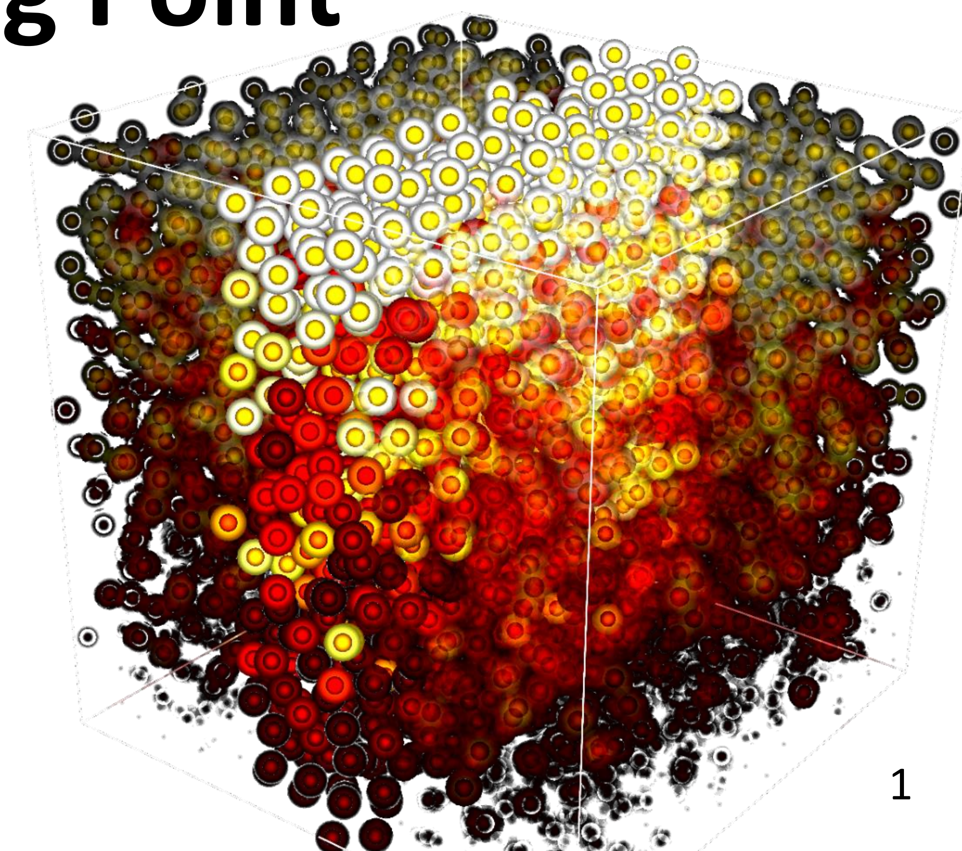
Thermal Fluxes in Wall Bounded Sheared Granular Beds Near the Jamming Point

<u>T. Forgber</u>, S. Radl
Graz University of Technology
Austria



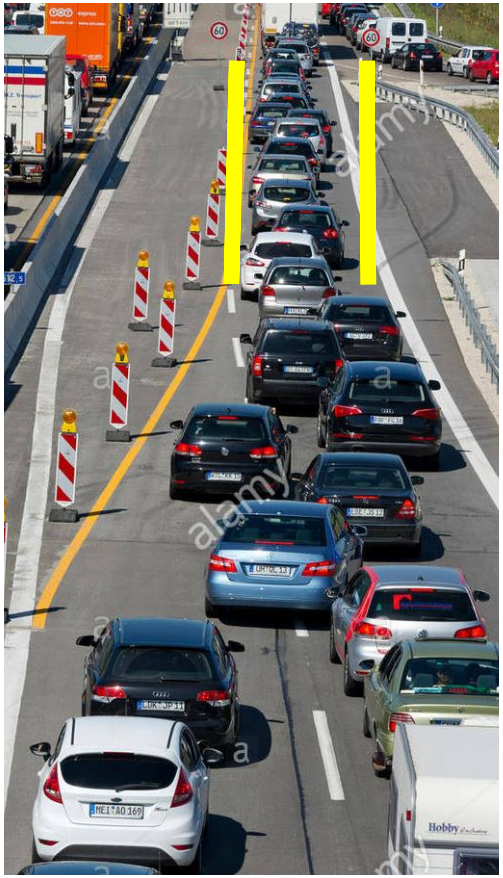
Introduction

Introduction

"Jamming occurs when a system develops a yield stress—behaves as a solid—in a disordered state." (Liu Research Group webpage)

