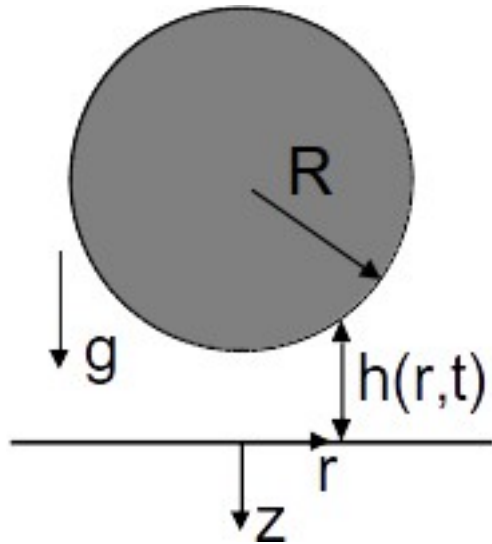


Is there solid-on-solid contact in a sphere-wall collision in a viscous fluid?

Sumit Kumar Birwa, G. Rajalakshmi, Rama Govindarajan and Narayanan Menon

Introduction

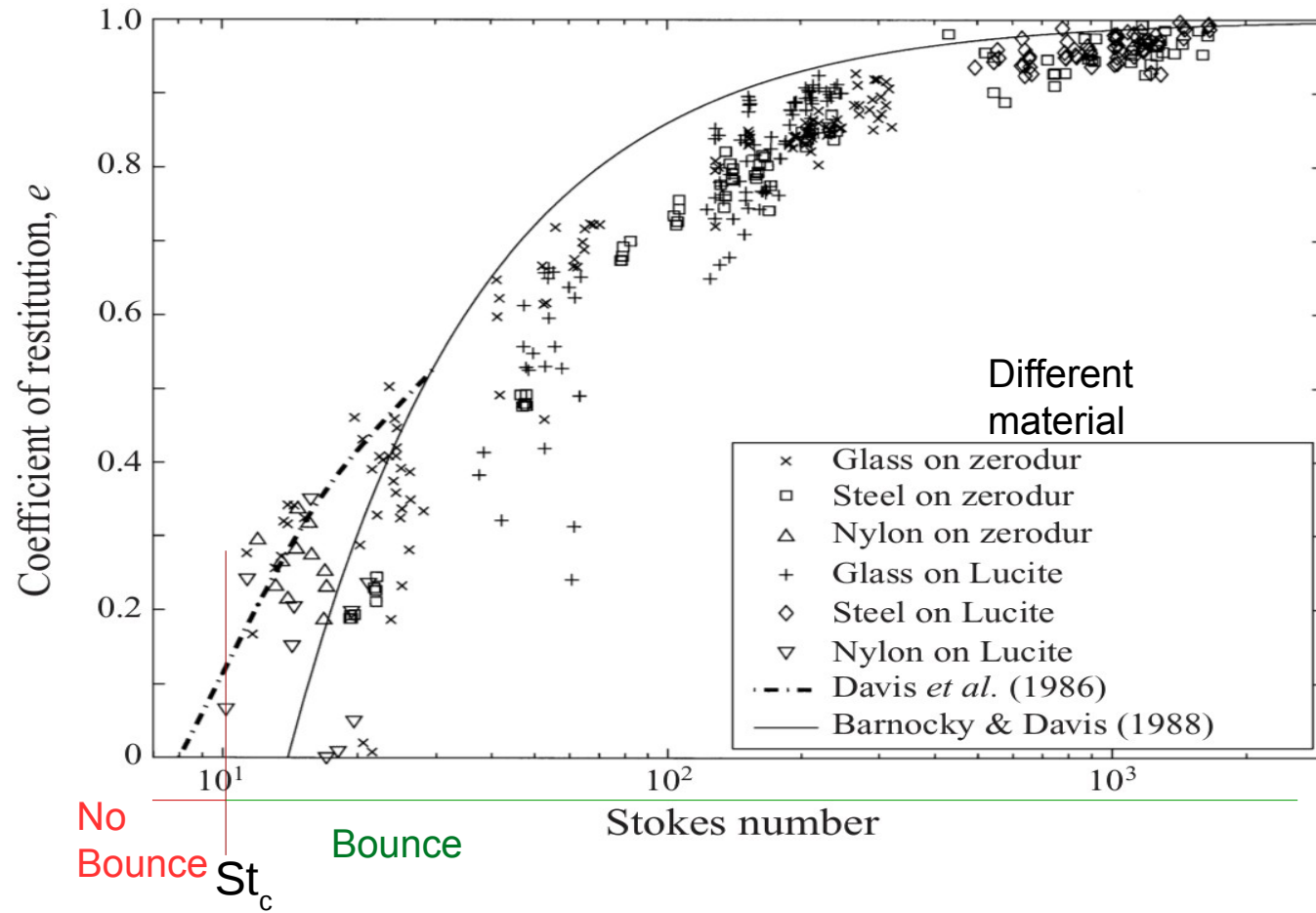


$$\text{Stokes Number, } St = \frac{2}{9} \frac{\rho_s u R}{\mu} = \frac{1}{9} RN$$

