advantage that in observing some stars of about the eighth magnitude, all stars of the eighth magnitude in that part of the sky are simultaneously and equally well observed and their positions can be measured and reduced as required. The accuracy of the observations is that inherent in the photographic plate and if this accuracy is not achieved by the first set of reductions, there is no reason why the reductions should not be repeated until it is.

These considerations are especially relevant

to the southern hemisphere where transit circles and observers are relatively few. For this hemisphere, the photographic method has the still greater advantage that, though the plates have to be taken south of the equator, they can be measured and reduced north of it where more adequate man power, automatic calculating machines and possibly also automatic measuring machines are to be found.

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SOME ASPECTS OF THE LICK PROPER MOTION PROGRAM

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Abstract. The Lick program of determination of stellar proper motions with respect to the extragalactic nebulae is discussed. The importance of measuring the stars at three levels of photographic magnitudes, approximately 8th, 12th and 16th, is pointed out. Approximately 25 stars at each magnitude level and 50 extragalactic nebulae are considered adequate for measurement on each $6^\circ \times 6^\circ$ plate. Some criteria are discussed for the selection of the stars to be measured. The proposed minimum interval of epochs is 20 years; a limited number of plates, however, could profitably be repeated with an epoch difference of 10 years.

The first set of plates taken with the 20-inch Carnegie astrograph, for the Lick proper motion program,^{1,2} has practically been completed by C. D. Shane and C. A. Wirtanen. Some preliminary results on the probable accuracy have also been obtained.³ The next immediate work is to proceed with a full investigation of the errors expected to be significant and to make detailed plans for future work. These plans depend upon the objectives of the program, and they involve the interval between the epochs of observations, the selection of objects to be measured, and the methods of measurement and of reduction of the plates. The purpose of this paper is to present a general outline of future work on this program.

Objectives of the program. These objectives, due to W. H. Wright,¹ are, first, the determination of stellar proper motions with reference to the extragalactic nebulae, and second, the evaluation of the precessional constant. In this paper these two objectives are reconsidered and some additional proposals are introduced.

The excellent astrometric quality of the Lick plates suggest that they may be used not only to determine proper motions referred to nebulae, but also to obtain accurate star positions. For reasons already given,⁴ stars on these plates have to be measured at three levels of photographic magnitude, approximately the 8th, 12th, and 16th.

Since stars of the 8th magnitude can be observed with meridian-circles, they should make it possible to build an inertial system of coordinates with reference to the extragalactic nebulae. Correction of the astronomical constants within the solar system, particularly of the precession constant, would result from a discussion of such material. These stars would also serve as proper-motion references in Hubble's zone of avoidance for nebulae, after the system of proper motions of the meridian-circle catalogues had been referred to the extragalactic nebulae from observations made outside the zone of avoidance.

Stars of about 12th magnitude may be of interest as a reference frame for photographic astrometry, because at the present time no reliable system for accurate positions exists at this level of brightness. These stars also could serve as references for objects down to the 16th magnitude, if a suitable objective grating is used. The proper motions of these stars would also be of the greatest importance, and they would be independently referred to the nebulae outside the zone of avoidance; the motions within the zone of avoidance, and all accurate positions, would rest upon those of the meridian-circle stars.

The measurement of faint stars around the 16th magnitude was not included in the original program. Since the proper motions of faint stars

are of great value in stellar statistics, the possibility of measuring these stars should be considered.

The faintest stars that can reliably be measured on the Lick plates are those of about 17.5 photographic magnitude. Almost all present information on stellar motions, however, comes from much brighter stars, and the importance of extending measurements to magnitude 17.5 may be evaluated from the following considerations:

(1) Information can be gathered from distant regions of the galaxy. With an expected mean distance of over 2 kpc for these faint stars, there is an opportunity to reach beyond the region of the maximum circular velocity. The theoretical model by J. H. Oort⁵ indicates a peak for the velocity curve at about 1.7 kpc from the sun toward the galactic center. Oort's model would give a difference of the order of 0".002 per year between the "normal" systematic motions of the nearby stars and those at a distance of 2.5 kpc toward the galactic center. The circular velocity curve obtained by N. U. Mayall⁶ from the radial velocities of the galactic Cepheids on the assumption that $R_{\odot} = 9$ kpc and $\Theta_{\odot} = 280$ km/sec would produce a difference in proper motions of 0".006. In either case differences of this order could be detected.

(2) The small random proper motions of distant stars would be insignificant in studying the systematic motions, particularly the rotation of the galaxy.

(3) The small secular parallaxes would eliminate possible spurious rotational effects due to the different mean parallaxes in different regions of the sky.⁷

(4) Information on motions of low-luminosity stars in the vicinity of the sun could be obtained.

While the foregoing considerations may justify the measurement of the faint stars for their proper motions, the accurate positions of these stars may be of less importance. If, however, the rectangular coordinates are measured, as has been planned, then they could be published together with the corresponding plate constants, since the latter would be determined for obtaining the positions of the brighter stars.

