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UBV(*RI*)$_C$–Hα photometry and GRISM spectroscopy of the young cluster Bochum 2 in the anticentre direction

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ABSTRACT

$UBV(RI)_C$–Hα CCD photometry and GRISM spectroscopy are presented for Bochum 2, a distant cluster in the galactic anticentre direction. The cluster is young, with late O-type members still on the main sequence. No red giant/supergiant is associated with the cluster. 28 possible cluster members are identified. The distance and mean reddening are ~6 kpc and $E(B-V)=0.80$, respectively. The reddening law for Bochum 2 matches the standard one. The upper main sequence of the cluster is well defined over a range ≥ 6.5 mag, with some spread due to differential reddening. No strong emission line or Wolf–Rayet star has been detected. There is no bright H II region associated with the cluster.

Key words: Hertzsprung–Russell (HR) diagram – open clusters and associations: individual: Bochum 2.

1 INTRODUCTION

Moffat & Vogt (1975, hereafter MV) first identified Bochum 2 during a systematic search through the Catalogue of Luminous Stars (Stephenson & Sanduleak 1971) for coincidence of early type stars with new or previously reported, real or suspected open clusters. They described Bochum 2 as a very compact and isolated group and obtained *UBV* photoelectric photometry with the 0.61-m Bochum telescope at ESO (La Silla, Chile) for eight stars in the cluster. They concluded that the cluster contained O-type stars, lay at ~5.5 kpc and suffered a mean extinction of $E(B-V)=0.89$. Moffat, Fitzgerald & Jackson (1979) gave MK spectral types of three brightest member stars and a spectroscopically derived mean reddening of $E(B-V)=0.84$ and a distance of 4.8 kpc.

UBV photometry of Bochum 2 down to $V=18.7$ has been obtained with the 0.6-m telescope at Las Campanas (Chile) by Turbide and Moffat (1993, hereafter TM). They have observed 87 stars in a 4×4 arcmin^2 field using as local photometric calibrators the eight stars measured by MV. TM identified 19 cluster members, two of which lie apparently isolated at ~3 arcmin from the main body of the cluster. TM essentially confirmed the parameters determined by MV and detected differential extinction within the cluster.

Bochum 2 is centred at RA$=6^h48^m50^s$ and Dec.$=+00°23'$ (J2000.0), $l^{II}=212.30$ and $b^{II}=-00.40$. It lies at a great distance from the Sun in the galactic anticentre direction. This cluster, therefore, seems important for investigations of the spiral structure, dynamics and chemistry of the outer disc of our Galaxy.

In this note we report $UBV(RI)_C$, Hα and GRISM CCD observations of Bochum 2 that we have secured as part of a long term programme aimed at the study of poorly known southern young and compact open clusters. Our observations do not extend to fainter stars compared with TM, but are based on an independent, high-quality photometric calibration and include R, I, Hα as well as CCD GRISM spectroscopic data.

2 OBSERVATIONS

The observations were carried out in early 1992 with the f/18 1.0-m telescope of the South African Astronomical Observatory (SAAO) at Sutherland. The CCD camera housed an RCA chip with 320×512 pixel, of size 30 μm. The scale was 0.388 arcsec pixel^{-1} corresponding to a field of view of 2.4×2.9 arcmin^2. Details of the camera and its operation are given in the yearly issues of the SAAO Handbook. The photometric quality of the sky is monitored in real time during the observations by an off-axis photoelectric photometer that continuously measures a bright, non--variable star close to the field imaged on the CCD.

The journal of the observations is given in Table 1.

2.1 Photometry

Observations of Bochum 2 were obtained in the $UBV(RI)_C$ bands and with a $\Delta\lambda\sim50$ Å interference filter centred at

Table 1. Journal of observations. The FWHM of stellar images is given under *Seeing.*

Date	Filter	Exp. time (sec)	Seeing (″)
Feb. 27, 1992	I	30	1.9
	I	360	1.8
	R	30	2.0
	V	60	2.0
	V	900	2.1
	U	270	2.3
	B	240	2.1
Feb. 28, 1992	R	10	1.1
	V	15	1.4
	I	7	1.0
	B	20	1.3
	U	60	1.4
	B	1200	1.4
	GRISM 10°	330	
	Hα	720	1.1

Table 2. Results from GRISM spectroscopy. The identification of stars is given in Fig. 1 and Table 3. Last column lists the spectral types reported by TM.

