Rover Configuration for Entertainment-Based Lunar Excursion

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Motivation

- Accessible and cheap as robot mission target
- Guaranteed solar power and uninhabited, barren terrain enables ambitious robotic endeavor
- Commercial technology available for leverage
- Continual line-of-sight between Earth and near side allows high-bandwidth communication
- Short time-delay and rich video enables mass interaction
- Apollo anniversaries demonstrate public interest in returning to the Moon
- Traditional agendas, science and national priority, no longer drive lunar exploration

Excursion Scenario

Two year, 1000km excursion to visit historic sites

Rover controlled via tele-operation

Traverse during lunar day, hibernate at night

Generate theme-park attractions from video, chassis pose & dynamics, amateur teleoperation

Launch from Proton rocket, Phobos class lander

Two identical rovers for adventure and reliability

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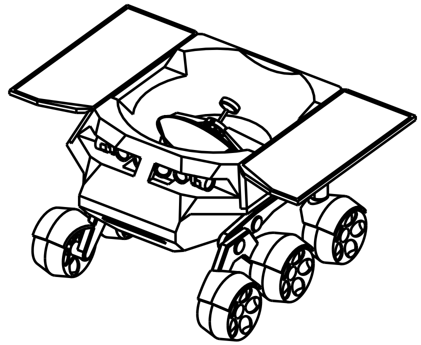
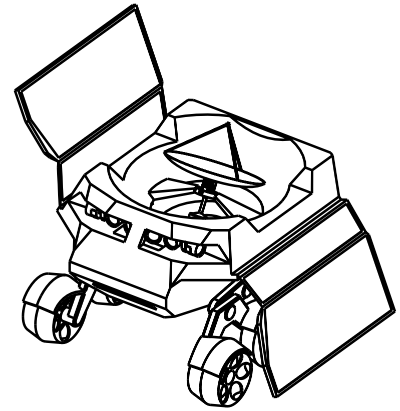
Operations



Exploration
Mode

Observation
Mode



Tele-operated	Stationary
Images of moving terrain	Images of moving rover
Draining power	Recharging
Performing safe-guarding	Performing telemetry

Rover failure => Lone rover operates self-reliantly, with reduced range and increased recharging time

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Lunar Environment

Day/Night Cycle

24 hours

	Exploration		Hibernation	
dawn	day	dusk	night	dawn

Surface temperatures

	-170 C		0	100 C	
night	liquid nitrogen			steam	day

Driving delay time (sec)

0.2	1.0	4.0 to 6.0
auto	airplane	lunar rover

Horizon (1.4m height)

0 km	2.2km	4.3km
	Moon	Earth

Radiation (rad/hr)

Earth	OSHA	Leo
10^{-6}	Moon	10^{1}

Hard Vacuum
Electrostatic dust
Soft soil

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Technical Challenges

Extremely high reliability and availability needs

Tight cost and time budgets

Overcome lunar environment: temperature, dust, ...

High-Bandwidth (> 8 Mbps) for telemetry and video

Autonomous safe-guarding during tele-operation

Locomotion capable of traversing unknown terrain

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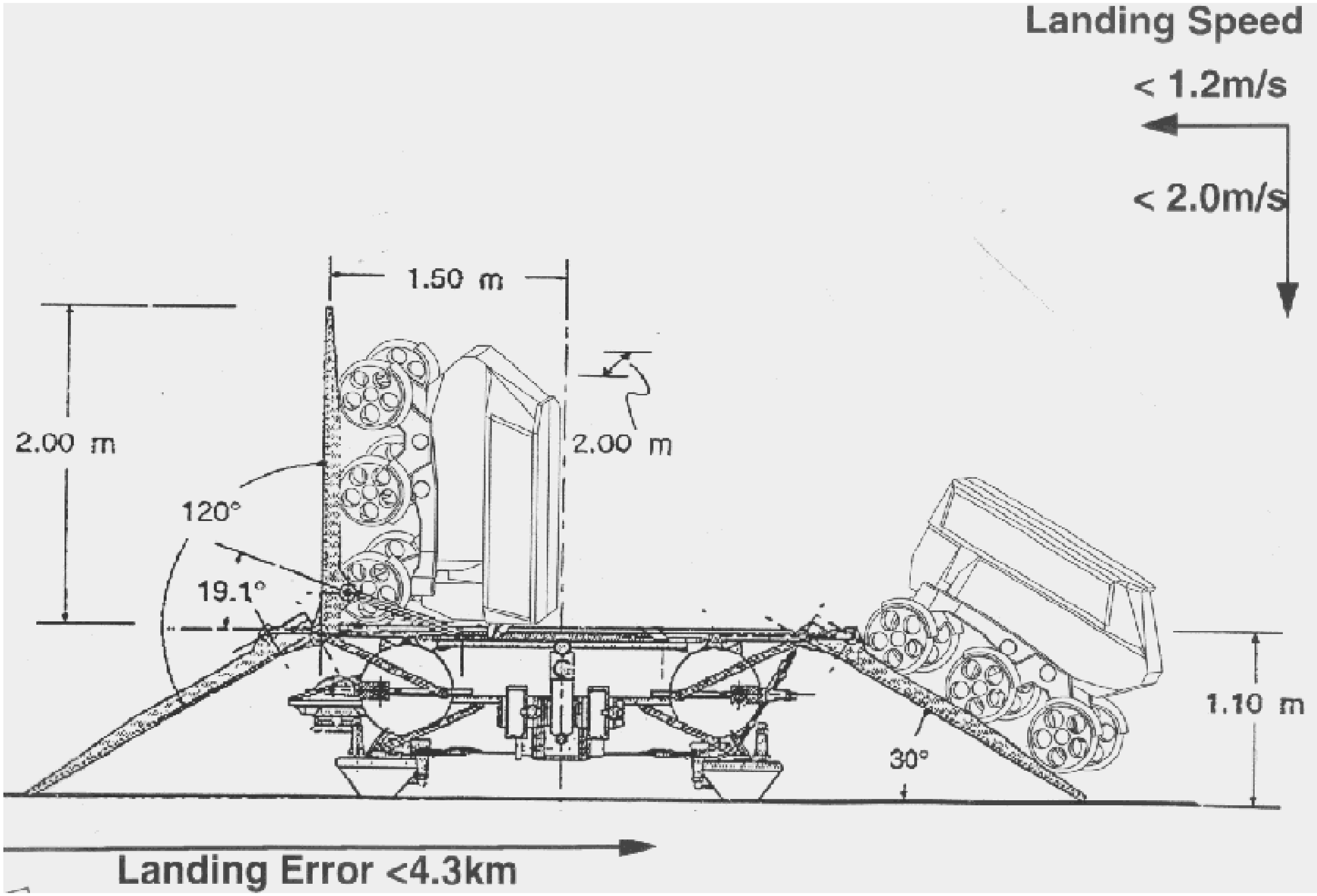
Products

