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HIGH PERFORMANCE *COMPUTING* NEWSLETTER

INSTITUTE FOR PLASMA RESEARCH, INDIA

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(2 Pages)

Landau Damping In One Dimensional Periodic Inhomogeneous Vlasov Plasmas

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Landau damping in a collisionless plasma is a well-known standard textbook example of wave particle interaction that is extensively studied in plasma physics. In this kinetic phenomenon, electron plasma waves of small amplitude are exponentially damped in a uniform, electrostatic, Maxwellian equilibrium due to wave particle resonance at phase velocity v_ϕ of the wave, even in the absence of any dissipative terms [1]. However, in the past most of the related studies were carried out in a uniform or homogeneous plasma equilibrium, whereas in most of the scenarios such as laboratories, tokamaks, and astrophysical plasmas, equilibria are inhomogeneous or non-uniform in nature. Prior to this work, a few attempts were made to address linear Landau damping in one dimensional (1D), bounded, inhomogeneous plasmas [2,3]. In another interesting work, using the fluid model and sheet simulations for 1D, non-uniform, warm plasmas with periodic boundaries [4], a mode coupling phenomenon was demonstrated that led to damping of high phase velocity waves with $v_\phi = \omega/k$, i.e., long wavelength perturbations (k~0), as these modes manage to couple to the background plasma due to the presence of short wavelength equilibrium inhomogeneity at scale k_0 in the system [4].

Using a high resolution [Nx x Nv = 2048 x 10000] OpenMP based ***Vlasov–Poisson solver [VPPM-OMP 1.0]*** in HPC clusters of IPR (*UDAY and ANTYA*), an extensive study of linear Landau damping in a periodic inhomogeneous collisionless 1D plasma has been performed without any approximations. An exact inhomogeneous equilibrium in the 1D periodic system is constructed and is shown to be numerically satisfying Vlasov–Poisson equations. This inhomogeneous equilibrium with a stationary inhomogeneous ion background, with spatial variation of density at scale k_0, is then perturbed with mode k such that three different regimes k_0>>k, k_0~k, and k_0<<k are addressed [5]. In k_0>>k regime, we demonstrate that even when the resonance conditions are not satisfied in velocity space, there is still damping in the amplitude of the electric field $|\delta E_{k=0.1}(t)|$, when the background equilibrium is inhomogeneous due to mode coupling between k_0 and k scales which produces coupled modes or "sidebands" with wave numbers $|k \pm Nk_0|$, where N is a coupling parameter [Fig 1]. It is also observed that for parameters considered, the time dependence of the energy density primary mode $|\delta E_k|^2$ does not evolve as $E_0^2 J_0^2(At/2)$ where E_0 is the initial amplitude of the wave and A is the amplitude of the equilibrium inhomogeneity [Fig 1]. One of the reasons for this is disagreement is attributed to the finite length Lx=20π that is used to perform current numerical experiments.

> ***"Presence of even weak ion inhomogeneity efficiently couples energy from Langmuir wave to sidebands leading to novel dynamics during a Landau damping process"***

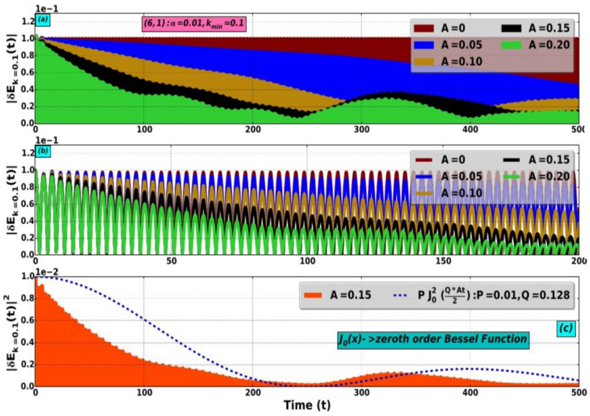


Figure 1: (a) Perturbed Fourier mode $|\delta E_{k=0.1}(t)|$, vs time signature for (k_0,k) : (6, 1) pair with various inhomogeneity amplitudes A. (b) Zoomed scale plot from t = 0 to t = 200 indicating increase in Landau damping with increase in A value. (c) Time evolution of electric field energy density in the primary perturbation mode $|\delta E_{k=0.1}(t)|^2$ for inhomogeneity amplitude A = 0.15 is shown along with best fit using zeroth order Bessel function $PJ_0^2(Qx)$, where x = At/2, and P=E_0^2 and Q are constants and initial amplitude E_0=0.1.

