Plasma-PEPSC

Plasma Exascale-Performance Simulations CoE

An Overview

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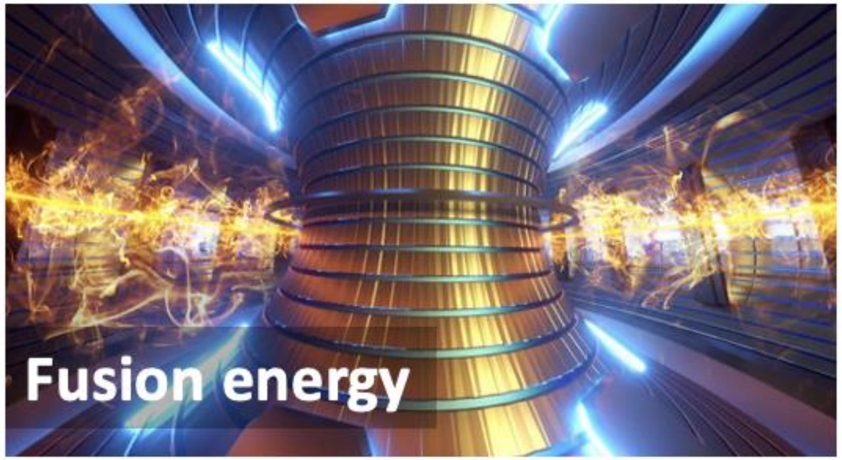
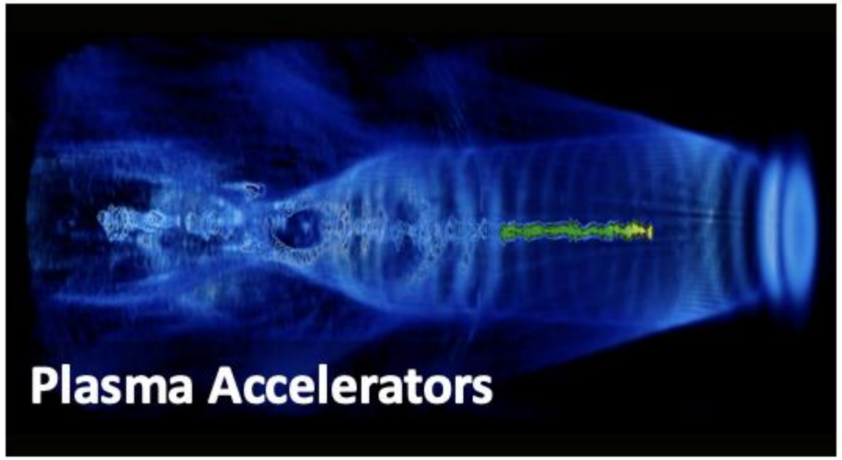
On behalf of KTH, MPG, IPP CAS, FORTH, BSC, TUM, SiPearl, HZDR, UoH, UL

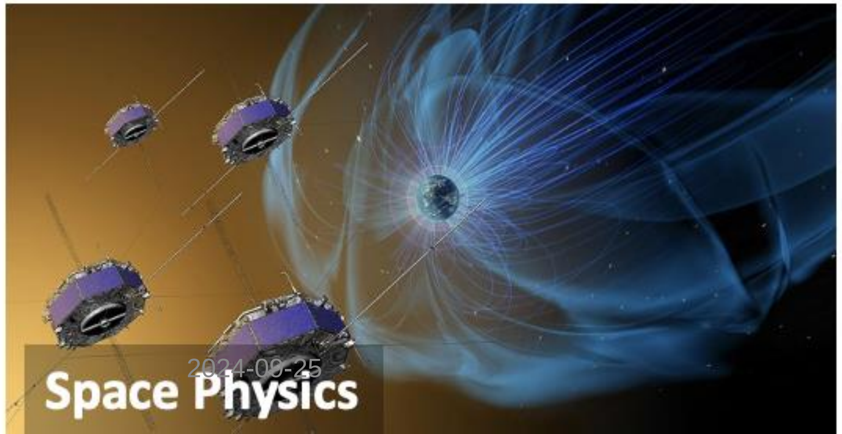
Outline

1. Motivation, Main Objective & Vision
2. Four Codes to Solve Plasma Physics Grand Challenges
3. How do we make them ready for European Exascale Systems?
4. Project Organization

Motivation, Main Objective & Vision







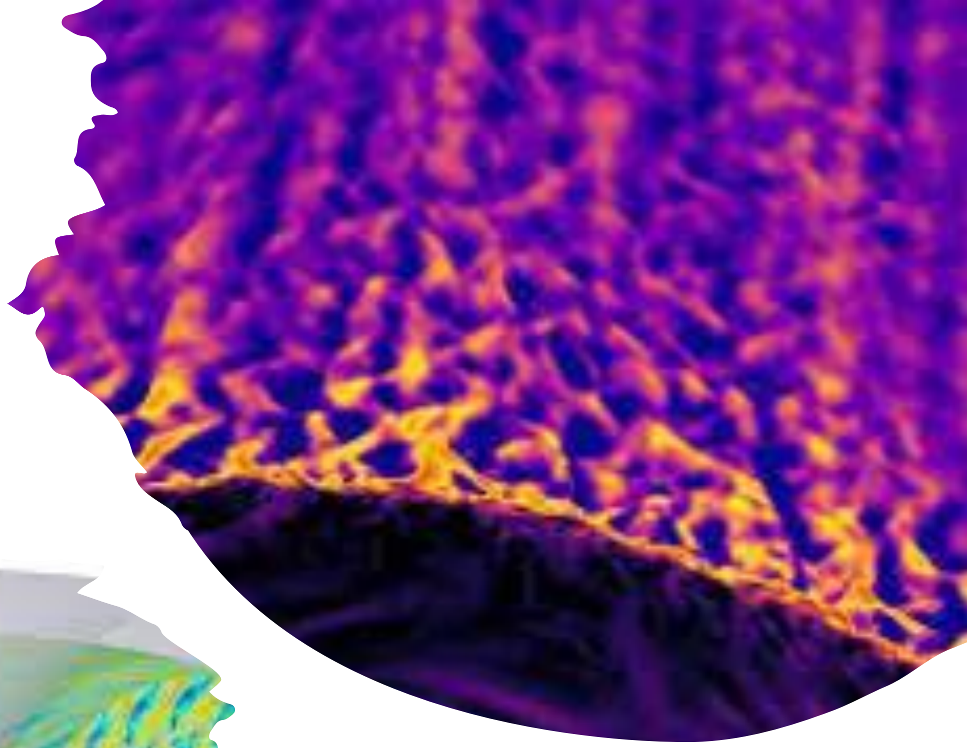
Plasma-PEPSC: Addressing Critical Challenges in Plasma Science with Exascale

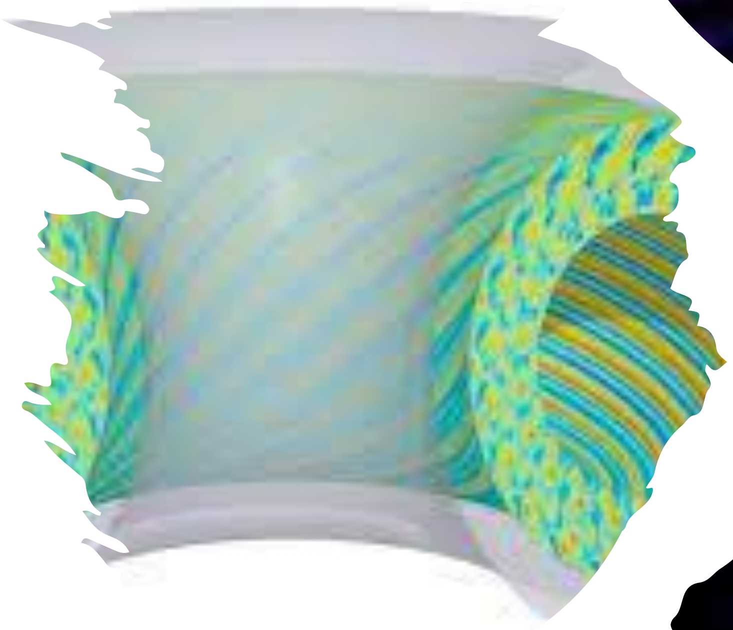
- Advancing Plasma Science Through Exascale Computing:
    - Plasma science is critical in numerous fields, from energy production to medical applications and space exploration.
    - Current challenges require advanced computational capabilities beyond what's currently available.
    - Exascale computing offers unprecedented power and scalability, enabling simulations at previously unattainable levels of detail and accuracy.

