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Ion-driven Destabilization of a Toroidal Electron Plasma - An Exploration using 3D3VPIC Simulation

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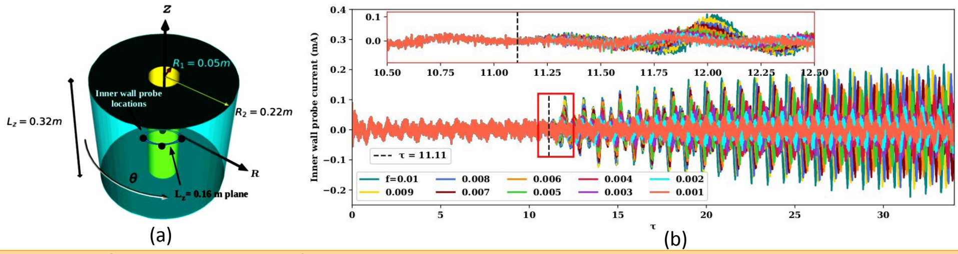


Figure 1: (a) Schematic diagram of the axisymmetric toroidal vessel with wall probes. (b) Inner wall probe current for increasing f values for Ar^+ upto τ = 34, where $\tau = t/t_D$, t_D is toroidal Diocotron period for QQS state. The time of introduction of ions is at τ = 11.11, as indicated by black dotted line. The inset plot shows onset of the growth of wall probe current amplitude.

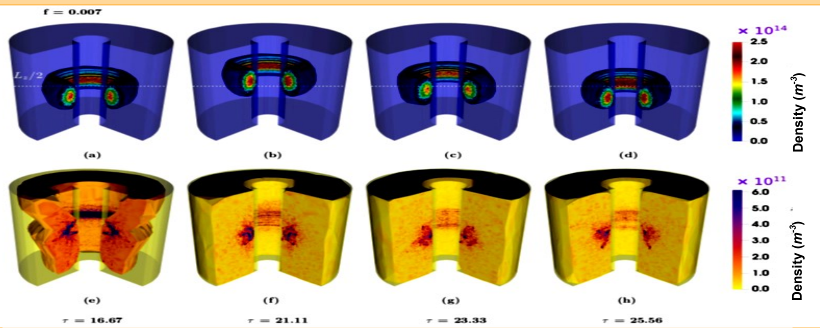


Figure 2: Time evolution of primary electron plasma (a-d) and ion plasma (e-h) with respective density values, for *f* = 0.007 at different simulation time periods τ = 16.67,21.11, 23.33 and 25.56.

Straight cylindrical trap or Penning-Malmberg trap, routinely confine electrons or ions, radially with uniform external magnetic field and axially with appropriate electric field end-plugs. Under suitable conditions, confined particles achieve thermal equilibrium [1] easily in these traps with homogeneous magnetic fields. In contrast, confinement of pure electron/ ion plasmas in a purely toroidal magnetic field has proven to be challenging. The issues restricting pure electron plasma from excellent confinement in a toroidal magnetic field, are the onset of nearly-ubiquitous toroidal diocotron oscillations and its instability driven by small fraction of ions generated from ions produced during electron-neutral collisions in experiments. Several attempts have been made to achieve long time containment of toroidal electron cloud in small aspect ratio device [2] by reducing the ion density via ultra vaccum conditions and in large aspect ratio device [3] using improved vaccum condition, increased magnetic field strength and a higher degree of symmetry. In a recent numerical study [4] with axisymmetric ($\partial/\partial\theta$ = 0) small aspect ratio (~ 1.6) torus (see Fig. 1 (a)), a quiescent quasi -steady (QQS) state of electron cloud has been found out, which is nearly devoid of toroidal diocotron oscillations. This QQS state has been achieved using combination of a mean field theoretic extremum entropy solution and high fidelity 3D3V particle-in-cell (PIC) simulations using PEC3PIC code. As a subsequent step, collisionless ion-driven destabilization of the toroidal electron in QQS state [5] has been investigated in the present study.

