

Science on the Fly

Autonomous Science for Rover Traverse

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Preview

Motivation and Objectives
Technology Research
Field Validation

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Science Autonomy

Science Autonomy is NOT to replace scientists with robots

Science Autonomy is to improve the quality and quantity of science data return from exploration missions

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Motivation for Science Autonomy

Exploration methods with all decision making on Earth are increasingly difficult to sustain

Factors motivating greater autonomy:

Mission duration

Operations costs

Instrument placement and operation

Verifying observations

Sampling and drilling control

Command complexity/contingencies

Communication bandwidth and data volume

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Science Autonomy Motivation

NEXT Space Robotics Study

Assessment the current and projected state-of-the-art in space robotics including surface exploration

Challenges relative to science autonomy:

Minor

Obstacle Detection
Obstacle Avoidance
Path Execution
Coverage Planning

Moderate

Map Building
Health Monitoring
Path Planning
Resource Planning

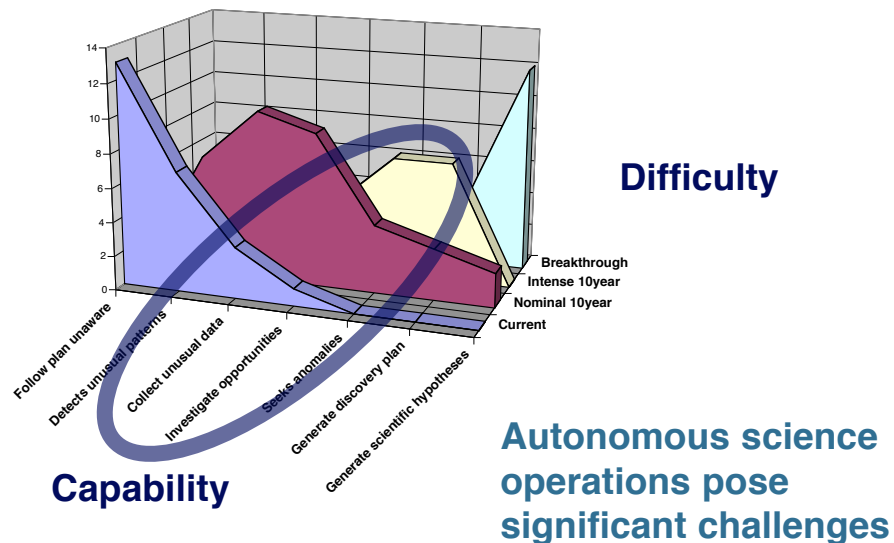
Major

Localization
Terrain Detection
Mission Planning
Exploration Planning
Science Data Understanding

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Science Autonomy



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Science on the Fly Motivation

Geology on the Fly

During 1997 Atacama Desert Trek an experiment in exploration method was conducted:

- Maintain rover in motion 75% of the time (science conducted during traverse)
- Traverse 1.5km (supervised teleoperation)
- Pause at 10 sites for detailed observation



Outcrop with fossilized stromatolite detected



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Science autonomy during rover traverse

Research:

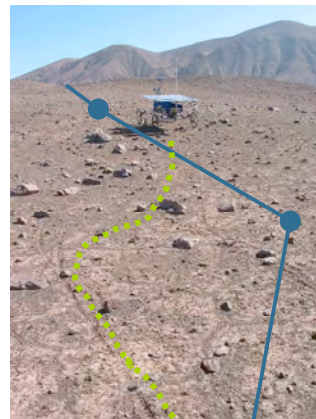
Feature detection (similar, dissimilar, and unique)

Feature classification and evaluation (significance)

Science-informed exploration

Science autonomy architecture

Focus on developing techniques and validating in ground-truthed rover experiments



Nominal Traverse
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On-the-Fly Observations

Feature Detection and Classification

Rocks and soils

- Size, color (white rocks), roundness, sphericity, mineral composition (carbonates), spectra, fluorescence(chlorophyll signature), etc.
- Similarity, dissimilarity, uniqueness

Regions

- Texture, color distribution, size distribution, statistical measures, etc.
- Boundary localization

