

LINEAR LIBRARY
C01 0068 2772



THE NEW SAAD INFRARED PHOTOMETRIC STANDARDS

BASED ON THE E REGIONS.

by

Brian S. Carter.

A Thesis submitted for the Degree of Master
of Science
to the University of Cape Town.

SEPTEMBER 1984.



The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

CONTENTS.

Page

1-1	Chapter 1 : Introduction.
2-1	Chapter 2 : The Objectives.
3-1	Chapter 3 : The Equipment.
4-1	Chapter 4 : The Method.
5-1	Chapter 5 : The Zero Points.
6-1	Chapter 6 : The Results.
7-1	Chapter 7 : The Comparisons.
8-1	References.
9-1	Acknowledgments.
A-1	Appendix A.
B-1	Appendix B.

CHAPTER 1
INTRODUCTION.

Infrared Astronomy.

The majority of the discoveries in infrared astronomy have been made in the last two decades. It was Sir William Herschel who discovered, at the end of the eighteenth century, the existence of what he called calorific rays. By passing the sun's rays first through a slit and then a prism, he found that a thermometer placed just outside the red end of the spectrum recorded a higher temperature than it did anywhere in the visible spectrum. In a series of papers in the Philosophical Transactions in 1800 he discussed how these rays could be reflected, refracted, transmitted and absorbed in a similar fashion to visible light and therefore deduced that these newly discovered rays were not a new type but an extension of the visible light spectrum.

It was almost 60 years before the next brightest infrared object in the sky was observed. In 1856 Piazzi Smyth just managed to detect the moon using a thermocouple instead of a thermometer. In 1870 the 4th Earl of Ross

(whose father had built the 72 inch telescope) observed the moon through its phases and deduced the range of surface temperature to be 500 deg. F (which is very close to the presently accepted temperature range).

At the beginning of this century observers at the Mt. Wilson and Lowell Observatories had improved the techniques sufficiently to enable infrared radiation measurements to be made of the brighter planets. From observations of the moon's rate of cooling when eclipsed, Wesselink deduced the surface to be covered by dust.

It was not until after the Second World War that the next major innovation came. Golay in 1947 devised a detector which, although used in the laboratory, was not generally suitable for astronomical purposes. It was around this time that the first of the modern-day detectors, lead sulphide (PbS), was used in the $1\mu\text{m}$ to $5\mu\text{m}$ region. It was discovered that PbS became more sensitive when cooled to liquid nitrogen temperatures.

The rate of discoveries then started to accelerate, spurred on by military applications. Rockets and balloon gondolas were sent up to make measurements above the majority of the earth's atmosphere. H.L. Johnson extended his UBV stellar photometry into the infrared region (Johnson 1964). Doped germanium photoconductors operating at liquid helium temperature were introduced and found to be more sensitive for the longer infrared wavelengths.

In the last few years PbS detectors have largely been replaced by indium antimonide (InSb). The modern infrared astronomer has a vast selection of detectors, filters, photometers and equipment to assist in specific infrared investigations. These include circular variable filters (CVF), arrays of detectors, sky-scanning photometers and purpose-built telescopes. Perhaps the major project in the last couple of years has been the infrared satellite IRAS which has collected a vast amount of astronomical data for the longer infrared wavelengths, most of which would have been impossible to obtain from a ground based station.

The Harvard Regions.

In a survey to establish the distribution of the brighter stars, Pickering et al (1885) divided the sky into 48 areas. The six declination zones were designated by the letters from A to F and centered on +75, +45, +15, -15, -45 and -75 degrees. It was intended that photometric sequences would be set up so that a selection of fainter stars at the centre of each region could be studied but this project was superseded by the more ambitious programme of Kapteyn's 206 selected areas (Kapteyn 1905). Nevertheless, much work over the years has been carried out on these regions. The nine E regions have long been studied in South Africa and were used in the past as the basis of the photographic standard system. Latterly they also formed the basis of the photoelectric standard system culminating in the UBVRI

standards used today at the South African Astronomical
Observatory (SAAO) (Menzies et al 1980).

CHAPTER 2

THE OBJECTIVES.

It is essential in any photometric system to use an accurate set of standards. Any single fundamental photometric measure can only be as good as the accuracy of the standards used to define it. The comparison of stars in different regions of the sky depends on the standards having consistent internal accuracy and having the same zero point over the whole sky.

The accuracy of infrared photometry has not hitherto been comparable to that which is achievable in visual region photometry but the need for the best possible set of standards is obvious. A first attempt to set up a reliable set of southern infrared standards was made by Glass (1974). As the sensitivity and stability of infrared detectors and electronics have improved it has been found that the accuracy of these original Glass standards was relatively poor, although adequate for their time.

Over the past decade a vast quantity of infrared photometric data has been gathered at the Cape using these original Glass standards. Large programmes have been undertaken, such as 2883 observations of 627 Mira and long period variables (Catchpole et al 1979), which has led to a better understanding of Mira variables (Feast et al 1982). Red variables in the Magellanic Clouds have been observed so that a period-luminosity relationship could be obtained (Feast et al 1980). The majority of red variable stars tend to be of long period so several years' observations are needed to give adequate coverage of their light curves. Stars such as RY Sagittarii (to be published) and Eta Carinae (Whitelock et al 1983) have been regularly observed over the last nine years. Many simultaneous collaborative programmes have been carried out which include X-ray, radio and infrared observations of the rapid burster MXB1730-335 (Lawrence et al 1983) and the IUE spectra, visual and infrared photometric observations of the X-ray binary V861 Scorpii (Howarth et al 1981). Several Novae have been monitored, e.g. Nova Serpentis 1983 (Feast and Carter 1983). The X-ray, optical and radio variable SS433 has been monitored since its discovery and found to have the 165.5 day spectroscopic period in its infrared data (Catchpole et al 1981). Many other infrared photometric projects have been carried out over the years, including R CrB stars, shell stars, symbiotic stars, Cepheids and many galaxies.

Since 1974, when the Glass standards were published, four other infrared groups have been set up at the other main southern observatories, i.e. the two Australian observatories, Mount Stromlo and Siding Spring Observatory (MSO) and Anglo-Australian Observatory (AAO) and the two observatories in Chile, European Southern Observatory (ESO) and the Cerro Tololo Inter-American Observatory (which uses the California Institute of Technology standard system) (CIT). Unfortunately there has been a serious lack of conformity. Each group has used a different set of filters and has different zero points. No standards are common to all the groups and only a few are in common between any of the systems. Several transformations between the various systems have recently been published (Elias et al 1983 and Glass 1983) but the large errors in the transformation equations show the need for more accurate standard stars.

Therefore, on the surface, the introduction by us of a new set of standards would appear in danger of adding confusion to the issue, but this is not, in fact, the case. Firstly, the new set is basically the same system as the Glass standards but with greatly increased accuracy. Secondly, the work involved has shown up several anomalies and inaccuracies in other systems. Thirdly, this work has shown why such large errors are apparent when comparing the various sets of standards and where the causes probably lie.

The observations for these new standards were started in August 1979. The standards were introduced at the SAAD at the beginning of March 1984. The set is likely to evolve with time, increase in number of stars and improve in accuracy.

CHAPTER 3

THE OBSERVING EQUIPMENT.

Introduction.

The only parts of the equipment used of direct scientific interest in the compilation of the new standards are the telescope, photometer and reduction programmes. We set them in context by discussing wider aspects of the overall project.

The Observatory.

The Royal Observatory at the Cape of Good Hope was established by the Board of Longitude in London on the 20th October 1820 (Warner 1979). On 1st January 1972 the Council for Scientific and Industrial Research (CSIR) in South Africa took over most of the financing of the Observatory and the name was changed to the South African Astronomical Observatory. The Observatory is the oldest scientific institution in South Africa.

The site originally chosen was some three miles from Cape Town but in the nineteen sixties it became obvious that this site was no longer suitable for modern astronomical work. Cape Town had grown over the past century and a half and its suburbs had spread many miles beyond the Observatory. With the introduction of the new name came the establishment of a new observing site near Sutherland in the Karoo.

The Site - Sutherland.

The observing site in the Karoo was built 18km from Sutherland, a little less than 400km by road from Cape Town. Sutherland lies on the dividing line between the winter rainfall area of the Western Cape and the summer rainfall area to the north and hence clear nights are evenly distributed throughout the year. The percentage of photometric nights (i.e. no clouds higher than 20 degrees above the horizon) was 51, 53, 46, 52 and 46 for the years from 1979 to 1983 (SAAD Annual Reports). The Karoo is a region of arid scrubland and very little surface water with the result that the atmosphere is dry. Dust in the atmosphere is rarely a problem.

The site was chosen after fairly extensive (if somewhat sporadic) site testing, in which the author took part. The telescopes are established on a flat hill above the surrounding countryside, at an elevation of 1758m above sea level. The geographical coordinates of the site are

-1h23m14.57s, -32° 22' 46".

The Telescope.

The telescope used in the observations of the new standards was a 0.75m Cassegrain telescope with a focal ratio of f/15, built by Grubb Parsons in 1974. The telescope replaced the counter weight side of an existing mounting used for a cluster of small refracting telescopes. The main drawback to this arrangement is that it is impossible to balance the telescope for all parts of the sky.

The telescope was not specifically designed for infrared work. The secondary mirror assembly, together with the supporting struts, is large and therefore emits unnecessarily large background infrared radiation at the longer wavelengths.

The Photometer.

The MkII infrared photometer was an updated version of the MkI photometer designed and constructed by Dr I.S. Glass. A full description of the MkI can be found in Glass (1973).

Fig 3.1 shows the photometer. A full description is given in Glass (1980), therefore we will not give a complete description here. The main point to notice is the two light paths into the cryostat. The "star" or main beam is

reflected into the cryostat from the front face of an aluminised, rotating, three-bladed chopping mirror. The "sky" or reference beam is reflected into the cryostat from the front face of an aluminised fixed mirror whenever the rotating chopper blade is not in its path. The detector in the cryostat therefore alternately sees the beam from the star and sky at a frequency of 12.5Hz. Chopping from the star to the sky is desirable for two reasons :-

- a. Some detectors suffer from low-frequency (1/f) noise so any slow sensitivity variations will be cancelled out.
- b. There is strong emission from the atmosphere and from the walls of the photometer at wavelengths greater than about $2\mu\text{m}$.

The Cryostat.

Fig 3.2 shows the cryostat. Again no full description is presented here as this can be found in Glass (1980).

The detector is a photovoltaic cell of indium antimonide (InSb) which is cooled to liquid (77 deg.K) or solid (<63 deg.K) nitrogen temperatures. Normally a vacuum pump is attached to the liquid nitrogen filling pipe which reduces the pressure in the liquid nitrogen container and hence causes the nitrogen to solidify. Fig 3.3 shows the vapour pressure of the liquid/solid nitrogen as a function of time, from the start of pumping on a typical occasion. The first plateau between 30 and 80 minutes occurs when the nitrogen is solidifying. It can be seen that about four

hours are required for the pressure to stabilize completely. The scale of temperature (righthand side of graph) was obtained from Kaye and Laby (1971). It should be noted that the temperature scale is not linearly related to the pressure scale, hence small changes in the pressure, when the pressure is low, represent a larger temperature change, compared with the effect of pressure changes at higher pressures.

It should also be noted that the filters and aperture wheel are inside the cryostat and not in the photometer itself. This is because the star light focus is inside the cryostat.

The Filters.

The J, H, K and L filters were made by the Optical Coating Laboratory Inc. and are wide band interference filters formed by the vacuum deposition of dielectric films. Fig 3.4 shows the characteristics of the filters. (Note that the wavelength scale is not the same in all plots and is non-linear for the L filter). The J, H, K and L filters are centred on approximately 1.25, 1.65, 2.2 and 3.4 μm respectively. More accurate filter effective wavelengths and half power band widths can be found in chapter 7. These wavelengths coincide approximately with the infrared atmospheric windows. At other infrared wavelengths water vapour and carbon dioxide in the atmosphere absorb most of the incident radiation. Fig 3.5 shows the atmospheric

transmission and absorption bands for the wavelengths covered by the J, H, K and L filters. The percentage transmittance was measured at sea level through a 1000ft horizontal air path with 5.7mm of precipitable water and at a temperature of 26 deg. C. (Courtesy of Santa Barbara Research Centre). Obviously the transmission of star light which passes through the whole atmosphere will be smaller but is basically similar in wavelength dependence.

The Electronics.

A full description of the electronic circuitry has been given by Glass (1980) and may be summarized as follows. The signal from the detector is amplified by a pre-amplifier which is partly inside the cooled cryostat. The output of the pre-amplifier is fed to a lock-in amplifier which is triggered by a reference signal derived from the rotating chopper. The lock-in amplifier adds the main signal (Star+Sky) and subtracts the reference signal (Sky). The resultant voltage output is :-

$$(Star+Sky) - (Sky) = (Star).$$

This output voltage is fed into a voltage-to-frequency converter and hence into a pulse counter within the computer interface board, thus forming an analogue integrator.

The Observing Procedure.

The apparent sky brightnesses in the main and reference beams are not in general identical. This arises because the detector is "viewing" slightly different parts of the telescope in the two cases, i.e. different areas of thermally emitting surfaces lie within the two beams. For this reason the star is first measured in the main beam and then in the reference beam and the difference taken, i.e.

$$[(\text{Star} + \text{Sky}_1) - (\text{Sky}_2)] - [(\text{Sky}_1) - (\text{Star} + \text{Sky}_2)] = 2(\text{Star}).$$

The actual observing procedure was to make observations in the following beam order : Main-Ref-Ref-Main. Each integration was 10 seconds and the four measures were referred to as a "module". This basic module was repeated until a sufficiently accurate result was obtained. It is obvious that faint stars need a greater number of modules than does a bright star. As the vast majority of these standards are bright only one module for J, H and K was required to gain an internal accuracy of <0.005 but this was always increased to a minimum of two modules. For the fainter L magnitudes it could require as many as 12 modules to reduce the internal error to <0.020 .

The Reduction Programmes.

Over the four and a half years that this project took to complete, a succession of fundamentally similar reduction programmes was used.

The first reduction programme was a simplified version of one originally written by the Caltech infrared group. The number of pulses counted from the voltage-to-frequency converter and the filter number were recorded on paper tape. The time of observation was recorded manually and punched onto cards. Both tape and cards were fed into the computer where the data were correlated and then reduced.

The first on-line reduction programme called MANFRED was then developed (by Dr L.A. Balona), controlled by a NOVA computer. The zero point was set by the first standard of the night which provided reduced results for subsequent stars which, although not final, were close enough to guide the observer concerning the quality of the night and enable him to recognise strange results (whether real or due to procedural error). A paper tape was made at the same time which was transported to Cape Town where a final reduction, using all the standard stars to set the zero point, could be made. NEWMAN (written by Drs Balona and P.A. Whitelock) is an update of MANFRED introduced when the paper tape and teletype were superceded by magnetic cartridge and VDU.

All the reduction programmes used the same basic formulae :

Let X_1 , X_2 , X_3 and X_4 be the measures from the basic module (Main, Ref., Ref., Main), t the integration time and n the number of modules.

$$\text{Then } \bar{X} = 1/4n \sum_{i=1}^n (X1-X2+X4-X3)/t$$

where \bar{X} is the mean deflection of the star.

The mean magnitude (m) is then given by

$$m = -2.5 \log \bar{X} - EM + G + Z$$

where E is the extinction coefficient for the appropriate wavelength, M is the air mass through which the observation was made, G is the amplifier gain expressed in stellar magnitudes and Z the appropriate zero point.

After each observing module the computer prints the running mean magnitude as calculated above. It also calculates a running standard error which informs the observer how accurate the observation is so far. This running standard error is calculated as follows :-

The mean square error (S^2) in the mean deflection of the star is given by :-

$$S^2 = \sum_{i=1}^n [\{ [(X1-X2)/2t] - \bar{X} \}^2 + \{ [(X4-X3)/2t] - \bar{X} \}^2]$$

$$s = S / [\sqrt{2n(2n-1)} \bar{X}]$$

which gives the running mean magnitude error (σ) as :-

$$\sigma = 1.25 \log [(1+s)(1-s)]$$

which is half the difference between the magnitude calculated with the deflection error added and the magnitude calculated with the deflection error subtracted.

The Atmospheric Extinction.

The atmospheric extinction coefficients used in the reductions were 0.10, 0.06, 0.10 and 0.15 magnitudes per air mass for J, H, K and L respectively. These values were taken from the Caltech observations, at a similar altitude to Sutherland, as described by Manduca and Bell (1979) and private communications. They were tested occasionally by following a star from near the zenith to as close to the horizon as possible (or vice versa) and although they varied slightly from night to night they were found to be constant within 20 per cent. This variation could not only be caused by the extinction slightly changing from night to night but by it drifting during the long run of observations on the same star or even a zero point drift. Errors introduced by using fixed atmospheric extinctions would be very small as the majority of observations were made near the zenith. If, for example, the extinction coefficient for a particular night was in error by 20 per cent the errors introduced by comparing an observation at the zenith with an observation at an air mass of 1.15 (30 degrees from the zenith) would be 0.003, 0.002, 0.003 and 0.004 for J, H, K and L. Obviously comparisons made nearly simultaneously at the same air mass would have no errors introduced.

The air mass M was originally calculated as :-

$$M = \sec Z$$

where Z is the zenith distance,

then latterly as :-

$$M = \sec Z(1-0.0012\tan^2 Z) \quad (\text{Young 1974}).$$

The difference between these two is negligible for fairly small air masses. The largest observed air mass in the reduction of these new standards was 1.4 where the difference between the formulae is only 0.002 air masses.

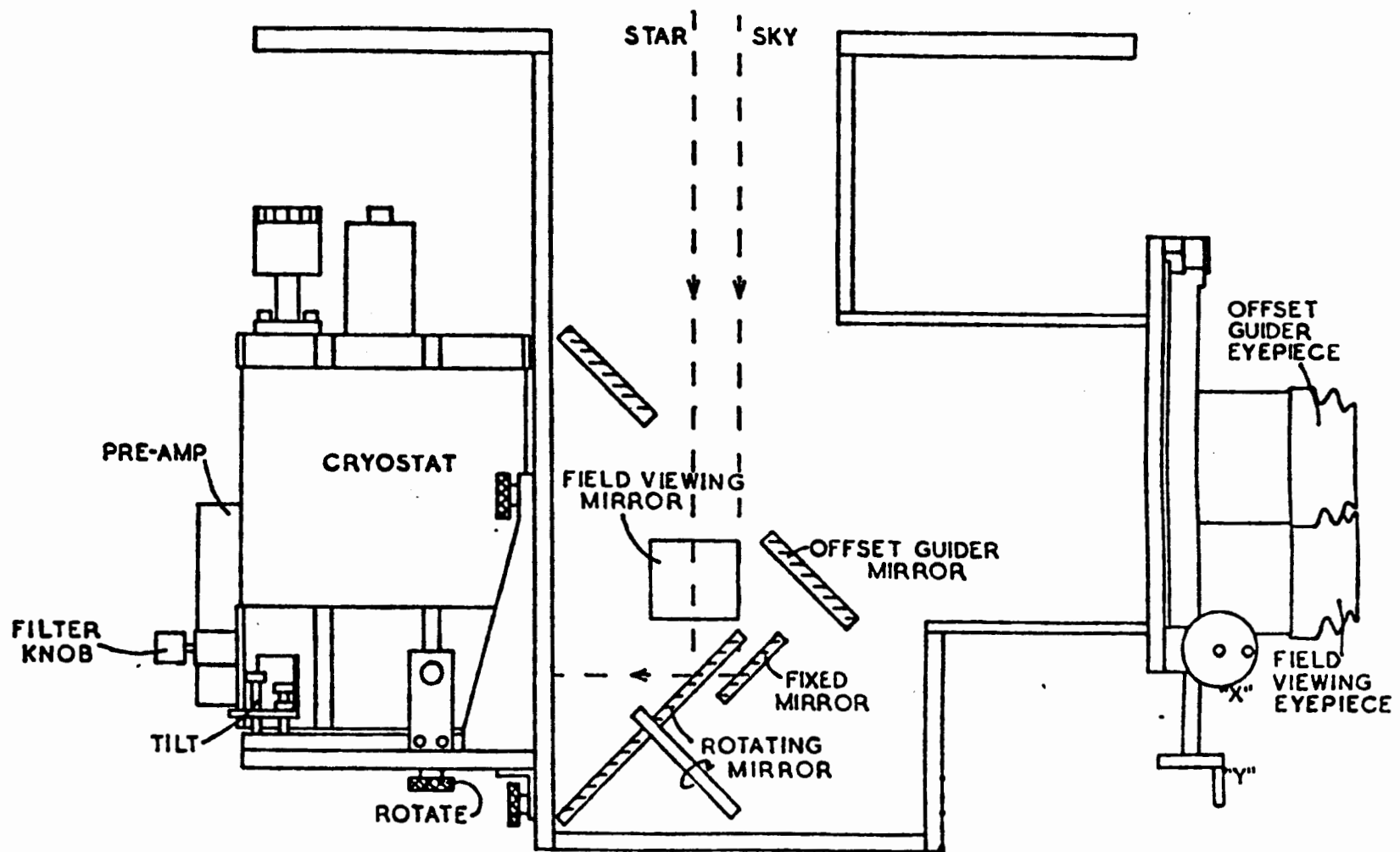


Fig. 3.1. The Photometer.

