Accelerating Discoveries at DIII-D With the Integrated Research Infrastructure

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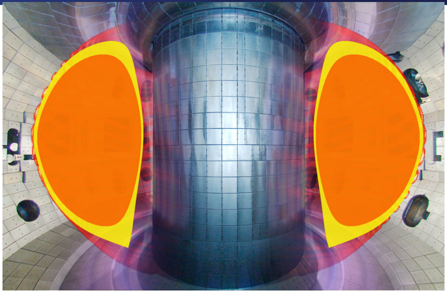

AI and Large Data Visualization Workshop
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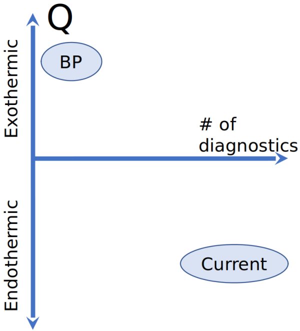
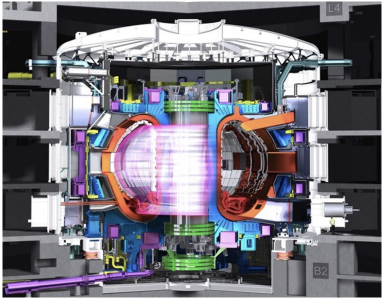
Realizing the ITER and FPP Vision Requires Urgent Action in Computation and Data Science

- The complexity of fusion, the stringent requirements for reliability and safety, and the ambitious timeline for success, necessitates the aggressive deployment of advanced data science and national HPC infrastructure to solve outstanding challenges
DOE AI for Science Town Hall Report (https://doi.org/10.2172/1604756)

- ITER data challenge:
  - $\sim$ 100 GB/s
  - 1-2 PB/day (Existing data archives $<$ 1 PB)
  - Exascale by 2035





- Fusion Power Plants may not produce as much data, but will be even more challenging to control.

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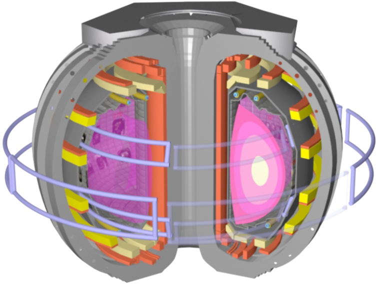
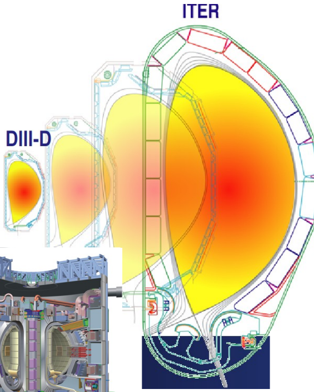
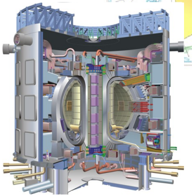
Current: Coupling DIII-D with NERSC High Performance Computing



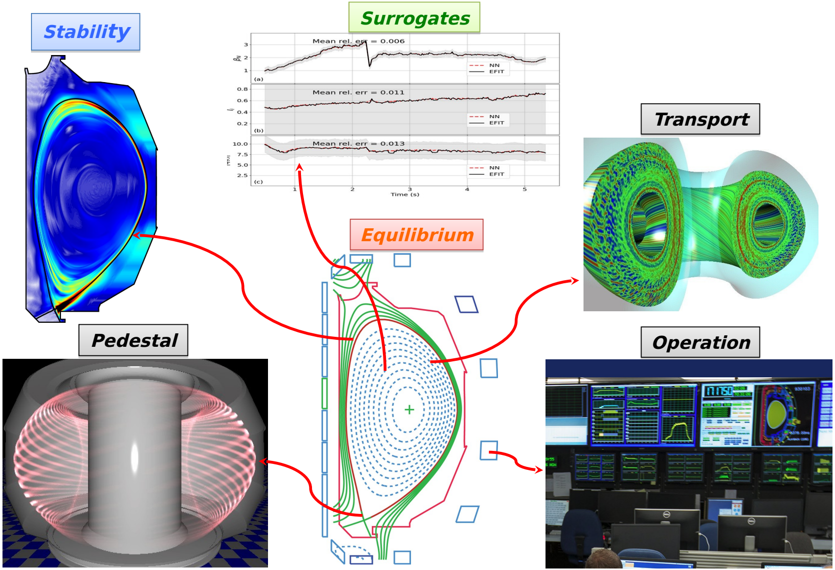
Future: Coupling ASCR High Performance Computing with other Facilities

