SENSOR DEVELOPMENT FOR THE DETECTION AND CHARACTERIZATION OF LUNAR DUST

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What you will hear today:

1. What hazards are presented by the presence of Lunar dust?
2. A few basics: what do we know about Lunar dust?
3. What are the implications for the development of sensor technologies?
4. Some examples of particulate sensor development at GRC.
5. Recent results of measurements of the fine and ultrafine content of Lunar regolith.
6. A summary telling you what you just heard.

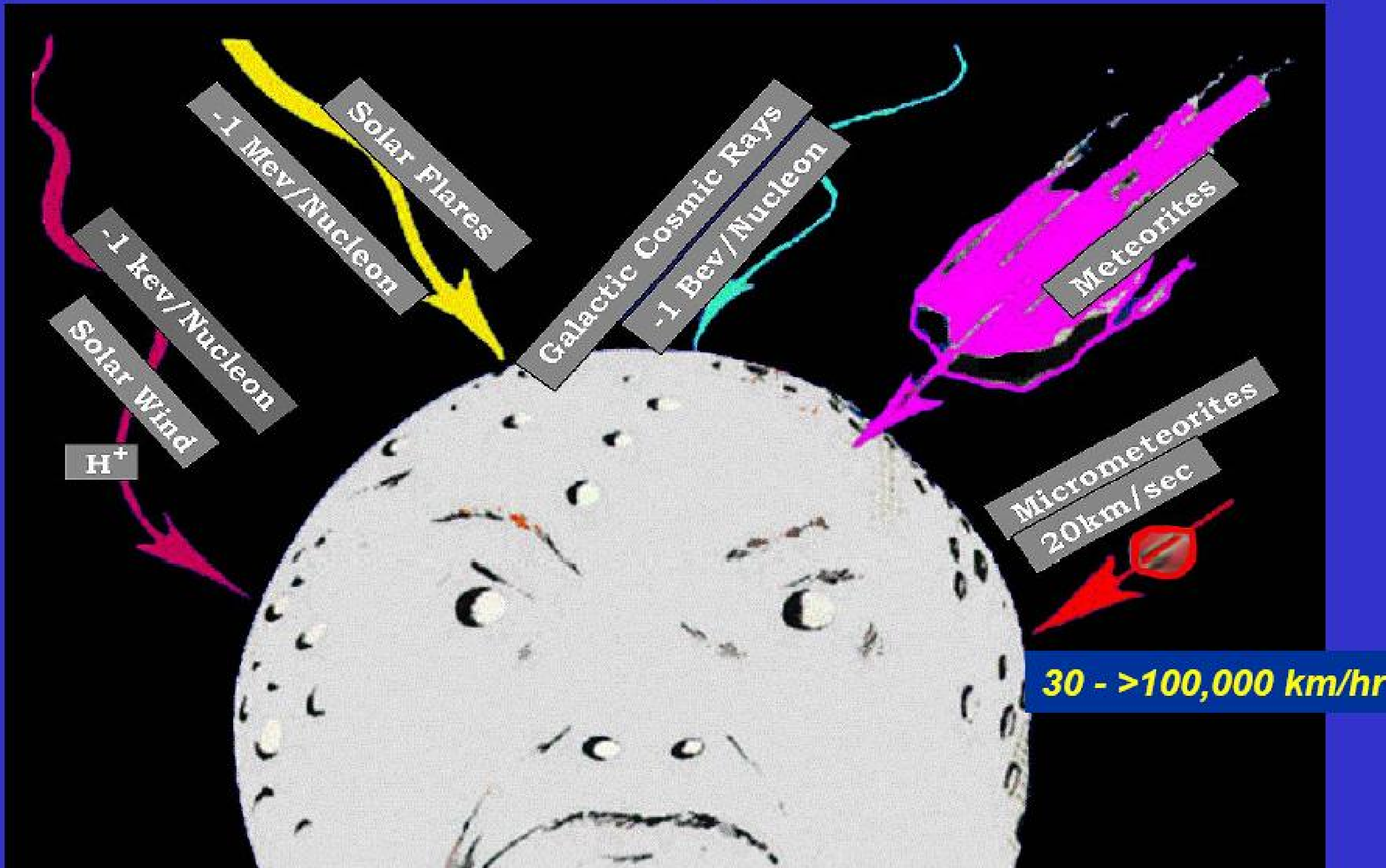
What Hazards are Posed by the Presence of Lunar Dust?

- Obscuration of camera and instrument viewports.
- Reduction of efficiency of solar panels
- Reduction of efficiency of of thermal radiators.
- Potential to clog filters.
- Potential to abrasively degrade mechanisms and seals.
- Respiratory health effects.
- Potential damage to electronic devices.
- Nuisance background for particulate-based fire detection systems.
- Contaminant for ISRU processes.
- Deep dust is possible trap for mobile platforms.
- Dust properties affect footing stability of structures.
- Dust fountains or other transporter effects could interfere with operations and exacerbate all of the above.

