Further Analysis on the Mystery of the Surveyor III Dust Deposits

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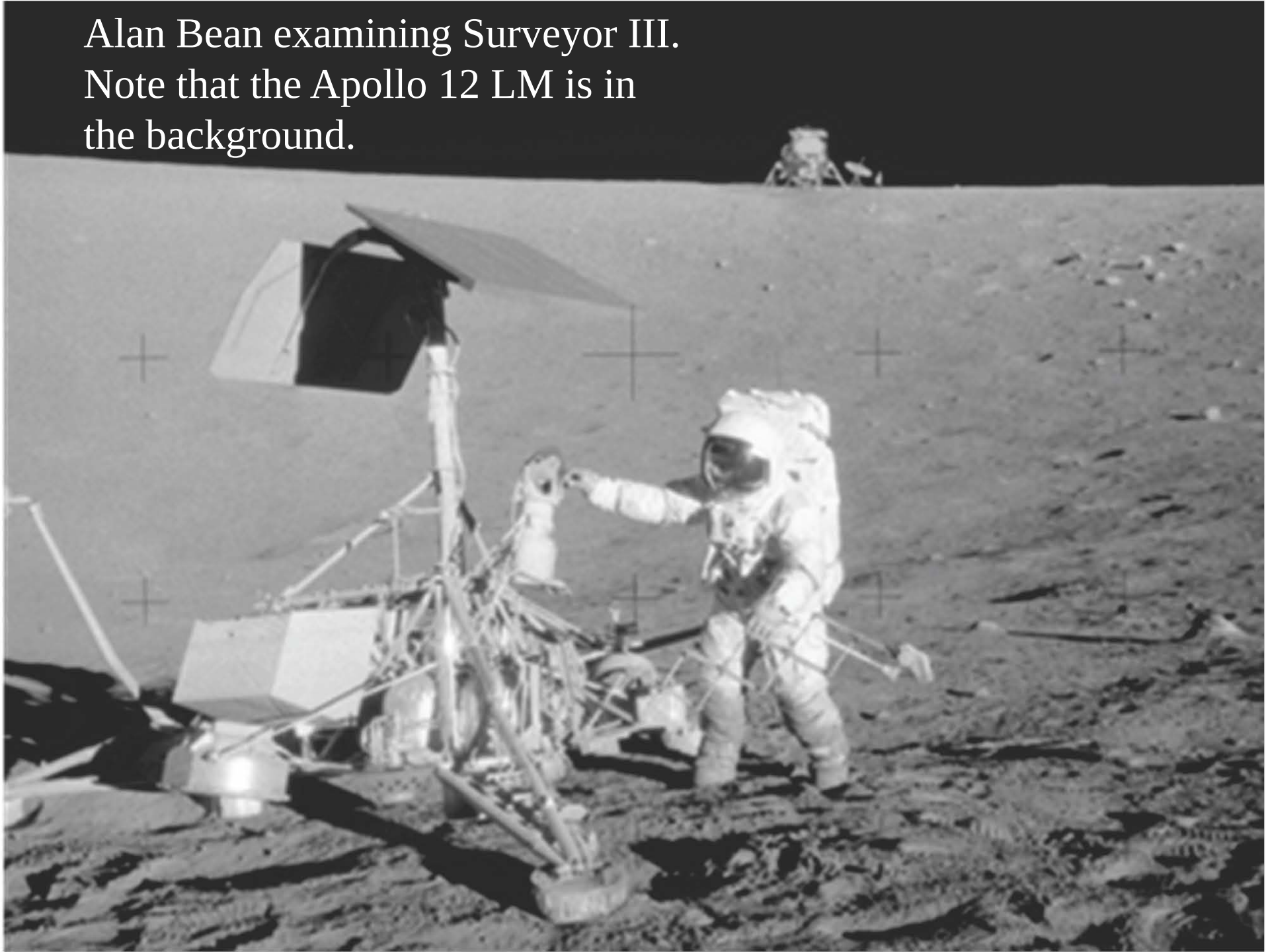
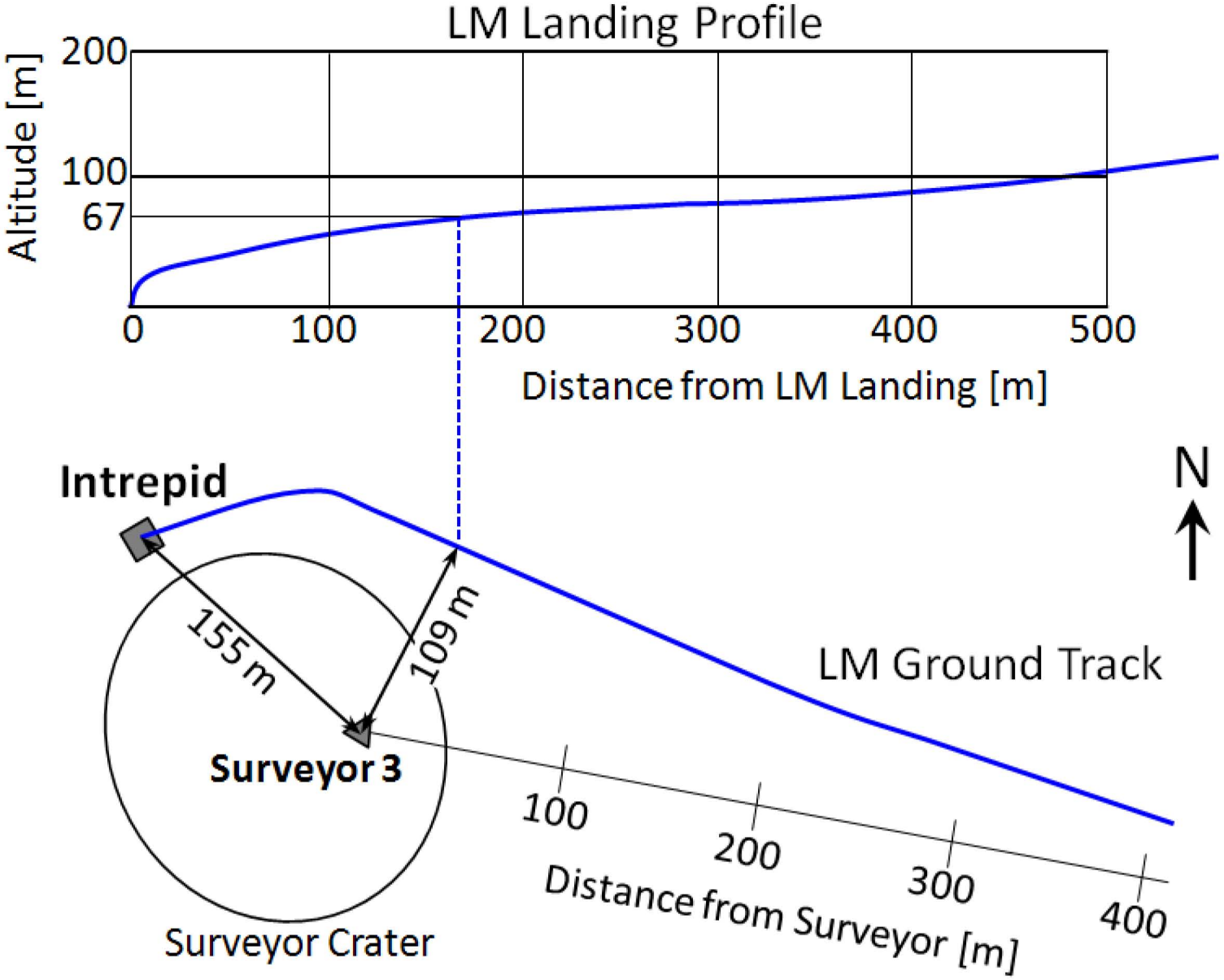
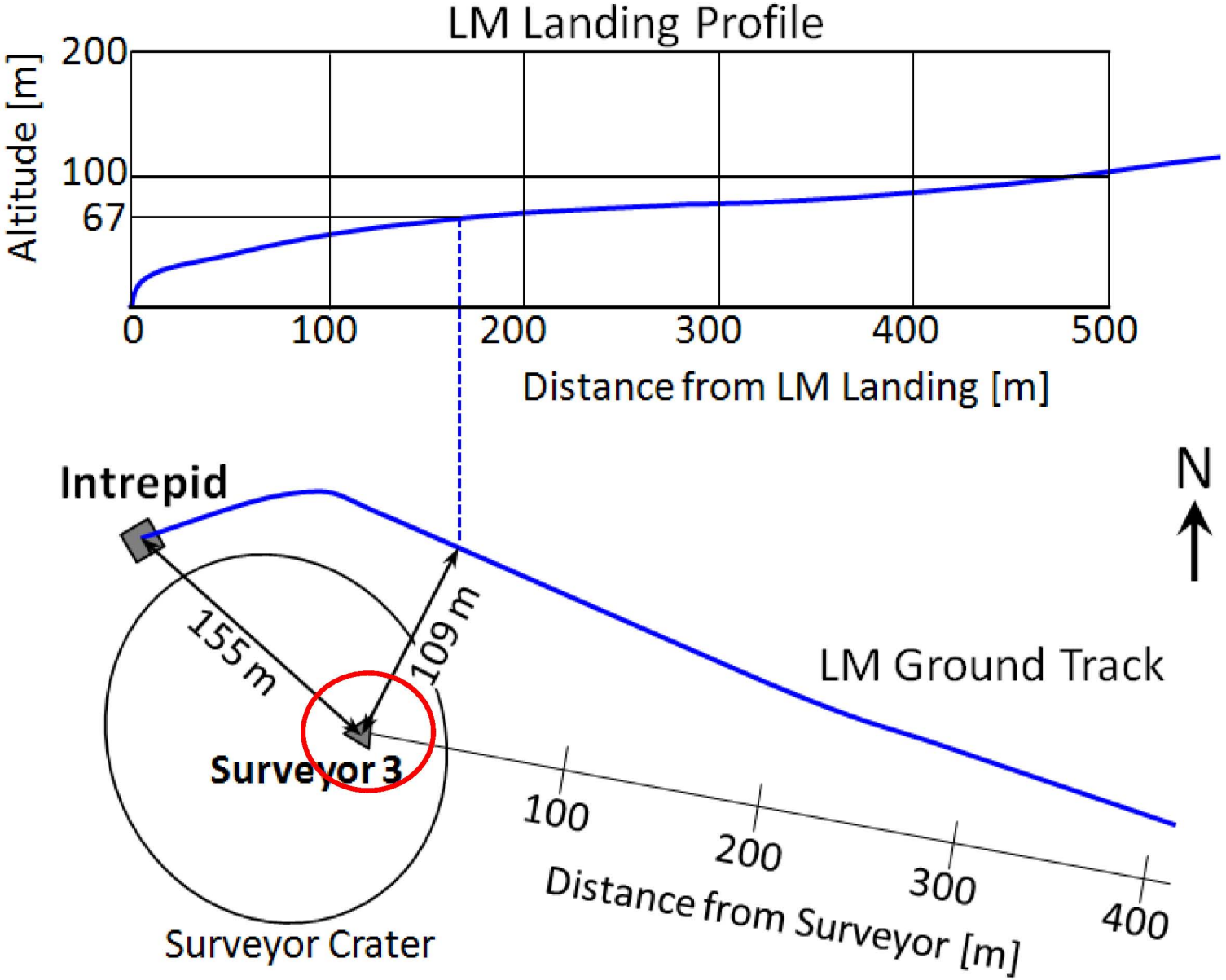
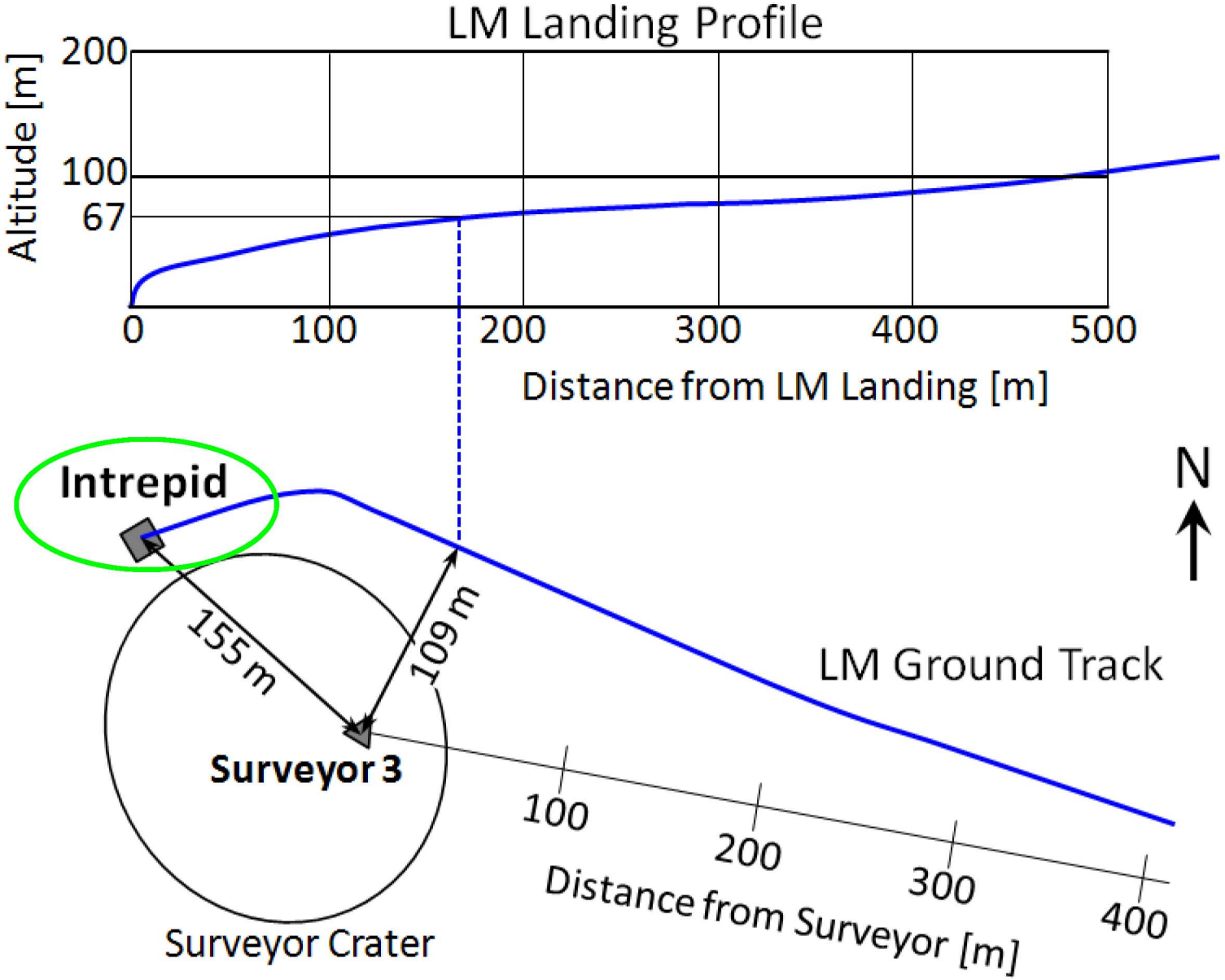
Background