Ratio of the characteristic time of a particle (or droplet) to a characteristic time of the flow or of an obstacle

R = radius
 u = velocity
 g = gravity

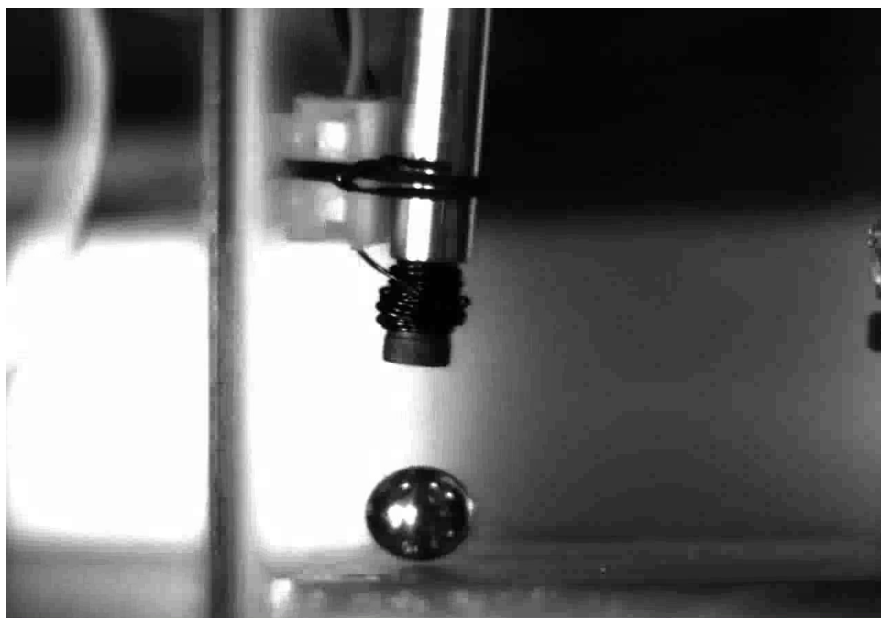
- Will this sphere bounce?
- If Yes, will it come in contact with the plane?



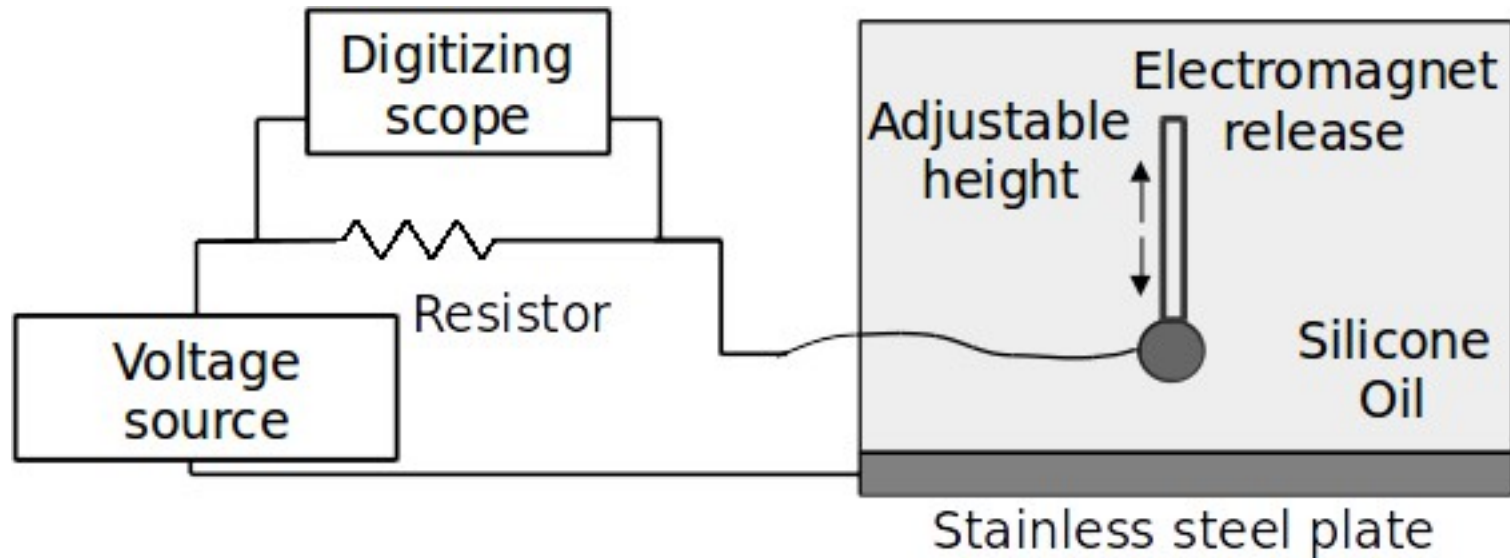
- ◆ Critical Stokes number (St_c) weakly dependent on elasticity of materials [1]
- ◆ Experiments performed by using high speed camera.

