On the Design of the Axel and DuAxel Rovers for Extreme Terrain Exploration

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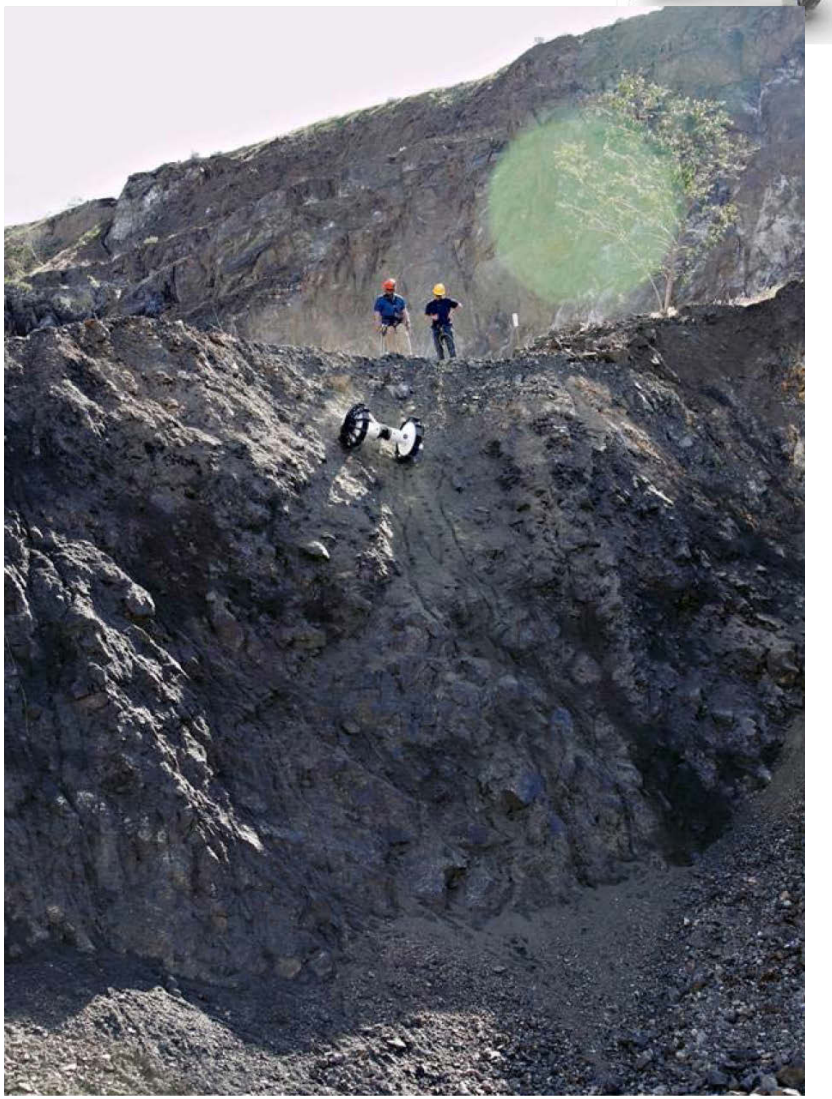
Outline

- Steep terrains of interest
- Axel & DuAxel Rovers: A novel approach to steep terrain access
- Design features and advantages
- Field Testing



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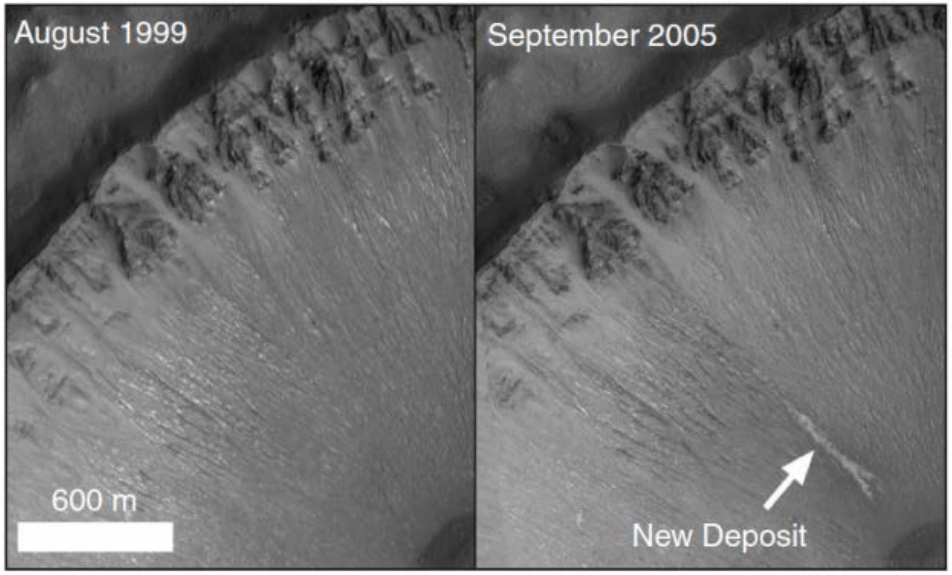
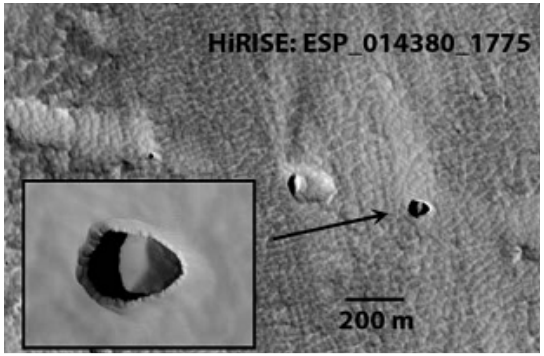
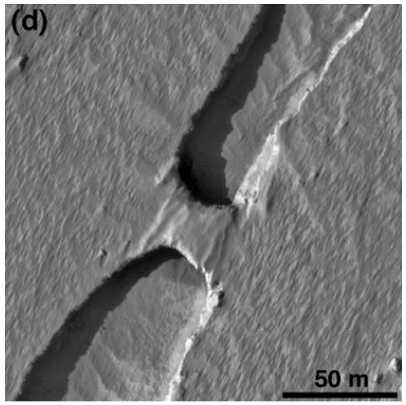
Extreme Areas of Extreme Interest

- Stratigraphic layers in polar caps, impact craters, and fluvial channels
- Lunar cold traps with temperatures of 40 K – 70 K may contain water ice in South polar Aiken basin region
- Lava Tubes & Pit craters under consideration for future human habitation