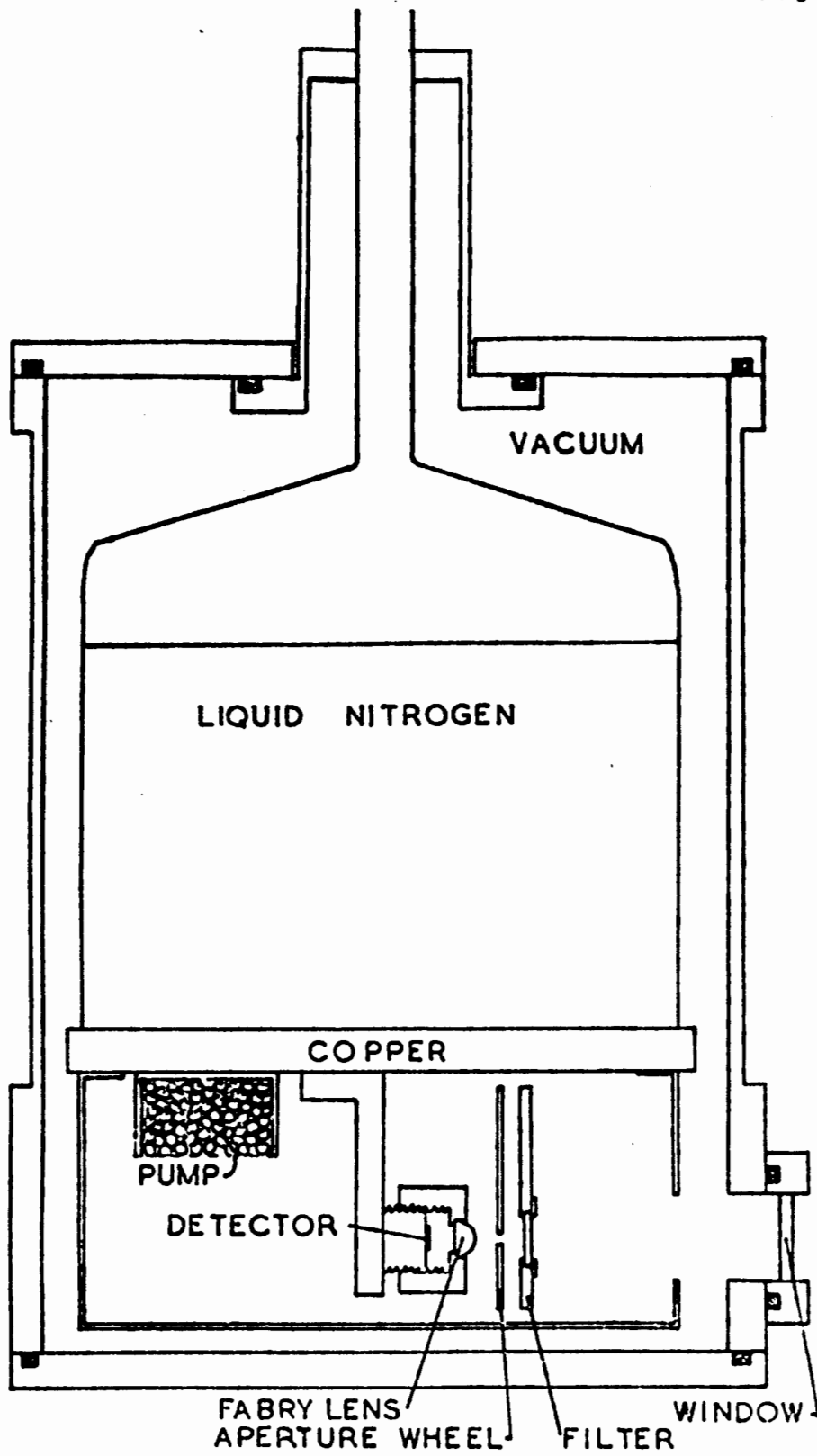


Fig. 3.2. The Cryostat.

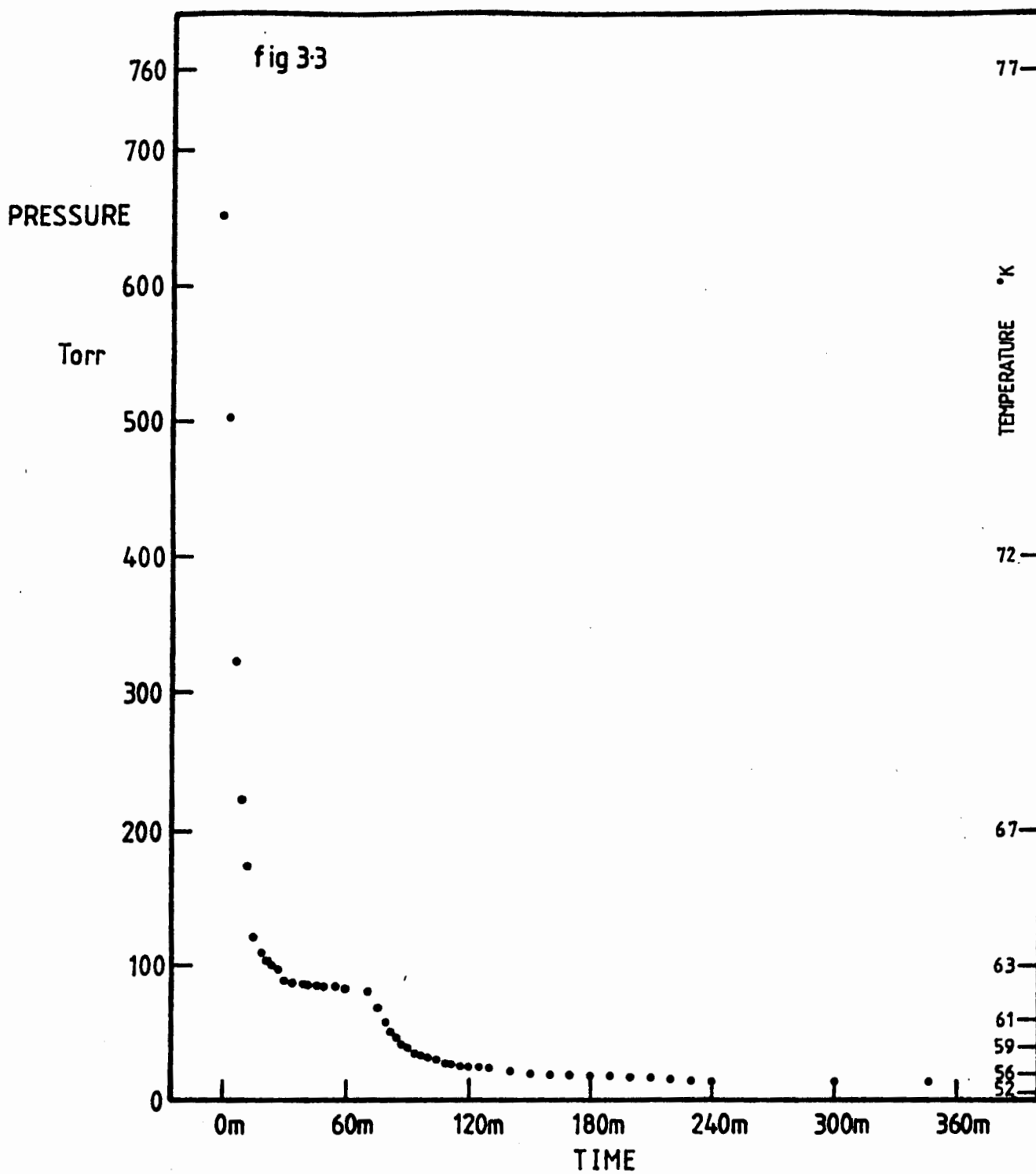
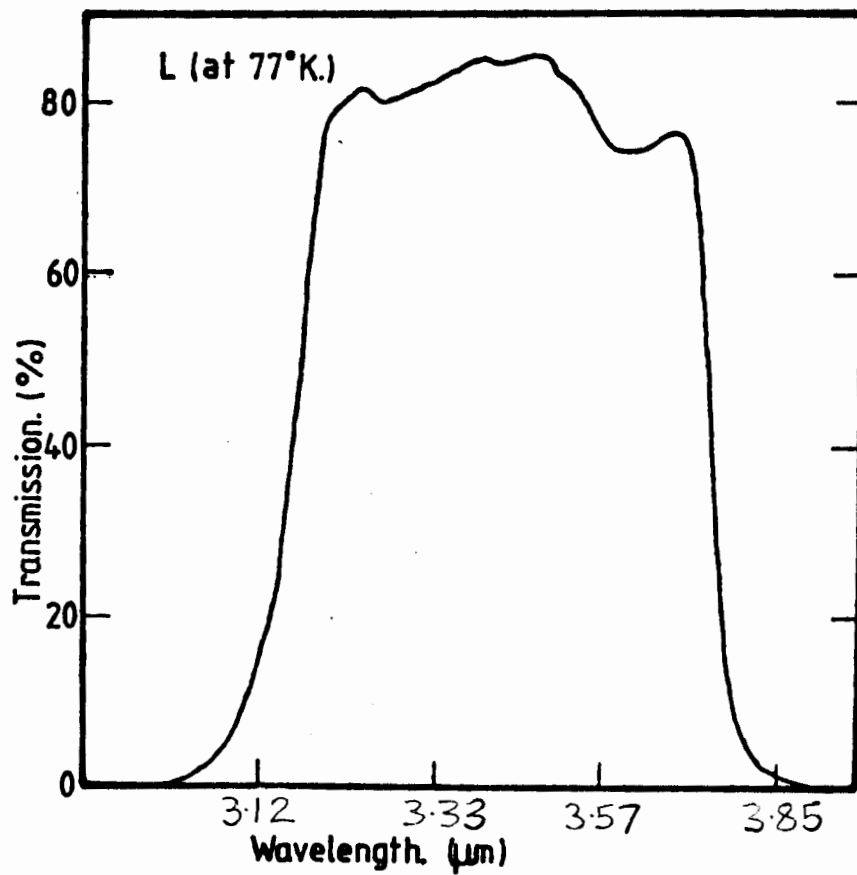
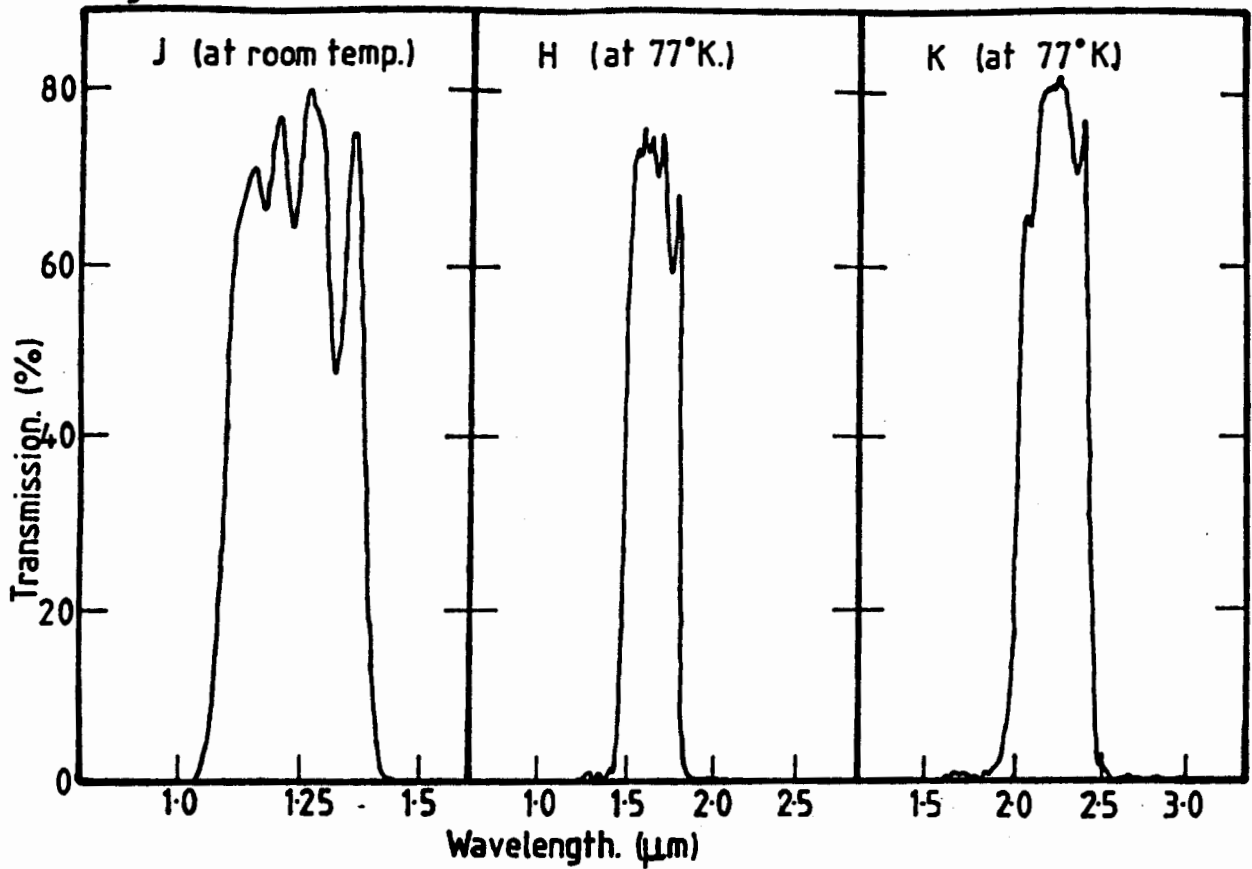


fig 34



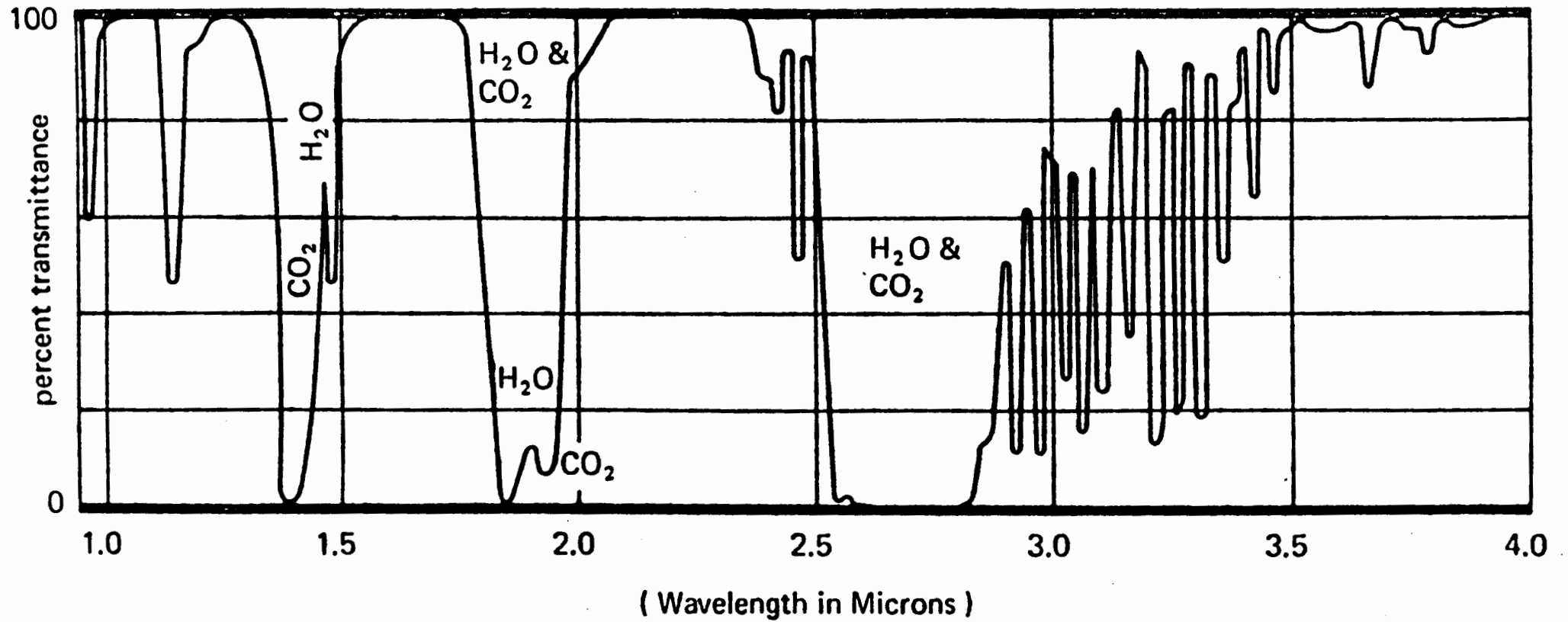


Fig. 3.5. The Atmospheric Transmission.

CHAPTER 4
THE METHOD.

Introduction.

From experience gained by the optical photometrists at the Cape, (Stoy 1956, Cousins and Stoy 1962, Cousins 1963, Cousins 1971, Cousins 1973, Cousins 1976 and Menzies and Laing 1980) the method we describe here appears to be the most logical approach to the problem of setting up a sound system of standards. However, the success or failure of the project could only be judged towards the end of the programme because of its high dependence on the consistency of the results.

All the observations made to establish these new standards were made by the author.

The selection of stars.

A vast amount of work has been carried out on UBVR photometry of the standard stars in the nine Harvard E regions, culminating in the present set of standards used at the SAAO (Menzies et al 1980). It therefore appeared

logical to select the new infrared standards from these well observed E region stars. This it was hoped would greatly reduce the possibility of selecting variable stars which would cause confusion during the analysis phase of the programme.

Two stars from each of the nine E regions were selected. Usually these two were the brightest (in the infrared) amongst the main sequence stars. Main sequence objects were chosen to reduce even further the possibility of selecting a variable. The two stars from each region were used to form two rings (No's 1 and 2) around the sky.

It was originally intended to use both rings for J, H, K and L but it soon became evident that a large fraction of the stars was too faint to allow the measurement of reasonably accurate L values. Sometimes even the brightest of the two stars was not sufficiently bright. For this reason the L measures were separated from the J, H and K ones and a special ring (ring L) selected, i.e. ring 1 and ring 2 were solely for J, H and K and ring L for L only. (For E1, E2, E3, E5, and E7 the ring L stars were the same as the ring 1 stars but for the other regions they were different).

Once magnitudes for the stars in these three rings could be fixed they were used to measure the magnitudes of another set of stars. These additional stars were of four types:-

a. Zero point stars which finally fixed the magnitudes of the ring stars (Chapter 5).

b. Three more stars from each E region, one of which was a brightish red star, the other two being fainter main sequence stars. (The J, H and K values for the L ring stars were also determined).

c. Stars which occurred in the standard lists of other observatories.

d. Stars which various SAAD observers wished to use as standards, either because of their position or in order to re-reduce old photometry more accurately.

The construction of the rings.

The three stars in the E1 region are denoted E11, E12 and E1L. Similarly for E2, they are called E21, E22 and E2L and so on up to E9.

In order to construct ring 1, star E11 was measured in J, H and K and immediately afterwards star E21 was observed at the same air mass but on the opposite side of the meridian. The time when the two stars could be observed at the same air mass was calculated beforehand. At the appropriate later time star E21 was measured and immediately afterwards E31 at the same air mass. These measurements continued until E91 was measured followed by E11. It is obvious that all these comparisons could not be made on the same night but had to be spread around the year. These measures were continued over about two years until at least

two of each comparison had been made. To forestall any systematic error caused by a certain filter being observed at slightly different air masses, if the first star was observed in the order J, H, K the second would be in the order K, H, J or vice versa.

The difference in each comparison was calculated and the sum of all the differences should of course be equal to zero. i.e.

$$(E11-E21)+(E21-E31)+\dots+(E91-E11) = 0.$$

If the sum so formed is not equal to zero a closing error is said to be present. This closing error should of course be very close to zero if the measurements have been made accurately, no star has varied or no systematic errors were present. Another ring using the same stars was made but instead of comparing adjacent regions, the alternate regions were used, i.e. E11 was compared with E31, E31 with E51 and so on until E81 was compared with E11.

Similarly, we should have

$$(E11-E31)+(E31-E51)+\dots+(E81-E11)= 0.$$

At first, values of J, H and K were arbitrarily assigned for star E11 and using the differences the values for the other stars were determined. Any small closing errors were distributed equally around the ring so that the value of E11 was the same at both ends.

The values obtained for the stars from these two rings were combined with weights in the ratio of 3:2 for the adjacent and alternate regions respectively as it was estimated the accuracy of the ring with the larger air mass observations was slightly inferior.

The same method was employed for the second set of (fainter) stars for J, H and K, i.e. for E12, E22, to E92.

The closing errors of the four J, H and K rings were as follows:-

	J	H	K
Adjacent region ring 1	-0.016	-0.021	0.000
Alternate region ring 1	-0.016	-0.022	+0.014
Adjacent region ring 2	-0.006	+0.012	+0.014
Alternate region ring 2	0.000	+0.018	+0.008

The two rings so calculated (by combining the four rings) were each internally accurate but on different arbitrary zero points. To put them on the same arbitrary zero point the two stars in each E region were compared. i.e. E11 with E12, E21 with E22 etc. A constant for J, H and K was applied to one of the rings so that the best agreement in all these differences was obtained i.e.

$$(E11-E12+c)_{cal} + (E21-E22+c)_{cal} + \dots + (E91-E92+c)_{cal} \\ - (E11-E12)_{obs} - (E21-E22)_{obs} - \dots - (E91-E92)_{obs} = 0.$$

At this point both rings were then on the same arbitrary zero point. Ultimately, the zero point correction as described in Chapter 5 was applied to all 18 stars and the resultant values formed the basis for the new standard system.

The single L star in each E region was used in a similar procedure to construct preliminary L values. Two rings were obtained as before, i.e. comparisons were made between the adjacent and alternate regions. These two rings were weighted in the ratio of 3:2 as with the J, H and K rings. The zero point correction (Chapter 5) was applied and the new values were adopted as the basis for L photometry on the new system.

The closing errors for the two L rings were as follows:-

Adjacent region ring	-0.092
Alternate region ring	-0.103

It can be seen that the closing errors for L are considerably larger than for J, H and K. There are two reasons for this: Firstly, the L band includes many saturated atmospheric absorption features as shown in Chapter 3, fig 3.5. Secondly, the noise introduced by diffraction at the chopper edge is much worse at longer wavelengths where the photometer is luminescent. It is hoped that the chopper noise will be drastically reduced when the Mk III infrared photometer comes into operation in

the near future. It may also prove profitable to abandon the L filter in favour of the L' filter as used at the AAO and ESO. This L' filter is centered at $3.8\mu\text{m}$ which avoids many of the atmospheric absorption lines. It should be noted that the original reason for choosing the L filter was that the PbS detectors cut off at longer wavelengths.

Method used to increase the number of standards.

The four groups of additional standard stars, mentioned earlier, were observed as follows. For J, H and K the extra star was observed sandwiched between observations of the two closest primary standards and in the case of L a measure was made adjacent to the primary L standard. A minimum of two such comparisons was made (more if necessary) until the error was less than 0.010 for J, H and K and 0.030 for L. The bracketed results in Chapter 6 were outside these errors. It is intended that these stars will be re-observed in the near future.

The last few sections appear to imply that each stage was separate and needed to be completed before moving onto the next section of observing. It is obvious, however, that each stage of observation (i.e. ring comparisons, zero point stars and extra standards) can be made during the same night. A typical sequence of observation, which included all these three, was :-

E12, BS0077, E11, E21, ZP star, E22, etc.

A check on the accuracy of the basic standard stars.

