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Direct observation of particle interactions and clustering in charged granular streams

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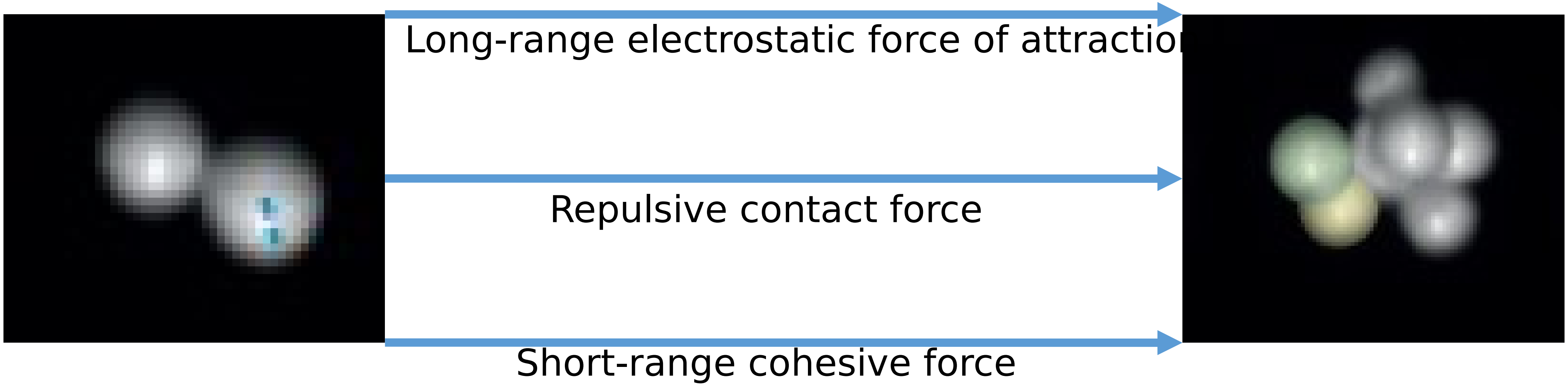
ntroduction:

- Understanding of fine particles-behaviour, nature has been a key interest for few scientists
- Brownian motion of particles was experimentally observed by Jean Perrin
- Zsom et at suggested, formation of planets starts from the clustering of the fine particles
- Observation of the transformation has been a technical challenge
- High Speed camera
- Digitization of the images causes distortions



