T-NA083-20
Fluid Referent Models

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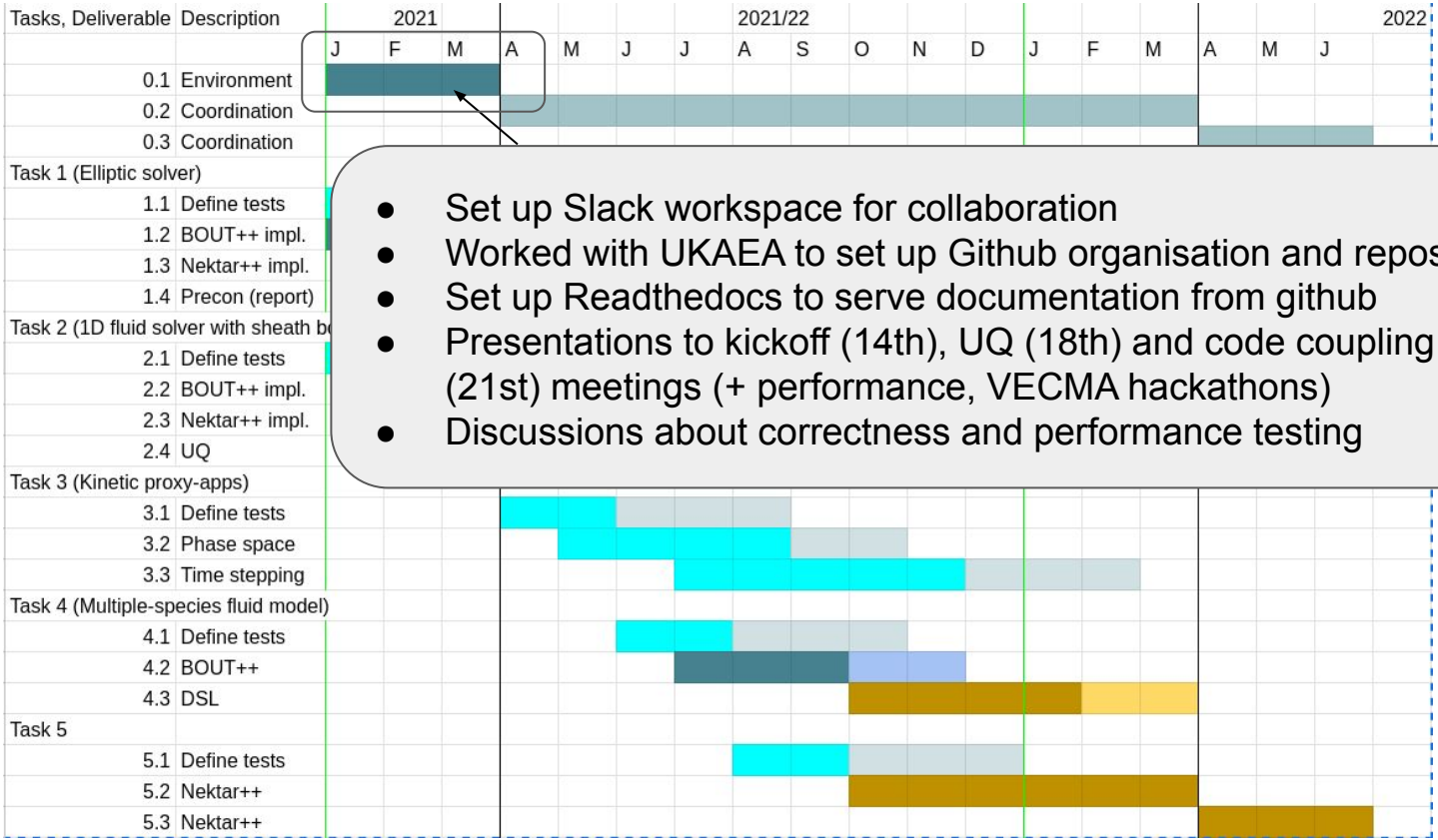
D.Moxey (Exeter)

