

Two reddened globular clusters projected close to the galactic center: Palomar 6 and Djorgovski 1^{*,**}

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Abstract. We present NTT V,I observations of Palomar 6 and Djorgovski 1, two obscured loose clusters in crowded fields. We derive a reddening of $E(B - V) = 1.33 \pm 0.10$, a distance $d_{\odot} \approx 8.9$ kpc, and a metallicity of $[Fe/H] \approx -0.4$ for Pal 6, and $E(B - V) = 1.71 \pm 0.10$, $d_{\odot} \approx 8.8$ kpc, and a similar metallicity ($[Fe/H] \approx -0.4$) for Djorg 1.

Key words: globular clusters: general; Pal 6; Djorg 1 – HR diagramm

1. Introduction

We are carrying out a systematic colour-magnitude diagram (CMD) study of globular clusters projected in the direction of the bulge. All of them lie in crowded fields and are considerably reddened, requiring accurate photometry by means of suitable instrumentation, good seeing and improved automatic extraction procedures. We have studied so far cases of globular clusters like NGC 6553, NGC 6528 and Terzan 1 (Ortolani et al. 1990, 1992, 1993, hereafter OBB). In the present article we study the cases of Pal 6 and Djorg 1 which are considerably fainter. Pal 6 (IAU 1740-262 = GCl-75 = ESO 520-SC21) is located at $\alpha_{1950} = 17^{\text{h}} 40^{\text{m}} 36^{\text{s}}$, $\delta_{1950} = -26^{\circ} 12' 03''$ ($l = 2.09^{\circ}$, $b = +1.78^{\circ}$). Djorg 1 (IAU 1744-330) was discovered by Djorgovski (1987) in a search of optical counterparts of IRAS sources. It is located at $\alpha_{1950} = 17^{\text{h}} 44^{\text{m}} 11^{\text{s}}$, $\delta_{1950} = -33^{\circ} 02' 54''$ ($l = 356.68^{\circ}$, $b = -2.48^{\circ}$). Their Galactic coordinates indicate that they are symmetrically projected with respect to the Galactic center. Pal 6 and Djorg 1 are loose clusters with respectively $c = 1.10$ and 1.50 (Träger et al. 1993). From

infrared photometry, Malkan (1982) derived $E(B - V) = 1.4$ for Pal 6 and Zinn (1985) from these same data estimated the metallicity to be $[Fe/H] = -0.74$. Djorgovski (1993) reports distance moduli and reddening of $(m - M)_o = 13.85$, $A_V = 4.49$ for Pal 6 and $(m - M)_o = 17.10$, $A_V = 5.20$ for Djorg 1. Preliminary CMDs of Pal 6 were shown in Ortolani (1986) and Ortolani et al. (1994a).

In Sect. 2 we present the observations. In Sect. 3 we discuss the CMDs and derive cluster parameters for Pal 6, whereas in Sect. 4 the same is done for Djorg 1. The concluding remarks of this work are provided in Sect. 5.

2. Observations and reductions

The star clusters Pal 6 and Djorg 1 have been observed with the *New Technology Telescope* – NTT at ESO, La Silla, using the ESO Multi-Mode Imager EMMI in the imaging/focal reducer mode, through the red arm, equipped with the 2024×2024 pixels LORAL ESO CCD # 34 with pixel size $15 \mu(0.35'')$. The whole field is $11.8' \times 11.8'$. Table 1 summarizes the observational data.

Table 1. Log-book of the NTT observations

Object	Date	Filter	UT	Exp.time(s)	Seeing (")
Dj 1	15.06.93	I	3 ^h 14 ^m	120	1.0
Dj 1	15.06.93	V	3 ^h 22 ^m	360	1.0
Dj 1	15.06.93	I	3 ^h 34 ^m	120	1.0
Pal 6	15.06.93	I	3 ^h 54 ^m	10	1.1
Pal 6	15.06.93	I	4 ^h 05 ^m	40	1.1
Pal 6	15.06.93	I	4 ^h 10 ^m	40	1.1
Pal 6	15.06.93	I	4 ^h 15 ^m	40	1.1
Pal 6	15.06.93	V	4 ^h 21 ^m	90	1.1
Pal 6	15.06.93	V	4 ^h 30 ^m	900	1.4

The reductions have been carried out following the standard procedure already described in OBB. Daophot II was used to extract the instrumental magnitudes, which have been calibrated

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* Observations collected at the European Southern Observatory, ESO, La Silla, Chile.