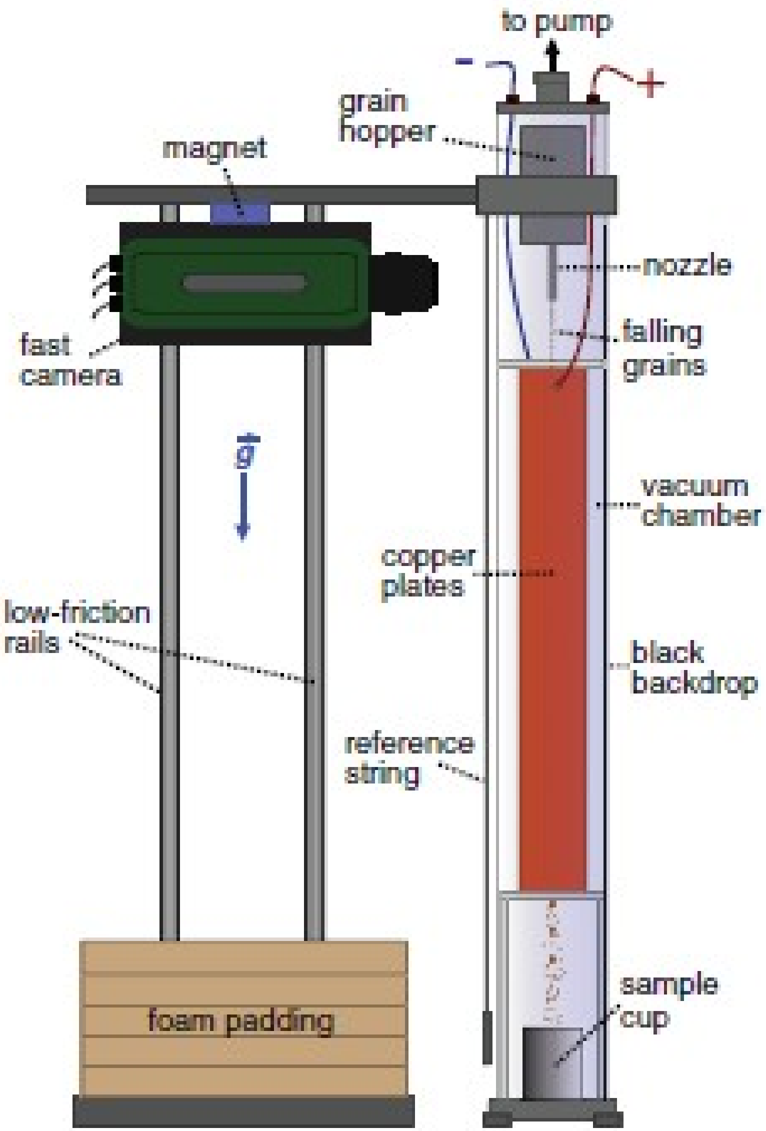
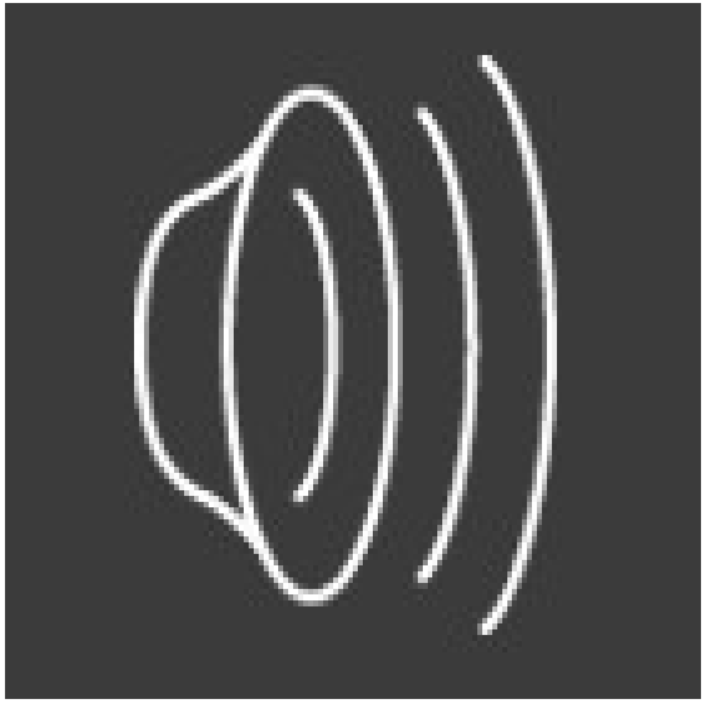
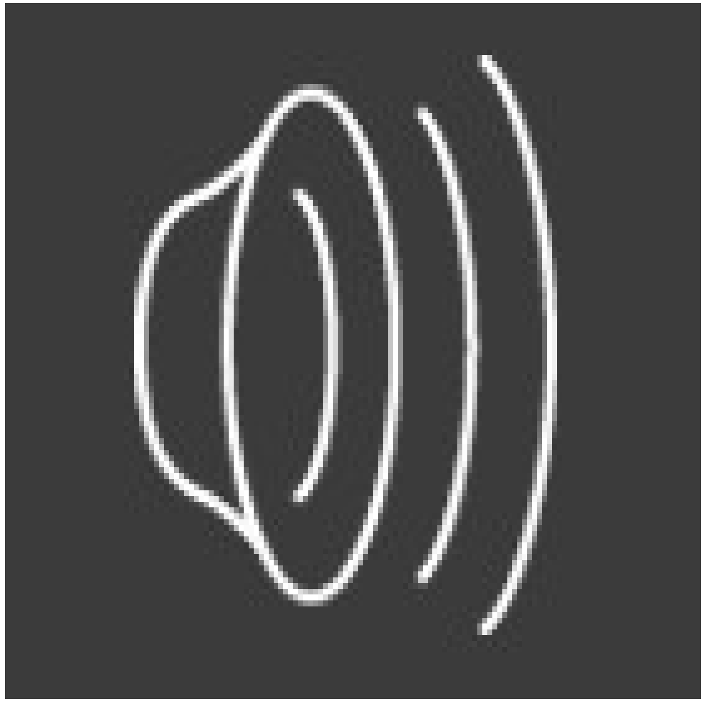


FIG. 1. The experimental setup. Grains freely fall inside a vacuum chamber from the hopper/nozzle through a region between two parallel copper plates held at a potential difference V ($\vec{E}$ points into the page). A camera connected to a carriage-rail system falls with the grains while simultaneously recording video. A vertical reference string hangs in front of the chamber to correct for camera yaw and roll.*

