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19 November 2025
Second Visualizing Offline and Live Data with AI (VOLDA) Workshop

# Towards accessible multivariate visualisations of gyrokinetic data

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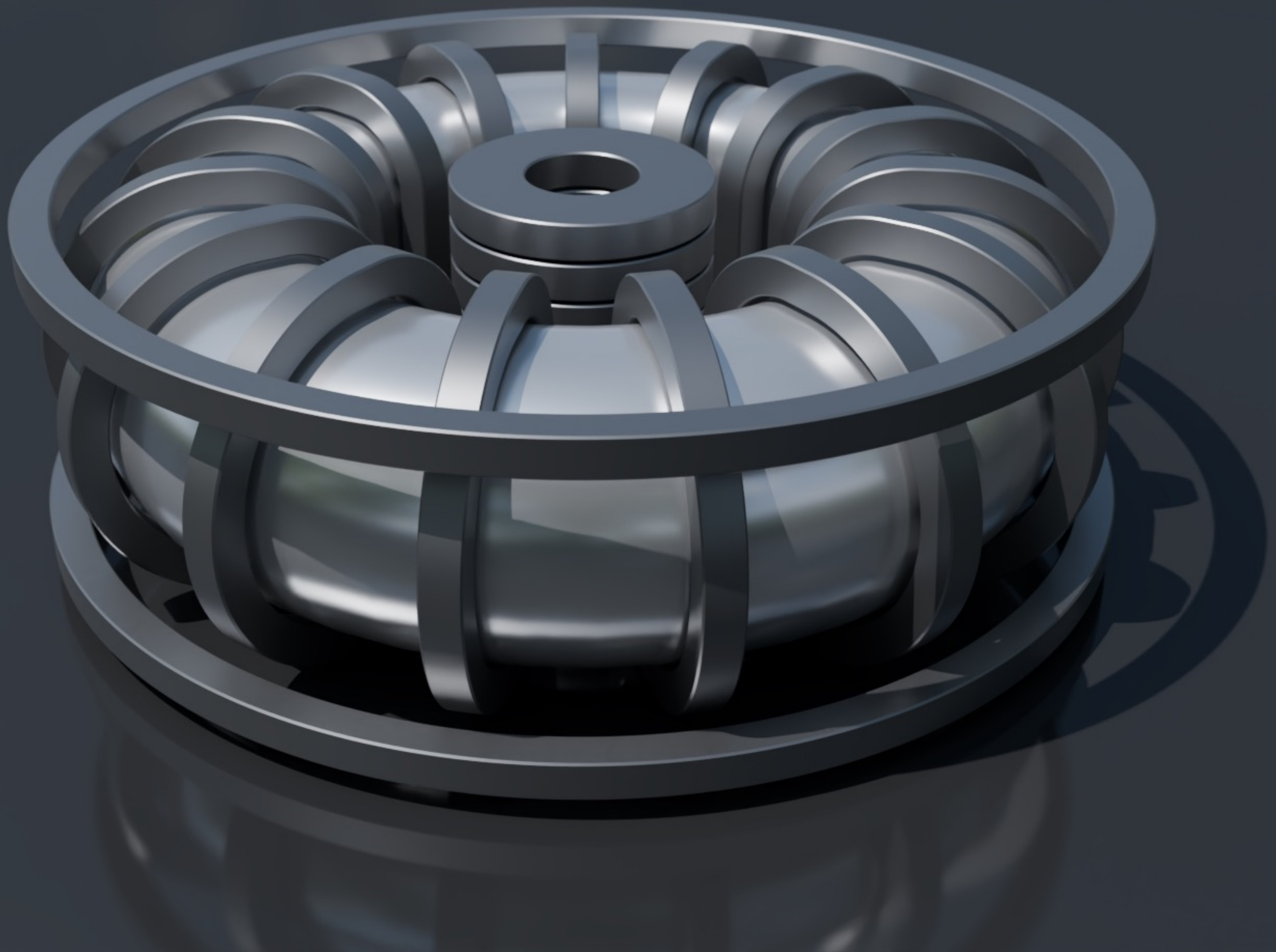

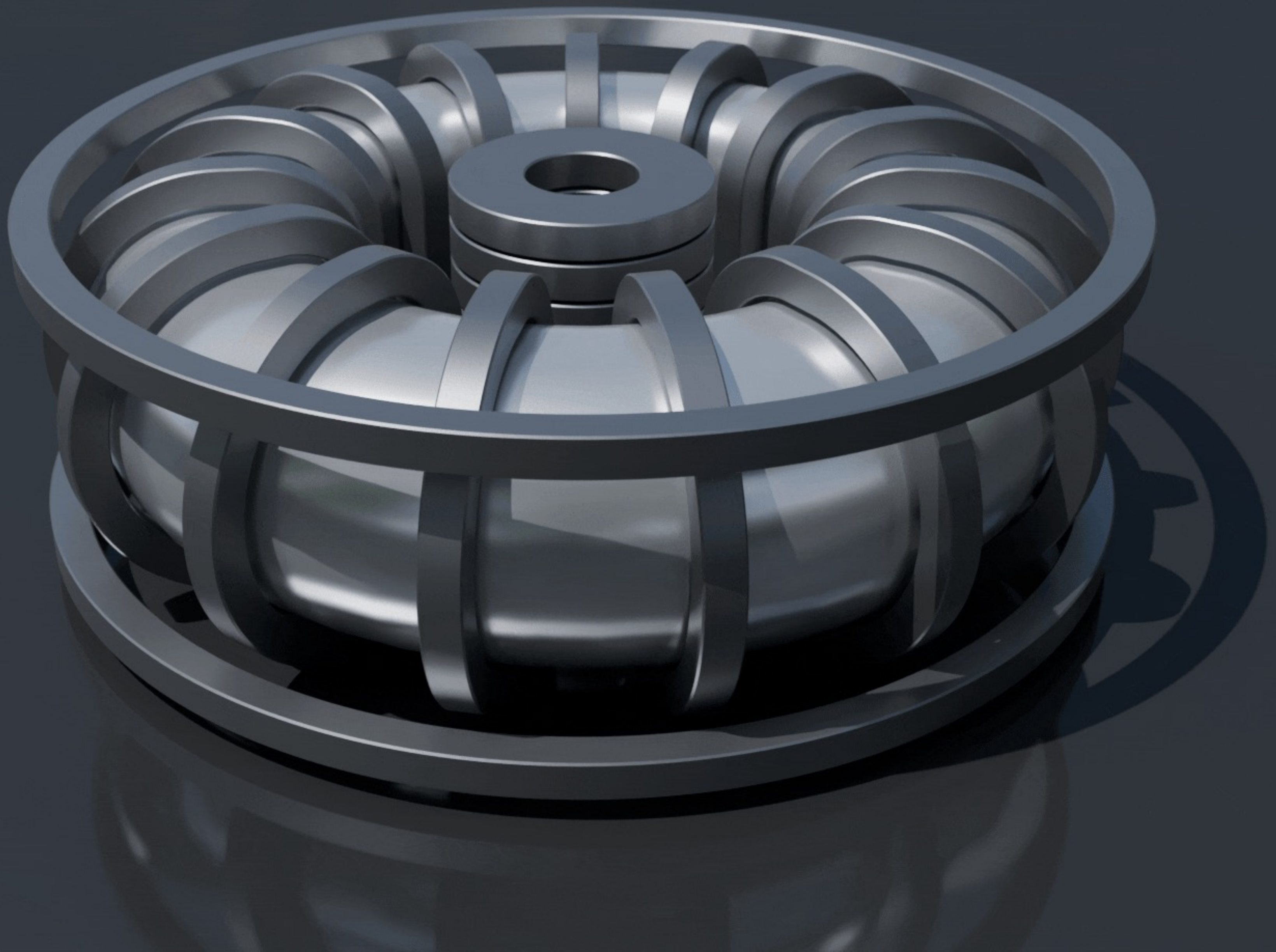

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1. Background
2. Data workflow
3. Advanced Visualisation
4. Outlook

# 1 Background

# Literature

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- Scientific exploration of multi-faceted (multi-dimensional, multi-variate, multi-modal, etc.) data requires effective visualisations; [1][2][3]
- There isn't a one size fits all solution for all applications. [1][2][3]
- Some possible techniques include:
  - 2D or 3D layering; [1]
  - Data fusion; [1]
  - Dimensionality reduction; [2]
  - Clustering; [2]
  - Advanced rendering; [3]


[1] J. Kehrer, H. Hauser, IEEE TVCG, 2012
[2] S. Liu et al, IEEE TVCG, 2016
[3] N. Bhatia et al, Front. Phys, 2025


- There is work in the literature on visualising gyrokinetic data; [4][5][6][7]
- Workflow is often tailored to a specific code and has different characteristics whether it's a particle code [4] or a continuum code [5][6][7];

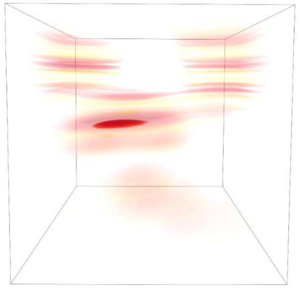

*Image from [5]*

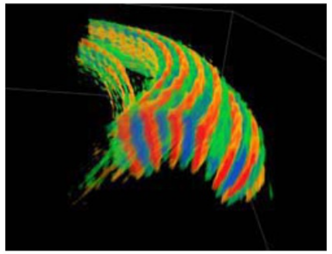

*Image from [6]*

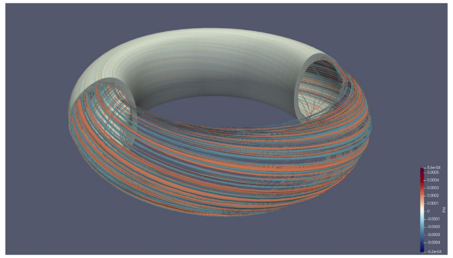

*Image from [7]*


[4] C. Jones et al, IEEE MCSE, 2008
[5] G. Stantchev et al, IEEE TPS, 2008
[6] D. Crawford et al, IEEE Visualization, 2004
[7] E. Feibush et al, Front. Phys., 2025

# Introduction to GKW

- Nonlinear gyrokinetic flux tube code, GKW; [1]
- Simulates micro instabilities and turbulence in magnetically confined plasmas;
- Massively parallel;
- Operates on a 5D distribution function;
- Outputs 3D field data;

## GKW

GKW is a gyro-kinetic simulation code for the study of turbulence in magnetised plasmas developed from the original linear code LINART.

*Copyright (C) 2003, 2004, 2005* A.G. Peeters, D. Strintzi

*Copyright (C) 2007, 2008, 2009, 2010, 2011* A.G. Peeters, Y. Camenen, F.J. Casson, W.A. Hornsby, A.P. Snodin, D. Strintzi, G. Szepesi

*Copyright (C) 2012, 2013, 2014, 2015* A.G. Peeters, Y. Camenen, F.J. Casson, W.A. Hornsby, A.P. Snodin, D. Strintzi, G. Szepesi, R. Buchholz, S. Grosshauser, P. Manas, P. Migliano, M. Siccinio, T. Sung, D. Zarzoso

| Repository | Description | Size | Last updated |
|---|---|---|---|
| gkw<br>Gyrokinetic Workshop | Gyro-kinetic simulation code for the study of turbulence in magnetised plasmas. A tool for fusion energy research. | 74.2 MB | 6 days ago |



[1] A.G. Peeters et al, Comp. Phys. Comm., 2009

# Challenges of visualising gyrokinetic simulation data

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- Disparity between simulation domain and “real” domain;
- Complex data features;
- Average feature size is much smaller than dataset bounds;
- Multi-dimensional and multi-variate data:
    - 5D distribution function + time;
    - $n_{\text{fields}} \times$ 3D field variables + time;
    - $n_{\text{moments}} \times$ 3D moments of distribution function + time;
- Expensive visualisation computation.

