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GPU accelerated preconditioning of the plasma kinetic equation

Why Simulate Plasma?

The more we understand how plasma behaves in a tokamak, the closer we get to achieving sustainable **net fusion energy**.

A **tokamak** is a device which uses a powerful magnetic field to confine plasma in torus shape in order to produce controlled thermonuclear fusion power.

We simulate fusion plasmas in tokamaks using their macroscopic fluid quantities.

To do this, **we solve the kinetic equation** to provide closures or solutions to those fluid equations which gives the most accurate representation of the plasma behavior.

First Order Kinetic Equation

$$\frac{\partial g_1}{\partial t} + \mathbf{v}_{\|}\cdot\left[\nabla g_1 - \frac{1-\xi^2}{2\xi}\nabla \ln B \frac{\partial g_1}{\partial \xi}\right] - \sum_b C(g_1, f_{0b}) = -\mathbf{v}_D\cdot\left(\nabla \ln n_0 - \left(\frac{3}{2} - s^2\right)\nabla \ln T_0\right) f_0 - \frac{q}{T_0} f_0 \frac{\partial \phi_1}{\partial t},$$

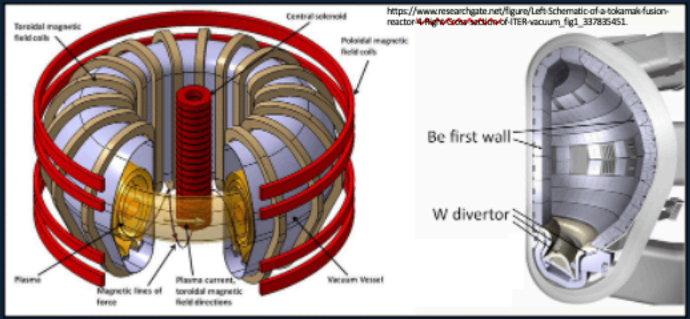
Bootstrap Current

$$\langle J_{\|} B\rangle = \sum_b q_b \left\langle B \int d\mathbf{v}\, v_{\|} f_{1b} \right\rangle,$$

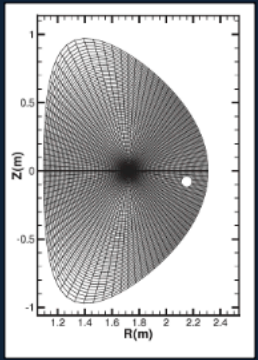
How Do We Solve This?

NIMROD, or the Non-Ideal MHD with Rotation Open Discussion, solves non-MHD equations with kinetic closures. It produces high level code to perform this.

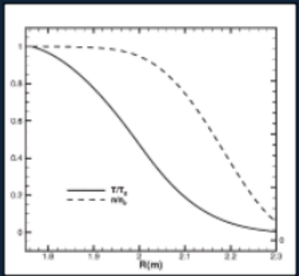
Even with the approximations NIMROD's code makes, the calculations can be complicated and time-consuming, even with the **use of supercomputers**.

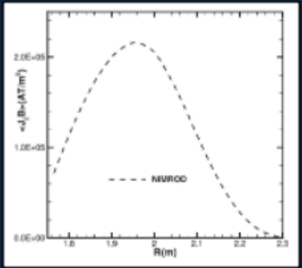


Tokamaks are designed to efficiently sustain and contain plasma long enough to allow fusion

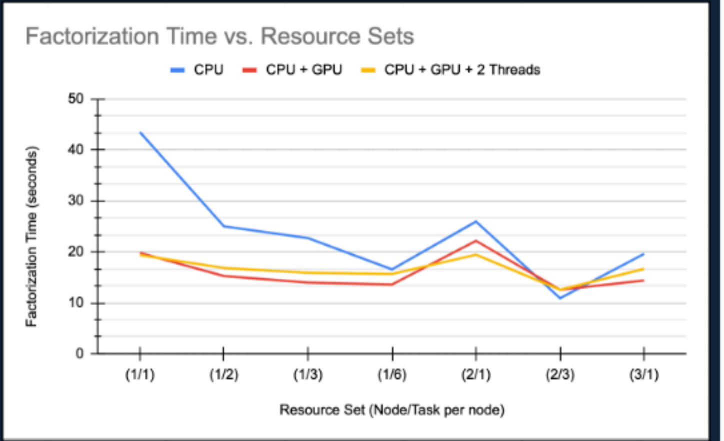


A plot of NIMROD's spatial grid which represents "1536 spatial unknowns"





(Above) A plot of temperature and density
(Below) NIMROD's solve for the bootstrap current based on input



Note the GPUs' effect decreases as the nodes increase, likely due to increased communication

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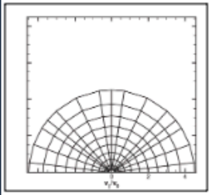
Preconditioning is Essential

Essential to NIMROD's computation of the kinetic equation is the **preconditioning** of matrices.

This is an **essential** step since it speeds up the solving for **700,000** unknowns shown in the coupling of the spatial and velocity grids



A plot of the NIMROD's velocity grid, showing that "there are 480 velocity space unknowns for every spatial node"

Recent changes in supercomputing architecture require NIMROD to determine how to utilize graphics processing units or **GPUs**

My research project was to study the efficiency of the GPU-enabled SuperLU, a third-party linear algebra package, when applied to the preconditioning process.

The Impact of GPUs

Utilizing the NERSC supercomputer, **Perlmutter**, I wrote scripts that allocated resource sets of varying CPUs, GPUs, threads, and nodes to precondition test matrices.

We see the factorization time **decrease significantly** when GPUs are employed, while the range of improvement decreases as the number of nodes increases

Overall, **the results** give us an understanding of how to utilize GPUs in the NIMROD code.

References

E.D. Held et. al, Physics of Plasmas 22, 032511 (2015)

C.R. Sovinec et. al, J. Comput. Phys., **195**, 355 (2004).