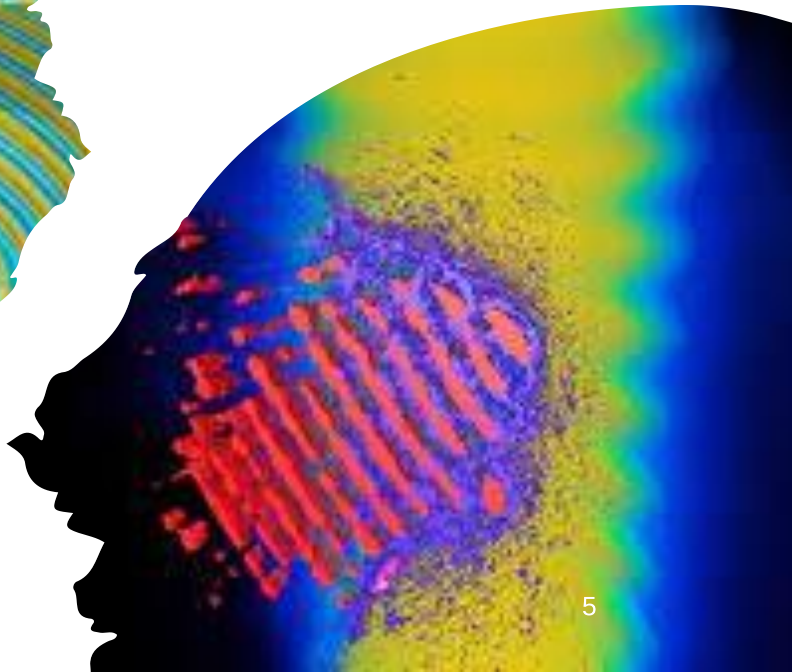
Plasma-PEPSC Main Objective

Enable unprecedented plasma simulations and associated extreme-data analytics to address plasma physics grand challenges that are impossible to solve on current extreme-scale systems and require exascale computing:

1. Controlling plasma-material interfaces
2. Optimizing magnetically confined plasmas
3. Designing next-generation plasma accelerators
4. Predicting space plasma dynamics in the Earth’s magnetosphere

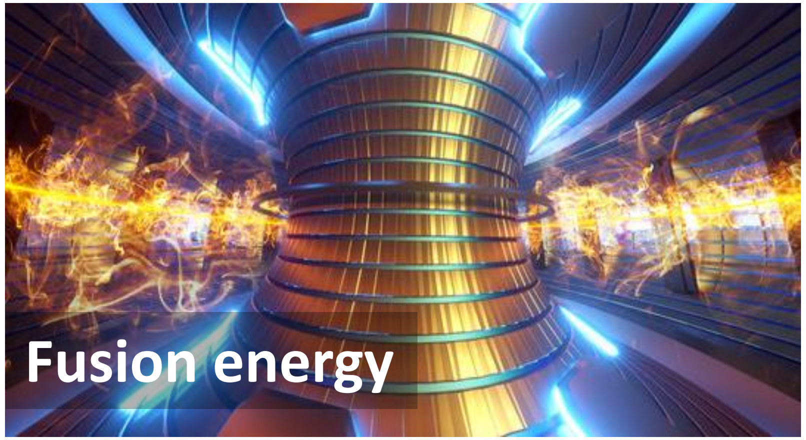


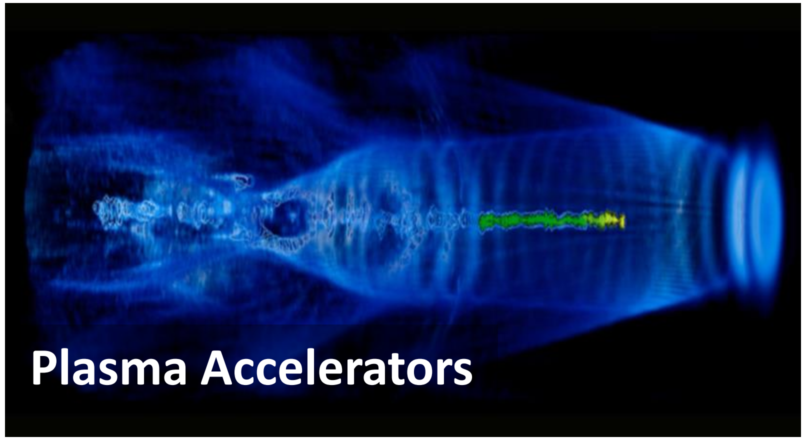


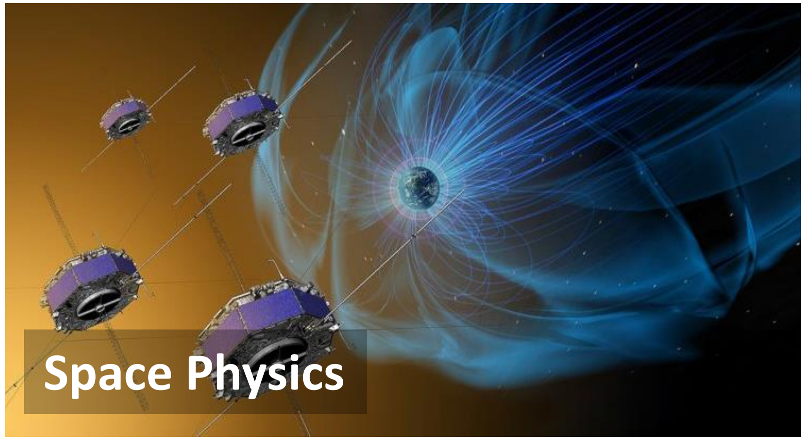


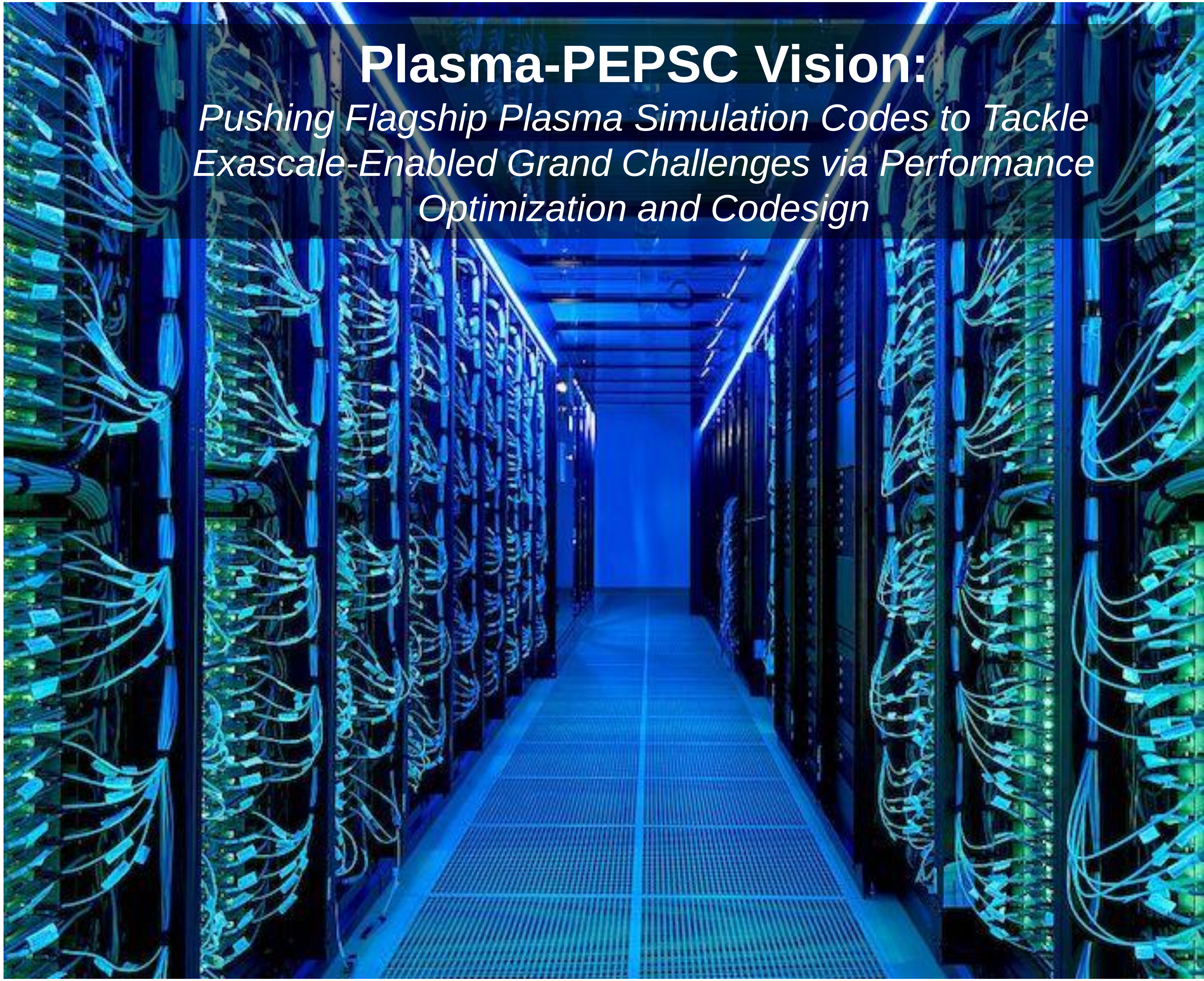
Plasma-PEPSC Vision:

Pushing Flagship Plasma Simulation Codes to Tackle Exascale-Enabled Grand Challenges via Performance Optimization and Codesign









Four Codes to Solve Plasma Physics Grand Challenges

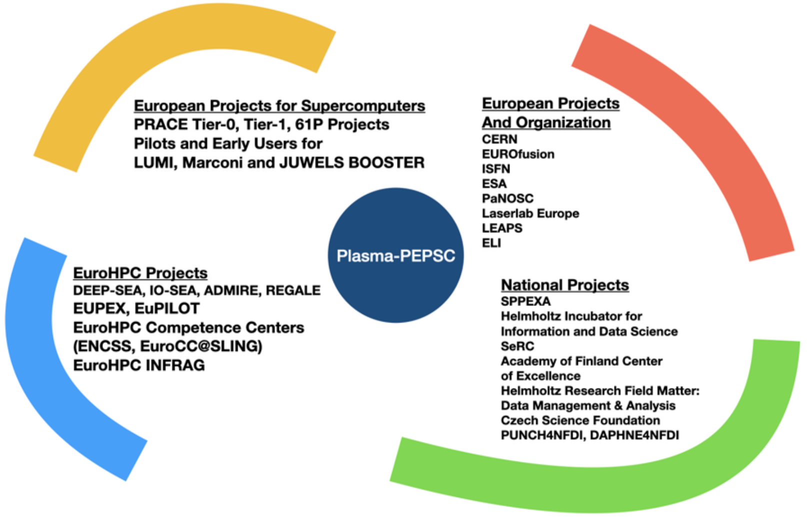
Plasma Simulation Code User Base

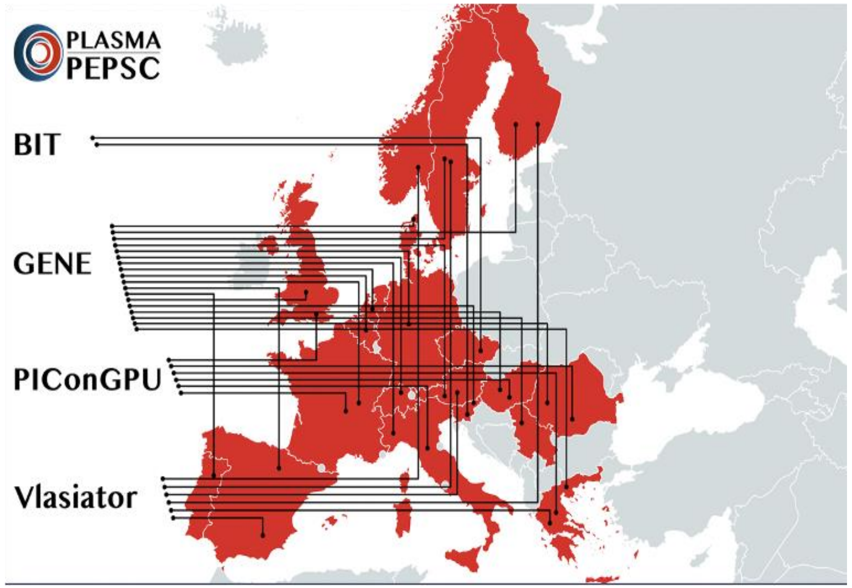
BIT Codes. Grand Challenge: Material-Plasma Interface. Dev. teams: IPP CAS, UL

GENE. Grand Challenge: Optimizing Magnetically confined plasmas. Dev. team: MPG

PIConGPU. Grand Challenge: Next-generation Accelerator. Main developer team: HZDR

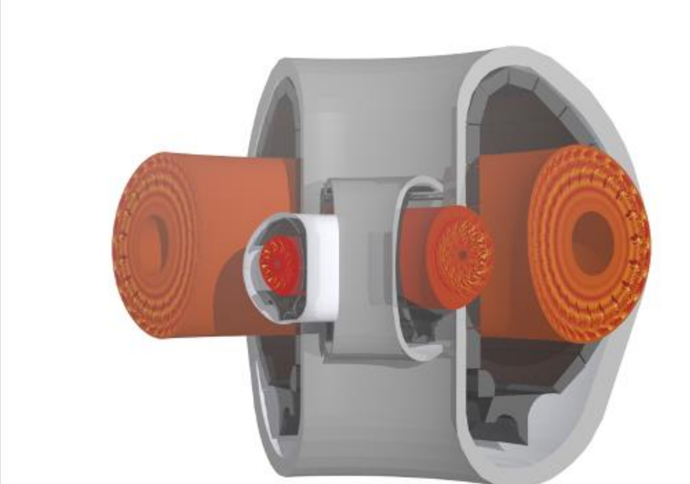
Vlasiator. Grand Challenge: Near-Earth Space Dynamics. Main developer team: UoH