Excalibur-Neptune meeting, 16th March 2021

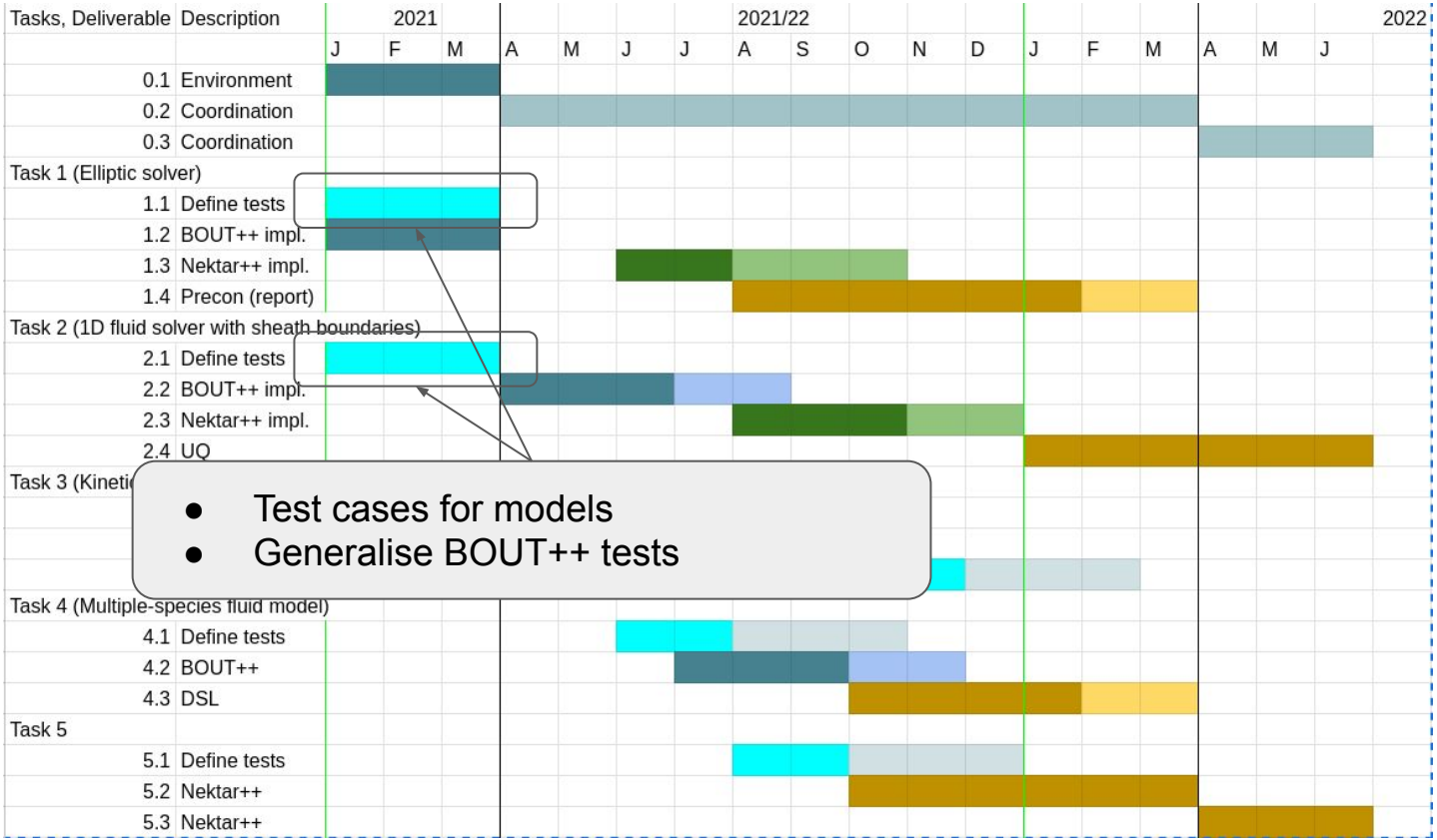
Overall project timeline

0.1 - Environment

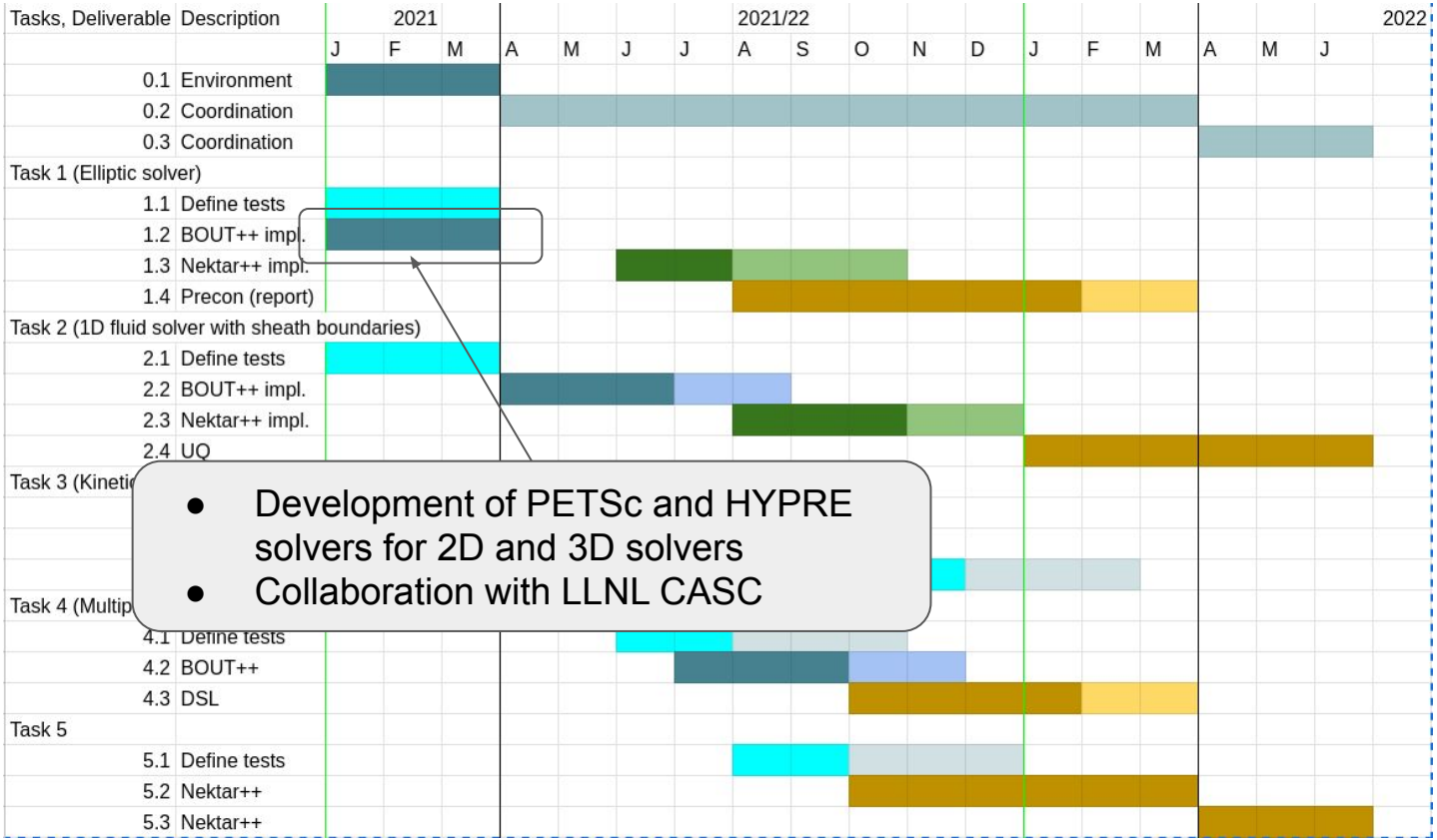


- Set up Slack workspace for collaboration
- Worked with UKAEA to set up Github organisation and repos
- Set up Readthedocs to serve documentation from github
- Presentations to kickoff (14th), UQ (18th) and code coupling (21st) meetings (+ performance, VECMA hackathons)
- Discussions about correctness and performance testing

