PROPER MOTIONS WITH RESPECT TO THE EXTRAGALACTIC REFERENCE FRAME

A. R. Klemola
Lick Observatory, Board of Studies in Astronomy and Astrophysics
University of California, Santa Cruz, California 95064 U.S.A.

ABSTRACT. The Lick proper motion program, one of several using galaxies as a reference frame, is summarized with a statement of work accomplished for the non-Milky Way sky. The problem of identifying relatively transparent regions at low galactic latitudes is discussed, with tabular results presented for 41 windows from the literature having observable galaxies. These fields may be helpful for attaching stellar proper motions directly to the extragalactic frame.

1. Introduction

The measurement of proper motions for galactic stars with respect to an inertial frame of reference is a long-sought goal of astrometry. The absence of readily observable representatives of an inertial system led early astrometrists to devise various well-known indirect approaches with results of various degrees of success. By the end of the second decade of this century, the extragalactic nature of the nebulae was finally becoming clear, as well as their value as essentially inertial reference points for astrometry.

During the 1930's two major undertakings were begun based on photography with wide-field astrographs. One was at the Lick Observatory, with a new 51-cm astrograph completed in 1941 but not fully operational until 1947 (Wright 1950). The other was the Pulkovo program based on existing normal astrographs at several institutions (Zverev 1940), following the first successful use of photography to measure stellar proper motions by Deutsch (1937). In 1964 a third entry to this group was the Yale-Columbia astrograph at Leoncito, Argentina, now functioning as a cooperative Yale and San Juan effort for the southern sky. The details of the various programs have been presented in numerous reports, including the broad summary by Vasilevskis (1973). Other participants involved with photographic astrometry of extragalactic frame include Kiev and groups using the Tautenberg Schmidt telescope. Details of each program are described best by members of each group.

A brief description of the Lick program is given, followed by a consideration of the low-galactic latitude zone, nominally too deficient in galaxies for direct attachment of proper motions to the extragalactic frame with astrographs. A survey of the literature for regions of low transparency (windows) is presented, many of which contain faint galaxies potentially useful for astrometry.

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2. Lick Northern Proper Motion (NPM) Program

The Lick NPM program has been described on numerous occasions over some 40 years, starting with the announcement of the commencement of work (Shane 1947) to the first major results (Klemola et al. 1987; Hanson 1987) and the most recent progress report (Klemola 1989). Its goal is the construction of a catalog of stellar positions and absolute proper motions, using galaxies as the reference frame, for the sky north of declination −23° (Wright 1950).

The NPM program, with 1246 fields each 6° x 6° photographed with the 51-cm double astrograph, consists of two parts (Fig. 1 in Klemola et al. 1987). The first part consists of the 903 fields outside the Milky Way, where measurements have been completed for 741 fields. Measurements are in progress for the remaining 162 fields. The second part, consisting of the Milky Way with 343 more fields, remains for future work.

Details of the observations, input catalogs, star selection, plate measurement and reductions are given in Klemola et al. (1987). The core of the NPM program lies in its two types of input catalogs, as these will govern the uses of the derived proper motions. One is the *Input Catalog of Catalog Stars (ICCS)*, a subset from the AGK3 for the sky north of declination −2.5° and a subset from the SAO south to −23°. These catalogs are used as reference stars for obtaining equatorial coordinates, with the AGK3 used also for intercomparison of proper motions for finding corrections to precession.

The other is the *Input Catalog of Special Stars (ICSS)*, with 109000 entries (including many duplicates) from 608 references located from systematic searches of the astronomical literature. The classes of selected objects cover the entire range encounterd in astrophysical studies (Table II in Klemola et al. 1987). The very strong concentration of many classes of stars towards the galactic plane means that proper motions for a major part of the *ICSS* will *not* become available until the completion of the Milky Way phase some years hence. The completion of the NPM program will also allow intercomparison of the Lick motions with numerous other astrometric catalogs for error studies (Klemola 1989).

