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B and *V* photometry of the faint open cluster UKS 2 (BH 66)⋆

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Abstract. Colour-magnitude diagrams are presented for the first time, of the faint southern star cluster UKS 2, which was for a long time reported as a globular cluster candidate.

The V vs. $B-V$ diagrams indicate that UKS 2 is an open cluster with age comparable to that of the Hyades.

It has a reddening of $E(B-V)=0.40$ and is located at a distance from the Sun of $d_{\odot}\approx 7$ kpc. The cluster is located outside the solar radius at galactocentric distance projected on the plane $r_{\rm GC}\approx 11$ kpc, and a height $z\approx -370$ pc.

Key words: open clusters: UKS 2 — HR diagram

1. Introduction

It is important to establish the nature of faint star clusters in the Galaxy, in order to better understand the Galactic structure, and the number and properties of objects related to the different subsystems (disk substructures, bulge and halo). In the later years we have been able to determine the properties of many misclassified objects. Some open cluster candidates turned out to be globular clusters, such as Lyngå 7 (Ortolani et al. 1993), NGC 6540 (Bica et al. 1994), or vice-versa AM-2 (Ortolani et al. 1995) and ESO 93-SC08 (Bica et al. 1999), both among the oldest open clusters. An interesting case was that of NGC 6749, previously included in both categories, globular and open clusters, in the latter case referred to as Berkeley 42. As unveiled by means of deep Colour-Magnitude Diagrams (CMD), it is a metal-poor globular cluster (Rosino et al. 1997; Kaisler et al. 1997). Another case is IC 1257, previously classified as open cluster, and now shown to be a compact halo globular cluster (Harris et al. 1997).

The faint star cluster UKS 2, also designated as UKS 0923−545, IAU 0923−545, BH 66 and ESO 166−SC11 is located in Vela at $l=276.003°$, $b=-3.008°$ (J2000.0 $\alpha=9^{\rm h}25^{\rm m}17$s and $\delta=-54°43'10''$). The designation UKS 2 arises from its detection on infrared plates taken with the 1.2 m UK Schmidt telescope, likewise the extremely reddened bulge globular cluster UKS 1 (Malkan et al. 1980; Ortolani et al. 1997). The first photometric study of UKS 2 was that of Malkan (1982). The cluster is also present in the survey by van den Bergh & Hagen (1975) as BH 66, where they reported an angular diameter of $3.5'$ and described it as a moderately rich cluster by means of B and R Cerro Tololo Curtis-Schmidt telescope plates. In the fourth list of the ESO/Uppsala survey (ESO B Atlas) of the southern sky (Holmberg et al. 1977; Lauberts 1982) it was classified as an open cluster with an angular diameter of $2'$.

UKS 2 has also been included in several globular cluster studies. Malkan (1982) derived a reddening $E(B-V)=0.7$ from integrated infrared photometry. Zinn (1985) estimated a metallicity [Fe/H] $=-0.29$ using Malkan's infrared photometry. Webbink's (1985) compilation lists $E(B-V)=0.74$ and [M/H] $=-0.37$, based on the same data sources. Using magnitude estimates of bright giants, Webbink obtained a horizontal branch level

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⋆ Observations collected at the European Southern Observatory - ESO, Chile; Tables 2 and 3 are available only in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

$V_{\rm HB} = 17.75$, implying a distance from the Sun $d_\odot = 9.0$ kpc. Armandroff (1988) presented a V CCD image of the cluster and pointed out that its appearance resembled that of an open cluster rather than that of a globular cluster. The cluster is poorly populated and rather loose to be considered a globular cluster, with a concentration parameter $c = 0.66$, as can be estimated from the core and limiting radii listed in Webbink (1985). No CMD is available for the cluster.

Recently Bica et al. (1998) studied an integrated near-infrared spectrum of UKS 2, deriving $E(B-V) = 0.20$, a metallicity of $[Z/Z_\odot] = -0.15$ and an age of 1 Gyr.

