
# Virtual Research Presentation Conference

## MAARS - Machine Learning-based Analytics for Automated Rover Systems

**Principal Investigator: Hiro Ono (347)**
**Co-Is: Deegan Atha, Flynn Chen, Shreyansh Daftry, Annie Didier, Shoya Higa, Olivier Lamarre, Kyon Otsu, Mike Paton, Sami Sahnoune, Bhavin Shah, Adam Stambouli, R. Michael Swan**
**Program: Strategic**

Jet Propulsion Laboratory
California Institute of Technology

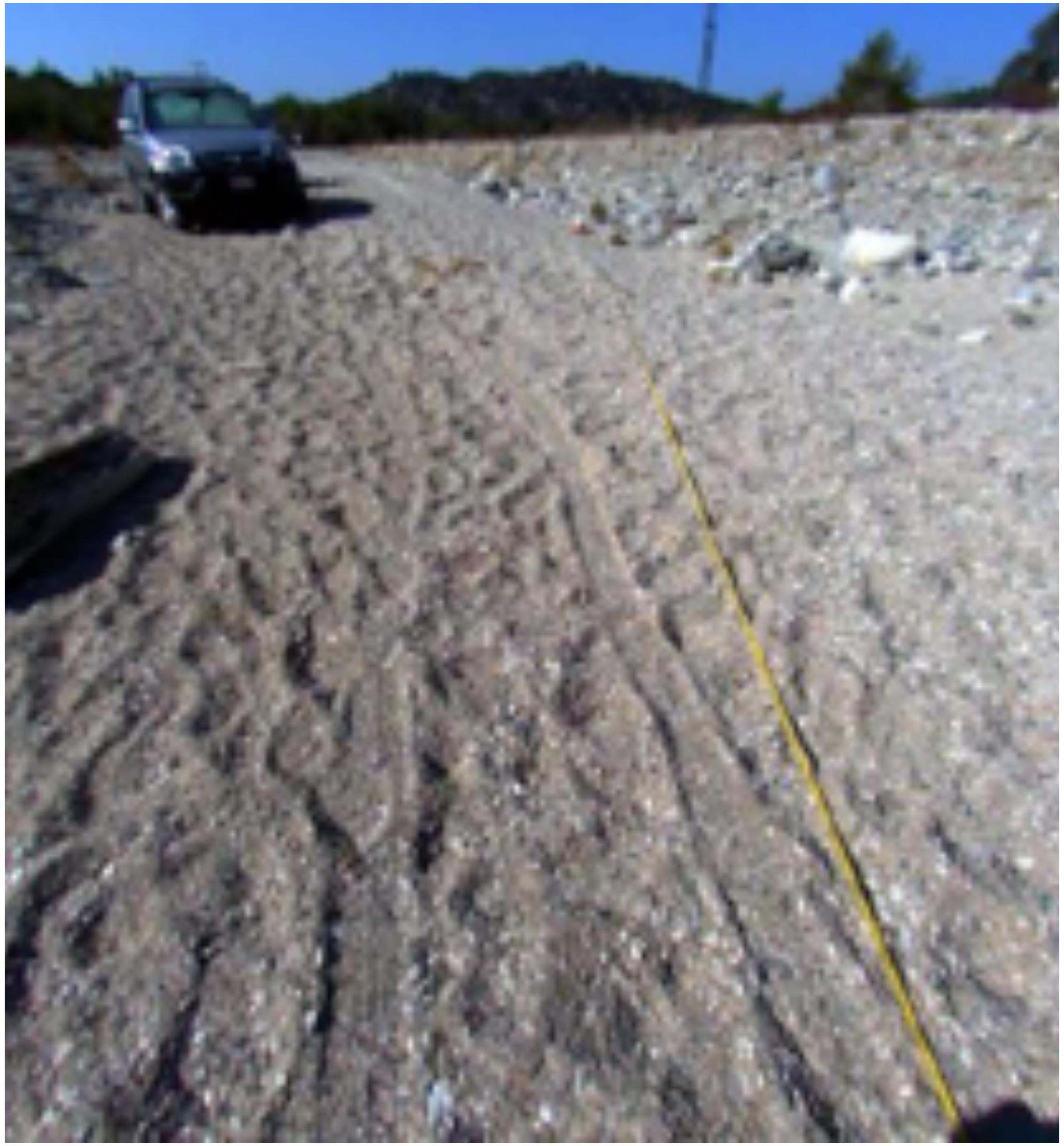
Assigned Presentation # 10

# MAARS: Task Overview

- FY18-20 Strategic R&TD (6x/4x)
- Task Goals
  - Develop i) drive-by-science and ii) risk/resource-aware path planning capabilities - Delivered
  - Deploy/benchmark on HPSC emulator/analog processor - Delivered
  - Field test/demo with Athena Rover - Delivered
- Particular emphasis on on-board deployment of deep learning

Athena Rover and a quadruped life form commonly seen in Arroyo Seco

# MAARS Final Demo, FY21



## Demonstrated Capabilities

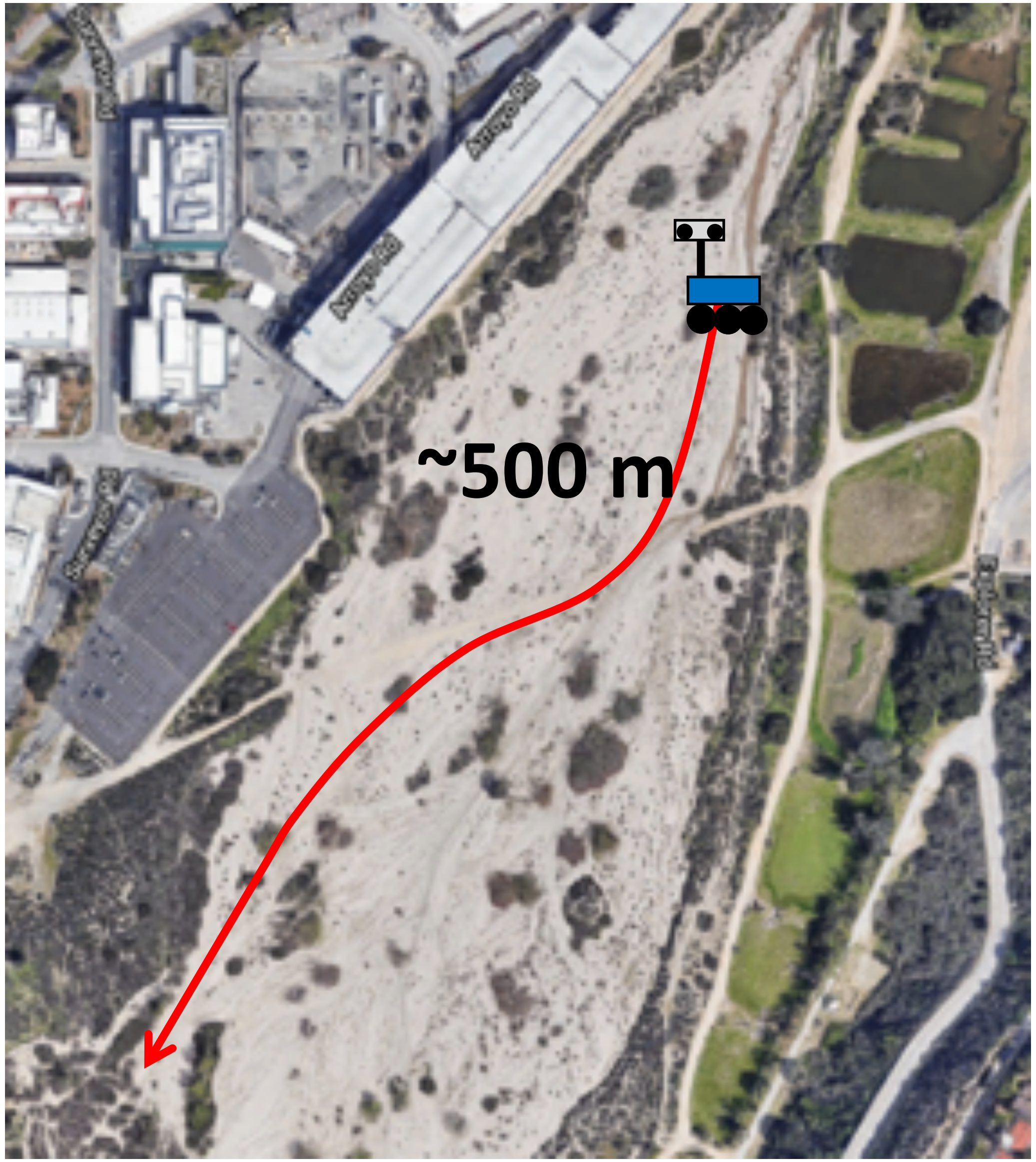
- Autonomous driving over ~500 m
- Terrain-aware navigation
- Onboard resource-aware strategic planning
- Drive-by science
- Real-time execution on HPSC-analog processors

