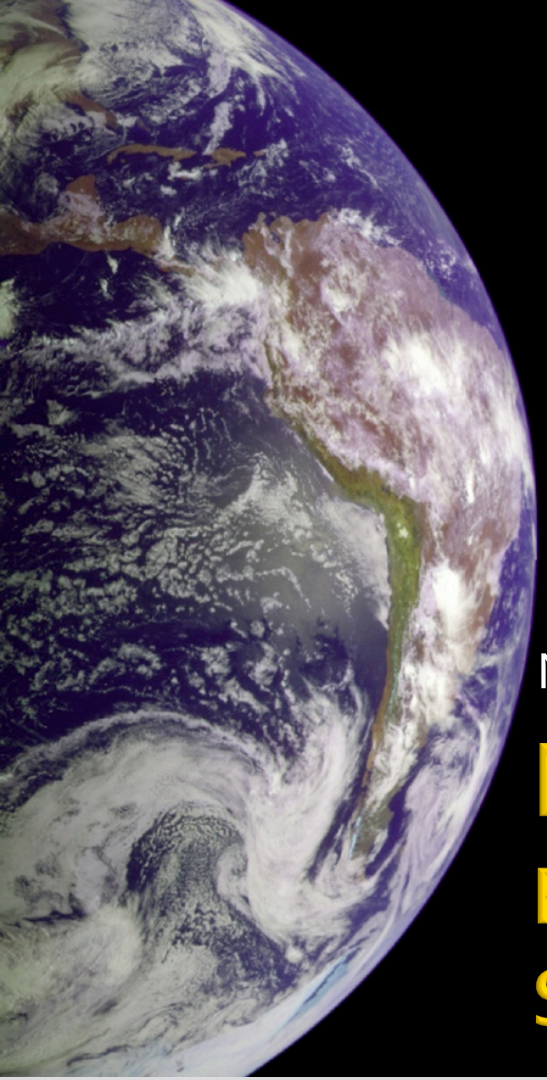


NIAC PI Workshop 2014

Nomadic Exploration:
Following Routes of Solar Sustenance and Temperate Climate

David Wettergreen
The Robotics Institute
Carnegie Mellon University

February 4, 2014

NASA Innovative Advanced Concepts

Outline

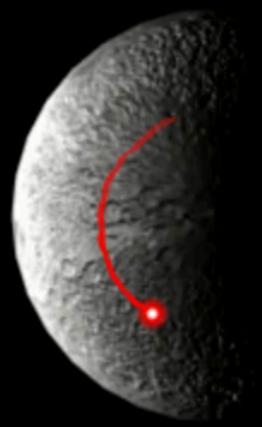
- Nomadic Exploration
  - Perpetually roaming planetary surface
- Past Work
  - Planetary Circumnavigation Study (NIAC Phase 1)
    - Found feasible missions, issues on Moon, Mercury: thermal cycles, lighting cycles
    - Indentified technical challenges
    - Insufficient surface detail
  - Sun-Synchronous Navigation
    - Polar experiment with solar-powered rover and planner
  - Lunar Mission Development
    - Rover design and prototype
    - Mission concepts: prospecting, spelunking
    - Thermal modeling, moderate thermal region post-terminator
- Current Plan
  - Integrate surface model (topography, lighting, thermal, communication) from lunar sources
  - Develop rover model and route generator
  - Prove lunar feature circumnavigation (no single point of light), regional sun-synchrony, and Magellan routes
- Future
  - Generalize to rovers and planets (Mercury, Asteroids)
  - Year 1 and Year 2 plans

Nomadic Exploration

- Perpetually roaming a planetary surface
- Routes of
  - Sunlight
  - Moderate temperature
  - Communication visibility

Nomadic Exploration

- Infinite *routes* of continual light and moderate temperature
- Moon
  - Magellan routes
  - Nomadic polar routes
  - Circumnavigate polar features



- Mercury
  - Equatorial circumnavigation in dawn terminator

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NASA/GSFC/ASU

http://lroc.sese.asu.edu

Past Work

Planetary Circumnavigation

NIAC Phase 1 Study, 2002

- Found feasible missions and issues on Moon, Mercury, Venus, and Mars
- Identified technical challenges
- Limited by insufficient surface detail

Planetary Circumnavigation

Mercury

- Mission Scenario
  - Equatorial circumnavigation
  - Dawn-following in terminator
  - Solar power
  - Passive thermal regulation
- Mission Options
  - High-latitude excursion

Equatorial Circumnavigation Specfications

Latitude	0° (equator)
Distance	15327 km
Rover Speed	3.6 kph, 1 m/s
Duration	4224 hrs

Planetary Parameters

Radius	2440 km
Minimum Temperature	-173 °C
Mean Temperature	167 °C
Maxmum Temperature	427 °C
Solar Irradiance	9127 W/m^2
Surface gravity	65.12 m/s^2
Diurnial period	176 days

Planetary Circumnavigation

Moon

- Mission Scenario
  - Polar circumnavigation
  - Dawn-following in terminator
  - Orbiter for communication
- Mission Options
  - Lower latitude at higher speed
  - Transit between regions of light

Polar Circumnavigation

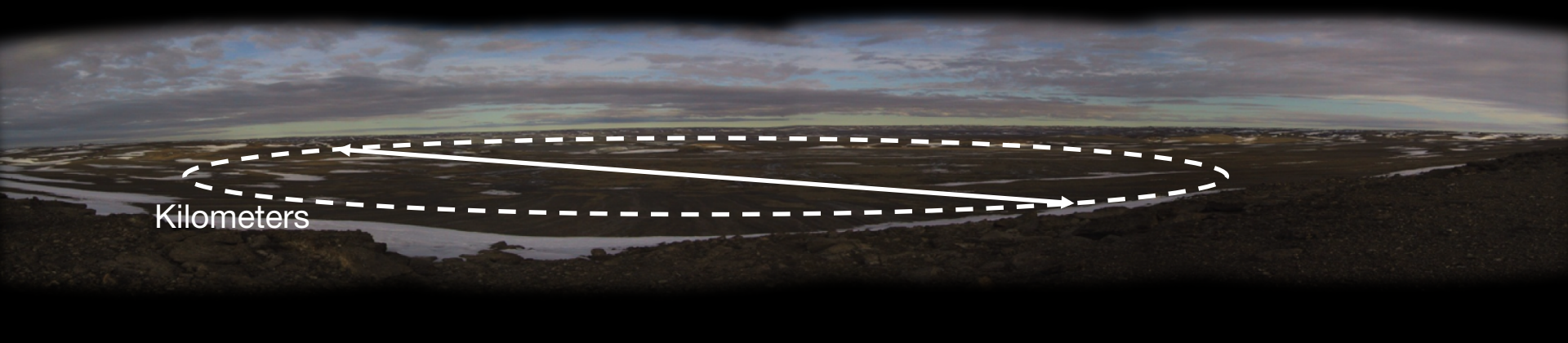
Latitude	85°
Distance	1895.2 km
Duration	28 days
Speed	2.8 KPH, 0.8 m/s
Communication Lag	2.5sec

