

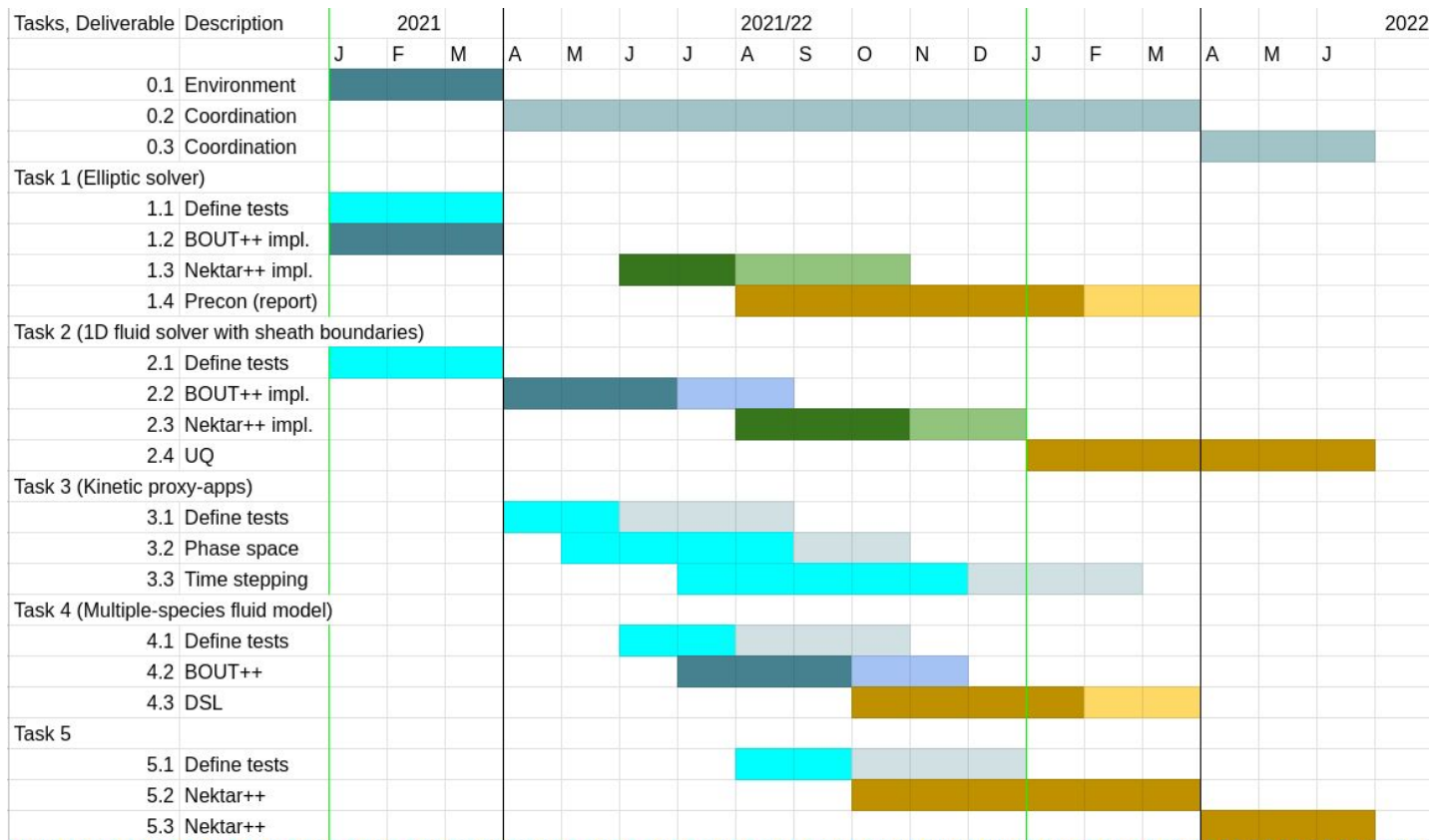
T-NA083-20

# Fluid Referent Models