## Above capabilities are enabled by:

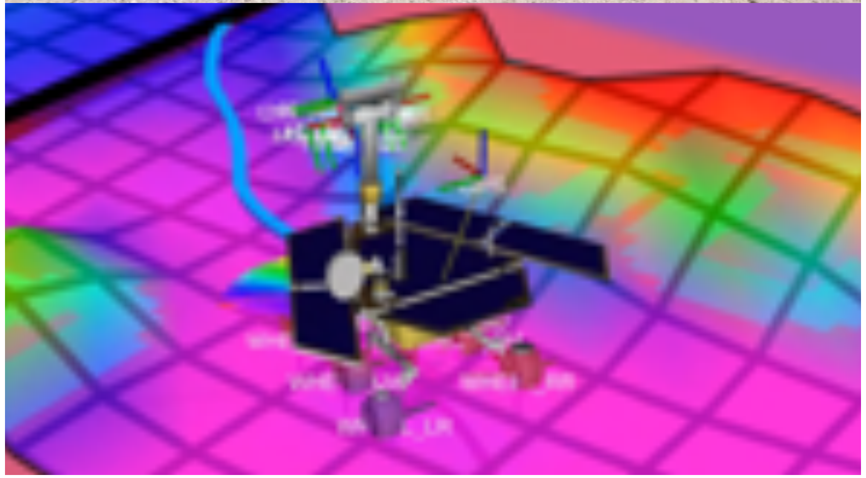
| | |
|---|---|
| Terrain Classifier<br>SPOC | Resource-aware planning<br>RAND |
| Image Captioning<br>SCOTI | UHURA |
| Image Understanding<br>SULU | Traversability Evaluation<br>VEEGER |