"Dust represents the single largest technical challenge to prolonged human presence on the Moon."

Harrison Schmidt; March 2005

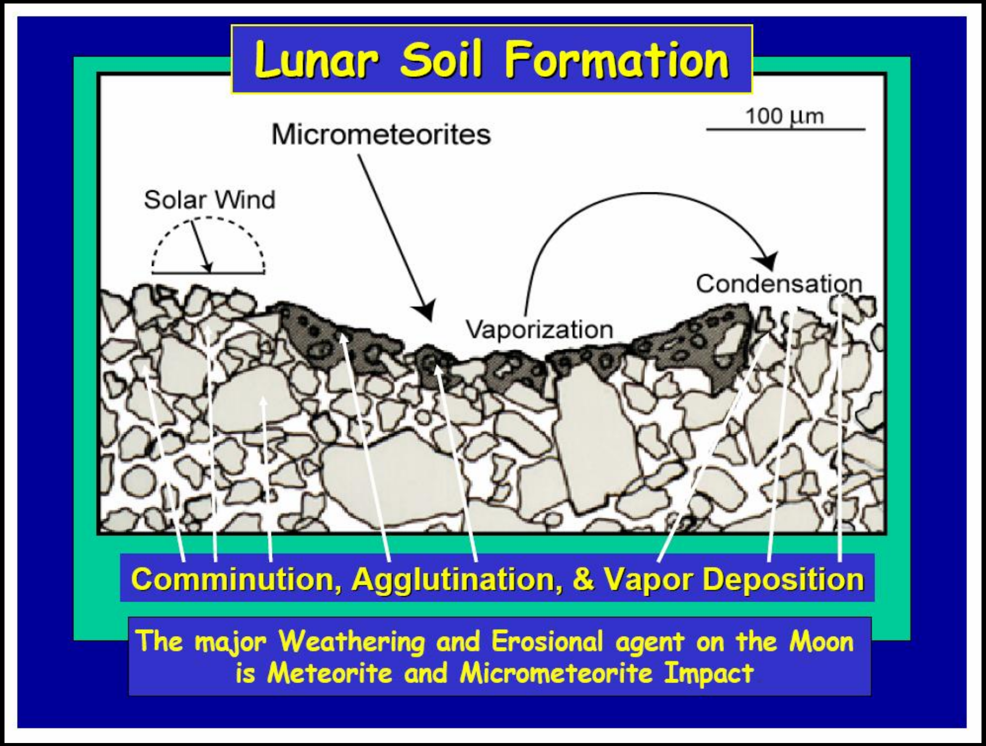
Our Unhappy Moon

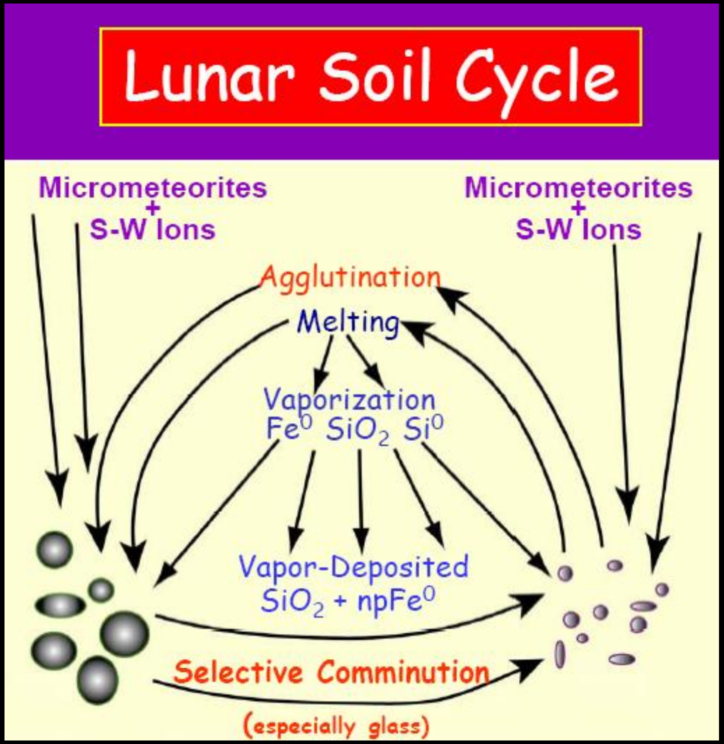


Courtesy: Larry Taylor; Univ. Tenn.

