# DOE Workshop on Roadmap for Multiphase flow, University of Illinois, May 2002

Presentations by Sankaran Sundaresan

1. Slides 3-16 the slides presented in the beginning of the workshop
2. Slides 18-24 the "summary" presentation made at the end of the conference

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## Major Challenge – I

### Dilute fluid-particle systems

- **Understanding and quantitative modeling of gas-particle interactions when the particle size is comparable to or larger than the Kolmogorov scale**

**John Eaton**

- **Turbulence modification by the particles**
- **Particle tracking computations**

**Mass loading of particles, Particle Reynolds number (Re)**

$$\text{Stokes number (St)} = \frac{\text{Particle time constant}}{\text{Kolmogorov time scale}}$$

$$\text{Size ratio} = \frac{\text{Particle size}}{\text{Kolmogorov length scale}}$$

Largest attenuation when St ~ O(10) and size ratio is ~ 1

Liquid: St = O(1) when size ratio ~ 1

Gas: St can be ≥ O(1) while size ratio is still << 1

# Major Challenge – II

## Concentrated fluid-like suspensions

- **Development of averaged equations of motion and associated closure for situations where the continuous phase inertia associated with the relative motion between the continuous and dispersed phases is important**

**Don Koch**

- Rapid granular flows (Lun et al., 1984)
- Gas-solid suspensions (Re <<1) ( Koch & Sangani, 1999)
- Suspension of spherical gas bubbles

(Re >>1, potential flow; Spelt & Sangani, 1998)

Shear flow | Fluidization | Buoyant rise

Instability on a length scale of ~ 10 – 50 particle diameters

Narrow-gap channel or Couette systems

**Boundary effects (Michel Louge)**

Bagnold (1954) | Hunt et al (2002)

- Rapid granular flows
- Gas-solid suspensions (Re <<1)
- Suspension of spherical gas bubbles (Re >>1, potential flow)

**Finite Re effects (relative motion)**

**in fluid-solid systems &**

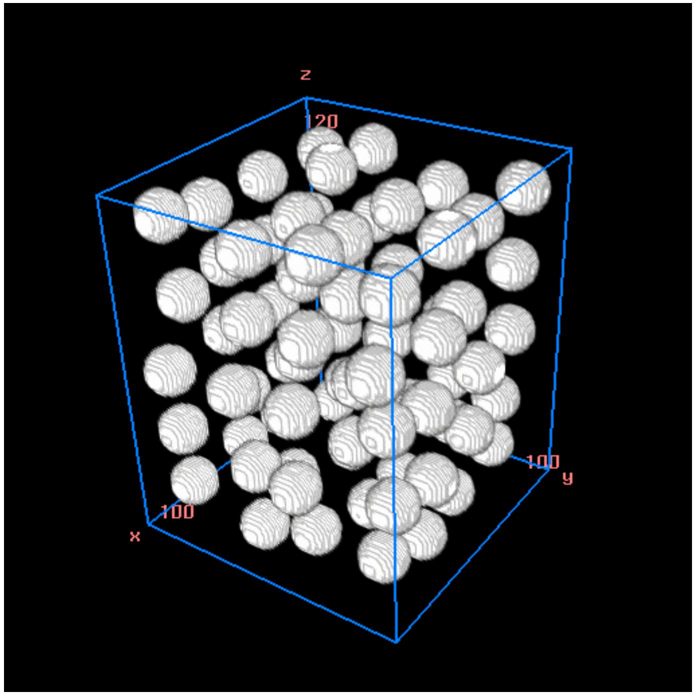
**in bubbly systems**

**(allowing for distortion)**

Closure through computational experiments

Ladd & Verberg (2001)