If one of the basic J, H and K standard stars was in error, whenever it was used to determine the value of an additional standard star the values obtained would be systematically different from that obtained by using the other basic standard star in the region. No such effect was present.

Conclusion.

In this chapter's introduction it was stated that the success or failure of the project could only be judged towards the end of the programme. This chapter has shown that the closing errors of the J, H and K rings are very small and each of the basic J, H and K standards has the same zero point. Chapters 6 and 7 will verify the excellent quality of the standards. It was therefore concluded the method was a success.

CHAPTER 5
ZERO POINTS.

Introduction.

The first general photometric system to achieve satisfactory accuracy was the UBV system for the visible and ultraviolet regions (Johnson and Morgan 1953). Its zero points were arbitrarily chosen to satisfy two conditions :-

a. That V be the observed magnitude through a specified yellow filter/photomultiplier combination, approximately equivalent to the old photovisual magnitude on the International System, reduced to outside the earth's atmosphere.

b. That the colours $B-V$ and $U-B$ should average to zero for specified main sequence stars of class A0 on the MK spectral classification system.

It would appear logical to extend this method of setting zero points to the JHKL photometric system, but certain practical difficulties present themselves, chiefly that the dispersion in the measured colours of A0V stars is relatively large in the infrared. Part of this problem arises from the intrinsic scatter of the colours themselves

and partly it is due to the difficulty of making accurate measures for a sufficiently large sample.

The existing infrared photometric systems with which the present results may be compared have employed a variety of methods for the determination of zero points to minimize these difficulties. Fortunately the differences between them have turned out to be fairly small.

We consider each in turn.

Previous Zero Point determinations.

a. Johnson.

Johnson did not include the H band originally so he only determined zero points for J, K and L. In his early work (Johnson 1964) he plotted various colour indices against B-V for main sequence stars and drew in smooth mean curves. The vertical scales of these plots were then adjusted so that when B-V was zero, V-J, V-K and V-L were also zero. Later Johnson (1966), using the more extensive photometric data contained in Johnson et al (1966), found that the mean values for AOV stars with the previously adopted zero points were :-

$$V-J = -0.01$$

$$V-K = -0.03$$

$$V-L = 0.00$$

b. SAAO.

Glass (1974) obtained his zero point by observing about 20 stars from Johnson et al (1966). These gave the zero points for the J, K and L filters. A pseudo-Johnson H magnitude was obtained from Johnson's J and K values by means of the interpolation formula $H=0.19J+0.81K$.

This method of determining zero points has three main drawbacks :-

i. The filters used by Glass did not have the same passband as Johnson's but the difference was not considered important at the time.

ii. Johnson's random and systematic errors were rather large and therefore were carried over to the Glass standards.

iii. This method was not an independent determination so any systematic (e.g. R.A.-dependent errors) in Johnson's work were also transferred.

c. ESO.

Engels et al (1981) decided upon a similar method to Glass (1974) but drew their selection of stars from seven different catalogues of infrared data. These included Johnson et al (1966), Glass (1974) and Thomas et al (1973) (which was the forerunner of the MSO system : the values for J, H, K and L have been superceded but the longer wavelength magnitudes are still in use).

As with Glass's zero point determination, any errors in the various catalogues were perpetuated. Added to this was the complication that all of these previous compilers used different filters and hence were not on the same system as Engels et al (1981).

d. CIT.

Frogel et al (1978) set their zero points by defining the magnitude of the A0V star Vega (BS7001) to be zero at all wavelengths.

Elias et al (1982) combined the values from Frogel et al (1978), together with the unpublished Caltech standards, to establish a well calibrated list of 16 bright infrared standards. This list contained stars from the whole sky, a few of which could be observed from both hemispheres. Using these basic JHKL standards, they measured the magnitudes of a further, much fainter, set of standards.

This determination of zero point has three main drawbacks :-

- i. Vega cannot be observed satisfactorily from the south.
- ii. On the UBV system Johnson et al (1966) give Vega the value of 0.03 for U, B and V.
- iii. Basing a photometric system on one star could lead to difficulties if it was subsequently found to be variable. In fact the Bright Star Catalogue (Hoffleit 1982) notes Vega as a variable of amplitude 0.02 in V and a period of 0.07 days.

e. and f. MSO and AAO.

MSO (Jones and Hyland 1982) and AAO (Allen and Cragg 1983) determined their zero point in a similar way to CIT. The main sequence A0 star BS3314 was used and given "near" zero colours.

i.e. Values for BS3314 :-

	K	J-H	H-K
MSO	3.940	-0.010	-0.006
AAO	3.940	-0.010	0.000

Its magnitudes are fixed and all adjustments to the two systems are made relative to these values. It can be seen that the K magnitude is identical in both systems but the other magnitudes differ slightly.

BS3314 is a better choice than Vega as it is observable from both the north and south. The problem of it possibly being a variable still remains. Johnson et al (1966) and Cousins (1971) found the colours for BS3314 not to be zero in the UBVRI system. They also give BS3314 a V magnitude of 3.90 whereas MSO and AAO give a K magnitude of 3.94.

Determination of Zero Points.

In this new set of standards the zero points were set by a method similar to that employed by Johnson (1964). Only four main sequence A0 stars observed were actually bright enough for an accurate measure of their L magnitudes. This is too small a sample for an accurate mean colour. (By chance the mean B-V is zero for these four stars but with a

standard error >0.01). Therefore 25 main sequence stars (Table 5.1) were selected, ranging in spectral type from B1 to A7 and having a range of B-V from -0.195 to +0.170. (It should be noted that the star classified as B1V is not the bluest star and has a B-V of only -0.035 which would suggest a misclassification). The spectral types were obtained from the Yale Bright Star Catalogue (Hoffleit 1964) and the V and B-V values were from Cousins (1971).

These stars were measured relative to the previously determined internally accurate E region standards which were based on arbitrary zero points. V-K was plotted against B-V (Fig 5.1). It can be seen from Fig 5.1 that these points lie fortunately on a good approximation to a straight line. By moving the vertical scale, this line, determined by least squares, was made to pass through the origin. Thus by adoption of the V values a correction to the K magnitudes was determined. The uniform adjustment to the K magnitudes obtained from the 25 stars was applied to the K values of all the basic E region standards. These corrected values are used henceforth.

A similar method was used to set the zero points for J and L. As the K values had already been determined, J-K was plotted against B-V (Fig 5.2) and the J values adjusted to set the zero point. Similarly the L zero point was determined by plotting J-L against B-V (Fig 5.4)

The plot of J-H versus B-V (Fig 5.3), used to set the H zero point, is not quite linear. A slightly curved line was drawn freehand through these points and, by adjusting the vertical axis, made to pass through the origin. Thus the H zero point was set. The difference between this method and that using a straight line was 0.01 magnitude in the sense that the curved line gave slightly brighter values of H.

The equations of these lines were found to be :-

$$V-K = (2.793 \pm 0.024)(B-V) + (0.000 \pm 0.013)$$

$$J-K = (0.719 \pm 0.007)(B-V) + (0.000 \pm 0.004)$$

$$J-L = (0.918 \pm 0.015)(B-V) + (0.000 \pm 0.008).$$

From Fig 5.3 the standard errors for H appear to be less than for J, K or L.

The advantage of plotting the various colours against B-V instead of spectral type are :-

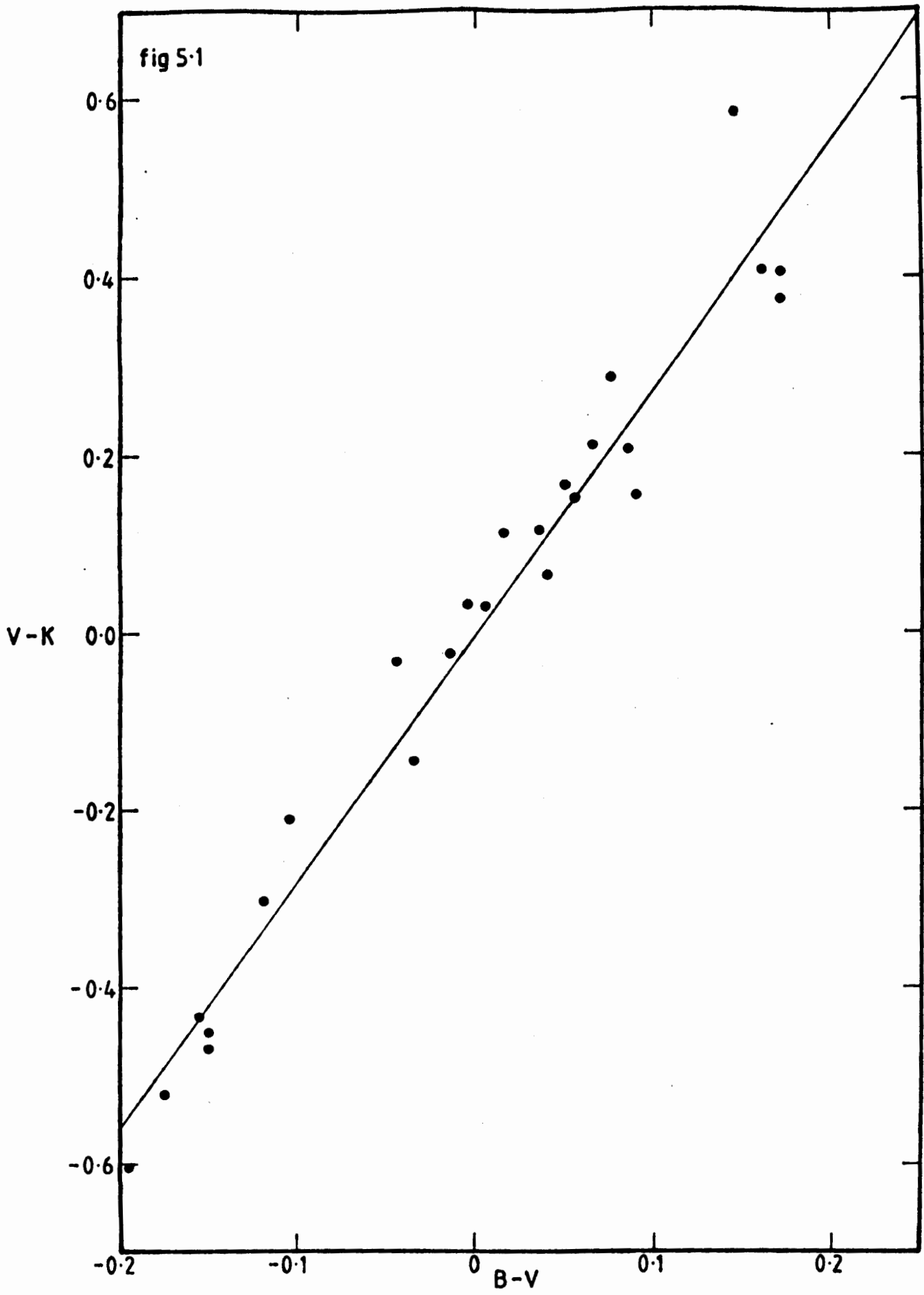
a. The lines are almost parallel to the reddening lines and therefore reddening can be ignored.

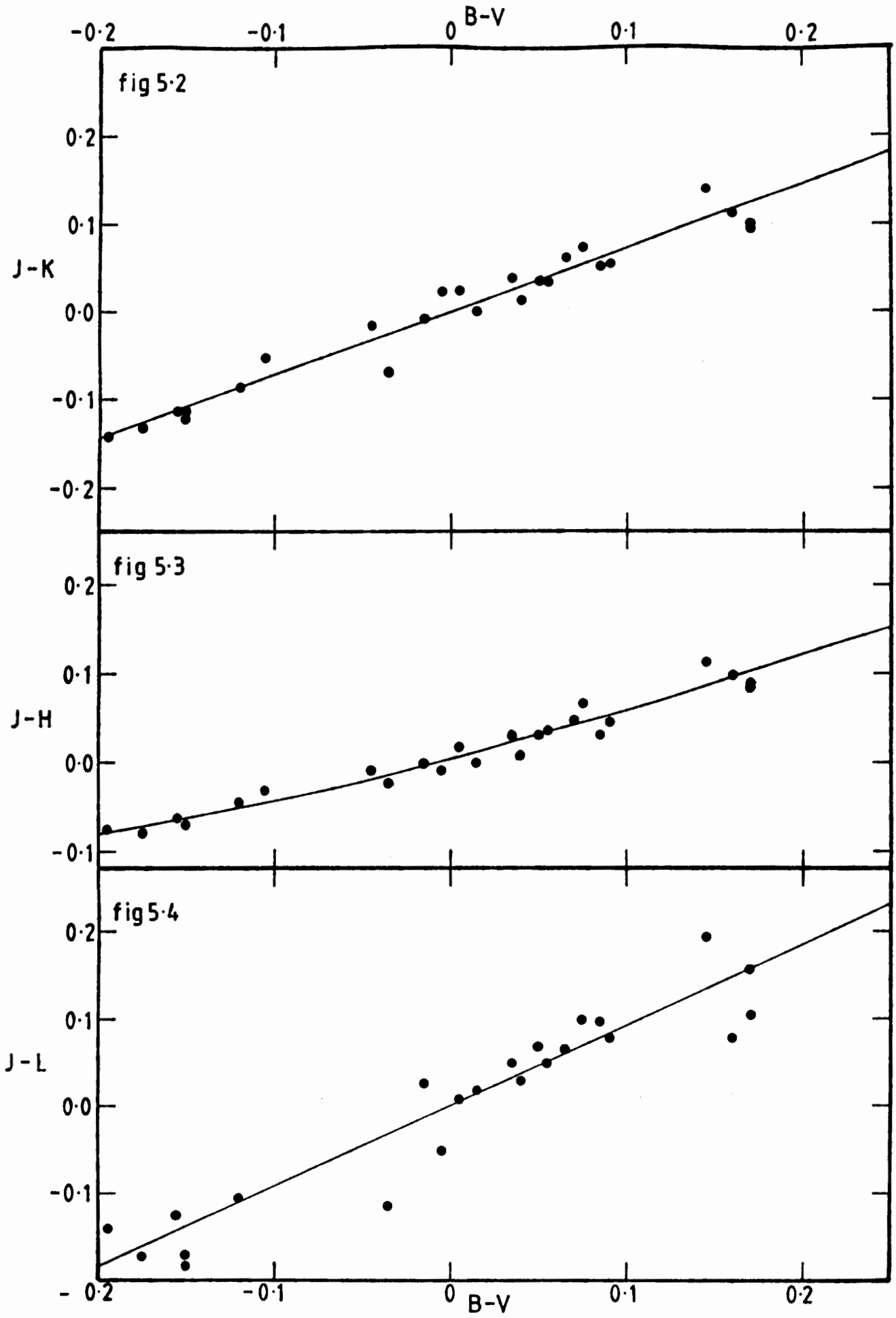
b. The horizontal scale is continuous and therefore is a more accurate guide to the temperatures of the main sequence stars than discrete spectral types.

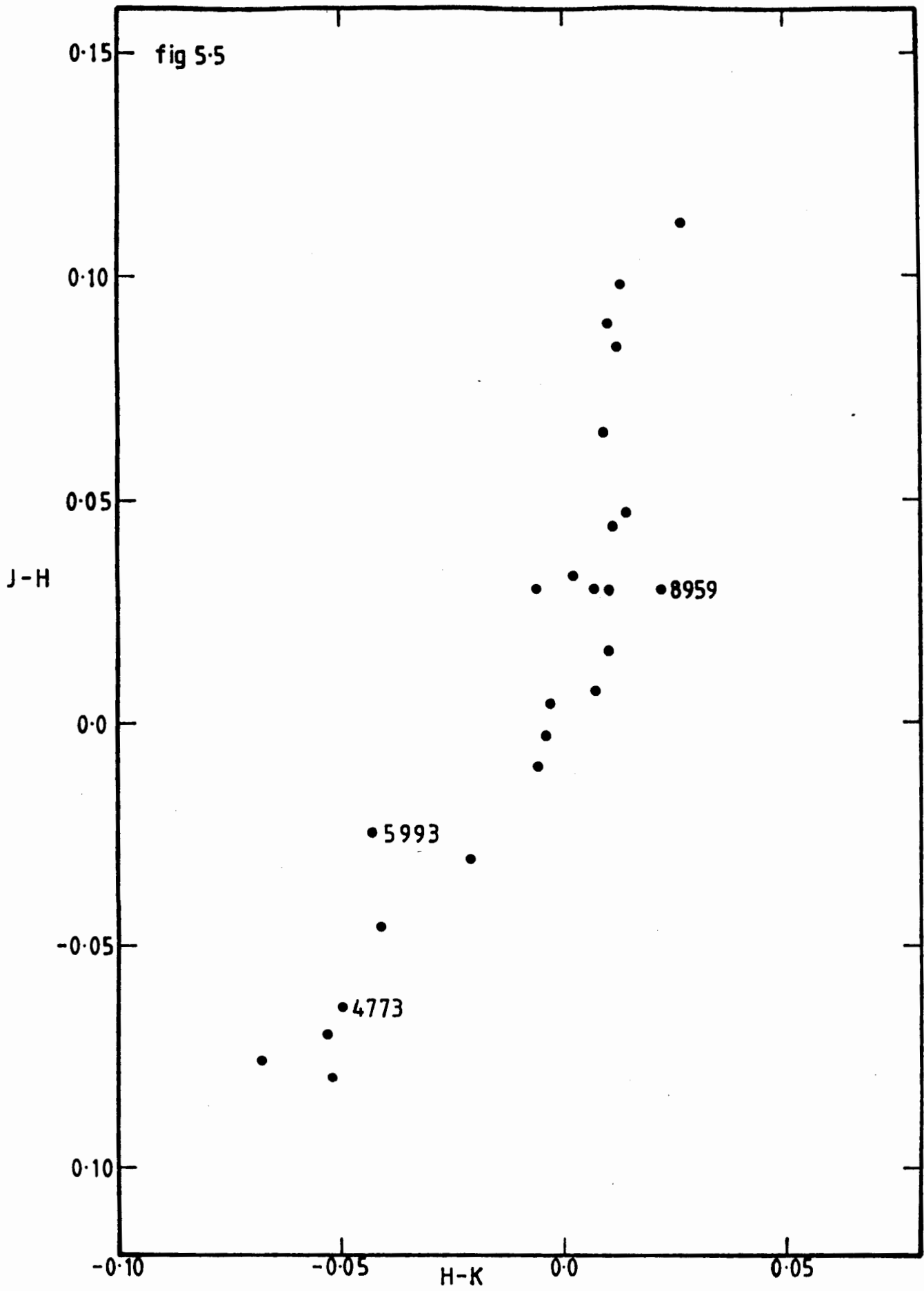
c. Spectral typing is notoriously prone to error and is dependent on the individual who does the classification. (This is exemplified by the B1V star mentioned earlier).

To ensure that none of the 25 main sequence stars were significantly peculiar, and thus liable to have unduly distorted the zero point settings, J-H was plotted against

H-K (Fig 5.5). Apart from BS5993 and BS8959 which stand off slightly in opposite directions, all the stars lie on a reasonably closely confined line. There is no evidence that BS4773 has anomalous colours as suggested by Koorneef (1983).







CHAPTER 6

THE RESULTS.

Introduction.

The style of presentation of a set of standard star tables mainly depends on the use to which they are to be put. Their two main users are :-

a. The astronomer who needs to know standard magnitudes in order to determine the magnitudes of programme stars.

b. The investigator who wishes to transform data from one IR photometric system to another.

Both need to know the J, H, K and L magnitudes tabulated against the star names. We examine the two requirements in turn.

For the Observer.

As observing time on telescopes is at a premium, time wasted during the night should be reduced to a minimum. For this reason it is desirable for the observer to have the following at his fingertips:

a. The star name.

b. Sufficiently accurate coordinates of the star.

- c. A visual magnitude to help identify the correct star.
- d. A spectral classification so that an estimate of colour can be made or a match made to a programme star.
- e. The J, H, K and L magnitudes.
- f. Notes which assist the observer in observing the correct star or notes on stars of special interest or application e.g. "double".

It should be noted that the chance of observing the wrong star on a large modern telescope with computer controlled setting or readouts is slight. However, the 0.75m telescope at Sutherland, although only 10 years old, is on an old mounting. The accuracy of the setting of this telescope falls a long way short of that which can be attained with the aid of computers and hence the problem of misidentification is present. This has now largely been eliminated with the introduction of a reliable digital setting display.

Appendix A gives a list of standards used by observers at Sutherland. It can be seen that all the star numbers have the prefix "SA". This is necessary for the reduction programmes used by the author to recognise them as standards.

e.g. SA0003 = BS0003
SAY5817 = Y5817
SAE101 = E101
SA75223 = HD75223

The r.m.s. errors.

The method employed to observe and calculate the new standards includes many cross checks from which it is possible to estimate the r.m.s. errors.

The errors in the magnitudes of the standards were calculated for each of the nine combinations (i.e. E11-E21, E21-E31, etc, E11-E31, etc, etc) in each of the rings. The r.m.s. error for each ring was then calculated, with the following results :

	J	H	K	L
Adjacent region ring 1	0.009	0.008	0.010	
Alternate region ring 1	0.012	0.011	0.011	
Adjacent region ring 2	0.011	0.010	0.012	
Alternate region ring 2	0.010	0.009	0.011	
Adjacent region ring L				0.024
Alternate region ring L				0.021

Another check on the accuracy of the basic standards is to compare the differences between the two primary stars in each region i.e. E11-E12, E21-E22, etc, calculated from the final, mean results with the individual observed values. The sum of the differences is of course zero, but the r.m.s. of the differences are found to be :-

J	H	K
0.007	0.006	0.007

From these figures it appears safe to assert that the largest error in the 18 primary standards is around 0.010 magnitudes. When using these nine pairs of primary

standards, to observe the additional standards, the maximum error introduced was less than 0.010 magnitudes (Chapter 4). Consequently it is estimated that the new standards have a maximum error of less than 0.020 magnitudes for J, H and K.

Considerable further work needs to be carried out on the L standard values but it is estimated that the maximum errors are of the order of 0.050 magnitudes.

