



Pathogen: Using Campaign Intent To Guide Onboard Planning for a Self-Reliant Rover

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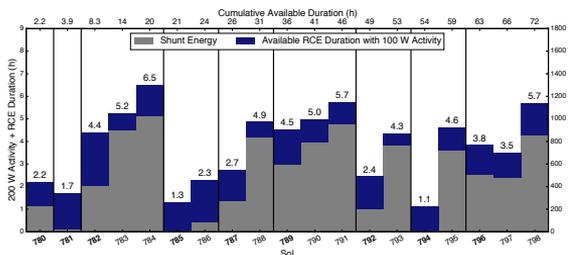
Outline

- Introduction
 - Self-Reliant Rovers
 - Campaign Intent
- Problem Definition
- Pathogen: Using Campaign Intent to Guide Planning
- Evaluations
 - Onboard Planning Evaluation
 - System Evaluation: Mars Yard Walkabout Campaign
- Video

Introduction

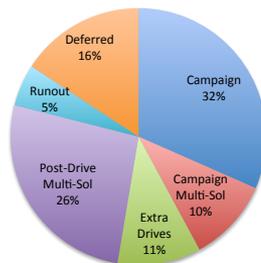
Motivation – MSL Case Study

- Large percentage of sols not making significant contributions to campaign
 - 48% low productivity sols
- Significant amount of unused vehicle resources



Pahrup Hills Estimate of Extra Available Duration

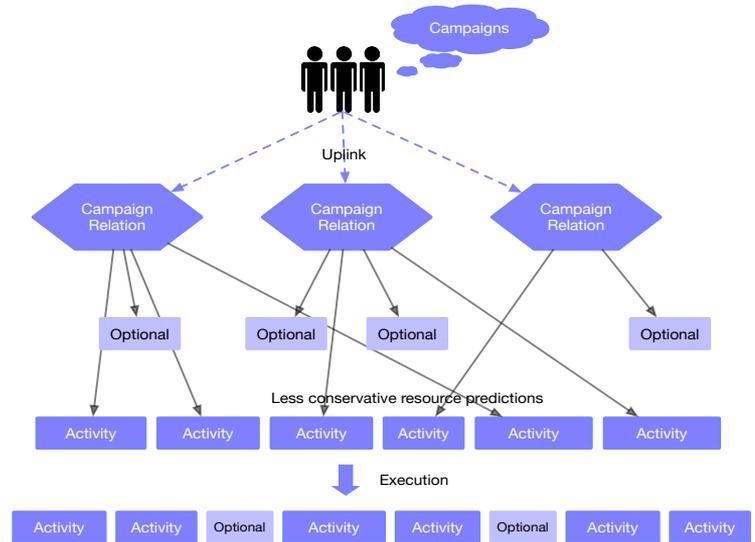
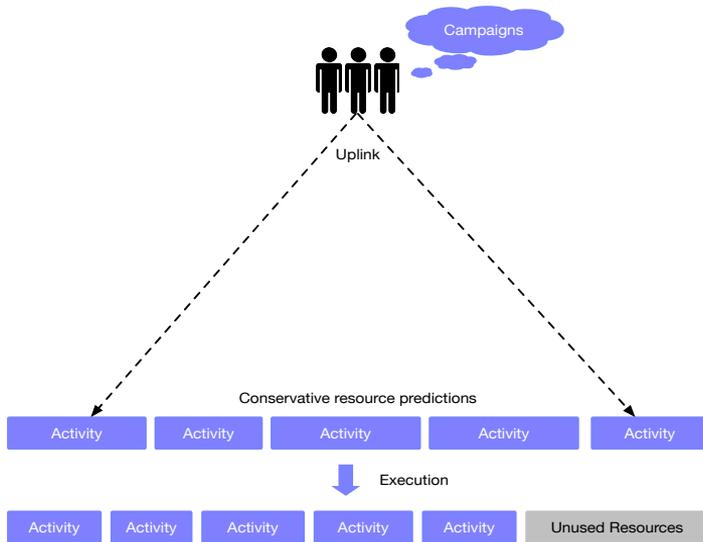
Pahrup Hills



- Opportunity exists to increase productivity
 - Sols within campaign not providing significant contribution to objectives
 - Unused vehicle resources
- Significant challenges to overcome
 - Predicting available vehicle resources
 - Can unnecessarily limit activity
 - Ground-in-the-loop requirements for target selection and effective drive planning
 - Ground unable to productively fill “restricted” sols following drives
 - Ground-in-the-loop requirements to respond to outcome of activity
 - E.g. drive faults

Introduction

Self-Reliant Rovers Approach



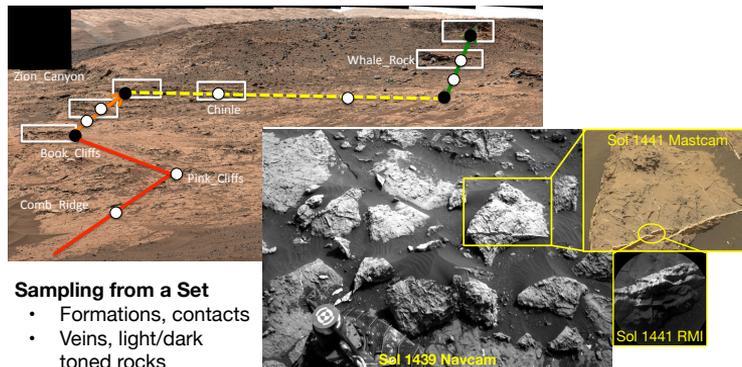
Current operations

- Detailed planning on the ground
- Conservative resource allocations to avoid over-subscription
- No onboard knowledge of relationships among activities
- Results in unused vehicle resources

SRR approach

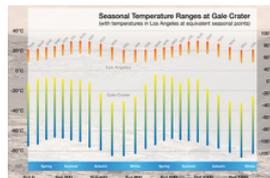
- Onboard planning, resource management
- Less conservative modeling, over-subscribe vehicle
- Campaign intent expresses relations among activities
- Results in increased resource use

