Low Velocity Dust Impacts on the Lunar Meteoroid Monitor

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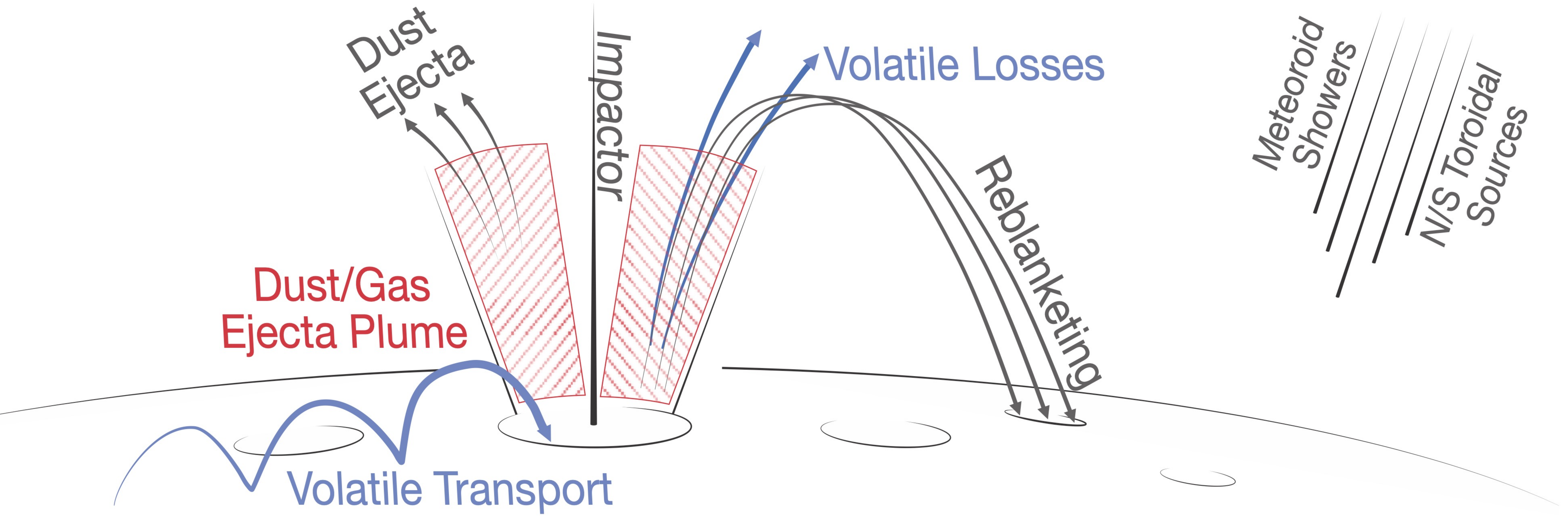
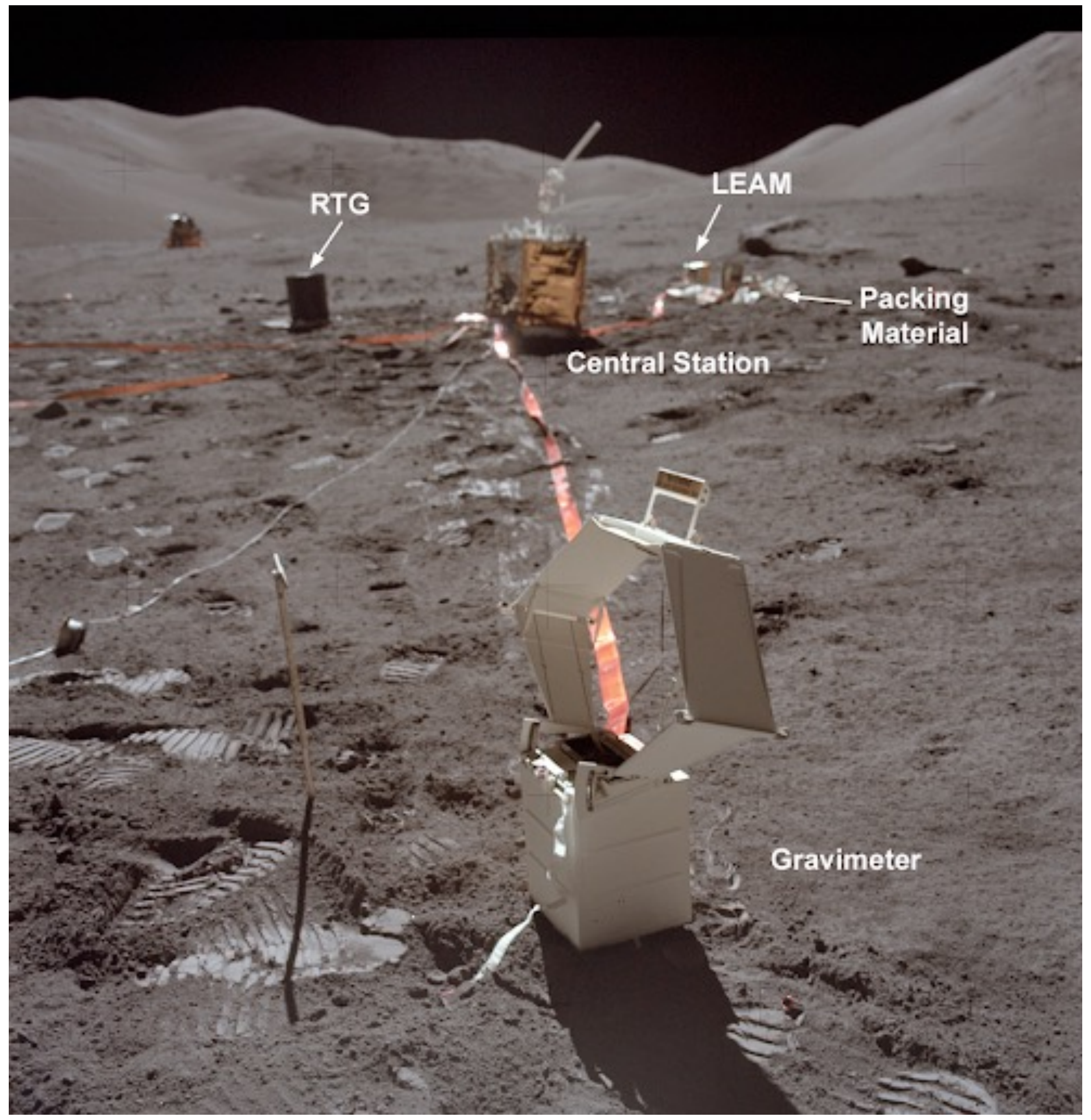
IMPACT

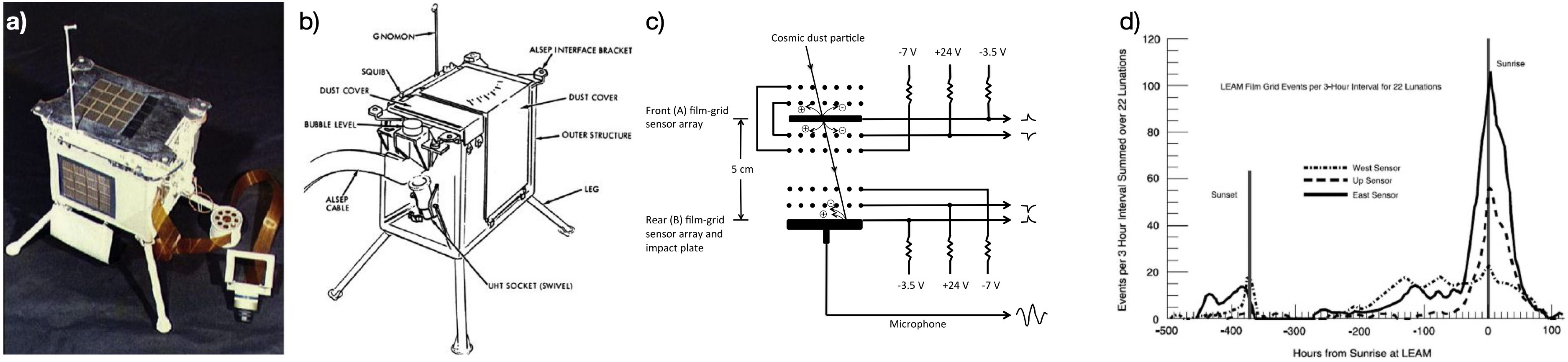
Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**



Meteoroid impacts contribute to sustaining the dilute lunar exosphere, mobilizing and transporting volatiles, and limiting their accumulation in permanently shadowed polar regions.

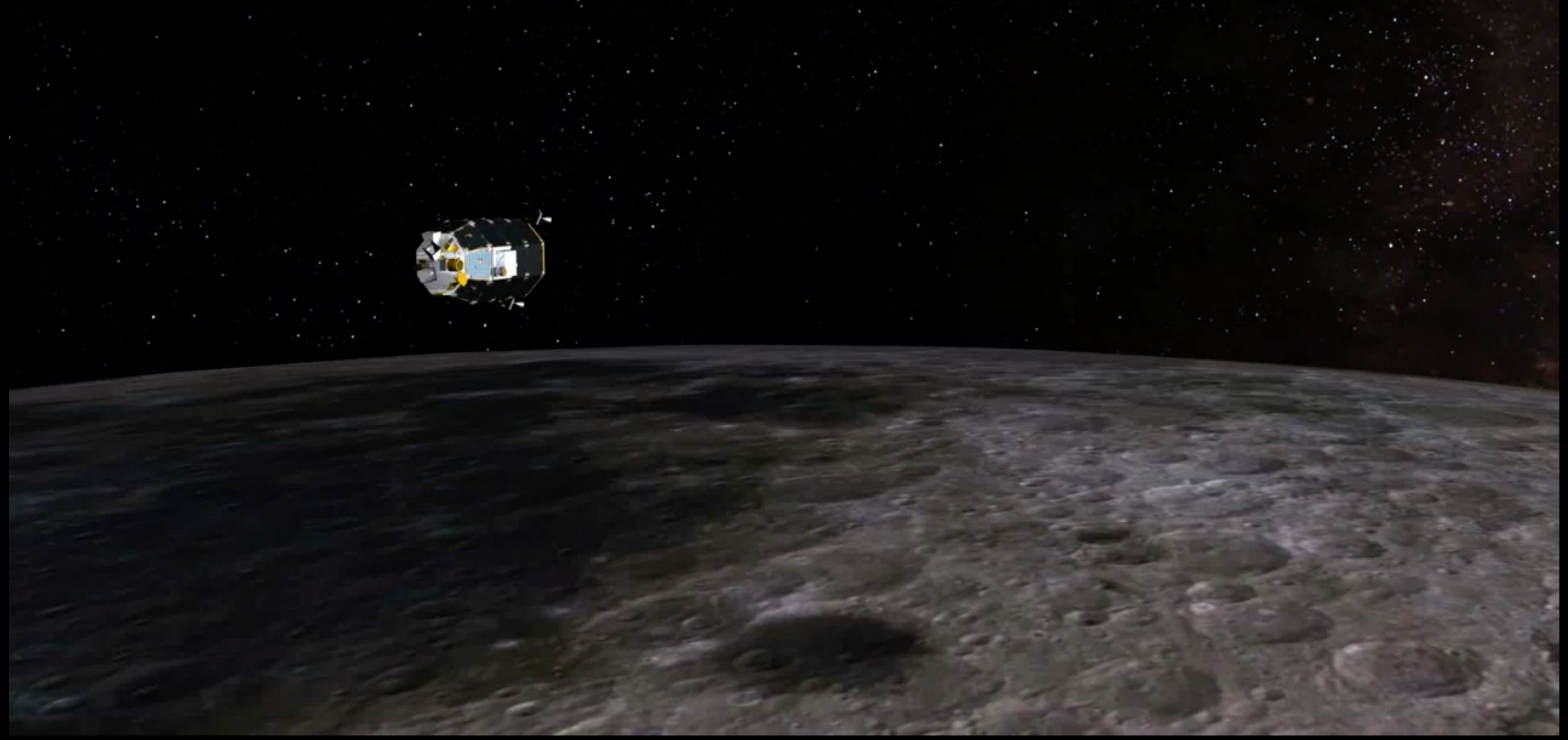
Apollo 17 Lunar Ejecta and Meteorites (LEAM) Experiment

