ENAE 788X Overview and Introduction

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- Overview of Planetary Robot Mobility

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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 web site at https://elms.umd.edu/
  - Communications for team projects
  - Lecture videos

Syllabus - Mobility Overview

- Free-space mobility
- Orbital maneuvering (proximity operations)
- 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 Scheme

- 30% homework
- 30% midterm (take-home)
- 40% team project (individual)

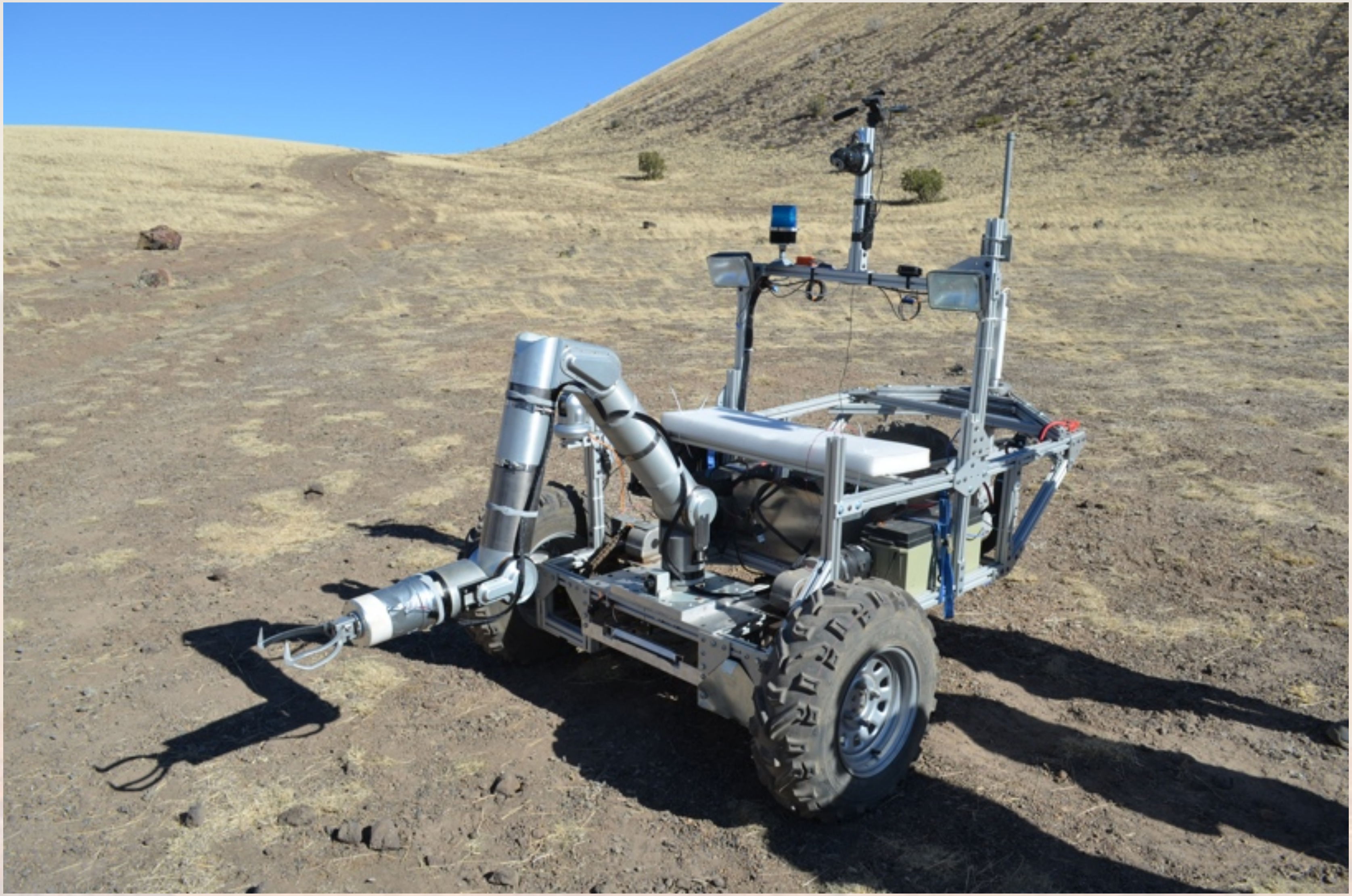
Term Design Projects

- Astronaut assistance rover
- Sample collection rover
- Minimum pressurized exploration rover
- Others by special request

AAR Design Project Statement

- Perform a detailed design of a small astronaut assistance rover, emphasizing mobility systems
  - Chassis systems (e.g., wheels, steering, suspension...)
  - Navigation and guidance system (e.g., sensors, algorithms...)
- Design for Moon, then assess feasibility of systems for Mars, and conversion to Earth analogue rover
- This is not a hardware project - focus is on detailed design (but may be built later!)

RAVEN in Telerobotic Sample Config



RAVEN in EVA Transport Config

Level 1 Requirements (Performance)

1. Rover shall have a maximum operating speed of at least 15 km/hour on level, flat terrain
2. Rover shall be designed to accommodate a 0.3 meter obstacle at minimal velocity
3. Rover shall be designed to accommodate a 0.1 m obstacle at a velocity of 7.5 km/hour
4. Rover shall be designed to accommodate a 30° slope in any direction at a speed of at least 5 km/hour with positive static and dynamic margins

Level 1 Requirements (Payload)

5. Rover shall be be designed for an instrument payload with a mass of 50 kg and volume of 0.25 m^3
6. Rover shall also accommodate a Ranger-classs sample-collection manipulator system with a mass of 50kg
7. Rover shall be designed to nominally transport a 95^{th} percentile American male crew in full pressure suit
8. Rover shall be capable of carrying two 95^{th} percentile crew in a contingency

