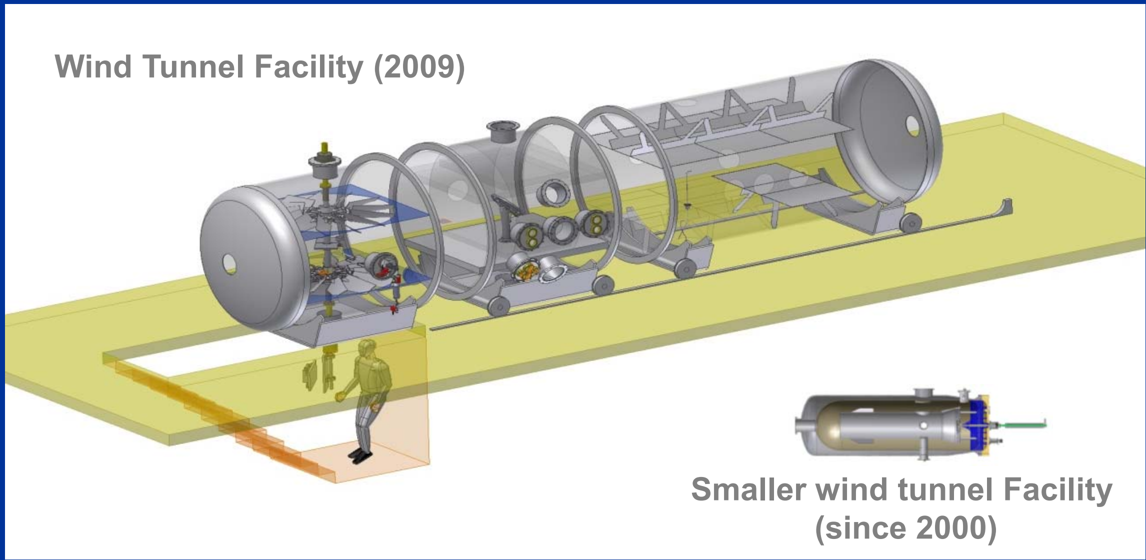
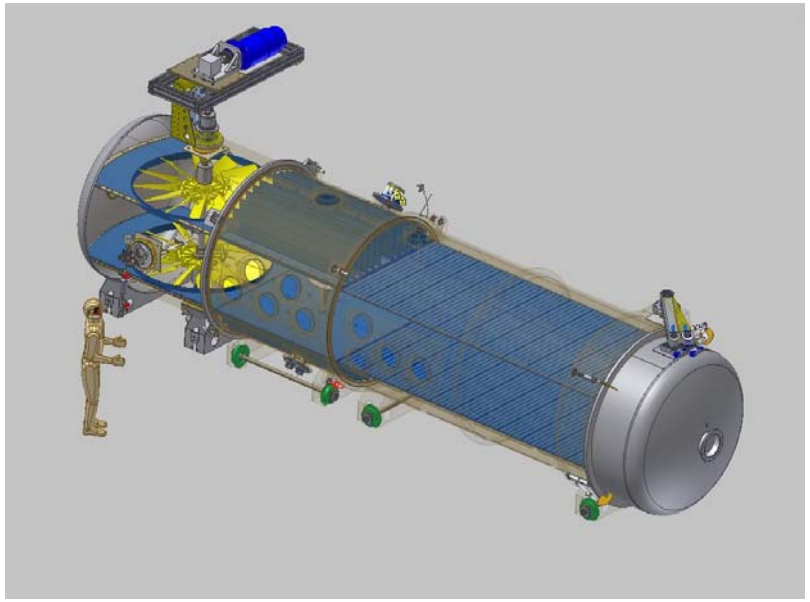
INSTITUT FOR FYSIK OG ASTRONOMI
DET NATURVIDENSKABELIGE FAKULTET
AARHUS UNIVERSITET

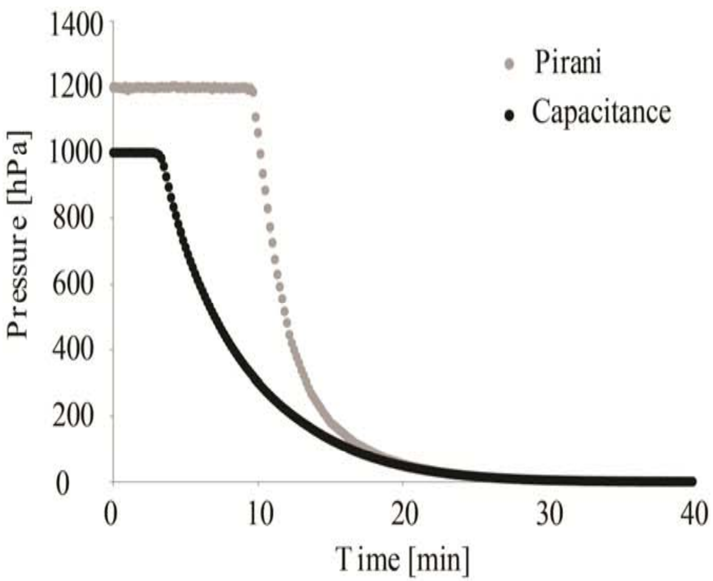
Environmental Simulators

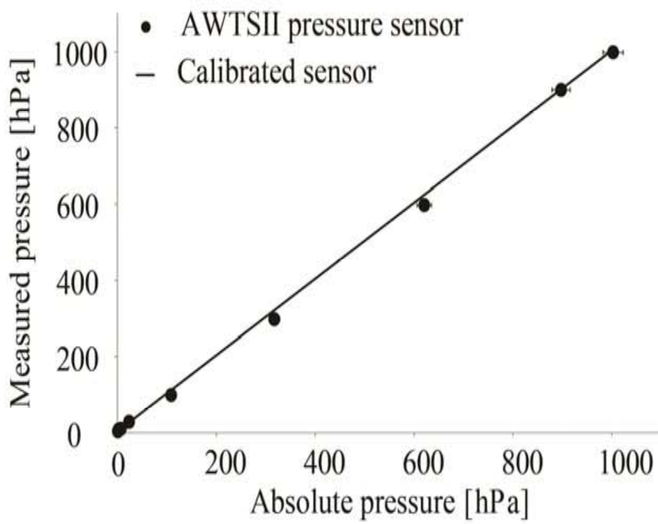


Jon Merrison
Jens Jacob Iversen
Stefano Alois

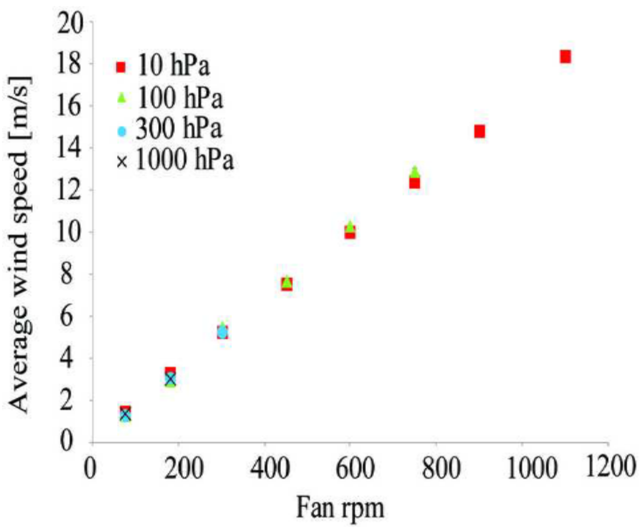
Aarhus Environmental Wind Tunnel Simulator (AWTS II)

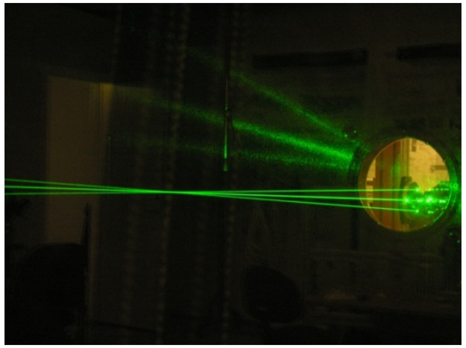


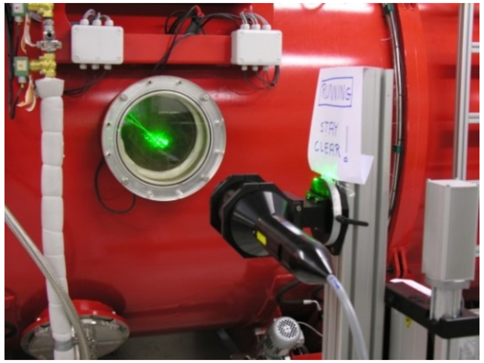




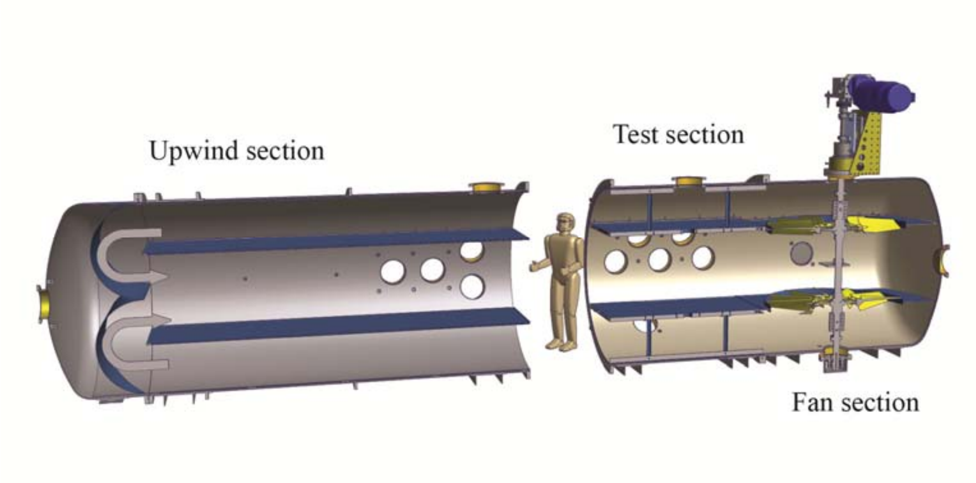
Wind speed and Turbulence

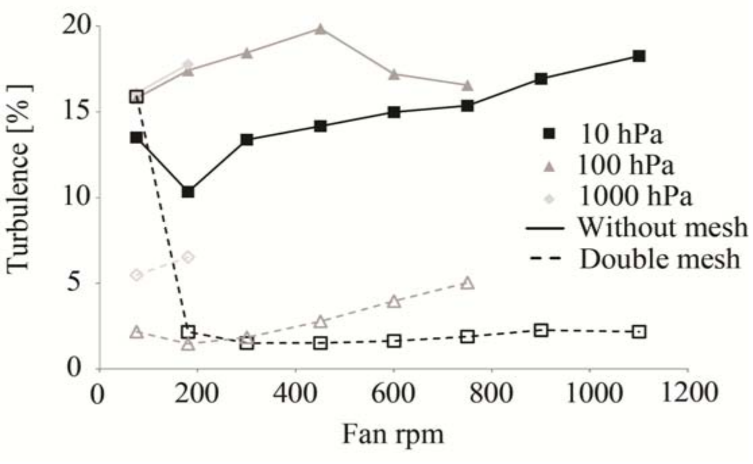




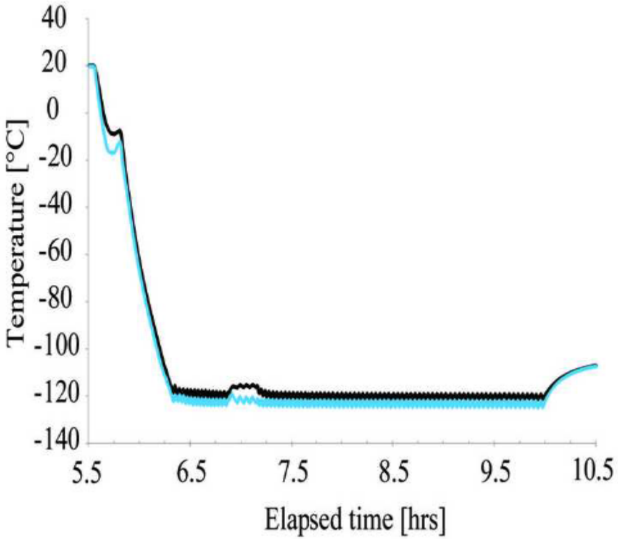


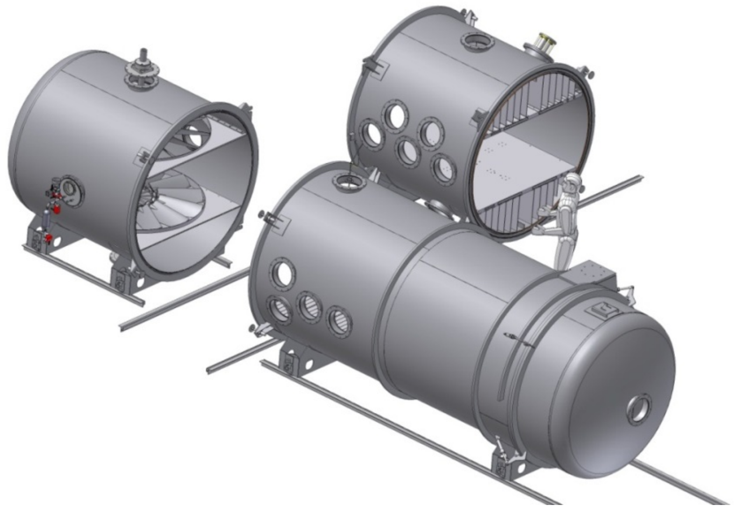
• Characterisation and calibration of wind flow using a combination of sensor technologies and over a wide range of environmental conditions.

