The Peculiar Colour-Magnitude Diagrams of the Metal-Rich Globular Cluster NGC 6553

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1. Introduction

NGC 6553 = GLC 88 (R.A. = $18^h\ 05^m\ 11^s$, DEC. = $-25°\ 55'.1$; 1950.0) is a metal-rich globular cluster of low Galactic latitude ($l = 5°.253$, $b = -3°.029$) at a heliocentric distance of about 5.7 kpc (Webbink, 1985), in the direction of the Galactic centre.

It shows the following interesting properties: (1) it is one of the most metal-rich galactic globular clusters (Morgan, 1959; van den Bergh, 1967; Bica and Pastoriza, 1983; Zinn and West, 1984); (2) it is a good example of an inner bulge globular cluster; (3) it shows a core with relatively dispersed, and therefore resolvable stars.

For these reasons, we decided to investigate NGC 6553 in detail: in a first important step, we obtained colour-magnitude diagrams (CMD) from B, V, R and I images, and then we identified members suitable for a detailed spectroscopic study in order to determine the cluster metallicity for a second step.

In this work, we present some of the resulting CMDs, and discuss the impact of these observations for studies of super-metallic populations.

2. Observations

BVRI frames were obtained at the 1.5-m Danish Telescope, equipped with the high resolution CCD ESO # 8. The frames used were taken with a seeing of about 0.8 arcsec.

The reductions were done at the ESO Garching computer centre using the Daophot and Romafot packages, in Midas environment.

3. Colour-Magnitude Diagrams

Due to its high metallicity, NGC 6553 presents a peculiar CMD morphology, as it can be seen in the V vs. (B-V) diagram for the whole field (Fig. 1 a) and for giant stars only (Fig. 1 b); as well as in the V vs. (V-I) for the whole field (Fig. 2 a) and for giants only (Fig. 2 b). The giant stars in this diagram, as well as in the other diagrams where we present the same selection for different colour combinations, are divided in two groups with different symbols according to their V-I colour (higher or lower than 3.2, roughly corresponding to the giant turnover in the V vs. (V-I) diagram).

3a. Morphology of the Red Giant Branch (RGB)

Figure 2 a shows that the RGB forms an arc, and that the stars at the RGB tip are as faint as the horizontal branch (HB) stars. This is due to a strong molecular opacity of TiO bands in the B, V and R filters, whereas in the I filter only the weak FeH Wing-Ford band is present in these spectral types. This is clearly seen in Figure 2 b where only stars from the upper RGB are selected. The curvature of the RGB arc might be used as a metallicity indicator.

The amplitude of the distortions that the RGB undergoes depends on the relative strength of the opacity in the different filters. The effect is so strong in the V vs. (B-V) diagram (Fig. 1) that it might be misleadingly interpreted as a wide giant branch arising from a metallicity dispersion. We thus leave a cautionary remark for CMD observations of composite metal-rich populations in galaxy nuclei, which become available with large telescopes and the Hubble Space Telescope.

