EU-US Workshop on Software Technologies for Integrated Modeling in Fusion
Gothenburg, December 1st to December 3rd, 2010

Tour de Project:
Proto-FSP CPES

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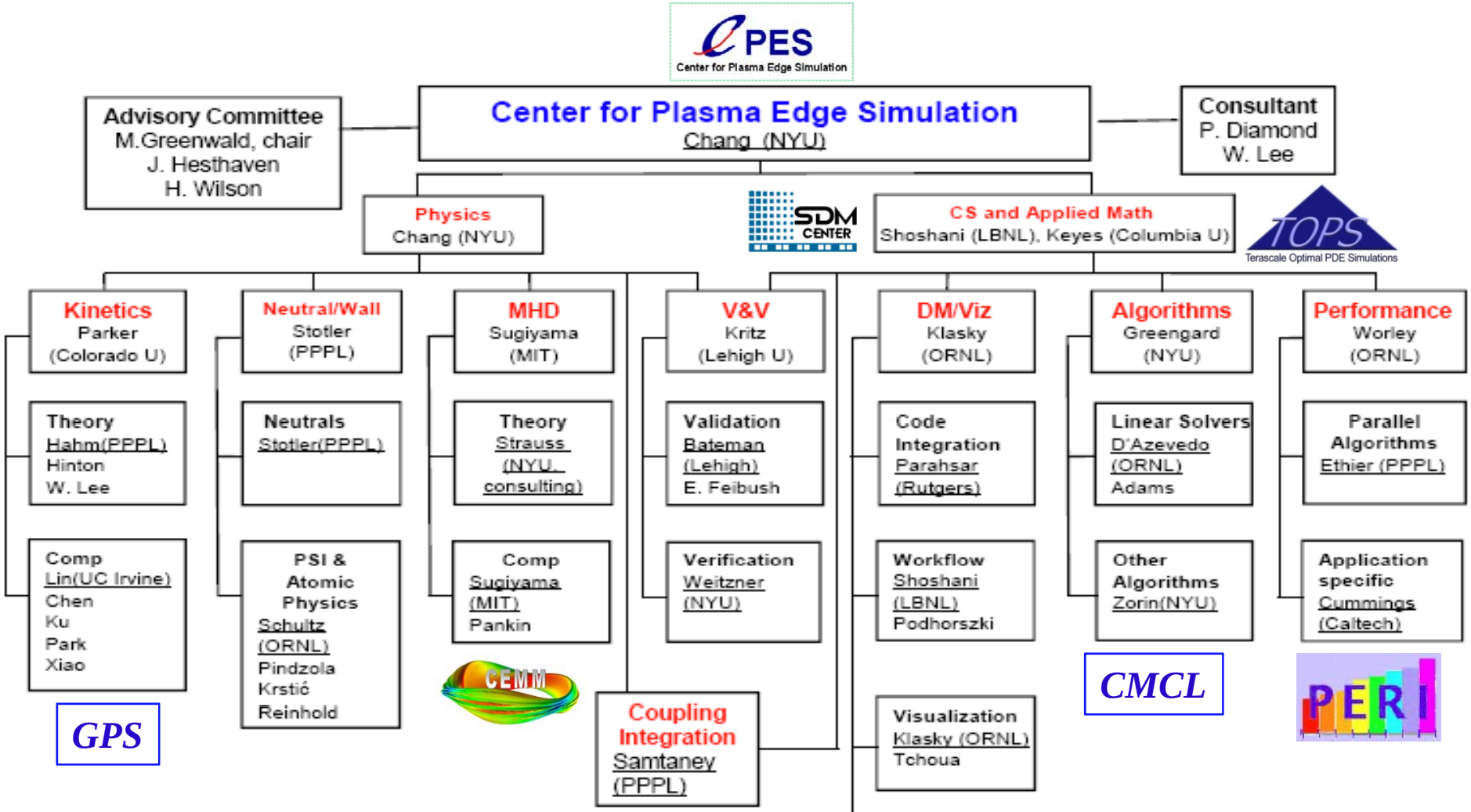
for the CPES Team



