TRIGONOMETRIC PARALLAXES AND THEIR CALIBRATION

Arthur R. Upgren

Van Vleck Observatory

1. INTRODUCTION

The precision obtained in equating a very precise linear dimension to a very small and imprecise angular dimension sets a limit on the precision of the distance scale of the Universe. Within the Solar System, errors in distances are of the order of one part in one hundred million, but beyond its limits only a single star, Barnard's star, has a distance known to better than one part in one hundred, and distances known to one part in twenty from parallaxes are limited to only a few hundred nearby stars. Yet most other distance methods and results must ultimately be calibrated against distances to nearby stars derived from the heliocentric parallax method and its observations and uncertainties.

The early work on the calibration of parallaxes and their systematic and accidental errors was mostly done by Frank Schlesinger. At about the beginning of this century, Schlesinger introduced rigorous practices to the then new use of photography in astrometry in the course of his observations using the Yerkes refractor. Among them were the use of magnitude compensation devices, standardized photographic emulsions and filters, and constraints obtained by observing only near the meridian. He also introduced dependences which increased the efficiency in the reduction of the measures over Turner's earlier plate-constant reduction method, although with diminished rigor acceptable at that time.

Schlesinger concerned himself with parallax errors of all kinds. Perhaps he best described his concern in his George Darwin lecture (Schlesinger 1927) when he remarked, "the history of the measurement of stellar parallaxes has presented, more than any department of astronomy, a continual struggle between the necessities of the problem and the methods for attacking it, very similar to the conflict that has gone on between heavier and heavier artillery and stronger and stronger armour-plate. A source of error having once been revealed, it is seldom that much time has elapsed until methods for eliminating it or avoiding it have been devised. After such improvements have been applied, new but

D. S. Hayes et al. (eds.), Calibration of Fundamental Stellar Quantities, 31–51.

https://doi.org/10.1017/S0074180900078761 Published online by Cambridge University Press

smaller sources of error come to light to challenge our patience and ingenuity". The calibration of parallaxes and of stellar luminosities and other properties from them, has continued to be a story of encountering and surmounting sources of error.

Schlesinger compiled and published the General Catalogue of Stellar Parallaxes (sometimes called the Yale Parallax Catalogue) in 1924 and a second edition in 1935. He made adjustments to the published errors in the parallaxes of each contributing observatory in order to more properly represent the true uncertainties in the data. Two independent methods were used for this purpose. In the first, the average difference without regard to sign was found from intercomparisons between the parallaxes of each observatory compared with every other observatory from which the external probable errors of each of the two series were estimated. The second method used differences between the trigonometric parallaxes of each observatory with spectroscopic parallaxes of the Mount Wilson Observatory.

Schlesinger looked into the constant differences between the various observatories and applied corrections based on the differences in order to remove them and thus place the parallaxes from all observatories onto a single system. These corrections are sometimes known as the Yale precepts and are published in the first two editions of the Yale parallax catalogue. Some differences occur between the two editions but these are mostly due to the addition of many more parallaxes in the later edition. The first edition lists trigonometric parallaxes for 1682 stars which were available in January 1924 whereas by January 1935, the closing date of the second edition, the stars with available trigonometric parallaxes had more than doubled, to a total of 3928 stars. The third edition of the catalogue was published in 1952 by Louise F. Jenkins and was renamed the General Catalogue of Trigonometric Stellar Parallaxes since it excluded spectroscopic and other distance determinations, unlike the two earlier editions. It contains 8832 parallax determinations for 5822 stars available by June of 1950. Later, Jenkins published a supplement to it now bound with it (Jenkins 1963) with parallaxes available at the end of 1962. It lists 730 new parallax determinations of 654 of these same stars and 632 new parallaxes of 577 additional stars, thus raising the total to 10194 parallaxes of 6399 stars with at least one parallax determination. These numbers may not be exact since observatories occasionally combine parallaxes made from two or more plate series or of two components of a binary star into a single published parallax. In both catalogue and supplement, Jenkins alters the Yale precepts somewhat from the earlier editions, adhering closely to Schlesinger's methods and conclusions. This third edition of the catalogue and its supplement together (hereafter abbreviated GCTSP) incorporate the corrections based on computed systematic differences between observatories in the final parallaxes adopted. The corrections assume a zero point for each observatory which is shifted into a zero point for the entire system of all observatories taken together. The zero point which Schlesinger and Jenkins adopted was that of the Allegheny Observatory since its parallaxes had been found to have the lowest mean external error. A new fourth edition of the catalogue being prepared by van Altena (1985) will be discussed later.

Schlesinger (1928) and later Hertzsprung (1952) determined that the average external standard error of a parallax appearing in the GCTSP is about 0".016 or 16 milliarcseconds. One milliarcsecond or 0".001 is the unit of angular measure in most common use by astrometrists. A milliarcsecond is frequently shortened to a "mas" and is equal to about five (precisely $2\pi/1.296$) nanoradians.

The years following the publication of the supplement in 1963 were years of change in the determination of trigonometric parallaxes. The changes have occurred in all aspects of parallax research including observation, measurement and reduction as well as the evaluation and analysis of published parallax errors. Major improvements have also been made in the evaluation of systematic differences between observatories in the period and since, and in the application of corrections to biased parallax samples which result in improved stellar luminosity calibrations. The result has been the reduction of the size of the external parallax error to less than half the error of the GCTSP stars. The selection and use of parallax standard stars and regions for calibration between observatories has received much attention in the last few years. Finally the parallax programs active in the last two decades are based upon a vastly improved and realistic experimental design wherein each parallax is likely to be of significance in deriving the luminosity distributions of many kinds of stars.

Many reviews have been written of the parallaxes determined up to the time of the completion of the supplement to the GCTSP. Among the ones with extensive treatment of errors are the papers by Strand (1963), Vasilevskis (1966), Gliese (1972), Upgren (1977) and Heck (1978). Some of their conclusions are discussed later in this paper. Mention should also be made of the recent review by van Altena (1983). He emphasizes new techniques which promise still greater precision to parallaxes made in the future. But the results and developments achieved since the publication of the GCTSP in 1963 have not received the attention given to the earlier data. This review is intended to focus on and summarize these recent improvements, beginning with the state of parallaxes in the period just prior to 1963.

