# DISTRIBUTION OF BHB STARS IN THE CLUSTER ω CENTAURI AND ITS EFFECT ON THE RADIAL CHANGE IN COLOUR AND ELLIPTICITY OF THE CLUSTER

K.K. Scaria and M.K.V. Bappu
Indian Institute of Astrophysics, Bangalore 560034
India

## 1. INTRODUCTION

Colour gradients in elliptical galaxies and nuclei of spiral galaxies are often taken as indicative of chemical abundance gradients. Several of the globular clusters show similar colour gradients (Gascoigne and Burr 1956, Chun and Freeman 1979). Martin (1938) has demonstrated that the red giants in ω Centauri are more concentrated to the centre than the RR Lyrae stars. Kadla et al (1976) show that there is radial change in ellipticity in several globular clusters. ω Centauri is elliptical in form. Dickens and Woolley (1966) find that the flattening observed in the cluster can be explained by the observed rotation of the cluster. King (1980) points out that the ellipticity in the inner parts of globular clusters, where the cluster is completely relaxed, must be due to rotation. Hence a radial change in ellipticity in globular clusters may be indicative of radial differences in rotational velocities in the cluster. The structure and stellar content of a cluster are very closely interwoven. In old stellar systems like globular clusters, one should expect mass segregation especially in the dense inner regions of the cluster. Hence the cluster should exhibit radial change in its luminosity function. We have studied the radial change in the distribution of giant branch stars and the horizontal branch stars in ω Centauri. We show herein how the observed change in their distribution, is related to the radial change in the colour of the cluster and also the radial change in its ellipticity.

## 2. RADIAL CHANGE IN COLOUR OF THE CLUSTER ω CENTAURI

Photoelectric spot measurements of the cluster ω Centauri, were made along the major and minor axes in U, B, V, R and I bands using a diaphragm 40 arcsec in diameter. These spot measures are spaced 40″ apart in the East-West direction and 60″ apart in the North-South direction. Fig. 2.1 shows the way the colour (B-I) changes with distance from the centre of the cluster along the major and minor axes. The distances from the centre are given in arc minutes. The regions marked $B_1$ and $B_2$ are 0.45 mag bluer than the centre. The red core extends out to a distance about 2 arcminutes from the centre. The extent of the blue Zone is from about 2′ to 4′ from the centre. Beyond $B_1$ $B_2$, the cluster rapidly reddens in colour. The presence of kinks indicated by arrows signify concentration of bright red stars in this region. The same bright red stars produce the bumps in the brightness profile of the cluster as seen in the scans of Gascoigne and Burr (1956) and Scaria and Bappu (1981). These bumps are also seen on both the wings of the surface brightness profile of 47 Tuc. The kinks in the colour profile are a common feature in globular clusters

