

Variability Characterization and Stochastic Multiscale Modeling of Composite Materials

Joel Johnston, Luke Borkowski, Aditi Chattopadhyay

School for Engineering of Matter, Transport and Energy

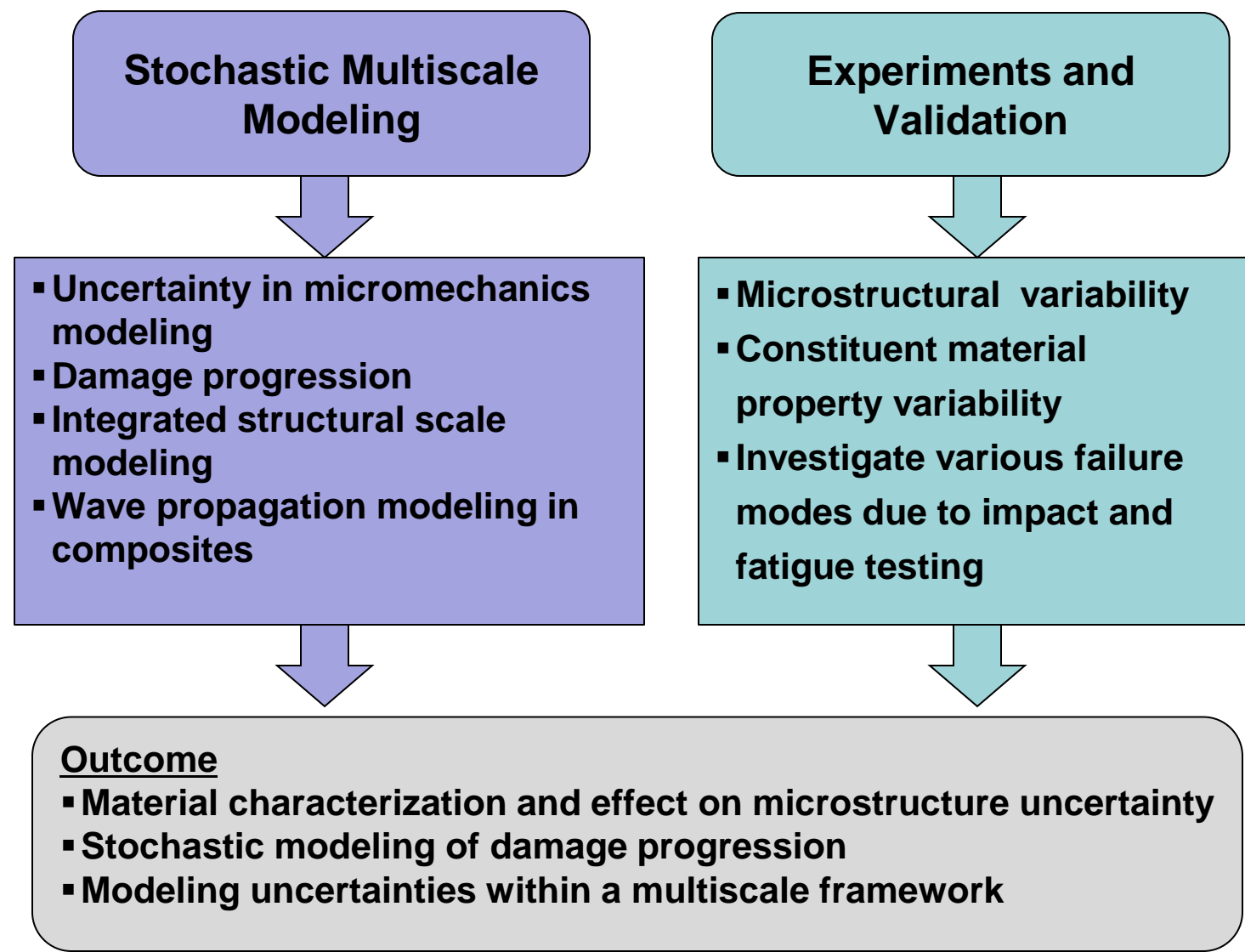
Research supported by Army Research Office