Yes, the spheres will bounce
above $St = St_c$

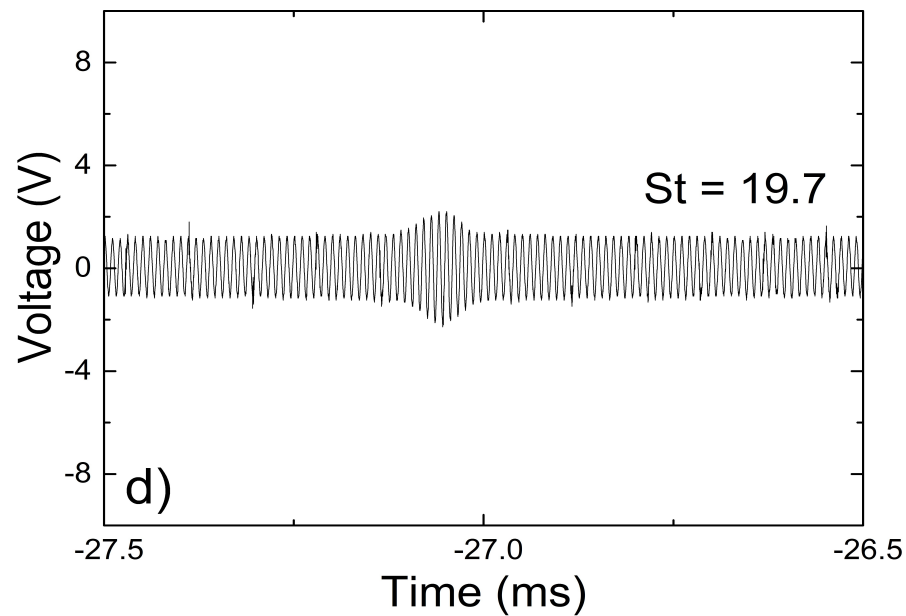
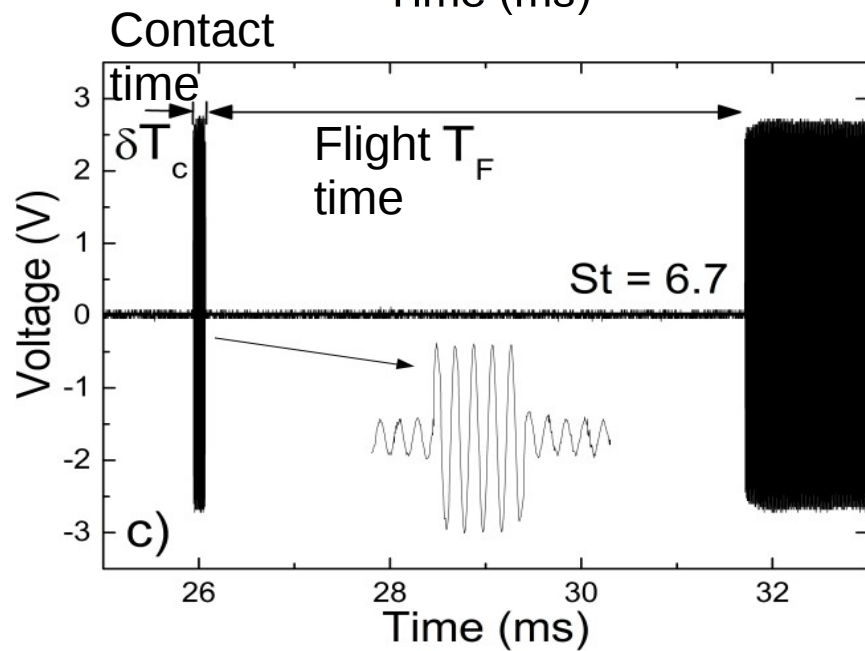