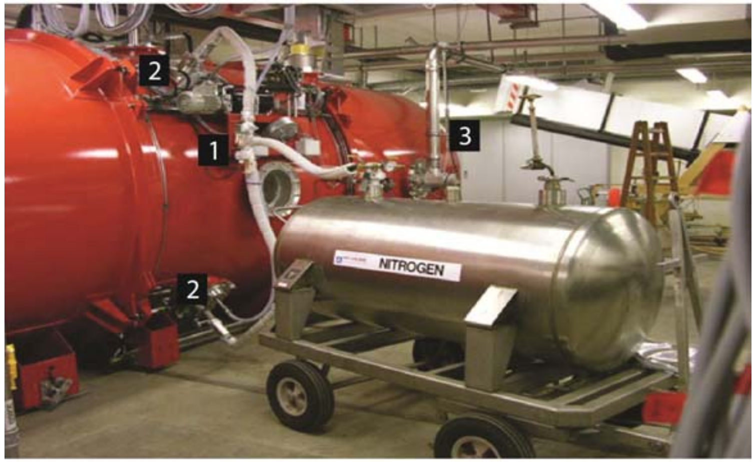


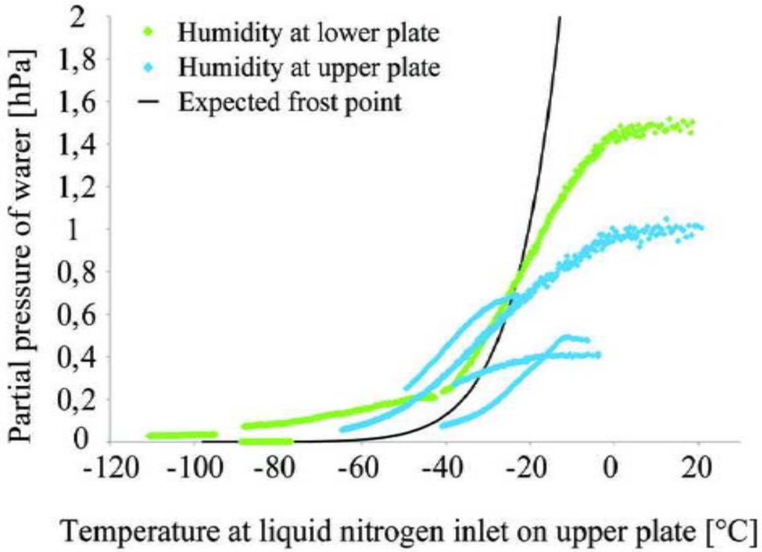


Temperature and Humidity

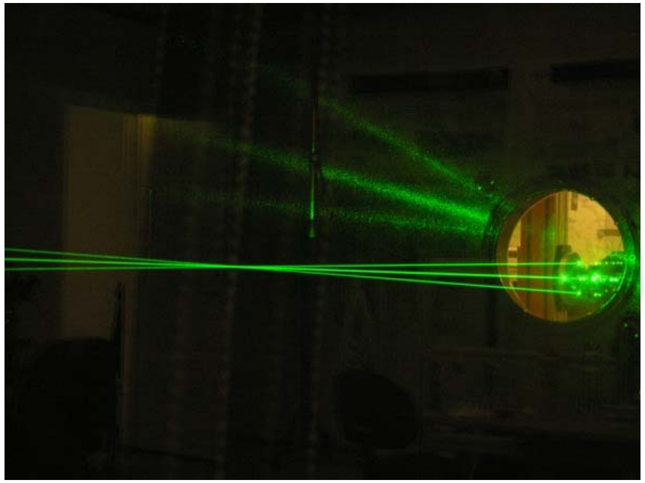


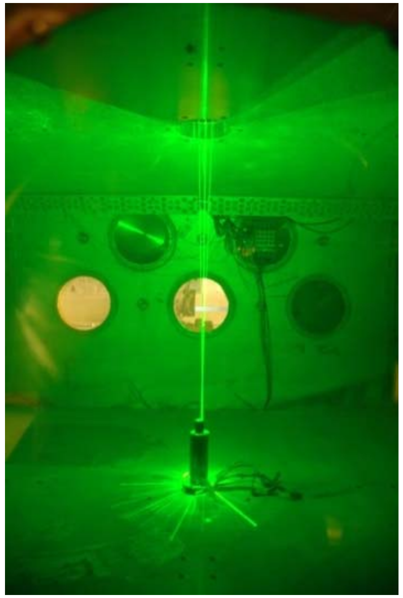


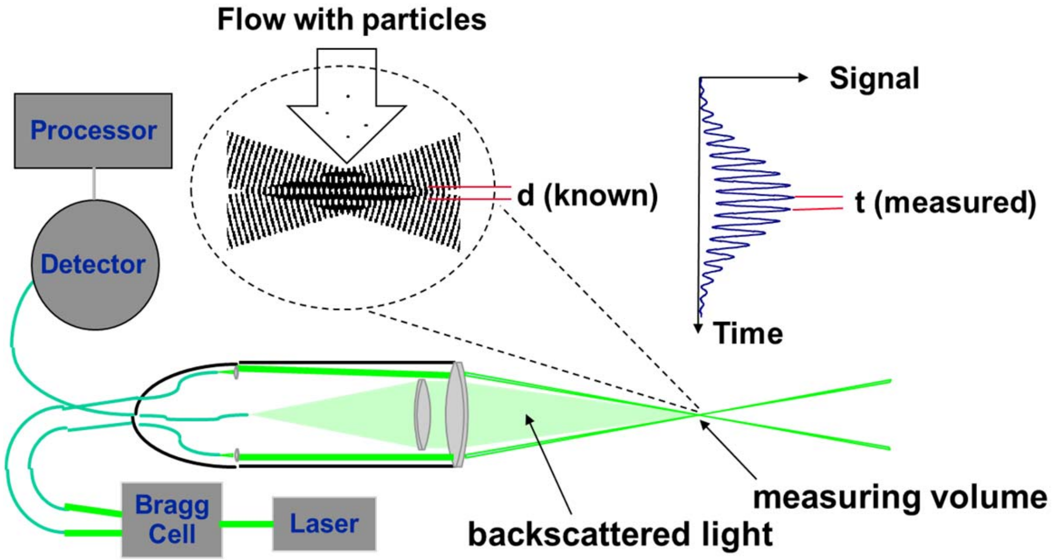


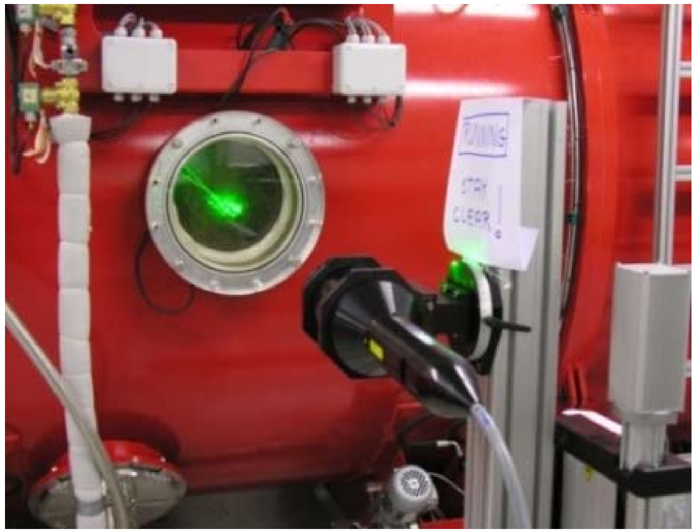


Laser Doppler Velocimeter (Anemometer)









Environmental Simulator(s)

Two types of experiment

1. Aerosolizer (suspended dust)
2. Entrainment (sand/dust transport)

Control;

- Fluid flow (wind speed, turbulence level;)
- Fluid density (gas pressure)
- Molecular Viscosity (composition)
- Temperature (future…2016)

Environmental Simulator(s)

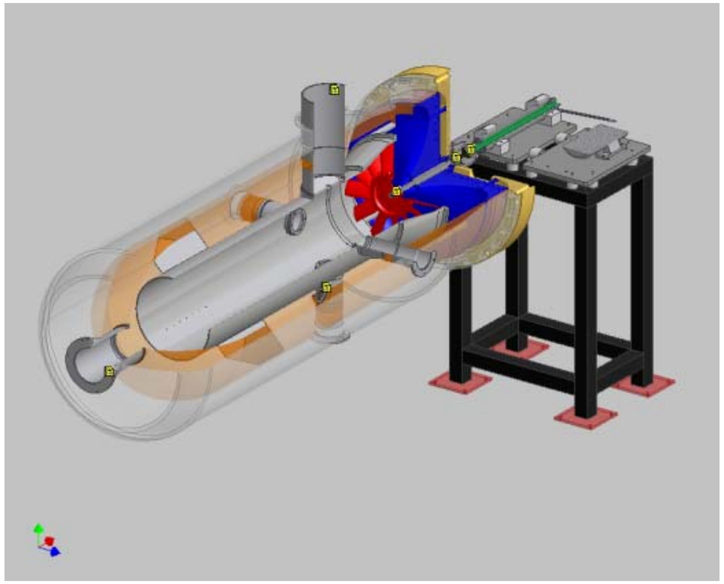
Sense (optically);

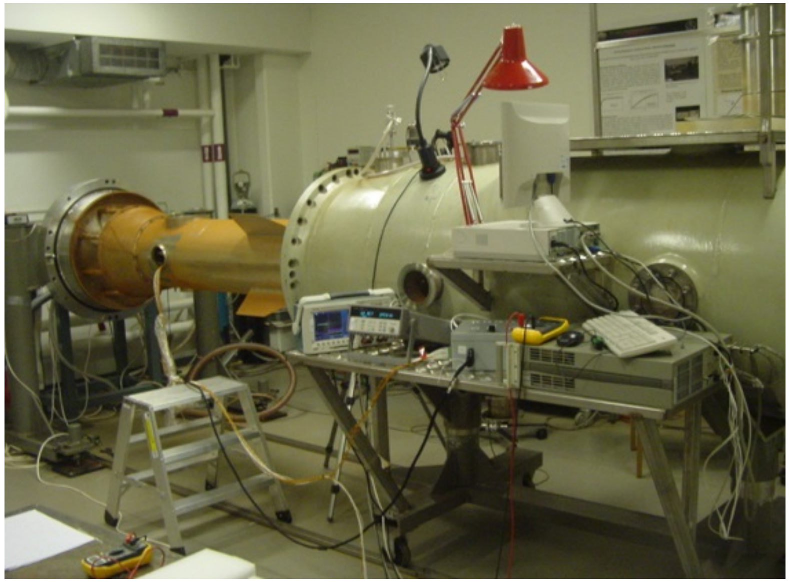
- Suspended grain velocity (specific space/time)
- Wind speed/turbulence (broad frequency range)
- Suspended concentration (t)
- Deposited dust concentration (t, U,)

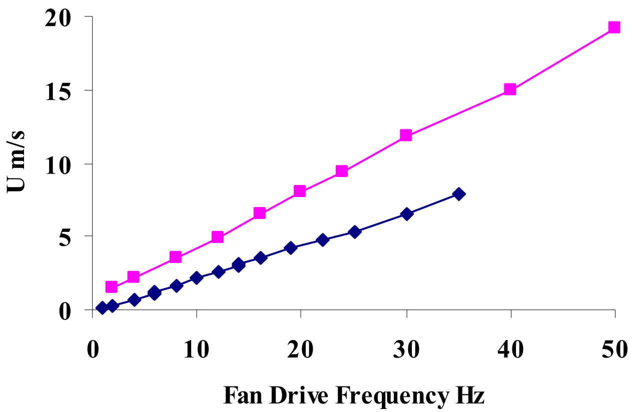
AWTS - I

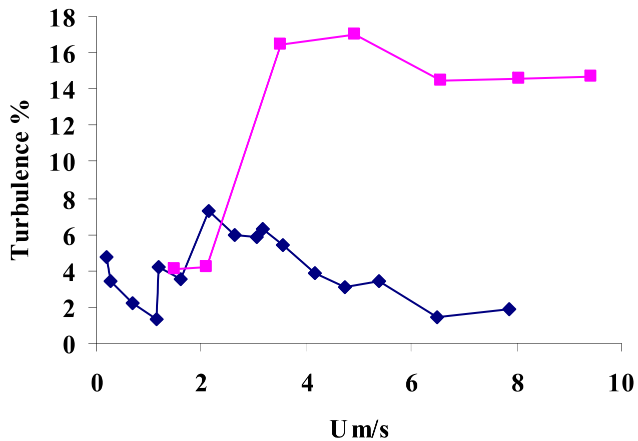
High dust concentrations, (deposition), High speed

Smaller, Poor vacuum
Poor temp. control

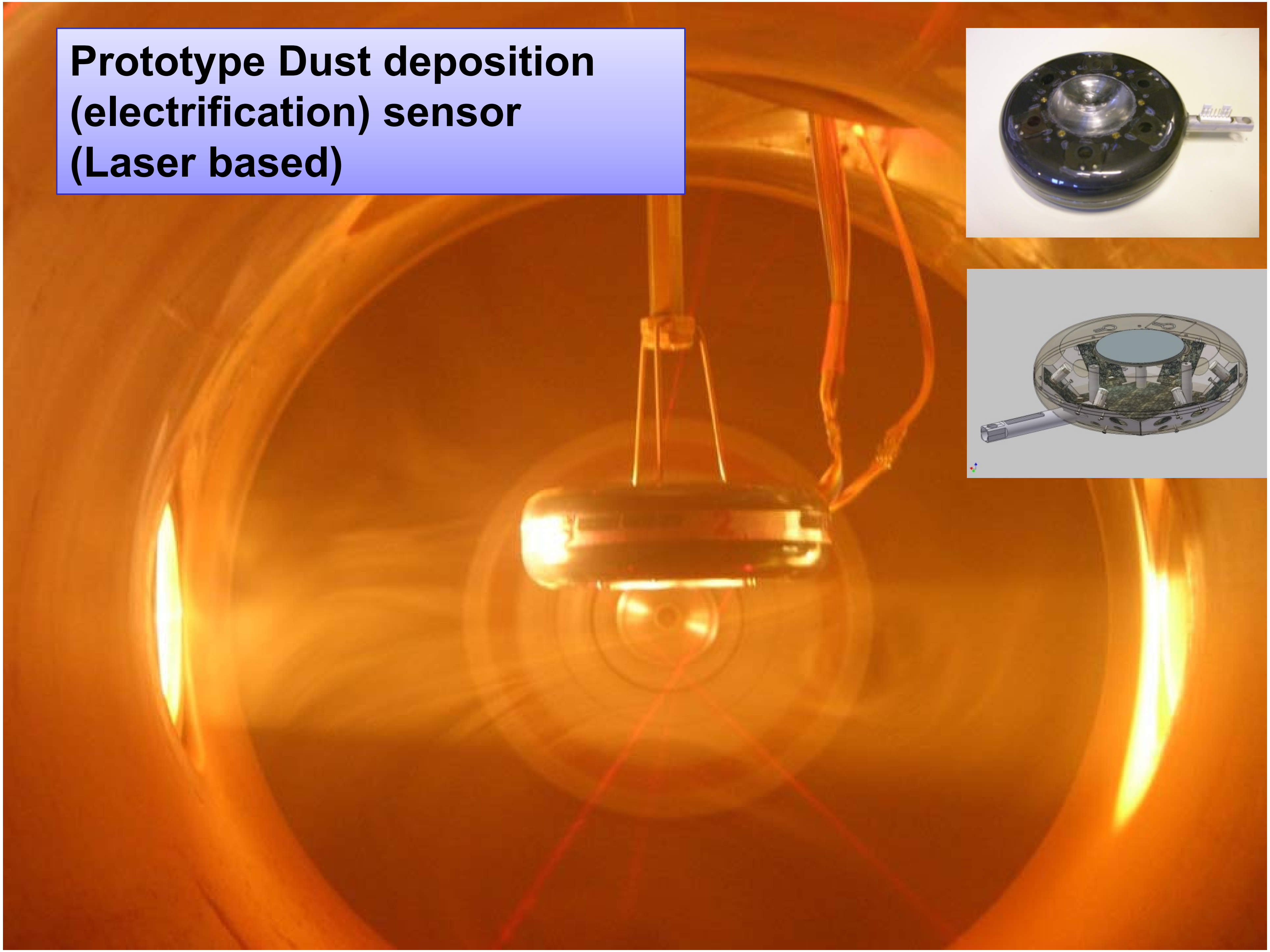




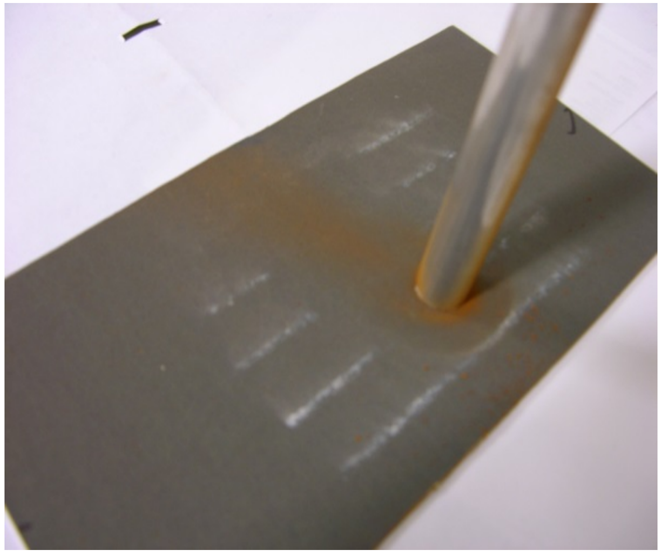


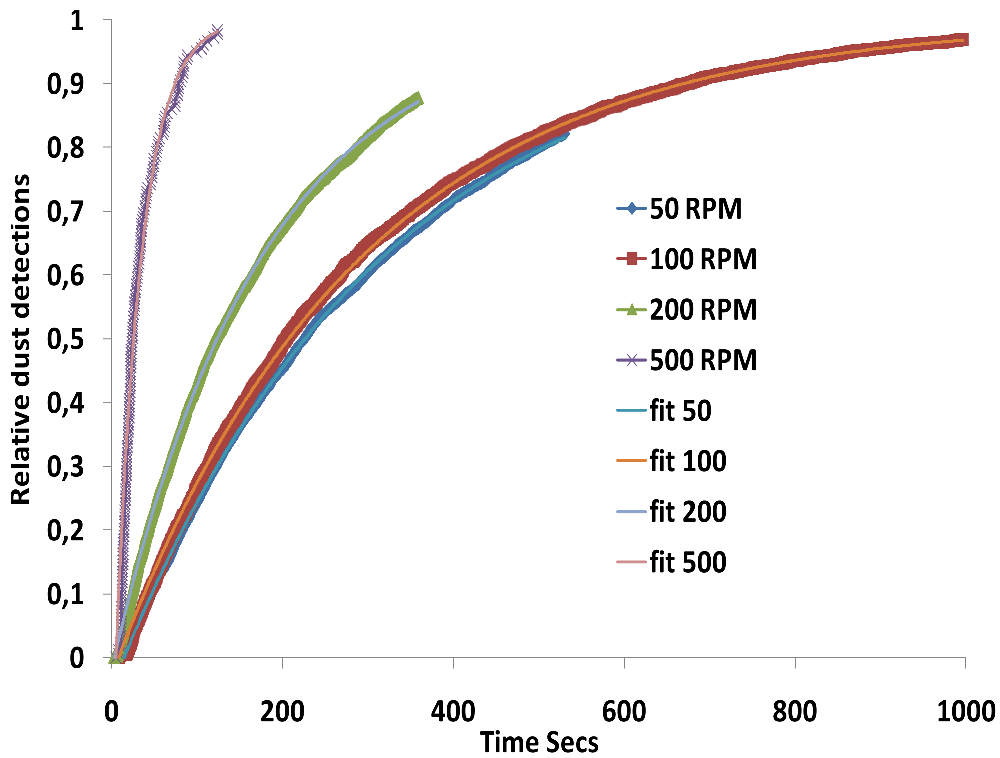


Prototype Dust deposition (electrification) sensor (Laser based)