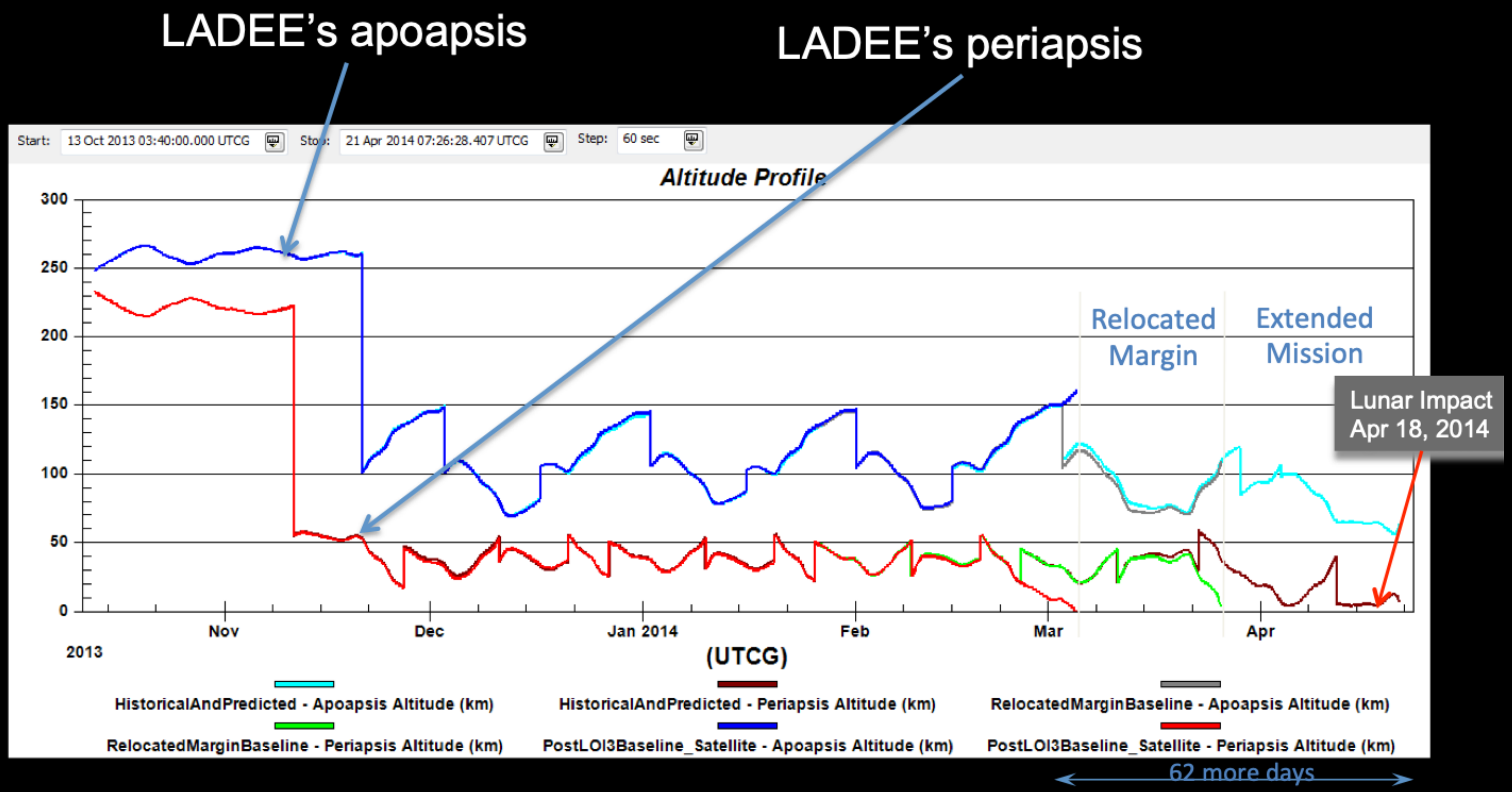




Berg et al., 1976

Lunar Atmosphere and Dust Environment Explorer
9/2013 - 4/2014

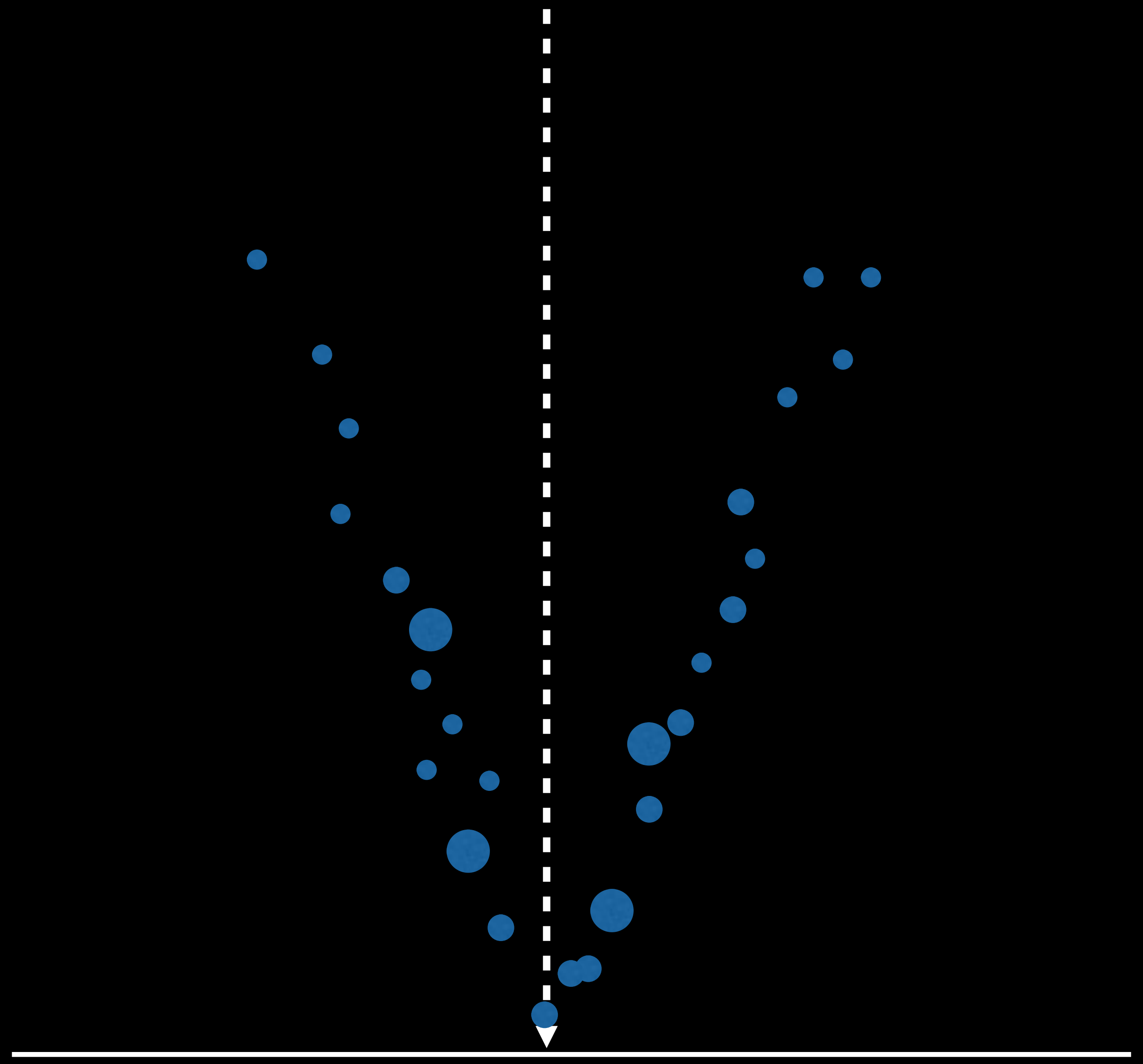


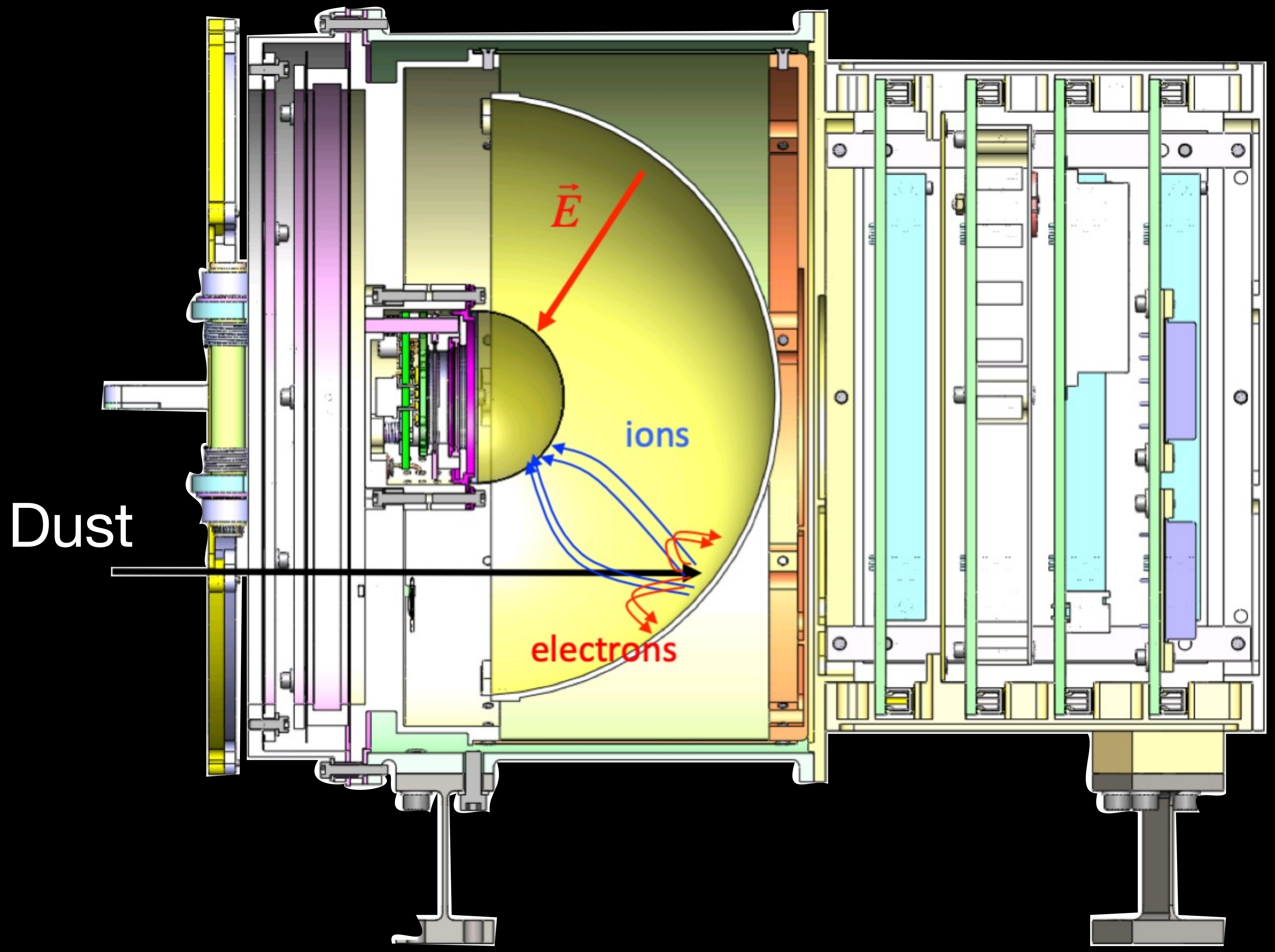


30 Apr 2014

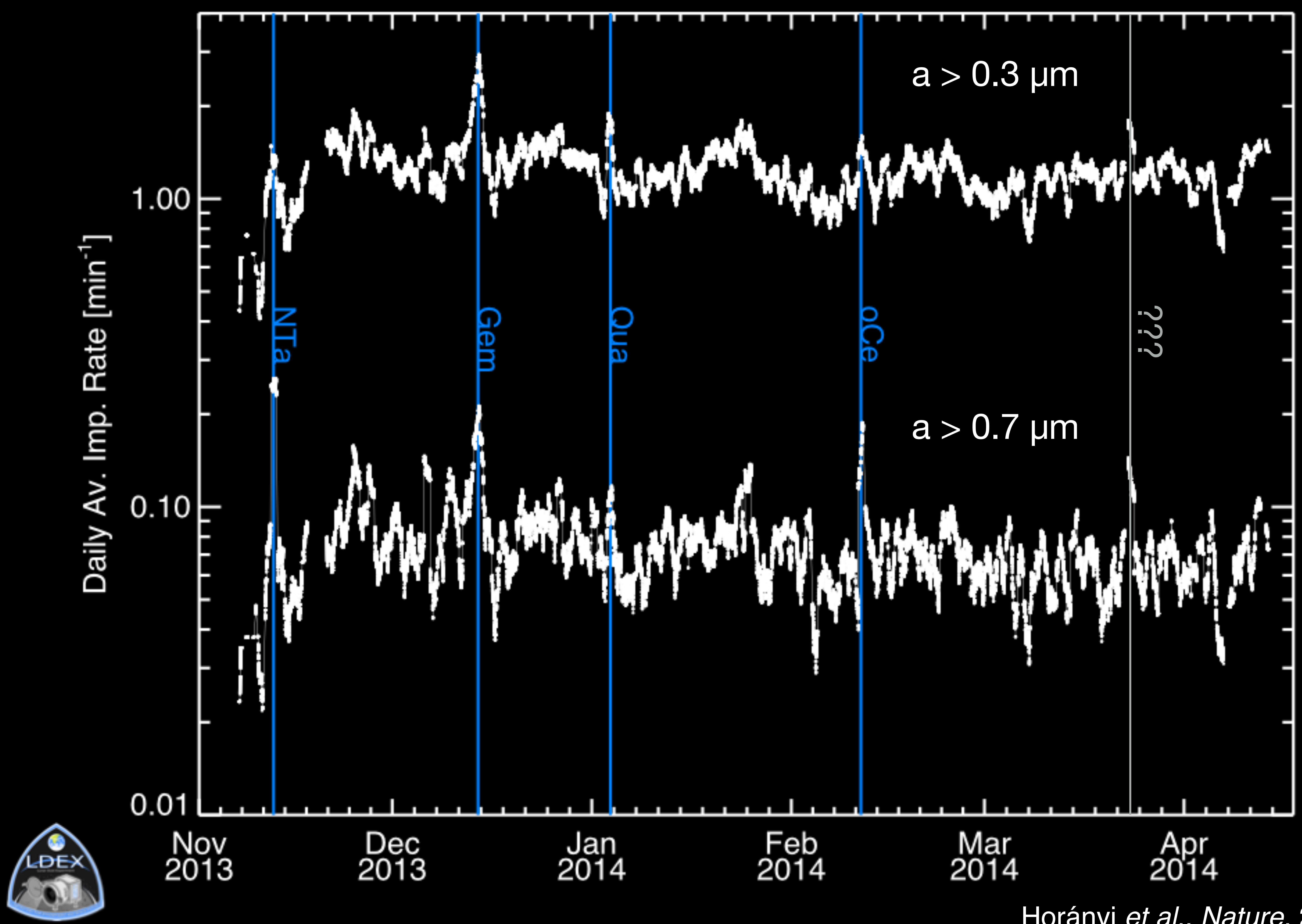