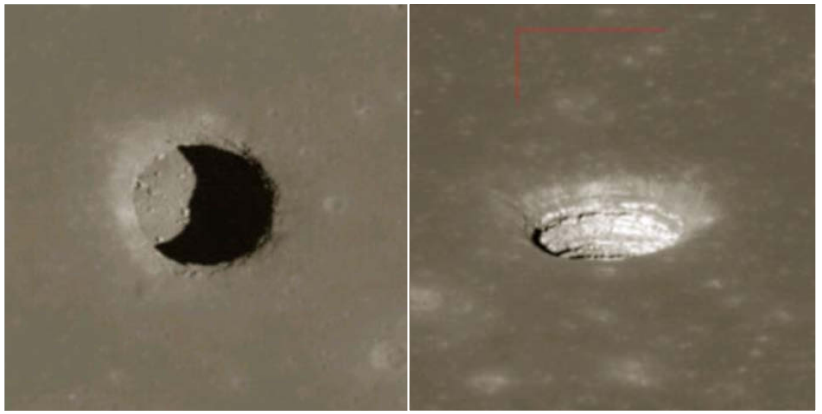




HiRISE observation of potential skylights

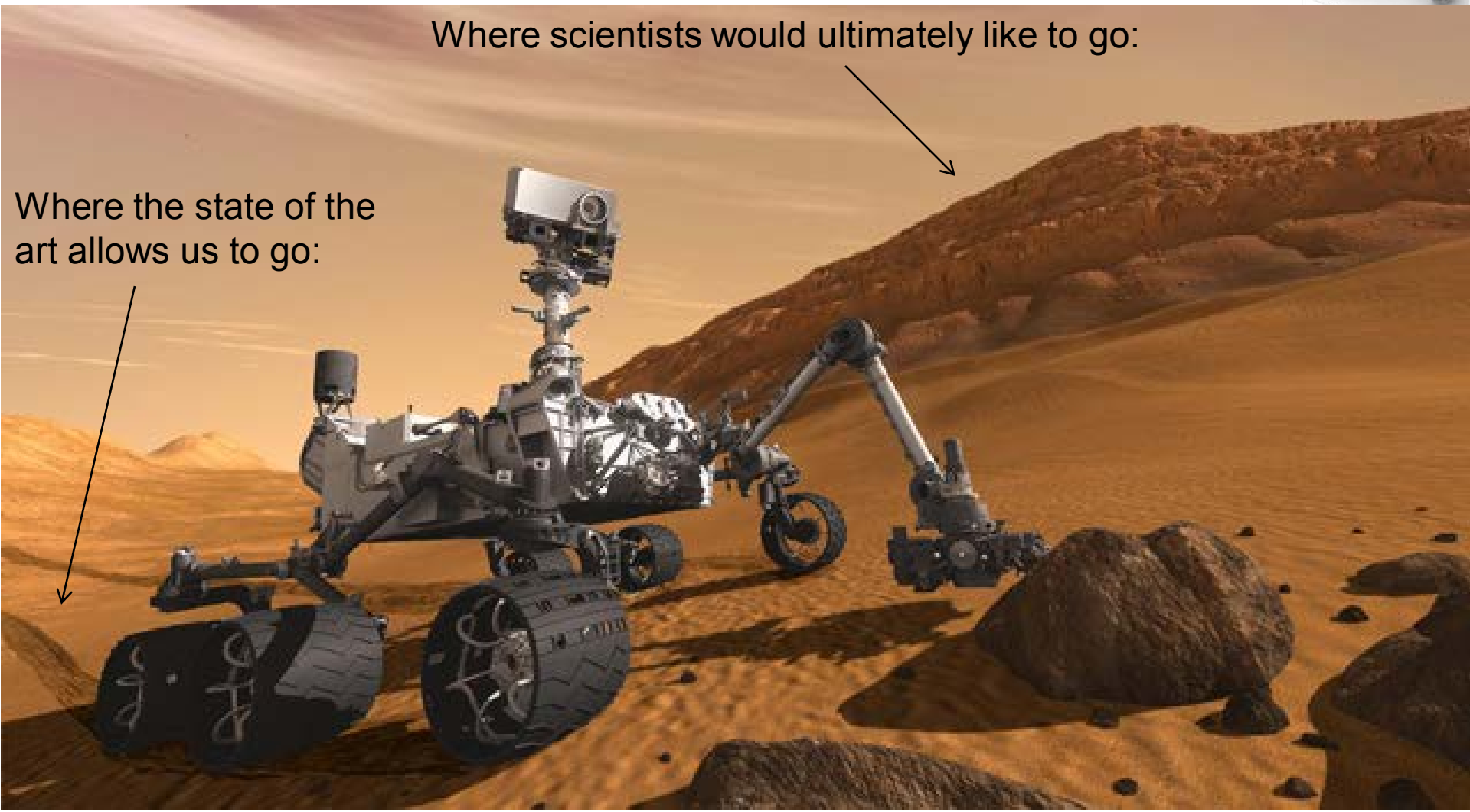


HiRISE image of a lava flow winding through the Tartarus Colles.



Pit crater in Mare Tranquillitatis (Moon) imaged by LRO.

