Kennedy Space Center

New NASA Technologies for Space Exploration

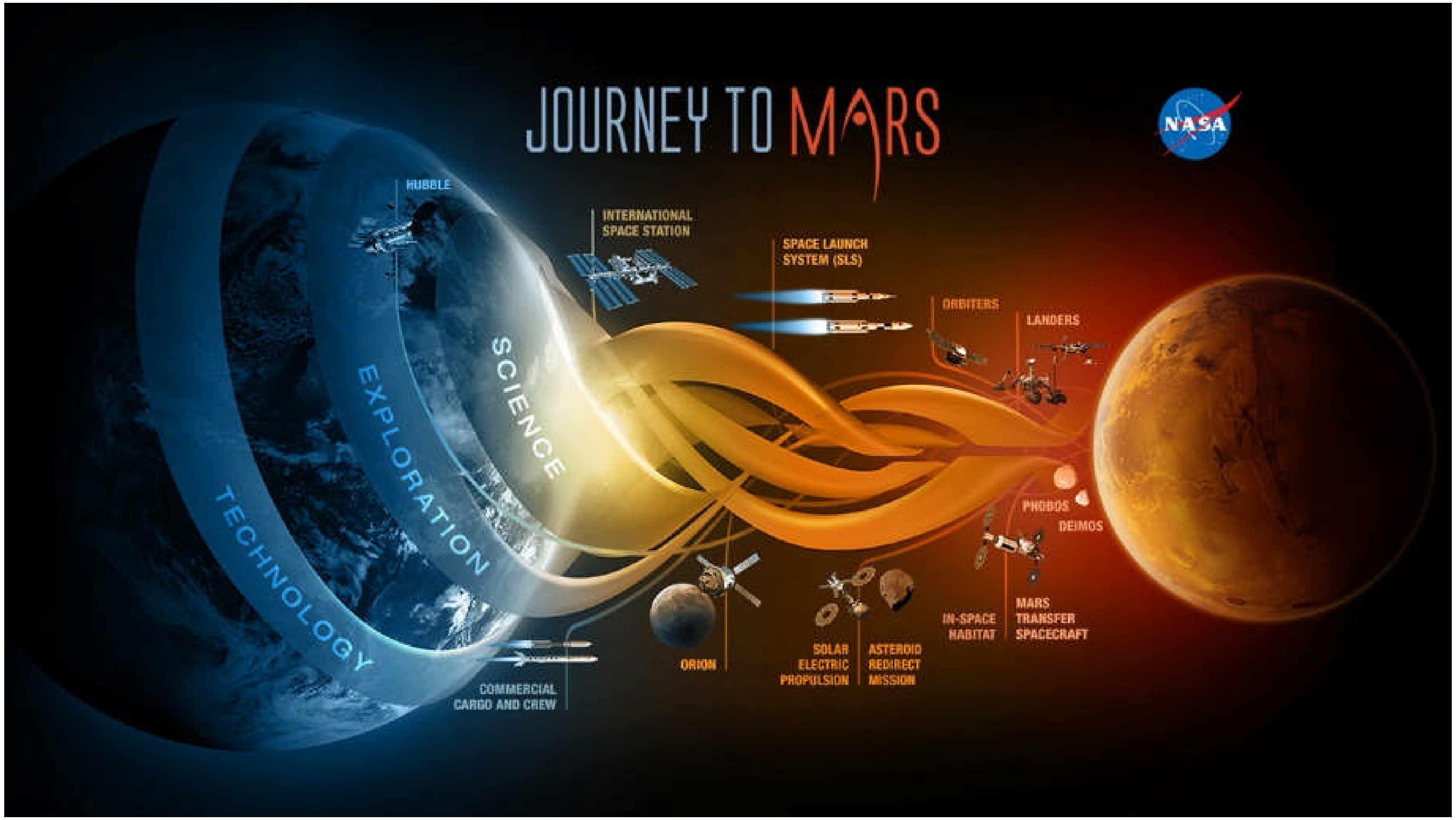
Carlos I. Calle, Ph.D.

Senior Research Scientist

NASA Kennedy Space Center

Universidad Autonoma de Nuevo Leon and Center for Research and Innovation In Aeronautical Engineering, Monterrey, Mexico, August 13-14, 2015

Kennedy Space Center

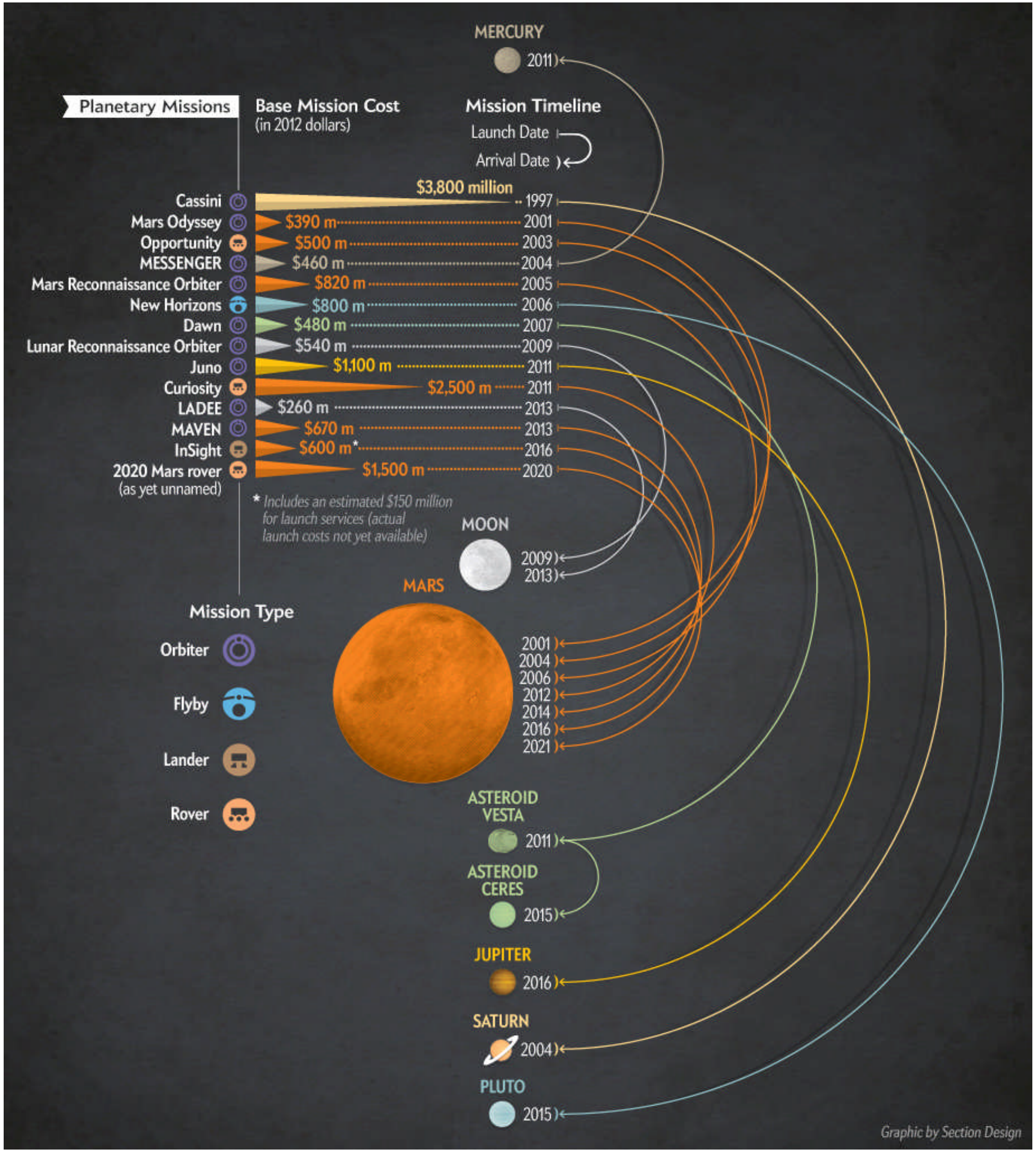


- While robotic explorers have studied Mars for more than 40 years, NASA's path for the human exploration of Mars begins in low-Earth orbit aboard the International Space Station. Astronauts on the orbiting laboratory are helping us prove many of the technologies and communications systems needed for human missions to deep space, including Mars. The space station also advances our understanding of how the body changes in space and how to protect astronaut health.
- Our next step is deep space, where NASA will send a robotic mission to capture and redirect an asteroid to orbit the moon. Astronauts aboard the Orion spacecraft will explore the asteroid in the 2020s, returning to Earth with samples. This experience in human spaceflight beyond low-Earth orbit will help NASA test new systems and capabilities, such as Solar Electric Propulsion, which we'll need to send cargo as part of human missions to Mars. Beginning in FY 2018, NASA's powerful Space Launch System rocket will enable these "proving ground" missions to test new capabilities. Human missions to Mars will rely on Orion and an evolved version of SLS that will be the most powerful launch vehicle ever flown

