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In-situ Resource Utilization for the Moon, Mars and Beyond……

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Outline

- Introduction
- KSC laboratory capabilities
- ISRU - Living off the land
  - Mineral Beneficiation
  - RESOLVE
  - Dust mitigation
- Fun stuff we do……

Stepping stone approach

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Applied Chemistry Laboratory (ACL)

The Applied Chemistry Laboratory develops technology for toxic-vapor detection, chemical scrubbers for toxic waste, *in situ* resource utilization processes, microencapsulation of materials for space applications, hypergolic-fuel dosimetry, hydrogen detection, self-healing wire insulation, minimally intrusive repair methods for electrical wiring, and environmental remediation.

Notable Achievements

- Developed a nitrogen oxide emission control for hypergols, which is being field-tested at a coal-fired power plant to control NOX and SOX emissions. Received one patent, filed four additional patent applications, and was awarded NASA Commercial Invention of the Year.
- Developed self-healing wire insulation concepts and minimally intrusive manual repair methods for electrical wiring. Demonstrated the ability to detect a break in electrical wiring insulation in the laboratory. Filed a provisional patent application.
- Fabricated, tested, and delivered a portable instrumentation system to monitor for leaks of hypergols during the fueling of spacecraft.
- Developed and tested a simple color indicator for the quick determination of hypergolic leaks within the Space Shuttle Auxiliary Power Unit (APU) fuel transfer lines.
- Developed and tested a groundwater treatment technology for removal of environmental contaminants from groundwater around industrial areas, such as rocket launch pads, and cleanup of Superfund sites. The technology was named NASA's 2005 Commercial Invention of the Year and NASA's 2005 Government Invention of the Year.

Skills

- Expert skills in polymer chemistry, analytical chemistry, physical chemistry, fluorescence, organic synthesis, electrochemistry, analytical-instrument development/testing, fabrication, and machining.

Laboratory Services

- Generation of hypergolic vapors from 10 parts per billion (ppb) to several parts per million (ppm)
- Chemical problem solving
- Analytical services, including gas chromatography/mass spectrometry (GC/MS), ion chromatography (IC), ultraviolet-visible spectroscopy (UV-Vis), Fourier transform infrared spectroscopy (FTIR), and fluorescence spectroscopy
- Electrochemistry: direct current/alternating current electrochemical experimentation and analysis
- Coulometric analysis of vapor samples
- Environmental test development and evaluation
- Instrumentation development

Corrosion Technology Laboratory

The Corrosion Technology Testbed at the Kennedy Space Center has evolved from a need to better understand the processes that degrade our launch sites to a state-of-the-art problem solution center. At the heart of the Testbed is an atmospheric corrosion test site, which was established in the 1960s and has provided over 40 years of historical information on the long-term performance of numerous materials. This site is located 100 feet from the Atlantic Ocean and is approximately 1 mile south of the Space Shuttle launch structures. The site has been documented as the most corrosive test site in the continental United States.

Capabilities

- Atmospheric Exposure
- Accelerated Corrosion Testing
- Seawater Immersion
- Electrochemical Evaluation
- Coatings Application
- Surface Analysis

Skills

Testbed staff includes scientists, engineers, and technicians with advanced degrees and expertise in the following areas:

- Corrosion Science and Engineering
- Chemistry/Electrochemistry
- Materials Science

Atmospheric Exposure Site

- Continuous online monitoring of temperature, humidity, wind speed, rainfall, total incident solar radiation, and UVB radiation.
- Real-time data acquisition and Internet-based viewing of samples.
- Onsite corrosion laboratory.

Electrochemistry Laboratory

State-of-the-art instrumentation and equipment for corrosion measurements, including direct-current and alternating-current methods.

Representative Projects

- Smart Coating Development (NASA)
- Self-Cleaning Coatings (NASA)
- Corrosion-Resistant Tubing for Shuttle Launch Sites (NASA)
- Galvanic Coatings for Protection of Steel in Concrete (NASA)
- Cost-of-Corrosion Study (DoD)
- Chloride Rinse Agent Investigation (Army)
- Polyurethane Replacement Coatings (NASA)
- Evaluation of Corrosion Mitigation Techniques for Flight and Other Critical Space Station Hardware (NASA)
- Coatings Support for Exploration and Spaceport Design (NASA)

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Electrostatics and Surface Physics Laboratory (ESPL)

The Electrostatics and Surface Physics Laboratory at the NASA Kennedy Space Center is the premier research facility dedicated to investigating electrostatics and surface physics problems. The lab analyzes electrostatic and characterizes materials to assist in detecting, mitigating, and preventing electrostatic charge generation on space flight hardware and Space Shuttle ground support equipment. The lab is also involved in dust mitigation efforts for lunar and Martian exploration and methods for planetary protection.

Skills

The staff includes scientists and engineers with advanced degrees in physics, materials science, and electrical engineering, with specialist skills in electrostatic testing and prevention, tribocharging properties of materials, and surface science.

Representative Projects

- Electrodynamic screens for dust mitigation
- State-of-the-art characterization of Apollo 14, 16, and 17 lunar regolith
- Electrostatic beneficiation of lunar regolith for *In Situ* resource utilization (ISRU)
- Prevention of ESD on replacement circuit boards for the Hubble telescope repair mission
- Spark incendivity testing of Space Shuttle and Station blankets
- Electrostatic precipitation for removal of contaminants in high-pressure GN_2 lines
- Investigation of glow discharge in dust devils on Mars
- Development of electostatically dissipative films using indium tin-oxide (ITO), and carbon nanotubes (CNTs)

Facilities/Capabilities

- Various vacuum systems (3 bell jars, 2 stainless-steel UHV-capable)
- Three environmental chambers with state-of-the-art electrostatics-measuring equipment (static monitors, charge decay, Coulomb meters)
- X-ray Photoelectron spectroscopy (XPS)
- Sputter coater
- Atmospheric plasma glow discharge sources
- UV source and monochromator
- Optical emission spectrometer
- Contact angle measurements
- Sample preparation facilities
- Lunar and Mars dust simulants and 200 g Apollo 14, 16 and 17 lunar regolith
- Atomic Force Microscopy (AFM)
- Field Emission Secondary Electron Microscope (FESEM) with EDS

Beyond 2010?

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- Shuttle retire September 2010
- Constellation cancelled?
- In the absence of manned missions, NASA plans science orbiters, rovers and landers, and possible mission to return samples of Martian rock and soil to Earth
- Technology development for advanced capabilities such as miniaturized surface science instruments and deep drilling to hundreds of meters will also be carried out in this period
- The program envisions significant international participation

Living Off the Land

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- In-Situ Resource Utilization
- Extracting resources from planetary bodies ("living off the land")
- Reduces reliance on Earth-supplied consumables
- Reduces mass launched from Earth to support a lunar outpost, increasing the payload capability for other objectives, such as science

Priorities for ISRU capabilities

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Regolith excavation and transport	For radiation/micro-meteorite shielding and thermal moderation
Water production	From regolith for life support and radiation shielding
Oxygen production	From regolith for life support and propulsion
Fuel production	From regolith for Earth return, lunar surface/orbital science expeditions, etc.
Energy production, transport, storage, and distribution	For outpost use
Structural and **building material** fabrication	For outpost use
Spare part, **machine**, and **tool** production	For outpost use
Construction and **site preparation**	Using *in-situ* materials and *in-situ* energy

ISRU cycle

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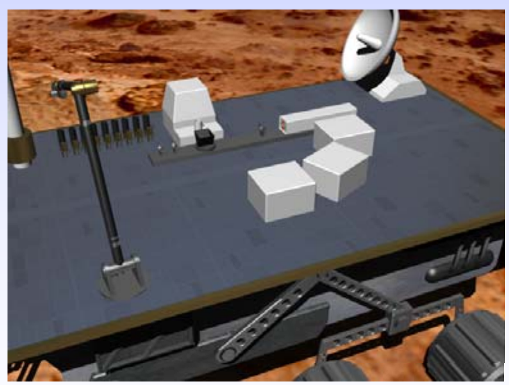
Identification

Access/Exploration

Mining

Beneficiation



Processing

Product

Waste

Lunar Mare soil

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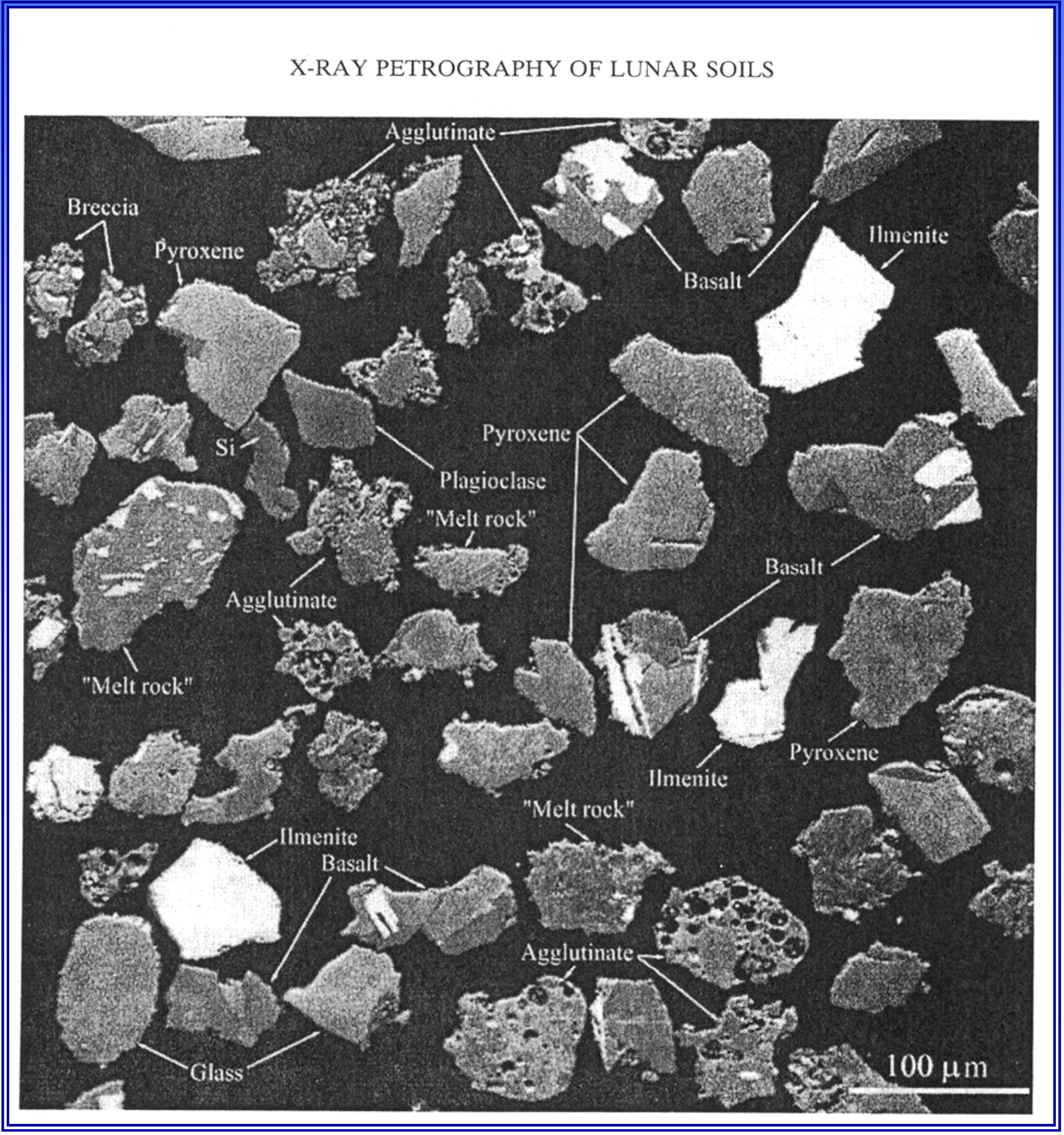

