Idaho National Engineering and Environmental Laboratory

Multiphase flow in complex fracture apertures under a wide range of flow conditions

INEEL: Paul Meakin, Glenn E. McCreery, Donald M. McEligot.

MIT: Daniel H. Rothman
Department of Earth, Atmospheric and Planetary Science.

University of Oslo: Bjorn Jamtveit (Geology) Jens Feder (Physics) Center for Physics of Geological Processes.

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Multiphase flow in complex fracture apertures under a wide range of flow conditions: motivation.

- In the shallow subsurface fracture apertures provide an important, often dominant pathway for fluid flow and the concomitant transport of dissolved and colloidal contaminants.
- We need a better understanding of multiphase flow in fracture apertures (better conceptual models) to more reliably predict the behavior of subsurface contaminants.
- An opportunity to combine cutting-edge basis research with practical applications. Reduce the delay between development of new modeling methods and their application to subsurface science.
- Advance the state-of-the-art in computer modeling of multiphase flow in complex confined geometries (fracture apertures and pore spaces).

Multiphase flow in complex fracture apertures under a wide range of flow conditions: challenges.

- There are NO computational methods available for the routine modeling of multiphase flow under a wide range of conditions.
- Serious problems with grid-based methods:
  - Artificial front broadening.
  - Grid entanglement.
  - Complex computer code.
- Innovative alternatives have been introduced but there have been few applications to subsurface science and most of these methods are still under development.

Multiphase flow in complex fracture apertures under a wide range of flow conditions: Modeling methods

- We will use particle based-methods to obviate the difficulties associated with interface tracking.

  When particles of different kind move the associated fluid—fluid interfaces and surfaces move with them. Tracking occurs automatically, and there is no need for complex code.

- Particle-based models take advantage of the universality of fluid flow. Navier Stokes flow will be obtained if:

  - The particle—particle interactions conserve momentum.
  - The particle—particle interactions are isotropic.
  - Mass is conserved.
  - Energy is conserved.
  - The collisions conform to detailed balance.
  - The Mach number is low.
  - Galilean invariance is preserved.

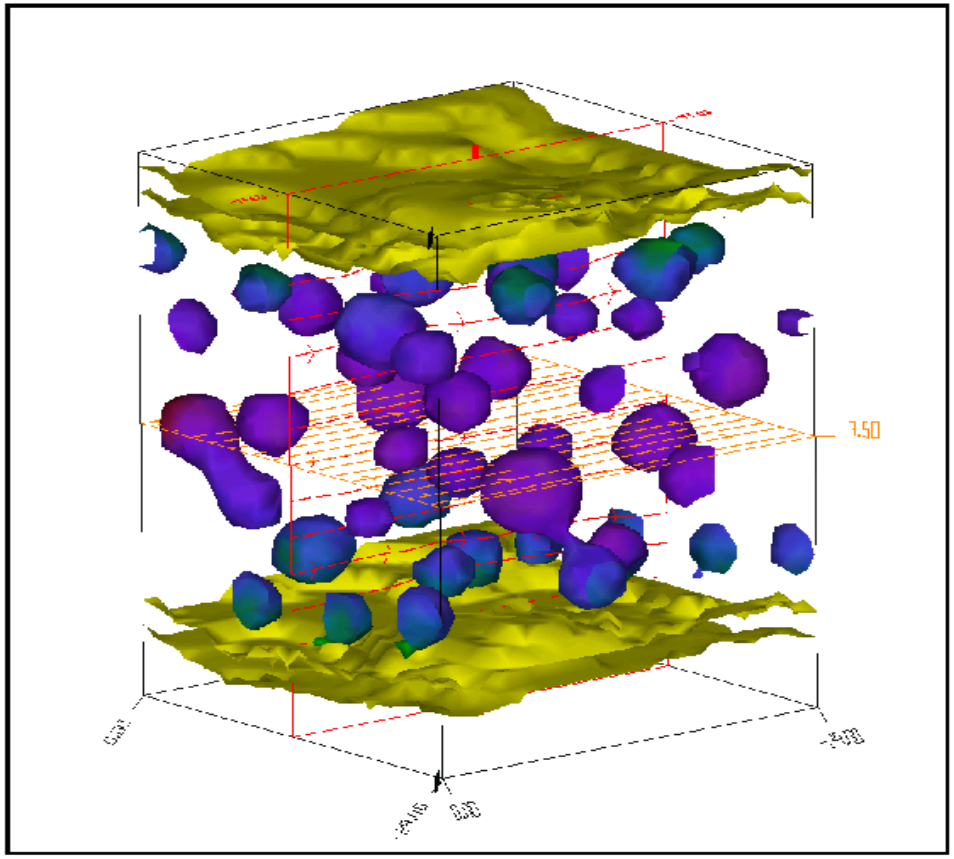
- Within these constraints models can be designed to optimize computational efficiency and simplicity.

