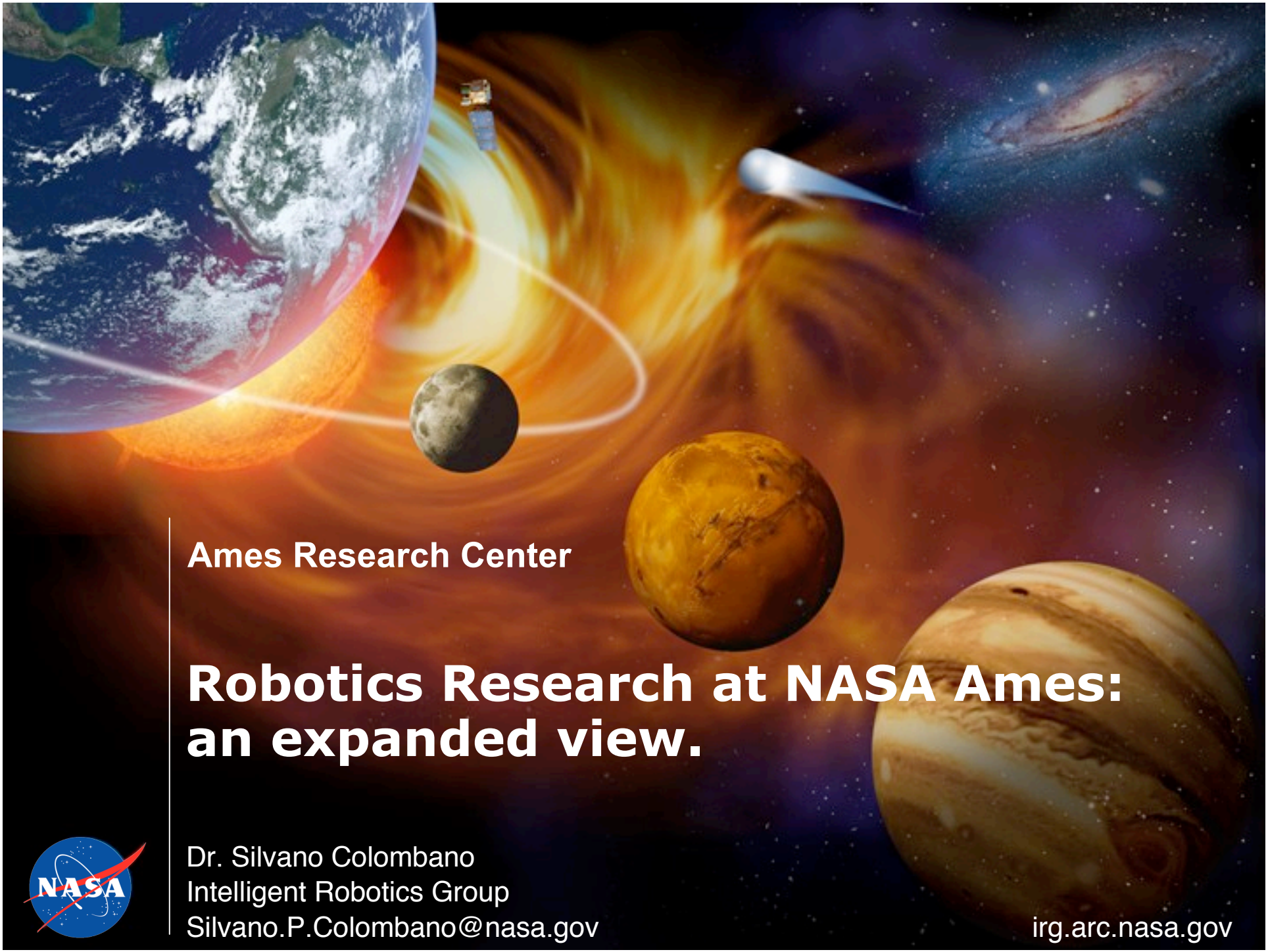

Ames Research Center

Robotics Research at NASA Ames: an expanded view.

Dr. Silvano Colombano
Intelligent Robotics Group
Silvano.P.Colombano@nasa.gov

irg.arc.nasa.gov

Intelligent Robotics Group

Overview

- Founded 1989
- 23 researchers (8 Ph.D.'s)
- Planetary rovers & software
- NASA & commercial work

Research themes

- **Scientific exploration**
  - Scouting / recon
  - Surface mapping & modeling
- **Utility robotics**
  - Site engineering
  - Inspection, mobile camera, etc.
- **Public service**
  - Disaster response
  - Education & outreach

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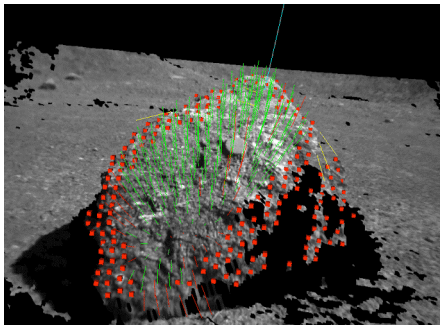
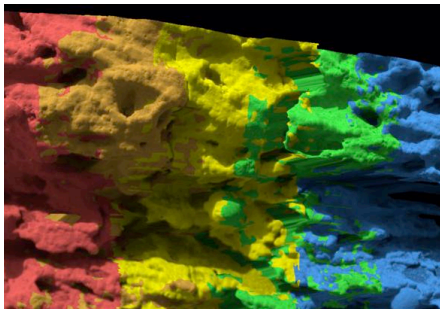
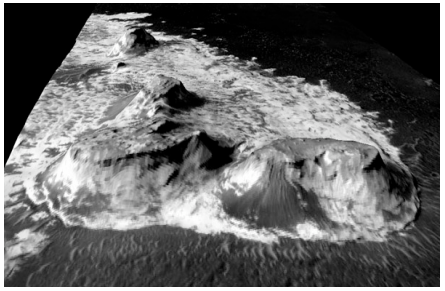
Research Areas

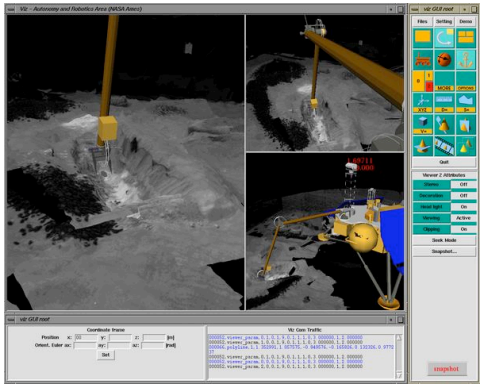
Perception

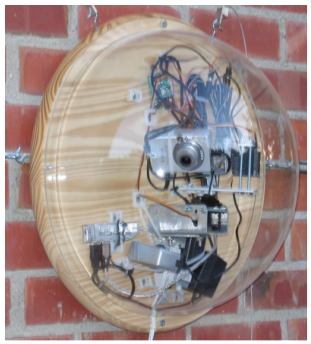


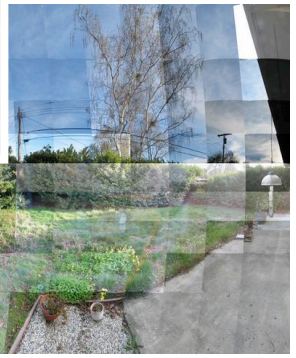




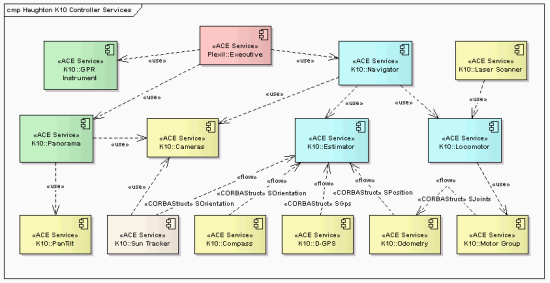
Interaction

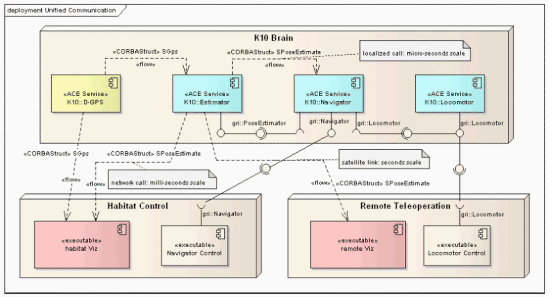


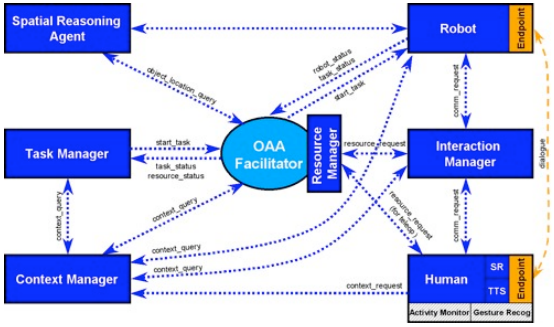




Architecture







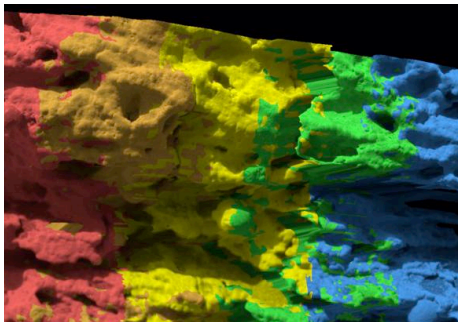
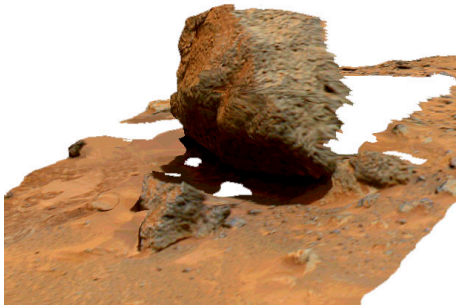
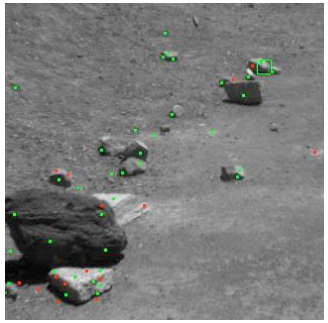
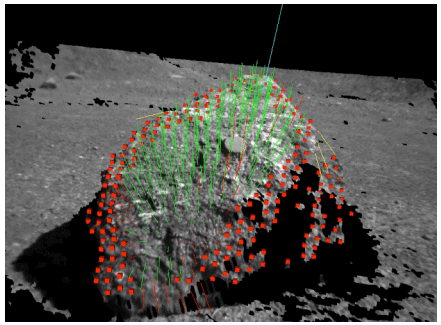
Perception

Science

- Systematic data collection
- Surface reconstruction
- Scientific image processing

