



VERVE

Visual Environment for Remote Virtual Exploration
A 3D Tool for Space Robots

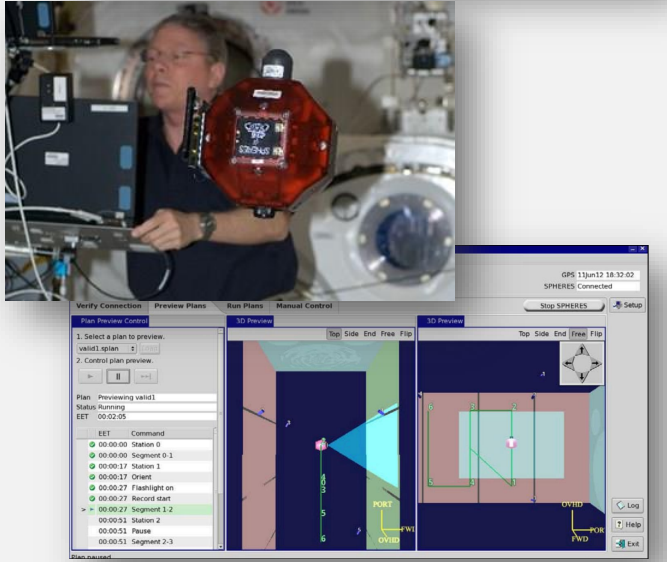
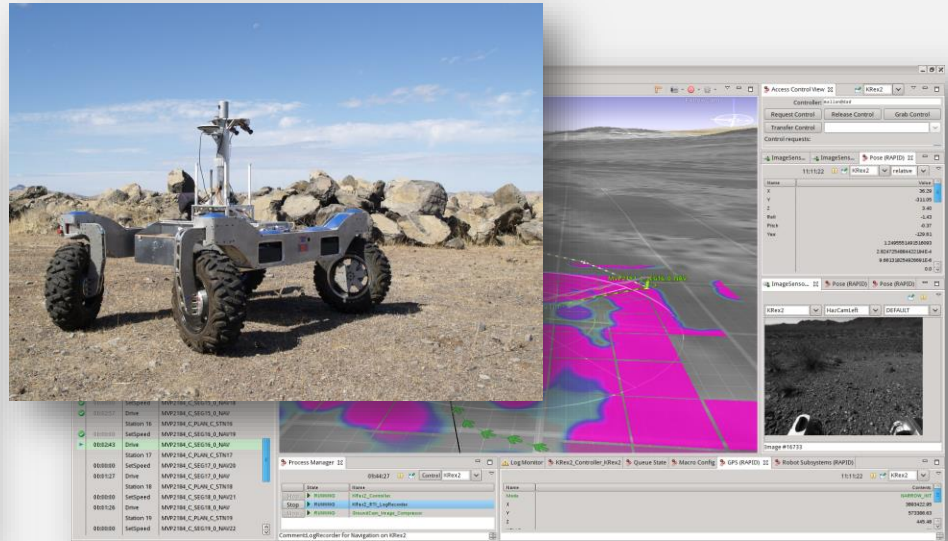
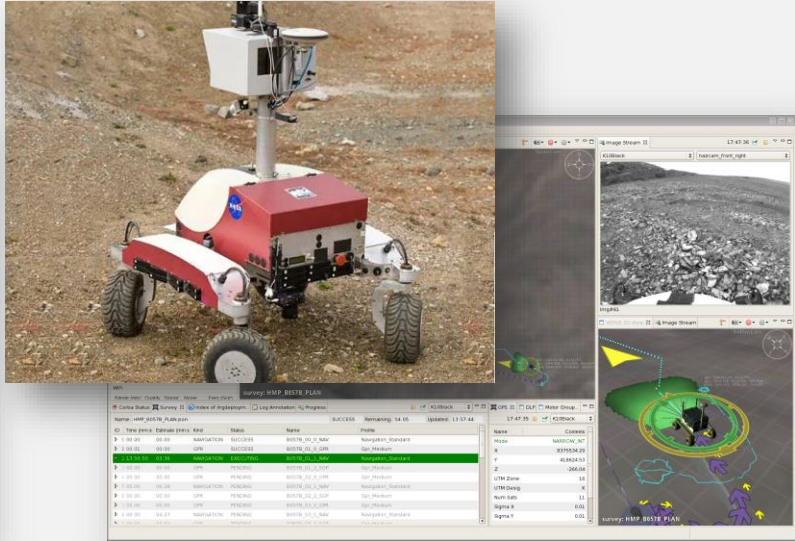
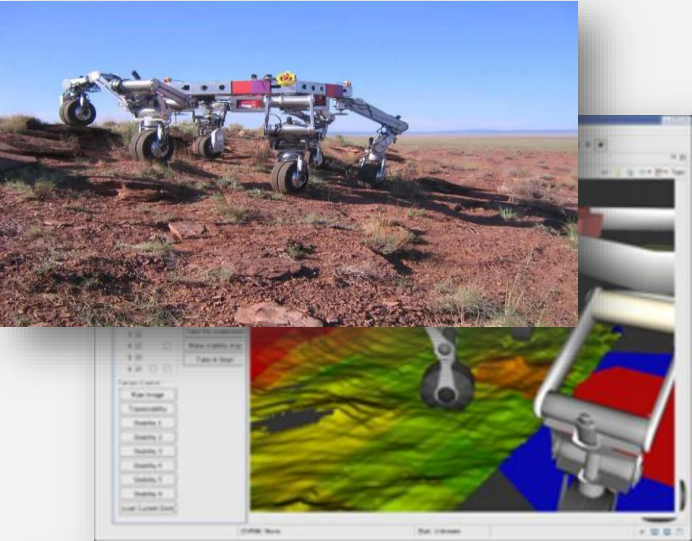
*DW Wheeler¹, Mark Allan¹, Julius Gyrofi¹
Presented by Mark Rose²*

2025/05

¹ KBR, Inc.