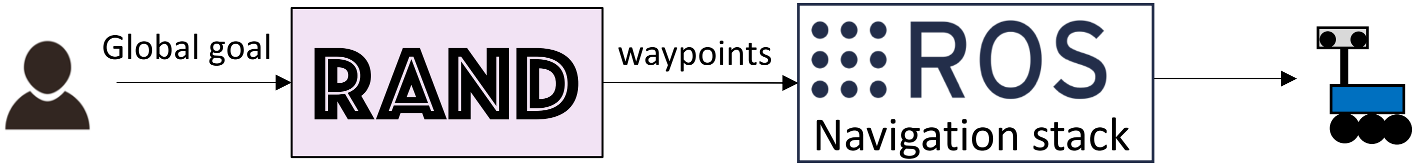
Capability 1

# Autonomous Driving over ~500m



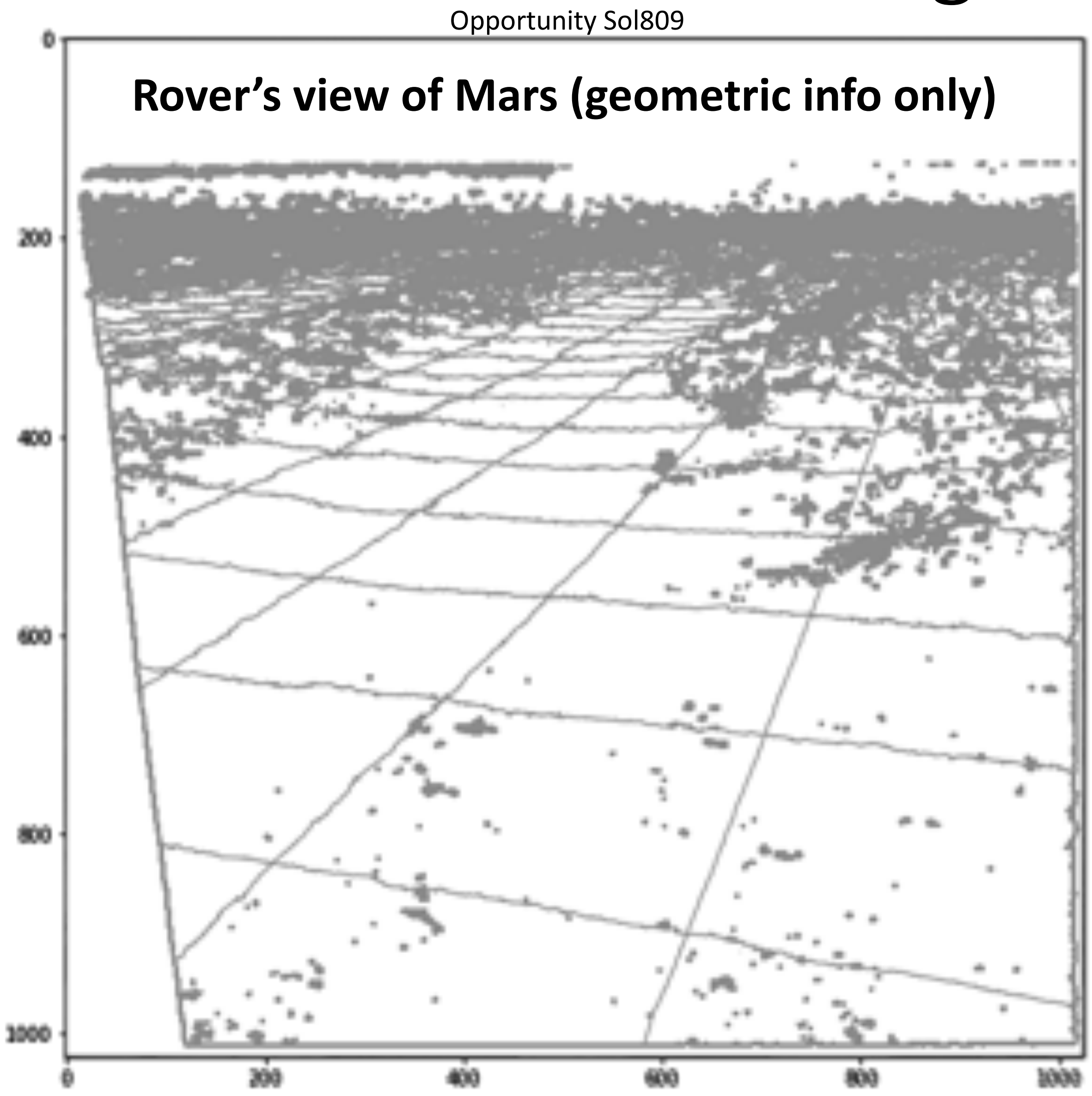

Work by Mike Paton, Kyon Otsu, and Olivier Lamarre





Capability 2

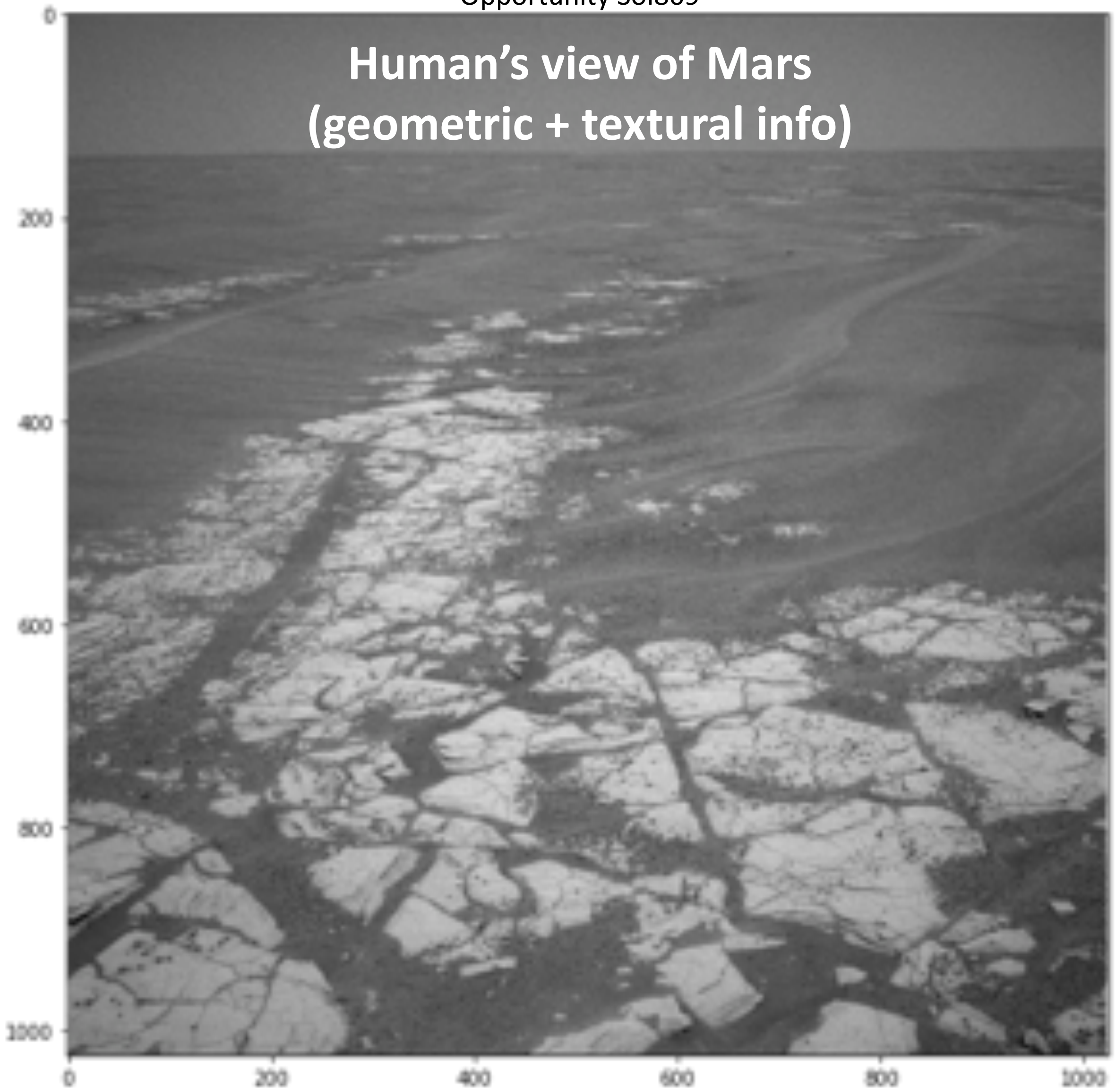
# Terrain-aware navigation



Capability 2

# Terrain-aware navigation

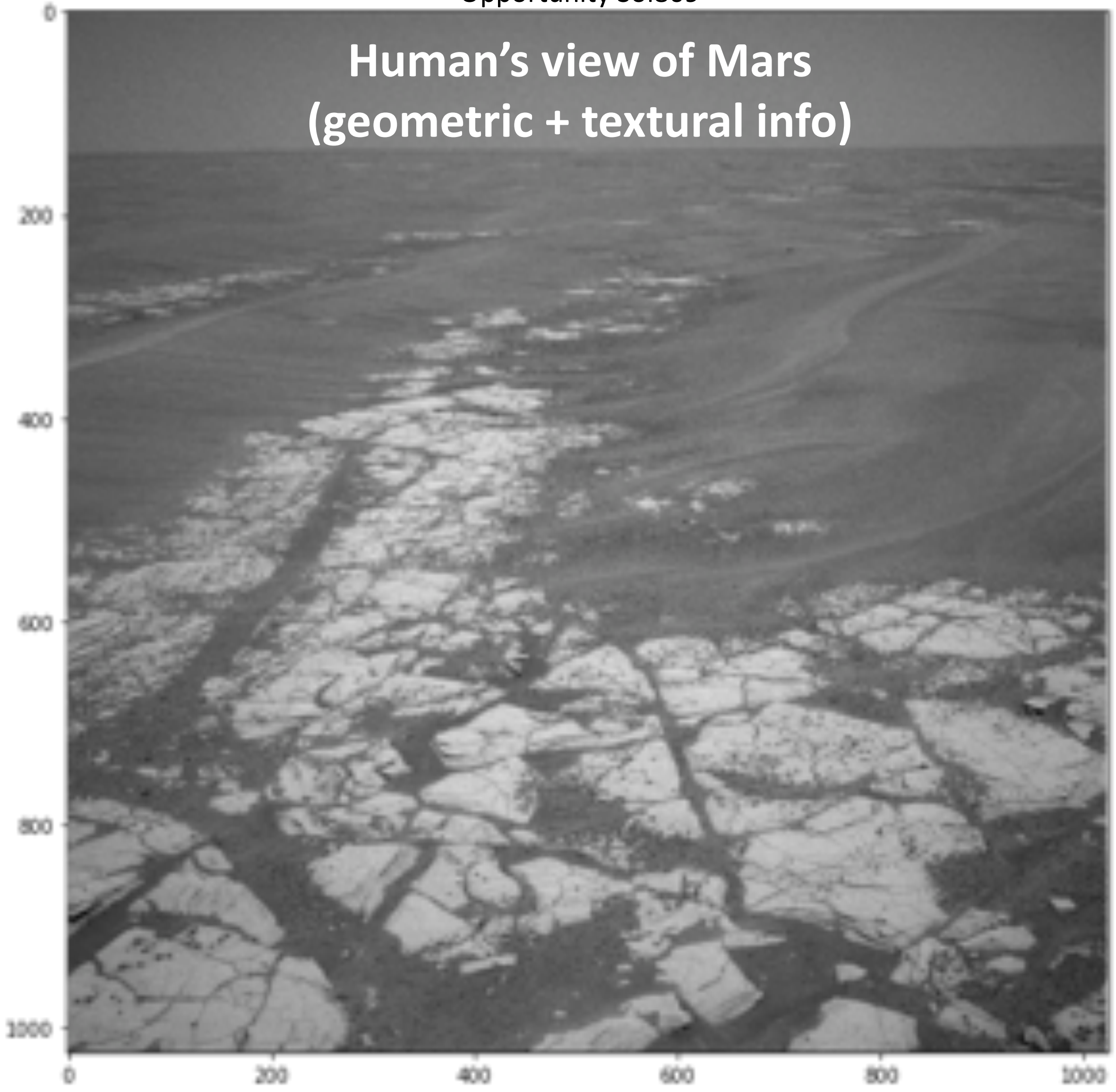
Opportunity Sol809



Capability 2

# Terrain-aware navigation

Opportunity Sol809

