HIGH-PRECISION PARALLAXES AND THEIR ASTROPHYSICAL APPLICATIONS

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ABSTRACT. As demonstrated by USNO CCD parallax program, a CCD attached to a modest aperature telescope is capable of measuring stellar trigonometric parallax to a precision better than 1.0 mas. consequently, many objects previously regarded as being too distant for ground-based trigonometric distance determinations can now be considered.

In this paper we show the High-precision parallaxes will provide a very good opportunity for the refinement of H-R digrammes and the calibration of luminosity criteria. we also refer to the open cluster and to determination of accurate stellar masses from close binanies.

1. INTRODUCTION

The impact which high-precision parallaxes will have on progress in astrophysics and on studies of Local Galactic structure has been described at several occasions. The usefulness of parallaxes, both as distance indicators and as the test objects for stellar astrophysics, has been amply demonstrated, and if one just looks at the flood of papers on parallax that appear each year, it is clear that the subject is not only old and inflexible, but also still very much active. The principal significance of determining trigonometric parallaxes is their use for determining absolute magnitudes (M) of a particular physical class of stars. The validity of the calibration of luminosity depends ultimately on the proportional error of the measured parallax. The error in absolute magnitude corresponding to an error ε_M in the parallax of a star whose true parallax is ε_π , is $\varepsilon_M = 2.17 \cdot \frac{\varepsilon_\pi}{\pi}$ .For a useful test of M's with accuracies of 0.1-0.2 mag., trigonometric parallaxes should be better than 5-10%. The effective horizon within which ground based trigonometric parallaxes have, on average, a relative error of 10 per cent, is about 10 parsecs. As demonsteated by Monet and Dahn (1992) a CCD attached to a modest apperture telescope is capable of measuring stellar trigonomtric parallaxes close to a milliarcsecond precision. The "10 per cent

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horizon" for USNO CCD parallax program will correspond to about 100 parsecs. The potentially very large numbers of stars for which significal parallaxes will be measurable, will enable luminosity calibrations to be carried out in regions of the H-R diagram which are not represented within a radius of 10 parsecs, many objects previously regarded as being too distant for ground-based trigonometric distance determinations can now be considered and also ultimately used for detailed study of the structure of parts of the main sequence depending on age and composition. For an assumed absolute parallax error of 0″.001, maximum measurable distance of 50-100 pcs are implied.

In the lower part of table 1, we give the limiting absolute magnitude (M_v) for v=19.0 and subdivide the space around the sun into shells according to the parallax intervals. The shells are labelled 1 to 7 as indicated in the lower part of table 1. If we take the CCD detector it will use the m.e.±0.″001 as a precision of parallax measurement, then in shells 4-5 where parallaxes have a relative accuracy of about 12%, hence mean error in M_v about ±0.^{m}26; shells 2 and 3 where the accuracy becomes close to ±0.^{m}1 ; and the inner shell 1 where the parallaxes have better than 2% and the mean errors in the absolute magnitude are well below ±0.1 magnitude.

Table 1

Parallax(P)	0.″050	0.″030	0.″020	0.″010	0.″008	0.″007	0.″006	0.″005
distance(pc)	20	33	50	100	125	145	170	200
relatve accuracy dp/p(%)	2	3	5	10	12	14	17	20
Mean error in M_v	0.04	0.06	0.11	0.22	0.26	0.30	0.37	0.43
relative accuracy in total mass	0.06	0.09	0.15	0.30	0.36	0.42	0.51	0.60
Limiting M_v for v=19.0		17	16	14.8	13.8	13.4	13.0	12.7
Shell		1	2	3	4	5	6	7

At the present time, Our 1.56m astrometric reflector is approaching completion. The main optical system of the telescope is an f/10 Ritchey-Chretien (RC) system having a focal length of 1560mm, thus giving a plate-scale of 13″.22/mm. The primary and secondary mirrors are made of the Cer-Vit.

Several observing programmes for the 1.56m telescope are planned. One of the principal goals of our 1.56m astrometric reflector is designed for determining trigonometric parallaxes of some nearby faint stars, such as red dwarfs, white dwarfs and subdwarfs, a few quasars, and for some nearby clusters such as the Hyades (Wan Lai 1986), the use of CCD detector attached to the 1.56m telescope for measuring trigonometric parallaxes has been considered, therefore this 120 anniversary of Shanghai Observatory is an appropriate occasion to evaluate what we have learnt about parallax, and how many questions, the answers to which still lie in further studies.