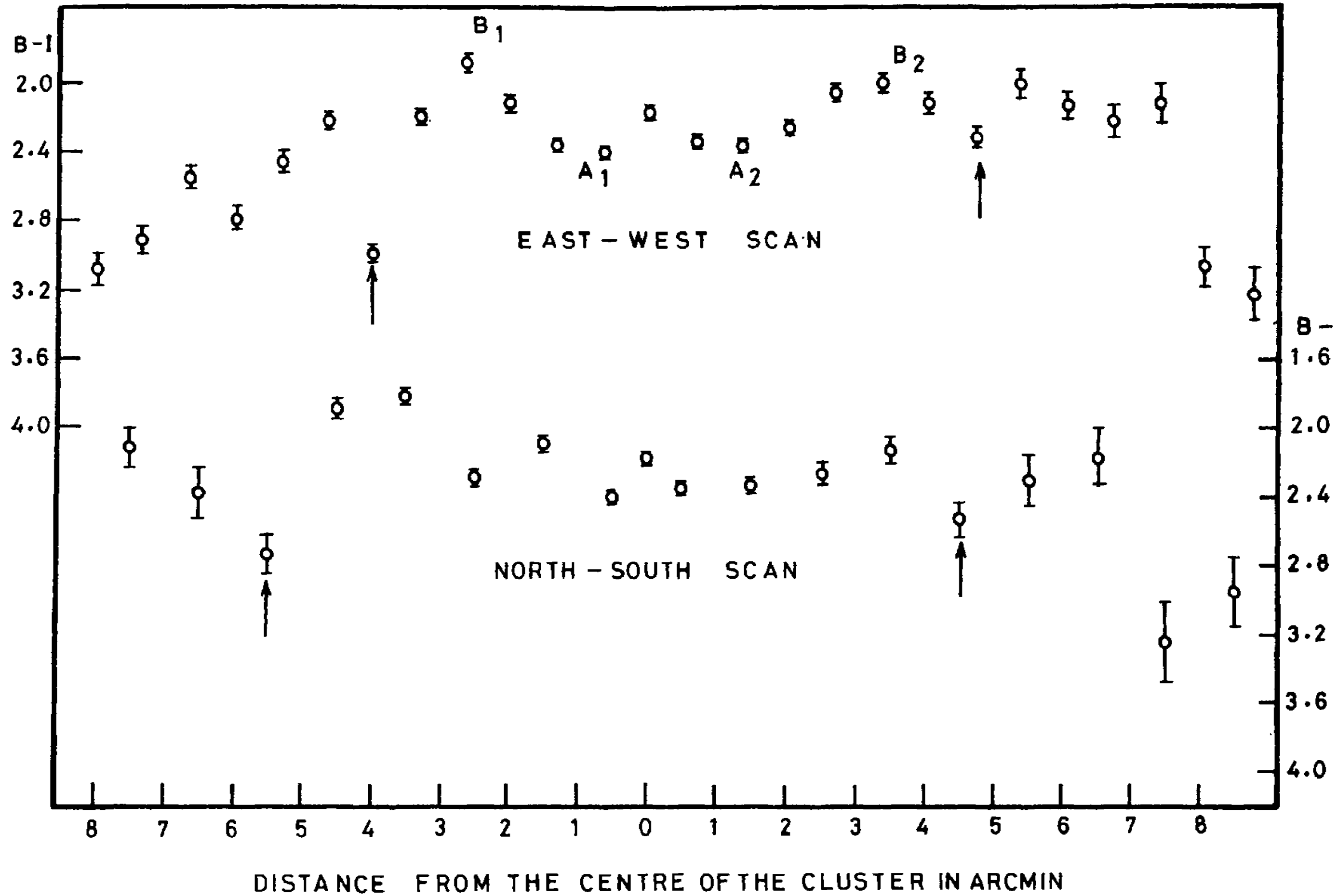



Figure 2.1 Distribution of (B-I) colour along the major and minor axes of $\omega$ Centauri.

(Strauss 1978). The outer Zone contains a large number of bright red stars and hence the surface brightness in this part of the cluster is dominated by the light coming from these stars. Similarly bright red stars dominate the surface brightness at the centre. The blue stars appear in relatively large number only in an intermediate region. The effect of these 3 zones on the ellipticity curve will be shown later.