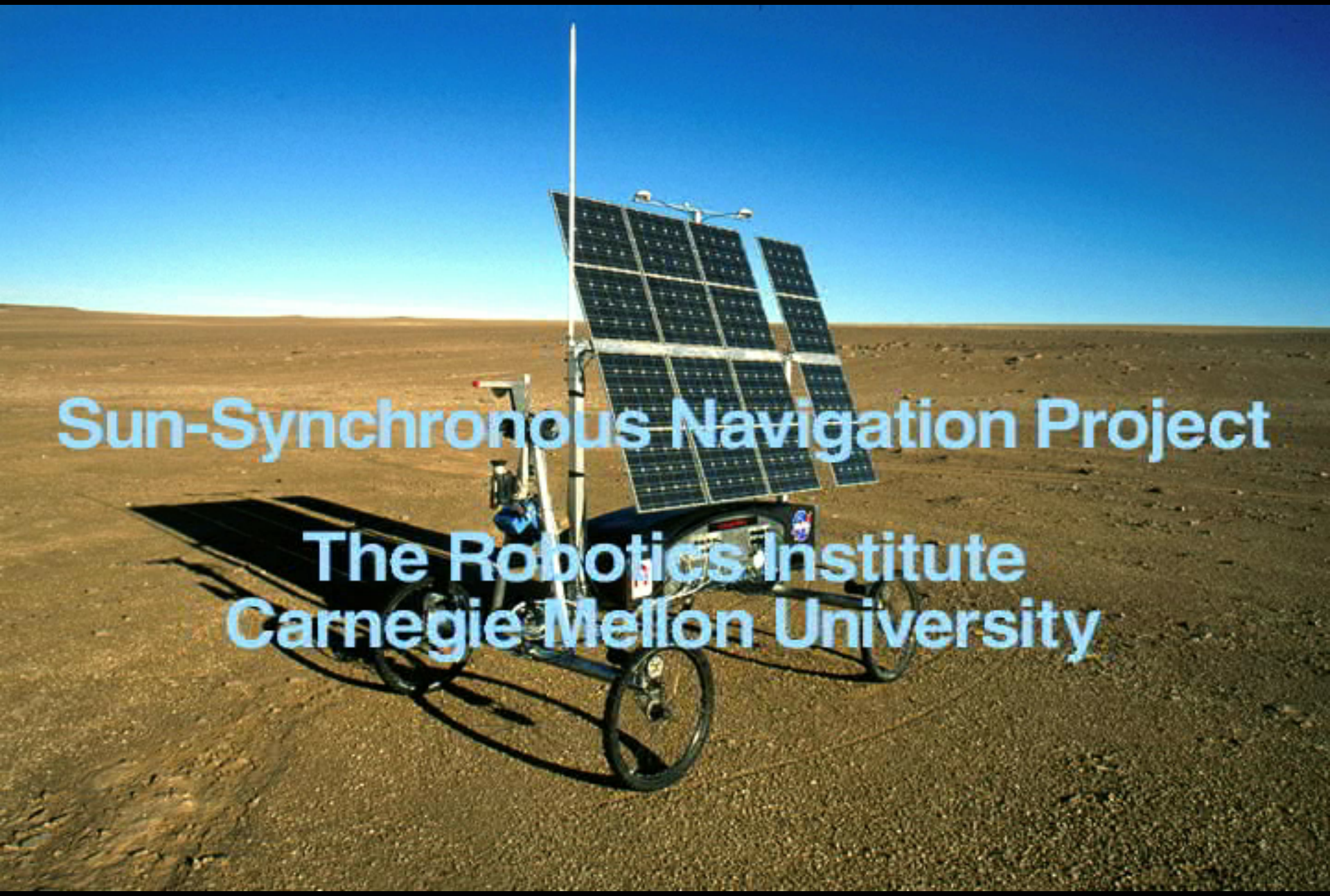
Planetary Parameters

Planet Radius	1737 km
Minimum Temperature	- 260 °C
Mean Temperature	- 20 °C
Maximum Temperature	120 °C
Surface Gravity	1.57 m/s^2
Solar Irradiance	1367 W/m^2
Diurnal period	28 days

Sun-synchronous Navigation

- Demonstrate concept of sun-synchronous navigation and quantify performance
- Conduct 24-hour experiments in planetary-analog terrain

