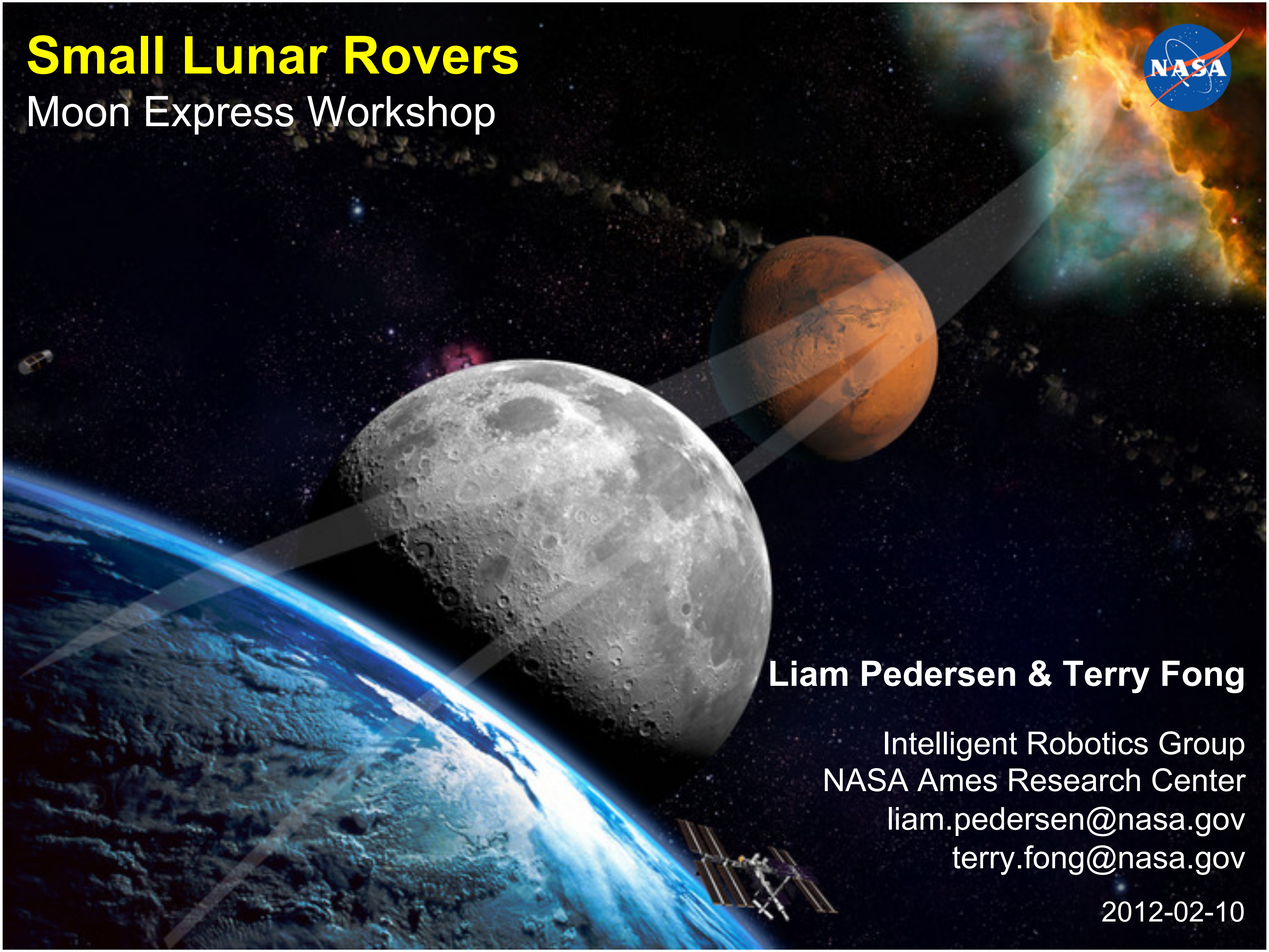

# Small Lunar Rovers

## Moon Express Workshop

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2012-02-10

# Lunar Rovers ≠ Terrestrial Rovers

## Radiation tolerant electronics

- TID (total ionizing dose) may be limited for short mission

## Thermal constraints

- Worse than orbit due to regolith and shading

## Power constraints

- Solar only