Absence of Lunar atmosphere (~ 10^{-12} torr):

- *Essentially no shielding or collisional quenching.*



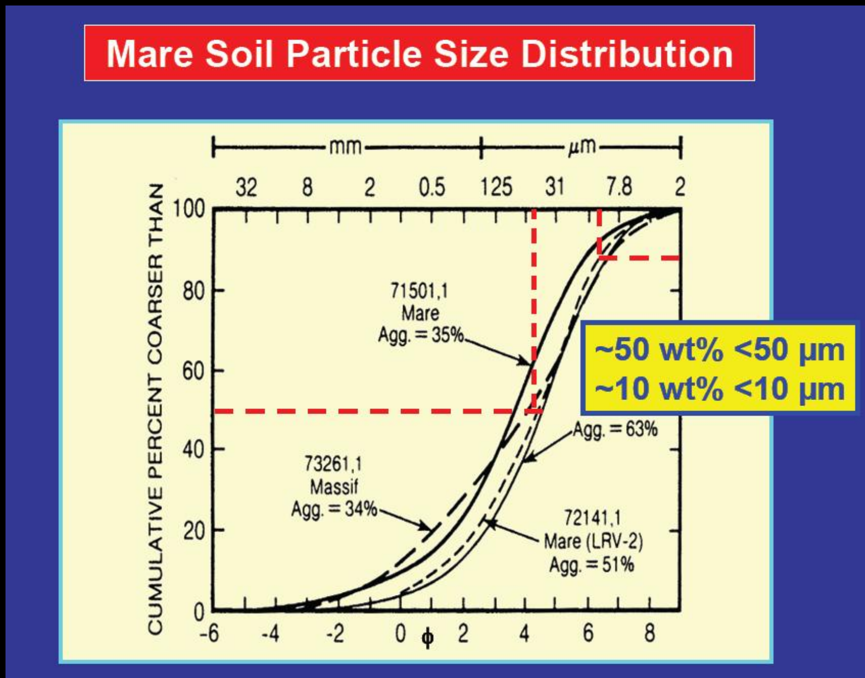


Significant potential for surface reactive states.

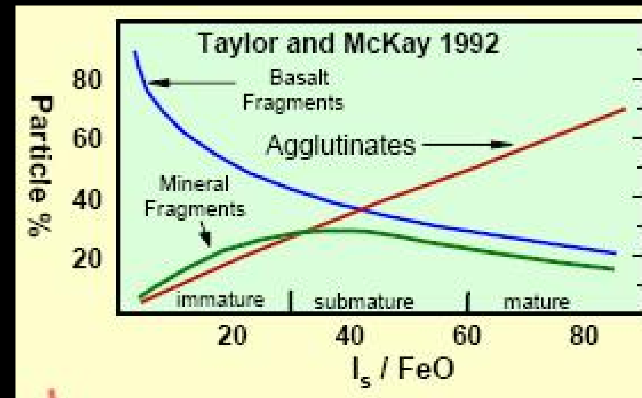
- All Apollo crews noted a distinct smell ("spent gunpowder") after reentering the LEM.

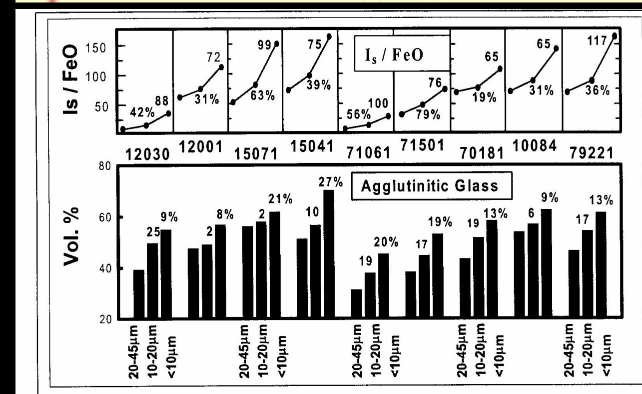
Courtesy: Larry Taylor; Univ. Tenn.

Unique Lunar environment influences particulate size and composition:



Lots of small particulates: 10% *by mass* less than 10 µ.





I_s / FeO = amount of total iron present as Fe°

Physical composition dependent on age and size.

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Courtesy: Larry Taylor; Univ. Tenn.

Requirements for dust sensor measurement technologies:

1. Development and demonstration of advanced sensor technologies suitable for end use in the new Exploration Initiative.

   - Environmental monitoring in spacecraft, airlocks, and habitation modules.
   - Process gauges for filtration, abatement, and resource generation systems.

2. Deployment of instrument payloads for fundamental characterization of dust properties (e.g. robotic missions or other probes).

3. Support both laboratory and field applications as necessary for ongoing terrestrial efforts in dust characterization, abatement, and mitigation.