ESnet





Kinetic Equlibrium Reconstruction is Our Starting Point



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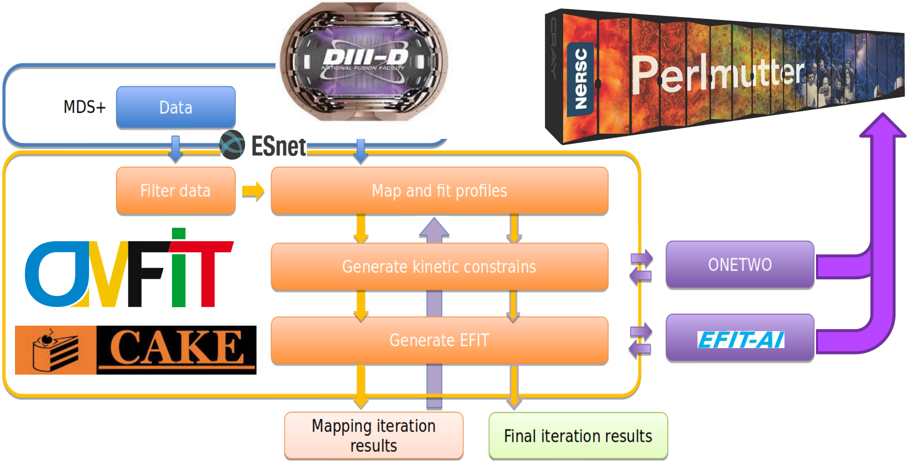
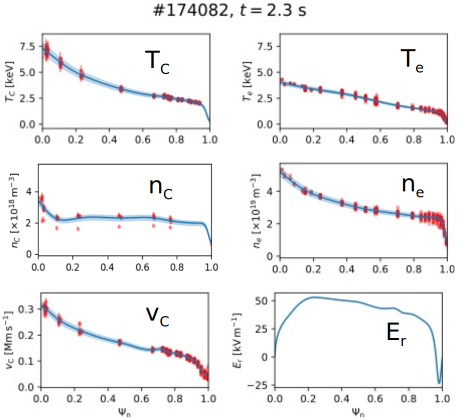
A Workflow Has Been Designed To Eliminate Bottlenecks

- CAKE originally required hours (overnight)
- We optimized this to ~ 20 **mins** (between shots)
- Further improvements are being developed

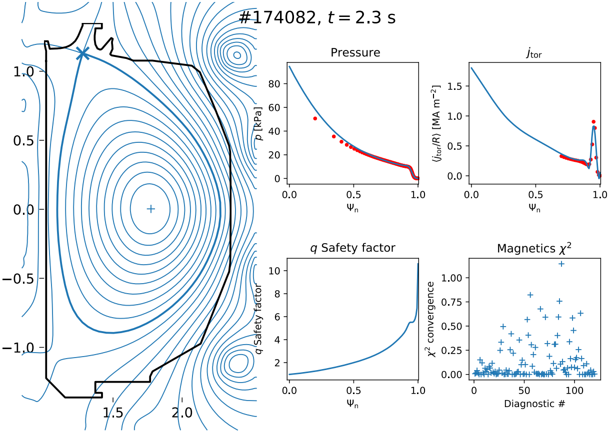


Consistent Automated Kinetic Equilibrium Reconstructions are Produced

Fitted Profiles



Equilibrium Reconstruction



CAKE fits plasma profiles to measurements to derive kinetic constraints (total pressure and toroidal current - including bootstrap)

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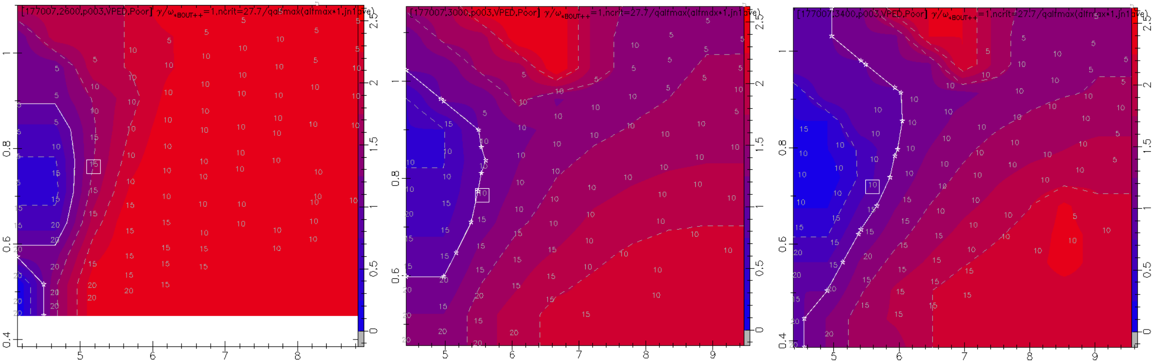
Analyses Can Show Paths to Increased Performance

