Entry, Descent, and Landing (EDL)

MAE 4160, 4161, 5160

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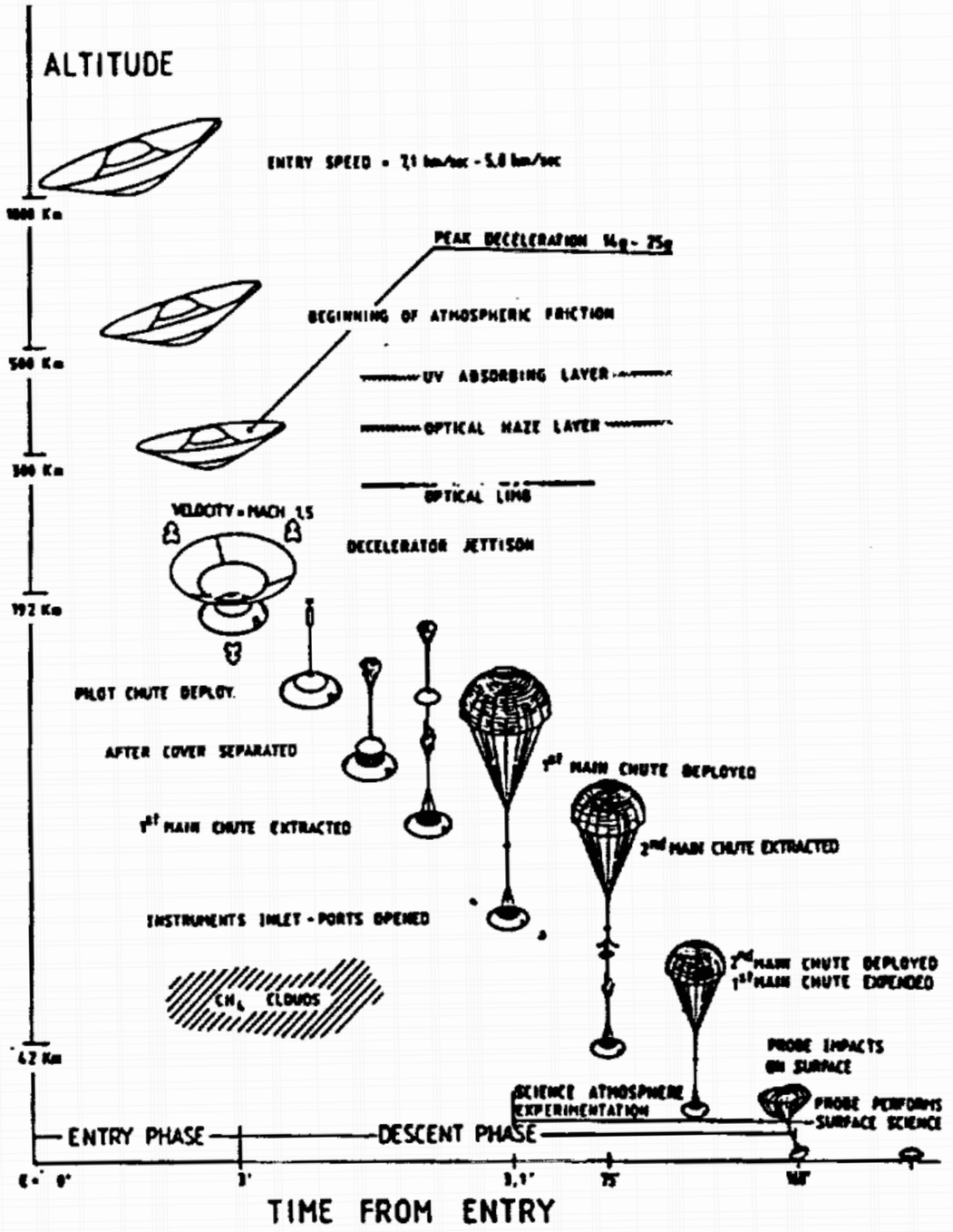
Today's topics:

- What is EDL?
- Why is it hard?
- Technologies
  - Parachutes
  - Heat shields
  - Airbags
- Case studies

This lecture is not about the rovers themselves (that's next lecture). This one is just about the EDL of those rovers/landers.

What is EDL?

This is the phase of the mission which begins when a spacecraft touches the top of a planetary atmosphere and ends when the spacecraft is on the surface of that planet.



Why is this hard?

- EDL is an **energy dissipation problem**. The spacecraft begins with a velocity in the range of 5-10 km/sec relative to the planet. It must end with a velocity of 0 km/sec relative to the planet without exceeding limits in heat, shock, or vibration.

- It is often the case that EDL is occurring somewhere very far away (Mars, Titan, Venus, etc.). Because of light time-of-flight to these destinations, the entire process must be autonomous.

Questions to ask yourself . . .

- With how much atmosphere will the spacecraft interact?
- How much mass must be delivered to the surface?
- What are the spacecraft’s limitations on shock, heat, and vibe?

Heat Shields

- **Ablative** heat shields function by lifting hit shock layer gas from the heat shield's outer wall by creating a cooler boundary layer. The outer layer of the heat shield chars, melts, and sublimes while the bulk undergoes pyrolysis and expels gases. These gases block convective and catalytic heat flux.

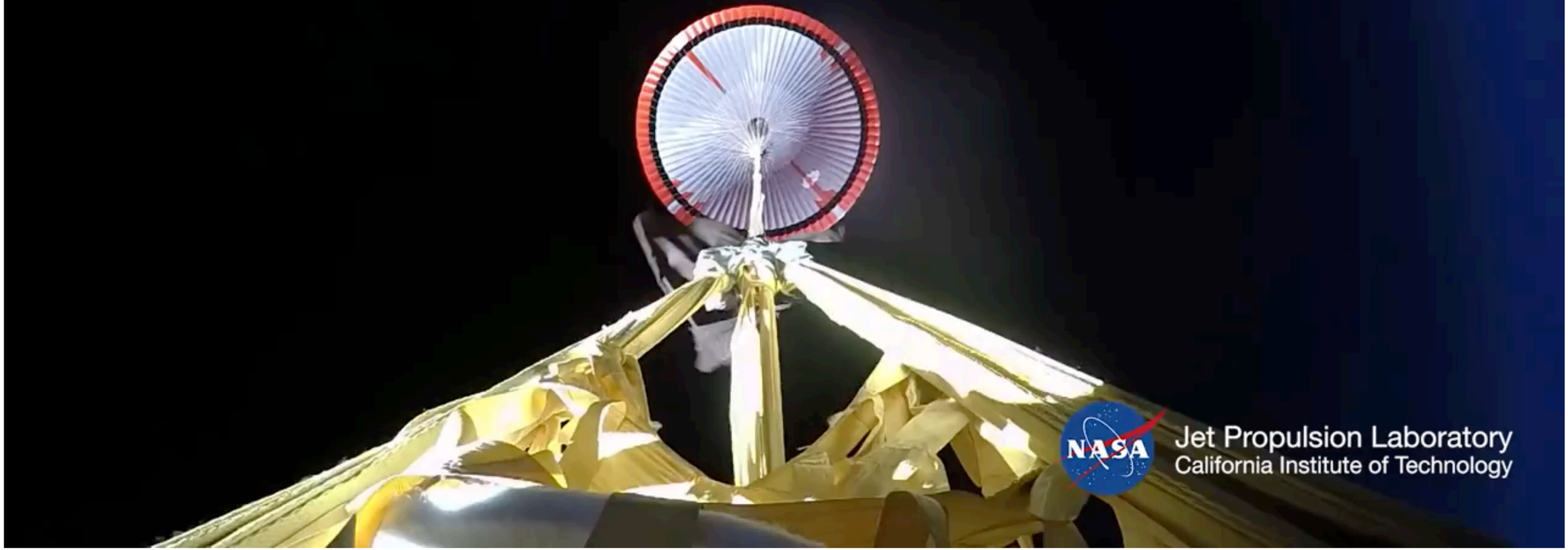
- **Thermal soak** is often also included in heat shields to prevent conduction when temperatures drop below minimum necessary for pyrolysis. These materials have remarkable thermal properties. The Shuttle tiles could be heated to 1000K on one side and remain only warm to the touch on the other.

