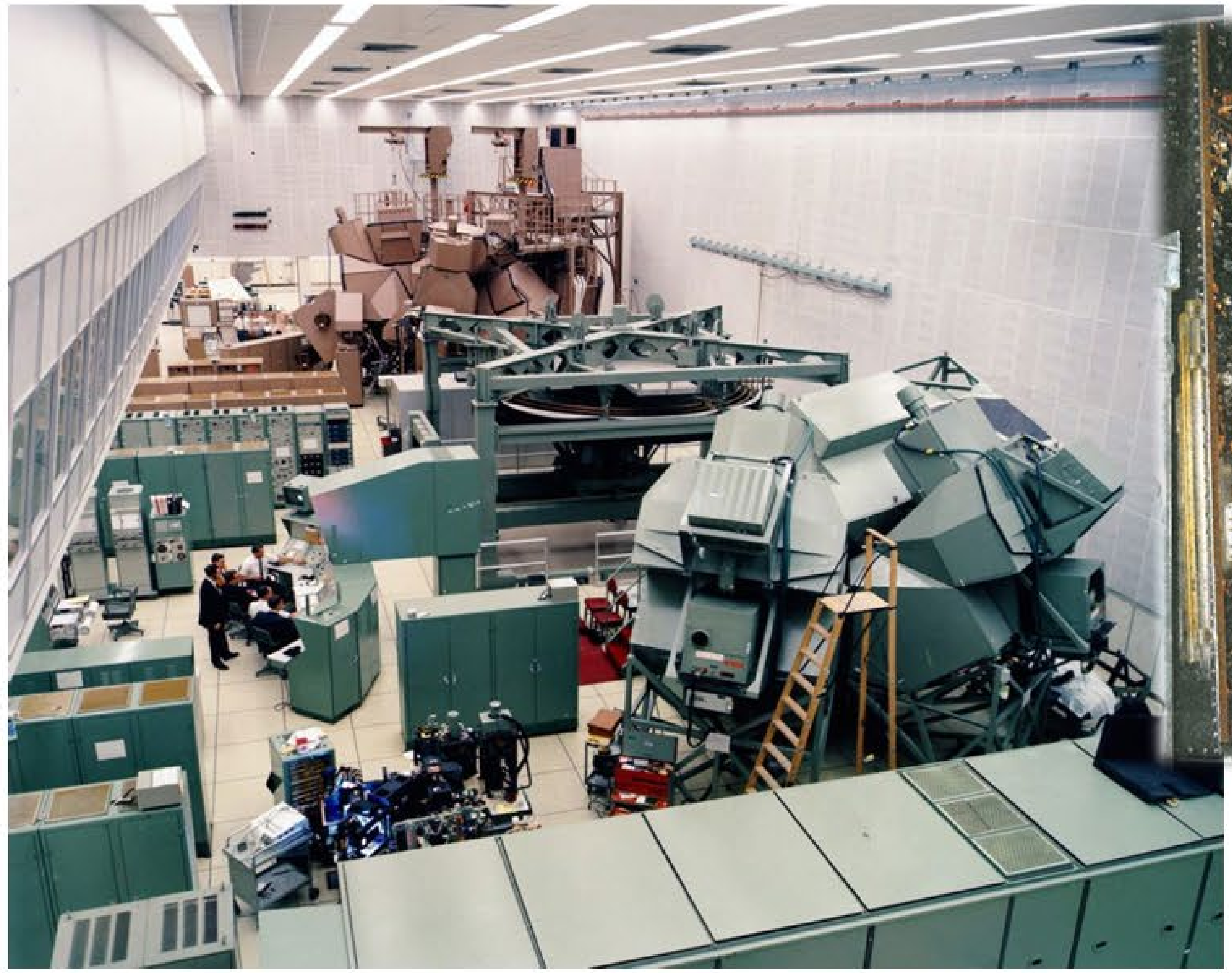
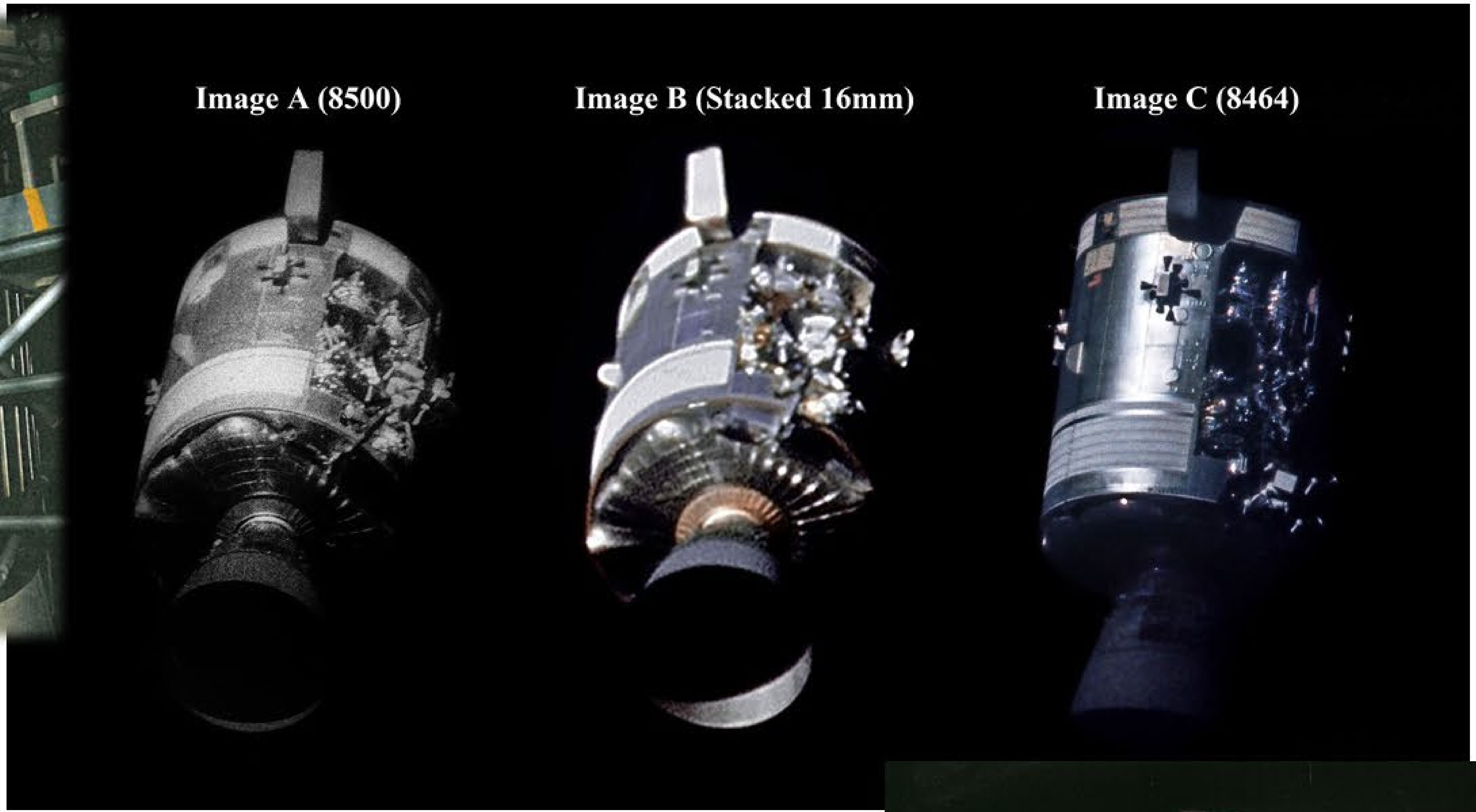
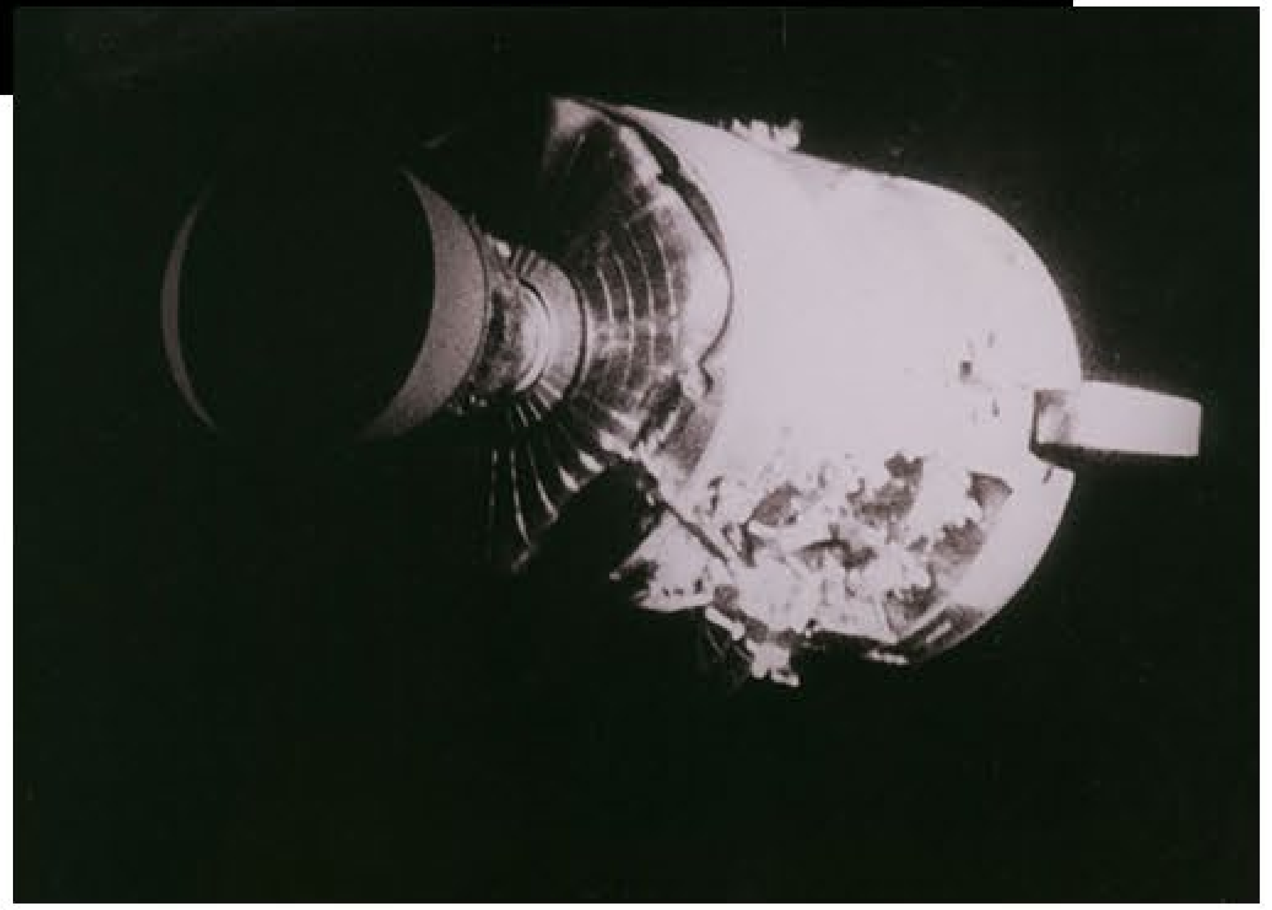
GA Industry Day