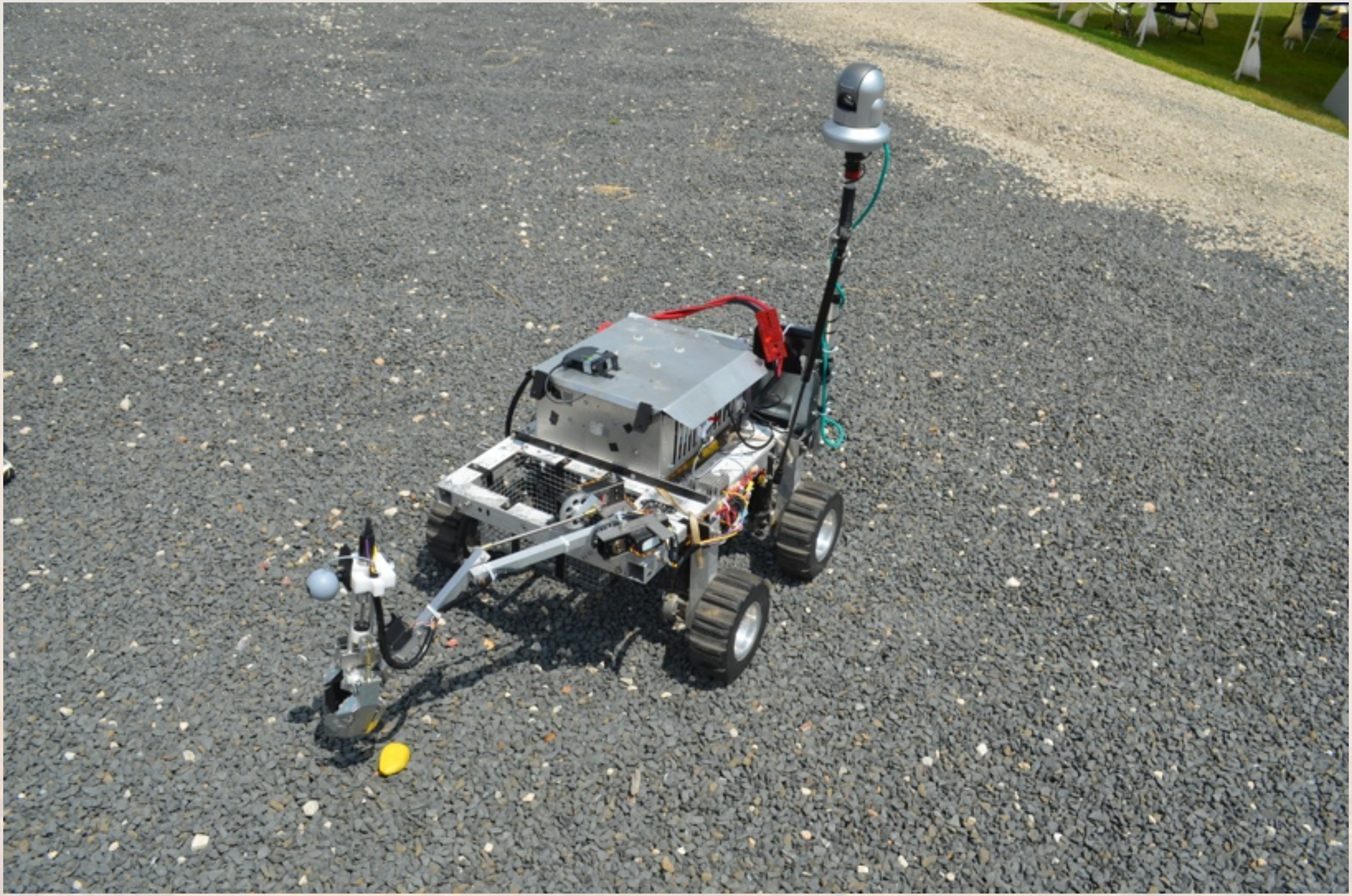
SP Crater - 30° slope

Future Application: Hi-SEAS Testing

RoboOps Design Project Statement

- Design a small remotely operated rover to participate in the 2015 RoboOps competition
- Rover must be capable of rapid and highly robust maneuverability in all terrains at the JSC Rockyard
- Design will be implemented by a group of undergrads in the spring (although you can help, too, if you want!)

RHEA – RoboOps 2012



Mobility in Craters (Moon)

Video shown in class available on web site

Mobility in Sand (Mars)

Video shown in class available on web site

Mobility in Rocks (Mars)

Video shown in class available on web site

RoboOps Requirements

- Rovers must fit within a 1x1x0.5 meter volume to start and deploy to operational configuration
- Rover must be <45 kg; tactical advantages go to lighter rovers
- Rovers must operate without local interaction for one hour
- Rovers must be controlled via cell networks from participating university's campus
- Rovers collect colored rocks to score points

LWPR Design Project Statement

- Design a mobility chassis for a minimum pressurized rover for lunar exploration
- Design for the moon, and do design modifications for implementation on Earth
- Goal is to keep complete rover below 2000 kg

NASA Space Exploration Vehicle

TURTLE Exterior

TURTLE Interior

Robotic Mobility

- Free Space
- Relative Orbital Motion
- Airless Major Bodies (moons)
- Gaseous Environments (Mars, Venus, Titan)
  - Lighter-than-"air" (balloons, dirigibles)
  - Heavier-than-"air" (aircraft, helicopters)
- Aquatic Environments (Europa)
- Surface Mobility (wheels, legs, etc.)
- Subsurface Access (drills, excavation)

Comparison of Basic Characteristics

Quantity	Earth	Free Space	Moon	Mars
Gravitational Acceleration	9.8 m/s (1 g)	–	1.545 m/s (0.16 g)	3.711 m/s (0.38 g)
Atmospheric Density	101,350 Pa (14.7 psi)	–	–	560 Pa (0.081 psi)
Atmospheric Constituents	78% N 21% O	–	–	95% CO 3% N
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