Science Dreams vs. Engineering Realties



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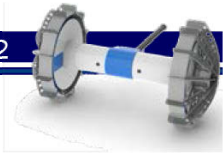
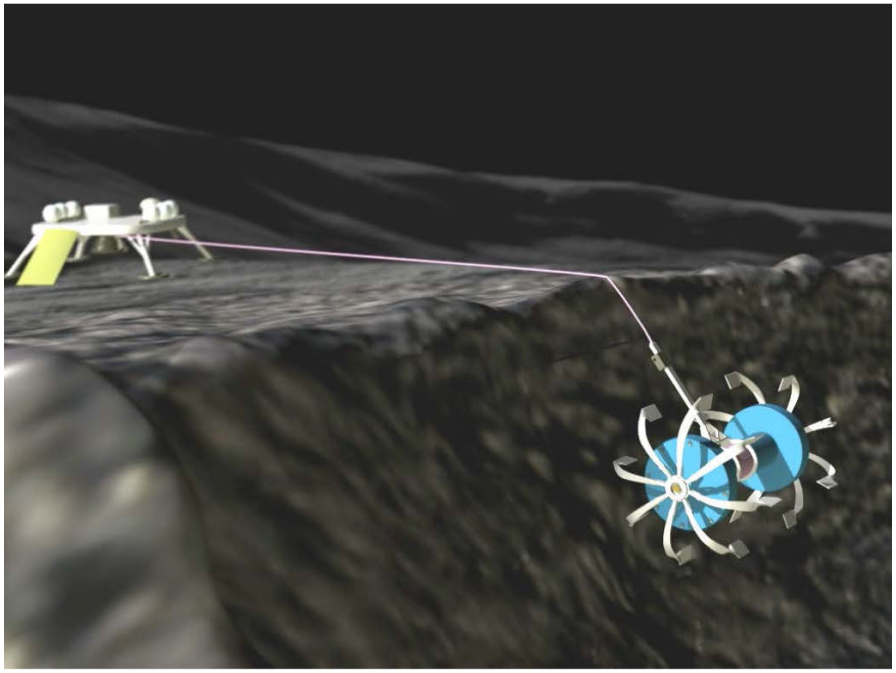
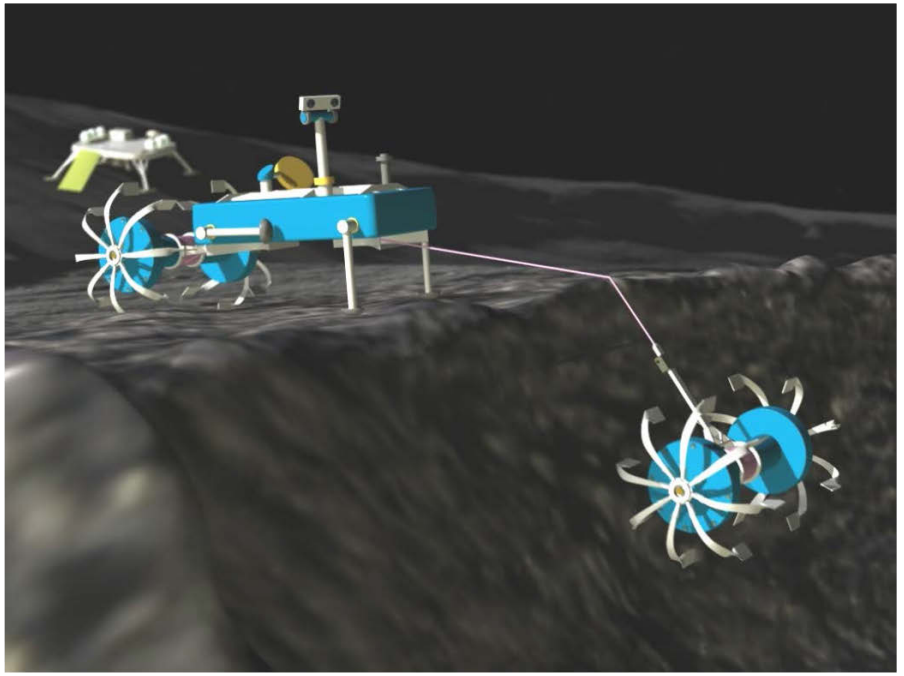
Tethered Systems Concepts







Axel

Fixed mother (lander)
mobile daughter (Axel)

Pros: simple deployment, minimal mass mobilized

Cons: Requires precision landing

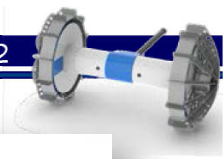
DuAxel

Mobile mother (untethered DuAxel)
Mobile daughter (two Axels)

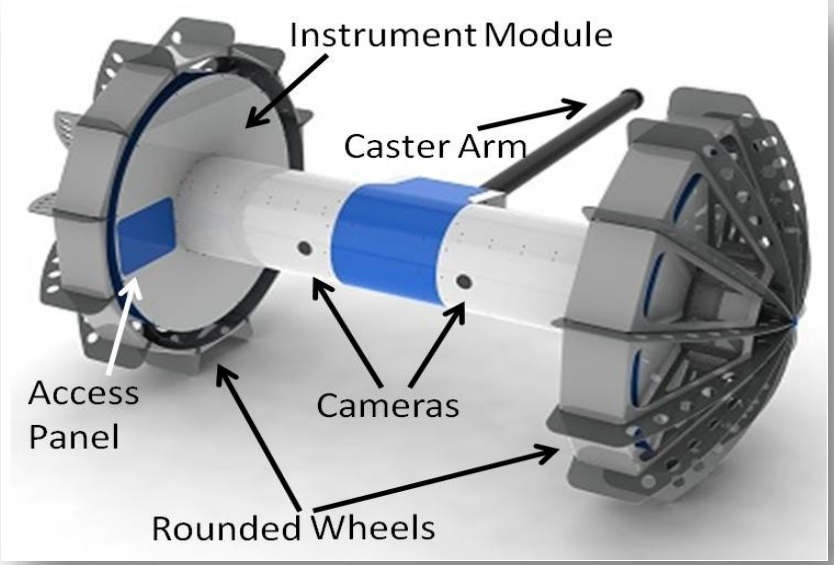
Pros: redundant capabilities, does not require precision landing

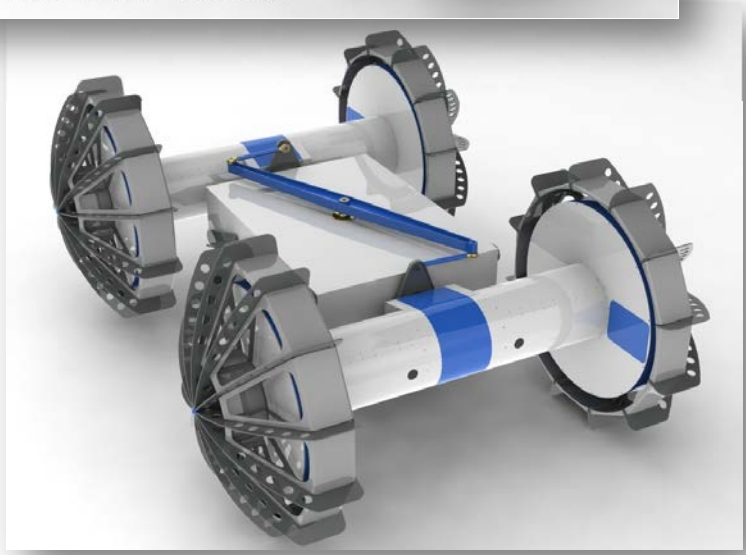
Cons: additional elements mobilized

Axel & DuAxel Concepts



- Each Axel rover has four primary degrees of freedom (two wheels, tether spool, & caster arm)
- Power & communication over tether with additional on-board energy storage
- Robust: can operate when flipped
- Simple: only a few rotatory joints to achieve mobility, camera pointing, and instrument placement
- Multiple science instruments tucked inside of wheels & deployed to the ground
- Instruments & body mounted stereo cameras can be pointed without descending/ascending slope
- Two Axels can dock to a central module to form a DuAxel rover which allows for long range mobility without consuming tether resource





