VERVE

Visual Environment for Remote Virtual Exploration

A 3D Tool for Space Robots

DW Wheeler[1], Mark Allan[1], Julius Gyrofi[1]
Presented by Mark Rose[2]

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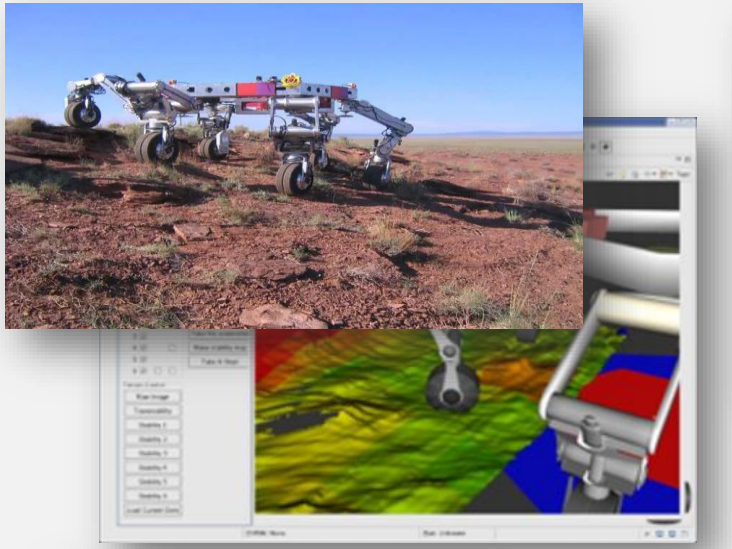
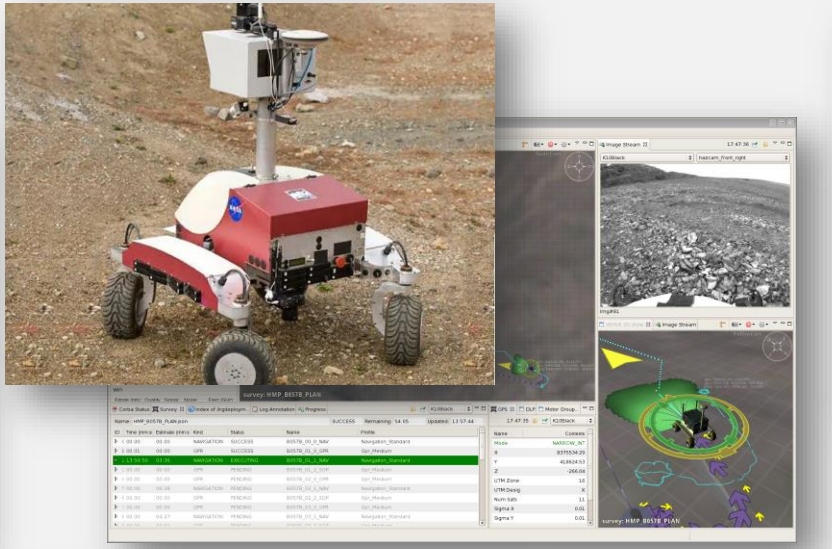
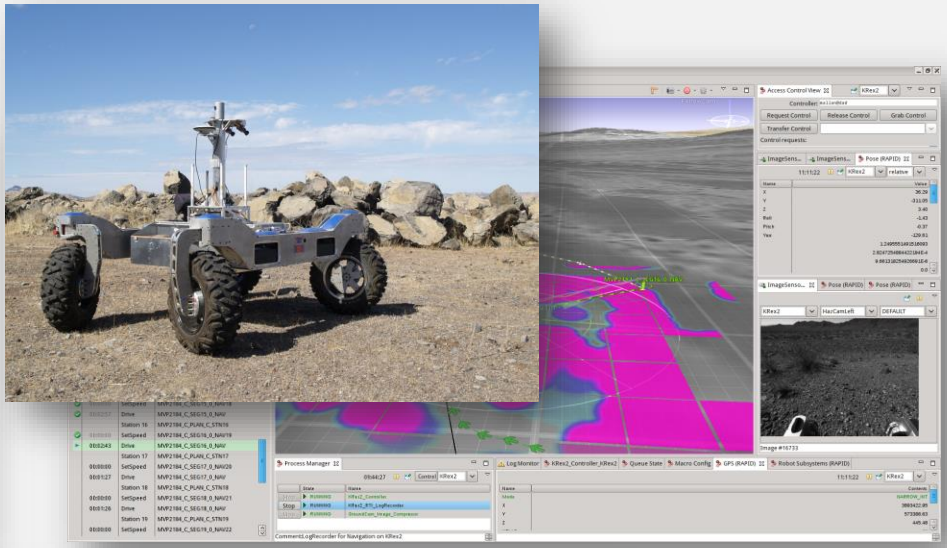
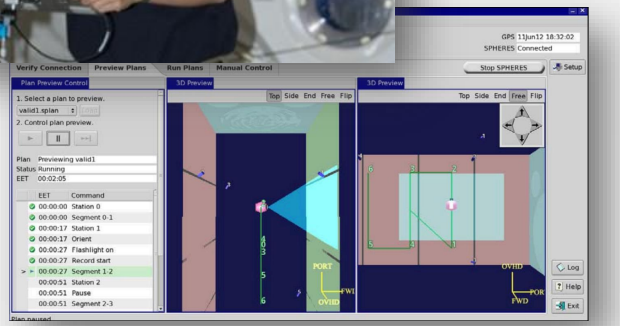
[1] KBR, Inc.
[2] NASA Ames Research Center

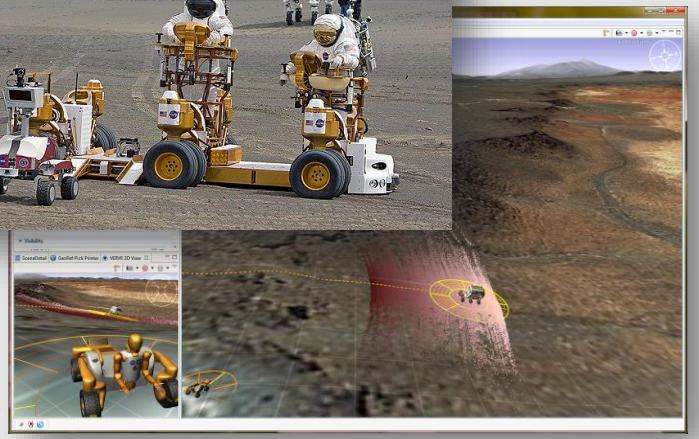
Intelligent Robotics Group





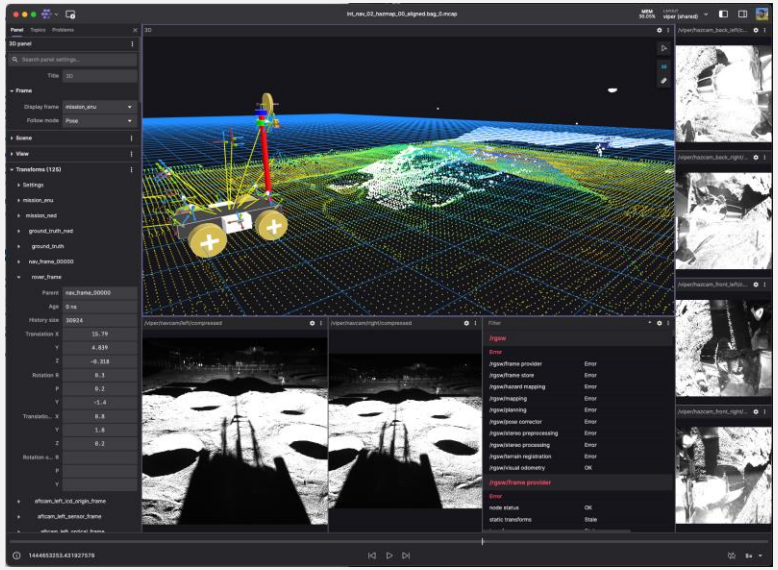






Robot Interfaces

- Virtual 3D interfaces concisely convey situational awareness for robotics
  - e.g. RViz, Foxglove
- Immersive telepresence commonly induces visual fatigue, nausea
  - Not suitable for high stress, high tempo mission ops
- 3D interfaces used for space robotics
  - RSVP (JPL) used to create, view, validate a Martian day's worth of activity
  - VIPER VERVE used interactively to command rover in real time



Foxglove as used for VIPER localization development and testing

TROV telepresence interface operating underwater robot

VIPER vs ISS vs Mars Rovers

Mars Rovers

No real time interaction

High latency (6-20 min round trip comms)

Long mission duration

VIPER

Real time science

Real time interaction

Med latency (6-10s round trip)

Med Mission duration

Extreme lighting

Continuous comm

Time delayed science

Natural terrain

Command sequencing

Intermittent comms

Limited shadow

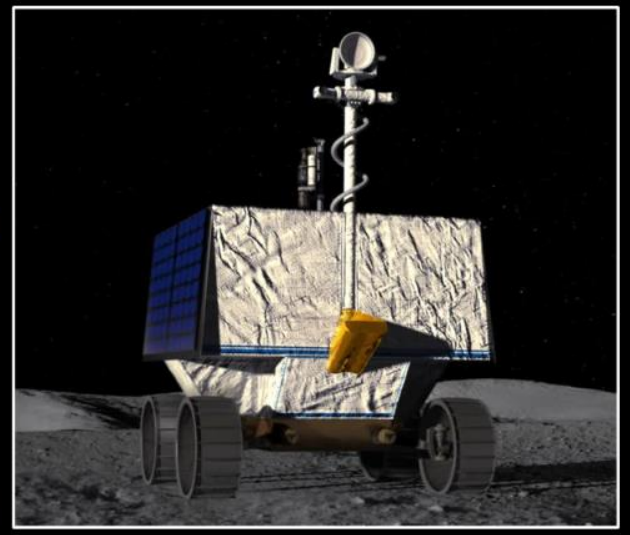
Low tempo ops

ISS Robotics

Low Latency (<2 s round trip)

