THE LICK NORTHERN PROPER MOTION PROGRAM

Robert B. Hanson
Lick Observatory, University of California
Santa Cruz, California 95064, U.S.A.

ABSTRACT. This paper reviews the Lick Northern Proper Motion (NPM) program, describing its goals, organization, and methods, summarizing its progress, and outlining the work remaining for the future. The first phase of the NPM program (outside the Milky Way) is now nearing completion. A detailed description of the NPM program has been given by Klemola, Jones, and Hanson (1987). Recent results using the NPM data in a study of solar motion and galactic rotation are presented in a separate paper in this Symposium.

1. INTRODUCTION

The NPM program, which has been underway at Lick Observatory for some 40 years, is a mammoth photographic survey of the northern sky; the chief goal is to measure absolute stellar proper motions with respect to an extragalactic reference frame, for some 300,000 stars in the blue magnitude range 9 – 18, selected in 1,246 fields covering the whole sky north of $-23°$. The arrangement of the NPM fields is given in Table I. The program includes a wide range of objects chosen for their astrophysical interest, a kinematically unbiased selection of stars for statistical studies, and other stars and galaxies used for astrometric and photometric reductions.

The southern hemisphere counterpart of the Lick NPM program is the Yale Southern Proper Motion (SPM) program (van Altena *et al.* 1986; López, Lee, and van Altena 1986). The SPM program was initiated by Brouwer (1962, 1965) at the Yale University Observatory in cooperation with the National University of San Juan, Argentina. The SPM photographs are taken with a 51 cm double astrograph at El Leoncito, Argentina. First-epoch photography, done mainly from 1966 to 1974, covers the sky south of declination $-17°$. Some more northerly fields were added later for a more direct comparison of the SPM with the Lick NPM program. Second-epoch photography began in 1986. Together the two programs will provide absolute proper motions over the whole sky.

The history of the NPM program has been reviewed by Vasilevskis (1973). Only a few highlights will be given here. The first epoch of photography, with the blue lens of the Lick 51 cm (20 in) Carnegie double astrograph, was carried out under the direction of C. D. Shane between 1947 and 1954 (mean epoch 1950.07). Under the direction of S. Vasilevskis, the yellow lens was installed in 1962, the Gaertner automatic measuring system was put into operation in 1966, and a pilot program (Klemola, Vasilevskis, Shane, and Wirtanen 1971) was done to test

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second-epoch procedures. Analyses for correction to precession, solar motion and galactic rotation were made based on the motions determined in the pilot program (Vasilevskis and Klemola 1971; Klemola and Vasilevskis 1971). The main second epoch of photography was begun in 1969; it is now 97% complete; all the declination zones from $-15°$ to $+90°$ are finished (mean epoch 1976.51). The NPM program is now under the direction of B.F. Jones and A. R. Klemola.

Plate surveys, measurements, and reductions for the NPM program are divided into two phases. The first phase, covering the sky away from the Milky Way (some 72% of the northern sky), is nearing completion. Surveys and measurements have been completed from 0° to +90°. Reductions for absolute proper motions and positions have been completed from 0° to +65°. The second phase of the NPM program, covering the remaining 28% of the northern sky in or near the Milky Way, remains for the future.

Table I. Distribution of Lick NPM fields: faint stars (mag. 15-17).

Zone	No. Fields	Outside Milky Way No.	Outside Milky Way %	Date Measured	Faint Stars per Field
+90	1	1	100	1987	144
+85	10	10	100	1987	144
+80	16	15	94	1986	144
+75	24	16	67	1985	144
+70	30	18	60	1980	144
+65	36	21	58	1980	144
+60	40	24	60	1980	144
+55	45	27	60	1979	144
+50	60	45	75	1979	144
+45	60	40	67	1979	144
+40	60	45	75	1977	72
+35	72	53	74	1975	72
+30	72	54	75	1976	72
+25	72	55	76	1975	72
+20	72	56	78	1977	72
+15	72	54	75	1978	72
+10	72	51	71	1978	144
+05	72	50	69	1979	144
00	72	55	76	1976	72
–05	72	53	74	—	144
–10	72	52	72	—	144
–15	72	54	75	—	144
–20	72	54	75	—	144
Totals	1246	903	72	—	--

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2. OBSERVATIONS, PLATE SURVEYS, AND MEASUREMENTS

Details of the photographic observations, the selection of objects at the Lick Survey machine, and the automatic measurement of the NPM plates are given by Klemola, Jones, and Hanson (1987).

A 17×17 inch plate taken with the 51 cm double astrograph covers a field of 6° × 6° at a scale of 55.″14/mm. Blue plates at both epochs use Kodak 103aO emulsion (no filter), while yellow second-epoch plates use Kodak 103aG emulsion (GG 14 filter). Both plates are exposed simultaneously, with an exposure of two hours (System I) and an offset exposure (System II) of 1.0 minute (1.5 minutes at second epoch), displaced about one arcminute eastward. This combination of long and short exposures, together with the use of parallel-wire objective gratings, allows measurement of stars from magnitude 9 to 18 on the blue plates and magnitude 5 to 18 on the yellow.

