Lunar Regolith Simulant Materials Workshop

Marshall Space Flight Center : January 24-26, 2005

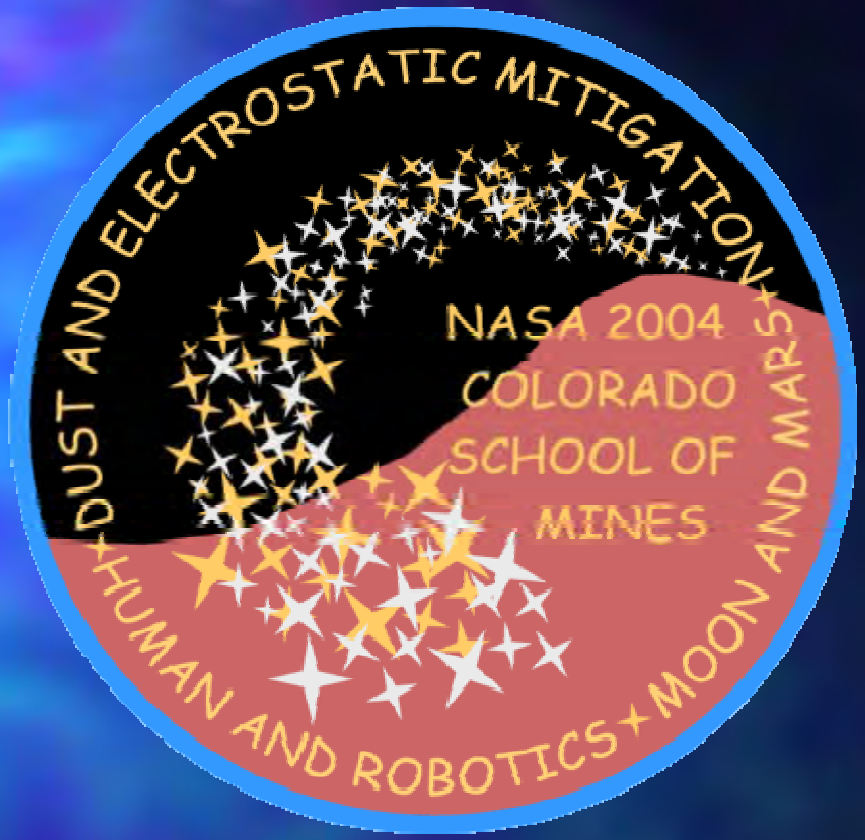
“The Moon as a Beach of Fine Powders”

***Masami Nakagawa: Colorado School of Mines**

Heather Angel: Colorado School of Mines

Juan H. Agui: NASA-Glenn Research Center

“Project Dust”



“Mitigation of Dust
and
Electrostatic Accumulation
for Human and Robotic Systems for Lunar
and Martian Missions”

Masami Nakagawa

Researcher Capabilities Summary

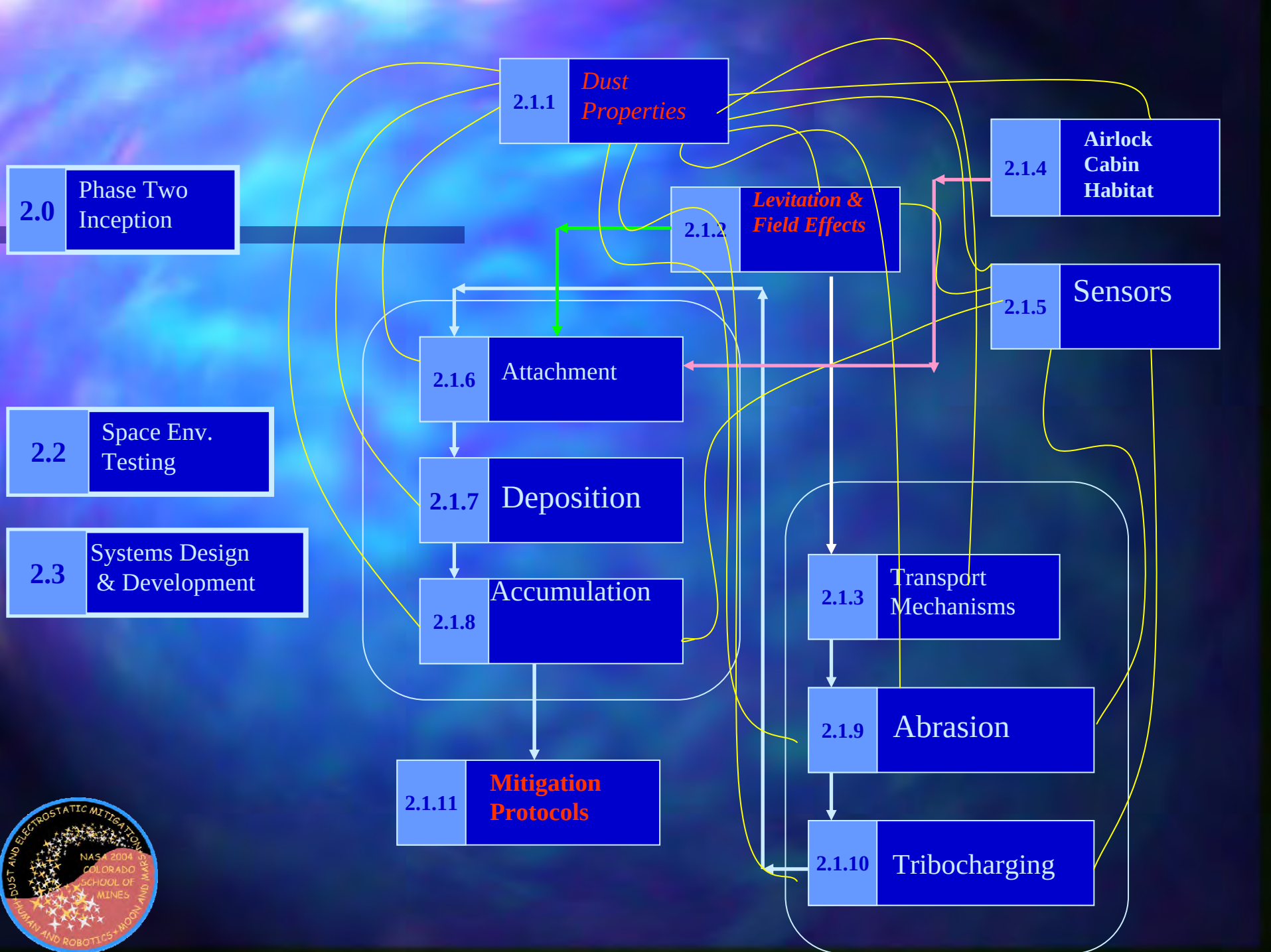
Colorado School of Mines
Mining Engineering Department
PSTG-Space Exploration Program

- ***PI***
- ***Particulate Science & Technology Lab***
- ***Innovative & Exploratory Experiments***
- ***Worldwide Research Network***