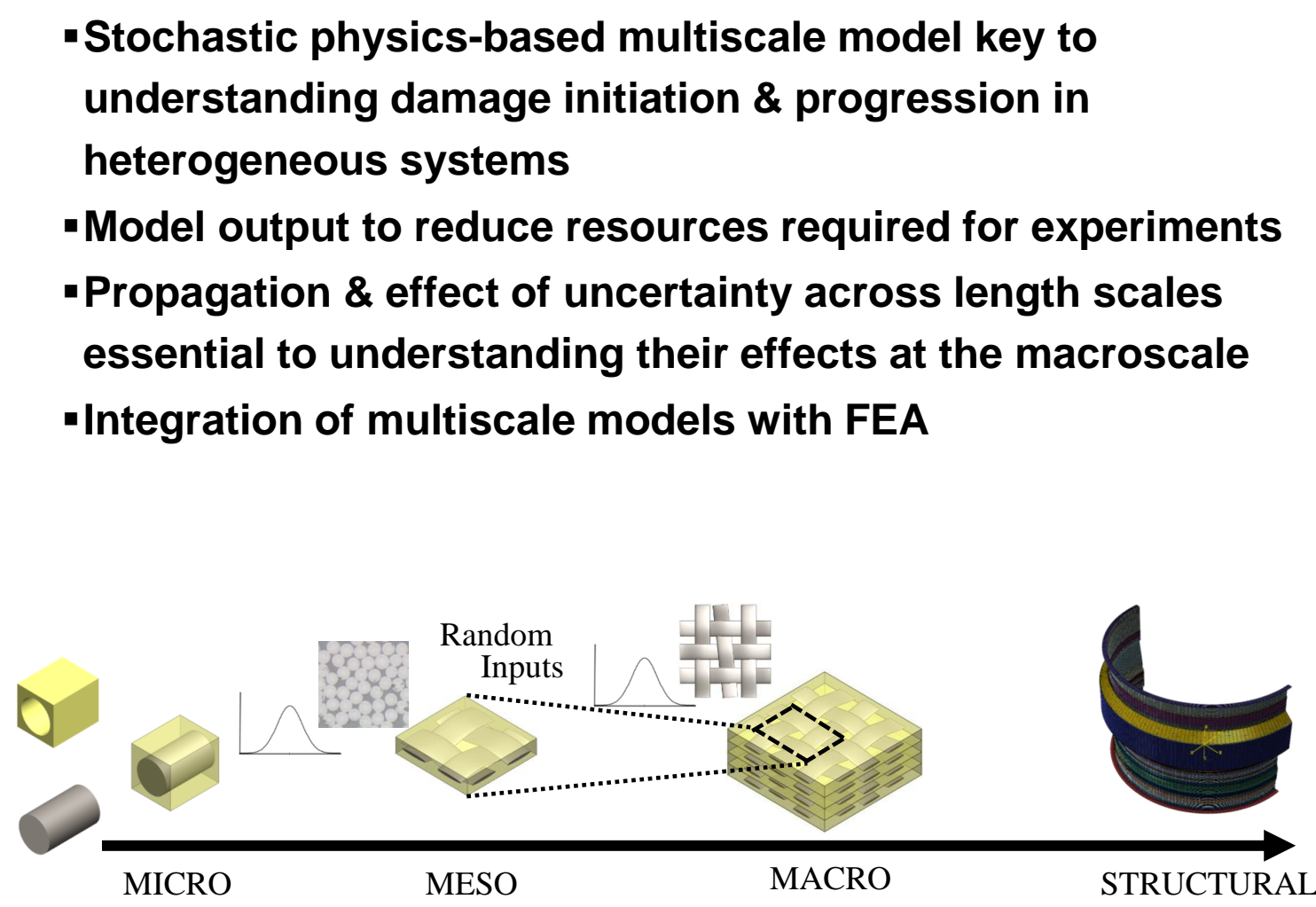
Objectives:

- Develop multiscale modeling framework for microstructural uncertainty quantification
- Quantify effect of microscale variability on damage and global behavior

