Final Report

1. DOE award number and recipient institution:

DE-FG02-06ER46298
Department of Physics and Astronomy
University of Rochester
Rochester, NY 14627

2. Project title and PI:

Critical Phenomena in Driven Granular Matter: Jamming and Glassy Behavior

PI: Stephen Teitel, Professor of Physics

3. Date of report: February 18, 2013
Period covered by report: May 2011 − April 2013

4. Research accomplishments:

• We have simulated the rheology of a simple system of bidisperse, soft-core, frictionless disks undergoing uniform steady state shearing near the jamming transition. We develop a mapping from this soft-core system to an effective system of hard-core particles, and show that this mapping recovers, in a simple way, the results of previous critical scaling analyses for the divergence of viscosity at jamming. Using this result to map soft-core particles above jamming to hard-core particles below jamming, we derive a relation that gives the exponent of the nonlinear Herschel-Bulkley shearing rheology above jamming in terms of the exponent of the diverging viscosity below jamming. This prediction is found to agree with our numerical results. Work resulted in publication # 4 below. Work to directly analyze rheology above jamming in terms of a finite-size-scaling analysis is continuing with graduate student Theodore Marschall.

• Preliminary simulations of a simple system of bidisperse, soft-core, frictionless disks undergoing uniform steady state shearing at finite temperature have been carried out to investigate the relationship between athermal ($T = 0$) jamming and thermalized ($T > 0$) glassy behavior. Results show that shear viscosity, at fixed packing fraction and strain rate, is a non-monotonic function of temperature, and suggests that athermal jamming is singularly decoupled from thermalized glassy behavior. Work is continuing on this project with collaborator Prof. Peter Olsson of Umeå University, Sweden.

• Numerical simulations have been carried out to determine the distribution of stresses on finite sized clusters embedded within a larger statically jammed system. We seek to determine if this distribution is well described by a maximum entropy assumption. Work is continuing of this project. This work is being carried out with graduate student Yegang Wu.

5. Publications Acknowledging DOE Support
(publications #1-3 refer to work done during the prior period of DOE support, but citations were not available at the time of the previous report, so I include them here)

1. *Glassiness, Rigidity and Jamming of Frictionless Soft Core Disks*
   Daniel Vågberg, Peter Olsson and S. Teitel
   Phys. Rev. E **83**, 031307 (2011)

2. *Finite-Size-Scaling at the Jamming Transition: Corrections to Scaling and the Correlation Length Critical Exponent*
   Daniel Vågberg, Daniel Valdez-Balderas, M. A. Moore, Peter Olsson and S. Teitel
   Phys. Rev. E **83**, 30303(R) (2011)

3. *Critical Scaling of Shearing Rheology at the Jamming Transition of Soft-Core Frictionless Disks*
   Peter Olsson and S. Teitel
   Phys. Rev. E **83**, 030302(R) (2011)

4. *Herschel-Bulkley Shearing Rheology Near the Athermal Jamming Transition*
   Peter Olsson and S. Teitel
   Phys. Rev. Lett. **109**, 108001 (2012)

6. Conference and Seminar Presentations on DOE Supported Projects

1. *invited participant*
   Aspen Center for Physics Workshop on Fluctuations and Response in Granular Materials, Aspen, CO, 5/22/11

2. *Discussant on Sheared Colloidal Glasses* (invited)
   Lorentz Center Workshop on Fluctuations and Response in Active Materials: From Driven Granular Systems to Swarming Bacteria, Leiden, The Netherlands, 6/20/11

3. *Athermal Jamming vs Thermal Glassy Behavior in Uniformly Sheared Frictionless Soft-Core Disks*
   12th New York Complex Matter Workshop, Cornell University, Ithaca, NY, 12/9/11

4. • *Athermal Jamming vs Thermalized Glassiness in a Simple Model of Soft-Core Interacting Particles*
   • *Mapping From Soft to Hard-Core Disks Near the Athermal Shear Driven Jamming Transition*
   • *Effect of Inertial Mass on Velocity Correlations of Shear Driven Soft-Core Disks Approaching the Athermal Jamming Transition*
   March Meeting of the American Physical Society, Boston, MA, 2/27/12

7. Personnel Supported

The following personnel received DOE support during this report period:

PI − Prof. Stephen Teitel, support for 1.45 months salary

Ph.D. Student − Mr. Yegang Wu, support for 14.29 months salary

Ph.D. Student − Mr. Theodore Marschall, support for 7 months salary

8. Research support:

The PI receives additional research support from:

- NSF-DCBET program, *Collaborative Proposal: Rheology and Flow of Geometrically Cohesive Granular Materials*, co-PI on grant with Prof. Scott Franklin of Rochester Institute of Technology, awarded 9/2011, $100,564 for three years
- NSF-DMR program, *Shearing Rheology and Glassy Behavior in Athermal and Thermalized Models of Granular Materials, Simple Liquids, and Amorphous Solids*, PI, awarded 9/2012, $296,676 expected for three years

Due to the termination of DOE funding, NSF funding was sought to continue work on this, and related, projects.

9. Unexpended funds:

There are no unexpended funds remaining from this DOE grant.