Shot 177007: $t = 2.6$s $\quad$ $t = 3$s $\quad$ $t = 3.4$s

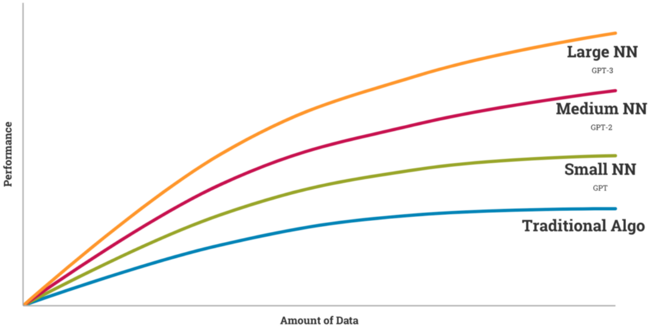


- Improved confinement leads to higher plasma density and pressure (upper right)
- Peeling and ballooning instabilities (white contour) prevent access
- 50 or more control parameters to tune
- Computations are normally to slow to follow in time during an experiment

Surrogate Models Can Improve Realtime Control

- Multiple projects have demonstrated useful surrogate models for plasma control

- Examples include:
  - kEFIT-NN (KSTAR)
  - EFIT-AI Surrogates
  - CAKE-NN
  - ...



- As more data becomes available, these tools will all improve
- Our accelerated workflow will enable kinetic reconstructions to be produced for full experiment histories and new devices as soon as they start operations

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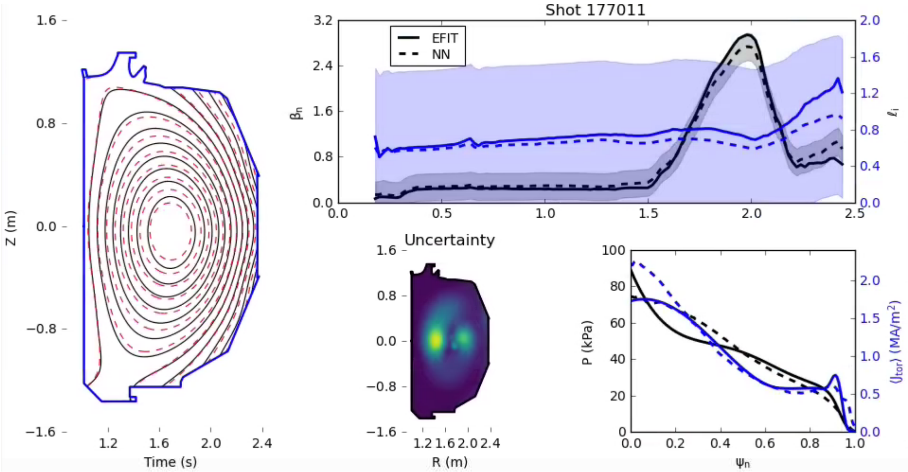
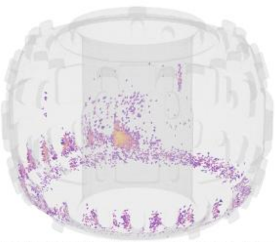
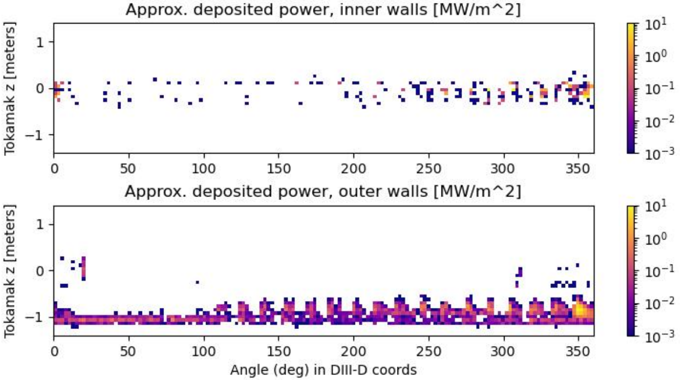
Example: EFIT-AI Surrogate Kinetic Equilibrium Reconstruction