Necessary attributes of mission-deployable sensor technologies:

- Minimal volume, mass, and power consumption.
- Reliability, durability, and autonomy of operation; low drift and minimal recalibration.
- Ability to address entire range from ≈ 10 nm – 20 μm, including the characterization of:

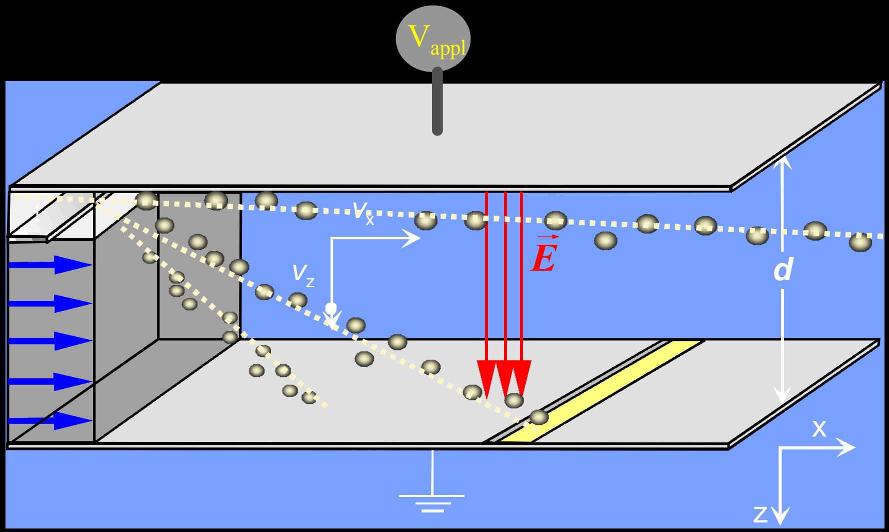
  1. Size distribution information (probably binned).
  2. Ambient electrical charge state.
  3. Total respirable fraction (current paradigm: surface area).
  4. Other: chemistry, reactivity, electrical/magnetic susceptibility?

None of these requirements are presently met by existing device technologies…

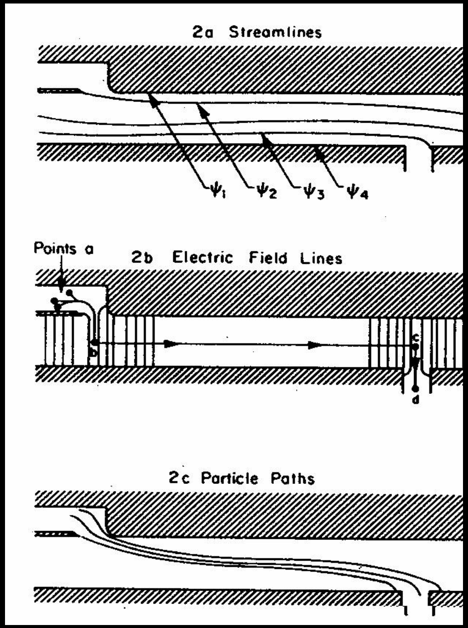
A few examples of dust sensor technology development at NASA-GRC (really):

Measurement of ultrafines (< 1 µm): Electrical Mobility Classification:

- Measurement of particle size determined by observing free drift in an applied electric field.
- The mobility, Z_p, expresses the ration of viscous to electrostatic forces, and is the equilibrium velocity per unit electric field.



Particles of differing mobilities are sequentially trapped by sweeping the transverse potential, V_{appl}.



Schematic EMC Process

$$Z_P = \frac{|\vec{V}|}{|\vec{E}|} = \frac{n_c(R_p)\varepsilon C(R_p)}{6\pi\mu R_p}$$

$$C = 1 + 1.7K_n$$

K_n = mean free path/particle radius (Martian atmosphere: mfp ≈ 50µm)

Typical values: 0.05 µm Z_p= 0.9 $cm^2/Vsec$
0.5 µm Z_p= 0.09 $cm^2/Vsec$

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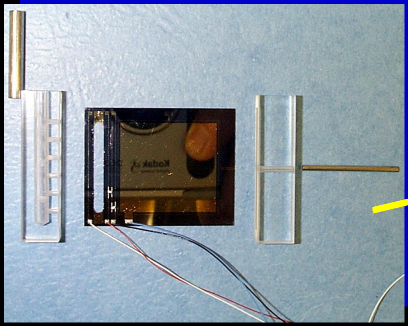
Schematic EMC Process

Complete cycle: From concept to application:

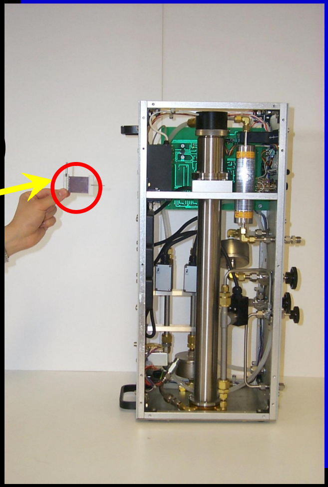
(design phase eliminated for brevity)

