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FRANCE 2030
PROGRAMME DE RECHERCHE
NUMÉRIQUE POUR L'EXASCALE

ExaDoST - Work Package 4
GYSELA Demonstrator

WP Leader:
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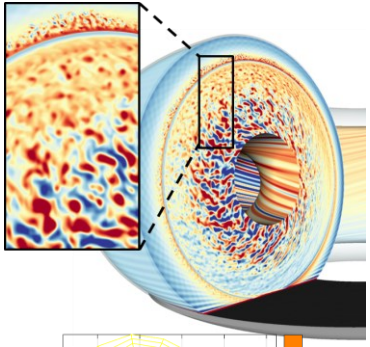
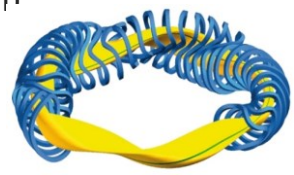
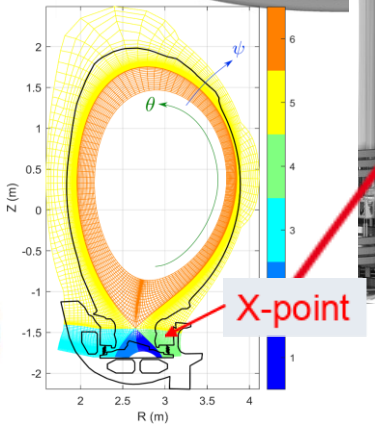
Gysela-X++ - Roadmap for exascale

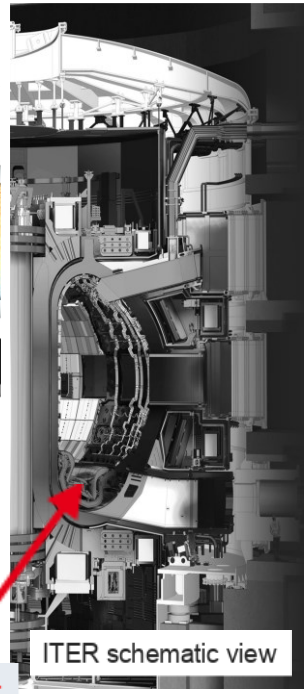
Why do we choose to rewrite GYSELA code ?:

- Portable code on new **exascale** accelarated architectures
  - EoCoE-II feedback: Efficient GPU porting = GPU dedicated kernels
    Modern C++ parallelised with MPI+Kokkos
- More **relevant density & temperature gradients** at edge-SOL
  - Non-uniform meshes (apply new SL scheme dev. in EoCoE-II)
- More realistic geometry → **X-point** configuration
  - Semi-Lagrangian scheme for multi-patches
  - Poisson solver with X-point
- **Stellarator** configuration (full 3D magnetic configuration)
  - Implementation of a 3D scalable Poisson solver
- **Scalable I/O and in-situ diagnostics**



