

A photometric study of the open cluster Haffner 6

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ABSTRACT

We have obtained CCD BV photometry of 665 stars in the region of the southern open cluster Haffner 6. The photometry of a nearby field is also reported. This poorly studied object is shown to be of intermediate age and to have a solar metallicity. Adopting a metal content $Z=0.020$, we found a colour excess $E(B-V)=0.43$, an apparent distance modulus $(m-M)=13.90$ and an age of about 1.0 Gyr. Consequently, we obtain a distance of about 3.4 kpc from the Sun. The main-sequence (MS) integrated luminosity function (ILF) is compatible with the standard Salpeter ($x=1.35$) initial mass function (IMF).

Key words: Hertzsprung–Russell (HR) diagram – stars: luminosity function, mass function – open clusters and associations: individual: Haffner 6.

1 INTRODUCTION

Haffner (1957) discovered 22 clusters in a photographic survey between the galactic longitudes $l=190^\circ$ and 215° . Haffner 6 ($\alpha_{1950}=7^h 17^m 50^s$, $\delta_{1950}=-13^\circ 12'$, $l=227:85$, $b=+0^\circ 25'$) is one of the faintest detected, with a photographic magnitude $m_{pg}=15$, and has an angular diameter of 4.0 arcmin. It is also designated as C0717–130 and IRAS 07176–134. More information is contained in the study of Fenkart et al. (1972), who observed four clusters (Haffner 8, Haffner 6, Basel 11 and NGC 2374) on a series of UBV plates obtained by a Schmidt telescope. They studied 88 stars in the region of Haffner 6, concluding that the cluster has an age of 7.9 Myr, a colour excess $E(B-V)=0.0$, and a true distance modulus $(m-M)_0=10.25$. Finally, Haffner 6 appears in a list of unstudied possible old open clusters proposed by Phelps, Janes & Montgomery (1994, table 4).

The aim of this paper is to present a new updated photometric study of Haffner 6 and to assign a reliable age to this object. In Section 2, we present observations, data reductions and a discussion of the photometric errors; in Section 3, we describe the cluster structure. Section 4 describes the CMD of Haffner 6, while Section 5 deals with the completeness corrections and the field stars' contamination. In Section 6, we determine the fundamental parameters of the cluster (age, absorption and distance), while in Section 7 we determine its integrated luminosity function (ILF). Finally, Section 8 gives some concluding remarks.

2 OBSERVATIONS, DATA REDUCTION AND PHOTOMETRIC ERRORS

Observations were conducted at La Silla, using the TK-coated 512×512 pixel CCD #29 mounted at the Cassegrain focus of the 0.92-m ESO–Dutch telescope, on two nights spanning 1994 March 11–12. All the nights were photometric, with an average seeing of 1.3 arcsec. The scale on the chip is 0.44 arcsec per pixel, the array covering about 3.3×3.3 arcmin² on the sky. Five fields, four in the region of the cluster and one about 15.0 arcmin to the north, were observed in the B and V passbands.

Table 1 summarizes the observations, while Fig. 1 shows a collage of the four CCD frames taken in the region of Haffner 6.

The standard fields Rubin 149, SA 98–650 (Landolt 1992) were observed each night just before (and PG 1657 just after) Haffner 6. Finally, a series of flat-field frames on the twilight sky were taken. The frames were flat-fielded and bias-corrected by means of standard routines in the ESOMIDAS software package, while the reductions were performed using the DAOPHOT package (Stetson 1991) and the accompanying ALLSTAR program, in the MIDAS environment, at the Department of Astronomy in Padova (Italy).

The instrumental b and v magnitudes have been transformed into standard Johnson B and V magnitudes using fitting coefficients (colour term and zero-point) derived from observations of the standard field stars from Landolt (1992),

after including airmass corrections. The transformations are given by the following equations:

$$(B - V) = 1.052(b - v) - 0.395, \quad (1)$$

$$V = v + 0.049(B - V) - 2.554. \quad (2)$$

The resulting magnitudes and colours are contained in two tables available upon request, together with the frame coordinates (X and Y) and the instrumental ALLSTAR rms errors σ , for the cluster and the field, respectively. The errors affecting this calibration are expected to be of the order of 0.01 mag. To obtain more realistic error estimates, we have performed some experiments with artificial stars (see Carraro & Ortolani 1994 for more details) by means of the ADDSTAR routine of DAOPHOT. We found errors of 0.04, 0.09 and 0.12 mag at V magnitudes 16, 18 and 20, respectively, and errors of 0.03, 0.08 and 0.13 mag at the same B magnitude levels. These values are consistent with the DAOPHOT outputs, and in reasonable agreement with the natural widths of the main sequence (MS) at the same magnitude levels, which turn out to be 0.14, 0.20 and 0.28 mag, respectively. We found basically the same errors for the field frames. The broadness of the MS is clearly due to various causes, among which are the photometric errors, the presence of a fraction of unresolved binary stars, a possible internal reddening and a spread in metallicity.

3 CLUSTER STRUCTURE

Haffner 6 has an angular diameter of about 4.0 arcsec. Fixing the cluster centre on its apparent geometrical centre, which turns out to be close to the intersection of the four observed fields (see Fig. 1), we have studied the trend of star counts at increasing distance from this point in the magnitude interval $15.0 \leq V \leq 17.0$. The result is shown in Fig. 2. The star counts have been normalized to the area of each circular corona, and from these numbers we have subtracted the field contribution in the same magnitude interval. This contribution has been estimated from the luminosity function (LF) of the field after correcting it for the effects of the incompleteness (see below). We found that the field contains 1.4 stars arcmin^{-2} in the magnitude range $15.0 \leq V \leq 17.0$. This value is in agreement with similar star counts in the Galactic plane (e.g. Carraro & Patat 1994).

The stellar density profile of Haffner 6 is quite similar to that of NGC 1245, with a lack of stars near the adopted

cluster centre and a peak about 2.0 arcsec away (Carraro & Patat 1994).

4 THE COLOUR-MAGNITUDE DIAGRAM

In Fig. 3, we have plotted the colour-magnitude diagram (CMD) for all the stars studied in the region of Haffner 6, while in Fig. 4 we have separately plotted the CMD as derived from each single frame. Looking at Fig. 3, the main features of the CMD can be described as follows.

The MS extends for more than 5 mag, down to $V \approx 21$, and the turn-off point (TO) is located at $V \approx 15.3$ and $(B - V) \approx 0.7$. The sequence is well defined, with a clear contamination of unresolved binary stars on the red edge. The presence of these objects is also responsible for a few stars above the TO. A gap in the MS, probably due to the overall contraction phase following the end of the MS H-burning inside a convective core, is detectable at $V \approx 15.2$. The top of the MS smoothly curves to the red, and several stars define, on the blue side of the gap, the so-called *blue hook*. Seven stars at $V \approx 14.3$ and $(B - V) \approx 1.5$ define the red giants clump of He-burning stars. No indications of a red giant branch (RGB) appear. Finally, the dispersed population of stars on the red edge probably comprises field objects.

The global aspect of this diagram bears a close resemblance to those obtained for the intermediate-age open clusters NGC 1245 (Carraro & Patat 1994), NGC 4815 (Carraro & Ortolani 1994) and NGC 752 (Daniel et al. 1994), all showing the absence of a subgiant population and the lack of an RGB. This suggests that Haffner 6 is an intermediate-age open cluster as well, with an age around 1.0 Gyr and a TO mass greater than $1.1 M_{\odot}$, this latter being the mass value at which the star's core in the MS H-burning phase switches from radiative to convective.

5 COMPLETENESS CORRECTION AND SUBTRACTION OF FIELD STARS

In order to perform a meaningful comparison between observed and theoretical ILFs, contamination by field stars and completeness corrections must be considered. We have tested the degree of completeness of our data by means of experiments with artificial stars. This is possible using the ADDSTAR routine of DAOPHOT. In this procedure one introduces a suitable number of artificial stars (usually 5–10 per cent) per magnitude bin in the original frame, and then reduces this new image following the same procedure as for the original one. The ratio between the number of stars recovered and the stars injected gives an estimate of the completeness factor Λ per magnitude bin (see, for example, Carraro & Ortolani 1994). Tables 2 and 3 show the derived completeness factor for the template frame # 1 and for the reference field in the V and B passbands. As one can see by looking at these tables, incompleteness problems arise only at the faintest magnitudes (typically 19.0), and the field suffers from this problem less than the cluster.