² NASA Ames Research Center

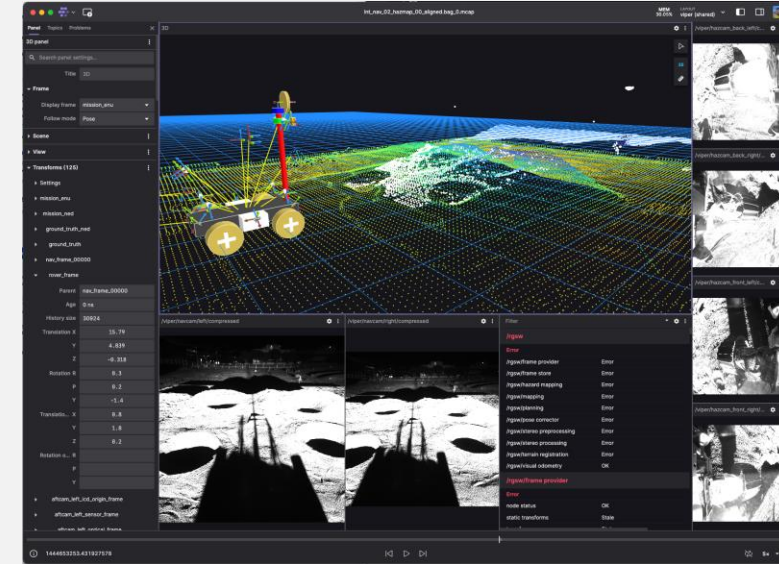
Intelligent Robotics Group



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

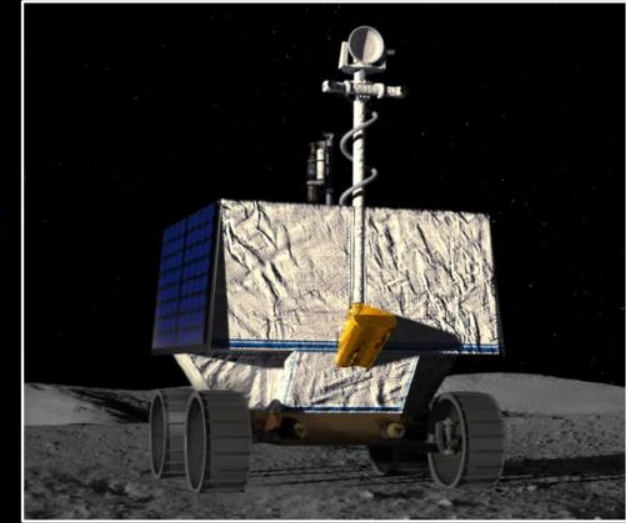
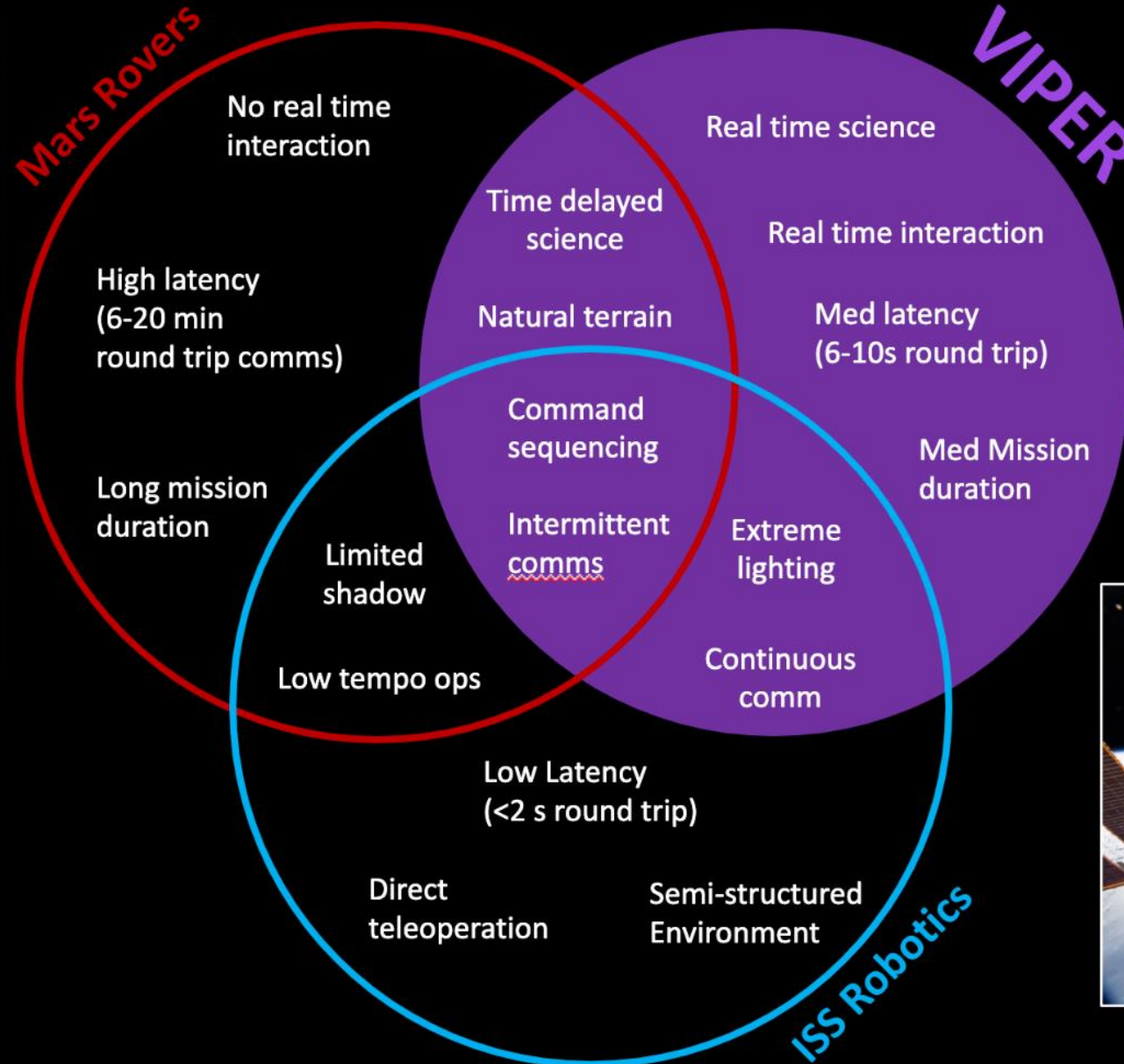


Foxglove as used for VIPER localization development and testing



TROV telepresence interface operating underwater robot

VIPER vs ISS vs Mars Rovers



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



The screenshot displays the VERVE software interface for VIPER, featuring several key components:

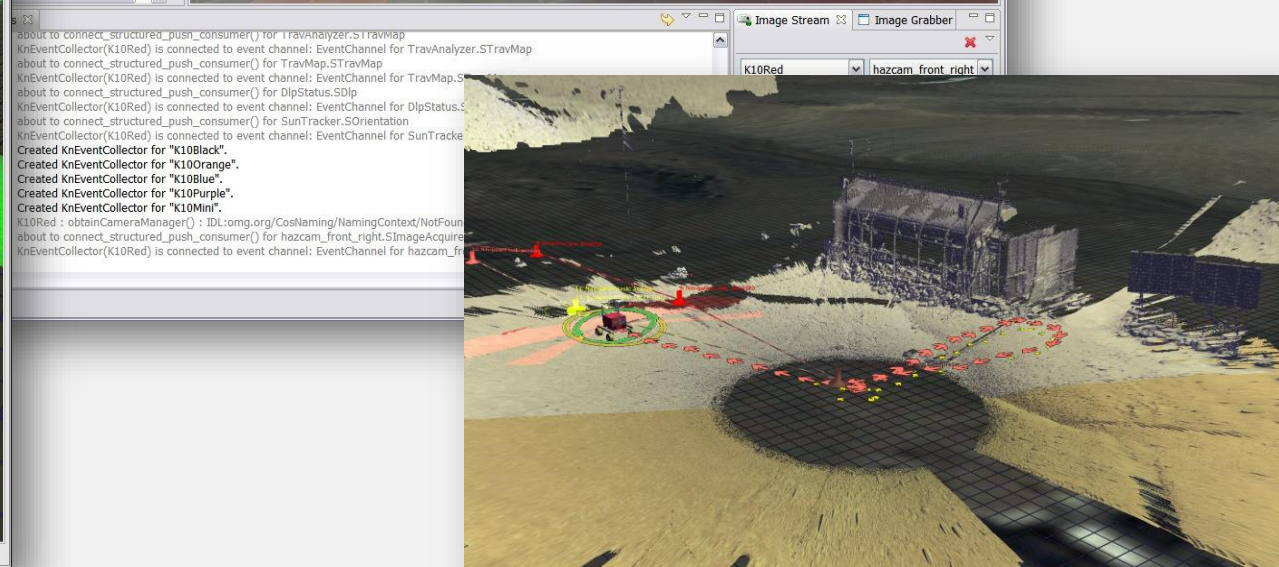
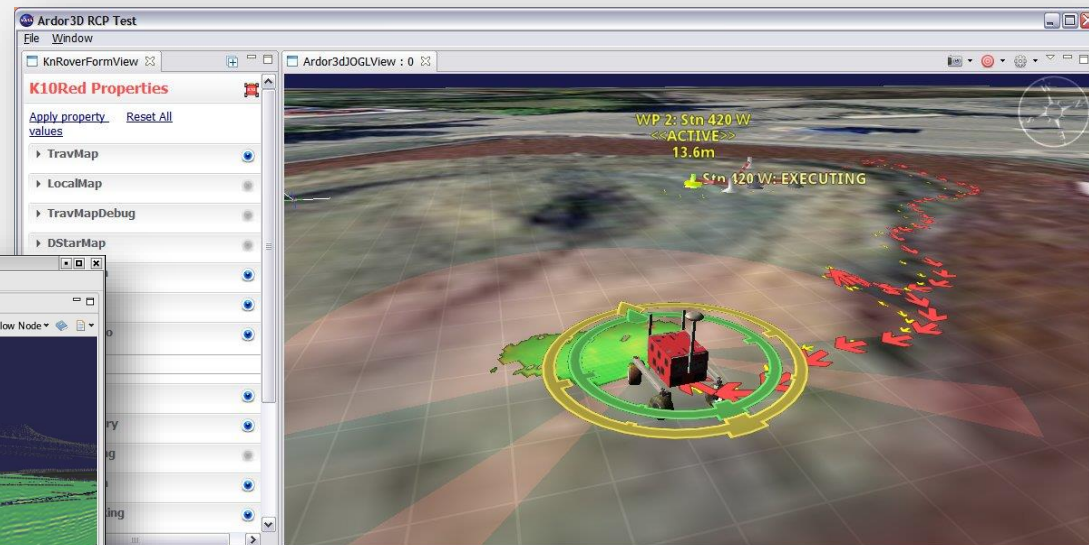
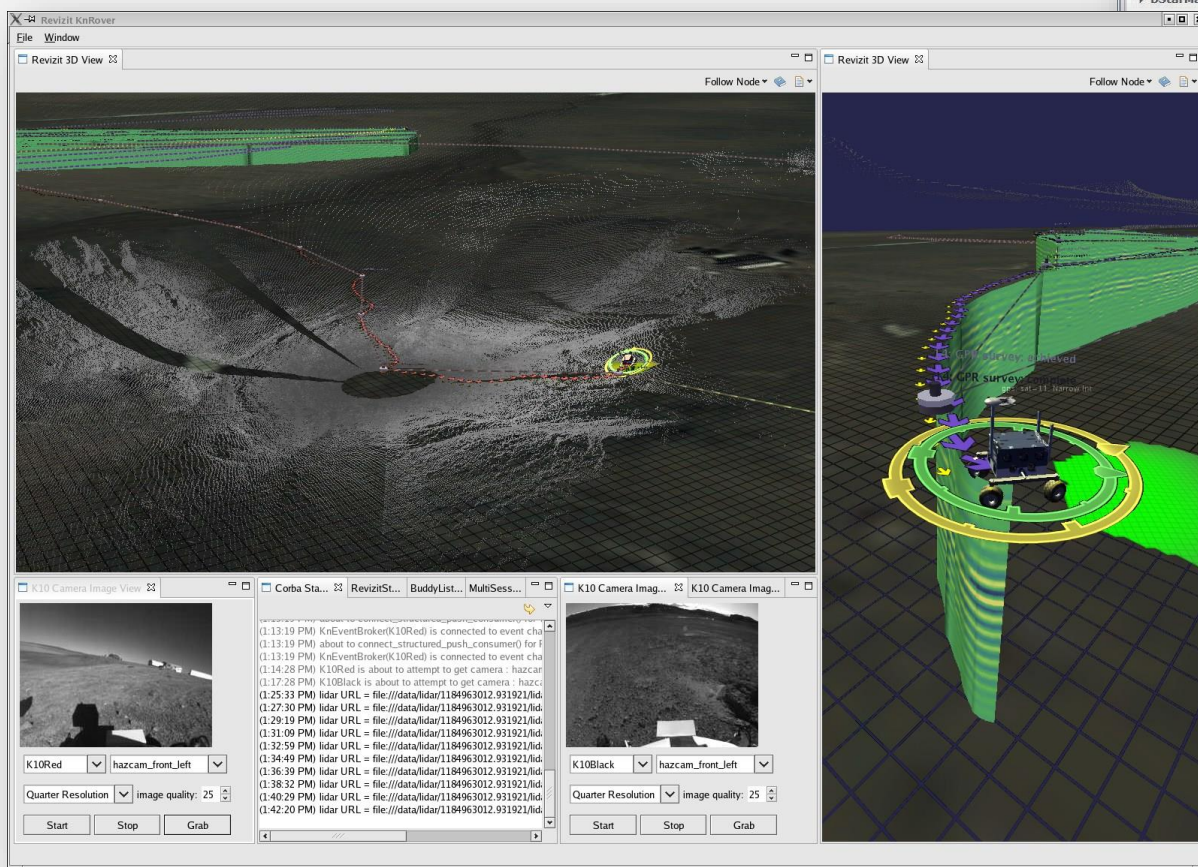
- 3D View:** The central 3D visualization of the rover and terrain, with callouts for **WHEEL LOADS** and **HGA Angles**.
- WHEEL LOADS:** A panel on the left showing load percentages for various wheels, such as 191.2%, 100.8%, 10.4%, 99.5%, 96.3%, 93.1% (TOTAL), 7.8%, 91.8%, 175.9%, 9.1%, 183.5%.
- Sensor Sample Manager:** A panel on the left for managing sensor data, including filters and sample types.
- Command Panel:** A panel on the right for controlling mobility (Drive/STOP), PTU pointing (PTU A-D), PTU absolute/relative settings, camera triggers, and No-Op actions.
- Health and Status:** A panel at the bottom center showing system health indicators like 5%, 20%, 4%, and 0%.
- Command Status View:** A table at the bottom left showing a log of commands, their estimated durations, and completion statuses.
- Virtual Camera View:** A panel at the bottom right showing a 3D view of the rover from a specific camera perspective.
- Image Viewer:** A panel at the bottom right showing a 2D image of the terrain with a grid overlay.

