Human Robot Site Survey
2007 Haughton Crater Field Test

haughton2007.arc.nasa.gov

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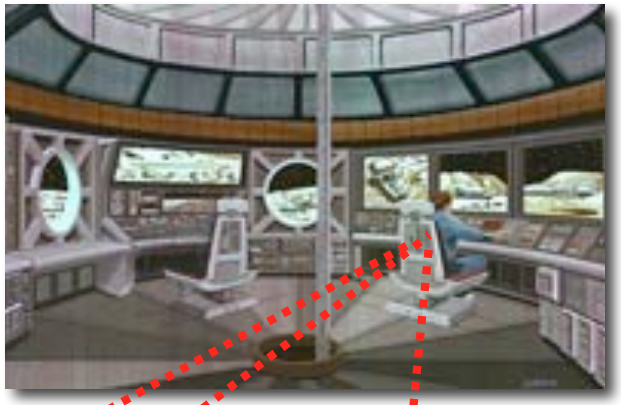
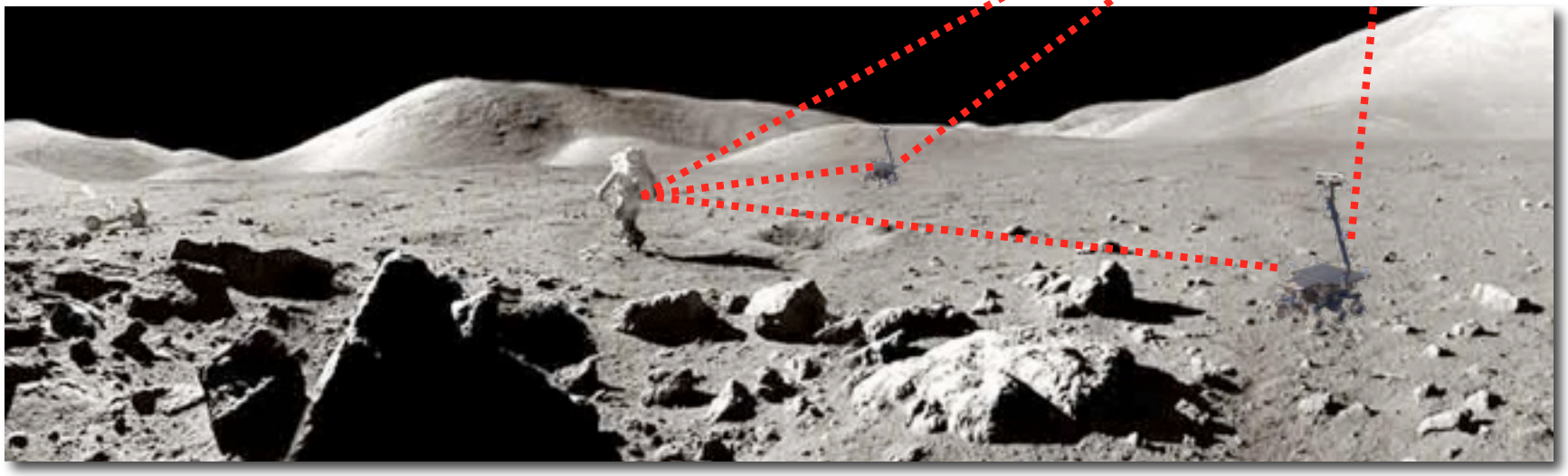
Human-Robot Site Survey Project

Systematic survey

- Civil engineering survey, geophysical study, resource prospecting, etc.
- Systematic, detailed coverage (necessary to ground-truth remote sensing)
- Unproductive for crew to perform manually (repetitive, tedious, time-consuming)





Source: T. Fong, M. Deans, et al., 2007. "Simulated Lunar Robotic Survey at Terrestrial Analog Sites" (Proc. LPSC)

Haughton Crater Field Test

10 July – 3 August 2007

- Two ARC K10 planetary rovers with survey instruments
  - 3D scanning lidar for topographic mapping
  - Ground-penetrating radar (GPR) for resource prospecting
- Test robotic survey systems and operational procedures
- Multiple lunar analog sites at Haughton Crater (Canada)

Haughton Crater
(Devon Island, Canada)

K10 rover

Field Test Location

Haughton Crater (75°22'N 89°41'W)

MARS INSTITUTE

CSA ASC

HAUGHTON-MARS PROJECT NASA CSA MARS INSTITUTE

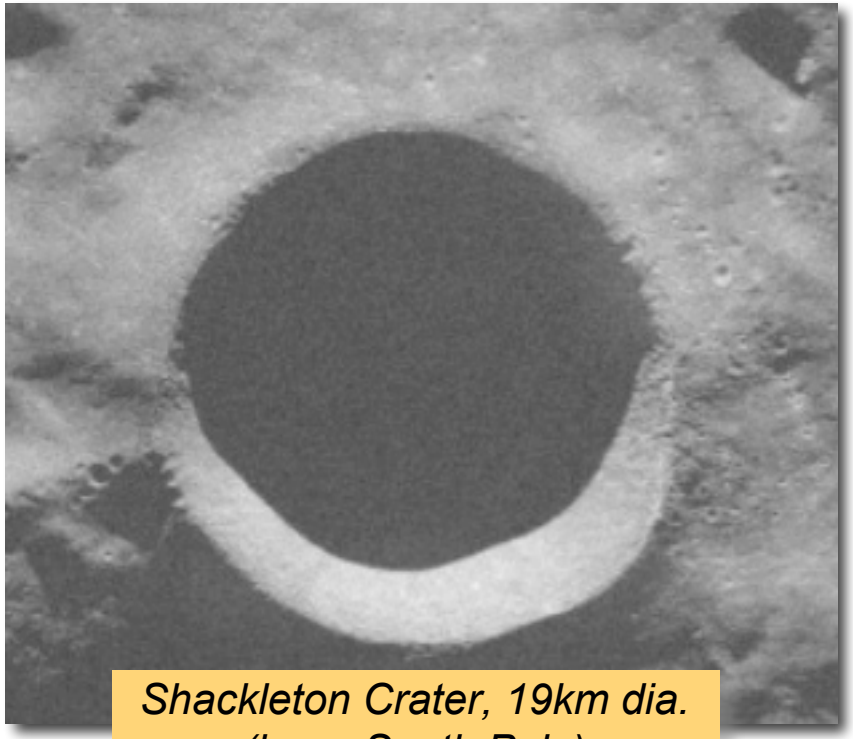
NASA

SETI INSTITUTE

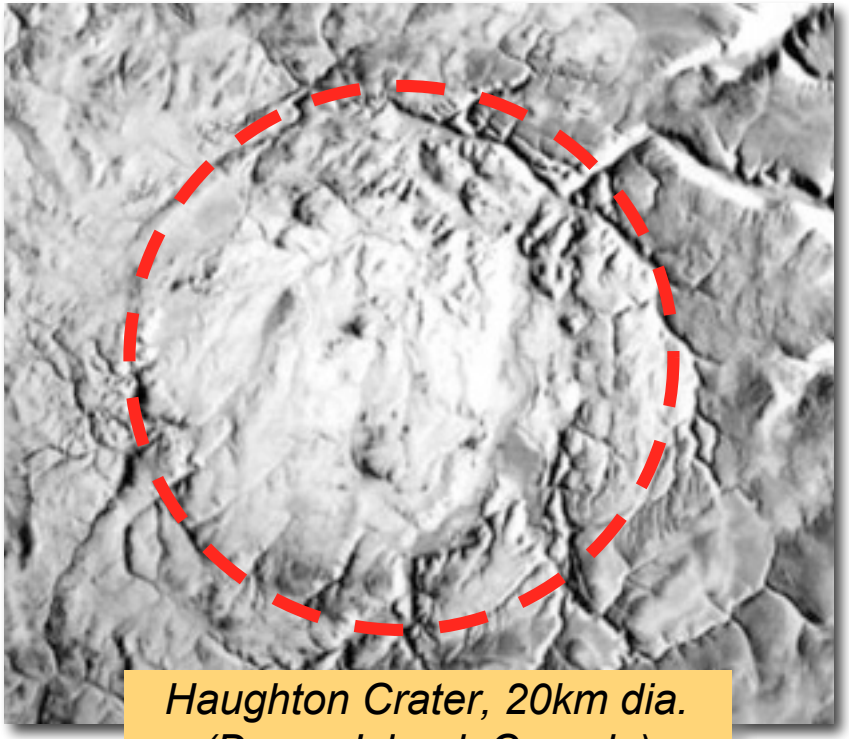
Haughton-Mars Project (marsonearth.org)

Haughton Crater: A Lunar Analog

Shackleton Crater at the South Pole of the Moon is 19 km in diameter and might present H_2O ice in surrounding shadowed zones. It is a prime candidate site for human exploration. Haughton Crater, also ~ 20 km in size, is by far the best preserved impact structure of its class on Earth and is located in a H_2O ground ice–rich rocky desert. Haughton may be the best overall ***scientific and operational analog for lunar craters such as Shackleton***.



Shackleton Crater, 19km dia.
(lunar South Pole)
2005 Arecibo radar image



Haughton Crater, 20km dia.
(Devon Island, Canada)
radar image

Field Test Conditions

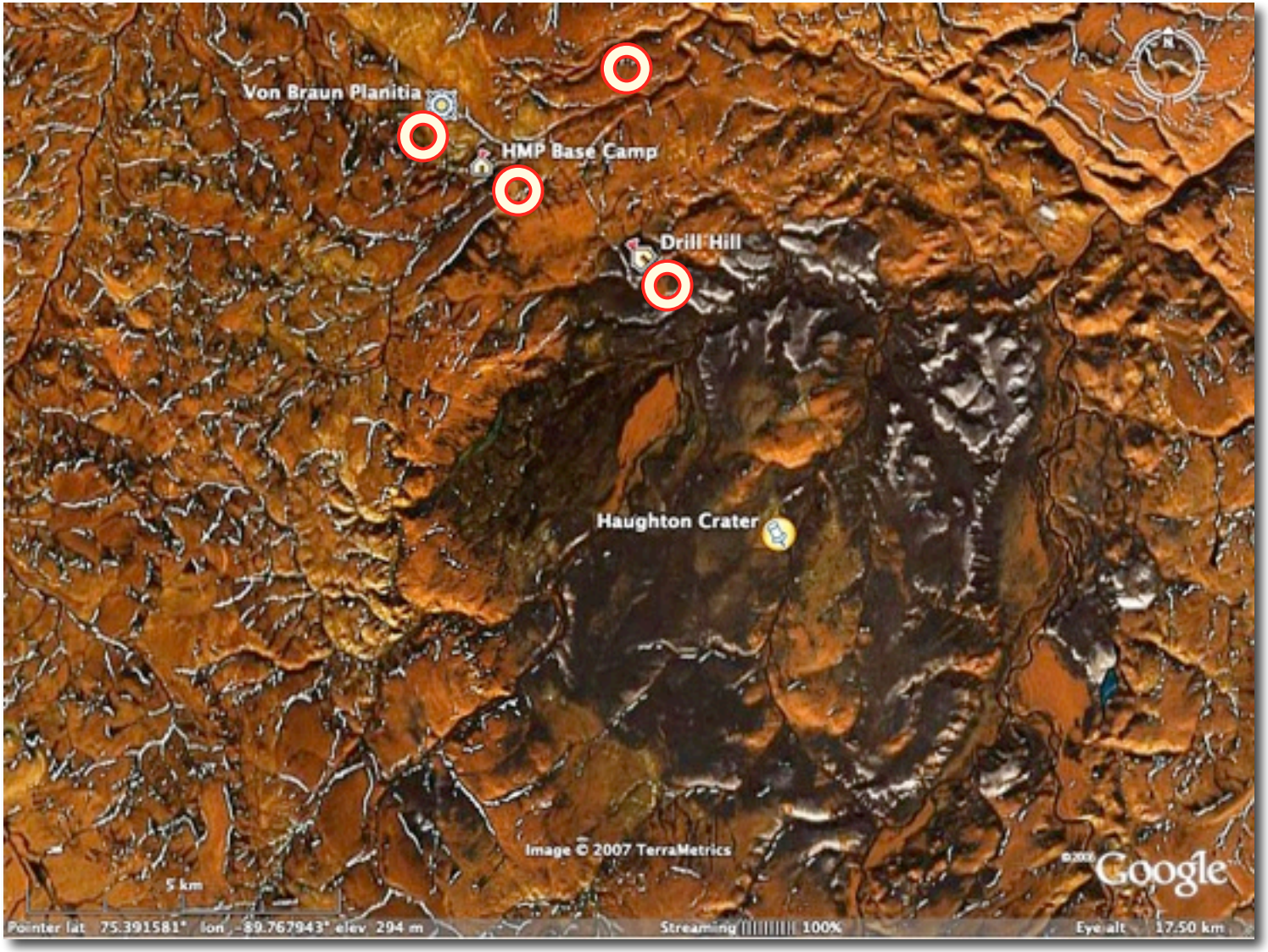
Weather (July)