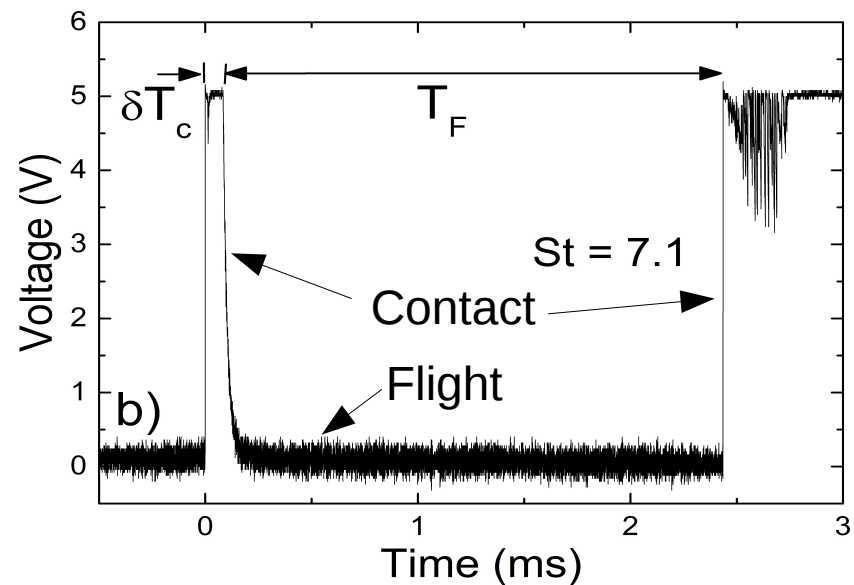
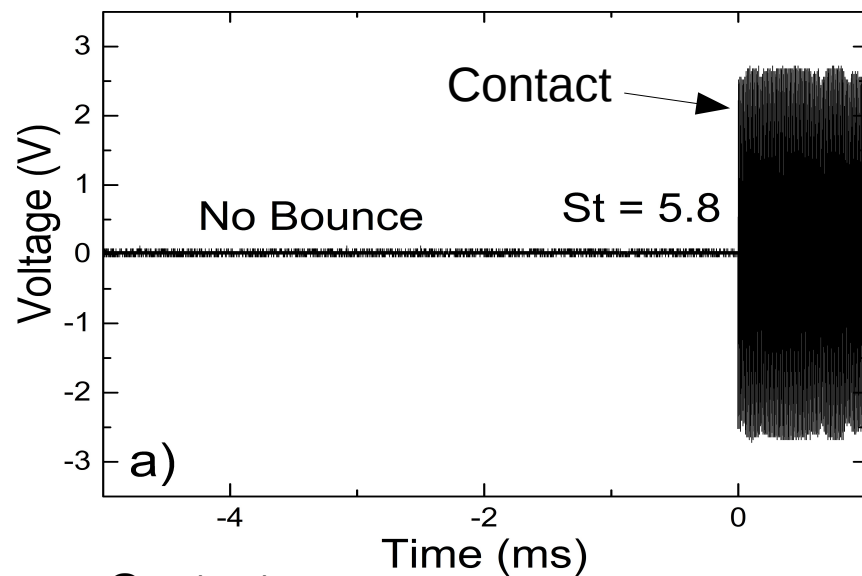
But does it come in contact with
the plane?