Started	Command	Est Dur	Status	Steps
05:22:39	Waypoint 1001	00:00:03	Completed	●●●●●
05:22:46	Set Pan/Tilt (-18.0°/-19.8°)	00:00:09	Completed	●●●●●
05:22:49	Nav-1001-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:26	Completed	●●●●●
05:27:33	Set Pan/Tilt (-58.2°/-24.6°)	00:00:12	Completed	●●●●●
05:27:38	Nav-1001-B [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:18	Completed	●●●●●
05:29:32	Waypoint 1002	00:00:06	Completed	●●●●●
05:29:38	Set Pan/Tilt (-51.2°/-25.0°)	+00:39:01	Overdue	●●●●●
05:29:44	Aft-1002-A [Default*] [No Lights] [AftCam Left] Stereo Image	+00:00:08	Completed	●●●●●
05:29:44	Nav-1002-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:47	Completed	●●●●●
05:44:10	Waypoint 1003	00:00:08	Completed	●●●●●
05:44:20	Set Pan/Tilt (-30.7°/-19.0°)	00:00:10	Completed	●●●●●
05:44:22	Aft-1003-A [Default*] [No Lights] [AftCam Left] Stereo Image	+00:00:04	Completed	●●●●●
05:44:22	Nav-1003-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:31	Completed	●●●●●
05:55:53	Waypoint 1004	00:00:08	Completed	●●●●●
05:56:16	Nav-1004-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:46	Completed	●●●●●

Applications – Robotic Field Tests



Robotic Site Survey at Haughton Crater



Applications – Robotic Field Tests



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

The screenshot displays the VERVE software interface, which is used for controlling the K10Black rover. The interface is divided into several panels:

- Top Left:** System status and battery information. It shows communication dropout, battery charges for Logic A, Right Av, Left Av, and Laptop, and temperature readings for Logic A, Right Av, Left Av, Ebox1, Ebox2, and Laptop.
- Top Center:** A 3D terrain view showing the rover's current position and planned path (red line) on a simulated lunar surface. A 'K10Black Properties' panel is visible on the left side of this view.
- Top Right:** A live video stream from the rover's camera, labeled 'hazcam_front_right'.
- Middle Left:** A table showing the status of various robot subsystems. The table has columns for Name, Status, Prev Status, Event, and Time.
- Middle Right:** A table showing the status of instrument subsystems. The table has columns for Name, Status, Prev Status, Event, and Time.
- Bottom Left:** A table showing the status of various sensors and instruments. The table has columns for Name, On, Voltag, Min Voltage, Current, and Max Current.
- Bottom Center:** A mission plan window showing a sequence of tasks. The table has columns for ID, Time (m/m:s), Estimate (m/m:s), Kind, Status, Name, and Profile.
- Bottom Right:** A detailed view of the mission plan, showing a 3D terrain view with a green path and a yellow arrow indicating the rover's current position and direction.

At the bottom of the interface, there is a URL: http://radish.arc.nasa.gov/irgdeployments/20100718_HMP/plans/K10Black/20100805/

Applications – Robotic Field Tests



Basalt Hills Mars analog site

The screenshot displays the VERVE for RAPID software interface, which is used for controlling the VIPER rover. The interface is divided into several panels:

- VERVE 3D View (Top Left):** Shows a 3D simulation of the rover on a Mars analog site. The terrain is color-coded (pink, blue, green). A path is shown with green arrows, and a distance of 5.8m is indicated. A "Macros on Pending Queue" window is visible.
- Plan Manager (Top Middle):** Lists plans on the rover and on the local file system. The rover plans include:

Name	ID	Version	Duration
Checkout Basic	MVP2181_B_PLAN	B	00:55:35
MVP_2184_C_P28_AS	MVP2184_C_PLAN	C	01:09:14
MVP_2185_D_P28_AS	MVP2185_D_PLAN	D	01:09:14
- Run Plan (Middle):** Shows the current plan being executed: MVP_2184_C_P28_ASOC (ID: MVP2184_C_PLAN, Version: C). The state is "Running". A list of commands and stations is shown:

Duration	Command	ID
00:0:108	Drive	MVP2184_C_SEG13_0_NAV
00:0:000	Station 14	MVP2184_C_PLAN_C_STN14
00:0:345	SetSpeed	MVP2184_C_SEG14_0_NAV17
00:0:000	Drive	MVP2184_C_SEG14_0_NAV
00:0:000	Station 15	MVP2184_C_PLAN_C_STN15
00:0:000	SetSpeed	MVP2184_C_SEG15_0_NAV18
00:0:257	Drive	MVP2184_C_SEG15_0_NAV
00:0:000	SetSpeed	MVP2184_C_SEG16_0_NAV19
00:0:243	Drive	MVP2184_C_SEG16_0_NAV
00:0:000	Station 17	MVP2184_C_PLAN_C_STN17
00:0:000	SetSpeed	MVP2184_C_SEG17_0_NAV20
00:0:127	Drive	MVP2184_C_SEG17_0_NAV
00:0:000	Station 18	MVP2184_C_PLAN_C_STN18
00:0:000	SetSpeed	MVP2184_C_SEG18_0_NAV21
00:0:126	Drive	MVP2184_C_SEG18_0_NAV
00:0:000	Station 19	MVP2184_C_PLAN_C_STN19
00:0:000	SetSpeed	MVP2184_C_SEG19_0_NAV22
- VERVE 3D View (Top Right):** Shows a different 3D view of the rover on the Mars analog site. A distance of 11.4m is indicated. A "Macros on Pending Queue" window is visible.
- Access Control View (Middle Right):** Shows the controller (ma11an0ad) and various control buttons (Request Control, Release Control, Transfer Control). It also displays control requests for ImageSens and Pose (RAPID).
- Process Manager (Bottom Left):** Shows the status of various processes:

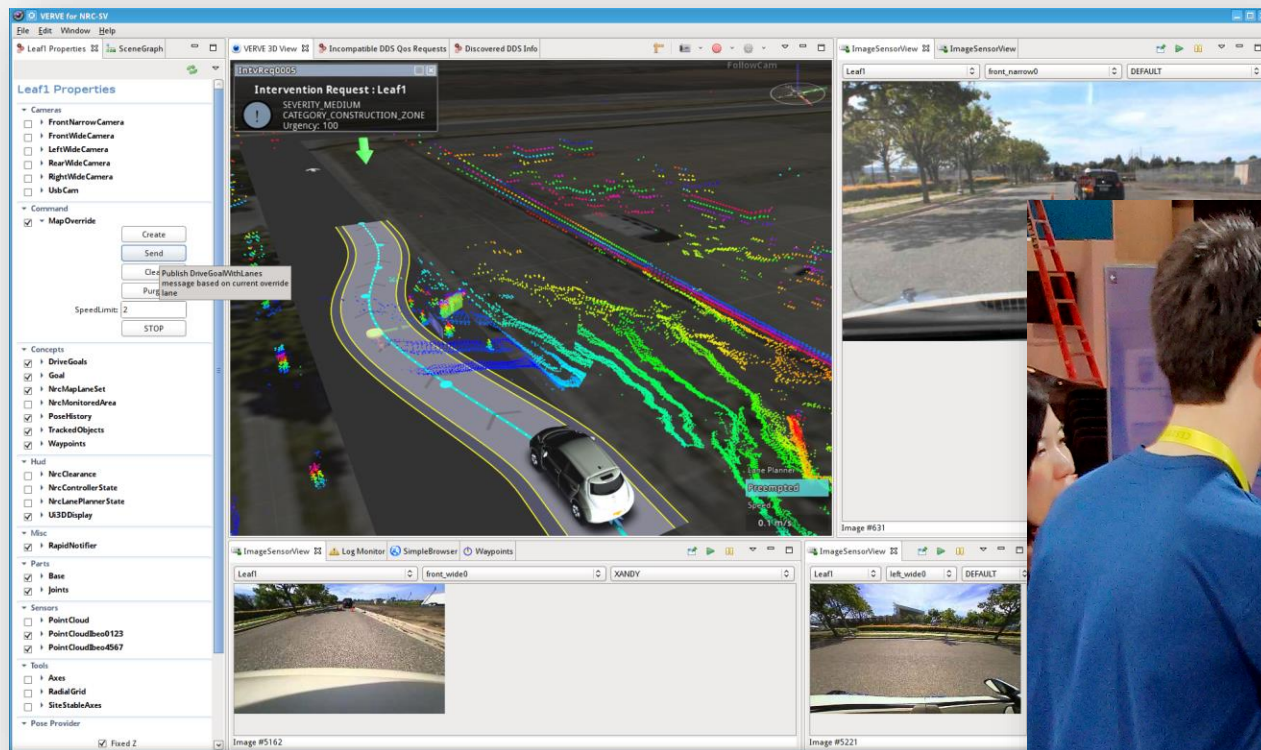
State	Name
▶ RUNNING	KRex2_Controller
▶ RUNNING	KRex2_RTI_LogRecorder
▶ RUNNING	GroundCam_Image_Compressor
- Log Monitor (Bottom Middle):** Shows the log of the KREX2 controller.
- Robot Subsystems (RAPID) (Bottom Right):** Shows the status of various robot subsystems:

Name	Contents
Mode	NARROW_INT
X	3893431.47
Y	573390.24
Z	445.60

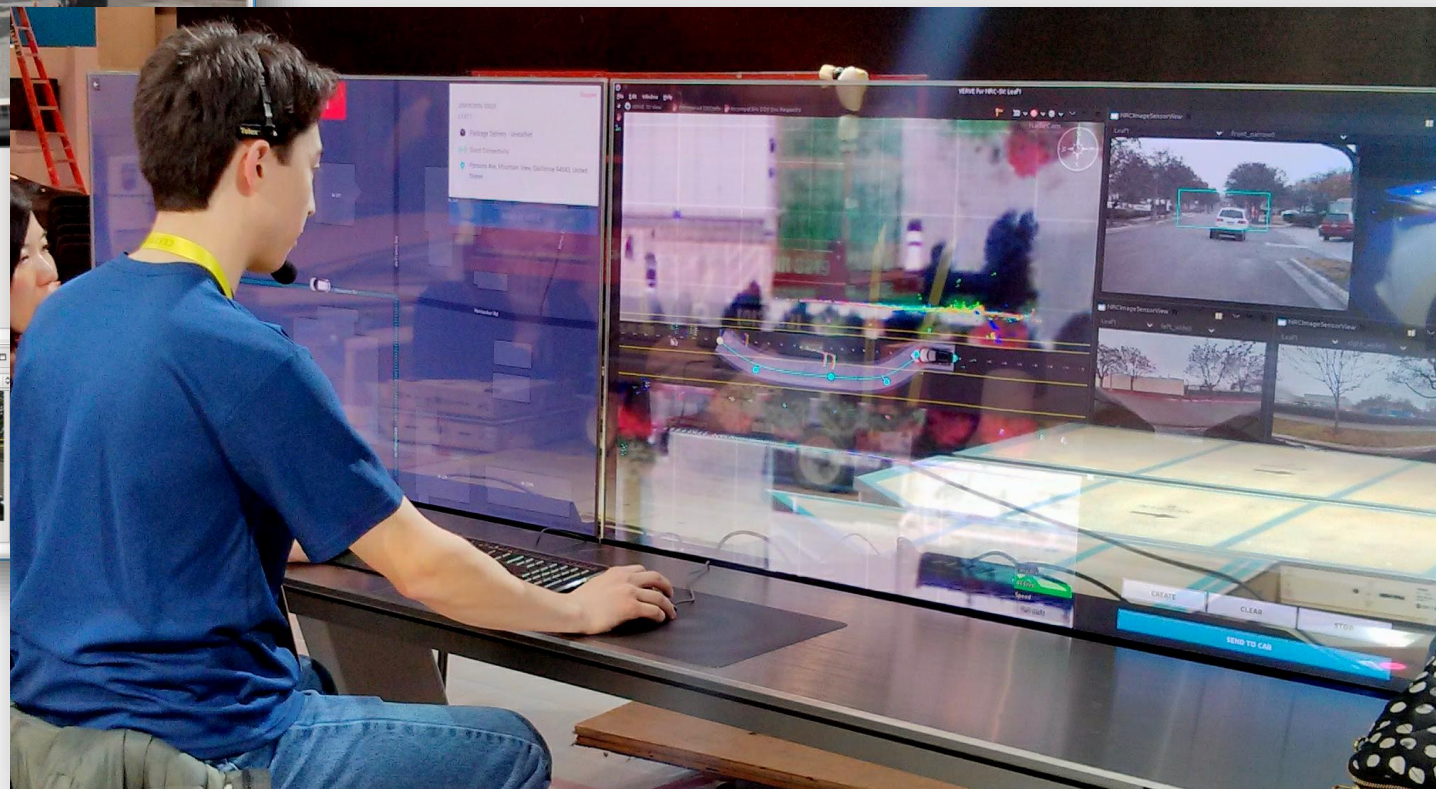
Applications – AV Fleet Management



Nissan Seamless Autonomous Mobility



CES 2017



Applications – Surface Telerobotics



Remote operation of terrestrial robots from International Space Station

Surface Telerobotics Workbench
Alert: 11Apr13 00:26:00.875 Notice: Crewmember@SSC2 now controls robot
Ack: 6
Rover Status: Navigation, Hazard, Task Runner, Panorama, Film, Inspection
Connection: Connected
Commandable: Yes
Battery: 61.5%

Run Task Sequence | Teleoperate

Teleoperate Controls

Forward: 50 cm, 1 m, 2 m
Backward: 50 cm, 1 m, 2 m
Rotate Left: 15°, 45°, 90°
Rotate Right: 15°, 45°, 90°
Panorama: Start, Cancel
Inspection: Start, Snapshot

23Apr13 00:25:58 Ground override disengaged.

Surface Telerobotics Workbench
Alert: 23Apr13 21:30:03.328 Notice: Crewmember@SSC2 now controls robot
Ack: 2
Rover Status: Navigation, Hazard, Task Runner, Panorama, Film, Inspection
Connection: Connected
Commandable: Yes
Battery: 53.9%

Run Task Sequence | Teleoperate

Task Sequence Controls

Name: TestFilm
Description:
Est Duration: 00:01:39
Elapsed Time: 00:01:19
State: Paused

Duration	Command
00:00:09	Drive
00:00:01	Station 00
00:00:01	Deployer
00:00:12	Drive
00:00:11	Inspection
00:00:01	Pause
00:00:10	Drive
00:00:09	Inspection
00:00:02	Pause
00:00:08	Drive
00:00:08	Inspection
00:00:01	Pause
00:00:10	Drive
00:00:01	Inspection
00:00:01	Pause
00:00:10	Drive

23Apr13 21:34:31 sent command RESUME_QUEUE



Applications – Smart SPHERES



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

SPHERES Smartphone Workbench

File Help

Ack 0

GPS 11Jun12 18:32:02
SPHERES Connected

Tip Verify SPHERES is following plan. Press pause to pause pl.

Verify Connection Preview Plans Run Plans Manual Control Stop SPHERES Setup

Plan Preview Control

1. Select a plan to preview.
valid1.splan

2. Control plan preview.

Plan Previewing valid1
Status Running
EET 00:02:05

EET	Command
00:00:00	Station 0
00:00:00	Segment 0-1
00:00:17	Station 1
00:00:17	Orient
00:00:27	Flashlight on
00:00:27	Record start
> 00:00:27	Segment 1-2
00:00:51	Station 2
00:00:51	Pause
00:00:51	Segment 2-3

3D Preview

3D Preview

Log Help Exit

SPHERES Smartphone Workbench

File Help

Alert 10Jun13 13:38:53.531 Connection to SPHERES established. Ack 1

GPS 10 Jun 13 13:38:53.531
Smartphone Co
SPHERES Dis

Tip Press skip to skip a step; press play to resume plan.

Verify Connection Preview Plans Run Plans Manual Control Stop SPHERES Setup

Plan Preview Control

1. Select a plan to preview.
SpiralClose16.splan

2. Control plan preview.

Plan Previewing SpiralClose16
State Paused
Est Duration 00:01:15

Duration	Command
00:00:10	Station 0
00:00:00	Traverse 0-1
00:00:00	Station 1
00:00:00	Orient & stop
00:00:00	Record start
00:00:04	Traverse 1-2
00:00:00	Station 2
00:00:00	Orient & stop
00:00:04	Traverse 2-3
00:00:00	Station 3
00:00:00	Orient & stop
00:00:04	Traverse 3-4
00:00:00	Station 4
00:00:00	Orient & stop
00:00:04	Traverse 4-5
00:00:00	Station 5
00:00:00	Orient & stop
00:00:04	Traverse 5-6
00:00:00	Station 6
00:00:00	Orient & stop
00:00:04	Traverse 6-7
00:00:00	Station 7
00:00:00	Orient & stop
00:00:04	Traverse 7-8
00:00:00	Station 8

3D Preview

3D Preview

Log Help Exit

10Jun13 13:38:53 No connection to SPHERES.