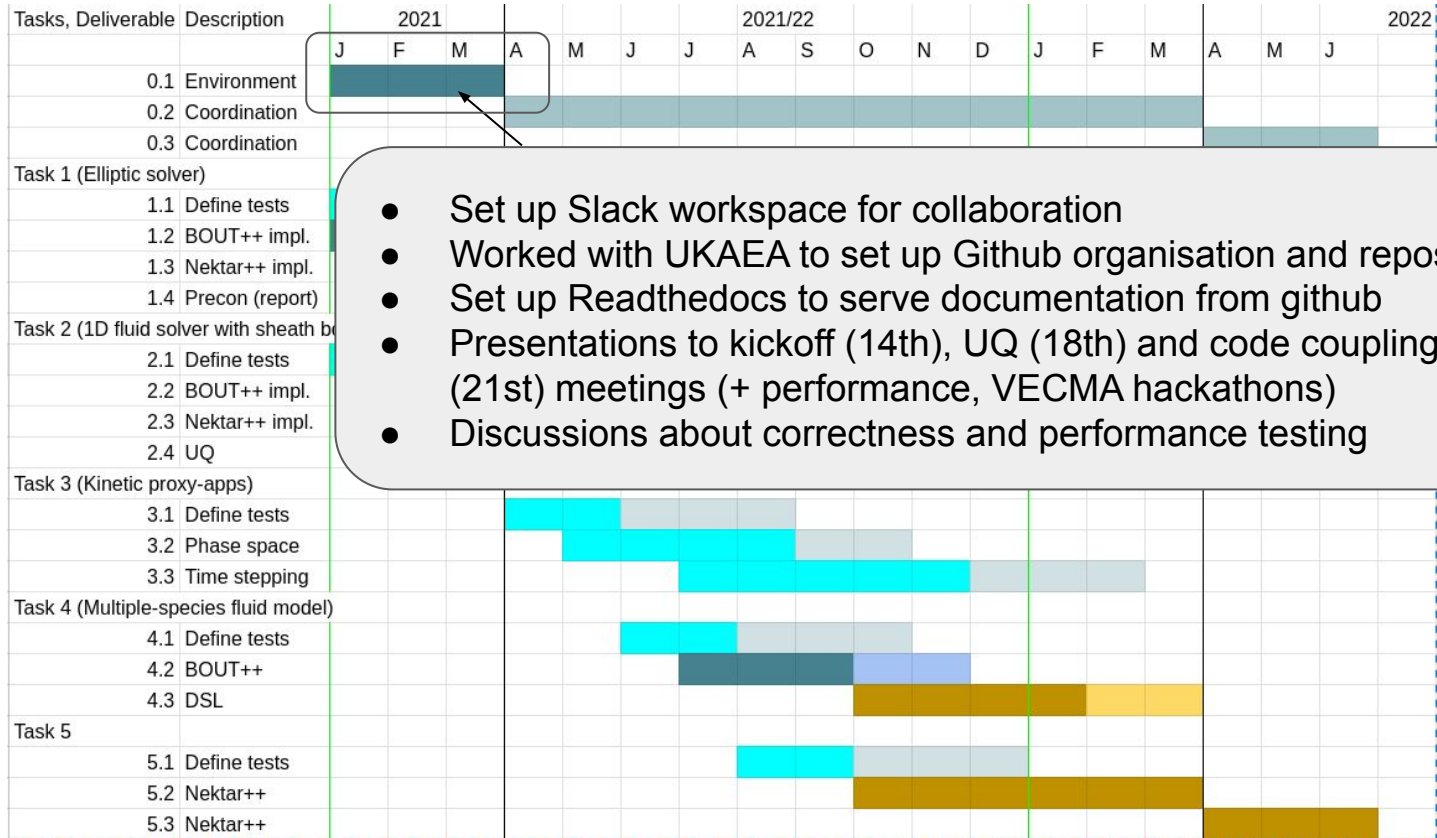
Ben Dudson, D.Dickinson, E.Higgins, P.Hill, S.Wright (York)  
D.Moxey (Exeter)