Direct teleoperation

Semi-structured Environment



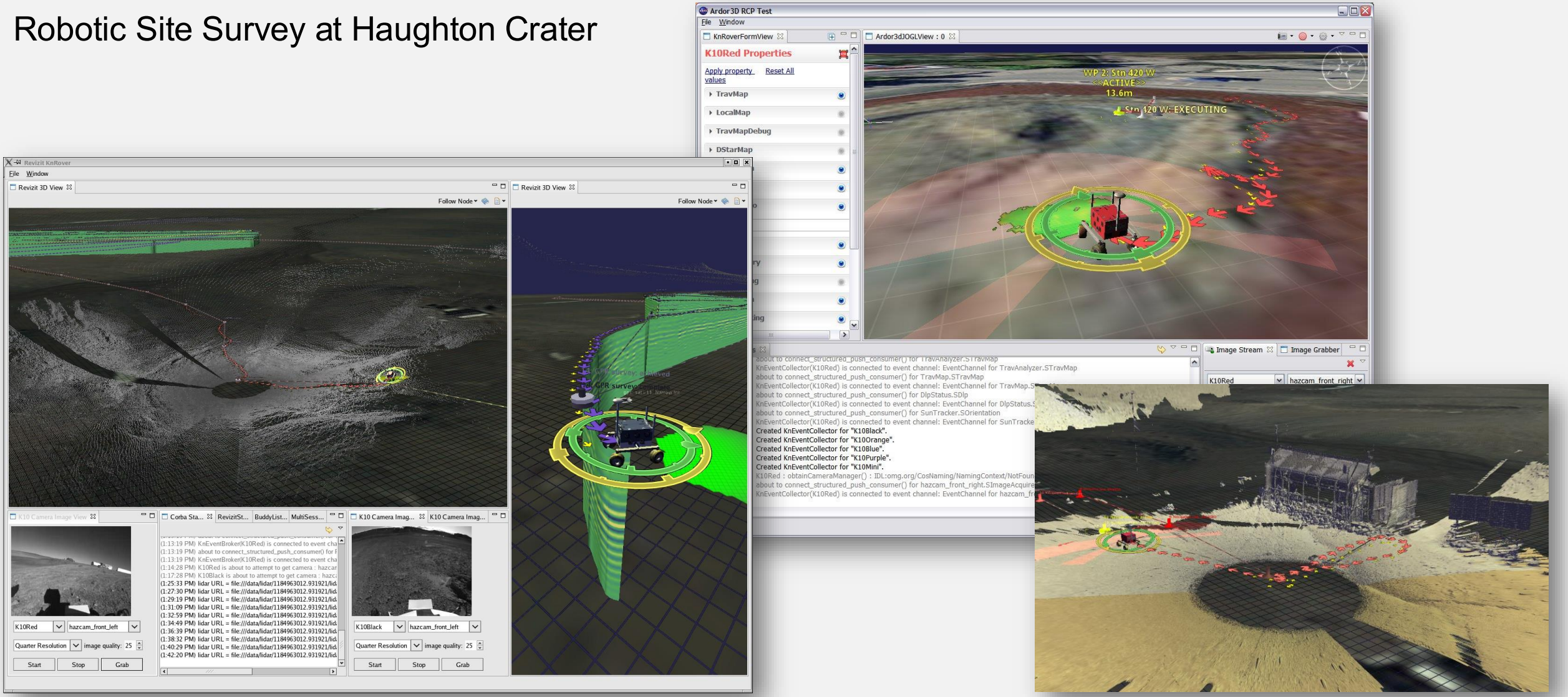
Core Capabilities

- Primary 3D view, third person perspective
  - Articulated robot avatar
  - Graphical representations of sensor data and derived data products
  - Robot environment
    - e.g. indoor structures, road networks, large scale terrain
  - Heads-Up Display (HUD)
- Camera sensor views
- Virtual camera sensor views
- Command panels
- Command monitoring
- Collaborative map markup

