Kinetic simulation of turbulent plasma in nuclear fusion reactors

Reach out PTG@IISc

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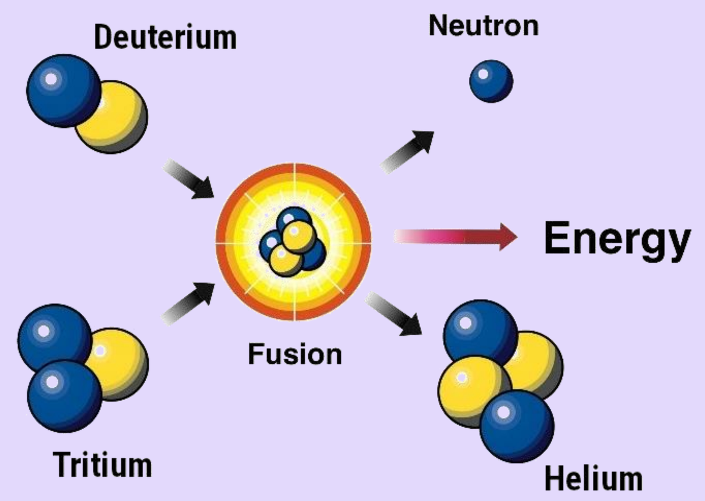
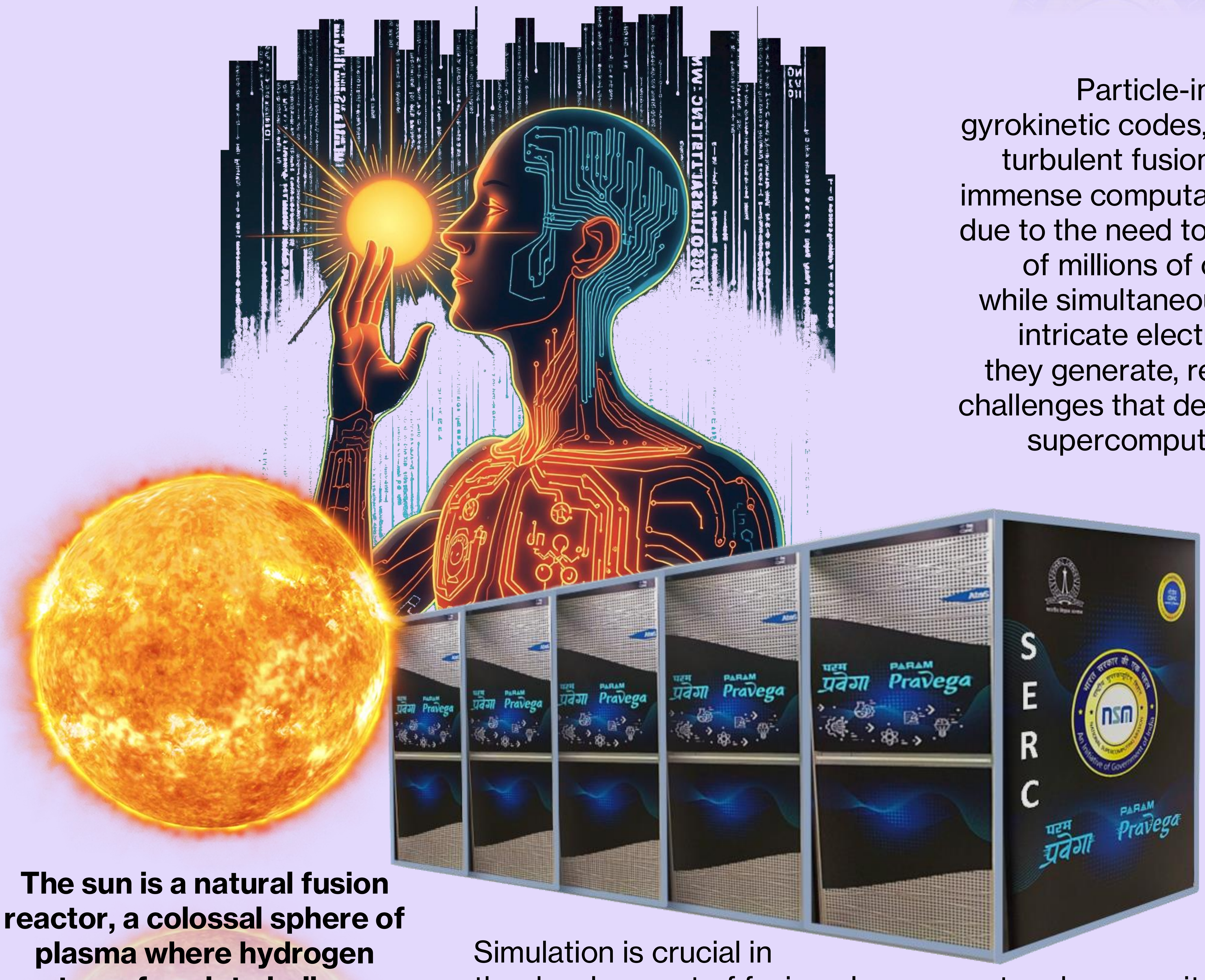