1



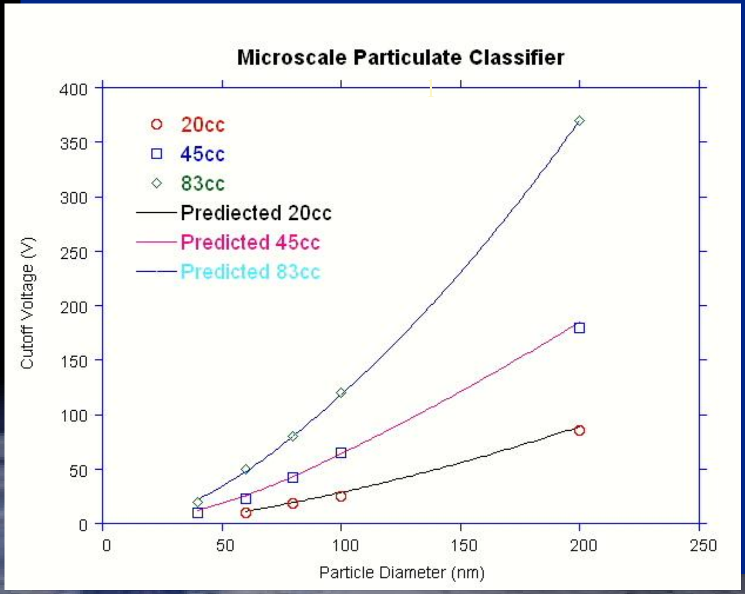
Low cost sensor fabricated using wafer processing techniques.

2



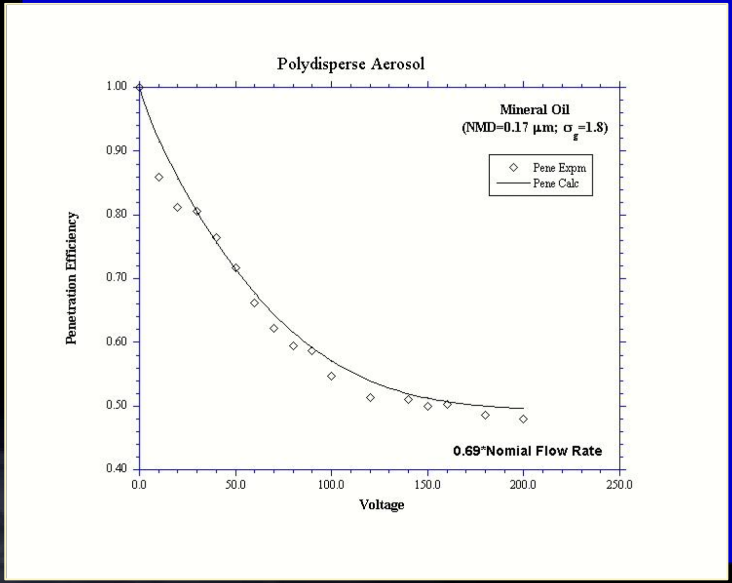
Completed sensor contrast with traditional macroscale classifier.

3



Good agreement between predicted and observed performance.

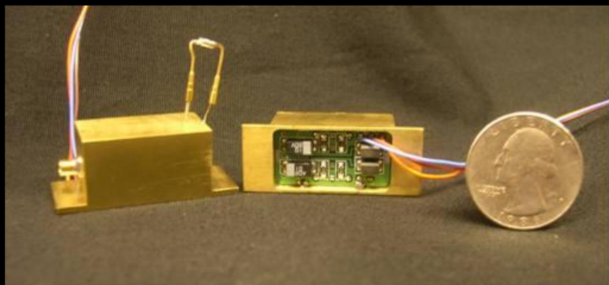
4



Correct retrieval of size distribution of test aerosol.

Further examples of supporting technology development:

Charged-based detection and particle counting…



Miniature femtoamp charge-sensitive preamplifier: Analog detection of charged particles.

MEMS-based condensate nucleate counter (CNC): Counting of single particle events.

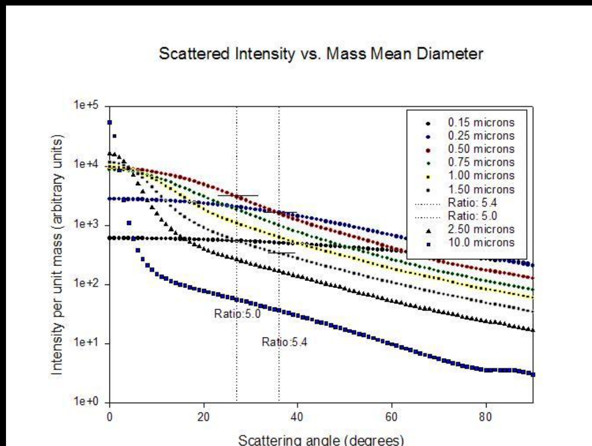
Digitally designed and machined discharge cage.

