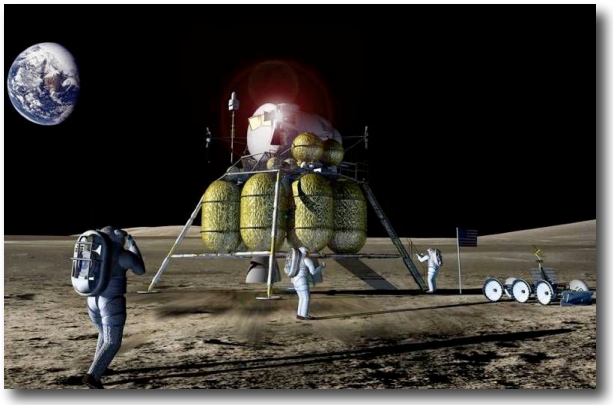
Ames Research Center

Human-Robotic Systems for Lunar Surface Operations

Terry Fong
Director, Intelligent Robotics Group
terry.fong@nasa.gov

irg.arc.nasa.gov

Lunar Surface Operations



Why human-robotic systems?

- Significantly reduce number & duration of **unproductive** EVA sorties
  - ➔ reduce mission cost and wasted crew time
- Off-load tasks (via autonomy or ground-control) from crew
  - ➔ better use of human resources on ground and in space
- Enhance mission architecture: more flexible and robust
  - ➔ greater sortie range, emergency resupply, etc.

Source: B. Clancey and T. Fong, 2006. "Human/Robotic Allocation Study" (for Constellation Advanced Projects Office)

Precursor Missions

Lunar Precursor & Robotic Program

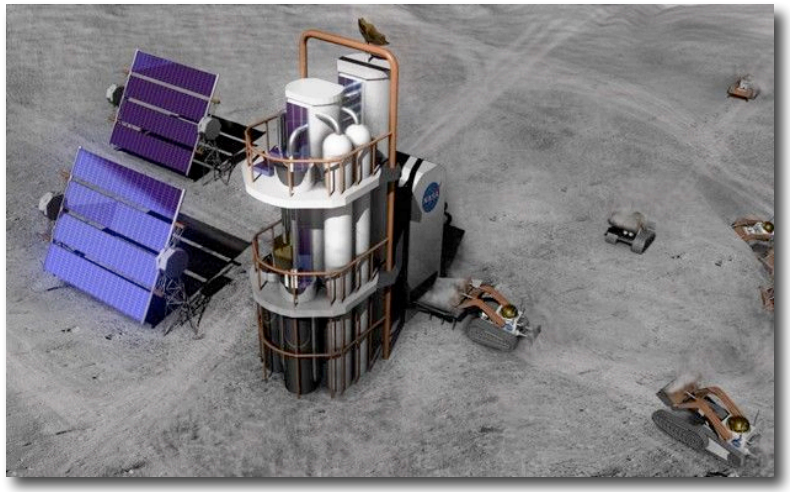
- Reduce risk for human missions
- Lunar Reconnaissance Orbiter
- Landers & robots

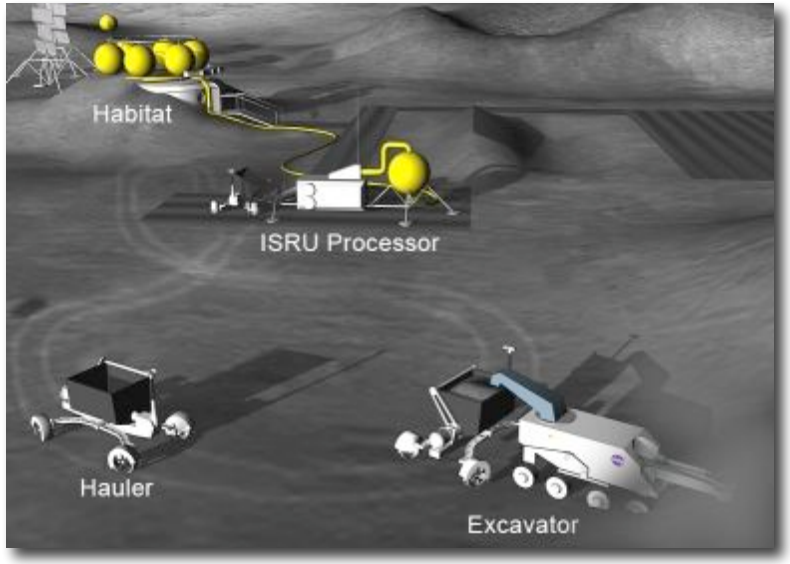
Tasks

- Characterize environment
- Conduct experiments
- Deploy infrastructure

Key issues

- Time-delayed teleoperation
- Earth-based (ground) operations
- Cost of ground operations





Sortie Missions

Lunar architecture

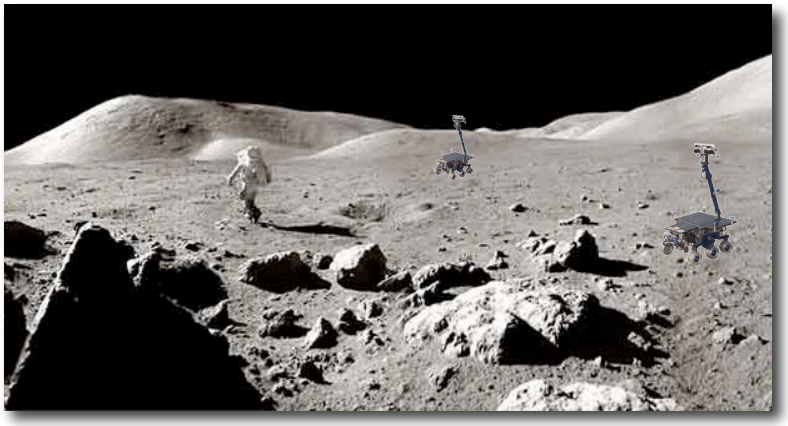
- Four crew to lunar surface
- Short-term stay (1-2 weeks)
- Robots & surface systems

Robot functions

- EVA support: expand range and capability of sorties
- Off-load simple, repetitive, time consuming tasks

Key issues

- Teleoperation (real-time on surface & time-delay from ground)
- Safety (human-robot proximity ops)
- Task coordination



Lunar Outpost

Lunar architecture

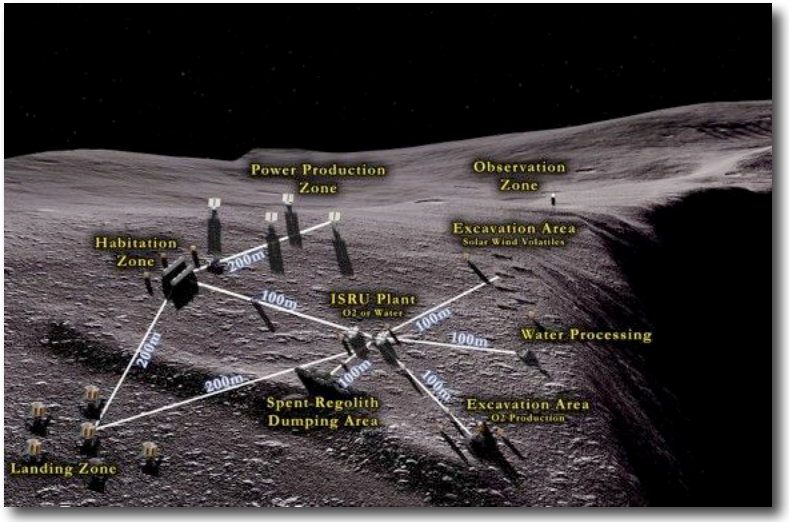
- Permanent base
- Surface exploration
- Long-term resource exploitation

Robot functions

- EVA and vehicle support
- Utility tasks: inspection, maintenance, site prep, etc.
- Heavy duty: large payload transport, assembly, construction, etc.