The aim of the present study is to define the nature of this cluster and derive its parameters based on CMDs. In Sect. 2 the observations are described. In Sect. 3 the CMDs of UKS 2 and field are presented, showing that we are dealing with an open cluster, and the parameters are derived. Concluding remarks are given in Sect. 4.

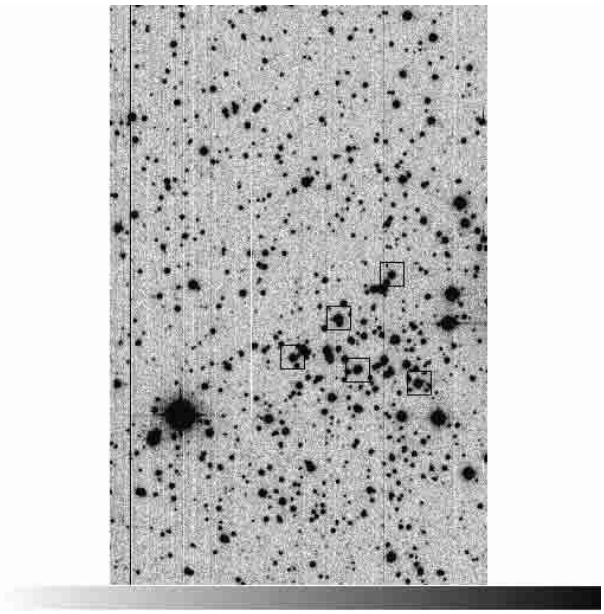

Fig. 1. 4 min V image of UKS 2. Dimensions are $4' \times 2.4'$. North is up and west to the left. Open squares mark red giants from left to right: 5, 1, 4, 3, 2

2. Observations and reductions

UKS 2 was observed at ESO (La Silla) with the 1.54 m Danish telescope in the night of 1988, March 18-19.

The 1024 × 620 RCA CCD ESO # 8 was employed, which has pixel size of 15 μm (0.235″ on the sky), and the frame size is $4' \times 2.4'$. We show in Fig. 1 a V image of UKS 2. The bright star in the image is in the Tycho catalogue, while no Hipparcos's star is present. The J2000 coordinates given in Sect. 1 were measured by ourselves on a digitized Sky Survey extraction, taking into account the highest concentration of stars seen in the CCD frame.

The log of observations is given in Table 1.

The transformation equations are

$V = 23.82 + v$

$B = b + 24.44 + 0.09(B-V)$

where coefficients are for 5 s (V) and 15 s (B) exposures and airmass of 1.15. The stellar photometry was made with the DAOPHOT II code in MIDAS environment. For the calibrations 29 independent B and V frames of 5 different Landolt (1983) standard stars were used. More specifications on this run can be found in the study of NGC 6553 (Ortolani et al. 1990).

The frame to frame photometric errors computed from the long and short exposures are $\Delta V = 0.01$ mag for $16 < V < 17$, 0.05 mag for $17 < V < 20$, and 0.09 for $20 < V < 21$. The $B-V$ errors are about 10% higher. It is well known that the true errors are somewhat larger than the frame to frame spread, because the two frames are affected by the same crowding and flatfield residuals.

In Tables 2 and 3, available only in electronic form at the CDS-Strasbourg, are given respectively, the stars within $r < 200$ pixels centered on the cluster (210 stars), and all 735 stars present in the full field.

Table 1. Log of observations

Target	Filter	Date	Exp. (min)	Seeing (")
UKS 2	B	18.3.88	30	0.85
	V	″	40	″
	B	″	25	″
	B	″	7	″
	V	″	4	″

3. Colour-magnitude diagrams

In Fig. 2 we show the whole frame V vs. $B-V$ CMD. We see a main sequence (MS) with a curved turnoff, and evidence for a clump of giants at the same magnitude level as the turnoff. The spread of the MS appears to be $2-3$ times wider than the photometric errors, indicating a true spread, probably due to differential reddening and field contamination.