Product	Generated by	Comments
Panoramic tele-presence	Imagery and motion sim	Travel aboard the lunar tourbus
Tours of Mission Control	Lunar mission	Exciting, interactive and educational
Amateur tele-operation	Proposed scenario	Be a part of lunar exploration, touch the Moon
Stereo movies	Real-time video imagery	Experience lunar realism
Documentaries	Development and operations	Watch the latest developments on nightly TV
3D maps for CD-ROM and virtual reality	Off-line image processing	Revisit historic sites and learn about the Apollo missions
Souvenir photographs	Photographic stills (color)	Bring home the Moon
Merchandising	Commercial venture	Play the LunaQuest arcade game, or play with a lunar rover toy

Lander



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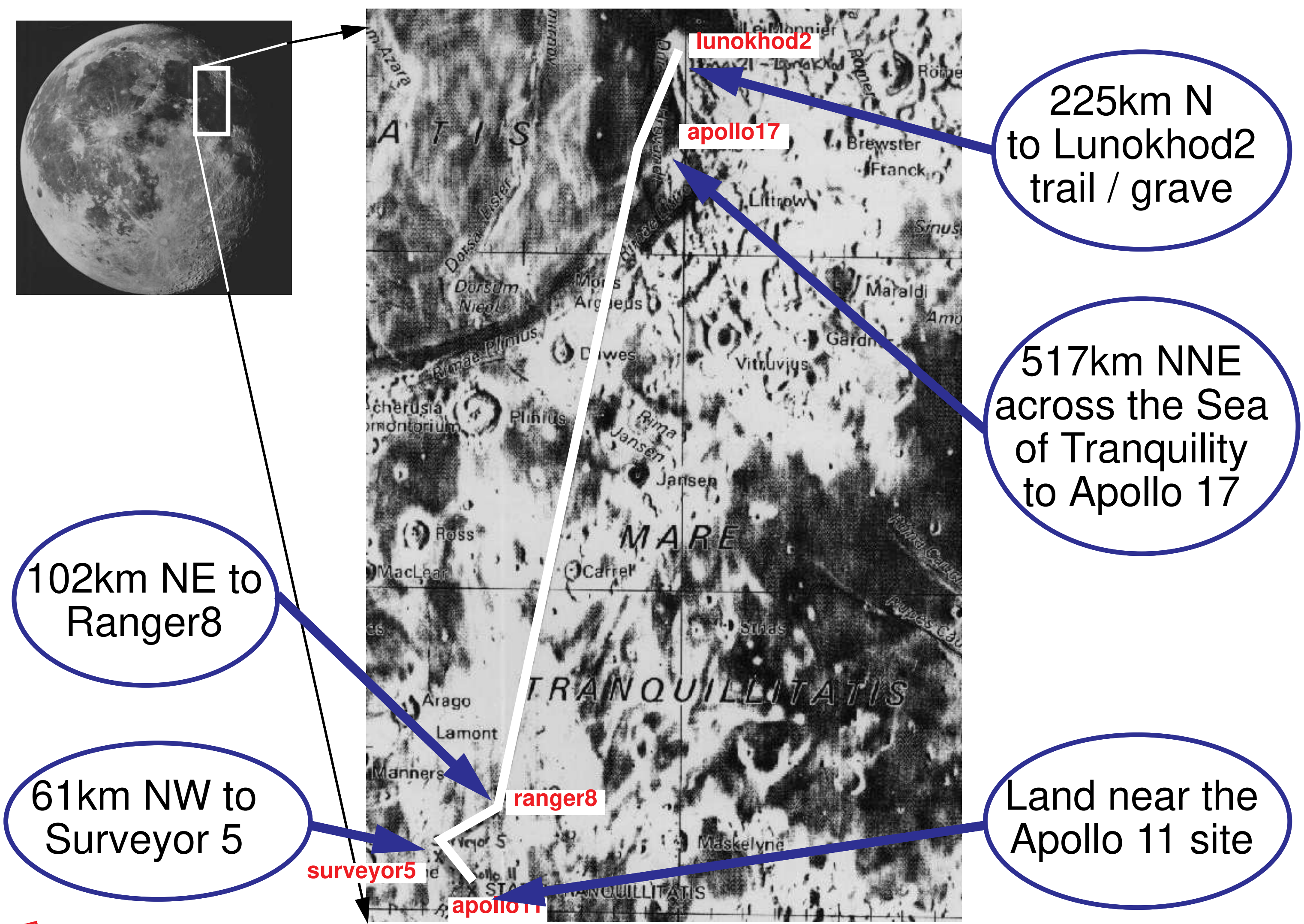
Traversal Route