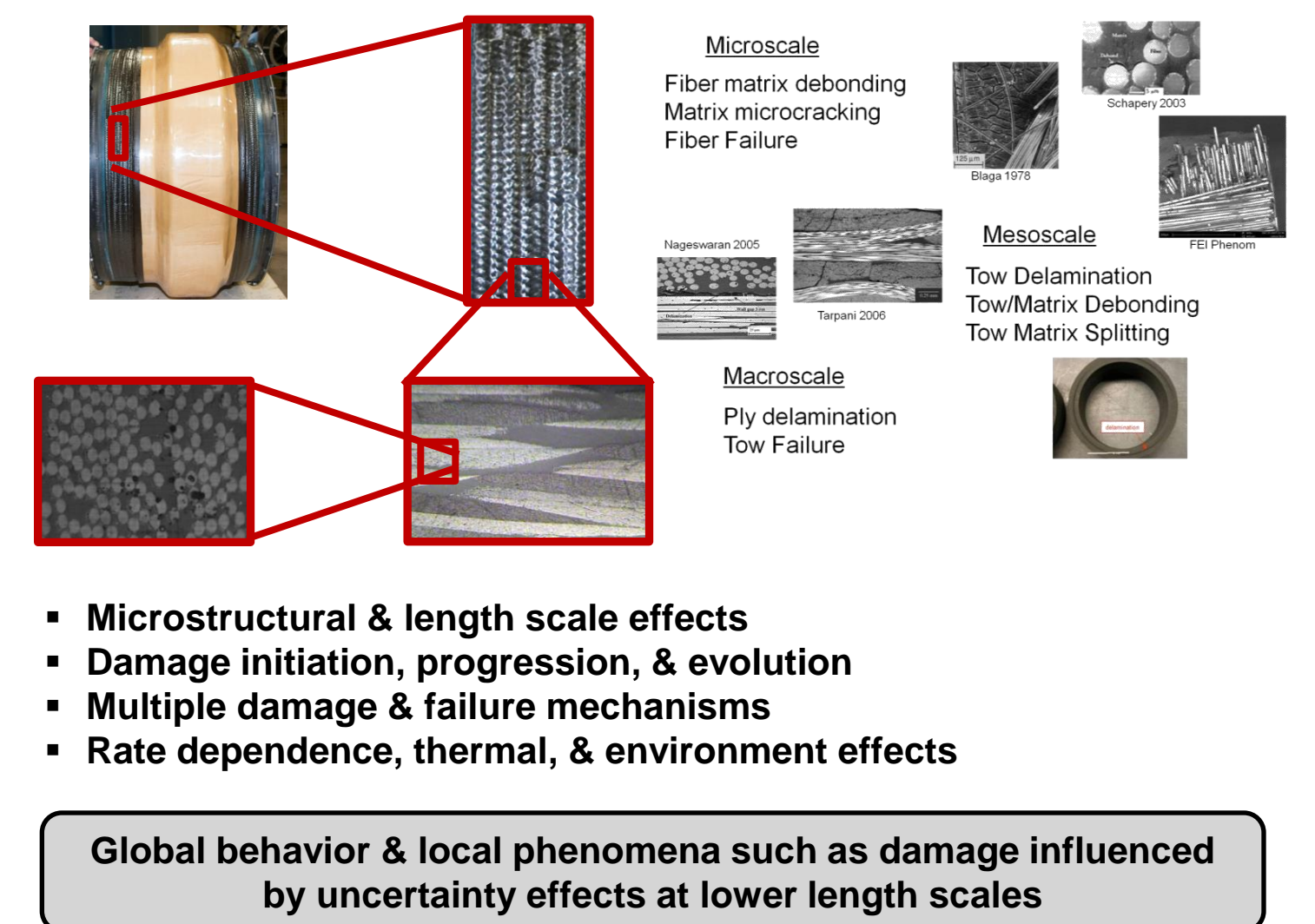
Project Objectives



Multiscale Modeling

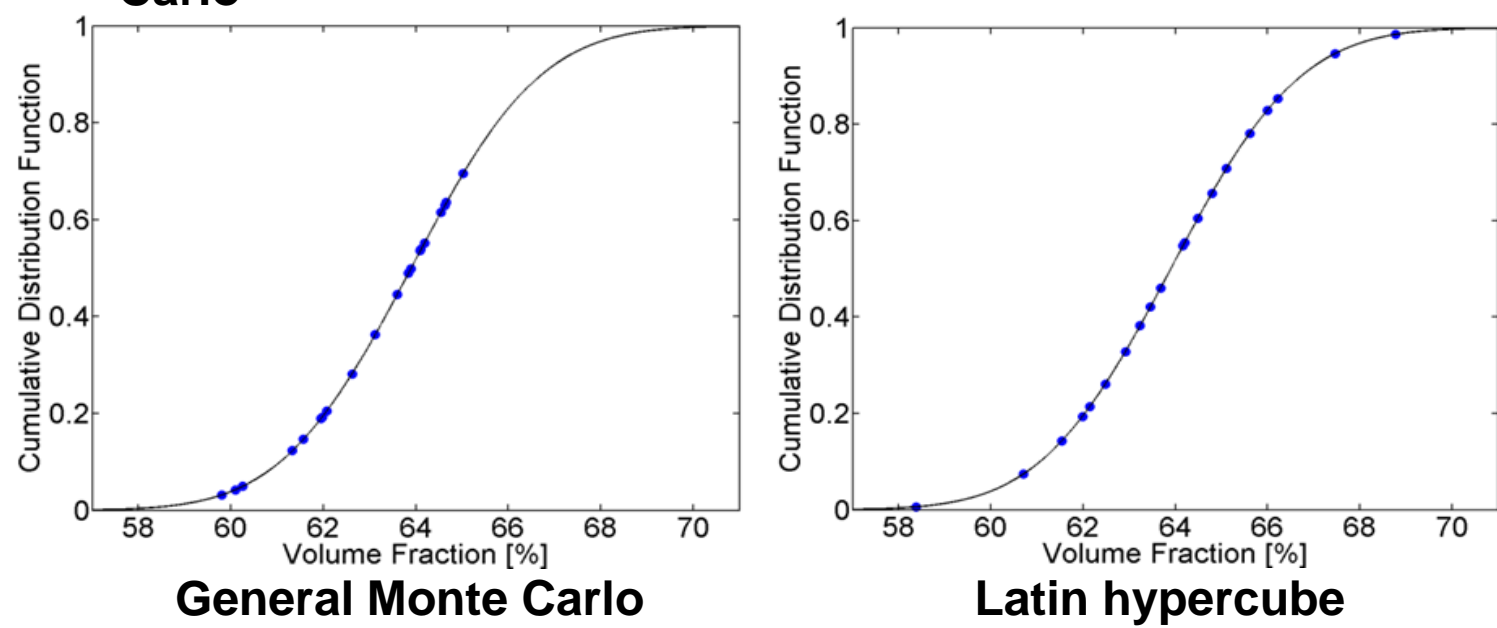


Effects of Microstructure on Uncertainty

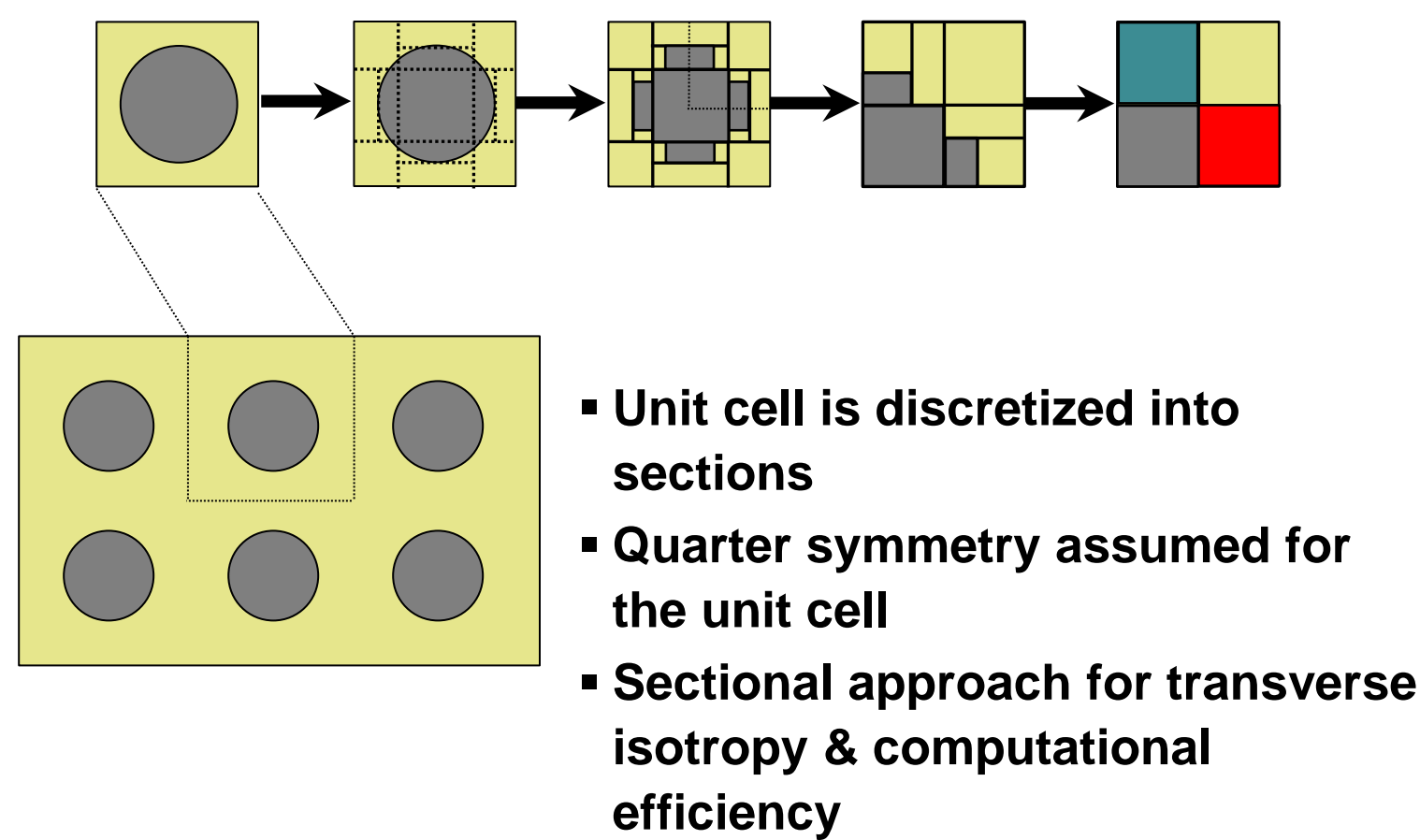


Stochastic Methodologies

- Using Latin Hypercube sampling in Monte Carlo simulations
 - Discretize the statistical distributions into intervals
 - Randomly choose points within those discretized intervals
- Compare Latin hypercube method with general Monte Carlo

