THE PALOMAR PROPER MOTION SURVEY

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Abstract. The present state of the Palomar Proper Motion Survey is described. Before the CDC automated-computerized plate scanner became operational in 1972, 153 plate pairs had been blinked, whereas since then 443 pairs have been machine processed. Of the remaining 350 fields, some 40 are probably beyond the capability of the present system due to excessive star density.

Some 21 000 new motions larger than 0."18 annually have been published. The accuracy of an individual motion is about $\pm 0.''016$ from a single machine-processed plate pair, as compared with $\pm 0.''025$ from hand measured plates.

There is an indication that the number of large motions per unit area increases with galactic latitude.

The National Geographic-Palomar Observatory Sky Survey consists of 936 pairs of blue and red plates taken with the 48-in. Schmidt telescope. They completely cover the sky from the North Pole to declination $-33°$ (1875), or 77% of the entire sky, and generally go down to about $m = 20$ (red) and 21.2 (blue). Since near this limit stars with sizable proper motions are not likely to be white it is obvious that for a proper motion survey the red plates must be repeated.

After a preliminary pilot program in 1958, the systematic Palomar Proper Motion Survey was begun in September 1962. First of all I should like to pay tribute to the Hale Observatories for their generosity in awarding guest-investigator privileges to me for the nine years 1962–1971. Altogether I have had twenty-five such assignments of dark-of-the-Moon nights with the 48-in. telescope, and this totals up to an equivalent of ten months use of this marvelous telescope. This enabled me to retake virtually all of the red plates, though some seventy of them were taken by the Observatory staff and loaned to me.

Financially, the program was made possible by continuous grants from the National Science Foundation for the next eleven years while the original acquisition of a complete set of duplicate negatives of the Survey was achieved through a grant from the Hill Family Foundation.

In 1965 I received a contract from the National Aeronautics and Space Administration, with Control Data Corporation as subcontractor to fabricate an automated-computerized plate scanner and measuring machine. This was completed in 1970, and to celebrate the event we held an IAU Colloquium on Proper Motions in Minneapolis in April of that year. Owing to various delays of different nature we didn't really get going with the processing of plates until January 1972. In the nineteen months since that time the machine has proved to be spectacularly and fantastically successful and since I personally had little or nothing to do with the design or the construction of it, I can say that, in my opinion, this plate scanner constitutes the most important addition to our astronomical instrumentarium in the last twenty-five years – with the exception of the big optical telescopes and radio dishes. I should like

Gliese, Murray, and Tucker, 'New Problems in Astrometry', 169–173.

to express my deep appreciation to the engineers of Control Data Corporation, and especially to James Newcomb, who was largely responsible for the hardware, and the optical system, and to Anton La Bonte who designed the software, and who guided us through the crucial periods of 'debugging', when the machine still exhibited various 'children's diseases'.

And so now, for the first time, I can really say – not what we are going to do, but what we actually have accomplished.

Between 1962 and 1971 we hand-blinked 153 pairs of plates on which we found 77000 proper motion stars. These have all been measured, and data for 62000 of them have been published. The remainder are ready for publication and should appear soon.

As of the day I left Minneapolis we had processed 443 pairs of plates with the machine, but this included ten pairs which had been previously hand-blinked.

At present the count thus stands as follows:

Hand-blinked	153	
Machine-processed	443	
(which includes	10	previously hand-blinked)
Number of fields processed	586	
Remaining	350	
	936	

Of the 350 pairs still remaining 117 can be processed now, and we hope to complete these by the end of 1973. The final 233 pairs are low-galactic latitude plates with very high star densities and these will require some changes in the software before they can be processed. We feel pretty confident that we can handle some 150 of them, and perhaps close to 200, but probably some 40 pairs are beyond the capabilities of the scanner at the moment.

Incidentally, since the number of star images appearing on the plates averages at least 80000 it means that in processing 443 pairs of plates we have determined x and y coordinates to one tenth of a micron for at least 70 million stars.