> ***"A small population of ions make an electron cloud in a quiescent quasi-steady (QQS) state to become unstable, which is found to grow algebraically."***

In this study, inhouse developed 3D3V OPENMP parallelized PIC code PEC3PIC is used with a grid size of *192 X 192 X 192* in Cartesian coordinates. Presently the code runs on 10 cores in a single node in ANTYA. Basic PIC algorithm has been used in this code where PIC superparticles are loaded with Halton sequence. Interpolation of particle charge from particle positions to the grid points is achieved by first-order cloud-in-cell (CIC) scheme. Poisson's equation is solved by a Multigrid Gauss-Seidel method. Inverse CIC scheme interpolates the electric field to the particle positions from grid points. The total energy of the system converges for *2560640* (or more) superparticle numbers. The density values of the ion plasma and secondary electron plasma are made a fraction ***f*** times lesser than the primary electron plasma using the fractional neutralization factor ***f*** = 0.007 in the code. Ar^+ ion used in the study has mass *72820.77* times the electron mass. A schematic diagram of the axisymmetric toroidal vessel with conducting boundary walls is shown in Fig. 1 (a), where the wall probes near inner wall location (separated by θ = π/2) are also shown. The radii of the inner and outer wall boundaries are R_1 = 0.05 m and R_2 = 0.22 m respectively. The height is Lz = 0.32 m. The device sizes described are identical to SMARTEX-C device at IPR, however unlike the experimental device, here electrostatic endplugs in the toroidal direction are absent, though the particle dynamics is fully 3D3V. The inhomogeneous toroidal magnetic field is highest at inner wall radius R_1 (B_0 = 0.03 T) and falls with R as $B = B_0 R_1/R$. After the electron cloud attains QQS state, Ar+ ion at densities 1000 times smaller than electron cloud density is introduced into the torus at certain time τ = 11.11, where $\tau = t/t_D$, t_D is toroidal Diocotron period for the QQS state (~1.8 X 10^{-6} s). The wall probe current obtained from one of the inner wall probe (no phase difference between the four wall probe data as the cloud is toroidally symmetric) with "double peak" nature indicates the "center of charge motion" (m = 1) of the electron plasma in the poloidal plane. The wall probe current at different values of ***f*** (ranging from 0.001 to 0.01) is shown in Fig. 1 (b). It is observed that soon after the ion loading, the amplitudes of the probe currents start to grow with time and the growth is more for higher values of ***f*** for any instant of time. This is also demonstrated in the inset plot displayed at the onset of the growth. The growth of the wall probe current is algebraic in nature for all values of ***f*** and saturates at later time of the simulation, mainly for higher ***f*** values.

To aid the analysis, spatial positions of the electron plasma inside the torus along with density contours are shown in Fig. 2 (a)-(d), at simulation times τ = 16.67, 21.11, 23.33, 25.56 respectively with ***f*** = 0.007 case. After ions were introduced, the "center of charge motion" (m = 1) of the electron plasma in the poloidal plane gains amplitude as time progresses. The electron plasma is displaced along the vertical and horizontal directions, with a distinguishable compression-expansion cycle due to toroidicity. The poloidal shape of the plasma shows elliptic nature representing m = 2 mode. In Fig. 2 (e)-(h), corresponding ion plasma and density are shown. In support of the present analysis, spectrogram of the wall probe current has been also performed [5] (not shown here). The spectrogram reveals dominant modes as m = 1 and m = 2 (with higher energy than the QQS case) and dynamical chirping infused coupling of low poloidal modes m = 1 to m = 9 (not seen in QQS case). Thus the present study shows that the toroidal electron plasma dynamics are affected by presence of small number of ions. Impact ionization and various collisional mechanisms between electron-neutral, ion-neutral collisions have been also considered in a separate study and shall be reported in future.

References:

1. *T. M. O'Neil and C. F. Driscoll, "Transport to thermal equilibrium of a pure electron plasma," Phys. Fluids 22, 266–277 (1979).*
2. *Lavkesh Lachhvani. "Long-time confinement of toroidal electron plasma in SMARTEX-C" Ph.D. thesis, (IPR,HBNI,2018).*
3. *M. R. Stoneking, J. P. Marler, B. N. Ha, et al. "Experimental realization of nearly steady-state toroidal electron plasmas" Phys. Plasmas 16, 055708 (2009).*
4. ***S. Khamaru,** R. Ganesh, and M. Sengupta. Phys. Plasmas 28, 042101, (2021).*
5. ***S. Khamaru**, R. Ganesh, and M. Sengupta, "Ion-driven destabilization of a toroidal electron cloud - A 3D3VPIC Simulation" Manuscript Under Review (2022).*

Running Container Workloads in a Batch Job on ANTYA

All workloads must be submitted as batch jobs on compute nodes to keep the frontend nodes free for user login sessions. In the previous article, an overview of containerization was given and this article focuses on submitting batch jobs with the codes inside a container image.