VERVE – Visual Environment for Remote Virtual Exploration

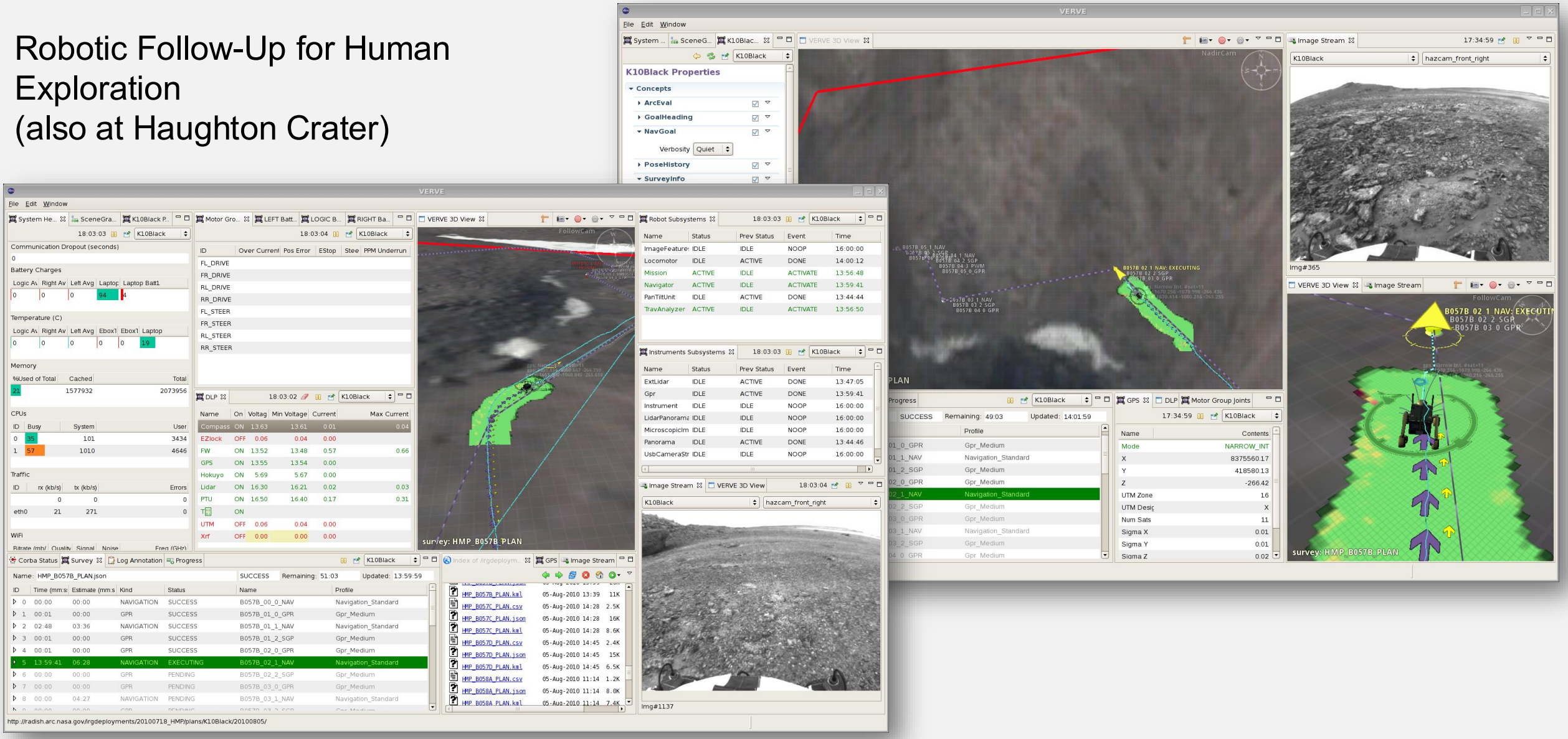
Applications – Robotic Field Tests

Robotic Site Survey at Haughton Crater



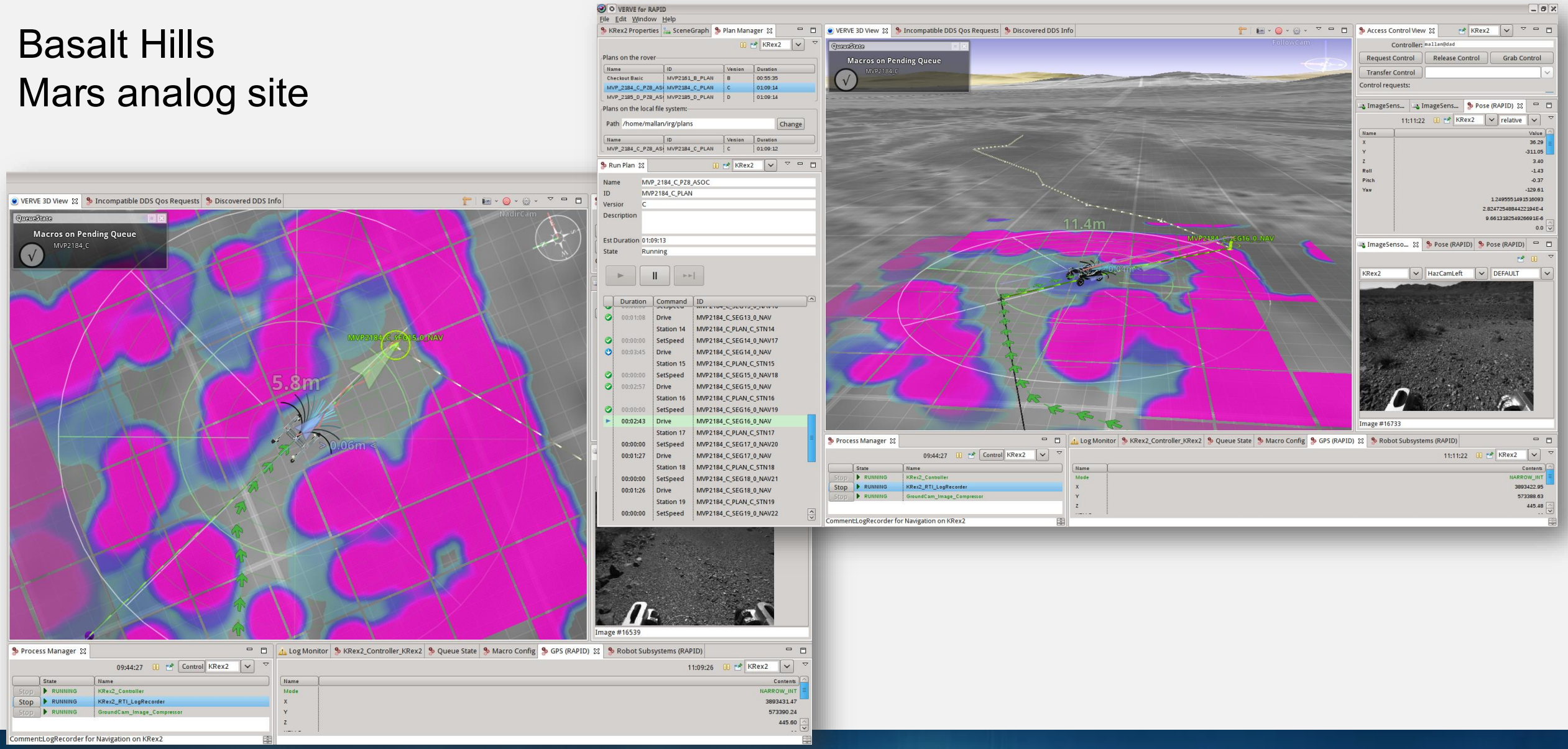
Applications – Robotic Field Tests

Robotic Follow-Up for Human Exploration
(also at Haughton Crater)