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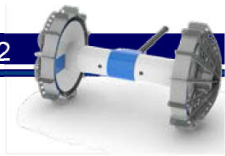
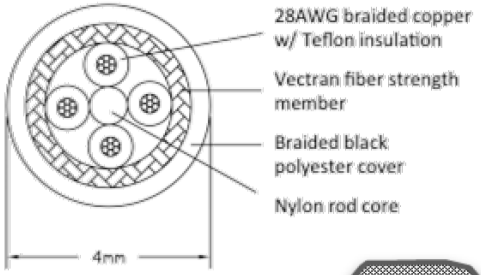
Axel System Overview





- Commutation between spool and body
- Commutation between arm and body

camera

planetary Gear
motor
brake
encoder

Instruments
Instruments
Instruments
Instruments
Fan
Avionics
Avionics
Fan
Batteries
Batteries

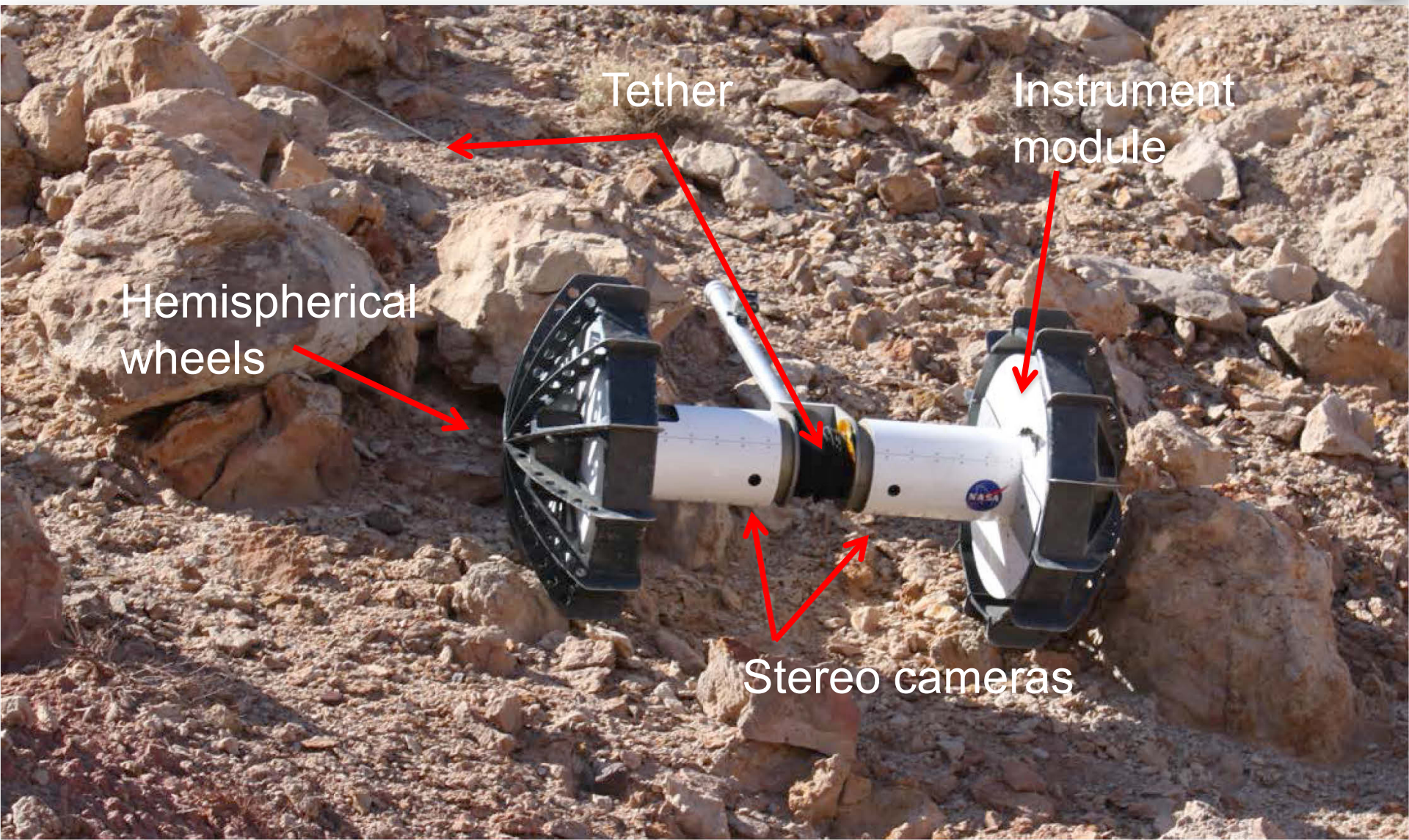
0.84m

- Rotating arm & drum in *same direction*, body rotates without reeling tether
- Rotating in *opposite directions*, applies twice the power for reeling the tether

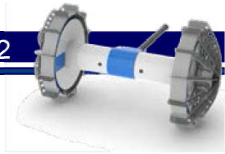
Instruments deploy out and down towards the ground