## Communications constraints

- Bandwidth, latency, availability, antenna size and pointing

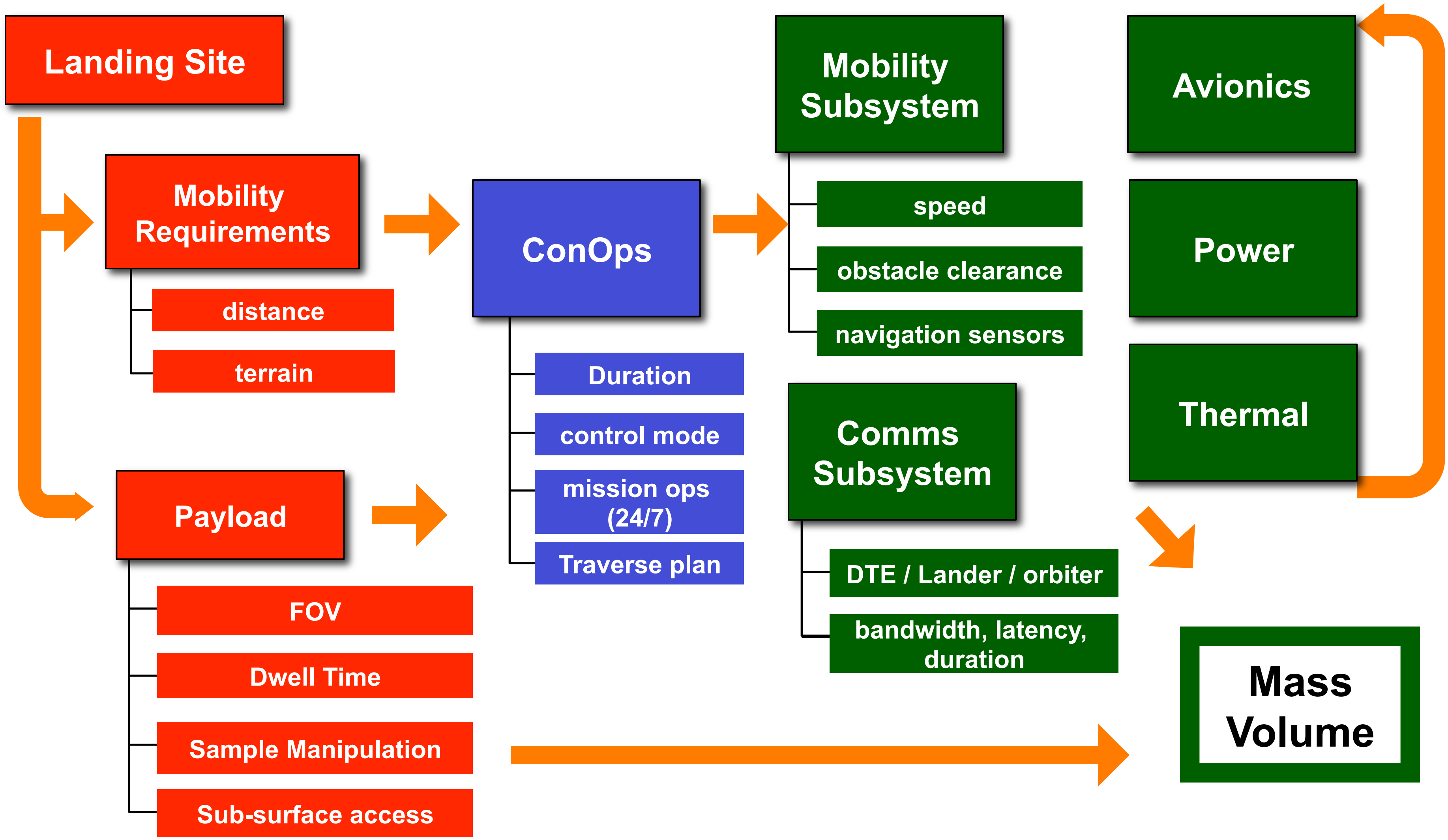
## Mass constraints

- 8-16% payload mass fraction for planetary rovers (Sojourner, MER)
- Ex. 1 kg payload implies a 10 kg rover (to first order)

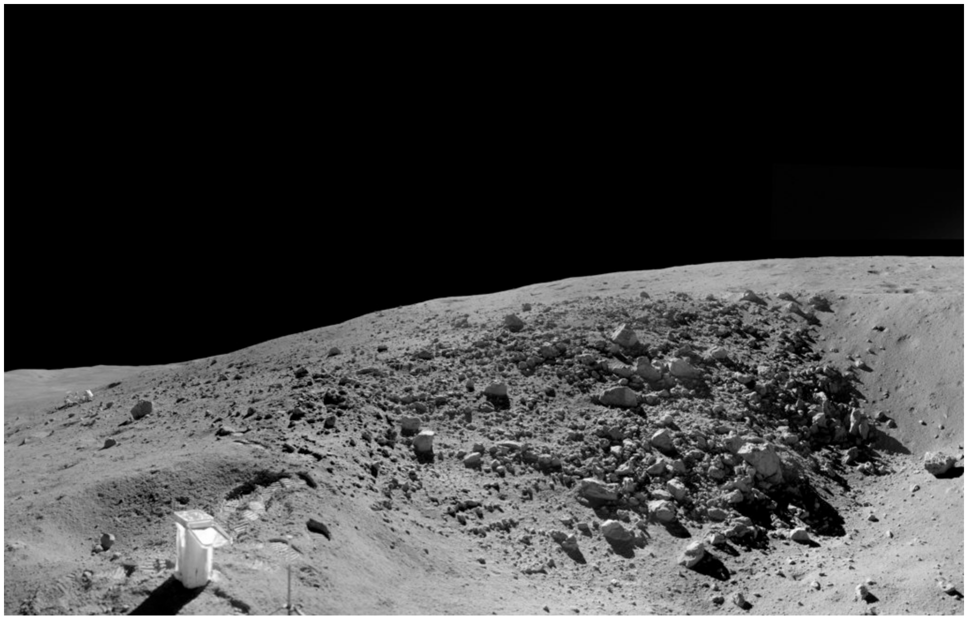
## Ops constraints

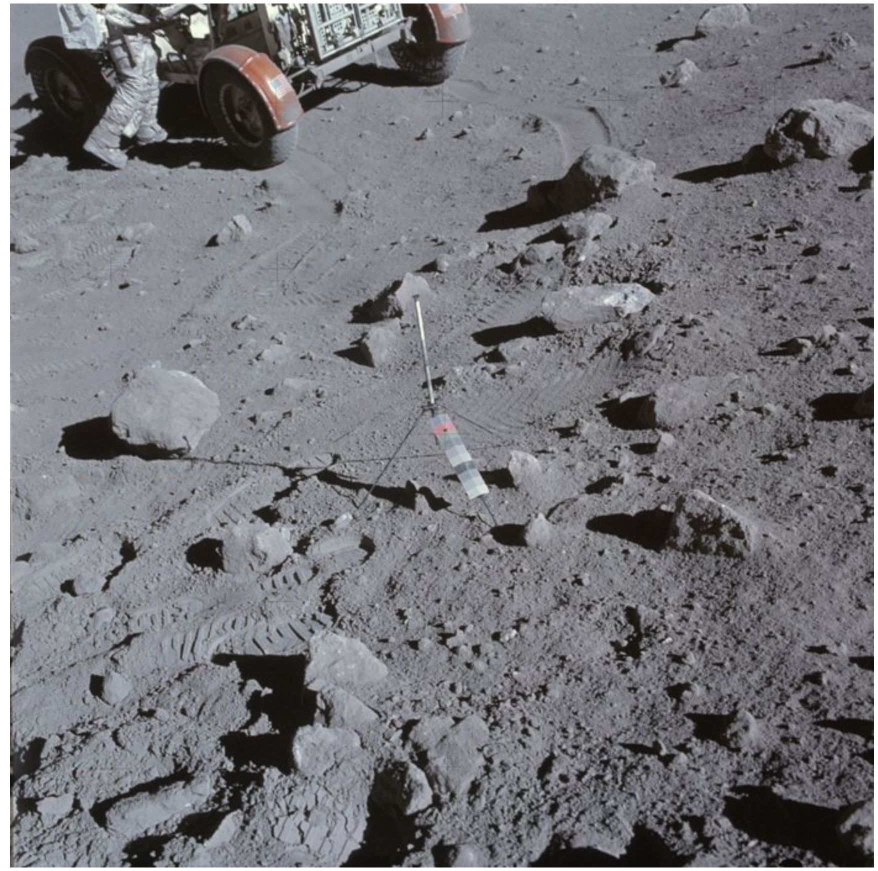
- Lander egress
- Potentially high-tempo operations (if not able to survive lunar night)

