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RADIAL ABUNDANCE GRADIENT IN GLOBULAR CLUSTERS

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ABSTRACT

The observed radial UBV colour variations (both B-V and U-B) of some globular clusters are examined for correlations with radial variations in the integrated spectra. The results show that the presence of a radial colour gradient is correlated with the presence of a gradient of the CN (and possibly the G-band) line strength, in the sense that the CN (and possibly the G-band) is stronger in the centre (where the cluster is redder) and becomes weaker in the outer region of the cluster (where the cluster is bluer). This may suggest that a primordial abundance, possibly nitrogen and carbon gradient was set up in the early stage of cluster formation.

I. INTRODUCTION

Although globular clusters are usually believed to be homogeneous aggregates of metal weak stars (apart from the mass segregation), there is now much evidence that some clusters are not homogeneous. The inhomogeneity of the large scale structure within individual globular clusters is deduced from the radial variations in the integrated colours of globular clusters (Stebbins, 1950; Gascoigne and Burr, 1956; Chun and Freeman, 1979-Paper 1), and the radial star count distributions (Oort and van Herk, 1959; Woolley and Dickens, 1967; Woolf, 1964).

From an intensive study of the surface photometry of globular clusters, Chun and Freeman (1979, paper 1) reported that 8 clusters out of 24 showed a radial colour gradient, the colours decreasing from the centre outwards by about 0.1 mag in B-V and 0.15 in U-B. However, the colours of the remaining 16 clusters are radially uniform within a few hundredths of a magnitude. We compare the physical properties of clusters with and without radial colour changes. The main result is that the existence of colour gradients does not appear to depend on a cluster's absolute magnitude, integrated spectral type or HB morphology, but does depend markedly on the cluster's central relaxation time T_R. Clusters with $T_R>10^8$ yrs show colour gradients while those with $T_R<10^8$ yrs do not. This strongly suggests that these gradients are not due to mass segregation through encounters but rather to processes that occurred early in the cluster's life (Freeman, 1978; Freeman and Chun, 1982-Paper 2).

In paper 2, 47 Tuc and ω Cen, which both show raidal colour gradients, were studied photographically to check out any radial changes in the luminosity function which might drive the colour gradients. The results showed that these clusters have an excess of the brightest giant stars per unit V luminosity towards the centre. This excess could result from a radial gradient of either the metal abundance (from the interpretation of the RR Lyrae stars in ω Cen by Freeman and Rodgers, 1975) or possibly of the stellar angular momentum (from the mixing theory by Norris and Bessell, 1975; Dickens and Bell, 1976; Bessell and Norris, 1976; Mallia, 1976). However, the nature of the inhomogeneity parameter is not clearly understood as yet. This is the reason why we want to study the integrated spectra of globular clusters. In this paper we look for correlation between the radial integrated spectrum and the colour gradient in globular clusters.

II. OBSERVATIONS

Two globular clusters, NGC 1851 and 2808, were chosen to compare their radial integrated

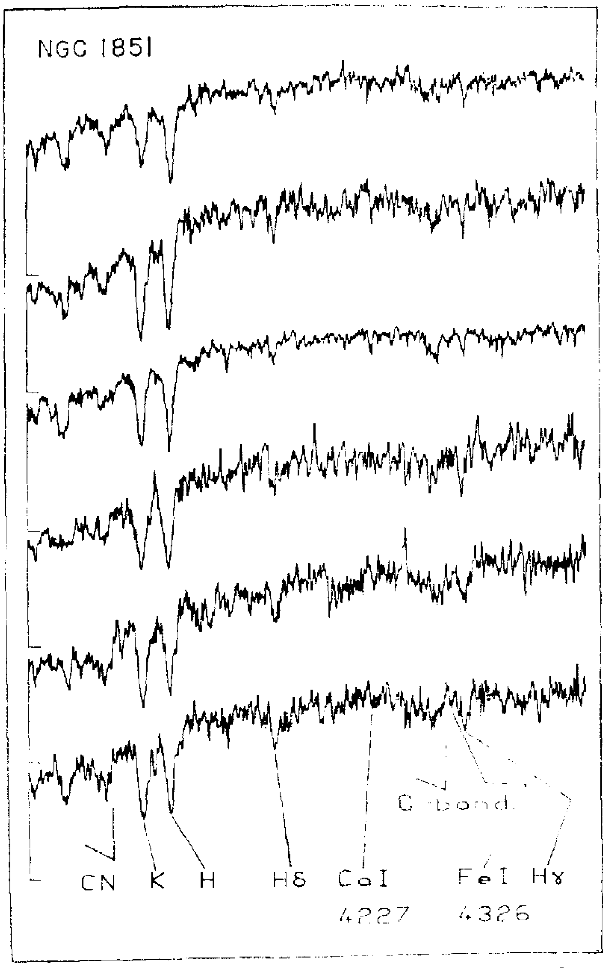
Table 1. Physical and dynamical cluster parameters