1.1, 2.1 - Test cases

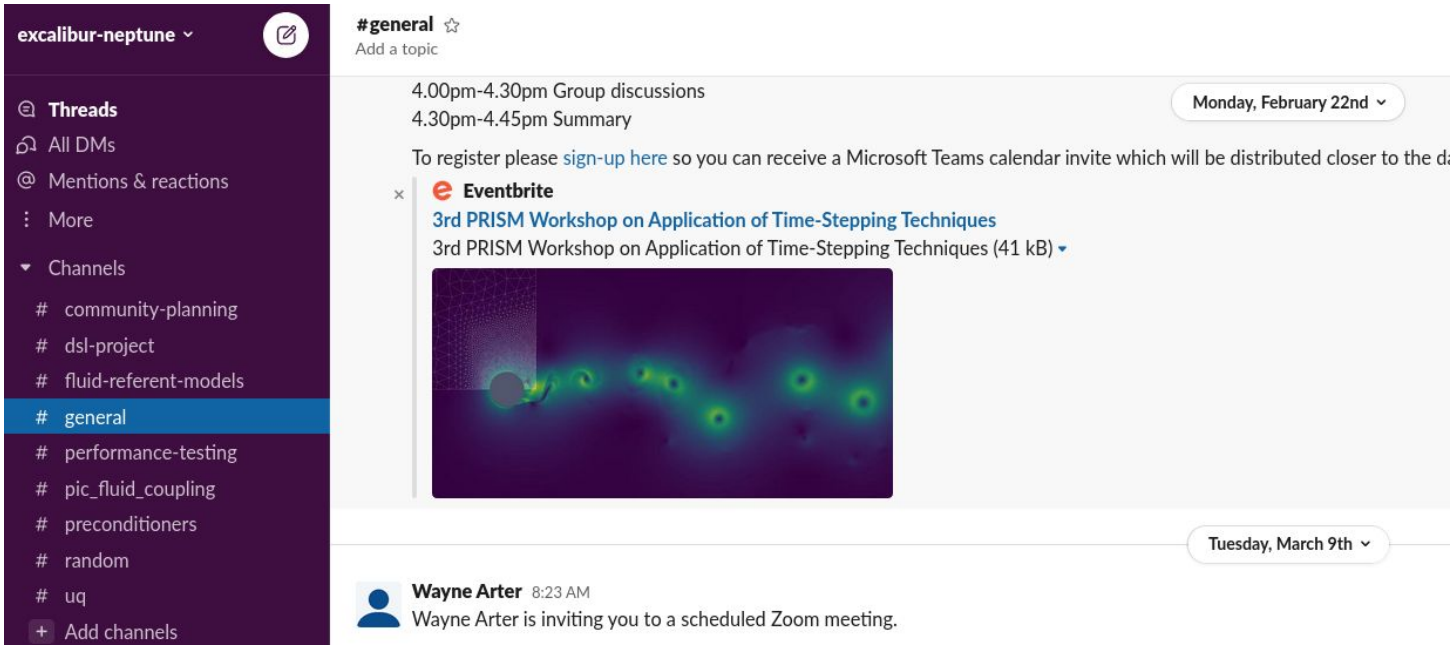


1.2 - Elliptic solver implementation



Task 0.1 - Environment

- Slack for communication, coordination
  https://excalibur-neptune.slack.com



Task 0.1 - Environment

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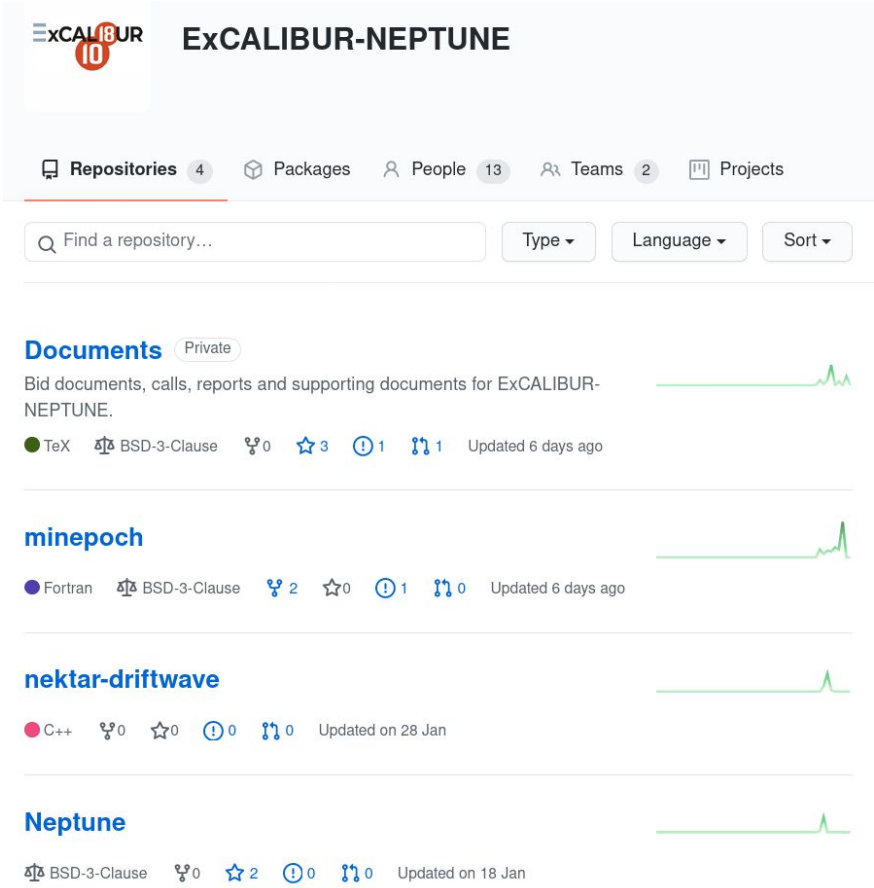
- Github for code, documentation
  https://github.com/ExCALIBUR-NEPTUNE/