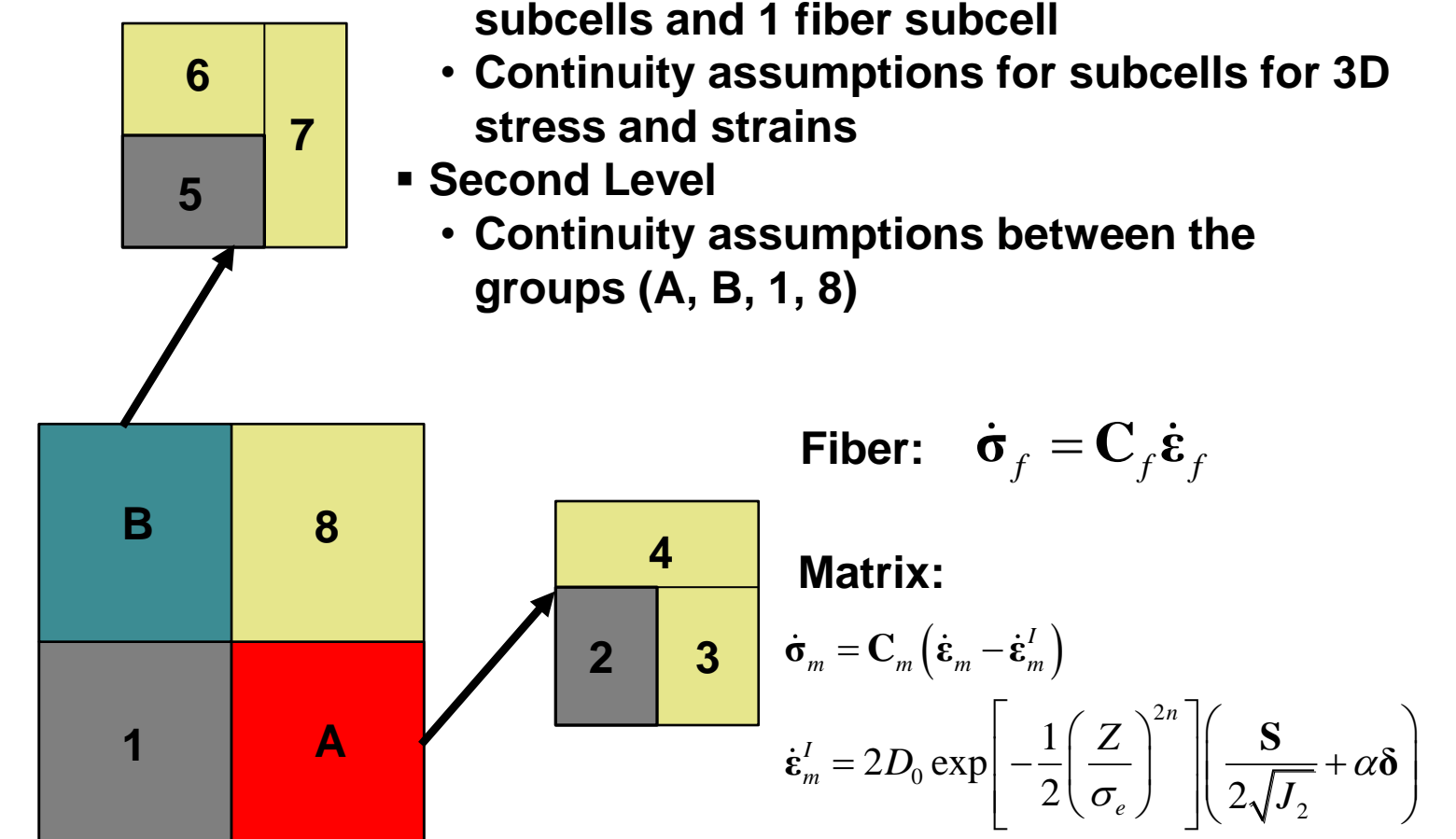


3D Sectional Model



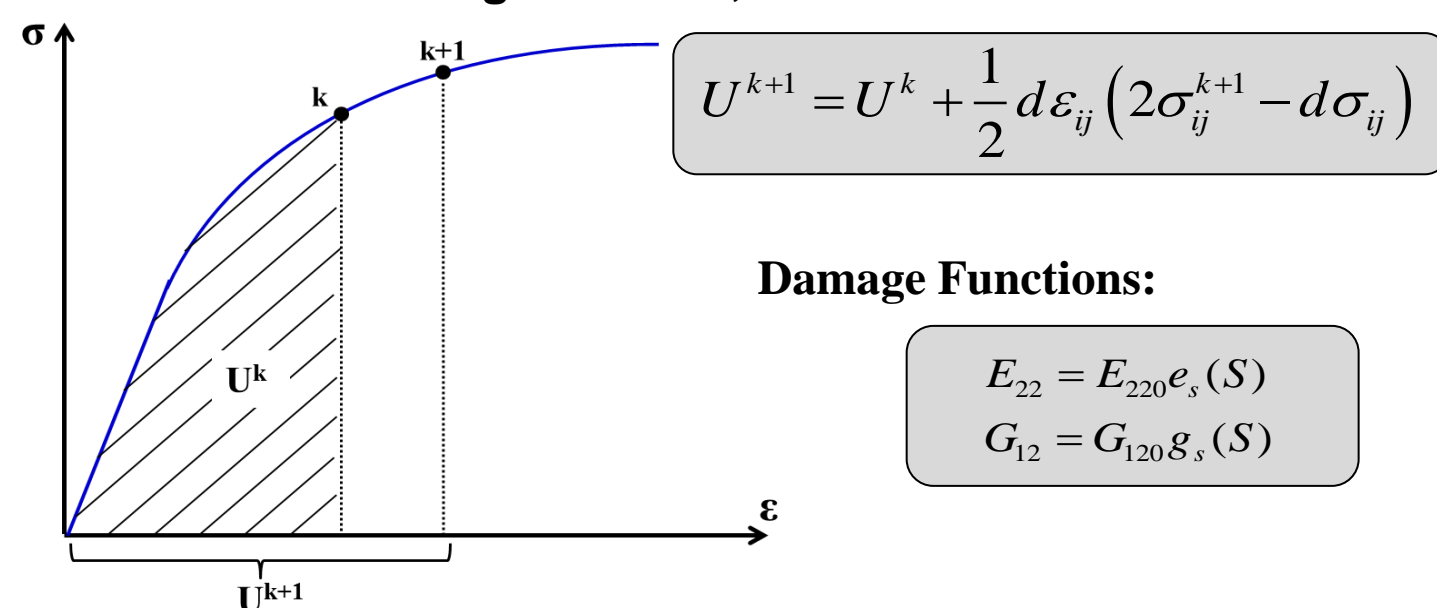
3D Sectional Model

- First Level
 - Sections B and A consist of two matrix subcells and 1 fiber subcell
 - Continuity assumptions for subcells for 3D stress and strains
- Second Level
 - Continuity assumptions between the groups (A, B, 1, 8)



Incremental Damage Theory