1.52m

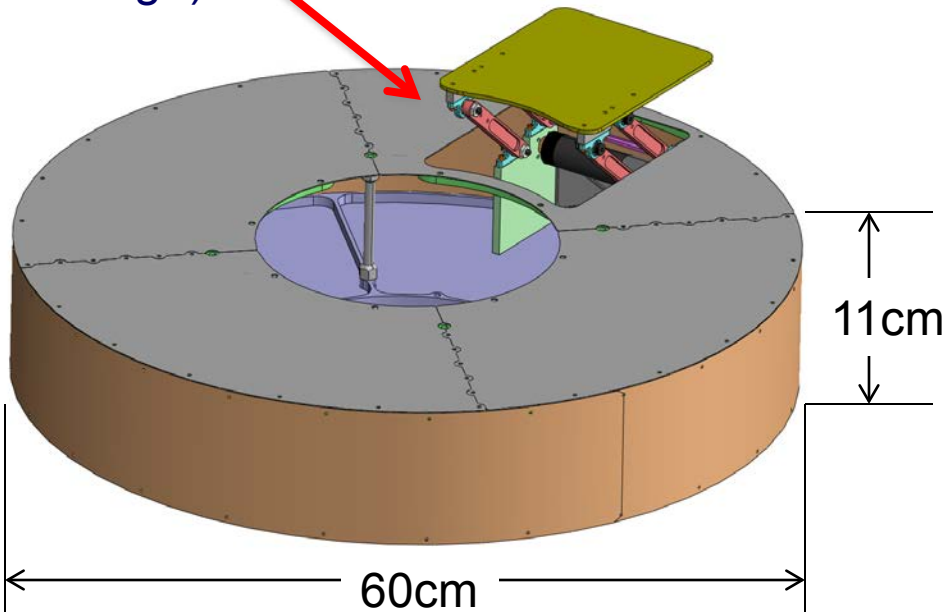
Axel Prototype Design Features



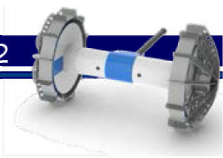
Instrument Module



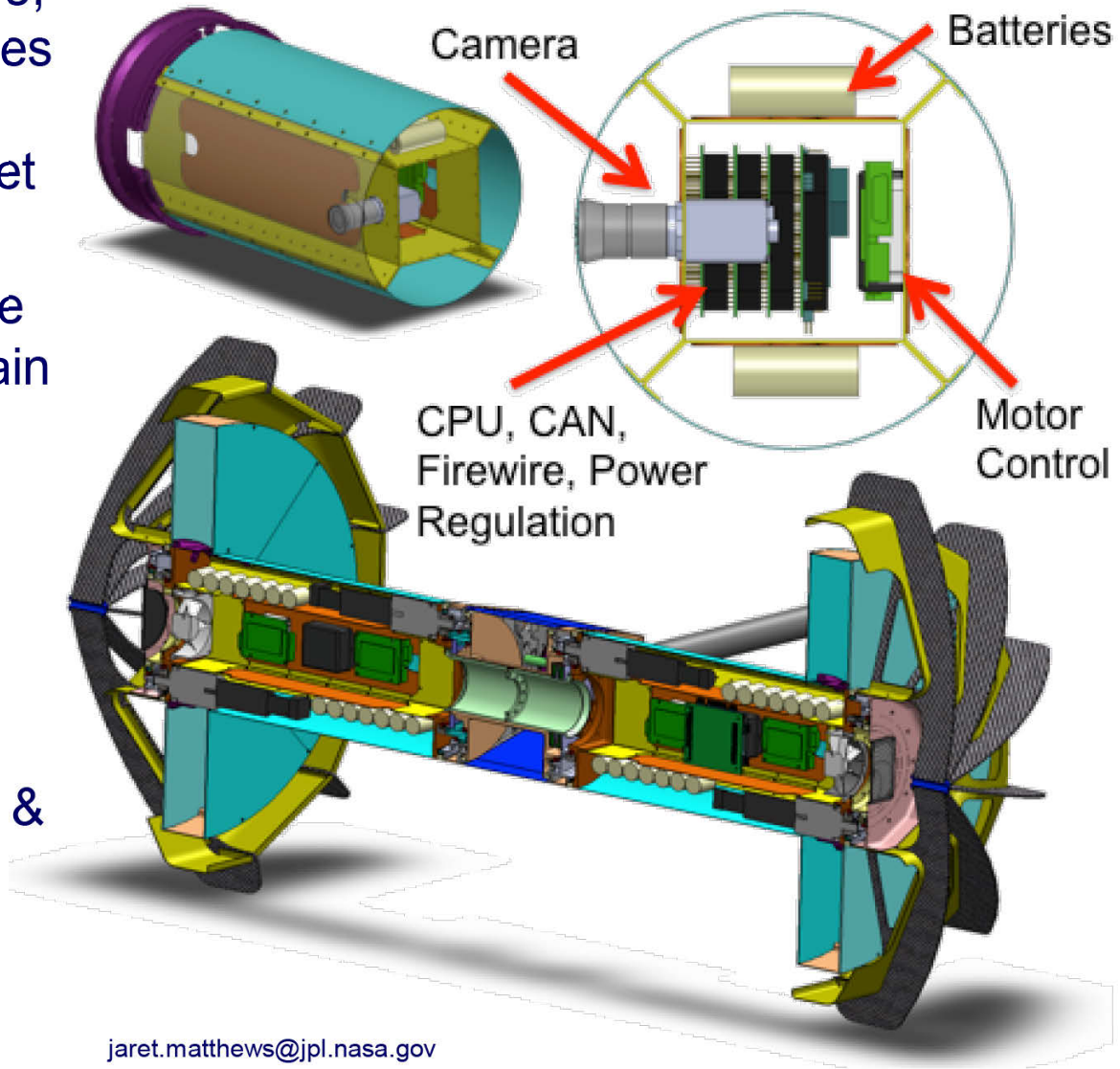
- Each wheel can accommodate an instrument module
- Instruments are mounted to the underside of a plate and are protected from the environment when the deployment mechanism retracted
- Each quadrant of the module can support one deployment mechanism (simple four bar linkage)



Mechanical Design Elements



- Wheels, body structure, and instrument modules comprised mostly of riveted aluminum sheet
- Avionics packaged inside of a square tube that comprises the main chassis structure and are easily accessed
- Instruments modules are independent of mobility system structure and can be removed for servicing & calibration



