

# CCD standards for $U$ and $I$ in the open cluster NGC 7790 \*

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**Abstract.** Photometric  $U$  and  $I$  standard sequences in field of the open cluster NGC 7790 are presented. The intention is to achieve wide ranges in magnitude and colour making these sequences suitable for calibrating deep CCD photometry. The 84 standard stars extend the  $BVR$  sequences of Odewahn et al. (1992) to the near UV and IR, respectively. – This work is part of a common project between the Universitätssternwarte Bonn, Germany, and the Institute of Astronomy of the Bulgarian Academy of Sciences to study binary open star clusters and clusters in the direction of the Galactic anticentre.

**Key words:** instrumentation: CCD camera – techniques: photometric – astronomical data bases: standard sequences – open clusters: individual: NGC 7790

## 1. Introduction

### 1.1. Photometric standard sequences for imaging detectors

Photometric calibration of the two-dimensional CCD detectors has to rest on standard sequences which should fulfil a number of fundamental requirements: The standard stars should cover a wide as possible range in colour and reach to faint magnitudes. The field of view should have the typical dimensions of a CCD field,  $5' \times 5'$ , say, and the crowding of stellar images should be a minimum. Of course, the internal and external errors of magnitudes and colours should approach the limits of feasibility.

Practically all modern calibrations refer ultimately to the homogeneous photoelectrically observed set of standard stars by A. U. Landolt (1983). The underlying photometric system is often called  $UBVRI$  system for simplicity. But it relies on a combination of systems from the northern and southern hemisphere which can be summarized under the names Johnson-Kron-Cousins (for the intricate history, see Landolt 1983).

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\* Based on observations collected at the National Astronomical Observatory Rozhen, Bulgaria

In 1985 Christian and co-workers published six photoelectric  $BVRI$  standard sequences suitable for video camera and CCD calibration. They had selected between 6 and 12 stars in or near 6 clusters (M 92, NGC 2264, NGC 2419, NGC 4147, NGC 7006, and NGC 7790). Seven years later Odewahn et al. (1992, OBH) extended three of the previous sequences (NGC 4147, NGC 7006, and NGC 7790) to fainter limits and to wider ranges in colour by means of CCD observations. But they restricted the photometric bands to  $B$ ,  $V$ , and  $R$ .

### 1.2. Standard stars in the open cluster NGC 7790

In 1995 we started the project “Structure of the Galaxy: evolution and kinematics of open clusters in the anticentre region” which is a common investigation of the Observatory Hoher List of the University of Bonn, Germany, and the Institute of Astronomy of the Bulgarian Academy of Sciences, Sofia. (Details and results of the project will be given later.) For calibration purposes we used several well-known standard sequences in star clusters, e.g. in M 67 (Montgomery et al. 1993), and in M 92 (Majewski et al. 1994), but most of our photometry was calibrated with standard stars in the open cluster NGC 7790.

The coordinates of NGC 7790 are R.A. =  $23^h 58^m 4$  and Dec. =  $+61^\circ 13'$  (2000) – Therefore, most of the year it can be observed from northern sky observatories. Being an intermediate-age open cluster, it is suitable for calibration of different types of astronomical objects like clusters and distant galaxies.

The basic sample of our calibration is the list of 10 NGC 7790 stars with magnitudes in  $BVRI$  from the work of Christian et al. (1985) which refer to the fundamental standards of Landolt (1983). We added the improved standards from Odewahn et al. (1992, OBH), in total 114 stars, but calibrated only in the  $BVR$  bands (see the preceding section). The ranges in magnitudes and colours are, e.g.,  $13.15 < V < 18.52$ ,  $0.39 < B - V < 1.71$ , and  $0.25 < V - R < 1.28$ . The stars are spread over a field of  $5' \times 3'5$  to the south-east of the cluster’s centre. Our aim was to extend these  $BVR$  sequences also to the pass-

bands  $U$  and  $I$  for as many stars as possible in OBH's (1992) field.

We note that Schmidt (1986) published Stroemgren photometry of stars in NGC 7790. Recently Stetson (2000) published Landolt calibrated  $BVRI$  data for about 240 stars in a field of  $6' \times 6'$  centred on NGC 7790.

### 1.3. Constructing the $U$ and $I$ standard sequences

Unfortunately, there exist no suitable standard stars for  $U$  in NGC 7790. The only available  $U$  data come from

- Sandage (1958): 22 stars, most of them with one single observation only,
- Alcalá & Arellano Ferro (1988, AAF): re-observation of 16 stars from Sandage's list with reference to the Landolt standards,
- Pedreros et al. (1984, PMF): photographic observations calibrated by Sandage's  $U$  sequence which they had corrected by 0.075 mag due to an apparent offset in the  $U$  scale (Sandage's observations are too blue).

The stars of these lists are spread over an area of about  $10' \times 10'$  around the centre of the cluster. The dynamical interval of these data – in magnitudes and colours – is not large enough for CCD receivers and improved techniques of data reduction.

From these lists we find 4 AAF stars and 9 PMF stars (from the corrected Sandage sequence) which coincide with  $BVR$  standard stars from OBH. We chose these 13 stars as primary standards in the passband  $U$ . They are listed in Table 3 with their OBH numbers; the first 4 stars are those from AAF. Note that we did not use star no.