EGU 2014

NASA Ames Research Center
NASA Goddard Space Flight Center



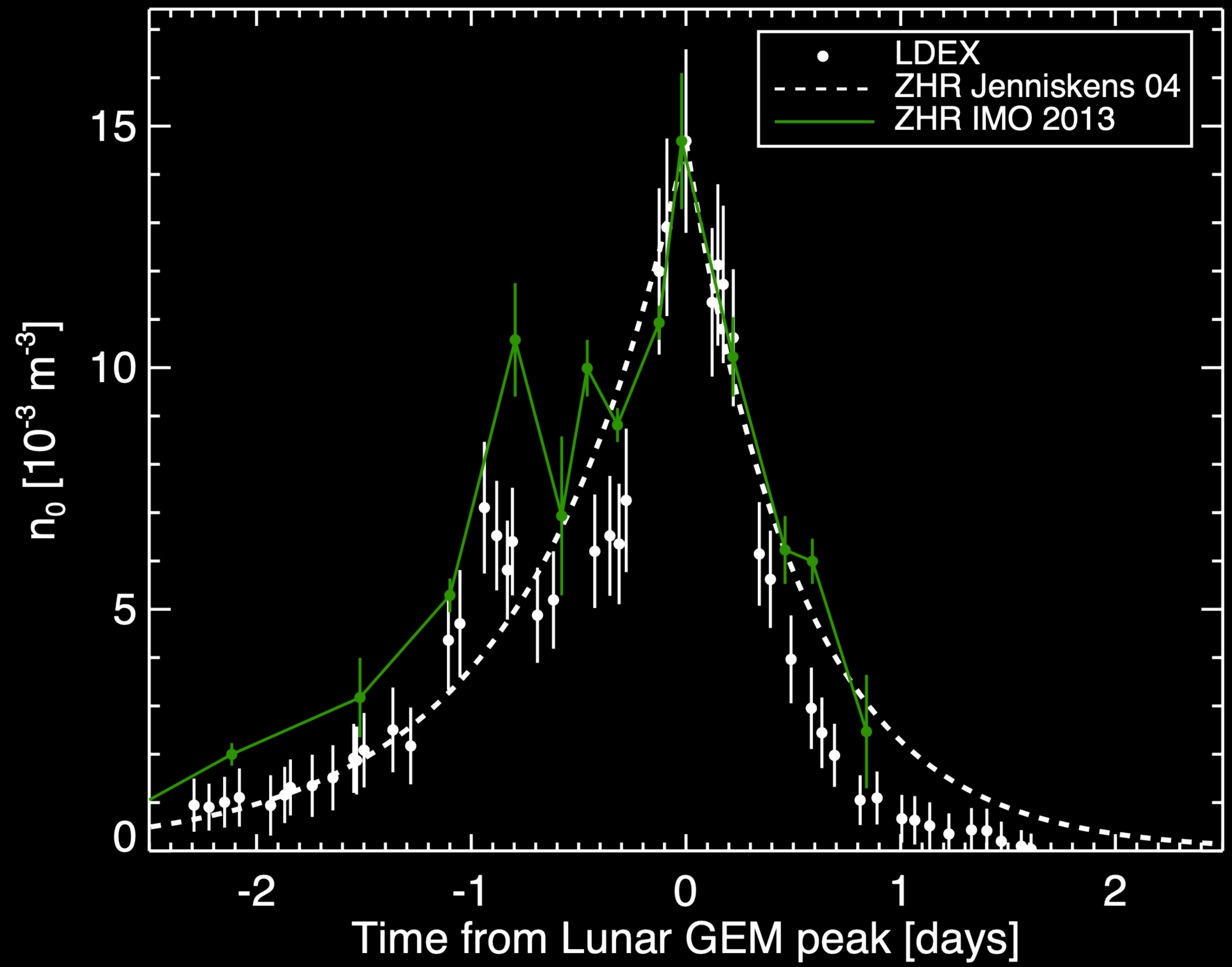


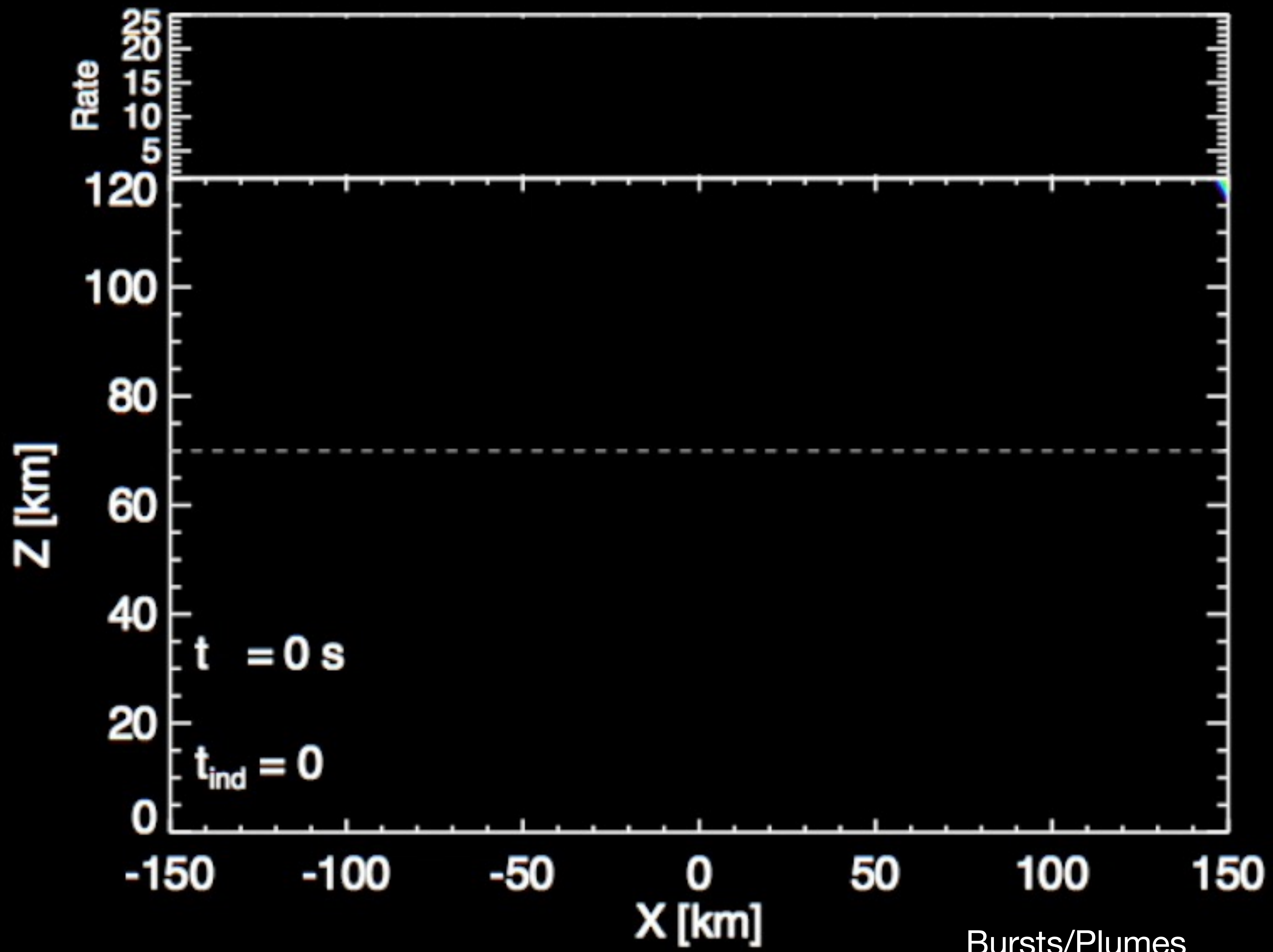
Impact Rate



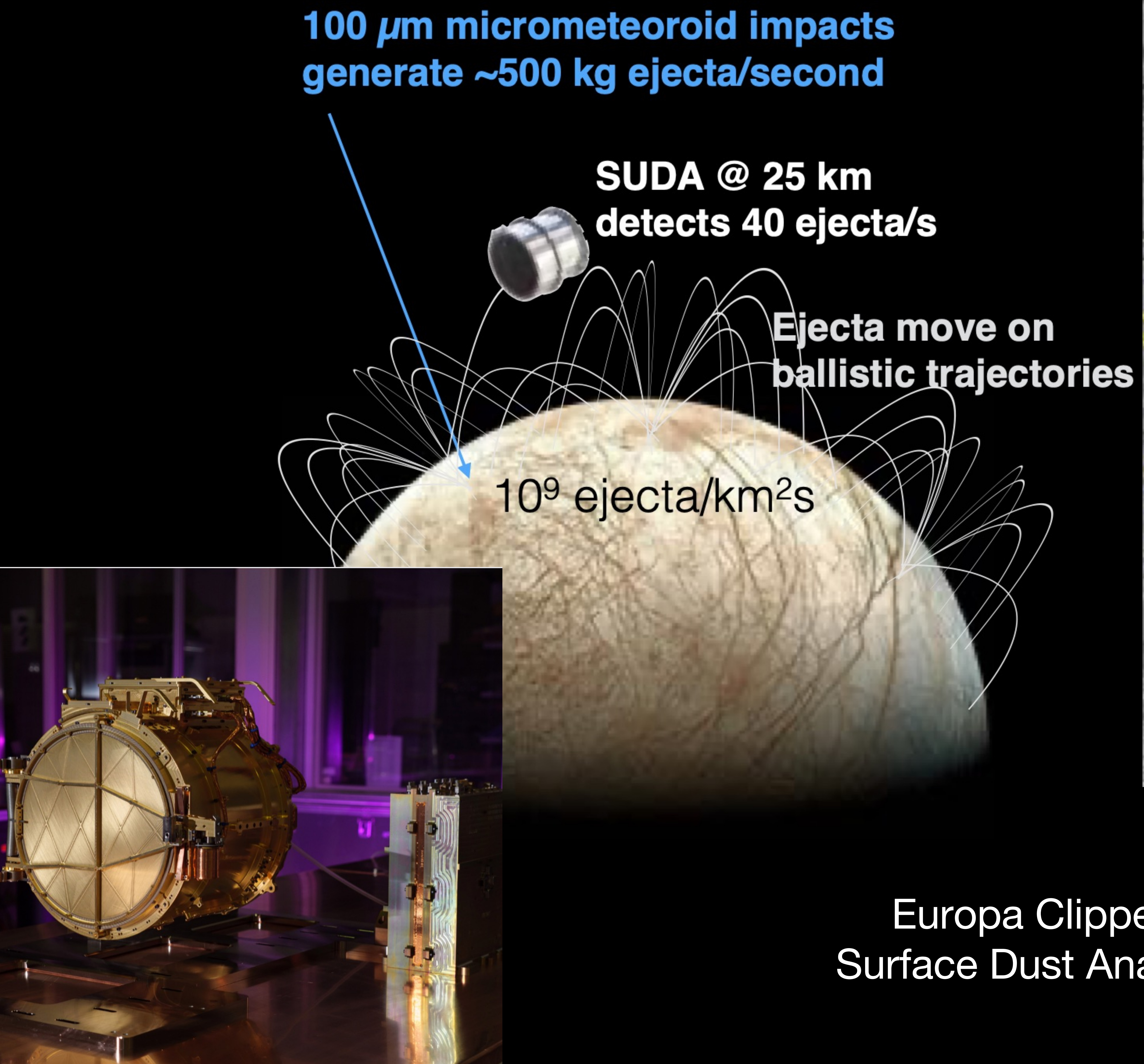
Horányi *et al., Nature,* 2015