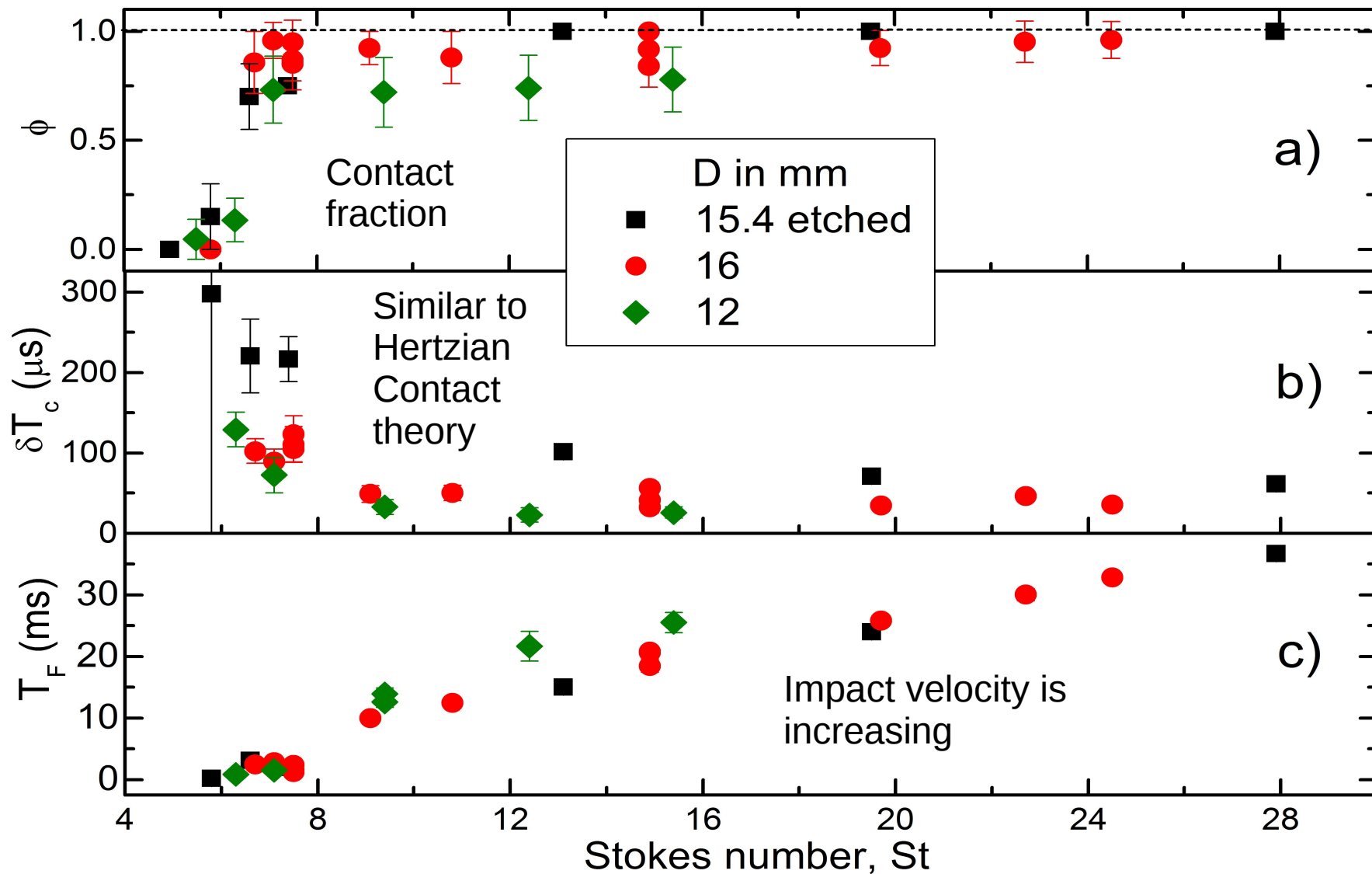
Experiments



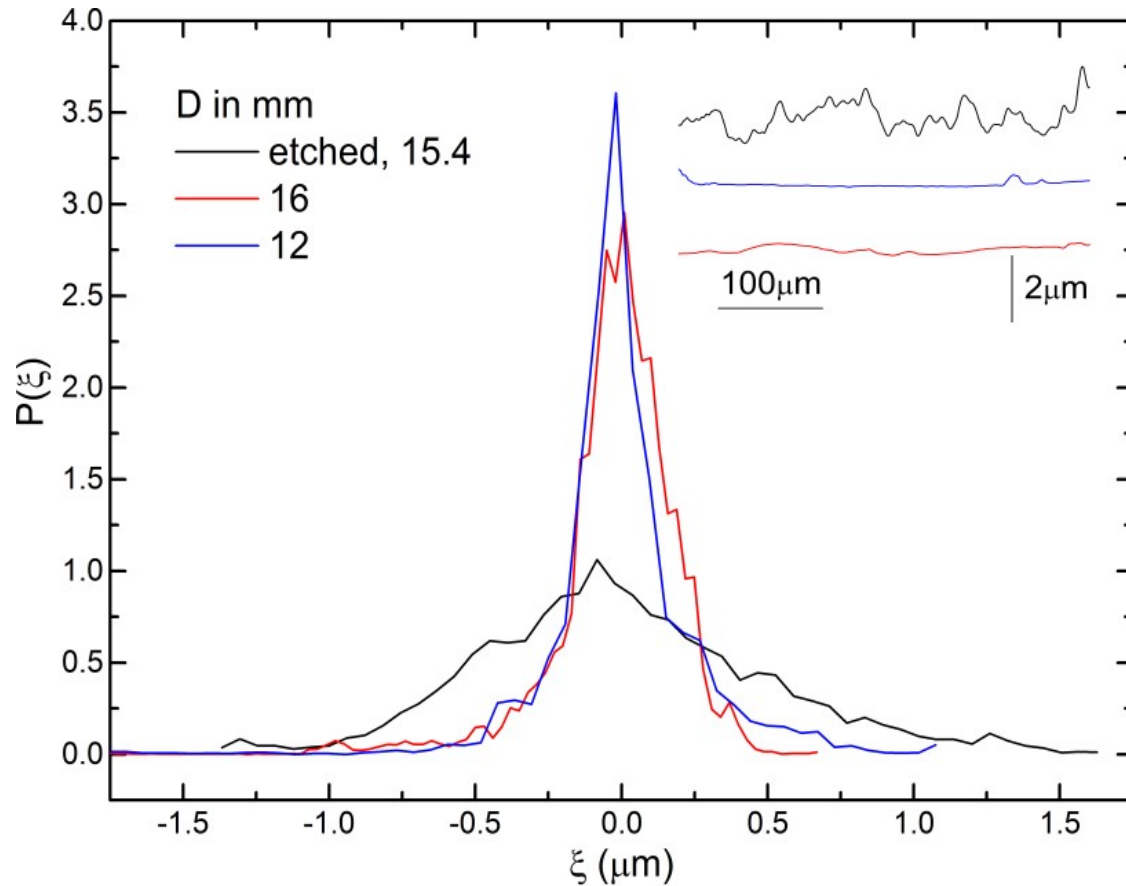
- Stokes number varied by changing the height.
- Three different balls 12, 16 and 15.4mm etched ball.
- Etched ball was prepared by etching 16mm ball in $\text{HNO}_3 + \text{H}_2\text{O}$, 1:3 mixture, for 10 mins.



