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Ubiquitous Mode in Tokamaks

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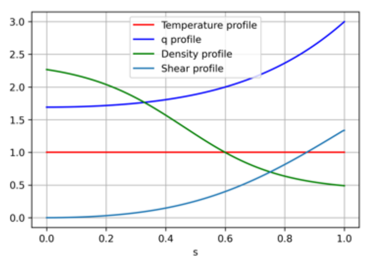
Anomalous transport in magnetically confined plasmas is believed to be driven by micro-instabilities, which are fueled by the free energy provided by density and temperature gradients [1] . Some well known instabilities include ion temperature gradient (ITG) modes, trapped electron modes (TEM), electron temperature gradient (ETG) modes, etc. which are driven by temperature gradient. However, there are modes that are driven purely by density gradient, one such example is universal drift mode (UDM). Similar to UDM, another mode driven by the density gradient present in trapped electrons is Ubiquitous mode (UM). UM rotates in ion diamagnetic drift direction in contrast to electron modes such as ETG, TEM, UDM, etc. Generally, long wavelength modes alone do not adequately account for all energy losses in anomalous transport. Consequently, the contributions from short to intermediate wavelength modes, such as Ubiquitous Modes (UMs), cannot be disregarded. Recent observations, particularly the flat temperature profiles alongside finite density gradients reported in LTX tokamak experiments [2,3], underscore the potential role of these modes in driving plasma instability. Furthermore, recent studies employing the ballooning approximation for tokamak plasmas have indicated that the onset of UMs under specific operating parameters can lead to a significant increase in plasma diffusion [4]. In present work, we study the linear properties of the UM and its dependencies on various parameters using a global gyro-kinetic model, GLOGYSTO [5] based on spectral method.

Profiles and parameters considered for the study are:

- Electron Temp, $T_e = 7.5$ KeV
- Ion Temp, $T_i = 2.5$ KeV
- Magnetic Field, $B_0 = 1$ T
- Major Radius, $R = 2$ m
- Minor Radius, $a = 0.5$ m
- $s = \rho/a,\ s_0 = 0.6$
- Density Gradient Length, $L_n = 0.2$
- $\eta = L_n/L_T = 0$



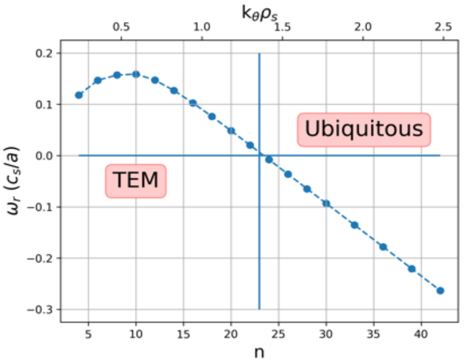


Fig.1 Real frequency normalised by c_s/a, c_s being the sound speed.

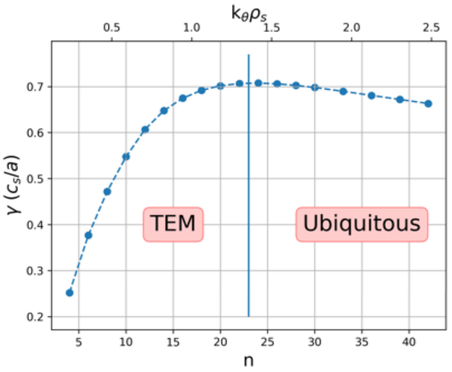


Fig.2 Growth rate normalised by c_s/a, c_s being the sound speed.

Growth rates and real frequency calculated for different toroidal mode numbers are shown in Figs. 1 & 2. Frequencies are normalised by **c_s/a**, where $c_s = \sqrt{k_B T_e / m_i}$ is the sound speed.

Wave numbers, **k_θ** is normalised with **$\rho_s = c_s/\omega_{ci}$** where **$\omega_{ci} = eB/m_i$** is the ion cyclotron frequency. For low **$k_\theta\rho_s(\leq 1.36)$** , real frequency is in electron drift direction, this is the regime of density gradient driven conventional TEM. However, for **$k_\theta\rho_s \geq 1.36$** , the mode direction reverses and rotates in the direction of ion diamagnetic drift. This branch of the dispersion curve corresponds to the ubiquitous mode.

