DYNAMICS OF NGC 188

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ABSTRACT. Radial velocities have been obtained of 48 stars (33 member giants) in NGC 188 to investigate the internal dynamics. The velocity dispersion drops from the center outward, but the observed central dispersion is undoubtedly inflated by undetected binaries. The binaries concentrate toward the center, but models of the binary population show that corrections for their effect on the dispersion of any small sample are uncertain. The dispersion in the outer ring indicates a cluster mass in agreement with the mass of visible stars.

1. INTRODUCTION

Radial velocity spectrometers have been used recently in several studies of the dynamics of globular clusters. The dynamics of open clusters can be studied in the same way, but only with more difficulty. The observations of the velocity dispersion of open clusters must be made more accurately, because the dispersions are smaller than in globulars, and the analysis is complicated by the presence of binary stars in open clusters. Nevertheless, present instruments do achieve the required accuracy, allowing study of the internal motions of open clusters and measurement of their masses. More distant clusters can be studied with velocities than can be done with proper motions. Mathieu (1984) has discussed internal motions in M11, M67, and NGC 2506. Here we discuss the very old cluster NGC 188. The details of this work will be published separately.

2. OBSERVATIONS

The velocities have been observed with the DAO radial velocity spectrometer. The properties of the instrument and the observing procedures have been described elsewhere (Fletcher et al. 1982; McClure 1985). Approximately 300 observations have been obtained over four years of 48 stars, with a typical accuracy of 0.6 km s^{-1}. A summary of the results is given in Table I. The velocity dispersion in the table for each ring is that dispersion necessary, when

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combined with the estimated errors in the velocities for each star, to reproduce the observed dispersion. Binaries and possible binaries have been omitted in calculating the dispersion, except two for which we have determined orbits. The limits quoted for the dispersion are 90% confidence limits.

TABLE I

Observed Velocities in NGC 188

Rings	Radius (arcmin)	Members	Binaries	Possible Binaries	Field Stars	Dispersion	Limits
						(km s^{-1})	
I+II	0-5.6	15	5	4	0	1.16	0.88-1.81
III+IV	5.6-13	9	1	1	1	0.51	0.22-1.06
V	13-20	9	0	1	14	0.20	0.12-0.40

3. DISCUSSION

In order to interpret the observed velocity dispersion, we have fit Michie-King cluster models to star-count data. The simplest, a single-mass, isotropic model (King 1966), is shown in Figure 1. The fit is to the star counts of van den Bergh and Sher (1960) at four different limiting magnitudes. The best fit model has $r_c = 4.67$ and $r_t = 44.4$. It agrees well with all four sets of counts, indicating that there is no strong mass segregation amoung the stars covered by the counts (0.55 to 1.2 $M_\odot$).