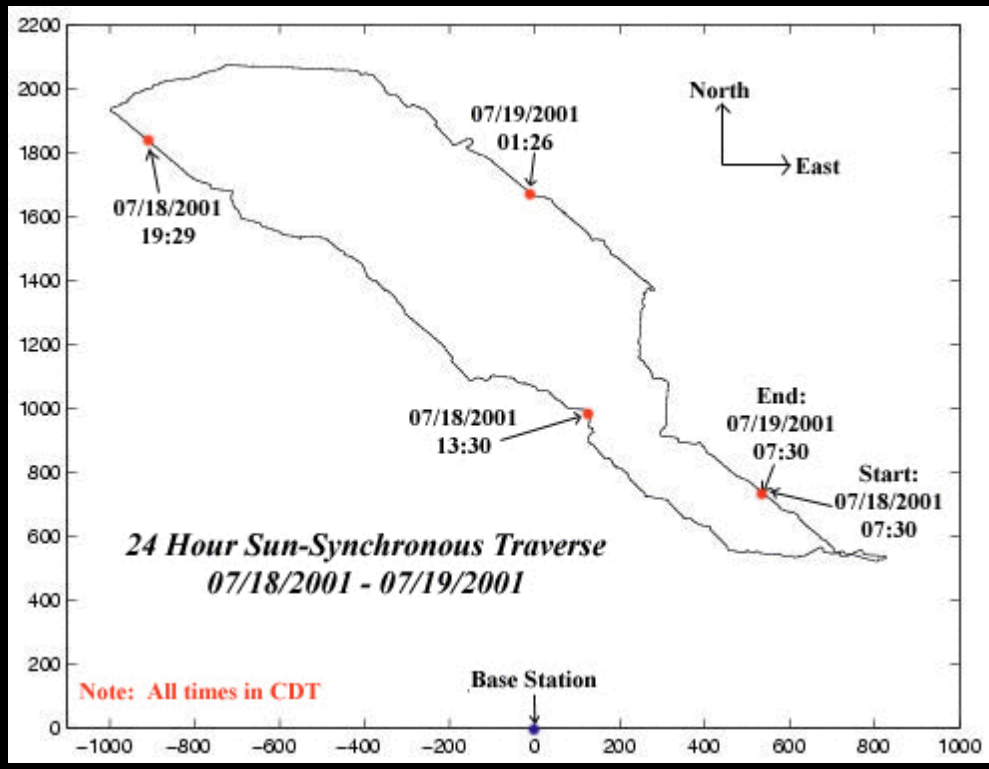



Sun-Synchronous Navigation Project
The Robotics Institute
Carnegie Mellon University

Polar Field Experiment, 2001

Haughton Crater Rim on Devon Island, Canada

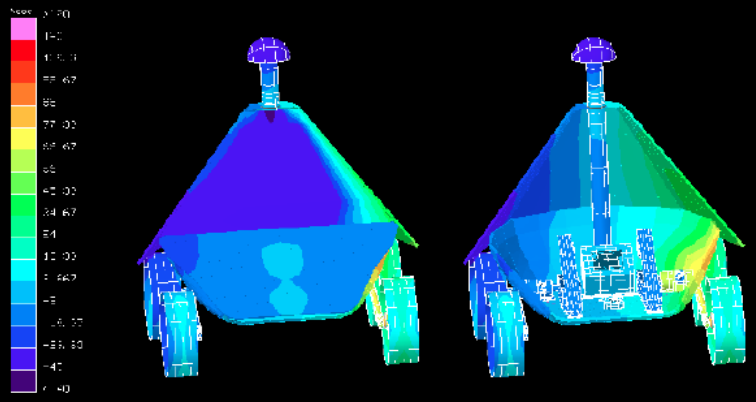
- Terrain
  - 75° N latitude
  - 7% obstacle density (max 34%)
- Operation
  - No intervention
  - Autonomous 90%
- Power
  - Completed on schedule with batteries charged
- Distance: 6.1km



Lunar Mission Development

- Rover design and prototype
- Mission concepts: prospecting (finding water ice), spelunking (skylights, lava tubes)
- Thermal modeling, moderate thermal region post-terminator