We used the same 13 stars for to construct the standard sequence in the passband  $I$ . The first 4 stars (see Table 3) have  $I$  magnitudes from the CCD work of Romeo et al. (1989). For the following stars we can refer to the basic sequence of Christian et al. (1985).

## 2. Observations and data reduction

The basic observational data for NGC 7790 are presented in Table 1. These frames have been taken with the "Photometrics" CCD camera at the 2 m RC telescope of Rozhen observatory. The detector has  $1024 \times 1024$  px<sup>2</sup>, with a pixel size of  $24 \times 24 \mu^2$ . The scale is  $0''.31/\text{px}$  without binning and  $0''.62/\text{px}$  with binning. At the RC focus of the 2m telescope the field of view is  $5' \times 5'$ . The filter system is close to Johnson's  $UBV$ , and Kron/Cousins  $RI$  one.

After standard image reduction with MIDAS, profile fitting photometry was carried out with DAOPHOT II (Stetson 1992) running under MIDAS.

## 3. Methods of calibration

For the final calibration we use an iteration method to improve the internal accuracy of the magnitudes. Photo-

**Table 1.** Observational data for NGC 7790 from the 2 m RC telescope

| date       | filter          | no. of frames<br>per filter | scale<br>["/px] | seeing<br>["] |
|------------|-----------------|-----------------------------|-----------------|---------------|
| 1998-02-28 | $U, B, V, R, I$ | 2                           | 0.62            | $\leq 2$      |
| 1998-08-23 | $U, B, V, R, I$ | 4                           | 0.62            | 1.5 ... 2     |
| 1998-08-23 | $U, B, V, R, I$ | 2                           | 0.31            | 1.5 ... 2     |
| 1998-09-06 | $U, B, V, R, I$ | 10                          | 0.62            | 2.5 ... 3     |

metric transformation coefficients are determined in three steps using the following transformation relations:

$$U_{st} = a_{0U} + a_{1U} \cdot U_{in} + a_{2U} \cdot (U_{in} - B_{in}) \quad (1)$$

$$I_{st} = a_{0I} + a_{1I} \cdot I_{in} + a_{2I} \cdot (R_{in} - I_{in}) \quad (2)$$

where  $M_{st}$  are the photometrically calibrated magnitudes and  $M_{in}$  are the instrumental ones.

- Step (1): Determine the transformation coefficients using the above discussed 13 stars and compute the First Step Standard Magnitudes (FSSM) for all the objects in the field of interest.

- Step (2): Use an enlarged standard sequence of 25 stars – 12 more stars added to the first 13 primaries with the FSSM (step 1) – and recompute the magnitudes of all stars in the field, in this way getting the Second Step Standard Magnitudes (SSSM).

- Step (3): Repeat step 2 for all stars with the magnitudes for the 12 added "standards" from the SSSM (step 2) and compute the Third Step Standard Magnitudes (TSSM) of all the stars in the field. Controlling the differences between SSSM and FSSM, and TSSM and SSSM, our results after three iterations seemed to be good enough so that no more iteration was needed. The enlarged primary standard sequence of 25 stars gave us higher accuracy because wider intervals of magnitudes and colours were used.

To check our calibration steps by the "classical way", the standard sequence in M 92 (Majewski et al. 1994) was observed in 1998-02-28. After extinction correction of the instrumental magnitudes, we applied the photometric calibration in the form

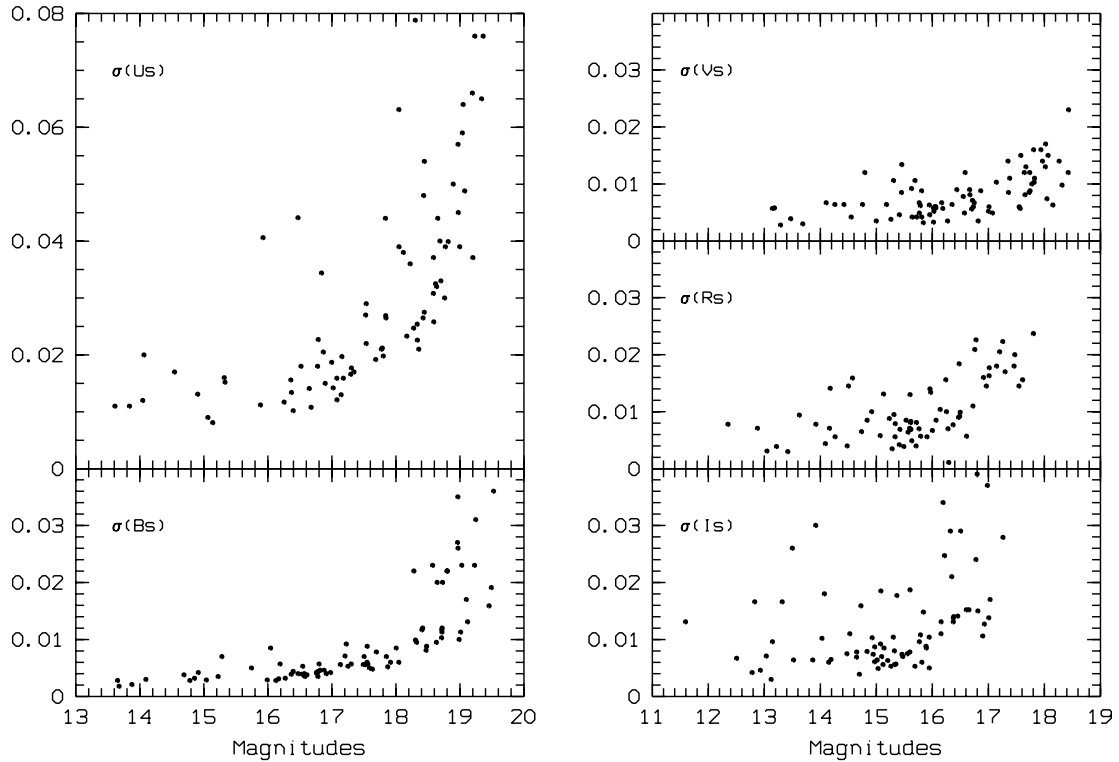
$$U_{st} = c_U + c'_U \cdot U_{ec} + c''_U \cdot (U_{ec} - B_{ec}) \quad (3)$$