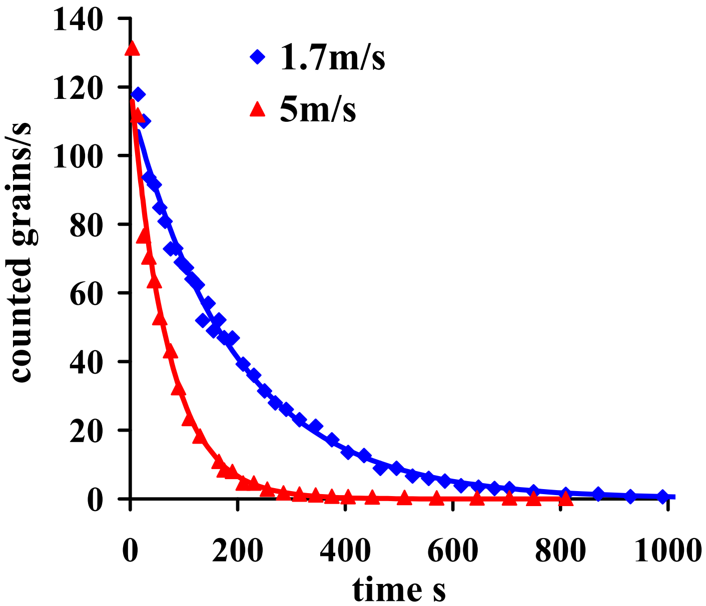


Deposition

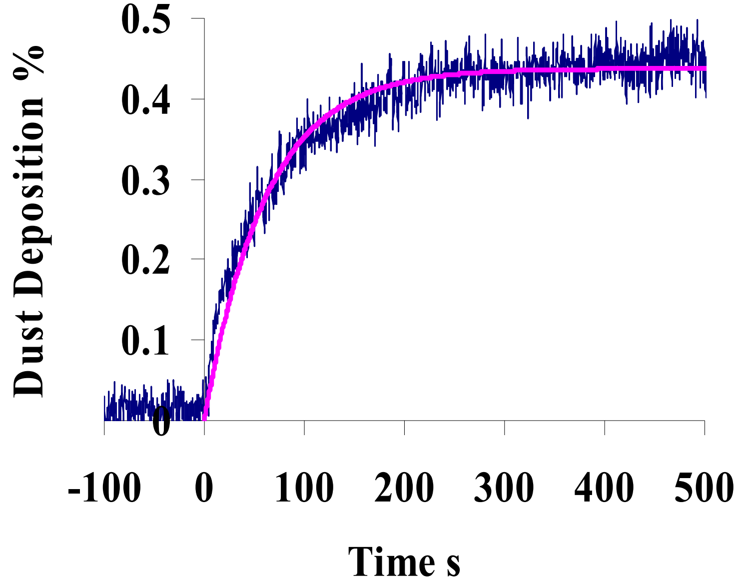




Relative dust detections
Time Secs
0
200
400
600
800
1000
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
50 RPM
100 RPM
200 RPM
500 RPM
fit 50
fit 100
fit 200
fit 500

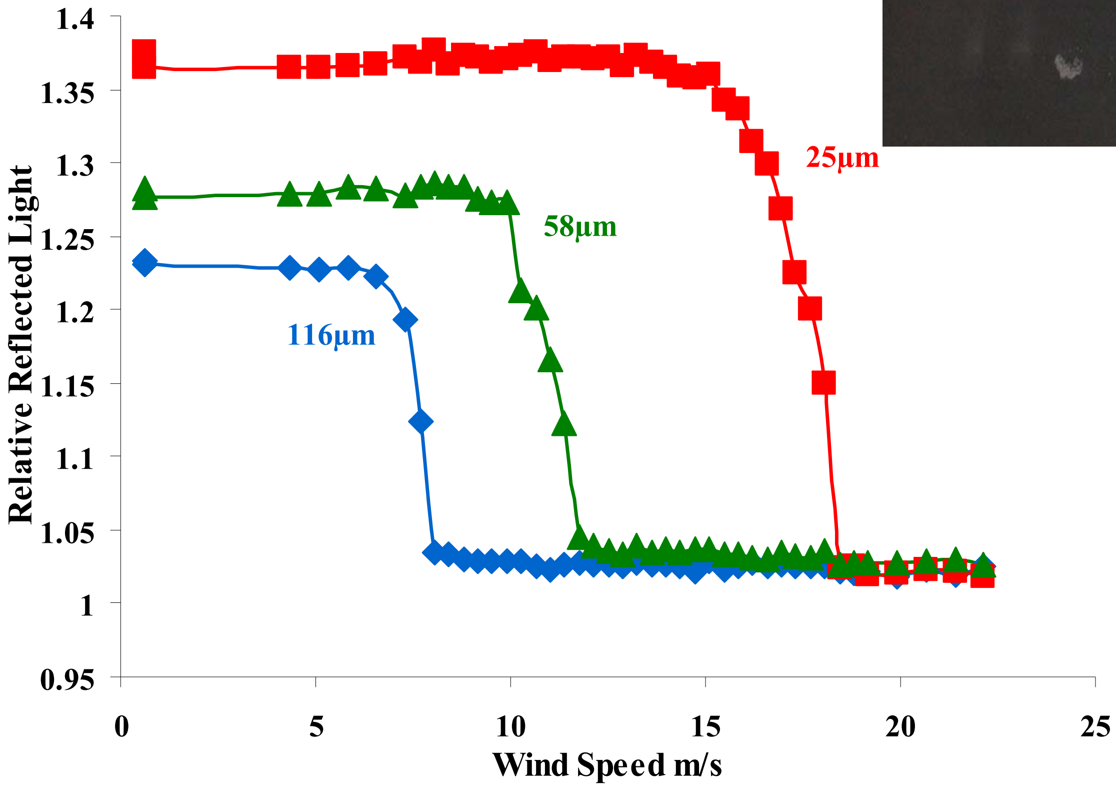


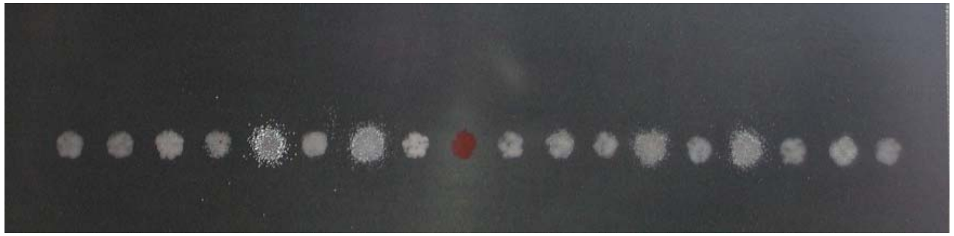
counted grains/s
time s
1.7m/s
5m/s
0
20
40
60
80
100
120
140
0
200
400
600
800
1000

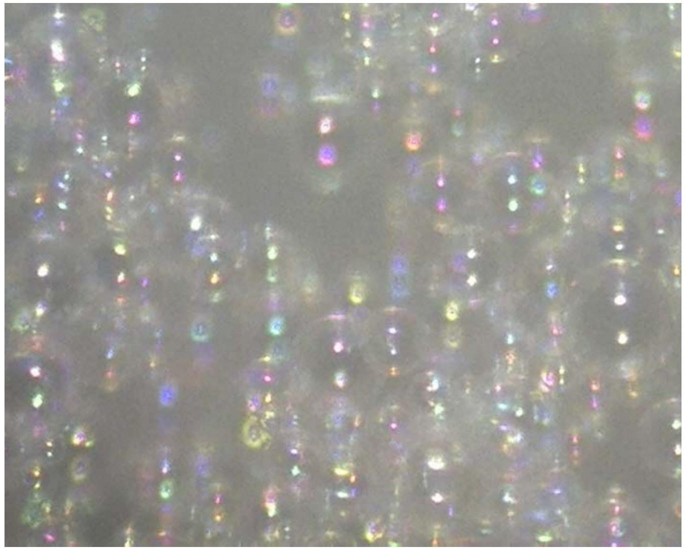


Dust Deposition %
Time s
0
0.1
0.2
0.3
0.4
0.5
-100
0
100
200
300
400
500

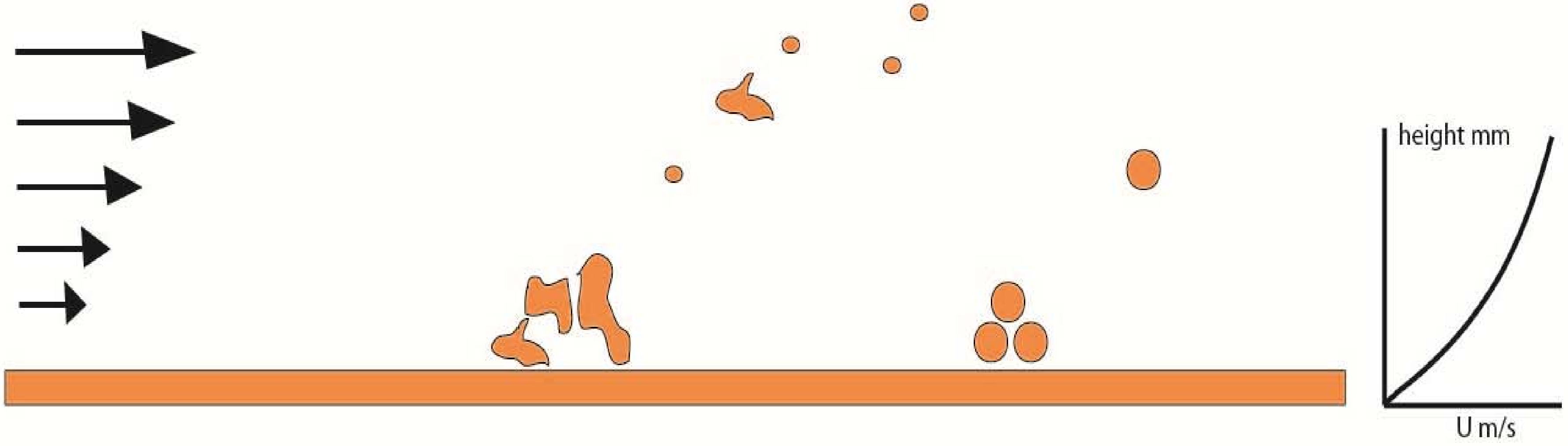
<u>Time limited</u> detachment (Ignoring bursting)





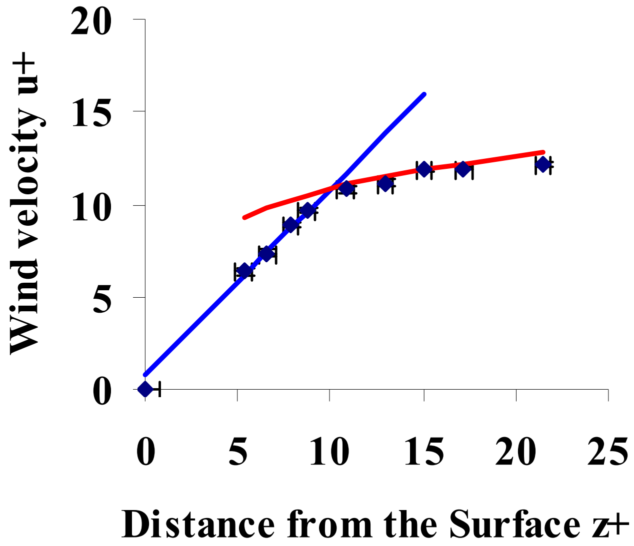


Boundary Layer model



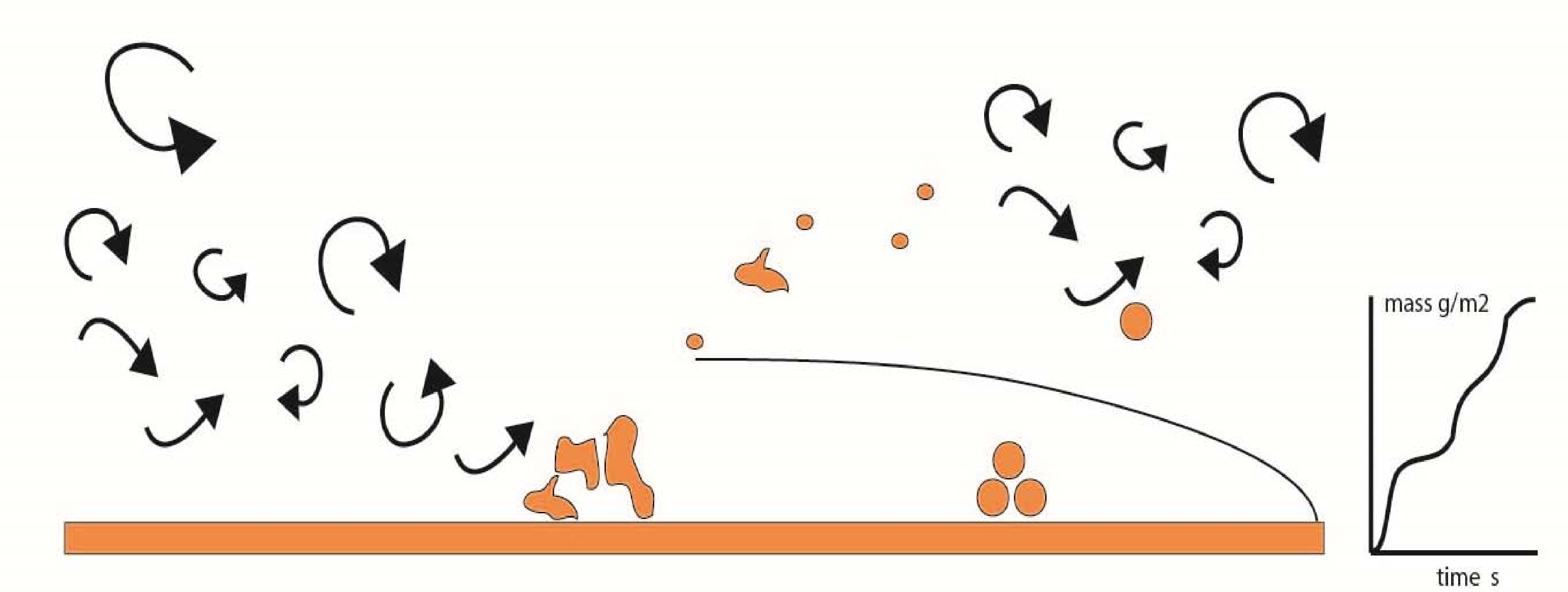
$$U = 2.5U_* \ln\left(\frac{\rho U_*^2}{\mu} Z\right) + 5.1U_*$$