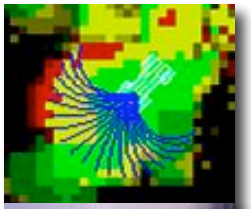
Key issues

- Multi-robot operation for multiple tasks (small crew size)
- Task allocation and coordination
- Technology obsolescence



Robotic Exploration Requirements

Surface mobility



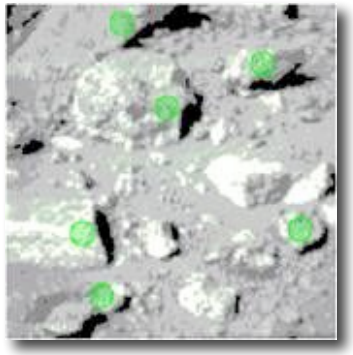
Mobile Autonomy

Terrain assessment, path planning, visual servoing

Mobility Mechanization

Extreme terrain access, energy efficiency

Perception, planning & execution



On-board and ground tools; data analysis, target selection, operations planning and execution

Human-robot interaction (HRI)

Teleoperation and supervision of robotic systems

Human-robot coordination

Instrument & sample manipulation

Position sensors, collect and process samples

May include sample containerization and return-rendezvous phases

Source: L. Pedersen, D. Kortenkamp, et al., 2001. Space Robotics Technology Assessment (NASA Exploration Team)

Human-Robotic Systems Project

Research areas

- Surface mobility
  - Humans
  - Payloads
  - Utility robots
- Handling
  - Cargo
  - Material
  - Payloads
- Human-robot interaction (HRI)

2006 Meteor Crater Field Test

Primary Objectives

- Address key technical challenges for lunar surface operations
- Develop requirements & mature surface systems
- Perform trade studies in relevant and analog environments

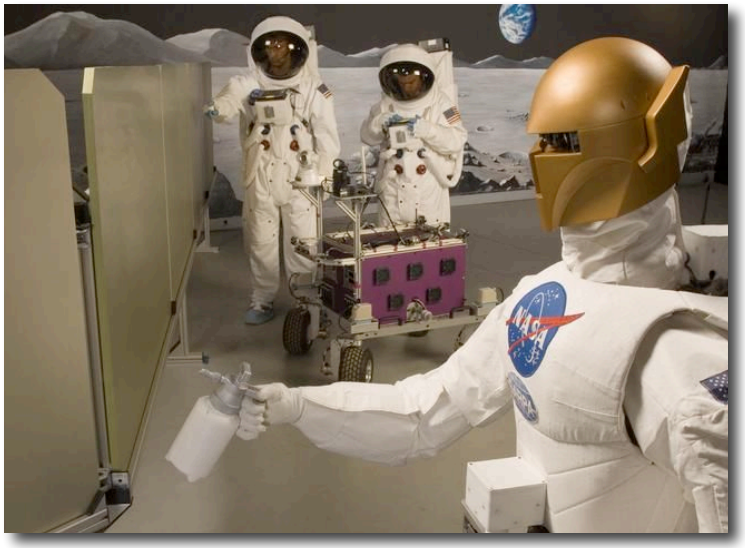
NASA Centers: ARC, GRC, GSFC, JPL, JSC, KSC, LaRC

Human-Robotic Systems Project

Human-Robot Interaction

Peer-to-Peer HRI Project (2005)

- Robots with “human traits”
  - Spatial language
  - Multi-modal interaction
- Human-robot dialogue
  - Coordination
  - Resolve problems
- Focus on operational tasks



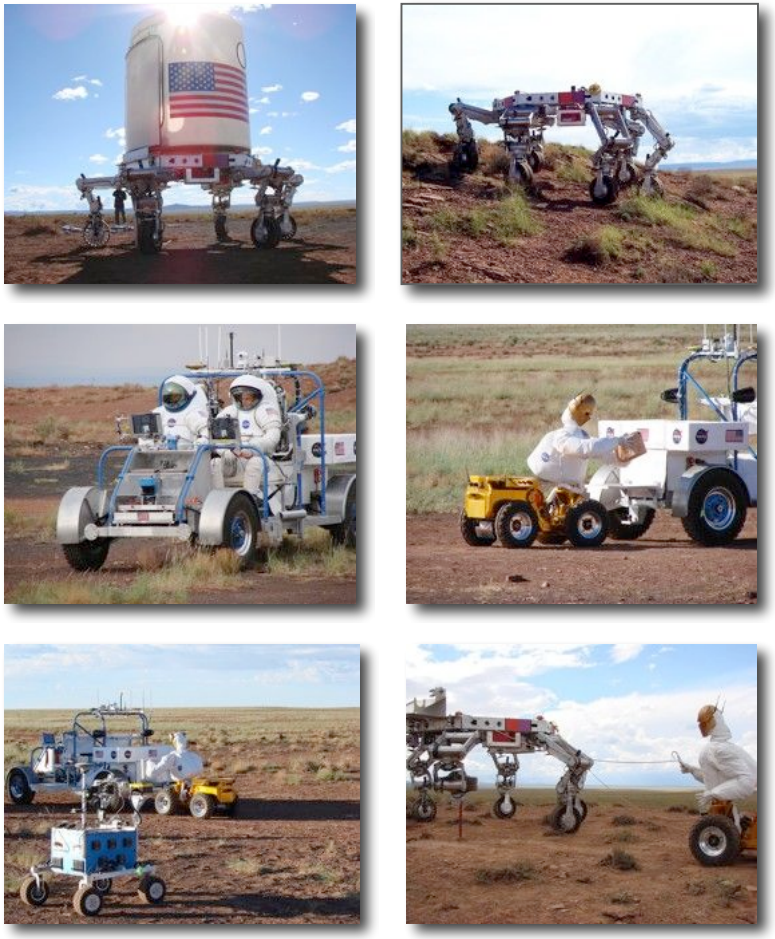
2006 Meteor Crater Field Test

Objective

- Examine coordinated human-robot operations in a field environment

Accomplishments

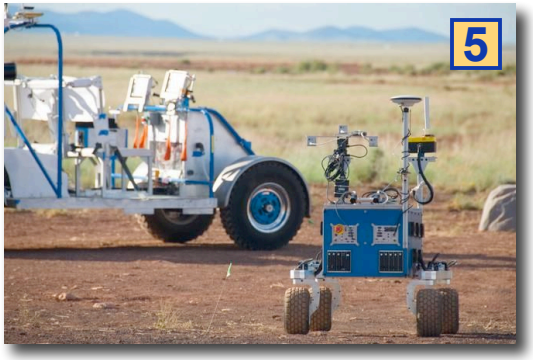
- Unpressurized human rover operations (manual & autonomous)
- Semi-autonomous payload removal (simulated IVA & ground control)
- Autonomous navigation and imaging for vehicle inspection
- Mobility tests: hill walking, maneuver heavy loads, etc.
- Manipulation tests: rig rappel line, drilling, collect geological samples



M. Diftler et al. 2007. "Crew/robot coordinated planetary EVA operations at a lunar base analog site", 38th LPSC

Coordinated Human-Robot Operations

1. ATHLETE positions Pressurized Rover Compartment (PRC)
2. Crew drive unpressurized rover to worksite
3. Crew dismount and walk to PRC to recharge suits
4. Centaur removes sample box (time-delayed teleop via satellite from Houston)
5. K10 performs autonomous “walkaround” (for remote visual inspection)



Visual Inspection

Rover-based imaging

- Autonomous approach & circumnavigation
- HDR gigapixel panorama
- Crew (IVA or ground) analyzes images for problems

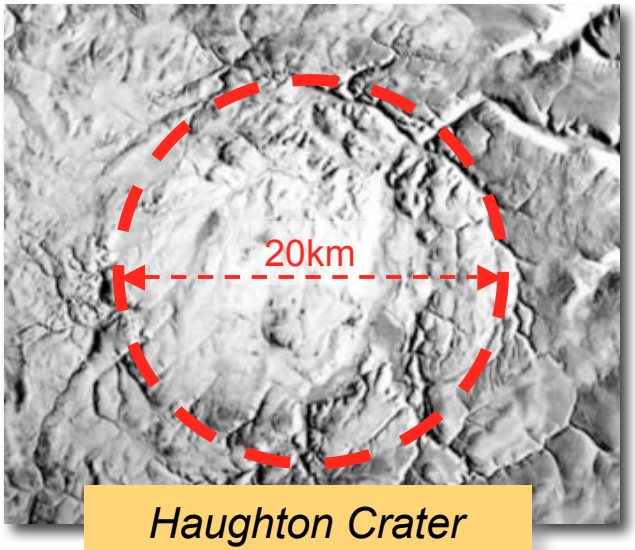
K10 inspection of SCOUT
Meteor Crater Field Test, Sept. 2006

