Jet Propulsion Laboratory
California Institute of Technology

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Machine Learning and Instrument Autonomy

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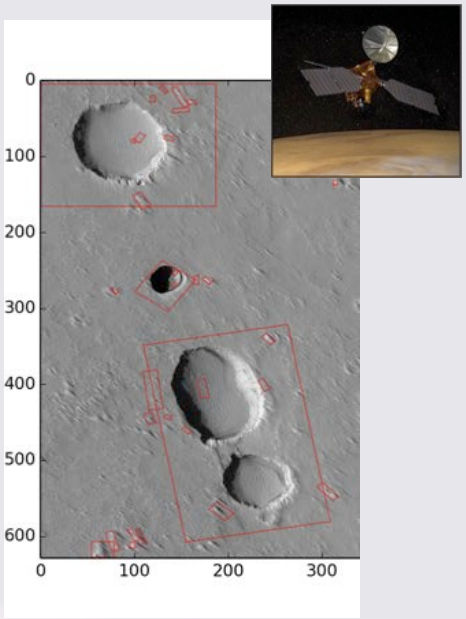
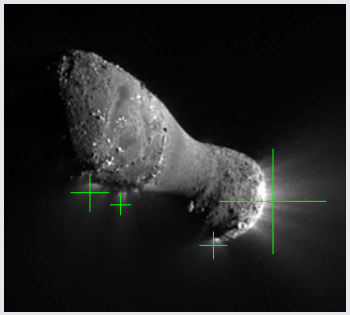
MLIA Research Areas

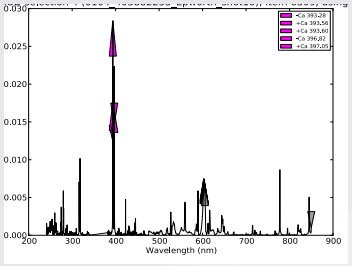
- Automated data analysis
- Ground-based and onboard
- Image analysis
- Remote sensing
- Computer vision
- Quality assurance
- Target detection
- Opportunistic science
- Science event monitoring
- Data summarization
- Data downlink prioritization
- Novelty/discovery
- Anomaly detection
- Data classification



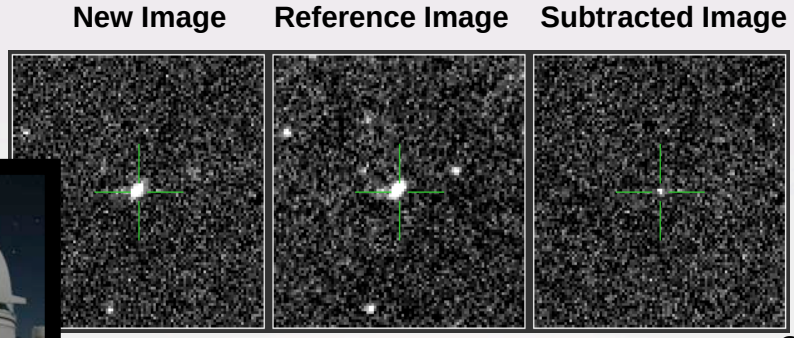
Classification of Mars landmarks



Onboard plume detection



Scientific discovery for MSL Chemcam



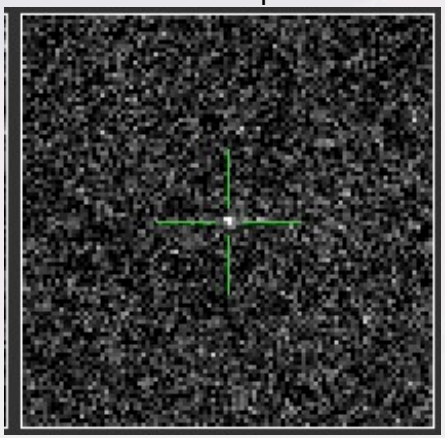
Identifying supernovae from iPTF images

Astronomical Data Quality Assurance
Real-Bogus Classification of Supernova Candidates

- Intermediate Palomar Transient Factory (iPTF) detects **500K-1M** astronomical transients (e.g., supernovae) per night
- **<1%** detection candidates real transients
- Number of detections exceeds human review capacity
- Real-time classifier (RB4) discriminates real transients from false positives, trained using labeled real/bogus examples
- Prioritizes best detections for rapid validation by human reviewers
- Running in real-time since August 1, 2014

