# BVRI CCD photometric standards in the field of GRB 990123

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**Abstract.** The CCD magnitudes in Johnson BV and Cousins RI photometric passbands are determined for 18 stars in the field of GRB 990123. These measurements can be used in carrying out precise CCD photometry of the optical transient of GRB 990123 using differential photometric techniques during non-photometric sky conditions. A comparison with previous photometry indicates that the present photometry is more precise.

## 1. Introduction

The optical follow up observations of the transients of gamma-ray bursts (GRB) are valuable for understanding the nature of these bursts. Such observations are therefore generally carried out even during non-photometric sky conditions. The optical transient (OT) are generally faint and located in such regions of the sky where accurate photometric standards are generally not available beforehand. For reliable determination of the photometric magnitueds of the OT, such standards are desired. In this paper, we provide Johnson BV and Cousins RI magnitude of stars in the field of GRB 990123, first reported by Piro (1999). These observations can be used to perform accurate photometry of the OT of GRB 990123, as most of its CCD observations have been carried out in non-photometric sky conditions. Use of differential photometric technique can provide accurate photometric magnitudes of the OT from such observations if accurate photometric standards are present in the field on the CCD images of the OT. To provide photometric standard stars in the field of GRB 990123, we observed the field along with M67. A total of 18 stars in the field have been calibrated and their standard BVRI magnitudes are presented here. The observations and data reduction have been described in sections 2 and 3 respectively. A comparison of the present photometry with earlier BR photometric measurements is given in section 4.

## 2. Observations

The observations of the field containing GRB 990123 have been carried out from 23rd January to 25th January, 1999 using CCD system attached to the 104-cm Sampurnanand telescope of the U.P. State Observatory, Nainital. The CCD camera has a 1024 × 1024 pixel² Tektronix front illuminated detector. For present observations we used 2 × 2 binning on the CCD chip. Thus each superpixel of the CCD corresponds to 0.76 arc second at the f/13 Cassegrain focus of the telescope. For calibrating the magnitudes, on the night of 25/26 January, 1999 the M67 "dipper asterism" field was also observed. The observing conditions were photometric. The log of CCD observations is given in Table 1. In addition to these observations, several twilight flat field and bias frames were also observed.

**Table 1.** Log of Observations of GRB 990123.

| Date | Field | Filter | Exposure (in seconds) |
|---|---|---|---|
| 24/25 Jan 99 | GRB | R | 1200 × 3 |
| 24/25 Jan 99 | GRB | B | 1200 × 3 |
| 24/25 Jan 99 | GRB | V | 1200 × 1 |
| 25/26 Jan 99 | GRB | B | 600 × 2 |
| 25/26 Jan 99 | GRB | V | 1200 × 3, 300 × 1 |
| 25/26 Jan 99 | GRB | R | 1200 × 2, 300 × 1 |
| 25/26 Jan 99 | GRB | I | 300 × 2 |
| 25/26 Jan 99 | M67 | I | 10 × 2, 8 × 1 |
| 25/26 Jan 99 | M67 | R | 8 × 1, 10 × 2, 15 × 1 |
| 25/26 Jan 99 | M67 | V | 60 × 1, 40 × 1 |
| 25/26 Jan 99 | M67 | B | 120 × 1 |

## 3. Data reduction

The CCD frames were cleaned using standard procedures. Image processing was done using ESO MIDAS and DAOPHOT softwares. Atmospheric extinction coefficients were determined from the observations of the brightest star present in the GRB field and were used in further analysis. Standard magnitudes of stars in the field of M67 were taken from Chevalier and Ilovaisky (1991). A total of 29 stars were used to determine the transformation coefficients and photometric zero points. They cover a wide range in colour ($-0.1 < B - V < 1.4$) as well as in brightness ($9.7 < V < 14.3$). The transformation coefficients were determined by fitting least square linear regressions to the standard BVRI photometric indices as function of the observed instrumental magnitudes normalised for 1 second exposure time. The following colour equations were obtained for the system.

$$B-V = (1.096 \pm .018) \, (b-v)_{CCD} - (0.763 \pm .023)$$

$$V-R = (1.051 \pm .023) \, (v-r)_{CCD} - (0.383 \pm .017)$$

$$V-I = (0.965 \pm .019) \, (v-i)_{CCD} - (0.123 \pm .017)$$

$$V = v_{CCD} + (0.015 \pm .013)(B-V) - (4.938 \pm .009)$$

where $v_{CCD}$, $(b-v)_{CCD}$, $(v-r)_{CCD}$ and $(v-i)_{CCD}$ represent the instrumental colour indices corrected for atmospheric extinction. The errors in the colour coefficients and zero points are obtained from the deviation of data points from the linear relation.