Tungsten field emitter fabricated via micro-EDM.

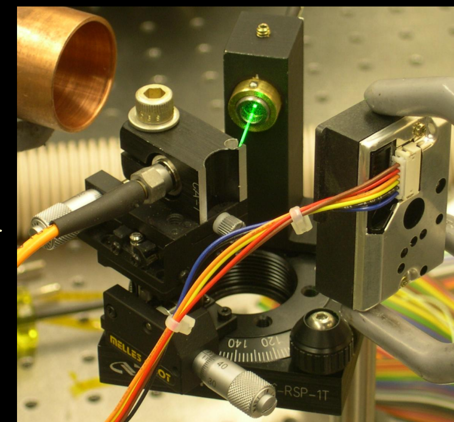
Compact field charger: Enhanced charging efficiency for ultrafine particulates.

Further examples of supporting technology development:

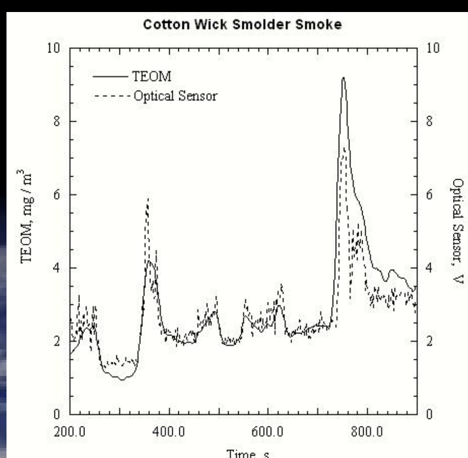
Optical scattering for size and morphology measurements:



Numerical modeling of ensemble scattering to achieve scattered signal directly proportional to third moment (i.e. mass loading).



Breadboard for mass-scaled scattering sensor.



Testing at NIST verifies performance by comparison with TEOM.

Present status of development effort:

- Fabricating integrated optical package using robust, low cost elements from CD read/write technologies (~ order cm^{3}).
- Derived ancillary output proportional to surface area.
- Package includes wireless transmission of 1451/802.15 packets with POTF imbedded processor for self cal. and diagnostics.

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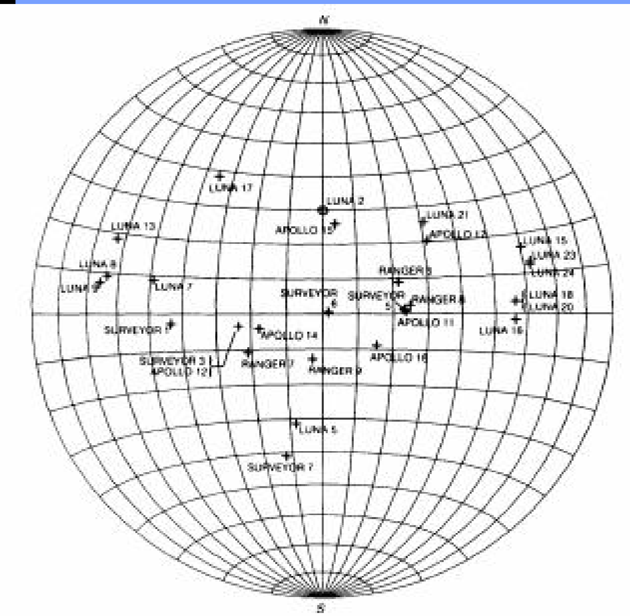
TABLE 2.1. History of lunar exploration.