Parachutes

- Difficult to model - simulations are inadequate for determining whether a parachute will be successful.
- Difficult to test (require rarified atmosphere and supersonic speeds)
- Come in different flavors (disk-gap, ribbon, etc.)
- May or may not sufficiently slow your lander, depending on the atmosphere of the celestial body on which you're landing

Mars 2020 Supersonic Parachute Test

Flight Test #1

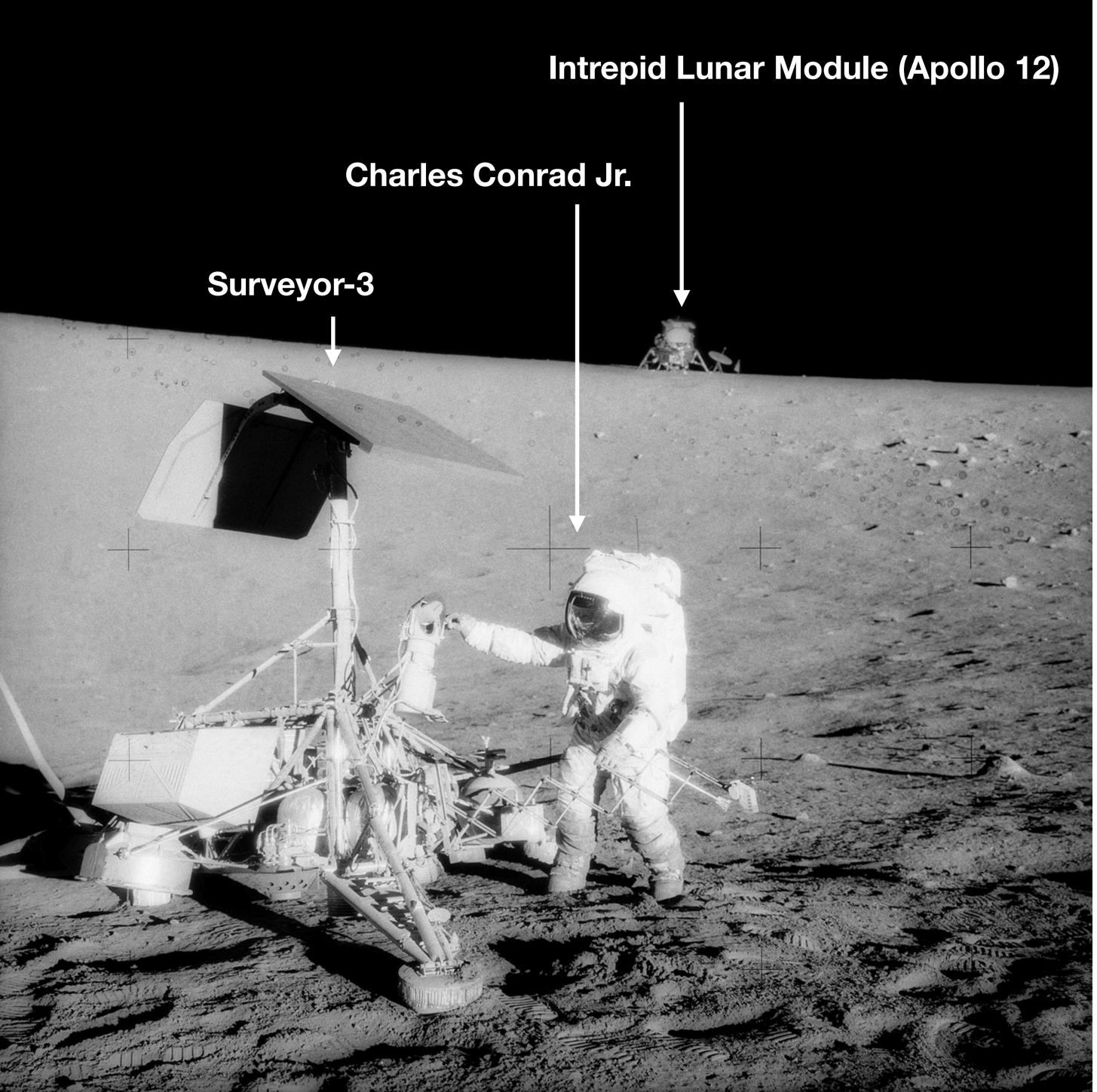


Jet Propulsion Laboratory
California Institute of Technology

Airbags

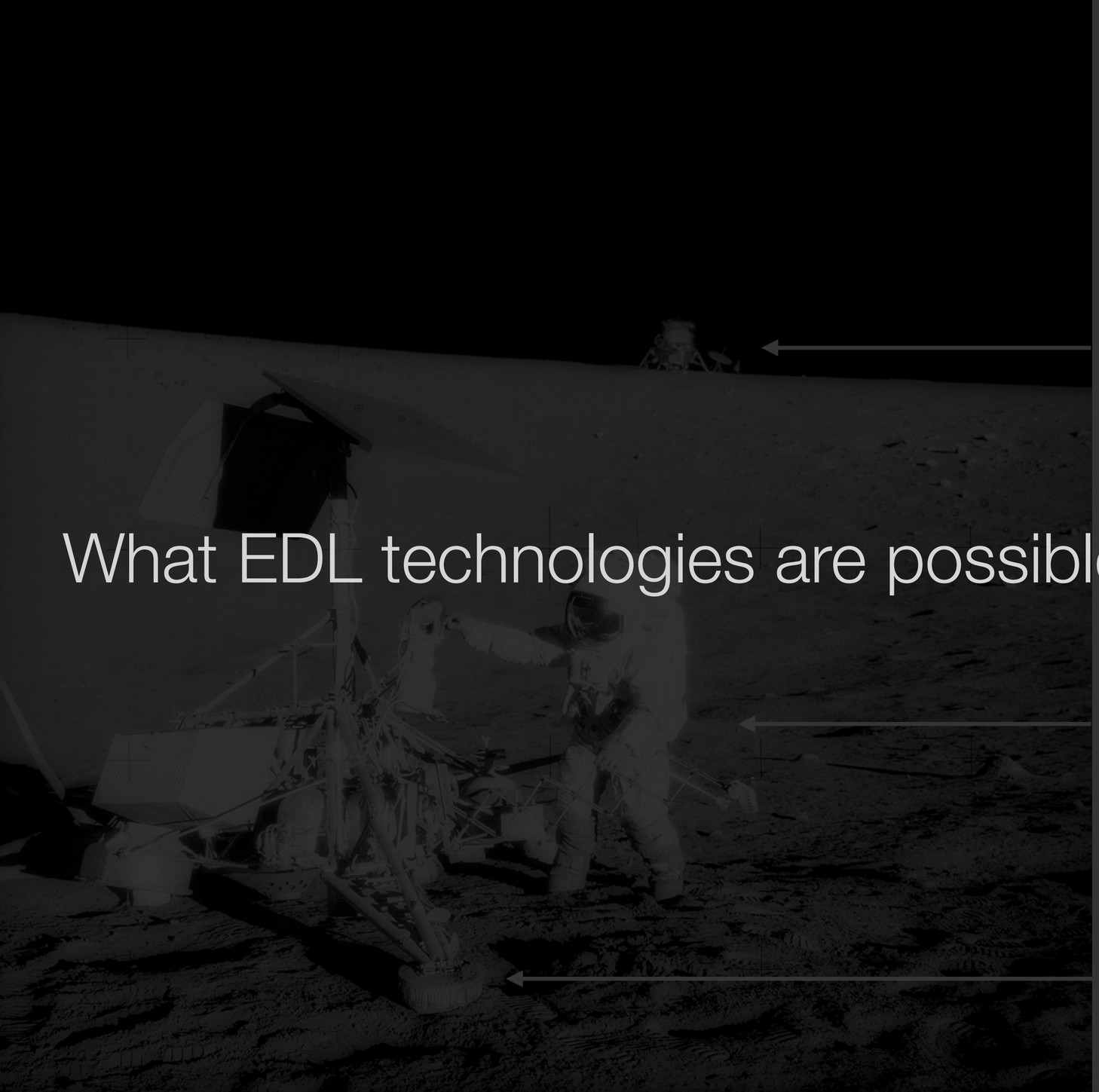
- Adequate for small-to-medium sized rovers (Spirit, Opportunity, Pathfinder)
- Use rockets to slow to a near-stop above the surface, then drop the airbag and have it bounce along the ground at highway speeds
- Built from a synthetic material called Vectran - almost twice the strength of Kevlar and better performance at low temperatures

MER airbags


Intrepid Lunar Module (Apollo 12)
Charles Conrad Jr.
Surveyor-3

The Moon

The Moon



Intrepid Lunar Module (Apollo 12)

What EDL technologies are possible/impossible on the Moon?