Applications – Robotic Field Tests

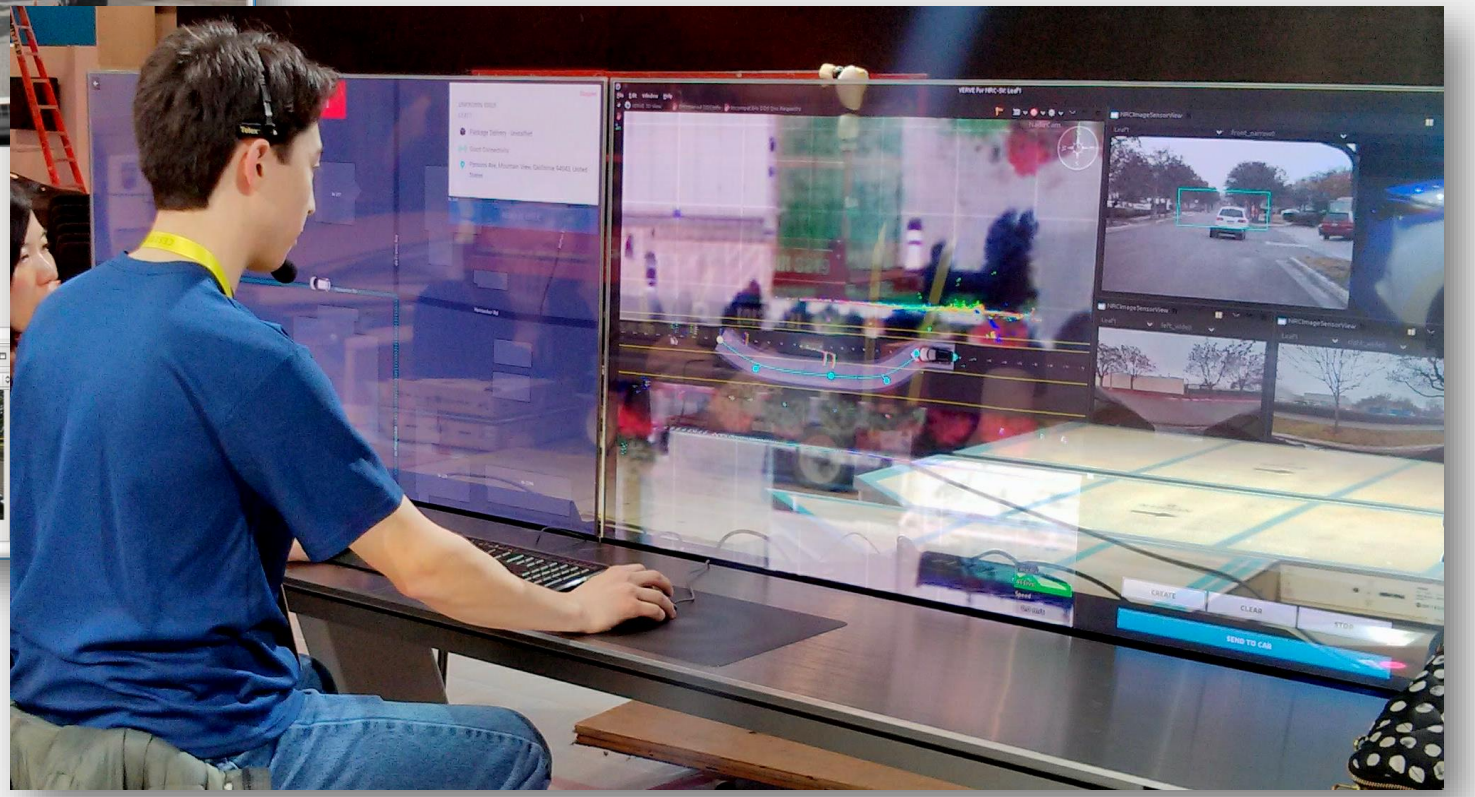
Basalt Hills
Mars analog site



Applications – AV Fleet Management

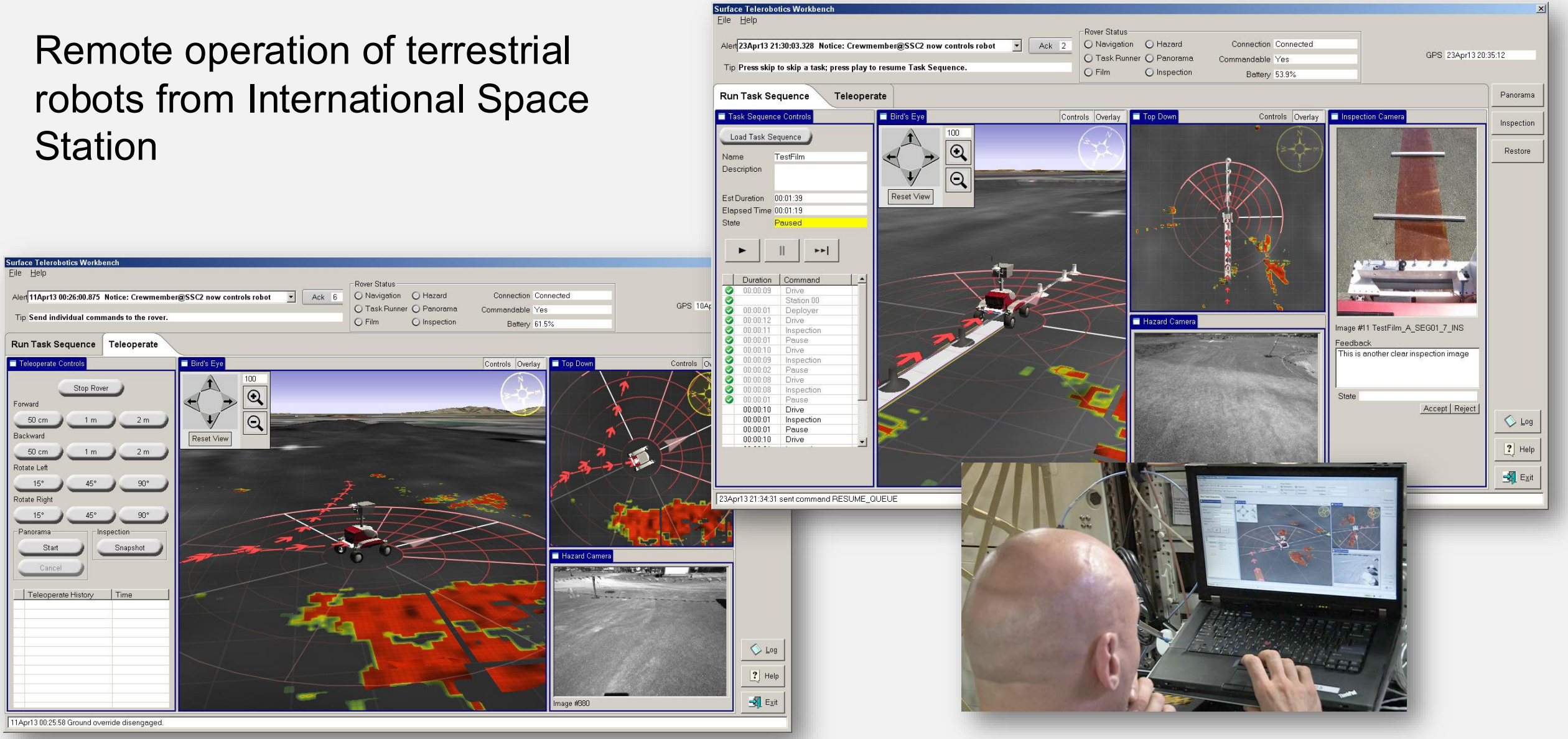
Nissan Seamless Autonomous Mobility

CES 2017



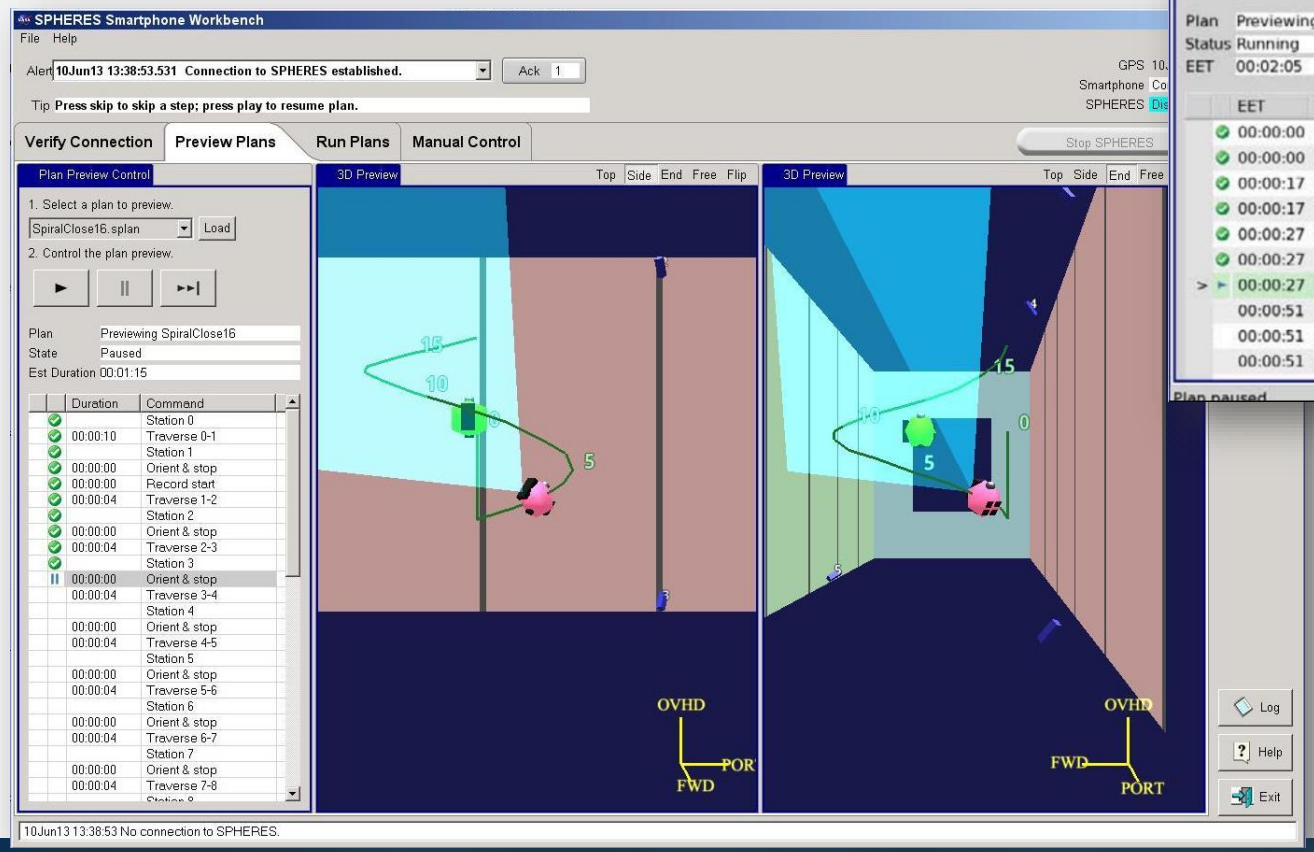
Applications – Surface Telerobotics

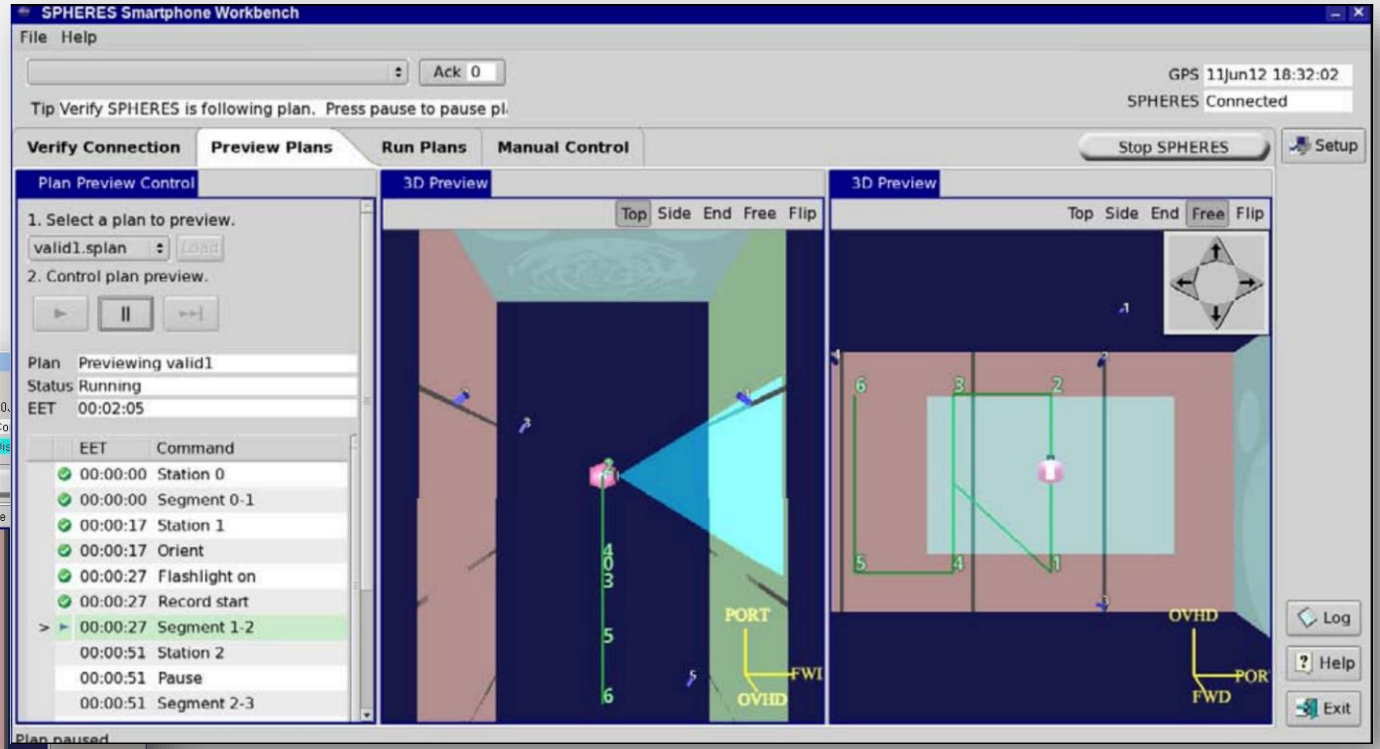
Remote operation of terrestrial robots from International Space Station