Overview of Robotic Mobility

- Free Space
- Lunar
- Mars
- Venus
- Minor bodies
- Technologies in development

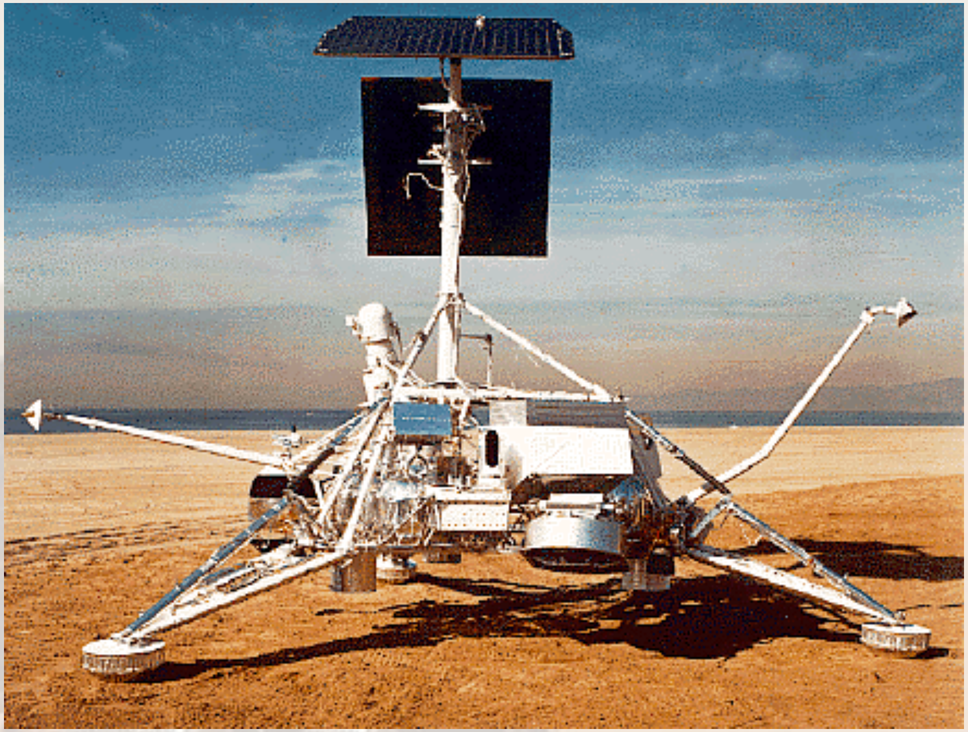
AERCam/SPRINT

Orbital Express

SPHERES

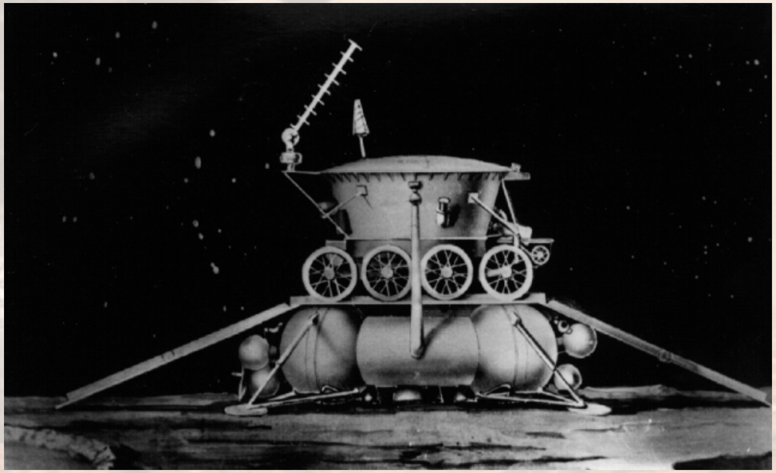
Surveyor

- 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



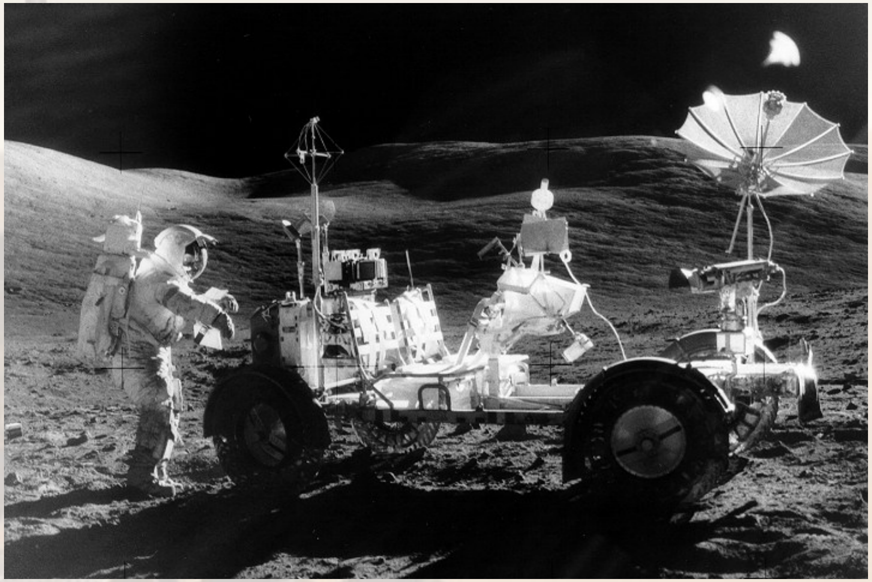
Lunakhod 1 and 2

- 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



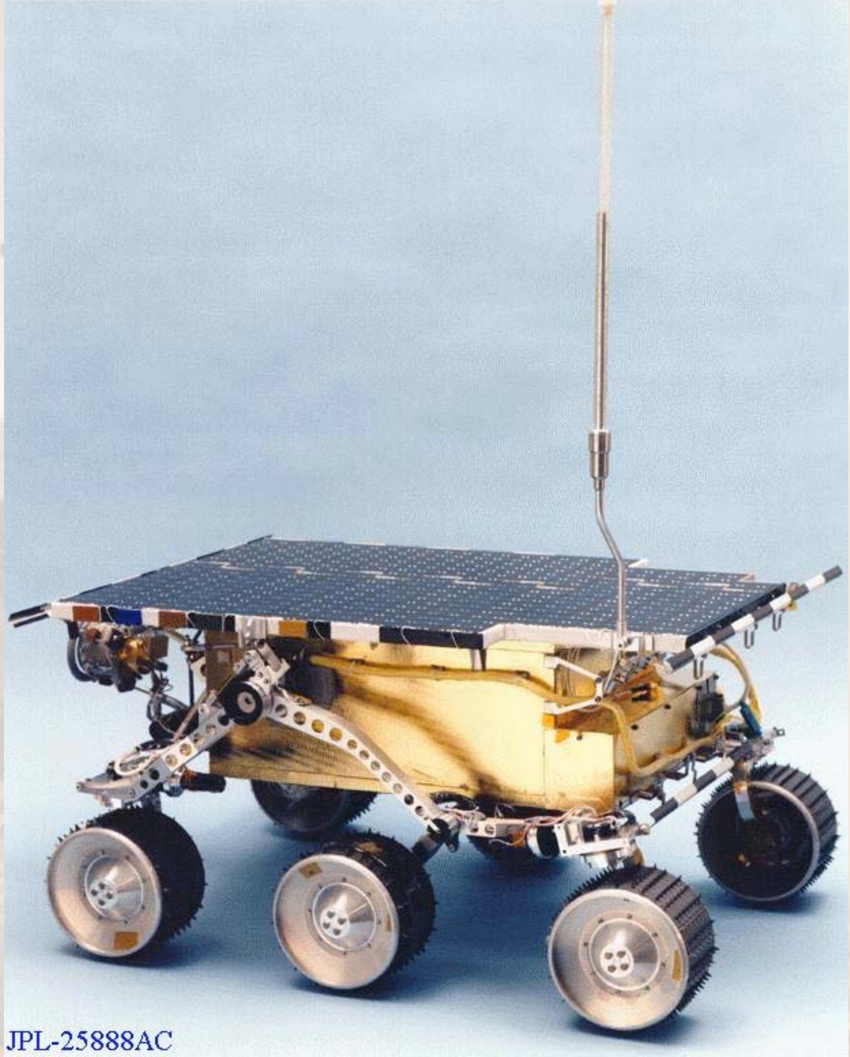
Lunar Roving Vehicle