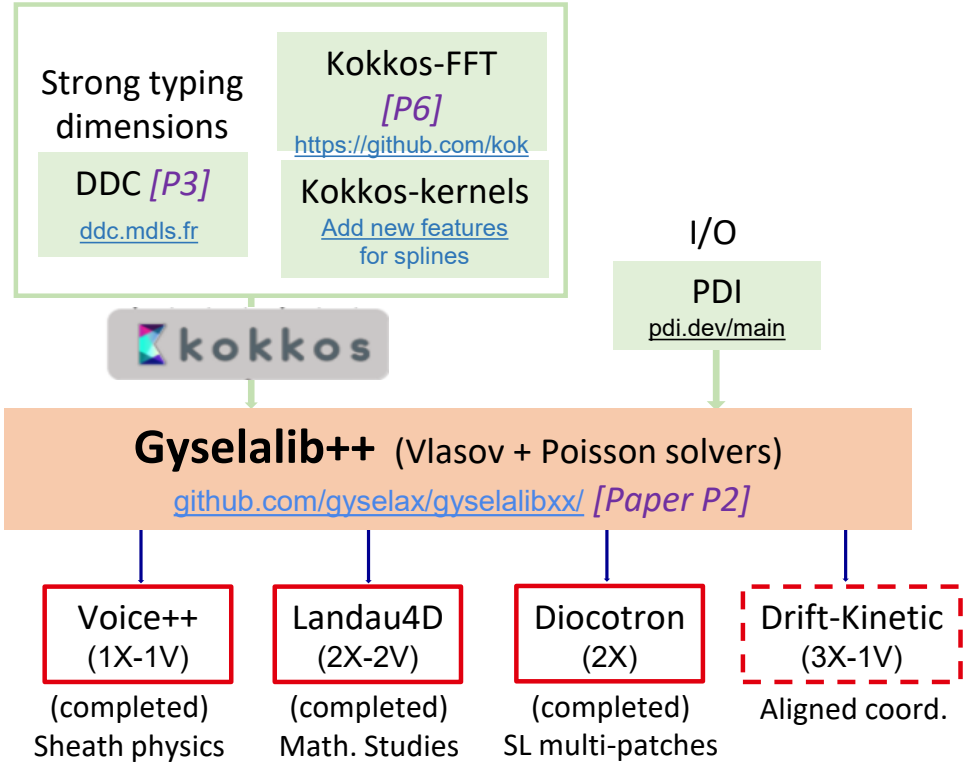






Gysela-X++ = Rewriting of the GYSELA code in modern C++ with X-point for exascale ITER core-edge turbulence simulations

Gyselalib++ a new modular C++ Kokkos-based library for **Gysela-X++** but not only …



- All mathematical building blocks to construct kinetic or gyrokinetic plasma simulation codes in C++, simulating a distribution function discretised in phase space on a structured grid.

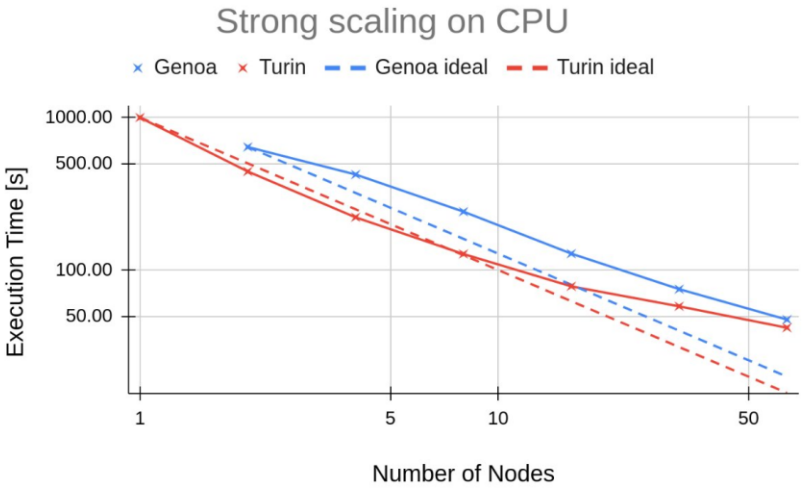
↓

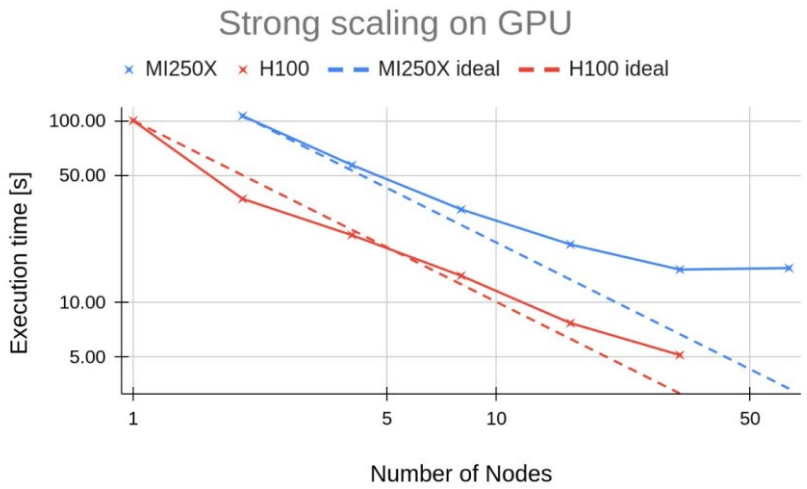
- Designed to be used for mathematical community for development of new numerical schemes