Tom Gibbs, NVIDIA
November 2025

The First Digital Twin: Apollo 13

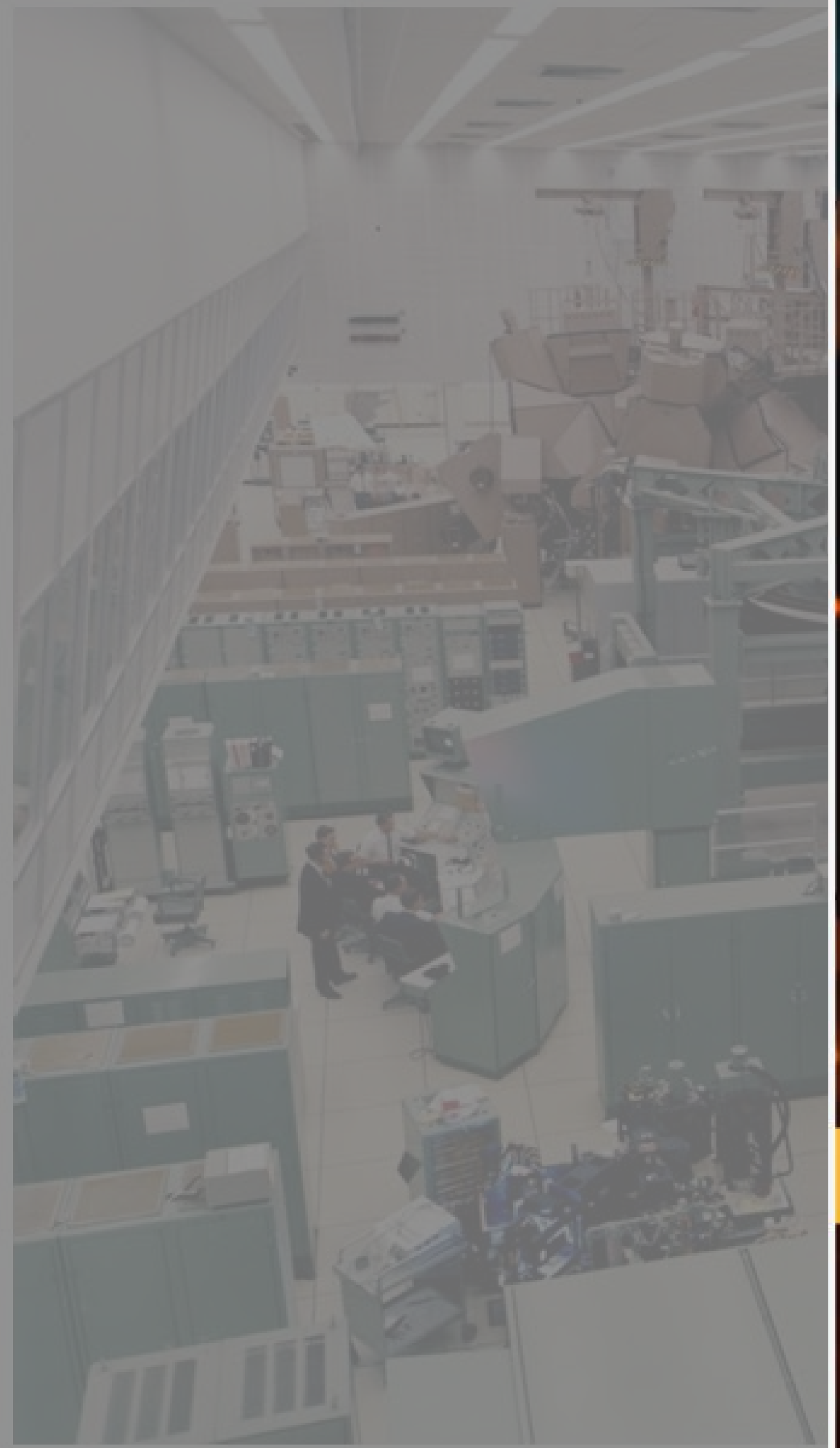


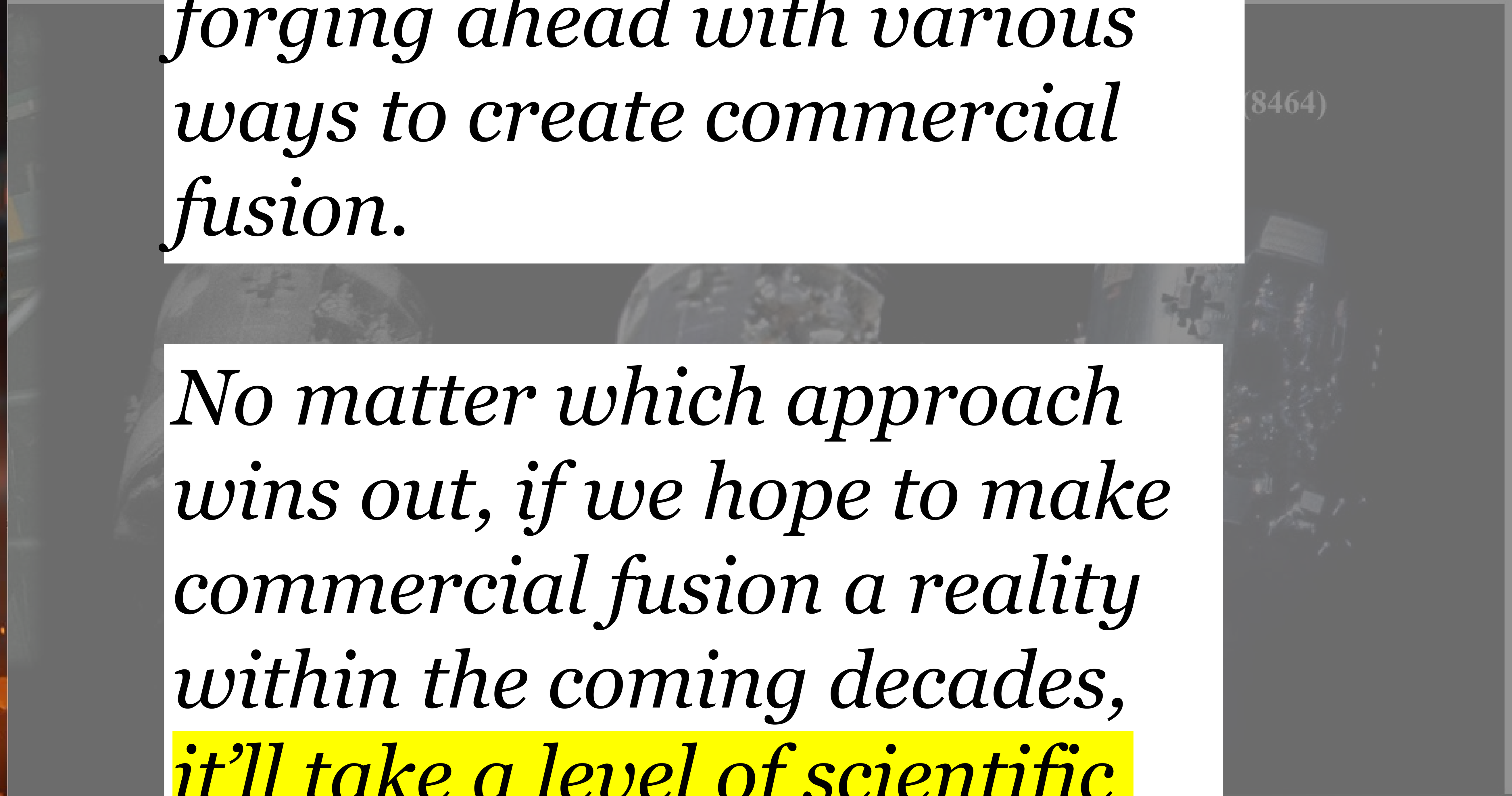


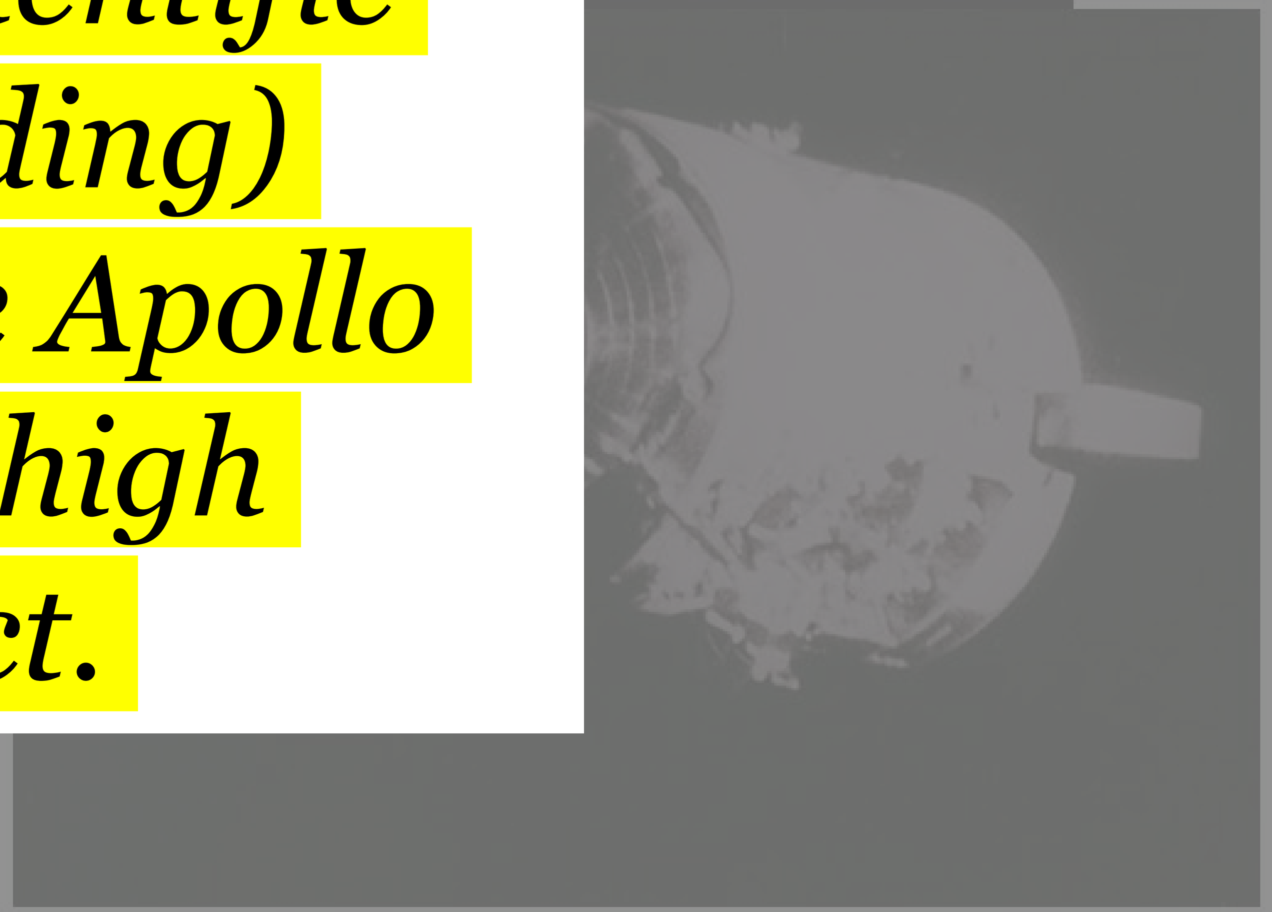


- 15 <u>simulators</u> were used to train astronauts and mission controllers
- Simulator → digital twin?
  - Adapted to match conditions of actual spacecraft
  - High fidelity model used to explore solutions and predict results

The ... n:



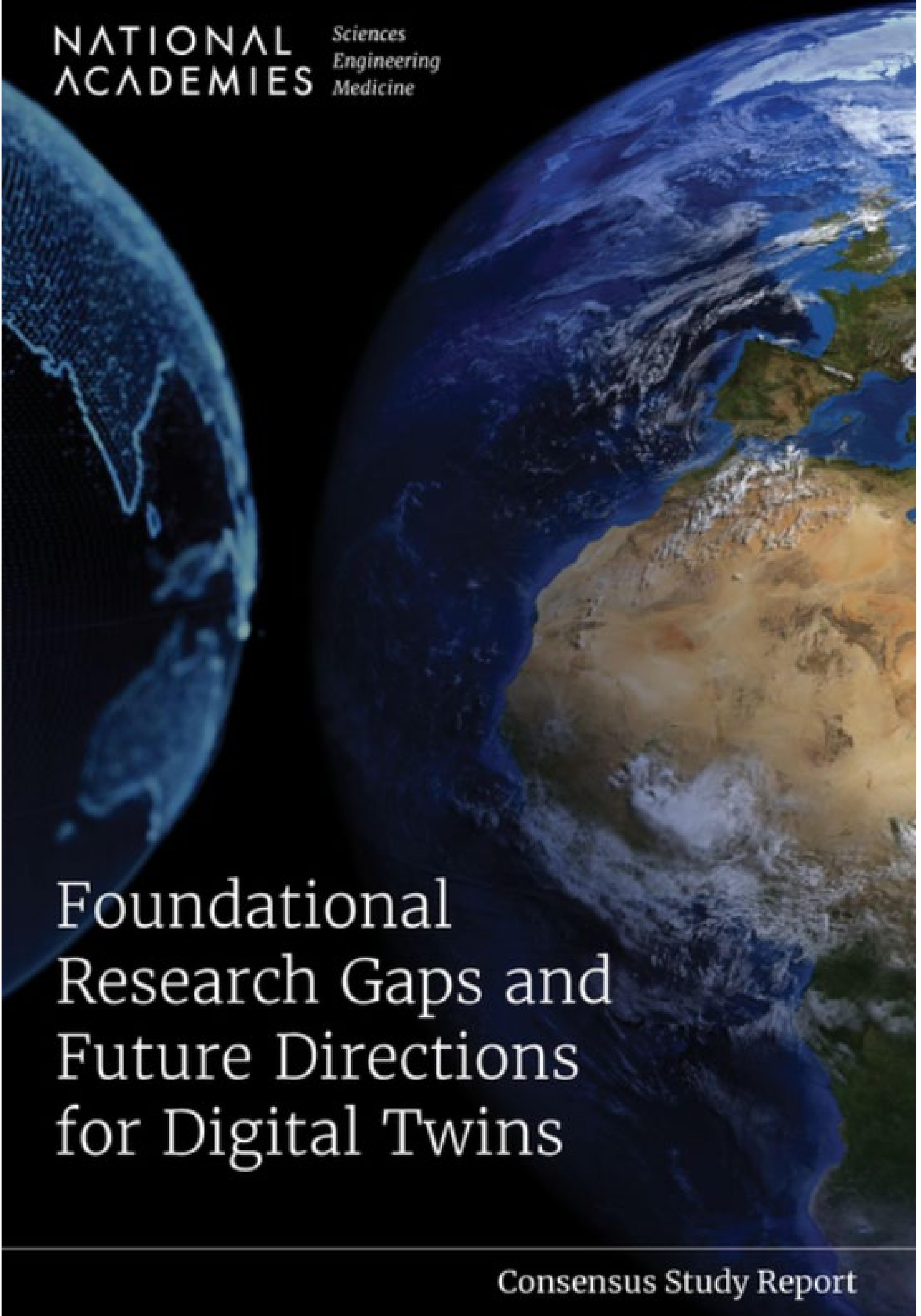




Dozens of private companies funded by some of the richest people in the world are forging ahead with various ways to create commercial fusion.

No matter which approach wins out, if we hope to make commercial fusion a reality within the coming decades, it'll take a level of scientific dedication (and funding) that would make the Apollo program look like a high school science project.

- 15 simulato... and ...
- Simulator – ...
  - Adapted ...
  - High fidelity model used to explore solutions and predict results



DIGITAL TWIN FOR SCIENCE DEFINITION

A Modeling Concept Introduced by Michael Grieves at a Society of Engineers Conference that is Being Reborn in the 21st Century

A digital twin is a set of virtual information constructs that mimics the structure, context, and behavior of a natural, engineered, or social system (or system-of-systems), it is

dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realize value

The bidirectional interaction between the virtual and the physical is central to the digital twin

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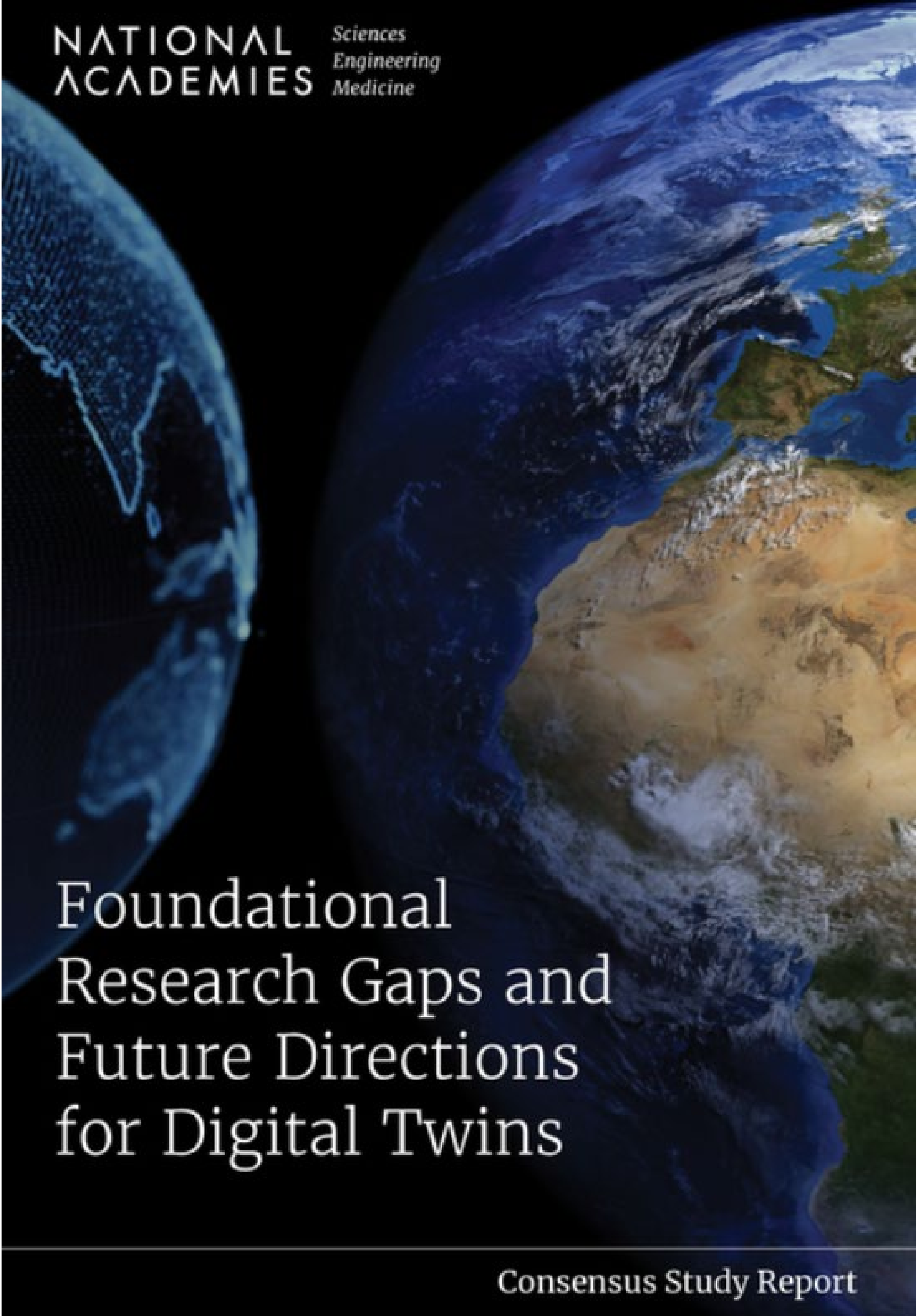

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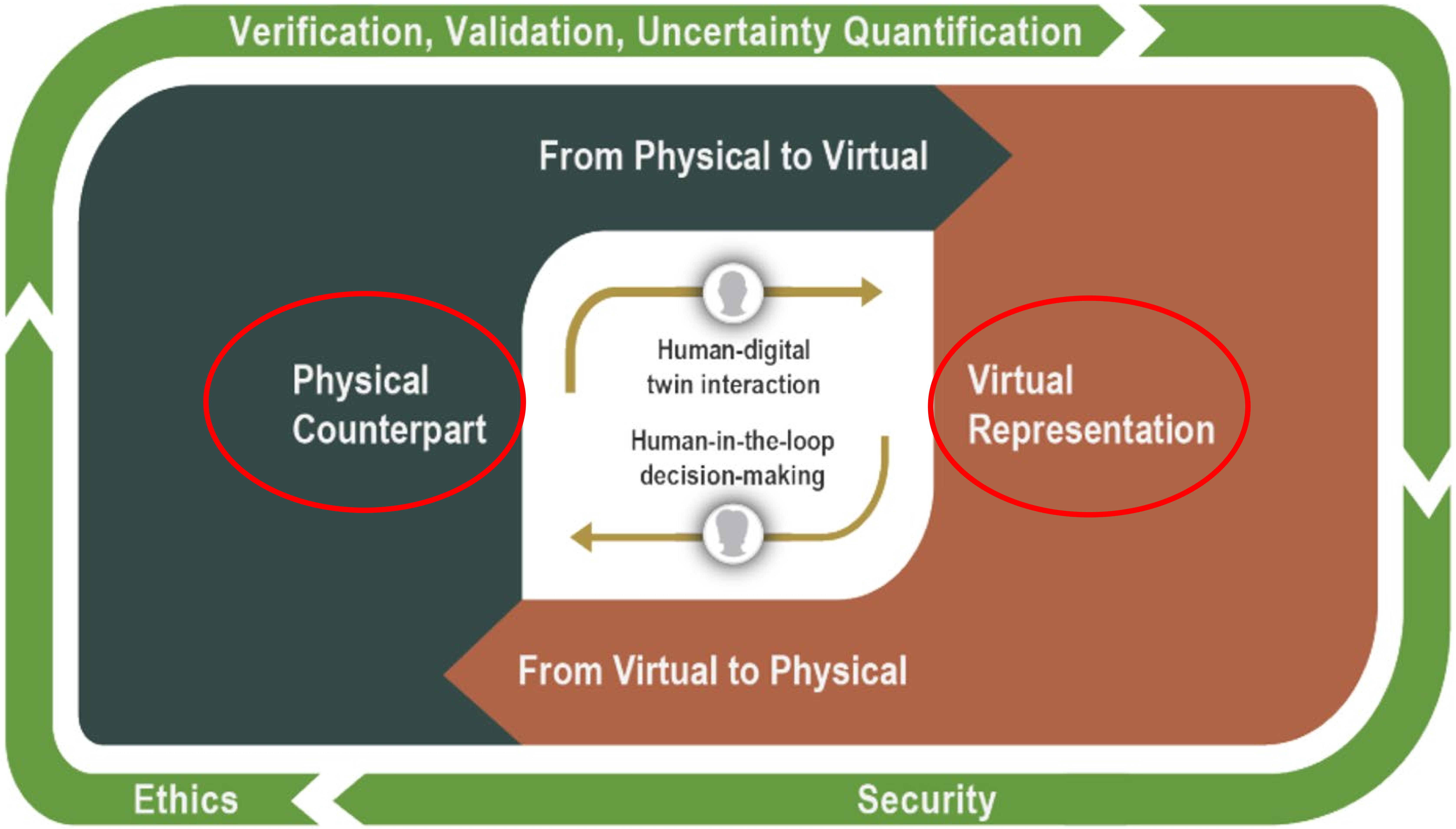
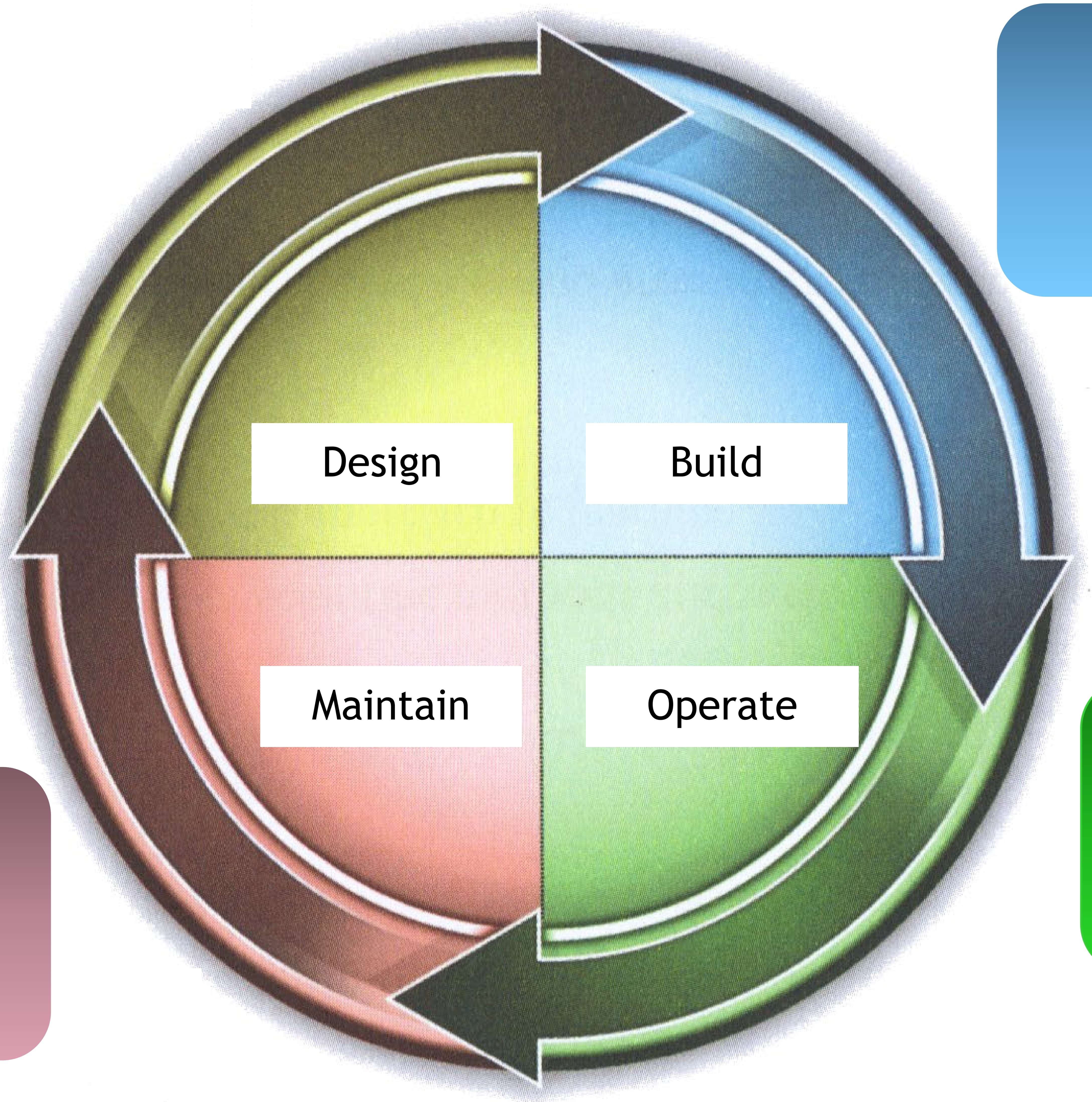


COMPREHENSIVE DIGITAL TWIN OBJECTIVES

A Full-Scale Model to Support the Complete Design Cycle

Key Issues to Model
Magnet Type and Placement
Diagnostic Type and Placement
Divertor Type and Placement