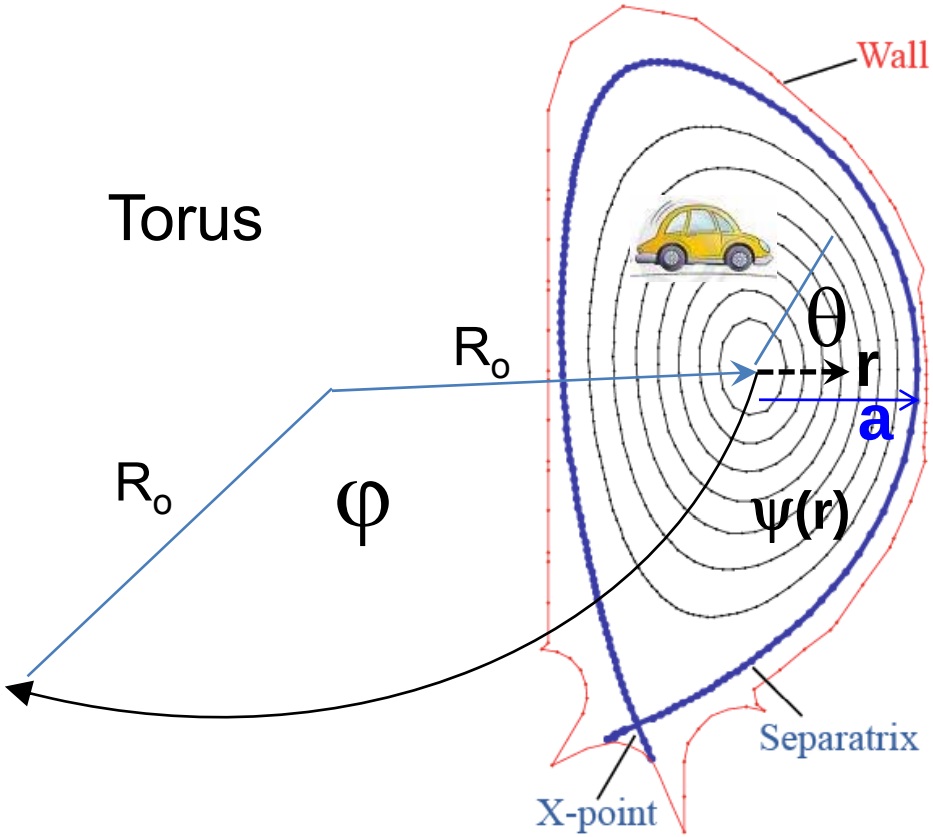
NOTES:

Each participants are listed according to the main work assignment, but they also participate in other group activities.

(9 Universities, 3 National labs, and 1 company)

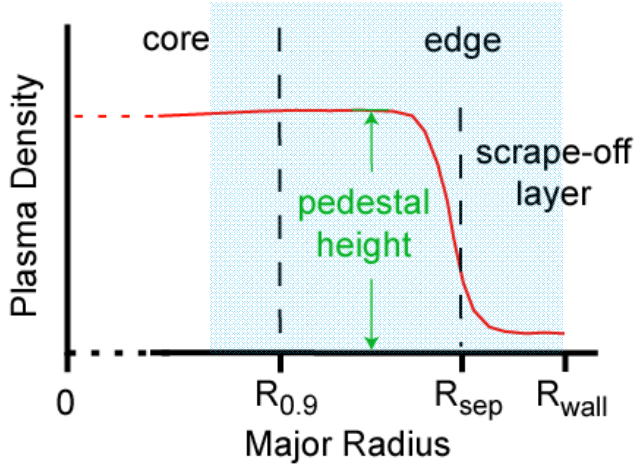
Volume Domain of CPES Mission

From somewhere in the core, across the magnetic separatrix surface and to the material wall (the most difficult domain)