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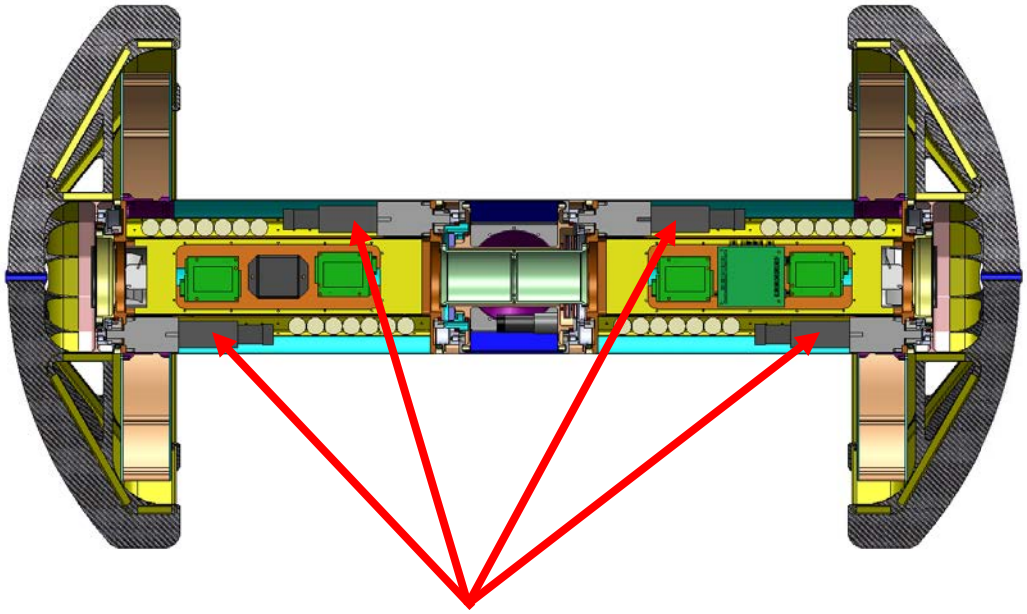
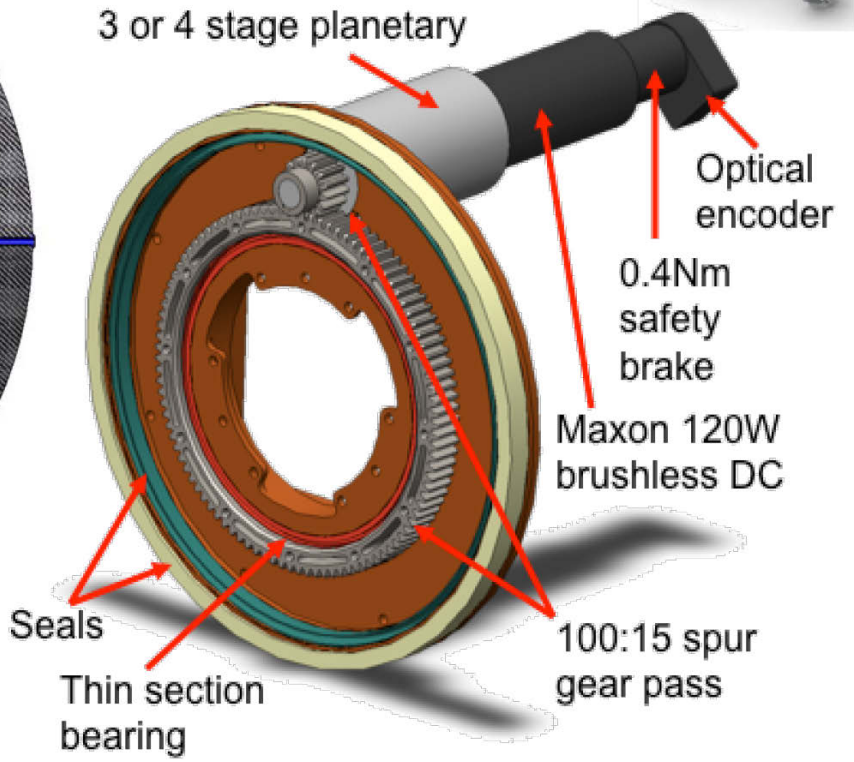
Common Drive Modules

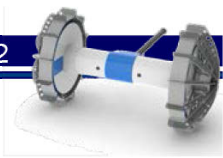


~Same output power

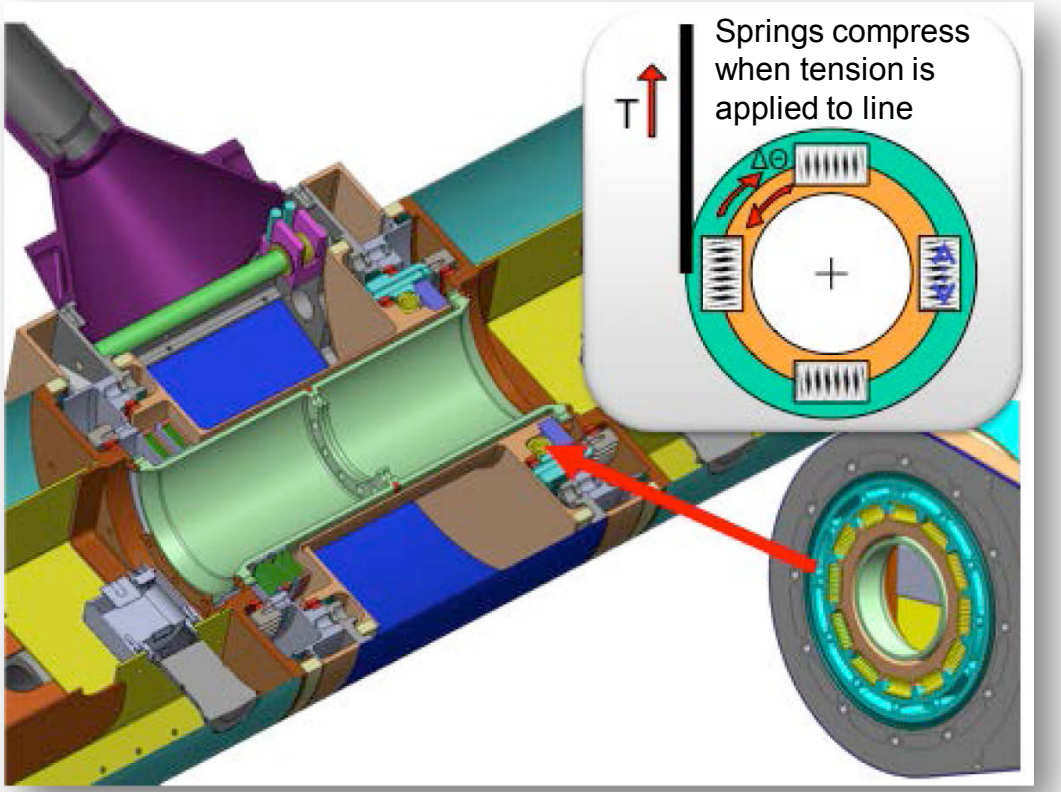


- Wheel and Tether drive actuators have similar mechanical output requirements (~30W to allow the 50kg Axel to drive/ascend at 10 cm/s)
- Tether requires more speed but less torque
- Wheel requires less speed but more torque
- Common design reduces unique part count and complexity

Tether Tension Sensing



- Based on automotive clutch plate concept
- Knowing spring constant, can encode relative angle between plates to determine line tension
- Absorbs some shock after sudden drop