M. Bualat et al. 2007. "Autonomous Robotic Inspection for Lunar Surface Operations", FSR '07

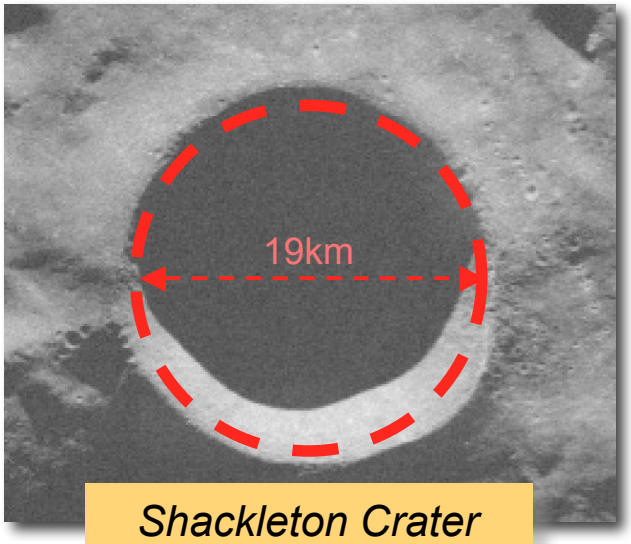
Basic Panorama

HDR Panorama

2007 Haughton Crater Field Test



Haughton Crater
(75°22'N 89°41'W)



Shackleton Crater
(lunar South Pole)

Overview

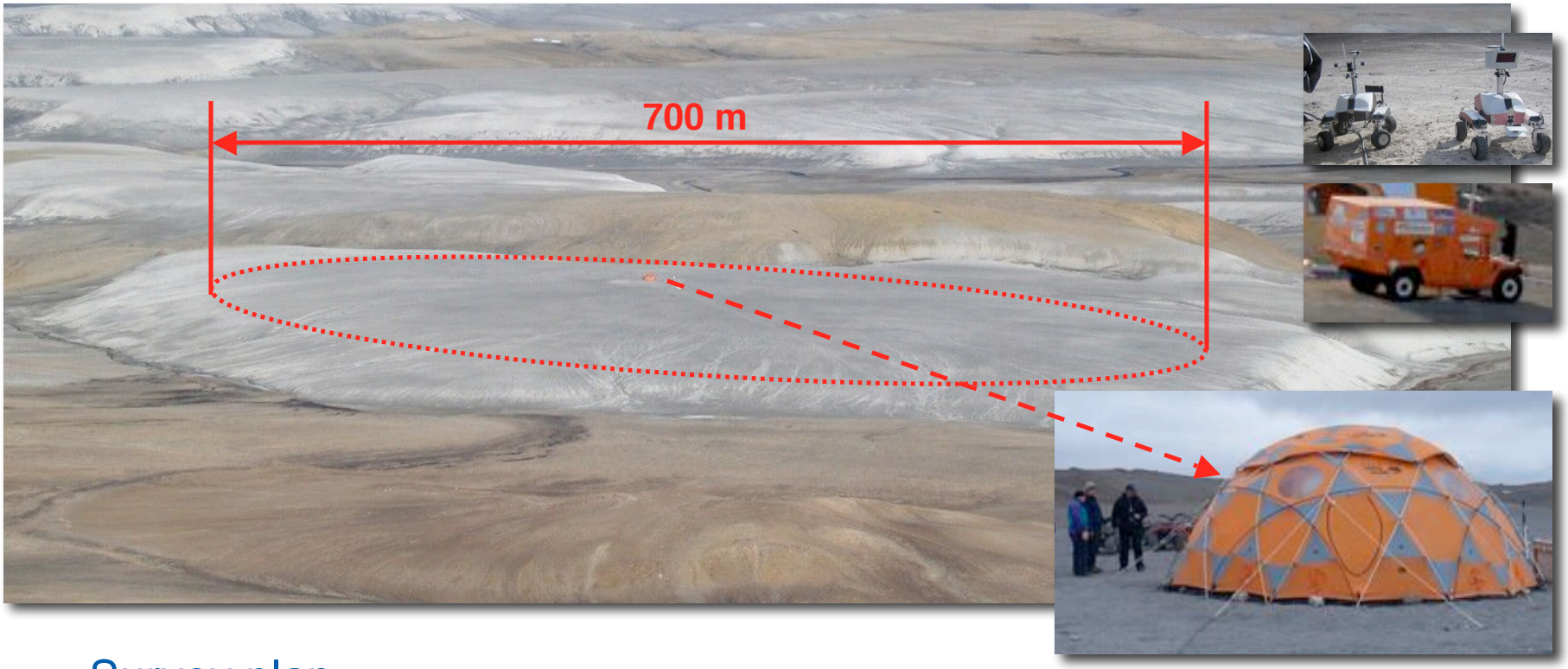
- Haughton Crater is a high-fidelity operational & scientific analog for Shackleton Crater (scale, structure, isolation, etc.)
- Examine systematic survey with multiple robots
- Simulate remote (habitat and ground control) robot operations

Human-Robot Site Survey

10 July – 3 August 2007

- Two K10 robots with survey instruments
  - 3D scanning lidar for topographic mapping
  - Ground-penetrating radar for resource prospecting
- Multiple lunar analog sites at Haughton Crater

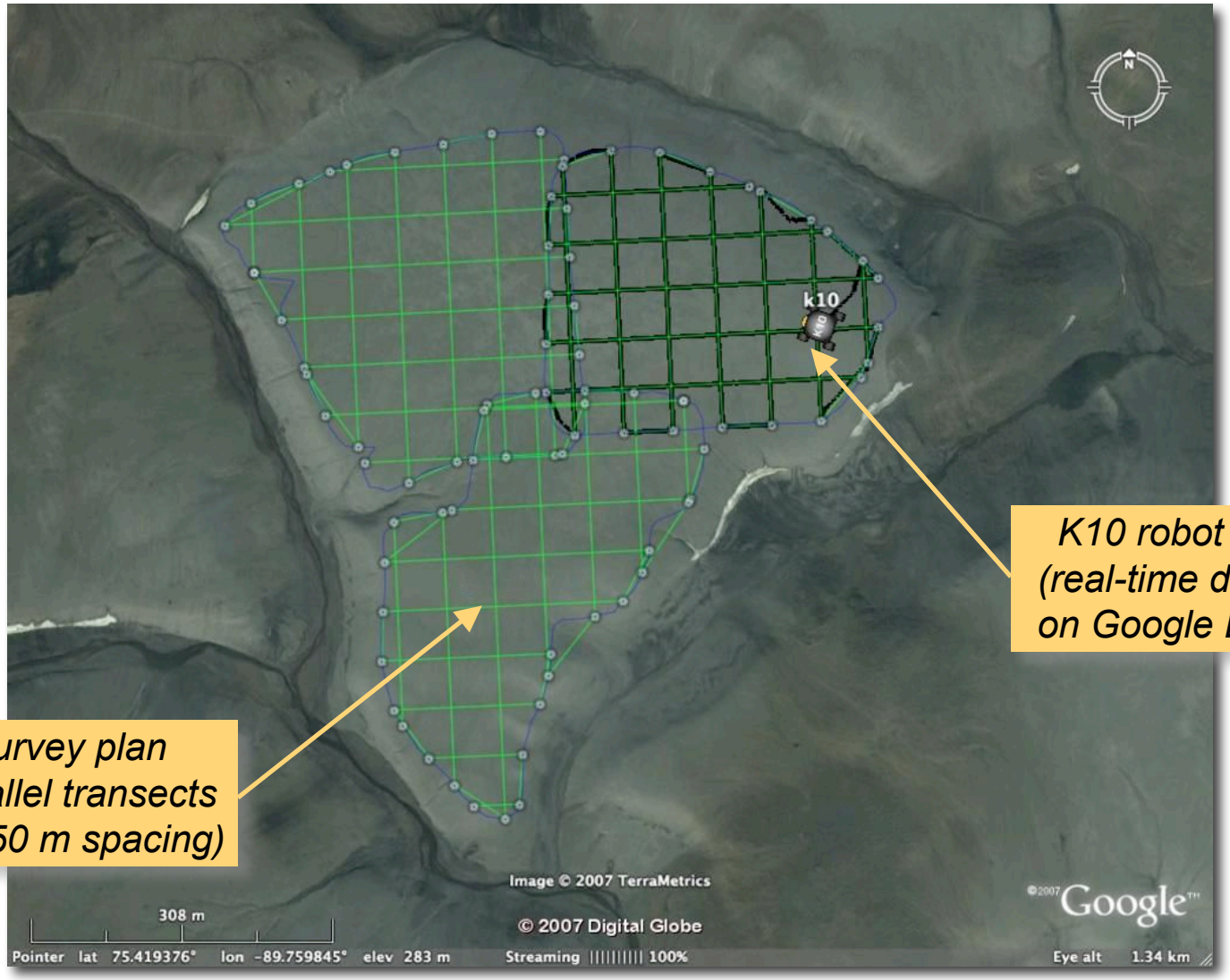
“Drill Hill” Survey



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)