## 3. RADIAL CHANGE IN THE DISTRIBUTION OF BLUE HORIZONTAL BRANCH (BHB) STARS IN $\omega$ CENTAURI

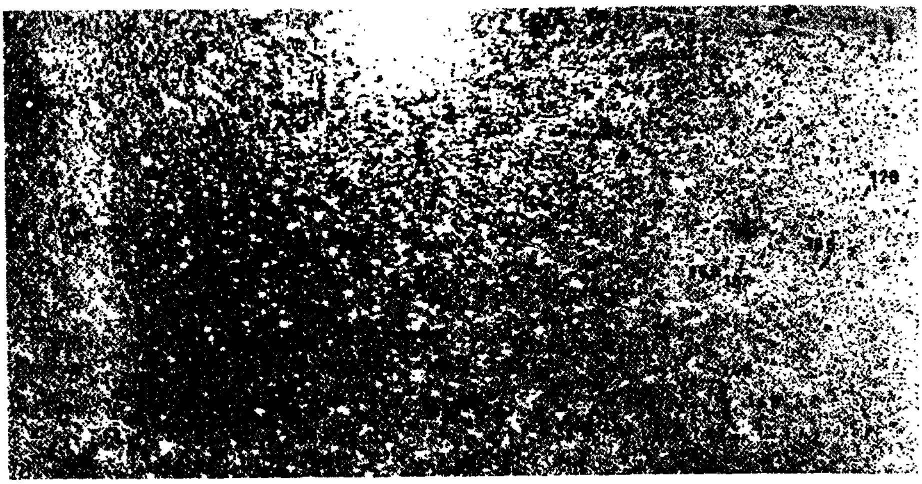
The usual photometric method in identifying the BHB stars fail close to the centre, because of overcrowding. Hence, we employ a photographic subtraction method to separate out the horizontal branch stars in the cluster even at the very centre. In the C-M diagram, the BHB stars stand out as a distinct group of stars well separated in colour from the main sequence and giant branch. Being a metal poor cluster, the red side of the RR Lyrae gap, is not well populated by stars. We have obtained photographs of the cluster in the B and infrared bands at the f/13 focus of the Kavalur 102 cm reflector. The exposures for the blue plate (103a0 + GG13) are adjusted in such a way that the plate limits are about 1.0 magnitude fainter than the apparent magnitudes of the BHB stars in $\omega$ Centauri. The infrared plate (IN+ RG8) is exposed long enough for the red giants to register, but limited by the requirement that the BHB stars do not appear on the plate. One thereby takes advantage of the fact that these blue stars are 2 to 2.5 magnitudes fainter in the I band, than in the B band. The negative of the infrared plate (I) is superimposed over the +ve of the blue plate. ($B^+$). The composite photograph ($B^+$ I–) is shown in plate 3.1. By comparing with Geyer's results of photographic photometry of $\omega$ Centauri (1967), we find that only stars bluer than (B-V) = 0.4 mag appear as black dots in the composite. All red stars appear as white dots. Stars of intermediate colour almost disappear from the composite. Twenty of the Geyer stars, given in Table 3.1, are marked in plate 3.1 a. For the central regions, we have plate 3.1 b. Star X is marked in both the plates for easy identification. Fig. 3.1 a. shows the radial change in the distribution of horizontal branch stars in the cluster. Log $N_{BHB}$ is the logarithm of the number of horizontal branch stars per sq. arc min and $r_e$ is the effective radius given by

$$r_e = \frac{1}{2} (r_1{}^2 + r_2{}^2)$$

(King 1962). Fig. 3.1b and 3.1c show the surface brightness distribution in B and I bands in the cluster. The important result is that the BHB stars show a sudden increase in density between 2′ and 4′ from the cluster centre. This is exactly the zone where the cluster has become 0.45 mag bluer in B-I colour. The counts also show that the system of blue stars has an elliptical distribution (Scaria and Bappu 1981).

## 4. RADIAL CHANGE IN ELLIPTICITY OF THE CLUSTER $\omega$ CENTAURI

Dickens and Woolley (1966) and Seistero and Fourcade (1971) show that there is radial change in the ellipticity of the cluster. We have used the Sabattier technique in photography to obtain equidensity contours of the cluster. Full details are given a



b

Plate 3.1 Distribution of BHB stars in the inner region of $\omega$ Centauri. 20 stars with UBV photometry by Geyer (1967) are identified in plate 3.1 a. Stars having colour (B-V) < .4 mag are seen as dark points while red stars are seen as white points.

Table 3.1
Geyer Numbers of stars identified on Plate 3.1a

| Geyer Number | V | B-V | U-B |
|---|---|---|---|
| B | 8.78 | -0.01 | -0.12 |
| 30 | 14.70 | 0.13 | 0.02 |
| 33 | 15.34 | -0.04 | -0.31 |
| 66 | 13.90 | 1.01 | 0.10 |
| 68 | 14.95 | -0.03 | 0.05 |
| 69 | 12.26 | 1.29 | 0.83 |
| 71 | 12.92 | 1.23 | 0.20 |
| 72 | 15.01 | 0.05 | -0.17 |
| 90 | 15.07 | -0.08 | -0.12 |
| 94 | 15.06 | -0.19 | -0.03 |
| 96 | 13.48 | 0.94 | 0.08 |
| 129 | 14.04 | 1.03 | 0.01 |
| 131 | 14.57 | 0.15 | 0.02 |
| 138 | 13.52 | 0.49 | -0.05 |
| 146 | 13.05 | 0.56 | 0.06 |
| 148 | 14.75 | -0.08 | 0.18 |
| 165 | 13.39 | 0.98 | 0.37 |
| 167 | 14.78 | 0.03 | 0.02 |
| 168 | 14.66 | 0.83 | -0.06 |
| 178 | 15.02 | 0.60 | -0.11 |