** Tables 2 and 3 are available in electronic form via anonymous ftp 130.79.128.5 at the CDS

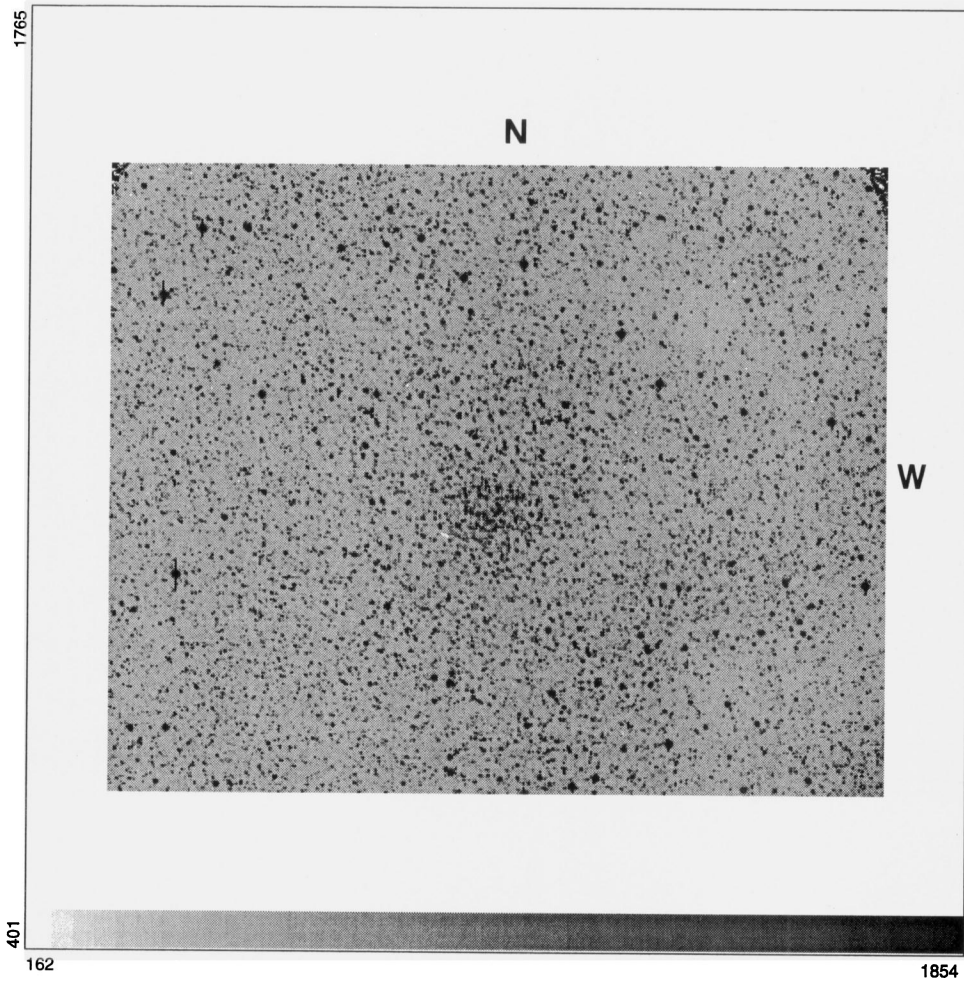


Fig. 1. V image of Pal 6. The size is $9.9' \times 8.0'$

using the same equations as described in detail in Ortolani et al. (1994b, OBB94b) on NGC 6440:

$$V = v + 0.02(V - I) + 23.88 \pm 0.015 \text{ mag}$$

$$I = i + 0.015(V - I) + 23.61 \pm 0.015 \text{ mag}$$

reduced to 1 sec. exposure time and 1.2 airmasses. Calibration errors are the same as discussed in OBB94 (about ± 0.04 mag). We show in Fig. 1 the V 15 min. exposure of Pal 6 and in Fig. 2a 2 min. I image of Djorg 1.