Navigation

- Local rover navigation
- Single-cycle instrument placement
- Dark navigation

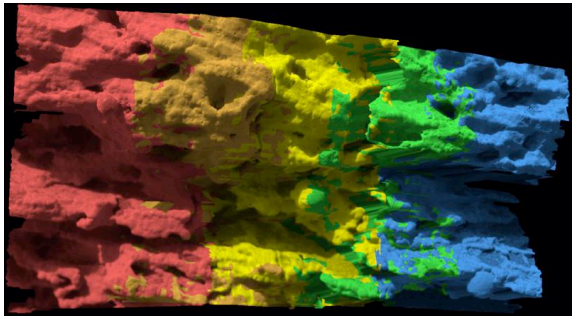
NASA Vision Workbench

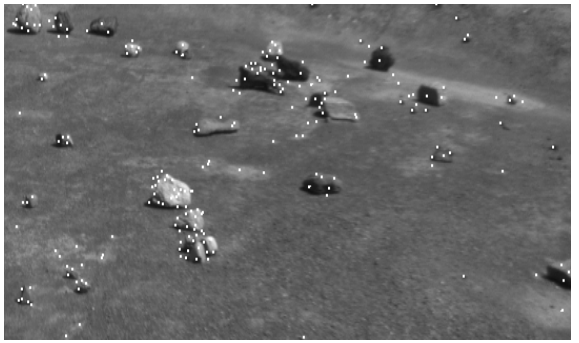
Overview

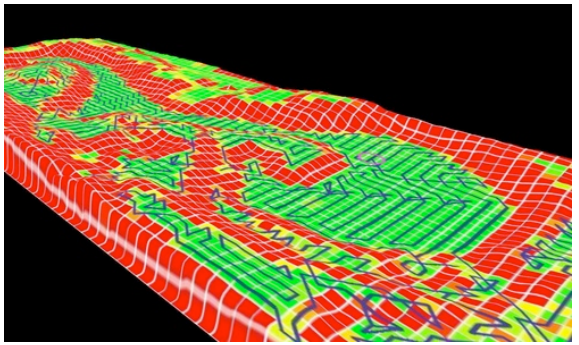
- Unified computer vision framework (Linux, OS-X, Win32)
- Open Source Release (NOSA license)
- **`ti.arc.nasa.gov/visionworkbench`**

Modules

- Core (abstract datatypes & utilities)
- Camera (models & calibration)
- Cartography (geospatial images)
- GPU (HW accelerated processing)
- HDR (high-dynamic range images)
- Interest Point (tracking & matching)
- Mosaic (composite & blend)
- Stereo Pipeline (high-quality DEMs)







M. Broxton, M. Deans, L. Edwards, M. Hancher, R. Sargent

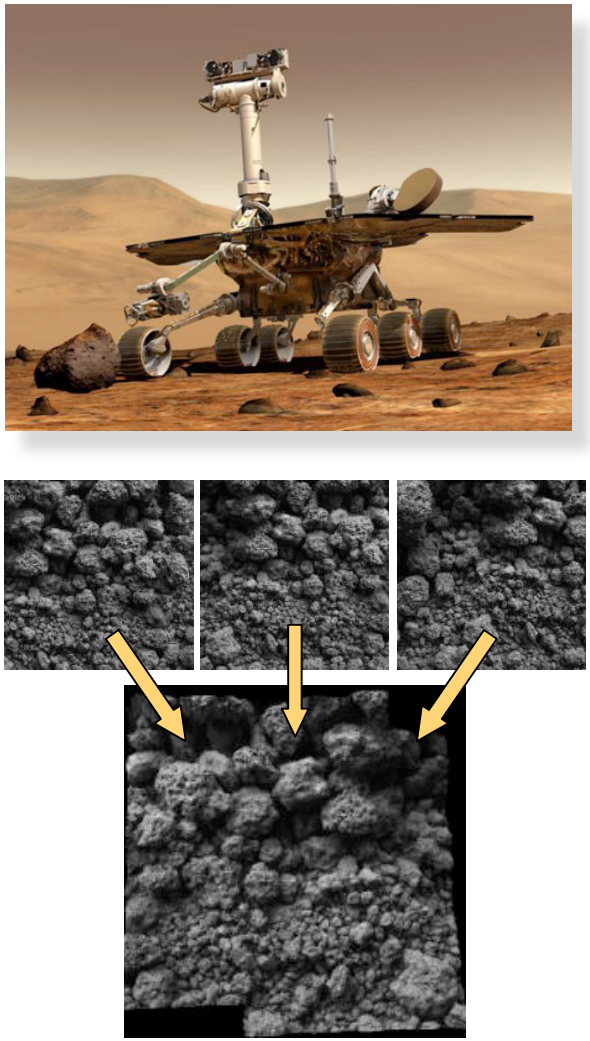
Astrobiology Machine Vision Toolkit

Problem: too much data !!!

- MER Primary Mission (90 days)
  - 811m drive
  - 15.2 GB data (12,429 images)
- Image analysis: (more than) a full-time job
- Even more difficult in the future
  - Longer missions, more bandwidth, etc.
  - MRO, MSL, LRO, ...

Solution: computer vision tools

- Semi-automatic image analysis
- Focal section merges
- 2D mosaics
- 3D surface reconstruction
- Appearance-based matching and retrieval

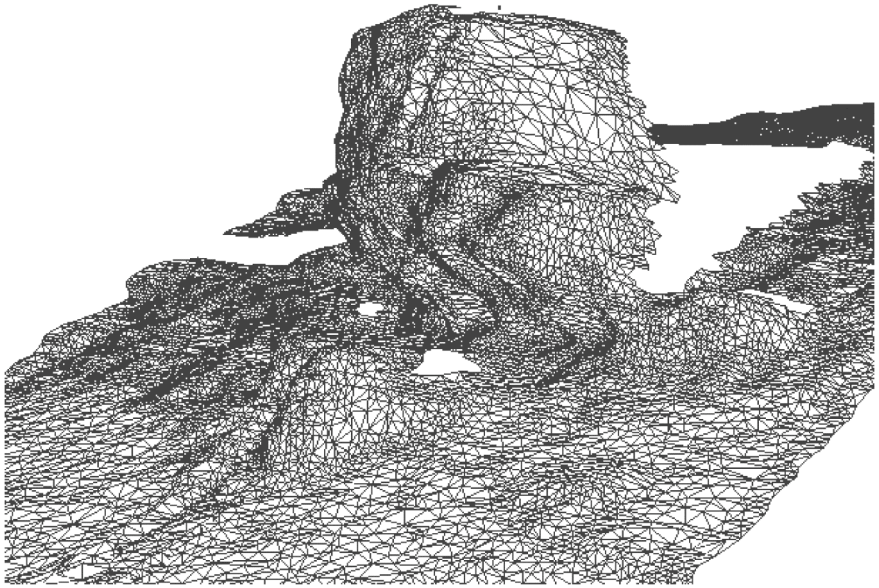


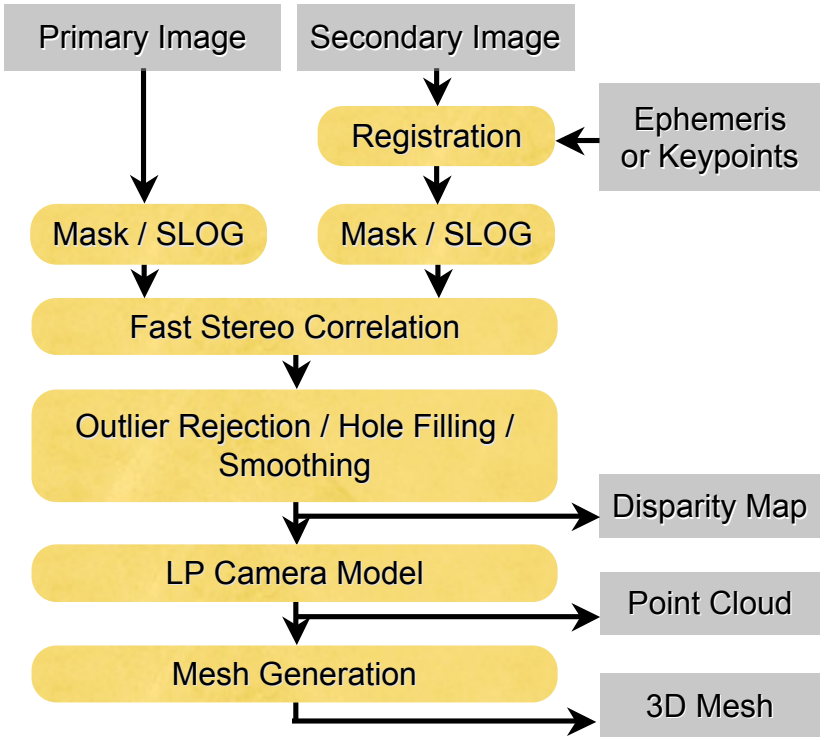
X. Bouyssounouse, M. Deans

3D Surface Modeling

Terrain Modeling with VisionWorkbench

- High-quality DEM from orbiter & rover image data
- Supports mission planning and science (ground control)
- Assists rover navigation and collision avoidance (on-board)





M. Broxton, L. Edwards, M. Hancher

Terrain Pipeline

Goals

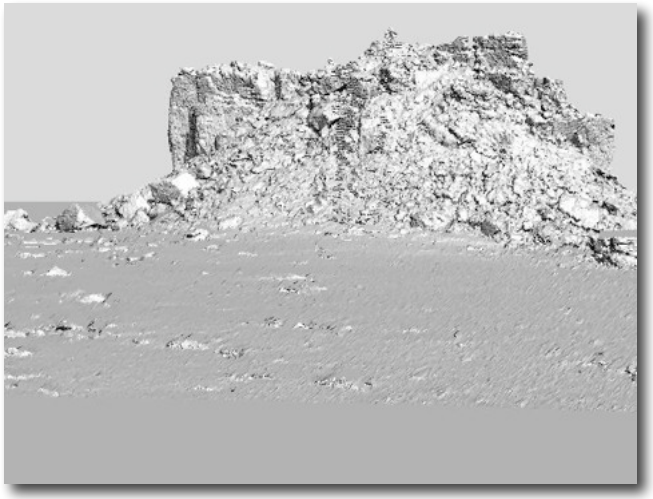
- Merge 3D data into coherent model
- Terrain models for robots & operators
- Support interactive visualization

Sensors

- Stereo imagers (area & line-scan)
- 2D lidar (Sick LMS, Hokuyo URG, etc.)
- 3D lidar (Optech ILRIS-3D, etc.)