Palomar 48" Telescope

Detected Supernova

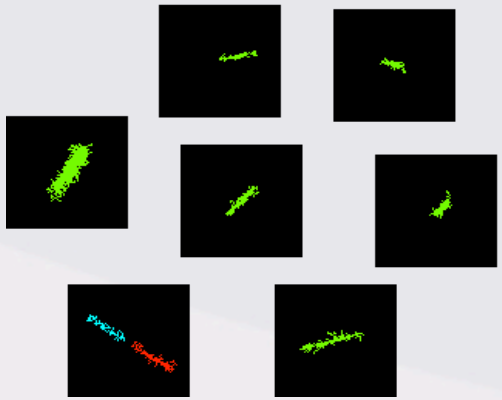


Contacts: Umaa Rebbapragada, Brian Bue

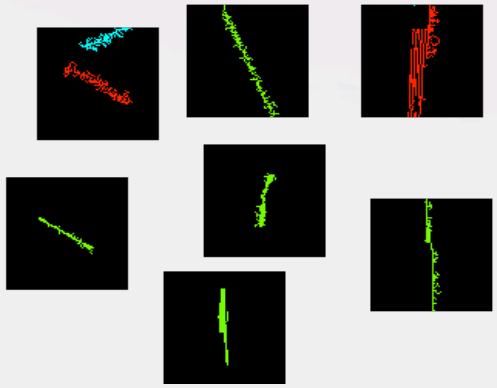
Deep Learning for iPTF Asteroid Detection

Goal: discriminate real iPTF asteroid detections from bogus candidates

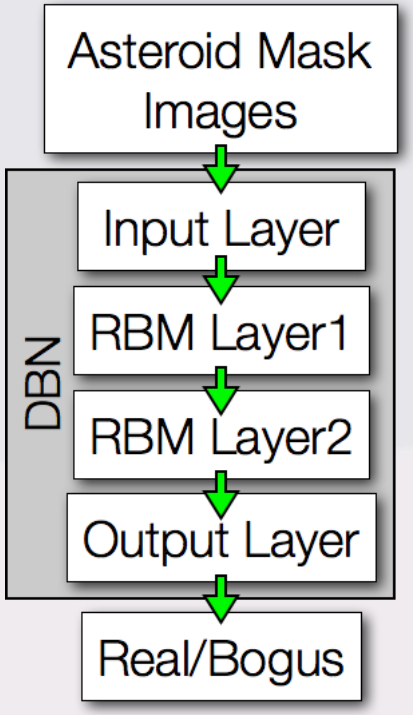
Confirmed Asteroids



Bogus Detections
(cosmic rays, processing artifacts)



Deep neural network



Deep network trained with raw imagery gives comparable accuracy to classifier using expert-engineered features

Contacts: Brian Bue, Umaa Rebbapragada

Detecting Fast transients on the Very Long Baseline Array (VLBA)

Ongoing, commensal experiment on VLBA radio telescopes

Searches for anomalous fast radio transients in streaming TB-scale time-series

Transients produced by Gamma Ray Bursts, intermittent radio pulsars or possibly merging black holes

