Electromagnetic forces in particle dust clouds

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INTRODUCTION

- Many aggregates are of a fractal nature, and the application of the concept of fractal geometry to the phenomenon of aggregation can greatly simplify the study of the process.
- However, as seen in the literature, the fractal dimensions and the site growth probability measures of the resulting fractal structures strongly depend on the properties of the forces that cause the aggregation.

General differential equation

- Spherical particle moving in a gas at low Reynolds' number (Re) :

$$m\frac{dV}{dt} = F - \frac{2}{3}\pi\rho_g r^3 \frac{dV}{dt} + F_d - 6r^2\sqrt{\pi\mu\rho_g}\int_0^t \frac{dVdx}{dx\sqrt{t-x}}$$

$$m\frac{dV}{dt} = F_e + F_d$$

If $\quad \mathrm{Re} \equiv \frac{2a_1 V_1 \rho_g}{\mu} << 1 \quad \rightarrow \quad F_d \propto V$

Then $\quad \frac{r}{l} << 1 \quad F_d = -\frac{4}{3}\pi\delta n_g m_g V_g r^2 V$

$$\frac{r}{l} \approx 1 \quad F_d = -6\pi\mu r V \Big/ \left(1 + A\frac{l}{r}\right)$$

$$\frac{r}{l} >> 1 \quad F_d = -6\pi\mu r V$$

The Stokes number: $\quad St \equiv \frac{m_1 V_1}{6\pi\mu a_1 r} << 1$

$$m\frac{dV}{dt} = F_e + F_d \quad \rightarrow \quad F_e = -F_d$$

$$\frac{6\pi\mu a_1 V_1}{1 + Al/a_1} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2} = \frac{6\pi\mu a_2 V_2}{1 + Al/a_2}$$

$$r = \left(\frac{q_1 q_2}{8\pi^2 \varepsilon_0 \mu} \right)^{1/3} \left[F_{E1} + F_{E2} \right] (t_f - t)^{1/3}$$

$$F_{E1} = \left(\frac{a_1}{1 + Al/a_1} \left(1 + \frac{a_1}{a_2} \frac{(1 + Al/a_2)}{(1 + Al/a_1)} \right)^2 \right)^{-1/3}$$

$$F_{E2} = \left(\frac{a_2}{1 + Al/a_2} \left(1 + \frac{a_2}{a_1} \frac{(1 + Al/a_1)}{(1 + Al/a_2)} \right)^2 \right)^{-1/3}$$

$$r = \left(\frac{5\mu_0 \mu_1 \mu_2 F_\theta}{8\pi^2 \mu} \right)^{1/5} \left[F_{M1} + F_{M2} \right] (t_f - t)^{1/5}$$

$$F_\theta = (3\cos^2\theta - 1)$$

$$F_{M1} = \left(\frac{a_1}{1 + Al/a_1} \left(1 + \frac{a_1}{a_2} \frac{(1 + Al/a_2)}{(1 + Al/a_1)} \right)^4 \right)^{-1/5}$$

$$F_{M2} = \left(\frac{a_2}{1 + Al/a_2} \left(1 + \frac{a_2}{a_1} \frac{(1 + Al/a_1)}{(1 + Al/a_2)} \right)^4 \right)^{-1/5}$$

Validity of the approximations

If a particle is released at *t=0* and allowed to move under the action of a constant force, then:

$$V = V_{MAX}\left(1 - e^{-t/\tau}\right)$$

$$\tau = \frac{2a^2\rho}{9\mu} = 10^{-4}s.$$

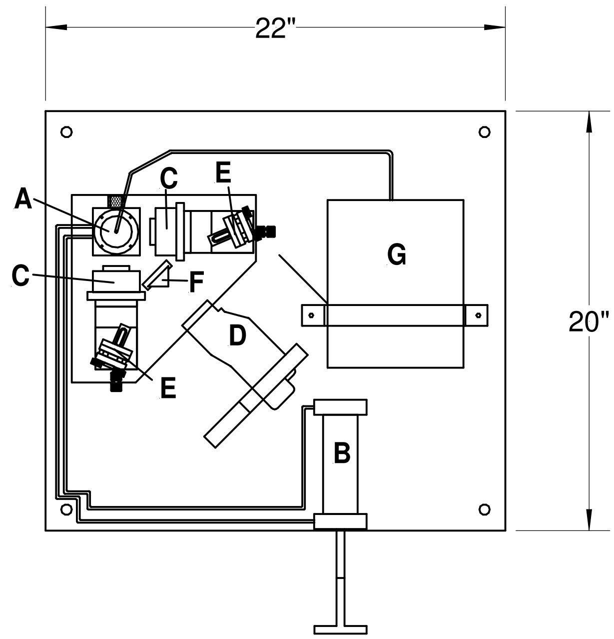
$$10\tau = 10^{-3}s \quad \rightarrow \quad 99.99\% \quad V_{\max}$$