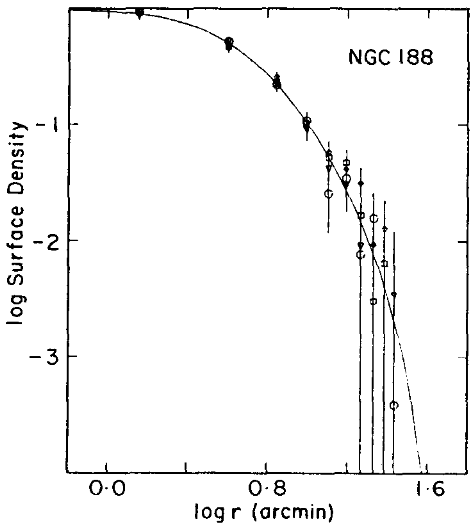

Fig. 1. Surface density

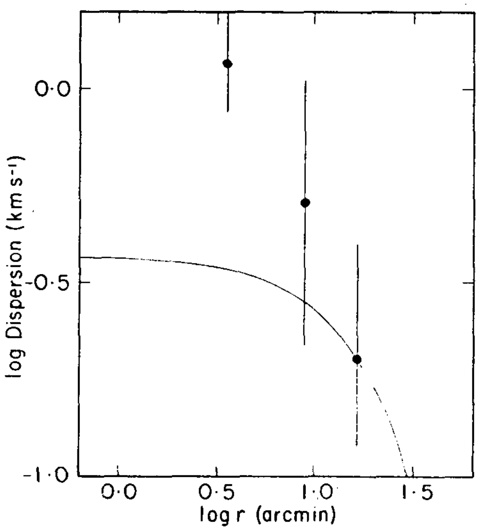

Fig. 2. Velocity dispersion

The observed velocity dispersion is shown in Figure 2 together with the model dispersion fit to the outermost data point. The mass implied by this fit is 650 $M_{\odot}$, with an allowed range of 230 to 2600 $M_{\odot}$ (90% confidence level). This mass is consistent with the mass seen in visible stars (about 900 $M_{\odot}$) and permits some additional mass in white dwarfs and low-mass red dwarfs. The two inner points are obviously inconsistent with the model dispersion profile, however, implying a higher cluster mass (8200 $M_{\odot}$ if the curve is fit to the inner point). We believe that the inner points are biased toward values higher than the real cluster dispersion by undetected binaries amoung the observed stars, and we discuss this possibility in the following paragraphs. Another possible explanation of the discrepancy in Figure 2 is that isotropic models are not appropriate, and that the velocities are highly anisotropic beyond about 2 core radii. We have generated anisotropic models which come closer to matching the observations, but they require a transition radius near 1 r_c (beyond which anisotropy becomes important). This is perhaps unlikely, because the relaxation time of the cluster (~10^8 years) is much less than the cluster age, allowing establishment of isotropic velocities to several core radii.

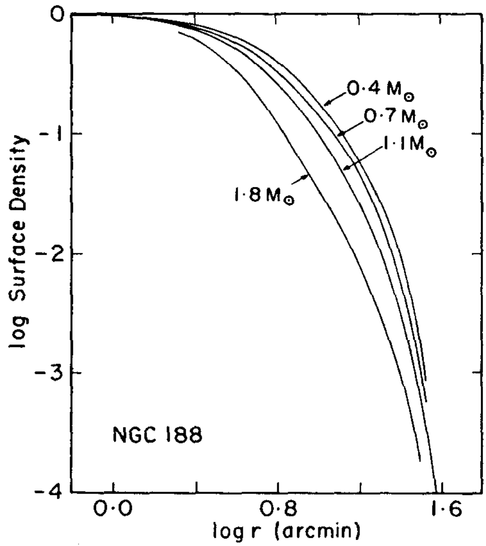

Fig. 3. Surface density from multi-mass models.

The extent of dynamical relaxation of the more massive binaries toward the cluster center can be assessed using a multi-mass Michie-King model. We have constructed such a model using four mass classes (1.8, 1.1, 0.7, and 0.4 $M_\odot$). Using a stellar mix matching the luminosity function of van den Bergh and Sher (1960) and the mass-luminosity relation from VandenBerg (1983) for the lower three mass classes, we then shifted one quarter of the stars into the next higher mass class, assuming that roughly this fraction of stars has a companion of comparable mass (Abt 1979). In Figure 3 the projected surface densities of each class are shown. The second and third mass classes correspond to the range of masses counted by van den Bergh and Sher, but they show only slight segregation, in agreement with the counts. The most massive class includes only binaries from the next lower class, and it shows noticable segregation toward the cluster center. While only 9% of all cluster stars are in this class, 43% of stars in the core are these massive binaries. Of the turnoff stars projected on the core, the model predicts that the fraction in the first mass class with relatively massive companions is enhanced to 41%. In contrast, amoung the turnoff stars projected on Ring V, this fraction should be reduced to 15%.

