Intelligent Robotics Group

Technologies and Capabilities 2025

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irg.arc.nasa.gov

NASA Ames Research Center

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Intelligent Robotics Group

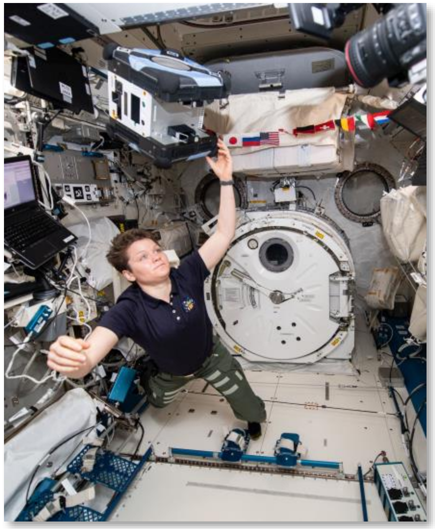
30+ Years of Space Robotics!

Overview

- 45 researchers
  - 80% have advanced degrees
- 10+ student interns yearly
- >90% NASA work
- TRL 1 to 9

Research themes

- **Robots for human explorers**
  - Improving efficiency & productivity
  - Free-flyers, lake lander, & rovers
- **Perception and Navigation**
  - Intelligent sensors and autonomy
  - Planetary and geospatial maps
- **Exploration user interfaces**
  - Robot operations and science data
- **Software Architecture**
- **Simulation**
  - Virtual and physical testbeds
  - Moon, Europa, ISS, UAVs



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IRG Collaborations

Academic

- Carnegie Mellon University
- Leland Stanford Junior University
- University at Buffalo
- Vanderbilt University
- MIT
- Case Western Reserve University
- Penn, University of Pennsylvania
- Arizona State University
- Berkeley, University of California
- Colorado School of Mines
- University of Illinois Urbana-Champaign
- Wisconsin
- Rutgers, The State University of New Jersey
- Brigham Young University, Provo, Utah
- Universiteit Gent
- USC
- University of Idaho
- Cornell University
- KAIST, Korea Advanced Institute of Science and Technology, 한국과학기술원
- SETI Institute
- CU Boulder
- EPFL

Commercial

- Google
- Astrobotic
- Nissan
- IFOS, Intelligent Fiber Optic Systems
- Tethers Unlimited
- Outward Technologies
- Otherlab
- Altius Space Machines
- TRACLabs
- BNS, Boulder Nonlinear Systems
- Honeybee Robotics
- digitalfish
- ProtoInnovations
- Energid, Robotics and Machine Vision
- SSL

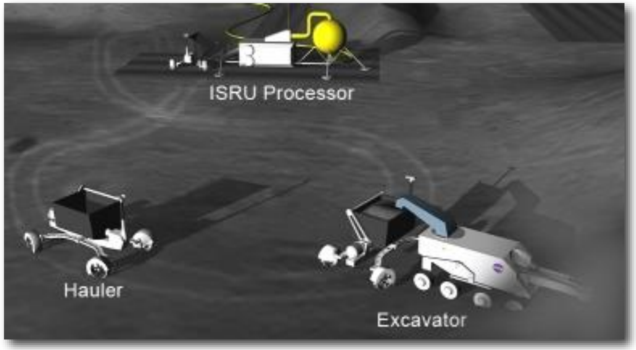
Government

- DARPA
- Naval Information Warfare Center Pacific
- National Geospatial-Intelligence Agency, United States of America
- NPS, Praestantia per Scientiam, 1909
- Marine Corps Warfighting Lab, "Semper Fidelis"
- Naval Research Laboratory, Washington, DC
- USGS, science for a changing world

Robotics for Human Exploration

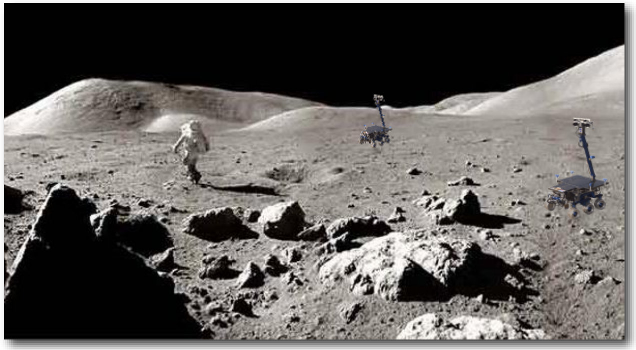
Purpose

- Increase human productivity
- Improve mission planning & execution
- Transfer **some** tasks to robots
  - e.g. dangerous, tedious, repetitive, and long-duration



Before Crew

- Recon (scouting) & prospecting
- Site prep, deploy equipment, etc.



Supporting Crew

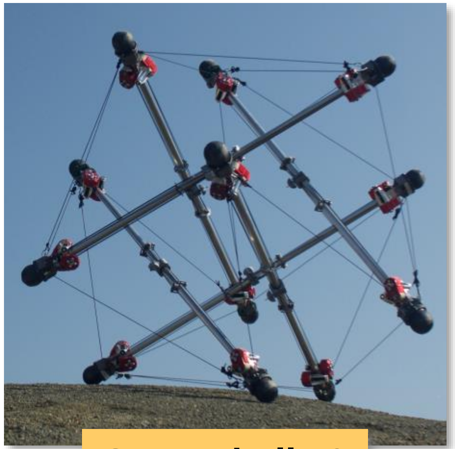
- Inspection, mobile camera, etc.
- Heavy transport & mobility

After Crew

- Follow-up & close-out work
- Site survey, maintenance, etc.