> ***"Containers (CPU as well GPU) can be launched on a single node (OpenMP) and on multiple nodes (MPI) depending on how the application has been built inside the container."***

How to Implement in ANTYA?

Example-1: As an example here to run CPU workload on a single node, we will use an existing container image of paraview to show how paraview can be launched as a batch job.

 # Copy the paraview container image available on ANTYA to your home or working directory.

```
[user@login1 ~]$ cp /home/application/singularity_images/singularity_3.4.1/paraview57.simg .
```

 # Here is the PBS job script for submitting paraview container job.

```
[user@login1 ~]$ cat jobscript_container.sh

#!/bin/bash
#PBS -q serialq
#PBS -N paraview_container
#PBS -l select=1:ncpus=1
#PBS -l walltime=00:10:00
#PBS -j oe
cd $PBS_O_WORKDIR
```

 # Load the singularity module

```
module load singularity/3.4.1/3.4.1
```

 # Run the following command to execute the container image and then launch the paraview from inside the container.

```
singularity exec paraview57.simg /opt/paraview_build/bin/paraview
```

Example-2: To run an MPI workload on multiple nodes, we will use an existing container image of of a hello world program which has been built with MPI to show how it can be launched as a batch job across multiple nodes.

 # Copy the hello-world container image available on ANTYA to your home or working directory.

```
[user@login1 ~]$ cp /home/application/singularity_images/singularity_3.4.1/ex_03.sif .
```

 # Here is the PBS job script for submitting container job across multiple nodes.

```
[user@login1 ~]$ cat jobscript_container_mpi.sh

#!/bin/bash
#PBS -q mediumq
#PBS -N hello_container_mpi
#PBS -l select=2:ncpus=40:mpiprocs=40
#PBS -l walltime=00:10:00
#PBS -j oe
cd $PBS_O_WORKDIR
```

 # Load the singularity module and openmpi module

```
module load singularity/3.4.1/3.4.1
module load module load openmpi/gcc/4.0.1
```

 # Run the following command to execute the container image and then launch the paraview from inside the container.

```
mpirun -np 80 --machinefile $PBS_NODEFILE singularity exec -B $TMPDIR ex_03.sif /data/hello_world_MPI.bin
```

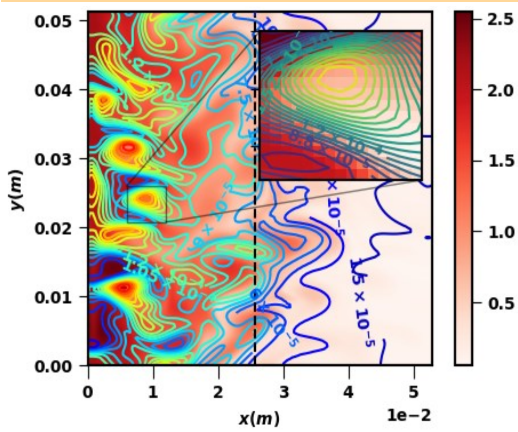
ANTYA UPDATES AND NEWS

1. New Packages/Applications Installed

- ⇒ **Latest hpc_sdk_22.9 available as module nvhpc/22.9**
- ⇒ **New CUDA toolkits available now as modules cuda11.8/11.8 cuda11.7/11.7**

HPC PICTURE OF THE MONTH

Plasma-Impurity Interaction in Edge and SOL of a Tokamak: An Evidence



Pic Credit: **Shrish Raj**

The figure shows superposition of 2D contour plot of Ar^{2+} density indicated by contour lines with plasma density indicated by colormap. The Ar^{2+} density is seen maximum at the plasma density hole. This plasma-impurity (argon) interaction has been captured in the impurity seeding simulation using BOUT++ in the 2D slab geometry. The input parameters used in the simulation are related to ADITYA-U tokamak. The dotted line represents the position of last closed flux surface (LCFS).