In Fig. 3 the V vs. $B-V$ diagram for a cluster extraction of $r < 0.8'$ ($r < 200$ pixels) is shown, where about 2/3 are cluster stars and 1/3 belong to the field. The clump of giants becomes clear at $V \approx 16.2$ and $B-V \approx 1.55$. The spread decreases relative to Fig. 2, making the overall appearance of the cluster CMD clearer.

In Fig. 4 an extraction of the field of radius $r > 1.6'$ ($r > 400$ pixels) is shown. No stars are seen in the giant clump region, confirming that those in Fig. 3 belong to the cluster. The MS is brighter, showing no curved turnoff, suggesting a somewhat younger age with respect to that

of the cluster, assuming that the bulk of the field stars are at a comparable distance.

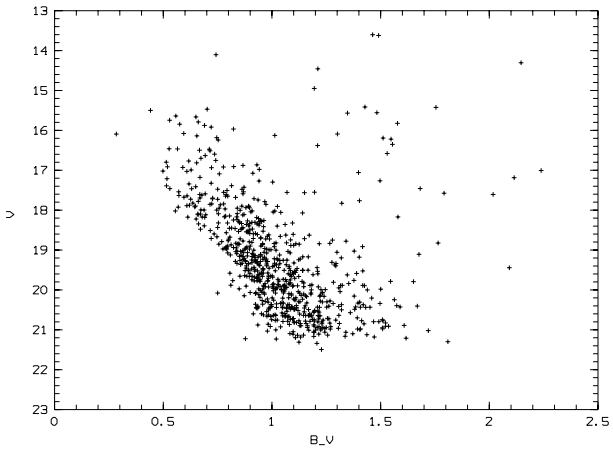

Fig. 2. V vs. $B-V$ diagram of the whole frame $4' \times 2.4'$

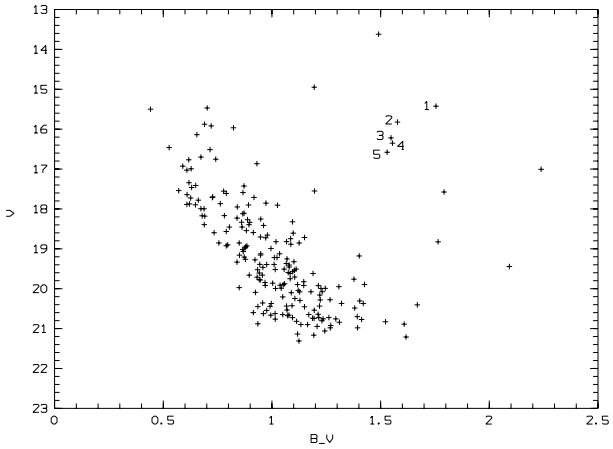

Fig. 3. V vs. $B-V$ of UKS 2 corresponding to an extraction of $r < 0.8'$ ($r < 200$ pixels). The five high probability member giants are labeled

3.1. Isochrone fitting

The Padova isochrones (Bertelli et al. 1994) have been updated (Girardi et al. 2000), where for solar metallicity, both overshooting and no-overshooting models are available.

In Fig. 5 we overimpose no-overshooting models of 0.5, 1.0 and 3.16 Gyr to the same cluster extraction of Fig. 2. Clearly the oldest isochrone can be ruled out, since the magnitude difference between the giant clump and turnoff is too large with respect to that of the cluster. Taking into account the location and shape of the turnoff, location of giants, and MS locus and spread, a compromise fit is shown in this Fig. 5. An age intermediate between 0.5