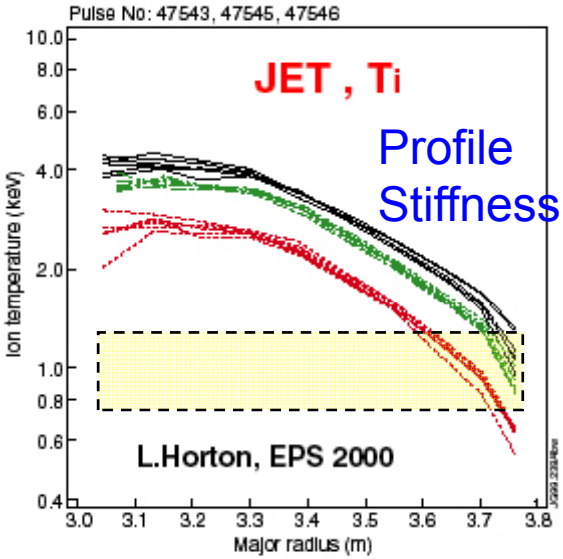
ITER Poloidal cross-section

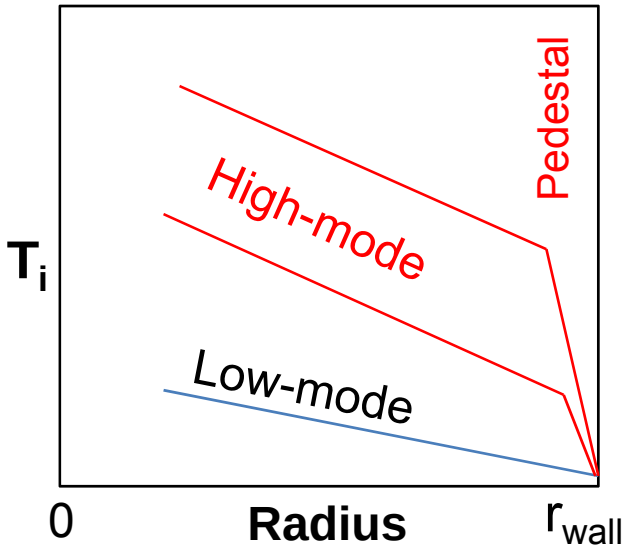
Poloidal magnetic flux label
ψ(r): 1 at r/a=1, 0 at r/a=0



Understanding edge physics, and its influence on core plasma, is critical for ITER and fusion

- Cold plasma near wall (T_{edge} ~100 eV)
- Plasma in the central core must be hot for fusion energy production (T_i >10 keV)
- $\nabla_r T_i$ is limited by turbulent transport
  - T_i is too low in core if T_{edge} ~0.1 keV (<1980)
- Formation of H-mode pedestal at edge
  - Strong core-heating **in separatrix geometry makes plasma to self-organize into H-mode**
  - **Stiff T_i profile, with rapid (<< τ_{conf}) influence of edge pedestal on core confinement**
  - $T_{edge} \approx$ 5 keV is aimed for ITER
  - **But, triggers fast collapse of pedestal (ELMs) → serious wall damage: can we control ELMs?**
- Little understanding → Integrated simulation in HPC





CPES Mission

- **Edge plasma physics is of multi scale (probably more than core plasma).**
  - **Usual: Neoclassical, micro-turbulence, MHD events, hot ions (+ rf waves)**
  - **Added complexity from the magnetic separatrix surface, atomic physics, impurity, radiation, material wall, 3D magnetic field, etc.**
  - **Edge plasma is fundamentally full-f kinetic**

- This leads to a **multi-layered CPES Mission**
  - **Develop new first-principles kinetic edge simulation codes (XGC0 and XGC1):** these were the missing edge components
  - **Develop a new integrated simulation framework to couple the multi-physics components**
  - **Make scientific discoveries on**
    - **Edge plasma physics (including pedestal, scrape-off, and wall load)**
    - **Edge effect on core plasma confinement**
- Well-coordinated collaboration among physicists, applied mathematicians, and computer scientists has been essential.

Multi-kinetic and multi-MHD codes + atomic and wall data in volumetric coupling

Kinetic Particle Physics

- **Neoclassical**
- **Turbulence**
- **Heat flux and torque from core**
- **Neutral, multi-species, atomic and radiation**
- **Wall load, neutral recycling, and sputtering**
- **3D perturbed magnetic field**
- **Non-local core-edge self-organization**

Multi-scale kinetic codes:

XGC1 for turbulence time &

XGC0-DEGAS2 for transport time

Mesh interpolation
Ampere's law solver

MHD physics

- **Linear**
- **Nonlinear**
- **Magnetic reconstruction**

- Energetic particle effect
- RF interaction

- Reduced dimensional core-edge coupling

Linear (Elite) and nonlinear MHD (M3D_mpp, NIMROD)

Free bd magnetic reconstruction (M3D_omp, TEQ)