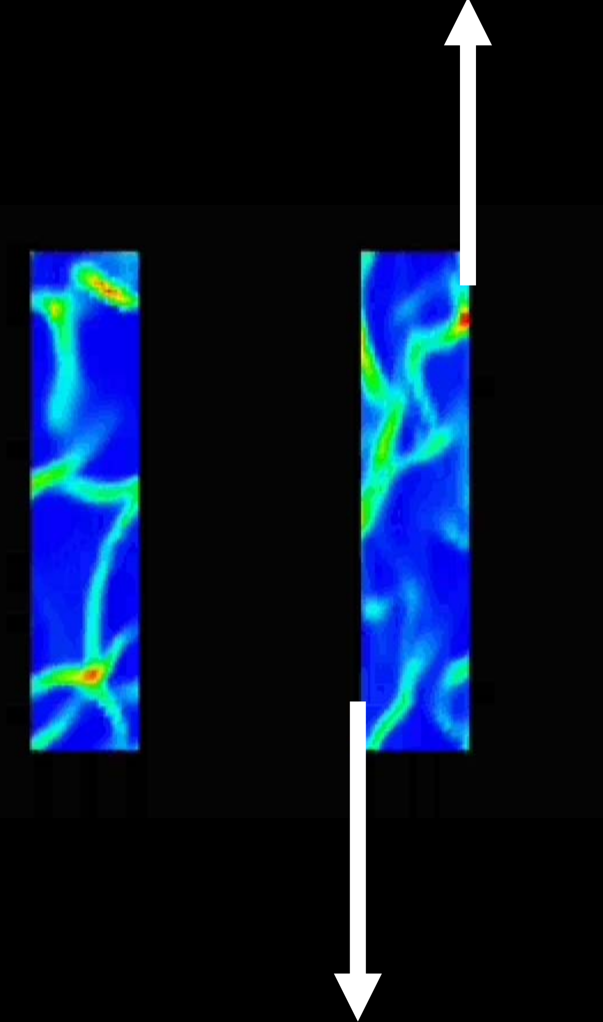
Bunner & Tryggvason (1999)