Robot Platforms

K10



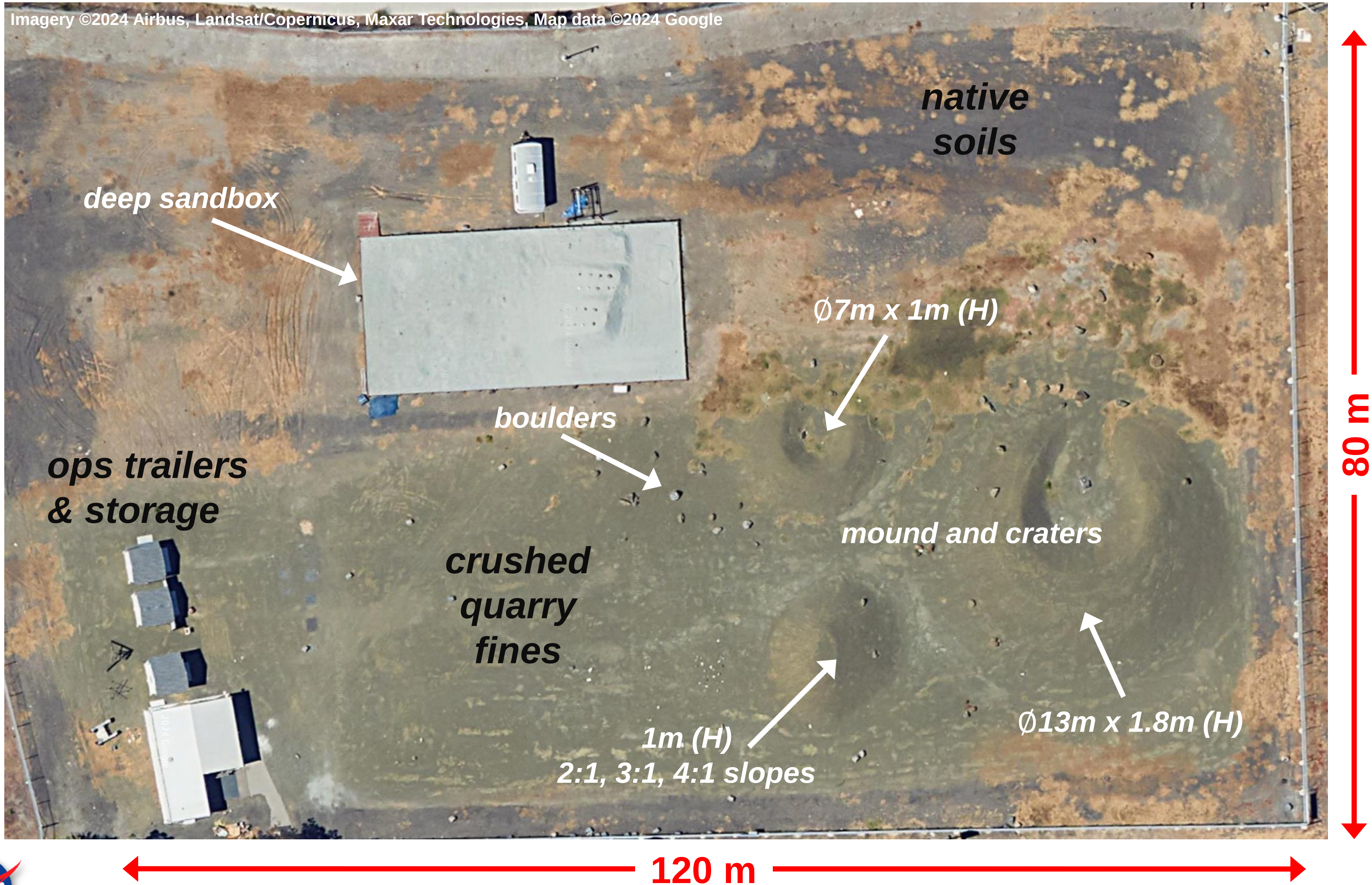
SUPERball v2

KREX-2

Astrobee

MGRU

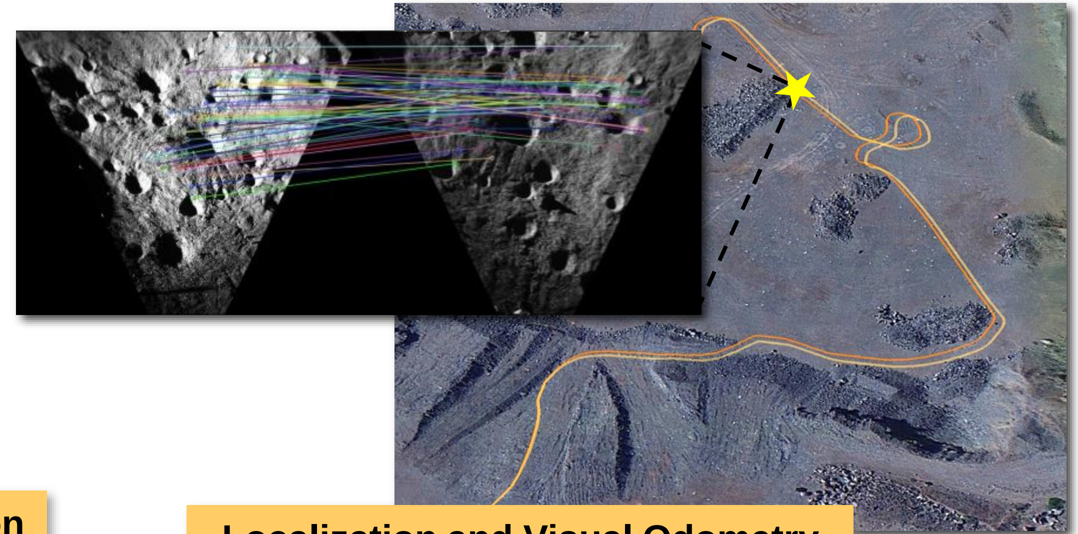
Roverscape Test Facility



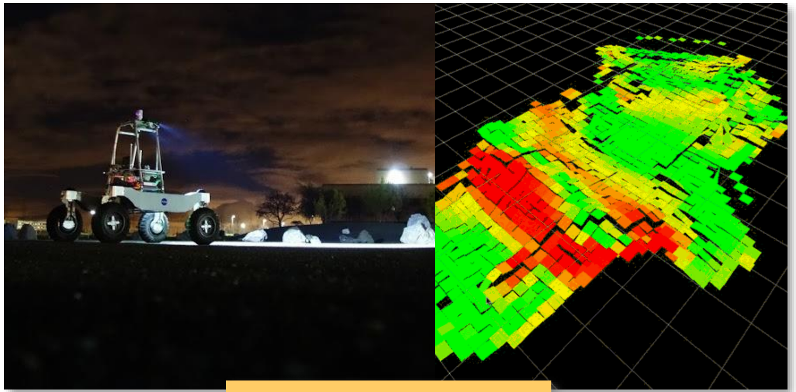
Perception and Navigation

Land, Sea, Air, and Space

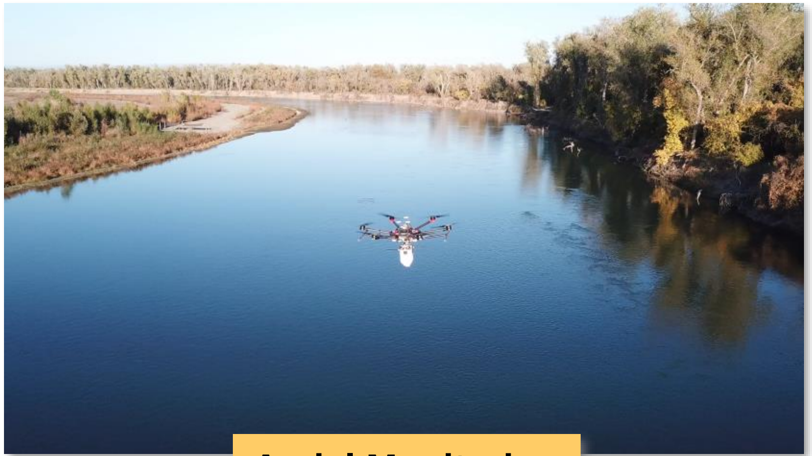
Intravehicular Robotics and Inspection



Localization and Visual Odometry



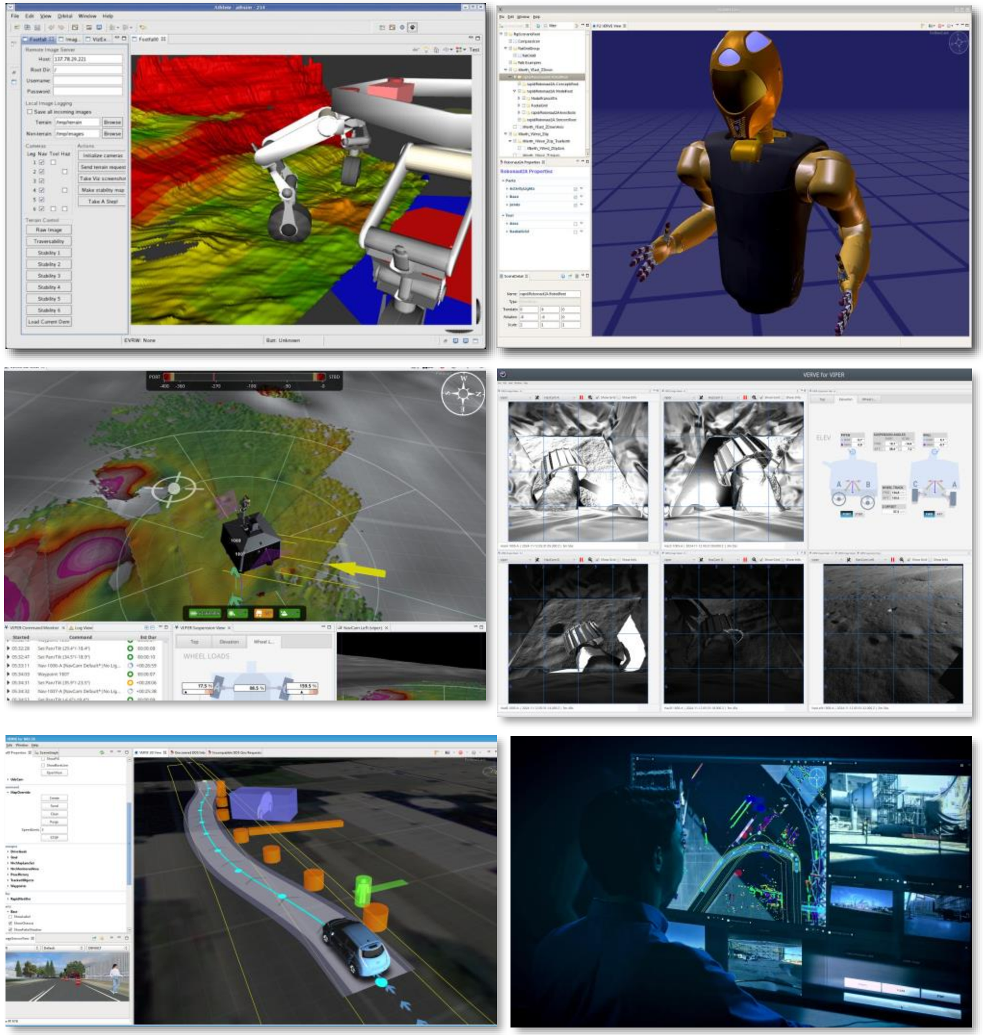
Dark Navigation



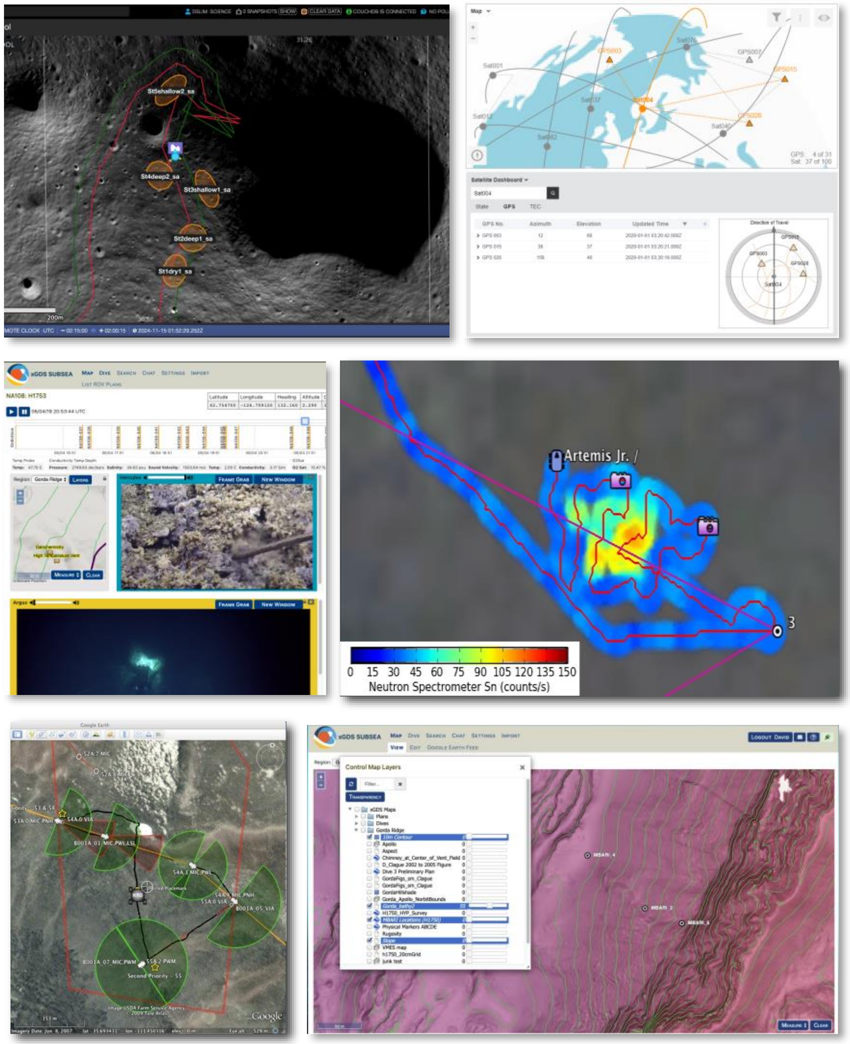
Aerial Monitoring

User Interfaces

Rovers, Cars, Humanoids, Satellites, and more…



Visual Environment for Remote Virtual Exploration (VERVE)