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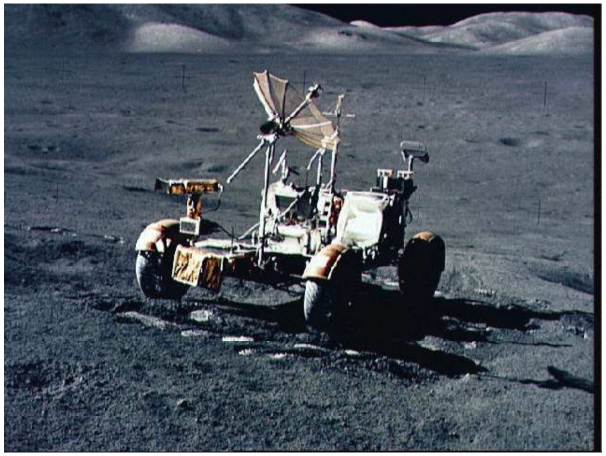
Rover Configuration

vital statistics

locomotion

communication

thermal



imagery

computing

power

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Vital Statistics

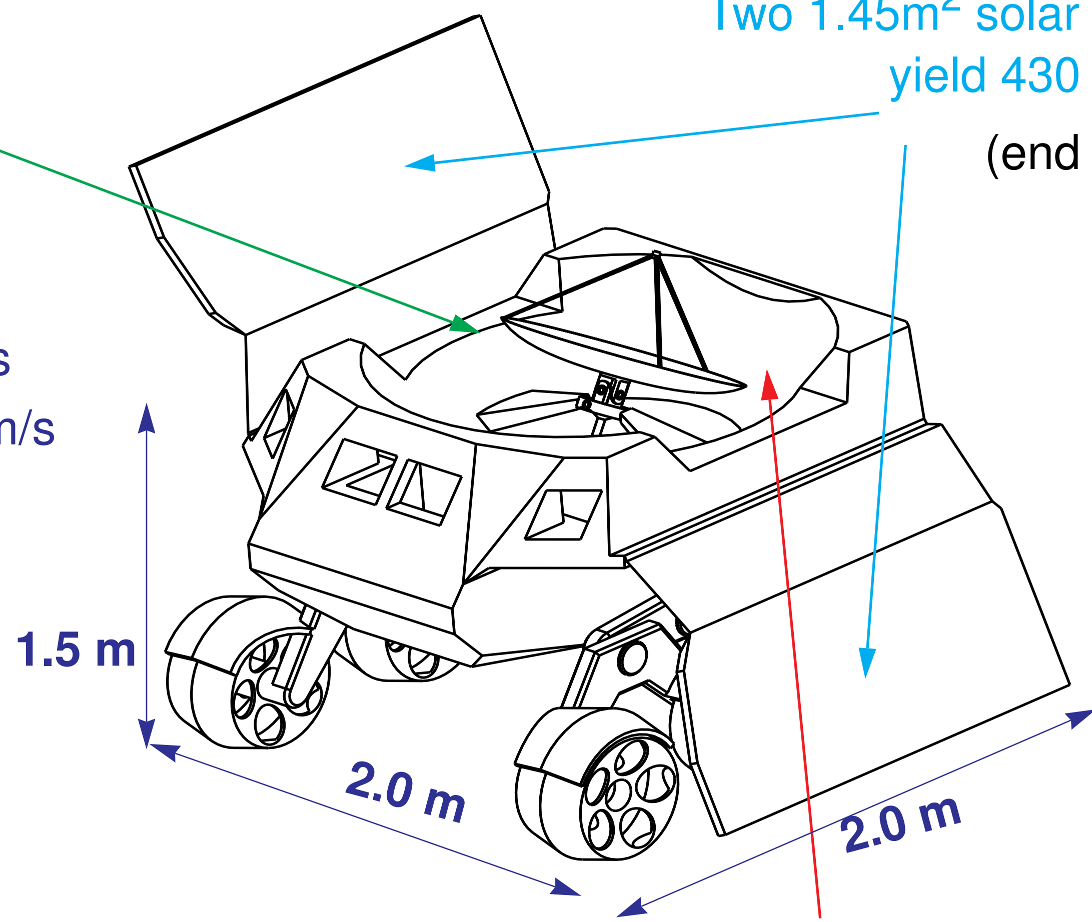
0.84m aperture
parabolic dish

Two 1.45m^2 solar panels
yield 430 Watts

(end of life)

Top speed: 1m/s

Avg speed: 0.4m/s



Mass <250kg

Range ~1500km

Mission Life ~2years

2.2m^2 of radiators
for heat dissipation

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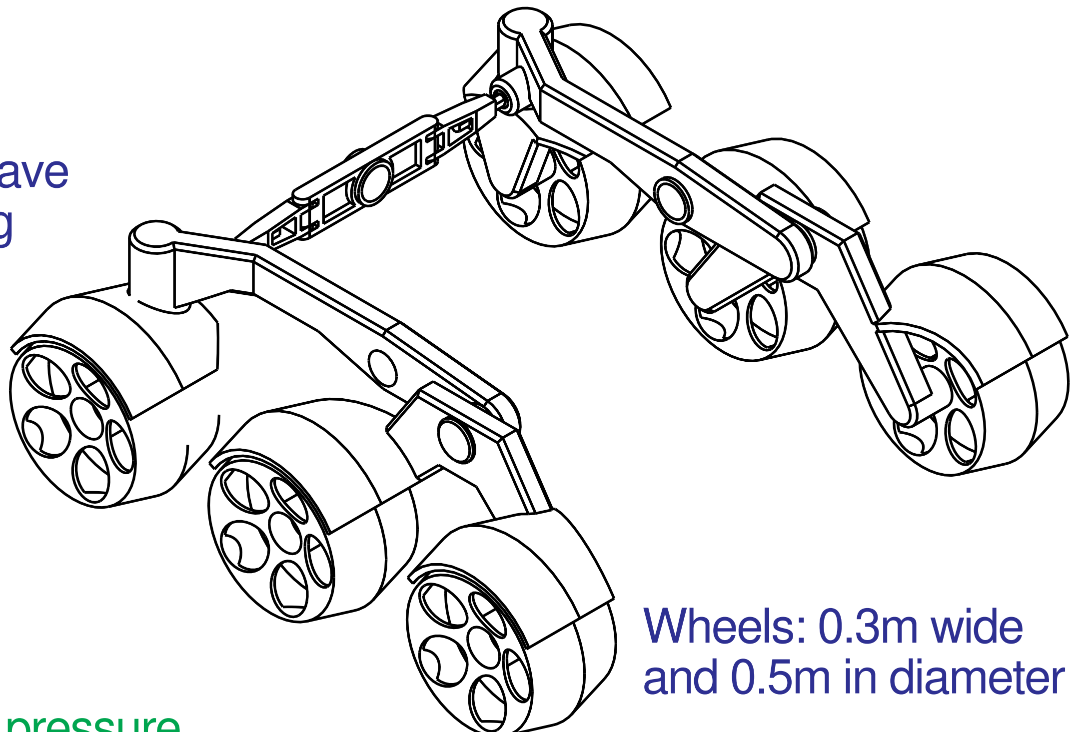
Locomotion

Vehicle stable on 25° slope and 0.25 m obstacle and can surmount 0.5m obstacles on flat terrain

rocker-bogie chassis configuration

Rear wheels have explicit steering



Each wheel driven independently

Wheels: 0.3m wide and 0.5m in diameter

Ground pressure ~ 3.0kPa

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Communication

Transponder Power: 18W
Transmitter pointing: 0.05 deg
Receiver pointing: 0.03 deg

Ku-band frequency used due to low atmospheric attenuation and small transponders due to large consumer base

Beamwidth chosen to be 2° to cover entire Earth and provide a reasonably sized dish

Precision pointing yields datarate of 12Mb/s while stopped and 2.5Mb/s in backup operation mode

Three Earth stations, using a 10m dish, needed worldwide to allow 24hour communication