Star #	V	Type	E_{U-B}	E_{B-V}	E_{R-I}	
21	11.01	O7	0.69	0.84	0.56	O8 V
20	11.21	O9	0.61	0.80	0.54	O9.5 V
23	11.38	O9	0.61	0.82	0.52	O9 IV
5	13.41	B2:				
10	14.13	B3:				

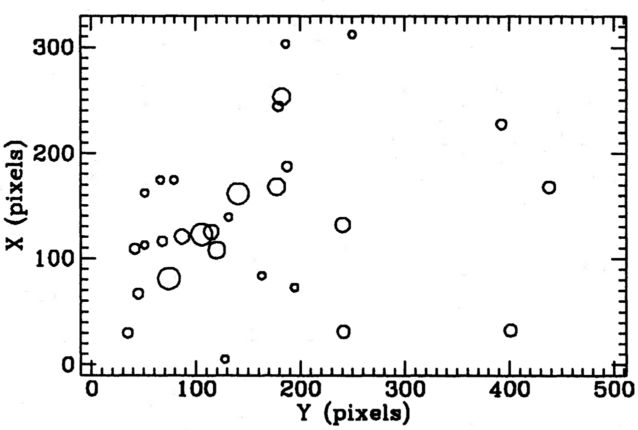

Figure 1. Identification map of the stars listed in Table 2. The field is 2.4 × 2.9 arcmin^2, with north upward and east leftward.

Hα. Data reduction was done in standard fashion with the IRAF software package in Cape Town. Photometry was performed with the DAOPHOT and ALLSTAR packages (Stetson 1991) in the MIDAS environment at the Department of Astronomy, University of Padova.

A large number of standard stars in the E-regions have been observed for calibration. Typically every 1–1.5 h we observed one red and one blue standard at low airmass, followed by one blue and one red standard at high airmass in order to have several independent determinations of the primary and secondary extinction coefficients during the night, as well as system colour equations. They were found to be constant throughout the two observing nights. We have used the most updated magnitudes for the standard stars which are continuously improved at SAAO (1994, private communication by SAAO team prior to publication).

The primary extinction coefficients for the two observing nights were

$$k_U=0.50,\ k_B=0.30,\ k_V=0.15,\ k_R=0.10,\ k_I=0.05 \qquad (1)$$

(± 0.015 in all bands) and the system colour equations (valid over the range $-0.1<B-V<+1.9$, see Fig. 2):

$$U=u+0.019(\pm 0.010)\times(U-B)+\text{const.} \qquad (2)$$

$$V=v-0.007(\pm 0.002)\times(B-V)+\text{const.} \qquad (3)$$

$$R=r+0.003(\pm 0.009)\times(V-R)+\text{const.} \qquad (4)$$

$$I=i+0.028(\pm 0.006)\times(V-I)+\text{const.} \qquad (5)$$

$$(B-V)=1.105(\pm 0.009)\times(b-v)+\text{const.} \qquad (6)$$

In Table 3 we report the photometry for 29 stars in the field of Bochum 2 selected to have an internal error not exceeding 0.020 mag in the V band. A finding chart is provided in Fig. 1. The previous set of equations, the excellent photometry quality of the sky and the low airmass at which the observations have been performed suggest that the data reported in Table 3 are accurate and well placed in the Cousin's photometry system. The adherence to the Cousin system over a wide colour range is evident from Fig. 2. Another check on the consistency of our magnitudes comes from the comparison between the sets of values obtained on the two observing nights (which have been calibrated separately with their own standards), which show no appreciable difference.