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Rock Detection Example

Scene Image

Difference Operator

Threshold

Smoothing Operator

Segmentation

Rocks

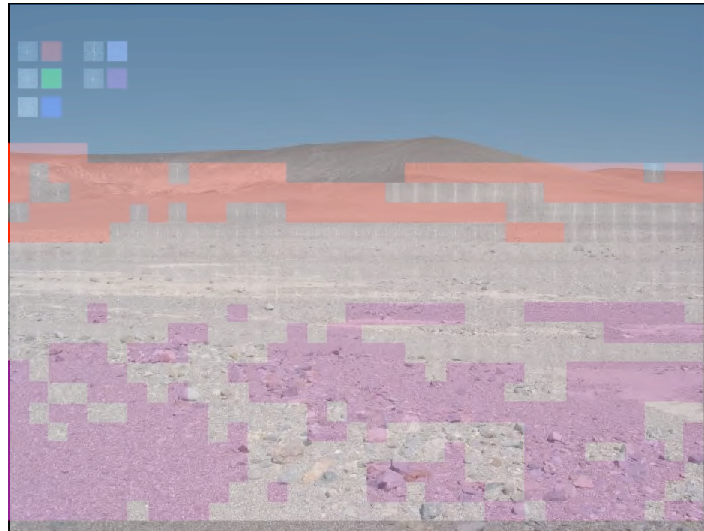


Illustrative example not necessarily an effective algorithm

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Region Segmentation Example



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Technical Approach and Metrics

Feature Detection

- Implement several candidate algorithms
- Apply each algorithm to image set
- Analyze detection performance (rate and errors)

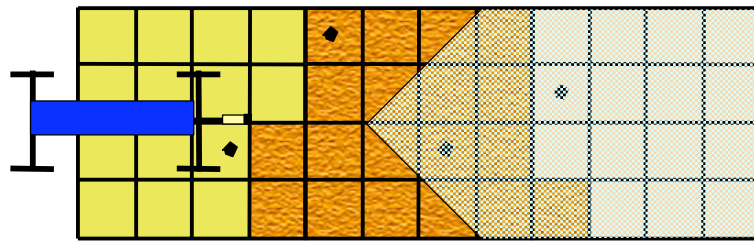
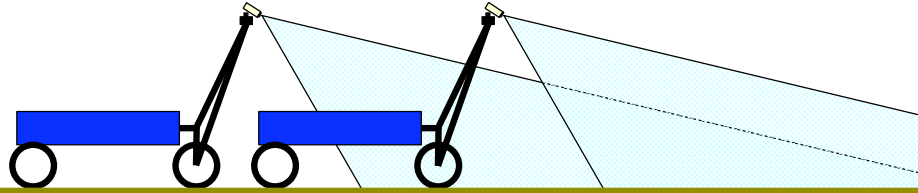
Feature Classification

- Implement classification approach (Bayesian)
- Apply to detected features
- Compare to manual classification