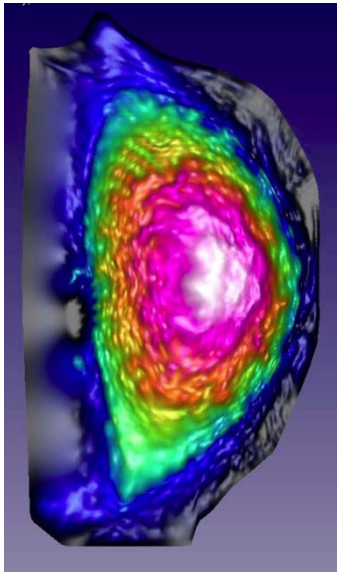
Ohmic Transformer
Collaboration with CEMM/SWIM/TSC

Future collaboration with SWIM and RF SciDAC

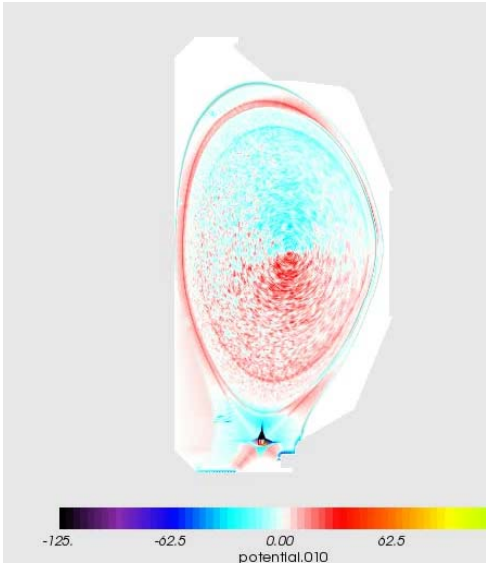
Future collaboration with FACETS

Wide range of component codes in CPES

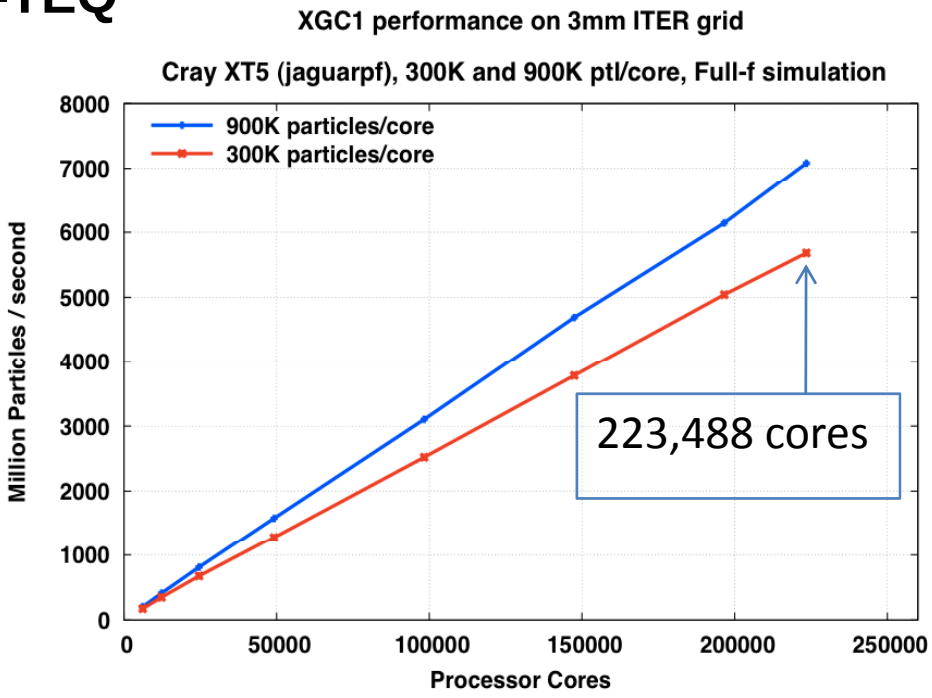
- Extreme scale code, pushing the edge of HPC**: XGC0 and XGC1**
- Small scale codes: **M3Domp, Elite, DEGAS_2 and TEQ**
- Intermediate scale codes: **GEM, M3Dmpp, XGC0**
  - Huge size turbulence data, requiring **in-memory coupling**: **XGC1, GTC, M3Dmpp**
  - Small size coupling data without frequent data exchange needs: a **file coupling** can do the job: **Elite, M3Domp**
- Some relationships are more convenient with **single executable** coupling: **XGC-DEGAS_2, XGC-TEQ**



