The Advanced Tokamak Modeling Environment (AToM) for Fusion Plasmas

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on behalf of the **AToM team**
http://scidac.github.io/atom/index.html

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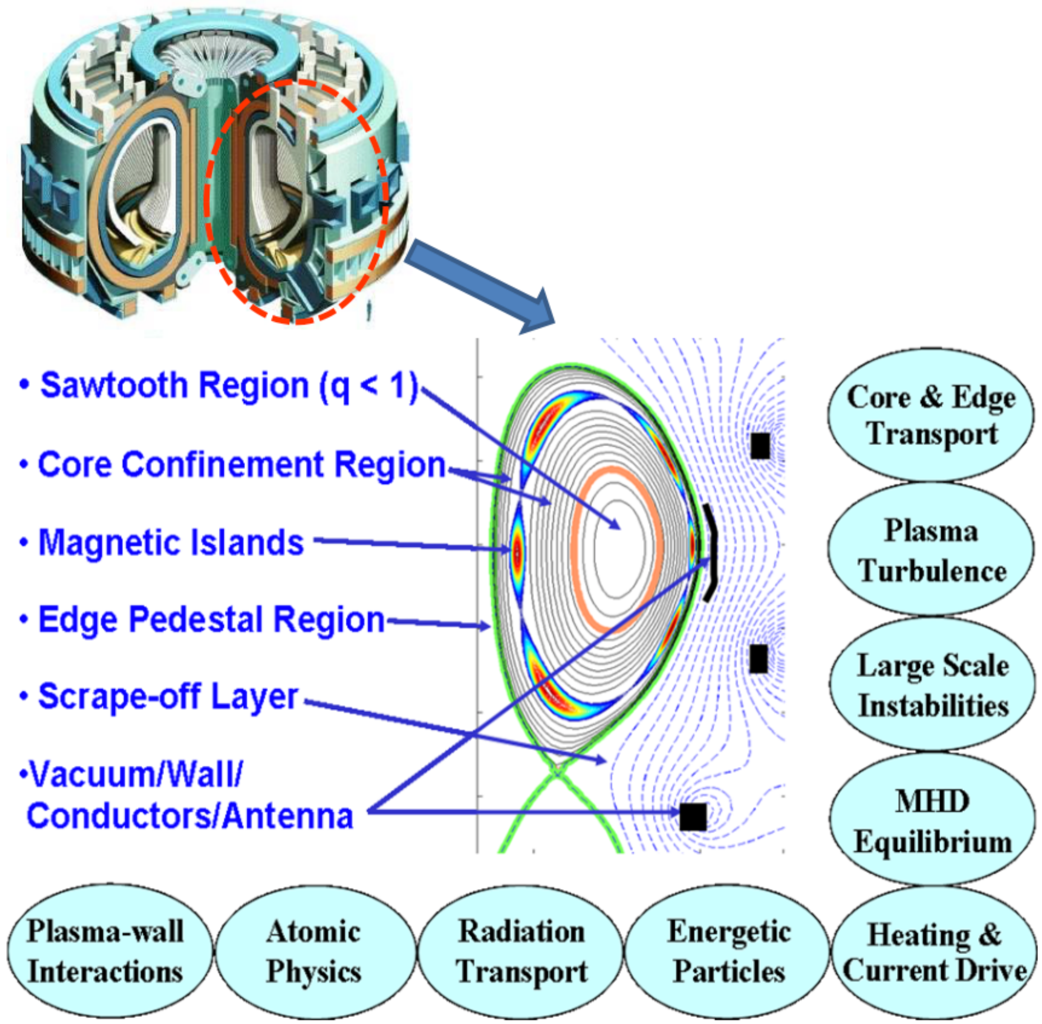
SciDAC
Scientific Discovery through Advanced Computing

UC San Diego

AToM is 1 of 9 SciDAC-4 partnerships working to address modeling needs of US MFE program

- AToM focus is **whole-device modeling (WDM):**

  assemblies of physics components that provide a sufficiently comprehensive integrated simulation of the plasma



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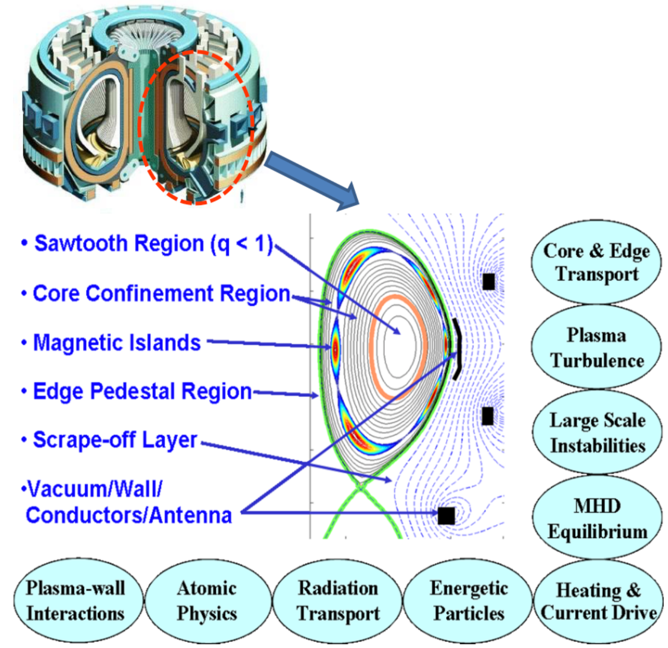

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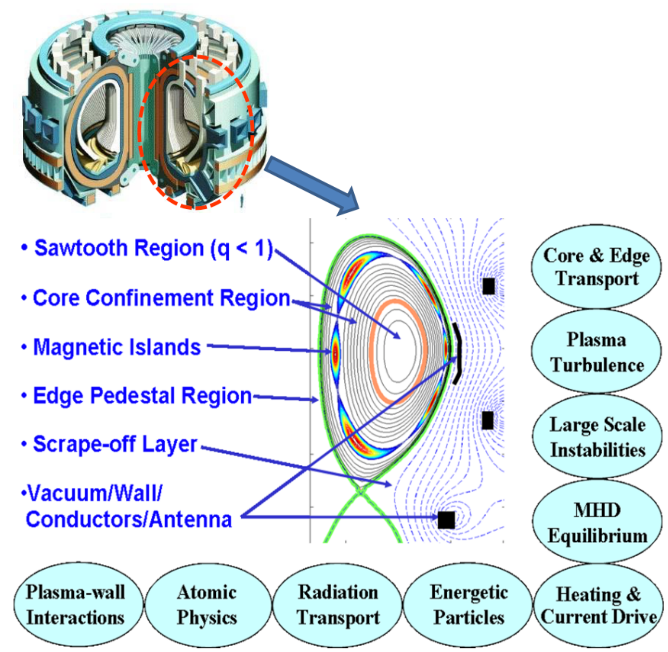

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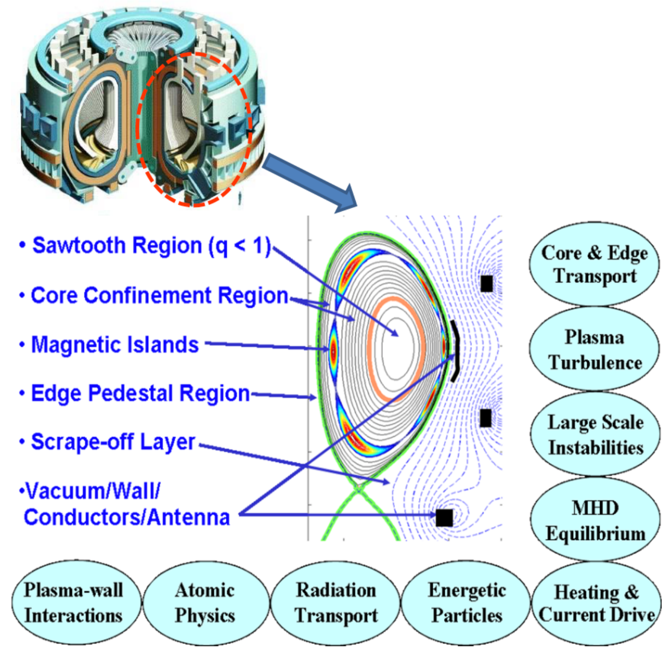