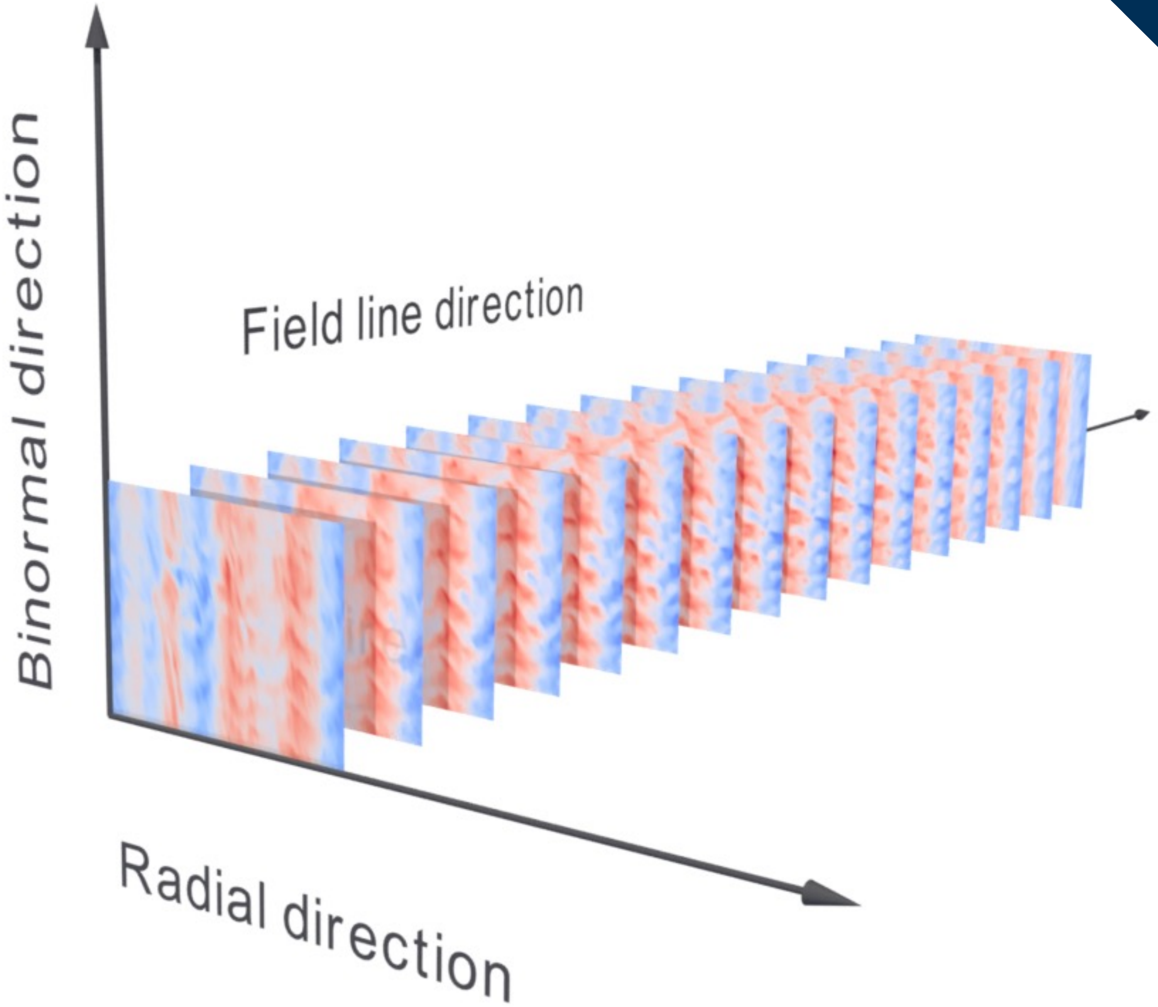
**Our goal: create reproducible and accessible workflows to alleviate some of these challenges!**

2

# Data workflow

# Data format

- 3D grid of quantities integrated in velocity space;
- $n_x \times n_y \times n_s$ grid
  - $n_x$ points in the *radial* direction;
  - $n_y$ points in the *binormal* direction;
  - $n_s$ points in the *field line* direction;
- Each point in one of the $n_s$ “slices” has the same “poloidal angle” in a toroidal coordinate system;
- The simulation domain is periodic along the binormal direction.

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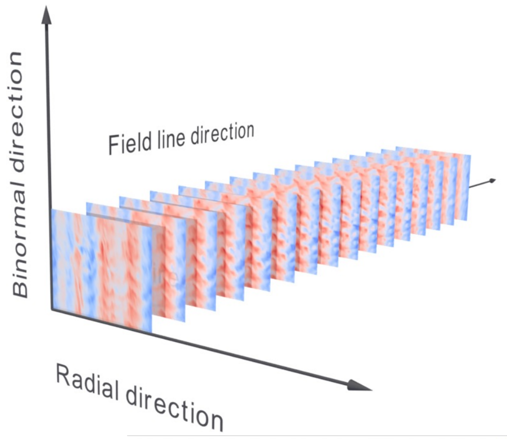
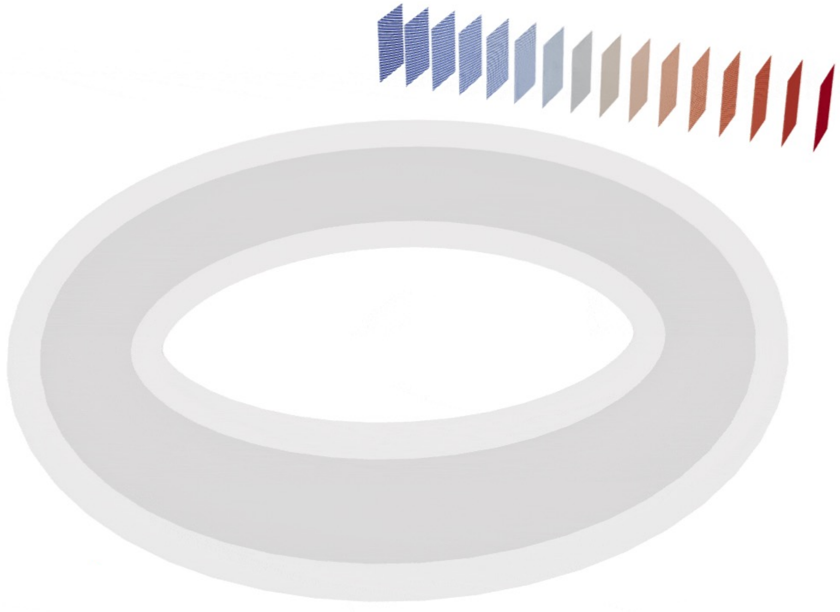
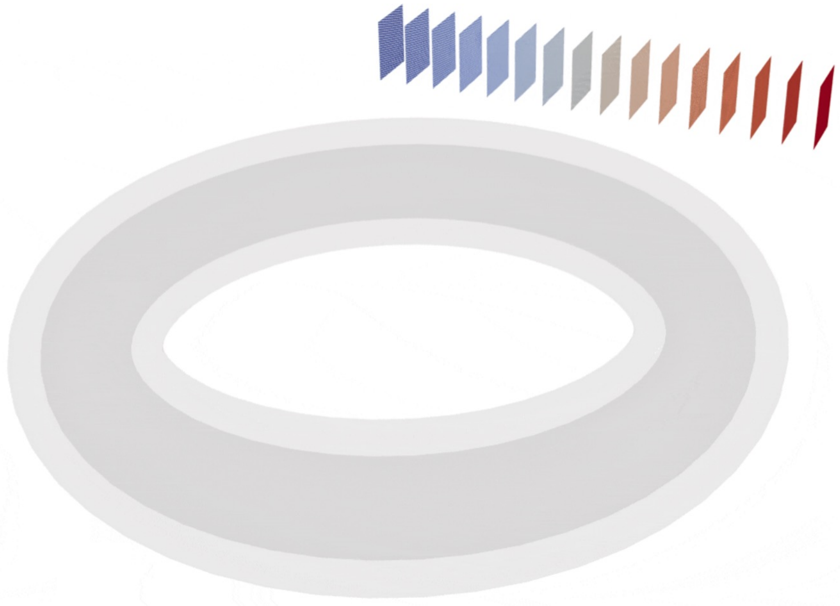
# Data processing

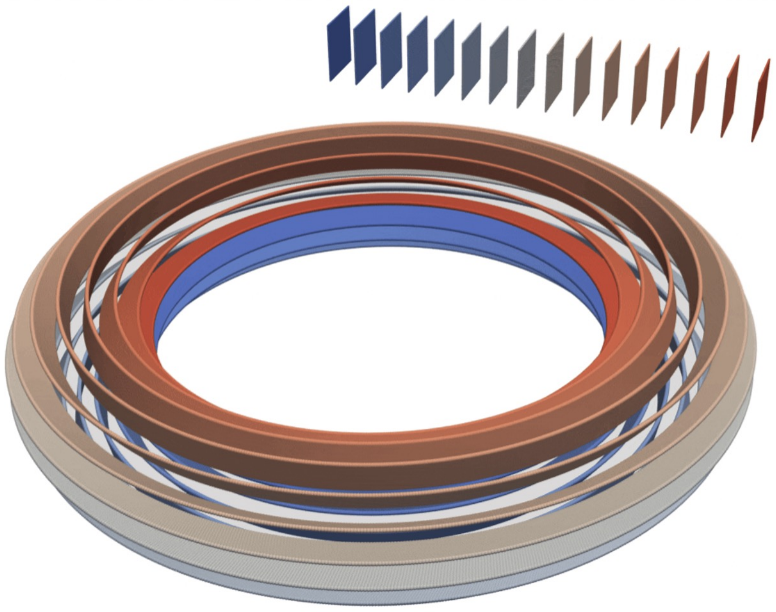


Coordinate transformation



Repetition along periodic *binormal* direction



Upscaling

# Data processing

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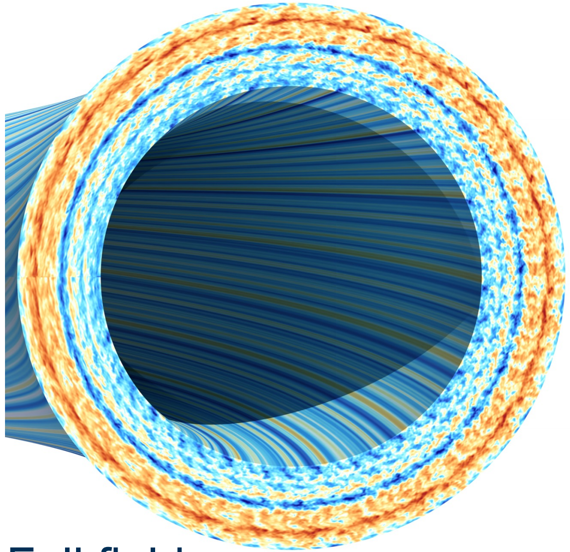
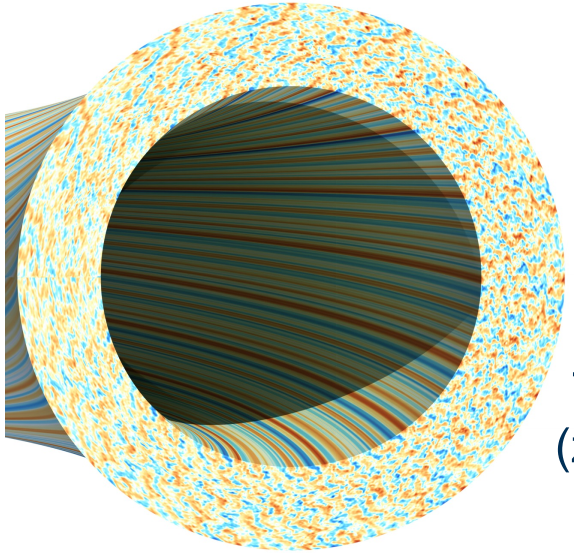
Shaping through Miller parameters