First application of Lick proper motions to galactic dynamics was performed following completion of measurements and astrometric reductions for 617 fields for the sky from declination −3° to +68° (Hanson 1987). The results for solar motion and galactic motion, though still provisional until the completion of the non-Milky Way phase, clearly demonstrate the value of wide-field photographic astrometry for resolving central problems of galactic motions. Hanson (1987) found for the Oort constants: $A = +11.31 \pm 1.06$ and $B = -13.91 \pm 0.92$ km $s^{-1}kpc^{-1}$, interpreted as a nearly-flat galactic-rotation curve with local circular velocity near 200 km s^{-1}. Solar motion displayed a well-defined trend, starting with an apex near the standard position, using low-latitude stars, to apexes trending towards the direction of galactic rotation, using stars in increasingly higher latitude zones. For a *single* NPM field the absolute zero-point error in attaching proper motions to the extragalactic frame is $0\overset{''}{.}2$ $cent^{-1}$. The final overall systematic zero-point error from the entire NPM program for 903 fields with galaxies for almost 2/3 of the sky will be some small fraction of this.

3. Astrometry at Low Galactic Latitude

The great abundance of astrophysically interesting stars in the Milky Way makes this band extremely valuable for galactic studies. It provides the astrometrist with the strongest motivation for measuring accurate absolute proper motions to the faintest levels of apparent magnitude. An impediment to this goal is caused by the intervening galactic interstellar absorption. The present work is the systematic survey for "windows" of reduced absorption, which may be of use for astrometry.

3.1 PROBLEM OF BRIDGING THE MILKY WAY

Various options exist for obtaining stellar proper motions in the Milky Way zone, approaching an inertial reference frame to varying degrees of success. These include the use of calibrated statistical parallaxes (e.g. Stone 1978), second-order catalogs nominally on a fundamental system, like the AGK3 and SAO (on FK4) and new Heidelberg PPM (on FK5), and soon the Cape CPC2 (on FK5). The frame provided by stars from the fundamental catalog FK5 itself, and by low-latitude radio stars attached to the extragalactic frame, is normally too sparse for direct use in photography. For the future there is promise of optical interferometry linking wide intervals of the sky to high precision, a potentially valuable means of bridging the Milky Way with a suitably dense network of reference stars. A future *Hipparcos*-type program would be valuable. Without going into the relative merits of these methods, we consider here the possibilities of *direct* attachment of low-latitude stars to the extragalactic frame.

Proper motion programs with wide-field astrographs are in progress at several observatories (e.g. Kiev, Lick, Pulkovo, Tautenberg, Yale-San Juan). These make explicit use of faint galaxies for fixing proper motions to the inertial reference frame for the 70–80% of the sky lying outside the Milky Way. However, an important limitation to these programs is the reduced surface density of reference galaxies, even being totally absent over extensive areas at low galactic latitudes with strong interstellar absorption. This limitation is an artifact, arising from observations made in the usual optical domain, a limitation not shared for observations made in certain far-infrared wavelength windows and the radio region, which are relatively unaffected by the intervening galactic absorbing medium.

A study of the wavelength dependence of interstellar reddening demonstrates the advantage of observations made in the infrared domain, compared to usual blue- and visual-band photography. With *relative* absorption set at A_V = 1.00 mag. for the V-band (0.553 μm), we note $A_I = 0.46$ mag. in the I-band (0.90 μm), and $A_K = 0.11$ mag. in the K-band (2 μm) (Allen 1976). Since much precision astrometry currently is based on detectors, like the photographic plate and CCD devices operating in the optical to near infrared domain (up to 1 μm), this report will be oriented to this band with its possibilities and limitations

Bridging the Milky Way should be tied to the construction of a network of reference stars, spanning the entire observed range of apparent magnitude and colors. This catalog should have a surface density suitable for small-field detectors (e.g. CCD's). For $|b| \leq 10°$ there are almost 7200 deg^2, so that the size of such catalog would be numerous multiples of this.