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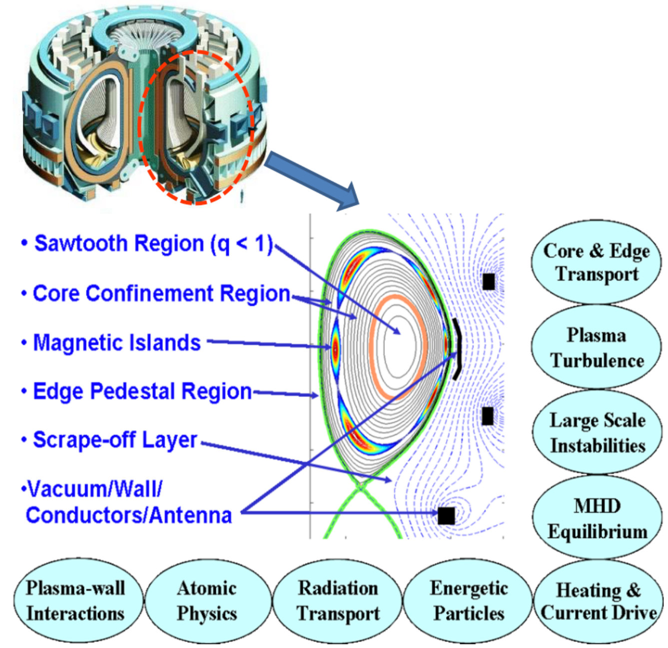
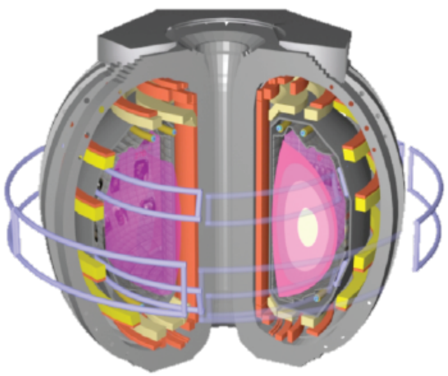
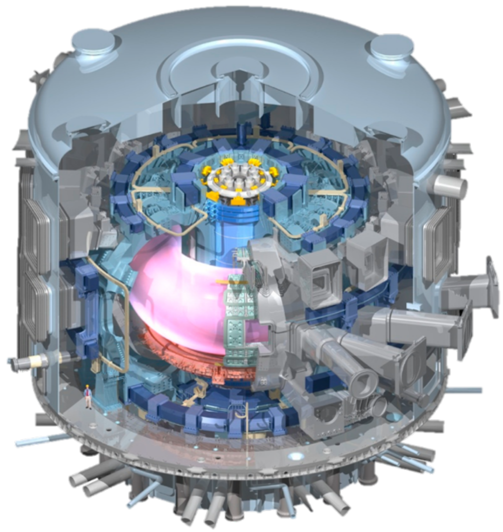
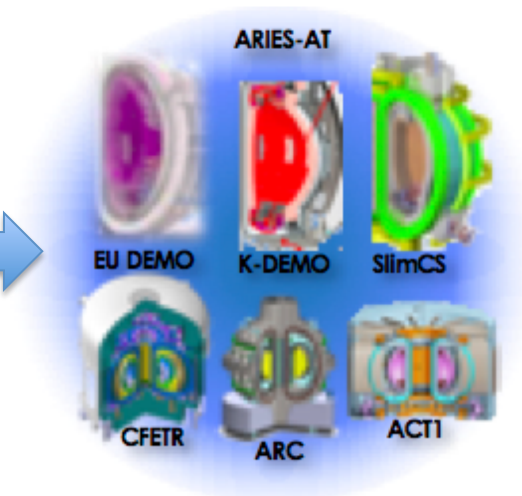
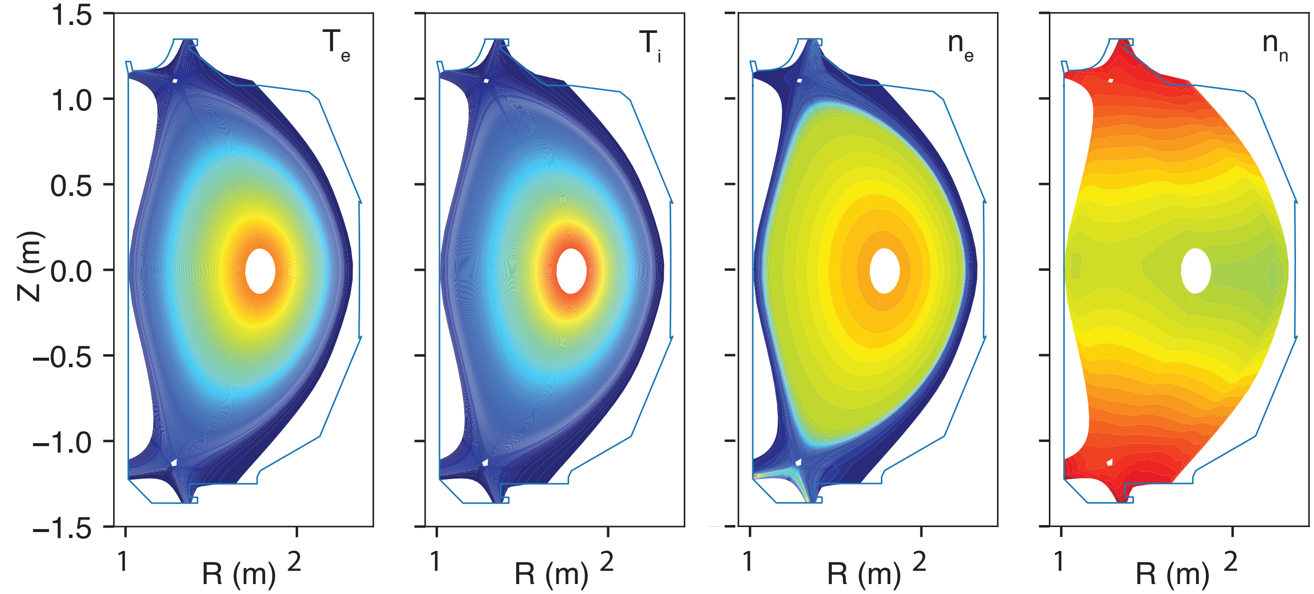


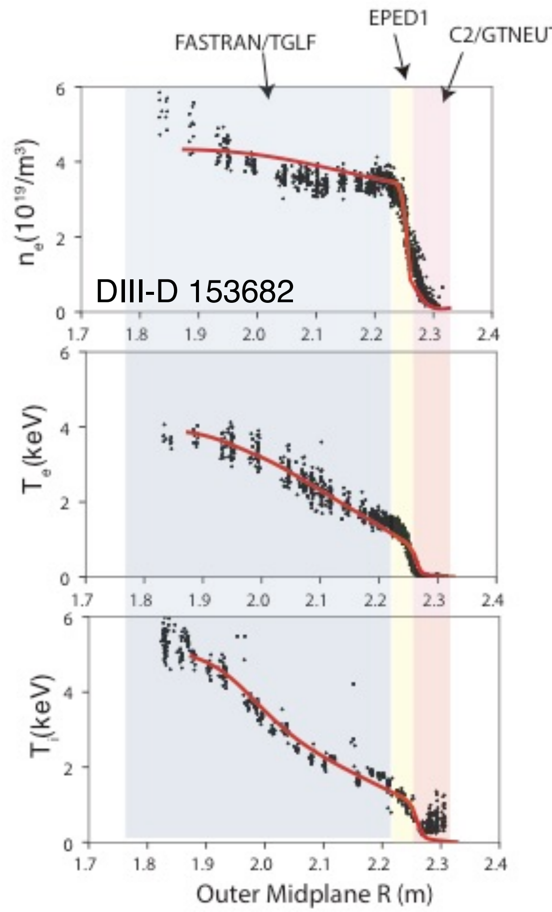
  - In practice, this means developing flexible software environment and workflows to couple existing and in-development physics components

AToM's scope and vision extends from current-day devices to future reactor facilities

Present-day experiments	Support ITER	Future reactor design
		
• Validate existing WDM capabilities • Identify modeling gaps • Drive new development	• Test WDM capabilities in burning plasma conditions • Optimize ITER operation scenarios	• Examine how to best optimize devices with varying goals and missions

Current AToM modeling capability enables coupled core-edge-SOL (CESOL) profile predictions