$$St \equiv \frac{m_1 V_1}{6\pi\mu a_1 r} \approx \frac{m_1}{36\pi\mu a_1} \times \frac{1}{(t_f - t)} = \frac{9.76\times10^{-5}}{6(t_f - t)}$$

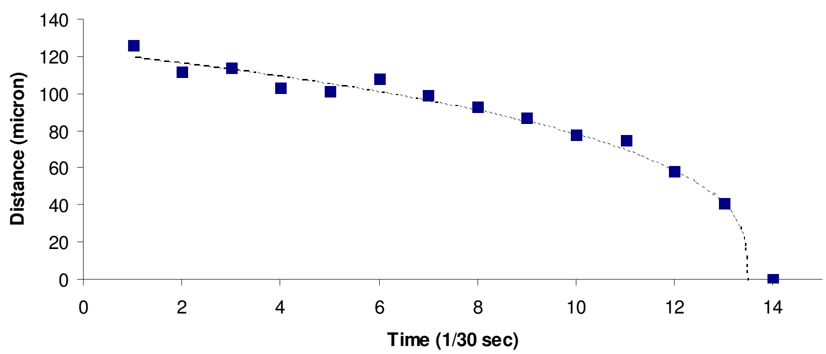
$$St \leq 10^{-3} \quad \rightarrow \quad \left(t_f - t\right) \geq 1/60\, s$$

$$\mathrm{Re} = 2.28\times10^{-2} \frac{C}{\left(t_f - t\right)^{2/3}} \qquad \left(t_f - t\right) = 1/30\, s$$

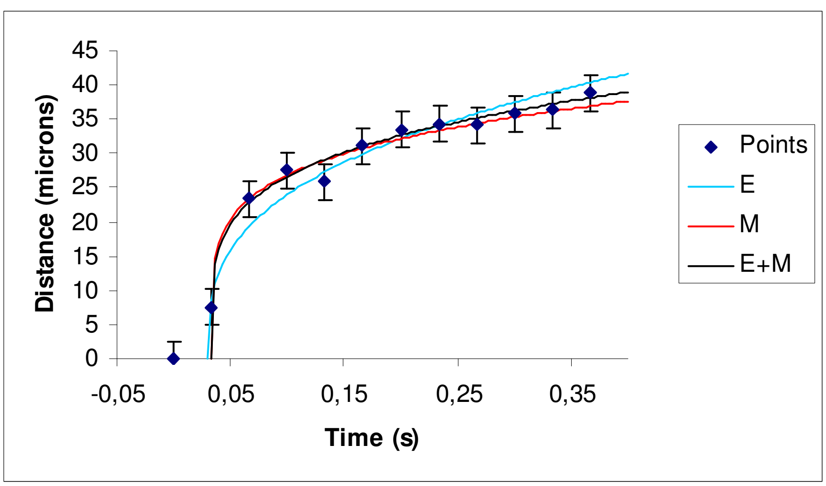
$$\mathrm{Re} \leq 10^{-3} \quad \rightarrow \quad C \leq 0.00454$$



$$r = \left(\frac{q_1 q_2}{8\pi^2 \varepsilon_0 \mu} \right)^{1/3} \left[F_{E1} + F_{E2} \right] (t_f - t)^{1/3}$$



