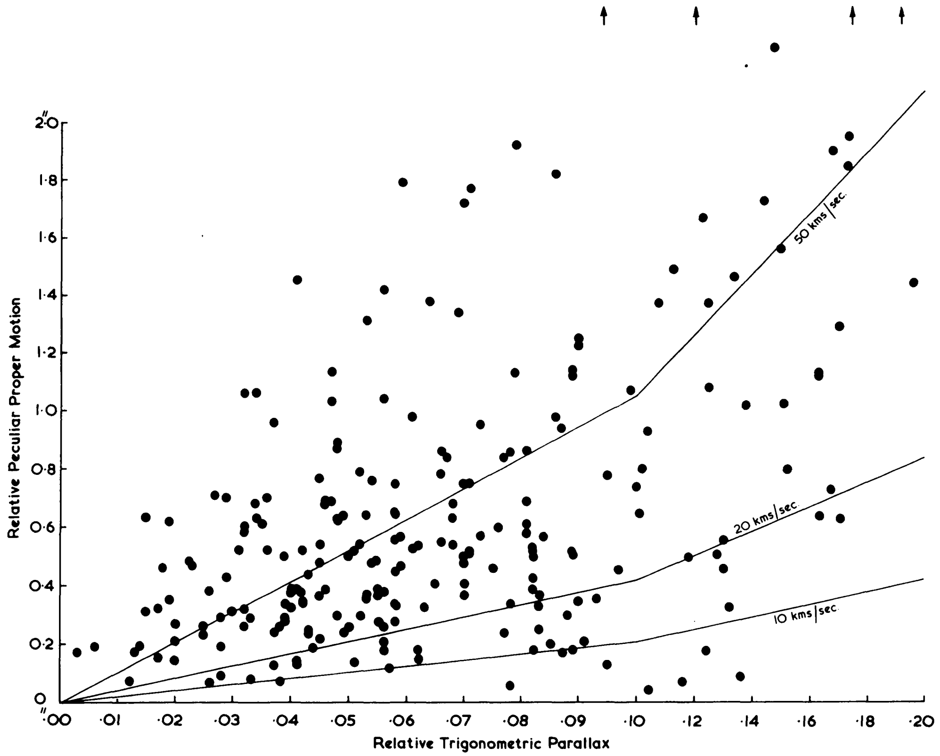

Fig. 1. Plot of total peculiar proper motion (ordinate) against trigonometric parallax (abscissa) for stars in Vyssotsky's catalogues for which parallaxes are given.

well illustrated in Figures 1 and 2 which show plots of relative parallax versus peculiar proper motion (i.e. corrected for standard solar motion) for two samples of K–M dwarfs from Vyssotsky's objective prism survey. Figure 1 shows the data for all stars in the catalogues for which parallaxes had already been measured at the time of the survey, and hence had been mostly selected on grounds of large proper motion, whereas Figure 2 shows the data for stars measured subsequently at Van Vleck Observatory and at Herstmonceux for which parallaxes had not been measured prior to the spectral survey. In both figures the straight line loci represent tangential velocities of 10, 20, and 50 km s^{-1}. In spite of the small number of stars in Figure 2, it is immediately clear that the relative proportions of stars with different total transverse velocieties is markedly different in the two selections. Taking the parallax range 0".04 to 0".10 as representative, the actual numbers are:

Transverse velocity (km s^{-1})	Figure 1 (Previous parallaxes)	Figure 2 (New parallaxes)
$\leqslant 10$	4	8
10–20	17	11
20–50	69	12
>50	50	1

Extropolation of small numbers is of course dangerous, but these figures are not inconsistent with the existence of a large number of K–M dwarfs with low velocities. That the bias is present among fainter stars also, is illustrated in Figure 3, which shows the same data for stars in the two catalogues of the 61-in. results for which $B-V>1.35$ which are presumably also M dwarfs and had generally been selected from Giclas' survey. Clearly some selection criterion independent of proper motion is essential in planning a parallax programme of faint stars on a telescope on which limited observing time is available. An obvious course would be to carry out a preliminary photometric survey in, say, R and I to find the red stars. Those with apparent magnitudes fainter than about $m_{pg}=12$ in high latitudes will most probably