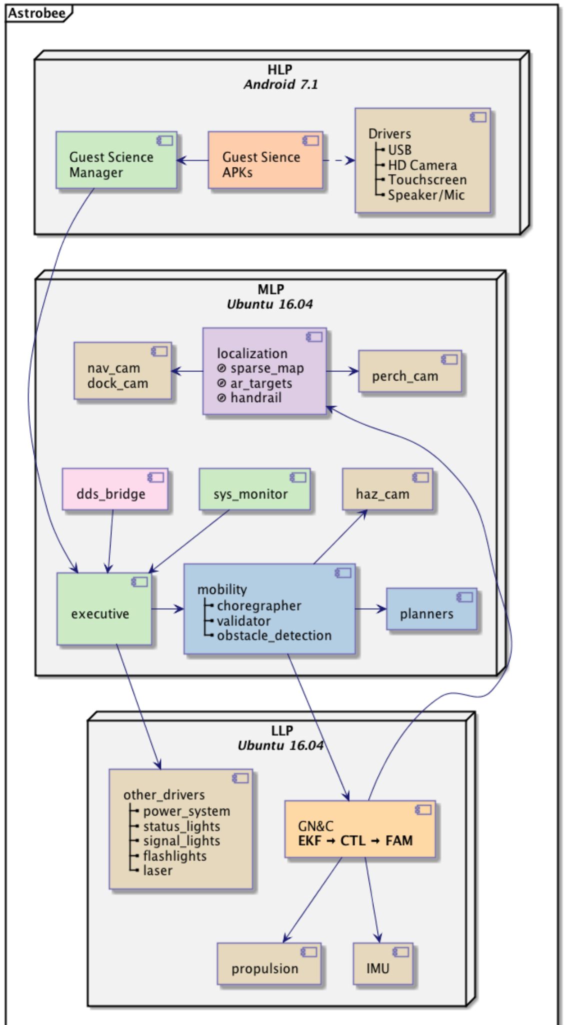


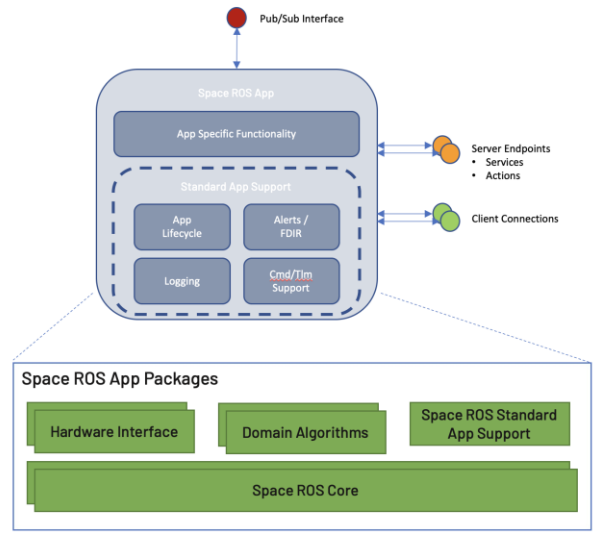
Ground Data Systems and Geospatial Tools

Software Architecture

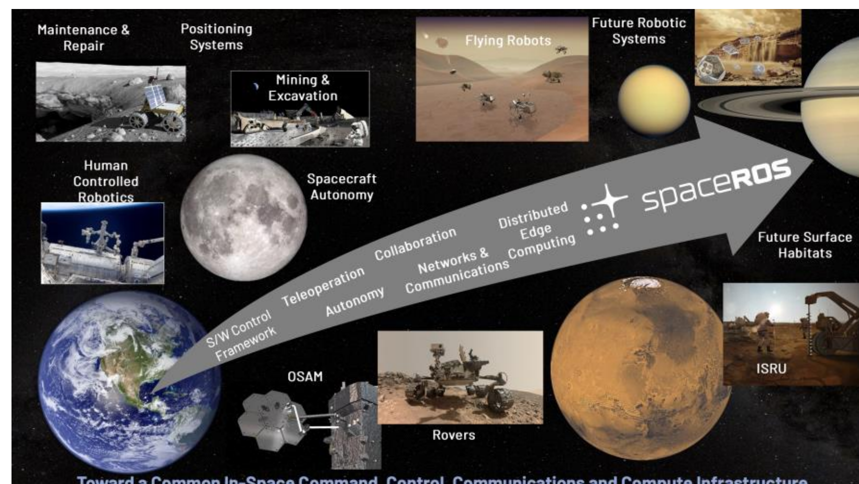
Astrobee Software

- NASA Software of the Year Runner-Up (2020)
- Dozens of research groups have tested their robot software on the ISS safely as Astrobee guest science
- Robust robot-to-robot and space-to-ground communication using the DDS protocol
- 46 Robot Operating System (ROS) nodelets in 14 processes distributed across 3 processors





- Robot Operating System (ROS) middleware for critical space missions
- Started as agreement between Blue Origin and NASA, now managed by OpenRobotics
- Open Source and on GitHub

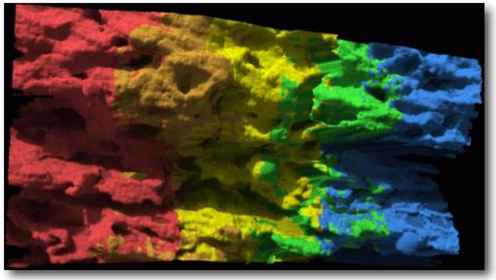


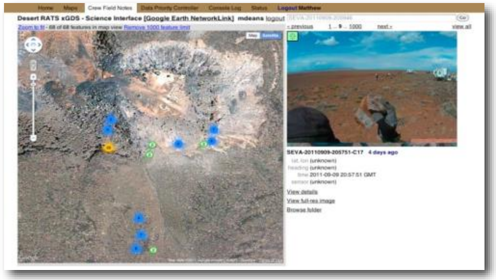
Space ROS

Open Source Software

Vision Workbench

Apache 2



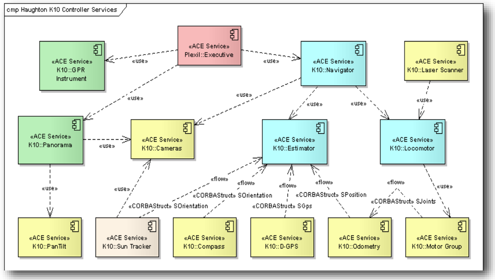


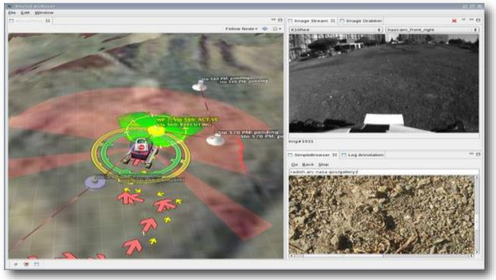
Exploration Ground Data Systems (xGDS)

Apache 2

RoverSW

NOSA 1.3





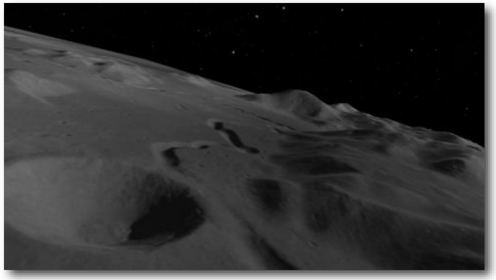
Visual Environment for Remote Virtual Exploration (VERVE)

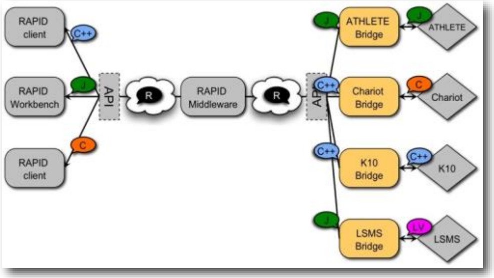
Apache 2

Neo Geography Toolkit

(Ames Stereo Pipeline)

Apache 2





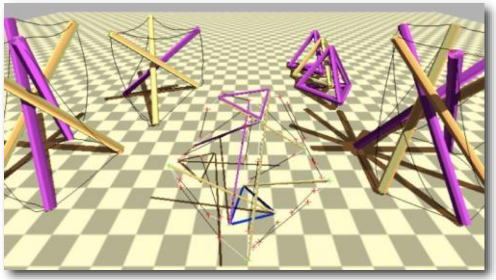
RAPID

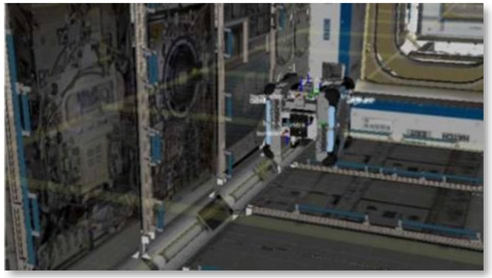
(NASA robot middleware)

Apache 2

NASA Tensegrity Robotics Toolkit

Apache 2





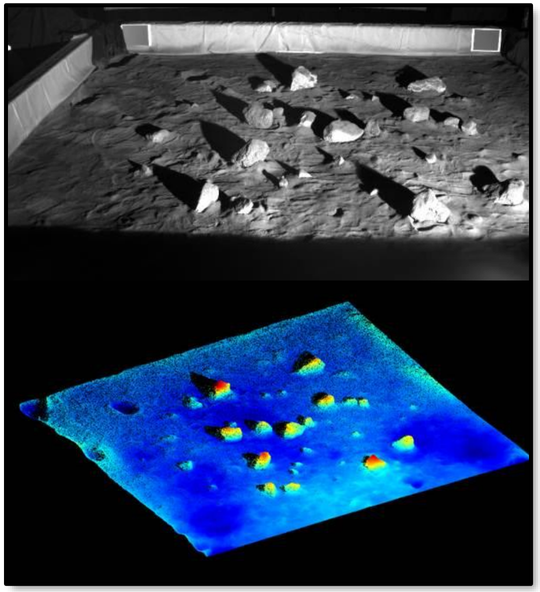
Astrobee Robot Software (ARS), Astrobee Simulator, Astrobee Control Station