2. CONTEMPORARY TRIGONOMETRIC PARALLAXES

Observations, measurements and reductions for parallax changed little during the first sixty years of this century. The observational requirements laid down by Schlesinger were described by him (Schlesinger 1924) and more recently by van de Kamp (1962) with some modifications. With few exceptions the parallaxes listed in the GCTSP have been made using long-focus refracting telescopes with apertures ranging from 50 to 100 centimeters and focal ratios of 10 to 20. The outstanding exception has been at Mount Wilson where parallax observations were made with the reflectors at that observatory by van Maanen. Photographic observations were made using standard emulsions and filters based on the properties of the visual or photographic refractors. The description by van de Kamp (1962) of the observational procedures developed at the Sproul Observatory is generally typical of the programs prior to that time. Measures were made on single-screw machines by hand, and typically between three and five comparison stars were measured along the x-axis (aligned in right ascension) only, since the parallactic stellar motion is mostly in right ascension. Reductions were made using the dependence method introduced by Schlesinger (1911,1924).

One of the most significant developments of recent years is the design and construction of an astrometric reflecting telescope by Strand resulting in the 1.5-meter reflector of the U.S. Naval Observatory at Flagstaff. At a conference on the cosmic distance scale, Strand (1958) called for the development of this telescope and pointed out that with minimized flexure and a comparatively coma free field, it would overcome the limitations of existing reflectors such as those at Mount Wilson. He described its features more extensively in the proceedings of a symposium on astrometry held at New Haven (Strand 1962). Although the parallaxes obtained with it are discussed later, it should be mentioned here that our knowledge of distances and luminosities of faint red dwarfs and white dwarfs is now almost completely based on the observations made with this telescope. Most other recent parallaxes continue to be obtained with conventional long-focus astrometric refractors.

The measurement of photographic plates has proceeded through two stages since the review by van de Kamp. About 1960, the single-screw measuring machines in use at the Van Vleck and U.S. Naval Observatories and others were replaced by two-screw machines with machine-readable output. The measures were still made by hand and hence no increase in measuring precision was realized for any one image. But other advances were made as a result of these second-generation machines. Among them were the elimination of accidental blunders since the transfer and recording of data were no longer made by hand. Furthermore a considerable reduction in measuring time per plate was realized along with a reduction of eyestrain and fatigue on the part of the measurer. The simultaneous introduction of computers further lowered the measuring time per plate through the elimination of the necessity for a careful and usually laborious orientation of each plate in direct and again in reversed mode made by hand by trial and error. The gain in measuring speed and computational ability allowed an increase in the number of reference stars to be measured as well as the simultaneous measurement of all star positions in both x and y coordinates. The second major achievement in measuring techniques of the last 15-20 years has been the replacement of the manual machines by automatic impersonal machines, beginning with those at the Lick and U.S. Naval Observatories and proceeding to the PDS microdensitometers now in use at Yale and elsewhere. Although they differ greatly in the details of engineering design and method of image centering, they share the advantages over their predecessors of centering with a repeatability of less than one micron (as opposed to about two microns for a typical hand measure) and of the removal of the personal differences between different measurers. From somewhat limited data, the parallaxes of the Van Vleck Observatory, measured automatically at Yale and the U.S. Naval Observatory are found to be more precise than their hand-measured counterparts. Stetson (1974, see also Upgren 1977) found that the total variance in external parallax error is reduced by about one-third for the automatically measured data. There is no reason to suppose that this gain is not realized at other observatories as well.

The use of computers has had perhaps the greatest single influence in parallaxes since it has led to a thorough revision in the reductions of the measures. As mentioned above, the time consumed in hand calculations placed several constraints upon the solutions. These included measures in right ascension only, limitation of the reference frame to three or four stars, and the use of dependences in the solution. The dependence solutions incorporate several disadvantages in which some precision is sacrificed; Eichhorn and Jefferys (1971) have given an extensive description of these limitations. Chief among them is the absence of residuals for the reference stars allowing errors in their measurements or significant proper motion or change in position to escape detection.

With time of computation no longer a constraint, dependence solutions have been replaced at most observatories by solutions employing linear (and sometimes quadratic) plate constants. A rigorous and elegant approach to the plate-constant technique using a non-iterative method was suggested by Eichhorn and Jefferys (1971) and applied to examples by Eichhorn and Russell (1976). Both methods and their constraints are fully described and compared by Russell (1978) who also describes the assumptions which reduce the non-iterative method to the more conventional plate constant solution method. Few parallaxes have been determined using the non-iterative technique, but a variant of it sometimes referred to as the central-overlap method (Gatewood and Eichhorn 1973) has been directly compared to the linear plate constant approach by Upgren and Breakiron (1980) in two sets of parallax solutions for seven stars. Later Upgren and Breakiron (1981) made new solutions for all 269 stars whose parallaxes had been determined at the Van Vleck Observatory in the period from 1960 to 1980. For most series, the parallaxes and proper motions of the two methods differed only insignificantly.

3. CALIBRATION OF INDIVIDUAL PARALLAXES

At the time of the publication of the supplement to the GCTSP in 1963, Schlesinger's analysis of parallax errors was still accepted. He had established the precepts upon which it was based along with a zero point for all parallaxes considered together adopted from those defined by the Allegheny Observatory. Allegheny was one of four observatories

https://doi.org/10.1017/S0074180900078761 Published online by Cambridge University Press

which together produced about 70% of the 10,194 parallaxes listed in that catalogue; the other three are the McCormick Observatory and the Cape and Yale Observatories in South Africa. Almost all of the remaining parallaxes had been determined at six other observatories. These are the Dearborn, Greenwich, Mount Wilson, Sproul, Van Vleck and Yerkes Observatories. Schlesinger's (1928) analysis showed external errors (here converted to standard errors) for five of these observatories ranging from 10 mas for Allegheny to 21 mas for Yale with intermediate values of 15, 18 and 20 mas for Mount Wilson, McCormick and Yerkes, respectively. Hertzsprung (1952) made a very simple but straightforward analysis of the combined parallaxes for the stars in the GCTSP and found the average external mean error for a parallax in it to be 16 mas, in good agreement with Schlesinger. Both of the conclusions have stood up under repeated analysis. Vasilevskis (1966) repeated and generally confirmed Schlesinger's results for individual observatories, and Upgren and Carpenter (1977) confirmed the Hertzsprung result.

The years since the GCTSP have seen a marked decline in the numbers of parallaxes published, due mainly to the decline in the number of observatories with fully active parallax programs. But in many ways, the limited results of recent years are of greater value. One of the three most productive of recent parallax programs is new; this is the U.S. Naval Observatory program using observations of the 1.5m astrometric reflector at Flagstaff which Strand had envisioned and developed. The initial program, its procedures and the selection of the stars included was described by Worley (1966) and the results for 485 stars were published in five lists between 1970 and 1978, and summarized by Harrington and Dahn (1980) and a sixth list with parallaxes of 97 additional stars has since been published by Dahn et al (1982).

