ENAE 788X Overview and Introduction

- Course Overview/Syllabus
  - Goals
  - Web-based Content
  - Policies
  - Project Content
- Overview of Planetary Robot Mobility
- Term Design Project

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Goals of ENAE 788X

- Learn the underlying fundamentals of mobility in extraterrestrial environments
- Learn the principles of mechanism design relevant to mobility systems
- Understand mobility trade-offs in the context of planetary surface robotics
- Perform an open-ended design task for a planetary surface rover

Web-based Course Content

- Data web site at http://spacecraft.ssl.umd.edu
  - Course information
  - Syllabus
  - Lecture notes
  - Problems and solutions
- Interactive Microsoft Teams site
  - Collaboration between design teams (think Slack/Zoom)
  - Backup to Zoom for lectures
  - Link at https://go.umd.edu/788XFall24Teams

Syllabus - Mobility Overview

- Free-space mobility
- Orbital maneuvering (proximity operations)
- Ballistic travel
- Atmospheric flight
  - Lifting
  - Buoyant
- Liquid mobility
  - Subsurface mobility
  - Surface mobility

Syllabus - Rover Hardware

- Terramechanics
- Wheel drive systems
- Wheel design
- Suspension systems
- Motors and gear trains
- Steering systems
- Tracked systems
- Legged locomotion

Syllabus - Rover Software

- Software engineering
- Robot control
- Sensors
- Manipulation
- Navigation and mapping
- Path planning
- Obstacle detection and avoidance

Grading Policies

- Grade Distribution
  - 25% Homework Problems
  - 30% Term Project midterm submission*
  - 45% Term Project final submission*
- Late Policy for Homework
  - On time: Full credit
  - Before solutions: 70% credit
  - After solutions: 20% credit

* Team Grades

A Word on Homework Submissions...

- Good methods of handing in homework
  - Scanned or electronic copies via e-mail (MUST put “ENAE788X” in subject line)
  - Or attached to person-person chat in Teams
  - We may use grading apps like GradeScope - still investigating
- Comments about homework submissions
  - Write neatly!
  - Put boxes around your answers

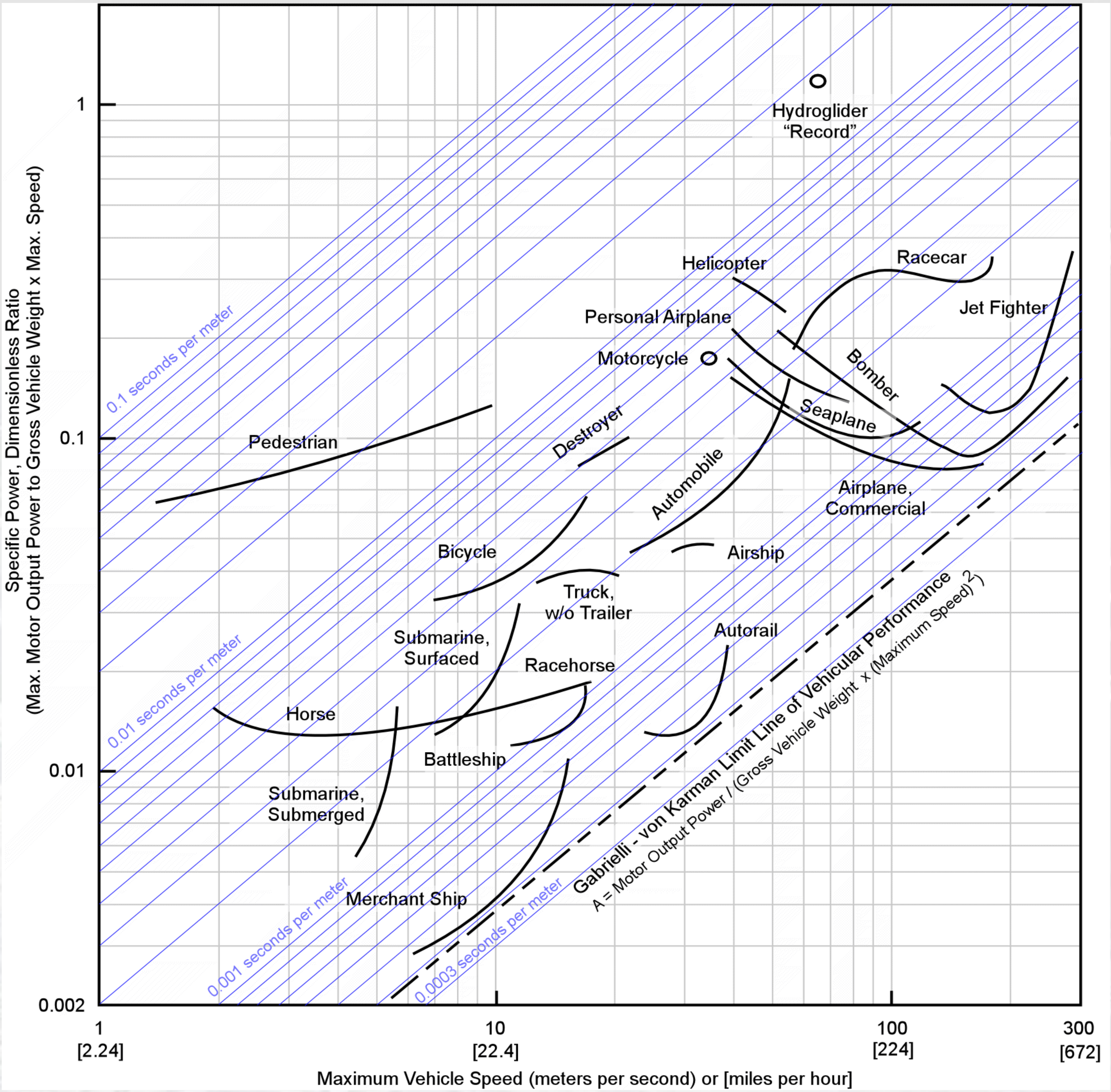
A Word about Homework Grading

- Homework is graded via a discrete filter
  - ✓ for homework problems which are essentially correct (10 pts)
  - ✓- for homework with significant problems (7 pts)
  - ✓-- for homework with major problems (4 pts)
  - ✓+ for homework demonstrating extra effort (12 pts)
  - 0 for missing homework
- A detailed solution document is posted for each problem after the due date, which you should review to ensure you understand the techniques used

Robotic Mobility

- Free space
- Relative orbital motion
- Micro-g environments (asteroids, comets)
- Airless major bodies (larger moons)
- Gaseous environments (Mars, Venus, Titan)
  – Lighter-than-"air" (balloons, dirigibles)
  – Heavier-than-"air" (aircraft, helicopters)
- Aquatic environments (Europa)
- Surface mobility (wheels, legs, etc.)

Gabrielli-von Karman Diagram



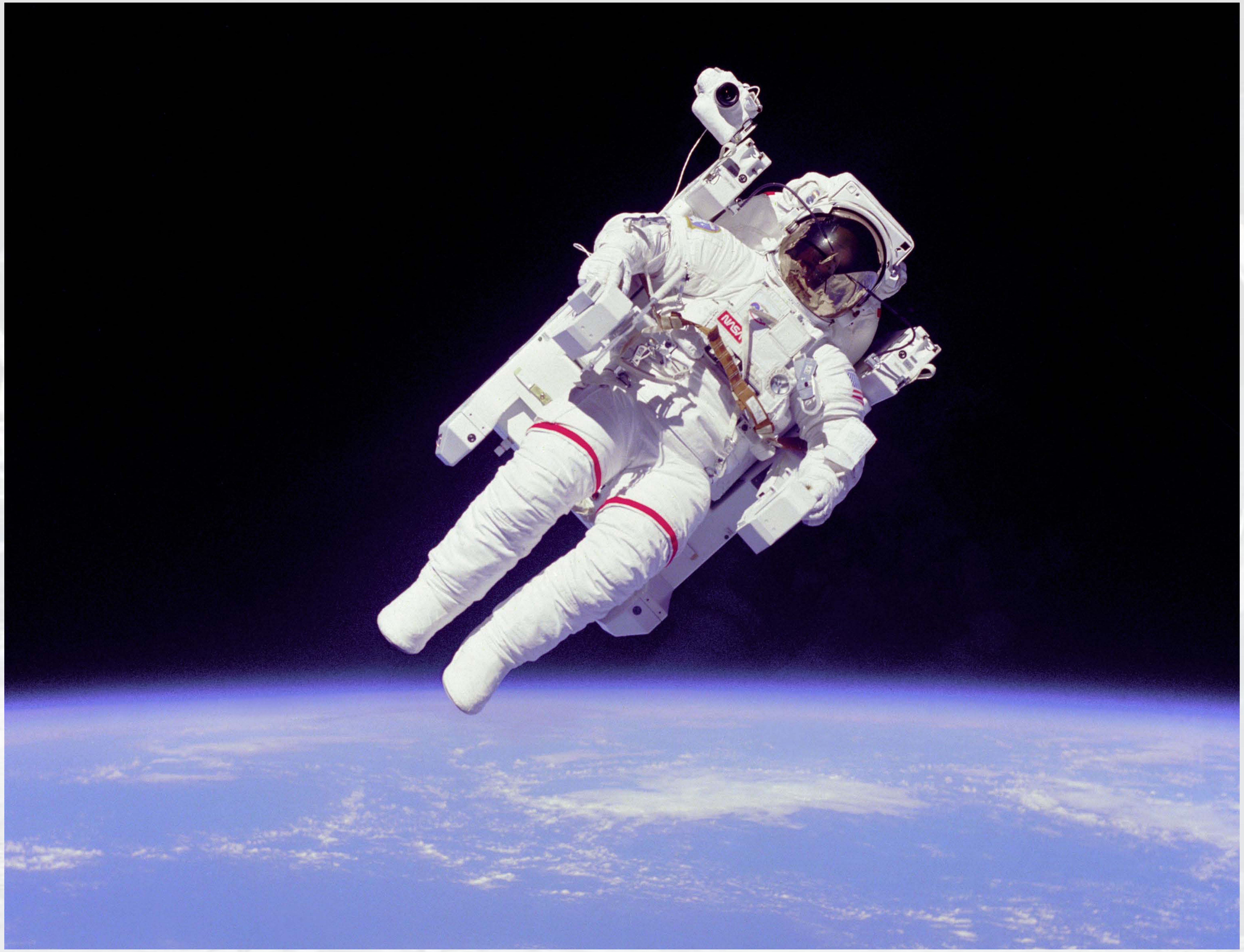
Possible Domains for Space Robotic Mobility

- Free Space
- Lunar
- Mars
- Venus
- Minor bodies

Comparison of Primary Location Characteristics

Quantity	Earth	Free Space	Moon	Mars
Gravitational Acceleration	$9.8\ m/s^2$ (1 g)	–	$1.545\ m/s^2$ (0.16 g)	$3.711\ m/s^2$ (0.38 g)
Atmospheric Pressure	101,350 Pa (14.7 psi)	–	–	560 Pa (0.081 psi)
Atmospheric Constituents	78% N_2 21% O_2	–	–	95% CO_2 3% N_2
Temperature Range	120°F -100°F	150°F -60°F	250°F -250°F	80°F -200°F
Length of Day	24 hr	90 min- Infinite	28 days	24h37m 22.6s

