Experimental Measurement of an Effective Temperature for Jammed Granular Materials

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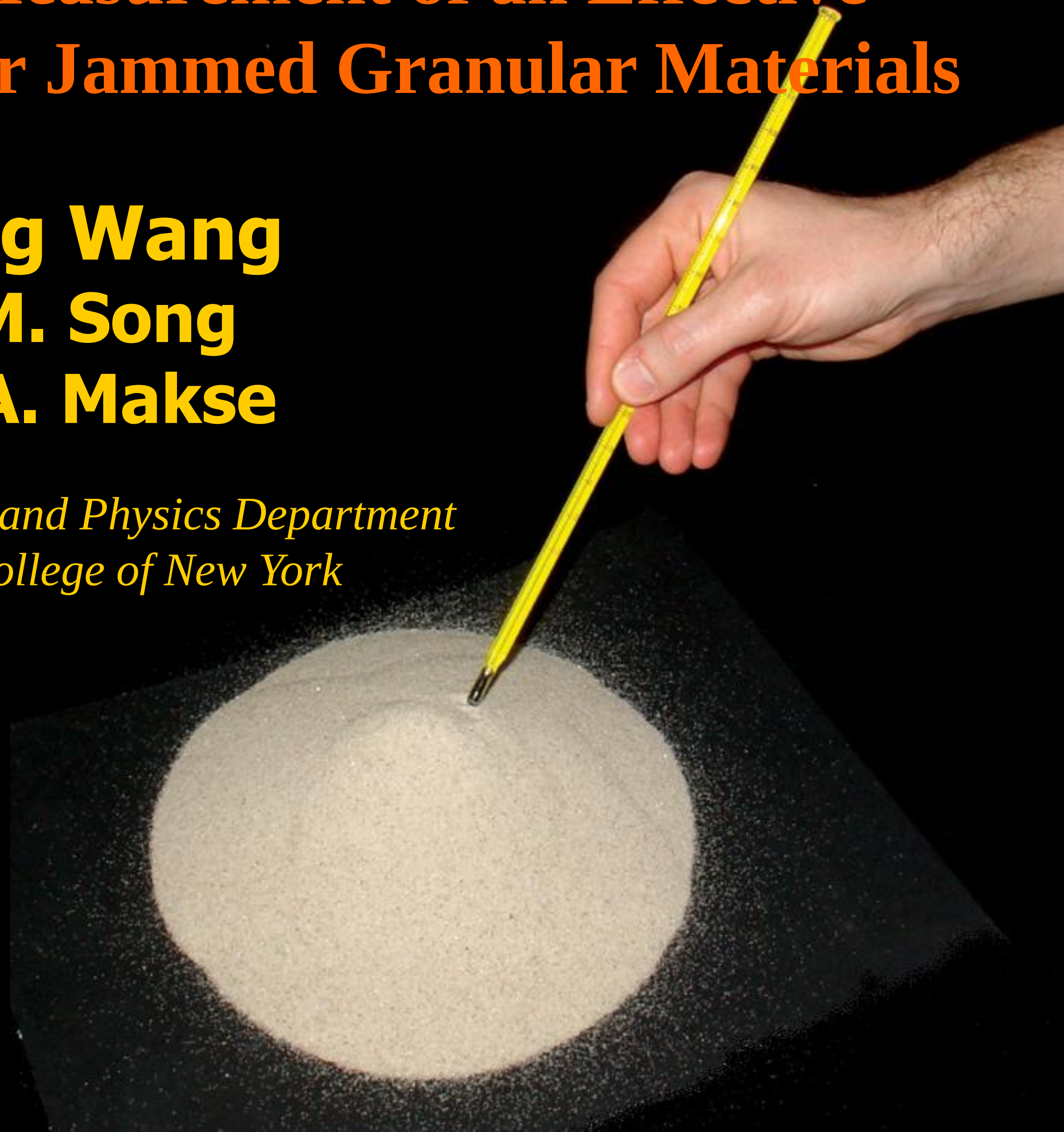


Dynamical Definition of Effective Temperature

We define Teff using a FDT theorem

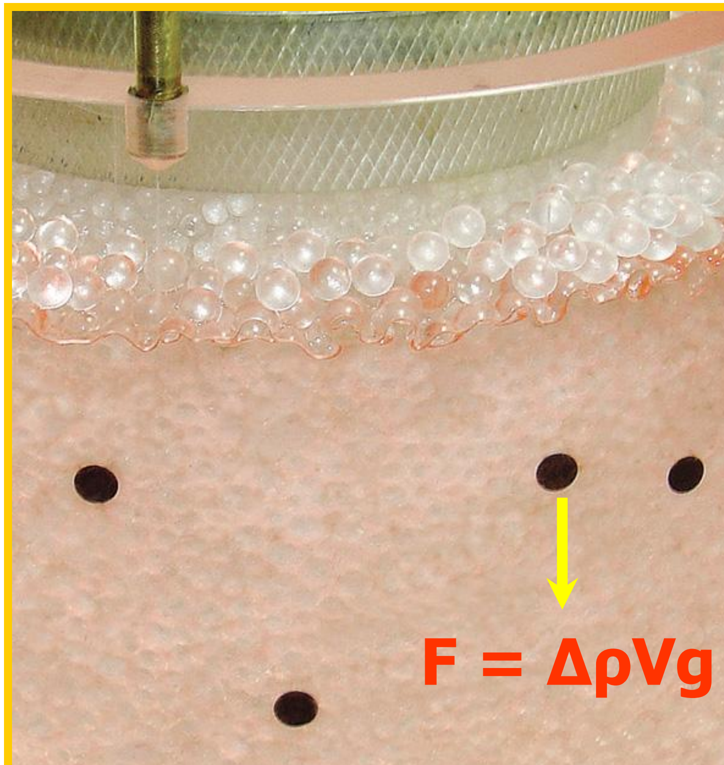
Follow add tracer in a slow granular shear flow