The range in apparent visual magnitude of the 582 stars with published parallaxes is quite constrained, with 88 per cent of the total being nearly uniformly distributed between magnitudes +12 and +16. Only 42 stars are brighter than this interval and 29 are fainter. Almost all of the stars are found to lie between absolute visual magnitudes +10 and +15 and are fairly evenly distributed within this interval. About one-third of the stars are white dwarfs and form a distinct sequence in the M_V, B-V color-magnitude diagram. The remainder define a narrow lower main sequence whose only significant departure appears to be for the few stars brighter than +10 which lie below the main sequence. These stars may represent a high-parallax tail of a distribution of comparatively distant stars.

The other two most productive parallax programs are modifications of older ones which employ long focus refractors on the campuses of small liberal arts colleges in the Eastern United States. These are the Sproul and Van Vleck observatories with 0.6m and 0.5m refractors, respectively. The Sproul effort has not sought to determine parallaxes as its sole, or even its primary goal. It has instead concentrated on specific nearby stars using very long plate series in order to obtain masses of known astrometric binary stars or to detect the presence of unseen companions of single stars. Nevertheless, it has been one of the most productive and steadiest sources of new and accurate parallaxes. The program is being modernized under the supervision of W.D. Heintz, whose aims have been given in a recent review (Heintz 1978).

The Van Vleck program is a departure from earlier astrometric work done at that observatory. The earlier material included in the GCTSP was published by C.L. Stearns in eight papers appearing in the Astronomical Journal between 1930 and 1959, which together contain data for 259 stars. Final solutions and more extensive details for these same 259 stars are also given by Slocum, Stearns and Sitterly (1938) for the 130 stars appearing in the first three of Stearns' lists and by Stearns (1960) for the 129 stars comprising the last five of his lists. After 1960, the program was greatly modified by H.K. Eichhorn and again by A.R. Upgren. The changes along with every Van Vleck parallax published between 1960 and 1980 have been summarized by Upgren and Breakiron (1981). This compilation lists 342 parallax solutions for 269 stars along with their photometry. The summary includes the 13 lists of Van Vleck parallaxes appearing in the Astronomical Journal between 1968 and 1980 by Upgren and his collaborators. The parallaxes and proper motions given in this summary supersede the similar data of the earlier lists since the solutions were redetermined using the original measures in order to provide data to 0.1 mas (as opposed to one mas in the original solutions). The summary also includes a list of parallaxes by Eichhorn and several solutions for individual stars. Since its publication, three further lists have been published giving parallaxes for a total of 68 additional stars (Weis, Nations and Upgren 1983 and references cited therein). These raise the post-1960 total to 410 solutions for 337 different stars.

The current Van Vleck program has as its principal concern the parallaxes of stars on the middle and lower main and subdwarf sequences. Its program stars like those of the Naval Observatory are almost all too faint to qualify for Schlesinger's original program model which limits parallax observations to stars brighter than apparent visual magnitude 5.5 and of spectral class A0 and later, thus selecting stars which are mostly closer than 100 parsecs with true absolute parallaxes larger than 10 mas. It has concentrated on the lists of K and M dwarf stars of Vyssotsky and his colleagues at the McCormick Observatory which were detected and identified spectrophotometrically. These stars avoid the high-velocity bias characteristic of earlier lists of faint nearby stars which are based on proper motion. The only other observatory with a large number of parallaxes of these stars is McCormick itself. But most of its parallaxes were placed on the program before Vyssotsky's lists and they still incorporate a selection effect towards high transverse velocity. The Van Vleck program includes the Vyssotsky stars of low transverse velocity in their proper proportion and has greatly reduced the high velocity bias present among even the nearest of stars in the catalogue of nearby stars by Gliese (1969).

Other observatories have also been active during part or all of the period since the GCTSP. Together they account for about half of all parallaxes published in that interval. An approximate count for each observatory through 1977 along with the breakdown of the GCTSP by observatory has been published previously (Upgren 1978). An exact updated list including parallaxes published since 1977 must await the completion of the new fourth edition of the Yale parallax catalogue but approximate numbers for each contributing observatory can be given here. Since 1963, these numbers are as follows: U. S. Naval 582, Van Vleck 410, Sproul 284, Yale 202, Allegheny 193, McCormick 179, Lick 128, Greenwich 78, Yerkes 71, and 20 are scattered among several other observatories.

The improvements in these modern parallaxes lead to a greater precision than even the former Allegheny parallaxes, the most precise of the data appearing in the GCTSP. Furthermore, and perhaps most important of all, they concentrate on the very nearby stars. Since the error in the distance and therefore the intrinsic luminosity of a star is determined by the error in parallax divided by the parallax itself, the nearby stars are the ones with the most precisely known absolute magnitudes. This is illustrated by Gliese (1983) who finds 585 stars with accurate photometry whose trigonometrically determined absolute magnitudes have errors that do not exceed 0.30 mag. His M_V, B-V color magnitude diagram shows a very narrow main sequence with no stars bluer than about A0, and only four of the nearest giant stars appear in it, indicating a sample severely limited in distance. Yet a glance at the frequency distribution of the parallaxes in the GCTSP reveals that only a few percent of them are sufficiently large to fulfill Gliese's conditions of accuracy. The frequency distribution is illustrated by Upgren (1978) and also in an analytical study by Hanson (1980) along with those of each of the four leading observatories contributing to it (Allegheny, McCormick, Cape and Yale). They mostly reflect the basic program of Schlesinger emphasizing the naked-eye stars. Hertzsprung's (1952) conclusion, mentioned above, that the standard error of a GCTSP parallax is 16 mas came from his realization that the lower part of the distribution closely resembled a Gaussian distribution about the median value of +18 mas for all parallaxes. He and others have realized that this distribution appeared to reflect the uncertainty in the observational process. The errors of the recent parallaxes are well known and are much smaller than the GCTSP data. The U.S. Naval Observatory claims 4 mas as the average standard error and that of the Van Vleck Observatory has been found to be 8 mas with only small variations from one star to another. About half of the difference between the errors of the two programs arises from the difference in focal lengths of the two instruments and half is due to the fact that the Naval data has been measured on automatic machines with a smaller uncertainty in image-centering ability whereas most of those of Van Vleck published to date have been measured by hand. Recent unpublished Van Vleck parallaxes have been measured using the PDS microdensitometer of the Yale Observatory. These as well as a few others measured on the SAMM machine of the Naval Observatory, suggest that automatic centering reduces the external error of Van Vleck parallaxes from 8 mas to 6 mas, in line with other current parallaxes and confirming Stetson's (1974) conclusion (see Section 2). Most of the recent data from the other observatories have individual errors falling between 4 and 8 mas.