Taylor *et al.*, Icarus, 124, (1996), 500-512

Characterization

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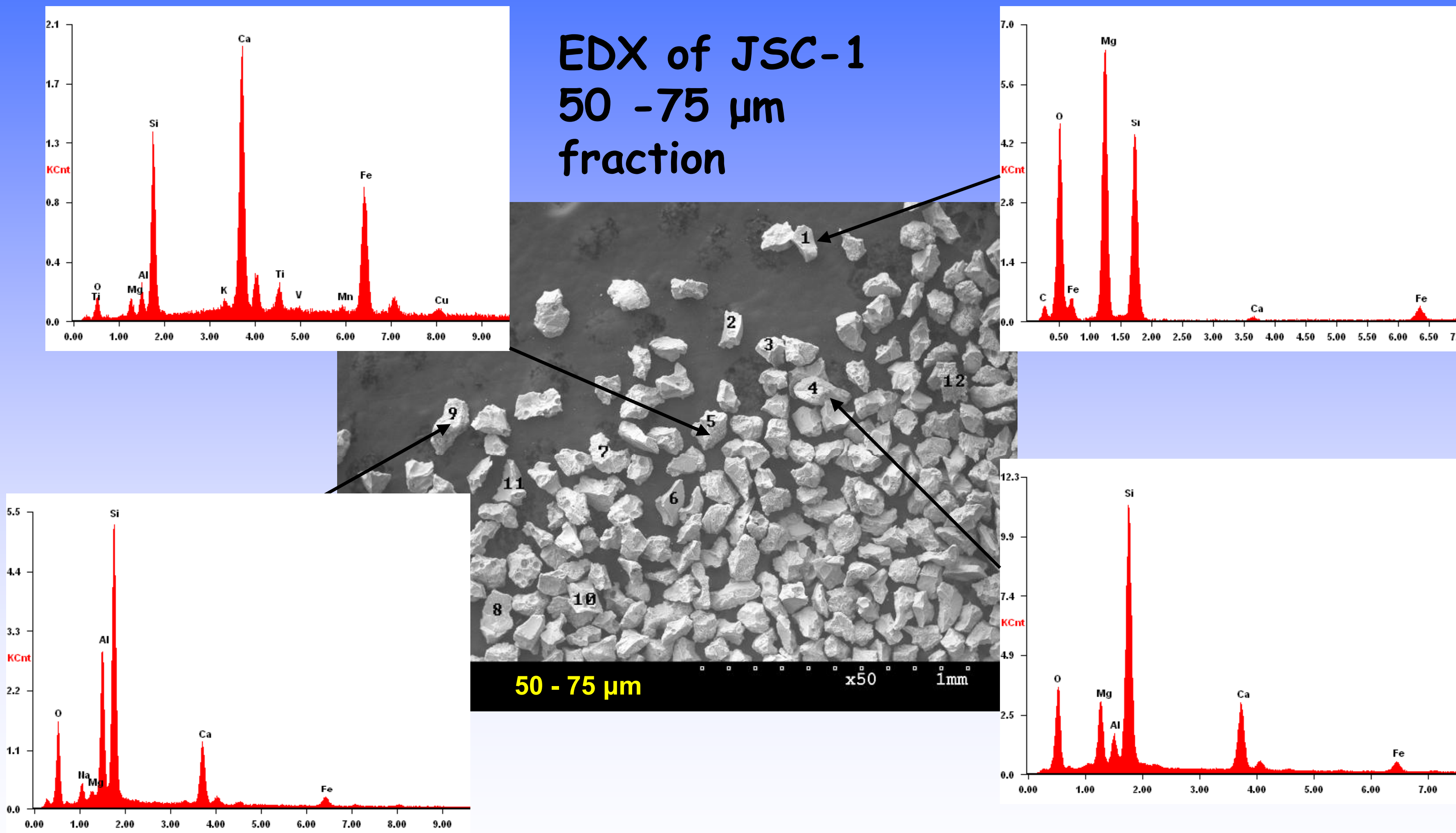
EDX of JSC-1 50 -75 µm fraction



Beneficiation

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- Electrostatic beneficiation of lunar regolith is being investigated as part of the (ISRU) program at Kennedy Space Center
- Refinement or enrichment of specific minerals in the fine powdery regolith into an industrial feedstock before it is chemically processed would reduce the size and energy requirements to produce virgin material and reduce the process' complexity
- This would allow for more efficient extraction (e.g. oxygen) for in situ resource utilization use.

Tribocharging

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- Contact electrification has been known since ~ 600 BC
- Tribocharging takes place when two dissimilar solids come in contact and separate - exchange of charges through contact area
- Electron transfer due to difference in work functions between the two materials (ϕ_1- ϕ_2)
  - Tribocharging of particles depends upon;

    particle size and shape
    frequent impaction
    contact material
    surface adsorbed materials
    surface composition
    surface electron band structure
    surface work function

Triboelectric series

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- **+ Positive end (lower work function)**

Zirconium	4.05 eV
Silver	4.26 eV
Aluminium	**4.28 eV**
Nylon	4.30 - 4.54 eV
Zinc	4.33 eV
Chromium	4.50 eV
Steel	**~ 4.60 eV**
Copper	**4.65 eV**
PMMA	4.68 eV
Polycarbonate	4.80 eV
Polystyrene	4.90 eV
Polyethylene	4.90 eV
Gold	5.10 eV
PVC	5.13 eV
Nickel	5.15 eV
Platinum	5.64 eV
PTFE	**5.75 eV**

- **- Negative end (higher work function**

Tribocharging

- The amount of charge and polarity transferred to different minerals depends upon the work function difference between the mineral composition and charging material
- Hence, when triboelectrically charged by different static mixers and passed through a charge separator, different minerals will be separated out
- Several passes may be required to maximize process

Principles of Tribocharging

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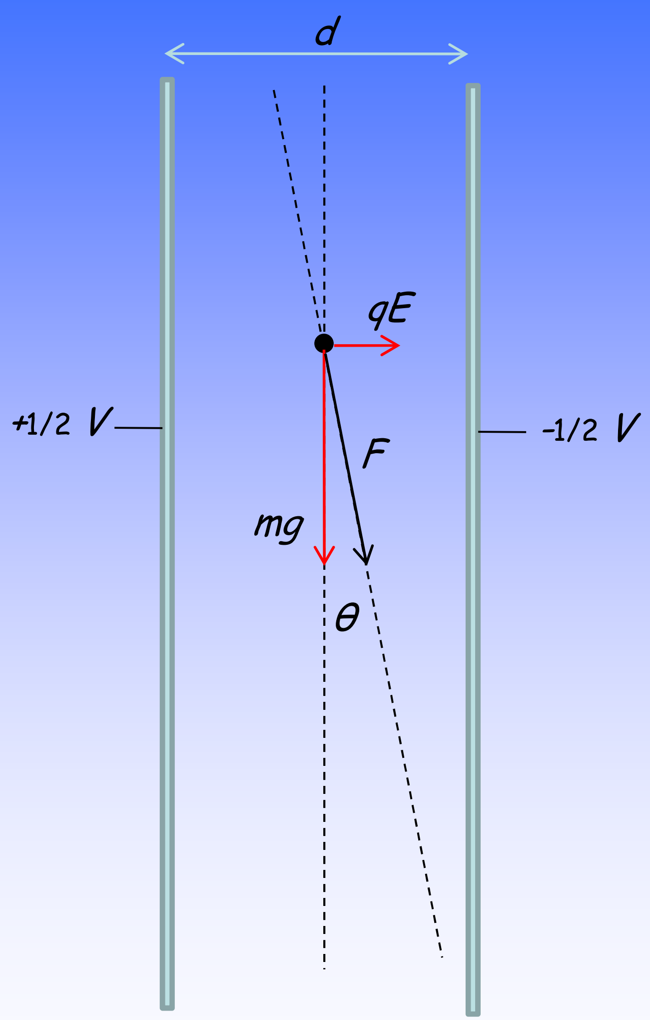
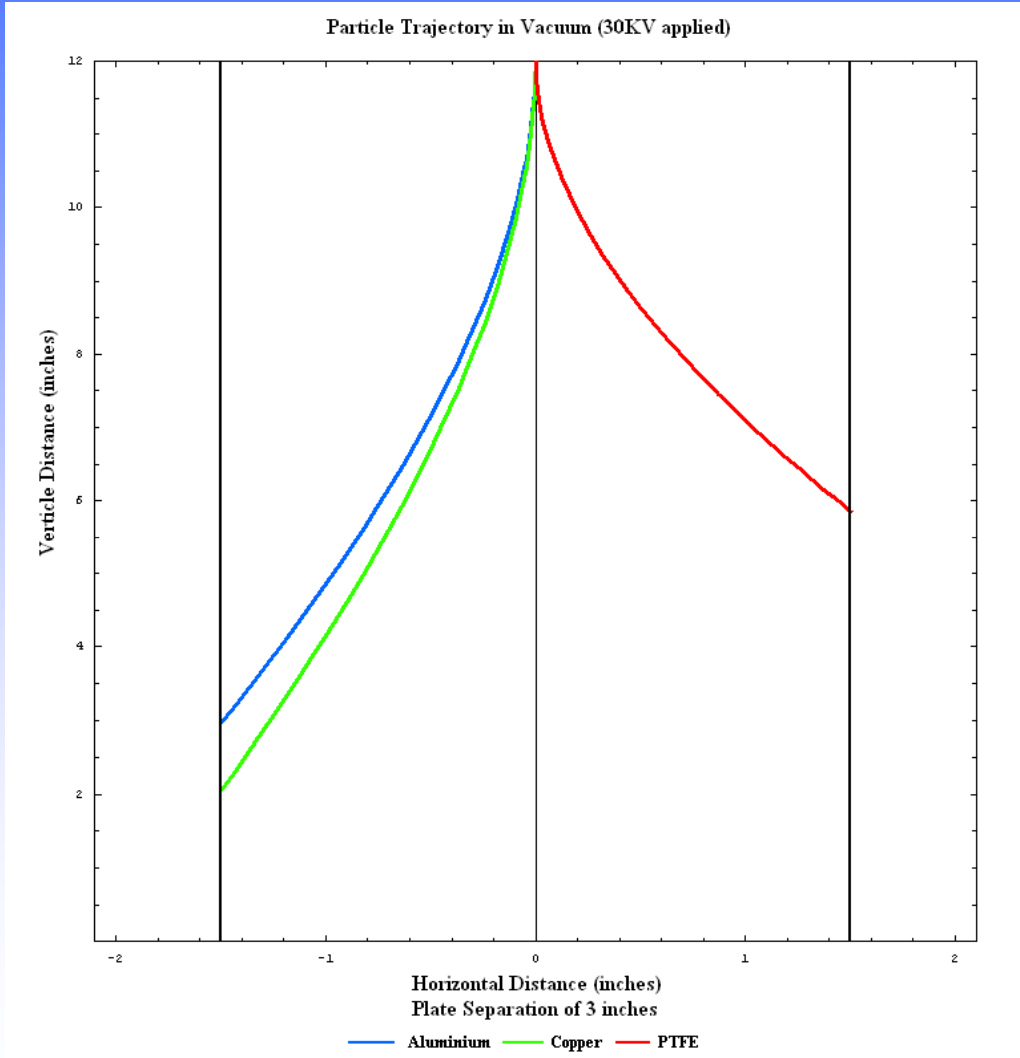


$$\tan \theta = qE/mg = (q/m)((V/d)/g)$$



Principles of Tribocharging

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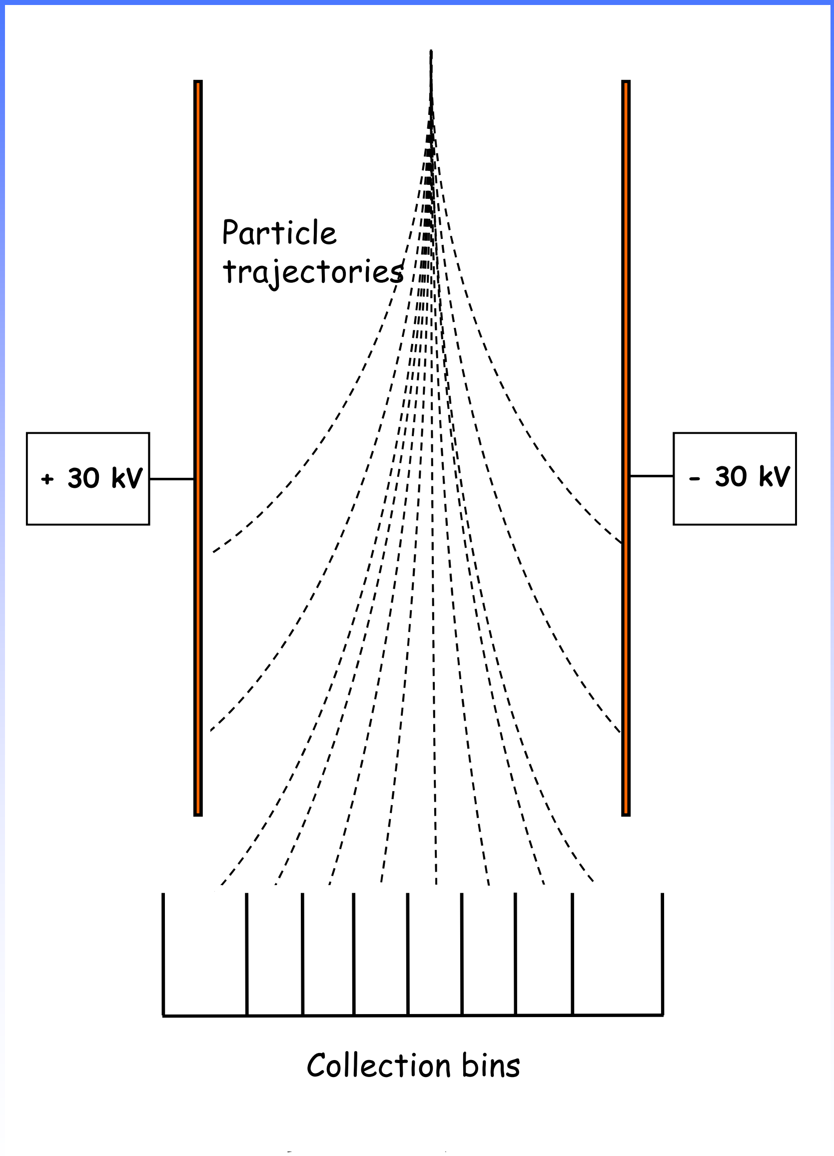