# Rover Design Space

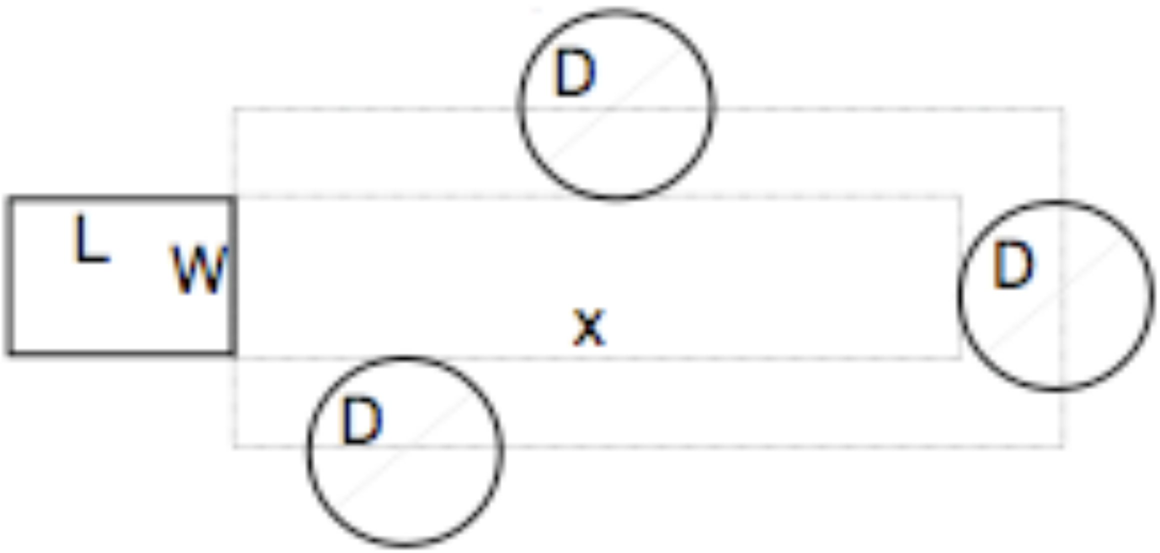


# Mobility Hazards





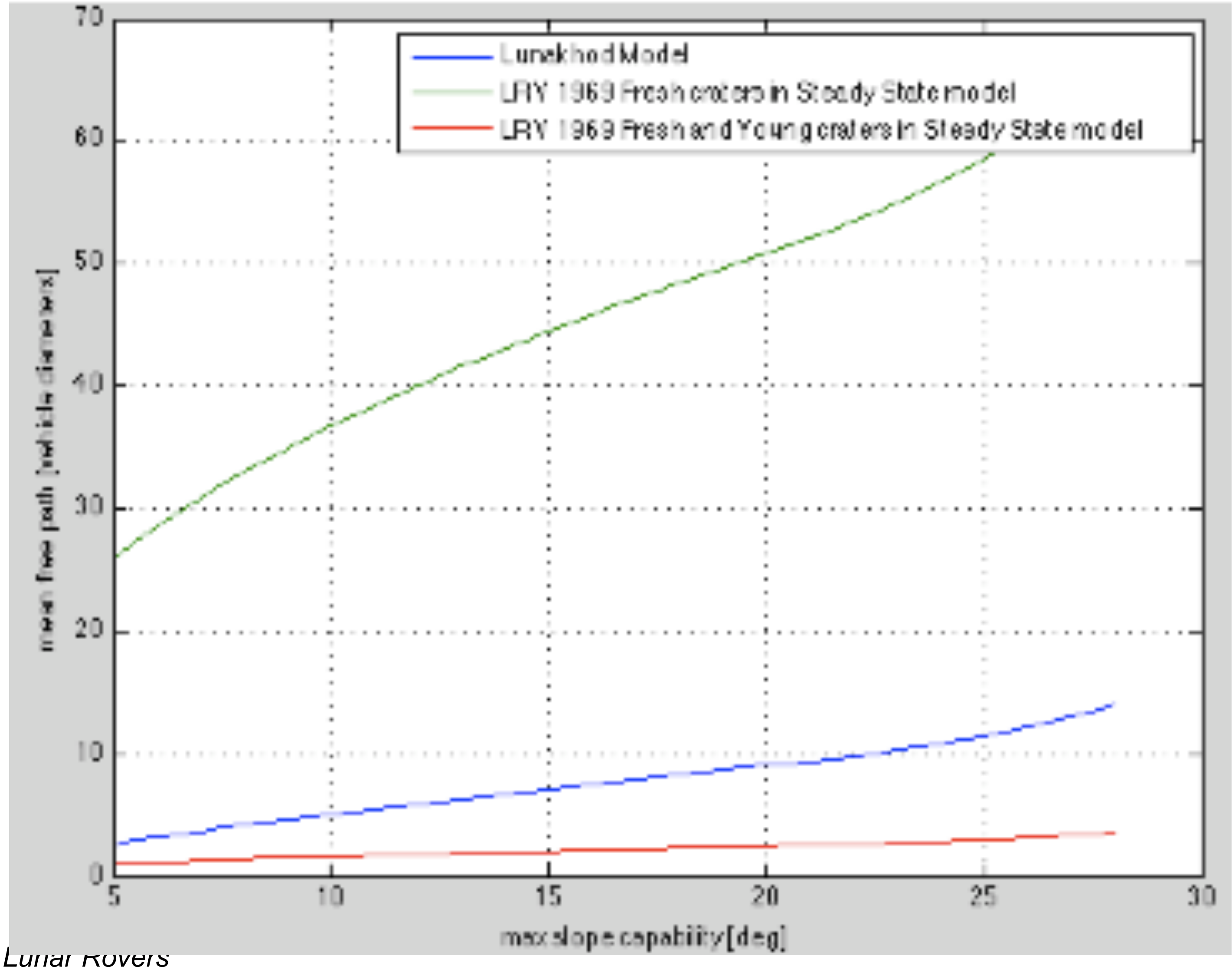
# Mean Free Path (x) Computation




$$\int_{D_0}^{\infty} (x + D/2)(W + D)\rho(D)\,dD = 1$$

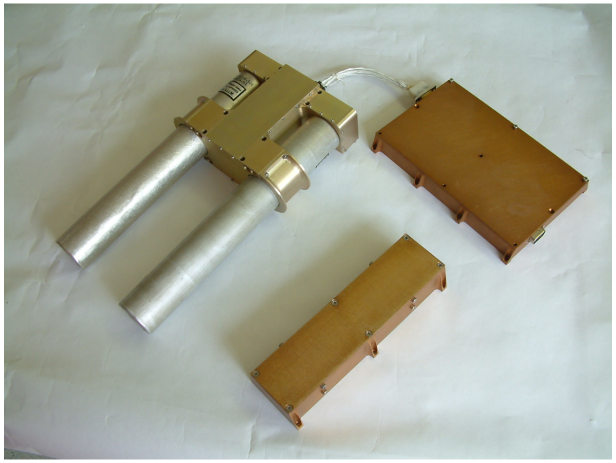
# Mean Free Path

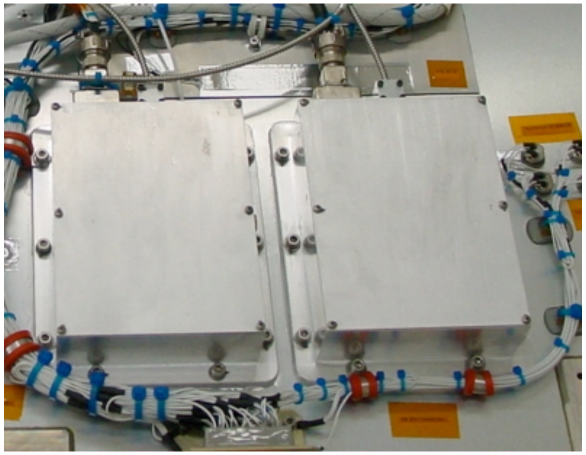
Rover body lengths before contacting a non-traversable crater