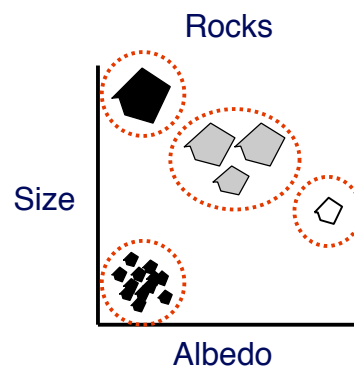
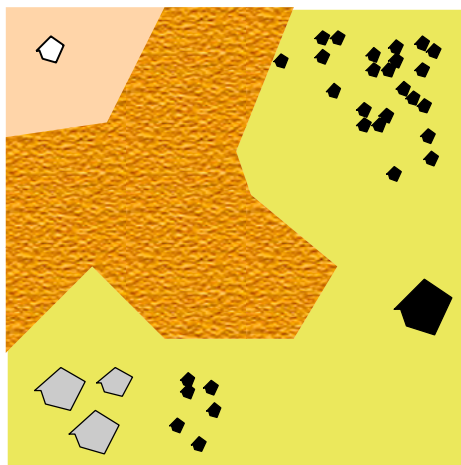
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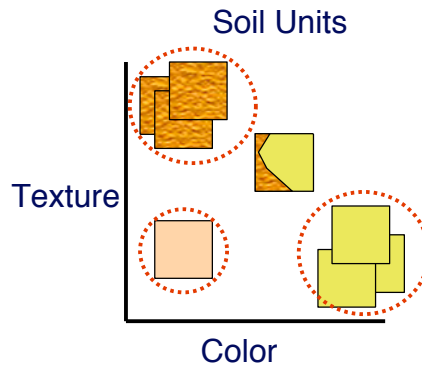
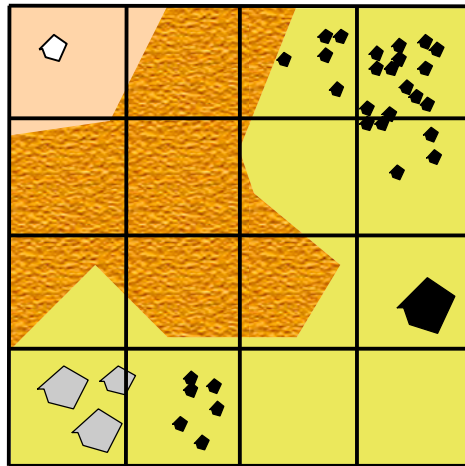
Science Observer



Observation Map – Rocks



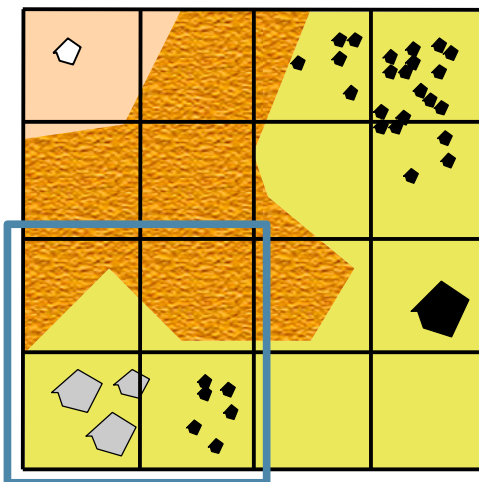
Observation Map – Soils



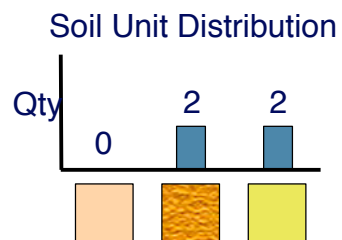
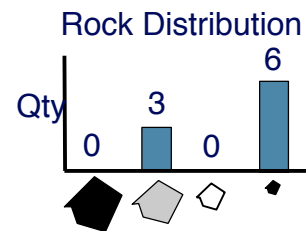
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Observation Map – Regions