The mode structure for ubiquitous mode for mode number, **n = 30** is shown Fig. 3 and a zoomed in for the same is shown in Fig 4. As can be seen from the plots, the mode is quite global and occupies a substantial fraction of minor radius. These aposteriori suggests that, a global calculation is necessary such as the present one to correctly account for global effects. Mode structure for the conventional TEM is shown in Fig.5 for the mode number, **n = 16**. A close-up view of the same is shown in Fig.6.

First ever gyrokinetic study of density gradient driven, trapped particle mode -- Ubiquitous Mode -- in regime relevant for Lithium Tokamak experiments LTX, suggest strong evidence for transport.

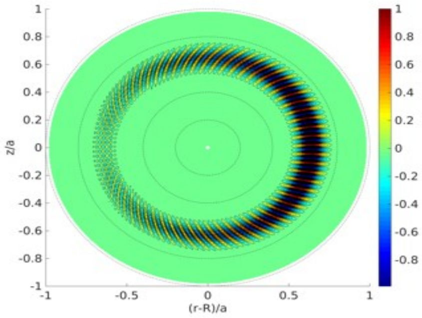


Fig. 3 Global Mode Structure corresponding to $n = 30$

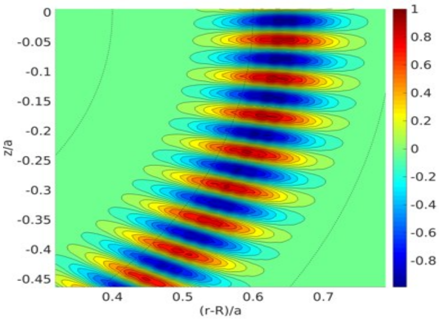


Fig. 4 Close-up view of the mode structure

Dependence on density gradient : Since the mode is essentially driven by density gradient, it is critical to study the mode's dependence as a function of gradient in density. Figs. 7 & 8 shown the real frequency and growth rate plots as a function of **R/L$_n$** respectively. It can be observed from that with

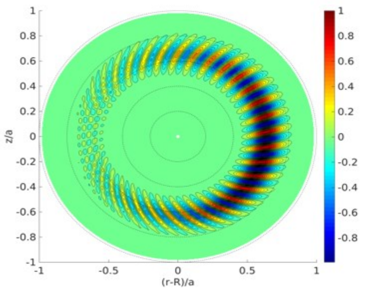


Fig. 5 Global Mode Structure corresponding to $n = 16$

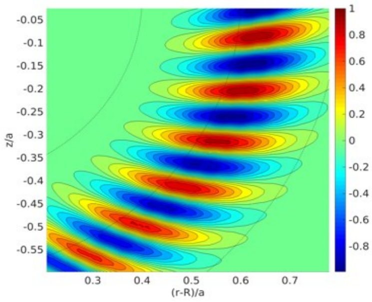


Fig. 6 Close-up view of the mode structure

increase in **R/L_n** i.e., increase in density gradient, growth increases almost linearly. Real frequency scales with diamagnetic drift frequency which is proportional to density gradient as the temperature profile is considered flat, therefore a linear variation in real frequency is observed with density gradient. For the results shown in the article, in total, 12-15 node-hours of ANTYA were used.

Dependence on η = L_n/L_T : Ubiquitous mode, so far, is studied for flat temperature profile as it is driven solely by density gradient and does not need gradients in the temperature profile. However, in practical scenarios, tokamaks generally exhibit finite temperature gradients. Therefore, the dependence of the mode on temperature gradient is investigated. For this, **η = L_n/L_T** is varied by keeping **L_n** constant; increase in **η** means increase in temperature gradient. **L_n, L_T** are kept the same for both of the species, electrons and ions. Real frequency and growth rates are shown in Fig. 9 & 10 respectively. Real frequency is observed to vary linearly with **η** as expected since it scales with diamagnetic drift. Growth rate, however, shows weak dependence on temperature gradient and the mode is likely to be present in finite temperature gradient scenarios.