Particle-in-cell (PIC) based gyrokinetic codes, used to simulate turbulent fusion plasmas, exhibit immense computational complexity due to the need to track the motion of millions of charged particles while simultaneously resolving the intricate electromagnetic fields they generate, resulting in scaling challenges that demand large scale supercomputing resources for accurate and Comprehensive simulations.

Nuclear fusion holds the potential to be a transformative energy source for the future, offering several key advantages:

- Fusion primarily uses deuterium, which is readily available in seawater, and tritium, which can be produced from lithium. This makes the fuel supply virtually inexhaustible.
- Fusion reactions do not produce greenhouse gases, contributing to a cleaner atmosphere and mitigating climate change.
- While fusion produces some radioactive waste, it is significantly less than that produced by nuclear fission, and the radioactivity decays much more rapidly.
- Fusion reactions are inherently safe. If a disruption occurs, the reaction stops immediately.

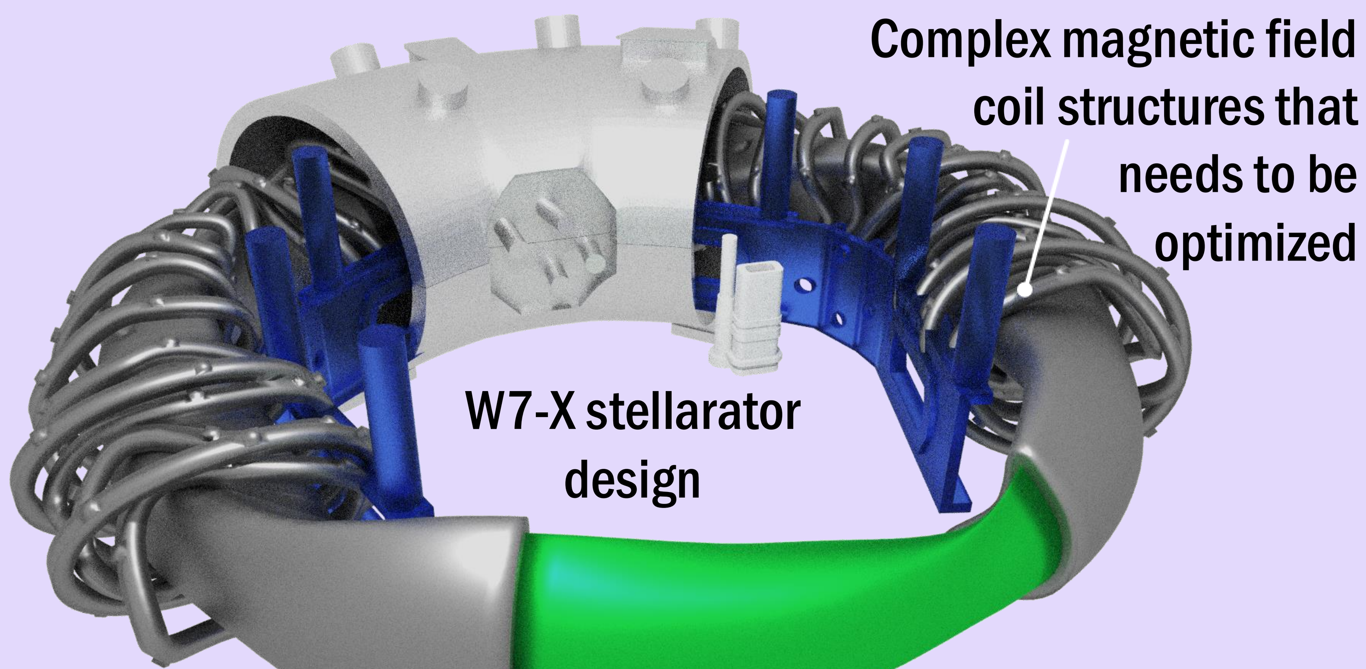
The sun is a natural fusion reactor, a colossal sphere of plasma where hydrogen atoms fuse into helium, releasing immense amounts of energy that sustain life on Earth.