in Scaria (1980). Fig. 4.1c shows the radial change in ellipticity of the cluster expressed as b/a, the axial ratio, and 4.1a shows the orientation of the major axis of the equidensity contours in the B and infrared (IN + RG8) bands. The results to note are (1) the cluster is near spherical close to the centre (2) the ellipticity shows a sudden increase between $2'$ and $4'$ from the cluster centre reaching a maximum around $3'$ (3) the increase in ellipticity is more pronounced in the blue band (4) the ellipticity reaches a second minimum beyond $4'$ from the centre, and (5) the core has an orientation much different from the orientation of the cluster in the outer regions. In fig. 4.1b we have plotted the (B-I) colour along the major and minor axes for the east, west, north and south wings separately. Fig. 4.1 shows that the near spherical region close to the centre corresponds to the red core of the cluster, the region showing maximum ellipticity is the region where the cluster is bluer and has larger number of horizontal branch stars and the region beyond 4′, where the second minimum in ellipticity is seen, is the region of "Kinks" in the colour profile.

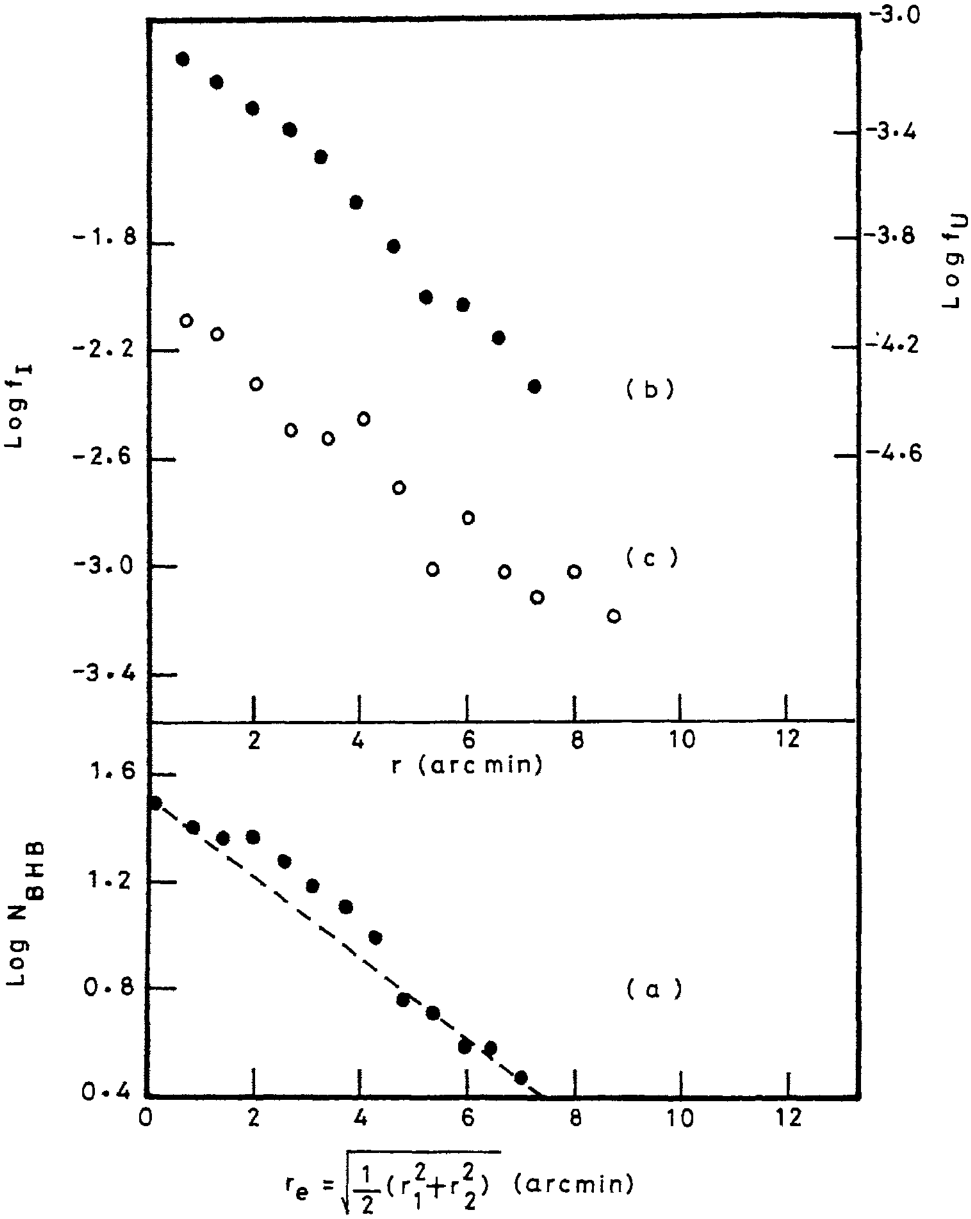



Figure 3.1 Log N as a function of distance from the centre. N is the number of BHB stars/Sq arcmin. Also marked in figure are log $f_U$ and log $f_I$ values where $f_U$ and $f_I$ refer to surface brightness in U and I bands.