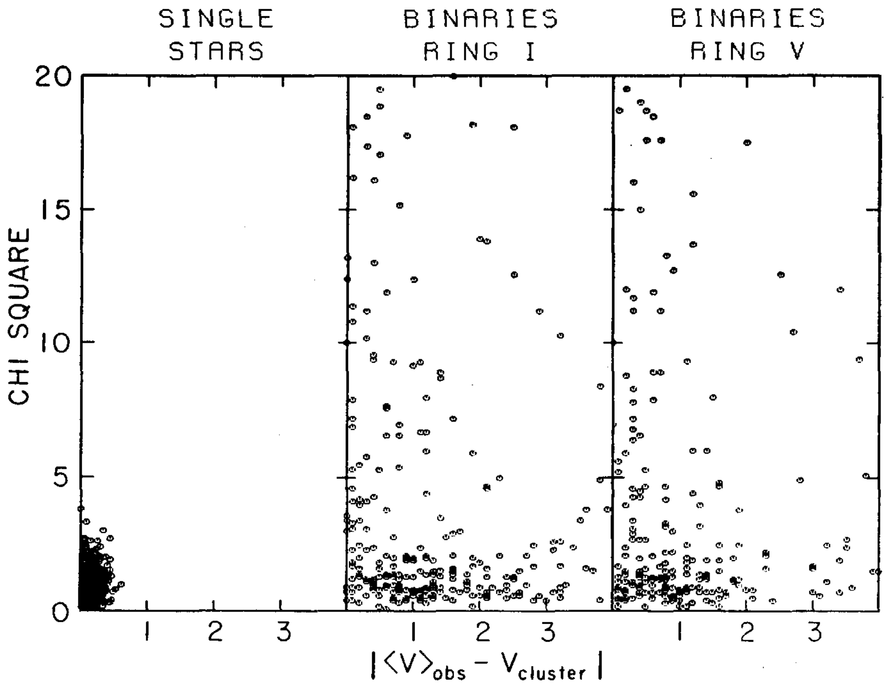

Fig. 4. Model observations of single and binary stars.

In order to correct the observed dispersion for undetected binaries, models of the binary population in each ring have been constructed following the procedure described by Harris and McClure (1983) for field and globular cluster giants, modified by the dynamical segregation discussed in the previous paragraph. The effects of the binaries on the observed central dispersion are not only important, but also (in a small sample of stars) unpredictable. Figure 4 illustrates their effect using parameters typical for our observations. One third to one half of the binaries show variability (chi square larger than 4) when observed over three years, and can be removed from the sample. However, the remainder of long-period or low-amplitude binaries have observed velocities distributed well away from the cluster velocity, and they seriously bias the observed dispersion. At present we have been unable to make corrections with enough confidence to be useful. Further experiments with other statistical approaches, such as the inter-quartile-range suggested by Mathieu (1983), are being done and will be described separately.

The enhancement of the density of binaries in the center of the model cluster agrees with the higher fraction of binaries detected amoung the observed giants in Rings I and II. Support for the model also comes from the presence of four W UMa stars near the center (Rings I-III) and of star I-1 (probably a recently coalesced binary that will be discussed in a separate paper) in Ring I. It is not clear if the blue-stragglers are more centrally concentrated than the turnoff stars, as would be expected if they are more massive.

McClure and Twarog (1977) showed that the giants brighter than V = 13.5 were less centrally concentrated than the turnoff stars, and argued that they had lost significant mass and relaxed away from the cluster center. From Figure 3, the segregation of even low mass stars is small enough that this explanation appears unlikely. Instead, we may be seeing a deficiency of giants in the core, rather than an excess in the outer parts, caused by their evolution and probable coalescence with close companions.

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DISCUSSION

ABT: Is your concentration of binaries to the cluster center consistent with calculations similar to those by Spitzer and Mathieu?
HARRIS: Yes. The age of the cluster is much greater than the relaxation time, and the binaries are concentrated (with 3/4 in the inner rings) in agreement with the multi-mass cluster model.
MATHIEU: Latham and I have been observing a magnitude limited sample of roughly 100 main sequence stars in M 67. We find the spectroscopic binaries to be quite centrally concentrated relative to the "single" stars, exactly as Harris' models suggest should be the case. Indeed, their spatial distribution is well described by a 2 $M_\odot$ component in thermal equilibrium. Interestingly, the binary spatial distribution is essentially identical to that of the blue stragglers.
JANES: How does the spatial distribution of the red giants compare with the distributions of some of the other groups?
HARRIS: They appear to be more widely distributed as McClure and Twarog suggested. Our membership results support this and we discuss it in the text.