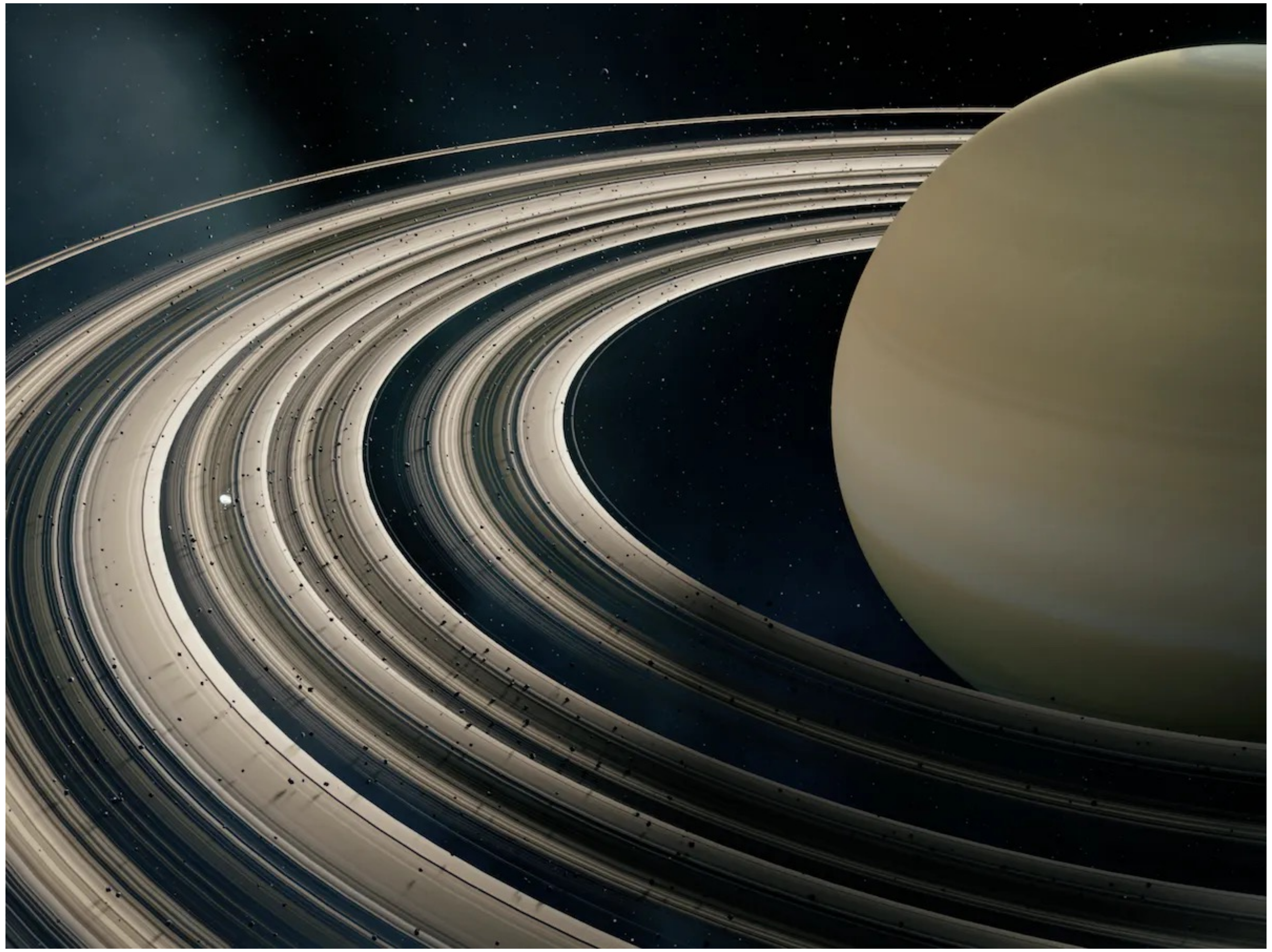
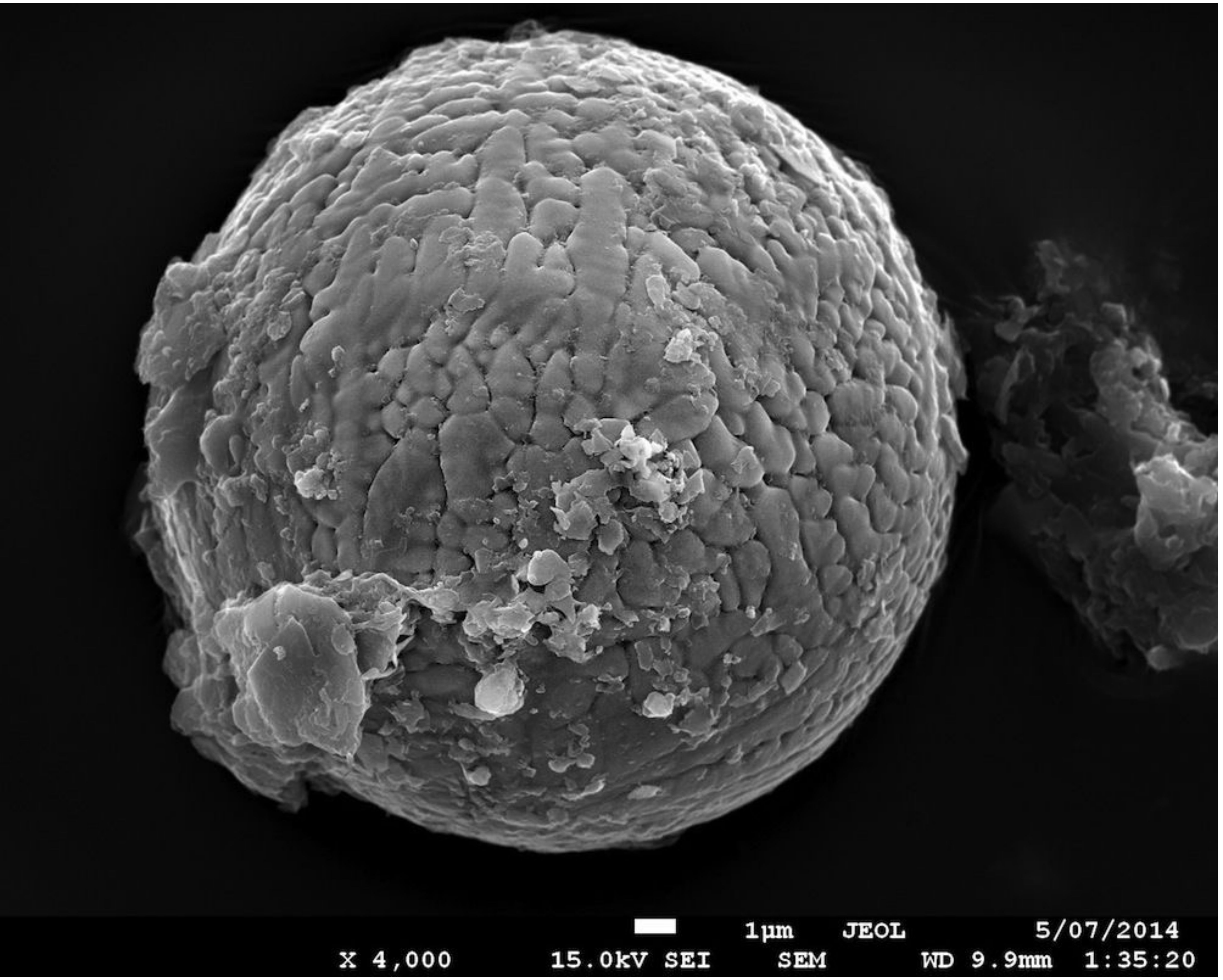
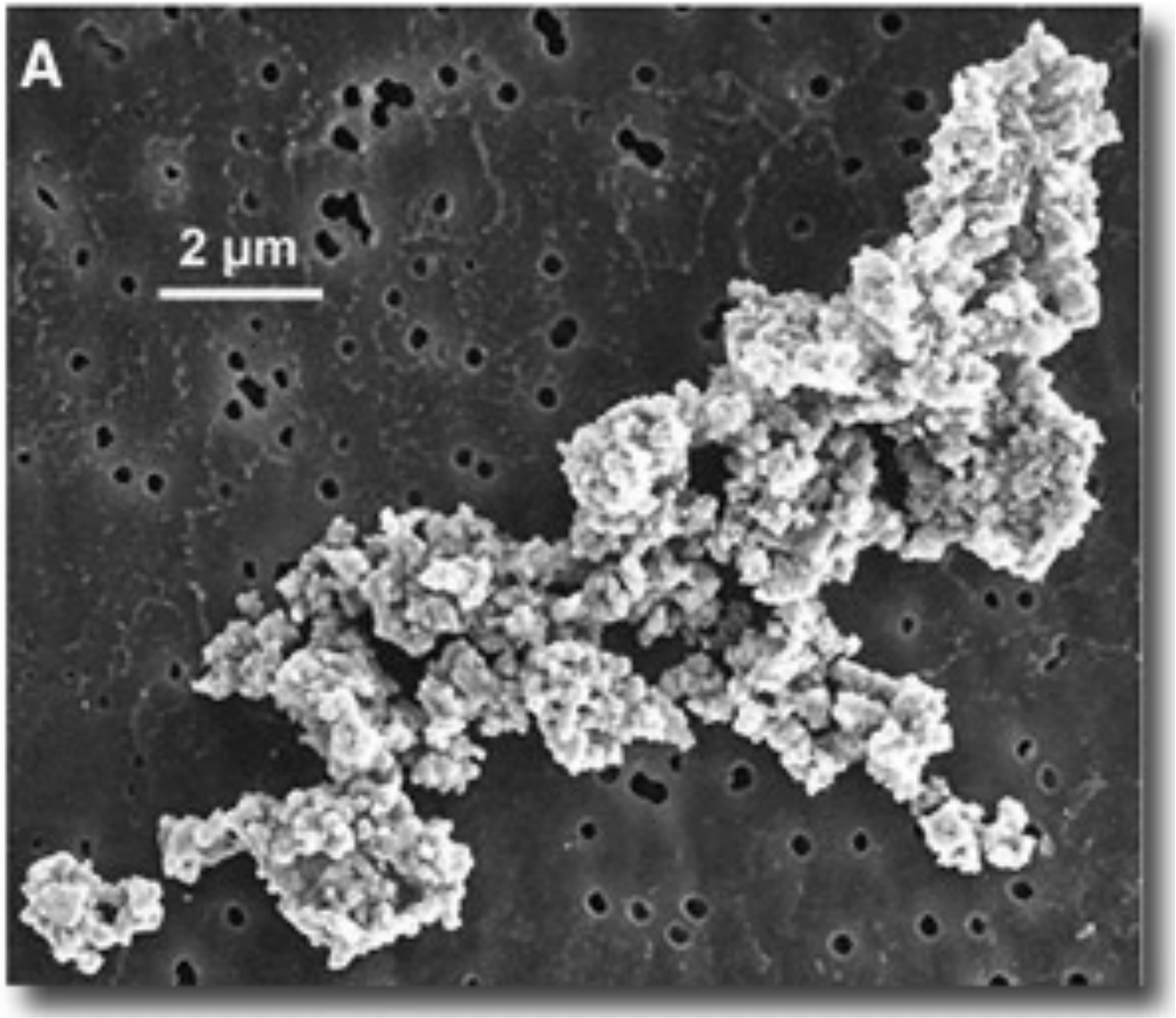


Overview of dust issues in space research

Workshop on Dust Charging and Beam-Dust Interaction in Particle Accelerators

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**
75 years of excellence in space science


1µm JEOL 5/07/2014
X 4,000 15.0kV SEI SEM WD 9.9mm 1:35:20


A
2 µm

Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT)

Introduction

The Institute for **M**odeling **P**lasma, **A**tmospheres, and **C**osmic Dust (IMPACT) is a member of the NASA **S**olar **S**ystem **E**xploration **R**esearch **V**irtual **I**nstitute (SERVII), focused on experimental and theoretical investigations of surfaces of solar system objects, including dusty plasma and impact processes, the origin of atmospheres, and the development of new instrument concepts.

IMPACT is conducting a series of laboratory experiments supplemented by theory and modeling, to determine:

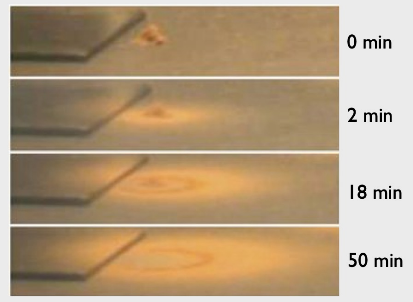
- The properties of the near-surface plasma environment;
- The charging of grains resting on dusty surfaces and stirred by activities;
- The microphysics of impacts of hypervelocity micrometeoroids and their interaction with the simulated planetary environment;

Small Lab Experiments

UV photoionized plasma:
- Dust charging experiments
- Dust Transport and Levitation

Space plasma analogs:
- Dusty surfaces
- Solar wind interaction with dust clouds

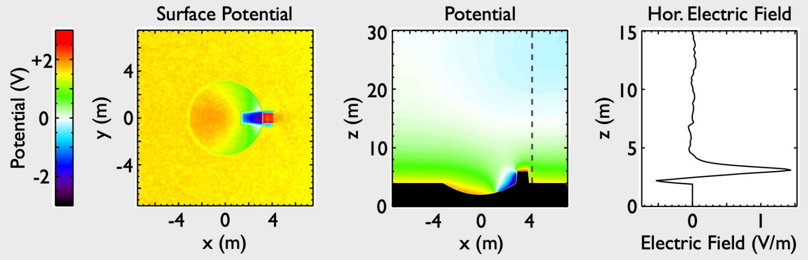
Regolith Characterisation
Crater Studies



Images of the migration of a pile of nonconducting dust grains (diameters < 25μm) on a conducting surface in plasma. The motion was verified to be in the direction of the electric force on grains.

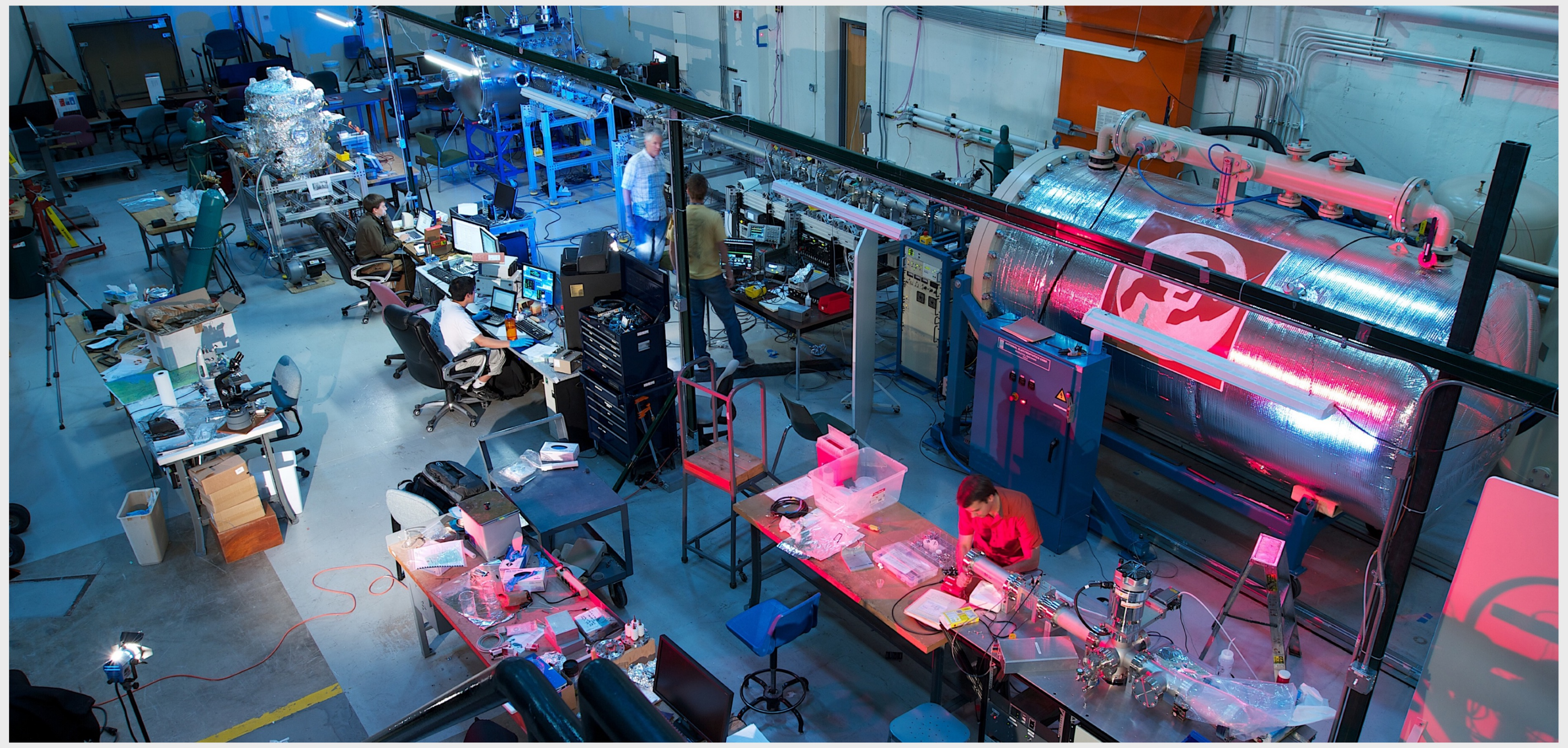
Theory/Computation

- Modeling of plasma and UV interaction with surfaces
- 3-D kinetic simulations of lunar plasma / shadow effects
- VORPAL PIC code
- Modeling of the space weather
- Numerical Simulations of hypervelocity impacts
- Modeling of dust exospheres and planetary rings
- Modeling of dusty plasma phenomena
- Modeling of dust mobilization and transport
- Micrometeoroid impact hazard



IMPACT's fully 3D self-consistent plasma simulation tool, VSim, is used to develop synthetic diagnostic tools to guide the analysis of in-situ data and to identify the effects of the spacecraft and its instrumentation on the near-surface measurements. The left two panels show the side and top views of the computed potential distribution of a S/C landing by a small lunar crater, when the Sun is 45° above the horizon. The right panel shows the horizontal component of the electric field induced by the spacecraft alone.