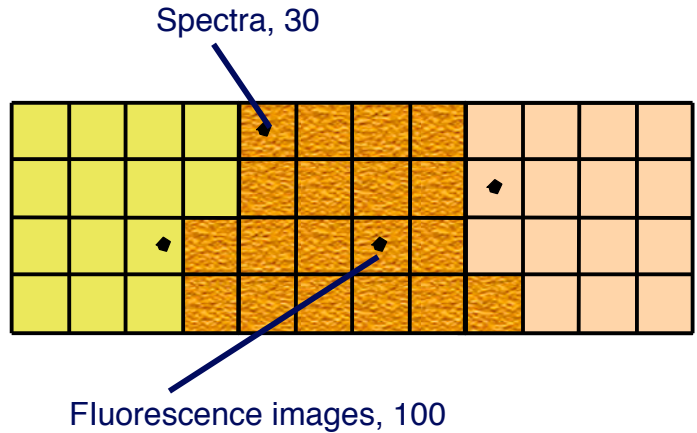
Region Characterization



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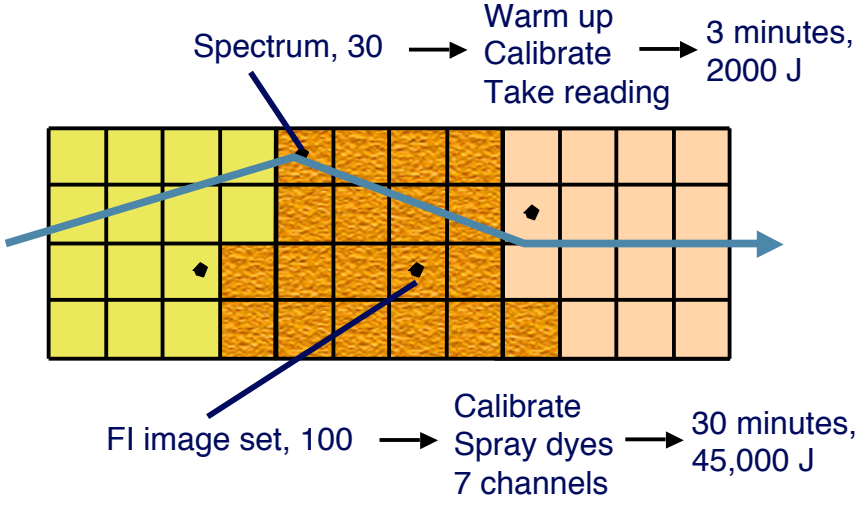
On-the-Fly Planning



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Science Planner



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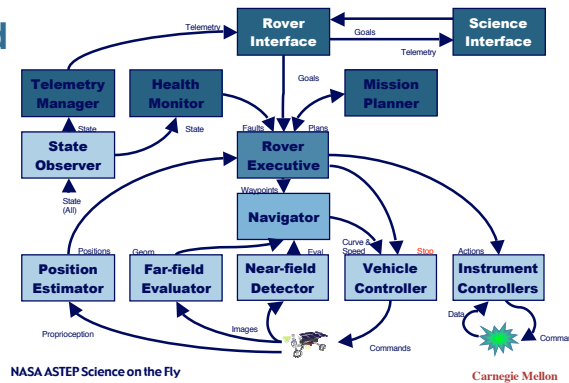
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Science Autonomy Architecture

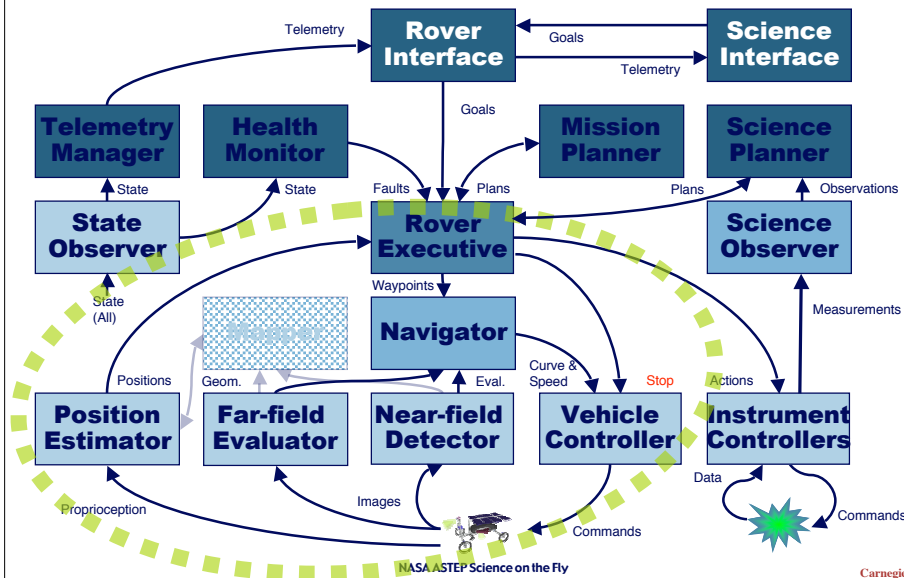
Deep Integration

Science observation is closely related to navigational observation and can be optimized