3. Palomar 6

We show in Fig. 3a,b V vs. $(V - I)$ CMD of Pal 6 for circular extractions of $r < 54''$ and $r < 35''$ respectively. In Table 2 the VI data for Pal 6 are presented. The diagrams show the clear presence of a red horizontal branch (HB) basically superimposed on the giant branch (GB), which is a characteristic of metal-rich globular clusters. The GB is curved, again typical of metal-rich clusters. The very central region of the cluster (Fig. 3b) clearly

shows a decrease of field contamination relative to Fig. 3a, with most of main sequence (MS) field blue stars disappearing. The cluster GB tip at $(V - I) \approx 3.80$ and $V \approx 17.2$ shows a curvature which can be used as a metallicity criterion (Ortolani et al. 1991). From a comparison to the V vs. $(V - I)$ CMDs of NGC 6528 (OBB92), NGC 6356 and 47 Tuc (Bica et al. 1994), we conclude that Pal 6 is comparable in metallicity to NGC 6356, i.e., $[\text{Fe}/\text{H}] \approx -0.4$. The latter value is somewhat higher than the value reported by Zinn (1985) of $[\text{Fe}/\text{H}] = -0.74$ (as 47 Tuc) based on Malkan (1982)'s integrated infrared photometry (Sect. 1).

In Fig. 4 we show the I vs. $(V - I)$ CMD of Pal 6 for the same aperture of Fig. 3a. Notice how the GB tip becomes brighter, an indication that I is less affected by blanketing effects.

3.1. Reddening

The distance modulus of Pal 6 can be derived using the location of the HB: from Figs. 3a and 4 we obtain $V = 19.70 \pm 0.15$ and $I = 17.0 \pm 0.15$ for the crossing of the GB with the HB. Adopting Buonanno et al. (1989)'s $M_{\text{HB}}^V = 0.95$ for $[\text{Fe}/\text{H}] = -0.4$, and $A_V = 3E(B - V) = 3.99$, we derive a true distance

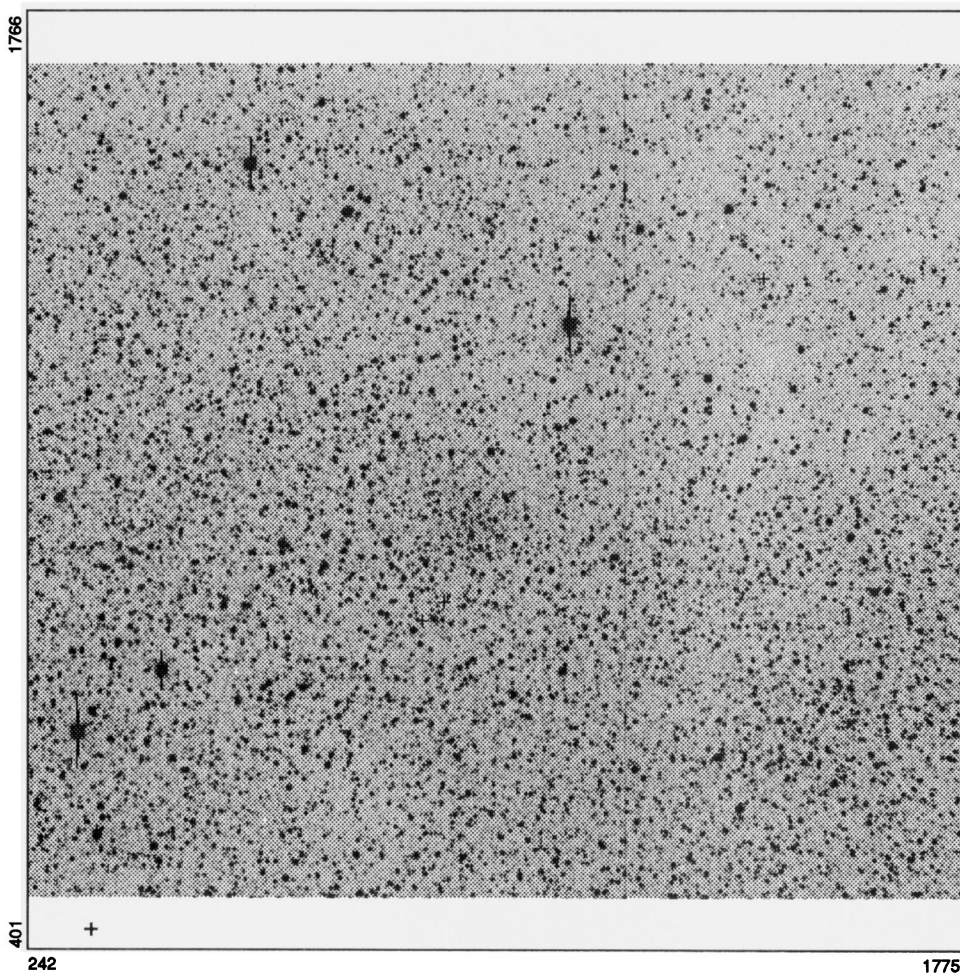


Fig. 2. I image of Djorg 1. The size is $8.9' \times 8.0'$. The orientation is the same as indicated in Fig. 1