Comparison of our data with the photometry of Bochum 2 by MV gives:

$$V-V_{\rm MV}=+0.08, \qquad \sigma=0.03 \qquad (7)$$

$$(B-V)-(B-V)_{\rm MV}=-0.03, \qquad \sigma=0.01 \qquad (8)$$

MV measured the eight brightest (and bluest) stars of Bochum 2 with a conventional aperture photoelectric photometer (diameter of ~11 arcsec, cf. TM). The discrepancies in the zero point with our observations may be easily accounted for by crowding effects, which are particularly severe in this cluster. MV magnitudes appear brighter and the colours redder, exactly what may be expected if fainter and redder stars entered the diaphragm during the measurement of the O and B members of Bochum 2.

Comparison of our data with the photometry of Bochum 2 by TM gives:

$$V-V_{\rm TM}=+0.26, \qquad \sigma=0.08 \qquad (9)$$

$$(B-V)-(B-V)_{\rm TM}=-0.03, \qquad \sigma=0.06 \qquad (10)$$

In this case, the difference in V is quite large. TM used MV magnitudes (after correction for crowding) as local calibrators for their photometry. However, comparison of MV and TM values results in

$$V_{\rm TM}-V_{\rm MV}=-0.09, \qquad \sigma=0.05 \qquad (11)$$

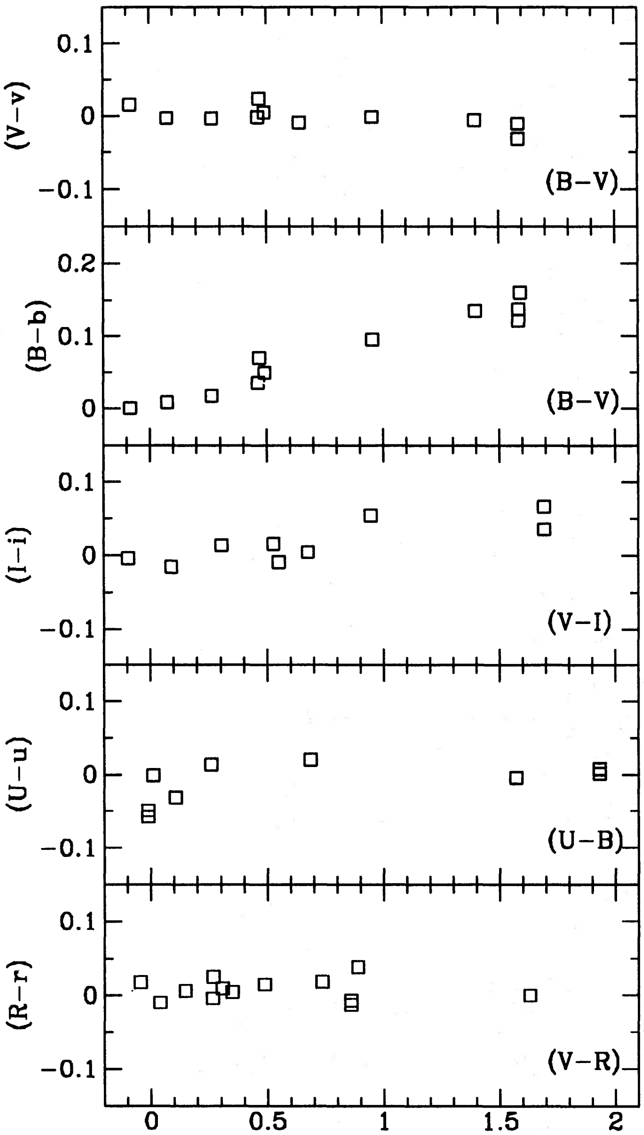

Figure 2. Comparison of instrumental and tabular values as functions of the colours of standard stars.

TM values appear *brighter* than MV ones, contrary to what is expected when correction for crowding is applied. As noted by Moffat (1995, private communication), the discrepancy between MV and TM values can be traced to a missing colour correction in the TM original computations.

2.2 GRISM spectroscopy

At the time of our observations, two GRISMs on loan from Osservatorio Astronomico di Padova were being tested with the CCD camera at the SAAO 1.0-m telescope in Sutherland (Munari & Menzies 1992). A short exposure of Bochum 2 was obtained with the 10° GRISM, resulting in a dispersion of 10 Å pizel^{-1} and 3600–8200 Å coverage for stars optimally placed on the chip. The GRISM was rotated to minimize overlapping of individual spectra and interference with zero-order stellar images (which is an unavoidable by-product of GRISMs used as normal filters in a conventional imaging camera).