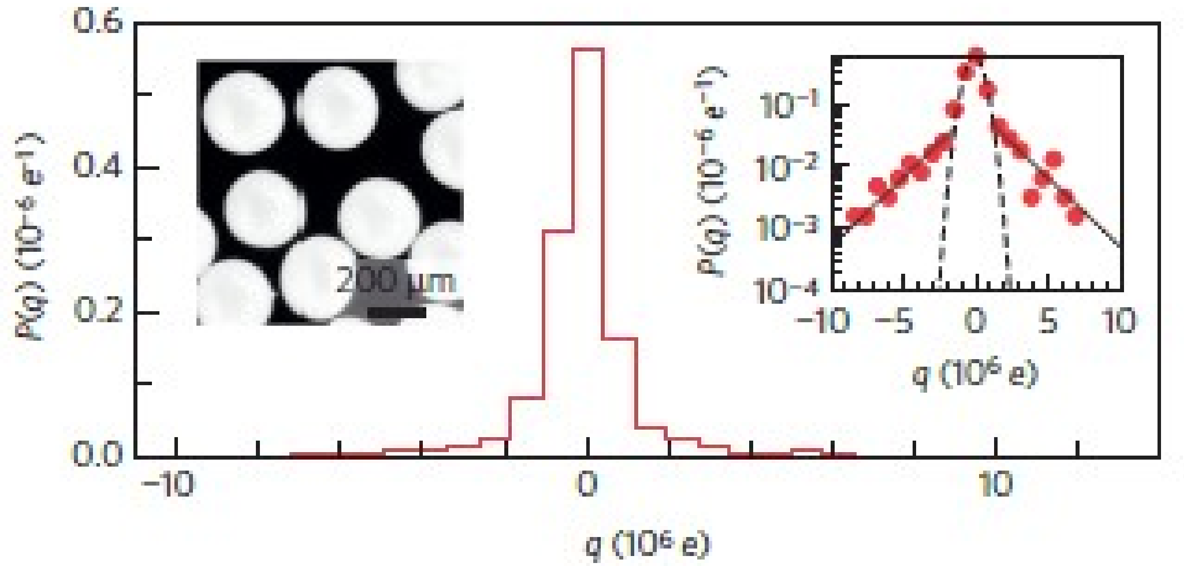


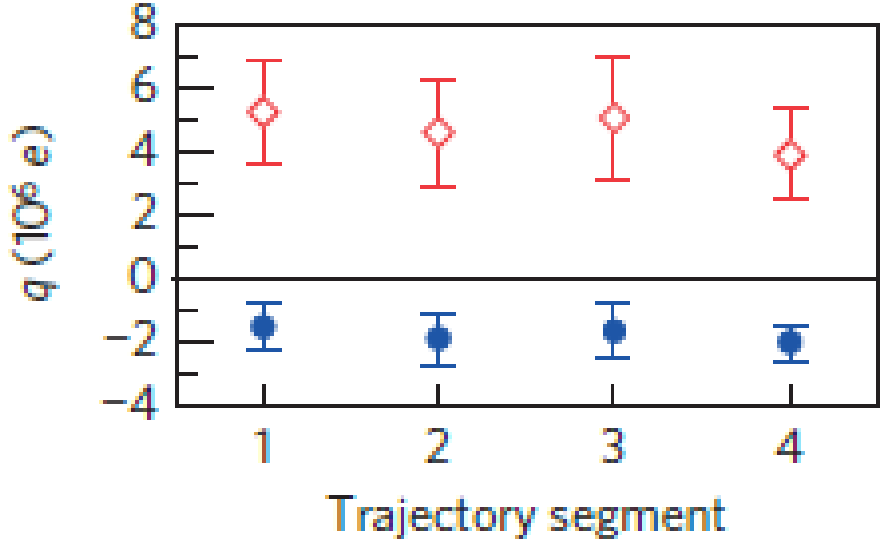
Experimental section:



sults and discussions:

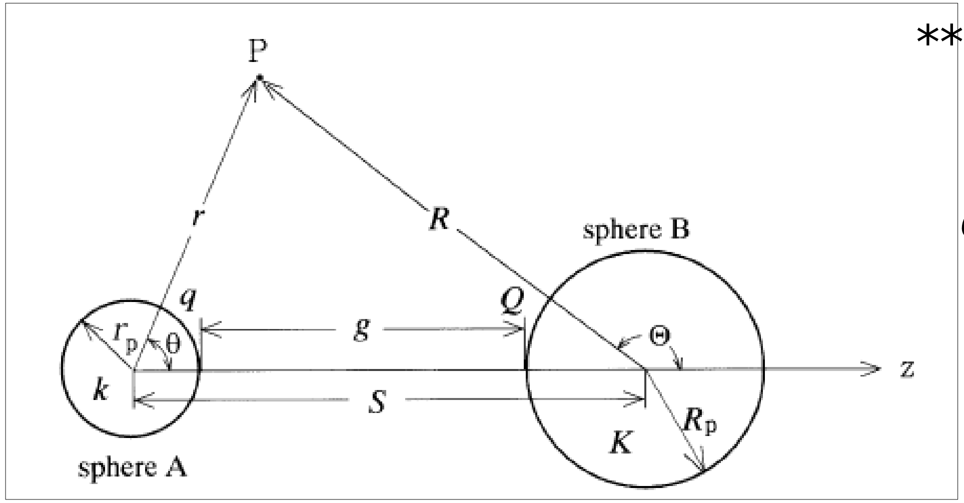
Fig.2: Charges $q1$ (red diamonds) and $q2$ (blue circles) on the two p