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- Slack for communication, coordination
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- Github for code, documentation
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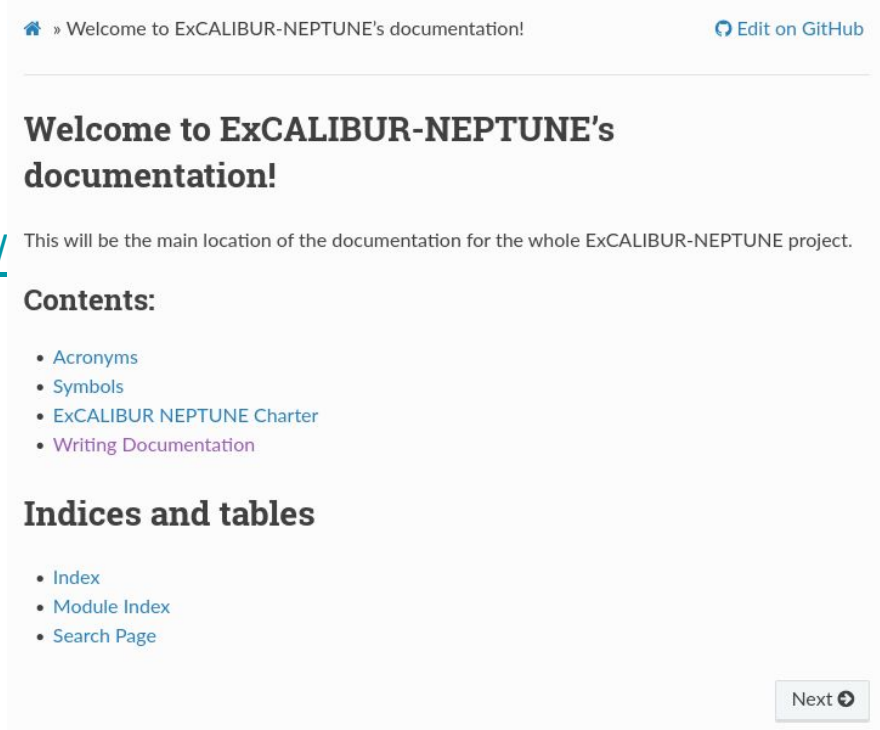
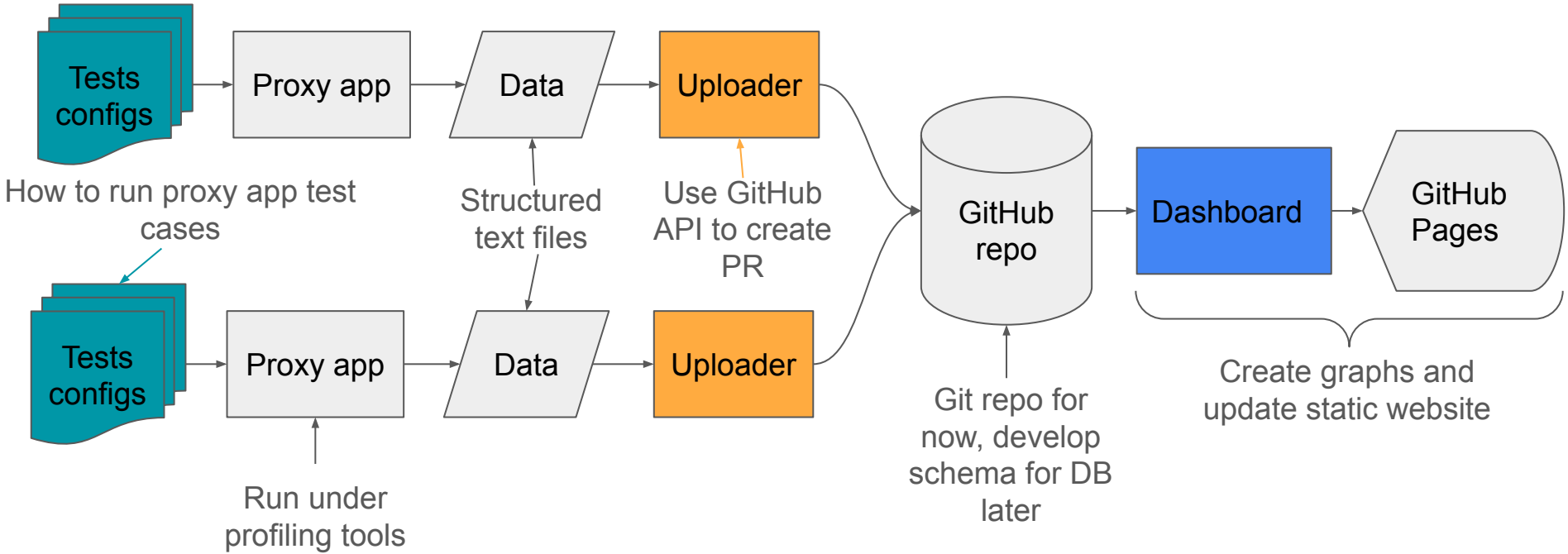
- ReadTheDocs serves docs
  https://excalibur-neptune.readthedocs.io



Task 0.1 - Environment - Performance testing

Designing set of tools for gathering and tracking performance data

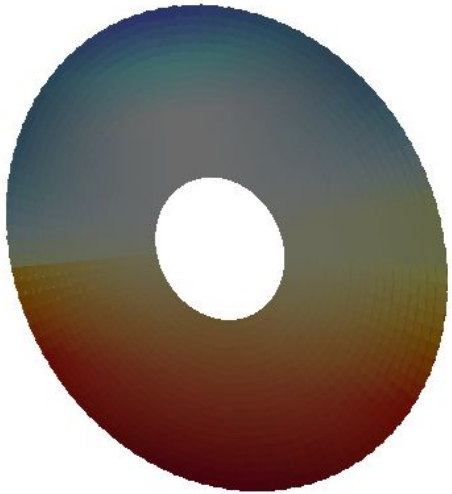


Task 1.2 - Elliptic solver

- Solving vorticity equation

$$\nabla \cdot \left(\frac{m_i n}{B^2} \nabla_\perp \phi \right) = \frac{1}{J} \frac{\partial}{\partial u^i} \left(J \frac{m_i n}{B^2} g^{ij} \left(\nabla_\perp \phi \right)_j \right)$$

- Perpendicular to magnetic field
  - Approximately an annulus (simplified)



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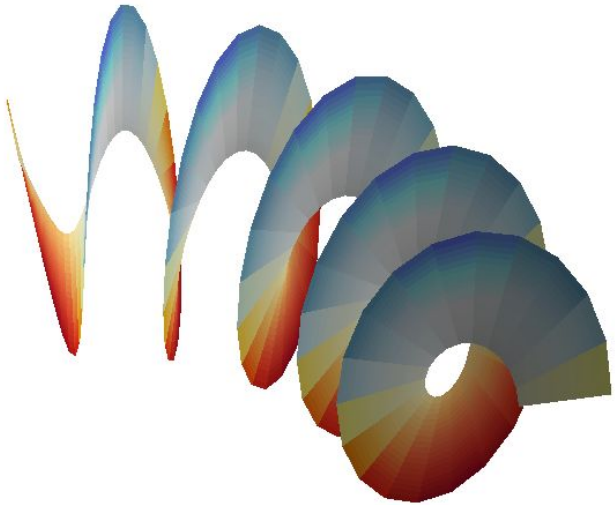
- Domain out of plane due to helical magnetic field



