Advanced Integrated Scenario Modeling

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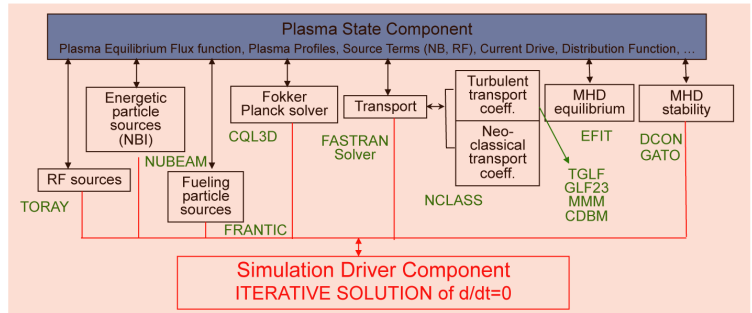
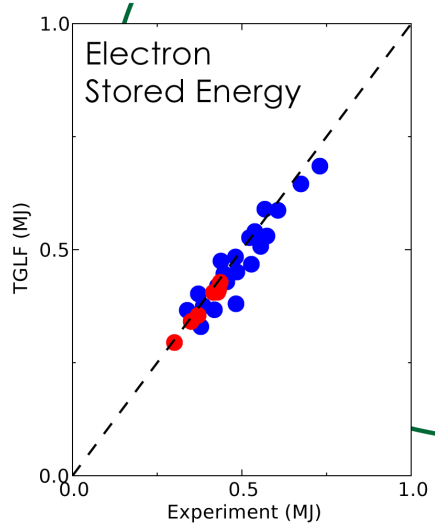
FEST Seminar

Jan 6, 2014

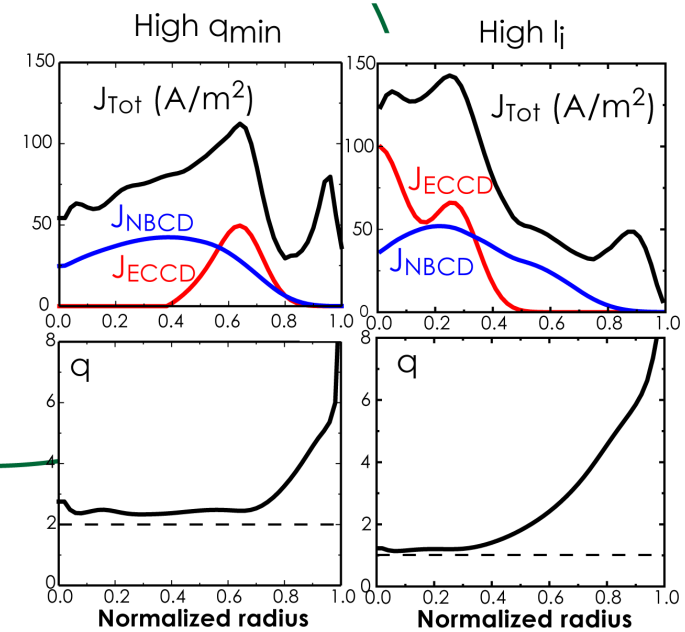
Integrated Modeling FASTRAN/IPS



Experimental Validation



Scenario Prediction/Optimization



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Goal: ORNL leadership of a CASL-like code/facility for comprehensive fusion reactor simulations and design

- Create 'best' integrated validated and verified simulation/design tool
- Lead the US effort to understand integrated scenario burning plasma physics on ITER and beyond
  - Continually add capability to address missing physics to an Integrated Fusion Simulation
  - Increase verification and experimental validation of modules/ simulations
  - Expand user base and connect early to ITER modeling effort
- Get community buy-in

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What would be "Unique Capabilities" of IFS?