Cluster	Sp. Type	Conc Class	Mod $(m\text{-}M)_{app}$	log r_c (min)	log r_t/r_c	log T_R	Colour Gradient
NGC 1851	F7	II	15.55	−0.92	1.83	7.56	NO
NGC 2808	F8	I	15.60	−0.60	1.75	8.18	YES

Spectral Type ; Kinman (1959)
Concentration Class ; Shapley and Sawyer (1927)
Column 4-6 ; Illingworth and Illingworth (1976)
Column 7 ; Peterson and King (1975)
Column 8 ; Chun and Freeman (1979; paper 1)

spectra. Table 1 lists some physical and dynamical properties of these two clusters. Except for the relaxation time and the presence of a radial colour gradient (see columns 6 and 7), these two clusters have very similar characteristics.

The observations were made at the South African Astronomical Observatory, Sutherland using the 74-inch telescope: the Image Tube Spectrograph, with a dispersion of 75 Å/mm, was employed and baked IIa-0 plates were used. As the radial variation is the main concern of this study, so spot observations at different distances from the cluster centre were made. The size of the measuring aperture was 18 arcsec by 6 arcsec, where the 18 arcsec slit was positioned in the radial direction. The slit was centered at $R=9$ arcsec and 27 arcsec from the cluster centres at locations with position angles (measured from north) 0°, 45°, ..., 315°. This gives a total of 16 areas for each cluster except for the south east region ($R=27$ arcsec)



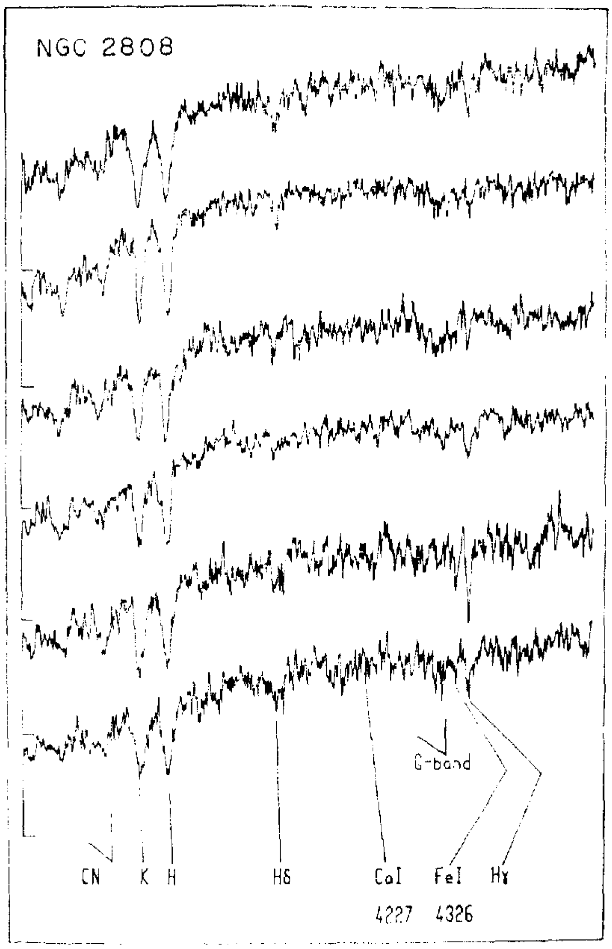


Fig. 1a,b Integrated spectra of NGC 1851 and NGC 2808. Upper three spectra come from the inner region ($0<R<18''$) and the lower three come from the outer region ($18''<R<36''$).

of NGC 1851, which was avoided because of the presence in the area of a UV bright star suspected as being an X-ray source (Vidal and Freeman, 1975; Bolton and Mallia, 1977). Some integrated spectra of the inner ($R=9$ arcsec) and outer ($R=27$ arcsec) parts of NGC 1851 and NGC 2808 are displayed in Figures 1a and 1b. The upper three spectra come from the inner parts, while lower three come from the outer regions.

The observations were reduced using the Joyce-Loebel microphotometer in Oxford. Calibration was made by spot sensitometer plates. The equivalent widths of the violet CN-W(CN), CaII K line -$W(K)$, G-band-$W(G)$ and $H\gamma$-$W(H\gamma)$ were measured for each spectrum. To make a uniform measurement of each equivalent width we take each line strength as the following absorption feature.