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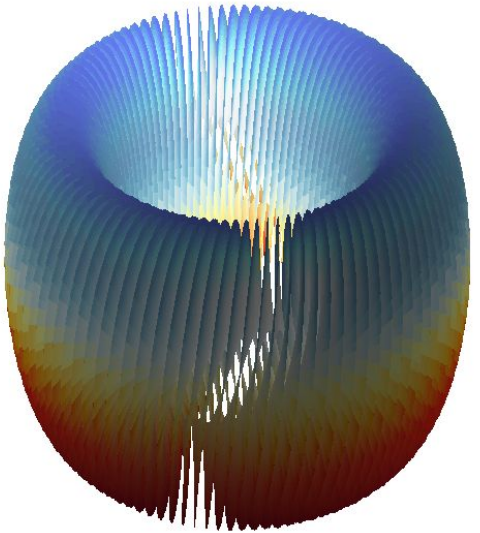
- Domain out of plane due to helical magnetic field

- In most cases this will be space-filling
  - A 3D problem, with 2D approximation/preconditioning



Task 1.2 - Elliptic solver

Solving vorticity equation

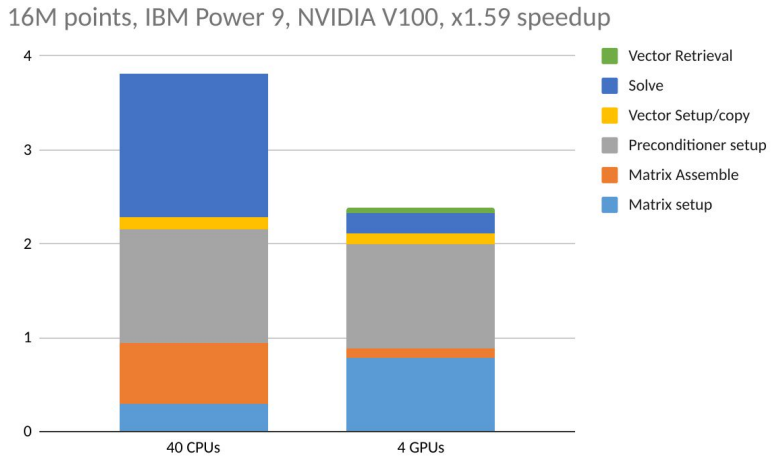
$$\nabla \cdot \left(\frac{m_i n}{B^2} \nabla_\perp \phi \right) = \frac{1}{J} \frac{\partial}{\partial u^i} \left(J \frac{m_i n}{B^2} g^{ij} \left(\nabla_\perp \phi \right)_j \right)$$

- Reference FFT-based method: 2D in logically rectangular domain
- PETSc based 3D solver developed previously (C.MacMackin et al)

- New Hypre implementation for 3D problem
- GPU tests on Lassen (LLNL)

Task 1.1 - Elliptic solver - Tests

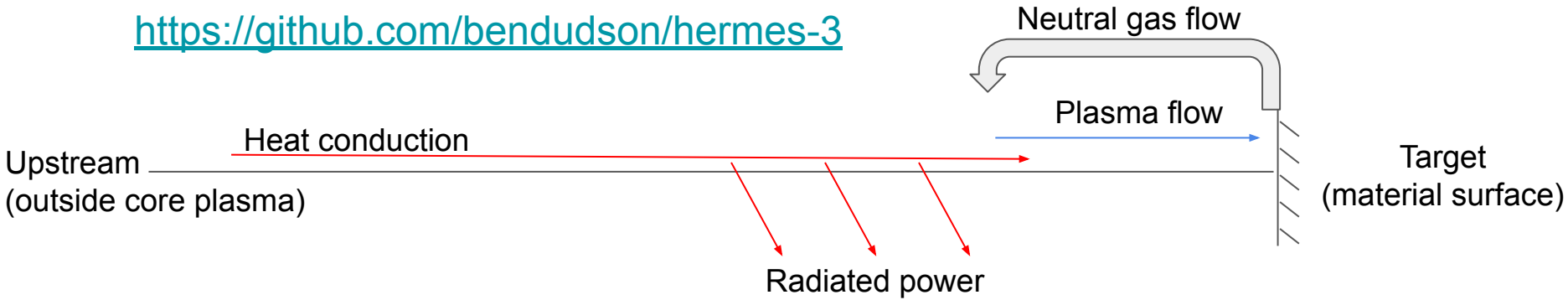
- **Correctness**: use forward operator and check round-trip is identical
  - Some subtleties: forward operator must use same discretisation to get good agreement at low resolution used in tests
  - Analytic solution used to check forward operator
- **Performance**: simple slab case doesn't exercise preconditioner very much, need more realistic case with X-point in domain
  - Analytic description of domain, metric tensor elements
  - Some speed up from using GPUs, especially if matrix coefficients change slowly



Task 2.1 - 1D fluid model

Based on tests developed for:

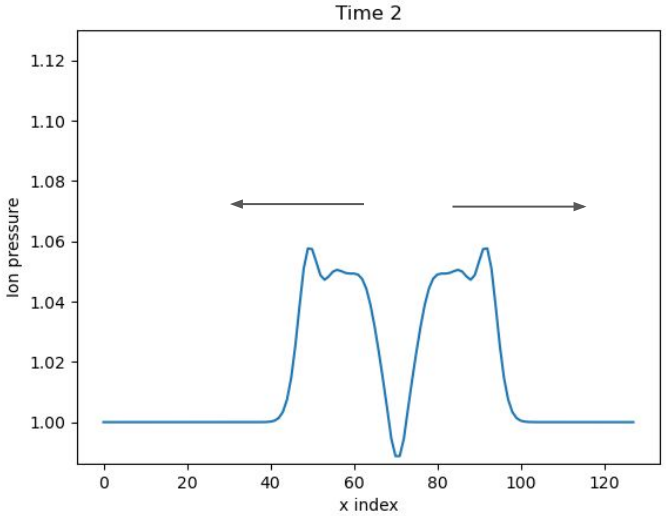
- **SD1D**, a 1D model of hydrogen plasmas
  https://doi.org/10.1088/1361-6587/ab1321
  https://github.com/boutproject/SD1D/
- **Hermes-3**, a 1D/2D/3D multi-species model under development
  https://hermes3.readthedocs.io
  https://github.com/bendudson/hermes-3

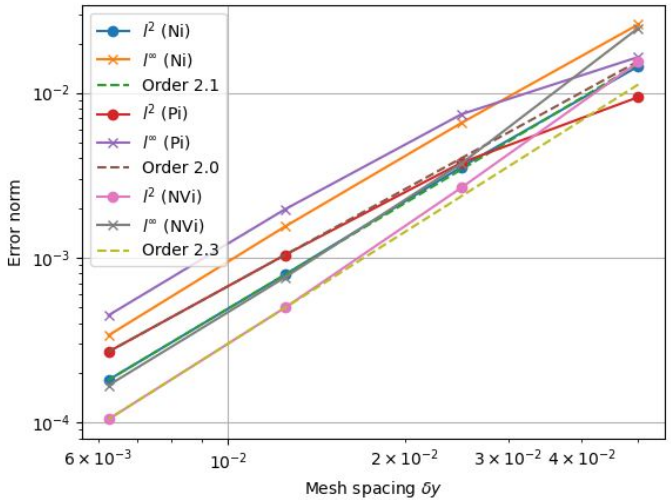


Task 2.1 - 1D fluid model - component tests

Check individual parts of the model

- 1D fluid flow, periodic domain. MMS convergence test https://github.com/bendudson/hermes-3/tree/master/tests/integrated/1D-fluid





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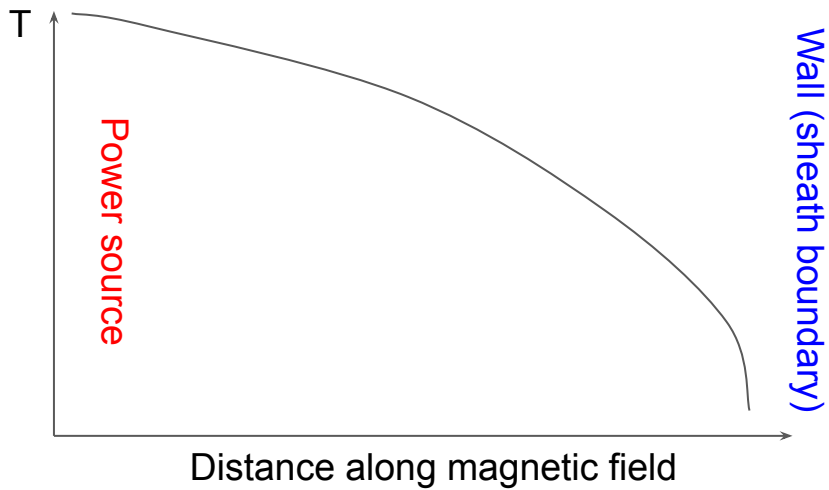
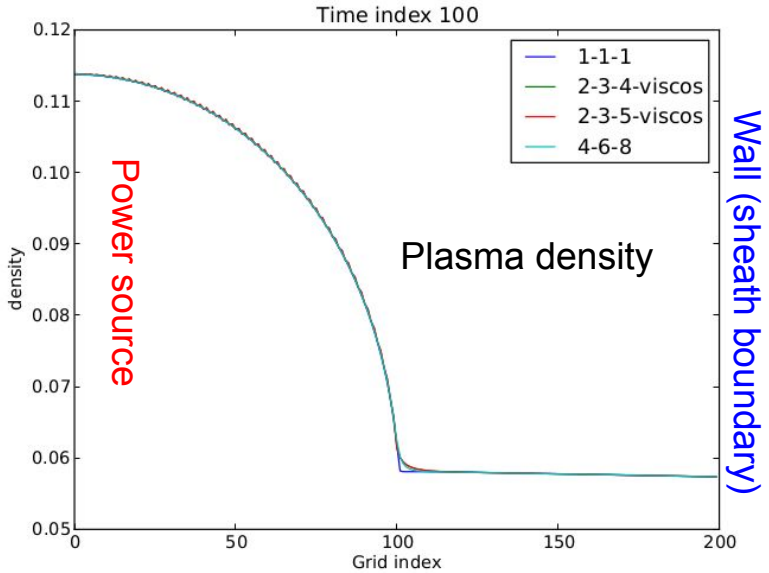
- Nonlinear heat conduction
  Analytic solution (2-point model)