- There exist many on-going IM projects in the U.S. as well as over the world including ITER-IO
  - IMAS, OMFIT/IMFIT, TASK, CORSICA, CRONOS, PTRANSP, …
- People tend to use their IM tool, if available
  - Are you willing to use IM tool from other institution simply because my IM tool takes a little bit longer time (2 hours compared with 2 hours 30 min) or because it's difficult to make more pretty plot or because I cannot check my simulation using IPHONE?
    ⇒ definitely NO?!
  - Each machine is tightly coupled to its own/major/historical IM tools
- In order to be a winner, we need "Uniqueness" that others cannot do "AT ALL"
  - "We can do a little bit better" is not sufficient

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Two future uniqueness identified in addition to existing strength with main strategy-“expending users”

- “Validated”
  - Tight coupling to the present experiments is essential to be a winner
  - Accurate scenario prediction for my “Tomorrow” DIII-D experiment is extremely challenging and even not feasible for a while (5yr, 10 yr, or more? JM’s bet =∞).
  - ITER Requirement: Validation of pulses before the operation ⇒ We are far away from this goal.
- System code capability
  - No system design tool exists with the state-of-art full physics modeling embedded

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Building Further Unique "Physics" Capabilities in Near-Future (0~5yr)

- Integrated Core-Edge-SOL Scenario
  - Strong community needs
  - Big failure of FACET project
- Integrated 3-D Scenario
  - Now, everybody looks like working on 3-D…
  - Infant (Note: 1.5-D modeling framework for integrated scenario is ~50 years old)

⇒ ORNL has strength on both areas

- We developed the world-leading codes
- Potential wide synergy among other EPP-PT topical areas (Edge, 3D)

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Challenging but we should be ambitious to be a winner

- We are not starting from scratch
  - C2: 2-D coupled core-edge-SOL transport
  - C3: 3-D transport
  - VMEC, SIESTA : 3-D MHD equilibrium
  - Working FASTRAN/IPS provides H/CD, scenario modeling protocol, connection to experiments, …
- During the lifetime of full development, we should be able to use progress to help solving some specific physics issues

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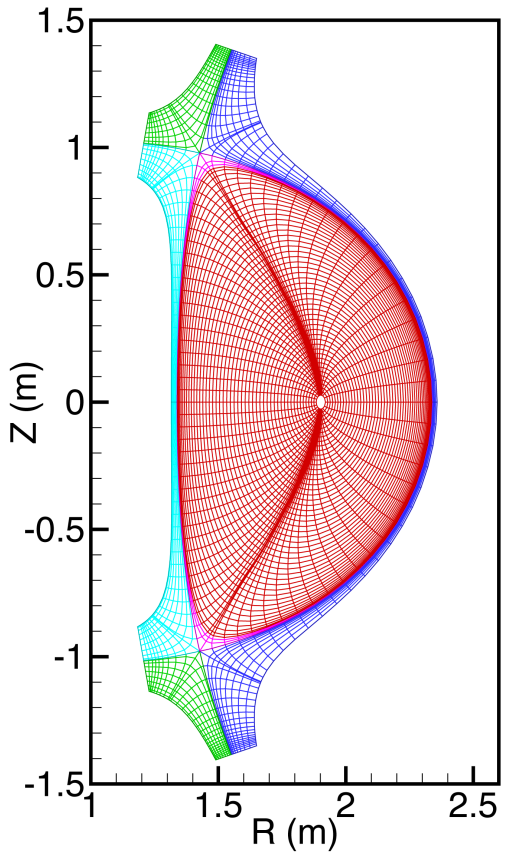
C2: Coupled 2-D core-edge-SOL transport



A **2-D multi-fluid model** extending the previous formulations of 1-D core and 2-D edge/SOL transports: Valid not only in the **collisional edge/SOL** regions but also in the **high temperature core** region.

