# Science Autonomy on a Lunar Micro-Rover to Maximize Return

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## 1 What's The Problem?

Many micro-rover missions planned this decade, and they may only last 1 Lunar Day (2 weeks).

Lunar missions can be operated in near real time, but processes are time-consuming as operators must:

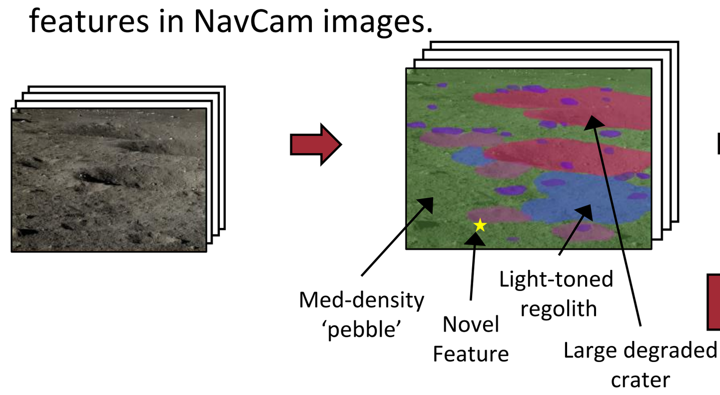
- Receive the most relevant science data in real-time with a constrained downlink capacity
- Analyze images to assess terrain and identify features of interest
- Quickly make decisions on instrument targeting
- Generate safe and power-efficient trajectories for navigation
- Work effectively over a network in remote and distributed teams

In light of these challenges, how can we maximize the scientific return in Lunar missions?

## 2 Technologies for Science Autonomy

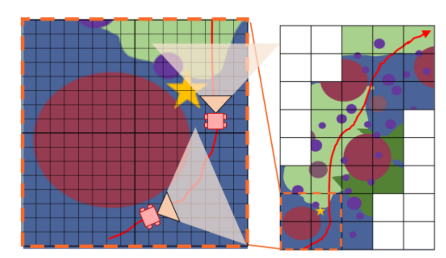
Mission Control is developing a vision-based science autonomy system under a project called the Autonomous Soil Assessment System: Contextualizing Rocks, Anomalies and Terrains in Exploratory Robotic Science (ASAS-CRATERS), with funding from the Canadian Space Agency.

Classify lunar geological features and identify novel features in NavCam images.



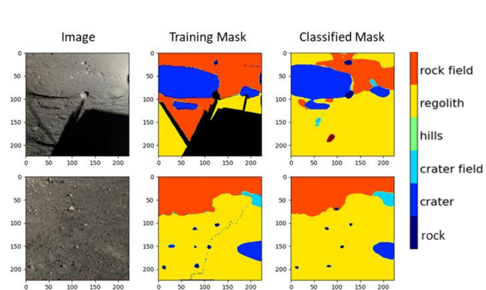

(Human-annotated for illustration)

Project and aggregate outputs on a map to provide context and scale.



Use cases:
- Ground segment operations support
- Autonomous instrument targeting

Completed early prototyping to test deep-learning models on the Chang'E dataset.

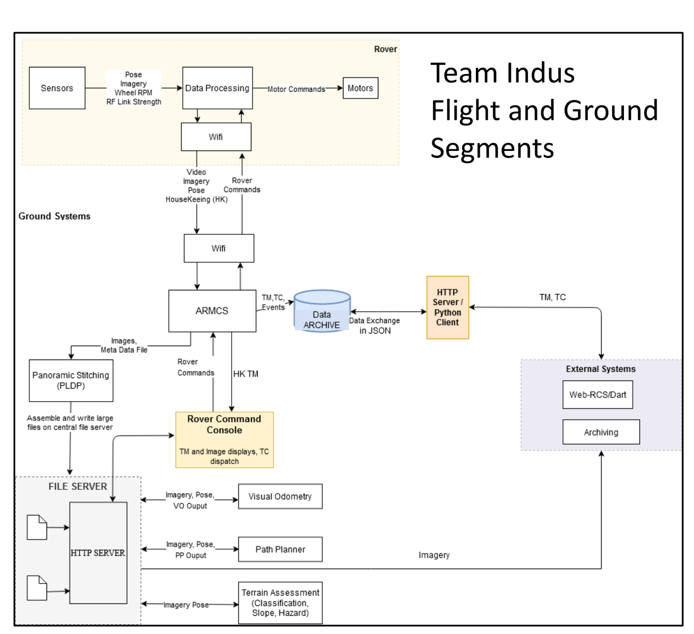



Integrated on compact and high-performance COTS processor with flight heritage. (Xiphos Q8S or Q7S).