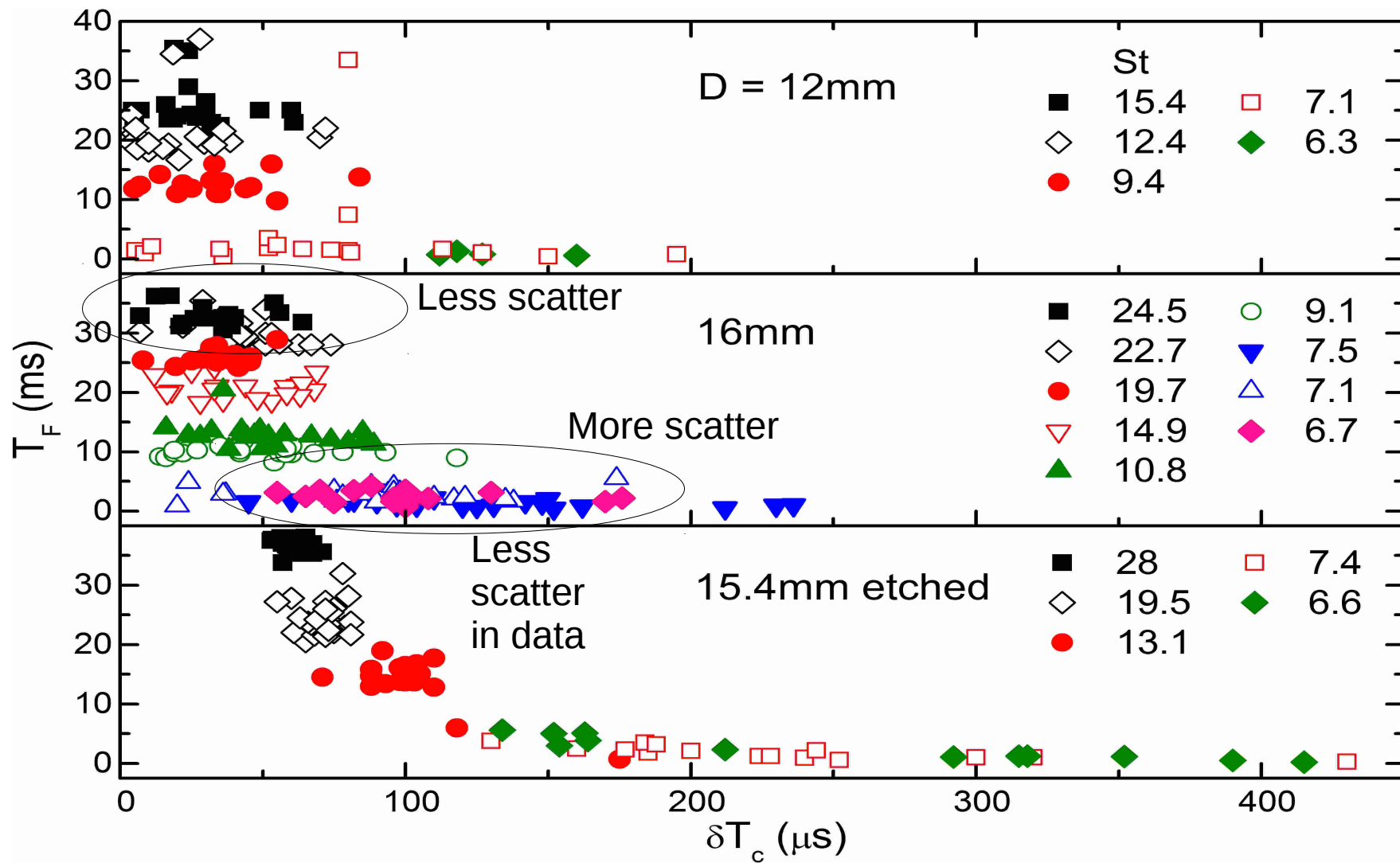
Results



Roughness



Etched sphere has a larger rms roughness. Roughness of the plate is of similar order.



- A very broad distribution of contact times reflects the variation in the local topography of the sphere.
- Much smaller variability in the flight time, particularly at larger Stokes number suggests that the total dissipation is not strongly affected by the duration of solid-on-solid contact.
- Despite the solid contact, the bulk of the kinetic energy of the sphere is lost due to fluid dissipation in the collision.
- At the largest Stokes number the contact time also becomes well-defined suggesting the effective radius of the Hertzian contact averages over the roughness of the etched sphere.

Theory

- Davis and Hinch, 1986
 - Two spheres colliding in a viscous medium bounce back above St_c without making physical contact
- Davis and Barnocky, 1988
 - Lubrication theory breaks down at distances comparable to roughness.
- Joseph and Hunt, 2001; Gondret and Petit, 2002
 - Effective coefficient of restitution as a function of stokes number falls on same curve for different elastic property of solids. (Critical $St = 10$)

$$\frac{\partial p}{\partial r} + \mu \frac{\partial^2 u_r}{\partial r^2} = 0$$

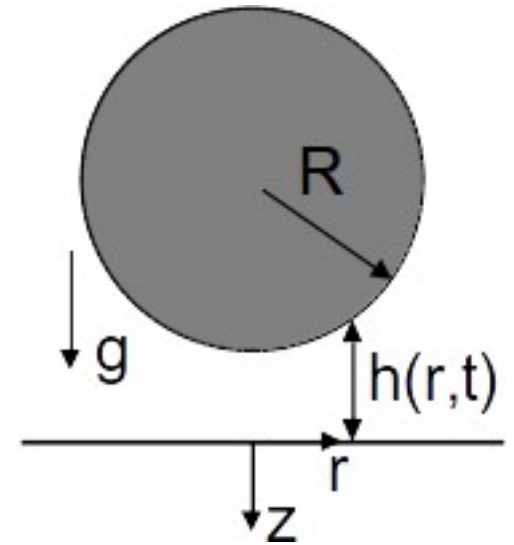
$$\frac{\partial h}{\partial t} = \frac{1}{12\mu r} \frac{\partial}{\partial r} r h^3 \frac{\partial p}{\partial r}$$