1 **Plasma continuity**
2 **Parallel momentum balance**
3 **Electron/Ion energy**
4 **Current continuity**
5 **Magnetic field diffusion**

* **ExB drift**
* **Diamagnetic drift**

A **parallel** transient **2-D numerical** method

1 **Finite volume method** in unstructured multi-block grid
2 All-speed compressible **pressure-correction** algorithm
3 **Fully implicit** time advancing
4 BiCGStab solver with **physics-base preconditioner**
5 Parallel computing: **domain decomposition**

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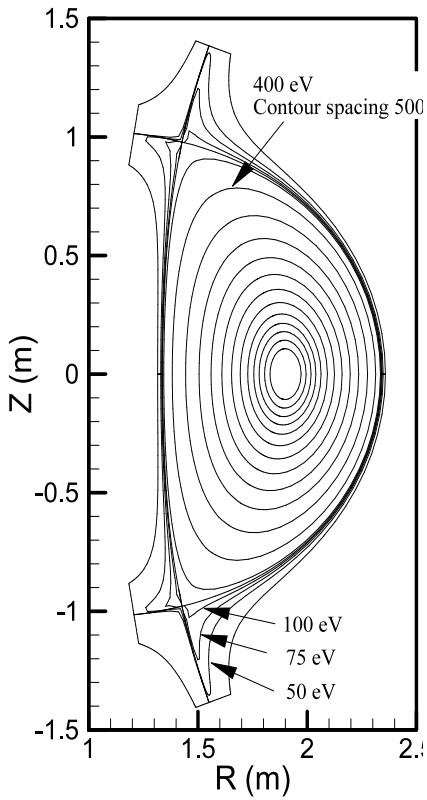
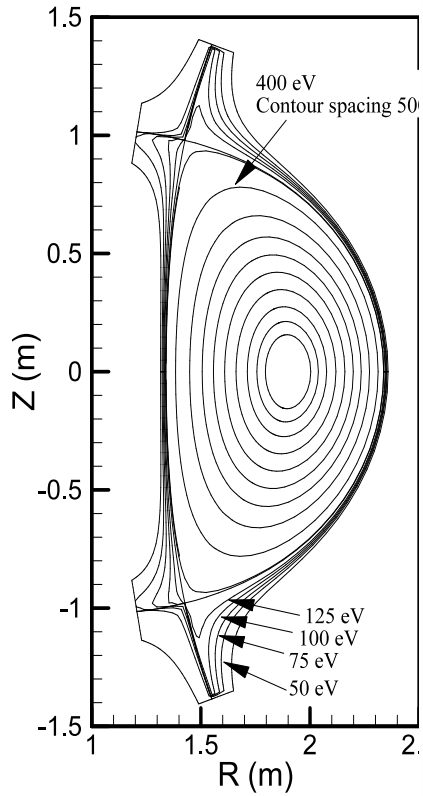
Electron temperature