- 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

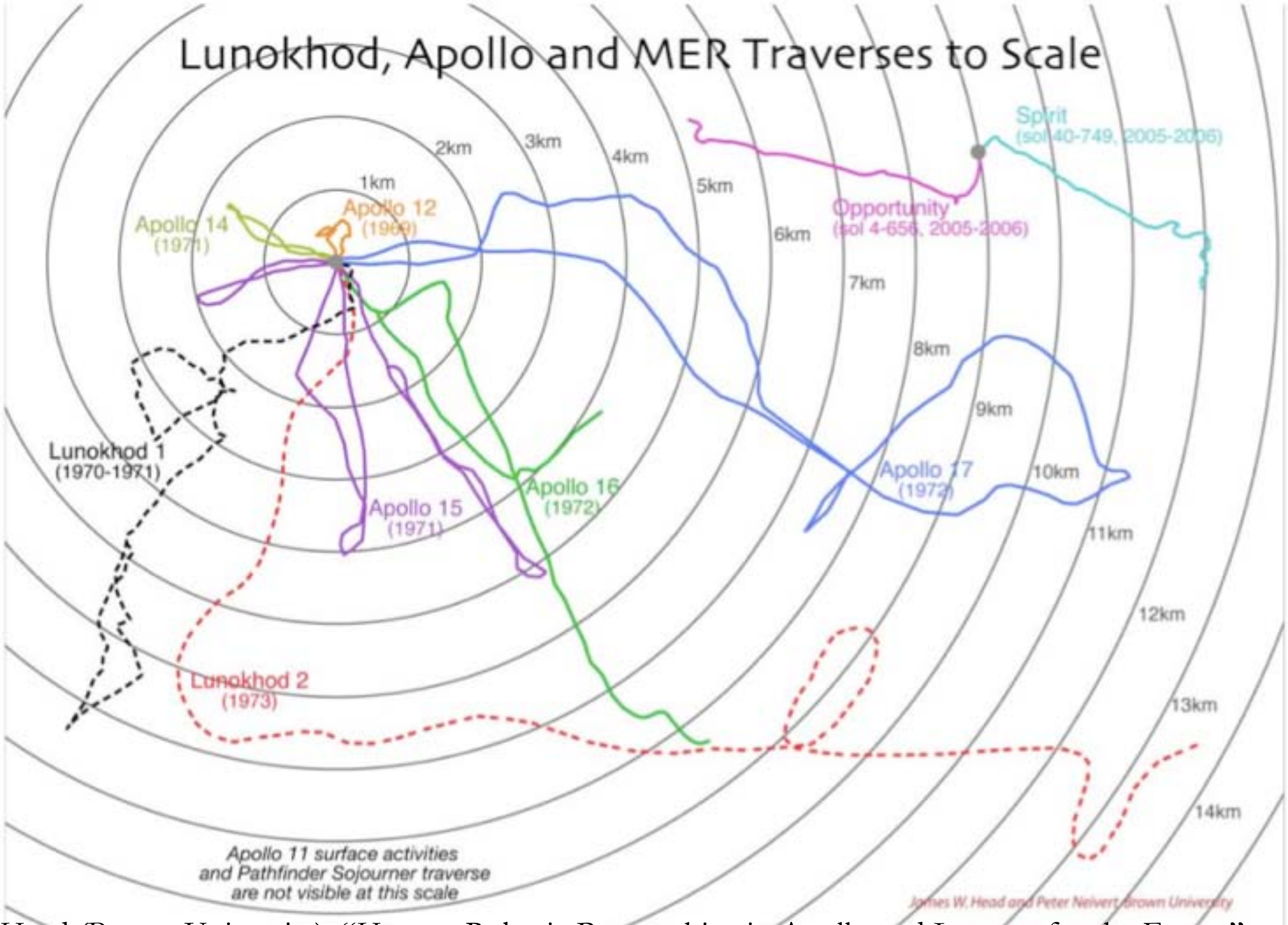
- Sojourner rover flown as engineering experiment
- 23 lbs, $25M
- Design life 1 week
- Survived for 83 sols (outlived lander vehicle)
- Total traverse ~100 m



Mars Exploration Rovers

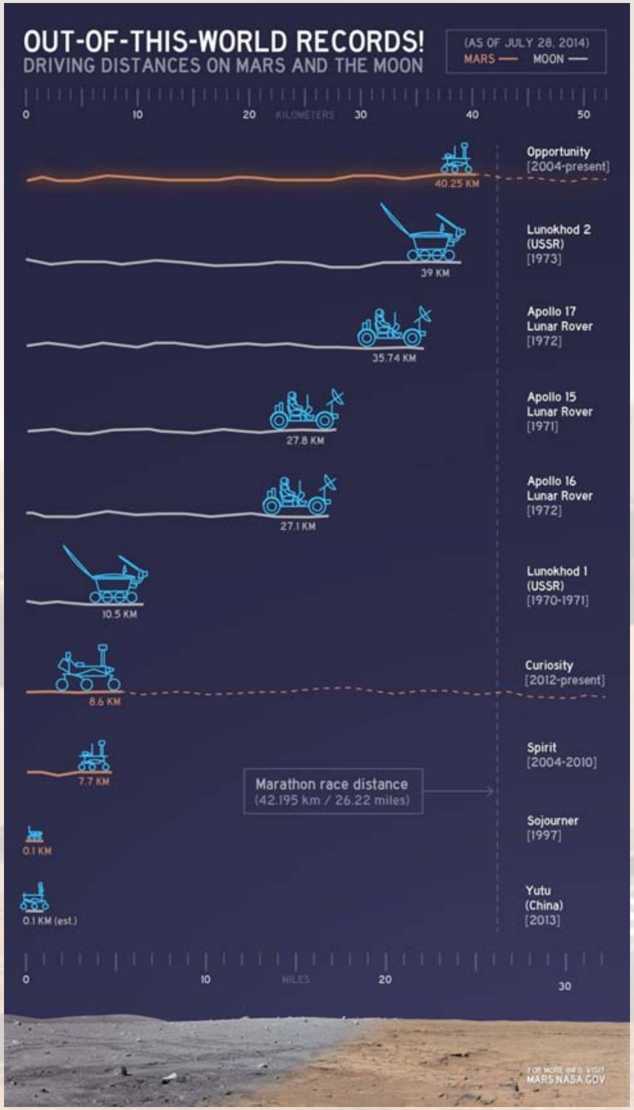
- Two rovers landed on Mars in January 2004
- Design lifetime 90 sols, 1 km (total)
- Mission success defined as 600 m total traverse
- By August 28, 2012:
  - Spirit 7731 m
  - Opportunity 35,017 m