- **Fine particle control**
- **Multi-scale mechanical properties**
- **Wave propagation in granular media**
- **Particulate mechanics in extreme environment**
- ***Dust Removal***
- ***Abrasion***
- ***Triboelectrostatic charging***
- ***Segregation***
- ***Acoustic manipulation of fine particles***

Vulnerability Matrix

Subsystem / System	Air Filters	Rotating Shafts / Parts	Sliding Shafts / Parts	Optics / Solar Panels	Radiator / Reflector Panels	Pressure Seals	Charge Accum Surfaces	Electrical Connectors / Switches	
Spacesuits	✓	✓	✓	✓	✓	✓	✓	✓	
Airlocks	✓	✓	✓			✓	✓	✓	
Exploration Vehicles	✓	✓	✓	✓	✓	✓	✓	✓	
Habitats	✓	✓	✓	✓	✓	✓	✓	✓	
Manufacturing Plants	✓	✓	✓	✓	✓	✓	✓	✓	
Exposed Hardware		✓	✓	✓	✓	✓	✓	✓	
Robots and Remotes		✓	✓	✓	✓	✓	✓	✓	


2.0 Phase Two Inception
2.2 Space Env. Testing
2.3 Systems Design & Development
2.1.1 Dust Properties
2.1.2 Levitation & Field Effects
2.1.3 Transport Mechanisms
2.1.4 Airlock Cabin Habitat
2.1.5 Sensors
2.1.6 Attachment
2.1.7 Deposition
2.1.8 Accumulation
2.1.9 Abrasion
2.1.10 Tribocharging
2.1.11 Mitigation Protocols
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NASA 2004
COLORADO SCHOOL OF MINES
HUMAN AND ROBOTICS MOON AND MARS

C C A C S

CENTER FOR COMMERCIAL APPLICATIONS OF COMBUSTION IN SPACE

"Project Dust" Team

COLORADO SCHOOL OF MINES

LASP University of Colorado
Laboratory for Atmospheric and Space Physics

University of Tennessee
Planetary Geosciences Institute

Space Infrastructure, Inc.

GRAINFLOW DYNAMICS

PDS
Productive Data Systems

Glenn Research Center
Kennedy Space Center

THE STATE UNIVERSITY of NEW YORK
SUNY Department of Physics

Hamilton Sundstrand
A United Technologies Company

STARSYS RESEARCH

sysRAND Corporation™

1) Organizational Responsibility Chart

PI: Nakagawa(CSM) **Co-PI:Hamburger(CSUOhio)**

sysRAND
(MANAGEMENT)

AerospaceExchange
Productive Data Solutions
Space Infrastructure
DigitalSpace

Agui & Sen

Walton

GRC

KSC

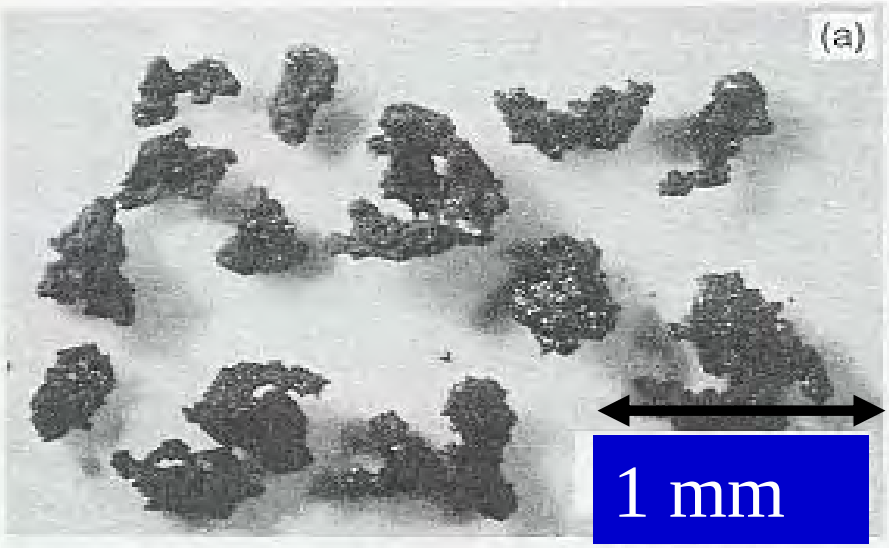
UT PGI

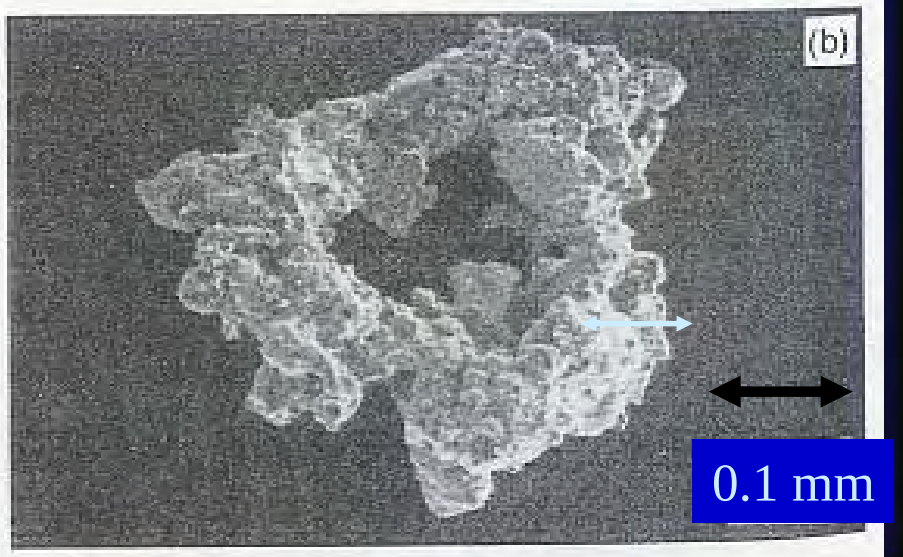
Team Colorado
- CSM
- CU LASP
- Space Infrastructure
- Starsys Research

Hamilton Sundstrand

What is Lunar Dust Like?

- Similar to Ash
  - Diverse Size Distribution
    - Mean size = 19 microns
  - SiO_2 (44.72%) and Al_2O_3 (14.86%)
  - Properties
    - Magnetic (Fe^0 Patina)
    - Jagged
    - High Porosity