On the other hand CMDs using I magnitudes as luminosity indicator do not

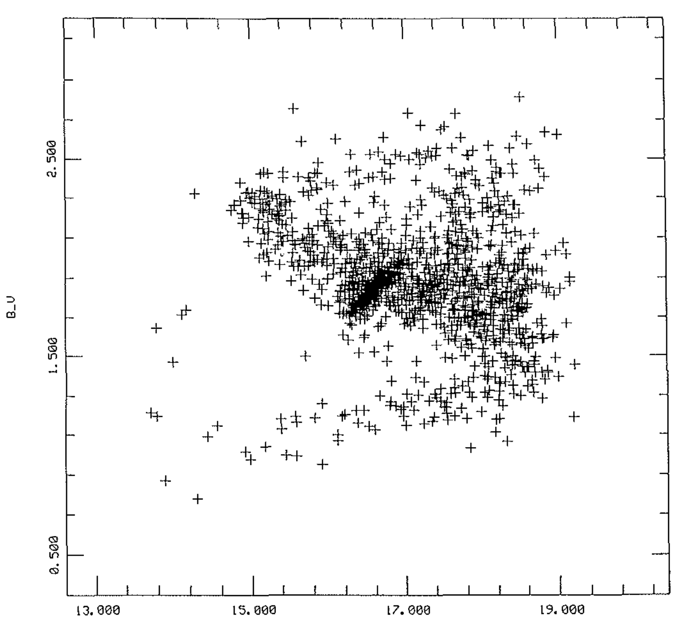

Figure 1 a: *V vs. (B-V) diagram.*

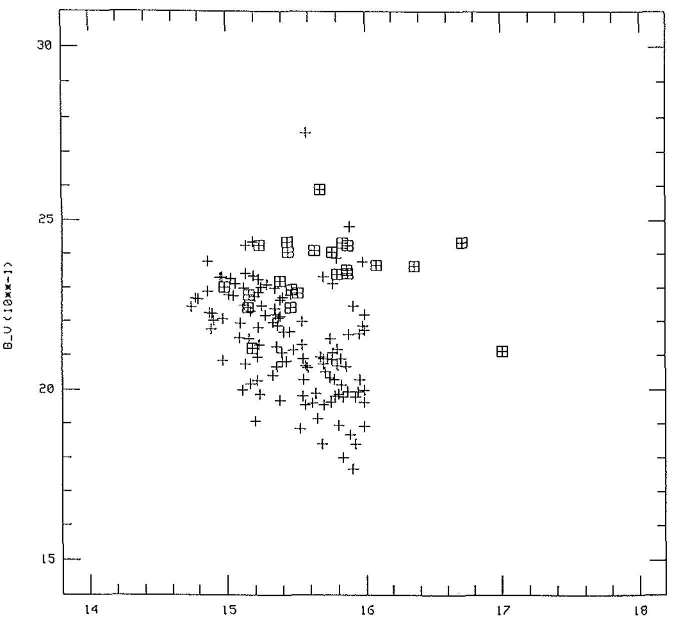

Figure 1 b: *Same as (1 a) but for bright member giants. Crosses and squares represent respectively hotter and cooler giants. Notice that in this colour combination their loci partly overlap.*

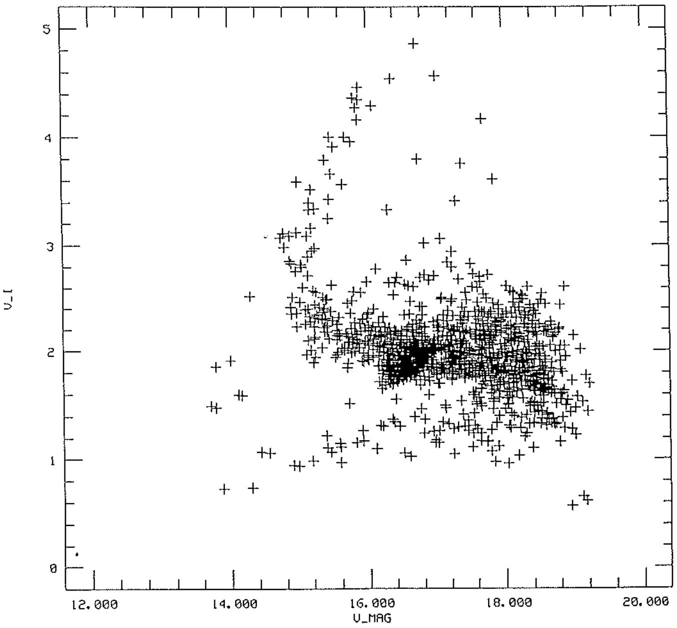

Figure 2a: *V vs. (V-I) diagram.*

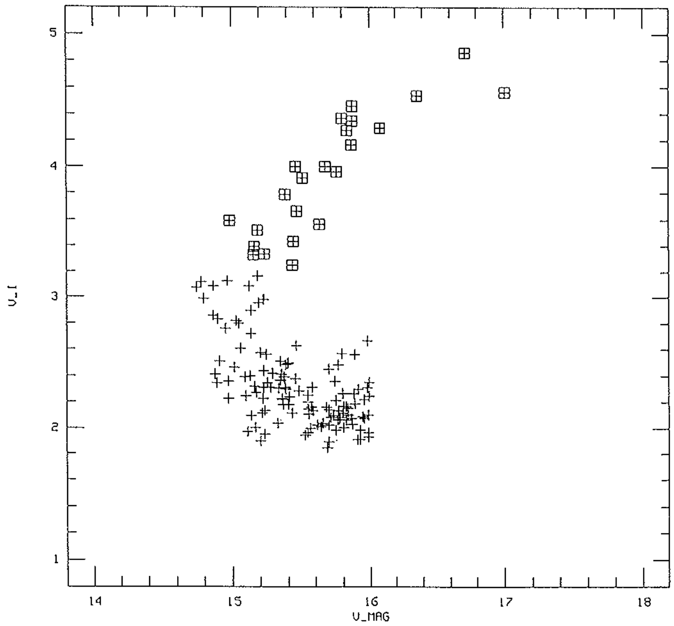

Figure 2b: *Same as (2a) but for bright member giants. Notice the pronounced arc.*

show a prominent turnover (e.g. Fig. 3), because of the weak opacity in it as discussed above. Consequently the CMD I vs (V-I) appears to be particularly suitable for metallicity dispersion studies in galaxies.