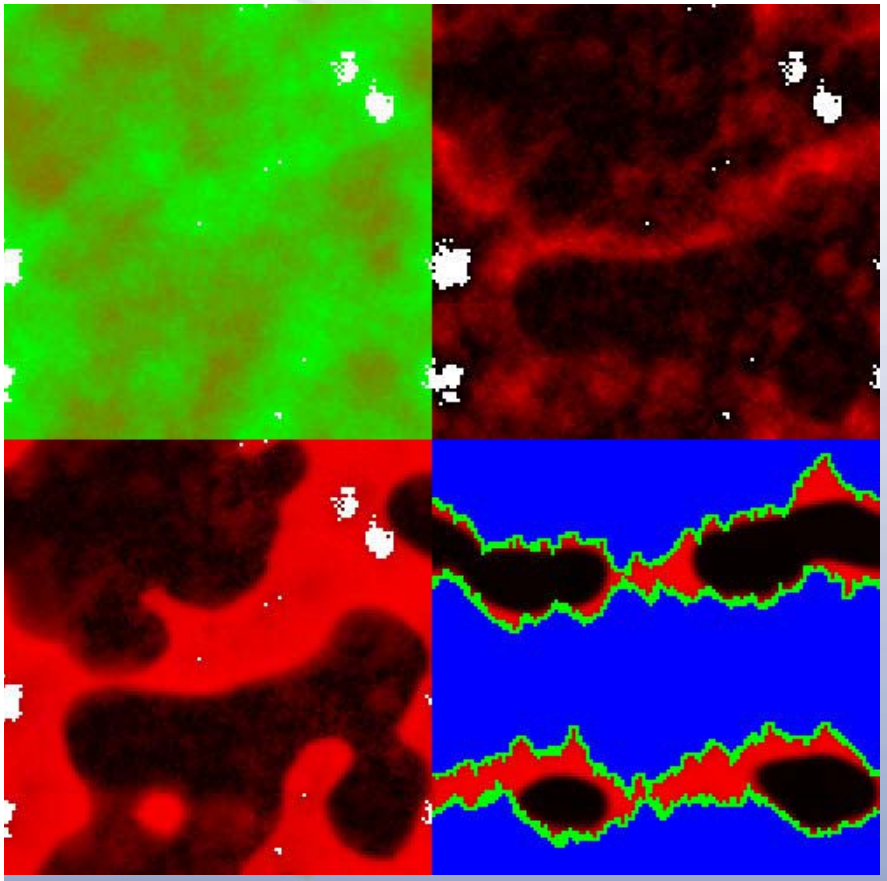
Particle-based modeling methods

- Lattice Boltzmann: MIT, UiO, INEEL
- Dissipative particle dynamics. INEEL, UiO
- Smoothed particle hydrodynamics. INEEL

- These methods are complementary. They all have their own specific strengths and weaknesses. We have developed basic code for all three methods. Their performance will be compared, and all three methods will be compared with experiments.
- Application to multiphase flow in fractures will require a number of innovations. No previous application of smoothed particle hydrodynamics or dissipative particle dynamics to multiphase flow in complex confined geometries (pore spaces or fracture apertures). Application of lattice Boltzmann models to multiphase flow in porous media was pioneered by Dan Rothman. No applications to multiphase flow in fracture apertures, film flow or high viscosity contrast multiphase flow.