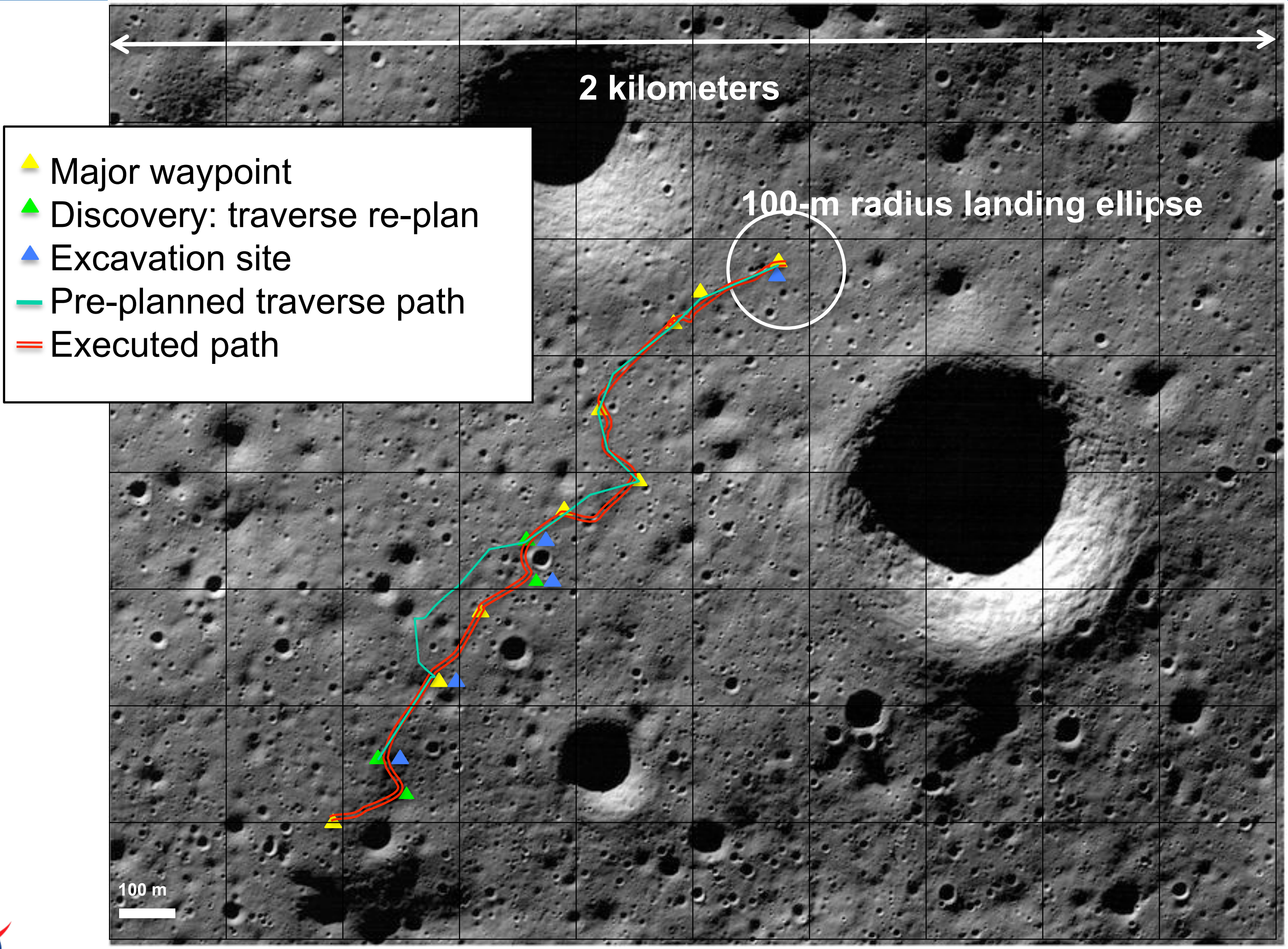
# Notional Payload for Prospecting (Polar Volatiles)

| Instrument | Principle Measurement | Mass (kg) | Power (W) | Dimensions (cm) | Data Rate (bytes/sec) |
|---|---|---|---|---|---|
| Neutron Spectrometer | Hydrogen at depth (to 1 wt% water @ 100 cm) | <1.5* | 2 | 18 x 12 x 6 | 89 |
| NIR Spectrometer | Volatiles & ice state (1.3 to 2.9 μm) | 2 | 4 | 10 x 10 x 3 | 540 |
| Pneumatic Excavator | Subsurface access (5 to 20 cm depth) | 2 | <5 | *tbd* | <100 |