Shuttle Manned Maneuvering Unit



AERCam/SPRINT

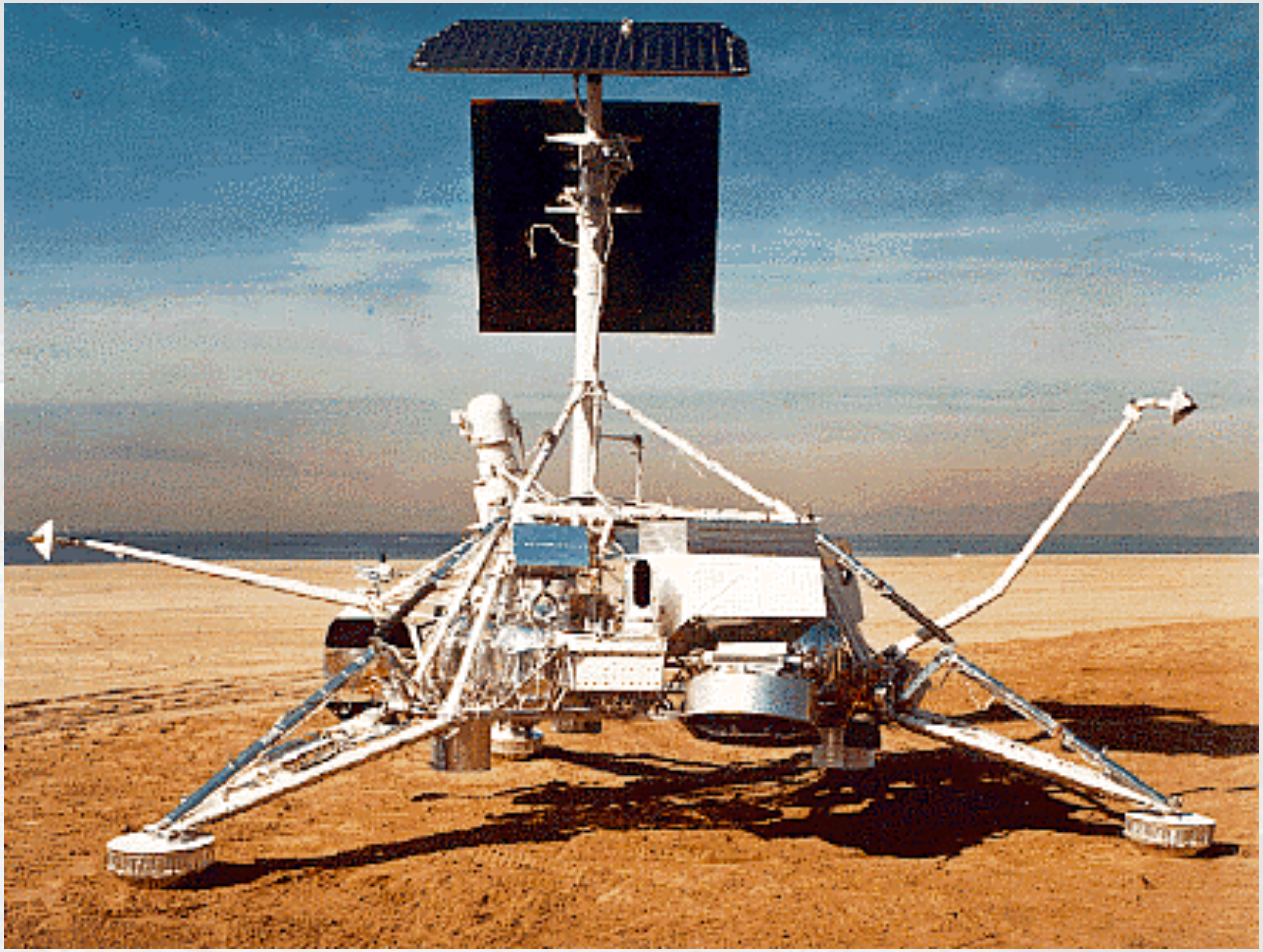
Orbital Express

SPHERES

ASTROBEE

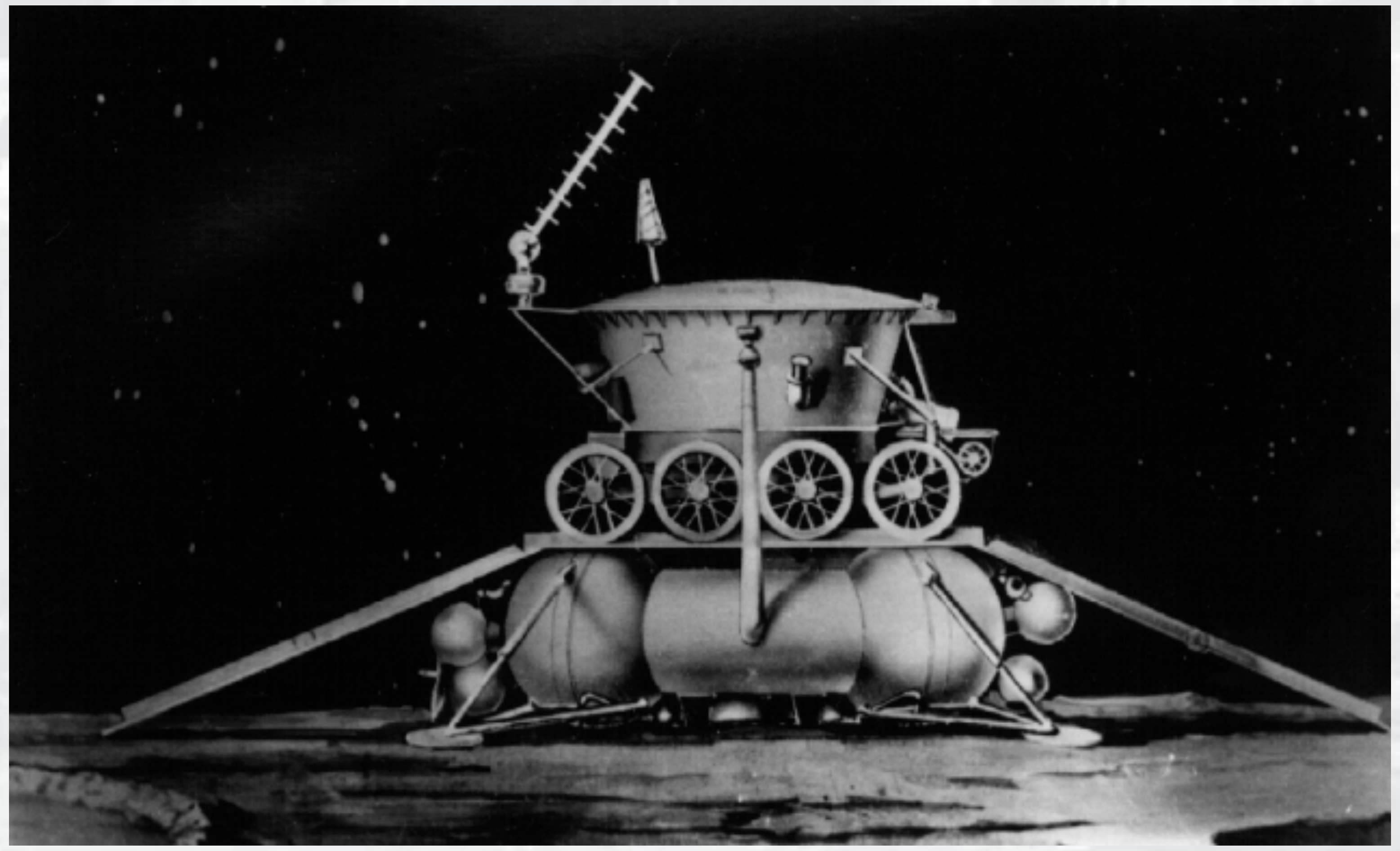
Surveyor

- Seven mission May 1966 - January 1968 (5 successful)
- Mass about 625 lbs
- Surveyor 6 performed a “hop”
  - November 1967
  - 4 m peak altitude, 2.5 m lateral motion



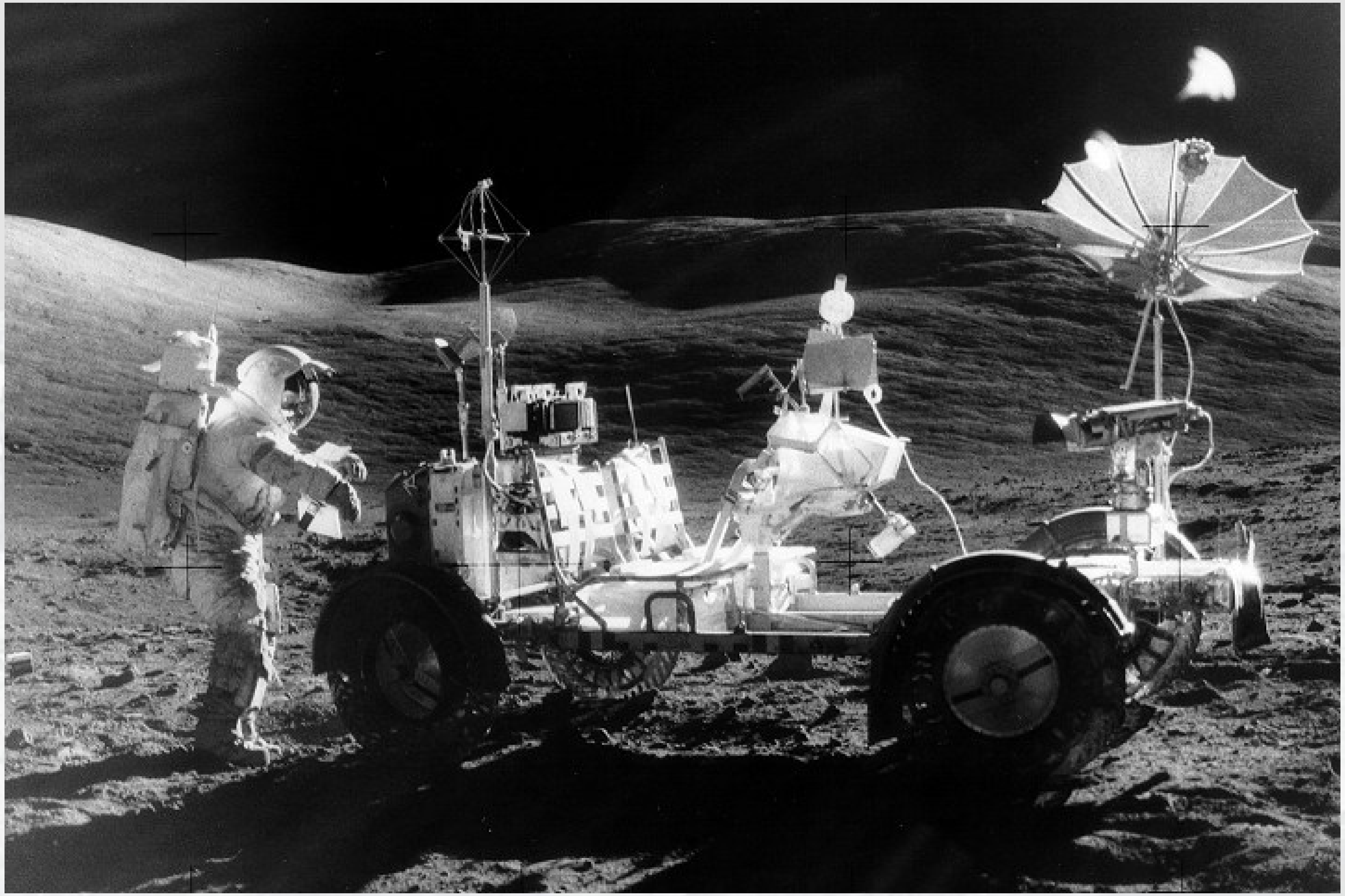
Lunakhod 1 and 2

- Soviet lunar rovers
  - 2000 lbs
  - 3 month design lifetime
- Lunakhod 1
  - November, 1970
  - 11 km in 11 months
- Lunakhod 2
  - January, 1973
  - 37 km in 2 months