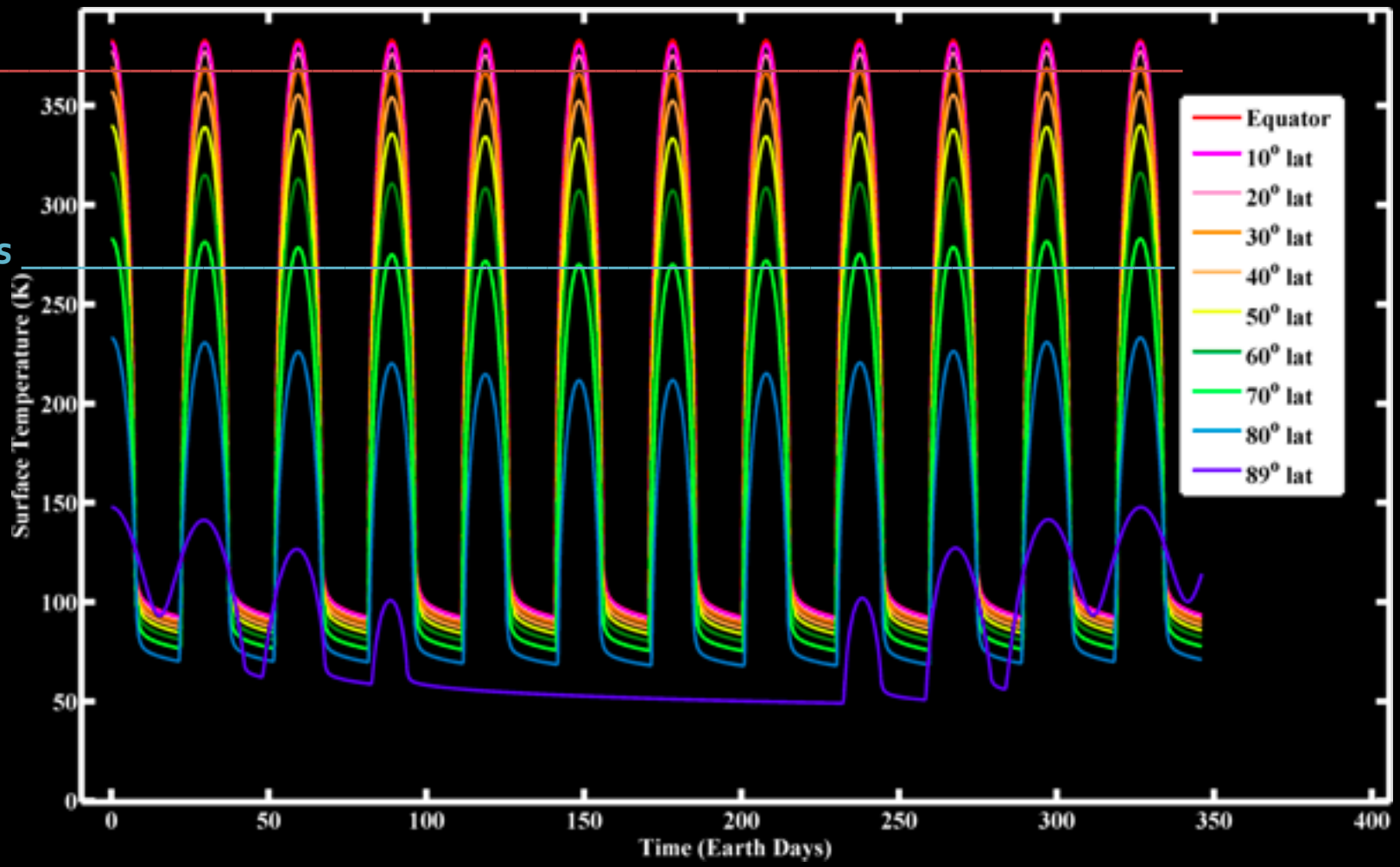
1 Earth Day After Lunar Dawn



Lunar Thermal Cycles

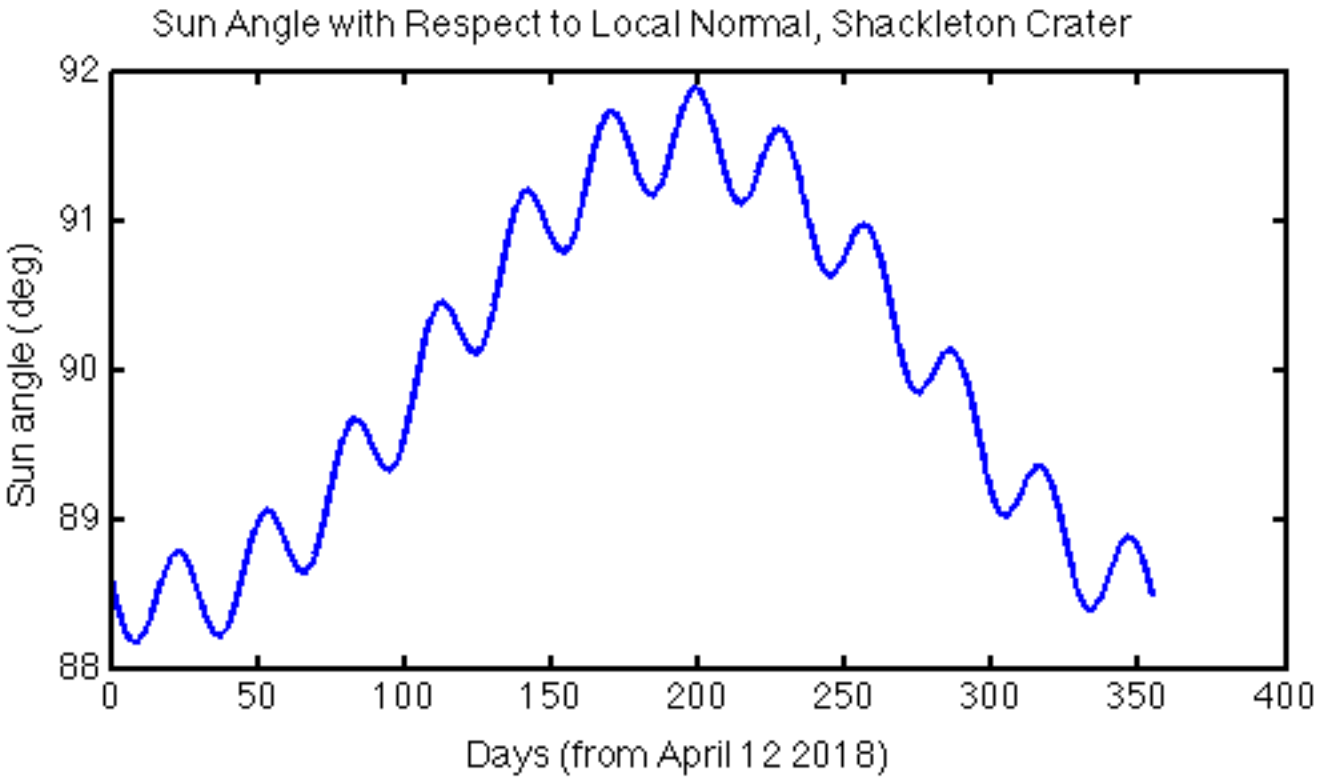
Water boils @ 1 atm

Water freezes @ 1 atm



[Diviner, UCLA]

Sun Angle Varies



Current Work

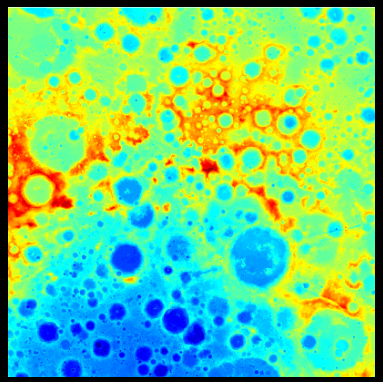
Current Research

- Objective: Map routes of perpetual navigation

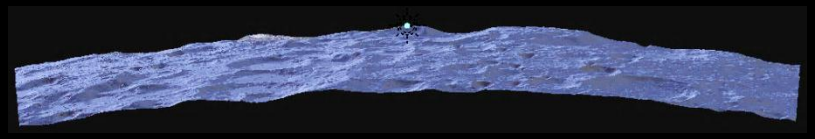
- Integrate high-resolution surface model (topography, lighting, thermal, communication) from recent lunar sources
- Develop rover model and route generator
- Compute lunar feature circumnavigation, regional sun-synchrony, and Magellan routes