- Winter in the high desert
- 0 to 15 deg C
- Mostly dry (some precipitation)
- Windy: 0 to 35 kt
- Mostly clear (clouds at 500 ft)

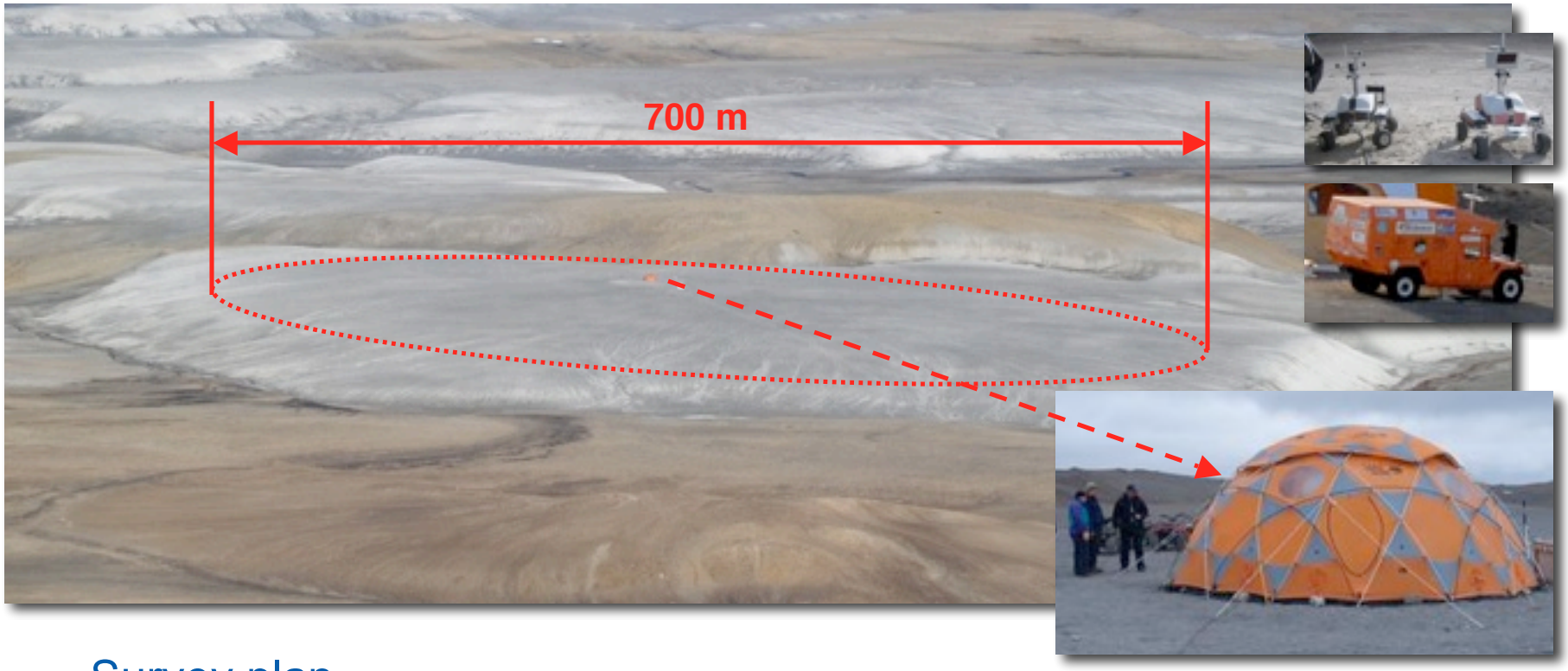
Environment

- Daylight 24/7
- Very, very dusty
- No vegetation
- Broad mixture of terrain

Survey Locations



“Drill Hill” Survey



Survey plan

- K10 robot on-site for 3 days
- HMMWV simulates pressurized rover (temporary habitat)
- Resource prospecting: subsurface ground-penetrating radar scans (parallel transects with 50 m spacing)

“Drill Hill” Survey

K10 robot path (real-time display on Google Earth)

Survey plan (parallel transects with 50 m spacing)

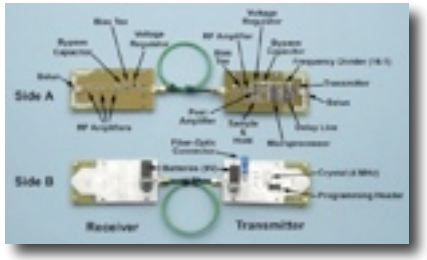
Survey Equipment

K10 rover (3rd generation)

- 4-wheel drive, 4-wheel steer
- Split rocker chassis
- Size: 1.3 x 0.9 x 1.0 m (HxWxL) with sensor mast
- Speed: 0.9 m/s (on 10 deg slope)
- Power: 1900 W (Li-ion batteries)
- Weight: 100 kg (including 25 kg payload)
- dGPS, stereo cameras, compass, 2D laser scanner

Optech ILRIS-3D (topographic mapping)

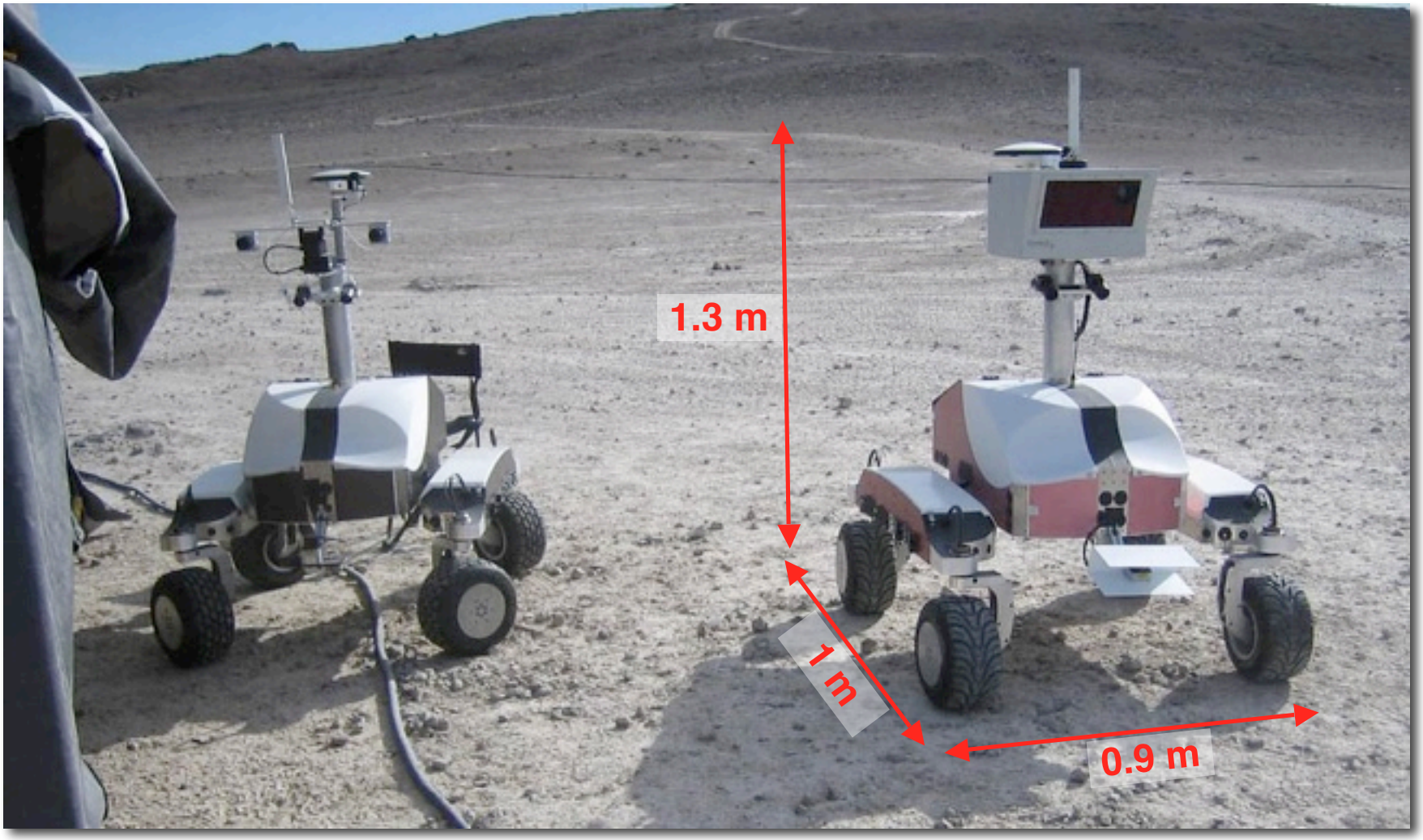
- Scanning 3D lidar with 40 deg FOV
- Range: 3 to 1,500 m
- Range accuracy: 7 mm @ 100 m



JPL CRUX GPR (subsurface mapping)

- Ground-penetrating radar
- 800 MHz center frequency
- 15 cm resolution to 5 m depth

K10's at Haughton



Access Routes

Equipment (CA ANG)

Field team (commercial air)

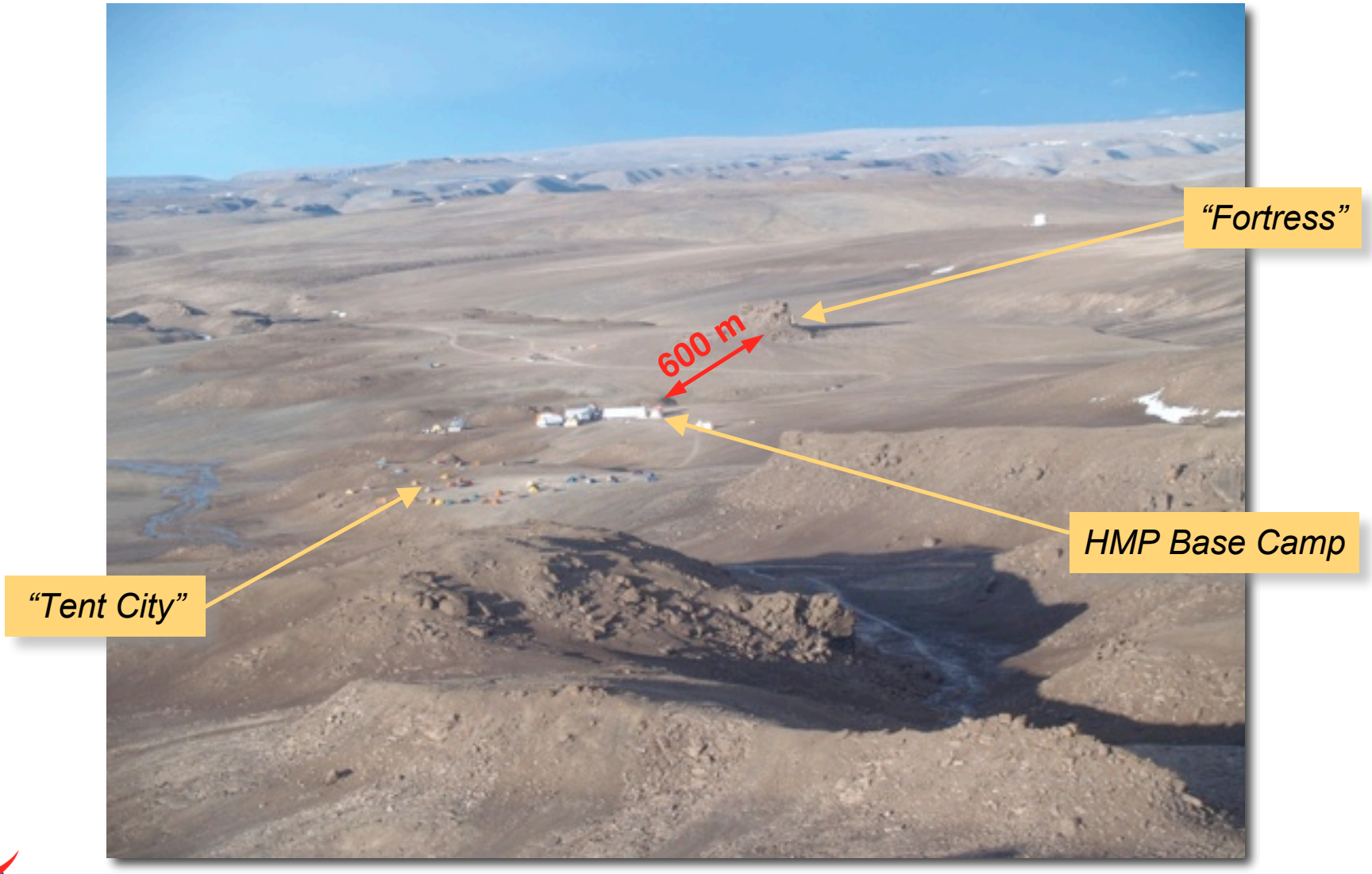
Haughton Field Team

Logistics

Field test equipment

- Two K10 robots, “FieldOps” gear, “HabOps” computers, spares, etc.
- 3,500 lbs. shipped from ARC (via C-130 and Twin Otter)
- Haughton-Mars Project: base camp, generators, satellite voice/data link