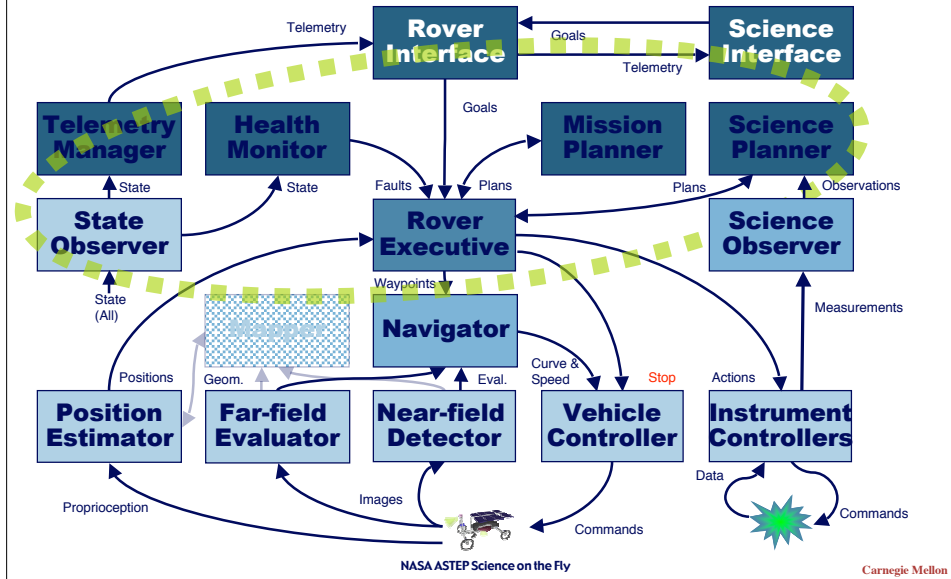
Science planning is intimately related to planning for locomotion and resources



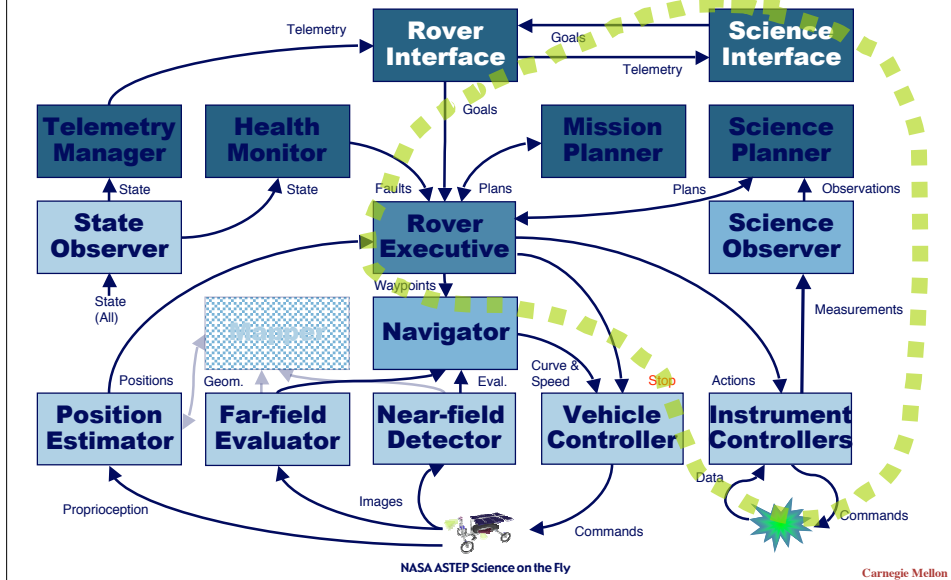
Architecture - Navigation



Architecture - Planning and Execution



Architecture - Science Autonomy



Validation and Verification

Two aspects:

1. **Validate detection and categorization perform correctly in the relevant domain**
2. **Verify that science-on-the-fly observation and planning improves science productivity**
 - Measured by comparison to control experiment with no science autonomy
 - Quantify of useful observations and quality of science interpretation