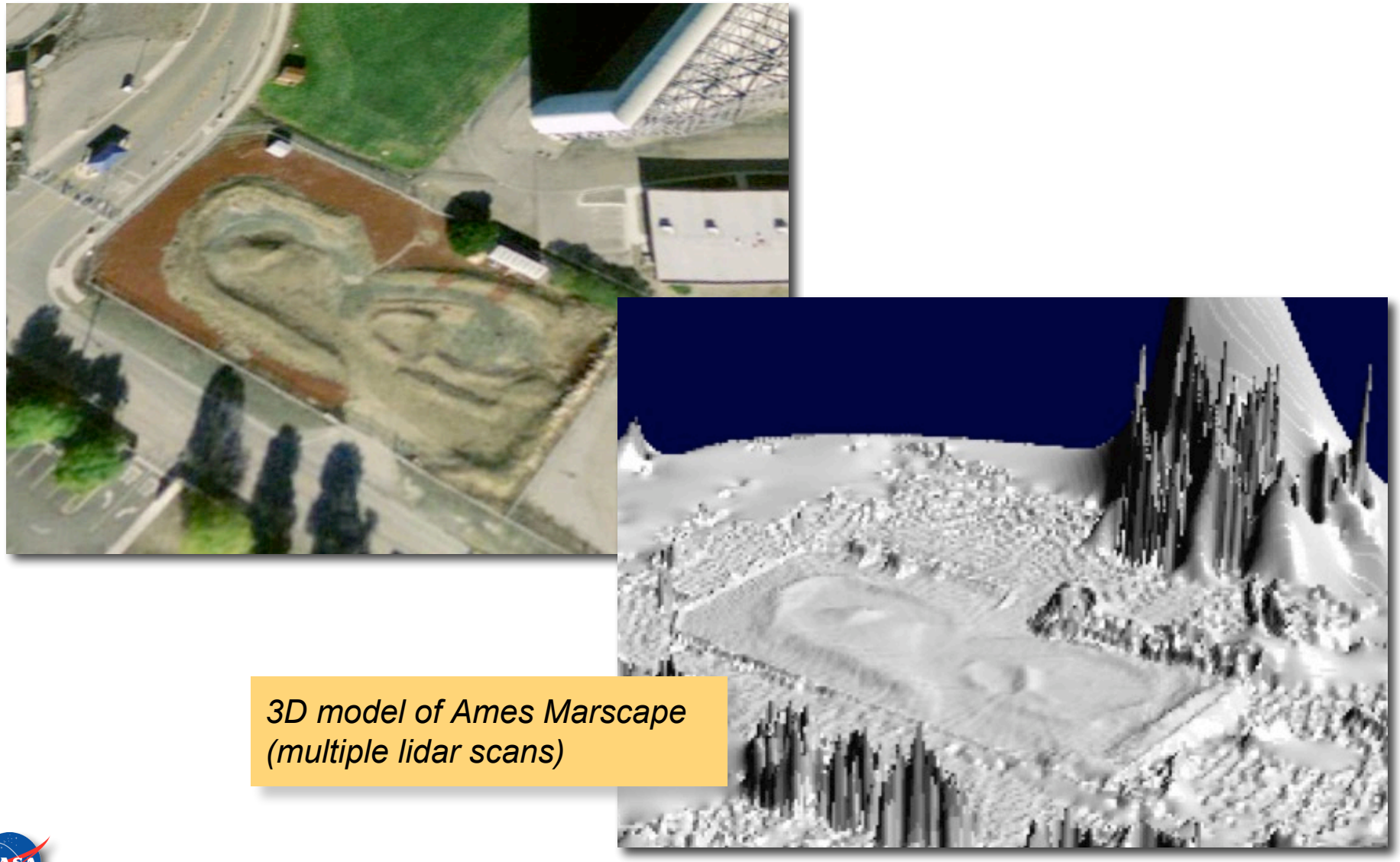
Data products

- Global model (aligned local models)
- Merged local models (e.g., stereo panorama)
- Individual local models (e.g., stereo pair)
- Error vectors (from alignment stage)



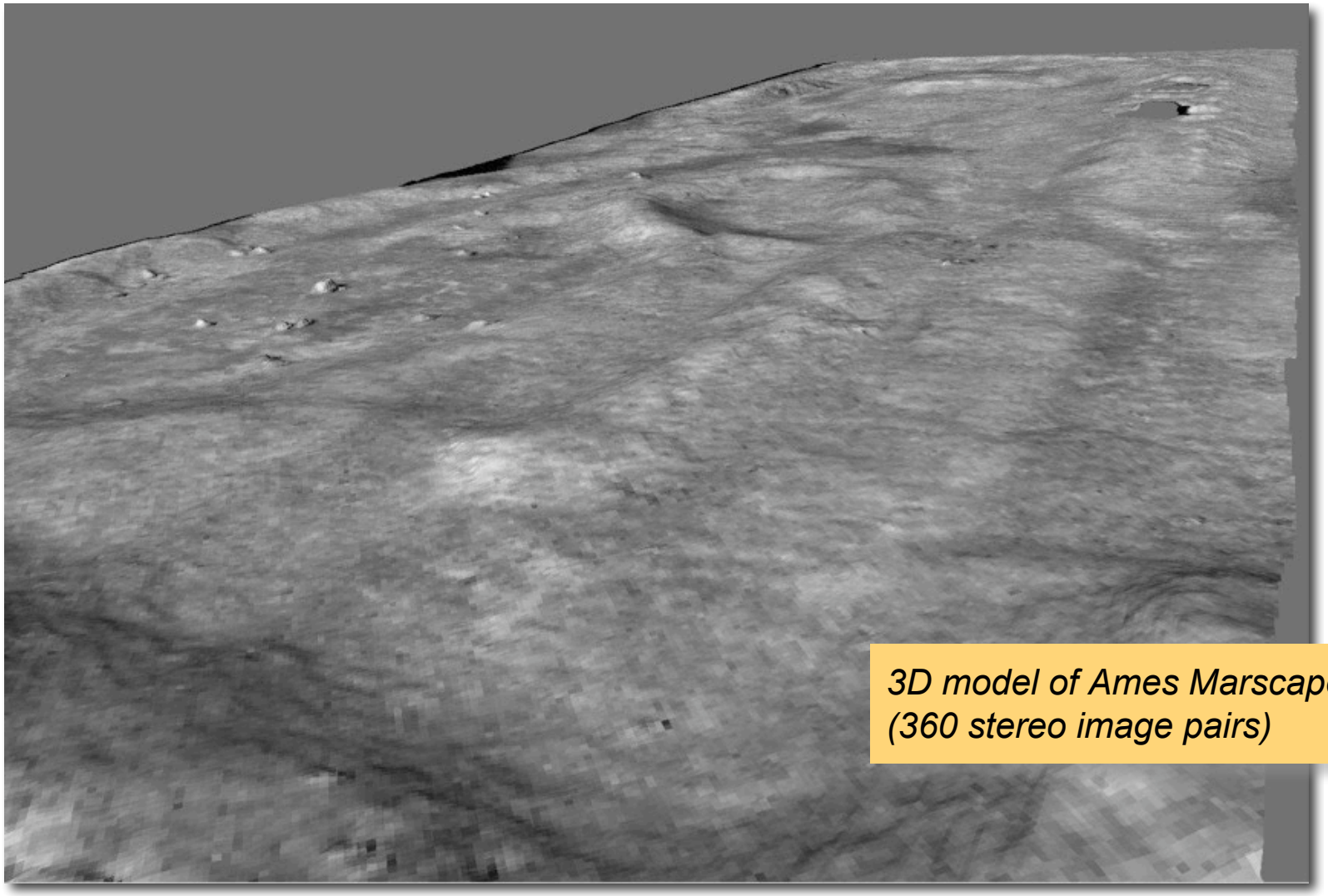
M. Broxton, M. Deans, L. Edwards, M. Hancher, D. Lees

DEM Mosaic



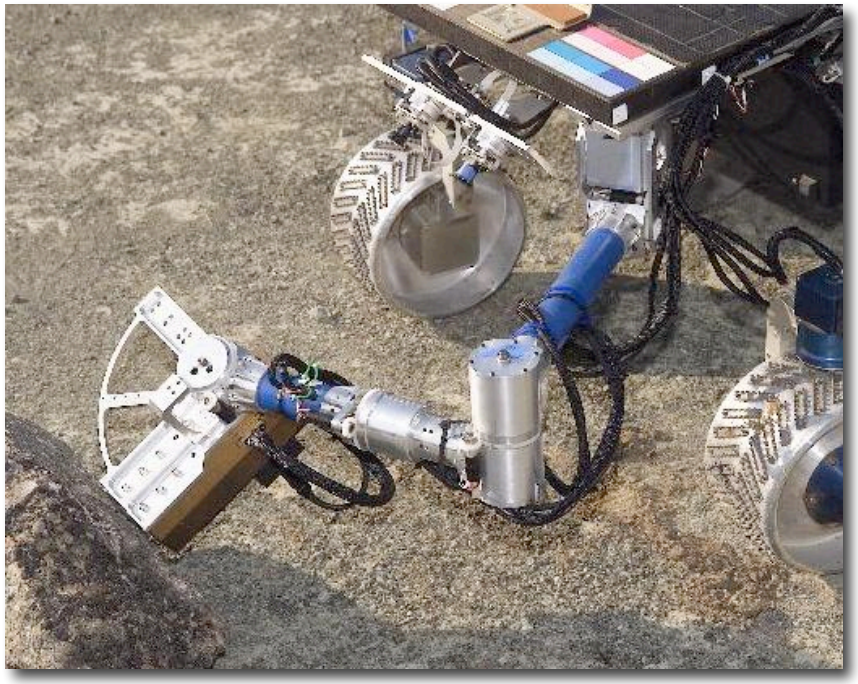
3D model of Ames Marscape (multiple lidar scans)

DEM Mosaic



3D model of Ames Marscape (360 stereo image pairs)

Vision-based Local Navigation



Navigation
- Multiple targets / cameras
- 10m range
- 1cm accuracy

→

Hand-off
(Multi-camera tracking)

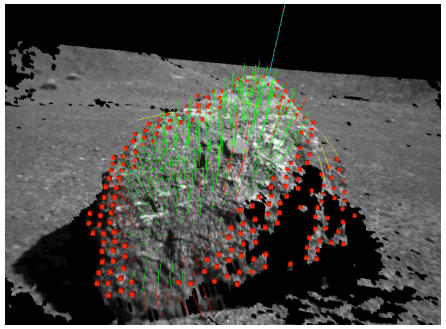
→

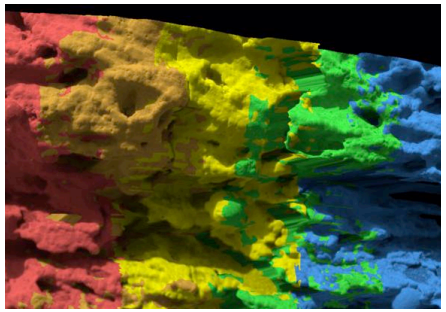
Placement
- Rock segmentation
- Instrument safety
- Arm motion planning

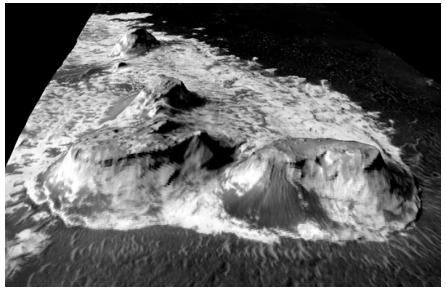
M. Deans, C. Kunz, L. Pedersen, R. Sargent