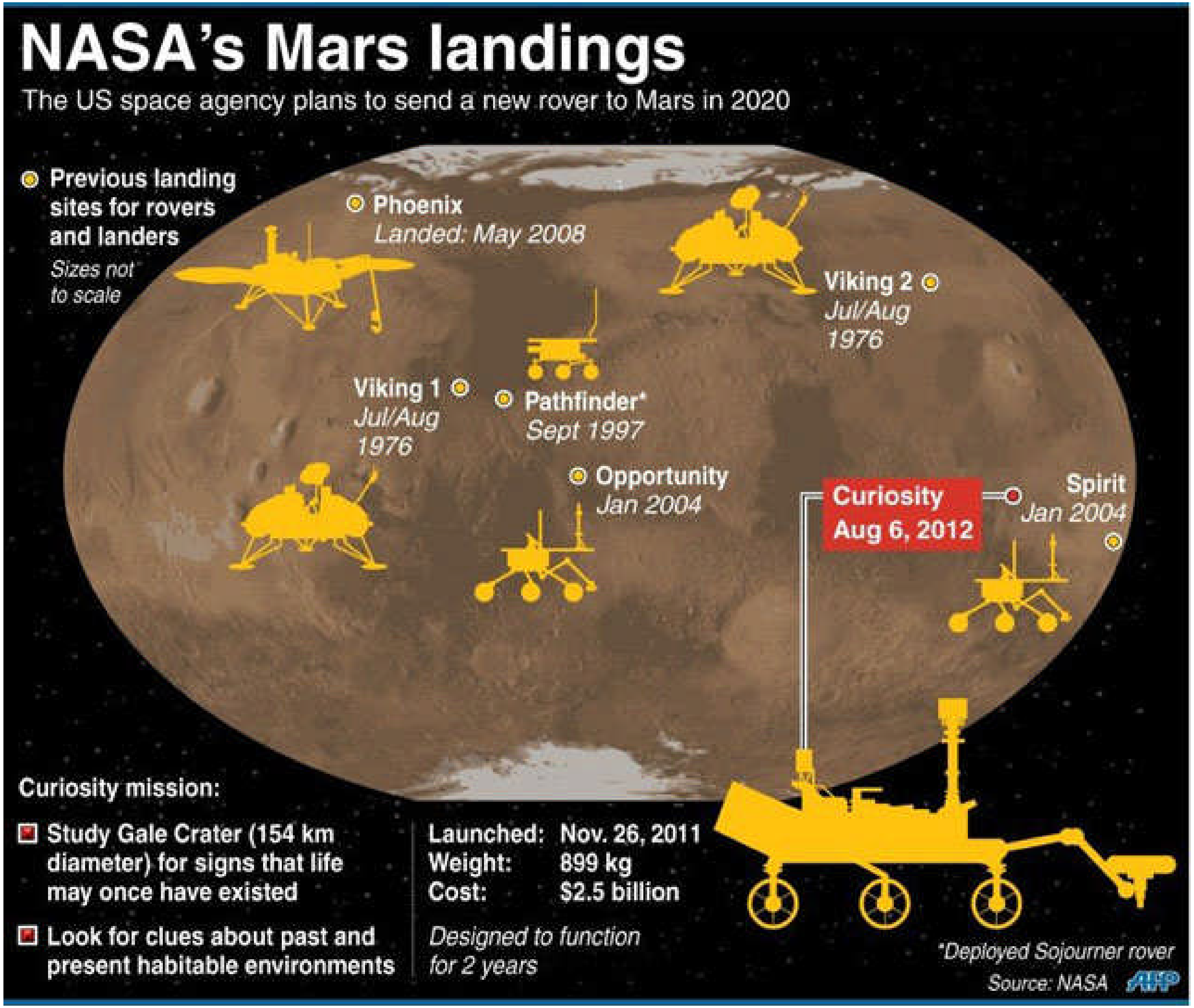
Kennedy Space Center

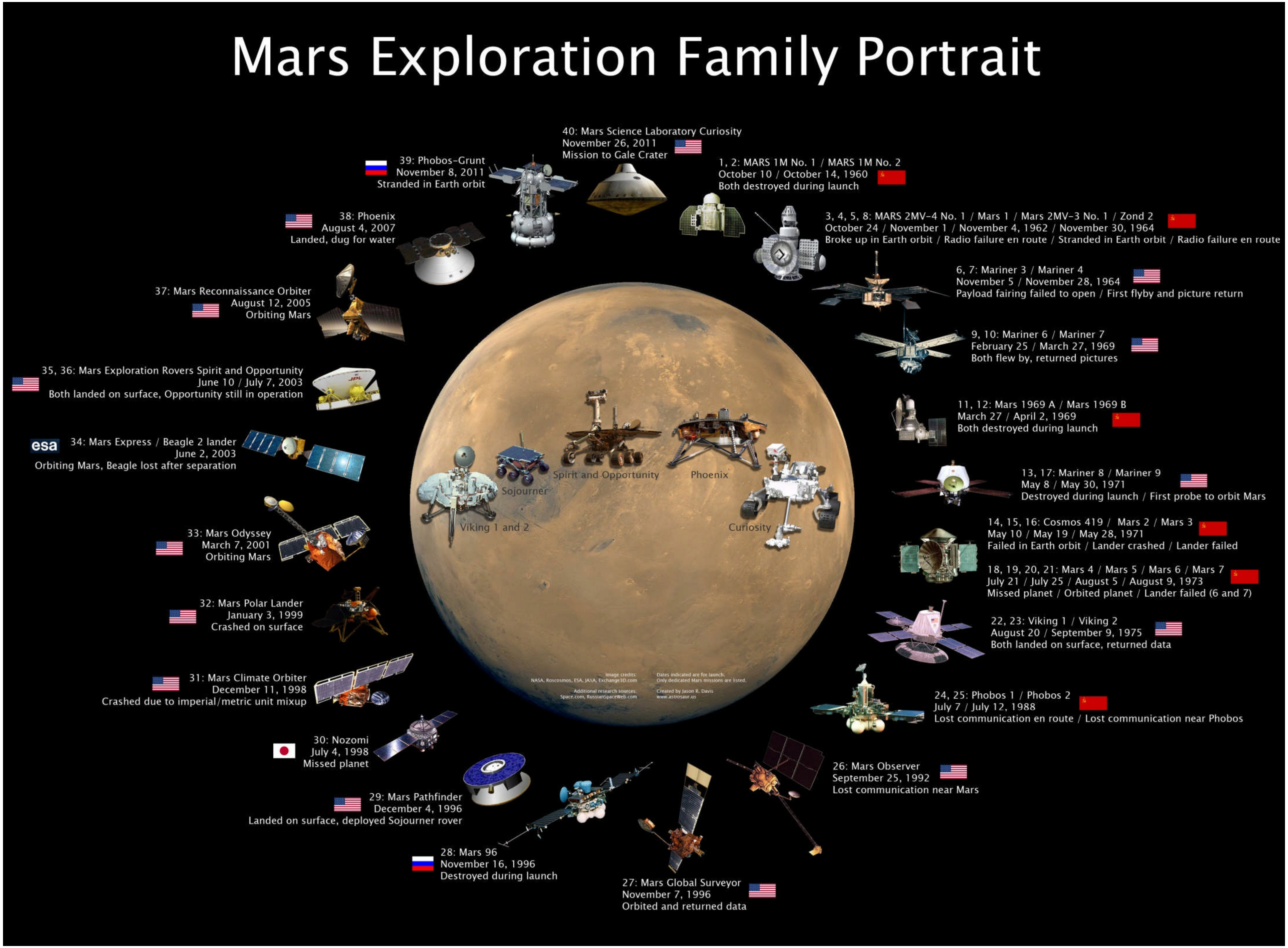
- NASA’s Space Launch System, or SLS, is an advanced launch vehicle for a new era of exploration beyond Earth’s orbit into deep space. SLS, the world’s most powerful rocket, will launch astronauts in the agency’s Orion spacecraft on missions to an asteroid and eventually to Mars, while opening new possibilities for other payloads including robotic scientific missions to places like Mars, Saturn and Jupiter.
- SLS will be the most powerful rocket in history and is designed to be flexible and evolvable

Kennedy Space Center



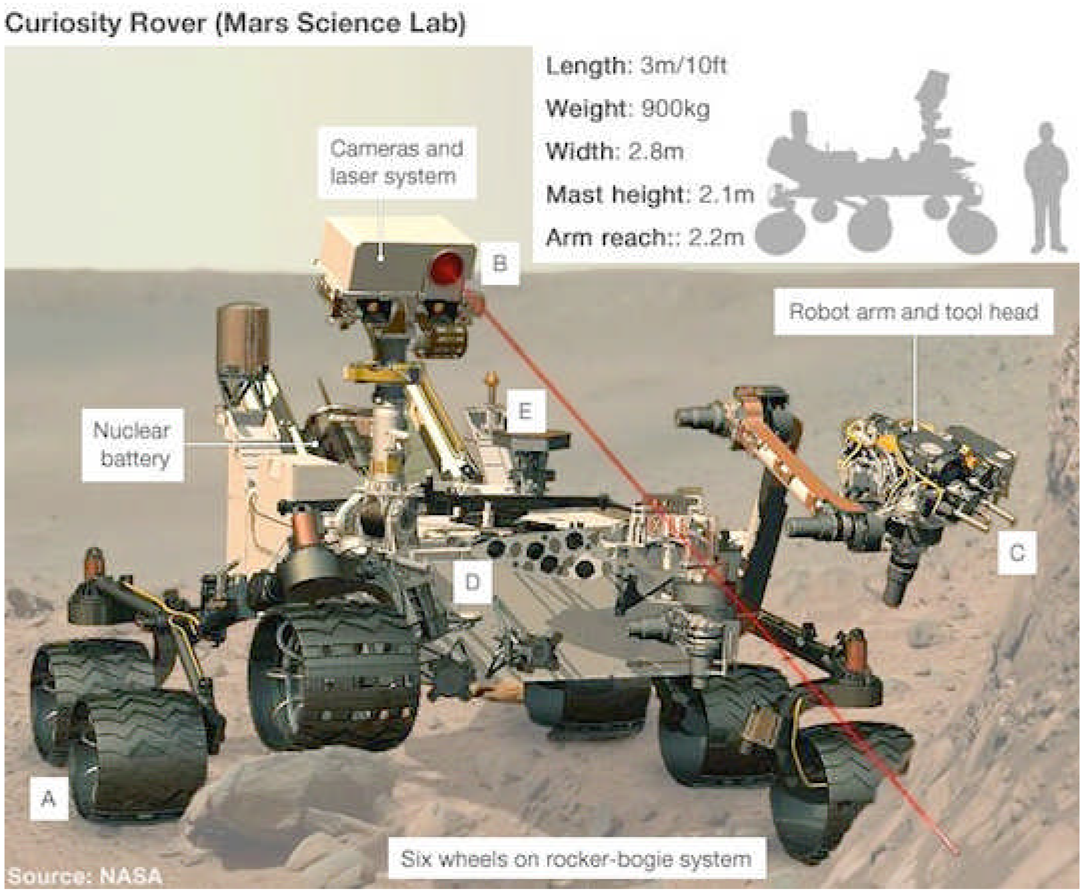
Kennedy Space Center




Mars Exploration Family Portrait
40: Mars Science Laboratory Curiosity
November 26, 2011
Mission to Gale Crater
1, 2: MARS 1M No. 1 / MARS 1M No. 2
October 10 / October 14, 1960
Both destroyed during launch
3, 4, 5, 8: MARS 2MV-4 No. 1 / Mars 1 / Mars 2MV-3 No. 1 / Zond 2
October 24 / November 1 / November 4, 1962 / November 30, 1964
Broke up in Earth orbit / Radio failure en route / Stranded in Earth orbit / Radio failure en route
6, 7: Mariner 3 / Mariner 4
November 5 / November 28, 1964
Payload fairing failed to open / First flyby and picture return
9, 10: Mariner 6 / Mariner 7
February 25 / March 27, 1969
Both flew by, returned pictures
11, 12: Mars 1969 A / Mars 1969 B
March 27 / April 2, 1969
Both destroyed during launch
13, 17: Mariner 8 / Mariner 9
May 8 / May 30, 1971
Destroyed during launch / First probe to orbit Mars
14, 15, 16: Cosmos 419 / Mars 2 / Mars 3
May 10 / May 19 / May 28, 1971
Failed in Earth orbit / Lander crashed / Lander failed
18, 19, 20, 21: Mars 4 / Mars 5 / Mars 6 / Mars 7
July 21 / July 25 / August 5 / August 9, 1973
Missed planet / Orbited planet / Lander failed (6 and 7)
22, 23: Viking 1 / Viking 2
August 20 / September 9, 1975
Both landed on surface, returned data
24, 25: Phobos 1 / Phobos 2
July 7 / July 12, 1988
Lost communication en route / Lost communication near Phobos
26: Mars Observer
September 25, 1992
Lost communication near Mars
27: Mars Global Surveyor
November 7, 1996
Orbited and returned data
28: Mars 96
November 16, 1996
Destroyed during launch
29: Mars Pathfinder
December 4, 1996
Landed on surface, deployed Sojourner rover
30: Nozomi
July 4, 1998
Missed planet
31: Mars Climate Orbiter
December 11, 1998
Crashed due to imperial/metric unit mixup
32: Mars Polar Lander
January 3, 1999
Crashed on surface
33: Mars Odyssey
March 7, 2001
Orbiting Mars
esa
34: Mars Express / Beagle 2 lander
June 2, 2003
Orbiting Mars, Beagle lost after separation
35, 36: Mars Exploration Rovers Spirit and Opportunity
June 10 / July 7, 2003
Both landed on surface, Opportunity still in operation
37: Mars Reconnaissance Orbiter
August 12, 2005
Orbiting Mars
38: Phoenix
August 4, 2007
Landed, dug for water
39: Phobos-Grunt
November 8, 2011
Stranded in Earth orbit
Viking 1 and 2
Sojourner
Spirit and Opportunity
Phoenix
Curiosity
Image credits:
NASA, Roscosmos, ESA, JAXA, Exchange3D.com
Additional research sources:
Space.com, RussianSpaceWeb.com
Dates indicated are for launch.
Only dedicated Mars missions are listed.
Created by Jason R. Davis
www.astrosaur.us

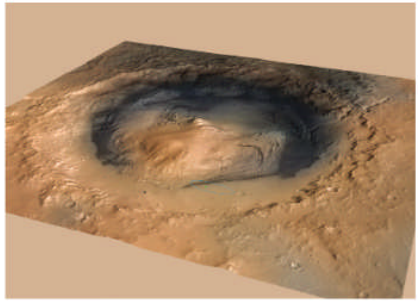
Mars Science Laboratory Mission

Kennedy Space Center



Curiosity Rover

- Launch: Cape Canaveral, Nov. 26, 2011
- Landing:
  - S-curve maneuvers similar to a piloted Shuttle landing
  - Gale Crater (size of Connecticut and Rhode Island combined)
  - Aug. 6, 2012
- 23-month mission



Kennedy Space Center

Mars 2020 Rover Mission

MISSION TIMELINE

LAUNCH

- Atlas V
- Period: Jul/Aug 2020

CRUISE/APPROACH

- 8 to 9-month cruise
- Arrive Jan/Mar 2021
- No changes from MSL (equivalent checkout capability, etc.)

ENTRY, DESCENT & LANDING

- MSL EDL system: guided entry and powered descent/Sky Crane
- 25 x 20 km landing ellipse*
- Access to landing sites ±30° latitude, ≤ 0 km elevation*
- ~950 kg rover
- Technology enhancements under consideration

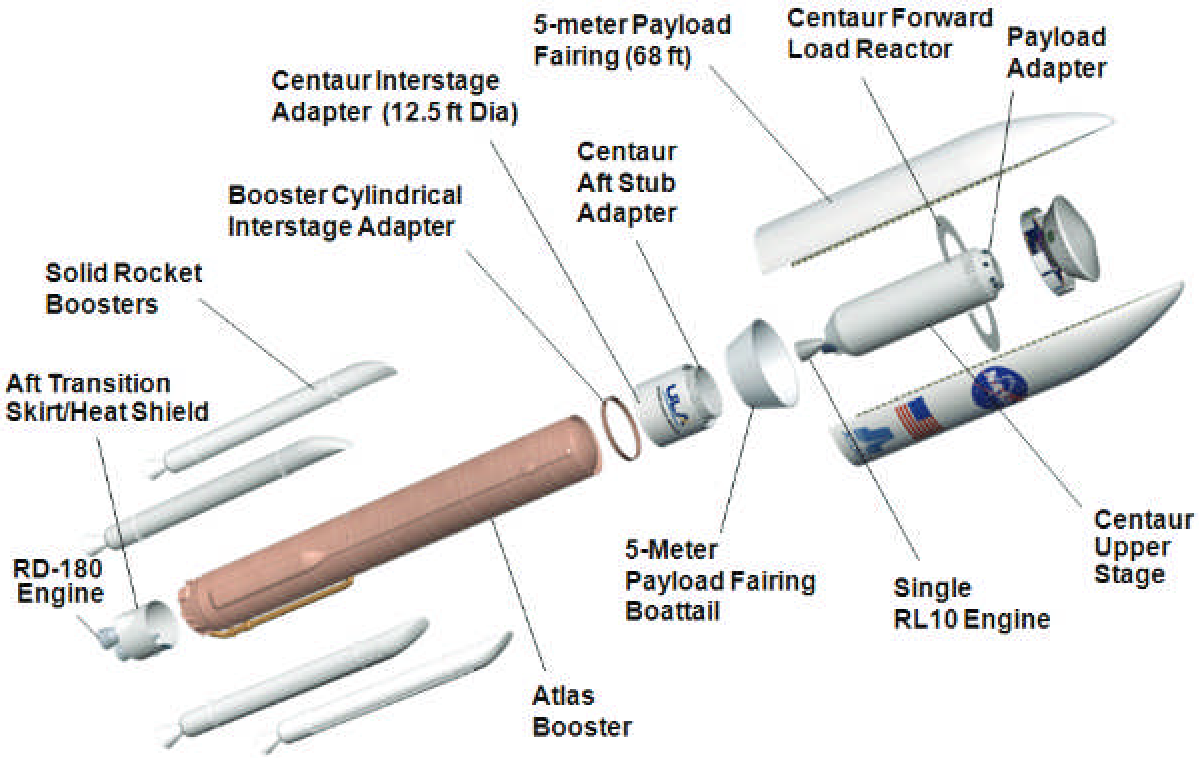
SURFACE MISSION

- Prime mission is one Mars year (669 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- Direct (uplink/downlink) and relayed (downlink) communication
- Fast CPU and large data storage