Table 6.1

Star	J	H	K	L	Note.
Y 5817	5.335	4.732	4.527	4.344	***
BS 0003	2.879	2.280	2.202	2.141	***
BS 0033	(3.957)	3.669	3.643	3.611	***
BS 0077	3.192	2.862	2.838	2.797	
BS 0100	3.635	3.546	3.536	3.479	
BS 0117	2.901	2.052	1.895	1.729	
HD2811	7.186	7.090	7.081		
BS 0180	3.001	2.444	2.365	2.285	
BS 0322	1.842	1.348	1.279	1.207	***
BS 0334	1.622	0.985	0.886	0.779	
BS 0370	4.000	3.713	3.671	3.639	***
E 132	4.450	3.624	3.487	3.334	
E 101	7.540	7.485	7.461		
BS 0443	6.054	6.025	6.026		***
E 142	6.038	5.855	5.830		
E 164	6.368	6.281	6.275		
BS 0519	2.158	1.242	1.059	0.885	
Y 392	6.120	5.387	5.240		
BS 0585	1.125	0.263	0.105	-0.080	
BS 0674	3.780	3.826	3.867	3.887	
BS 0705	4.004	3.974	3.964	3.955	
BS 0721	4.496	4.542	4.585		
BS 0841	2.786	2.230	2.152	2.087	
BS 0919	3.778	3.680	3.667	3.700	
HD19904	6.738	6.656	6.637		

Table 6.1 (cont.)

Star	J	H	K	L	Note.
BS 1006	4.382	4.036	3.980	3.947	
BS 1008	2.997	2.572	2.527	2.499	
BS 1195	2.668	2.156	2.084	2.050	
E 241	6.627	6.552	6.543		
BS 1264	0.730	-0.228	-0.447	-0.598	***
BS 1291	5.871	5.638	5.609		***
BS 1302	4.289	4.109	4.075	4.069	***
BS 1316	4.238	3.447	3.307	3.199	***
BS 1326	2.058	1.434	1.349	1.281	***
E 244	5.754	5.436	5.395		
BS 1552	4.033	4.084	4.145	4.201	
Y 1181	5.864	5.285	5.071		***
BS 1698	2.586	1.954	1.851	1.761	
BS 1953	3.358	2.754	2.667	2.577	
BS 1983	2.701	2.438	2.411	2.378	
BS 2015	3.890	3.740	3.721	3.664	***
HD38921	7.579	7.544	7.551		
BS 2020	3.578	3.494	3.482	3.476	
BS 2290	5.507	5.172	5.117		
BS 2354	5.374	5.040	4.998		
BS 2348	5.840	5.852	5.874		***
BS 2451	3.339	3.369	3.399	3.378	***
BS 2548	4.304	4.047	4.014	3.978	***
BS 2546	3.850	3.052	2.887	2.750	***
BS 2579	6.634	6.618	6.637		***

Table 6.1 (cont.)

Star	J	H	K	L	Note.
BS 2626	6.236	6.231	6.237		***
BS 2693	0.784	0.482	0.399	0.258	***
BS 2882	5.548	5.206	5.157		
BS 3113	4.344	4.232	4.205	4.151	
BS 3138	4.568	4.243	4.213	4.171	
BS 3131	4.400	4.335	4.326	(4.301)	
BS 3314	3.917	3.920	3.924	3.891	***
BS 3484	2.818	2.319	2.242	2.187	
HD75223	7.312	7.286	7.271		
BS 3614	1.896	1.284	1.181	1.061	
E 439	5.814	5.562	5.521		
BS 3672	6.086	6.129	6.173		***
BS 3670	5.930	5.936	5.937		***
BS 3674	5.492	5.537	5.575		***
E 429	4.680	4.002	3.888	3.791	
BS 3718	1.635	0.730	0.536	0.387	
BS 3842	3.972	3.482	3.405	3.313	***
BS 3871	3.709	3.311	3.234	3.161	
BS 3903	2.608	2.108	2.028	1.943	
BS 4023	3.757	3.742	3.729	3.728	
BS 4102	3.331	3.138	3.104	3.083	
BS 4174	1.335	0.462	0.292	0.137	***
BS 4167	3.276	3.135	3.107	3.091	
BS 4216	(1.196)	(0.704)	(0.611)	(0.532)	
BS 4257	2.203	1.665	1.586	1.510	***

Table 6.1 (cont.)

Star	J	H	K	L	Note.
BS 4450	2.017	1.514	1.437	1.339	
HD101452	7.024	6.862	6.849		
BS 4520	3.340	3.251	3.229	3.205	
BS 4523	3.722	3.342	3.295	3.242	
E 570	6.492	6.522	6.548		
BS 4600	4.357	4.117	4.085	4.033	***
BS 4620	5.298	5.285	5.280		***
E 550	5.748	5.502	5.467		
BS 4638	4.311	4.381	4.434	(4.483)	
BS 4652	2.874	2.079	1.938	1.801	***
BS 4689	3.808	3.783	3.775	3.765	
BS 4743	4.364	4.440	4.508	(4.505)	
BS 4757	3.032	3.040	3.060	3.039	***
BS 4773	4.167	4.231	4.281	4.295	
BS 4802	3.730	3.700	3.693	3.662	
BS 4989	3.994	3.690	3.646	3.589	
BS 5028	2.704	2.697	2.690	2.676	
BS 5132	2.801	2.907	2.980	3.023	***
BS 5249	4.322	4.426	4.482		
BS 5412	5.623	5.635	5.651		***
BS 5453	4.376	4.440	4.490	4.561	
BS 5444	3.036	2.200	2.052	1.941	***
BS 5457	5.166	4.901	4.858		***
BS 5471	4.388	4.468	4.520	4.561	
BS 5494	5.619	5.586	5.579		***

Table 6.1 (cont.)

Star	J	H	K	L	Note.
HD130163	6.852	6.841	6.824		
BS 5571	3.166	3.258	3.327	3.381	***
BS 5605/6	4.212	4.268	4.312		***
BS 5646	(3.880)	(3.890)	(3.896)		
BS 5649	1.902	1.386	1.307	1.226	
Y 3501	5.710	5.010	4.770		***
BS 5897	2.269	2.097	2.064	2.035	
BS 5993	(4.017)	(4.042)	(4.085)	(4.134)	
SR3	7.848	6.961	6.458		***
Oph S1	9.026	7.250	6.282		***
BS 6136	2.954	2.186	2.046	1.924	
BS 6371	(3.596)	(3.111)	(3.039)	(3.007)	***
BS 6380	2.584	2.380	2.343	2.315	***
BS 6416	3.935	3.440	3.353	3.308	***
BS 6461	0.582	-0.112	-0.259	-0.397	
E 756	8.323	7.616	7.523		
Y 3958	5.757	5.110	4.865		
BS 6500	3.773	3.804	3.825		
BS 6537	4.526	4.510	4.510		***
E703	8.102	8.113	8.140		
BS 6572	5.727	5.708	5.711		***
BS 6736	5.796	5.766	5.771		
BS 6879	1.752	1.738	1.731	1.725	
E 764	6.278	5.647	5.375		***
BS 7120	2.848	2.134	2.010	1.890	

Table 6.1 (cont.)

Star	J	H	K	L	Note.
BS 7581	2.292	1.652	1.563	1.491	***
E 830	4.376	3.542	3.390	3.273	
E 861	5.146	4.443	4.265	4.135	***
E 844	5.283	5.043	5.008		***
BS 7779	5.580	5.575	5.579		***
BS 7787	5.256	5.145	5.123		***
BS 7869	1.464	0.904	0.823	0.746	
BS 7950	3.711	3.680	3.687	3.673	
BS 7951	0.934	-0.024	-0.216	(-0.377)	***
BS 8075	4.066	4.036	4.042	4.013	
Y 5117	3.954	3.223	3.067	2.969	***
BS 8181	3.271	2.970	2.933	(2.910)	
HD205772	7.779	7.685	7.663		
BS 8278	3.203	3.059	3.043	(3.039)	
BS 8425	2.010	2.066	2.103	2.127	***
BS 8431	4.384	4.351	4.349	4.335	
BS 8477	5.086	4.746	4.688		
BS 8524	4.925	4.714	4.672		***
BS 8551	3.008	2.380	2.299	2.227	
BS 8556	2.354	1.797	1.715	1.639	***
BS 8576	4.274	4.270	4.273	4.257	
E 941	6.402	6.158	6.119		
E 942	5.806	5.513	5.479		
BS 8635	4.930	4.595	4.532		***
BS 8657	3.388	2.664	2.552	2.444	***

Table 6.1 (cont.)

Star	J	H	K	L	Note.
E 901	7.988	7.949	7.947		
BS 8709	3.114	3.067	3.053	3.051	***
BS 8728	1.054	1.010	0.999	0.975	***
BS 8848	3.220	2.991	2.955	2.929	
BS 8959	4.578	4.548	4.526	4.481	
BS 9016	4.566	4.550	4.540	4.549	

1

Table 6.2

NOTES.

Y 5817	High Proper Motion.
BS 0003	Var? , B S Cat. 4th Ed., Hoffleit (1982).
BS 0077	SAAO IR Standard for SMC.
BS 0322	E161
BS 0370	E136 1 & L
BS 0443	E140 2
BS 1264	Var. , B S Cat. 4th Ed., Hoffleit (1982).
BS 1291	E243 2
BS 1302	E264 1 & L
BS 1316	E229
BS 1326	E265
Y 1181	High Proper Motion.
BS 2015	SAAO IR Standard for LMC.
BS 2348	E345 2
BS 2451	E386 Var? , B S Cat. 4th Ed., Hoffleit (1982).
BS 2548	E347 1 & L
BS 2546	E336
BS 2579	E349
BS 2626	E352
BS 2693	Var? , B S Cat. 4th Ed., Hoffleit (1982).
BS 3314	AAO & MSO Zero Point star.
BS 3672	E478
BS 3670	E494 2
BS 3674	E479 1
BS 3842	E447 L

Table 6.2 (cont.)

NOTES.

BS 4174	Var? , B S Cat. 4th Ed., Hoffleit (1982).
BS 4257	Var. , B S Cat. 4th Ed., Hoffleit (1982).
BS 4600	E540 1 & L
BS 4620	E578 2
BS 4652	E555
BS 4757	Var. , B S Cat. 4th Ed., Hoffleit (1982).
BS 5132	Var. , B S Cat. 4th Ed., Hoffleit (1982).
BS 5412	E639
BS 5444	E640
BS 5457	E641 2
BS 5494	E643
BS 5571	E693 L
BS 5605/6	E696 1
Y 3501	High Proper Motion.
SR3	Finding Chart Grasdalen et al (1973).
Oph S1	Finding Chart Grasdalen et al (1973).
BS 6371	E743
BS 6380	E761 1 & L
BS 6416	E744
BS 6537	E797 2
BS 6572	E749
E 764	Y 4338 Var? , Menzies et al (1980).
BS 7581	E869 L
E 861	Y 4794
E 844	E844 2

Table 6.2 (cont.)

NOTES.

BS 7779	E845
BS 7787	E871 1
BS 7951	Var. , B S Cat. 4th Ed., Hoffleit (1982).
Y 5117	High Proper Motion , Var. AX Mic. Flare Star.
BS 8425	E970
BS 8524	E972 1
BS 8556	E974 L
BS 8635	E963 2
BS 8657	E944
BS 8709	Var? , B S Cat. 4th Ed., Hoffleit (1982).
BS 8728	Var? , B S Cat. 4th Ed., Hoffleit (1982).

CHAPTER 7
THE COMPARISONS.

Introduction.

Two methods can be employed to establish the quality of the new standards. Their night to night consistency in normal use as standards can be monitored and they can be compared with other sets of standards.

When using these standards on good photometric nights, after the zero point for the night has been set using the mean value calculated from all the standards, the differences between the observed and actual values should be close to, and scatter around, zero. (If this is found to be the case, when used on poorer nights any drifts in zero point due to transparency or seeing changes can be allowed for).

The initial reason for comparing the values of the new standards with previously established ones was to check for obvious errors. Any differences found should be within the combined errors of the two sets of results. Differences greater than these expected amounts would need to be

investigated and their cause established, whether they arose from observational method or equipment faults.

The following paragraphs describe in detail what might be discovered from such comparisons.

The importance of comparisons between systems.

Ideally the various systems should be identical and infinitely accurate. In this case there would be no difference between any of the individual values. As this is not the case in practice, the differences must be interpreted carefully and their origins determined. If the differences are not entirely random it is obvious that their average value would not be a useful criterion of accuracy. In this case it would be necessary to determine which stellar parameters are correlated with the systematic effects. The parameters chosen for investigation were as follows :-

- a. Magnitude.
- b. Colour.
- c. Right Ascension.

The differences were plotted against these quantities and the results are discussed below in detail, together with conclusions gained by investigating the scatter in the differences between the systems.

a. Magnitude dependent effects.

In a plot of magnitudes, any non-linearity between the systems would obviously appear as curvature or inflection. This could be caused in several ways :-

i. The amplifiers or detectors could be non-linear in their responses.

ii. The amplifiers or detectors could be saturated when observing bright objects.

iii. The amplifier gain steps could have been calibrated incorrectly.

In fact , no evidence was found, within the accuracy of the systems, for any non-linear effects between the systems. The plots are therefore not shown.

b. Colour dependent effects.

The use of non-identical filters in the various systems will give rise to colour dependent terms in the magnitude differences between stars. The gradient of the resultant colour equation can be determined by plotting the differences against the stellar colour. If the best fit line does not pass through the origin, a difference in zero point is present and a constant term must be included in the colour equation.

c. Right Ascension dependent effects.

If a colour equation were present it would increase the scatter in a plot of differences against right ascension; therefore in most cases the differences were corrected according to the colour equation before being plotted against R.A. This plot should ideally be a horizontal line with a mean about zero. A constant difference in zero point would be indicated by a uniform displacement from the zero line. Any inflections would indicate that the zero point differs in different parts of the sky. If such inflections were repeated on all the inter-system comparisons, it would be implied that the errors are in the new standards.

d. The scatter between systems.

Various conclusions could be drawn from the amount of residual scatter which is present in the previous plots. If the scatter were equally large in all the comparisons it would not be very informative. This situation could arise from any of several conditions, viz :-

i. The new standards could be of good quality and all the rest poor.

ii. The exact opposite to i.

iii. All equally poor.

Fortunately none of these is, in fact, the case. If, on the other hand, the amplitude of the scatter varies between systems it would indicate the least accurate system is that in which the scatter is largest. If the scatter were particularly small between the new standards and any of the

other systems it would indicate that the errors of the new standards are comparable with those or even better.

Another important reason for making these comparisons is to try to establish a method of transformation between the systems. This was found to be possible but not very satisfactory. To obtain a meaningful transformation between systems stars of extreme colours must be used. The majority of extremely red stars are variable and therefore it would be necessary for the observations to be carried out simultaneously. None of the stars used in the calculation of the transformation presented here were redder than $J-K = 1.15$ and therefore it would be unwise to extrapolate far beyond this value.

The comparison of filters.

As previously stated, the various different standard sets have been compiled using different filters. A comparison of the filter's effective wavelengths and half power band widths in microns is given as follows :-

	J	Band width	H	Band width	K	Band width	L	Band width
SAAO	1.24	0.30	1.654	0.297	2.220	0.410	3.448	0.570
ESO	1.25	0.3	1.65	0.4	2.2	0.6	3.7	0.7
AAO	1.20	0.3	1.64	0.3	2.19	0.45	3.8	0.6
CIT	1.25	0.24	1.65	0.3	2.22	0.41	3.49	0.54
MSO	Only profiles given.							

The comparisons.

In what follows, each comparison is examined in turn. For simplicity J-K has always been used to indicate the colour of the star. It should be noted that the same J-K scale was used throughout, even though only the plot for the CIT data has points of $J-K > 1.15$. This is to facilitate simpler visual comparisons between the plots. As previously discussed, the quality of the new L values is not of the same standard as the J, H and K. No attempt has been made to interpret the L data and they are only plotted for completeness. The tables of the stars in common between systems give the star name and the differences in the sense, new standards minus the other system.

1. Johnson

Table 7.1 gives the standards in common with Johnson (1966). Figs 7.11, 7.12 and 7.13 show the differences in J, K and L plotted against the colour J-K. All three show large amounts of scatter, especially in the J difference for BS0519. As Johnson's stars were not used as standards and were only compared for historical reasons, no attempt to determine a colour equation was made. It can be seen, though, that there is little or no colour term and that the zero points agree well. Figs 7.14, 7.15 and 7.16 show the J, K and L differences plotted against R.A. Owing to the large scatter it is difficult to draw any conclusion but possibly the J zero point wanders (especially between 7 and

11 hours).

2. SAAO.

Table 7.2 gives the stars in common with SAAO (Glass 1974). Figs 7.21, 7.22, 7.23 and 7.24 show the J, H, K and L differences plotted against the stellar colour J-K. Our H, K and L filters and those used by Glass were from the same batch and therefore essentially identical in both systems. The J filters although different are almost identical in response (Robertson and Catchpole 1980). It was therefore somewhat disturbing to find what appeared to be a large colour equation especially in J. The broken lines indicate the linear least squares fit to the J, H and K plots. The cause of these trends is shown in Figs 7.25, 7.26, 7.27, and 7.28 (which are the J, H, K and L differences plotted against R.A.). It can be seen from the J, H and K plots that an R.A. term exists. Of the eight stars with $J-K < 0$, six are between 12 and 14 hours. This has the effect of distorting the plots of the J, H and K differences against colour.

3. ESO.

Table 7.3 gives the stars in common with ESO (Engels et al 1981). Figs 7.31, 7.32, 7.33 and 7.34 show the J, H, K and L differences plotted against the colour J-K. It can be seen from these plots that a large scatter exists, especially in J. The three lines which represent the colour equations between the two systems, fitted by least squares, were found to be as follows :-

$$J = (0.070 \pm 0.005)(J-K) - (0.059 \pm 0.009)$$

$$H = -(0.053 \pm 0.003)(J-K) - (0.038 \pm 0.005)$$

$$K = (0.004 \pm 0.003)(J-K) - (0.033 \pm 0.005)$$

These equations are equivalent to the following transformation formulae :-

$$J(\text{ESD}) = J(\text{NEW}) - 0.070(J-K)(\text{NEW}) + 0.059$$

$$H(\text{ESD}) = H(\text{NEW}) + 0.053(J-K)(\text{NEW}) + 0.038$$

$$K(\text{ESD}) = K(\text{NEW}) - 0.004(J-K)(\text{NEW}) + 0.033$$

These transformation formulae were applied to the new standard values and the differences were recalculated. The r.m.s. of these differences were as follows :-

J	H	K
0.043	0.023	0.023

Figs 7.35, 7.36, 7.37 and 7.38 show the colour equation-corrected J, H and K differences and the L differences plotted against R.A. The scatter is still very large but no clear R.A. term exists.

4. AAO.

Table 7.4 gives the stars in common with AAO (Allen and Cragg 1983). Figs 7.41, 7.42, 7.43 and 7.44 show the J, H, K and L differences plotted against the colour J-K. The plots for J, H and K show good agreement with only a small colour term and small zero point shift in each case. The three lines which represent the colour equation between the two systems, fitted by least squares, were found to be as follows :-

$$J = -(0.014 \pm 0.001)(J-K) - (0.007 \pm 0.003)$$

$$H = -(0.021 \pm 0.001)(J-K) - (0.018 \pm 0.003)$$

$$K = -(0.011 \pm 0.002)(J-K) - (0.008 \pm 0.003)$$

These equations are equivalent to the following transformation formulae :-

$$J(\text{AAD}) = J(\text{NEW}) + 0.014(J-K)(\text{NEW}) + 0.007$$

$$H(\text{AAD}) = H(\text{NEW}) + 0.021(J-K)(\text{NEW}) + 0.018$$

$$K(\text{AAD}) = K(\text{NEW}) + 0.011(J-K)(\text{NEW}) + 0.008$$

These transformation formulae were applied to the new standard values and the differences were recalculated. The r.m.s. of these differences were as follows :-

J	H	K
0.013	0.014	0.016

Figs 7.45, 7.46, 7.47 and 7.48 show the colour equation-corrected J, H and K differences and L differences plotted against R.A. There is a small zero point shift between the first 12 hours compared with the second.

5. MSO.

Table 7.5 gives the stars in common with MSO (Jones and Hyland 1982). Figs 7.51, 7.52 and 7.53 show the J, H and K differences plotted against the stellar colour J-K. Except for J, the agreement is fairly good with small colour terms and zero point differences. The three lines which represent the colour equation between the two systems, fitted by least squares, were found to be as follows :-

$$J = (0.046 \pm 0.003)(J-K) + (0.001 \pm 0.004)$$

$$H = -(0.008 \pm 0.002)(J-K) - (0.018 \pm 0.004)$$

$$K = (0.007 \pm 0.002)(J-K) - (0.003 \pm 0.004)$$

These equations are equivalent to the following transformation formulae :-

$$J(\text{MSD}) = J(\text{NEW}) - 0.046(J-K)(\text{NEW}) - 0.001$$

$$H(\text{MSD}) = H(\text{NEW}) + 0.008(J-K)(\text{NEW}) + 0.018$$

$$K(\text{MSD}) = K(\text{NEW}) - 0.007(J-K)(\text{NEW}) + 0.003$$

These transformation formulae were applied to the new standard values and the differences were recalculated. The r.m.s. of these differences were as follows :-

J	H	K
0.018	0.016	0.016

Figs 7.54, 7.55 and 7.56 show the colour equation-corrected J, H and K differences plotted against R.A. As with the comparison with the AAO data, these plots show a zero point shift between the first 12 hours compared with the second.

For practical use the MSD system is always transformed to the AAO system using the formulae in Jones et al (1980). From this we can check the new AAO and MSD transformations. Let us take as an example the new values for the star Y1181.

$$J = 5.864 \quad H = 5.285 \quad K = 5.071 \quad (1)$$

Transformed to the MSD system using the new formulae these give :-

$$J = 5.927 \quad H = 5.309 \quad K = 5.073 \quad (2)$$

Transforming to the AAO system using Jones et al (1980) gives :-

$$J = 5.888 \quad H = 5.320 \quad K = 5.088 \quad (3)$$

Transforming the new value to the AAO system using the new

formulae gives :-

$$J = 5.873 \quad H = 5.309 \quad K = 5.073 \quad (4)$$

The differences (3) - (4) are :-

$$J = 0.015 \quad H = 0.011 \quad K = 0.015$$

It would appear that a discrepancy exists in one or more of the transformation formulae.