Approaching Haughton Crater



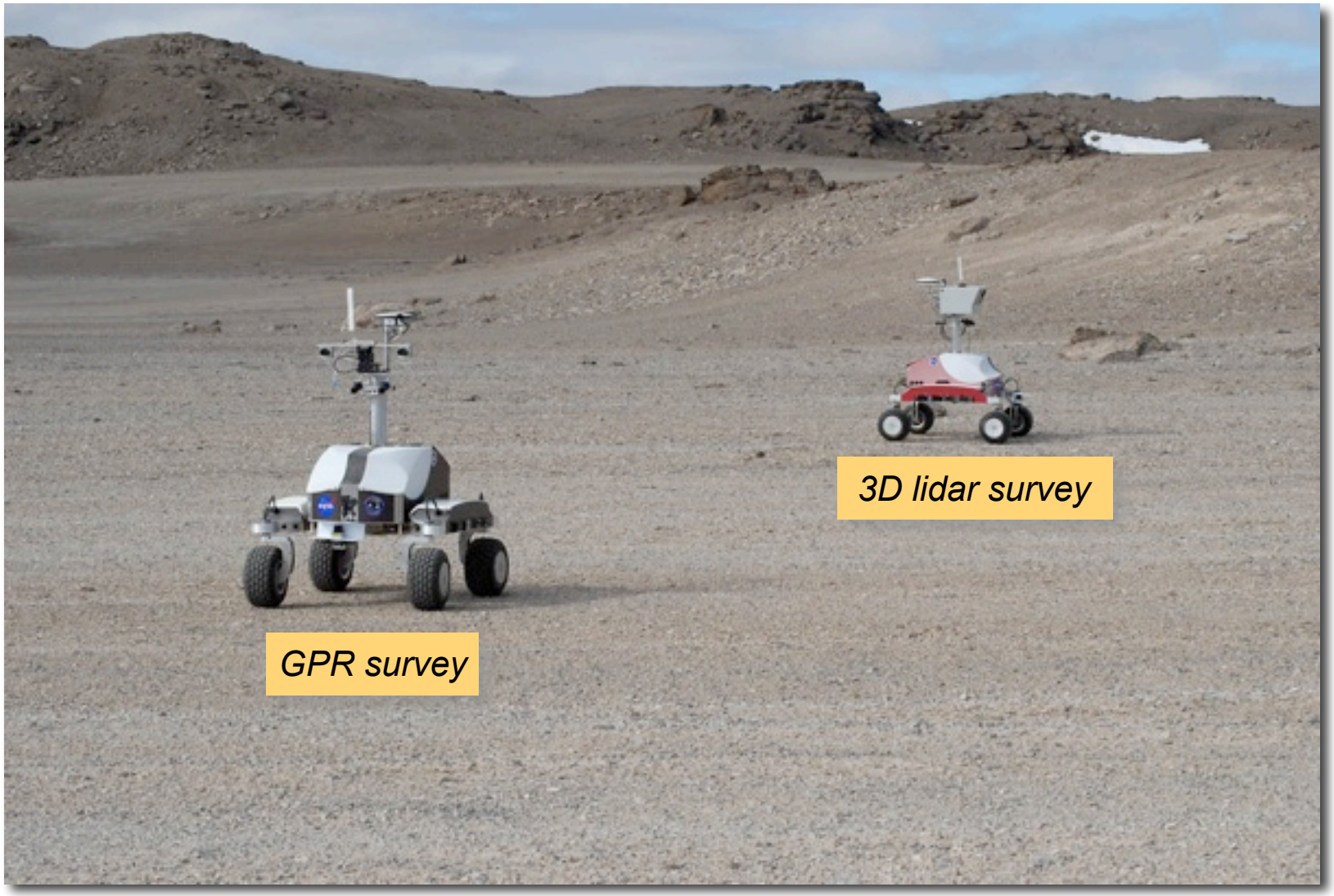
HMP Base Camp

Deployment

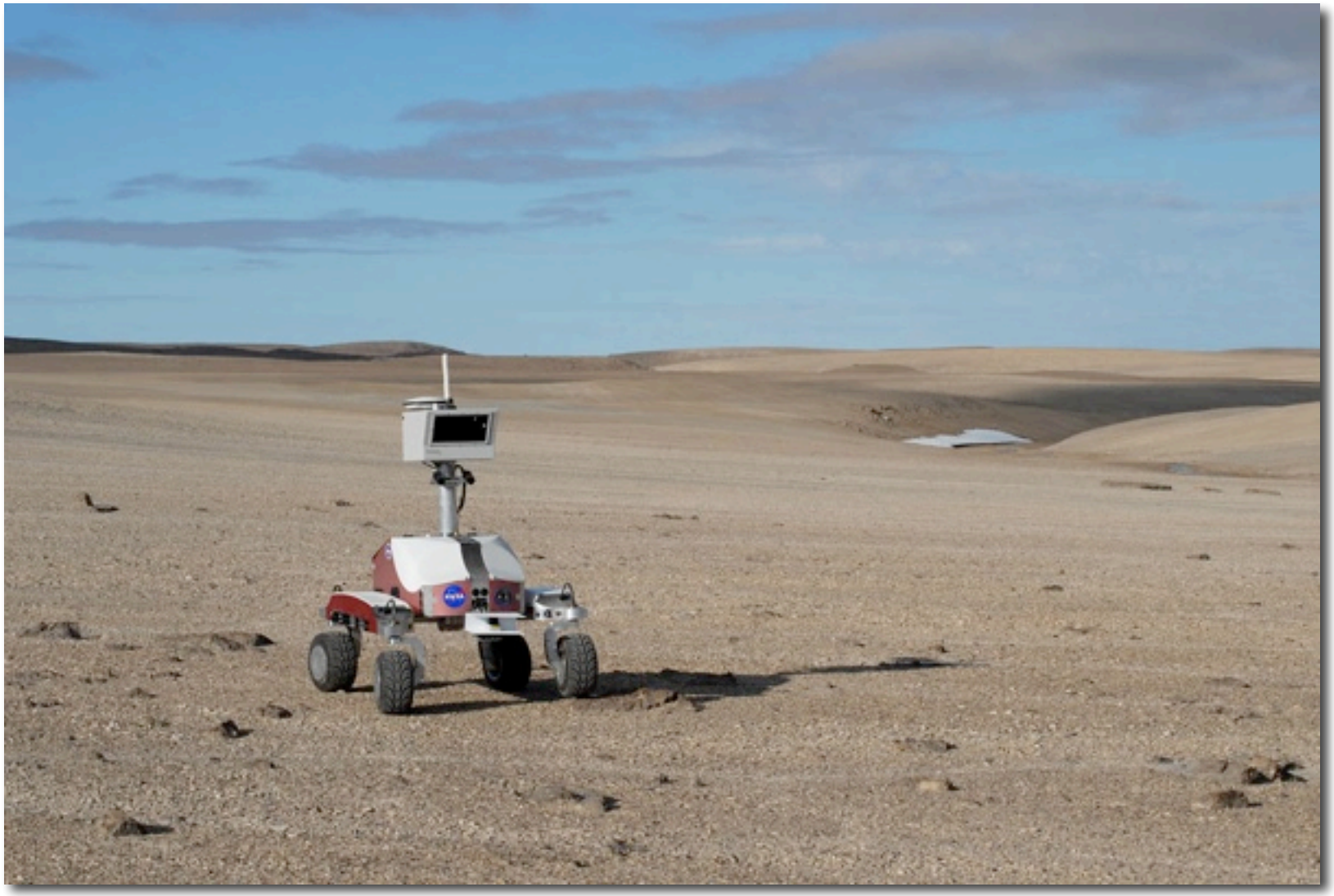
HMP Lodging

"Tent City"