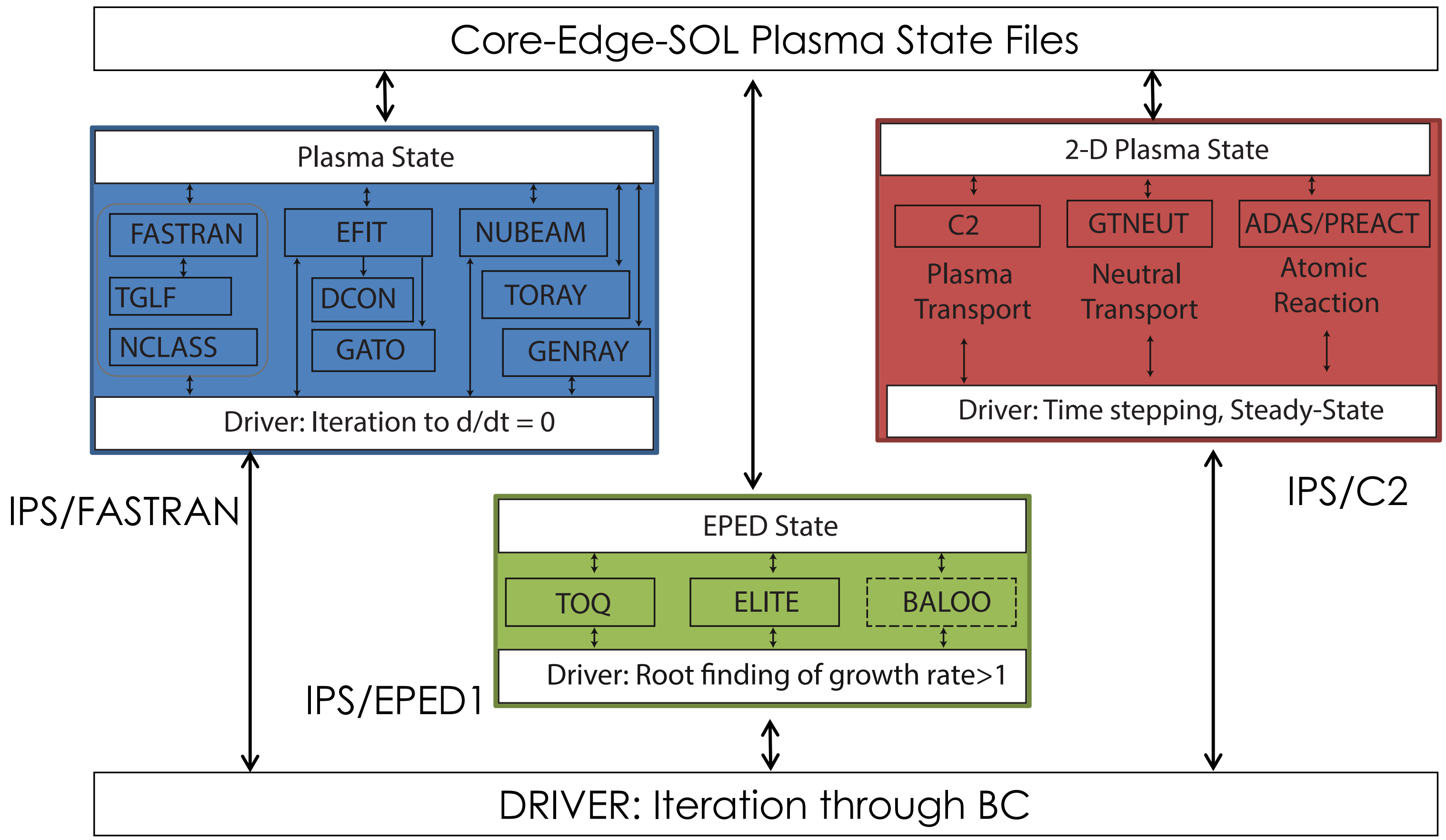


- **Future research directions:**
  - Self-consistent impurity transport from wall to magnetic axis
  - Implementing validated theory-based scrape-off layer (SOL) transport models

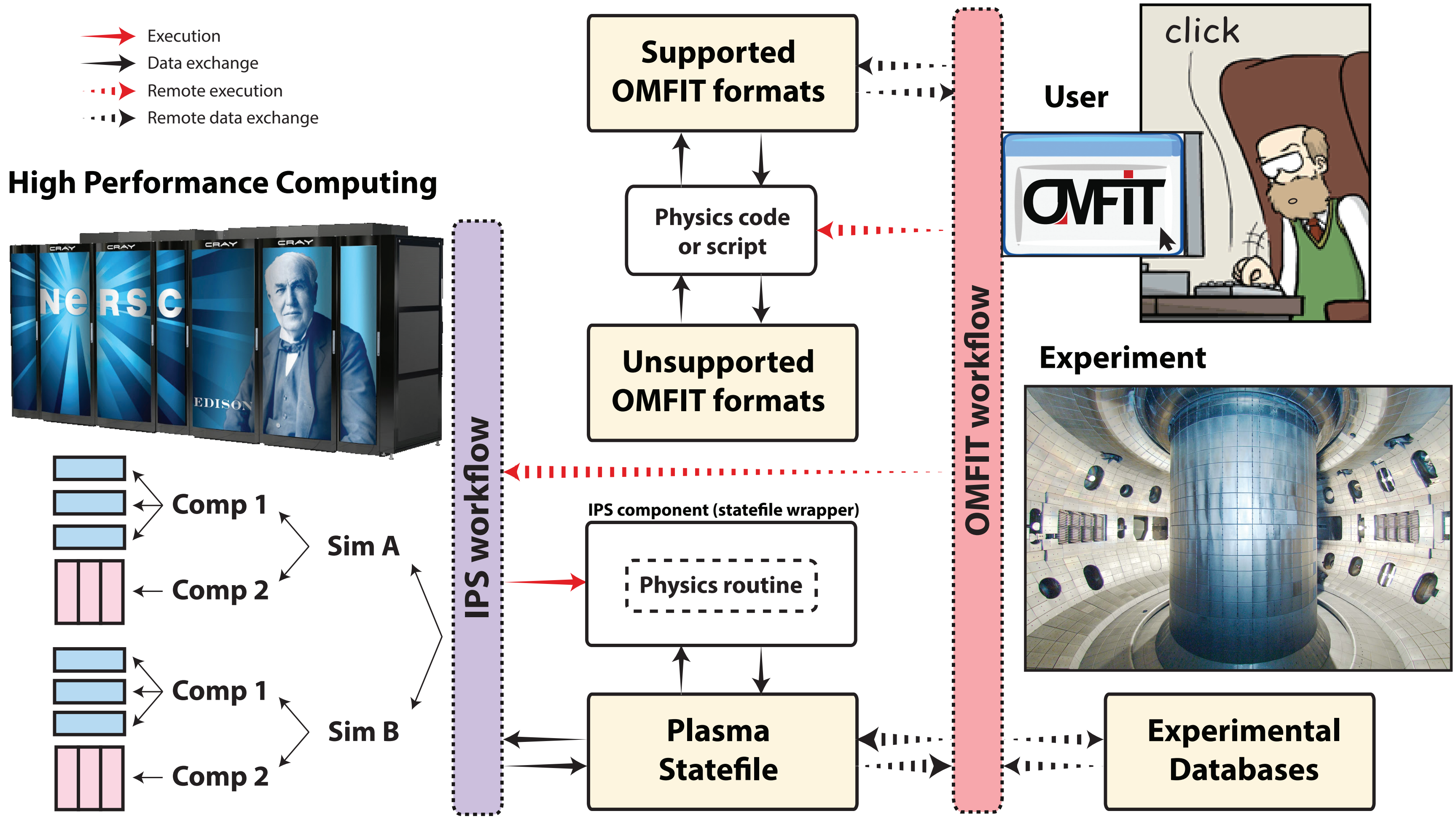
J.M. Park *et al*, 2018 IAEA FEC

AToM supports flexible workflows based on coupling of multiple physics components

- CESOL prediction requires coupling 15 physics components, executed on NERSC Edison Cray XC30 machine