Lattice Boltzmann simulations

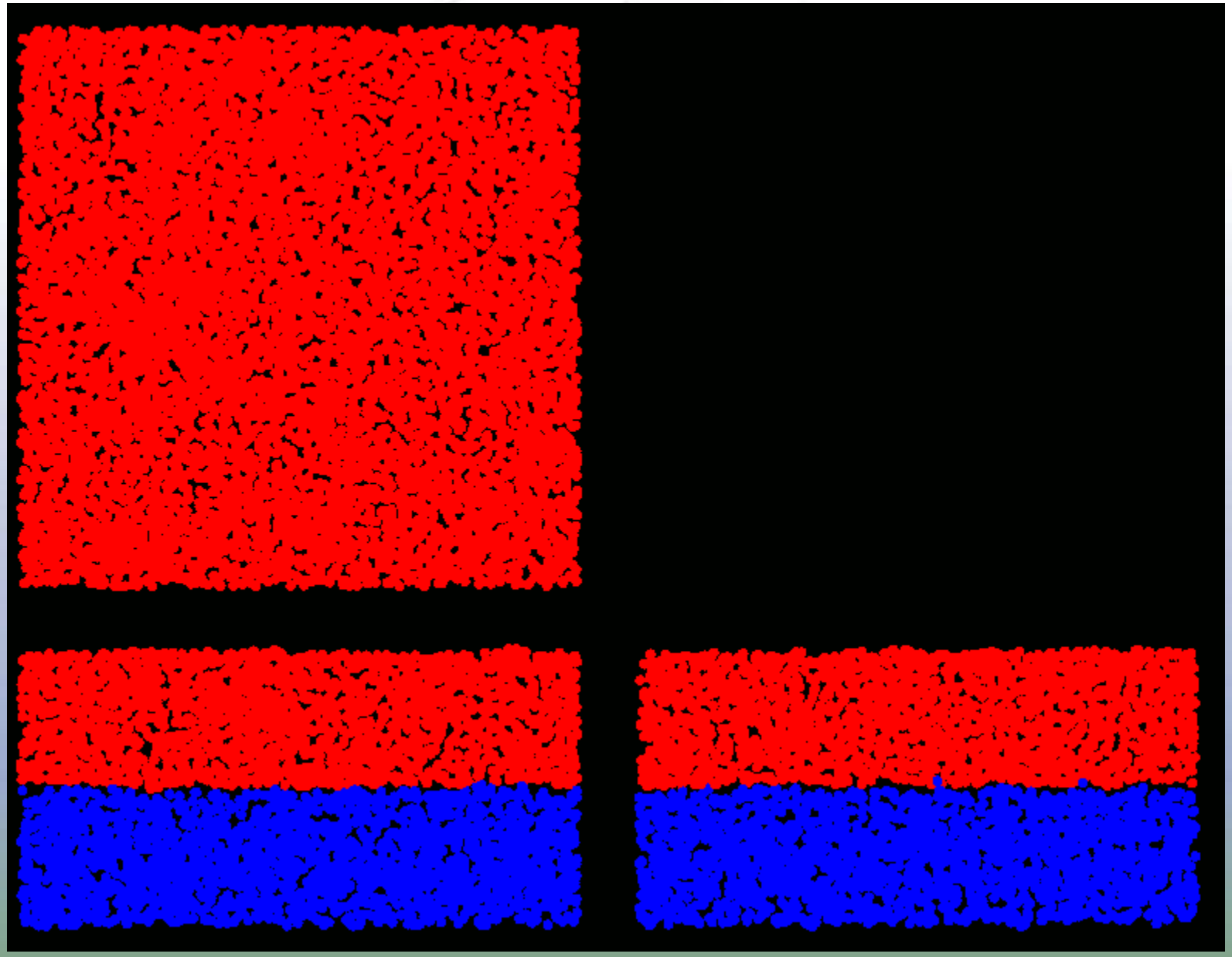




MIT

INEEL

Rayleigh—Taylor instability



Rayleigh—Taylor instability

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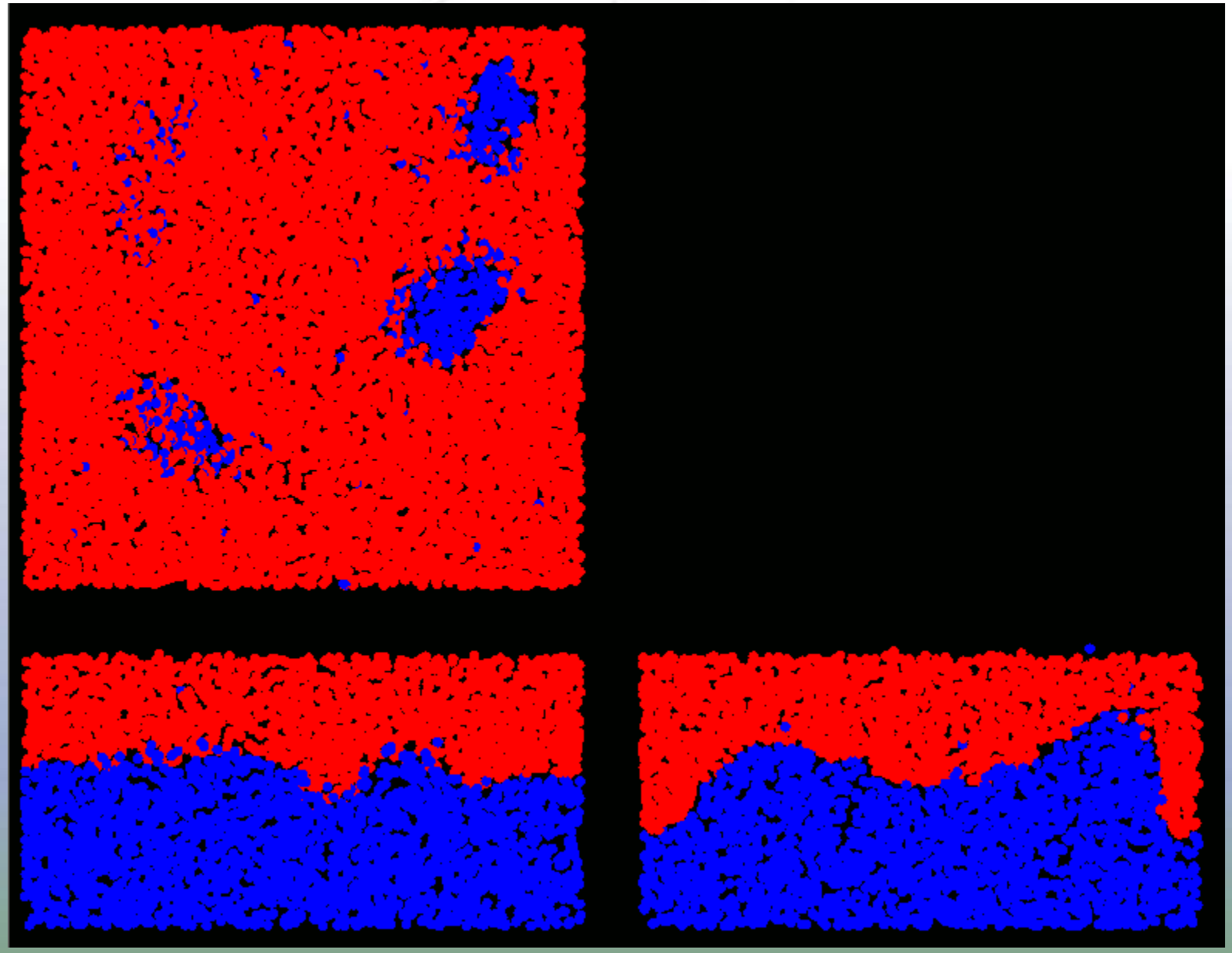

