THE ENERGY EXCHANGE BETWEEN DIFFERENT MASSES IN AN EXPANDING GRAVITATING SYSTEM

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Abstract

We investigate whether or not the energy exchange occurs between two species groups of particles in an expanding two-component gravitating system, and we derive the relaxation time scale for energy exchange in such a phase. This is accomplished by solving the dynamic equation coupled with Poisson's equation. We derive a characteristic time determined by the various mass and velocity ratios. When the expansion time does not exceed the characteristic time, energy exchange between the two components is possible and depends on the mass ratio. Once the characteristic time is exceeded, there is virtually no relaxation at all in system. When $m_2 \gg m_1$, the transfer of energy becomes inefficient. Therefore, energy exchange between two species of particle in an expanding two-component gravitating system depends not only on the mass ratio but also on the expansion time.

1. Equipartition time in an expanding System

In this section, we will derive the collision integral for gravitating particles in an expanding system, and solve the evolution equation for the distribution function. In this case, the density of particle in the system decreases as a function of time t. This is a main difference in comparison to all preceding discussions. In accordance with the usual convention(Spitzer 1969; Binney and Tremaine 1987), we suppose $m_2 > m_1$.

In discussing a non-rotating and spherically symmetric gravitating system composed of two species of particles, the distribution function cannot be described by the multiplication of two single particle distributions or

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by the simple algebraic addition used by Merriti (1981). It is necessary, at least, to consider the two-body correlation function $g(1,2)$(Sugimoto 1985),

$$f(1,2) = f_1 f_2 + g(1,2), \tag{1}$$

here f_1 and f_2 are the single particle distribution functions for two species of particles with masses m_1 and m_2 respectively. We also suppose that the particles with the mass m_1 and particles with the mass m_2 both have Maxwellian velocity distributions, but with different kinetic temperatures Θ_1 and Θ_2. We obtain a analytical solution:

$$\tau_{12} = \frac{9\pi^{1/2}(< v_1^2 > + < v_2^2 >)^{3/2}}{2^{1/2}G(m_1 + m_2)\Lambda_{12}} t^2, \tag{2}$$

$< v^2 >$ is the mean square velocity dispersion of the particles. This formula expresses the equipartition time between two species of particles in an expanding gravitating system. It also illustrates the evolution of the time scale of energy exchange between the different masses with the decreasing density of the particles. τ_{12} is a function of the expansion timescale t.

2. The Energy Exchange

In the present section, we discuss the condition for energy exchange in an expanding, two-component gravitating system. During the process of collision, the change in the momentum $\Delta\mathbf{p}$ in terms of the angle θ is

$$\Delta\mathbf{p} = -m_{12}(1 - cos\theta)(\mathbf{v}_1 - \mathbf{v}_2), \tag{3}$$

here m_{12} is the reduced mass. If $m_1 \ll m_2$, the momentum may reverse its sign, $|\Delta\mathbf{p}/\mathbf{p}|_{max} = 2$. Then we have the relation $\mathbf{v}_1^{'} = -\mathbf{v}_1 + 2\mathbf{v}_2$. In this case the energy exchange becomes

$$\Delta E = \frac{m_1}{m_2}(\mathbf{v}_1 - \mathbf{v}_2) \cdot \Delta\mathbf{p}, \tag{4}$$

and we can find that the transfer of energy becomes very inefficient when $m_1 \ll m_2$. When the masses are comparable, that is if $m_1 \approx m_2$, then the momentum may be lost completely. The energy exchange becomes $\Delta E \simeq (\mathbf{v}_1 - \mathbf{v}_2) \cdot \Delta\mathbf{p}$, this means that the transfer of energy is efficient.

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