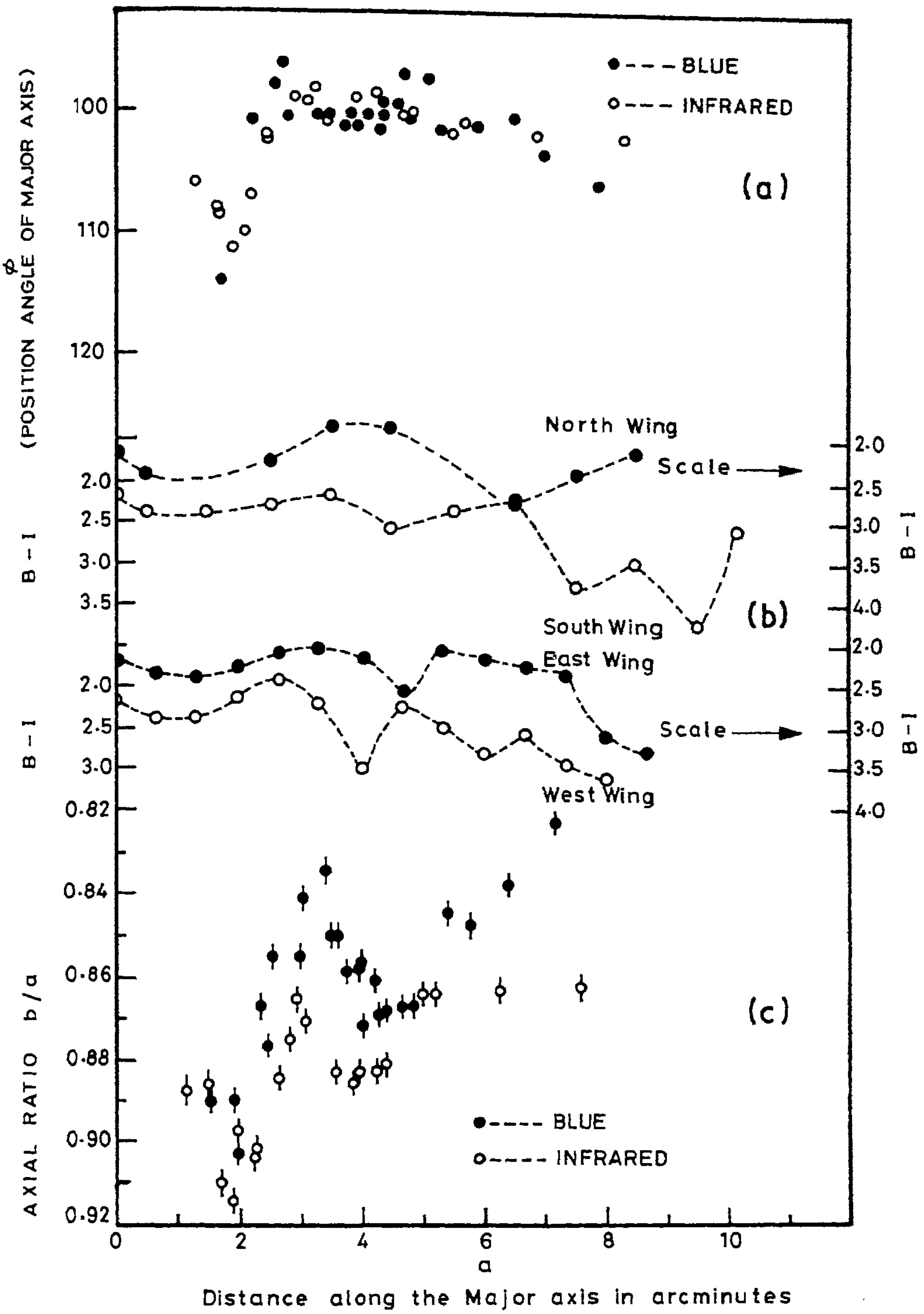



Figure 4.1 Variation with distance from the centre, of the ellipticity, the position angle of the major axis of the isophote and (B-I) colour in $\omega$ Centauri.

Thus at the centre and in the outer regions where the red stars dominate the surface brightness of the cluster, the ellipticity is low. This shows that the red stars in the cluster have a near spherical distribution. The region where the blue stars are in greater numbers, is also the one of larger ellipticity, which proves that the blue stars have a more elliptical distribution.

## 5. RADIAL CHANGE IN ELLIPTICITY OF ω CENTAURI AND OF OTHER GLOBULAR CLUSTERS

In Fig. 5.1 we have compared the radial change in ellipticity in ω Centauri with similar changes seen in M5 and M92. The distances of M5 and M92 have been normalised to the distance of ω Centauri. Data for M5 and M92 have been taken from Kadla et al (1976). All the three clusters show close similarity in their ellipticity versus distance from the centre, relationship. The core has an orientation much different from the orientation seen for the outer regions. This change is about 90° in the case of M5. Similar radial changes in ellipticity are seen in M3, M13, M15 and 47 Tuc. Scaria and Bappu (1981) have shown that the bluer outer region of the cluster 47 Tuc ($r > 2'$) is more elliptical compared to the inner region ($r < 2'$).

## 6. RADIAL CHANGE IN ELLIPTICITY OF ω CENTAURI AND RADIAL CHANGE IN ROTATION OF NUCLEI OF M31 AND M32

Rotation in ω Centauri is clearly shown by Harding (1965). The ellipticity, especially in the dense inner region of the cluster, must be due to rotation. Hence the larger ellipticity seen in the intermediate region (between 2′ and 4′ from the centre) could be due to larger rotational velocities. We have seen before, that, this is to some extent due to larger number of blue stars in this zone. In fig. 6.1 we reproduce the rotation curve obtained by Peterson (1978) for the nucleus of M31. The close similarity between the ellipticity curve for globular clusters and rotation curve for the nucleus of M31, shows that probably similar dynamical processes produce both these effects. Scaria and Bappu (1981) have given evidence to show that the background radiation has properties similar to the blue horizontal branch stars and the increase in colour and ellipticity in the intermediate region in ω Centauri is partly contributed by the background radiation. In one of the other globular clusters that we are studying currently, M5, a large radial change in ellipticity and position angle of the major axis are noticed. The distribution of the BHB stars is found to be very elliptical. Also the orientation of the major axis of the system of blue stars is found to be very much deviated as compared to the orientation of the red central core of the cluster.

