INNOVATE NEW MEXICO™ TECHNOLOGY SHOWCASE

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INNOVATE NEW MEXICO™
Discover The State of Innovation

NEW MEXICO ECONOMIC DEVELOPMENT DEPARTMENT

Magnetic vortex fluids offer new routes for non-contact mixing and heat transfer

Presented by: Kyle Solis
Sandia National Laboratories
kjsolis@sandia.gov

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RESEARCHERS AND FUNDING

- **James E. Martin**
  - Distinguished Member of Technical Staff
  - Nanoscale Sciences Department
  - Sandia National Laboratories
  - Driven colloids, ER/MR fluids, composite materials, polymers

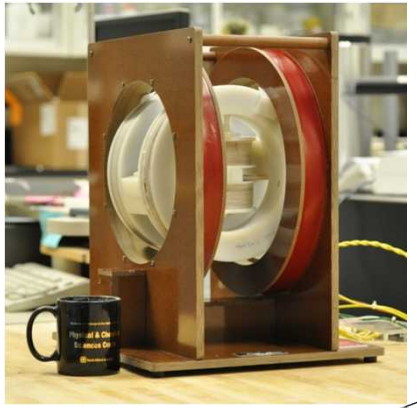
- **Kyle J. Solis**
  - Senior Member of Technical Staff
  - EM Systems Engineering & Qualification
  - Sandia National Laboratories
  - Applied electromagnetics, complex fluids, surface science

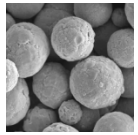
- **Funding**
  - Department of Energy, Office of Basic Energy Sciences, Division of Materials Science
  - SNL Laboratory Directed Research & Development

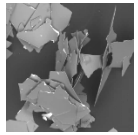
Sandia National Laboratories | Laboratory Directed Research & Development

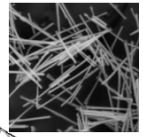
THE INNOVATION

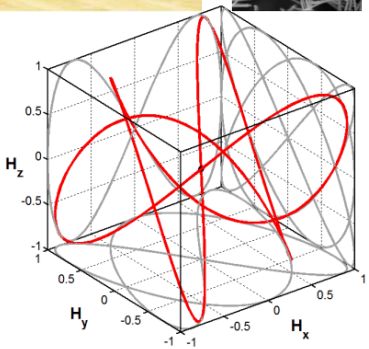
- Create deterministic vorticity in particle suspensions by applying particular multiaxial, time-dependent, uniform magnetic fields (*symmetry-breaking*, *rational triads* [2:3:4]).
- A *vortex fluid* is a magnetic particle suspension possessing a *uniform torque density*.
- Implications: strong mixing, active wetting, negative viscosity, biomimetic dynamics & droplet control.

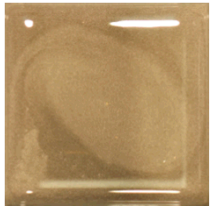


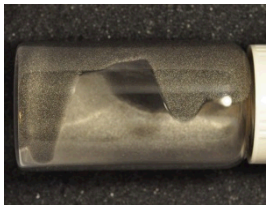












BACKGROUND

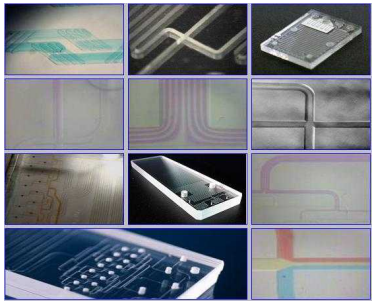
- *Emergent dynamics of driven colloids* is a growing research area. (Annual CECAM* workshop Lausanne, Switzerland)
- Numerous possibilities by tuning various interactions: van der Waals, surface/interfacial & steric, Coulomb, dipolar, hydrodynamic *etc*.
- Limitations of conventional methods of moving liquids:
  - *Natural convection* requires gravity and a destabilizing thermal gradient.
  - *Forced convection* requires moving parts: pumps, impellers, valves & seals.
  - *Thermomagnetic convection* requires thermal gradient and large field gradients.
  - *Magnetohydrodynamics* requires large currents and strong magnetic fields.

*Centre Européen de Calcul Atomique et Moléculaire

APPLICATION

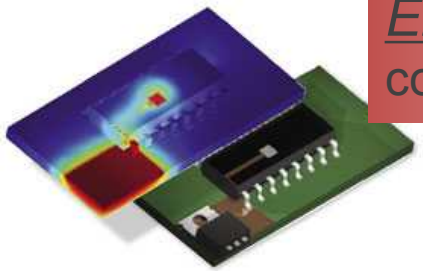
- Vigorous, *non-contact* fluid flow is important for technologies that employ mass/heat transfer.
- Magnetically-based systems offer a number of advantages for controlling transport phenomena:
  - Manipulate magnetic particles (move, orient, and arrange).
  - Magnetic fields easily penetrate most enclosure materials.
  - Easy to generate magnetic fields in practice.
  - Magnetic field of 35Oe has same energy density as electric field of 10kV/cm.
- *Vortex fluids* entail many benefits:
  - *Scale invariant*: The mixing torque is independent of particle size.
  - *Homogeneous mixing*: Efficient mixing throughout entire volume w/o instabilities.
  - *Adaptive to complex geometries*: Ideal for small, complicated channels/cavities.
  - *Easily-recoverable particles*: No complicated separation processes. Field gradient.
  - *Modest magnetic fields*: Efficient mixing with fields ~0.01T.