K10's at Haughton



K10 Lidar Survey



K10 Lidar Survey

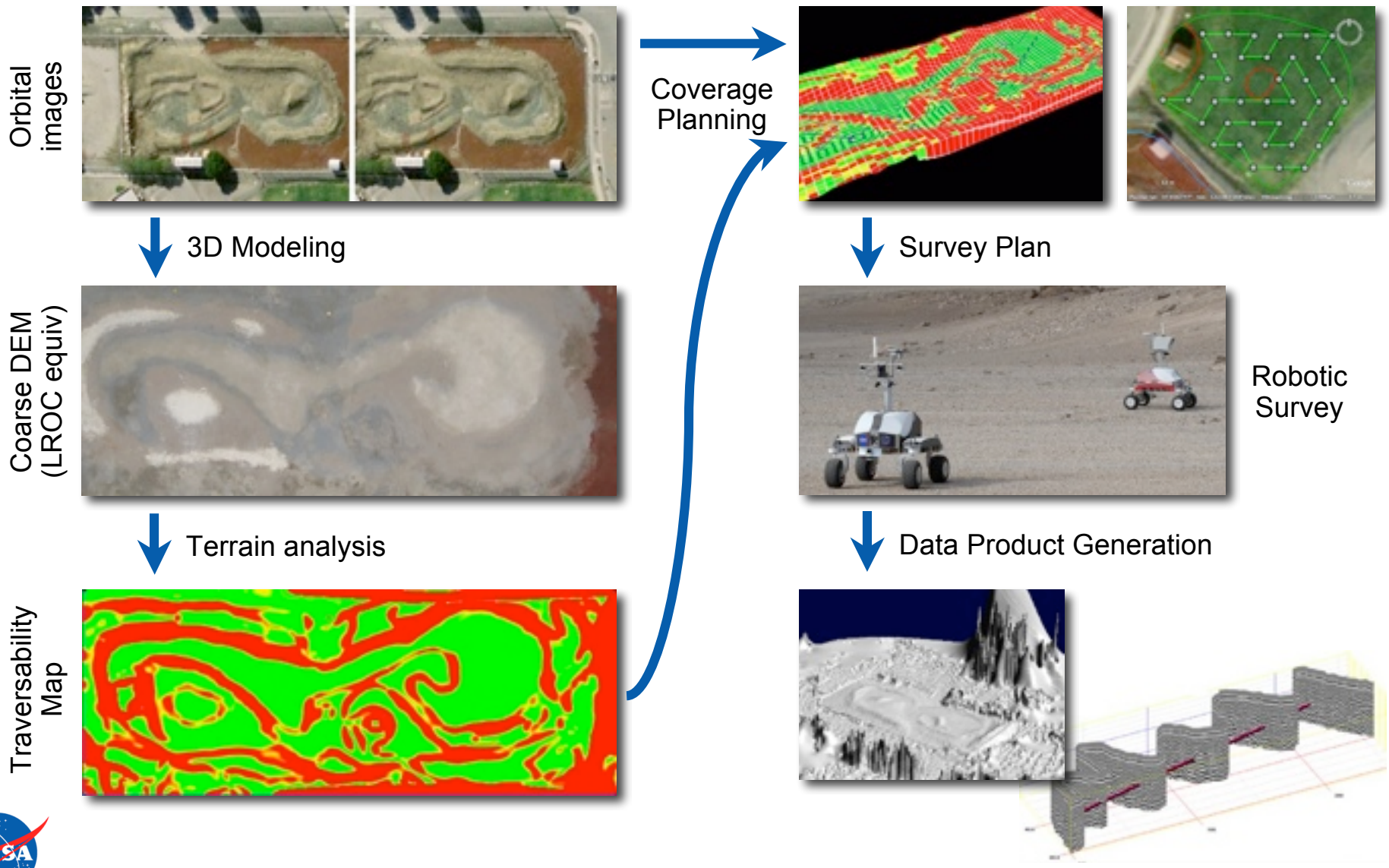
K10 Lidar Survey

K10 GPR Survey

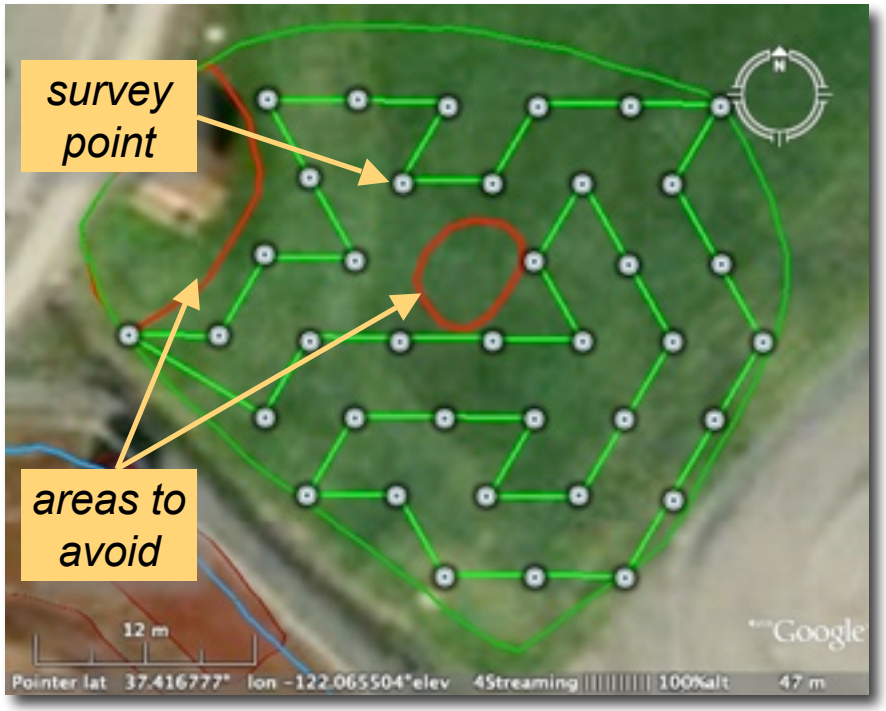
K10 GPR Survey

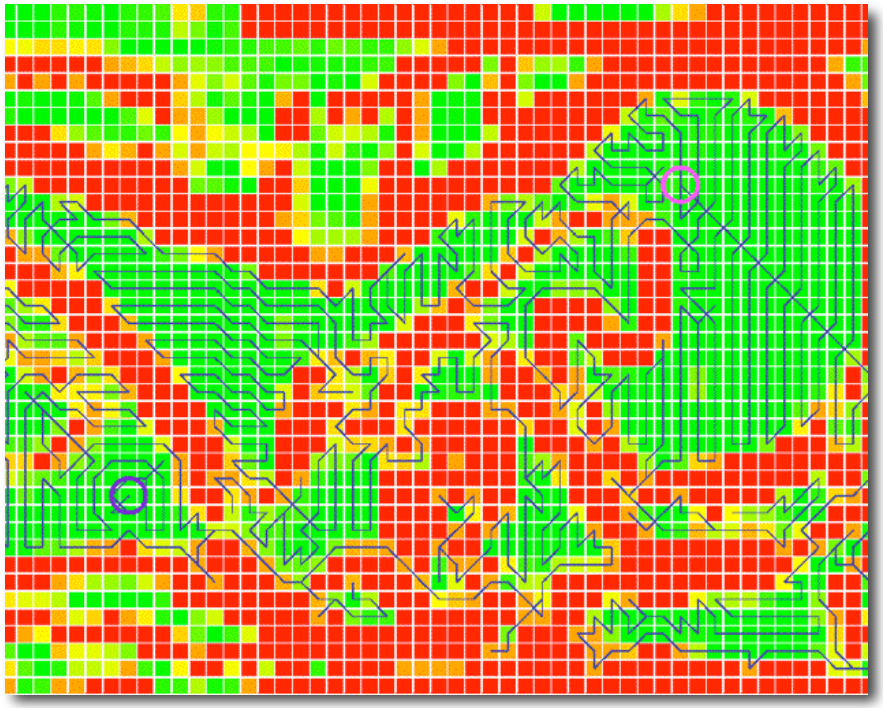
K10 GPR Survey

Site Survey Dataflow



Coverage Planning





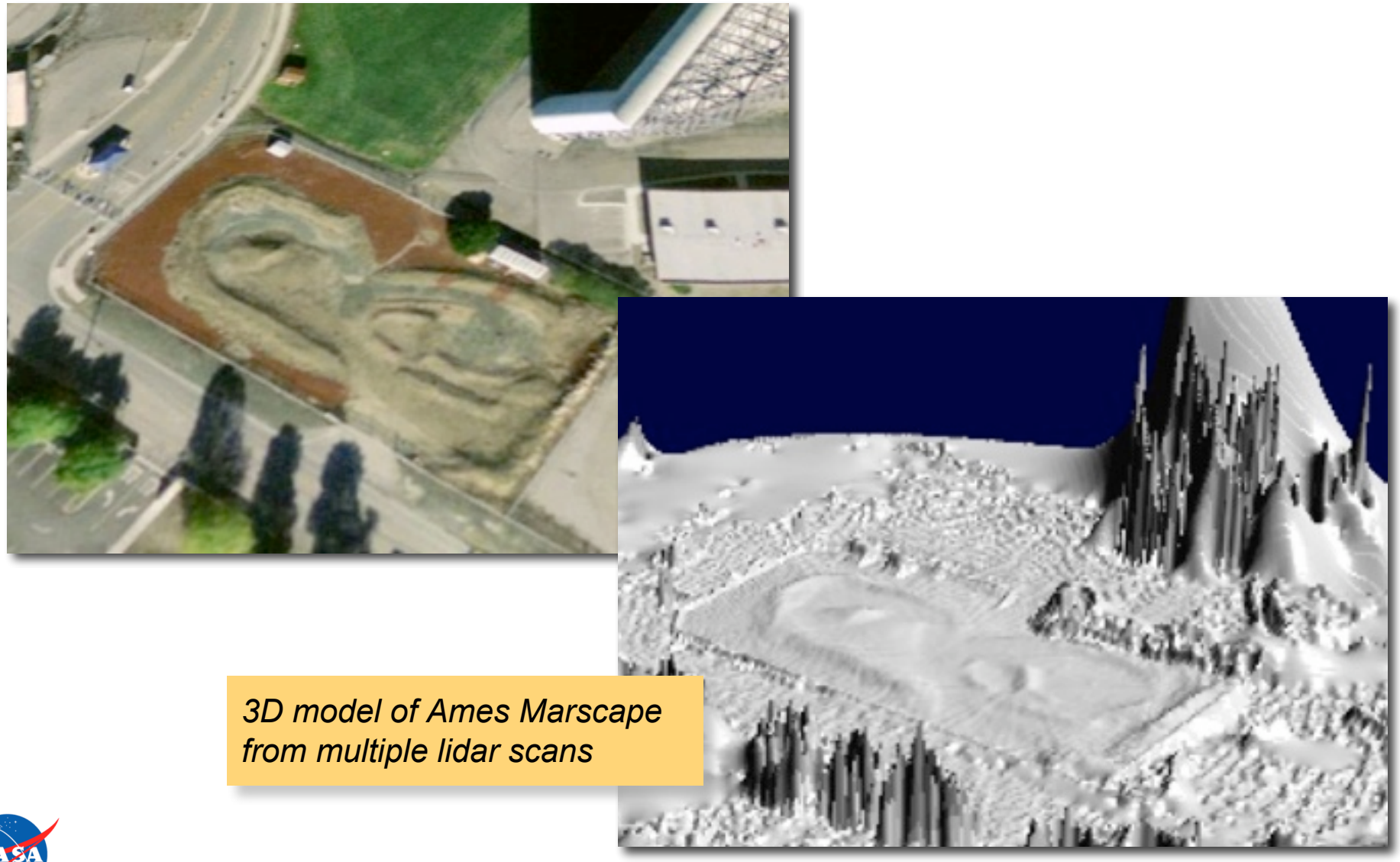
3D lidar

- Choose locations for taking panoramic scans
- Uniform sample spacing
- Google Earth + off-line planner

Ground-penetrating radar

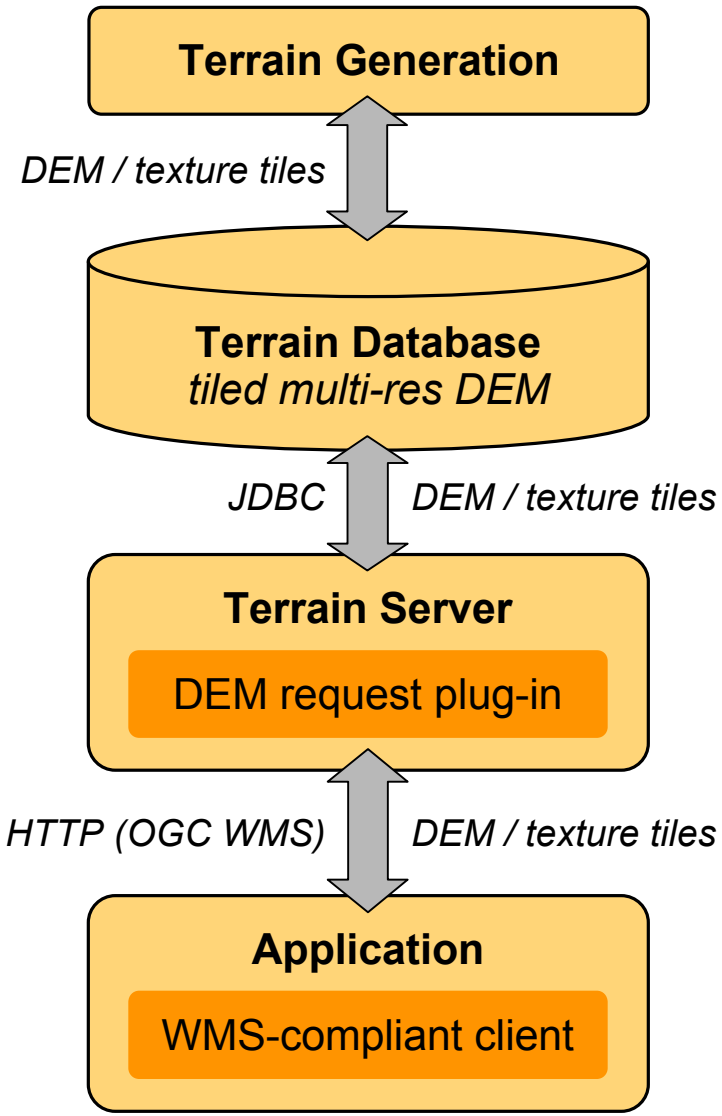
- Choose path for GPR scanning
- Line transect survey
- Grid-based “path transform” (Zelinsky et al. 1993)

3D Terrain Modeling



3D model of Ames Marscape from multiple lidar scans

Terrain Pipeline Dataflow



- Stereo imagers, 2D/3D lidar, etc.
- Stereo correlation
- Point cloud surface fitting

- Iterative Closest Point alignment
- Image/feature based correspondence
- Incremental update & source data

- Terrain patch creation
- DEM output conversion (e.g., image)