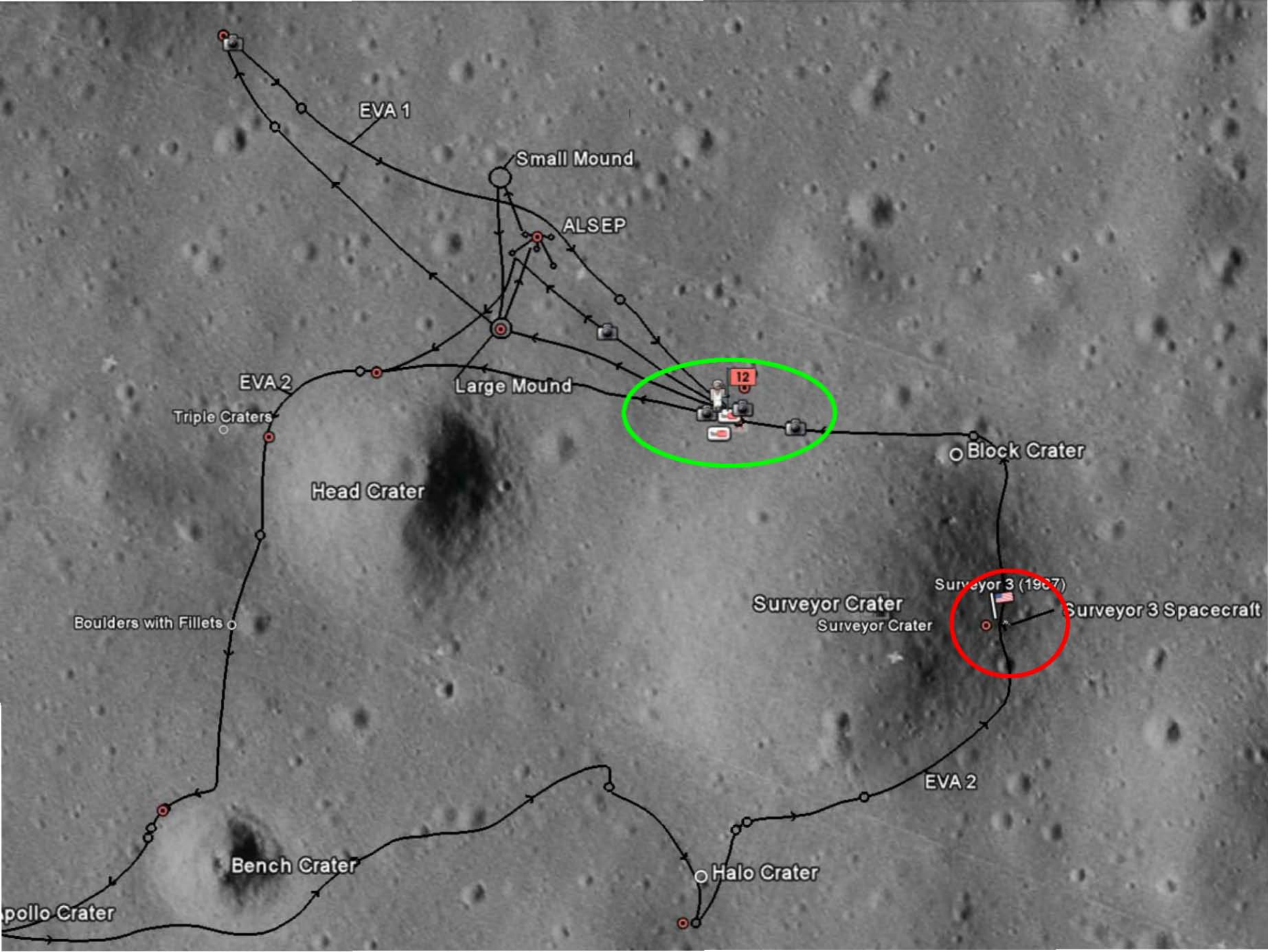
- The Apollo 12 lunar module (LM) landing near the Surveyor III spacecraft at the end of 1969 has remained the primary experimental verification of the predicted physics of plume ejecta effects from a rocket engine interacting with the surface of the moon.
- This was made possible by the return of the Surveyor III camera housing by the Apollo 12 astronauts, allowing detailed analysis of the composition of dust deposited by the LM plume.
- It was soon realized after the initial analysis of the camera housing that the LM plume tended to remove more dust than it had deposited.
- In the present study, coupons from the camera housing have been reexamined.
- In addition, plume effects recorded in landing videos from each Apollo mission have been studied for possible clues.

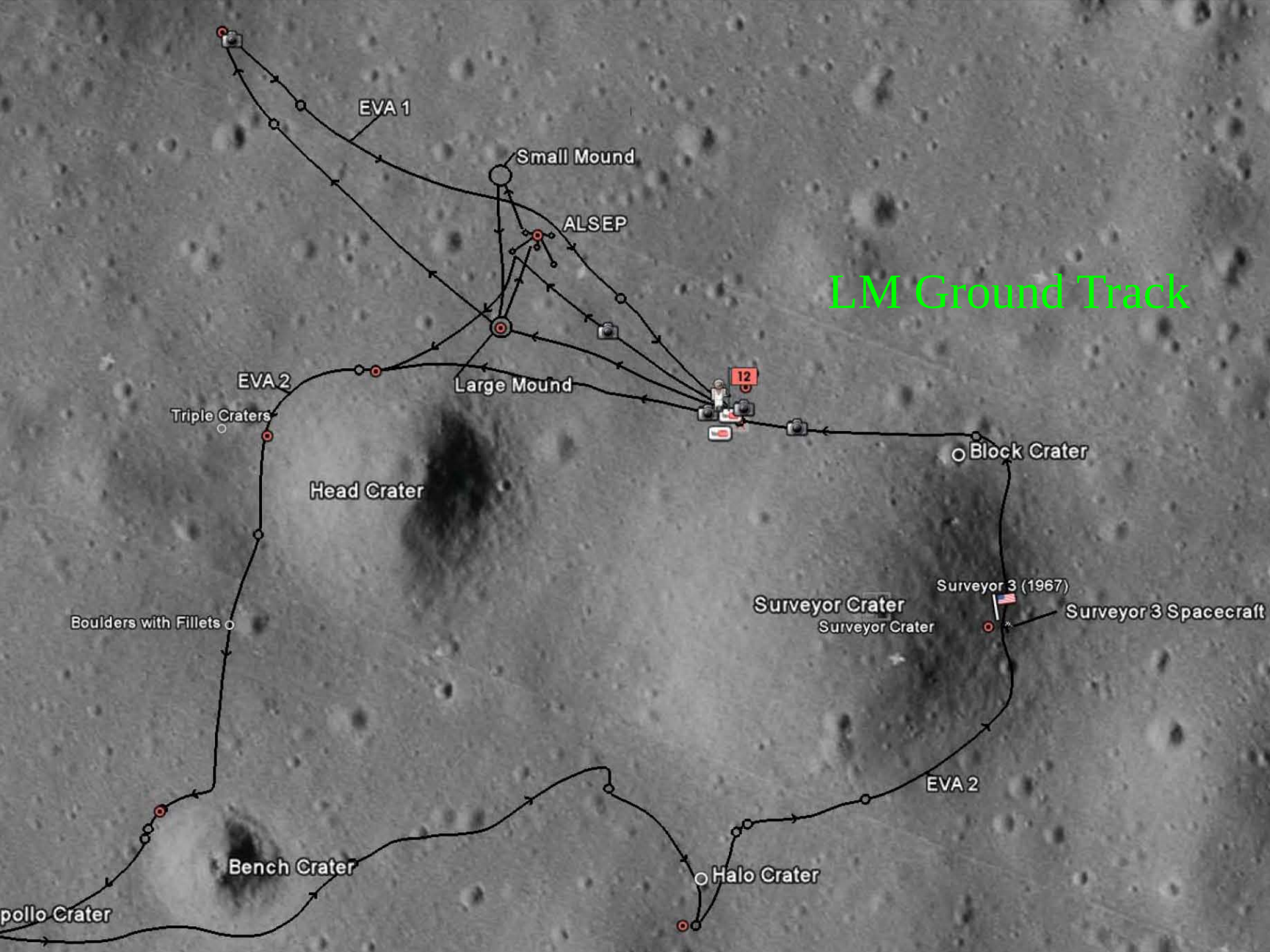

Alan Bean examining Surveyor III. Note that the Apollo 12 LM is in the background.

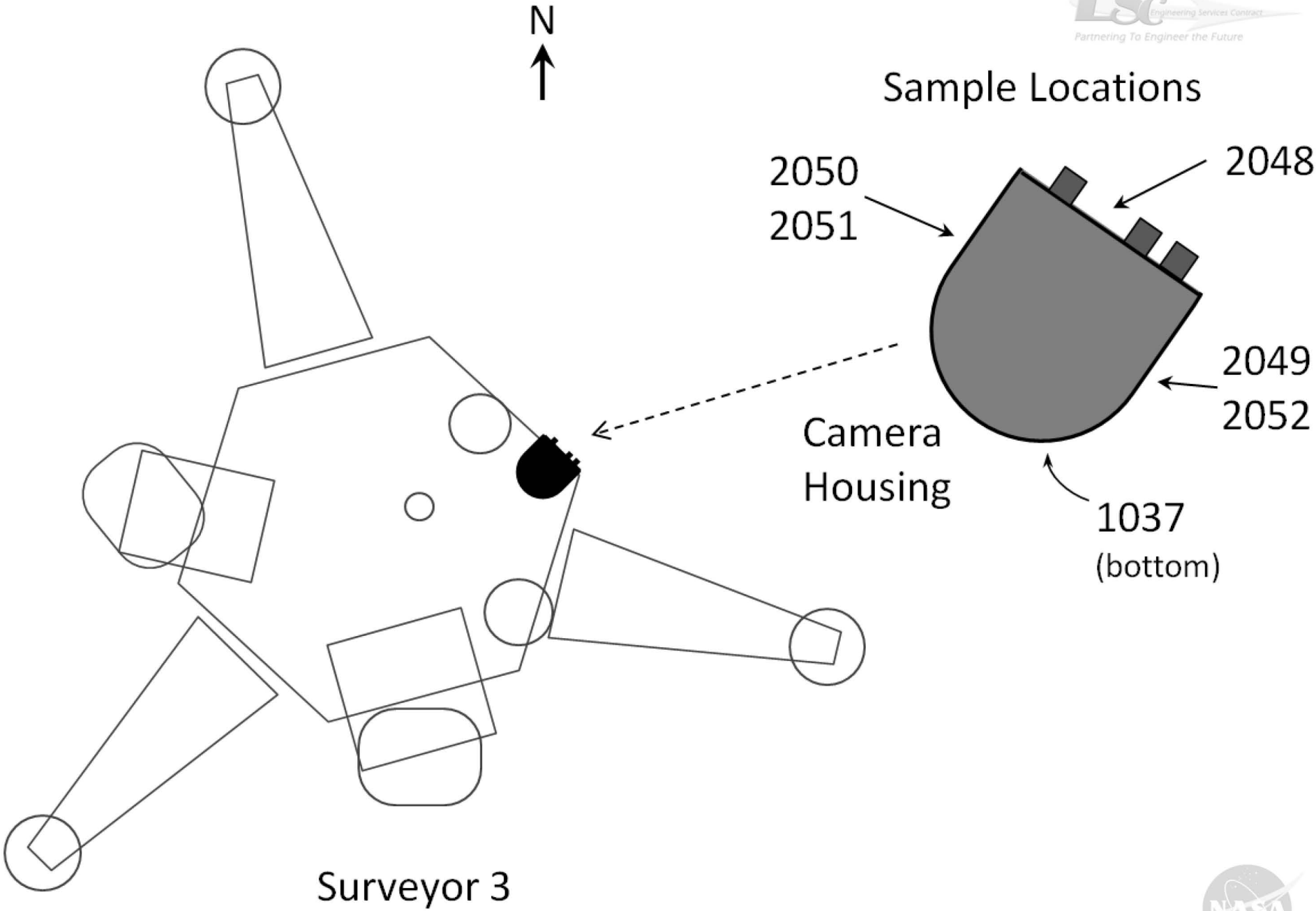

LM Landing Profile
Altitude [m]
200
100
67
0
100
200
300
400
500
Distance from LM Landing [m]
Intrepid
N
155 m
109 m
LM Ground Track
Surveyor 3
100
200
300
400
Distance from Surveyor [m]
Surveyor Crater

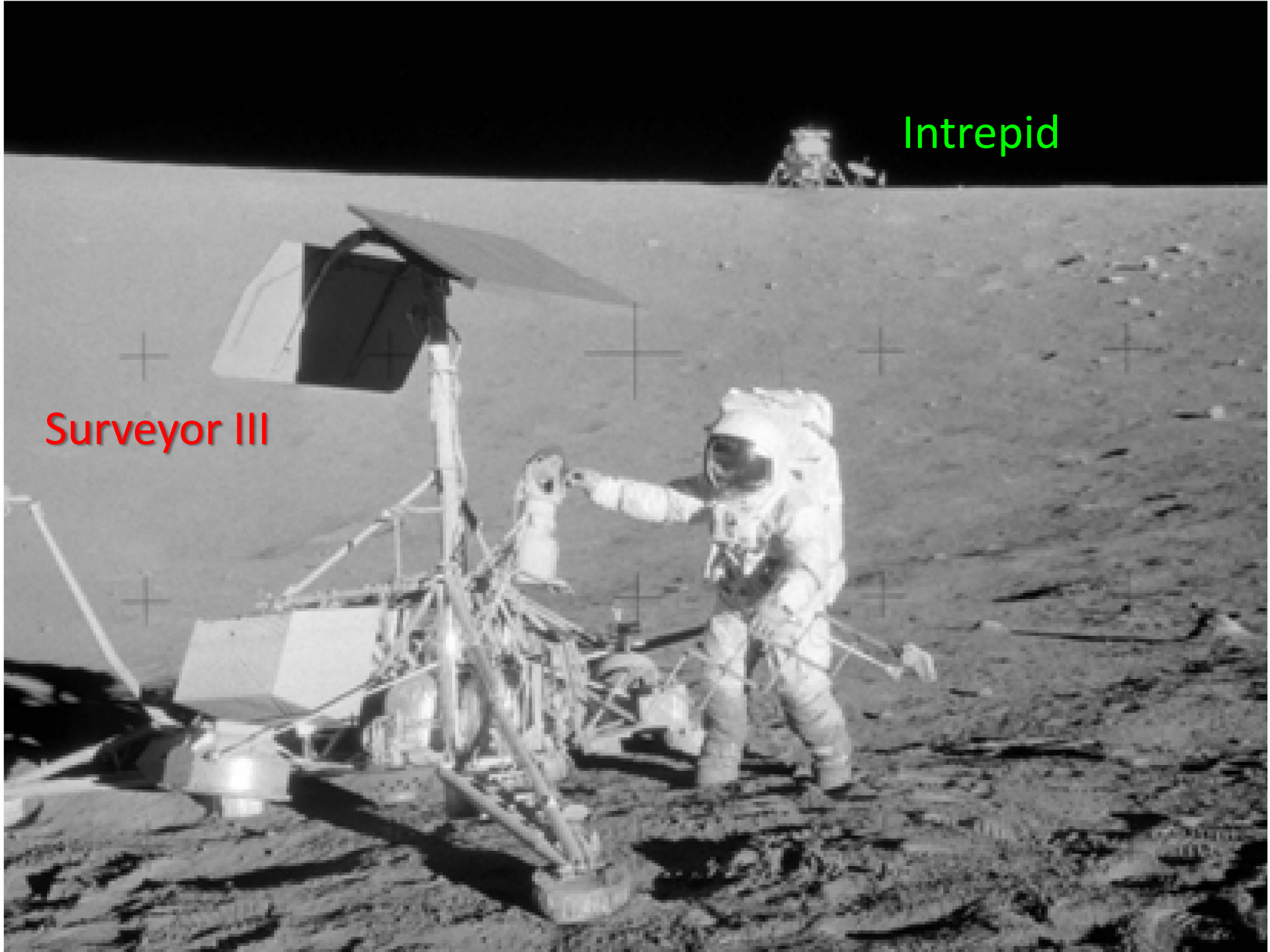

LM Landing Profile
Altitude [m]
200
100
67
0
100
200
300
400
500
Distance from LM Landing [m]
Intrepid
N
155 m
109 m
LM Ground Track
Surveyor 3
100
200
300
400
Distance from Surveyor [m]
Surveyor Crater