Objects included in the NPM program are selected for each field at the Gaertner blink survey machine, and their approximate coordinates are used as input to the Gaertner automatic measuring machine. The choice of stars and galaxies for inclusion in the NPM program will be discussed in Sec. 3.

After each NPM field has been surveyed, the plates are measured on the Gaertner Automatic Measuring machine, which has been extensively upgraded during the course of the NPM program (Klemola, Robinson, and Vasilevskis 1974; Klemola, Jones, and Hanson 1987). For each image measured, precise (X, Y) coordinates and a photometric measure (P) are obtained.

3. SELECTION OF PROGRAM STARS AND GALAXIES

The NPM survey selects a variety of objects for measurement. Some are of individual interest, others are needed for the NPM data reductions, and some are chosen at random.

Galaxies are measured in the NPM program for the fundamental purpose of providing the absolute zero point of proper motion in each field. The galaxies selected for measurement lie in the blue magnitude range 14–18, with most in the fainter half between 16–18. Typically, from 50 up to a limit of 100 galaxies are selected in each 6° × 6° NPM field. The mean number of galaxies per field is about 80.

About 50 positional reference stars are selected in each field for the transformation of the measured rectangular coordinates into equatorial coordinates. For the NPM fields in the declination zones 0° to +90°, the AGK3 catalog (Dieckvoss *et al.* 1975) was used. For the NPM fields at −5° and southward, the Perth70 catalog (Høg and von der Heide 1976) will be used.

Faint anonymous stars in the blue magnitude range 15–17 serve several important functions in the NPM program. First, they are used as the reference stars for the derivation of relative proper motions in each field. Second, they are used in the photometric reductions. Third, the faint reference stars provide tests of the precision of the NPM proper motions. Finally, the eventual total of nearly 100,000 NPM faint stars will provide a large kinematically unbiased sample for use in galactic structure studies. Either 72 or 144 faint anonymous stars are selected in each NPM field (*cf.* Table I).

Stars of blue magnitude 10–13 ("bridge stars") provide the linkage between the long exposure (System I), in which the reference galaxies and faint stars are

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measured, and the short exposure (System II), in which the brighter stars are measured. To ensure an adequate number and uniform distribution of bridge stars, some 15 to 30 anonymous stars in this magnitude range are added to the survey in each NPM field.

Representative samples of stars (about 20–50, to magnitude 17) are chosen at random in each of the Kapteyn Selected Areas covered by the NPM program, in order to provide additional absolute proper motions for use in galactic studies in these Areas. The Pulkovo program (Fatchikhin 1974) provides absolute proper motions for 14,600 stars in 85 fields. We have selected an average of 50 of these stars for measurement in each of 73 fields included in the Pulkovo program.

Besides measuring stars needed for astrometric or photometric purposes, the NPM program will determine proper motions for large numbers of stars (and other objects), of many different types, which are of more general astronomical interest. Table II lists the types of "special stars" that are included in the NPM program. To select the NPM "special stars", some 50 astronomical publications have been systematically searched by A. R. Klemola for objects of probable astrophysical or kinematical interest, covering the blue magnitude range from 7 to 18, north of declination −33°. The resulting Lick *Input Catalog of Special Stars* now contains over 70,000 entries in machine readable form.

Table II. Some classes of objects included in the NPM program.

Class Name (generally non-variable)	Class Name (variable)
Ap, Am stars	α CVn
Barium stars	β Cep
Carbon stars	Cepheids
CH-stars	δ Scu
Common proper motion stars	Eclipsing (all types)
Faint blue stars (objects)	Irregulars (all types)
Helium stars, hydrogen-deficient	Miras
Horizontal-branch stars	Nova, nova-like
Metal-deficient stars	R CBr
O-B stars	RR Lyr
Planetary nebulae (central stars)	RV Tau
Quasi-stellar objects	Semi-regulars
Red dwarf stars	U Gem
Red giant and subgiant stars	Unique
S-type stars	Unstudied variables
Subdwarfs (all types)	Z Cam
White dwarfs	
Wolf-Rayet stars	
Miscellaneous types	

4. ASTROMETRIC AND PHOTOMETRIC REDUCTIONS

The NPM reductions for positions, relative and absolute proper motions, and

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photographic photometry are described in great detail by Klemola, Jones, and Hanson (1987). Here we will only summarize the results of these reductions.

The astrometric reductions demonstrate the high precision of the NPM data, equaling the early predictions by Shane and Vasilevskis (1954). The precision of a position is on the order of 0.″06 for a star with one measured image. The zero-point error of the reduction using the AGK3 stars in each NPM field is on the order of 0.″05. Overlap tests find the RMS error of the NPM proper motion of an individual faint star ($15 < B < 17$) to be $\sigma_\mu = 0.''16/\mathrm{cent}/\Delta\mathrm{T}$, where ΔT is the epoch difference in centuries. For an epoch difference approaching 30 years, this corresponds to $\sigma_\mu = 0.''5/\mathrm{cent}$. The RMS error of the zero point of absolute proper motion, determined by galaxies in each field, is 0.″2/cent for a typical NPM field.