Rayleigh—Taylor instability

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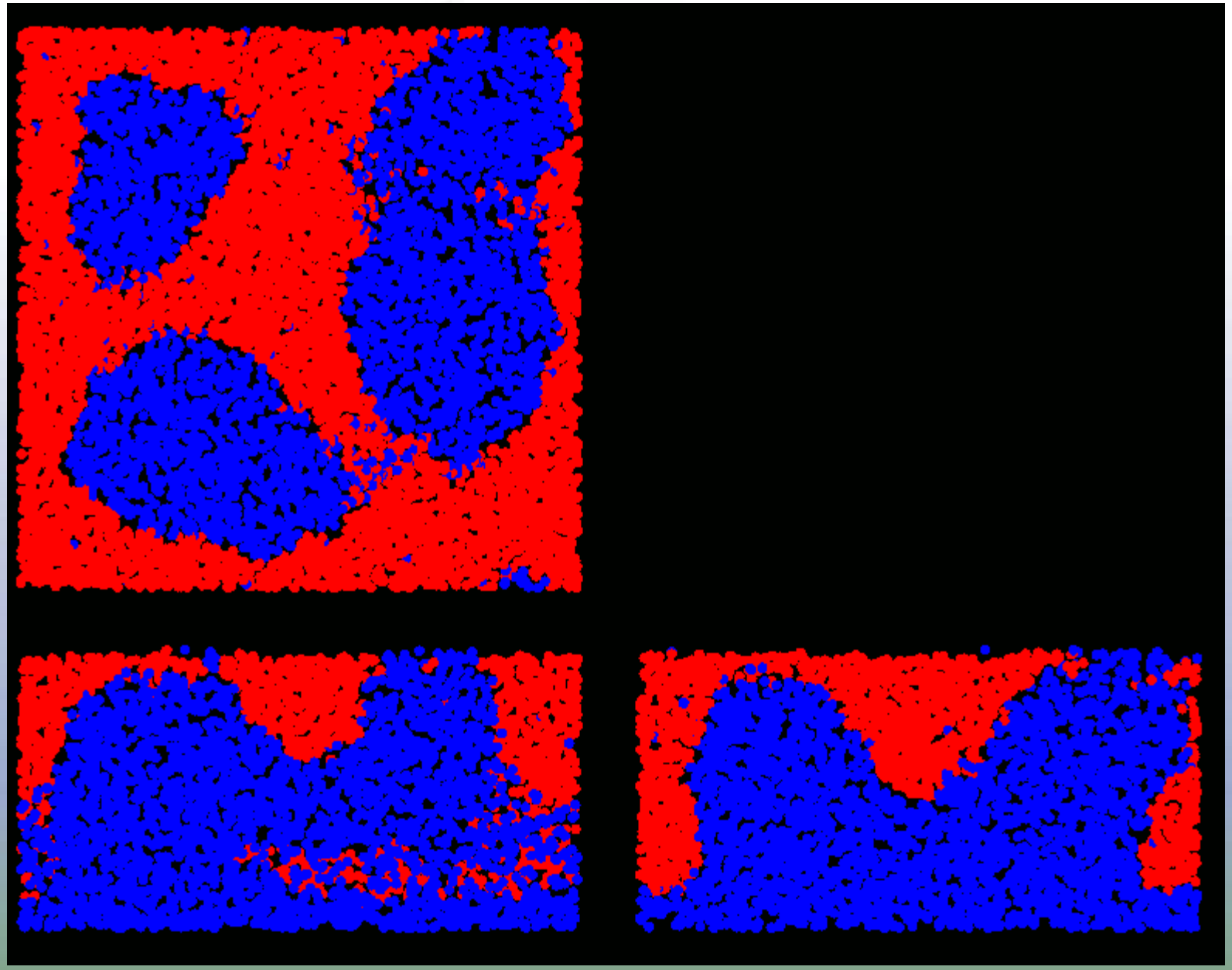