Table 2. BVRI Standard magnitudes of the objects in the region of GRB 990123.

| ID | h | m | s | o | ′ | ″ | V | $\sigma V$ | B–V | $\sigma_{B-V}$ | V–R | $\sigma_{V-R}$ | V–I | $\sigma_{V-I}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15 | 25 | 27.0 | 44 | 46 | 23.2 | 14.84 | 0.00 | 0.57 | 0.00 | 0.32 | 0.00 | 0.58 | 0.00 |
| 2 | 15 | 25 | 36.5 | 44 | 44 | 37.6 | 15.47 | 0.00 | 0.63 | 0.01 | 0.36 | 0.01 | 0.67 | 0.01 |
| 3 | 15 | 25 | 11.8 | 44 | 46 | 2.1 | 15.96 | 0.00 | 0.64 | 0.00 | 0.41 | 0.01 | 0.78 | 0.01 |
| 4 | 15 | 25 | 21.1 | 44 | 46 | 46.9 | 16.28 | 0.00 | 0.67 | 0.00 | 0.39 | 0.00 | 0.71 | 0.01 |
| 5 | 15 | 25 | 38.6 | 44 | 43 | 20.3 | 16.72 | 0.00 | 0.60 | 0.01 | 0.32 | 0.01 | 0.63 | 0.01 |
| 6 | 15 | 25 | 21.7 | 44 | 46 | 52.7 | 16.80 | 0.00 | 1.35 | 0.01 | 0.82 | 0.00 | 1.54 | 0.01 |
| 7 | 15 | 25 | 38.8 | 44 | 44 | 30.1 | 17.65 | 0.06 | 1.29 | 0.07 | 0.83 | 0.08 | 1.34 | 0.08 |
| 8 | 15 | 25 | 17.9 | 44 | 46 | 29.5 | 18.10 | 0.01 | 1.13 | 0.01 | 0.66 | 0.01 | 1.17 | 0.01 |
| 9 | 15 | 25 | 39.1 | 44 | 44 | 46.1 | 18.48 | 0.05 | 1.32 | 0.07 | 0.67 | 0.08 | 1.25 | 0.07 |
| 10 | 15 | 25 | 19.6 | 44 | 47 | 53.0 | 18.66 | 0.01 | 1.45 | 0.02 | 0.86 | 0.01 | 1.64 | 0.01 |
| 11 | 15 | 25 | 19.3 | 44 | 45 | 58.1 | 18.72 | 0.01 | 0.47 | 0.01 | 0.04 | 0.02 | 0.53 | 0.02 |
| 12 | 15 | 25 | 15.6 | 44 | 45 | 5.6 | 18.96 | 0.03 | 0.87 | 0.04 | 0.53 | 0.04 | 0.98 | 0.05 |
| 13 | 15 | 25 | 32.7 | 44 | 44 | 29.9 | 19.01 | 0.01 | 0.53 | 0.02 | 0.37 | 0.01 | 0.69 | 0.02 |
| 14 | 15 | 25 | 25.3 | 44 | 45 | 24.7 | 19.16 | 0.05 | 1.36 | 0.07 | 0.70 | 0.07 | 1.23 | 0.07 |
| 15 | 15 | 25 | 16.4 | 44 | 47 | 28.4 | 19.65 | 0.02 | 1.39 | 0.04 | 0.88 | 0.02 | 1.71 | 0.03 |
| 16 | 15 | 25 | 13.8 | 44 | 44 | 50.1 | 19.87 | 0.03 | 0.43 | 0.04 | 0.27 | 0.03 | 0.34 | 0.06 |
| 17 | 15 | 25 | 26.6 | 44 | 43 | 55.3 | 20.14 | 0.03 | 1.06 | 0.06 | 0.80 | 0.03 | 1.23 | 0.04 |
| 18 | 15 | 25 | 27.5 | 44 | 44 | 43.6 | 20.31 | 0.03 | 0.48 | 0.05 | 0.40 | 0.03 | 0.43 | 0.09 |