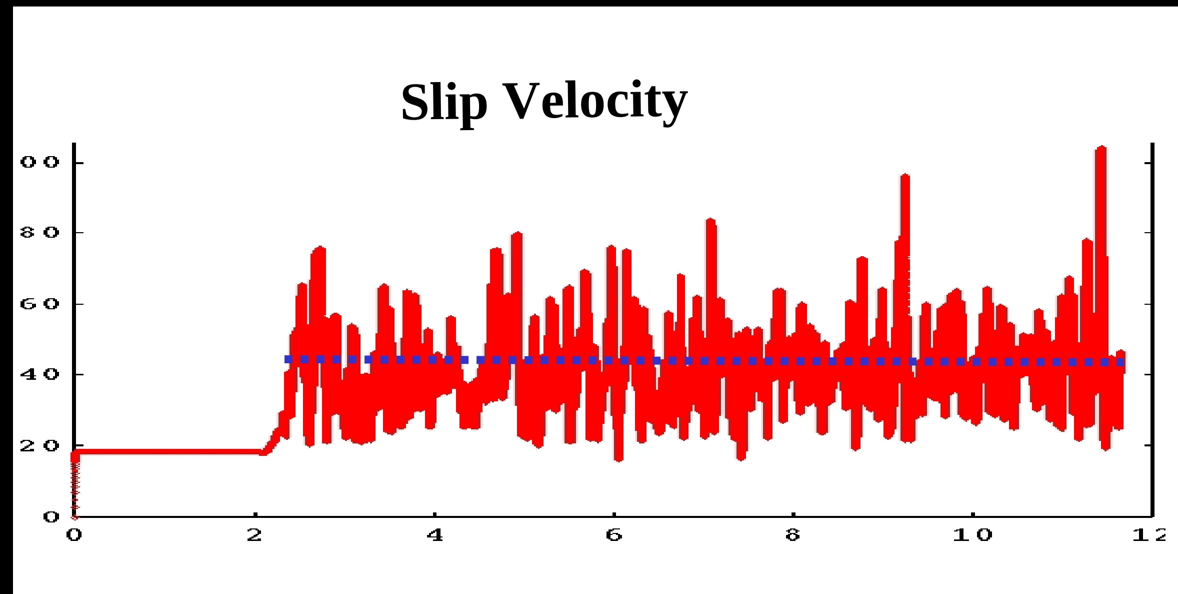


# Major Challenge - III

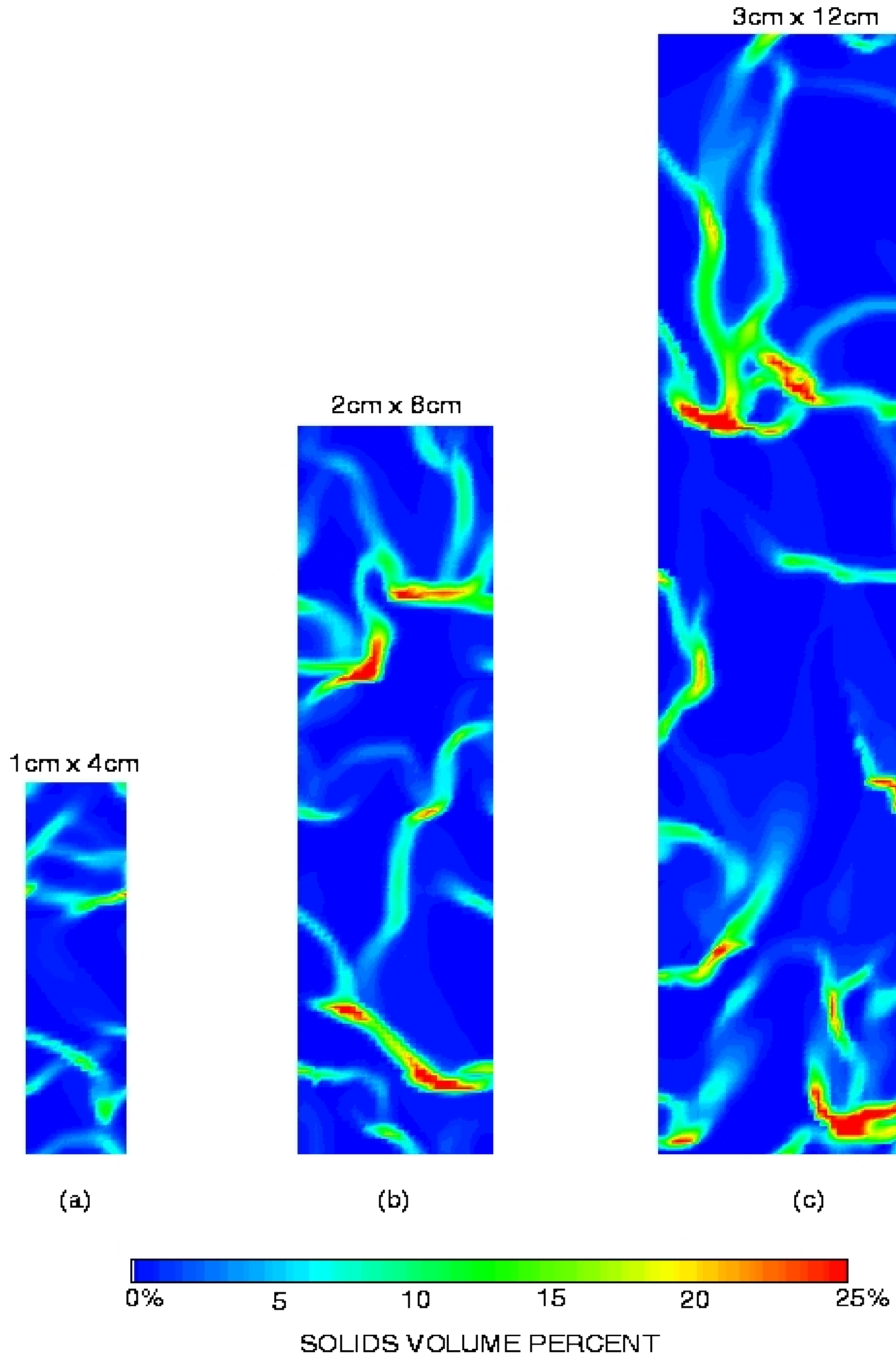
- **Understanding instabilities associated with the inertia of relative motion between the phases and development of coarsened equations of motion**