3b. Morphology of the Horizontal Branch

NGC 6553 shows a very red HB, which in some diagrams does even cross the RGB. The HB is otherwise tilted, which can be attributed to three effects:

(i) At about the same magnitude as the HB, there might be a clump of ascending RGB stars, in a phase where the H-burning shell crosses the chemical discontinuity left by the convective envelope. The tilting might be partly due to the presence of this clump (see Fusi Pecci, 1989).

(ii) Differential blanketing, which affects the magnitudes along the HB depending on the stellar temperatures, can produce a tilting in the same direction as observed.

(iii) A differential reddening across the cluster field could also produce similar tiltings (Armandroff, 1988).

4. Reddening and Age

The reddening and the age of NGC 6553 were estimated by comparing its CMDs with those of 47 Tuc, of an age typical of old globular clusters, and Pal 12, an exceptionally young globular cluster of the outer halo. They were all observed with the same instrumentation and reduced in the same way (Ortolani, 1988; Aurière and Ortolani, 1988; Gratton and Ortolani, 1988).

The reddening is estimated to be about E(B-V) = 1.0, from a comparison of loci in the turn-off and SGB regions with respect to 47 Tuc. Since NGC 6553

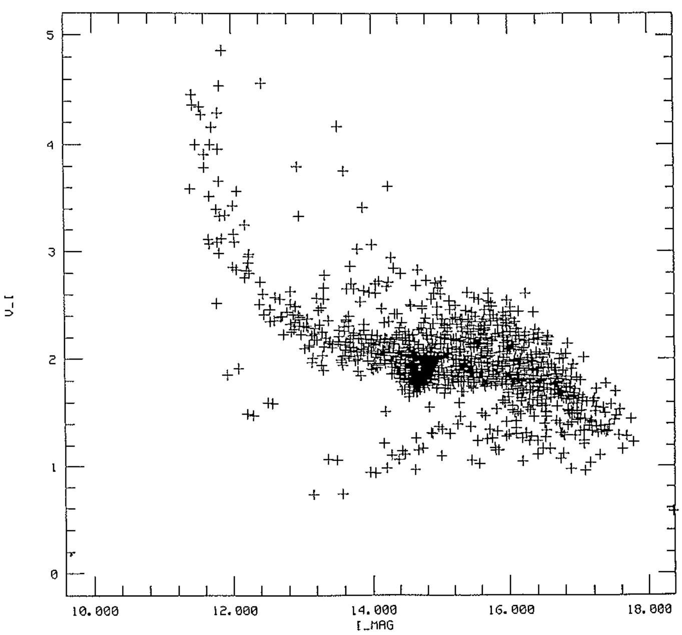

Figure 3a: *I vs. (V-I) diagram.*

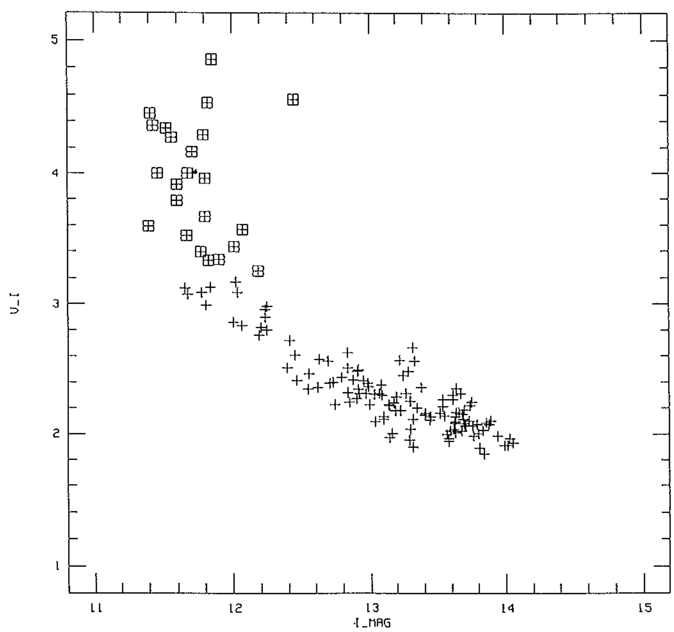

Figure 3b: *Same as (3a) but for bright member giants. This colour combination appears to be suitable for metallicity dispersion studies in composite populations like galaxy nuclei.*

is considerably more metal-rich than 47 Tuc, part of this "reddening" should be due to an opacity difference: adopting the usual value of E(B-V) = 0.8 for NGC 6553 (Webbink, 1985), an opacity difference of 0.2 magnitudes is found.