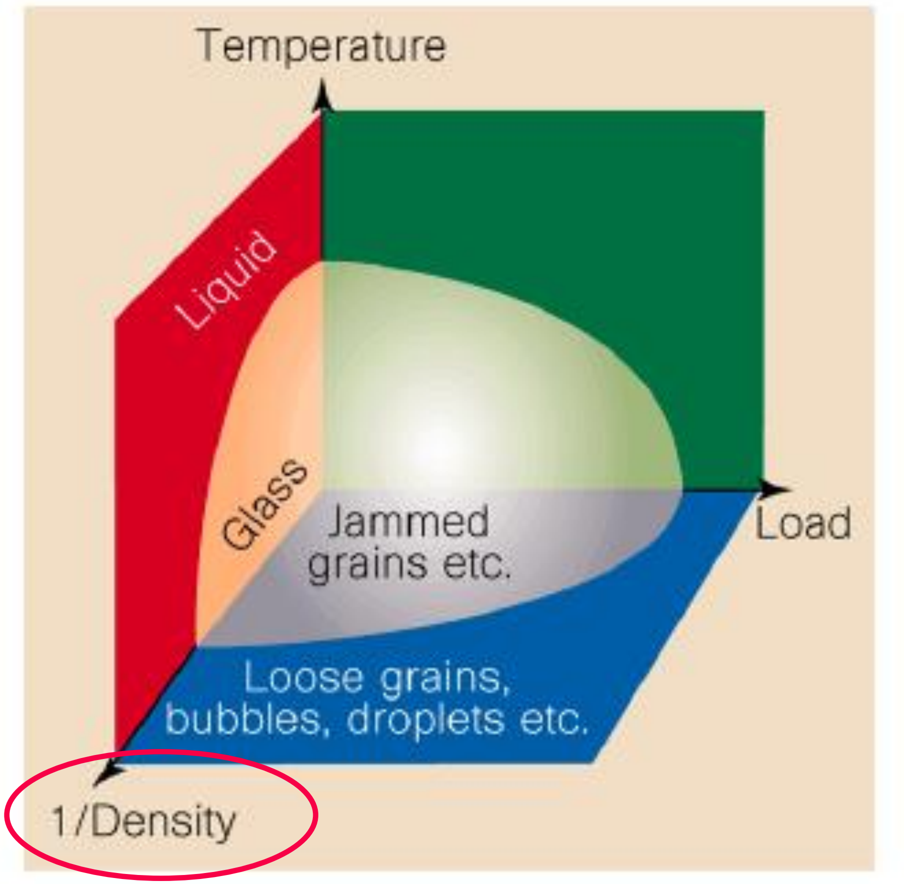
- Stress relaxation time of a system exceeds a certain value
- Can be found in many applications as
  - Supercooled liquids
  - Glass
  - Foams and emulsions
  - **Granular materials**

- Granular material at high packing density relevant for **reactors, geomechanics**, etc.
- Thus, effect of jamming on **local particle temperature** is interesting

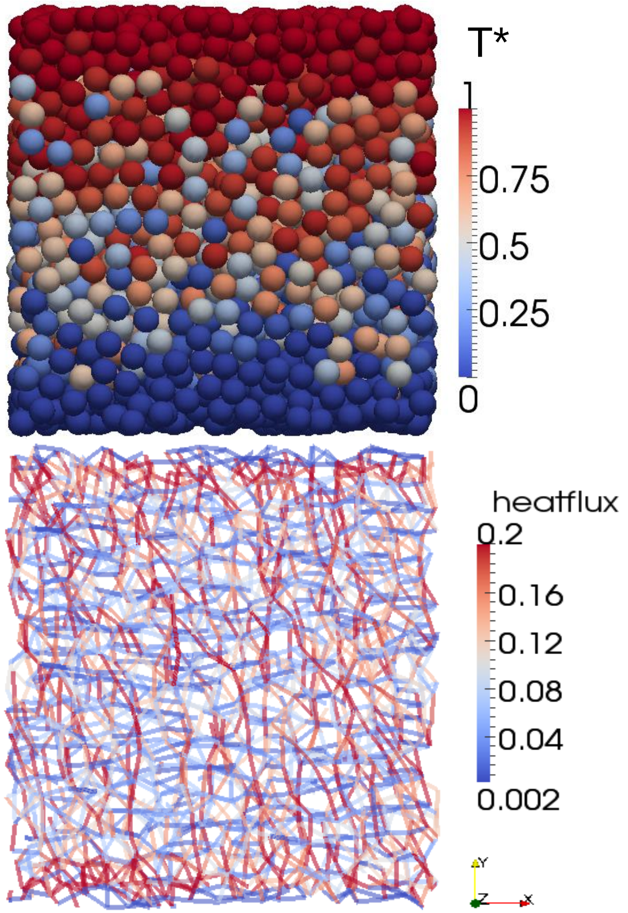


Introduction

Jamming Point Diagram[1]