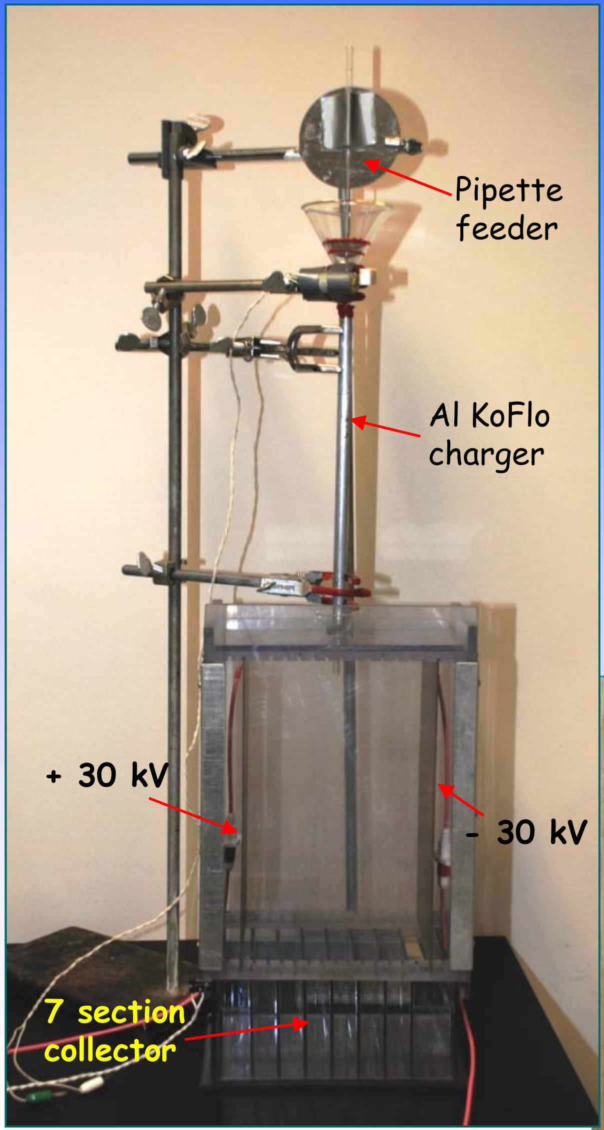

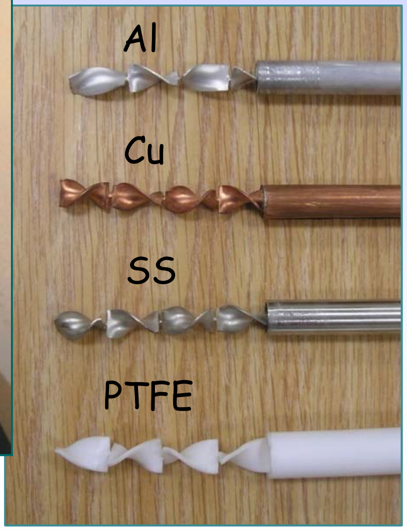

Lunar regolith

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- Lunar dust principally basalts containing
  plagioclase $(Na,Ca)Si_3AlO_8$
  pyroxene $(Mg,Fe,Ca)Si_2O6$
  olivine $(Mg,Fe)_2SiO_4$
  and ilmenite $FeTiO_3$
- Two simulants developed to replicate the mineralogy and chemistry of lunar soil from Apollo missions: NASA JSC-1 and JSC-1A

Mineral	Wt. %
Plagioclase	20 - 50
Pyroxene	40 - 65
Olivine	2 - 15
Ilmenite	2 - 15

Summary of compositions obtained from literature

- Electrostatic charging of lunar dust compared favorably to JSC-1[1]
- Successful separation of ilmenite (up to 55%) has been reported[2] using high-voltage electrode in N_2 environment – ilmenite favored as H_2 ore

[1] M. Horanyi et. Al., J. Geophys. Res. 103, E4, (1998) 8575-8580

[2] W.M. Agosta, Lunar & Planetary Science XV, (1984) 1-2

KSC-1 in vacuum

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KSC-1 50 - 75 μm **Al**

	Na	Fe	O	Ti	C	Si	Al
Bottom tray	-9%	-69%	-6%	-48%	+26%	+17%	+6%
-ve plate	+31%	-43%	-	-38%	+12%	+15%	-
+ve plate	-	-	-	+40%	-7%	+11%	-23%

KSC-1 50 - 75 μm **Cu**

	Na	Fe	O	Ti	C	Si	Al
Bottom tray	-10-%	+11%	-	-34%	-11%	+20%	+13%
-ve plate	-7%	+86%	-	+14%	-8%	-	-8%
+ve plate	-27%	-	-	-32%	-	+11%	-

KSC-1 50 - 75 μm **PTFE**

	Na	Fe	O	Ti	C	Si	Al
Bottom tray	-	-36%	-	-31%	-10%	-+23%	+18%
-ve plate	+13%	-32%	-	-26%	+9%	-	-
+ve plate	-	+27%	-	+46%	+9%	-7%	+30%

KSC-1 1st pass

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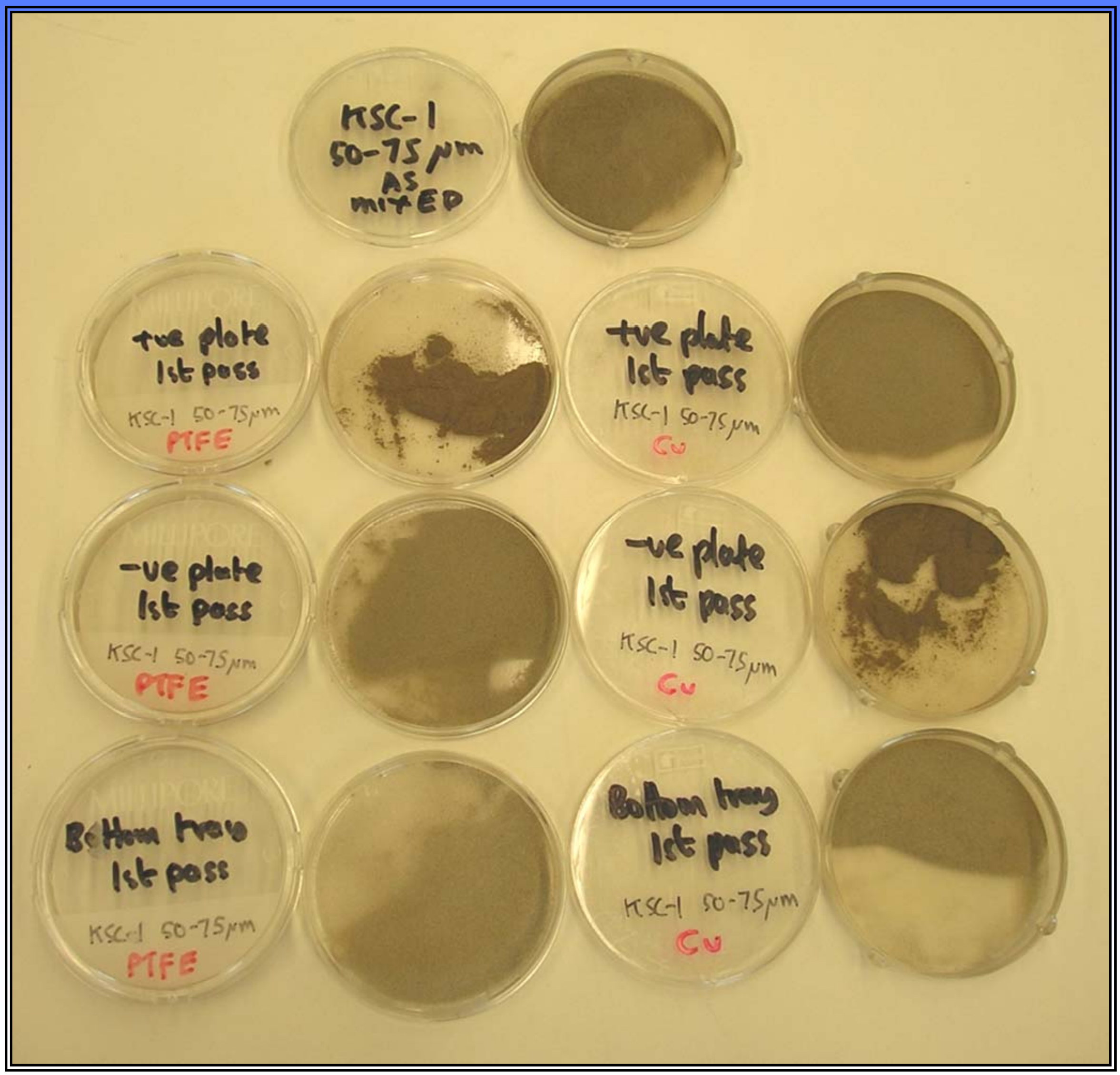

KSC-1 1st pass

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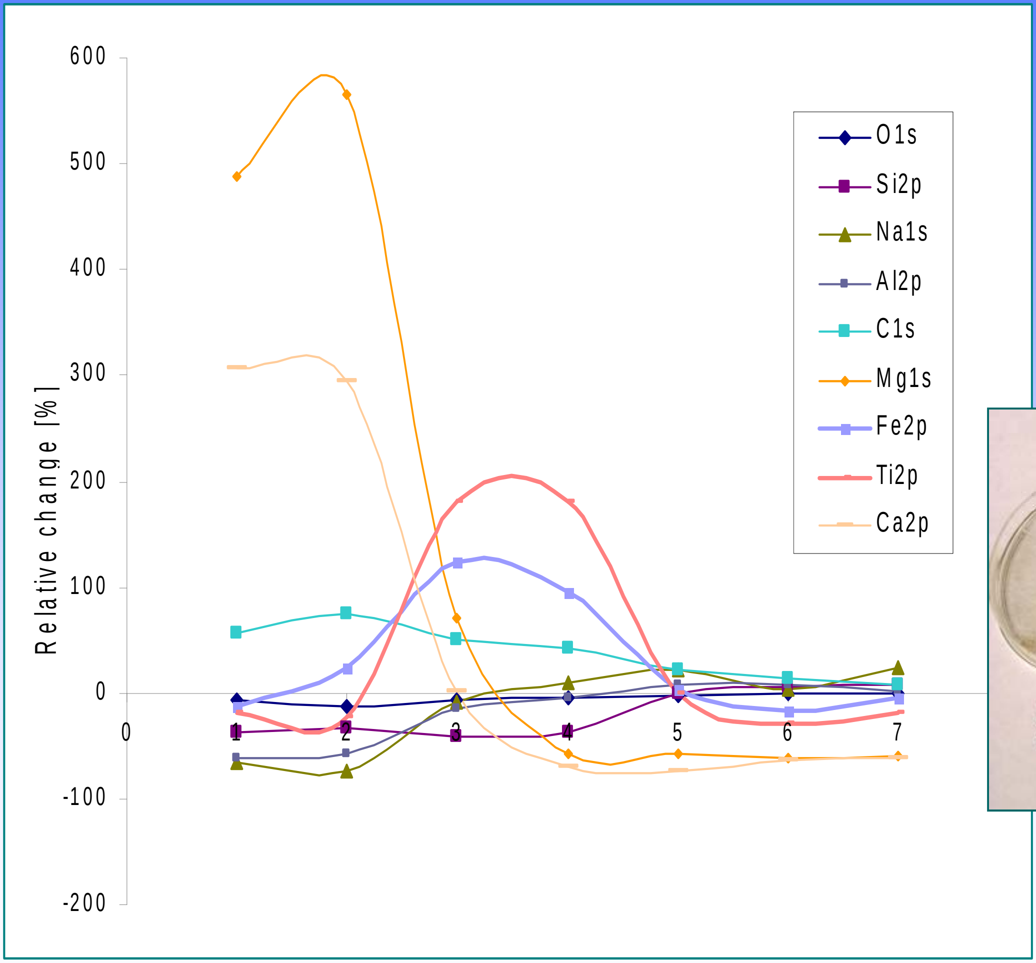

- Results from 7 tray bin
- Relative changes as determined by XPS

RESOLVE

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- Regolith and Environment Science & Oxygen and Lunar Volatile Extraction
- LWRD (Lunar Water Resource Demonstration) is part of RESOLVE (Regolith and Environment Science & Oxygen and Lunar Volatile Extraction)
- RESOLVE is an ISRU ground demonstration:
  - A rover to explore a permanently shadowed crater at the south or north pole of the Moon
  - Drill core samples down to 1 meter
  - Heat the core samples to 150C
  - Analyze gases and capture water and/or hydrogen evolved
  - Use hydrogen reduction to extract oxygen from regolith
- The field demo took place on Mauna Kea as an analog site for the Moon (EBU2)
- JSC, GRC, KSC, NORCAT, CSA and CMU involved
- EBU1 established feasibility

RESOLVE/Scarab Rover

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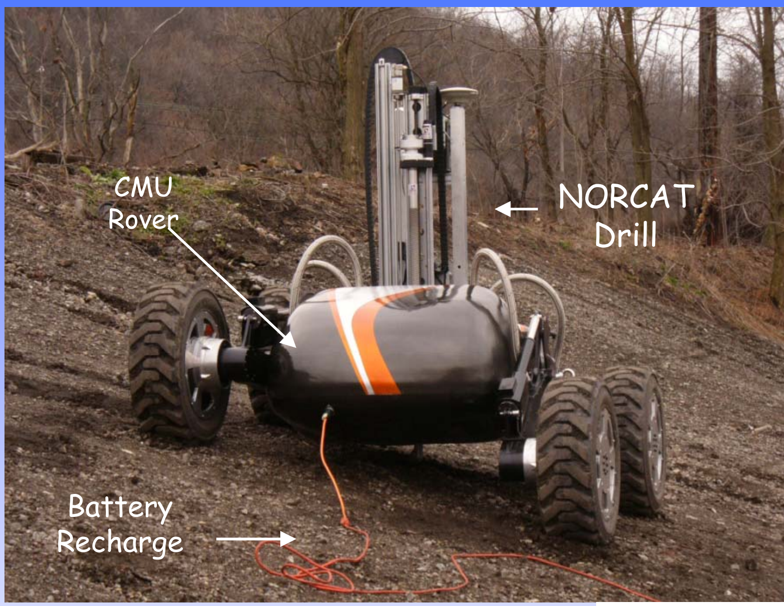

