ISSUE 36 NOVEMBER 2023

GAṆANAM (गणनम्)

HIGH PERFORMANCE *COMPUTING* NEWSLETTER

INSTITUTE FOR PLASMA RESEARCH, INDIA

INSIDE THIS ISSUE

(2 Pages)

Oblique whistler waves in space and laboratory plasma regimes: Simulations

Gayatri Barsagade (Basic Theory and Simulation Division, IPR)

Email: gayatri.barsagade@ipr.res.in

Whistler waves are a type of plasma wave, one of the first to be observed. These waves have been studied for more than 100 years. It is an electromagnetic wave mainly observed in space plasmas, lab plasmas, and solid-state physics. It was recently reported that in spacecraft observation of large amplitude whistler wave and/or the associated relativistic electrons energization [1]. In particular, the STEREO observation by Cattell et al [2] reports the detection of obliquely propagating whistler wave with amplitudes as high as 240 mV/m in the Earth's downside outer radiation belt. The propagation angle ranges from 45° to 70°, with an ambient magnetic field of 300-350nT. Electron density is *2-5 cm*$^{-3}$, leading to plasma to electron gyrofrequency ratio (ω_p/Ω) of about 3.

The observed peak frequency is approximately 0.2 times the electron gyrofrequency (Ω), falling within the whistler frequency (ω) range. Also, in laboratory oblique whistler waves are reported in large volume laboratory plasma device (LVPD) [3], i.e., for densities higher than the space plasmas. These whistlers exhibit oblique propagation characteristics and are known to be associated with density perturbations that undergo intense nonlinear steepening, particularly when they propagate close to the resonant cone angle [4]. The whistler resonance cone angle is defined by condition where refractive index tends of infinity . The present study investigates into the parameter range of laboratory experiments where these oblique whistler fluctuations occur. We are using fluid theory to study the oblique whistler wave phenomenon. We have developed the 1D electromagnetic fluid serial code. The run time for the space plasma regime is 40 minutes, while it is 48 hours for the LVPD plasma regime. We have used a flux-corrected transport scheme for solving the electron fluid equation, while Maxwell's equations are simultaneously solved using forward time central spatial difference scheme. Periodic boundary conditions are used for one-dimensional computation domain. We choose 256 grid points for $\theta = 0^\circ$, 70°, 77° and 512 grid points for $\theta = 86^\circ$, 88° cases with the time steps $\delta t = 0.0001\Omega t$. The numerical evolution is initialized using the linearly prescribed analytical plane wave solution. The simulation code prepared and benchmarked by verifying linear whistler dispersion relation for $\theta = 0^\circ$ and 70° in Fig 1. Fig 2 shows the density fluctuation n/n_o versus normalized distance $\Omega x/c$. and dimensionless time Ωt for amplitude $\boldsymbol{\varepsilon = 0.01}$, $\boldsymbol{\omega_p = 0.2\ \Omega}$, $\boldsymbol{\omega = 3\ \Omega}$, $\boldsymbol{\theta_{res} = 78.48^\circ}$ these parameters taken from the spacecraft observation [1]. **Fig 2a** for $\boldsymbol{\theta = 70^\circ}$ whistler wave propagating away from the resonance cone angle do not exhibit significant wave steepening. **Fig 2b** for $\boldsymbol{\theta = 77^\circ}$ whistler wave propagating near to resonance cone angle undergo nonlinear wave steepening and high frequency oscillations near to upper hybrid wave get excited due to quasi-longitudinal nature of oblique whistler wave. Fig 3 shows the density $n(x,t)/n_0$ in **Fig 3c** for $\boldsymbol{\theta = 86^\circ}$, $\boldsymbol{\omega = 0.05\Omega}$, $\boldsymbol{\varepsilon = 0.01}$, $\boldsymbol{\omega_p = 150\Omega}$, $\boldsymbol{\theta_{res} = 87.13^\circ}$ and **Fig 3d** for $\boldsymbol{\theta = 88^\circ}$, $\boldsymbol{\omega = 0.003\Omega}$, $\boldsymbol{\varepsilon = 0.01}$, $\boldsymbol{\omega_p = 344.83\Omega}$, $\boldsymbol{\theta_{res} = 89.82^\circ}$ for parameters from the LVPD experiments. For the LVPD parameter shows that the strong nonlinear nature of the whistler wave is capable of producing a modification in the upper hybrid frequency, causing it to downshift from its linearly expected frequency [5].

The simulation study is performed in the parameter range of spacecraft observation and laboratory experiments where these oblique whistlers' fluctuations occur, utilizing fluid theory and a 1D electromagnetic fluid serial code.

