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Dust removal and cleaning of optical surfaces in lunar environments

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28th SPINE WS, 10/06/2021

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Content

- Context
- Tools available at ONERA to better understand dust charging / adhesion
- Status of DUSTREM current activity in the field of dust mitigation techniques for optical surfaces

Context

- “I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust.” Gene Cernan, Apollo 17 Technical Debrief

- “Dust is still a principal limiting factor in returning to the lunar surface for missions of any extended duration. However, viable technology solutions have been identified, but need maturation to be available to support both lunar and Mars missions.” Dust Mitigation Gap Assessment Team, Final Report, 2016

Lunar Dust Shapes

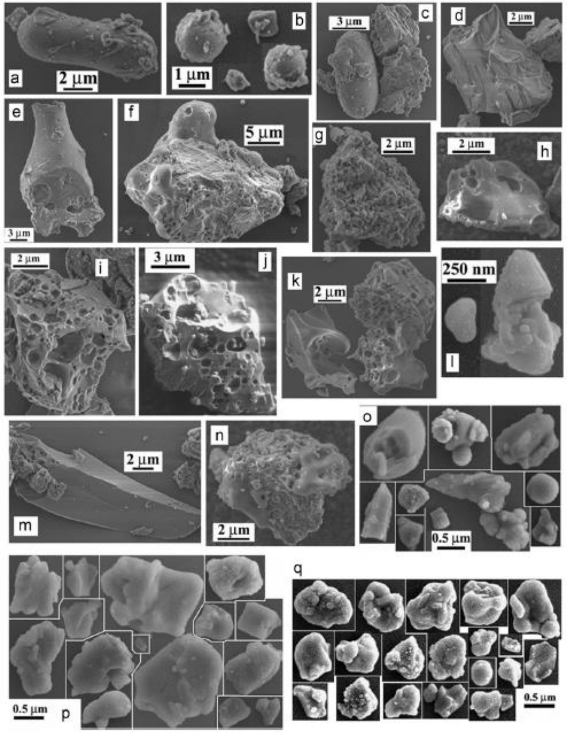
irregular shapes

asperities

rugged forms

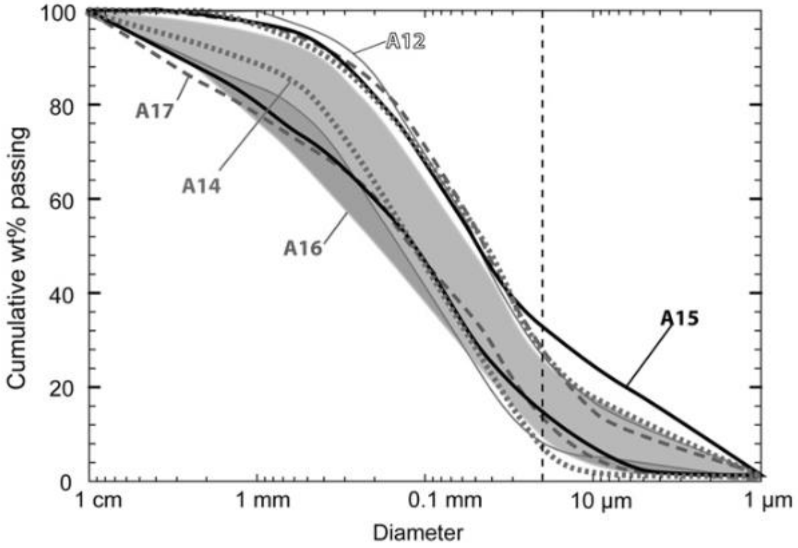
porosity

somewhat elongated



Liu, 2011

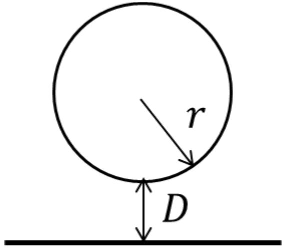
Oxyde	Apollo 11 (wt. %)	Apollo 12 (wt. %)	Apollo 14 (wt. %)	Apollo 15 (wt. %)	Apollo 16 (wt. %)	Apollo 17 (wt. %)
SiO_2	42.2	46.3	48.1	46.8	45.0	43.2
TiO_2	7.8	3.0	1.7	1.4	0.54	4.2
Al_2O_3	13.6	12.9	17.4	14.6	27.3	17.1
FeO	15.3	15.1	10.4	14.3	5.1	12.2



