A FLUID-DYNAMICAL METHOD FOR COMPUTING THE EVOLUTION OF STAR CLUSTERS

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One way that can be used to study the development of a stellar system is the fluid-dynamical approach, whereby the stars are considered as the constituent particles of a continuous fluid whose behavior is described by moment equations derived from the Boltzmann equation. This method is most useful for systems with very many stars, where it complements the *n*-body technique which is feasible only for small systems. The fluid-dynamical approach begins by defining suitable moments of the velocity distribution at each point in space. In studying the evolution of a star cluster it is necessary to consider moments of at least fourth order in the velocities in order to represent all the essential physical effects, including an outward 'heat flow' caused by the escape of the most energetic stars, and an excess or deficiency of high velocity stars relative to a Maxwellian distribution. Allowing for unequal radial and transverse velocity dispersions, we find that six moments in all are required, for which six fluid-dynamical equations may be derived by taking the corresponding moments of the Boltzmann equation. The fluid-dynamical equations contain relaxation terms which may be evaluated from the Fokker-Planck equation, assuming that deviations from a Maxwellian velocity distribution are small. In the absence of other effects, the relaxation terms have the effect of making the various deviations from a Maxwellian velocity distribution decay exponentially with decay times which are closely related to the classical relaxation time. The resulting fluid-dynamical equations can then be solved numerically to yield the values of all quantities as functions of position and time.

This method has been used to compute in detail the evolution of several types of stellar systems, including (1) a globular cluster of mass $2\times10^5\ M_\odot$, (2) a galactic cluster of mass 100 $M_\odot$, and (3) a dense galactic nucleus of mass $10^8\ M_\odot$. The effect of a tidal boundary has been simulated in each case by assuming that the system is bounded in space by a perfectly absorbing wall. In each case the results show the qualitative type of behavior predicted by classical relaxation theory – a steadily increasing central concentration, a decreasing total mass, and an increasing anisotropy of the velocity distribution in the outer part of the system. Also, the time scales agree in a rough mean sense with those predicted classically, but are found to be quite sensitive to changes in the structure of the system. As the central part of the system relaxes toward a more nearly isothermal structure, the evolution time slows down relative to the relaxation time, although it continues to speed up in absolute terms. Differences in the way that

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different systems evolve indicate that the ratio of relaxation time to dynamical time is an important parameter for the evolution of stellar systems. Finally, the results show clearly that the rate of mass loss, particularly for small systems, is strongly affected by the existence of a tidal boundary.

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