- Provides a complete reconstruction in milliseconds
- Inference uncertainty is quantified by an ensemble of models

Predictive Analyses Can Qualify the Safety of Experiments





- Beam ions are traced to determine whether any components are at risk
- These calculations requires a close equilibrium prediction as well (still being refined)
- This enhances the usefulness of a digital twin experiment

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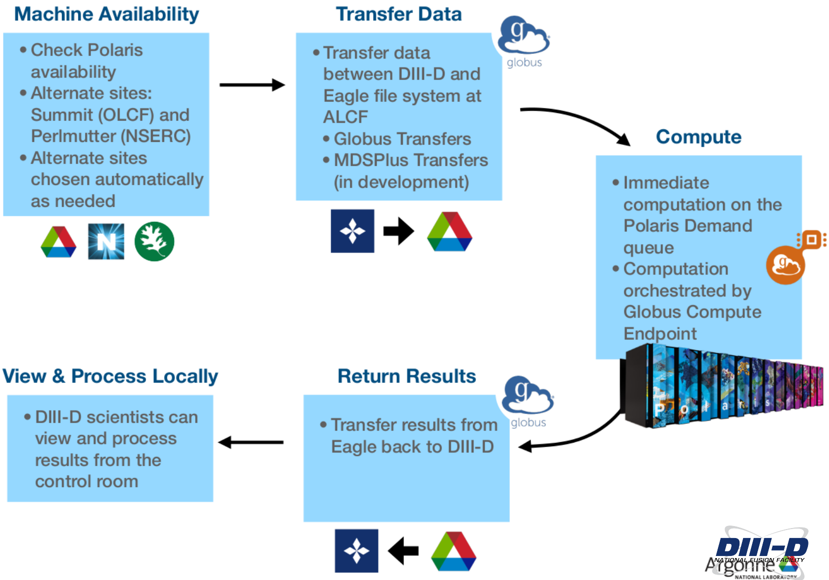
Globus Infrastructure Enables the IRI Goals

- IonOrb workflow demonstrates the use of Globus Flows
- Single API can provide deployment onto systems with different architectures and job schedulers
- Fully capability is still under development



IRI Workflows can Accelerate Scientific Discovery

The automated workflows developed on DIII-D offer a foundation for more advanced analysis and can serve as prototypes for other experiments

- These capabilities are already making an impact on DIII-D research
- High quality data will allow AI development that can unlock much greater speed

Future Plans

- Continue to streamline and productionalize workflows
- Complete adoption of Globus for workflow execution and data transfer
- Automate more workflows in this ecosystem

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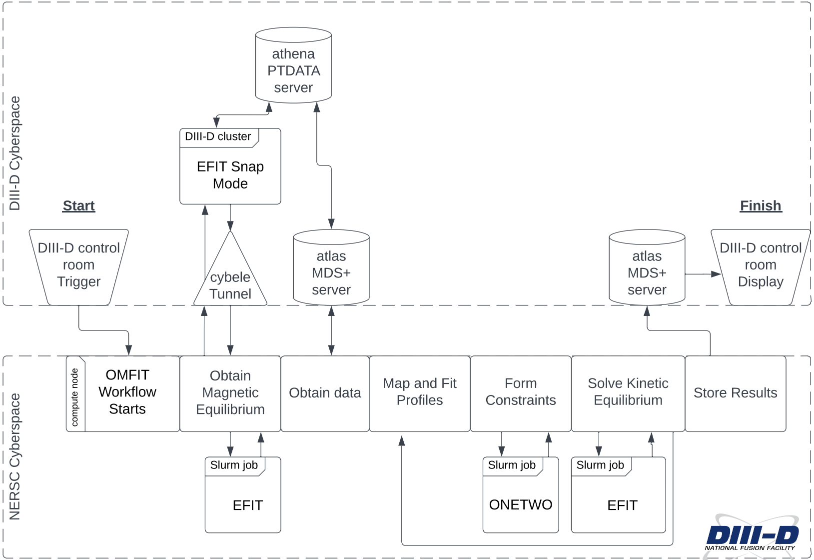
Superfacility Efforts Have Accelerated Time-to-Solution