Key Issues to Model
Material Selection
Manufacturing Methods

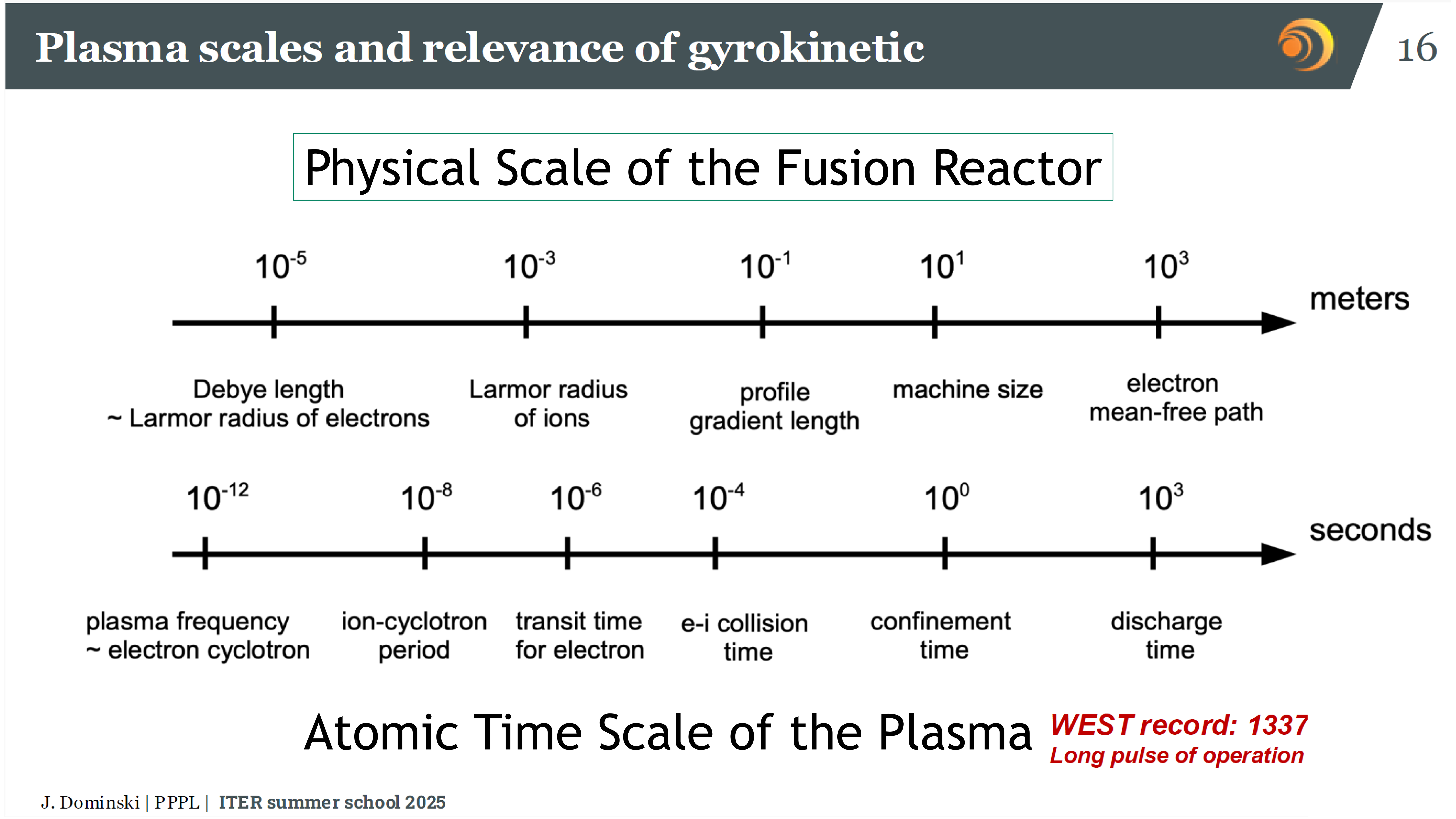


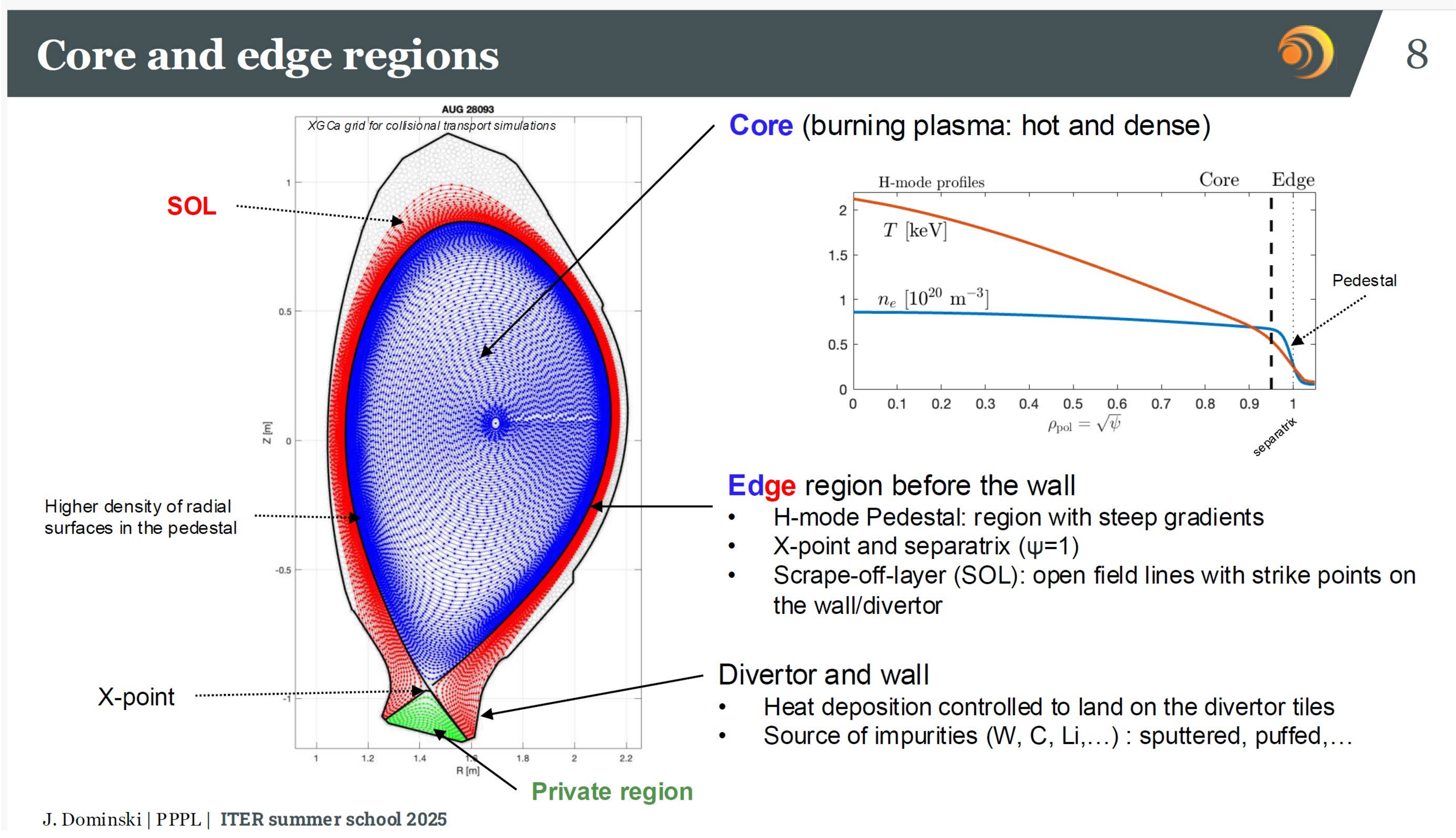
Key Issues to Model
Autonomic Plasma Control
Optimize Reactor Settings
Between Shots

Key Issues to Model
Upgrade Frequency
Damage Avoidance

THE SCALE CHALLENGES THE VIRTUAL MODEL FOR THE FUSION TWIN

Accuracy Must Be Achieved Over 15 Orders of Magnitude





Typical Pulse Time 2-10 seconds*

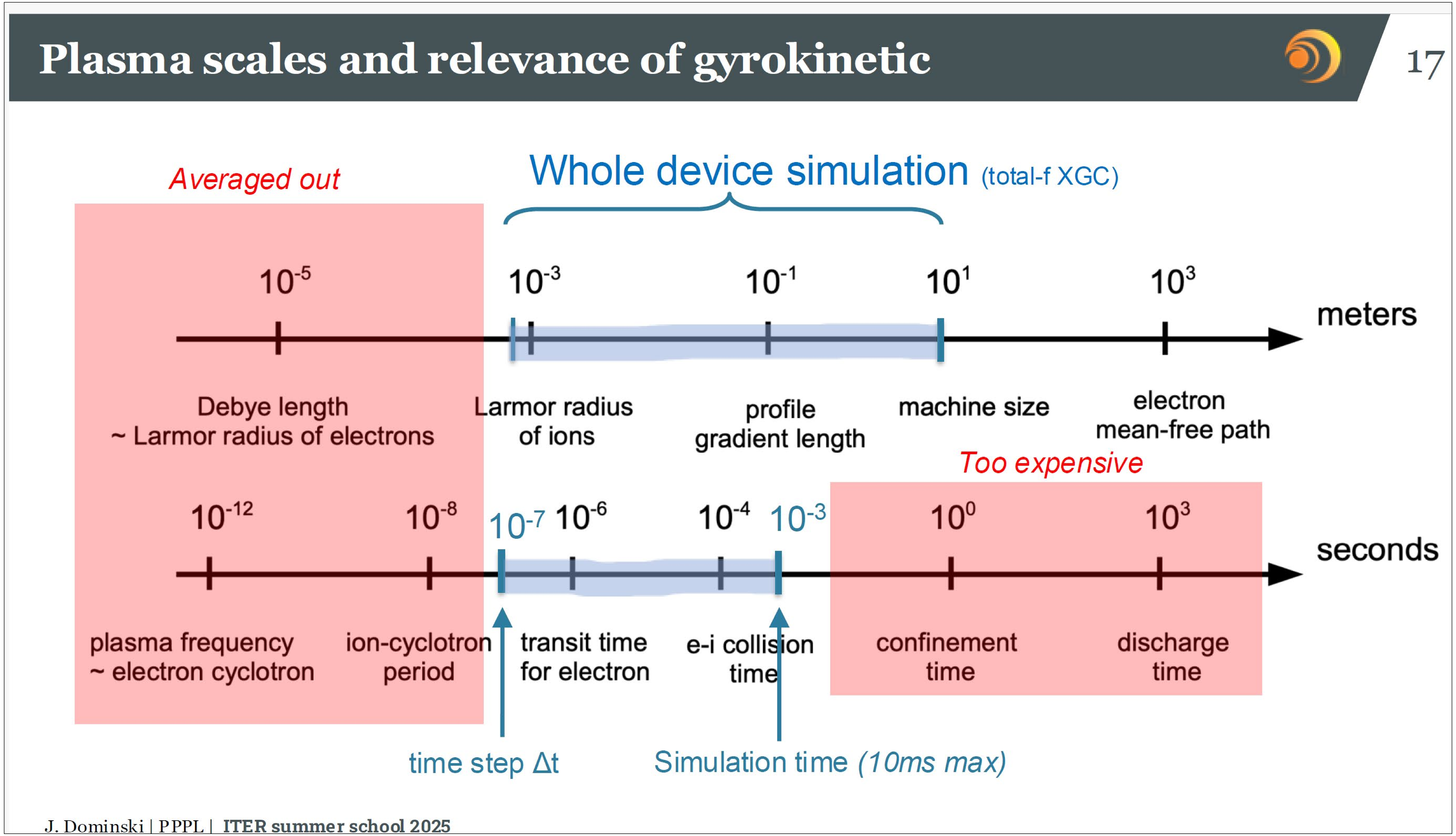
Time Between Shots 15 minutes

Each Region Typically
Requires a Different Type of Model

*WX-7 Recently Achieved 43 Seconds

CONVENTIONAL HIGH FIDELITY SIMULATION CONSTRAINTS

A Portion of the Physical Asset Can Be Modeled at High Fidelity on Time Scale of Days



Whole Device Simulation required 2.5 Days on Polaris (2,240 A100 GPUs)

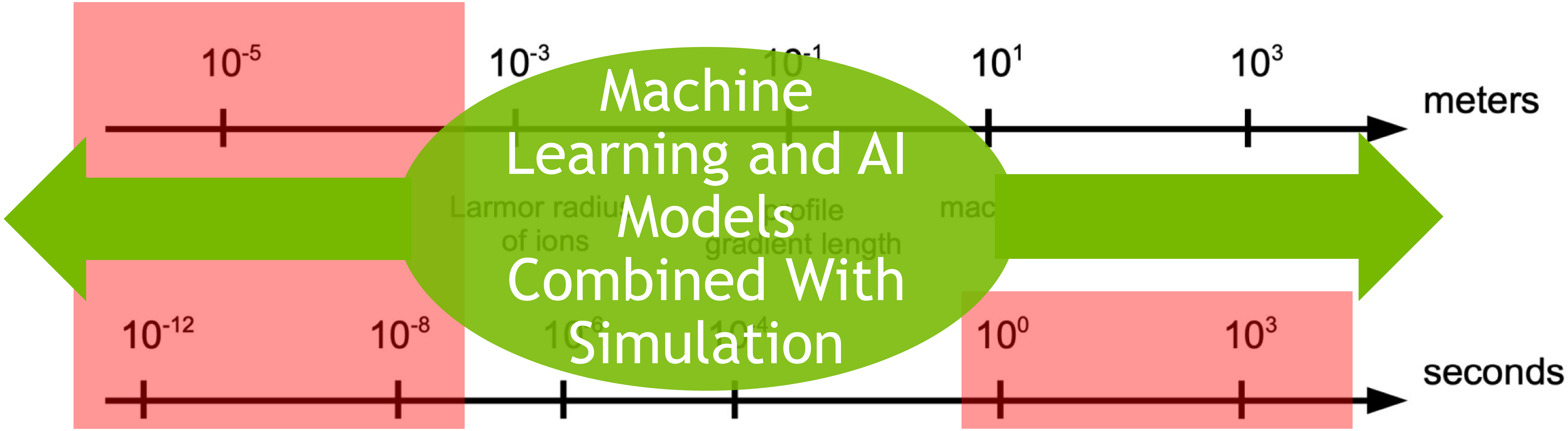
Interactivity Requirements

Typical Pulse Time 2-10 seconds

Time Between Shots 15 minutes

MACHINE LEARNING AND AI SHOW PROMISE

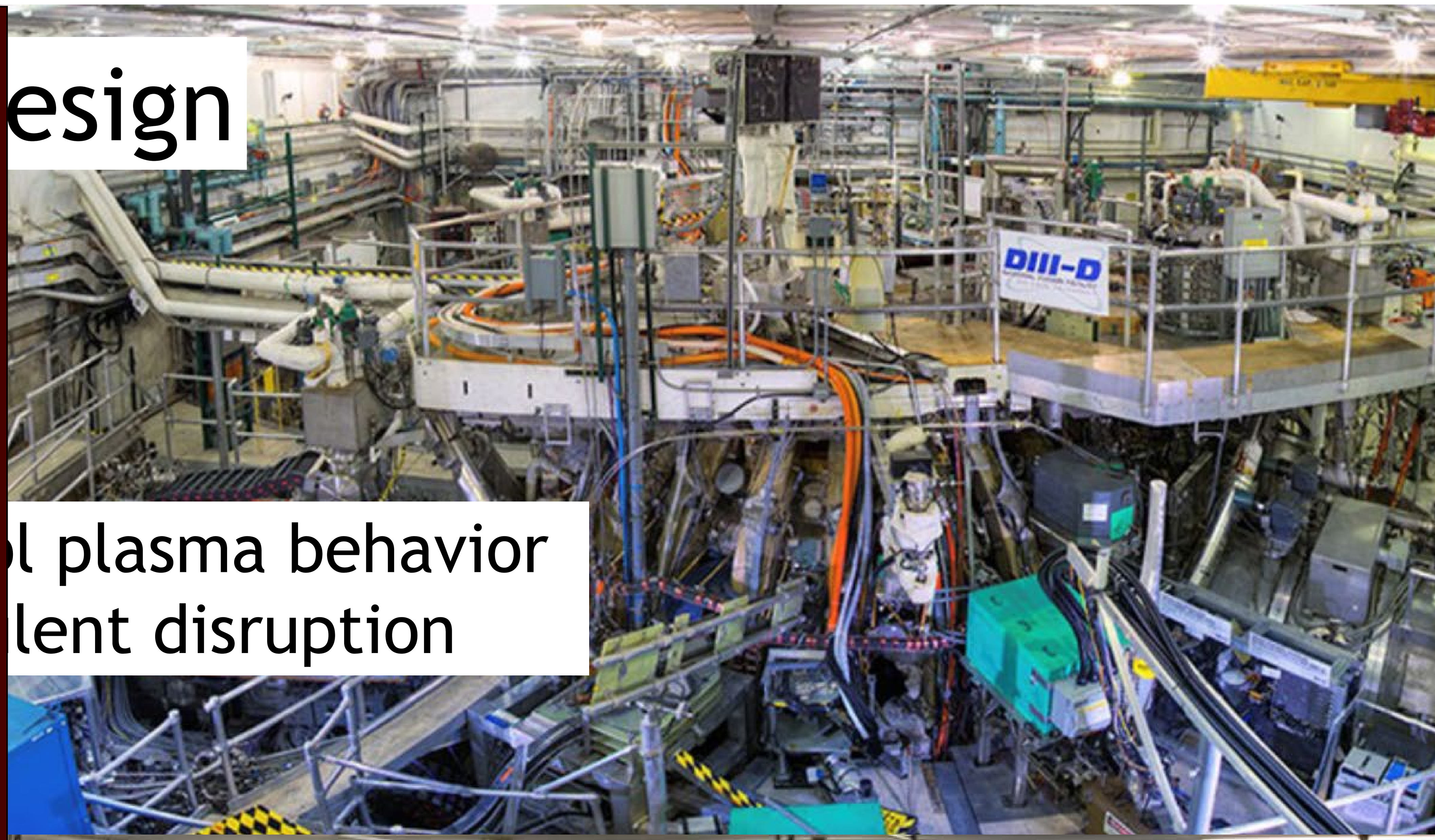
Equivalent Accuracy at Required Time Scales

