S001-P18
ポスター３：11/6　AM1/AM2 （9:00-12:30）

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Dynamic Load Balancing for Particle-based Plasma Simulations

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Numerical modeling of collisionless and weakly collisional plasma dynamics is becoming more and more important for a variety of applications in laboratory, space, and astrophysical plasmas. An efficient parallelization strategy is indispensable to fully exploit the advantage of the modern supercomputing capability. Conventional plasma kinetic numerical simulations employ the Particle-In-Cell (PIC) scheme for some of the particle species. In other words, a large number of particles are distributed over the computational domain, whereas the electromagnetic field or some fluid quantities are defined on the mesh. While mesh-based simulations can easily be parallelized using the domain-decomposition approach, the use of computational particles makes it problematic because the inhomogeneity in the particle distribution introduces a significant load imbalance between different processes. The PIC simulations have been used for investigating elementary plasma processes, including magnetic reconnection and collisionless shocks. However, the load imbalance may become a major obstacle for those simulations at the largest scale available with modern supercomputers.

Furthermore, the ever-increasing computational resource is now allowing us to perform kinetic modeling of more complicated problems both in terms of physics as well as initial and boundary conditions. For instance, global modeling of the solar wind interaction with a planetary magnetosphere (or a more general celestial body) involves various different plasma parameters such as composition, collisionality, and ionization rate. Whereas a fluid approximation may be reasonable at high density (or highly collisional) regions close to the planet, the kinetic effect has to be taken into account at least partially for realistic modeling, particularly in dilute regions far from the planet. It may be reasonable to adopt a hybrid model in which only some of the species are represented as particles, whereas the rest may be approximated as fluids. This makes the issue of load imbalance even worse because regions without particles will arise naturally in a simulation box. Since a significant density inhomogeneity is intrinsic to these problems, the load imbalance problem has to be solved for the efficient use of parallel computers even as small as hundreds of cores.

To resolve the issue of load imbalance in particle-based numerical plasma modeling, we adopt an approach that has been used in some of the existing PIC simulation codes [Germaschewski et al., 2016, Derouillat et al., 2018, Rowan et al., 2021]. Namely, the computational domain is divided into smaller chunks, which are then distributed over the computational nodes. The size of a chunk is chosen to be sufficiently small such that each process can accommodate multiple chunks. The computational load is balanced by distributing chunks so that loads of different processes become as close as possible. Since the algorithm itself is quite general and can be applied to more general particle-based simulations, we try to develop a code in C++ as a general framework that can be utilized in different applications with different basic equations. In other words, the dynamic load balancing capability is separated from the rest of the code as much as possible. This report will discuss the initial results obtained with the code, including the basic algorithm, implementation, and comparison with other approaches [e.g., Nakashima et al. 2009, Ishiyama et al. 2012].