Gyselalib++ : Kokkos backend = **efficient portability on both CPU and GPU arch.**

First tests: Landau4D case (256 x 256 x 256 x 256) up to 64 nodes (512 GPU)

- Adastra (CINES/France) : AMD CPU Genoa + AMD GPU MI250X
- Pitagora (CINECA/Italy) : AMD CPU Turin + NVIDIA GPU H100



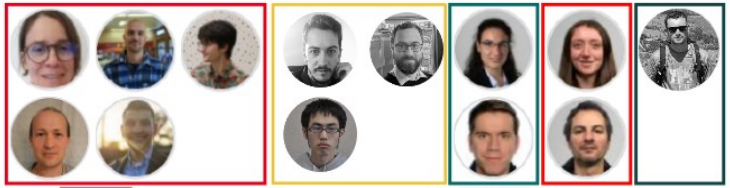


Promising results in 4D version but all the optimisation efforts will be performed on the 5D version

Gyselalib++: A collaborative open source project

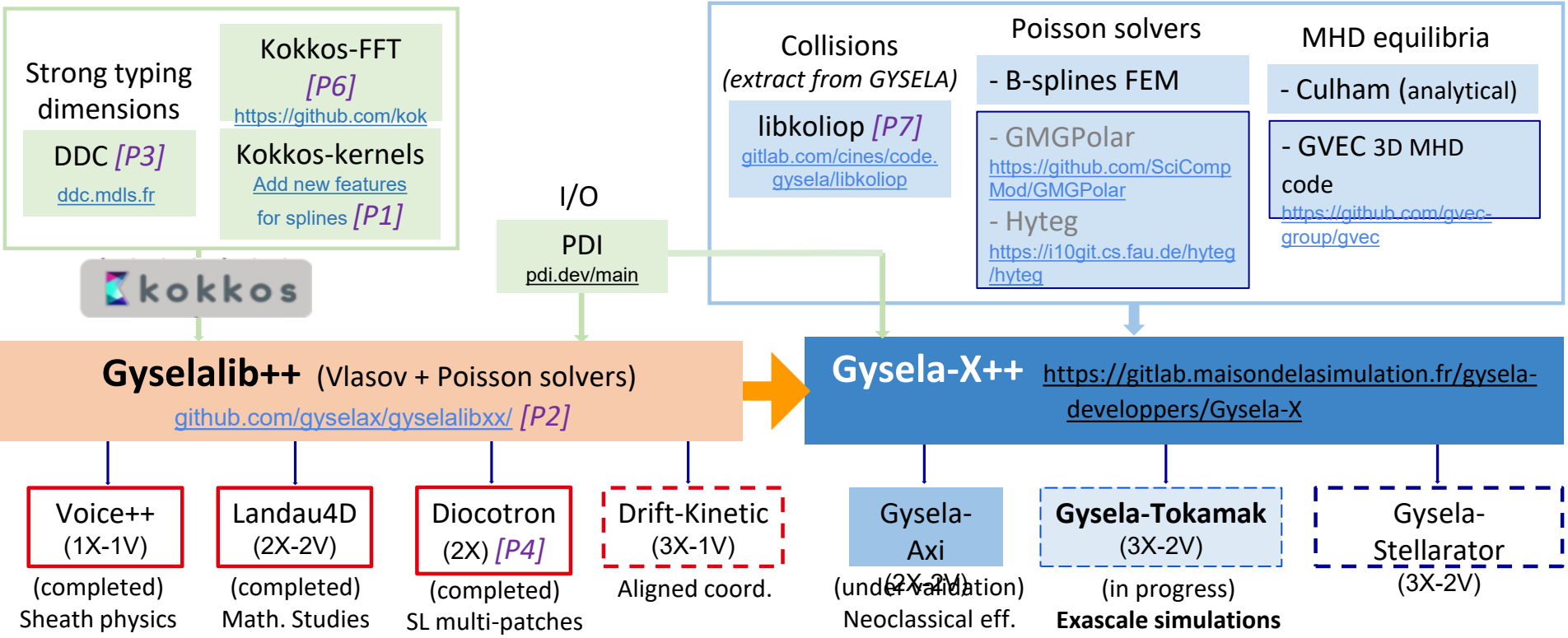
github.com/gyselax/gyselalibxx/
gyselax.github.io/gyselalibxx/