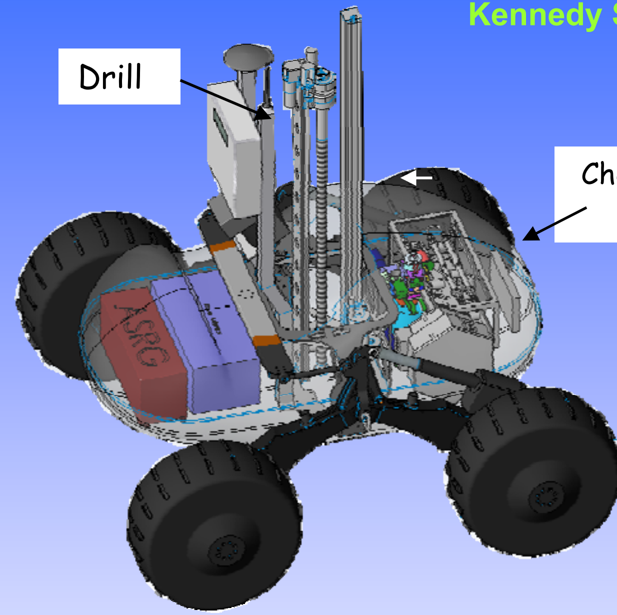

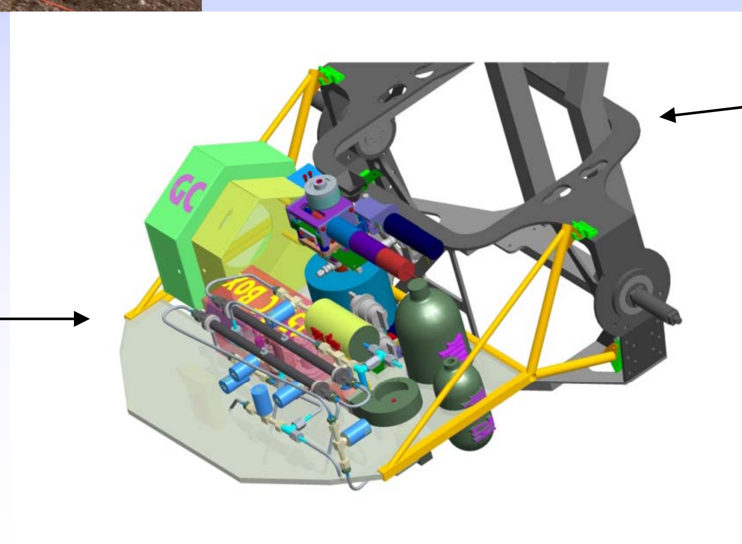

Lunar-like terrain on Mauna Kea

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Purpose of LWRD

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- Capture up to 6 g of water per regolith/soil core sample and quantify up to 20 g of water (backup to GC measurements)
- Capture and quantify up to 0.10 g of hydrogen from same core sample (backup to GC measurements)
- Quantify within 20% accuracy

Assembly of LWRD

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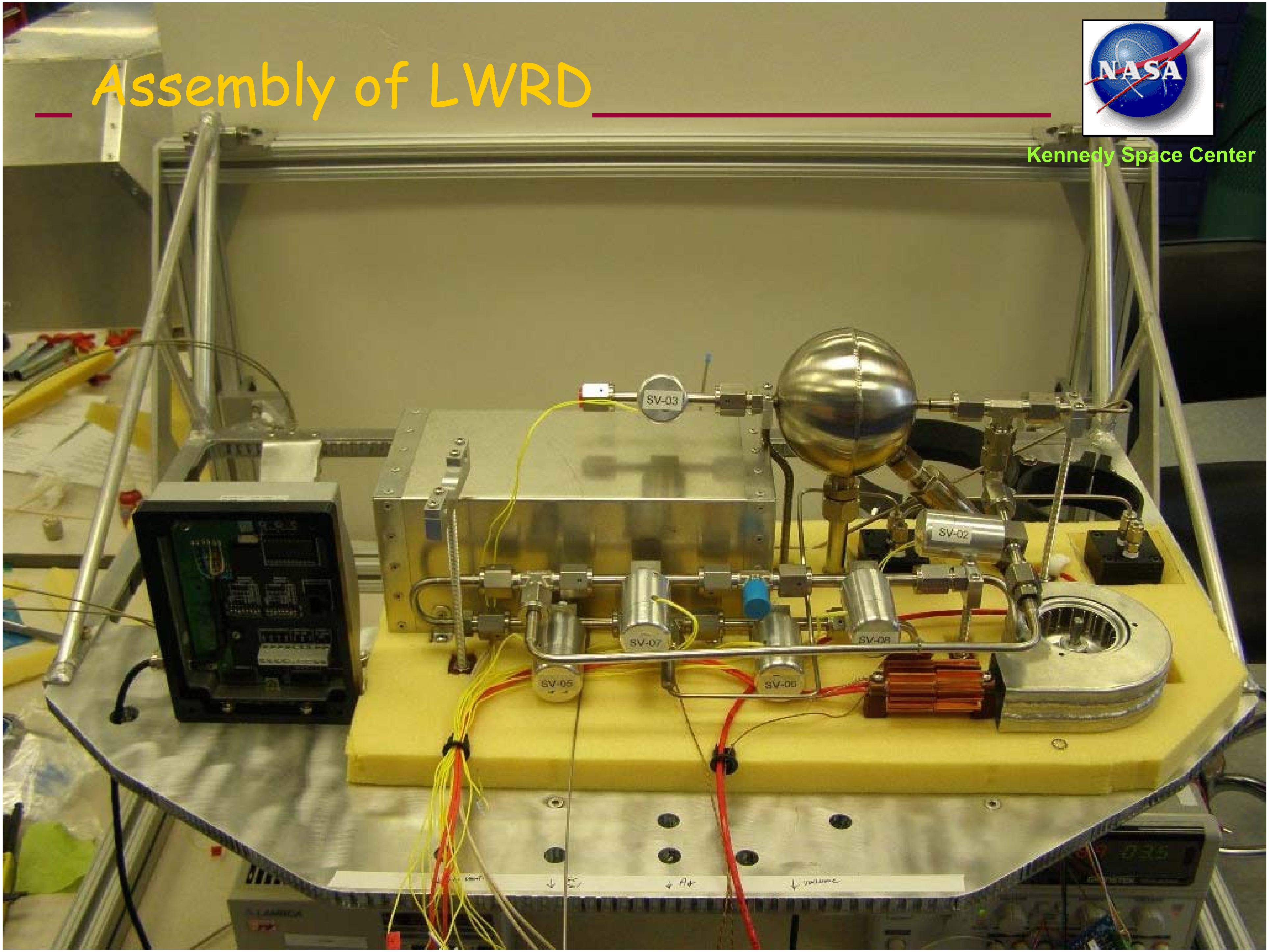

Water beds added

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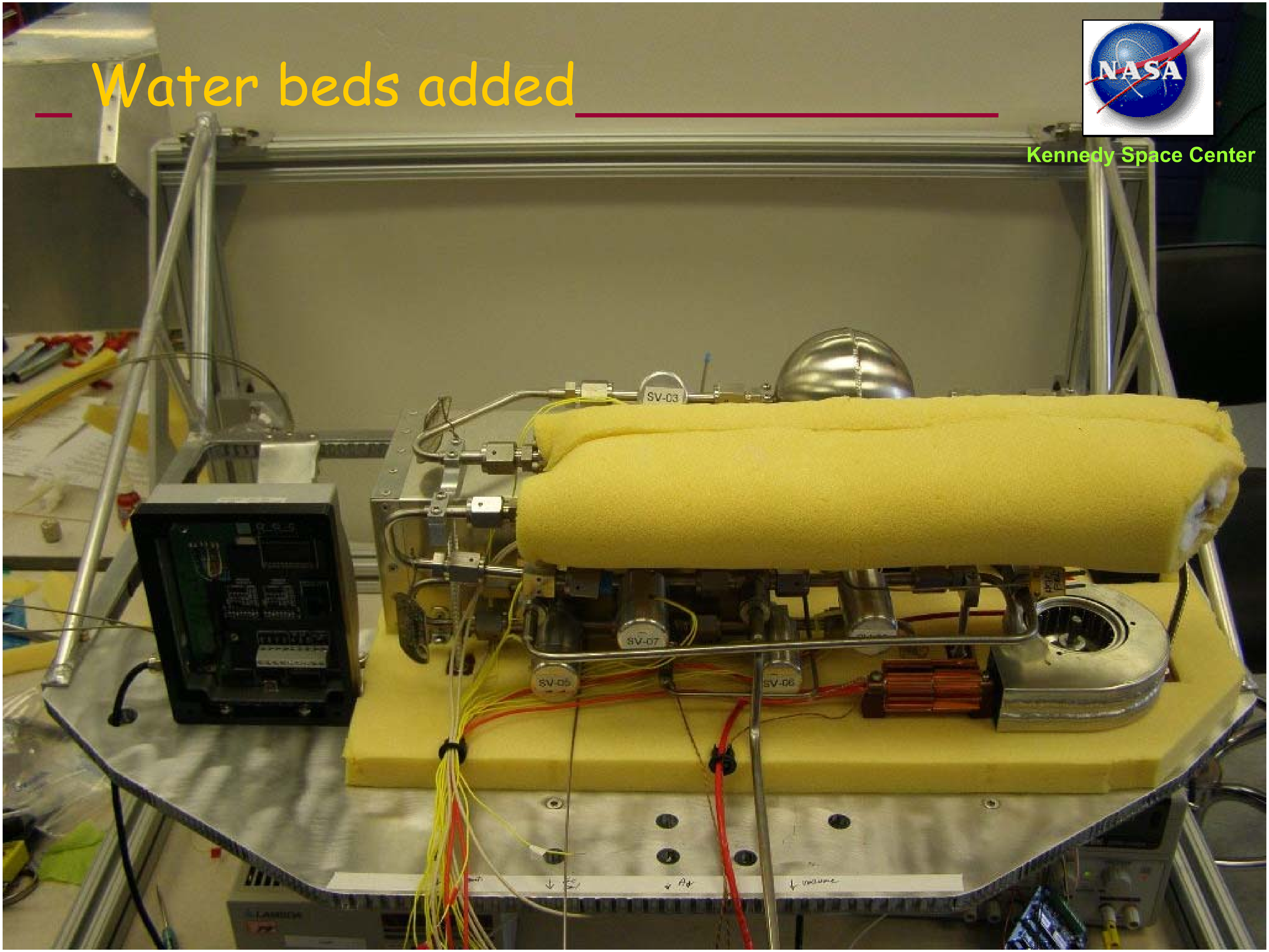

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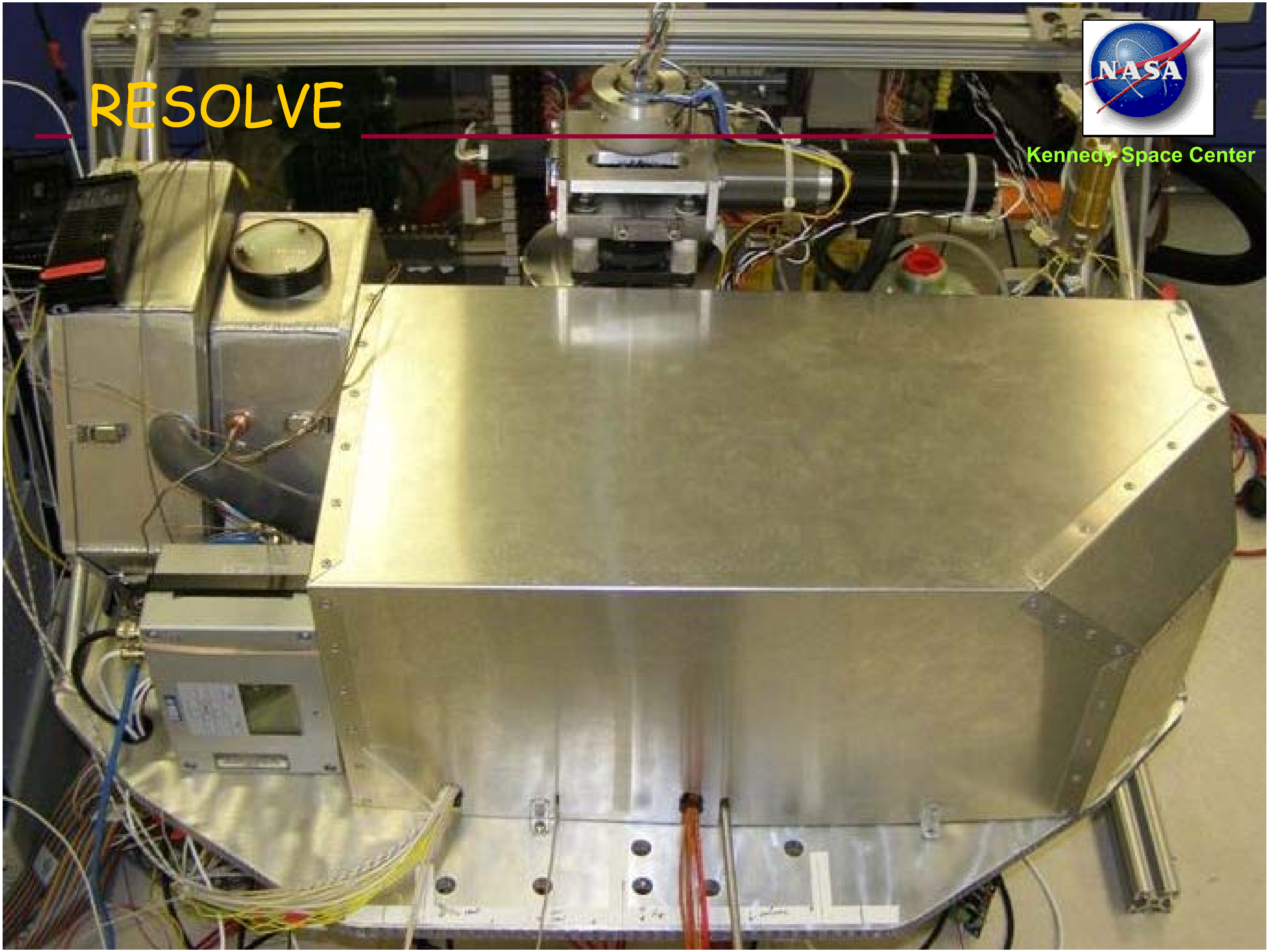