Research Areas

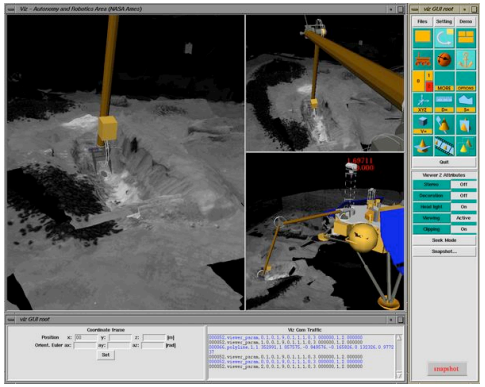
Perception

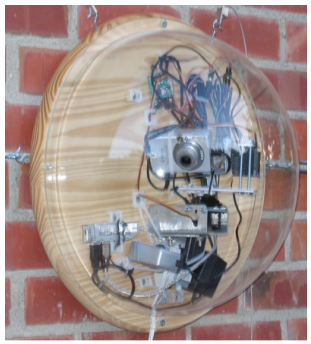


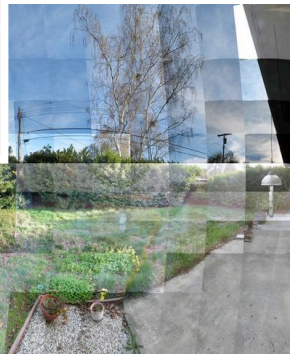




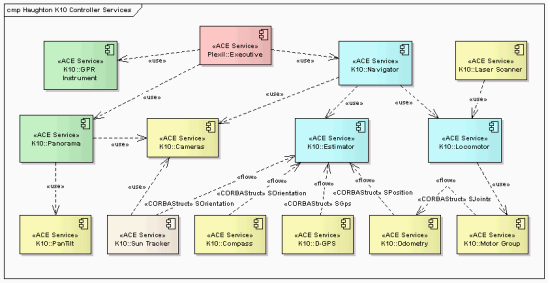
Interaction

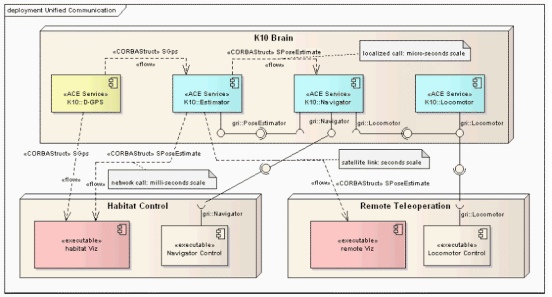


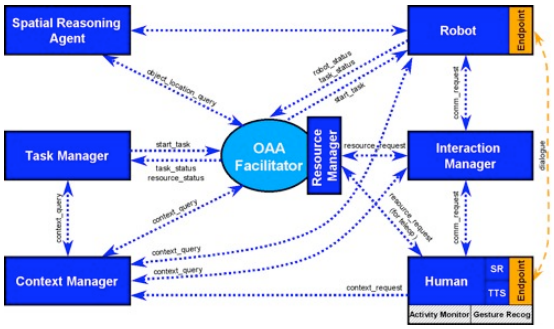




Architecture







Interaction

Peer-to-Peer HRI

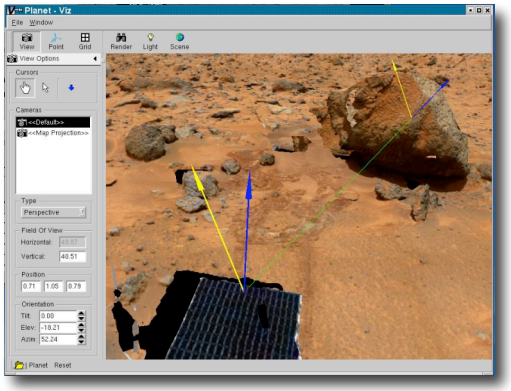
- Human-robot teaming: dialogue and coordination

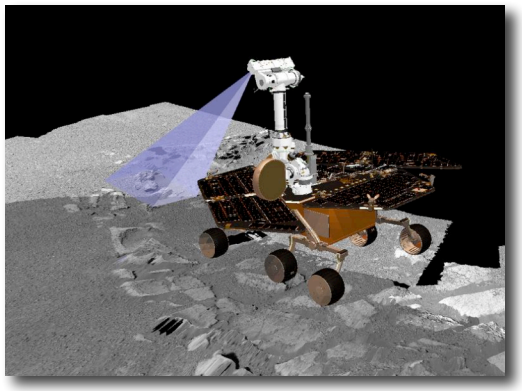
Viz

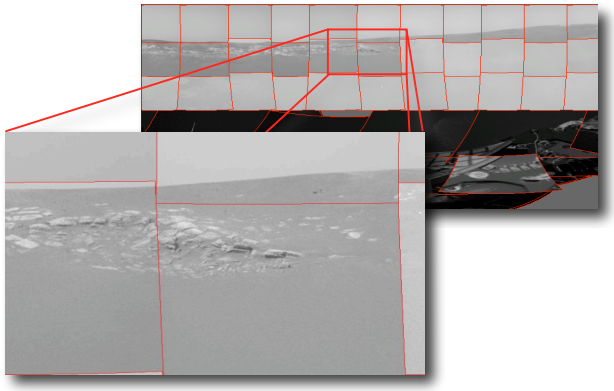
- Simulation / scientific visualization
- Rover mission operations

Global Connection

- Giga-pixel panoramas (high dynamic range & time-lapse)
- Disaster response, education & community building







Peer-to-Peer HRI Project

Improve human-robot teaming

- "Robots with human traits"
- Provide interaction support
- Support operational tasks (construction, inspection, etc.)

Human-robot dialogue

- Coordinate teamwork
- Resolve execution problems

Partners

- NASA ARC (T. Fong)
- NASA JSC (R. Ambrose)
- CMU (I. Nourbakhsh & R. Simmons)
- NRL (A. Schultz)
- NIST (J. Scholtz)
- MIT (J. Arnold)

- ✓ *Interaction operating system*
- ✓ *Cognitive architectures*
- ✓ *Adaptive user interfaces*
- ✓ *Human-robot dialogue*
- ✓ *Adjustable autonomy*
- ✓ *Quantitative metrics*

Peer-to-Peer HRI Study (Nov 2005)

Use case: Seam welding

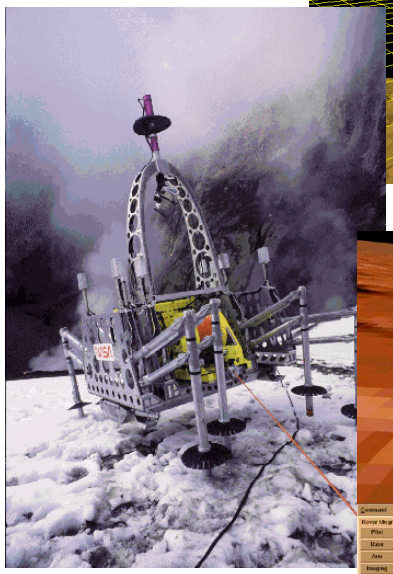
- Construction of work hangars, shelters, etc.
- Contingency handling (e.g., repair rupture or break)
- Robots (“welder” + “inspector”) and humans (2 EVA, 1 IVA)

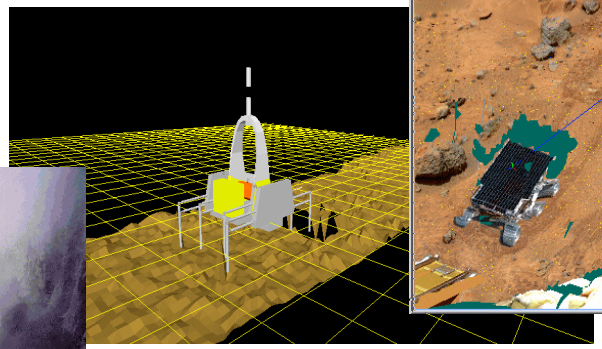
Dialogue

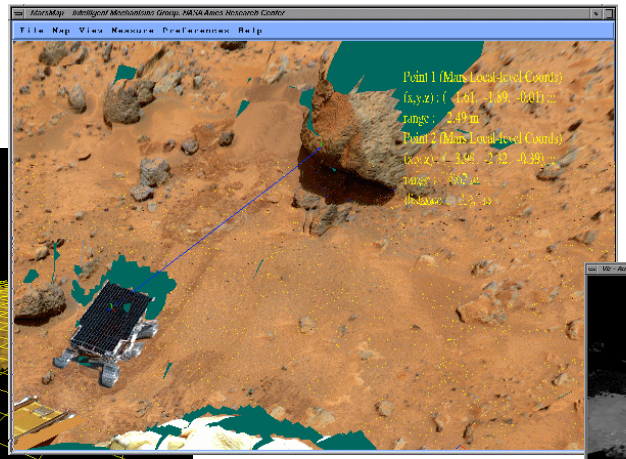
- Robots ask questions (“Is this weld okay here?”)
- Spatial language (“Shine the light to my left”)

Exploration User Interfaces

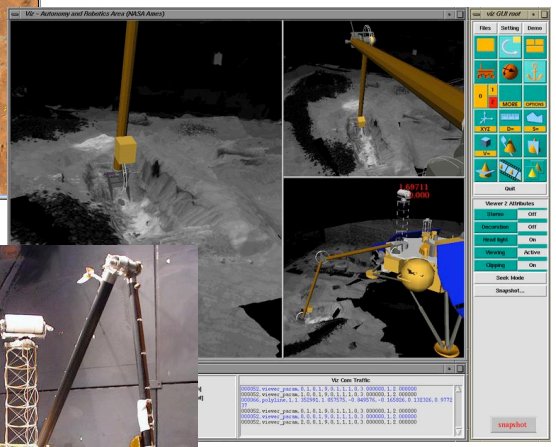
Dante II + Virtual Environment Vehicle Interface (VEVI)



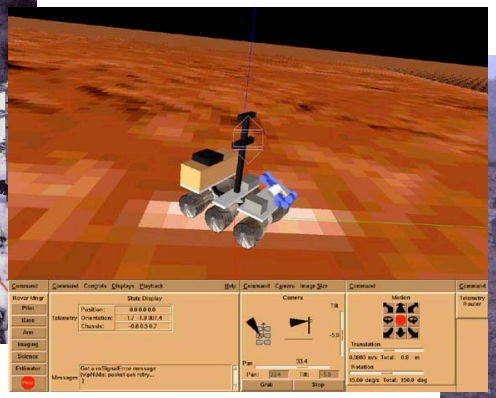


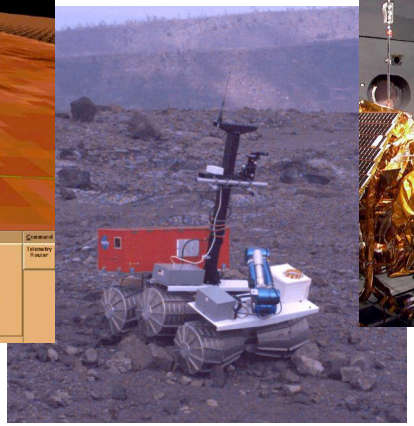


Mars Pathfinder + MarsMap



Mars Polar Lander + Viz





Marsokhod + VEVI

M. Allan, L. Edwards, L. Keely, D. Lees

Viz (2002-2005)

Interactive 3D UI

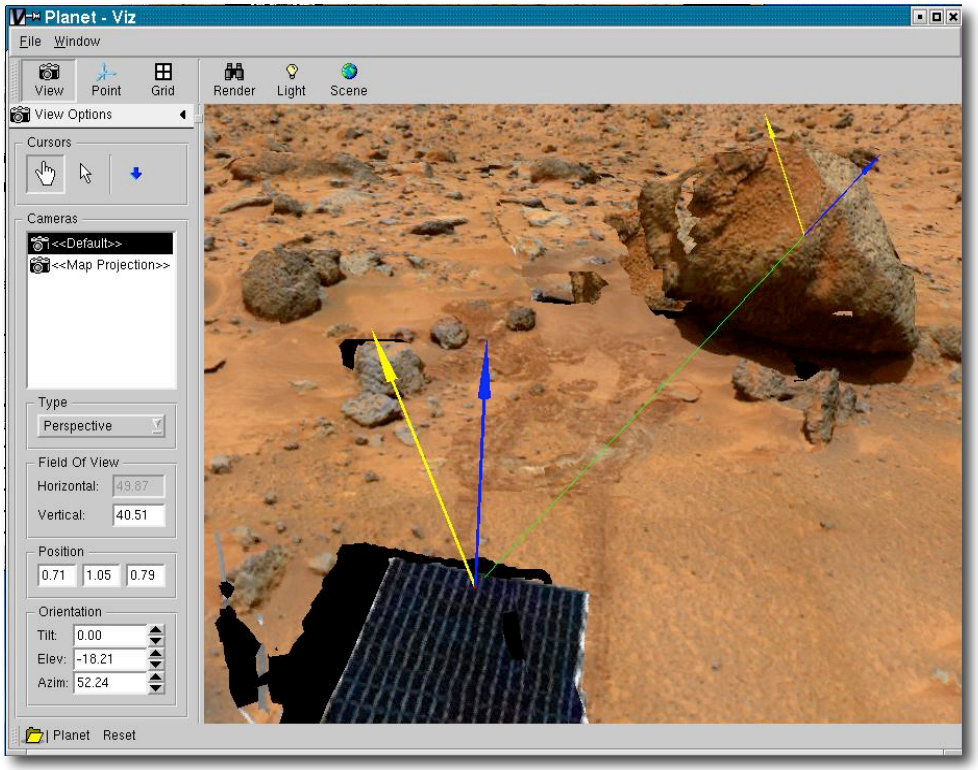
- Stereo viewing
- Background image

Simulation

- Time of day lighting
- Viewpoint + pose
- Object kinematics

Site understanding tools

- Point, distance, azimuth measure
- Elevation + slope maps
- Sun + planet vectors
- Surface area measure
- Terrain cross-section
- Markers + ancillary data