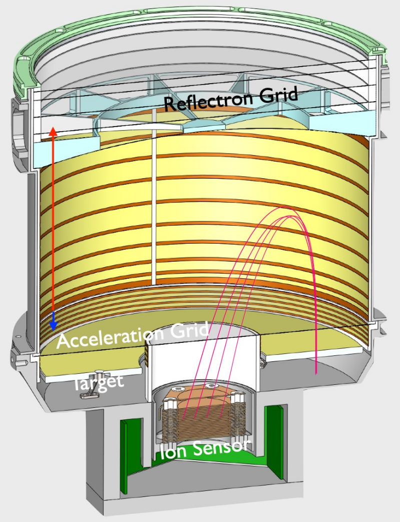
The Dust Accelerator



The 3 MV dust accelerator installed at the Dust Accelerator Laboratory (DAL). The accelerator is used to simulate the effects of dust impacts with speeds of up to 10's of kms^{-1} for micron- and submicron-sized projectiles. The facility is now fully operational and in regular use by the IMPACT team and the larger US and international community.

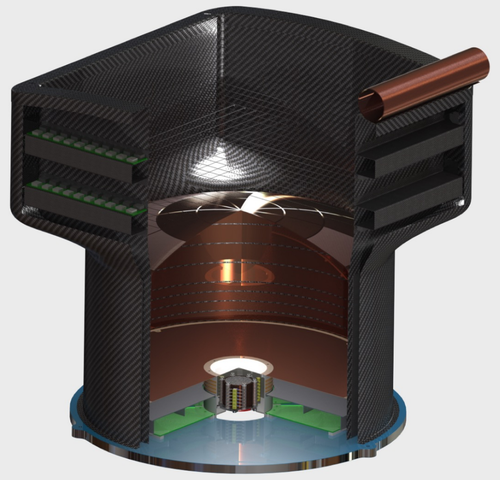
Instrument Development

Surface Dust Analyser (SUDA)



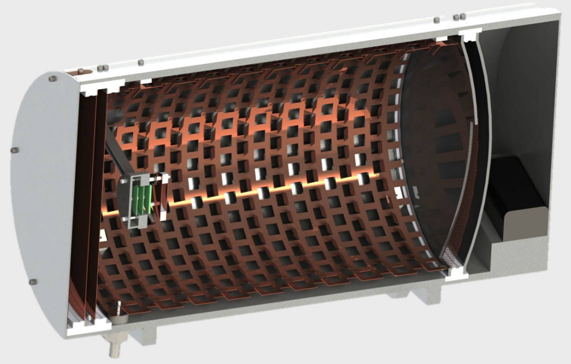
SUDA is a high resolution impact mass spectrometer developed for NASA's planned mission to the Jupiter moon Europa. SUDA will determine the composition of material ejected from Europa's surface. This novel technique will provide spatially resolved compositional maps of Europa's surface. Knowledge of the surface composition is essential for verifying the existence of a sub-surface ocean and for assessing the habitability of the moon. The major design challenge is coping with hard radiation environment in the inner Jovian system.

Hyperdust



HyperDust is a highly versatile instrument, suitable for a number of mission scenarios, targeting interstellar dust, asteroids, comets, Phobos, Deimos, or other airless bodies in the solar system. The instrument combines a large area mass spectrometer with high mass resolution with a trajectory sensor in front of the instrument. Together the two subsystems form a so-called Dust Telescope. Using conventional manufacturing techniques would result in a heavyweight instrument difficult to fit on future flight opportunities. Thus, a major focus of this development is to drastically reduce the mass. This will be achieved by novel engineering approach and using high-tech, composite materials.

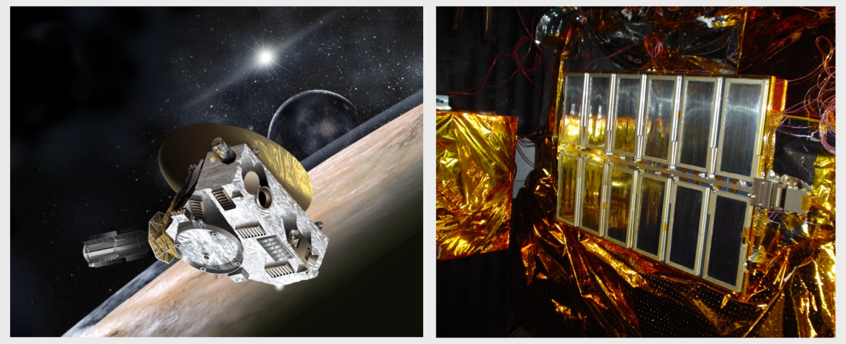
Nanodust Analyzer (NDA)



NDA is a linear time-of-flight pectrometer is developed for the detection and chemical analysis of nanometer-sized particles originating near the Sun. Nano-dust particles are thought to be produced by mutual collisions between interplanetary dust particles slowly spiraling toward the Sun and are accelerated outward to high velocities by interaction with the solar wind plasma. The NDA instrument is designed to reliably detect and analyze nanometer-sized dust particles while being pointed close to the Sun's direction, from where they are expected to arrive. Measurements by such an instrument will determine the size-dependent flux of the nano-dust particles and its variations, it will characterize the composition of the nano-dust and, ultimately, it may determine their source.

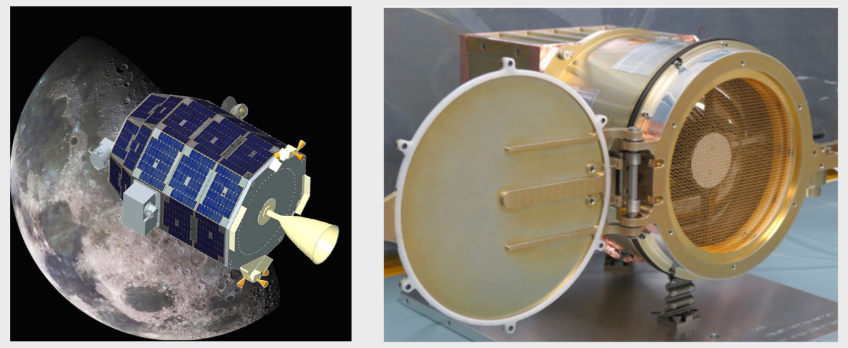
Space Missions

New Horizon - Student Dust Counter (SDC)



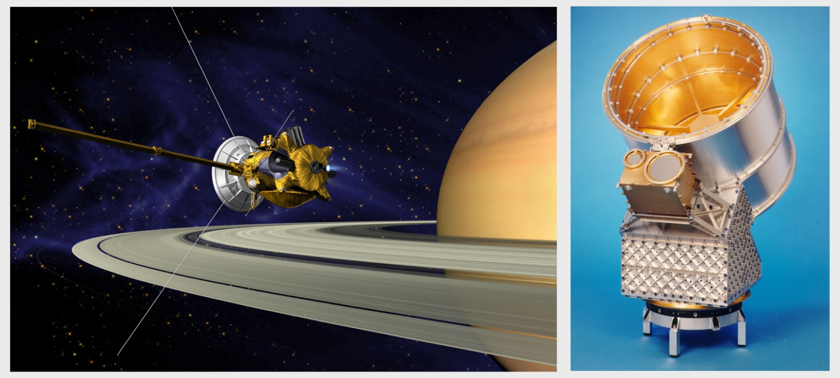
The New Horizons Pluto-Kuiper Belt Mission, launched in January 2006 and due to arrive at Pluto in 2015, will help us to understand the icy worlds at the edge of our solar system. The Student Dust Counter onboard the spacecraft is the first student-built instrument ever to fly on a NASA planetary mission. It will take the first measurements of dust distribution beyond 18 AU.With guidance from LASP professionals, the SDC team of graduate and undergraduate students designed, built, and tested the instrument, and students will continue to run the SDC for at least another decade.

LADEE - Lunar Dust Experiment (LDEX)



LADEE is designed to characterize the tenuous lunar atmosphere and dust environment from orbitThe Lunar Dust Experiment onboard of the LADEE spacecraft provides new information on the physical characteristics of lunar dust, from its interactions with the moon's atmosphere and the solar wind to astronaut safety issues.

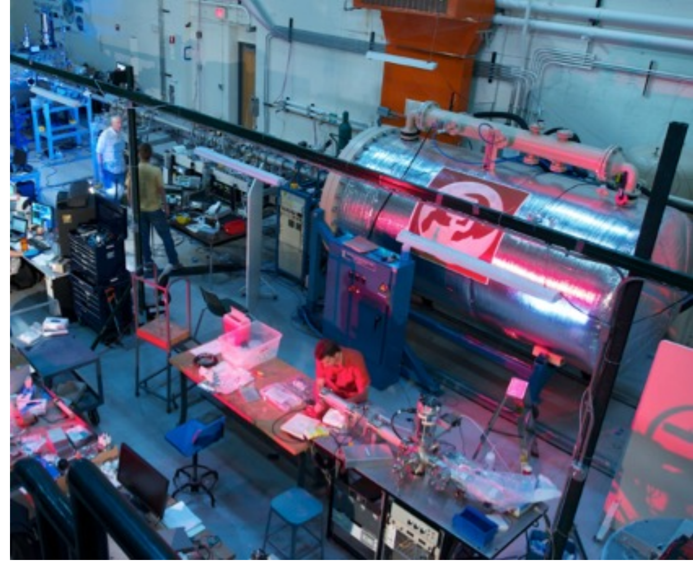
Cassini - Cosmic Dust Analyzer (CDA)

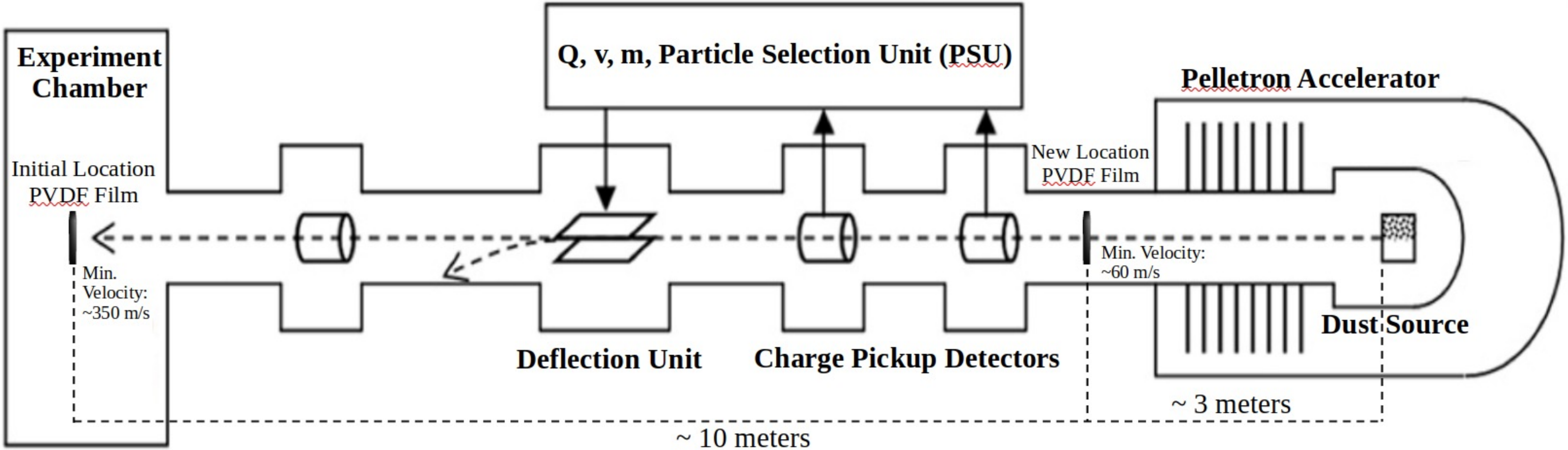


The Cosmic Dust Analyser (CDA) onboard of the Cassini spacecraft determines the speed (1–100 km/s), mass (10^{-15}-10^{-9} g), electric charge (~1fC) and elemental composition of individual micrometeoroids and derives dust densities between 10^{-9} and 10 m^{-3}. The Cassini/Huygens spacecraft reached Saturn in July 2004 after 7 years of cruise phase and explores the Saturnian system since then. Major contributions of CDA include the discovery of nanograins emerging from the Saturnian system, the discovery of ice geysers on the tiny moon Enceladus, and the compositional analysis of the water ice grains in Saturn's E ring system, which led to the discovery of large reservoirs of liquid water below the icy crust of Enceladus.