Campaign Intent



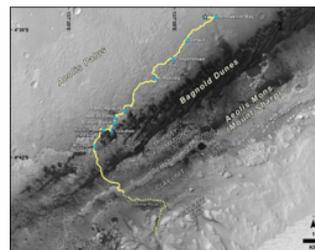
Sampling from a Set

- Formations, contacts
- Veins, light/dark toned rocks
- Textures, layers



Temporally-Periodic Sampling

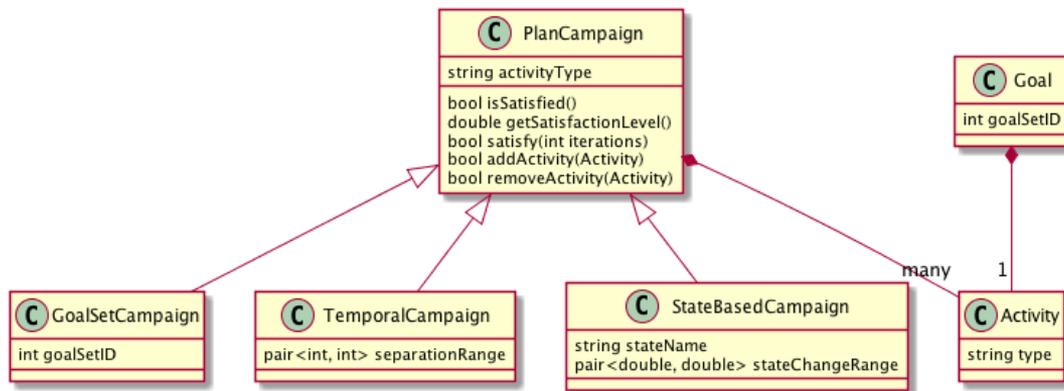
- Across diurnal cycle
- Over seasons
- Periodic vehicle maintenance



State-Based Sampling

- Drilling at varying elevations
- Surveys over rover traverse

Expressing Campaign Intent



- **Goal Set Campaign**
 - Activities scheduled from a defined group
 - Value is a function of number achieved within group
- **Temporal Campaign**
 - Activities scheduled based on temporal separation preferences
 - Value is a function on compliance with requested cadence
- **State-Based Campaign**
 - Activities scheduled based on state-change separation preferences
 - Value is a function on compliance with requested separation

Problem Definition

Inputs

- Goals
 - Priority
 - Utility
- Campaigns
 - Periodic
 - Goal Set
- Exogenous Activities
 - Communication windows
 - Night (inactive)
- Constraints
 - Energy limits
 - Instrument heating
 - Handover state-of-charge

Problem Definition

Outputs

- Generate sequence of activities which
 - Maximize utility
 - Comply with engineering constraints
- Execute in real-time on rover hardware
- Provide best plan available within allotted time (anytime)
- Re-planning may be triggered by
 - Arrival of new goals
 - Divergence from predicted state

Pathogen: Using Campaign Intent To Guide Planning

Overview

Result: Valid plan

Generate seed nodes

while ! *Done* **do**

 Pick best pending node

 Expand that node

 Update pending nodes

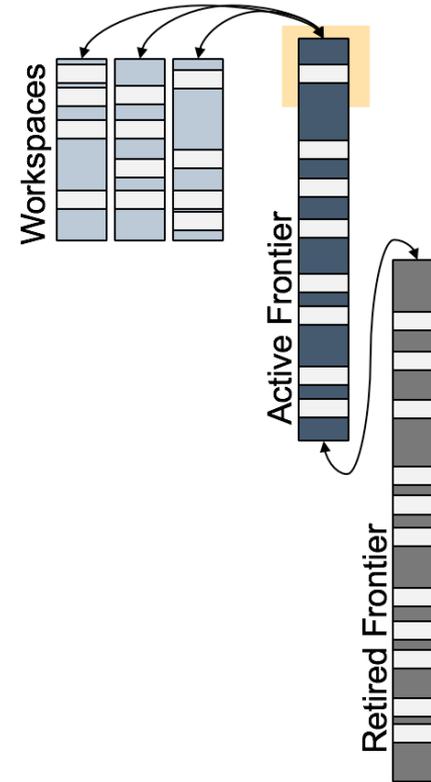
end

Pick best pending node

Pathogen: Using Campaign Intent To Guide Planning

Node Expansion

- Per-thread workspace frontier
 - Grows in depth-first bursts
 - Merged back to main frontier
- Active frontier repository
 - Sorted by heuristic value
 - Threads check out / merge work
 - Limited size for efficiency
- Retired frontier nodes
 - Collects least-promising nodes
 - Called back to active frontier as needed

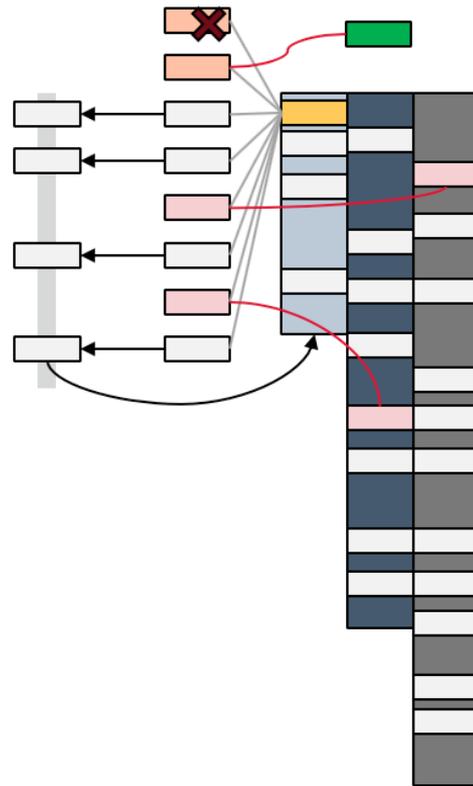


```
Result: Valid plan
Generate seed nodes
while ! Done do
  Pick best pending node
  Expand that node
  Update pending nodes
end
Pick best pending node
```

Pathogen: Using Campaign Intent To Guide Planning

Successor Generation

- Check if prunable
 - Conflicts
 - Max can't beat best node
- Create successor nodes
- Score them
- Prune any poor children
- De-duplicate versus examined nodes
 - Uses hash function on plan
- Update best node metrics
- Push into workspace / frontier