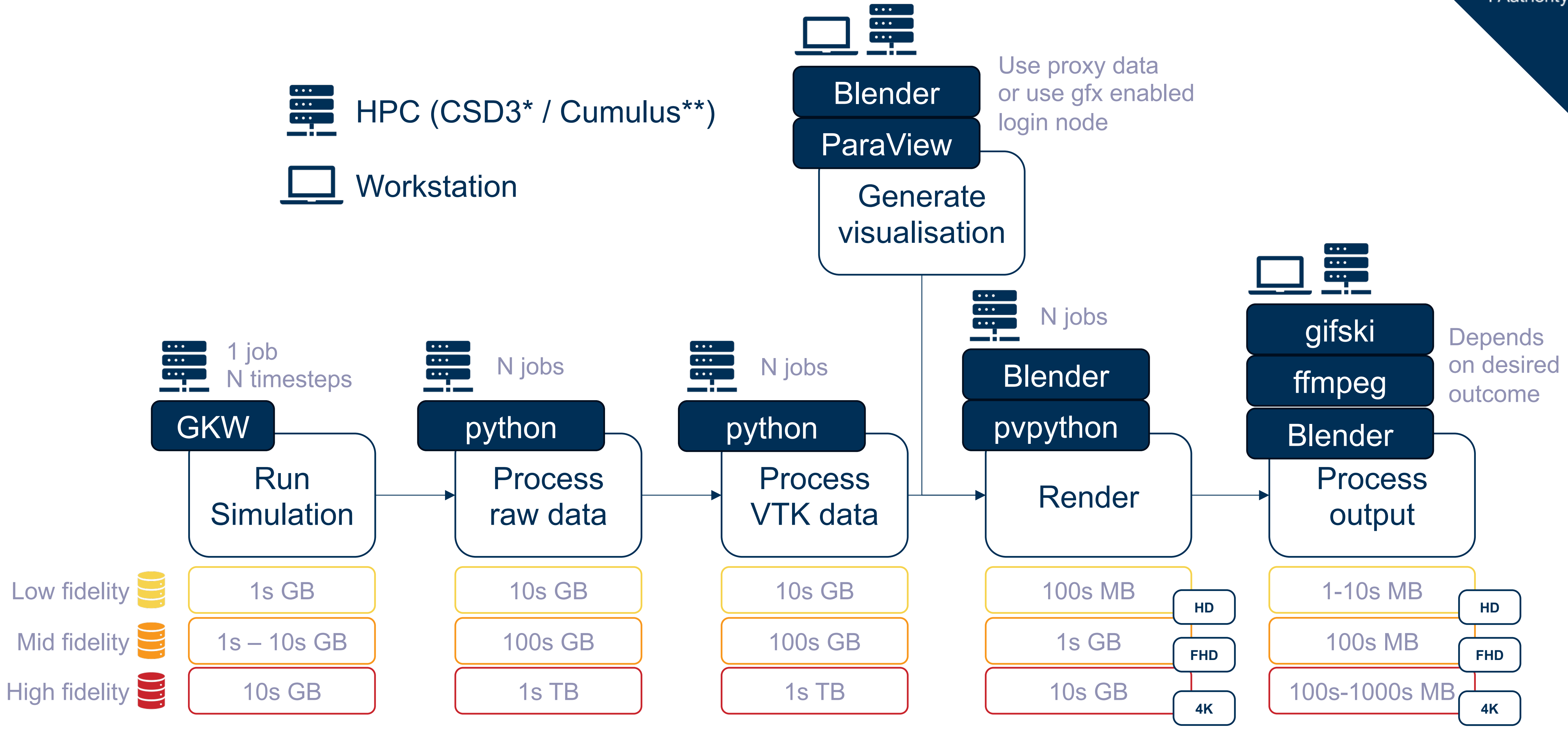
Full field

Zonal flow (zero frequency only)



Turbulent flow (zero frequency removed)

# Workflow

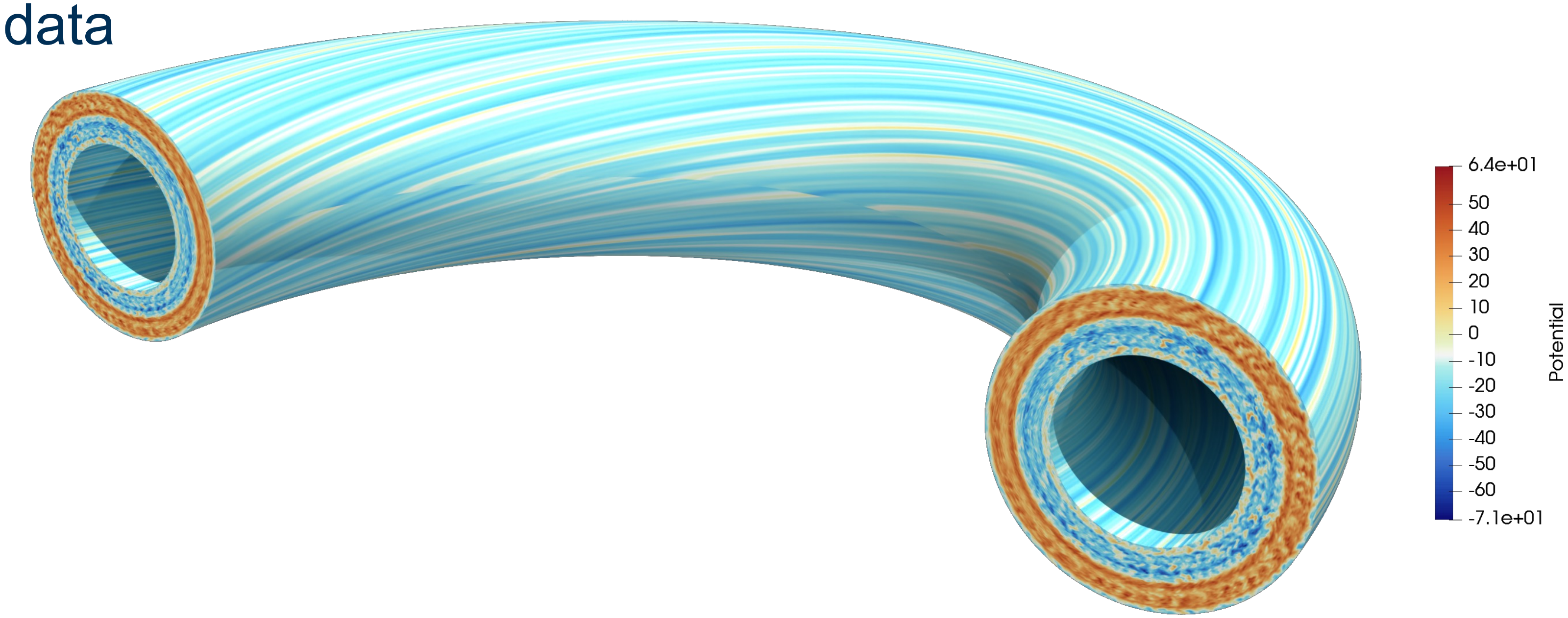



* Cambridge University HPC facilities
** UKAEA local HPC facilities

# 3 Advanced Visualisation

# The dataset

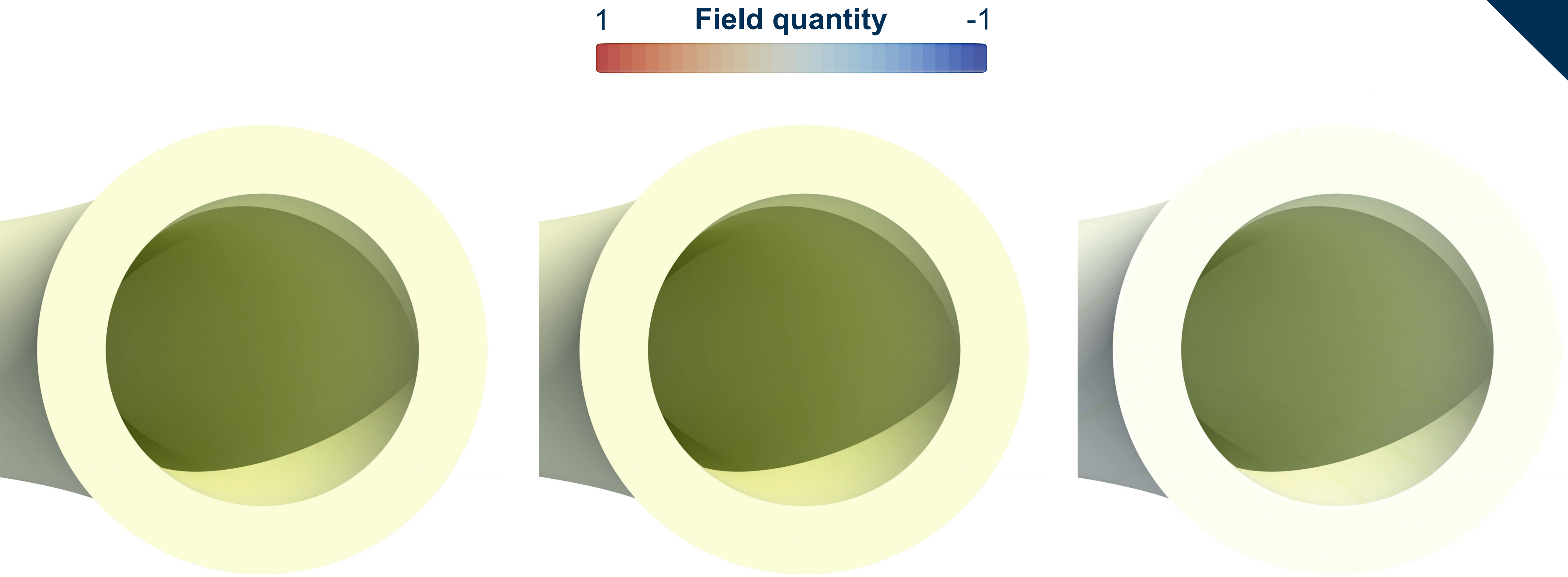
- GKW simulation from a cyclone benchmark*:
  - ~3 GB of raw output in total;
  - 266 timesteps;
  - Well resolved in *binormal* and *radial* direction;
  - Upscaled by a factor of 50 in the *field* direction;
  - ~12 GB of upscaled VTK data per timestep;
  - Field output includes:
    - Electrostatic potential;
    - Density;
    - Temperature;




