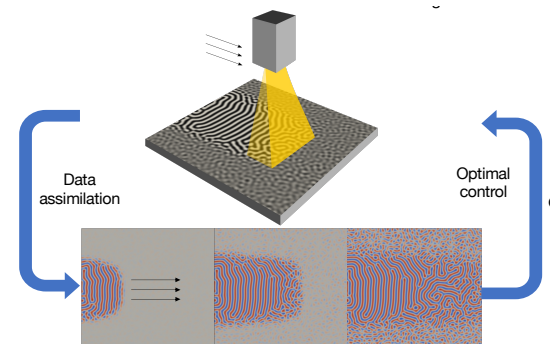
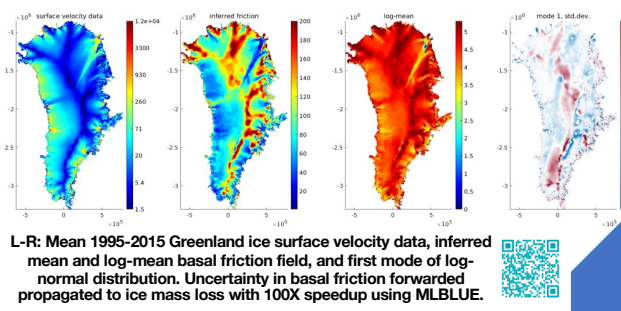


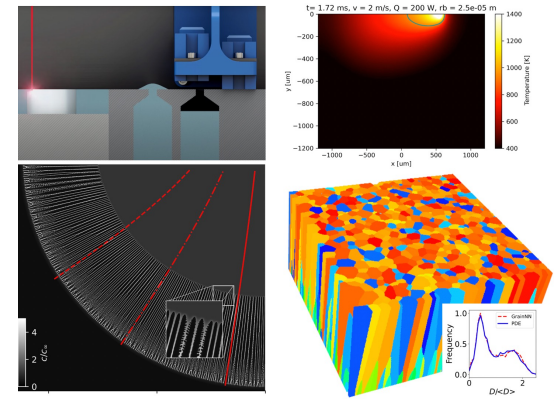
# M2dt: Multifaceted Mathematics for Predictive Digital Twins

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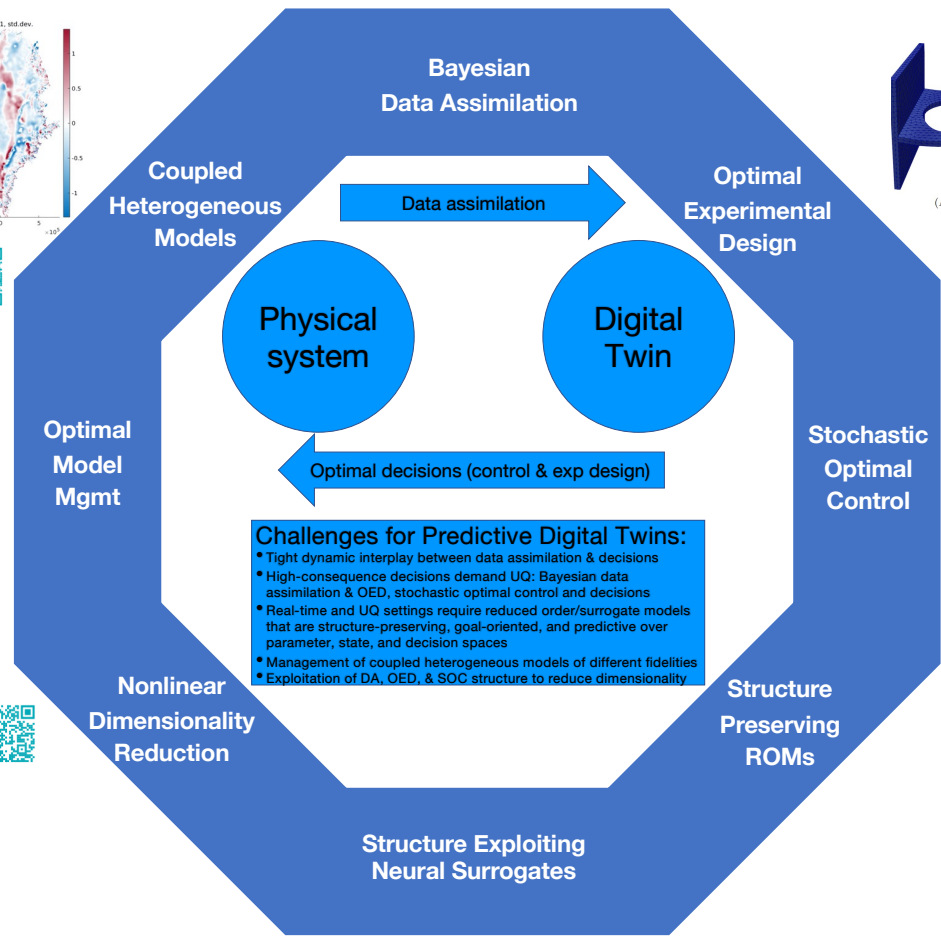
$$\int \mathcal{M}^2 dt$$