# Notional Traverse Plan for Prospecting



# ConOps: Driving

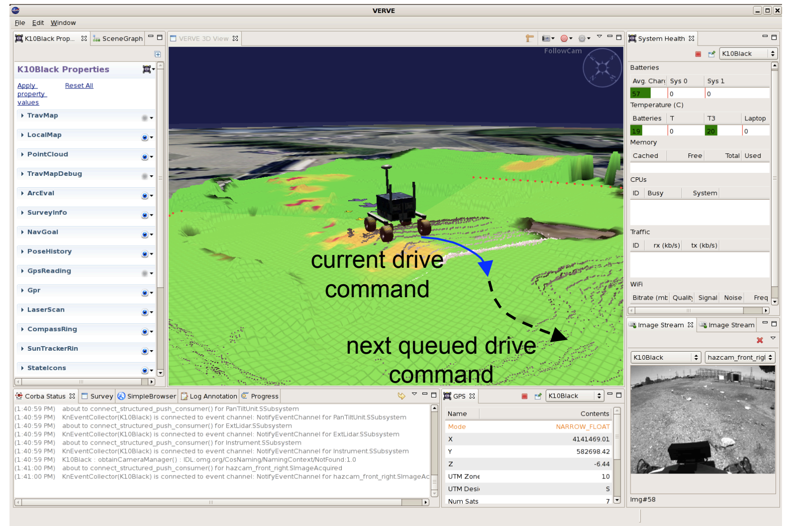
## Near Real-Time Tele-Operation

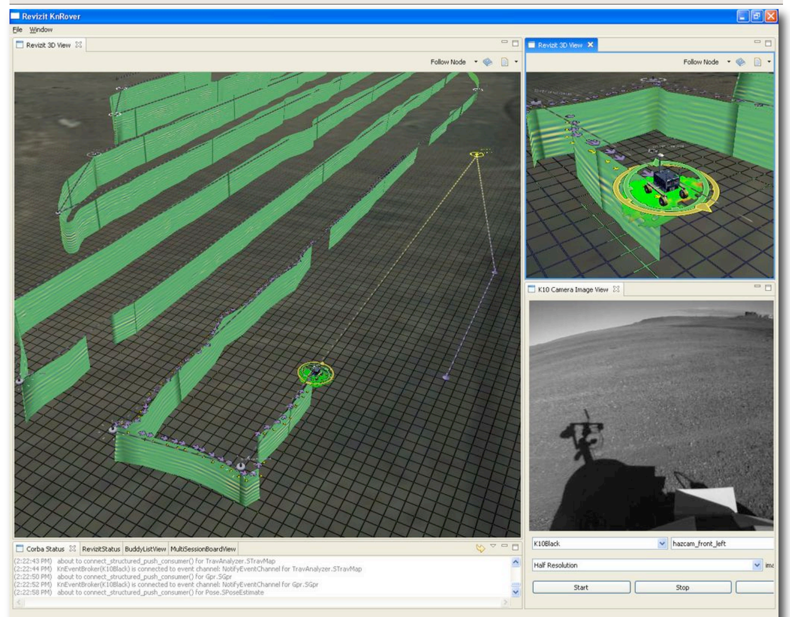
- Navigation data (images, 3D scans) acquired every 1m,
- MOC specifies next immediate drive commands based on prior navigation images (if sufficient coverage)
  - Mapping and drive command generation may be done automatically off-board
- Rover executes next drive command, pausing until all queued navigation images (and related navigation data) downloaded.

  If no drive commands available, rover stops and waits further instructions

## Autonomous Navigation

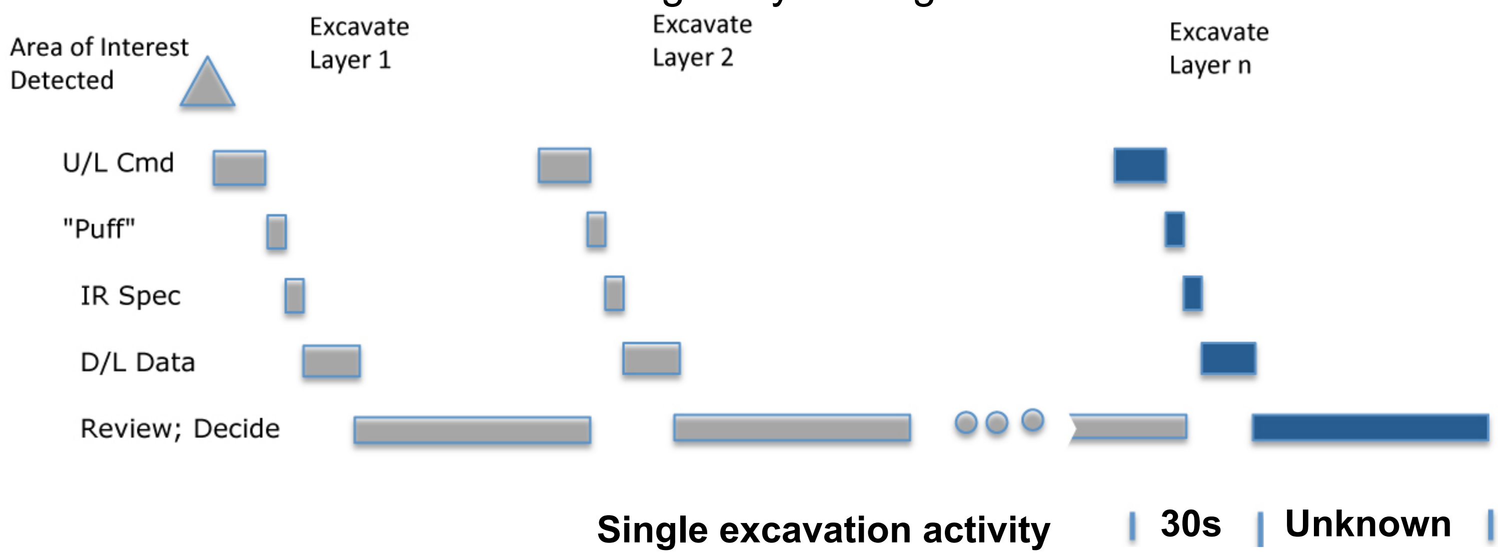
- Recover from loss of communications (e.g. drive back to last good comm location).
- Intentionally traverse no comm zone