$$I_{st} = c_I + c'_I \cdot I_{ec} + c''_I \cdot (R_{ec} - I_{ec}) \quad (4)$$

where  $M_{st}$  are the standard magnitudes after photometric calibration and  $M_{ec}$  are the extinction corrected instrumental magnitudes.

## 4. Results

The  $U$  and  $I$  magnitudes of the primary standard stars are given in Table 3 and denoted  $U_s$  and  $I_s$ . The standard errors  $\sigma(U_s)$  and  $\sigma(I_s)$  of the individual magnitudes are also listed. They are the result of the whole process of reduction and calibration. The mean value is  $\langle \sigma \rangle = 0.0165$  mag in  $U$  and  $\langle \sigma \rangle = 0.0122$  mag in  $I$ . The larger



**Fig. 1.** Estimated errors of the calibration vs. standard star magnitudes

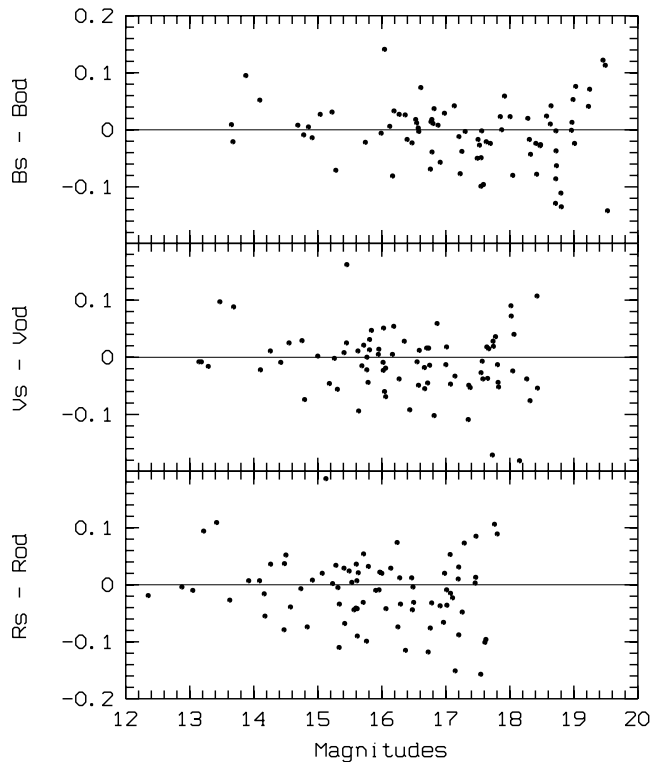
error in *U* reflects the fact that the CCD receivers are less sensitive in the ultraviolet which means a smaller signal-to-noise-ratio for the observed stars.

The quality of our calibration can be read off columns 6 to 9 of Table 3. Here, the magnitudes  $U_{M92}$  and  $I_{M92}$  are given which are the results from the calibration via the M92 standard sequence. The sums of the differences  $d(U)$  and  $d(I)$  to our basic calibration are in both cases exactly 0.000 mag. Therefore no shift in magnitude between the different calibrations can be seen. The mean differences (positive or negative) between the magnitudes of the two calibrations are 0.033 in *U* and 0.013 in *I*, resp.

The NGC 7790 field of OBH is not completely identical to our field because they chose the south eastern part of the cluster whereas we centred our frames onto the cluster's centre. In addition, not all stars have measurable *U* values. As the result, in the overlapping section there are 84 stars with the complete *UBVRI* data set in common to the OBH work. The *UBVRI* magnitudes of all our stars are listed in Table 4 with with their OBH numbers. We have chosen the notation  $U_s$ ,  $B_s$  etc. The errors of the individual stellar magnitudes have been added. The last three columns of the table display the differences between the magnitudes *BVR* from our work and those from the OBH sequence.