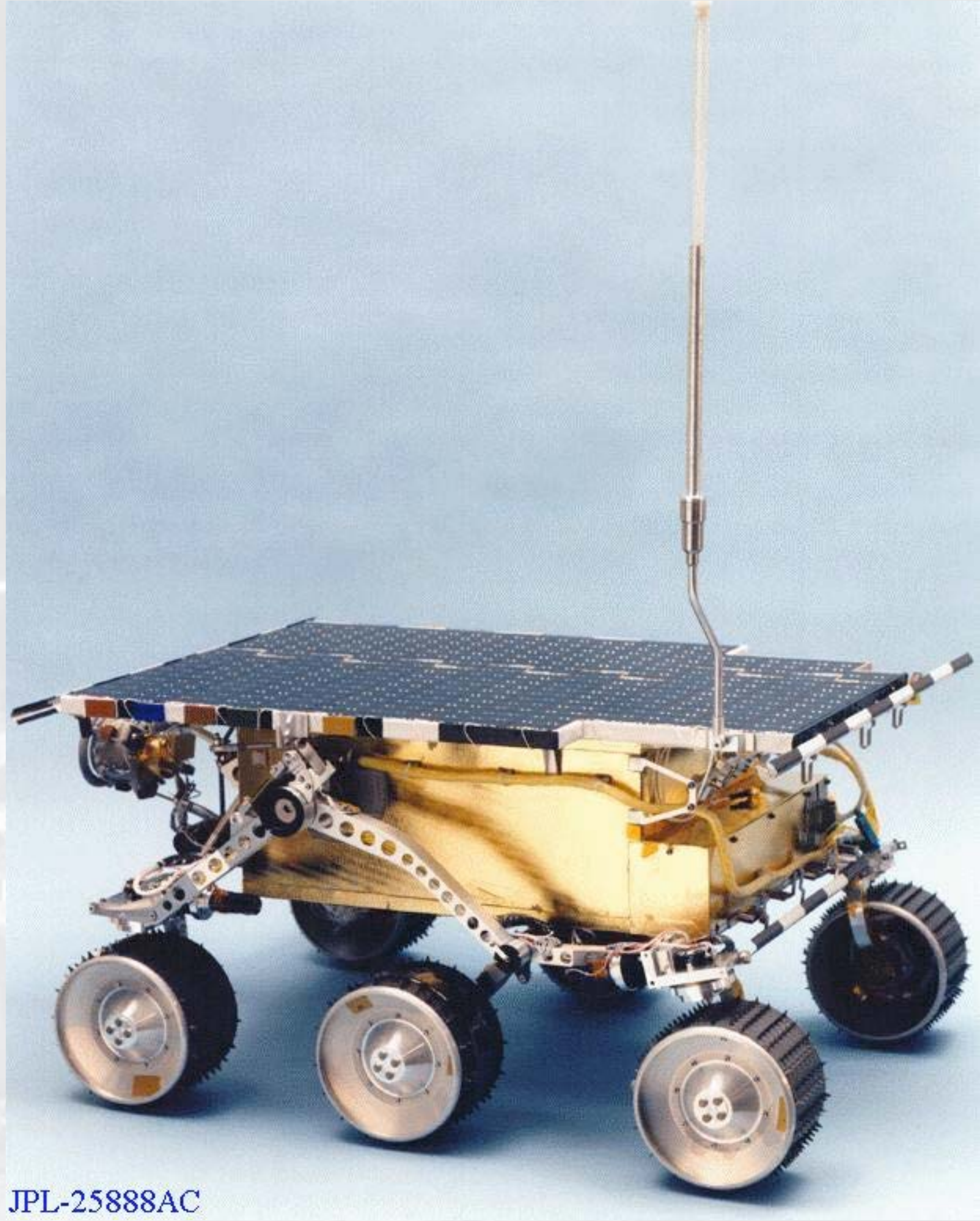
Lunar Roving Vehicle

- Flown on Apollo 15, 16, 17
- Empty weight 460 lbs
- Payload 1080 lbs
- Maximum range 65 km
- Total 1 HP
- Max speed 13 kph



Mars Pathfinder

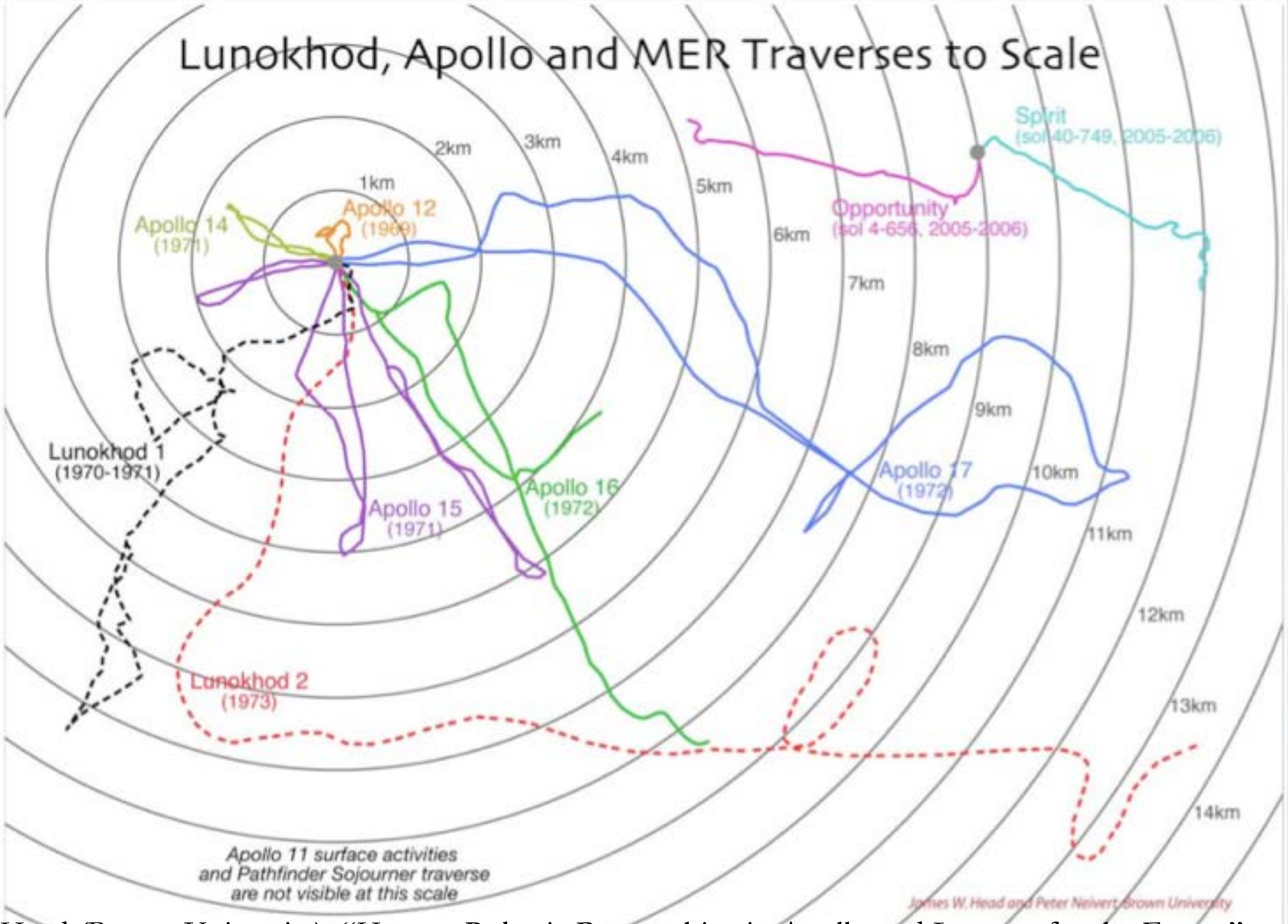
- Sojourner rover flown as engineering experiment
- 23 lbs, $25M
- Design life 1 week
- Survived for 83 sols (outlived lander vehicle)
- Total traverse ~100 m



Mars Exploration Rovers

- Two rovers landed on Mars in January 2004
- Design lifetime 90 sols, 1 km (total)
- Mission success defined as 600 m total traverse
- By August 28, 2012:
  - Spirit 7731 m
  - Opportunity 35,017 m