Excalibur-Neptune meeting, 16th March 2021

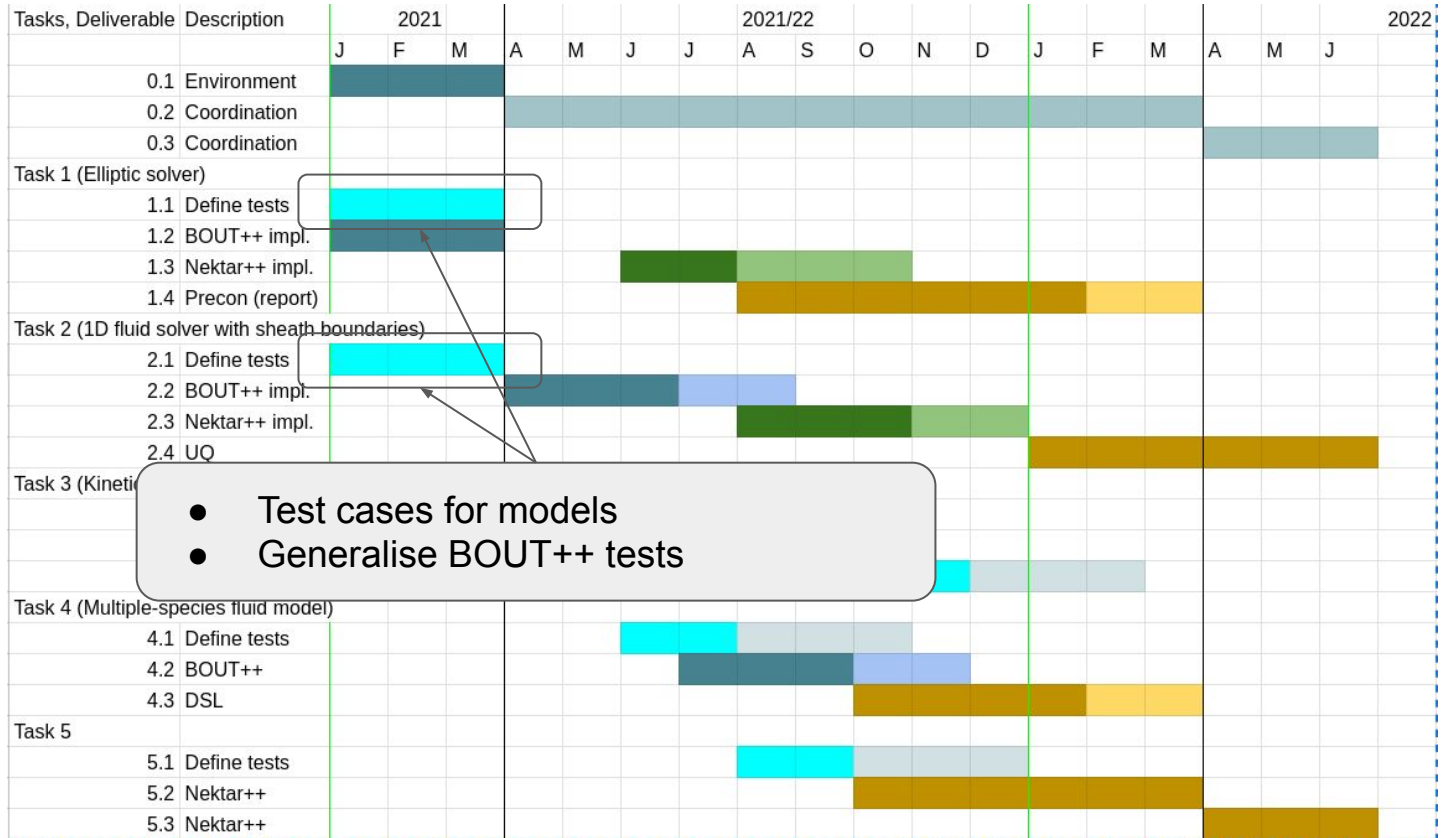
# Overall project timeline



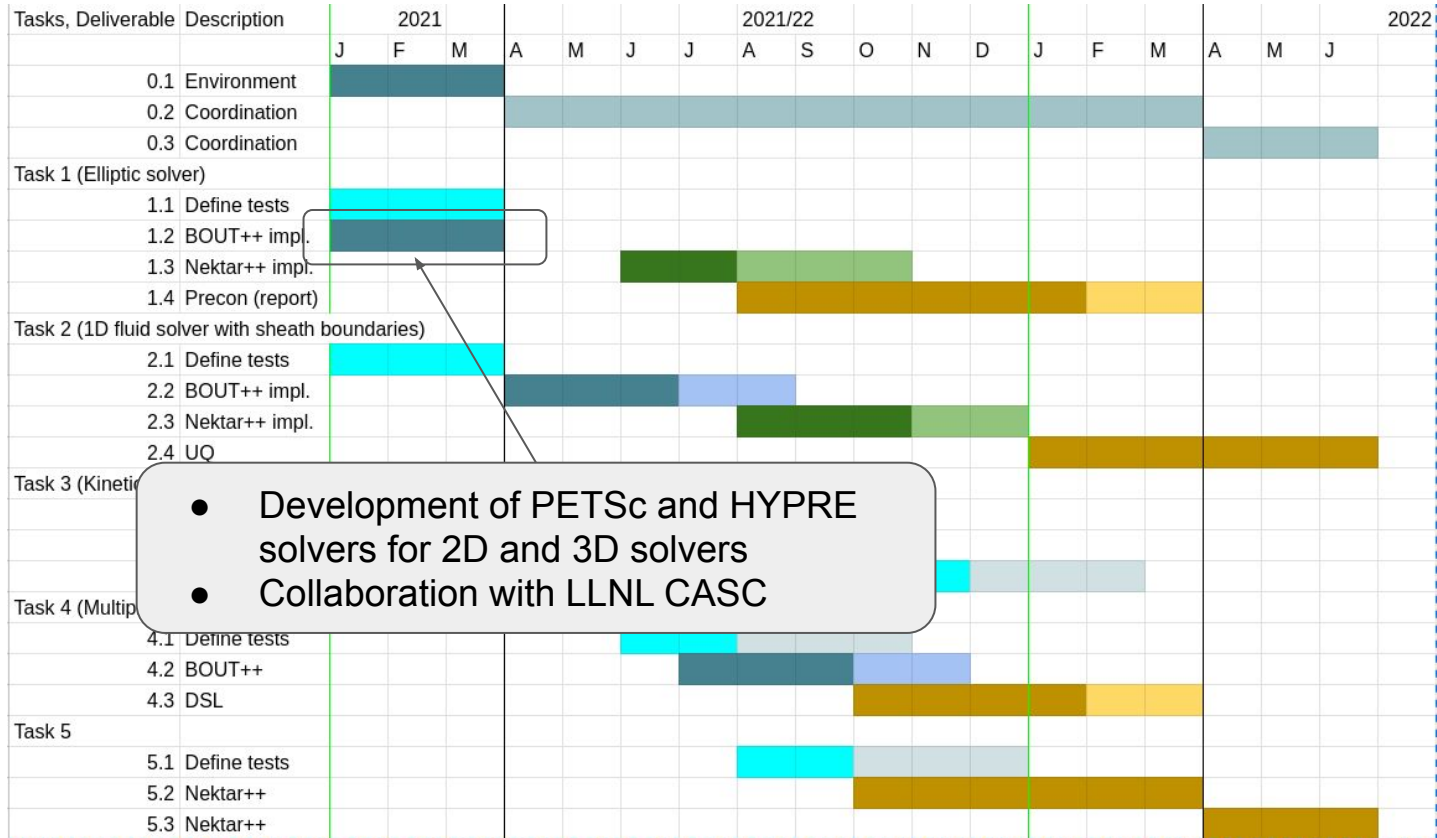
# 0.1 - Environment



# 1.1, 2.1 - Test cases



## 1.2 - Elliptic solver implementation



# Task 0.1 - Environment

- Slack for communication, coordination

<https://excalibur-neptune.slack.com>

The screenshot displays the Slack interface for the 'excalibur-neptune' workspace. On the left sidebar, the 'Channels' list includes: # community-planning, # dsl-project, # fluid-referent-models, # general (highlighted), # performance-testing, # pic\_fluid\_coupling, # preconditioners, # random, # uq, and an 'Add channels' button. The main area shows the '#general' channel with a star icon and an 'Add a topic' link. A meeting announcement is visible, scheduled for Monday, February 22nd, with times 4.00pm-4.30pm for group discussions and 4.30pm-4.45pm for a summary. The text states: 'To register please [sign-up here](#) so you can receive a Microsoft Teams calendar invite which will be distributed closer to the d...'. Below this is an Eventbrite link for the '3rd PRISM Workshop on Application of Time-Stepping Techniques' (41 kB). A preview image shows a dark blue field with several bright green spots. At the bottom, a message from Wayne Arter, dated 8:23 AM, says: 'Wayne Arter is inviting you to a scheduled Zoom meeting.'