Journal of Open Source Software (JOSS) paper 2025
https://doi.org/10.21105/joss.08582



- The code uses **semantic versioning** and is **currently at v0.3.0**.
- Tests are run using **ctest**:
  - **Unit tests** implemented **using the google test framework and** a small number of **non-regression tests**.
  - Both CPU runners (provided by GitHub) and Nvidia GPU runners (using a self-hosted CEA runner) are used.
- The code also includes **extensive documentation** https://gyselax.github.io/gyselalibxx/ (updated automatically)
  - API documentation generated from comments in the code using **Doxygen**.
  - More general functionality documentation is written in markdown files.
- Packaging : **Spack recipe** available – GUIX under investigation

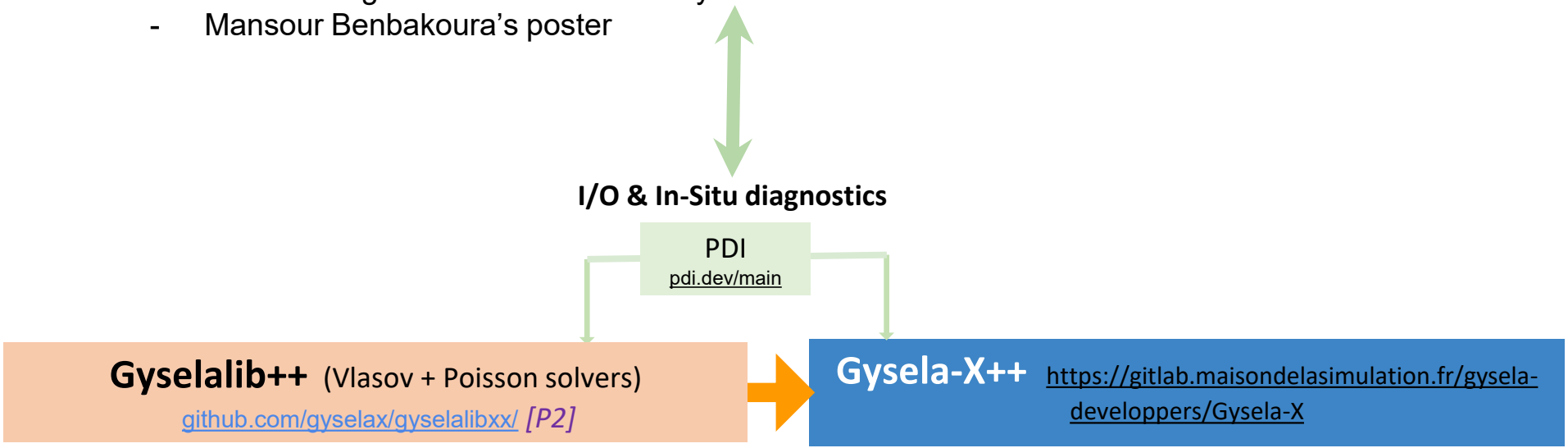
Gysela-X++ dev. based on a new modular C++ Kokkos-based library (**Gyselalib++**)



Gyselalib++: A library for Gysela-X++ & **Mini-app for Exa-Dost via PDI**

- WP1: Restart file writing optimisation
  - Méline Trochon's poster
- WP2: Design of in-situ diagnostics workflow (PDI + DASK + Ray)
  - Andrès Bermeo Marinelli's talk
- WP3: AI based algorithms in the data analysis workflow
  - Mansour Benbakoura's poster

Scientific focus for WP4-GYSELA
Ariel De Vora



Publications

1. Asahi, Y. et al. (2024) Development of Performance Portable Spline Solver for Exa-Scale Plasma Turbulence Simulation, SC24-W: Workshops of the International Conference for High Performance Computing, Networking, Storage and Analysis, 10.1109/SCW63240.2024.00154.