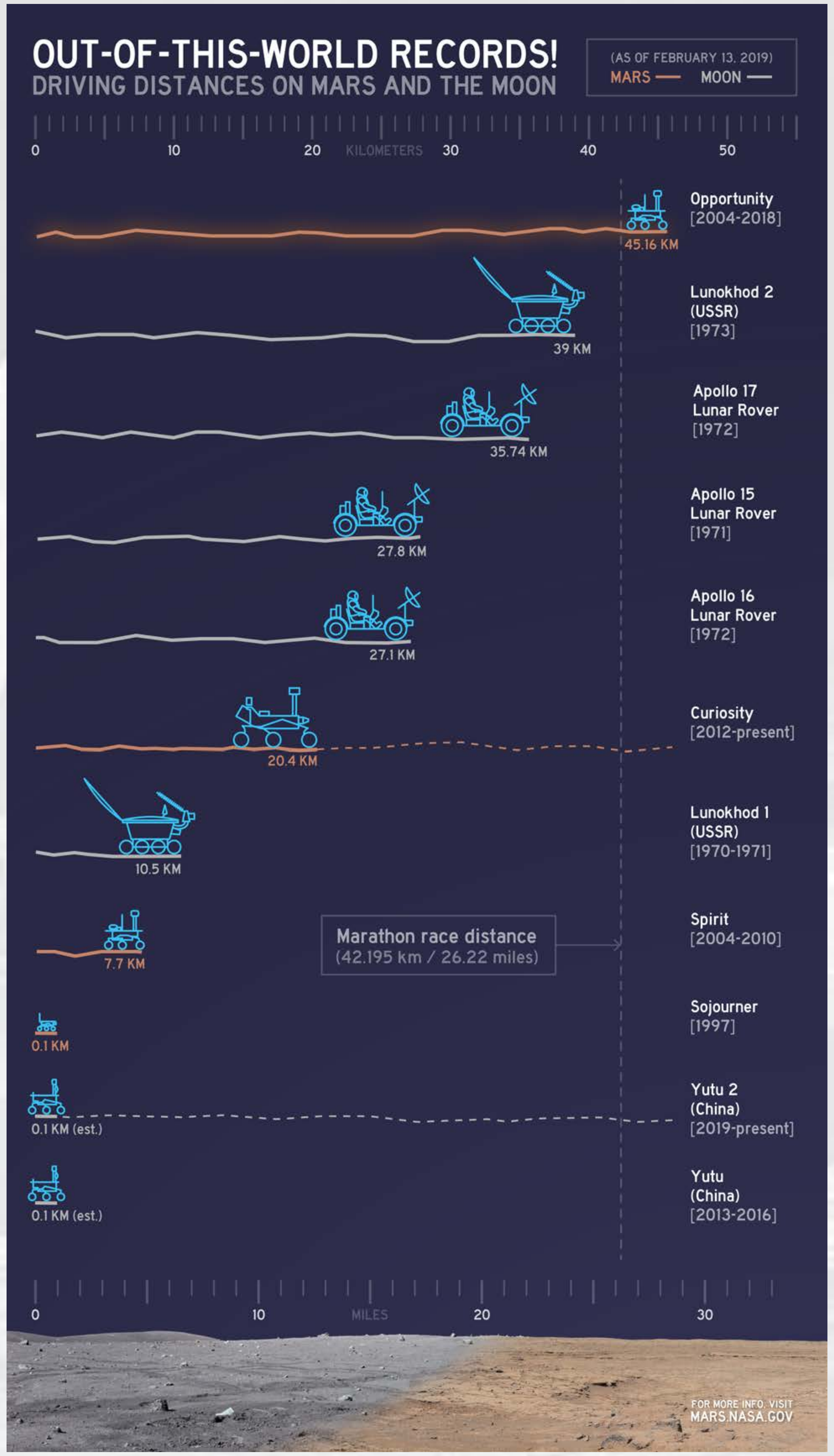
Historical Comparison of Traverses



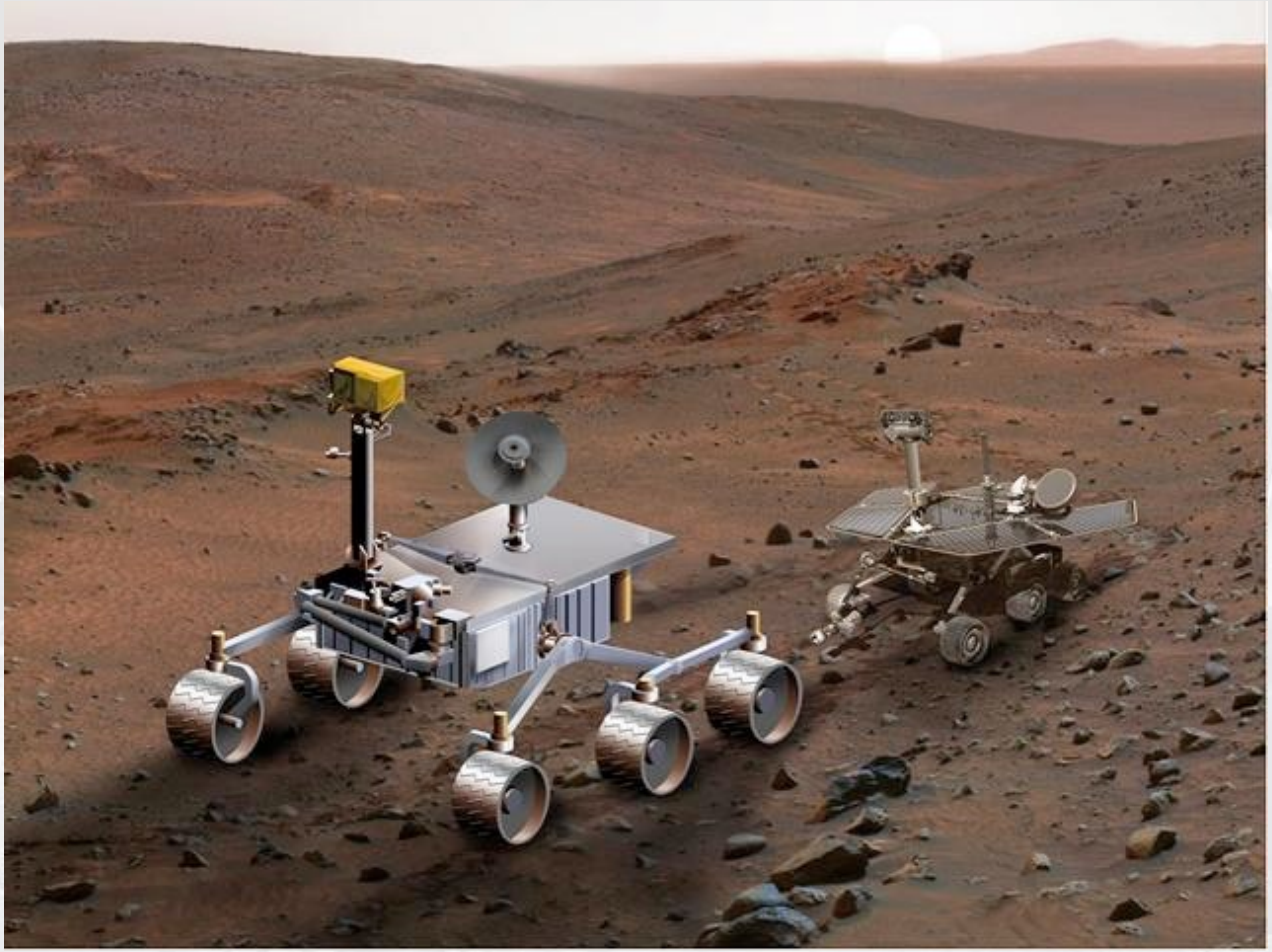
from James W. Head (Brown University), "Human-Robotic Partnerships in Apollo and Lessons for the Future" presentation to the NASA OSEWG Workshop on Robots Supporting Human Science and Exploration, Houston, TX, August 5, 2009

Current Status Based on Distance

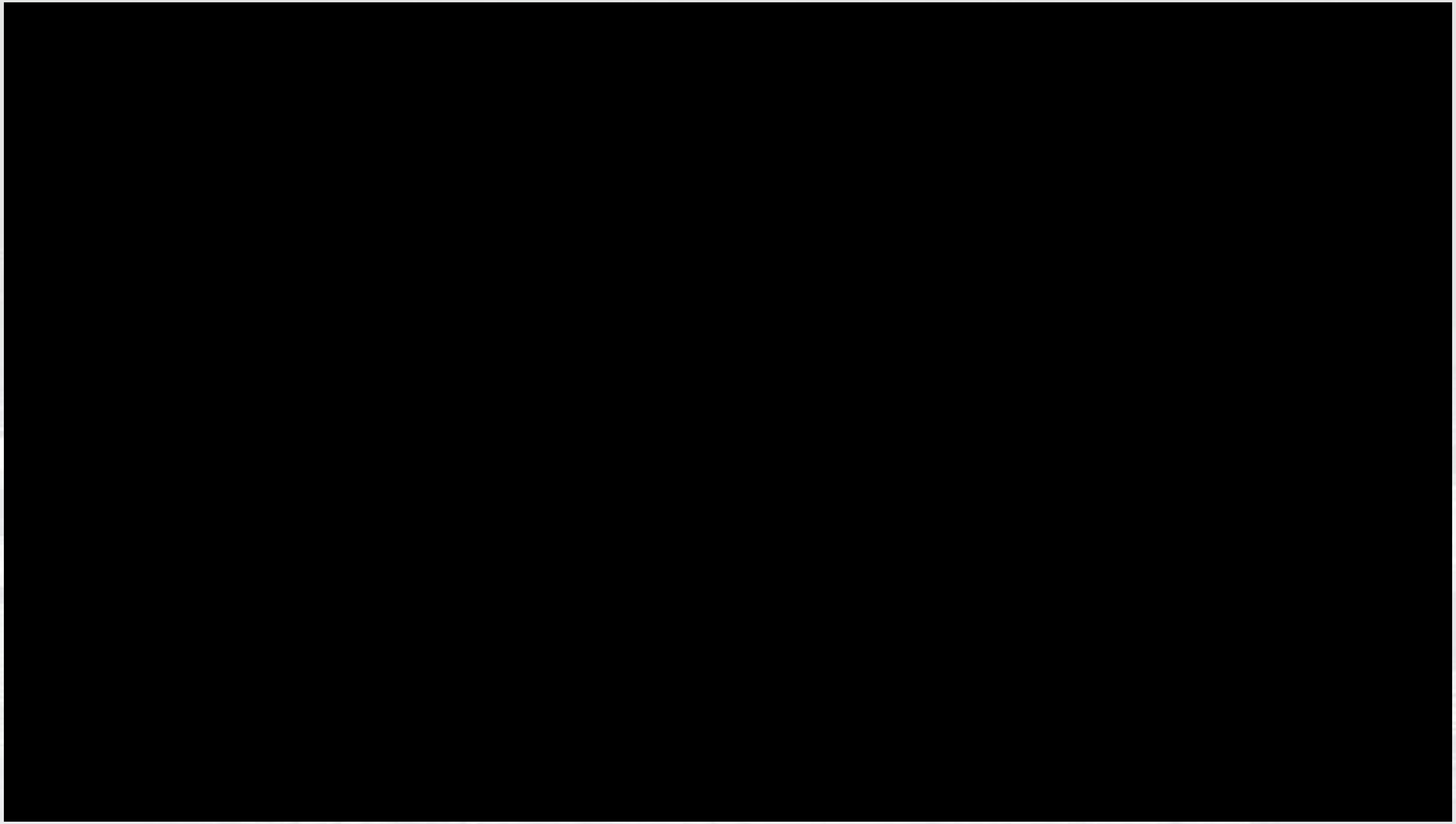
- Spirit: Sol 2555 (dead)
  7.73 km
- Opportunity: Sol 5111 (dead)
  45.16 km
- Curiosity: Sol 4282
  32.13 km
- Perseverance: Sol 1247
  28.11 km



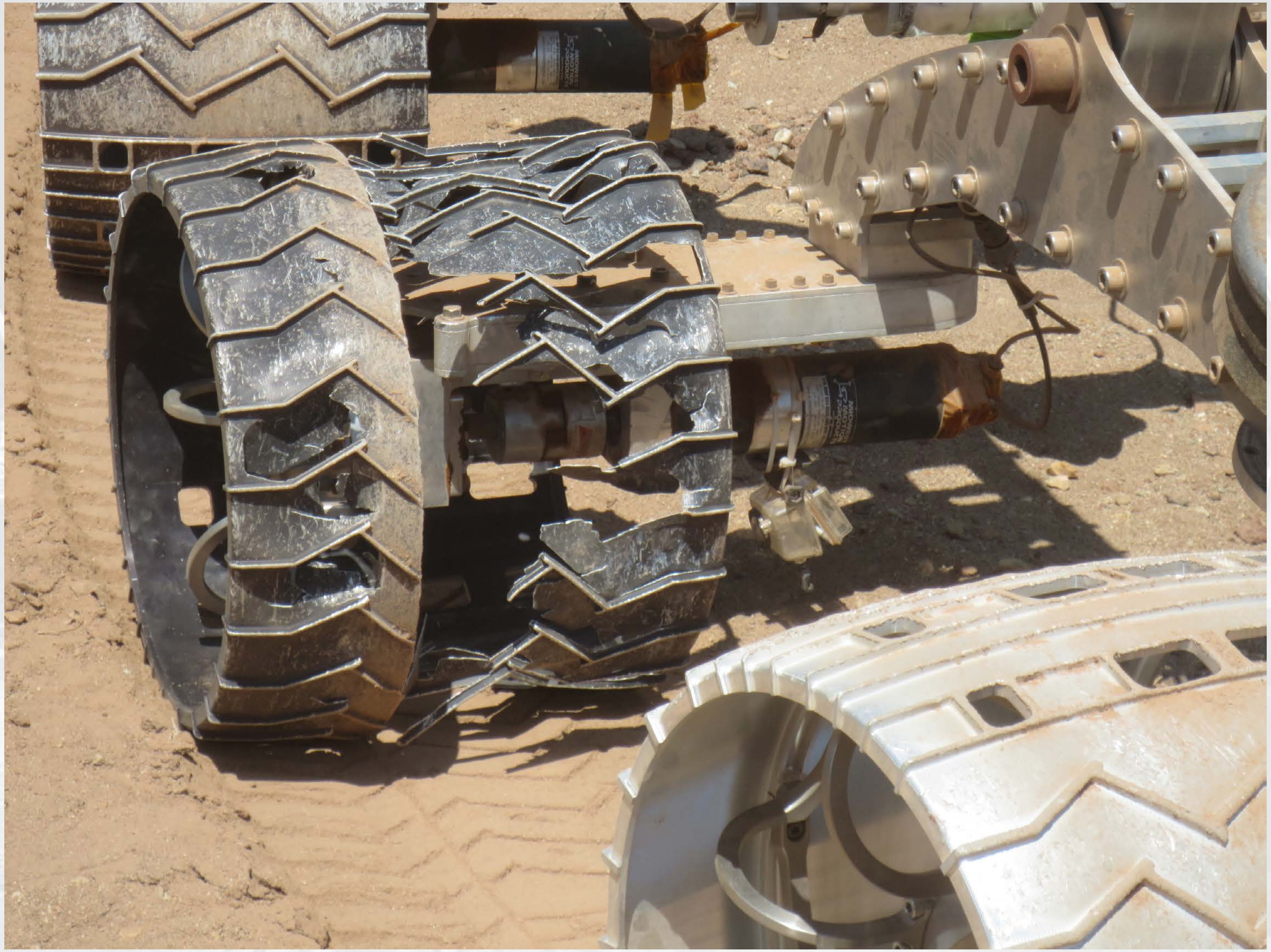
Mars Science Laboratory (and MER)