Uses online adaptive pattern recognition

Online since July 2011

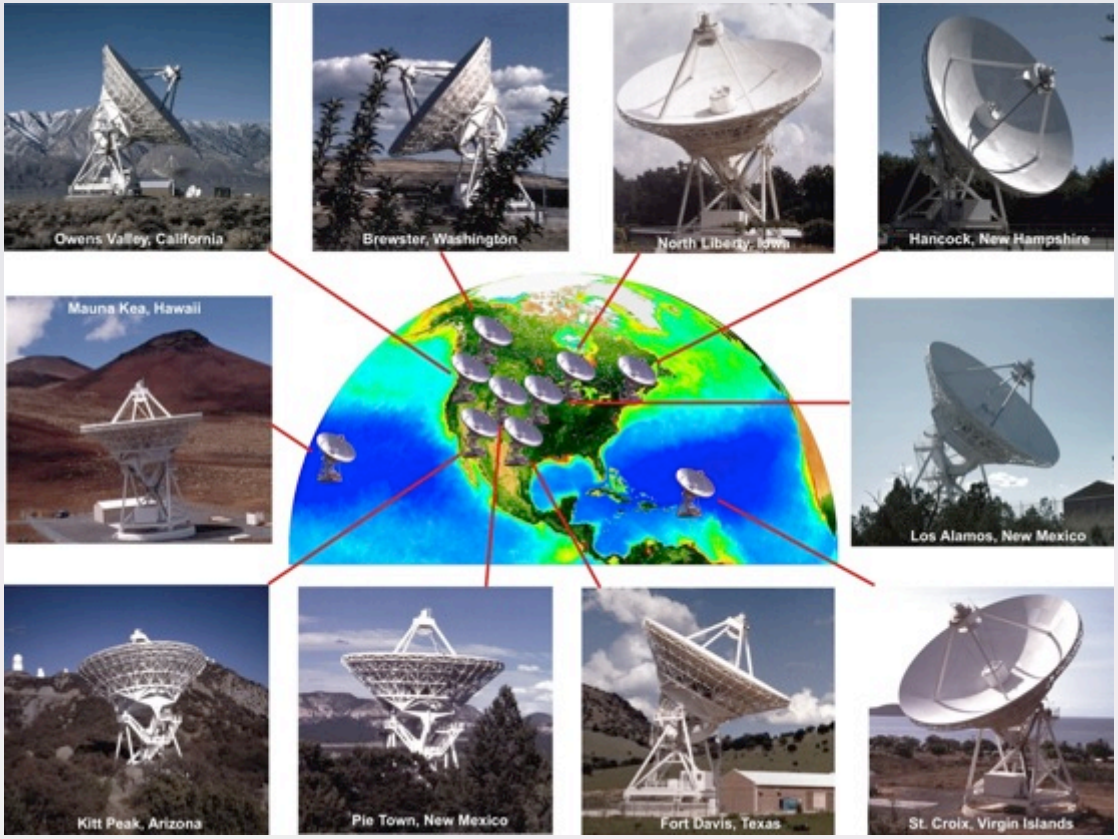


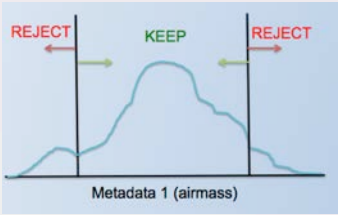
Image: NRAO

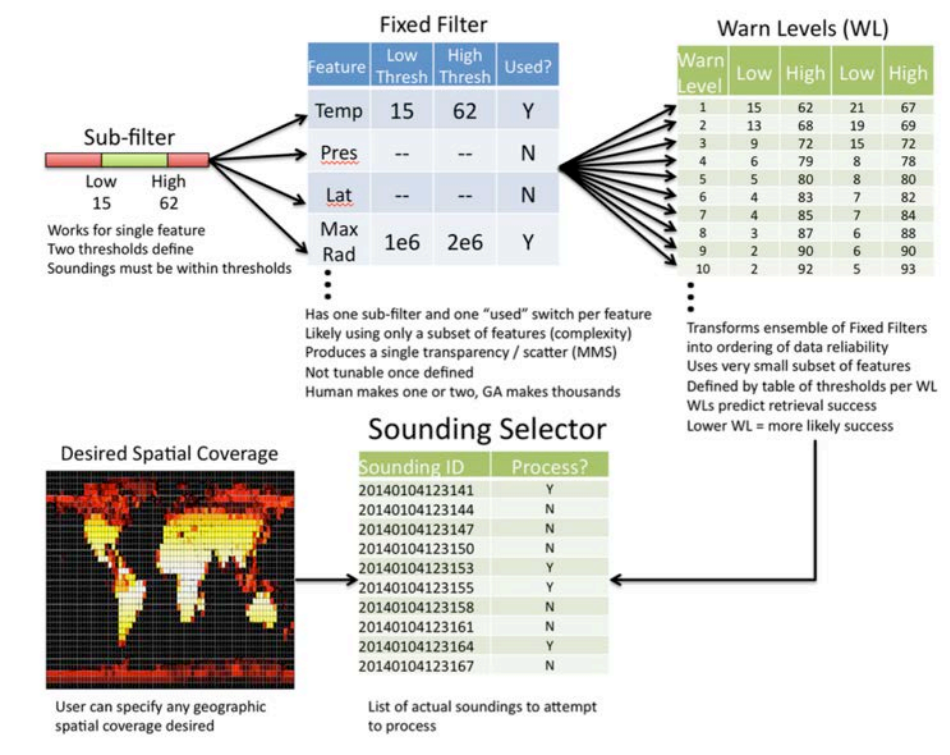
Contact: K. Wagstaff, D. Thompson

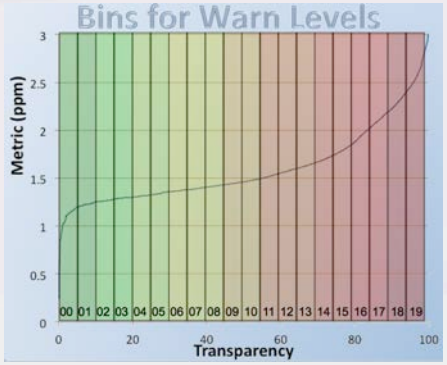
DOGO Intelligent Data Filtering for OCO-2

DOGO: Data Ordering for Genetic Optimization

- Prioritizes high-quality incoming OCO-2 soundings for further analysis
- Lets retrieval algorithms initially focus on cleanest data
- Advises scientists on which data to analyze