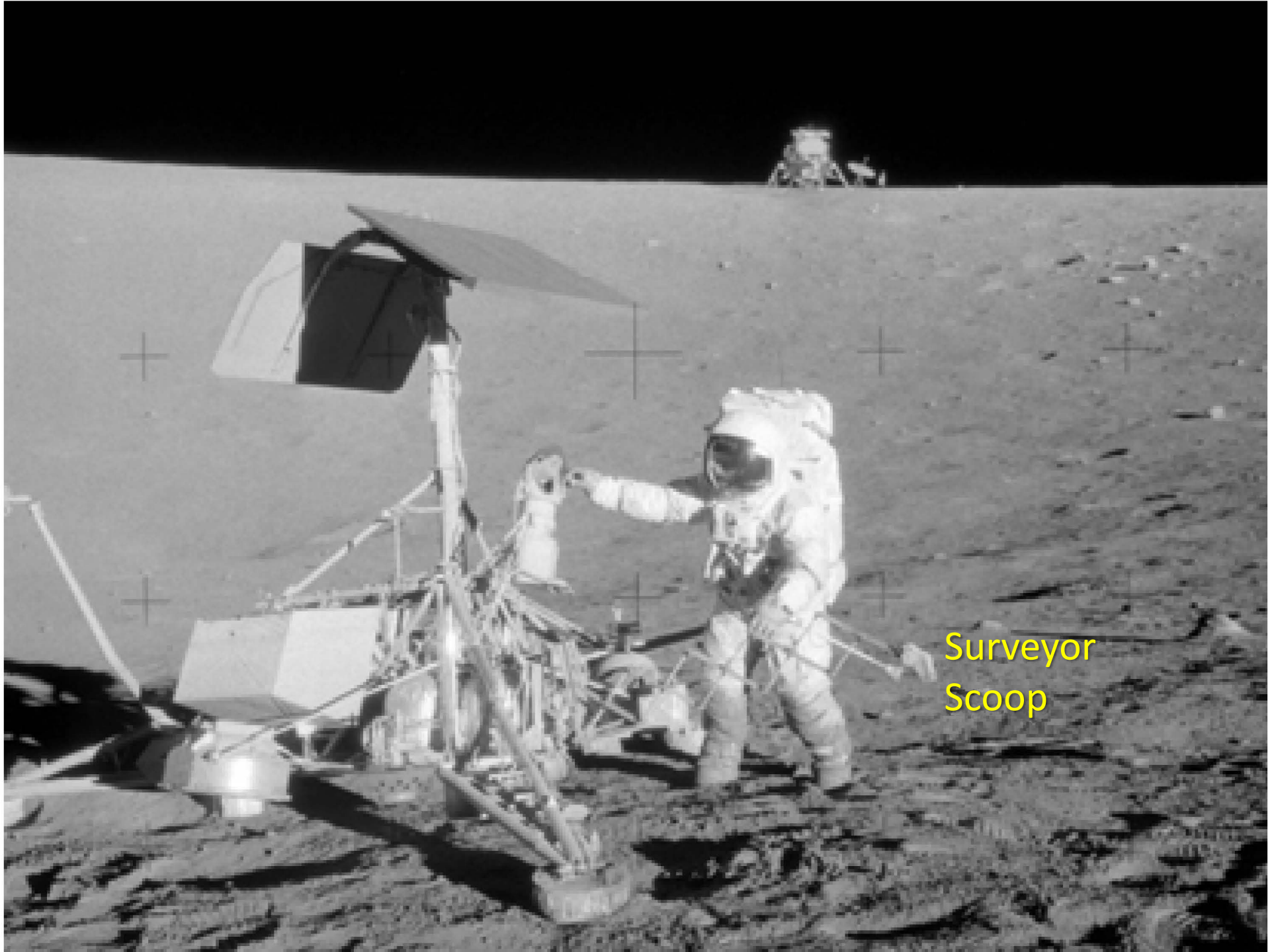

LM Landing Profile
Altitude [m]
200
100
67
0
100
200
300
400
500
Distance from LM Landing [m]
Intrepid
155 m
109 m
Surveyor 3
Surveyor Crater
N
LM Ground Track
100
200
300
400
Distance from Surveyor [m]

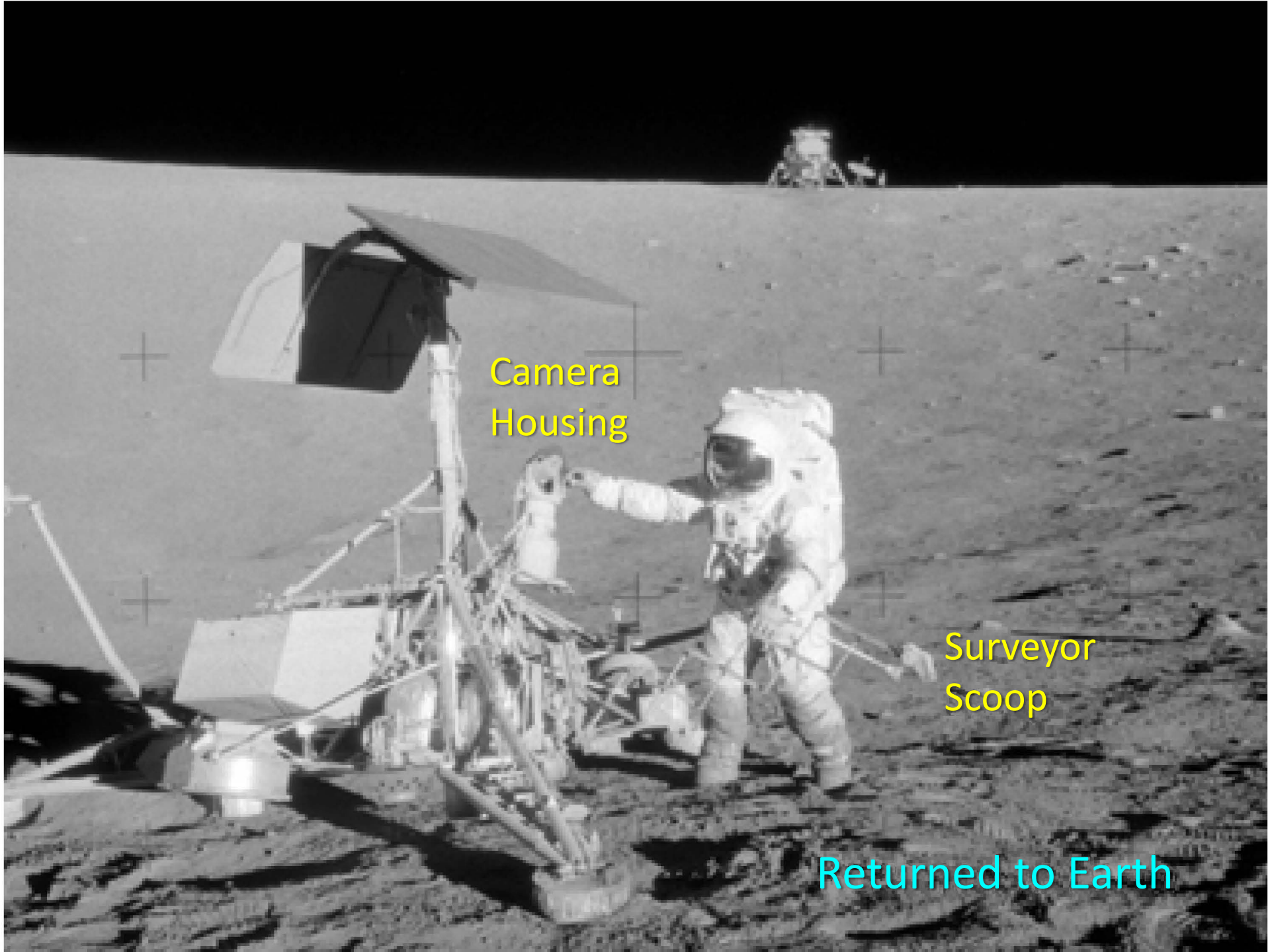

EVA 1
Small Mound
ALSEP
EVA 2
Large Mound
Triple Craters
12
Block Crater
Head Crater
Surveyor Crater
Surveyor Crater
Surveyor 3 Spacecraft
Boulders with Fillets
EVA 2
Bench Crater
Halo Crater


LM Ground Track
EVA 1
Small Mound
ALSEP
EVA 2
Large Mound
12
Triple Craters
Block Crater
Head Crater
Surveyor 3 (1967)
Surveyor Crater
Surveyor Crater
Surveyor 3 Spacecraft
Boulders with Fillets
EVA 2
Bench Crater
Halo Crater
pollo Crater

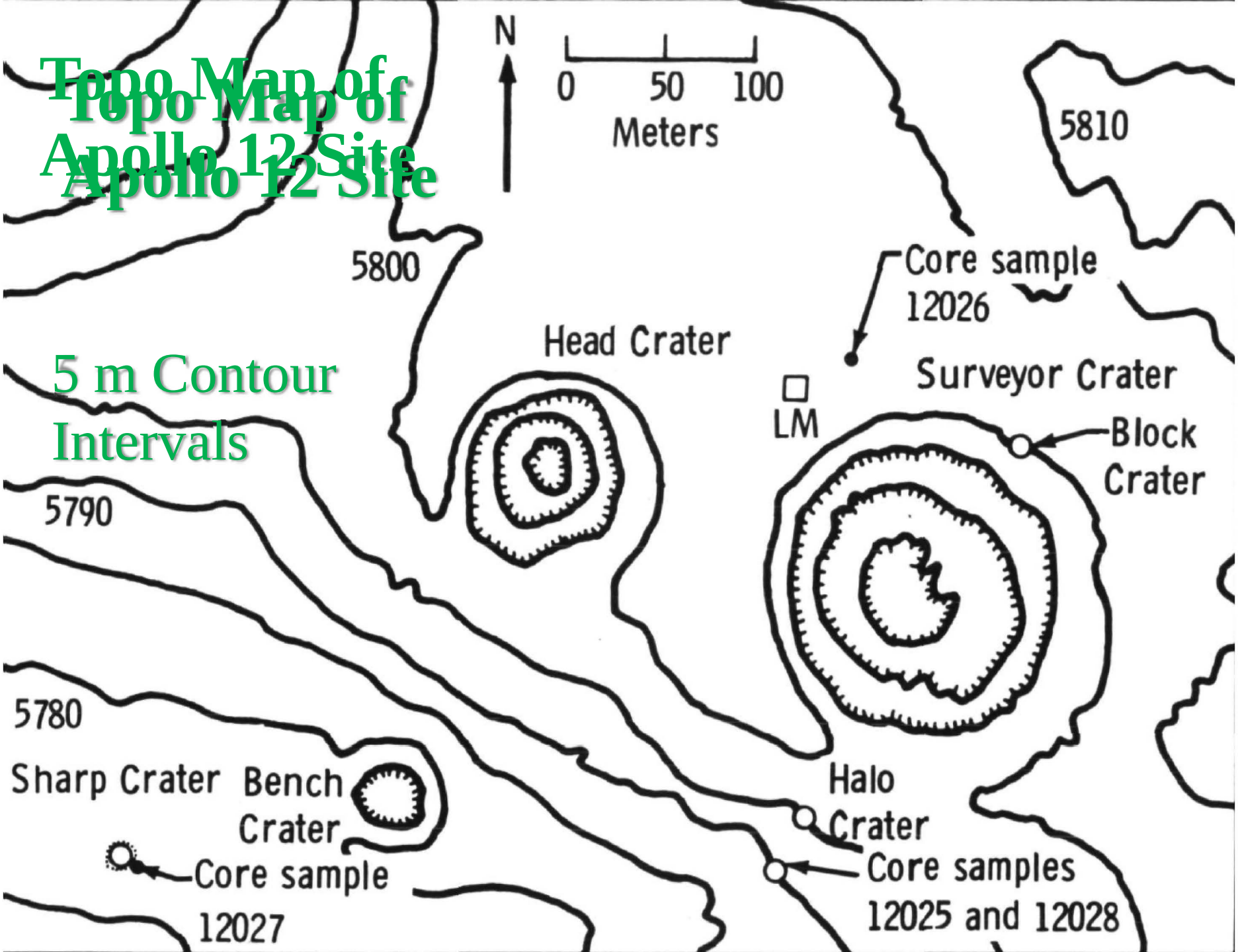

N
Sample Locations
2050
2051
2048
2049
2052
Camera
Housing
1037
(bottom)
Surveyor 3