MSL Mission Overview



Curiosity Wheel Problems

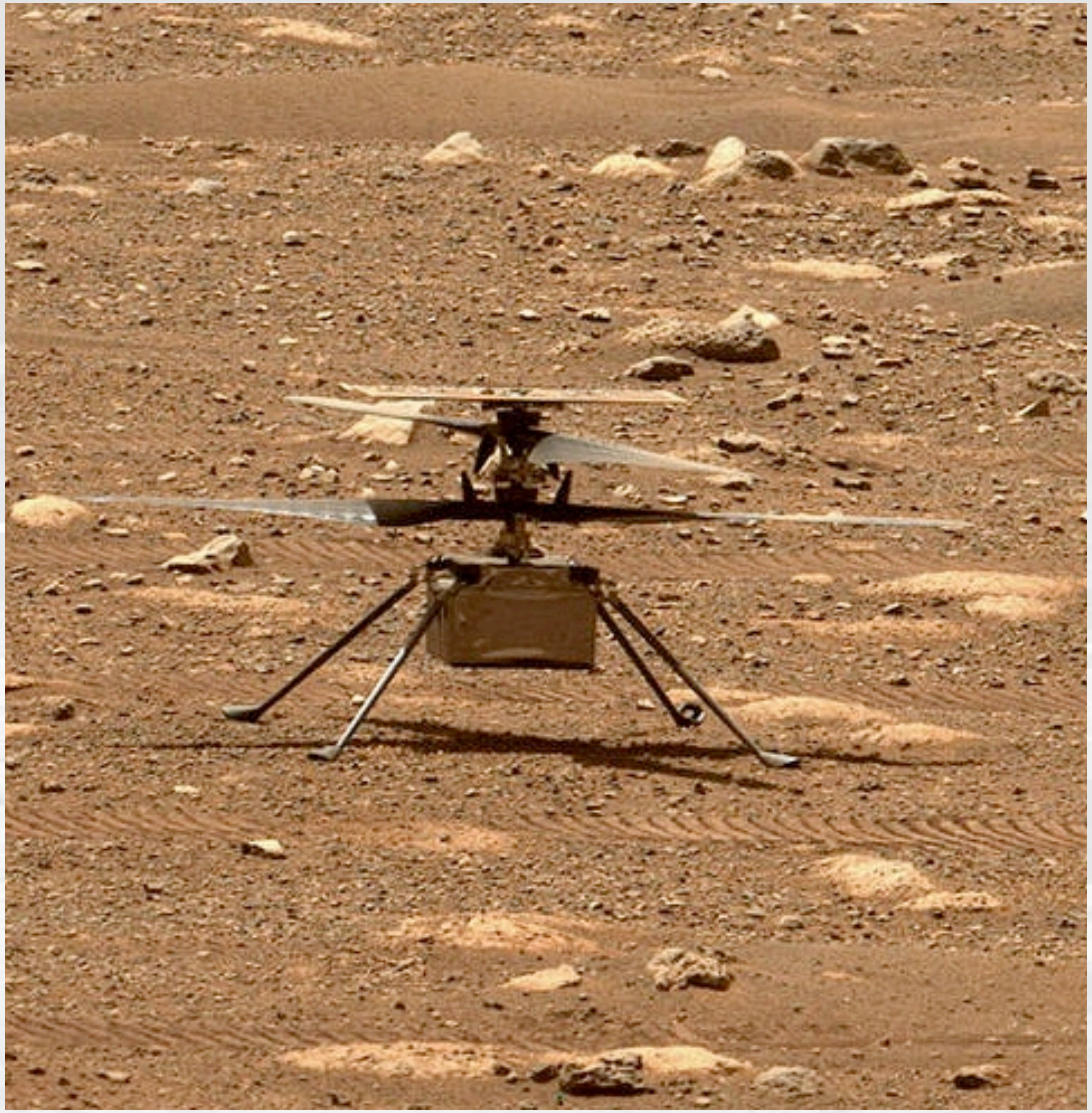


Planetary Aerial Mobility

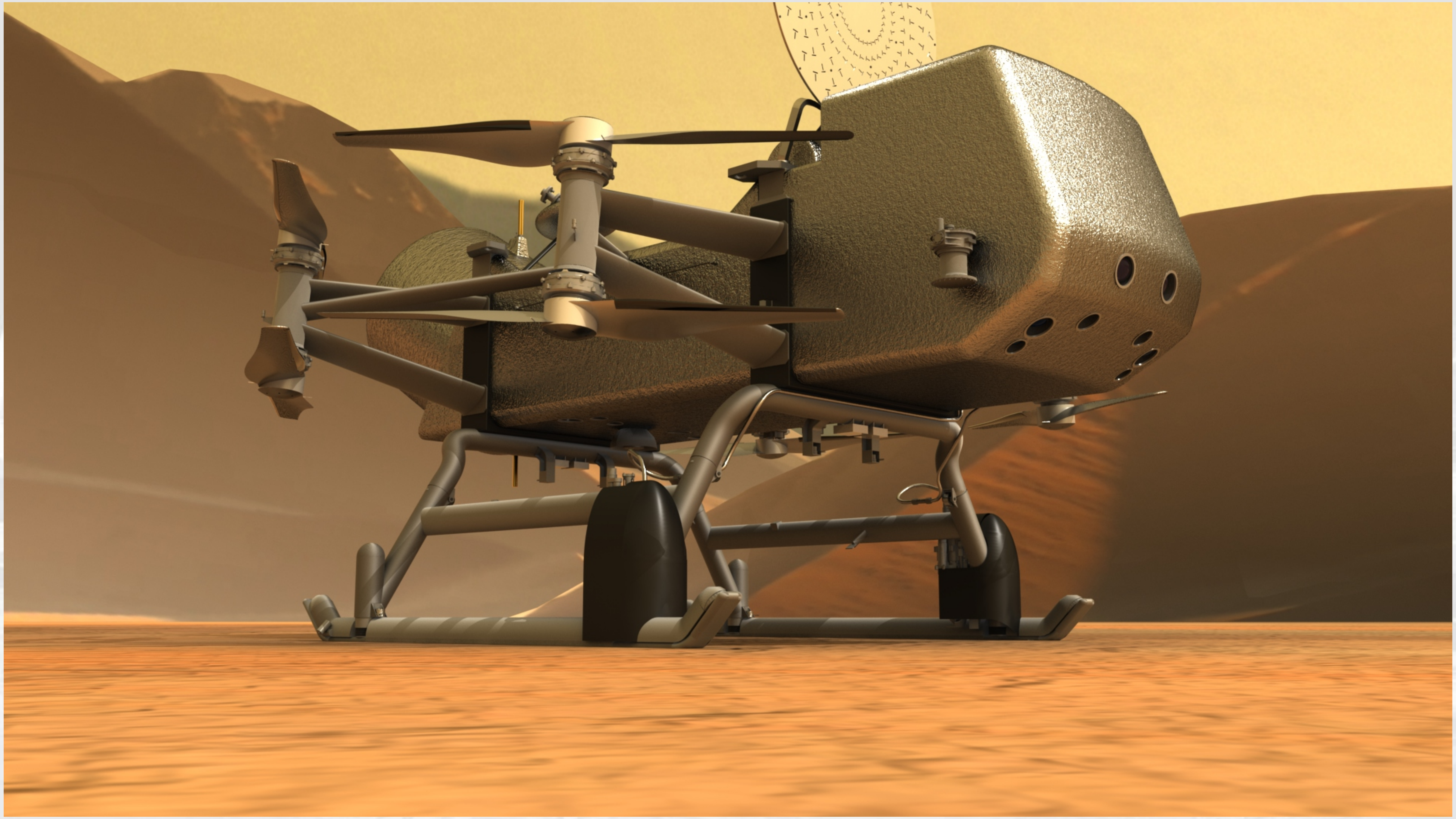
- Deployed during EDL phase or surface deployed
- Lighter-than-atmosphere
  - Thermal balloons
  - Light gases
- Heavier-than-atmosphere
  - Fixed wing (glider or powered)
  - Rotary wing
- Single mission or multiple flights

Ingenuity – Mars Helicopter (2021)

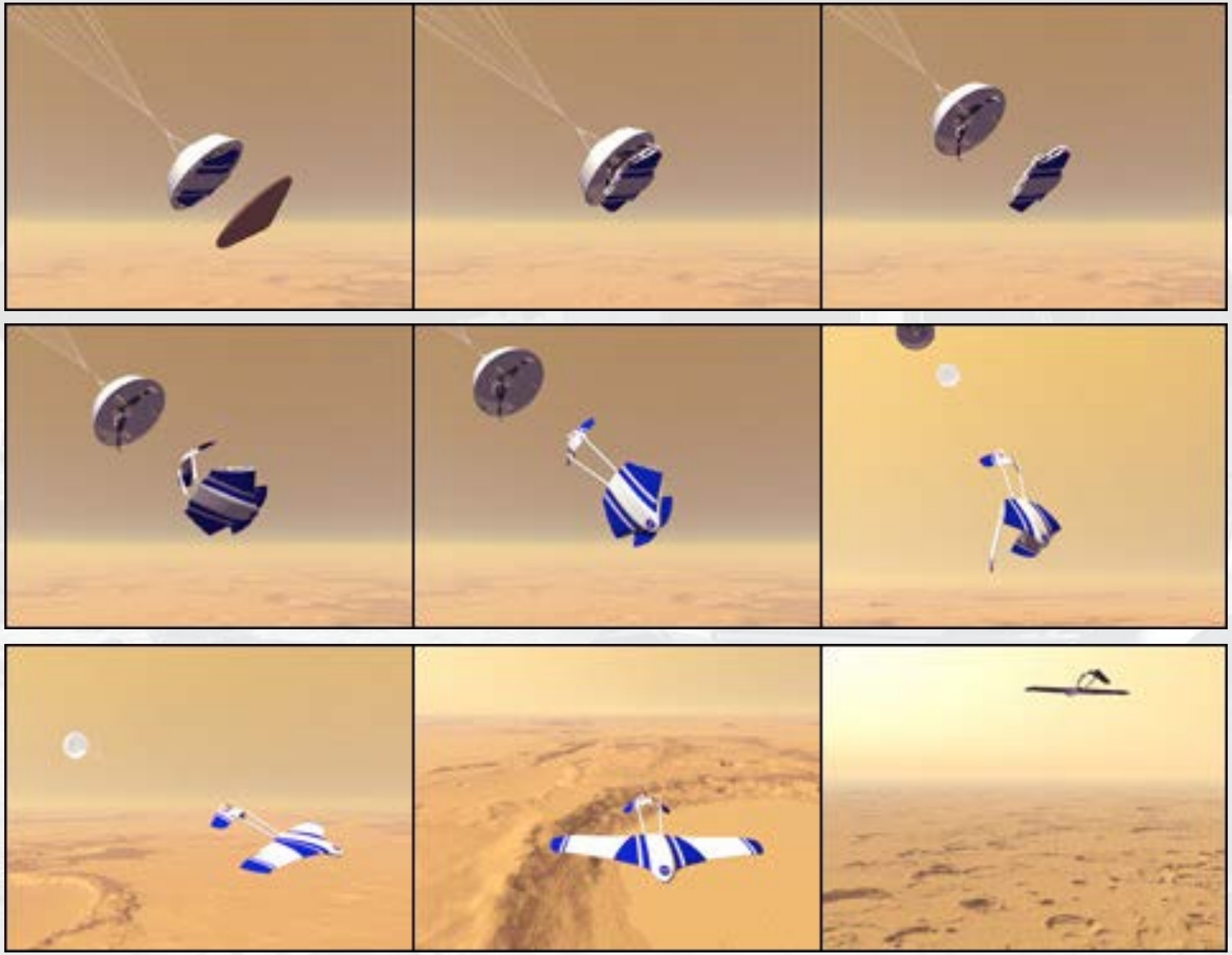
- Mass 1.8 kg
- 72 flights
- Flight time 2:08:55
- Distance travelled 17.242 km
- Max speed 36 km/hr
- Max altitude 24 m