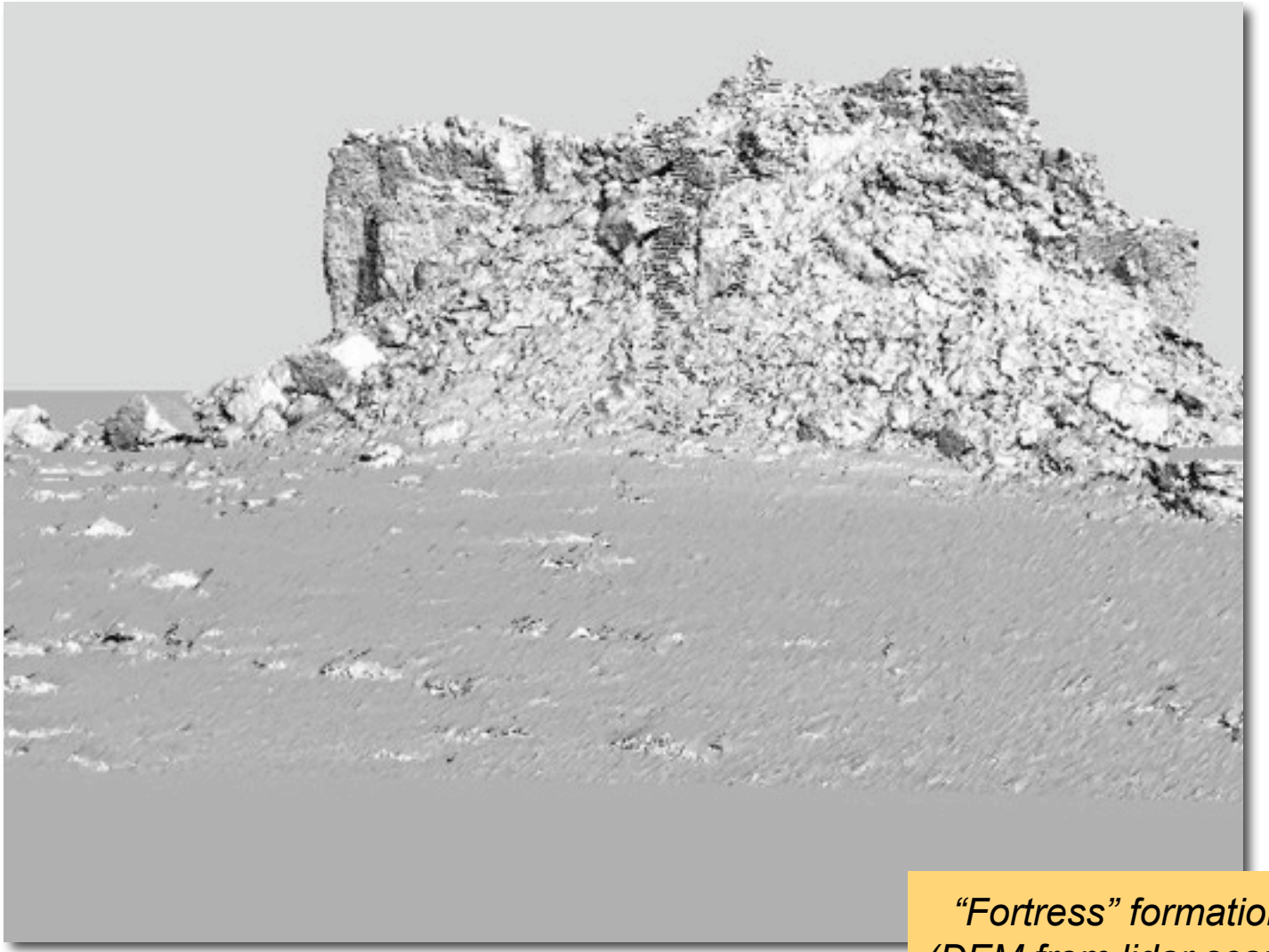
- JPEG 2000 + meta-data
- Viz 3D UI, Google Earth, etc.

3D Terrain Modeling

K10 Red lidar survey

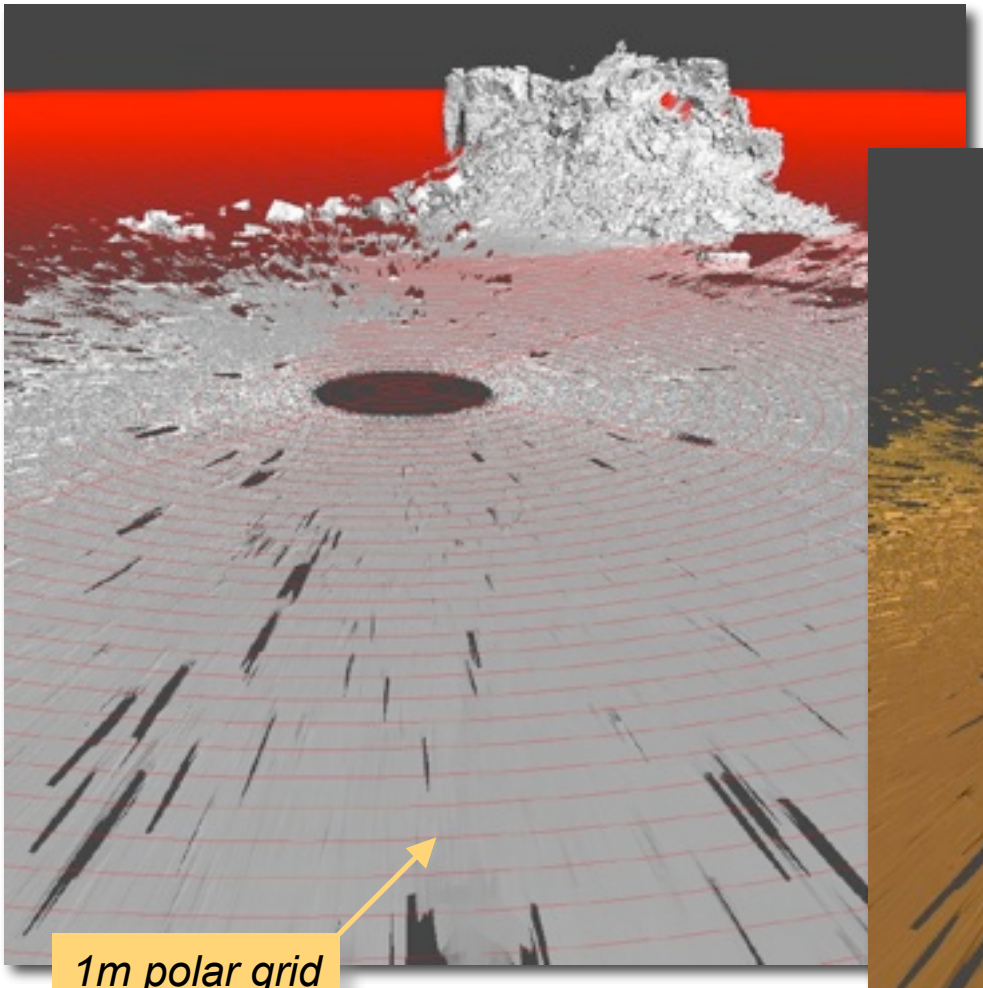
"Fortress" formation near HMP base camp

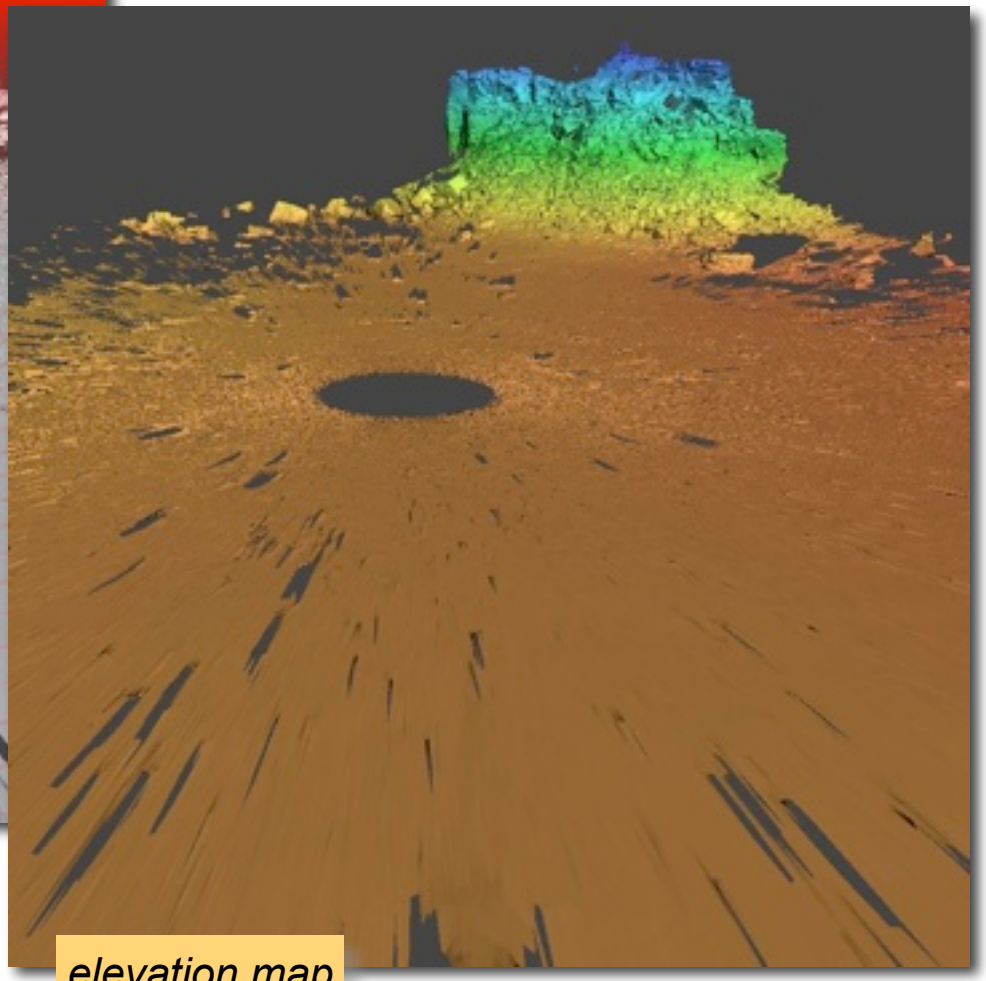
3D Terrain Modeling



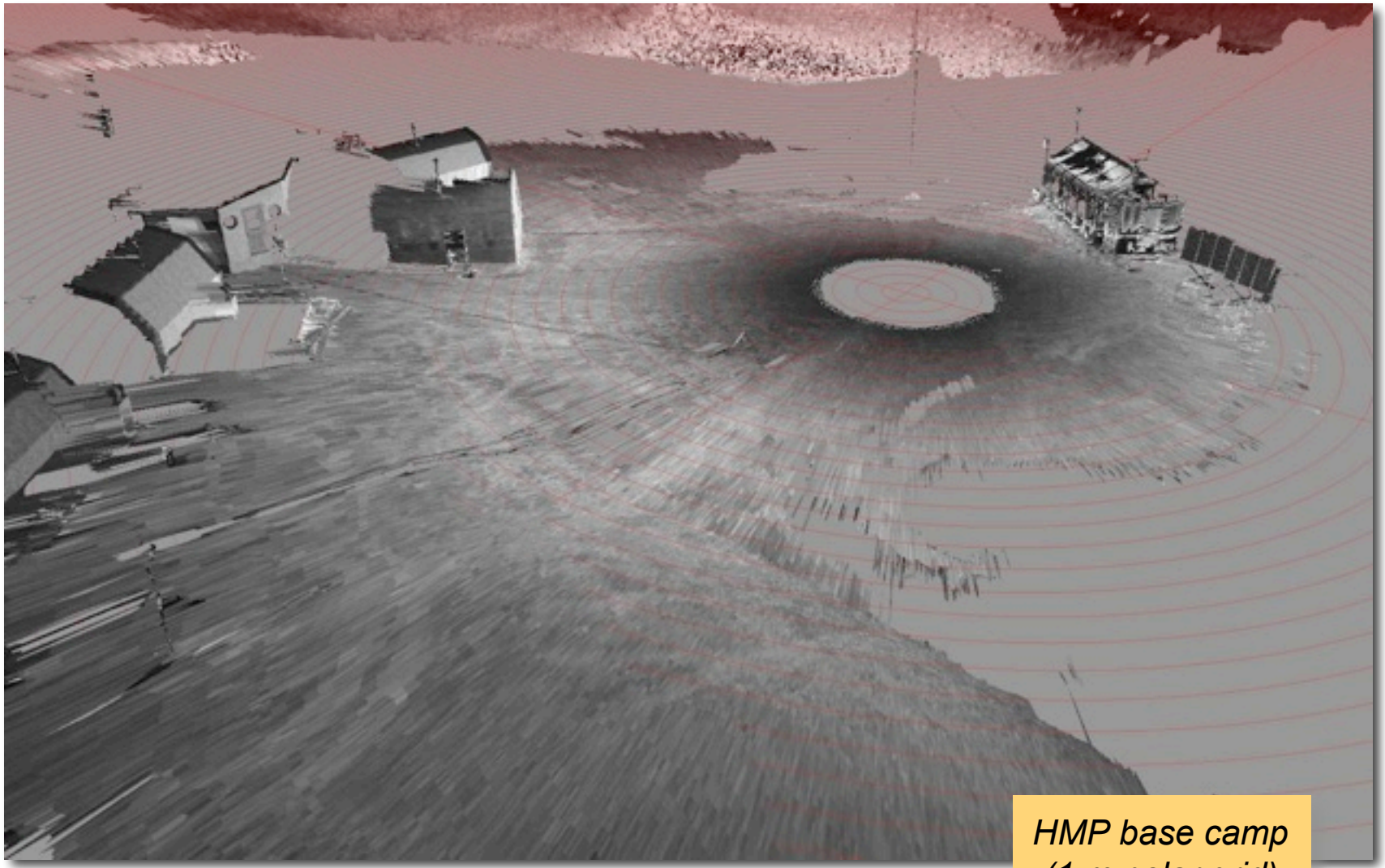
"Fortress" formation
(DEM from lidar scans)