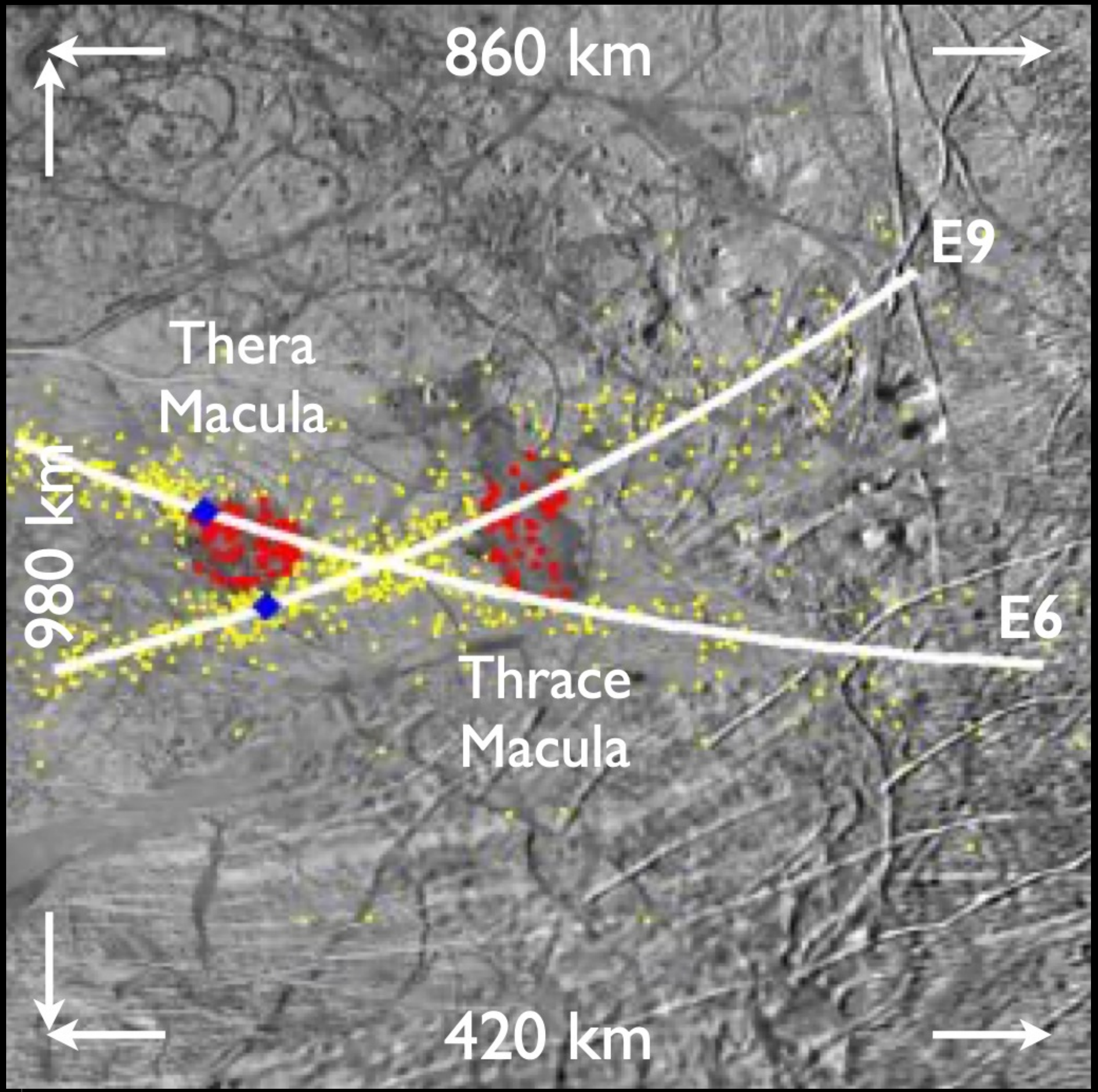
Probing the Structure of the Geminids





Bursts/Plumes

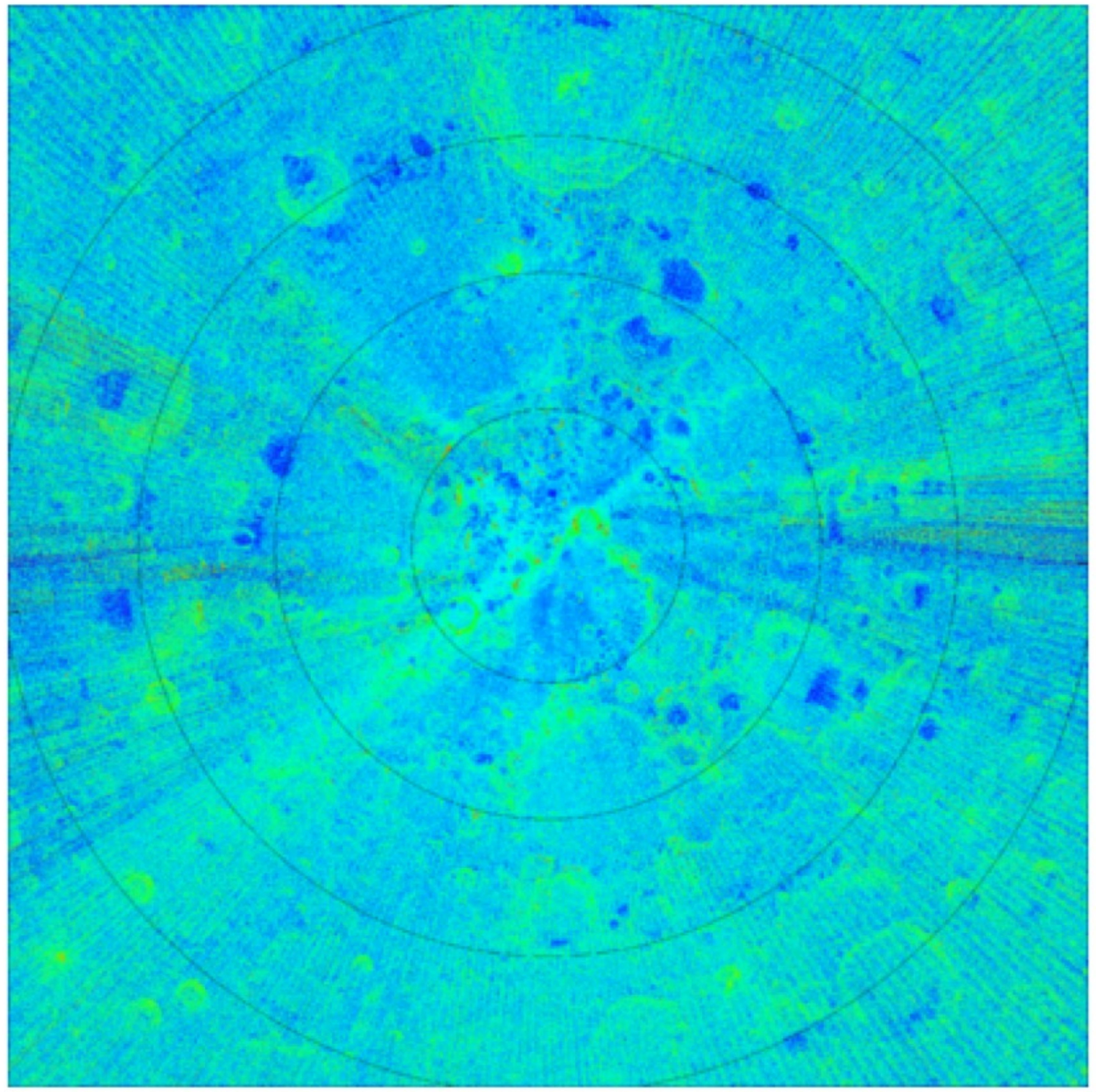




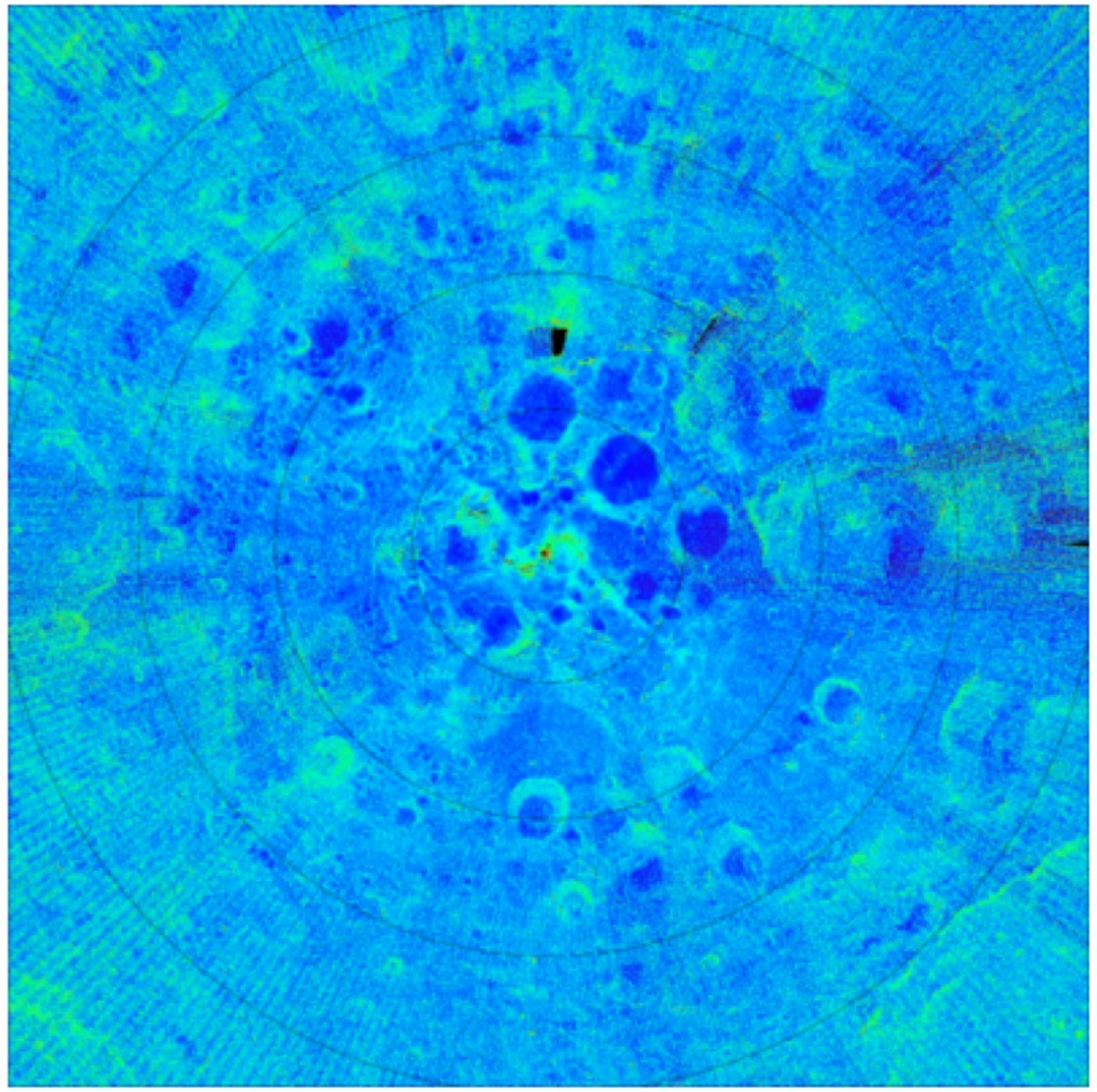
Europa Clipper Mission
Surface Dust Analyzer (SUDA)