* EDL in work

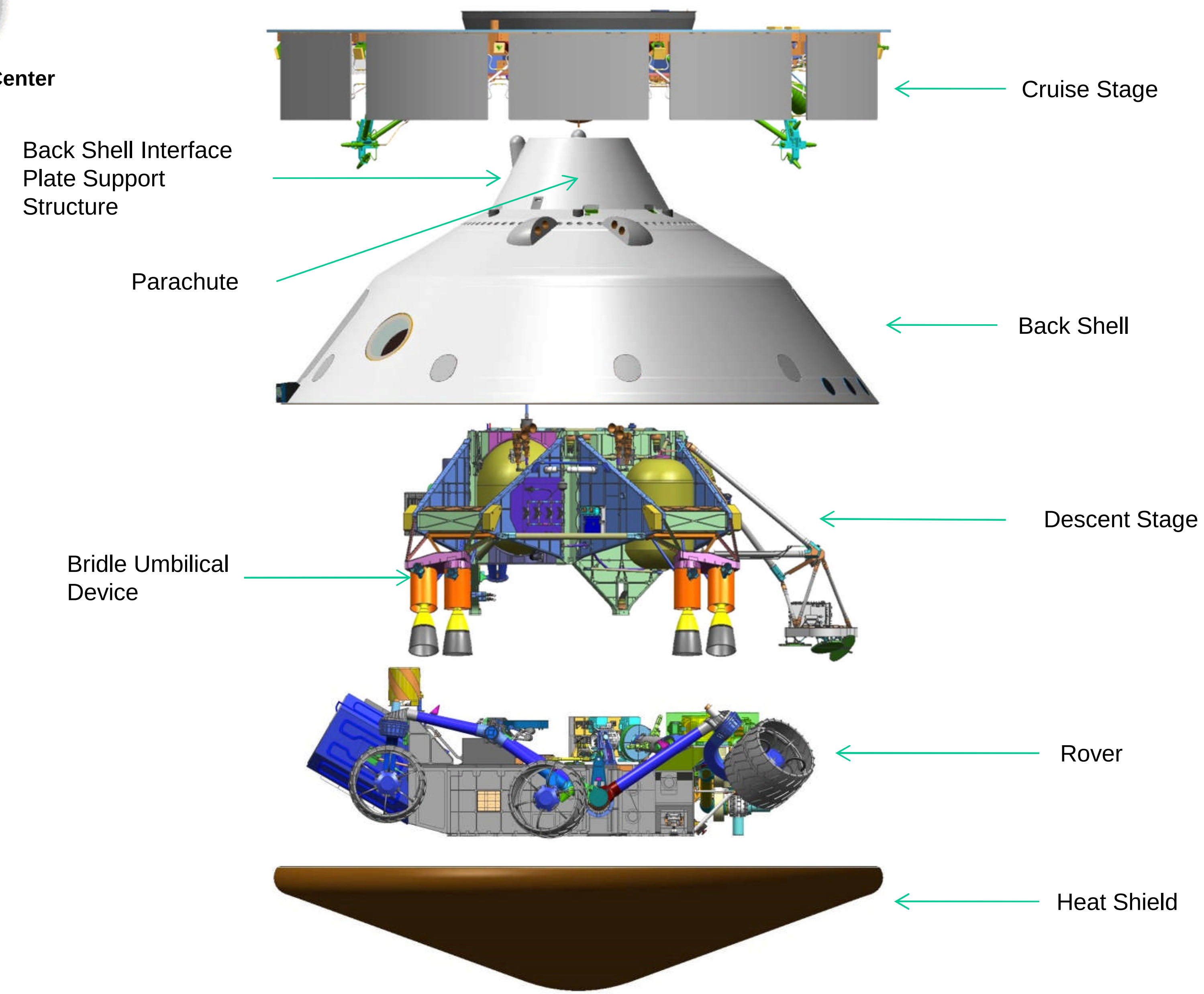
Kennedy Space Center

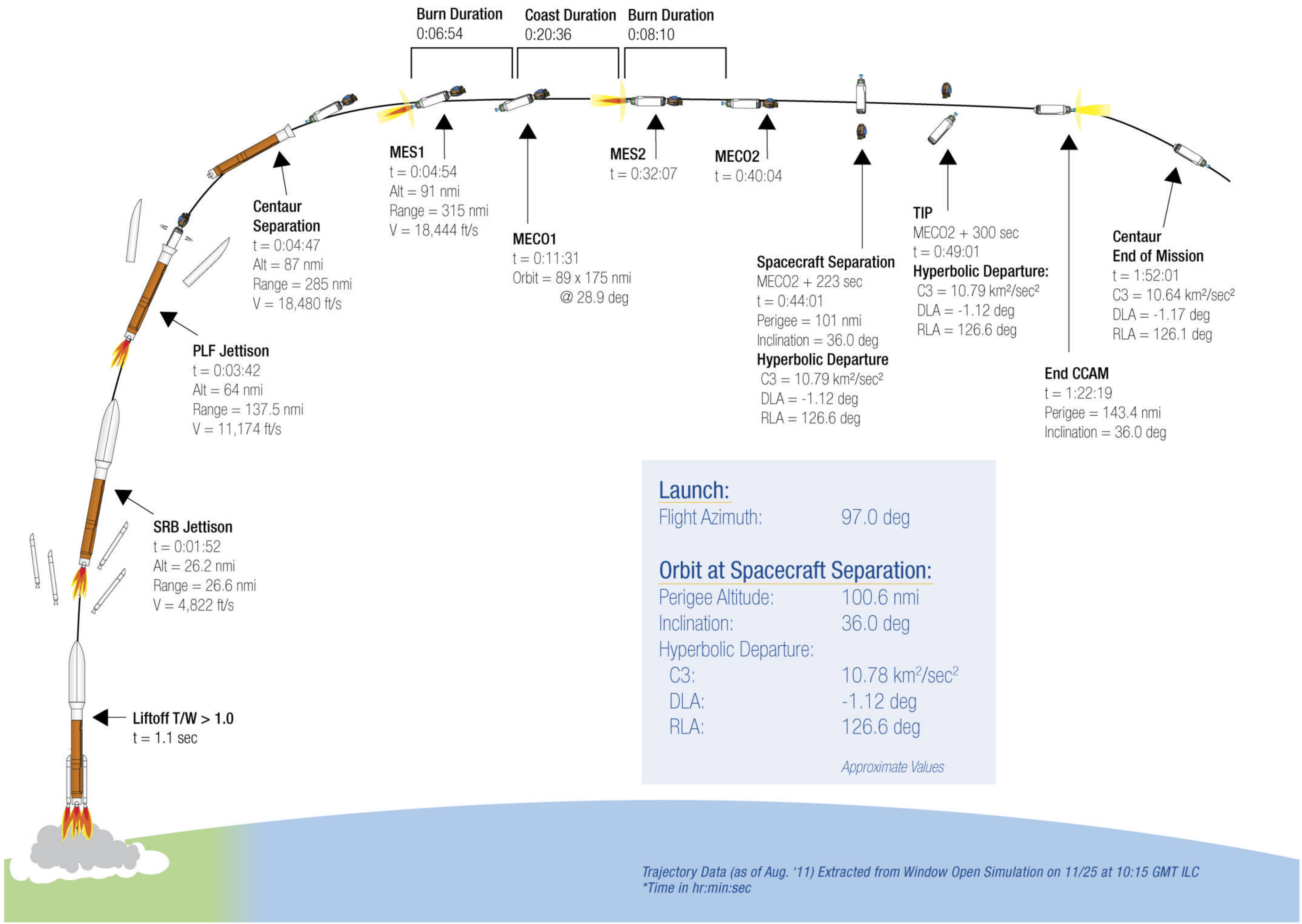
Launch Vehicle

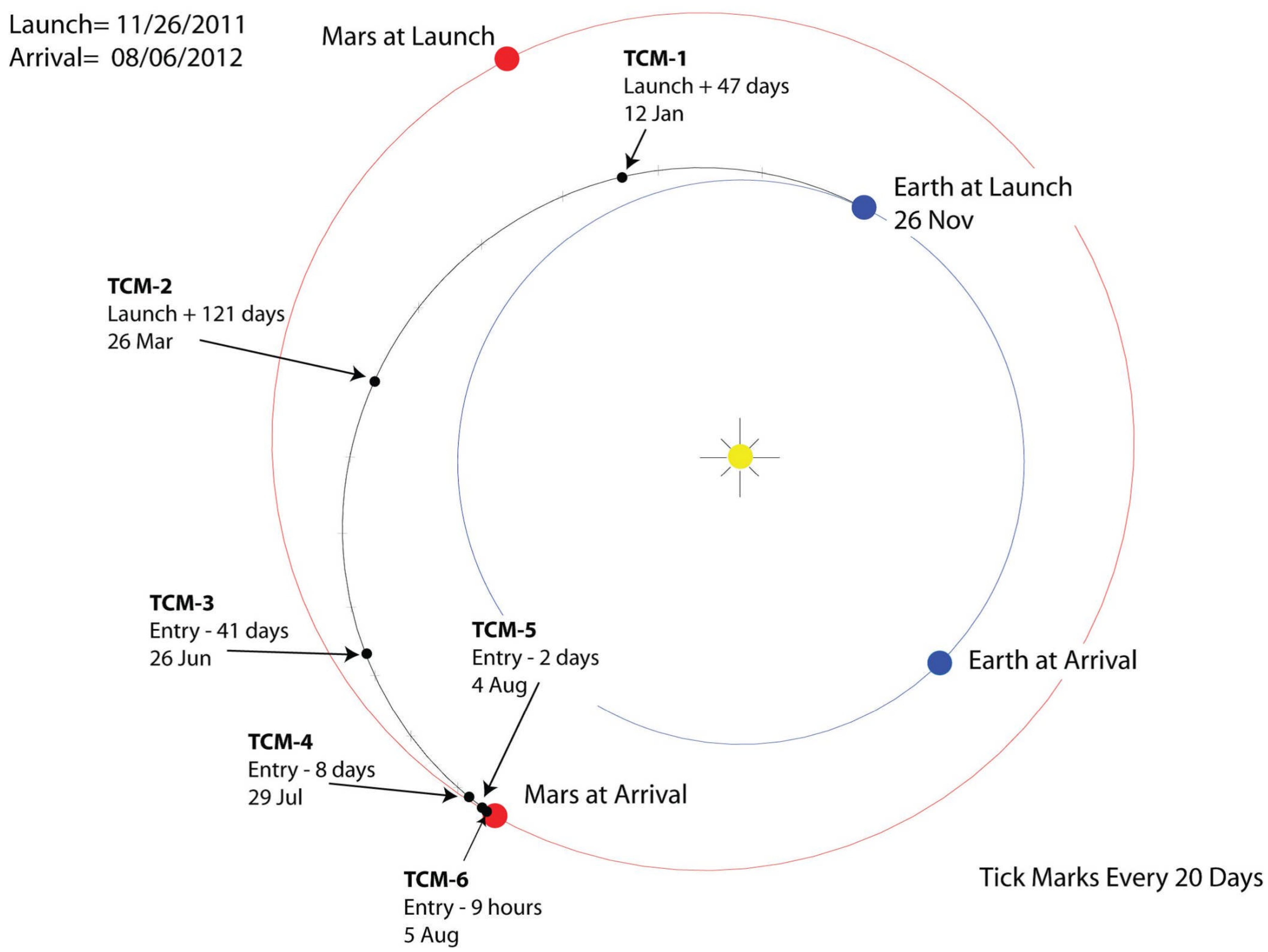


Atlas V 541 launch vehicle, expanded view

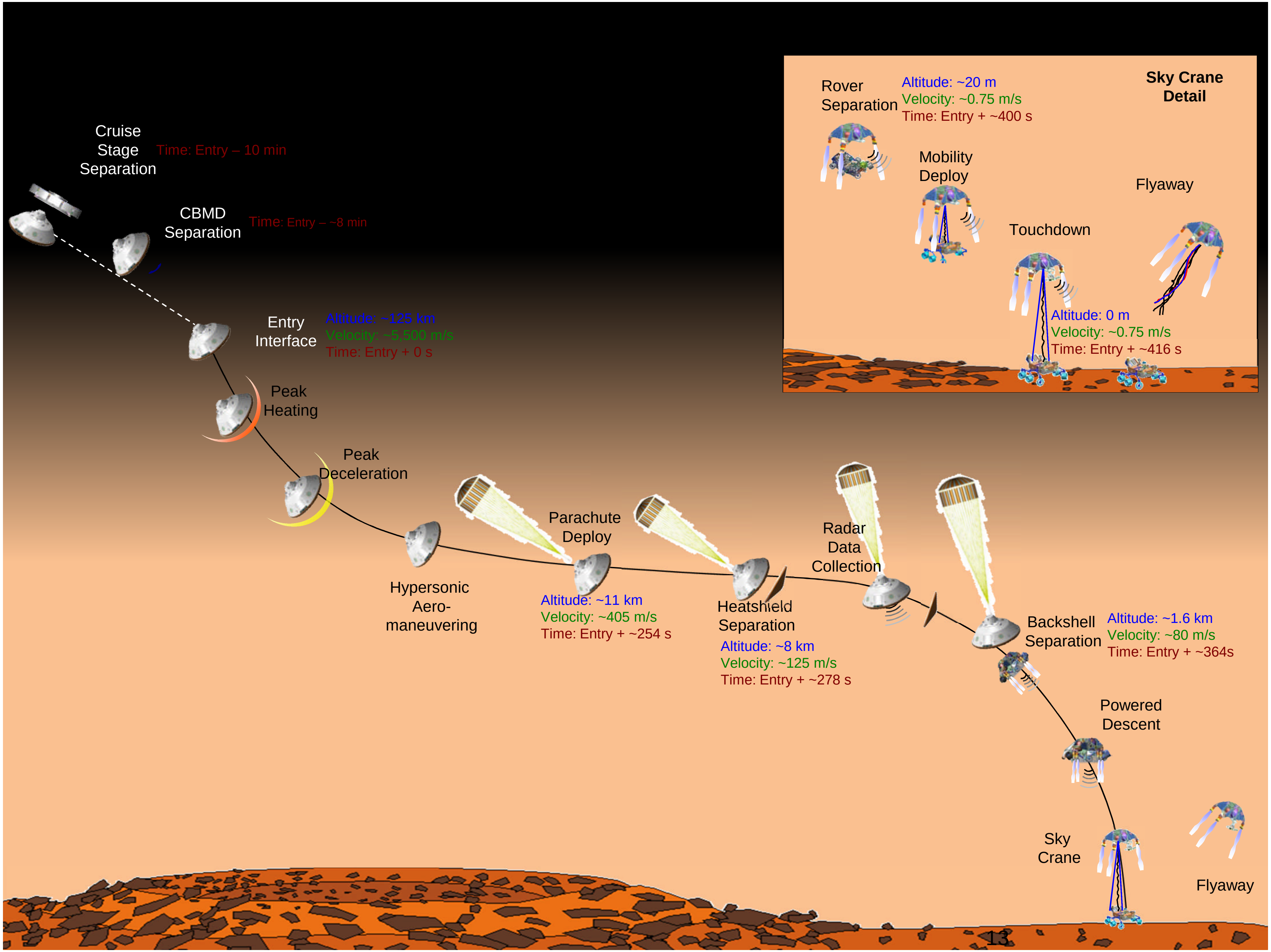
Kennedy Space Center




Burn Duration
0:06:54
Coast Duration
0:20:36
Burn Duration
0:08:10
MES1
t = 0:04:54
Alt = 91 nmi
Range = 315 nmi
V = 18,444 ft/s
MECO1
t = 0:11:31
Orbit = 89 x 175 nmi
@ 28.9 deg
MES2
t = 0:32:07
MECO2
t = 0:40:04
Spacecraft Separation
MECO2 + 223 sec
t = 0:44:01
Perigee = 101 nmi
Inclination = 36.0 deg
Hyperbolic Departure
C3 = 10.79 km²/sec²
DLA = -1.12 deg
RLA = 126.6 deg
TIP
MECO2 + 300 sec
t = 0:49:01
Hyperbolic Departure:
C3 = 10.79 km²/sec²
DLA = -1.12 deg
RLA = 126.6 deg
End CCAM
t = 1:22:19
Perigee = 143.4 nmi
Inclination = 36.0 deg
Centaur
End of Mission
t = 1:52:01
C3 = 10.64 km²/sec²
DLA = -1.17 deg
RLA = 126.1 deg
Centaur
Separation
t = 0:04:47
Alt = 87 nmi
Range = 285 nmi
V = 18,480 ft/s
PLF Jettison
t = 0:03:42
Alt = 64 nmi
Range = 137.5 nmi
V = 11,174 ft/s
SRB Jettison
t = 0:01:52
Alt = 26.2 nmi
Range = 26.6 nmi
V = 4,822 ft/s
Liftoff T/W > 1.0
t = 1.1 sec
Launch:
Flight Azimuth: 97.0 deg
Orbit at Spacecraft Separation:
Perigee Altitude: 100.6 nmi
Inclination: 36.0 deg
Hyperbolic Departure:
C3: 10.78 km²/sec²
DLA: -1.12 deg
RLA: 126.6 deg
Approximate Values
Trajectory Data (as of Aug. '11) Extracted from Window Open Simulation on 11/25 at 10:15 GMT ILC
*Time in hr:min:sec



