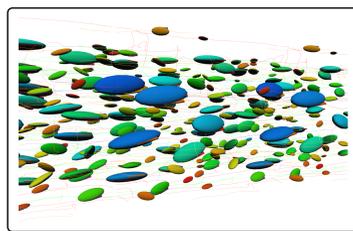
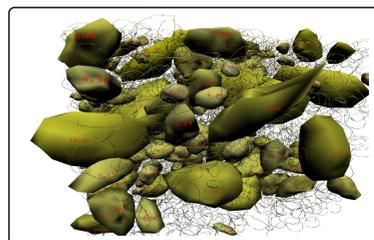


# Concrete SRM, Twenty Years in the Making

ITL: Steven G. Satterfield, William L. George, Judith E. Terrill EL: Nicos S. Martys, Chiara F. Ferraris, Edward J. Garboczi



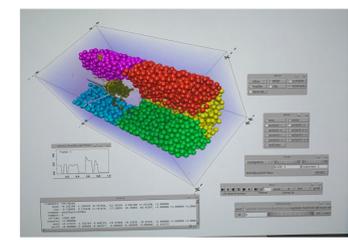
Highly Idealized Simulations



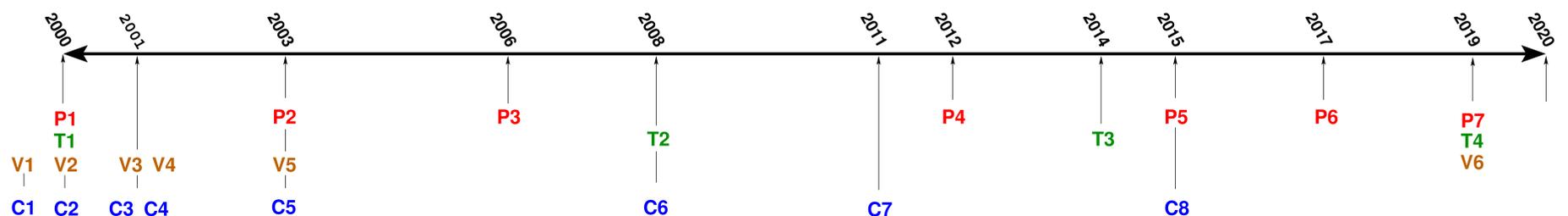
Focus Plus Context



Immersive Visualization



Virtual Measurement & Analysis



## Physical Experiments



Slump-cone measurement



A Concrete Rheometer



Mortar SRM in rheometer

- P1** 2000: Began vane-rheometer experiments, inter-industry tests
- P2** 2003: Identified need for an SRM
- P3** 2006: Need for 3 SRMs identified
- \* **P4** 2012: Cement SRM released
- \* **P5** 2015: Revised cement SRM released
- \* **P6** 2017: Mortar SRM released
- \* **P7** 2019: Concrete SRM released, ASTM X.XXXX released: Standard Test Method for Measuring the Rheological Properties of Cementitious Materials Using a Coaxial Rotational Rheometer

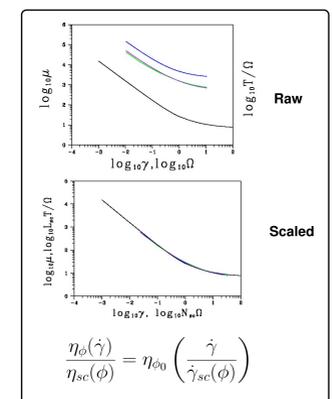
## Fluid Theory

$$\frac{\partial \rho}{\partial t} = -\rho \nabla \cdot v$$

$$\rho \frac{\partial v_i}{\partial t} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_k} \left[ \mu \left( \frac{\partial v_i}{\partial x_k} + \frac{\partial v_k}{\partial x_i} - \frac{2}{3} \delta_{ik} \nabla \cdot v \right) \right] + \frac{\partial}{\partial x_i} (\zeta \nabla \cdot v)$$

The Lagrangian formulation of the continuity and generalized Navier-Stokes equations.

Force:  $\sigma = \frac{\text{Force}}{\text{Area}}$       Viscosity:  $\eta = \frac{\sigma}{\dot{\gamma}}$

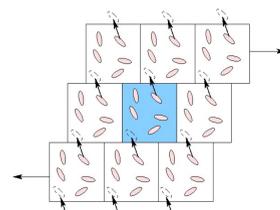


Universal Scaling

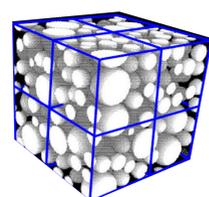
- T1** 2000: DPD (Dissipative Particle Dynamics), Newtonian Fluids
- T2** 2008: SPH (Smoothed Particle Hydrodynamics), non-Newtonian Fluids
- T3** 2014: Universal Scaling of viscosity
- \* **T4** 2019: 10 published papers to date, 30+ presentations

\* : Technology Transfer

## Computational Experiments



Couette Flow with Lees-Edwards Boundary Conditions



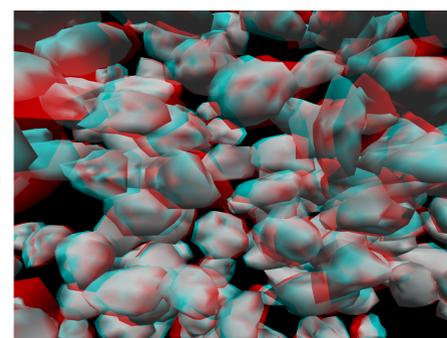
3D Spatial Decomposition



Mira supercomputer at Argonne Nat'l Lab

- C1** Pre-2000: 3D Spheres, DPD, Couette Flow
- C2** 2000: Simulation of the flow of ellipsoids
- \* **C3** 2001: Virtual Cement and Concrete Testing Lab (VCCTL) software released
- C4** 2001: 10 processes – Shared-memory parallelism
- C5** 2003: 100 processes – Distributed Memory parallelism with MPI
- C6** 2008: 1,000 processes – Parallel file I/O, SPH / non-Newtonian fluids
- C7** 2011: 10,000 processes – Reduced global communications
- C8** 2015: 100,000 processes – More global communications eliminated

## Immersive Visualization



View this image with glasses



Immersed in a simulation

- V1** pre-2000: Pre-immersive visualization, in mono
- V2** 2000: 1-Wall RAVE
- V3** 2001: Visualization of the flow of ellipsoids
- V4** 2001: DIVERSE, in collaboration w/Virginia Tech
- V5** 2003: HEV/SAVG
- \* **V6** 2018: HEV released on NIST github