Rayleigh—Taylor instability

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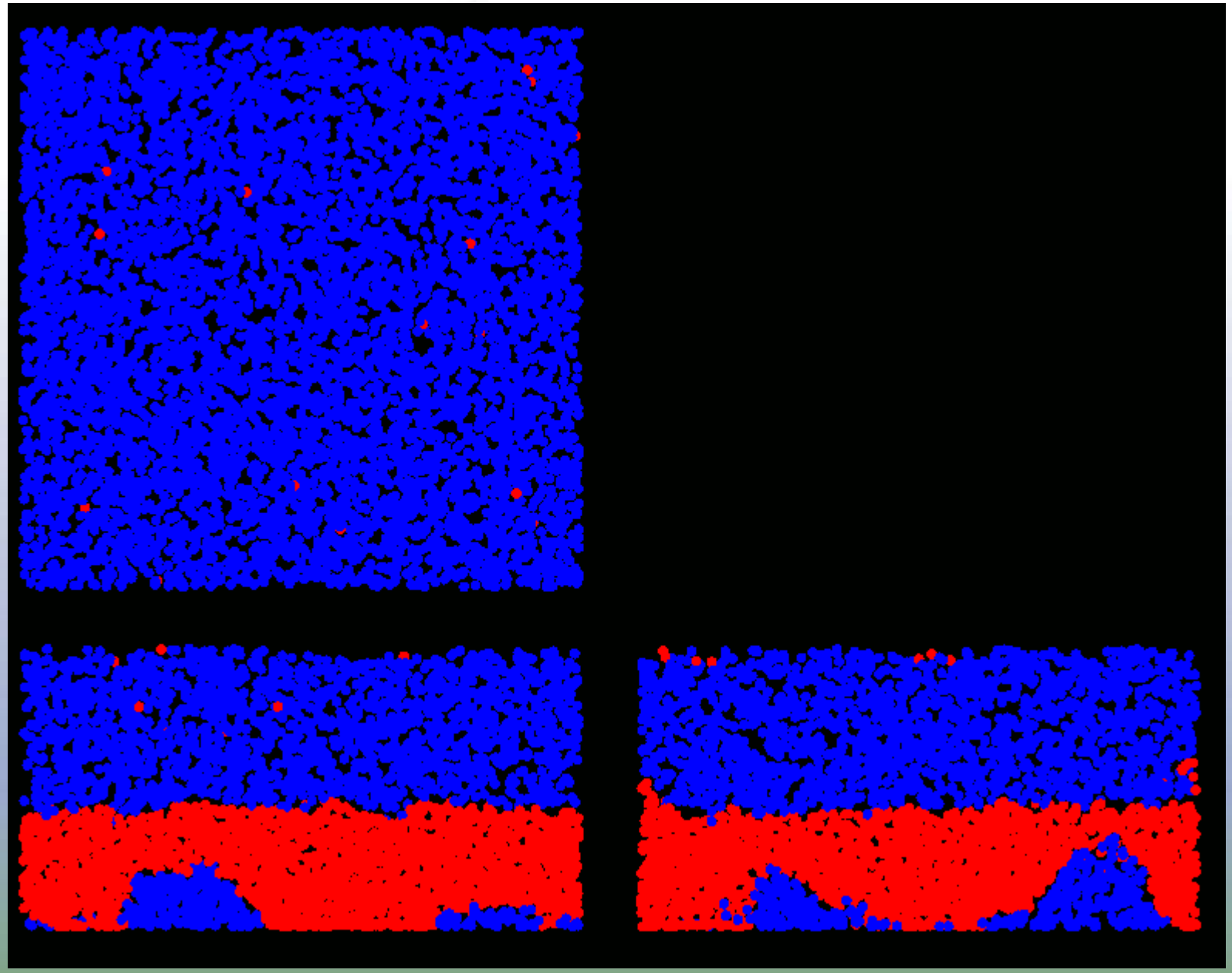