6. CIT.

Table 7.6 gives the stars in common with CIT (Elias et al 1982 and Elias et al 1983). Figs 7.61, 7.62, 7.63 and 7.64 show the J, H, K and L differences plotted against the colour J-K. The agreement for the stars with $J-K < 1$ is excellent. If it can be assumed that the relationship between the two systems is linear, the two red stars are in anomalous positions. These imply that for the two red stars, either the new values are too bright or CIT values are too faint. This could occur if both red stars were extended sources and CIT used a smaller aperture than that used here. The aperture size is not stated for CIT (Elias et al 1982). The two red sources are interpreted as members of a cluster embedded within the Ophiuchus dark-cloud region (Grasdalen et al 1973 and Wilking and Lada 1983) and appear visually to be embedded in nebulosity. It is therefore more than likely that they are extended. It might also be noted that when they were observed simultaneously in the infrared, on the 0.75 and 1.9 m telescopes at Sutherland in May 1984, the larger telescope values were fainter than the values predicted by the transformation formulae (Robertson and

Catchpole 1980). The infrared photometer on the 0.75 m telescope used an aperture of 36 arc seconds diameter compared with 12 arc seconds for the 1.9 m telescope. It is also possible that both of these red sources have close companions or that the reference beams were not empty of stars.

For these reasons the two red sources were ignored when the transformation formulae were calculated. The three lines in Figs 7.61, 7.62 and 7.63, which represent the colour equations between the two systems fitted by least squares, were found to be as follows :-

$$J = (0.128 \pm 0.001)(J-K) + (0.002 \pm 0.002)$$

$$H = (0.017 \pm 0.003)(J-K) - (0.004 \pm 0.003)$$

$$K = (0.020 \pm 0.005)(J-K) + (0.003 \pm 0.003)$$

These equations are equivalent to the following transformation formulae :-

$$J(\text{CIT}) = J(\text{NEW}) - 0.128(J-K)(\text{NEW}) - 0.002$$

$$H(\text{CIT}) = H(\text{NEW}) - 0.017(J-K)(\text{NEW}) + 0.004$$

$$K(\text{CIT}) = K(\text{NEW}) - 0.020(J-K)(\text{NEW}) - 0.003$$

These transformation formulae were applied to the new standard values and the differences were recalculated. The r.m.s. of these differences were as follows :-

J	H	K
0.008	0.010	0.009

Figs 7.65, 7.66, 7.67 and 7.68 show the colour equation-corrected J, H and K differences and the L differences plotted against R.A. It can be seen there is no zero point shift.

As with the AAO and MSO we can check the new transformation formulae with the transformation from AAO to CIT published in Elias et al (1983).

Again we take the new value for star Y1181.

$$J = 5.864 \quad H = 5.285 \quad K = 5.071 \quad (1)$$

Transformed to the AAO system using the new formulae give :-

$$J = 5.873 \quad H = 5.309 \quad K = 5.073 \quad (2)$$

Transformed to the CIT system using the formulae in Elias et al (1983) give :-

$$J = 5.786 \quad H = 5.283 \quad K = 5.062 \quad (3)$$

Transforming the new values to the CIT system using the new formulae gives :-

$$J = 5.760 \quad H = 5.276 \quad K = 5.052 \quad (4)$$

The differences (3) - (4) are :-

$$J = 0.026 \quad H = 0.007 \quad K = 0.010$$

Again there seems to be a discrepancy in one or more of the formulae.

Conclusion.

It can be seen from the comparison between the new standards and CIT (after the colour equation has been applied) that there is excellent agreement. The largest difference is 0.022 (H difference for HD101452) and as previously stated the r.m.s. of the differences is 0.010 or less. This scatter is well within the combined errors of the two systems. The estimated internal accuracy of the CIT standards is 0.01 for H and K and 0.03 for J (Elias et al 1982). The estimated errors of the new standards as stated earlier are less than 0.02 for J, H and K.

From the previous paragraph we conclude that the quality of the new standards is within the accuracy claimed. MSO and AAO do not give estimated errors for their standards; however Allen and Cragg (1983), when comparing these two, conclude that the r.m.s. deviation is of the order of 0.01. This is consistent with the r.m.s. colour equation-corrected differences found here, when comparing the new standards with MSO and AAO.

ESO (Engels et al 1981) give the error of a single observation to be less than 0.03 magnitudes in all filters. If we accept the possible maximum errors of the new standards to be less than 0.02 the maximum colour equation-corrected difference between the two systems should be less than 0.05. Of the 72 differences, seven are larger than predicted, the largest being 0.115 (J difference for

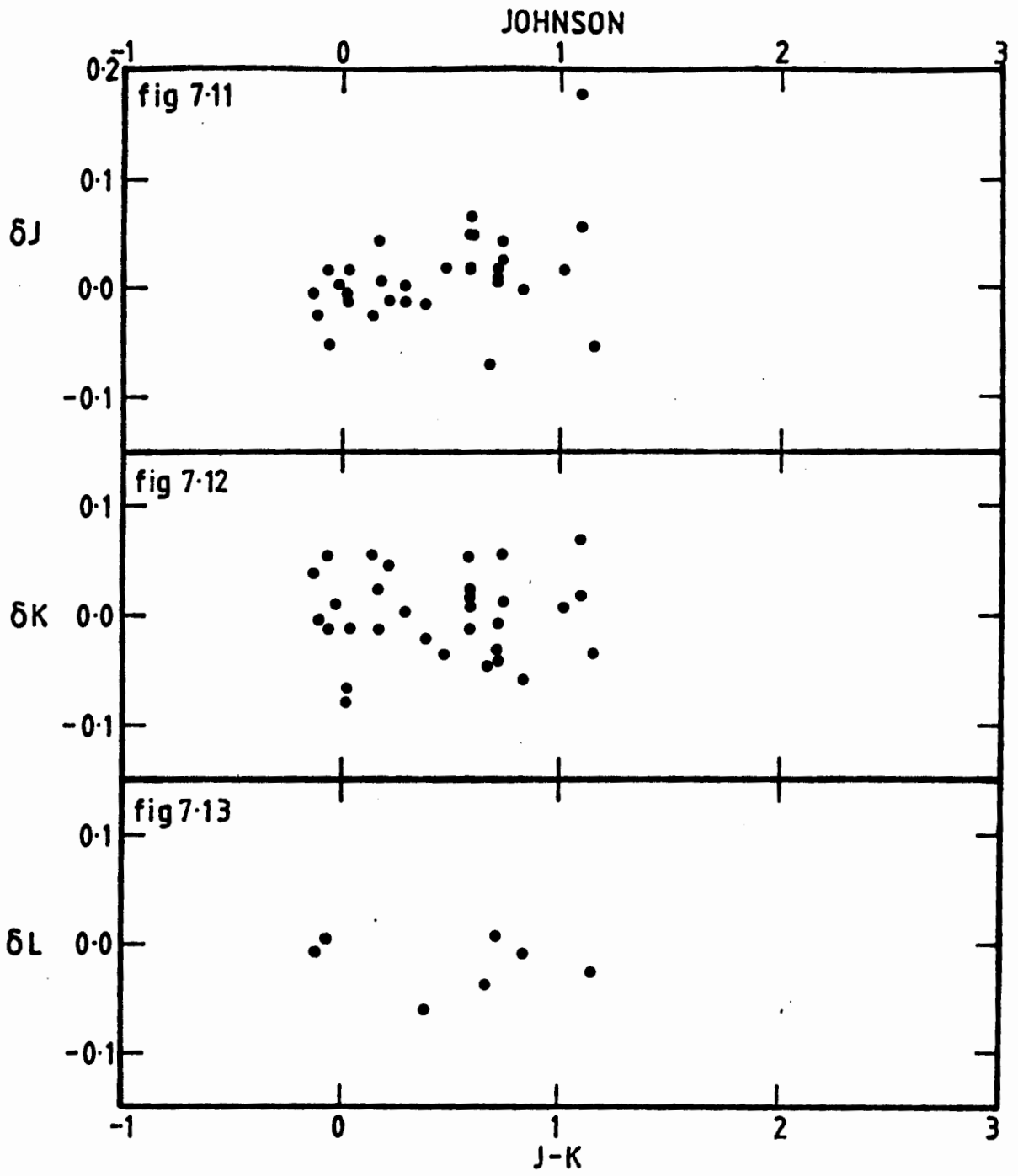
BS4450). It is therefore probable that the stated errors for the ESO standards were underestimated.

The last three paragraphs assume that the linear transformations previously given between each pair of systems are valid. This may not necessarily be true when comparing observations made with filters of different bandwidths as is the case here. Stellar emission or absorption features could be included or excluded and hence increase the differences from the linear relationship. An extreme example of this is the observations of Nova Coronae Austrinae 1981. An observation made at Cerro Tololo Inter-American Observatory using the CIT system gave a J-H of 0.00 (Vrba and Rydgren 1981). Two days earlier an observation made at the SAAO gave a J-H of -0.90 (Catchpole et al 1985). This is mainly caused by part of the very strong HeI emission line at $1.083\mu\text{m}$ being included in the SAAO J filter and excluded from the CIT J filter.

As mentioned in the introduction to this chapter, the accuracy of the new standards can be tested by monitoring their consistency in normal use. Although only a small number of nights using the new standards have been reduced so far the results are promising. Appendix B is a computer reduction output for the standards only, for the night of 10/11 April 1984, observed by the author. It can be seen from the small residuals that the quality of the night and quality of the standards were good.

Table 7.1
 Comparison between New and Johnson Standards.
 (New - Johnson)

Star	Delta J	Delta K	Delta L
BS 0003	-0.071	-0.048	-0.039
BS 0334	0.042	0.056	
BS 0519	0.178	0.069	
BS 0585	0.015	0.005	
BS 1195	0.018	0.014	
BS 1302	-0.011	0.045	
BS 1326	0.008	-0.031	
BS 1552	-0.027	-0.005	-0.009
BS 1698	0.026	0.011	
BS 1983	0.001	0.001	
BS 2451	-0.051	-0.011	
BS 2693	-0.016	-0.021	-0.062
BS 3113	-0.026	0.055	
BS 3484	0.048	0.052	
BS 3614	0.006	-0.009	
BS 3718	0.055	0.016	
BS 3871	0.019	-0.036	
BS 3903	0.048	0.008	
BS 4023	-0.013	-0.011	
BS 4167	0.006	-0.013	
BS 4216	0.066	0.021	
BS 4450	0.017	-0.013	
BS 4743	-0.006	0.038	
BS 4757	0.002	0.010	
BS 5028	-0.006	-0.080	
BS 5993	(0.017)	(0.055)	(0.004)
BS 6736	0.016	-0.069	
BS 7120	-0.002	-0.060	-0.010
BS 7951	-0.056	-0.036	(-0.027)
BS 8278	0.043	0.023	
BS 8551	0.018	-0.041	0.007



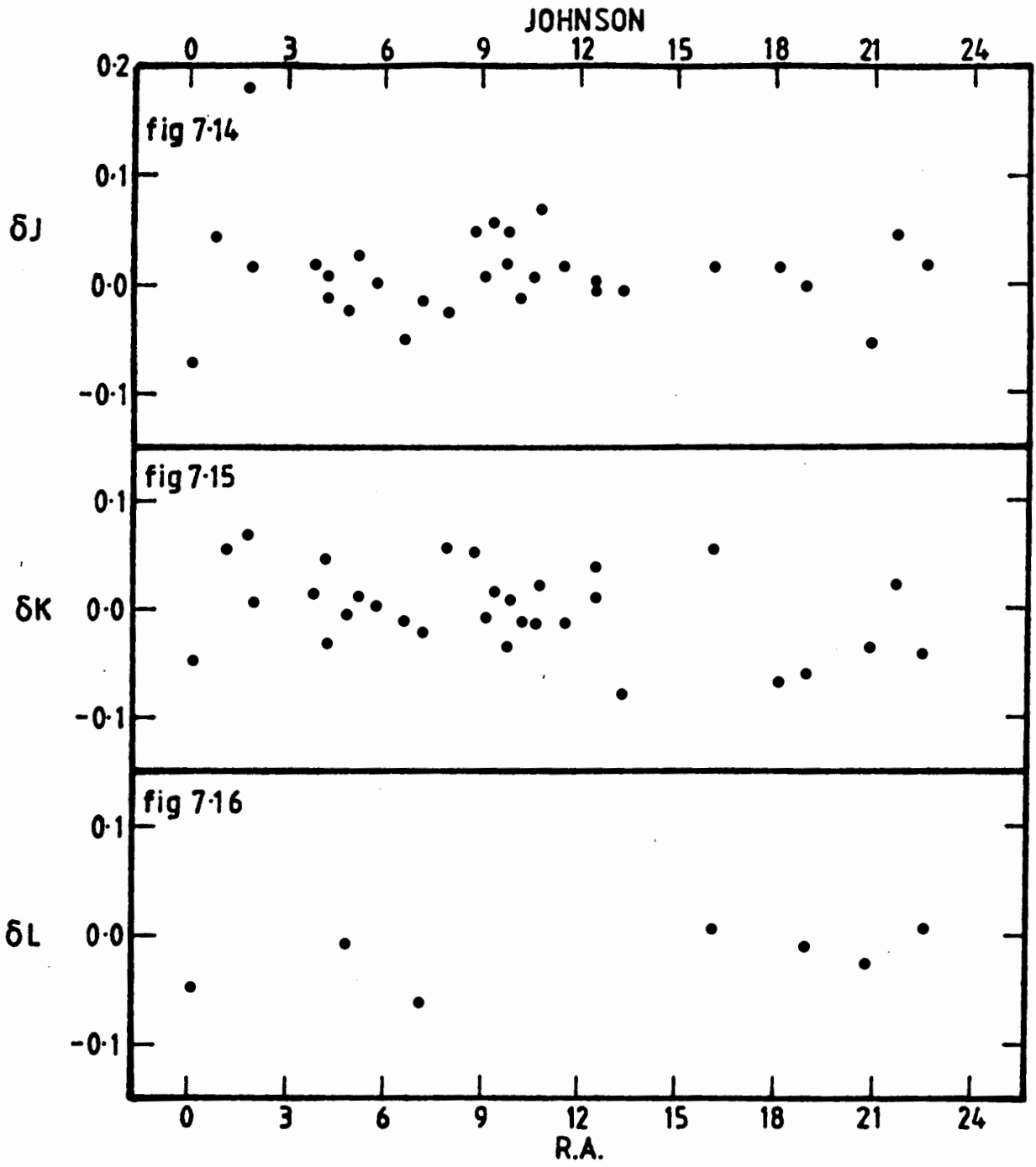
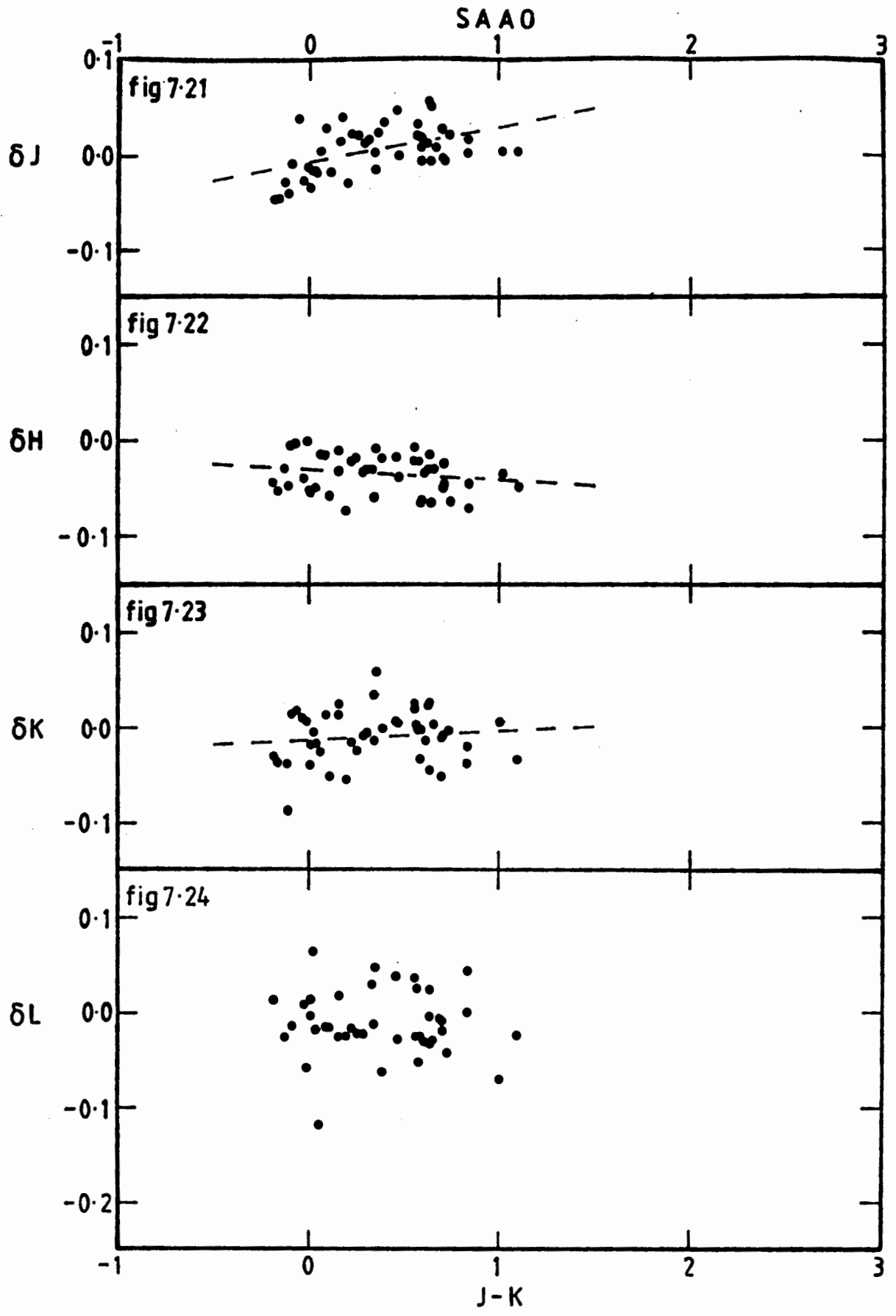


Table 7.2
Comparison between New and SAAD Standards. (New - SAAD)

Star	Delta J	Delta H	Delta K	Delta L
BS 0003	0.009	-0.030	0.002	-0.029
BS 0033	0.017	-0.031	-0.007	
BS 0077	0.022	-0.008	0.058	0.047
BS 0180	0.051	-0.016	0.025	0.025
BS 0322	0.032	-0.022	0.019	0.037
BS 0334	0.022	-0.065	-0.004	-0.041
BS 0585	0.005	-0.037	0.005	-0.070
BS 0841	0.056	-0.030	0.022	-0.003
BS 1008	0.047	-0.018	0.007	0.039
BS 1326	0.028	-0.026	-0.011	-0.019
BS 1983	0.011	-0.032	-0.009	-0.022
BS 2015	0.040	-0.010	0.011	-0.026
BS 2020	0.028	-0.016	0.012	-0.014
BS 2451	0.039	-0.001	0.019	
BS 2693	0.034	-0.018	-0.001	-0.062
BS 3314	-0.013	0.000	0.004	-0.059
BS 3484	0.018	-0.011	0.002	0.027
BS 3614	-0.004	-0.046	-0.009	-0.009
BS 3718	0.005	-0.050	-0.034	-0.023
BS 3842	0.022	-0.008	0.025	
BS 3871	-0.001	-0.039	0.004	-0.029
BS 3903	0.018	-0.022	-0.002	-0.027
BS 4102	0.021	-0.022	-0.016	-0.017
BS 4257	0.013	-0.035	-0.014	-0.030
BS 4450	0.007	-0.066	-0.003	-0.051
BS 4520	-0.020	-0.059	-0.051	-0.015
BS 4638	-0.029	-0.029	-0.036	-0.027
BS 4757	-0.028	-0.040	0.010	0.009
BS 4773	-0.043	-0.049	-0.089	
BS 4802	-0.020	-0.050	-0.017	-0.018
BS 4989	-0.016	-0.060	-0.014	-0.011
BS 5028	-0.036	-0.053	-0.040	-0.004
BS 5132	-0.049	-0.043	-0.030	0.013
BS 5249	-0.048	-0.054	-0.038	
BS 5649	-0.008	-0.064	-0.033	-0.024
BS 5897	-0.031	-0.073	-0.056	-0.025
BS 6461	0.002	-0.072	-0.039	0.043
BS 6879	-0.018	-0.052	-0.019	0.015
BS 7120	0.018	-0.046	-0.020	0.000
BS 7869	-0.006	-0.066	-0.047	-0.034
BS 7950	-0.019	-0.050	-0.003	0.063
BS 8181	0.001	-0.030	0.033	(0.030)
BS 8278	0.013	-0.031	0.023	(0.019)
BS 8425	-0.010	-0.004	0.013	-0.013
BS 8551	-0.002	-0.050	-0.051	-0.003
BS 8709	0.004	-0.013	-0.027	-0.119
BS 8848	0.020	-0.019	-0.025	-0.021



