§20. Kinetic Self-Organization – Development of Open-EXEMPLAR Code –

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It has been well established that the magnetohydrodynamic (MHD) plasma is a good medium in which self-organization takes place. The idea of "self-organization" which was shown in those previous works is: The parallel plasma current provides a free magnetic energy by which a current-driven kink instability (global instability) is excited to give rise to a global topological change in magnetic field configuration, whereby a nonlinear rapid energy dissipation takes place. On top of the above conditions, if a superfluous entropy (thermal energy) produced during the process is swiftly removed from the system to an surrounding world, a new stable ordered structure is established.

We have developed the a multi-dimensional EXplicit fully ElectroMagnetic code with full relativistic PLasma pARticle dynamics(EXEMPLAR). In order to clarify the mechanism of the self-organization (the spontaneous generation of a structure) in a kinetic plasma in an "open" system, our EXEMPLAR code has been extended to the open system (Open-EXEMPLAR).

We would like to discuss the development of the Open-EXEMPLAR code. If there is no plasma around the boundary, namely, in the case of a vacuum boundary, the treatment for the absorbing of electromagnetic waves passing through the boundary is quite easy. In this case, there are two major approaches. One is the solving the one-way propagation wave method. The another is the artificial absorbing medium methods(e.g. perfect matching method). This case does theoretically classify in the closed system, because the energy flow(electromagnetic wave) propagates outward/inward, however, the constituent(plasma) does not go out and come in the system. We note that, in the open system, the surrounding system has plasma, namely, the plasma with electromagnetic waves goes out and comes in the internal system passing through the boundary.

In general applications in the open system, e.g. the magnetic reconnection, the most relevant boundary condition for the fields is that they should be able to radiate away into space and should not be reflected at boundary. In the case of the open system, the treatment for the absorbing boundary condition for both wave and particles is difficult. Because plasma passing through the boundary generates the surface current on the boundary and this generated current creates the electromagnetic wave, simultaneously. In order to overcome this physical issue, we adopt three numerical methods: the first is the first order Lindman's wave absorption method[2], and the second is Buneman's current accumulation method[1], and the third is Takamaru's constant current flux method[3].

The problem is that the decision as to what is "outgoing" involves non-local information or some kind of wave analysis of the field. the Open-EXEMPLAR code leaves the interpretation of the field data in terms of "waves" to post-processors. Fortunately, the discrimination against "incoming" radiation can be based on local field information when one knows that the angle of incidence is not too far from normal. In this case, the first order Lindman's wave absorbing method is applicable. Buneman's cuurnet accumulation method is a rigorous method for finding the electric field in electromagnetic plasma simulations without resorting to computational expensive transforms. A finite grid interpretation of the divergence equation $\nabla \cdot \boldsymbol{J}$ is offered which allows the current density and thus new local electric and magnetic field strengths to be determined directly from knowledge of charge motion.

An important feature of absorption is that "absorbed" particles leave their charge behind on the boundary. Such boundary charging makes up for the fact that the writen-off particles are, in reality, only just a little way beyond the boundary and the simulated plasma ought to continue to "feel" them.

One finds that on average as many ions escape as electrons, so the total boundary charge remains moderate. However, the immobility of the boundary charges is somewhat non-physical and in the first version of Open-EXEMPLAR the boundaries have been made slightly conducting. Surface currents proportional to the surface fields are there subtracted from those fields.

Boundary charging may also occur when influx of particles from the exterior is programed. Suppose the exterior is taken to be uniform hot plasma. the electron flux will exceed the ion flux and one cannot introduce the incoming particles as neutral pairs. Our charge-conserving method keeps track of all charge movements and does not allow the non-physical process of creation of a single charge of one sign. Conventional code would imply the simultaneous creation of a charge of the oppsite sign at the same location. However, this conventional no-physical approach is extraced by using Takamaru's constant flux method. In this physical-year, we have checked the first version of the Open-EXEMPLAR.

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[3] H.Takamaru,et.al.,J.Phys.Soc.Jpn,66,3826(1997)