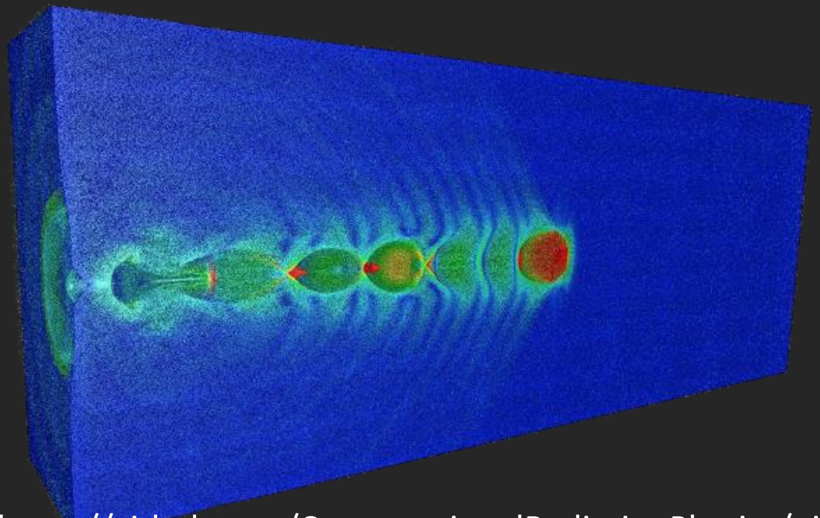
Plasma-PEPSC Flagship Codes

GENE



https://genecode.org/

PIConGPU

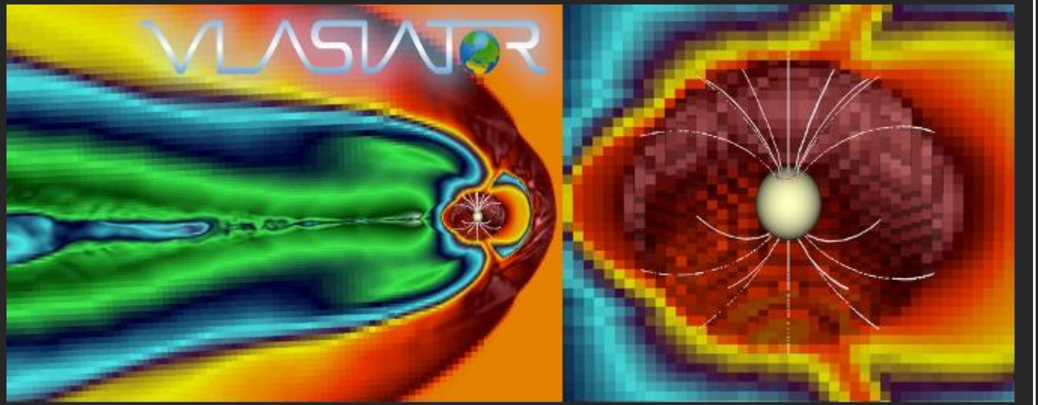


https://github.com/ComputationalRadiationPhysics/picongpu

BIT

https://repo.tok.ipp.cas.cz/tskhakaya/bit1

Vlasiator

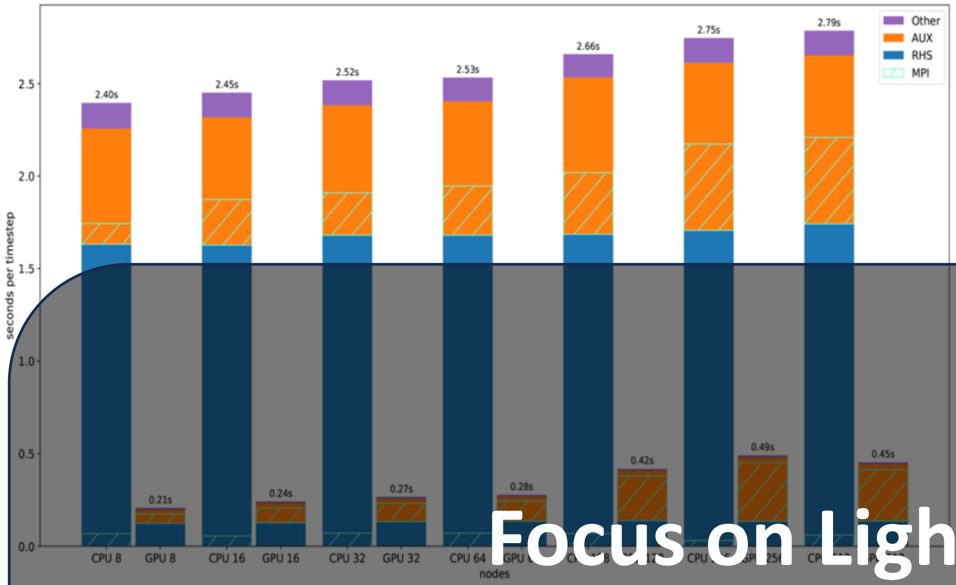


https://github.com/fmihpc/vlasiator

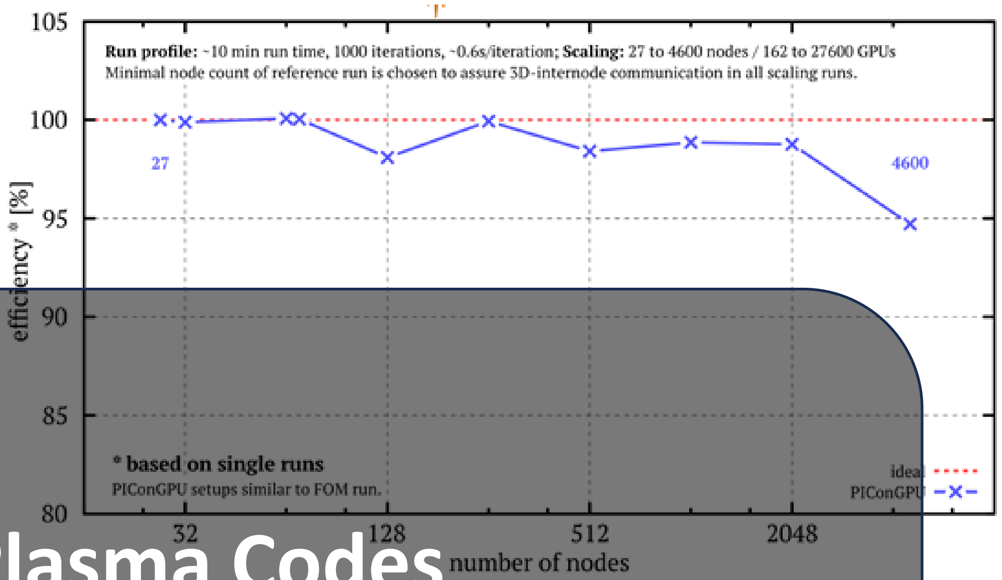