Adhesion by Van der Waals Force

Van der Waals force is the result of dipolar interactions : London, Debye, Keesom

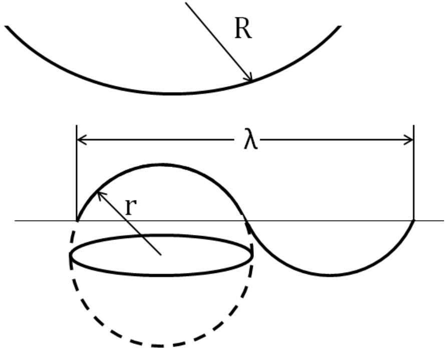
For a spherical dust of radius Rp in contact with a flat substrate, the forces derives from an analytical model and writes



$$F_{VdW} = \frac{A.r}{6D^2}$$

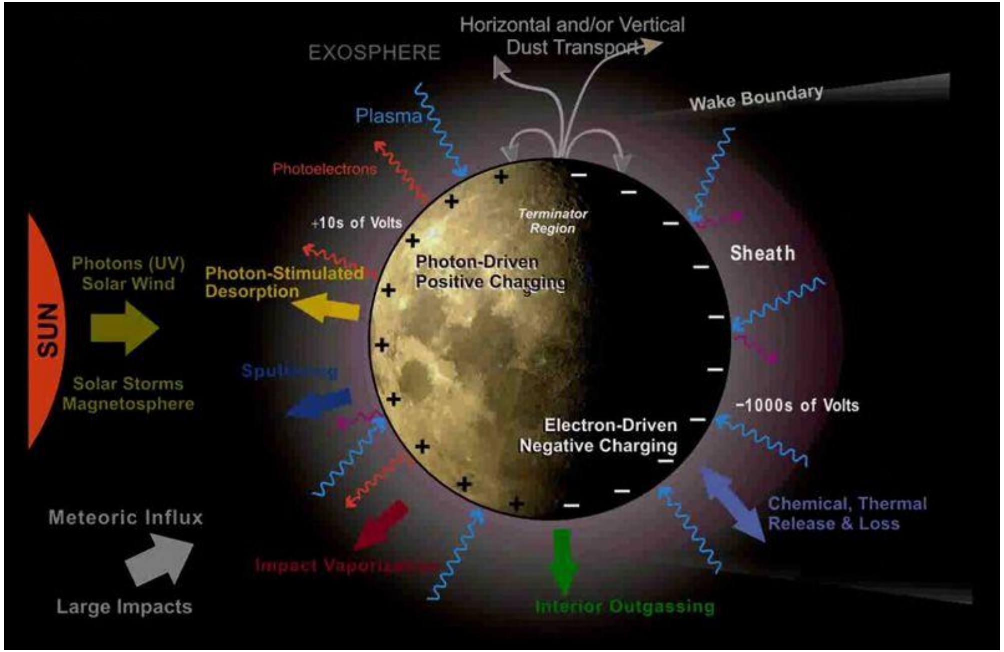
A : Hamaker constant
r : particle radius
D : contact distance
(minimum: $D_0 \sim 0{,}3$ nm)

For a substrate of roughness rms



$$F_{VdW} = \frac{A.r}{6H_0^2}\left[\frac{1}{1+\frac{58.r.rms}{\lambda^2}} + \frac{1}{\left(1+\frac{1{,}82\ rms}{H_0}\right)^2}\right]$$