- **Correlation Function: "Brownian motion"**

$$<|x(t)-x(0)|^2> \sim 2Dt \quad (D = \text{diffusivity})$$

- **Response function: gently pull with an external force F**

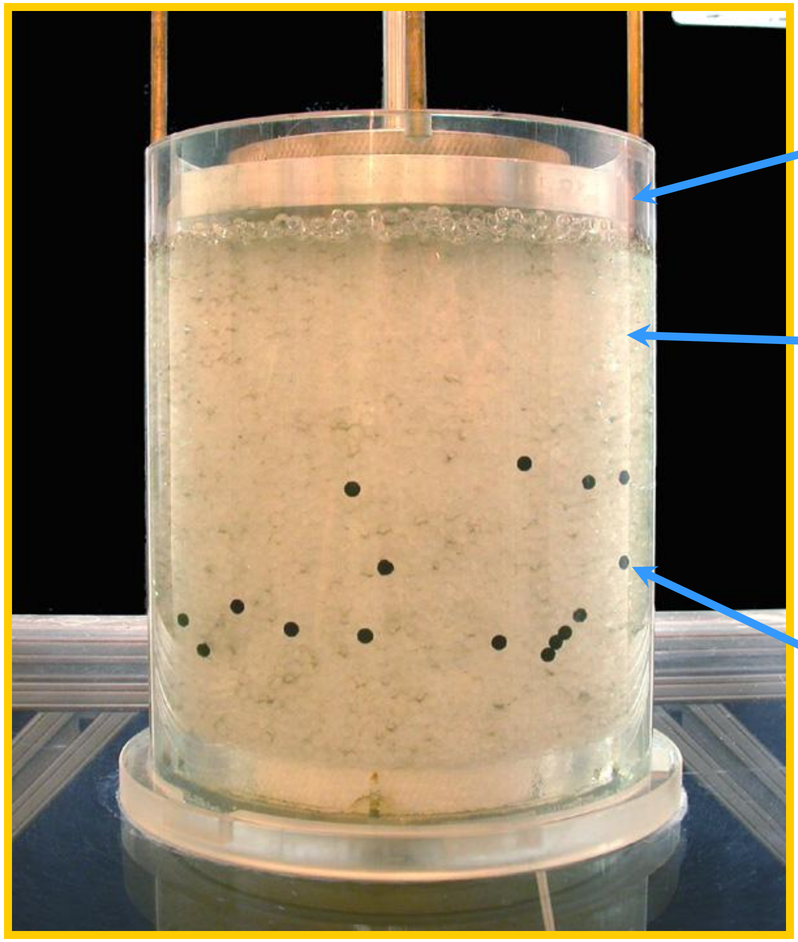
$$<|x(t)-x(0)|> \sim M\,F\,t \quad (M = \text{mobility})$$



- **Stokes-Einstein relation:**

$$<|x(t)-x(0)|^2> = 2\,T_{eff} <|x(t)-x(0)|>/F$$

Experimental set-up to measure the effective temperature in quasi-static granular materials