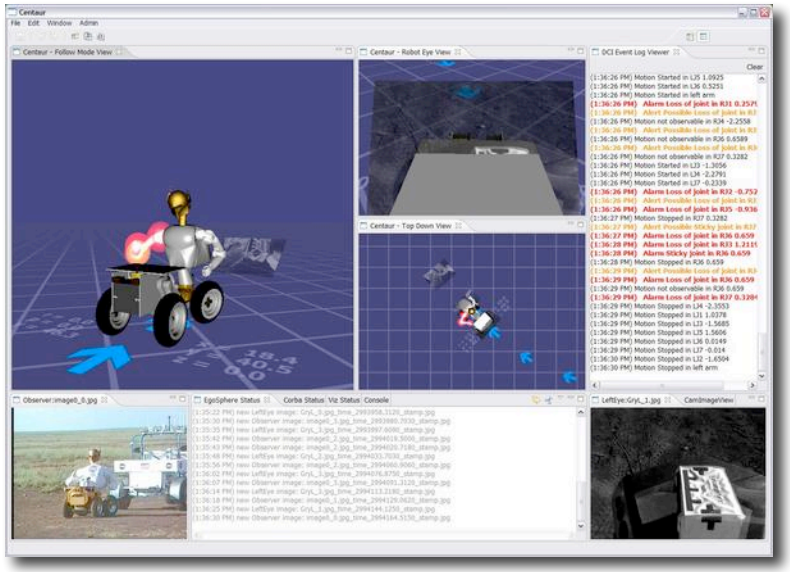
Missions: MPL, MER, Phoenix, MSL
Field Tests: K9/Mojave, IS Level 1, CDS

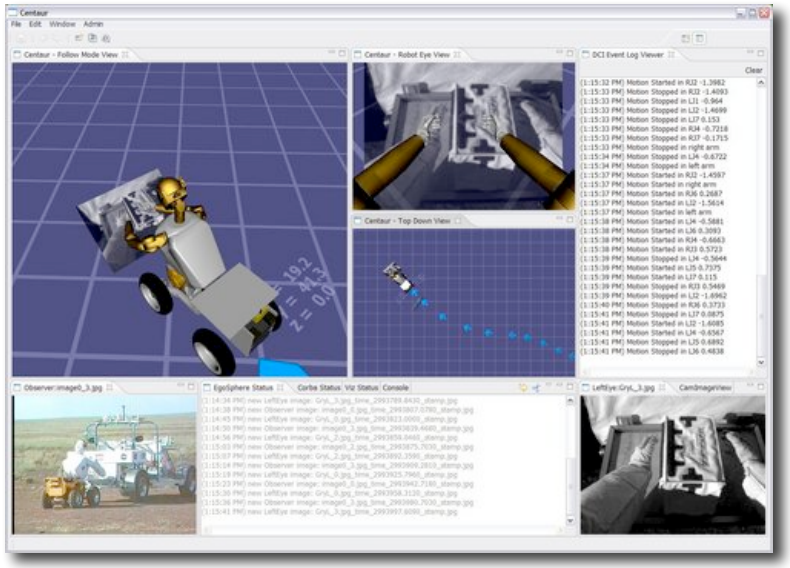
Viz (2006)

Centaur operations

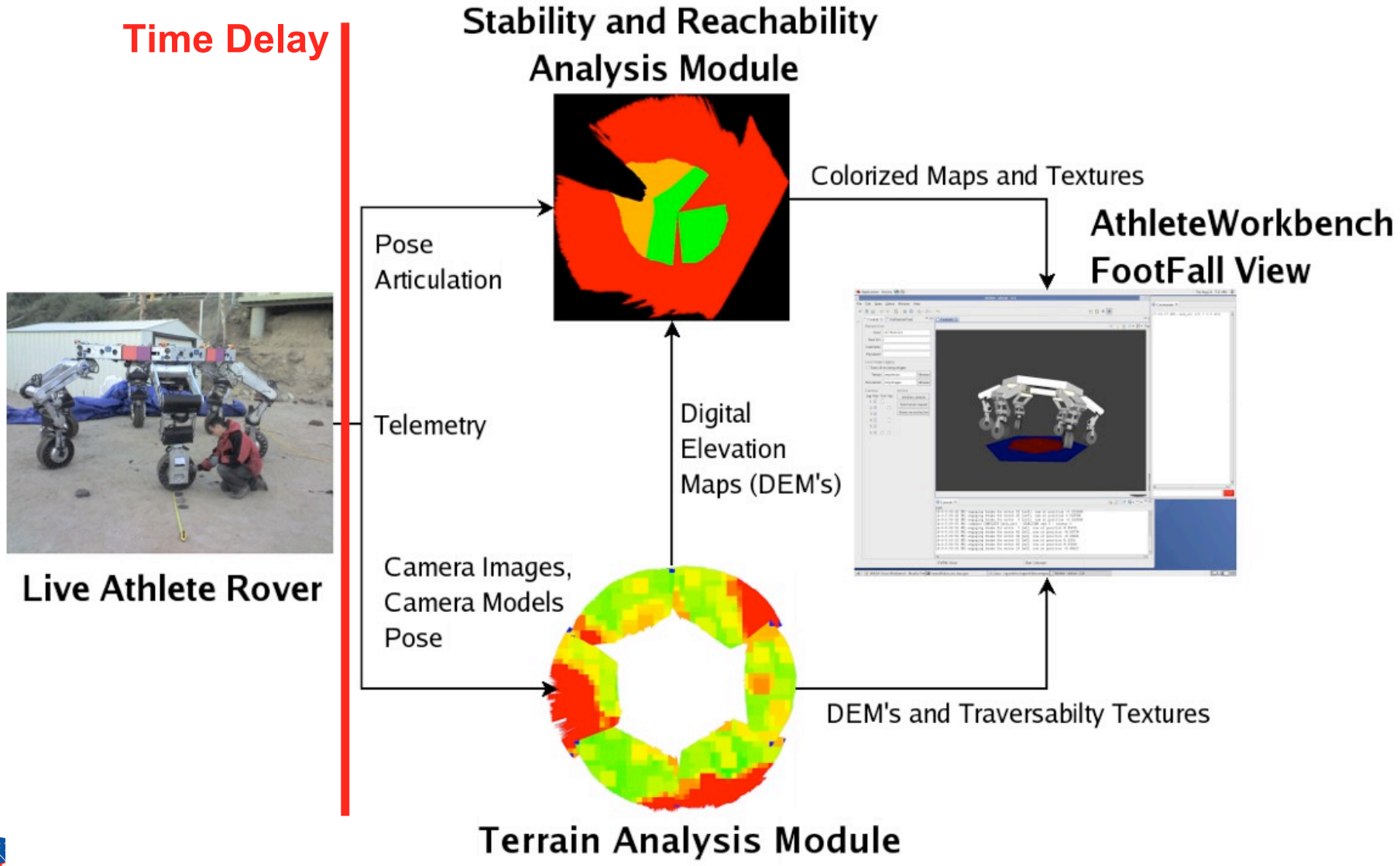
- Robonaut with wheels
- Interactive 3D UI
  - Mixed reality
  - Health and status
  - Assisted localization