Te : keV



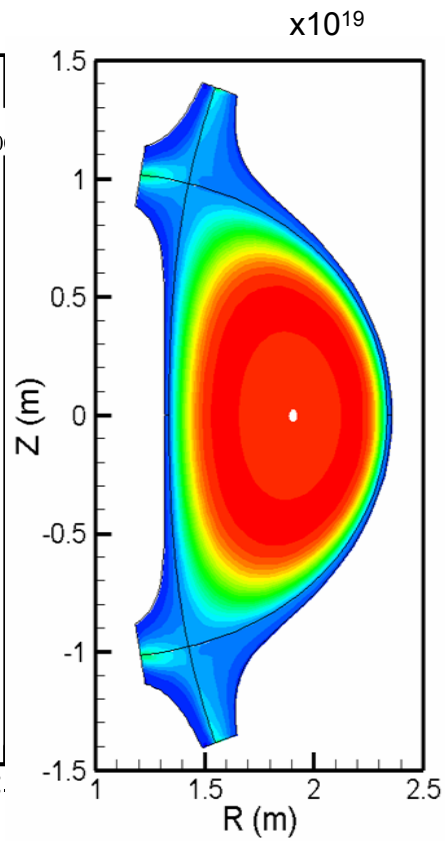
Ion temperature

Ti : keV



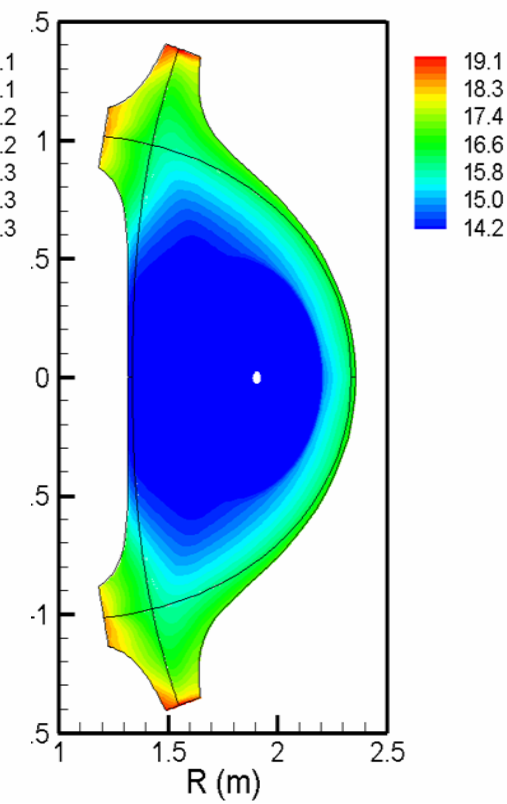
Ion density

n_i



Neutral density

$Log(n_n)$



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C2 Equations

- **Self-consistent ExB and diamagnetic drifts**
- **Parallel viscous force**
  - o **local form**

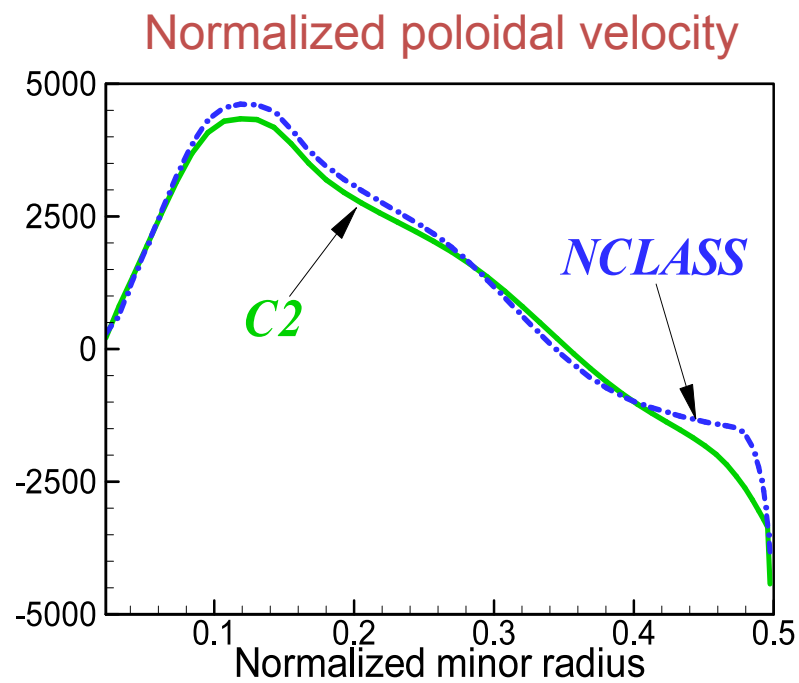
$$\mathbf{b}\cdot\nabla\cdot\Pi_{\|} = -\frac{4}{3}B^{3/2}\partial_{//}\left(\frac{\eta_1}{B^2}\partial_{//}\left(\sqrt{B}\left(u_{//}-V_{\perp}\right)\right)\right) - \frac{4}{3}B^{3/2}\partial_{//}\left(\frac{\eta_2}{B^2}\frac{2}{5p_i}\partial_{//}\left(\sqrt{B}\left(q_{//}-\frac{2}{5}p_iV_{\perp}\right)\right)\right)$$

with neoclassical viscosity coefficients valid in all collisional regimes, μ_{ij}

$$\eta_1 = \frac{1}{3}\frac{\langle B^2\rangle}{\langle(\mathbf{b}\cdot\nabla B)^2\rangle}\mu_{11}\quad \eta_2 = \frac{1}{3}\frac{\langle B^2\rangle}{\langle(\mathbf{b}\cdot\nabla B)^2\rangle}\mu_{12}$$