ELM in M3D



Wall-to-wall ITG in full-f XGC1

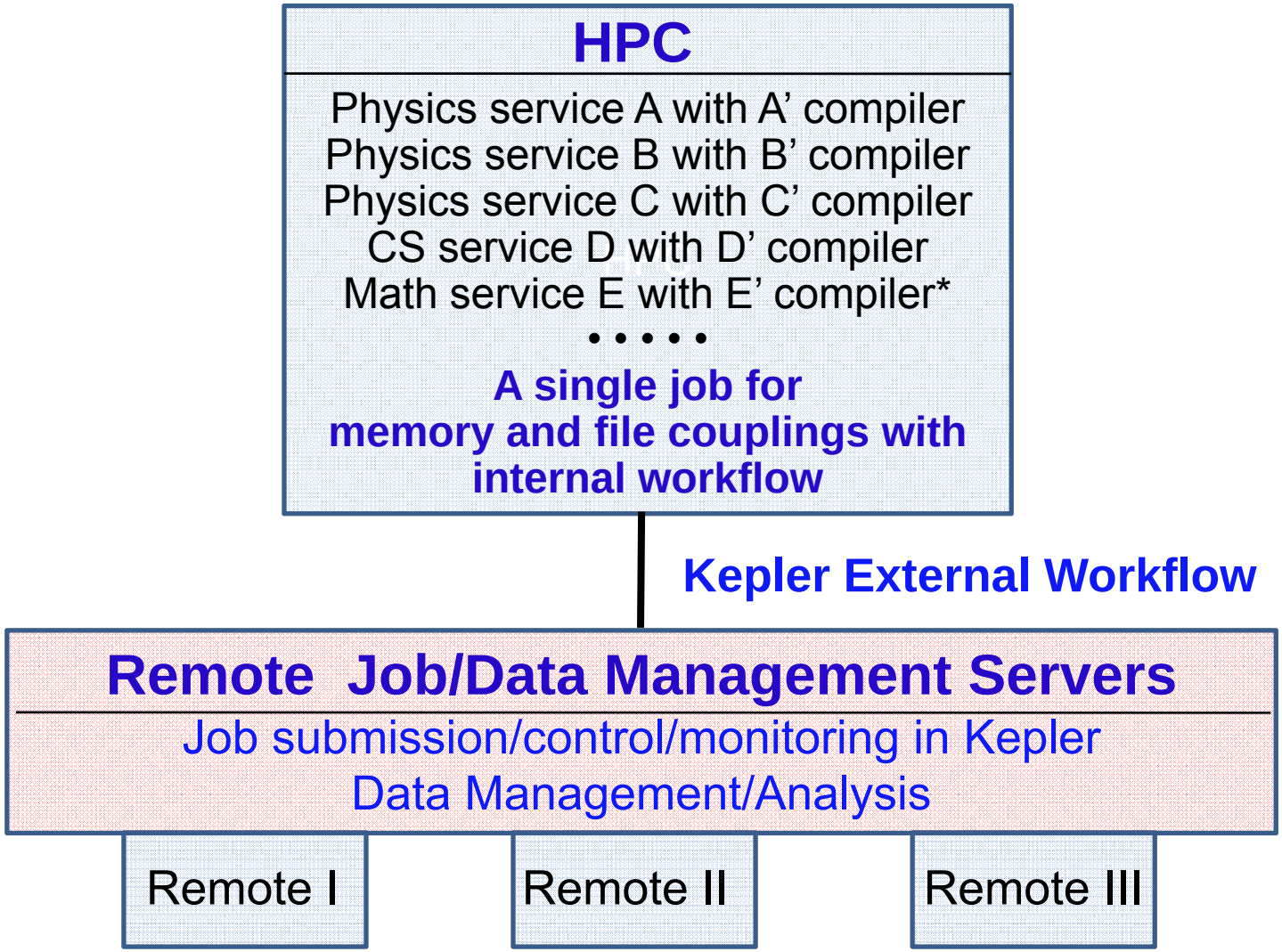


EFFIS Design Principles

- Accept widely-different physics codes
  - Single processor to extreme scale parallelism
  - Highly efficient I/O
  - PDE and Monte Carlo
  - Memory- and file-based couplings simultaneously
- Allow the component codes to keep their independence in the integrated simulation
  - Independent compiler and library options
  - Independent code developments and debug within the framework
- Code integration through I/O layer only with simple APIs
- Include automated workflow to local or remote **data servers** for real-time monitoring and orchestration, provenance capturing and searching, metadata collecting and searching, and data storing and analyzing
- Be supported by efficient and reliable **data mover**
- Have long lifecycle