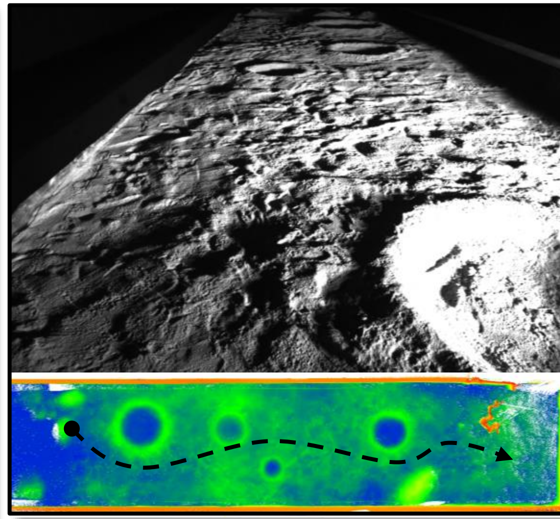
Apache 2

Public Datasets

Temporary mirror:
ti.arc.nasa.gov/dataset

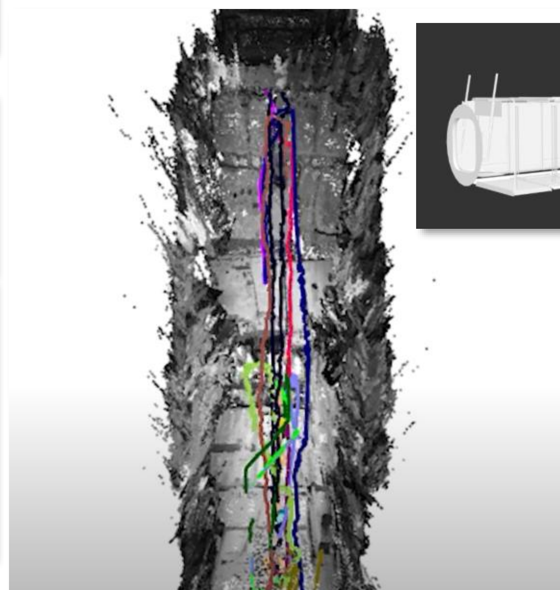
POLAR
Stereo images, hazard detection, Lunar poles, high dynamic range

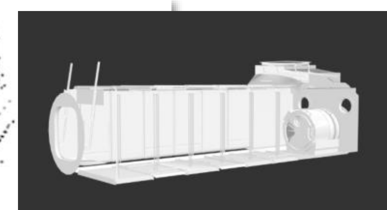




POLAR *Traverse*
Visual odometry, incremental SLAM, Lunar poles

FROST
Icy moons, rover scale, terrain surface geometry, 3D scans, DEMs





Astrobee ISS
Visual-inertial SLAM, free-flyer benchmark, cluttered ISS spaces

Highlighted Projects

Astrobee

***Video**: Astrobee's "Bumble Bee" robot performs first on-orbit activities with NASA astronauts on ISS.*

https://www.nasa.gov/astrobee

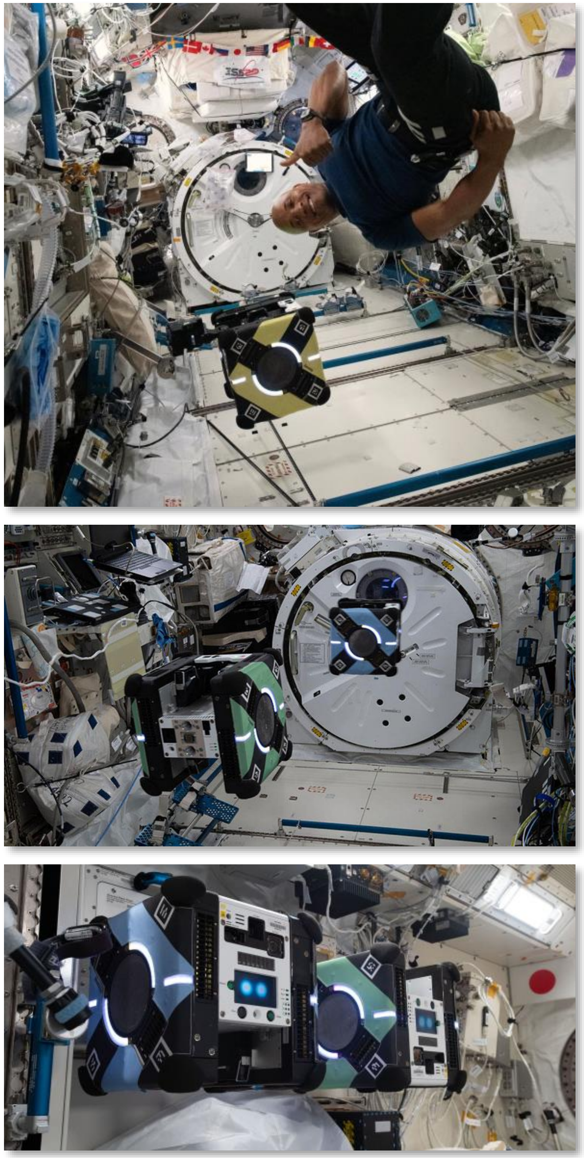
Astrobee

Overview

- Developed and launched three free-flying robots to the ISS in 2019
- IRG led project with involvement in all aspects of flight development from software to hardware to operations
- Three robots with dock, robot and ground software
- Upgrade from prior SPHERES free-flyers, adding a suite of six cameras to perform inspection and survey tasks, the ability to operate without astronaut supervision throughout the ISS, recharge autonomously, swap in research payloads, and use a robot arm to grasp objects and perch on handrails
- Robots autonomously move through the ISS to support guest scientist research projects and student programming competitions

Achievements

- As of 9/30/2024: four years with 179 on-orbit operations, 1350 on console hours, and over 30 guest science partners
- NASA Software of the Year Runner-Up (2020) http://github.com/nasa/astrobee
- Operation for over three hours straight with no crew intervention
- Four years supporting domestic and international student programming competitions with thousands of participants



Astrobee activities on the ISS

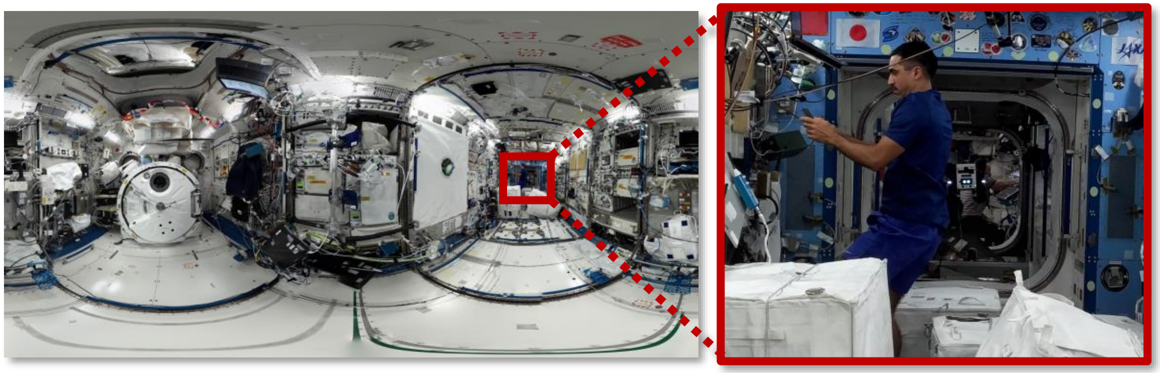
Integrated System for Autonomous and Adaptive Caretaking (ISAAC)

Overview

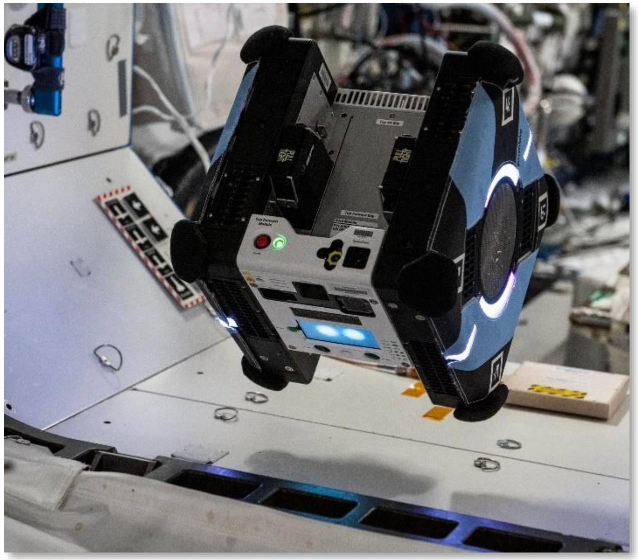
- Research project to develop technology for autonomous caretaking of spacecraft primarily during uncrewed mission phases
- Led by Ames with help from JSC
- Integrated autonomous intra-vehicular robots (IVR) with spacecraft infrastructure (power, life support, etc.) and ground control

Achievements

- Built a panoramic tour of the ISS interior with an autonomous multi-robot team of Astrobee free-flyers
- Integrated synthetic vehicle telemetry with real robot telemetry in an on-orbit demonstration of localizing an ECLSS fault
- First robotic navigation between ISS modules
- First robotic localization of a sound source in space



First panorama captured by a free-flying robot in space – mosaic of 56 Astrobee SciCam images