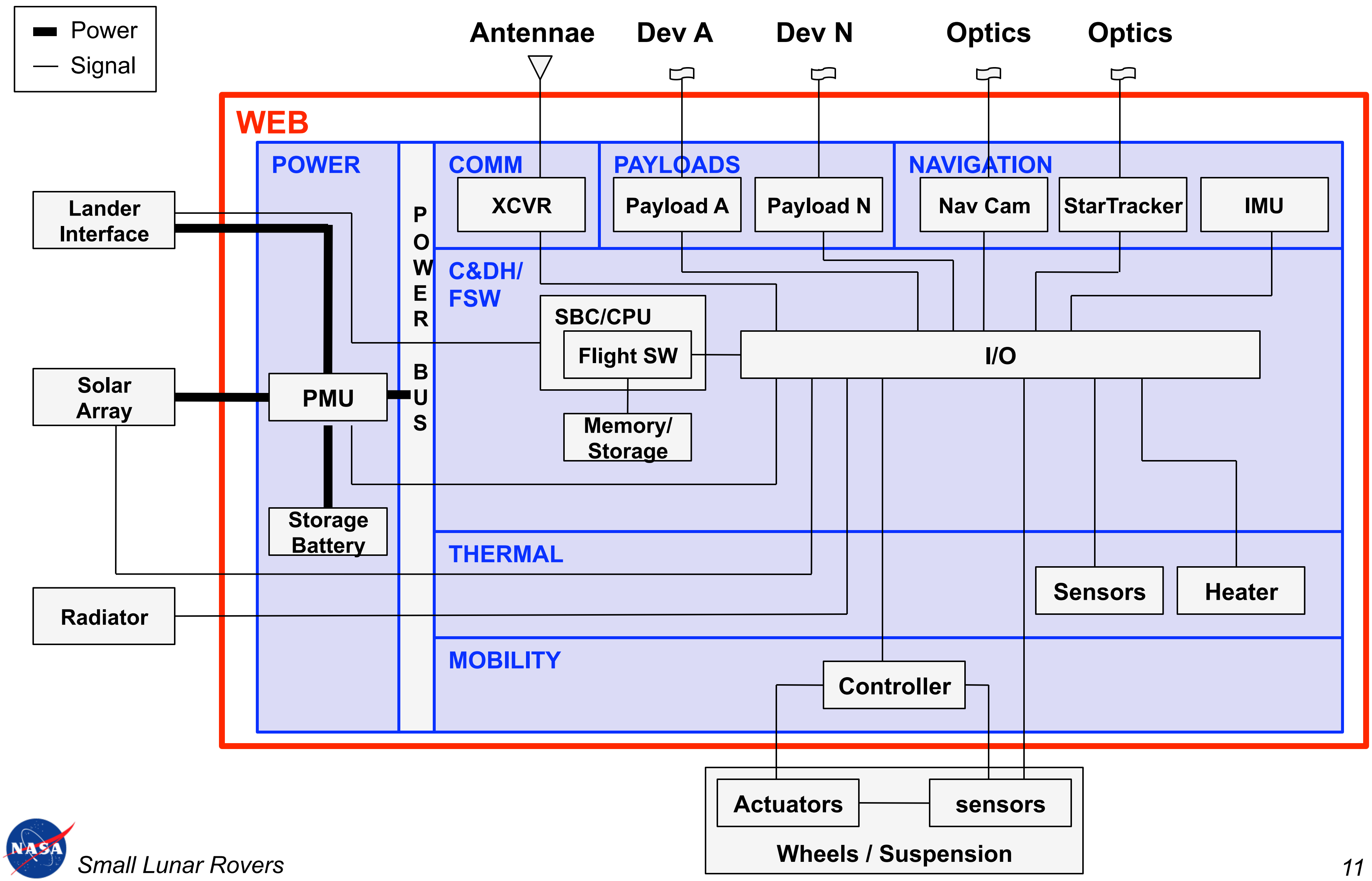



# ConOps: Excavation

- Command uplink, excavation, stereo image and NIR spec acquisition and downlink approx 30 sec.
- MOC reviews data and makes decision on whether to excavate additional layer.
- Repeat until either target depth achieved (0.2 – 0.5m), “frost line” achieved, or MOC decides to move on to next target.
- Assuming 5 excavation layers and 10 mins review time for each, the complete excavation activity takes approx 1 hour, or 10 hours for 10 excavations.
- Data review and decision making likely limiting factor.



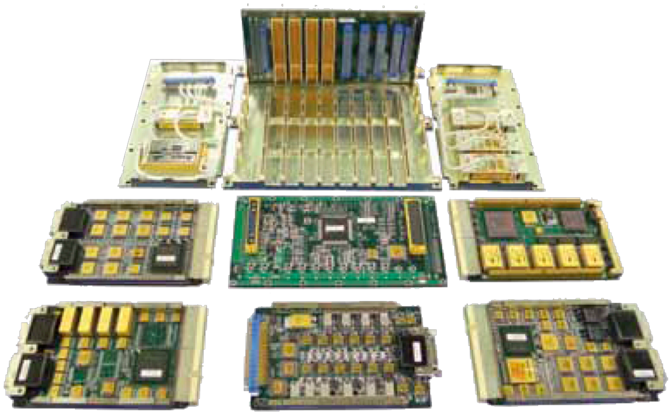
# Functional Block Diagram



# Avionics

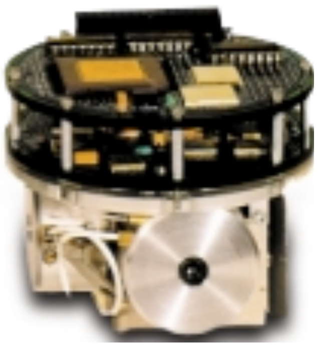
## Typical Integrated Avionics Package

- < 5kg, < 32W@28V
- 266 MIPS/266 MFLOPS CPU
- 16MB NVRAM, 512MB SDRAM, 512MB DDR RAM
- RS 422, LVDS, & 1553 IO, Power switches, analog and solar array inputs



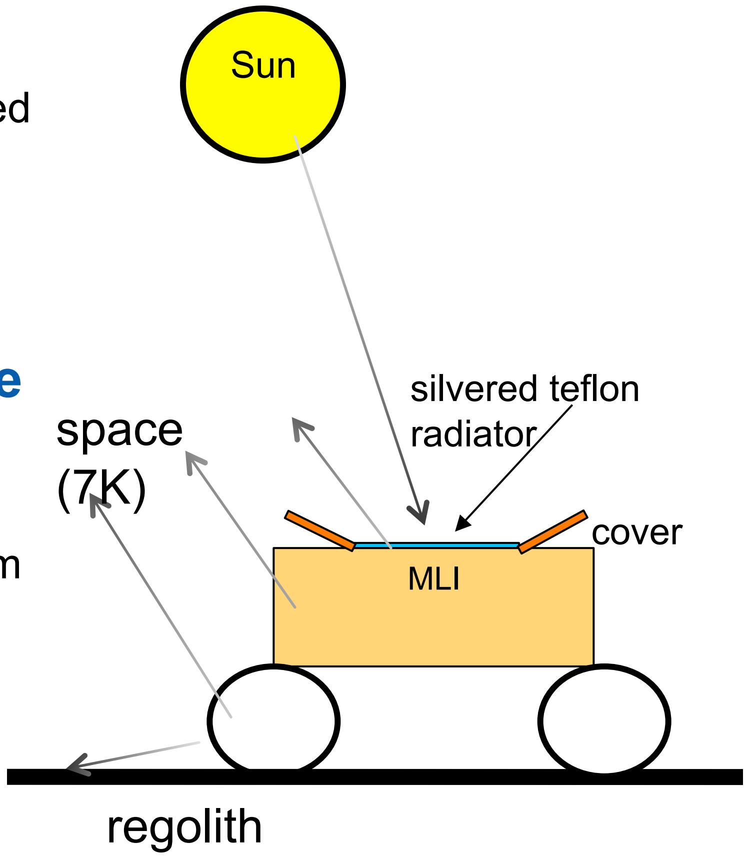
## MER Tactical grade INS

- 12W, 750g

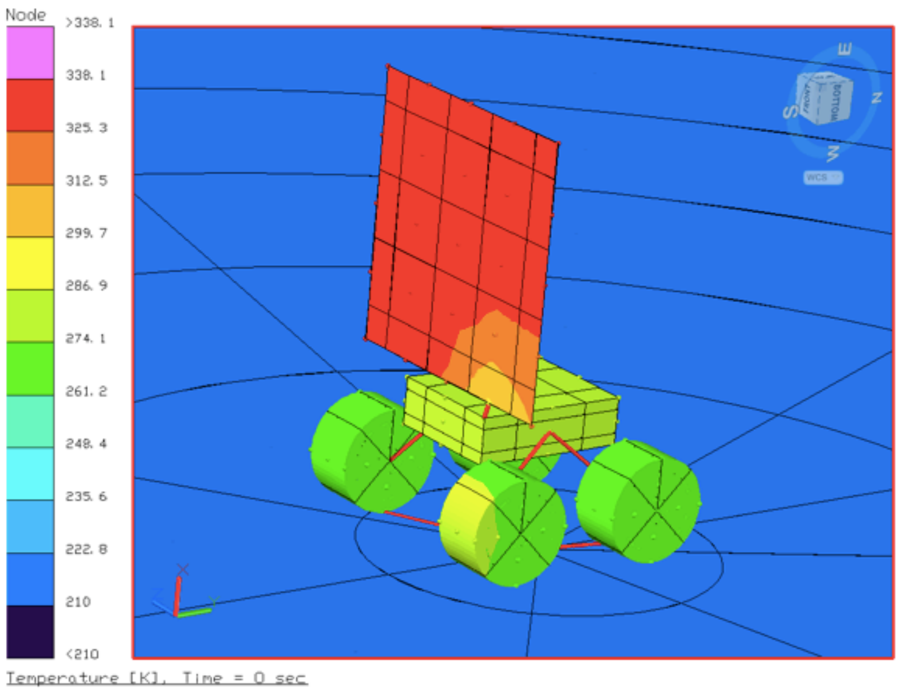


# Thermal

- **Maintain systems within operating ranges**
  - Batteries 10 to 30C (-85 to 45C claimed for some Li-ion batteris)
  - Electronics -10 to 50C
  - Avoid repeated temperature changes
- **Thermal variation is challenge**
  - Dissipate power under max solar illumination
  - ... but retain heat during solar minimum
- **Lunar environment**
  - Heat radiation from regolith (radiated heat proportinal to temp difference^4)
  - Variable radiator/sun geometry (equatorial)
  - Dust on radiative surfaces