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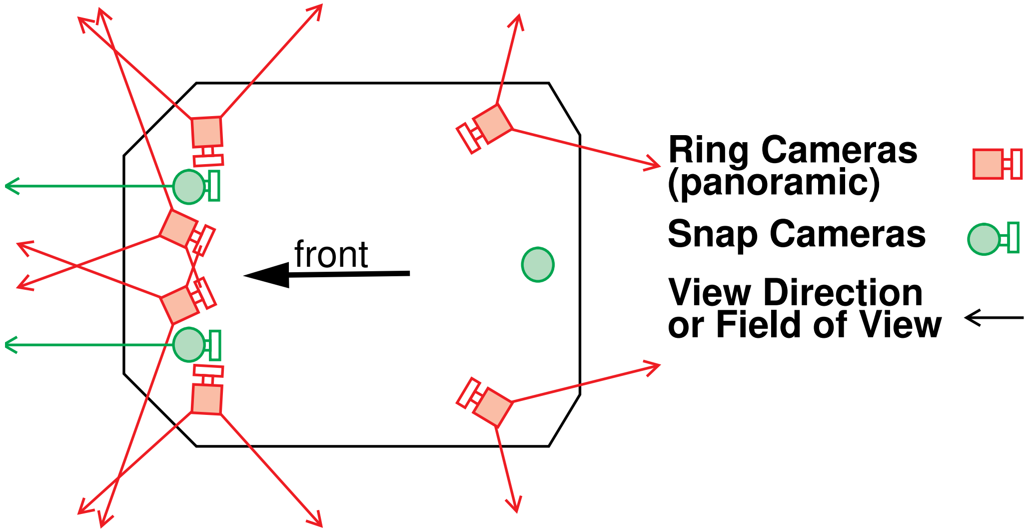
Imagery

Camera Configuration with Fields of View



Name	Field of view	Image size	Data rate	Comments
Ring	90° hor 60° ver	586 x 384 x 6bit	eighty images per sec	images processed into 360° panorama (2304x384, 20 ips)
Snap	90° hor 60° ver	1500 x 1000 x 8bit	1 image every five secs	six position filter wheel allows color and graytone stills

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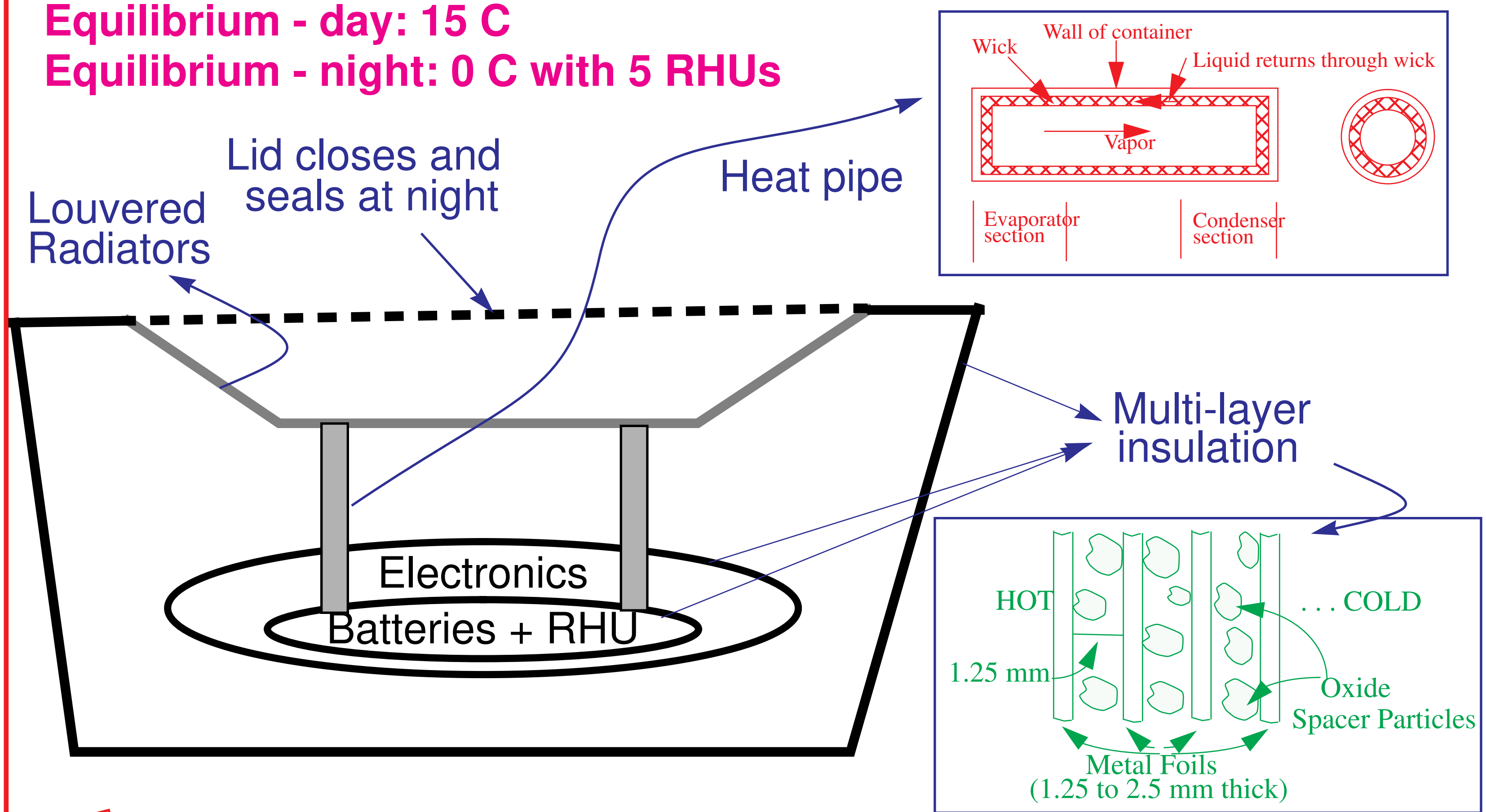
Thermal