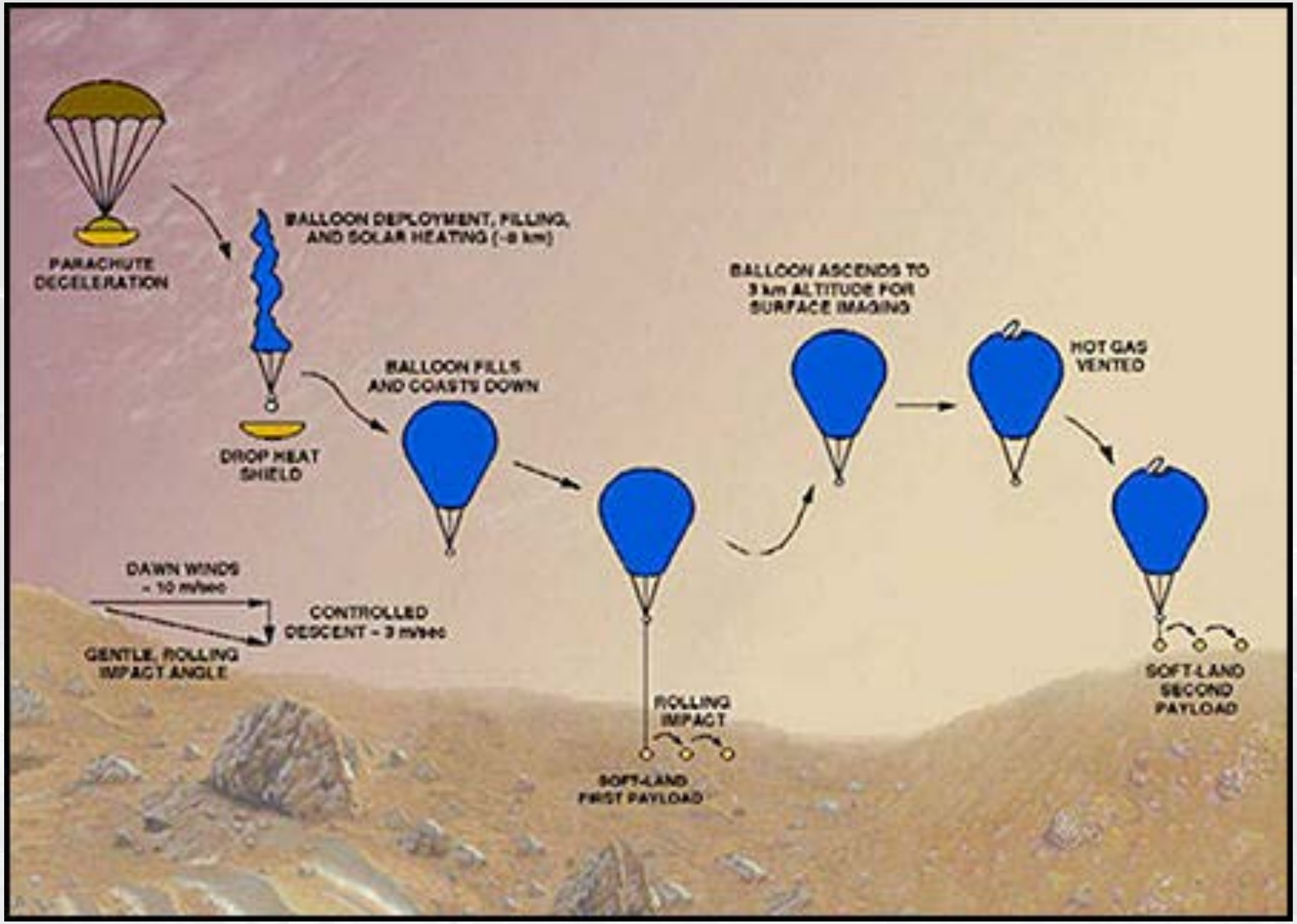
Titan Dragonfly



ARES Deployment



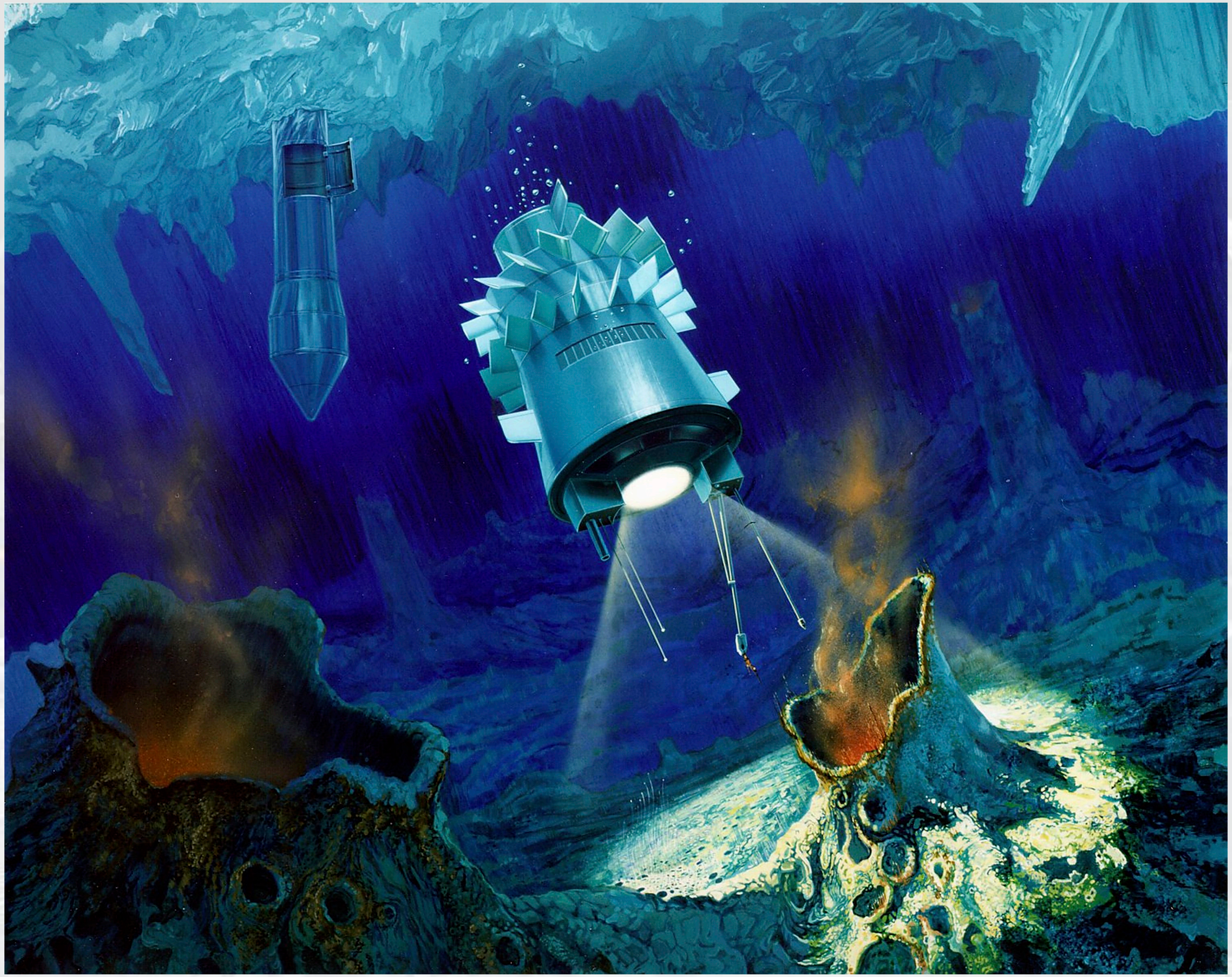
Mars Balloons



Huygens Probe

- Titan entry January 2005
- Descent imaging used to survey surface at different scales
- Wind motion provided horizontal traverse of surface

Ice World Exploration Vehicle

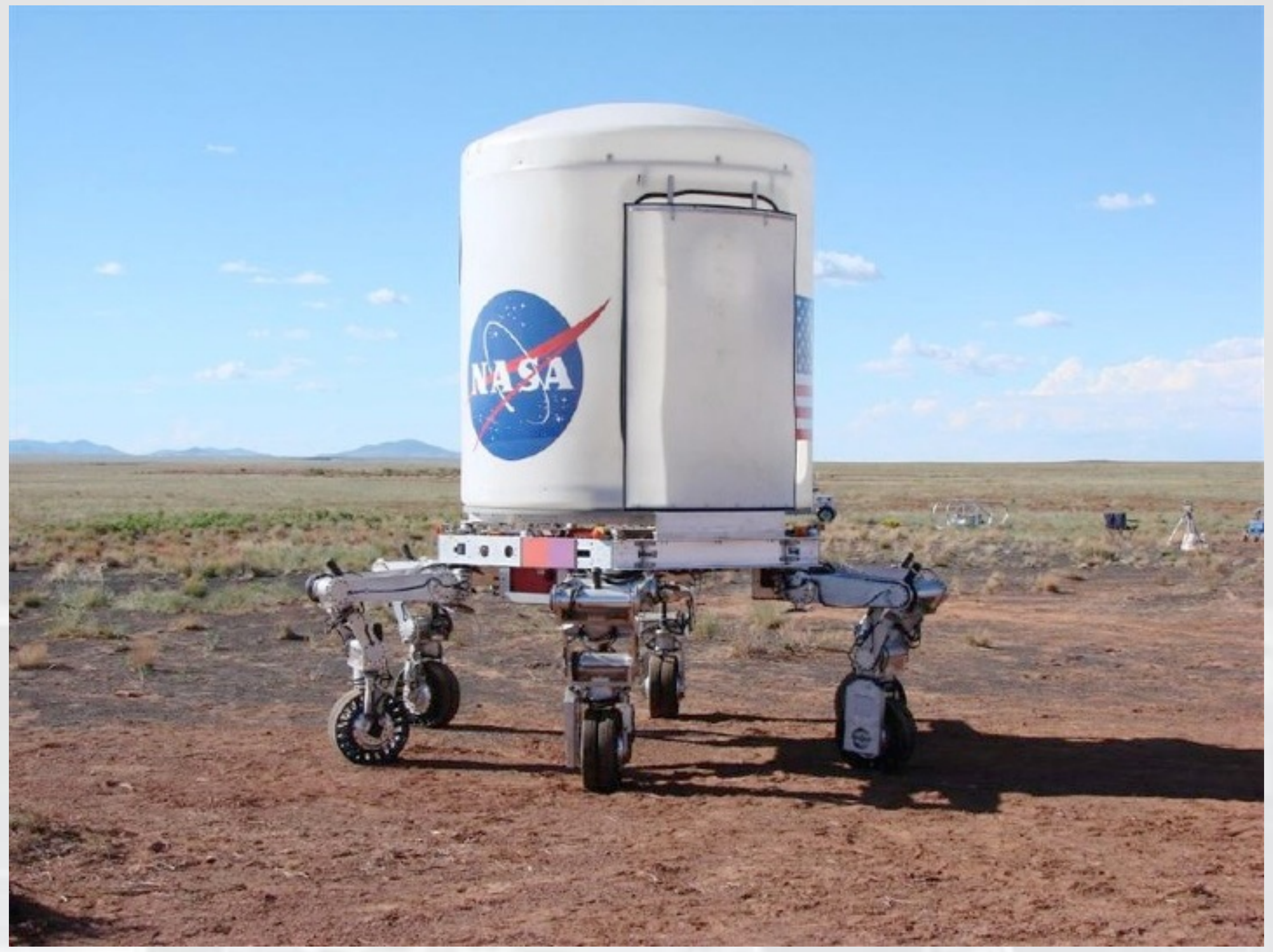


Field Trials for New Mobility Technologies

SCOUT (JSC)

