THE DYNAMICS OF 47 TUCANAE

G. S. Da Costa
Yale University Observatory
Box 6666, New Haven, CT 06511

K. C. Freeman
Mt. Stromlo and Siding Spring Observatory
Private Bag, P.O. Woden, ACT 2606
Australia

Observations made at Las Campanas Observatory and at the Anglo-Australian Observatory have been used to determine line-of-sight velocities with an average accuracy of 3 kms^{-1} for 135 member stars in the globular cluster 47 Tucanae. The velocities were derived from cross-correlation techniques applied to 30 A/mm spectra obtained with digital sky-subtracting detectors. The spectra themselves have been used to analyze the cyanogen anomalies on the red giant branch in this cluster (Norris et al., 1984). When combined with the velocities published by the CORAVEL group (Mayor et al., 1983), these observations yield velocities for 212 stars with projected distances from the cluster center ranging from 3 to 68 core radii. After radial binning and analysis these observations yield the following results:

(i) The inner parts of the cluster show appreciable differential rotation with a maximum projected rotation velocity of approximately 6 kms^{-1} in the region 6 - 18 core radii. However, at larger radii the rotation declines rapidly and is essentially zero for radii greater than 30 core radii. This result is illustrated in Figure 1. To within the errors of the determinations, the position angle of the maximum rotation and that of the major axis of the stellar density distribution coincide.

(ii) In contrast to M3 (Gunn and Griffin 1979), "thermal equilibrium" multimass models (c.f. Da Costa and Freeman 1976) can ONLY reproduce the observed velocity dispersion values by including a substantial amount of "dark matter"; i.e. unlike M3, there is "missing mass" in 47 Tuc. In order to retain a fit to the surface brightness profile of the cluster, this "dark mass" (which provides perhaps 30 to 40 percent of the total cluster mass) cannot have a distribution much different from that of the cluster giants if it is in the form of stars and "thermal equilibrium" is maintained. In this case the obvious candidates for the dark matter are the white dwarf remnants of the stars more massive than the current turnoff mass, though many more such remnants are required than the number expected from extrapolating the present mass function. The difference between M3 and 47 Tuc in this case then

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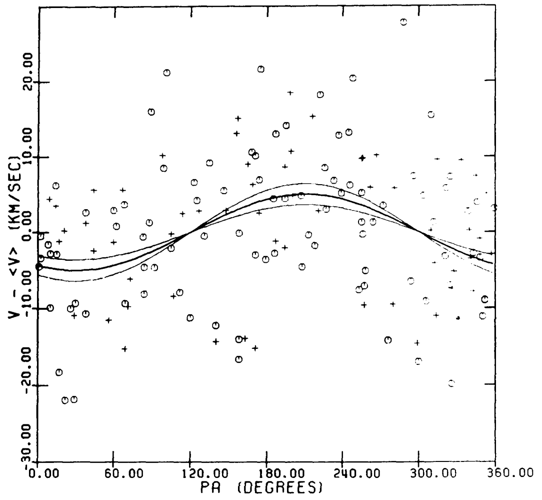

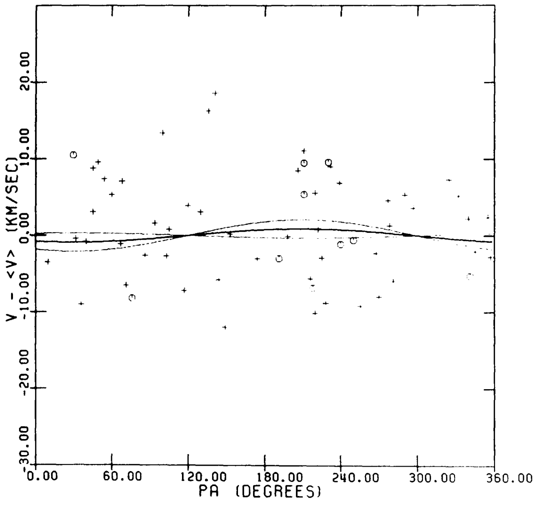

Figure 1. In the upper panel velocity difference (observed-mean for the entire sample) is plotted against position angle (increasing from North to East) for stars in the inner 5 radial bins (3 to 25 core radii). Open circles represent stars observed by the CORAVEL group including the stars in common with the LCO/AAO observations. The velocity error for these stars is approximately 1 kms^{-1}. Plus signs represent stars observed at Las Campanas or at the AAO (or both) only. These stars have errors of approximately 3 kms^{-1}. The thick line is the fitted curve v - < v > = A cos(PA - PA$_o$) with A = -5.0 kms^{-1} and PA$_o$ = 30°. The thin lines are ±1σ (1.4 kms^{-1}) for A with PA$_o$ fixed. The ±1σ uncertainty in PA$_o$ is ± 15°. The lower panel is a similar plot but for the outer 2 radial bins (25 to 65 core radii). For these stars A = -0.9 ± 1.2 kms^{-1} at PA$_o$ = 30°.

implies that the 47 Tuc initial mass function had many more massive stars than did that for M3. The work of Freeman (1977), who demonstrated large IMF variations in the 8 - 1.5 solar mass range in young Magellanic Cloud clusters, provides observational support for this interpretation.