: Particle-charge distribution P(q) for mono-dispersed grains

Jakajima-Sato model:



** $$\varphi_0 = \sum_{n=0}^{\infty} \left\{ a_n \left(\frac{r_p}{r} \right)^{n+1} P_n(\cos \theta) + A_n \left(\frac{R_p}{R} \right)^{n+1} P_n(\cos \Theta) \right.$$

ϕ_0-axisymmetric electrostatic potential

P_n- Legendre polynomial of n^{th} order

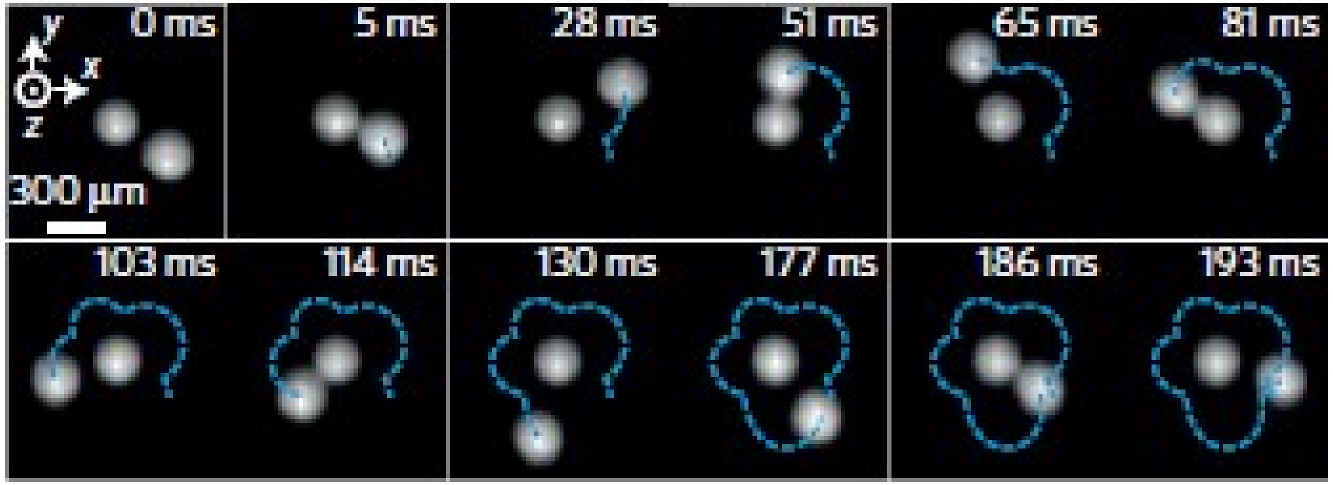


Fig.3: Sequence of zoomed-in still frames tracking the interaction of two oppositely charged grains

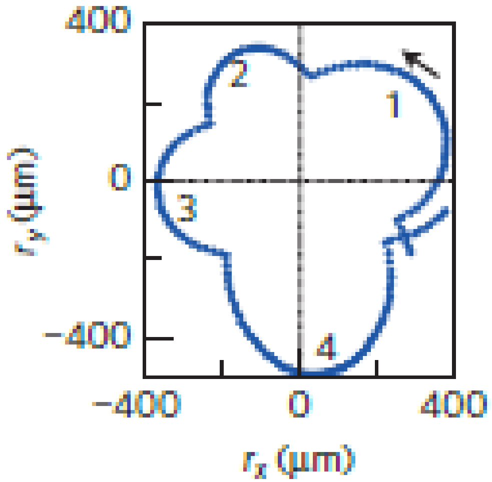


Fig.4: Horizontal (*rx*) and vertical (*ry*) components, in the *x*–*y* imaging plane

rocker-Grier algorithm:

$$f(r,t) = \sum_{t=1}^{N} \delta(r - r_i(t))$$

Ideal equation

$$\begin{pmatrix} \epsilon_x \\ \epsilon_y \end{pmatrix} = \frac{1}{m_0} \sum_{i^2+j^2 \leq w^2} \begin{pmatrix} i \\ j \end{pmatrix} A(x+i, y+j)$$