Five stars of Bochum 2 produced measurable spectra, which are presented in Fig. 3. The continuum has been normalized through the division of a low-order polynomial fit outside the absorption features. The three main telluric absorption bands in the red/near-IR are indicated as well as the Balmer series of hydrogen and some diagnostic He lines. Spectral classification and corresponding colour excesses are given in Table 2.

None of the members of Bochum 2 looks like a WR star or shows evidence for emission lines at the low resolution of our observations. The lack of strong emission lines is consistent with the results from the analysis of the Hα image. As noted by Moffat (1995, private communication), the enhanced intensity of He I lines at $\lambda\lambda$4471, 5876 Å is probably due to blending with the diffuse interstellar bands at $\lambda\lambda$4428, 5050, 6011 Å as well as the interstellar Na I D lines.

3 THE COLOUR–MAGNITUDE DIAGRAM

The V, $(B-V)$ and V, $(V-I)$ diagrams of the 29 stars in Table 3 are presented in Fig. 4. The main sequence (MS) appears well defined. Star 25 (lying at a distance of ~ 2 arcmin from the cluster centre) may be easily identified as a non-member of the cluster. The width of the MS does not increase with increasing V magnitude. This may be read as an indication that at the magnitude limit of the stars listed in Table 3, photometric errors play no appreciable role and that the contamination by field stars is insignificant. The broadness of the MS may be ascribed to overcrowding in the central cluster region and to differential reddening.

We have performed some fit with $Z=0.020$ theoretical isochrones of the Padova group (cf. Carraro et al. 1993; Bertelli et al. 1994). The isochrones are based on a standard [He/H] ratio. The best fit is obtained for the isochrone corresponding to an age of 7×10^6 yr, scaled to $E(B-V)=0.80$ and $(m-M)_o=14.0$.

Owing to the few stars measured, and the consequent small number fluctuation, we restrain from comparison with theoretical or empirical standard initial mass functions.

4 REDDENING

Previous studies by MV and TM suggested a mean extinction across the cluster of $E(B-V)=0.89$. The fit of our photometry with theoretical isochrones favours a somewhat lower reddening of $E(B-V)=0.80$. The latter is confirmed also by data in Table 2, where colour excesses have been computed by comparing colours in Table 3 with the intrinsic colours based on spectral types, using the calibration of Fitzgerald (1970) and Cousin (1981).

The wavelength dependence of the extinction toward Bochum 2 is a good match to the standard law of Savage & Mathis (1979). This is evident from Fig. 5, where colour excesses of the three O-type cluster members are compared to the standard reddening law.

5 CONCLUSIONS

Bochum 2 lies on the outskirts of the galactic disc in the anticentre direction and therefore it is an important target for