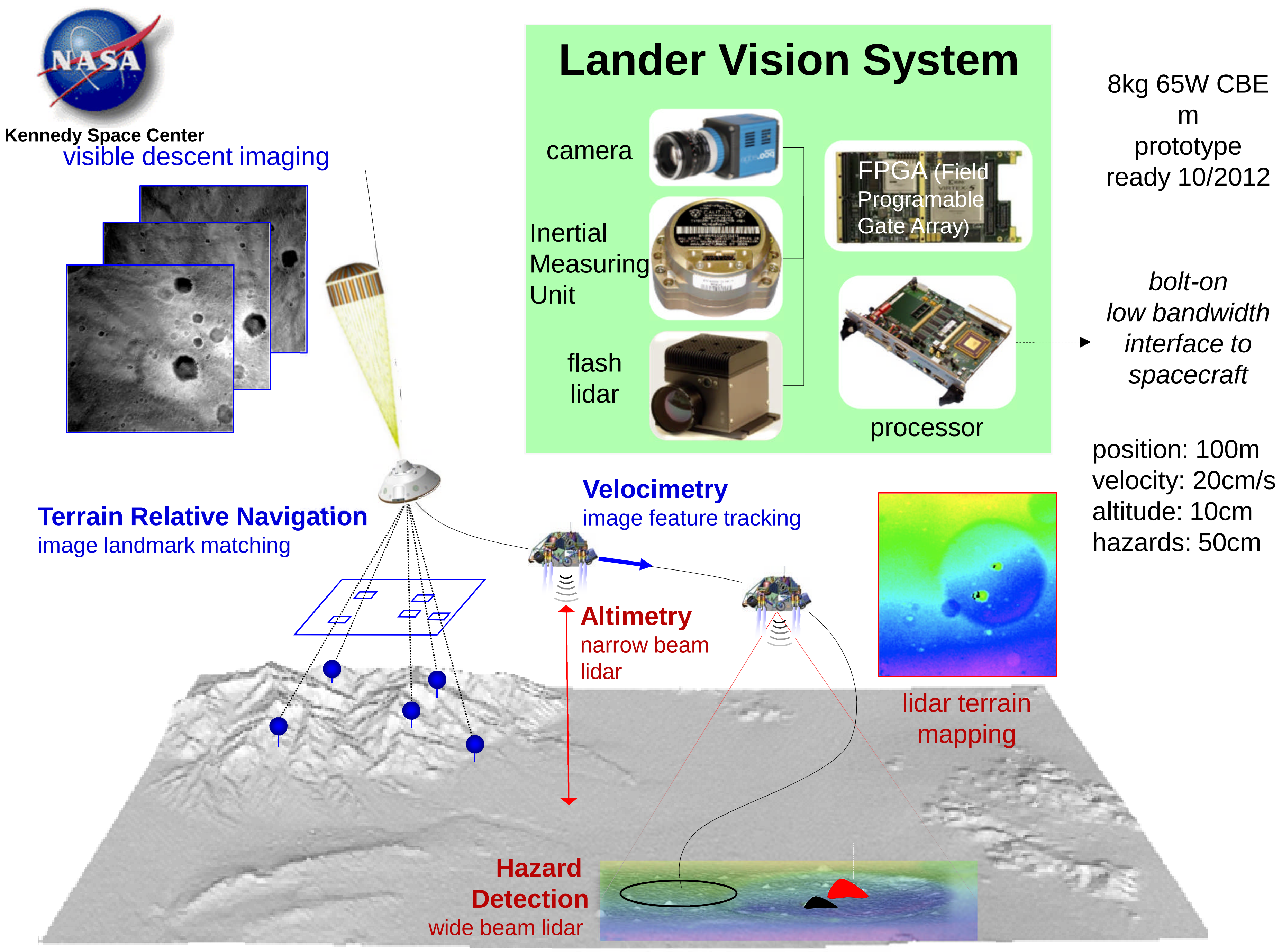
Launch= 11/26/2011
Arrival= 08/06/2012
Mars at Launch
TCM-1
Launch + 47 days
12 Jan
Earth at Launch
26 Nov
TCM-2
Launch + 121 days
26 Mar
TCM-3
Entry - 41 days
26 Jun
TCM-5
Entry - 2 days
4 Aug
Earth at Arrival
TCM-4
Entry - 8 days
29 Jul
Mars at Arrival
TCM-6
Entry - 9 hours
5 Aug
Tick Marks Every 20 Days



Cruise Stage Separation
Time: Entry – 10 min
CBMD Separation
Time: Entry – ~8 min
Entry Interface
Altitude: ~125 km
Velocity: ~5,500 m/s
Time: Entry + 0 s
Peak Heating
Peak Deceleration
Hypersonic Aero-maneuvering
Parachute Deploy
Altitude: ~11 km
Velocity: ~405 m/s
Time: Entry + ~254 s
Heatshield Separation
Altitude: ~8 km
Velocity: ~125 m/s
Time: Entry + ~278 s
Radar Data Collection
Backshell Separation
Altitude: ~1.6 km
Velocity: ~80 m/s
Time: Entry + ~364s
Powered Descent
Sky Crane
Flyaway
Sky Crane Detail
Rover Separation
Altitude: ~20 m
Velocity: ~0.75 m/s
Time: Entry + ~400 s
Mobility Deploy
Flyaway
Touchdown
Altitude: 0 m
Velocity: ~0.75 m/s
Time: Entry + ~416 s

Kennedy Space Center

High-Resolution Self-Portrait by Curiosity Rover Arm Camera on Sol 84 (Oct. 31, 2012)


Kennedy Space Center
visible descent imaging
Lander Vision System
camera
Inertial Measuring Unit
flash lidar
FPGA (Field Programable Gate Array)
processor
8kg 65W CBE
m
prototype
ready 10/2012
bolt-on
low bandwidth
interface to
spacecraft
position: 100m
velocity: 20cm/s
altitude: 10cm
hazards: 50cm
Terrain Relative Navigation
image landmark matching
Velocimetry
image feature tracking
Altimetry
narrow beam
lidar
lidar terrain
mapping
Hazard
Detection
wide beam lidar

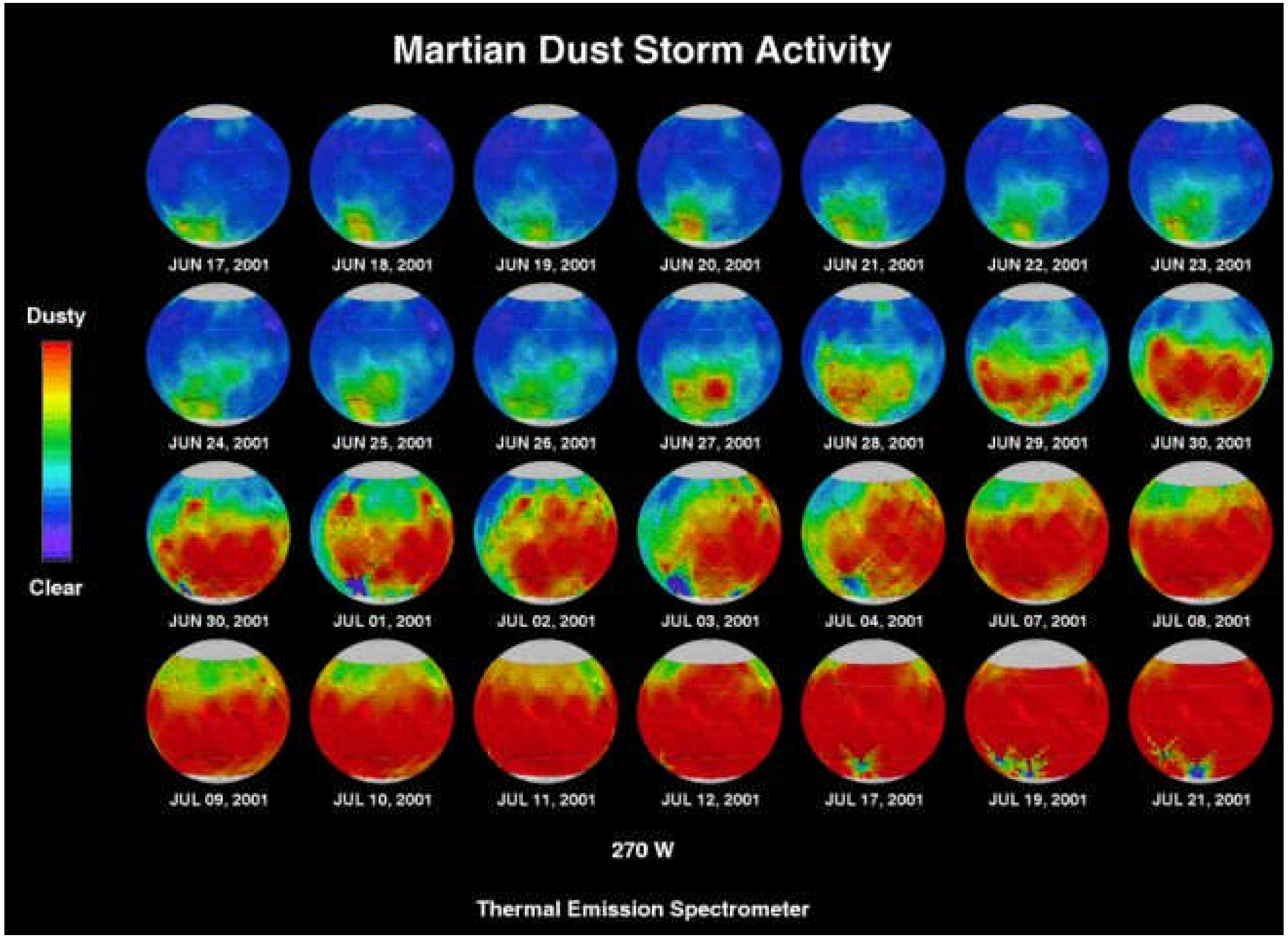
Technology Development:

- Dust Removal
- Energy Storage

Engineers and scientists are working hard to develop the technologies astronauts will use to one day live and work on Mars, and safely return home from the next giant leap for humanity.

Kennedy Space Center

Martian Dust Storm

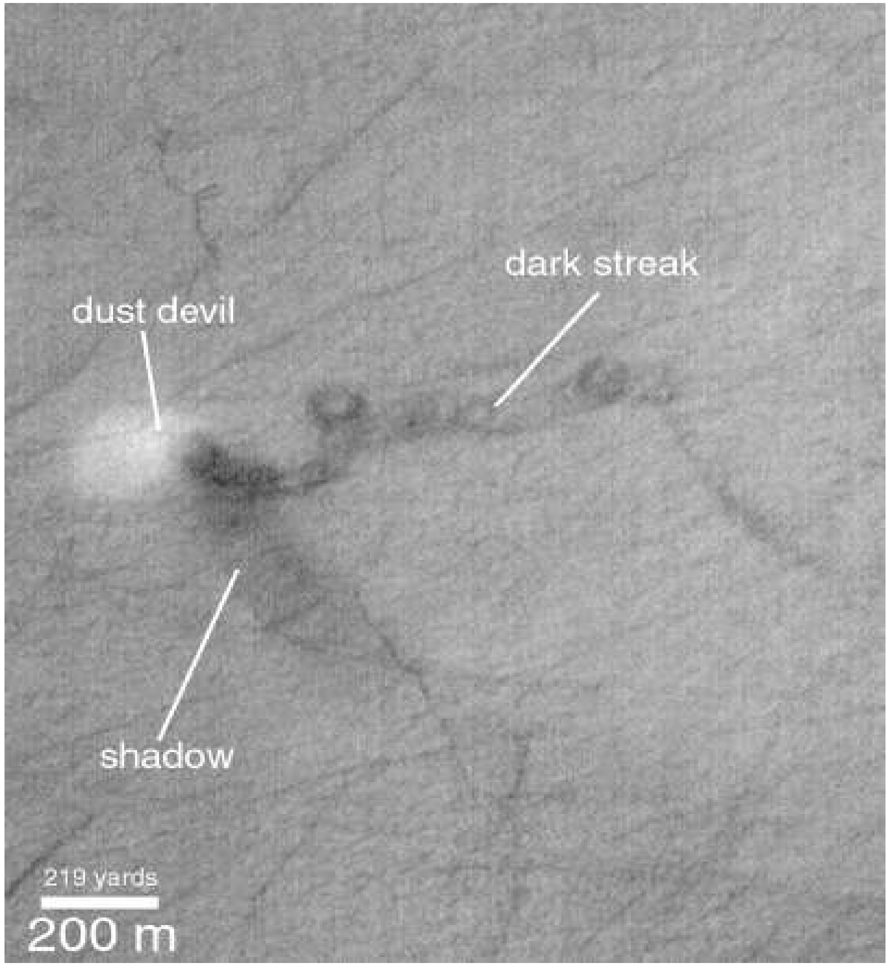


Kennedy Space Center

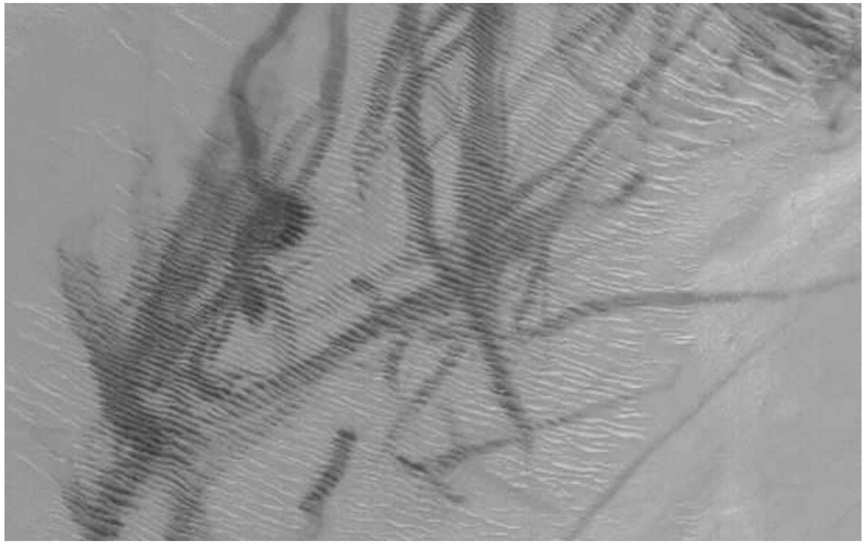
Lunar Environment

- Top layer of the lunar regolith is comprised of dust
- Lunar dust is an abrasive powder that clings to space suits, robots, and virtually all machinery
- Apollo 12, November 1969:
  - A total of 3 hours, 31 minutes were spent on the lunar surface before the LM ascent engine fired for liftoff
  - Lunar dust tracked into the LM became a problem
  - Since the dust became weightless after liftoff from the Moon, the astronauts had trouble breathing without their helmets.