Intrepid
Surveyor III


Surveyor
Scoop


Camera
Housing
Surveyor
Scoop
Returned to Earth

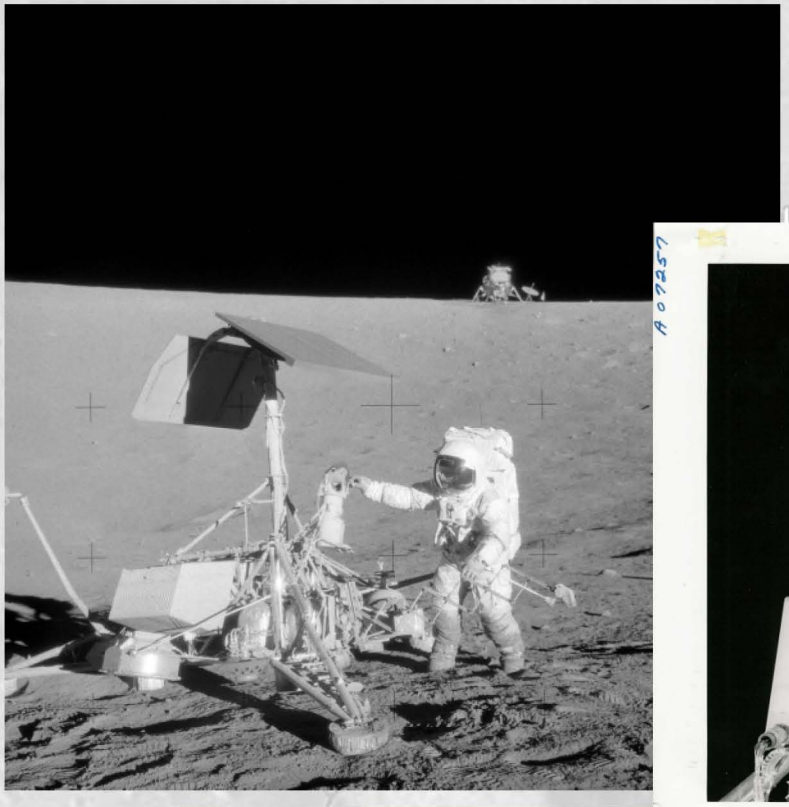
Topo Map of Apollo 12 Site

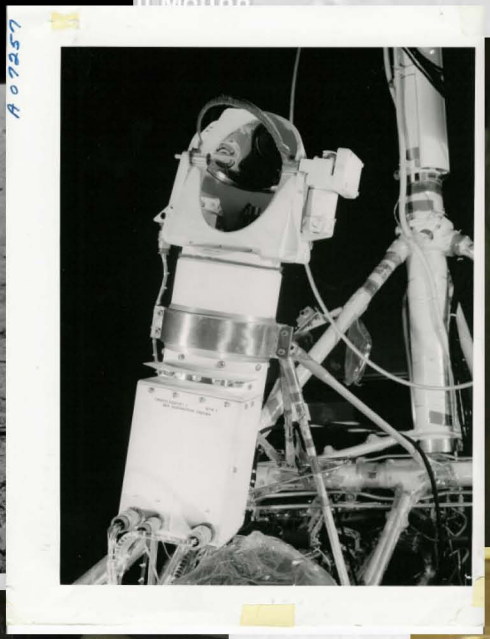


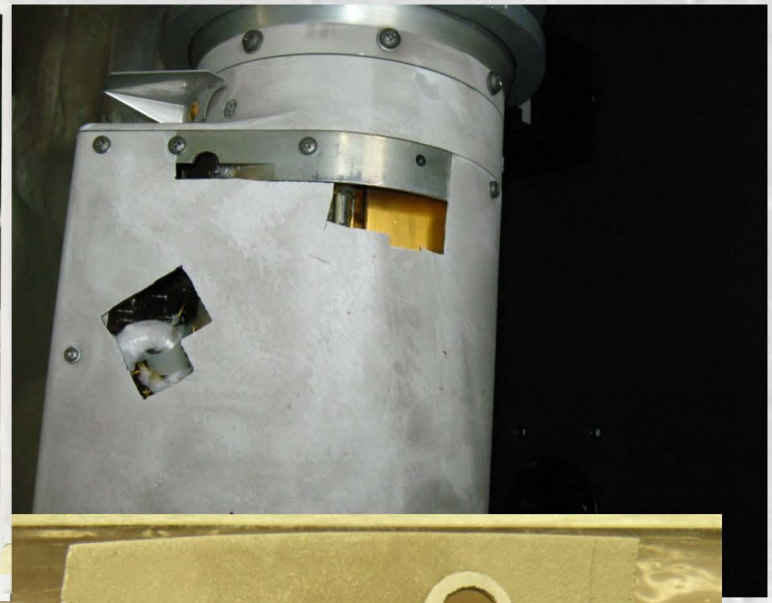
5 m Contour Intervals

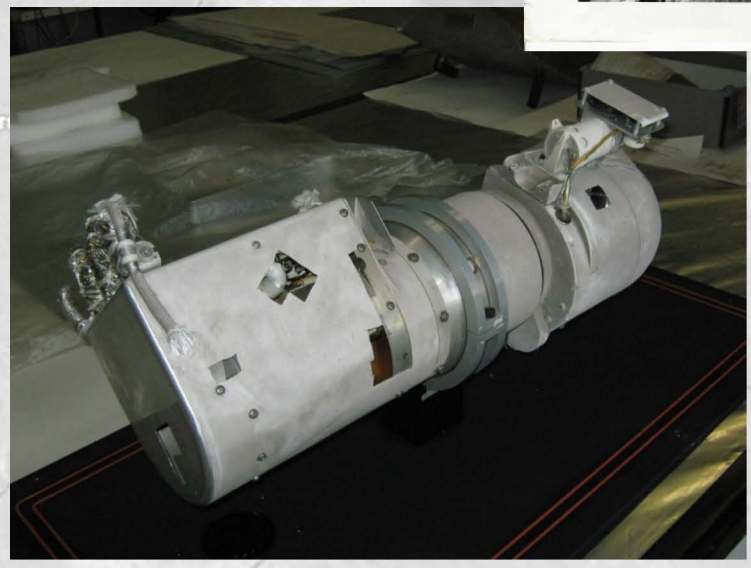
Surveyor Housing

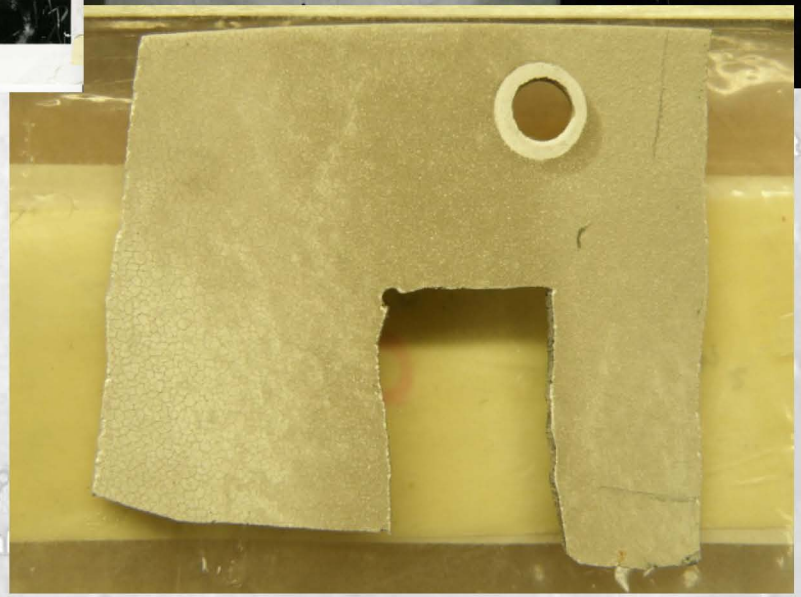
Sample #2050



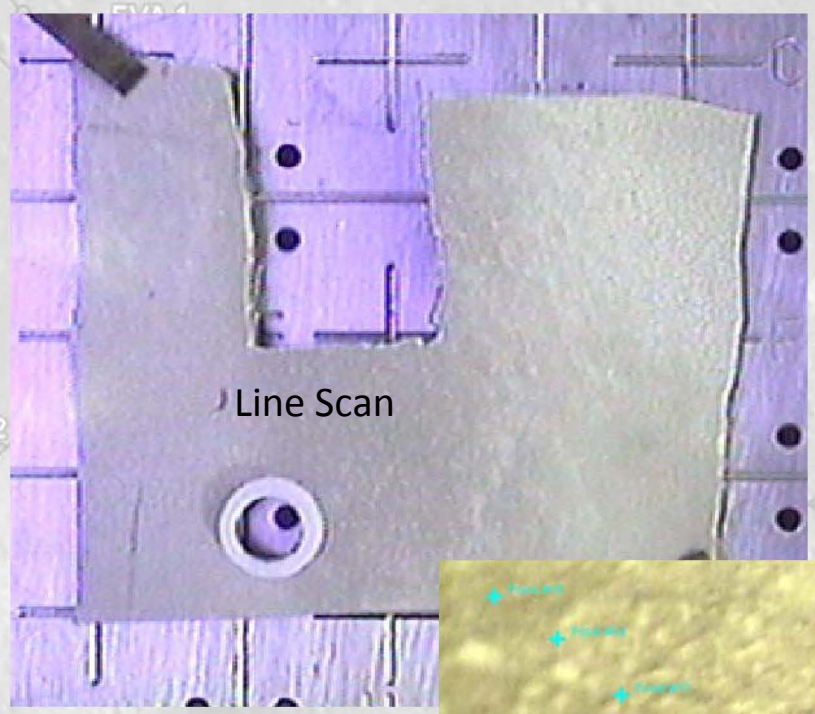






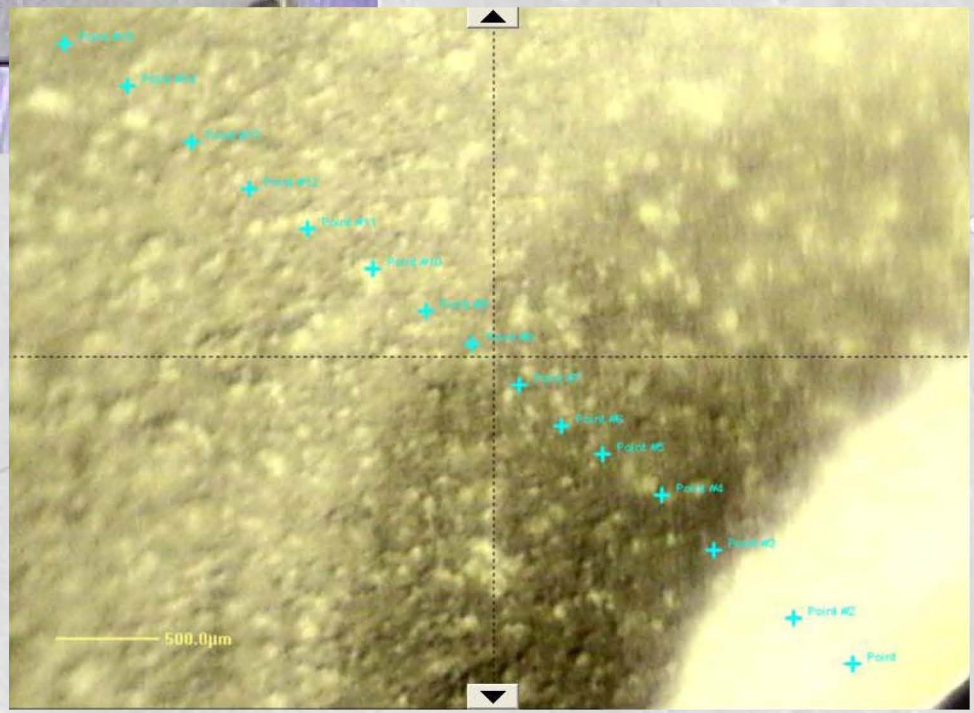


X-Ray Photoelectron Spectroscopy (XPS)