Mission	Launch Date	Accomplishment	Data*
Luna 1	01/02/59	first lunar flyby	
Luna 2	09/12/59	first lunar impact	
Luna 3	10/04/59	first photos of lunar farside	P
Ranger 3	01/26/62	missed the Moon by 36,793 km	
Luna 4	04/02/63	missed the Moon by 8,500 km	
Ranger 4	04/23/62	crashed on the lunar farside	
Ranger 5	10/18/62	missed the Moon by 724 km	
Ranger 6	01/30/64	impact lander; television failed	
Ranger 7	07/28/64	impact lander	P
Ranger 8	02/17/65	impact lander	P
Ranger 9	03/21/65	impact lander	P
Luna 5	05/09/65	crashed on the Moon	
Luna 6	06/08/65	missed the Moon by 161,000 km	
Zond 3	07/18/65	photographed lunar farside	P
Luna 7	10/04/65	crashed on the Moon	
Luna 8	12/03/65	crashed on the Moon	
Luna 9	01/31/66	first lunar soft landing	P
Luna 10	03/31/66	first lunar satellite	SE,CO
Surveyor 1	05/30/66	first soft-landed robot laboratory	P,SM
Lunar Orbiter 1	08/10/66	lunar satellite	P,R,SE,M
Luna 11	08/24/66	lunar satellite	P
Luna 12	10/22/66	lunar satellite	P,M,SE
Lunar Orbiter 2	11/06/66	lunar satellite	P,R,SE,M
Luna 13	12/21/66	soft landing on the Moon	P,C
Lunar Orbiter 3	02/05/67	lunar satellite	P,R,SE,M
Surveyor 3	04/17/67	soft-landed robot laboratory	P,SM
Lunar Orbiter 4	05/04/67	lunar satellite	P,R,SE,M
Explorer 35	07/19/67	lunar satellite	
Lunar Orbiter 5	08/01/67	lunar satellite	P,R,SE,M
Surveyor 5	09/08/67	soft-landed robot laboratory	P,SM,C
Surveyor 6	11/07/67	soft-landed robot laboratory	P,SM,C
Surveyor 7	01/07/68	soft-landed robot laboratory	P,SM,C
Luna 14	04/07/68	lunar satellite	
Zond 5	09/14/68	first lunar flyby and Earth return	
Zond 6	11/10/68	lunar flyby and Earth return	P
Apollo 8 (G)†	12/21/68	first humans to orbit the Moon	P
Apollo 10 (G)†	05/18/69	first docking maneuvers in lunar orbit	P
Luna 15	07/13/69	crashed on the Moon	
Apollo 11 (H)†	07/16/69	first humans on the Moon (07/20/69)	P,S,SM,G, M,SW,D
Zond 7	08/08/69	lunar flyby and Earth return	P
Luna 16	09/12/70	first robot sample return (100 g)	S
Luna 17	11/10/70	first robot rover (322 days, 10.5 km)	P,C,SM,R
Apollo 12 (H)†	11/14/69	second human landing on the Moon	P,S,SM,G,M,SW,D,A
Apollo 13 (H)†	04/11/70	aborted human landing	P
Zond 8	10/20/70	lunar flyby and Earth return	P
Apollo 14 (H)†	01/31/71	third human landing on the Moon	P,S,SM,G,SW,D,A
Apollo 15 (J)†	07/26/71	fourth human landing on the Moon	P,S,C,SM, R,G,CO,SE,SW,D,A
Luna 18	09/02/71	crashed on the Moon	
Luna 19	09/28/71	lunar satellite	P,SE
Luna 20	02/14/72	second robot sample return (30 g)	P,S
Apollo 16 (J)†	04/16/72	fifth human landing on the Moon	P,S,C,SM, R,G,CO,SE,A
Apollo 17 (J)†	12/07/72	sixth human landing on the Moon	P,S,SM,R, G,SE,M
Luna 21	01/08/73	robot lunar rover (139 days, 37 km)	P,C,SM,R
Luna 22	05/29/74	lunar satellite	P
Luna 23	10/28/74	failed robot sampler	
Luna 24	08/09/76	third robot sample return (170 g)	S

Sample return missions

We have had numerous Lunar missions…

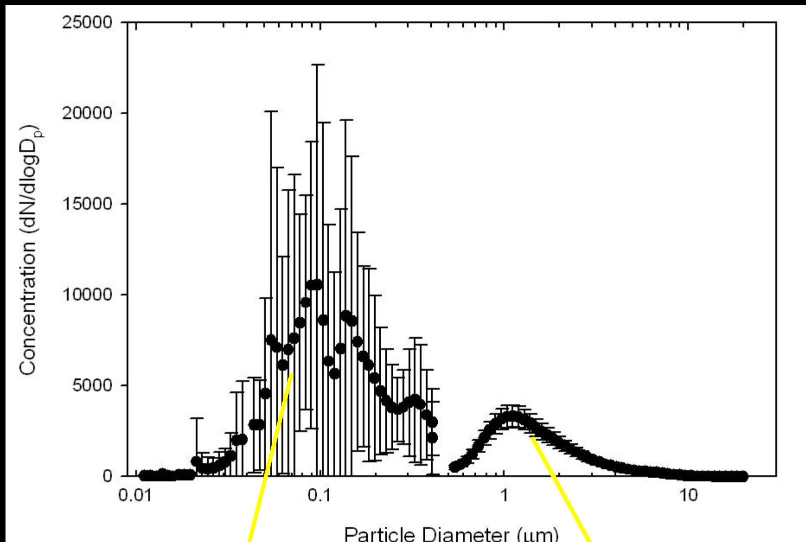
All have been equitorial (know little about the polar regions).