2. REFINEMENT OF H-R DIAGRAM

2.1 THE PROBLEM OF SUBDWARF SEQUENCE

The subdwarfs run parallel to the main sequence, and lie between the least evolved stars (main sequence stars) and the most highly evolved stars (white dwarfs). An increase in both number and precision of subdwarf distances and luminosities has been shown to be of considerable importance in the investigation of a number of problems. High-precision parallaxes should provide better determination of subdwarf sequences in the color-magnitude diagram and help to answer a few of the scientific questions that are currently under investigation. Such data lead to the following (Eggen 1973):

(1) the main sequence band in the (M_{bol}, R-I) plane for old disk-population stars is relatively narrow and coincident with the main sequence band of the Hyades star in the range R-I=0.27-0.8 mag.

(2) the band of the subdwarf sequence in the (M_{bol}, R-I) plane crosses the Hyades main sequence near the range R-I=0.27-0.7 mag.

(3) the main-sequence band for the old disk-population stars redden than R-I=0.7 mag. diverges from that of the Hyades stars, reaching a displacement near 1.5 mag. below the Hyades at R-I near 1.6 mag.

The existence of very subluminous, high velocity objects has been recognized for some time but previous have lacked the individual distance determinations needed to establish reliable luminosities. The well-delineated sequence of extreme subdwarfs extending from M_v = 11.5 to 14.5 mag. was found by Monet and Dahn (1992, Fig. 10). This may be taken as one of the most important results achieved by astrometrist in recent years.

2.2 HELIUM CONTENT OF SOME NEARBY LOW-MASS UNEVOLVED STARS

The original helium abundance in the Galaxy made from studies of the helum content of nearby low-mass unevolved stars should also be possible. The values required to locate a star in the empirical (T_{eff}, M_{bol})or (T_{eff} ,L) H-R diagram are : the apparent visual magnitude m_v , the bolometric correction BC, the effective temperature T_{eff} and the distanced d (or parallax π).It was suggested that such attempt to determine the helium content of nearby low mass unevolved stars should be chosen a sample of stars according to the following conditions :

1. limiting the subject to the study of certainly unevolved stars.
2. having accurately determined effective temperatures.
3. having accurately determined trigonometric parallaxes.
4. having not too large bolometric correction.

Effective temperature determinations for individual dwarf and subdwarf stars which T_{eff}<4000 K remain quite uncertain, and the spectra of such cool stars are dominated by numerous molecular bands that the true continum has never been observed. Greenstein et al (1970) introduced the methed of fitting blackbody energy distributions to broad band energy distributions to broadband photometric observations. A compilation of T_{eff} vs V-I values based on temperature derived from blackbody fitting have given by Monet and Dahn (1992; Fig.11). Then the effective temperature of these stars may come from the (V-I) photometric index. Bessell (1991) recently reported the determinations of bolometric corrections for M dwarfs in Kron-Cousins I bandpass using broadband photometry. Figure 13 of Monet and Dahn (1992) shows a compilation of adopted BC, vs V-I calibration based on M_{bol} determinations by Greenstein.

The main problem is to ensure the passage from m_{bol} to M_{bol} and the passage requires the knowledge of distance. Stellar trigonometric parallaxes with a precision below 1.0 mas could become a precious tool in the study of helium content of nearly low mass unevolved stars. Astrometrists and others egaged in parallax research would do well to seriously consider an increase in their effort to provide information to answer these and other questions relating to the locate and breadth of the lower main sequence.