In this study, we systematically investigate the linear properties of the ubiquitous mode utilizing a global gyrokinetic model. We examine the mode's dispersion relation and its structural characteristics. The mode structures are found to occupy a substantial portion of the minor radius, underscoring the importance of global calculations. Additionally, we analyze the driving mechanisms of the mode by exploring its dependence on density and temperature gradients. Our findings indicate that the primary driving factor for the mode is the density gradient, while the temperature gradient exhibits a weak influence on the growth rate.

References:

1. *Horton W., Rev. Mod. Phys. 71 735 (1999)*
2. *Majeski et al Phys. Plasmas 24, 056110 (2017)*
3. *Boyle et al Phys. Rev. Lett. 119, 015001 (2017)*
4. *Shen et al Nuclear Fusion 59 106011 (2019)*
5. *Brunner Ph. D. Thesis 1701, EPFL, Switzerland (1997)*

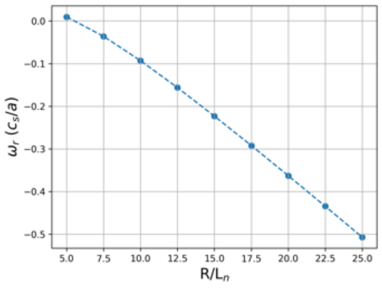


Fig. 7 Real frequency with respect to R/L_n

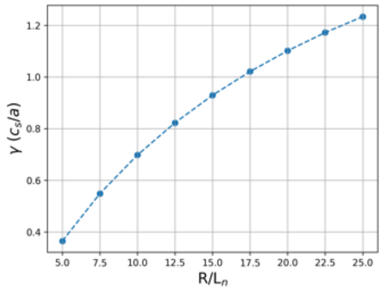


Fig. 8 Growth rate with respect to R/L_n

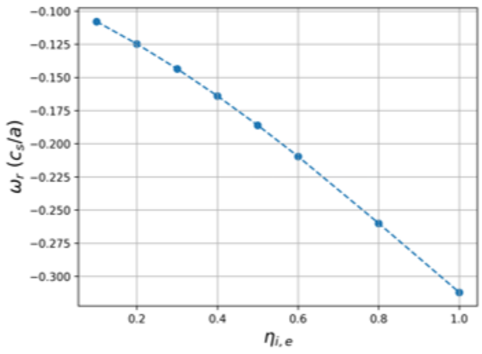


Fig. 9 Real frequency with respect to η

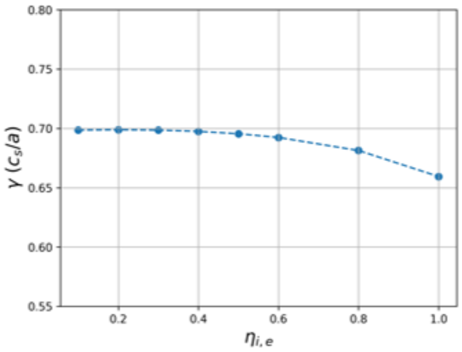
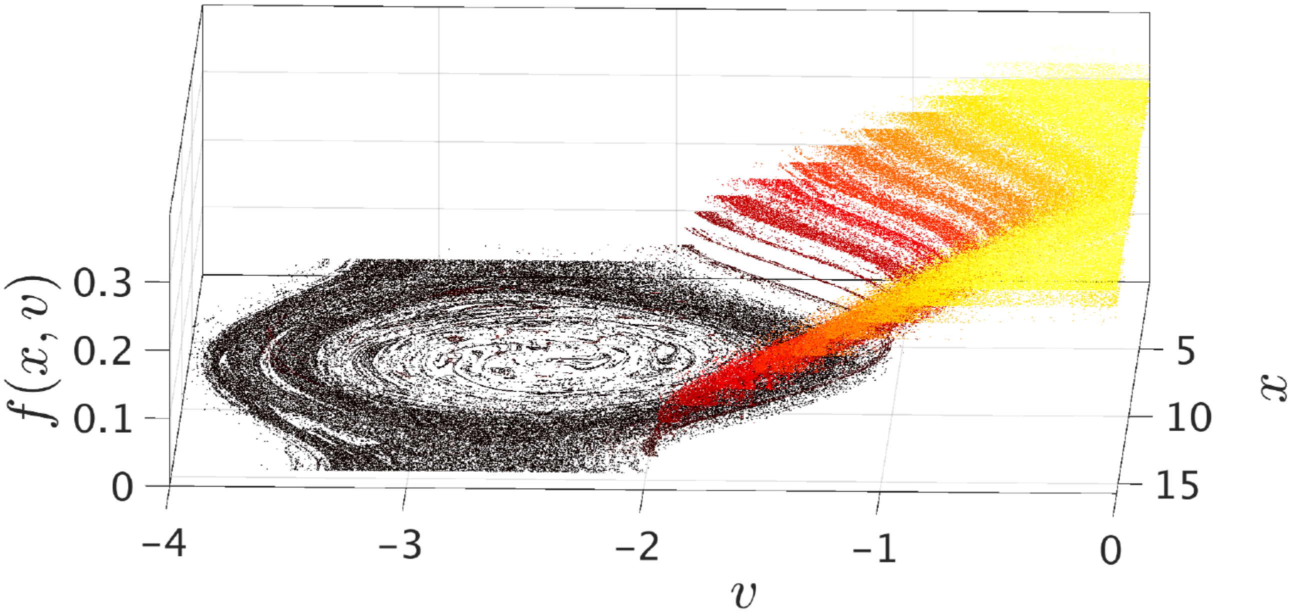