Charging Lunar Environment



Credits : NASA

Any dust gets charged by the space environment : solar wind and VUV

Charging on dayside

- illuminated dust gets positive ~10 V
- shaded dust gets negative TBD

Charging on night side

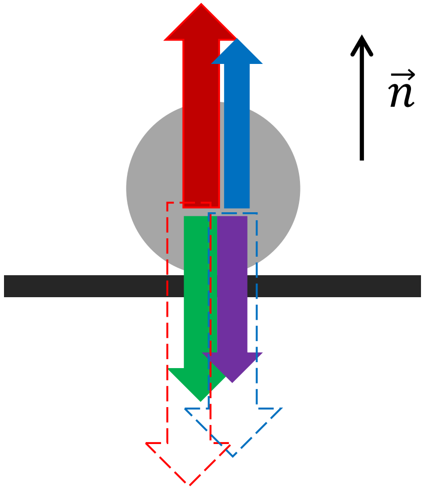
- dust gets negative down to - 100s V

+ specific features observed at Terminator

Electrostatic Forces

$$\overrightarrow{F_e} = q\vec{E} - \frac{q^2}{16\pi\varepsilon_0 z^2}\vec{n} + (\vec{P}.\nabla)\vec{E} - \frac{3}{2}\frac{\pi\varepsilon_0 r^6 E^2}{z^4}\vec{n}$$

Coulomb **Image** **Dielectrophoretic** **Polarisation**



q : electrostatic charge
E : electric field
z : distance betwwen the particle center and the substrate

<u>Coulomb and dielectrophoretic forces</u> can be directed towards
… or <u>away</u> from the substrate

Test Challenges

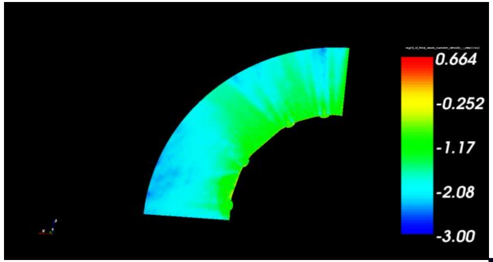
- Detailed assessment of fine dust adhesion is tricky to achieve because of experimental limitations below 10 µm. Macroscopic integrated results are often presented but they need to be achieved in representative conditions.

- The performance of mitigation techniques is difficult to assess because of the narrow limit between the dust mobilization and adhesion that depends on both
  - their size, shape and composition
  - the surface material composition, roughness, location
  - the environment (room, ground vacuum tank, space)

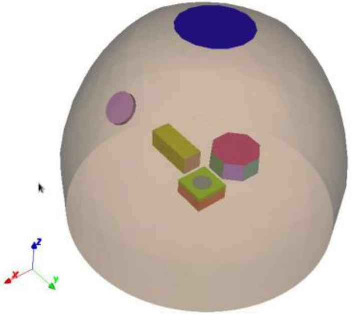
- All available chambers can be improved (higher fidelity simulants, dust delivery systems, ionization, radiation, volatiles) to provide more realistic environments

ONERA tools and facilities in the field of the physical understanding of lunar dust behaviour

Available Tools : SPIS software

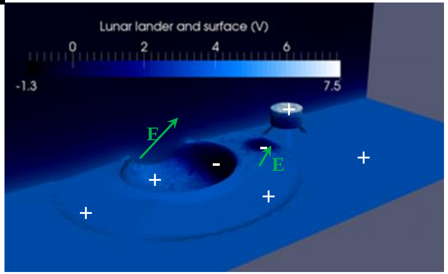


airless body scale
(Bennu asteroid)

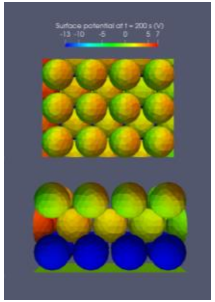


mesoscopic scale
(sub-system)

macroscopic scale
(lander
and crater)

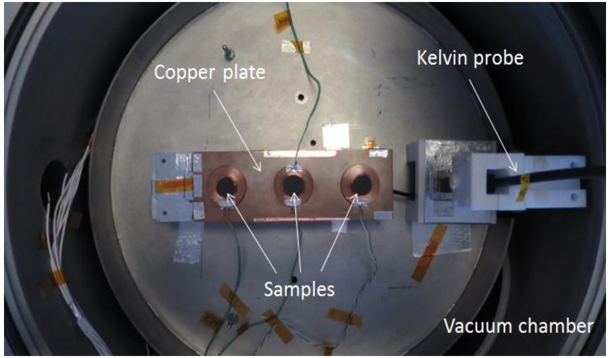


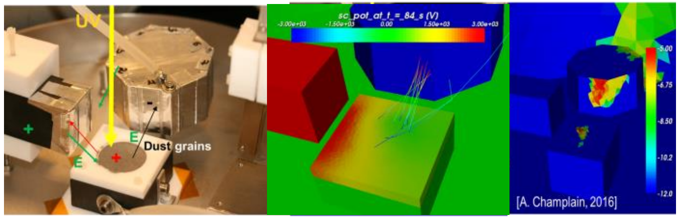
microscopic scale
(dust beds
single dusts)