* Data types are abbreviated as follows: A = atmosphere and ion studies; C = surface chemistry; CO = chemical mapping from orbit; D = dust analysis; G = surface-based geophysics; M = meteoroid studies; P = photography; R = radiation environment studies; S = samples returned to Earth; SE = selenodesy measurements; SM = soil mechanics studies; SW = solar wind studies.

Supporting both laboratory and field applications:

Example: Recent measurements of the fine and ultrafine content of Lunar regolith.



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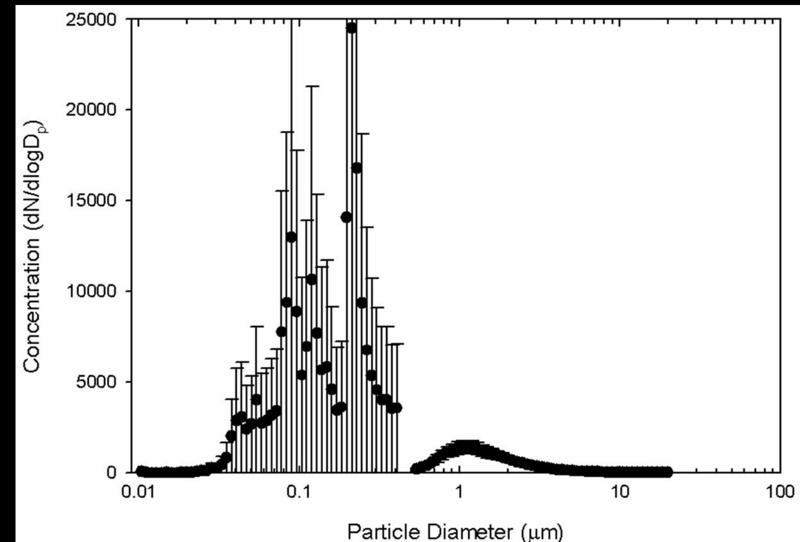

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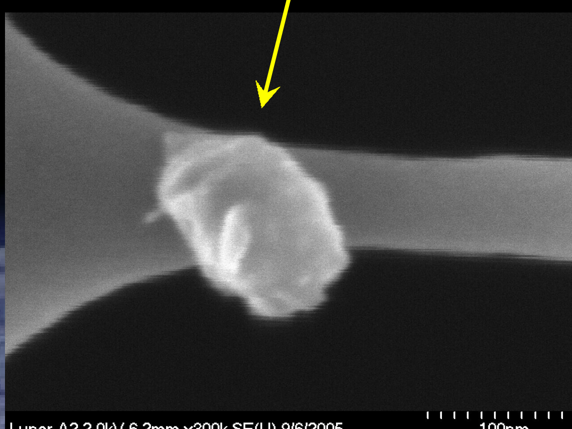

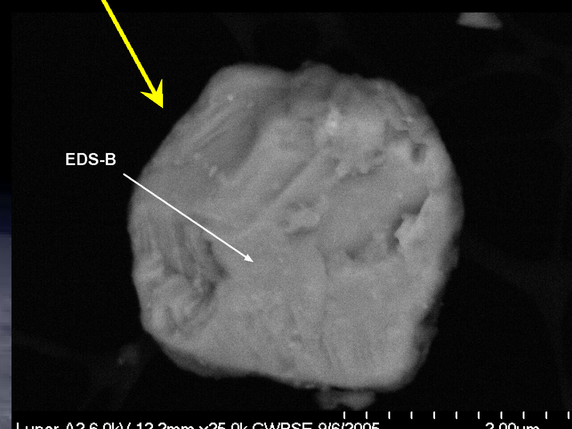

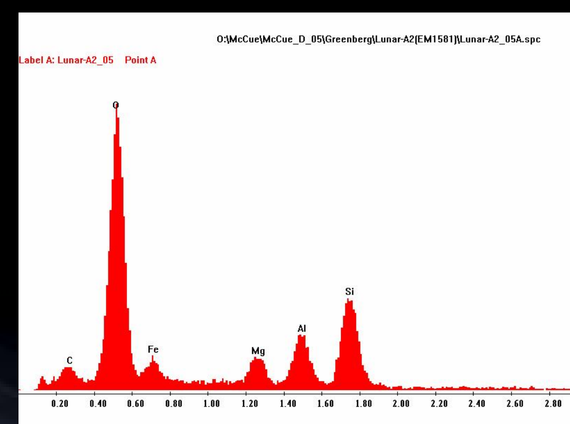

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Summary:

- Dust measurement technologies are necessary to support a continuum of needs in the ongoing Exploration Program.

- Advanced technology development is needed to address a number of fundamental mission requirements.

- Our group can (and continues to) pursue these objectives.