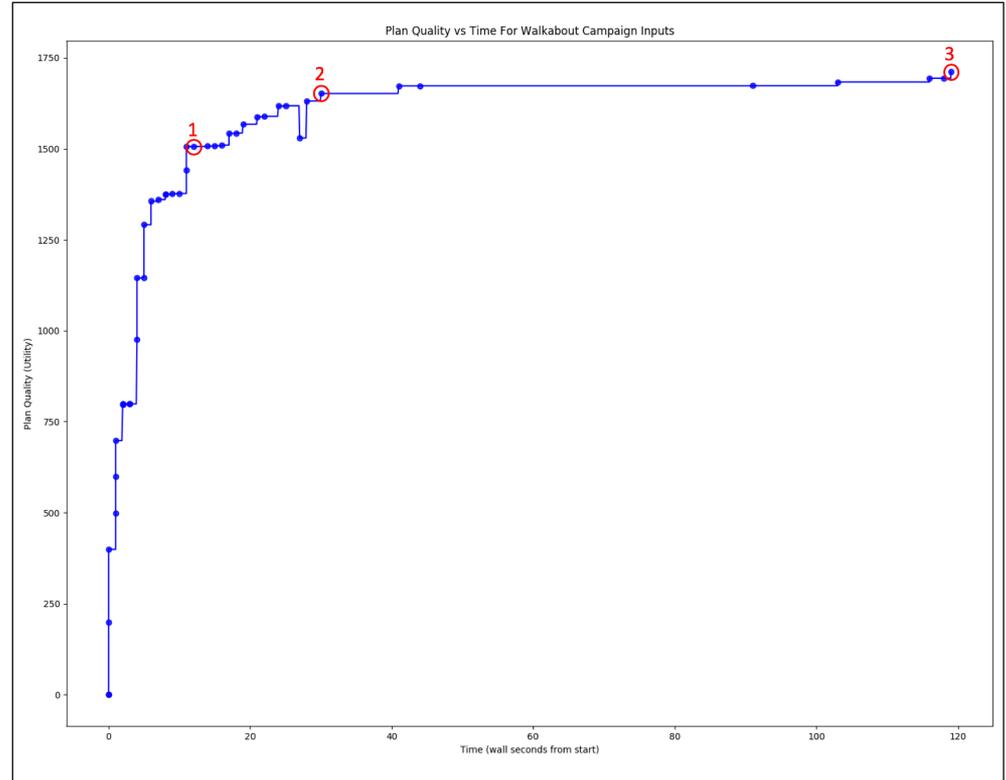


```
Result: Valid plan
Generate seed nodes
while ! Done do
  | Pick best pending node
  | Expand that node
  | Update pending nodes
end
Pick best pending node
```

Onboard Planning Evaluation

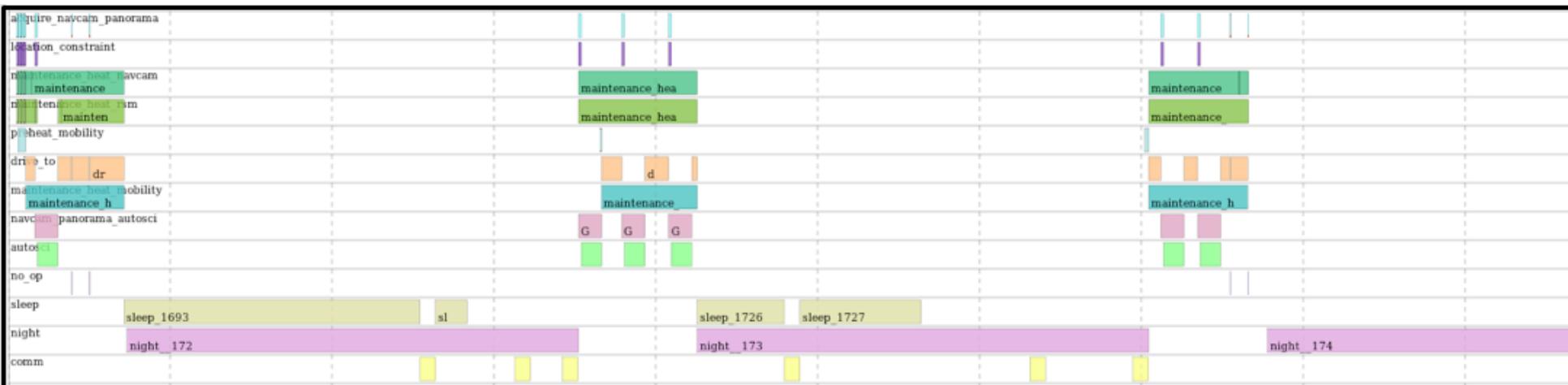
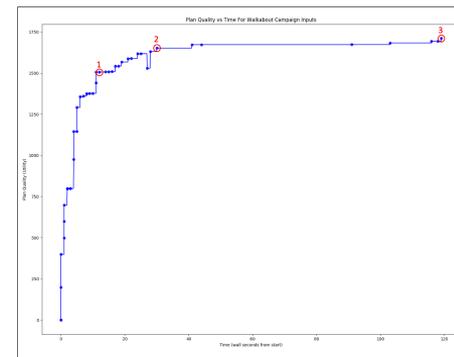
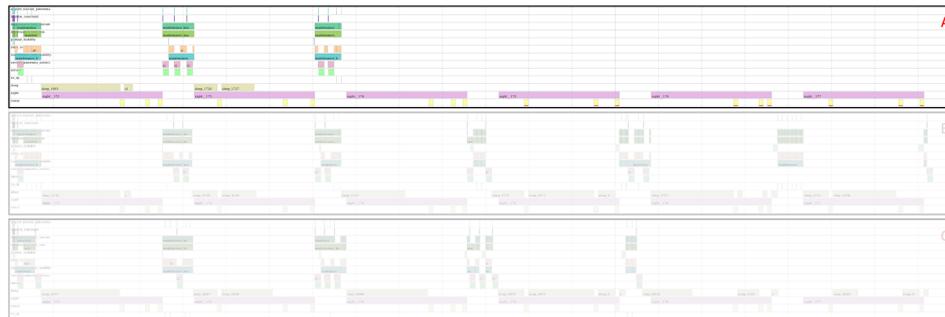
Plan quality

- Generate acceptable plans quickly
- Take full advantage of time available for planning
- Return highest-quality plan possible for a given amount of planning time