Focus on Lighthouse Plasma Codes

Demonstrated scalability of current Petascale Systems

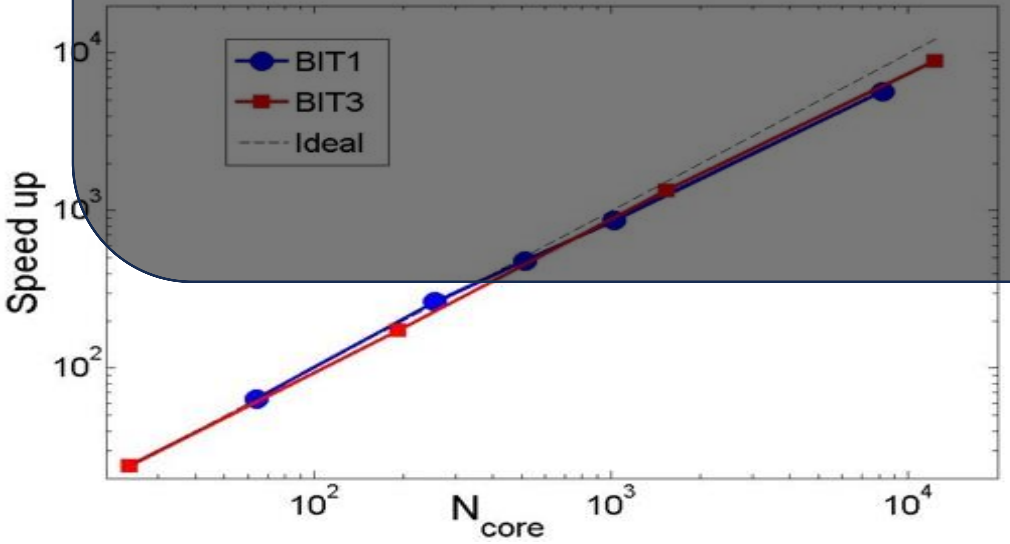
GENE Scaling

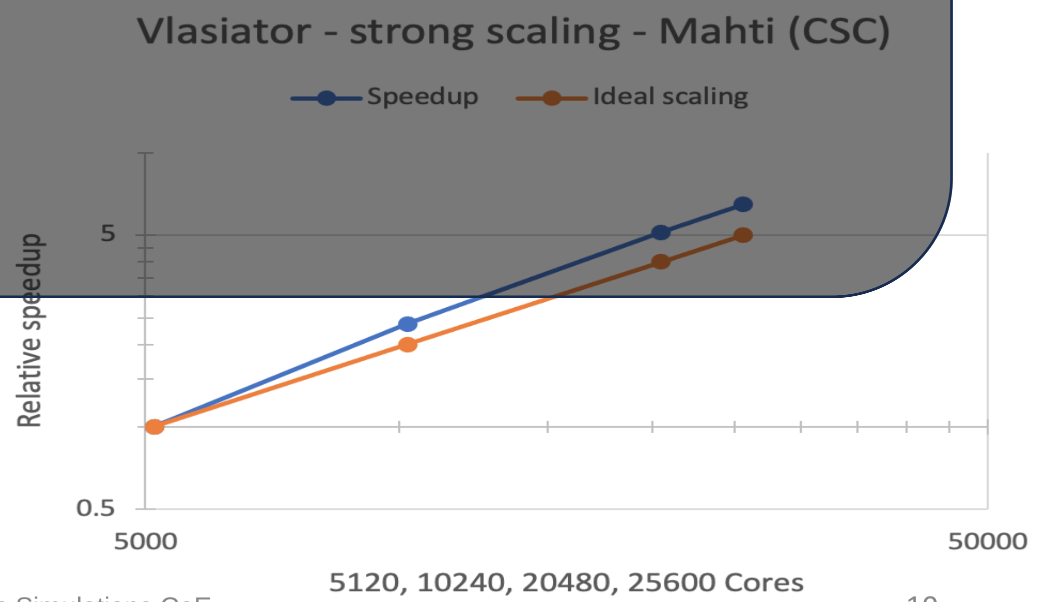


PIConGPU Scaling



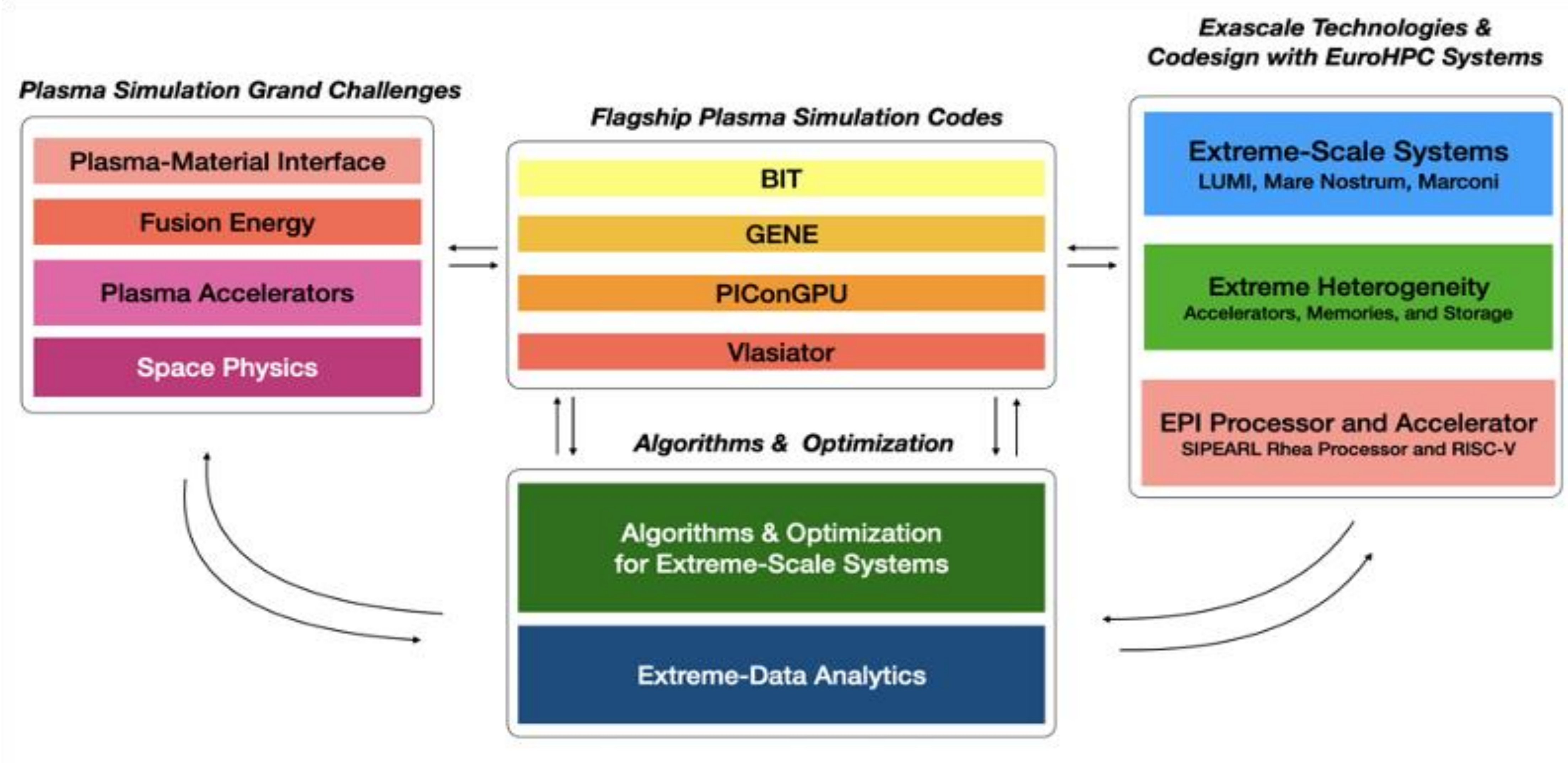
BIT Scaling



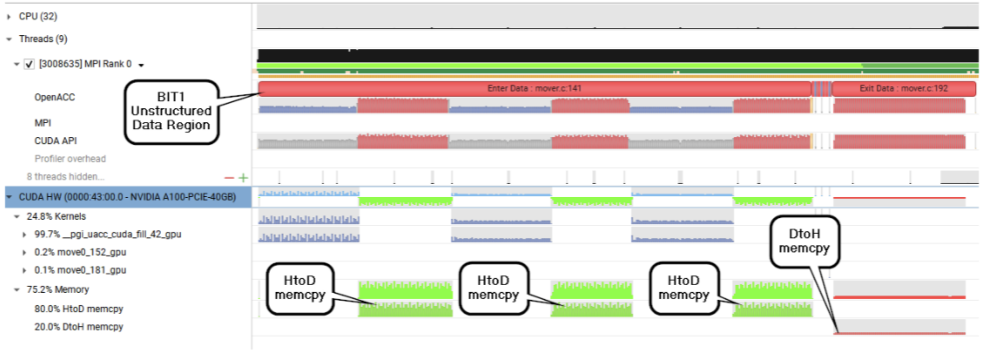


How do we make them ready for European Exascale Systems?