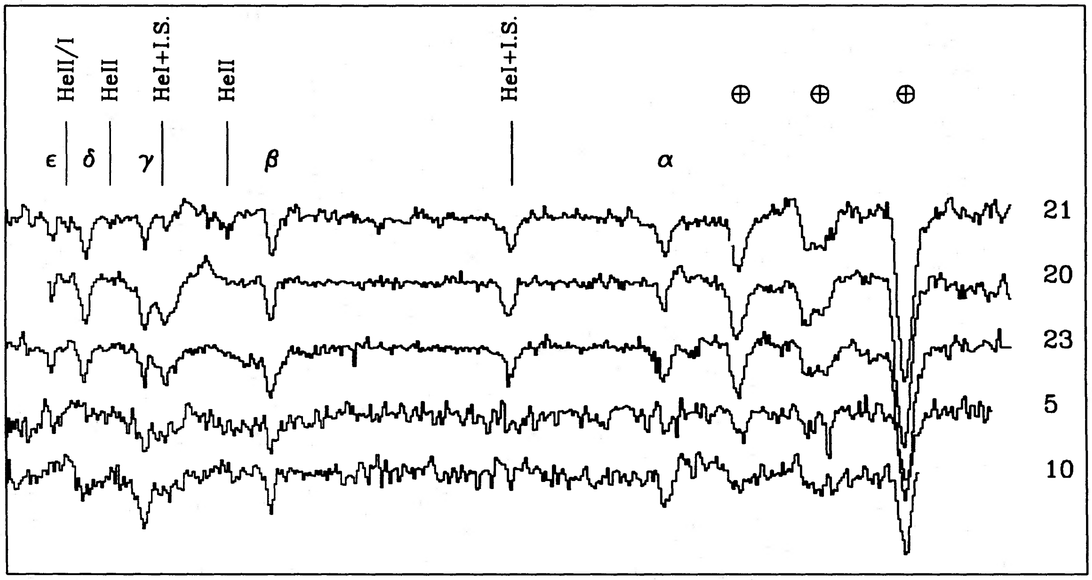

Figure 3. GRISM CCD spectra for five stars of Bochum 2. The continuum has been normalized. Telluric absorption bands, Balmer hydrogen series and some diagnostic helium lines are marked.

Table 3. $UBV(RI)_C$ photometry of Bochum 2. Columns give our identification number and those used by MV and TM, proper name, the *X* and *Y* positions on the chip, and the *UBVRI* magnitudes and associated internal errors (in millimag) as provided by the DAOPHOT package.

ID	MV	TM	Name	X	Y	V	σ_V	B-V	σ_{B-V}	V-I	σ_{V-I}	V-R	σ_{V-R}	U-B	σ_{U-B}
1		9		108.58	41.36	16.95	10	0.83	13	1.22	15				
2		11		161.87	51.11	17.36	10	0.72	14	0.97	16				
3	5	59		107.46	119.81	13.89	2	0.37	3	0.82	4	0.42	19		
4		16		83.69	163.16	17.24	8	0.69	12	0.93	14				
5	4	18		167.80	177.45	13.41	1	0.71	1	0.80	13	0.48	18		
6	7	20		253.21	182.34	13.71	2	0.68	3	0.78	2	0.45	18		
7		22		72.76	194.56	17.38	9	0.73	14	0.98	16				
8		10		66.76	44.96	16.84	12	0.73	15	0.97	18				
9		12		174.38	66.06	17.36	10	0.79	14	1.04	16				
10	8	56		120.31	86.51	14.13	3	0.57	4	0.71	5	0.38	22		
11		19		244.13	178.98	16.48	6	0.87	9	1.14	9				
12		62		187.49	187.42	16.95	7	0.96	11	1.10	11				
13	6	26		131.73	240.40	14.61	1	0.58	2	0.83	1				
14		27		31.26	241.30	15.98	3	0.68	4	0.97	4				
15		14		5.05	127.66	17.11	10	0.69	13	1.04	13				
16		36		32.58	401.05	15.10	1	0.78	2	0.99	2				
17		52		115.93	67.68	16.20	4	0.65	6	0.87	8				
18		40		167.79	438.17	15.00	1	0.94	4	1.04	2				
19		8		29.77	34.77	16.20	4	0.82	6	1.16	6				
20	3	54	BD+0°1617 C	80.83	74.15	11.21	2	0.49	3	0.72	4	0.36	4	-0.52	3
21	2	58	BD+0°1617 B	122.36	105.44	11.01	2	0.53	4	0.75	5	0.38	4	-0.48	4
22		79		124.88	114.71	14.71	14	0.64	18	0.89	19				
23	1	61	BD+0°1617 A	161.24	140.71	11.38	3	0.51	4	0.70	5	0.36	4	-0.52	4
24		13		174.16	79.02	17.35	10			1.25	13				
25		35		227.67	392.42	16.93	6			1.88	7				
26		51		112.15	50.68	17.76	19			1.25	31				
27		21		303.17	186.22	17.44	9			1.30	13				
28		60		138.80	131.32	17.43	22			1.03	33				
29		66		312.46	249.79	17.41	11			1.00	32				