The photometric reductions give blue and yellow magnitudes for each NPM object. The precision is severely limited by the lack of photometric standards over the wide magnitude range covered by the Lick plates. The NPM B magnitudes are generally good to the $0.2 - 0.5$ mag level, and the $B - V$ colors at the $0.1 - 0.3$ mag level. The photometry is thus adequate for statistical use.

5. THE NPM CATALOG AND ITS APPLICATIONS

The final results of the NPM program will be published as the *Lick Northern Proper Motion (NPM) Catalog*, in both machine-readable and hard-copy form. This catalog is now in the initial stages of preparation; when completed it will contain some 300,000 stars, selected for statistical or astrophysical purposes, over the blue magnitude range 9–18. The proper motions are referred to some 70,000 galaxies. Precise positions and BV photographic photometry will also be published.

There is much work remaining before the full *Lick NPM Catalog* will be completed. We anticipate publishing the catalog in two parts. The surveys, measurements, and reduction methods described by Klemola, Jones, and Hanson (1987) will form the basis for *Part I* of the *Lick NPM Catalog* (Klemola, Jones, and Hanson 1988), for the sky outside the Milky Way. Also included will be the southern NPM fields to $-20°$ declination, now being surveyed and measured. *Part II*, for the remaining fields at low galactic latitude, will appear in the more distant future, after that phase of the NPM program is completed. We expect to use data from the European astrometric satellite HIPPARCOS (Kovalevsky 1986) to aid in bridging the zone of avoidance; the measurement of the Milky Way fields thus awaits the completion of the HIPPARCOS Input Catalog (Turon-Lacarrieu and Réquième 1986), and the final reductions for the NPM Milky Way fields will not begin until the completion of the HIPPARCOS program.

Several major applications of the NPM data are planned or in progress. Hanson (1987) has used the first NPM results to study galactic rotation and solar motion. Other studies at Lick in the near future will investigate such topics as (1) galactic rotation as a function of galactocentric distance; (2) solar motion, galactic rotation, and stellar density as a function of distance from the galactic plane; (3) the kinematics and luminosity calibration of stars of various types (*e.g.*, the RR Lyr variables); (4) the corrections to the constants of precession; and (5) comparison of the NPM proper motions with the results from other programs. The *NPM Catalog* will serve as a valuable data base for many studies in galactic structure, stellar kinematics, and astrometry.

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Discussion:

KOVALEVSKY The comparison between the proper motion obtained by the survey with the proper motion of HIPPARCOS could provide a very important supplementary information to fix the HIPPARCOS system. Their method should be seriously envisaged.

HANSON Yes, we intend to make the comparison. However the range of apparent magnitude common to the Lick and HIPPARCOS programs is very limited, since we cannot measure accurate proper motion for stars brighter than B = 9. This is why we need to use the HIPPARCOS Input Catalogue to guarantee a useful sample of stars in common to bridge the zone of avoidance (Milky Way Fields) as well as to make an extensive comparison of the Lick and HIPPARCOS results.

TURON In the first version of the Input Catalogue there are already 13000 stars in common with the Lick Northern Proper Motion Program, considering only the AGK3 stars from the Lick Program.

WIELEN How many quasars are measurable on the Lick plates?

HANSON Very few, at least in the sense that we do not measure fainter than B 18. Fainter than this, the proper motion precision degrades rapidly. Quantitatively, the number per NPM field brighter than B = 18 would be on the order of 1 to 10 per field.

JASCHEK Could you say something about the percentage of stars at magnitude 16 which have proper motions larger than, say three times their errors?

Did you produce additions to the list of stars with large proper motions?

HANSON 1) At this stage we have not yet looked in detail at the individual motions. From the proper motion reduction, approximately 10% of the 16th magnitude stars have proper motions larger than three times their error.

2) The large majority of high proper motion stars in the Lick NPM Program are stars discovered previously by 16 other observers. The goal of the Lick program is to measure precise absolute proper motions for these stars

VAN ALTENA The southern extension of the Lick NPM is the Yale San Juan SPM at El Leoncito, Argentina. Our analysis of a low-region overlap near the south galactic pole yields an accuracy of $\pm$0.005/yr for a 20-year baseline. The accuracy is similar to the Lick NPM accuracy. In our case we were fortunate to have our first epoch plates taken both in the blue and visual regions. We are starting the second epoch now and hope to complete the observations during a ten-year period so that we can

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maintain an average 20-year baseline. Our selection of stars to measure will be aided by the work of the Lick astronomers and will also include stars from the CDS at Strasbourg and the HIPPARCOS Input Catalogue. Collaborating in this project are Carlos E. Lopez at the Observatorio Astronomical "Felix Aguilar" and Terrence Girard at Yale.

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