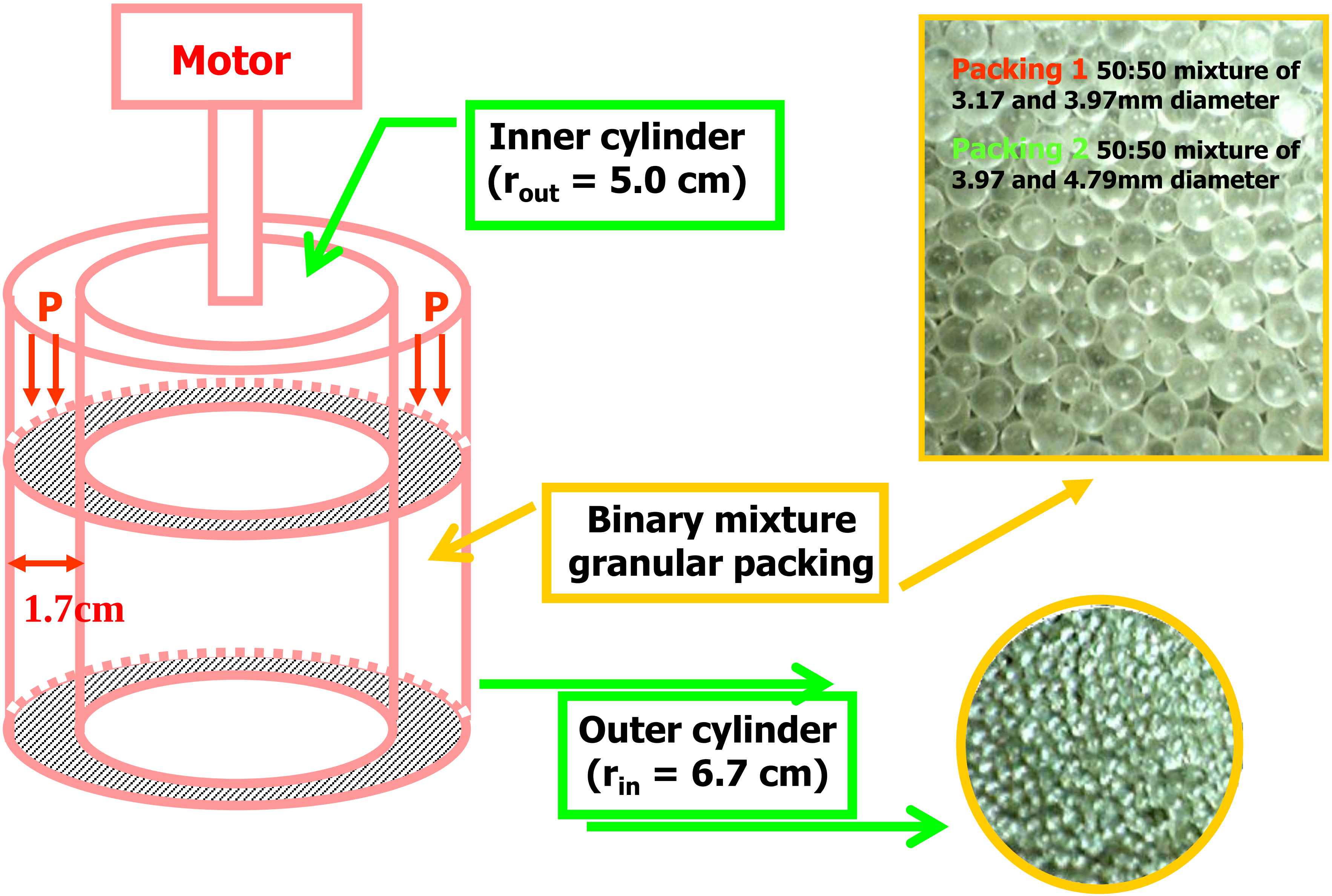


System consists of:

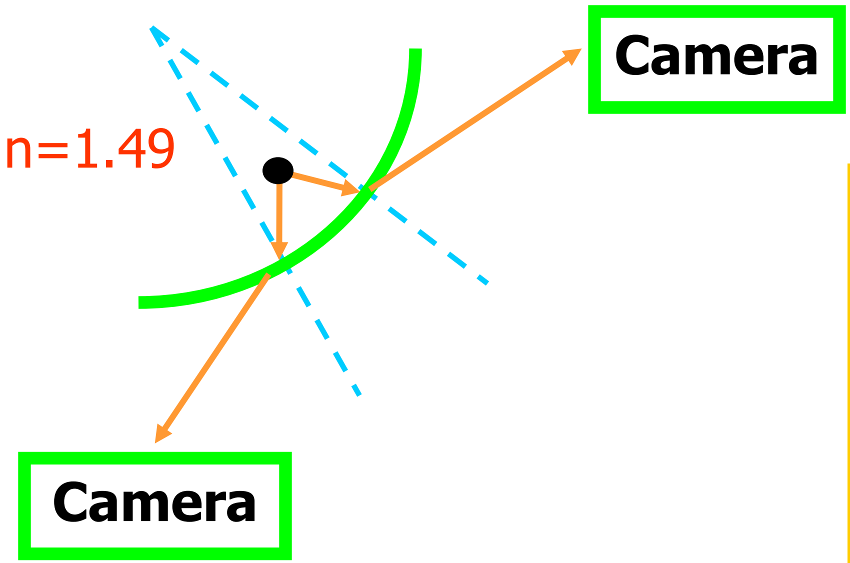
- Slowly sheared **Couette Cell** (0.01/s) at constant pressure(0.4kPa).
- Background **PMMA (acrylic)** particles (50:50 mixture of 3.17 and 3.97mm diameter) in a refractive index and density matching **solution.**
- **20 tracers** with a different density from the background particles.

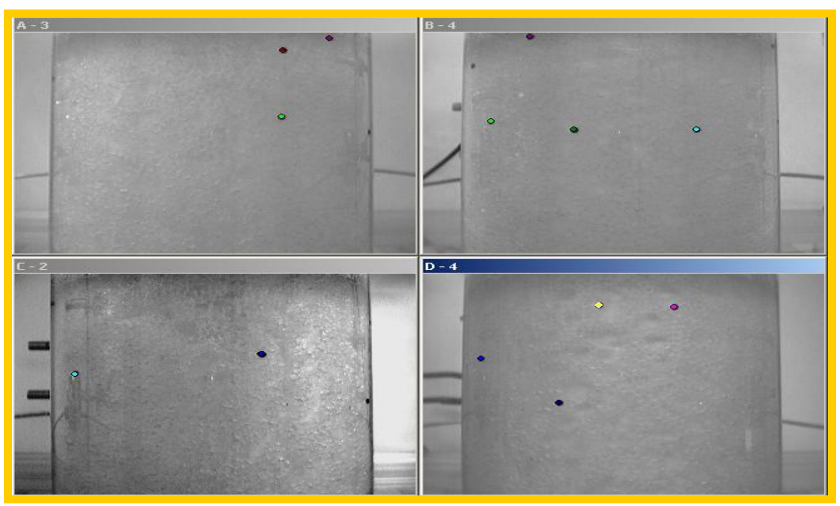
Tracer trajectories are tracked and used to determine the effective temperature.