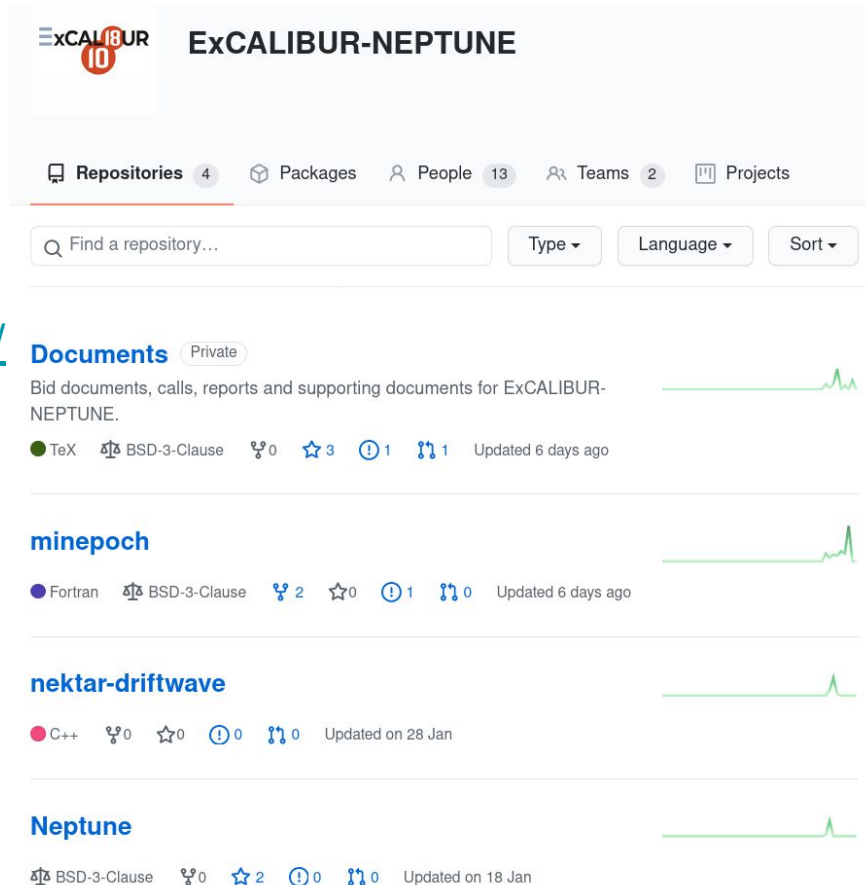
# Task 0.1 - Environment

- Slack for communication, coordination

<https://excalibur-neptune.slack.com>

- Github for code, documentation

<https://github.com/ExCALIBUR-NEPTUNE/>



The screenshot shows the GitHub repository page for ExCALIBUR-NEPTUNE. The repository is categorized under 'Documents' and is marked as 'Private'. The description states: 'Bid documents, calls, reports and supporting documents for ExCALIBUR-NEPTUNE.' The repository statistics show 0 forks, 3 stars, 1 issue, and 1 pull request, with a last update 6 days ago. The repository is written in TeX and uses the BSD-3-Clause license. Below the repository information, there are three sections: 'minepoch', 'nektar-driftwave', and 'Neptune'. Each section shows its own statistics and last update date. The 'minepoch' repository has 2 forks, 0 stars, 1 issue, and 0 pull requests, updated 6 days ago. The 'nektar-driftwave' repository has 0 forks, 0 stars, 0 issues, and 0 pull requests, updated on 28 Jan. The 'Neptune' repository has 0 forks, 2 stars, 0 issues, and 0 pull requests, updated on 18 Jan.