RESOLVE

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RESOLVE

RESOLVE

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RESOLVE – RVC Results

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Requirements Met:

- GC was repackaged, significantly reducing mass and volume
- GC capabilities were greatly improved by design and development of 2nd GC oven, providing multi-temperature capability
- OPC server provided the ability to change streams (methods), providing the capability to sample a wider range of concentrations
- Demonstrated separation of complex gas mixture containing lunar-relevant gases (helium, hydrogen, nitrogen, oxygen, methane, carbon dioxide, and carbon monoxide)
- A minimum of 8 GC samples were collected during reactor heatup
- Able to quantify nitrogen, oxygen, carbon dioxide, and water
- Minimum of four RVC/LWRD samples were processed (six completed)

RESOLVE – LWRD Results

Requirements Met:

- Heater power < 1000 W
- Reactor temperature
- Demonstrated ability to capture up to 6 grams of water per core sample
- Demonstrated ability to quantify up to 20 grams water produced/evolved
- Maintain LWRD at or above 130 °C
- Demonstrated ability to capture and quantify hydrogen

RESOLVE – Overall Results

- Remote navigation and control
- Autonomous and manual operation
- Drill site selection
- Roving
- Sample acquisition
- Volatiles characterization
- Volatiles capture
- Oxygen extraction

RESOLVE

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Dirt That Hurts

- The Mossbauer Spectrometer and APXS instruments on the *Spirit* and *Opportunity* rovers are studying the chemical composition of the soil on Mars, which will tell us what chemicals might be detrimental to humans if they inhale the dust
- Trace metals could be toxic to lungs, and dust could also affect electronic devices like computers and vehicles that humans will need on Mars
- NASA is also concerned that dust and soil could have the potential to develop electric charges
- *Spirit* and *Opportunity* are taking pictures and making "mini-movies" of dust devils to try to understand dust and soil movement on Mars

Dirt That Hurts

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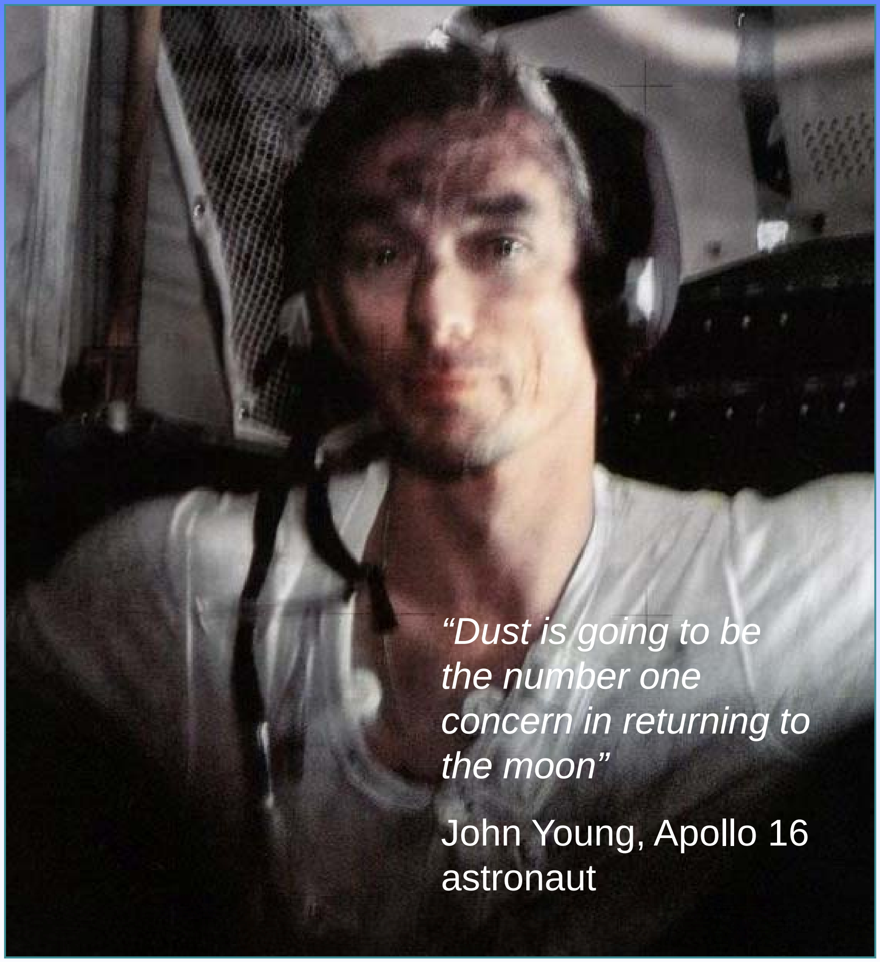

"Dust is going to be the number one concern in returning to the moon"

John Young, Apollo 16 astronaut

Martian Dust storms

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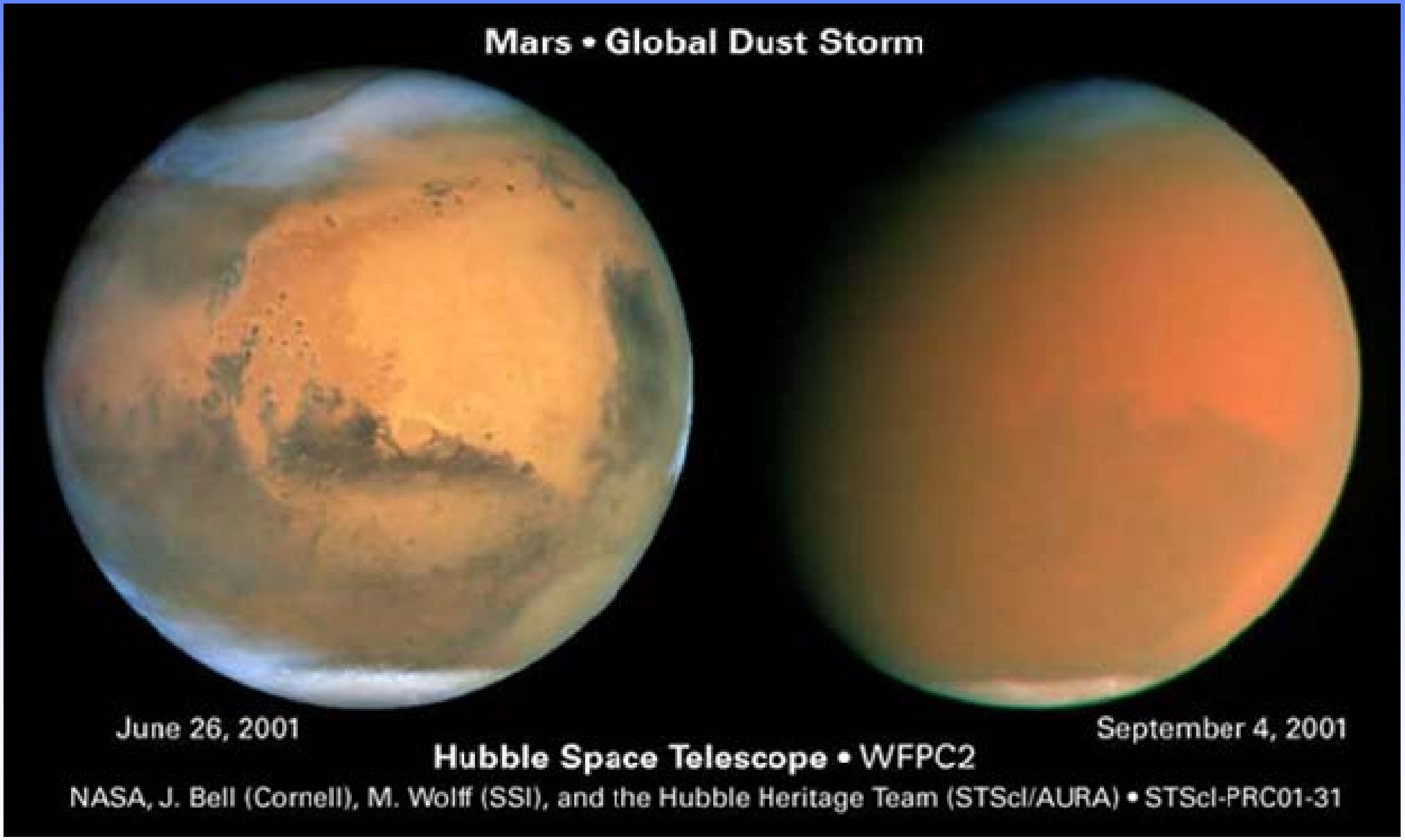

Martian Dust storms

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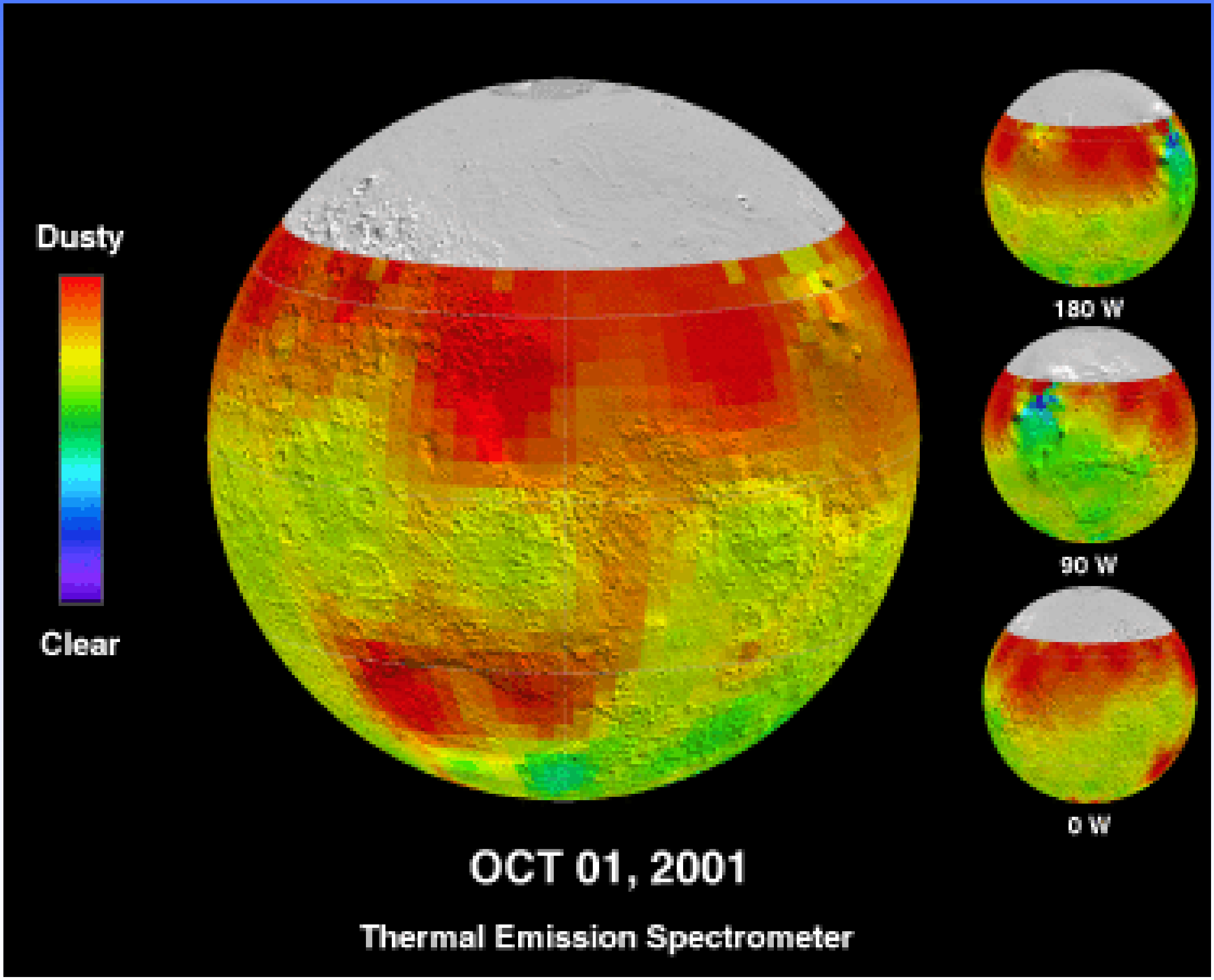