Interval between the epochs of observations. The time interval is determined by the accuracy desired. Fifty nebulae on each plate would define the reference frame with a probable error of $\pm 0".02$ in a comparison of two plates. This ac-

curacy makes it possible to compare two positions of a star of the 8th magnitude, with reference to the frame of the nebulae, with a probable error of $\pm 0".10$. Smaller errors are to be expected for the fainter stars.^{3,4} In 25 years individual stellar proper motions could be obtained with a probable error of $\pm 0".004$. This value is of the order of the average probable errors of proper motions in the GC and N30,⁸ but larger than the average probable errors in the FK3. In view of the work to be put into the repetition of the plates and into the measurement and reduction of them, the photography of the whole second set of the plates does not seem advisable before at least 20 years, i.e. before 1967. This time interval does not, however, apply to a partial repetition of photographs. Some systematic motions may be determined with sufficient accuracy from limited material in a much shorter time.

Let us assume that 200 fields, properly distributed, will be rephotographed after 10 years, i.e. during 1957 to 1963, with the main objective to determine the constants of galactic rotation, and that 25 stars of magnitude 12 to 13 will be measured in each field. Since two images of each star of this group will be measured on each plate for bridging the gap in magnitude between the nebulae and the bright stars, the expected probable error in position comparison for these stars is of the order $\pm 0".07$, which results in a precision of $\pm 0.07/10\sqrt{200 \times 25} = \pm 0".0001$ for the astronomical constants involved. Since the mean random motion for this group of stars should not exceed $\pm 0".01$ per annum, and if this number is treated like the mean error, the corresponding probable error for the same constants would again be of the order of $\pm 0".0001$. Both errors combined would give a probable error for the galactic constants of less than $\pm 0".0002$, which is about half the amount of the present error. Similar conclusions can be drawn from measurements of the faint stars. The bright stars would make it possible to evaluate the constant of precession with the accuracy of the present determinations, and to give an independent check.

Finally, such a short-term partial repetition would be invaluable in showing how the full second epoch set of plates should be treated as regards measurement and reduction. Therefore a limited number of fields could profitably be repeated as early as 1957.

Selection of stars to be measured. The selection of the stars is the most important part in plan-

ning the future work, and it should be made in cooperation with representatives from various fields of astronomy in order to achieve the greatest benefit from the effort put into the program. Although this section outlines in general terms a possible selection of stars, the detailed planning should be postponed until the matter has been discussed with all interested parties.

Since the importance of relating the Lick program to meridian-circle observations appears to be beyond question, the selection of the bright stars should be done in cooperation with the meridian-circle observers.

Various criteria have been used in the selection of stars for meridian observations intended to be related to the extragalactic nebulae. A Russian list of stars,⁹ related to the Russian program of observations of nebulae,¹⁰ was compiled with stars mainly of late spectral types.¹¹ Although some statistical considerations were mentioned, apparently the main reason for this selection was to have stars faint photographically and still bright enough for meridian circles. Unfortunately, these stars are not measurable on the Lick plates because they are between the magnitude levels of the bright and the intermediate stars.⁴

The Washington lists include stars in the visual magnitude range from 5.5 to 8.5, with favorable observational histories, and with a uniform spacing of 75 stars per 100 square degrees.¹² Although the first Washington list, from $\delta = +50^\circ$ to $+90^\circ$, was made before these criteria were formulated, it happens to satisfy them. The second list, from $\delta = +35^\circ$ to $+50^\circ$, has been made in accordance with these criteria. Both lists were kindly sent by F. P. Scott to the Lick Observatory, and a sample examination of these lists was made to find their relationship to the astrograph program. The findings, reported to Washington, show that an average of 13 to 14 stars in these lists can be measured on a $5^\circ \times 5^\circ$ field of the Lick plates. The safe limits of photographic magnitude for measurability are 7.2 to 8.2. The distribution of the measurable stars is not always entirely satisfactory.

The third Washington list, south from $\delta = +35^\circ$, is being made up with an effort to select the stars within the magnitude limits mentioned above. When this third list is available, it will be examined at Lick to see whether it and the two earlier lists might be supplemented with some additional stars to improve the distribution of the stars measurable on the astrograph plates.*

So far as the sample survey of the Lick plates shows, and the desired accuracy indicates, the selection of brights stars should attempt to include 15 stars in a $5^\circ \times 5^\circ$ field, with a minimum of 3 stars in each quadrant of the plates. This criterion is not compatible with the limitation to certain spectral classes because of the scarcity of suitable stars in some regions. Since the examination of the plates indicates that the quality of the images deteriorates appreciably beyond the $5^\circ \times 5^\circ$ field, the effect upon the reliability of the measurements over the full field should be investigated. For this reason, the field $5^\circ \times 5^\circ$ was taken as a safety measure, although use of the whole field, $6^\circ \times 6^\circ$, of the Lick plates would make possible the measurement of more stars and an improvement in their distribution.