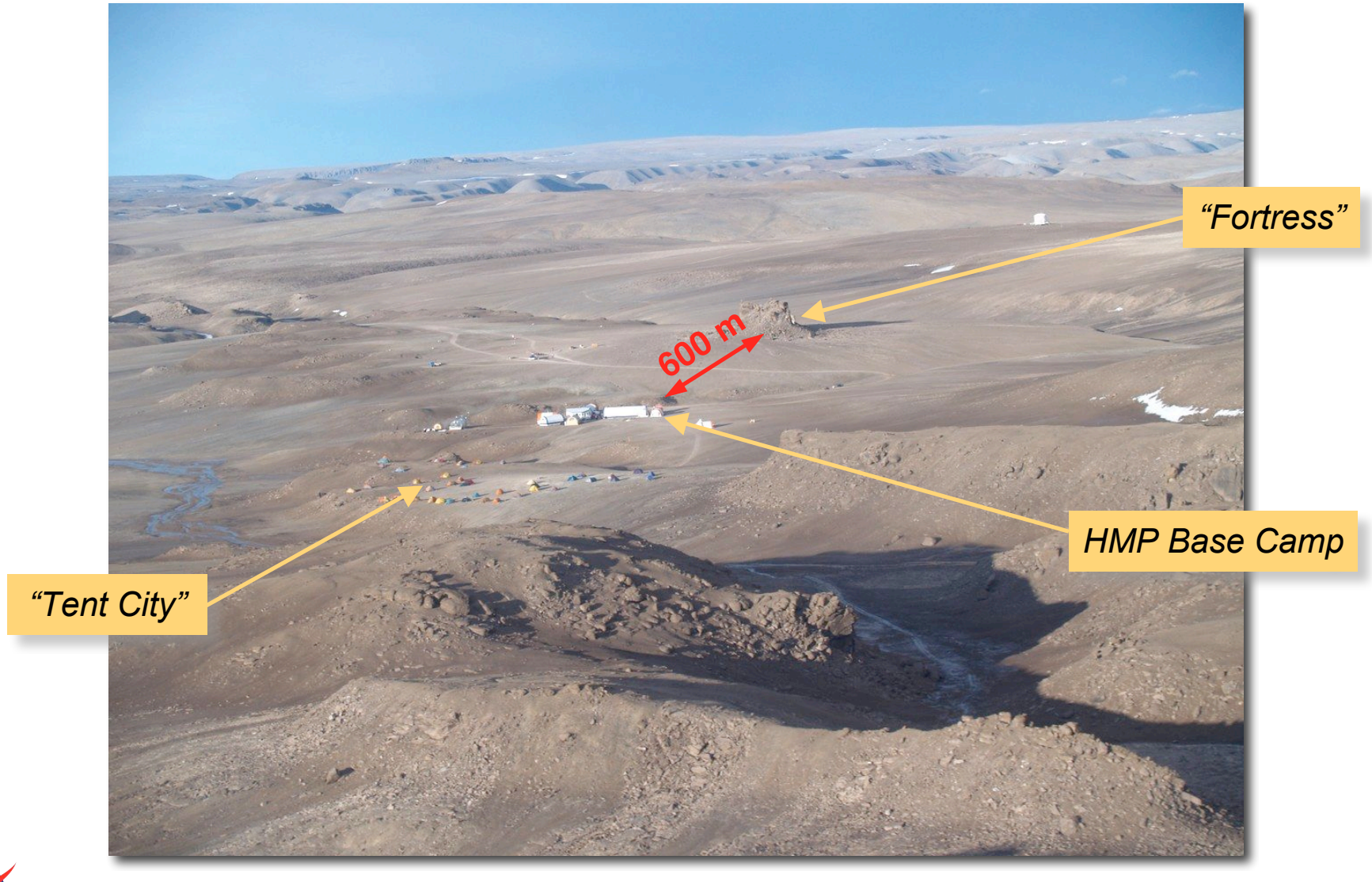
“Drill Hill” Survey



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

Survey plan (parallel transects with 50 m spacing)