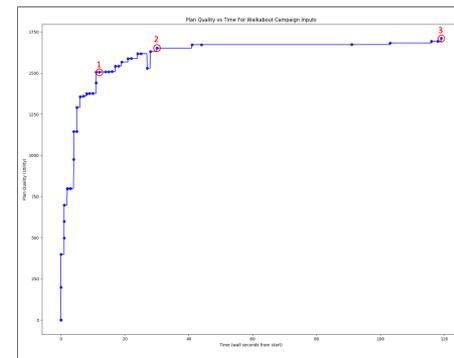
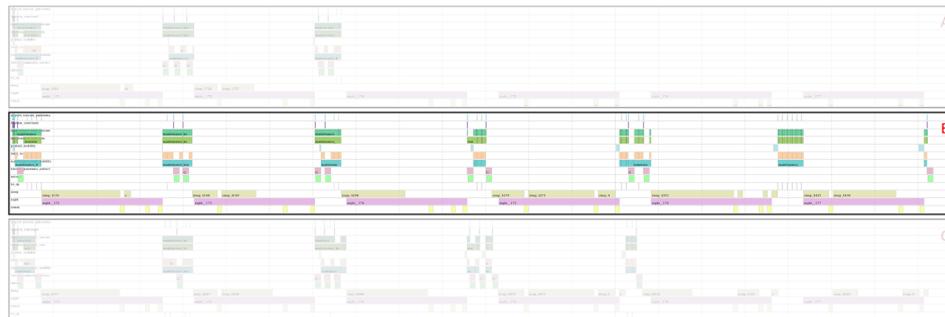
Onboard Planning Evaluation

- Early iterations only accomplish a subset of the goals



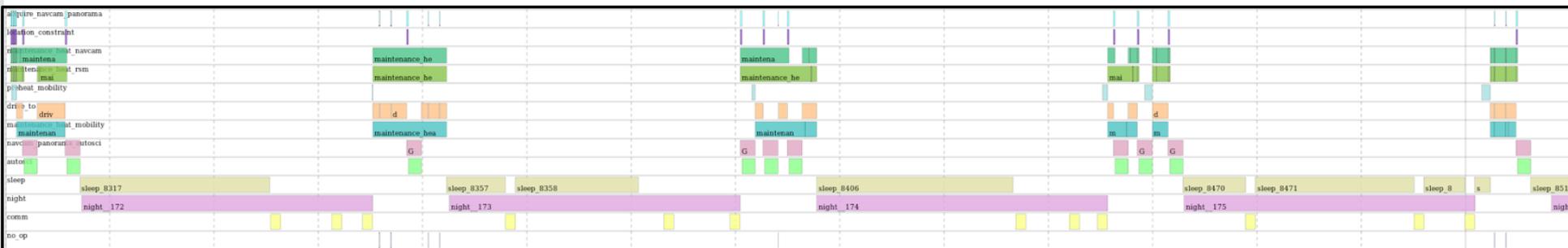
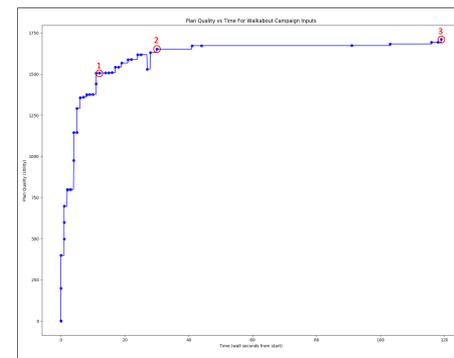
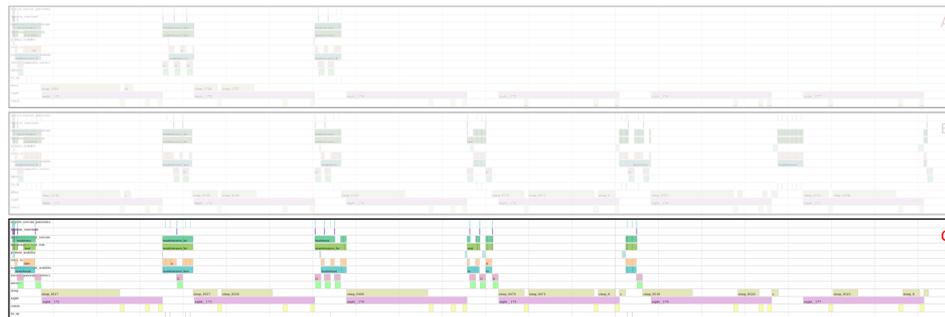
Onboard Planning Evaluation

- After ~30 seconds: finds plan that accomplishes all goals in 7 sols



Onboard Planning Evaluation

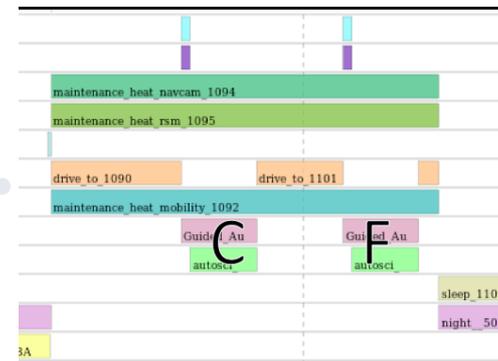
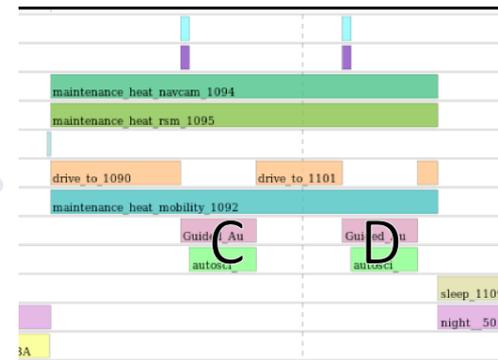
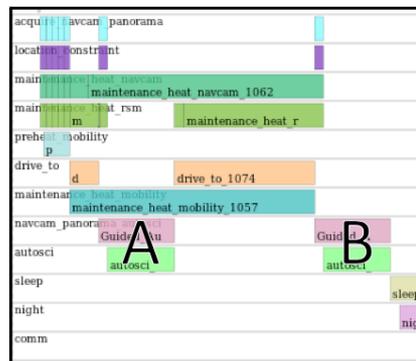
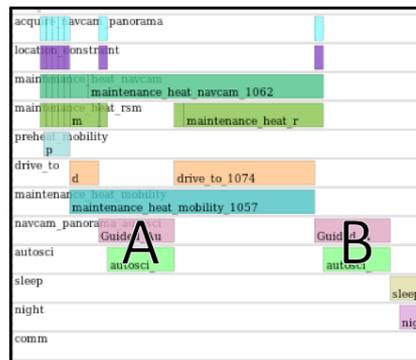
- After 2 minutes:
finds plan that
accomplishes all
goals in only 5
sols



Onboard Planning Evaluation

- Higher-utility goals given priority when resources are limited

Label	Target Name	Target Utility
A	Zoot	100
B	Sweetums	200
C	Fozzie	100
D	Janice	100
E	Animal	100
F	DrJulius Strangepork	200