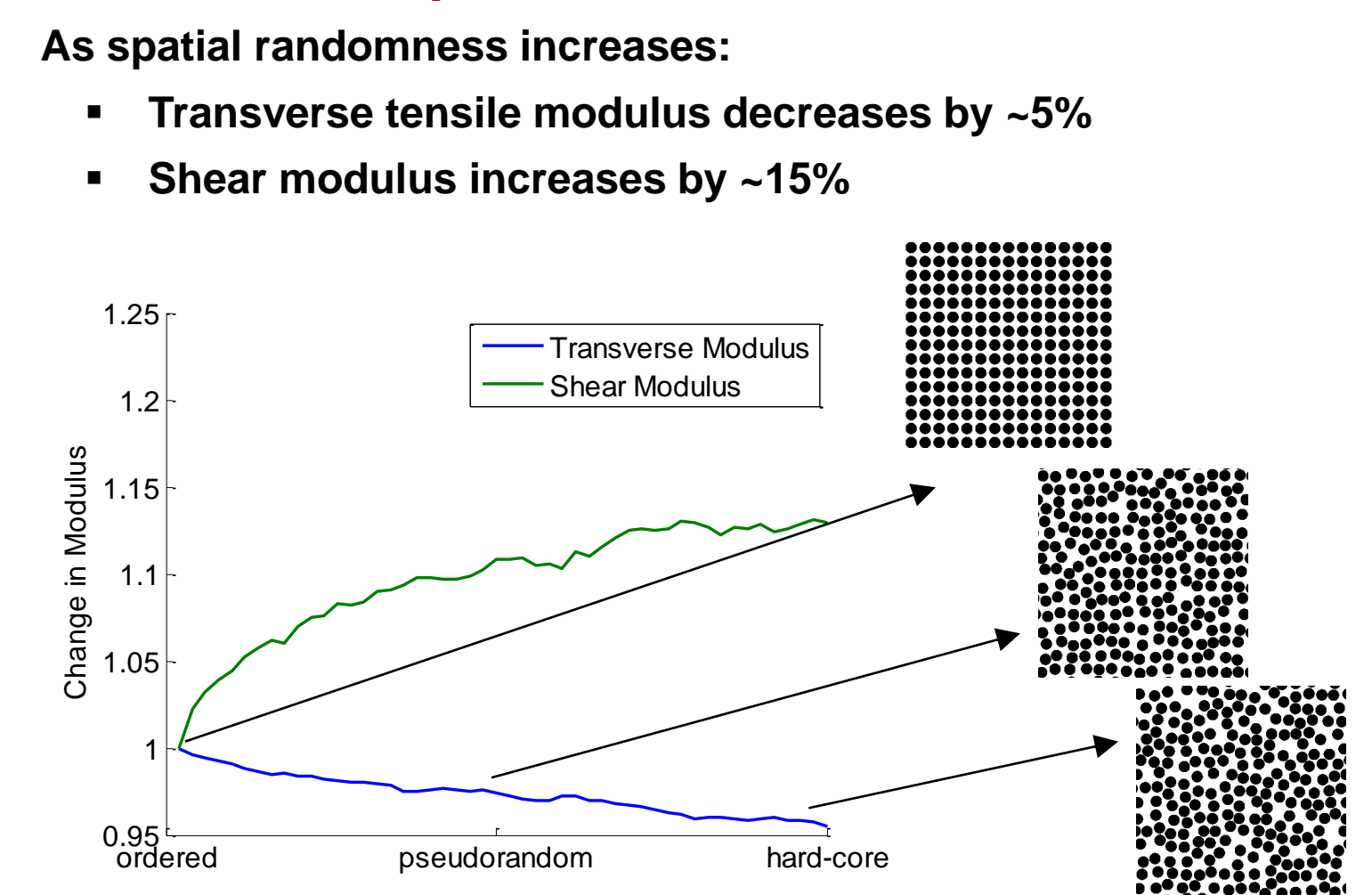
- Theory based on work potential model (Schapery, 1990)
 - $U = W_E + W_S$
 - Where U is the total potential work, W_E is the elastic strain energy, and W_S is the energy for structural change
- Incorporated incremental Schapery theory within stochastic sectional micromechanics
- Moduli are degraded using the "e" and "g" factors which depend on the microdamage variable, S