Robonaut/Centaur (JSC)

ATHLETE (JPL)



ATHLETE With Larger Legs

Desert RATS 2008 - Moses Lake, WA

Drill Sampling Robot - CMU

K-10 (NASA Ames)

ATHLETE (JPL)

Chariot (NASA JSC)

Chariot with Plow Blade

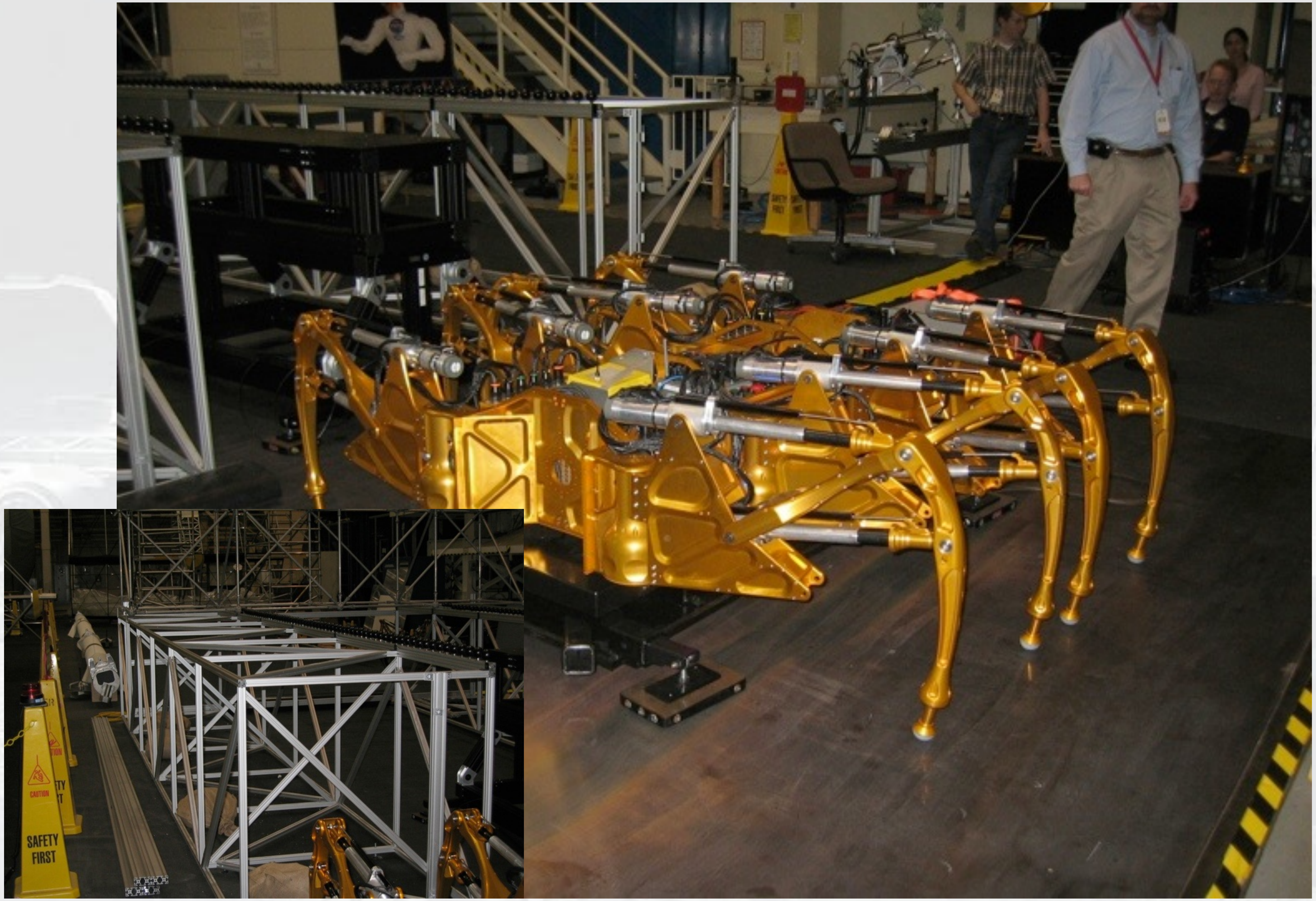
Chariot B Climbs a Boulder Field

Space Exploration Vehicle

Walking Robots

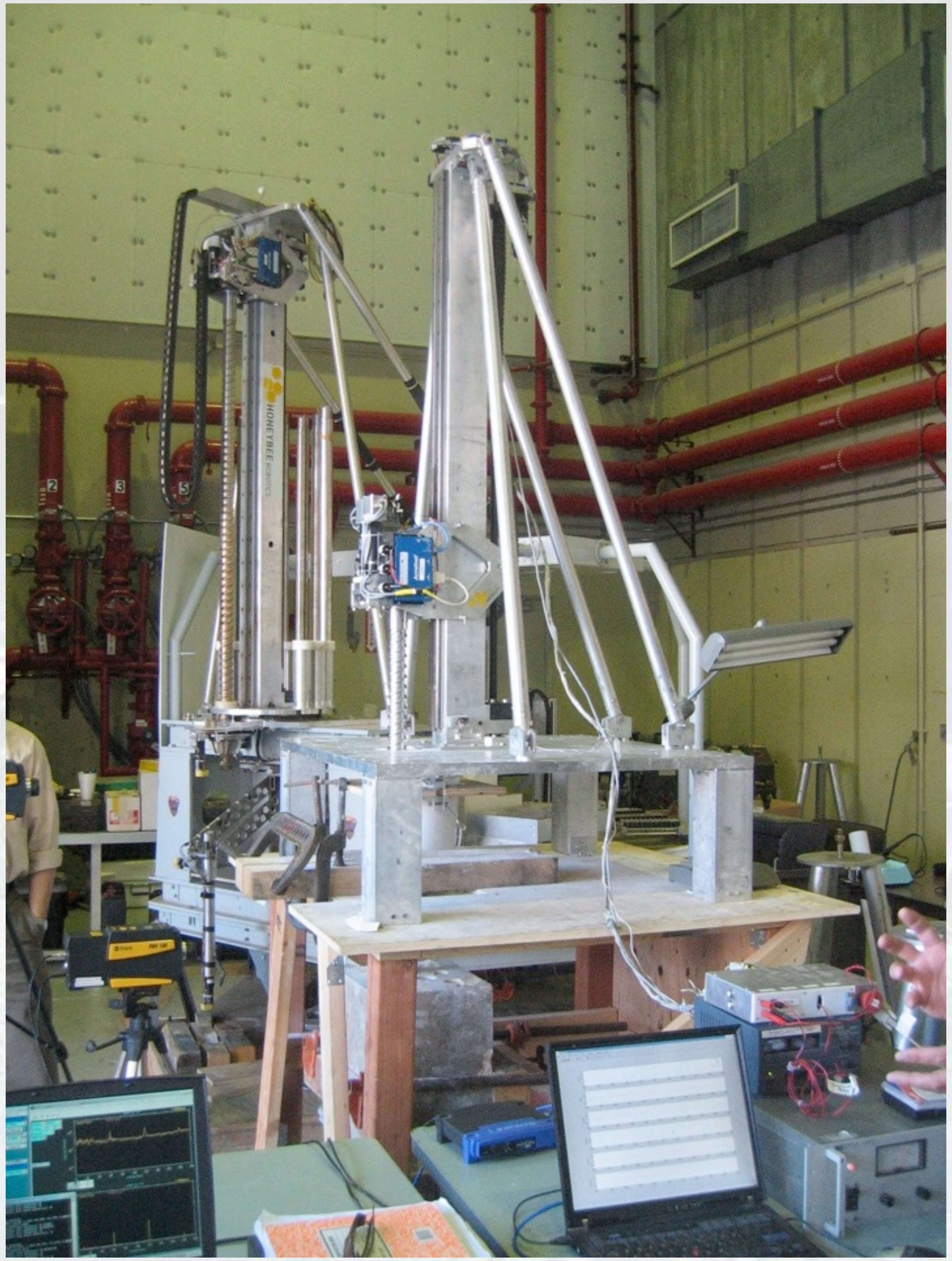

Photo by Bill Ingalls/NASA

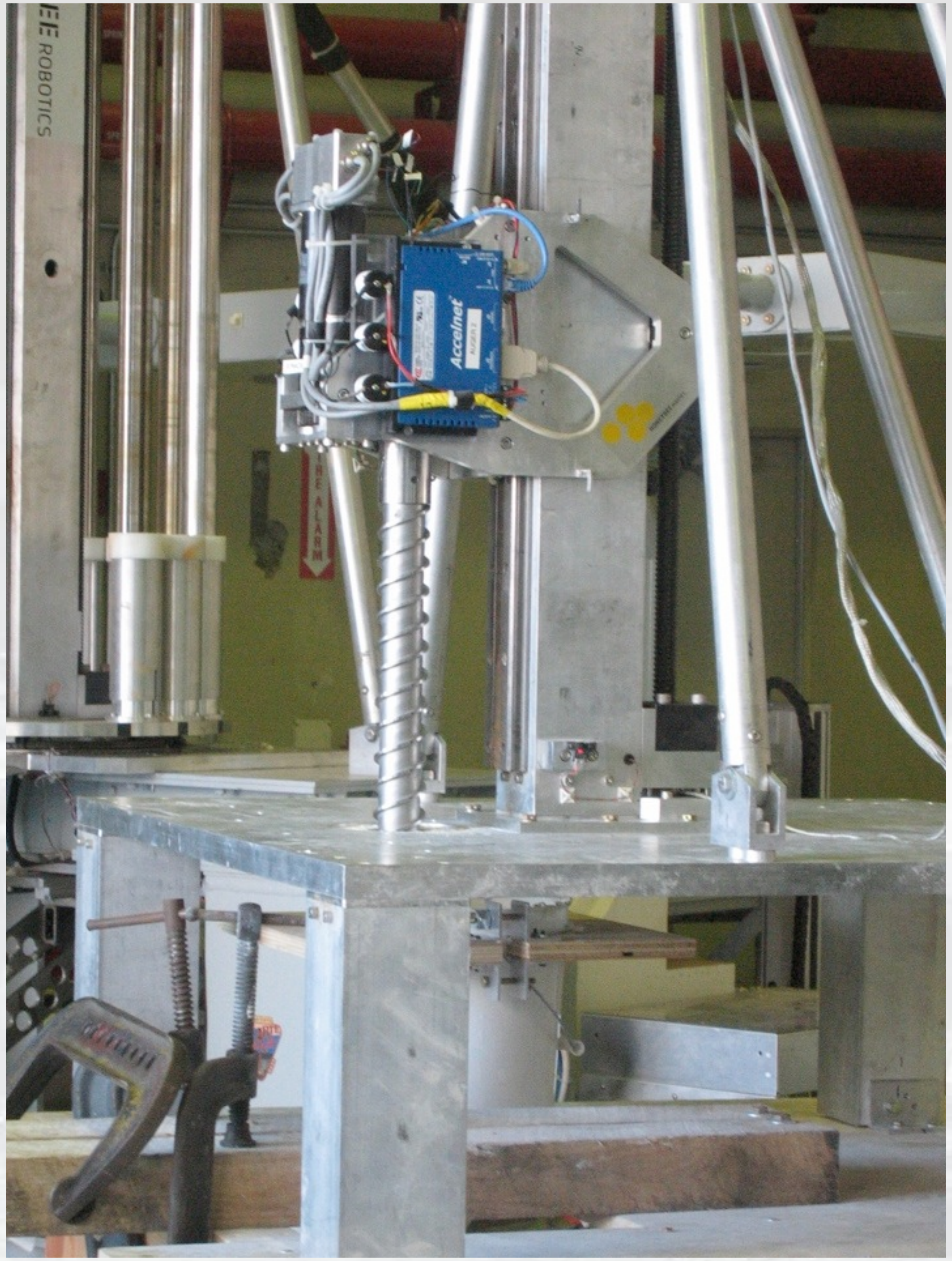
Scorpion King (JSC)