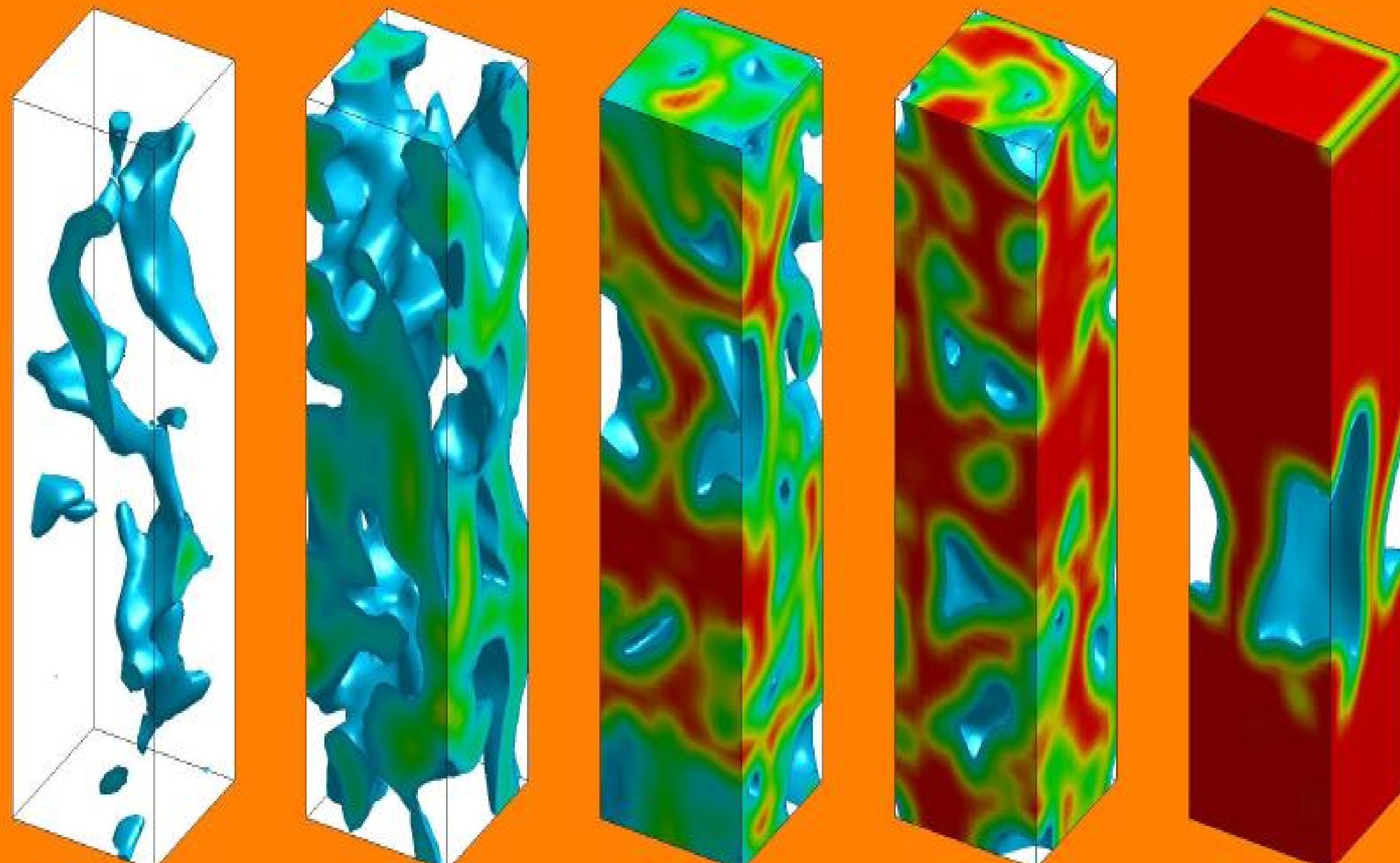
**Don Koch**



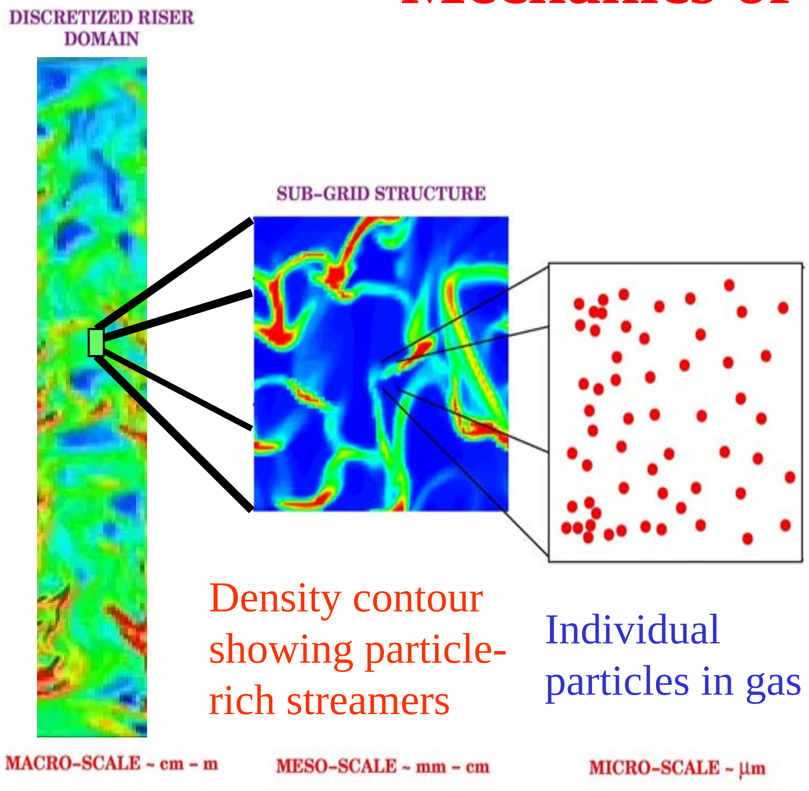



Time


3cm x 12cm
2cm x 8cm
1cm x 4cm
(a)
(b)
(c)
0%
5
10
15
20
25%
SOLIDS VOLUME PERCENT



# Mechanics of Gas-Particle Flows




Goal: Understand the origin of nonuniform structures at different length and time scales and their consequences.

Engineering Need

Tools to probe macro-scale flow features directly