## 7. CONCLUSIONS

The red stars in ω Centauri and probably in other globular clusters, show a more spherical distribution than the BHB stars. The increase in the blueness of the cluster, Omega Centauri, between 2′ and 4′ from the cluster centre, is partly due to a sudden increase in the ratio of BHB/RGB stars. If the analogy between the ellipticity curve of ω Centauri and the rotation curves of M31 and M32 nuclei, is correct,

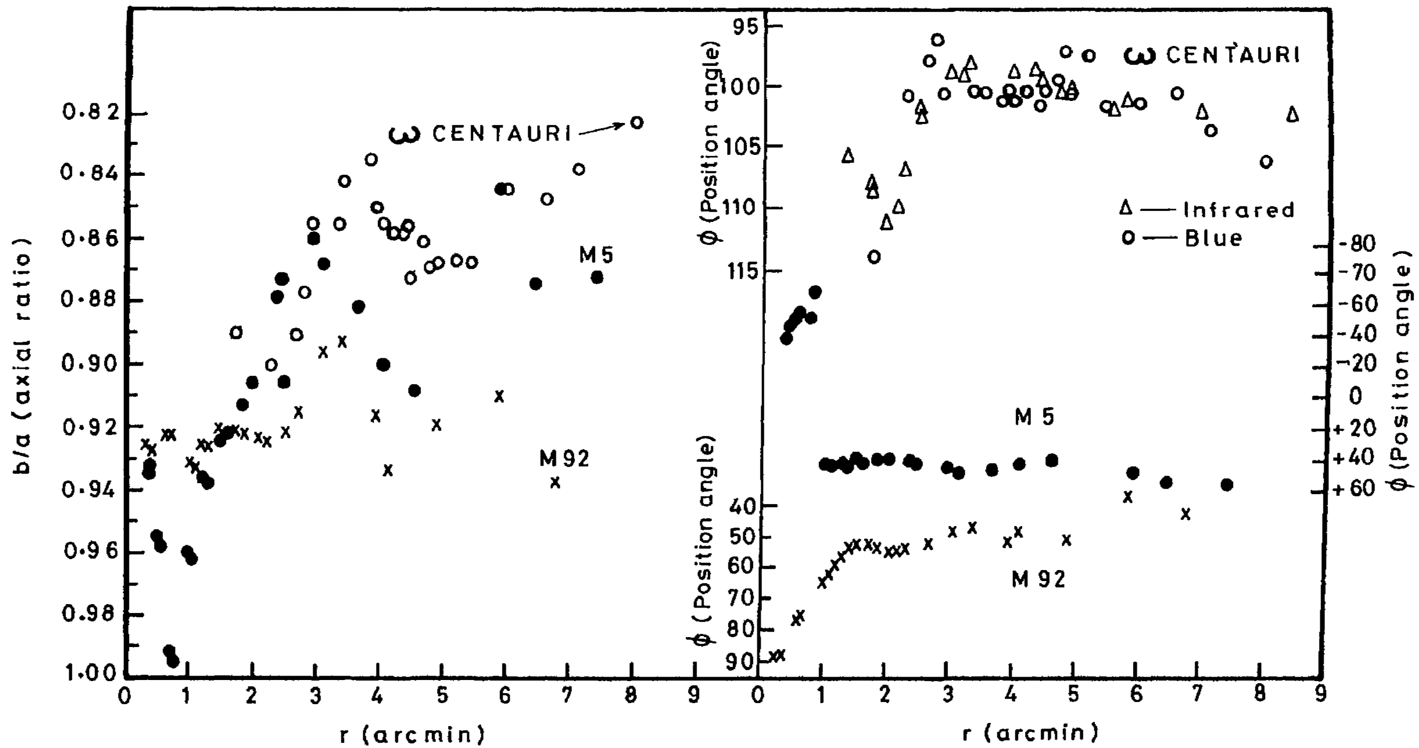



Figure 5.1 Radial change in ellipticity and position angle of the major axis of the isophote, in the globular clusters ω Centauri, M5 and M92. Data for M5 and M92 are taken from Kadla et al. (1976).