Performing a close-up inspection of a hatch seal

Sound source localization - Collaboration with Bosch USA SoundSee team

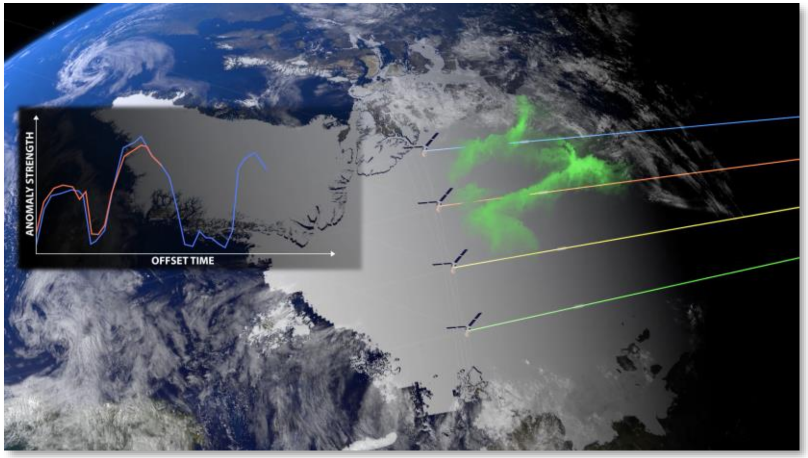
Distributed Spacecraft Autonomy (DSA)

DSA-Starling Flight Demonstration

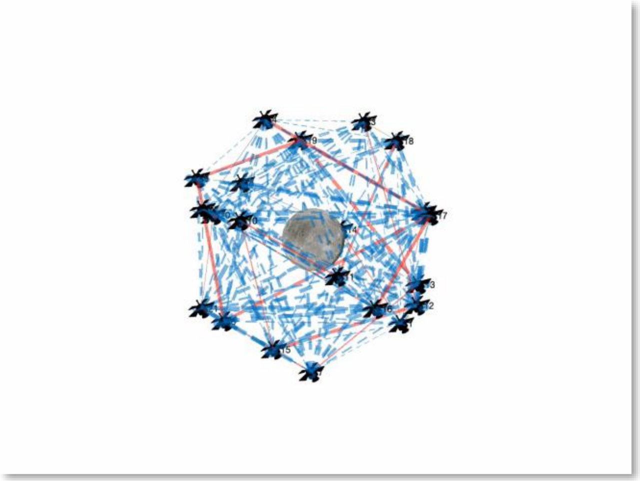
- Four CubeSats with crosslinks
- Demo autonomous, coordinated monitoring of transient space weather phenomenon

Firsts in Space

- 1^{st} fully autonomous distributed space mission
- 1^{st} fully distributed reactive operations on multiple spacecraft
- 1^{st} deployment of general-purpose automated reasoning and distributed automated planning onboard multiple spacecraft

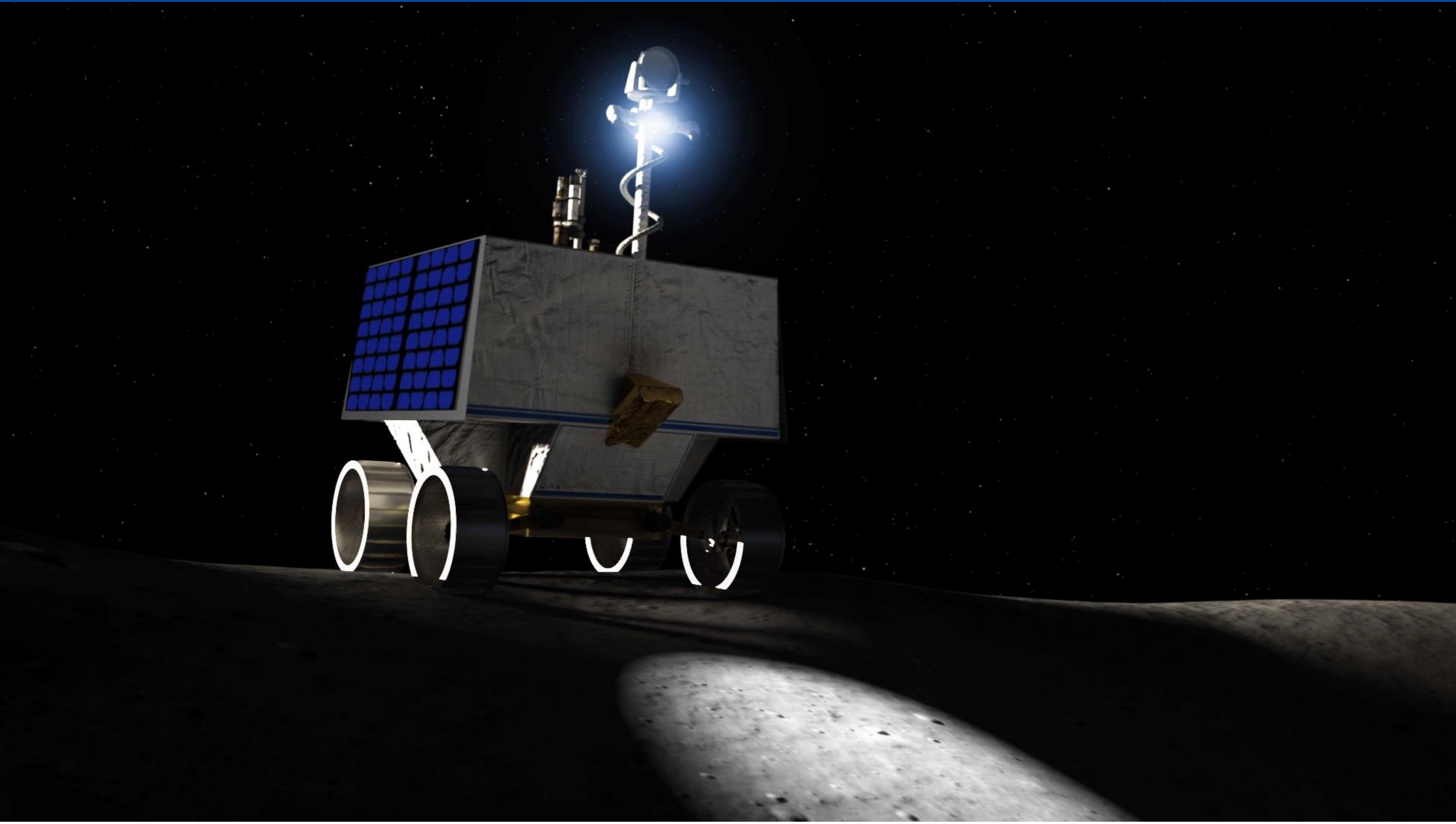


Video: *Conceptual rendering of Starling CubeSat swarm with DSA conops to measure ionospheric phenomena*



Video: *DSA explores optimization of coordinated measurements from multiple vehicles and viewpoints*

Volatiles Investigating Polar Exploration Rover (VIPER)



Video: *VIPER mission to explore permanently shadowed regions in the Lunar South Pole*

Credit: *NASA Scientific Visualization Studio*

Music Provided by Universal Production Music: "The Butterfly Effect" – David Thomas Connolly

Volatiles Investigating Polar Exploration Rover (VIPER)

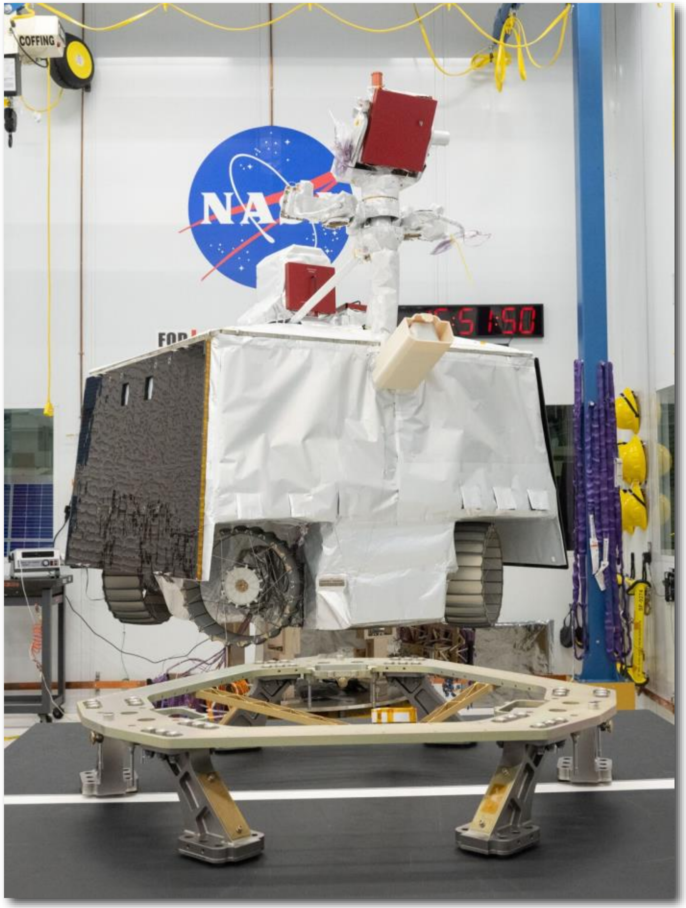
Search for subsurface volatiles (e.g. water ice) in the polar regions of the Moon

Mission planned for 2024

- Rover completed and tested
- In holding pattern, looking for industry partner due to budget

IRG Role:

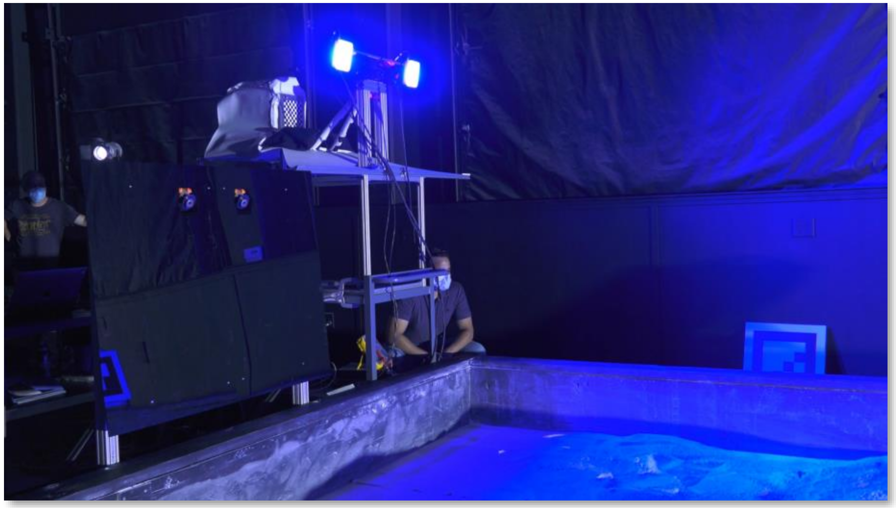
- Onboard software
- Navigation systems
- Robot driving tools
- 3D Lunar terrain maps from satellite images for mission planning
- Software to support high-tempo science operations