* Benchmark of *DIII-D* like circular plasma

# Solid rendering

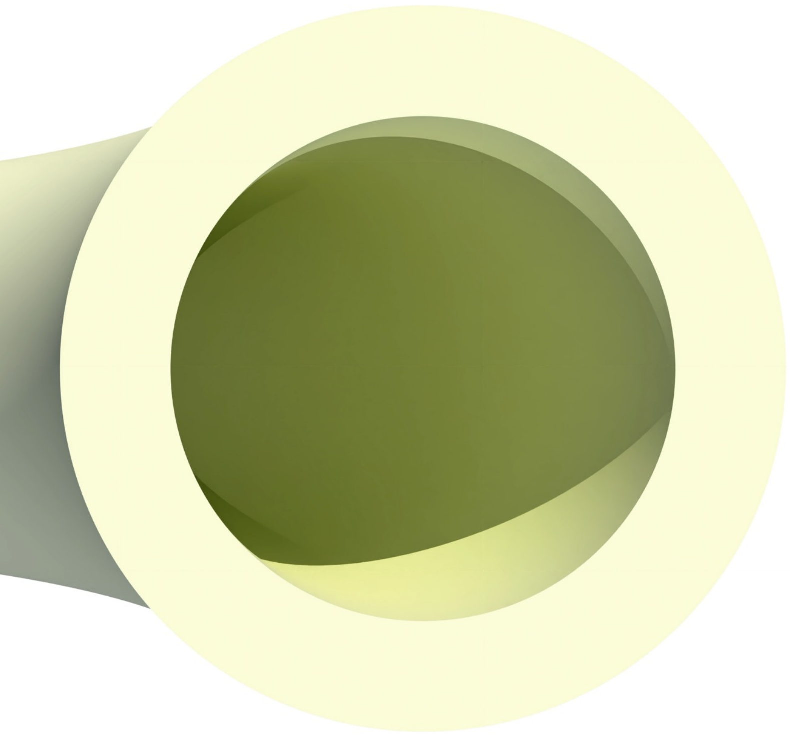


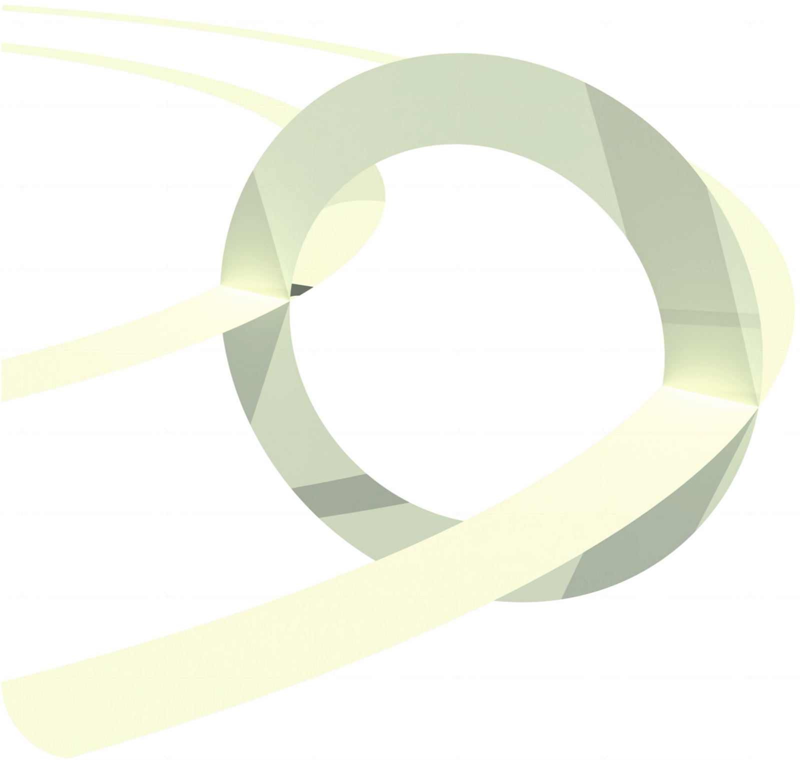


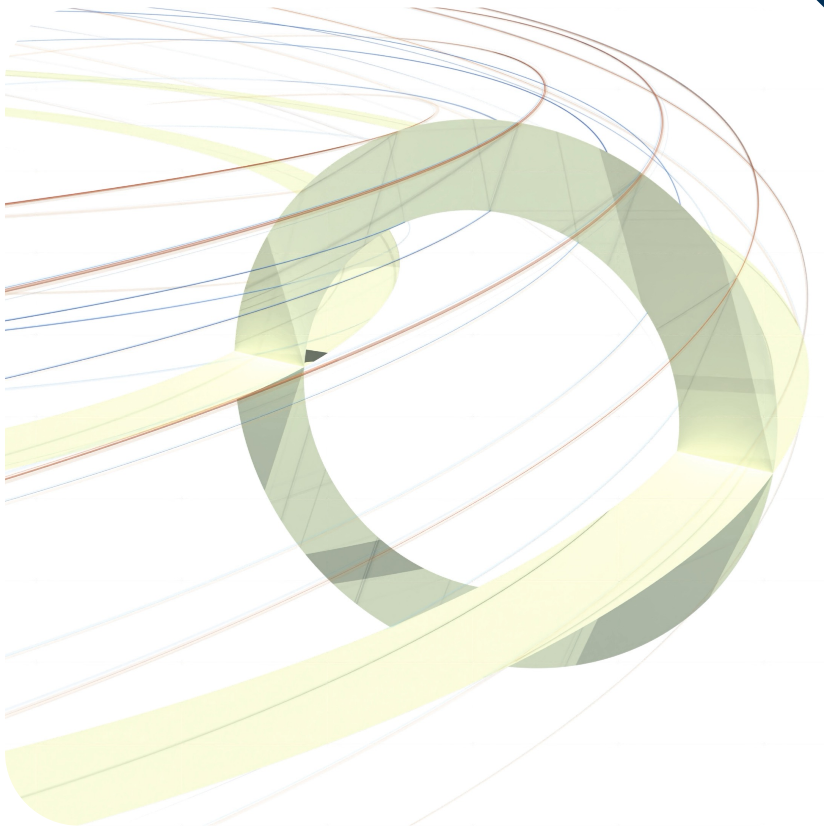

Potential | Density | Temperature

# Solid rendering





Clipped mesh


Mesh slices


Mesh slices with Potential isosurfaces

# Volume rendering

# Volume rendering

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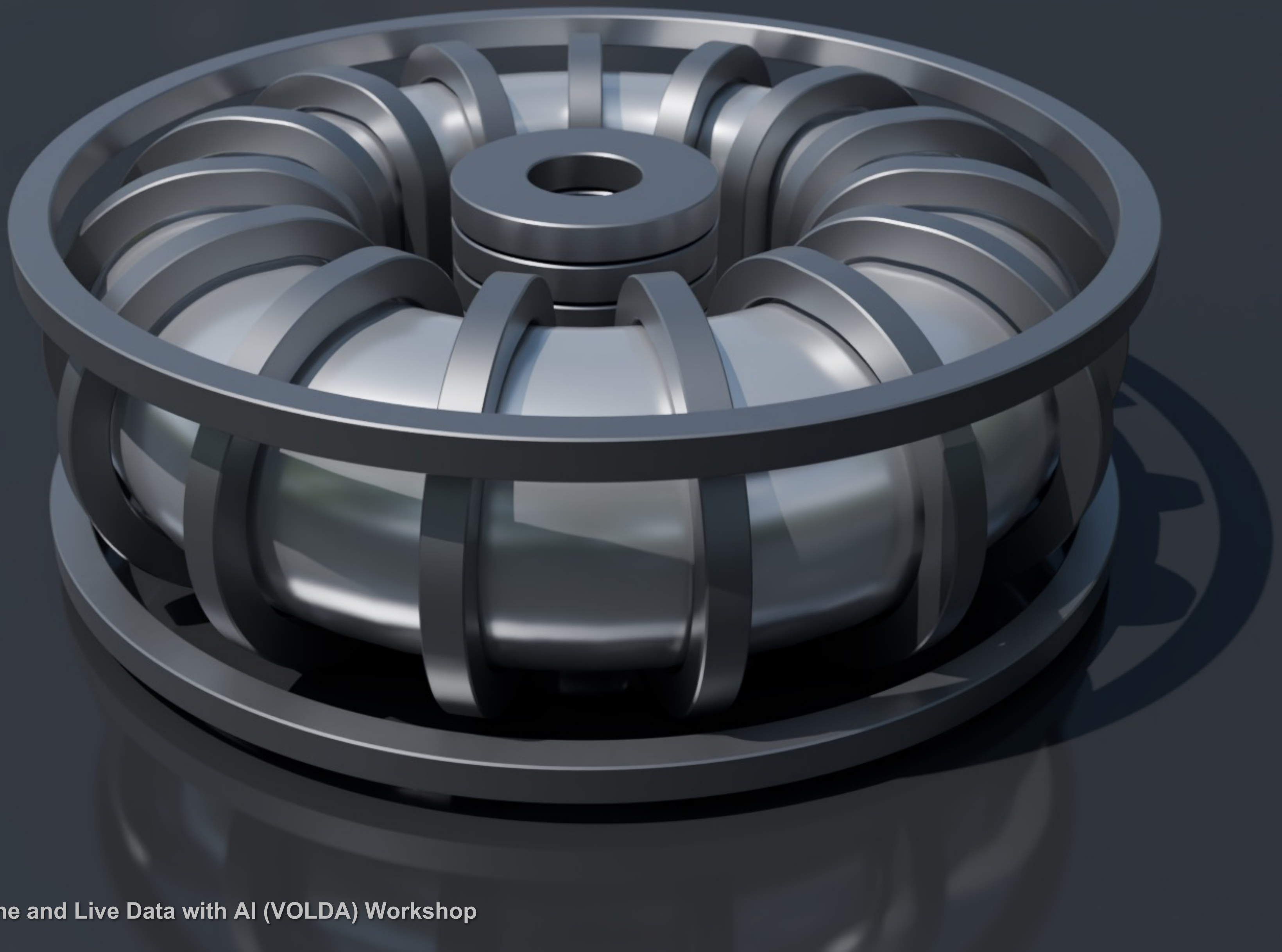

# Volume rendering

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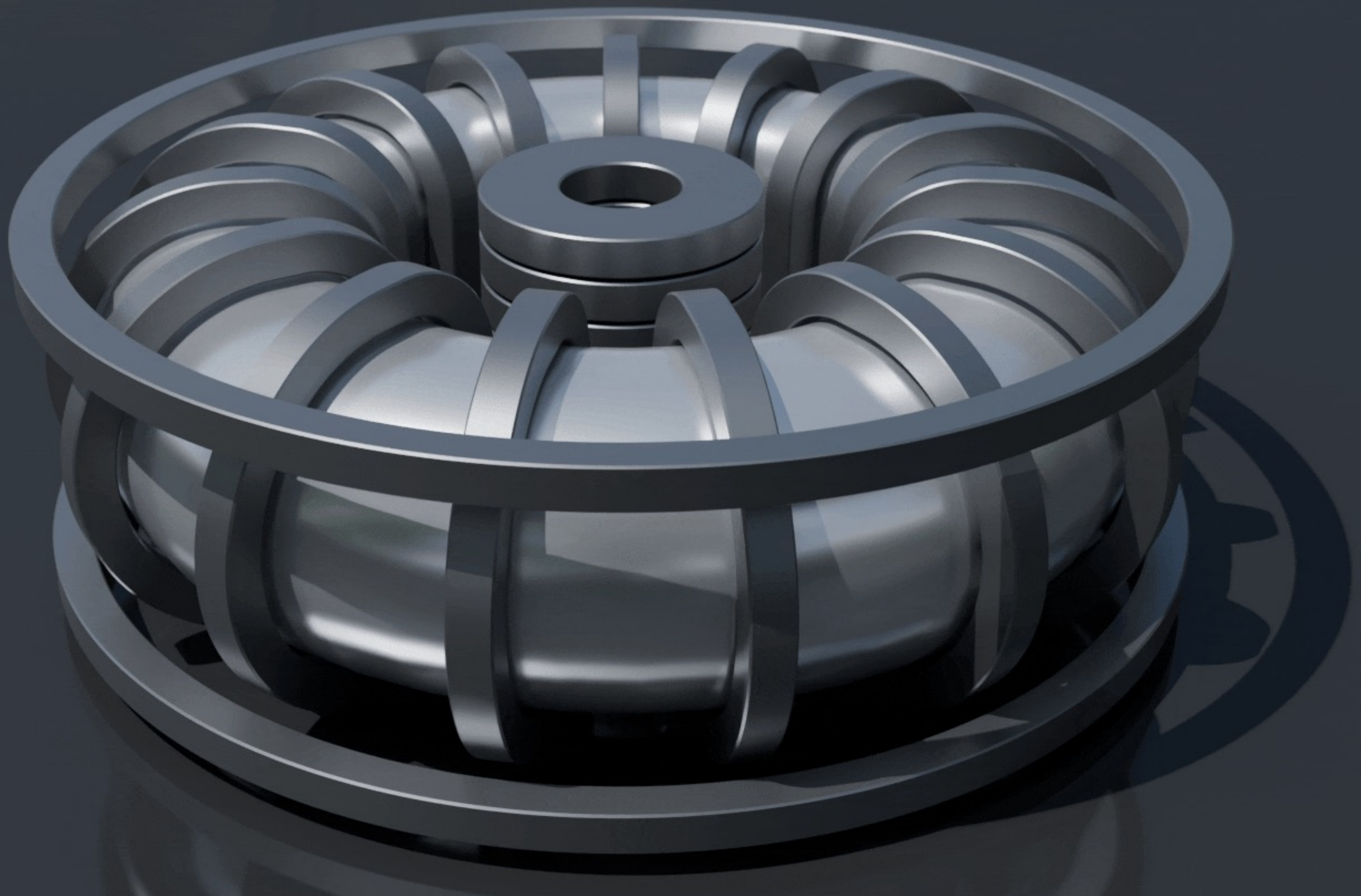