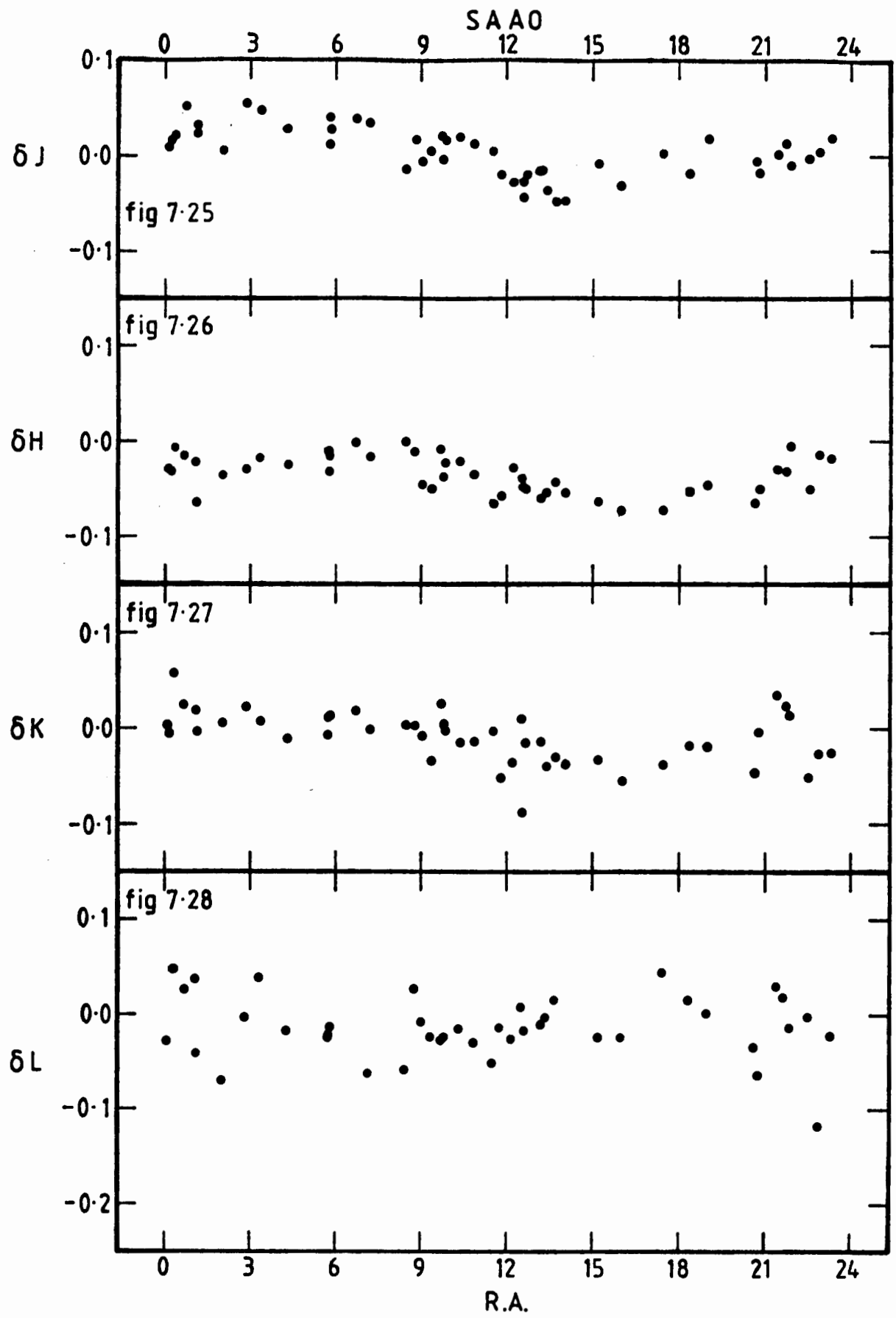
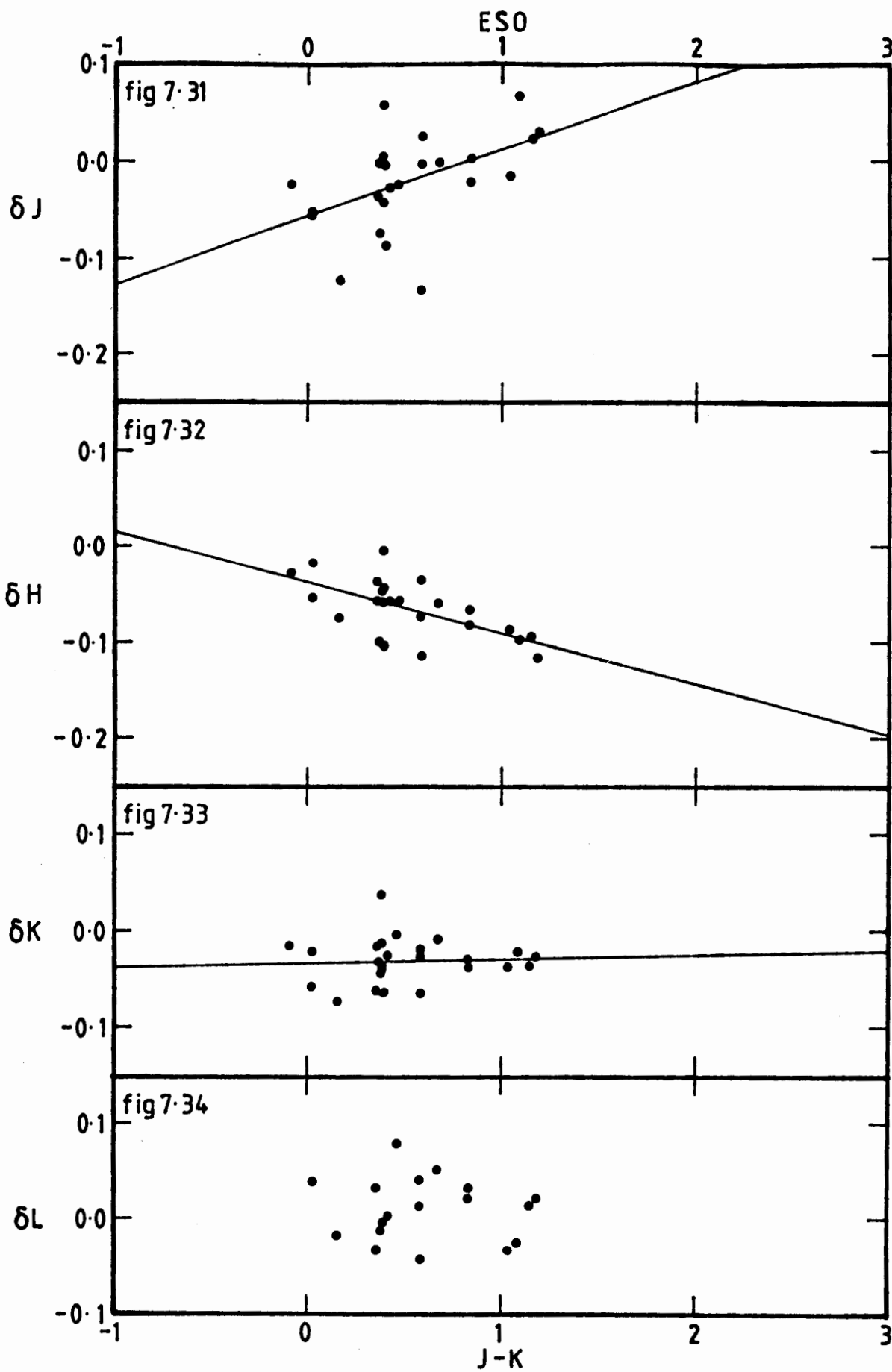


Table 7.3
Comparison between New and ESO Standards. (New - ESO)

Star	Delta J	Delta H	Delta K	Delta L
BS 0003	-0.001	-0.060	-0.008	0.051
BS 0077	-0.038	-0.058	-0.062	-0.033
BS 0519	0.068	-0.098	-0.021	-0.025
BS 0721	-0.024	-0.028	-0.015	
BS 1006	-0.088	-0.104	-0.040	-0.003
BS 1008	-0.023	-0.058	-0.003	0.079
BS 1195	-0.002	-0.074	-0.026	0.040
BS 1264	0.030	-0.118	-0.027	0.022
BS 2290	-0.043	-0.048	-0.043	
BS 2354	-0.076	-0.100	-0.032	
BS 2693	0.004	-0.058	-0.011	-0.012
BS 2882	0.058	-0.004	0.037	
BS 3138	-0.002	-0.037	-0.017	0.031
BS 4023	-0.053	-0.018	-0.021	0.038
BS 4174	-0.015	-0.088	-0.038	-0.033
BS 4167	-0.124	-0.075	-0.073	-0.019
BS 4216	0.026	-0.036	-0.019	0.012
BS 4450	-0.133	-0.116	-0.063	-0.041
BS 4523	-0.028	-0.058	-0.025	0.002
BS 6461	0.002	-0.082	-0.039	0.033
BS 6736	-0.054	-0.054	-0.059	
BS 7120	-0.022	-0.066	-0.030	0.020
BS 7951	0.024	-0.094	-0.036	0.013
BS 8477	-0.004	-0.044	-0.062	



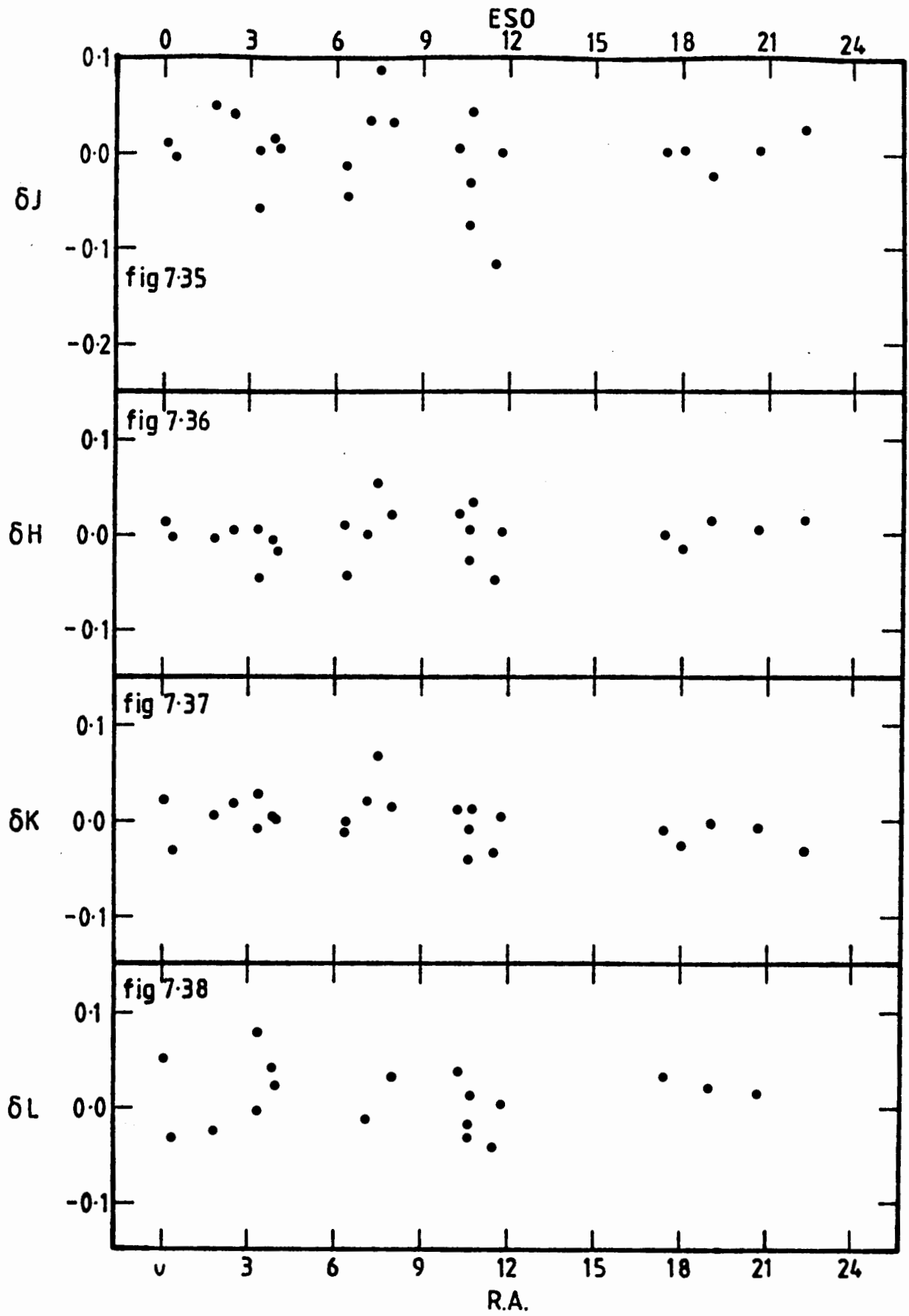
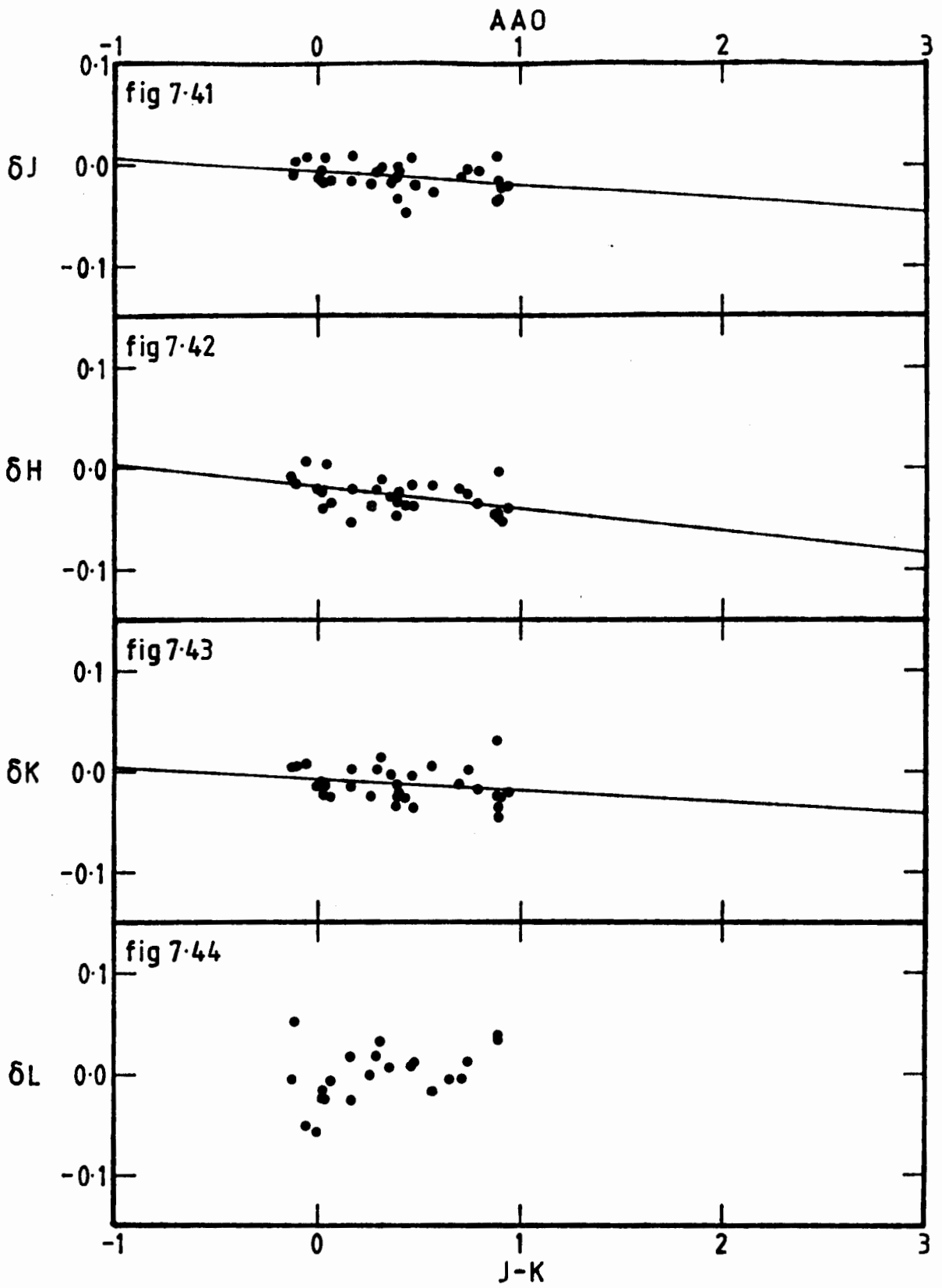


Table 7.4
Comparison between New and AAO Standards. (New - AAO)

Star	Delta J	Delta H	Delta K	Delta L
BS 0033	-0.003	-0.011	0.013	0.031
BS 0077	-0.018	-0.028	-0.002	0.007
Y 392	0.010	-0.003	0.030	
BS 1006	-0.008	-0.024	-0.020	
BS 1008	0.007	-0.018	-0.003	0.009
BS 1552	0.003	-0.016	0.005	0.051
Y 1181	-0.006	-0.035	-0.019	
BS 1698	-0.004	-0.026	0.001	0.011
BS 1983	-0.009	-0.022	0.001	0.018
BS 2015	0.010	-0.020	0.001	-0.026
BS 2290	-0.013	-0.038	-0.033	
BS 2451	0.009	0.009	0.009	-0.052
BS 2882	-0.002	-0.034	-0.023	
BS 3314	-0.013	-0.020	-0.016	-0.059
BS 3842	-0.028	-0.018	0.005	-0.017
BS 3871	-0.021	-0.039	-0.036	0.011
BS 4523	-0.048	-0.038	-0.025	
BS 4638	-0.009	-0.009	0.004	(-0.007)
BS 4689	0.008	0.003	-0.015	-0.025
BS 5028	-0.006	-0.023	-0.010	-0.024
Y 3501	-0.020	-0.040	-0.020	
Y 3958	-0.033	-0.050	-0.045	
Y 4338	-0.022	-0.053	-0.025	
Y 4794	-0.034	-0.047	-0.035	0.035
BS 7950	-0.019	-0.040	-0.023	-0.017
Y 5117	-0.016	-0.047	-0.023	0.039
BS 8278	-0.017	-0.051	-0.017	(0.019)
BS 8477	-0.034	-0.024	-0.012	
BS 8551	-0.012	-0.020	-0.011	-0.003
BS 8709	-0.016	-0.033	-0.027	-0.009
BS 8848	-0.020	-0.039	-0.025	-0.001



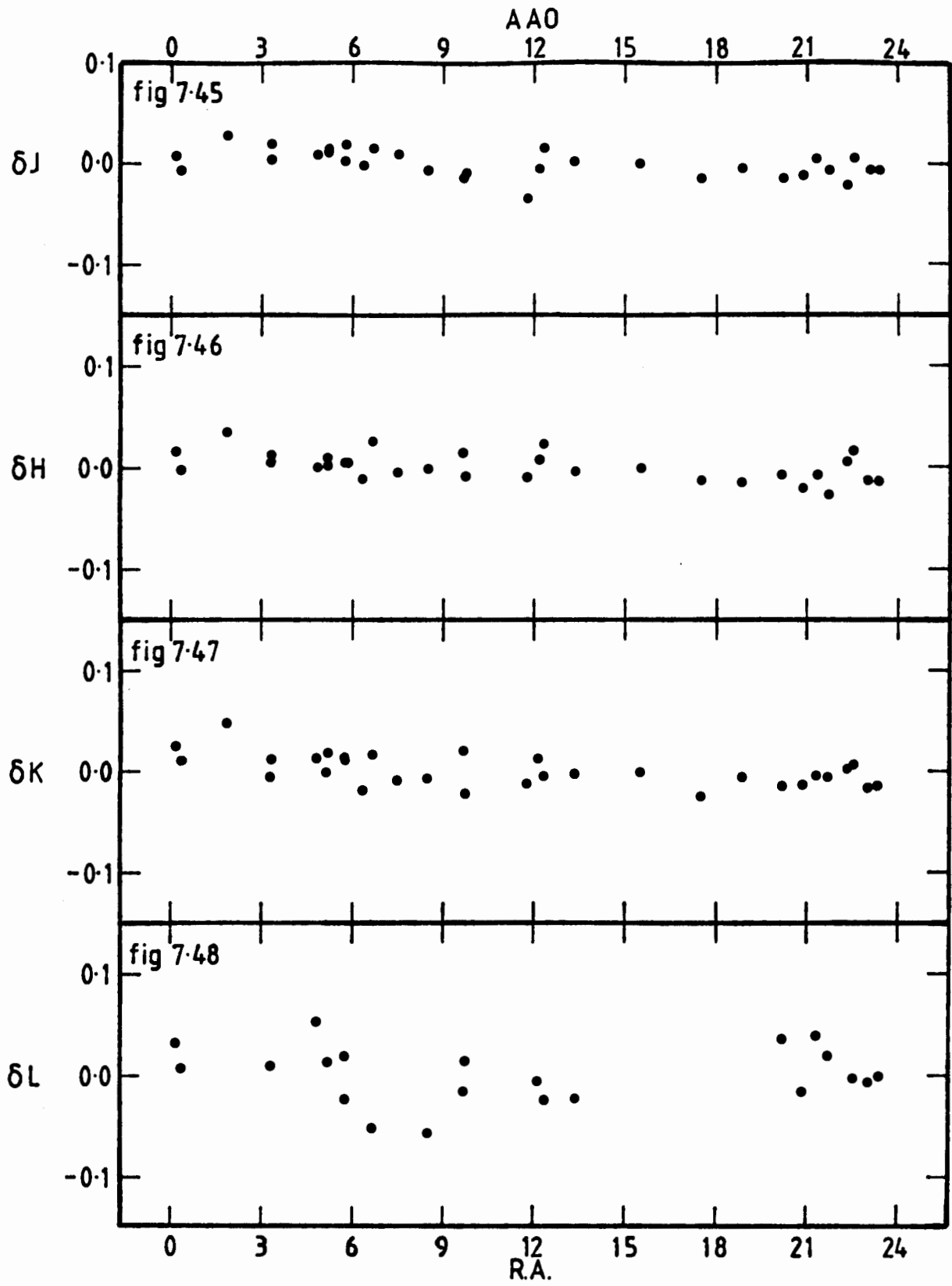
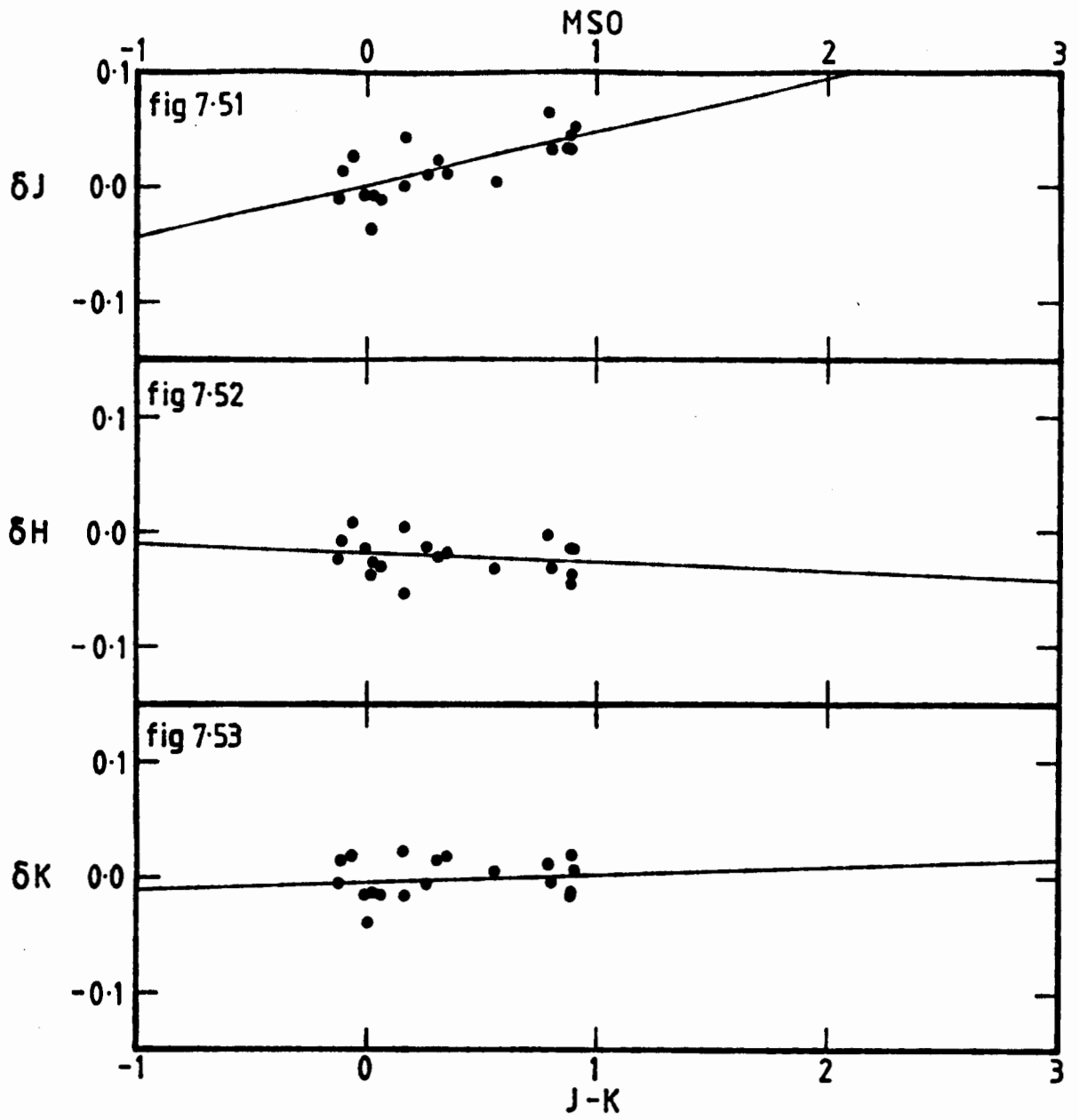