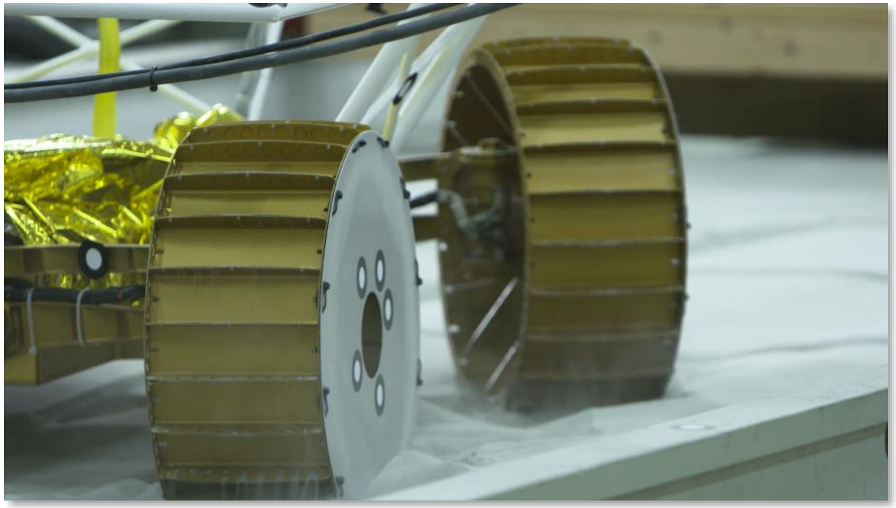
VIPER sits fully integrated in clean room

VIPER Development

Video: *Testing of antenna pointing stability while driving*



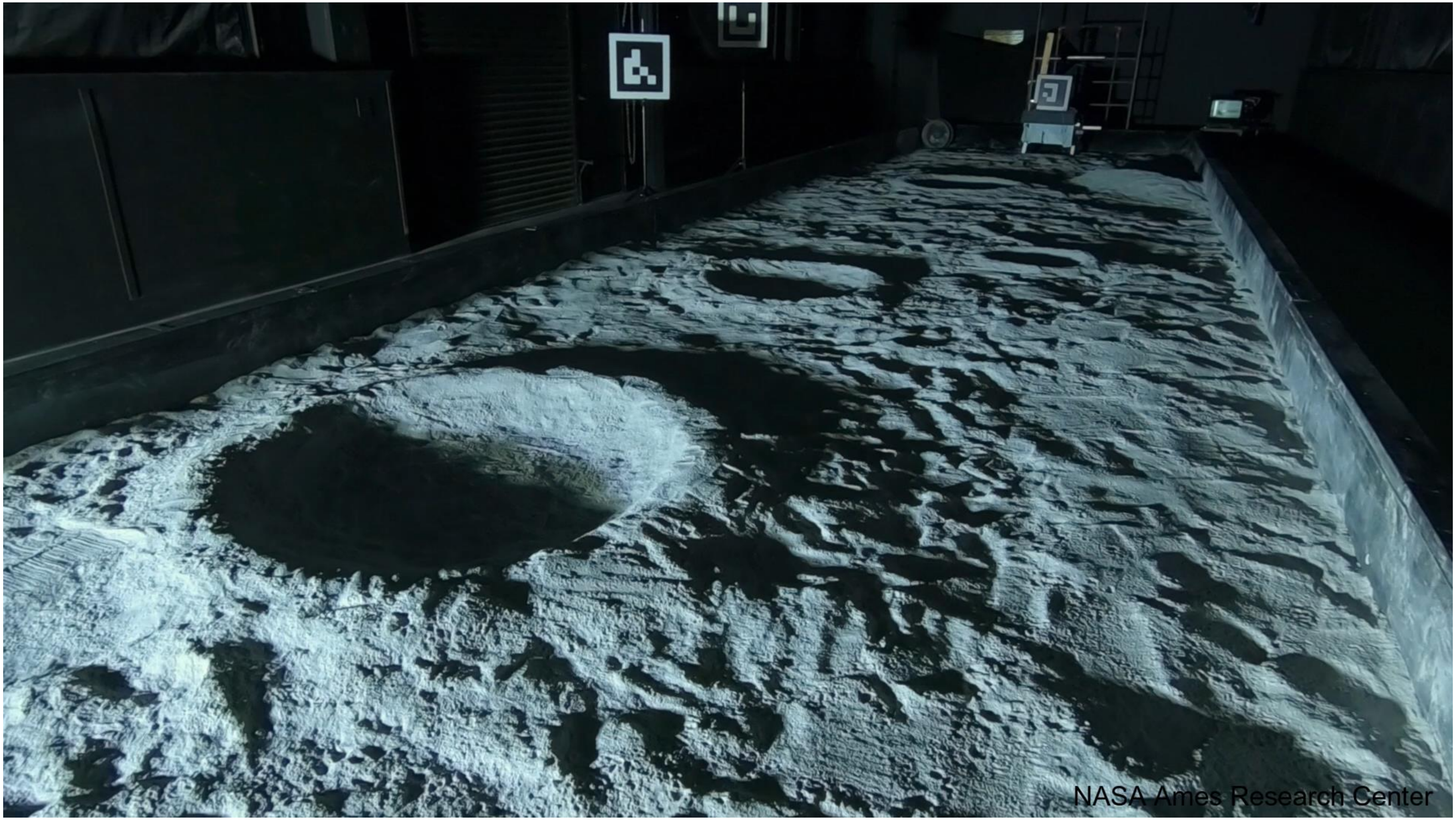
Video: *LED headlights for driving in shadow*



Video: *Rover mobility and wheel testing in NASA SLOPE lab*

Video: *VIPER driving interface showing waypoint driving*

Lunar Lab Regolith Testbed



Video: *Flythrough of "Lunar Lab" regolith testbed*

Lunar Lab Regolith Testbed

A high-fidelity physical test environment for development of rover optical navigation hardware

Developed during VIPER mission in collaboration with SSERVI institute

Two sandboxes filled with regolith (Lunar dust) simulant:

- 4.0m x 4.0m x 0.5m with 8 tons of JSC-1A *mare* simulant
- 4.0m x 20m x 0.1m with 12 tons of LHS-1 *highlands* simulant

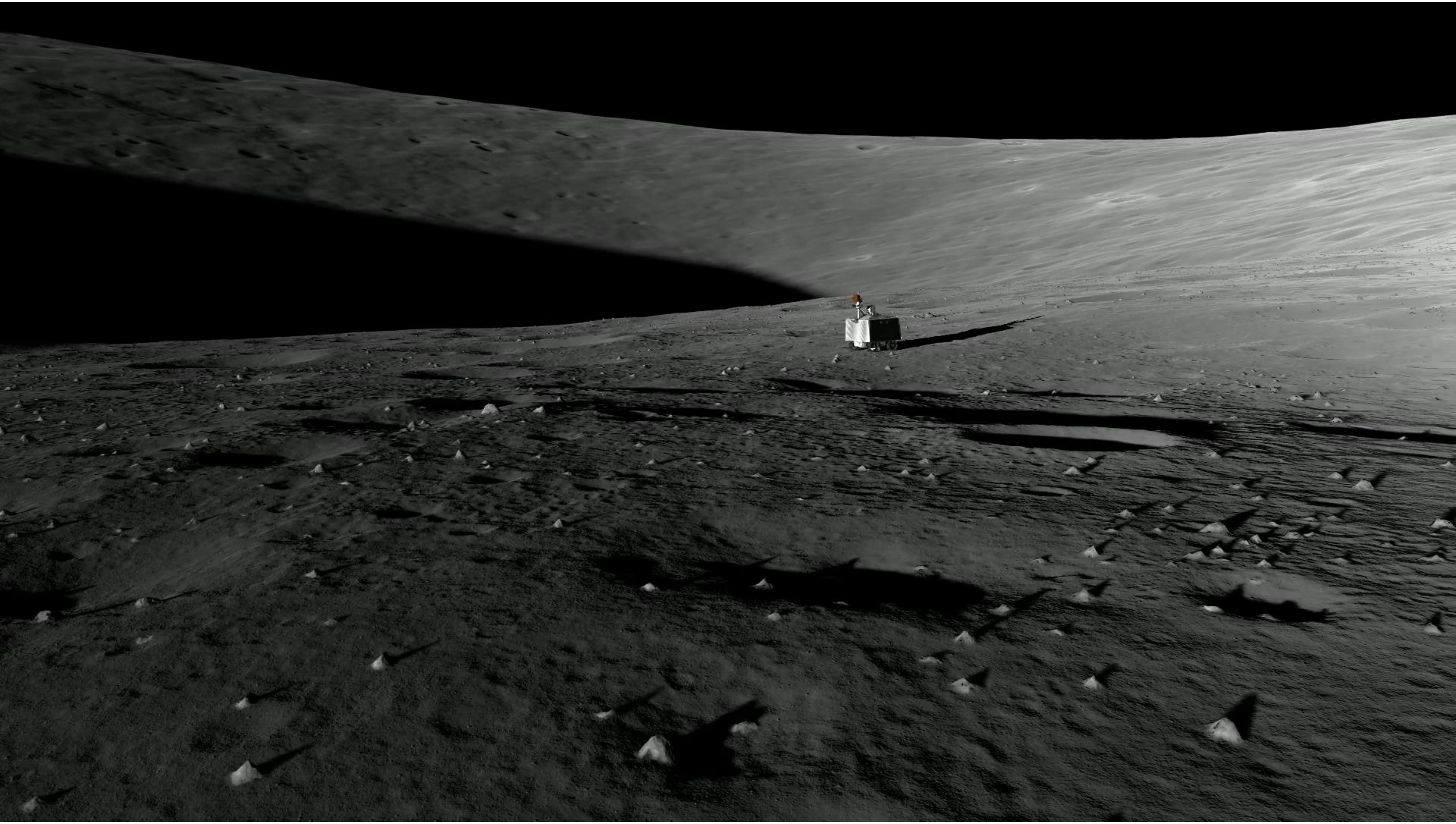
Simulate navigation conditions relevant to Lunar poles

- **Lighting**: shadows, opposition effect, lens flares, glare
- **Terrain**: craters, rocks, slopes, berms, dust, terramechanics
- **Sensor**: dynamic range, noise, lens sharpness

Rover hazard camera looking at regolith interface and wheel tracks in the lab.