Simulating Lunar Terrain and Lighting

DEM

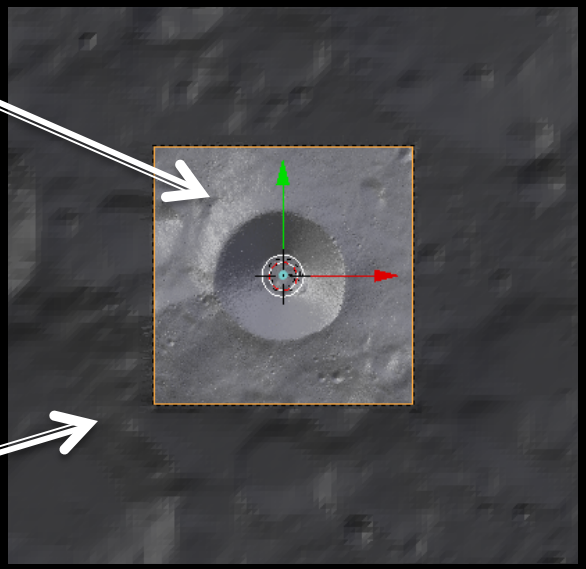


Reverse Projection



Hi-res Mesh in Frame

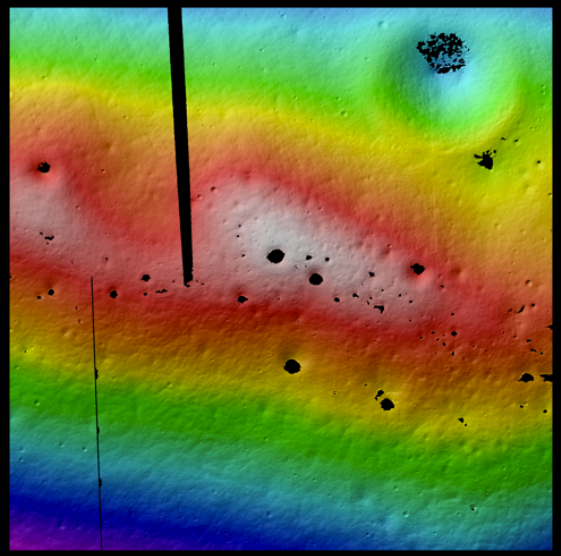
Low-res Mesh outside Frame



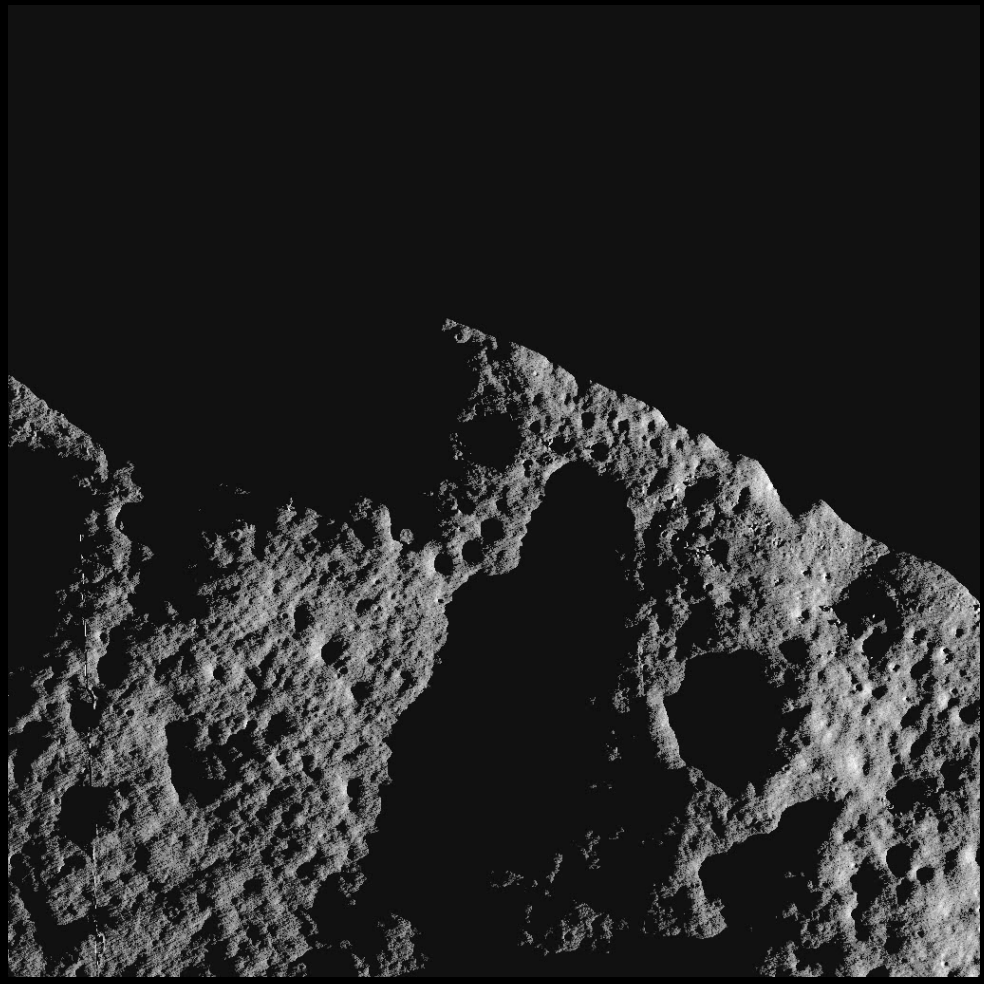
Render with Lighting

Shackleton Crater

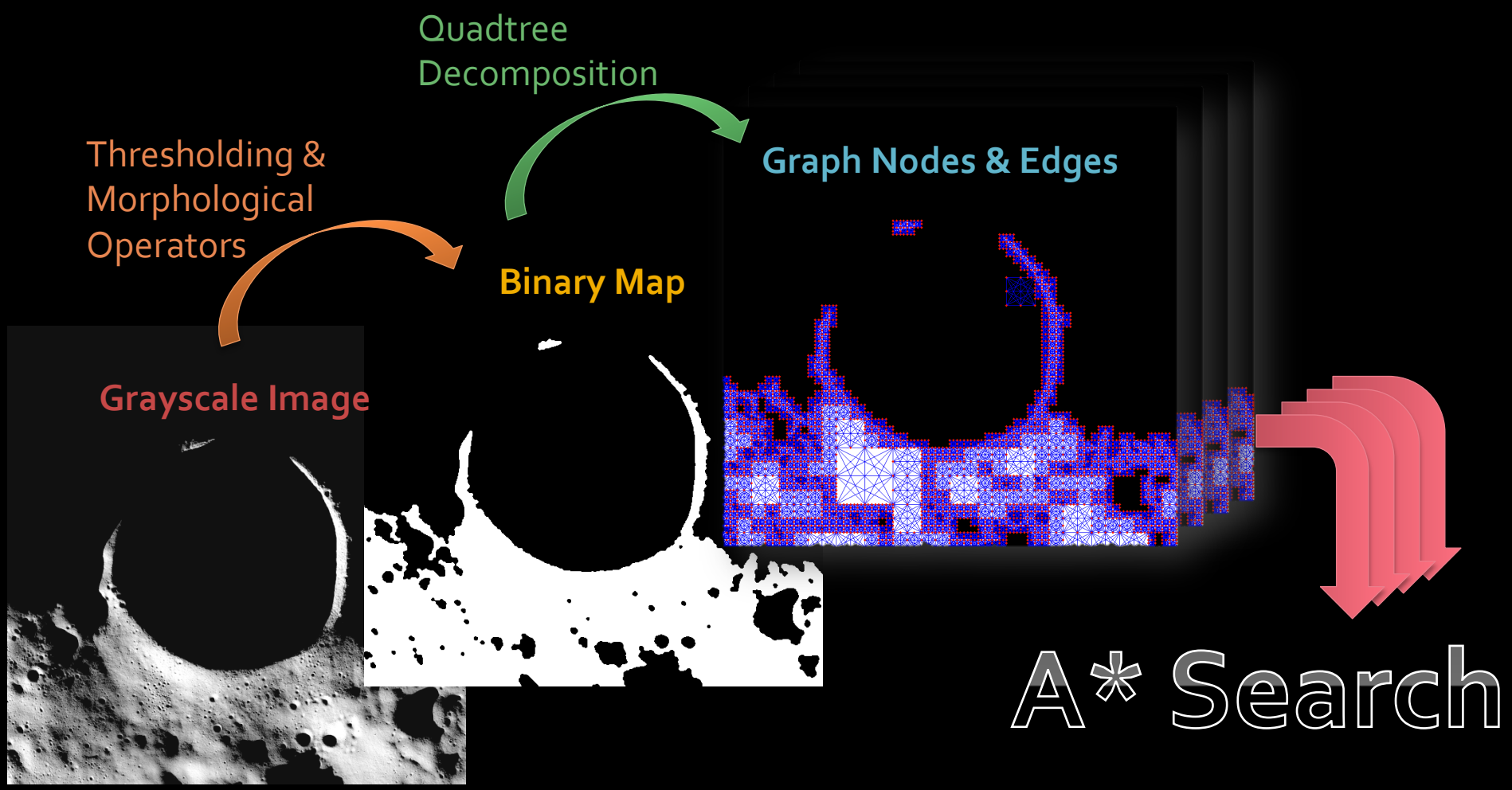
Malapert Peak



Malapert Summit Region, 84.9°S



Circumnavigation Route Planner



Shackleton Crater

Future Work

Upcoming

Year 1

- Collect vast, dispersed lunar data
- Build comprehensive lunar models
- Develop nomadic route planner
- Compute routes on the Moon

Year 2

- Incorporate thermal and communication modeling in planning
- Evaluate and identify best routes
- Consider execution (ground game)