Martian Dust Devils

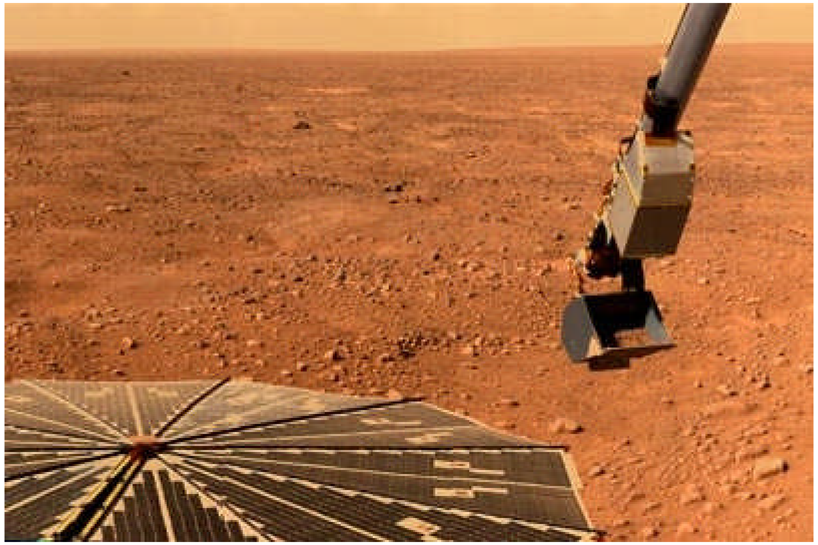


Martian dust devil (left) and dust devil tracks (below) photographed from orbit



Martian Dust Environment

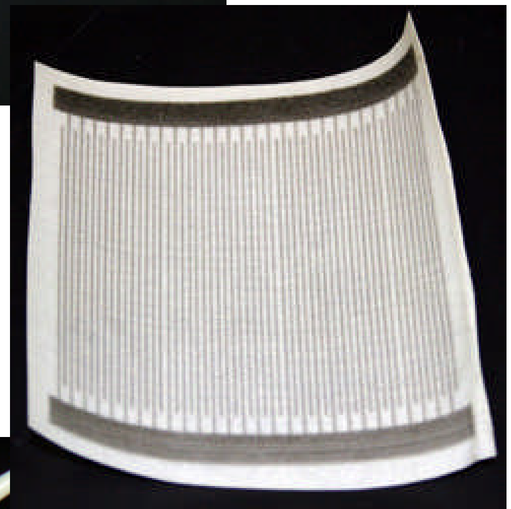
- Estimates from optical data: Average dust particle in the Martian atmosphere: 1.5 μm in diameter
- Average particle size changes with dust storm activity:
  - 2001: Derived particle data ranged from 2 to 5 μm
- Data from MI on Spirit & Opportunity (Landis et al 2006)
  - Suspended atmospheric dust: 2-4 μm
  - Settled dust uploaded by wind, diameter: ≤ 10 μm
  - Saltating particles: ≤ 80 μm
- Particle in soil (MI on Spirit on Scamander crater) ~ 220 μm

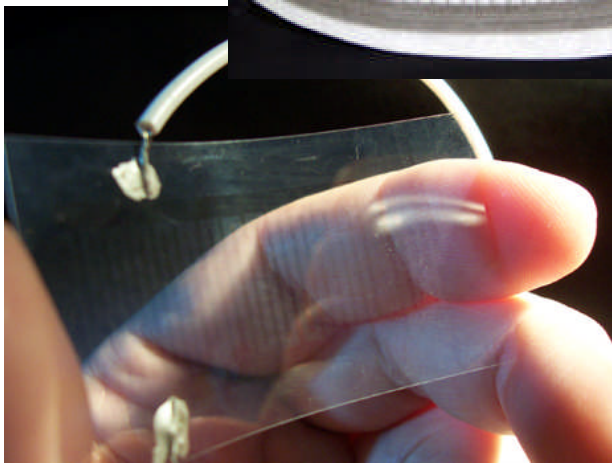


Kennedy Space Center

Electrodynamic Dust Shield

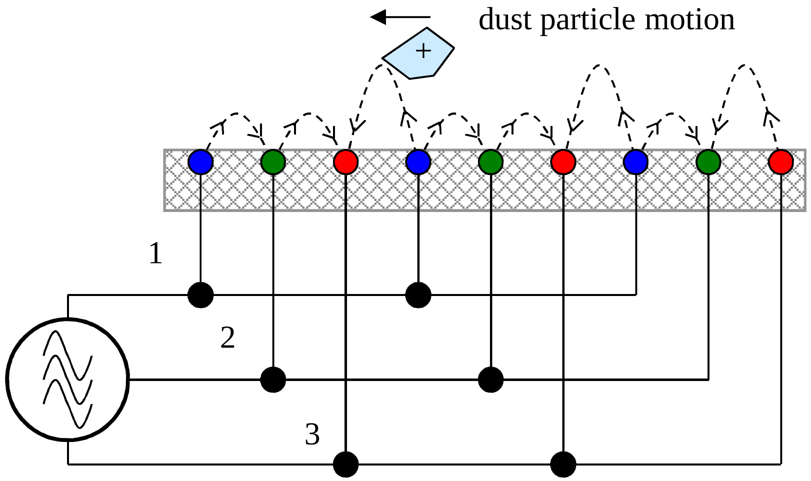
- With the EDS, Particles are removed by applying a multi-phase traveling electric field to electrodes that are embedded in the surface
- Electrodes:
  - Thin wires on opaque surfaces
  - CNT electrodes on fabric
  - Transparent, flexible electrodes on transparent surfaces for optical devices, windows, visors
- Applications developed:
  - Solar panels
  - Optical systems
  - Thermal radiators
  - Flexible films
  - Fabrics

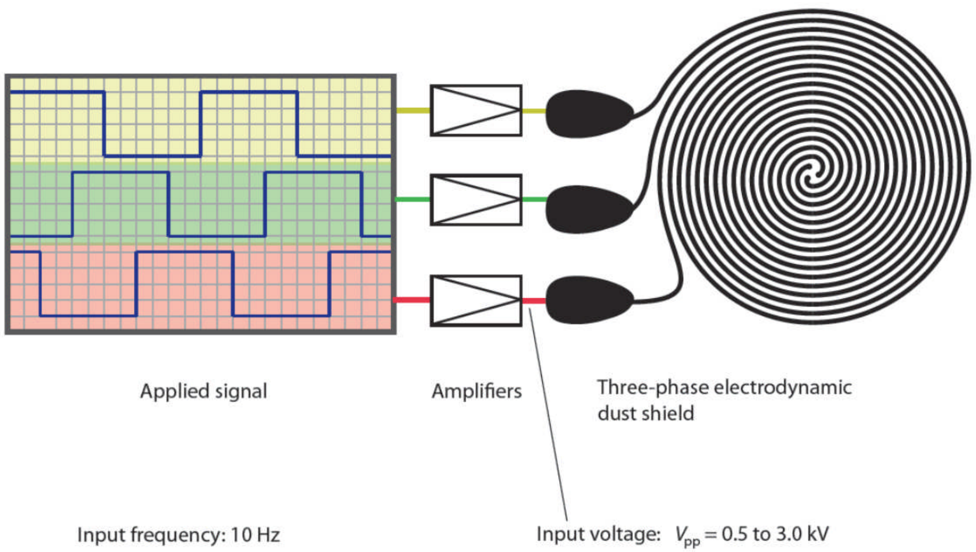


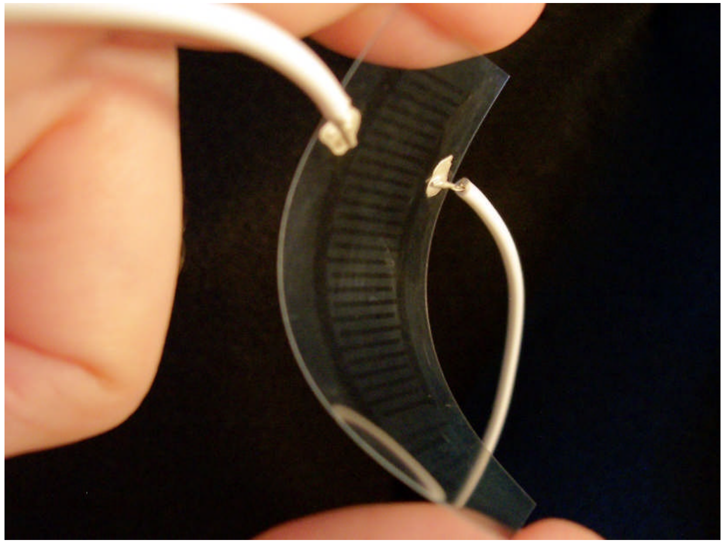


Kennedy Space Center

What’s Under the Hood



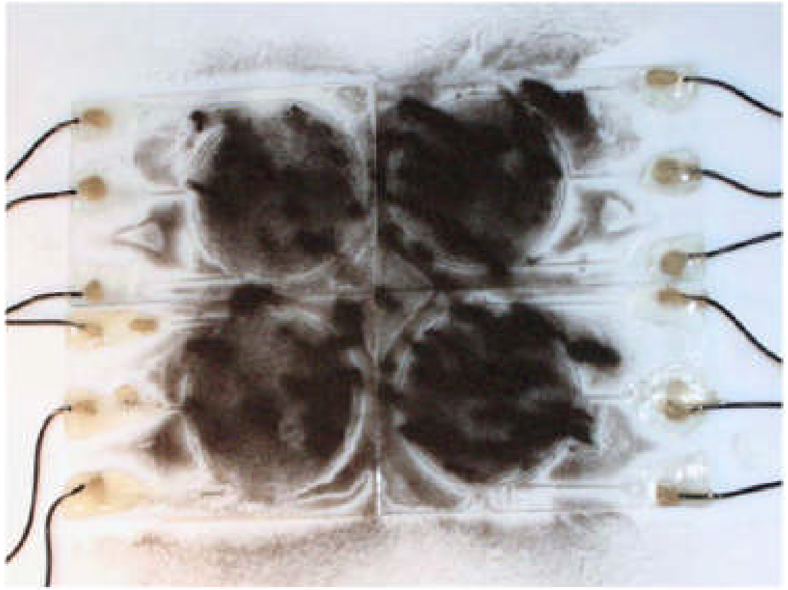




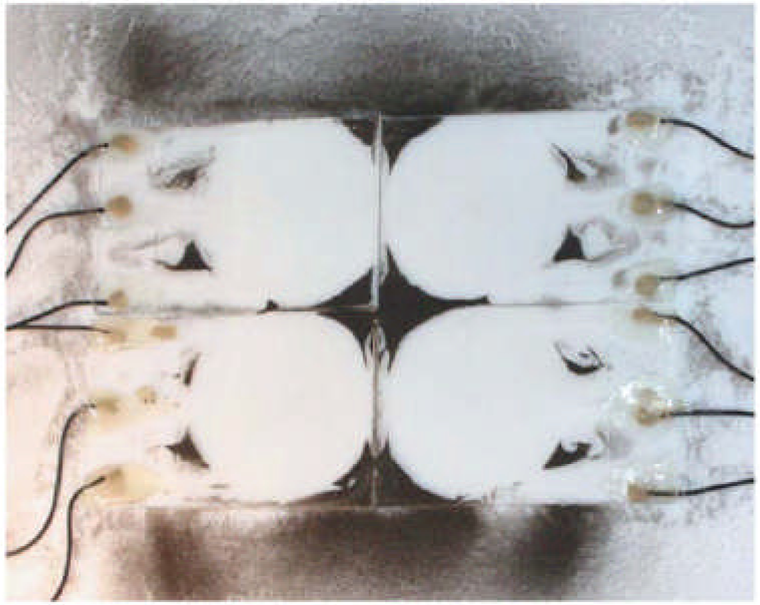
Three-phase dust shield with indium tin oxide transparent electrodes on a film (top) and glass substrate (bottom)