Available Facilities : DROP chamber

Dust charging
- Charging under electron and VUV
- Contactless surface potential probe
- DC electrical conductivity



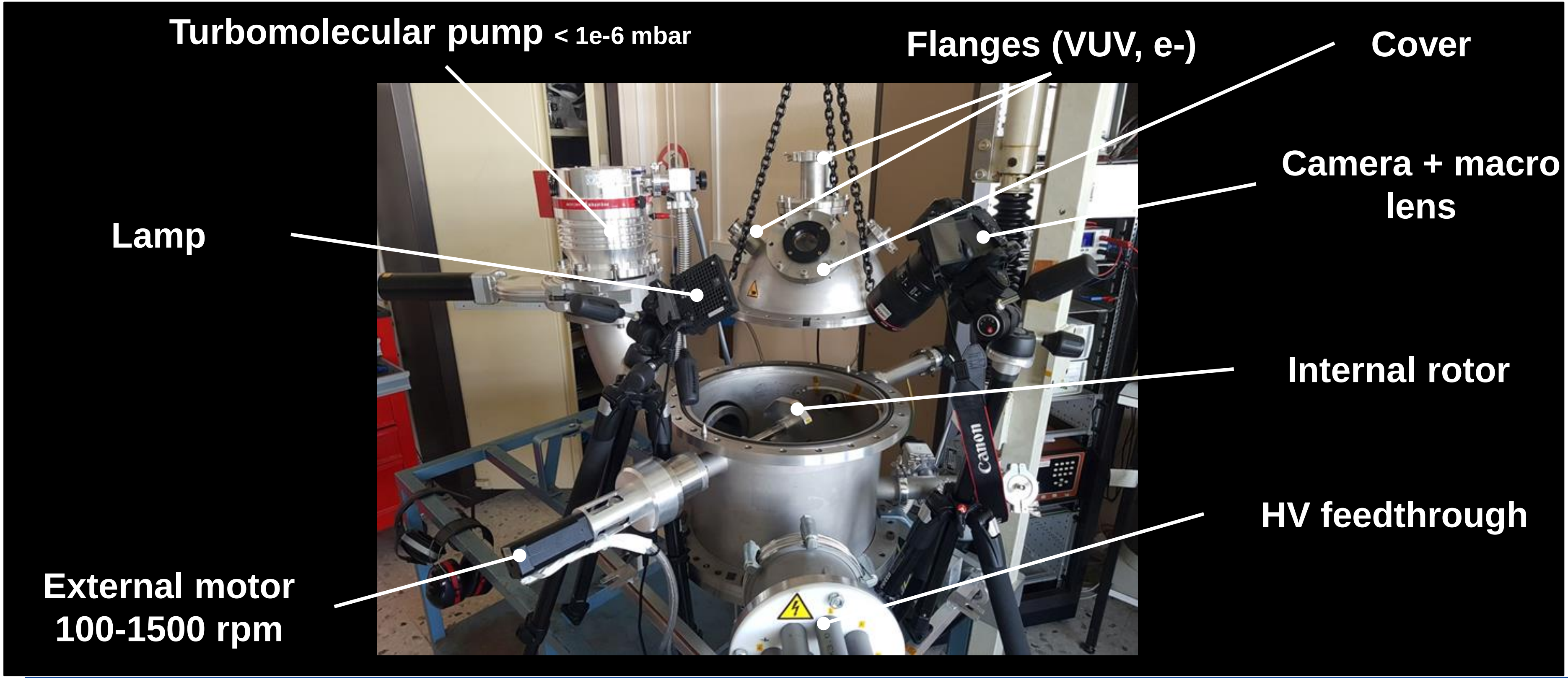


Dust migration assessment by HV electrostatic forces

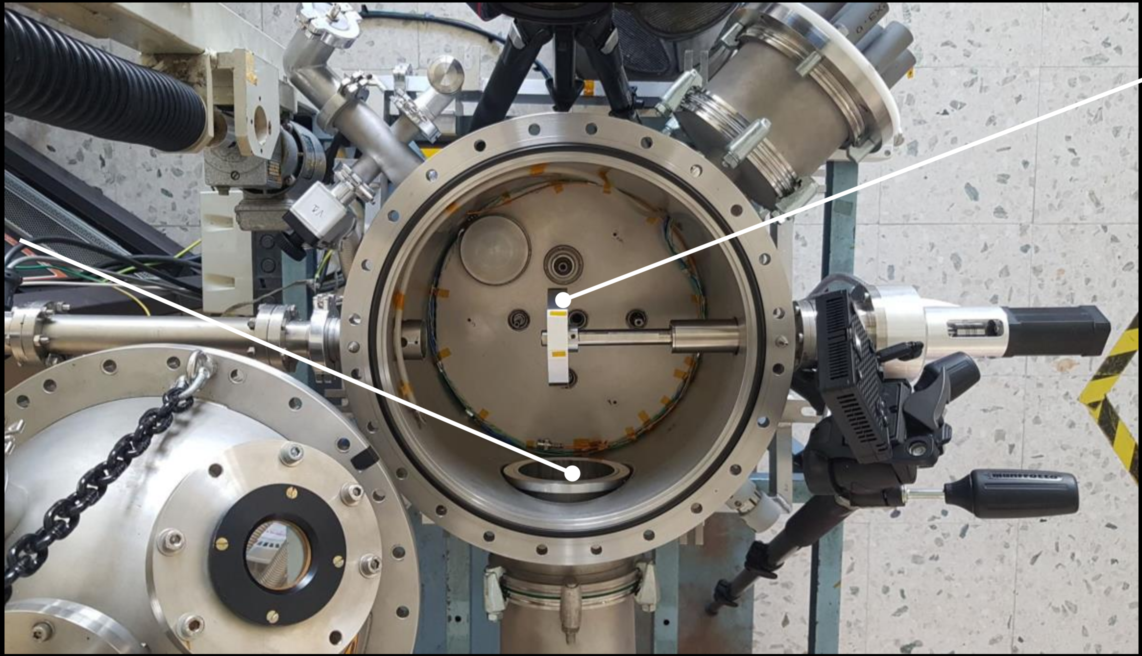
2000 V Weighing: 70 µg	2500 V Weighing: 140 µg	3000 V Weighing: 200 µg

Dust contamination visual inspection

DROP : Adhesion Force Evaluation by Centrifugal System



DROP : Adhesion Force Evaluation by Centrifugal System



pumping system protection

Sample holder
ϕ 10.6 cm
8 faces
2*3 cm^2 samples

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DUSTREM Project Status

Dust removal and cleaning of optical surfaces

- Adhesion to optical surfaces can lower their performance
- Possible solutions :
  - Charged dust particles may be reduced bypiezo crystal ultrasonic vibration and negatively charged coating
  - Mechanical brushes
  - Electrodynamic Dust Shield (EDS) proposed in the 2000s