3D Terrain Modeling



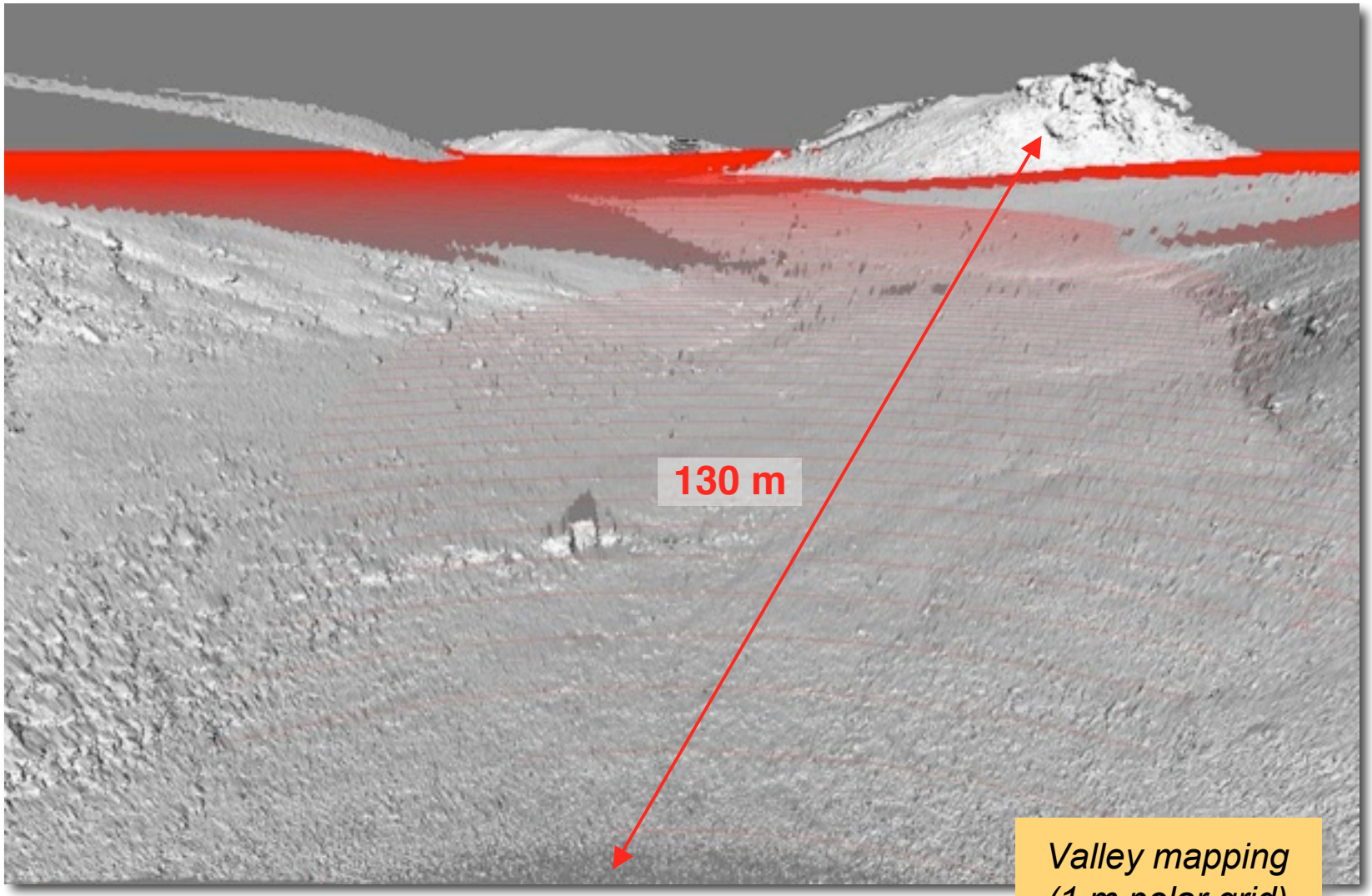


3D Terrain Modeling



HMP base camp (1 m polar grid)

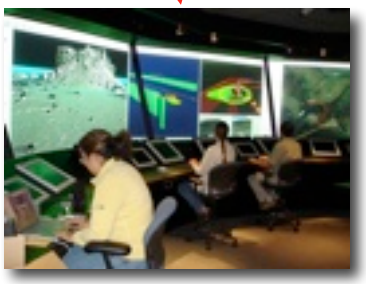
3D Terrain Modeling



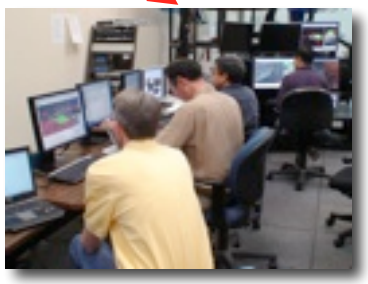
Valley mapping
(1 m polar grid)

Remote Operations

Haughton Crater (75°22'N 89°41'W)



ARC



JSC

Ground Ops

"Lunar Outpost"

"Mobile Habitat"

IVA Ops

IVA Ops (“Lunar Outpost”)

IVA Ops (“Mobile Habitat”)

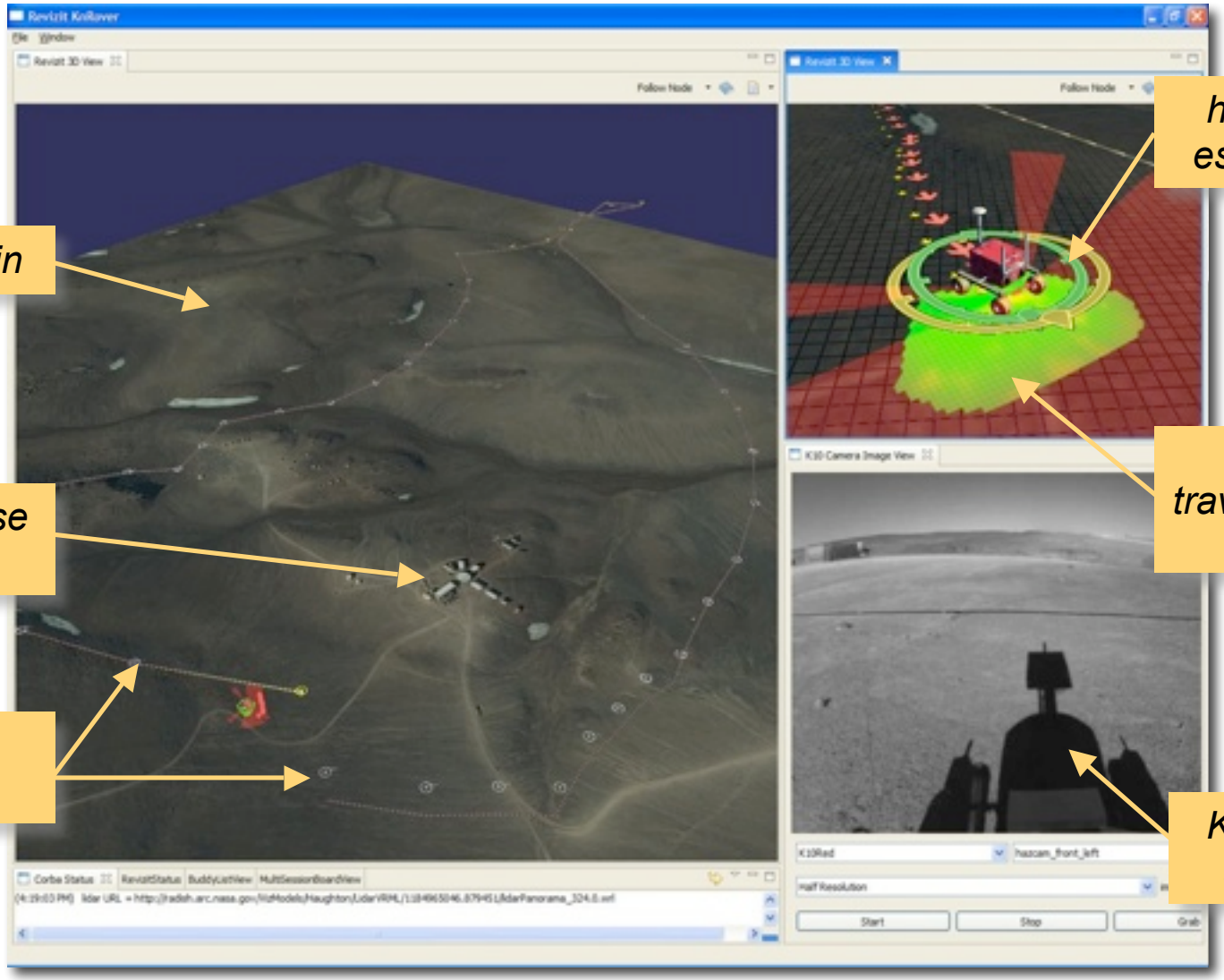
Ground Ops (JSC Code ER “Cockpit”)

Ground Ops (JSC Code ER “Cockpit”)