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Experimentation

Design rover traverse

Following Atacama operations concept

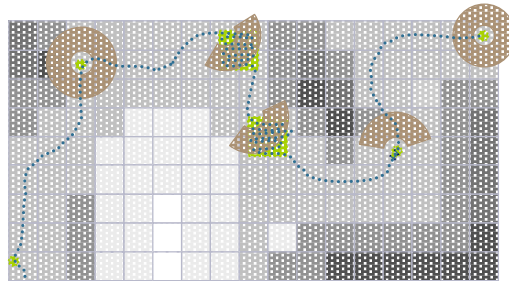
Possibly cross geologic boundary

Complete science goals

Observe environment and detect features

Categorize features and compute statistics

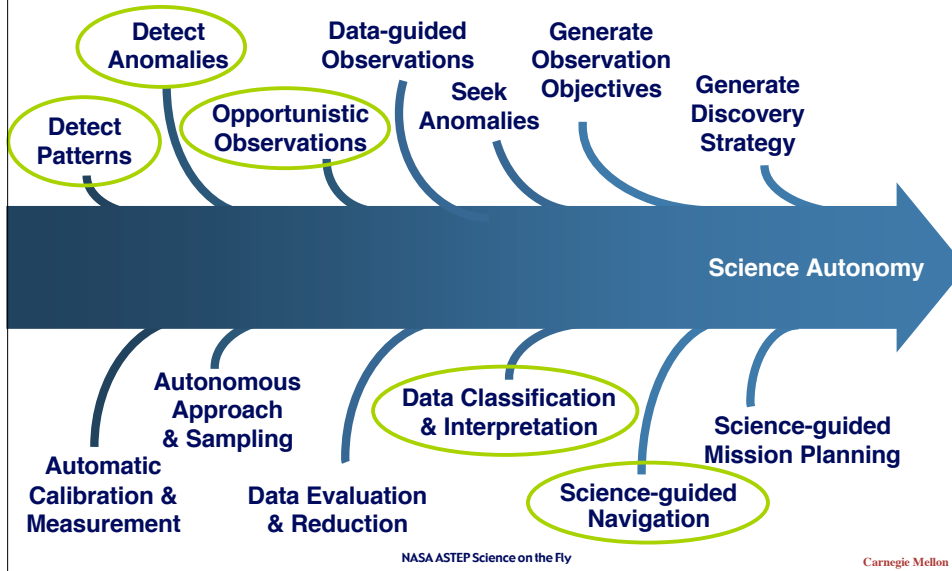
Compare automatic versus manual analysis (validate)



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Developing Science on the Fly



Science on the Fly

Science autonomy during rover traverse

Technology

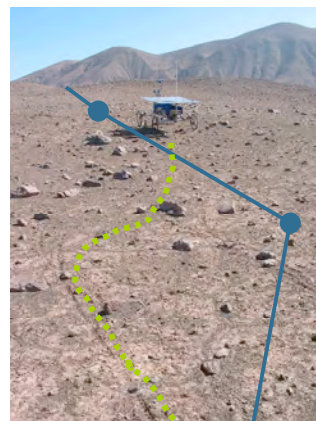
Feature detection

Feature classification and evaluation

Science-informed exploration

Science autonomy architecture

Focus on developing techniques and validating in field experiments



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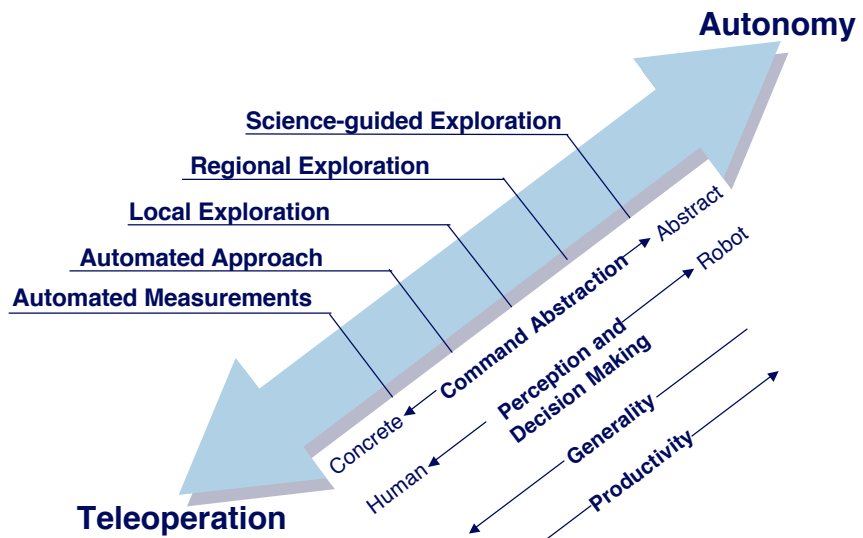
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Extra Motivation