Physical Surface Properties

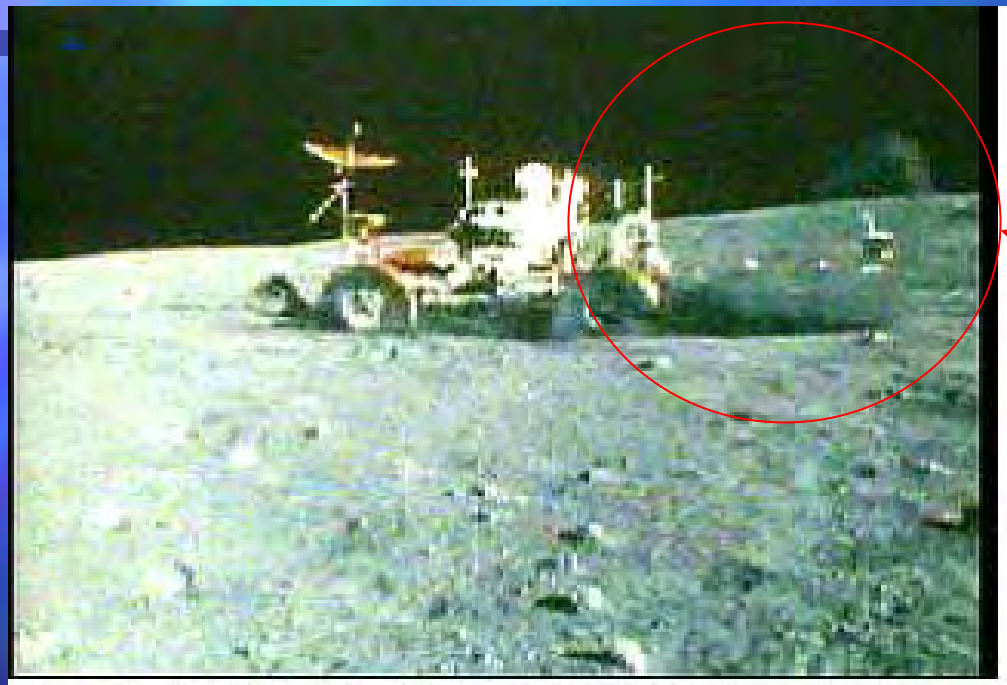
Material Properties

Moon & Mars Environment-----HARSH!

Mechanical Properties

Rubbing Friction in vacuum

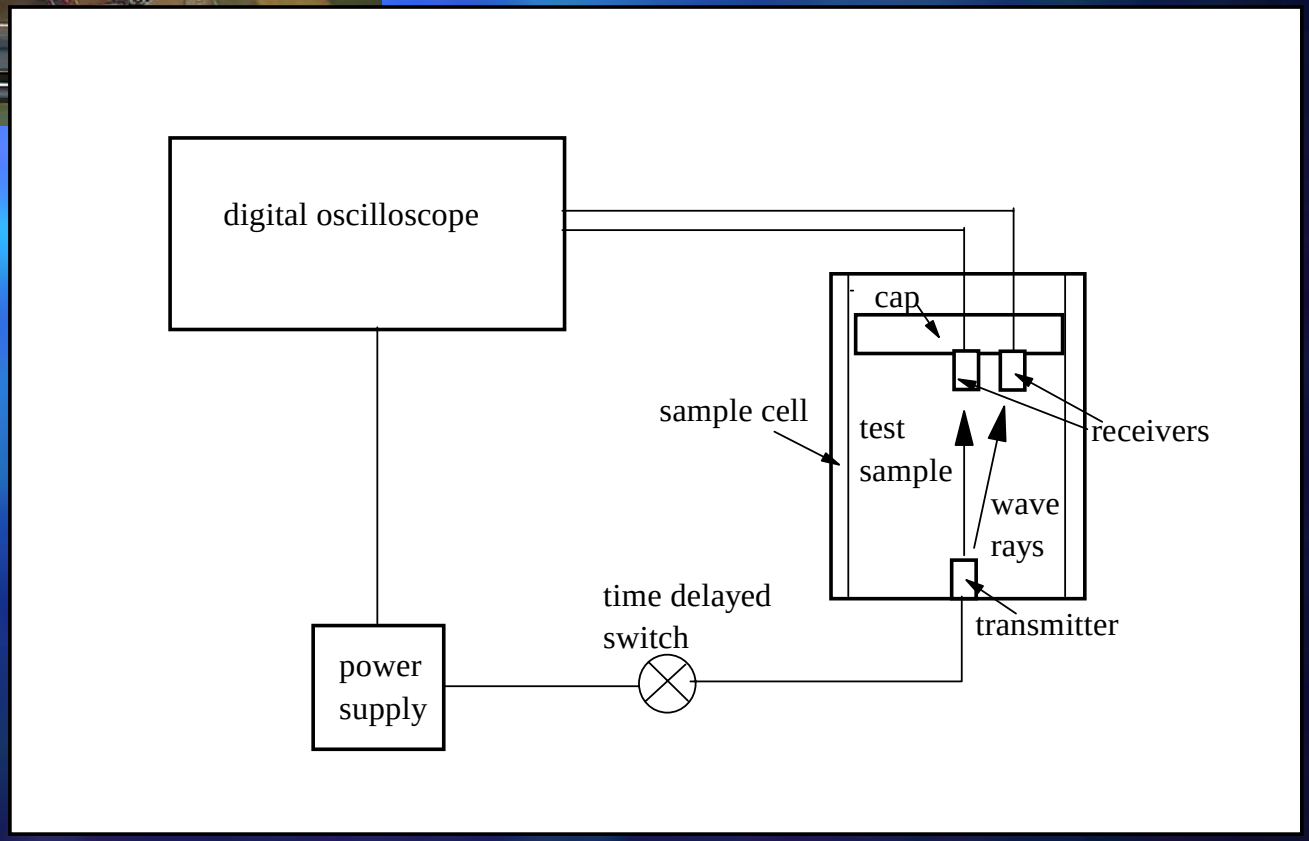
The U.S. Burew of Mines found that exposing lunar simulant to vacuum long enough for nearly complete outgassing caused increased friction between the tool and lunar simulant----from 1.5 to 60 times more friction. On the lunar surface, it will probably be even higher due to incompletely oxidized minerals and total absense of moisture. Tools should be made from (or coated with) materials which will minimize friction, and experiments should be performed on simulants that have been sitting in vacuum.



Dust Plume

Figure 1. Apollo rover driven on lunar surface. Arrow indicates the dust plume from drive wheel.