Boundary Layer Wind Tunnels



$$U = \frac{\rho U_*^2}{\mu} Z$$

Turbulence model(s)



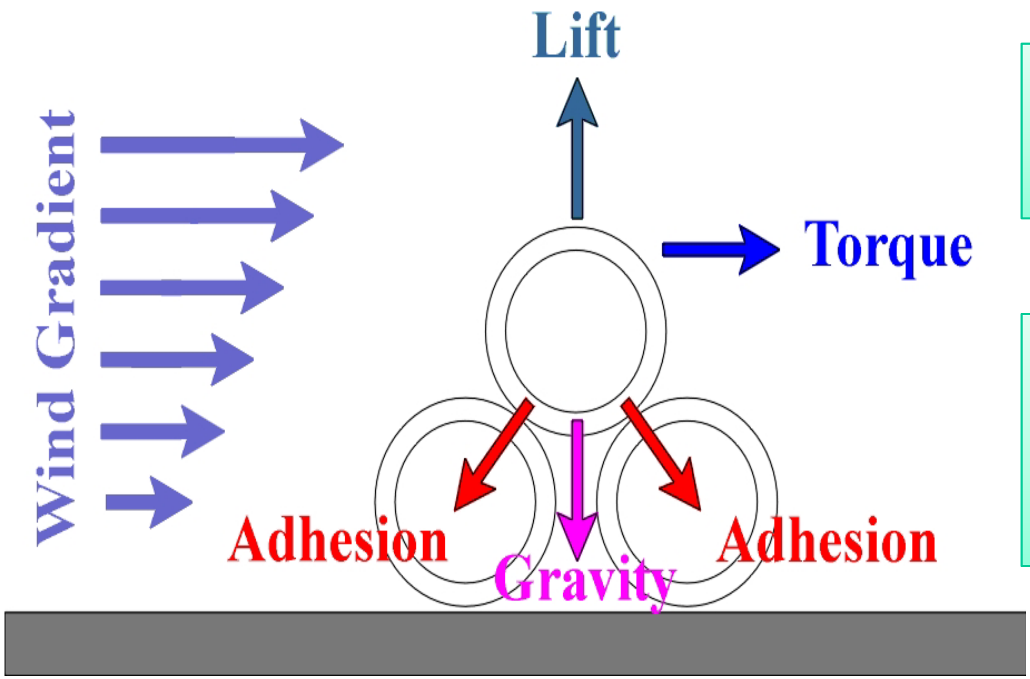
Experimental; ”**Bursting**”/flurries/ejections/sweeps
(Coherent ejection structures in space/time)

Energy spectrum coherent vortices
(Robinson 1991, Ibrahim et al. 2004)

Detachment Threshold: Force Balance Equation

Drag : Lift and Torque

$$F_{lift} + F_{Torque} = F_g + F_{adh}$$

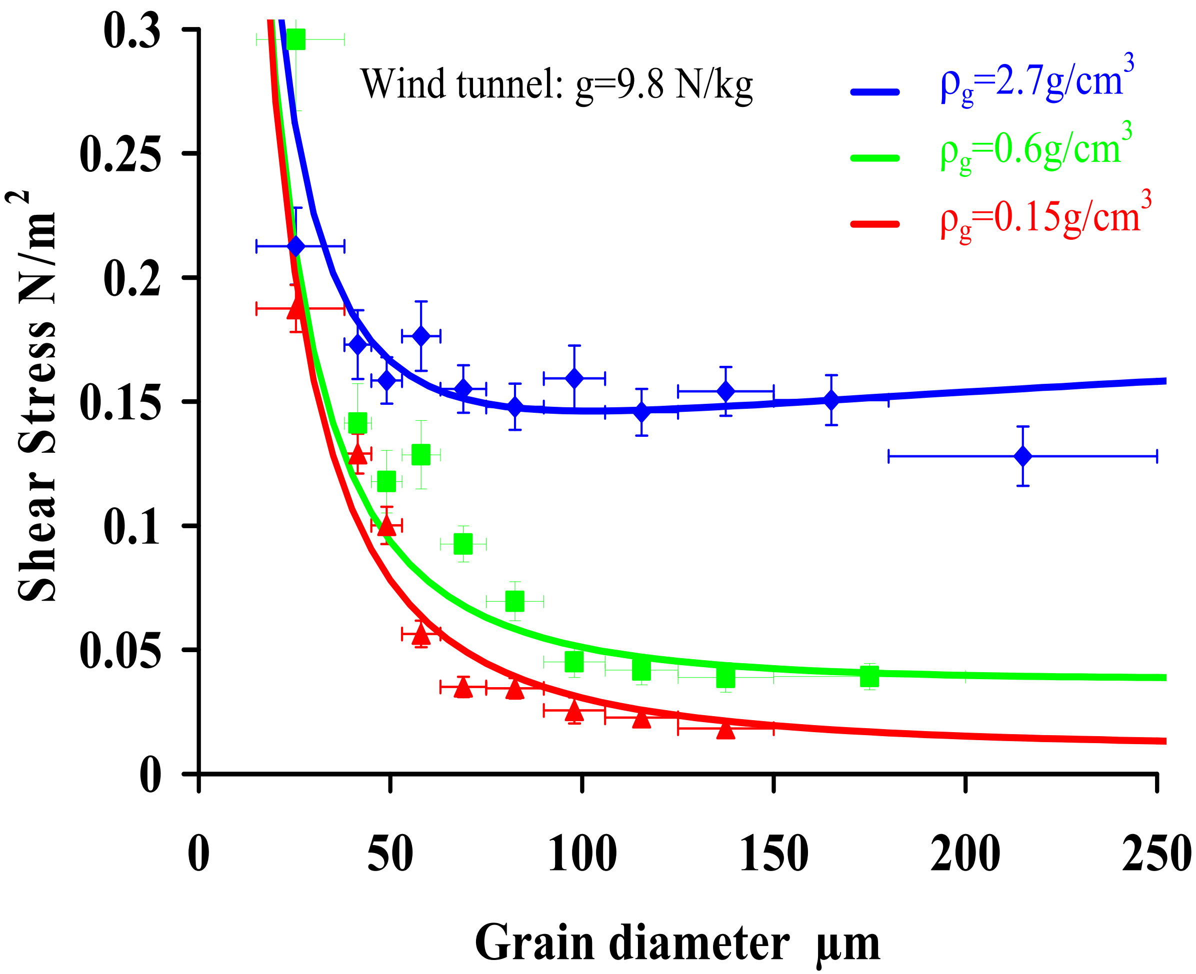


Dust dominated by Adhesion + drag

Adhesion dominated by water bridging at ordinary RH

Gravity (density):	Not always known
Drag lift and Torque:	Empirically determined, poorly defined (power law fit)
Adhesion:	Not known but = C.d

Wind Tunnel Simulator Experiment



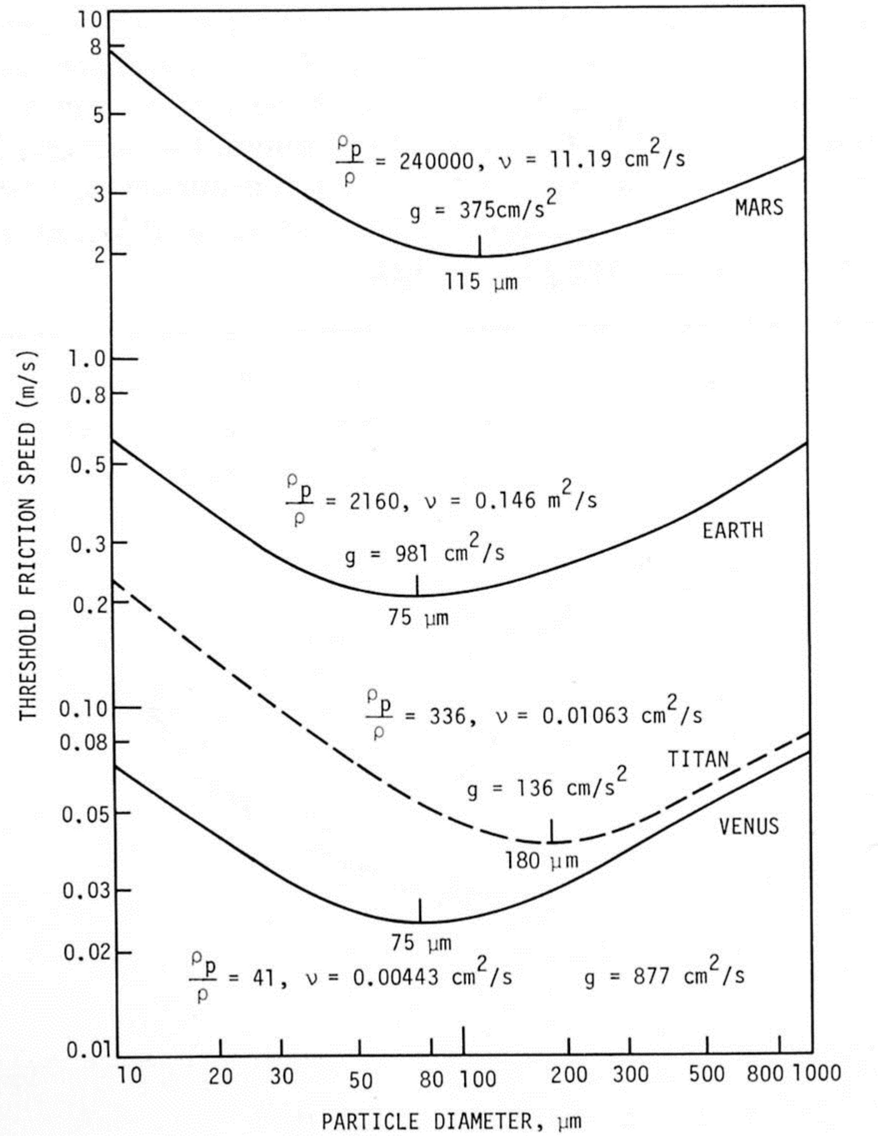
$$\rho u_*^{\,2} \approx \frac{\frac{\pi}{6} g \rho_g d^3 + C_{adh} \cdot d}{C_L \cdot d^2 + C_T \cdot d^3}$$