Our Methodology

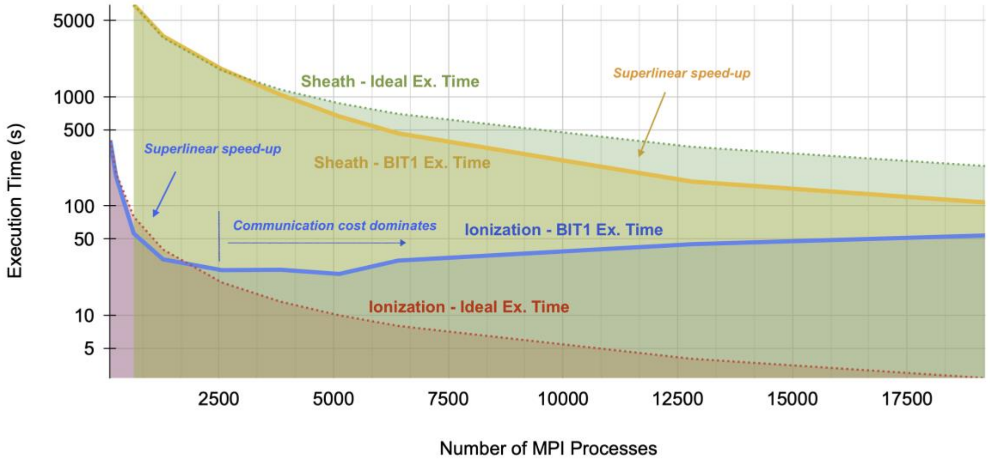


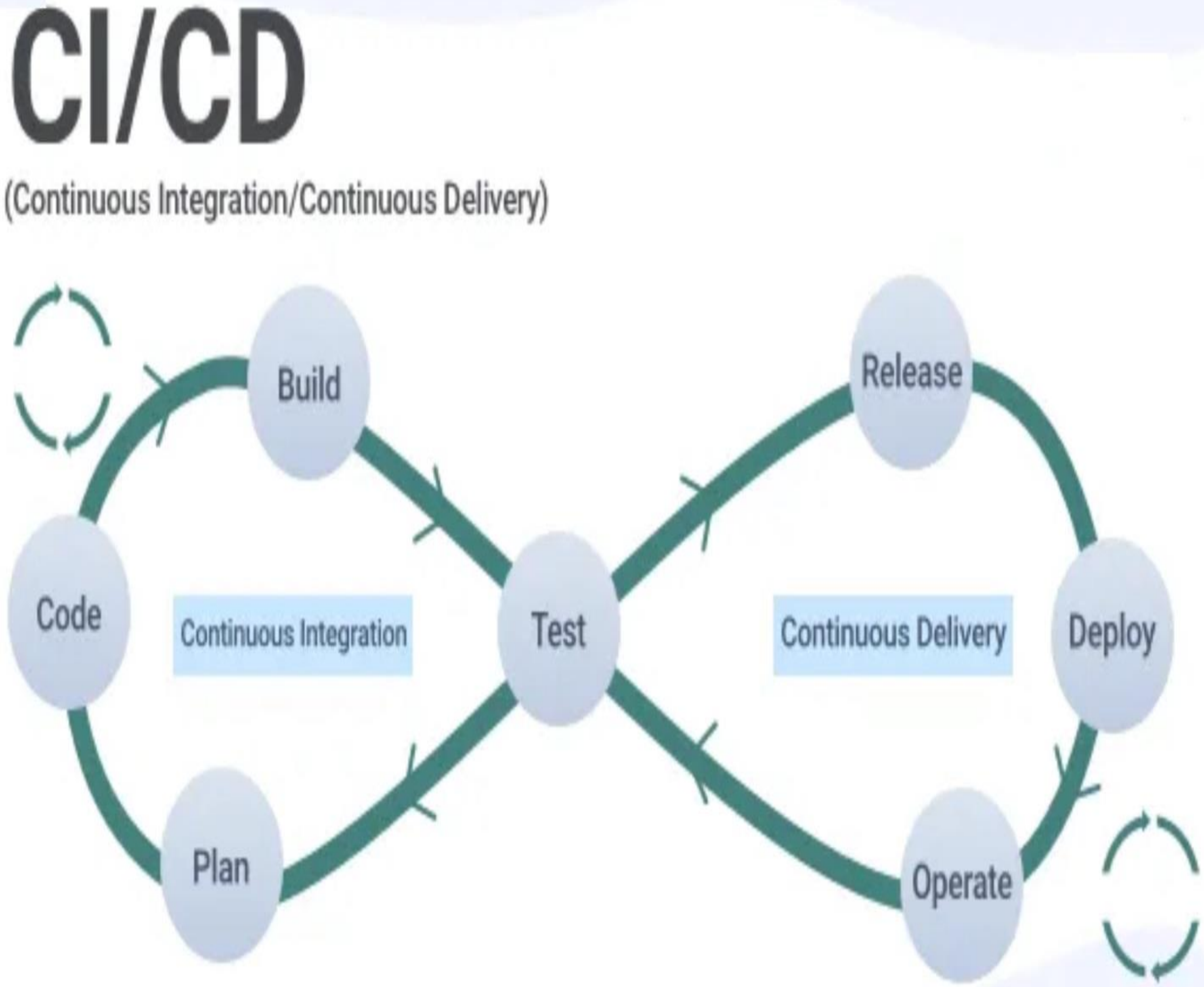
Performance Optimization



We maximize the performance of four European critical plasma on European exascale and pre-exascale systems, building on

- **algorithmic advances** - *load balancing, data compression, resilience, in-situ data analysis, visualization*
- **programming model and library developments** – *MPI, efficient parallel I/O*
- **Heterogeneous system programming** – Nvidia and AMD GPUs (new features and interoperability),





https://medium.com/digital-transformation-and-platform-engineering/a-quick-guide-to-continuous-integration-and-continuous-delivery-4df594ae281

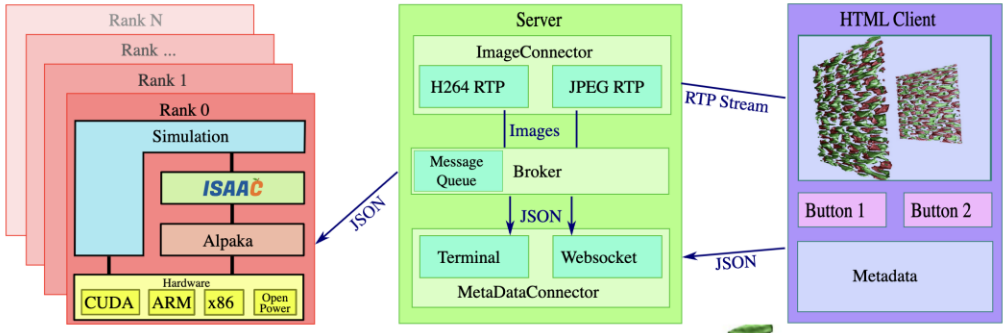
Software Engineering at Scale

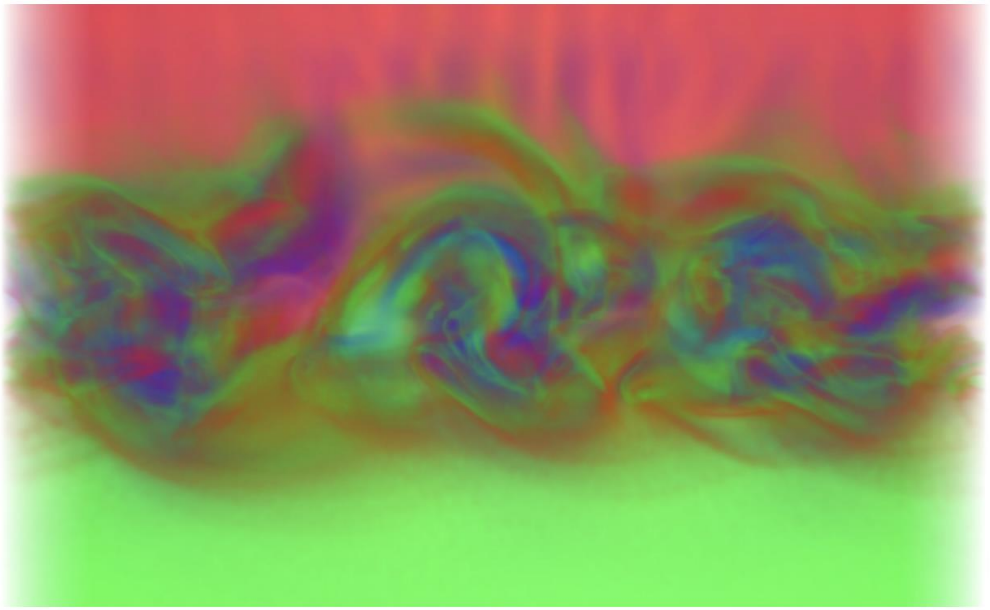
Establish and ensure an integrated HPC software engineering approach for deploying, verifying, and validating extreme-scale kinetic plasma simulations that can serve as a community standard.

Enabling Data Analysis at Scale

Enable high-throughput analysis of the large simulation result datasets from the four high-fidelity kinetic plasma simulations with

- optimized and scalable parallel I/O
- data compression techniques
- online data analysis building on efficient data streaming
- integrated AI-based data analysis

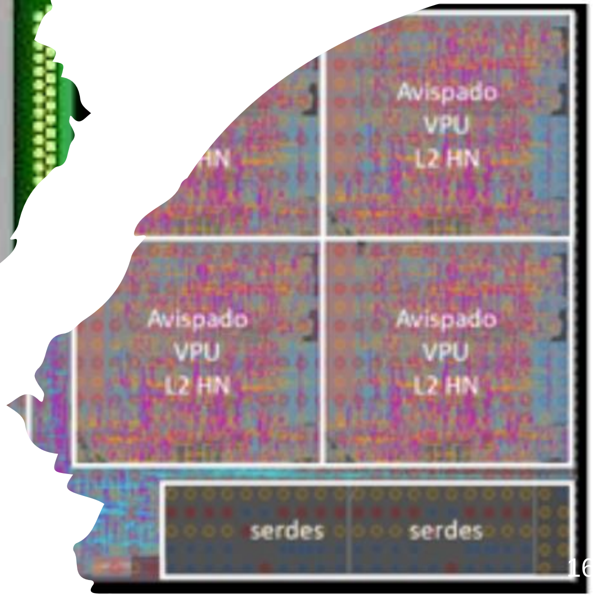




https://computationalradiationphysics.github.io/isaac/

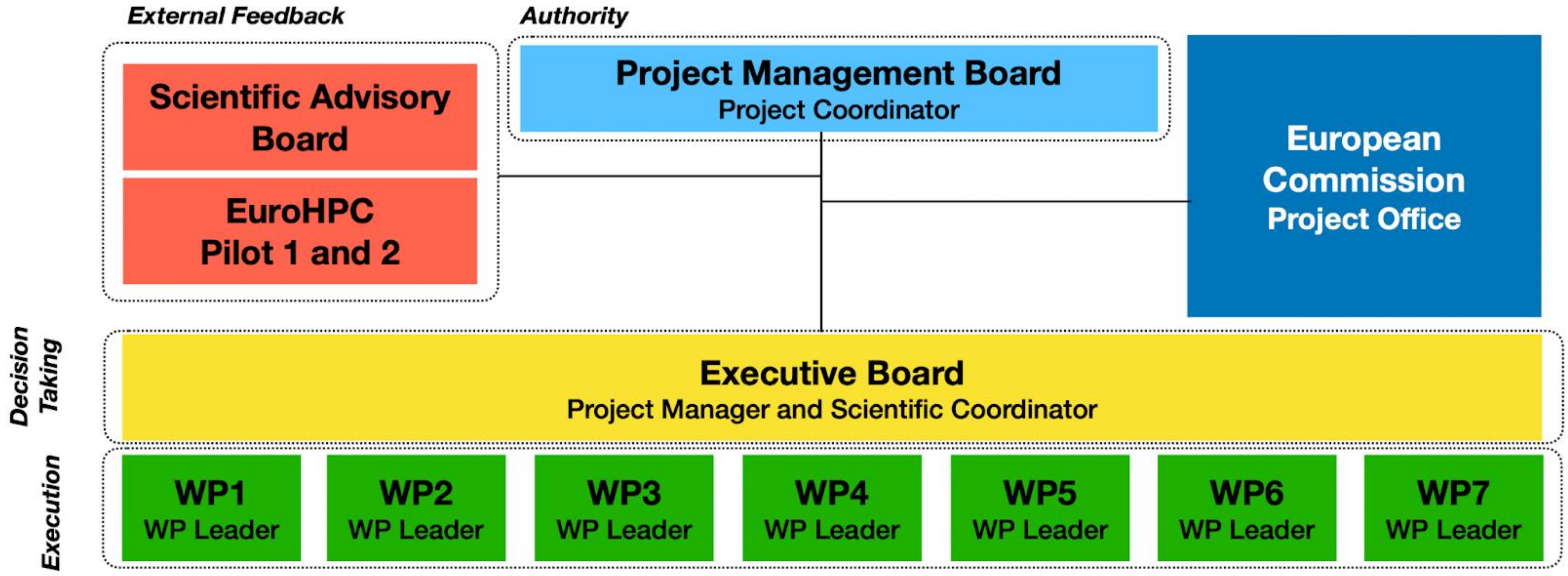
Preparing for Next-generation and future Technologies via Co-design