In publishing our data there is some difference in what we give as between the hand-blinked and the machine-processed plates. For the hand-blinked plates we give positions to $0^{m}.1$ in R.A. and $1'$ in Decl.; we give estimated photographic magnitudes and colors and motions to $0''.01$ and $1°$. For the machine-processed plates we have computer print-outs giving R.A. to $0^{s}.1$, Decl. to $1''$ (though we publish only to 1^{s} and $0'.1$), machine-determined red magnitudes and proper motions to $0''.001$ and $1°$. We now have such data for close to a quarter of a million stars with motions larger than $0''.09$ annually. Obviously, most of these data are of statistical interest only, but the stars with the larger motions merit individual attention. Since all our motions are relative and require corrections to render them absolute, and since in extreme cases this correction might amount to $0''.016$, I have arbitrarily selected $0''.18$ annually as the lower limit of motion for stars of individual interest – this to make sure that no

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motion larger than 0″.2 annually would be overlooked. Thus, after the first print-out has been obtained, we run off a second one which lists, first, all motions larger than 0″.18 annually, and, second all motions between 0″.18 and 0″.09. For every star in the first list I personally check the motion and estimate the photographic magnitude and the color from the blue and red plates.

These data are published as rapidly as possible, and to date we have published about 14000 new motions larger than 0″.18 which, together with the hand-blinked plates gives us some 21000 new motions larger than 0″.18 annually from the Palomar plates alone. This is more than twice as many as have been published by all other proper motion surveys together – except of course, for the Bruce Survey. When the entire Survey has been completed we hope to publish a catalogue of more than 50000 stars with motions larger than 0″.2 annually. We now also have more than 1000 new motions larger than 0″.5 annually from the Palomar plates alone, and another 1000 low-luminosity stars from the machine-processed plates. Further we have another 1500 new white dwarfs, for a total of some 4500, and 1600 new double stars with common proper motion, bringing our total to 4700, and these include some 250 binaries with one degenerate component, about ten with both components degenerate, and two with both components virtually identical white dwarfs. Among these 1600 are a few triples but these amount to fewer than one percent – and to-date we have not yet found even one genuine quadruple and certainly no new moving clusters.

It is not feasible to check individually the more than 200000 smaller motions, which possess mainly statistical value. The data for these will probably not be published in book-form, but will be provided to, and made available at the NASA Data Center at Greenbelt Maryland, either on microfilm, or on magnetic tape, or both. For all of these stars we shall also provide a Quality-index-rank, based on several quality indices devised by La Bonte which depend on the roundness of the image and several other factors, and we shall provide statistical probabilities for and against the reality of the motions of any given quality rank. For these stars we have only machine-determined red magnitudes and no colors.

Two further questions need to be answered viz. how complete is our survey, and what is the accuracy of the motions. We have no real data on the completeness as yet – only guesses. We know, e.g. that the computer rejects double stars, especially in the 4–10″ separation range when the components are nearly equal, because the images are not round. We have also programmed out all motions larger than 2″.5 annually and most stars with images larger than 250 μ diameter because of the uncertainties in the reconstruction of the image-centers, though we need some of these, as SAO stars, for the determination of celestial positions. Our present guess is that for motions between 0″.2 and 2″.5 annually we are at least 90% complete for stars brighter than 18 (red) but we do not really know whether possible, and occasional mal-functioning of the machine can reduce this drastically in some areas.

As to the accuracy we have some real data here. The hand-blinked, and hand-measured plates give motions with a mean error of about 0″.025 – this is determined from overlaps, and by comparison with previous Bruce motions. For the machine-processed plates we find, from overlaps between adjacent plates, that the rms error for a motion measured on a single pair of plates is about 0".016 for stars fainter than 12.5 (red), if the plate interval is 11 years or more. For brighter stars the errors are undoubtedly larger, and this is also true in the few instances where we were forced to process plates with intervals much shorter than 11 years.