Local Particle Temperature? Effective Heat Conductivity?[2]



[1]A. J. Liu and S. R. Nagel, ***Nature*** 396, N6706, 21 (1998)
[2]Mohan et al. (2013), ***Fluidization XIV***

Simulation Method

Simulation Method

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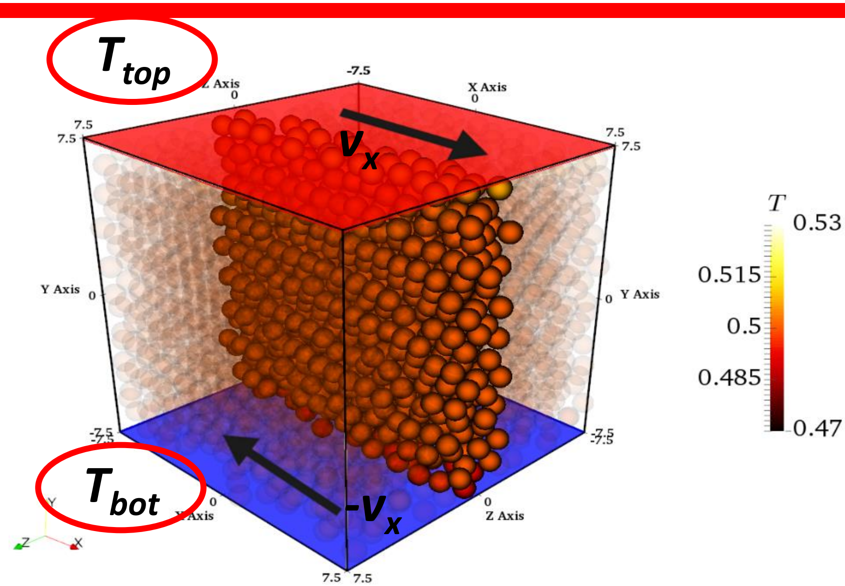


- Deformation of box with **constant wall velocity**, periodic BC
- Parameter dependency:
  - **Biot number**
  - Wall velocity (shear rate)
  - **Volume fraction**
  - Particle conductivity
- **Thermal fluxes** are simulation result

Biot number

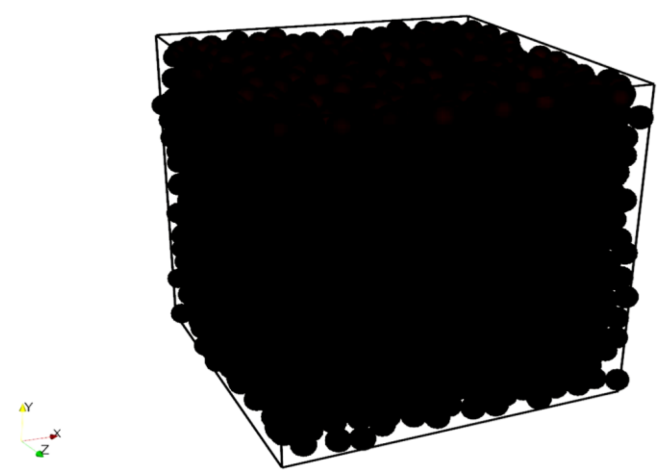
$$Bi = \frac{\alpha\, d_p}{\lambda_p}$$

$$\dot{\gamma} = \gamma\, d_p^{3/2} / \sqrt{k_n/\rho_p}$$

Dimensionless shear rate

Peclet number

$$Pe = \frac{(d_p/2)^2}{\lambda_p/(\rho_p\, c_p)}\, \gamma$$



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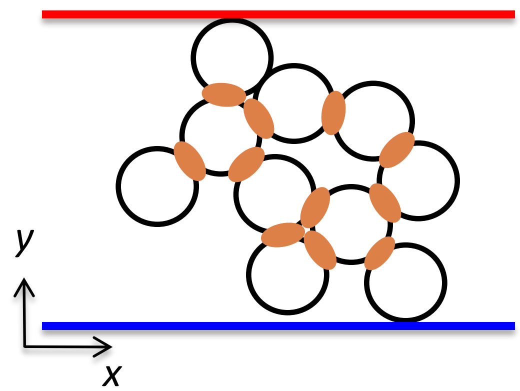
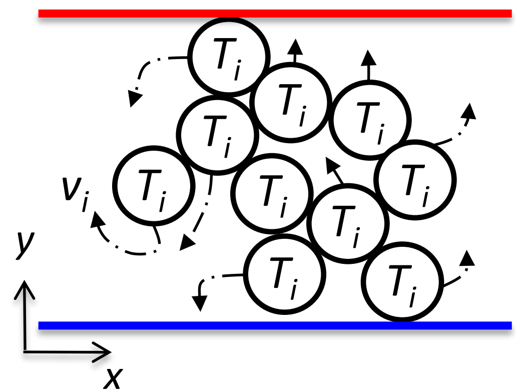