Microgravity Wave Measuremnts



Lunar Sourcebook

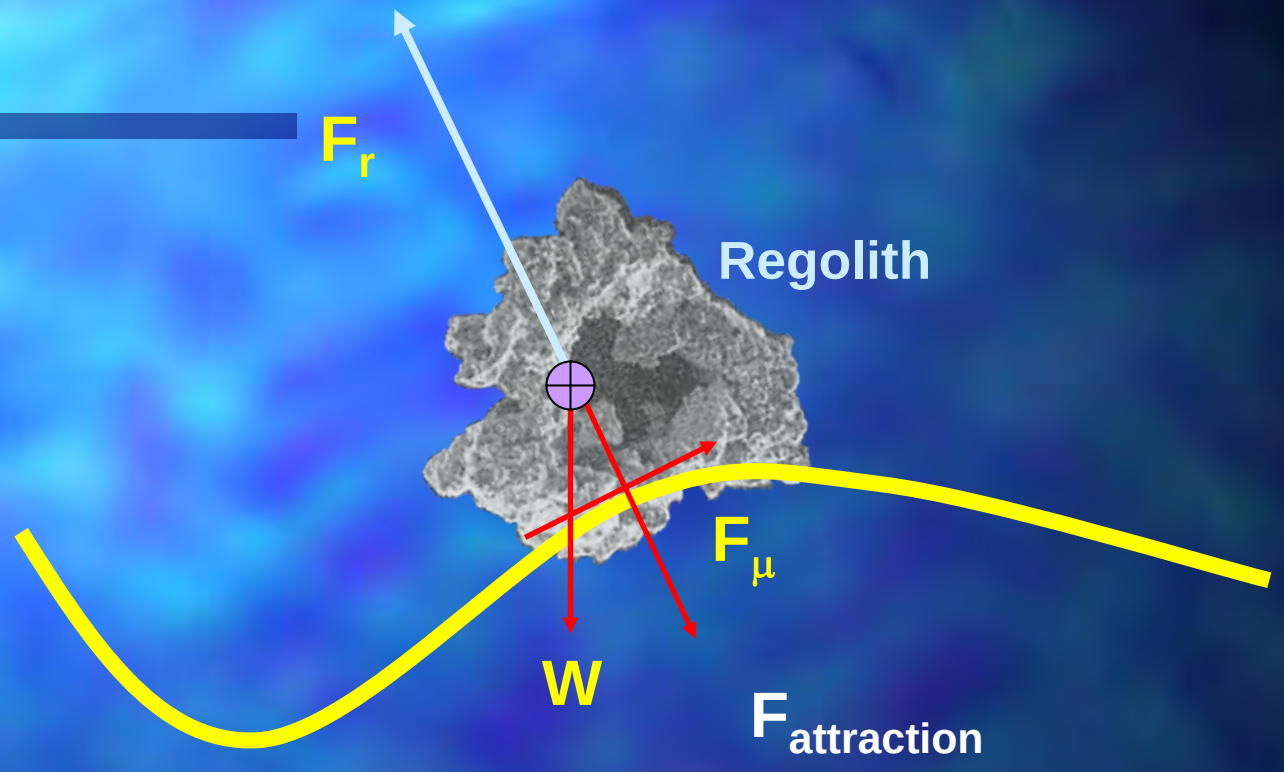
Seismic velocity
92m/s---> 114m/s

Test No.	Particle size (mm)	Sample compaction	Density (kg/m^3)	Wave velocity 1g pre-drop (m/s)	Wave velocity μg test (m/s)	Wave velocity 1g post-drop (m/s)
1	glass 2	dense	1388	317	62	259
2	glass 2	loose	1367	369	73	370
3	glass 2	loose	1348	340	54	339
4	glass 2	loose	1377	363	75	323
5	glass 2	dense	1377	363	71	415
6	glass 2	dense	1367	282	60	370
7	glass 4	loose	1375	488	57	225
8	glass 4	loose	1349	340	80	360
9	glass 4	dense	1369	296	53	198
10	glass 4	dense	1393	315	74	372
11	glass 6	loose	1359	300	83	315
12	glass 6	dense	1346	236	70	382
13	glass 6	loose	1357	334	75	376
14	glass 6	dense	1362	332	74	372
15	alumina 2	dense	661	215	84	172
16	alumina 2	loose	655	167	70	175
17	alumina 2	loose	643	184	83	165
18	alumina 2	dense	653	197	88	220
19	alumina 2	dense	678	244	92	218

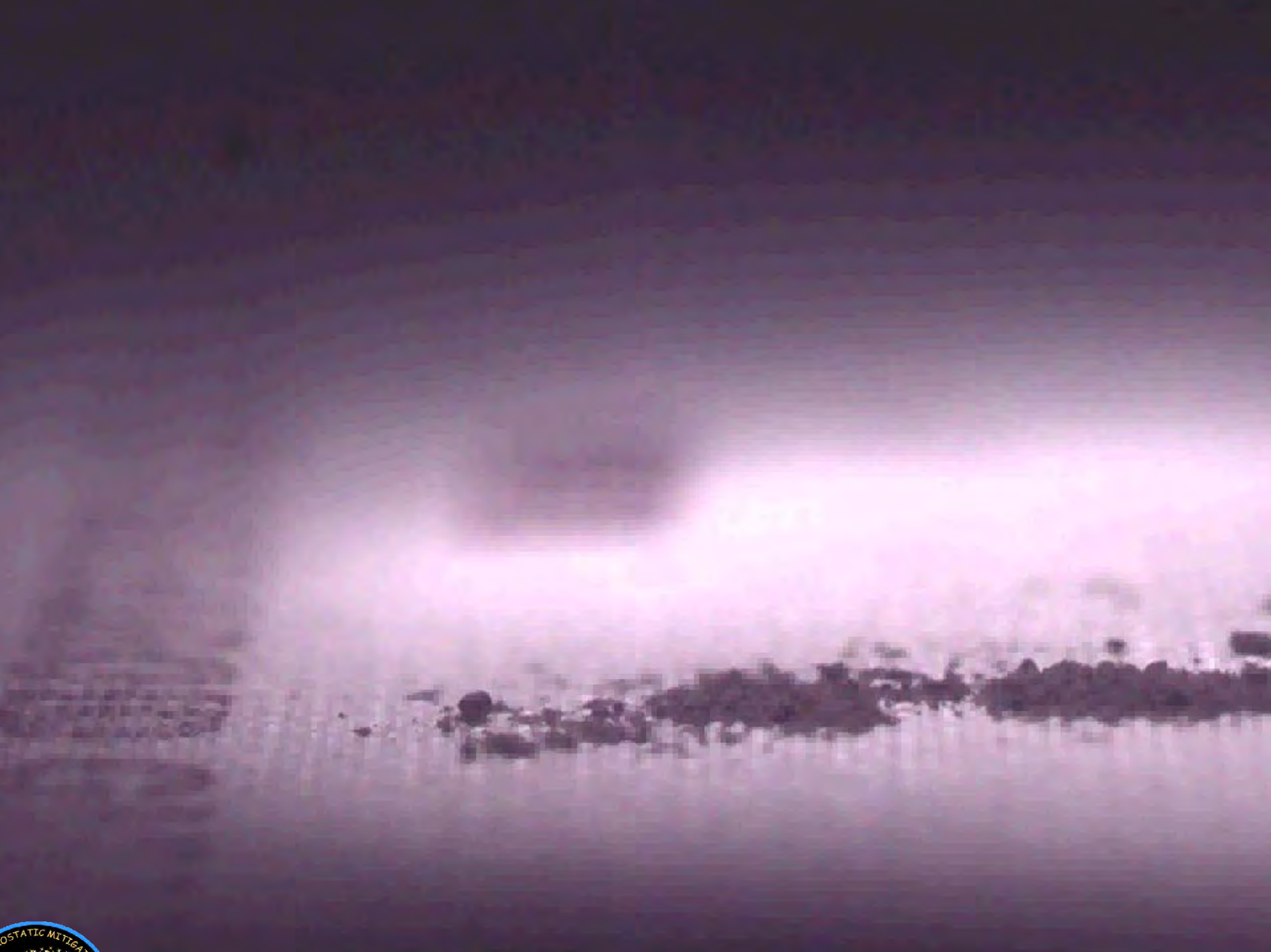
- *Brushing*
- *Vacuuming*
- *Air Dusting*
- *Shaking*
- *Electrostatics*
- *Magnets*