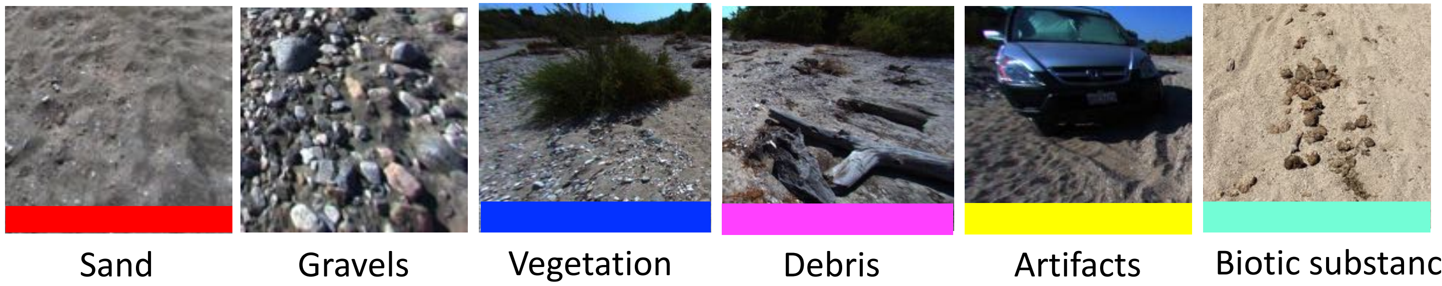


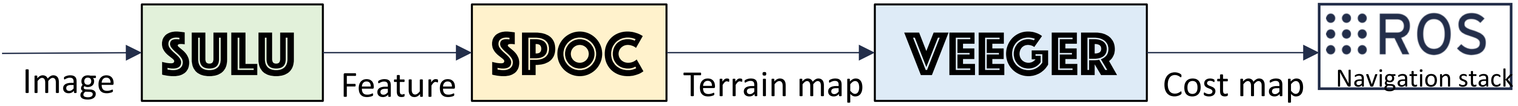

## Terrain type informs:

- Mobility risks (e.g., sand traps)
- Slip, sinkage
- Driving energy
- Localization accuracy (with visual odometry)

Capability 2

# Terrain-aware navigation

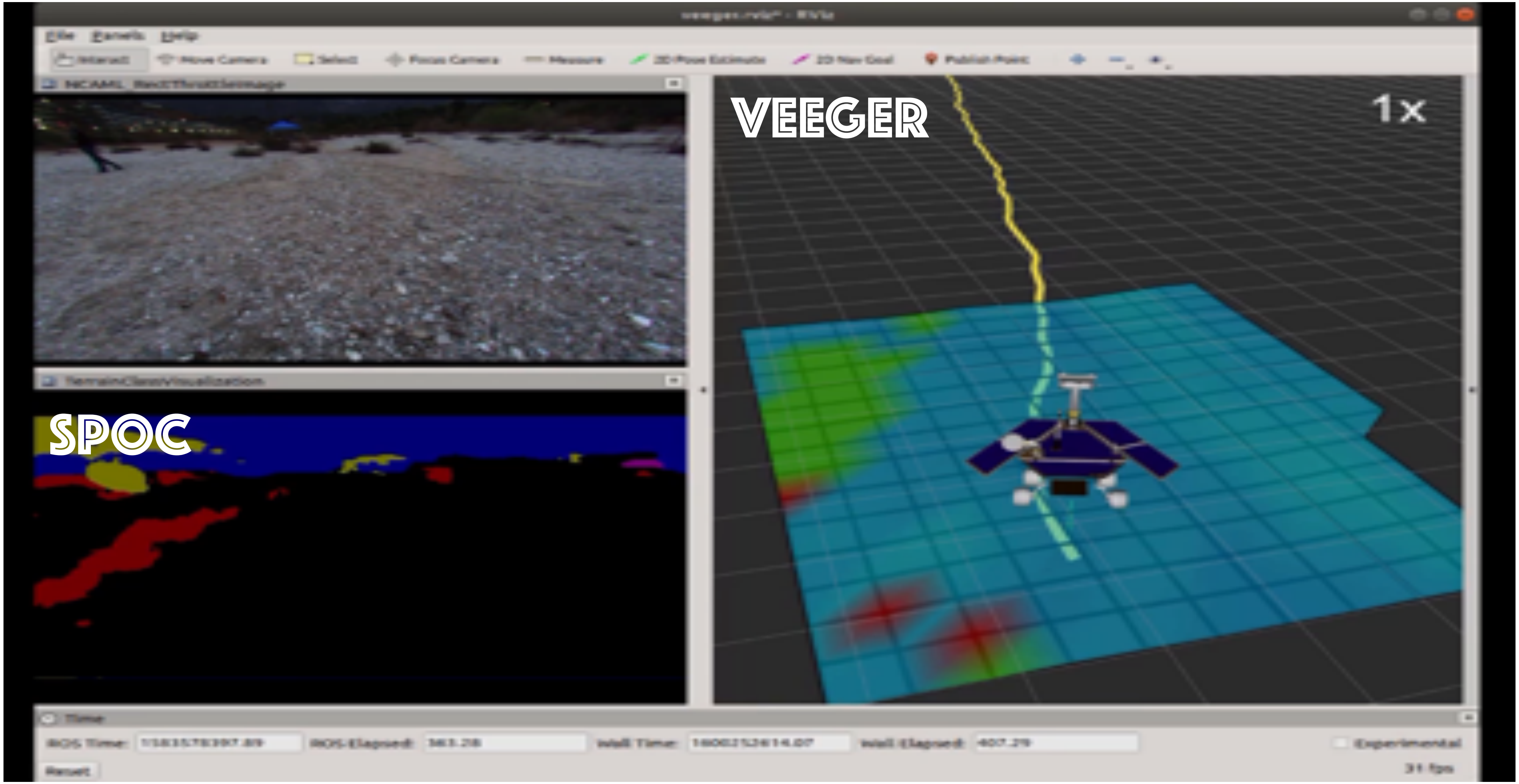



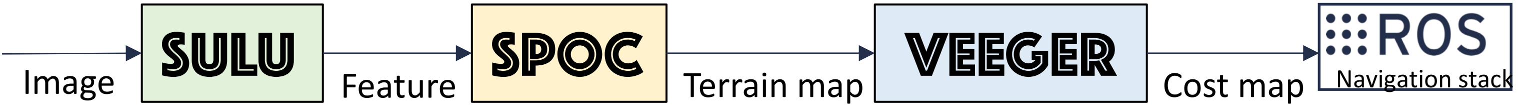




Work by Deegan Atha, Shreyansh Daftry, R. Michael Swan, Shoya Higa, Flynn Chen, Yumi Iwashita