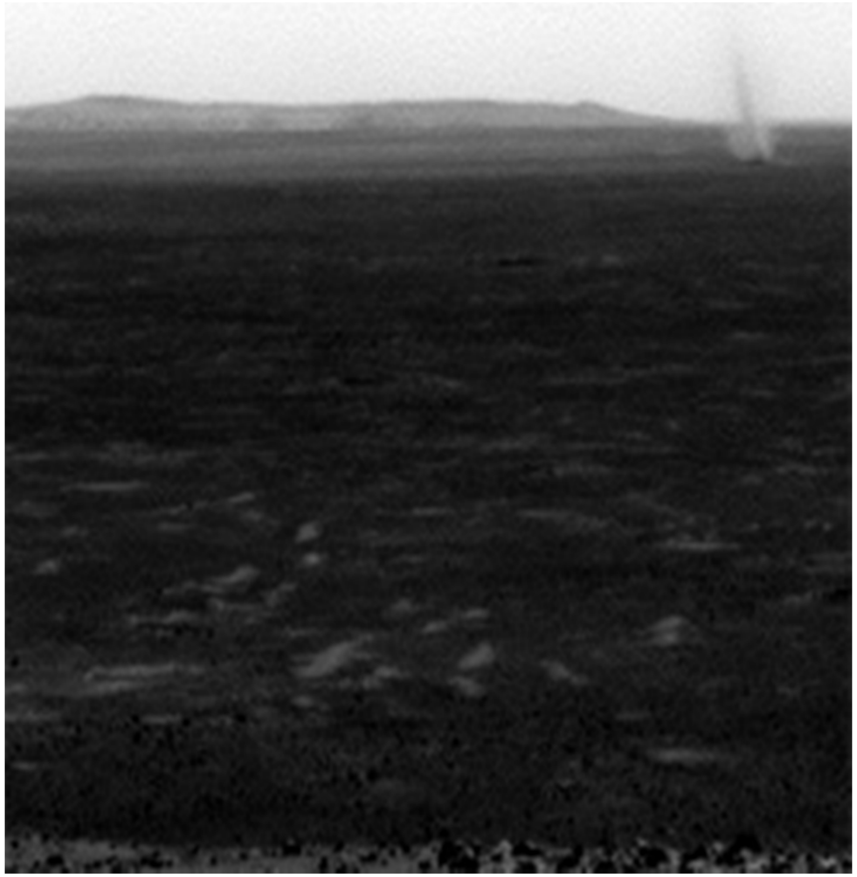
$C_{adh} = 2.7\times10^{-5}\ N/m$

$C_L = 1.45$

$C_T = 4.4\times10^{4}\ m^{-1}$

Entrainment threshold wind speed

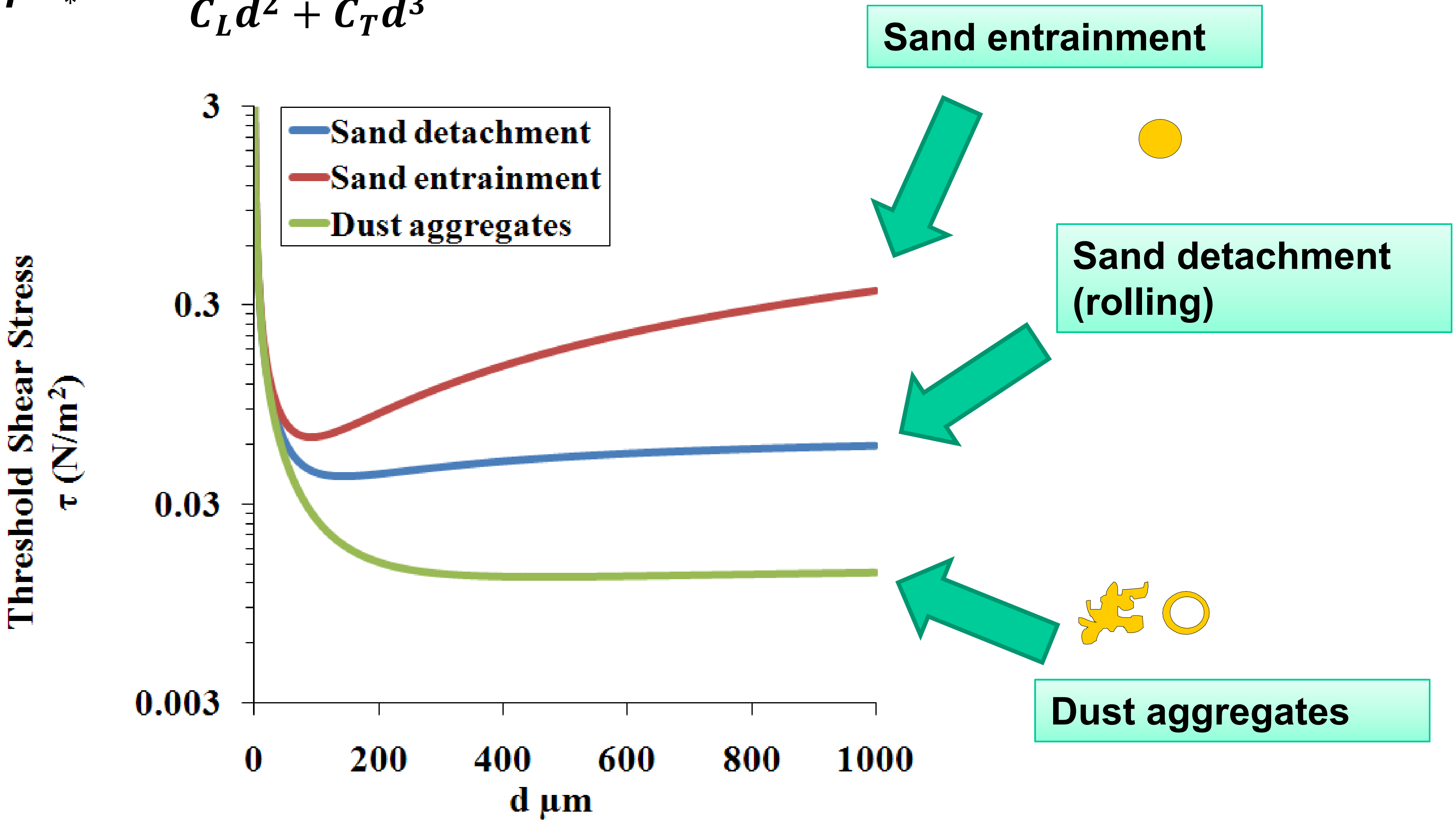




Greeley + Iversen 1985

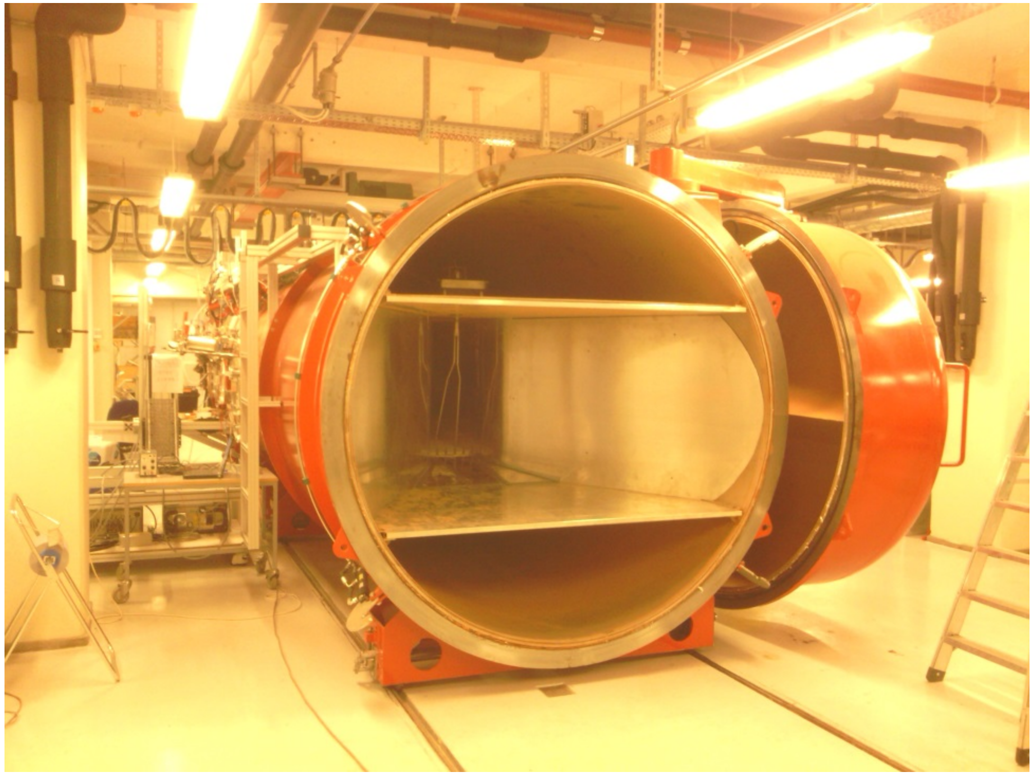
Detachment Threshold (boundary layer model)

$$\rho U_*^2 = \frac{\frac{\pi}{6} g \rho_g d^3 + C_{adh} d}{C_L d^2 + C_T d^3}$$

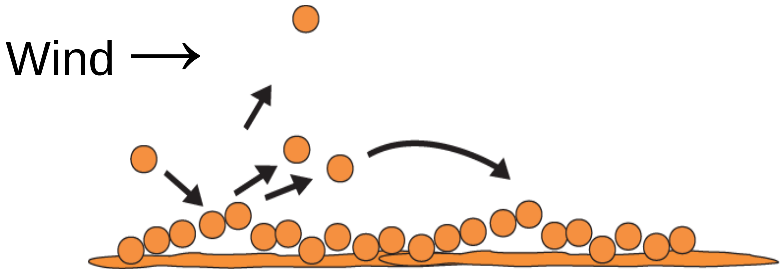


Entrainment / Transport studies

Keld Rasmussen
Anthony Rondeau

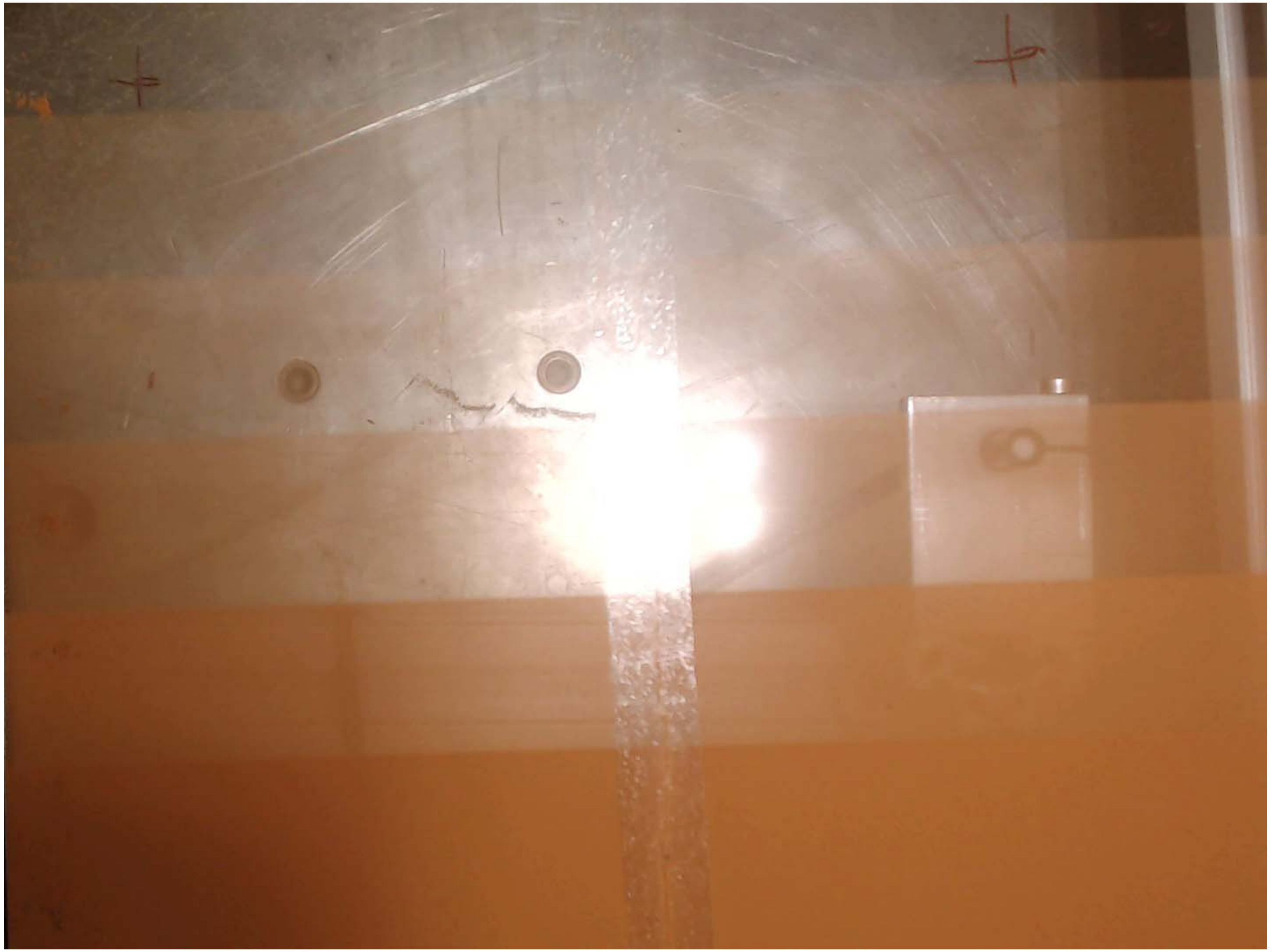


wind speeds > 10m/s



- Flow Threshold
- Transport/removal rate
- Trajectories
- Size/velocity sand
- Aggregate dispersion