# Thermal




| | Emissivity | Absorptivity | Temperature |
|---|---|---|---|
| Rover | 0.88 | 0.88 | 282 - 292 K |
| Wheels | 0.88 | 0.88 | 273 - 283 K |
| Solar panel (front/back) | 0.83/0.76 | 0.81/0.27 | 335 - 342 K |

## Thermal model developed in Thermal Desktop:

- Heat generated in the rover = 100 W
- Drive motors inside WEB
- Lunar regolith surface temperature = 210 - 250 K
  - Rover in sunlight (from side)
- Rover body covered in high emissivity and absorptivity material (Maxorb), no radiator required

## Avoid hydrogen containing materials

- Interfere with neutron spectrometer
- Common phase change materials

## Future Trades

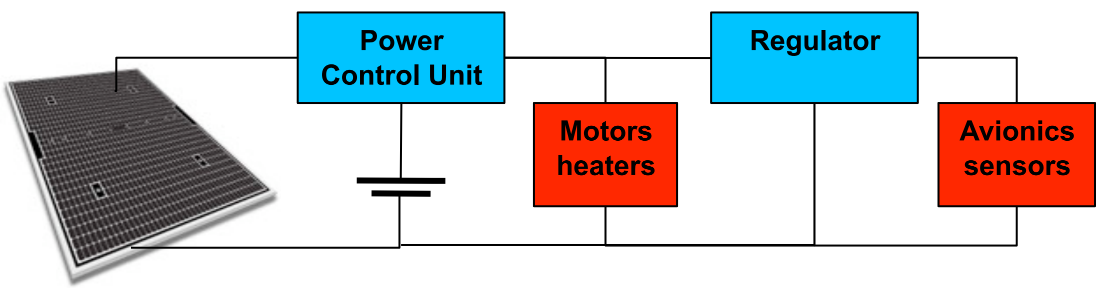
- Use radiator if greater power needs
- In wheel hub motors

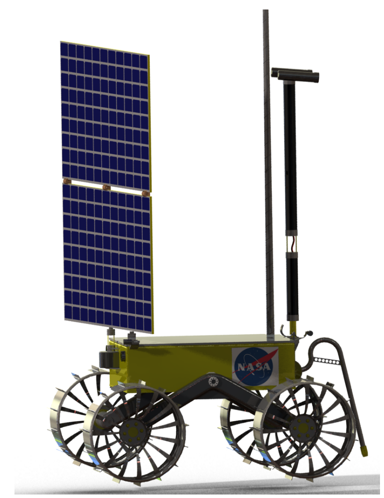
# Power

## Vertically mounted actuated solar panel

- Sized for max load (~100W) + losses (~20%) + 30% contingency
- Single DOF sufficient
- Single panel (~100 W/kg current operational SOA) + actuator lighter than 4 rigid body mounted panels.
- Compact packaging for launch.

| **Mass Budget (kg)** | | **Margin** | **Total** |
|---|---|---|---|
| Solar Panel | 1.74 | 50% | 2.62 |
| Batteries | 1.77 | 50% | 2.65 |
| Power control unit | 3.49 | 0% | 3.49 |
| Voltage regulator | 3.05 | 0% | 3.05 |
| Wiring | 1.00 | 25% | 1.25 |
| Total | 11.05 | 18% | 13.06 |