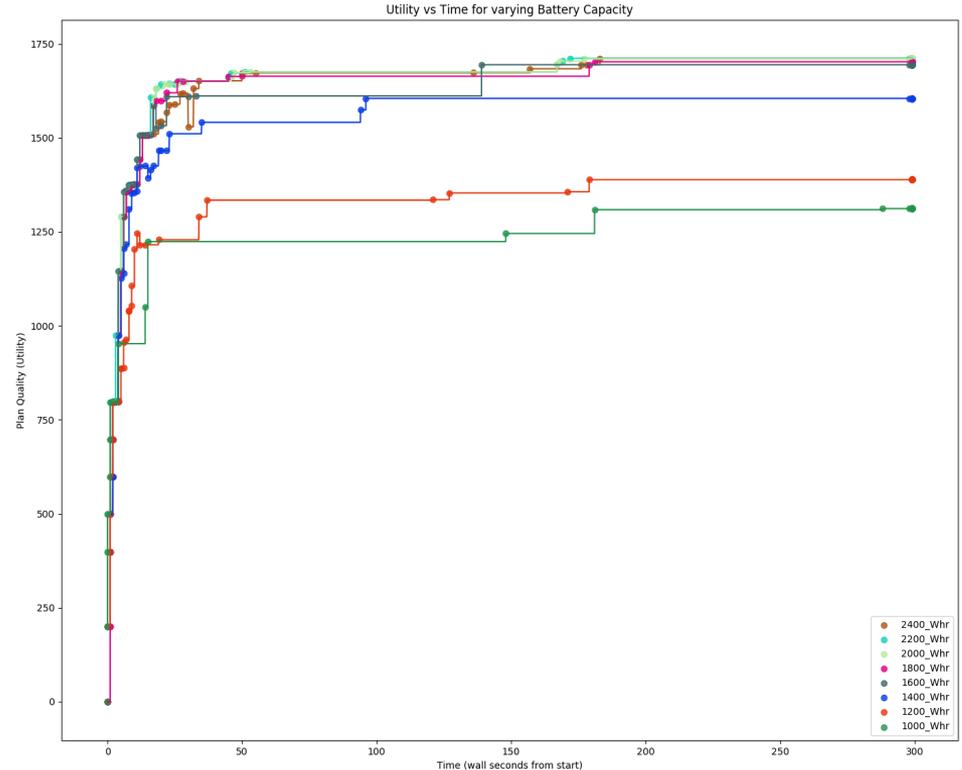


Onboard Planning Evaluation

Constraints

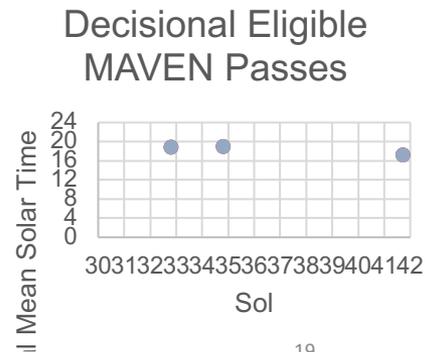
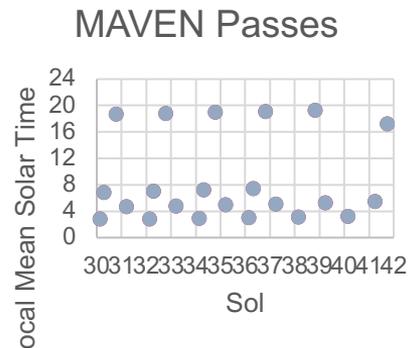
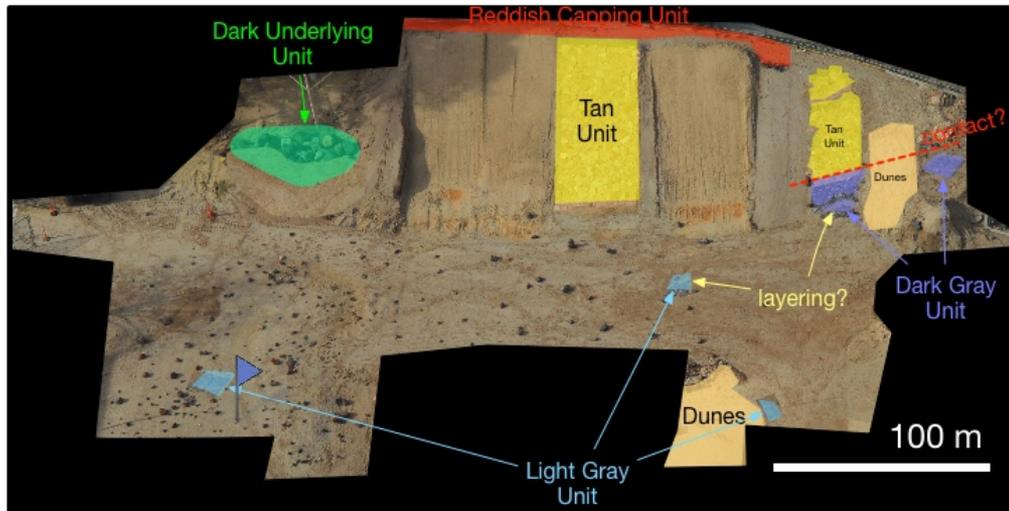
- Able to produce productive plans in when energy resources are tightly constrained

Battery Capacity (Whr)	# Goals Achieved
1000	5
1200	7
1400	9
1600	10
1800	10
2000	10
2200	10
2400	10



Evaluation: Mars Yard Walkabout

- Objective:
 - Evaluate ability to enable high productivity with limited communication
- Methodology
 - Walkabout campaign using SRR
 - Create geological scenes in Mars Yard
 - Use Maven-like comm windows
 - MSL scientists conducted campaign
 - Diana Blaney, Abigail Fraeman, Vivian Sun
 - 7 sols to complete walkabout with 3 uplink opportunities
 - Compared SRR performance with projected MSL performance