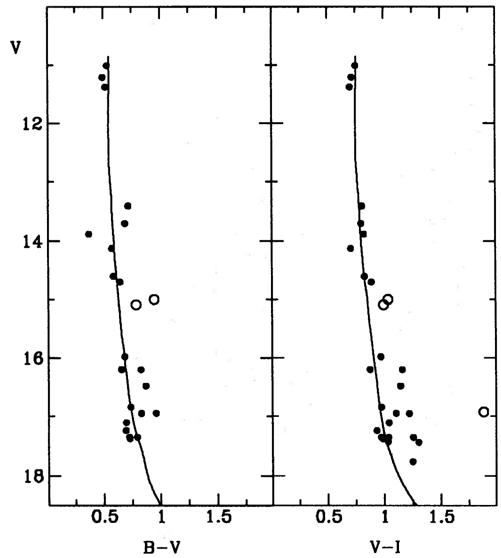

Figure 4. Colour magnitude diagrams for the stars in Table 1. Stars separated by ≥2 arcmin from the cluster centre (the right-most three in Fig. 1) are plotted as open circles. The solid line is the fitting isochrone discussed in the text.

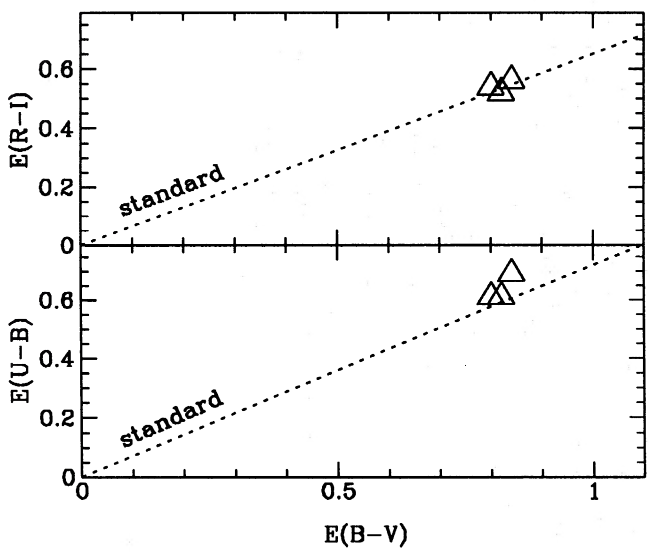

Figure 5. Reddening relation for the three O-type members of Bochum 2. The dashed lines give the standard law of Savage & Mathis (1979).

studies of the spiral structure, dynamics and chemistry of the Galaxy. It appears that:

(i) the cluster lies in a relatively empty field which facilitates member segregation;

(ii) of the 29 stars we have observed, only one (25 in Table 3) can be easily identified as a field star. TM suggested a higher contamination from field stars and over the same area (2.4×2.9 arcmin^2, corresponding to 5 pc at the cluster distance) they identified about 20 members;

(iii) the cluster is quite young (7×10^6 yr on the Padova isochrone scale), with a true distance modulus of $(m-M)_0 = 14.0$, a reddening of $E(B-V) = 0.80$ and late O-type stars still on the main sequence. TM estimated a younger age (5×10^6 yr);

(iv) no WR, strong emission-line star or H II region has been found to be associated with the cluster;

(v) the extinction law matches the standard one and there is evidence for differential reddening across the cluster, and

(vi) previously published photometry could be in error by some tenths of a magnitude.

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REFERENCES

Bertelli G., Bressan A., Chiosi C., Fagotto F., Nasi E., 1994, A&AS, 106, 275

Carraro G., Bertelli G., Bressan A., Chiosi C., 1993, A&AS, 103, 381

Cousin A. W. J., 1981, S. Afr. Astron. Obs. Circ., 6, 4

Fitzgerald M. P., 1970, A&A, 4, 234

Moffat A.F. J., Vogt N., 1975, A&AS, 20, 85

Moffat A. F. J., Fitzgerald M. P., Jackson P. D., 1979, A&AS, 38, 197

Munari U., Menzies W. M., 1992, SAAO Newsl., 19, 2

Neckel Th., Klare G., 1980, A&AS, 42, 251

Savage B. D., Mathis J. S., 1979, ARA&A, 17, 73

Stephenson C. B., Sanduleak N., 1971, Publ. Warner and Swasey Obs., 1, 1

Stetson P. B., 1991, DAOPHOT II user manual

Turbide L., Moffat A. F. J., 1993, AJ, 105, 1831