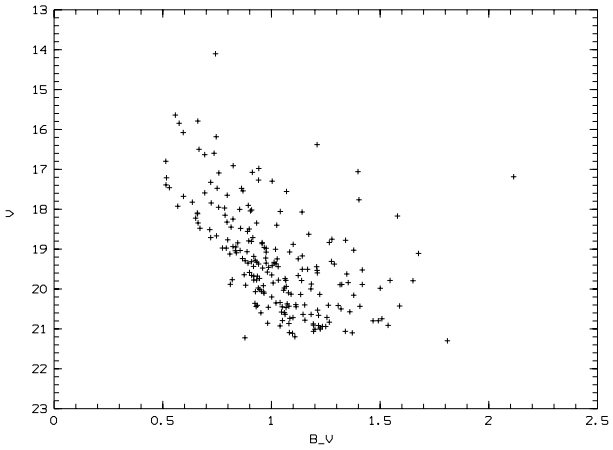

Fig. 4. V vs. $B-V$ diagram for surrounding field at $r > 1.6'$ ($r > 400$ pixels)

and 1 Gyr is suggested, around 800 Myr. This fit leads to $E(B-V) = 0.39$, and a distance modulus of $(V-M_V) = 15.55$. Adopting a standard total-to-selective absorption $R = 3.1$, we obtain $A_V = 1.21$, a true distance modulus $(m-M)_0 = 14.34$ and a distance from the Sun $d_\odot = 7.4$ kpc.

In Fig. 6 the overshooting models are fitted to the cluster CMD. Basically the conclusions are the same as above, because the intrinsic spread and underpopulation of this cluster do not provide enough constraints. We derive the same age of 800 Myr, a reddening $E(B-V) = 0.42$ and $A_V = 1.30$, $(V-M_V) = 15.45$. The true distance modulus is $(m-M)_0 = 14.15$ and the distance from the Sun is $d_\odot = 6.8$ kpc.

We adopt an age of 800 Myr thus comparable to that of the Hyades. Therefore UKS 2 can be classified as an old disk cluster, according to Friel (1995 and references therein), where old means ages of 700 Myr and older. Such objects are often referred to as intermediate age clusters (IACs).

The sample of confirmed old open clusters by means of CMDs is steadily growing in recent years. Considering the compilations by Janes & Phelps (1994), Friel (1995), Carraro et al. (1998) and the more recent one by Dutra & Bica (2000), their number amounts to approximately 100. UKS 2 is a new entry in the family of old open clusters.

We conclude that UKS 2 has a reddening $E(B-V) = 0.40$ and a distance of $d_\odot = 7.0 \pm 1.0$ kpc. The age is compatible with that derived from the integrated spectrum by Bica et al. (1998), and the reddening is higher than their value, probably because of contamination by foreground stars in the integrated spectra.

We assume the distance of the Sun to the Galaxy center to be $R_\odot = 8.0$ kpc by Reid (1993). The Galactocentric coordinates are then $X = -8.73$ kpc ($X < 0$ refers to our side of the Galaxy), $Y = -6.95$ kpc and $Z = -0.37$ kpc. The distance from the Galactic center is $R_{\rm GC} = 11.2$ kpc,

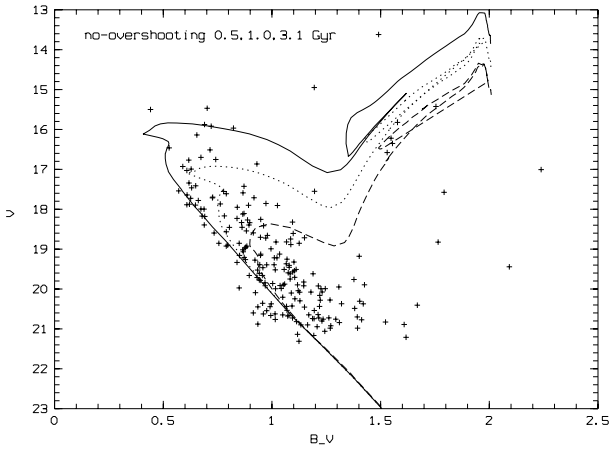

Fig. 5. No-overshooting Padova isochrones of solar metallicity overimposed on the cluster CMD. Ages are: 0.5 (solid), 1.0 (dashed), 3.16 (dotted) Gyrs

