9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Towards visualizing multi-dimensional gyrokinetic simulation data

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The turbulent transport in magnetically confined plasmas is a complex phenomenon in fusion energy research – believed to be caused by micro-instabilities and to lead to reduced confinement time, pressure and operational performance. Understanding turbulent transport can have a significant impact in the design of a viable fusion reactor.

Researchers have been developing gyrokinetic simulation codes to study turbulent transport for decades.[1,2] These codes have large compute requirements – capable of operating at the exascale – and generate vast amounts of data – ranging from GBs to TBs for a single timestep. At UKAEA (United Kingdom Atomic Energy Authority) one of the gyrokinetic codes used is GKW (Gyrokinetic Workshop).[3]

GKW is a Vlasov code with a 5D formulation – 3 spatial and 2 velocity dimensions – employing a combination of finite difference and pseudo spectral methods.[1] Additionally, there's the multi-dimensionality associated with all field data produced (e.g. potential, density, and temperature). Furthermore, the simulation happens on a transformed fixed-grid domain that follows the magnetic field lines and is not trivially visualizable in the toroidal geometry of a Tokamak.

Some work has been done in the past in visualizing gyrokinetic data with various rendering techniques (from point to volume rendering) and integrating the multi-dimensionality of the data into intuitive applications.[4,5] Also, work has been done showing the advantages of using advanced visualization tools such as Nvidia Omniverse for various complex fusion use cases.[6,7]

In this work we aim to combine both research efforts and showcase the development of UKAEA's visualization capabilities surrounding GKW's multi-dimensional simulation data (see Figure 1). Our main goal is to develop visualization workflows that: (i) rely on modern tools for computer graphics and visualization – such as Blender, Omniverse and ParaView; (ii) use state-of-the-art computing platforms and hardware – such as modern HPC infrastructure (e.g. Nvidia OVX) (iii) suit a variety of end products and target audiences – from impactful images and videos to fully-fledged interactive experiences; and (iv) enhance the ability to explore and use the data – enable everyone from plasma physicists to data scientists reach new findings that would not be possible otherwise.

We believe that this work has the potential to change how scientists working with gyrokinetic data interact with and leverage advanced visualizations to further their research.

References
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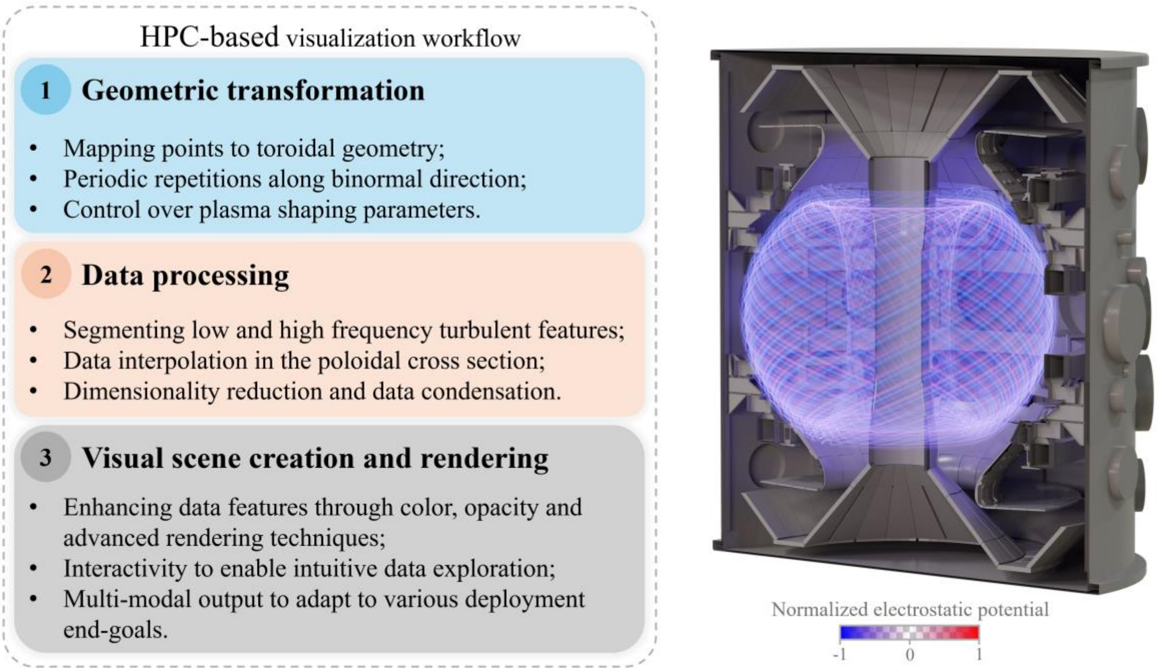

Figure 1. Outline of visualization workflow for multi-dimensional gyrokinetic data consisting of three main processes from raw simulation data to visualization output; featuring an example render of the electrostatic potential data of a simulation test case as an emissive volume within the Mast-U CAD model.