impact.colorado.edu


DANGER
HIGH VOLTAGE
KEEP AWAY





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

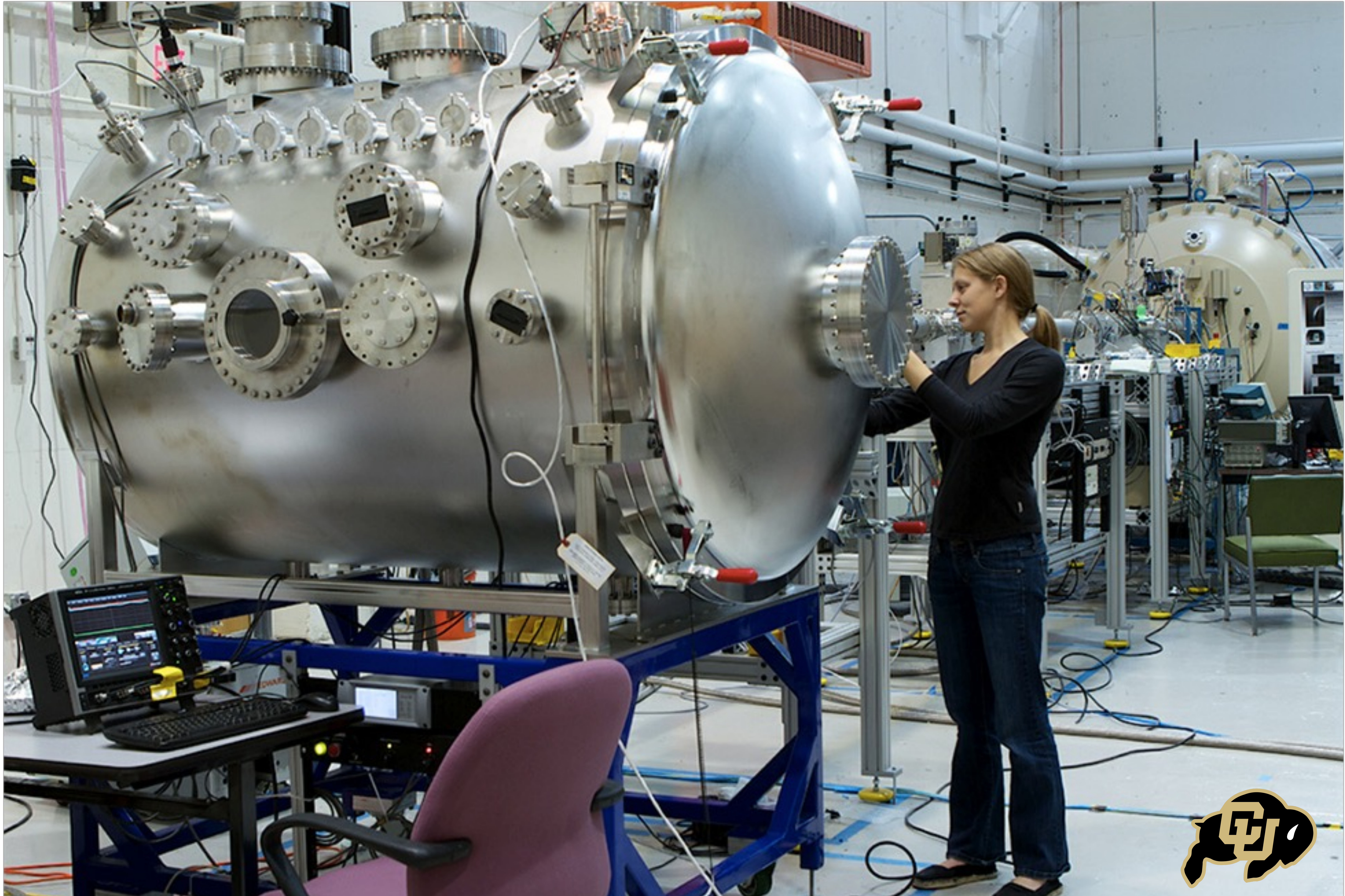
Dust Source

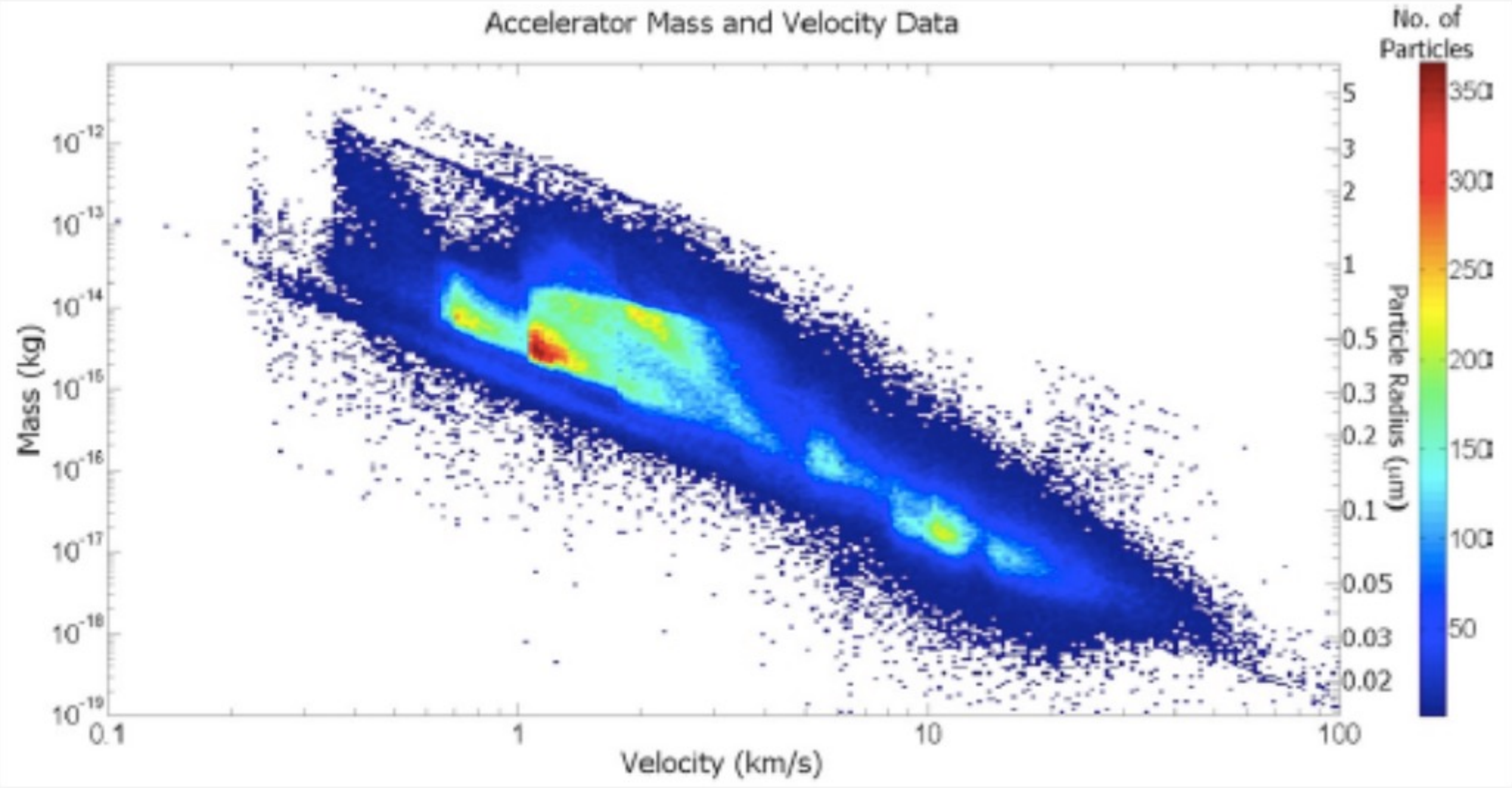
Deflection Unit

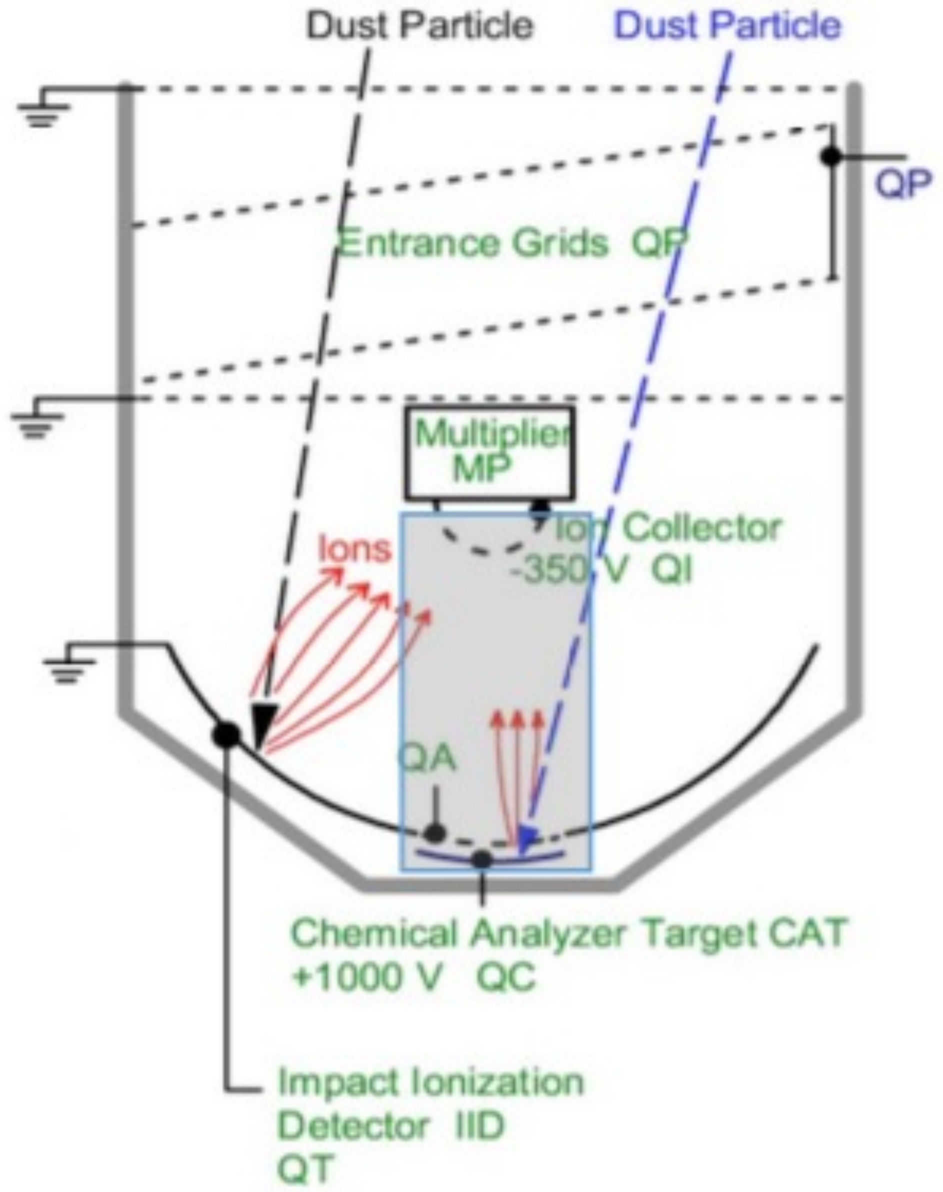
Charge Pickup Detectors

~ 3 meters

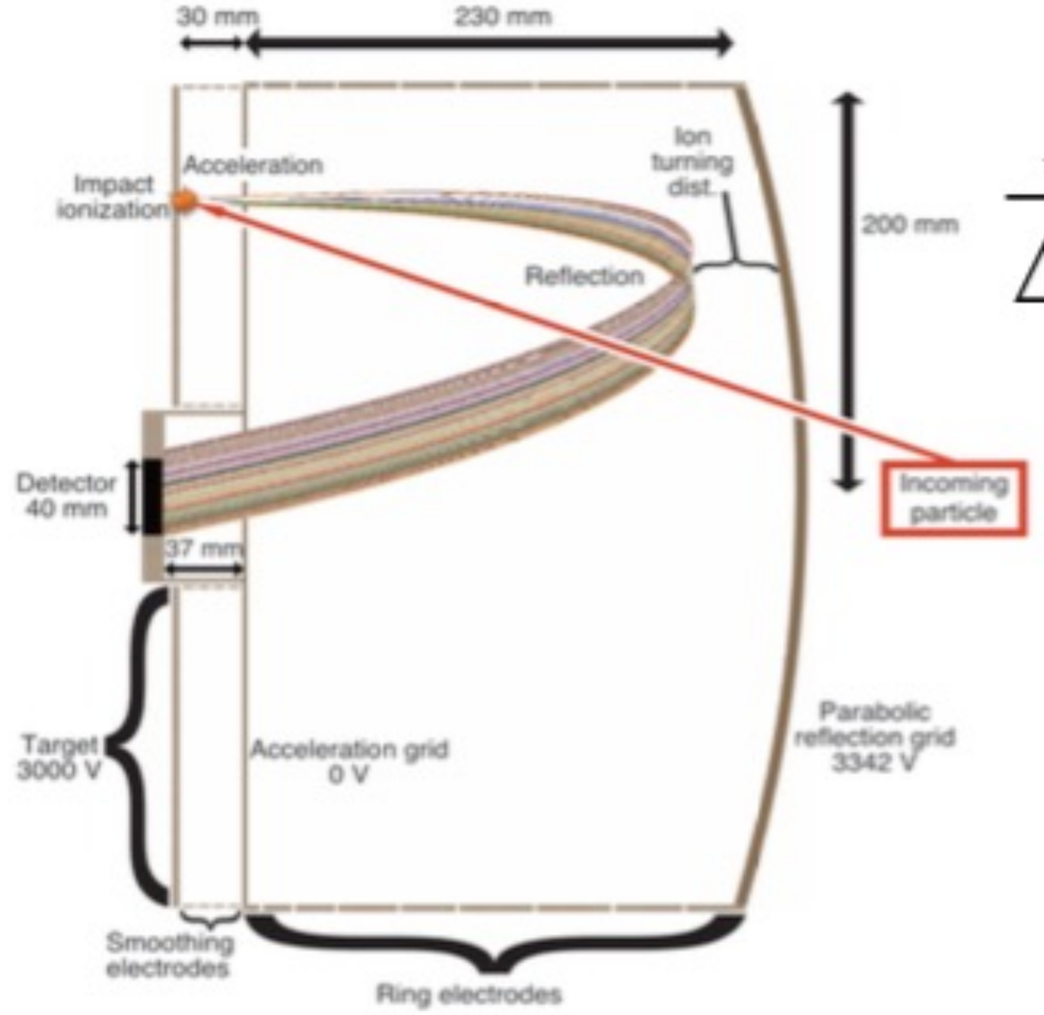
~ 10 meters



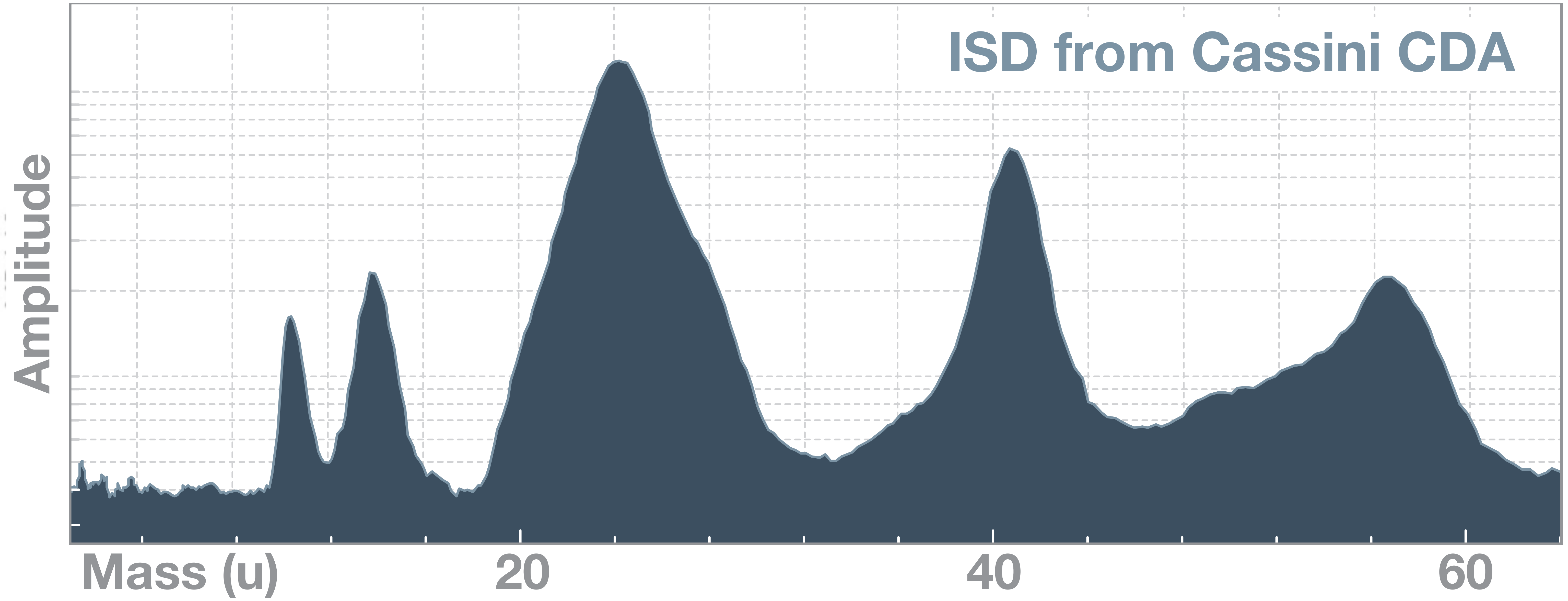

Accelerator Mass and Velocity Data
No. of Particles
Mass (kg)
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
0.1
1
10
100
Velocity (km/s)
5
3
2
1
0.5
0.3
0.2
0.1
0.05
0.03
0.02
Particle Radius (um)
350
300
250
200
150
100
50