Capability 2

# Terrain-aware navigation

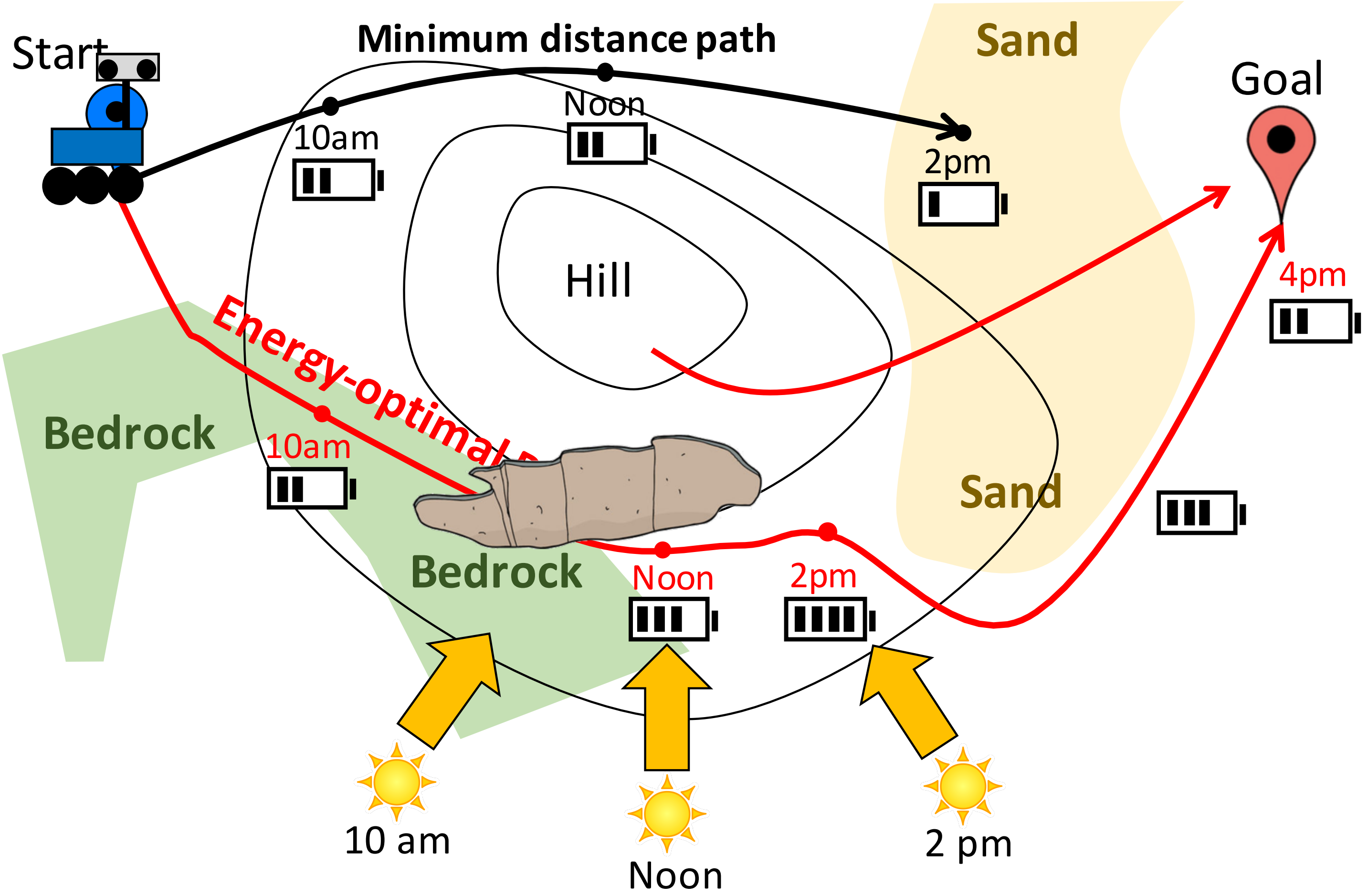


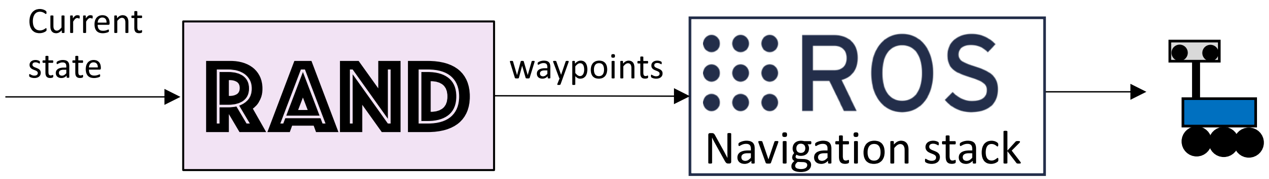




Work by Deegan Atha, Shreyansh Daftry, R. Michael Swan, Shoya Higa, Flynn Chen, Yumi Iwashita