modulus for Pal 6 of $(m - M)_0 = 14.76$, corresponding to $d_{\odot} = 8.95$ kpc. Consequently, Pal 6 is located close to the Galactic center. As a check, in order to minimize possible uncertainties due to blanketing effects, we derived the distance for observed I and V HB values of NGC 6356 and 47 Tuc and their distance moduli (Bica et al. 1994), obtaining for Pal 6 $(m - M)_0 = 14.83 \pm 0.03$, in excellent agreement with the previous method.

3.2. The field around Pal 6

Figure 5 shows the V vs. $(V - I)$ diagram of the field surrounding Pal 6 in an area $r > 2.3'$, which excludes most of the cluster stars. The CMD morphology of the bulge population appears very similar to that of the Baade Window (Terndrup 1988; Ortolani & Rich, in preparation). In particular the GB is very extended in the red and inclined with the tip at a fainter V luminosity than the HB, which indicates, on the average, a metallicity at least solar. In this field the position of the HB is $V = 17.2 \pm 0.15$ and $(V - I) = 1.55 \pm 0.10$. Comparing this to the Baade Window HB, and adopting Terndrup's reddening of $E(B - V) = 0.45$, we derive $E(B - V) = 1.45 \pm 0.10$, in agreement with the reddening derived for Pal 6 (Sect. 3.1).

The disk MS in Fig. 5 superimposes well with the BW's disk MS, however the bulge population is much more reddened, suggesting that the reddening comes from dust clouds located beyond the bulk of the disk MS stars.

4. Djorgovski 1

We show in Fig. 6a a V vs. $(V - I)$ CMD for a rectangular extraction of $2.1' \times 2.0'$ centered on Djorg 1. These VI data are available in electronic form at CDS Strasbourg (Table 3). The disk MS contamination is visible in this diagram. In Fig. 6b we show V vs. $(V - I)$ for $r < 54''$. The disk MS contamination becomes less important, while the cluster features are more evident. A cluster red HB basically superimposed on the GB can be identified at $V \approx 20.8 \pm 0.15$, $(V - I) \approx 3.30 \pm 0.10$. The GB extends up to $V \approx 18.6$ and possibly up to $(V - I) \approx 4.90$ at $V \approx 19.3$. If these few possible GB stars belong to the cluster (Fig. 6b), the cluster metallicity would be similar to that of NGC 6356 ($[\text{Fe}/\text{H}] \approx -0.4$). In Fig. 7 the I vs. $(V - I)$ CMD is presented.