Charles Conrad Jr.

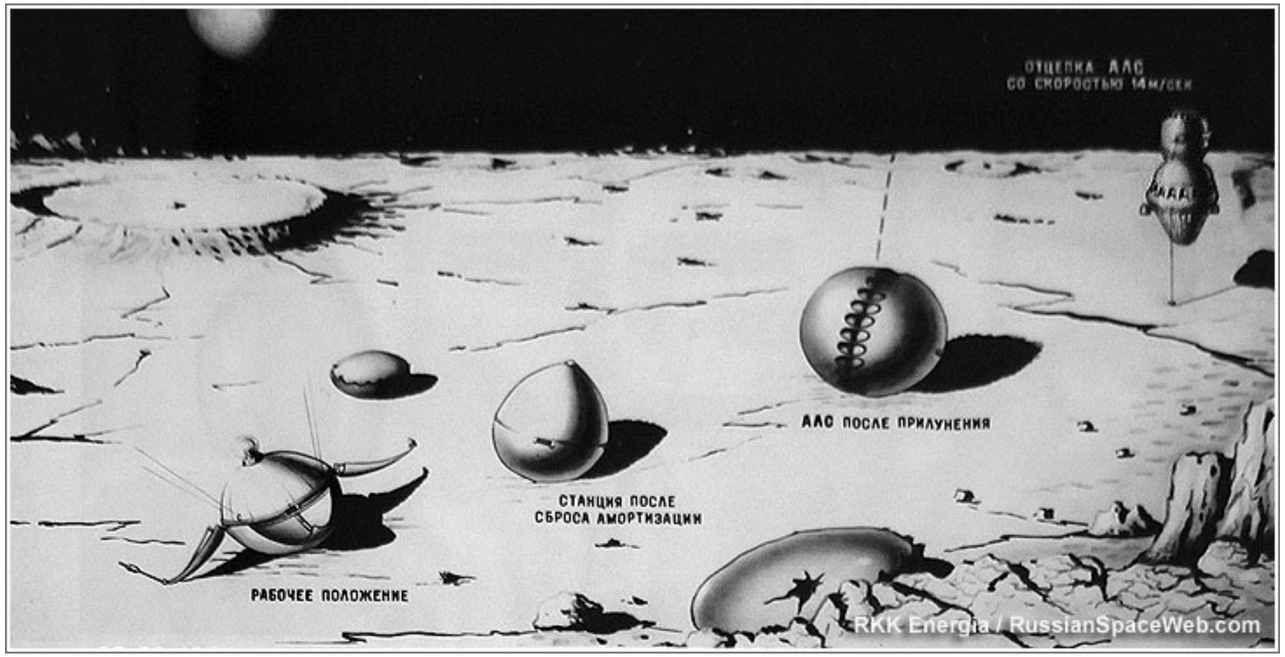
Surveyor-3

Missions we'll consider . . .

- Luna 9 (USSR, Feb. 1966)
- Surveyor 3 (USA, April 1967)
- Apollo 11 (USA, July 1969)
- Luna 16 (USSR, Sept. 1970)

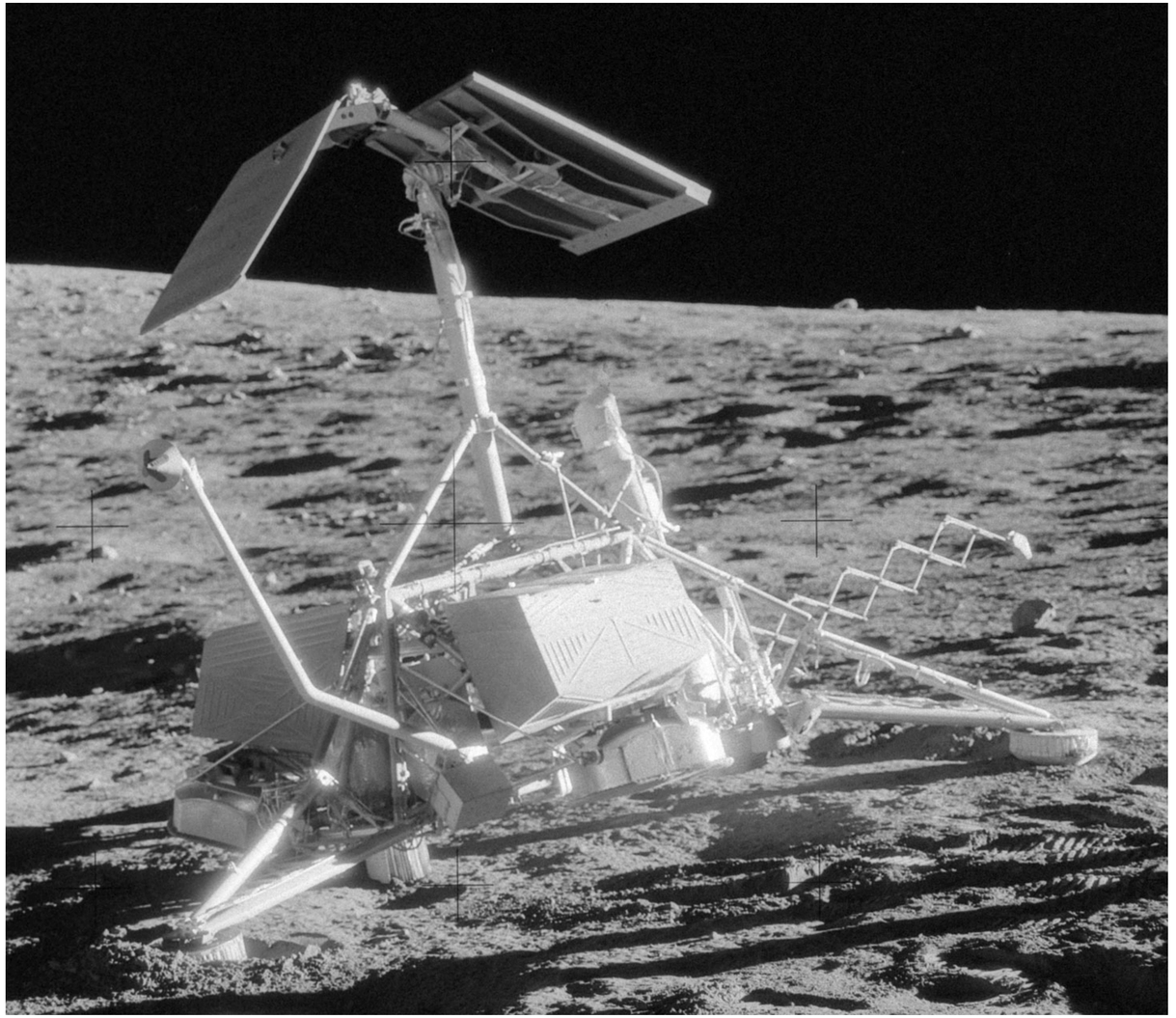
Luna 9

- First spacecraft to survive landing on the Moon
- 99 kg hermetically sealed container with scientific payload and radio/television equipment
- Employed retro-rockets to slow the spacecraft, and an airbag to cushion impact
- Craft impacted at 22 kph (14 mph), bounced several times, and then came to rest, deployed its cameras, and began to radio images (9 of them)
- Soviet authorities did not immediately release images, but scientists in England that were monitoring the craft recognized the signal format as the same as that used by newspapers for transmitting images.
- The images were decoded and disseminated by the BBC. There is speculation that the USSR deliberately used this encoding so that the images would be intercepted.
- Learned that moon ground could support a lander.



