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Development of fluid-particle hybrid code for low-density laser-produced plasmas
低密度レーザー生成プラズマのための流体・粒子ハイブリッドコードの構築

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A hybrid radiative transfer module consisting of Monte-Carlo photon kinetics and low-rank moments with a variable Eddington tensor has been installed to our radiation hydrodynamics code in order to appropriately take an anisotropic radiation field into account. Although a conventional method based on a diffusion-type equation results in an excessive diffraction around an optically-thick object, the developed hybrid code can reproduce the anisotropic field in such a situation with reasonable computational costs.

1. Introduction

Laser-produced plasmas are now expected to be used to demonstrate astrophysical phenomena in laboratories [1]. However, development of appropriate numerical methods is needed to design such experiments because conventional numerical models may not provide a proper solution in low-density ablation plasmas. We have proposed a hybrid method with a variable Eddington tensor and Monte-Carlo photon kinetics and examined to reproduce an anisotropic radiation field by the developed code.

2. Numerical methods

Numerical simulations were conducted using RAICHO code [2], a radiation hydrodynamics code including fundamental energy transfer processes in laser-produced plasmas such as laser absorption, electron thermal conduction, and x-ray radiation transport. Moment equations of radiative transfer equation are obtained by integrating the original equation over the entire solid angle. The Eddington tensor is required to close the moment equations and is expressed as follows;

$$\mathsf{f}^{\nu} \equiv \frac{\int_{4\pi} I^{\nu} \mathbf{\Omega}\mathbf{\Omega} d\mathbf{\Omega}}{\int_{4\pi} I^{\nu} d\mathbf{\Omega}} \quad , \qquad (1)$$

where f, I, and $\mathbf{\Omega}$ are the Eddington tensor, the specific radiative intensity, and the photon direction, respectively. In this study, the Eddington tensor is estimated by the Monte-Carlo method [2].

3. Test problem of an anisotropic field

We have set a computational domain of 2000×1000 μm^2 with 200×100 grids (Fig. 1). An aluminum plate (1 μm in thickness) is placed as an emitter, and an aluminum cylinder (200 μm in diameter) is placed at a 900-μm distance from the plate. A 2ω laser is injected from the right side in Fig. 1 and is linearly ramped in 0.05 ns (maximum intensity of 1×10^{12} W/cm^2). A laser-produced plasma is generated on the surface of the plate and form an anisotropic radiation field in the vacuum region filled with the minimum-limit density around the cylinder.

The obtained result shows that the radiation temperature decreases with increasing distance from the light source caused by the laser ablation as expected. However, a significant change is observed in the low-density region around the cylinder. This discontinuity results from a "shadow" extending from the cylinder because the radiation is anisotropic rather than isotropic in this region. As well known, the shadow phenomenon is missed by solving the moment equations with a diffusion approximation; nevertheless the proposed method can appropriately reproduce it.

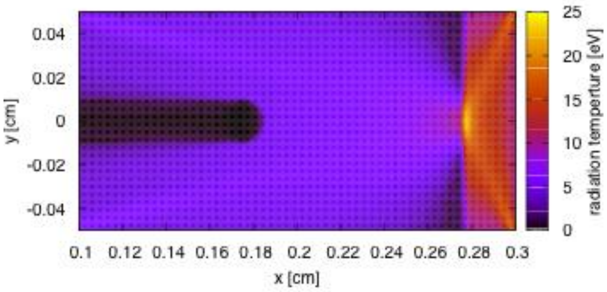

Fig. 1: Snapshot of radiation temperature.

References

[1] Y. Kuramitsu et al.: Phys. Rev. Lett. **108** (2012) 195004.
[2] N. Ohnishi: High Energ. Dens. Phys. **8** (2012) 341.