ExCALIBUR-NEPTUNE

Repositories 4 Packages People 13 Teams 2 Projects

Find a repository... Type Language Sort

**Documents** Private

Bid documents, calls, reports and supporting documents for ExCALIBUR-NEPTUNE.

TeX BSD-3-Clause 0 forks 3 stars 1 issue 1 pull request Updated 6 days ago

**minepoch**

Fortran BSD-3-Clause 2 forks 0 stars 1 issue 0 pull request Updated 6 days ago

**nektar-driftwave**

C++ 0 forks 0 stars 0 issues 0 pull request Updated on 28 Jan

**Neptune**

BSD-3-Clause 0 forks 2 stars 0 issues 0 pull request Updated on 18 Jan

# Task 0.1 - Environment

- Slack for communication, coordination  
<https://excalibur-neptune.slack.com>
- Github for code, documentation  
<https://github.com/ExCALIBUR-NEPTUNE/>
- ReadTheDocs serves docs  
<https://excalibur-neptune.readthedocs.io>

» Welcome to ExCALIBUR-NEPTUNE's documentation!

[Edit on GitHub](#)

## Welcome to ExCALIBUR-NEPTUNE's documentation!

This will be the main location of the documentation for the whole ExCALIBUR-NEPTUNE project.

### Contents:

- Acronyms
- Symbols
- ExCALIBUR NEPTUNE Charter
- [Writing Documentation](#)

### Indices and tables

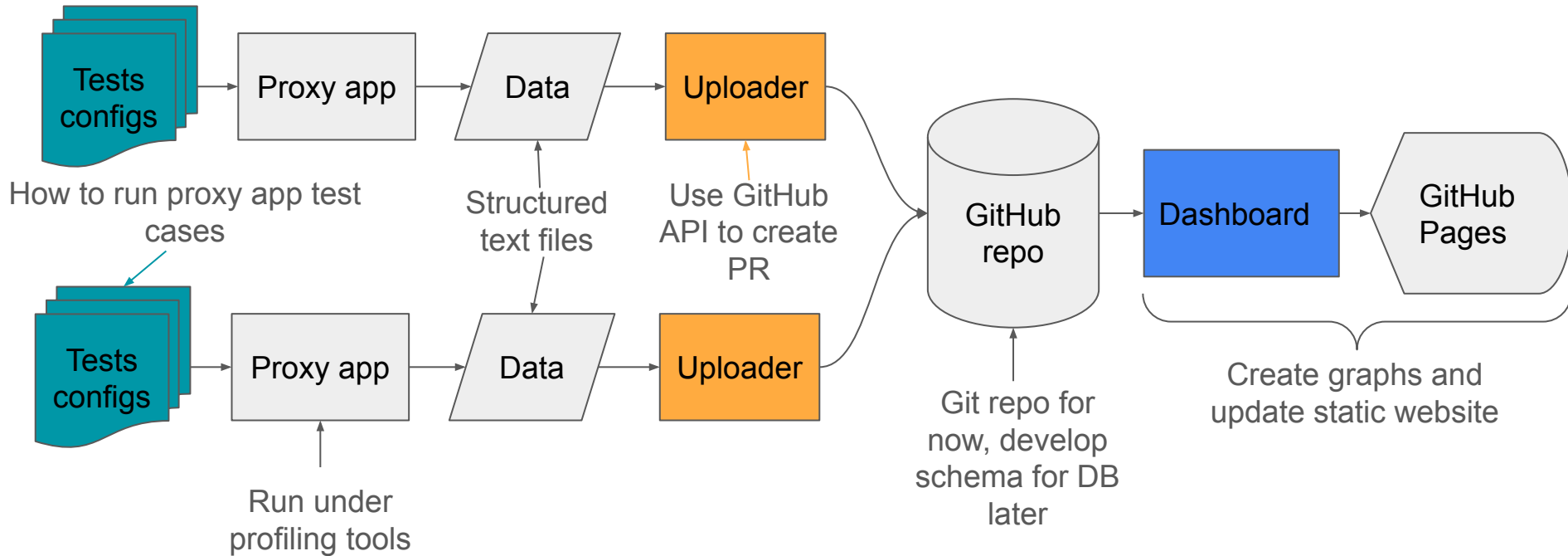
- Index
- [Module Index](#)
- [Search Page](#)