Surveyor 3

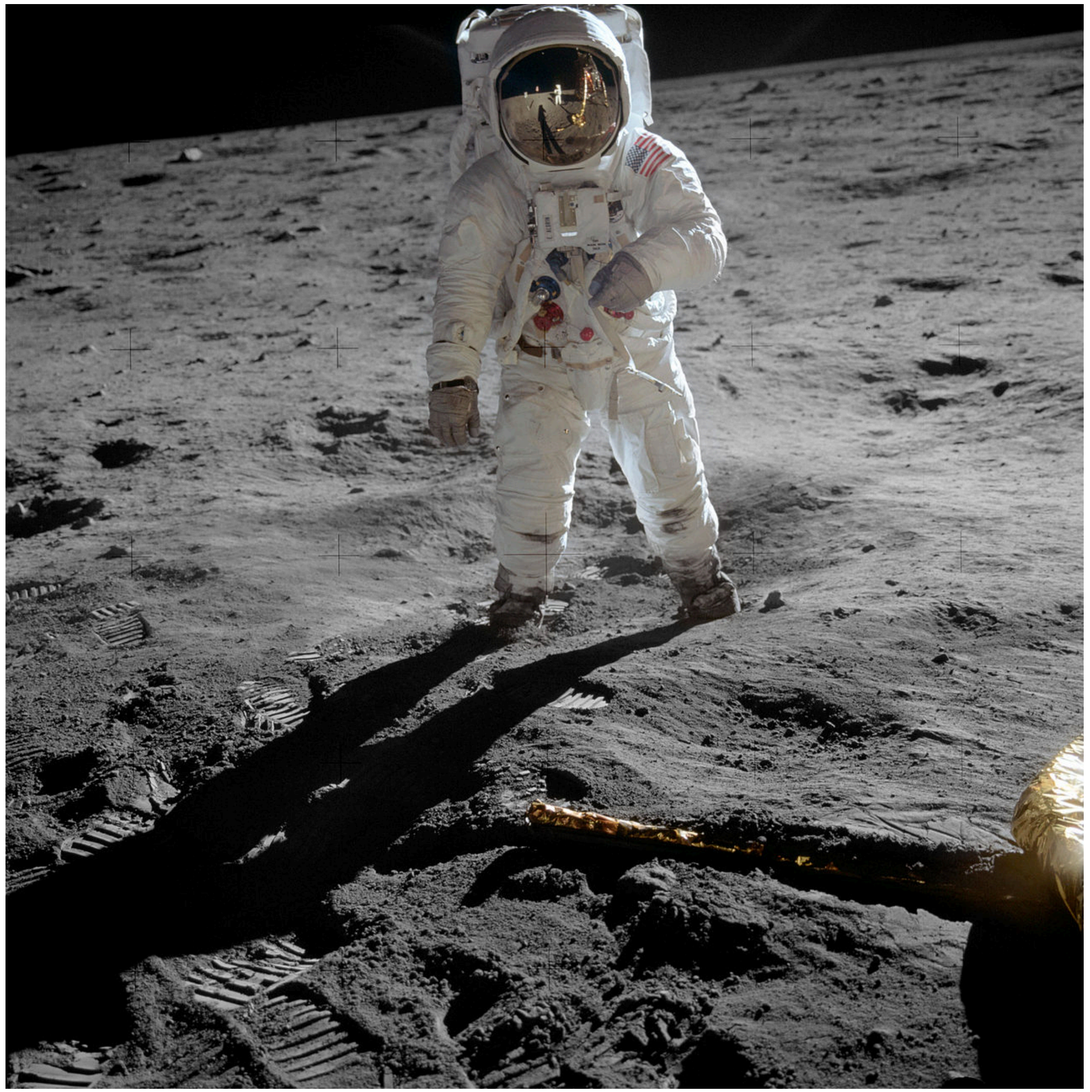
- Third Surveyor mission (first successful, second crashed into Moon)
- Planned to use retro-rockets to slow to zero relative velocity at 14 ft. (4.3m) above the lunar surface, and then free fall to the surface
- Highly reflective rocks confused descent radar, engines failed to cut off at 14 feet
- Surveyor 3 bounced twice. The first bounce to 35 feet, the second bounce to 11 feet, and then settled into a soft landing
- Became the target for the Apollo 12 landing sight, the crew landed within walking distance
- Remains the only probe visited by humans on another world.



On the Moon, photographed by Alan Bean

Apollo 11

- First time humanity set foot on another world.
- Powered manual descent by Armstrong
- An indicator light informed alluring that at least one of the 170 cm probes hanging from each of Eagle’s footpads had touched the surface, at which point Armstrong was supposed to shutoff the engines
- The engines stayed on for another 3 seconds until Eagle landed



Aldrin, photographed by Armstrong

Luna 16

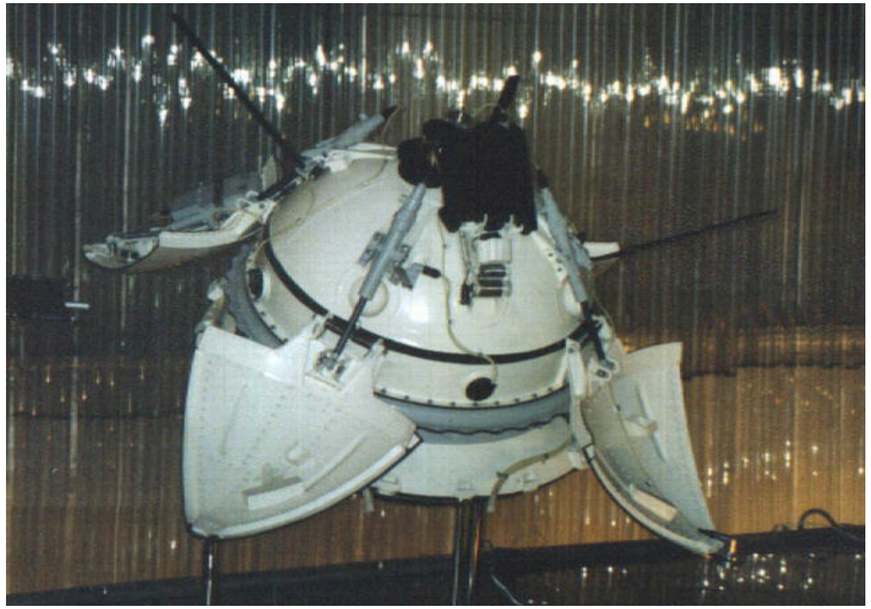
- First robotic sample return mission to the Moon
- Composed of a descent stage, ascent stage, and atmospheric reentry stage
- Powered descent to lunar surface, ascent stage direct to Earth injection, reentry via parachute

Mars

- Mars 3 (USSR, 1971)
- Viking 1 (USA, 1976)
- Pathfinder/Sojourner (USA, 1997)
- Spirit/Opportunity (USA, 2004)
- Curiosity (USA, 2012)
- InSight (USA, 2018)

