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A spacecraft during mission typically switches from chemical propulsion to electric propulsion once it lifts out of the Earth's gravity as the thrust requirement to drive it reduces substantially. Consequently, electric propulsion technology is commonly used for deep space mission, satellite orbit keeping and orbit correction. In the last few decades, the amount of man-made space junk (space debris) has increased enormously and has become a potential danger for space stations, space shuttles and other live satellites. A bi-directional plasma thruster, mounted on a satellite, can be used to remove space debris during satellite operation (Takahashi et al., Sci. Rep., vol. 8, 2018, p. 14417). A directed ion beam ejected from a plasma thruster imparts a net force on space debris to decelerate and facilitates manoeuvring and re-entry of space debris into the Earth's atmosphere where it can burn out. We present a detailed 1D3V PIC-MCC (particle in cell-Monte Carlo collision) simulation of a bi-directional plasma thruster. To this end, a PIC-MCC solver which resolves thruster axial direction and all three velocity dimensions is used to study a magnetic nozzle plasma thruster with both ends open (bi-directional plasma thruster). We show that such a bi-directional plasma thruster can be used to accelerate-decelerate a live satellite and also to remove space debris by altering the magnetic field spatial profile in the plasma expansion region.

Symmetric Magnetic Field Plasma Expansion: For

the symmetric magnetic field expansion case, the magnetic field expansion rate l_b is kept the same on both sides of the heating region. In principle, this kind of bi-directional thruster mounted on a spacecraft imparts zero net thrust on the device and can be

A bi-directional plasma thruster, simulated through a 1D3V PIC-MCC solver, demonstrates the potential to accelerate-decelerate satellites and effectively remove space debris by manipulating the magnetic field spatial profile in the plasma expansion region.

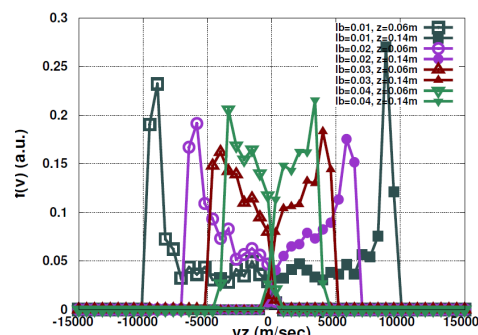


Figure 1 : Ion velocity distribution function at two symmetric spatial locations, $z = 0.06$ and $z = 0.14$ m, with respect to the heating region for a symmetric magnetic field expansion. Here, the Ar neutral pressure is fixed at 1.23 mTorr.

GANANAM (गणनम्)

HIGH PERFORMANCE COMPUTING NEWSLETTER
INSTITUTE FOR PLASMA RESEARCH, INDIA



Numerical Simulation Of A Bi-directional Plasma Thruster for Space Debris Removal

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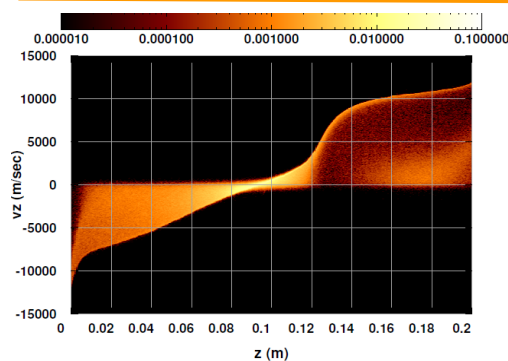


Figure 2 : Ion phase space plot for an asymmetric bi-directional plasma thruster. Left-hand side $l_b = 0.04$ and right-hand side $l_b = 0.01$.

used to impart a non-zero thrust on debris flying in space. Thus, a symmetric bi-directional plasma thruster can decelerate debris and push it into the Earth's atmosphere, where it will be burnt.

In figure 1, the ion velocity distribution function at two symmetric spatial locations, $z = 0.06$ and $z = 0.14$ m, with respect to heating region, is shown for the symmetric magnetic field expansion case. While the plasma expands into a diverging magnetic field, an electric field is generated in the bulk plasma and accelerates the charged particles. The strength of this electric field depends on the magnetic field expansion rate. For $l_b = 0.01$, which is the fastest rate of magnetic field expansion in our simulation, a directed ion beam having a velocity of approximately 9000 m s^{-1} is generated. The ion beam velocity reduces as l_b increases and, for $l_b = 0.04$, the ion beam shows a shifted Maxwellian velocity distribution. Broadening in the ion velocity distribution function is due to ion-neutral charge exchange collisions and electron-neutral ionization.