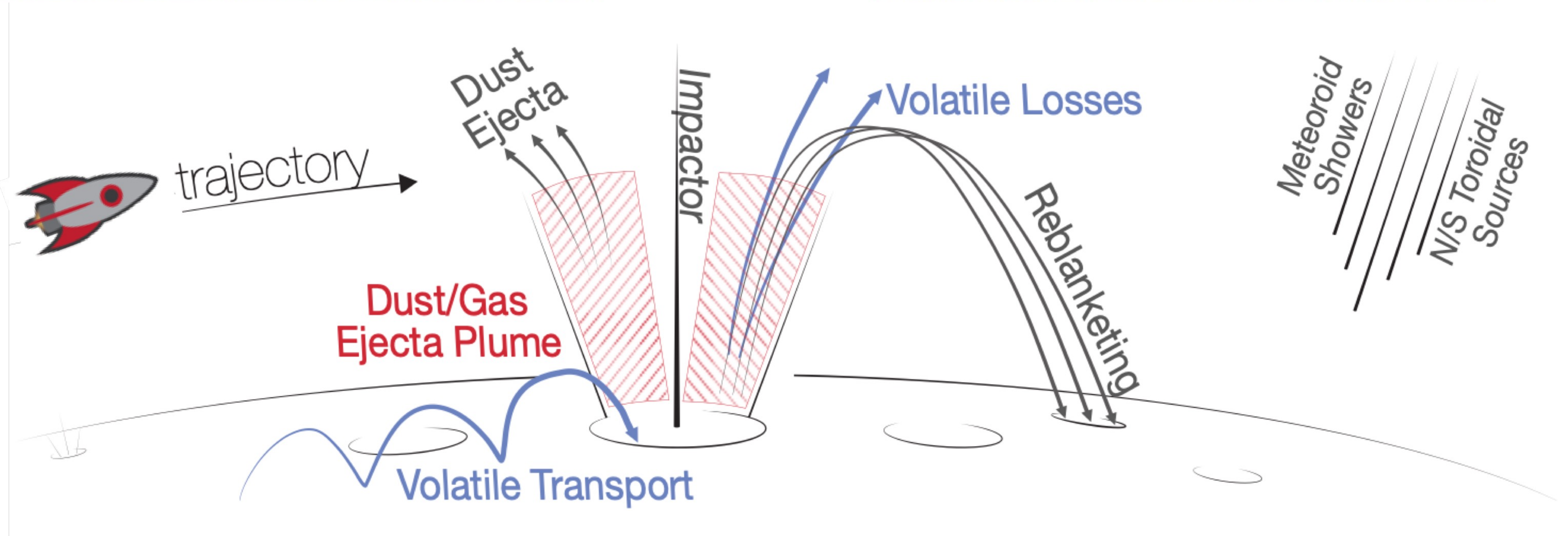

DANGER
CONFINED SPACE
KEEP OUT
UNLESS AUTHORIZED
5/10/2023

North Pole

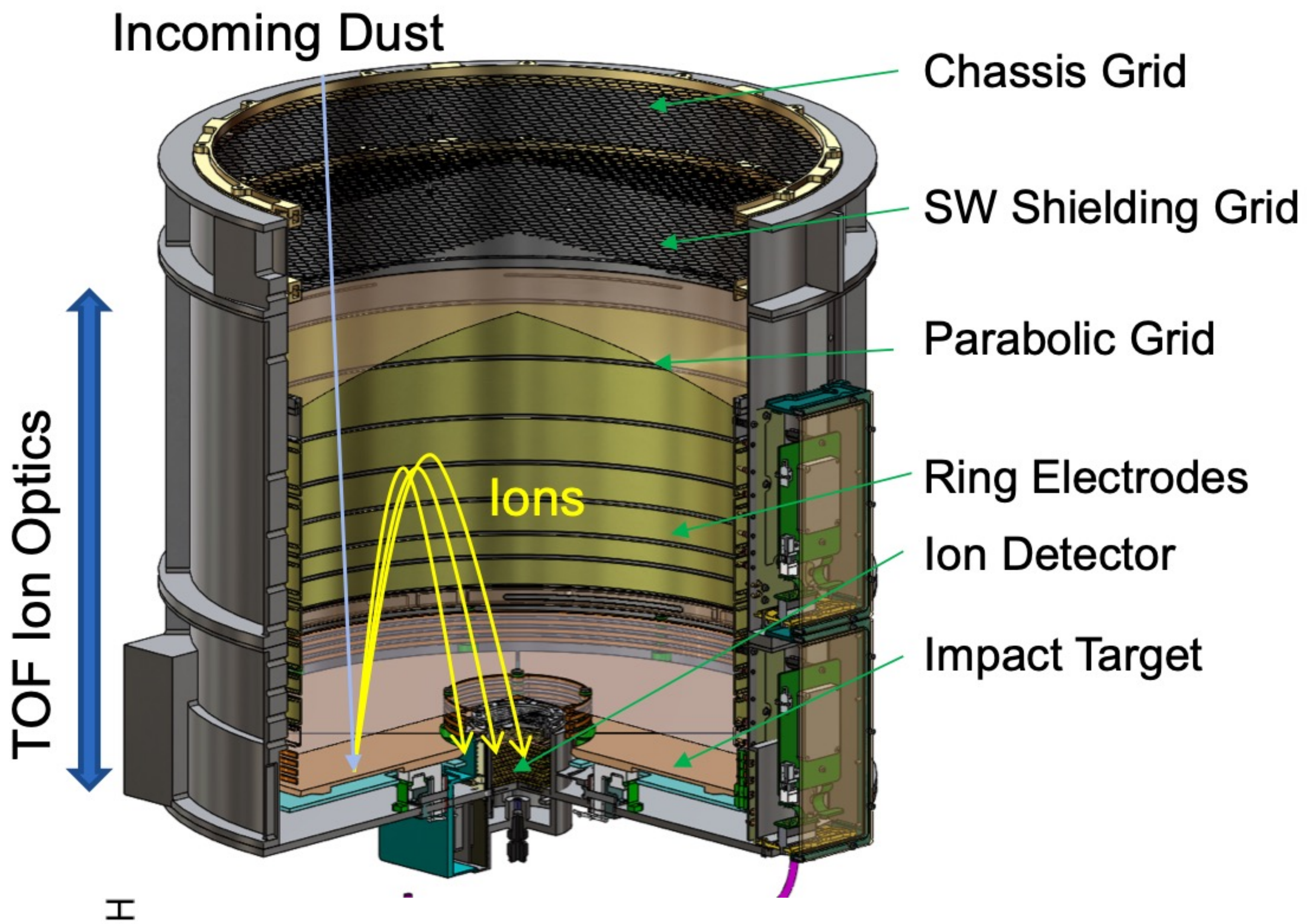


South Pole

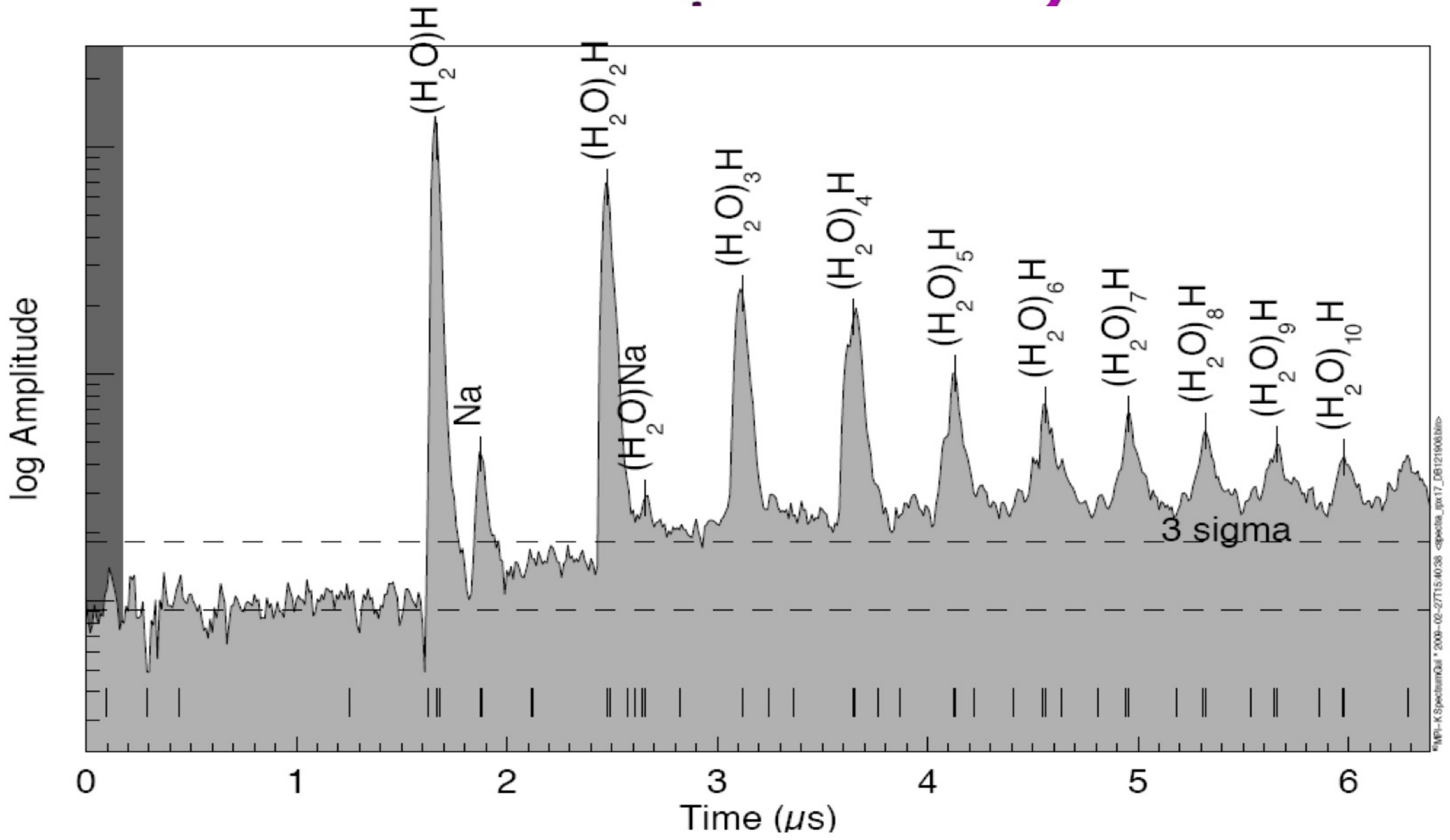


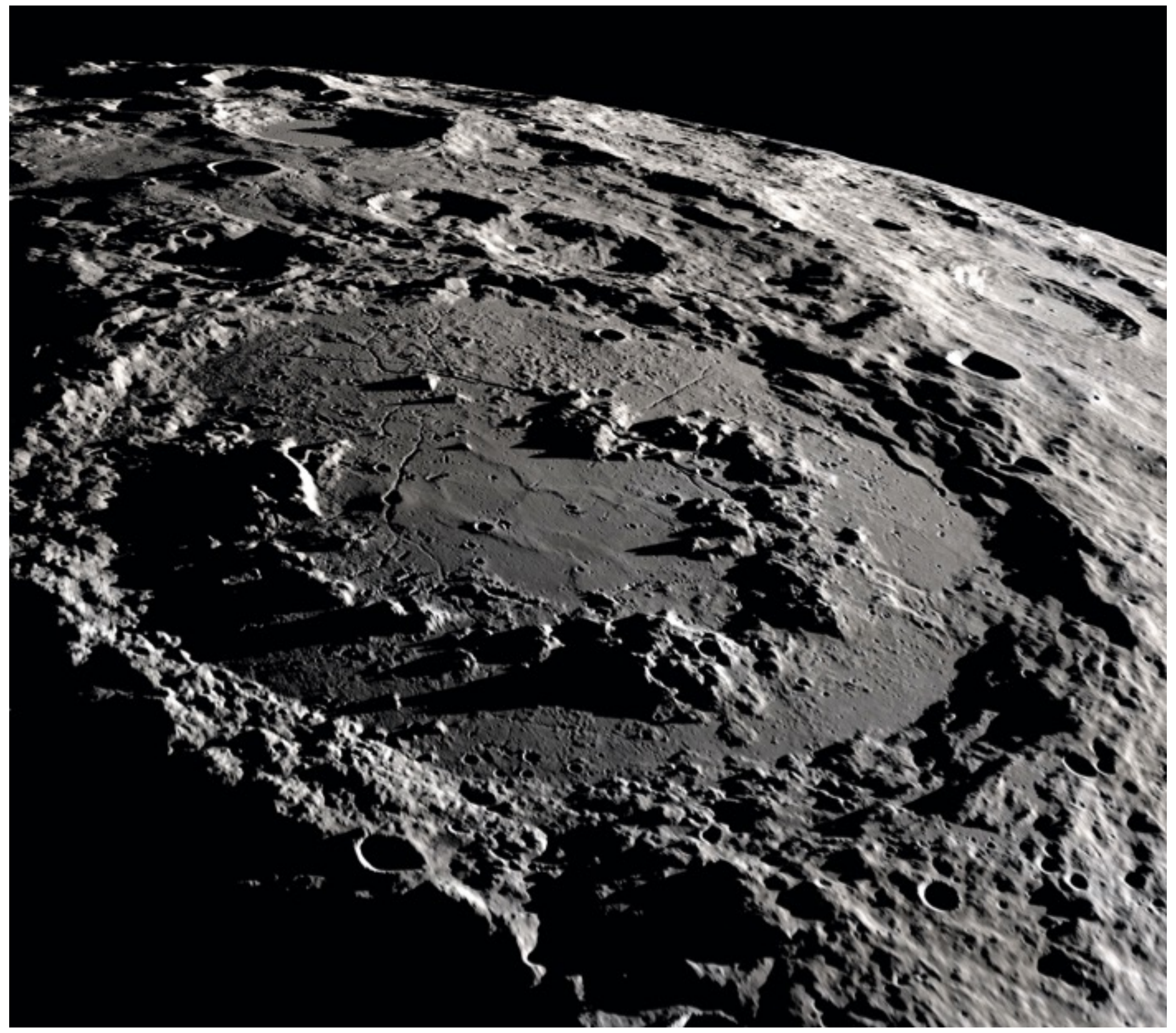


LDEX+



- **SW Shielding grid**
  - Reduces incoming SW electron flux
- **Impact target:**
  - Impact plasma generation
  - Clean target with high atomic mass
- **TOF ion optics:**
  - Spatial and temporal focusing onto detector
  - Reflectron-type ion optic design
  - High mass resolution & collection efficiency
- **Ion detector:**
  - Provides high dynamic-range

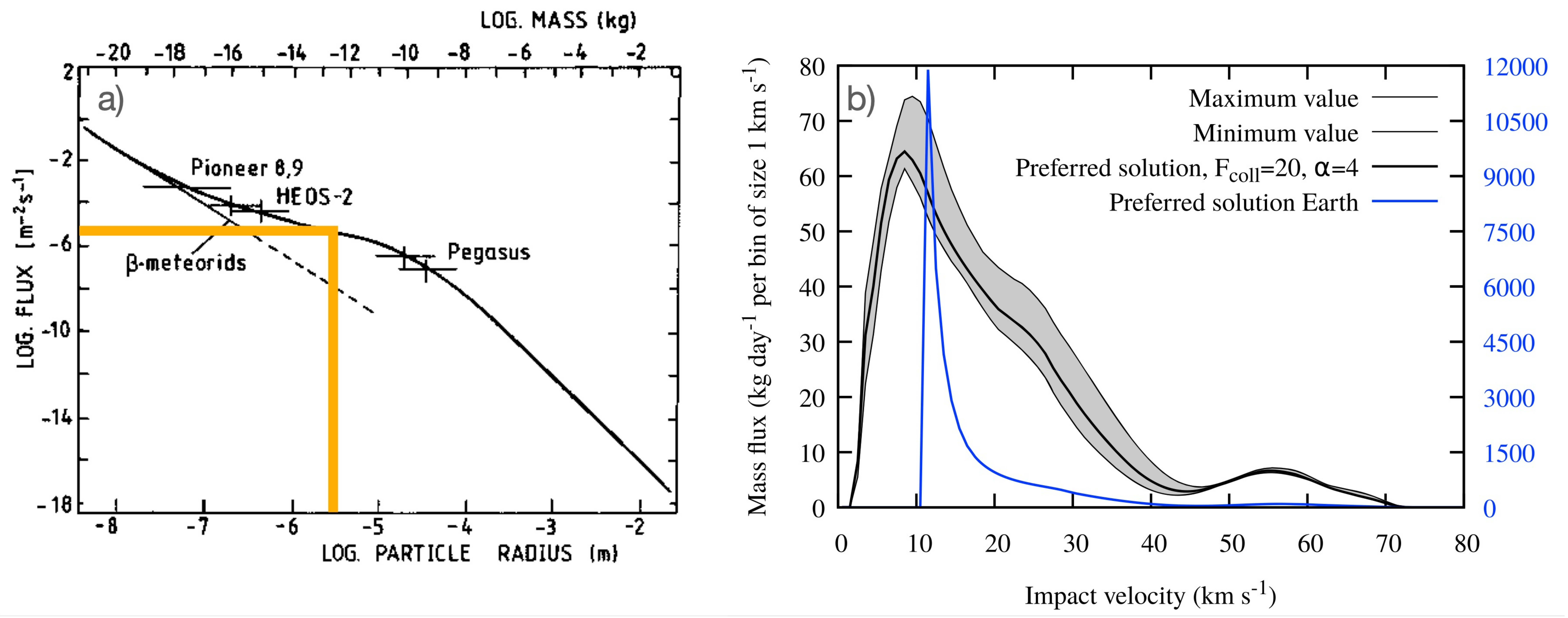




ARTEMIS Science Definition Report (2020)

Goal 6k: Study and assess effects on materials of long-duration exposure to the lunar environment—Exposure to extreme temperatures, **micrometeoroid bombardment**, and radiation affect the long-term integrity of materials on the lunar surface.

Goal 7m: Monitor real-time environmental variables affecting safe operations, which includes **monitoring for meteors, micrometeors, and other space debris** that could potentially impact the lunar surface.



a) The flux of interplanetary meteoroids at 1 AU as function of their size (mass) with the orange lines identifying that a threshold dust radius of 3 µm is expected to generate 20 particle impacts per week/m^2 (Grün et al., 1985).

b) The speed distribution, independent of the size of a meteoroid, scaled with the mass flux at the Moon (black solid line) and at Earth (blue solid line) (Pokorny et al., 2019).