We have plotted the errors versus the calibrated magnitudes for all passbands in Fig. 1. The means  $\langle \sigma \rangle$  of the individual errors can be read off Table 2. As expected, the mean error in the *U* band is fairly large:  $\langle \sigma \rangle = 0.032$  mag. The individual errors become large above  $U = 19$  mag, but still are quite small for magnitudes below  $U = 18$  mag (see Fig. 1). With only few exceptions, the individual errors in *B* and *V* are less than 0.03 mag below 19 mag. For the *R* band the errors are as usually quite small – less than 0.02 mag for all magnitude intervals – except for a group of stars between 17 to 18 mag which show errors of about 0.06 mag. This might be due to the effect of severe crowding because the *R* fields are quite rich of stars. The errors from the *I* frames are fully acceptable; they are less than 0.04 mag below  $I = 16$  mag.

Finally, we compare our results with those of Odewahn et al. (1992, OBH). The ranges in the magnitudes *BVR* and the means of the individual errors are compared in the first two sections of Table 2. The errors of our work are a bit smaller, but, in principle, the results are quite similar. The differences  $d(B)$ ,  $d(V)$ , and  $d(R)$ , in the sense “our magnitude minus OBH’s magnitude”, are listed in the last columns of Table 4. The differences have been plotted in Fig. 2 vs. the magnitudes of this paper. No systematic difference between the two calibrations can be seen. Indeed, the mean deviations from the zero-axes are only 0.05 mag



**Fig. 2.** Comparison of our calibrated  $BVR$  magnitudes with the corresponding magnitudes of Odewahn et al. (1992)

(see also the last column of Table 2; only star no. 106, which has the extremely large difference of 0.5 mag in all three bands, has been omitted from the calculation).

The sum of all differences in each passband gives the shift in magnitude between the two standard sequences. It is apparent from Table 2 (right section) that the shifts are only two thousandths of a magnitude.

We conclude that our calibration of the standard sequence in the NGC 7790 field perfectly agrees with OBH’s calibration for the bands  $B$ ,  $V$ , and  $r$ , and we, therefore, have an additional strong indication that our calibrations for the bands  $U$  and  $I$  are in good state, too.

## 5. Concluding remarks

We have constructed a primary standard sequence of 13 stars in  $U$  and  $I$  in the field of the open cluster NGC 7790. With these standards we were able to extend the  $B$ ,  $V$ , and  $R$  sequences of Odewahn et al. (1992) to the two other ones enclosing bands  $U$  and  $I$ . These new standard sequences contains 84 stars in wide ranges of magnitude and colour.

We strengthen that three reasons support the reliability of the new  $U$  and  $I$  sequences:

- We applied a three step iteration method which integrates additional stars into the process of calibration. This

leads to higher accuracy for a sample of stars comprising wider intervals of magnitude and colour.

- An additional calibration, using the commonly accepted standard sequence in the globular cluster M 92 (Majewski et al. 1994), agrees very well with our primary calibration.
- A comparison of our results for the in between lying bands  $BVR$  with those of Odewahn et al. (1992) again gives perfect agreement.

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**Table 2.** Magnitude intervals and error budgets of standard sequences in NGC 7790 and summary of the comparison

| Filter | This paper      |                          | Odewahn et al. 1992 |                          | Difference $d$ |                       |
|--------|-----------------|--------------------------|---------------------|--------------------------|----------------|-----------------------|
|        | range           | $\langle \sigma \rangle$ | range               | $\langle \sigma \rangle$ | shift          | $\langle  d  \rangle$ |
| $U$    | 13.61 ... 20.01 | 0.032                    |                     |                          |                |                       |
| $B$    | 13.61 ... 19.54 | 0.009                    | 13.64 ... 19.67     | 0.024                    | -0.002         | 0.049                 |
| $V$    | 13.14 ... 18.48 | 0.009                    | 13.15 ... 18.52     | 0.014                    | -0.002         | 0.047                 |
| $R$    | 12.35 ... 17.88 | 0.017                    | 12.37 ... 17.92     | 0.021                    | +0.002         | 0.059                 |
| $I$    | 11.59 ... 19.67 | 0.015                    |                     |                          |                |                       |

**Table 3.**  $U$  and  $I$  magnitudes of the 13 primary standard stars

| No. | $U_s$  | $\sigma(U_s)$ | $I_s$  | $\sigma(I_s)$ | $U_{M92}$ | $d(U)$ | $I_{M92}$ | $d(I)$ |
|-----|--------|---------------|--------|---------------|-----------|--------|-----------|--------|
| 29  | 13.611 | 0.0110        | 12.782 | 0.0042        | 13.622    | -0.011 | 12.789    | -0.007 |
| 30  | 13.838 | 0.0110        | 12.929 | 0.0046        | 13.868    | -0.030 | 12.935    | -0.007 |
| 36  | 15.063 | 0.0090        | 13.917 | 0.0300        | 15.116    | -0.053 | 13.936    | -0.019 |
| 37  | 15.330 | 0.0152        | 14.149 | 0.0060        | 15.308    | +0.021 | 14.142    | +0.007 |
| 51  | 14.903 | 0.0131        | 13.865 | 0.0064        | 14.882    | +0.021 | 13.840    | +0.025 |
| 58  | 16.358 | 0.0156        | 14.724 | 0.0159        | 16.363    | -0.005 | 14.754    | -0.030 |
| 59  | 16.895 | 0.0150        | 15.302 | 0.0104        | 16.871    | +0.025 | 15.298    | +0.003 |
| 62  | 18.277 | 0.0247        | 13.500 | 0.0260        | 18.318    | -0.041 | 13.488    | +0.013 |
| 65  | 17.079 | 0.0121        | 15.080 | 0.0185        | 17.147    | -0.068 | 15.097    | -0.017 |
| 72  | 14.541 | 0.0170        | 13.521 | 0.0064        | 14.521    | +0.020 | 13.513    | +0.008 |
| 77  | 17.020 | 0.0142        | 15.074 | 0.0092        | 17.025    | -0.005 | 15.043    | +0.031 |
| 88  | 17.178 | 0.0159        | 14.649 | 0.0078        | 17.090    | +0.088 | 14.654    | -0.005 |
| 97  | 15.924 | 0.0406        | 11.593 | 0.0131        | 15.886    | +0.038 | 11.595    | -0.002 |