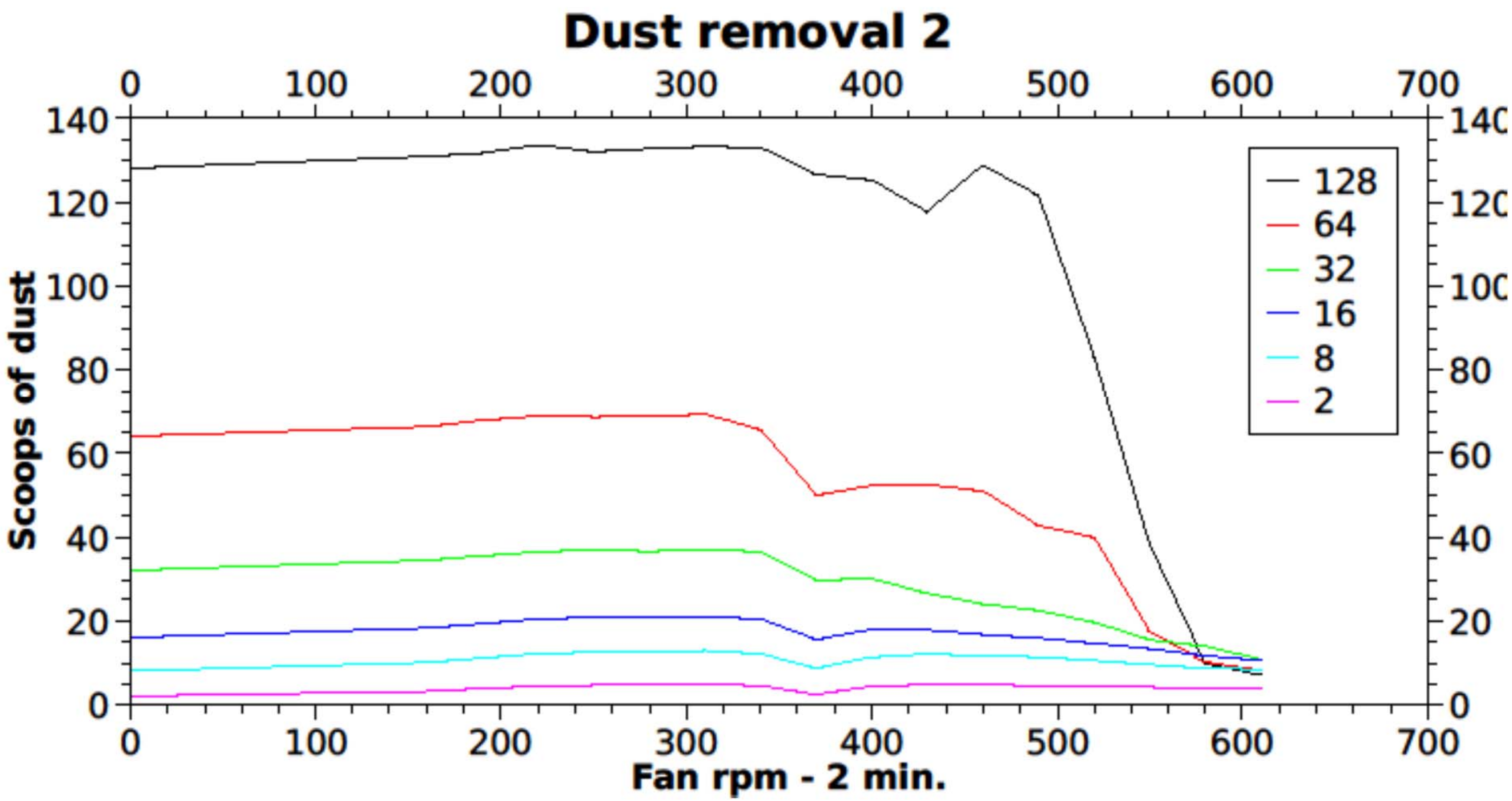
Re-suspension rate



Re-suspension rate

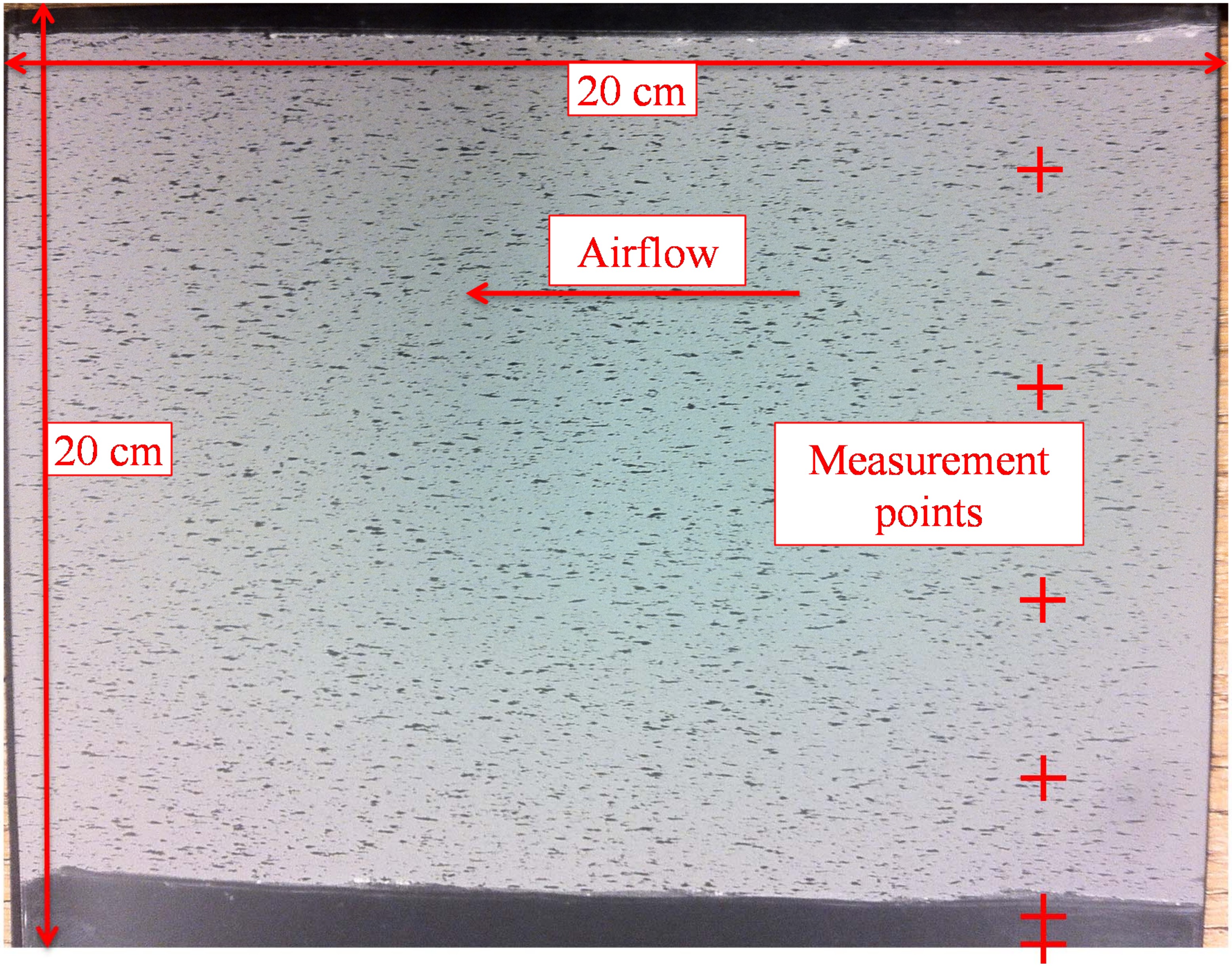
Re-suspension rate

Dust thickness

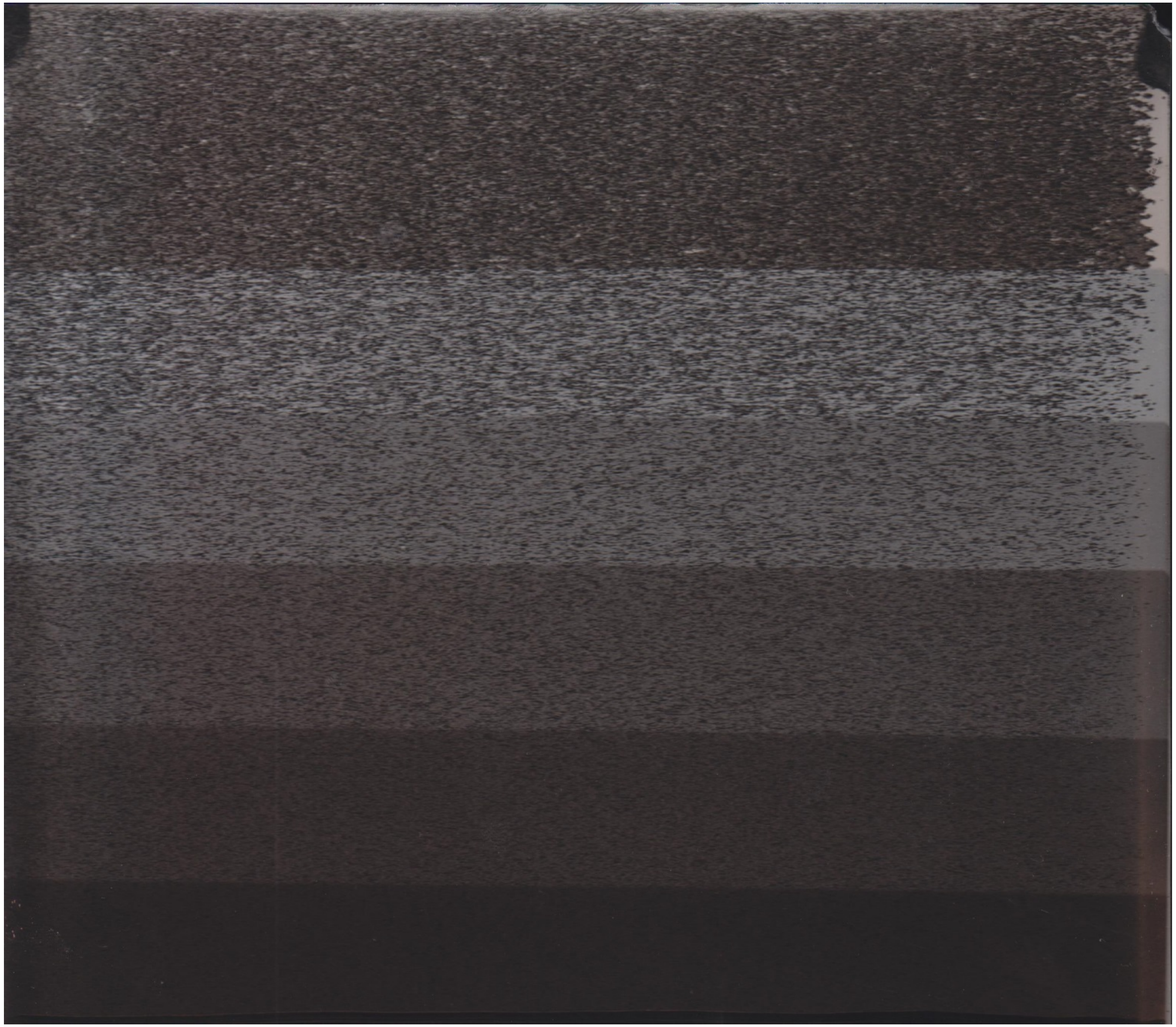


Wind Speed

Re-suspension rate



Re-suspension rate

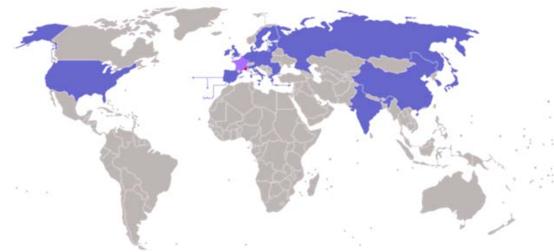


IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

International Thermonuclear Experimental Reactor

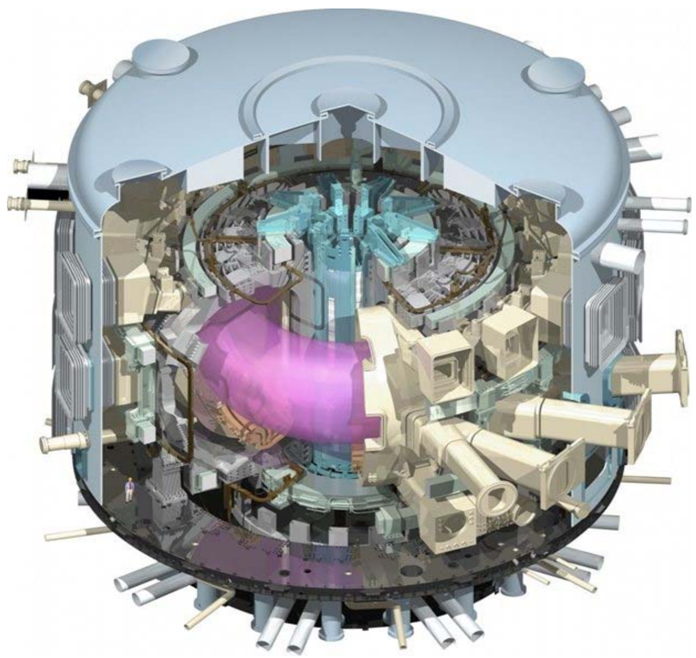
iter
china eu india japan korea russia usa

(Jean-Christophe Sabroux)

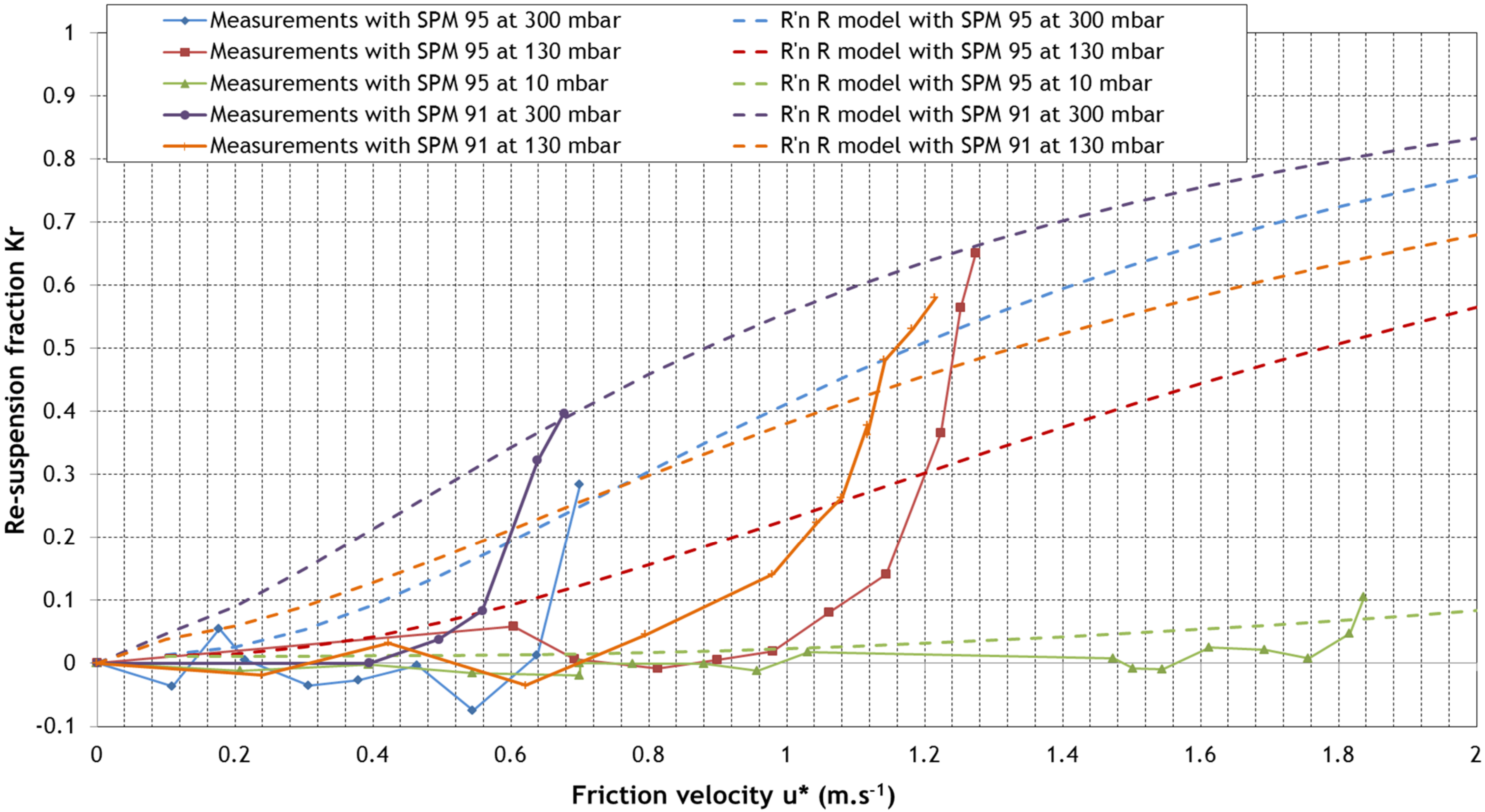


**10s kg dust (Be, W, C)
as a result of the erosion of the vacuum chamber walls by the plasma.**

2013 studies
(Anthony Rondeau IRSN);
Dust re-entrainment studies

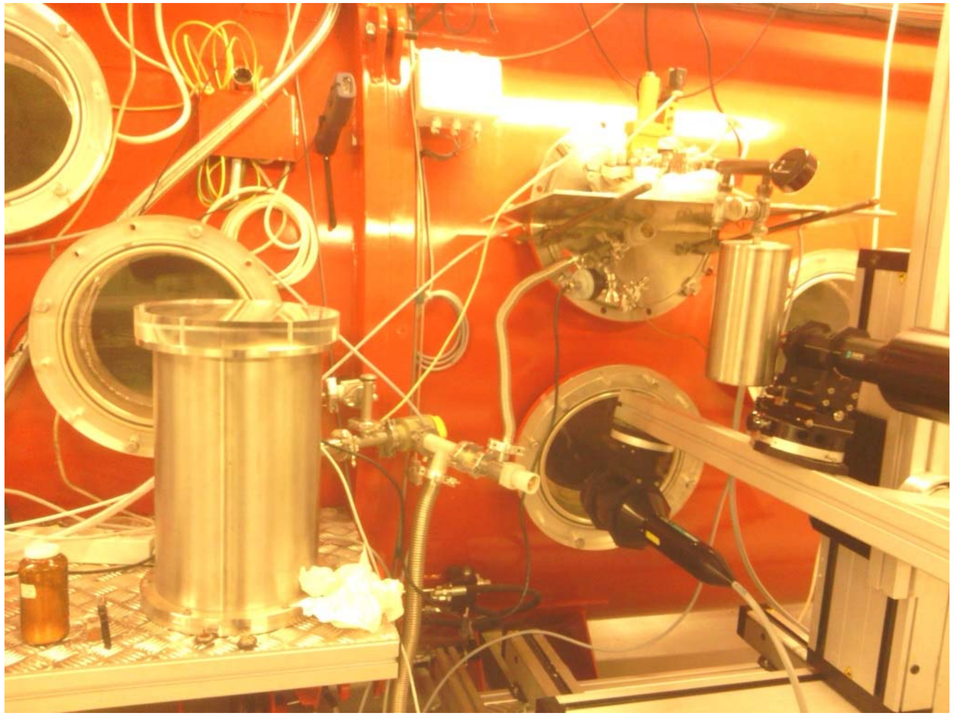


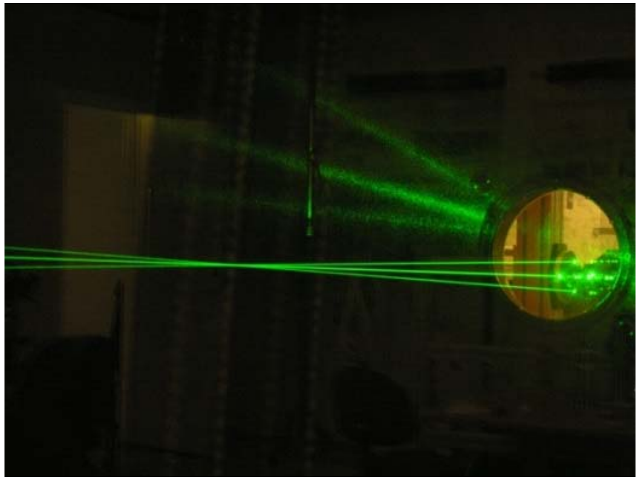
Re-suspension rate



Aerosol studies

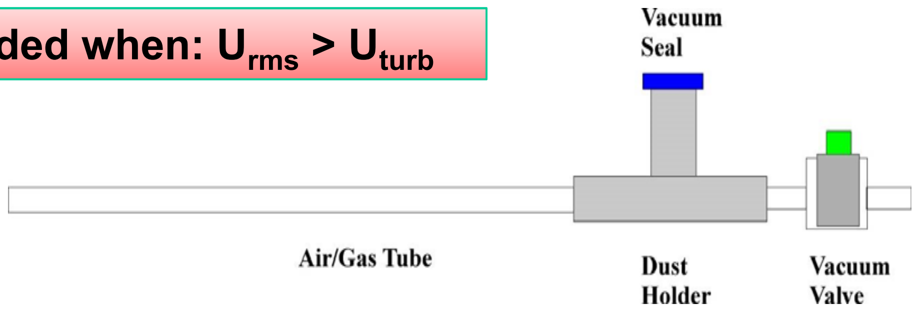
Andreas Jakobsen

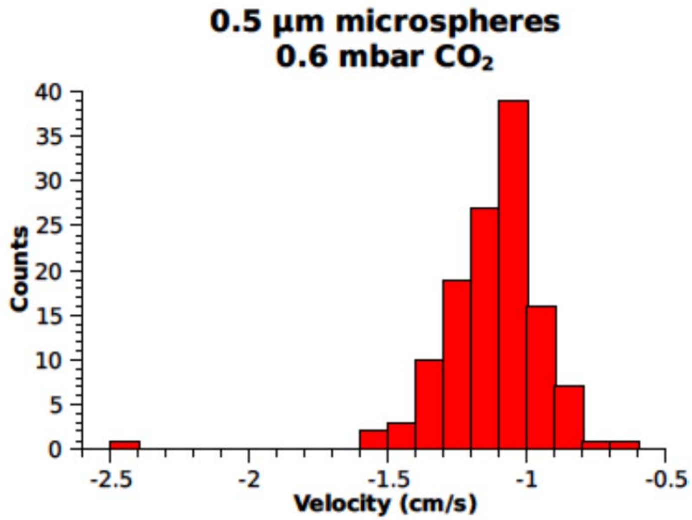




P= 0.5mbar – 30mbar
d= 250nm – 40µm (silica microspheres)