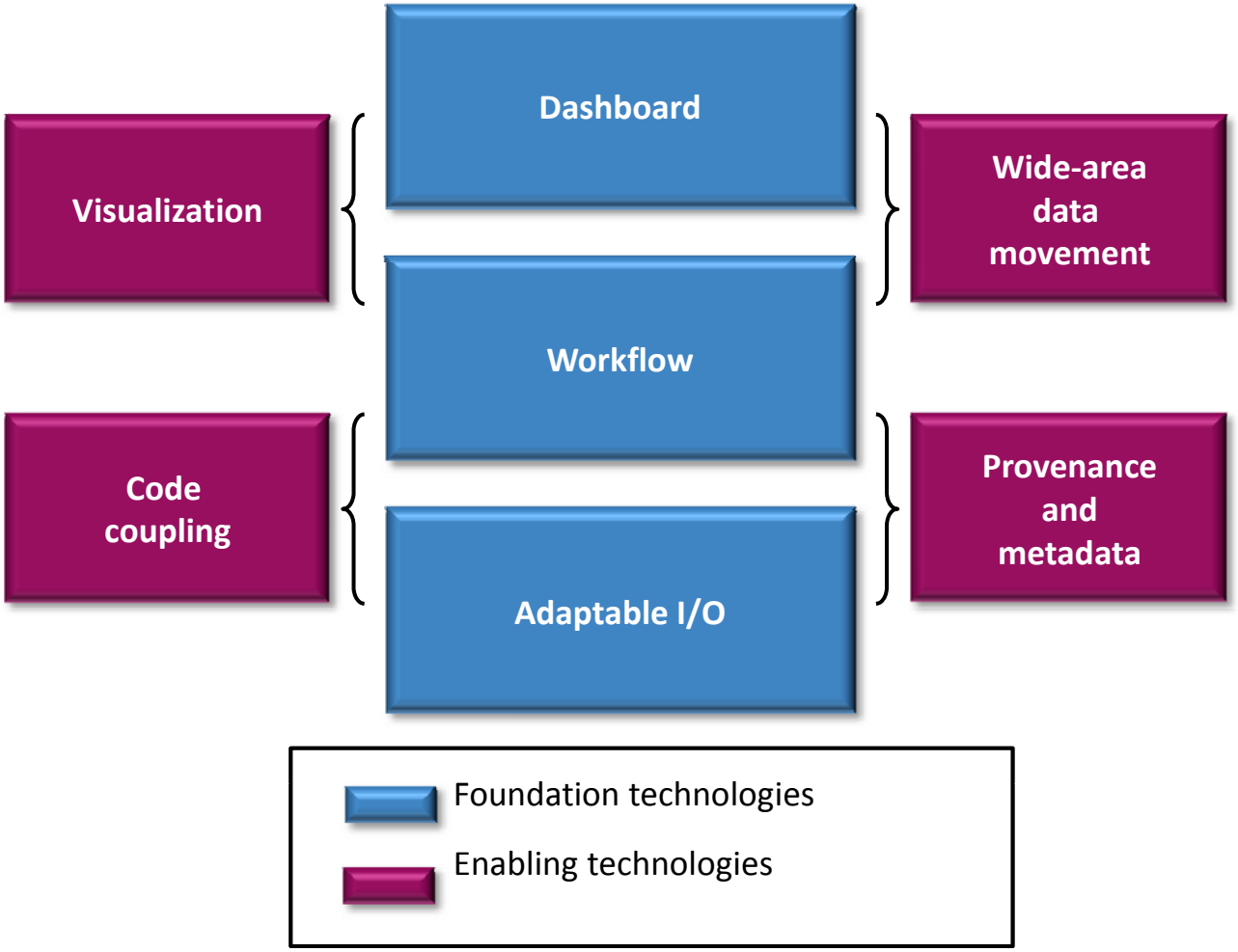
EFFIS Design in Service Oriented Architecture