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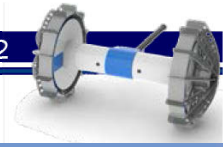
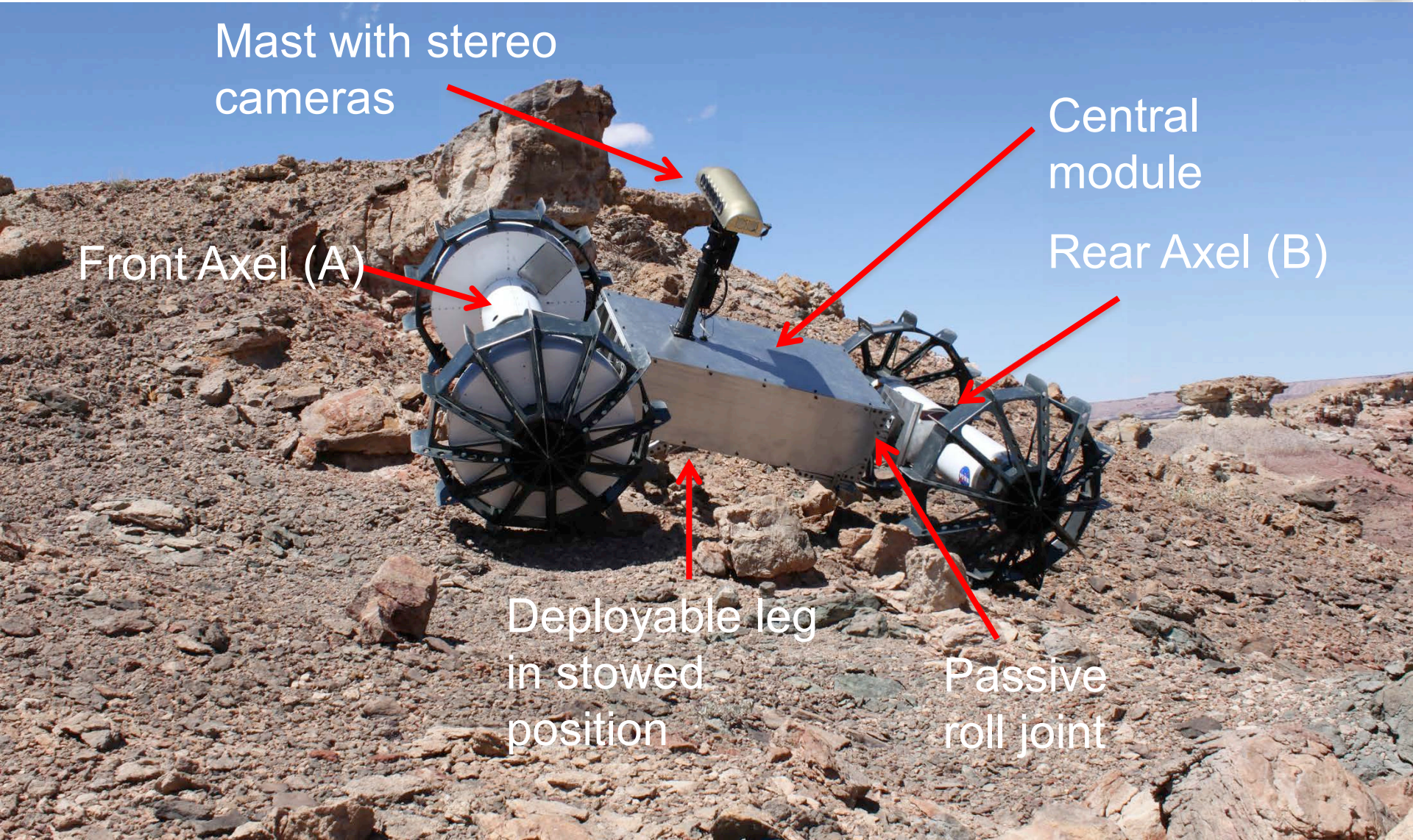
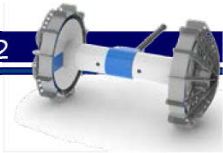
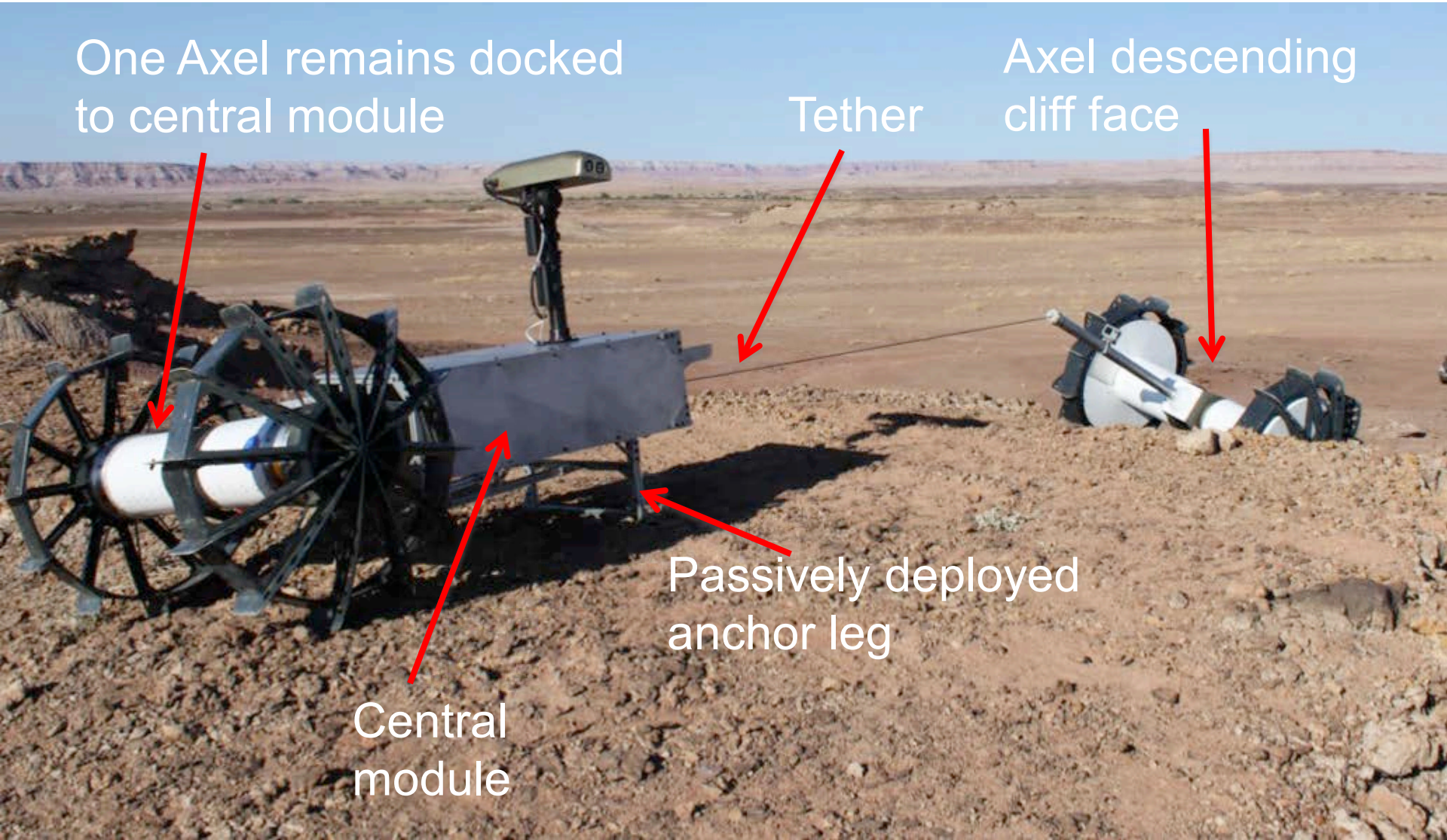
DuAxel System