3.2 BORDERS OF THE ZONE OF AVOIDANCE

The definition of the *border* of the zone of avoidance, a somewhat subjective concept, is operationally taken as the boundary where suitable reference galaxies for photographic astrometry become insufficient in surface density to permit proper motions to be attached to the extragalactic frame. This contrasts greatly with observations made with CCD's in essentially transparent high-latitude fields, where by magnitude B $\sim$ 23 the surface density of galaxies predominates over the stars. The borders lie between galactic latitudes 8° to 20°, as shown from galaxy counts by Hubble (1934), Mayall (1934), Shapley (1957), Steinlin (1962), and Shane and Wirtanen (1967). The so-called boundary depends on numerous factors, including aperture, field size, wavelength region, and others, contributing to the magnitude limit reached. The problem of image crowding by galactic stars is another factor. Deep photography with the large northern and southern Schmidt telescopes, reaching 2–4 magnitudes fainter than astrographs, would produce a more reduced boundary for the zone of avoidance. A still more radical picture emerges for observations made in the infrared and finally radio regions, where absorption effects finally become non-significant. This illustrates the qualifications needed in defining the edge of the zone of avoidance.

3.3. LOW-LATITUDE OPTICAL WINDOWS

Certain low-latitude regions are sufficiently transparent to reveal galaxies on deep photographic surveys. Other so-called windows are simply directions of low absorption only to some intermediate heliocentric distance, beyond which they become more or less opaque to galaxies lying beyond. A listing of 41 windows with observable galaxies is presented in Table 1 and shown in Fig. 1 as solid points. Published coordinates are converted to equinox 1950 and new galactic coordinates as needed. Some windows are poorly defined on the sky and need re-examination.

An additional 49 regions of relatively low absorption with no information about background galaxies are also plotted in Fig. 1 as open circles. Many of these deserve furthur study for possible detection of faint galaxies suitable for fixing the astrometric frame. Some cited regions overlap with others or are essentially identical. All are retained in this *provisional* compilation. References contributing to this listing of low-absorption regions include Blanco (1988), Blanco and Terndrup (1988), Ichikawa et al. (1982), Terndrup (1988), and others. This compilation of windows of both varieties (with and without detected galaxies) will be discussed in greater detail in a paper now in preparation.

The descriptive names of individual windows in Table 1 are usually those used in publications. Some new names were assigned in the absence of clear and unique designation. In addition, a systematic designation based on the prefix LLW (low latitude window) and new galactic coordinates is assigned to each region. The quantity ρ is the great circle distance (degrees) of the window from the galactic center, while r_o is the galactocentric distance (= 8.0 tan ρ kpc) computed for fields within 30° of the galactic center. The final column gives a reference code.