- **12 layers**
  - **2 layer liquid cooled undergarment**
  - **2 layer Pressurized bladder system**
  - **7 layer thermal insulation**
  - **Outer layer**
    - **Combination of Gortex, Kevlar and Nomex**
    - **Porous**

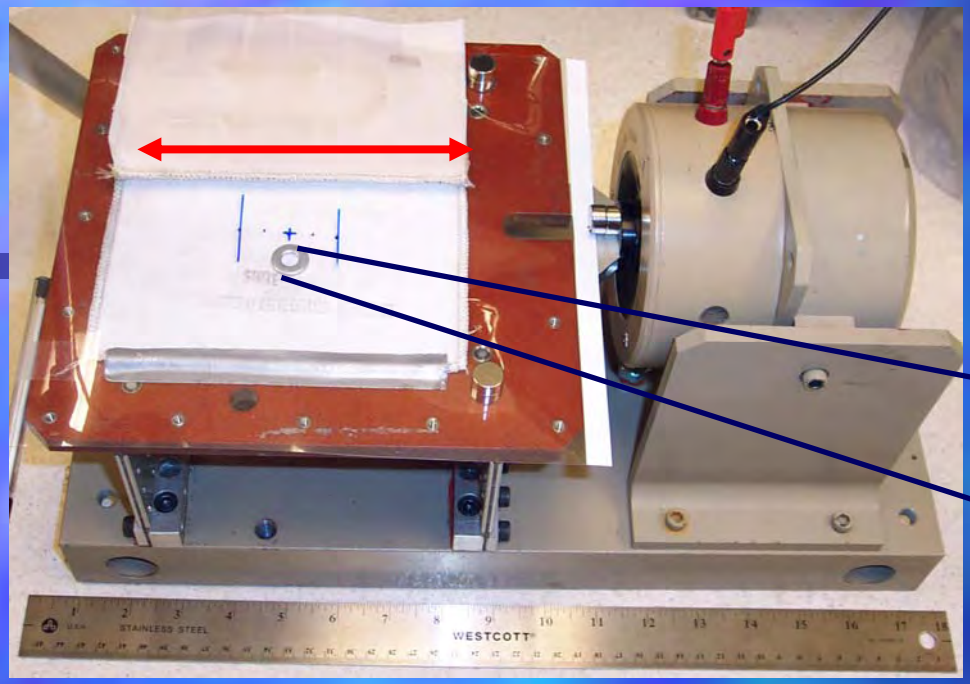
Shaking Techniques

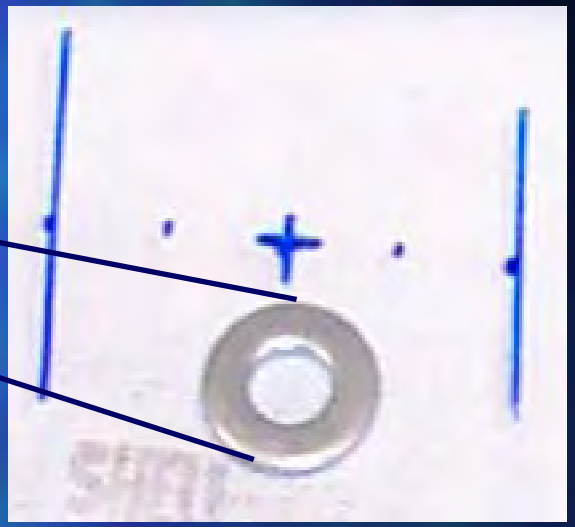


Sinusoidal Shaking



Heather Angel(CSM, Junior)
Summer 2004 L.E.R.C.I.P Intern





Before

After