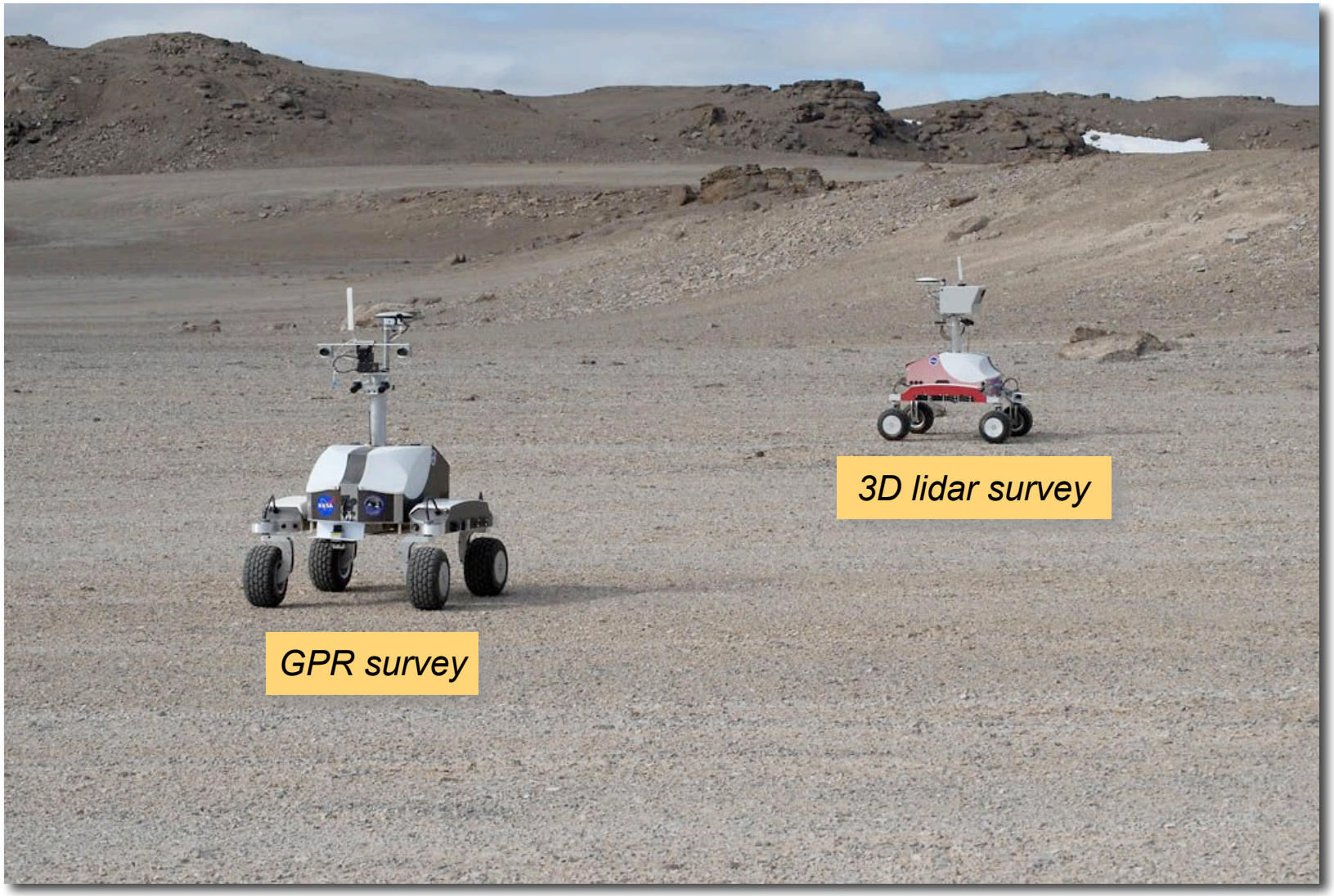
Approaching Haughton Crater



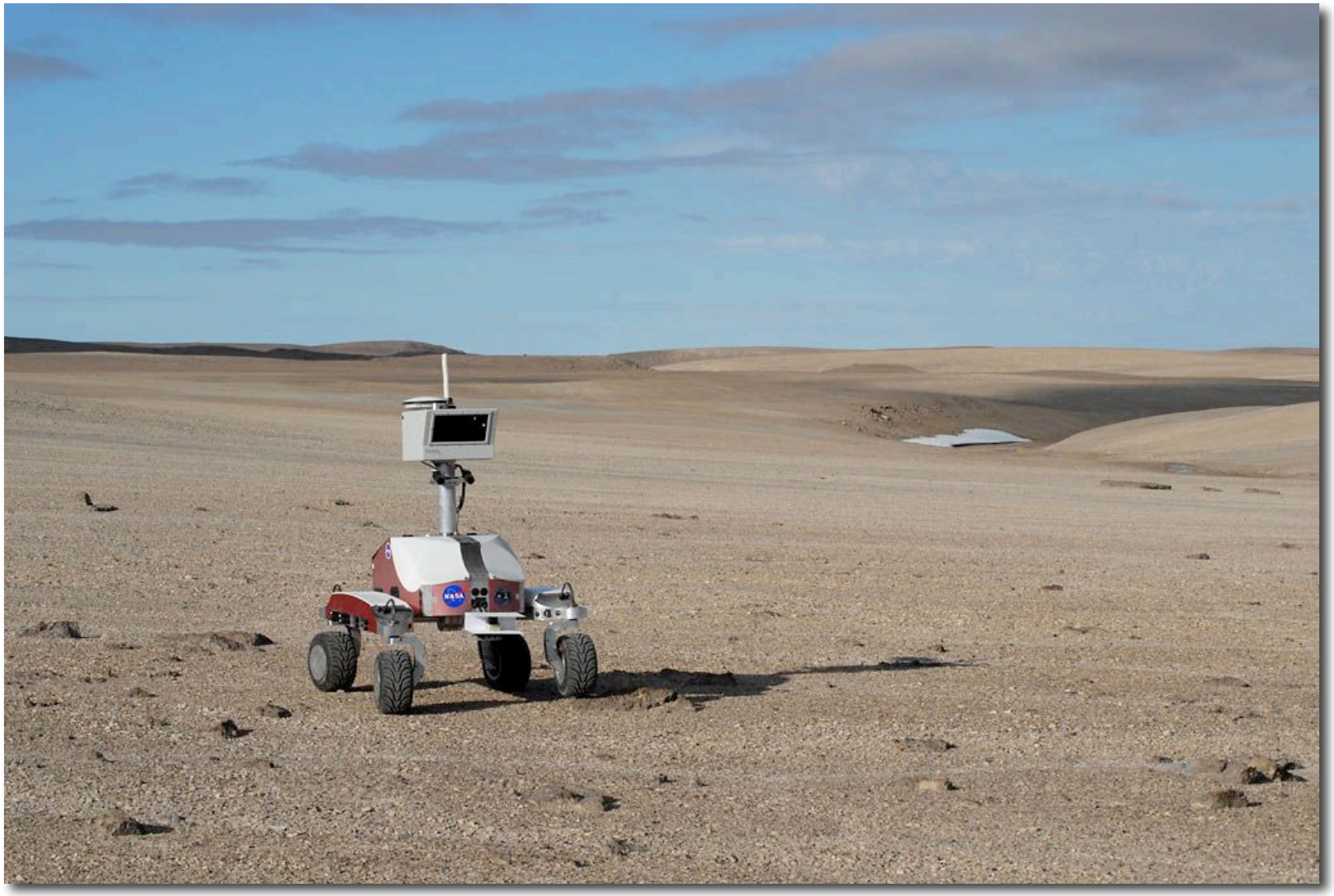
HMP Lodging

"Tent City"