$$m_0 = \sum_{i^2+j^2 \leq w^2} A(x+i, y+j)$$

$$m_2 = \frac{1}{m_0} \sum_{i^2+j^2 \leq w^2} (i^2 + j^2) A(x+i, y+j)$$

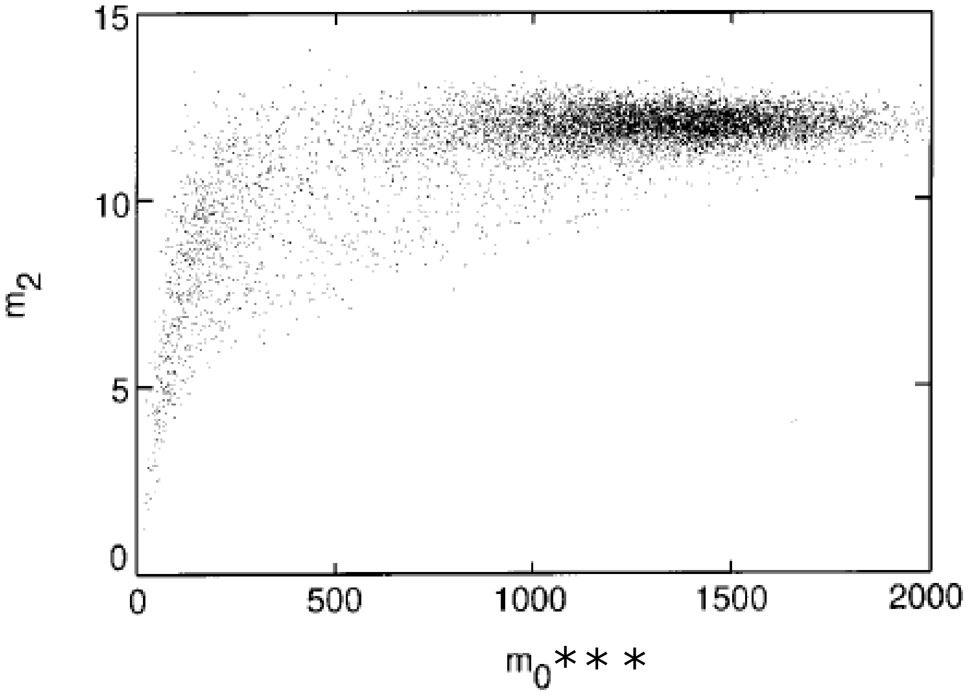
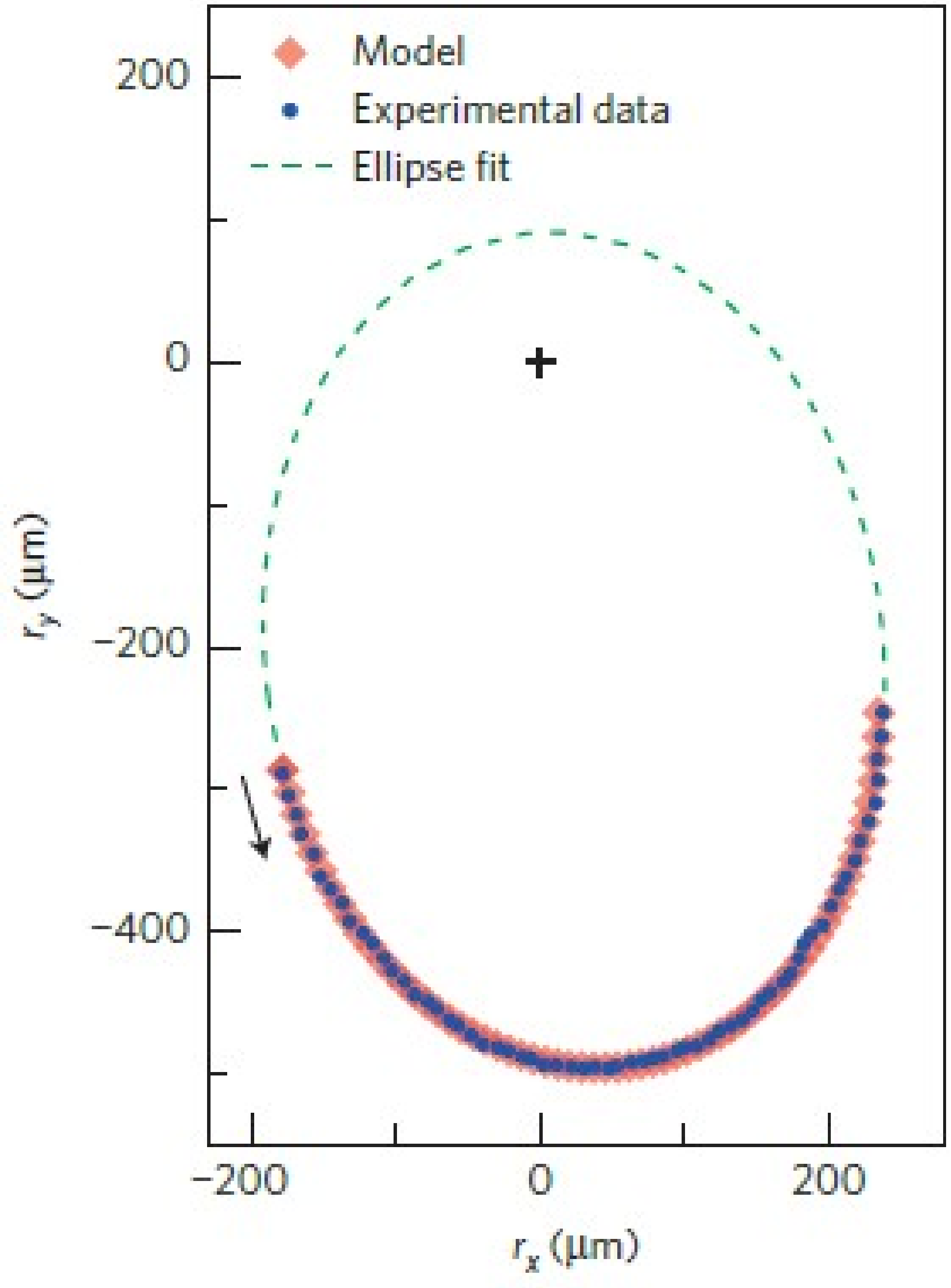