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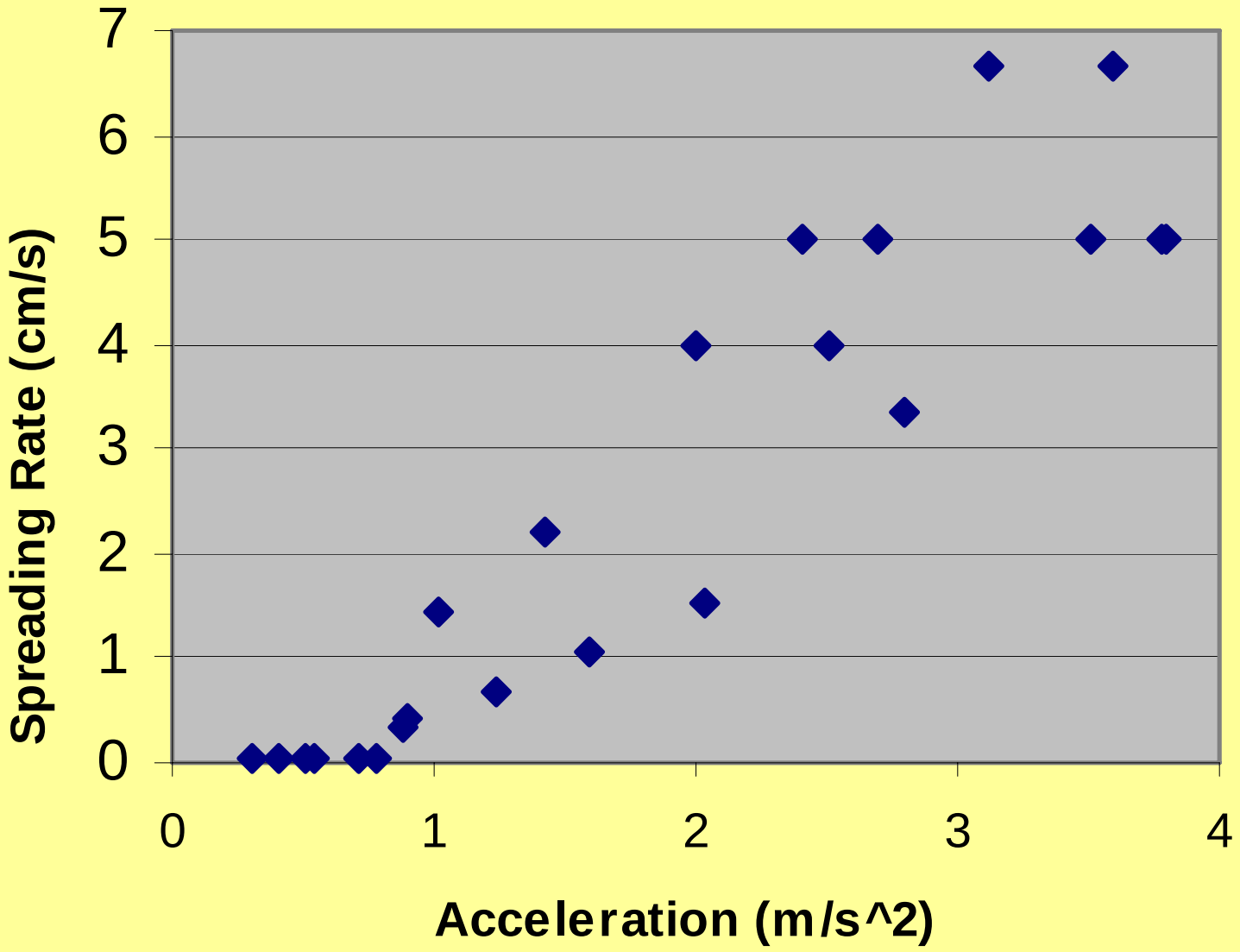
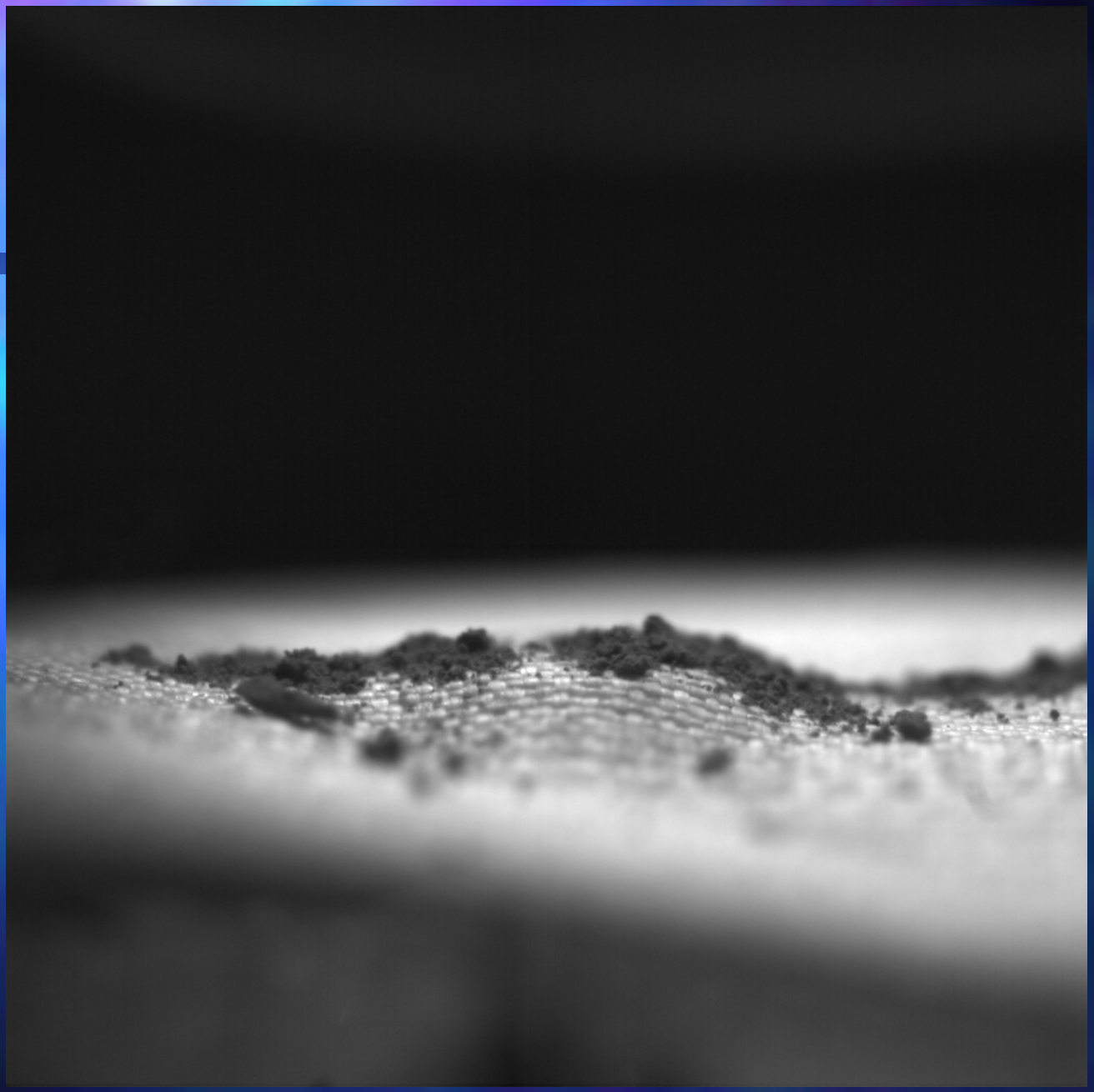

Spreading Rate (cm/s)
0
1
2
3
4
5
6
7
0
1
2
3
4
Acceleration (m/s^2)

Next Step...Attachment to the Spacesuit

Local Sinusoidal Shaking

- Small DC motor
  - Technology used in cell phones
  - Small
  - Lightweight
  - Vibration from unevenly weighted shaft



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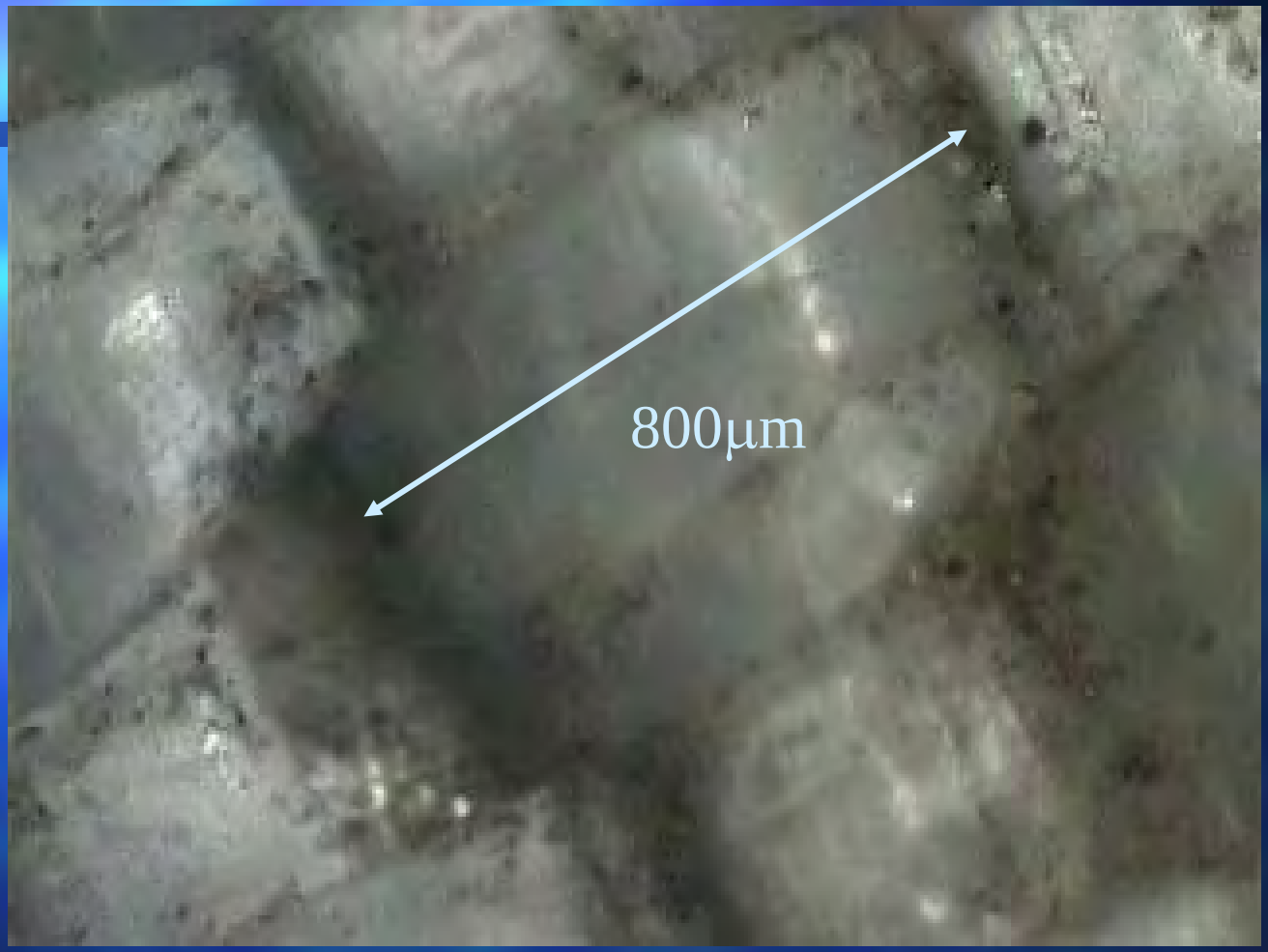