Simulation is crucial in the development of fusion plasma reactors because it allows us to explore and understand the complex behavior of plasmas under extreme conditions without the prohibitive costs and risks associated with physical experiments.

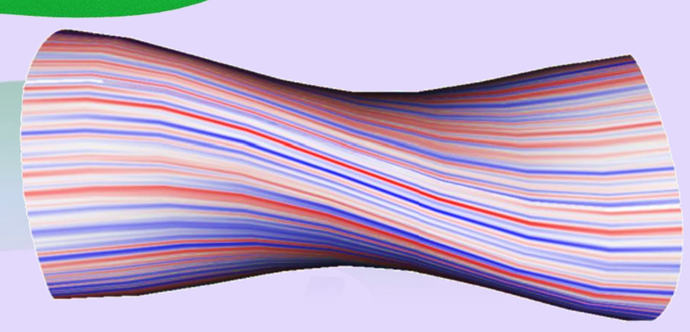
- **Technological Challenges:**
  - Achieving sustained and commercially viable fusion energy remains a significant scientific and engineering challenge. Maintaining the extremely high temperatures and pressures required for fusion is incredibly difficult.

The tokamaks and stellarators are two leading contenders for magnetic confinement based fusion reactors. While the sun's core reaches about 15 million degrees Celsius, fusion reactors on Earth need to operate at significantly higher temperatures, typically exceeding 100 million degrees Celsius, to achieve sufficient reaction rates due to the lower plasma density compared to the sun's core.

Turbulence in optimal stellarator designs



Our simulation studies in different stellarator designs reveal that zonal flows (self-generated, banded flows within the plasma) significantly reduce ion heat transport, improving confinement.



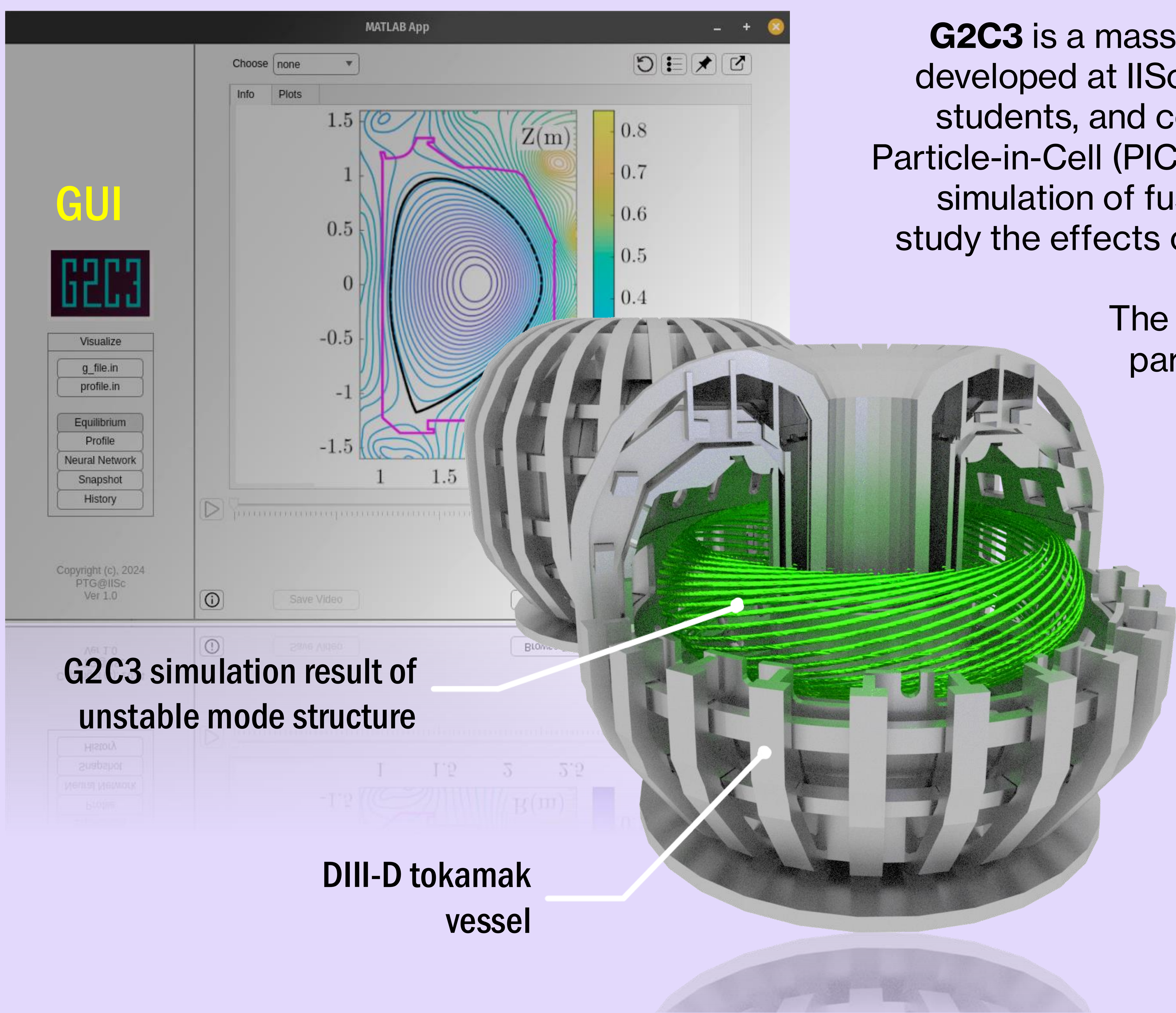
Turbulent mode structure in LHD stellarator

