1. Introduction

Described herein are the results of the photometric calibration program for the season 1986–1987 (August, 1986 to May, 1987).

The Cal Tech (CIT) photometric system (Elias *et al.* 1982) was taken as the system of reference for the Arcetri InSb photometer. This system, like that of Johnson (1965, 1966), is based on the assumption that Vega (BS 7001, α Lyr) has magnitude $\equiv 0$ in each filter band. A network of stars was defined as the TIRGO (Telescopio InfraRosso del Gornergrat) standard network and was divided into two categories: 1) a group of 10 "primary standards" for which CIT magnitudes are taken as given (J, H, K, L, and CO); and 2) a group of 18 "secondary standards" which will be measured relative to the first group, and subsequently become part of the TIRGO standard network. The M filter band has α Lyr as the defining standard and will necessarily require more measurements than the other bands for a reliable calibration.

The calibration philosophy in detail is given in Hunt and Natta (1984). Previous results of the calibration program from the 1984–1985 and 1985–1986 observing seasons are discussed in Hunt (1986). Therein are given magnitudes in four bands (J, H, K, and L′) for 9 secondary standards (the TIRGO L′ passband has $\lambda_{\rm cuton} = 3.55\ \mu m$, $\lambda_{\rm cutoff} = 4.18\ \mu m$, and $\lambda_{\rm eff} = 3.91\ \mu m$). Also given are the (null) results of an attempted color transformation to determine the degree of similarity between the TIRGO photometric system and that of CalTech; the two systems were indistinguishable to within the measurement errors.

The data used in the present analysis were taken from service observing time in the 1986–1987 observing season and from program time in which one of the authors (LH) is a collaborator; the data comprise 26 nights and more than 400 individual observations. A relatively complete determination of the TIRGO standard network is given in what follows and includes magnitudes in four filter bands (J, H, K, and L′) for 18 secondary standards.

Unfortunately, the data from the 1986–1987 observing season (September – June) suffer from the same systematic error described in Hunt (1986). This systematic error, on the order of 0.2–0.3 magnitudes, affects only the brightest stars; the causes are not yet clearly understood. A more complete discussion is given in Section 2.4. It should be noted that the correction described in Hunt (1986) is not applicable to the data of 1986–1987.

In what follows, the observations used for the analysis are briefly described and the mean zero points and atmospheric extinction coefficients for the observing season are given. Values for magnitudes of the secondary standard network are given in four bands, and the (null) results of a color transformation between the CIT system and the TIRGO photometric system are described. Finally, the systematic error affecting bright star data together with minor problems in data acquisition are discussed.

2. The 1986–1987 Observations and Results

The observations were taken from service observing time (13 nights with 203 observations of primary standards in four filter bands) and from program observing time (13 nights with 221 observations of primary standards in four filter bands).

2.1 Mean Zero Points and Atmospheric Extinction Coefficients

The mean zero points [1] and the atmospheric extinction coefficents in each band are given in Table 1A. For each night in each band, linear regressions of the observed zero points of *primary* standards as a function of air mass were calculated. For the estimate of the atmospheric extinction, the number of observations involved in the regression was required to be ≥ 4. If the slope of the regression (i.e., extinction in mag airmass^{-1}) was determined with an error of 3σ or better, the extinction was considered measurable and the value was used both in the determination of the magnitudes of the secondary standards, which will be discussed below, and in the calculation of the mean values of the extinction given in Table 1A. The mean zero points were calculated as weighted averages where the weight was either: 1) the inverse of the squared formal error in the mean (standard deviation of the nightly observations divided by the square root of the number of observations: $\sigma/\sqrt{n_{obs}}$) when the extinction was not measurable, or 2) the weighted (with the number of observations) scatter in the air mass fit when the extinction was measurable. The values for the atmospheric extinction presented in Table 1A coincide very well with various estimates from other observatories (see Table 1B).

It should be noted (e.g., Hunt 1986) that these averages should never substitute a nightly determination of both zero points and atmospheric extinction.

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[1] Zero point $\equiv$ 2.5 *log*(counts for mag = 0)

Observed magnitude = -2.5 *log*(counts) + Zero point

As in 1984–1985, the data are suggestive of a seasonal change in transparency; moreover, the extinction can change noticeably from night to night.