- Fully operational in OCO-2 DAC – enabled mission to meet Level 1 requirements







Runner Up for 2015 NASA Software of the Year Award

Contact: L. Mandrake

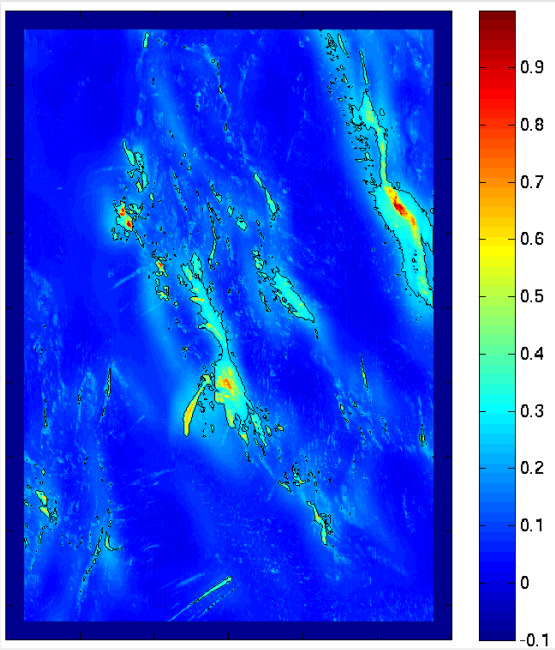
Classification of Image Landmarks

Content-based image retrieval: automatically locate visually salient regions (e.g. craters, dust devil tracks) in image data

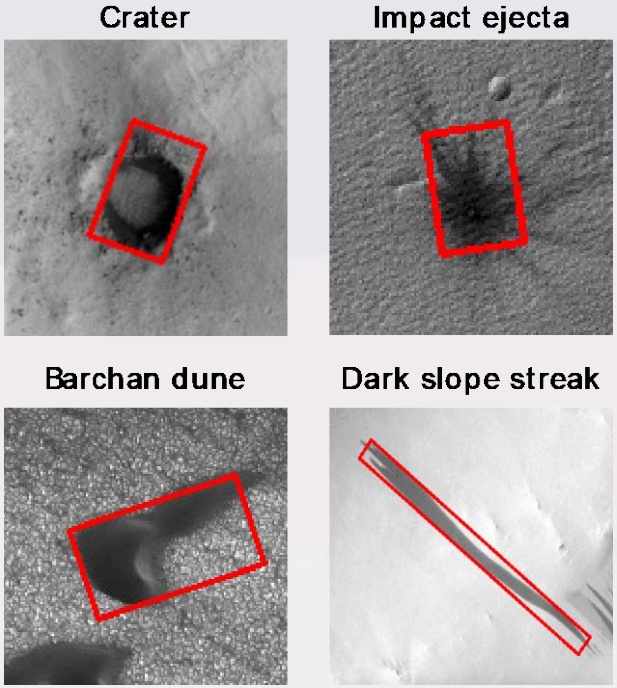
Approach:

1) Determine high salience regions by computing statistical differences between pixel and surrounding context
2) Classify landmarks using machine learning model and labeled training data