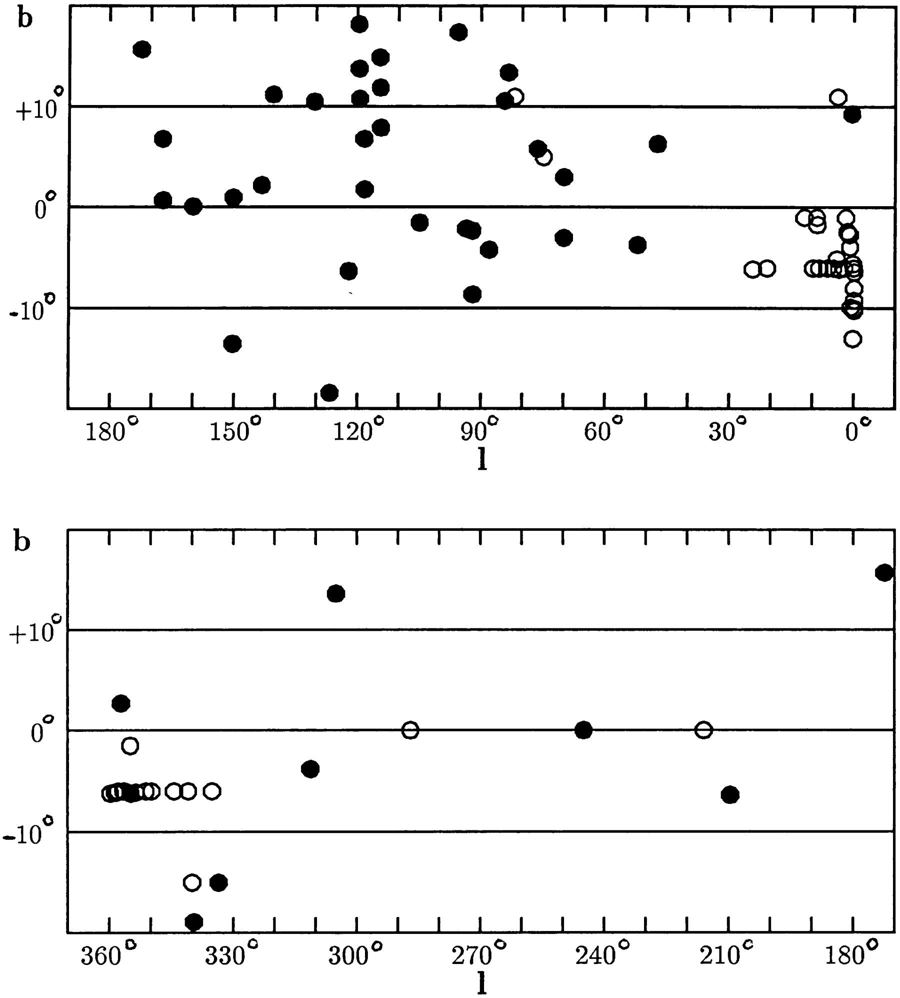

Fig. 1. Distribution of galactic windows (o) with galaxies and low-absorption regions (o) with no reported galaxies. Galactic coordinates (new system).

Table 1. Low-Latitude Windows (Eq. 1950)

Designation	Name	α h m s	δ ° ′	ρ °	r_0 kpc	Ref
LLW119.6+10.8	Shapley 8	00 02 42	+73 03	119.0		9
LLW118.4+01.8	Shapley 6	00 06 24	+64 00	118.3		9
LLW119.8–18.2	Shapley 10	00 32 06	+44 15	118.2		9
LLW122.2–06.3	Shapley 11	00 42 54	+56 16	121.9		9
LLW126.8–18.4	Shapley 12	01 09 18	+44 01	124.7		9
LLW130.6+10.5	Shapley 13	02 26 00	+71 39	129.7		9
LLW150.4–13.5	Per Cluster	03 15 11	+41 15	147.8		10
LLW143.4+02.2	Shapley 15	03 33 48	+58 08	143.3		9
LLW140.6+11.2	Shapley 14	04 05 00	+66 55	139.2		9
LLW150.3+01.0	Shapley 16	04 06 48	+52 50	150.3		9
LLW160.0+00.0	3C129	04 46 00	+45 00	160.4		14
LLW167.3+00.7	Aur	05 11 12	+39 53	167.3		1
LLW167.4+06.8	Shapley 17	05 38 06	+43 10	165.7		9
LLW209.6–06.4	van den Bergh	06 19 12	+00 24	149.7		13
LLW172.5+15.7	Shapley 18	06 34 24	+42 49	162.6		9
LLW245.0+00.0	Pup	07 53 10	–28 04	115.0		2
LLW305.1+13.6	Cen Cluster	13 01 16	–48 55	056.0		10
LLW000.6+09.3	Oph Cluster	17 09 12	–23 18	009.3	1.3	5
LLW311.3–03.8	Cir	17 09 18	–65 06	036.6		3
LLW357.2+02.7	45 Oph	17 25 12	–29 49	003.9	0.5	12
LLW333.6–15.0	Ara-Pavo	17 39 48	–59 00	030.1	4.6	10
LLW354.9–06.2	Sco-Sgr	17 55 12	–36 27	008.0	1.1	10
LLW339.6–18.9	Tel	18 23 48	–55 22	027.5	4.2	10
LLW047.4+06.3	Aql I	18 52 48	+15 39	047.7		1
LLW052.2–03.7	Aql II	19 39 06	+15 11	052.3		1
LLW083.5+13.4	Sandage 1	19 40 00	+50 35	083.6		8
LLW095.7+17.4	Shapley 2	19 53 00	+62 57	095.5		9
LLW070.0+03.0	Vul-Cyg North	19 53 22	+33 53	070.0		10
LLW076.4+05.8	Cyg A	19 57 44	+40 36	076.3		11
LLW084.4+10.6	Sandage 2	19 58 00	+50 00	084.5		8
LLW070.0–03.0	Vul-Cyg South	20 17 12	+30 38	070.0		10
LLW088.1–04.2	Cyg Cl	21 19 51	+43 51	088.1		4
LLW092.2–02.3	Markkanen	21 30 24	+48 13	092.5		7
LLW093.7–02.1	Lindgren-Bern	21 35 00	+49 10	093.7		6
LLW092.1–08.6	Shapley 1	21 52 12	+43 13	092.1		9
LLW105.0–01.5	Cep	22 33 36	+56 18	105.0		1
LLW114.7+14.9	Shapley 5	22 35 36	+75 18	113.8		9
LLW114.6+11.9	Shapley 4	22 55 00	+72 36	114.1		9
LLW114.5+07.9	Shapley 3	23 13 12	+68 53	114.3		9
LLW119.7+13.8	Shapley 9	23 54 54	+76 01	118.7		9
LLW118.5+06.8	Shapley 7	23 58 36	+68 57	118.3		9