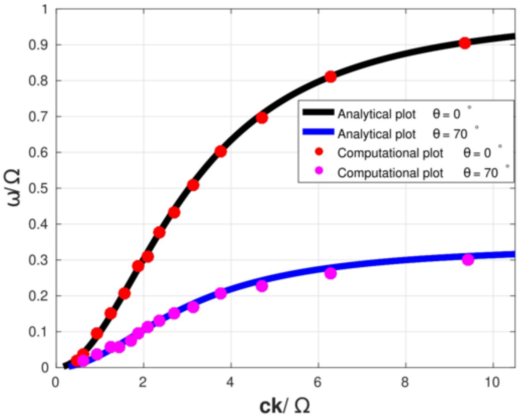


Figure 1 The general dispersion relation for initial perturbation ε=0.01 and ω_p= 3 Ω with propagation angle $\theta = 0^\circ$ and 70°. The dots represent the values of the corresponding wave computed using wave parameter in the nonlinear numerical evolution.

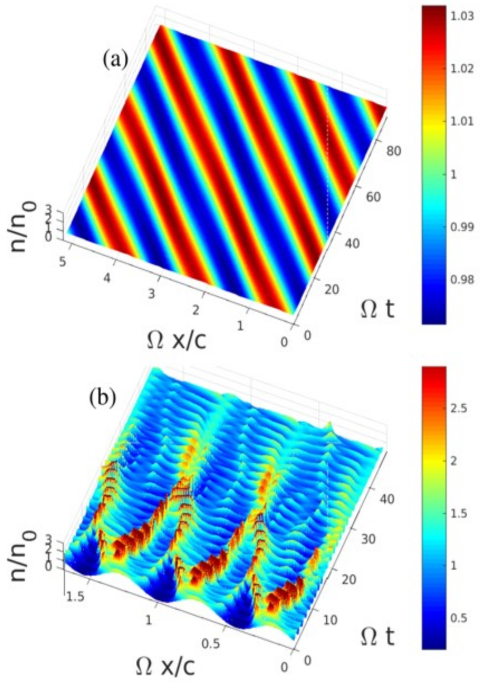


Fig 2. Evolution of density perturbation profile for the whistlers at (a) $\theta = 70^\circ$, $\omega = 3\ \Omega$, $\omega_p = 0.2\ \Omega$, $\theta_{res} = 78.48^\circ$ (b) $\theta = 77^\circ$

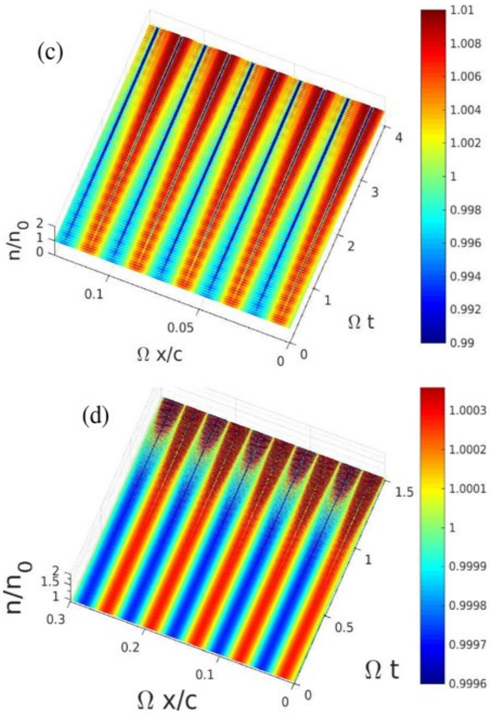


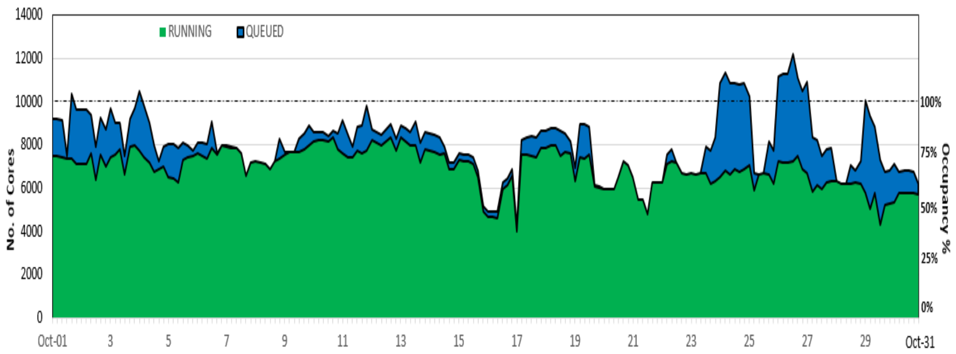
Fig 3. Evolution of density perturbation profile for the whistlers at (a) $\theta = 86^\circ$, $\omega = 0.05\ \Omega$, $\omega_p = 150\ \Omega$, $\theta_{res} = 87.13^\circ$ (b) $\theta = 88^\circ$, $\omega = 0.003\ \Omega$, $\omega_p = 344.83\ \Omega$, $\theta_{res} = 89.82^\circ$

References:

1. *Cully, C. M. et al., THEMIS observations of long-lived regions of large-amplitude whistler waves in the inner magnetosphere Geophys. Res. Lett., 35, L17S16, doi:10.1029/2008GL033643. (2018).*
2. *Cattell, C., et al. (2008), Discovery of very large amplitude whistler-mode waves in Earth's radiation belts, Geophys. Res. Lett., 35, L01105, doi:10.1029/2007GL032009*
3. *A. K. Sanyasi et al., Phys. Plasmas 24, 102118 (2017).*
4. *P. H. Yoon et al., J. Geophys. Res. 119, 1851, https://doi.org/10.1002/2013JA018993 (2014).*
5. *G. Barsagade and D. Sharma, Phys. Plasmas 29, 112104 (2022).*

ANTYA Utilization: OCTOBER 2023

ANTYA Daily Observed Workload



ANTYA HPC USERS' STATISTICS

OCTOBER 2023

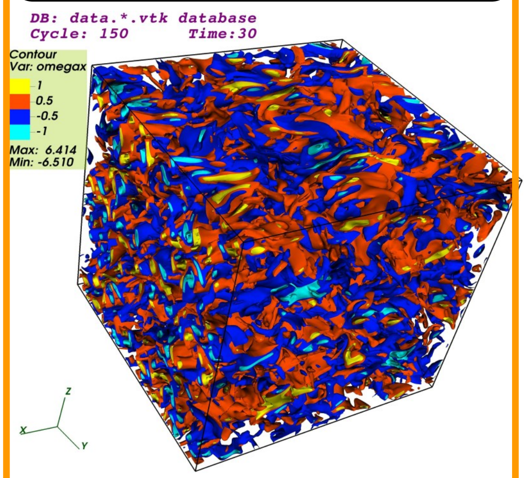
- ♦Total Successful Jobs~ **2494**
- ♦Top Users (Cumulative Resources)

• CPU Cores	Amit Singh
• GPU Cards	Suruj Kalita
• Walltime	Lucky Saikia
• Jobs	Jugal Chowdhury

Other Recent Work on HPC (Available in IPR Library)

Finite Element Simulation of Eddy Current brake for High speed Helium Turbine	Alli Amardas
GYROKINETIC Simulation of Micro-Instabilities in ADITYA-U.	Amit Kumar Singh
Self-induced Convective Pattern formations in a Weakly Coupled Dusty Plasma	Ankit Dhaka
Plasma boundary simulations of limiter ramp-up phase of ITER	Arzoo Malwal
Ion Temperature Gradient Modes In Tokamaks	Gopal Krishna M
Laser-cluster interaction in an ambient magnetic field with a circularly polarized laser light	Kalyani Swain
Observation of sub-sonic plasma flow in a nonuniform magnetic field in the Helicon Plasma device	Mariammal M
Particle-in-Cell simulation of laser-plasma interaction: the terahertz light generation	Mrityunjay Kundu
Ion temperature dynamics for the edge and Scrape-off layer plasma turbulence	Nirmal K. Bisai
Development and Testing of a Pneumatic Mechanical Punch for Application in Cryogenic Pellet Injection	Pareshkumar M. Panchal
Ubiquitous Modes In Tokamaks	Sagar Choudhary
Determination Of Coordinates Of Toroidal Loop Current On Aditya-U	Sameer Kumar
Unravelling The Influence Of Fluid Helicity On MHD Dynamo Action	Shishir Biswas
Practical Pedagogical Approaches in HPC for Optimizing Complex Programming Algorithms: A Nuclear Fusion Application Case Study	Someswar Dutta
Turbulent Spot formation in Three-Dimensional Yukawa Liquids using Large-Scale Molecular Dynamics Simulation - Effect of System Size	Suruj Jyoti Kalita
Numerical Simulation of an Expanding Magnetic Field Plasma Thruster Using Iodine Fuel	Vinod Saini
Modeling of Unmitigated and Mitigated Disruptions with Tungsten wall in ITER.	Trivesh Kant
Full-wave simulation of 2.45GHz ECR plasma for STARMA	Tulchhi Ram

HPC PICTURE OF THE MONTH



Pic Credit: Shishir Biswas

Title: Turbulent Dynamics of 3-dimensional Taylor-Green (TG) flow

Description: This figure represents the vorticity iso-surfaces (or Iso-ω surface) for turbulent 3-dimensional Taylor-Green (TG) flow in the incompressible limit. Taylor-Green vortex is laminar and anisotropic at early stages but eventually becomes completely turbulent.

Solver used: It is generated using an In-house developed multi-node, multi-card, weakly compressible magneto hydrodynamic GPU based suite **GMHD3D**.

Simulation Details: This simulation uses 256^3 grid resolution. The full simulation took 70.526 Hrs. in 4 P100 GPU cards (2 Nodes) on ANTYA Cluster.

Visualization: For this 3D Iso-surface visualization, an open source visualization package **VisIt 3.1.2** was installed in ANTYA Visualization node.

Acknowledgement

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

On Demand Online Tutorial Session on HPC Environment for New Users Available
Please send your request to ***hpcteam@ipr.res.in.***

Join the HPC Users Community
hpcusers@ipr.res.in
If you wish to contribute an article in GAṈANAM, please write to us.

Contact us
HPC Team
Computer Division, IPR
Email: ***hpcteam@ipr.res.in***