MOC, June 2000



Salience Map

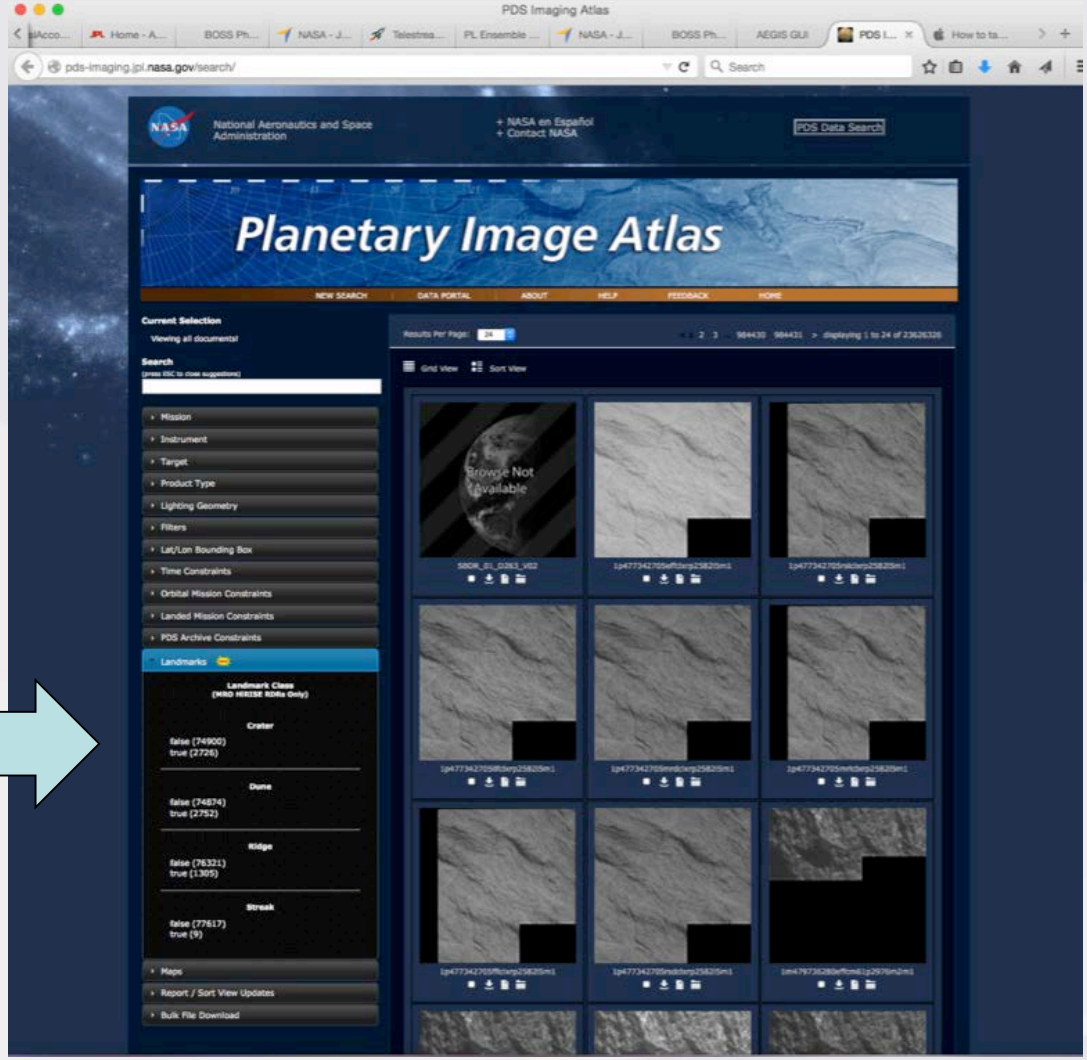


Examples of classified landmarks

Contact: Kiri Wagstaff

Landmarks Deployed to PDS (Planetary Data System)