Agg.	Temps	+/-	Ce	+/-	Cm	+/-	CHISQ/nu
1	0.178980 0.072160 0.071790	0.108289 0.056960 0.234027	0.000040 0.000000	0.000005 0.000118	 0.000037 0.000037	 0.000003 0.000104	0.519591 0.488089 0.585946
2	0.003536 0.000116 0.000212	0.003159 0.000200 0.000414	0.000058 0.000011	0.000002 0.000019	 0.000046 0.000038	 0.000001 0.000016	0.809534 0.267948 0.262064
3	0.017067 0.003014 0.017173	0.006229 0.001896 0.013820	0.000094 0.000093	0.000002 0.000036	 0.000078 0.000000	 0.000001 0.000031	0.641703 3.005803 0.715176
4	0.057990 0.011481 0.050937	0.034461 0.012890 0.106480	0.000037 0.000033	0.000002 0.000054	 0.000032 0.000003	 0.000001 0.000050	0.183755 0.253269 0.201825
5	0.005279 0.000543 0.005259	0.005464 0.000922 0.009385	0.000045 0.000045	0.000002 0.000029	 0.000036 0.000000	 0.000001 0.000023	0.282068 0.906924 0.322864
6	0.099794 0.033228 0.084284	0.033444 0.017879 0.135270	0.000059 0.000060	0.000003 0.000094	 0.000053 0.000000	 0.000002 0.000088	0.308537 0.500922 0.380735
7	0.021254 0.003064 0.013567	0.009225 0.002441 0.014023	0.000071 0.000054	0.000002 0.000031	 0.000059 0.000015	 0.000001 0.000027	0.348228 0.797455 0.356773



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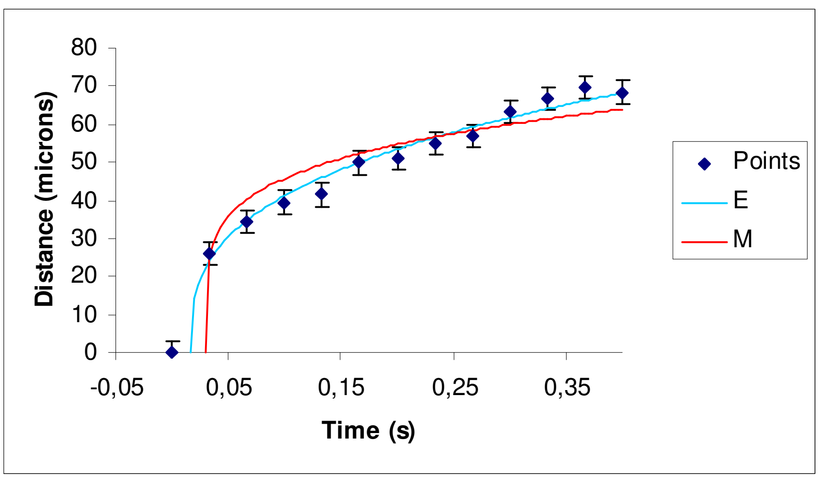

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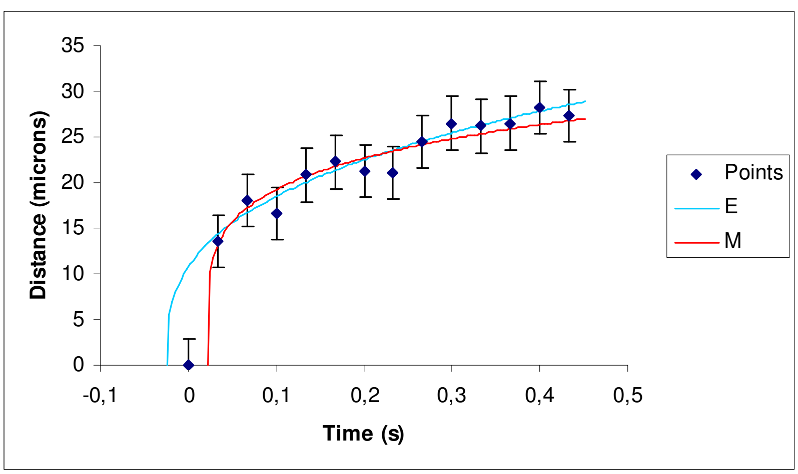

Conclusion

We have a non-disturbing tool that permit:

1- Identification of the force (electric or magnetic) causing the aggregation.

2- A way to measure the product of the electric charges or the product of the magnetic moments.

Work supported by ESA and CSA.

SUPPORT

- FROM ESA, via the program ELIPS, joint venture with CSA-ASC: In order to provide:
- Technical assistance for the Impact Precursor Facility (IPE) on the International Space Station.