Historical Comparison of Traverses

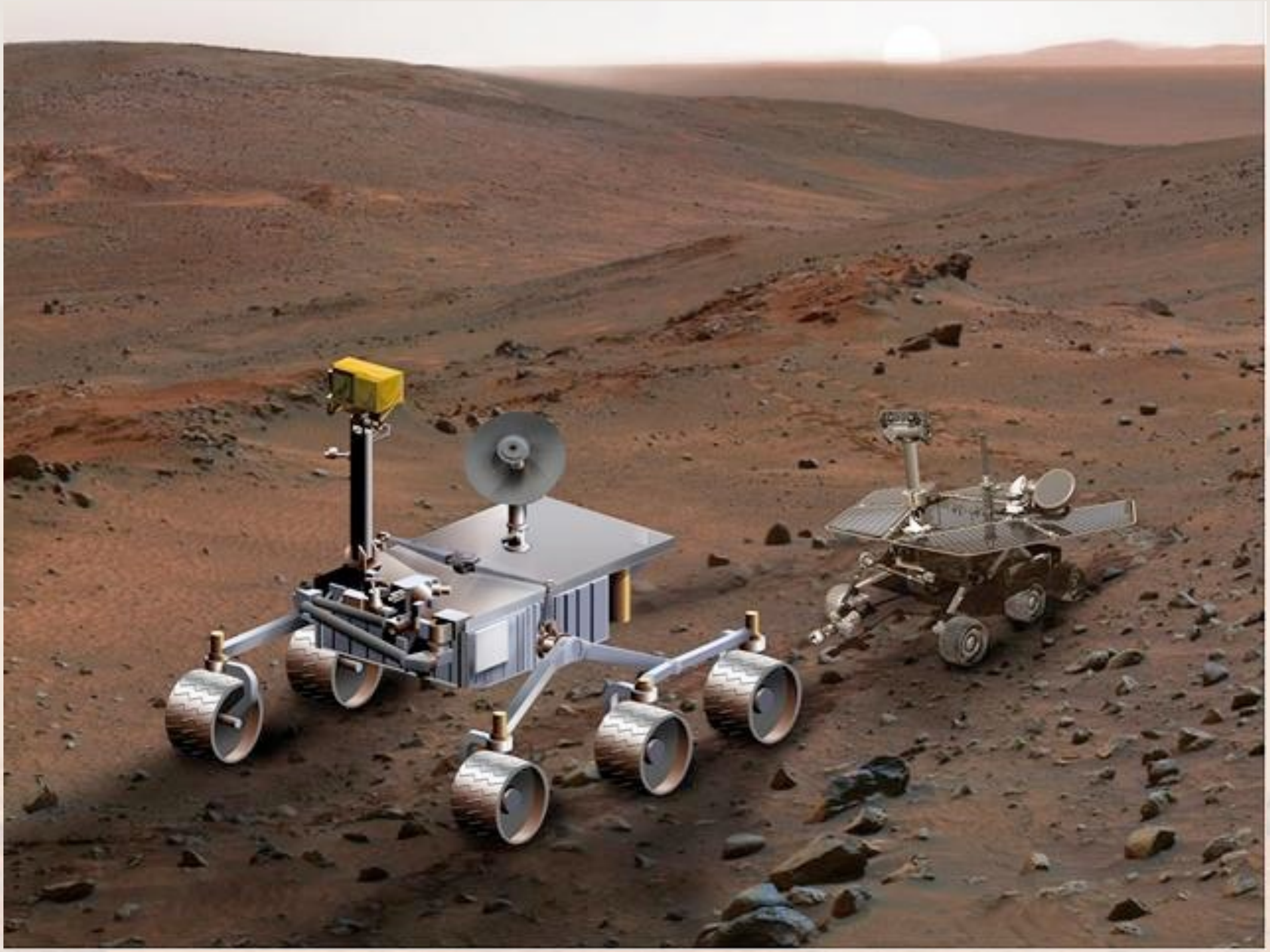


from James W. Head (Brown University), "Human-Robotic Partnerships in Apollo and Lessons for the Future" presentation to the NASA OSEWG Workshop on Robots Supporting Human Science and Exploration, Houston, TX, August 5, 2009

Current Status Based on Distance



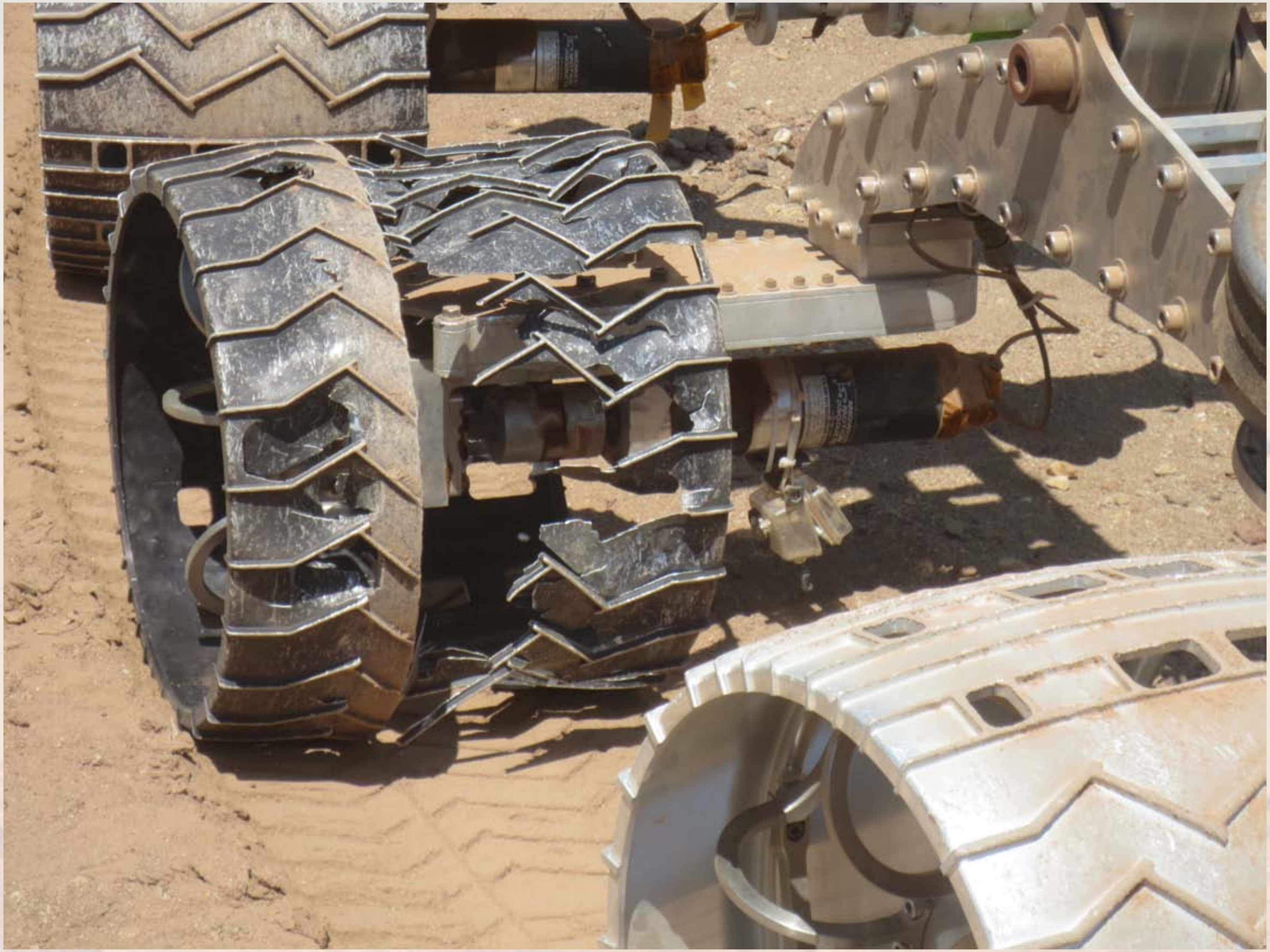
Mars Science Laboratory (and MER)