# Volume rendering

# Volume rendering

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# Volume rendering

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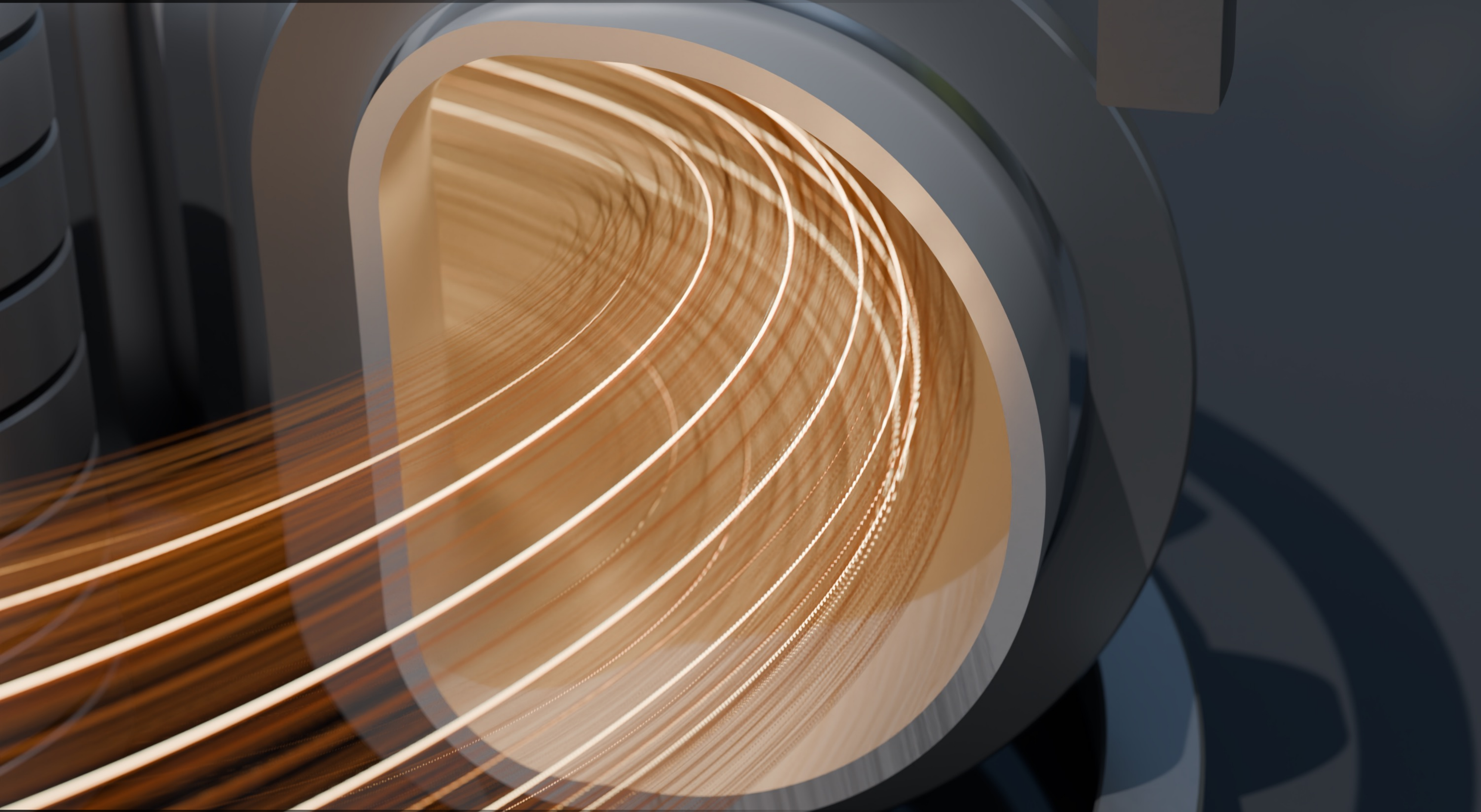
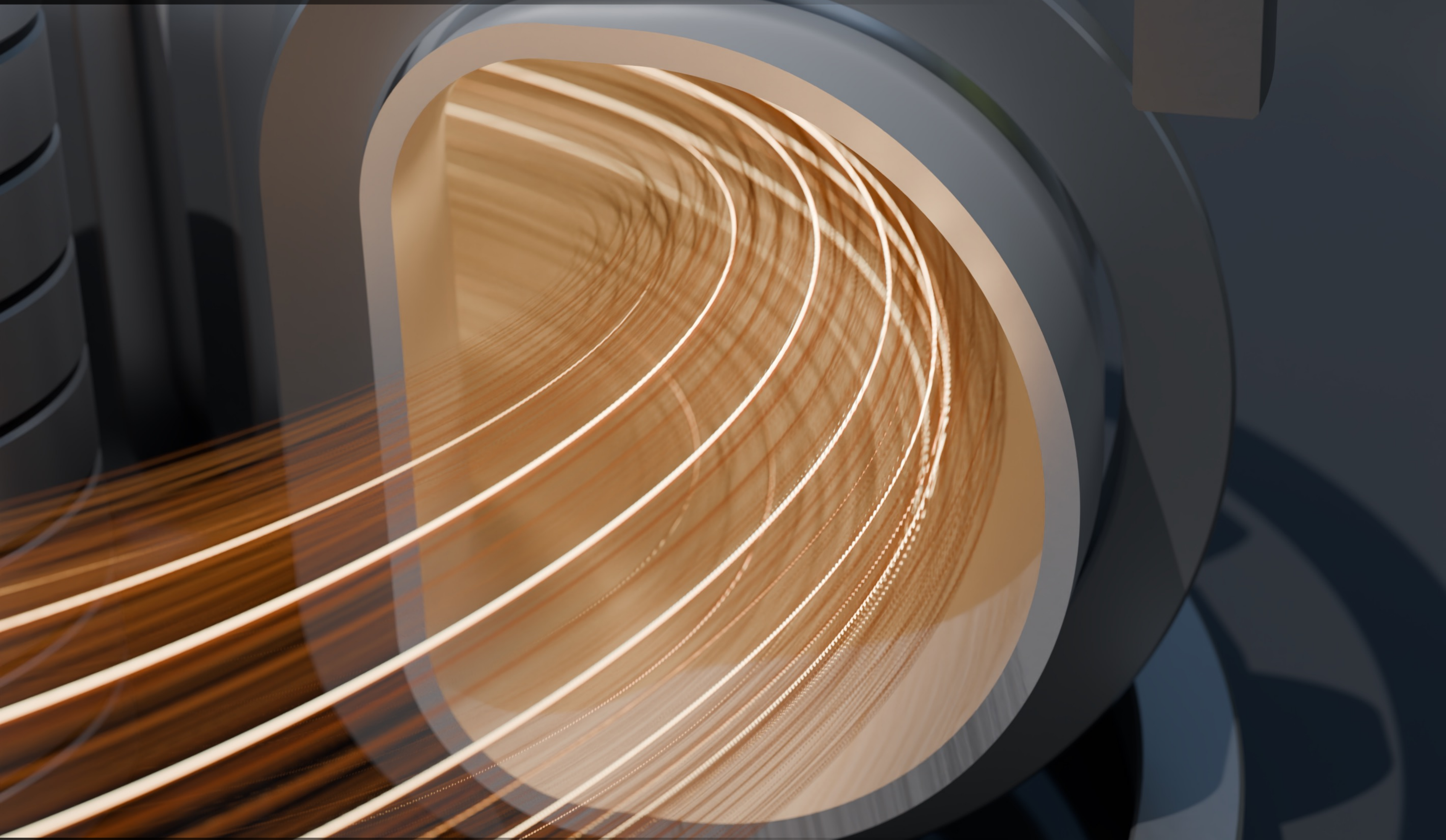
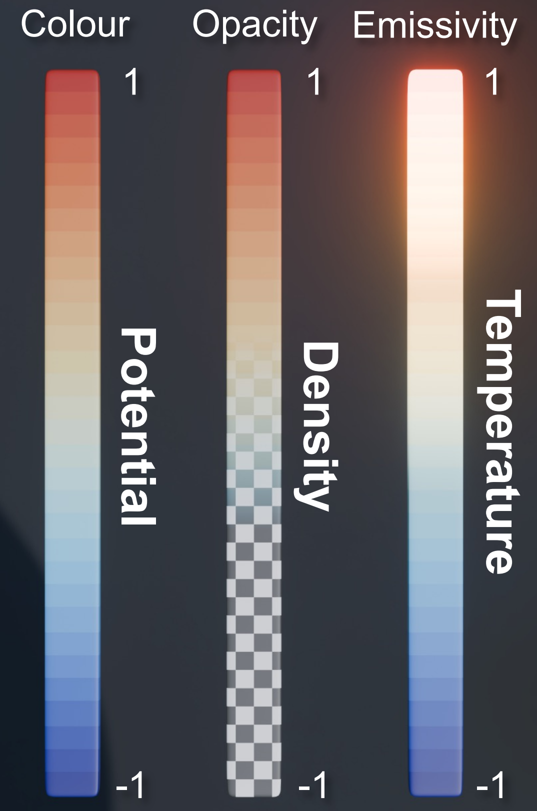