In order to calibrate stars in the GRB field, firstly the magnitudes of the brightest star (star no. 1 of Table 2) in the field were calculated using CCD frames observed on the night of 25/26 January, 99 and applying the above transformations. For increasing the photometric precision of fainter stars, B,V and R CCD images taken on the nights of 24/25 and 25/26 January, 99 were co-added in the same filter. Thus the total exposure in B, V and R filters becomes 120, 80 and 100 minutes respectively. I magnitudes were determined using the observations of 25/26 January, 99 alone having a total exposure of 10 minutes. From these added images, PSF magnitudes were determined using DAOPHOT software. The standard magnitudes of the stars were then determined differentially using the brightest star as the local standard star. The magnitudes thus determined along with their errors are given in Table 2. In this table column 1 is the identification number; column 2 and 3 are the Right Ascension and Declination (Epoch 2000) of the stars in the CCD frame taken from the catalogue of Monet (1997); Column 4,6,8 and 10 give standard *V, (B–V), (V–R)* and *(R–I )* magnitudes respectively; and in columns 5,7,9 and 11 are given the associated DAOPHOT errors. These errors are primarily related to signal to noise ratio and do not include the errors related to colour transformations and magnitude zero points.
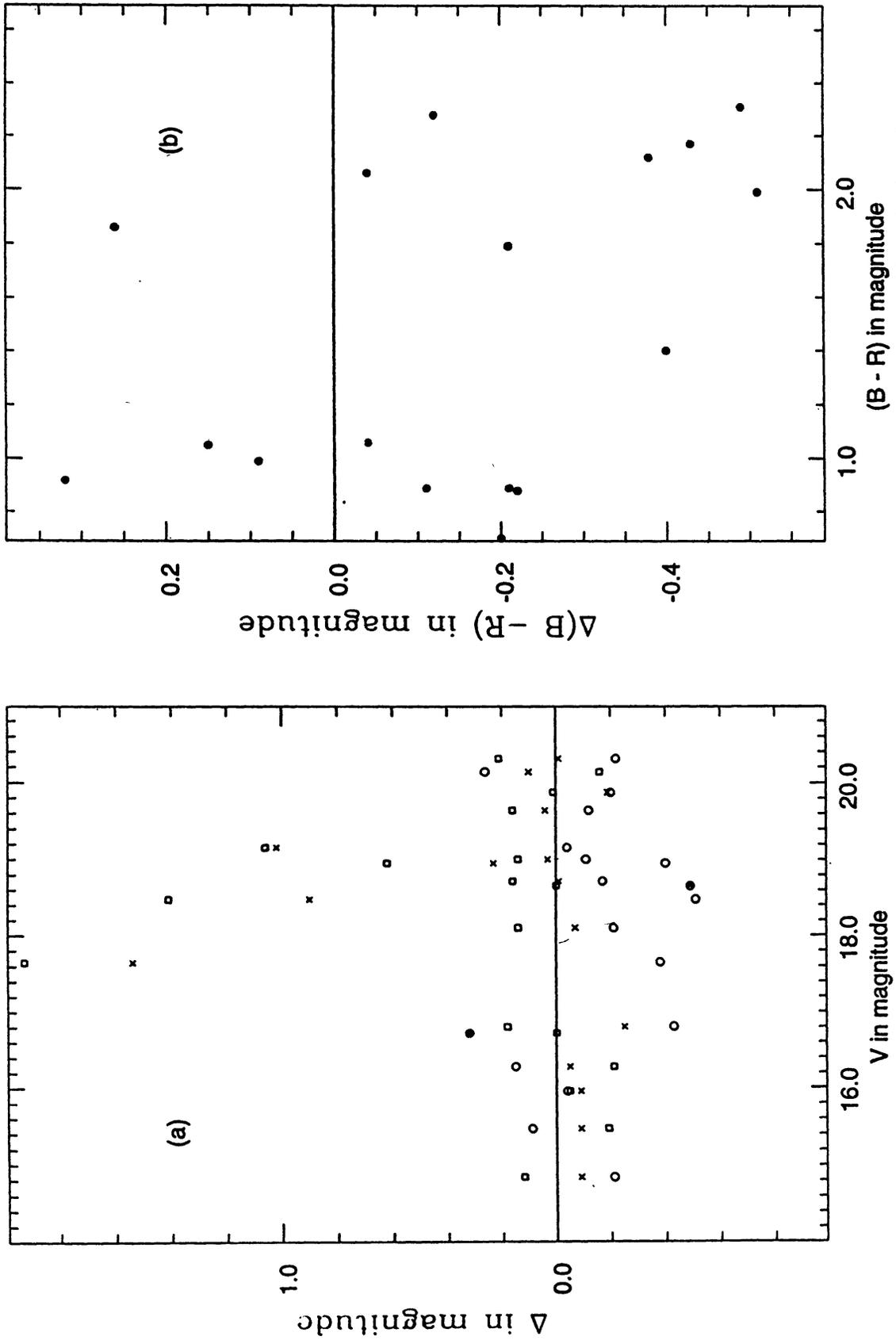
**Figure 1.** Comparison of present photometry with that of Monet (1997). The difference in B, R and (B–R) in the sense (present–Monet) has been plotted against present V magnitude in Figure (a). Crosses, squares and open circles represent ΔB, ΔR, Δ(B–R) respectively. In Figure (b), Δ(B–R) has been plotted against present (B–R).