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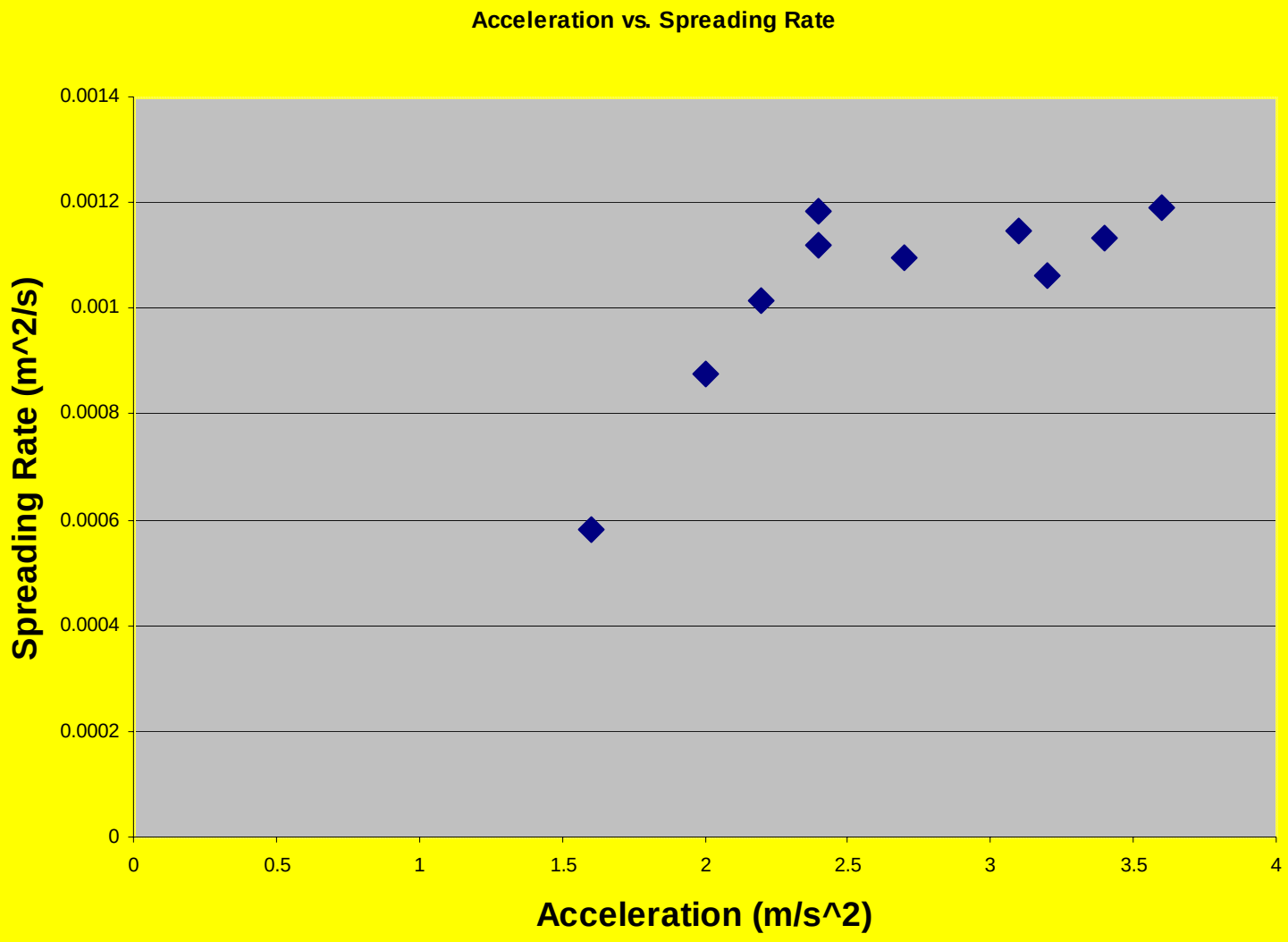
Acceleration vs. Spreading Rate
Spreading Rate (m^2/s)
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Acceleration (m/s^2)

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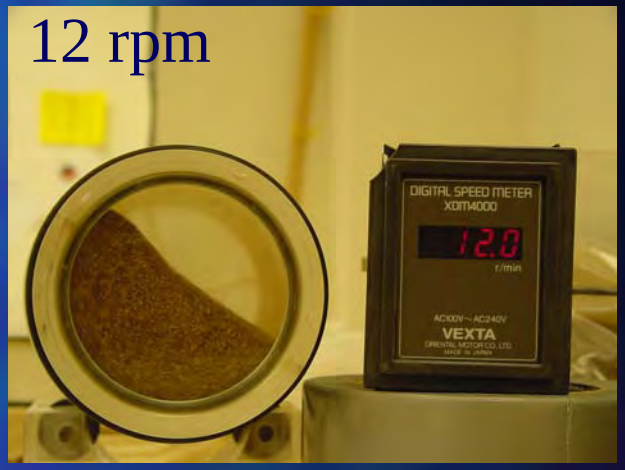
Flowability of Martian Dust