Sketch of Experimental Set-Up

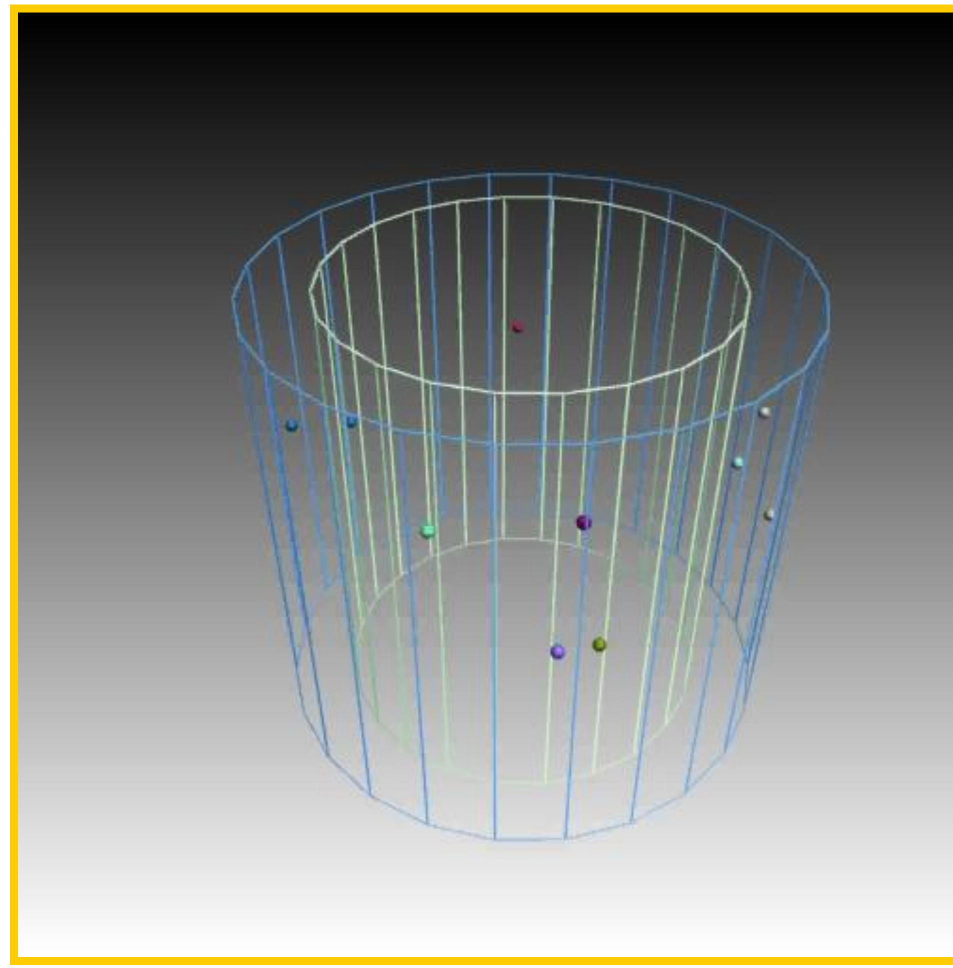


Technique of tracking tracers

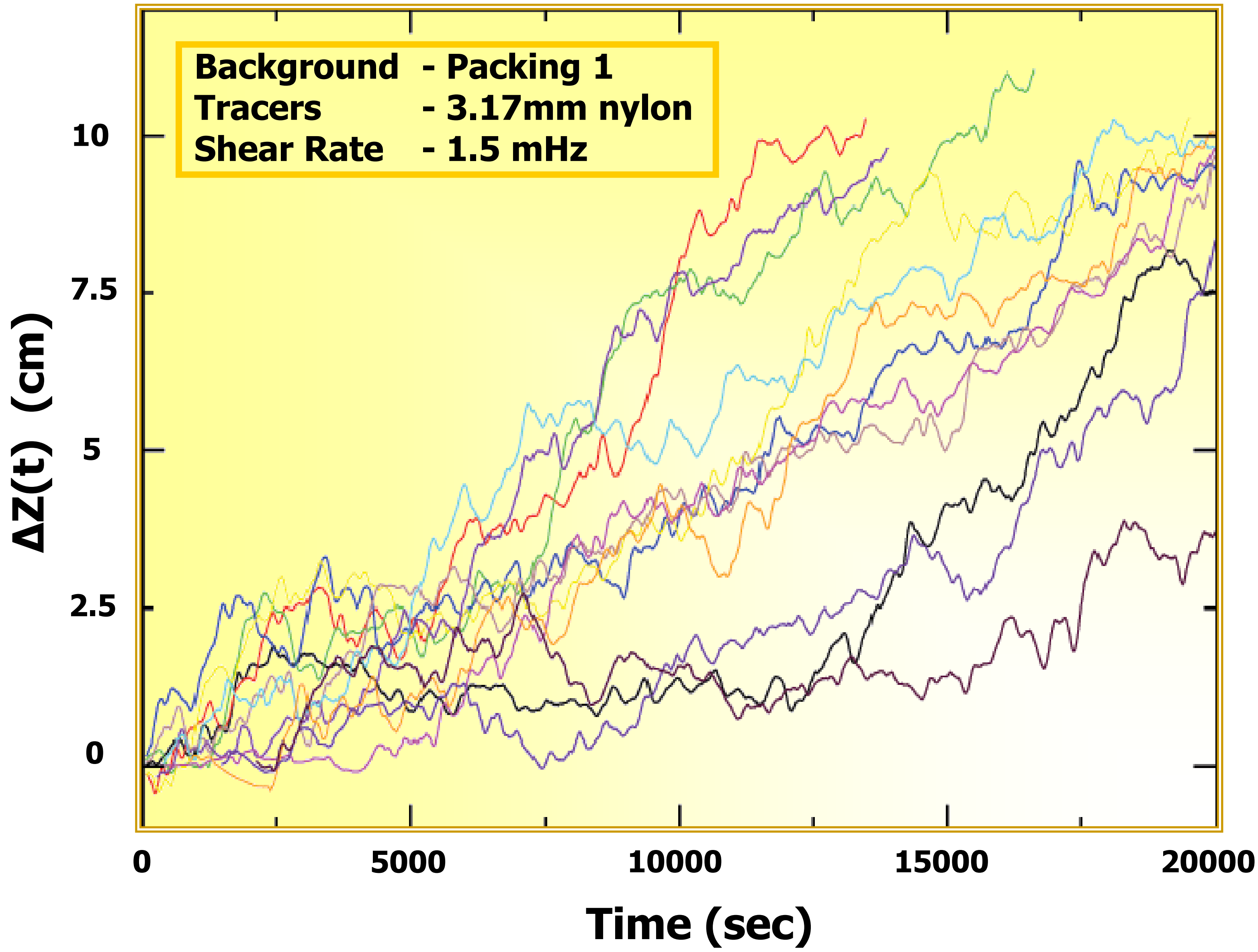