Centaur (JSC) at Meteor Crater

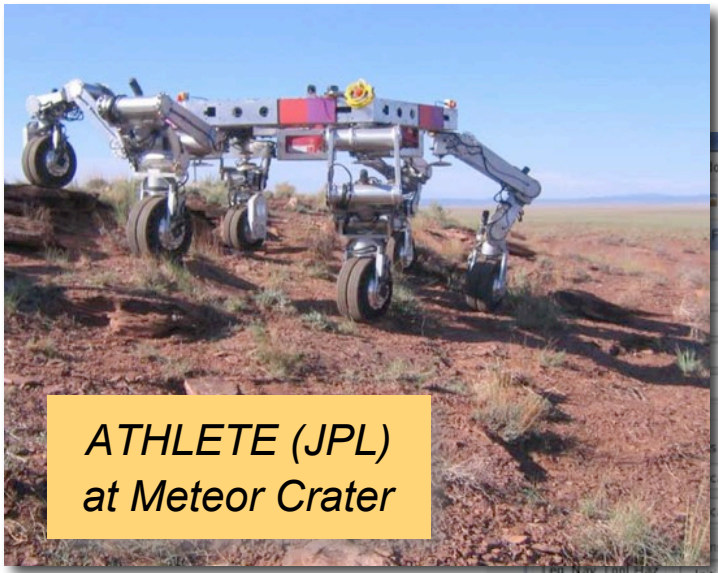




ATHLETE Footfall Planning

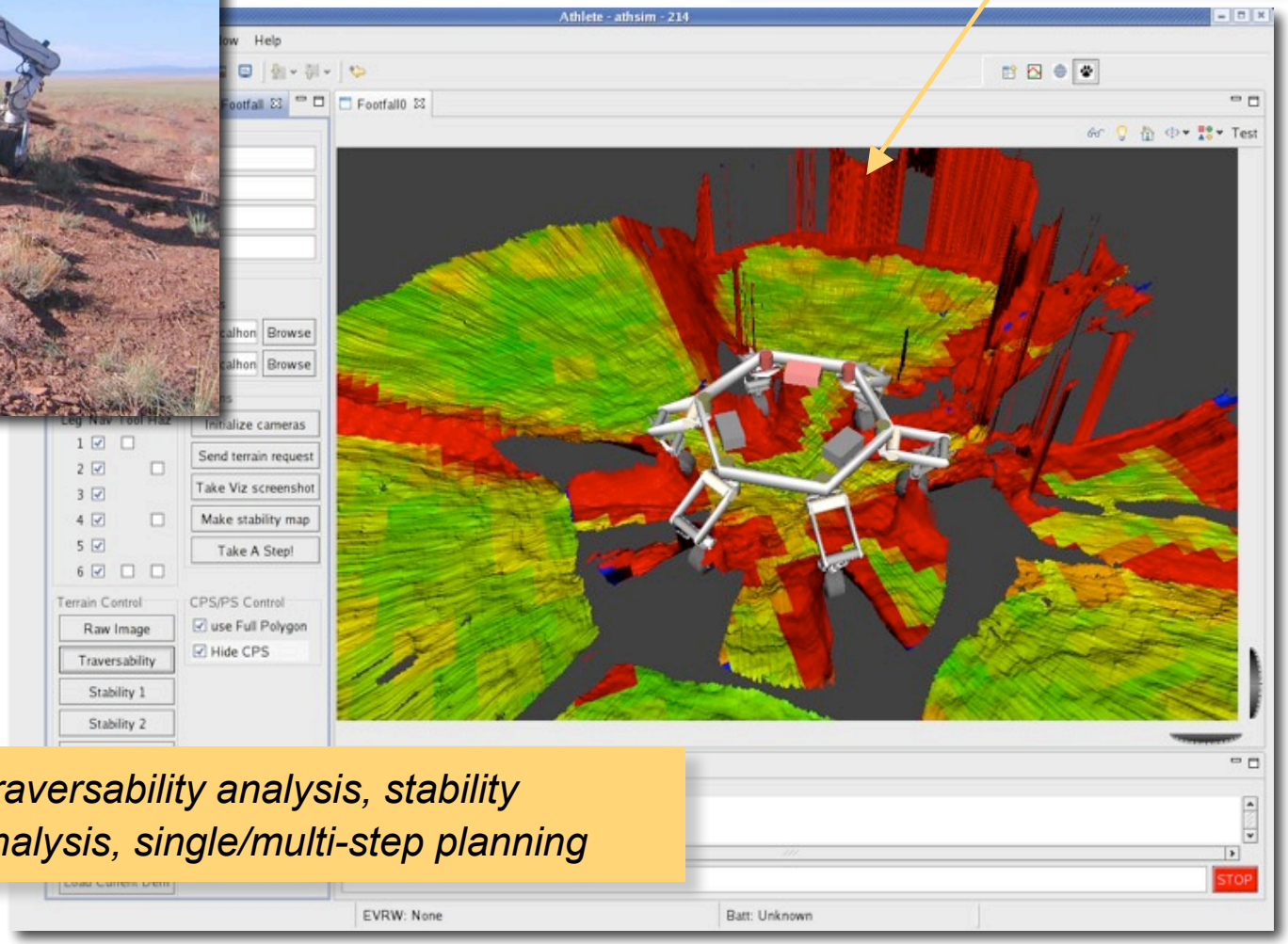


ATHLETE Footfall Planning



ATHLETE (JPL) at Meteor Crater

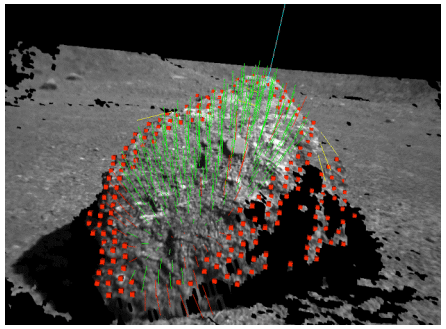
Viz in ATHLETE Workbench (Eclipse-based framework)

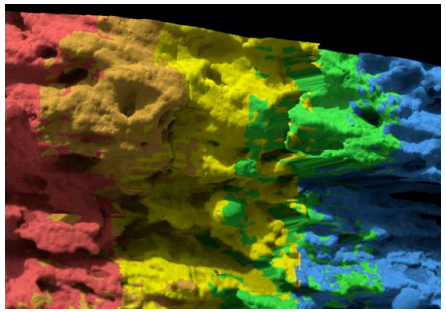


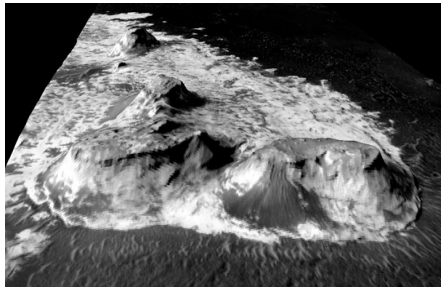
Traversability analysis, stability analysis, single/multi-step planning

Research Areas

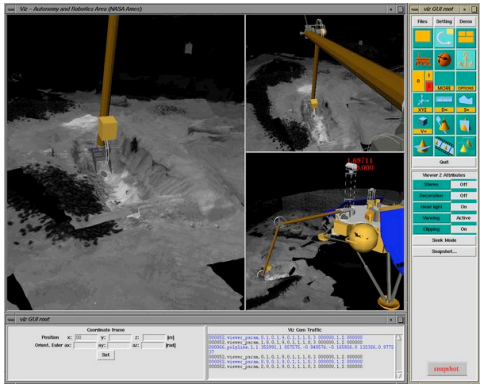
Perception

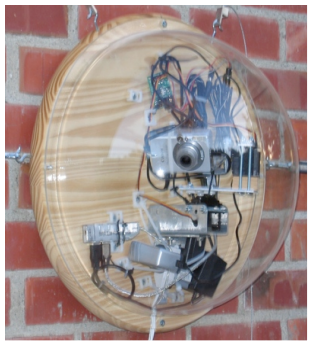


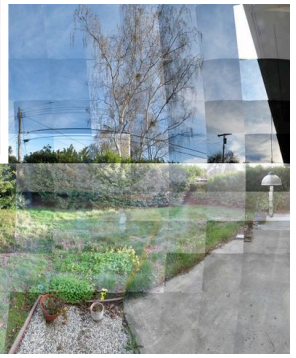




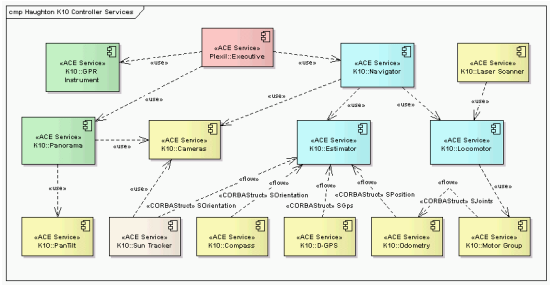
Interaction

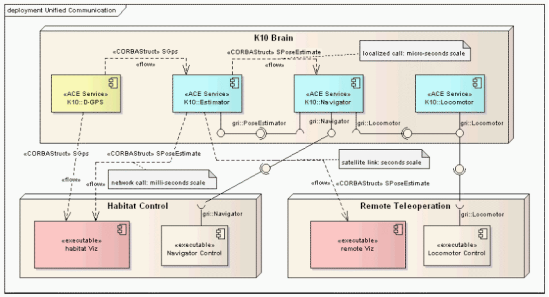


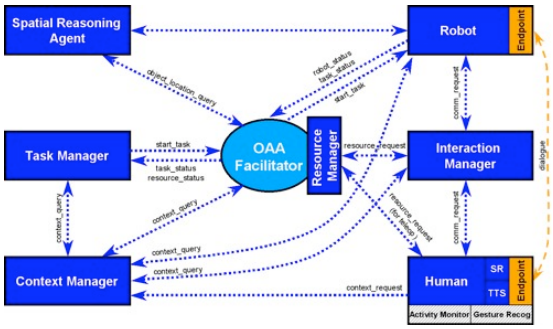




Architecture







Architecture

Robotic systems software

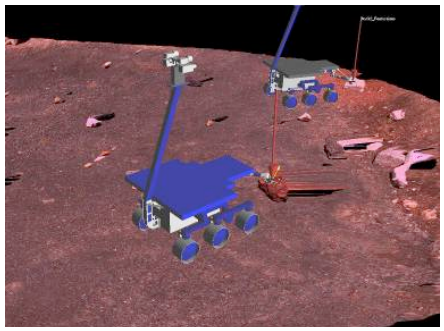
- Service oriented robotic architecture
- Continuous navigation and locomotion

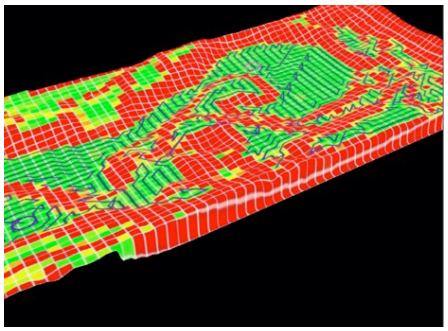
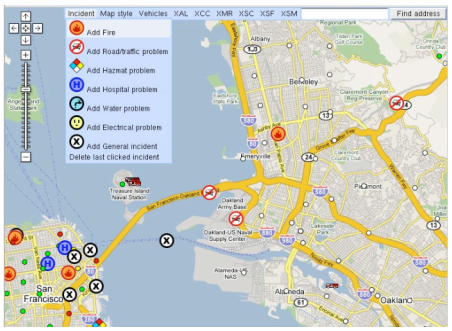
Disaster response systems

- Geo-spatial imaging
- Emergency operation center (EOC) tools

Human-robot site survey

- Comprehensive, systematic survey
- Human-robot teaming (remote HRI)



Google NASA Disaster Response Project

Objectives

- Software tools for response
- Improve efficiency & speed
- Help save lives and property

Approach

- Improve situational awareness after an event
- Make geospatial data easy to acquire & use
- Release open-source tools

Focus areas

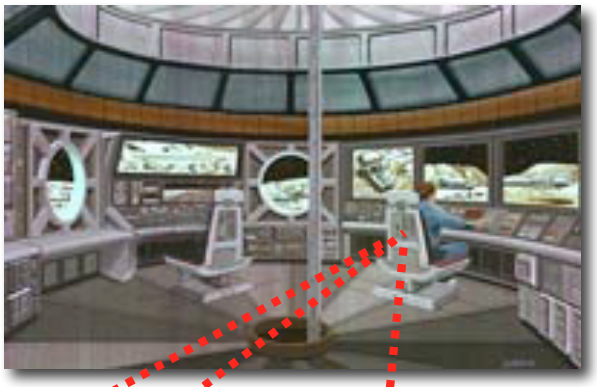
- Rapid response imaging
- User interfaces (command post & mobile)
- Outreach, education and community building

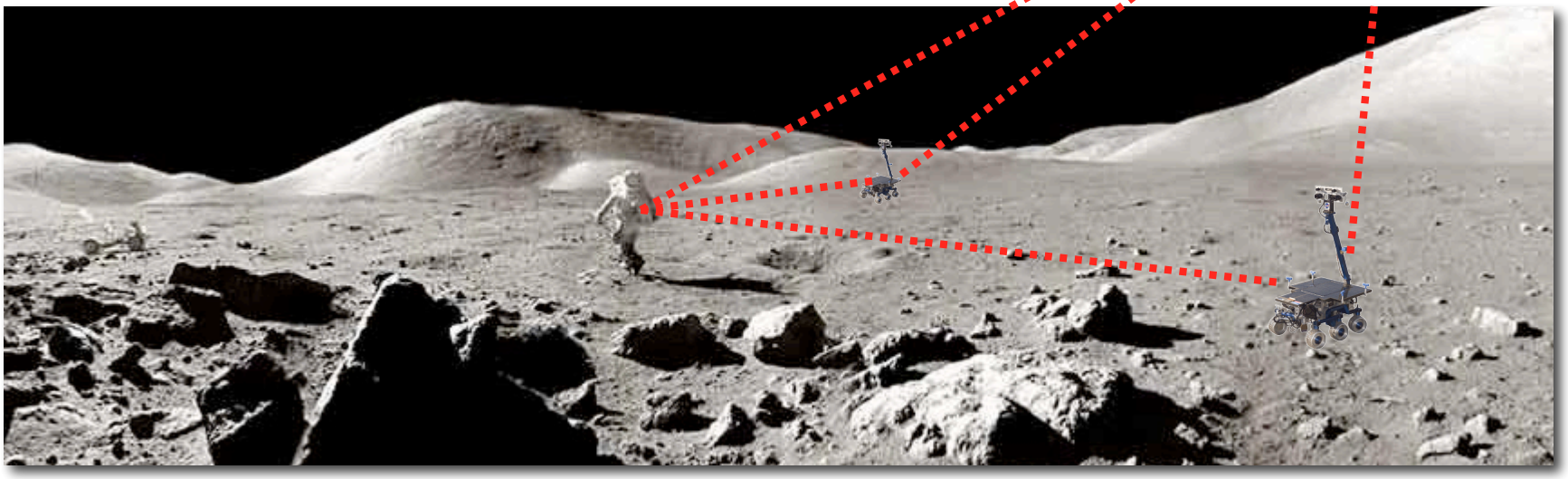
M. Allan, P. Finch (SGE), T. Fong, T. Morse, L. Pedersen, R. Sargent, T. Smith