- **Conduction** due to particle-particle contact

$$\mathbf{q}^{cond} = \frac{1}{V}\sum_{co} 2\,\lambda_P\, A_{co}^{1/2}\,(T_i - T_j)\,\mathbf{r}_{ij}$$

- (Granular) **Convection** due to individual particle motion

$$\mathbf{q}^{conv} = \frac{1}{V}\sum_{i} m_{eff,i}\, c_{p,i}\, T_{vol,avg,i}\, \mathbf{v}_i$$



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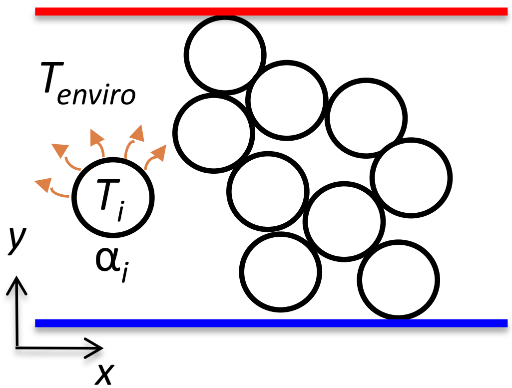


- **Transferred** thermal energy to the environment, fixed T_{enviro}, fixed Biot number

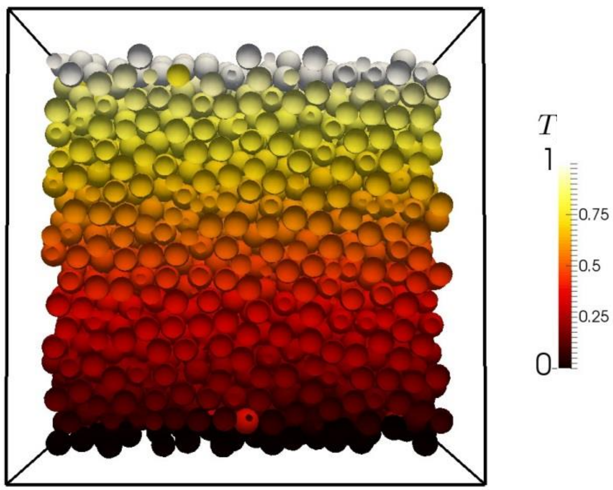
$$q^{trans,i} = \alpha\left(T_i - T_{f,i}\right)$$

- **Particle-Particle radiative** flux currently not considered. Energy emission **does not heat particles**.