From the machine-processed plates there emerges a definite indication that the number of large motions per unit area decreases markedly as we go from the galactic poles to lower galactic latitudes. It is, of course, conceivable that, as we go to lower latitudes, and higher star-densities our machine processing becomes progressively more incomplete. However, within the range of magnitude and motion accepted by the computer we seem to pick up roughly the same percentage of known motions and I am inclined, therefore, to accept this decrease in the frequency of motions with latitude as at least partially real.

Finally, a few comments on the first large area which has been completely processed, viz. the region of the South Galactic Pole. As boundaries we took 22^h and 3^h40^m in R.A. and $+4°$ to the southern plate edge – but this varies from $-32°53'$ to $-32°42'$ (1950) because of precession. Within this area, which totals some 3000 sq deg or 0.07 of the sky we list a total of 6970 stars from all sources, brighter than 21.5 *pg* and with motions larger than 0".18 annually. Of these, 5900, or 86% were found in the Bruce or Palomar Surveys. Because of this large number of stars in a restricted area it has become possible, for the first time, to analyze the magnitude distribution for groups of stars with total proper motions between very narrow limits, which means, stars which are statistically at the same distance. In this way, then, one could obtain a new and independent check on where the maximum of the luminosity function lies. The details are given in the publication on the South Galactic Pole, and here I need only mention the result which comes to:

Maximum of the luminosity function lies at $M = +15.4$ *pg*.

We hope to do the same for the North Galactic Pole region and here we are not limited in declination to 33° as we were at the South Galactic Pole, and we expect to analyze the entire area between 10^h and 15^h40^m, and $-4°$ and $+57°$ or about 4400 sq deg or 0.107 of the sky. This region is covered by 130 plates all of which have now been hand-blinked or machine processed, and we expect to make up a final catalogue of some 10000 stars with motions larger than 0".18 annually and brighter than 21.5 *pg*, for all of which we shall have colors. We hope, also, to obtain statistical information on a further 50000 stars with motions between 0".18 and 0".09 but we shall have only red magnitudes and no colors for the majority of these.

DISCUSSION

Klock: To what precisions may the magnitude be determined by your machine?

Luyten: The repeatability of the machine measurement on one plate gives a mean error of about $0^m.15$ – on overlaps of different plates it is probably a little larger than $0^m.2$.

Franz: How close can the images of two faint stars be on a Palomar Schmidt plate and still be measured separately with normal accuracy?

Luyten: This is really the main flaw in our present procedure. Double stars with equal components and separations of 4″–10″ are likely to be rejected by the computer but more narrow and wider doubles are generally accepted. Doubles with a large magnitude difference generally are accepted as a single star.

Van Herk: Is the number of stars with large proper motions increasing from the galactic plane towards the poles?

Luyten: Definitely – the only reservation I have is that possibly, in the lower galactic latitudes where the star-density is greater, the machine misses more proper motion stars. However the percentage of known proper motion stars which the machine is expected to pick up appears to be the same in high as in low latitudes.

Eichhorn: This machine is obviously an extremely useful piece of equipment, and potentially of enormous value for photographic astrometry. Can you comment on the future of the machine, in particular, make a statement as to whether there are any plans to deposit the machine – at least after the termination of your project – at a place where it would be accessible to other qualified observers, at least in the U.S.?

Luyten: If all goes well we expect to finish the processing of all high latitude plates this calendar year. The high-density low-latitude plates will require changes in the software, and this may take a year or more. But we should be completely finished sometime in 1975 and personally I should welcome applications for the use of the machine. It is an extremely versatile instrument and it is not expensive to operate

Fricke: Could Dr Luyten tell us something about the faint end of his improved luminosity function, in particular, to what absolute magnitude limit is the function reliably known in his opinion?

Luyten: I have only statistical evidence, as there are no parallaxes. The faintest star we have found is 20.8 m_{pg} with a motion of 1″.77. I think it is safe to say that down to absolute magnitude 17 m_{pg} we are reasonably sure, at 18 we are getting incomplete and at 19 we end.