Accessing the Nonlinear Physics of Astrophysical Plasmas

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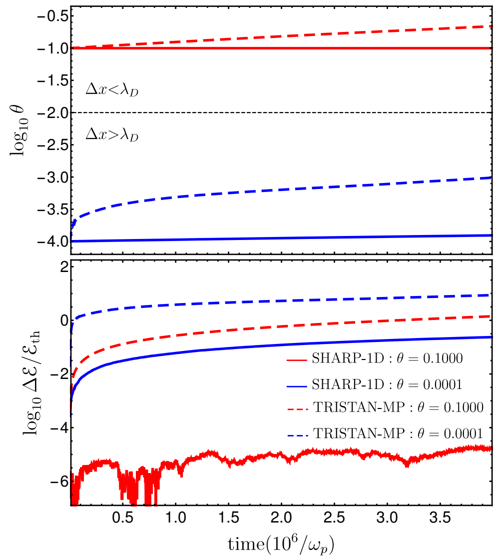
Astrophysical plasmas are ubiquitous and differ from laboratory plasmas in key aspects. They are typically cold $k_B T \ll m_e c^2$, collisionless, and usually contain relativistic sub-populations. To study the evolution of such plasmas, typically, it is necessary to employ a fully kinetic treatment of the plasmas, as described by Boltzmann equation coupled with Maxwell's equations.



This can be accomplished via Particle-in-cell (PIC) algorithms, which combine Eulerian and Lagrangian methods to efficiently solve for plasmas full evolution. Due to numerical heating in PIC algorithms, exploring nonlinear and long term (e.g., millions of ω_p^{-1}) evolution is typically unreliable. However, the use of higher order interpolation (up to 5th order spline) has been shown to be a key in increasing the accuracy of the coupling between the Eulerian and Lagrangian parts of the algorithm and thus ensuring long term stability (without the need to resolve the Debye length in some instances) [1]. This greatly improves energy conservation while exactly conserving both the charge and the total momentum. I have developed a fully relativistic PIC codes (called SHARP), in 1D [1], 1D3V, 2D and 2D3V, where up to fifth order spline shape function are implemented. The computation cost of using SHARP codes are much lower than using higher resolution simulations with typical (1st or 2nd order) interpolation to achieve comparable accuracy. Thus, SHARP codes enable the reliable explorations of the nonlinear evolution of astrophysical plasmas. In my talk, I will present some results where these codes have been used to study the nonlinear evolution of tenuous beam-plasmas instabilities [2] .

References

[1] Shalaby, M., Broderick, A. E., Chang, P., et al. 2017, ApJ, 841, 52

[2] Broderick, A. E., Chang, P., & Pfrommer, C. 2012, ApJ, 752, 22

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