- CAKE originally required hours to run (usually overnight)
- We optimized this to **23 mins**



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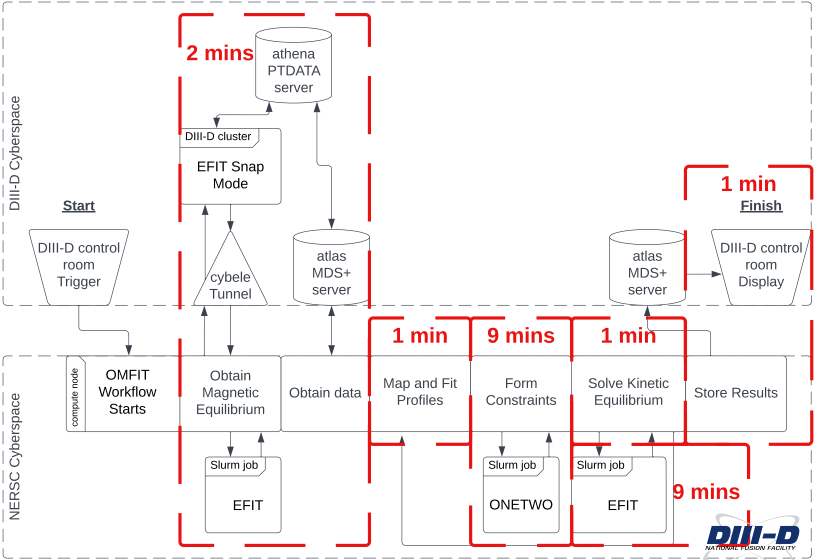
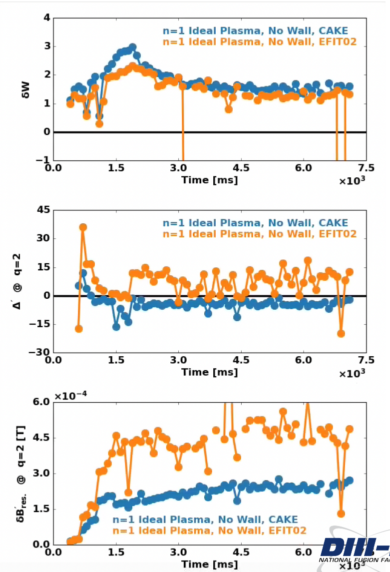


Solutions Provide MHD Stability Insights Not Previously Available

- Ideal MHD, global kink stability (δW) not changed significantly
  - Previously able to predict RWM limits with automated EFITs (done after experiments)
- Local tearing drive (Δ') changes from destabilizing ($\Delta' > 0$) to stabilizing when including pedestal pressure and current
  - Could inform I_p and power ramp rates, which can set J and P profiles
- Local resonant response to error fields (δB_{res}) changes significantly
  - Could inform error field correction - enabling access to low torque and low density for efforts like low torque ITER baseline ELM control



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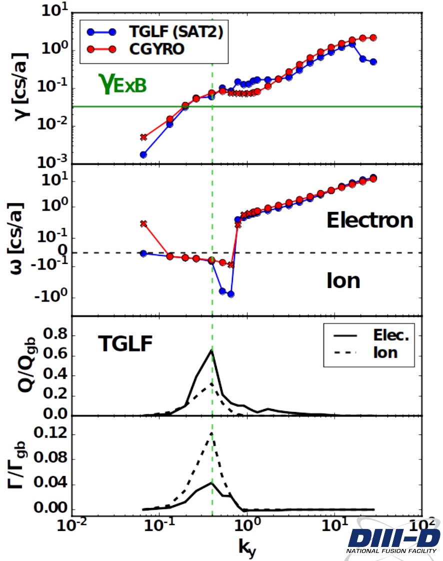
Between-shot TGLF can help DBS experimentalists aim for theoretically-important parts of the transport spectra

- Linear eigenvalue spectrum calculated by TGLF (SAT2) is in good agreement with higher-fidelity linear gyrokinetics (CGYRO)
- The flux-spectra predicted by TGLF (Γ, Q) has a peak at $k_y \approx 0.4$
- This information can be used to aim DBS between shots to study this wavenumber range while scanning physics parameters
  - Focus on the peak of the transport spectrum ($k_y = 0.4$) for subsequent shots.



[Q. Pratt et al., NF 2023]