Many plausible reasons have been advanced for the much greater precision of almost all of the recent parallaxes over the earlier ones but to date no thorough study has been made which evaluates the relative merits of each. Vasilevskis (1969) cites five possible reasons for the high precision of the first parallax results of the Lick Observatory program which was begun about that time. He states them as follows: (1) automatic guiding and measurement, (2) inclusion of magnitude and color terms into the plate reduction, (3) up to 24 properly selected reference stars for each parallax star, (4) parallax solution made simultaneously in both rectangular coordinates, and (5) careful analysis of plate constants and residuals.

We can extend his list to include several additional factors which are likely to influence the sizes of errors: (6) the number of plates upon which the solution is based, (7) the number of evening and morning epochs at which plates have been taken and (8) increased rigor in the parallax solutions arising mainly from the use of computers. Not all of these likely sources of improvement have been carried out at each observatory but collectively in some degree they are very likely to account for most, if not all of the error reduction.

The first of Vasilevskis' points, automatic guiding and measurement has not yet been available or implemented at all observatories due often to a lack of funding or support staff. The second and third are interrelated since an insufficient number of reference stars can lead to underdetermined solutions. As mentioned in Section 2 one of the limitations of the dependence method of solution is the inability to examine the residuals for the comparison stars. Since most of the recent parallaxes used one or another form of the plate constant method of solution in both coordinates, as opposed to dependences and measures in right ascension only for the earlier data, it is likely that large residuals have been eliminated only in the recent parallaxes. Although their cumulative effect cannot be evaluated, they would affect points 5 and 8 above.

The number of reference stars used was almost uniformly low in earlier measures but have more recently been variable among observatories. The parallaxes of Yerkes and Lick made since the new programs were started there by van Altena (1971) and by Vasilevskis (1975), respectively, average about 20 reference stars per field. For Van Vleck, the average number of reference stars is smaller, being about 10 with most series falling between 6 and 15. This smaller number is the result of a brighter limiting magnitude due to the much smaller aperture of the telescope (0.5m vs 1.0 and 0.9m for the Yerkes and Lick refractors, respectively). The Naval Observatory on the other hand, has included generally 4 to 6 reference stars per field similar to parallax programs of the past.

About one thousand or some ten percent of all published parallaxes now have simultaneous measures in both x and y coordinates and almost all of these are recent ones. The weight of the declination component is always much less than that in right ascension and is a function of the eccentricity and orientation of the parallactic ellipse, but it can be combined with the right ascension component into a single parallax of higher weight, providing no systematic differences are present. Recently Lutz and Upgren (1980) analyzed sets of data from four observatories, which at that time included 484 stars from the Naval, 248 from Van Vleck, 199 from Sproul and 75 from McCormick, the only sufficiently large samples of combined parallaxes from individual observatories. They concluded that in all four sets of data, the parallaxes in the two coordinates are measures of the same intrinsic quantity, but that all four observatories overestimated the precision of the y-parallaxes but not the x-parallaxes. No reason for the overestimation could be found, but the study showed the value of measures in both x and y, as well as the publication of all results to 0.1 mas rather than to 1 mas as had been the common practice in earlier work.

The increase in plates, epochs and time invervals (between first and last observation) is more uniform among modern programs. The number of plates per solution was frequently as low as 15 or 20 for GCTSP data, but few recent parallaxes have been made from less than 30 plates. The number of epochs has also risen from about 5 to 8 to about 8 to 12, and the time interval from 2 to 4 years up to 4 to 7 years for the modern data. Finally the program design has resulted in an increase in the number of useful parallaxes. The ratio of the external standard parallax error divided by the parallax, is a measure of the value of the parallax, and as is described in a later section, a value of 0.15 for this ratio is a useful threshold value to adopt when defining a good or high-weight parallax and we adopt this definition here. Since the standard error in absolute magnitude is related to the ratio by the quantity $5 \log_{10} e$ or about 2.17, this threshold corresponds closely to Gliese's limit of 0.3 magnitudes mentioned above. The GCTSP contains only 376 stars (or 4% of its total number) with good parallaxes, whereas the Naval and Van Vleck Observatories have produced 375 and 160, respectively, or 64% and 47% of their total output (see Upgren, 1983a for a more detailed distribution).

One other source of error should be mentioned here for completeness. Many new developments in technique and instrumentation promise a further decrease in parallax error in the future, to possibly as low as 1 to 2 mas. At that level of precision, the correction from relative to absolute parallax becomes of importance because its error is about of this same size. The presently active programs discussed here, however, have adopted the mean corrections to absolute given by van Altena (1974) based on the mean apparent magnitude and galactic latitude of the reference stars, which appear to be sufficient.

4. SYSTEMATIC ERRORS IN PARALLAXES AND THE ZERO POINT OF THE SYSTEM

At a conference on problems in astrometry held at Evanston in 1953, Schilt (1954) and Harris (1954) both devoted their attention to parallaxes, and to Schlesinger's and Jenkins' precepts in particular. Schilt found evidence to suggest that these systematic zero-point corrections were not sufficiently well established to warrant their use in the GCTSP but Harris made an independent evaluation of the external errors and concluded that the Yale precepts are generally reliable, at least for the longer parallax series. Schilt (1958) continued his analyses of discrepancies between parallaxes from different observatories and examined the possibility that the frequent absence of agreement between parallaxes for the same stars might be due to the parallaxes of the different sets of reference stars used. However, Vasilevskis (1966) suggested that this is not a serious problem. Strand (1958, 1963) also reviewed the sources of systematic and accidental error. He and Vasilevskis were critical of the Yale precepts as was Schilt earlier. In his review, Vasilevskis repeated Schlesinger's early (1928) analysis using much of the recent data available to him. Since these investigations, many more questions have been raised about the validity of the Yale precepts used to place all observatories on the common system in use in the GCTSP, as well as the size and nature of the precision of the parallaxes of each observatory.

In the GCTSP, Jenkins adopted a value of +3 mas for converting most Allegheny parallaxes into an absolute system. A few of the more recent ones were corrected by +2 mas. Comparisons to Allegheny determined the corrections for the other observatories. Schilt's (1954) analysis also compared others to Allegheny as the standard. He concluded that corrections amounting to only -1 mas were necessary for McCormick and Greenwich but the others required corrections between -4 and -6 mas. Most disturbing was the difference of -5 mas between the only two observatories located in the Southern Hemisphere, Cape and Yale, and the two largest northern contributors, Allegheny and McCormick. This implied a zero-point difference of that size between the parallaxes of stars at southerly declinations and the stars observed from north of the Equator with no satisfactory explanation for its existence.