Applications - Astrobee

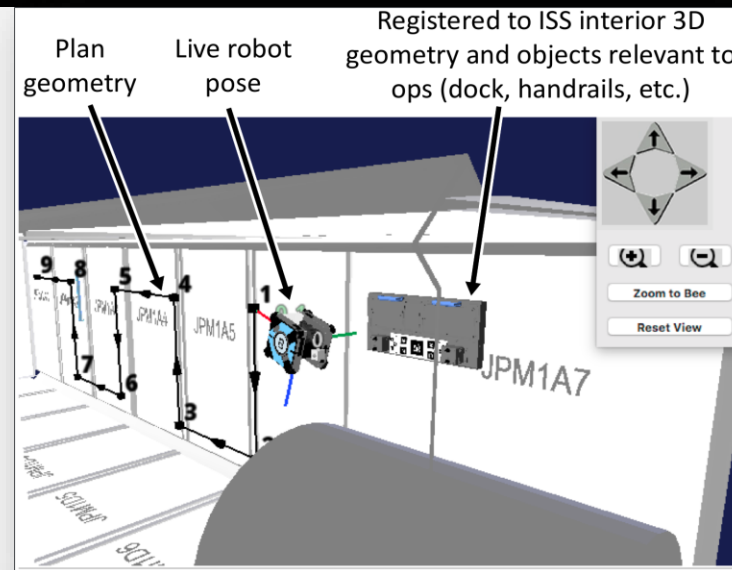


Remote operation of free-flying robots on International Space Station (Astrobees)

The screenshot shows the Crew Control Station interface with several key components highlighted in purple boxes:

- Tab Panel:** Overview, Guest Science, Run Plan, Teleoperate, Tab Panel (selected).
- Top Bar:** Honey, Comm, Est Batt, Control, TEAM6@TEAM6-msi, Docking Station, GPS 12Jul17 17:42:24.
- Health Panel:** Table with columns for Item and Status.

Item	Status
Operating State	Ready
Mobility State	Flying
Plan Name	GuestScience1
Plan State	Paused
- Bee Commanding Panel:** Includes Manual Move Inputs (Aft, Fwd, Roll, Port, Stbd, Pitch, Ovhld, Deck, Yaw) and Options (Face Forward, Check Obstacles, Check Keepouts).
- Miscellaneous Commands:** Camera to Stream, Streaming, Dock, True, Send.
- Interactive Map:** 3D view of the station interior with robot B and various LAB and JPM labels.
- Camera Controls:** Navigation arrows, Zoom to Bee, Reset View, Hide Preview, Zoom to Preview, Snap Preview to Bee.
- Status Bar:** 17:40:03 Honey: Translate: 0, 0, 0; Rotate: 0, 0, 0, 1 Completed.



The status display shows a table of available robots:

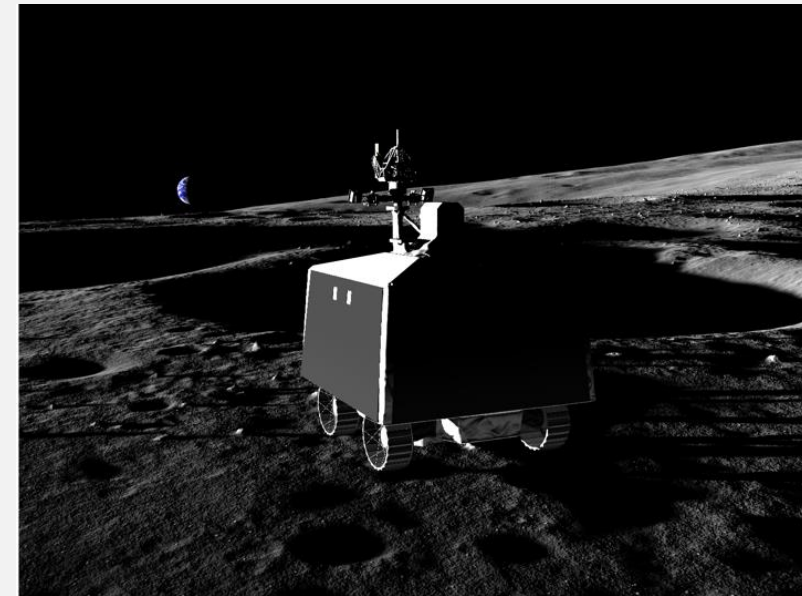
Name	Comm	Health	Est Batt	Control	Summary	Plan	Plan Status
Bumble	Green	Green	3:10	ddwheeie@parsnip	0-1 Segment	Display1	Executing
Honey	Green	Green	1:50	ddwheeie@parsnip	0-1 Segment	Display2	Executing
Queen	Red	Red					

Below the table is a secondary control interface for commanding robots, including a 'Send Command' button and a 3D view of the robots in formation.

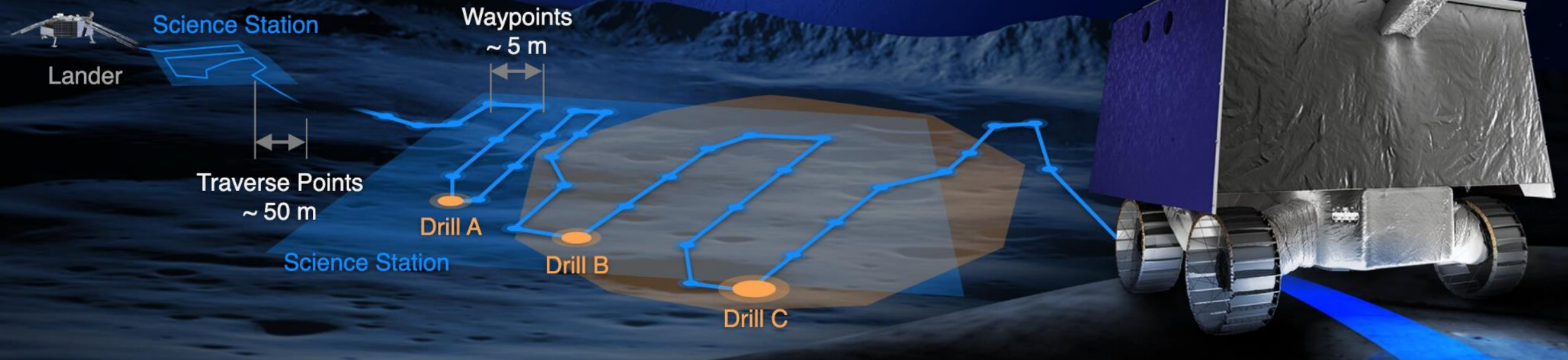
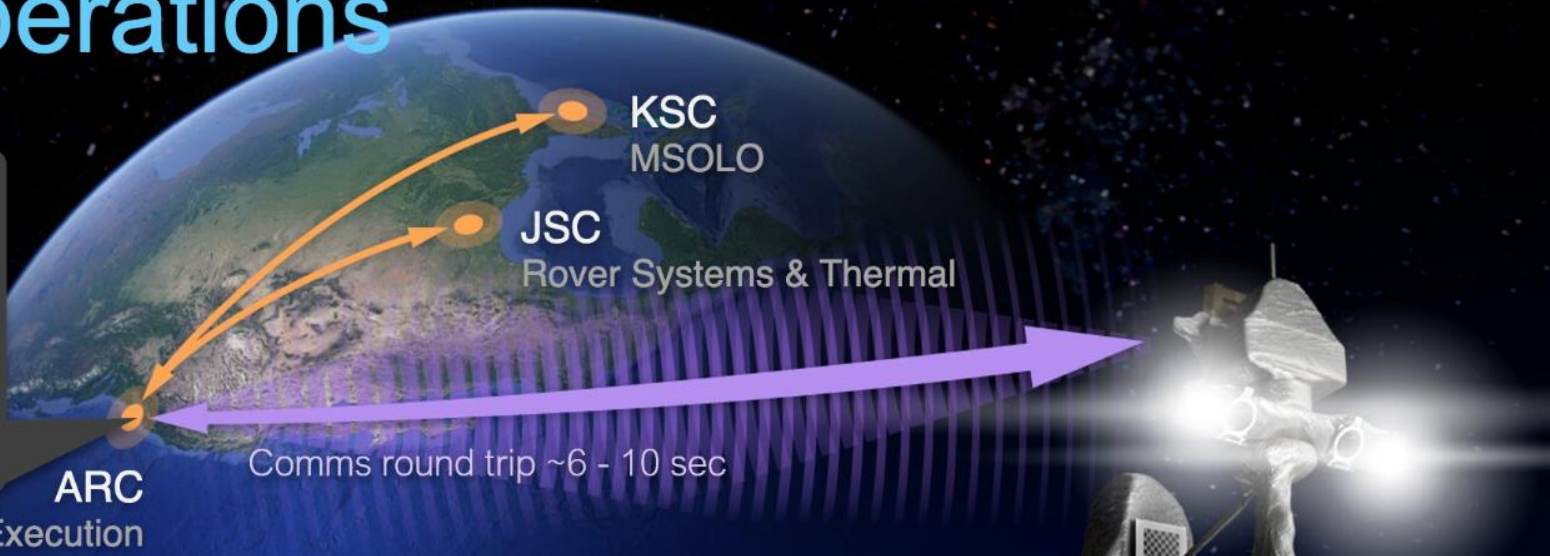
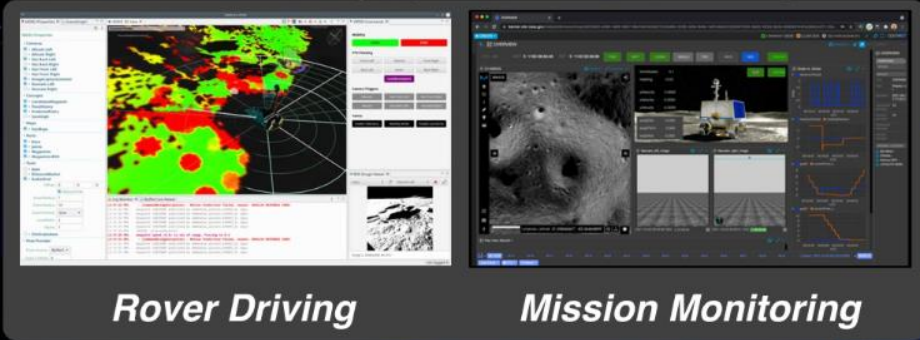
Annotations:

- Send a command simultaneously to all selected robots (e.g. initiate guest science formation flight)
- Current pose and plan geometry for all available robots

- 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



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

Typical Driver VERVE Layout

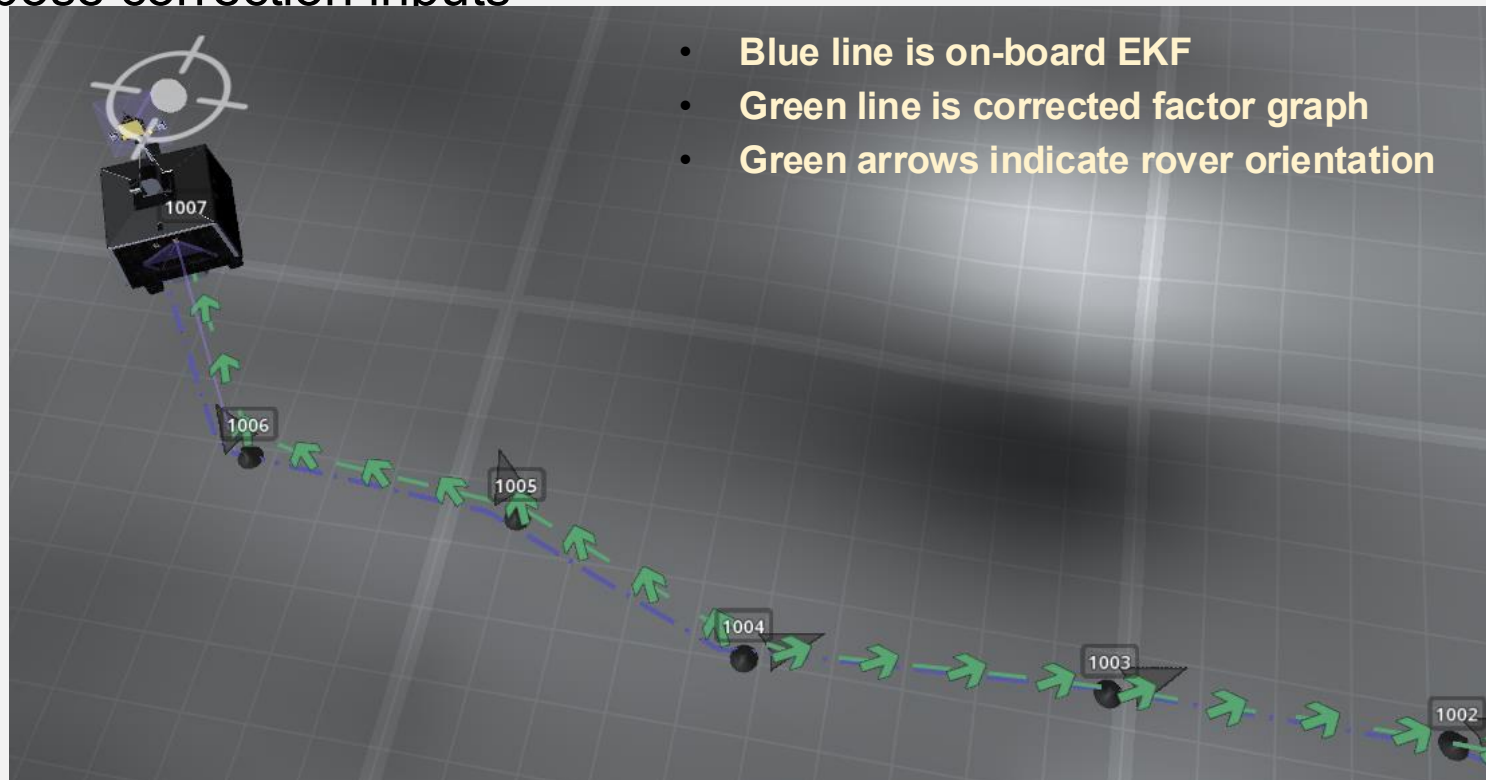


The screenshot displays the VERVE for VIPER software interface, which is used for controlling the rover. The interface is divided into several key sections:

- 3D View:** The central 3D visualization of the rover and its environment, showing terrain elevation and rover orientation. A scale at the top indicates HGA Angles from -400 to 0.
- Wheel Loads:** A panel on the left showing the percentage of load on each of the six wheels. The total load is 93.1%.
- Sensor Sample Manager:** A panel on the left for managing sensor data, including filters and sample types.
- Command Panel:** A panel on the right containing mobility controls (Drive/STOP), PTU pointing controls, PTU Absolute/Relative settings, camera triggers, and No-Op buttons.
- Health and Status:** A panel at the bottom center showing a status bar with battery level (53%), temperature (20°C), and other indicators.
- Command Status View:** A table at the bottom left showing a log of commands, their estimated durations, and their completion status.
- Virtual Camera View:** A panel at the bottom center showing a 3D view of the rover's camera feed.
- Image Viewer:** A panel at the bottom right showing a 2D image of the rover's camera feed with a grid overlay.

Started	Command	Est Dur	Status	Steps
05:22:39	Waypoint 1001	00:00:03	Completed	●●●●●●●●
05:22:46	Set Pan/Tilt (-18.0°/-19.8°)	00:00:09	Completed	●●●●●●●●
05:22:49	Nav-1001-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:26	Completed	●●●●●●●●
05:27:33	Set Pan/Tilt (-58.2°/-24.6°)	00:00:12	Completed	●●●●●●●●
05:27:38	Nav-1001-B [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:18	Completed	●●●●●●●●
05:29:32	Waypoint 1002	00:00:06	Completed	●●●●●●●●
05:29:38	Set Pan/Tilt (-51.2°/-25.0°)	+00:39:01	Overdue	●●●●●●●●
05:29:44	Aft-1002-A [Default*] [No Lights] [AftCam Left] Stereo Image	+00:00:08	Completed	●●●●●●●●
05:29:44	Nav-1002-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:47	Completed	●●●●●●●●
05:44:10	Waypoint 1003	00:00:08	Completed	●●●●●●●●
05:44:20	Set Pan/Tilt (-30.7°/-19.0°)	00:00:10	Completed	●●●●●●●●
05:44:22	Aft-1003-A [Default*] [No Lights] [AftCam Left] Stereo Image	+00:00:04	Completed	●●●●●●●●
05:44:22	Nav-1003-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:31	Completed	●●●●●●●●
05:55:53	Waypoint 1004	00:00:08	Completed	●●●●●●●●
05:56:16	Nav-1004-A [Default*] [No Lights] [NavCam Left] Stereo Image	+00:00:46	Completed	●●●●●●●●

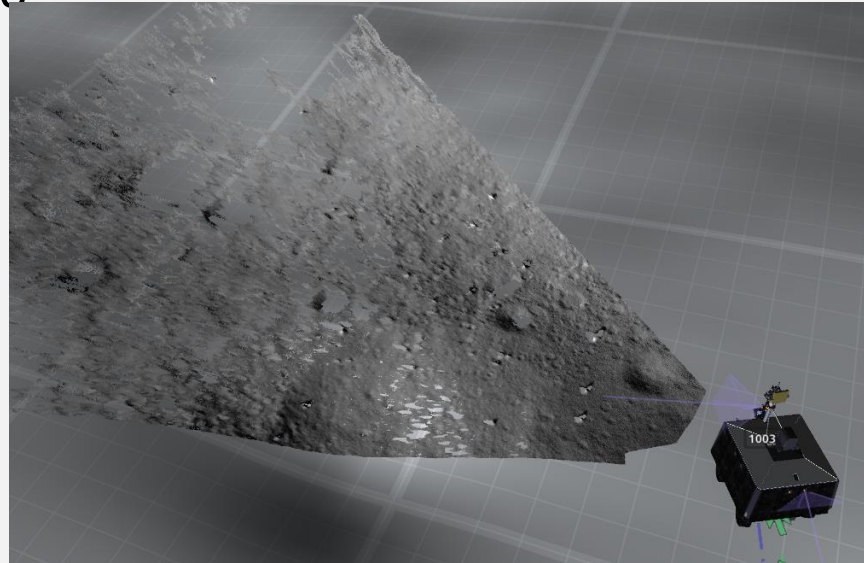
- Rover pose maintained by Rover Ground Software (RGSW) factor graph
 - On-board Extended Kalman Filter (EKF)
 - Visual Odometry (VO) from stereo images
 - Terrain Registration (TR) from stereo panoramas
 - Manual pose correction inputs