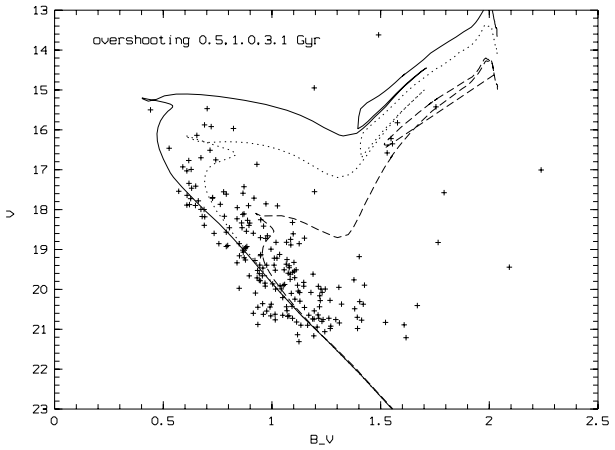

Fig. 6. Overshooting Padova isochrones of solar metallicity overimposed on the cluster CMD. Ages are: 0.5 (solid), 1.0 (dashed), 3.16 (dotted) Gyrs

and the distance projected on the plane $r_{\rm GC}$ is about the same. We are dealing with an old open cluster outside the solar radius, as expected since essentially all the sample is found there. A possible explanation for this distribution is that inner radius old open clusters would have been dissolved by tidal encounters with giant molecular clouds (Friel 1995 and references therein).

The location of the cluster in the $|z|$ vs. distance from the galactic center projected on the plane $r_{\rm GC}$ (see Fig. 4 of Bica et al. 1999) shows that it is relatively close to the plane (370 pc), while the oldest open clusters (age $>$ 2 Gyr) often attain heights from the plane of 1 kpc or more.

The age of UKS 2, together with the distance from the plane, can be used for a simple estimation of the vertical velocity. Assuming that it is in its initial orbit, $|v_z| \sim$ 0.4 km s^{-1}. For the oldest open clusters that estimation gives a comparable value. This is consistent with the stellar disk thickness being supported by vertical motions.

Table 4. Red giants

Star	X	Y	V	$B-V$
1	393.58	495.50	15.424	1.755
2	529.41	386.05	15.824	1.577
3	484.20	569.93	16.220	1.548
4	426.07	408.99	16.351	1.554
5	316.54	429.61	16.579	1.530

Proper motions and radial velocity studies are required to shed more light on formation and evolution of disk substructures.

3.2. Red giants

Since UKS 2 is a relatively distant faint open cluster, it can be an important contribution to the old disk sample of clusters, in terms of understanding their kinematics, metallicities and age distributions. In a recent study in this direction, Scott et al. (1995) determined radial velocities for 11 old open clusters, and compiled data for additional 24 such objects. This means about one third of the verified old open clusters. It is thus important to extend radial velocity and metallicity determinations for more open clusters. For this purpose, we identify the giants in UKS 2 in view of future studies to observe these stars individually. In the CCD image (Fig. 1) are marked the 5 red giants identified in the CMD of Fig. 3. In Table 4 are given their identification, V and $B-V$ colours. Four of the giants appear to be typical clump giants, and the coolest one might be a Hayashi line red giant.

4. Conclusions

By means of BV Colour-Magnitude Diagrams, UKS 2 is shown to be an open cluster and clearly not a globular cluster. We derive an age similar to that of the Hyades, so that the cluster appears to belong to the old disk system.

We derived a reddening $E(B-V) = 0.40$, and a distance from the Sun $d_\odot \approx 7.0$ kpc. It is outside the solar radius, and owing to its relatively large distance from the Sun, it is an important target to trace this subsystem properties farther away, such as kinematics and metallicity.

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