2. E. Bourne et al. (2025) Gyselalib++: A Portable C++ Library for Semi-Lagrangian Kinetic and Gyrokinetic Simulations. Journal of Open Source Software (JOSS), https://doi.org/10.21105/joss.08582

3. T. Padioleau et al. (2025) DDC: The Discrete Domain Computation library. Journal of Open Source Software (JOSS), submitted https://github.com/openjournals/joss-reviews/issues/8256

4. P. Vidal et al. (2025) Local cubic spline interpolation for Vlasov-type equations on a multi-patch geometry. arXiv preprint arXiv:2505.22078, Journal of Scientific Computing, submitted.

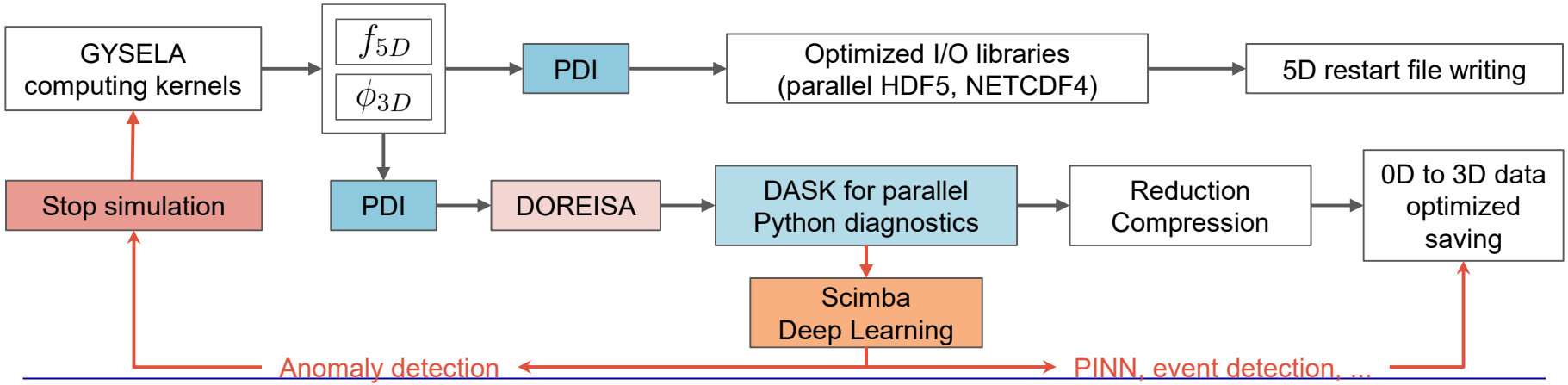
5. Li, Y., et al. (2025). Semi-Lagrangian methods of a plasma hybrid model with multi-species kinetic ions and massless electrons. arXiv preprint arXiv:2504.04282.

6. Asahi, Y. et al. (2025) kokkos-fft: A shared-memory FFT for the Kokkos ecosystem. Journal of Open Source Software (JOSS), https://doi.org/10.21105/joss.08391

7. Malaboeuf, E. et al. (2025) Porting a Fortran plasma simulation to Exascale on AMD GPUs using both OpenMP and Kokkos, SC25 Workshop WAPD, 2025, accepted.

Gysela-X++: I/O & In Situ Analytics

- **Coupling with PDI and DEISA**
  - Seamless Python/C++ interoperability, saving in HDF5 or NetCDF4 format *[DONE]*
- **Gysela-X++ coupled with Xarray and Dask**
  - Post-process using labeled, multi-dimensional array abstractions *[DONE]*
  - Dask-backed Xarrays enabling scalable, parallel, and out-of-core data analysis *[DONE]*
- **Integration of Artificial Intelligence algorithms (Scimba)**
  - Deep learning for anomaly and event detection (Faster R-CNN, YOLO) *[WIP]*
  - AI-assisted diagnostics (intelligent data compression) *[WIP]*



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