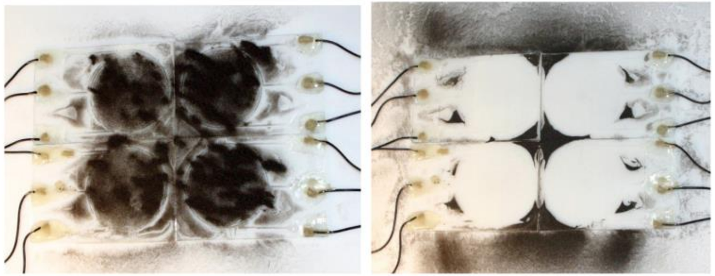
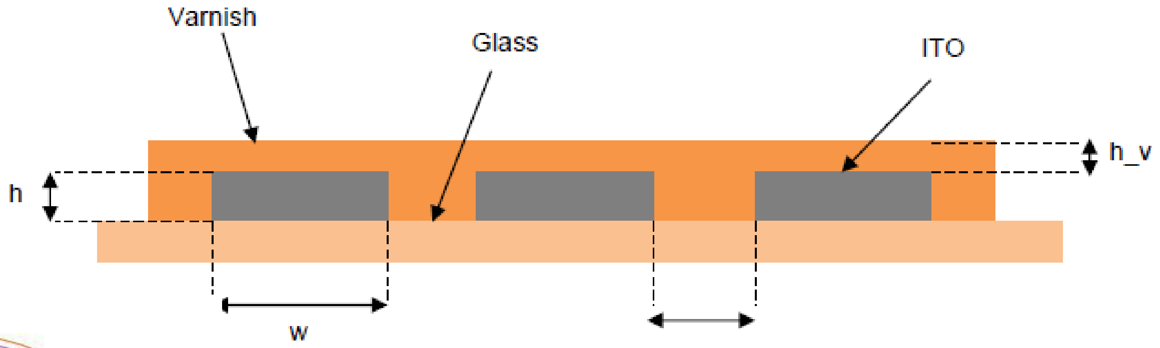
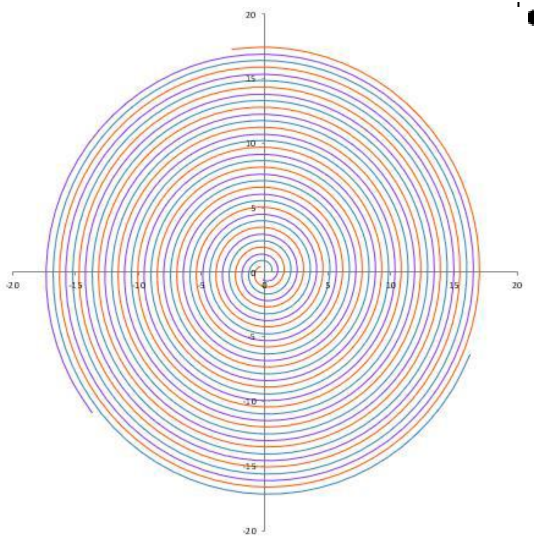


FIGURE 3–1. SIMULANT DUST REMOVAL WITH NASA KENNEDY SPACE CENTER'S EDS AT 10-6 KPA (CALLE ET AL. ACTA ASTRONAUT. 69, 2011: 1082-1088).

- ESA contract started in 2020 led by COMAT
  - ESA TO : Christian Schwarz
  - Develop and produce, using the knowledge and technical expertise of ONERA, a prototype allowing the lunar dust removal from the optical surface instruments (lenses, visor, etc.)
  - Characterize the prototype performance with several EDS samples (6) and different ranges of lunar dust (4)
  - Provide to ESA prospects and potential applications of the DUST REMOVAL system

Preliminary Design





n°	EDS - Design parameters			
	Parameters	Abv	Unit	Value Range
	Mechanical parameters			
1	Spacing of ITOs path	x	mm	0.01-1
2	ITO thickness	h	nm	50-200
3	Vernish thickness	h_v	nm	100-1000
4	ITO Width	w	µm	10-1000
5	ITO layout	-	-	Spirals or Comb
	Electrical parameters			
6	Voltage	V	V	50-1000
7	frequency	f	Hz	10-100
8	Voltage shape	-		Rectangular
9	Number of phases	N_phi	-	1-4

Available Lunar Dust Simulants

10s of LDS worldwide

4 LDS to be used + possibly other LDS under developement by Polito de Torino, Università degli Studi di Cassino e del Lazio Meridionale (paper under publication) pending on budget allocation