Applications – Smart SPHERES

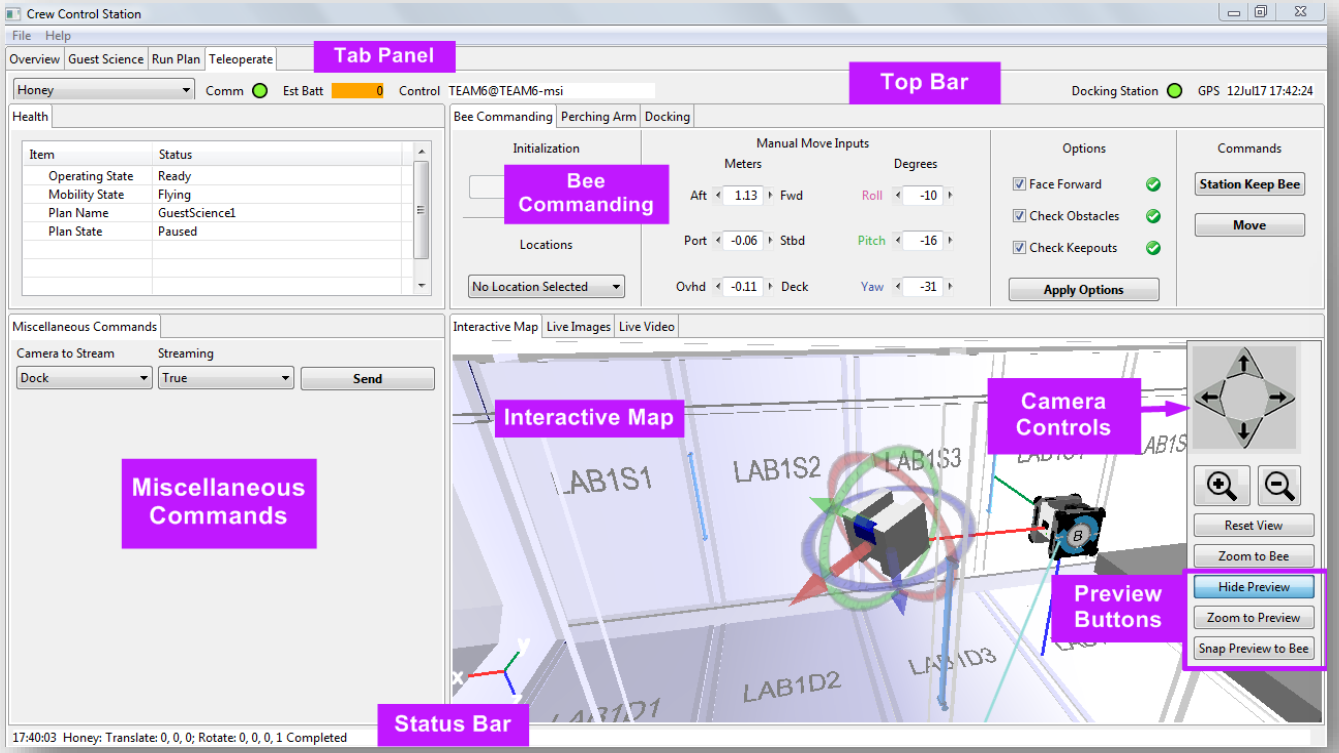
Remote operation of free-flying robots on International Space Station (Smart SPHERES)

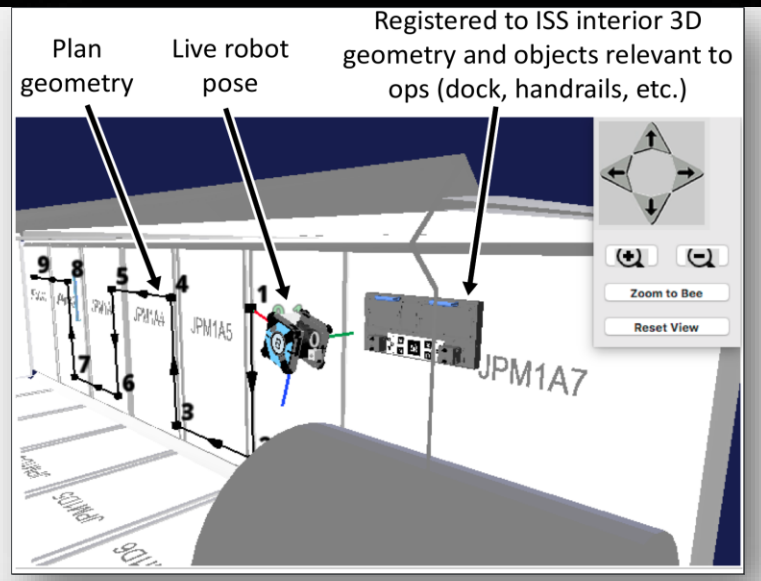


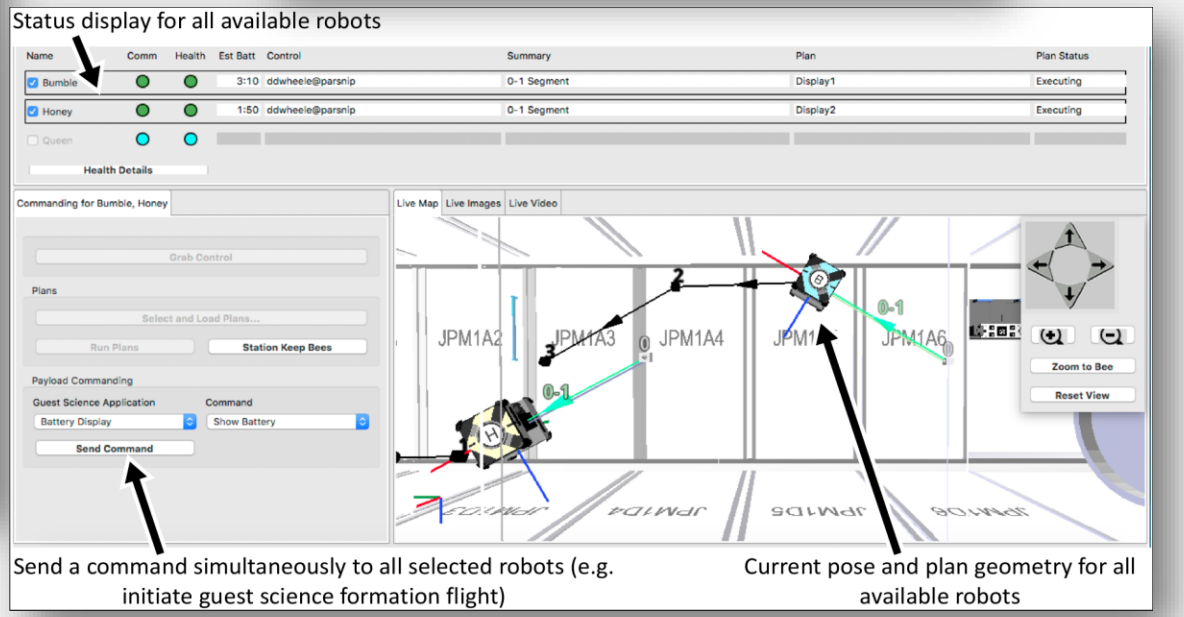


Applications - Astrobee

Remote operation of free-flying robots on International Space Station (Astrobees)

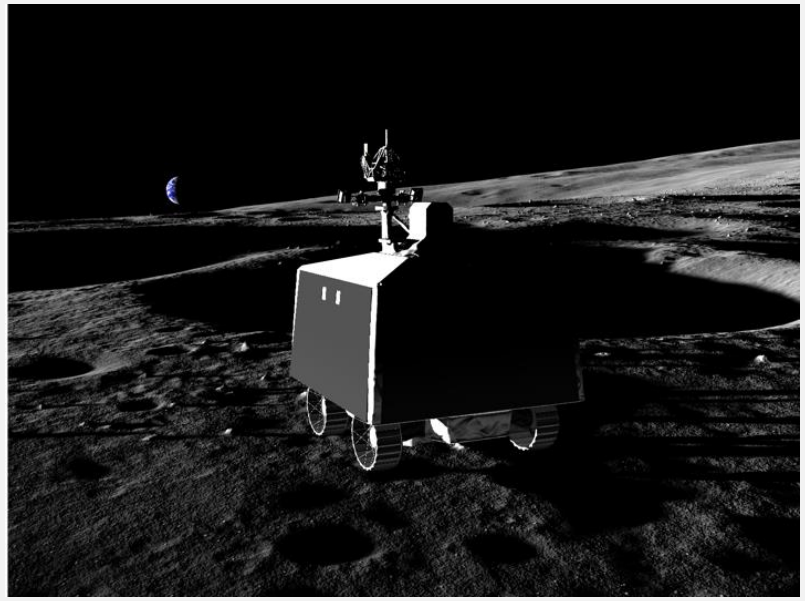




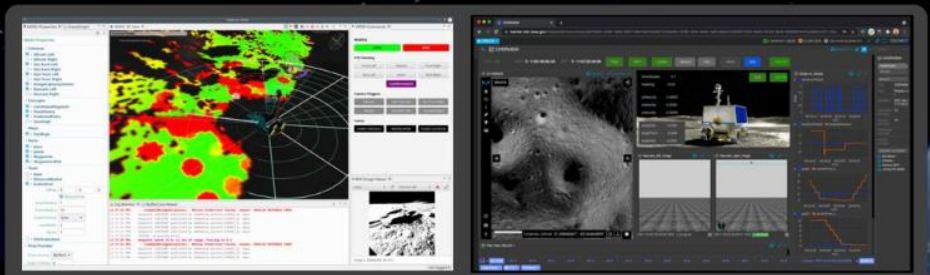


Applications - VIPER

- Volatiles Investigating Polar Exploration Rover (VIPER)
  - NASA rover to explore subsurface volatiles at the lunar south pole
- Real time driving operations, real time science
- Drive Team
  - Driver (Driver)
  - Co-Driver (Co-D)
  - Rover Navigation (Nav)
  - Real Time Science (RT-Sci)
- VERVE used by Drive Team for situational awareness
  - Driver and Co-D have command authority