6 COLOUR EXCESS, DISTANCE MODULUS AND AGE OF HAFFNER 6

Fenkart et al. (1972) found that Haffner 6 is about the same age as Hyades, has no significant reddening and has a dis-

Table 1. Journal of observations, ESO–Dutch 0.92-m telescope, La Silla (Chile).

Frame	Date (UT)	Time (UT)	Filter	Exposure (s)	FWHM (arcsec)
# 1	1994 March 12	1 ^h 31 ^m	V	300	1.5
# 1	1994 March 12	1 ^h 39 ^m	B	900	1.4
# 2	1994 March 12	2 ^h 12 ^m	V	300	1.3
# 2	1994 March 12	2 ^h 18 ^m	B	900	1.3
Field	1994 March 12	2 ^h 47 ^m	V	300	1.2
Field	1994 March 12	2 ^h 54 ^m	B	900	1.3
# 3	1994 March 13	1 ^h 32 ^m	V	300	1.2
# 3	1994 March 13	1 ^h 38 ^m	B	900	1.2
# 4	1994 March 13	2 ^h 07 ^m	V	300	1.2
# 4	1994 March 13	2 ^h 13 ^m	B	900	1.2

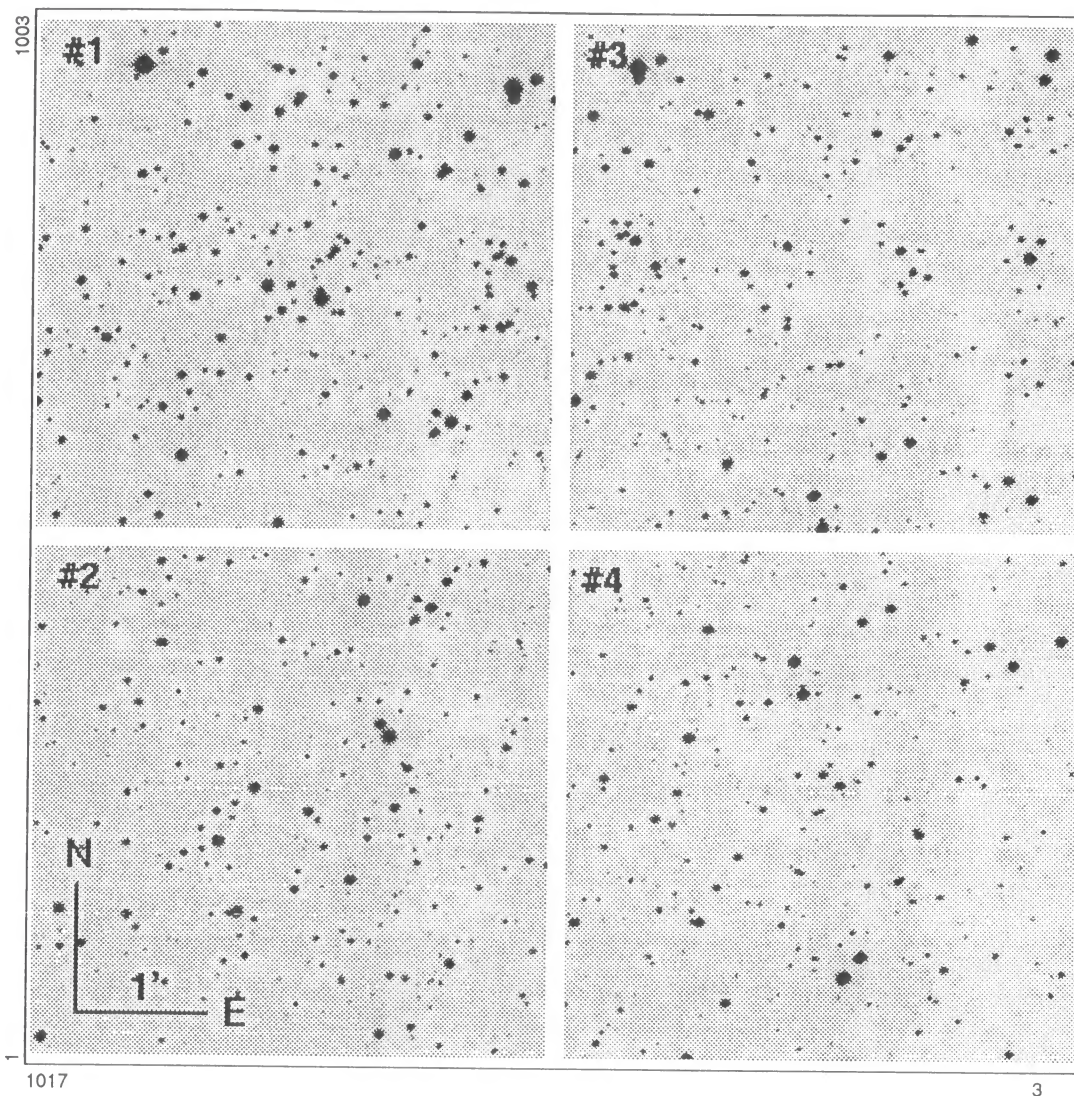


Figure 1. CCD V images of the four fields in the region of Haffner 6.

tance of 1.2 kpc. Their results come from a UBV analysis of about 80 stars brighter than $V \approx 15.0$. This is the magnitude level of the TO (see Fig. 3), and thus they were not able to identify the MS. The CMD we present, due to the larger sample of stars detected and the very clean appearance of the basic features, allows us to define the fundamental parameters of the cluster more accurately.

A first indication of the age comes from the magnitude difference between the TO and the clump, usually indicated by ΔV . Adopting the age calibration from Carraro & Chiosi (1994), we find an age of about 1 Gyr from a measured $\Delta V \approx 1.0$. This age indicator is almost independent of the cluster metal abundance.