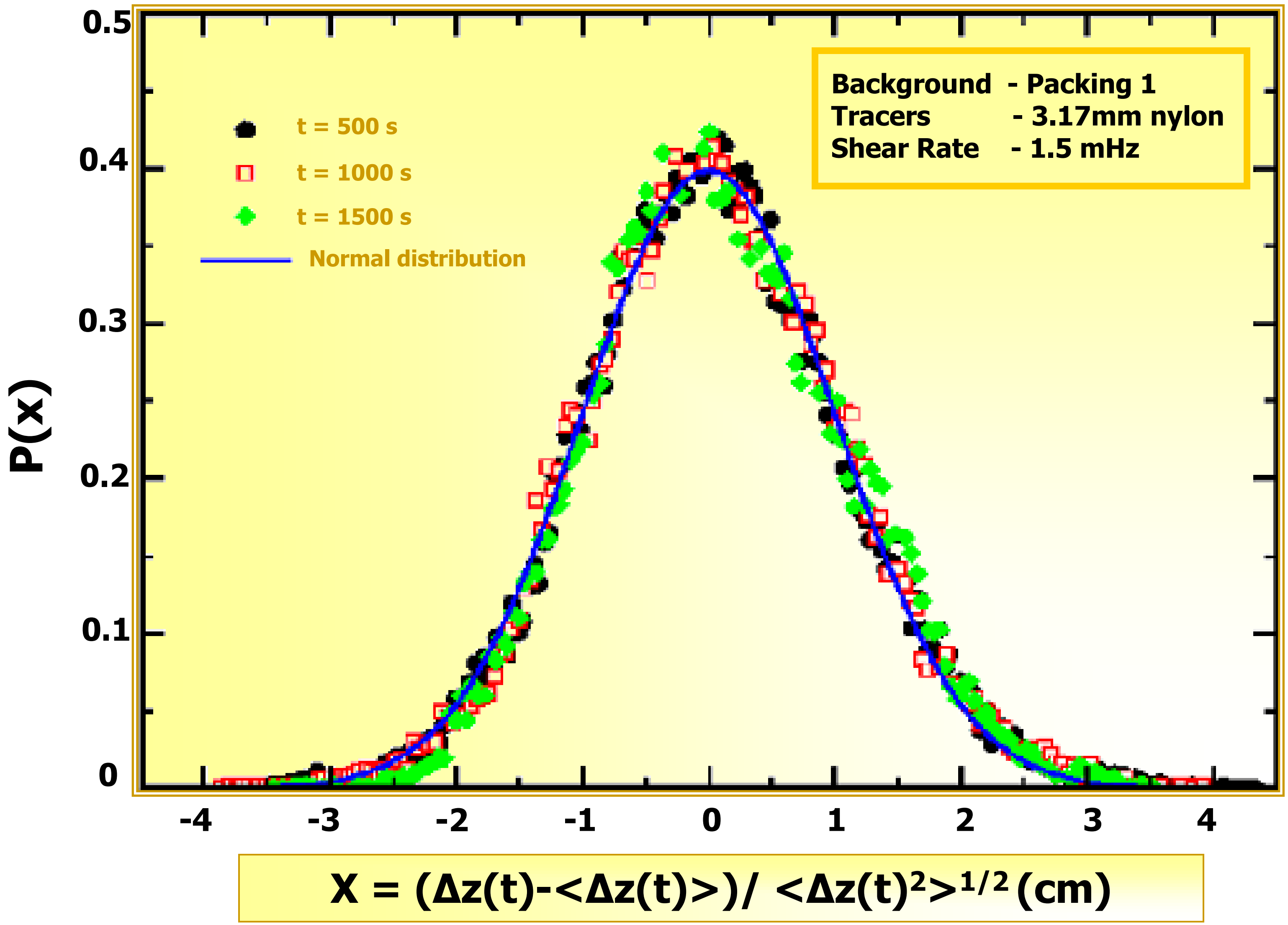
120 x realtime



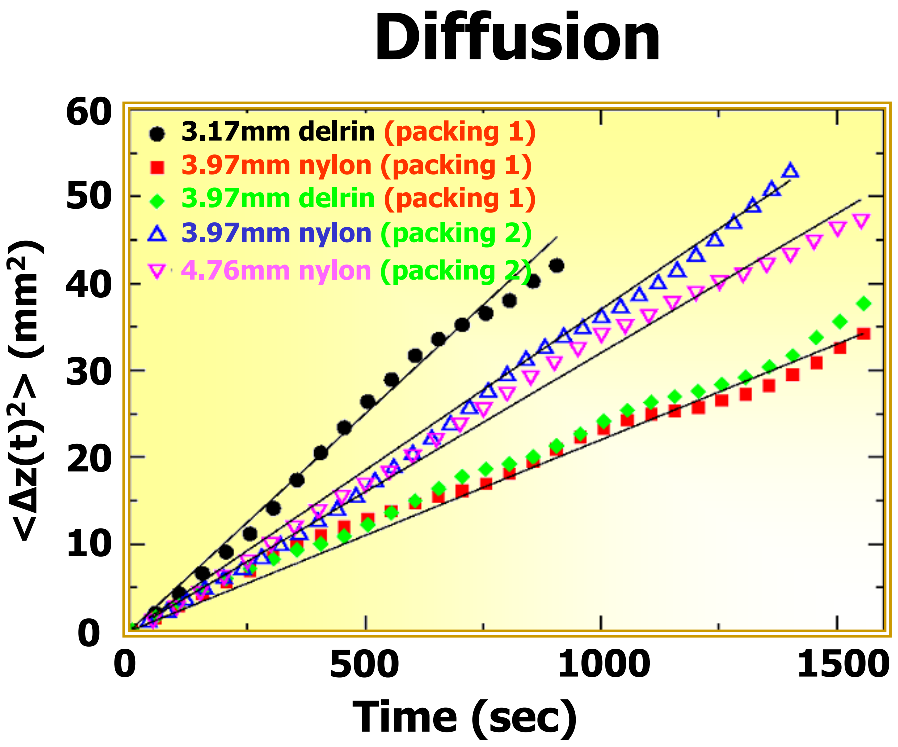
Trajectories of tracers

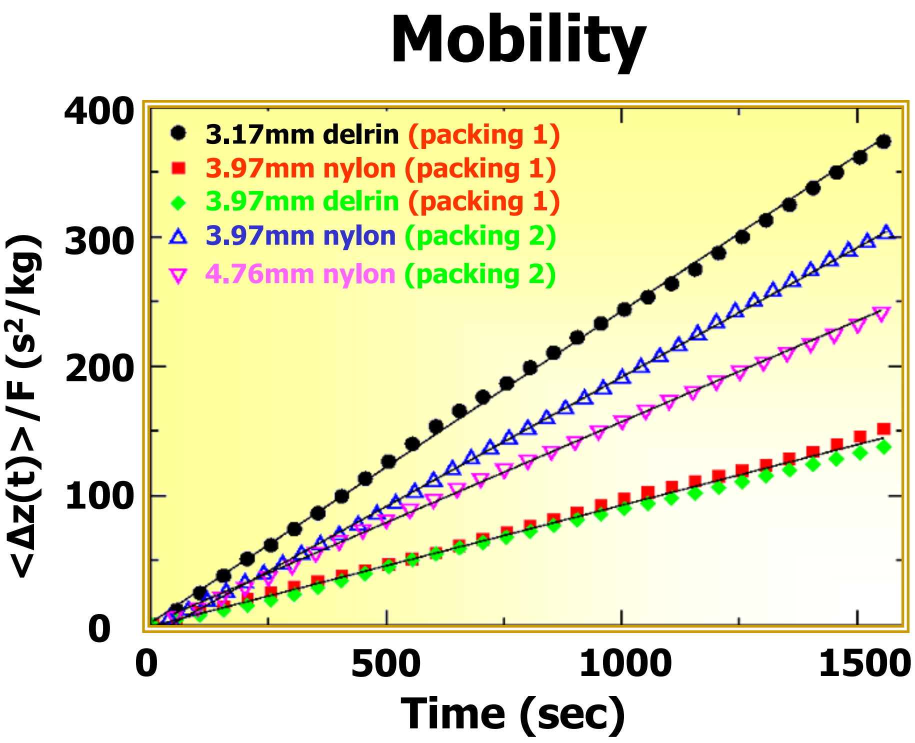