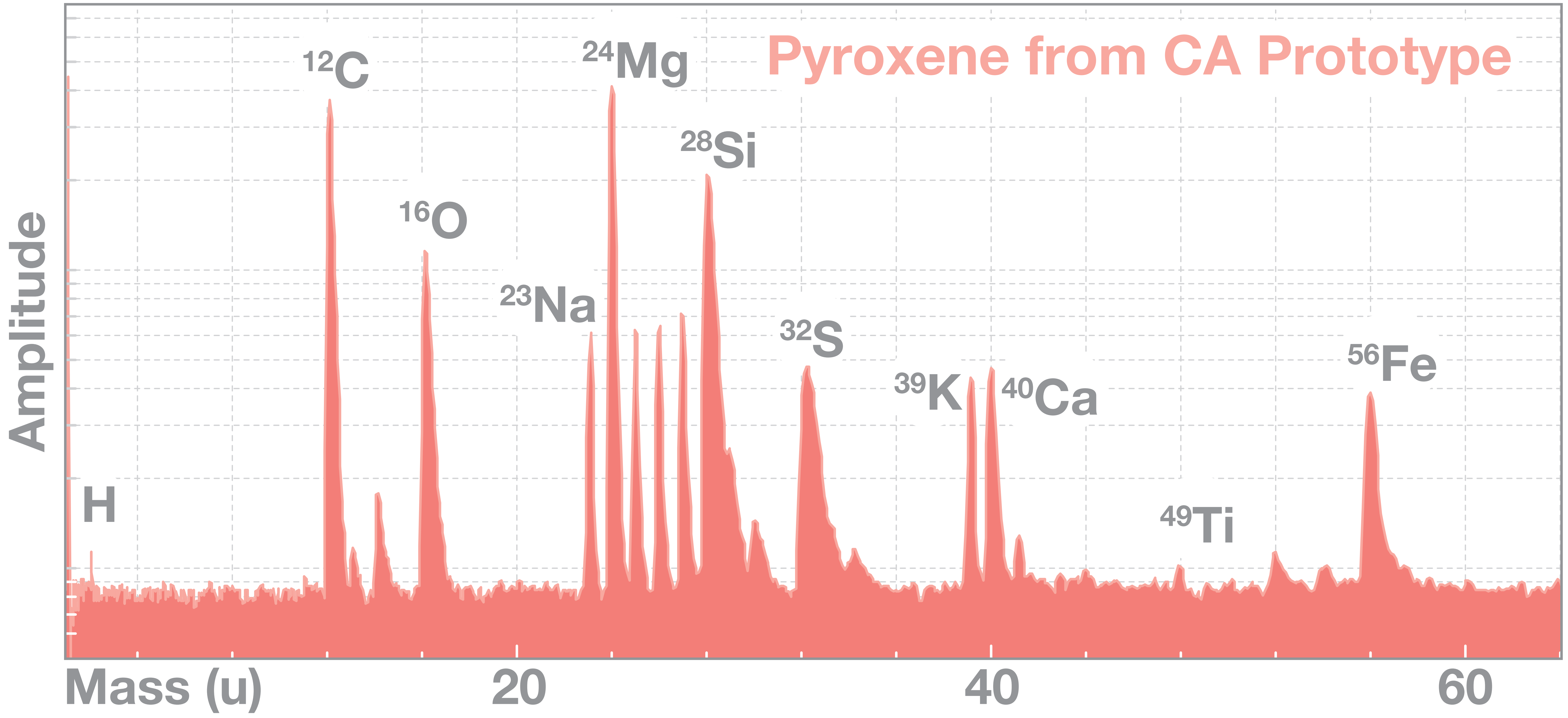


$$\frac{M}{\Delta M} \approx 30$$



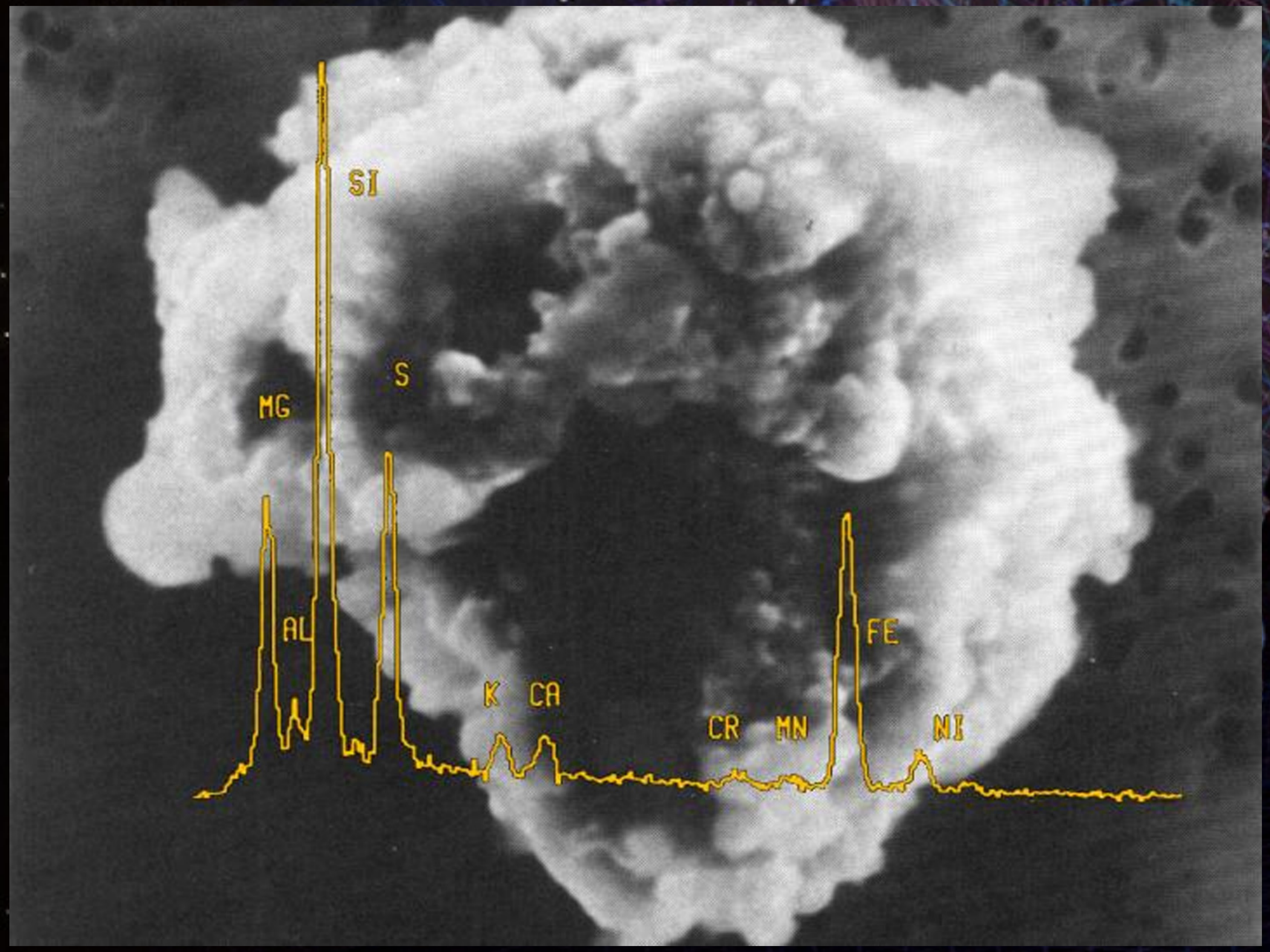
$$\frac{M}{\Delta M} \approx 200$$

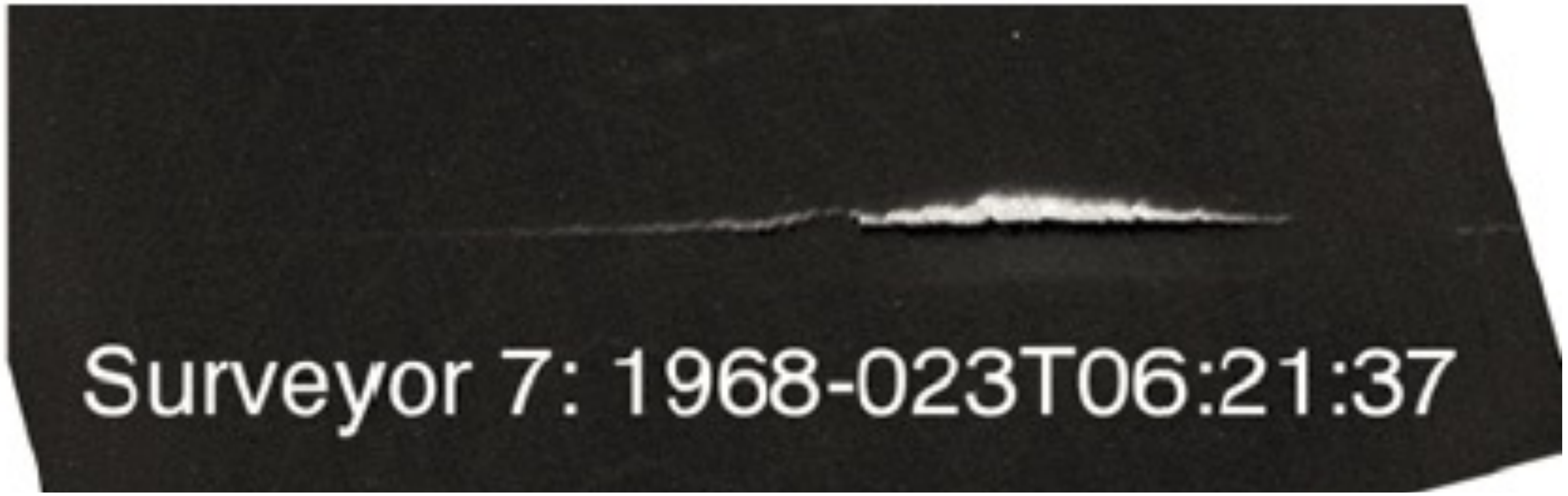




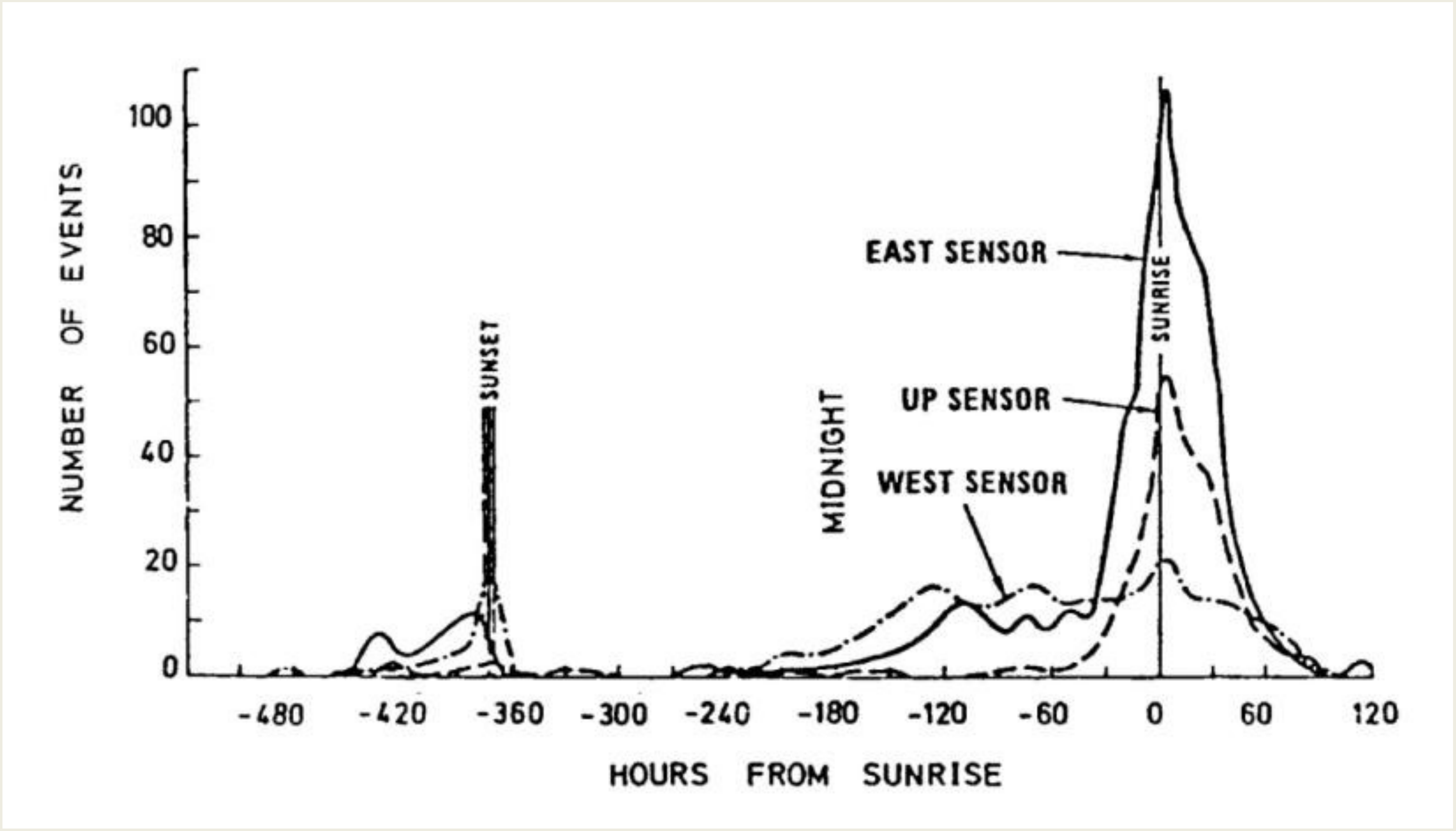
"Dust particles, like photons, are born at remote sites in space and time. From knowledge of their birthplace and bulk properties, we can learn about the remote environment out of which the particles were formed."