We use isochrone fitting to estimate the colour excess and the distance modulus. We have fitted the cluster sequence with isochrones of different metal abundance Z , including convective overshoot (Alongi et al. 1993; Bressan et al. 1993). Our findings are summarized in Table 4 and in Fig. 5. The errors affecting these determinations are about 10 per

cent, and derive from the age range of isochrones which provides an acceptable global fit. All the isochrones fit the MS, the RG clump, and the detailed structure of the TO region, in particular the *blue hook*. A careful inspection of Fig. 5, however, shows that the extension of the *blue hook* and the MS curvature are better defined by the $Z=0.020$ isochrone. On the other hand, a $B-V$ versus $U-B$ diagram for the field #1, obtained using a U frame of 30-min exposure taken on March 17, shows that a comparison with the Hyades MS in the range $0.55 \leq (B-V) \leq 0.65$ gives $E(B-V) = 0.45$ and a colour excess $\delta(U-B) \sim 0.0$. Although this estimate is rather uncertain due to the strong dispersion shown by the stars in the two-colour diagram, inserting this value in the relation calibrated by Cameron (1985) we obtain $[\text{Fe}/\text{H}] \sim 0.08$, or equivalently $Z \approx 0.02$ (Bertelli et al. 1994).

To confirm these conclusions we have constructed a synthetic CMD (see Cararo & Patat 1994), imposing a number of stars in the magnitude interval $16.5 \leq V \leq 18.5$ (96

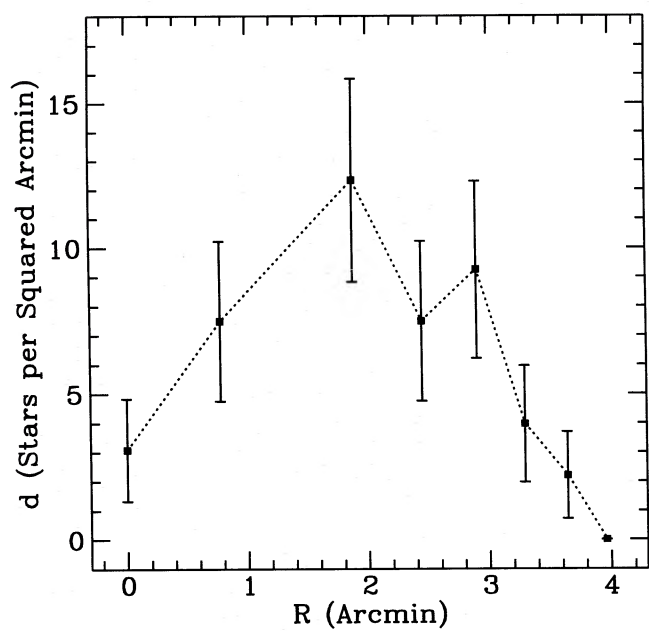


Figure 2. Star counts in Haffner 6 as a function of the radius.