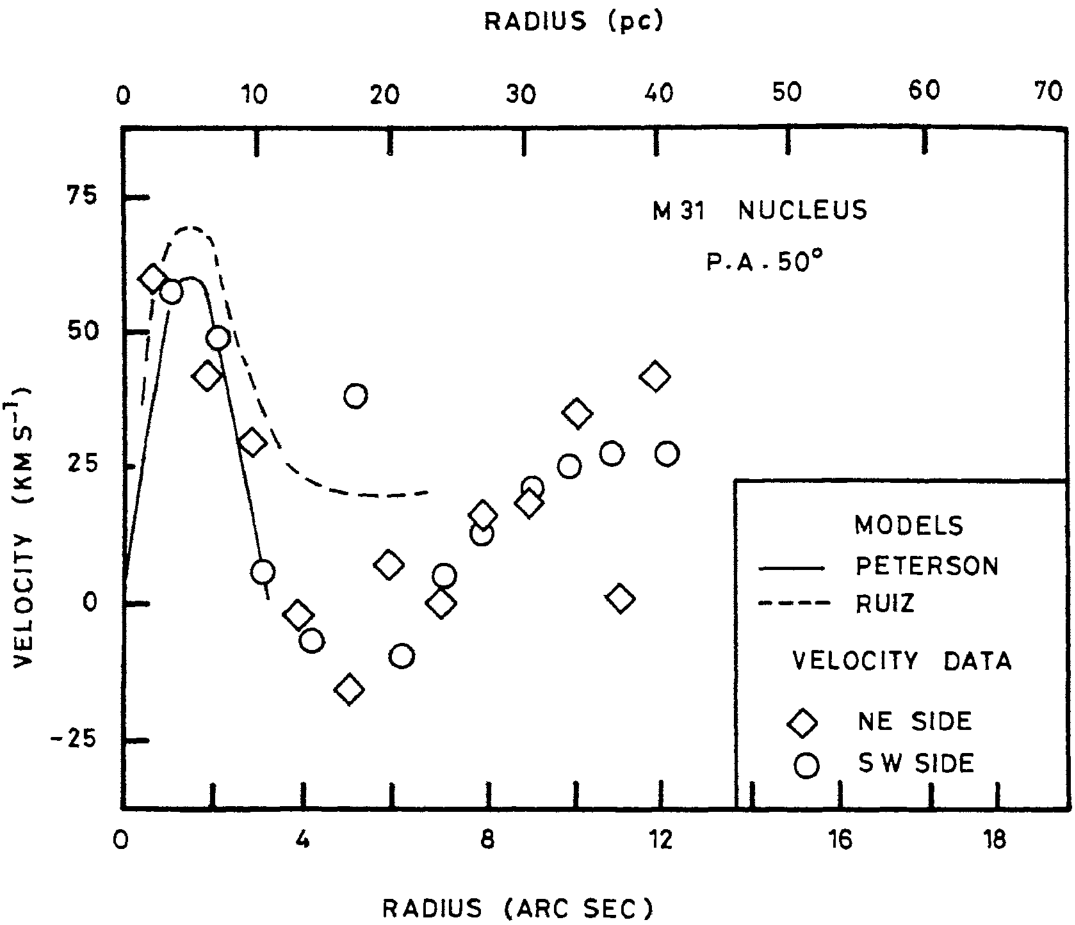


Figure 6.1 Rotation curve for the nucleus of M31 taken from Peterson (1978).

then the BHB stars in the intermediate region in $\omega$ Centauri (between $2'$ and $4'$) should show larger velocity dispersion than stars seen elsewhere in the cluster. Modern methods in measuring radial velocities of stars should be able to solve this problem.

REFERENCES


Chun, M.S., and Freeman, K.C. 1979, Ap.J., *277*, 93.

Dickens, R.J., and Woolley, R.Vd. R. 1967, R.O.B., No. 128.

Gascoigne, S.C.B., and Burr, E.J. 1956, M.N.R.A.S. *116*, 570.

Geyer, E.H. 1967, Z. Astrophys., *66*, 16.

Harding, G.A. 1965, R.O.B., No. 99.

Kadla, Z.I., Richter, N., Strugatskaya, A.A. and Hogner, W. 1976, Sov. Astron., 20, 49.

King, I.R. 1962, A.J., *67*, 471.

King, I.R. 1980, "Globular Clusters" Ed. D. Hanes and B. Medore, p. 113.

Martin, W. Chr. 1938, Ann. Sterrew. Leiden, XVII, Part 2.

Peterson, C.J. 1978, Ap.J., *221*, 80.

Scaria, K.K. 1980 Kodaikanal Observatory Bullettin (in press).

Scaria, K.K., and Bappu, M.K.V. 1981 Journal of Astrophysics and Astronomy (in press).

Strauss, F.M. 1978, Astron, Astrophys. Suppl., *33*, 315.