MSL Mission Overview

Video shown in class available on web site

MSL Wheel Problems

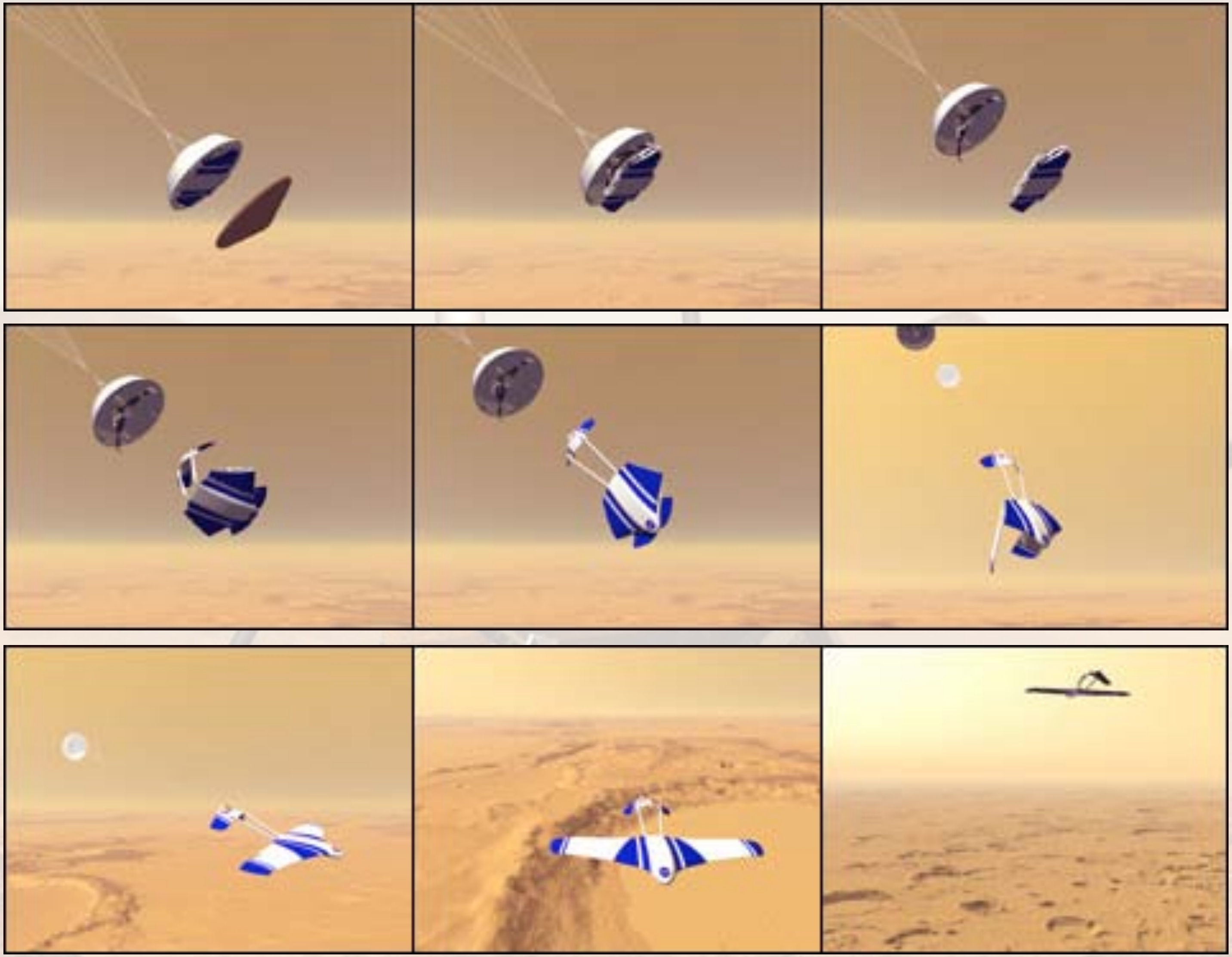


Mars Aircraft

- Deployed during EDL phase
- Glider or powered

ARES - NASA LaRC Proposal

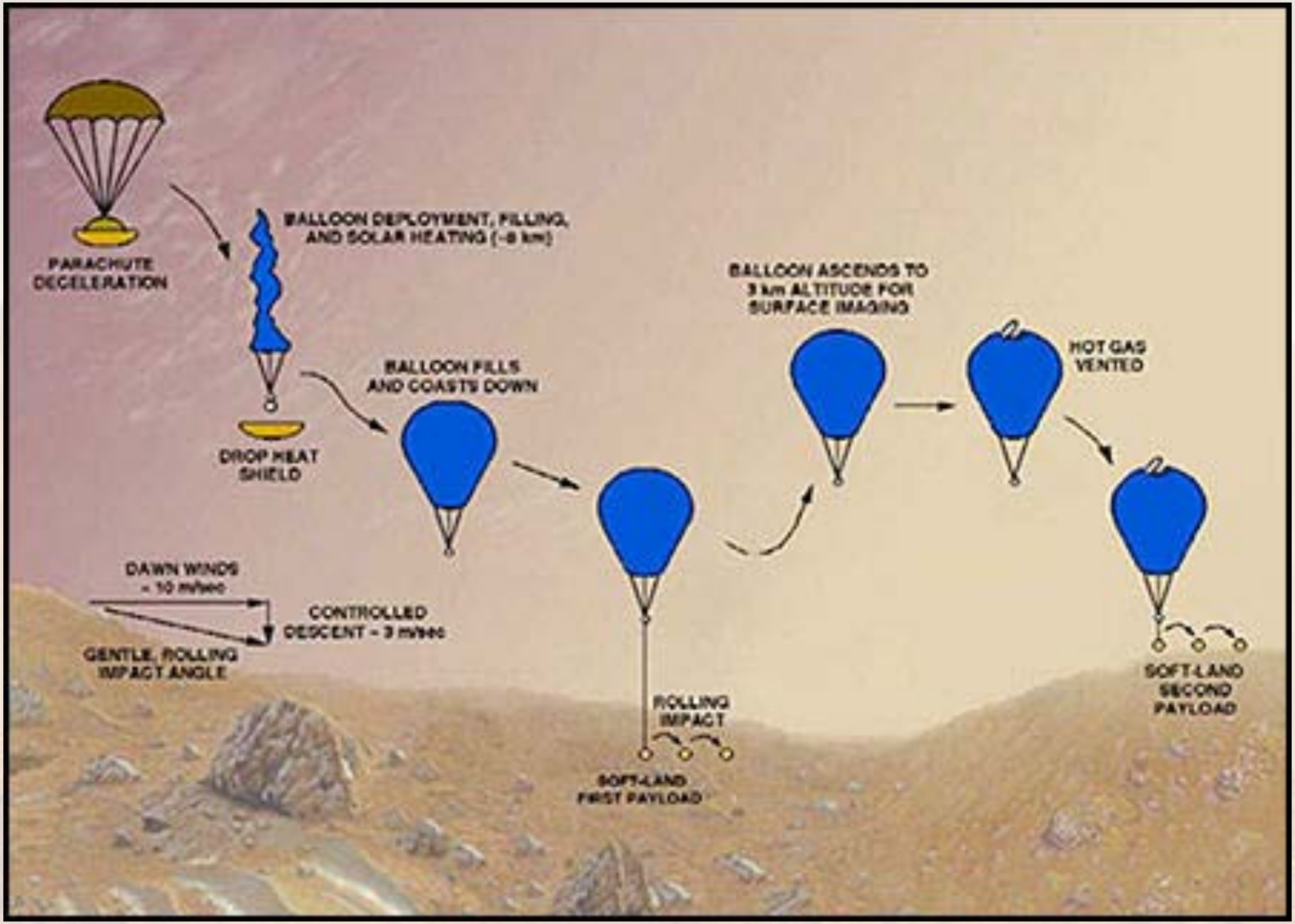
ARES Deployment



ARES Half-Scale Dropped from 100Kft

Video shown in class available on web site

Mars Balloons



Huygens Probe

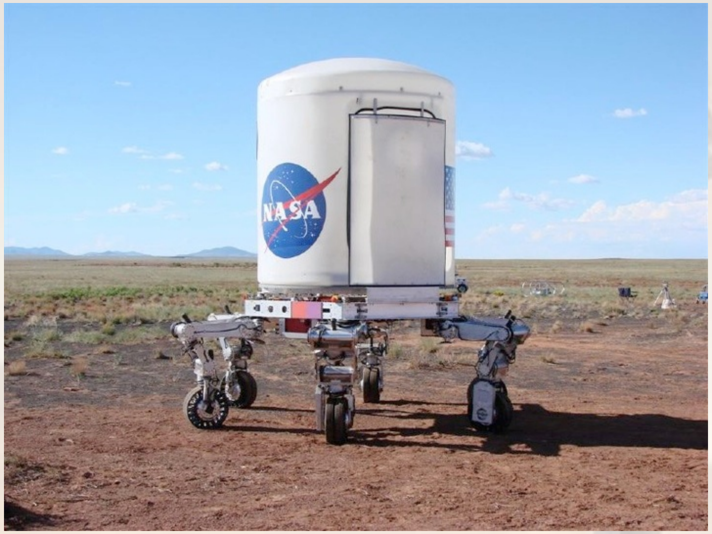
- Titan entry January 2005