Table 7.5
Comparison between New and MSO Standards. (New - MSO)

Star	Delta J	Delta H	Delta K
Y 5817	0.032	-0.031	-0.003
BS 0033	(0.024)	-0.021	0.013
BS 0077	0.012	-0.018	0.018
Y 392	0.046	-0.015	0.020
BS 1552	0.017	-0.007	0.015
Y 1181	0.065	-0.002	0.011
BS 2015	0.043	0.005	0.021
BS 2451	0.029	0.009	0.019
BS 3314	-0.007	-0.014	-0.016
BS 3842	0.004	-0.032	0.005
BS 4638	-0.009	-0.023	-0.006
BS 5028	-0.034	-0.039	-0.040
Y 3958	0.033	-0.037	-0.015
Y 4338	0.053	-0.013	0.005
BS 7950	-0.006	-0.027	-0.013
Y 5117	0.034	-0.045	-0.013
BS 8278	0.001	-0.053	-0.017
BS 8709	-0.010	-0.030	-0.017
BS 8848	0.012	-0.012	-0.005



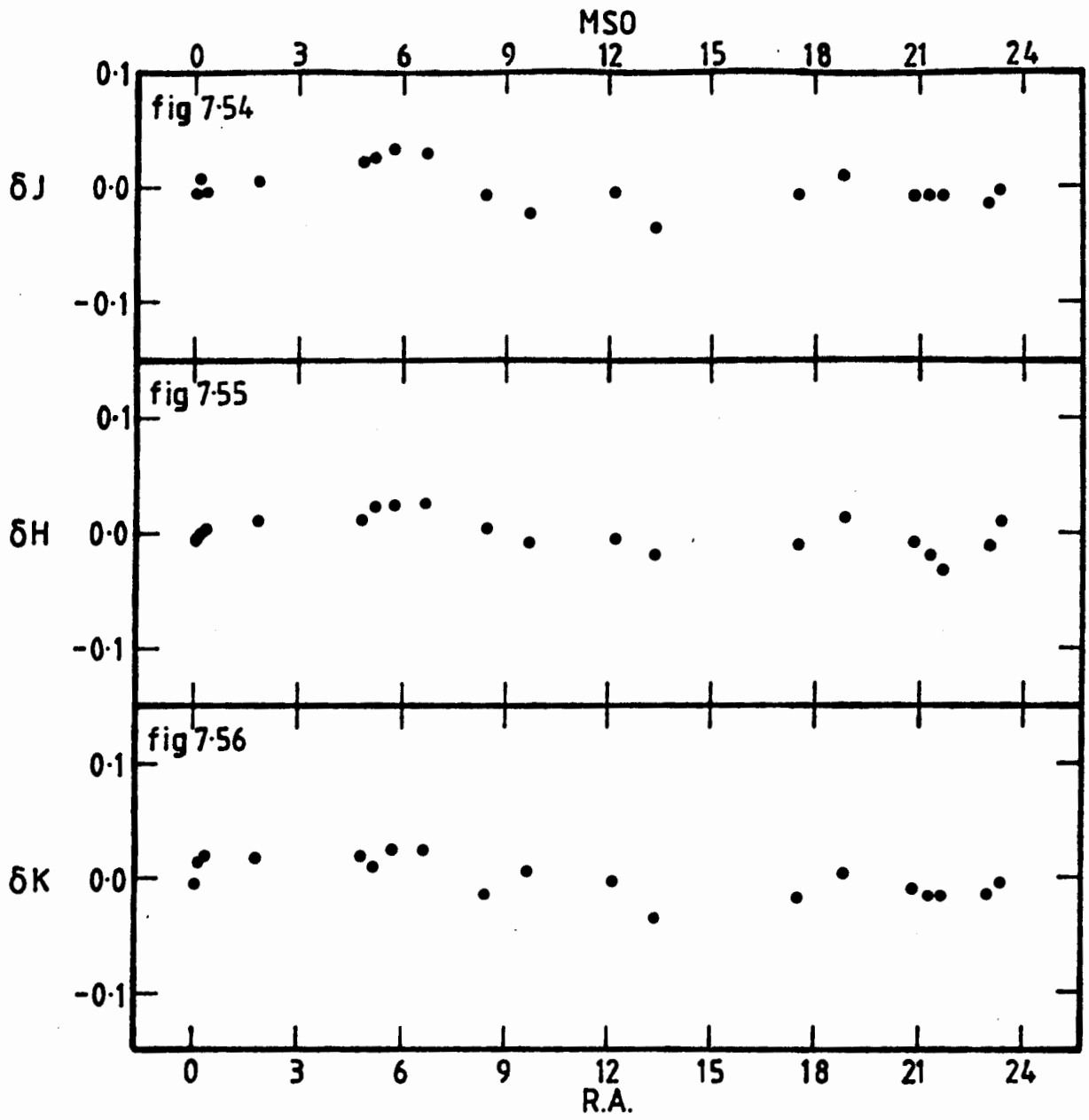
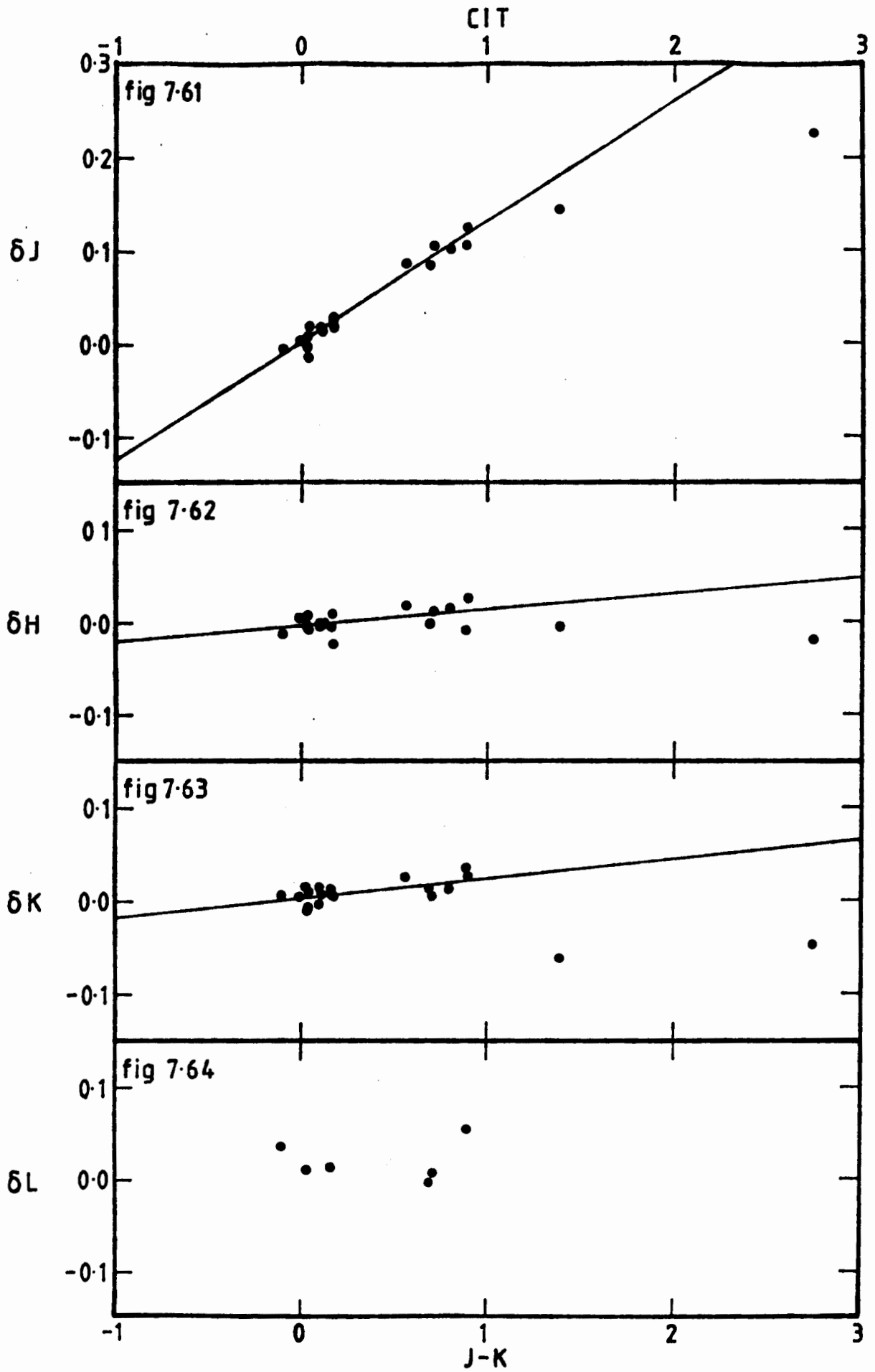
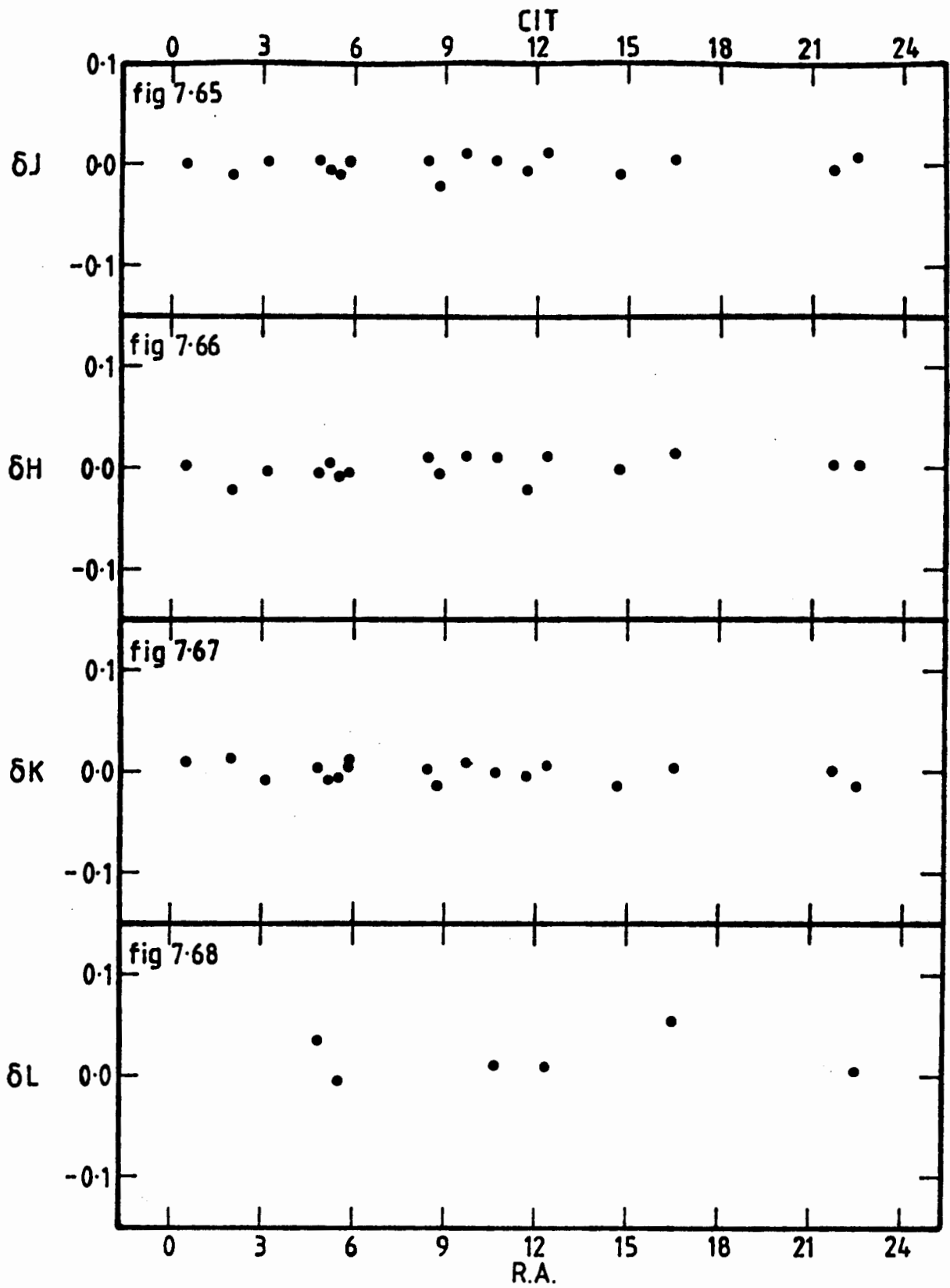


Table 7.6
Comparison between New and CIT Standards. (New - CIT)

Star	Delta J	Delta H	Delta K	Delta L
HD2811	0.016	0.000	0.016	
Y 392	0.105	-0.010	0.034	
HD19904	0.018	-0.004	-0.003	
BS 1552	-0.007	-0.011	0.005	0.036
Y 1181	0.100	0.014	0.012	
BS 1953	0.083	-0.001	0.012	-0.003
BS 2015	0.028	-0.004	0.012	
HD38921	0.009	-0.006	0.016	
BS3314	0.004	0.006	0.005	
HD75223	-0.013	-0.009	-0.009	
BS 3842	0.086	0.018	0.024	
BS 4167	0.026	0.010	0.007	0.011
HD101452	0.019	-0.023	0.004	
BS 4689	0.018	0.008	0.010	0.010
HD130163	-0.003	-0.004	-0.011	
Dph S1	0.226	-0.020	-0.048	
SR3	0.143	-0.004	-0.062	
BS 6136	0.124	0.026	0.026	0.054
HD205772	0.014	0.000	0.008	
BS 8551	0.103	0.010	0.004	0.007





REFERENCES.

- Allen, D.A. & Cragg, T.A., 1983. *Mon. Not. R. astr. Soc.*, 203, 777.
- Catchpole, R.M., Robertson, B.S.C., Lloyd Evans, T.H.H.,
Feast, M.W., Glass, I.S. & Carter, B.S., 1979.
SAAO Circ., Vol. 1, No. 4, 61.
- Catchpole, R.M., Glass, I.S., Carter, B.S. & Roberts, G., 1981.
Nature, 291, 392.
- Catchpole, R.M., Glass, I.S., Roberts, G., Spencer Jones, J. and
Whitelock, P.A., 1985. *SAAO Circ.* (Submitted).
- Cousins, A.W.J. & Stoy, R.H., 1962. *R. Obs. Bull.*, No. 49.
- Cousins, A.W.J., 1963. *R. Obs. Bull.*, No. 70.
- Cousins, A.W.J., 1971. *R. Obs. Ann.* No. 7.
- Cousins, A.W.J., 1973. *Mem. R. astr. Soc.*, 77, 223.
- Cousins, A.W.J., 1976. *Mem. R. astr. Soc.*, 81, 25.
- Elias, J.H., Frogel, J.A., Matthews, K., & Neugebauer, G., 1982.
Astron. J., 87, 1029.
- Elias, J.H., Frogel, J.A., Hyland, A.R. & Jones, T.J., 1983.
Astron. J., 88, 1027.
- Engels, D., Sherwood, W.A., Hamsteker, W. & Schultz, G.V., 1981.
Astr. Astrophys. Suppl., 45, 5.
- Feast, M.W., Catchpole, R.M., Carter, B.S. & Roberts, G., 1980.
Mon. Not. R. astr. Soc., 193, 377.
- Feast, M.W., Robertson, B.S.C., Catchpole, R.M., Lloyd Evans,
T., Glass, I.S. & Carter, B.S., 1982. *Mon. Not.
R. astr. Soc.*, 201, 439.
- Feast, M.W. & Carter, B.S., 1983. *IAU Circ.*, 3781.
- Frogel, J.A., Persson, S.E., Aaronson, M. & Matthews, K., 1978.
Astrophys. J., 220, 75 (Appendix).
- Glass, I.S., 1973. *Mon. Not. R. astr. Soc.*, 164, 155.
- Glass, I.S., 1974. *Mon. Not. astr. Soc. Sthn. Afr.*, 33, 53.

REFERENCES. (Cont.)

- Glass, I.S., 1980. The SAAD Infrared Photometers, SAAD.
- Glass, I.S., 1983. Mon. Not. astr. Soc. Sthn. Afr., 42, 43.
- Grasdalen, G.L., Strom, K.M. & Strom, S.E., 1973.
Astrophys. J., 184, L53.
- Henry Draper Catalogue, 1918-1924. Ann. Harv. Coll. Obs.,
Vol. 91-99.
- Hoffleit, D., 1964. Catalogue of Bright Stars, 3rd ed.,
Yale Univ. Obs.
- Hoffleit, D., 1982. Catalogue of Bright Stars, 4th ed.,
Yale Univ. Obs.
- Howarth, I.D., Wilson, R., Carter, B.S., Menzies, J.W., Roberts, G.,
Whitelock, P.A., van Dessel, E.L., de Loore, C.,
Burger, M. & Sandford, M.C.W., 1981.
Astr. Astrophys., 93, 219.
- Jenkins, L.F., 1952. General Catalogue of Trigonometric
Stellar Parallaxes, Yale Univ. Obs.
- Johnson, H.L. & Morgan W.W., 1953. Astrophys. J., 117, 313.
- Johnson, H.L., 1964. Bol. Obs. Ton. Tac., 3, 305.
- Johnson, H.L., 1966. Ann. Rev. Astr. Astrophys., 4, 193.
- Johnson, H.L., Mitchell, R.I., Iriarte, B. & Wisniewski, W.Z.,
1966. Commun. Lunar Planet. Lab., 4, 99.
- Jones, T.J., Hyland, A.R., Robinson, G., Smith, R. & Thomas, J.,
1980. Astrophys. J., 242, 132.
- Jones, T.J. & Hyland, A.R., 1982. Mon. Not. R. astr.
Soc., 200, 509.
- Kapteyn, J.C., 1906. Plan of Selected Areas, Hoitsema,
Groningen.
- Kaye, G.W.C. & Laby, T.H., 1971. Tables of Physical and
Chemical Constants 13th ed., p.142, Longman.
- Koornneef, J., 1983. Astr. Astrophys. Suppl., 51, 489.
- Lawrence, A. ... , Glass, I.S., Carter, B.S., ... (+49 authors),
1983. Astrophys. J., 267, 301.

REFERENCE. (Cont.)

- Manduca, A. & Bell, R.A., 1979. Publ. Astr. Soc. Pacific,
91, 848.
- Menzies, J.W., Banfield, R.M. & Laing, J.D. 1980. SAAO Circ.,
Vol.1, No 5, 149.
- Menzies, J.W. & Laing, J.D., 1980. SAAO Circ., Vol.1, No.5, 175.
- Pickering, E.C., Searle, A. & Wendell, O.C., 1885. Ann. Harv.
Coll. Obs., 14, 477.
- Robertson, B.S.C. & Catchpole, R.M., 1980. Mon. Not.
astr. Soc. Sthn. Afr., 39, 82.
- Stoy, R.H., 1956. Vistas in Astron., 2, 1099.
- Thomas, J.A., Hyland, A.R. & Robinson, G., 1973. Mon. Not.
R. astr. Soc., 165, 201.
- Vrba, F.J. and Rydgren, A.E., 1981. IAU Circ. No. 3604.
- Warner, B., 1979. Astronomers at the Royal Observatory Cape
of Good Hope, Balkema, Cape Town.
- Whitelock, P.A., Feast, M.W., Carter, B.S., Roberts, G.
& Glass, I.S., 1983. Mon. Not. R. astr. Soc., 203, 385.
- Whitelock, P.A., Carter, B.S., Feast, M.W., Glass, I.S.,
Laney, D., Menzies, J.W., Walsh, J. &
Williams, P.M., 1984. Mon. Not. R. astr. Soc. (In press)
- Wilking, B.A. & Lada, C.J., 1983. Astrophys. J., 274, 698.
- Young, A.T., 1974. Method of Experimental Physics, Vol.12,
Part A, Optical and Infrared, Astrophysics, p.152,
ed. Carleton, N., Academic Press.

Acknowledgments.

I would like to thank all my colleagues who have wittingly or unwittingly assisted me, especially Dr Ian Glass who was the original instigator of this project and who has given me much advice, Dr A W J Cousins who explained the possible and probable errors in the system and Prof. Brian Warner for advice.

I would also like to thank Drs Dave Kilkenny and Bill Martin for their original suggestion that I should try to obtain an MSc.

Many thanks to Maz who proof read the manuscript and who has encouraged me. Thanks also to Melanie and Heidi who never once shuffled daddy's papers.