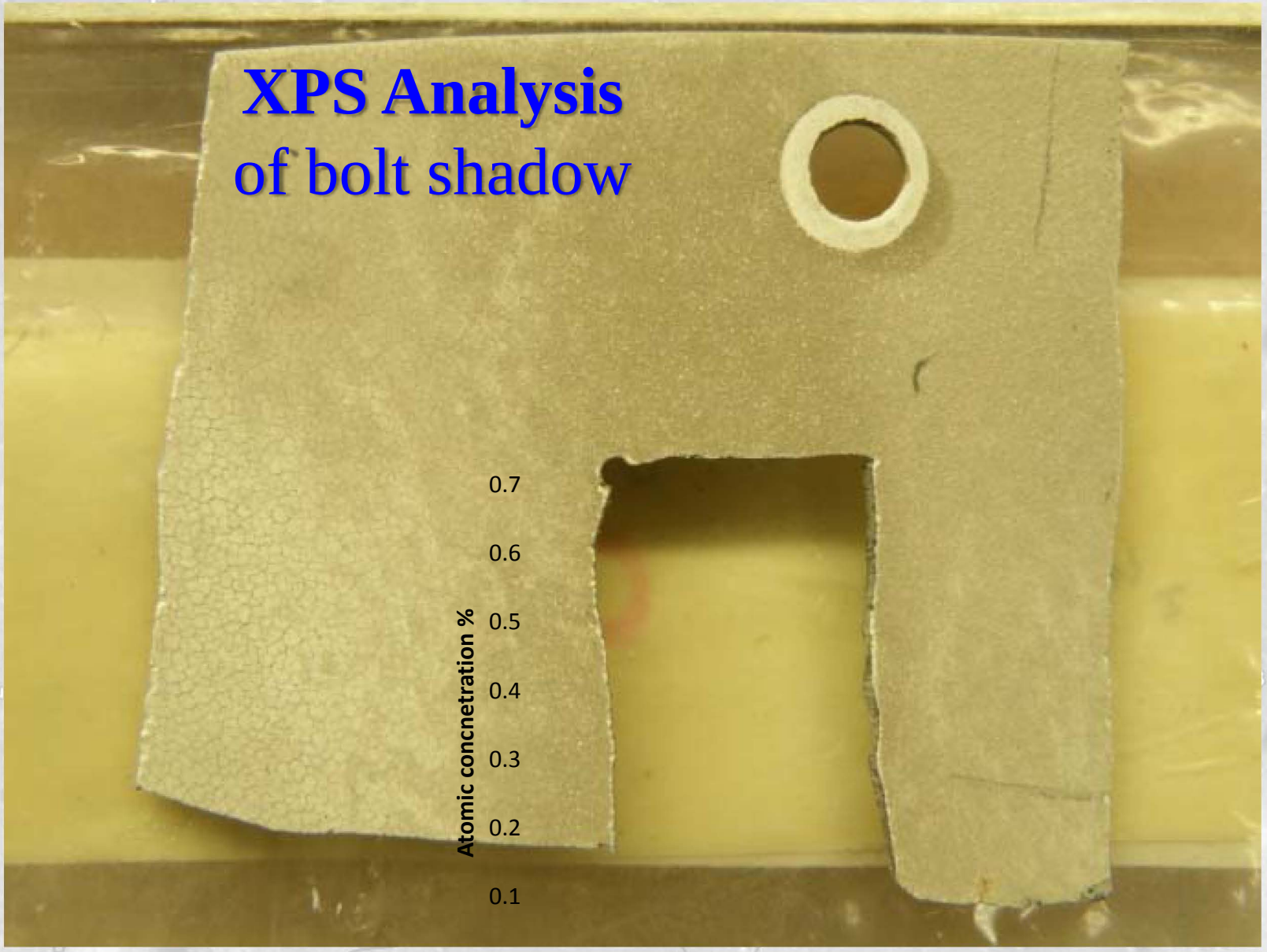


Surveyor III
Camera Housing
Coupon

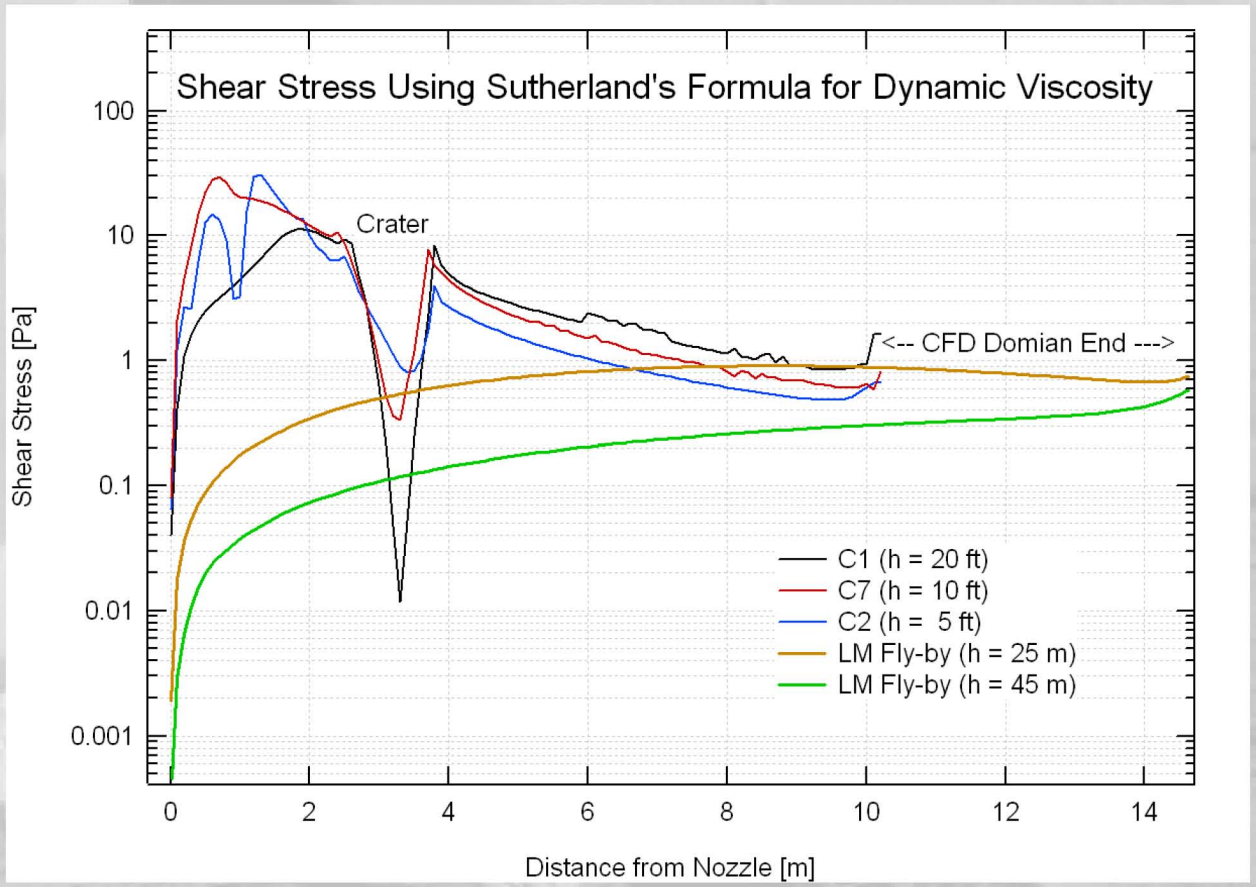
Bolt Hole



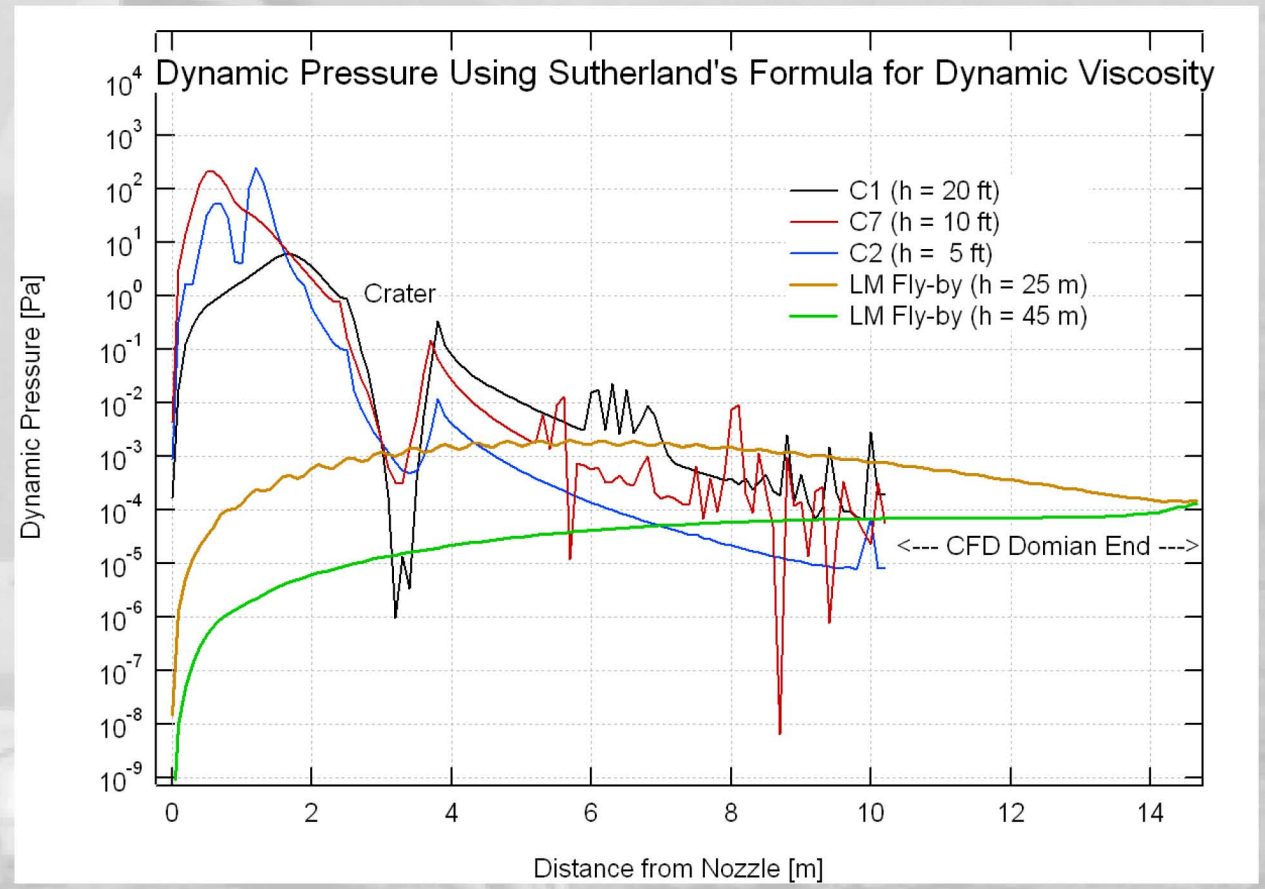
XPS Analysis of bolt shadow



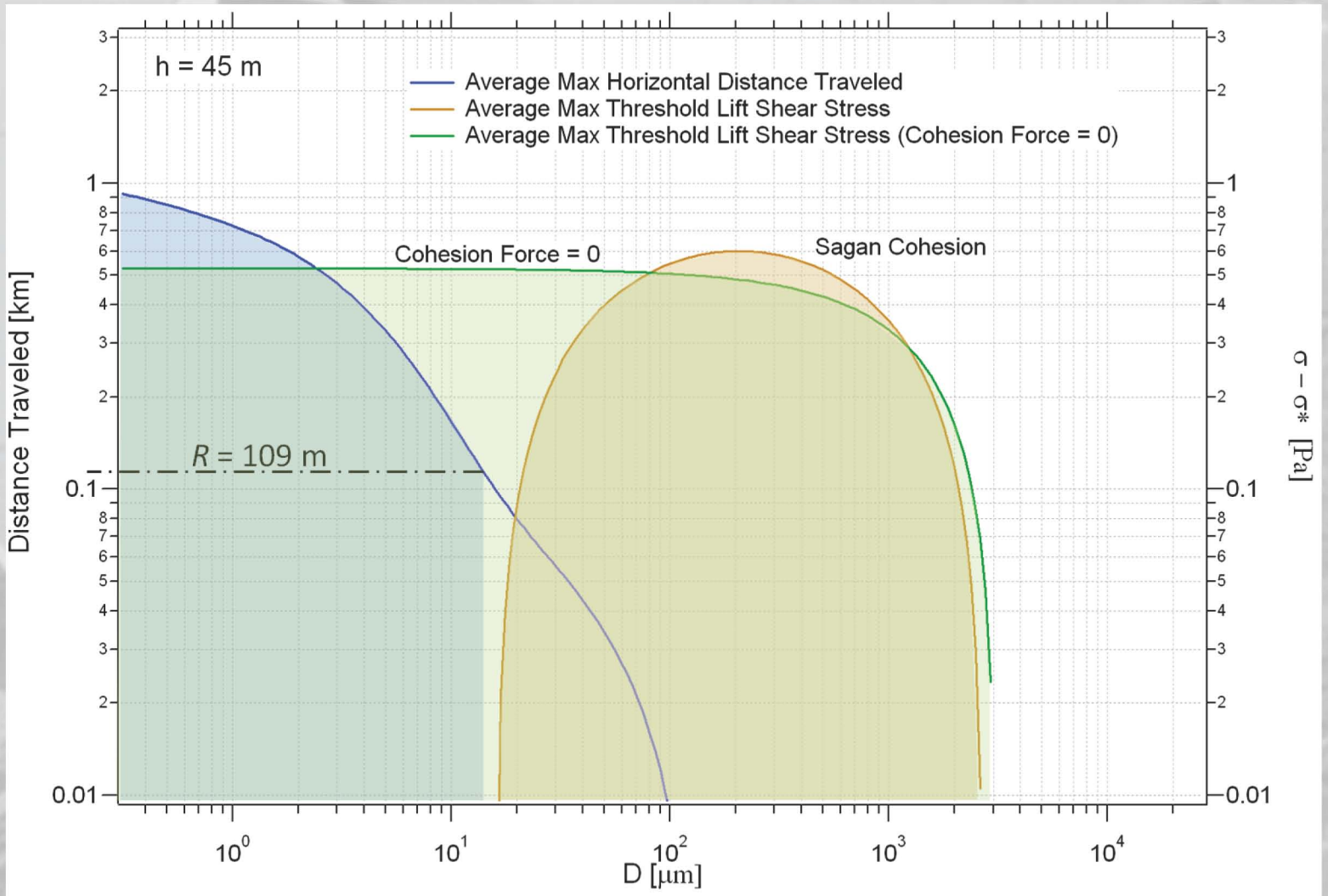
Shear stress along the surface for five cases generated by Fluent CFD: *h* = 5, 10, 20, 25 [ft] and 45 [m].



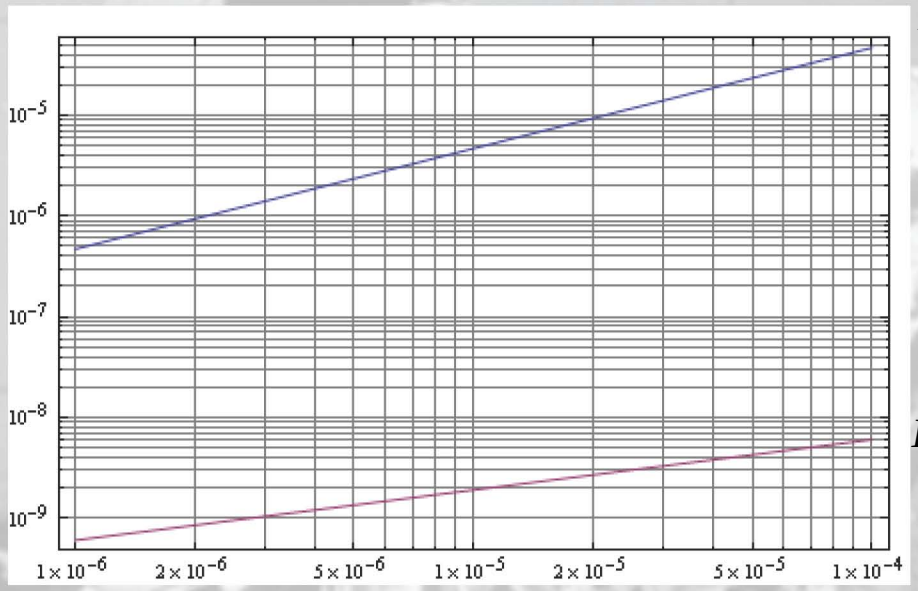
Dynamic Pressure along the surface for five cases generated by Fluent CFD: *h* = 5, 10, 20, 25 [ft] and 45 [m].



LM Flyby simulation at *h* = 45 [m]. Left axis: (blue line) radial distance traveled by particle from ground track position. Right axis: (green and brown lines) region where shear stress is greater than threshold shear stress, resulting in particle lift for zero cohesion force (green line) and for Sagan's cohesion force (brown line).



Interparticle Force
(*cohesion* force or *pull-off* force)



$$F_{sp} = 2\pi\gamma D$$

γ = 0.075 [J/m^2]

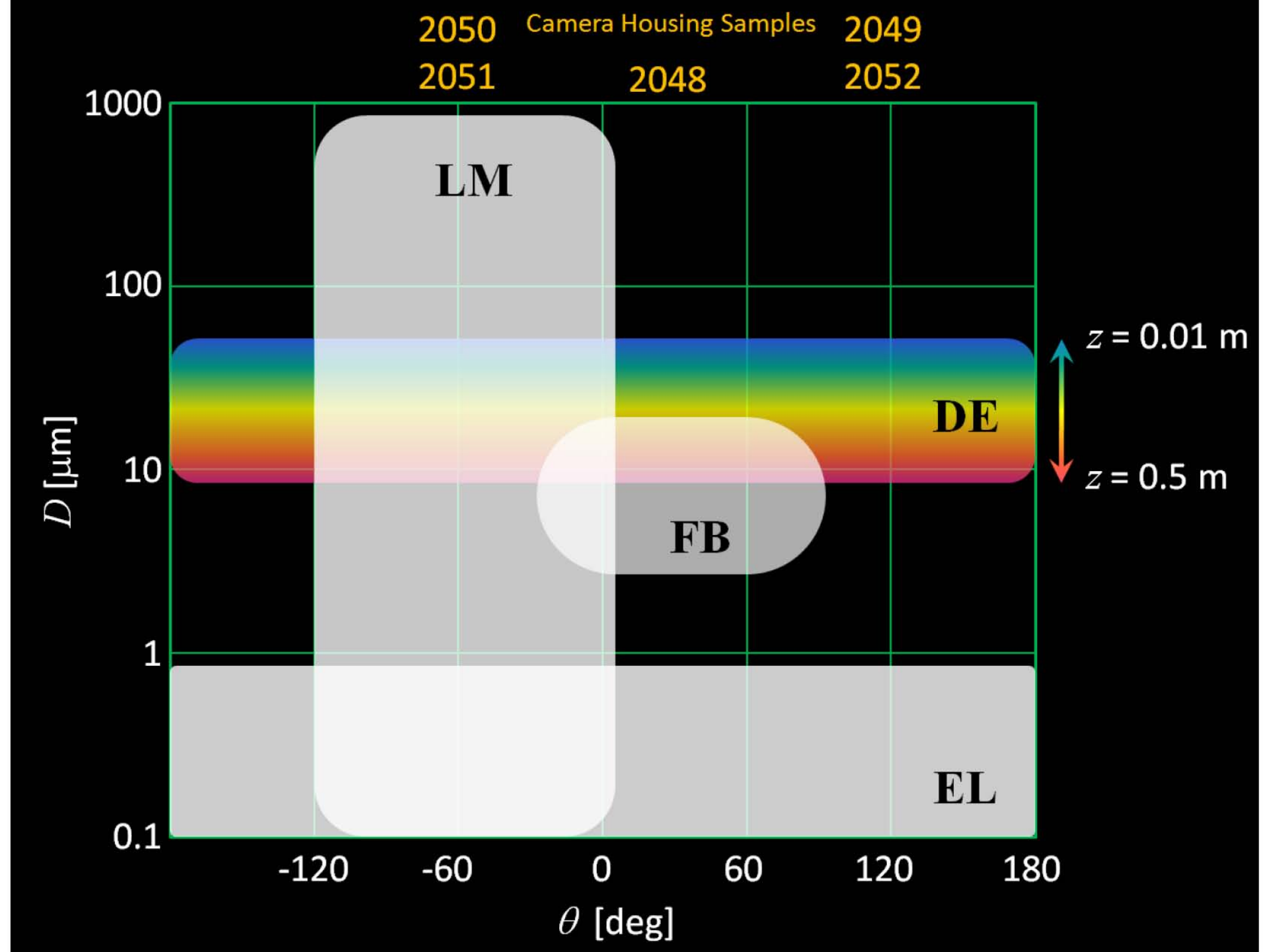
Walton, O.R., "Review of Adhesion Fundamentals for Micron-Scale Particles", Powder and Particle Journal, **26**, 2008, pp. 129-141.

$$I_p = K\, D^{3-n}$$

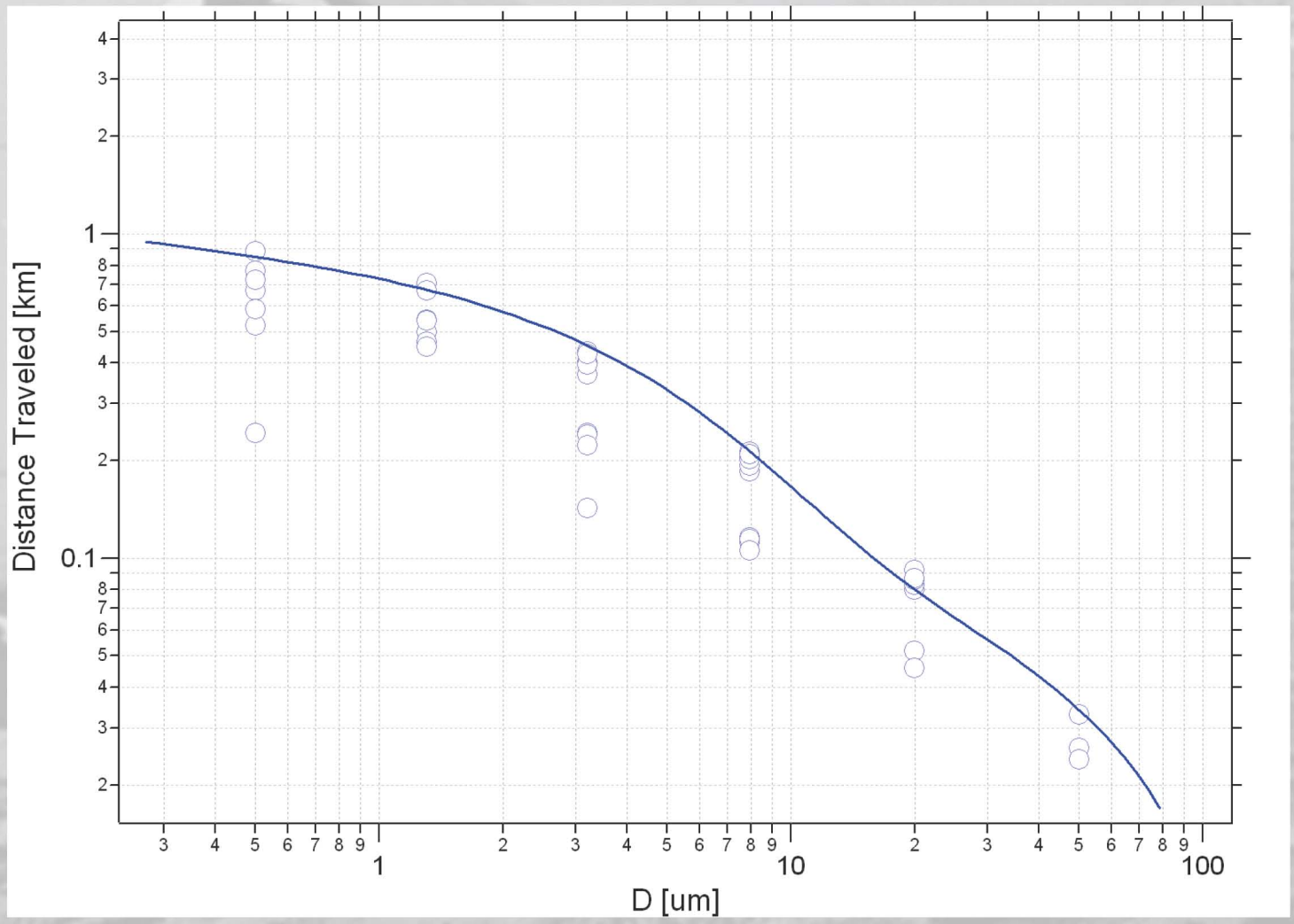
$K = 6\times10^{-7}$ [N/m$^{1/2}$]

n = 5/2

Iversen, J.D, B.R. White, "Saltation Threshold on Earth, Mars, and Venus", *Sedimentology*, **29**, 1982, pp. 111-119.