Kennedy Space Center

EDS for Optical Systems High Vacuum Testing



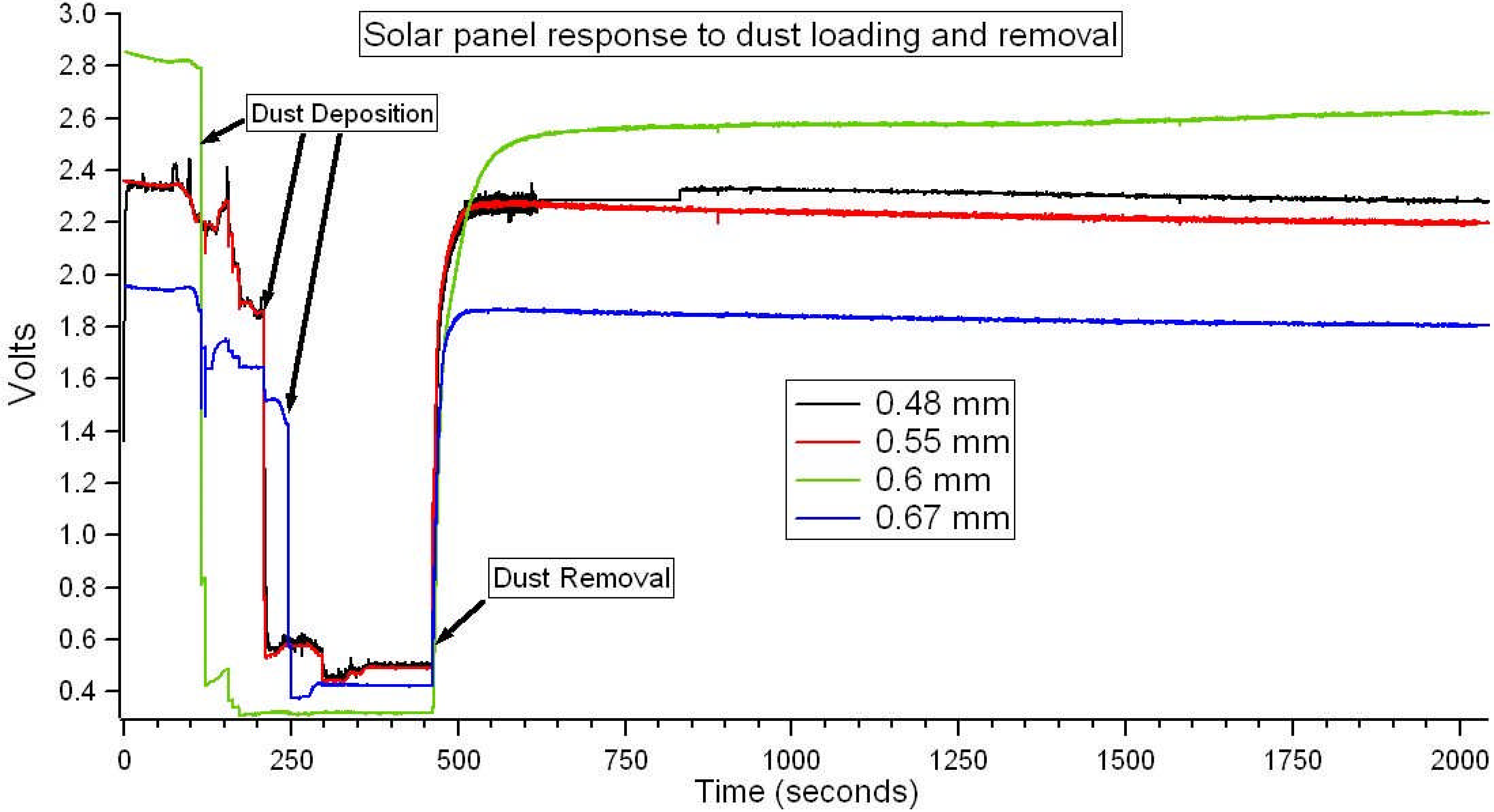
(a)



(b)

Transparent EDS coating on glass (a) before and (b) after dust removal at vacuum. Dust removal efficiencies are greater than 99%.

Solar Panel Response

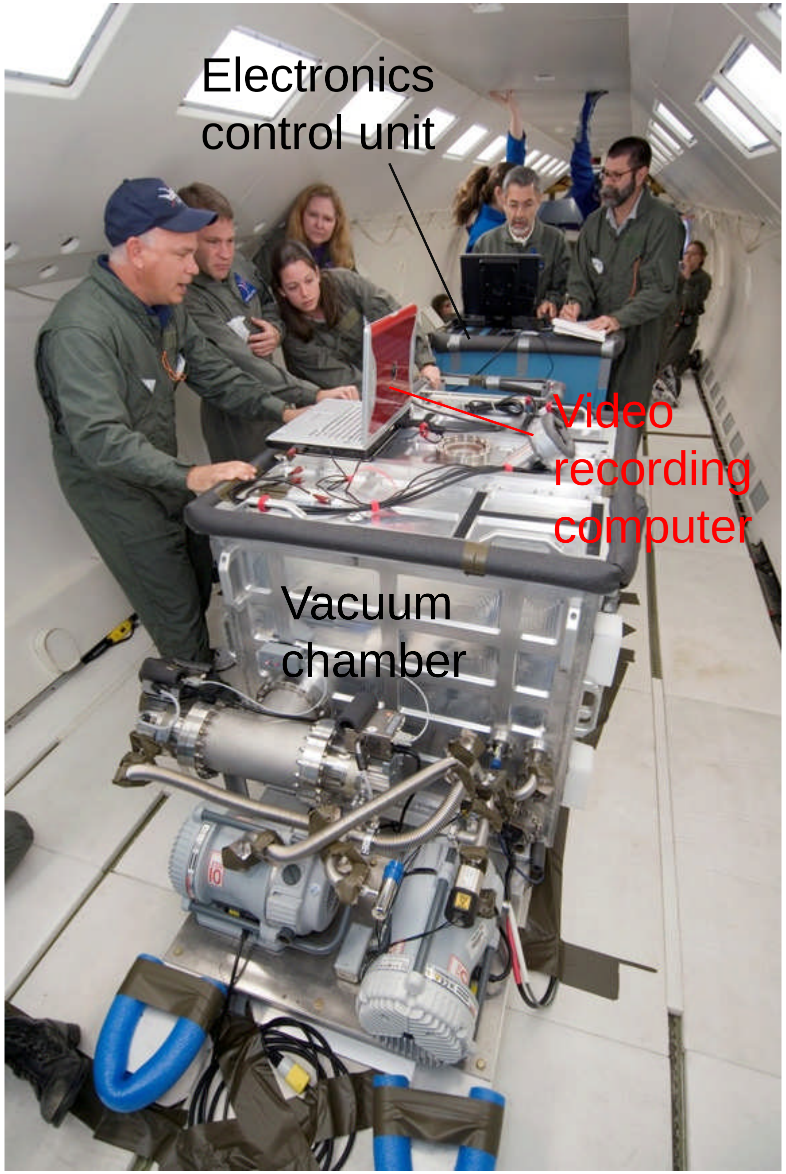


Solar panel response to 20 mg, 50-75 μm JSC-1A dust deposition and removal under high vacuum conditions. Removal was accomplished using Dust Shields of four different spacings.*

* Calle, C.I., C.R. Buhler, J.L. McFall, and S.J. Snyder, “Particle removal by electrostatic and dielectrophoretic forces for dust control during lunar exploration missions,” *Journal of Electrostatics* 67, 89–92 (2009)

Reduced Gravity Flight Experiments

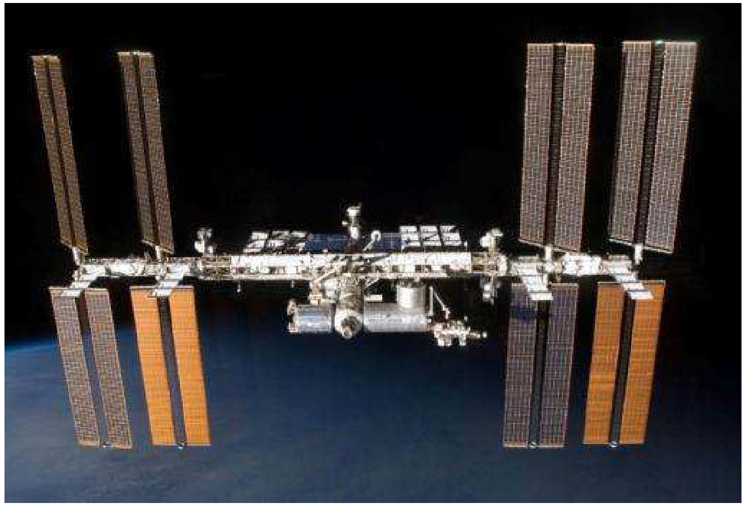
- Experiments were performed under lunar and Martian gravity
- Four dust containment boxes with metal filters were used for each RGF

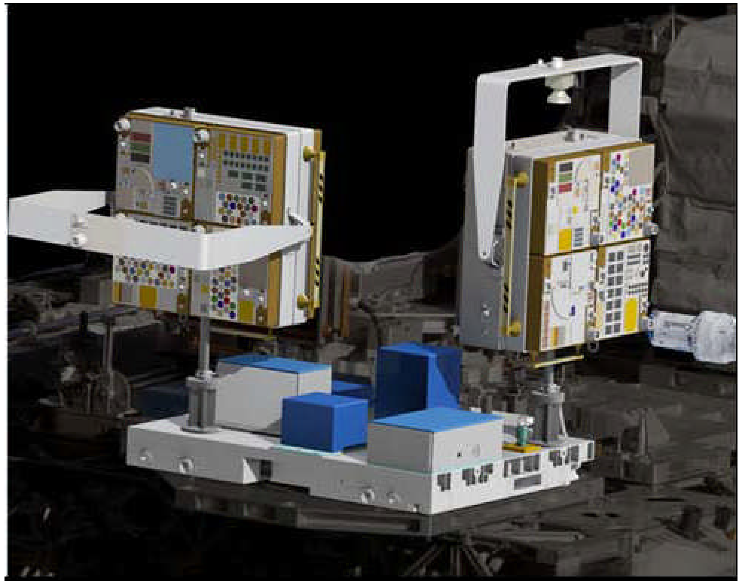


Kennedy Space Center

ISS Experiment

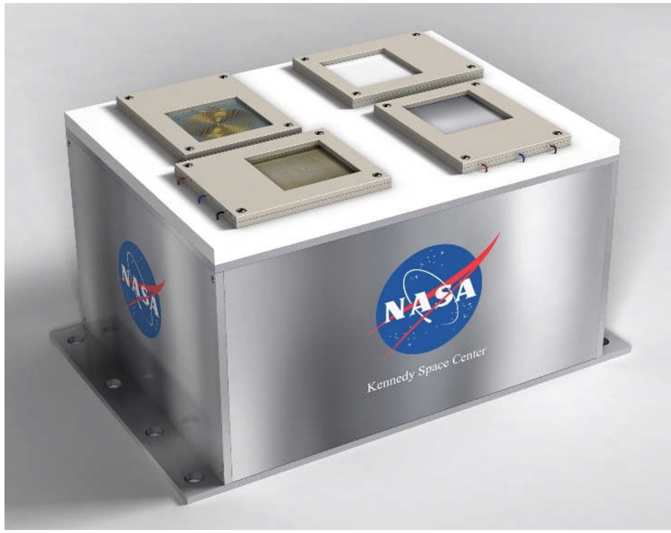
- The EDS has been extensively tested
  - In the laboratory under simulated lunar and Martian conditions:
  - On a reduced gravity flight at lunar and Martian gravity
- A flight experiment is being developed to fly on ISS as part of the Materials International Space Station experiment
  - MISSE is an external platform for space environmental effects
  - Will expose experiments to the ram, wake, zenith, and nadir directions
  - Our payload will face the wake direction, to expose the EDS panels to the space environment most closely resembling the lunar environment

