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Physics of collisional self-gravitating many-body systems

Junichiro Makino[1]

[1] Department of Astronomy, University of Tokyo

Many of self-gravitating particle systems in the universe are collisional systems, whose evolution is driven by two-body relaxation. One example is the central regions of galaxies. The half-mass relaxation time of a typical galaxy is much longer than the age of the Universe(Hubble time), and it can be regarded as a collisionless system. However, the relaxation time of, e.g., the innermost tens of parsecs is shorter than the Hubble time, and thermal evolution through two-body relaxation plays a fundamental role in the evolution of central stellar systems of galaxies. For smaller systems such as globular and open clusters or young and compact clusters, the relaxation time is much shorter than the Hubble time. For the clusters of galaxies, relaxation is important, since, when we regards galaxies as particles, the relaxation time of clusters of galaxies is generally short.

From theoretical point of view, self-gravitating collisional systems are of great interest because of its unique nature. Though the evolution is driven by thermal relaxation, it has no true thermal equilibrium. Moreover, the assumption of local thermal equilibrium cannot be applied, since the mean free path of particles is much larger than the system size. Thus, even for the simplest system composed of point-mass particles of equal mass, the evolution is rather complex. Roughly speaking, if there is an spherical self-gravitating system, it has temperature gradient which drops outward, since otherwise it cannot have a finite mass. In this case, however, heat flows outward in thermal timescale. In the case of thermally stable system, this heat flux reduce the temperature gradient. However, self-gravitating system is thermally unstable, and temperature gradient increases. In the case of a simplified model with continuous approximation, the density and temperature at the center of the system diverges in a finite time. In real systems with finite number of stars, binary stars will be formed when the central density becomes high enough, and the energy generated from binary will balance the heat flux. Thus, we can define a steady state solution. This steady state, however, turned out to be thermally unstable, and the central density exhibits nonlinear oscillations of large amplitude.

This strongly nonlinear behavior results in unusual events such as tidal interaction, collision, and merger of stars, in the central regions of of star clusters or galaxies, and these events may be related to the fact that exotic stars such as millisecond pulsars or X-ray binaries are overabundant in globular clusters. Also, formation and growth of massive black holes is probably strongly coupled to the thermal evolution of stellar systems.

Collisional evolution thus plays an important role in many astrophysical systems. The study of collisional evolution, however, is fundamentally difficult due to its nonlinear and nonequilibrium nature, and in many cases numerical experiments are essential to get insights. In particular, the direct N-body simulation has proved itself useful. The increase of the computing power, partly through the advent of special-purpose GRAPE systems, has helped in this aspect.

In the talk, I'll overview the basic aspects of collisional systems and some recent topics.