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

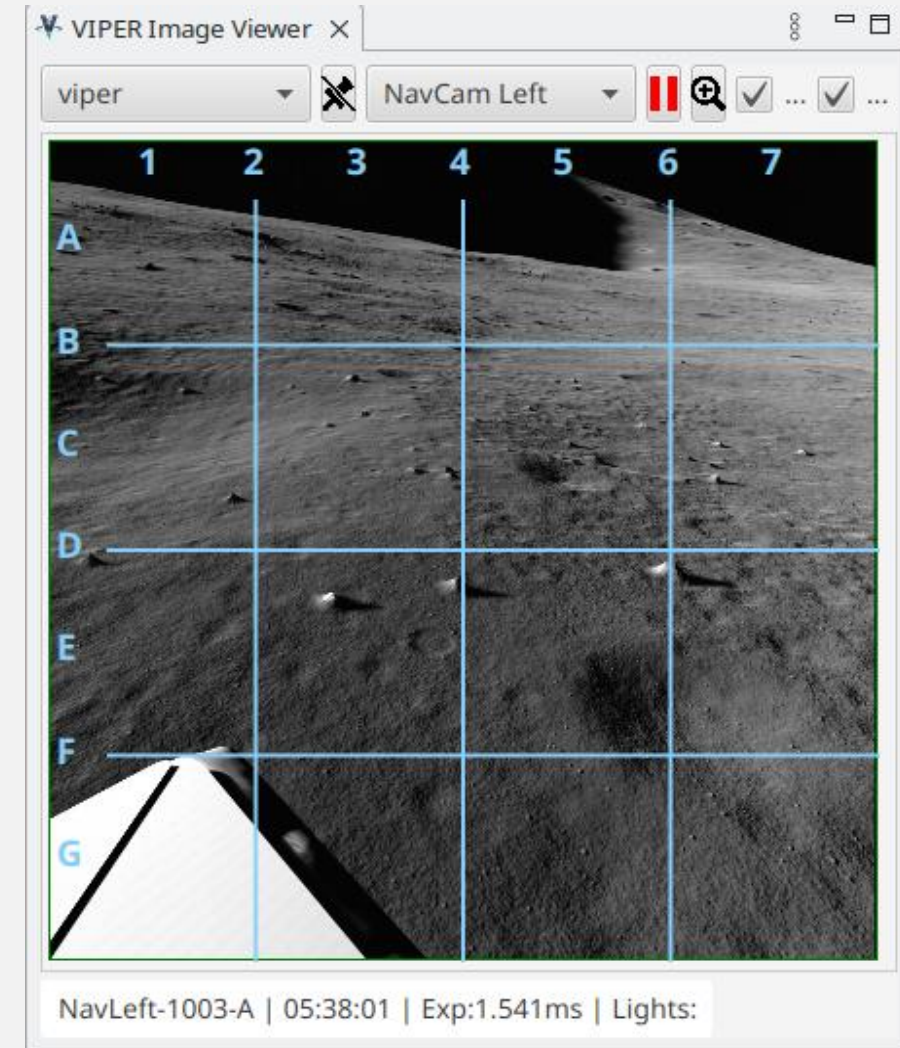
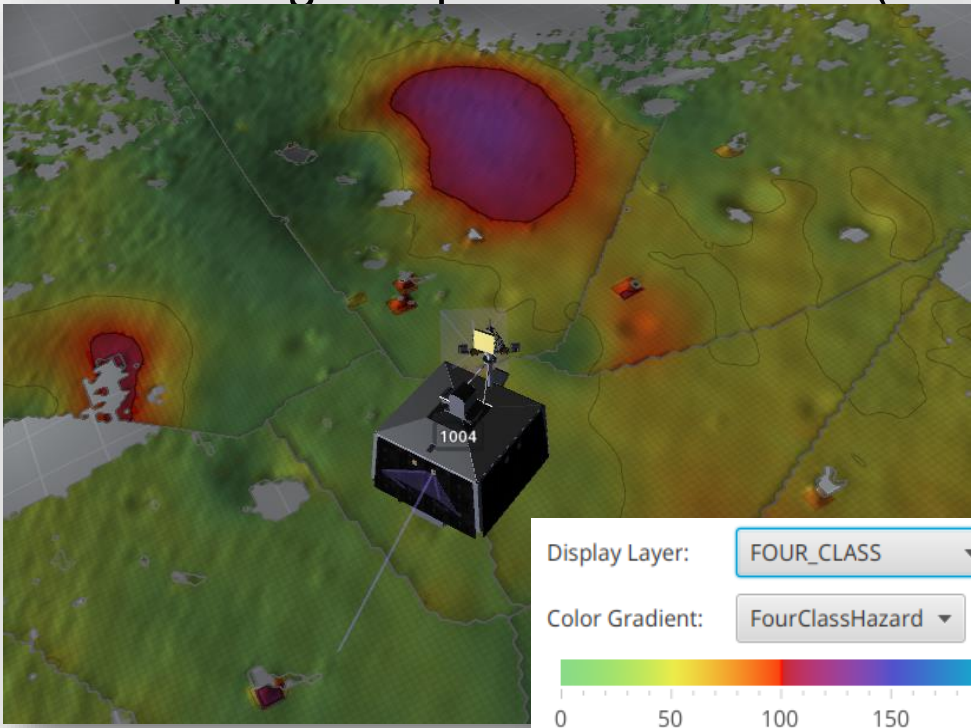