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Improving Productivity



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Growing Science Data Volume

Focused Science Missions

Focused Investigation
Single Measurements
Flybys and Landers

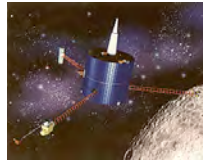


Venera Lander



Discovery Science Missions

Broad Investigation
Multiple Repeated Measurements
Orbiters and Rovers



Lunar Prospector

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MSL

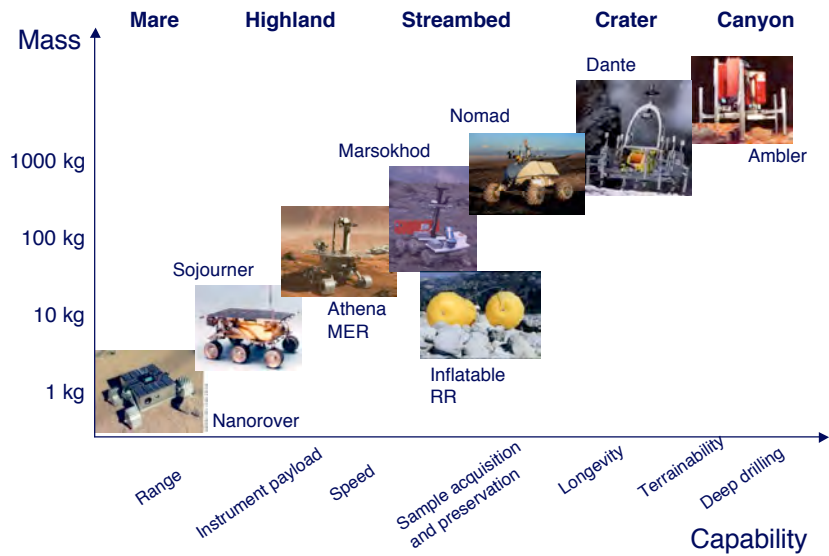


Comprehensive Science Missions

Global Exploration
Regional, Seasonal Measurements
Long-duration Orbiters and Rovers

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Increasing Capability



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Taxonomy

Exploration Strategy
Sample Selection Criteria
Sample Detection
Sample Acquisition
Data Validation
Data Verification
Science Analysis
Science Interpretation
Science Discovery



Increasing
Complexity

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Taxonomy

Exploration Strategy	Static survey, fixed coverage pattern (grid, spiral, random) Dynamic survey, variable coverage pattern, feature following Directed search, feature-based Opportunistic observation Opportunistic investigation
Sample Selection Criteria	Inquiry-independent (fixed by non-science constraints) Inquiry-nonspecific Pattern scientist specified Pattern derived from scene (automatic classification) Pattern generated (autonomous inquiry)
Sample Detection	Select search area Identify pattern Reach position/time/survey constraint Evaluate detection likelihood
Sample Acquisition	Sample localization/feature tracking Sample approach Instrument deployment Sample collection Sample processing Sample curation Sample disposal
Data Validation	Calibrate sensors Data quality assurance Dynamic range and sensitivity of measurements
Data Verification	Effective experimental procedure Clear sample naming convention Comparison to sample specification Correct feature likelihood
Science Analysis	Filtering/enhancement Data reduction (eliminating data) Data compression Statistical analysis: categorize, diversity, priority
Science Interpretation	Feature detection Sample classification Probabilistic analysis
Science Discovery	Distinguish uniqueness Evaluate significance Generate Hypothesis