$W(CN)$: absorption feature between 3843 Å and 3883 Å

$W(K)$: absorption feature between 3918 Å and 3948 Å

$W(G)$: absorption feature between 4280 Å and 4315 Å

$W(H\gamma)$: absorption feature between 4332 Å and 4348 Å

Each line strength index is defined as follows:

$$S(CN)=\frac{W(CN)}{W(H\gamma)}$$

$$S(K)=\frac{W(K)}{W(H\gamma)}$$

$$S(G)=\frac{W(G)}{W(H\gamma)}$$

The results of the measures for NGC 1851 and NGC 2808 are summarized in Table 2. Here the line strength comes form the mean of the measured $S(CN)$, $S(K)$ and $S(G)$ indices for the 8 areas at each radius. The tabulated error is the calculated standard deviation of the individual 8 measurements in each radius area. These results are displayed in Figures 2a and 2b. The previous observational result (Chun and Freeman, 1979; paper 1) of surface photometry has been added for comparison.

The most striking result from these measures is that the radial *CN* and possible G-band variations are correlated with the radial colour (both in B-V and U-B) gradients in NGC 2808. On the other hand, for NGC 1851 which does not show any radial colour gradients, we could not find any radial variation in either the CN or G-band strengths. This result is comparable with the recent observational result of Smith (1979) for 47 Tuc, which showed that the core of 47 Tuc has stronger features in the observed line strength indices of (CN), (K) and (G) than the halo by about 20%.

III. DISCUSSION

Combining the luminosity function of 47 Tuc with the colour-magnitude diagram of its inner part (Chun and Freeman, 1978), one can reproduce the observed radial colour variations. This implies that the radial colour variation is associated with radial changes in the stellar population of 47 Tuc. Assuming that the luminosity function of M3 is typical of globular clusters (Sandage, 1954), one calculates that 63% of the total V light (58% of B light) comes from the stars brighter than $M_v=0.5$. This indicates that our observed radial variation of the spectral features can result from a difference of chemical abundance in these bright stars.

From the star counts of the clusters with the radial colour gradients, we found that these clusters have the excess of giant stars in the central parts. We interpreted these phenomena as a result of a radial mass loss gradient induced by the radial abundance gradient in these clusters. The fractional excess of the asymptotic giant branch (AGB) stars in the central area may be explained as a result of mass loss gradient.

Can we reproduce the observed colour change

Table 2. Line strength indices

Cluster	NGC 1851		NGC 2808	
distance	$0<R<18''$	$18''R<36''$	$0<R<18''$	$18''<R<36''$
$S(CN)$	1.90±0.23	1.56±0.30	3.01±0.49	1.69±0.36
$S(K)$	4.73±1.25	3.68±1.60	5.23±1.08	3.58±0.98
$S(G)$	2.26±0.55	2.25±0.56	2.30±0.57	1.81±0.39