TABLE 1A

TIRGO 1986 – 1987 Mean Zero Points and Extinction Coefficients

(1)	(2)	(3)	(4)	(5)
J	15.50 ± 0.09	18 (97)	0.126 ± 0.040	5
H	15.24 ± 0.07	18 (97)	0.060 ± 0.019	3
K	14.48 ± 0.06	18 (113)	0.076 ± 0.026	7
L′	13.33 ± 0.07	15 (99)	0.185 ± 0.091	3

Notes to Table 1A:

(1) Filter band

(2) Mean zero point, $< ZP >$, with standard deviation, σ, of the set of observations about the mean

(3) Number of nights used to calculate mean values for zero points, (number of observations)

(4) Mean atmospheric extinction, $< k_\lambda >$, with standard deviation, σ of the set of observations about the mean

(5) Number of nights used to calculate mean values for atmospheric extinction

TABLE 1B

Atmospheric Extinction Coefficients

(1)	ESO (2)	AAT (3)	KPNO (4)
J	0.081 ± 0.008	0.10 – 0.16	≈ 0.11
H	0.058 ± 0.006	0.06 – 0.10	0.10 – 0.15
K	0.113 ± 0.005	0.08 – 0.14	0.07 – 0.18
L	0.130 ± 0.005	≈ 0.20[5]	0.12 – 0.28

Notes to Table 1B:

(1) Filter band

(2) Engels *et al.* (1981)

(3) Allen and Cragg (1983)

(4) Low and Rieke (1974)

(5) Extinction for L′ passband

2.2 Secondary standard estimated magnitudes in J, H, K, and L′

The 18 secondary standard stars were observed on an average of 3 nights in each band. The estimated magnitudes from the 1986–1987 observing season are given in Table 2 together with the number of nights and the number of observations used in the determination. Each observed magnitude is a result of an independent observation during a night in which at least 3 primary standards were observed; the observed magnitudes were corrected for atmospheric extinction when measurable. The mean values are calculated using the weighted mean of the observed magnitudes where the weight is inversely proportional either: 1) to the square of the standard deviation of the zero points during the night (when the extinction was not measurable), or 2) to the square of the spread associated with the linear (in air mass) regression used to calculate the zero points (when the extinction was measurable). The errors quoted reflect the standard deviation of the observed magnitudes around the mean value and do not reflect the formal statistical counting errors associated with the individual observations.

When measurements in L were of sufficiently low signal-to-noise to warrant special consideration (≤ 100), the magnitudes given in Table 2 were calculated using the S/N ratios as weights, instead of the using the error associated with the nightly fit. In addition, the quoted errors are the weighted (with S/N) deviation about the (weighted) mean.

Table 3 contains a reproduction of the Table 3 contained in Hunt (1986), that is, the estimated secondary star magnitudes from the 1984–1985 observing season. Also included are those stars which had only one observation and so did not appear in the version of the table given in Hunt (1986). These two tables can be compared to one another to provide a rough idea of the repeatability of the measurements and of the sort of errors that should realistically be associated with these magnitudes.

For convenience, Table 4A provides the TIRGO primary standard list with magnitudes from Elias *et al.* (1982). Table 4B provides the secondary star magnitudes obtained by calculating the weighted mean of the two data sets 1984–1985 and 1986–1987. The weights used are the inverse squares of the formal errors of the mean (i.e., the number of observations used in the mean individual calculation divided by the squares of the errors cited in the respective tables). The error associated with these magnitudes is the weighted deviation

of the two data points about the (weighted) mean. Caution should be exercised when adopting those magnitudes derived from only a few observations.

It should be mentioned that the J and H magnitudes for BS 2421 and the H magnitude for BS 3403 were derived only from the 1984–1985 observations; the 1986–1987 measurements suffered from the systematic error described in Section 2.4. In addition, the L′ magnitude for BS 3304 is omitted because of an unexplained inconsistency between the 1984–1985 and the 1986–1987 results.

For the nine secondary standards which have J, H, and K magnitudes given in Elias *et al.* (1982), the mean difference (TIRGO - CIT) in the J passband is 0.025 ± 0.045 mags. When BS 3403 is included (a discrepancy already noted in Hunt (1986)), the mean difference becomes 0.04 ± 0.065. In either case, the result is consistent with 0.00 magnitudes of difference between the CIT and the TIRGO J magnitudes. For the H and K passbands, the mean differences are even lower: 0.01 ± 0.025 mags in H (10 stars) and -0.01 ± 0.02 mags in K (10 stars). For the two secondary standards which have L magnitudes in Elias *et al.* (1982), the mean difference is 0.01 ± 0.04 mags. On the basis of these rudimentary checks, the TIRGO and the CIT photometric systems are not measurably different.