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**Table 4.** Magnitudes of all 84 standard stars and the errors of the individual values. The last three columns give the difference between the listed magnitudes and those from the *BVR* sequence of Odewahn et al. 1992

| No. | $U_s$  | $\sigma(U_s)$ | $B_s$  | $\sigma(B_s)$ | $V_s$  | $\sigma(V_s)$ | $R_s$  | $\sigma(R_s)$ | $I_s$  | $\sigma(I_s)$ | d( <i>B</i> ) | d( <i>V</i> ) | d( <i>R</i> ) |
|-----|--------|---------------|--------|---------------|--------|---------------|--------|---------------|--------|---------------|---------------|---------------|---------------|
| 8   | 17.144 | 0.0130        | 16.912 | 0.0040        | 16.270 | 0.0035        | 15.904 | 0.0056        | 15.471 | 0.0070        | -0.057        | -0.038        | -0.010        |
| 9   | 18.170 | 0.0233        | 18.045 | 0.0060        | 17.073 | 0.0049        | 16.497 | 0.0099        | 15.887 | 0.0088        | -0.080        | -0.047        | -0.031        |
| 10  | 18.332 | 0.0254        | 18.479 | 0.0088        | 17.550 | 0.0060        | 16.963 | 0.0145        | 16.373 | 0.0131        | -0.026        | -0.027        | -0.066        |
| 11  | 18.222 | 0.0360        | 17.916 | 0.0060        | 17.011 | 0.0060        | 16.466 | 0.0090        | 15.945 | 0.0050        | +0.059        | +0.018        | +0.012        |
| 12  | 18.761 | 0.0300        | 19.010 | 0.0113        | 18.045 | 0.0074        | 17.458 | 0.0180        | 16.899 | 0.0106        | -0.024        | -0.024        | +0.003        |
| 16  | 16.776 | 0.0180        | 16.544 | 0.0053        | 15.946 | 0.0063        | 15.610 | 0.0081        | 15.203 | 0.0063        | +0.012        | +0.005        | +0.007        |
| 17  | 16.395 | 0.0102        | 16.168 | 0.0031        | 15.638 | 0.0042        | 15.333 | 0.0056        | 14.969 | 0.0061        | -0.081        | -0.094        | -0.110        |
| 18  | 19.074 | 0.0488        | 19.119 | 0.0131        | 18.151 | 0.0063        | 17.545 | 0.0145        | 16.928 | 0.0127        | -0.427        | -0.181        | -0.157        |
| 20  | 16.517 | 0.0180        | 16.271 | 0.0032        | 15.717 | 0.0042        | 15.409 | 0.0042        | 15.031 | 0.0049        | +0.027        | +0.021        | +0.029        |
| 21  | 16.838 | 0.0344        | 16.577 | 0.0035        | 16.020 | 0.0033        | 15.709 | 0.0040        | 15.324 | 0.0056        | -0.003        | -0.009        | -0.031        |
| 22  | 18.335 | 0.0226        | 17.204 | 0.0071        | 15.767 | 0.0049        | 14.916 | 0.0100        | 14.029 | 0.0102        | -0.012        | +0.000        | +0.008        |
| 23  | 17.536 | 0.0290        | 16.569 | 0.0040        | 14.999 | 0.0035        | 14.090 | 0.0044        | 13.035 | 0.0071        | +0.003        | +0.002        | +0.007        |
| 24  | 17.344 | 0.0170        | 17.250 | 0.0053        | 16.573 | 0.0049        | 16.610 | 0.0057        | 15.688 | 0.0053        | -0.038        | -0.049        | +0.365        |
| 25  | 16.996 | 0.0187        | 16.781 | 0.0035        | 15.838 | 0.0032        | 15.282 | 0.0035        | 14.696 | 0.0039        | +0.018        | +0.047        | +0.034        |
| 26  | 17.536 | 0.0220        | 17.503 | 0.0070        | 16.731 | 0.0060        | 16.279 | 0.0070        | 15.812 | 0.0060        | -0.017        | +0.016        | +0.012        |
| 27  | 18.424 | 0.0265        | 18.471 | 0.0081        | 17.568 | 0.0057        | 17.016 | 0.0177        | 16.453 | 0.0141        | -0.028        | -0.007        | -0.036        |