Camera Housing Samples
2050
2051
2048
2049
2052
LM
DE
FB
EL
z = 0.01 m
z = 0.5 m
1000
100
10
1
0.1
D [µm]
-120
-60
0
60
120
180
θ [deg]

Radial distance traveled by particle from ground track position as a function of particle diameter for *h* = 45 m. Circles represent different starting points, both *x* and *y*. Solid line is the average maximum value of the individual trajectories.

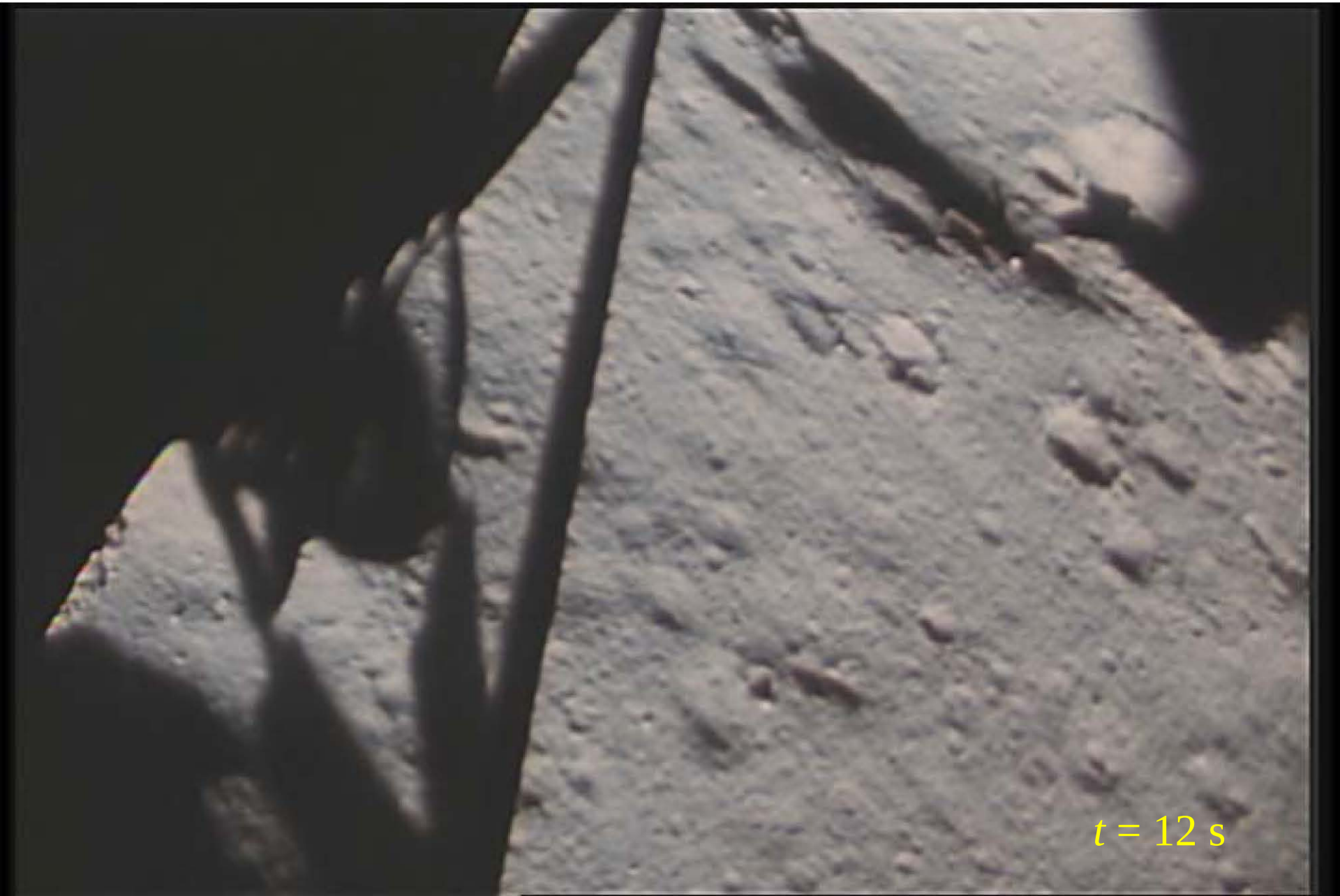


Apollo 12 After Touchdown

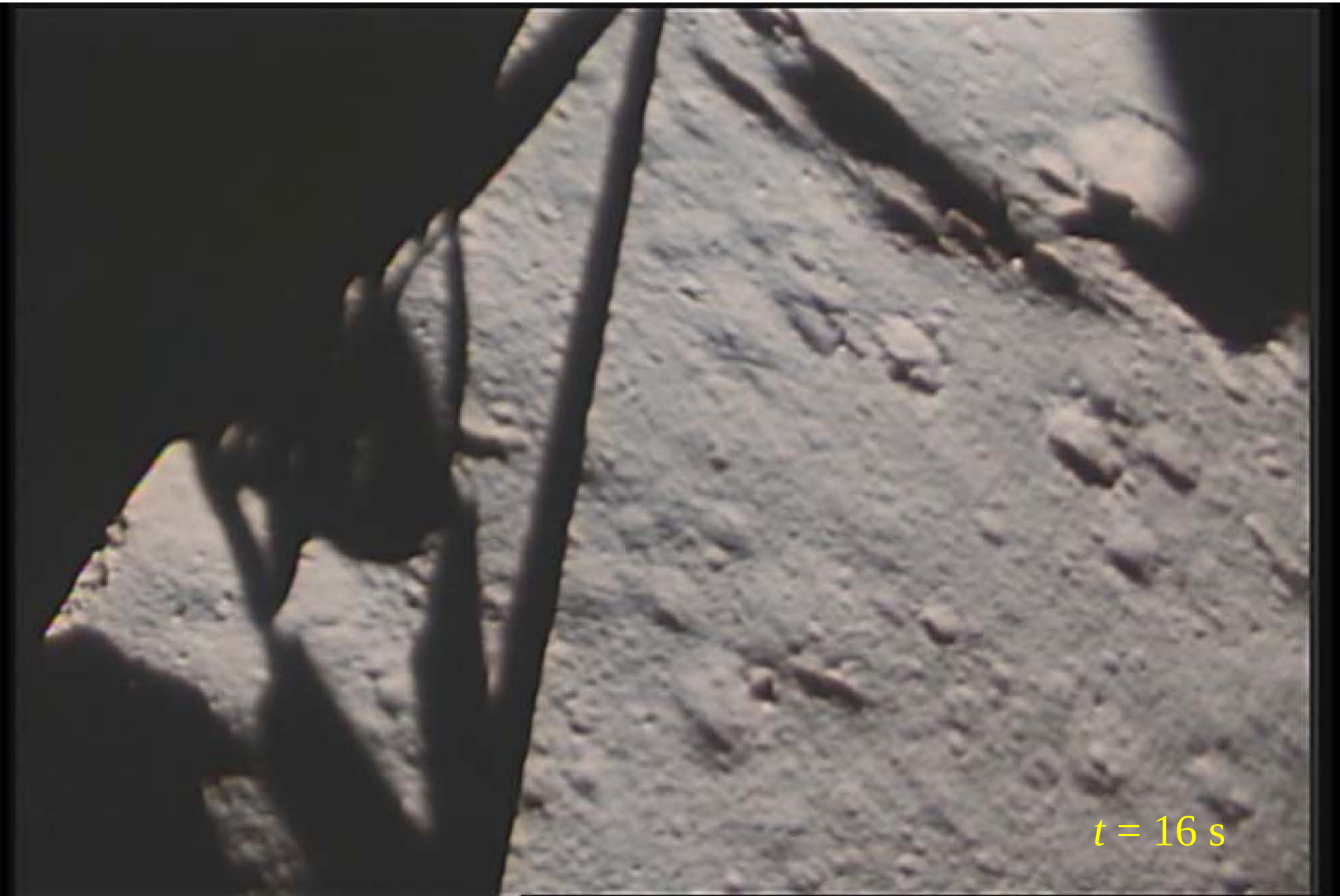
Apollo 12 After Touchdown

Apollo 12 After Touchdown

Apollo 12 After Touchdown

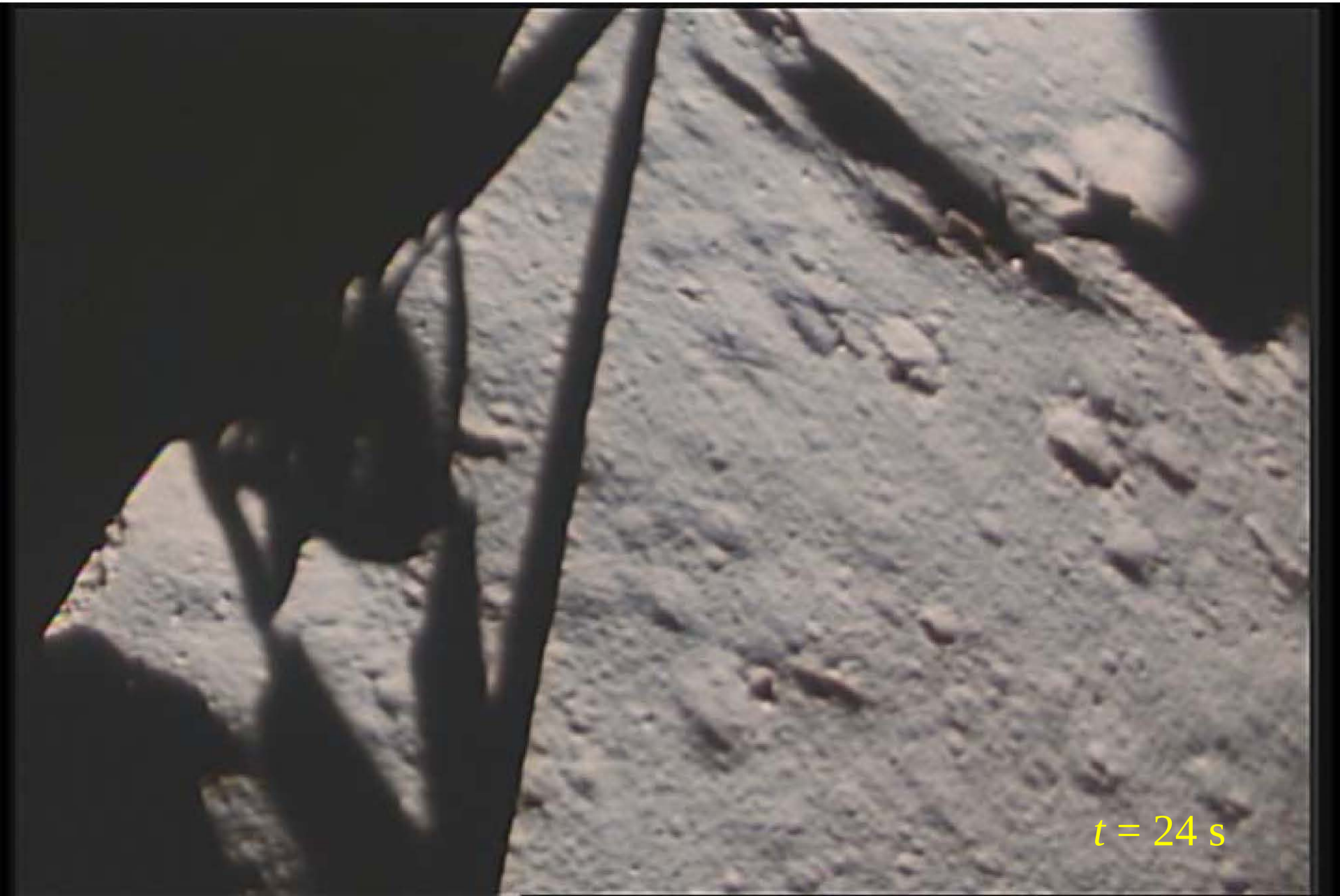


Apollo 12 After Touchdown

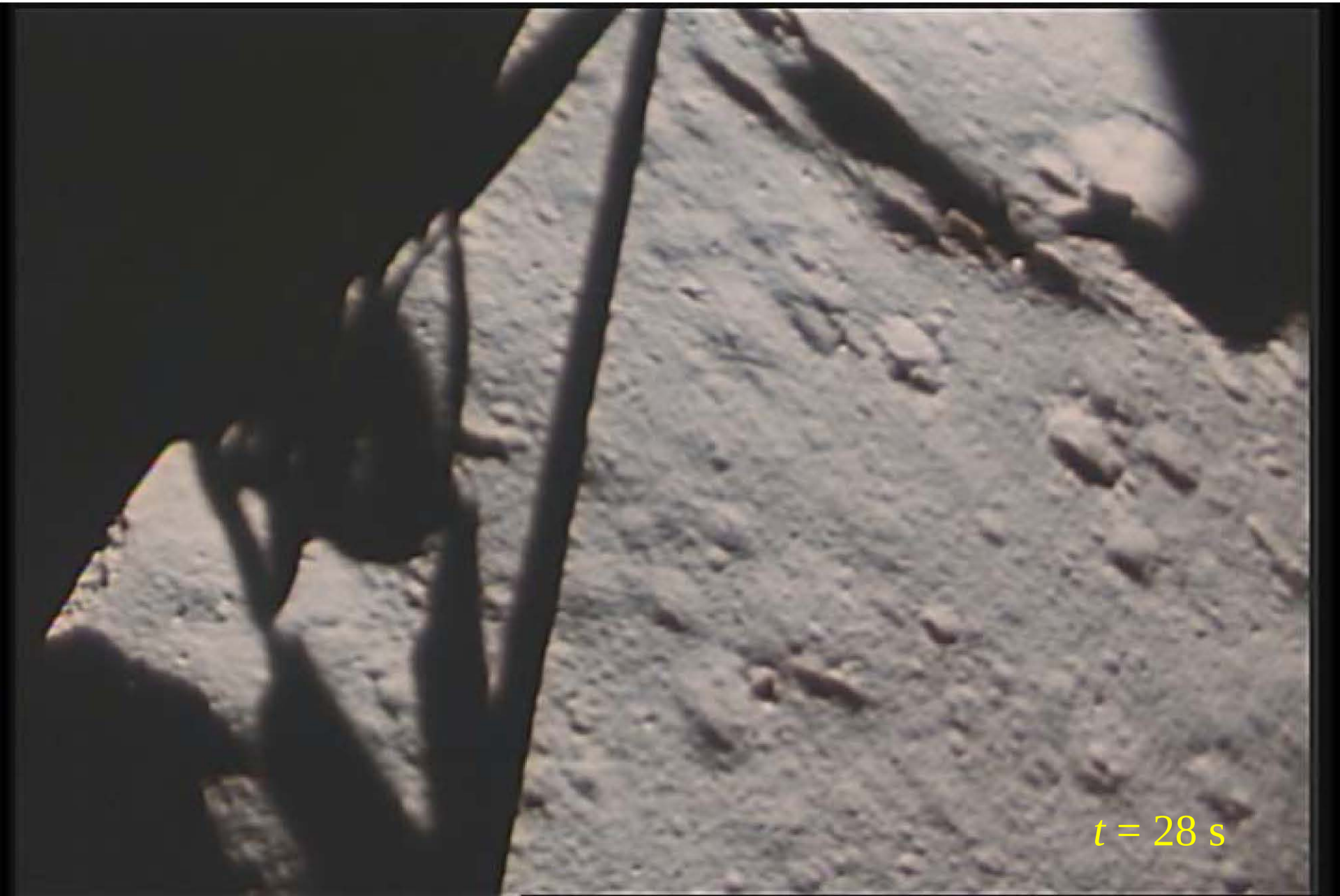


Apollo 12 After Touchdown

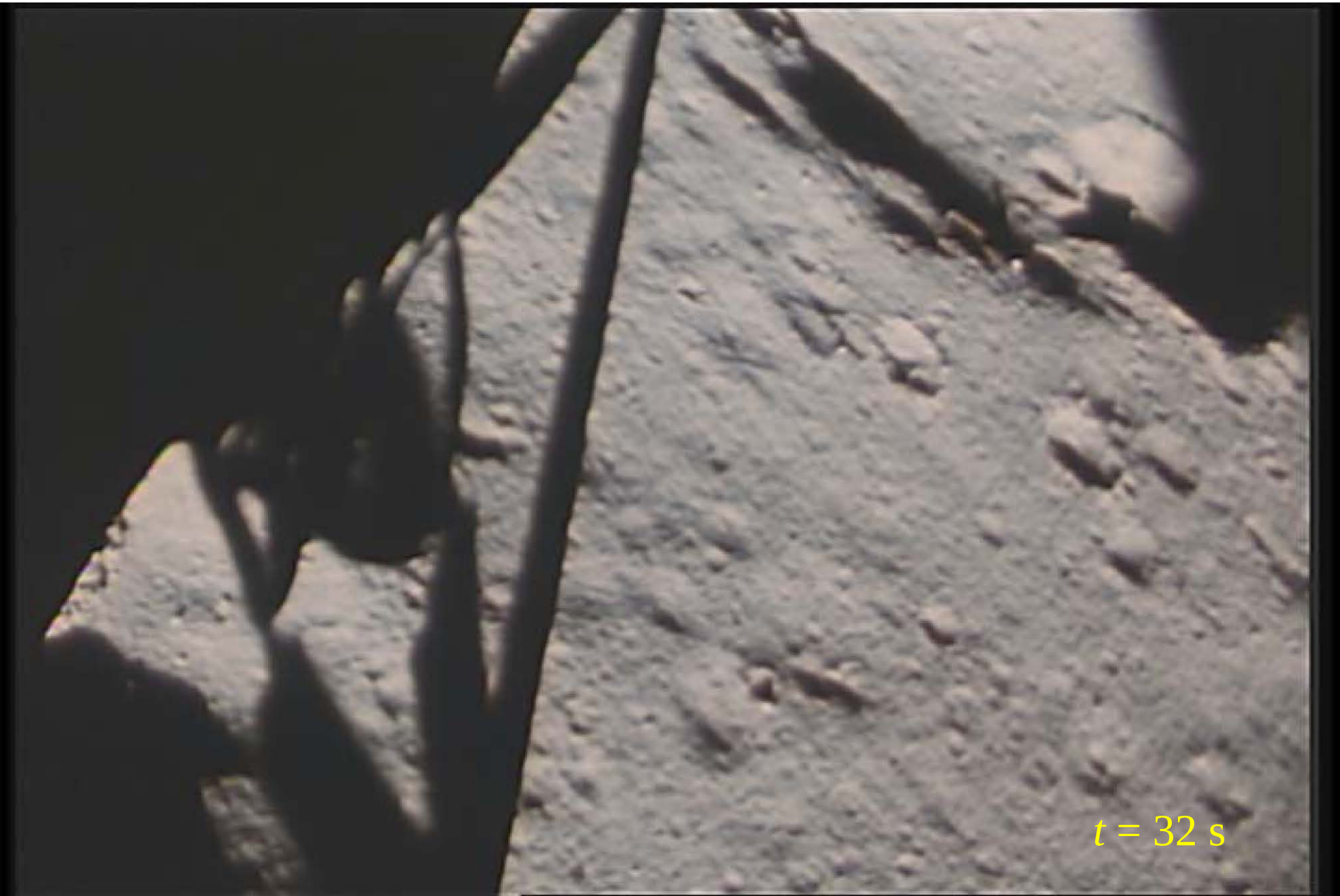
Apollo 12 After Touchdown



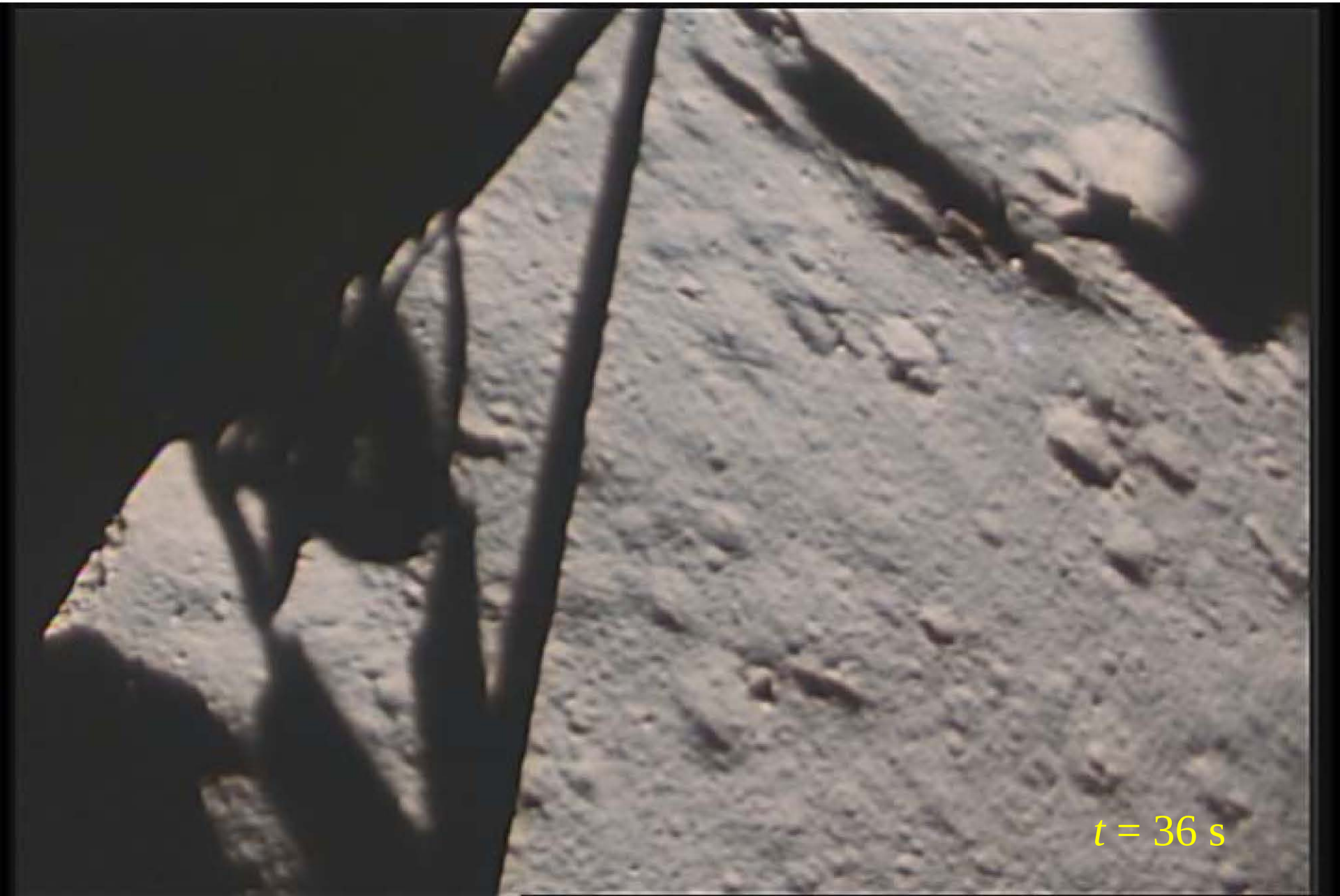
Apollo 12 After Touchdown



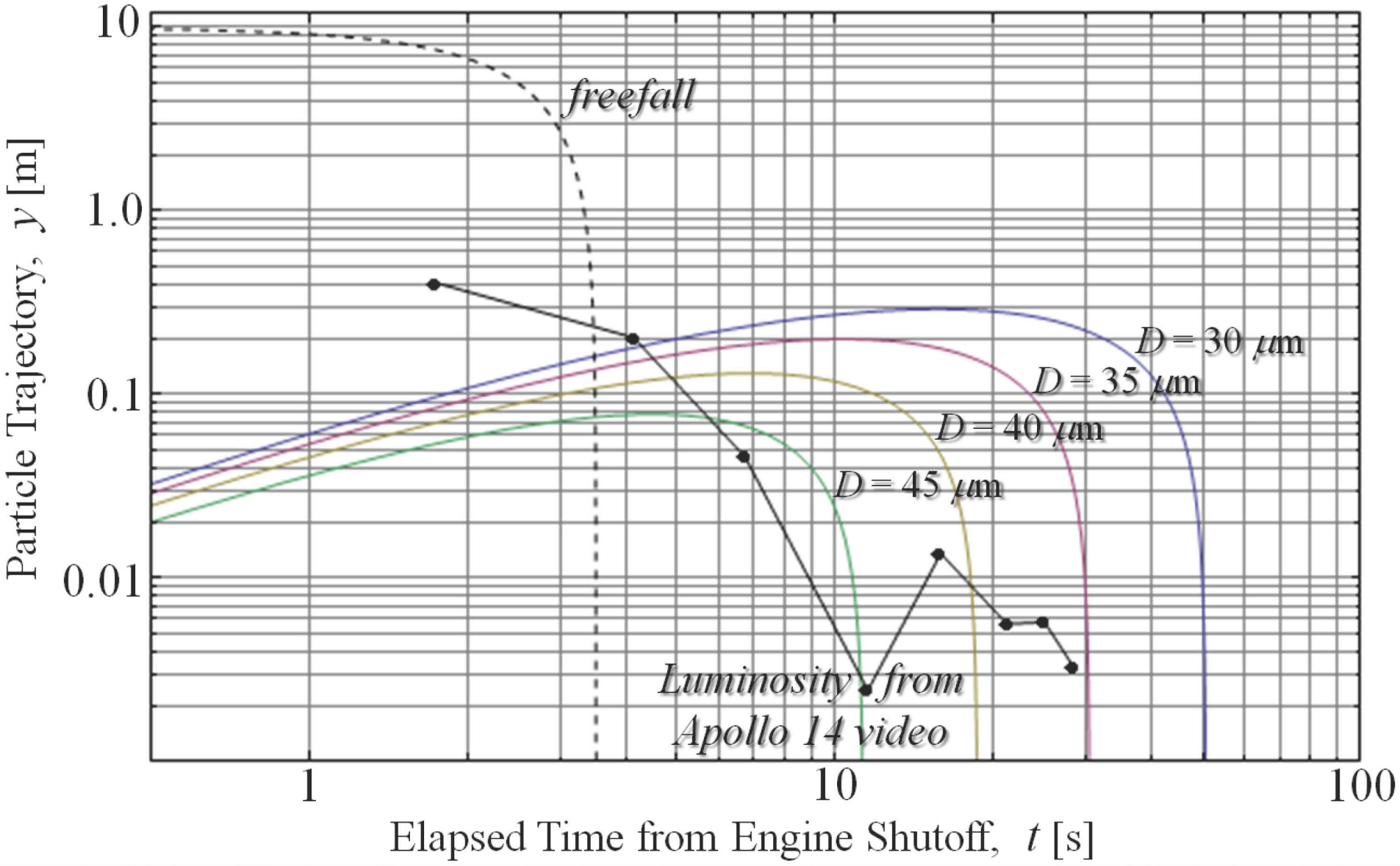
Apollo 12 After Touchdown



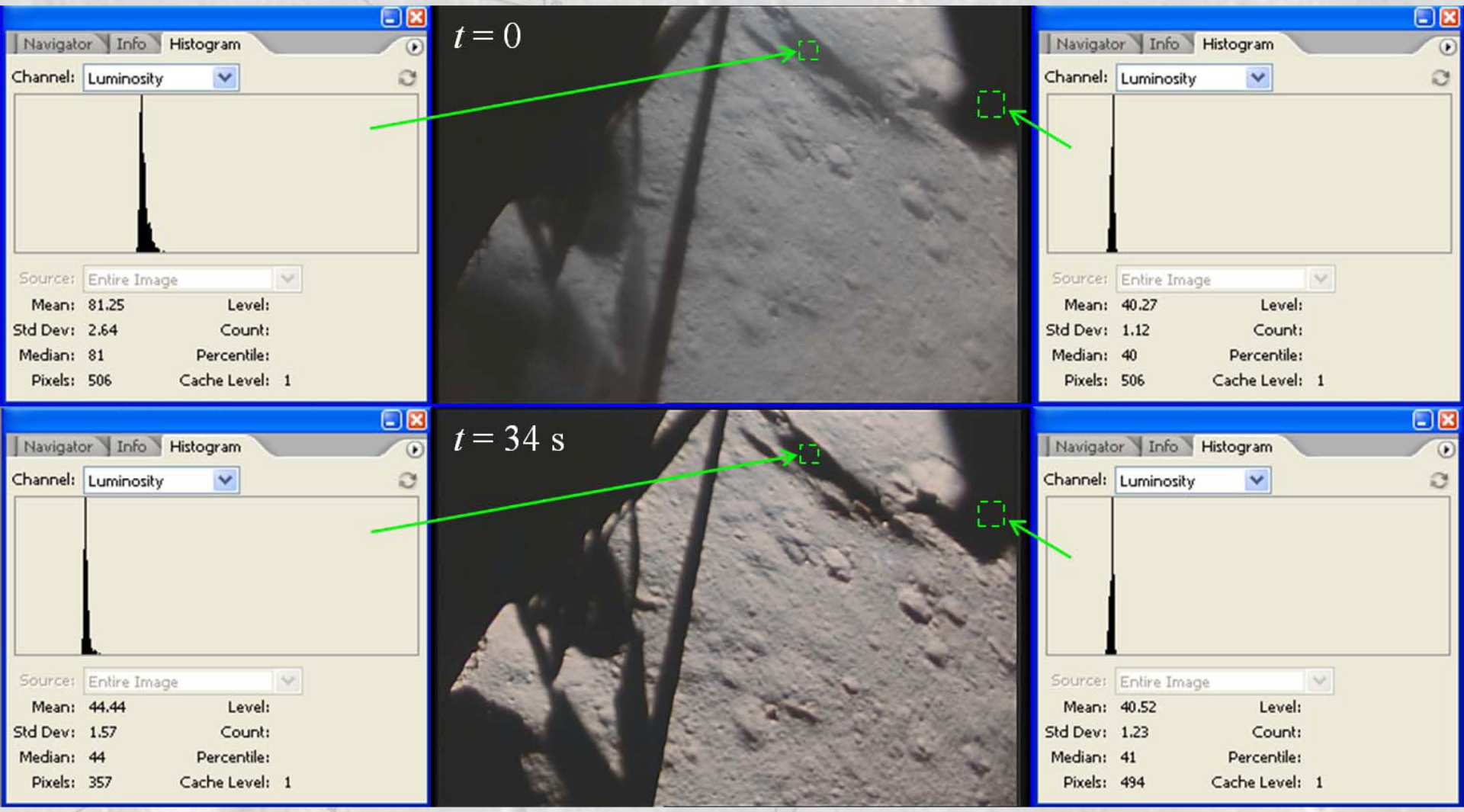