Image viewer with labeled grid overlay

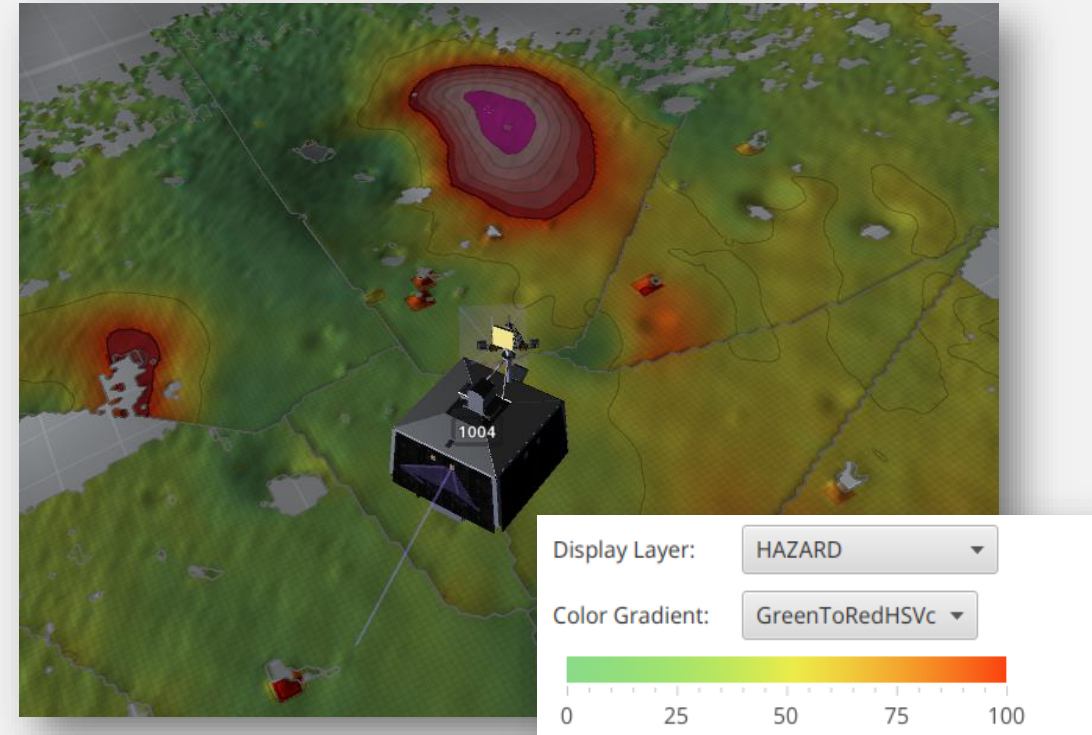
VIPER - Hazard Maps



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

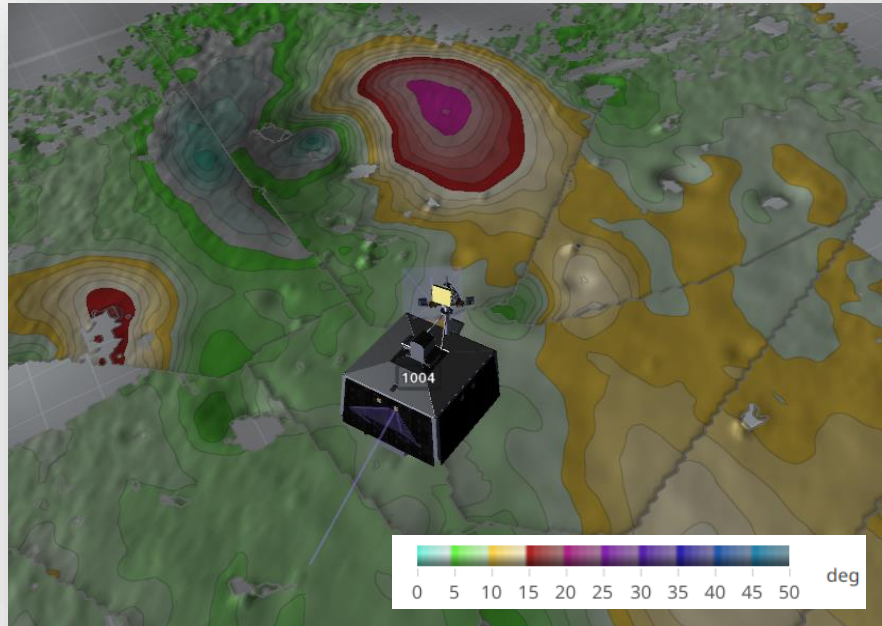


"Four class" hazard gradient

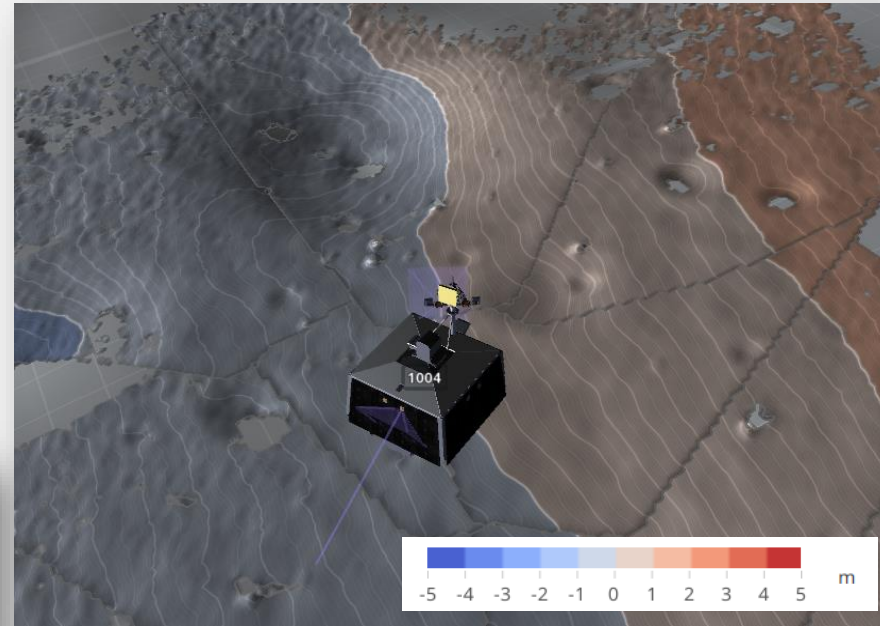


Hazard gradient switches to slope display at operational limit

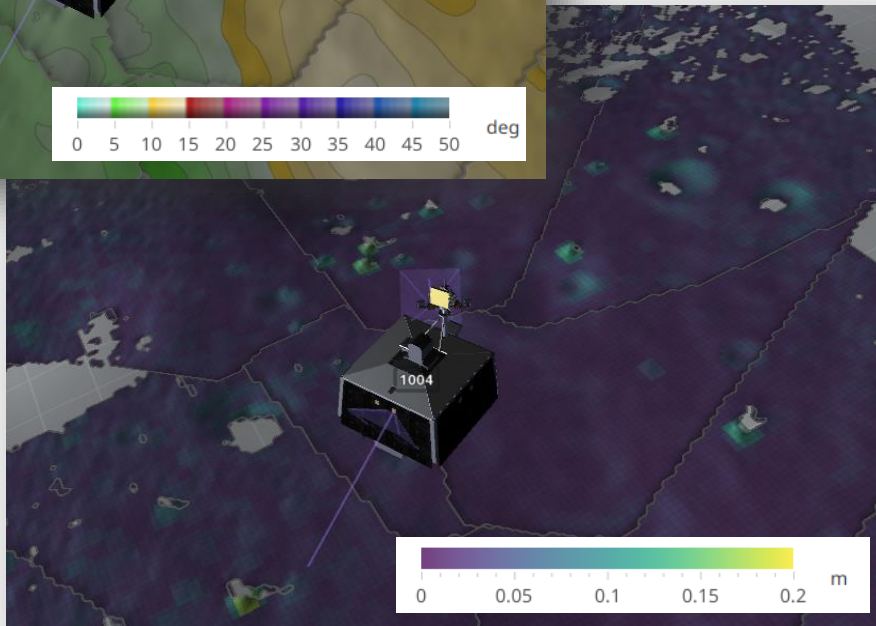
VIPER - Hazard Maps



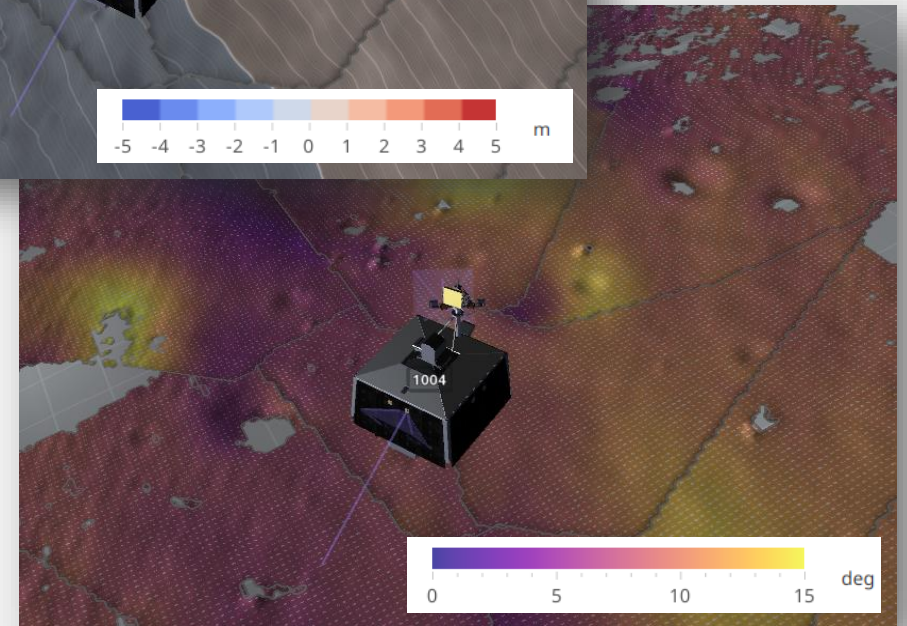
Slope



Relative Height



Step Height

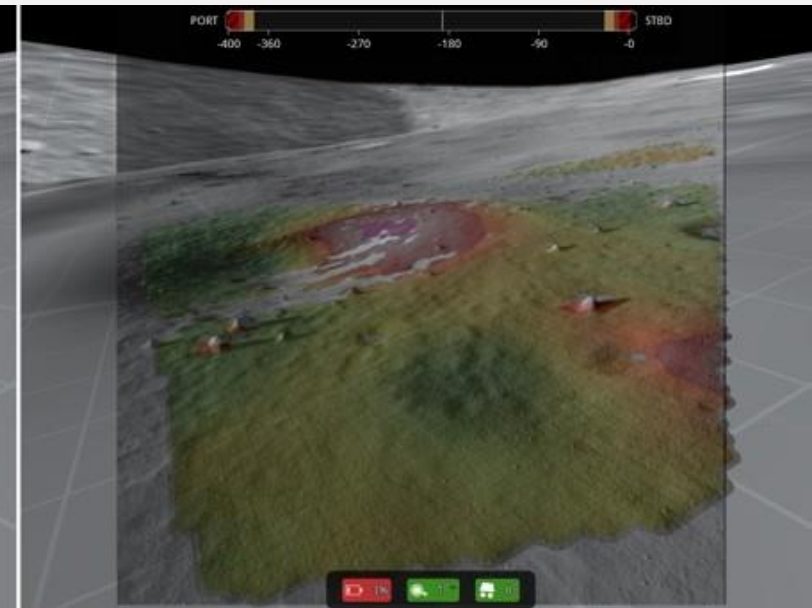
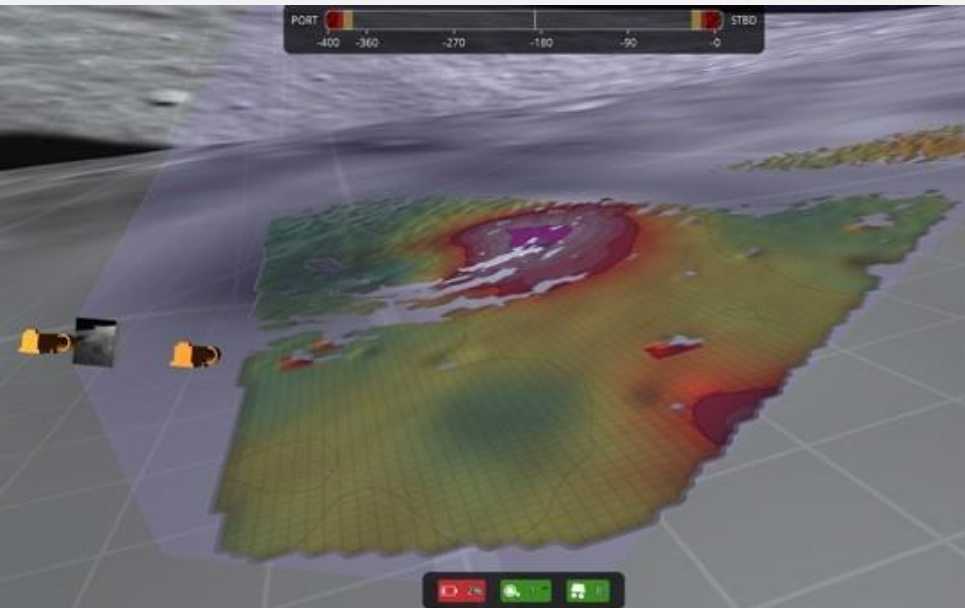


Gradient

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





VERVE

Visual Environment for Remote Virtual Exploration
A 3D Tool for Space Robots