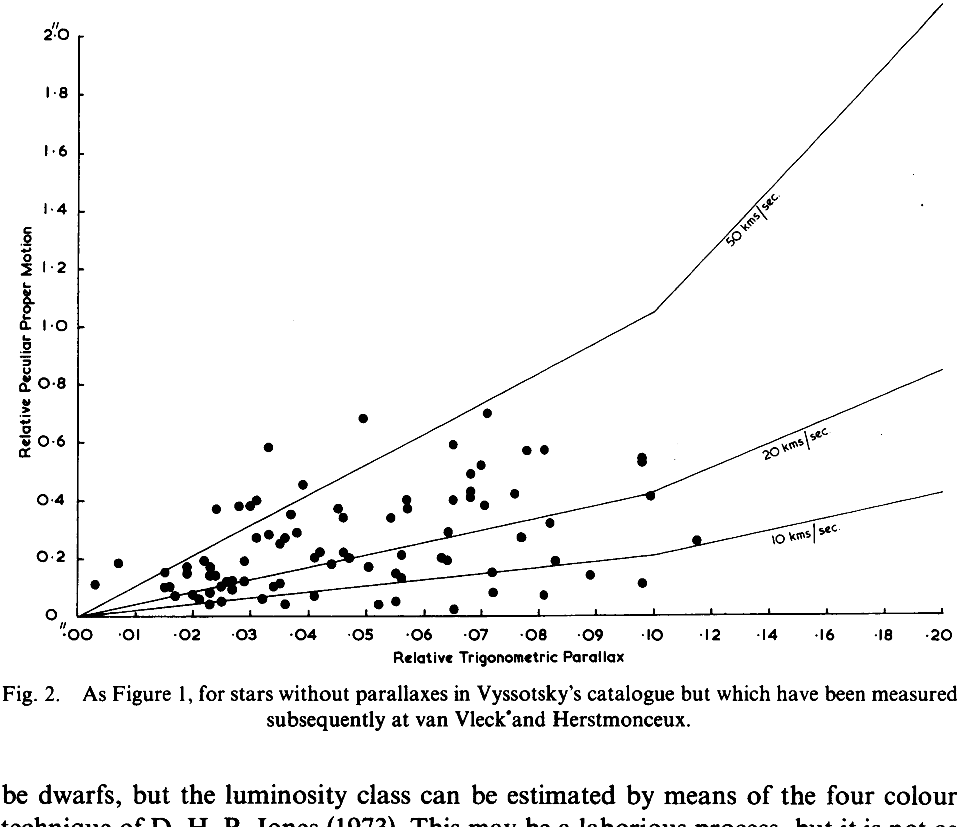

Fig. 2. As Figure 1, for stars without parallaxes in Vyssotsky's catalogue but which have been measured subsequently at van Vleck and Herstmonceux.

be dwarfs, but the luminosity class can be estimated by means of the four colour technique of D. H. P. Jones (1973). This may be a laborious process, but it is not as laborious as the accumulation of sufficient plates for a parallax determination.

Alternatively, objective prism techniques such as that used by Sanduleak (1964) in the north galactic pole region could be used to detect M stars to about $m_v=16.5$, or perhaps fainter on the large Schmidt telescopes.

White dwarfs and other sub-luminous stars are also obvious candidates for parallax work. Greenstein and Eggen (1966), in their contribution to the Flagstaff symposium, proposed a list of some 60 white dwarfs for which parallaxes were

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needed. Already about 25% of these have been observed with the 61-in. reflector. As Strand and Riddle (1970) have pointed out, several stars in the Giclas survey, with intermediate colours, which were put on the 61-in. programme as white dwarf suspects, have turned out to be high velocity stars with small parallaxes, and they urge that in future, such stars should also be first studied photometrically before parallax observations are started.

However, even after rigorous screening by photometric and spectroscopic observations, the lists of large proper motion stars by Giclas and, for the very faint stars, by Luyten, will eventually provide many suitable candidates for parallax observations.