VIPER Mission Operations



Rover Driving ***Mission Monitoring***

KSC
MSOLO

JSC
Rover Systems & Thermal

ARC
Systems & Execution

Comms round trip ~6 - 10 sec

Lander

Science Station

Waypoints
~ 5 m

Traverse Points
~ 50 m

Drill A

Drill B

Drill C

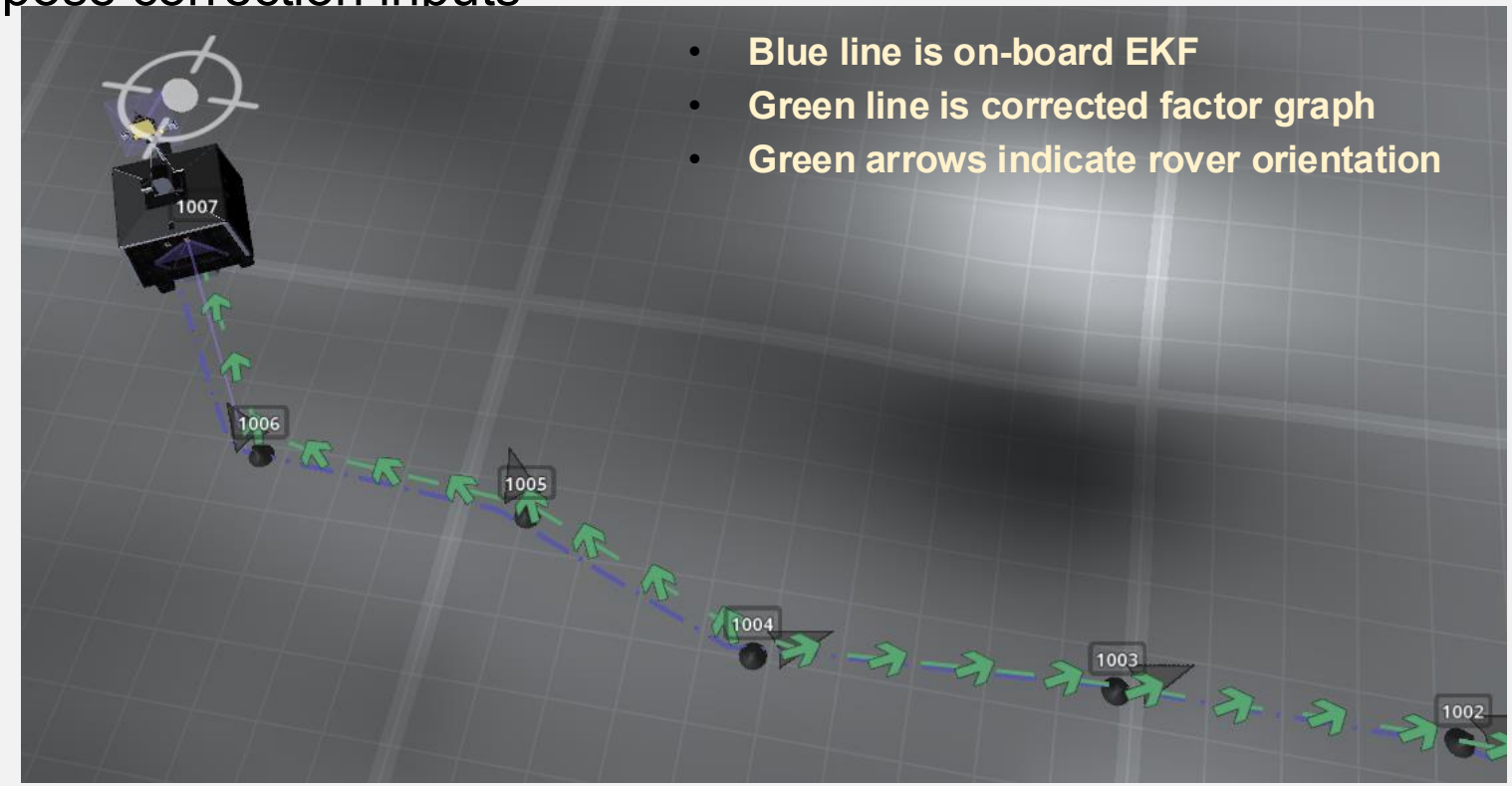
Science Station

Mons Mouton (84.6°S, 31.0°W)
near Nobile Crater

Typical Driver VERVE Layout

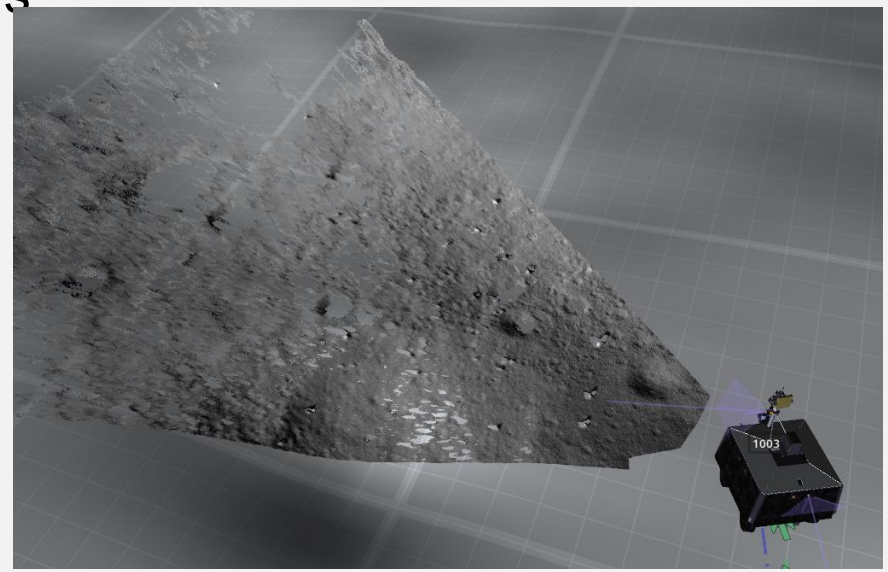
VIPER - Rover Pose

- Rover pose maintained by Rover Ground Software (RGSW) factor graph
  - On-board Extended Kalman Filter (EKF)
  - Visual Odometry (VO) from stereo images
  - Terrain Registration (TR) from stereo panoramas
  - Manual pose correction inputs



VIPER - Images and Derived Image Products

- VIPER Cameras
  - NavCam – gimbaled stereo pair on mast
  - AftCam – fixed wide angle stereo pair in rear stereo panel
  - HazCams – wide angle monocular cameras in each wheel well
- Derived Image Products
  - Stereo point clouds
  - Hazard maps



Stereo point cloud projected in 3D view

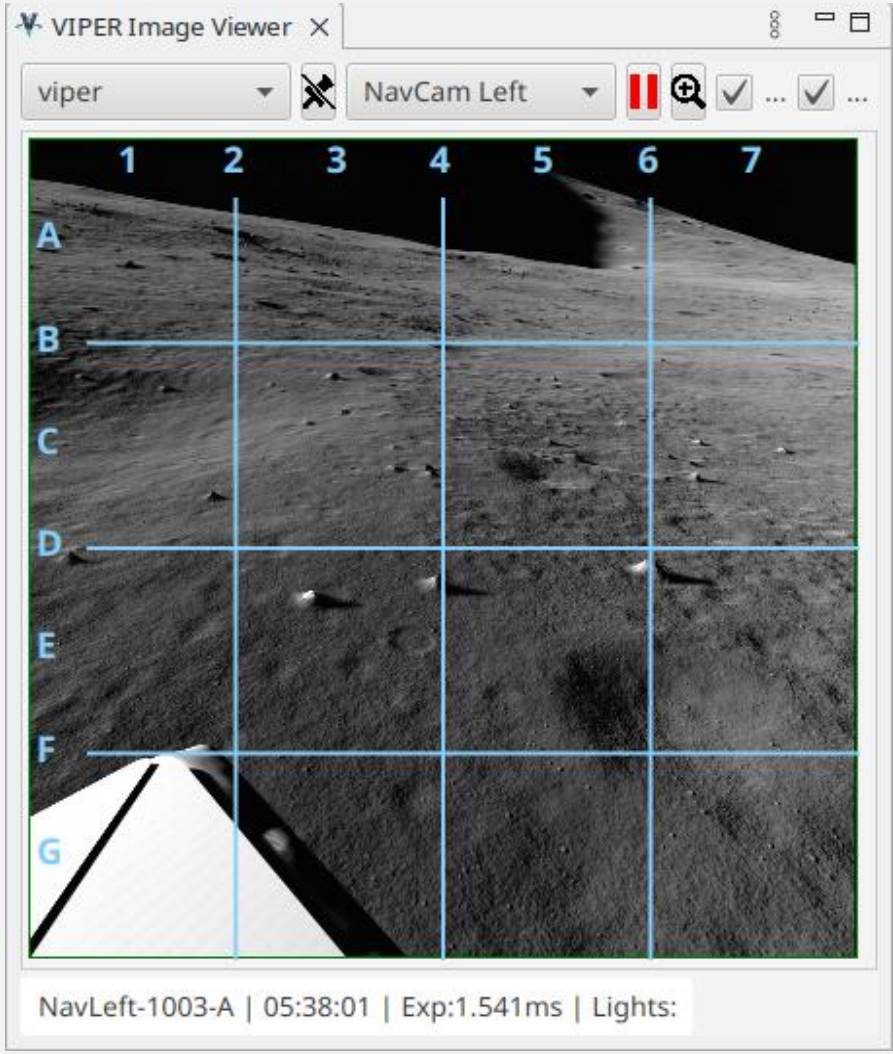
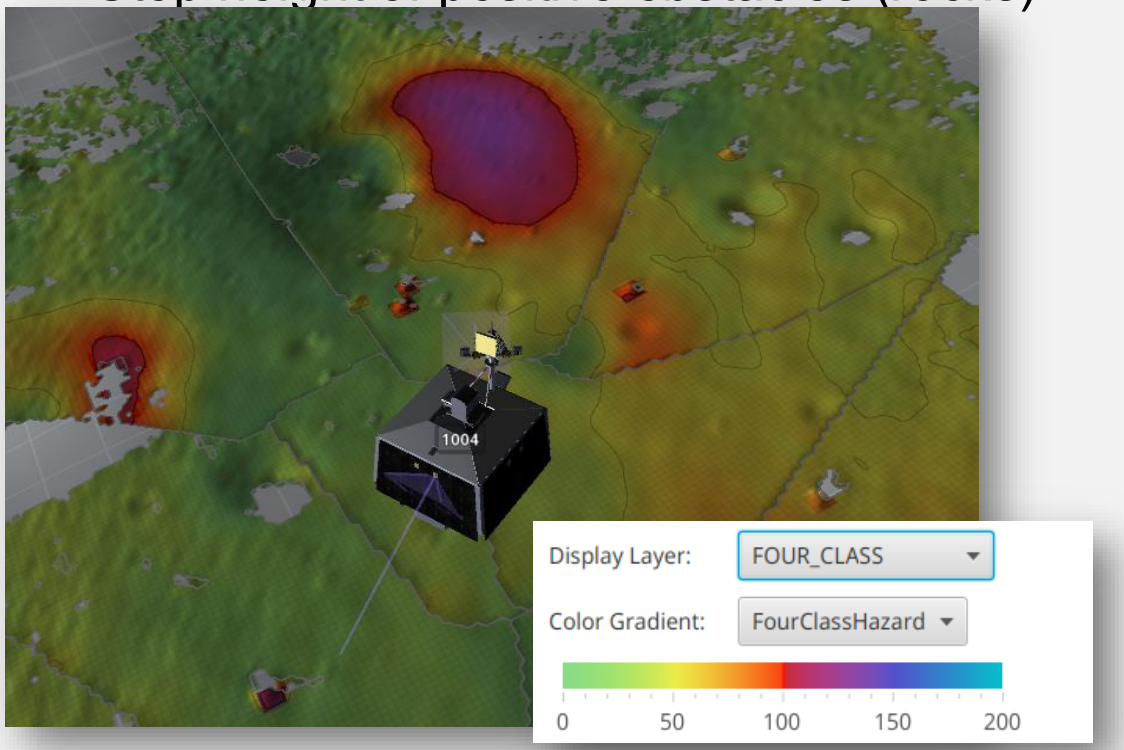