Approach: Probe details of mesoscale structures and develop effective coarse-grained equations

# Major Challenge – IV

## Fluid-like to solid-like transition

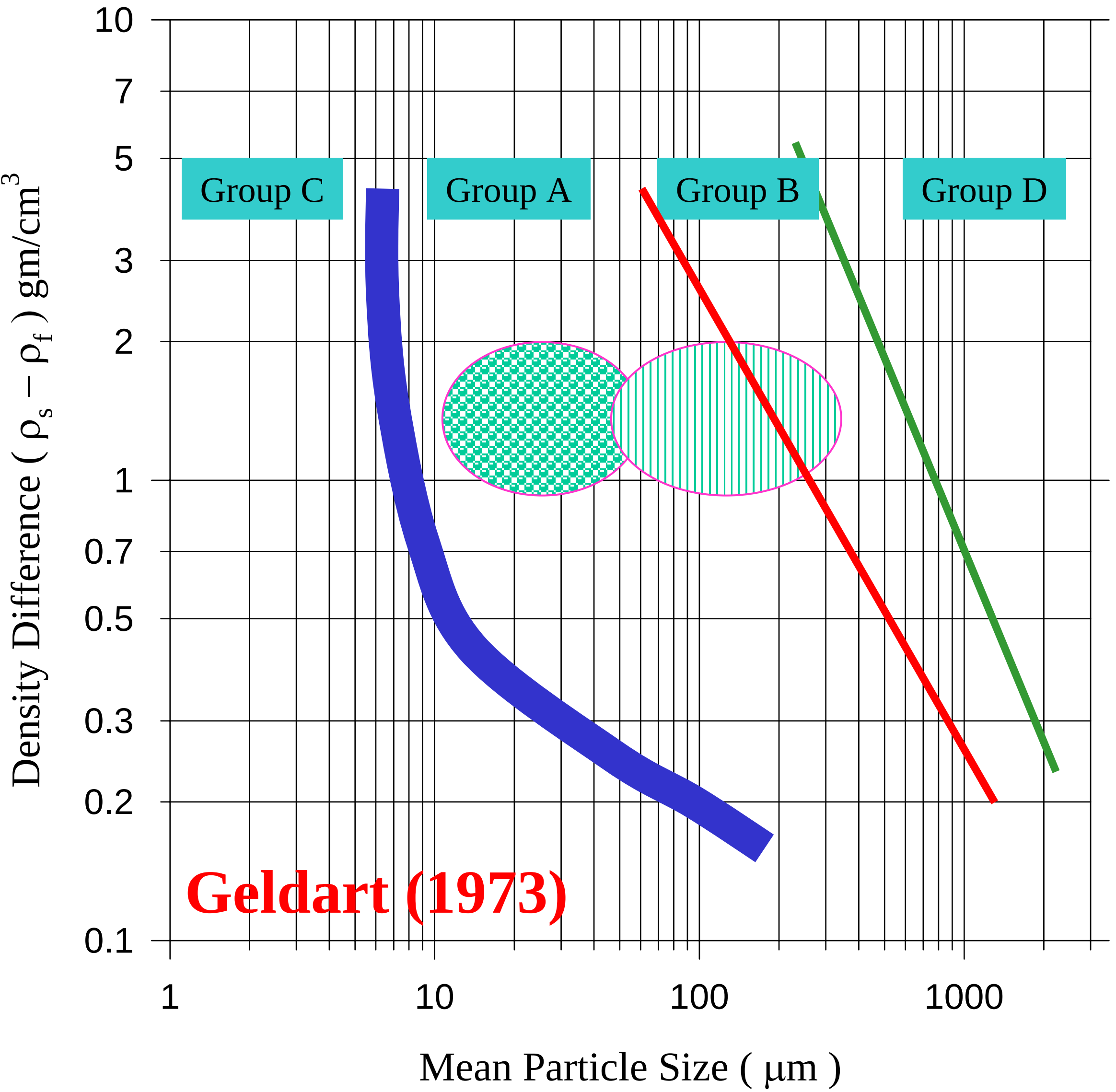
- **Development of quantitative models for contact stresses in dense granular assemblies resulting from frictional and cohesive interactions between the particles**