Physical simulation of crater features and high dynamic range solar illumination

Lunar Rover Simulator (RSim)

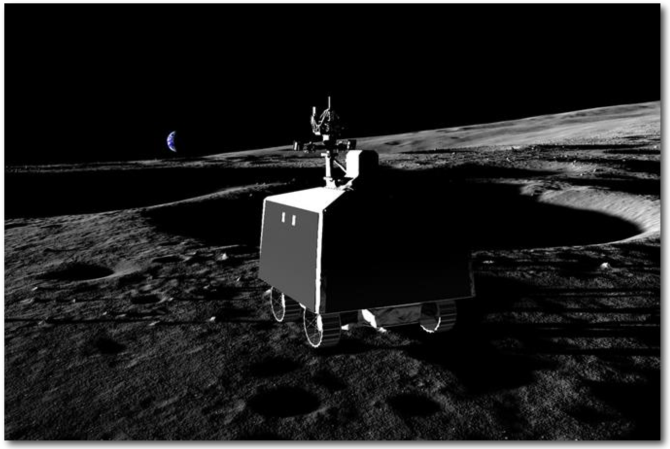


Video: *VIPER drives over simulated Lunar South Pole terrain in RSim*

Lunar Rover Simulator (RSim)

Key Features

- High dynamic range rendering
- Real-time shadows
- Support for high resolution terrains
- Support for custom terrain appearance
- Rover wheel tracks and slip modeling
- Rover lights with custom pattern
- Simulated lens flare and noise
- Lunar regolith reflectance model
- Accurate Sun & Earth ephemeris
- Based on Gazebo Classic r11 (with many lunar customizations)



Model of VIPER at Lunar South Pole in RSim with a view of Earth

VIPER at Lunar South Pole in RSim with hazard lights turned on in a permanently shadowed region

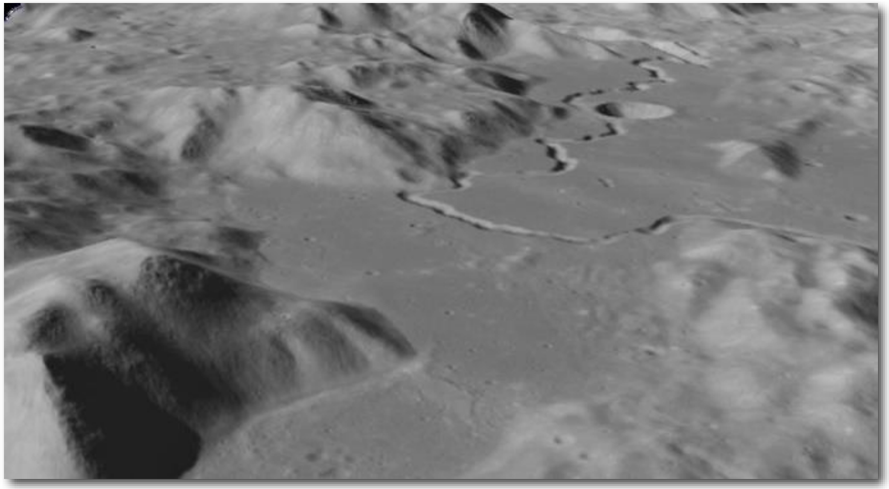
Digital Terrain Models – Ames Stereo Pipeline (ASP)

Automated stereogrammetry

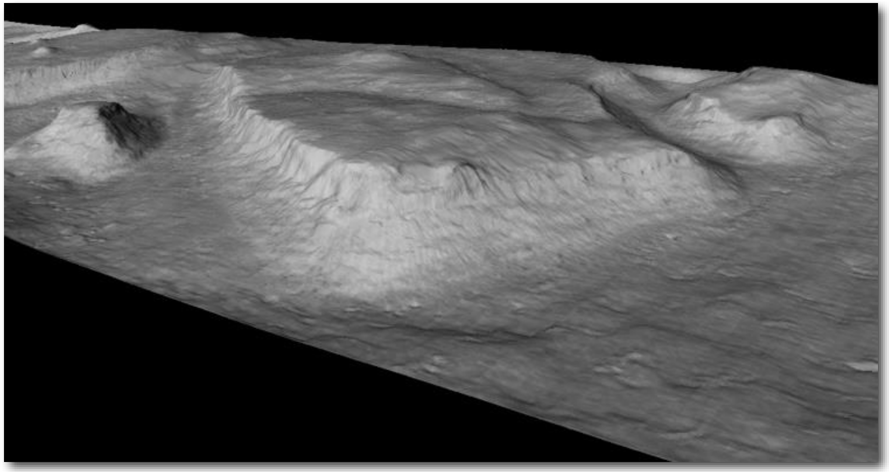
- Command-line processing tools (including bundle adjustment, albedo reconstruction, etc.)
- C++ code hosted on GitHub (Apache 2 license)
- Linux and OS-X binaries
- **Used by multiple missions and across hundreds of publications**

Planetary data (to date)

- Apollo Metric Camera
- Lunar Reconnaissance Orbital Camera (LROC-NA)
- Mars High Resolution Imaging Science Experiment (HiRISE)
- Mars Orbiter Camera (MOC)
- MRO Context Camera (CTX)



Hadley Rille – Moon *(40 m/post DEM + 10 m/pixel)*



Galaxius Fluctus – Mars *(20 m/post DEM + 5 m/pixel)*

https://github.com/NeoGeographyToolkit/StereoPipeline

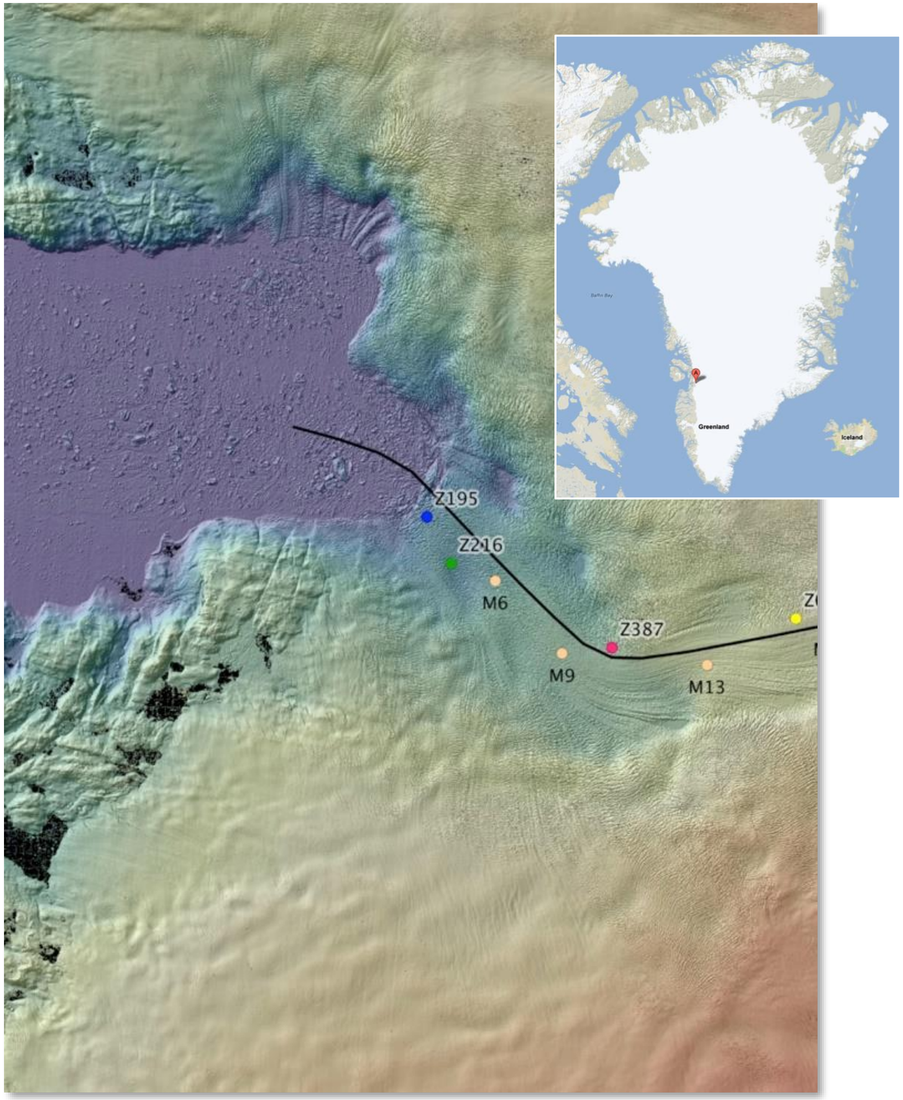
Ames Stereo Pipeline *for Earth*

3D terrain modeling

- Digital Elevation Models (DEM) produced from commercial satellite images
- 60% success rate processing Digital Globe stereo pairs without human input

Earth science studies

- Glacier volume changes and movement
- Evolution of subglacial lakes
- Sea ice movements
- Climate change measurements



