MULTI-COMPONENT MODELS FOR THE STRUCTURE AND EVOLUTION OF SPHERICAL STELLAR SYSTEMS

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ABSTRACT. We present stationary analytical models for the structure of spherical stellar systems with several mass components. Evolution is simulated by increasing the central velocity of escape. We compare our models to the results of numerical simulations. An observable kinematical effect of mass segregation is pointed out.

1. MULTI-COMPONENT ANALYTICAL MODELS

This paper is an investigation of the structure and evolution of spherical stellar systems with components of different masses. One expects mass segregation to occur in these systems. In the course of evolution, the more massive stars (or galaxies) concentrate toward the center, and the lighter ones form an extended halo. Multi-component dynamical models are then required to interpret their structure and kinematics.

Our models are based on two assumptions. The phase density distribution is a sum of pseudo-maxwellian isotropic distributions. The precise functional form of the distribution has been tested on one-component models (Davoust, 1977; hereafter paper I). Each of the components is in hydrostatic equilibrium, but there is no equipartition of energy between them (not even at the very center). The evolution is simulated by increasing the central velocity of escape, k. The sole limitation of the models, in view of recent observational developments, is that they are not rotating.

The phase density distributions are :

$$f_i = K_i \left[e^{-\frac{m_i(E-E_e)}{\sigma^2}} - 1 + \frac{m_i(E-E_e)}{\sigma^2} \right]$$

where E is the energy, E_e the energy of escape and m_i the masses of individual stars. The space densities and velocity dispersions are derived by straightforward integrations, as in paper I.

J. Goodman and P. Hut (eds.), Dynamics of Star Clusters, 317–319.

The only free parameter of our models is k, the normalized central velocity of escape (see paper I). The central density ratio Cij between components i and j must be adjusted so that the ratio of total mass of components i and j remains constant.

As our models evolve (as k increases), the Cij's increase and the deviations from equipartition between the components, Sij, decrease. The heavier components are closest to equipartition. The deviation is always in the same sense: the heavier component has a larger velocity dispersion than required for equipartition.

The core structure of our 3-component isotropic model with the mass function of Spitzer and Shull (1975) is given in the table below for different values of k. In the lower part of the table, we give the same parameters derived from the results of Spitzer and Shull's (1975) numerical simulations. The main features of the evolution of the numerical models are well reproduced in the isotropic model. This validates our two basic assumptions. One discrepancy, the fact that the mass ratios Mij in the core (containing 4% of the total mass of the system) decrease after a maximum in our isotropic 3-component model, is weakened by the fact that the corresponding Cij's do increase mmonotonically. This discrepancy is due to the fact that the halo density of the isotropic model falls off more rapidly than in the numerical simulations. This affects the total mass and in turn the core radius.

k	C21	C31	M21	M31	S21	S31	S32
1.0	.822	.863	.805	.773	2.293	4.186	1.825
1.4	.959	1.765	.923	1.435	2.181	3.338	1.531
1.8	1.230	5.145	1.142	3.473	2.055	2.715	1.321
2.2	1.838	39.70	1.430	11.82	1.924	2.286	1.188
2.6	2.640	265.	1.307	10.43	1.793	1.986	1.108
3.0	3.890	1545.	1.253	8.05	1.669	1.770	1.060
t			**M21**	**M31**	**S21**	**S31**	**S32**
260			1.069	1.143	1.826	3.519	1.928
860			1.407	3.479	2.061	2.646	1.284
1460			1.686	10.43	2.077	2.448	1.179
1860			2.135	32.68	1.422	1.769	1.243

2. KINEMATICAL EFFECTS OF MASS SEGREGATION

The velocity dispersion decreases monotonically with increasing distance in one-component globular cluster models. This is not the case in multi-component models with important mass segregation (Kondrat'ev and Ozernoy, 1981).

We have determined the radial profile of the total velocity dispersion in our 3-component isotropic model and in the 3-component Monte-Carlo models of Spitzer and Shull (1975) and the 4-component ones of Hénon (1975). The results are very similar. At the beginning of the evolution the profiles are monotonously decreasing. As evolution proceeds, the total velocity dispersion goes through a maximum, at a radius containing about 10% of the total mass in our and Hénon's (1975) models, and 12 to 20% in Spitzer and Shull's (1975) model. In this region, the velocity distribution is still isotropic in the numerical simulations, and justifies using our isotropic model.

While the three models show distinctive features, the maximum in the central region is always present at later evolution times. It should be indicative of mass segregation in stellar systems with flat central density, such as globular clusters and clusters of galaxies, but not in systems with sharply peaked mass concentration, such as elliptical galaxies or systems of globular clusters, where it may be the result of strong velocity anisotropy (Bailey and MacDonald, 1981).

This maximum should be observable in globular clusters of our Galaxy, provided the luminosity of the stars scales with their mass, i.e. that there is no large population of heavy remnants, such as white dwarfs and/or neutron stars. The radius at which the hump occurs depends on the concentration and the total mass of the cluster, but it is comparable to, if not larger than, the core radius of the cluster. This radius is about 6 arc sec. in the worst case, and several arc min. in the most favorable ones. The maximum is only 1 or 2 kms^{-1} above the central value and might be difficult to detect with present techniques.

Finally, this feature is present in the Coma (Kent and Gunn, 1982) and Perseus (Kent and Sargent, 1983) clusters of galaxies and reveals mass segregation in these clusters.

A more detailed version of the paper is available from the author.

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