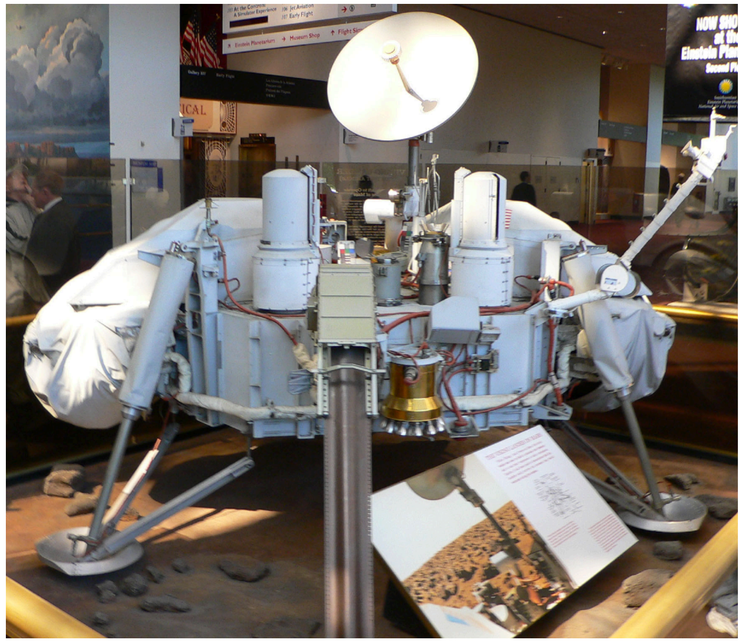
Mars 3

- First spacecraft to attain soft landing on Mars
- Spherical 1.2 diameter landing capsule (very similar to Luna 9), 2.9m heat shield, parachute system, and retrorockets)
- Failed 20 seconds after landing, transmitted a gray image with no details
- Associated orbiter continued to transmit planetary images



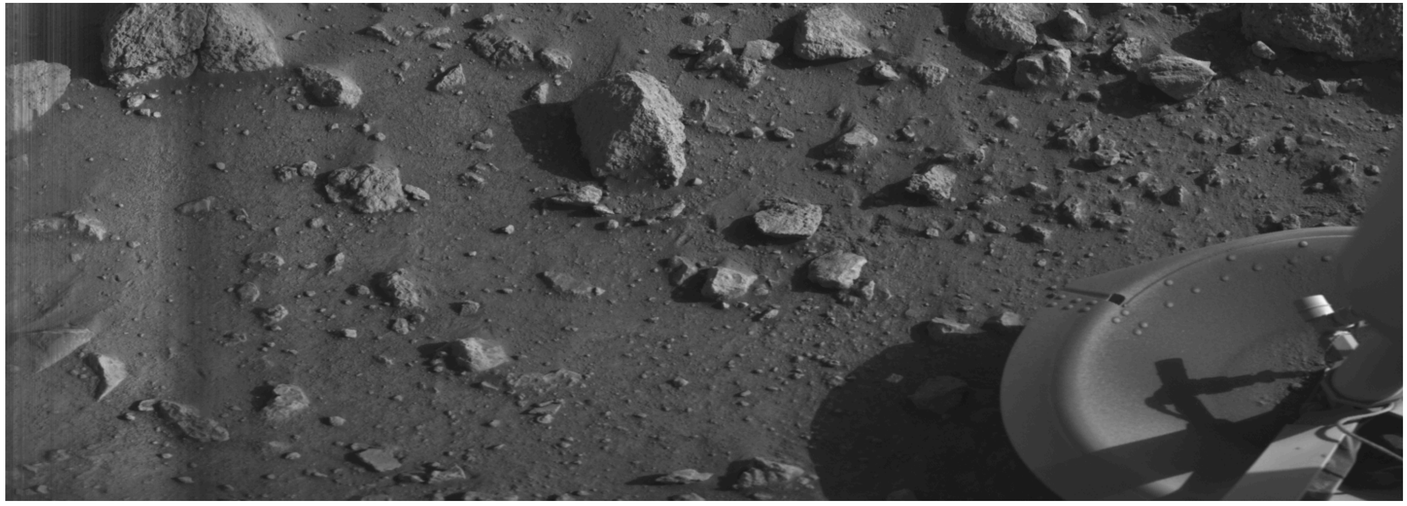
Viking 1

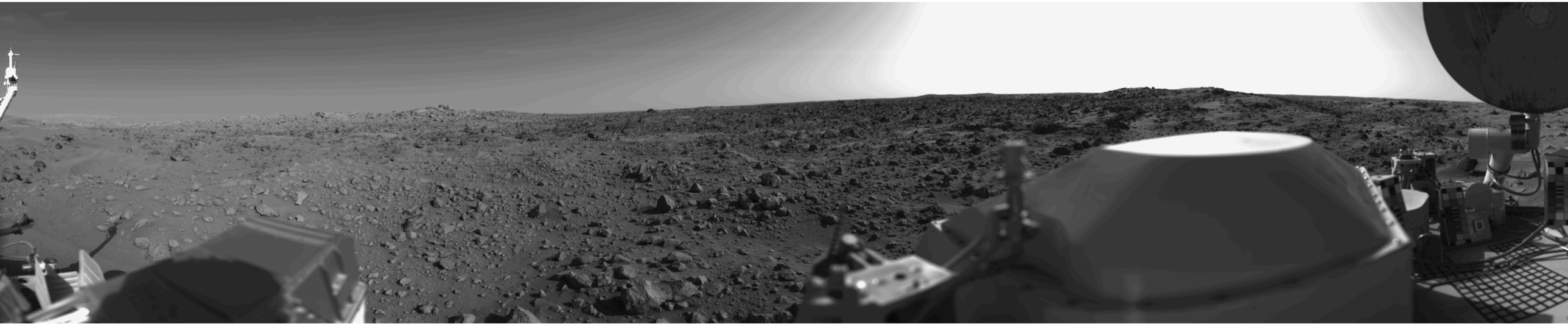
- Second spacecraft to soft land on Mars, and the first to successfully complete its mission
- Surface mission lasted over 6.25 years
- Landed on the seventh anniversary of Apollo 11 moon landing
- Descent system included aeroshell heat shield, 16m diameter lander parachutes (slowed craft to 60 m/s), and retrorockets.
- Legs included honeycomb aluminum shock absorbers for landing
- Transmitted the first ever clear image from the surface of Mars