K10's at Haughton



K10 Lidar Survey



K10 Lidar Survey

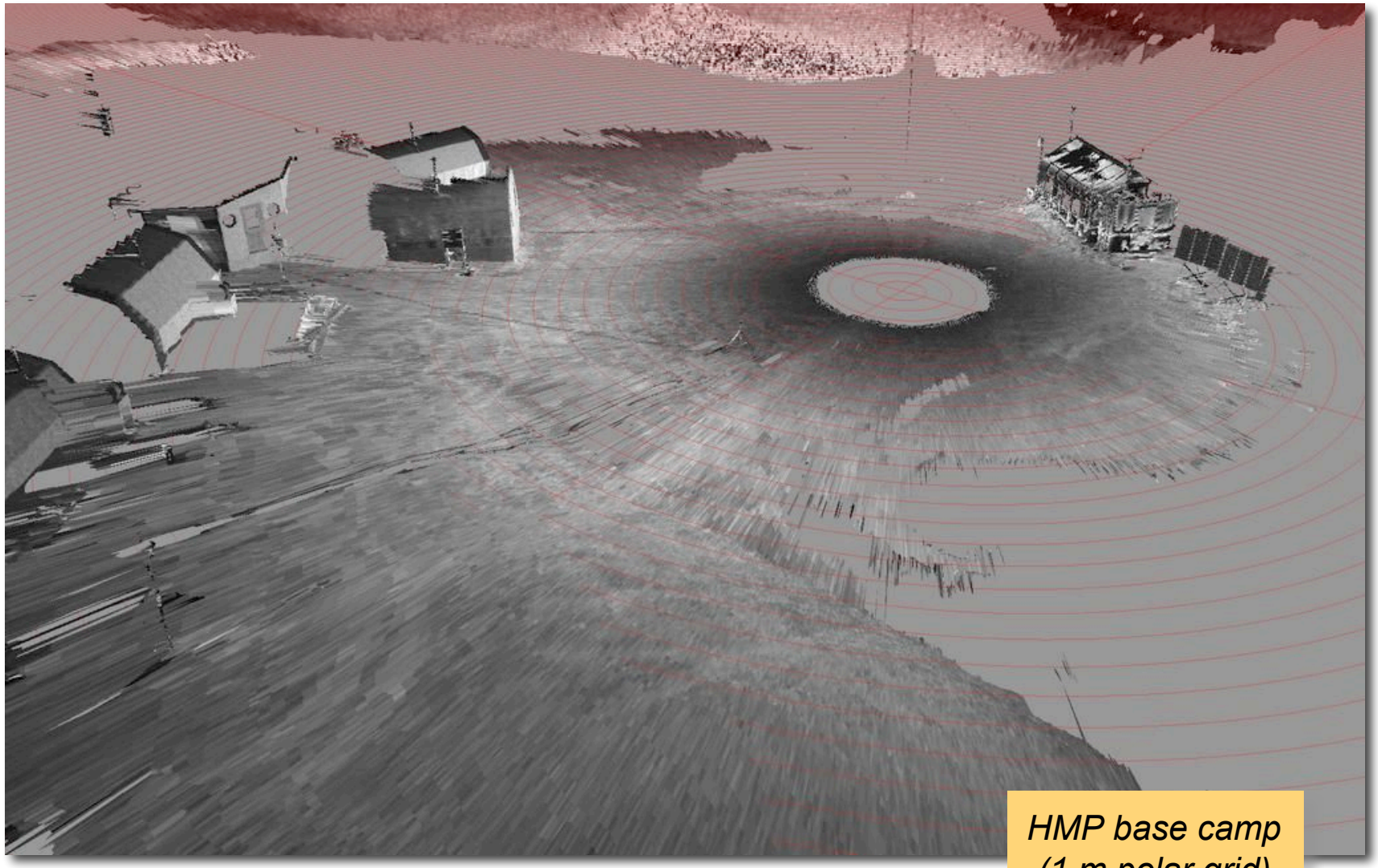
K10 Lidar Survey

K10 GPR Survey

K10 GPR Survey

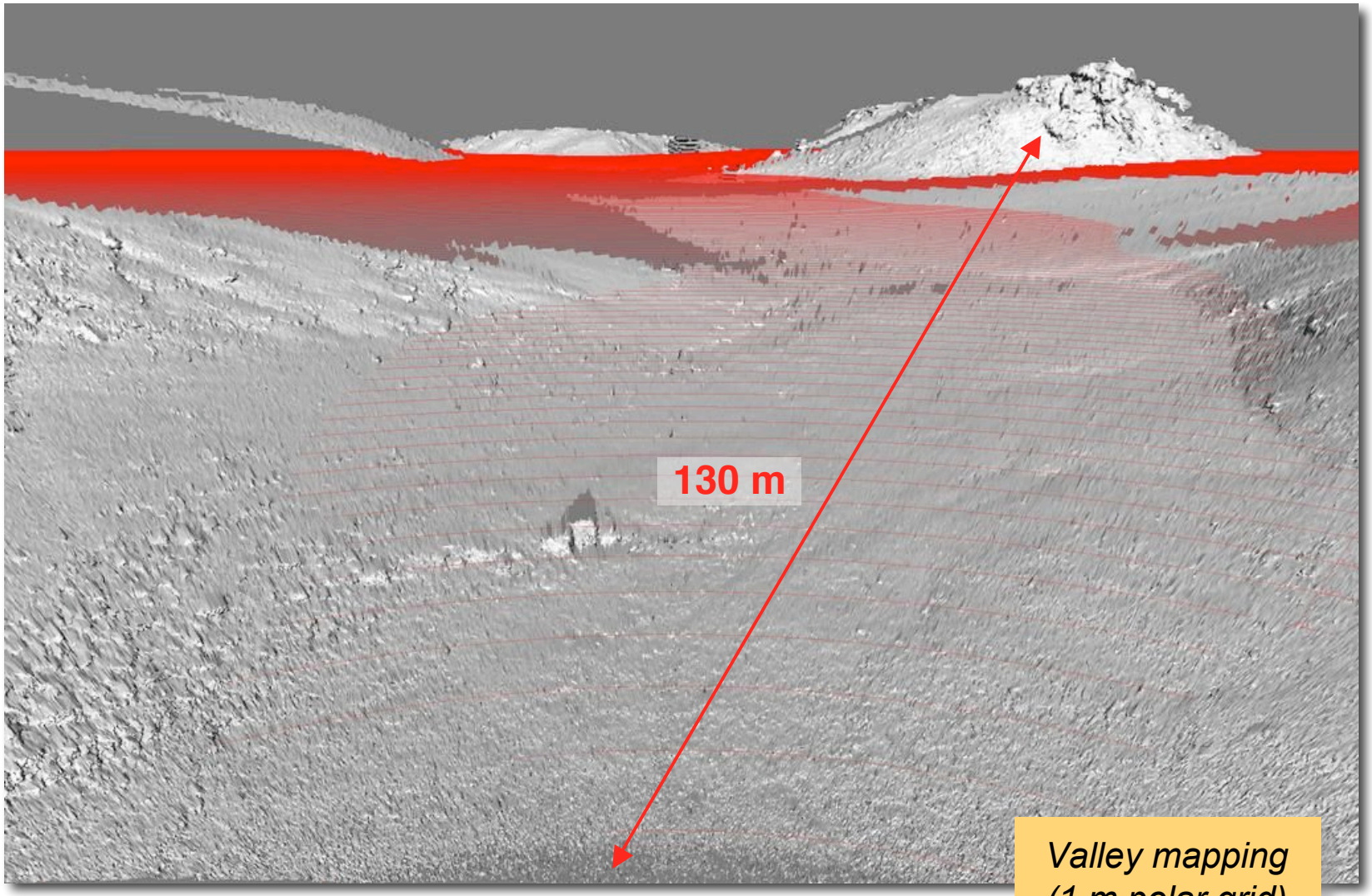
K10 GPR Survey

3D Terrain Modeling



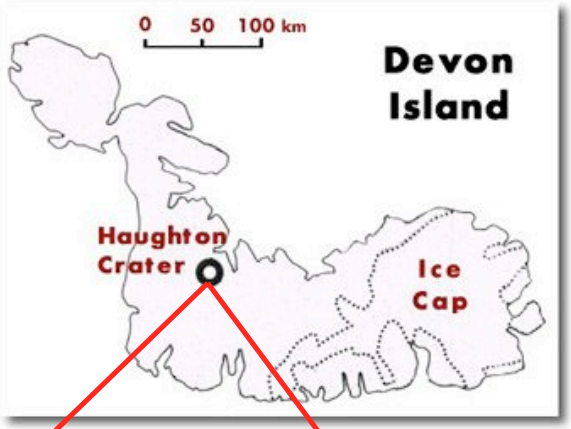
HMP base camp (1 m polar grid)

3D Terrain Modeling



Valley mapping (1 m polar grid)

Remote Operations



ARC

JSC

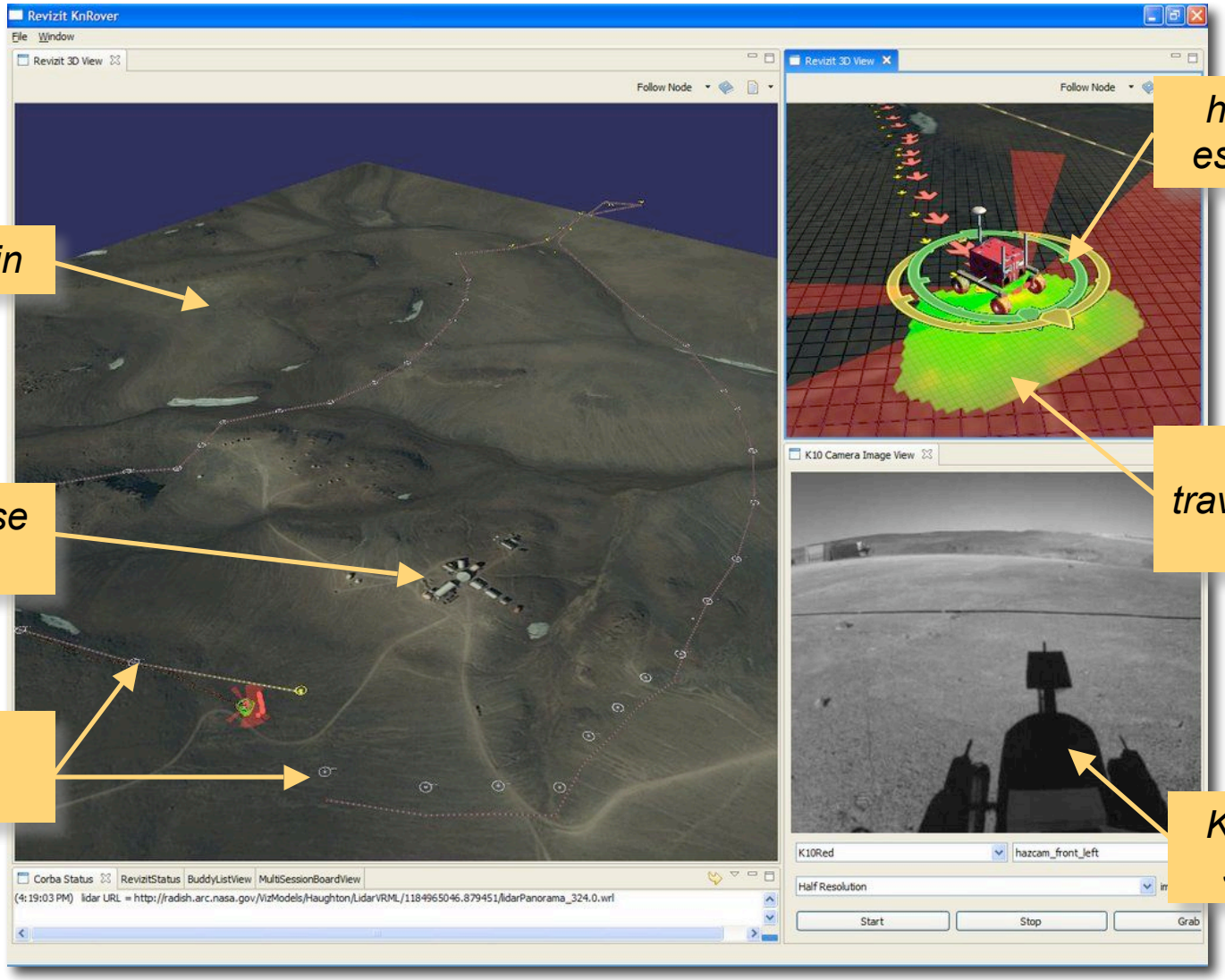
Ground Ops

"Lunar Outpost"