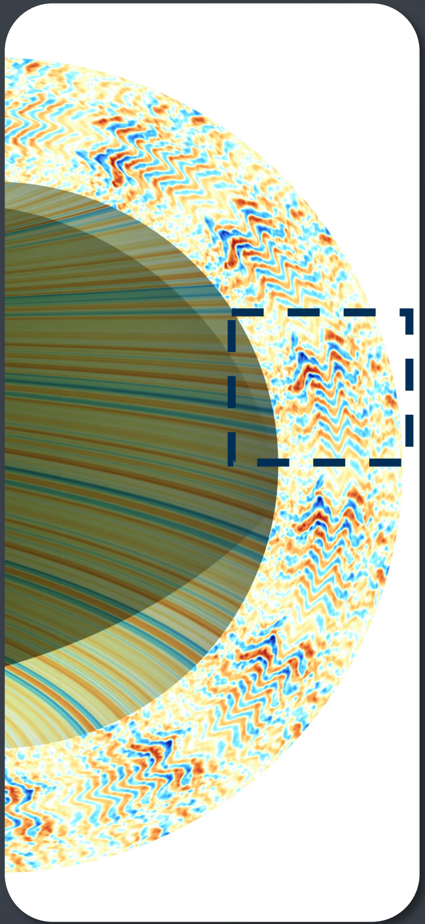
# Volume rendering

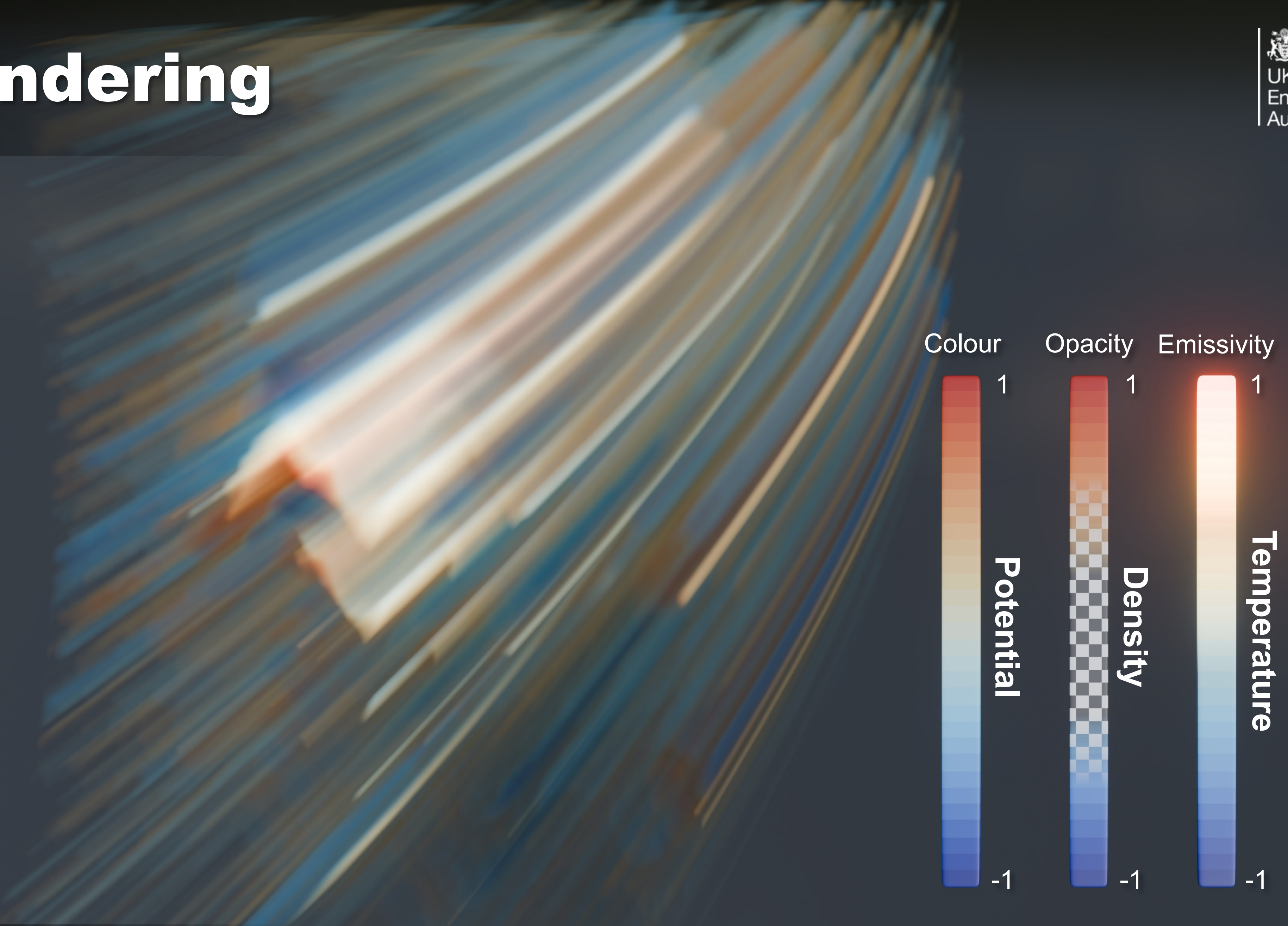




# Volume rendering







# Volume rendering

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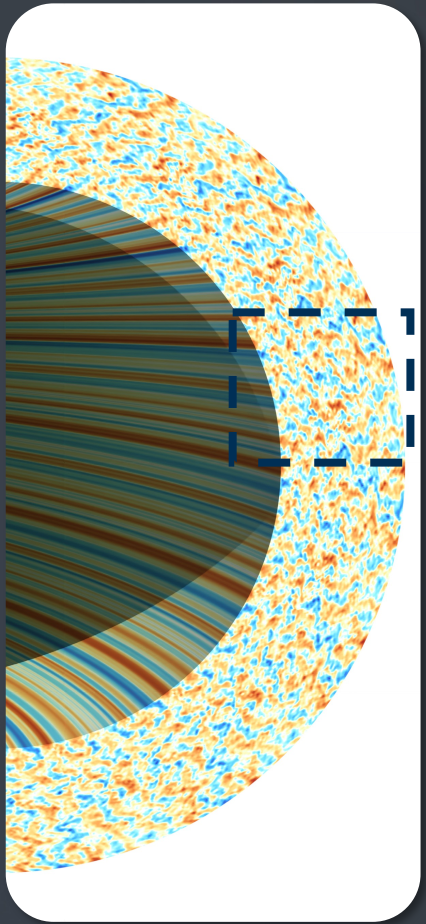

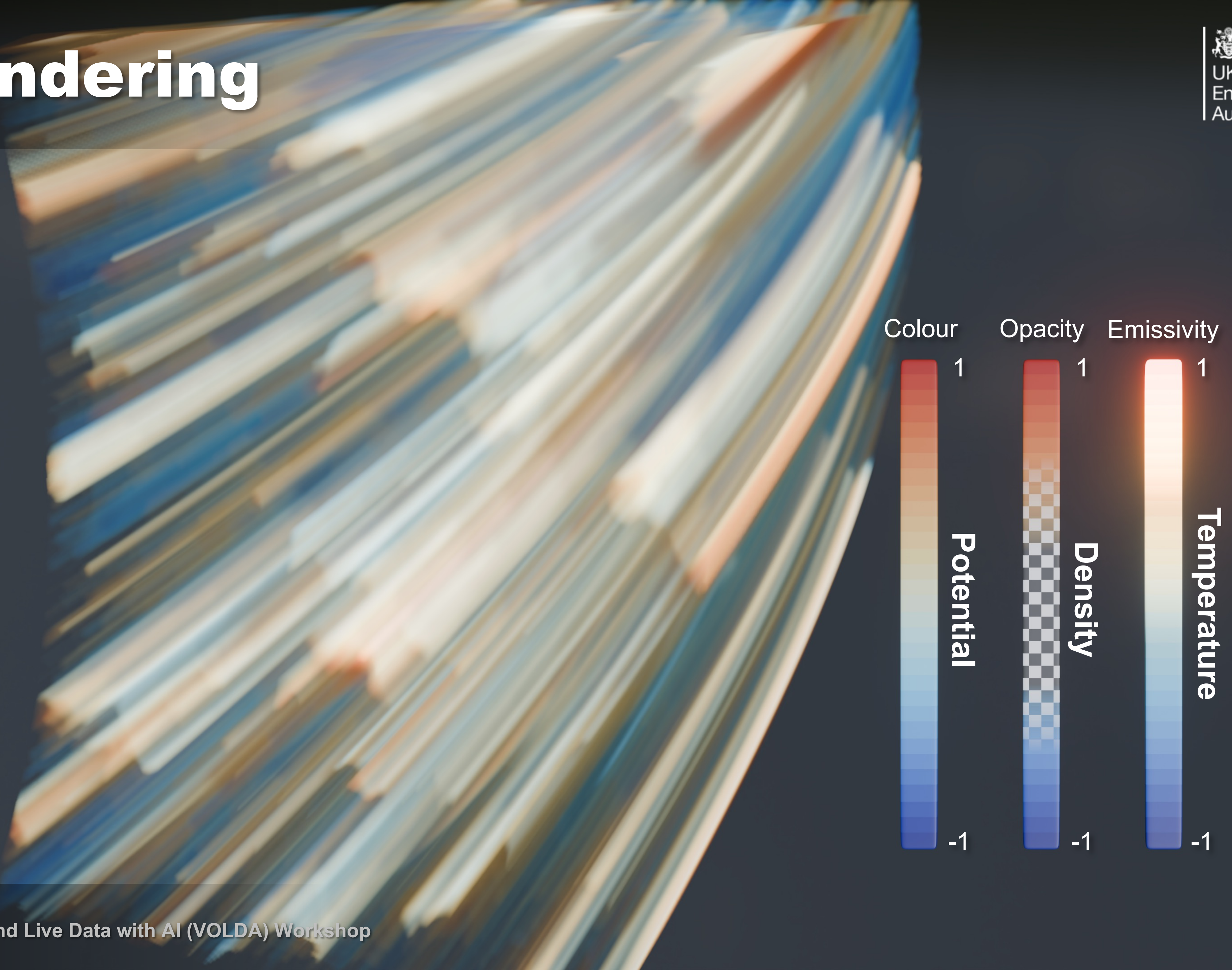

# 4 Outlook

# Improvements to the data workflow

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- Package as ParaView and Blender plugins – reduce disk IO;
- Fully integrate current workflows into Pyrokinetics; [1]
- Tackle full multidimensionality – 5D distribution function;
- In-situ visualisations.

**pyrokinetics** Public

Python library to run and analyse gyrokinetics simulations

Python ☆ 38 7

**Supported GK codes**

The following gk codes are supported in pyrokinetics

- CGYRO
- GS2
- GENE
- TGLF
- GKW
- STELLA
- GX

ParaView Catalyst



[1] B.S. Patel, Journal of Open-Source Software, 2024

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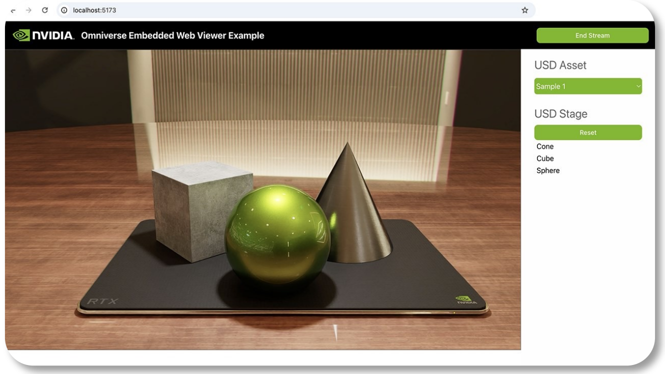
# Integrated simulation & visualisation platform

- Interactive high-fidelity advanced visualisations require specialised hardware;

- OVX cluster unlocks:
    - High throughput visualisations;
    - GPU direct storage for exascale simulations;
    - Remote rendering via streaming to web interface;
    - … and so much more!