E. Grün

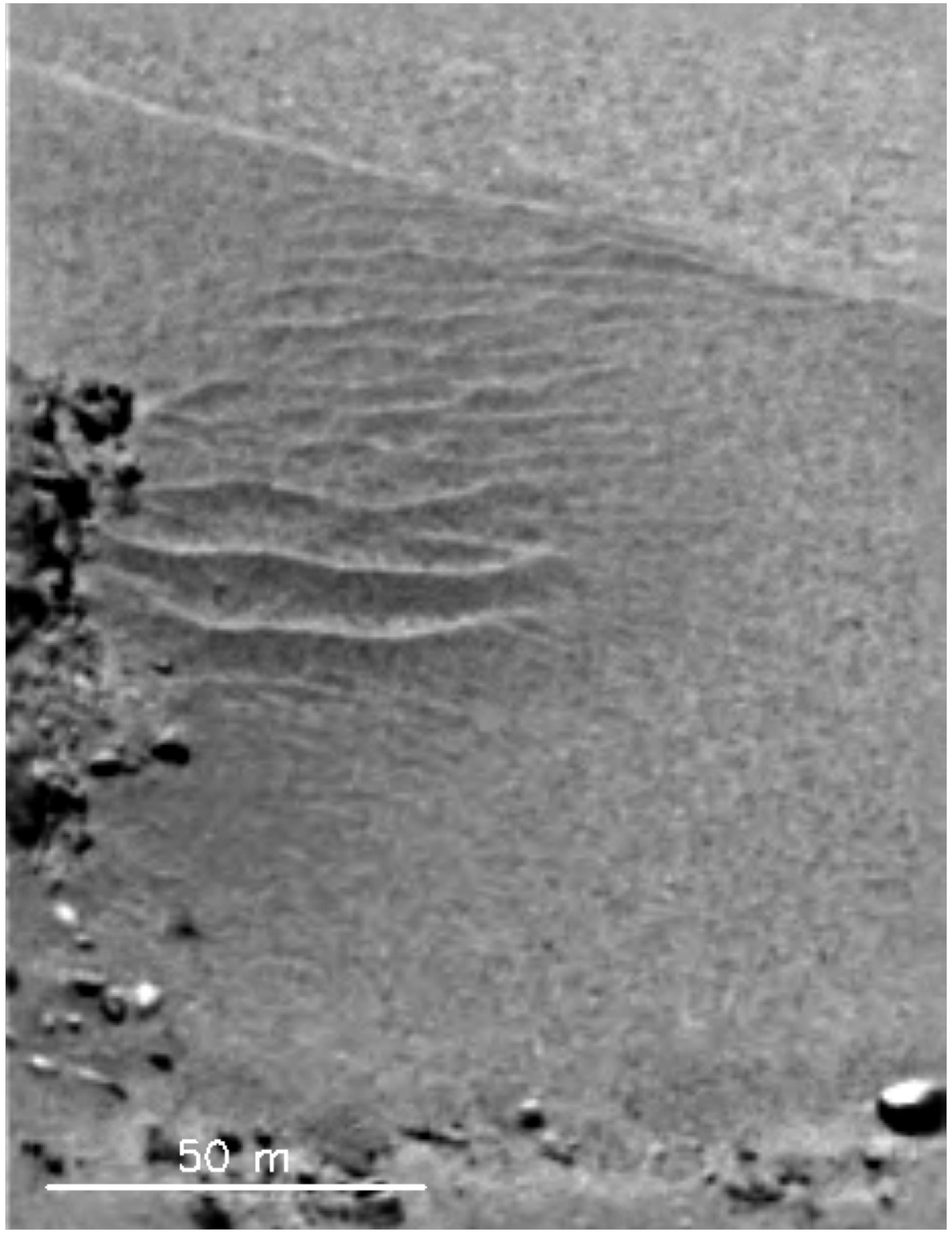




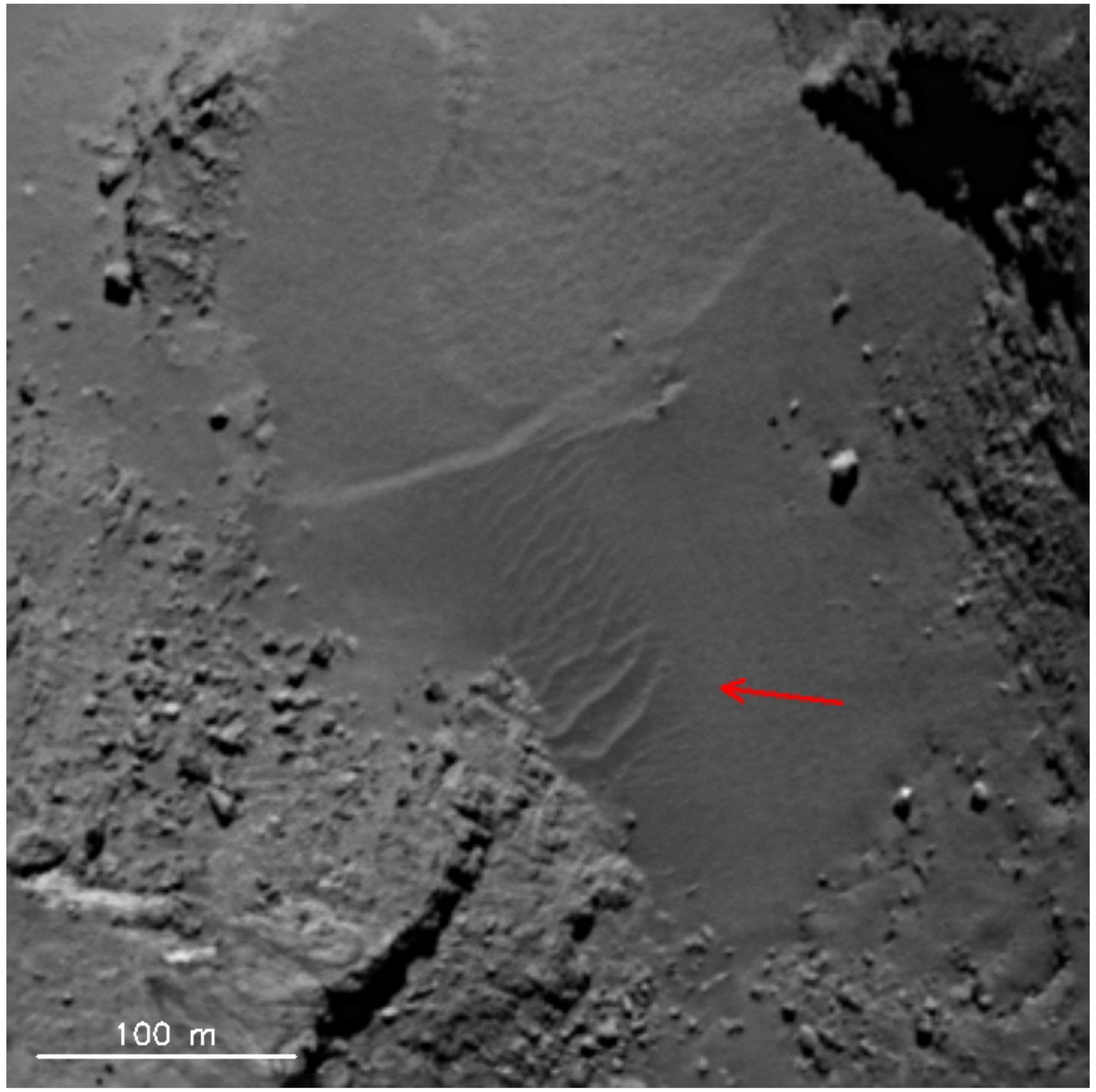
Surveyor 7: 1968-023T06:21:37



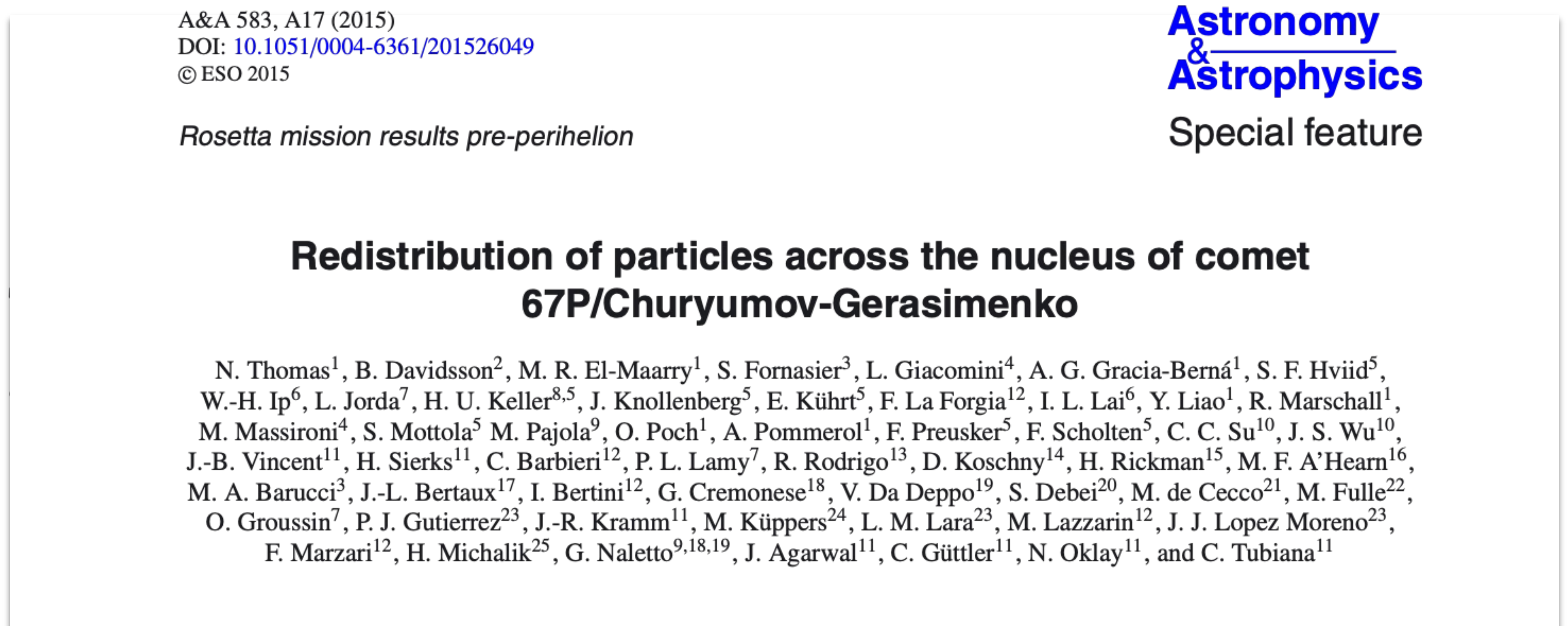
NEAR / EROS 2001



Aeolian ripples in the Hapi region on 67P. Image: NAC_2014-09-17T23.52.43.330Z_ID10_1397549400_F22.



Aeolian ripples in the Hapi region on 67P seen at a viewing geometry more orthogonal to the surface. Image: NAC_2014-09-02T21.44.22.575Z_ID10_1397549800_F22.

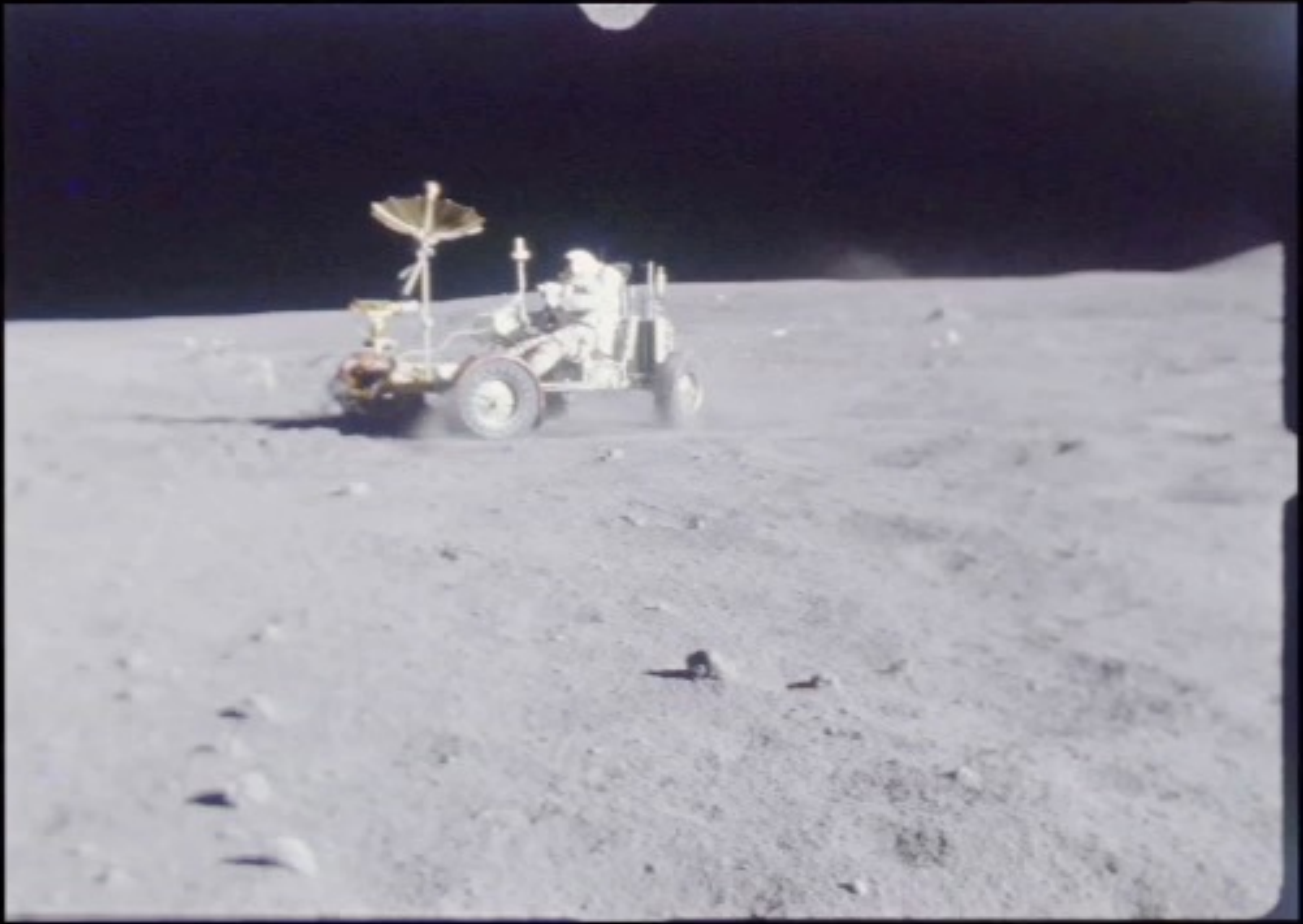

A&A 583, A17 (2015)
DOI: 10.1051/0004-6361/201526049
© ESO 2015

Astronomy
&
Astrophysics
Special feature

Rosetta mission results pre-perihelion

Redistribution of particles across the nucleus of comet 67P/Churyumov-Gerasimenko

N. Thomas[1], B. Davidsson[2], M. R. El-Maarry[1], S. Fornasier[3], L. Giacomini[4], A. G. Gracia-Berná[1], S. F. Hviid[5], W.-H. Ip[6], L. Jorda[7], H. U. Keller[8,5], J. Knollenberg[5], E. Kührt[5], F. La Forgia[12], I. L. Lai[6], Y. Liao[1], R. Marschall[1], M. Massironi[4], S. Mottola[5] M. Pajola[9], O. Poch[1], A. Pommerol[1], F. Preusker[5], F. Scholten[5], C. C. Su[10], J. S. Wu[10], J.-B. Vincent[11], H. Sierks[11], C. Barbieri[12], P. L. Lamy[7], R. Rodrigo[13], D. Koschny[14], H. Rickman[15], M. F. A'Hearn[16], M. A. Barucci[3], J.-L. Bertaux[17], I. Bertini[12], G. Cremonese[18], V. Da Deppo[19], S. Debei[20], M. de Cecco[21], M. Fulle[22], O. Groussin[7], P. J. Gutierrez[23], J.-R. Kramm[11], M. Küppers[24], L. M. Lara[23], M. Lazzarin[12], J. J. Lopez Moreno[23], F. Marzari[12], H. Michalik[25], G. Naletto[9,18,19], J. Agarwal[11], C. Güttler[11], N. Oklay[11], and C. Tubiana[11]



New physics:

Dust is many orders of magnitude heavier than ions and can carry many orders of magnitude larger + or - time dependent charge.

new spatial scales

new time scales

unusual dynamics

new waves & instabilities

Dust charge:

electron and ion fluxes

secondary and photoelectrons

dust – dust collisions

Dust - acoustic wave

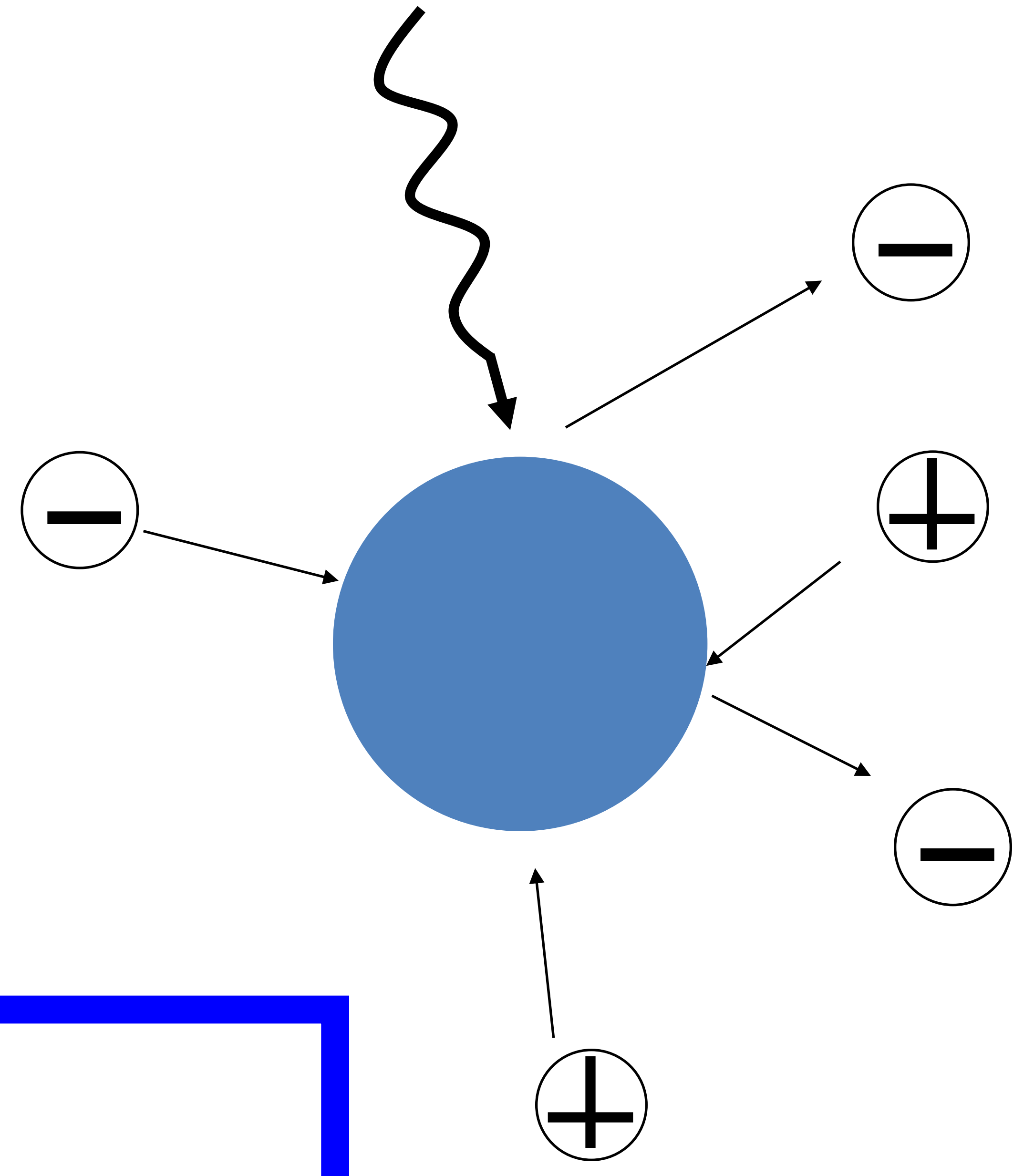
Rao et al., 1990

Barkan et al., 1995

Dust Charging Processes

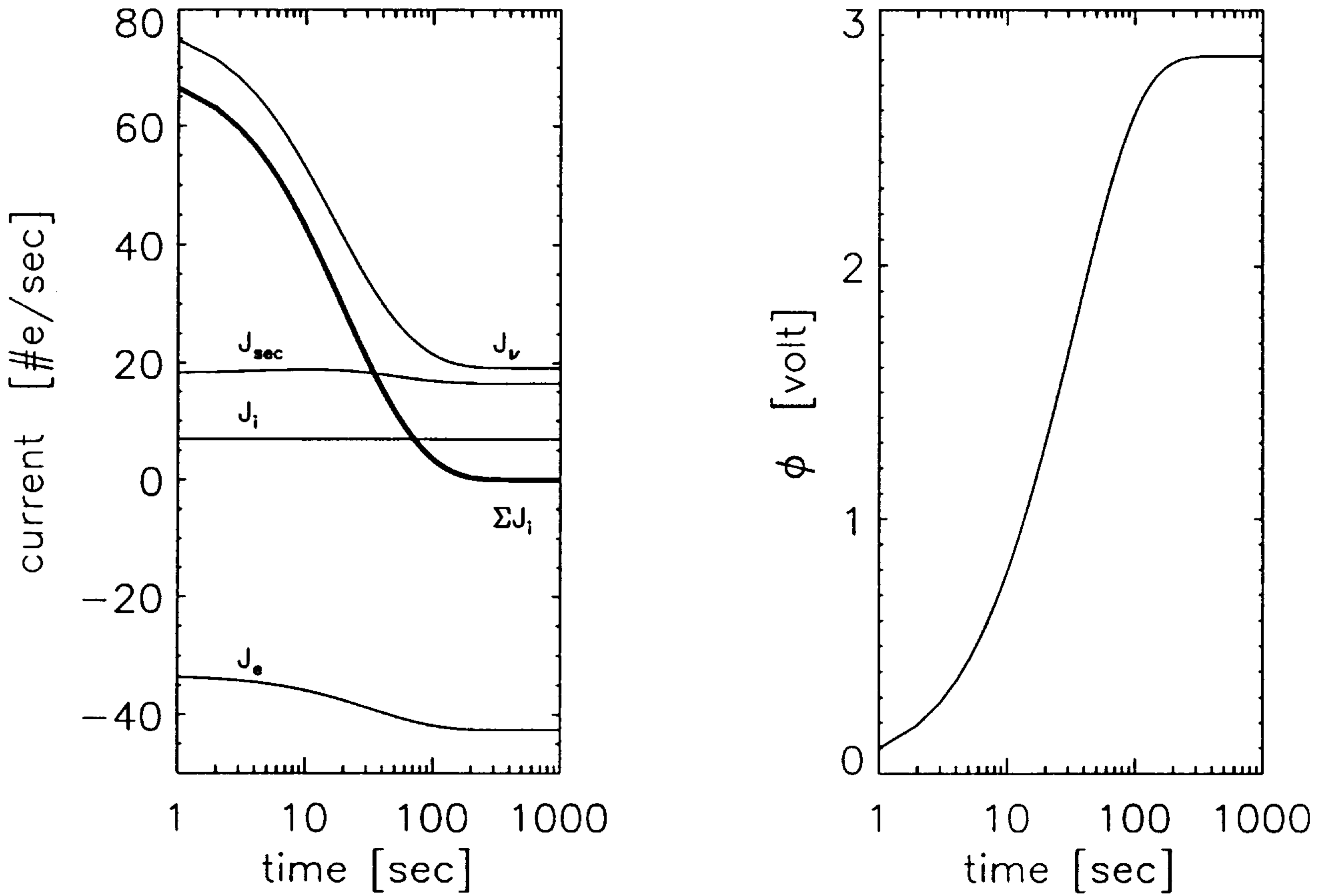
- electron and ion collection
- secondary emission
- UV induced photoelectron emission

- …….