Fig.5: Clustering of colloidal images in the (*m0* , *m2*) plane.

Relative position of the two grains from trajectory segment



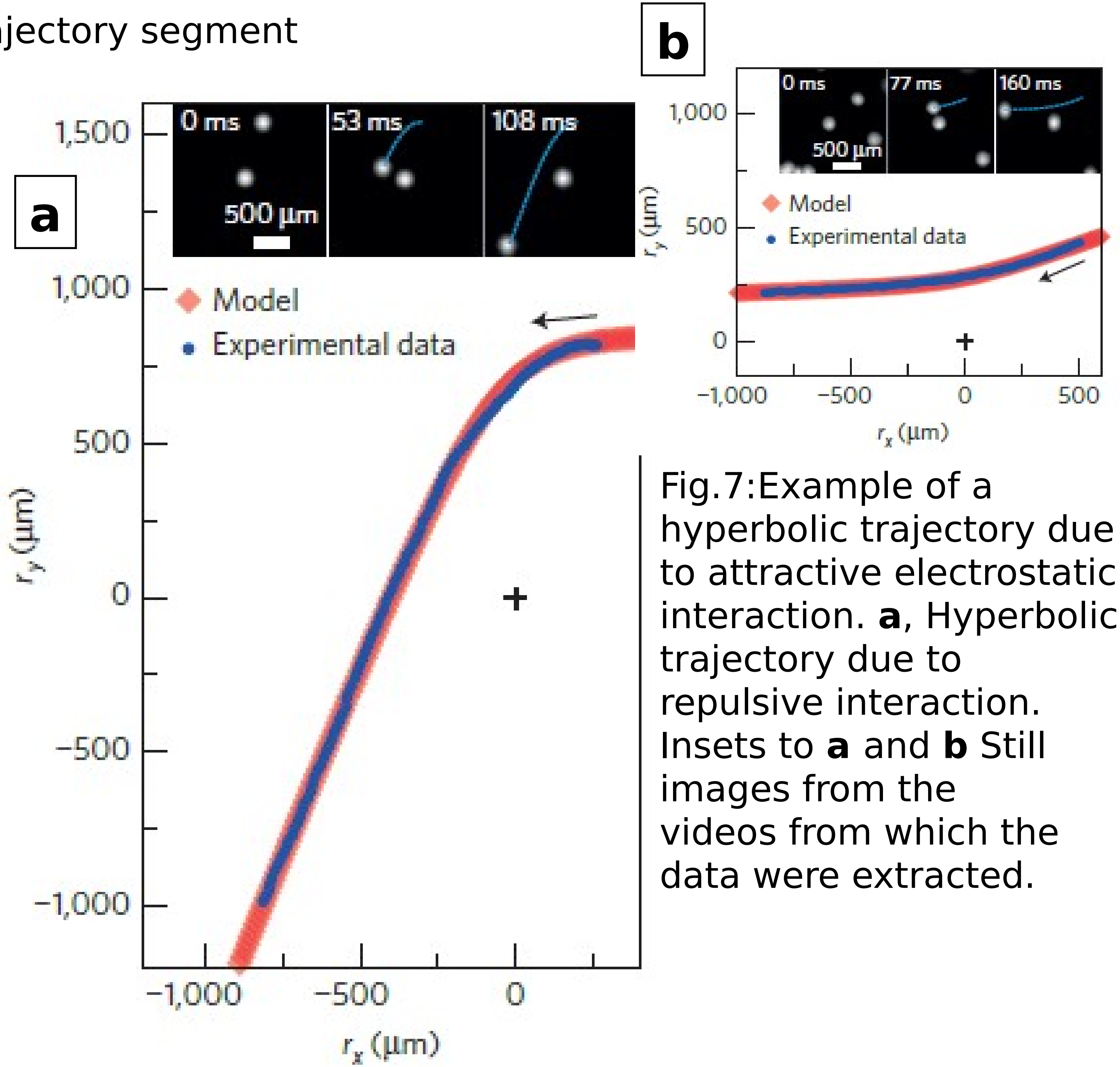


Fig.7:Example of a hyperbolic trajectory due to attractive electrostatic interaction. **a**, Hyperbolic trajectory due to repulsive interaction. Insets to **a** and **b** Still images from the videos from which the data were extracted.

$$m \frac{d^2x}{dt^2} = F$$

$$m = \frac{m_1 m_2}{m_1 + m_2}$$

The sum E_0 of the translational kinetic energy (in the centre-of-mass reference frame) and electrostatic potential energy determines:

Solution for r(t) determines the shape of the curve elliptical
… hyperbolic ($E_0 > 0$)

Leapfrog approximation:

$$\frac{dy}{dt} = \frac{y_{i+1} - y_{i-1}}{2h}$$

$$y_{i+1} - y_{i-1} = 2hf(y_i, t_i)$$

$$y(t_{i+1}) = y(t_i) + hy'(t_i)$$

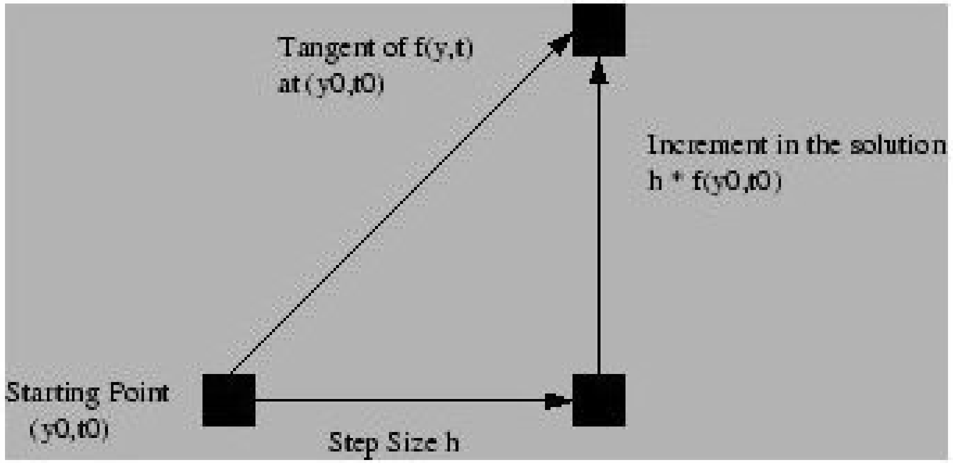


Figure: The general idea for extending a solution using a forward Euler method.*1