For estimating the age, the magnitude difference between the turn-off and the HB is used (see Buonnano et al., 1989). NGC 6553 seems to be slightly younger than the classical globular clusters (see Ortolani et al., 1989), which would have important implications for the epoch of the inner bulge formation.

5. Impact of the CMDs of NGC 6553

The colour-magnitude diagrams of NGC 6553 are very important for the study of super-metallic populations: in particular those present in bulges of elliptical galaxies. Indeed a major difficulty of population syntheses using stellar libraries is the adoption of isochrones for a super-metal-rich population; theoretical computations of such isochrones are not available, and the CMDs of NGC 6553 provide, for the first time, information on the CMD morphology for such systems.

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On the Theoretical Ratio of Some Nebular Lines

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1. Introduction

As pointed out by Rosa (1985) and Wampler (1985), the response of the IDS system seems to show a dependence on the value of the input intensity. Peimbert and Torrès-Peimbert (1987) give a review of different determinations of the factor K in the relation between the flux F and the instrumental signal $S = F^{(1+K)}$. The value of K seems to be small (0.03) if the emission lines appear over a strong continuum – which is rare for planetary nebulae –, and K is higher (0.08) for lines over a weak continuum. The value adopted by Peimbert and Torrès-Peimbert is 0.07.

These corrections must be taken into account, as systematic errors will affect the determination of physical parameters. In particular, if line intensities are uncorrected, then:

- the extinction factor c (Hβ) is too high, by about 0.15;
- the electron temperature is too low;
- the He/H abundance is underestimated and the heavy element abundance is too high, if the determination is based on collisionally excited emission lines.

2. ESO Observations of Planetary Nebulae

Since 1984, two of us (A.A. and B.S.) have conducted a spectroscopic survey of the planetary nebulae of our Galaxy, in the spectral range 400 to 740 nm and with a low resolution of about 1 nm (see Acker and Stenholm, 1987). We have used first the IDS system, and since July 1987, a CCD detector, both mounted on the Boller & Chivens Cassegrain Spectrograph at the 1.5-m telescope at La Silla. We have obtained spectra of more than 1 000 planetary nebulae: about 400 spectra taken with the IDS and 120 with the CCD are measured.

2.1 The [O III] doublet

Here we compare theoretical predictions with observed values for the emission lines ratio [O III]r 500.7 nm versus [O III] at 495.9 nm, taking into account the interstellar extinction c.

Figure 1a presents the raw data for IDS spectra. For the 342 spectra measured, we found:
I (500.7)/ I (495.9) = 3.01 ± 0.23.

On Figure 1a we see that, for faint lines (I (495.9) $< 10^3$), the ratio of the [O III] doublet shows highly dispersed values. For very strong lines (I (495.9) $> 10^5$), the ratio becomes too faint, due to saturation effects. The central part of the relation shows clearly that the observed ratio is higher than the theoretical one. Figure 2a shows that the relation I (500.7)/I (495.9) versus I (495.9) has the same appearance for the CCD data as for the IDS data.

The coefficient β′ is calculated as follows, assuming a theoretical value of 2.88 for the [O III] doublet as proposed by Mendoza (1983), and the value of the extinction c derived from our data through the Balmer decrement (see Acker et al., 1989) using the "HOPPLA" code written by J. Köppen:
(I (500.7)/I (495.9) obs =
$(2.88 \times 10^{0.013\,c})^{\beta'}$

By selecting the lines with intensities in the range 10^3–10^5 we found:
β′ = 1.0316 ± 0.0478 (CCD)
β′ = 1.0317 ± 0.0403 (IDS)

These values lead to the following values of the "Rosa-coefficient" β = 1/β′:
β = 0.969 ± 0.047 (CCD)
β = 0.969 ± 0.038 (IDS)

These values are similar to the value given by Rosa (1985): β = 0.96 ± 0.02.

On Figures 1b and 2b, we report the corrected IDS (1b) and CCD (2b) intensities, using the "Rosa-coefficient" β = 0.969. Figure 1c gives the mean relations calculated for the IDS data.

The excellent agreement we found between the IDS and the CCD data suggests that the discordance with the theoretical predictions cannot be due to instrumental effects only. To check this assumption, we study now the possible non-linearity shown by the [N II] red lines.