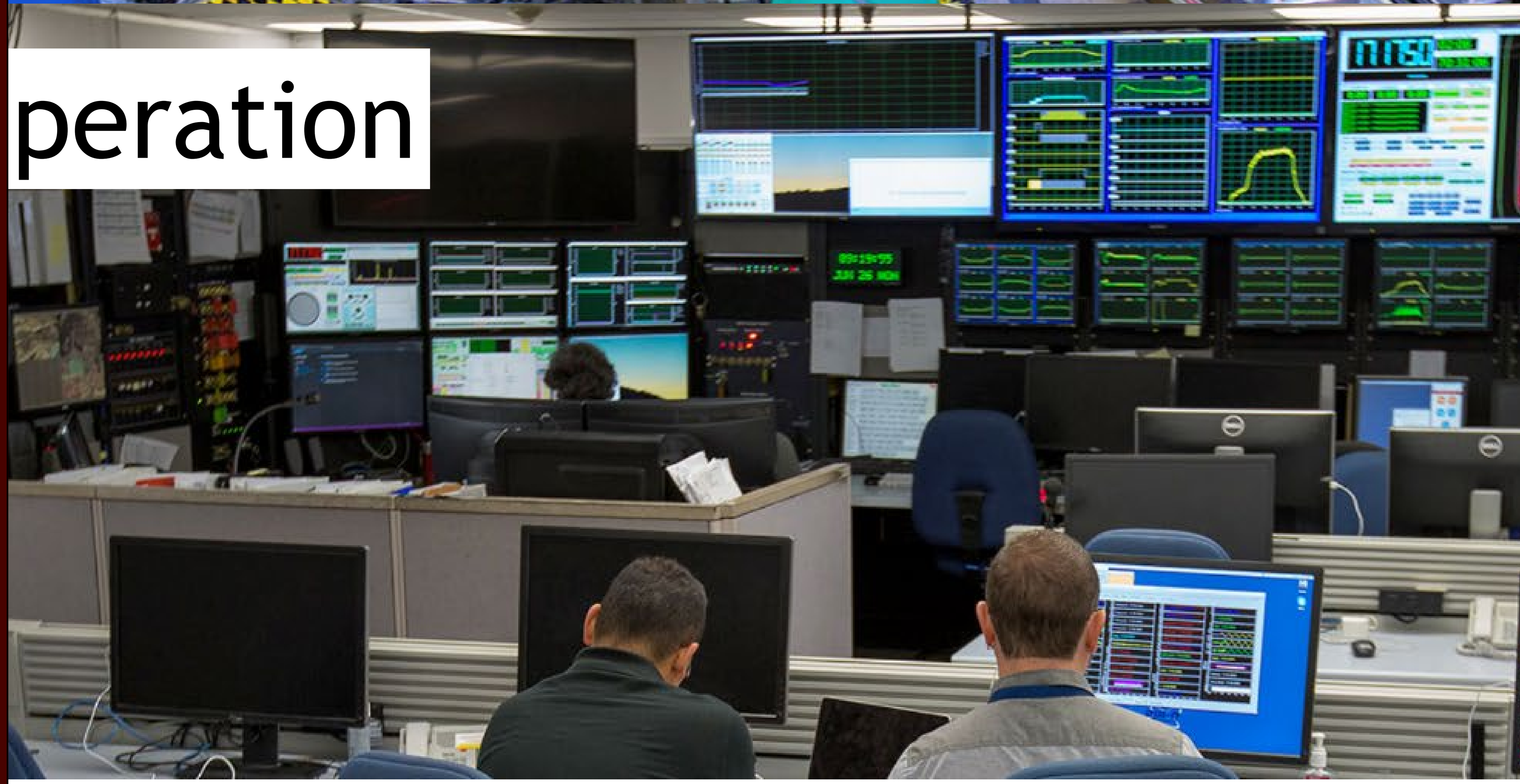


WEST record: 1337s
Long pulse of operation

DIGITAL TWIN INITIAL PROOF OF CONCEPT WITH DIII-D

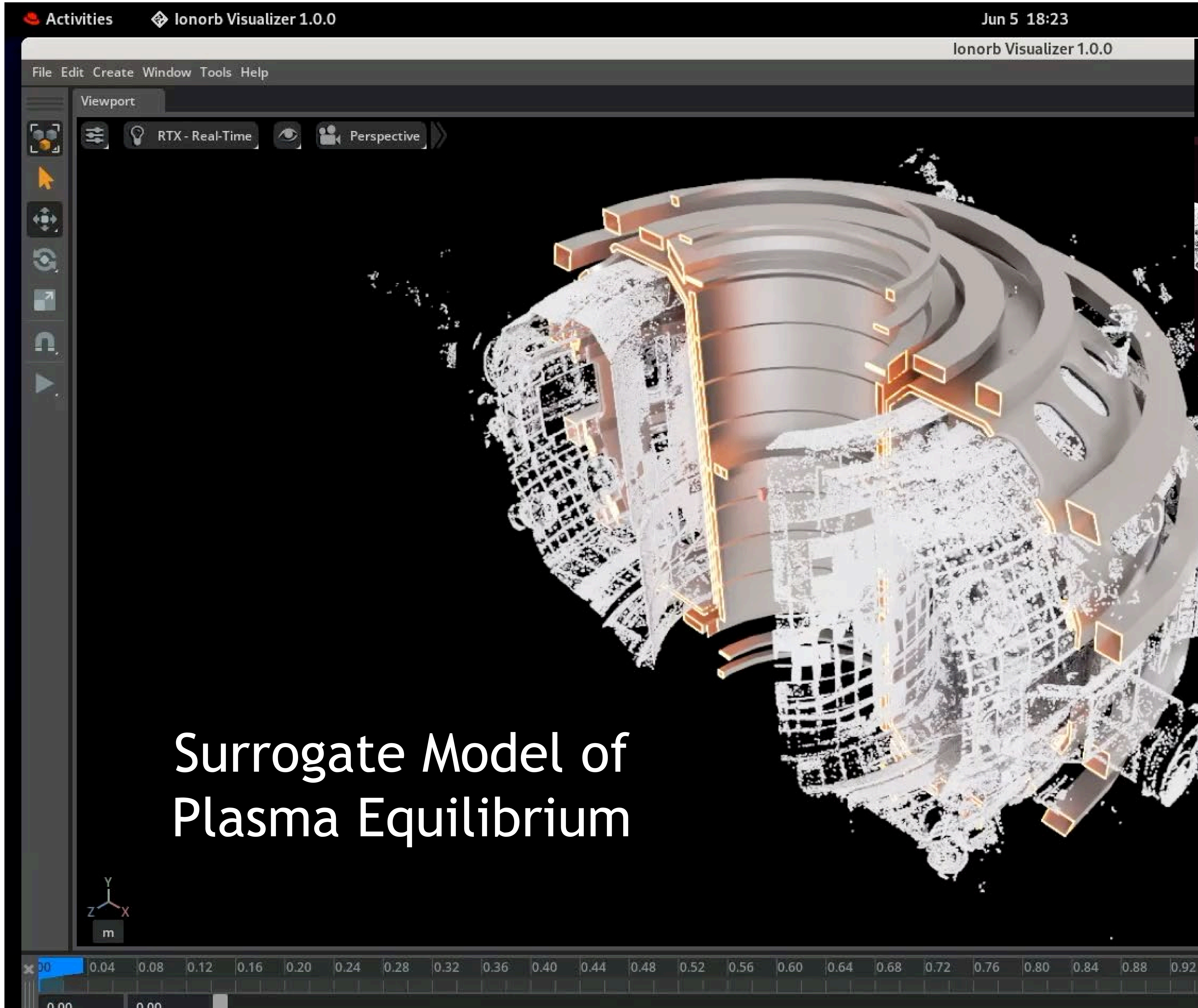
Building Toward A Twenty-First Century Moon Shot

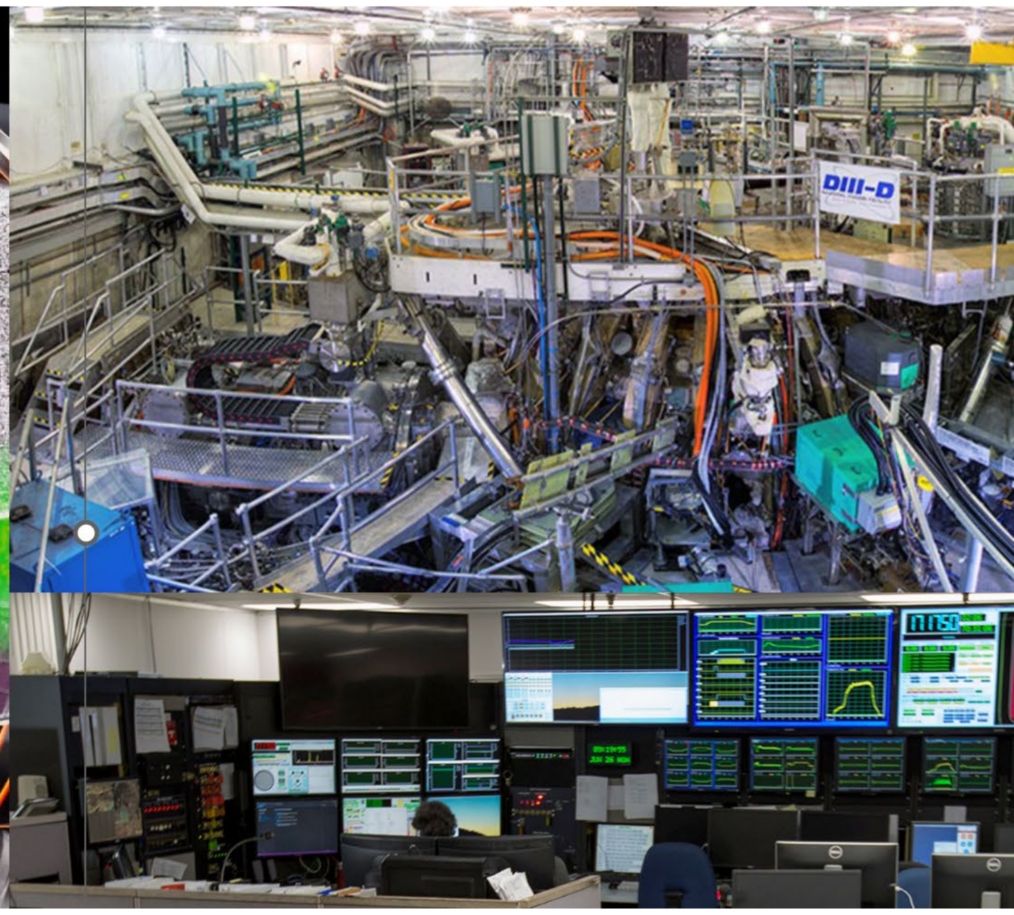




CURRENT STATUS BUILDING ON THE DIII-D PROOF OF CONCEPT

Aiming Toward A Twenty-First Century Moon Shot





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CURRENT STATUS BUILDING ON THE DIII-D PROOF OF CONCEPT

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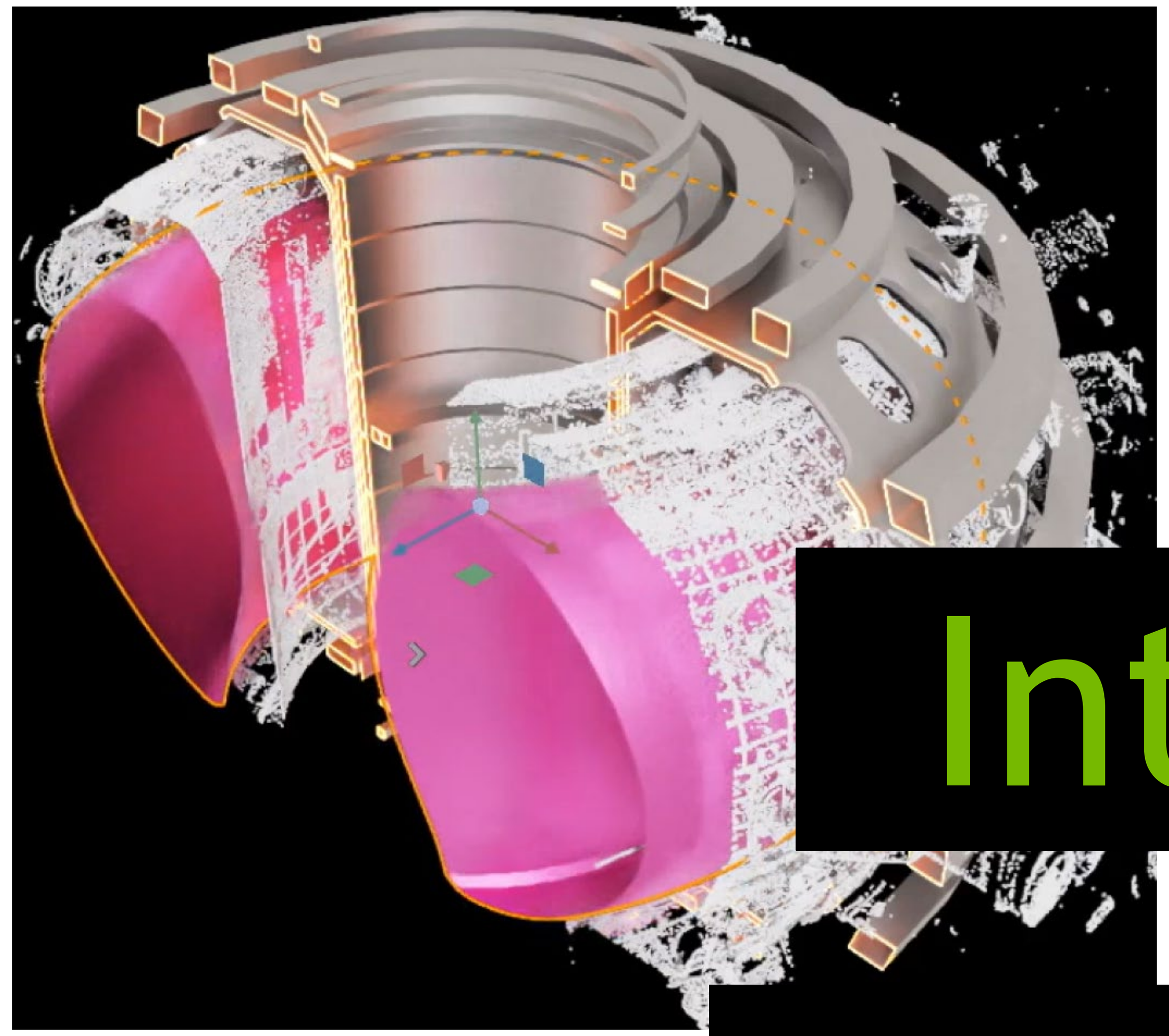
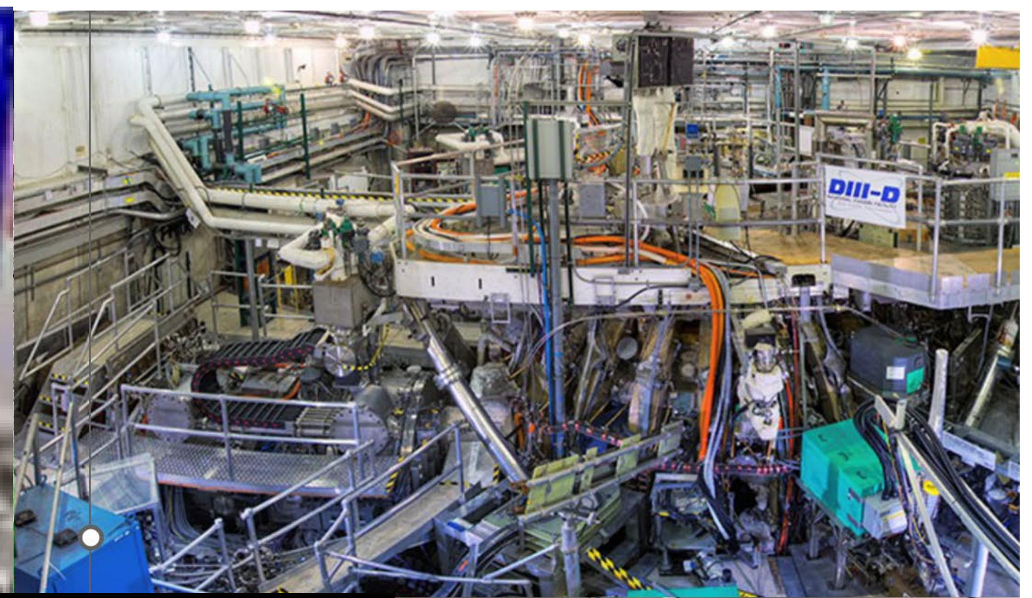
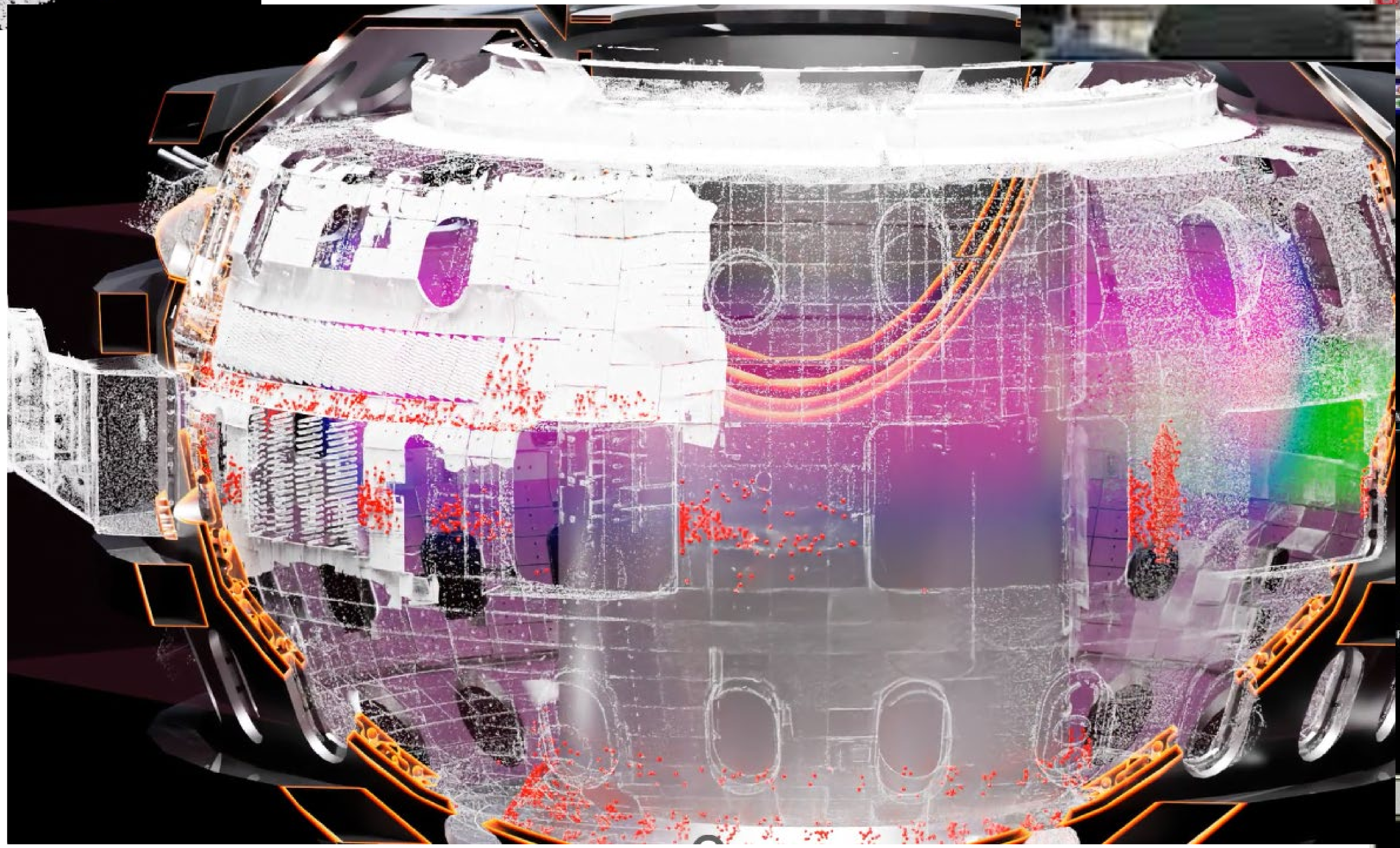
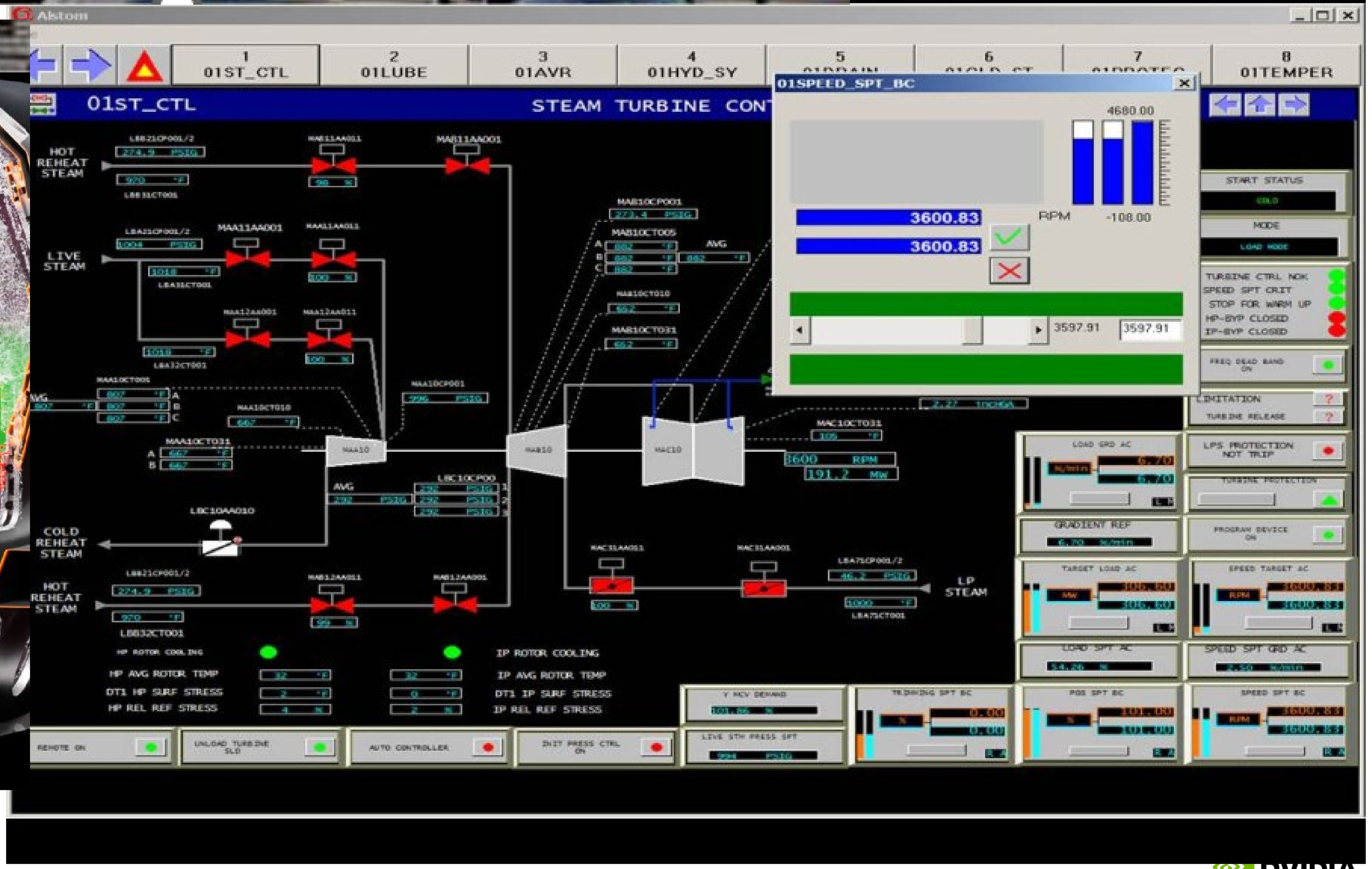