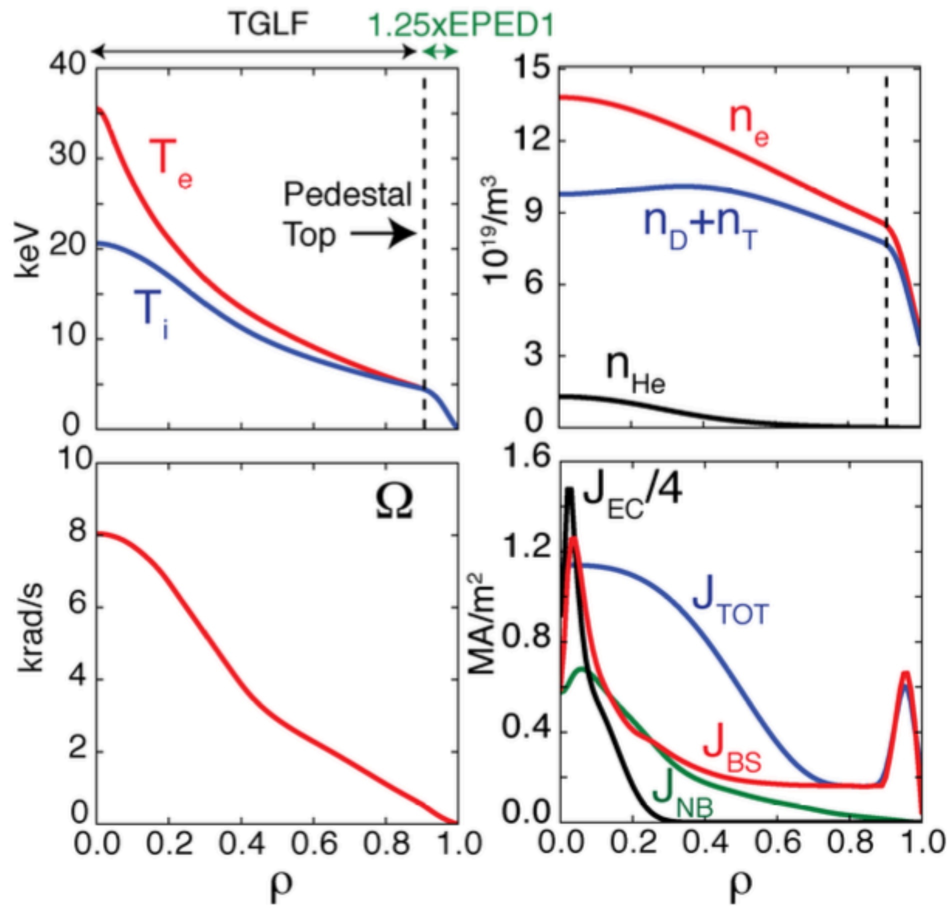
AToM couples IPS and OMFIT computing frameworks and effectively exploits their synergy



PhD comics © J. Cham

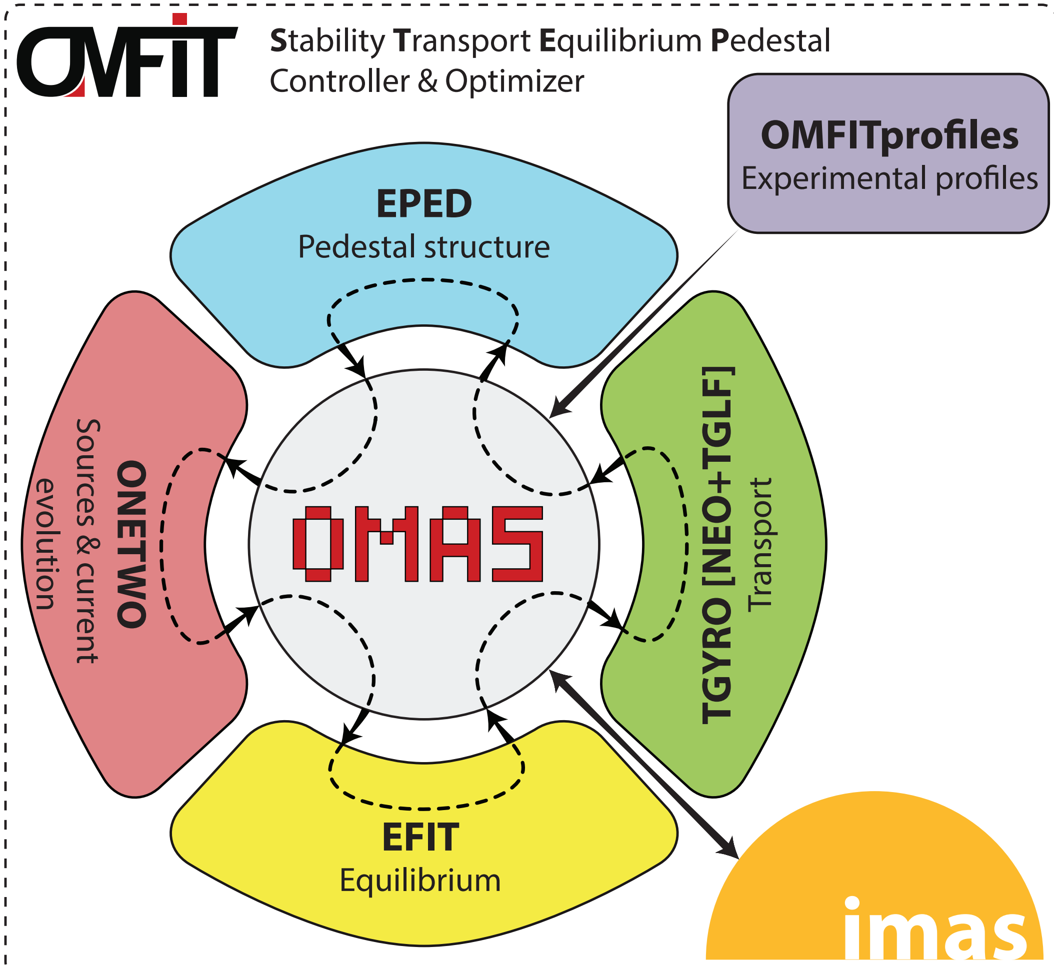
AToM modeling capabilities ready to support ITER research needs

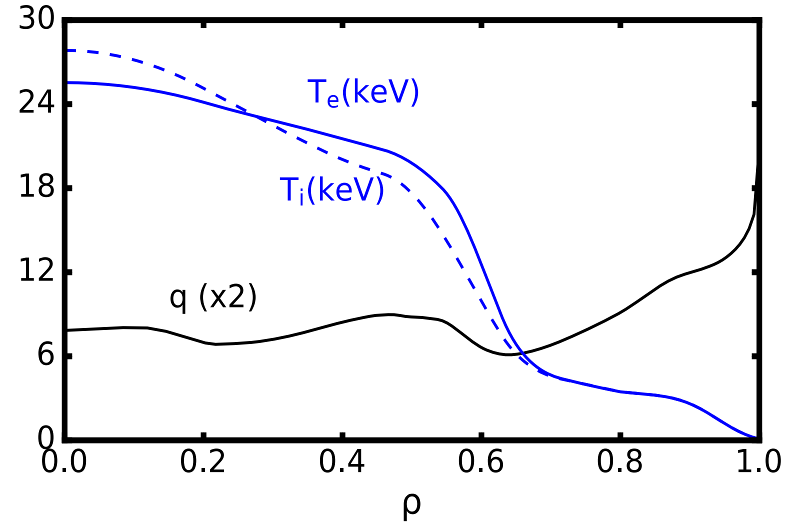
- **Example**: modeling an ITER steady-state hybrid scenario
- AToM's OMFIT framework includes full support for ITER IMAS data model
  - Enables access to ITER reference scenarios
- **Future work:** apply AToM capabilities to key ITER startup questions (e.g. H/He, half field/current operations)



C. C. Petty *et al.*, Nucl. Fusion 2017

OMFIT STEP module supports discharge design and optimization for current and future machines





Predicted ITER steady-state Q ≥ 5 scenario with day-1 heating

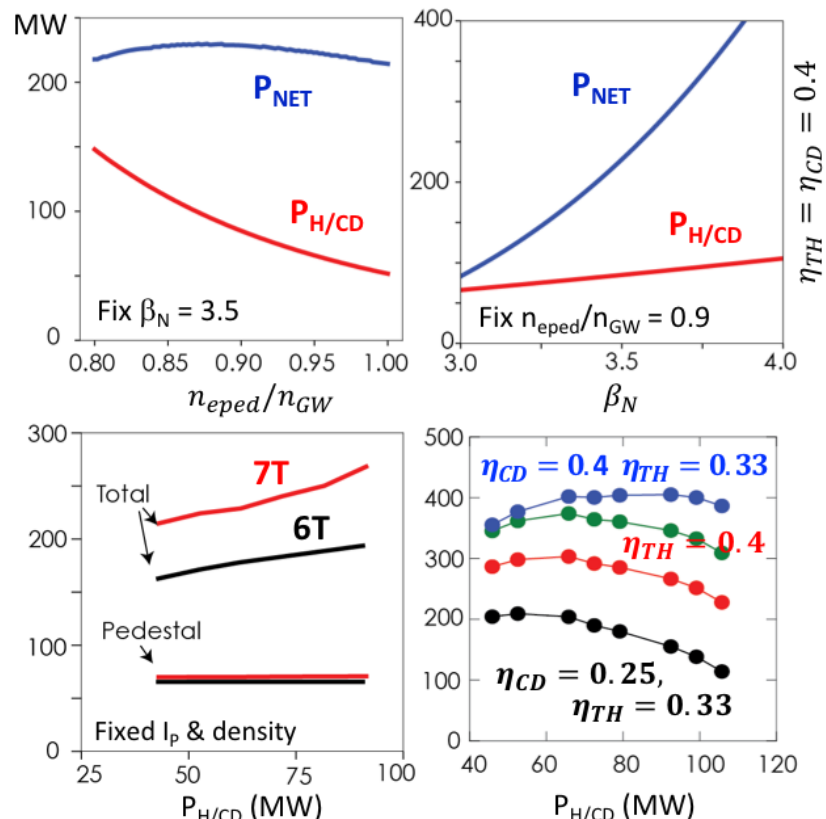
(J. McClenaghan *et al*, 2018 IAEA FEC)