Capability 3

# Onboard resource-aware strategic planning

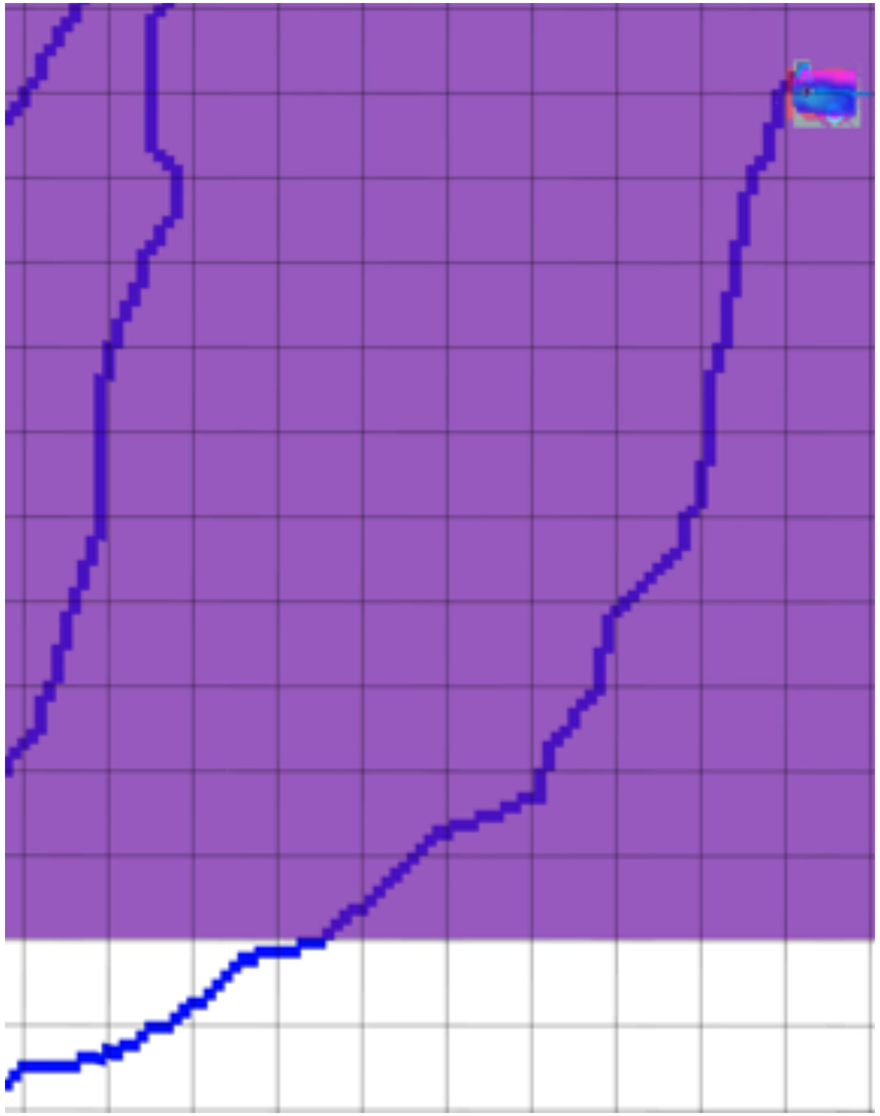


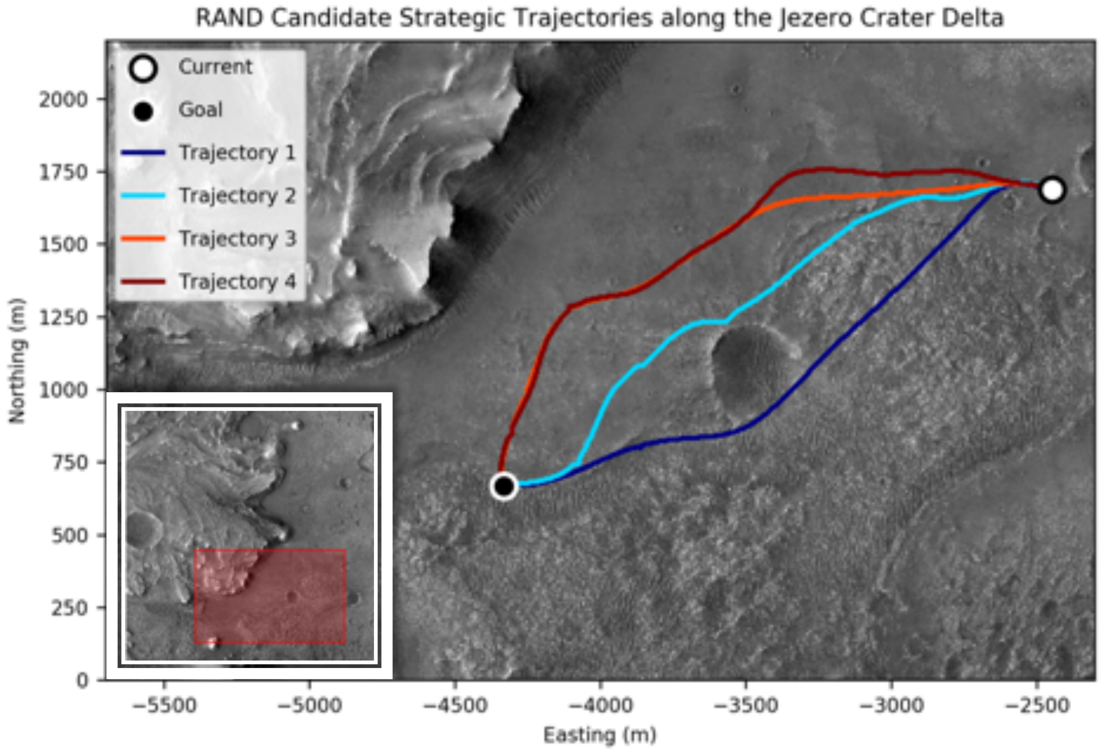

Work by Olivier Lamarre, Kyon Otsu, Mike Paton, Shun Nomura, Yuiko Kikuchi

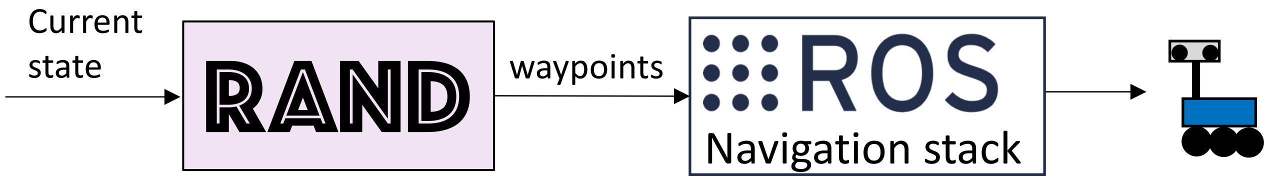
Capability 3

# Onboard resource-aware strategic planning



- Allows quick, strategic-level replanning without full-fledged on-board strategic path planning.
- Plans depend on space and time, with an awareness on energy levels:




Work by Olivier Lamarre, Kyon Otsu, Mike Paton, Shun Nomura, Yuiko Kikuchi

Capability 4

# Drive-by Science

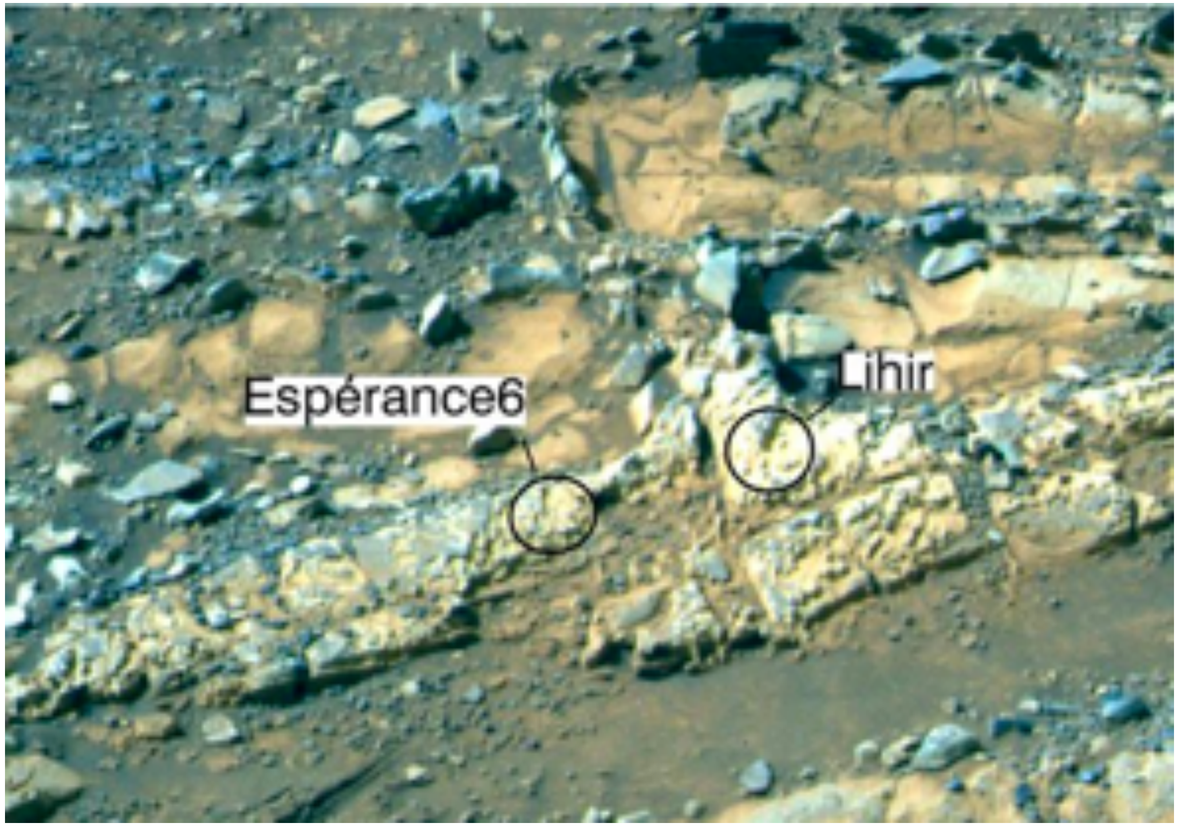
## UGMP

Unnoticed Green Monster Problem

Capability 4

# Drive-by Science

Serendipitous discoveries that might have been an “unnoticed green monster”




Evidence of neutral water (boxwork features) in Matijevic Hill (Opportunity Sol 3100 – 3143)[1]

Iron Meteorite “Lebanon” (Curiosity Sol 640)