- A continuous and integrated co-design methodology for the four plasma codes to provide/receive direct input to/from the design and development of the
  - Rhea - EPI Processor from SiPearl
    - Powering Jupiter
  - EPAC – EPI Accelerator
- Post-Moore technologies and Quantum Computing for plasma simulations
  - Effort that can feed into EuroHPC quantum computing initiatives

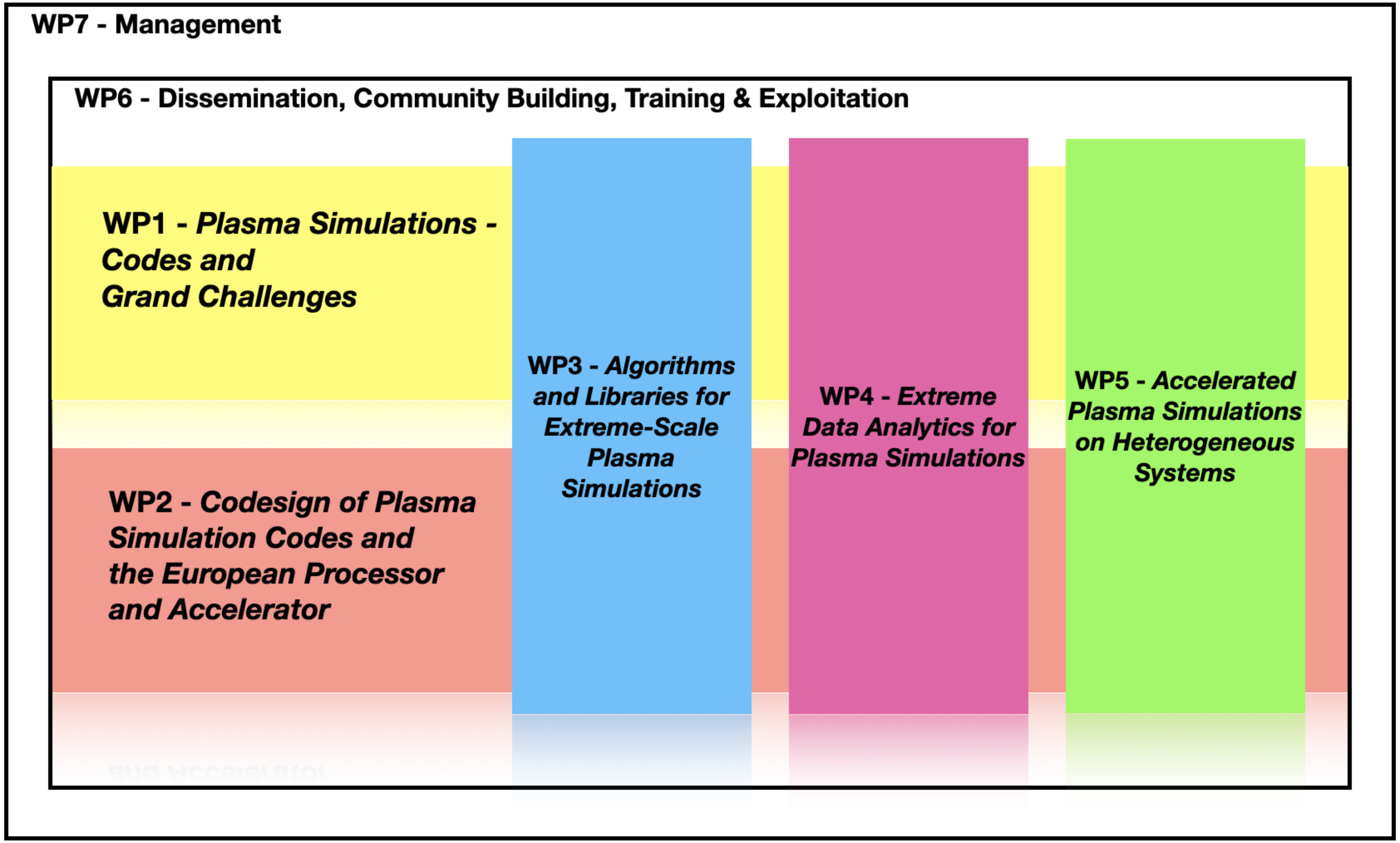


Project Organization

Management Structure

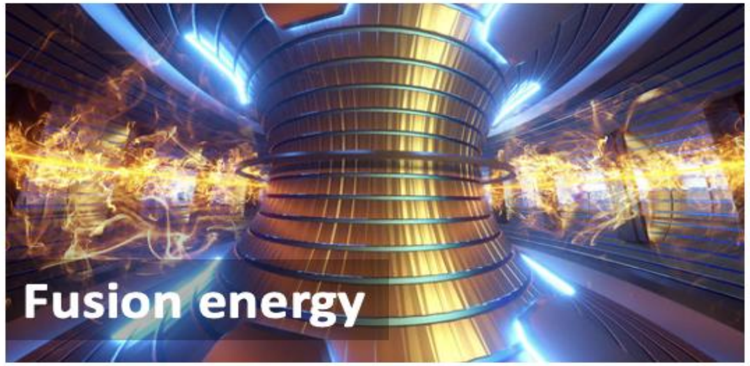


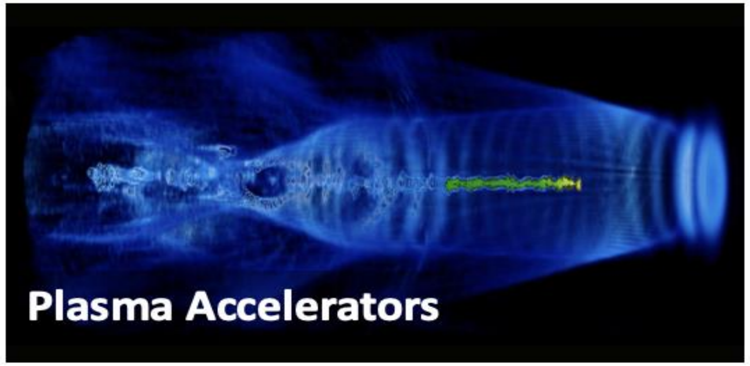
Work Package Structure

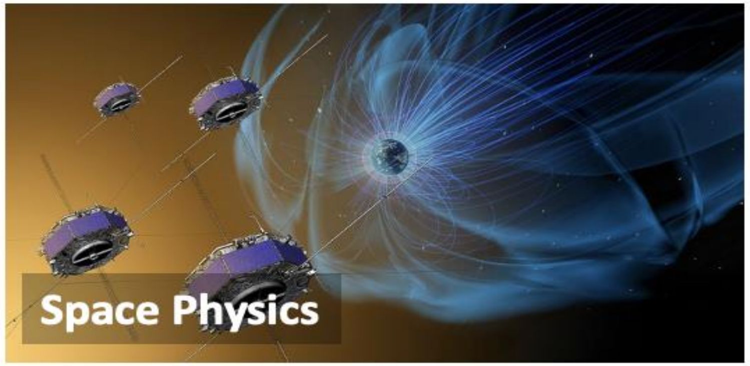


Five Technical WPs

WP1 - *Plasma Simulations – Codes and Grand Challenges*







WP2 - *Co-design of Plasma Simulation Codes with the European Processor and Accelerator*