Table 1 (continued)

References: 1 = Bok (1944); 2 = Fitzgerald (1968); 3 = Freeman et al. (1977); 4 = Huchra et al. (1977); 4 = Johnston et al. (1981), Wakamatsu and Malkan (1981); 6 = Lindgren and Bern (1980); 7 = Markkanen (1978); 8 = Sandage (1976); 9 = Shapley (1935); 10 = Shapley (1957); 11 = Shapley (1957), Spinrad et al. (1982); 12 = Terzan and Ounnas (1988); 13 = van den Bergh (1976); 14 = Weinberger (1980).

3.4 SOME LOW-LATITUDE OPTICAL SURVEYS FOR GALAXIES

Böhm-Vitense (Lick) Low-Latitude Optical Survey. Deep photographs of 52 low-latitude non-stellar objects from the Shane and Wirtanen (1967) galaxy survey show that 44 are galaxies (Böhm-Vitense 1956).

Dodd and Brand (Edinburgh) Low-Latitude Optical Survey: A survey to mag. 22 yielded 29 galaxies in longitude interval l = 245° to 255° in Puppis and Pyxis (Dodd and Brand 1976).

Weinberger (Innesbruck) Very-Low-Latitude Optical Survey. A survey for l = 33° to 213° and b $\leq 2°$ yielded 207 galaxies (Weinberger 1980). This valuable survey reveals possibilities for astrometry. See Pfleiderer et al. (1981).

Hauschildt (Hamburg) Low-Latitude Optical/Radio Survey: Palomar Sky Survey red prints yielded about 260 galaxies, of which 65 form part of the study of a possible extension of the Perseus Supercluster across the Milky Way at l = 140° to 165° (Hauschildt (1987).

3.5 LOW-LATITUDE GALAXIES FOUND AT LONGER WAVELENGTHS

Low-Latitude Galaxies from Radio Surveys. Large numbers of radio sources are known within the Milky Way band ($|b| < 10°$), while systematic surveys now in progress will provide many more, as part of a current drive to obtain the whole-sky distribution of galaxies. Radio surveys have the potential of adding many galaxies for low-latitude astrometry.

Low-Latitude Galaxies from Far-Infrared Surveys. The advantage of working in the far infrared in the low-latitude zone is clearly demonstrated from the absorption penetrating ability of the *Infrared Astronomy Satellite (IRAS)*, observing at the four bands 12, 25 60 and 100 μm. Examination of sources at latitudes $|b| \geq 10°$ yielded many galaxies (Dow et al. 1988), while there is some promise for locating optically hidden galaxies in in lowest latitudes ($|b| < 10°$) despite the great confusion of sources there.

There are unique applications for precision astrometry in high-absorption, low-latitude areas, once infrared detector technology reaches the necessary level, emulating the success of the CCD. There are interesting recent developements with detectors working in the K-band at 2 μm (Koo 1988), where extinction, as noted earlier, is only one-tenth that in the optical domain . The possible role of infrared astrometry to defining the low-latitude reference frame deserves study.