The analysis of the precision of parallaxes at each observatory and the way that systematic differences have been dealt with in the GCTSP has made much progress since the mostly qualitative criticisms of Schilt (1954), Strand (1963) and Vasilevskis (1966) but their conclusions have generally been supported. In the last decade, since the reviews by Gliese (1972) and Upgren (1977) of the methods by which the information about both kinds of errors has been derived, much more rigor has been introduced into these problems. New studies of both systematic and accidental errors were begun in order to define the best possible system for the new fourth edition of the Yale Parallax Catalogue for which these data must be well evaluated. These studies have had the effect of quantitatively confirming the principal conclusions and concerns of the earlier work. The advances were made possible in part by the recent improvement in the ability of photometric systems to calibrate stellar luminosities and distances. Thus, Turon Lacarrieu and Creze (1977) and Norgaard-Nielsen (1977) used photometric parallaxes to calibrate the zero point of the parallax system and compared them to the trigonometric parallaxes of each observatory separately. Systematic differences were then obtained between the latter for each of the major contributors to the GCTSP data. Both conclude that sizeable systematic corrections of 3 mas are necessary, in contrast to Schlesinger, who believed that the precepts based on the Allegheny system were accurate to less than 1 mas. Later Hanson (1980) concluded that the absolute zero point of the GCTSP parallaxes without systematic observatory corrections can be confirmed to within 1 mas. Lutz (1978) presented a thorough review of most of these attempts along with the earlier ones. Although his review appeared only about a year after those of Upgren (1977) and Heck (1978), it addresses in detail for the first time the analyses of Turon Lacarrieu and Creze and of Norgaard-Nielsen and their use of photometric parallaxes, and covers both recent parallaxes and the upcoming revision of the Yale Parallax Catalogue. The subsequent series of papers by Hanson and Lutz and their colleagues (Hanson 1979,1980, Lutz 1979,1983, Lutz and Upgren 1980, Lutz, Hanson, Marcus and Nicholson 1981, Hanson and Lutz 1983) has re-examined the parallax system and its zero point, and the external parallax errors of individual observatories in an effort to determine the best precepts to use for a new parallax catalogue. They have also investigated the calibration of absolute magnitudes and the systematic effects involved. This last problem is as important as the others because it requires the evaluation of two corrections in order to remove two well-known biases which occur whenever mean absolute magnitudes are derived from trigonometric parallaxes. These are the Malmquist correction (Malmquist 1920) and the correction described by Lutz and Kelker (1973). They must be applied to samples of stars which are magnitude-limited and distance-limited, respectively.

The major conclusions of these papers have formed the bases for the new Yale Parallax Catalogue although in describing it, van Altena (1984) concludes that a unique system of zero points may not yet be possible to achieve. The premises upon which the new catalogue is based and the conclusions of van Altena and of the papers cited above represent much progress in the analysis of trigonometric parallaxes and their uncertainties. They also illuminate the difficulties in calibrating parallaxes individually or collectively and in deriving stellar distances and luminosities from them.

The recent papers which attempt to derive the external parallax errors of individual observatories include Hanson (1978), Schmidt-Kaler (1978), Upgren (1978), Hanson (1980), Lutz et al. (1981) and Hanson and Lutz (1983). The last three form a series dealing with the systematic effects in trigonometric parallaxes as well. They summarize most major previous conclusions and intercompare errors determined from comparisons between observatories, with photometric parallaxes and with parallaxes of member stars of nearby open clusters derived from the cluster modulus. The agreement between all three methods is close and demonstrates that for some observatories (e.g. McCormick and the recent Van Vleck program) a single standard external error characterizes the data satisfactorily. For others such as Allegheny, Yale and the new Lick program, the error is a function of features peculiar to each individual program. The standard errors of 10, 16 and 17 mas for Allegheny, McCormick and Yale remain close to Schlesinger's original findings, for example, while Lick's estimate of 6 mas and Van Vleck's of 8 mas are substantiated.

On the second point dealing with systematic differences, much recent work has also been done. The main problem encountered in attempting to define a system, is the absence of standard stars on which it could be based. Schlesinger and his contemporaries realized this and addressed it more than once. He proposed a list of standard stars for parallax observation (Schlesinger 1926) but its length of 171 stars was unrealistically long and the stars included on it covered mostly only brighter apparent magnitudes.

Later Strand (1958) made a more realistic appeal for the observation of a specified group of stars by all observatories. He recommended as standards groups of subgiant K stars and high-velocity F stars, thus recognizing that standards would have very precisely determined parallaxes. They would improve the calibration of luminosities of these kinds of stars of high astrophysical interest in addition to their use as parallax standards. Strand identified 16 dwarf stars of spectral classes F,G and K with parallaxes listed in the GCTSP between 30 and 50 mas and with proper motions indicative of high velocity and possibly of a subluminous nature as well. The GCTSP numbers of these 16 stars are: 422, 674, 757, 1395, 1857, 1890, 2697, 2810, 2863, 3044, 3425, 3496, 3552, 4852, 5092 and 5098. At his suggestion made in 1956, Allegheny, Cape, McCormick, Sproul and Yerkes placed some or all of the stars on their programs and he directed that Yerkes emphasize subdwarfs in their program. Later, Van Vleck added all of the stars and Yale some of them to their programs. Although no collaborative venture has yet been undertaken to produce joint parallaxes from the participating observatories, the observational data is by now quite substantial, and some of these stars will serve as calibrating standard stars in any future collaborative investigation.

In 1978 the problem of parallax standards was raised anew (Lutz 1978, Upgren et al. 1978, Upgren and Lutz 1979) and a working group was created for this purpose in 1979 by IAU Commission 24. This is not the first such group; in 1955 the same commission designated a similar group which resulted in Strand's initiative. But that was the period of the lowest ebb in parallax work and the effort was not very successful because so few programs remained active in the years immediately afterwards. The efforts of the present working group have been published (Upgren 1982). The rationale for the stars chosen is most fully evident in the paper featuring inter-observatory comparisons of parallaxes by Lutz et al. (1981). Figure 1 of that paper illustrates the severe shortcomings in basing the observatory corrections upon mean differences between observatories as Schlesinger had done. The chief problem lies in the fact that the stars observed in common by two or more observatories are rarely representative of the stars constituting the majority of the program of any one of them. Lutz et al. display the distribution in apparent magnitude and in declination for the five leading contributors to the GCTSP; Allegheny, Cape, Greenwich, McCormick and Yale. The southern observatories overlap Allegheny and McCormick only near the Celestial Equator, and Greenwich not at all. Furthermore, Allegheny and Yale adhere closely to the original Schlesinger program featuring bright stars whereas the others do not. The formulation of precepts from such unrepresentative samples is further complicated by different distributions of the colors of the program stars, and by seasonal effects which are closely correlated with right ascension. The most severe of the latter form are caused by the hemispheric difference from which arises an out-of-phase temperature variation throughout the year. Lutz et al. conclude that the observatory corrections of the past are neither statistically nor physically justified. For the new parallax catalogue, the fact remains that no proper set of standards are available and the heterogeneous collection of data compiled in it cannot be accorded observatory corrections of much value. But it is hoped that for any future fifth edition of the catalogue, the success of the present program of standards will play a role.