⇆ **standard neoclassical expression if flux-surface averaged**

$$\langle\mathbf{B}\cdot\nabla\cdot\Pi_{\|}\rangle = \langle B^2\rangle\left(\mu_{11}\hat{u}_\theta + \mu_{12}\frac{2}{5}\frac{\hat{q}_\theta}{p_i}\right),$$



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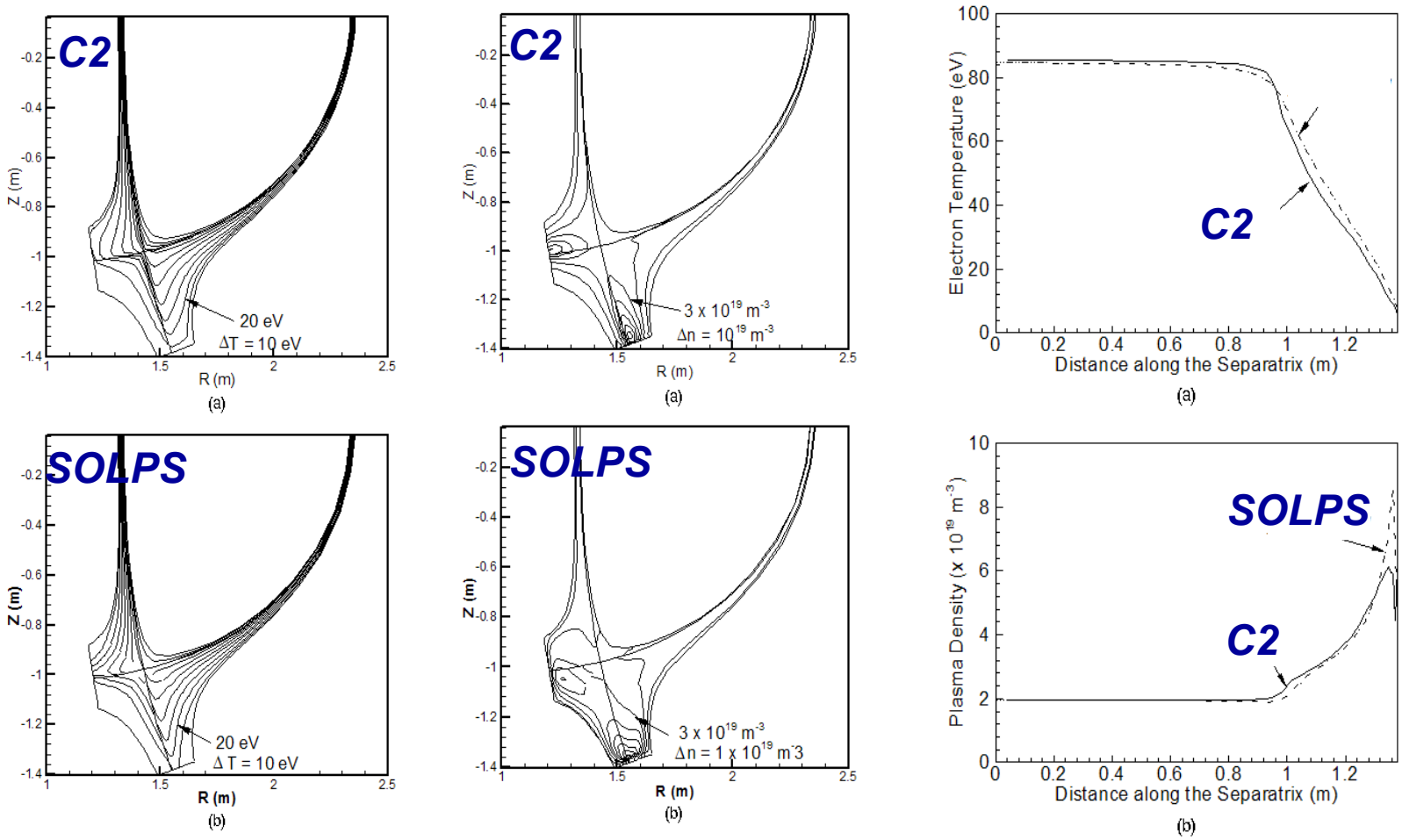
Benchmark against SOLPS