Measurement of stars of intermediate brightness around the 12th photographic magnitude was originally considered as a regrettable necessity to bridge the magnitude gap between the nebulae and the bright stars. Wright, however, points out: "Thus there should eventually become available a group of stars of approximately the 11th magnitude, quite uniformly distributed over the sky (barring the zone of avoidance) at the rate of perhaps one per square degree, with especially well determined proper motions. The reduction of these measurements could be effected when the data were desired."

The objectives of the program, as outlined in a previous section, suggest that the reductions should be effected as soon as the measurements are available. The requirements for the desired accuracy indicate that the number of stars to be measured is the same as that originally proposed by Wright, i.e. one star per square degree. This spacing would give a total of almost 29,000 stars north of $\delta = -23^\circ$, which, of course, includes part of the zone of avoidance.

Since these stars of medium brightness will serve to bridge the magnitude gap between bright stars and nebulae, and they may also form a position reference for photographic astrometry, their uniform distribution on the plates is essential and easily achieved because of

* Since the Conference approved the proposal of Dr. O. Heckmann to make a third AG catalogue and to use the Washington List as positional reference for the photographs, the AG catalogues may serve as a homogeneous bridge between the Lick plates and the meridian-circle observations. The same considerations apply to the southern hemisphere if the Yale southern zones are repeated. Therefore there seems to be little need of a close relationship between the Lick program and the meridian-circle lists.

their abundance. If the uniformity in positional distribution is the only criterion, however, there is a probability of favoring G-type stars, especially in high galactic latitudes. Statistical considerations may require a different distribution of spectral types; for instance, a uniform distribution in spectral classification could also be attempted. A survey of stars in the Selected Areas on the Lick plates shows that this end can partly be achieved if the selection is started from both ends of the spectral scale, with the positional distribution adjusted as needed by taking more G-type stars. If the spectral classes are not available, the colors could be used instead, and the Palomar 48-inch Schmidt photographs will be an excellent source for such data.

While some stars of special types could be included if their proper motions are needed, their number is likely to be too small to result in automatic inclusion by the general criteria described above. As previously stated, and as now emphasized, the final selection of stars to be measured should be made in cooperation with astronomers from various fields of interest.

Since the faint stars down to photographic magnitude 17.5 may be of no significant importance in astrometry, they could be selected entirely on the basis of stellar statistics. As a general rule, an average of one star per square degree could be used, with a higher density of stars in some critical fields and a lower one in average regions. Since the information on faint stars is very scarce at present, a uniform distribution in their positions as well as in their colors should be an objective for the proposed limited repetition of photographs taken during 1957 to 1963. The results obtained from these plates, and the additional information from other fields of astronomy that may become available by the time of the final repetition, may indicate more clearly how to select the stars on the complete second-epoch set of plates.

The selection of nebulae for good measurability has to be left entirely to the discretion of

the person measuring the plates. The requirement of the uniform positional distribution is obvious, and the number of nebulae should be about 50 on each plate. In low galactic latitudes, where this number cannot be obtained, all the suitable nebulae should be measured.

Measurement and reduction of the plates. The general principles involved in the design of a measuring engine have been considered at the Lick Observatory. The experience with the electronic engine at the Watson Scientific Computing Laboratory as well as with a smaller one now being designed for the Lick Observatory may introduce some alterations in these principles.

The methods of reduction of large-field photographs have become well established by the work at the Yale University Observatory. Any modifications, if necessary, can be made after all the questions concerning the program are finally settled. Special care has to be exercised in the determination of positions, since they are subject to systematic effects, which, fortunately, may automatically be eliminated in most cases from the differential determinations of the proper motions.

REFERENCES

1. W. H. Wright, *Proc. Am. Phil. Soc.* **94**, 1, 1950.
2. C. D. Shane, *Pub. A.S.P.* **59**, 182, 1947.
3. C. D. Shane and S. Vasilevskis, Symposium on Astrometric Problems of Faint Stars, I.A.U. meeting in Rome, Sept., 1952.
4. S. Vasilevskis, *A.J.* **58**, 126, 1953; *Lick Obs. Bull.* **20**, 79, 1953.
5. *Ap. J.* **116**, 233, 1952.
6. *Publ. Obs. Univ. Michigan* **10**, 19, 1951.
7. J. H. Oort, *Bull. Astr.* **15**, 217, 1950 = *Colloq. Intern. Centre Nat. Rech. Sc.* No. 25, 55, 1950.
8. H. R. Morgan, *A.J.* **54**, 145, 1949.
9. Sternberg State Astr. Inst., *Catalogue of Faint Stars, List of Stars -30° to $+90^{\circ}$* , Parts 1 and 2, 1951.
10. Sternberg State Astr. Inst., *Catalogue of Faint Stars, List of Selected Areas with Extragalactic Nebulae*, 1952.
11. M. S. Zverev, *A.J. USSR* **17**, No. 5, 54, 1940.
12. I.A.U. Rome meeting, Sept., 1952, Draft Reports.

Lick Observatory,
University of California,
Mt. Hamilton, Calif.,
1953 September.