Science Questions (SQ) and Objectives	LMM Requirements	LMM Performance
SQ1 Continuously monitor the meteoroid flux bombarding the lunar surface by detecting, on average, 10 fully characterized meteoroid hits a week.	**R1:** Detector area: 0.5 m^2	0.5 m^2
	R2: Duty cycle: 100%	100 %
	R3: Unobstructed FOV: π str	1.5 π str
SQ2 Measure the mass of the impacting meteoroids.	**R4:** Mass (radius) threshold @ 10 km/s 3×10^{-10} g (3 μm)	3×10^{-10} g (3 μm)
	R5: Mass resolution error factor ≤ 3	2
SQ3 Measure the speed of the impacting meteoroids.	**R6:** Speed range (uncertainty) 5 - 40 km/s (10 %)	3 - 70 km/s (10%)

NEW HORIZONS

The First Mission to the Last Planet

NASA's New Horizons is designed to help us understand worlds at the edge of our solar system—making the first reconnaissance of Pluto and its moon, Charon—and venturing deeper into the distant, mysterious Kuiper Belt.

Science at the Frontier

Pluto is the largest body in the "third zone" of our solar system known as the Kuiper Belt, populated by smaller, icy objects different from the rocky inner planets or the outer gas giants. The National Academy of Sciences named the exploration of this zone—particularly Pluto-Charon—as a high priority.

Ancient Relics

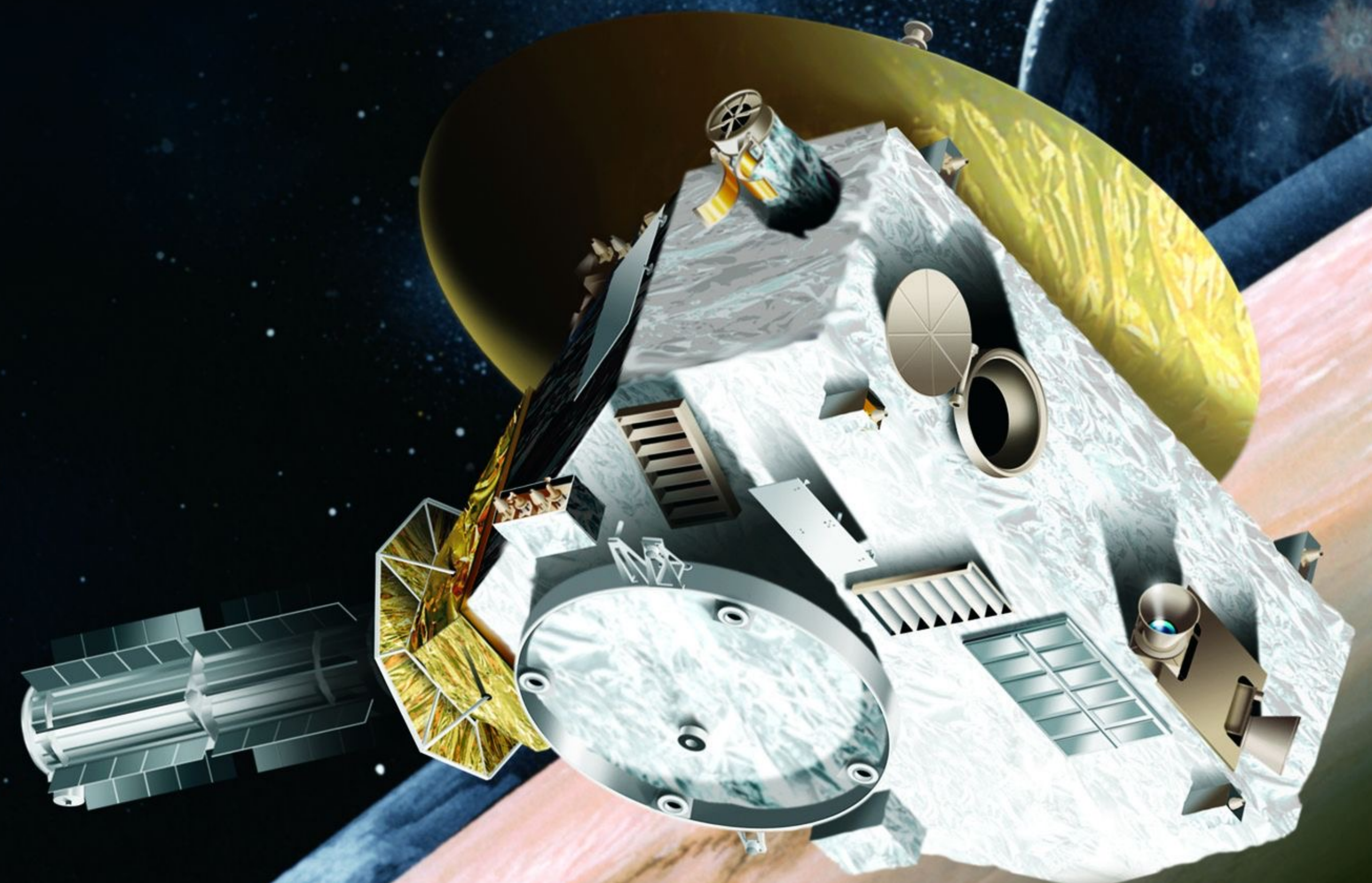
Known as "ice dwarfs," Kuiper Belt worlds are planetary embryos, ancient relics that formed more than 4 billion years ago. Because they are literally the bodies out of which the larger planets accumulated, the ice dwarfs can teach us much about planetary formation—and New Horizons plans to investigate those building blocks.

Binary Planet

Charon is half the size of Pluto; together they form a "binary planet" whose gravitational balance point is between the two bodies. Although binary planets and stars are thought to be common in the galaxy, New Horizons would be the first mission to any binary object.

Seeds of Life

The Kuiper Belt is a major source of comets. New Horizons can shed light on the number and size of such "impactors" by cataloging the various craters on Pluto, Charon and other Kuiper Belt Objects. Those objects are known to contain organic molecules and water ice—the raw materials out of which life evolves. New Horizons seeks to explore the composition of this material on the surfaces of Pluto, Charon and Kuiper Belt Objects.



Pluto's Atmospheric Escape

Pluto's atmosphere is escaping to space like a comet—but on a planetary scale. Nothing like this exists anywhere else in the solar system. Scientists believe Earth's original hydrogen/helium atmosphere was lost to space this way. By studying Pluto's atmospheric escape, we can learn a great deal about the evolution of Earth's atmosphere.

The Need to Explore

As the first voyage to a new class of planets on the solar system's farthest frontier, New Horizons would be a historic mission of exploration. The United States is the only nation to reach every planet from Mercury to Neptune with a space probe; New Horizons would allow the United States to complete the reconnaissance of the solar system.

A Team Approach

Principal Investigator Alan Stern, director of the Southwest Research Institute (SwRI) Space Studies Department, leads a mission team that includes The Johns Hopkins University Applied Physics Laboratory (APL), Ball Aerospace Corporation, the Boeing Company, NASA Goddard Space Flight Center, NASA Jet Propulsion Laboratory, Stanford University, KinetX, Inc., Lockheed Martin Corporation, University of Colorado, Department of Energy and a number of other firms, NASA centers and university partners.

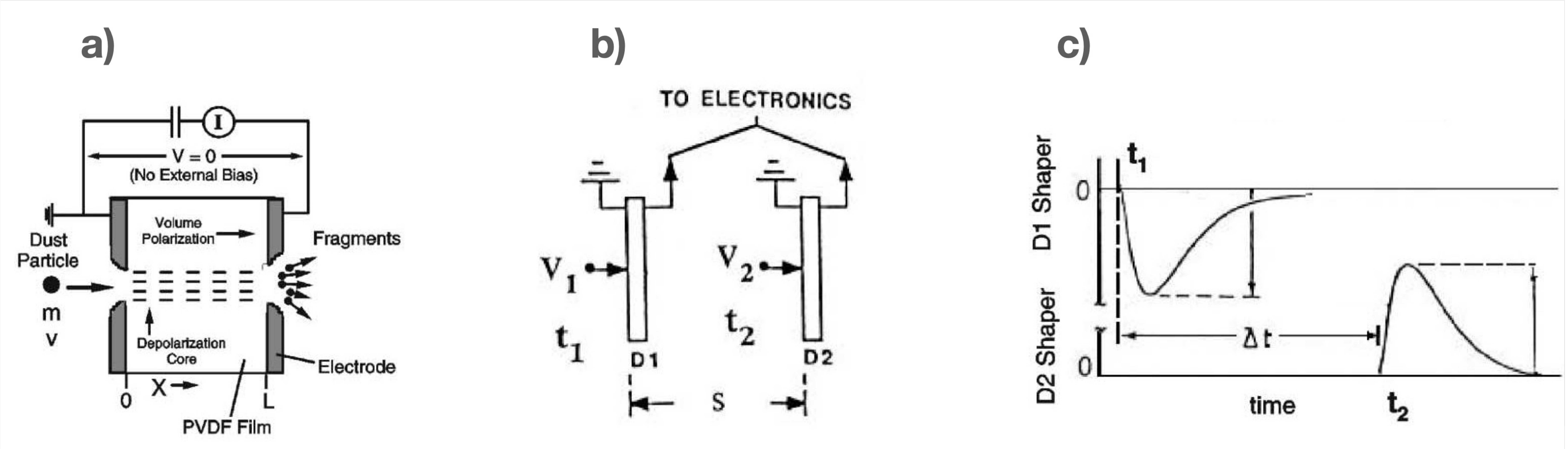
A NASA New Frontiers Mission
To learn more about New Horizons, visit
http://pluto.jhuapl.edu

NASA SwRI APL The Johns Hopkins University APPLIED PHYSICS LABORATORY

Artist's concept of the New Horizons spacecraft (baseline design) and Pluto-Charon