Human-Robot Site Survey

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)





M. Allan, X. Bouyssounouse, M. Bualat, M. Deans, T. Fong, L. Flückiger, L. Keely, L. Kobayashi, P. Lee (SETI), S. Lee, D. Lees, V. To, H. Utz

Haughton Crater Site Survey Field Test

10 July – 3 August 2007

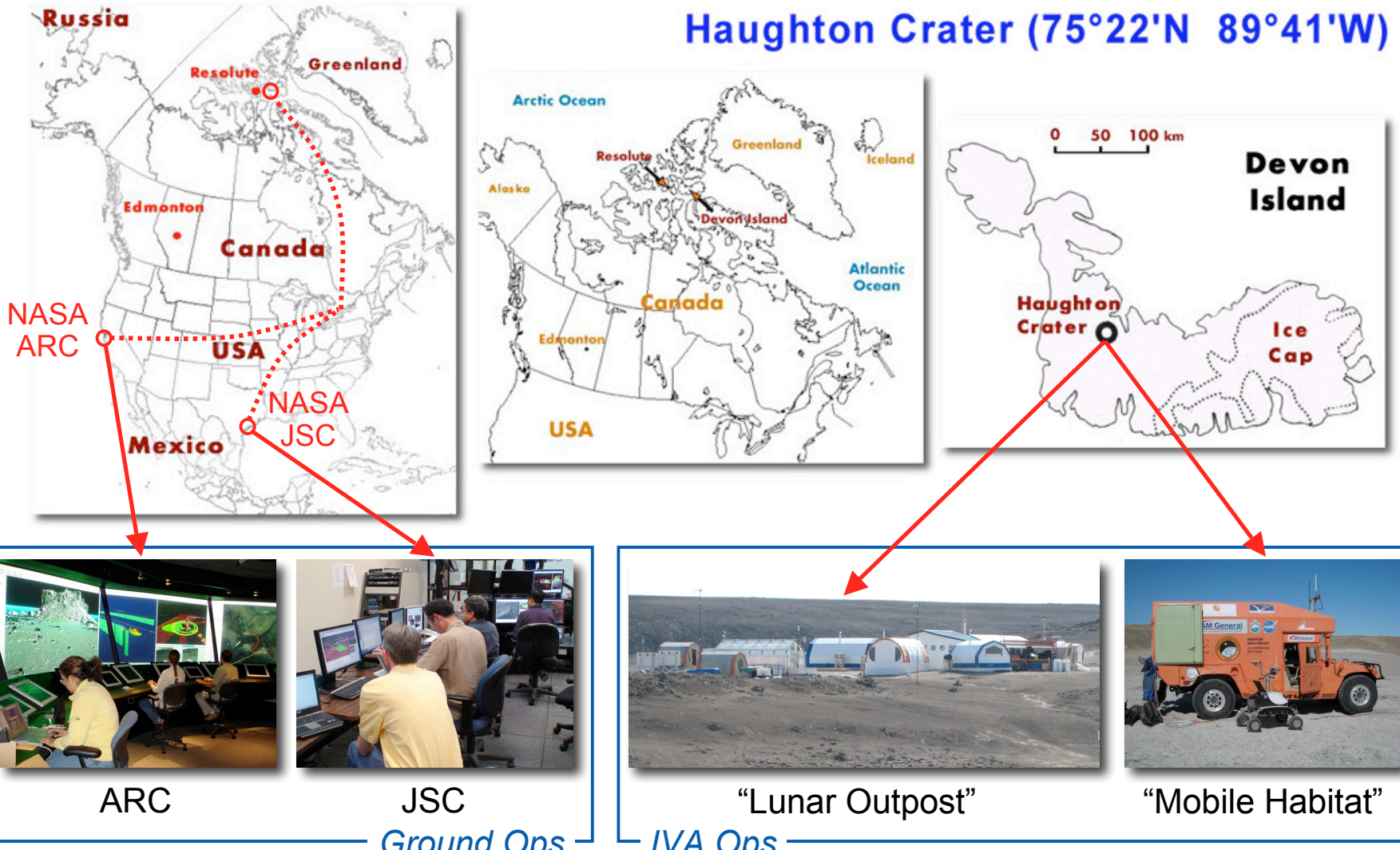
- Two K10 rovers with survey instruments
  - 3D lidar for terrain mapping
  - Ground-penetrating radar for resource prospecting
- Test robotic survey and operational procedures
- Multiple lunar analog sites at Haughton Crater

Haughton Crater
(Devon Island, High Arctic, Canada)

K10 rover

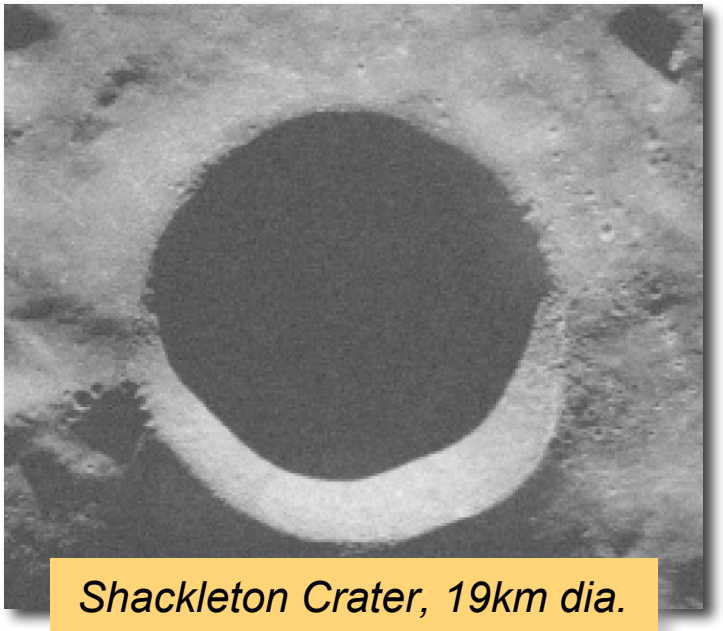
haughton2007.arc.nasa.gov

Remote Operations

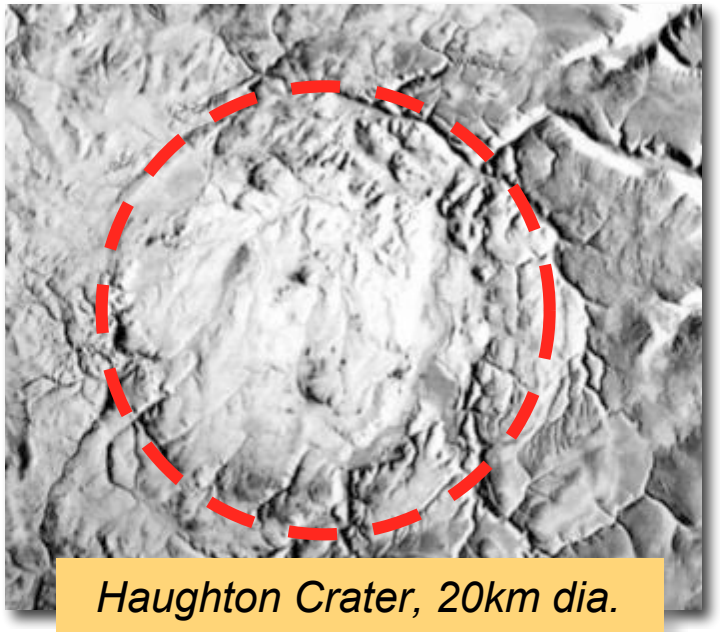


Haughton Crater as Lunar Analog

Shackleton Crater might present H_2O ice in surrounding shadowed zones. It is a prime candidate site for human exploration.
Haughton Crater is the best preserved impact structure of its class on Earth and is located in a H_2O ground ice rich rocky desert.



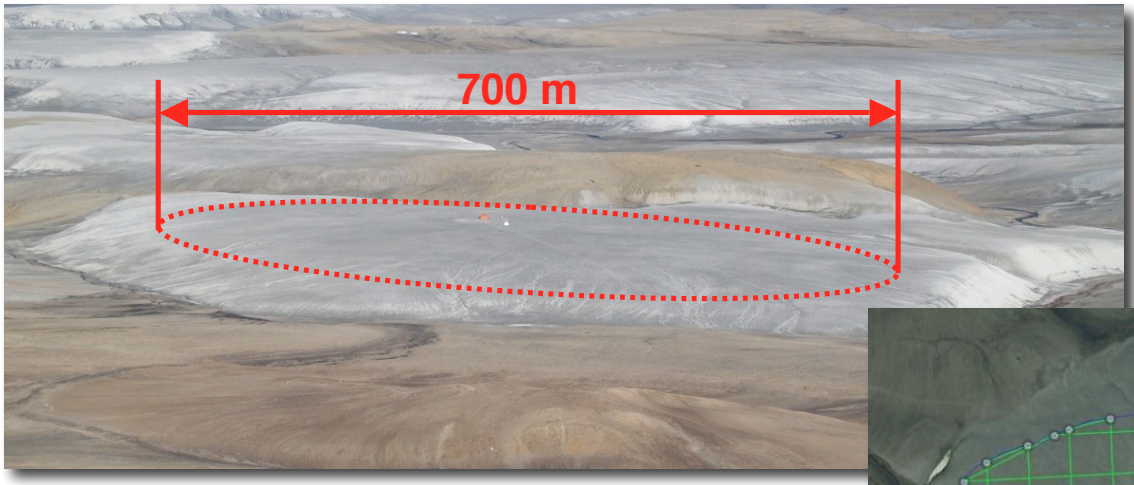
Shackleton Crater, 19km dia.
(lunar South Pole)
2005 Arecibo radar image



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

⇨ Haughton may be the best ***scientific & operational analog*** for Shackleton

“Drill Hill” Survey

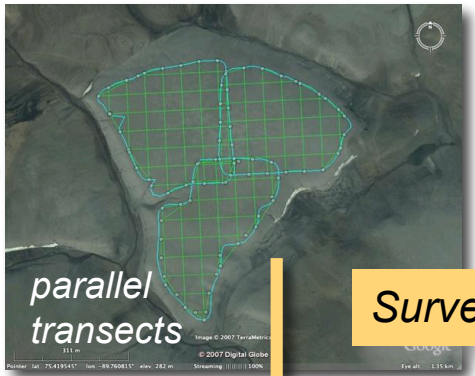


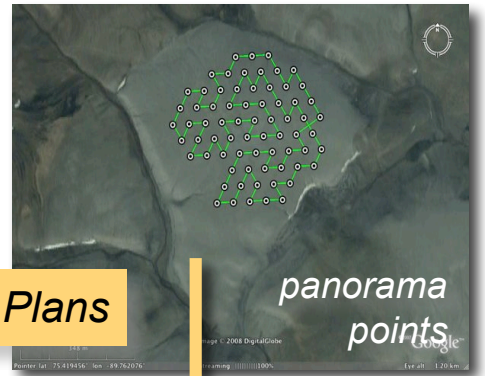
K10 robot path (real-time display in Google Earth)