  **Michel Louge – Friction**

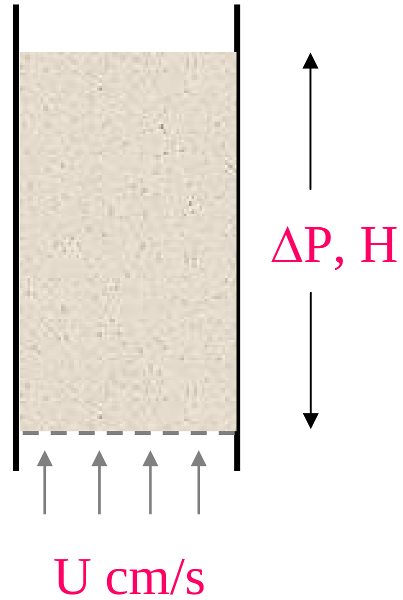
  **Harry Swinney – Jamming & Glass-like states**

  **Daun Zhang – Interaction of time scales**

# Understand contact stresses in granular assemblies

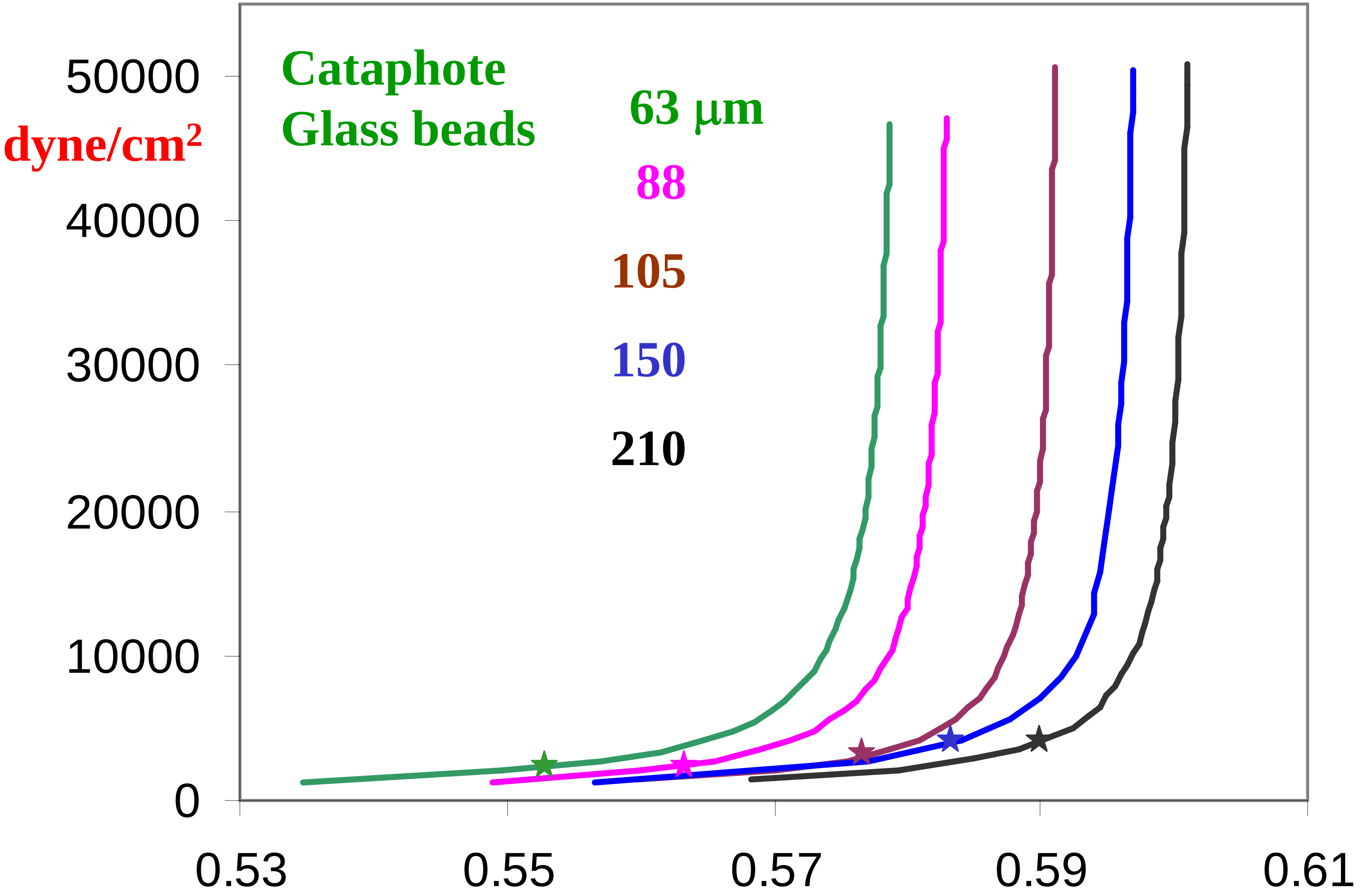



Fluidization experiments




Discrete element simulations

# Compressive yield stress vs. particle volume fraction



# Major Challenge - V

- **A thorough understanding of the competition between mixing and segregation in granular systems, including techniques to control these through manipulation of inter-particle cohesive interactions**

**Julio Ottino**

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# Disperse Flows

Sankaran Sundaresan

| | |
|---|---|
| **John Eaton** | **Don Koch** |
| **Michel Louge** | **Julio Ottino** |
| **Tom O'Brien** | **Olivier Simonin** |
| **Harry Swinney** | **Duan Zhang** |

# Technology

**Power/energy industries**

**Transportation**

**Chemical process industries**

**Pharmaceuticals**

**Consumer product industries**

**Agriculture**

**Space exploration**

# Academic Disciplines

**Chemical** **Mechanical**

**Civil** **Environmental**

**Atmospheric sciences**

**– climate change, meteorology**

**Physics** **Geophysics**

**Metallurgy** **Materials Science**

Increasing disperse phase fraction

**Carrier phase turbulent modification by particles**

- effects of collisions
- particle size ~ Kolmogorov, St ~ 10
- effects of polydispersity
- impact on heat transfer

**Two-fluid models**

- effects of fluid inertia at particle scale
- boundary conditions
- instabilities
- LES
- effects of polydispersity, fines
- other forces (electrostatics, etc.)