Composite Failure Theories

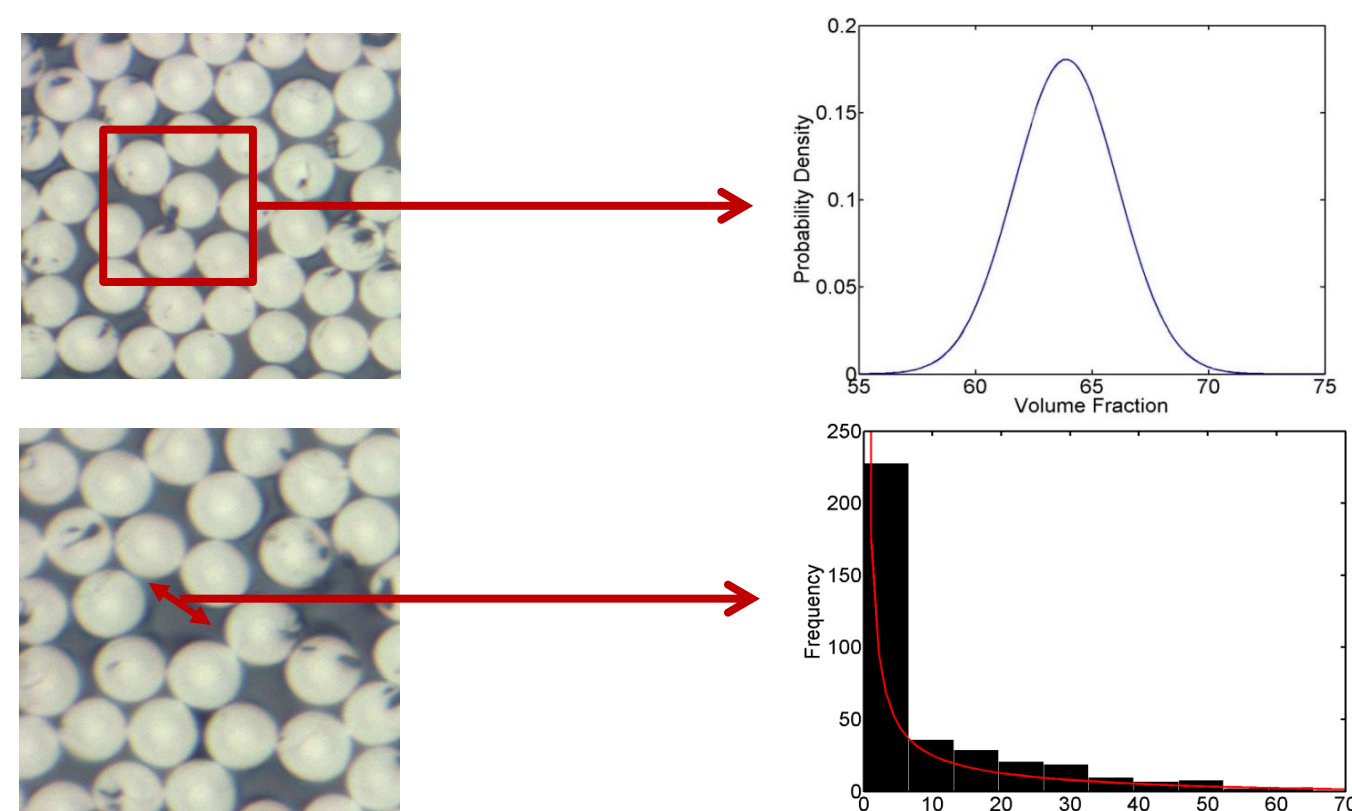
- Microfailure Theory (Max. Stress)
 - Failure of individual subcells
 - Rate dependent failure parameters for matrix subcells
 - Macroscale Failure Theory
 - Failure of unit cell
 - Modified Hashin-Rotem failure criterion to incorporate shear stress effects
 - Four individual failure modes
- Tensile Fiber Mode: $\left\{\frac{\sigma_{11}^2}{\sigma_A^2} + \frac{1}{\tau_A^2}(\sigma_{12}^2 + \sigma_{13}^2) = 1, \sigma_{11} > 0\right.$
- Compressive Fiber Mode: $\left\{\frac{\sigma_{11}^2}{\sigma_A^2} + \frac{1}{\tau_A^2}(\sigma_{12}^2 + \sigma_{13}^2) = 1, \sigma_{11} < 0\right.$
- Tensile Matrix Mode: $\left\{\frac{1}{\sigma_T^2}(\sigma_{22} + \sigma_{33})^2 + \frac{1}{\tau_T^2}(\sigma_{23}^2 - \sigma_{22}\sigma_{33}) + \frac{1}{\tau_A^2}(\sigma_{12}^2 + \sigma_{13}^2) = 1, \sigma_{22} + \sigma_{33} > 0\right.$
- Compressive Matrix Mode: $\left\{\frac{1}{\sigma_T^2} \left[\left(\frac{\sigma_T}{2\tau_T}\right)^2 - 1\right] (\sigma_{22} + \sigma_{33}) + \frac{1}{4\tau_T^2} (\sigma_{22} + \sigma_{33})^2 + \frac{1}{\tau_T^2} (\sigma_{23}^2 - \sigma_{22}\sigma_{33}) + \frac{1}{\tau_A^2} (\sigma_{12}^2 + \sigma_{13}^2) = 1, \sigma_{22} + \sigma_{33} < 0\right.$