Interactive Surrogates of the Full Shot





Plan to Extend the DIII-D Interactive Digital Twin for 2026

Plan to Extend the DIII-D Interactive Digital Twin for 2026

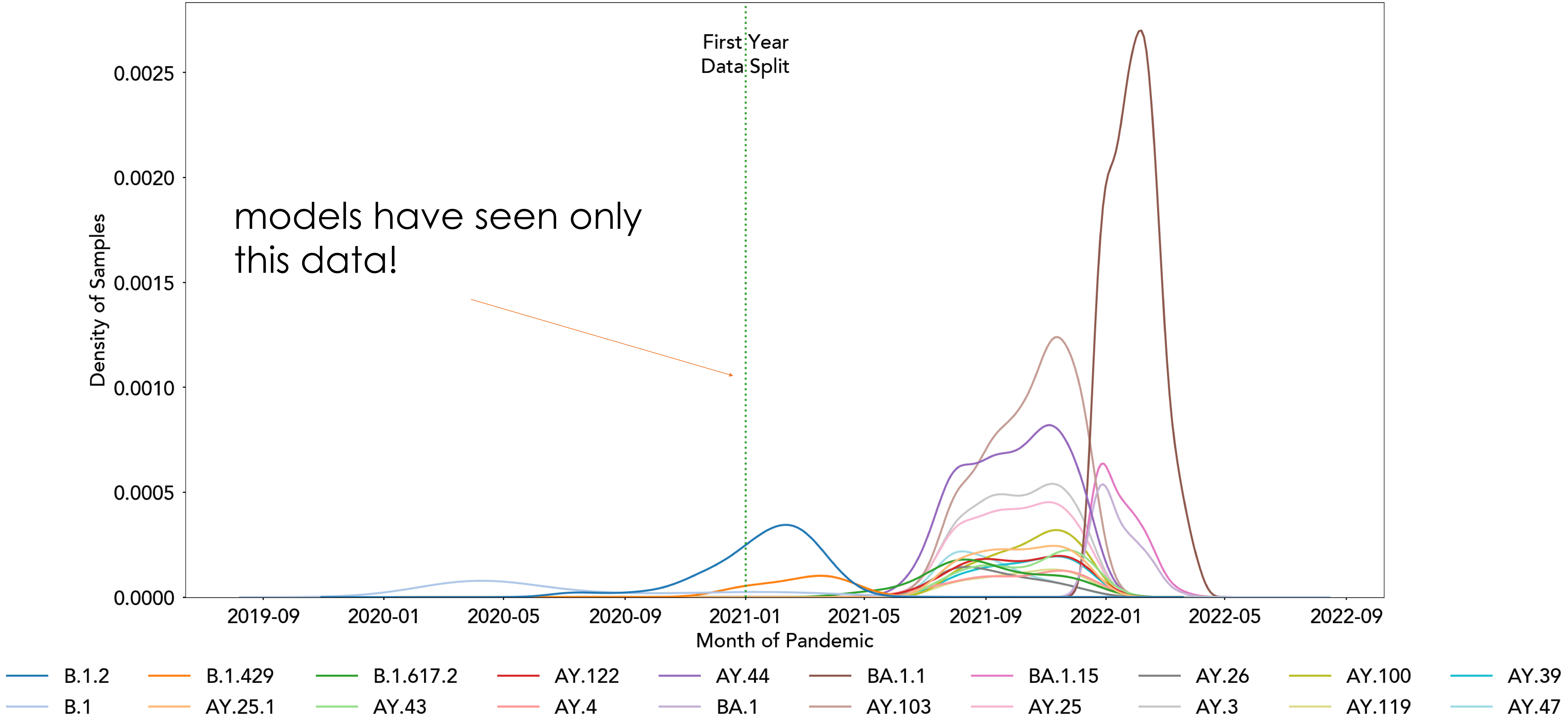
Q: What are the control settings needed to get the plasma boundary and separatrix strike point required for the experiment on the next shot.

Q: How did the last shot diagnostic output compare to desired pulse characteristics and recommend to new experimental settings?

Q: What was the plasma density, and how should setting be adjusted to achieve the density requested

BACKUP

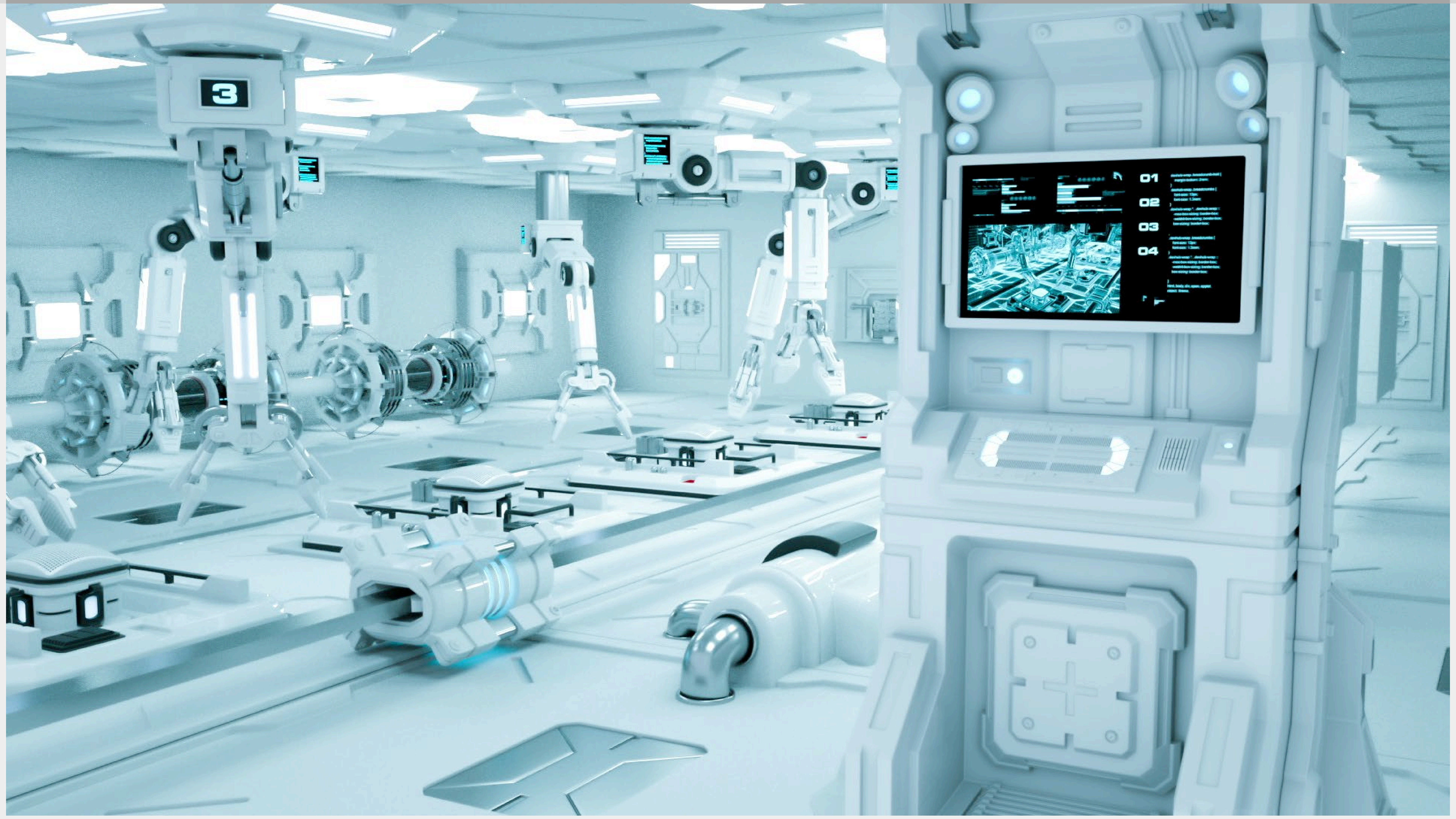
GenSLMs finetuned on SARS-CoV-2 genomes can distinguish variants



POC ANL and U Chicago
Smart "Factory" for Probing & Designing Complex Biological Systems

- Accelerate the discovery process
- Elevate human creativity to higher level goals
- Democratize biological systems design approaches
- Unbiased data collection and evaluation

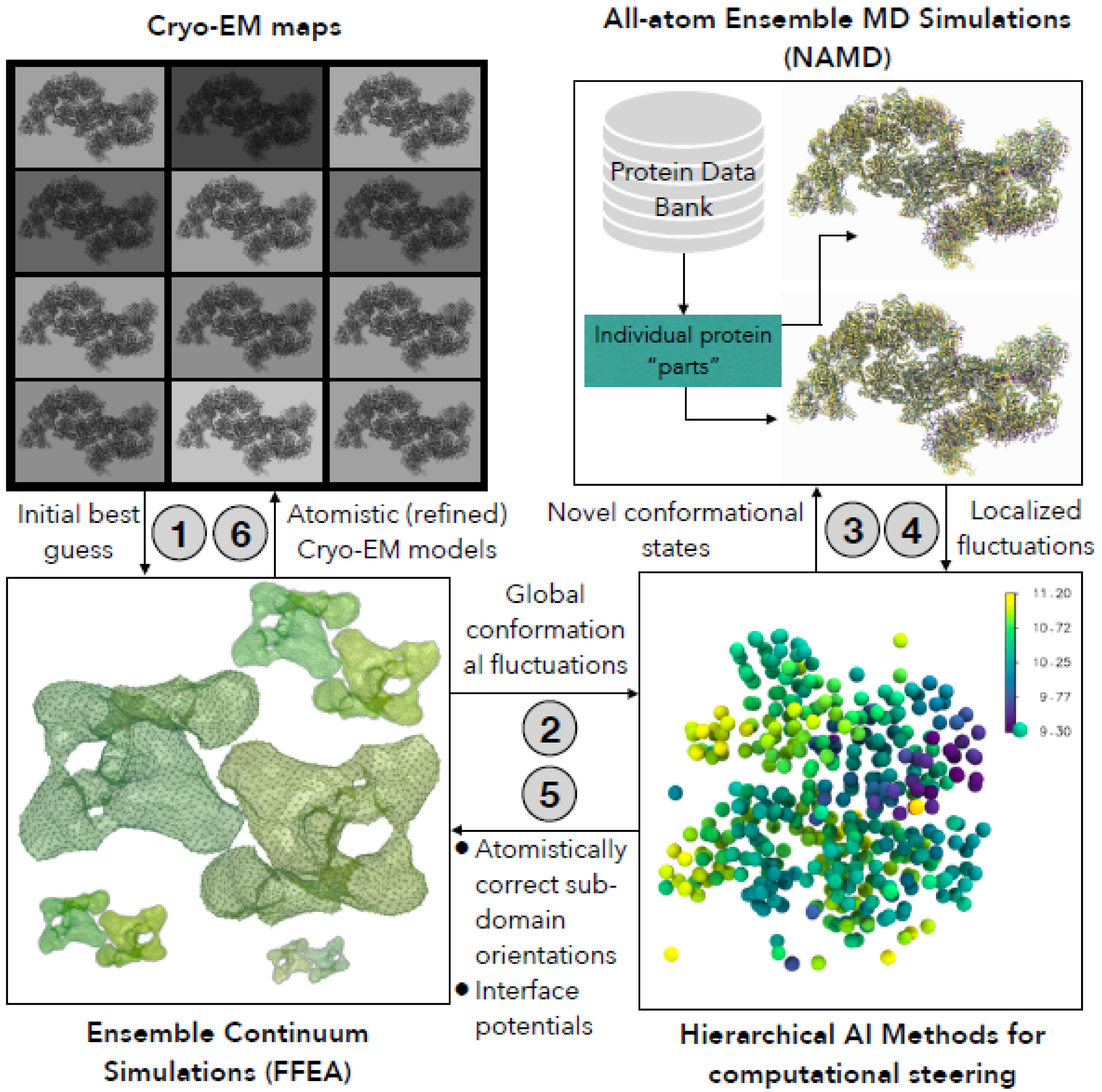
ARTIFICIAL INTELLIGENCE GUIDED, ROBOTICALLY EXECUTED EXPERIMENTS

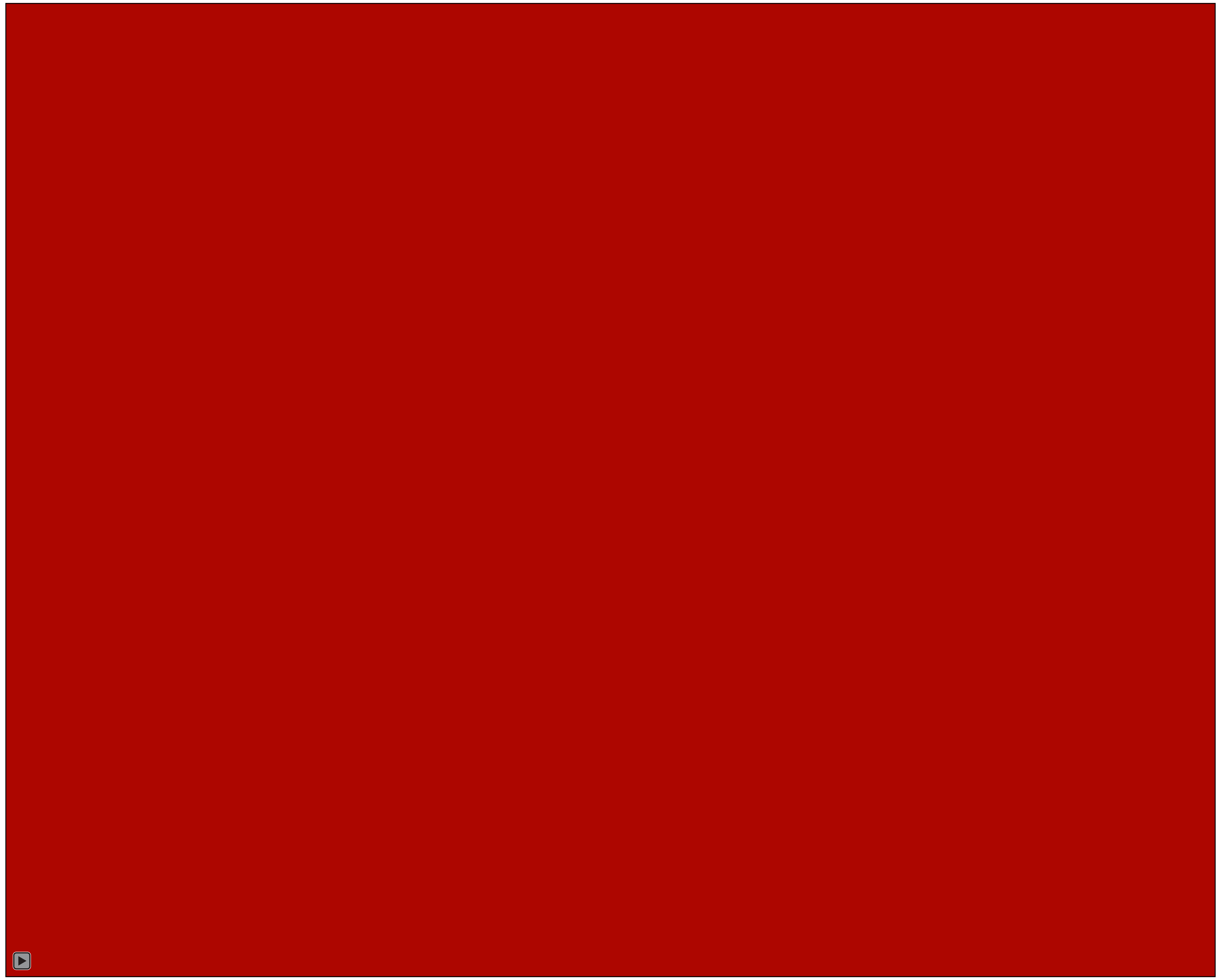


Using foundation models to predict SARS-CoV-2 evolution

- Periodically retrain on new variants sequenced across specific time window
- Performance: CS-2, Selene, Polaris