| 28  | 17.840 | 0.0269        | 17.587 | 0.0050        | 16.817 | 0.0035        | 16.370 | 0.0077        | 15.892 | 0.0085        | -0.096        | -0.102        | -0.115        |
| 29  | 13.611 | 0.0110        | 13.675 | 0.0018        | 13.289 | 0.0028        | 13.047 | 0.0031        | 12.782 | 0.0042        | -0.021        | -0.016        | -0.010        |
| 30  | 13.838 | 0.0110        | 13.875 | 0.0021        | 13.470 | 0.0039        | 13.217 | 0.0039        | 12.929 | 0.0046        | +0.095        | +0.097        | +0.094        |
| 31  | 14.064 | 0.0200        | 14.094 | 0.0030        | 13.685 | 0.0030        | 13.419 | 0.0030        | 13.122 | 0.0030        | +0.052        | +0.088        | +0.109        |
| 32  | 16.253 | 0.0117        | 15.990 | 0.0029        | 15.410 | 0.0046        | 15.069 | 0.0058        | 14.646 | 0.0069        | -0.006        | +0.008        | +0.020        |
| 34  | 18.635 | 0.0320        | 18.632 | 0.0095        | 17.743 | 0.0088        | 17.201 | 0.0205        | 16.652 | 0.0152        | +0.010        | +0.019        | +0.031        |
| 35  | 18.996 | 0.0390        | 19.490 | 0.0191        | 18.315 | 0.0098        | 17.610 | 0.0156        | 17.007 | 0.0138        | +0.113        | -0.076        | -0.101        |
| 36  | 15.063 | 0.0090        | 15.038 | 0.0029        | 14.551 | 0.0042        | 14.263 | 0.0056        | 13.917 | 0.0300        | +0.027        | +0.025        | +0.036        |
| 37  | 15.330 | 0.0152        | 15.222 | 0.0035        | 14.753 | 0.0064        | 14.479 | 0.0040        | 14.149 | 0.0060        | +0.031        | +0.029        | +0.037        |
| 38  | 17.077 | 0.0159        | 16.816 | 0.0046        | 16.186 | 0.0057        | 15.790 | 0.0057        | 15.348 | 0.0057        | +0.037        | +0.054        | +0.032        |
| 39  | 18.970 | 0.0570        | 18.728 | 0.0200        | 17.640 | 0.0120        | 16.980 | 0.0480        | 16.191 | 0.0340        | -0.063        | +0.018        | +0.020        |
| 40  | 19.362 | 0.0760        | 18.970 | 0.0260        | 17.776 | 0.0100        | 17.067 | 0.0420        | 16.264 | 0.0630        | +0.013        | +0.036        | +0.053        |
| 41  | 18.772 | 0.0390        | 18.643 | 0.0200        | 17.737 | 0.0120        | 17.193 | 0.0580        | 16.593 | 0.0490        | +0.042        | +0.028        | +0.010        |
| 42  | 19.194 | 0.0660        | 18.967 | 0.0350        | 17.930 | 0.0440        | 17.351 | 0.0670        | 16.760 | 0.0410        | +0.249        | +0.341        | +0.431        |
| 43  | 19.202 | 0.0371        | 19.455 | 0.0159        | 18.424 | 0.0120        | 17.803 | 0.0237        | 17.260 | 0.0279        | +0.122        | +0.107        | +0.089        |
| 45  | 16.646 | 0.0141        | 16.365 | 0.0039        | 15.809 | 0.0042        | 15.490 | 0.0039        | 15.119 | 0.0056        | +0.026        | +0.031        | +0.024        |
| 48  | 16.470 | 0.0441        | 16.124 | 0.0028        | 15.259 | 0.0038        | 14.735 | 0.0065        | 14.191 | 0.0065        | +0.006        | -0.002        | -0.007        |
| 49  | 18.895 | 0.0500        | 18.280 | 0.0220        | 16.585 | 0.0120        | 15.601 | 0.0130        | 14.526 | 0.0110        | +0.020        | +0.012        | +0.036        |
| 51  | 14.903 | 0.0131        | 14.854 | 0.0032        | 14.421 | 0.0064        | 14.163 | 0.0071        | 13.865 | 0.0064        | +0.005        | -0.009        | -0.016        |
| 53  | 17.305 | 0.0177        | 16.978 | 0.0042        | 16.351 | 0.0064        | 16.000 | 0.0067        | 15.597 | 0.0078        | +0.029        | +0.028        | +0.020        |