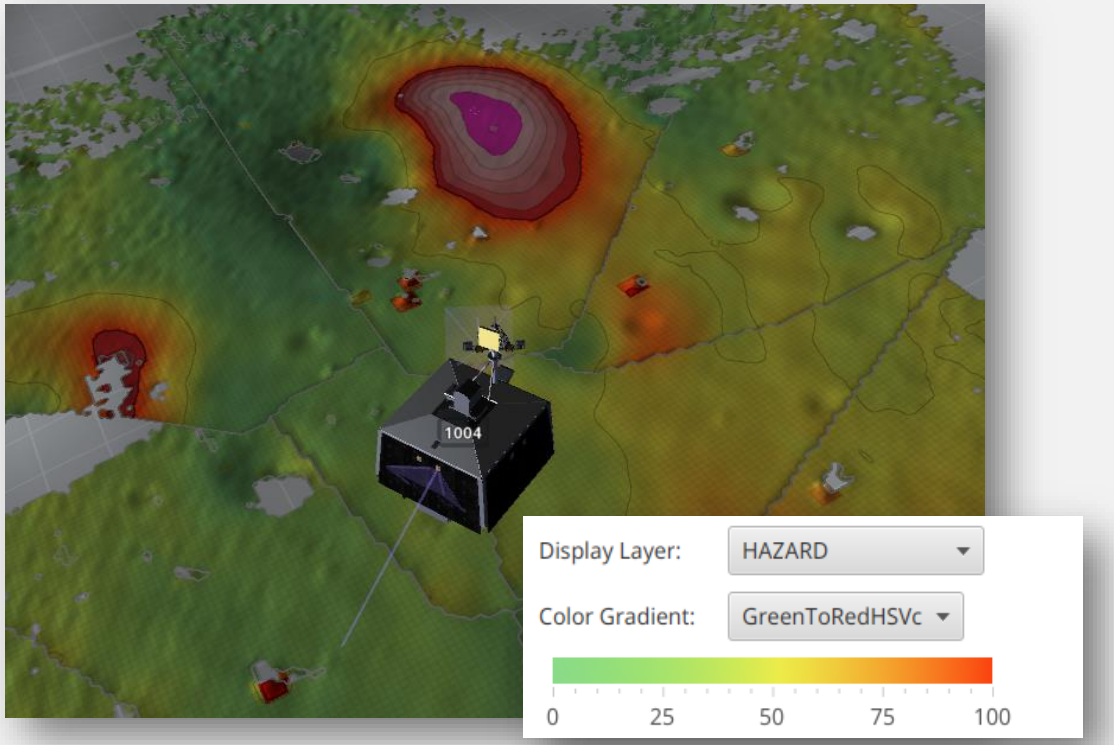
Image viewer with labeled grid overlay

VIPER - Hazard Maps

- Visual indication of mobility risk
- Geometric analysis of stereo point cloud
  - Terrain slope
  - Step height of positive obstacles (rocks)