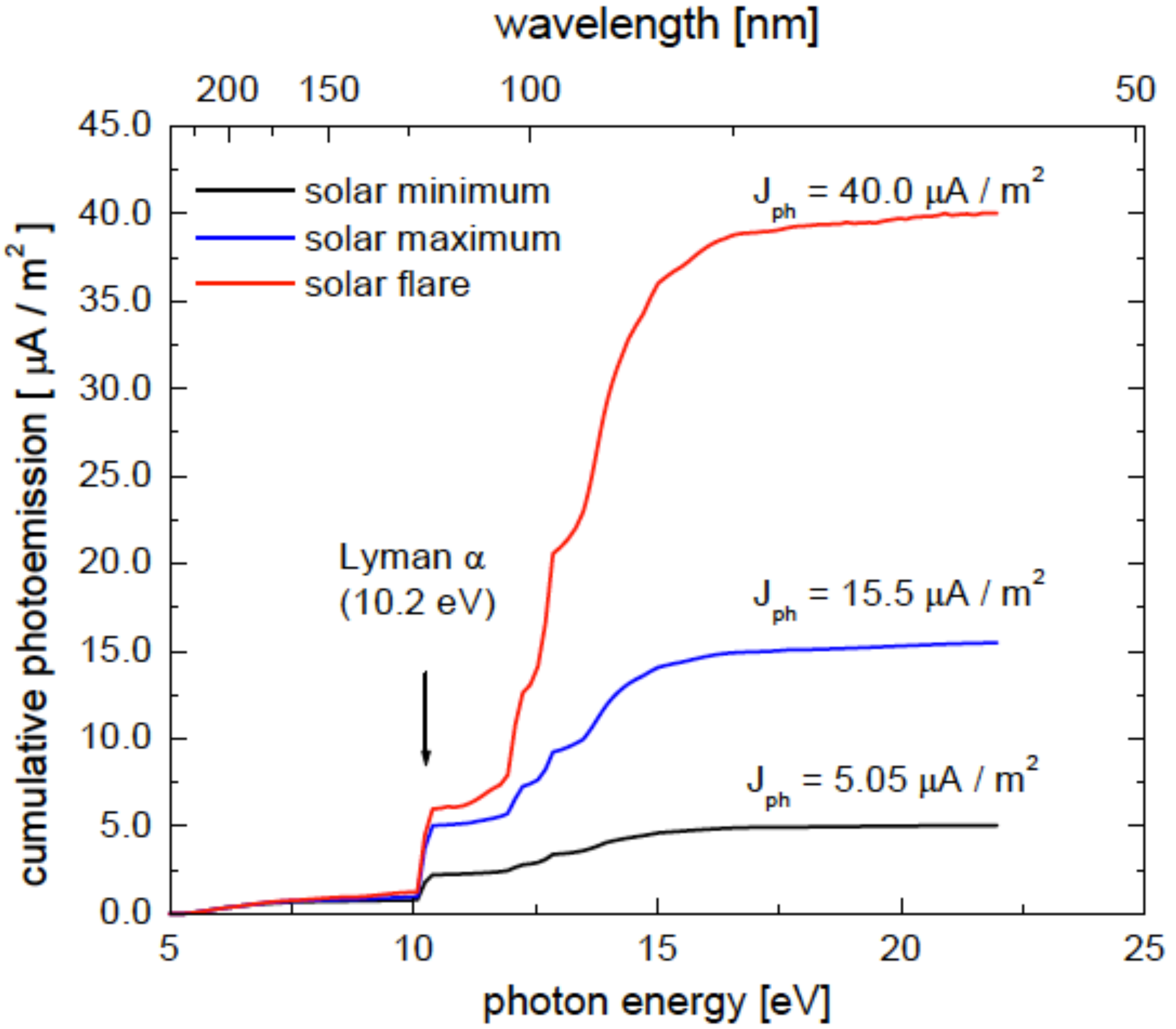
Total current to a grain = 0

$\Sigma I = I_e + I_i + I_{sec} + I_{pe} = 0$



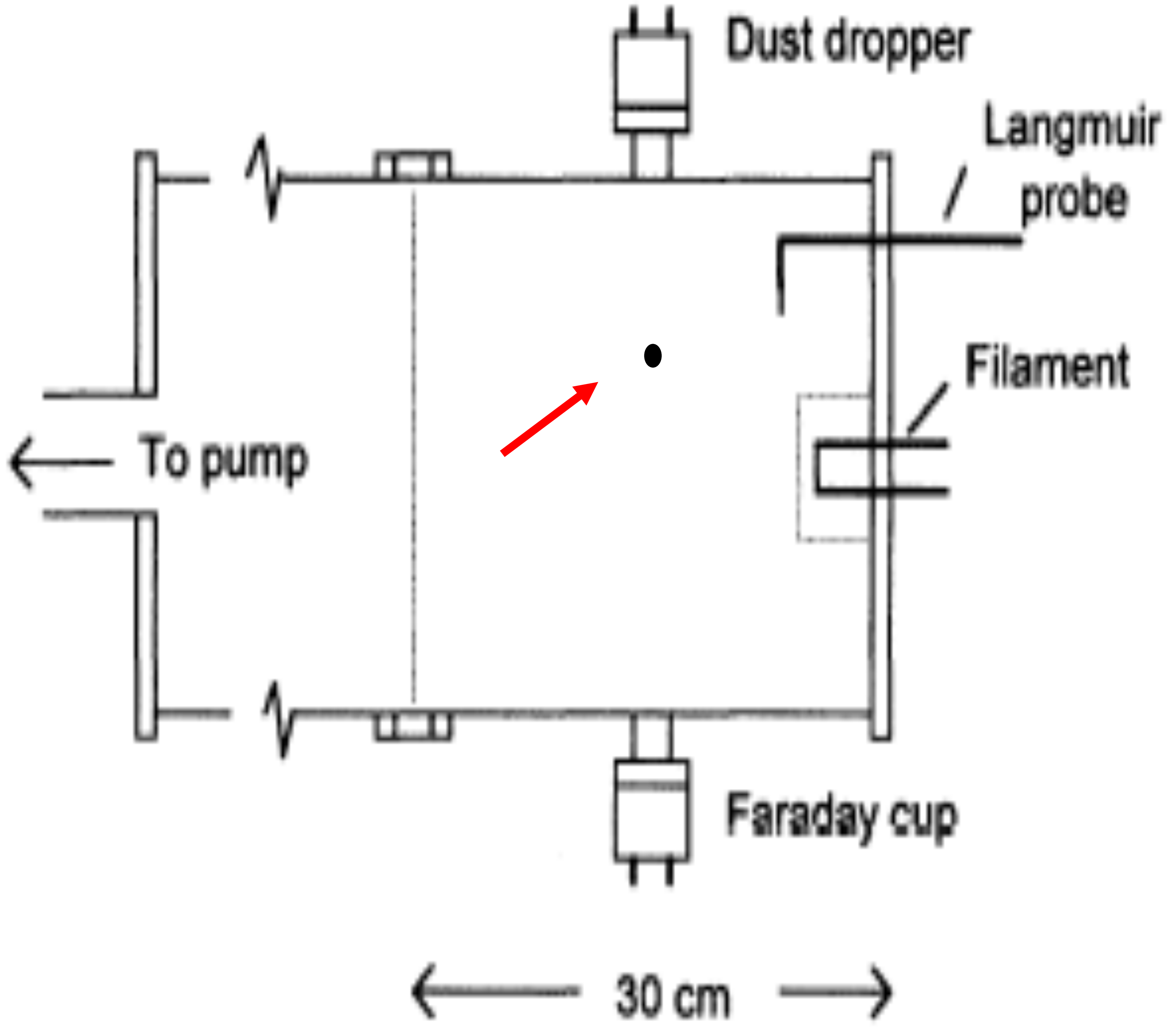
1 µm radius particle @ 1 AU

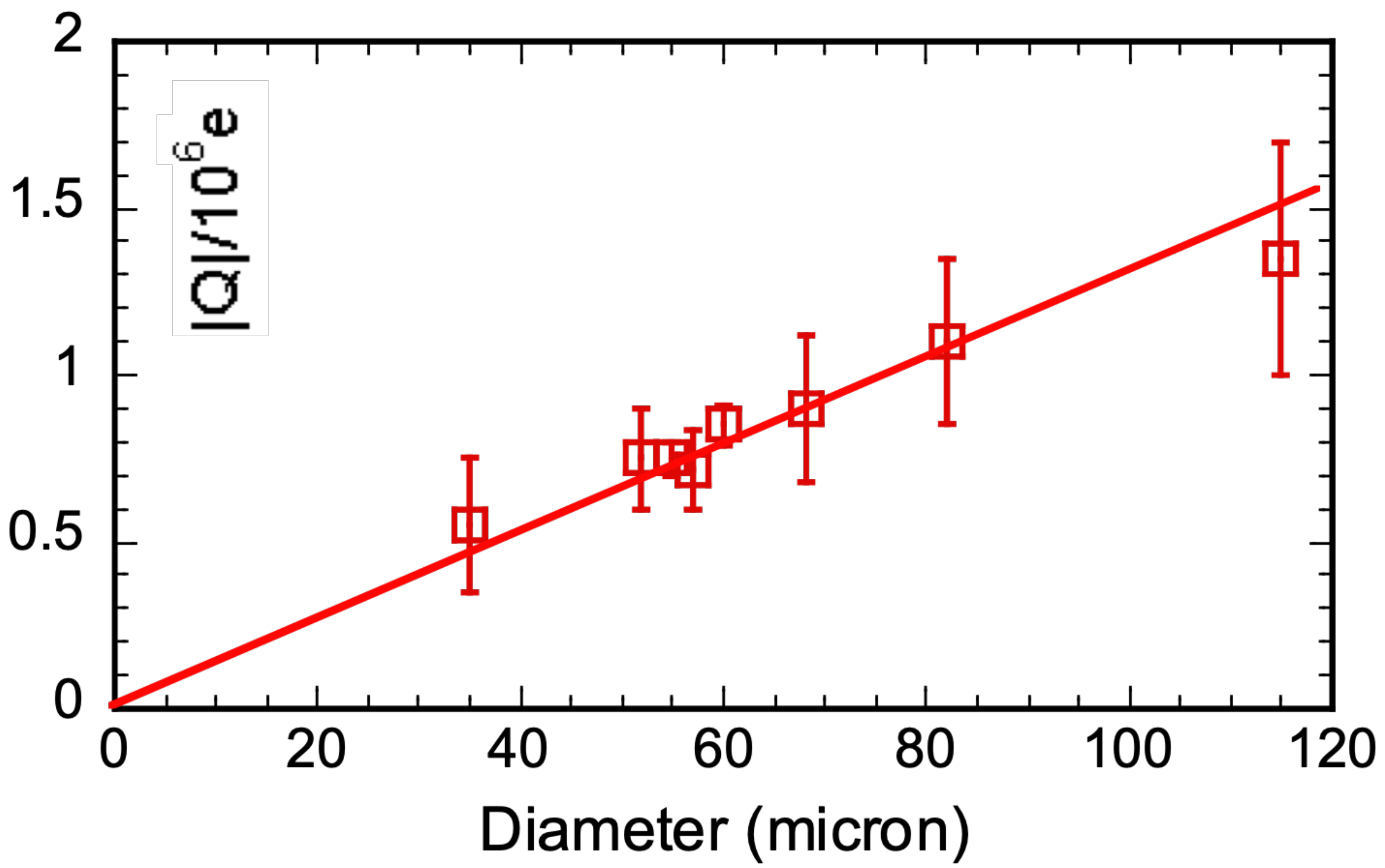
UV CHARGING

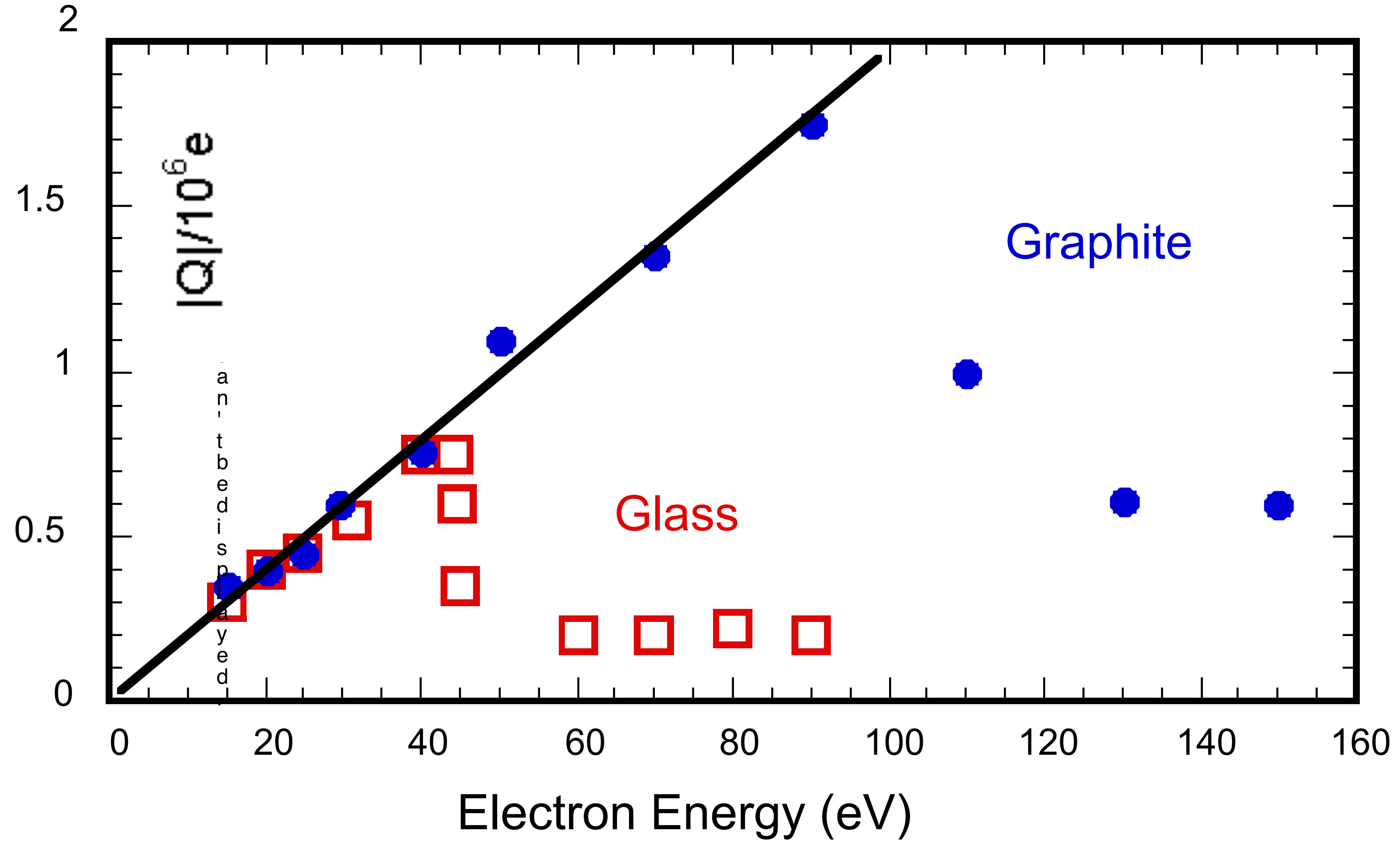


Sternovsky et al., 2008

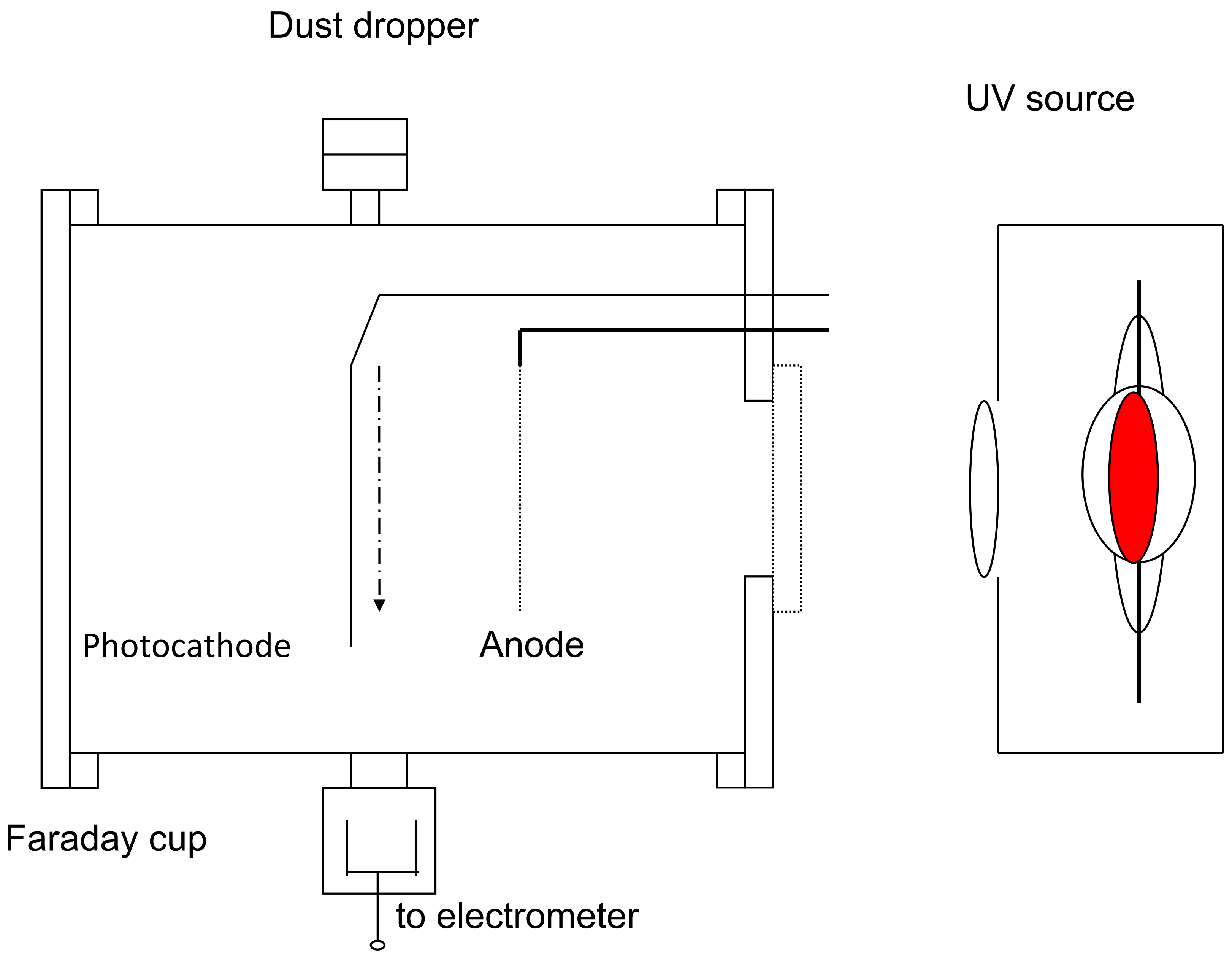
Dust Charge Measurements

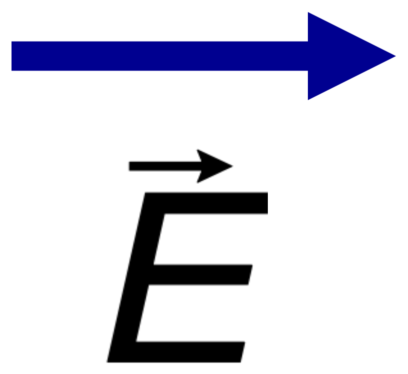


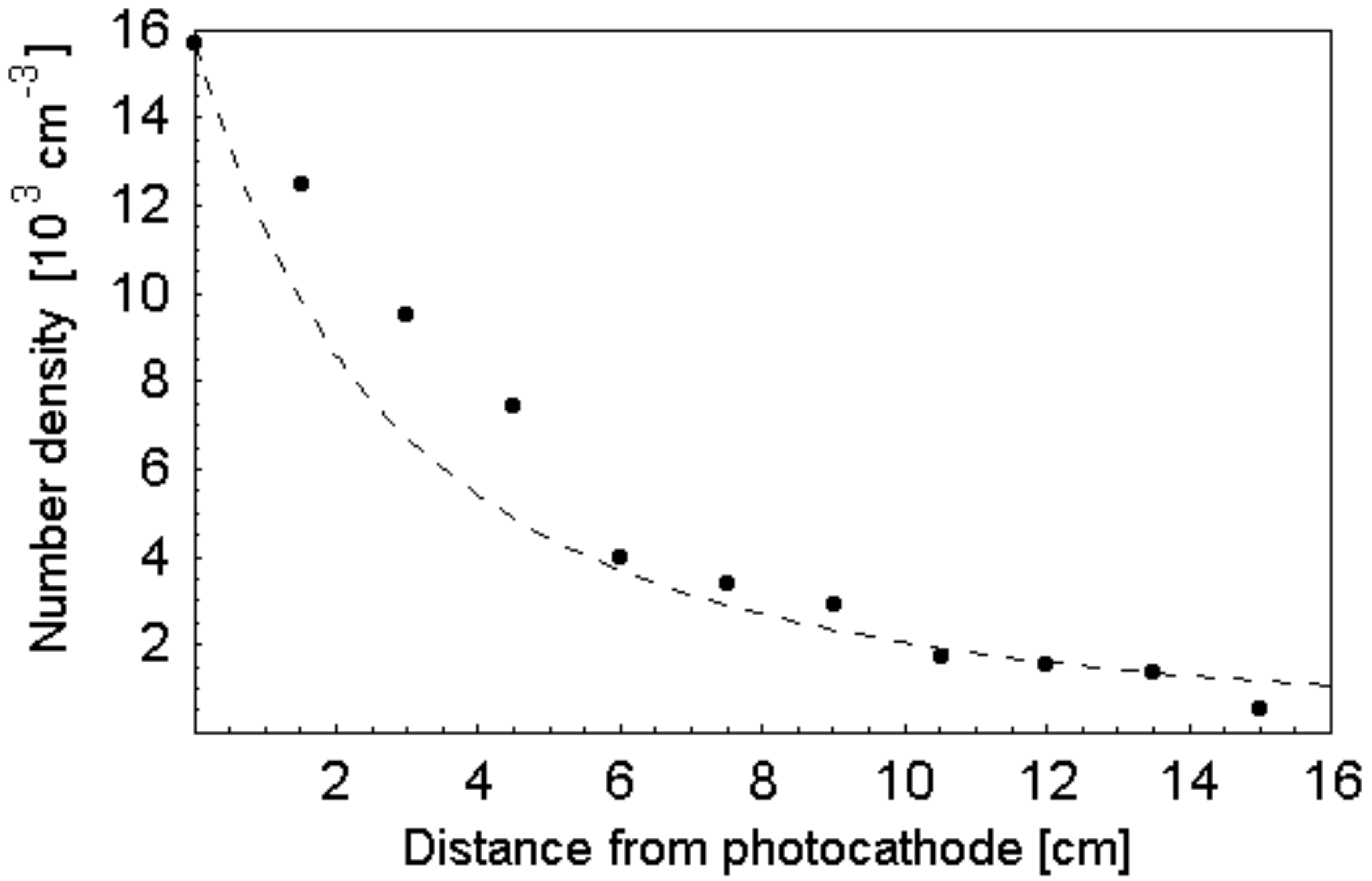


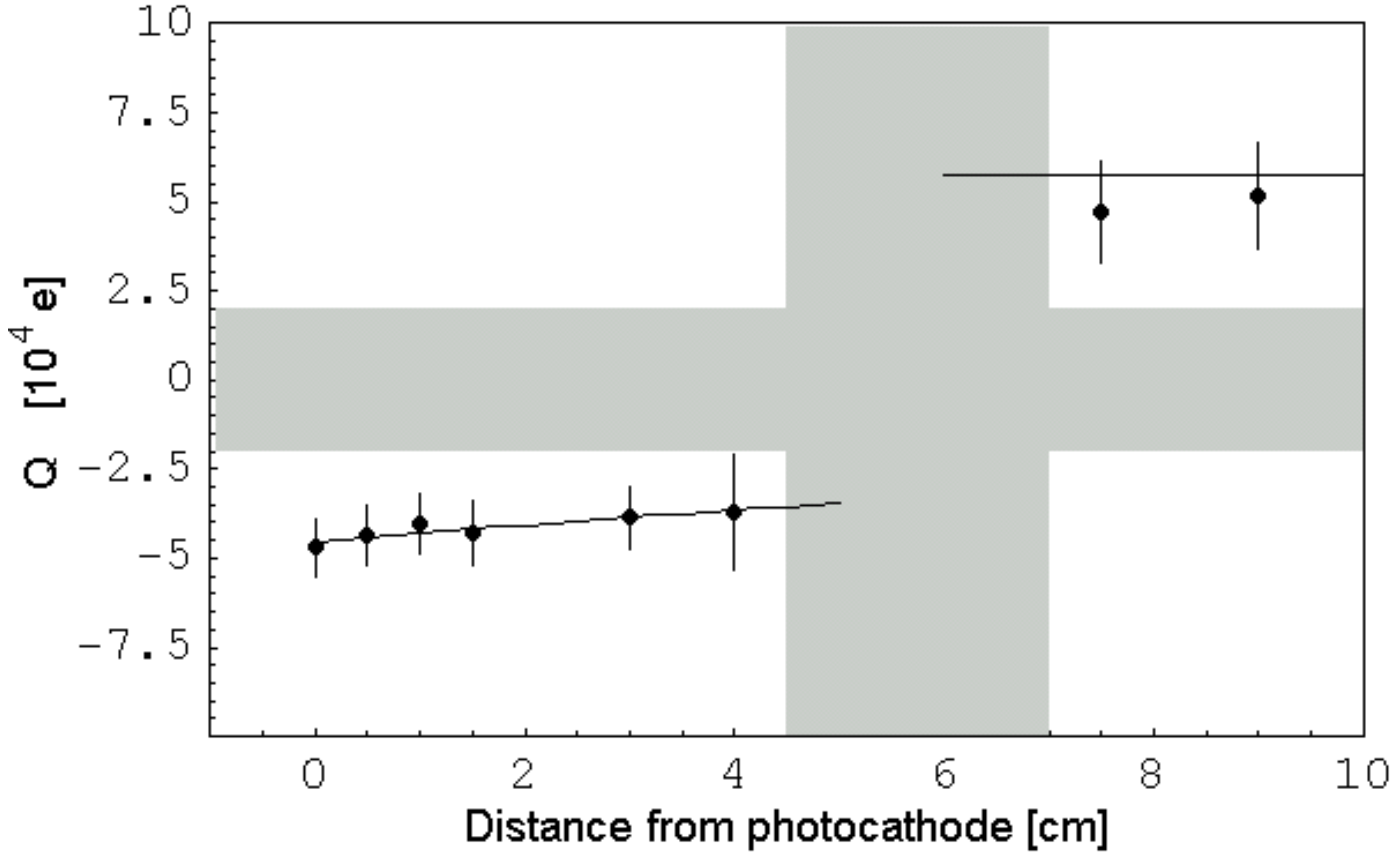


UV CHARGING

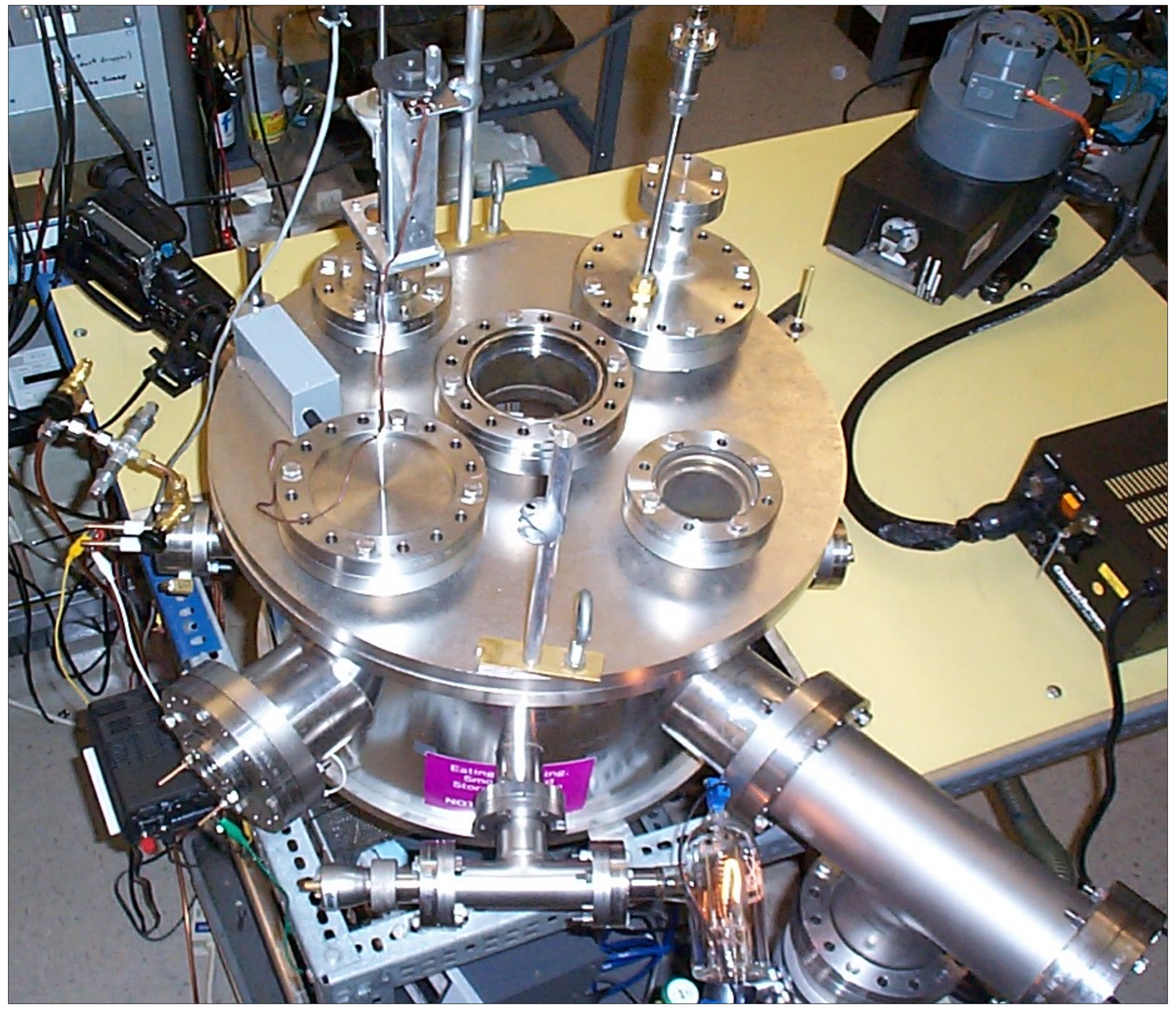

Dust dropper
UV source
Photocathode
Anode
Faraday cup