$T_e = T_i = 100$ eV, $n_i = 2 \times 10^{19}$ m^{-3}

(C2 run with prescribed boundary conditions at core-edge interface)



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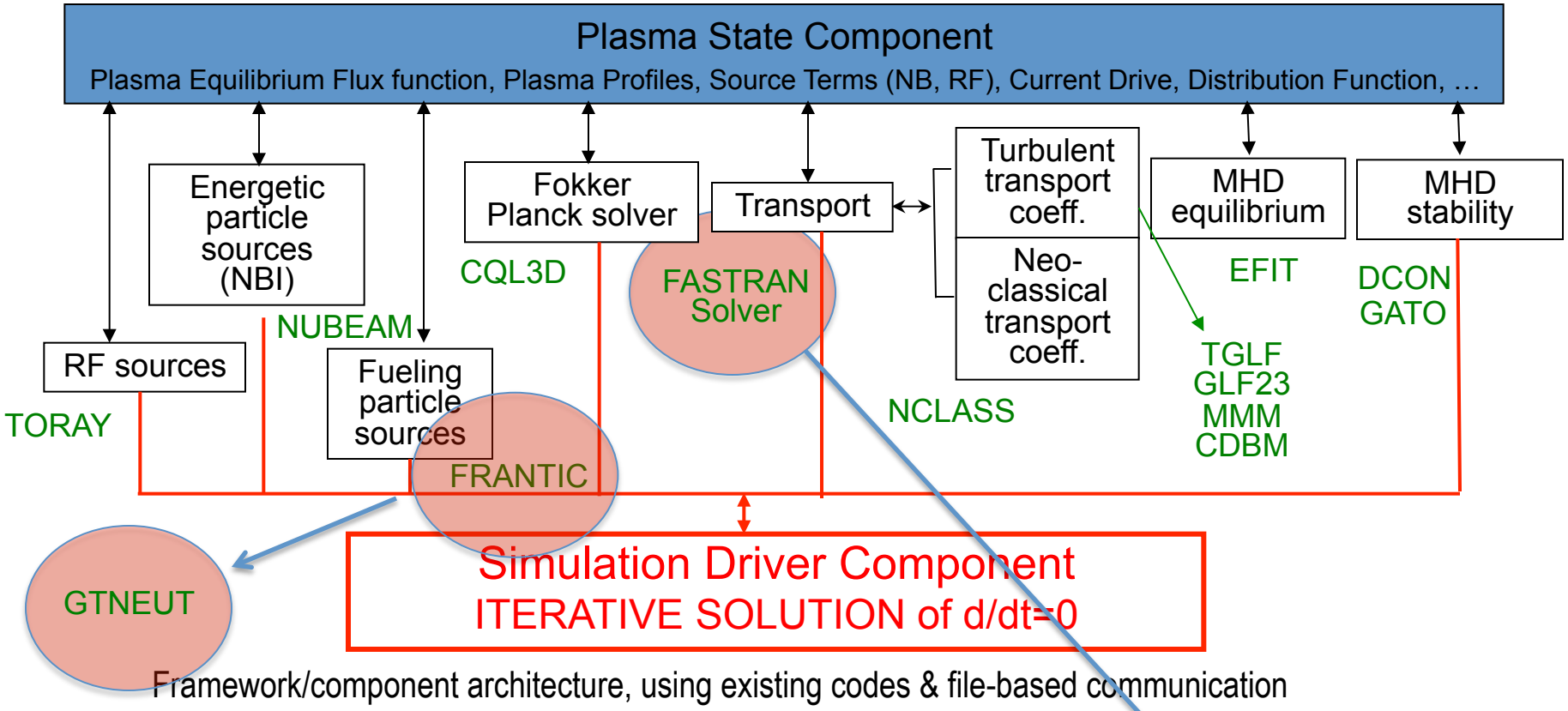
C2/IPS is under development