Spatial Randomness

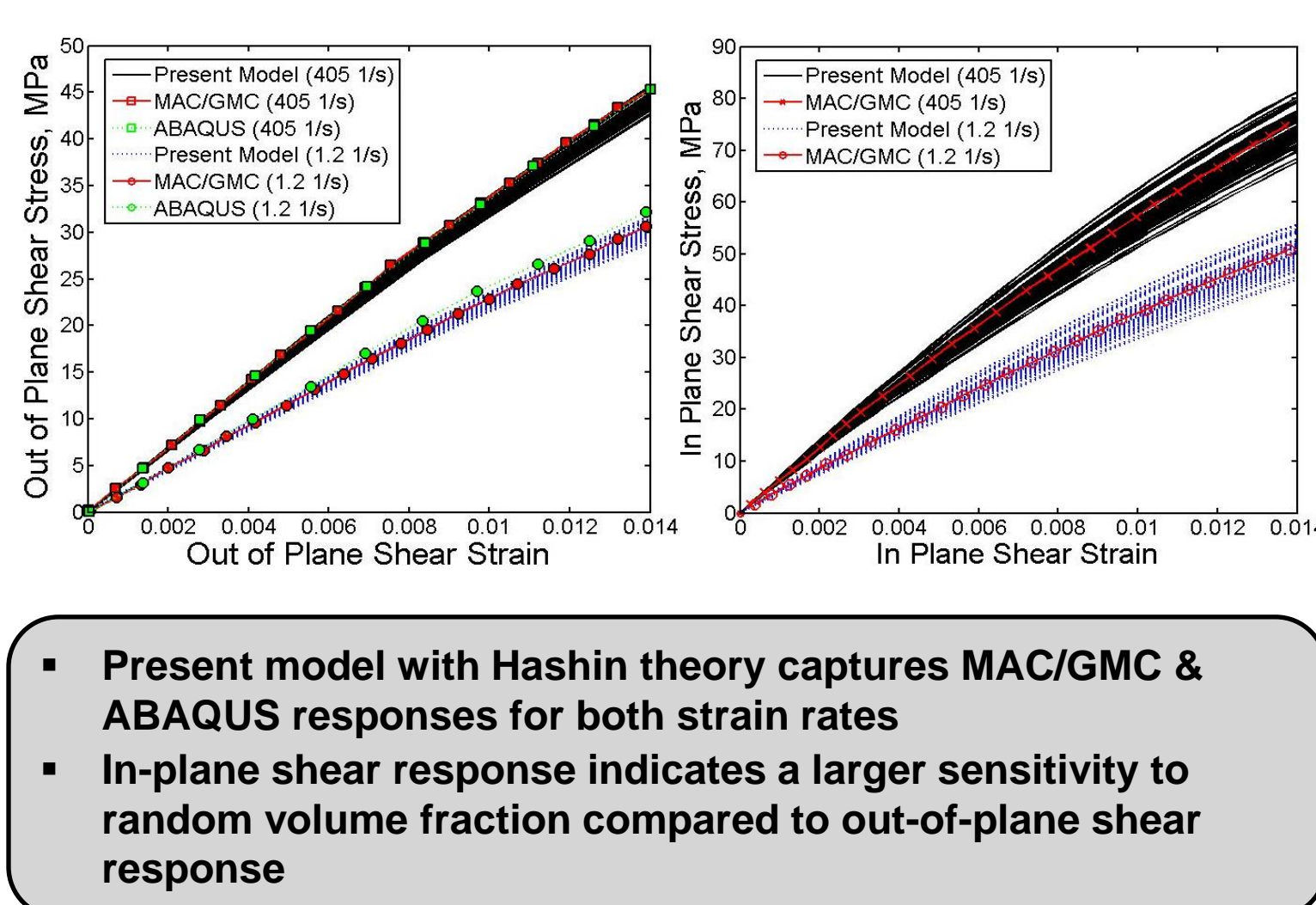


Characterization Results

- Fiber volume fraction, fiber diameter, & spacing statistical distribution functions from optical microscopy
- Results from microscopy analysis of the polymer matrix composite used as random inputs in the multiscale models



Model Validation



Failure Theory Comparison