3.6. LOW-LATITUDE INDICATORS OF OPACITY OR TRANSPARENCY

Dark Cloud Surveys as Markers of Regions to Avoid. Dark clouds mark lines of sight where galaxies and QSO's are unlikely to be observable in optical domain. These are compiled for the northern (Lynds (1962) and southern (Hartley et al. 1986) skies, with catalogs of 1802 and 1101 clouds, respectively. Together these catalogs permit delineation of parts of the the low-latitude zone into areas of graded levels of opacity on a scale of 1 (absorption about 1 mag.) to 6 (highly opaque).

Molecular Gas Distribution as Markers of Transparency. Observations of mm-wavelength emissions from the CO molecule is a useful tracer of molecular gas concentrations around the galaxy. Conversely *low* measures of CO emission are useful for pointing out directions with *low* total absorption. A partial survey in the galactic plane in the longitude range $l = 4.3°$ to $90°$ revealed over 100 small regions with no molecular clouds, which corresponds to total visual absorption A_v under than 1.5 mag. (Verter et al. 1983). These may be directions useful for galaxy surveys.

Galactic H I Reddening Maps as Markers of Transparency. Reddening measurements provide total galactic absorption towards the region. Likewise, neutral-hydrogen column-density measurements relate reasonably well to reddening and, hence, the corresponding absorption. Contour maps of galactic reddening, derived from H I column-density measurements and spatially smoothed using the Shane-Wirtanen galaxy counts, have been constructed by Burstein and Heiles (1982). These H I reddening maps cover the sky for galactic latitudes $10° \leq |b| \leq 65°$. They may be useful for pointing out useful directions for deep galaxy surveys.

3.7. SOME STRATEGIES FOR LOW-LATITUDE ASTROMETRY

Several methods are available, or possibly becoming available, for providing reference objects close to an inertial system within the Milky Way. These include various imaging and interferometric methods in the optical and radio domains relating positions to the global system, as well as the enhanced capabilities of modern meridian astrometry. The present survey supports the option for direct attachment of faint Milky Way stars to the low-latitude extragalactic frame. The role of astrometry conducted in the absorption-penetrating infrared domain remains open to exploitation for the future. Observations from space will likely exert great impact when balanced against many of the ground-based approaches. For now it appears premature exclude any particular promising approach for *current* astrometric observations.

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REFERENCES

Allen, C. W. (1976) *Astrophysical Quantities* (3rd Ed), (The Athlone Press: University of London), p. 263.

Blanco, V. M. (1988) Astron. J. **95**, 1400.

Blanco, V. M., and Terndrup, D. M. (1989) Astron. J. **98**, 843.

Bok, B. J. (1944) Pop. Astron. **52**, 318.

Böhm-Vitense, E. (1956) Pub. Astron. Soc. Pacific **68**, 430.

Burstein, D., and Heiles, C. (1982) Astron. J. **87**, 1165.

Deutsch, A. N. (1937) Bul. Obs. Central Pulkovo **15**, Pt. 5, 8.

Dodd, R. J., and Brand, P. W. J. L. (1976) Astron. Astrophys. J. Sup. **25**, 519.

Dow, M. W., Lu, N. Y., Salpeter, E. E., and Lewis B. M. (1988) Astrophys. J. **324**, L51.

FitzGerald, M. P. (1968) Astron. J. **73**, 983.

Freeman, K. C., Karlsson, B., Lyngå, G., Burrell, J. F., van Woerden, H., Goss, W .M., and Mebold, U. (1977) **55**, 445.

Hanson, R. B. (1987) Astron. J. **94**, 409.

Hauschildt, M. (1987) Astron. Astrophys. **184**, 43.

Hubble, E. P. (1934) Astrophys. J. **79**, 49.

Huchra, J., Hoessel, J., and Elias, J. (1977). Astron. J. **82**, 674.

Hubble ,E. P. (1934) Astrophys. J. **79**, 49.

Ichikawa, T., Hamajima, K., Ishida, K., Hidayat, B., and Raharto, M. (1982) Pub. Astron. Soc. Japan **34**, 231.