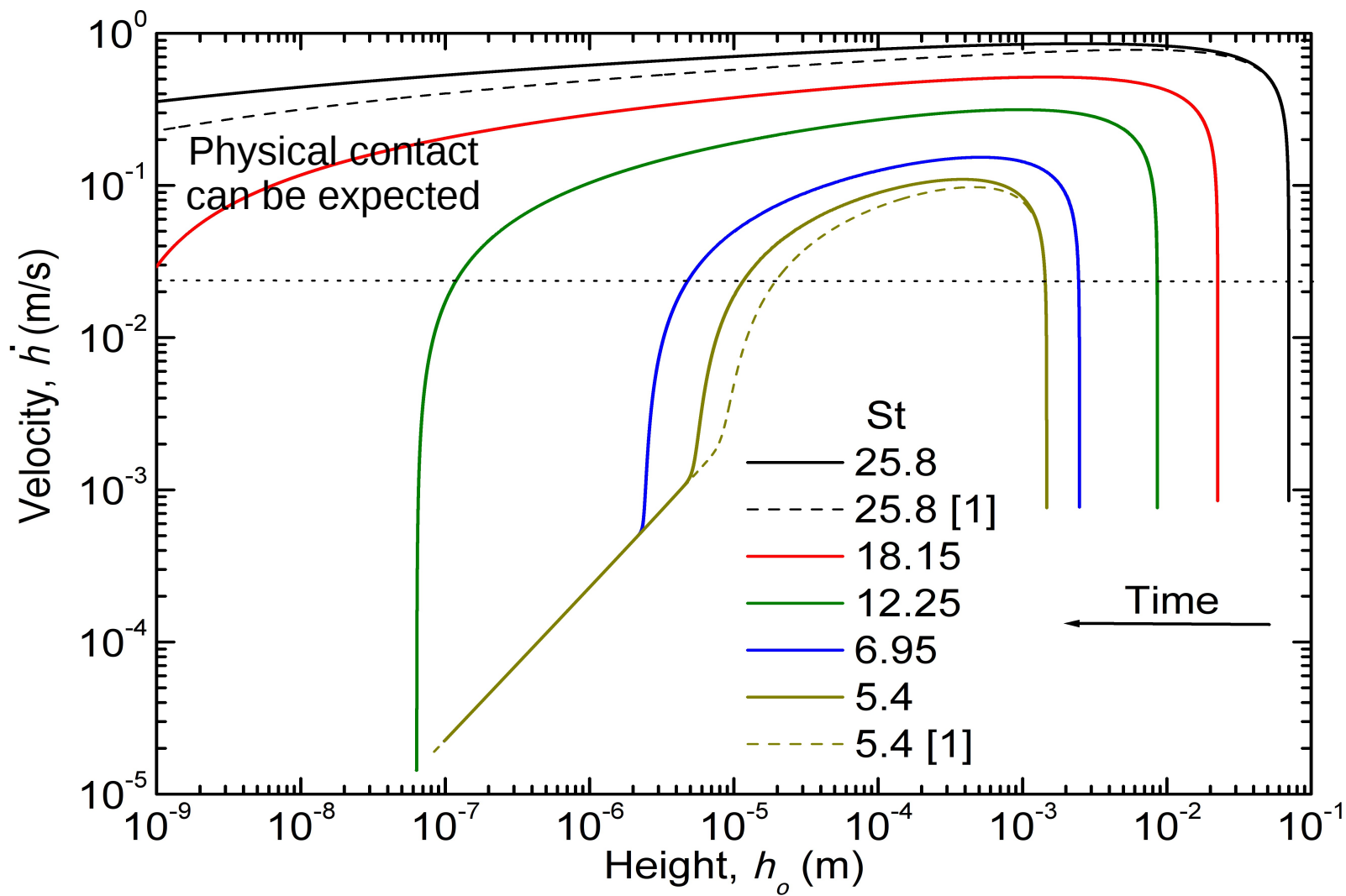
$$\text{Hydrodynamic force, } F = \frac{6\pi\mu u R^2}{h(0,t)}$$

Major assumptions used:

- 1) Steady state
- 2) $u_r \gg u_z$
- 3) Parabolic profile

Not
always
true

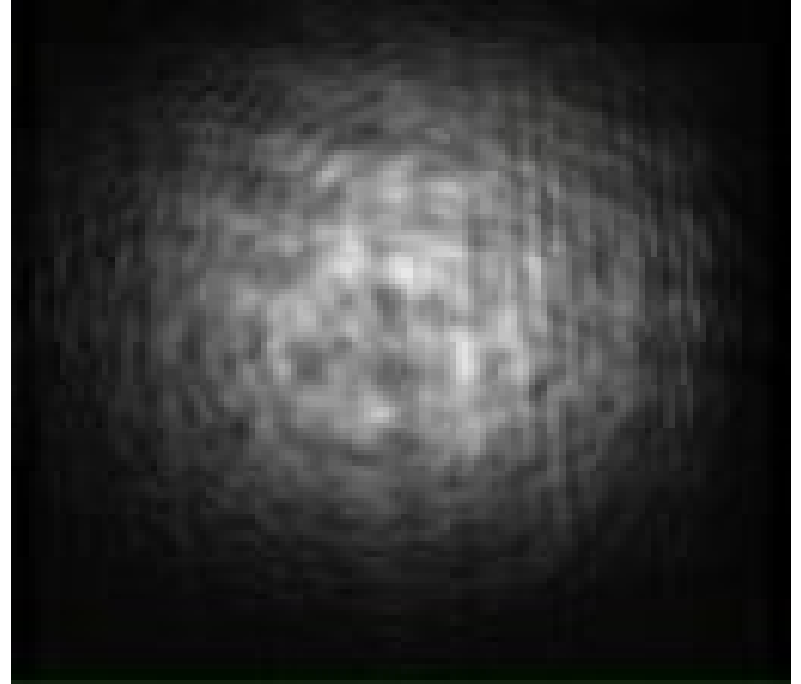




Current work

Attempting to understand the dynamics close to collision in three steps:

- Side view of sphere by high speed camera.
- Newton rings experiment
- Evanescent wave coupling



Summary

- The lubrication approximation is questionable at small enough distances.
- It seems clear that direct solid contact is likely to be a general feature, even close to the threshold of bouncing.
- The dissipation remains dominated by fluid mechanics, and the contact mechanics are largely controlled by surface roughness and bulk solid properties.

Questions

