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It is necessary for particle simulation of dense plasmas to calculate precisely the Coulomb interaction among close and distant particles. It is, however, very expensive to calculate forces among all particles. In the particle-particle particle-mesh (PPPM) method originated by Hockney and Eastwood [1], the Coulomb forces among close particles are directly summed up in the P-P method, while the PIC method is employed for the calculation of the forces among distant particles. In the PPPM method, errors of the force calculation arises from the PM method. We have made the following improvements in a three dimensional code "SCOPE (Strongly COupled Plasma particleE code[2]": the introduction of fine meshes for the PM calculation in addition to the coarse-grained PP meshes, the use of the third-order spline function for both the charge assignment and the electric-field interpolation, the use of the forth-order finite-difference scheme for the Poisson equation, and the exclusion of the double-counted electric field.

The SCOPE has been parallelized for both Intel Paragon XP/S (scalar-disributed memory) and NEC SX-4 (vector-shared memory) [3]. Parallelization has been achieved by distributing PP lattice zones into processing elements (PE). A macro task method is introduced for the sheared memory machine (SX-4) with few modifications of the original code, while the nx library supported by Intel is used with considerable changes of the code necessary for the distributed memory machine (Paragon). Scalable speed up has been obtained up to 512 PE of Paragon with the speed up of 360 and 32 CPU of SX with the speed up of 25. 32 CPU of SX is approximately five times as fast as 512 PE of Paragon. Performance of the parallelized codes is also evaluated.

The Lyapunov exponents in a phase space of various plasma states (dilute, liquid and solid states) are measured with the use of SCOPE[4]. Recently, there has been great deal of research devoted to finding relations between the Lyapunov exponent and macroscopic statistical quantities. The Lyapunov exponent is the growth rate of the trajectory instability in phase space, namely a Lyapunov exponent is defined in a long time limit as an exponential expansion rate of a separation distance between two adjacent trajectories in a  $6N$  phase space. In the particle simulations, we consider two independent systems, reference and displaced systems. In the displaced system, initial positions and momenta of the individual particles are displaced from their corresponding values in the reference system. The maximum Lyapunov exponents were observed by using the conventional rescaled method and by taking time average of the instantaneous expansion rates with respect to the displacement.

We have investigated the dependence of the Lyapunov exponent on the Coulomb coupling constant,  $\Gamma = e^2/aT$ , where  $a$  is the particle sphere radius; i.e.,  $4\pi/3 = 1/n$ , and  $e$ ,  $n$  and  $T$  represent charge of a particle, number density and temperature in energy units. In the case of  $\Gamma \ll 1$ , a plasma can be regarded as a dilute plasma, while a plasma with  $\Gamma > 1$  is regarded as a strongly coupled plasma. It is found that the Lyapunov exponent normalized by the plasma frequency is independent of  $\Gamma$  for  $\Gamma < 0.05$ , proportional to  $\Gamma^{2/5}$  for  $1 < \Gamma < 150$ , and to  $\Gamma^{-6/5}$  for  $\Gamma > 170$ . These states correspond to the dilute gas, dense liquid and solid plasmas, respectively. The large jump of the Lyapunov exponent is also observed at  $\Gamma \approx 170$  corresponding to the phase transition from liquid to solid state. In short range force systems, the Lyapunov exponent is believed to be proportional to the collision frequency [5]. However it is shown that the Lyapunov exponent is found to be of the same order as the plasma frequency for  $\Gamma < 0.05$ , which is very large compared with the collision frequency for such dilute plasmas.

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