*Timelapse of days 1 and 2 of OVX cluster installation*




NVIDIA OMNIVERSE™

*Omniverse web streaming**

** Image from "NVIDIA Omniverse Kit App Streaming" app page in Azure Marketplace*

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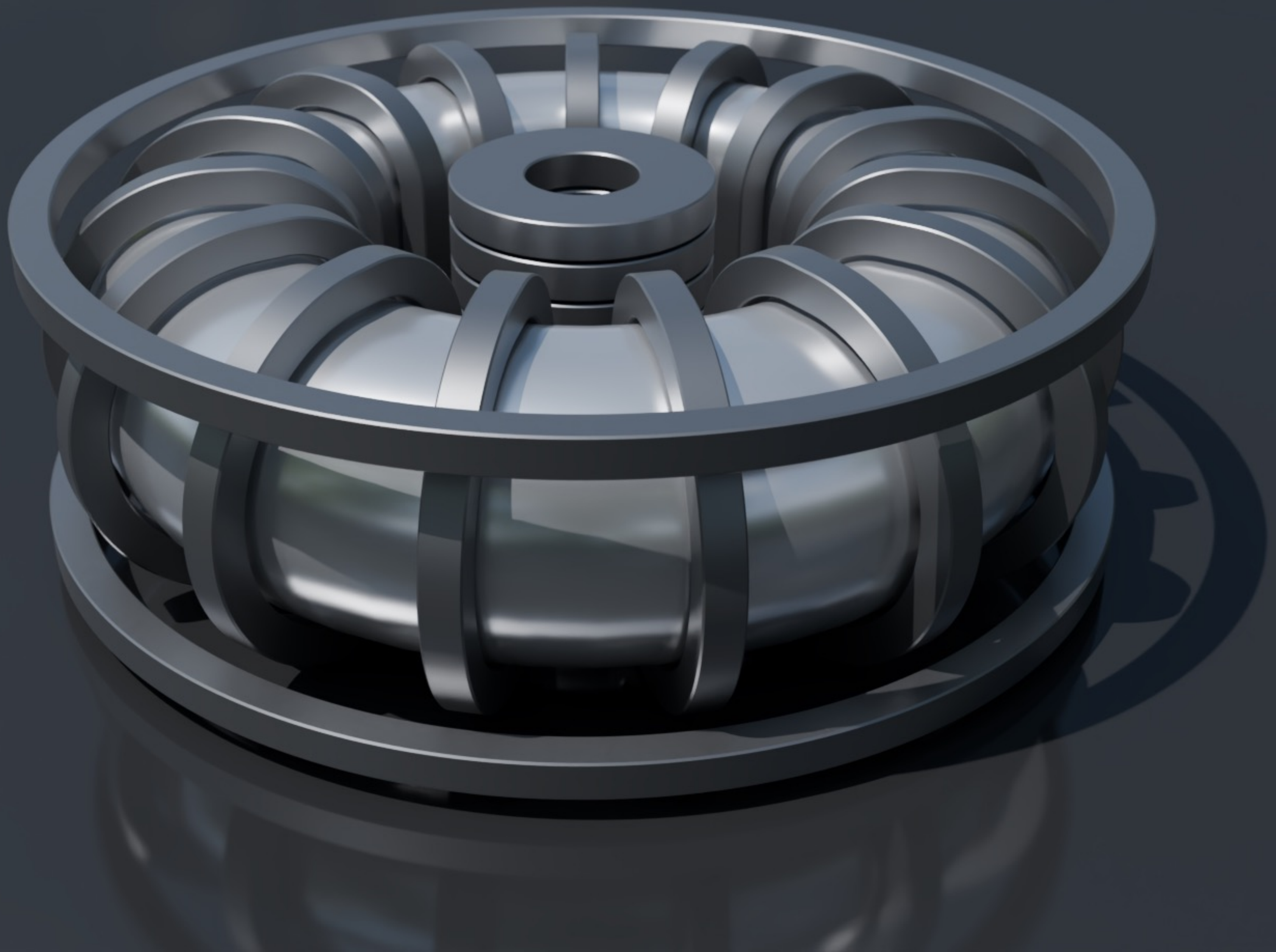

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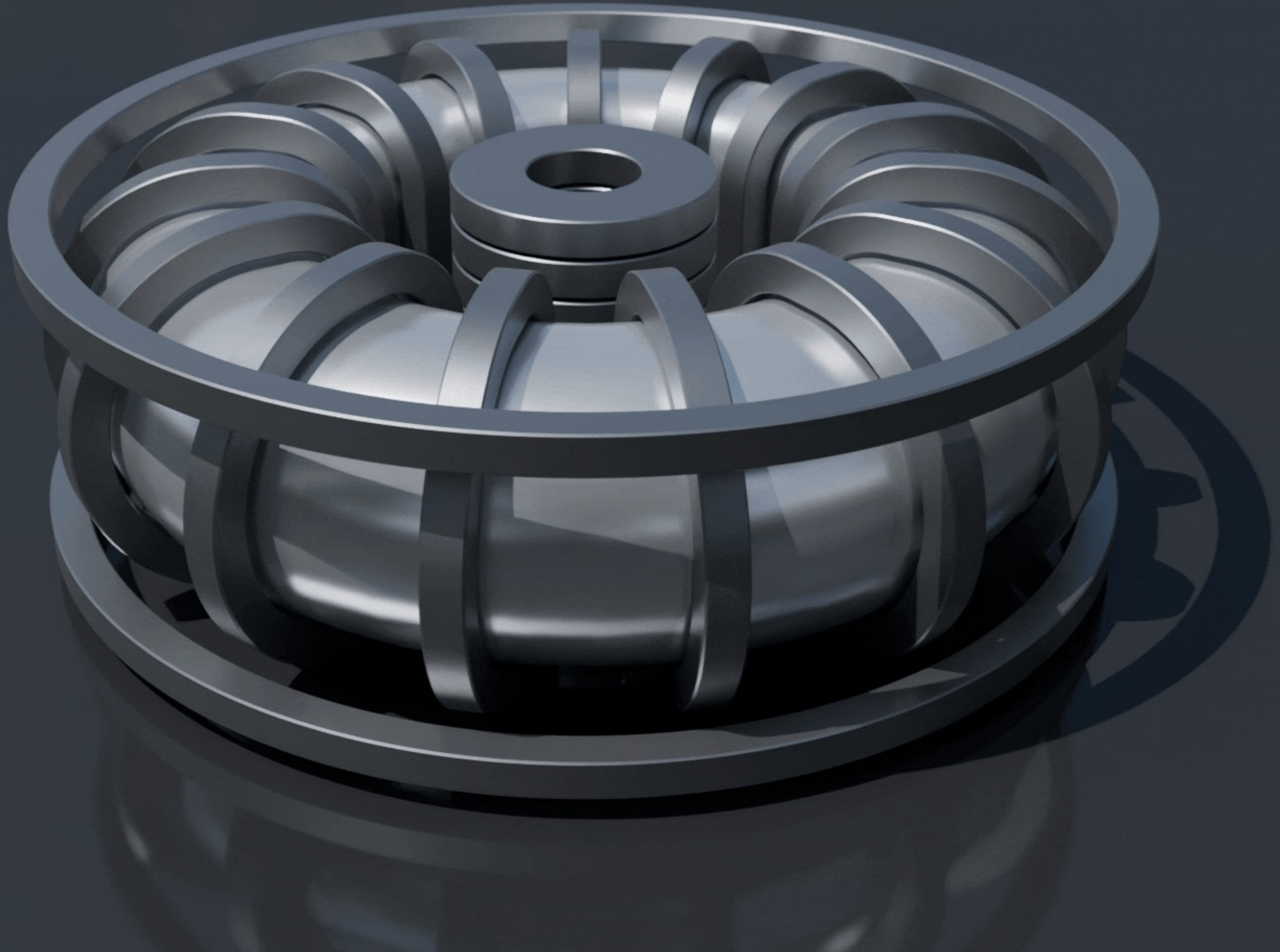

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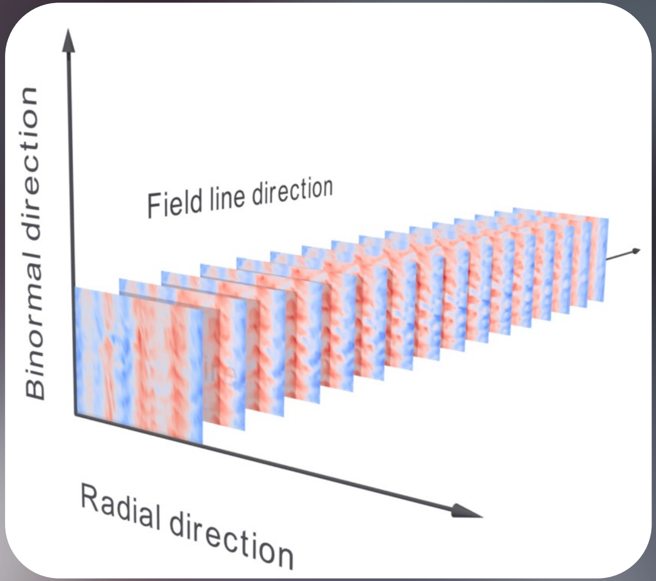
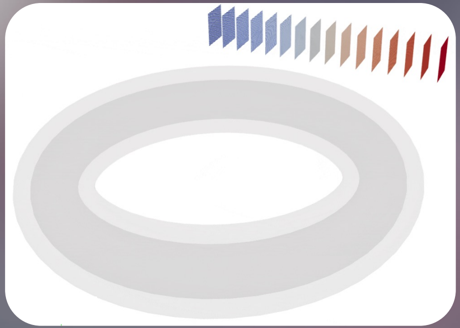
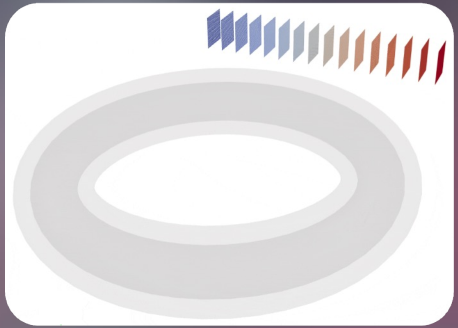
# Conclusion

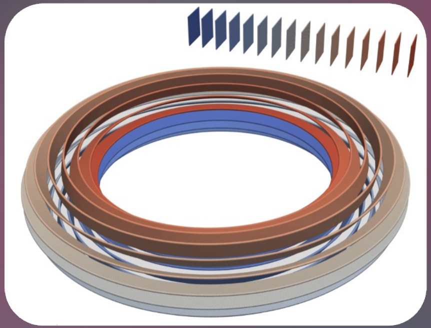
## Data processing workflow

- Python-based using libraries such as: numpy, vtk, scipy (soon to be integrated in Pyrokinetics);
- High performance processing of billions of data points;
- Highly scalable and adaptable to different systems.