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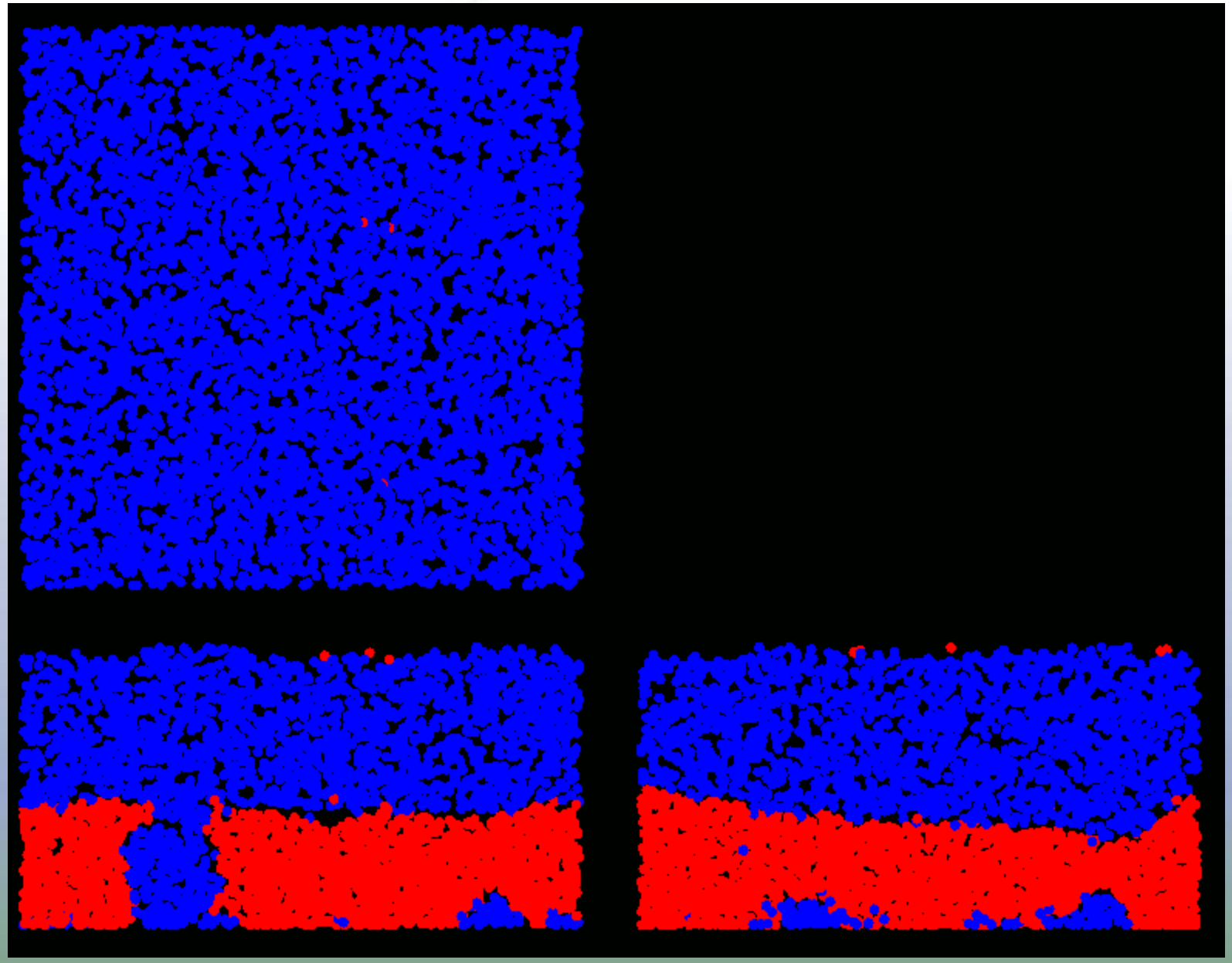