2.3 Color transformation between the TIRGO and the CIT photometric systems

As outlined in Hunt (1986), an attempt was made to transform the TIRGO photometry to the CIT system using the method given in Harris *et al.* (1981). This technique differs from the "formal" technique presented in Hardie (1962, see also Henden and Kaitchuck 1982) in that a series of nights is fitted simultaneously, varying from night to night the zero point and atmospheric extinction, while keeping fixed the color transformation terms. For each filter, the color term was taken to be proportional to the color nearest the filter (e.g., for J, J-H; for H, H-K; for K, H-K; for L, K-L). The transformation equations included a first order color term only.

Eighty (80) individual observations were subjected to the color transformation equations. The resulting color terms are not consistent from one data set to another, nor are they well-determined within any given data set. The preponderance in the standard network of blue stars (that have colors usually within the photometric accuracy with which they can be measured) and the concomitant paucity of observations of red stars cause the data set to be intrinsically unsuitable for any sort of color transformation. For this reason, an

attempt was made to apply the transformation only to those stars with J-H ≥ 0.05. The results of applying the transformation equations to this subset of data were not consistent with any of the results from the data set as a whole, thus reinforcing the supposition that the data are not well-adapted to color transformation. An additional complication arose because the red stars that have colors much redder than the measurement errors are rather bright; in fact, the systematic error described in Section 2.4 precluded the use of the majority of stars that are crucial in the determination of any color transformation (i.e., those that have red colors).

The color term in L is similarly ill-determined. In spite of the *a priori* expectations of a determinable color term in L between the TIRGO and the CIT photometry, there is no consistent measurable difference between the two. Again, this is most likely a result of the paucity of red stars in the data set. Unfortunately, the number of red stars with CIT magnitudes in L is relatively small and, thus, any transformation from the TIRGO L$'$ magnitudes to those of the CIT photometry will be arduous.

Work is underway to procure a sufficient number of observations of the red stars in the standard network so as to obtain a color transformation particularly for the L magnitudes. At present, for lack of evidence, the TIRGO magnitudes J, H, and K can be considered interchangeable with those of the CIT photometric system. Caution should be exercised when publishing TIRGO L magnitudes, however; the TIRGO passband in L is, strictly speaking, an L$'$ filter, not the L passband of the CIT photometry.

2.4 Systematic Error in Bright Star Measurements

As described in Hunt (1986), the TIRGO photometric data since August, 1985 exhibit a correlation between observed zero point and apparent magnitude in the sense that the magnitudes of bright stars are systematically fainter than they should be. In DC mode, the Arcetri photometer is linear over 6 orders of magnitude (Lisi and Hunt 1986) and can accurately measure incident flux from about 1 to 2 counts (normalized to 1 second at low gain) to more than 3×10^6 counts. In AC mode, that is modulating between source and source + sky, hardware modifications made in the summer of 1985 gave rise to a change in the high frequency response of the "back-end" electronics. The severity of this change seems to depend on the magnitude of the flux level difference between the two alternating signals. This effect results in bright star magnitudes which

are systematically fainter than they should be. The causes are currently under investigation.

Previously (Hunt 1986), an empirical correction that depended on the count rate was introduced. However, that correction is applicable only to the 1985–1986 data and not to the 1986–1987 data as there have been subsequent changes made to the data acquisition software. For the 1986–1987 observations, the effect does not seem to be a continuous one, but rather to suddenly onset at a count rate of $\approx 10^5$ counts (normalized to 1 second at low gain) and to get progressively worse as the count rate gets higher. As a result, objects which have a count rate $\gtrsim 10^5$ should not be used in any astronomical program. *It should be stressed that*: 1) the correction given in Hunt (1986) is not applicable to the 1986–1987 observations, and 2) the solution to this systematic error for the 1986–1987 observations is to eliminate from consideration all objects which have a count rate $\gtrsim 10^5$.

2.5 Other Problems with Data Acquisition

There has been, since August, 1985, a malfunction of the modulating secondary: the amplitude of the chopper throw depends on the frequency of the modulation. This phenomenon becomes evident as soon as one commences measurement of a faint source adopting a beam switch amplitude defined with a bright standard or when one changes filter and, thus, integration time and modulation frequency. Clearly, small apertures exacerbate the problem as fine adjustments of the chopper amplitude can be problematic. This problem will be resolved in the next few months; in the meantime, refer to the resident astronomer for further elucidation.

3. Concluding Remarks

The results from the 1986–1987 observing season continue to be encouraging. Photometric accuracy and extinction coefficients of the Gornergrat are comparable with those of other observatories. Magnitudes are presented for 18 stars which can be tentatively adopted as photometric standards. The question of a color transformation between the TIRGO and the CIT photometry is still open, but the resolution of the problem is in progress.

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