Asymmetric Magnetic Field Plasma Expansion :

The spatial magnetic field asymmetry in a bi-directional plasma thruster can produce a net momentum flux in a particular direction. This configuration, simultaneously, can be used in space debris removal and to control the live satellite velocity. This kind of bi-directional plasma

thruster can be mounted on a spacecraft and can be used to accelerate or decelerate the spacecraft depending upon the magnetic field

configuration.

In the following, we have shown the instantaneous ion phase space at $t = 25 \mu\text{s}$ for asymmetric magnetic field expansion cases. In figure 2, we have chosen $l_b = 0.01$ on the right of the heating region and $l_b = 0.04$ on the left side of the heating region to introduce an asymmetric B-field expansion. A directed ion beam is seen on the right of the heating region where the magnetic field expansion rate is high. Although ions get accelerated on the left-hand side of the heating region where $l_b = 0.04$, the amplitude of the directed beam is small in comparison with the right. Thus, this configuration produces non-zero net thrust in a particular direction to control the satellite speed.

Figure 3 shows the net ion thrust in a particular direction with an asymmetry parameter α . Here, we have defined $\alpha = (l_{b,\text{right}} - l_{b,\text{left}})/(l_{b,\text{right}} + l_{b,\text{left}})$, where $l_{b,\text{left}}$ and $l_{b,\text{right}}$ are the plasma expansion rates on the left and right sides of the heating region, respectively. Here,

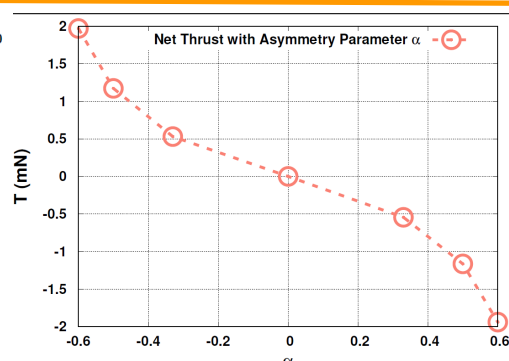


Figure 3 : Net ion thrust in a particular direction with an asymmetry parameter α , where the Ar neutral pressure is fixed at 1.23 mTorr. Here, we define $\alpha = (l_{b,\text{right}} - l_{b,\text{left}})/(l_{b,\text{right}} + l_{b,\text{left}})$, where $l_{b,\text{left}}$ and $l_{b,\text{right}}$ are plasma expansion rates on the left and right sides of the heating region, respectively.

thrust is defined as, $T = m' v_{\text{exh}}$, where m' (ion flow rate \times Ar atomic mass) is the ion mass flow rate and v_{exh} is the ion exhaust velocity at the thrust measurement spatial location. For $\alpha = 0$, the net ion thrust is zero, which is a symmetric case and this type of magnetic field configuration can be used to decelerate flying space debris. With an increasing asymmetry parameter α , the net ion thrust in a particular direction increases. For $\alpha = \pm 0.6$, the maximum ion thrust is achieved, having an amplitude of nearly 2 mN. Here, a positive thrust value indicates a net force on the right-hand side and a negative value indicates a net force on the left-hand side. In a real working device, both the direction and amplitude of the net ion thrust are controlled by a magnetic coil current and the fuel gas flow rate.

Our simulations presented here show that an asymmetric magnetic field configuration at both ends of the heating region can produce a net thrust in a particular direction depending upon the magnetic field spatial profile, demonstrating unambiguously that a bi-directional plasma thruster operational mode can be switched by changing the magnet coil current. In this configuration, for the parameters considered here, the maximum value of the net ion thrust, in a particular direction, is approximately 2 mN with $l_b = 0.01$ on the right-hand side and $l_b = 0.04$ on the left-hand side of the heating region. The net ion thrust reduces with decreasing magnetic field gradient in the expansion chamber.

Note: This set of simulations was performed at ANTYA, IPR using a single GPU node

References:

- Saini & R. Ganesh 2022 Numerical Simulation Of A Bi-directional Plasma Thruster For Space Debris Removal. *Journal of Plasma Physics*. 88(2):905880203.
- TAKAHASHI, K., CHARLES, C., BOSWELL, R.W. & ANDO, A. 2018b Demonstrating a new technology for space debris removal using a bi-directional plasma thruster. *Sci. Rep.* 8, 14417.
- MEIGE, A., BOSWELL, R.W. & CHARLES, C. 2005 One-dimensional particle-in-cell simulation of a current-free double layer in an expanding plasma. *Phys. Plasmas* 12, 052317.
- EBERSOHN, F.H., SHEEHAN, J.P., GALLIMORE, A.D. & SHEBALIN, J.V. 2017 Kinetic simulation technique for plasma flow in strong external magnetic field. *J. Comput. Phys.* 351, 358–375.