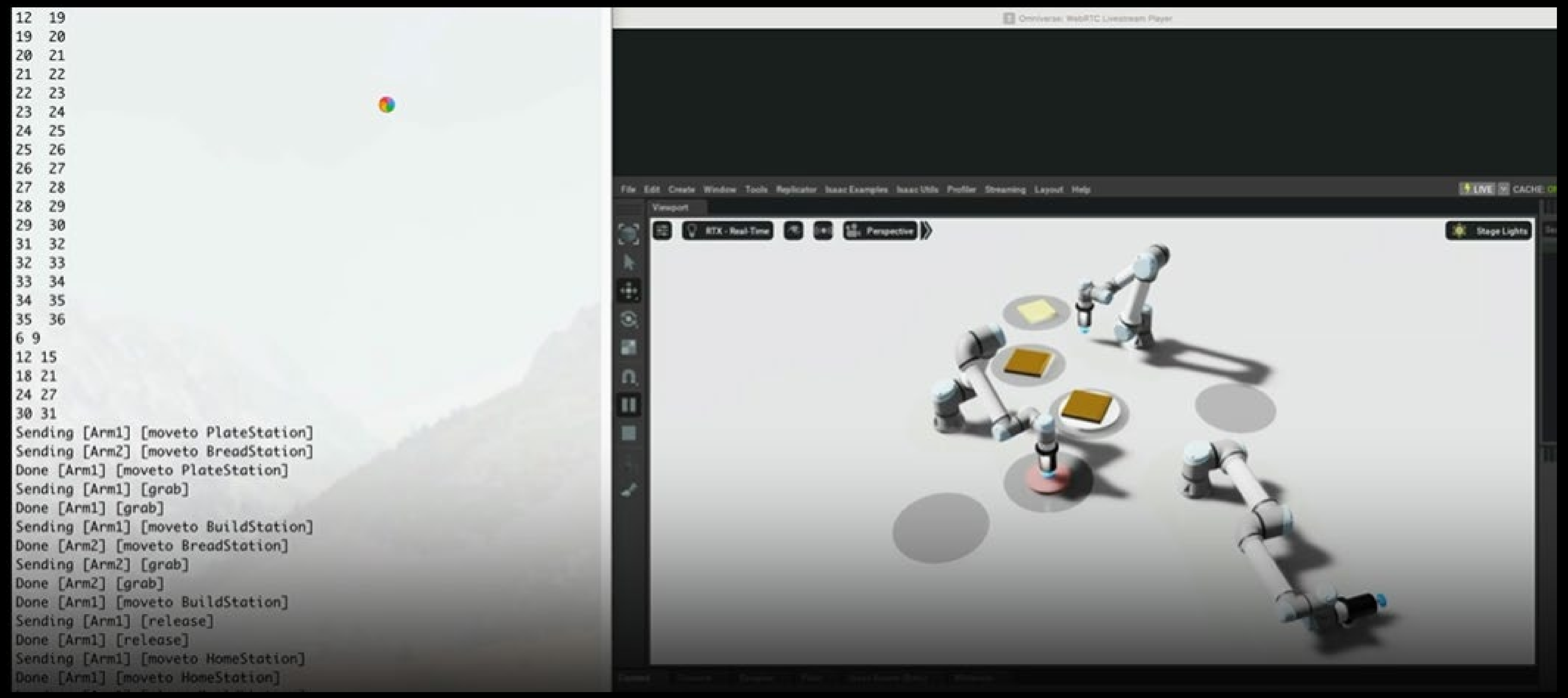
Science goal: Understand how to "trap" the SARS-CoV-2 replication-transcription complex (RTC) using Low Res CryoEM

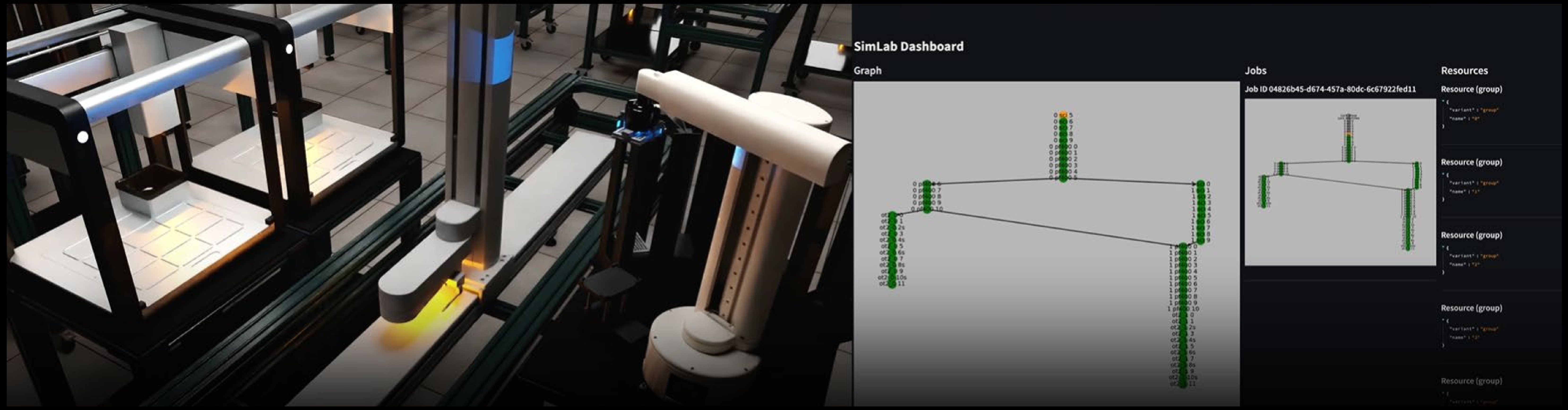


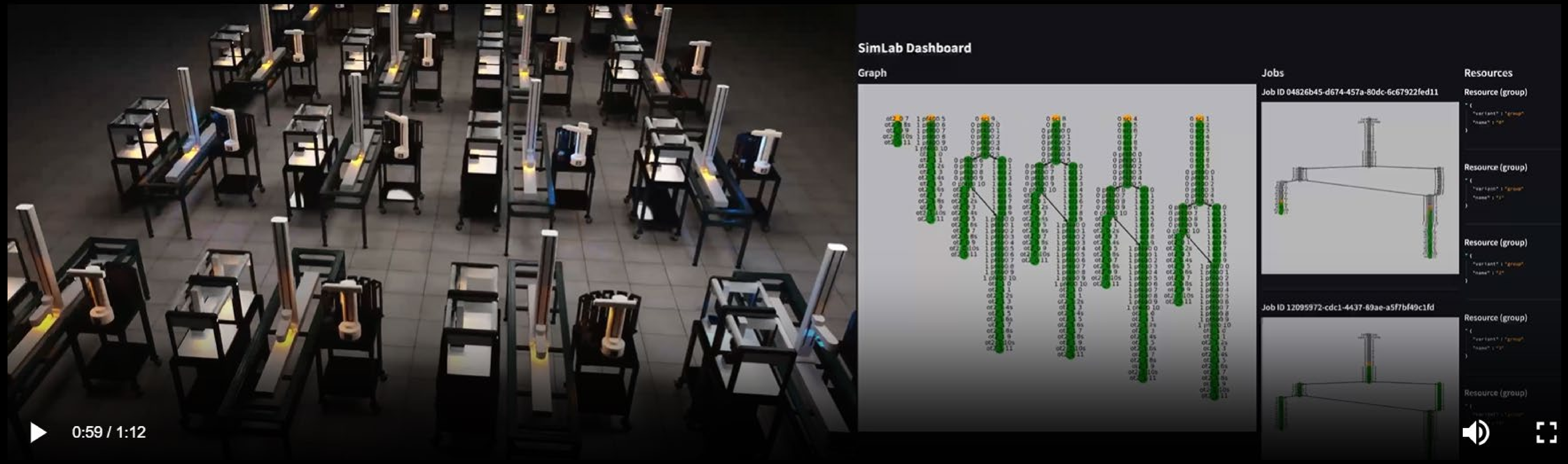


Use chatGPT and IssacSim with Omniverse to Automate Robots in the BioLab

https://people.cs.uchicago.edu/~rorymb/videos/sandwich3.mp4

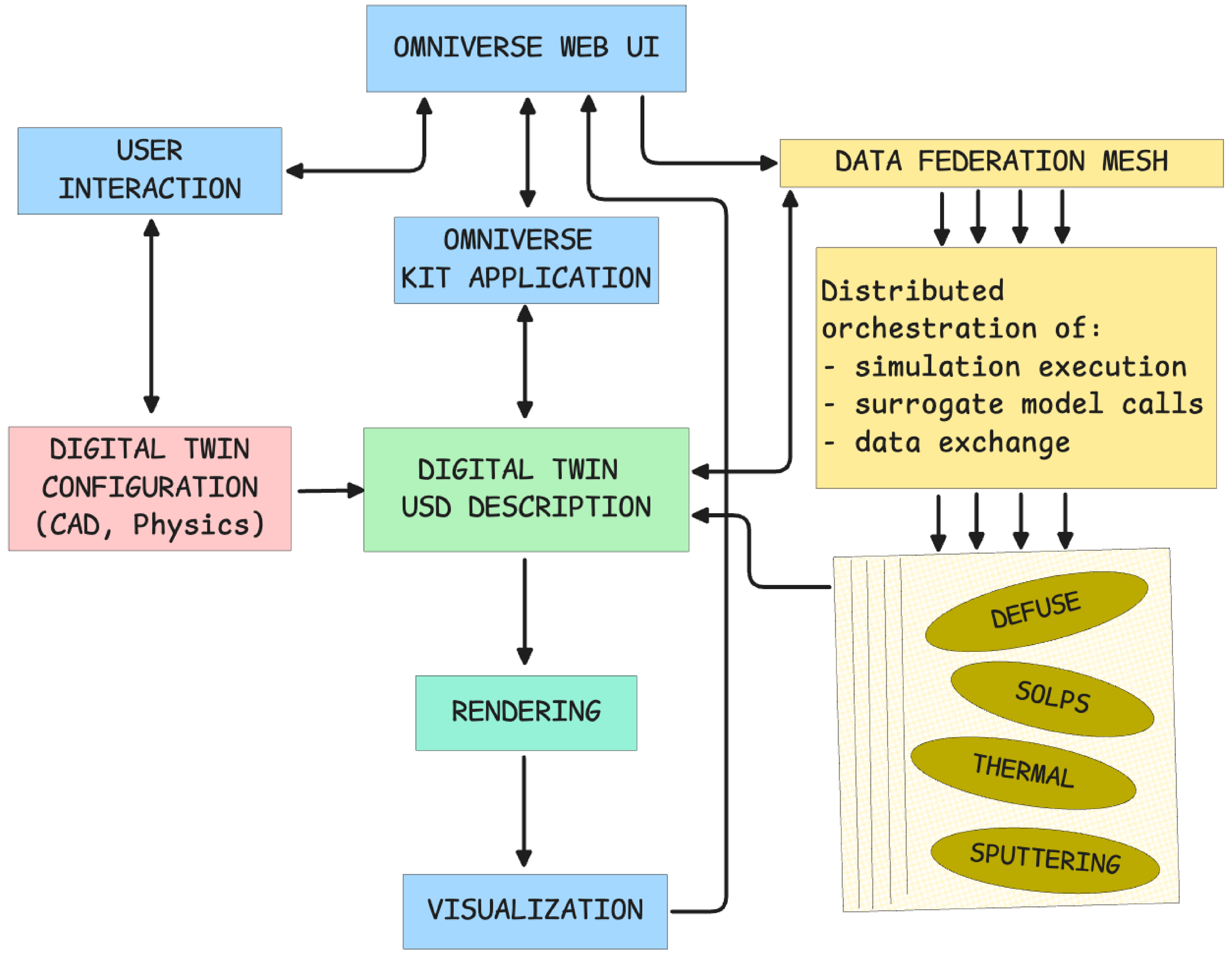


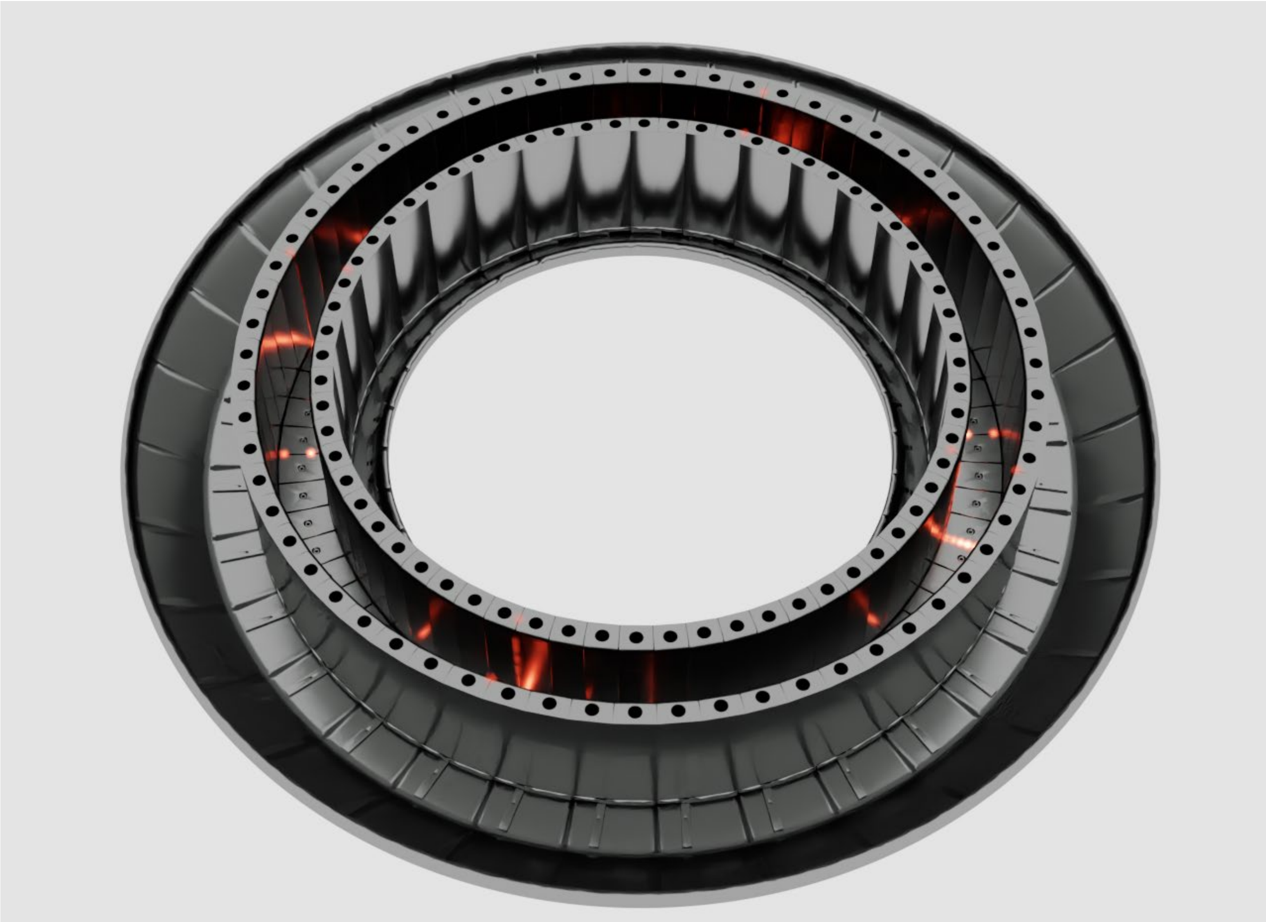


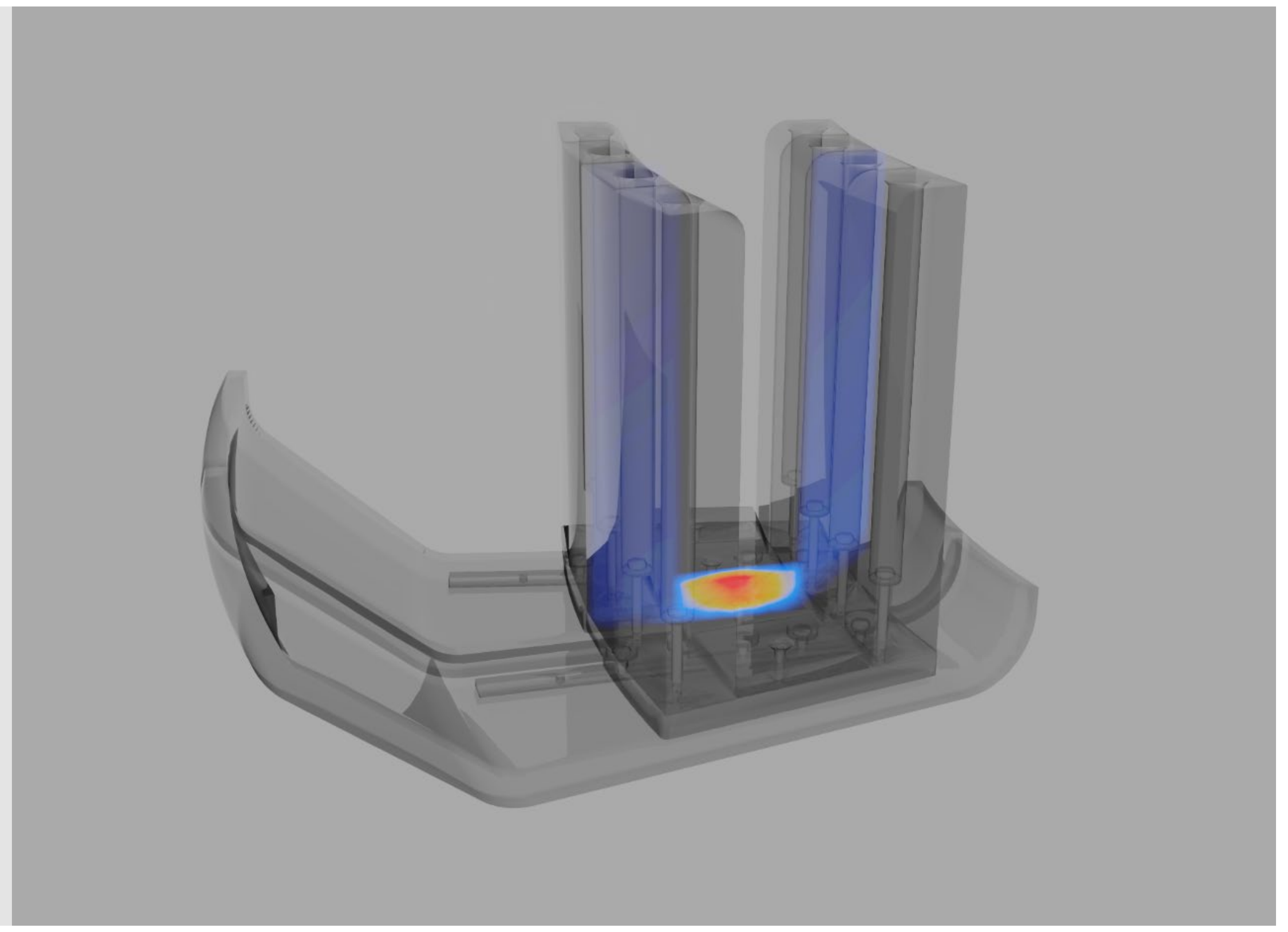


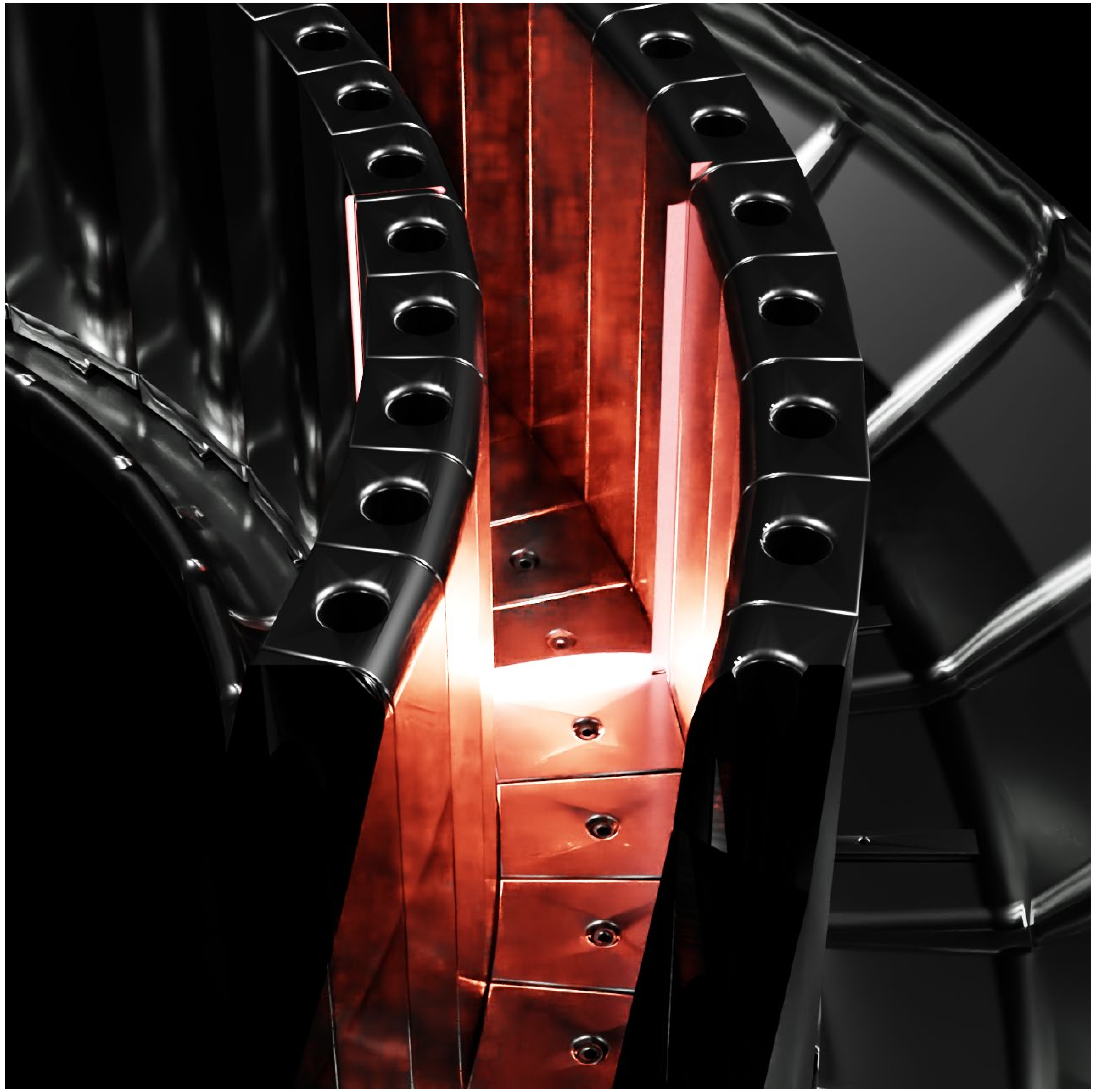
EPFL TCV Digital Twin

Ongoing EUROFusion POC Project for orchestrating and visualizing reactor simulations and surrogate models