NEED/MARKET POTENTIAL



Biotechnology: noncontact control & mixing in microdroplet arrays for bioassays, microfluidic applications.

Aerospace: cooling in microgravity environments



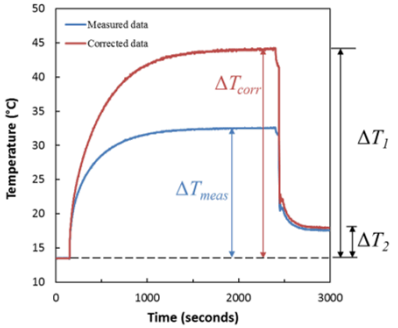
Electronics: liquid-based cooling (no fan noise)

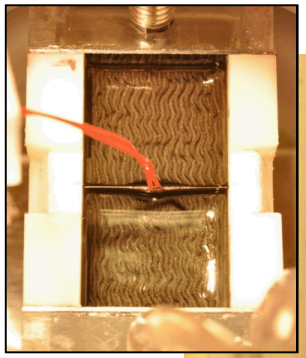
Chemical process industries: Surface-functionalized/heterogeneous particles: biological, catalysis, magnetic fluidized bed reactors.

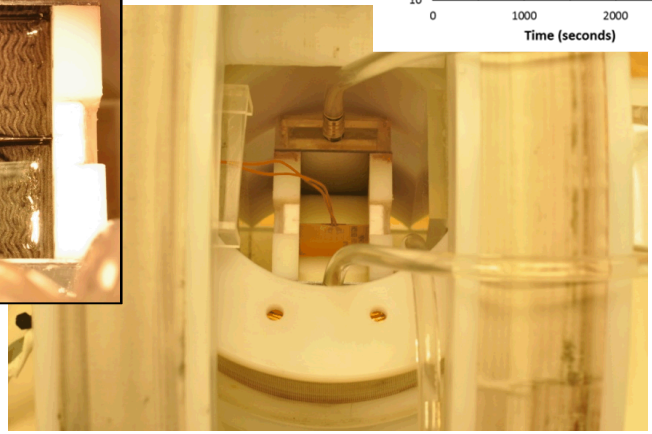
DATA AND RESULTS

Thermal "valve"

- Resistance thermometry
- 100:1 control range
- Apparent thermal conductivity 18.3W/m·K

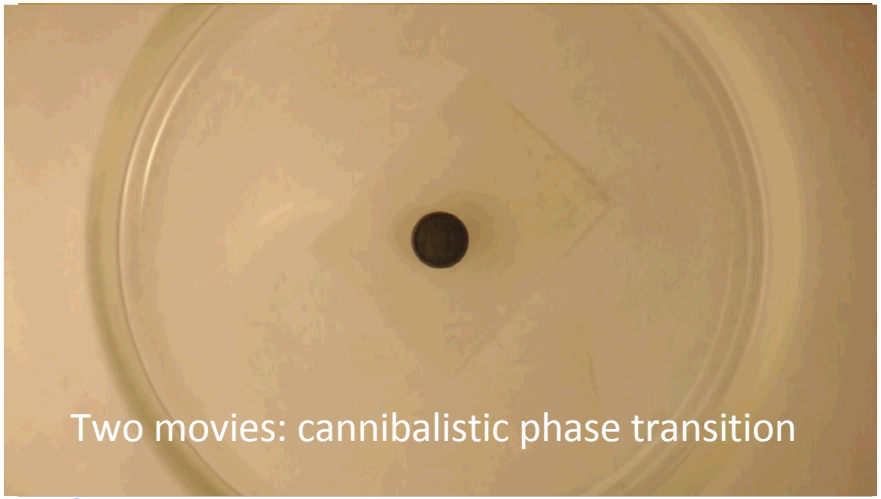






Biomimetic dynamics

- Non-equilibrium emergent phenomena
- Controlled dispersal/sequestration
- Controlling droplet transport



CURRENT STATUS

- 15+ publications, 3 cover articles, 1 patent pending, news releases.
- Quantified torque density of magnetic mixing.
- Quantified heat transfer efficiency/capabilities.
- Discovered 2 classes of fields: *symmetry-breaking* and *rational triads*.
- Developed symmetry theories to predict vorticity/mixing behavior.
- Demonstrated multi-axis control through field-symmetry transitions.
- Remaining engineering challenges of developing application-specific technology.