"Mobile Habitat"

IVA Ops

Lidar Survey Displays



3D terrain

HMP base camp

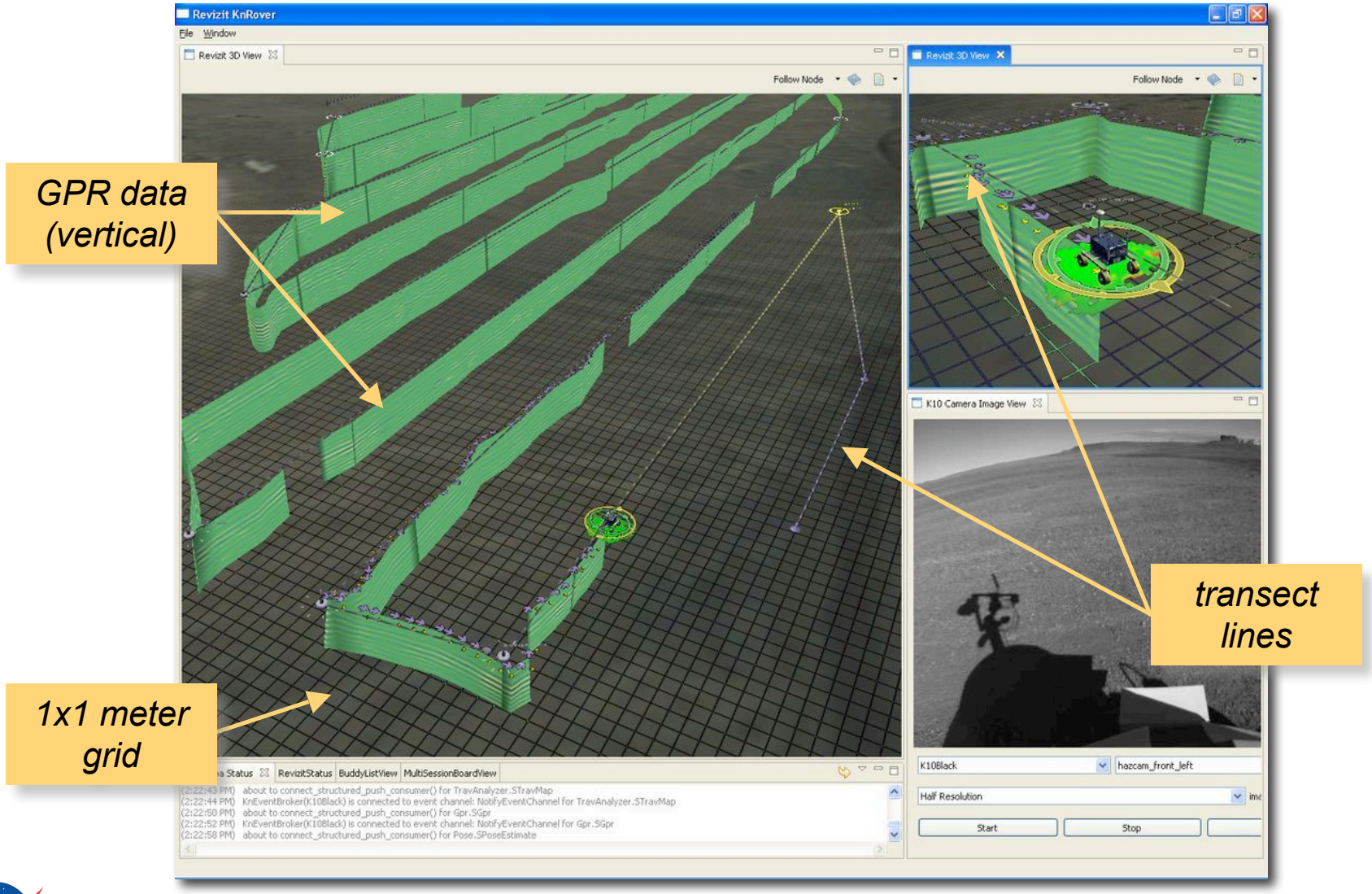
survey points

heading estimates

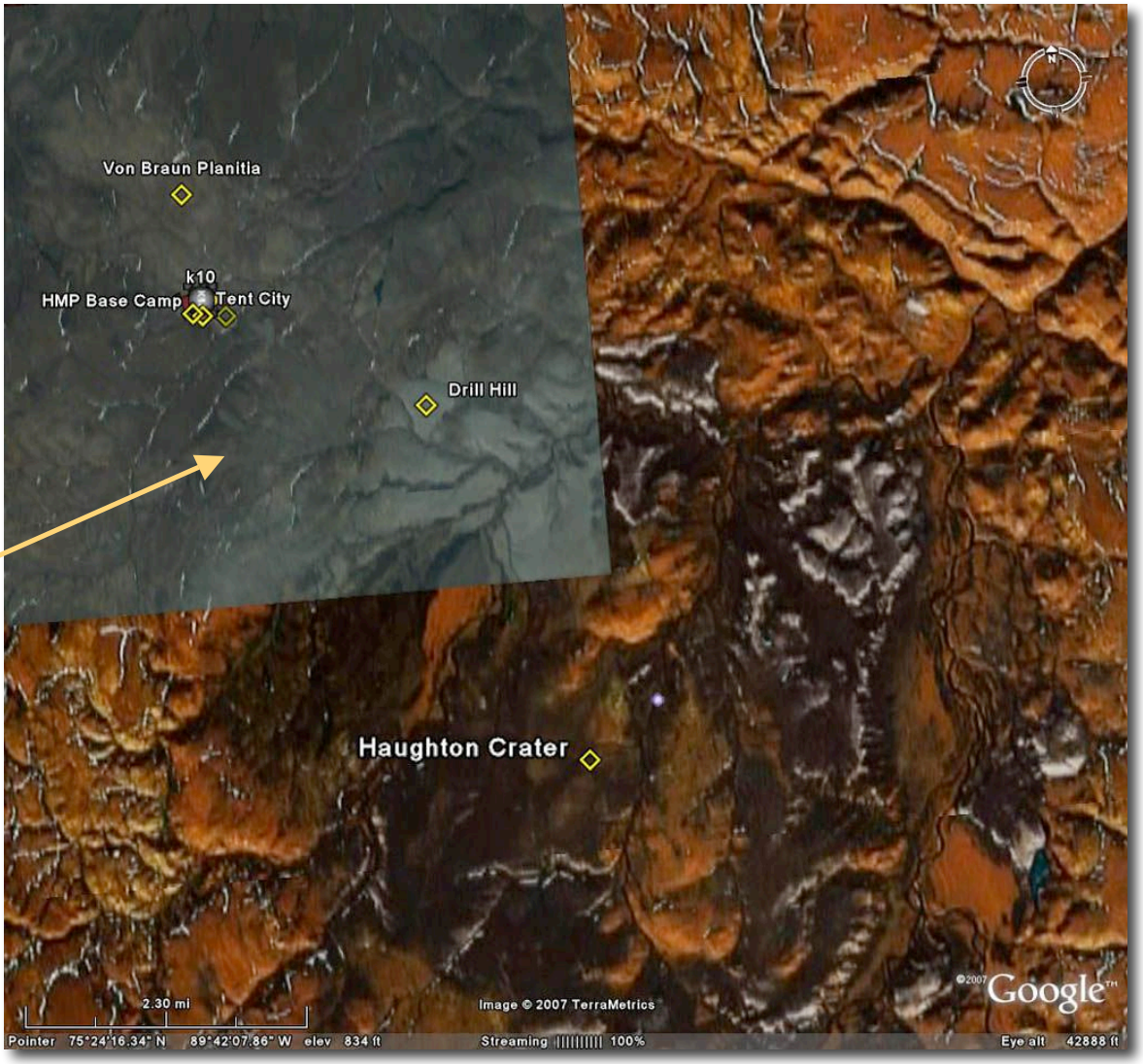
local traversabiliy map

K10 rover shadow

GPR Survey Displays

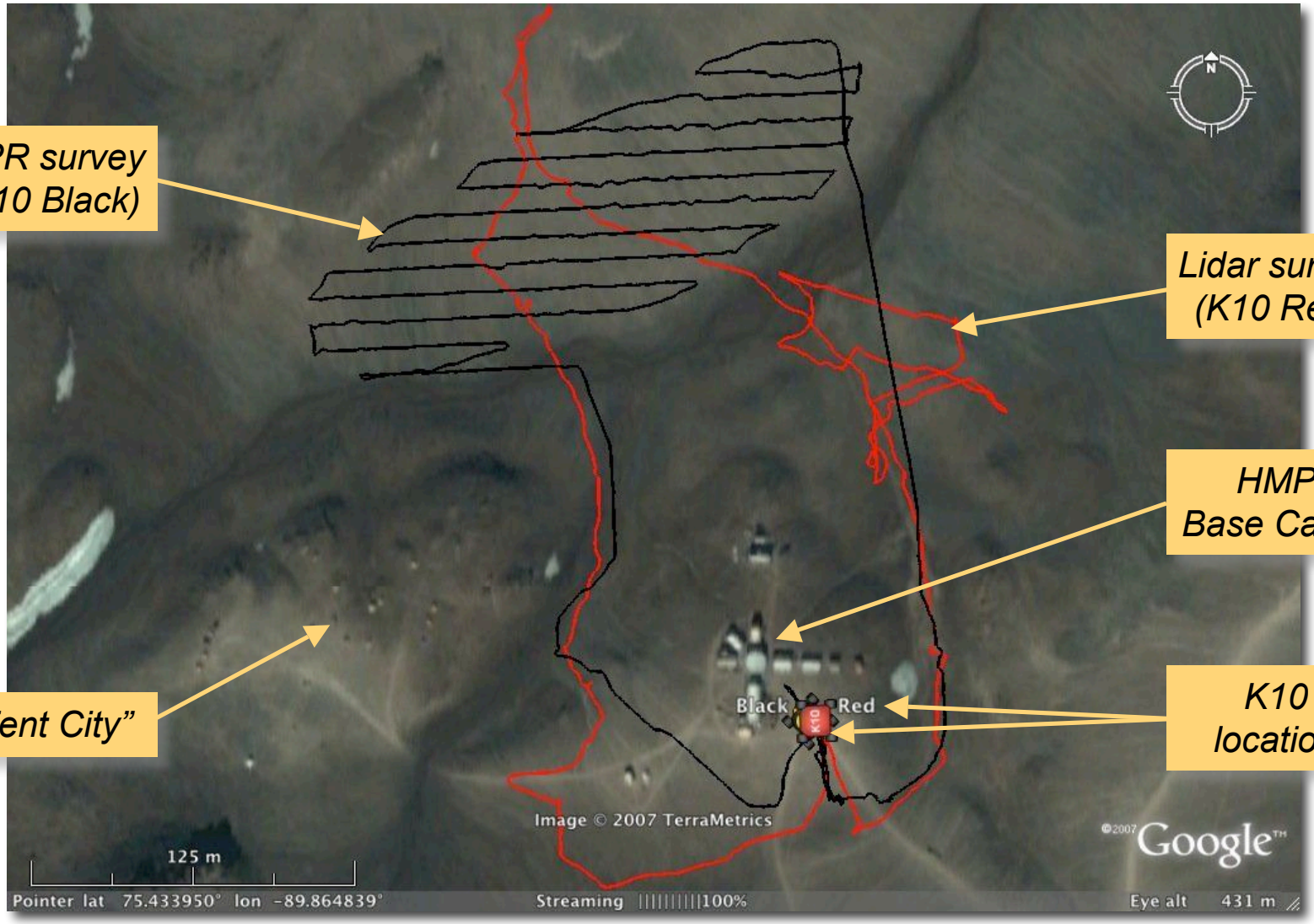


Google Earth



Satellite image overlay

HMP Base Camp Survey (20 July 2007)



SBIR Development Opportunities

Phase I

- Establish feasibility & technical merit of a proposed innovation
- $100K (6 months)
- Process: solicitation (July) / submission (Sept) / award (mid-Nov)

Phase II

- Major R&D phase (40% of Phase I projects)
- $600K (2 years)

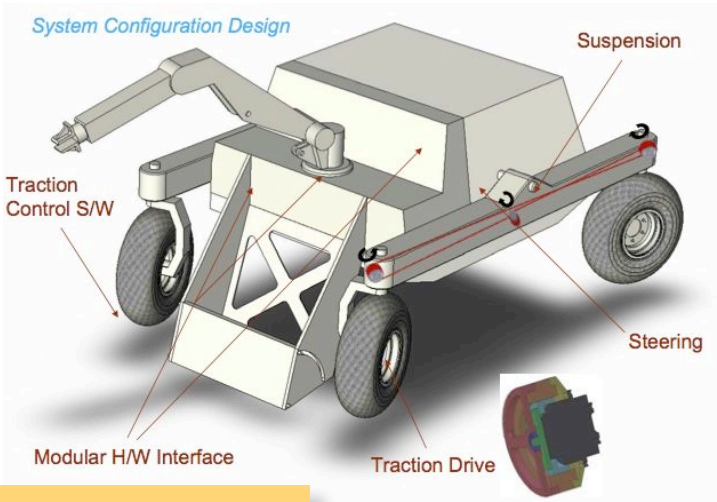
Relevant topics

- S5 Robotic Exploration Technologies
  - S5.03 Sample Collection, Processing, & Handling Devices