Apollo 12 After Touchdown



Freefall and Darcy law particle trajectories compared to luminosity



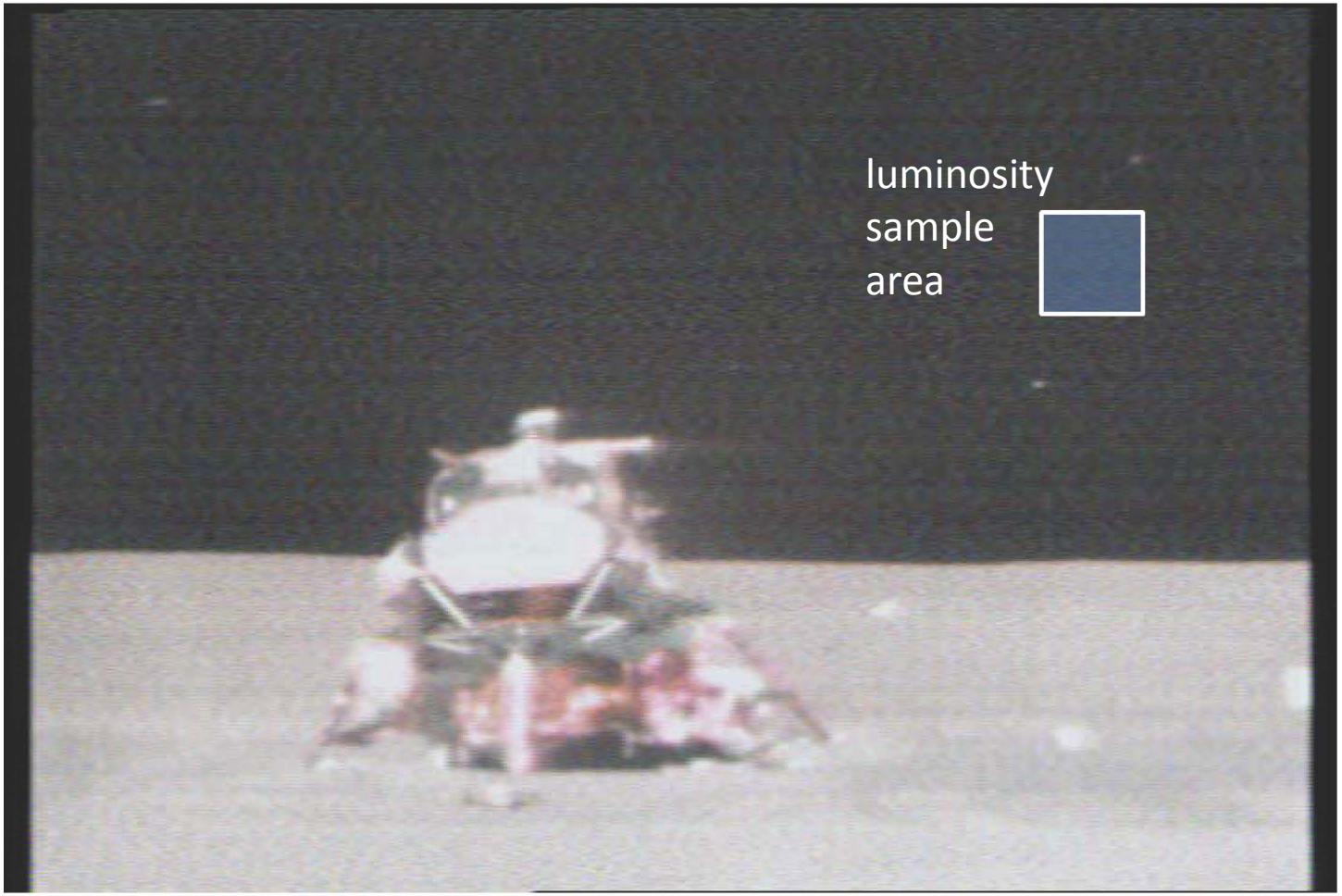
Luminosity measurements of Apollo 14 landing videos following engine cutoff



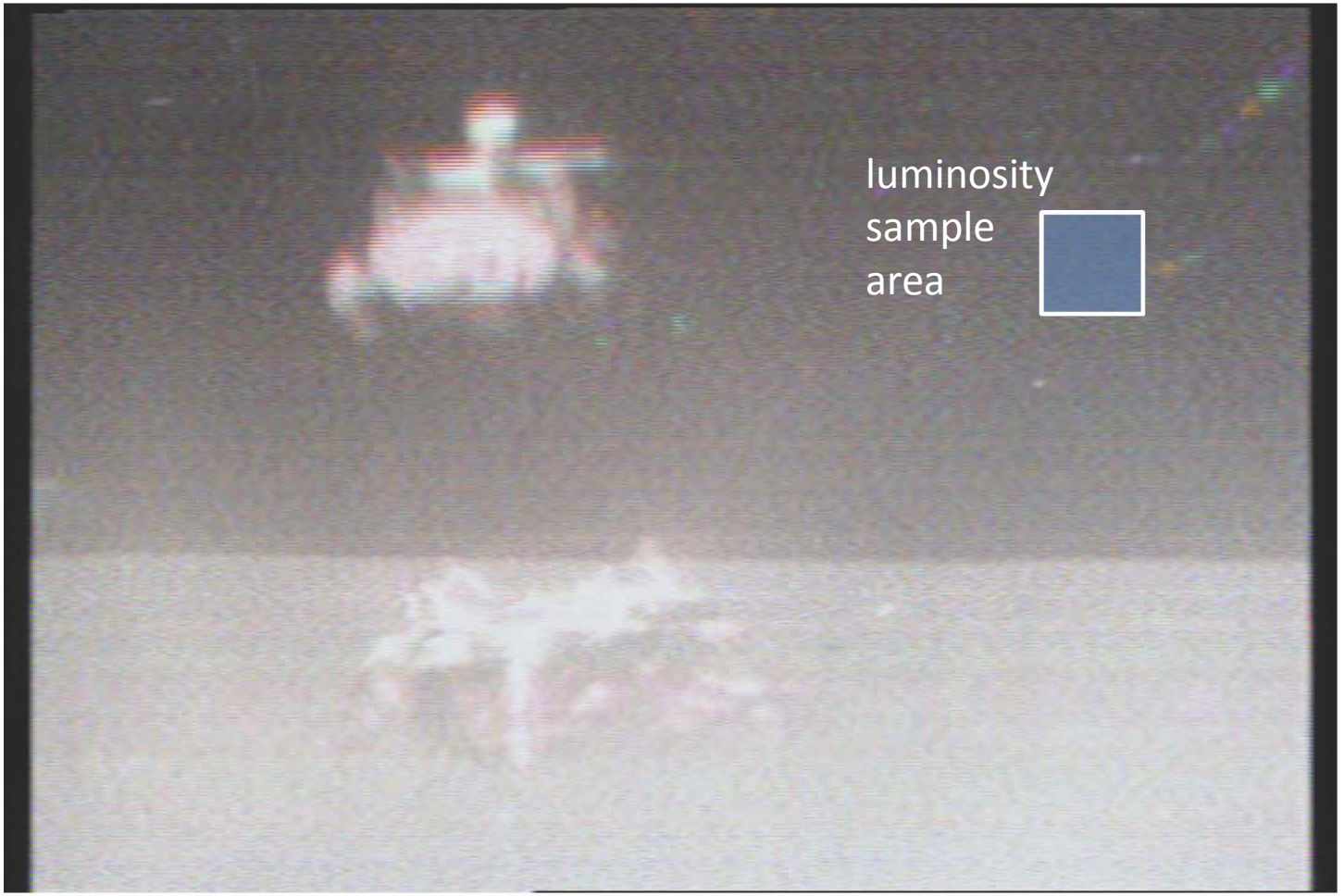
Apollo 15: Descent

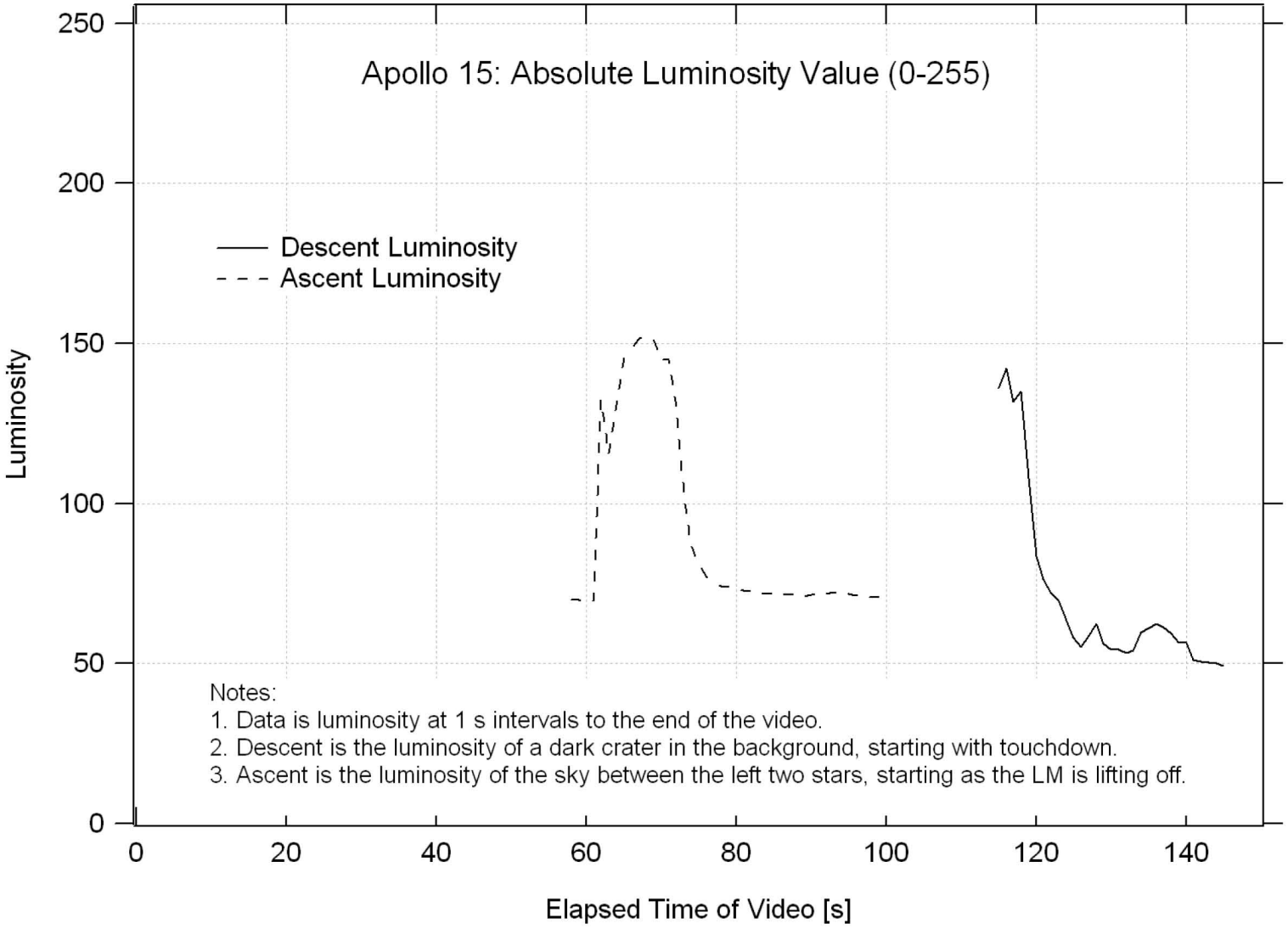
Apollo 15: Descent

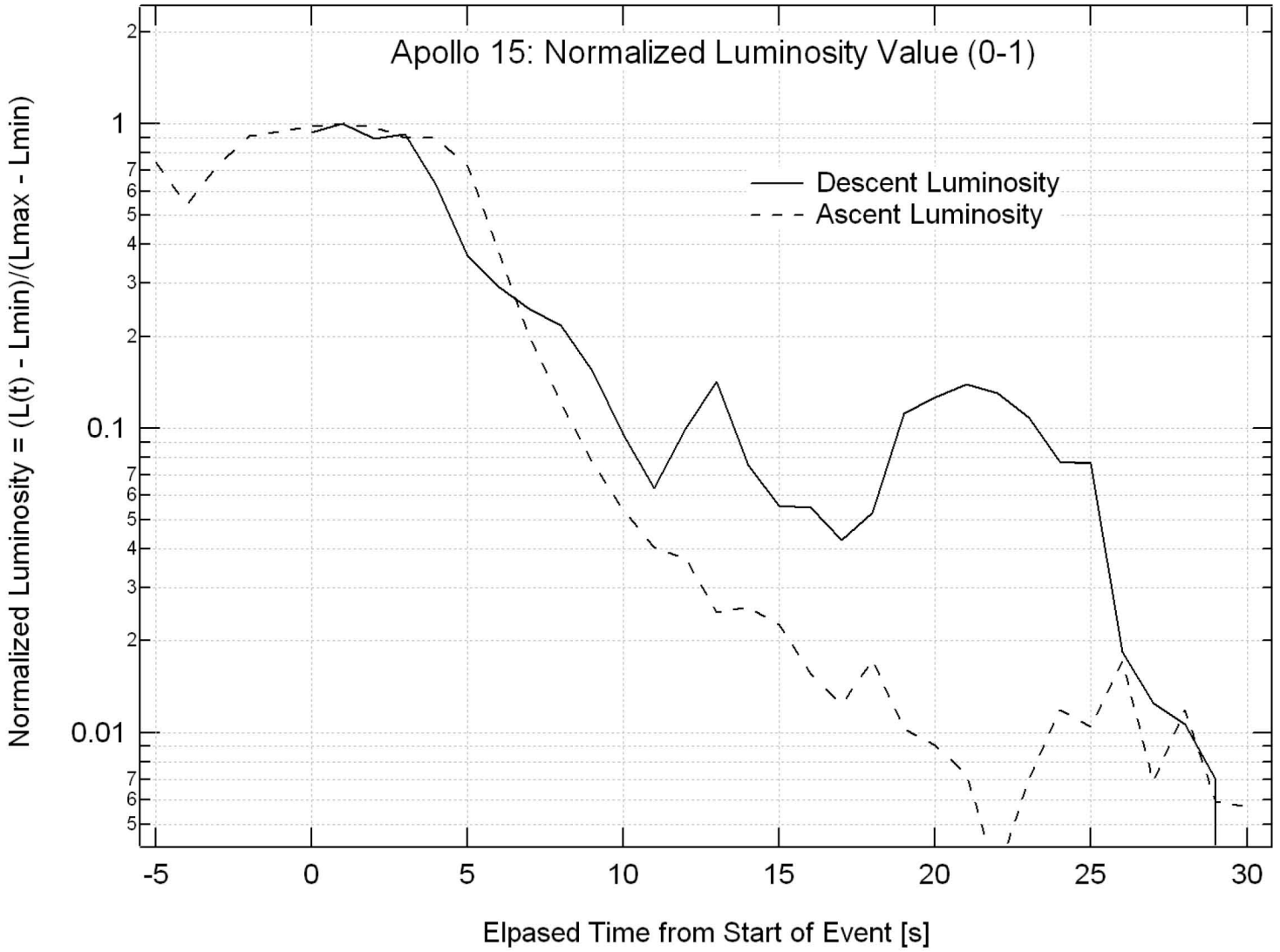
Apollo 15: Ascent



Apollo 15: Descent




Apollo 15: Absolute Luminosity Value (0-255)
Descent Luminosity
Ascent Luminosity
Luminosity
Elapsed Time of Video [s]
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Notes:
1. Data is luminosity at 1 s intervals to the end of the video.
2. Descent is the luminosity of a dark crater in the background, starting with touchdown.
3. Ascent is the luminosity of the sky between the left two stars, starting as the LM is lifting off.


Apollo 15: Normalized Luminosity Value (0-1)
Descent Luminosity
Ascent Luminosity
Normalized Luminosity = (L(t) - Lmin)/(Lmax - Lmin)
Elpased Time from Start of Event [s]
2
1
7
6
5
4
3
2
0.1
7
6
5
4
3
2
0.01
7
6
5
-5
0
5
10
15
20
25
30

Further Analysis on the Mystery of the Surveyor III Dust Deposits

Summary

- Several likely scenarios are proposed to explain the Surveyor III dust observations.
- These include electrostatic levitation of the dust from the surface of the Moon as a result of periodic passing of the day-night terminator; dust blown by the Apollo 12 LM flyby while on its descent trajectory; dust ejected from the lunar surface due to gas forced into the soil by the Surveyor III rocket nozzle, based on Darcy's law; and mechanical movement of dust during the Surveyor landing.
- Even though an absolute answer may not be possible based on available data and theory, various computational models are employed to estimate the feasibility of each of these proposed mechanisms.
- Scenarios can then be tested which combine multiple mechanisms to produce results consistent with observations.