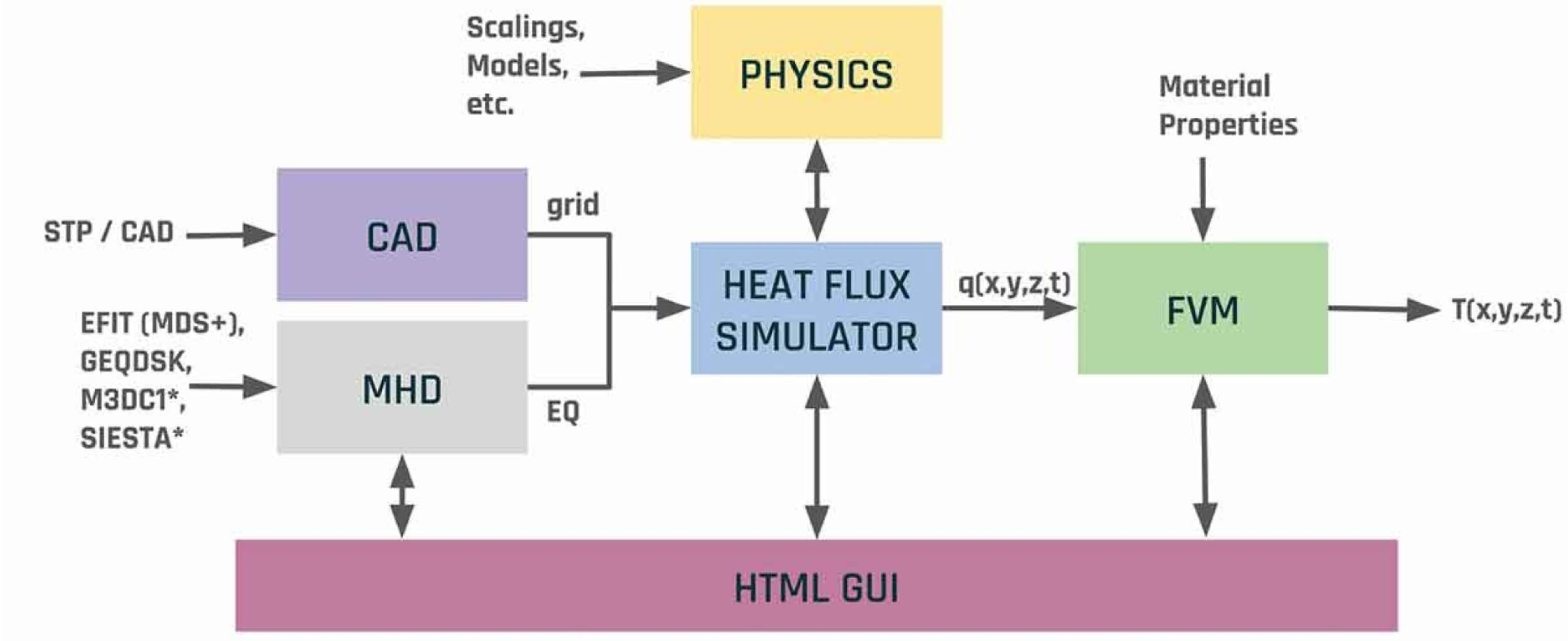


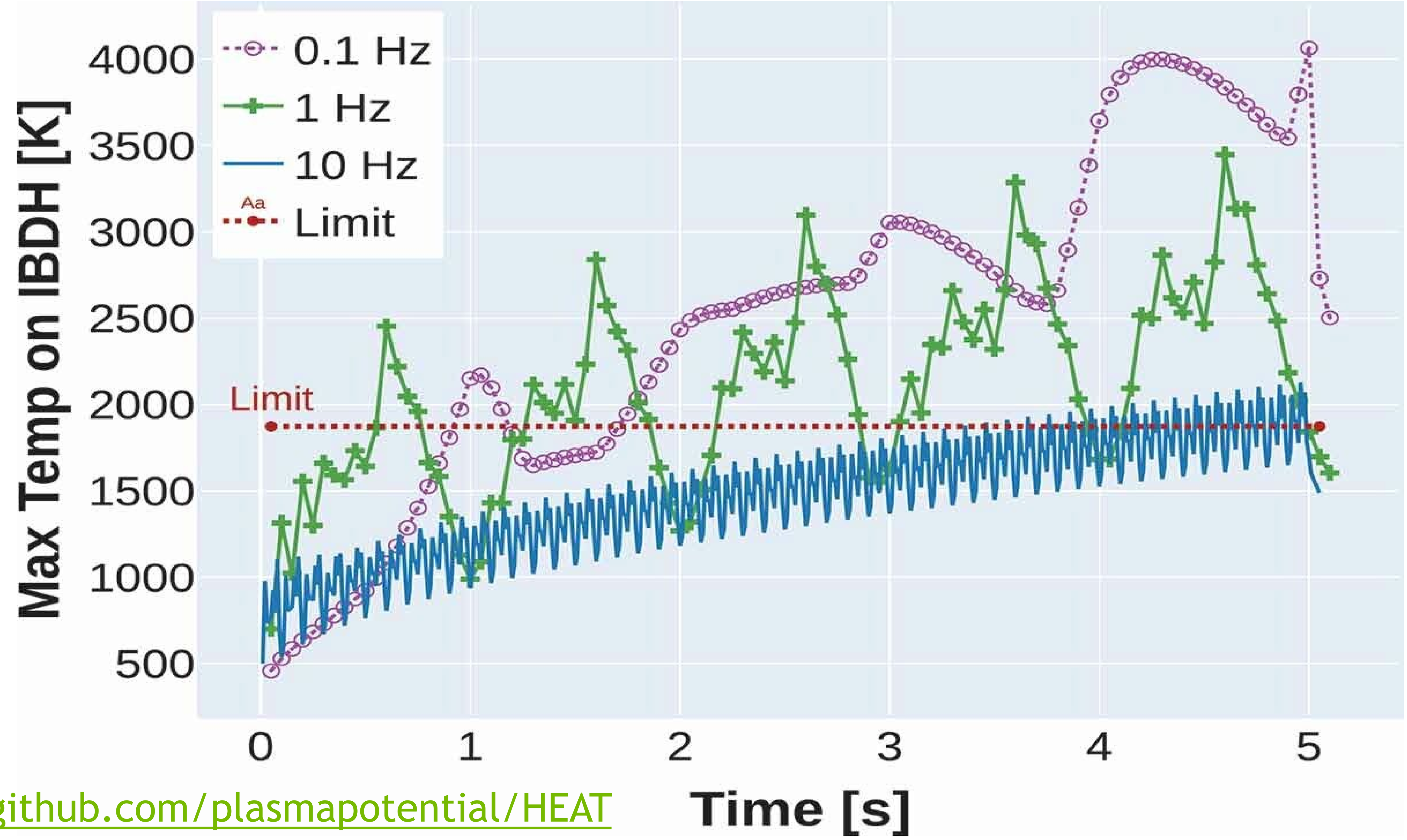


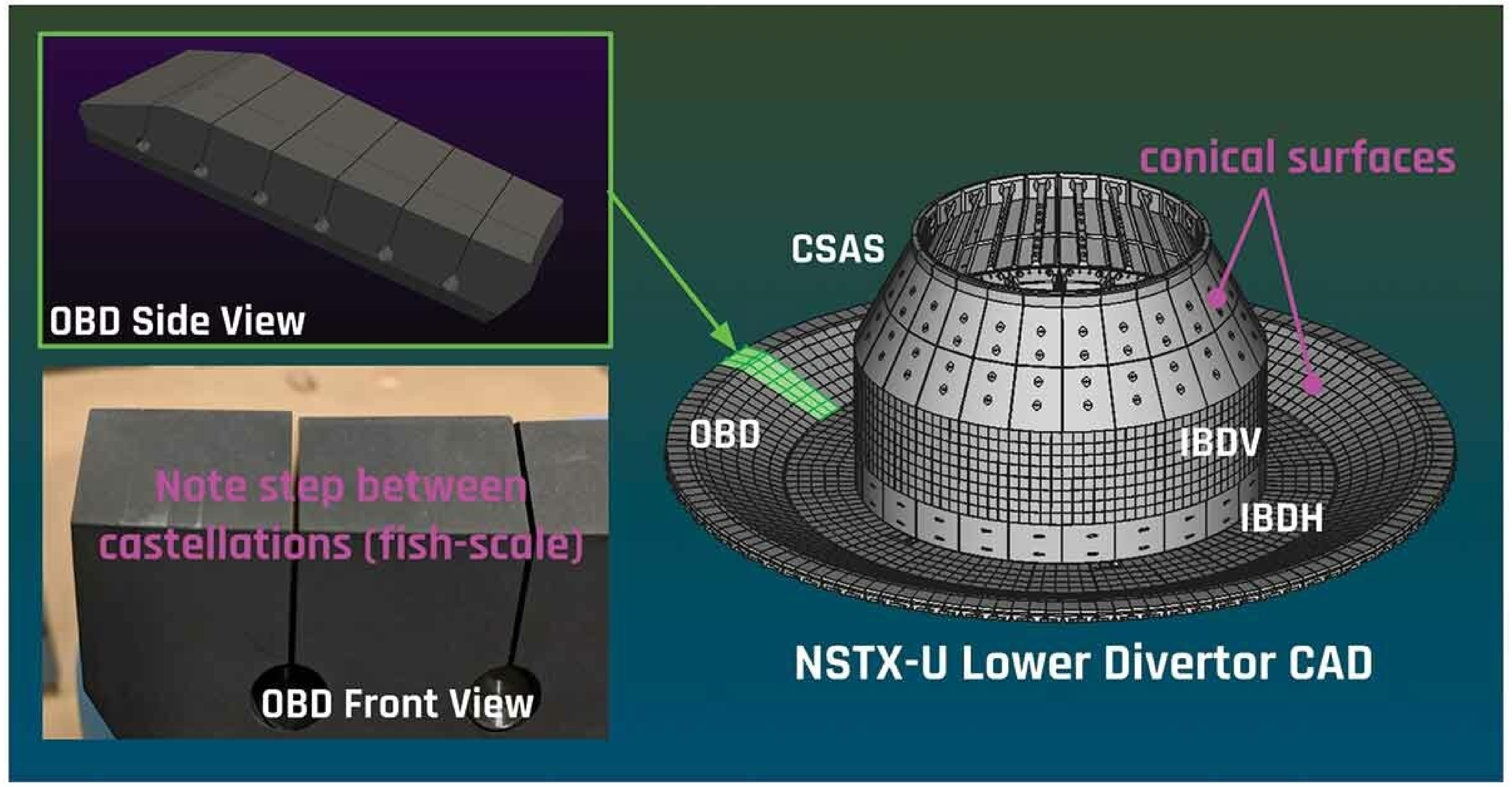
EPFL EUROfusion NVIDIA

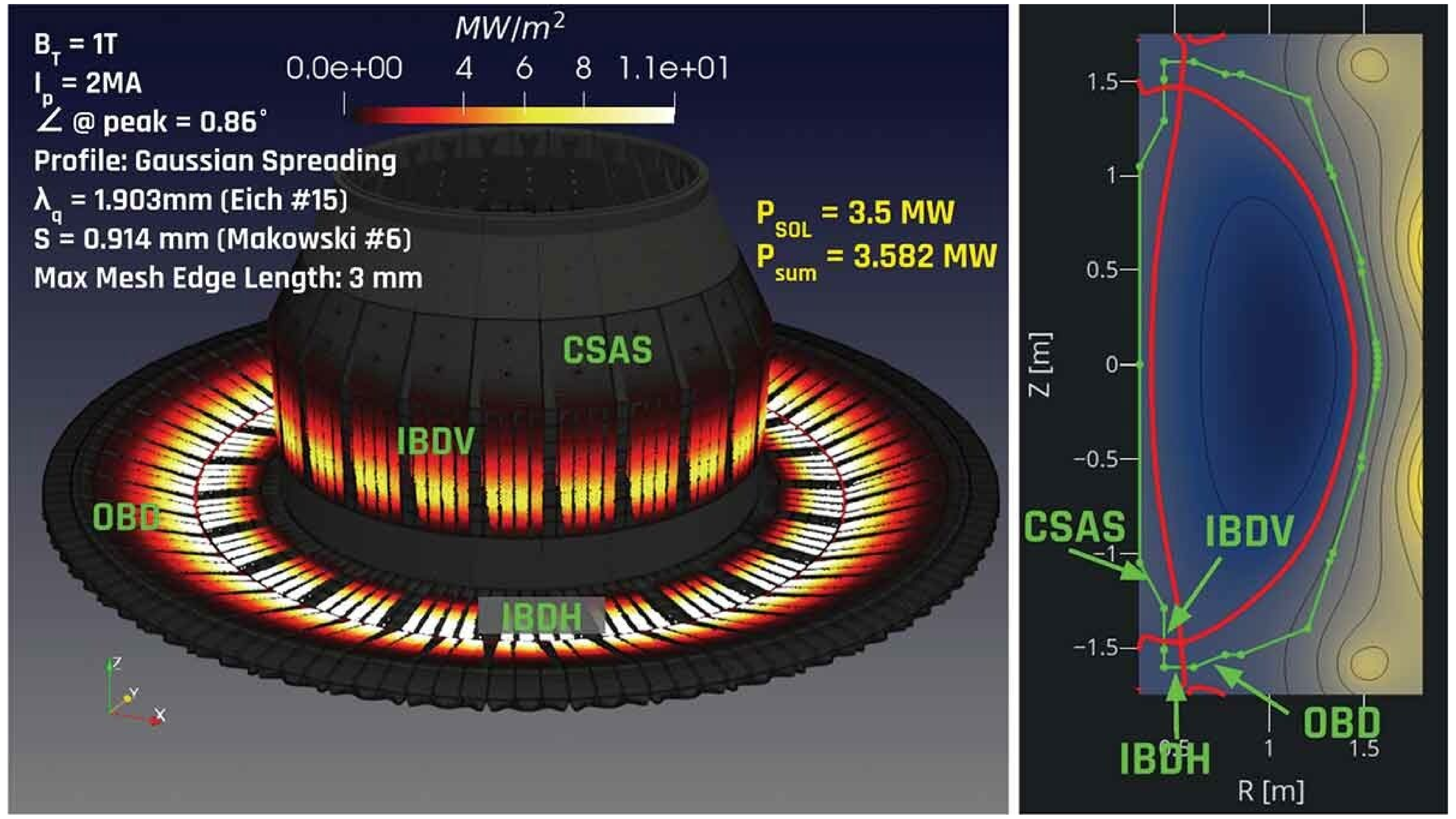
PLASMA FACING MATERIAL DESIGN

Key Model Capability for Many Startups in Design Phase





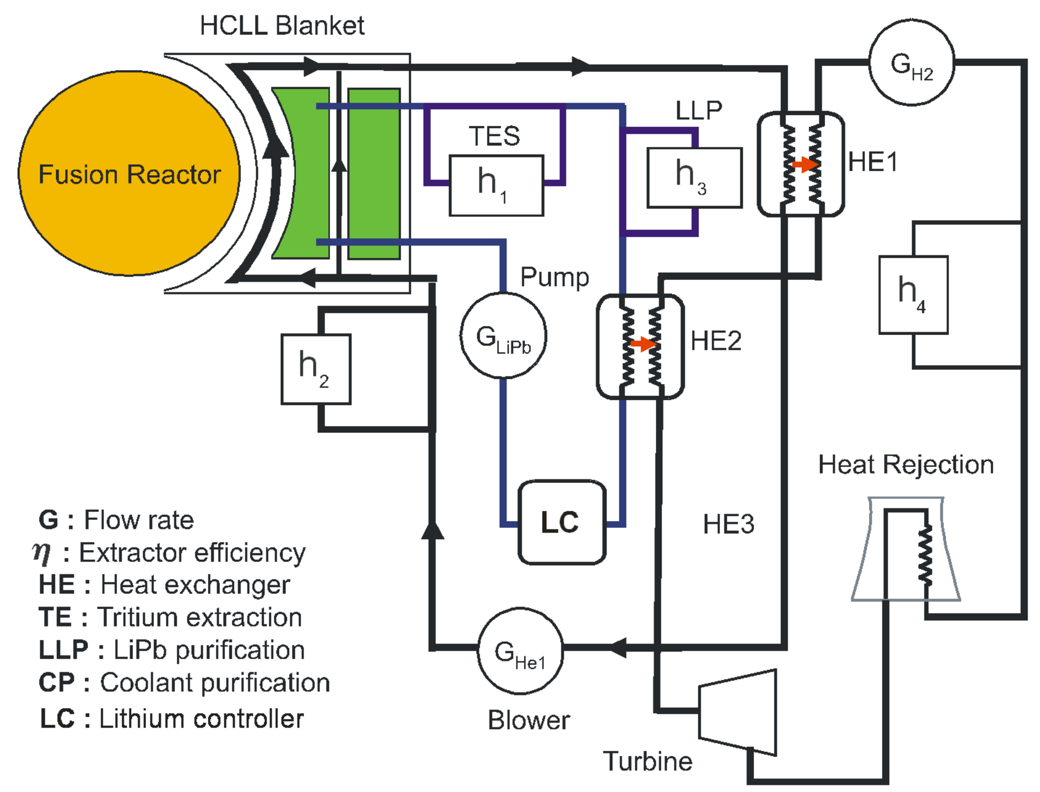


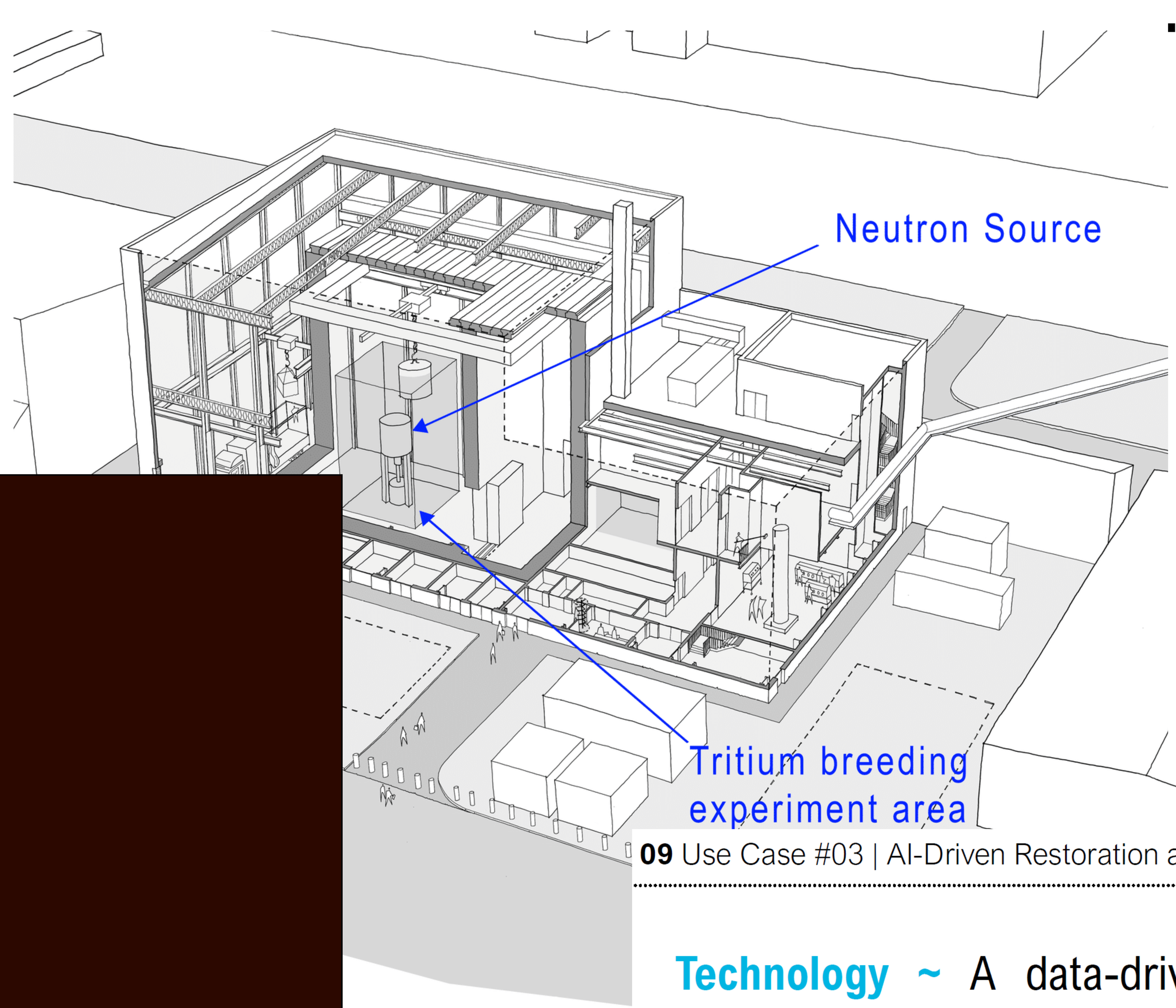


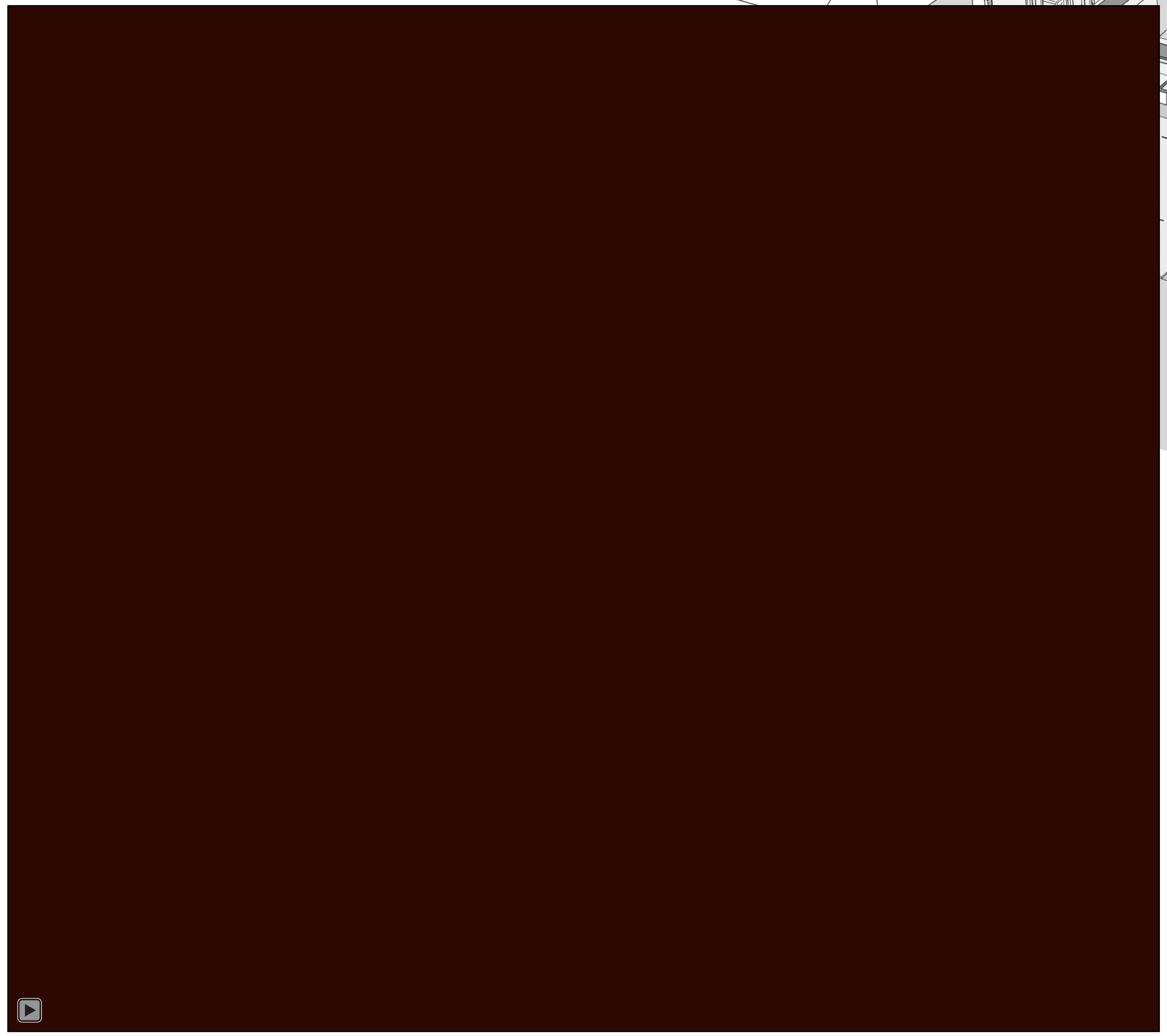
https://github.com/plasmapotential/HEAT

POC WITH UKAEA TO MODEL THE BREEDER BLANKET

A Critical Component Required to Create Tritium







09 Use Case #03 | AI-Driven Restoration and Monitoring Framework for Plasma-Facing Mirrors

IDOM

Challenge ~ Degradation of plasma-facing mirrors leads to the **corruption of interferometric measurements** that are critical to estimating the conditions of the plasma. There is a pressing need for **alternative strategies that strengthen the robustness of plasma-facing mirrors** and offer **redundancy to associated diagnostics**.

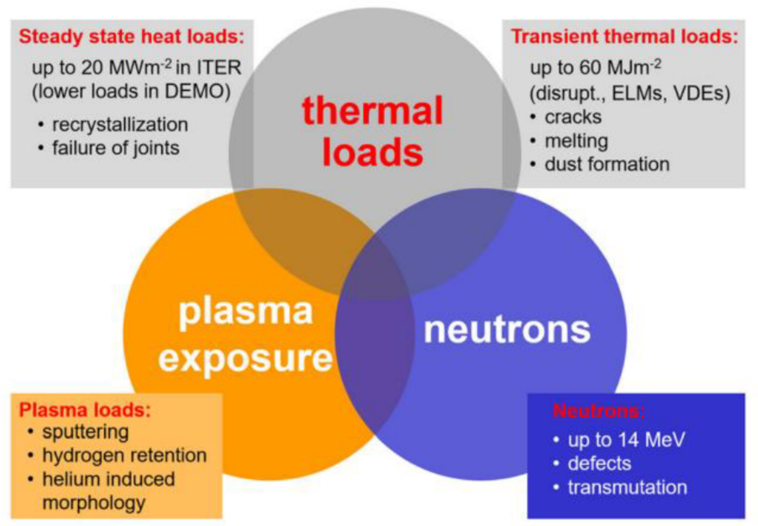


Figure 6 | Wall loads in D-T burning magnetic confinement experiments (Linke et al., 2019)

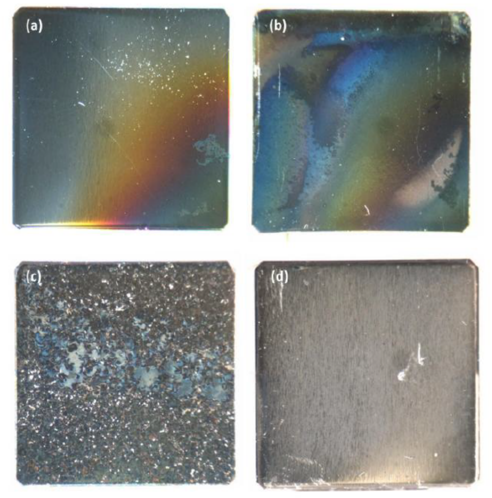


Figure 7 | Photos of mirrors from different divertor positions after ILW-3 (Moon et al., 2019)

09 Use Case #03 | AI-Driven Restoration and Monitoring Framework for Plasma-Facing Mirrors

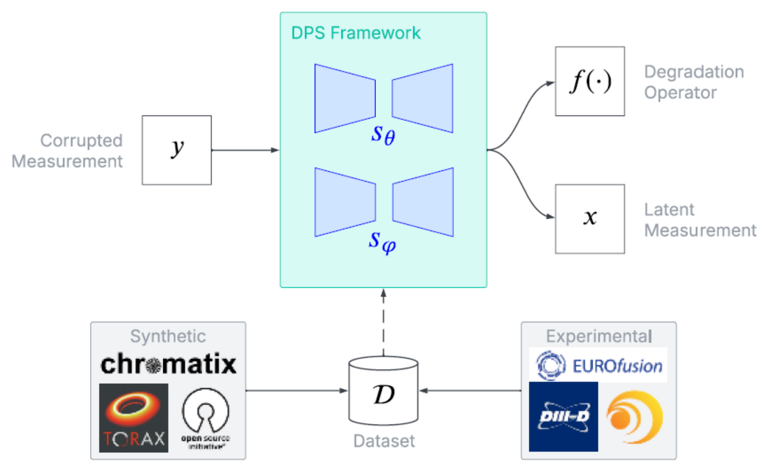
IDOM

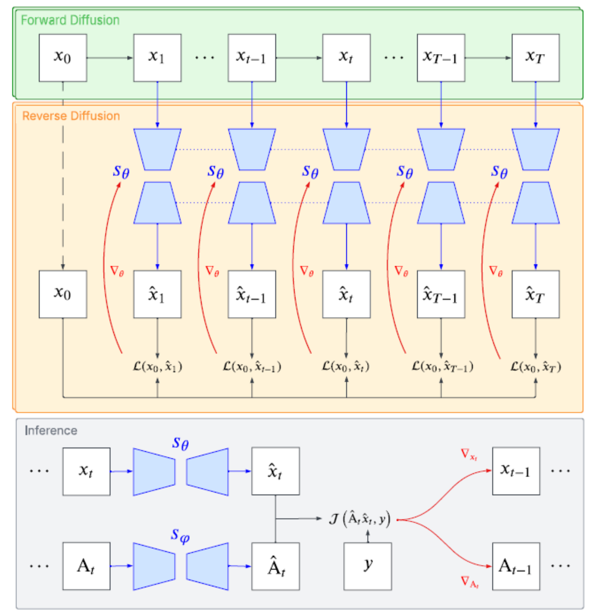
Technology ~ A data-driven framework using **diffusion models** (i.e., Diffusion Posterior Sampling) to:

(i) **Restore corrupted diagnostics.**

(ii) **Estimate the degradation** of mirror for health monitoring.

$$y = f(x) + n$$





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SUMMARY

- First Introduced by NASA as Part of the Manned Space Mission to the Moon
- The Critical Component of a Digital Twin is the Bi-Directional Interaction of the Virtual Model with the Physical Asset or System being Modeled
- Conventional Models are Sufficiently Accurate but Generally too Slow to Be Interactive
- With Sufficient Training AI Models Are Capable of Real Time with Comparable Accuracy that Can be Mapped to the Appropriate Time Scale for the Full Asset Being Modeled
- The Current Progress of the Digital Twin for Tokamaks is Underway with Multiple Experimental Facilities

FIRE COLLABORATIVES

- FIRE Collaboratives: FES wants the new collaboratives to function as virtual, centrally managed teams bridging FES's basic science research programs and the needs of the fusion industry, including the eight companies in the Milestone Program. A FIRE Data Repository would make their findings available to other researchers and end users.
- The FIRE program was announced in May 2023 with four cross-cutting areas of focus: fusion materials, fusion blanket and fuel cycle systems, fusion enabling technologies, and advanced simulations for design and optimization. The six chosen collaboratives are listed below:
- Advanced Profile Prediction for Fusion Pilot Plant Design (APP-FPP). Lead organization, Massachusetts Institute of Technology. Members include Oak Ridge and Lawrence Livermore National Laboratories.
- Fuel Cycle Fusion Innovation Research Engine (FC-FIRE). Lead organization, Savannah River National Laboratory. Members include Idaho, Los Alamos, Oak Ridge, and Sandia National Laboratories.
- Accelerating Fusion Blanket Development through Nuclear Testing (BNT). Lead organization, INL. Members include Oak Ridge, Pacific Northwest, Princeton Plasma Physics, and Savannah River National Laboratories.
- Target Injector Nexus for Development Research (TINDeR). Lead organization, General Atomics. Members include SLAC National Accelerator Laboratory and LLNL.
- Rapid High-Fidelity Bulk Irradiated Materials Data Generation to Accelerate Solutions for Commercial Fusion Energy Systems. Lead organization, MIT.