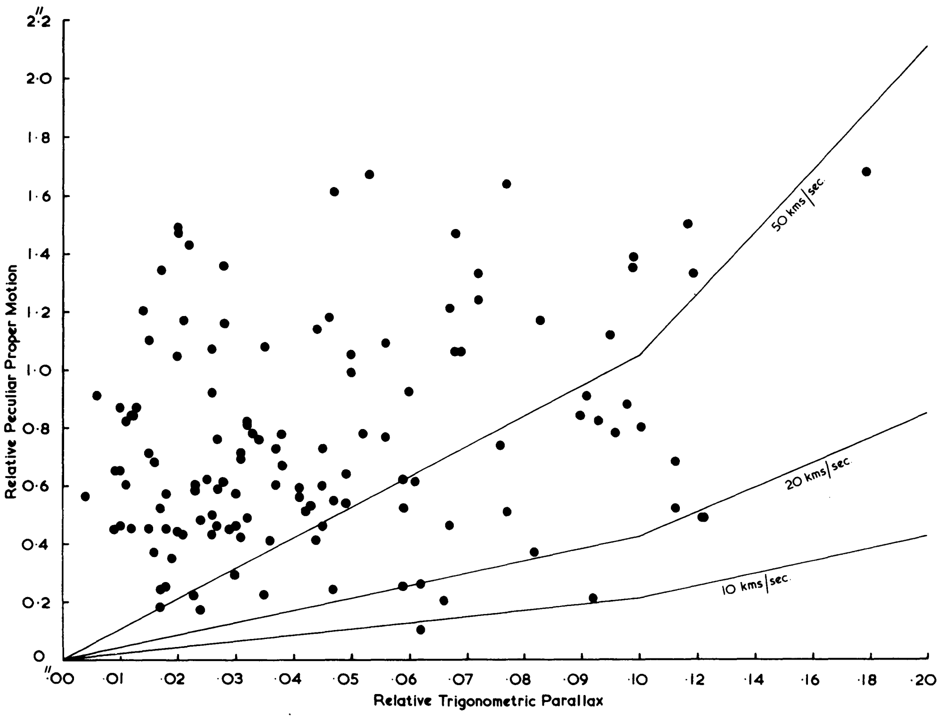

Fig. 3. As Figure 1, for red dwarfs in the first two catalogues of results from the 61-in. reflector.

The search for nearby stars has hitherto invariably been bedevilled by selection effects. However, with modern fast plate measuring techniques becoming available, an entirely new attack on the problem is possible. The area which can be photographed on a 14 in. sq plate, with the 48 in. Palomar Schmidt and the UK Schmidt on Siding Spring is about a thousandth of the whole celestial sphere. Even at present, more than a thousand stars are known to be within 20 pc of the Sun, or on the average about one per Schmidt field. It is not unreasonable to suppose that, with the extension of the magnitude limit to $m_{pg} = 18$ or 19, there may be between five and ten times as many nearby stars as are known already. We are therefore planning to carry out a parallax programme on a few fields, with the UK Schmidt, in which every star will be measured.

Even with a GALAXY machine this is a major undertaking, but is just feasible in high latitude fields. Assuming a density of 1000 stars per sq deg a parallax series could be measured in about three months. No doubt, faster measuring machine will become available in due course, so that it would be worthwhile to take plates on fields with a higher star density for future parallax and ultimately proper motion measurements. The aim would be to achieve a standard error of a single parallax of say 0ʺ01; a few spurious large parallaxes might then be expected on purely statistical grounds. But with a field of say 30000 stars there should be only two with errors four times the standard error, and it should be possible to pick out stars which are really within 20 pc.

With such a programme we will not only be able to find individual stars with large parallaxes, which can then be observed on a larger telescope, it will also be possible to measure statistical trigonometric parallaxes for groups of faint stars, such as M-dwarfs out to much larger distances.

3. Proper Motions

I would like to consider proper motion work in two categories, namely surveys for stars with large motions and investigations which demand high resolution. The former is well represented by Luyten's current survey. The whole northern sky is covered by Palomar Schmidt plates at two epochs and the labour is now that of blinking, aided by automatic measuring equipment, computation and publication. However, although the southern sky has been almost completely covered to $m_{pg} \simeq 16$ by the Bruce Proper Motion Survey, the search for large motions among fainter stars must await the completion and later repetition of the southern surveys now being undertaken on the ESO and UK Schmidt telescopes.

The second category, of high resolution proper motion work, includes such problems as cluster membership and studies of stellar population, density and kinematics from proper motion dispersions, which require relative proper motions of high accuracy, and also problems requiring absolute motions such as secular parallaxes and general studies of the systematic motions in the Galaxy.

The existence of the Palomar Survey plates, or, for practical purposes, glass negative copies of them, ensures that astrometric information on about the same scale as the 'Carte du Ciel' is potentially available at epoch around 1950, for objects brighter than $m_{pg}=21$. This material could be of great use in deriving proper motions of individual faint objects which may become of interest, and also for general kinematic studies. In particular it is in principle possible to refer such measurements directly to the system of external galaxies except in the zone of avoidance. The small scale of the Palomar survey is a disadvantage in high resolution work, nevertheless glass copies of the originals combined with modern plates have been used successfully to study proper motions in the region of the Pleiades by B. F. Jones (1973).

It seems evident that good plates taken at the fast foci of large telescopes on star clusters will always be potentially of value for membership studies of intrinsically faint stars, white dwarfs, lower main sequence stars and young stars contracting on to the main sequence. Van Maanen's cluster plates, taken at the Cassegrain focus of the Mount Wilson 60-in. have proved very useful down to about $m_{pg} = 17$, but there is an obvious need to extend the material to fainter magnitudes.