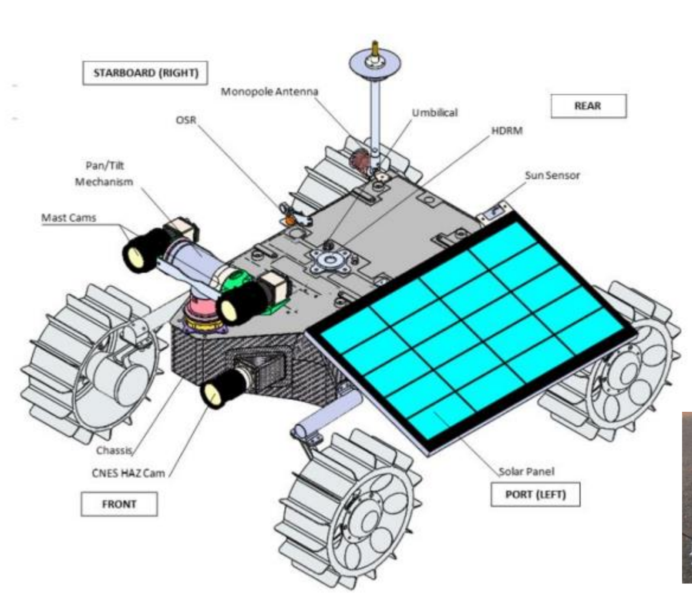
Preliminary radiation analysis complete.

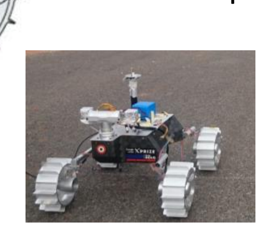
### Ek Chotti si Asha (ECA) micro-rover by Team Indus

- 4 Wheel – Independent Drive
- 1 DoF Rocker-Arm suspension + Fixed Link
- < 0.5m size scale
- Stereo VO + IMU + Sun Sensor
- 2.405 GHz ISM Band – IEEE 802.15.4 Radio
- Monopole Antenna
- 4s2p – 14.8V – 2.48 Ah LiPo Battery
- 10s2p Solar Panel
- Dual Core ARM A9 SOC
- 6 PRT + 8 Thermistors for Passive Thermal Control
- 20-65 Mbps surface link with WiFi (rover-lander)
- 2Mbps Lander-Earth link



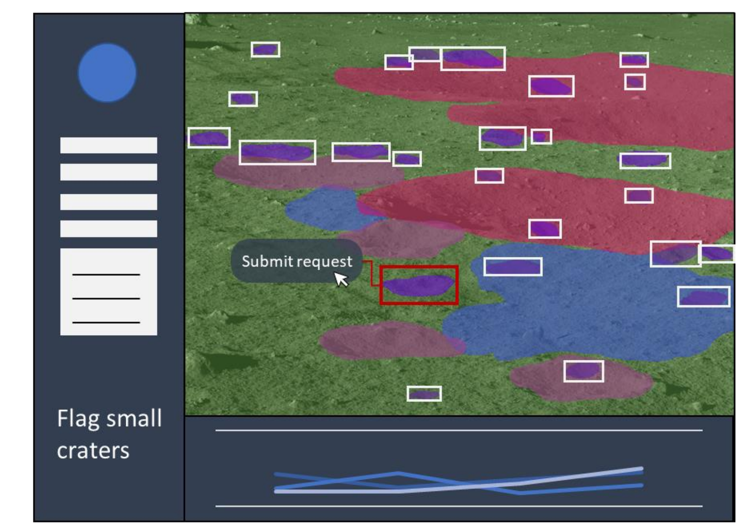

Baseline ConOps uses a tactical cycle every 2m
- Localize with Visual Odometry on ground
- Science team updates plan
- Navigation team assesses feasibility
- Decision is made on plan
- Uplink path command