Jakobshavn Glacier *DEM (2500 sq. km @ 3 m/pix)*

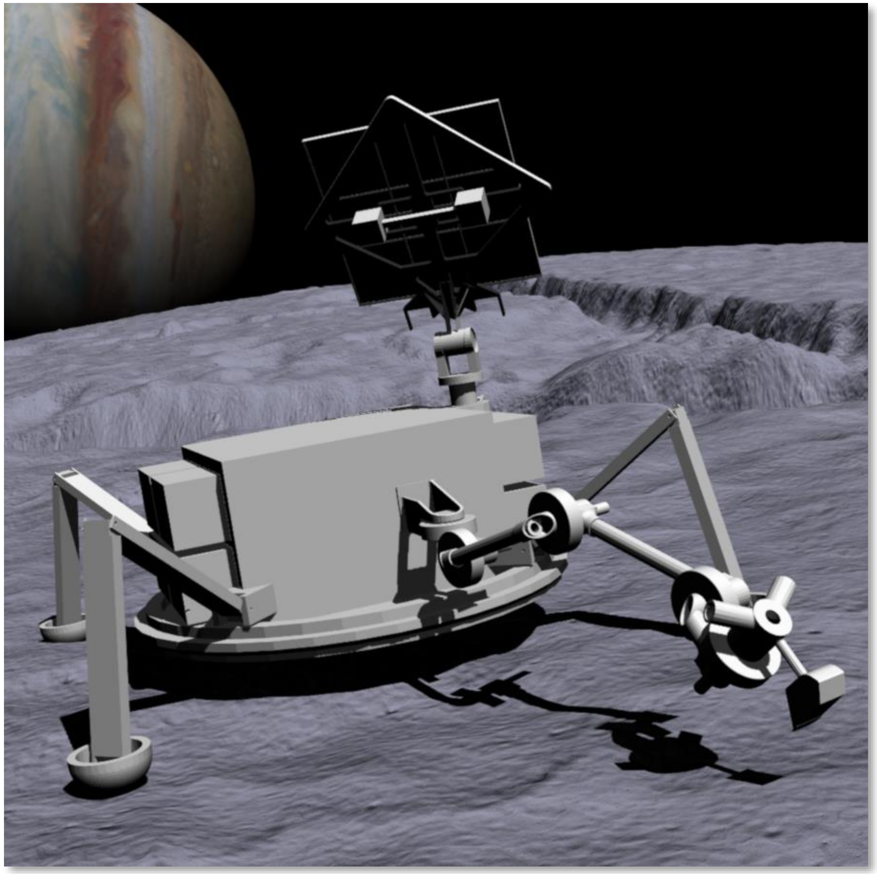
Ocean Worlds Autonomy Testbed for Exploration Research and Simulation (OceanWATERS)

Open-source simulator for developing onboard autonomy software for the robotic exploration of ocean worlds, such as Europa, Enceladus, and Titan

Emulates:

- Surface conditions
- Robotic manipulator operation
- Lander systems

Simulator modeled on the Europa Lander mission, but could be configured for other lander missions and planetary bodies



Europa Lander model visualized in OceanWATERS simulator

Extreme Perception

Novel sensors and perception to enable robots to see in extreme environments

Approach blends capabilities in:

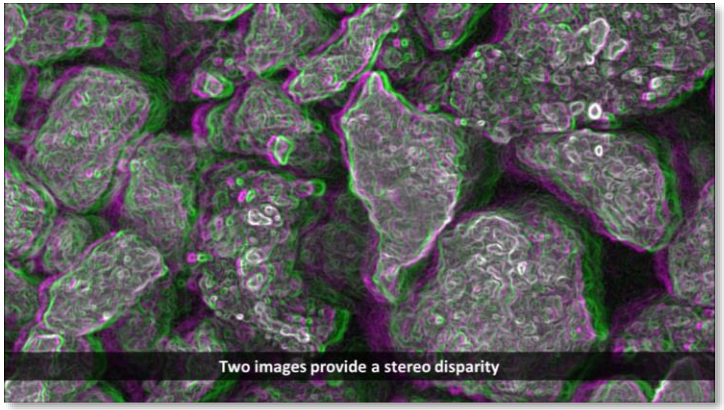
- Computer vision
- Intelligent optics
- Edge computing

Advanced decision making and in-situ processing techniques optimize information collection

Innovations:

- Thermal vision-based navigation for landing on icy and low-contrast surfaces
- Cold-gas projectiles that map in ballistic flight and form monitoring networks once emplaced
- Programmable microscopes that model individual grains of soil in 3D

PER micro-rover in high dynamic range Lunar scene

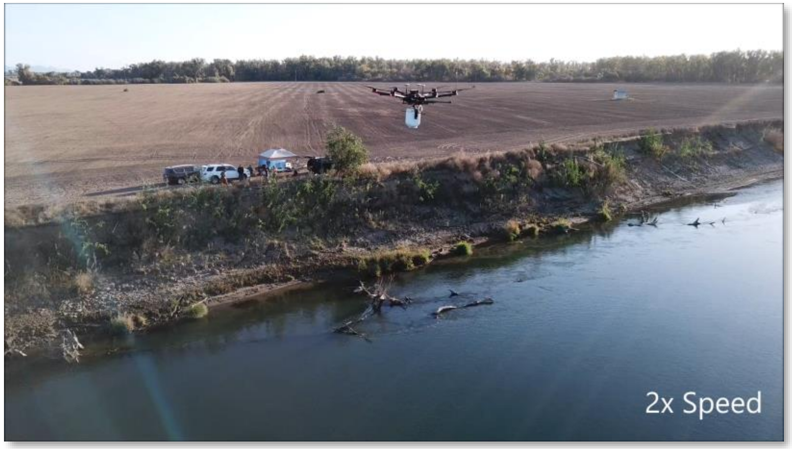


***Video:** 3D microscopic images of regolith grains*

Streamflow: River Observing System (RiOS)

Mapping the flow of rivers from a UAV

- Monitor water resources
- Detect and predict flooding events
- Understand how spills and plumes evolve



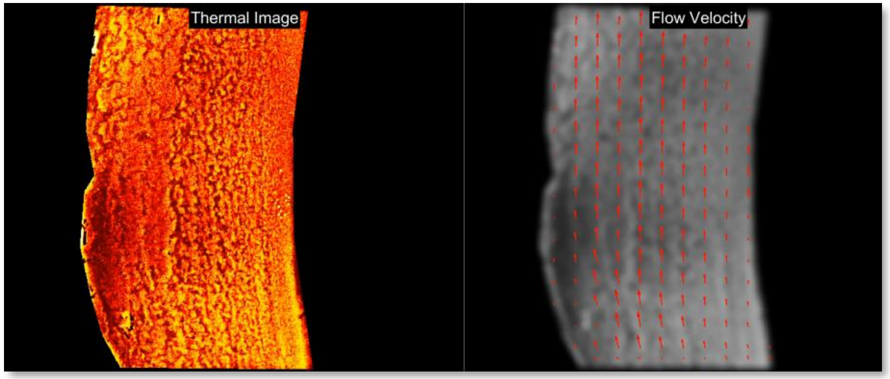
A UAV maps the flow field of the Sacramento River using RiOS

Thermal-visual sensing

- Payload of high-sensitivity thermal cameras, visible light cameras, and egomotion sensing
- Exploit difference in temperature of water surface due to turbulence to track flows

Dense flow maps

- Particle image velocimetry (PIV), a type of optical flow, allows for velocity estimates at each pixel
- Combine with bathymetry (depth) to estimate total flow volume



***Video**: Vector field of flow values generated from water surface*

Planetary Cave and Skylight Exploration

Caves as destinations for exploration on Moon and Mars

- Radiation shielding for human habitation
- Pristine environments to search for signs of life
- Access to deep geology for scientific study
- Skylights are accessible surface entrances to lava tube caves

Skylight Project

- Proposed tech demonstration mission (led by CMU) to visit a skylight on the moon with a commercial micro-rover and peer inside
- IRG leading sensing and map building capability

BRAILLE Project

- Development of rover autonomy for Mars cave exploration and mapping
- Sensor suite includes non-contact spectroscopy payloads for detecting life signs

Skylight project field testing at West Desert Sinkhole, Utah

***Video**: BRAILLE project field testing at Valentine Cave, Lava Beds National Monument, California*

Tensegrity Robotics

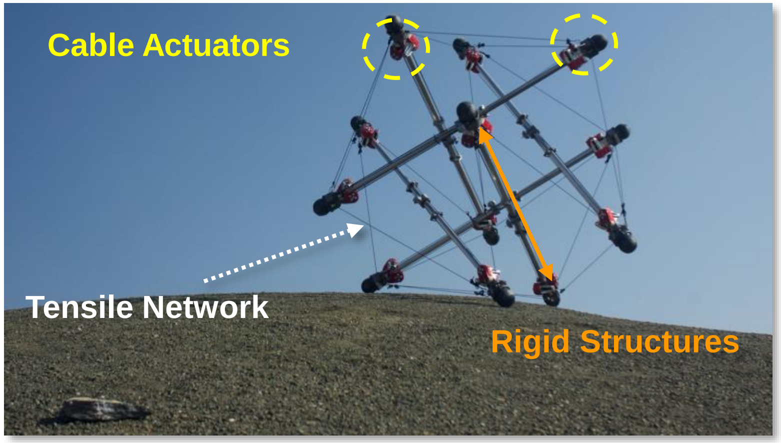
Tensegrities - Robots made of rigid structures held together by a cable network under tension

Many benefits for extreme environment exploration

- High strength-to-weight ratio
- Passive compliance and global force distribution
- No lever arms to magnify forces
- Avoids rigid-rigid connections
- Tunable stiffness (pre-tensioning)

Projects include:

- SUPERball v2 – tensegrity rover
- BREEZE – inflatable flyer for Venus
- Tensegrity landers



SUPERball tensegrity rover with three types of components

***Video**: SUPERball dropping from a tall platform and rolling away.*

Field Testing and Planetary Analogs

30 years experience in field settings

- SUBSEA – Remote presence ocean science
- BASALT – Human EVA sim with distributed science teams
- ARADS – Drilling and search for life in the Atacama desert
- MVP – Rover prospecting in the Mojave
- PLRP – EVA sim with divers, submersibles, real-time remote science
- Devon Island (remote science team & real-time remote rover ops)
- And others: lava tubes, artic islands, river systems and more!

Capabilities

- Robotic hardware, software, and instruments
- Test planning, data collection, monitoring, and operations

Field testing at Hawaii Volcanoes National Park (top), the Neutral Bouyancy Lab at NASA JSC (middle), and the Atacama Desert (bottom)

Work With Us!

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