Next ➔



# Task 0.1 - Environment - Performance testing

Designing set of tools for gathering and tracking performance data

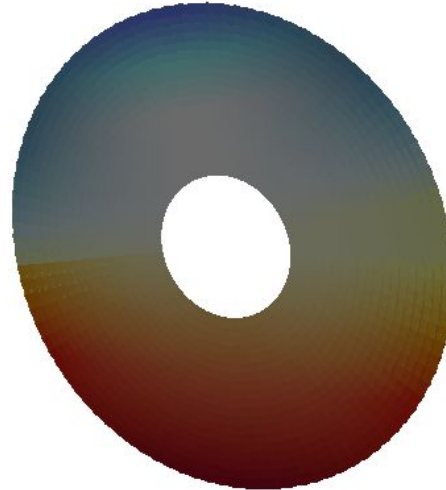


## Task 1.2 - Elliptic solver

- Solving vorticity equation

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

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

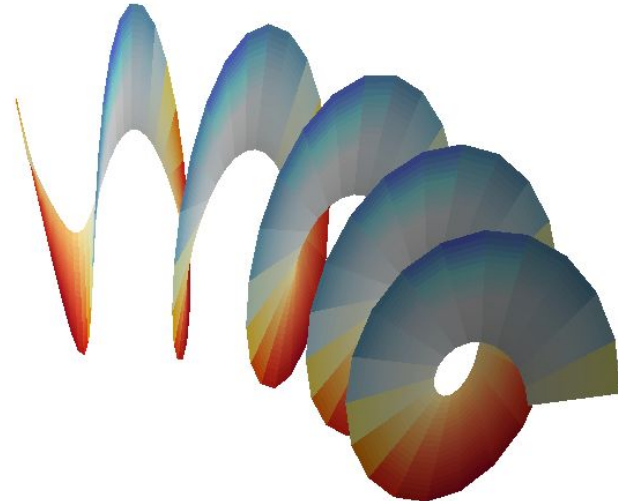


## Task 1.2 - Elliptic solver

- Solving vorticity equation

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

- Perpendicular to magnetic field
  - Approximately an annulus (simplified)
- Domain out of plane due to helical magnetic field

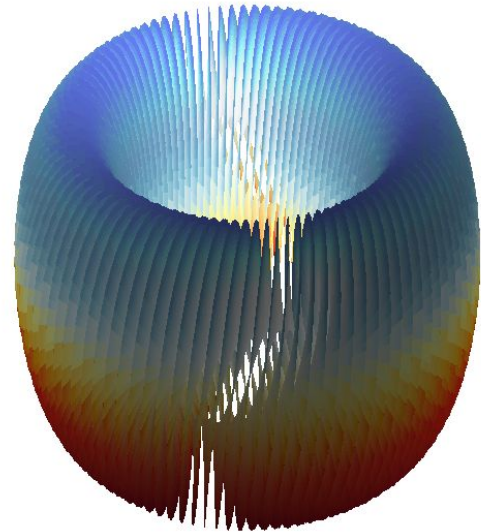


## Task 1.2 - Elliptic solver

- Solving vorticity equation

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

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

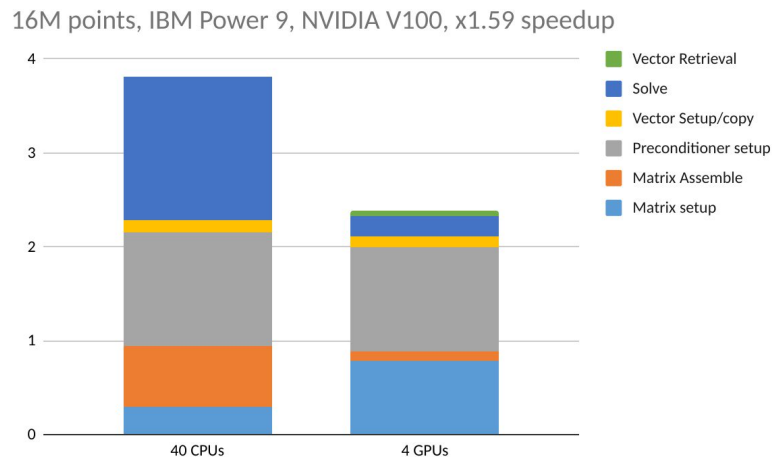
Solving vorticity equation

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

- Reference FFT-based method: 2D in logically rectangular domain
- PETSc based 3D solver developed previously (C.MacMackin et al)
- New Hydre implementation for 3D problem
- GPU tests on Lassen (LLNL)

# Task 1.1 - Elliptic solver - Tests

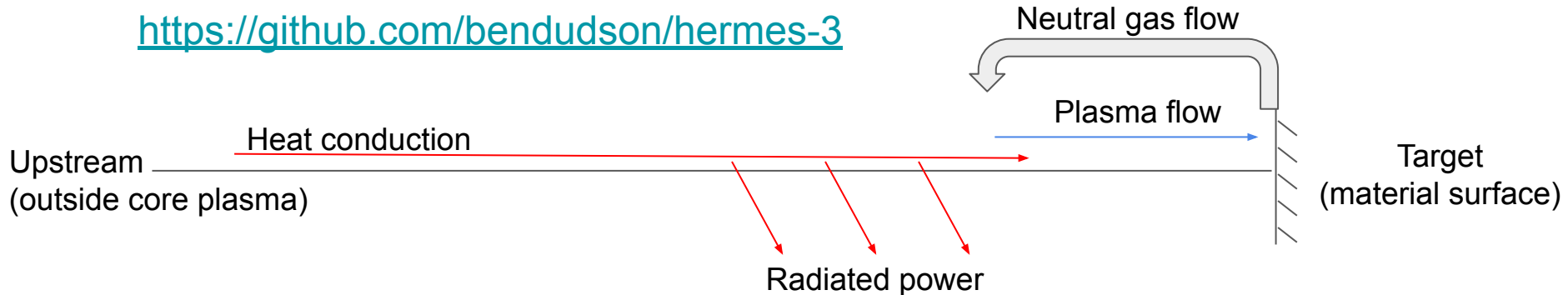
- **Correctness:** use forward operator and check round-trip is identical
  - Some subtleties: forward operator must use same discretisation to get good agreement at low resolution used in tests
  - Analytic solution used to check forward operator
- **Performance:** simple slab case doesn't exercise 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>