Day: Operate and dissipate excess heat
Night: Hibernate and warm enclosures

Equilibrium - day: 15 C
Equilibrium - night: 0 C with 5 RHUs



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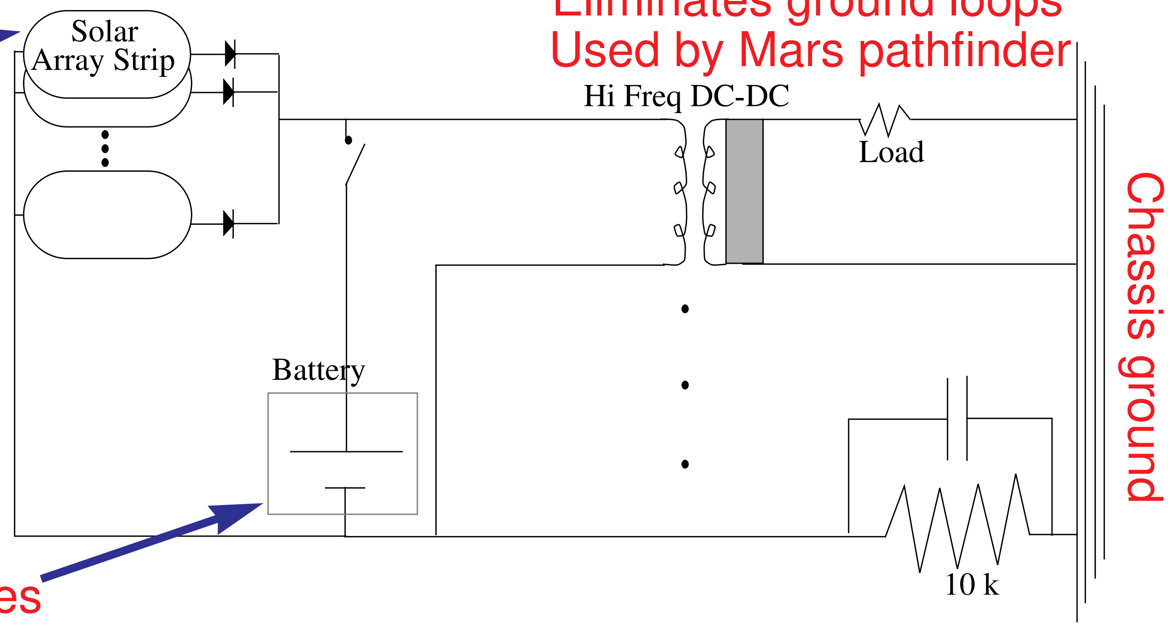
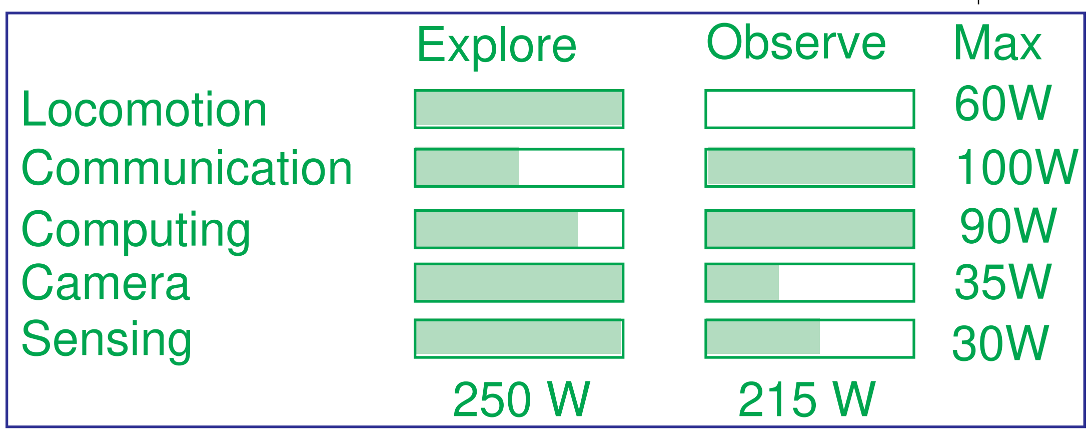
Power