Survey plan (parallel transects 50 m spacing)

Robotic Site Survey

Coverage Planning

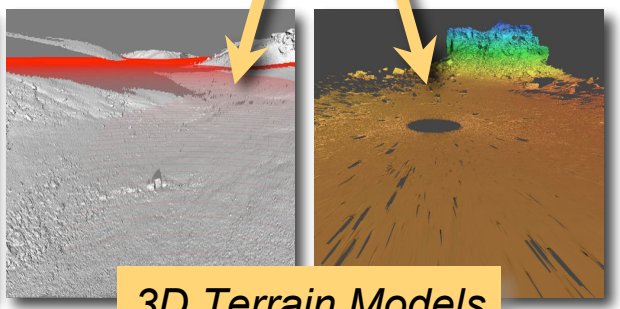




Survey Plans

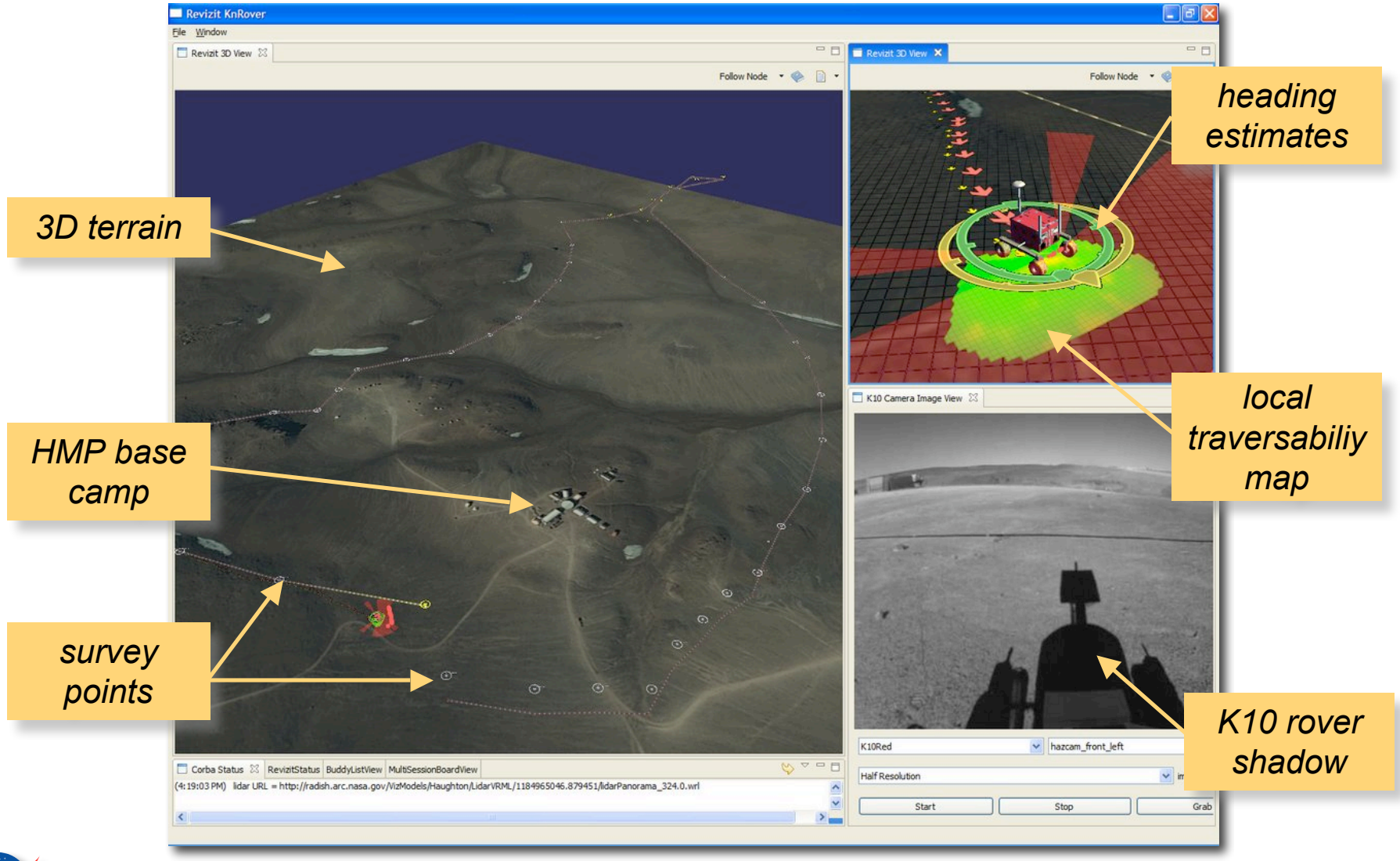
Survey Site

GPR Profiles

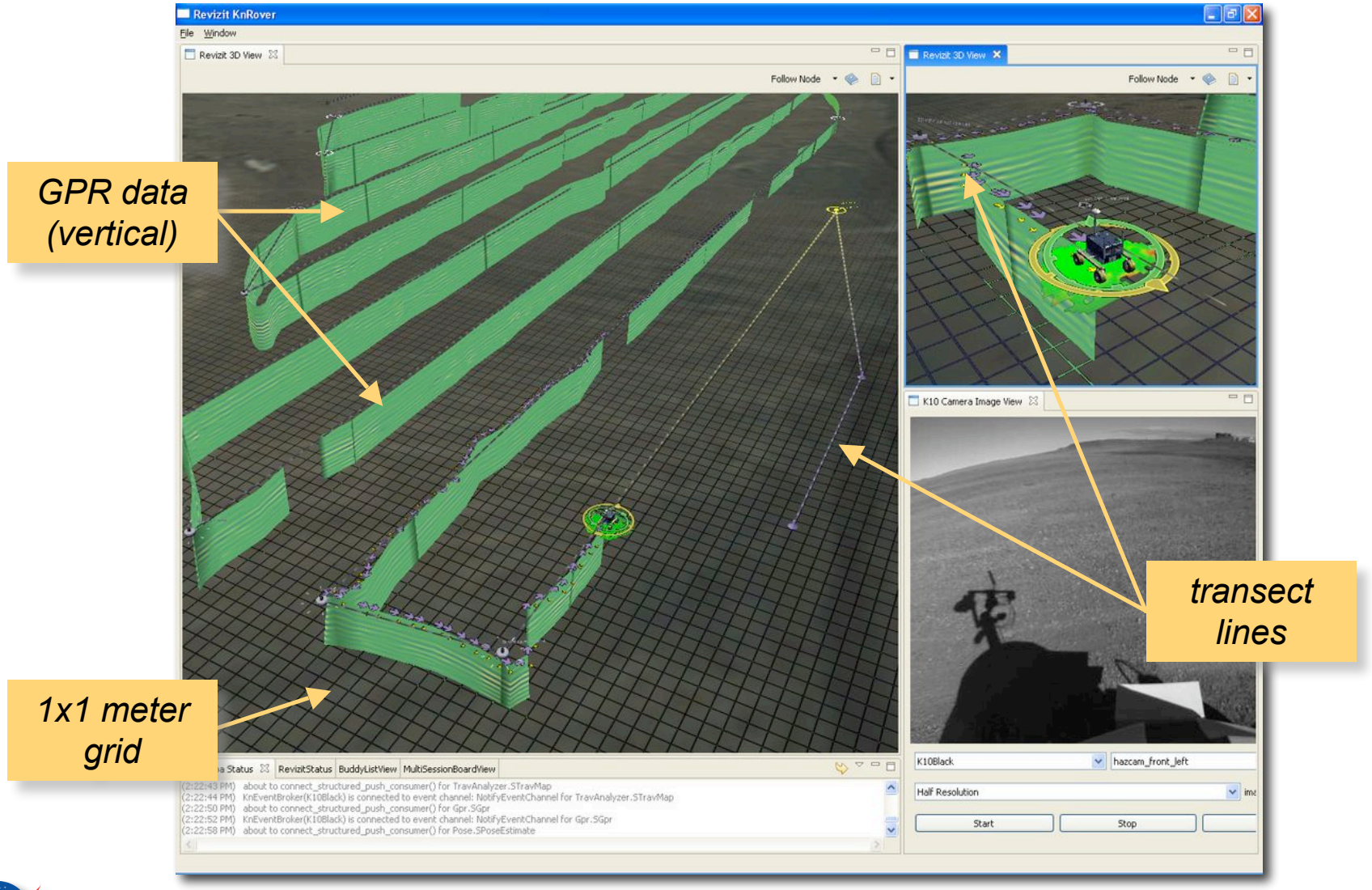


3D Terrain Models

Lidar Survey Displays

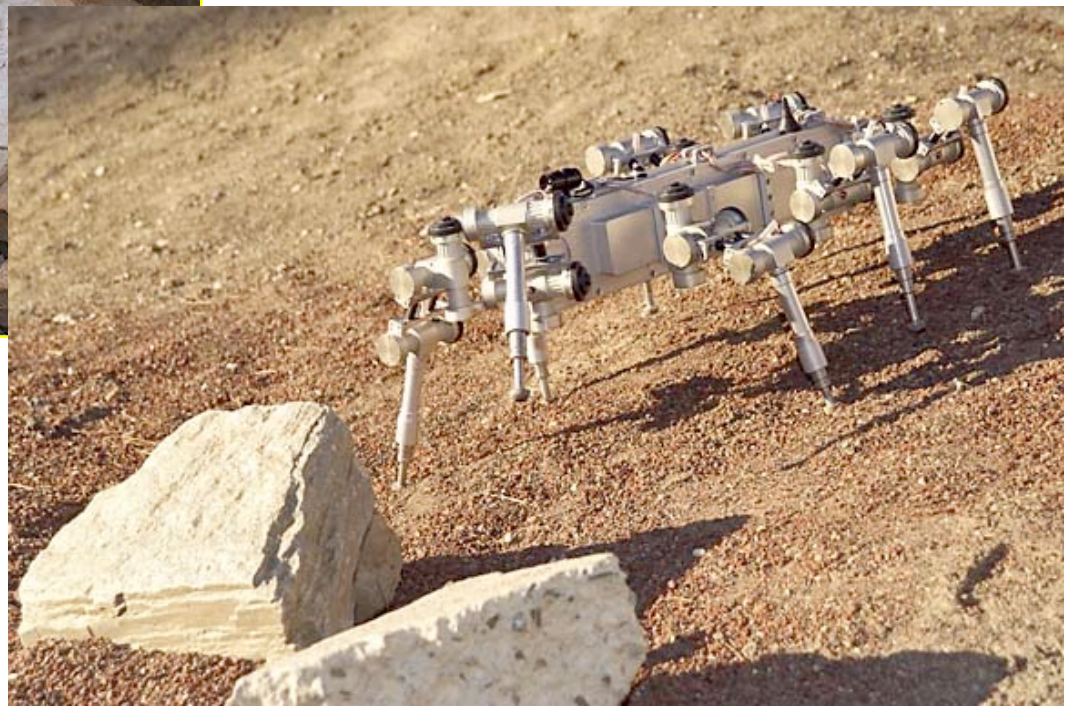


GPR Survey Displays



Scorpion: legged locomotion

(Collaboration with Prof. Frank Kirchner)



Concept Simulation :
Rappelling Scorpion