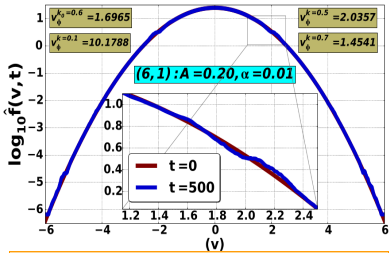


Figure 3: Spatially averaged distribution function f(v, t) plot with respect to velocity (v) at t = 0, 500 ω_{pe}^{-1} for (k_0,k):(6,1) pair with A = 0.20. Phase velocities [v_ϕ] corresponding to interacting modes due to mode coupling are mentioned in the plot for reference.

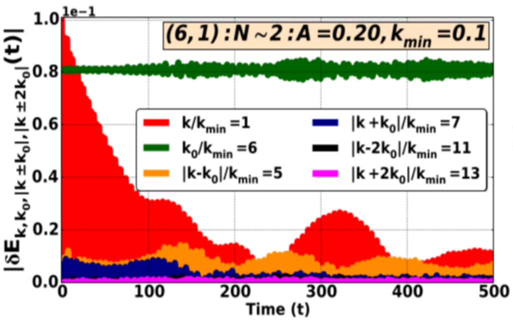


Figure 2: Evolution of $|\delta E_{k,k0,k\pm k0,k\pm 2k0}(t)|$ vs time for [k_0,k]: (6,1) pair with A = 0.20. The portrait shows the energy exchange between participating k,k_0, and k±Nk_0 modes due to mode coupling.

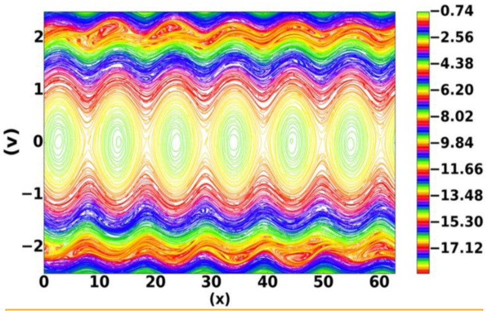


Figure 4. Phase space portrait of the electron distribution function f(x, v, t) at t = 500 ω_{pe}^{-1} for (k_0,k):(6,1) pair with A = 0.20 and α = 0.01. Formation of contour structures due to particle trapping can be seen around |v| = 1.45,1.69,2.03 similar to v_ϕ of interacting modes. The huge structure at v = 0 is due to the chosen equilibrium profile.

For the particular case (k_0,k):(6,1) with high inhomogeneity amplitude, it is observed that the energy exchanges due to mode coupling between participating modes and damping of the primary perturbation k=0.1 mode even though its phase velocity v_ϕ>>v_{the} [Fig 2]. Also, novel features such as particle trapping can be seen due to wave particle interactions, the electrons trapped in the potential well at these v_ϕ locations, leading to local flattening of the distribution function [Fig 3] and trapping structures in phase space plots [Fig 4]. These new findings may be of importance in understanding collisionless dynamics in laboratory plasmas, astrophysical plasmas, and in general, collisionless plasma turbulence.

References:

1. *L. Landau, J. Phys. USSR 10, 25 (1946).*
2. *E. A. Jackson and M. Raether, Phys. Fluids 9, 1257 (1966).*
3. *R. C. Harding, Phys. Fluids 11, 2233 (1968).*
4. *P. K. Kaw, A. T. Lin, and J. M. Dawson, Phys. Fluids 16, 1967 (1973).*
5. *Sanjeev Kumar Pandey, Rajaraman Ganesh, "Landau damping in one dimensional periodic inhomogeneous collisionless plasmas", AIP Advances 11, 025229 (2021).*

Environment Modules-III: Ease of Use of Modules And Sharing Your Custom Modulefiles With Other HPC Users

In the last two issues, we have described how to use applications using the module utility and create custom modulefiles for the applications installed in the user home directory. In this issue we focus on the ease of using the modules and how one user's custom modulefiles can be shared with other users, thus avoiding the need to install the same application again.