| 54  | 17.773 | 0.0210        | 17.560 | 0.0057        | 16.551 | 0.0078        | 15.969 | 0.0134        | 15.366 | 0.0177        | -0.002        | -0.008        | +0.022        |
| 55  | 18.653 | 0.0440        | 18.987 | 0.0100        | 18.021 | 0.0170        | 17.471 | 0.0200        | 17.030 | 0.0170        | +0.053        | +0.072        | +0.085        |
| 56  | 19.338 | 0.0650        | 19.246 | 0.0310        | 18.263 | 0.0140        | 17.626 | 0.0500        | 16.982 | 0.0370        | +0.071        | -0.038        | -0.096        |
| 58  | 16.358 | 0.0156        | 16.042 | 0.0085        | 15.453 | 0.0134        | 15.127 | 0.0131        | 14.724 | 0.0159        | +0.141        | +0.162        | +0.186        |
| 59  | 16.895 | 0.0150        | 16.609 | 0.0038        | 16.027 | 0.0052        | 15.715 | 0.0081        | 15.302 | 0.0104        | +0.074        | +0.051        | +0.054        |
| 60  | 18.356 | 0.0210        | 18.004 | 0.0085        | 16.863 | 0.0088        | 16.239 | 0.0156        | 15.601 | 0.0187        | +0.023        | +0.059        | +0.074        |
| 62  | 18.277 | 0.0247        | 17.132 | 0.0056        | 15.448 | 0.0085        | 14.502 | 0.0145        | 13.500 | 0.0260        | +0.042        | +0.025        | +0.052        |
| 65  | 17.079 | 0.0121        | 16.768 | 0.0040        | 16.022 | 0.0058        | 15.595 | 0.0071        | 15.080 | 0.0185        | +0.014        | -0.023        | -0.041        |
| 66  | 16.866 | 0.0205        | 16.529 | 0.0039        | 15.953 | 0.0046        | 15.632 | 0.0049        | 15.259 | 0.0053        | +0.018        | +0.014        | +0.021        |
| 67  | 18.046 | 0.0631        | 17.872 | 0.0052        | 17.000 | 0.0052        | 16.487 | 0.0092        | 15.943 | 0.0104        | +0.000        | -0.013        | -0.004        |
| 68  | 18.591 | 0.0258        | 18.717 | 0.0117        | 17.652 | 0.0081        | 17.012 | 0.0163        | 16.375 | 0.0138        | -0.086        | -0.037        | -0.009        |
| 69  | 19.050 | 0.0640        | 18.797 | 0.0220        | 17.824 | 0.0110        | 17.202 | 0.0430        | 16.505 | 0.0290        | -0.111        | -0.052        | -0.088        |
| 72  | 14.541 | 0.0170        | 14.780 | 0.0028        | 14.259 | 0.0064        | 13.920 | 0.0078        | 13.521 | 0.0064        | -0.009        | +0.011        | +0.007        |
| 73  | 17.844 | 0.0265        | 17.302 | 0.0057        | 16.166 | 0.0067        | 15.531 | 0.0085        | 14.943 | 0.0074        | -0.003        | +0.005        | +0.004        |
| 74  | 18.302 | 0.0788        | 18.323 | 0.0095        | 17.358 | 0.0085        | 16.779 | 0.0226        | 16.217 | 0.0247        | -0.043        | -0.049        | -0.032        |
| 75  | 18.702 | 0.0330        | 18.713 | 0.0103        | 17.727 | 0.0085        | 17.146 | 0.0180        | 16.607 | 0.0152        | -0.129        | -0.171        | -0.151        |
| 76  | 18.974 | 0.0450        | 18.804 | 0.0220        | 17.965 | 0.0140        | 17.445 | 0.0480        | 16.930 | 0.0470        | -0.135        | -0.229        | -0.335        |
| 77  | 17.020 | 0.0142        | 16.759 | 0.0042        | 16.042 | 0.0060        | 15.615 | 0.0083        | 15.074 | 0.0092        | -0.069        | -0.060        | -0.042        |
| 78  | 19.037 | 0.0590        | 19.028 | 0.0230        | 18.065 | 0.0150        | 17.466 | 0.0520        | 16.799 | 0.0390        | +0.076        | +0.040        | +0.013        |
| 79  | 20.099 | 0.1240        | 19.228 | 0.0230        | 18.017 | 0.0130        | 17.288 | 0.0540        | 16.577 | 0.0410        | +0.041        | +0.090        | +0.073        |