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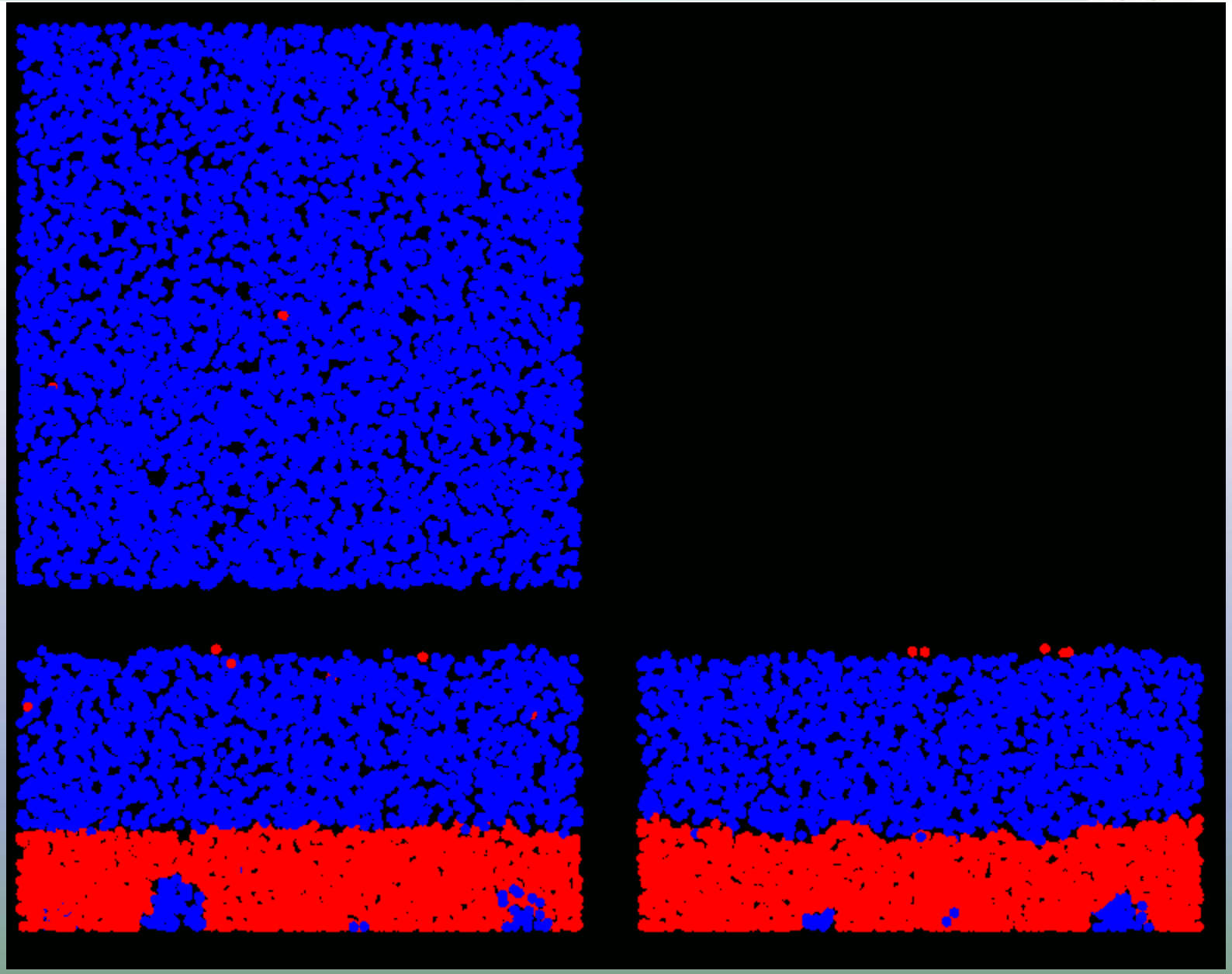
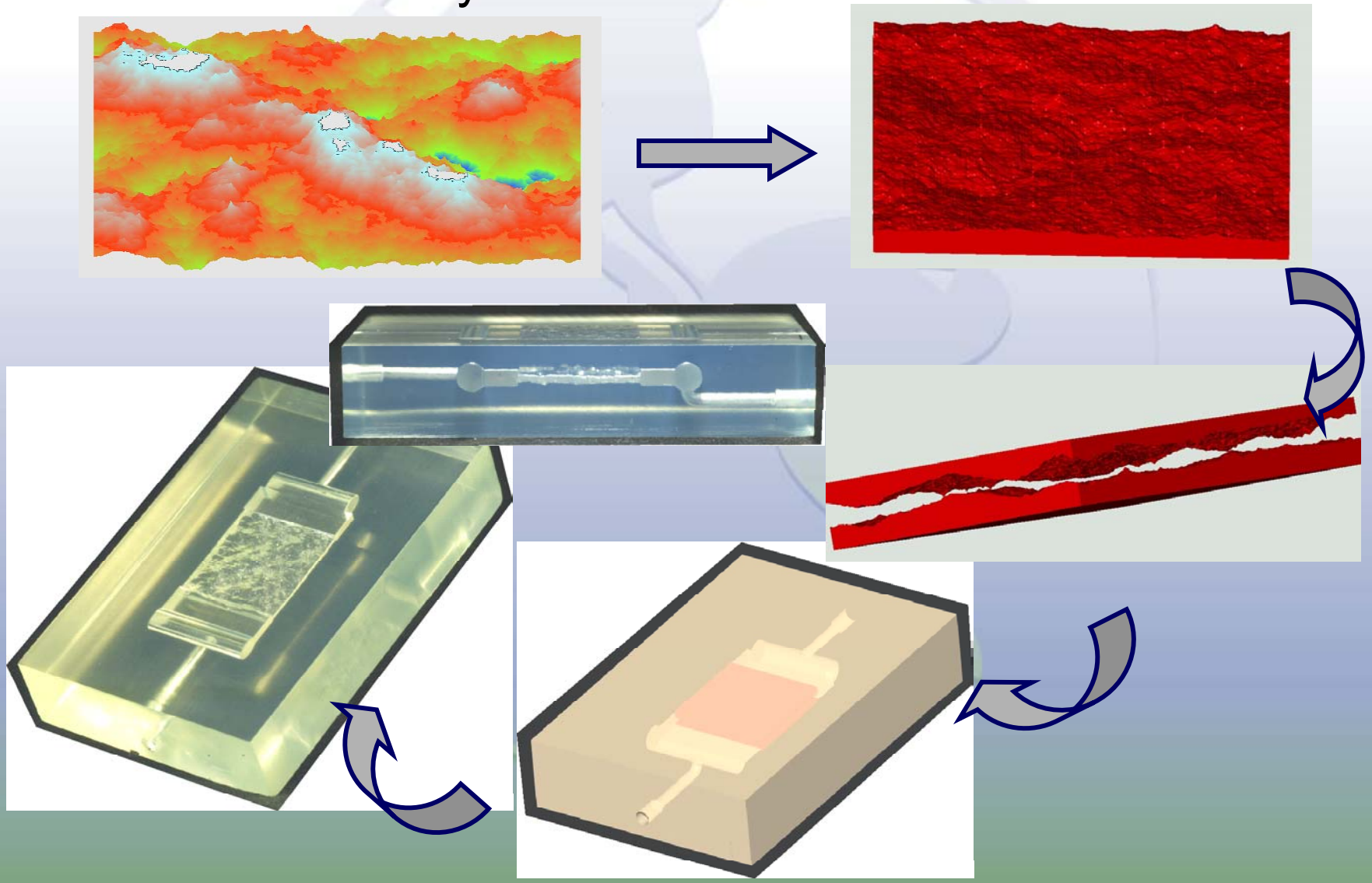