Viking 1 model

First clear image from Mars surface

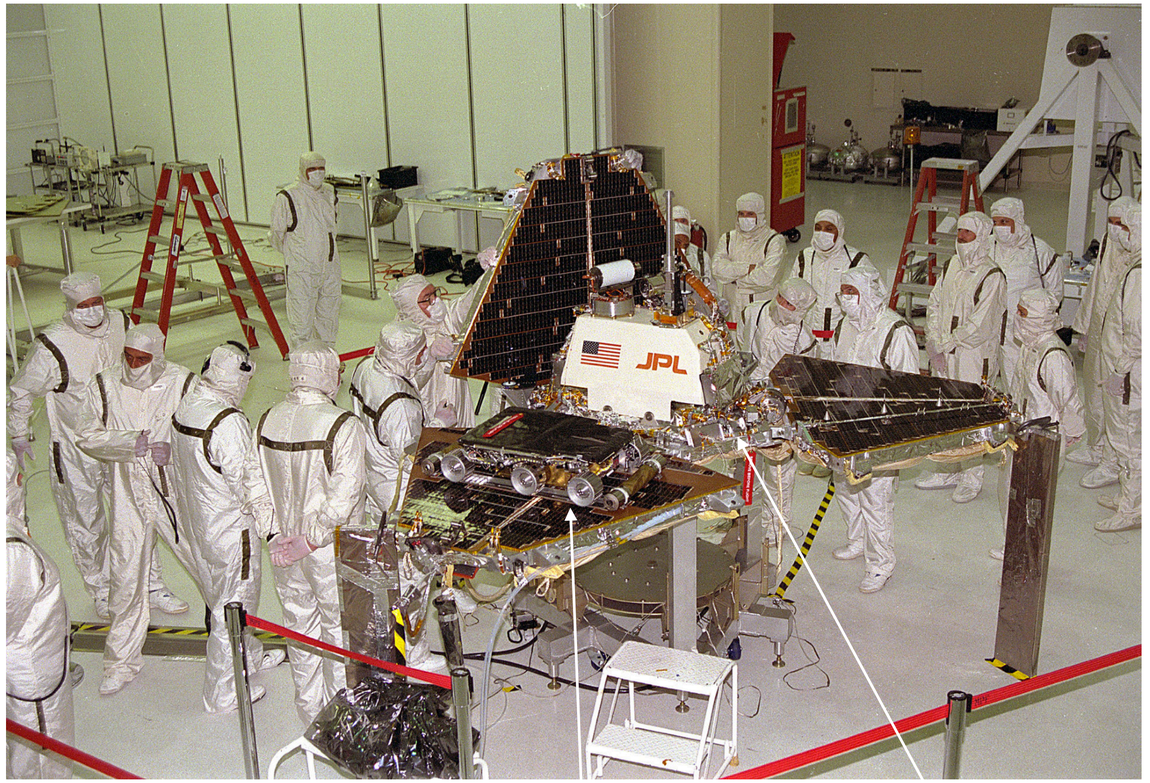




First panoramic image from Viking 1

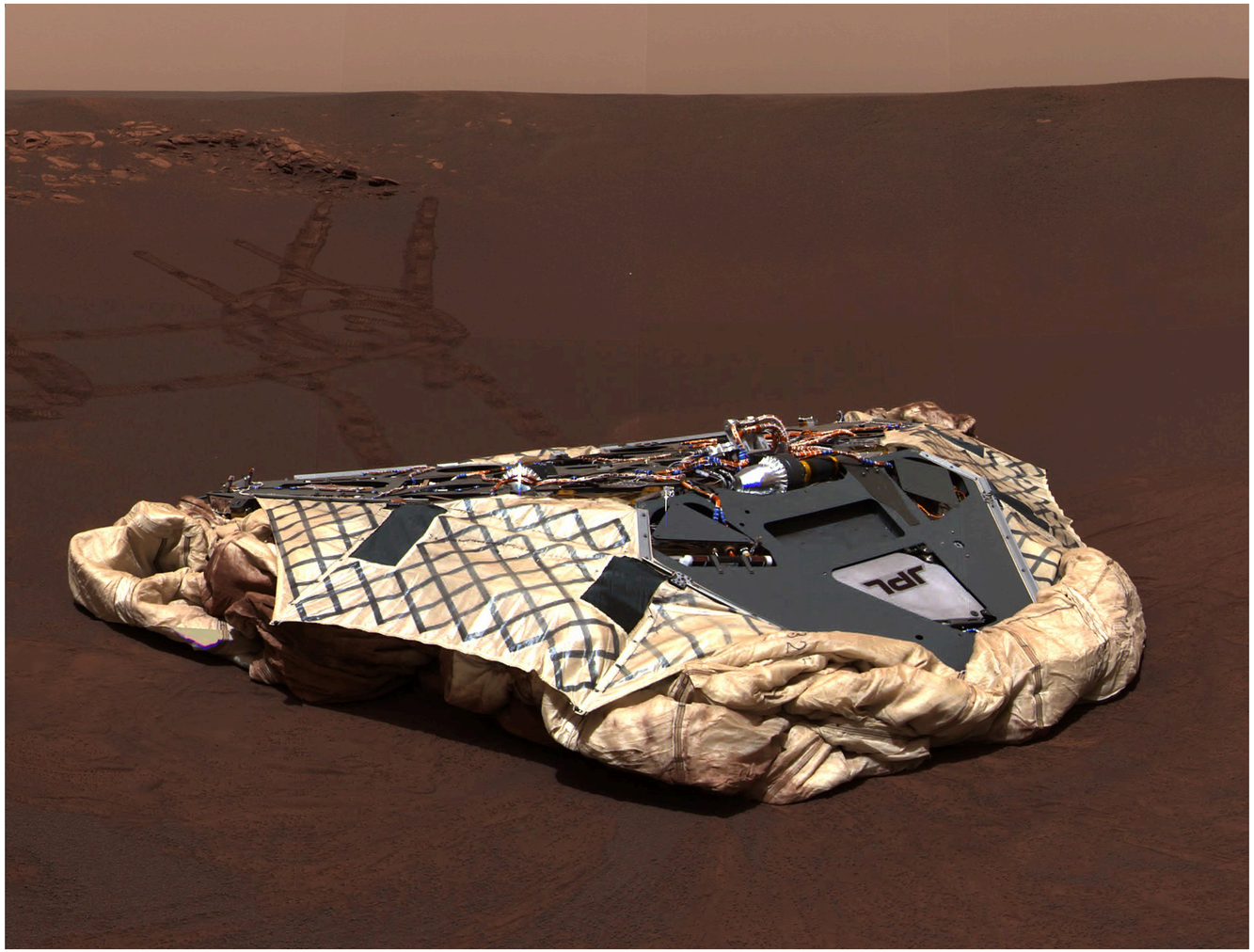
Pathfinder/Sojourner

- Pathfinder acted as a base station for the Sojourner rover
- Hit atmosphere at 6.1 km/s, slowed to 370 m/s using a heat shield
- Deployed supersonic disk-band parachute to slow to 68 m/s
- Pyrotechnically released heat shield
- Lander was lowered 20m below the back shell on a tether
- At 355m above the ground, airbags deployed using solid-rocket motor gas generators
- Retrorockets in the back shell reduced velocity to 0 m/s at 15-25m above the ground
- Cut the bridle to the lander/airbags, lander impacted at 14m/s and experienced 18G of deceleration
- Bounced 15 times
- EDL lasted 4 minutes

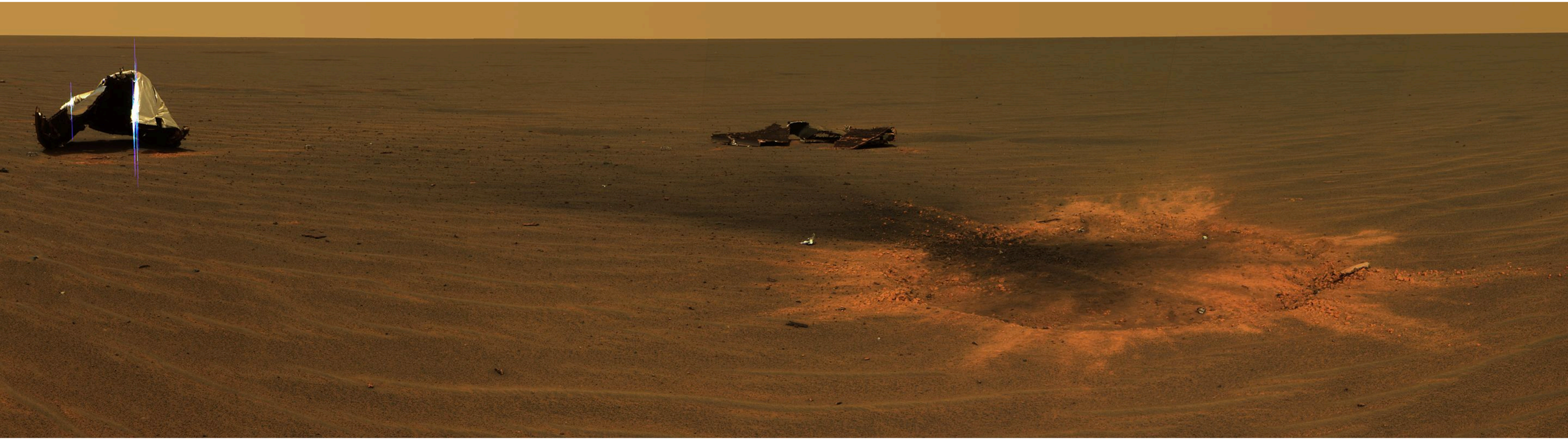


Spirit/Opportunity (MER)

- Very similar EDL to pathfinder
- Slowed initially by a heat shield
- Hypersonic parachute deployed
- Lander lowered by tether
- Slowed by retrorockets
- Airbags inflated
- Lander cut from back shell, dropped/bounced