- Logically straightforward
  - Replace FASTRAN by C2
  - Add 2-D neutral transport model : GTNEUT
  - Otherwise, re-use components in FASTRAN/IPS

C2

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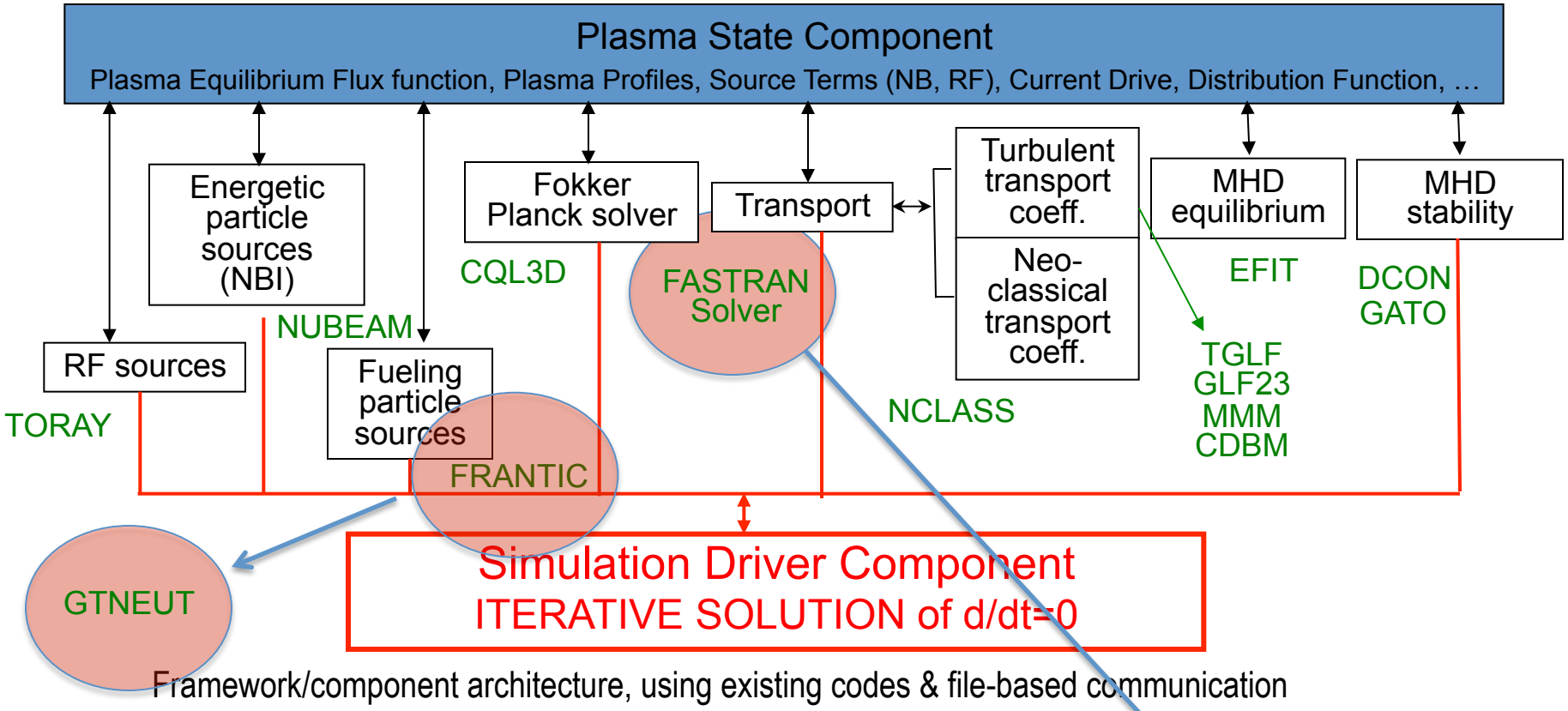
C2/IPS is under development