$$q_s = -\lambda_p \frac{\partial T}{\partial y}$$

- **Reference heat flux** equals flux in the pure solid

Simulation Method



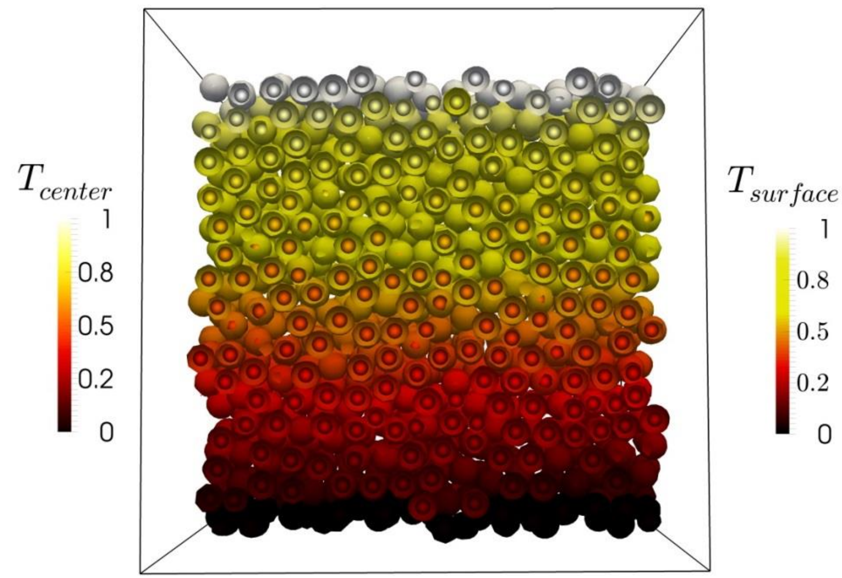
+

LIGGGHTS

particle motion

ParScale

intra-particle
temperature
profile



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Results

Results

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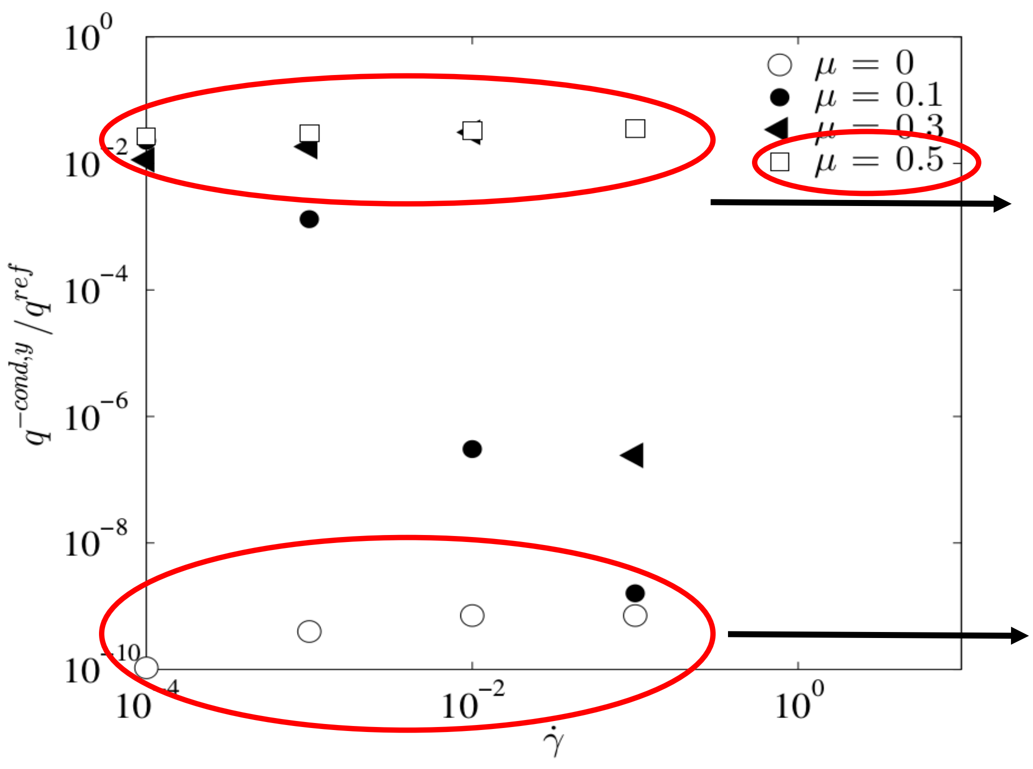
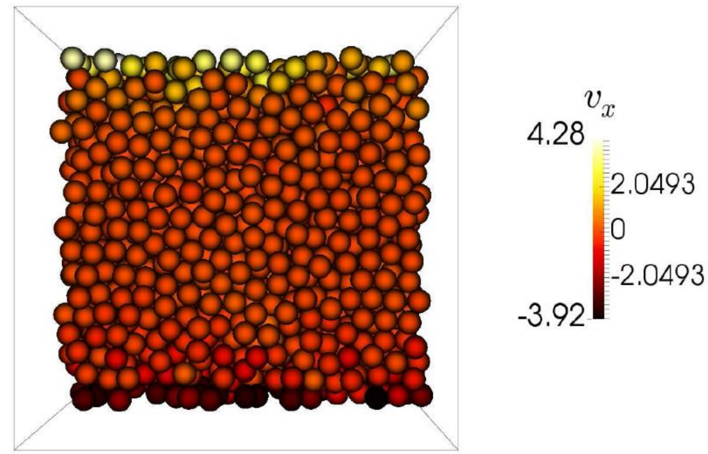
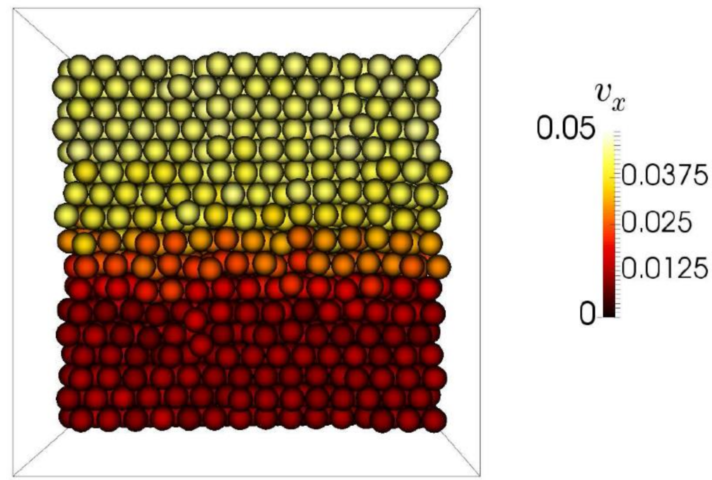
Crystallized versus Non-crystallized Flow