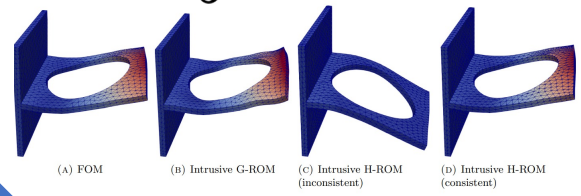
Predictive digital twin (bottom) of block copolymers for directed self-assembly of unconventional non-equilibrium 3D nano-structures (top).



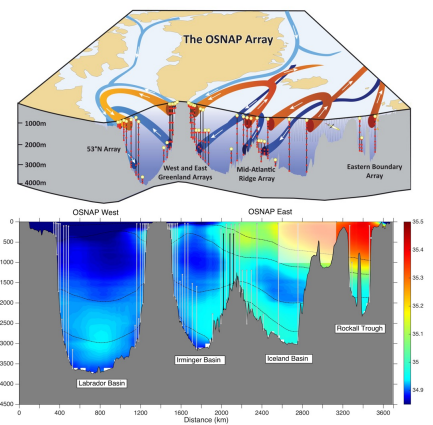
Digital twins for additive manufacturing. TL: Power bed laser fusion for metal alloys. BL: High resolution phase field simulation of solidification. TR: Nonlinear heat transfer for solidification. BR: Graph neural network microstructure w/comparison to ground truth PDEs.



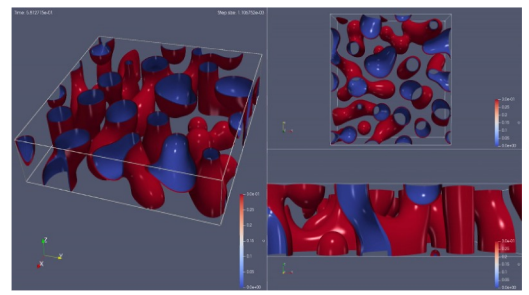
- Challenges for Predictive Digital Twins:**
- Tight dynamic interplay between data assimilation & decisions
  - High-consequence decisions demand UQ: Bayesian data assimilation & OED, stochastic optimal control and decisions
  - Real-time and UQ settings require reduced order/surrogate models that are structure-preserving, goal-oriented, and predictive over parameter, state, and decision spaces
  - Management of coupled heterogeneous models of different fidelities
  - Exploitation of DA, OED, & SOC structure to reduce dimensionality



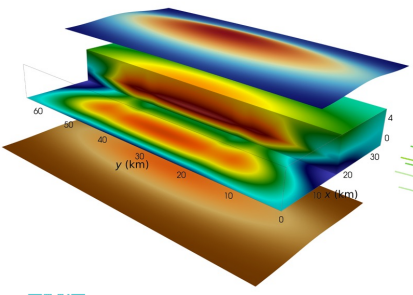
Variationally-consistent Hamiltonian reduced order model (D) provides significantly improved approximation of dynamics of an elastic bracket (A) compared to traditional Galerkin ROM (B) and inconsistent Hamiltonian ROM (C).



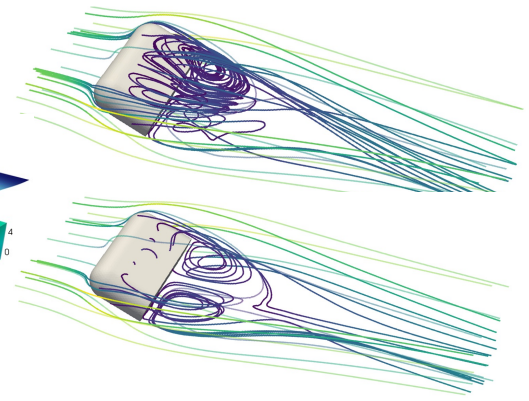
Experimental design of ocean observing system based on sensitivity of QoI to mooring locations.



Bayesian calibration of block copolymer models for digital twins of guided self-assembly of nanostructures.



Digital twin for real-time tsunami forecasting (top) from observations of pressure field (middle) induced by seafloor motion (bottom).



No (top) and optimal (bottom) flow control under uncertainty with derivative informed neural operators (DINOs). DINOs provide 100X speedups.