(End-to-end Framework for Fusion Integrated Simulation)

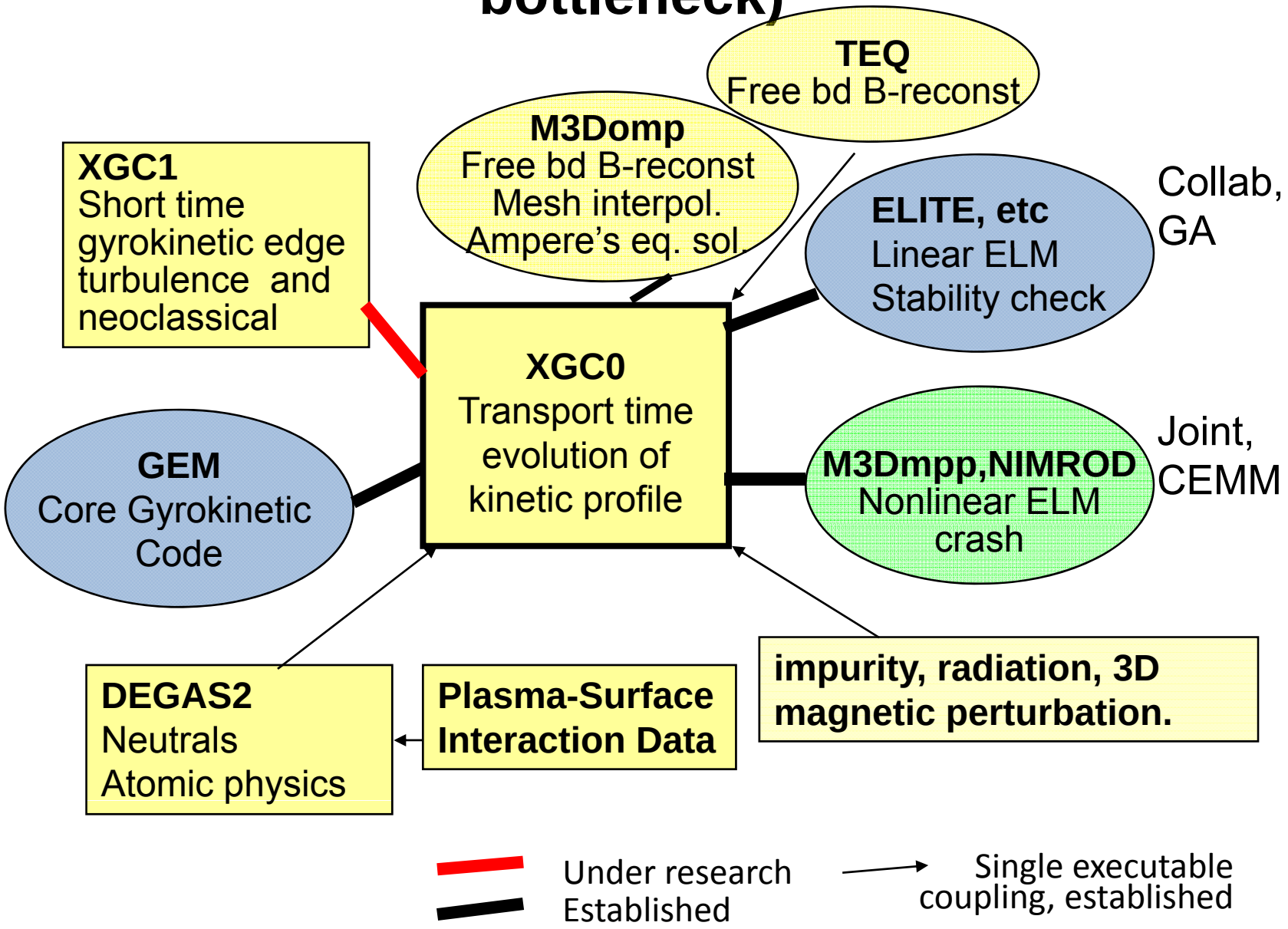


CPES uses modern computer science tools

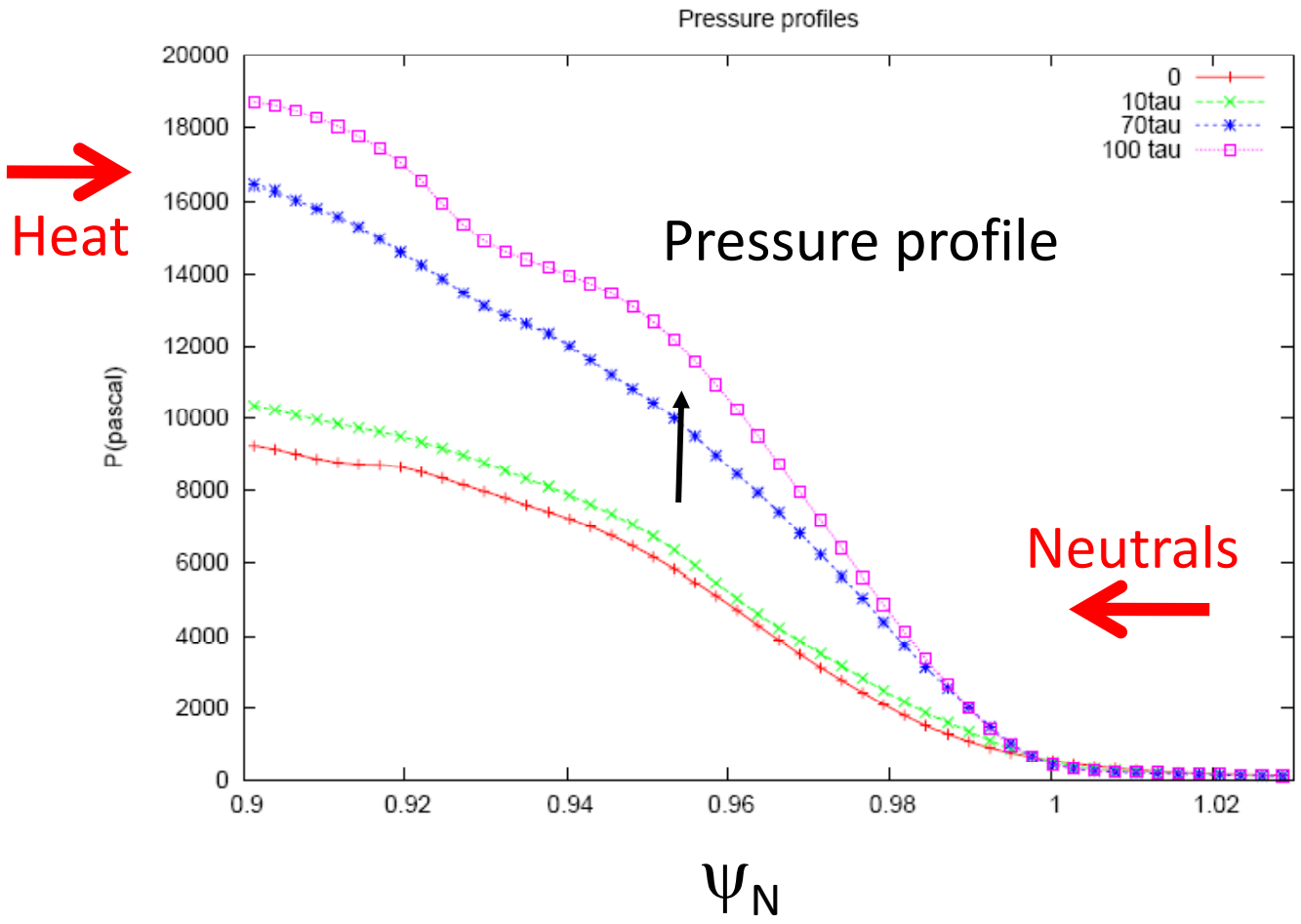
EFFIS tools



Status of multiscale code Integration in CPES on EFFIS framework (1day goal, Nonlinear MHD is bottleneck)



XGC0: world's only production kinetic transport modeling code in realistic edge geometry, with neutrals, impurity, wall recycling, 3D magnetic field, etc.



Strong Coupling for RMP penetration: Damped Iteration Solution on EFFIS/Adios