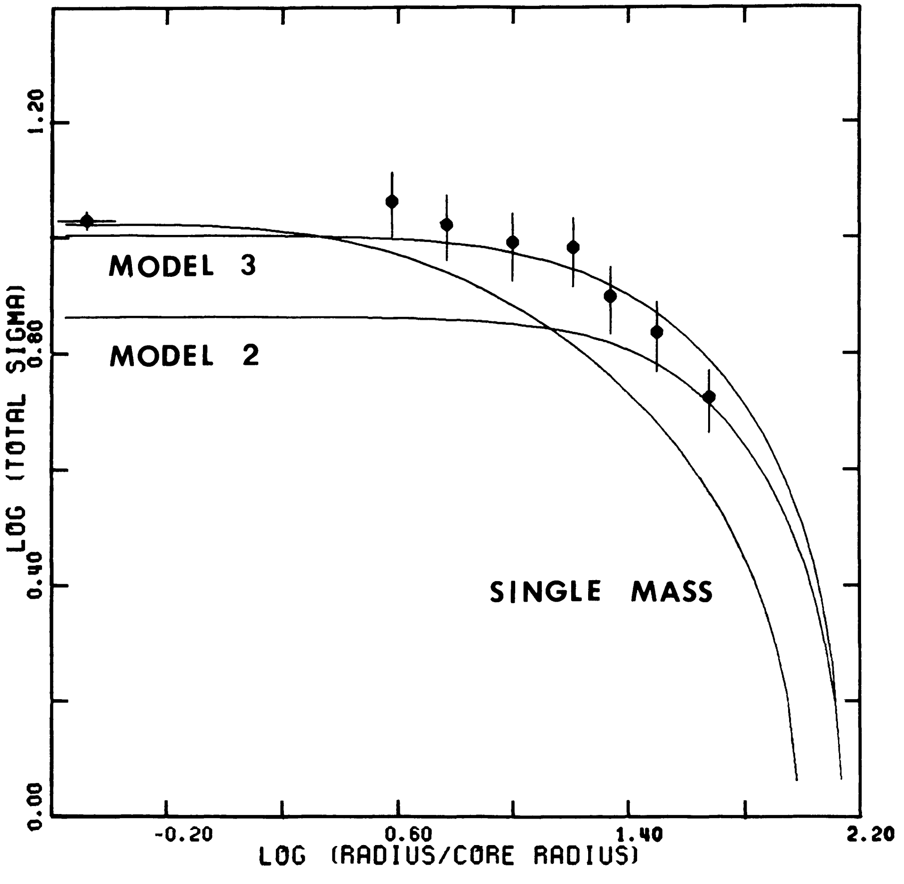

Figure 2. The logarithm of the total line-of-sight velocity dispersion (i.e. no correction for the rotation) is plotted against the logarithm of the radius in units of the core radius. The error bars are $\pm 1\sigma$ errors that result principally from the finite number (typically 30) of stars in each radial bin. With the exception of the curve labeled "single mass", the model curves are multi-mass isotropic King models from Da Costa (1977); a description of their properties is given in the text. The "single mass" curve is the dispersion predicted by the single mass isotropic King (1966) model which fits best the surface brightness profile of the cluster, scaled to fit the observed central velocity dispersion (Illingworth 1976). Note that this model has a smaller limiting radius than the multi-mass models which give superior fits to the surface brightness profile.

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The requirement for additional mass in 47 Tuc is illustrated graphically in Fig. 2 where the model velocity dispersion profiles are compared with the observations. Model 2 is the model which fits best the surface brightness and star count data for the cluster (Da Costa 1979, 1982). The number of remnant stars in the model was set by assuming that the stars more massive than the current turnoff mass followed a Salpeter initial luminosity function and that all such stars have produced a remnant that remains within the cluster. The model M/L_V is 2.6 and the remnants contribute 9% of the total cluster mass. In these respects the model is similar to those of Gunn and Griffin (1979) for M3. However, as is obvious from Fig. 2, this model fails completely to reproduce the observed line-of-sight velocity dispersion measurements.

For model 3, the number of white dwarf remnants was increased until the model central velocity dispersion agreed with the observed value. For this model the number of remnants is approximately 7 times the number for model 2 and these stars make up 35% of the total cluster mass. The model M/L_V is 4.0 and it provides acceptable fits to both the star count and surface brightness data. Illingworth and King (1977) have reached similar conclusions from similar models fitted only to the surface brightness profile and the central velocity dispersion.

The difference between M3 and 47 Tuc can also be seen in a consideration of their central M/L_V values. These can be calculated directly from the observed central surface brightness, core radius and central velocity dispersion with little dependence on model parameters. For M3 using the data of Gunn and Griffin (1979), $(M/L_V)_o = 0.7 \pm 0.1$ but for 47 Tuc the value is almost a factor of two higher; $(M/L_V)_o = 1.3 \pm 0.1$.

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