05-01698

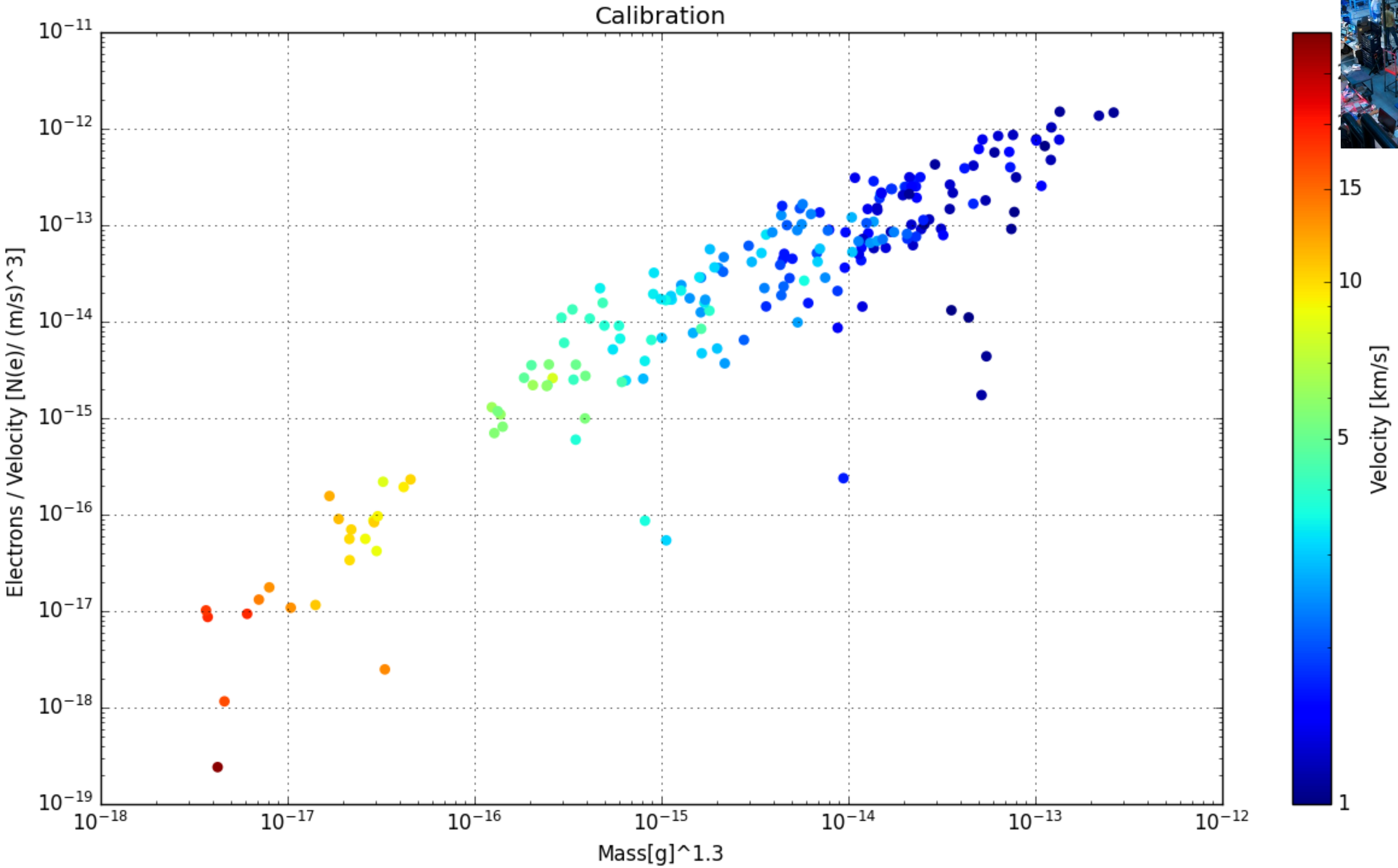
Principle of Operation

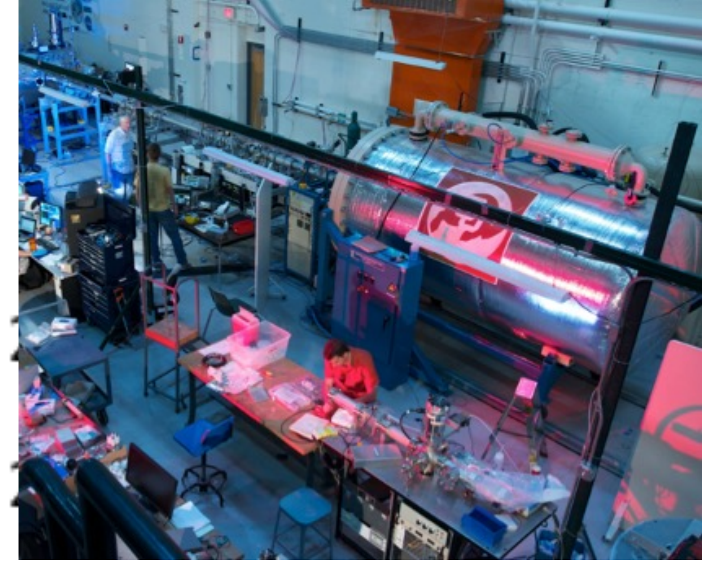


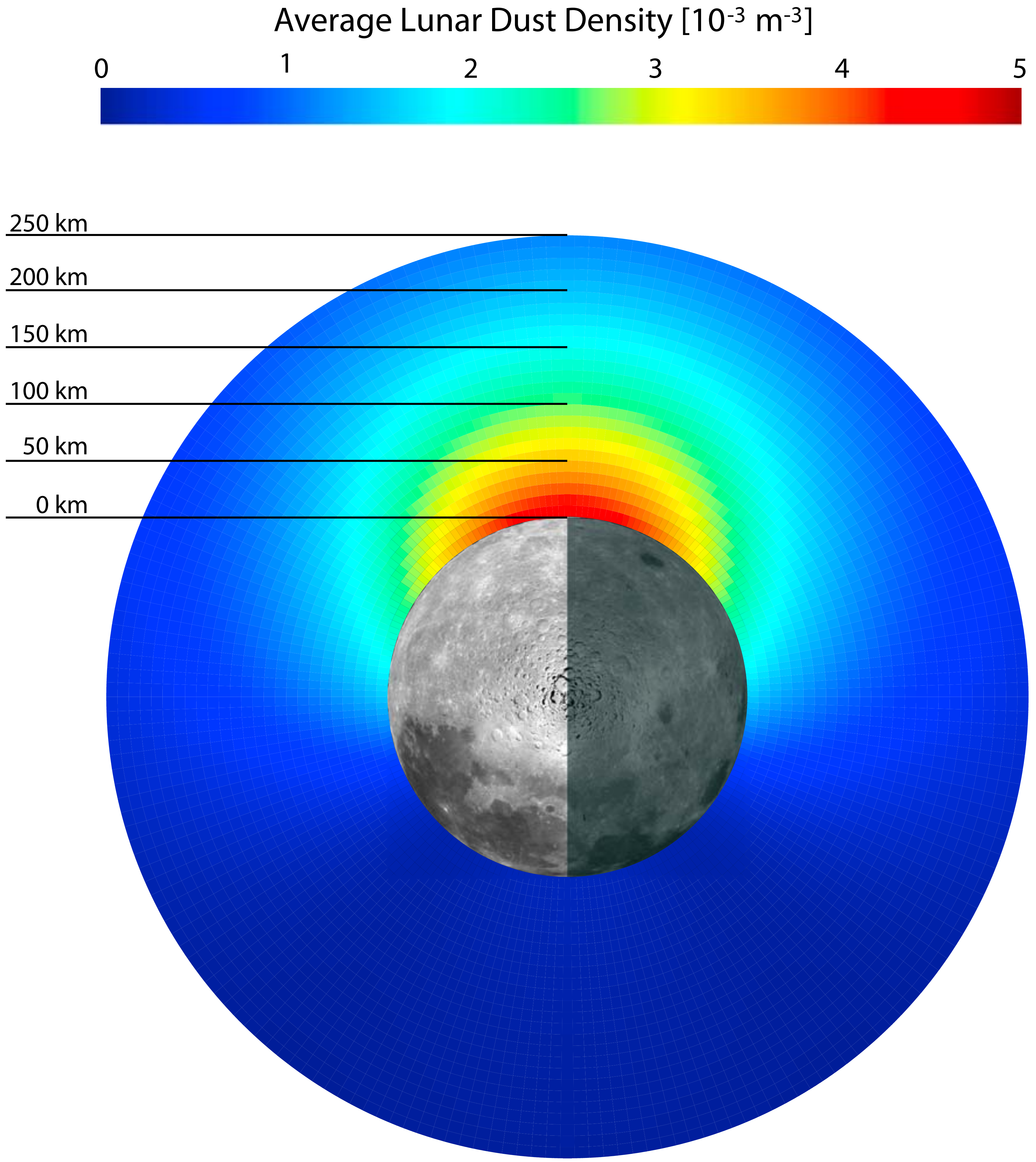
LMM is an impact dust detector that measures the speed and mass of individual particles.

It employs two thin, permanently polarized polyvinylidene fluoride (PVDF) plastic sensors that generate an electrical signal when dust particles penetrate their surface (Auer 2001 Tuzzolino et al., 2001).