$Pe = 0.01$, $Bi = 0.1$, $\phi_P = 0.64$



Softer particles

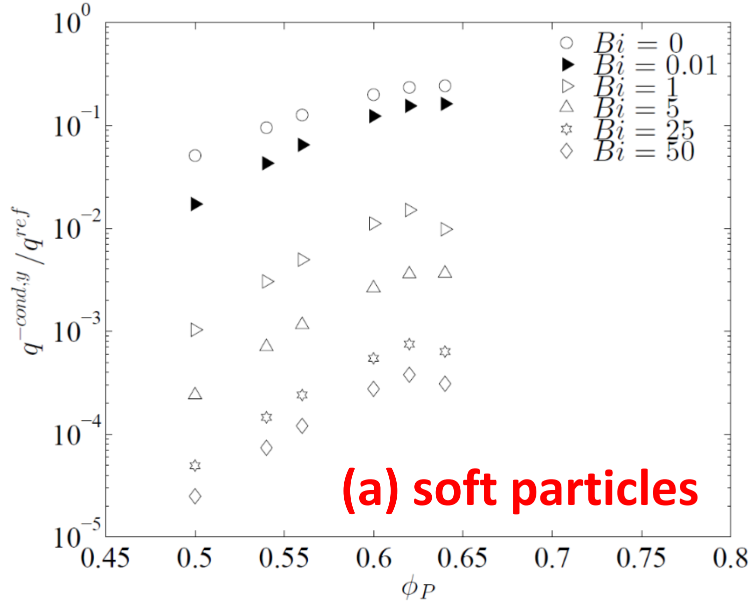




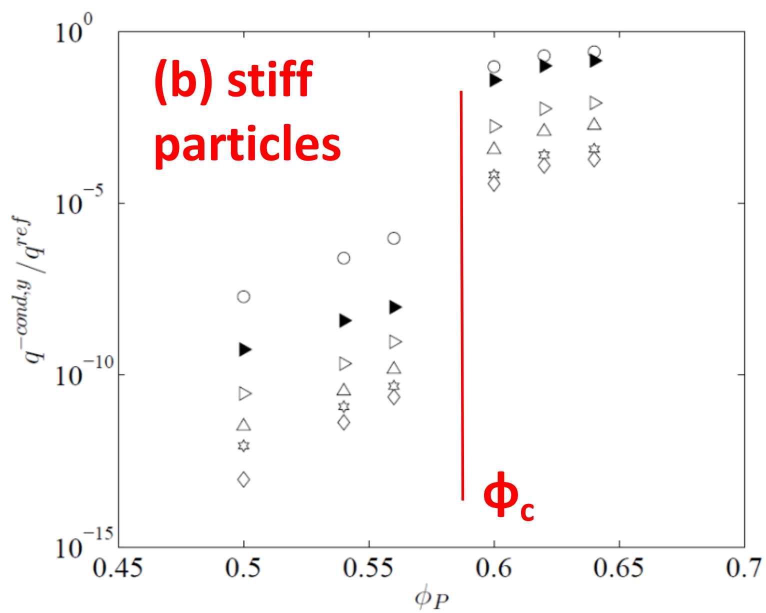
Results

Scaled conductive flux

Pe = 0.01, (a) $\dot{\gamma} = 10^{-1}$, (b) $\dot{\gamma} = 10^{-4}$



- Significant **increase of the conductive thermal transport rate** in case of jamming
- Critical jamming volume fraction depends on **particle stiffness**