ATоM workflows will provide practical tools to design and optimize future reactors

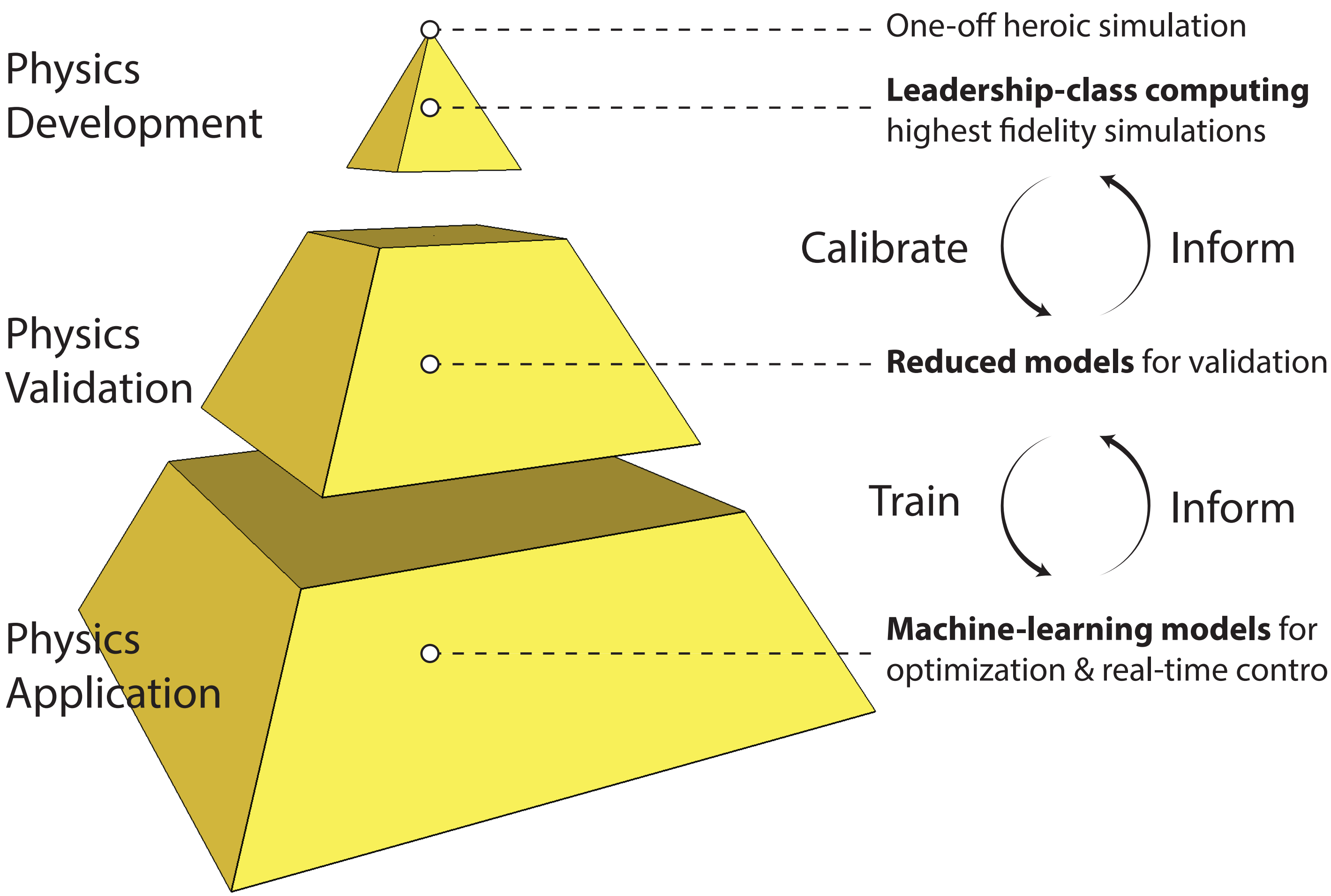
- Combine efficient, validated tools with HPC resources to explore parameter space and optimize
- **Example**: AToM tools used to identify target operating scenarios for compact advanced tokamak DEMO (C-AT DEMO)

(R. J. Buttery *et al*, 2018 IAEA FEC)

Scalings of C-AT DEMO P_{net} with physics parameters and $P_{H/CD}$



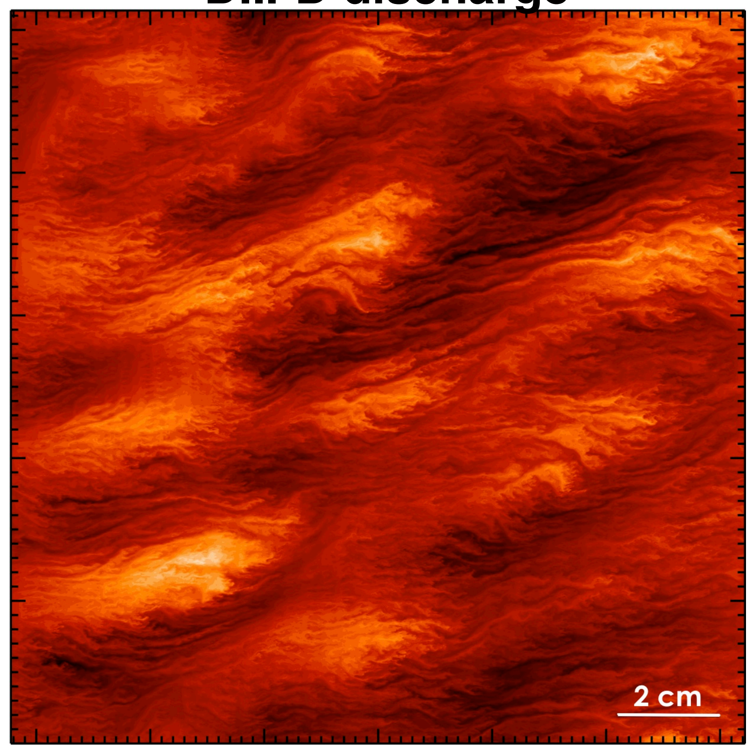
Practical integrated studies require hierarchy of fast, efficient, and accurate physics components



Core transport components provide template for future physics component development

- Nonlinear gyrokinetic simulations yield highest fidelity transport predictions but require $10^3 – 10^7$ core-hours to simulate small fraction of plasma volume & duration

Simulated T_e fluctuations for a DIII-D discharge



N. T. Howard *et al.,* Phys. Plasmas 2015
C. Holland *et al.*, Nucl. Fusion 2017

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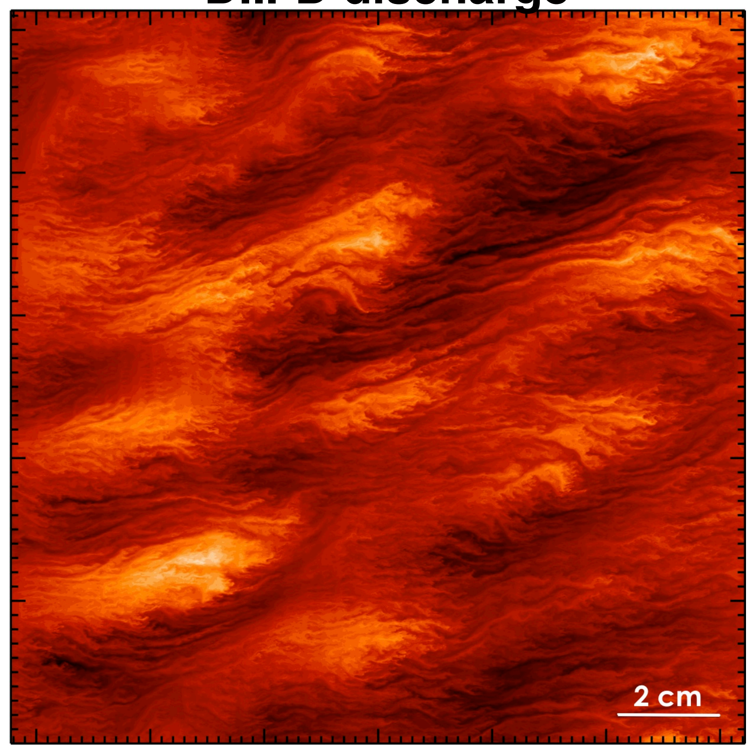