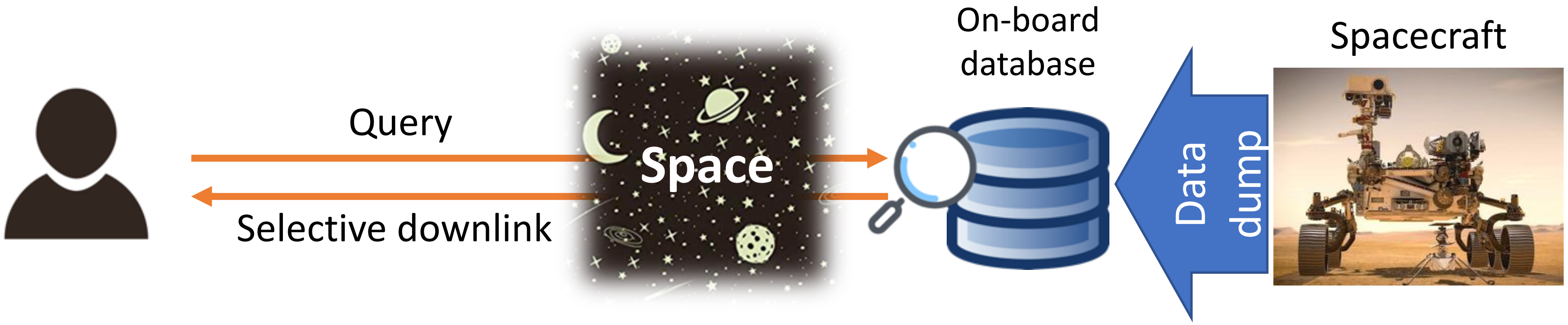
[1] R. Arvidson et al., Ancient Aqueous Environments at Endeavour Crater, Mars *Science* **343** (6169), 2014

Capability 4

# Drive-by Science

## Current paradigm

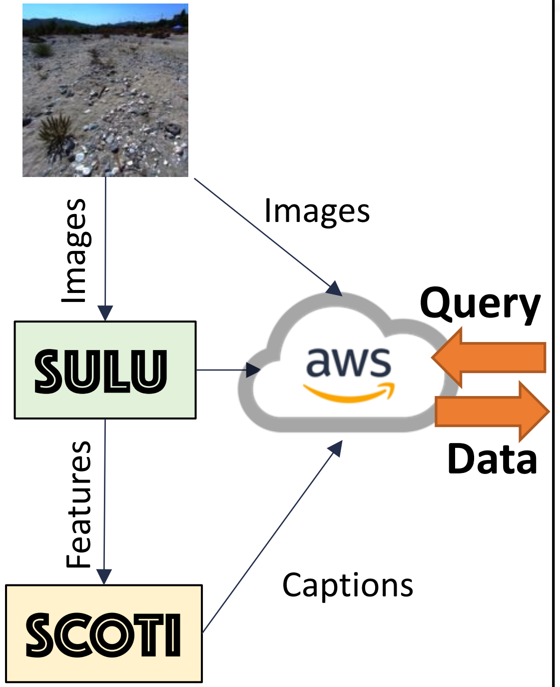

## Drive-by Science ("Interplanetary *Google* Search")

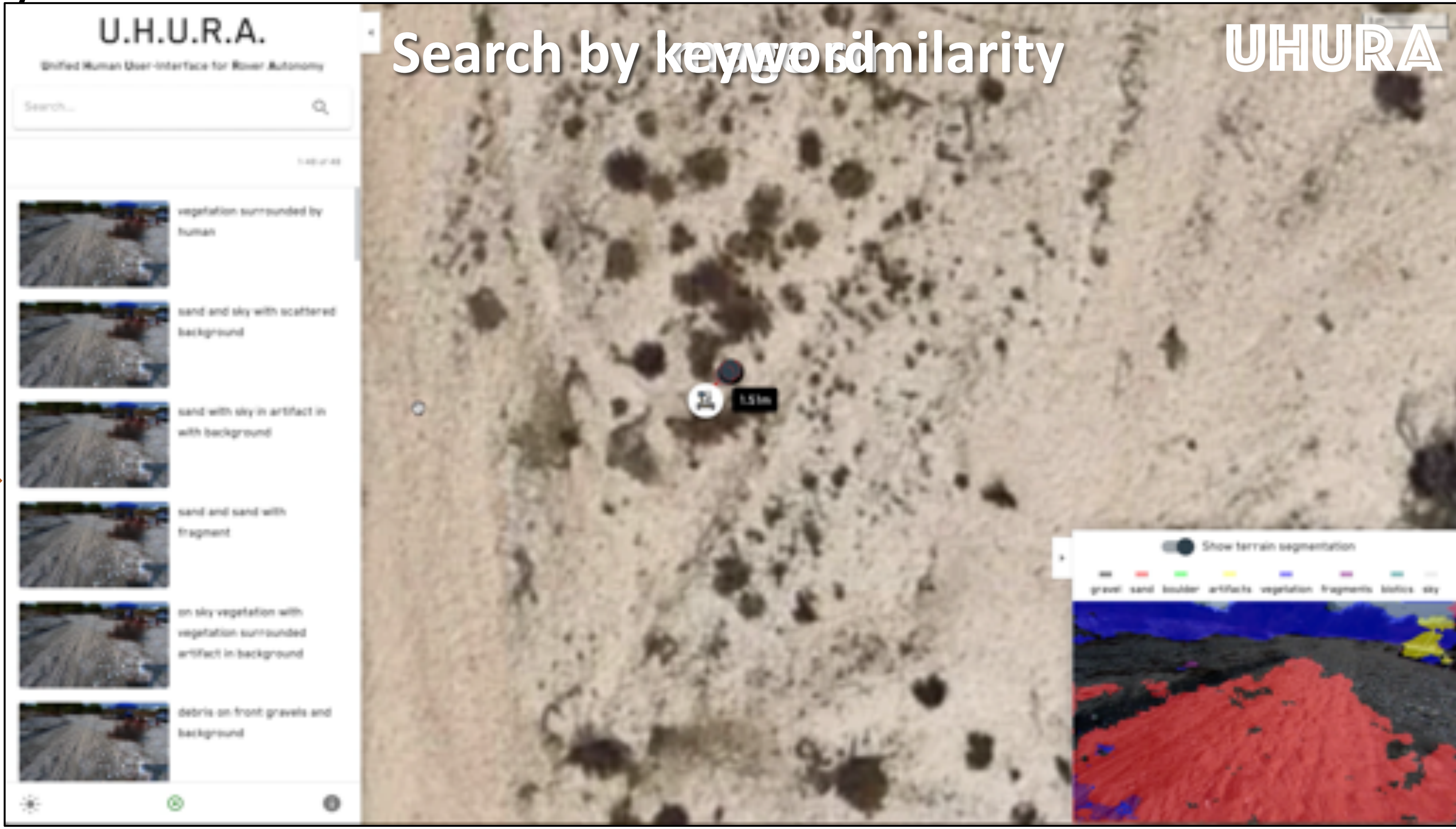


Capability 4

# Drive-by Science

## Arroyo Demo



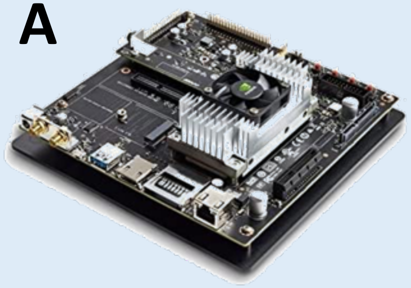

**SCOTI**: Annie Didier, Brandon Rothrock, Vivian Sun, Tanvir Islam, David Qiu, Virisha Timmaraju, Bhavin Shah
**UHURA**: Sami Sahnoune, Adam Stambouli, George Fosmire

Capability 5

# Real-time execution on HPSC-analog processors

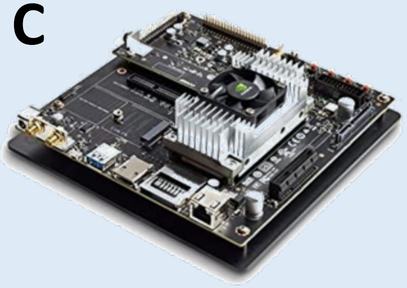
**Jetson TX2 x2**

**A**



**Navigation stack, RAND**

**C**



**SPOC, SCOTI, SULU, VeeGer**

Athena has comparable processing power as HPSC (high performance spacecraft computing)

| | CPU | Co-processors |
|---|---|---|
| HPSC | ARMv8 (A53) x 8 | Optional |
| Qualcomm Snapdragon 855 | ARMv8.2-A (A55, A76) x 8 | GPU (768 cores)<br>DSP (Hexagon 690) |
| Jetson TX2 | ARMv8-A (A57) x 4<br>Denver 2 x 2 | GPU (256 cores) |