2.9 m^2 thin Si cells
430 W after 2 yrs
Commercial parts

Regulation at component level
Eliminates ground loops
Used by Mars pathfinder



15 kg NiMH batteries
1050 WHr after 2 yrs
Commercial technology



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Computing

Maximize computing by maximizing performance per watt

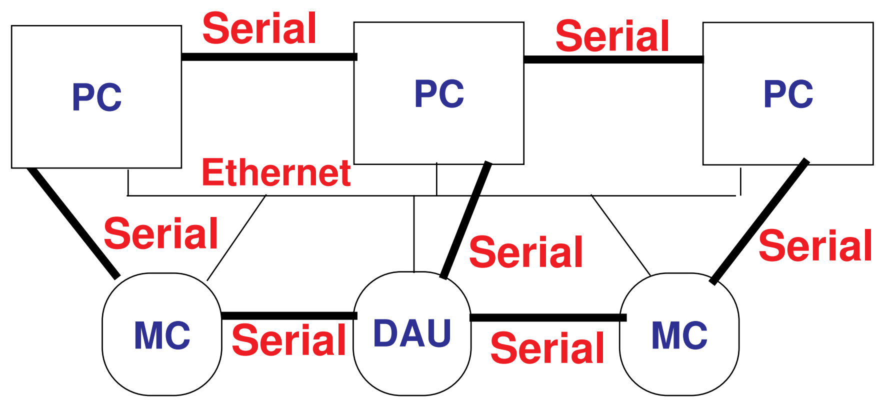
Minimize component list to reduce Rad-qualification and development costs

Many commercial chips suitable due to only moderate radiation levels

PC: 131 Mips, 2 frame buffers, 64 I/O, 16MBytes

MC: 27 Mips, frame buffer, 40 I/O 4 MBytes, IMU port

DAU: Cassini (REU) chip for A/D 8051 motor controllers



1553 + 1773 hi-speed serial link

Ethernet: low speed backup link

Combined specs: 460 Mips, 8 frame buffers, 56MBytes 2 IMU ports, 290 I/O, and 4 serial lines per board

Operating System: VxWorks

Primary processor: MIPS R3081

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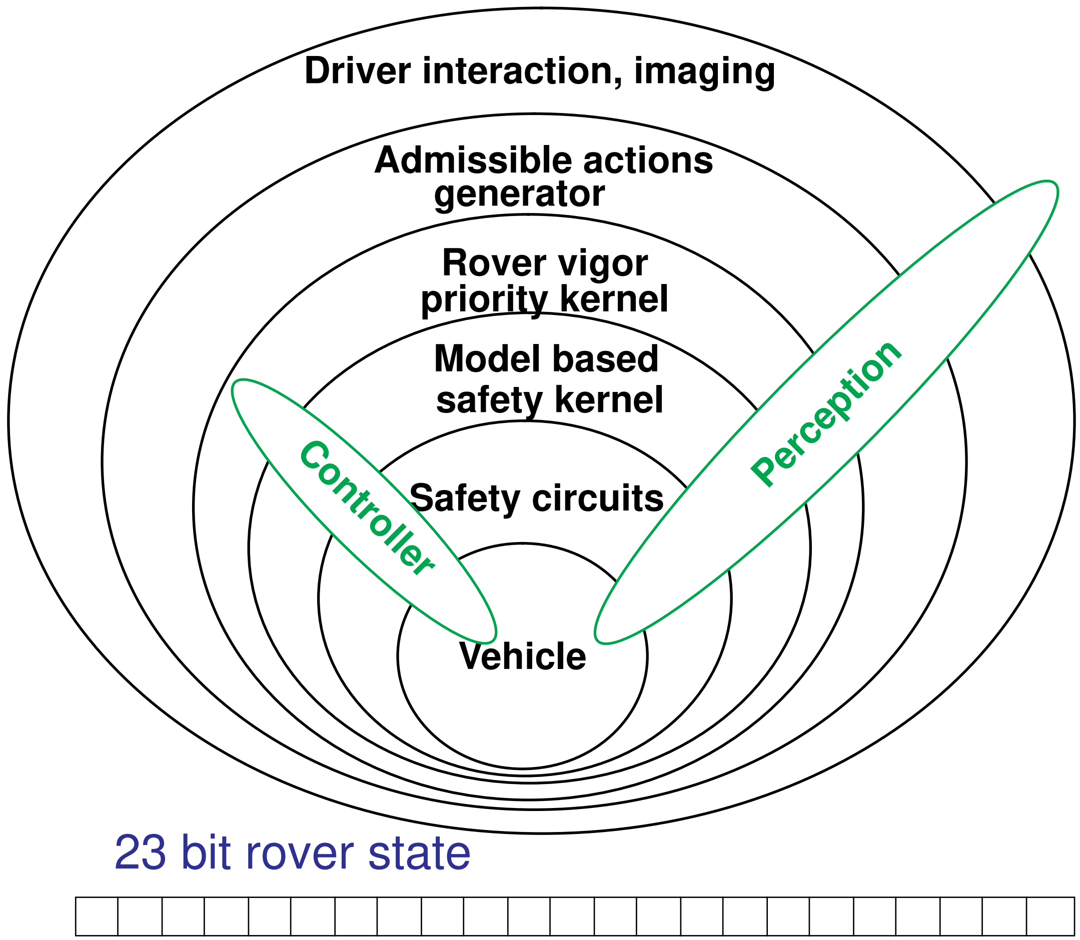
Software