1. Ease of use for users requiring several modules for running their jobs:

- **If the user needs a specific environment regularly, instead of loading the modules one by one each time, the user can save this environment with the use of module save command:**

```
$ module list
Currently Loaded Modulefiles:
 1) shared    2) anaconda/3    3) intel-2019    4) visit/3.1.2
$ module save visit-with-python-mpi
$ module restore visit-with-python-mpi

Multiple environments can be saved with different names which
are easy to remember and identify.
```

- **To see a list of your module savepacks, use the command module savelist:**

```
$ module savelist
Named collection list:
visit-with-python-mpi
```

2. Sharing your custom modulefiles (here visit 3.1.2) with other testuser:

- **First change permissions for accessing your $HOME (Forbid all)**

```
$ chmod -R og-rwx $HOME
```

- **Next change the permissions of privatemodules (refer previous issue) directory and directory where you have installed visit 3.1.2.**

```
$ chmod -R 755  privatemodules/
$ chmod -R 755  visit
```

- **Now Grant the permission to specific user having username testuser**

```
$ setfacl -m u:testuser:rx ${HOME}
Now testuser can access the privatemodules and visit directories, but
to avail the application as module following commands need to be run
from testuser's accounts:

$ export MODULEPATH=/cm/local/modulefiles:/cm/shared/modulefiles:/
home/cm/shared/modulefiles:/home/yourid/privatemodules/

$ module use /home/yourid/privatemodules/modulefiles

$ module load visit/
visit/2.13    visit/3.1.2
```

Other Recent Work on HPC (Available in IPR Library)

Terahertz Emission from Laser Interaction with Nano-Particles Embedded Argon (Ar) Gas	PRATEEK VARSHNEY
Spot formation in 3D Yukawa liquid	SURUJ JYOTI KALITA

Acknowledgement

The HPC Team, Computer Division IPR, would like to thank all Contributors for current issue of GAṆANAM.

ANTYA UPDATES AND NEWS

1. PBS Altair Access Portal (*https://10.20.39.6:4443*) is now available for running data analysis and visualization work from your local web-browser.

2. ANTYA MAINTENANCE DOWN-TIME FOR 2 DAYS (JUNE 2-3)

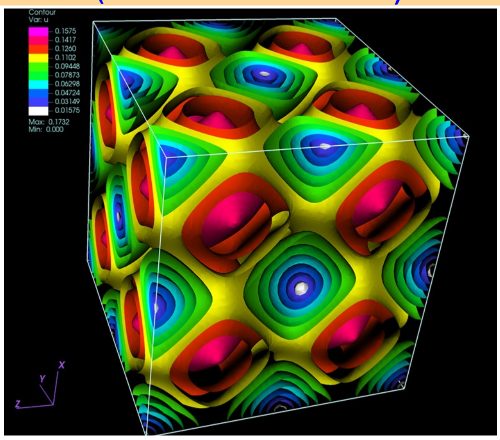
⇒ **Storage faulty hardware replacement and firmware up-gradation**

⇒ **Compute nodes firmware up-gradation**

⇒ **Scheduler up-gradation to the latest version**

Recurrence Study using Famous Astrophysical Roberts Flow

(HPC Picture of the Month)



Pic Credit: **Mr Shishir Biswas**

The above figure is generated from In-house developed multi-node multi-card compressible magneto-hydrodynamic GPU based solver GMHD3D with opensource visualization software VisIt.

3D Roberts is found to show recurrence of velocity and magnetic field iso-surfaces for a 3-D nearly ideal magnetohydrodynamic plasma. The full simulation took 63.526 Hrs in 4xP100 GPU cards for 128^3 grid resolution.

TO CHECK ALL THE AVAILABLE QUEUES FOR JOB SUBMISSION

```
$ qstat -q
```

On Demand Online Tutorial Session on HPC Environment for New Users Available

Please send your request to ***hpcteam@ipr.res.in.***

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