Suspended when: $U_{rms} > U_{turb}$

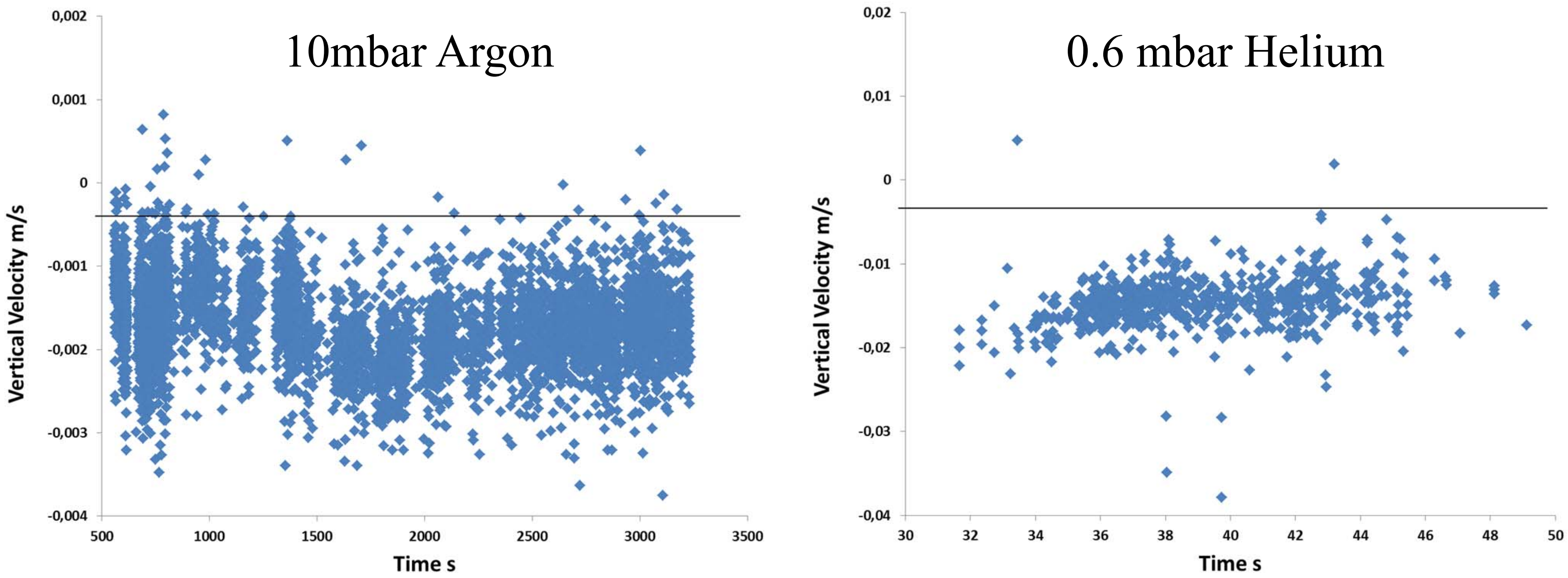




- Settling rate (fluid drag)
- Aggregation/dispersion
- Electrification

Aerosol settling Studies

0.5 μm spheres



$$R_e = \frac{\rho U r}{\mu}$$

ρ – pressure
U – measured/controlled
r - microspheres
μ - composition

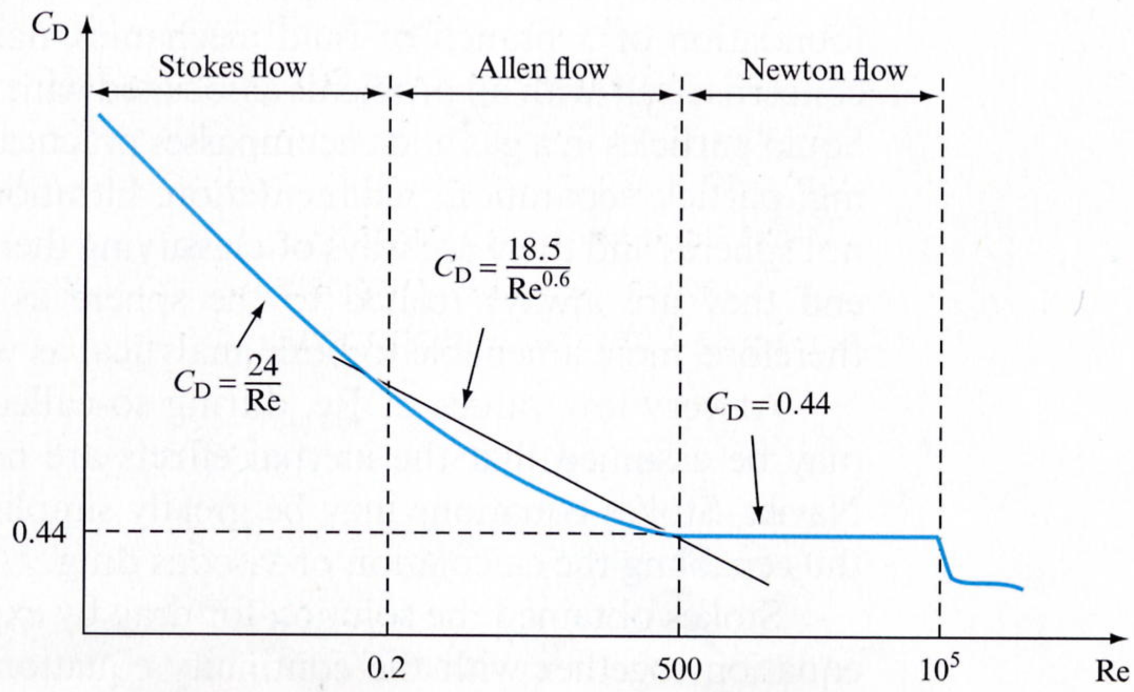
Aerodynamic Drag
SETTLING SPEEDS

$$U = \frac{r\rho_p}{\rho}\sqrt{\frac{m_{mol}}{KT}}$$

$$U = \frac{2\rho_p r^2}{9\mu}$$

$$U = \sqrt{\frac{8\rho_p}{3\rho}\frac{r}{C_d}}$$

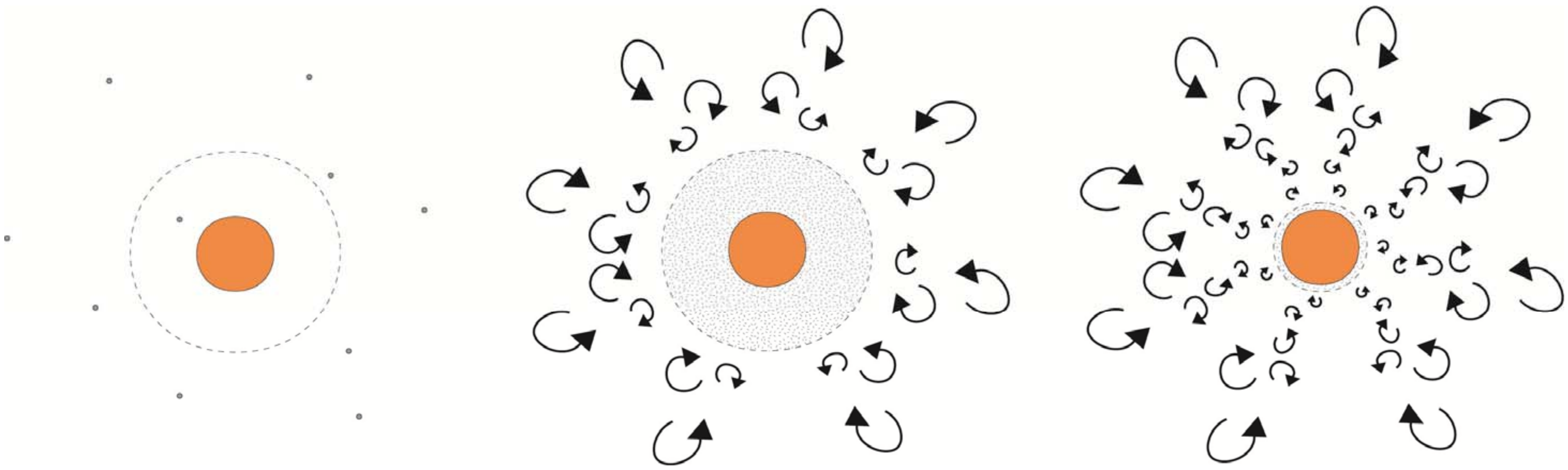
Epstein



$\lambda = 70$nm
At STP

Knudsen Number

Aerodynamic Drag



Epstein | **Stokes** | **Newton**

$$U = \frac{r\rho_p}{\rho}\sqrt{\frac{m_{mol}}{KT}}$$

$$U = \frac{2\rho_p r^2}{9\mu}$$

$$U = \sqrt{\frac{8\rho_p}{3\rho}\frac{r}{C_d}}$$

Aerodynamic Drag

Sand Transport

Dust Transport

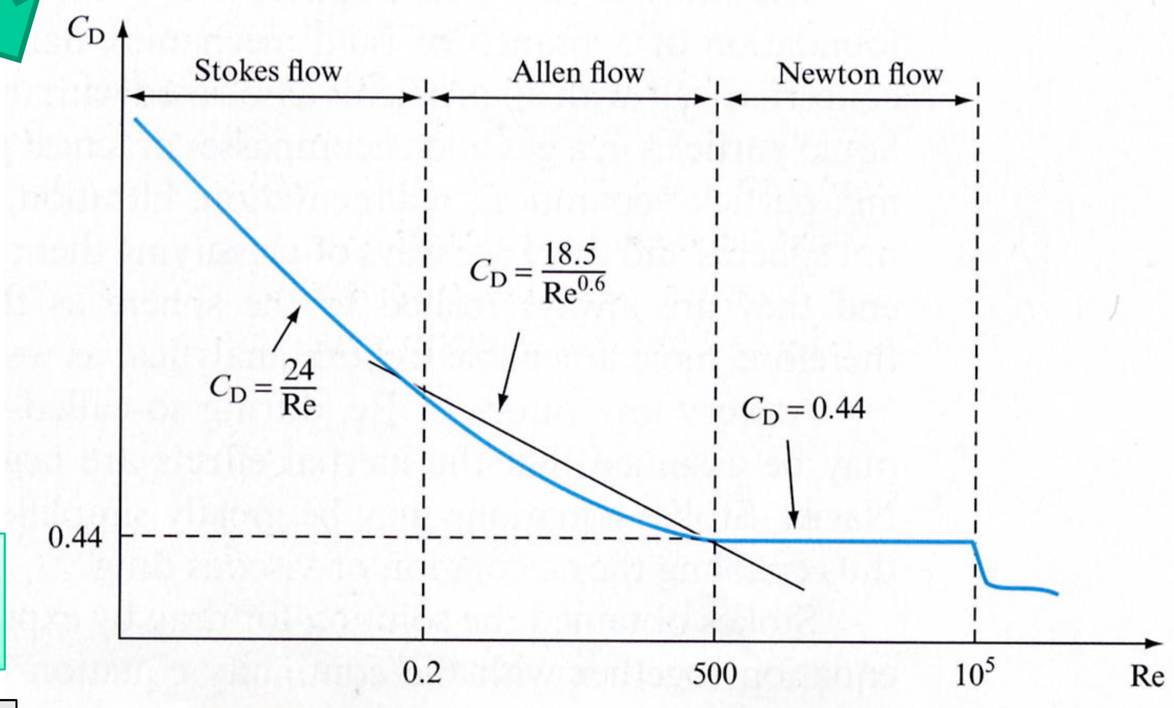
Very Small grains
Low pressure

$$Kn = \frac{\lambda}{r}$$

Knudsen Number

Slip Factor
(Cunningham correction)

$$S = 1 + K_n\,(\alpha + \beta\exp(-\gamma/K_n))$$

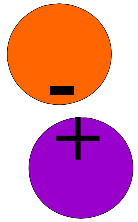


Reynolds Number

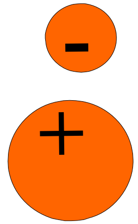
$$Re = \rho U d/\mu$$

Electrification dust/sand

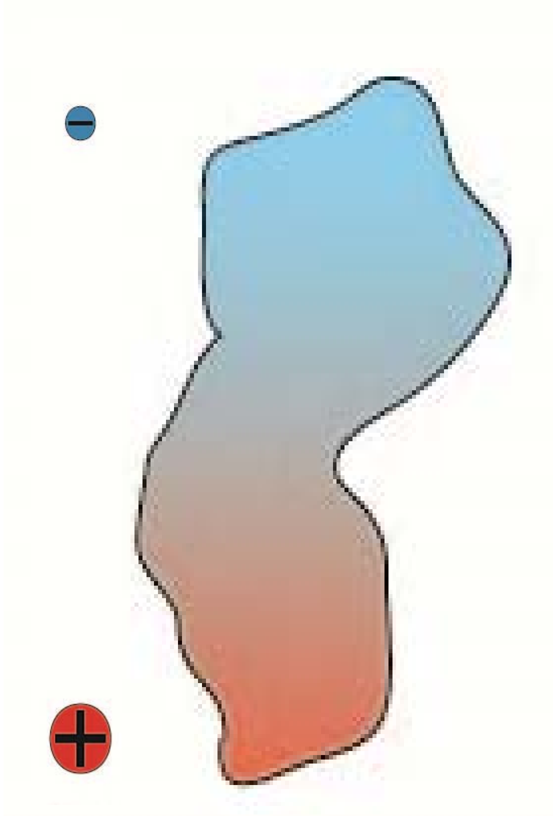
Contact Electrification



Q < 0.1 mC/m^2



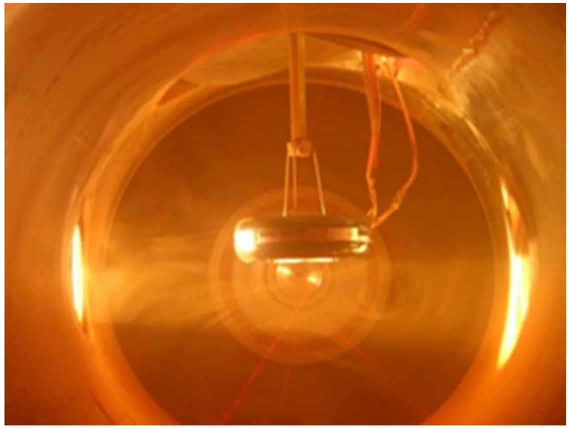
Tribo-electrification (frictional-electrification)