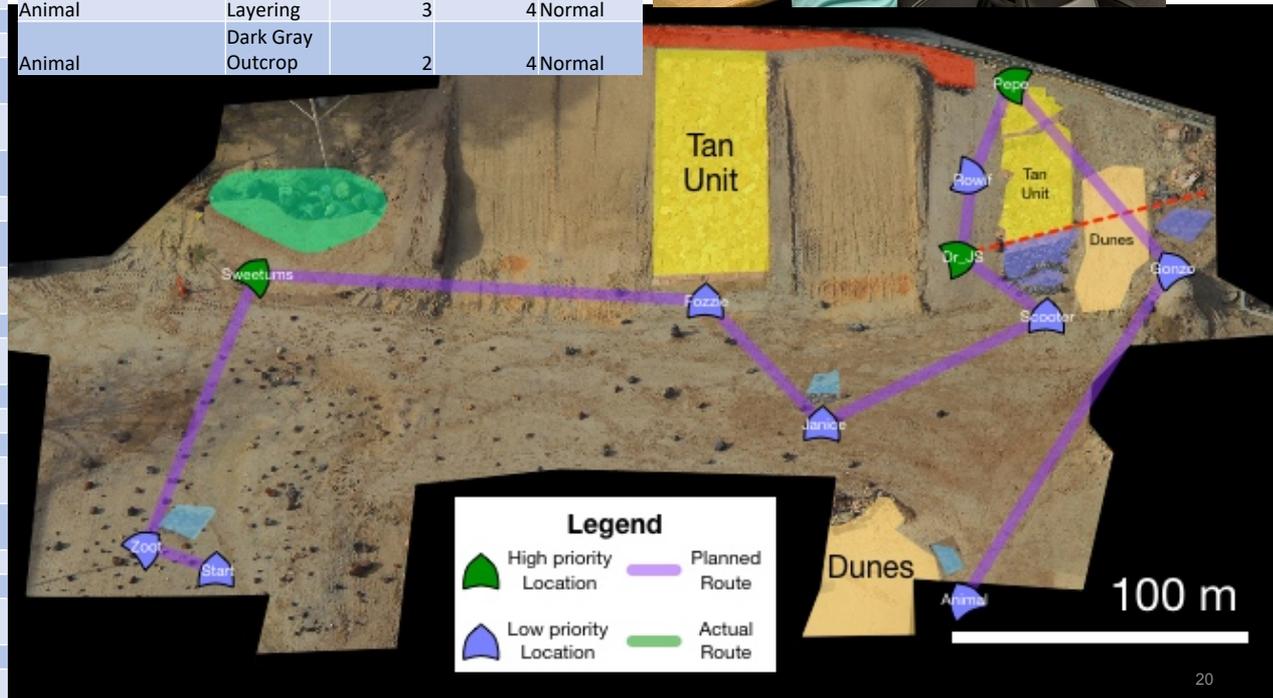


Scientist Objectives and Initial Plan

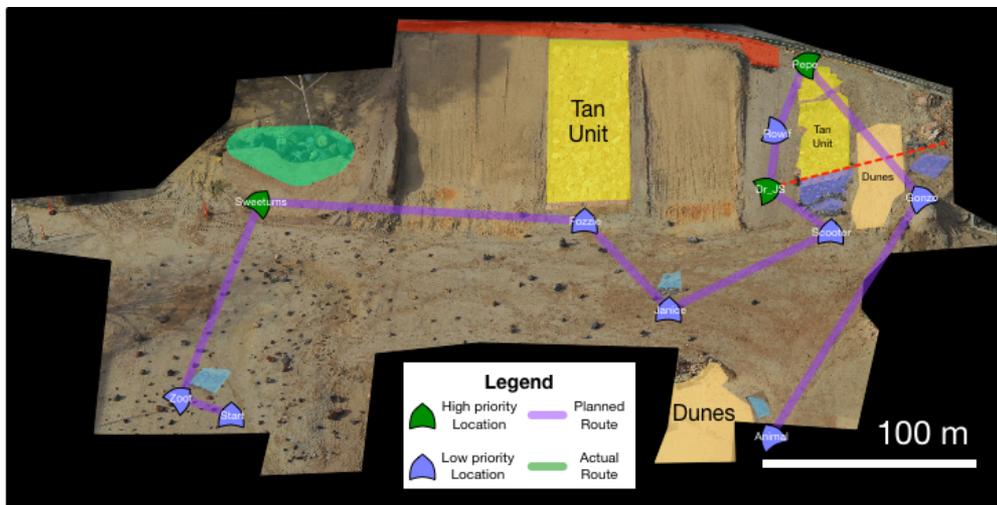


Location	Detector	Num Follow-Ups Min	Num Follow-ups Max	Priority
Zoot	Light Gray Outcrop		2	4 High
Zoot	Layering		3	4 Normal
Zoot	Dark Gray Outcrop		2	4 Normal
Sweetums	Dark Gray Outcrop		2	4 High
Sweetums	Dark Rock		2	4 High
Sweetums	Contact (Dark/Tan)		2	4 Normal
Fozzie	Tan Outcrop		2	3 Normal
Fozzie	Layering		2	4 High
Fozzie	Contact (Dark/Tan)		2	3 Normal
Fozzie	Reddish Rock		1	2 Normal
Janice	Light Gray Outcrop		2	4 High
Janice	Layering		3	4 Normal
Janice	Dark Gray Outcrop		2	4 Normal
DrJuliasStrangeportk	Contact (Dark/Tan)		2	4 High
DrJuliasStrangeportk	Layering		2	4 High
DrJuliasStrangeportk	Dark Gray Outcrop		1	2 Normal
DrJuliasStrangeportk	Tan Outcrop		1	2 Normal
Rowlf	Layering		3	6 Normal
Rowlf	Tan Outcrop		3	6 Normal
Pepe	Reddish Rock		2	4 Normal
Pepe	Contact (Dark/Tan)		2	4 High
Pepe	Layering		2	4 Normal
Gonzo	Sand		2	3 High
Gonzo	Contact (Dark/Tan)		2	4 High
Gonzo	Layering		2	3 Normal
Gonzo	Dark Gray Outcrop		2	2 Normal

Location	Detector	Num Follow-Ups Min	Num Follow-ups Max	Priority
Scooter	Dark Gray Outcrop		2	4 High
Scooter	Layering		1	2 Normal
Scooter	Contact (Dark/Tan)		1	2 Normal
Scooter	Dark Rock		2	4 Normal
Animal	Light Gray Outcrop		2	4 High
Animal	Layering		3	4 Normal
Animal	Dark Gray Outcrop		2	4 Normal