Gaussian distribution of tracer displacements at different times



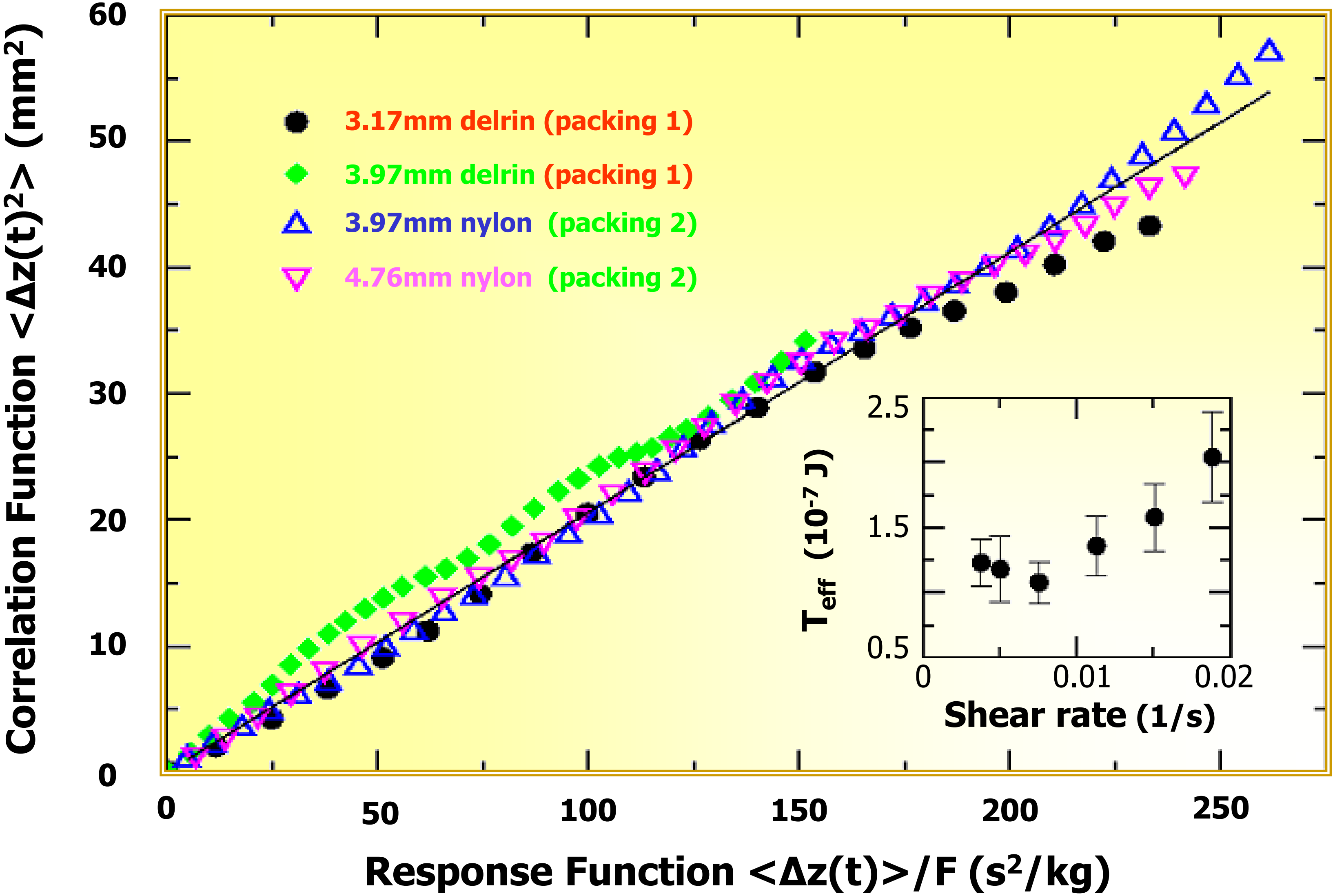
Diffusion and mobility for different tracers and packings