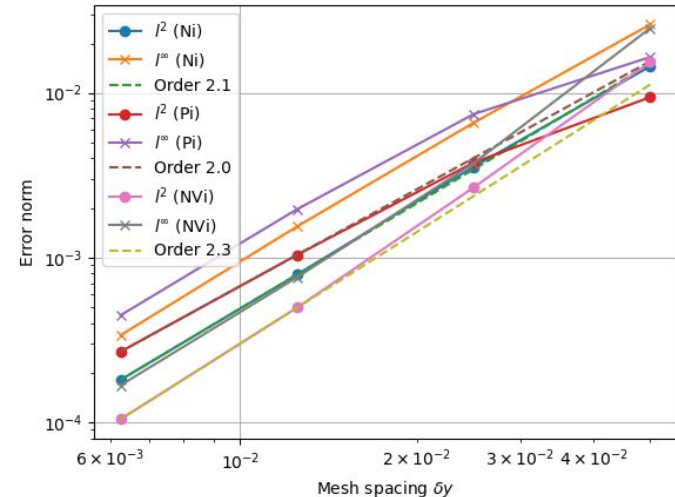
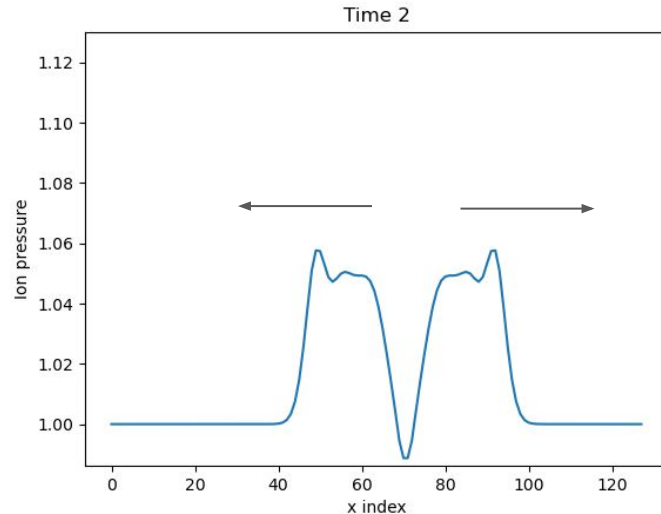


# Task 2.1 - 1D fluid model - component tests

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>





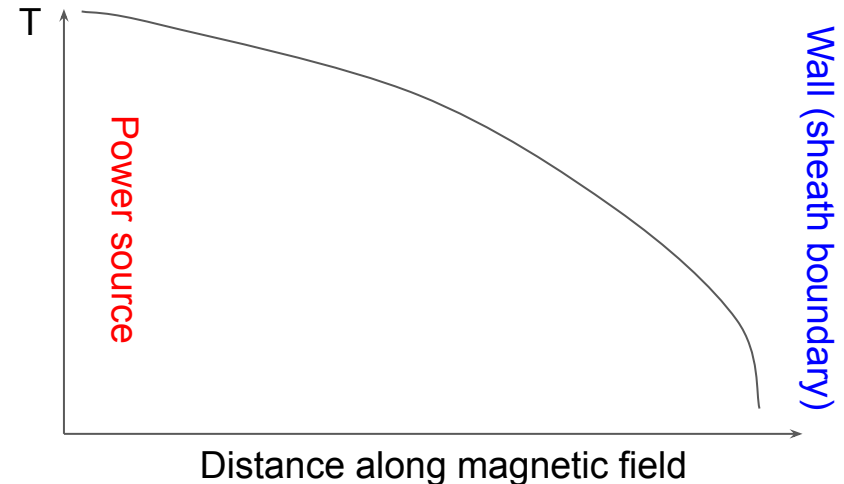
# Task 2.1 - 1D fluid model - Component tests