High disperse phase fraction

**Contact force models**

- effects of friction, cohesion on packing & rheology
- boundary conditions
- effects of polydispersity, fines
- transition between quasi-static & rapid flow

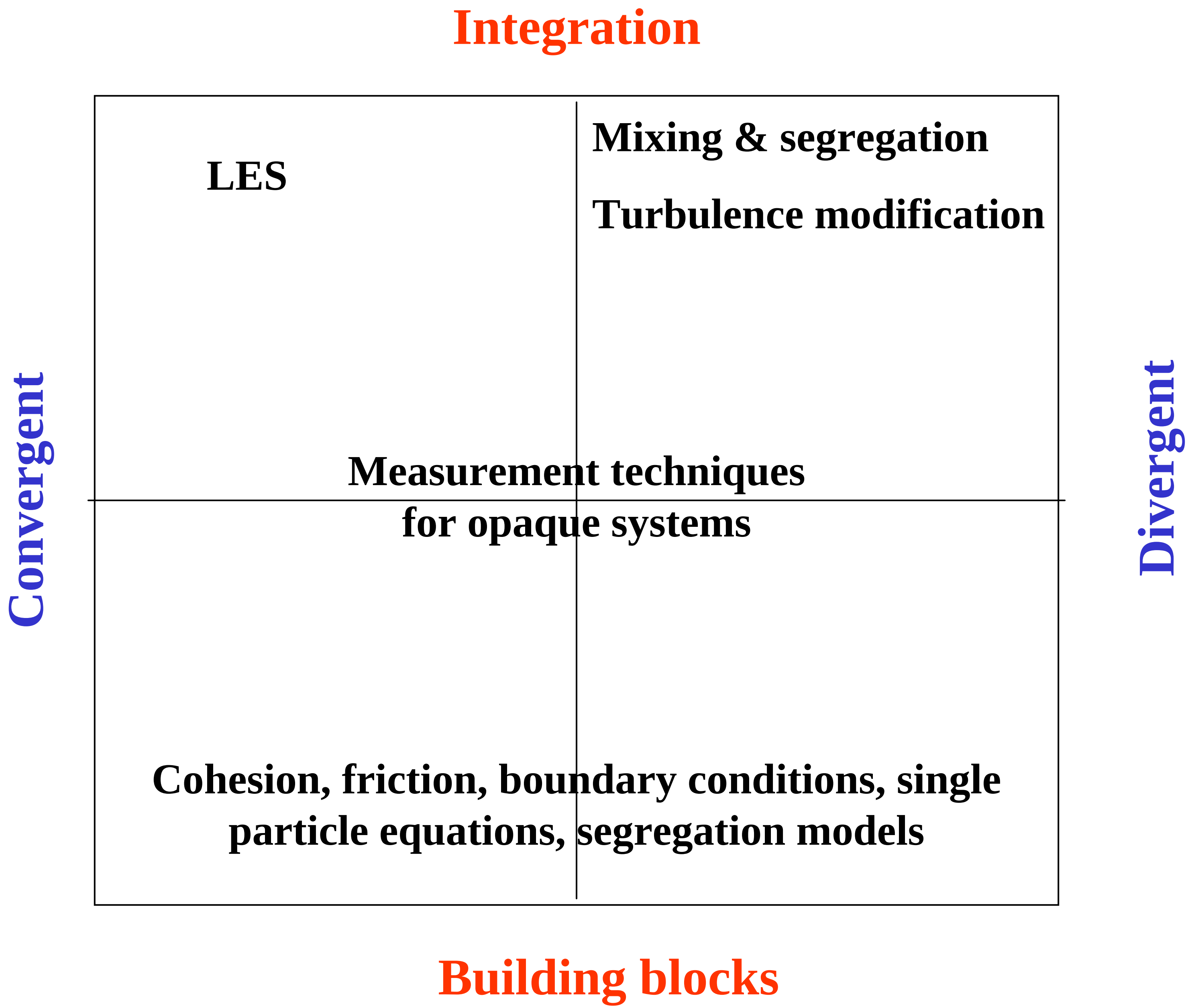
**Self-organization**

- e.g., in vibrated & fluidized beds
- segregation
    - segregation models (density, size, shape)
    - effect of cohesion
    - role of interstitial fluid
- mixing and segregation

Multi-scale (length & time)

# Other recommendations

- model experiments and simulations for benchmarking
- early collaborations between research groups
- develop measurement techniques for opaque systems


Integration
LES
Mixing & segregation
Turbulence modification
Convergent
Divergent
Measurement techniques
for opaque systems
Cohesion, friction, boundary conditions, single
particle equations, segregation models
Building blocks