The report of the working group defines two closely related objectives. The first is the necessity for the ongoing monitoring of each telescope in order to evaluate any changes which may affect the degree to which it must by modeled; i.e. the plate constants beyond the customary linear and second-order ones, which may be necesary to transform its projection characteristics into cartesian coordinates. Most refractors are suitably represented by additional first and second-order terms for magnitude, color or coma or their combinations. Russell (1976, 1978) studied most active astrometric instruments from positions in the field of Praesepe and the report recommends the extension of her treatment to include this cluster and two others, the Pleiades and IC 4756. Regular evening and morning parallax observations of these clusters, near the Equator and fairly evenly spaced in right ascension, will be sufficent for this purpose.

The second objective provides for parallax standard stars (or star fields) scattered around the sky. For this purpose, the report identifies 72 stars or stellar systems in three lists. The first two lists differ only in priority; it is hoped and intended that the 20 stars comprising the first list will be placed on all progr^ms except in cases where the declination is inappropriate. The members of the working group realized the hesitation on the part of some program directors to commit more than a small portion of the telescope time to standards. The second list of 26 additional stars is made in order to encourage those whose time permits to extend their observations of standard regions. The central stars on both lists are all fainter than apparent visual magnitude 6.5. Brighter stars make up a third separate list since they require extensive magnitude reduction devices which may introduce magnitude effects such as the one that Hanson (1980) found in the Allegheny parallaxes. The program intended for the HIPPARCOS satellite, if successful, may reduce the necessity for the third list since all stars brighter than this limit will be included in its program. In selecting the standards, the group sought to optimize the following features: (1) widespread and uncorrelated distributions in right ascension, declination, apparent magnitude and color for the reasons found by Lutz et al., (2) absence of detectable orbital motion in the central star or stars, (3) availability of past parallax observations, (4) minimal disruption of presently active parallax programs, (5) availability of sufficient numbers of suitable reference stars and (6) astrophysical interest of the central star or stars. The success of this endeavor depends above all upon the willingness of parallax observers to devote a reasonable part of the available telescope time to calibration, in the same manner as do participants in photometric and spectroscopic programs.

The corrections to absolute magnitudes arising from errors in trigonometric parallaxes are not as easily applied as might be believed. Mention has been made of this difficult problem, which exists because it is not possible to define or obtain a sample of stars which is not limited in distance or apparent magnitude or both. Lutz (1983) has reviewed the Malmquist and Lutz-Kelker biases which result from samples with these two limitations. The Malmquist bias is the more easily evaluated of the two corrections, for samples drawn from a luminosity function whose form and space density are known or assumed. The Lutz-Kelker bias is not so easily handled because a true volume-limited sample cannot be obtained. Errors in parallaxes, unless they are extremely small with respect to the parallaxes themselves, produce a bias in any sample limited in observed parallax. Such a sample favors stars whose true parallaxes are smaller on average than the observed values. Lutz and Kelker (1973) sought to evaluate the correction to the absolute magnitudes computed from the parallaxes and their errors. They were successful for stars for which the error to parallax ratios are less than 0.175, a severe restriction. Our constraint of 0.15 and Gliese's equivalent limit of 0.3 in absolute magnitude are both based in part upon this limit. Since the errors are independent of the sizes of the parallaxes in most cases, the magnitude correction increases in size with increasing distance or decreasing observed parallax until this limit is reached. Lutz (1979) and others have tried to extend the range in distance over which the correction can be applied, but their efforts have not been entirely successful. The most significant consequence of this limit is the apparent inability of trigonometric parallaxes to determine the absolute magnitudes of distant luminous stars without introducing a bias affecting the luminosities by a large and unknown amount. Unless systematic effects of this kind become better understood, it remains doubtful that even large numbers of parallaxes of the very bright stars all of which are distant, will be of use in their luminosity calibration. For these stars, secondary distance methods of greater reliability will continue to be necessary and are usually available.

Perhaps the most significant of the new devices which may be used for parallax is HIPPARCOS, the new astrometric space satellite of the European Space Agency. This is one of many new and promising ways of surpassing the limit in precision of the long-focus refractor coupled with the photographic plate from which most of todays parallaxes have been determined. These methods are discussed by van Altena (1983). It should be noted here, however, that the calibration of stellar luminosities from parallaxes requires long and often tedious observations of a great number of stars of any one type, and that makers and users of new instruments and techniques are all too often mutually exclusive groups of people. The development of a method does not guarantee its extensive use. The advantage of HIPPARCOS, if it is successful at all, lies in the assurance of just this very necessary abundance of data in a reasonably short time. As a consequence, our discussion of parallax programs of the future will be mostly limited to this instrument.

Within a decade or two, the parallaxes of some 100,000 stars should be completed and reduced. This program is to include all of the 40,000 brightest stars in the sky; the faint limit in apparent magnitude of this group is about 8 visual or 9 photographic. Below this completeness limit stars would be included in decreasing numbers with increasing faintness to the detection limit of about 12 visual or 13 photographic. Although the parallax errors are not yet known, preliminary estimates are 2 mas for stars brighter than the completeness limit increasing to 5 mas at the detection limit. The effectiveness of this satellite in improving the absolute magnitudes of stars, using these errors, has been studied by Gliese (1979), Pagel (1979), Lutz (1983), Murray (1983) and Upgren (1983a,b). These investigators have described the constraints imposed by the Lutz-Kelker limit on magnitude calibration and the expected completeness and precision of the HIPPARCOS program upon nearby stars of all kinds. They conclude that the usefulness of the program in absolute magnitude calibration will be confined to the A, F and early G stars of the main and subdwarf sequences as well as the giant and subgiant sequences. For stars brighter than these, the space density is too low; too few of them lie within about 75 parsecs, the maximum distance at which the expected parallax error ratio is still smaller than the Lutz-Kelker limit. At the other extreme, they noted that too few of the stars intrinsically fainter than the early G dwarfs appear brighter than the completeness limit of the program, but this is no problem since the fainter stars are being adequately covered by the present ground based programs. By working in close collaboration with the ground based observers, and observing the same sets of standard stars, HIPPARCOS will make a great contribution to luminosity calibration by parallax.