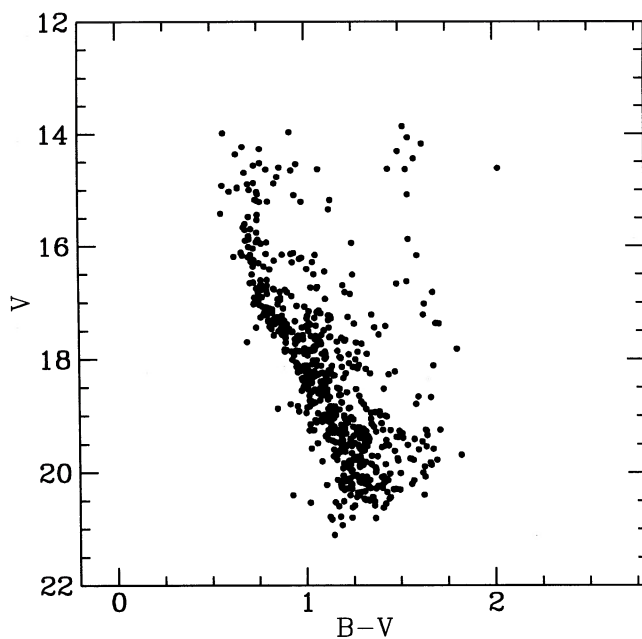


Figure 3. CMD of Haffner 6 for all 665 stars studied.

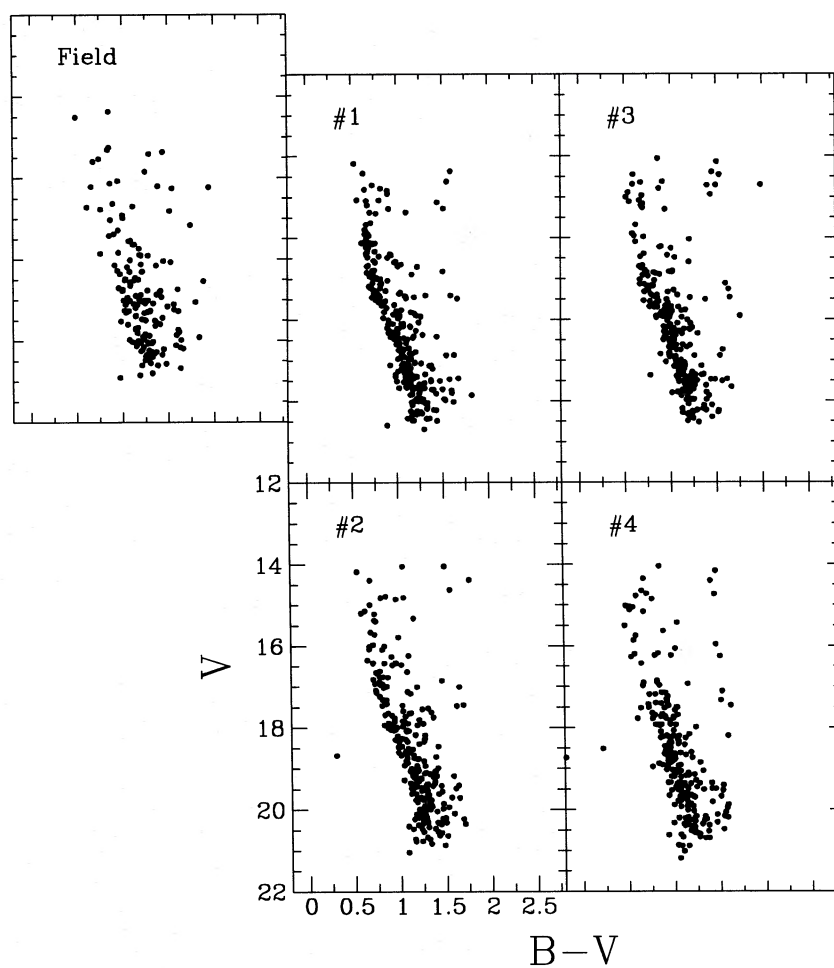


Figure 4. CMDs of the single fields into which Haffner 6 has been divided.