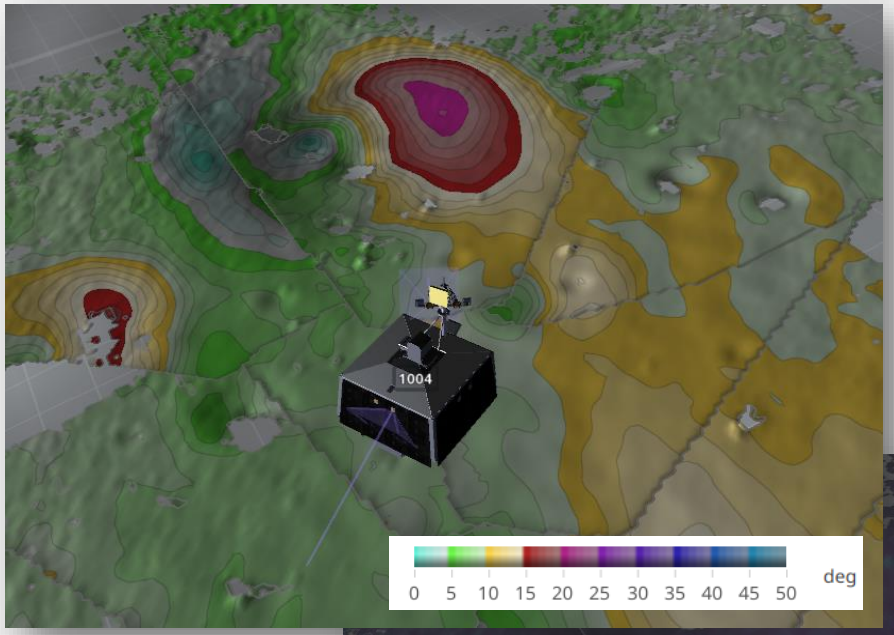


"Four class" hazard gradient

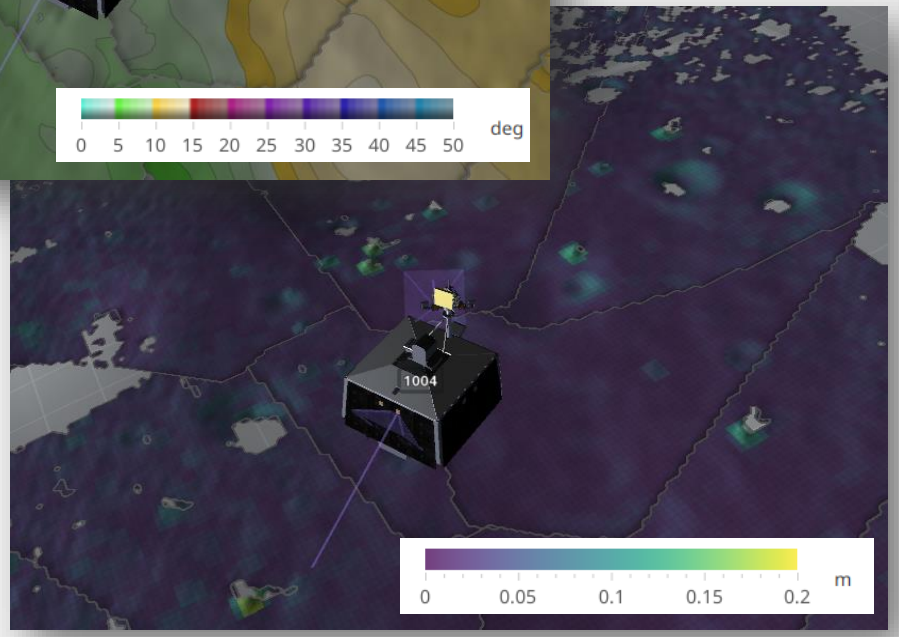


Hazard gradient switches to slope display at operational limit

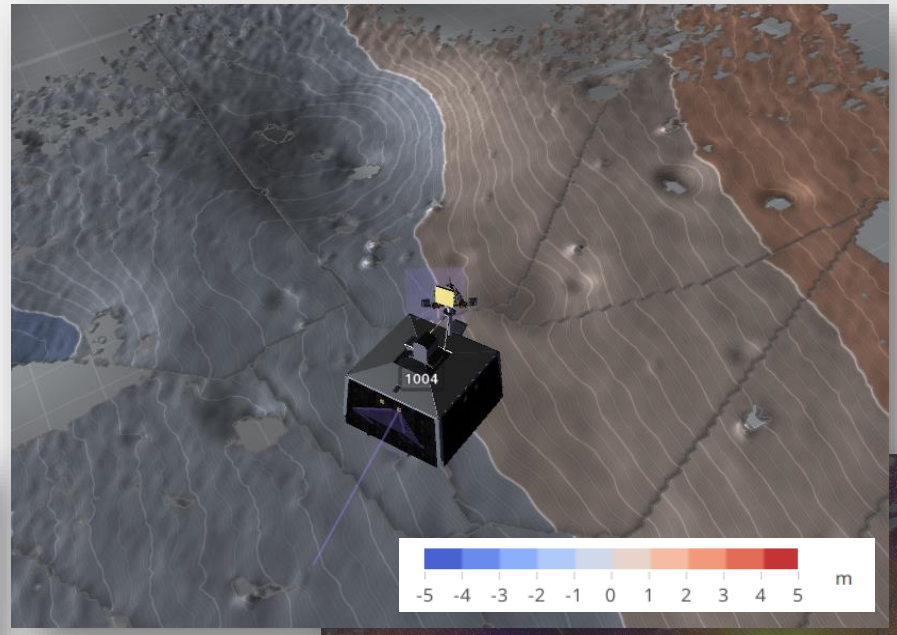
VIPER - Hazard Maps



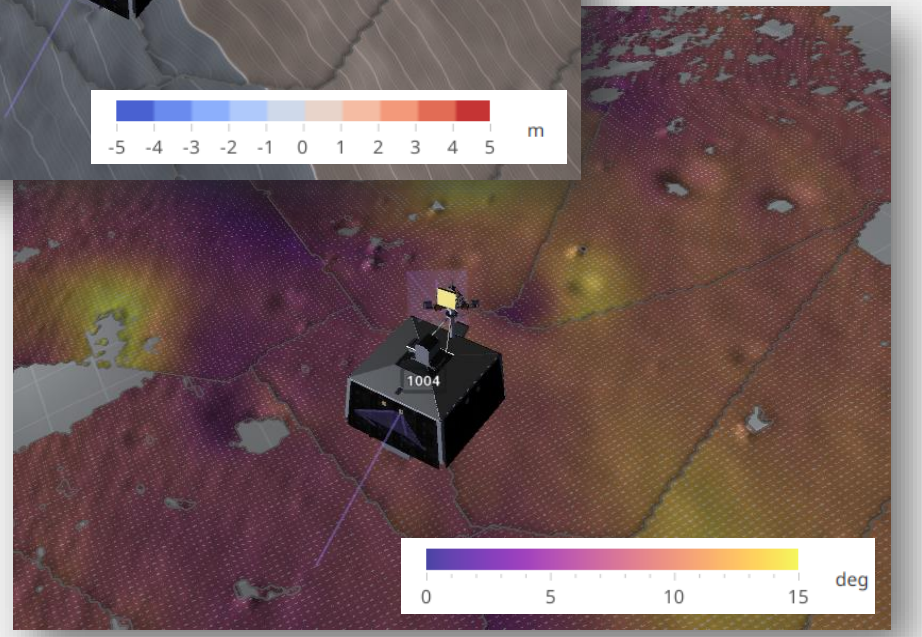
Slope



Step Height



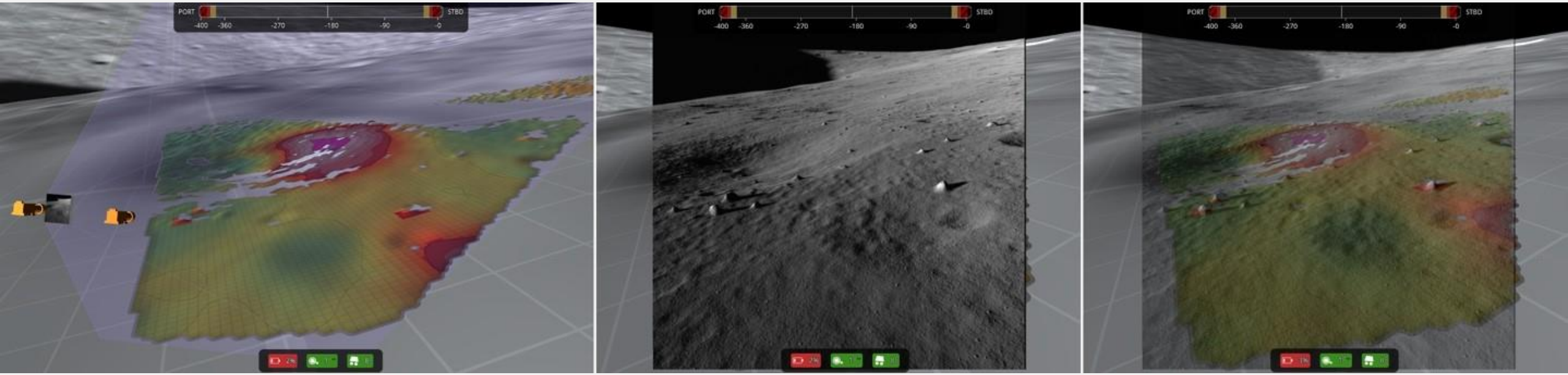
Relative Height



Gradient

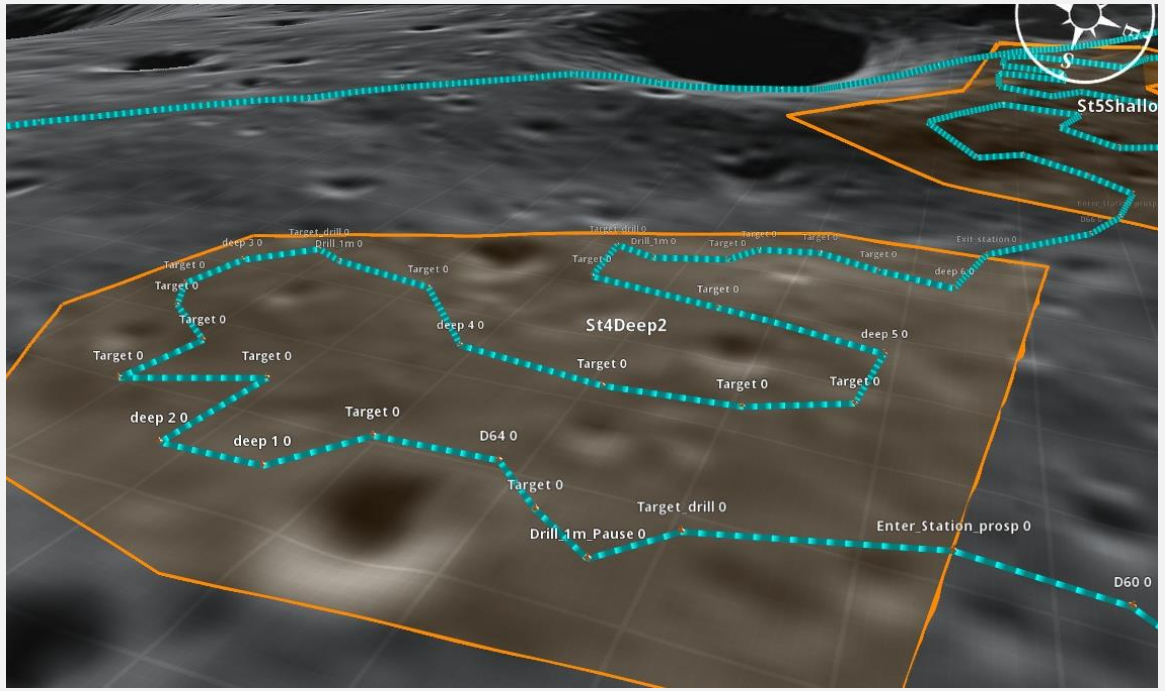
VIPER - Photo Quads

- Small billboards of images, placed in 3D view where image was taken
- View "flies" to billboard so user maintains spatial awareness
- Image transparency can be adjusted to correlate image features with basemap, map markup, and hazard map



VIPER – Maps, Map Markup, and Traverse Plan

- Large scale terrain maps
  - Multiple heightmap and ortho-imagery layers
  - Supports offline and WMS served maps
  - Supports dynamic reloading (e.g. science instrument heat maps, comm maps, etc.)
- Map Markup
  - GeoJSON, Open Street Map (OSM), Keyhole Markup Language (KML)
  - Markup dynamically updated in VERVE instances and other web clients
  - Map-based communication tool
    - Keep-out zones
    - Areas of interest
- Traverse plan
  - Extended markup features to convey direction of motion, path bounds



VIPER traverse plan rendered in VERVE

VERVE

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