**Table 3.** Statistical results of the photometric comparsion. The mean and standard deviations are based on N stars.

| Range in magnitude | ΔR Mean ± σ | N | ΔB Mean ± σ | N | Δ(B-R) Mean ± σ | N |
|---|---|---|---|---|---|---|
| 14<V<17 | −0.02±0.16 | 6 | −0.04±0.19 | 6 | −0.02±0.27 | 6 |
| 17<V<20 | +0.08±0.12 | 8 | −0.08±0.19 | 8 | −0.16±0.20 | 8 |
| (B–R)<1.4 | +0.02±0.15 | 9 | −0.02±0.14 | 9 | −0.04±0.19 | 9 |
| (B–R)>1.4 | +0.06±0.14 | 5 | −0.13±0.24 | 5 | −0.26±0.25 | 9 |

## 4. Comparison with previous photometry

In this section, we compare the present CCD photometry with available previous B and R photographic magnitudes given in the PMM USNO – A1.0 catalogue by Monet (1997). In figure 1, we plot the differences (present - Monet) as a function of present V magnitude and (B–R) colour. There is a large difference in B and R magnitudes of four objects, out of which two objects (no. 7 and 9) are galaxies. For the remaining 14 stars, the difference in R and B magnitudes is 0.03 ± 0.14 and −0.06±0.18 respectively. Considering the fact that the B and R magnitudes of Monet (1997) are based on Palomar Schmidt plates, the agreement between the two photometries is excellent. The results of statistical comparison are given in Table 3. From this table and figure 1, it appears that these differences have dependence on brightness as well as on colour and have expectedly large scatter. Least square linear regression to data points yield following relations :

$$\Delta B \;=\; (0.004\pm0.028)V-(0.13\pm0.51)$$

$$\Delta R \;=\; (0.025\pm0.021)V-(0.41\pm0.38)$$

$$\Delta(B-R) \;=\; (-0.02\pm0.04)V+(0.26\pm0.65)$$

$$\Delta(B-R) \;=\; (-0.124\pm0.10)(B-R)+(0.06\pm0.15)$$

Sokolov et al. (1999), reported that when estimating the magnitude of GRB 990123, by using the R magnitudes of star nos. 1 and 2 as references, there is a difference of 0.3 magnitudes. However, if R magnitudes of these reference stars as determined by us are used, this discrepency vanishes. This indicates that the magnitudes obtained by us are more precise.

## 5. Conclusion

We have determined BVRI magntudes of 18 stars in the field of GRB 990123. These magnitudes can be used to calibrate photometric magnitudes of the OT of GRB 990123 even in non photometric sky conditions using differential photometric techniques. We have used these magnitudes to calibrate various photometric observations of the OT of GRB 990123 given in GCN circulars. Based on these calibrated magnitudes, Sagar et al. (1999) have presented the BVR light curves of the OT. A comparison with earlier photometry indicates that present photometric magnitudes are reliable.

# References

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