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Extra Robots

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Volcanic Gas Measurement

Goal: **Measure gasses to determine activity, distribution and concentration**

Challenges

Locomotion: dexterity in extreme terrain

Behavior: sensing and adapting to terrain

Interface: conveying status to scientists



Dante

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Geologic Measurement and Sampling

Goal: **Autonomous geological sampling**

Challenges

Autonomy: minimize command cycles

Visual servoing: changing appearance of target

Reliability: knowing when it is not working



Marsokhod

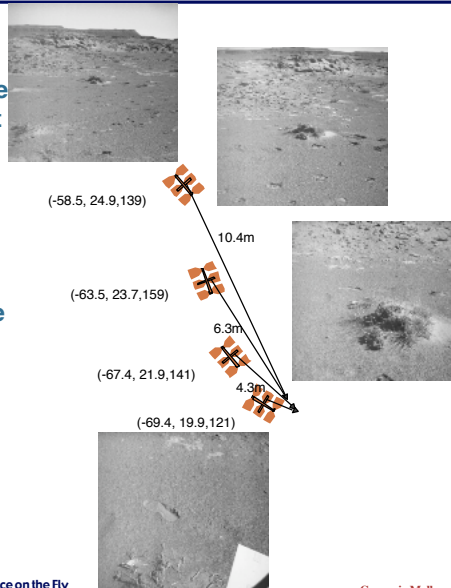
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Autonomous Target Approach

Visual-servoing as autonomous behavior for data acquisition

- *Motion correlator* compares left image with prior template to determine target direction
- Motion correlation drives fast pan-tilt
- *Range correlator* compares left and right images to determine pixel disparity and range to target
- Range and motion correlation provide input for robot heading and velocity (guidance)



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Regional Geologic Characterization

Goal: **Long-distance desert exploration**

Challenges

Communication: limited bandwidth

Duration: practice of sustained operation



Nomad



Detection: sensing fidelity capable of scientific discovery

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Long-duration Exploration



Goal: **Robotic navigation with reasoning about resources for sustained exploration**

Perpetual operation through balancing with power generation and consumption

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Long-Duration Exploration Experiment

Power

Followed resource profile and schedule to complete traverse with batteries fully charged

Terrain

7% (max 34%) obstacle density

Operation

6.1km, No faults, Autonomy 90%

9.1km, One fault, Autonomy 50%



Hyperion on Devon Island, Canada

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Antarctic Meteorite Search

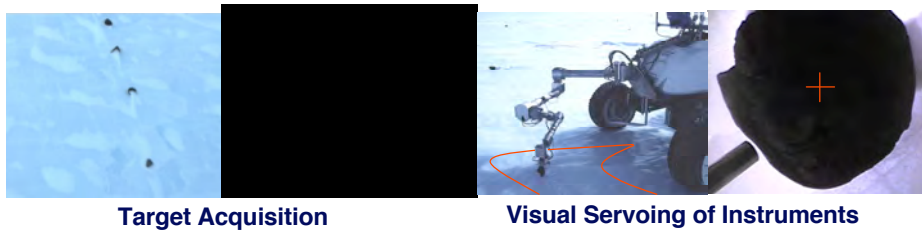


Goal: Automatic detection and classification of rocks on stranding surfaces in the Antarctic where meteorites tend to concentrate

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Rock Detection and Classification

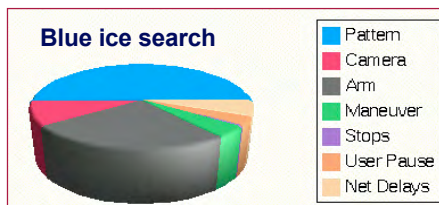


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Meteorite Discovery

2500 m² searched in 16 hours, 42 samples classified



1 rock / 10 m², time to target: 45 min



1-2 rocks / m², time to target: 16 min



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