Experimental program

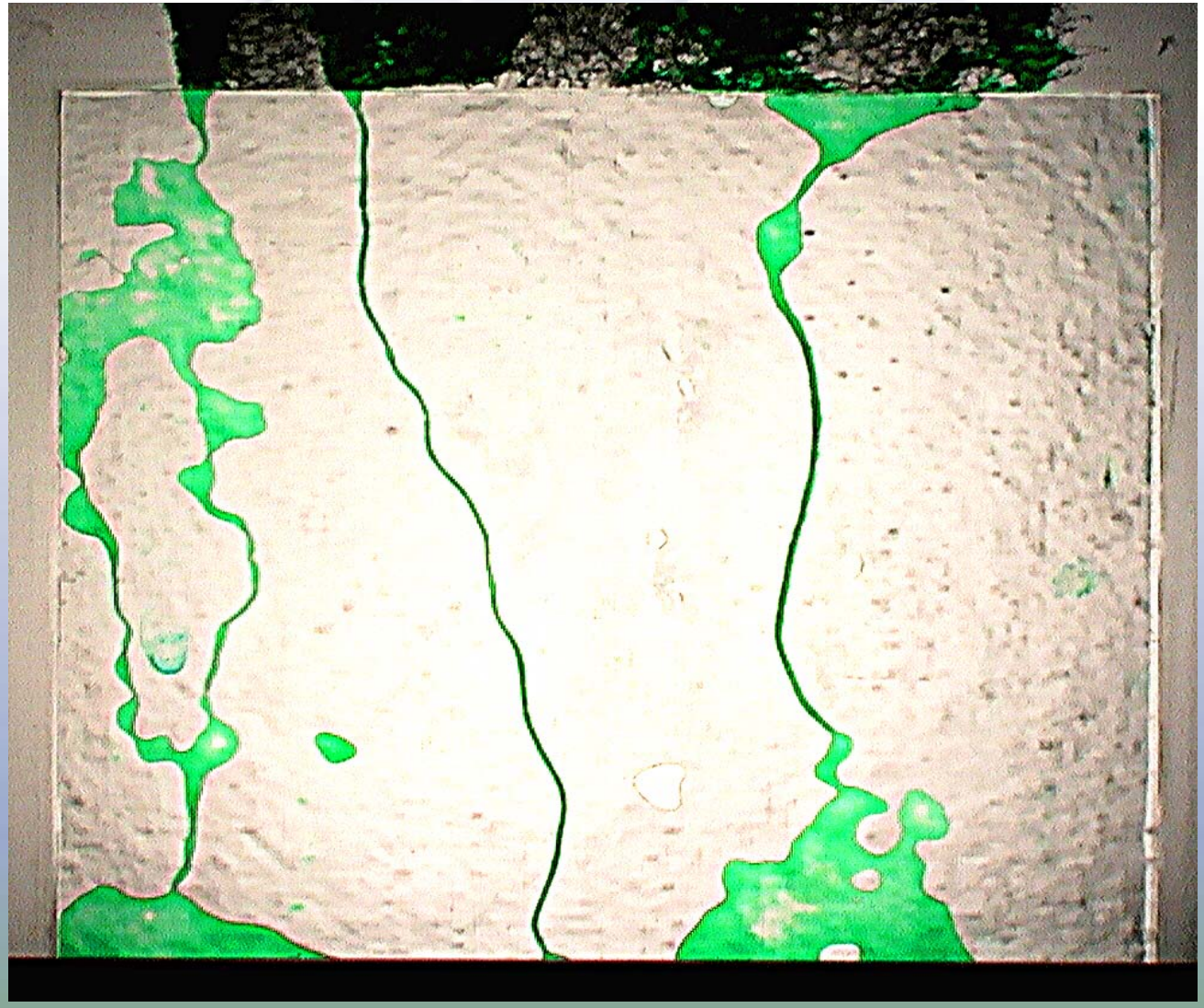
- The integration of experiments and computer modeling is a primary focus for this program: Experiments will be used to test computer models results and computer simulations will be used to extend and motivate experiments.
- A basic experimental setup has been designed and built.
- Cell design will be based on stereolithographic fabrication (not machining). Daphne Stoner, Vance Deason, Robert Stedfeld
- Fracture apertures can be designed on the computer, or the complex geometry of fracture surfaces can be measured, transported to CAD design software and then exported to the format needed for fabrication.
- Very detailed apertures can be fabricated at relatively low cost.
- Open questions:
- Transparent coating to control wetting properties.
- Accuracy and reproducibility of flow cells.
- Fabrication from rock-like materials – powdered basalt, ceramics….

Flow Design and Fabrication

Synthetic Fractal Surface



Preliminary flow experiment in stereolithographically fabricated cell



Anticipated Results

- Development of the capability to model multiphase fluid flow in complex fracture apertures under a wide range of conditions.
- Information and understanding needed to develop and refine conceptual models – pathway to large scale applications.
- Computer models that can be used (after some modification) for other applications:
  - Flow in fractured porous media, fracture junctions …
  - Transport of dissolved and colloidal solids.
  - Fluid/rock interactions – dissolution, mineral growth.
  - Impact of multiphase flow on biological processes.
- Contributions to fundamental physics and computer modeling.