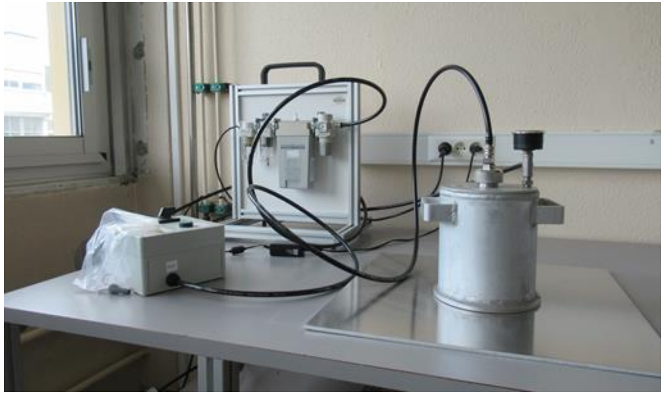
Oxyde	JSC-1A (wt. %)	DNA-1 (wt. %)	TUBS-M (wt. %)	UoM-B (wt. %)
SiO_2	46.67	50.75	48.61	30.99
TiO_2	1.71	1.16	2.29	0.22
Al_2O_3	15.79	18.77	13.28	13.78
Fe_2O_3	3.41	-	-	51.73
FeO	5.57	8.81	10.14	-
MnO	0.19	-	0.18	0.43
MgO	9.39	2.78	8.73	2.07
CaO	9.90	7.63	8.31	3.14
Na_2O	2.83	4.90	3.67	0.83
K_2O	0.78	5.21	1.71	0.62
P_2O_5	0.71	-	0.51	0.17

Ref:
1. https://www.nasa.gov/sites/default/files/atoms/files/03_jsc-1a_lunar_regsimulant_update_bgustafson.pdf
2. Selection of lunar regolith simulant, 3DP-MON-RP-0001, , Monolite U. K., London, England (ESTEC contract 22835/09/NL/AF)
3. S. Linke et al. Planet. Space Sci., 180 (2020)
4. G.H. Just, et al. https://doi.org/10.1016/j.actaastro.2020.04.025

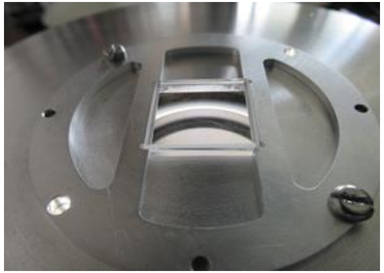
Test Philosophy & Schedule

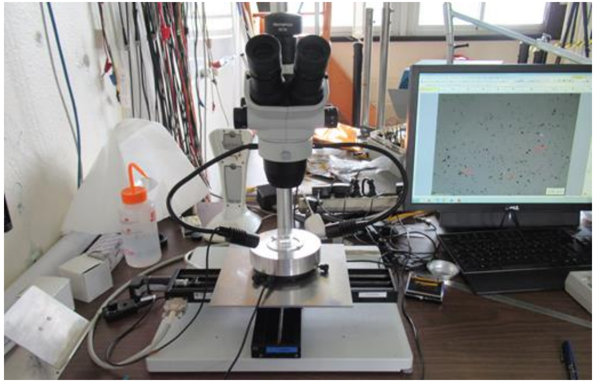
1. Classify LDS by size (size<25 µm, 25 µm < size < 50 µm, size > 50 µm) : done
2. Assess dust deposit quality (homogeneous & aggregates-free) : under progress
3. Assess LDS worst-case in terms of adhesion (centrifugal system) : under progress
4. Evaluate EDS efficiency at ambient room conditions : Q1 2022
5. Assess EDS efficiency under vacuum : Q2 2022

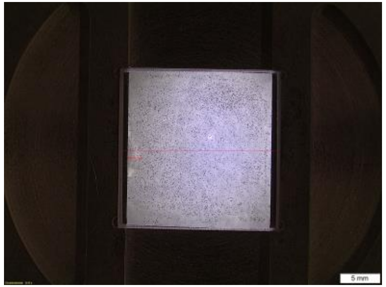
DDC (Dust Deposit Chamber)