Fig. 10 Growth rate with respect to η

HPC Picture of the Month



Pic Credit: **Vinod Saini**

Title: Iso-contour of the electron phase-space distribution f(x,v,t) for chirp driven system.

Description: The parameters for the simulation are as following:- the initial Maxwellian plasma is driven with the drive amplitude E_0 = 0.025 and frequency is swept from ω_d = 1 to ω_d = 0.5 for chirp time interval ∆t_d = 200 with chirp coefficients are ζ = −2.5 × 10 −3 , η = 1. Late time contour plot of f(x,v,t) at t=2000, where an external downward chirp is applied from the start for a period ∆t_d = 200, after the drive is turned off, using PIC solver. Because of inherent noise in particle simulations, small scale structures in electron phase space are highly noisy. These structures are seen at the less populated tail of the distribution function, which contributes to statistical noise.

Solver User: An in house developed 1D3V PIC-MCC solver is used here

Simulation Details: This simulation result is produced using 512 spatial grid points and 4000 velocity grid point. PIC solver is fully ported on GPU and single GPU card on Antya is used for simulation

Visualization: A licensed Matlab is used to plot the simulation data

Introduction to NVIDIA HPC SDK for High Performance Computing

High-Performance Computing (HPC) has transformed the way to solve scientific, engineering, and industrial problems by using powerful, efficient, and scalable computers that handle large data and perform complex calculations rapidly. The NVIDIA HPC SDK (Software Development Kit) provides developers with a robust platform to build, optimize, and deploy HPC applications. It includes compilers, libraries, and tools that are essential for developing applications that run on NVIDIA GPUs and CPUs.

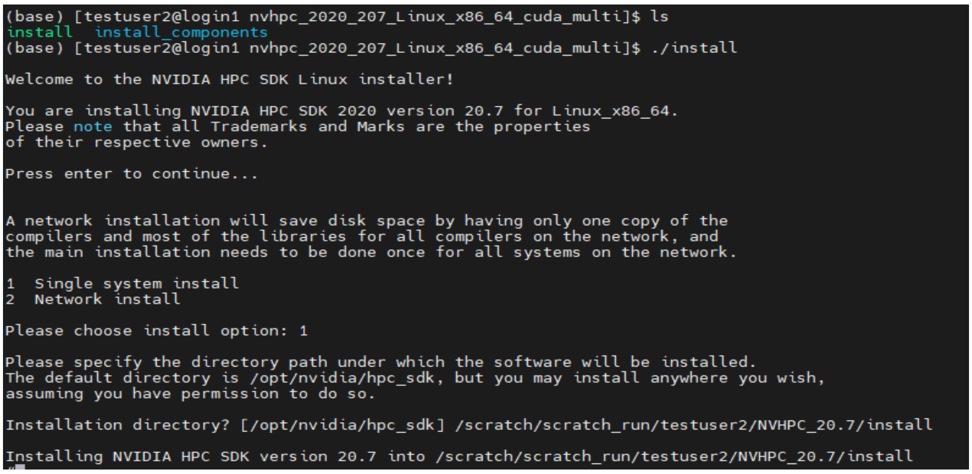
NVIDIA HPC SDK (Refer here) also supports GPU acceleration using CUDA and other parallel computing standards like OpenACC and OpenMP. This helps developers use the powerful parallel processing abilities of NVIDIA GPUs, greatly improving their applications' performance and efficiency. The SDK works well with popular development environments and supports languages like Fortran, C, and C++.