- Descent imaging used to survey surface at different scales
- Wind motion provided horizontal traverse of surface

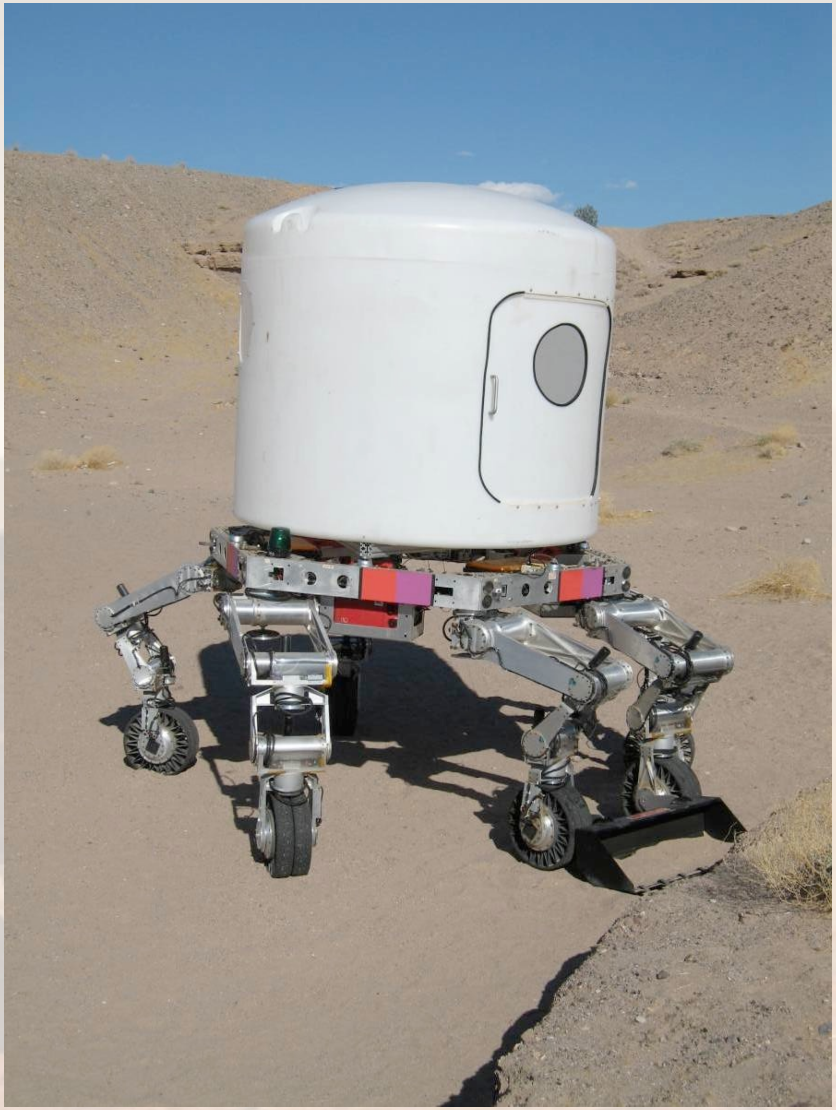
Field Trials for New Mobility Technologies

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

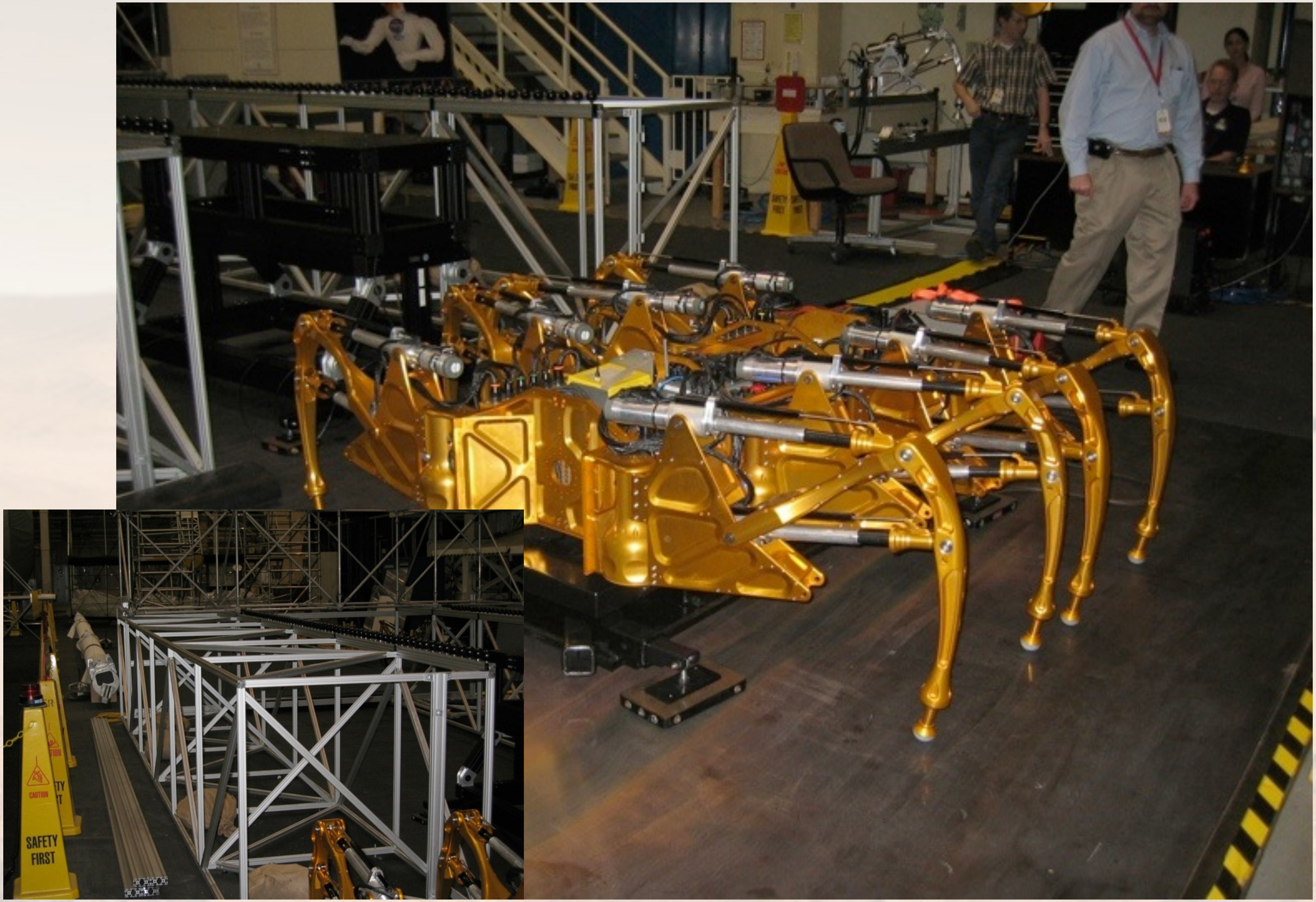
Chariot B Climbs a Boulder Field

Video shown in class available on web site

Lunar Electric Rover

Walking Robots

Scorpion King (JSC)