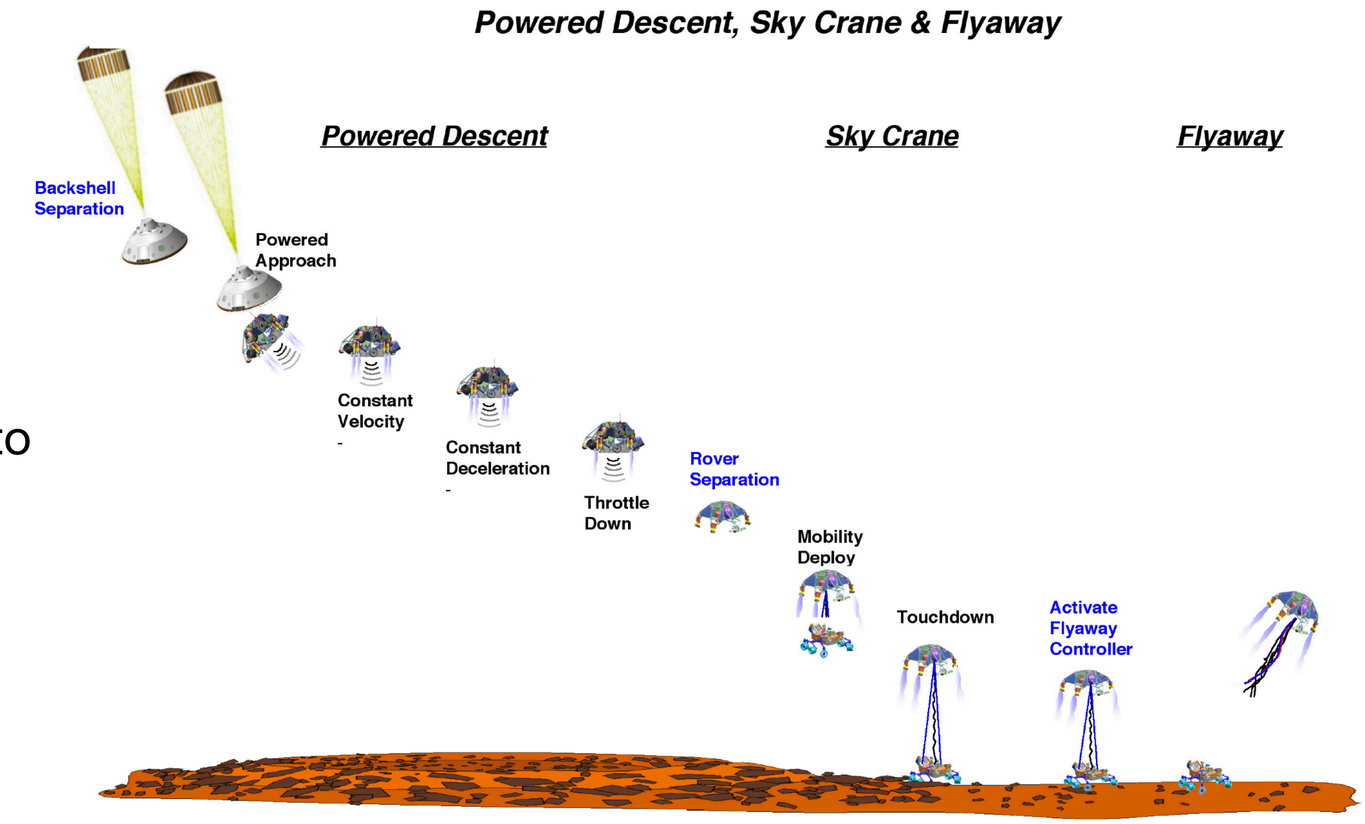
Empty lander imaged by *Opportunity*



Heat shield impact site, imaged by *Opportunity*

Curiosity

- Too large for airbags
- Descent slowed by heat shield
- Hypersonic parachute deployed
- Heat shield dropped to expose sensing equipment
- Lander cut loose from parachute, rockets used to slow descent
- Rocket-controlled hover above the surface
- Rover lowered by tether to the surface
- On contact, tether is cut and rocket-propelled back shell flies away



Curiosity EDL

InSight

- Heat shield to slow descent
- Deploy hypersonic parachute
- Jettison heat shield
- Extend landing legs
- Activate landing radar
- Jettison back shell
- Turn on landing rockets
- Approach ground at 5mph
- Turn off rockets at touchdown

InSight in the cleanroom

Venus

- Venera 3-14
- Vega 1
- Vega 2

Venera

- Venera 3: first impact on another planet, contact lost before entry
- Venera 4: crushed by atmospheric pressure before impact
- Venera 5: crushed by atmospheric pressure before impact
- Venera 6: crushed by atmospheric pressure before impact
- Venera 7: **first soft landing on another planet, transmitted for 23 minutes**
- Venera 8: **transmitted for 50 minutes**
- Venera 9: **transmitted for 53 minutes, first pictures from the surface**
- Venera 10: **transmitted for 65 minutes**
- Venera 11: **transmitted for 95 minutes**
- Venera 12: **transmitted for 110 minutes**
- Venera 13: **transmitted for 127 minutes**
- Venera 14: **transmitted for 57 minutes**

Venera 7

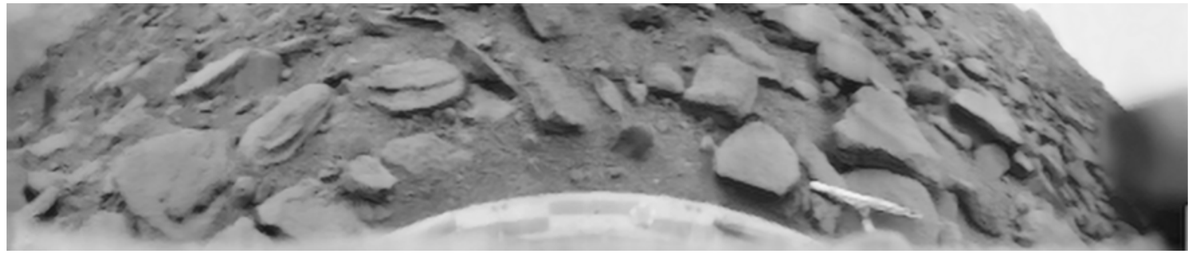


image from Venera 9

Venera

- Hermetically sealed pressure vessels
- Descent using a heat shield, followed by parachute deployment
- Atmosphere near the surface so thick that the parachute could be cut loose, and the lander used aerobraking with the heat shield

Venera 7

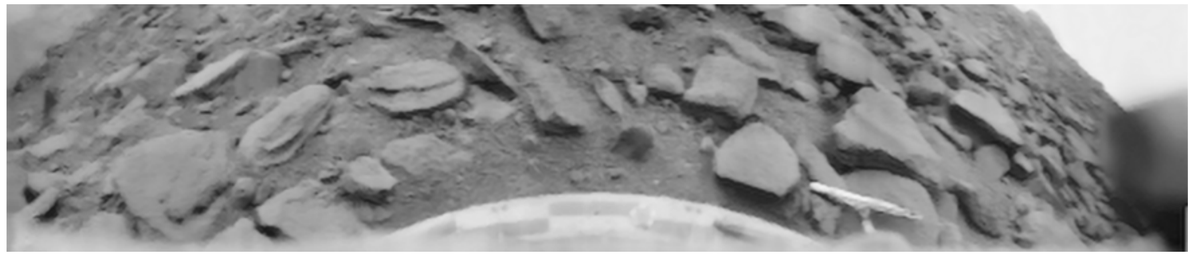


image from Venera 9

Vega 1/2

- Surface lander identical to those used by Venera
- Also deployed a balloon experiment
- Balloon package pulled out of its compartment by parachute at 61km altitude
- Second parachute opened at 55km, extracting the furled balloon
- Balloon inflated 100 sec later at 54 km
- Jettison parachute and inflation system
- Balloon floated stably at 53-54km
- Drifted westward at an average speed of 69m/s
- Traversed 11,600km total