- Integrated Materials Program to Accelerate Chamber Technologies (IMPACT). Lead organization, University of Tennessee. Members include ORNL and INL.
- The total anticipated funding for FIRE collaboratives is $180 million for projects lasting up to four years. Additional awards may be made in the future, contingent on the availability of congressional appropriations

FUSION START UPS

TOP FUSION ENERGY STARTUPS

Companies With >/= $100K Funding

Commonwealth Fusion Systems
Tokamak
HQ Cambridge, Massachusetts USA
TOTAL FUNDING $2,048,874,368

Neo Fusion
Tokamak
HQ Hefei, Anhui China
TOTAL FUNDING $2,029,370,000

TAE Technologies
Tokamak
HQ Foothill Ranch, California USA
TOTAL FUNDING $1,452,213,060

Helion Energy
Magneto Pinch
HQ Everett, Washington USA
TOTAL FUNDING $1,026,205,451

Pacific Fusion
Magneto Pinch
HQ Fremont, California USA
TOTAL FUNDING $900,000,000

ENN Energy Research Institute
Tokamak
HQ Langfang, Hebei China
TOTAL FUNDING $400,000,000

Energy Singularity
Tokamak
HQ Pudong, Shanghai China
TOTAL FUNDING $361,100,000

General Fusion
Magneto Pinch
HQ Richmond, British Columbia Canada
TOTAL FUNDING $338,887,239

Zap Energy
Z Pinch
HQ Seattle, Washington USA
TOTAL FUNDING $331,765,047

Tokamak Energy
HQ Oxford, Oxfordshire UK
TOTAL FUNDING $308,879,922

Proxima Fusion
Tokamak
HQ Munich, Bavaria Germany
TOTAL FUNDING $204,839,130

Marvel Fusion
Inertial Confinement
HQ Munich, Bavaria Germany
TOTAL FUNDING $164,100,000

Focused Energy
Inertial Confinement
HQ San Francisco, California USA
TOTAL FUNDING $121,699,000

Xcimer Energy
Inertial Confinement
HQ Denver, Colorado USA
TOTAL FUNDING $104,875,000

Type One Energy
Tokamak
HQ Oak Ridge, Tennessee USA
TOTAL FUNDING $90,722,145

https://www.fusionenergybase.com/organizations

Proposed codes to operate/accelerate on STELLAR-AI - 5 year plan

Scope	Code / Responsibility	Code Description	PPPL Lead / PoC
HPC-AI hardware procurement	STELLAR-AI		Stephane Ethier
Code acceleration / algorithm R&D with Nvidia, Microsoft, additional software developers and contributors	M3D-C1	Linear / nonlinear extended MHD - high-order FEM, unstructured mesh - tokamak & stellarator	Nate Ferraro
	NIMROD	Linear / nonlinear extended MHD - FEM in 2D + finite Fourier in toroidal dimension	Fatima Ebrahimi
	XGC	Non-linear Gyrokinetic PIC turbulence including X-point - tokamak and stellarator	Robert Hager
	Gkyell	Multi-scale / multi-physics continuum code - turbulence and transport	Ammar Hakim
	DEGAS2	Monte-Carlo neutral particle transport	George Wilkie
	PETRA-M	Fully 3D full-wave electromagnetic FEM for RF heating and current drive	Syunichi Shiraiwa
	GX	Nonlinear gyrokinetic turbulence - Fourier-Hermite-Laguerre spectral methods	Javier Escoto
	T3D	Transport solver for modeling macro-scale profile evolution	Jai Sachdev
	HYM / NOVA	HYM = Hybrid and MHD Simulation Code - fluid electrons, kinetic ions - for FRCs	Elena Belova
	NOVA	Stability properties of plasmas with energetic particles in tokamaks	Nikolai Gorelenkov
	NUBEAM	Comprehensive computational model for Neutral Beam Injection (NBI) in tokamaks	Alexei Pankin
	TRANSP	Integrated interpretive and predictive analysis of tokamak plasmas	Marina Gorlenkova
	SOLPS-ITER	Scrape-Off Layer Plasma Simulation - plasma fluid solver + Monte-Carlo kinetic neutral transport	Eric Emdee
	LM CFD	Computational fluid dynamics (CFD) for liquid metal flow in 3D geometries including MHD effects	Andrei Khodak
	HEAT	Heat flux Engineering Analysis Toolkit (HEAT) for heat flux incident upon PFCs	Michael Churchill
	OpenMC	Community-developed Monte Carlo neutron and photon transport simulation code	Michael Churchill
	StellFoundry	High-fidelity digital models and prototypes for the design of stellarator fusion power plants	Michael Churchill