Additionally, the NVIDIA HPC SDK includes a collection of highly optimized libraries for various mathematical and scientific computations. These libraries, such as cuBLAS for linear algebra, cuFFT for fast Fourier transforms, and cuSPARSE for sparse matrix operations, are designed to deliver higher performance and ease of use. It also supports communication libraries such as OpenMPI, NCCL etc. Below is the list of compilers and libraries available with SDK.

Programming Models	Compilers	Core Libraries	Math Libraries
• Standard C++, Fortran	• NVCC & NVC	• Libcu++	• cuBLAS & cuTENSOR
• OpenACC & OpenMP	• NVC++	• Thrust	• cuSPARSE & cuSolver
• CUDA	• NVFORTRAN	• CUB	• cuFFT & cuRAND

Source: https://developer.nvidia.com/hpc-sdk

There are two ways to install the NVIDIA HPC SDK: 1) Using Target Environment-based installation, and 2) Container-based installation. To install the NVIDIA HPC SDK in your environment, visit the SDK download page. Select a compatible version of the SDK according to the drivers and CUDA version available with the system. Follow the installation instructions for the target platform and refer to the steps below for installing the SDK into users' environment after downloading and extracting the compatible version from the SDK download page. After installation, detailed instructions regarding environment setup will be shown to the user.



```
(base) [testuser2@login1 nvhpc_2020_207_Linux_x86_64_cuda_multi]$ ls
install  install_components
(base) [testuser2@login1 nvhpc_2020_207_Linux_x86_64_cuda_multi]$ ./install

Welcome to the NVIDIA HPC SDK Linux installer!

You are installing NVIDIA HPC SDK 2020 version 20.7 for Linux_x86_64.
Please note that all Trademarks and Marks are the properties
of their respective owners.

Press enter to continue...


A network installation will save disk space by having only one copy of the
compilers and most of the libraries for all compilers on the network, and
the main installation needs to be done once for all systems on the network.

1  Single system install
2  Network install

Please choose install option: 1

Please specify the directory path under which the software will be installed.
The default directory is /opt/nvidia/hpc_sdk, but you may install anywhere you wish,
assuming you have permission to do so.

Installation directory? [/opt/nvidia/hpc_sdk] /scratch/scratch_run/testuser2/NVHPC_20.7/install

Installing NVIDIA HPC SDK version 20.7 into /scratch/scratch_run/testuser2/NVHPC_20.7/install
```

To verify the installation of the SDK toolkit, various example codes related to different libraries and compilers are included with the HPC SDK installation. Users can load the SDK toolkit into their environment using the command mentioned above and run any of the example scripts to verify the installation of the HPC SDK.

```
#To load the NVHPC SDK module in user environment
[user@login1 ~]$ module load /scratch/scratch_run/user/NVHPC_20.7/install/modulefiles/nvhpc/20.7

[user@login1 ~]$ which nvc
/scratch/scratch_run/user/NVHPC_20.7/install/Linux_x86_64/20.7/compilers/bin/nvc
```