 *
 * New IR Standards. *
 *

1 99999 8888 55555
 1 9 9 8 8 5
 1 9 3 8 8 5
 1 99999 8888 55555
 1 9 8 8 5
 1 9 8 8 5
 1 9 8888 55555

EDITION June 1984

RA	(1985)	Dec	V	Sp	Star	J	H	K	L	Note.
---	-----	---	-	--	----	-	-	-	-	-----
00 04 32	-37 25 51	8.6	M2V	SAY5817	5.335	4.732	4.527	4.344	High proper motion	
00 04 34	-05 47 29	4.6	K1III	SA0003	2.879	2.280	2.202	2.141		
00 10 30	-15 33 01	4.9	F7V	SA0033	(3.957)	3.669	3.643	3.611		
00 19 08	-64 58 28	4.2	F9V	SA0077	3.192	2.862	2.838	2.797	IR Standard for SMC.	
00 25 28	-43 45 47	3.9	A7V	SA0100	3.635	3.546	3.536	3.479		
00 29 16	-04 02 24	5.7	M0III	SA0117	2.901	2.052	1.895	1.729		
00 30 35	-43 41 23	7.5	A3V	SA2811	7.186	7.090	7.081			
00 40 37	-46 10 02	4.6	G8III	SA0180	3.001	2.444	2.365	2.285		
01 05 25	-46 47 56	3.3	G8III	SA0322	1.842	1.348	1.279	1.207		
01 07 50	-10 15 42	3.4	K1.5IIICN1	SA0334	1.622	0.985	0.886	0.779		
01 14 31	-45 36 41	5.0	G0V	SA0370	4.000	3.713	3.671	3.639		
01 26 51	-45 55 26	7.0	K4/5III	SAE132	4.450	3.624	3.487	3.334		
01 26 57	-46 13 44	7.7	A0V	SAE101	7.540	7.485	7.461			
01 31 01	-45 39 09	6.2	A1V	SA0443	6.054	6.025	6.026			
01 37 52	-43 00 15	6.7	F0V	SAE142	6.038	5.855	5.830			
01 41 05	-50 06 51	6.6	A3V	SAE164	6.368	6.281	6.275			
01 45 31	-50 53 28	5.5	M3III	SA0519	2.158	1.242	1.059	0.885		
01 52 06	-22 30 31	9.0	M1.5V	SAY392	6.120	5.387	5.240			
01 59 18	-21 09 01	4.0	M0.5IIIBa0.2	SA0585	1.125	0.263	0.105	-0.080		

02	15	58	-51	34	53	3.6	B8V/IV	SA0674	3.780	3.826	3.867	3.887	
02	21	29	-68	43	39	4.1	A3V	SA0705	4.004	3.974	3.964	3.955	
02	26	26	-47	46	15	4.2	B5IV	SA0721	4.496	4.542	4.585		
02	48	28	-32	28	07	4.5	G8IIIb	SA0841	2.786	2.230	2.152	2.087	
03	01	44	-23	40	58	4.1	A4IV	SA0919	3.778	3.680	3.667	3.700	
03	10	08	-39	06	29	7.0	A4III	SA19904	6.738	6.656	6.637		
03	17	26	-62	37	57	5.5	G3/5V	SA1006	4.382	4.036	3.980	3.947	5" SW of #V5.2 & High proper motion.
03	19	20	-43	07	36	4.3	G8III	SA1008	2.997	2.572	2.527	2.499	High proper motion.
03	48	53	-36	14	43	4.2	G9II/III	SA1195	2.668	2.156	2.084	2.050	
03	54	09	-45	27	37	6.9	A3V	SAE241	6.627	6.552	6.543		
04	00	41	-62	12	04	4.5	M4III	SA1264	0.730	-0.229	-0.447	-0.598	
04	08	06	-45	54	15	6.6	F3V	SA1291	5.971	5.638	5.609		
04	10	20	-42	01	56	4.9	F2IV/V	SA1302	4.289	4.109	4.075	4.069	
04	12	03	-44	24	22	6.7	K3/4III	SA1316	4.238	3.447	3.307	3.199	
04	13	30	-42	19	52	3.9	K2III	SA1326	2.058	1.434	1.349	1.281	
04	13	42	-46	10	10	6.8	F8/GOV	SAE244	5.754	5.436	5.395		
04	50	24	+05	34	49	3.7	B2III+B2IV	SA1552	4.033	4.084	4.145	4.201	
05	11	05	-45	00	41	8.5	M1p	SAY1181	5.864	5.285	5.071		High proper motion.
05	12	30	+02	50	39	4.5	K3III	SA1698	2.586	1.954	1.851	1.761	
05	32	28	-76	21	08	5.2	K2III	SA1953	3.358	2.754	2.667	2.577	High proper motion.
05	43	50	-22	27	10	3.6	F6V	SA1983	2.701	2.438	2.411	2.378	
05	44	45	-65	44	28	4.4	A7V	SA2015	3.890	3.740	3.721	3.664	IR standard for LMC.
05	46	52	-38	14	10	7.6	A0V	SA38921	7.579	7.544	7.551		
05	46	56	-51	04	18	3.8	A5V	SA2020	3.578	3.494	3.482	3.476	
06	19	42	-48	43	58	6.6	G3V	SA2290	5.507	5.172	5.117		
06	24	20	-63	25	11	6.5	G3III/IV	SA2354	5.374	5.040	4.998		

06	25	20	-48	10	04	5.8	B9V	SA2348	5.840	5.852	5.874	
06	37	18	-43	10	57	3.2	B8III	SA2451	3.339	3.369	3.399	3.378
06	49	29	-46	35	53	5.1	F5V	SA2548	4.304	4.047	4.014	3.978
06	49	32	-45	25	54	6.6	K5/MOIII	SA2546	3.850	3.052	2.887	2.750
06	52	20	-43	57	24	6.5	B8V	SA2579	6.634	6.618	6.637	
06	58	16	-45	44	48	6.2	A0V	SA2626	6.236	6.231	6.237	
07	07	47	-26	22	08	1.8	F8Ia	SA2693	0.784	0.482	0.399	0.259
07	30	10	-37	18	28	6.6	G4V	SA2882	5.548	5.206	5.157	
07	57	04	-30	17	37	4.8	A2Vv	SA3113	4.344	4.232	4.205	4.151
07	57	30	-60	15	45	6.1	G0V	SA3138	4.568	4.243	4.213	4.171
07	59	12	-18	21	27	4.6	A2Vn	SA3131	4.400	4.335	4.326	(4.301)
08	24	55	-03	51	25	3.9	A0V	SA3314	3.917	3.920	3.924	3.891
08	45	40	-13	29	32	4.3	G8II IbCN-0.5	SA3484	2.818	2.319	2.242	2.187
08	46	48	-39	44	38	7.5	A1V	SA75223	7.312	7.286	7.271	
09	03	38	-47	02	16	3.8	K2III	SA3614	1.896	1.284	1.181	1.061
09	11	42	-45	47	13	6.7	F3/5V	SAE439	5.814	5.562	5.521	
09	13	35	-44	05	01	5.8	B5V	SA3672	6.086	6.129	6.173	
09	13	03	-47	16	34	5.9	B9V	SA3670	5.930	5.936	5.937	
09	13	51	-43	09	54	5.2	B3/5V	SA3674	5.492	5.537	5.575	
09	19	42	-45	06	32	6.7	K2III	SAE429	4.680	4.002	3.888	3.791
09	20	50	-25	54	04	4.7	M1III	SA3718	1.635	0.730	0.536	0.387
09	37	26	-43	07	22	5.5	G8II	SA3842	3.972	3.482	3.405	3.313
09	43	32	-27	42	02	4.8	A8V+F7II/III	SA3871	3.709	3.311	3.234	3.161
09	50	45	-14	46	33	4.1	G7-III-IIIb	SA3903	2.608	2.108	2.028	1.943
10	14	06	-42	02	51	3.8	A2V	SA4023	3.757	3.742	3.729	3.728
10	24	06	-73	57	18	4.0	F2IV	SA4102	3.331	3.138	3.104	3.083

10 35 18	-78 31 47	4.1	M0III	SA4174	1.335	0.462	0.292	0.137	
10 36 40	-48 08 51	3.8	F4IV+F3	SA4167	3.276	3.135	3.107	3.091	
10 46 07	-49 20 26	2.7	G5III+G2V	SA4216	(1.196)	(0.704)	(0.611)	(0.532)	
10 52 53	-58 46 24	3.8	K1III	SA4257	2.203	1.665	1.586	1.510	Brightist Star.
11 32 16	-31 46 28	3.5	G7III	SA4450	2.017	1.514	1.437	1.339	
11 39 29	-39 03 48	7.6	A2/3m	SA101452	7.024	6.862	6.849		
11 44 54	-66 38 44	3.6	A7III	SA4520	3.340	3.251	3.229	3.205	
11 45 48	-40 25 07	4.9	G5V	SA4523	3.722	3.342	3.295	3.242	High proper motion.
11 58 25	-45 44 55	6.3	B8/9V	SAE570	6.492	6.522	6.548		
12 02 53	-42 21 00	5.2	F5V	SA4600	4.357	4.117	4.085	4.033	
12 07 28	-48 36 33	5.3	B9.5/A0V	SA4620	5.298	5.285	5.280		
12 10 41	-44 11 58	6.6	F5V	SAE550	5.748	5.502	5.467		
12 10 52	-52 17 06	4.0	B3V	SA4638	4.311	4.381	4.434	(4.483)	
12 13 15	-45 38 26	5.3	K3III	SA4652	2.874	2.079	1.938	1.801	
12 19 08	-00 35 01	3.9	A2IV	SA4689	3.808	3.783	3.775	3.765	
12 27 13	-50 08 52	3.9	B2V	SA4743	4.364	4.440	4.508	(4.505)	
12 29 05	-16 25 55	3.0	B9.5V	SA4757	3.032	3.040	3.060	3.039	
12 31 33	-72 03 01	3.9	B5V	SA4773	4.167	4.231	4.281	4.295	
12 36 53	-48 27 32	3.9	A2V	SA4802	3.730	3.700	3.693	3.662	
13 13 19	-59 01 24	4.9	F7IV	SA4989	3.994	3.690	3.646	3.589	
13 19 45	-36 38 00	2.8	A2V	SA5028	2.704	2.697	2.690	2.676	
13 38 56	-53 23 26	2.3	B1III	SA5132	2.801	2.907	2.980	3.023	
13 57 45	-44 43 51	3.9	B2IV/V	SA5249	4.322	4.426	4.482		
14 29 10	-45 15 18	5.5	B8V	SA5412	5.623	5.635	5.651		
14 36 52	-49 21 40	4.0	B5V	SA5453	4.376	4.440	4.490	4.561	
14 35 20	-46 10 50	5.6	K3III	SA5444	3.036	2.200	2.052	1.941	

14	38	12	-46	31	09	6.1	F6V	SA5457	5.166	4.901	4.858		
14	41	01	-37	43	47	4.0	B3V	SA5471	4.388	4.468	4.520	4.561	
14	45	28	-47	22	43	5.7	A1V	SA5494	5.619	5.586	5.579		
14	46	49	-39	51	50	7.0	A0	SA130163	6.952	6.841	6.824		
14	57	33	-43	04	27	2.7	B2IV	SA5571	3.166	3.258	3.327	3.381	
15	04	05	-46	59	35	3.9	B5V+B5IV	SA5605/6	4.212	4.268	4.312		
15	10	53	-48	40	54	3.9	B9.5Vne	SA5646	(3.880)	(3.890)	(3.896)		Brighter *
15	11	12	-52	02	35	3.4	G8III	SA5649	1.902	1.386	1.307	1.226	Brighter of Pair.
15	29	18	-41	13	16	10.2	M4	SAY3501	5.710	5.010	4.770		High Proper Motion.
15	53	49	-63	23	07	2.8	F2III	SA5897	2.269	2.097	2.064	2.035	
16	05	56	-20	37	46	4.0	B1V	SA5993	(4.017)	(4.042)	(4.085)	(4.134)	
16	25	15	-24	32	10		Very Faint	SASR3	7.848	6.961	6.458		\ Difficult to Find III
16	25	39	-24	21	27		Very Faint	SAOPH S1	9.026	7.250	6.282		> Not Suitable as a Standards. / Chart Grasdalen Ap.J.Lett.,184,L53,1973.
16	27	48	+00	41	52	5.4	K4IIIp	SA6136	2.954	2.186	2.046	1.924	
17	09	37	-44	32	22	5.1	G8/K0III+G	SA6371	(3.596)	(3.111)	(3.039)	(3.007)	
17	11	05	-43	13	14	3.3	F2V	SA6380	2.584	2.380	2.343	2.315	
17	17	55	-46	37	11	5.5	G8/K0V	SA6416	3.935	3.440	3.353	3.308	
17	24	03	-55	31	01	2.8	K3Ib/IIa	SA6461	0.582	-0.112	-0.259	-0.397	
17	26	01	-45	07	09	10.4		SAE756	8.323	7.616	7.523		
17	27	27	-46	51	36	9.7	M4	SAY3958	5.757	5.110	4.865		Fainter & Redder of pair.
17	29	44	-60	40	21	3.6	B8Vn	SA6500	3.773	3.804	3.825		
17	34	32	-46	29	47	4.6	A0V	SA6537	4.526	4.510	4.510		
17	35	34	-44	33	20	8.1	B3III/IV	SAE703	8.102	8.113	8.140		
17	40	09	-46	54	53	5.8	A0V	SA6572	5.727	5.708	5.711		
18	02	57	-24	21	43	6.0	O8If	SA6736	5.796	5.766	5.771		
18	23	11	-34	23	34	1.8	B9.5III	SA6879	1.752	1.738	1.731	1.725	

18	48	57	-23	51	18	10.6	M6	SAY4338	6.278	5.647	5.375		
18	54	13	-22	41	28	5.0	K3II/III	SA7120	2.848	2.134	2.010	1.890	
19	54	14	-41	54	31	4.1	K0II/III	SA7581	2.292	1.652	1.563	1.491	
20	04	04	-46	08	24	7.0	K3/4III	SAE830	4.376	3.542	3.390	3.273	
20	12	49	-45	12	31	8.0	M1/2V	SAE861	5.146	4.443	4.265	4.135	
20	18	13	-47	37	38	6.1	F5V	SAE844	5.283	5.043	5.008		
20	21	27	-42	05	52	5.6	A0V	SA7779	5.580	5.575	5.579		
20	22	52	-42	28	19	5.6	A5V	SA7787	5.256	5.145	5.123		
20	36	31	-47	20	41	3.1	K0III	SA7869	1.464	0.904	0.823	0.746	
20	46	52	-09	33	05	3.8	A1V	SA7950	3.711	3.680	3.687	3.673	
20	46	57	-05	05	00	4.4	M3III	SA7951	0.934	-0.024	-0.216	(-0.377)	
21	05	06	-17	17	35	4.1	A1V	SA8075	4.066	4.036	4.042	4.013	
21	16	22	-38	55	34	6.6	M0V	SAY5117	3.954	3.223	3.067	2.969	High proper motion AX Mic Flare Star.
21	25	13	-65	26	06	4.2	F6V	SA8181	3.271	2.970	2.933	(2.910)	
21	37	45	-41	06	57	8.2	A5IV	SA205772	7.779	7.685	7.663		
21	39	16	-16	43	50	3.7	F0p	SA8278	3.203	3.059	3.043	(3.039)	
22	07	17	-47	02	03	1.7	B7IV	SA8425	2.010	2.066	2.103	2.127	
22	07	31	-33	03	44	4.5	A2V	SA8431	4.384	4.351	4.349	4.335	
22	13	44	-41	27	11	6.2	G5V	SA8477	5.086	4.746	4.688		
22	22	13	-46	00	16	5.6	F0V	SA8524	4.925	4.714	4.672		
22	27	06	+04	37	12	4.8	K0III	SA8551	3.008	2.380	2.299	2.227	
22	28	23	-43	34	22	4.0	G6/8III	SA8556	2.354	1.797	1.715	1.639	
22	30	39	-32	25	24	4.3	A0V	SA8576	4.274	4.270	4.273	4.257	
22	30	54	-46	39	27	7.2	F5V	SAE941	6.402	6.158	6.119		
22	35	49	-43	32	57	6.8	F8V	SAE942	5.806	5.513	5.479		
22	41	43	-47	17	17	6.0	G0V	SA8635	4.930	4.595	4.532		

22	44	48	-46	37	36	5.5	K2III	SA8657	3.388	2.664	2.552	2.444
22	48	59	-44	30	12	8.1	A0V	SAE901	7.988	7.949	7.947	
22	53	51	-15	54	03	3.3	A3V	SA9709	3.114	3.067	3.053	3.051
22	56	49	-29	42	07	1.2	A3V	SA8728	1.054	1.010	0.999	0.975
23	16	34	-58	19	05	4.0	F1III	SA8848	3.220	2.991	2.955	2.929
23	37	03	-45	34	32	4.7	A2V	SA8959	4.578	4.548	4.526	4.481
23	48	09	-28	12	48	4.6	A0V	SA9016	4.566	4.550	4.540	4.549

10/11 APR 1984
 STANDARDS ONLY.
 COLOUR EQUATION

Brian Carter.

30 INCH

$$J = J(\text{INST}) + 0.000 * (J - H) \text{INST}$$

ZERO-POINT CORRECTIONS

	ZP	ZSE	N	EXT.COEF.
J	11.701	0.002	16	0.100
H	10.970	0.002	16	0.060
K	10.548	0.002	16	0.100
L	6.976	0.011	8	0.150

STAR NOT USED IN ZERO-POINT DETERMINATION IF RESIDUAL GREATER THAN 0.100

STAR	RA	DEC	HJD		AIR		F	MAG	SE	NO	G	A	RESIDUALS(STND.-PRG.)			
			SAST	2445801.+	MASS								J	H	K	L
SA3113	757.1	-3017.6	1924	.22633	1.001	J	4.350	0.002	1	7	4	-0.006				
			1925	.22710	1.001	H	4.226	0.002	1	7	4		0.006			
			1926	.22795	1.001	K	4.206	0.004	1	7	4			-0.001		
			1928	.22950	1.002	L	4.172	0.033	2	10	4				-0.021	
SA3113	757.1	-3017.6	1938	.23637	1.004	J	4.350	0.002	1	7	4	-0.006				
			1939	.23729	1.004	H	4.228	0.002	1	7	4		0.004			
			1941	.23814	1.005	K	4.195	0.002	1	7	4			0.010		
			1935	.23453	1.003	L	4.167	0.022	3	10	4				-0.016	
SA3842	937.4	-4307.4	2045	.28462	1.019	J	3.977	0.002	1	7	4	-0.005				
			2046	.28544	1.018	H	3.474	0.002	1	7	4		0.008			
			2048	.28631	1.018	K	3.390	0.003	1	7	4			0.015		
			2049	.28759	1.018	L	3.338	0.020	2	10	4				-0.025	
SA3674	913.8	-4309.9	2141	.32314	1.046	J	5.504	0.003	1	10	4	-0.012				
			2143	.32423	1.048	H	5.551	0.003	1	10	4		-0.014			
			2144	.32511	1.049	K	5.576	0.002	1	10	4			-0.001		
SA3670	913.0	-4716.6	2157	.33423	1.078	J	5.938	0.002	1	10	4	-0.008				
			2159	.33512	1.079	H	5.929	0.002	1	10	4		0.007			
			2200	.33590	1.081	K	5.935	0.004	1	10	4			0.002		
SA4216	1045.9	-4919.0	2205	.34048	1.045	L	0.549	0.011	2	8	4				-0.017	
SA3842	937.4	-4307.4	2215	.34731	1.056	J	3.982	0.002	1	7	4	-0.010				
			2214	.34636	1.055	H	3.487	0.003	1	7	4		-0.005			
			2213	.34539	1.054	K	3.402	0.008	1	8	4			0.003		
			2210	.34371	1.051	L	3.323	0.021	3	8	4				-0.010	
SA4600	1202.9	-4221.0	2310	.38694	1.016	J	4.359	0.007	1	7	4	-0.002				
			2315	.39013	1.016	H	4.120	0.002	1	7	4		-0.003			
			2313	.38894	1.016	K	4.080	0.009	1	7	4			0.005		
			2318	.39257	1.015	L	4.038	0.026	3	10	4				-0.005	

30 NOV 1984

SA560576	1504.1 -4659.6	0055 .45954	1.080	J	4.206	0.002	2	6	4	0.005	0.003	0.001	
		0055 .45916	1.030	H	4.265	0.002	1	6	4				
		0056 .46021	1.079	K	4.311	0.004	1	6	4				
SA5132	1338.9 -5323.0	0102 .46400	1.071	J	2.795	0.002	1	4	4	0.006	0.001	-0.004	
		0103 .46482	1.071	H	2.906	0.002	1	4	4				
		0104 .46560	1.071	K	2.984	0.002	1	4	4				
SA5457	1438.2 -4631.2	0111 .47060	1.044	J	5.159	0.004	2	9	4	0.007	-0.002	-0.009	
		0110 .46988	1.044	H	4.903	0.004	1	9	4				
		0111 .47079	1.044	K	4.867	0.003	1	9	4				
SAY3501	1531.3 -4114.0	0121 .47750	1.063	J	5.704	0.004	2	9	4	0.006	0.003	0.003	
		0121 .47754	1.063	H	5.007	0.002	2	9	4				
		0125 .48004	1.058	K	4.767	0.003	2	9	4				
SA560576	1504.1 -4659.6	0132 .48522	1.048	J	4.202	0.003	2	7	4	0.010	0.005	0.003	
		0135 .48680	1.047	H	4.263	0.002	2	7	4				
		0137 .48842	1.046	K	4.309	0.003	2	7	4				
SA6380	1711.1 -4313.2	0315 .55500	1.053	J	2.585	0.003	1	4	4	-0.001	0.001	-0.002	0.041
		0313 .55412	1.054	H	2.379	0.002	1	5	4				
		0312 .55316	1.056	K	2.345	0.004	1	5	4				
		0309 .55136	1.058	L	2.274	0.012	3	8	4				
SASR3	1625.2 -2432.0	0326 .56385	1.012	J	7.845	0.003	3	14	4	0.003	-0.013	-0.014	
		0330 .56666	1.011	H	6.974	0.006	3	13	4				
		0333 .56912	1.010	K	6.472	0.005	3	13	4				
SA6537	1734.5 -4629.8	0343 .57445	1.060	J	4.532	0.002	2	8	4	-0.006	-0.007	-0.016	
		0346 .57605	1.058	H	4.517	0.002	2	8	4				
		0348 .57763	1.056	K	4.526	0.004	2	8	4				
SA6380	1711.1 -4313.2	0532 .65042	1.043	J	2.566	0.003	2	4	4	0.018	0.007	0.005	0.053
		0534 .65196	1.044	H	2.373	0.003	2	4	4				
		0537 .65354	1.046	K	2.338	0.003	2	4	4				
		0539 .65552	1.049	L	2.262	0.012	3	7	4				