# COLOR AND POPULATION GRADIENTS IN GLOBULAR CLUSTERS

S. DJORGOVSKI
Palomar Observatory, MS 105–24, Caltech, Pasadena, CA 91125

G. PIOTTO
Dipartimento di Astronomia, Universitá di Padova, Italy, and ESO

G. MALLEN-ORNELAS
Palomar Observatory, MS 105–24, Caltech, Pasadena, CA 91125

ABSTRACT We present preliminary results from a survey for color and population gradients in globular cluster cores. Color gradients, in the sense of becoming bluer inwards, are always found in post-core-collapse clusters. They seem to be caused by the demise of red giants, and possibly an increased number of blue stragglers. This may be a consequence of stellar interactions during and after the core collapse. No gradients are seen in clusters with King-model morphology.

We present preliminary results from our survey of color and population gradients in globular cluster cores. The motivation for this survey was the discovery of prominent color gradients in some high-concentration globulars. Piotto *et al.* (1988) in their study of M30, using direct surface photometry and digital star counts, identified as the cause of the color gradients the differences in radial distributions of red giant and subgiant branch stars (RGB) and blue horizontal branch stars (BHB). Using a different technique, analysis of color pixel histograms, on their images of M15, Bailyn *et al.* (1989; and this volume) argued that the color gradients are due to a heretofore unidentified population of faint blue objects. Further studies by Djorgovski *et al.* (1988) demonstrated the existence of gradients in NGC 4147 and NGC 6624, and a suggestion that the gradients occur in post-core-collapse (PCC) clusters, but not in King-model (KM) clusters. The gradients are always in the sense of becoming bluer inwards, which is the opposite from what may be expected from the seeing and crowding effects, and are confirmed in independent data sets and different colors.

The data for our survey are obtained at ESO, Palomar Observatory, CTIO, and LCO, and consist of multicolor CCD images taken in good seeing. In addition, we use two-dimensional spectra from the IUE archives for the clusters with small or collapsed cores. Some examples of the color profiles, from the data obtained at ESO 2.2-m telescope in June 1989, are shown in Figure 1.

As in the previous studies, we find that the PCC clusters (e.g., NGC 6284, 6293, 6397, 6558, 6624, 6626, 7078, 7099, and possibly NGC 4147) show color gradients, and always in the sense of being bluer in the inner regions, and the KM clusters (e.g., NGC 6093, 6864, and 6715) do not. The typical $(B-I)$

gradient amplitudes are ~ 0.1 – 0.3 mag per decade in radius. In the case on NGC 6284, the gradients may be leveling off by the radius of ~ 30 arcsec.

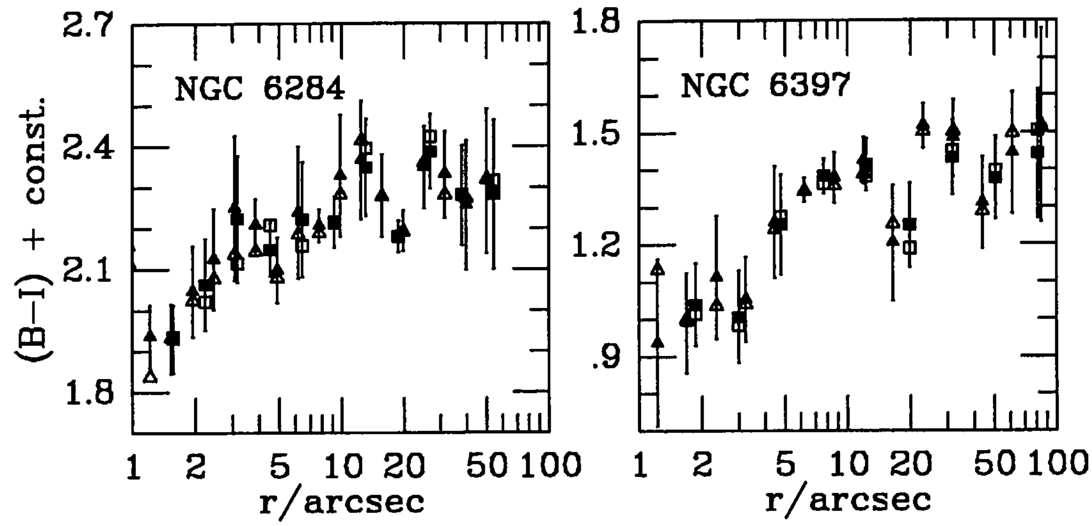


Figure 1 Color gradients in two PCC clusters, NGC 6284 (left), and NGC 6397 (right), derived from the data obtained at ESO. The error-bars indicate errors due to the random distribution of stars, and the sky subtraction. The color zero-points are uncertain by ~ $0.2^m$. Solid symbols correspond to the mean colors, and open symbols to the median colors in annular apertures. Squares and triangles correspond to different radial samplings of the same CCD frames. The description of the methodology used is given in Piotto *et al.* (1988).