The Hubble Space Telescope is a satellite also capable of high-precision astrometry. It is to be a 2.4-meter f/24 Cassegrain configuration of Ritchey-Chretien optical design. In the course of many other kinds of observations, it is expected to obtain parallaxes for a few hundred stars with standard errors of about 0.5 mas. If the calibration of the Malmquist and Lutz-Kelker biases can be improved and extended to parallax data of higher percentage error than 15 to 20 percent, then it may be possible to extend high-precision calibration of absolute magnitudes from parallaxes to greater distances than is now possible. In this event, some thinly populated luminous stars might be successfully observed and the bright limit in absolute magnitude of -1 to -2 expected from HIPPARCOS might be increased. Pagel (1979) has summarized the uses of small parallaxes and points out that parallaxes of at least the closest few stars as bright as absolute magnitude -5 may be useful, but only if no systematic errors are present. However, the number of parallaxes to be obtained with the Space Telescope is limited and it is likely that its major astrometric contribution will be made in two other areas. These are the nearby stars where the detection of small perturbations could lead to the discovery and study of brown dwarfs and large planets, and the parallax standard stars where its very high precision may establish the zero point of parallaxes from both the HIPPARCOS and the ground-based programs. Observations of the standards by the Space Telescope would increase the value of all recent and future parallaxes from other sources.

5. SUMMARY

It is perhaps fitting that a new edition of the Yale Parallax Catalogue be published at this time for it summarizes the period of the supremacy of the photographic plate and the long-focus refractor. In the last twenty years, the full potential of these conventional devices has been more fully realized. The field of positional astronomy is rife with new techniques and devices promising further gains in parallax precision. It is hoped that the best of these find dedicated astrometrists willing to make the lengthy parallax observations necessary for the calibration of distances and other properties of sufficient numbers of stars. But for another decade at least, our distance scale shall still be reliant upon the more conventional parallaxes, calibrated hopefully on standard stars and regions for the first time.

The author wishes to acknowledge the National Science Foundation for continuing support for the astrometric program of the Van Vleck Observatory, most recently under Grants AST-8121463 and AST-8318649.

REFERENCES

Dahn, C. C. et al. 1982, Astron. J. 87, 419.
Eichhorn, H. K. and Jefferys, W. H. 1971, Publ. Leander McCormick Obs. Vol. XVI, p. 267.
Eichhorn, H. K. and Russell, J. L. 1976, Mon. Not. R. Astr. Soc. 174, 679.
Gatewood, G. D. and Eichhorn. H. K. 1973, Astron. J. 78, 769.
Gliese, W. 1969, Veroff. Astron. Inst. Heidelberg, No. 22.
Gliese, W. 1972, Q. J. R. Astr. Soc. 13, 138.
Gliese, W. 1979, European Satellite Astronomy, C. Barbieri and P. L. Bernacca, eds., University of Padua, Padua, Italy, p. 195.
Gliese, W. 1983, IAU Colloquium No. 76, The Nearby Stars and the Stellar Luminosity Function , A. G. D. Philip and A. R. Upgren eds., L. Davis Press, Schenectady, N. Y., p. 5.
Hanson, R. B. 1978, IAU Colloquium No. 48, Modern Astrometry , F. V. Prochazka and R. H. Tucker eds., Univ. Obs., Vienna, p. 31.
Hanson, R. B. 1979, Mon. Not. R. Astr. Soc. 186, 875.
Hanson, R. B. 1980, Mon. Not. R. Astr. Soc. 192, 347.
Hanson, R. B., and Lutz, T. E. 1983, Mon. Not. R. Astr. Soc. 202, 201.
Harrington, R. S. and Dahn, C. C. 1980, Astron. J. 85, 454.
Harris, D. 1954, Astron. J. 59, 59
Heck, A. 1978, Vistas in Astronomy 22, 221.
Heintz, W. D. 1978, IAU Colloquium No. 48, Modern Astrometry , F.V. Prochazka and R. H. Tucker eds., Univ. Obs., Vienna, p. 82.
Hertzsprung, E. 1952, Observatory 72, 242.
Jenkins, L. F. 1963, General Catalogue of Trigonometric Stellar Parallaxes , Yale University Observatory, New Haven.
Lutz, T. E. 1978, IAU Colloquium No. 48, Modern Astrometry , F. V. Prochazka and R. H. Tucker eds., Univ. Obs., Vienna, p. 7.
Lutz, T. E. 1979, Mon. Not. R. Astr. Soc. 189, 273.
Lutz, T. E. 1983, IAU Colloquium No. 76, The Nearby Stars and the Stellar Luminosity Function , A. G. D. Philip and A. R. Upgren eds., L. Davis Press, Schenectady, N. Y., p. 41.
Lutz, T. E., Hanson, R. B., Marcus, A. H. and Nicholson, W. L. 1981, Mon. Not. R. Astr. Soc. 197, 393.
Lutz, T. E. and Kelker, D. H. 1973, Publ. Astron. Soc. Pacific 87, 617.
Lutz, T. E. and Upgren, A. R. 1980, Astron. J. 85, 1390.
Malmquist, K. G. 1920, Lund Astron. Obs. Medd., Ser. II, No. 22.
Murray, C. A. 1983, Proceedings of an International Colloquium on the Scientific Aspects of the Hipparcos Mission, Held at Strasbourg, France, p. 115.
Norgaard-Nielsen, H. U. 1977, Astron. Astrophys. 59, 203.
Pagel, B. E. J. 1979, European Satellite Astronomy, C. Barbieri and P. L. Bernacca, eds., University of Padua, Padua, Italy, p. 211.
Russell, J. L. 1976, Thesis, University of Pittsburgh.
Russell, J. L. 1978, IAU Colloquium No. 48, Modern Astrometry , F.V. Prochazka and R. H. Tucker eds., Univ. Obs., Vienna, p. 355.
Schilt, J. 1954, Astron. J. 59, 55.
Schilt, J. 1958, Astron. J. 63, 173.
Schlesinger, F. 1911, Astrophys. J. 33, 161.