Approx. 100% CPU usage with:

| | TX2 | Frequency | Use GPU? |
|---|---|---|---|
| Navigation (localization) | A | 6 Hz | Y |
| Navigation (stereo, mapping, path planning) | A | 1 Hz | |
| SPOC/SULU | C | 2 Hz | Y |
| SCOTI | C | 0.5 Hz | |
| VeeGer | C | 1 Hz | |
| RAND Executive | A | On demand | |
| UHURA downlink | C | 0.2 Hz | |

# Publications

**Journal + Conference**

- Vision-Based Estimation of Driving Energy for Planetary Rovers Using Deep Learning and Terramechanics. S. Higa, Y. Iwashita, K. Otsu, M. Ono, O. Lamarre, A. Didier, and M. Hoffmann. *IEEE Robotics and Automation Letters* Vol 4, Issue 4. Also in *IROS 2019*.

**Journal**

- SCOTI: Science Captioning of Terrain Images for data prioritization and local image search. D. Qiu, B. Rothrock, T. Islam, A. Didier, V. Sun, C. Mattmann, M. Ono. *Planetary and Space Science*. 2020.

**Book Chapter**

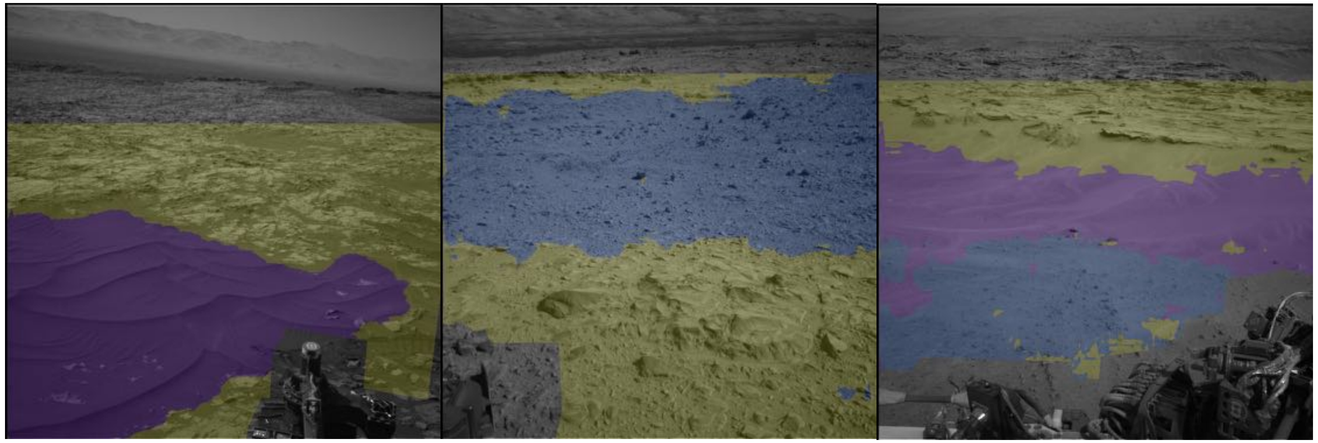
- Machine Learning for Mars Rover Operations. M. Ono, B. Rothrock, Y. Iwashita, V. Timmaraju, S. Sahnoune, D. Qiu, T. Islam, A. Didier, C. Laporte, D. Atha, V. Sun, K. Stack, and C. Mattman. Aye, K. M., D'Amore, M., Helbert, J., & Kerner, H. R. (Eds.). (2021). Machine Learning for Planetary Science (1st ed.). Elsevier.

**Conference**

- Make Planetary Images Searchable: Content-Based Search for PDS and On-Board Datasets. M. Ono, B. Rothrock, C. Mattmann, T. Islam, A. Didier, V. Sun, D. Qiu, P. Ramirez, K. Grimes, G. Hedrick. *LPSC* 2019
- MAARS: Machine learning-based Analytics for Automated Rover Systems. M. Ono et al. *IEEE Aerospace* 2020.

# SPOC

Soil Property and Object Classification



Soil Bedrock Sand

**Overall accuracy: 91.3%**

| | | **Predicted Class** | | | |
|---|---|---|---|---|---|
| | | **Soil** | **Bedrock** | **Sand** | **Big Rock** |
| **Actual Class (%)** | **Soil** | **91.06** | 5.95 | 2.94 | 0.05 |
| | **Bedrock** | 0.22 | **97.61** | 1.96 | 0.20 |
| | **Sand** | 0.67 | 12.52 | **86.62** | 0.19 |
| | **Big Rock** | 6.44 | 77.54 | 2.69 | **13.33** |

- Trained by ~100K citizen science labels on MSL NAVCAM (from AI4Mars)
- Validation score by ~1K labels from JPL experts (RPs, MSL scientists)
- Label collection was partially supported by 6x Mobility Study Funding

- Infused to MSL Ground Ops
- Winner, JPL Software of the Year Award (2020)
- Honorable Mention in NASA SOYA

Work by Deegan Atha, R. Michael Swan, Brandon Rothrock, Ryan Kennedy, Jeremie Papon, Henry Leopold, Hiro Ono


Current and Past MAARSians
MAARS
Machine learning-based Analytics for Automated Rover Systems
2017-2020
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Deegan Atha
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Travis Brown
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Flynn Chen
347-Intern
Cindy Chiu
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Larkin Folsom
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George Fosmire
347-Intern
Sourish Ghosh
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Gabrielle Hedrick
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Jerry Hong
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Tanvir Islam
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Sami Sahnoune
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Katie Stack
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Adam Stambouli
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Sean Suehr
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Vivian Sun
347 Intern
R. Michael Swan
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Virisha Timmaraju
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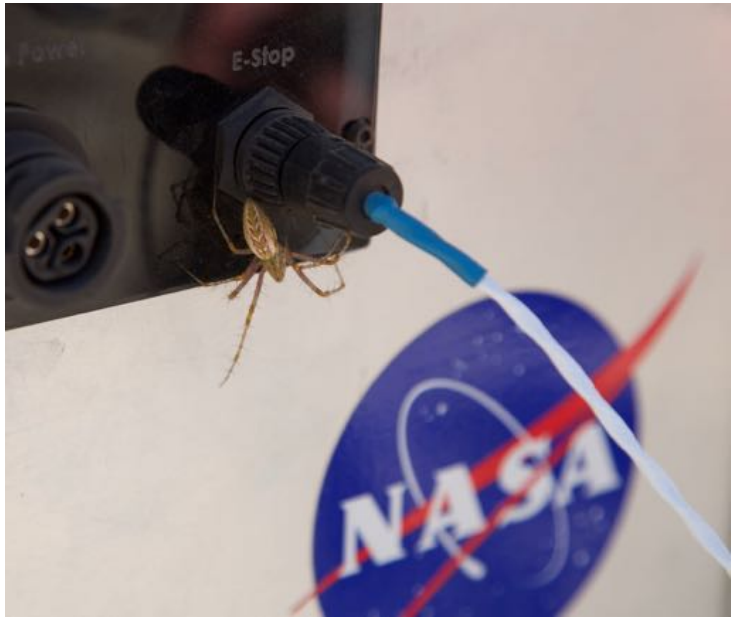
Athena

# Behind the scenes…

Civilization’s oldest and newest modes of transportation




An incy wincy hitchhiker

Field work with social distance

Athena needs a rest…

So do humans

Driving under the orange sky