- Generalize to Mercury and others

Thank You

Questions?

Carnegie Mellon University

THE ROBOTICS INSTITUTE

ASTROBOTIC

Additional Material

Mercury

- Technology
  - Extreme temperature electronics
  - Thermal transfer and regulation
  - Radiation / solar wind hardening
  - Localization and navigation
  - Health and resource maintenance
  - *In situ* radiometric age dating
  - High-bandwidth communication

Moon

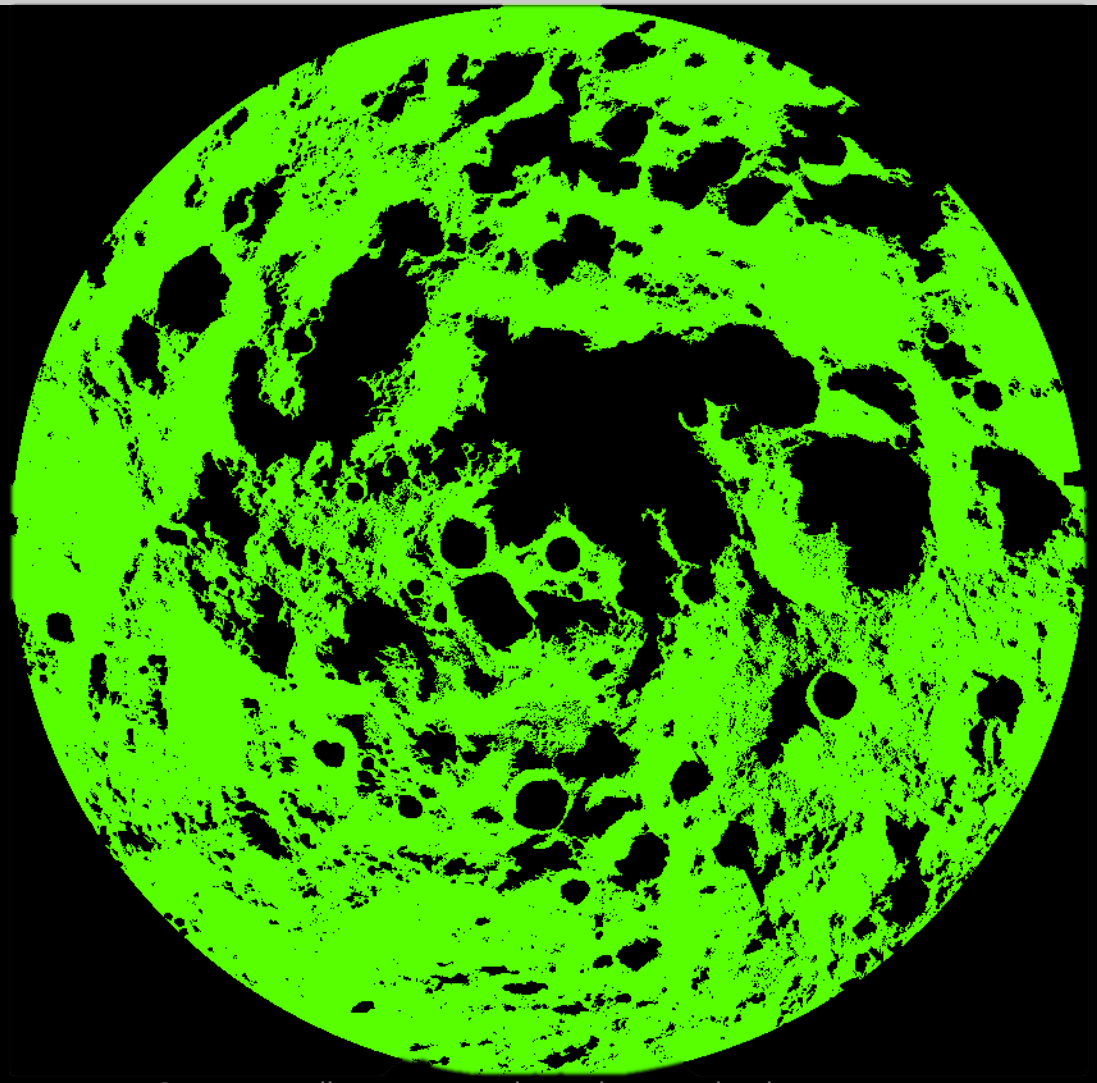
- Technology
  - High efficiency solar cells
  - Extreme surface mobility
  - Resource-cognizant navigation
  - Billion-cycle components
  - Robust batteries
  - Electrostatic dust mitigation
  - Subsurface access and shallow drilling
  - Miniaturized sample processing and instruments