Balloon experiment

Titan

- Huygens

Huygens Probe

- Heat shield for protection during initial interaction with the atmosphere
- Sequence of parachutes to slow descent through the atmosphere
- Parachute descent all the way to the surface

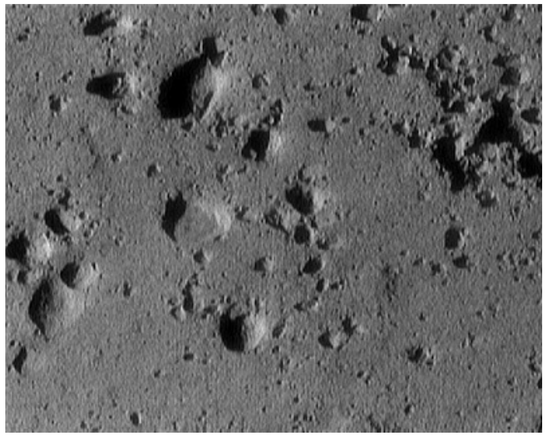
Asteroids and Comets

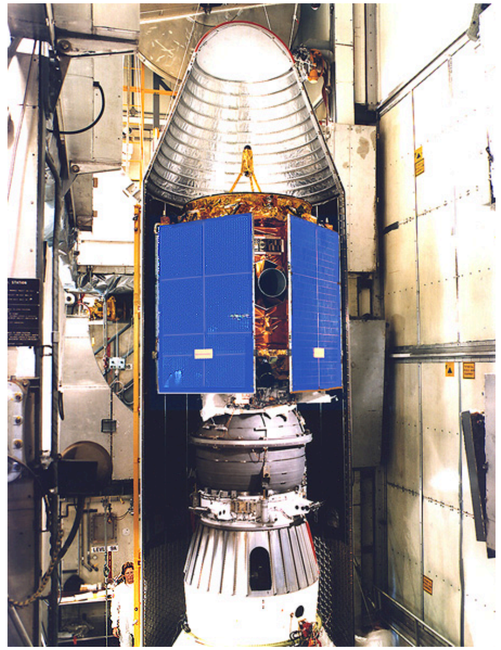
- NEAR Shoemaker
- Hayabusa/Hayabusa 2
- Rosetta

NEAR Shoemaker

- First soft landing on an asteroid
- Impacted at 1.5-1.8 m/s
- Landing was a secondary mission, the spacecraft was not designed as a lander

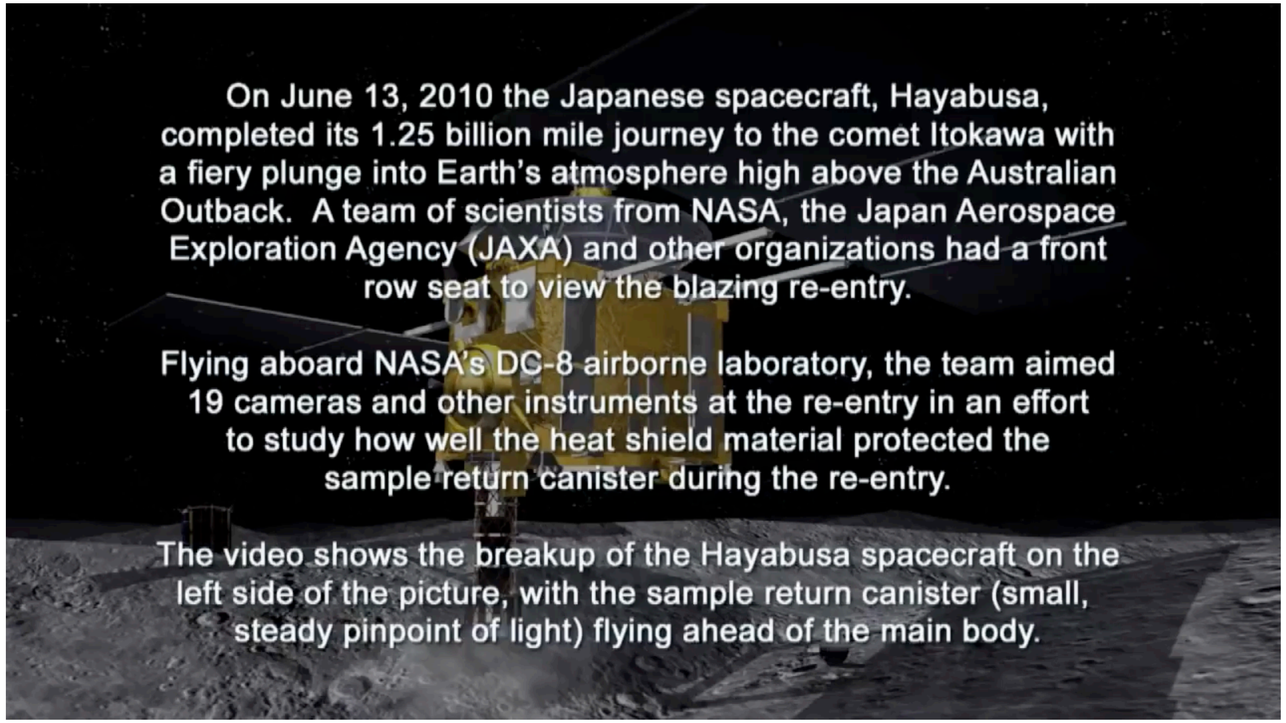
Eros





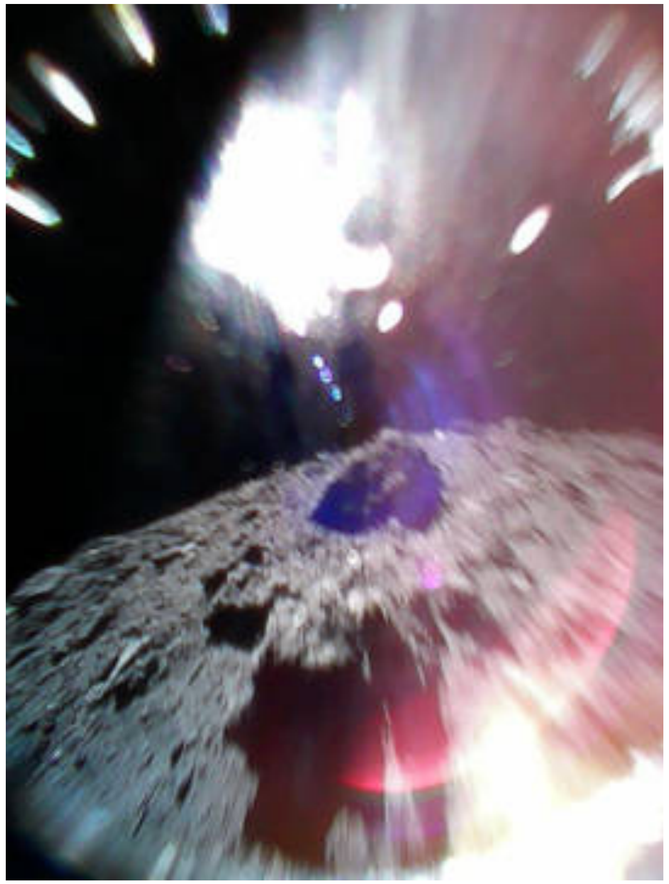
Hayabusa

- First sample return from an asteroid (Itokawa)
- Was not designed to “land,” but to simply touch the surface with a sampling device and move away
- Despite intention to touch-and-go, the craft did and and sit on the surface for ~30 min



Hayabusa 2

- Sample return mission from Ryugu
- Deployed four small rovers to investigate the asteroid surface in situ, a series of target markers, a deployable camera, an impactor, and a sensor suite called MASCOT
- Currently on its way home



First photograph from the surface of an asteroid

Rosetta/Philae

- First soft landing on a comet by the lander Philae
- Bounced when anchoring harpoons failed to deploy, and a thruster designed to hold the probe to the surface did not fire
- Bounced twice then landed in a sub-optimal orientation