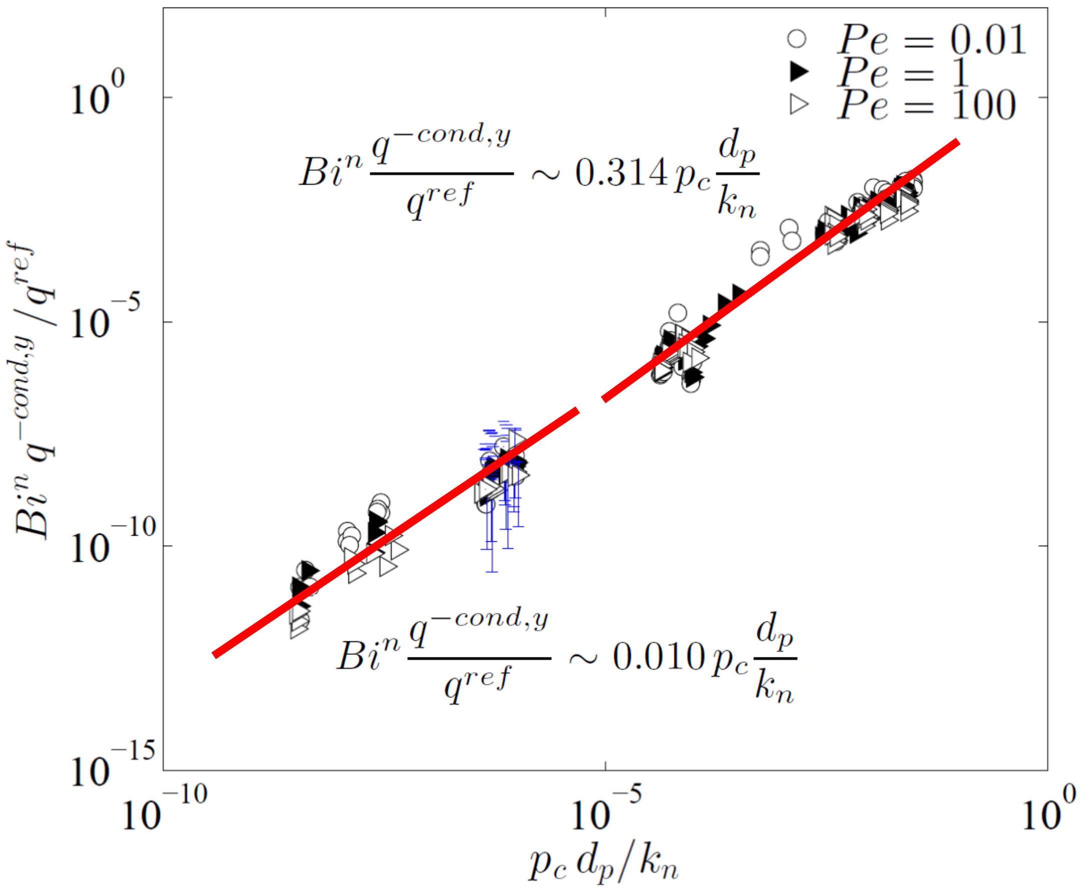


- Effect seen for **all Biot numbers**
- Critical volume fraction does not depend on **Peclet** number

Results

Conductive flux versus Dimensionless Contact Pressure

n ~ 4/5 leads to a collapse of all data

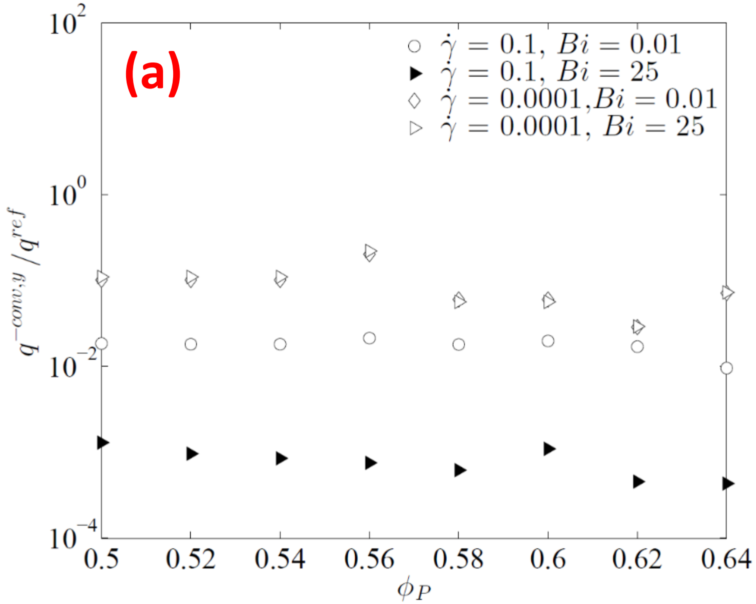


- **Correlate** dimensionless conductive flux with dimensionless contact pressure
- Increase in dimensionless contact pressure in jammed system **explains high conductive heat flux**
- **Large fluctuations** in pressure and heat flux when transitioning between regimes