Serpentine Mobility

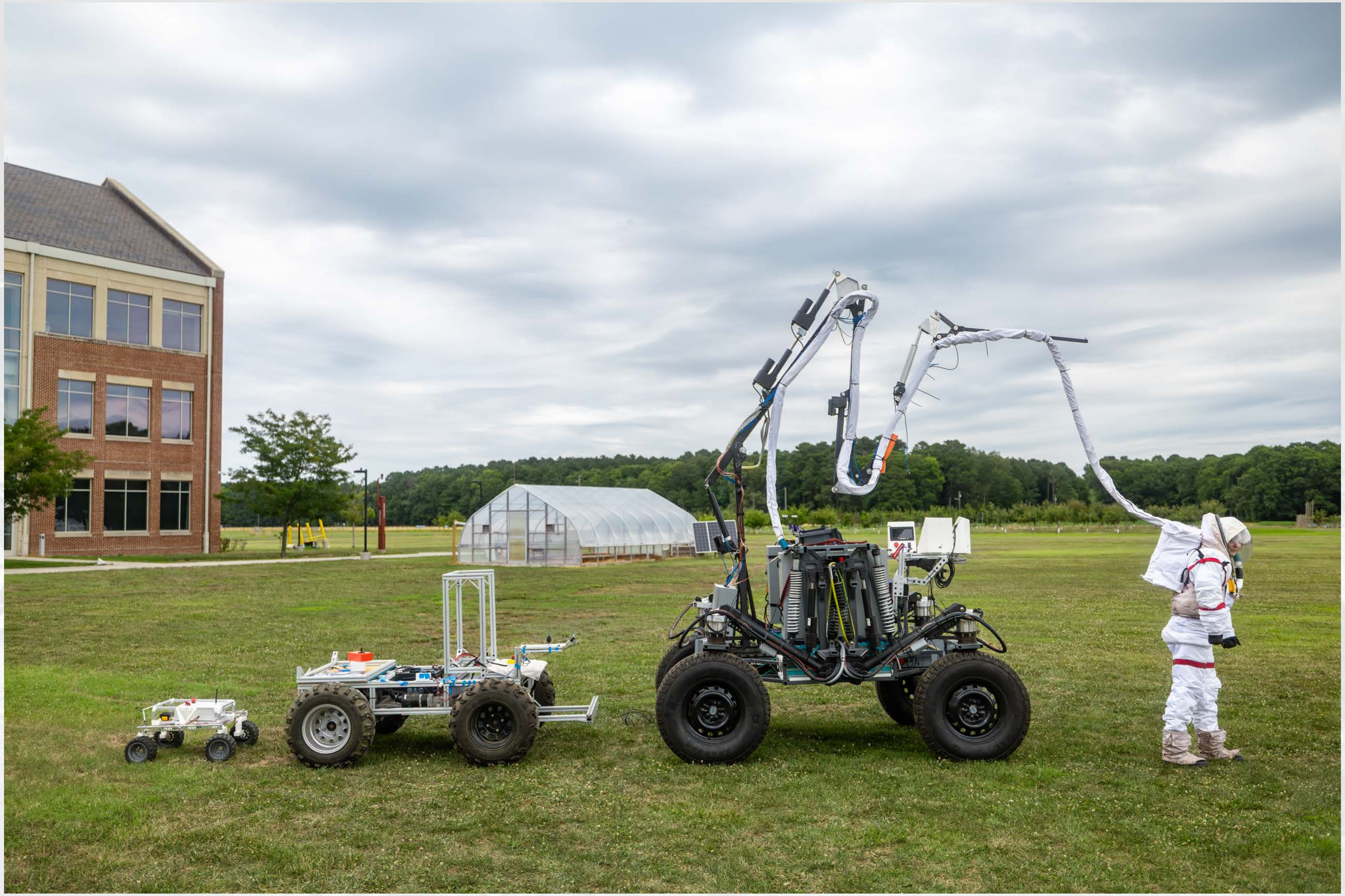
Sub (Solid) Surface Access





The SSL Rover Fleet

SSL Rovers (Side View)

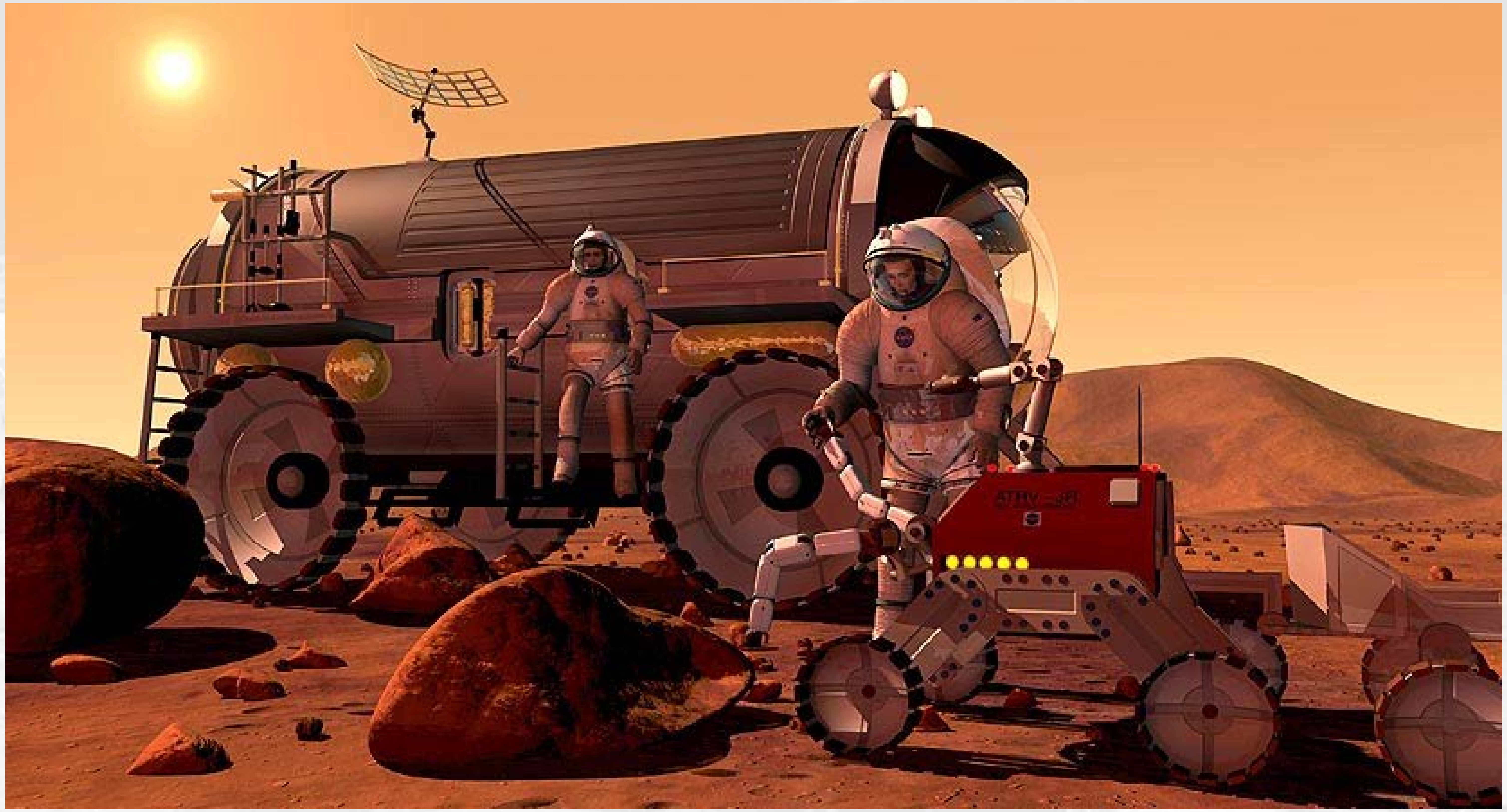


SSL Wheel Test Rig

SSL Wheel Test Rig

Future Human Planetary Exploration

- Will involve mobility platforms at multiple levels
  - Small explorers
  - Unpressurized crew-carrying vehicles
  - Pressurized rovers
  - Specialized systems
- Need for robustness and repairability



Term Design Project Goals

- Provide opportunity to use principles of class to perform open-ended realistic design
- Reinforce experiences with engineering in teams, making technical presentations
- Address a problem of real relevance to NASA

Lunar Terrain Vehicle (LTV)

- NASA has awarded three development contracts for a lunar terrain vehicle (LTV)
- Will fill the same role as the Apollo Lunar Roving Vehicle with additions:
  - Rechargeable
  - Longer range
  - Deployable on CLPS landers
  - Remotely controllable without crew

Term Design Project

- Perform the preliminary design of an Artemis Lunar Light Utility Vehicle, based on RFP specifications to be released
- (Ideally) 2-person teams
- Design requirements to come as NASA releases them, but probably will include
  - System designed to accomplish servicing and maintenance tasks in support of human exploration
  - Can be autonomous or teleoperate from the moon or Earth
  - Mass $\leq$ 500 kg
  - More design requirements to come

Design Project Statement

- Perform a detailed design of an LLUV rover, emphasizing mobility systems
  - Chassis systems (e.g., wheels, steering, suspension…)
  - Support systems (e.g., energy storage)
  - Navigation and guidance system (e.g., sensors, algorithms...)
- Design for Moon, then assess necessary modifications for Mars, and conversion to Earth analogue rover

Term Project Overview

- Teams of 2-3 students (~5-8 teams in class)
- Review requirements as published
- Consider design approaches and options
- Perform trade studies to refine and verify design(s)
- Use CAD to create vehicle design drawings
- Prepare a "work in progress" status report – due Monday, Oct. 21
- Continue design work and analysis, incorporating feedback from status report and adding analysis areas as they are presented in class
- Final report due Monday, Dec. 9

Homework for This Lecture

- Form teams of 2-3 students for term project
- Post your team roster to "General" discussion group on Teams site by end of this week
- Feel free to use discussion area of Teams to find team members if you need to
- Also, each person should find a technical paper (journal or rigorous conference paper) on some aspect of rovers applicable to the term project
- Upload a PDF of the paper to the "background research" channel on Teams, along with a brief description in the message you attach it to
- Papers must be unique! If someone else posts your paper first you have to find a different one. (It pays to do this assignment early!) Papers are due by Monday 9/9

A Note on Online Research

- Some good places to start
  - https://ntrs.nasa.gov/search (NASA documents)
  - https://arc.aiaa.org (AIAA papers)
  - https://ttu-ir.tdl.org/handle/2346/58495 (Proceedings of the International Conference on Environmental Systems)
- The UMd library has access to many journals - they also have code you can load to add a “reload@umcp” button in your browser so you can download using the university’s licenses