to electrometer

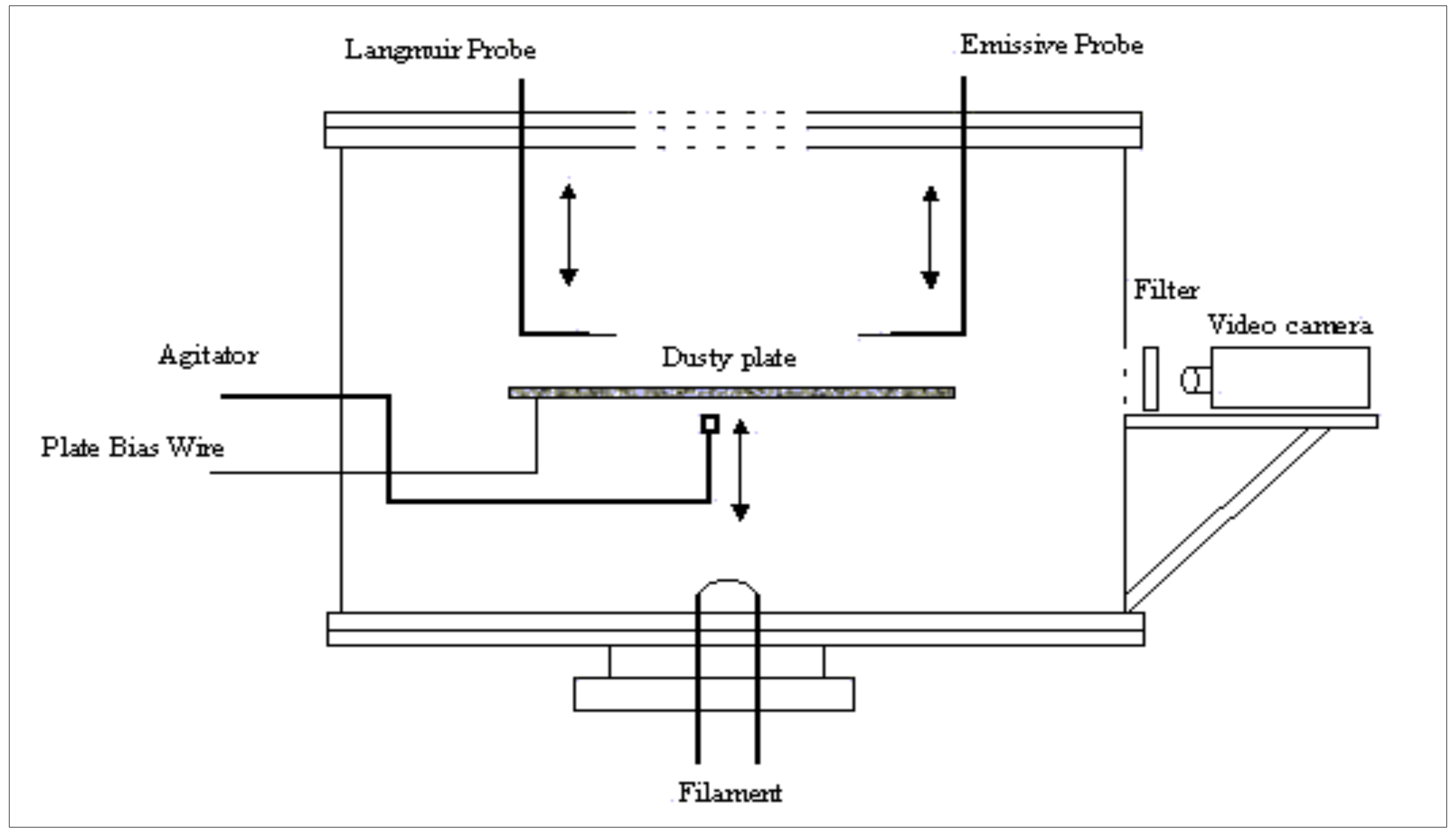

$\vec{E}$

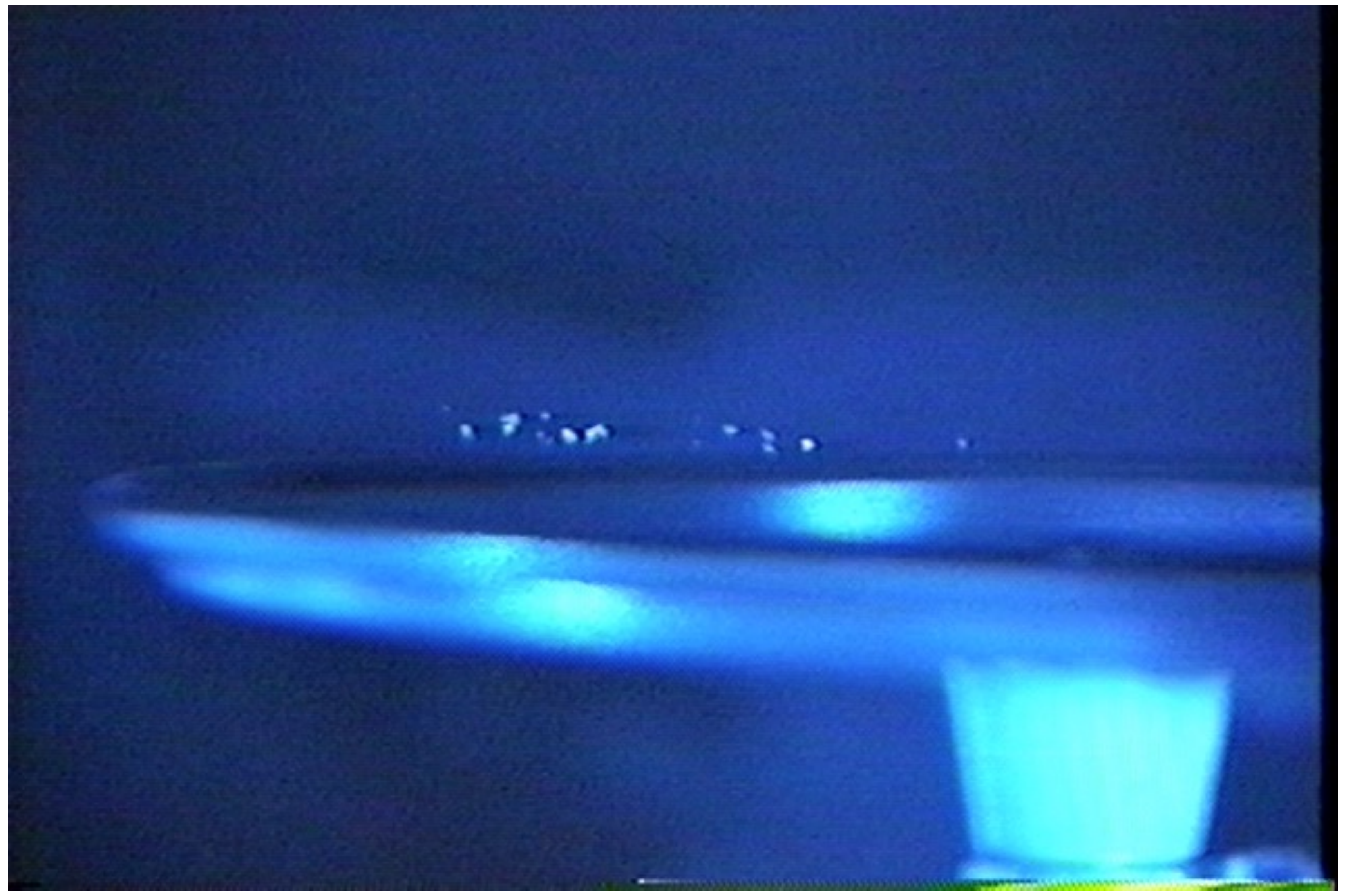

Number density [10^3 cm^{-3}]
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
Distance from photocathode [cm]


Q [10^4 e]
10
7.5
5
2.5
0
-2.5
-5
-7.5
0
2
4
6
8
10
Distance from photocathode [cm]

LEVITATING DUST

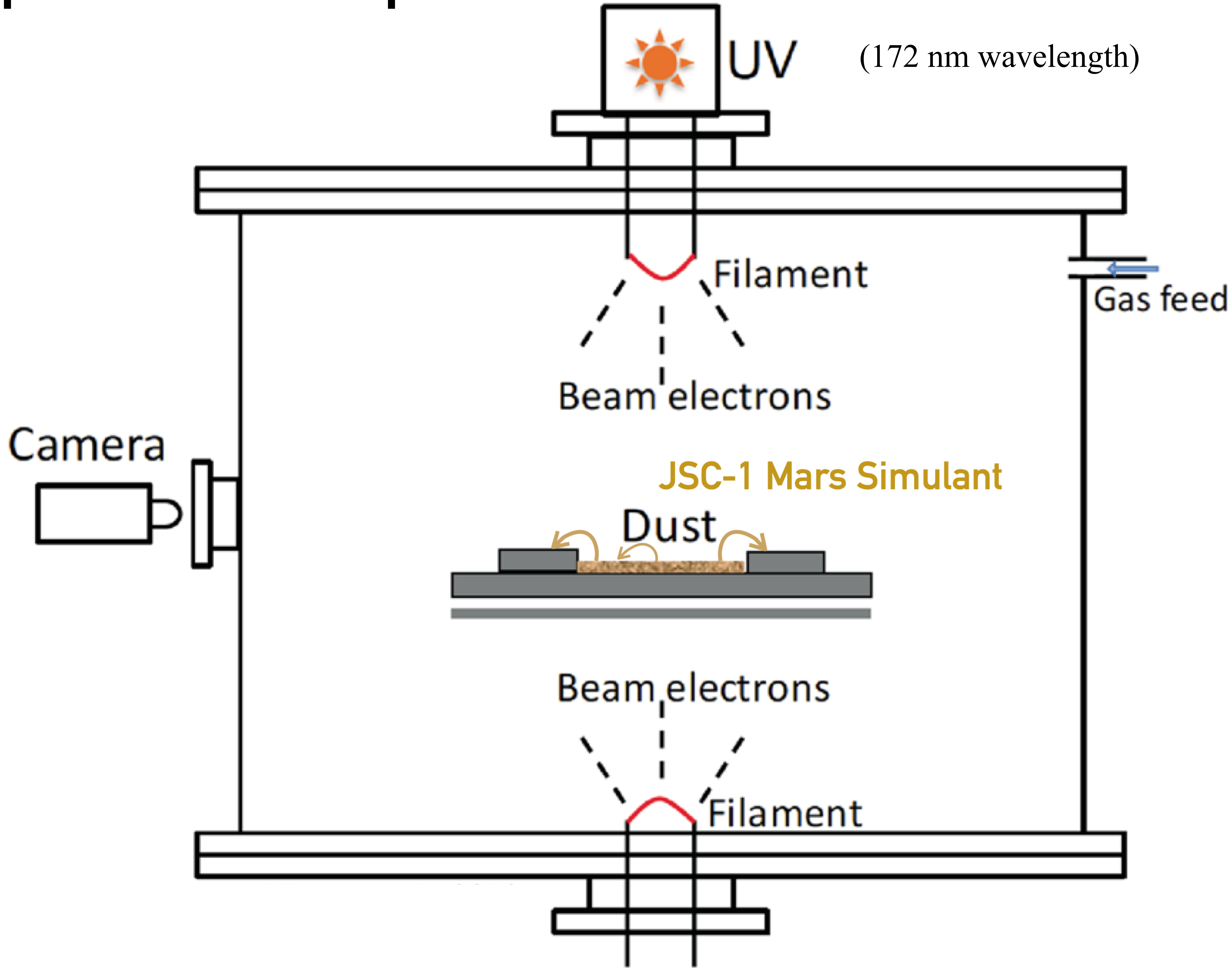






Sickafoose et al., 2002

Experimental Setup

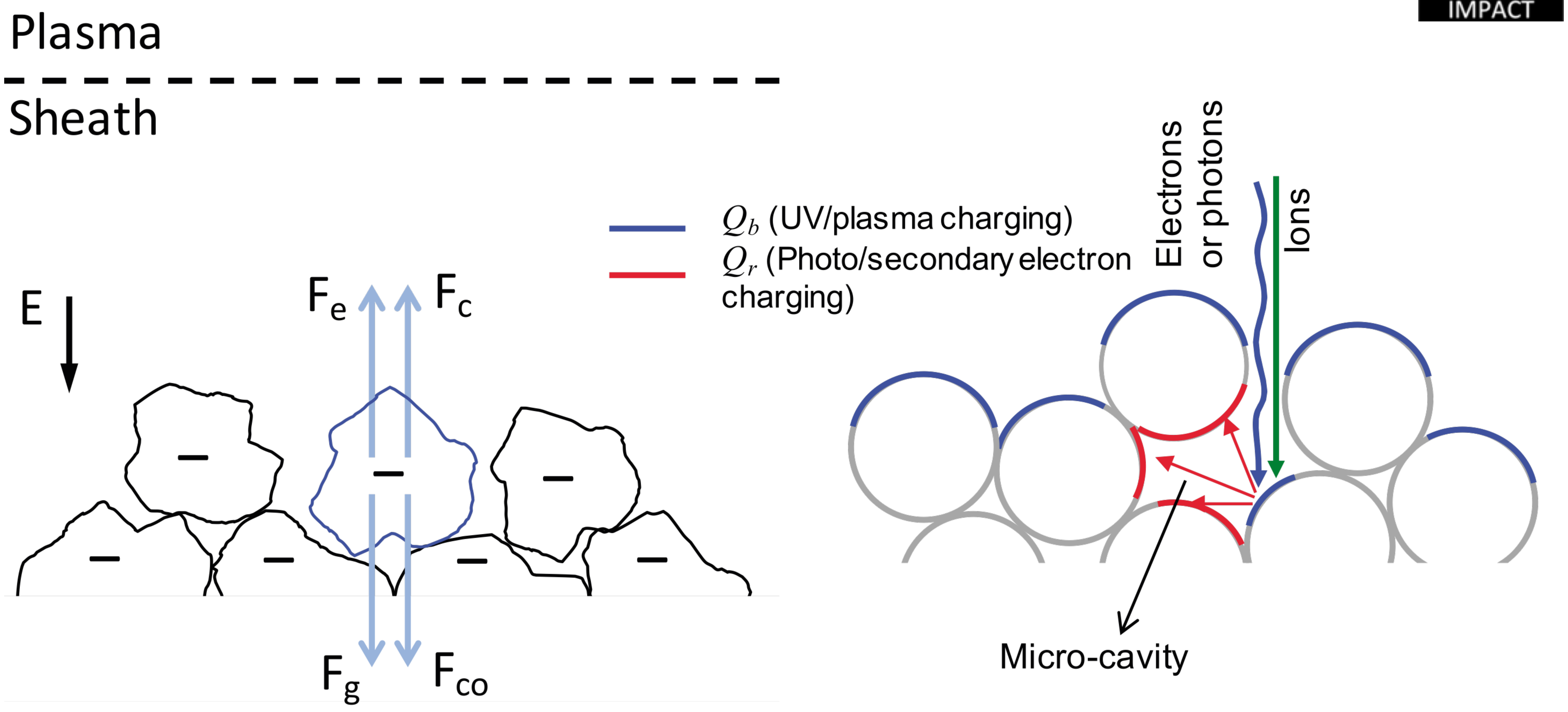


slow motion
2000 fps

Large negative charges under UV illumination!

Negative grid potential (-3 kV)

Positive grid potential (+0.5 kV)



(A)