Table 2. Completeness factors Λ relative to the template frame # 1.

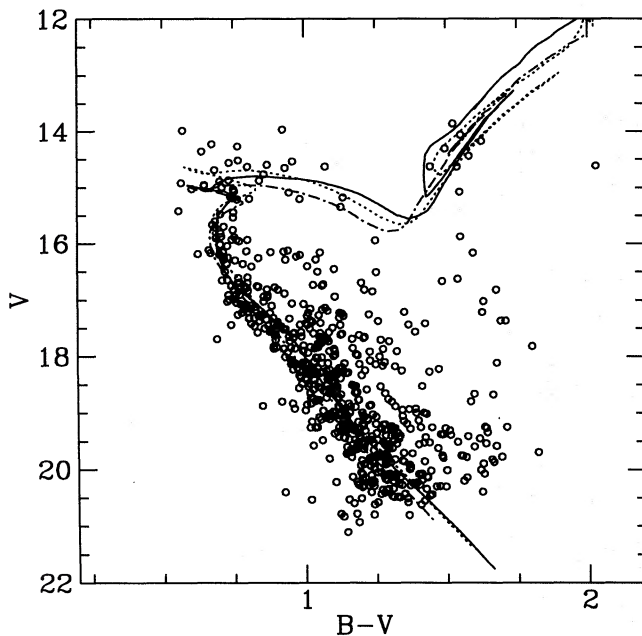
Magnitude interval	Λ_V	Λ_B
≤ 14.0	100 per cent	100 per cent
14.0–15.0	96 per cent	96 per cent
15.0–16.0	94 per cent	95 per cent
16.0–17.0	89 per cent	88 per cent
17.0–18.0	79 per cent	84 per cent
18.0–19.0	59 per cent	63 per cent
19.0–20.0	2 per cent	1 per cent

Table 3. Completeness factors Λ relative to the reference field.

Magnitude interval	Λ_V	Λ_B
≤ 14.0	100 per cent	100 per cent
14.0–15.0	100 per cent	100 per cent
15.0–16.0	100 per cent	100 per cent
16.0–17.0	100 per cent	100 per cent
17.0–18.0	99 per cent	98 per cent
18.0–19.0	78 per cent	80 per cent
19.0–20.0	31 per cent	50 per cent

Table 4. Age determinations of Haffner 6.

Z	$E(B-V)$	$m-M$	Age (Gyr)
0.004	0.65	14.20	1.0
0.008	0.50	14.00	1.0
0.020	0.43	13.90	1.0

**Figure 5.** The CMD of Haffner 6. Superimposed are isochrones of different metal abundance Z . The dotted line represents a $Z=0.020$ isochrone for an age of 1.0 Gyr, plotted adopting $E(B-V)=0.43$ and $(m-M)=13.90$. The dashed-dotted line represents a $Z=0.008$ isochrone for an age of 1 Gyr, plotted adopting $E(B-V)=0.50$ and $(m-M)=14.00$. The solid line represents a $Z=0.004$ isochrone for an age of 1 Gyr, plotted adopting $E(B-V)=0.65$ and $(m-M)=14.20$.

objects) as in the observed CMD, a fraction of binaries (15 per cent), a small age dispersion (5×10^7 yr) and a simulation of the photometric errors. The synthetic CMD is shown in Fig. 6, from which it can be seen that a global good agreement has been reached with the observational CMD of Fig. 3.