Drive admissibility
Map merging
Star tracker
Kalman filter
Triangulation ranging
Stereo ranging
Device control
Hybrid torque-velocity
Teleop feedforward
Basic safeguarding



Modular, distributed, self-scheduling w.r.t. processor availability
Priority is rover survival

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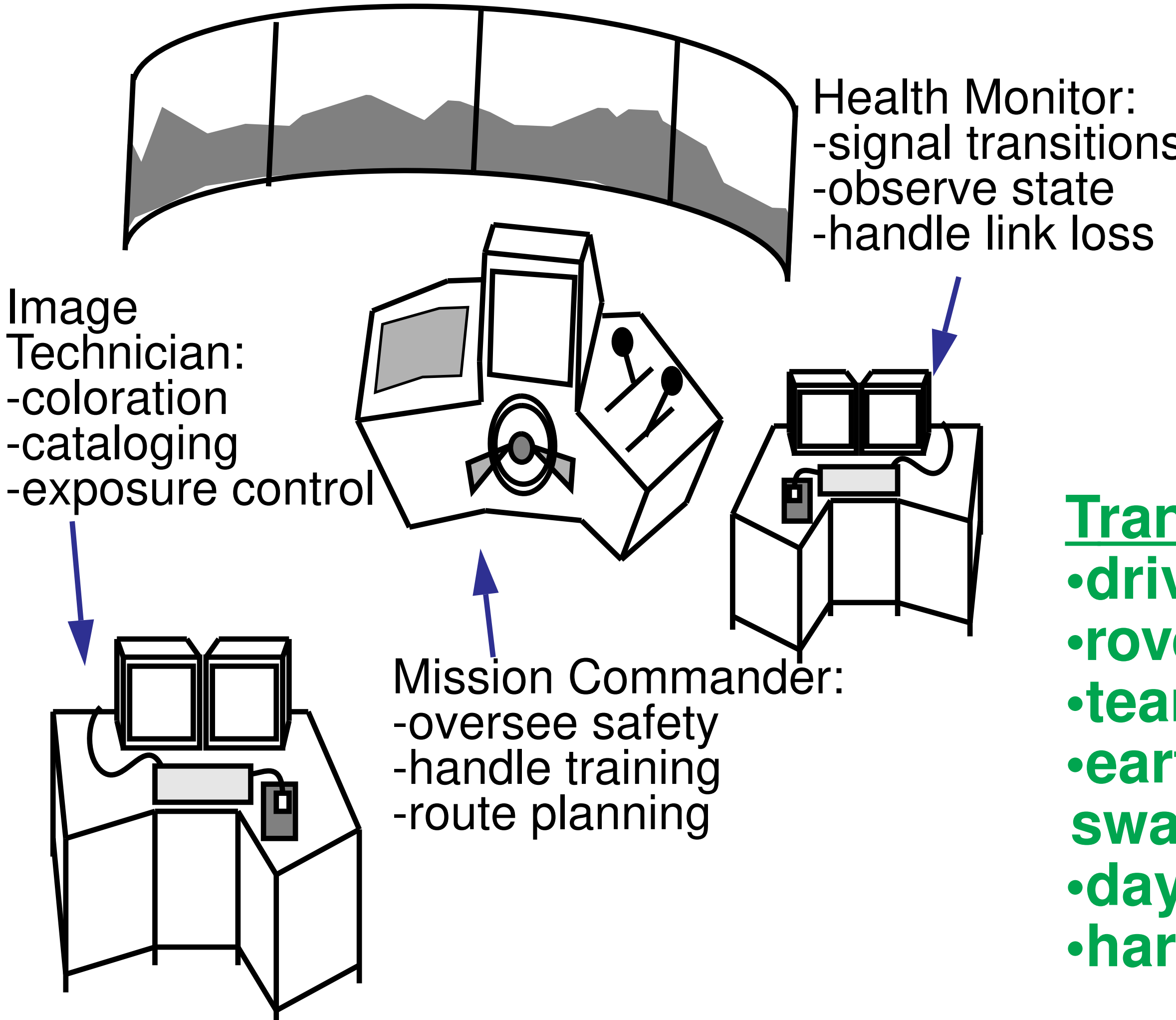
Mission Control



Transitions

- **driver change**
- **rover leapfrog**
- **team shift**
- **earth station swap**
- **day-night-day**
- **hardware update**

Response team always on-call

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Perspectives

- Entertainment motivates a return to the Moon
- Robot technology and configuration appear mission feasible
- Excursion objective of 1000km is invaluable for lunar inquiry, unprecedented for robotics
- A demonstrated lunar capability is critical to lunar commerce

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There's More: Science

- Geology is a visual science
- Surface exploration has been limited to points
- Science agenda and payload can fit
- There is education and entertainment in science

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...One More Thing

This presentation gives a sketch of a configuration document scheduled for review at Carnegie Mellon Univ in December. Individuals wishing to comment upon the proposed mission and rover may contact:

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