MAKE IN INDIA

G2C3

Global Gyrokinetic Code using Cylindrical Coordinate

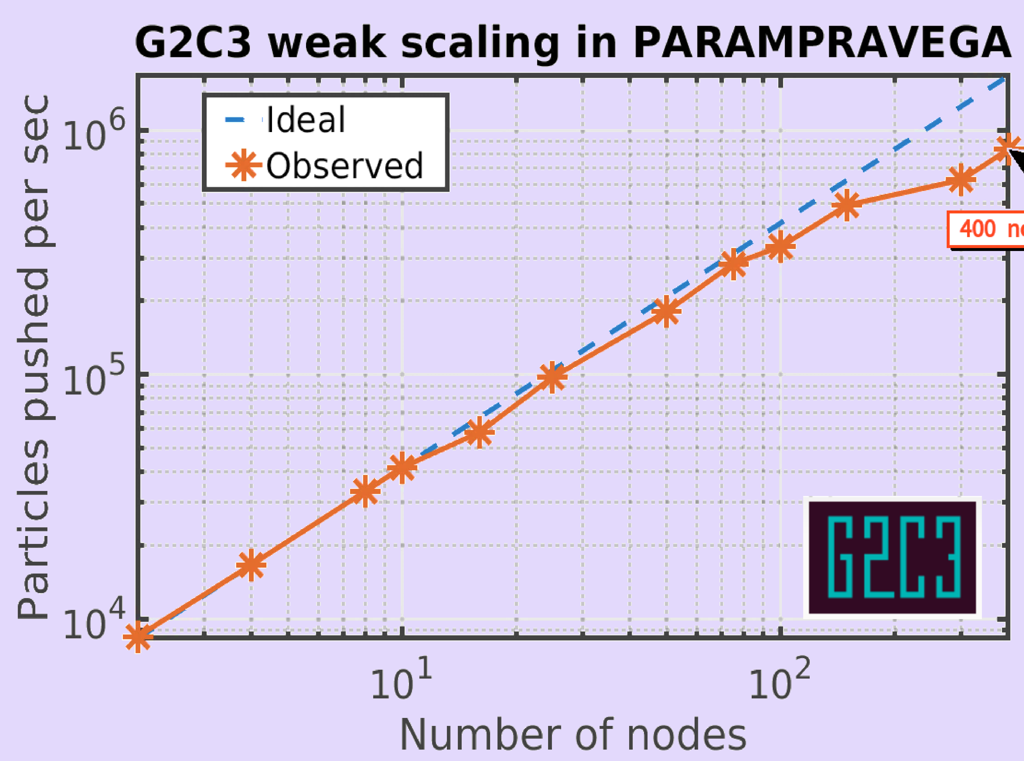
G2C3 GUI for data analysis



G2C3 is a massively parallel Indigenous code developed at IISc by a team of physicists, PhD students, and computational scientists. It is a Particle-in-Cell (PIC) code to perform gyrokinetic simulation of fusion plasma in a tokamak and study the effects of turbulence and instabilities.

The particles in the simulation are partitioned and allotted different MPI's, enabling an efficient Parallelization with ~ 10 million grid points and ~ 1 billion particles.

Scaling analysis



The G2C3 code demonstrates an approximate O(N) scaling of particle push throughput with node count, indicating efficient parallelization.

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