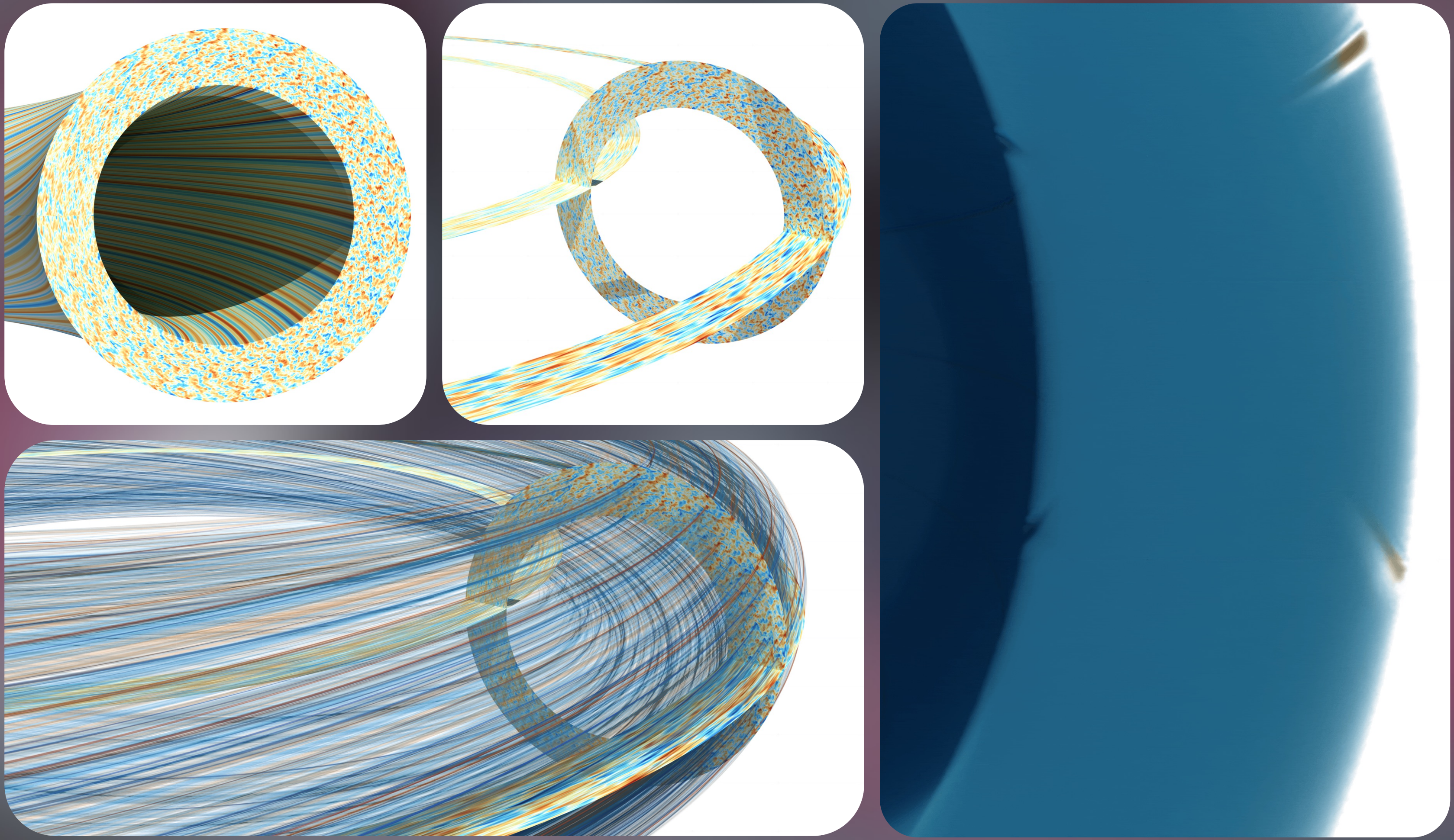
# Conclusion



## Advanced visualisation

- Using ParaView's advanced tooling for scientific visualisations;
- High fidelity representation of simulation data;

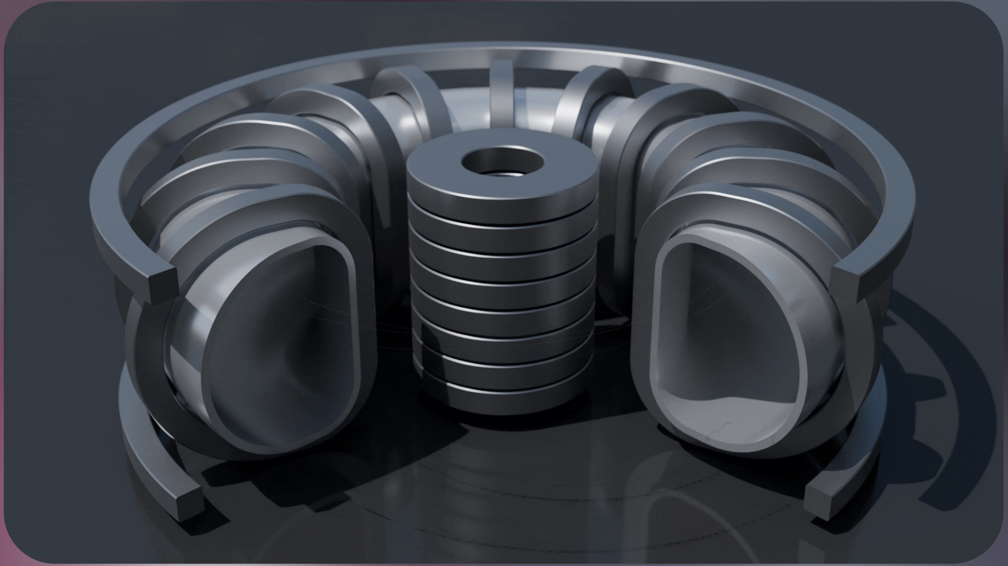
ParaView

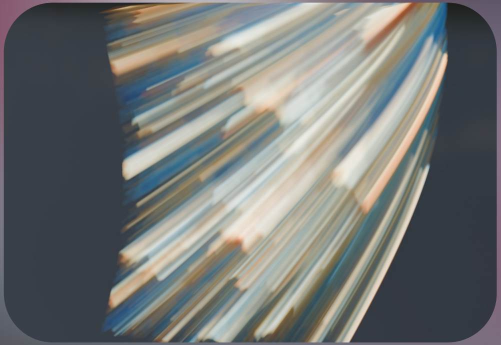


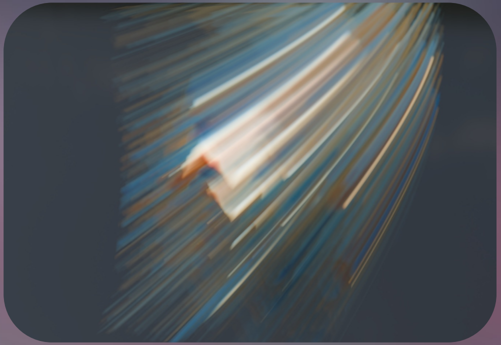
# Conclusion

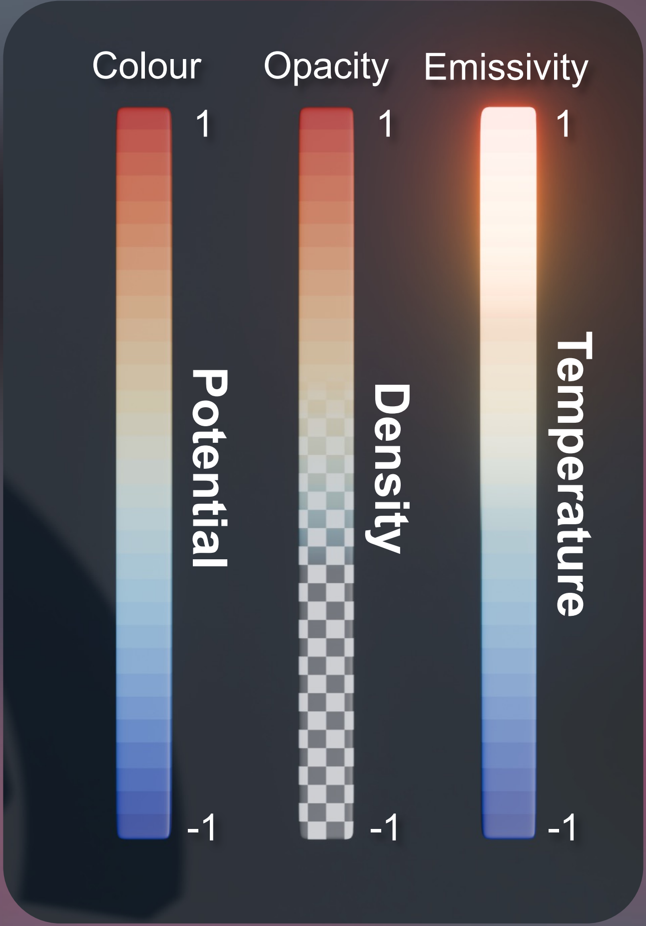
## Advanced visualisation

- Using Blender's state-of-art Cycles renderer;
- Leveraging graphics shaders to encode multiple field data;
- Integration with CAD context.









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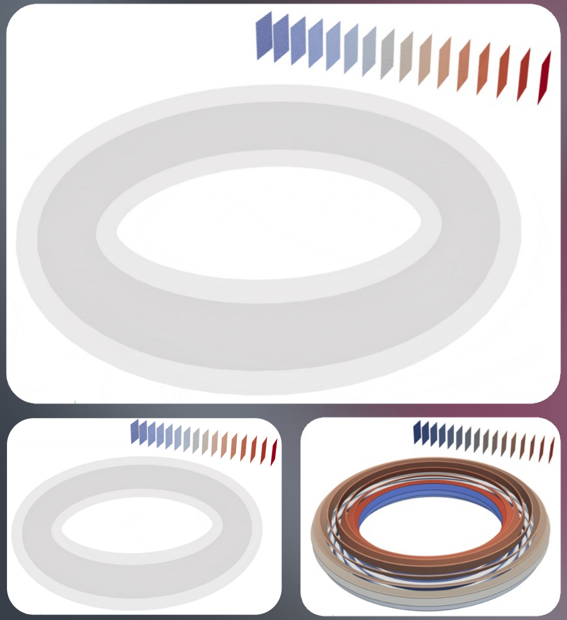
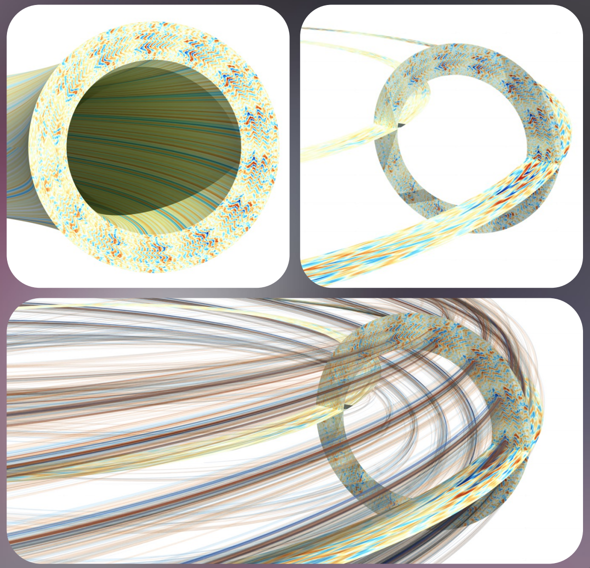
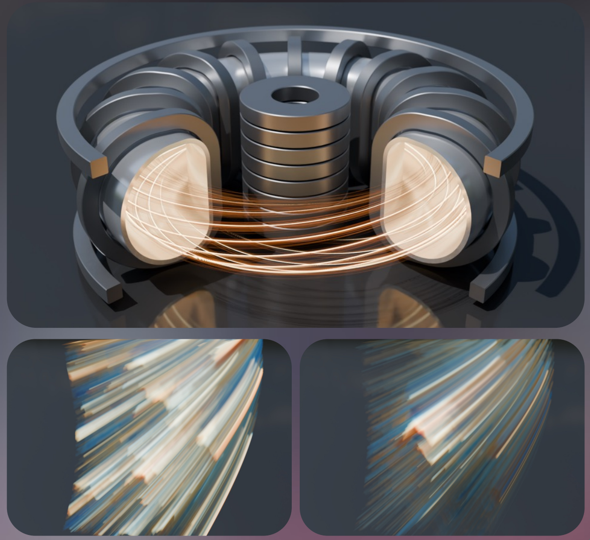
Python-based data processing



Paraview-based advanced scientific visualisations



Blender-based advanced scientific visualisations



Get in touch!
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