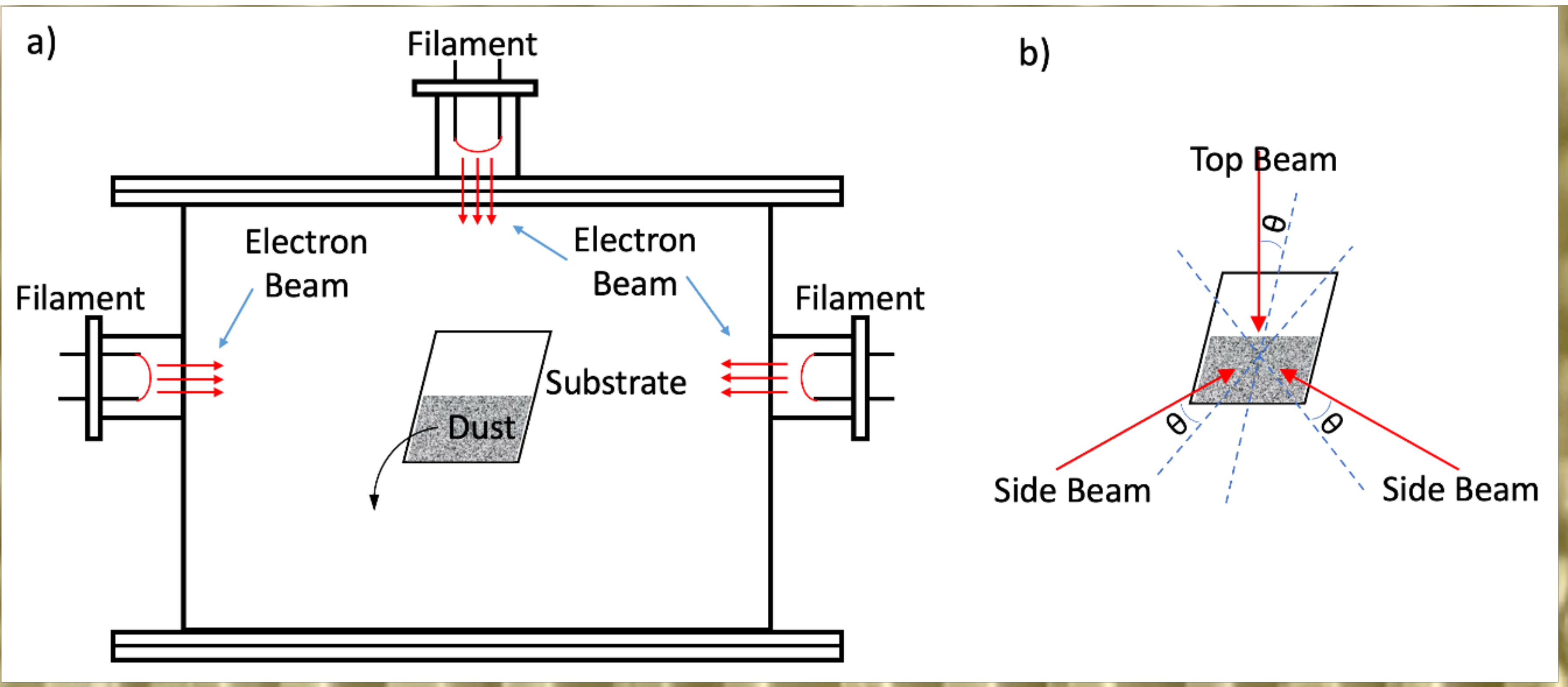
(B)

Wang et al., GRL, 2016

Schwan et al., GRL, 2017

Hood et al., GRL, 2018

Multiple Fixed Electron Beams



Farr et al., 2022

38-45 µ Mars [UV, 0.005mTorr, 1hr]

30-50 micron JSC

timelapse
1 fpm

1. **Dust charging can fundamentally shape the dynamics of small grains.**
2. **Dust immersed in plasmas can act as sinks or sources, altering the density, composition, and energy distribution of electrons and ions.**
3. **Charging of surfaces can be surprisingly complicated, leading to mobilization and transport.**

There is a lot of possible overlap between space and industrial problems.