Check individual parts of the model

- 1D fluid flow, periodic domain. MMS convergence test

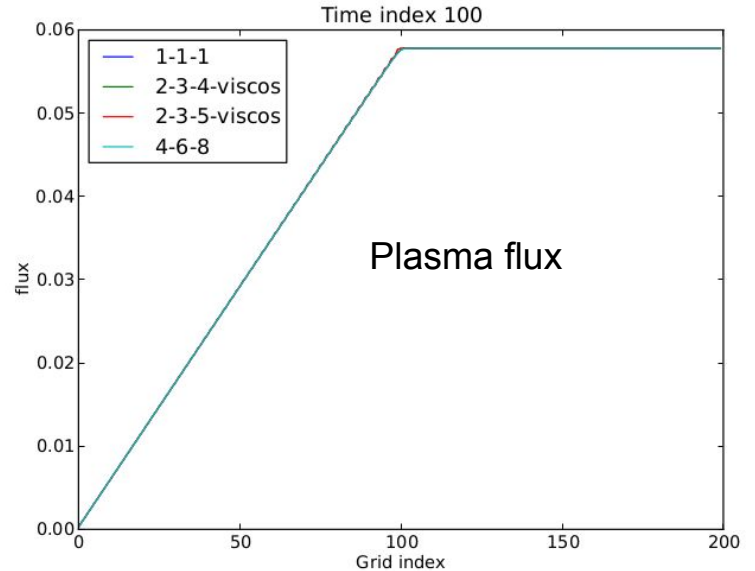
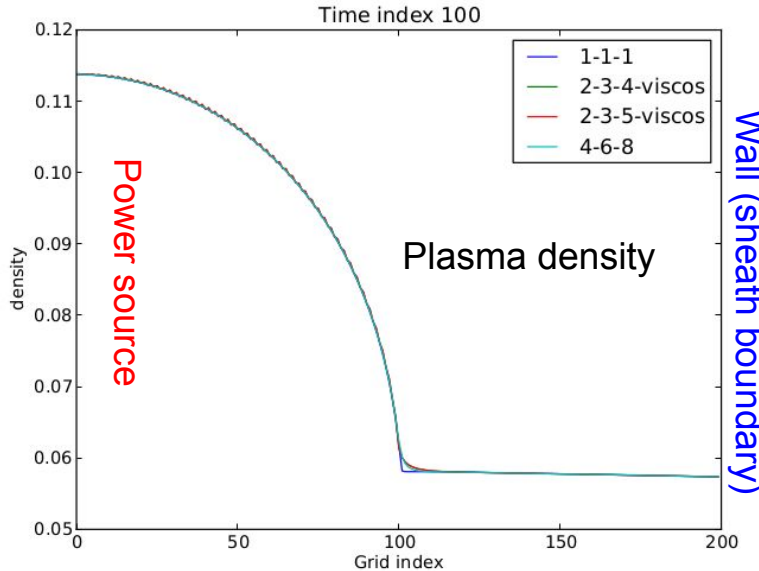
<https://github.com/bendudson/hermes-3/tree/master/tests/integrated/1D-fluid>

- 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

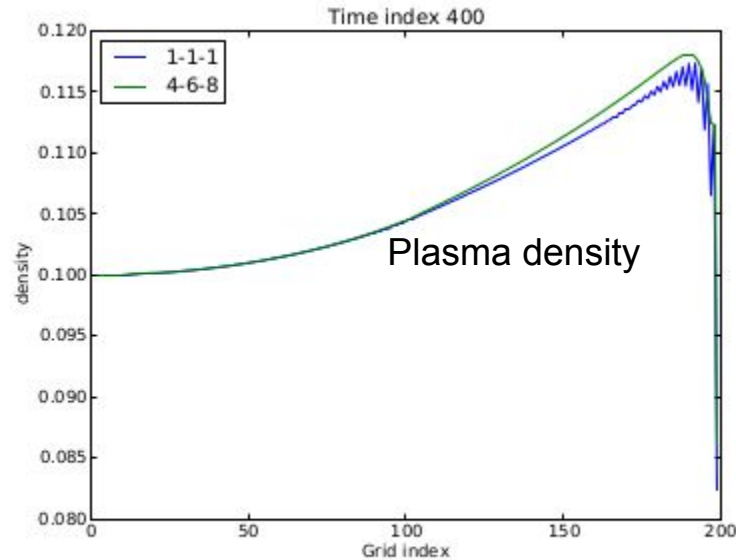
- Outflow boundary conditions on one side, no-flow on the other
- Source over part of the domain -> Sharp changes in gradients



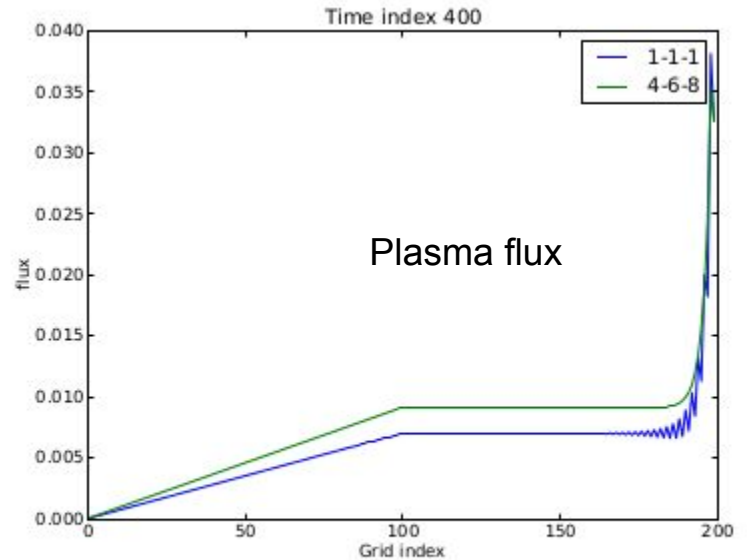
# Task 2.1 - 1D fluid model - Boundary conditions

Sheath boundary conditions (sound speed)

recycling of plasma  $\rightarrow$  neutral gas  $\rightarrow$  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