Serpentine Mobility

Video shown in class available on web site

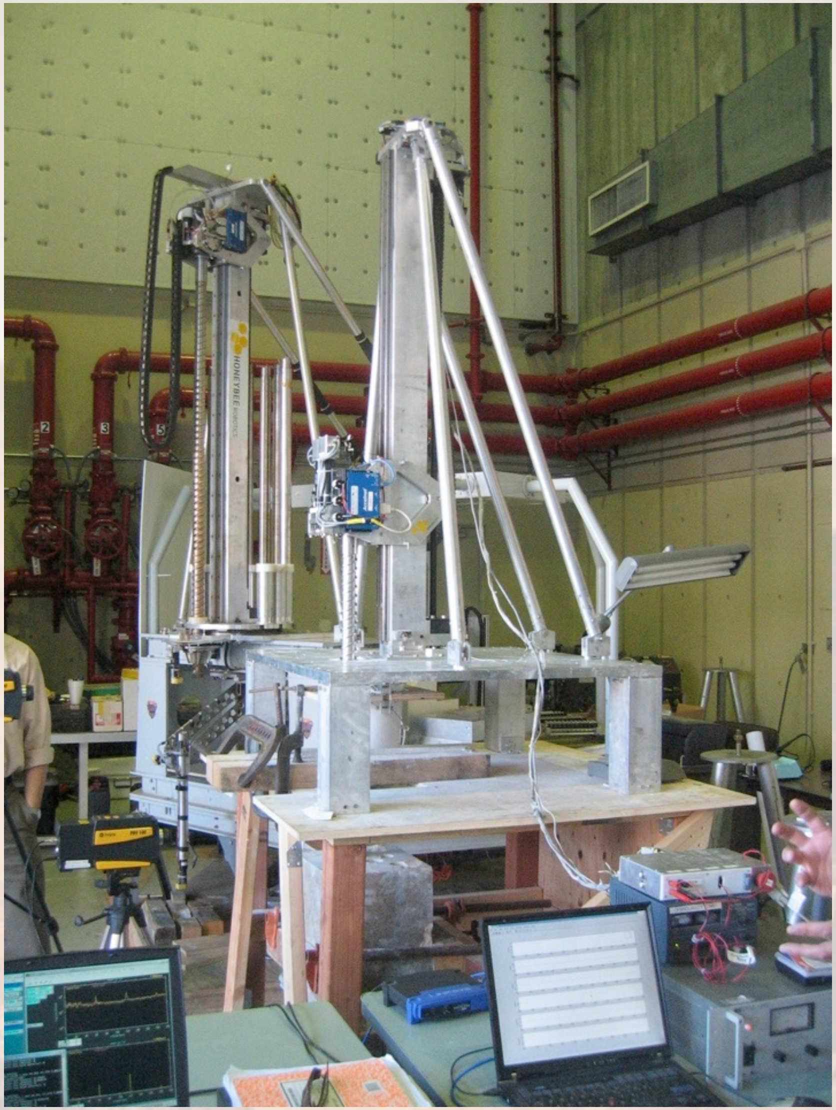
Serpentine Climbing and Grasping

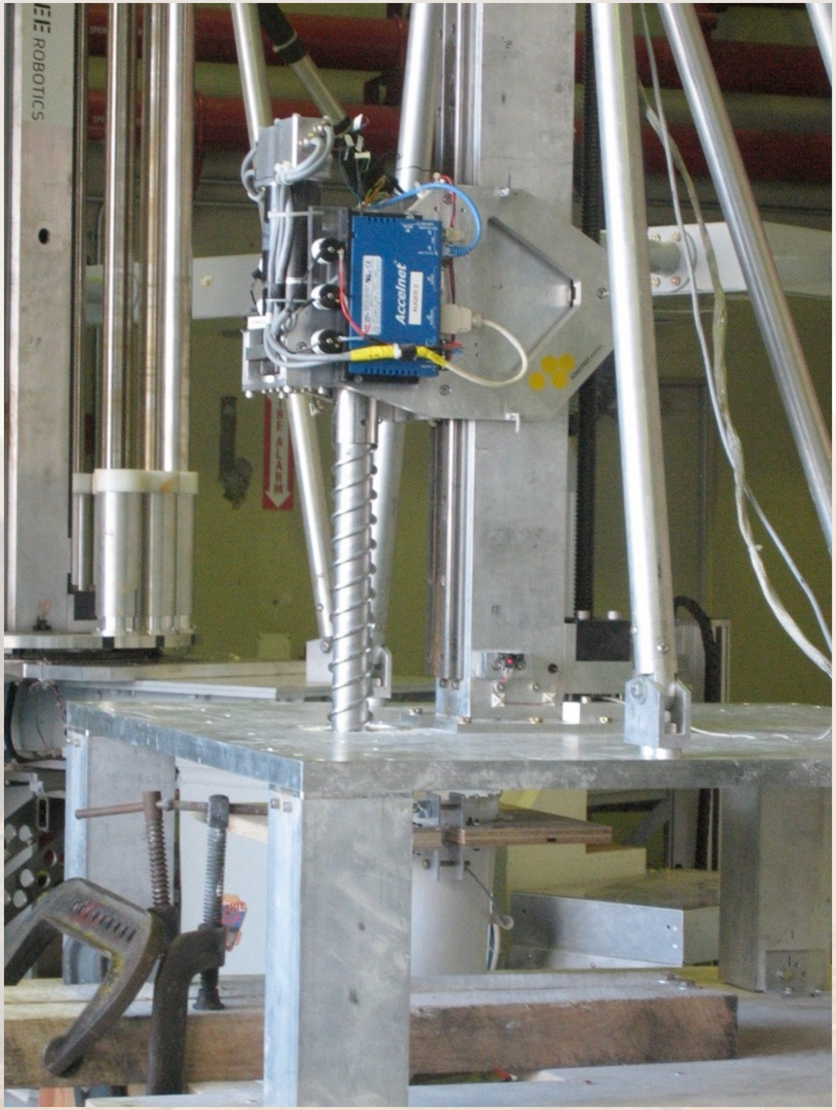
Video shown in class available on web site

Tetwalker (GSFC)

Video shown in class available on web site

Sub (Solid) Surface Access





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