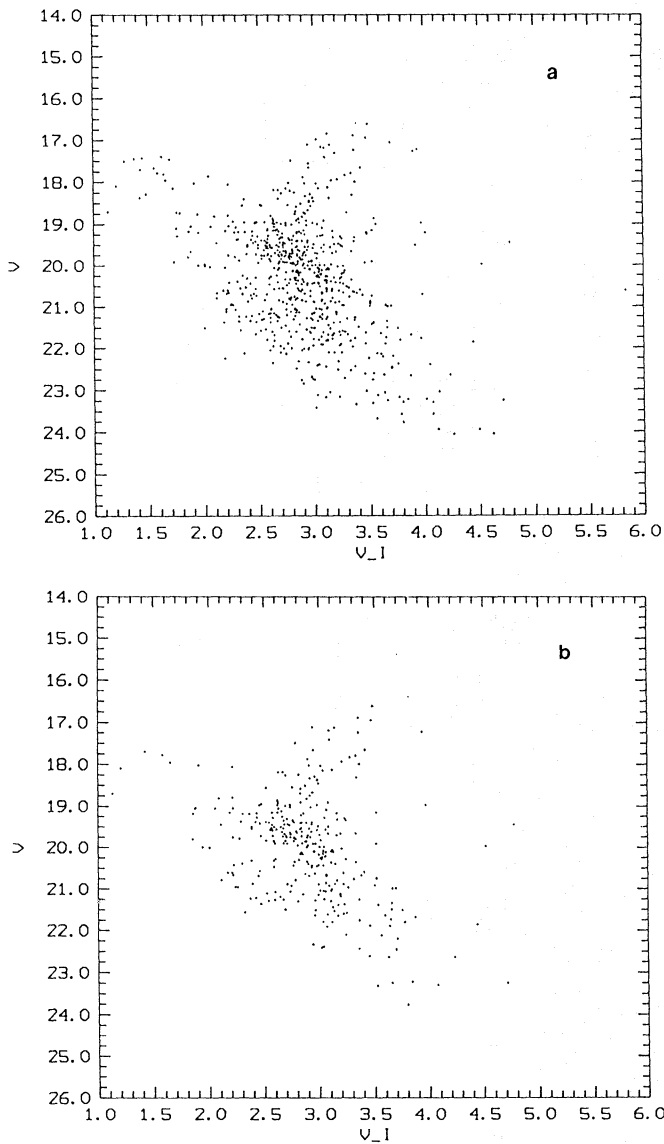


Fig. 3a and b. V vs. $(V - I)$ CMD of Pal 6 for an extraction of a $r < 54''$, b $r < 35''$

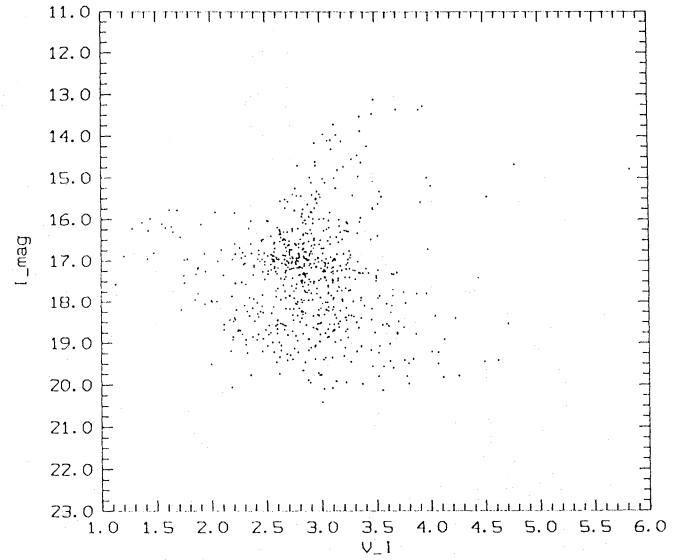


Fig. 4. I vs. $(V - I)$ CMD of Pal 6 for $r < 54''$

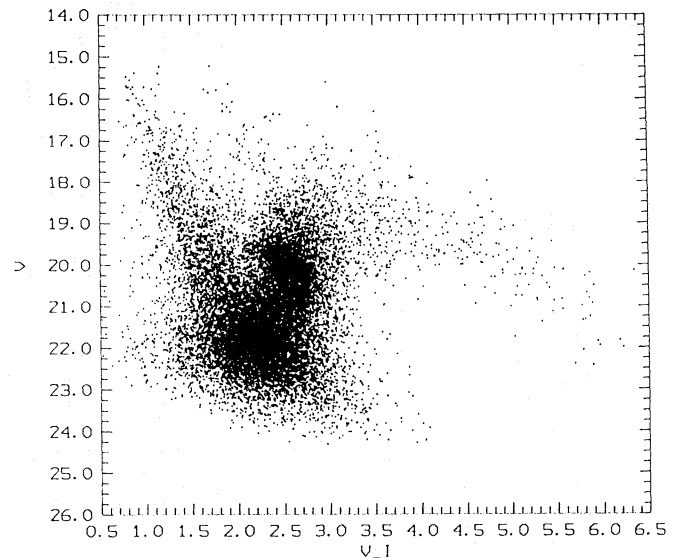


Fig. 5. Field around Pal 6 ($r > 2.3'$)

4.1. Reddening and distance

Following Sect. 3.1, i.e., taking NGC 6356 as reference, we derive for Djorg 1 $E(B - V) = 1.7 \pm 0.10$, basically coinciding with the value estimated by Djorgovski (1993). Since the metallicity of Djorg 1 seems to be similar to that of Pal 6 (and NGC 6356), the same procedures of Sect. 3.1 were employed to derive a true distance modulus for Djorg 1 of $(m - M)_0 = 14.72 \pm 0.15$, considerably closer to the Sun than Djorgovski (1993) estimated value of $(m - M)_0 = 17.10$. Our estimate places the cluster at $d_{\odot} \approx 8.8$ kpc, thus very close to the Galactic center.

5. Concluding remarks

We have studied the V vs. $(V - I)$ and I vs. $(V - I)$ CMDs of Pal 6 and Djorg 1, two low latitude clusters symmetrically located with respect to the Galactic center.