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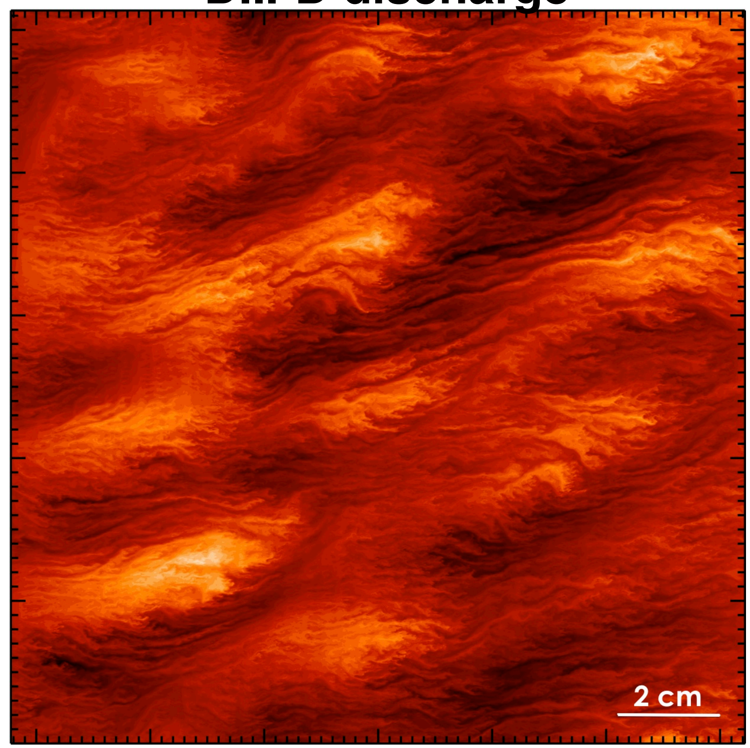
- …but require **20+ million core-hours** to simulate a small fraction of plasma volume for a few milliseconds on current computing platforms

Simulated T_e fluctuations for a DIII-D discharge



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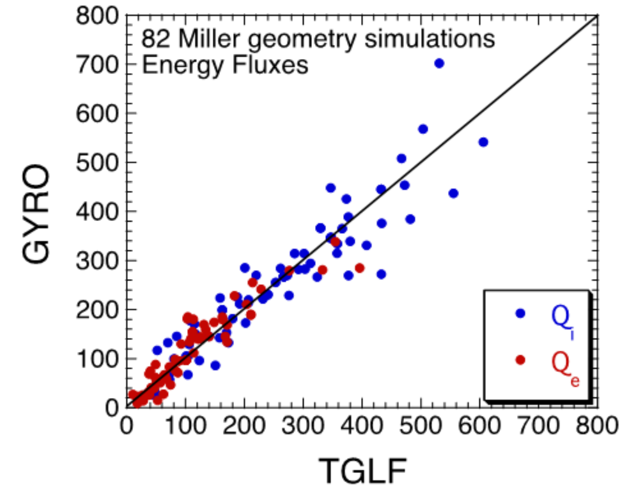
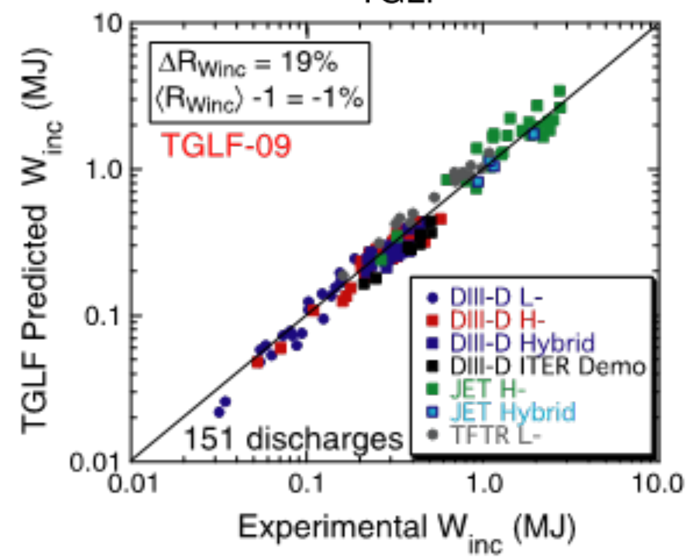
- Resolve bottleneck via reduced models that combine physics understanding and high-fidelity simulation results to make equivalent predictions in core-seconds





G. M. Staebler *et al*, Nucl. Fusion 2017

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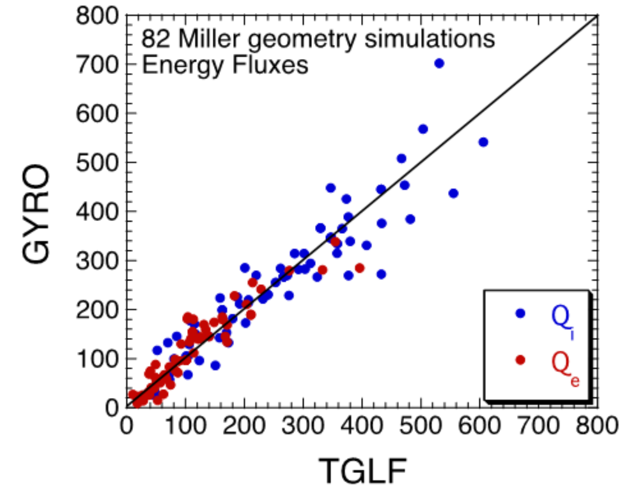

