FARRSIGHT: A Forward Adaptively Refined and Regularized Semi-Lagrangian Integral Green's Function Hierarchical Tree-code Accelerated Method for the Vlasov-Poisson System*

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We present a new forward semi-Lagrangian particle method for the Vlasov-Poisson (VP) system. There is a substantial body of literature devoted to numerical methods for the VP system. Recent methods for solving the VP system include deformable particles [1] and high-order, adaptive [2], and/or discontinuous-Galerkin Eulerian methods [3,4]. In contrast to these, we do not use any operator splitting and obtain the electric field by summing regularized pairwise particle interactions using a hierarchical treecode. We use remeshing and adaptive mesh refinement to maintain an efficient representation of phase space.

The remeshing scheme uses a recursive tree search and biquadratic interpolation, providing for efficiency and good convergence with refinement in mesh size.

Computational cost with the treecode scales as $O(N \log N)$ in N points rather than the prohibitive N^2 of direct summation of pairwise interactions. Our code is further accelerated by running on a GPU. We use the GPU-accelerated treecode BaryTree [5].

We benchmark our method on several standard test cases in the literature: weak Landau damping, strong Landau damping, and a strong two-stream instability. We also study a mismatched beam problem as studied in [1], and find that the AMR allows us to concentrate resolution of the nonlinear beam problem to where the beam is located as it rotates and spirals out into a tenuous halo.
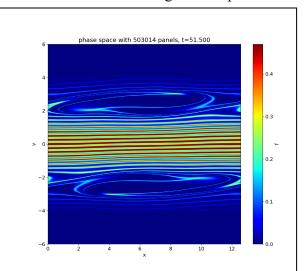
Figure 1 – Image of a strong Landau damping simulation,

$$f(x, v, 0) = \frac{1}{\sqrt{2\pi}v_{th}} \exp\left(-\frac{v^2}{2v_{th}^2}\right)\left(1 + 0.5\cos\left(\frac{x}{2}\right)\right).$$

This uses two levels of adaptive refinemet, from height 8 to height 10, or a mesh of between 513^2 and 2049^2 points. We see the ability of the AMR scheme to capture the filamentary structures arising in the distribution, and the details of the trapping occuring in the phase space vortex at about velocity 2.5.

References

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