Framework/component architecture, using existing codes & file-based communication

- Challenges/opportunities
  - TGLF and poloidal anisotropic radial transport
  - Ready for many interesting DIII-D analysis
    - Pedestal difference between +/-BT in ITER SS discharges
    - High β SS discharges with radiative divertor

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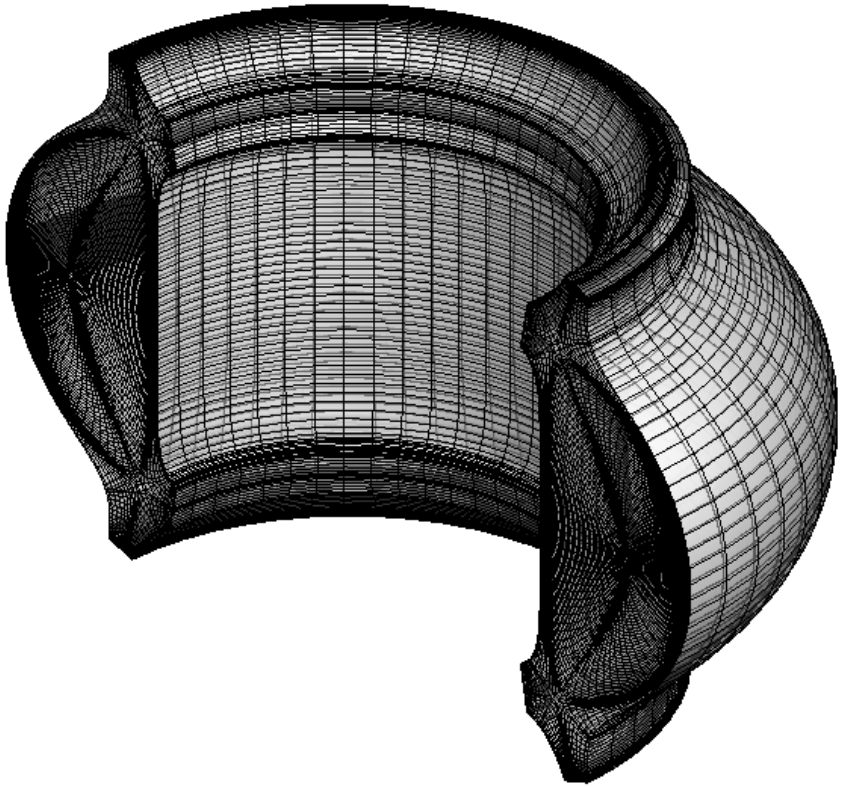
C3: Coupled 3-D transport



- Prototype 3-D transport code
  - Simple 3-D extension of C2
  - Employ C2 equations
- Field aligned grid based on 2-D equilibrium
  - Non-orthogonal
- Reproduce C2 modeling if BC is axisymmetric

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Suggested focused area for near-term (5yr) in integrated scenario modeling

- Integrated core-edge-SOL scenario
  - Close to production run

- Integrated 3-D scenario
  - Close to demonstration run

⇒ Toward building "Uniqueness" that others cannot do "AT ALL"

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