Continuous Illumination

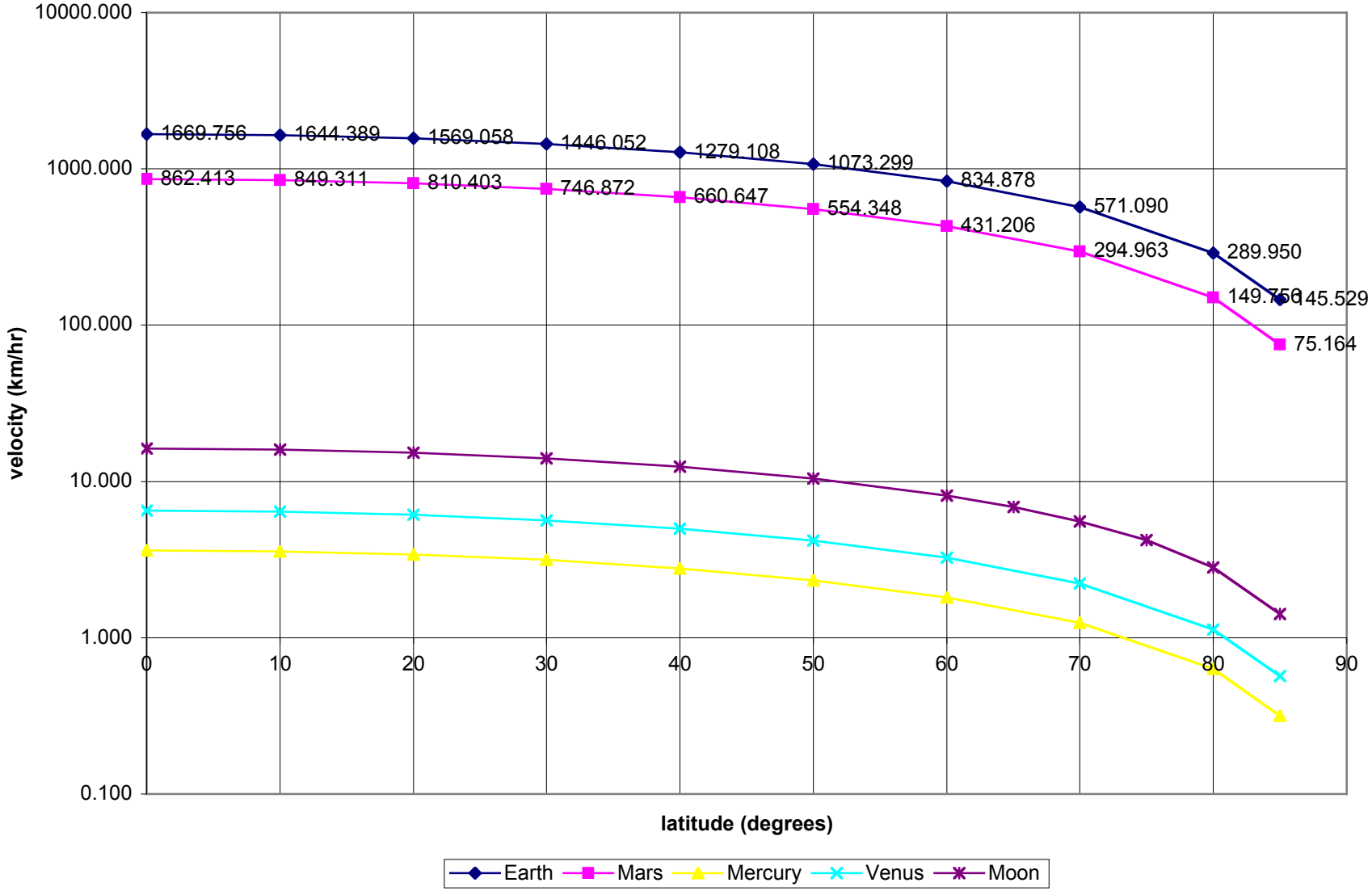
No/ [ ]	Site name	Lat./ [°]	(Hemisphere)	Long./ [°]	(Hemisphere)	Altitude/ [km]	Integral illum. time per year/[%]	Site extension/ [km^2]	Illum. period w/o shadows/ [h]	Illum. period 10 h shadow
1a	Mountain near Fincannon site F#1	88°49′	S	123°54′	E	1630	74.55	0.080	1174	1137
1b	Mountain near Fincannon site F#2	88°52′	S	132°29′	E	1421	75.97	0.666	4183	4220
2a	Shackleton A4	89°47′	S	54°	E	1420	78.76	0.168	2869	2947
2b	Shackleton A1	89°42′	S	161°55′	W	1681	83.26	0.058	2680	2855
2c	Shackleton A2	89°46′	S	153°18′	W	1713	78.68	0.058	3515	3515
2d	Shackleton A3	89°48′	S	154°47′	W	1660	73.52	0.168	1324	1320
2e	Shackleton A5	89°18′	S	131°07′	E	1276	71.10	0.125	2301	2333
3	Highest Polar Mountain within SPA	85°42′	S	116°32′	W	2873	79.21	**1.037**	1395	1393
4	Faustini Crater	87°46′	S	95°01′	E	0562	67.52	0.849	575	632
5a	Near Nobile Crater#1	85°18′	S	37°09′	E	**6748**	78.67	0.055	4584	4585
5b	Near Nobile Crater#2	85°34′	S	37°38′	E	6027	76.10	0.324	3771	3906
5c	Near Nobile–Leibniz Mountain	85°28′	S	31°06′	E	6290	73.54	0.529	4712	4757
6a	Malapert Mountain#1	85°58′	S	3°6′	W	4931	77.39	0.203	2692	2833
6b	Malapert Mountain#2	86°	S	2°10′	E	5137	73.73	0.608	4224	4708
7	de Gerlache Rim Mountain	88°41′	S	68°20′	W	1750	80.54	0.123	3835	4222
8	Connecting Ridge Shackleton/de Gerlache	89°28′	S	136°40′	W	1947	**85.71**	0.125	**5588**	**5588**