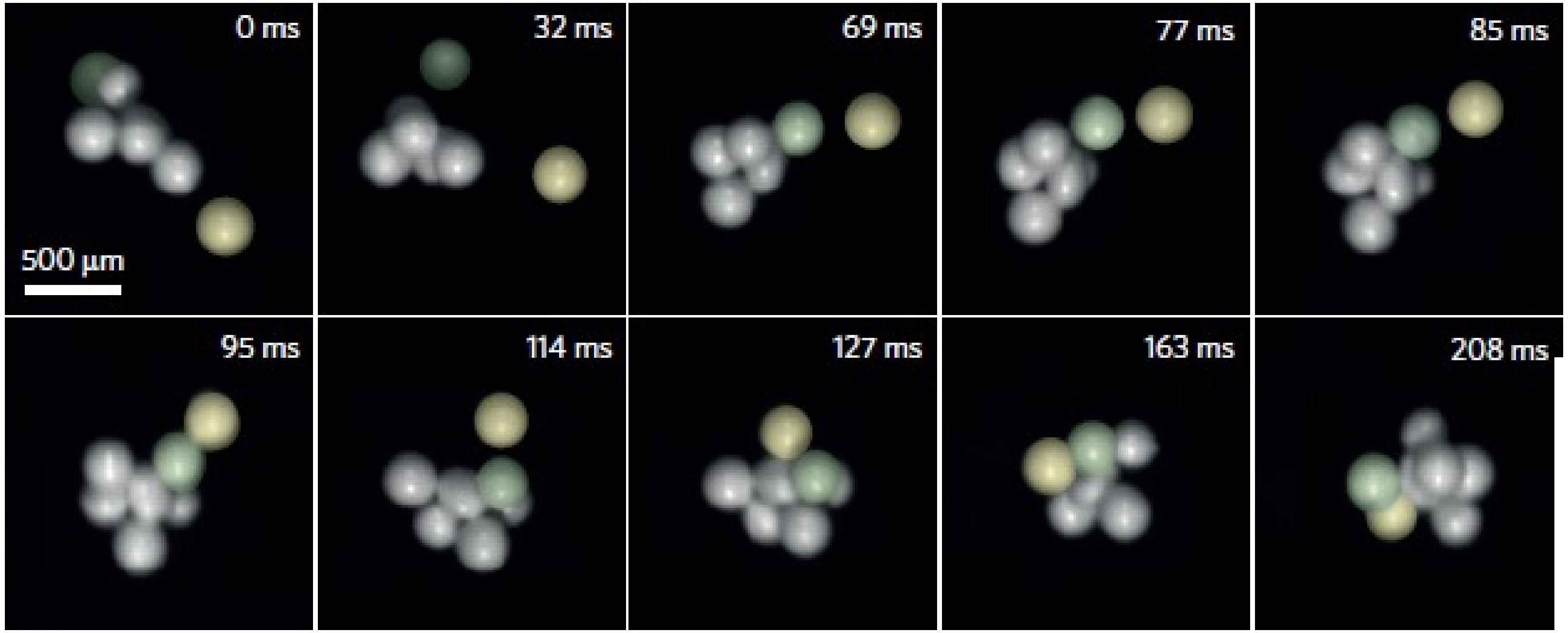


Fig.8: Time sequence of two particles (coloured green and yellow) aggregating onto an already formed five-particle cluster

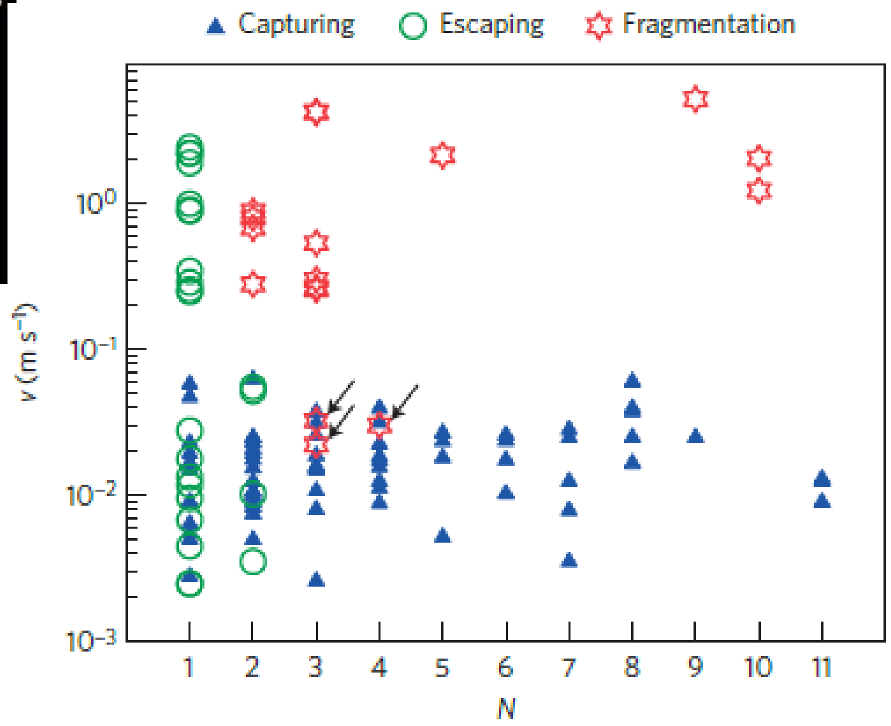


Fig.9: Collision outcomes for a single particle colliding with relative velocity v (in the x–y plane) with a cluster comprised of N particles: capture

Conclusions:

- Multiple bounces enabled by the electrostatic potential well very effectively dissipate kinetic energy, all of which increases the likelihood of capture and aggregation.
- Small size dispersion, such as in our nearly mono-disperse sample, suffices to generate highly charged particles, an effect likely to become amplified for larger dispersions.
- The charge-stabilized granular molecules observed highlight how intra-cluster particle configurations are controlled by dielectric polarization.

Future work:

- Investigate of how particle stick on surface?
- Transport of simulated dust on charged surfaces (observation and model)
- Charged particulates’ behaviour near the vicinity of glass surface

Thank you

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