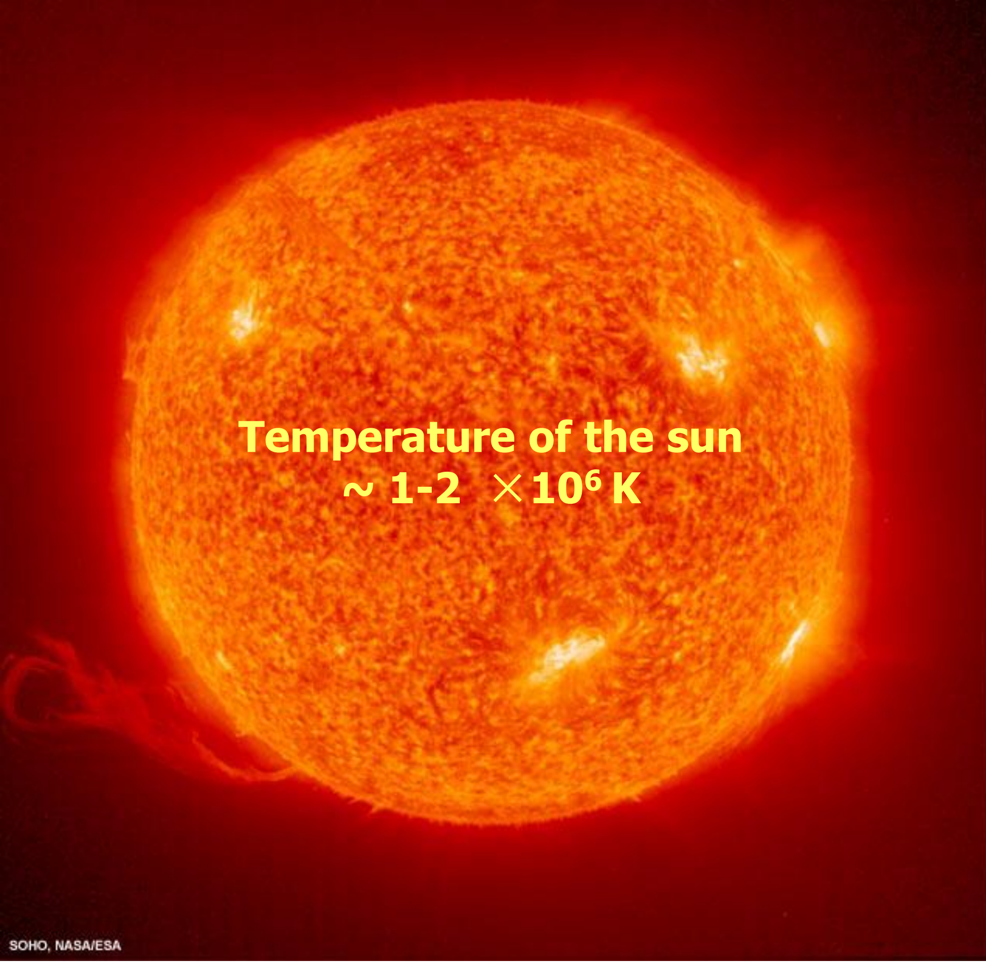


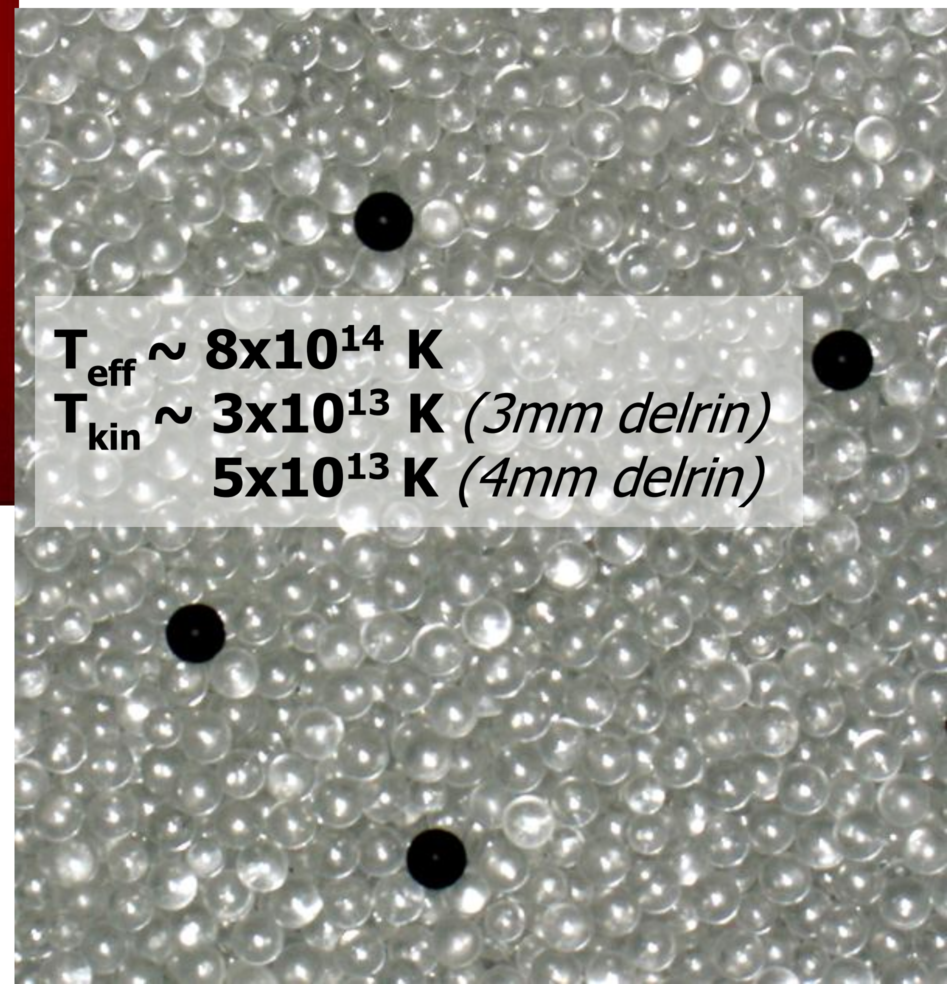
- Diffusivity and Mobility **increase** with decreasing tracers size.
- Mobility is independent of drag force: **linear response regime**

Same effective temperature for tracers with different sizes and different densities

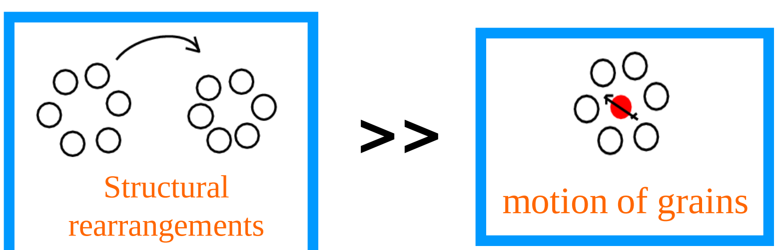


$T_{eff} > T_{kin} > T_{sun}$





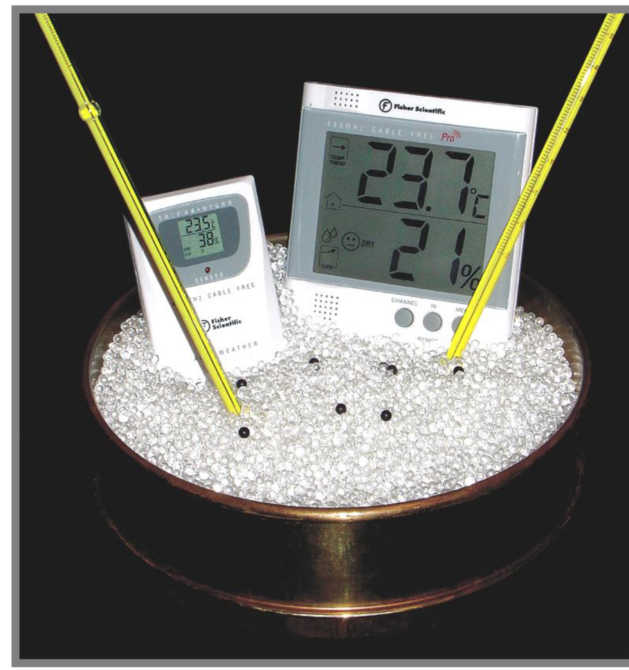
T_{eff}>T_{kin}:
average energy to rearrange few grains is much higher than their kinetic energy.



Conclusions

1. We have tested **the existence of T_{eff}** for various particle sizes and densities in a slowly sheared granular material very close to jamming. (*Song et al. , PNAS, 2004*)

2. All tracers **independently of their characteristics** equilibrate at the same T_{eff}, which is given by packing density.



3. T_{eff} is **a state variable** for the nearly jammed systems

4. Question: has T_{eff} a physical thermodynamic meaning?

5. Further work: test whether T_{eff} remains the same for different types of driving (tapping or shaking), and for different observables.