# Power: Solar Panels

**100W/kg is comercial satellite SOA**

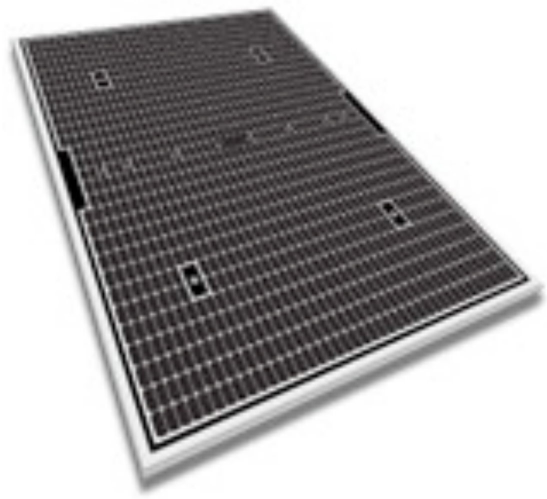
**ISS 32 W/kg**

**Orion Ultra-flex 160 W/kg (very large).**

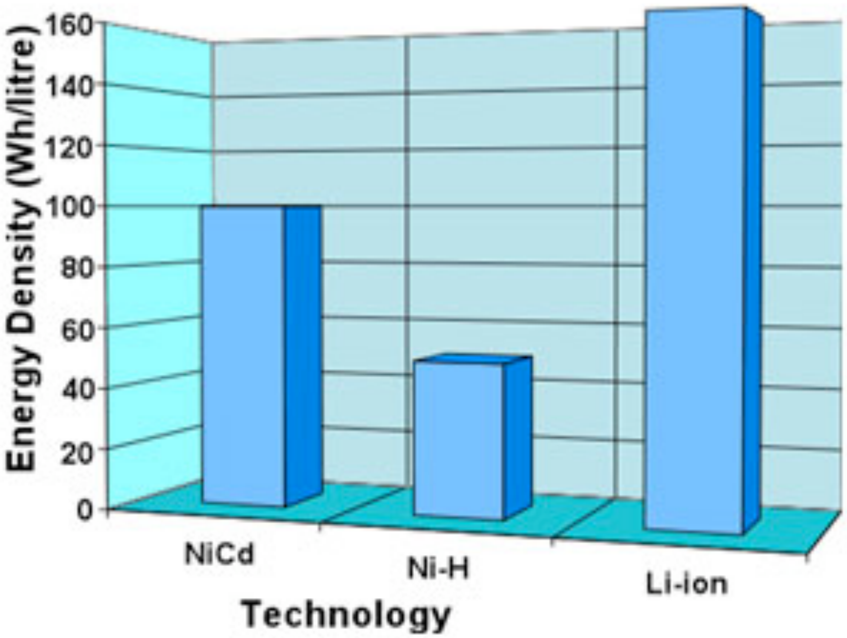
**E.g.:**

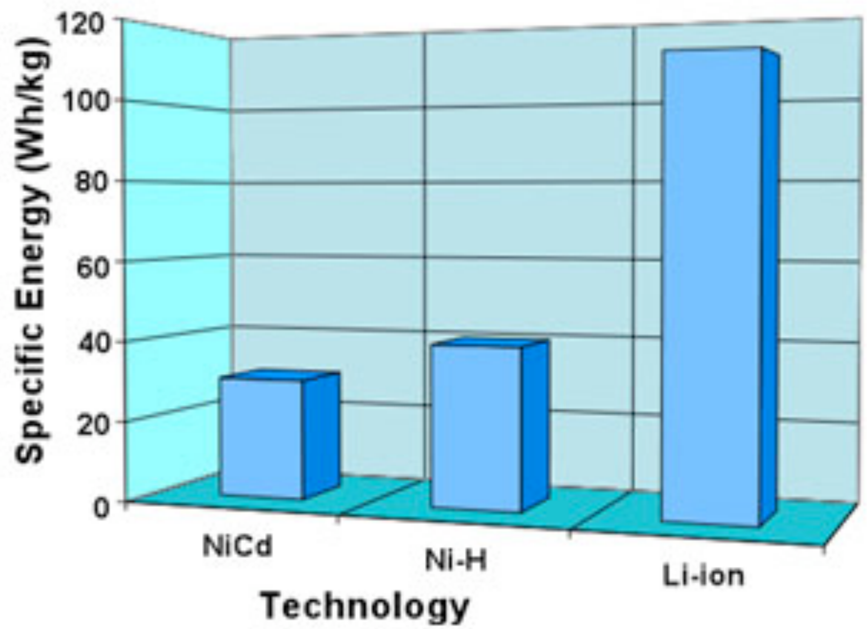
**Emcore Triple Junction ZTJ Space Solar Panel**

- **Average efficiency 29.5%**
- **low mass 84 mg/cm2**
- **radiation resistance with P/Po = 0.89 @ 1-MeV, 5E14 e/cm2 fluence**



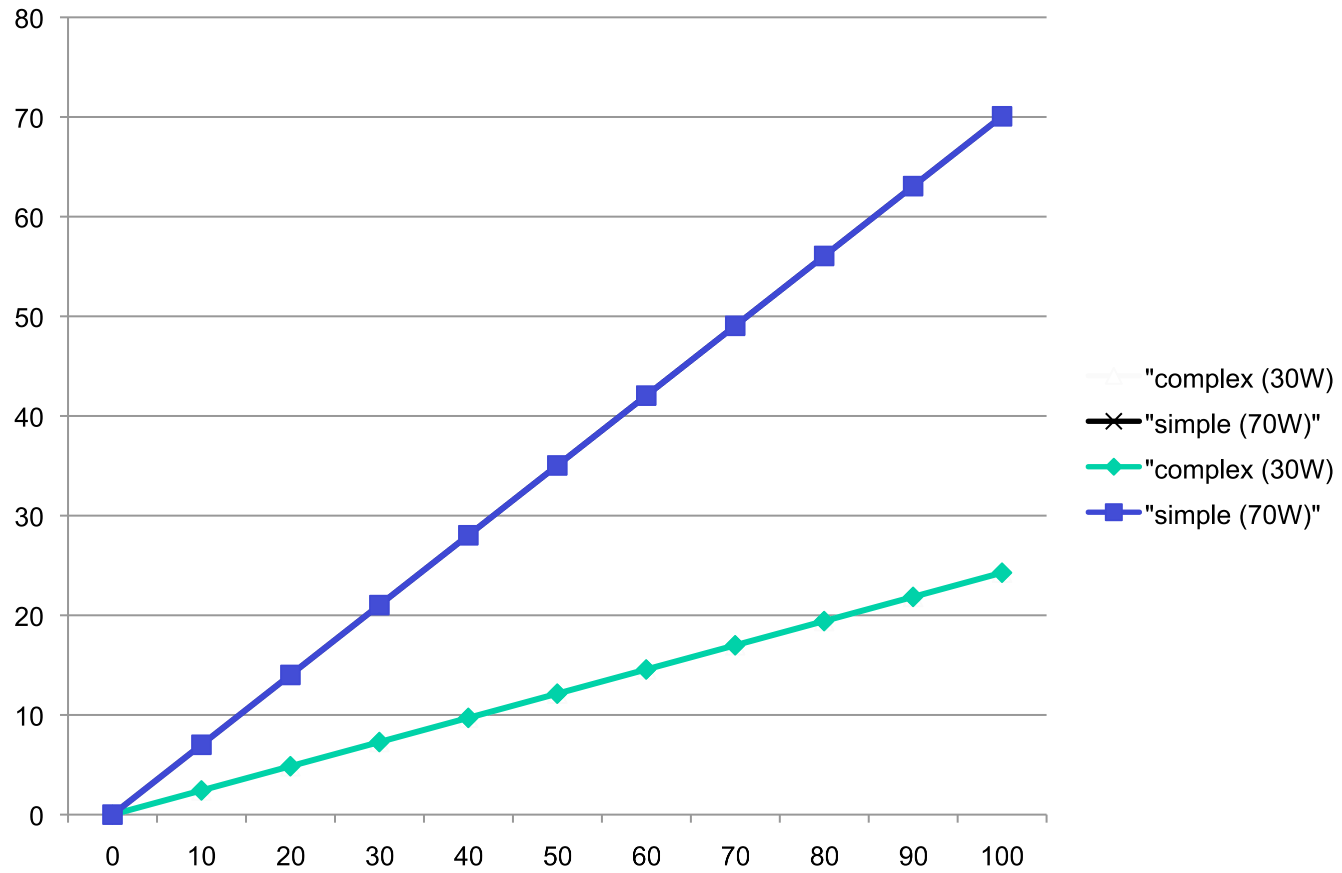
# Power: Batteries



# Power: Batteries for Night Time Survival

Li-Ion battery mass
110 W-hr/kg
100% discharge




Night duration (hrs)

# Rover Size Trade

| | 1 kg (Nano-rover) | 10kg (Packbot) | 50-100kg (MER) |
|---|---|---|---|
| Navigation | ---<br>10cm look ahead<br>cm obstacles<br>10m from lander<br>(comms, navigation) | +-<br>1m look ahead<br>10cm obstacles<br>100m from lander<br>(coms) | +++<br>10m look ahead<br>>10cm obstacles<br>> 1km from lander |
| Cost | $$$ | $$ | $ |
| Risk | Very High:<br>shadows, cold traps, low thermal inertia, no battery, loss of comms | High:<br>shadows,cold traps, loss of comms, | Medium:<br>Thermal solutions exist<br>Can accommodate flight h/w |