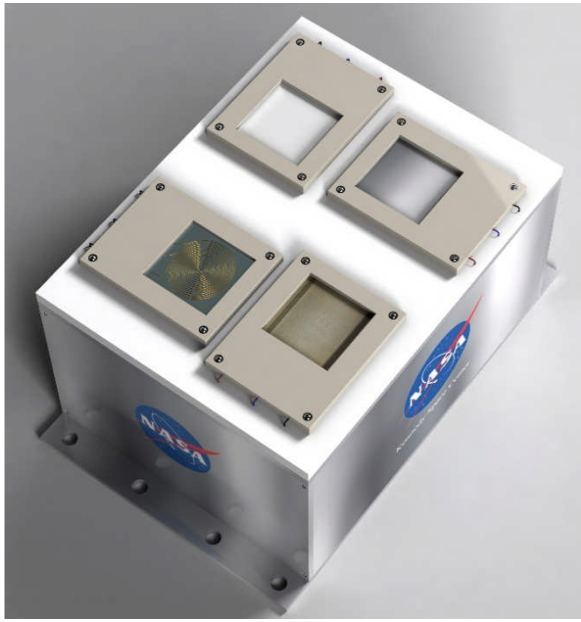




Kennedy Space Center

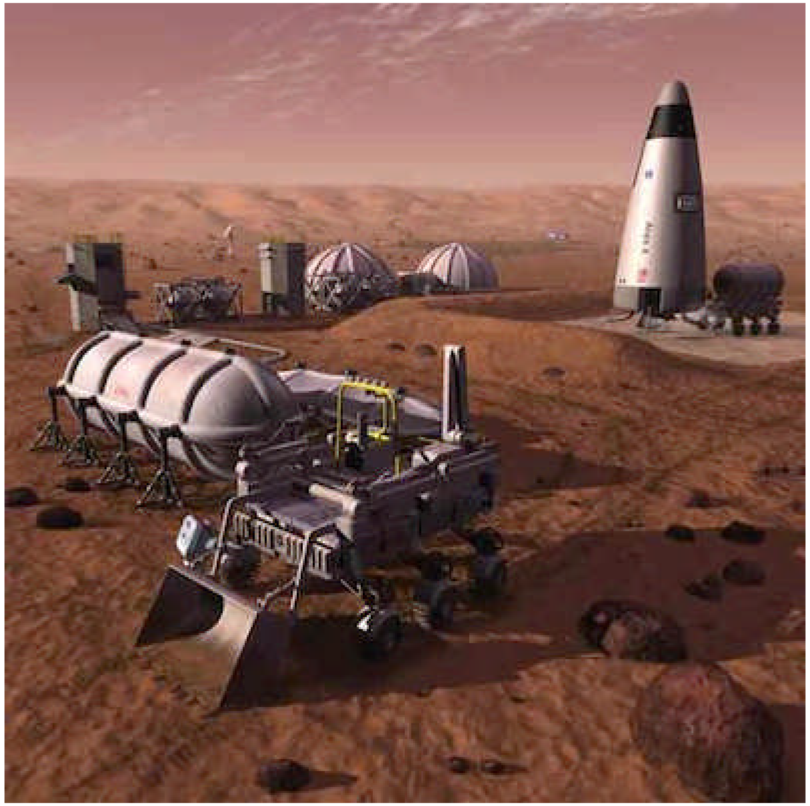
Payload Concept





Kennedy Space Center

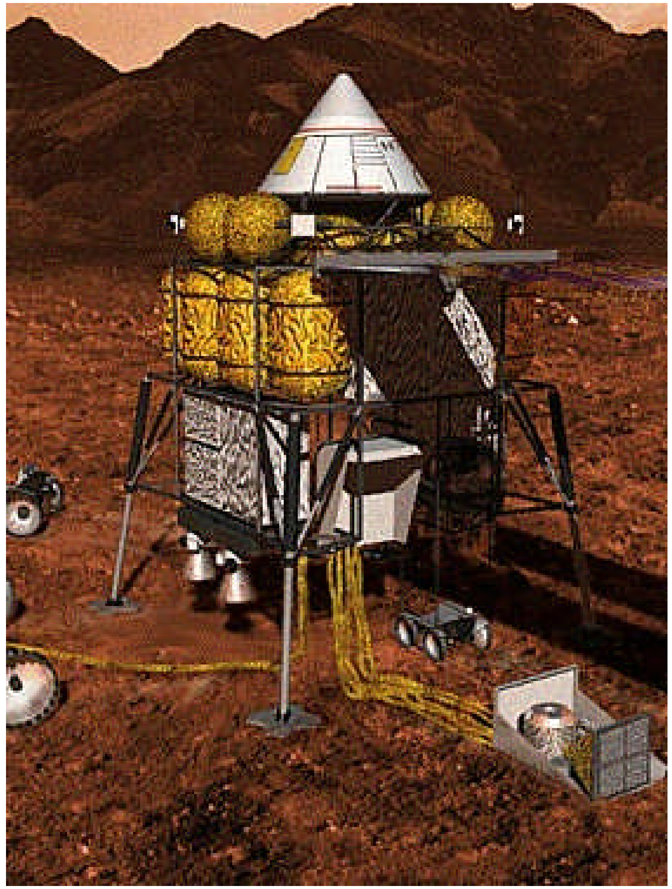
Mars Resource Utilization Demonstration



- Instrument package for demonstration on how to live off the land
- NASA intends to include an in-situ resource utilization (ISRU) experiment on its new Mars rover that would pull carbon dioxide from the planet’s atmosphere, remove dust and other contaminants and prepare the gas for chemical processing into oxygen.
- Oxygen: For use in propulsion, life support, power systems

Living Off the Land

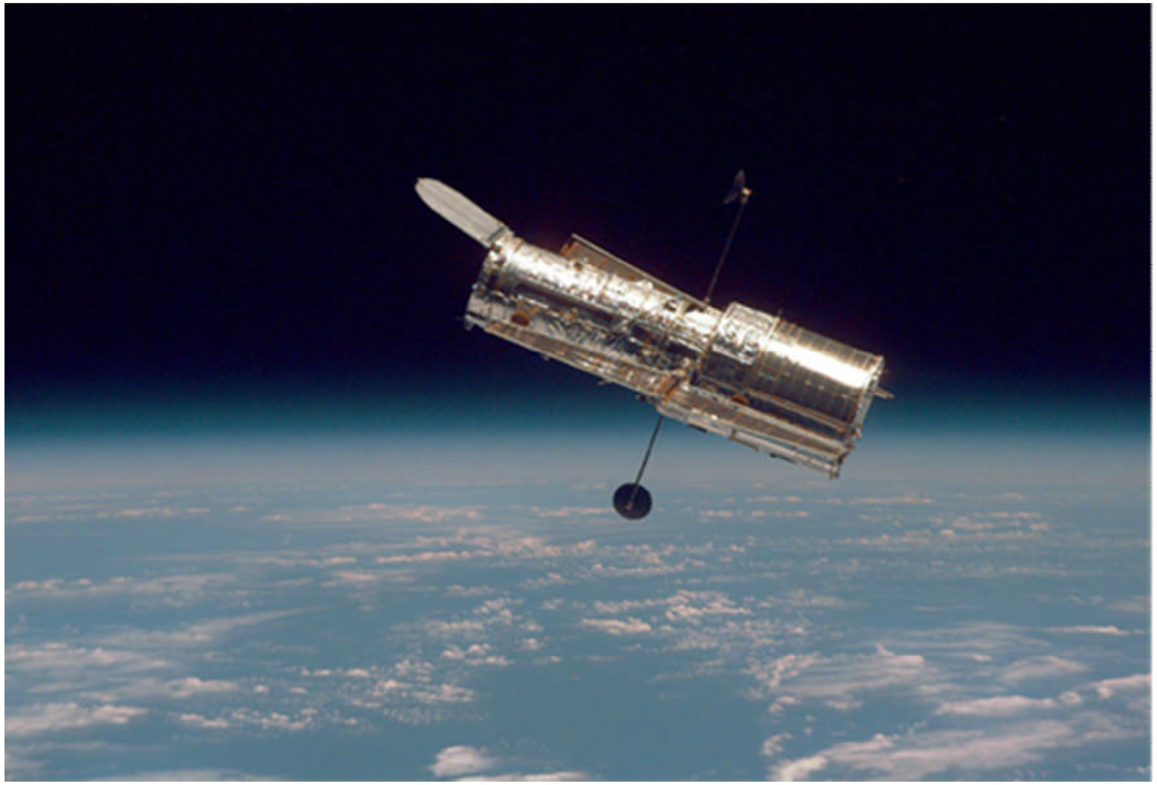
- NASA's ISRU Project: production of
  - mission consumables
  - surface construction
  - manufacturing and repair
  - space utilities and power
- Oxygen, methane, and water production from Martian atmospheric gas requires prior dust removal
- Electrostatic Precipitator that works at 1/100 of an atmosphere



ISRU plant for vehicle propellant production

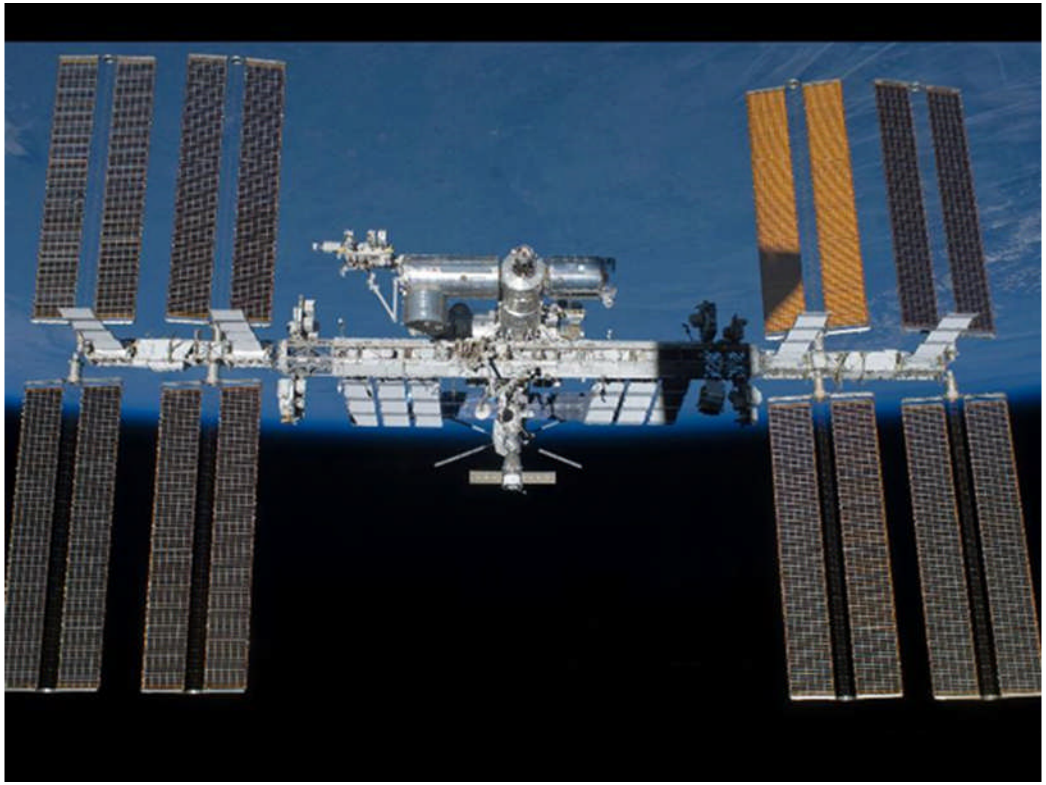
New Energy Storage Devices

Current missions: Hubble Space Telescope



- Nickel-hydrogen (Ni-H_2)
- Charge-use cycle of 97 minutes
- Reliable
- Deep discharge capability

International Space Station



- Nickel-hydrogen (Ni-H_2)
- Charge-use cycle of 90 minutes
- Expected replacement to lithium in 2017
- One lithium ORU to replace two nickel-hydrogen ORU’s

Kennedy Space Center

Curiosity/Mars Science Laboratory

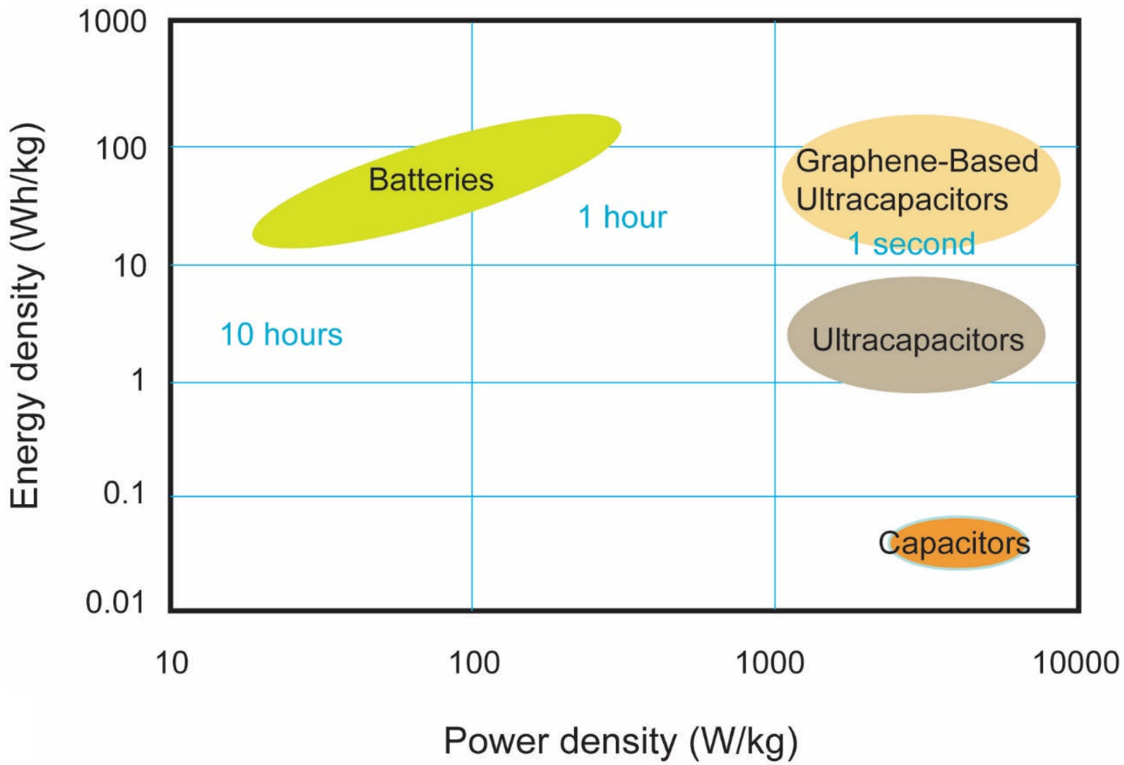
- Lithium
- Charge-use cycle multiple times per day
- Peak power demands exceed MMRTG power Source

Kennedy Space Center

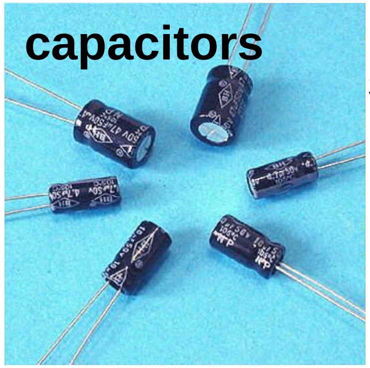
Graphene-Based Supercapacitors

Graphene-based ultracapacitors:

- High power densities
- High energy densities



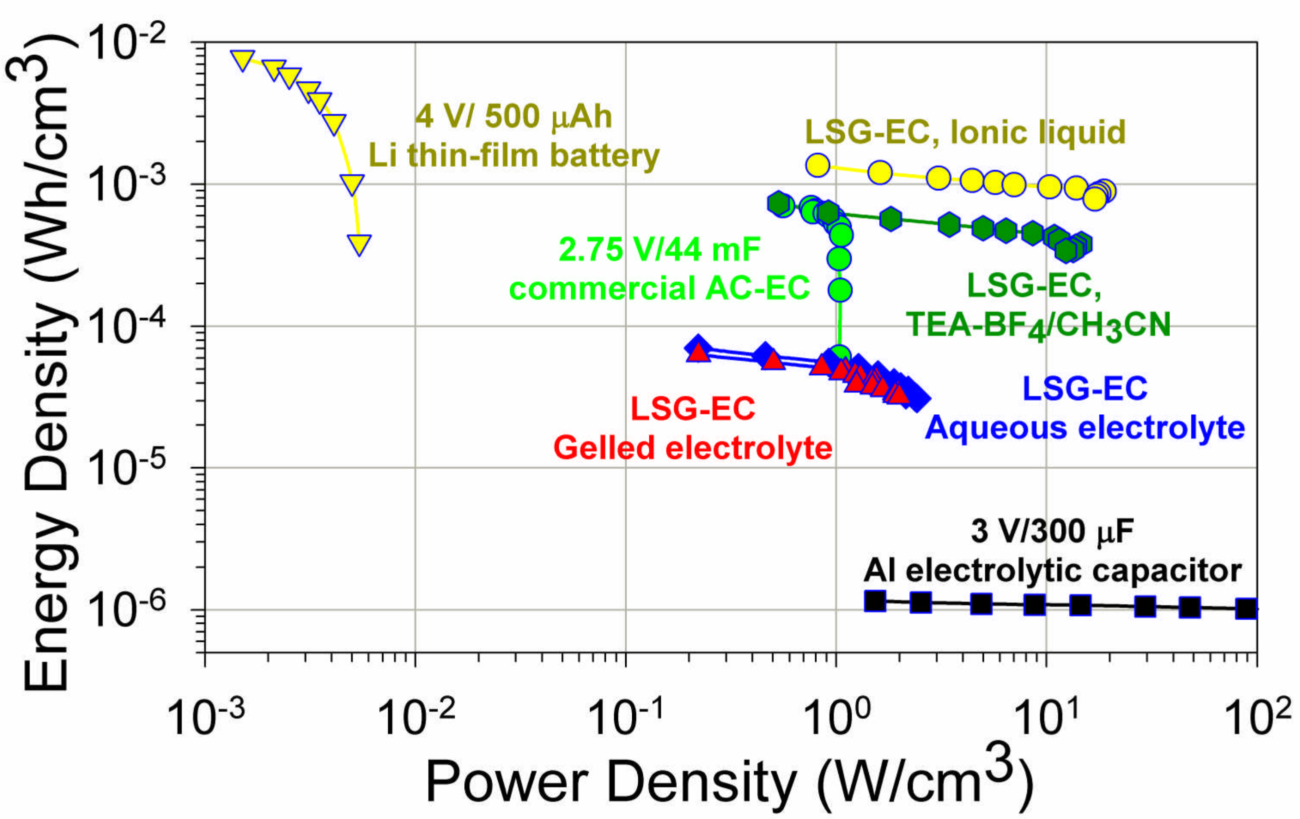
Energy and power density comparison for batteries, conventional ultracapacitors, and the expected performance of graphene-based ultracapacitors. Charging times are shown in blue.



supercapacitors

Kennedy Space Center

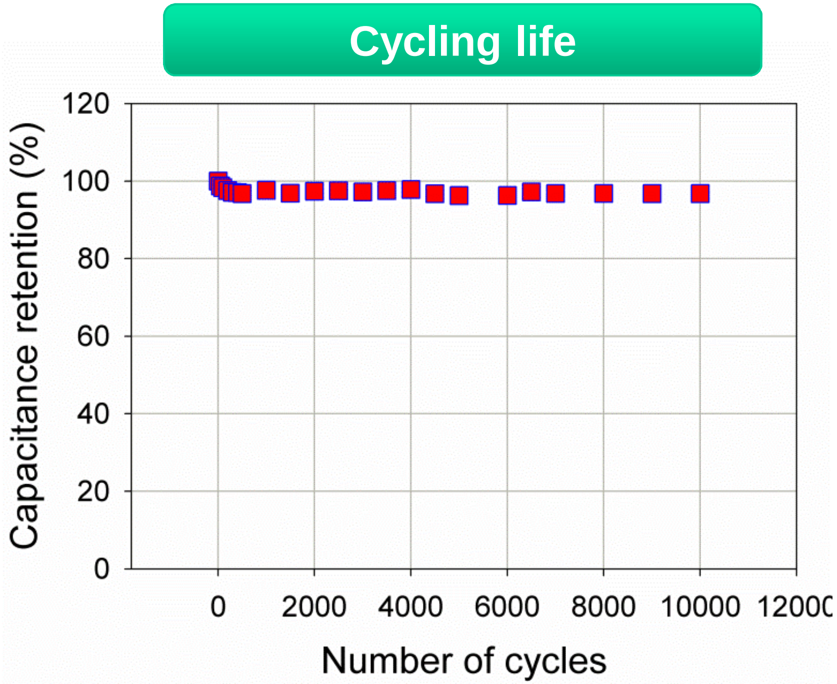
Comparison of LSG, AC, Thin-film Li

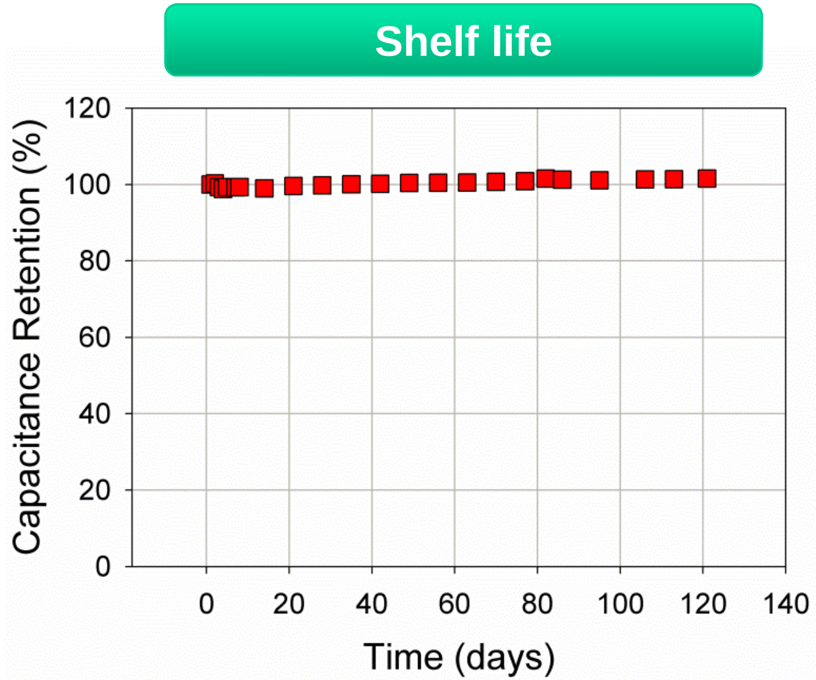


- The plot shows the energy density and power density of the stack for all the devices tested (including current collector, active material, electrolyte and separator).
- Additional features: flexible, lightweight, current collector free and binder free

Kennedy Space Center

Cycling and Shelf-Life





Space Applications

- Higher power density will enable a new class of operations
- Potential for much wider temperature operation: carbon melting point (4900K)
- Increased safety-margin due to reduced fire and toxicity risk
- In-situ resource available from regolith or waste stream

Mission Concept

https://www.youtube.com/watch?v=P4boyXQuUIw&feature=player_detailpage

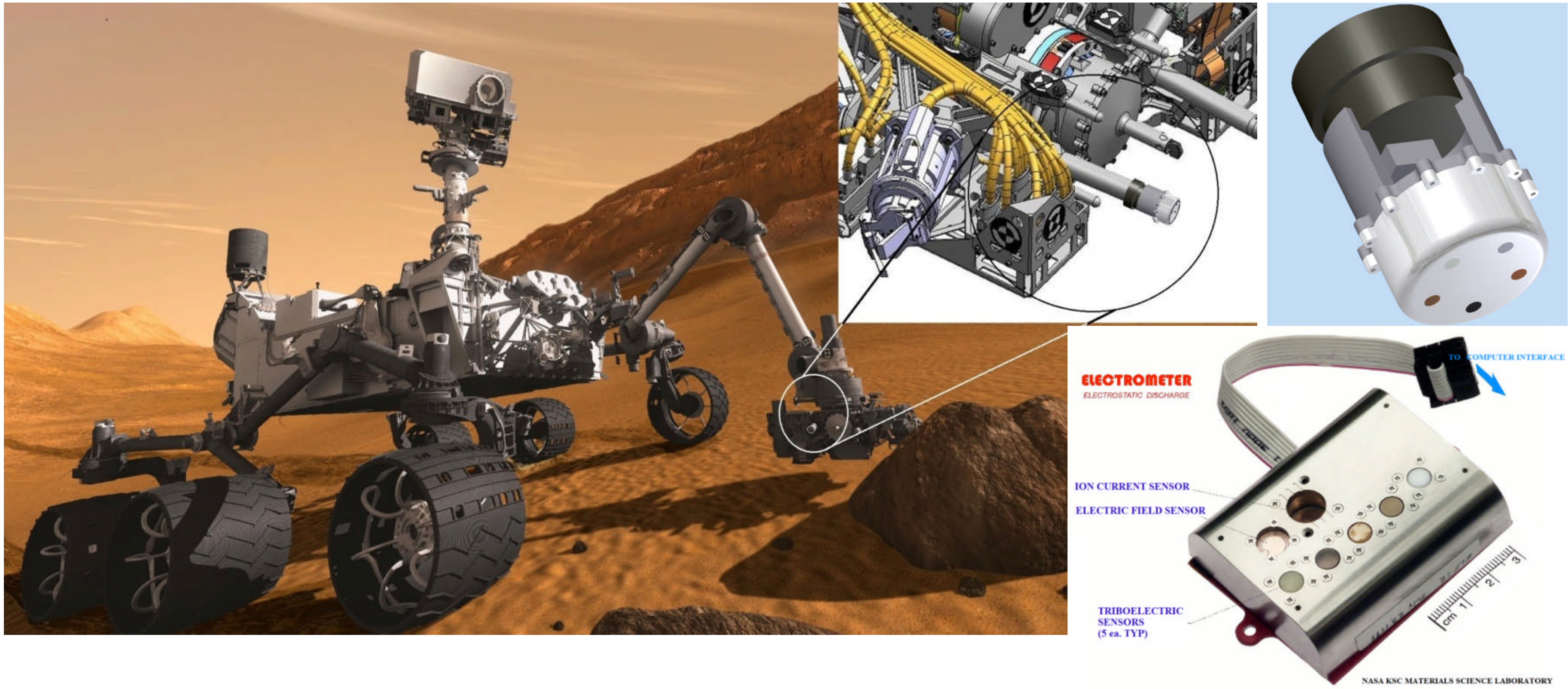
Kennedy Space Center

The Team

- **NASA Team:**
- Paul J. Mackey
- Michael R. Johansen
- Michael D. Hogue, Ph.D.
- James Phillips III
- **UCLA Team:**
- Richard Kaner, Ph.D.
- Maher El-Kady, Ph.D.

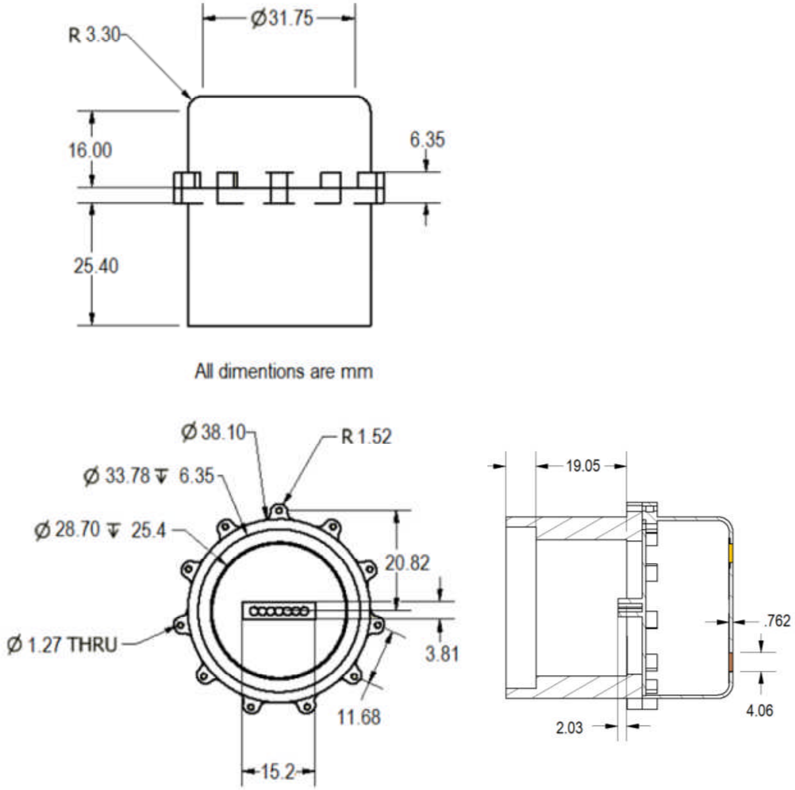
BACK UP SLIDES

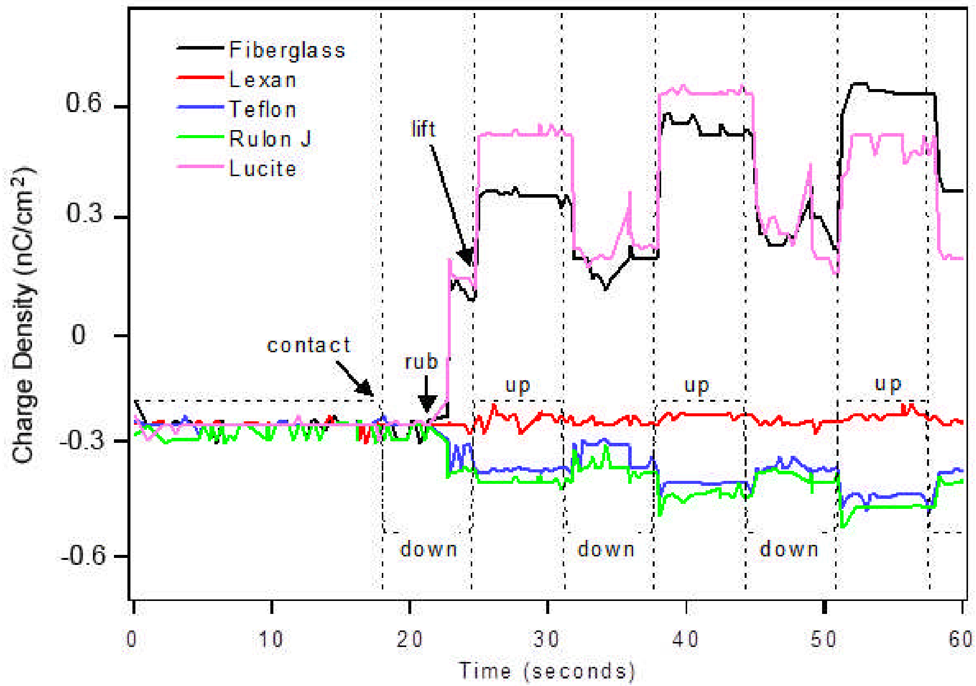
KSC’s Sensor Array



- Electrostatics Sensor Array instrument shown in possible location on Mars rover
- Instrument may be used in future Mars mission
- Able to identify differences in some properties of the minerals in the regolith
- It will aid in determination of places to deploy other instruments

Kennedy Space Center





MECA electrometer in contact with simulant at Martian atmospheric conditions.