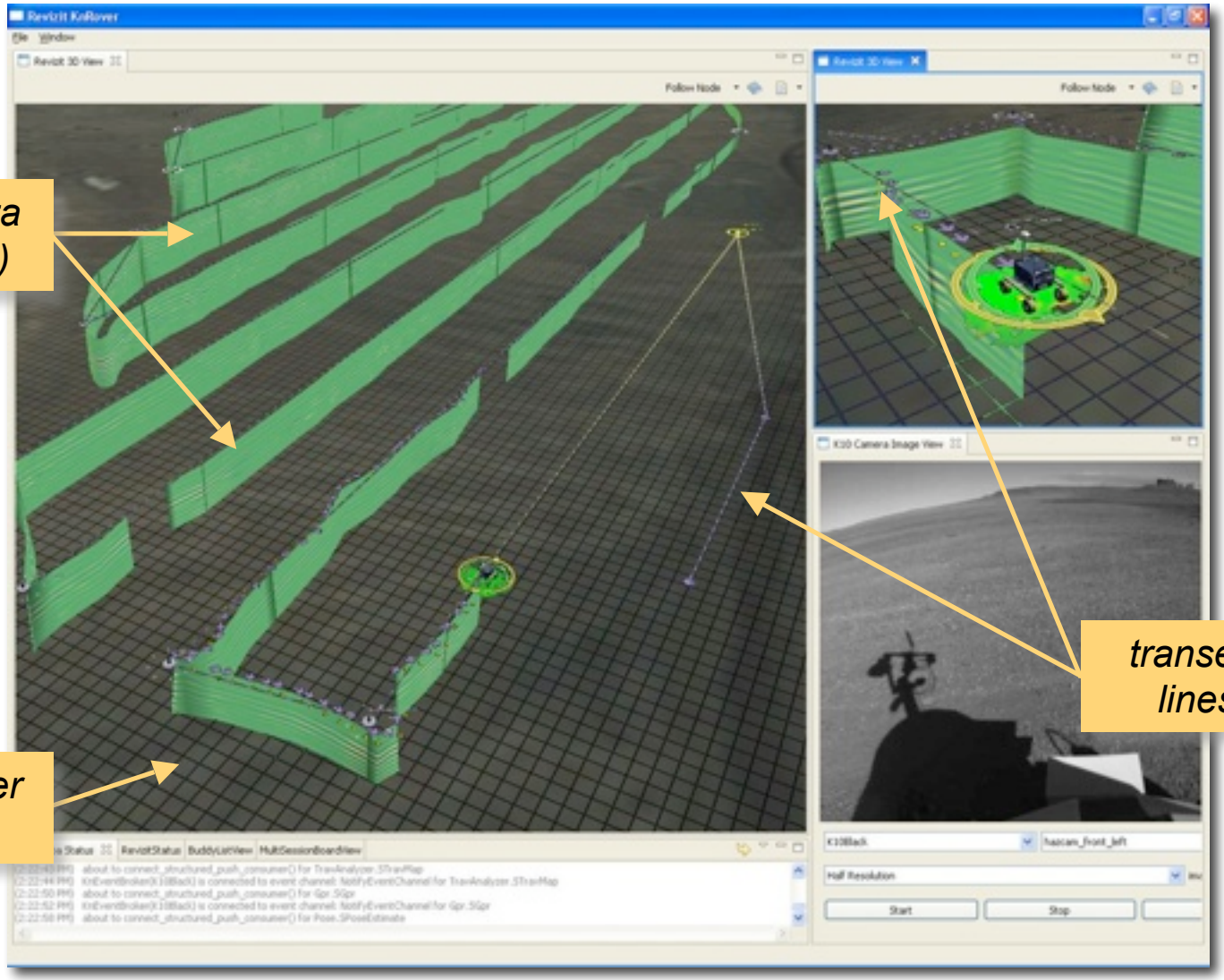
Ground Ops (ARC)

Viz Explorer

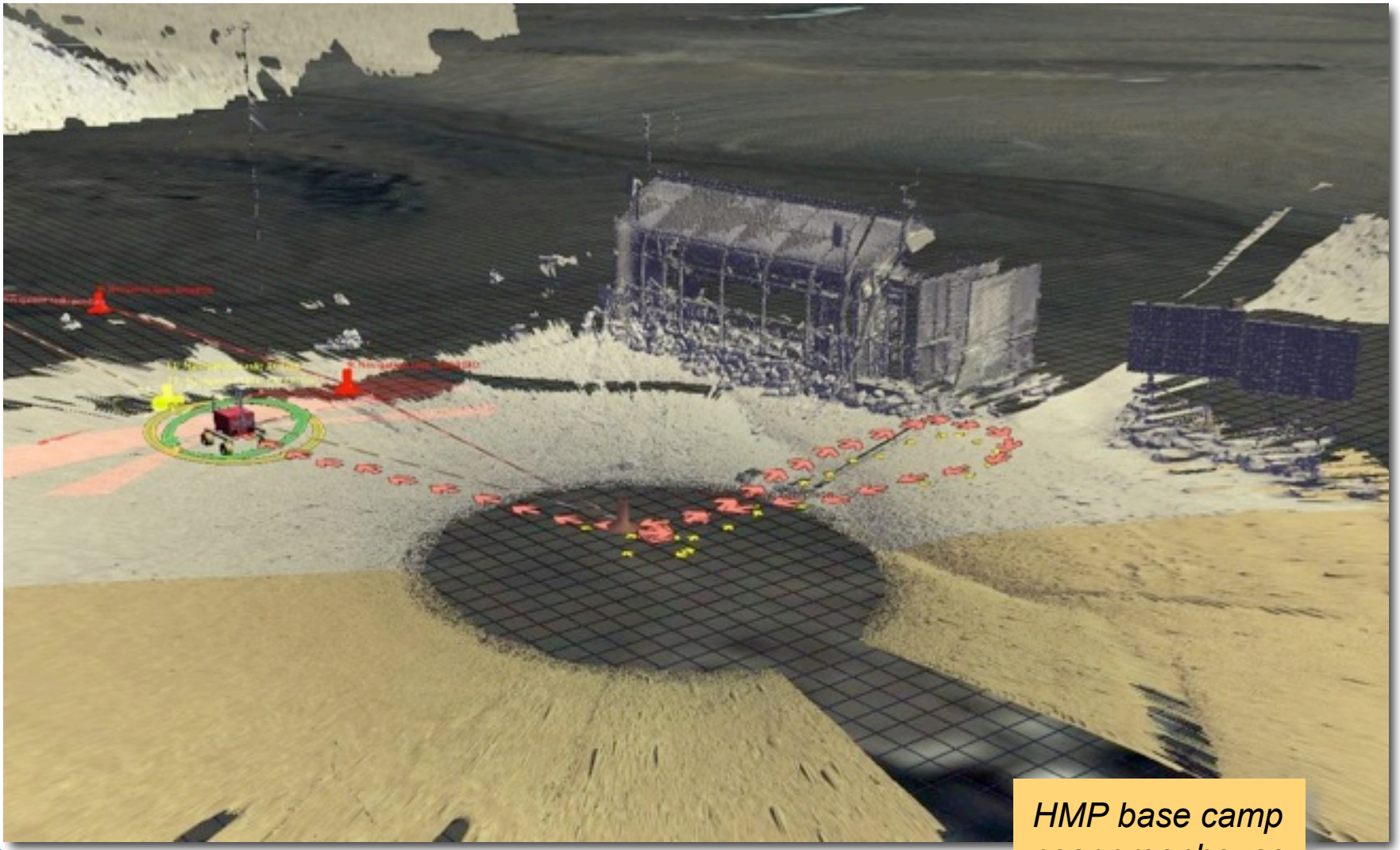
Lidar Survey Displays



GPR Survey Displays



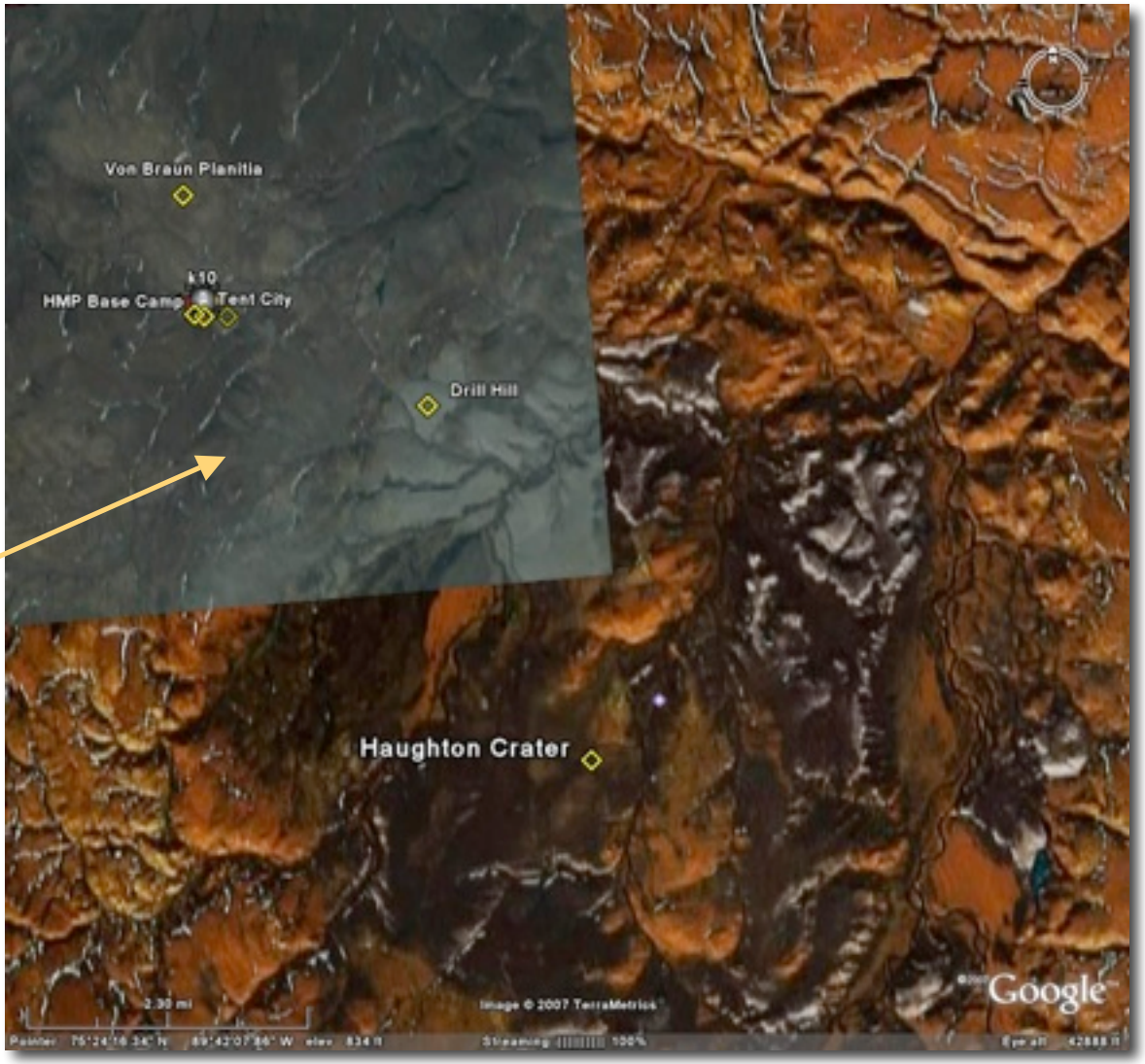
HMP Base Camp Survey (20 July 2007)



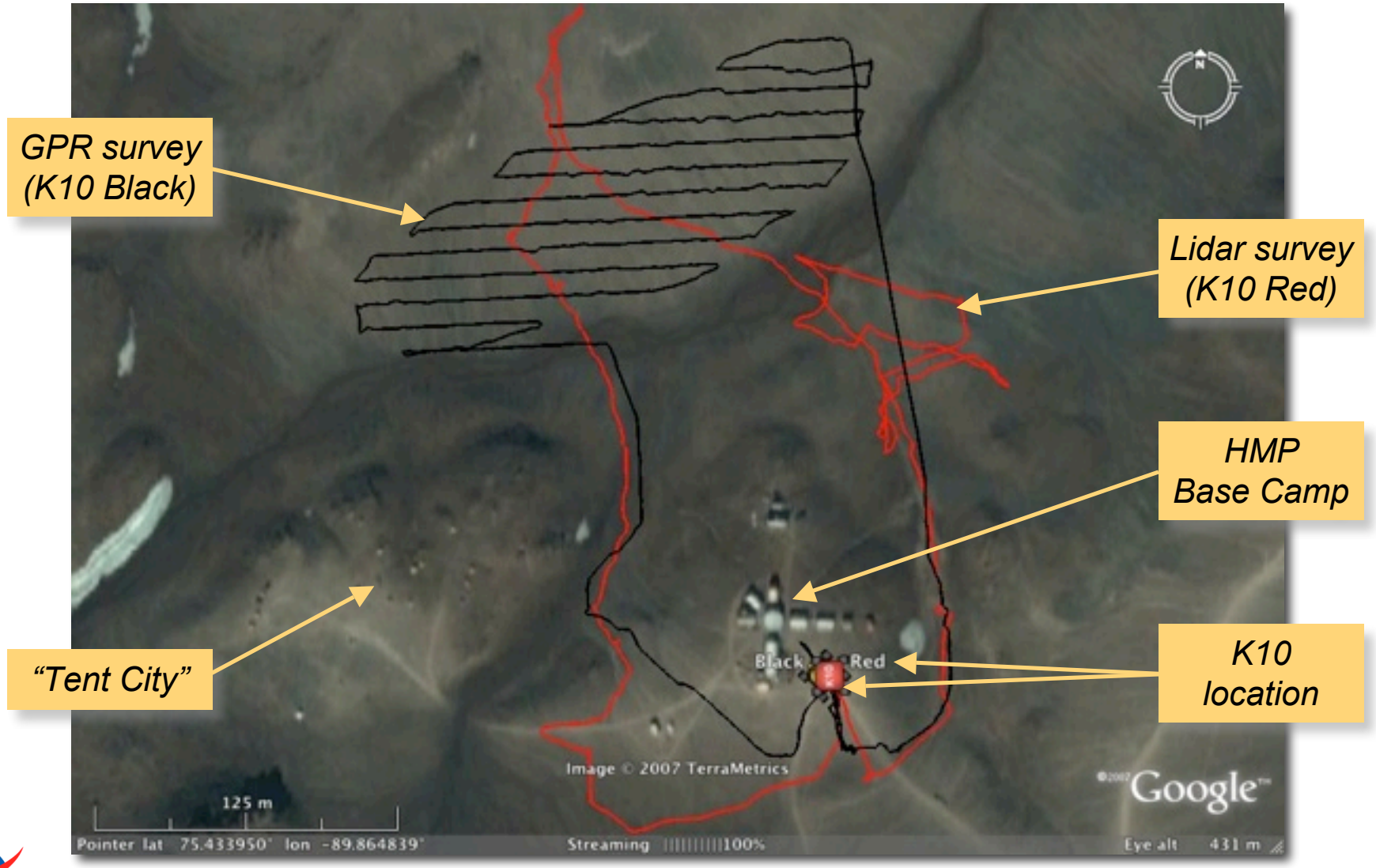
HMP base camp near greenhouse

Google Earth

Satellite image overlay



HMP Base Camp Survey (20 July 2007)