[Ref: manuscript under review]

This figure is generated in Python code with the data obtained from the BOUT++ simulation which took around 10 hours on 16 cores of ANTYA.

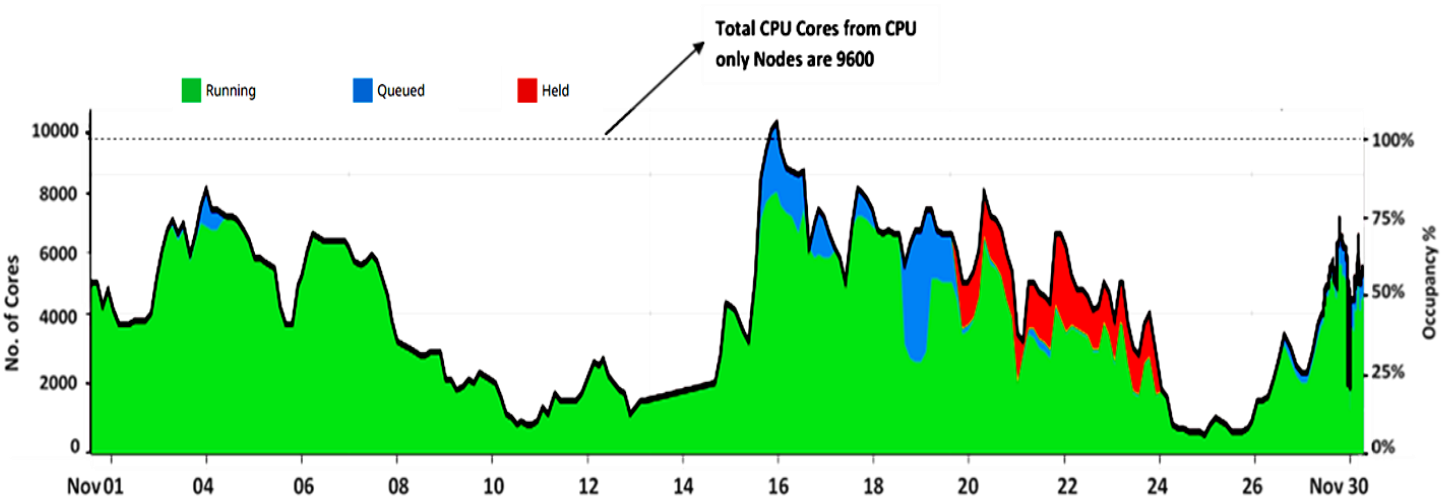
TIP OF THE MONTH

Historical Jobs Checking: A user can check all historical jobs submitted in the last 30 days with the following command:

```
[user@login1 ~]$ qstat -ax -u username
#This will list out all the jobs with username (user login ids). This can be helpful in comparing and analyzing the jobs performance.
```

ANTYA Utilization: NOVEMBER 2022

ANTYA Daily Observed Workload



Note: *The red portion of the utilization chart shows the cores being held by the jobs which have occupied the resources but not running and using the allotted resources. This happened during the GPU hardware issue and affected some of the CPU nodes.*

Other Recent Work on HPC (Available in IPR Library)

Argon, neon, and nitrogen impurity transport in the edge and SOL regions	SHRISH RAJ
Development and Validation of Room Temperature Bore Cryostat for Testing of HTS Solenoid Magnet up to 55 K	MAHESH M GHATE
Gyrokinetic simulation of multi-scale Ion temperature gradient instabilities in the ADITYA-U Tokamak	AMIT KUMAR SINGH
Kelvin-Helmholtz instability in a compressible dust fluid flow	KRISHAN KUMAR
Particle-In-Cell simulation of electrostatic waves in the ionosphere	RAKESH MOULICK
Study of thermal performance of upgraded primary chamber of plasma pyrolysis system using CFD analysis	DEEPAK SHARMA

ANTYA HPC USERS' STATISTICS— NOVEMBER 2022

- **Total Successful Jobs — 3669**
- **Top Users (Cumulative Resources):**
  - **CPU Cores** — Amit Singh
  - **GPU Cards** — Shishir Biswas
  - **Walltime** — Vinod Saini
  - **Jobs** — Someswar Dutta

Acknowledgement

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

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