Schlesinger, F. 1924, Probleme der Astronomie (Seeliger Festschrift), Springer-Verlag, Berlin, p. 422.
Schlesinger, F. 1926, Astron. J. 36, 185.
Schlesinger, F. 1927, Mon. Not. R. Astr. Soc. 87, 506.
Schlesinger, F. 1928, Astron. J. 38, 189.
Schmidt-Kaler, Th. 1978, IAU Colloquium No. 48, Modern Astrometry, F.V. Prochazaka and R. H. Tucker eds., Univ. Obs., Vienna, p. 55.
Slocum, F., Stearns, C. L., and Sitterly, B. W.(1938), Publ. Van Vleck Obs. Vol. I.
Stearns, C. L. 1960, Publ. Van Vleck Obs. Vol. III.
Stetson, P. C. 1974, Thesis, Wesleyan University.
Strand, K. Aa. 1958, Astron. J. 63, 152.
Strand, K. Aa. 1962, Astron. J. 67, 706.
Strand, K. Aa. 1963, Stars and Stellar Systems Vol. III, Basic Astronomical Data ,K. Aa. Strand ed., University of Chicago Press, Chicago, p. 55.
Turon Lacarrieu, C. and Creze, M. 1977, Astron. Astrophys. 56, 273.
Upgren, A. R. 1977, Vistas in Astronomy, 21, 241.
Upgren, A. R. 1978, IAU Colloquium No. 48, Modern Astrometry , F.V. Prochazka and R. H. Tucker eds., Univ. Obs., Vienna, p. 69.
Upgren, A. R. 1982, IAU Trans. Vol XVIIIB, p. 197.
Upgren, A. R. 1983a, IAU Colloquium No. 76, The Nearby Stars and the Stellar Luminosity Function , A. G. D. Philip and A. R. Upgren eds., L. Davis Press, Schenectady, N.Y., p. 57
Upgren, A. R. 1983b, Kinematics, Dynamics and Structure of the Milky Way, W. L. H. Shuter, ed., D. Reidel, Dordrecht, p. 15.
Upgren, A. R. and Breakiron, L. A. 1980, Astron. J. 85, 71.
Upgren, A. R. and Breakiron, L. A. 1981, Astron. J. 86, 776.
Upgren, A. R. and Carpenter, K. G. 1977, Astron. J. 82, 227.
Upgren, A. R., Gatewood, G. D., Lutz, T. E. and Ianna, P. A. 1978, Bull. A. A. S. 10, 649.
Upgren, A. R. and Lutz, T. E. 1979, Dudley Obs. Report No. 14, Problems of Calibration of Multicolor Photometric Systems , A. G. D. Philip, ed., L. Davis Press, Schenectady, N. Y., p. 235.
van Altena, W. F. 1971, Astron. J. 76, 932.
van Altena, W. F. 1974, Astron. J. 79, 826.
van Altena, W. F. 1983, Ann. Rev. Astron. Astrophys. 21, 131.
van Altena, W. F. 1985, IAU Symposium No. 109, Astrometric Techniques , H. K. Eichhorn ed., D. Reidel, Dordrecht, in press.
van de Kamp, P. 1962, Stars and Stellar Systems Vol. II, Astronomical Techniques , W. A. Hiltner ed., University of Chicago Press, Chicago, p. 487.
Vasilevskis, S. 1966, Ann. Rev. Astron. Astrophys. 4, 57.
Vasilevskis, S. 1969, Bull. A. A. S. 1, 209.
Vasilevskis, S. 1975, Publ. Lick Obs. Vol. XXII, Part IV.
Weis, E. W., Nations, H. L., and Upgren, A. R. 1983, Astron. J. 88, 1515.
Worley, C. E. 1966, Vistas in Astronomy 8, 33.

DISCUSSION

GLIESE: In your excellent paper you showed a color-luminosity diagram of 585 stars with accurate absolute magnitudes (standard error < 0.3). I presented that diagram last June at Middletown, having just received a preliminary version of van Altena's next parallax catalogue. Meanwhile some dubious cases have been cleared up and further photoelectric data became available. Today we have 681 stars with precise M_V data.

JASCHEK: I have seen claims that the U.S. Naval Observatory program provides parallaxes accurate to ±0.002 arcsec. Could you comment?

UPGREN: I think ±0.004 arcsec is the average external error of a USNO parallax.

STRAND: The USNO parallax program published so far had an external error of 0.004 arcsec. However the present use of fine grain plates has reduced this error to 0.002 arcsec. Another development is to extend the program beyond the 16^{th} magnitude by use of a CCD camera and for bright stars experiments are being made with a metallic spot on the filter, reducing the parallax star by about 10 magnitudes relative to the comparison stars. Such filters have been used successfully by Dr. Pascu of USNO in observations of the satellites of Jupiter.

UPGREN: The Van Vleck Observatory and many others are also experimenting with fine-grain emulsions which promise a substantial reduction in external parallax error.

JASCHEK: There was a program at the US Naval Observatory to obtain colors and spectra of all parallax stars. Is that still going on?

STRAND: Photometric observations in the UBV system are made of all stars selected as candidates for parallax observations prior to being placed on the program to ascertain if they have measurable parallaxes.

KEENAN: May I ask, that for the benefit of those engaged in statistical calibrations, parallax observers should not limit themselves to stars expected to give "good" parallaxes, but should give us a complete magnitude-limited sample down to V = 5.0?

UPGREN: Hipparcos will produce parallaxes for all of the 40,000 stars brighter than about the eighth magnitude. However, ground-based telescopes may do well to observe some of the standards among these brighter stars if only to check on any zero-point errors in these data.

POPPER: How are the external errors of the newer parallax series evaluated? There has been no discussion of the parallaxes of visual binaries with good orbits. Must we wait for results from Hipparcos or will they be included in the bright star program at USNO mentioned by Dr. Strand?

https://doi.org/10.1017/S0074180900078761 Published online by Cambridge University Press

UPGREN: Parallaxes of binaries have been done at the Sproul Observatory. Dr. Heintz may discuss this work later in this meeting. External errors of recent parallaxes are determined in a variety of ways including comparison with results from cluster members and spectroscopic parallaxes of distant stars among the reference stars.

BESSELL: If one wishes to use a parallax from a catalogue when should one use the Lutz-Kelker correction?

UPGREN: I'm not sure of the justification for applying that correction to individual stars.

MILLWARD: You showed us a table which indicates that Hipparcos will be able to obtain good parallaxes for 26 stars of magnitude -1.0 or brighter. How many of these stars are main sequence objects?

UPGREN: Most of these stars are main sequence objects, although the brightest star at M = -3 is a supergiant, Canopus.

JASCHEK: The Hipparcos limit of completeness is about 7.5 to 8.0 mag. After this limit and up to 12th mag. there exist a large number of programs of astrophysically important stars (Am, Ap, Miras, RR Lyr. etc.). There exist about 180 specific programs of this kind, so that eventually we shall get parallaxes for all these groups.

UPGREN: If the intrinsically bright groups among these kinds of stars are all very distant, it may be difficult to apply the Malmquist and Lutz-Kelker corrections in such a way to produce correct, unbiased luminosities. Secondary distance methods may still be better for some kinds of stars.

SEGGEWISS: How did you estimate the fraction of "good" parallaxes for the Hipparcos data?

UPGREN: By calculating the proportion of stars at each apparent magnitude which lie within the horizon determined by $\sigma/\pi < 0.15$ and the estimated precision of the Hipparcos data. Details are given in my paper in IAU Colloquium No. 76 held last June at Middletown.