Johnston, M. D., Bradt, H. V., Doxey, R.E., Margon, B., Marshall, F. E., and Schwartz, D. A. (1981) Astrophys. J. **245**, 799.

Klemola, A. R. (1989) IAU Colloq. No. 100, *Fundamentals of Astrometry* eds. H. Eichhorn, C.A. Murray, and A. Upgren (Kluyver Academic Pub., Dordrecht). In press.

Klemola, A. R., Jones, B. F., and Hanson, R. B. (1987) Astron. J. **94**, 501.

Koo, D. (1988) Bul. Am. Astron. Soc. **21**, 114.

Lindgren, H., and Bern, K. (1980) Astron. Astrophys. Sup. **42**, 335.

Lynds, B. T. (1962) Astrophys. J. Sup. **7**, 1.

Markkanen, T. (1978) Astron. Astrophys. Sup. **34**, 181.

Mayall, N. U. (1934) Bul. Lick Obs. (1934) **16**, 177.

Pfleiderer, J., Gruber, M. D., Gruber, G. M., and Velden, L. (1981) Astron. Astrophys. **102**, L21.

Sandage, A. (1976) Pub. Astron. Soc. Pacific **88**, 367.

Shane, C. D. (1947) Pub. Astron. Soc. Pacific **59**, 182.

Shane, C. D., and Wirtanen, C. A. (1967) Pub. Lick Obs. **22**, pt. 1.

Shapley, H. (1935) Harvard Bull. No. 899, 17.

Shapley, H (1957) The Inner Metagalaxy (Yale University Press: New Haven).

Spinrad. H., and Stauffer, J. (1982) Mon. Not. Roy. Astron. Soc. (1982). **200**, 153.

Steinlin, U. W. (1962) Astron. J. **67**, 370.

Stone, R. C. (1978) Astron. J. **83**, 393.

Terndrup, D. M. (1988) Astron. J. **96**, 884.

Terzan, A., and Ounnas, Ch. (1988) Astron. Astrophys. Sup. **76**, 205.

van den Bergh, S. (1976) Astron. J. **81**, 104.

Vasilevskis, S. (1973) Vistas in Astron. **15**, 145.

Verter, F., Knapp, G.R., Stark, A. A., and Wilson, R. W. (1983) Astrophys. J. Sup. **52**, 289.

Wakamatsu, K., and Malkan, M. A. (1981) Pub. Astron. Soc. Japan **33**, 57.

Weinberger, R. (1980) Astron. Astrophys. Sup. **40**, 123.

Wright, W. H. (1950) Proc. Am. Philos. Soc. **94**, 1.

Zverev, M. S. (1940) Astron. J. USSR **17**, 54.

Discussion

BASTIAN: From your graph on the galaxy density distribution it seems to me that the width of the zone of avoidance is generally 20°. Did you ever think of bridging this gap by plate overlap methods? The distance to be bridged amounts to only 3 to 4 of your plate-edge lengths, so you would not need an excessive number of overlap "steps." I do not say it would be easy, but it *might* work.

KLEMOLA: The reply is in two parts. First, the overlap is only 1° for a full 6°x6° plate. This is insufficient for the standard overlap technique. Second, the actual width of the Zone of Avoidance is wider than displayed here because the innermost galaxies are often too weak on astrograph plates. Therefore, we stop at a slightly higher latitude from the equator than the innermost isopleth of 5 galaxies per square degree.

Bronnikova: If you observed in red regions, could you not avoid the problems with the zone of avoidance?

Klemola: I have included the K-band at 2 microns, where the absorption is only one-tenth of the value in the yellow region. Infrared technology is progressing, so that it is becoming useful to consider interesting applications of infra-red astrometry to low latitude problems. There are still important questions as to what will be visible for extragalactic objects at this wavelength.

MURRAY: Have you any plans to obtain colours for your faint anonymous stars?

KLEMOLA: Yes, we do obtain colors from the blue and yellow plates. These are only approximate, owing to inadequate photometric standard stars. Our colors for faint stars are mainly useful for statistical applications.