## 3 Science Operations Support in the Ground Segment

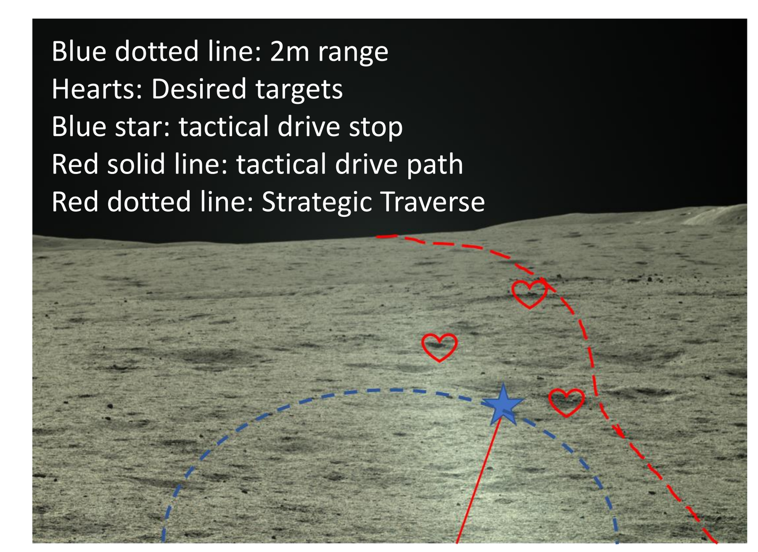
Benefits of automated feature classification in science backroom operations:
- Pre-annotated images can save a lot of time
  - Very little time to make a request to stop and target instruments when rover is driving
- Create objects from classified feature
- Pass object to other consoles in operations team, e.g. to submit a targeting request
- Add objects to a database, this enables:
  - Intelligent feature-based query during real-time mission operations
  - Rapid statistical analysis in real-time (e.g. crater counting, Size Frequency Distribution)
- Add other measurements, data products, metadata to object model




Mock UI: Target selection using classifier outputs

With Team Indus, we're also developing a decision-making framework to make sure our tactical cycle strategy can meet the needs of the science team in an efficient and safe manner. This framework should balance several things such as:
- Newly discovered targets
- Deviation from mission plan
- Path cost (time, rover energy)
- Data storage/link budget

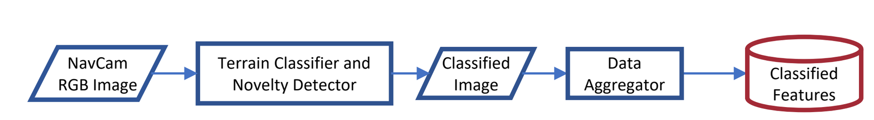
To speed up decision-making, we can partially automate surface characterization to create data products for science and navigation.



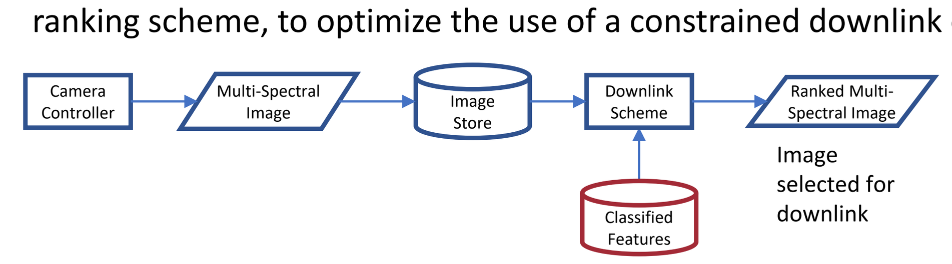

Mock UI: Planning path to visit targets of interest

## 4 Enabling Autonomous and Intelligent Instrument Operations

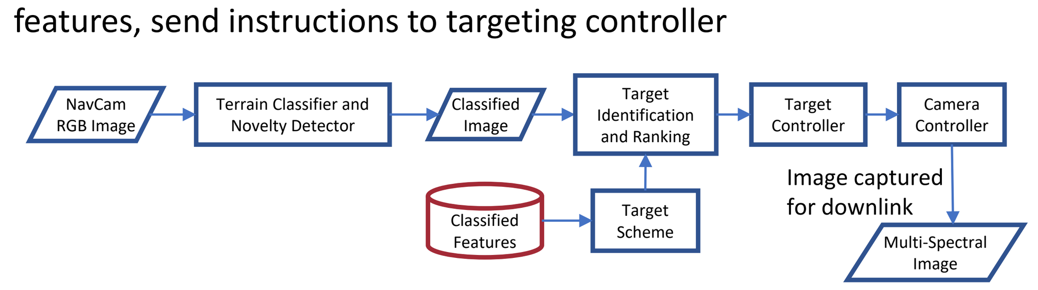
**Generating database of geological features**
Continuously classify features in rover camera imagery, and collect in a database to reference for Continuous Measurement and Targeted Measurement scenarios below




**Continuous Instrument Measurements**
Rank science instrument data for real-time downlink based on classified features and ranking scheme, to optimize the use of a constrained downlink capacity.