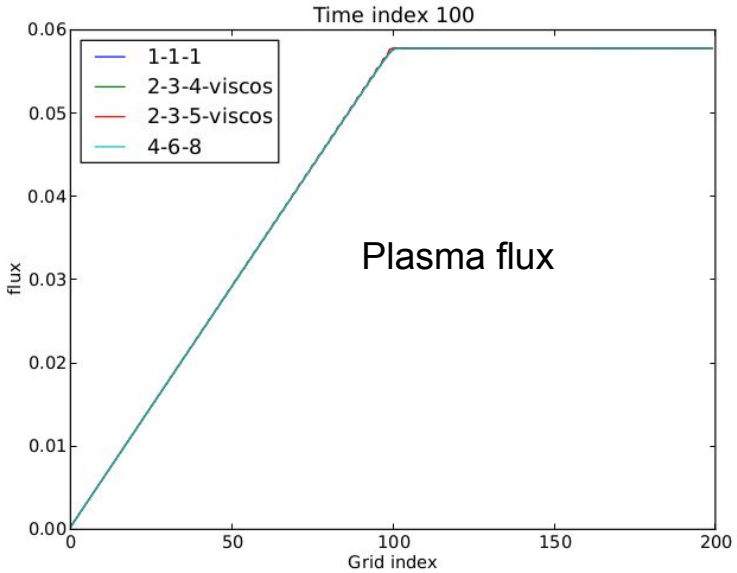
- Conservation checks
  E.g. particle balance in a closed system



Task 2.1 - 1D fluid model - Sources

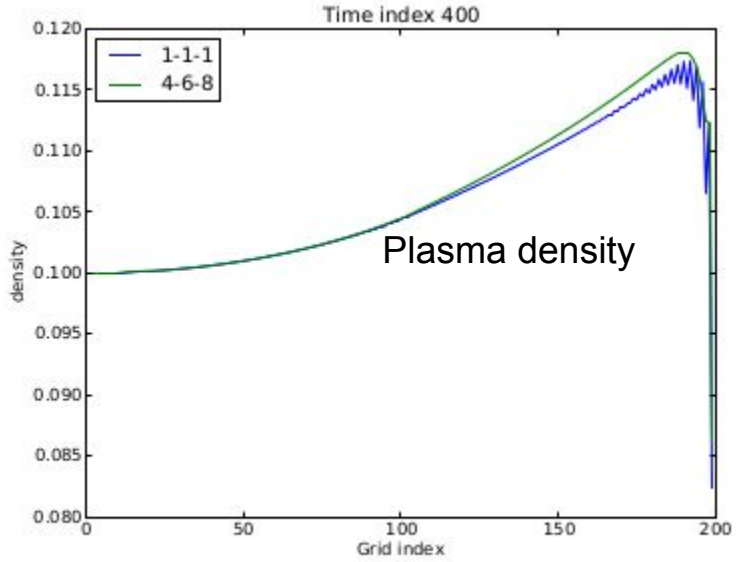
- Outflow boundary conditions on one side, no-flow on the other
- Source over part of the domain -> Sharp changes in gradients



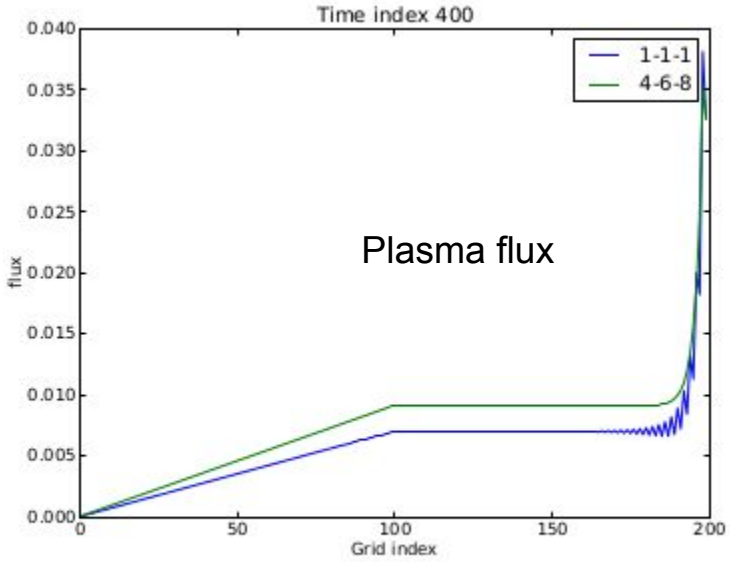


Task 2.1 - 1D fluid model - Boundary conditions

Sheath boundary conditions (sound speed)
recycling of plasma -> neutral gas -> plasma (atomic reactions)



(a) Density n



(b) Flux $nV_{||}$

Task 2.1 - 1D fluid model - Multi species

- Separate ion and electron temperatures
- Coupling (collisions) between species

- Extension to multiple ion species
  D, T, He, Be, W, Ne, Ar, …

- Reactions and collisions between species