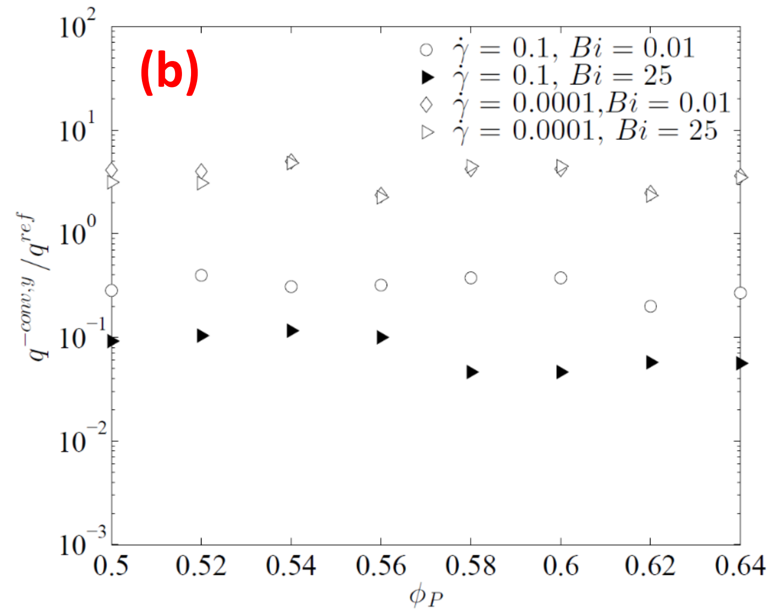
Results

Convective flux versus Particle Concentration

(a) *Pe* = 1, (b) *Pe* = 100



- **Convective flux unaffected** by change of particle concentration
- No significant effect due to jamming transition



- Nearly **independent of Biot number for stiff particles**
- **Peclet number** key for modeling convective flux

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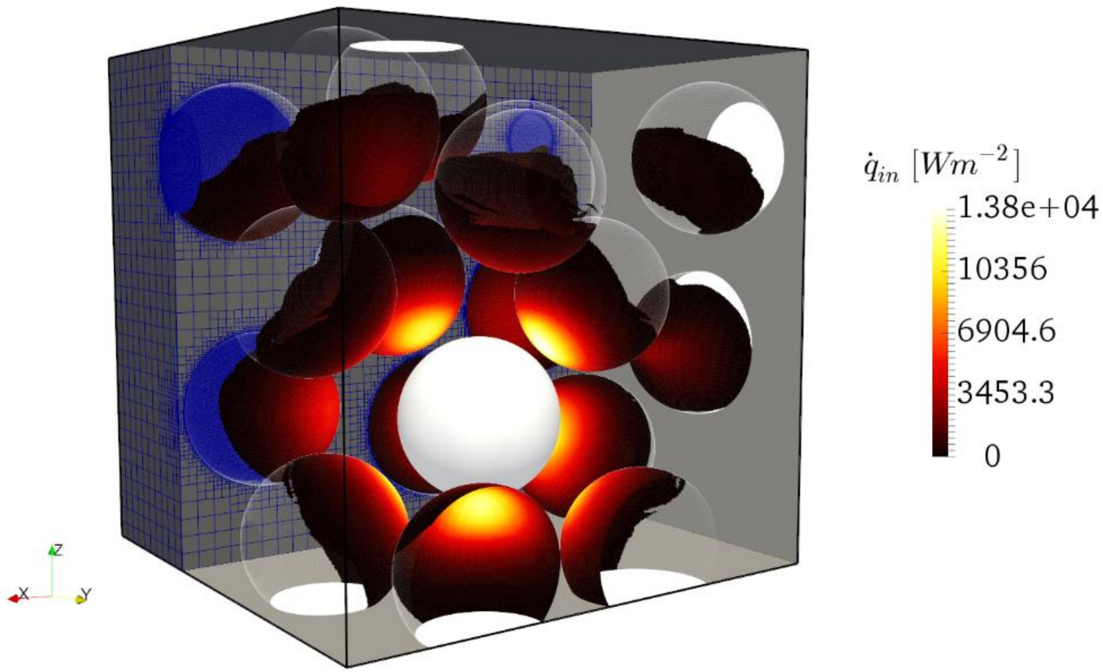
Conclusion & Outlook

Conclusion & Outlook

- Detailed simulation of **convective, conductive, and transferred** thermal fluxes **including intra-particle temperature** profiles
- **Drastic increase of the conductive flux** in a jammed system. **Closure relationship** for conductive flux provided based on contact pressure
- **Convective** flux unaffected by jamming
- Current research focus: **include radiation** by fast algorithm to quantify shadowing effect
- More: PTF poster session, **Tue, Nov 15th, 6.00 p.m.**



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Thank You!

Questions?

Funding Information
EC Grant #604656, and "NAWI Graz" by providing access to dcluster.tugraz.at.

SEVENTH FRAMEWORK PROGRAMME

NanoSim