- EPI Processor
- EPI Accelerator
- Quantum Computing

WP3 - *Algorithms and Libraries for Extreme-Scale Plasma Simulations*

- MPI
- Load-balancing
- Resilience & Fault-tolerance

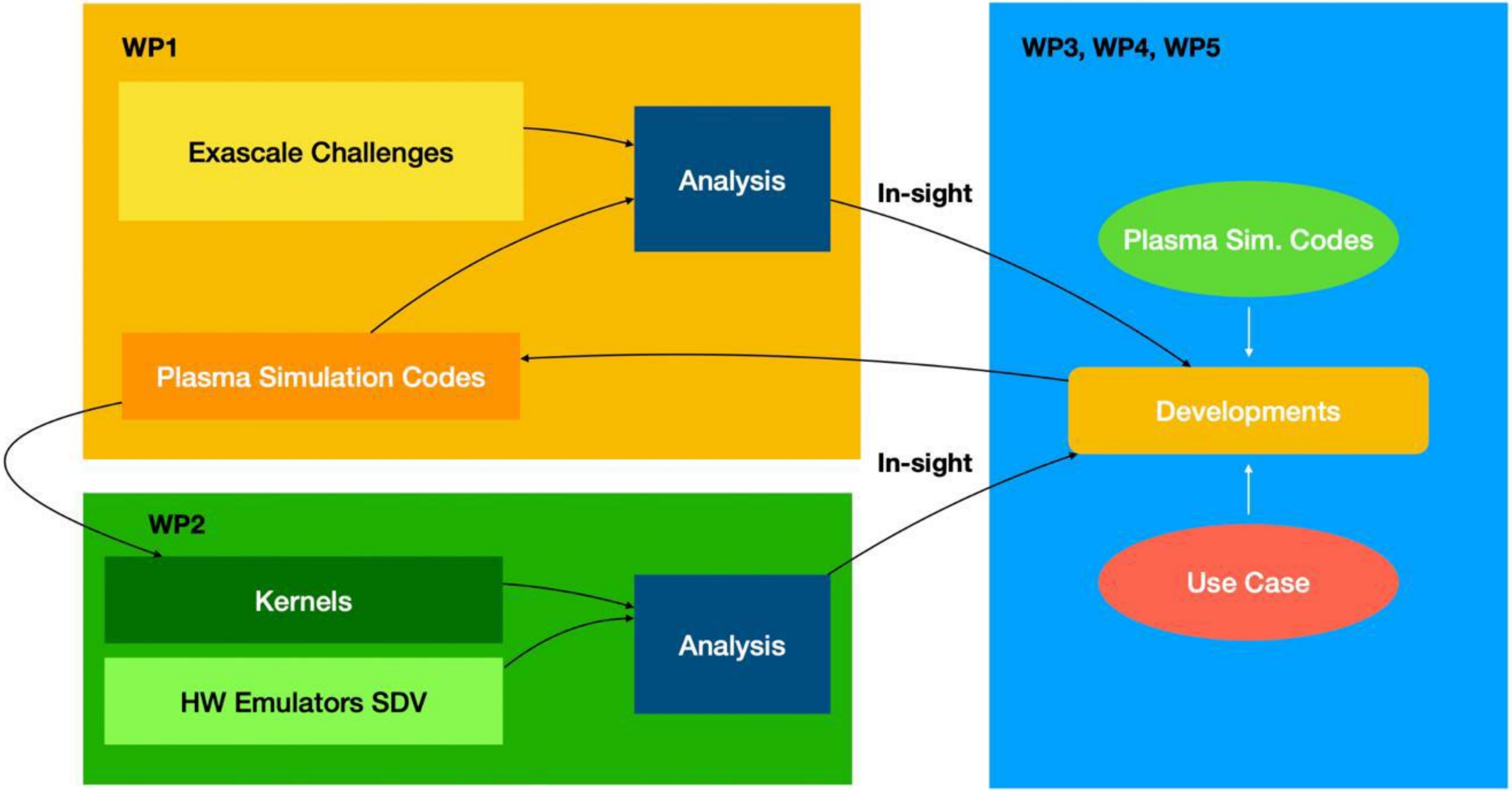
WP4 - *Extreme Data Analytics for Plasma Simulations*

- Parallel I/O
- In-situ data analysis
- Compression

WP5 - *Accelerated Plasma Simulations on Heterogeneous Systems*

- Redesigning Algorithms, Porting, and Optimization for Accelerators
- Application Data Placement and Migration for Heterogeneous Memories

WP Interactions and Associated Contributions

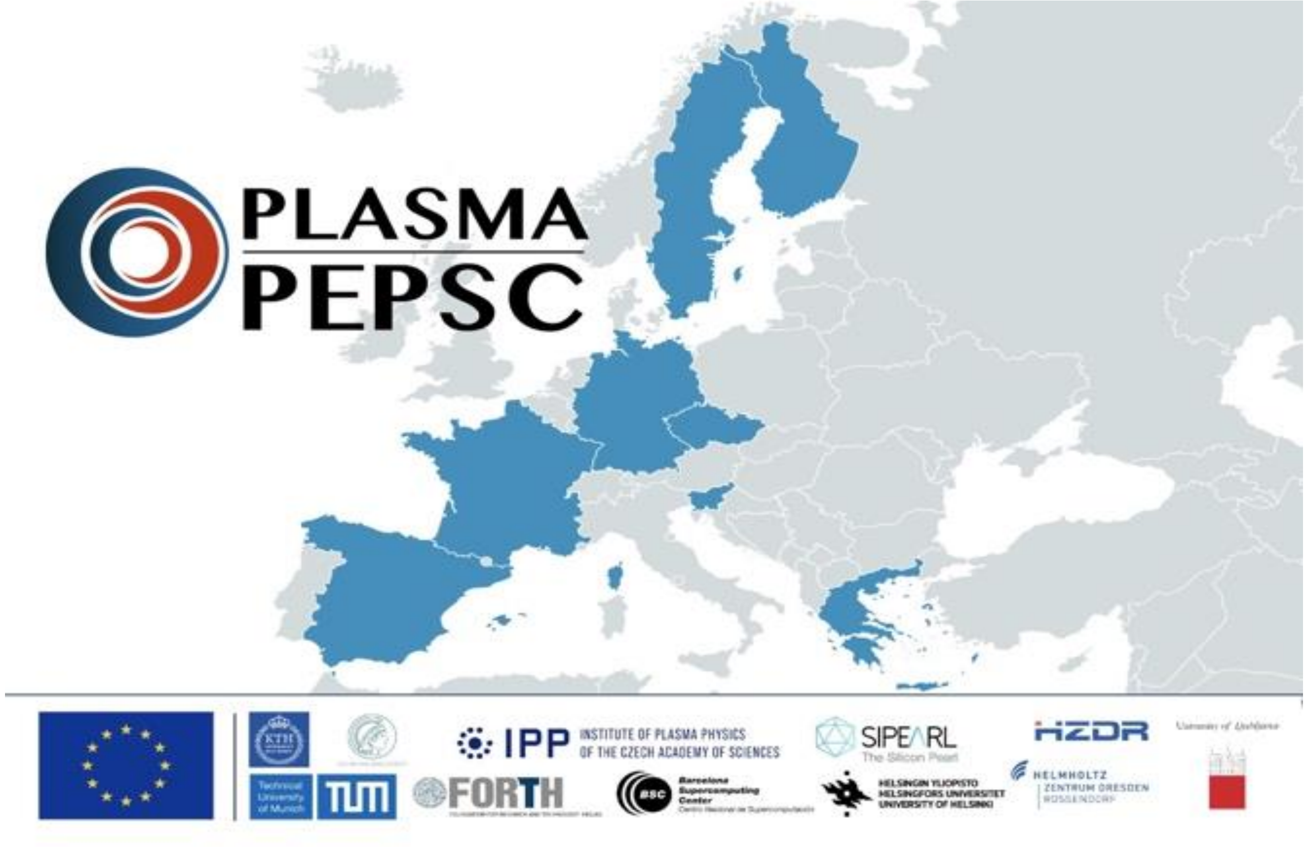


Today Topics - Summary

- Plasma-PEPSC is a grand challenge-driven Center of Excellence for plasma simulation with applications to fusion, plasma accelerators, and space physics

- Four lighthouse plasma codes for upcoming and future exascale systems
  - Performance Optimization
  - Software Engineering
  - Data Analysis at Scale
  - Codesign with emerging technologies, including SiPearl processor, EPAC accelerator, and quantum technologies

- World-wide usage and adoption in the computational plasma physics and HPC communities
  - Plasma simulation software running efficiently on (pre-)exascale systems.
  - Input to the European processor and accelerator developments.
  - Publications on best practices and novel methods to deal with extreme parallelism, accelerators, and extreme data.
  - Training and education material in plasma simulation tools, HPC and tools for extreme-scale data analytics.



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