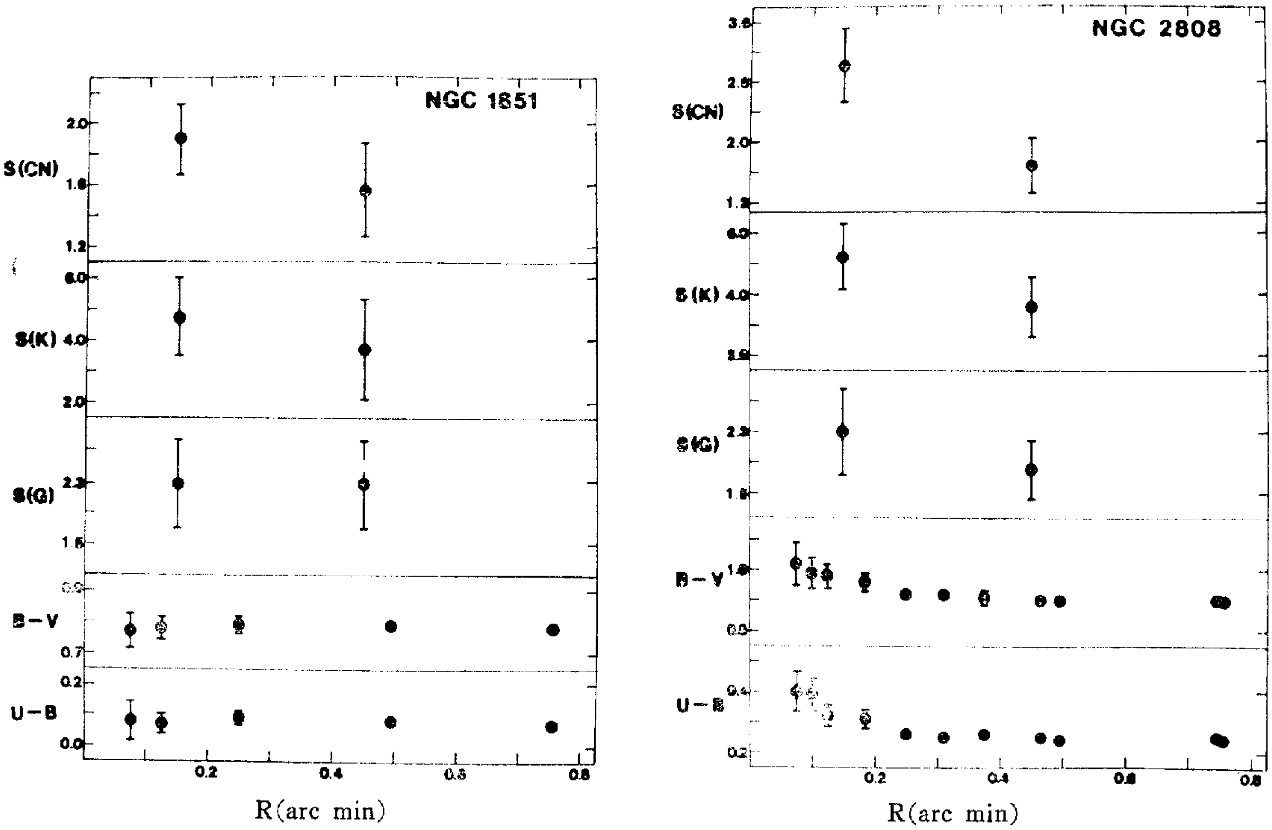


Fig. 2a,b Line strength indices of the *CN*, *K* and G-band features for the inner and outer region of clusters. Concentric aperture measures for NGC 1851 and NGC 2808 are also displayed for comparison. Note the radial variation of *S(CN)* and *S(G)* for NGC 2808 which showed the radial colour variation, while NGC 1851 does not show any significant variation in line strength. Indices are the mean value from 8 measures at the same radial distance and errors are the standard deviation of these 8 measures.

from the variation of the line strength itself? We have computed the fractional absorption due to violet CN, Ca II K and the G-band in the B filter waveband, and have found that these 3 features remove 6.1% of the flux available to the B waveband. From the variation of the line index of NGC 2808 in Table 2, this will change the B magnitude by 0.03, which is far less than 0.1 in B-V. This means that the abundance gradient itself does not produce directly the radial colour change. However, the fractional excess of the AGB stars, as an indirect result of the abundance gradient, could produce the observed radial colour variation between the interior and exterior regions.

The observed result in Figure 2 shows that the radial colour gradient is correlated with the variation of CN and possible G-band strength. From the nuclear burning in stellar evolution we know that carbon will be converted to nitrogen. This may lead to a conclusion that regional carbon enrichment can not be explained as a result of evolutionary product. So there will be no problem to regard carbon gradient as a result of primordial product. As the nitrogen is the secondary product from the primordial carbon and oxygen, then these elements (carbon and nitrogen) will make the variation of CN and G-band.

If the above argument is correct, then we may say that the radial gradient of the metal abundance was set up at the time of formation of the cluster. The clusters with long relaxation times have life times $T_L=(5\sim100)T_R$ and it may be that, for these clusters, there has not been enough time for the radial gradient of this metal abundance to diffuse away beyond detectability, as a result of relaxation. On the other hand, in clusters with $T_L=(100\sim1000)T_R$ where no colour gradients are seen, the effects of diffusion may be enough to obliterate any initial inhomogeneity.

IV. CONCLUSION

The following conclusions were made from this investigation.

1) The observed radial colour gradients (both

in B-V and U-B) are correlated with the variation of CN and possible G-band variation.

2) We suggest that metal abundance gradients were set up at the time of formation of the cluster.

3) Mass loss rate depends appreciably on the metal content.

4) Abundance gradient may be explained as a result of mass loss gradient.

5) Mass loss gradient will make the fractional excess of AGB stars in the central region of the cluster.

6) The critical central relaxation time required for the radial gradient to show up observationally in clusters will lie around 10^8 years.

7) All clusters should show CN variation. However, the clusters with short relaxation time ($T_R < 10^8$ yrs) will distribute the abundance gradient uniformly as a result of dynamical relaxation, while the longer ones will persist this gradient.

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