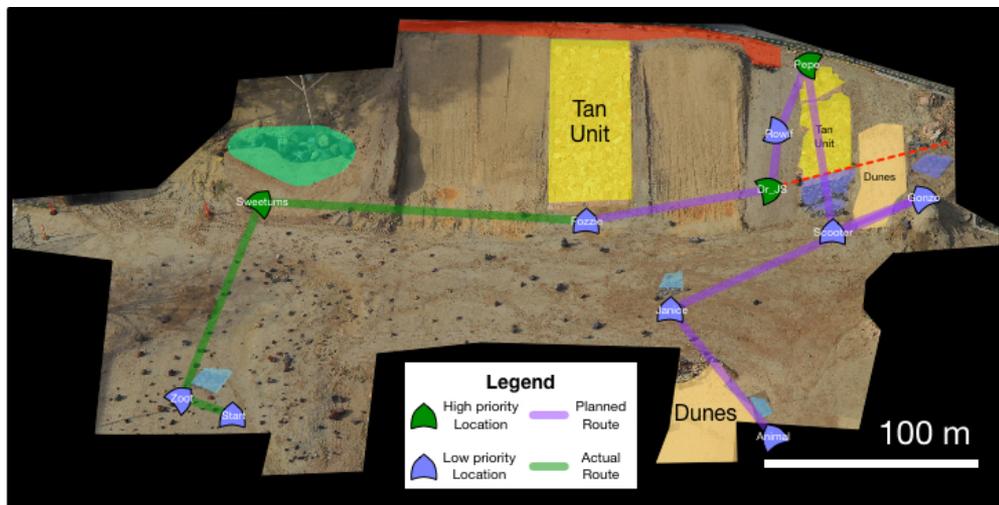
System Evaluation: Mars Yard Walkabout Campaign Results



Sol Path from Initial Plan

Sat 31	Drive + Post Drive Imagery	Assessing
Sun 32	Untargeted Remote Sensing	
Mon 33	Targeted Science, Drive to Zoot, Survey Zoot, Drive toward Sweetums	Plan 1
Tue 34	Arrive at Sweetums, Survey Sweetums, Drive to Fozzie	
Wed 35	Survey Fozzie, Drive to Janice, Survey Janice, Drive toward Scooter	Plan 2
Thr 36	Arrive at Scooter, Survey Scooter, Drive to DrJS, Survey DrJS, Drive to Rowlf, Survey Rowlf	
Fri 37	Drive to Pepe, Survey Pepe, Drive to Gonzo, Survey Gonzo, Drive toward Animal	
Sat 38	Survey Animal	Plan 3
Sun 39	Unused	

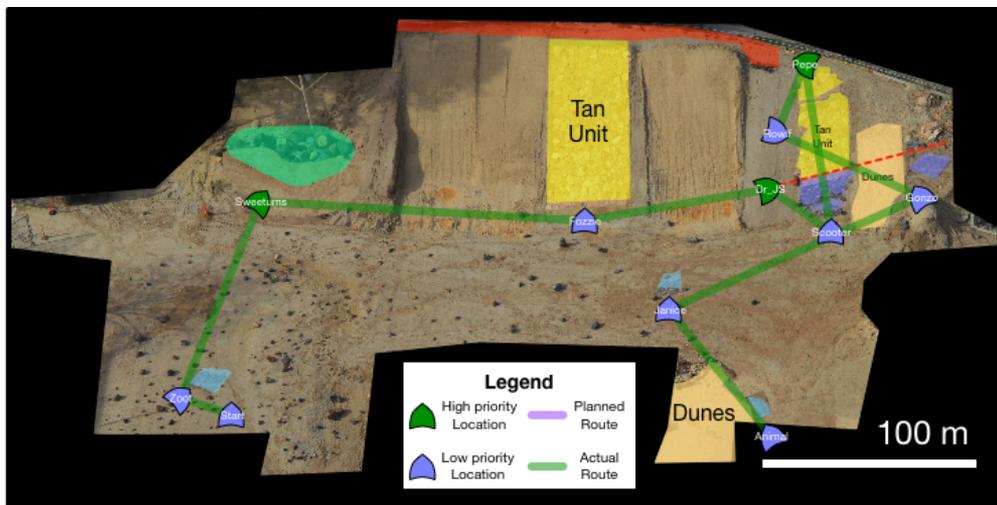
System Evaluation: Mars Yard Walkabout Campaign Results



Sol Path after Plan 1 Execution

Sat 31	Drive + Post Drive Imagery	Plan 1: Assessing
Sun 32	Untargeted Remote Sensing	
Mon 33	Targeted Science, Drive to Zoo, Survey Zoo, Drive to Sweetums	Plan 2
Tue 34	Survey Sweetums, Drive to Fozzie, Survey Fozzie	
Wed 35	Drive to DrJS, Survey DrJS, Drive to Rowif, Survey Rowif, Drive to Pepe	Plan 3
Thr 36	Survey Pepe, Drive to Scooter, Survey Scooter, Drive to Gonzo, Survey Gonzo	
Fri 37	Drive Janice, Survey Janice, Drive to Animal, Survey Animal	
Sat 38	Unused	
Sun 39	Unused	

System Evaluation: Mars Yard Walkabout Campaign Results

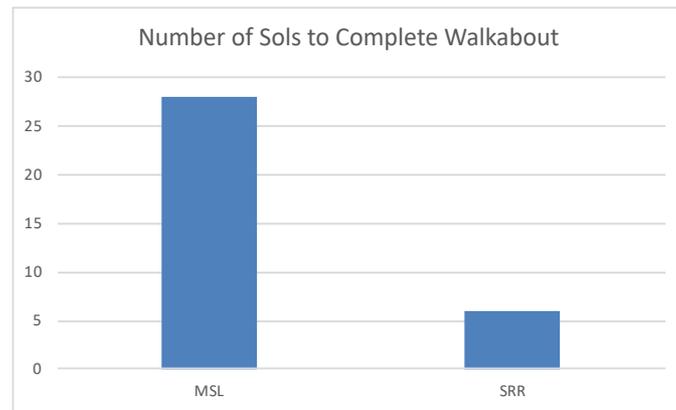
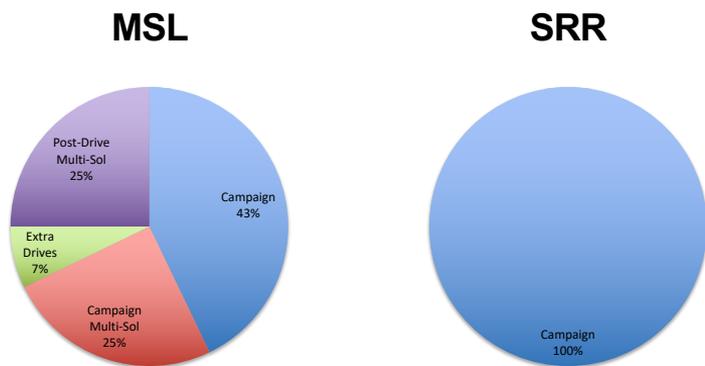