**Targeted Instrument Measurements**
Classify features, identify and rank targets, based on scheme and previously classified features, send instructions to targeting controller



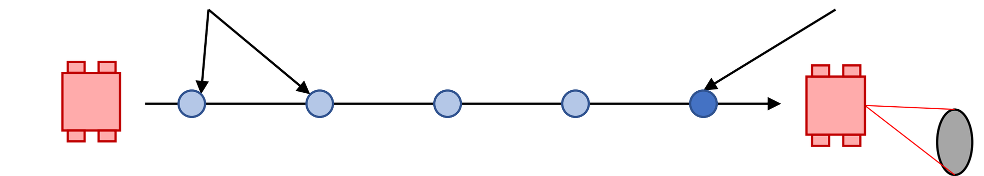

## 5 Lunar Rover Operations Scenarios

The ways the autonomy-enabling technologies benefit operations will depend on the scenarios of how a rover and science instruments are used.

**Transit Scenario**
Continuous navigation to areas of interest without science stops. Tactical cycle every 2m to localize and plan paths.

**Panoramic Scenario**
Long stop:
- High-resolution panorama
- Evaluation and targeting

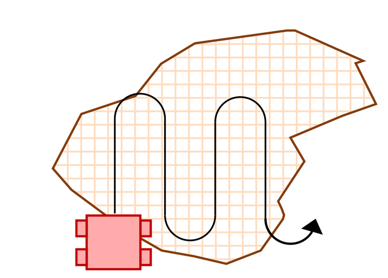
No long stop for **Transit Scenario**



Key Benefits:
By speeding up terrain assessment, the science team can make faster tactical decisions, and more reliably identify novel or high-value features for investigation.

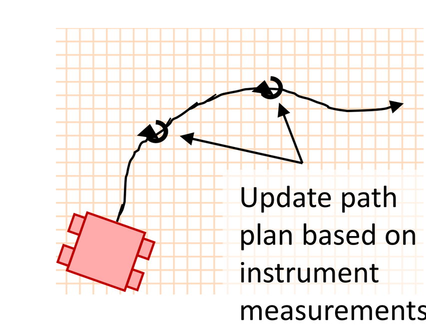
**Investigation Scenario**
Investigate high-value feature of interest. May require multiple rover maneuvers to acquire data from different perspectives.

**Mapping Scenario**
Map an area of interest, as identified from rover or orbital data, with science instrument measurements.



Key Benefits:
Instrument data can rapidly be mapped and assessed in the context of terrain features.

**Prospecting Scenario**
Feedback loop to prospect for key instrument measurements
- Continuous measurements as rover drives
- Use hypotheses and measurements for navigation and instrument targeting

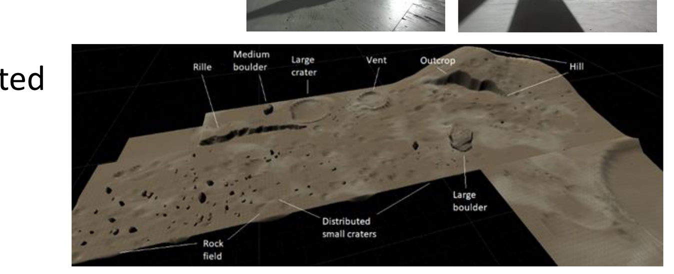



Key Benefits:
Analyzing instrument features in the context of terrain types and features can help inform navigation decisions for prospecting

## 6 Analogue Testing

We will test this system in Summer 2021, at an indoor Lunar analogue facility
- ECA rover
- 3 analogue environments
- 1 week of missions in each analogue
- Each mission is defined by a different architecture, varying how technologies are used in ground and flight segments with varying Level of Autonomy

We will define science goals and objectives and make a traverse plan to achieve objectives using the operations scenarios. We will evaluate how the technologies in each architecture and mission test impacts the mission performance, with key metrics like:
- Traverse time and energy
- Surface hazards encountered/avoided
- Achieving science objectives
- Time spent making decisions
  New features discovered and investigated



20x30m indoor Lunar analogue test facility under construction at Mission Control

We look forward to publishing our results next year!

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