Martian dust devils

Martian dust devils

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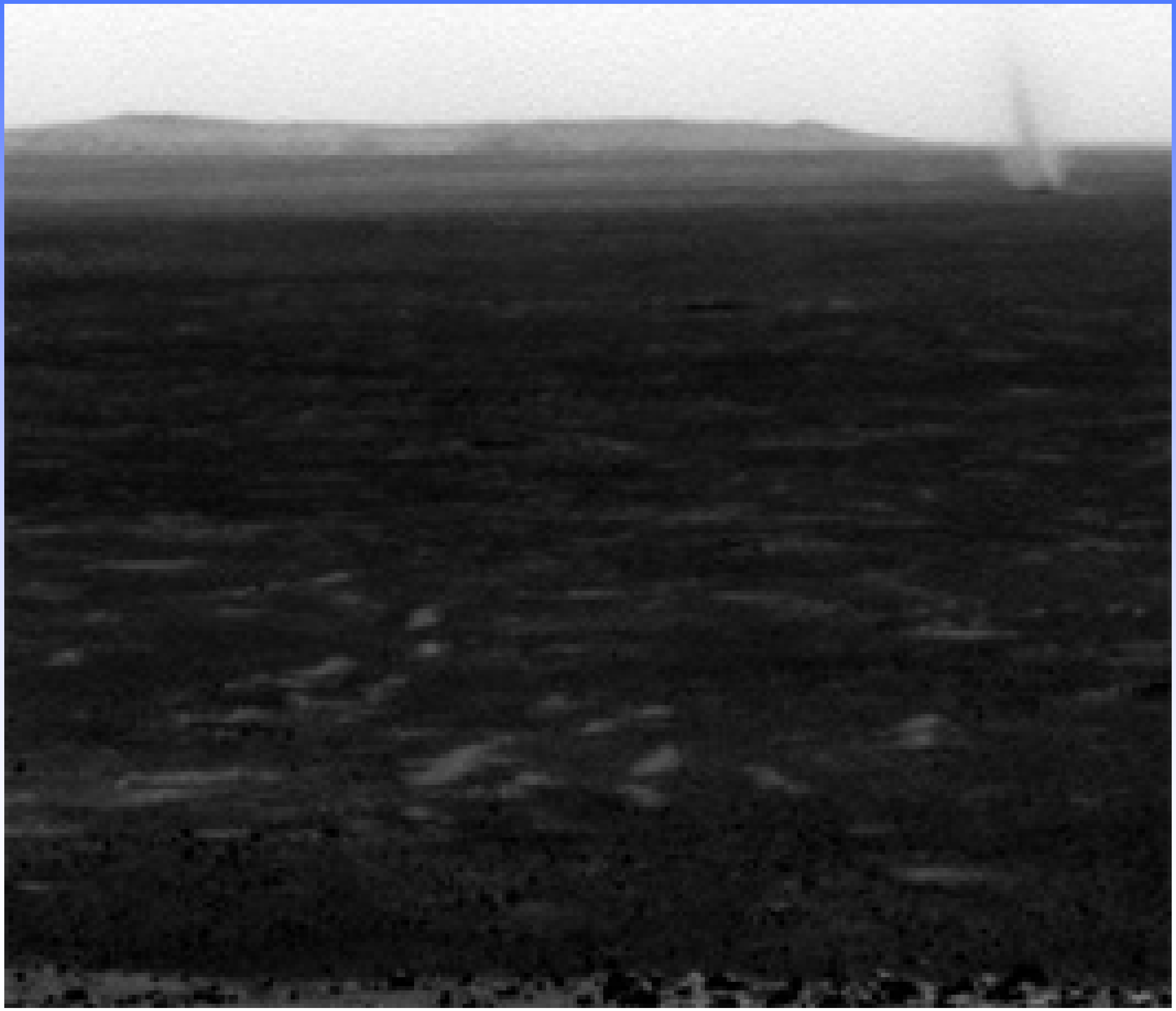

Electrodynamic dust shield

- NASA KSC's Electrodynamic Dust Shield Technology removes dust from optical systems and prevents dust accumulation
- Dust Shield is based on the Electric Curtain concept developed at NASA in 1967*
- Masuda at U. Tokyo built first prototypes (1970s)
- NASA KSC and University of Arkansas developed EDS for Mars
  (NASA Science Mission Directorate NRA – 2003-2006)
- KSC currently developing technology for lunar applications (ESMD Dust Project)

* Tatom, F.B., V. Srepel, R.D. Johnson, N.A. Contaxes, J.G. Adams, H. Seaman, and B.L. Cline, "Lunar Dust Degradation Effects and Removal/Prevention Concepts", *NASA Technical Report No. TR-792-7-207A*, p. 3-1 (1967)

Controlled dust motion

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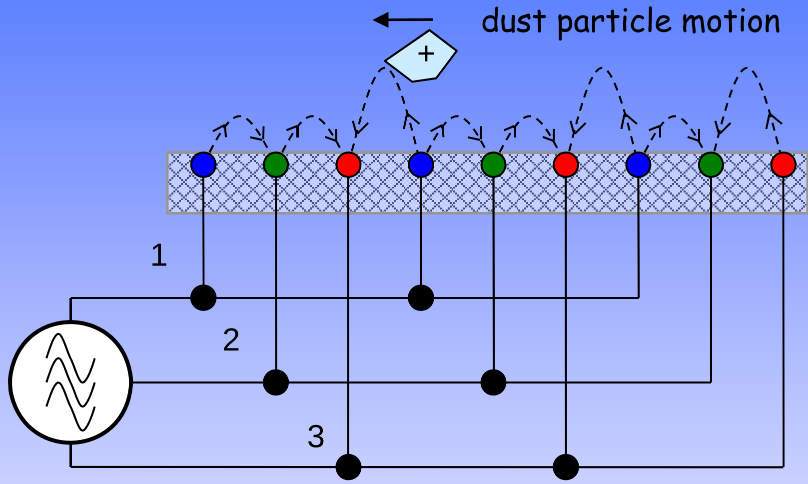
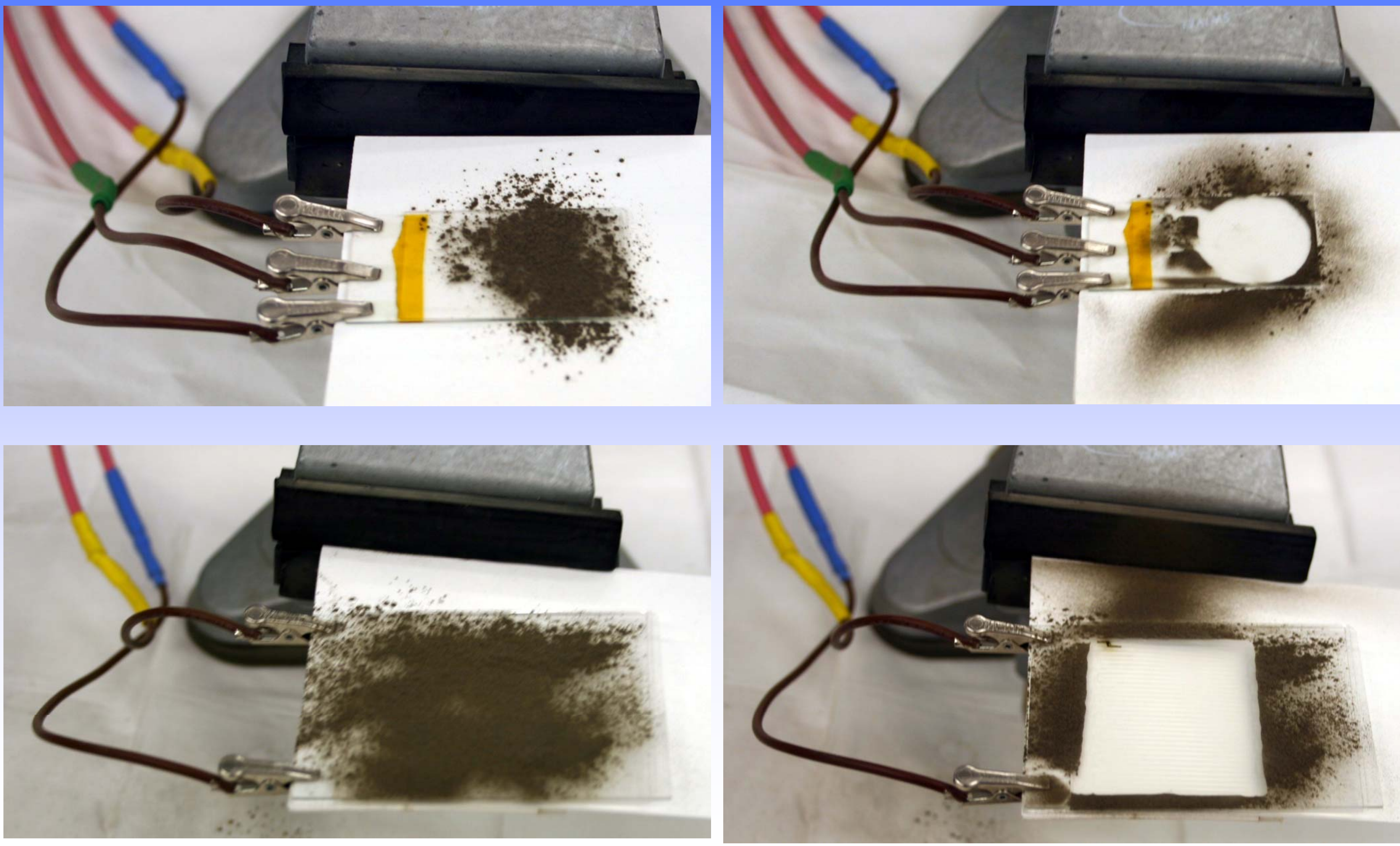


Three-phase electrode pattern with **phase 1** electrodes at V_1=-V, **phase 2** electrodes at V_2=+V, and **phase 3** electrodes at V_3= +V. Charged particles will move in a particular direction.

Three-phase dust shield with indium tin oxide transparent electrodes in a spiral pattern configuration on a glass substrate

Transparent Dust Shields



Flexible Dust Shield on Fabric

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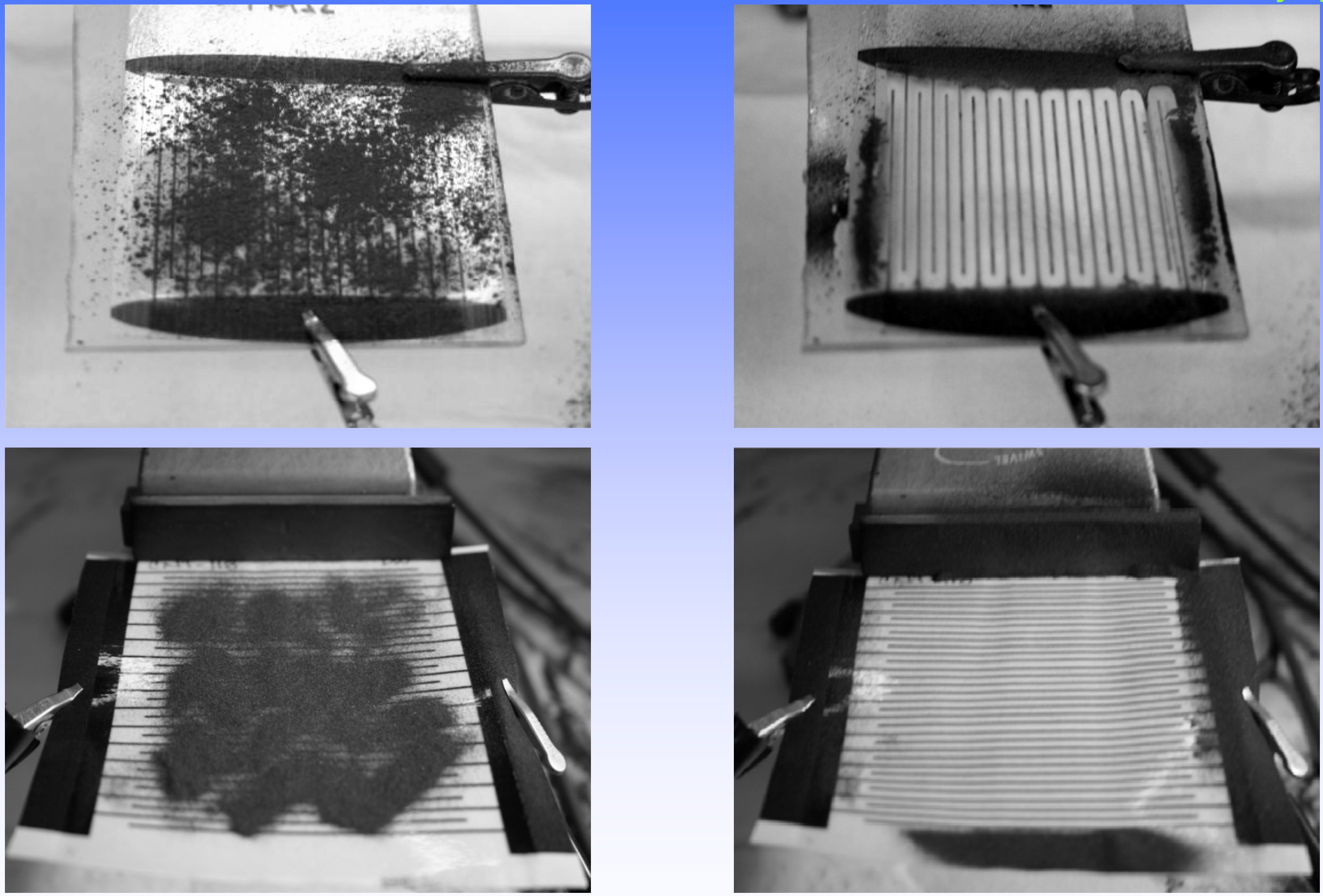