We find evidence that they have similar metallicities of $[\text{Fe}/\text{H}] \approx -0.4$, comparable to NGC 6356, and somewhat higher than that of 47 Tuc and lower than those of NGC 6528 and NGC 6553. Both clusters are highly reddened and are located nearby the Galactic center.

The field bulge population nearby Pal 6 has similar characteristics as the Baade Window, except for a stronger reddening.

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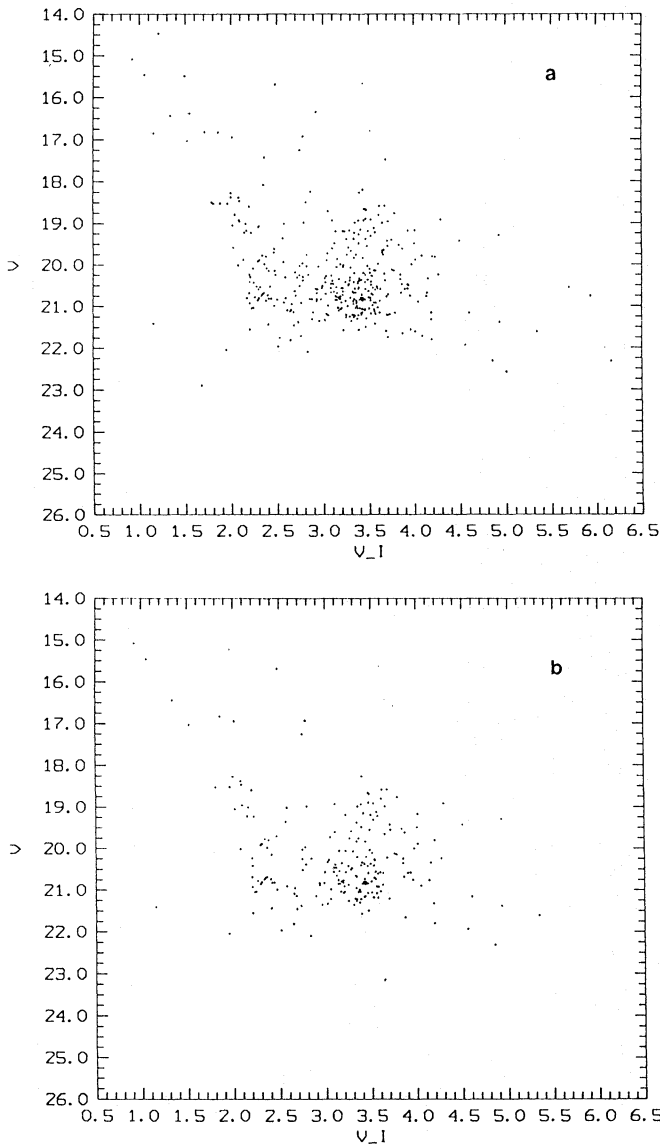


Fig. 6a and b. V vs. $(V - I)$ CMDs for Djorg 1: **a** area of $2.1' \times 2.0'$ centred on the cluster; **b** $r < 54''$

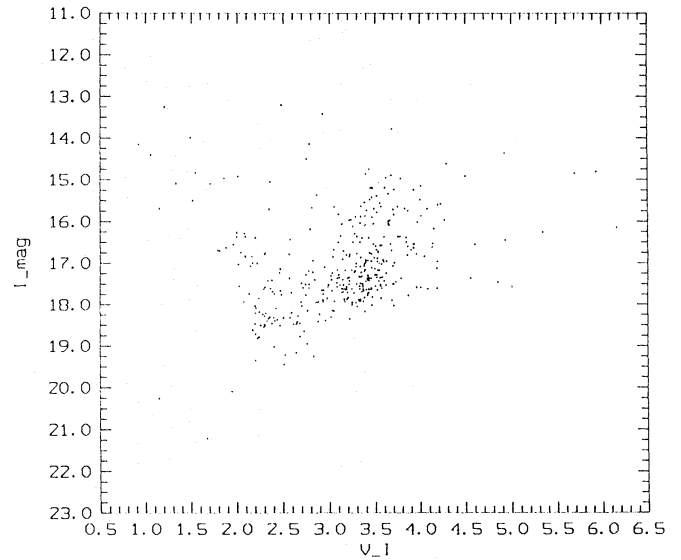


Fig. 7. I vs. $(V - I)$ for Djorg 1, as in Fig. 6a

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