[Koebel 2012]

South Polar Connected Region



Velocity of One-day Circumnavigation

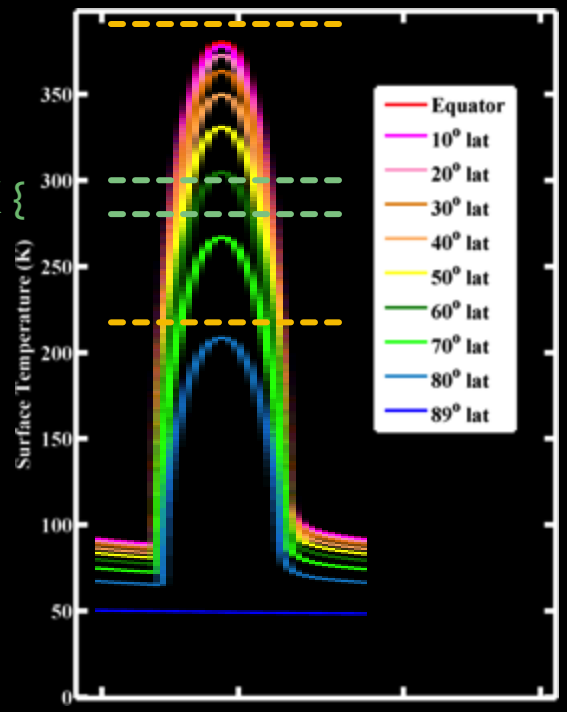


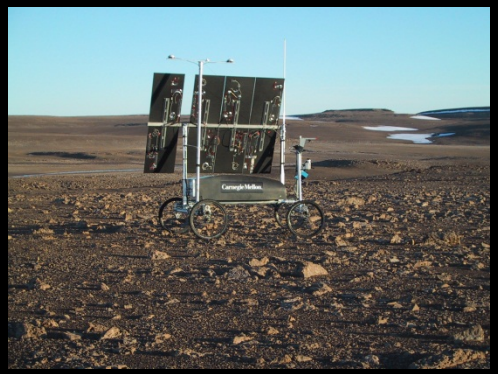
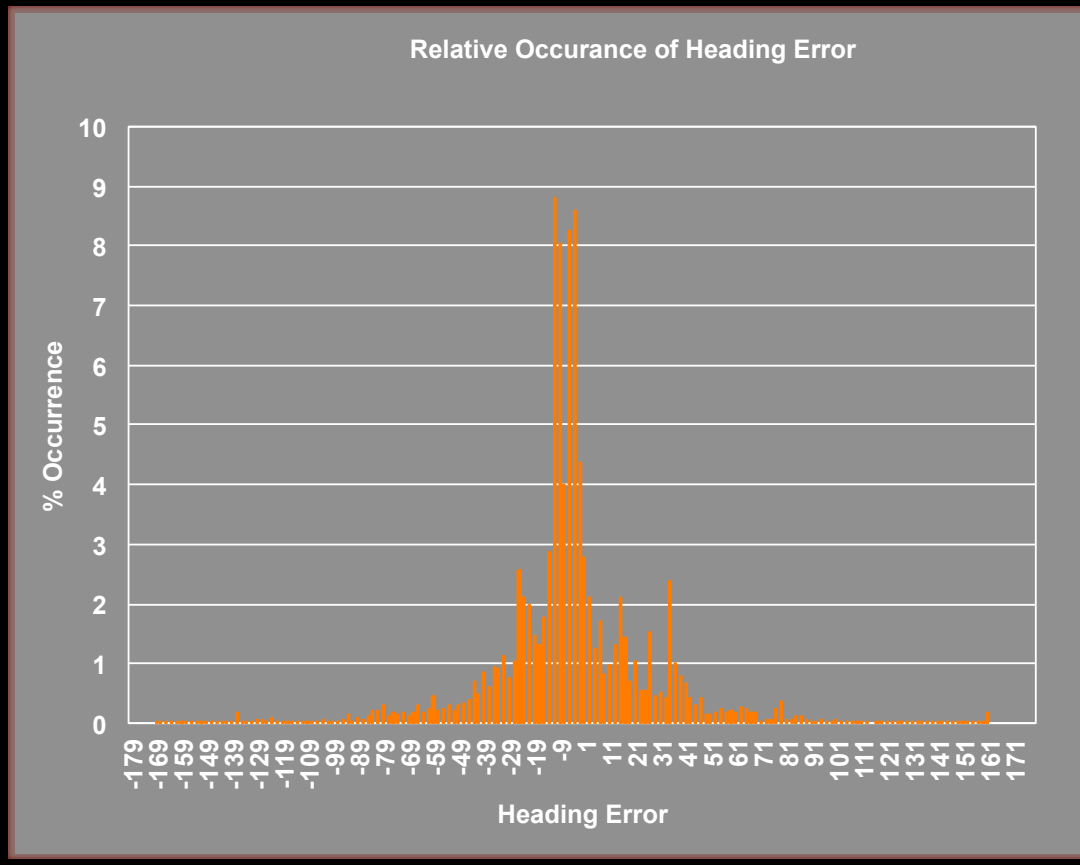
Moon

Mil Spec

Room Temp ± 10K {

Mil Spec



Sun-Synchronous Experiment

- Sun-synchrony
  - Average heading tracks path with average near zero
  - Some deviation including reversals