- Before and after photographs of a dust shield on fabric with JSC-1A, 50-75 µm lunar simulant in air

Purpose of Experiment

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- Demonstration of Electrodynamic Dust Shield at
  - High vacuum
  - Lunar gravity on Reduced Gravity Flight
    - Over 120 experiments
      - JSC 1A simulant
      - Apollo 16 samples
- Used LaRC vacuum chamber

Reduced Gravity Experiments

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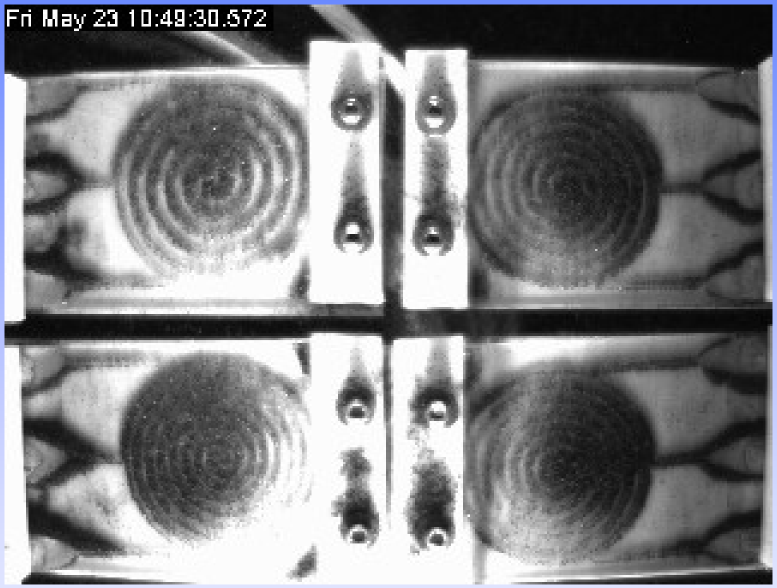

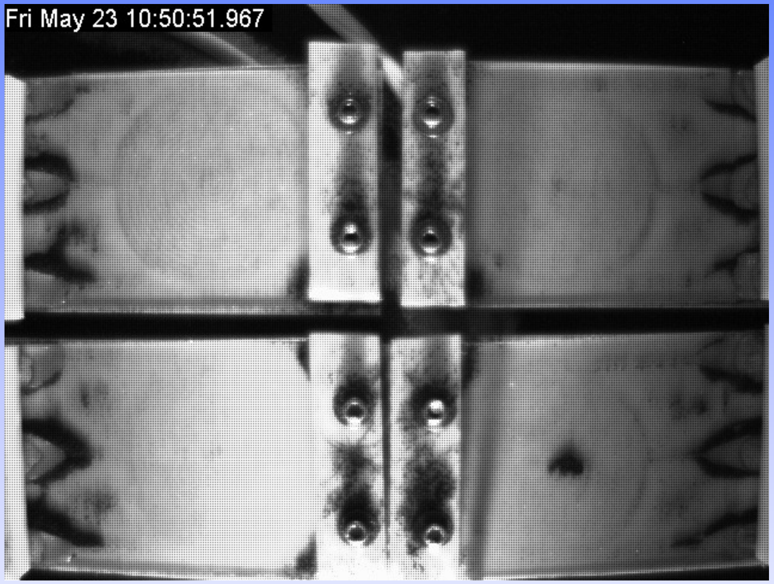

- Before and after stills of four transparent dust shields in one of the boxes used in RGF 1. Sample size: 50-100 μm

Removal of JSC-1A (<10μm)

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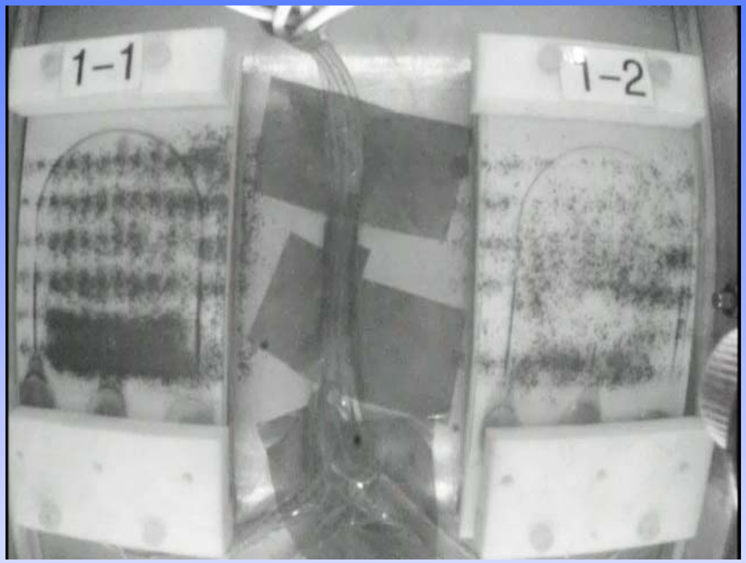
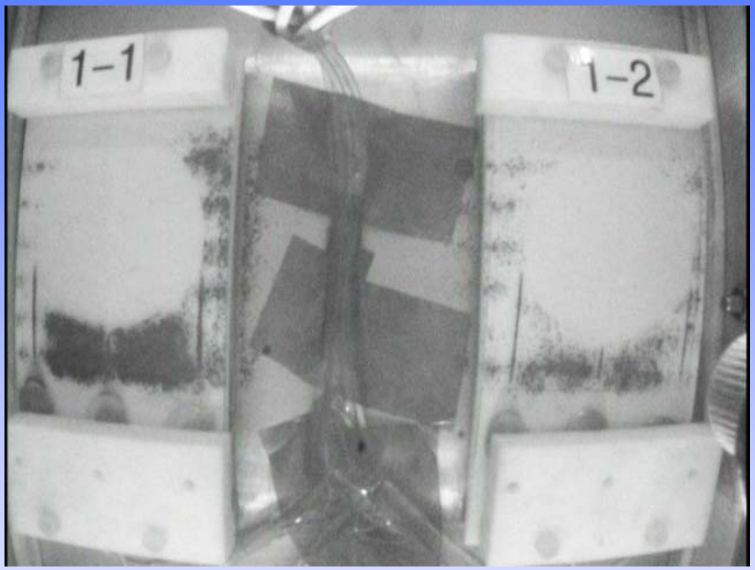
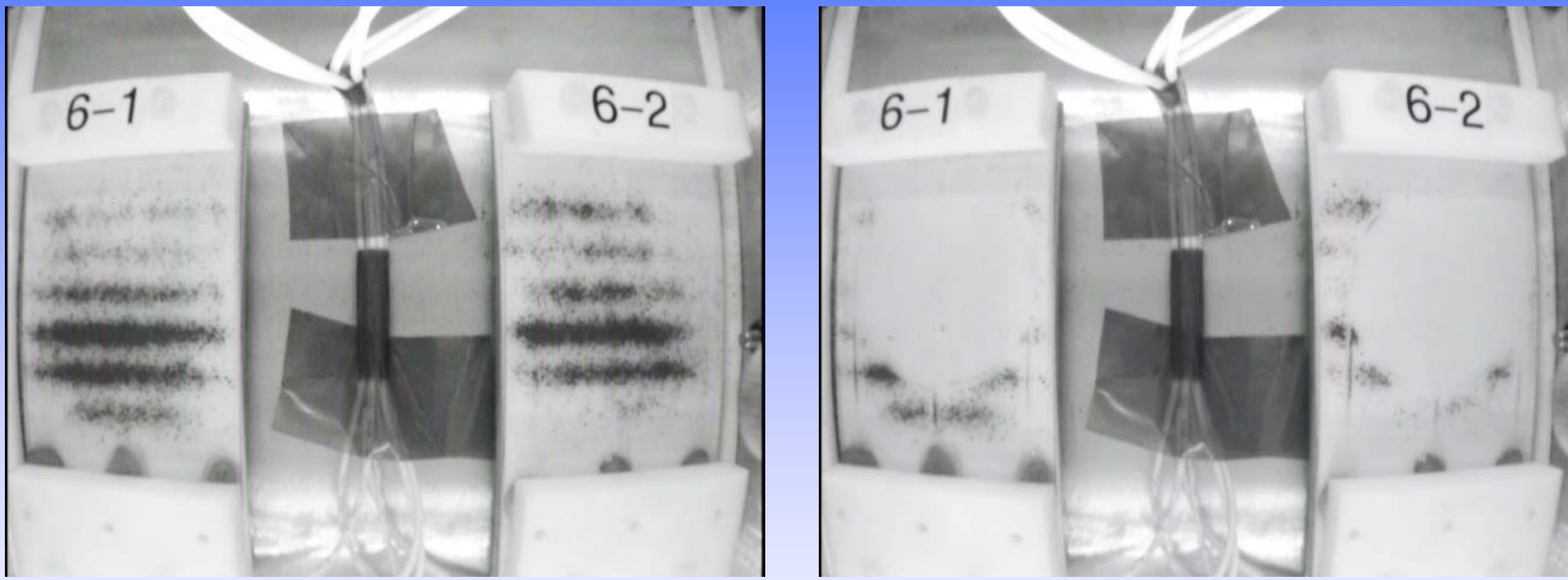




- Before and after stills of one of the boxes with JSC-1A (<10 μm fraction)
- Experiment performed during RGF 2 at $^{1}/_{6}$ g and at 10^{-6} kPa

Removal of Apollo 16 Sample



- Before and after stills of Apollo 16 sample removal
- Experiment performed at $^{1}/_{6}$ *g* and at 10^{-6} kPa

RGF flights

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EDS for RESOLVE

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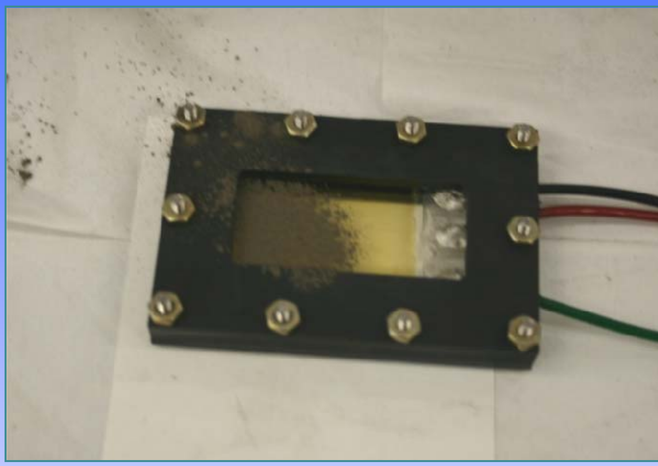