A field in which I am personally particularly interested at the present time is the study of stellar kinematics and space density from proper motions in the Selected Areas. It is very fortunate that old astrometric plates on the northern areas were taken at the Radcliffe Observatory at Oxford early in this century; these plates reach about $m_{pg} = 15$ and are providing very accurate material to this limit. However, there are several interesting questions at fainter magnitudes, for example the suspected high density of low velocity M-dwarfs near the Sun, which can only be answered by measuring proper motions. I would very much like to see an accumulation of astrometric plates down to say $m_{pg} = 20$ in the Selected Areas.

4. Conclusion

In this review I have suggested, for the purpose of discussion, various parallax and proper motion programmes, which require large telescopes. A great lead has been given by the USNO 61-in. reflector, but it is unrealistic to suggest that there should be many such telescopes primarily dedicated to astrometry. There is much more work to be done than can be undertaken on one telescope, and indeed there are problems at magnitudes beyond the practical limit of the 61-in. Astrometric specialists should therefore seek observing time on large reflectors for their own researches; but, such telescopes being multi-purpose, it is clear that careful planning and perhaps co-ordination of programmes is needed in order to make the optimum use of the time available.

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DISCUSSION

Bok: It is good to hear that Mr Murray will pay special attention to Kapteyn Selected Areas in his work on the wholesale attack for the determination of individual parallaxes in a given field. I recommend that Selected Area 141 near the South Galactic Pole be given special attention.

Luyten: I was very glad to hear that you intend to try the wholesale parallax method again. I think we could save you some time if you have forty parallax plates with 30000 stars each; we could process them all in about two days.

Gliese: I am pleased to learn that you will start a parallax programme near the South Galactic Pole with the 48 in. at Siding Spring. This will help to answer the question of the frequency of red dwarfs near the Sun. In this polar region Prof. Luyten has published several hundred red stars with proper motions $\mu \gtrsim 0\farcs2$ yr^{-1} which should be dwarfs. This is the only survey including stars fainter than $m_{pg} = 17$. The problem is that nothing is known about the true space velocity distribution of the very low-luminosity red dwarfs. Adopting the velocity distribution of the McCormick stars also for these objects I have computed the number of red dwarfs with $\mu \geqslant 0\farcs20$ yr^{-1} to be expected from Luyten's luminosity function. As the number of observed stars is somewhat smaller than expected, this preliminary estimate does not fit the assumption of an extremely large number of late dwarfs in the solar neighborhood. It even does not fit Miss Weistrop's results if the ratio of dMe to dM stars varies appreciably with luminosity.

Elsmore: May I ask Mr Murray, concerning the proper motion determinations with the Schmidt at Siding Spring, with what time intervals are successive plates taken?

Murray: I would want at least 15 years. Of course the accidental errors can be reduced by taking several plates at each epoch.

Bok: I hope that in the search work for candidates for parallax programs special attention may be given to the search of specific spectral groups by the use of variations upon the Hoag-Schroeder transmission grating approach with the grating placed near the Cassegrain Focus of an $f/8$ reflector. With the new 140 to 158 in. reflectors now getting into operation one may expect to obtain data for stars to $V = 18$ (or fainter) over areas of one square degree in the sky.

Strand: The 61 in. astrometric reflector has proven not only to be excellently useful to trigonometric parallaxes, but has also proven successful for such work as photoelectric observations of close binaries and for image tube work on galaxies and globular clusters.

Blanco: Near the Galactic Poles one can readily segregate dwarf M stars for parallax programmes by obtaining objective-prism plates with emulsions sensitive to near-infrared light. Dispersions of about 1000 to 2000 or more at the atmospheric 'A' band (λ7590), and unwidened spectra allow one to reach relatively faint stars. The spectra are not adequate for luminosity determinations, but of the stars one finds, the fainter ones are likely to be dwarfs, since a faint giant would have to be at intergalactic distances to be so observed.

Murray: I did measure proper motions for 21 of these stars, listed by Sanduleak from Warner and Swasey objective-prism plates. It is these motions which suggest the possible high density of M dwarfs near the Sun.

Eichhorn: It is well known that the 'acceleration' of the motion of a star is connected with its radial velocity and its parallax, beside the proper motion. Since we may expect that the accuracy of proper motion determinations and radial velocity determinations will increase, perhaps drastically, it will become possible to determine individual distances from measuring the changes in the proper motions of the stars. In order to do this, it might be wise to take plates of regions at intervals of, say 25 to 50 years. We must, of course, realise that this work may conceivably benefit generations of astrometrists that will live long after all of us will have been gone.