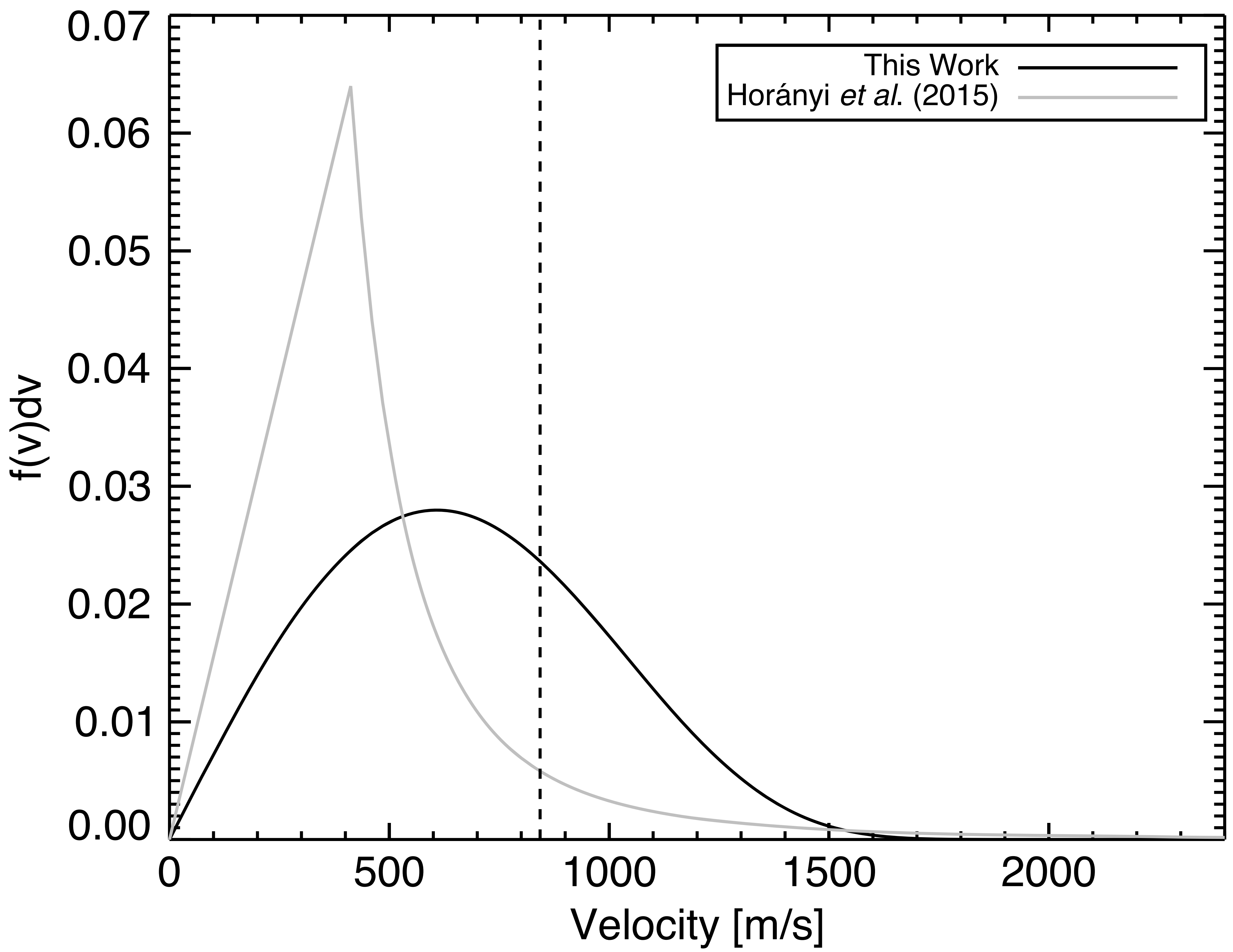
PVDF Calibrations



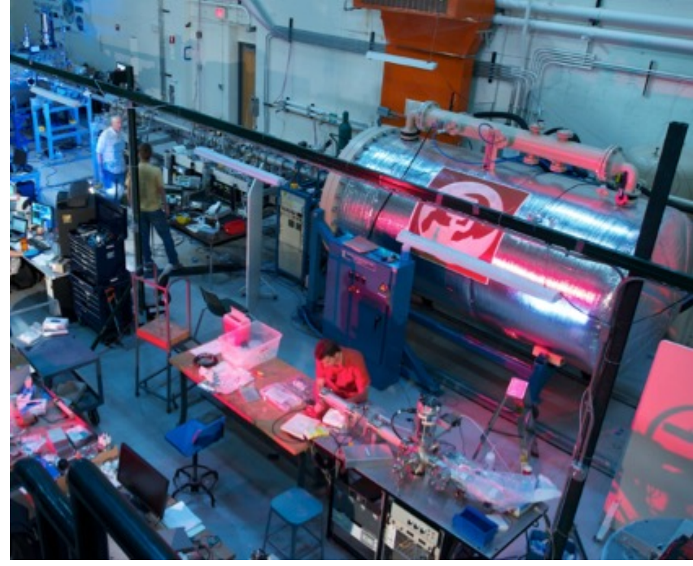


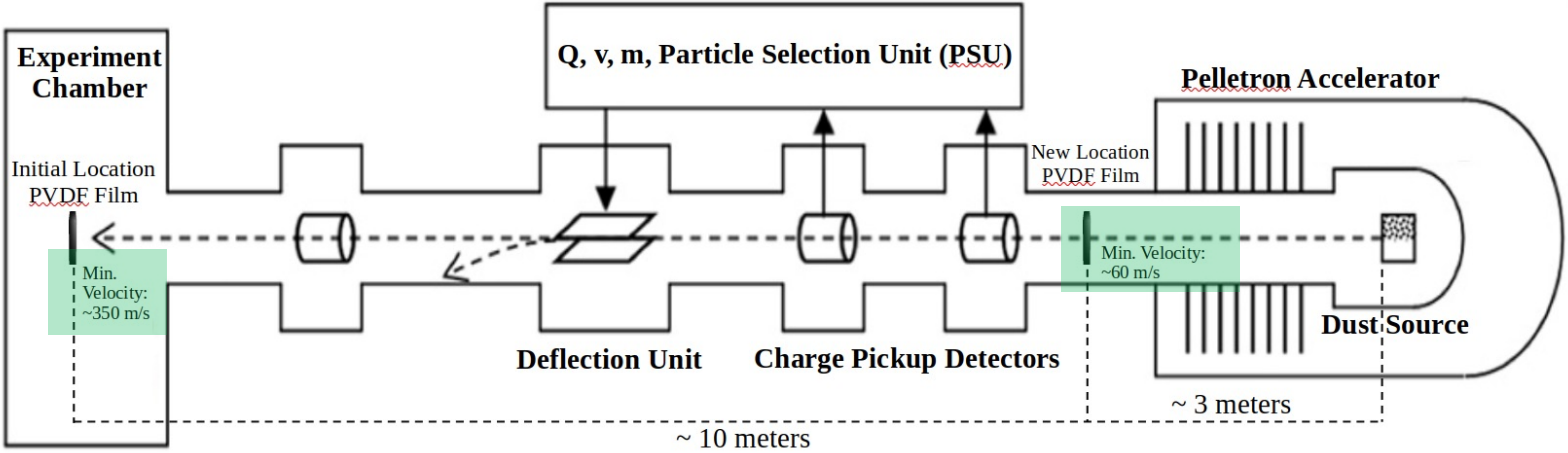


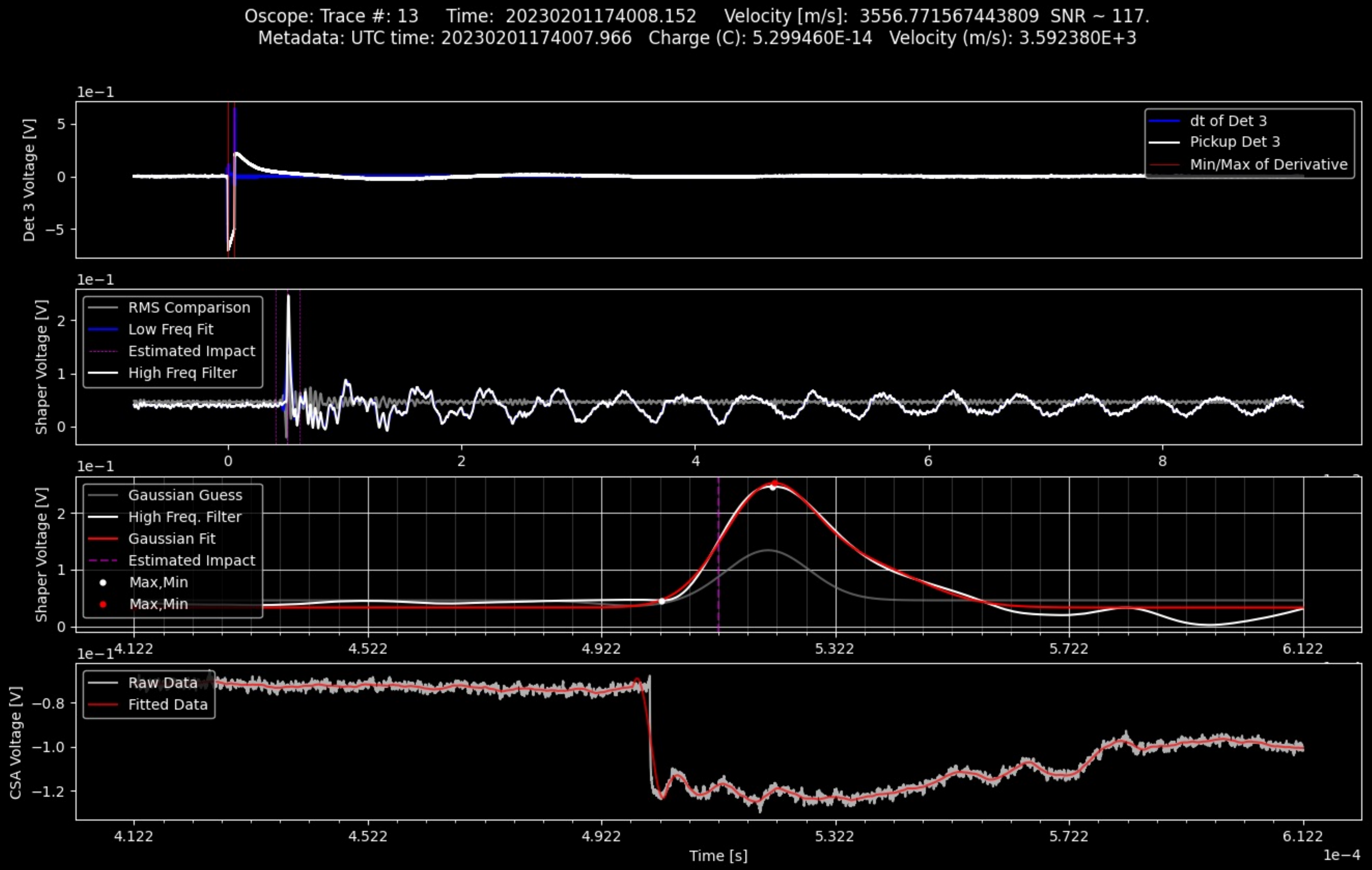
The annually averaged lunar dust density distribution, given in equation (2), for particles with $a \geq 0.3\ \mu$m in a reference frame where the Sun is in the $-x$ direction and the apex motion of the Moon about the Sun is in the $+y$ direction.



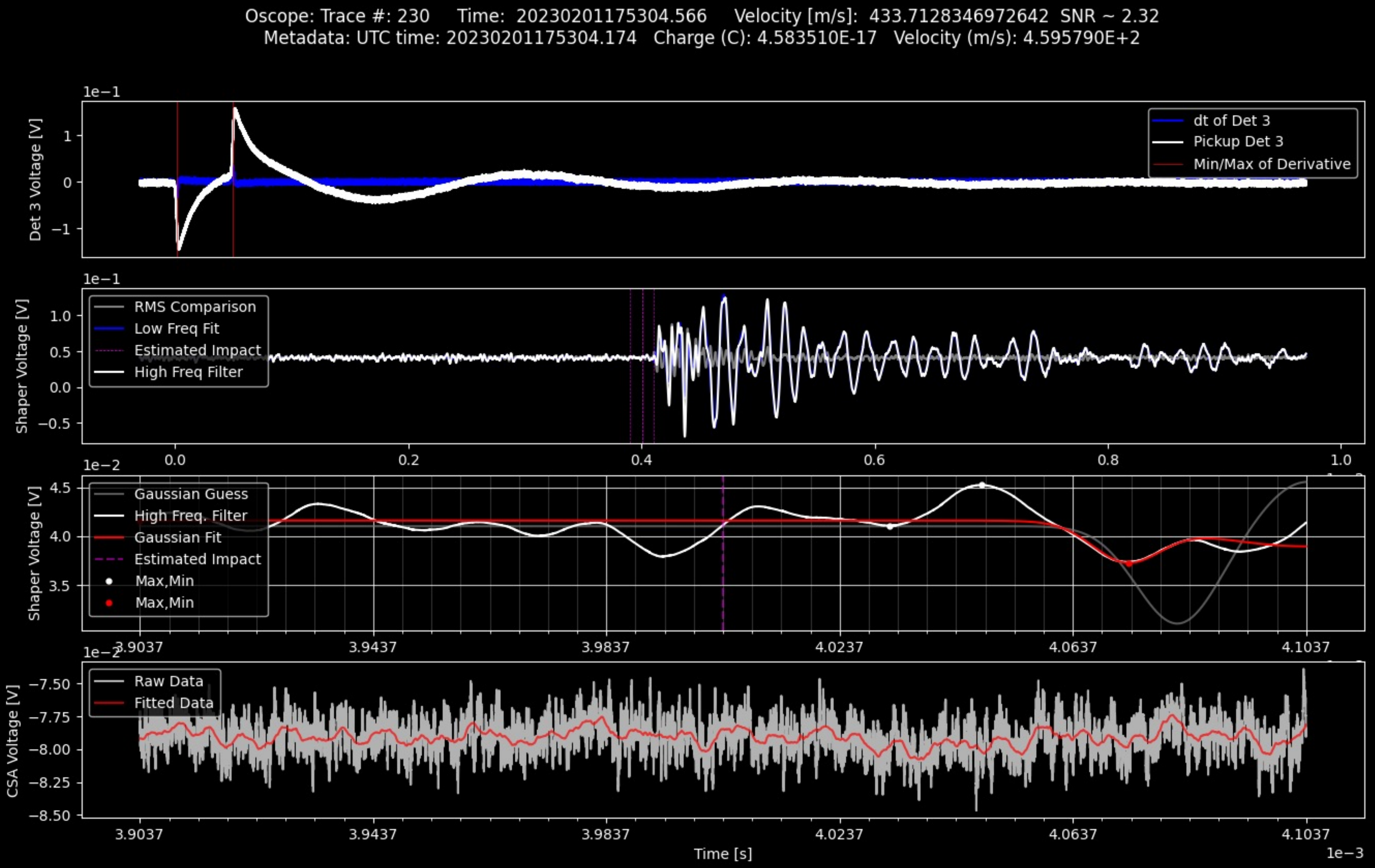
The velocity distribution function from equation (1) (black) along with the previously derived distribution (grey) from *Horányi et al.* [2015, Methods]. The vertical dashed line indicates the velocity to reach the highest altitude visited by LDEX of 250 km. For velocities $\gtrsim$840 m/s, the distribution function derived in this work is an extrapolation.



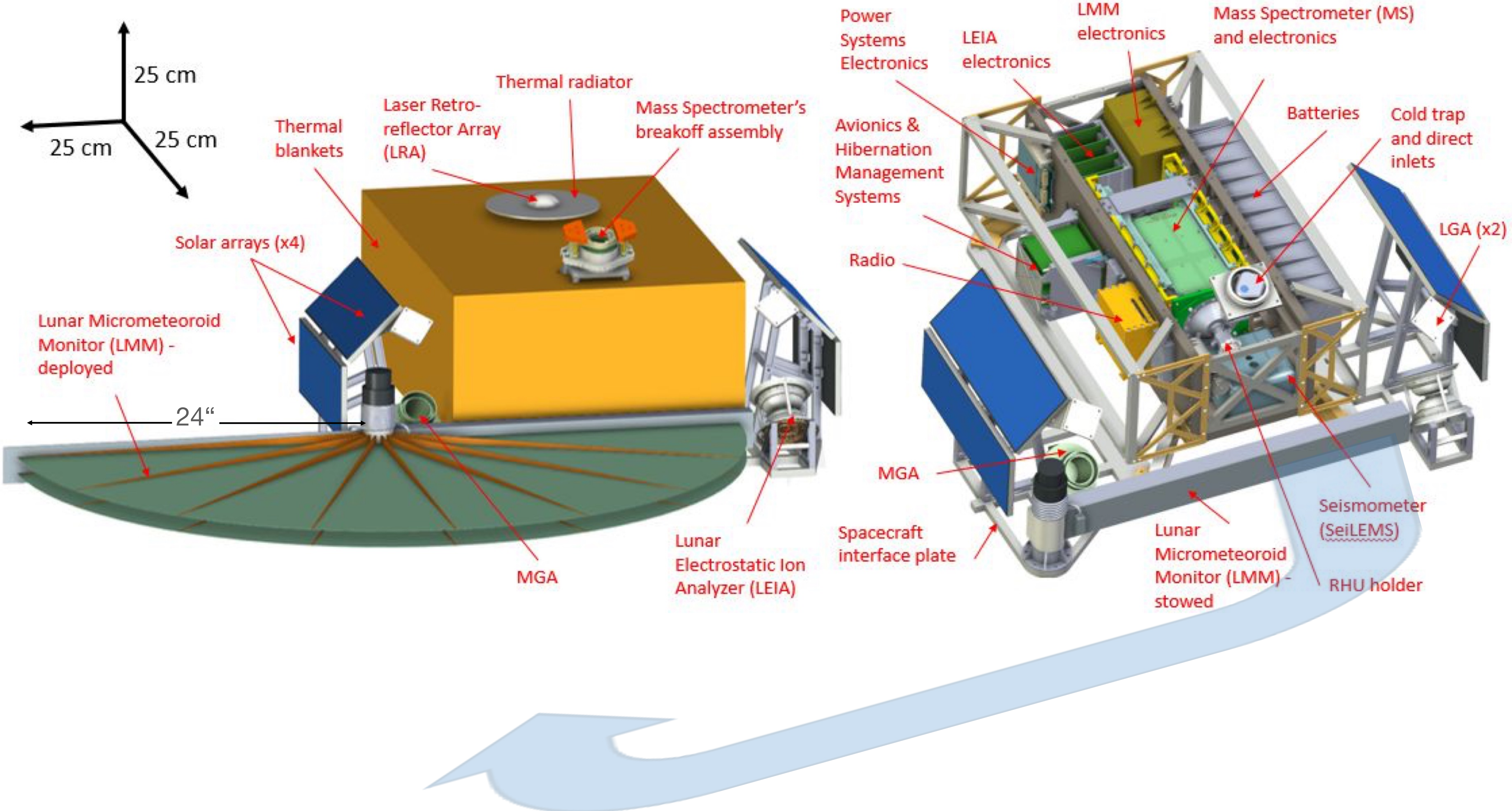

Experiment Chamber
Q, v, m, Particle Selection Unit (PSU)
Pelletron Accelerator
Initial Location PVDF Film
New Location PVDF Film
Min. Velocity: ~350 m/s
Min. Velocity: ~60 m/s
Deflection Unit
Charge Pickup Detectors
Dust Source
~ 3 meters
~ 10 meters



Oscope: Trace #: 13 Time: 20230201174008.152 Velocity [m/s]: 3556.771567443809 SNR ~ 117.
Metadata: UTC time: 20230201174007.966 Charge (C): 5.299460E-14 Velocity (m/s): 3.592380E+3
Det 3 Voltage [V]
dt of Det 3
Pickup Det 3
Min/Max of Derivative
Shaper Voltage [V]
RMS Comparison
Low Freq Fit
Estimated Impact
High Freq Filter
Gaussian Guess
High Freq. Filter
Gaussian Fit
Estimated Impact
Max,Min
Max,Min
CSA Voltage [V]
Raw Data
Fitted Data
Time [s]



Oscope: Trace #: 230 Time: 20230201175304.566 Velocity [m/s]: 433.7128346972642 SNR ~ 2.32
Metadata: UTC time: 20230201175304.174 Charge (C): 4.583510E-17 Velocity (m/s): 4.595790E+2
1e−1
Det 3 Voltage [V]
dt of Det 3
Pickup Det 3
Min/Max of Derivative
1e−1
Shaper Voltage [V]
RMS Comparison
Low Freq Fit
Estimated Impact
High Freq Filter
1e−2
Shaper Voltage [V]
Gaussian Guess
High Freq. Filter
Gaussian Fit
Estimated Impact
Max,Min
Max,Min
1e−2
CSA Voltage [V]
Raw Data
Fitted Data
Time [s]
1e−3


25 cm
25 cm
25 cm
Thermal blankets
Laser Retro-reflector Array (LRA)
Thermal radiator
Mass Spectrometer's breakoff assembly
Solar arrays (x4)
Lunar Micrometeoroid Monitor (LMM) - deployed
24"
MGA
Lunar Electrostatic Ion Analyzer (LEIA)
Power Systems Electronics
LEIA electronics
LMM electronics
Mass Spectrometer (MS) and electronics
Avionics & Hibernation Management Systems
Batteries
Cold trap and direct inlets
Radio
LGA (x2)
MGA
Spacecraft interface plate
Lunar Micrometeoroid Monitor (LMM) - stowed
Seismometer (SeiLEMS)
RHU holder

SUMMARY

LMM is designed with

a) a deployable structure for the large area detector, while providing a compact configuration for stowing through launch

b) low-power electronics for impact detection and signal processing that enables maintaining continuous operation of LMM throughout the lunar night

c) a thermal design to enable the continuous operation over a lunar day, where the temperature extremes of the surface can vary over a range -170 °C to +120 °C.

LMM is envisioned to be part of the payload for a series of Lunar Environmental Monitoring Stations (LEMS) deployed on the lunar surface with an expected lifetime of > 2 years.