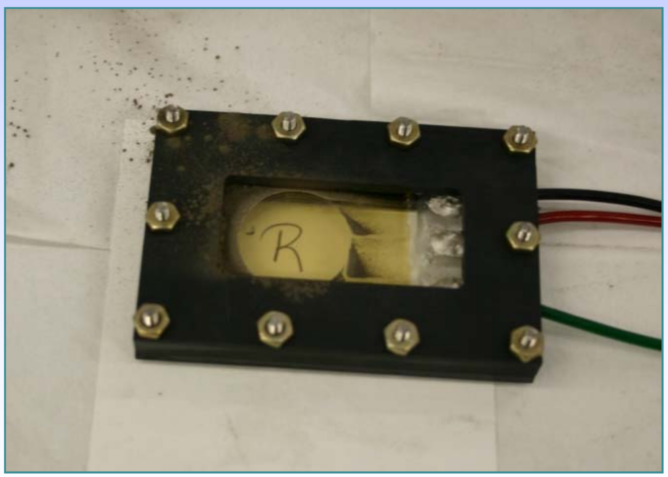

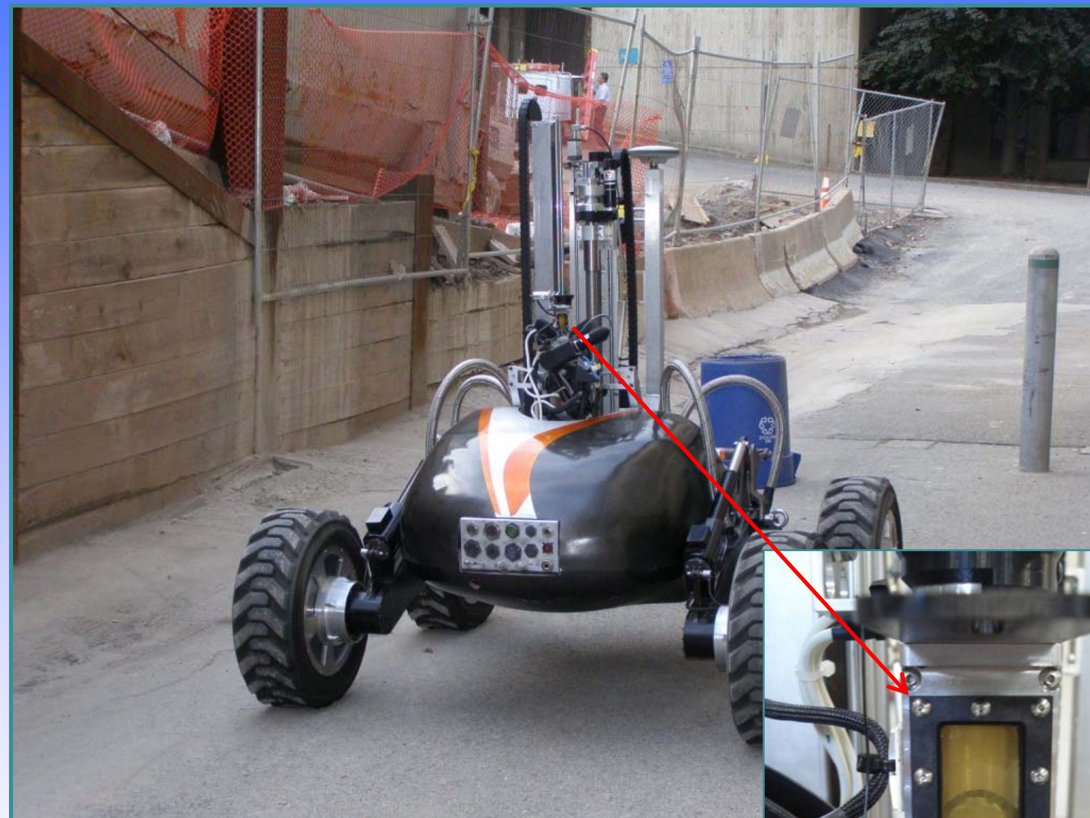

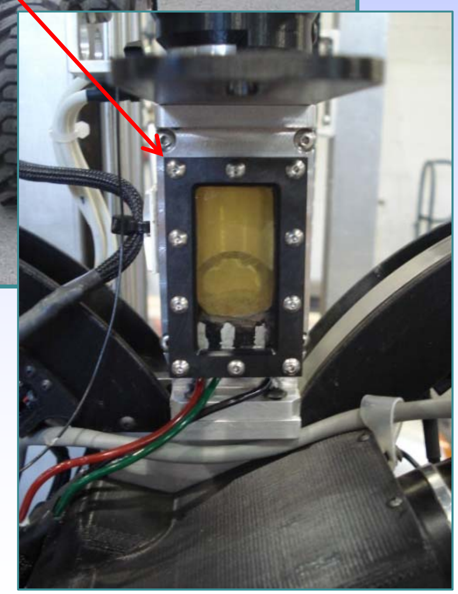

Spiral EDS mounted on RESOLVE rover

Space food

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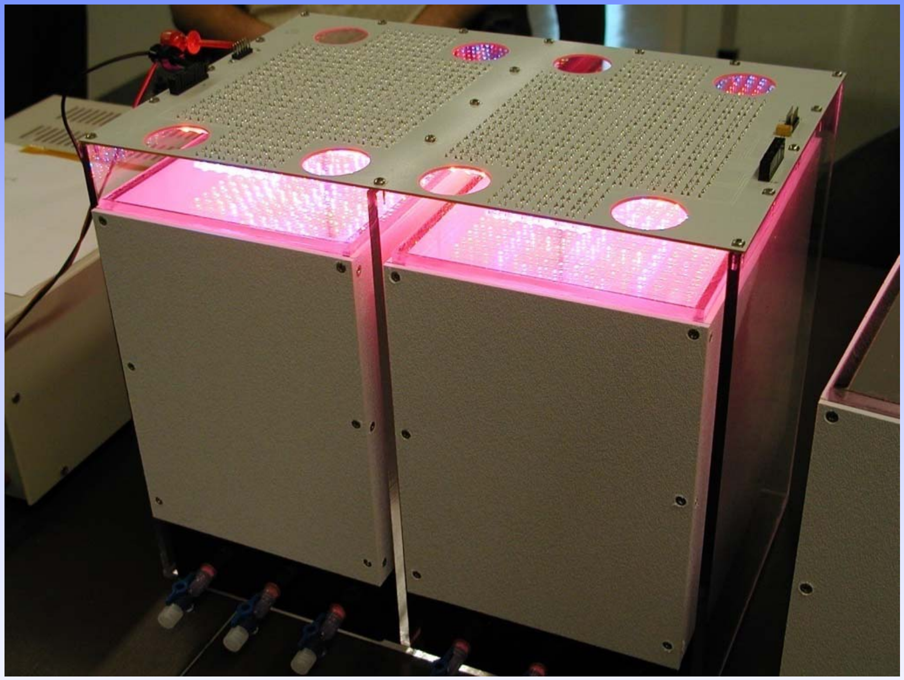

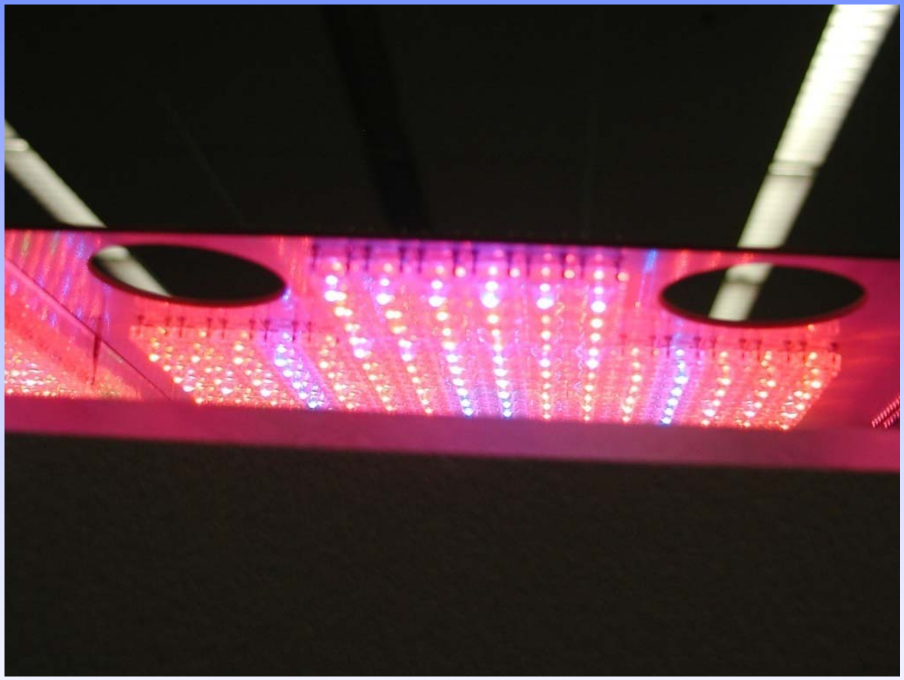

Plants growing under red and blue LEDs

Plants for space habitats

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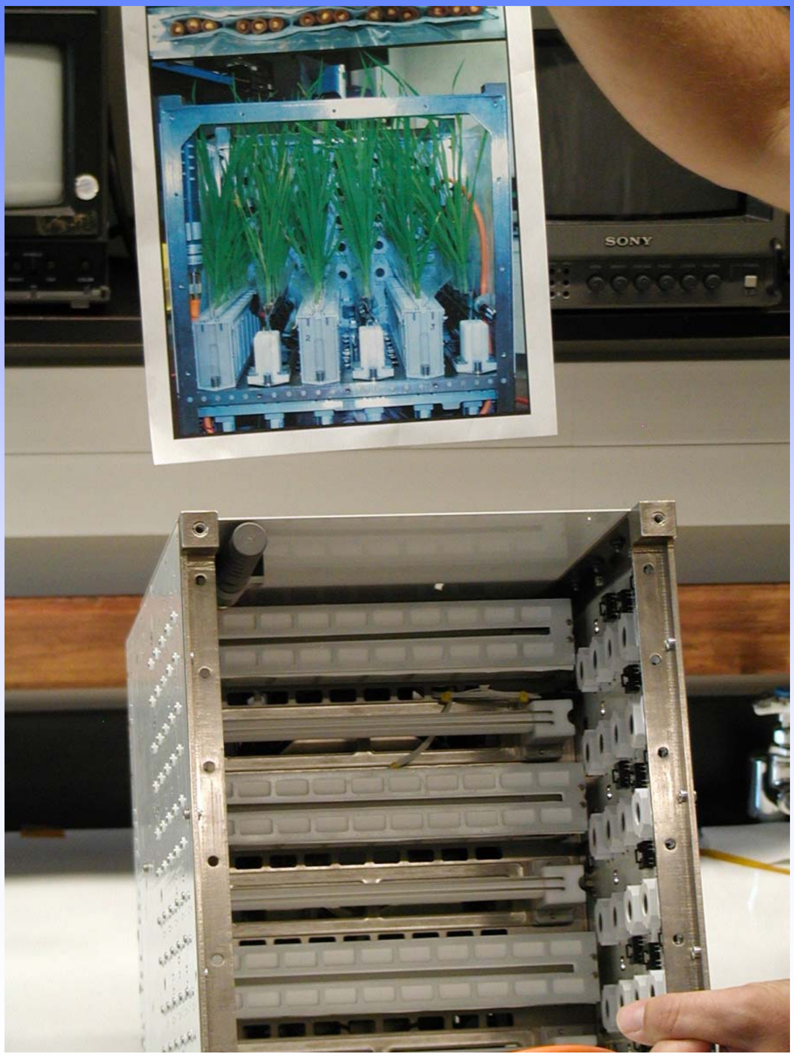

Plants growing under various environments


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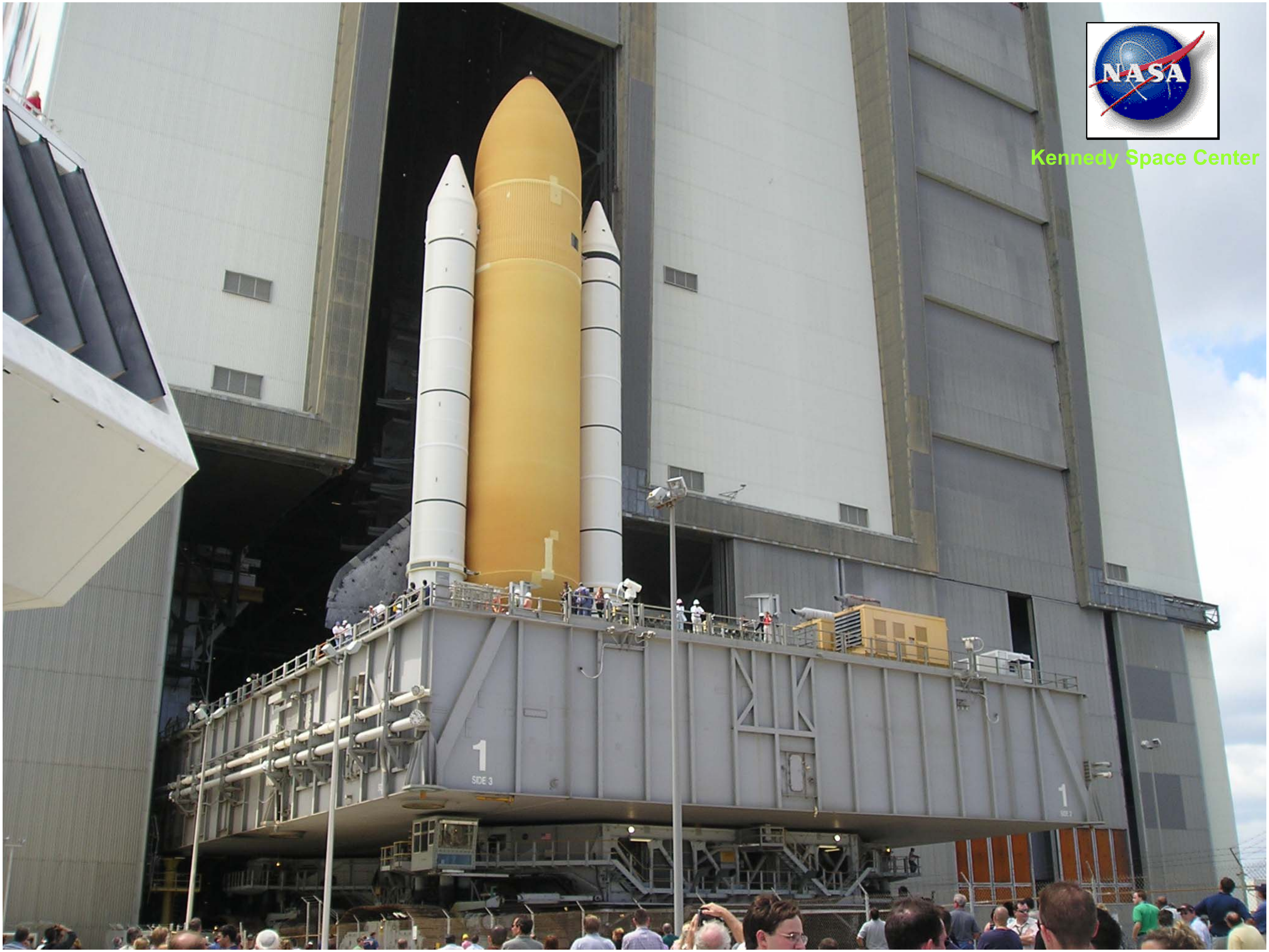
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