2.3 DEGENERATE SEQUENCE

The existence of an abrupt falloff in the observed luminosity function of white dwarfs have been established , and some attention was given to the question of whether this falloff could be due to incompleteness in the observations or to some defect in the theory. Winget et al.(1987) accepted the falloff as real. Figure 4 of Iben and Laughlin (1989) shows the theoretical white dwarf luminosity function for assumed disk age of 9,12,15 and 18 Gyr. The observational estimates plotted along with the theoretical luminosity functions have been taken from Winget et al.(1987), who base their estimates on data reviewed in Liebert, Dahn and Monet (1988). A good theoretical fit is the one which has the same general slope as that defined by the observational data at luminosities less than the maximum and which shows a steep dropoff at a luminosity which is coincident with the luminosity of the dimmest white dwarfs observed. The best fit to the data using the simple theory leads to acceptable agreement for rather wide range of disk age (6-14 Gyr). The age estimated this way hings almost entirely on the last data point, and of course, the current observing program should devote to cool degenerate candidates for parallax determinations.

3. OPEN CLUSTERS

Our knowledge of distance scales rest on rather weak fundations. The distance scale now accepted for our Galaxy depends, first, on data for two or three moving clusters, and second on the assigned mean absolute magnitudes for unreddened RR Lyrae stars. In moving cluster's technique, we depend for the present largely on the Hyades moving cluster. This paticular cluster beautifully shows convergence of proper motions and, by combining proper motion and radial velocity data, we obtain precise individual absolute magnitudes for the members of the moving group. This provides us with the basic calibration for absolute magnitudes of main sequence stars of spectral types A,Fand G, including stars of comparable spectral class to our sun. The Hyades distance scale can be checked by individual trigonometric parallaxes of stars belonging to the cluster. It is a great pity that the telescopes devoted to work on trigonometric parallaxes have not made greater efforts to determine trigonometric parallaxes for individual members of the Hyades moving cluster, especially for the main sequence stars of spectral classes F,G,and K, which seem to be within reach.

With a relative accuracy of 4% for an individual parallax in Hyades and measuring of 16 members, this would provide a cornerstone with an accuracy of 1-2% or better in the distance scale.

4 BINARY SYSTEM AND MASS ESTIMATION

Stellar mass is the parameter which is of fundamental importance to the tests of theories of stellar constitution and evolution. Binary systems are the main source of fundamental data on stellar masses. Considerable progress has been made in recent years in the quality and quantity of such data, and stellar masses of high accuracy have led to a number of qualitatively new and interesting results on the properties and evolution of normal stars. Stellar masses with accuracies of 1-2% can lead to far deeper astrophysical insight than merely improving "mean" spectrum mass relation. Such deeper astrophysical insights are the precise effects of main-sequence stars or test of stellar struture calculations with different opacity tables or convection theories. Due to the great sensitity of all other parameters to the stellar masses, few usefull results on such questions can be extracted from masses with uncertainties of even 5%. For many visual binaries the accuracy by which the semi-major axis, expressed in angular measure a', has been determined is not unsatisfactory. Owing to obtain absolute dimension, the apparent orbits must be combined with parallaxes or spectroscopic orbits. The trigonometric parallaxes which are required for converting a' into astronomical units, a, and the fact that the masses are proportional to the cube of the semi-major axis. Hence, a relative accuracy of the masses, say 3 per cent or better, requires the parallax to be known with a relative accuracy of 1 per cent. Parallaxes close to a milliarcsecond precision will provide such 1 per cent accuracy for the stars in the inner sphere of table 1.

5. ABSOLUTE MAGNITUDES AND OTHER BASIC PARAMETERS OF A PARTICULAR PHYSICAL CLASS OF STARS

It has been known for some time that it would be of great interest to obtain determinations of absolute magnitude of a particular physical class of stars, but in recent years, we have become increasingly aware of the difficulties we face in the calibration of scalaes of absolute magnitude.

Owing to the expcted high-precision parallaxes with CCD camera system the star located at less than 200 parsecs of the sun will enable us to obtain absolute magnitude with a mean error of 0.4 at least.

With such material the analysis will allow us to fine locate the position of a particular physical class of stars in the H-R diagram in order to study their evolution. For example, Are B_e stars a stage during the evolution of B stars? B_e stars are on the main-sequence or about 0.5 to 1 magnitude above this sequence? Are A_p and A_m stars on or above the main sequence? It is crucial to know their absolute magnitude for a better understanding of the evolutionary scheme of these objects, and we hope to get some light on the important question of correlations between absolute magnitude and various characteristics of the central star and circumstellar region of B_e stars for example.

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