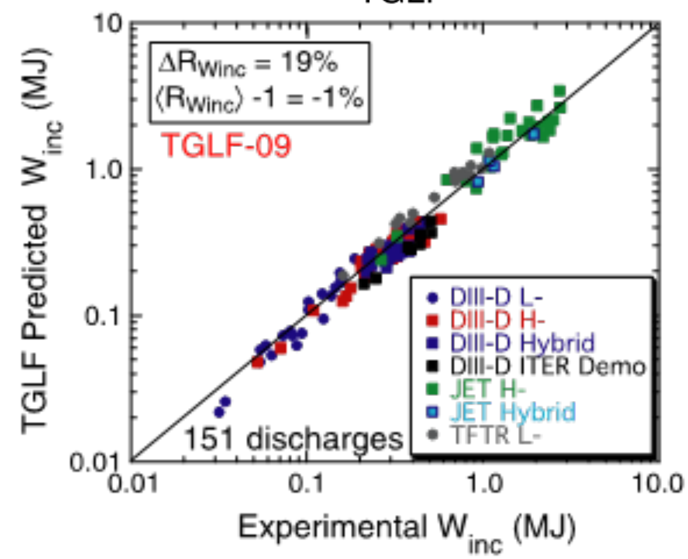

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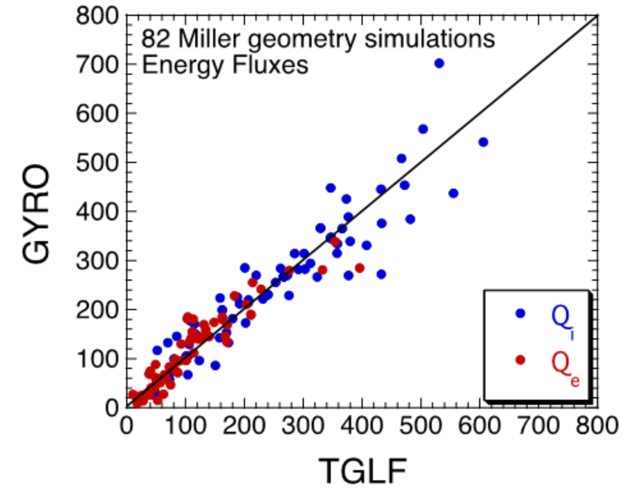
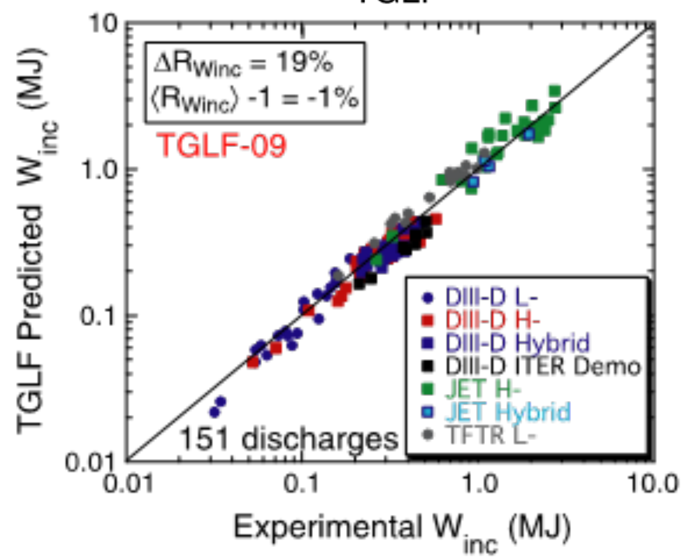
- Improving and expanding reduced model capabilities requires significant increases in high-fidelity simulations
  - More parameters at higher resolution





G. M. Staebler *et al*, Nucl. Fusion 2017

Core transport components provide template for future physics component development

- Recent optimization work by AToM team members suggests a **10x increase in high-fidelity code performance on next-generation exascale platforms** is possible

- Enables scope and scale of new high-fidelity simulations to **improve our reduced models and thereby our practical predictive modeling capabilities**

AToM working to deliver practical, high-fidelity whole-device modeling capabilities

- Future research areas for AToM include topics such as:
  - Improving reduced model components for areas such as core and edge transport
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  - **Development of a validation and future scenario use case database to track model development, coordinate with other SciDAC-4 centers**

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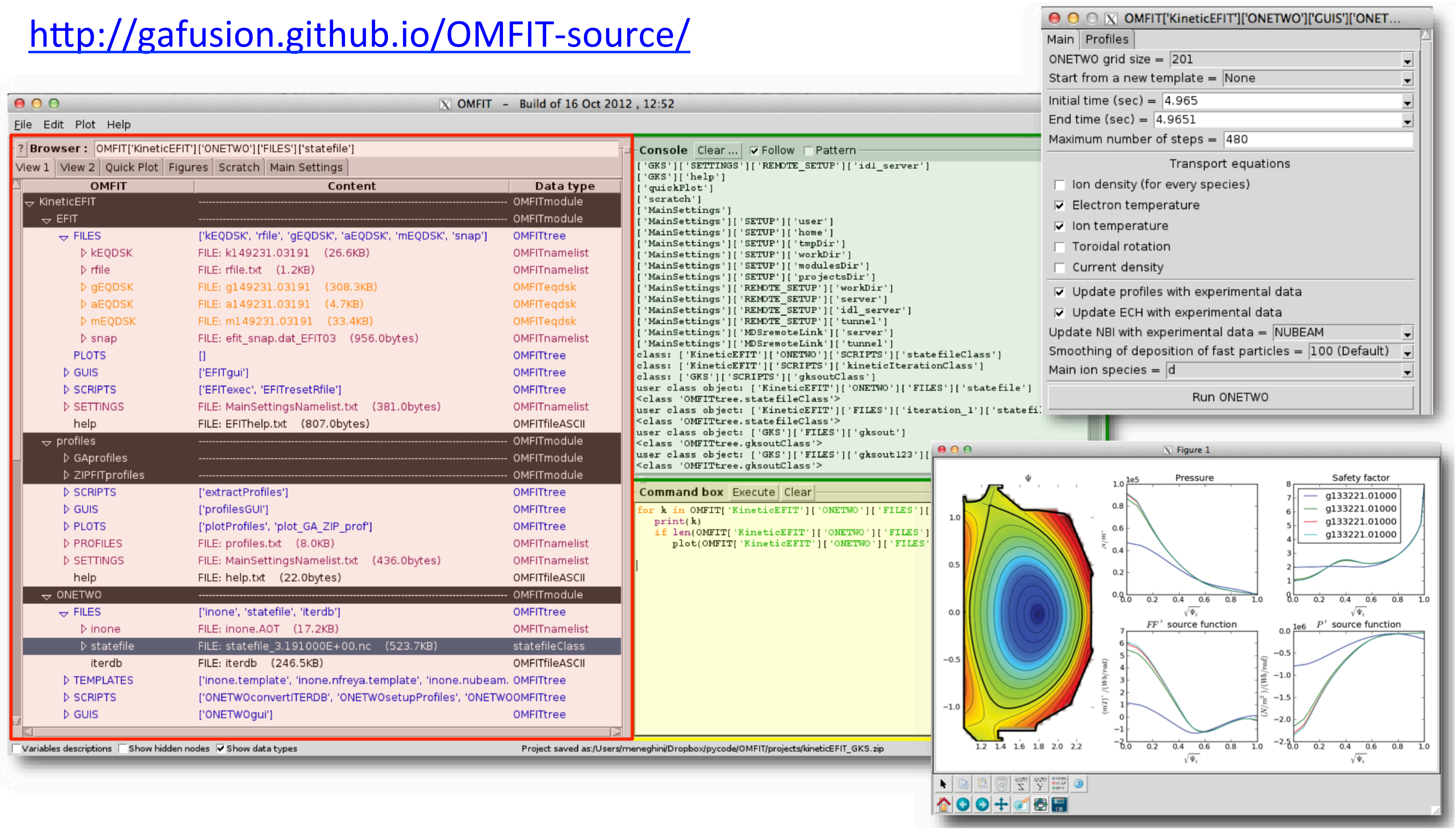
- **Longer term goal**: partnering with other SciDAC centers to integrate and improve both high-fidelity and reduced model components for:

– RF heating & current drive	(PI: P. Bonoli)
– energetic particle transport	(PI: Z. Lin)
– plasma edge & scrape-off layer physics	(PI: C. S. Chang) (PI: D. Hatch)
– plasma-material interactions	(PI: B. Wirth)
– disruptions	(PI: S. Jardin) (PI: X. Tang)
– runaway electrons	(PI: D. Brennan)

Backups

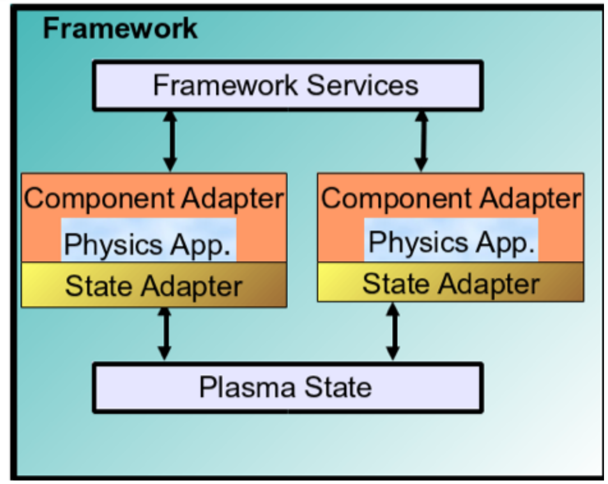
OMFIT- One Modeling Framework for Integrated Tasks