  - S5.04 Surface and Subsurface Robotic Exploration
- X7 Lunar Operations
  - X7.02 Human Systems Interaction
  - X7.03 Surface Mobility and Transportation

sbir.nasa.gov

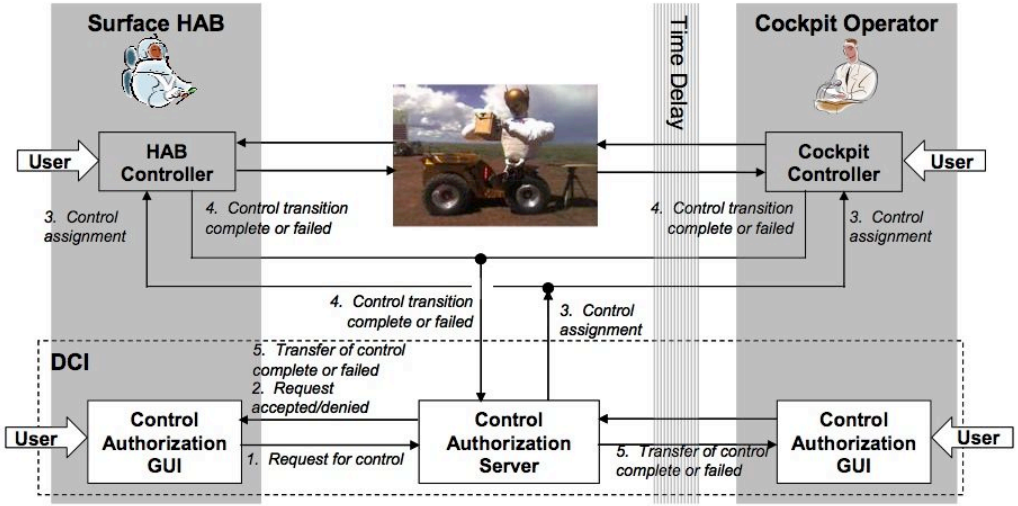
SBIR Examples

2007 Phase II (X7)



Lunar All-Terrain Utility Vehicle for EVA

Field Reconfigurable Manipulator for Rovers



Software Framework for Coordinating Human-Robot Teams

Other Development Opportunities

Google Lunar X Prize

- www.googlelunarxprize.org
- $30M prize purse
- Land & drive robot on the moon

Human-Robotic Systems Project

- Deployment mechanisms
- Instruments (e.g., terramechanics)
- Human-paced HRI
- Sensors (localization & navigation)
- Standardized architectures (e.g., JAUS)

Intelligent Robotics Group
Intelligent Systems Division
NASA Ames Research Center

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