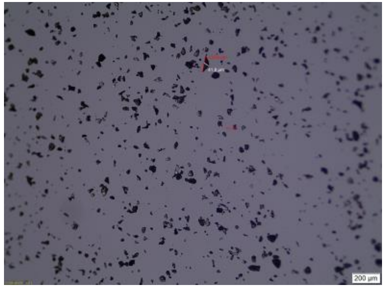


Binocular Loop





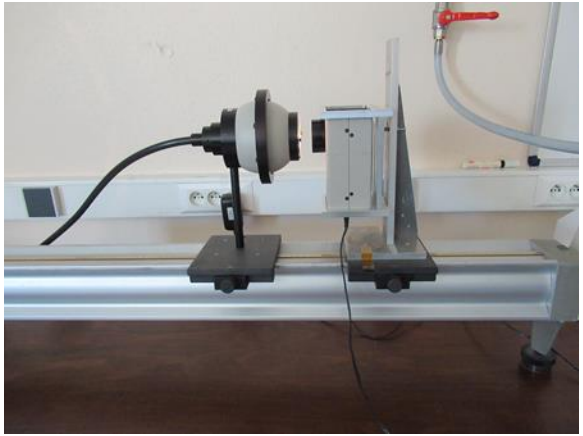


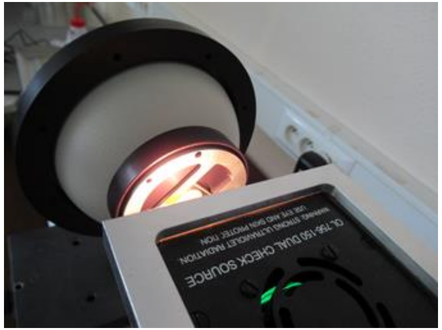


Storage Nitrogen chamber

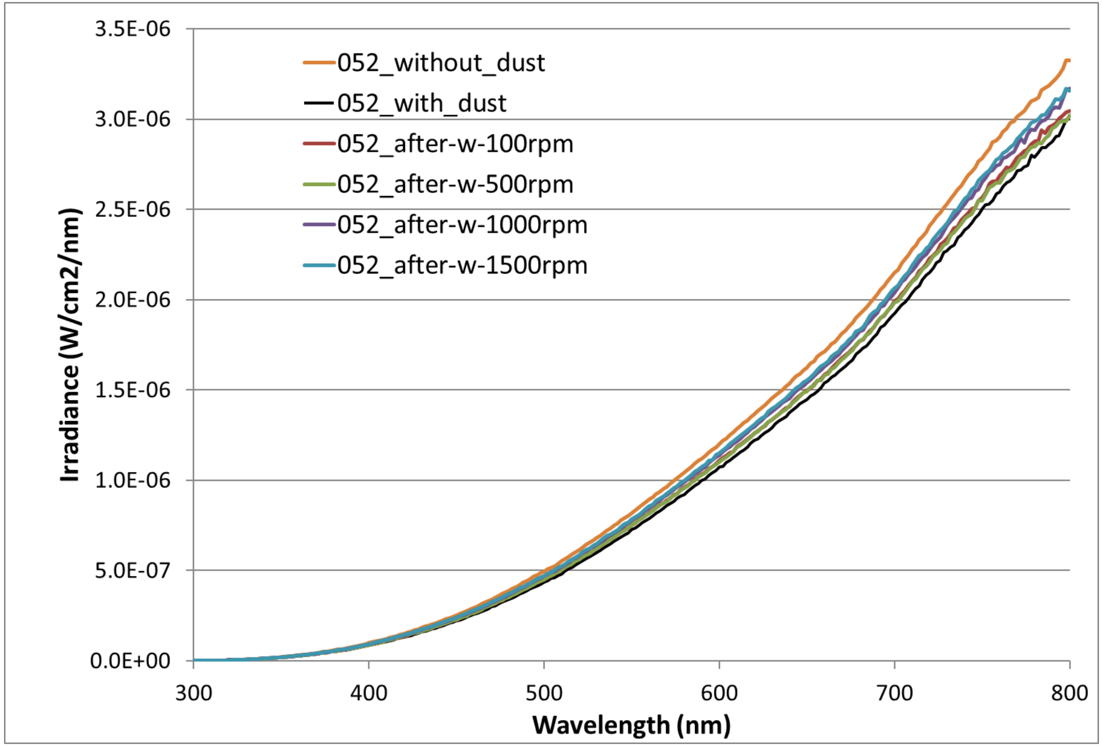
Microbalance (res. 1 µg)

Spectroradiometry





Obscuration by JSC-1A 25-50 µm and Centrifugation effects



Summary

- Lunar missions will have to cope with optical surfaces contamination by lunar dust
- To our knowledge, the current study is the first attempt in EU to mitigate this
- Let's start with proven concepts, try to reproduce qualitative results and then to optimize these techniques through an empirical parametric study (= ESA study)
- Plenty of physics to understand (partly using SPIS) to better optimize prototypes and increase TRL in near future

Questions ?