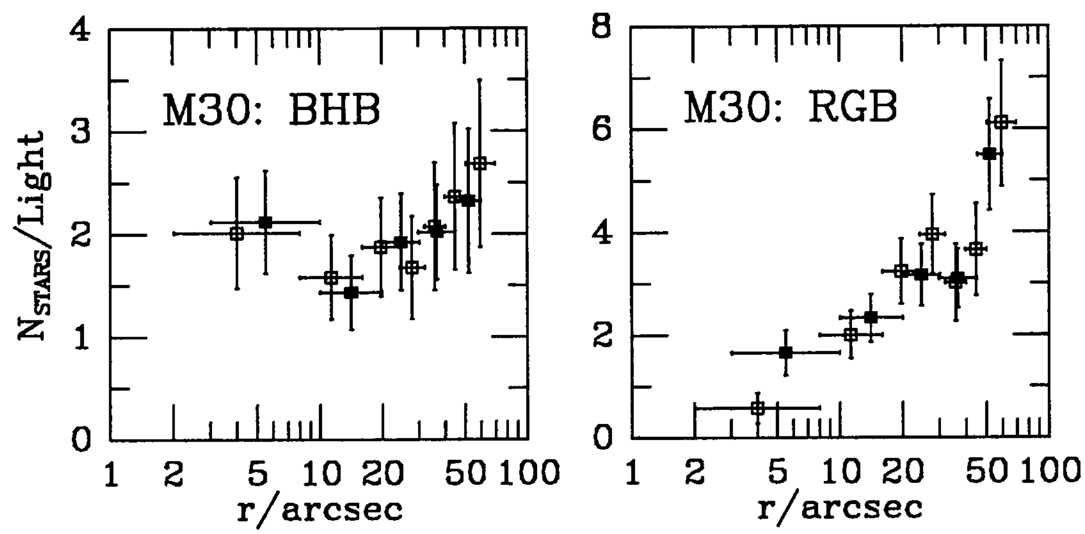


Figure 2 Star counts in M30 (NGC 7099), normalized by the underlying *V*-band light from unresolved stars (after the subtraction of RGB and BHB stars in Daophot): horizontal branch stars (BHB; left) and red giants and subgiants (RGB; right). The vertical error-bars are Poissonian, and the horizontal error-bars indicate the radial bin widths. Note the strong depression of RGB stars towards the center.

Piotto *et al.* (1988) and Djorgovski *et al.* (1988) have shown that the gradients in M30 can be attributed largely or entirely to the differences in distributions of bright stars, BHB and RGB. The CMD for M30 from Piotto *et al.* indicates that there is no excess of bright blue stars near the center of M30, but rather that there is a deficiency of red giants! To check this interpretation, we normalized the star counts (BHB and RGB) in several annuli by the underlying light (both the total surface brightness, and the surface brightness due only to the unresolved stellar component), in three bands. An example is shown in Figure 2. Whereas the normalized star counts for the BHB stars remain nearly constant, or are just slightly depressed towards the center, the normalized counts for the RGB stars show strong radial gradients.

The preliminary analysis of data for other PCC clusters supports this conclusion: in some cases bright red giants are noticeably depressed towards the center, in others the subgiants are depressed, and in some clusters both. The ratios of BHB/RGB star counts in PCC clusters generally increase towards the centers. The detection of an apparent excess of blue stragglers in the core of NGC 6397 by Aurierere *et al.* (1990), which we confirm with independent data, may also be related to this phenomenon. We also detect blue stragglers near the center of NGC 4147, and possibly near the center of M30 as well.

We thus tentatively conclude that the color gradients are largely caused by the depletion of red giants and/or subgiants near centers of PCC clusters, possibly accompanied by the production of blue stragglers. We cannot yet exclude a contribution from an additional faint blue population, e.g., as proposed by Bailyn *et al.* for M15; in fact, we may be seeing such population in our data on NGC 6397. Analysis of the IUE data, now in progress, may be able to clarify this issue (cf. also Dupree *et al.* 1979).

The phenomenon of color gradients must be somehow generic to the collapsed cores. The actual physical mechanism is unclear at this point. It can work either by stripping the envelopes of RGB stars (e.g., in binaries), or by preventing the RGB progenitors of ever ascending the red giant branch. A theoretical study of the phenomenon is now in progress, in collaboration with D. Chernoff and S. Phinney. The process may be important for the formation of binary and millisecond pulsars in globular clusters. This is perhaps the first time that an internal dynamical evolution process is being implicated in modifying substantially the stellar population in globular clusters.

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