Step-by-Step Guide: Configuring Jupyter Kernels for Multiple Virtual Environments

Configuring Jupyter kernels for multiple virtual environments can significantly enhance development workflow by isolating dependencies for different projects. This step-by-step guide will walk through the process of setting up separate kernels for distinct virtual environments, allowing user to manage package dependencies effortlessly.

Step 1: Creating new environment using miniconda3

create new environment using conda

```
[user@login1 ~]$ module load miniconda/3
```

```
[user@login1 ~]$ conda create --name test_env python=3.9
```

Step 2: Activate the environment

activate the newly created environment

```
[user@login1 ~]$ conda activate test_env
```

after activating the environment, environment changes to test_env

```
(test_env) [user@login1 ~]$
```

Step 3: Install ipykernel and dependencies for the project

install ipykernel using conda

```
(test_env)[user@login1 ~]$ conda install ipykernel
```

install all other dependencies needed for development workflow using conda or pip

```
(test_env)[user@login1 ~]$ conda install pandas numpy matplotlib
```

Step 4: Create kernel for your environment

create kernel for newly created environment, this kernel will encompass all the dependencies installed

```
(test_env)[user@login1 ~]$ python -m ipykernel install --user --name=test_env
```

Step 5: Launch Jupyter Notebook (Refer [Issue 3](#) here for configuring jupyter notebook in local browser)

The screenshot displays the Jupyter Notebook interface. At the top, there's a file browser showing a list of files: 'AdjustText Verification Steps.ipynb', 'jupyter_test.sh', 'jupyterlog.out', and 'port_forwarding.txt'. A dropdown menu is open, showing the 'test_env' kernel selected. Below this, the notebook interface shows a code cell with the following Python code:

```
In [1]: import matplotlib.pyplot as plt
import numpy as np

# Data for plotting
t = np.arange(0.0, 2.0, 0.01)
s = 1 + np.sin(2 * np.pi * t)

fig, ax = plt.subplots()
ax.plot(t, s)

ax.set(xlabel='time (s)', ylabel='voltage (mV)',
       title='About as simple as it gets, folks')
ax.grid()

fig.savefig("test.png")
plt.show()
```

The plot shows a sine wave oscillating between 0.0 and 2.0 mV over a time range of 0.00 to 2.00 seconds. The title of the plot is 'About as simple as it gets, folks'.

In the Jupyter interface, select the desired kernel for each notebook from the "Kernel" dropdown menu. With this setup, user can easily switch between different projects, each having its own special needs for software. The isolation of dependencies for individual projects ensures a clean and organized workspace, eliminating potential conflicts between packages. Ultimately, this setup enhances productivity by streamlining the management of project-specific requirements within the Jupyter Notebook environment.

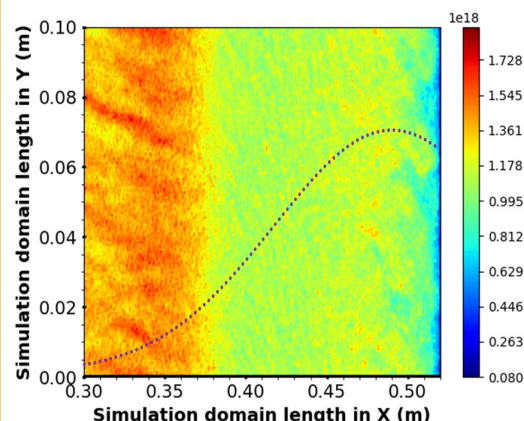
ANTYA UPDATES AND NEWS

1. New Packages/Applications Installed

To check the list of available modules

\$ module avail -l

HPC PICTURE OF THE MONTH



Pic Credit: [Miral Shah](#)

Title: Plasma Density in a Transverse Magnetic Filter Field

Description: This study presents a 2D snapshot of ion density in (m^{-3}), in the domain of an XY-plane and a magnetic field (7 mT shown by purple dotted line) perpendicular to the plasma flow in the ROBIN negative ion source. Using a 2D-3V PIC-MCC model, strip structures suggestive of instabilities were identified within the ROBIN configuration in the presence of the transverse magnetic filter. The study aims to investigate the impact of the transverse magnetic filter on plasma density and the formation of instabilities in the ROBIN negative ion source

1] M. Shah, B. Chaudhury, and M. Bandyopadhyay, "Investigation of EDF evolution and charged particle transport in ExB plasma based negative ion sources using kinetic simulations," *Sci. Rep.*, vol. 13, no. 20044, pp. 1–11, 2023, doi: 10.1038/s41598-023-45656-5.