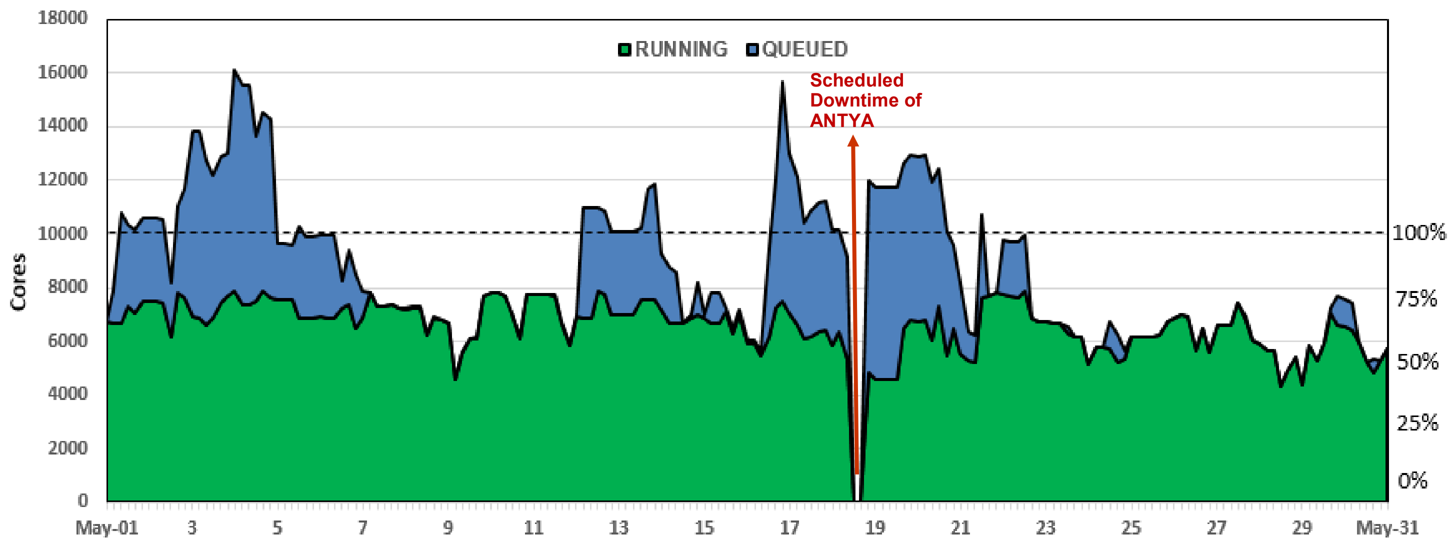
```
#List of example scripts present in example directory
[user@login1 ~]$ cd /scratch/scratch_run/user/NVHPC_20.7/install/Linux_x86_64/20.7/examples
AutoPar  CUDA-Fortran  CUDA-Libraries  F2003  MPI  OpenACC  OpenMP  README

#Submit an interactive job in any one of the gpu and test the example scripts by traversing into the desired example directory.
[user@gn01 AutoPar]$  make all
[user@gn01 cuBLAS]$  make all
```

Users may use interactive mode only for testing above installation.

NOTE

The NVIDIA HPC SDK comes in various versions, each supporting a specific set of GPU devices, driver versions, and compute capabilities. Installing an incompatible version may lead to errors related to driver versions, compute capabilities, libraries and more. Therefore, users should refer to the documentation and download the SDK version that is compatible with their GPU device.

ANTYA Utilization: MAY 2024



ANTYA Daily Observed Workload

Other Recent Work on HPC

Excitation of 2-D and 3-D Pinned Solitons in a Flowing Dusty Plasma	**Prasanta Amat**
Spontaneous Convective Patterns in a Dusty Plasma	**Ankit Dhaka**
Plasma boundary simulations of limiter ramp-up phase of ITER	**Arzoo Malwal**
Convective cell to shear flow instability in 2D Yukawa liquids driven by Reynolds stress: A first principles study	**Rajaraman Ganesh**
Short-pulse laser-cluster interaction in an ambient magnetic field	**Kalyani Swain**
Laser-cluster interaction in an ambient magnetic field with circular polarization	**Kalyani Swain**
Design Development of Toroidal Field Coil for Prototype Center Stack	**Aditya Kumar Verma**

ANTYA HPC USERS' STATISTICS—

MAY 2024

Total Successful Jobs~ 1522

♦**Top Users** (Cumulative Resources)

• **CPU Cores**	**Amit Singh**
• **GPU Cards**	**Shishir Biswas**
• **Walltime**	**Shishir Biswas**
• **Jobs**	**Prince Kumar**

Acknowledgement

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

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