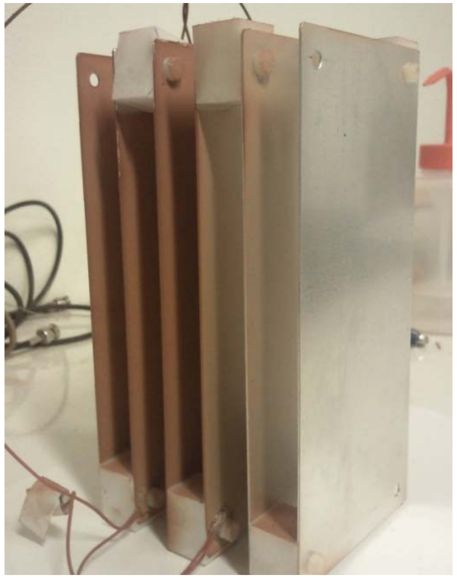


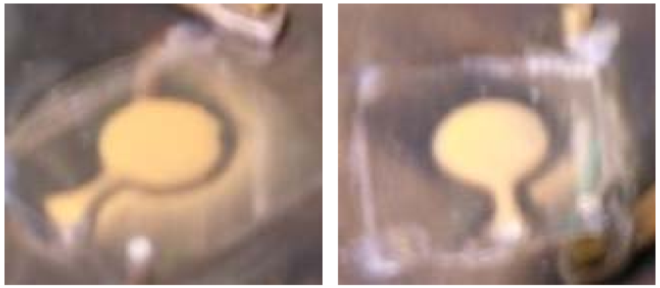
fracto-electrification

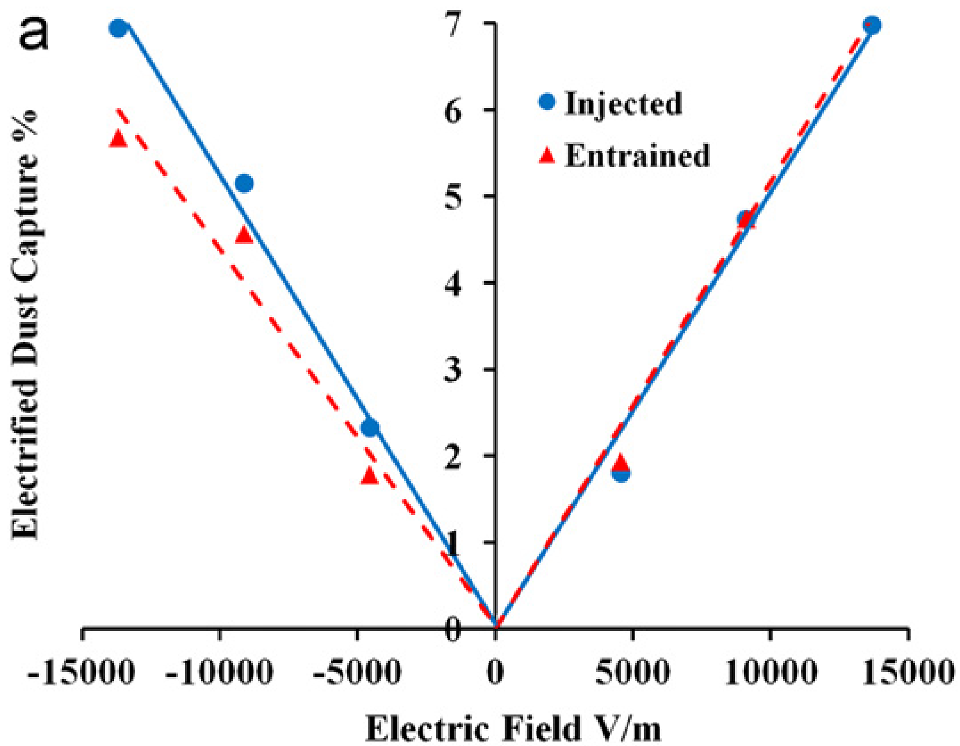
Electrification dust/sand

$Q = +/- 10^3 - 10^5$ e

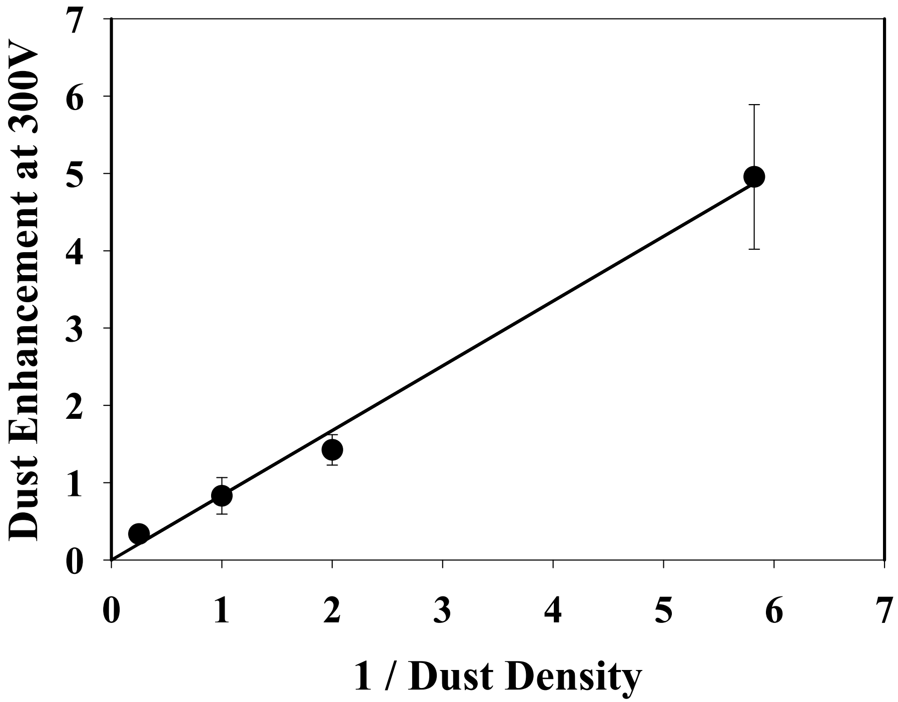


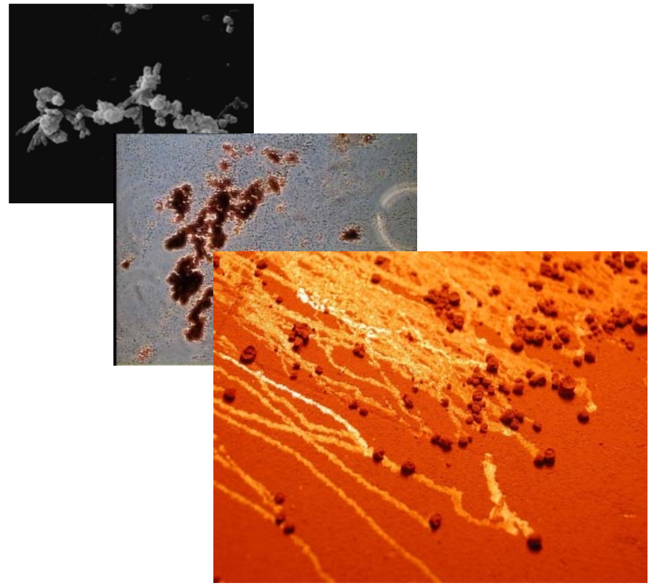


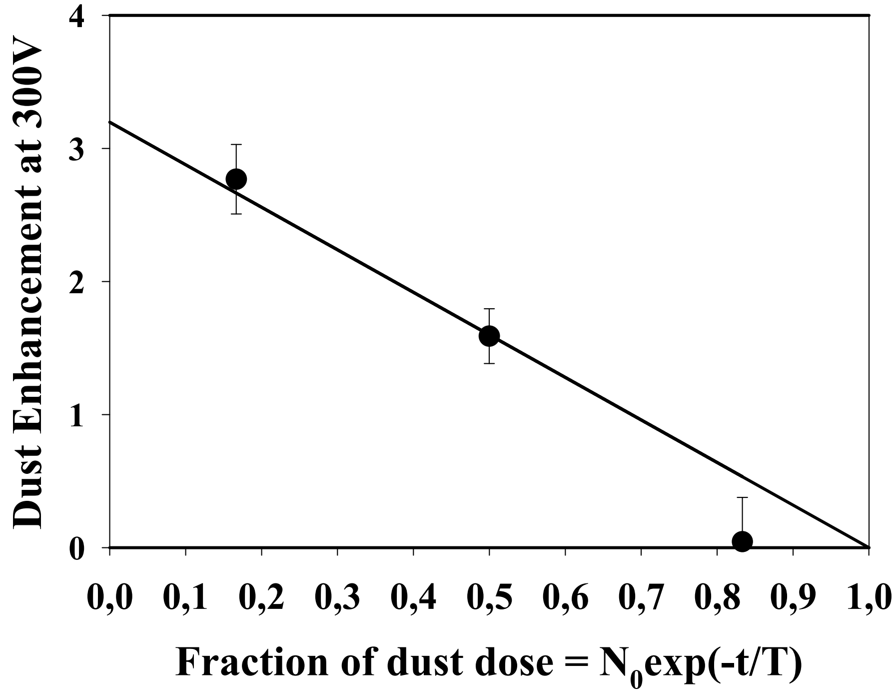




Electrification – aggregation (electrostatic self assembly)



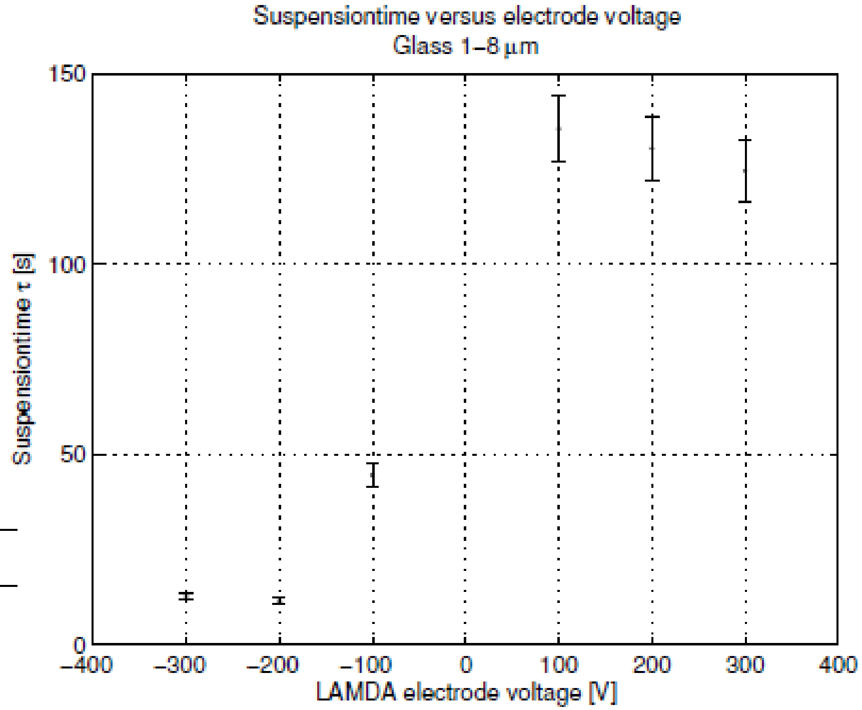




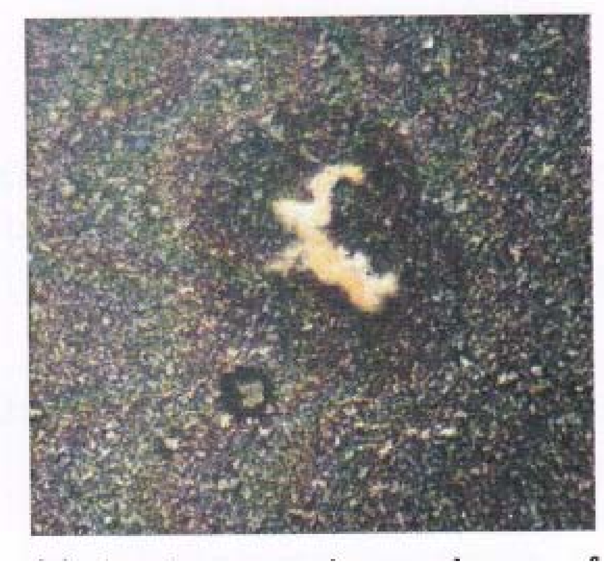
- Less electrified with time
- Less electrified with concentration
- No gas dependence
- Dispersion insensitive
- Weak mineral dependence

Electrification - aggregation

Electrified dust aggregates! (partially dispersed)



Mineral	τ (+) (s)	d (+) (μm)	τ (−) (s)	d (−) (μm)
Glass 1-8 μm	123 ± 13	1.5	23 ± 19	5.4
Glass 10 μm	167 ± 46	1.1	16 ± 4	7.7
Quartz < 2 μm	81 ± 17	2.2	21 ± 6	5.4
Quartz < 63 μm	71 ± 10	2.5	30 ± 7	3.9
$CaCO_3$	123 ± 19	1.4	19	6.0
HWMK101	117 ± 26	1.6	18	6.8
Gufunes	140 ± 57	1.2	29 ± 4	3.8



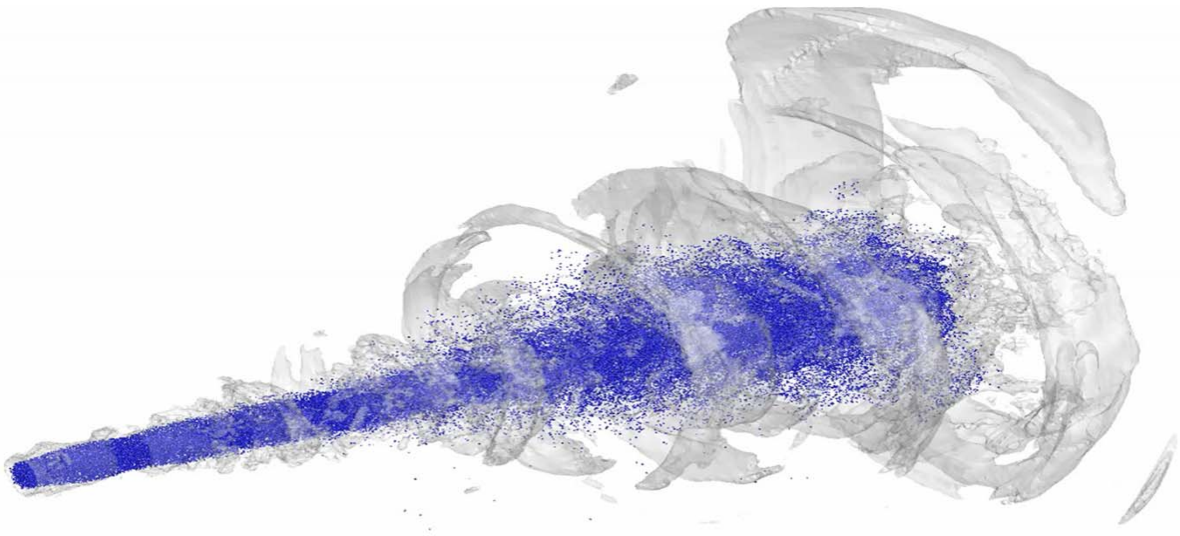
0V on electrodes;

Mineral	τ (+) (s)	d (+) (μm)	τ (−) (s)	d (−) (μm)
Glass 1-8 μm	34 ± 5	5.4	29 ± 6	4.3

Modelling

Prof. Jörn Sesterhenn, TU Berlin

CFD + particle tracking



- **Collisions during aerosolization (needed for electrification/aggregation**)
- Fluid stresses, flow structure/rates, grain trajectories
- Vary parameters we cannot in the lab (T,P, etc..)

Plans for future (2015-2018)

- **Aggregation (Electrification) studies (with VERTIGO)**
- **Dust detachment/resuspension studies (with VERTIGO + IRSN)**

- Fast Camera + PIV system (Assuming EUROPLANET funded)
[individual particle tracking]

- Gas cooling system = air temperature control
(Assuming EUROPLANET funded)

- Dust trapping (electrostatic/EM traps) ????

- Measure surface shear stress (directly ????)

Volcanology, Aeolian studies

- Extremely turbulent (no nice boundary layer)
- Intense sedimentation / entrainment
- High (‘saturate’) aerosol concentration
- High wind speeds

Summary of Operational parameters

Table 4. Operational parameters relevant to the AWTSII and AWTSI simulation wind tunnel facilities

	AWTS II	AWTS I
Dimension chamber	w = 2.5m, h = 2.5m, l = 10.0m	Dia. = 1.0m, l = 2.5m
Dimension Test Section volume	w = 1.81m, h = 0.995m, l = 2.00m	Dia. = 0.4m, l = 0.5m
Pressure Low	0.07 mbar	0.3 mbar
Pressure High	1000 mbar	1000 mbar
Gas Purity	<1% impurity	<5% impurity
Evacuation Time (to 10mbar)	24 minutes	40 minutes
Temperature Low	-120 (±10) ºC	-60 (±20) ºC
Temperature High	+80 ºC	+25 ºC
Wind generation Low	0.8 m/s (50 RPM)	1.5 m/s (2Hz)
Wind generation High	20 m/s (1200RPM)	15 m/s (50Hz)
Wind Sensor Ranges	LDA/LAMDA (0-15m/s), Pitot tube (3-30m/s)	LDA/LAMDA (0-15m/s),
Dust (Salten Skov I); Injection Rate	0 – 1200 mg/min. (manual/automated)	0 – 1200 mg/min. (manual)
Dust Suspension Time (wind speed)	30 - 300 secs (10-1 m/s)	20 - 200 secs (10-1 m/s)
Concentration (per injected mass unit)	3.7×10^{4} m^{-3} mg^{-1}.	4.3×10^{5} m^{-3} mg^{-1}
Deposition (per injected mass unit)	2000 mg/%	463 mg/%
Optical Lighting Irradiance (400nm-700nm)	0.1 $W/m^2/nm$	none
Wind Turbulence	4 – 18%	3 – 16%

Volcanology Network ESRs

- **ESR 10 -electrification/aggregation, suspension/deposition**

Aerosol experiments, Entrainement experiments

WT exps at AU, Modelling TUB (+UNIGE, MVO)

(Jonathan Merrison (AU), co-supervisors: Ulrich Kueppers (LMU), Jörn Sesterhenn (TUB))

- **ESR 1 -electrification/aggregation, (relating to field obs.)**

2mnths WT exps at AU

- **ESR 5 -aggregation, (effects of atmosphere - humidity)**

2mnths WT exps at AU

- **ESR 7 - mineral activation (erosion simulations)**

2mnths erosion exps at AU

- **ESR 13 - aerosol ash types (testing CAS-DPOL)**

3mnths WT exps at AU

WT