Table 4. Continued

| No. | $U_s$  | $\sigma(U_s)$ | $B_s$  | $\sigma(B_s)$ | $V_s$  | $\sigma(V_s)$ | $R_s$  | $\sigma(R_s)$ | $I_s$  | $\sigma(I_s)$ | d( $B$ ) | d( $V$ ) | d( $R$ ) |
|-----|--------|---------------|--------|---------------|--------|---------------|--------|---------------|--------|---------------|----------|----------|----------|
| 80  | 16.368 | 0.0134        | 16.190 | 0.0057        | 15.627 | 0.0092        | 15.314 | 0.0095        | 14.925 | 0.0103        | +0.033   | +0.011   | -0.005   |
| 82  | 14.045 | 0.0120        | 13.651 | 0.0028        | 13.144 | 0.0057        | 12.877 | 0.0071        | 12.505 | 0.0067        | +0.009   | -0.008   | -0.004   |
| 83  | 17.294 | 0.0166        | 16.878 | 0.0046        | 16.059 | 0.0060        | 15.566 | 0.0064        | 15.014 | 0.0064        | +0.008   | -0.019   | -0.044   |
| 84  | 19.413 | 0.0860        | 19.525 | 0.0360        | 18.431 | 0.0230        | 17.760 | 0.0510        | 16.951 | 0.0470        | -0.142   | -0.054   | +0.106   |
| 85  | 17.684 | 0.0192        | 17.631 | 0.0048        | 16.701 | 0.0056        | 16.140 | 0.0104        | 15.553 | 0.0075        | -0.021   | +0.016   | +0.029   |
| 86  | 17.802 | 0.0198        | 17.695 | 0.0078        | 16.670 | 0.0081        | 16.065 | 0.0085        | 15.457 | 0.0074        | -0.024   | -0.055   | -0.042   |
| 87  | 18.584 | 0.0308        | 18.719 | 0.0113        | 17.816 | 0.0103        | 17.256 | 0.0223        | 16.778 | 0.0240        | -0.002   | -0.044   | -0.048   |
| 88  | 17.178 | 0.0159        | 16.799 | 0.0057        | 15.808 | 0.0088        | 15.231 | 0.0088        | 14.649 | 0.0078        | +0.011   | +0.013   | +0.002   |
| 90  | 18.688 | 0.0400        | 18.573 | 0.0230        | 17.669 | 0.0130        | 17.073 | 0.0430        | 16.345 | 0.0210        | +0.024   | +0.015   | -0.015   |
| 94  | 17.156 | 0.0197        | 16.784 | 0.0044        | 16.060 | 0.0058        | 15.617 | 0.0069        | 15.136 | 0.0085        | -0.039   | -0.069   | -0.090   |
| 95  | 16.674 | 0.0108        | 16.395 | 0.0044        | 15.785 | 0.0062        | 15.420 | 0.0069        | 14.970 | 0.0087        | -0.017   | -0.044   | -0.068   |
| 96  | 16.786 | 0.0227        | 16.472 | 0.0040        | 15.765 | 0.0067        | 15.337 | 0.0079        | 14.834 | 0.0079        | -0.023   | -0.022   | -0.034   |
| 97  | 15.924 | 0.0406        | 14.688 | 0.0038        | 13.181 | 0.0058        | 12.351 | 0.0078        | 11.593 | 0.0131        | +0.008   | -0.008   | -0.019   |
| 98  | 15.138 | 0.0081        | 14.912 | 0.0042        | 14.104 | 0.0067        | 13.625 | 0.0094        | 13.145 | 0.0096        | -0.014   | -0.022   | -0.027   |
| 99  | 17.787 | 0.0212        | 17.525 | 0.0056        | 16.747 | 0.0067        | 16.292 | 0.0011        | 15.767 | 0.0096        | -0.027   | -0.014   | -0.034   |
| 100 | 19.232 | 0.0760        | 18.962 | 0.0270        | 17.807 | 0.0160        | 17.105 | 0.0460        | 16.322 | 0.0290        | -0.001   | -0.013   | -0.023   |
| 103 | 17.836 | 0.0440        | 17.490 | 0.0056        | 16.716 | 0.0071        | 16.251 | 0.0100        | 15.787 | 0.0108        | -0.050   | -0.045   | -0.074   |
| 104 | 15.884 | 0.0112        | 15.743 | 0.0050        | 15.181 | 0.0064        | 14.835 | 0.0085        | 14.474 | 0.0075        | -0.022   | -0.046   | -0.074   |
| 105 | 18.816 | 0.0399        | 17.551 | 0.0088        | 15.689 | 0.0106        | 14.573 | 0.0159        | 13.319 | 0.0166        | -0.049   | -0.015   | -0.039   |
| 106 | 18.444 | 0.0540        | 19.099 | 0.0170        | 17.937 | 0.0160        | 17.299 | 0.0170        | 16.812 | 0.0150        | +0.527   | +0.504   | +0.545   |
| 107 | 18.586 | 0.0371        | 17.224 | 0.0092        | 15.306 | 0.0106        | 14.175 | 0.0141        | 12.828 | 0.0166        | -0.077   | -0.056   | -0.055   |
| 108 | 18.619 | 0.0325        | 18.305 | 0.0099        | 17.142 | 0.0103        | 16.477 | 0.0184        | 15.839 | 0.0148        | -0.017   | -0.033   | -0.044   |
| 109 | 18.443 | 0.0275        | 18.406 | 0.0117        | 17.380 | 0.0110        | 16.757 | 0.0209        | 16.156 | 0.0131        | -0.024   | -0.053   | -0.076   |
| 110 | 18.048 | 0.0390        | 17.851 | 0.0070        | 16.665 | 0.0090        | 15.957 | 0.0140        | 15.322 | 0.0080        | +0.023   | -0.018   | -0.009   |
| 112 | 17.527 | 0.0270        | 17.548 | 0.0060        | 16.436 | 0.0090        | 15.761 | 0.0070        | 15.094 | 0.0070        | -0.099   | -0.092   | -0.099   |
| 113 | 15.318 | 0.0160        | 15.281 | 0.0070        | 14.794 | 0.0120        | 14.473 | 0.0570        | 14.072 | 0.0180        | -0.071   | -0.074   | -0.079   |
| 114 | 18.116 | 0.0380        | 18.418 | 0.0120        | 17.350 | 0.0140        | 16.724 | 0.0110        | 16.154 | 0.0110        | -0.078   | -0.109   | -0.118   |
| 115 | 18.432 | 0.0480        | 18.721 | 0.0120        | 17.578 | 0.0150        | 16.911 | 0.0160        | 16.381 | 0.0140        | -0.037   | -0.038   | -0.037   |