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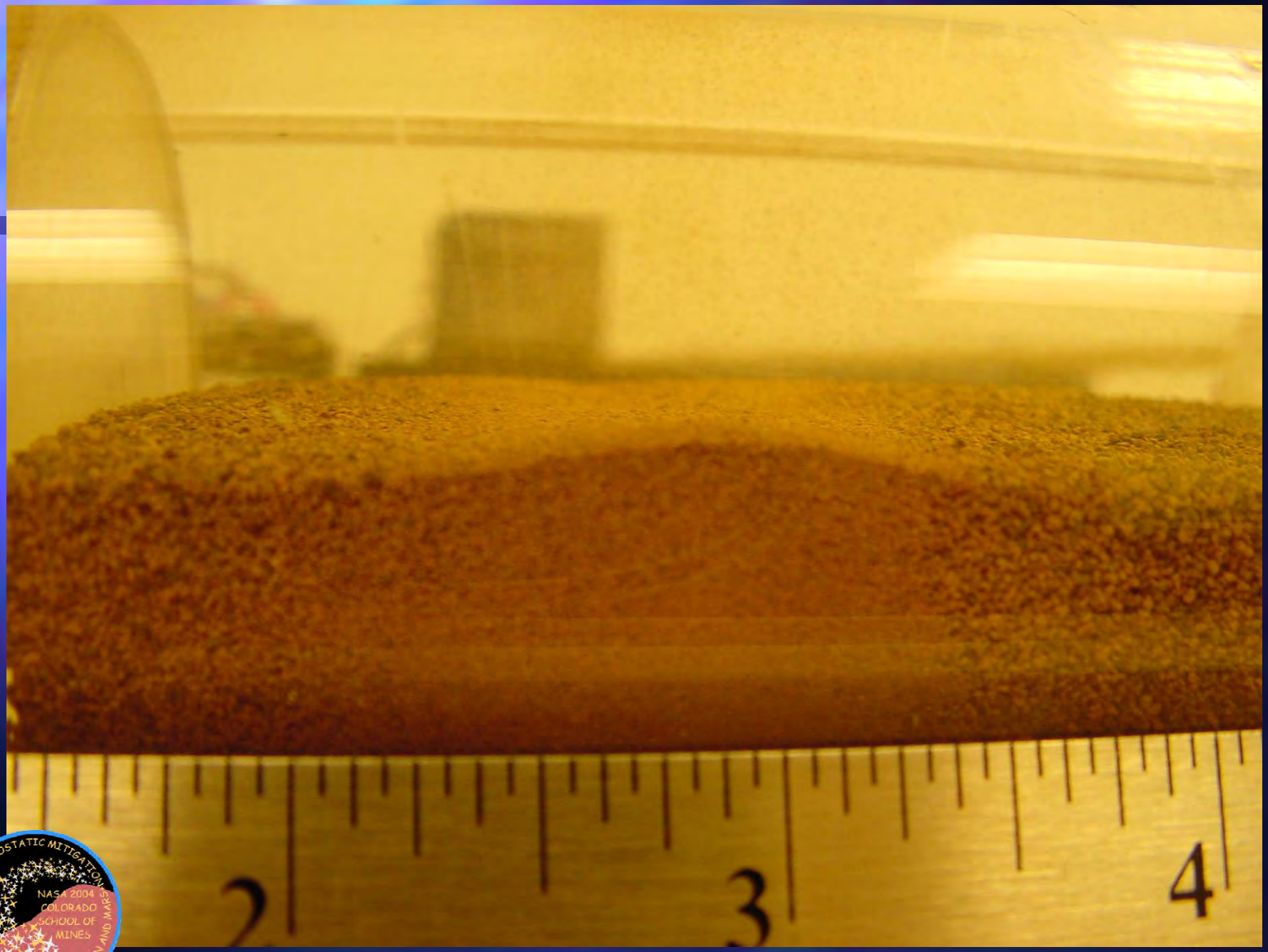

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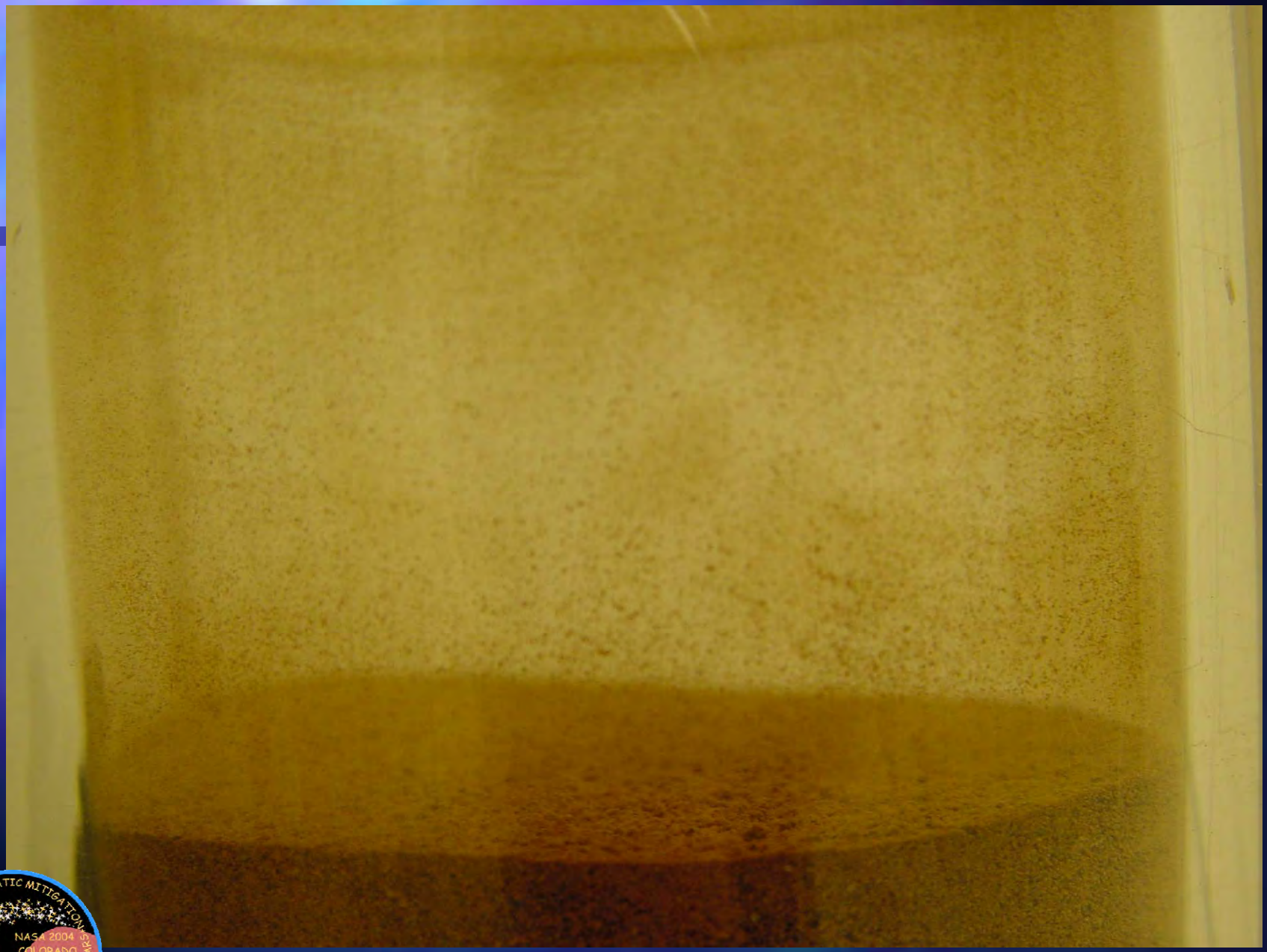

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Lunar Simulant

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