TIP OF THE MONTH

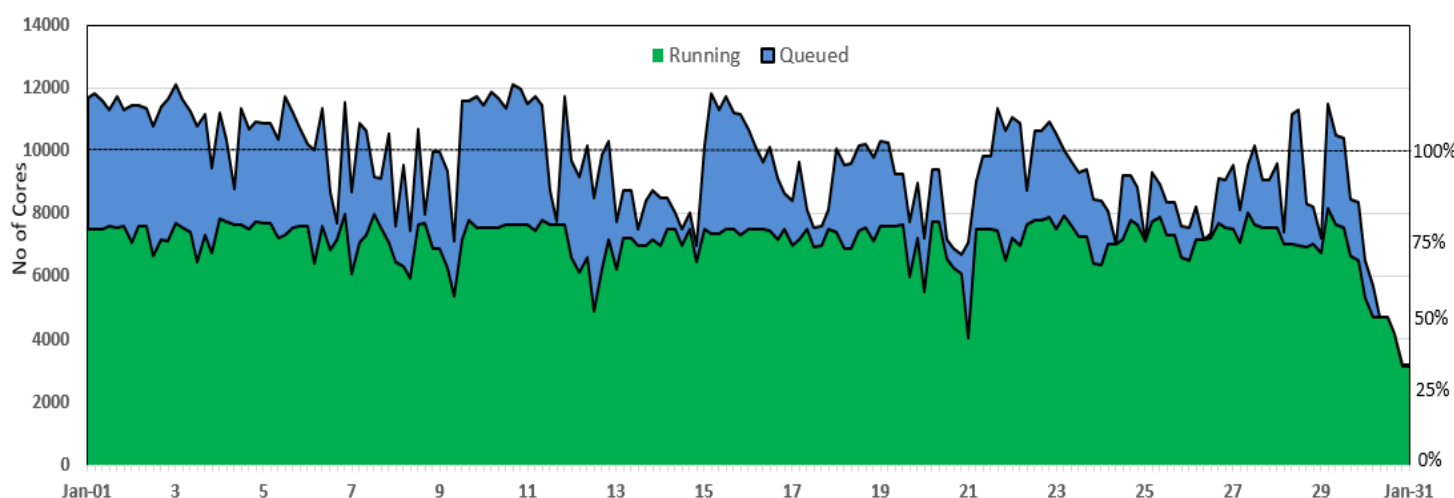
Singularity containers in HPC ensure portability and reproducibility for scientific applications, enabling seamless deployment across diverse clusters with compatibility for various system architectures and software dependencies. To run a Singularity container image in an HPC environment, type

\$ singularity exec container_path exe_in_container

```
[user@cn231 ~]$ singularity exec
/home/user/container
/path/to/exe/in/container
```

ANTYA Utilization: January 2024

ANTYA Daily Observed Workload



Other Recent Work on HPC (Available in IPR Library)

Destabilization of a toroidal electron plasma vortex by ions via impact ionization of background neutrals	R. Ganesh
Ubiquitous Modes in Tokamaks	Sagar Choudhary
Off-target gradient driven flows in 3D simulations of ADITYA-Upgrade tokamak scrape-off-layer plasma transport	Arzoo Malwal
Nuclear Analysis Requirements for Compact Fusion Pilot Plants	Shishir P. Deshpande
Numerical Simulation Of An Expanding Magnetic Field Plasma Thruster: A Comparative Study For Argon, Xenon and Iodine Fuel Gases	Vinod Saini
On Rotation/spin of Plasma Blob in Edge and Scrape-off Layer Regions	Nirmal K. Bisai
Numerical Simulation of an Expanding Magnetic Field Plasma Thruster Using Iodine Fuel	Vinod Saini
Radiation conditions improvement in ITER tokamak complex due to leakage through penetration	Jyoti Agarwal
TRAPPED ELECTRON COUPLED ITG TURBULENCE SIMULATION FOR ADITYA-U	Amit Kumar Singh
Development of a Monitoring Dashboard for High Performance Computing (HPC) Cluster to Enable Better Utilization of the Resources	Hemant Durgaprasad Joshi

ANTYA HPC USERS' STATISTICS— JANUARY 2024

Total Successful Jobs~ 1435

♦ Top Users (Cumulative Resources)

• CPU Cores **Amit Singh**

• GPU Cards **Suruj Kalita**

• Walltime **Vinod Saini**

• Jobs **Souvik Mondal**

Acknowledgement

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

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