Sol Path after Plan 2 Execution

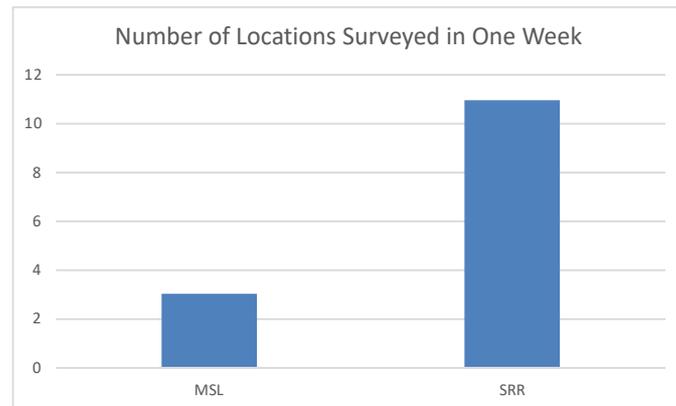
Sat 31	Drive + Post Drive Imagery	Plan 1
Sun 32	Untargeted Remote Sensing	
Mon 33	Targeted Science, Drive to Zoot, Survey Zoot, Drive to Sweetums	Plan 2: Assessing
Tue 34	Survey Sweetums, Drive to Fozzie, Survey Fozzie	
Wed 35	Drive to DrJS, Survey DrJS, Drive to Scooter, Survey Scooter	Plan 3
Thr 36	Drive to Pepe, Survey Pepe, Drive to Rowlf, Survey Rowlf	
Fri 37	Drive to Gonzo, Survey Gonzo, Drive Janice, Survey Janice, Drive to Animal	
Sat 38	Survey Animal	
Sun 39	Unused	

System Evaluation: Mars Yard Walkabout Campaign

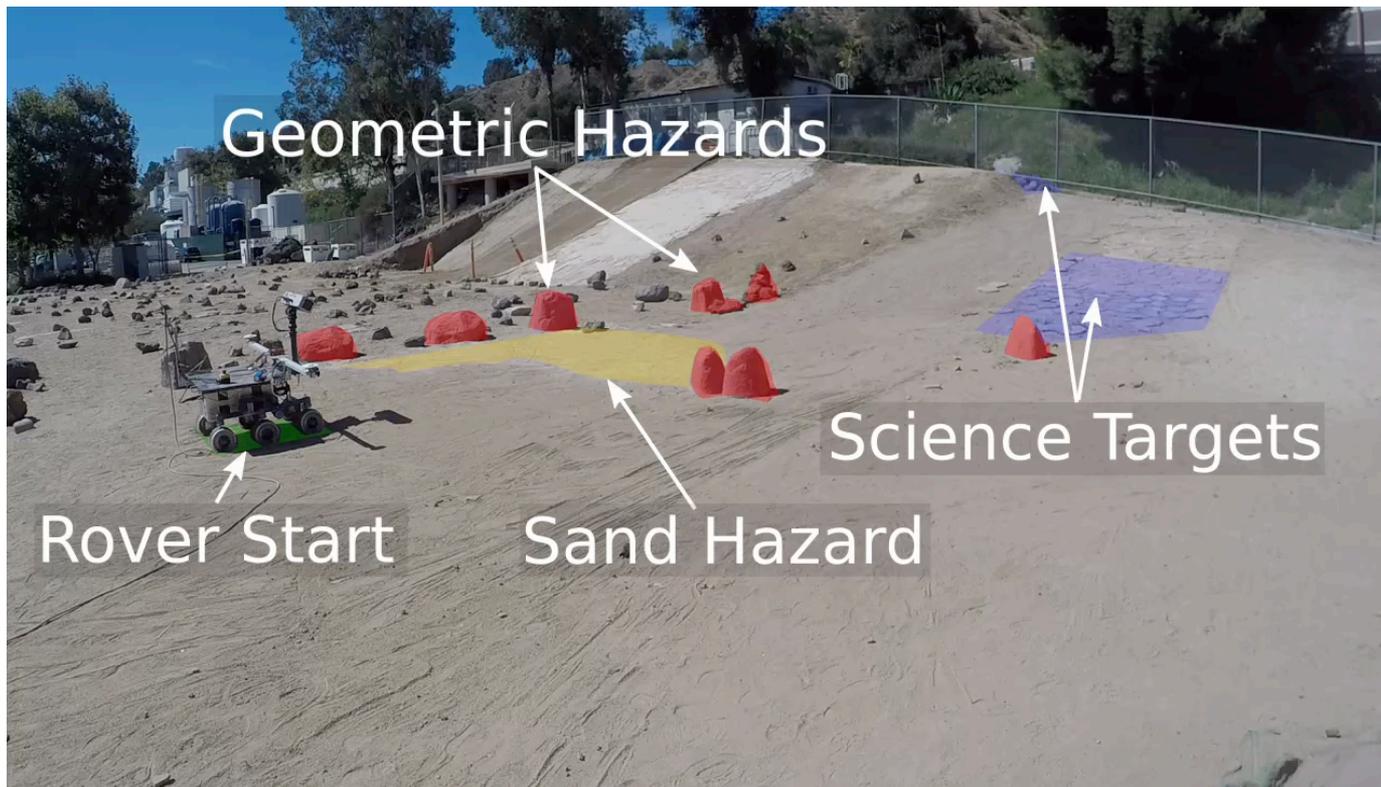
Results



- SRR productivity vs. MSL
 - **47% increase in number of productive sols**
 - SRR able to make full use of every sol
 - **80% (4.7x) reduction in number of sols** to survey all locations
 - **267% (3.7x) increase in locations surveyed** in one week



Video



Self-Reliant Rover Team

- Dan Gaines (PI)
- Ryan Mackey (Co-I)
- Gregg Rabideau (Co-I)
- Ashwin Vasavada (Co-I)
- Bob Anderson
- Ali Agha
- Gary Doran
- Chet Joswig
- Heather Justice
- Ksenia Kolcio (Okean)
- Mike Paton
- Brandon Rothrock
- Joe Russino
- Jacek Sawoniewicz
- Steve Schaffer
- Vincent Wong
- Kathryn Yu

Advisors

- Issa Nesnas (Initiative Lead)
- Magdy Bareh
- Lorraine Fesq
- Mark Maimone



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