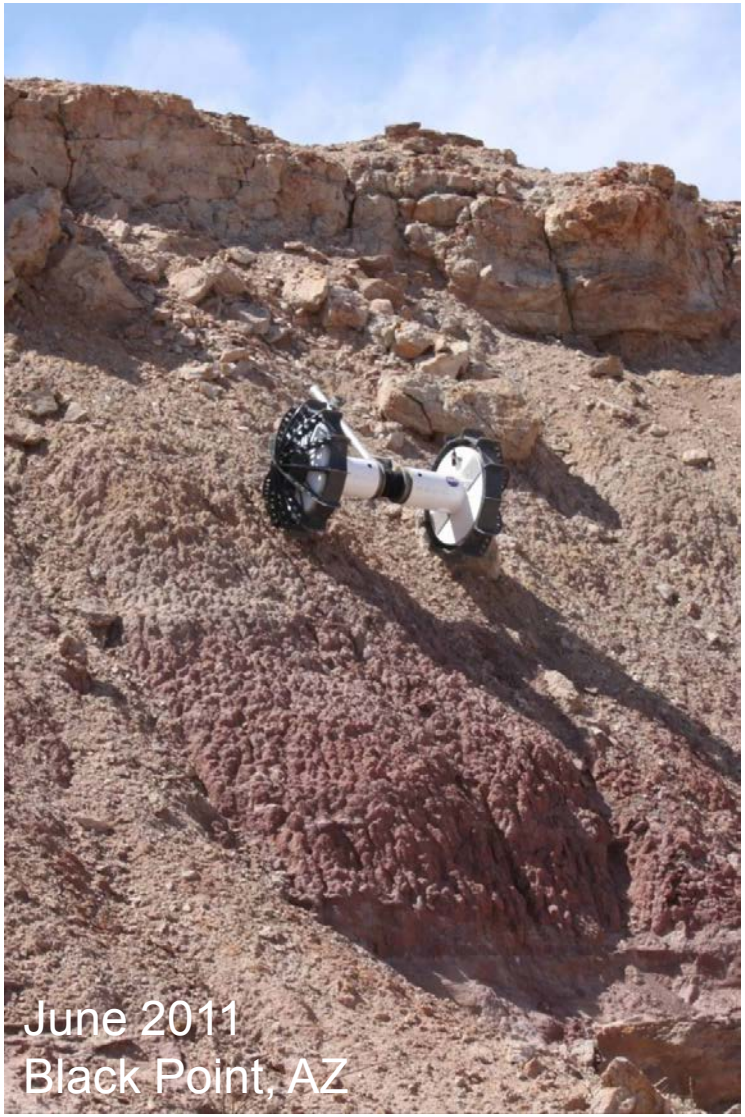


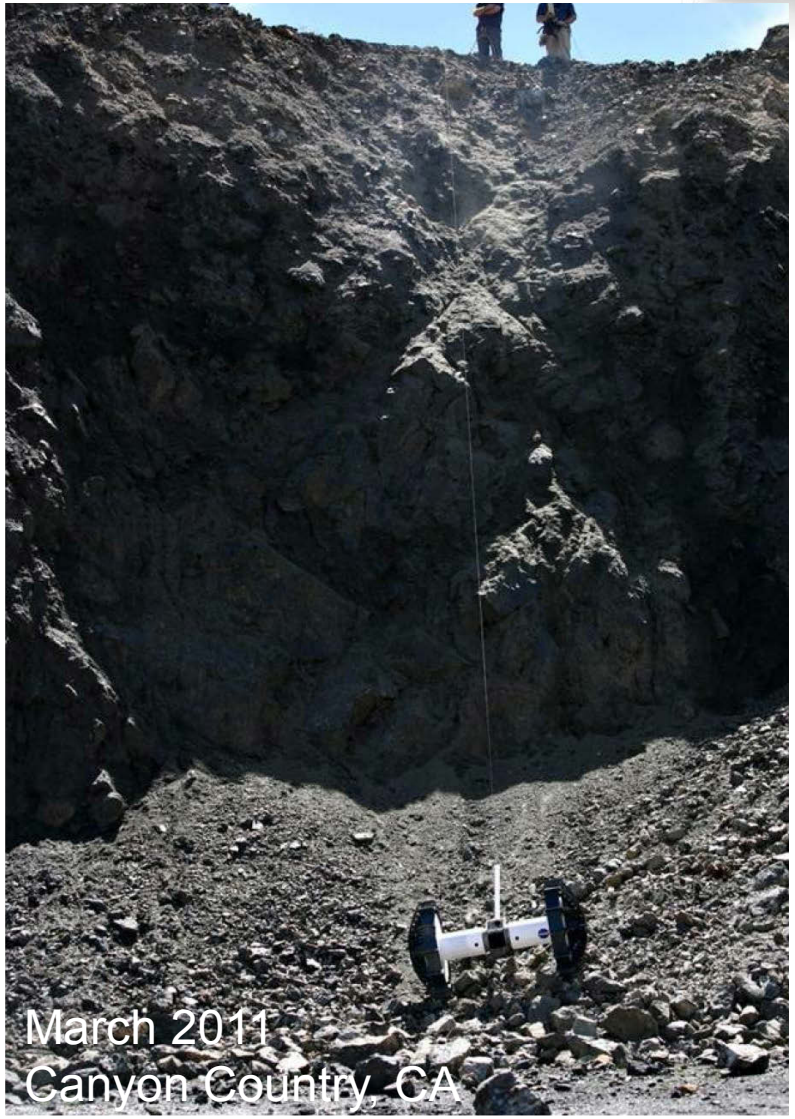
Axel Deployment





Traversing Nearly Vertical Terrain





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Questions?

- Thanks to:
  - Axel Principal Investigator: Issa Nesnas
  - Prof. Joel Burdick and his Caltech team
  - JPL Research & Technology Development Program
  - Dr. Daniel McCleese
  - Dr. Jonas Zmuidzinas

- Resources:
  - I. A. Nesnas, J. Matthews,et al, “Axel and DuAxel Rovers for the Sustainable Exploration of Extreme Terrains,” accepted for the *Journal of Field Robotics,* 2012.
  - http://www-robotics.jpl.nasa.gov/systems/index.cfm
  - http://robotics.caltech.edu/~pablo/axel/home.html

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