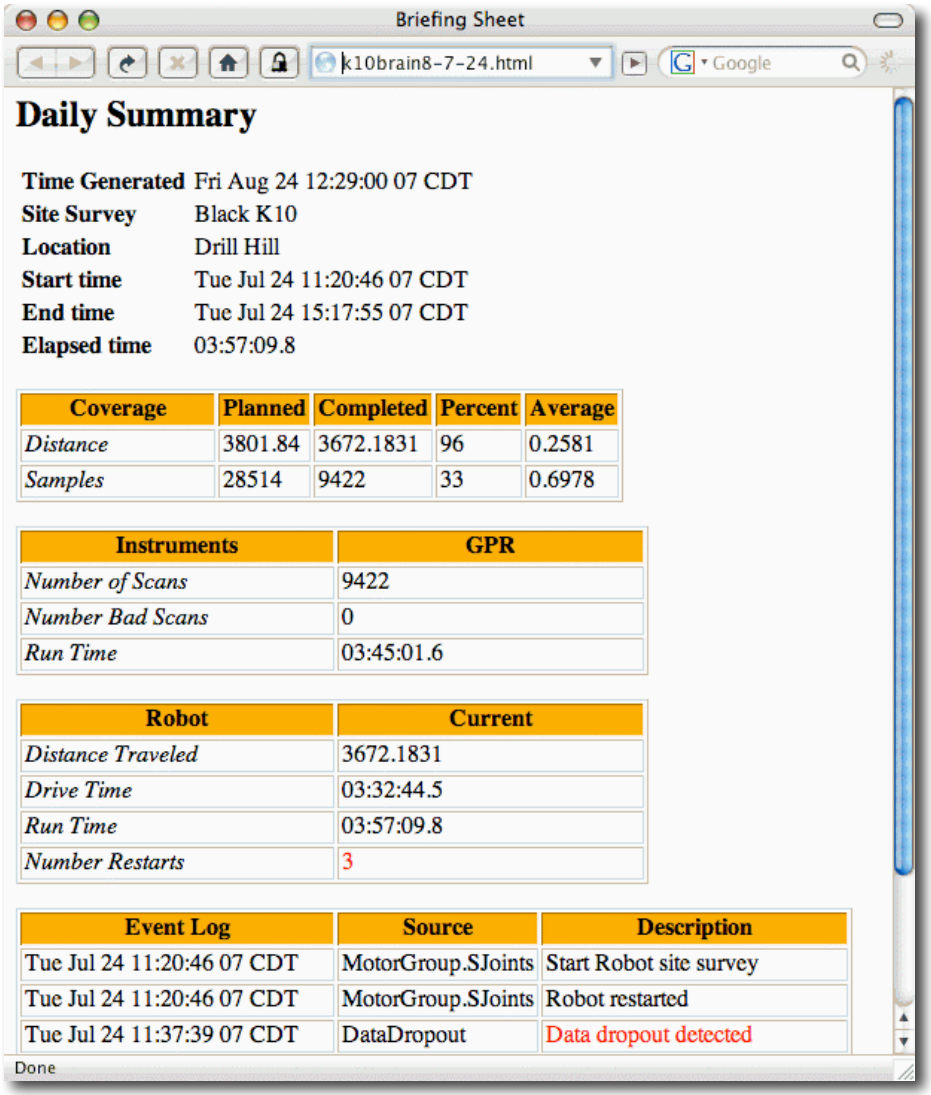
Drill Hill Survey (23-27 July 2007)

Auto-Summarization & Notification

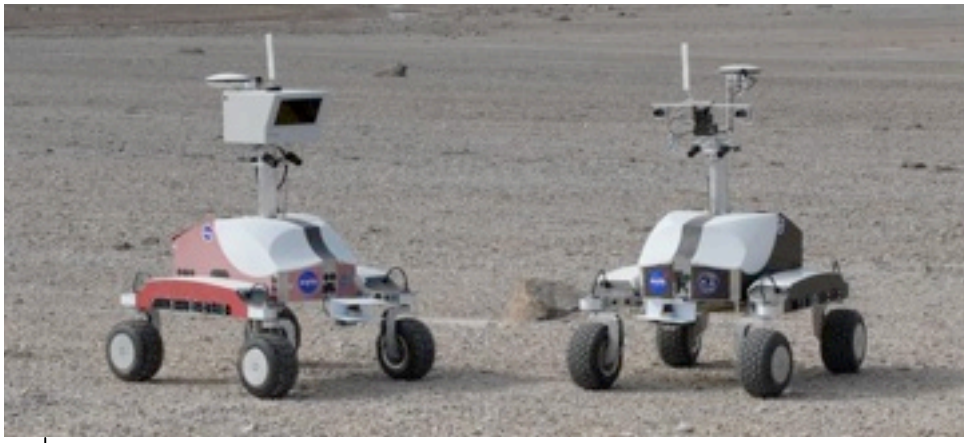
2007 Phase 1 SBIR (X7.02)

- Support system health & performance monitoring
- Monitor data for problems (robots or instrumentation)
- Perform computations summarizing daily progress
- Notify users of alarms, alerts and reports based on roles
- Distribute reports (web or email)

PI: Debbie Schreckenghost (Traclabs, Inc.)



Auto-Summarization & Notification



Telemetry logs

Condition Monitoring

Computation

Summary Generation

Notification

Summary Report

Scientist Agent ⟺ ***Display Email***

RoverOperator Agent ⟺ ***Display Email***

FieldCoord Agent ⟺ ***Display Email***

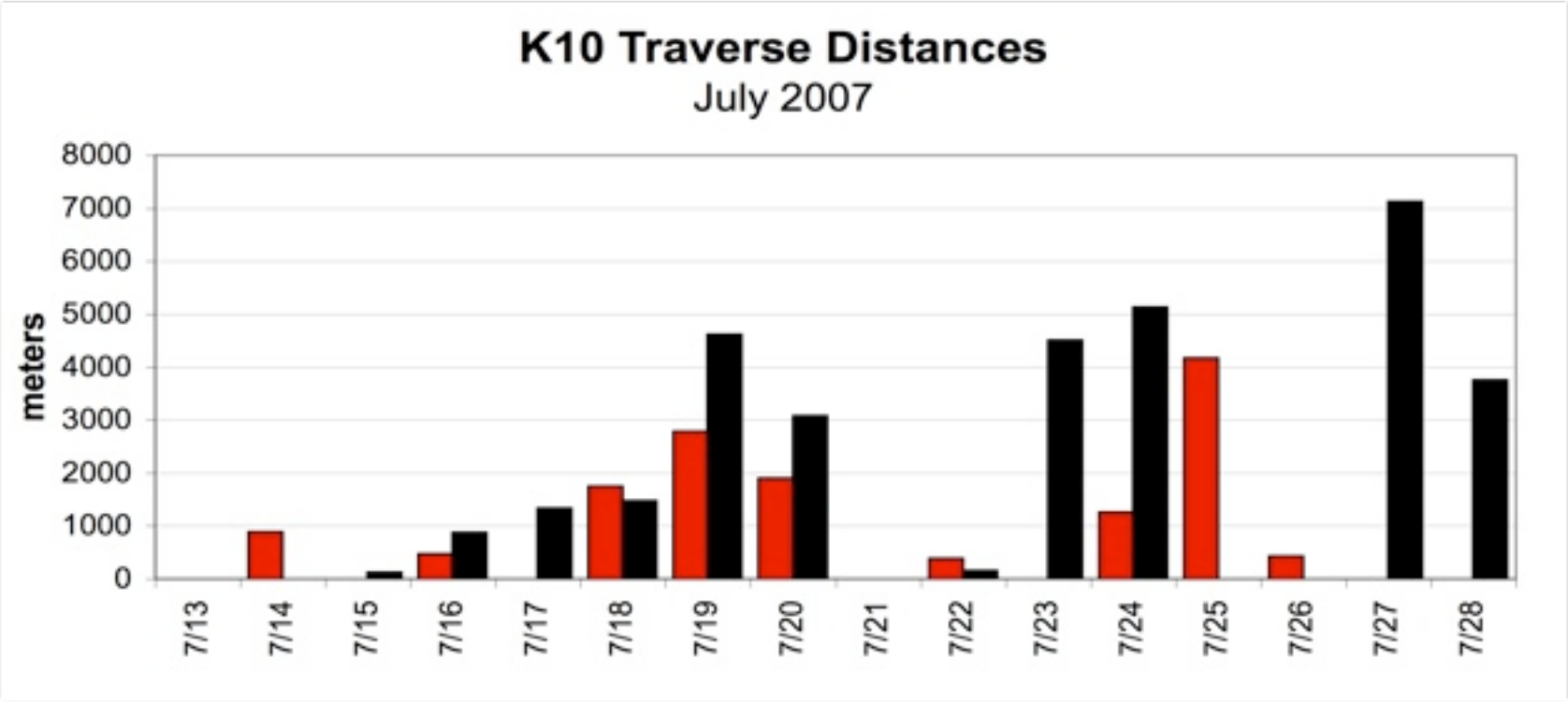
DataAnalyst Agent → ***Email***

ResearchCoord Agent → ***Email***

Statistics

Robotic survey

- 200+ hours of rover operations (incl. 10 hours out of comm range)
- 46.2 km of driving (K10 Red + Black)
- 25 lidar panoramas (250 scans)
- 30 GB of survey data



Statistics

Cost (field-test only)

- 6 people field team
- 25 days (10 July – 3 August 2007)

Category	Cost	Notes
Transport (personnel)	$29,384	Commercial air (SFO - HMP)
Transport (equipment)	$13,942	3,500 lbs (via ANG + Twin Otter)
Lodging + ME&I	$32,572	21 days at Haughton, 4 travel days
Contracts	$119,279	HMP support, satellite comm, field transport, fuel, etc.
TOTAL	**$195,178**	

Lessons Learned

Operations

- Dense coverage requires long distance driving
- Continuous navigation is a key enabler for long-duration, long-distance driving
- Instrument constraints have a huge impact on systems operations

Visualization tools

- Essential for rapid contingency handling & high duty-cycle
- Provide awareness of robot status & perception
- Unified science & robot data facilitates situational awareness

Software Architecture

- Modular reconfigurable architecture enabled rapid instrument integration and field test adaptations
- COTS tools greatly facilitated development
  - Google Earth: geo-spatial display & public outreach
  - CORBA: robust comm performance across satellite links

Conclusion

Key Points

- Systematic survey is one task that should be performed by robots
  - Robotic surveying is realistic & achievable (TRL 5)
  - Unproductive for crew to have to perform manually
- Intermittent control is sufficient for IVA & ground operations
- Mission performance can be increased by off-loading utility tasks (routine, tedious, repetitive) to robots

Project Team

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