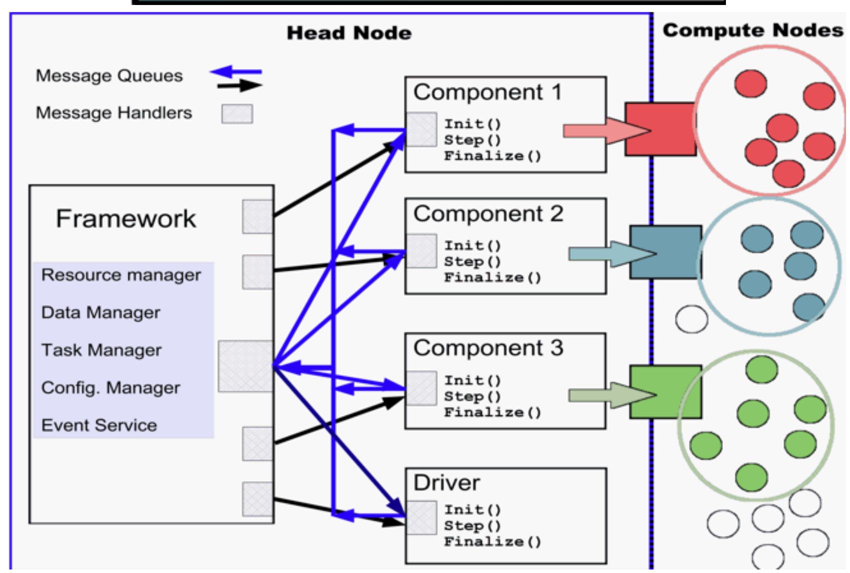
http://gafusion.github.io/OMFIT-source/



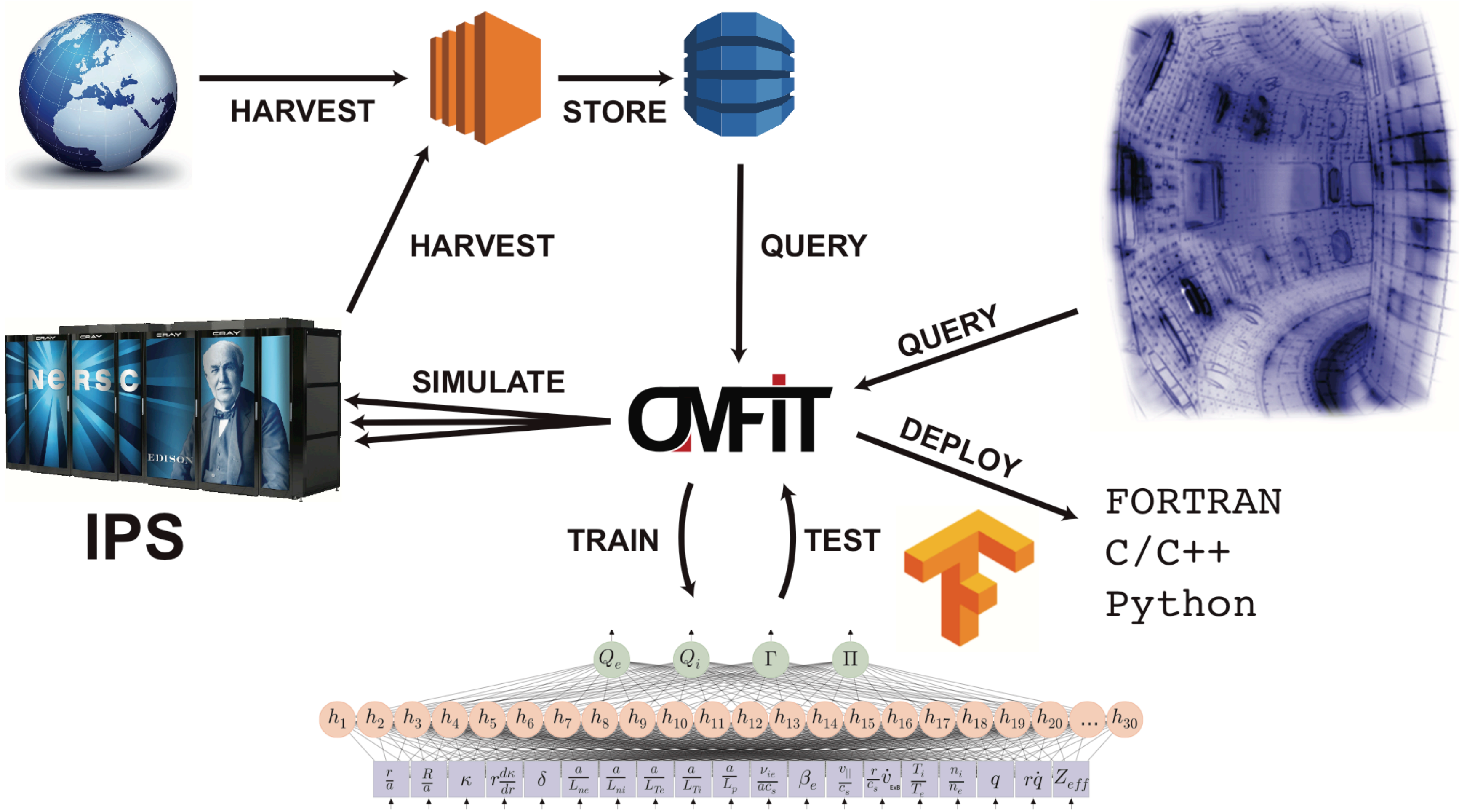
IPS- Integrated Plasma Simulator

- Python-based HPC component framework
- Components are python-wrapped binaries
- Framework runs in a single batch allocation, manages resources for components
- Components launch task on compute nodes using standard system mechanisms
- PlasmaState holds primary data for exchange
- Reader-makes-right model





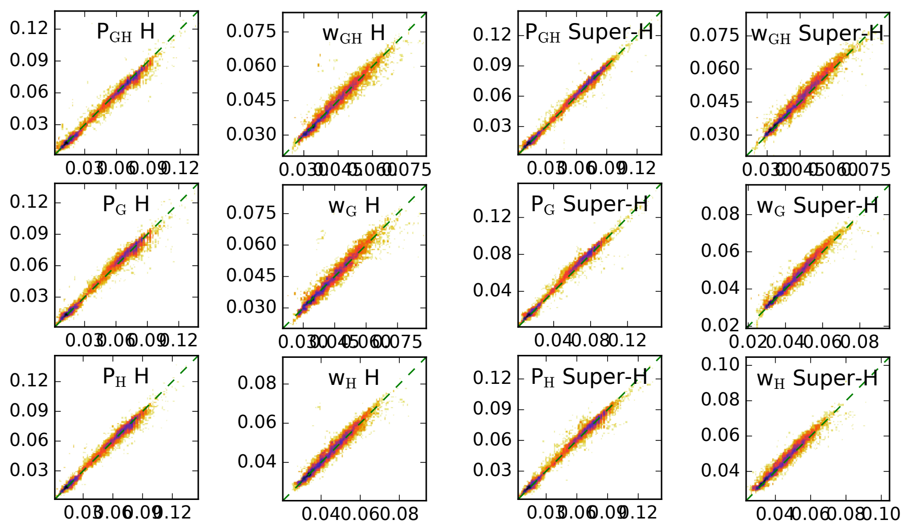
AToM has established a reliable infrastructure to generate machine-learning based reduced models

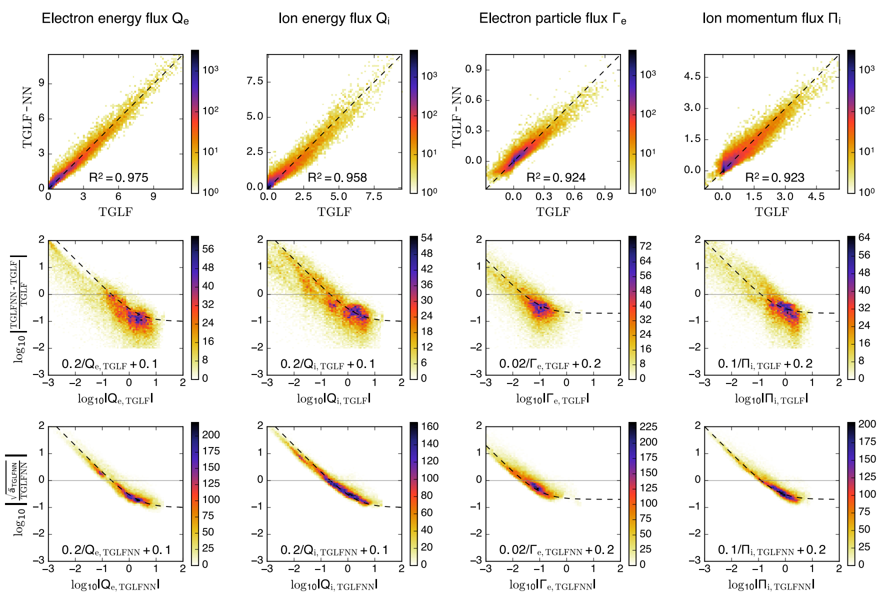


Neural-net versions of TGLF and EPED achieve significant speed-up while maintain good fidelity

EPED1-NN trained on database of 20,000 EPED1 runs for DIII-D, KSTAR, JET, ITER, CFETR parameters (10^9 speedup)

TGLF-NN trained (with TENSORFLOW) on database of 500,000 cases from multi-machine database (10^5 speedup)





O. Meneghini *et al*, Nucl. Fusion 2017