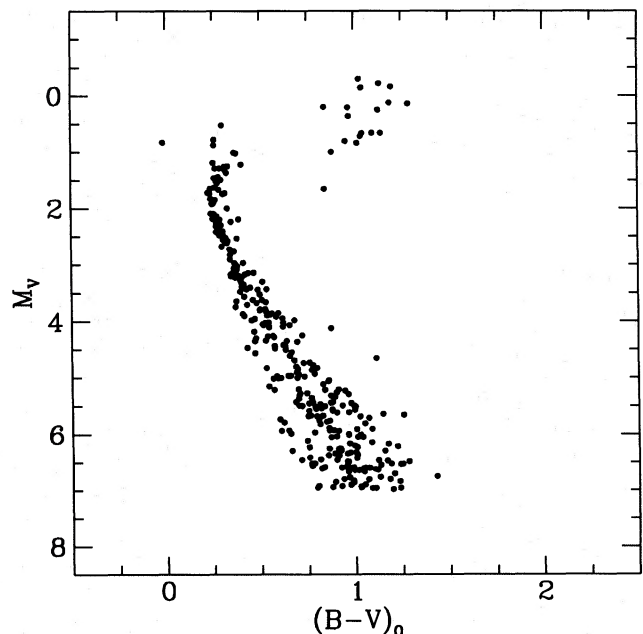
7 FIELD STAR SUBTRACTION AND LUMINOSITY FUNCTION

The availability of a field region 15.0 arcsec to the north allows us to correct the MS stars' distribution for contamination due to the presence of possible field stars. After correcting the star counts per magnitude bin for incompleteness by means of the factors Λ from Table 3, we have subtracted these numbers from the corresponding numbers in the MS cluster LF. The result is shown in Fig. 7. The error bars in the observed ILF take into account the errors in the star counts and the errors arising from the completeness correction.

The theoretical ILF has been constructed adopting the $Z=0.020$ model (see below for the Z choice), including convective overshoot by Bressan et al. (1993), and averaging the results of 100 simulations. In these simulations we have imposed the total number of MS stars as counted in the observed CMD after correcting for completeness and field star contamination. The error bars are the standard deviations from the mean counts per magnitude bin. We achieve a good agreement imposing the classical Salpeter exponent $x = 1.35 \pm 0.10$ on the IMF underlying our simulations.

8 CONCLUSIONS

This study has shown that Haffner 6 is an intermediate-age open cluster, whose metallicity is likely to be solar. The

**Figure 6.** Best-fitting synthetic CMD for Haffner 6. The age is 1 Gyr, and the metal abundance $Z=0.020$.

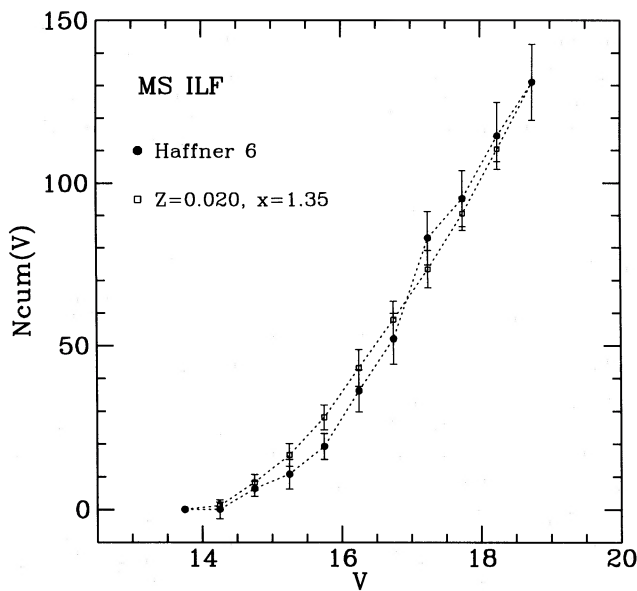


Figure 7. MS ILF for Haffner 6.

present work supersedes the previous one by Fenkart et al. (1972), due to the larger number of stars detected and the extension of the MS down to $V \approx 21$. Although a good agreement with their age determination is obtained, we found different values for the colour excess and the distance modulus. In particular, the latter turns out to be about 2.4 mag larger, and this shifts the object from 1.2 to 3.4 kpc from the Sun. The reasons for this are not clearly understood. However, our results rely on a better CMD and should therefore be more reliable.

The greatest uncertainty arises from the lack of information on the metal abundance $[\text{Fe}/\text{H}]$. Due to this, the uncertainties in colour excess and distance modulus turn out to

be 0.2 and 0.3 mag, respectively. These values are quite different from those of Fenkart et al. (1972). This fact, together with the good global fit we have achieved, suggests that the disagreement in the two works does not depend entirely on the metal-abundance estimates. Nevertheless, spectroscopic observations of the cluster giants are of great importance, and are strongly recommended.

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