Landmark classification deployed as Planetary Data Systems web service



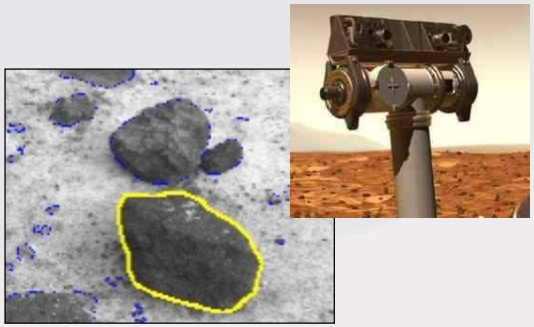
New landmarks search box

pds.jpl.nasa.gov

AEGIS Intelligent Targeting System

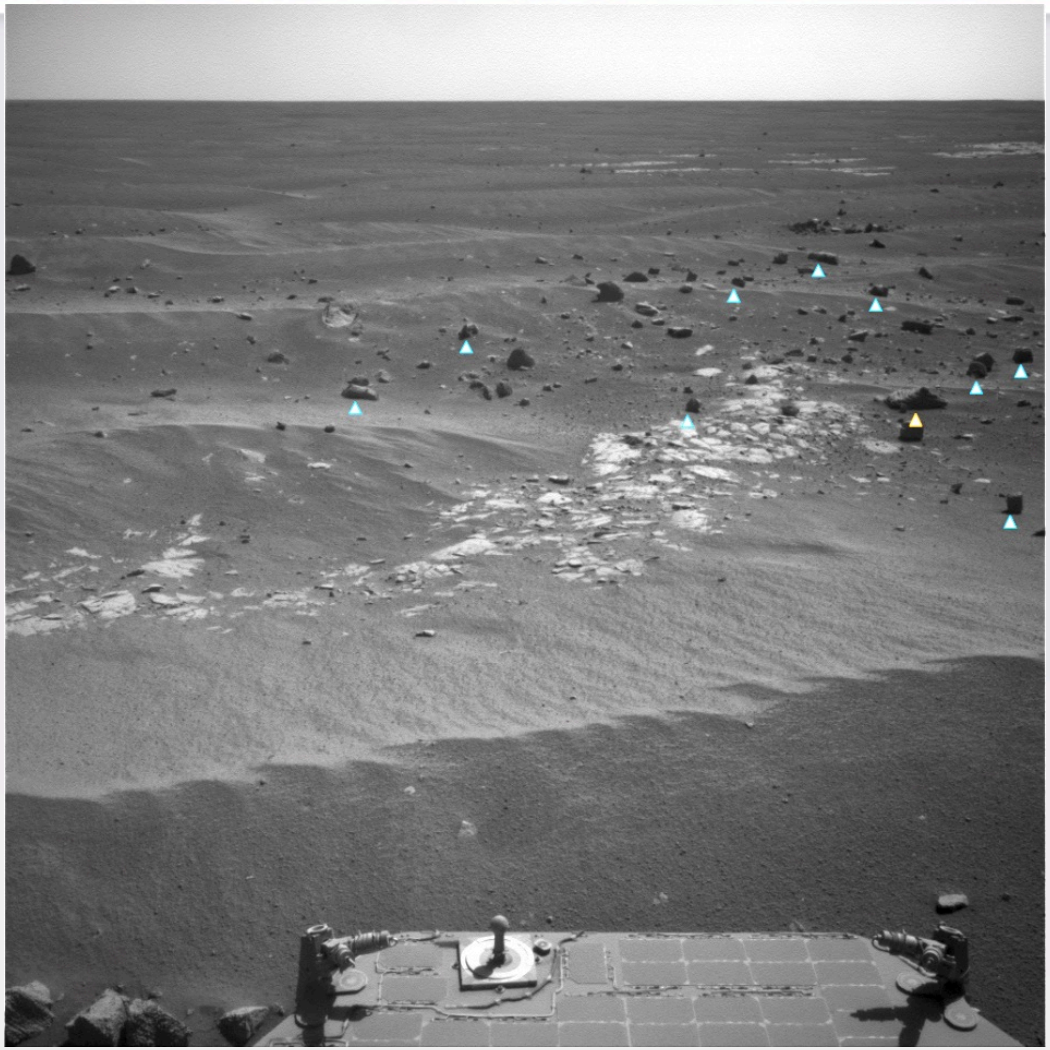
(Autonomous Exploration for Gathering Increased Science)

- Operational onboard MER Opportunity rover and recently uploaded MSL Curiosity rover
- Provides intelligent targeting and data acquisition capabilities
- Enables automated data collection for rover remote sensing instruments
  - Identify rock targets onboard through image analysis
  - Guided by scientist specified criteria
  - Can be run at end of drive or mid drive
  - No communication with ground required
- Winner of 2011 NASA Software of the Year Award



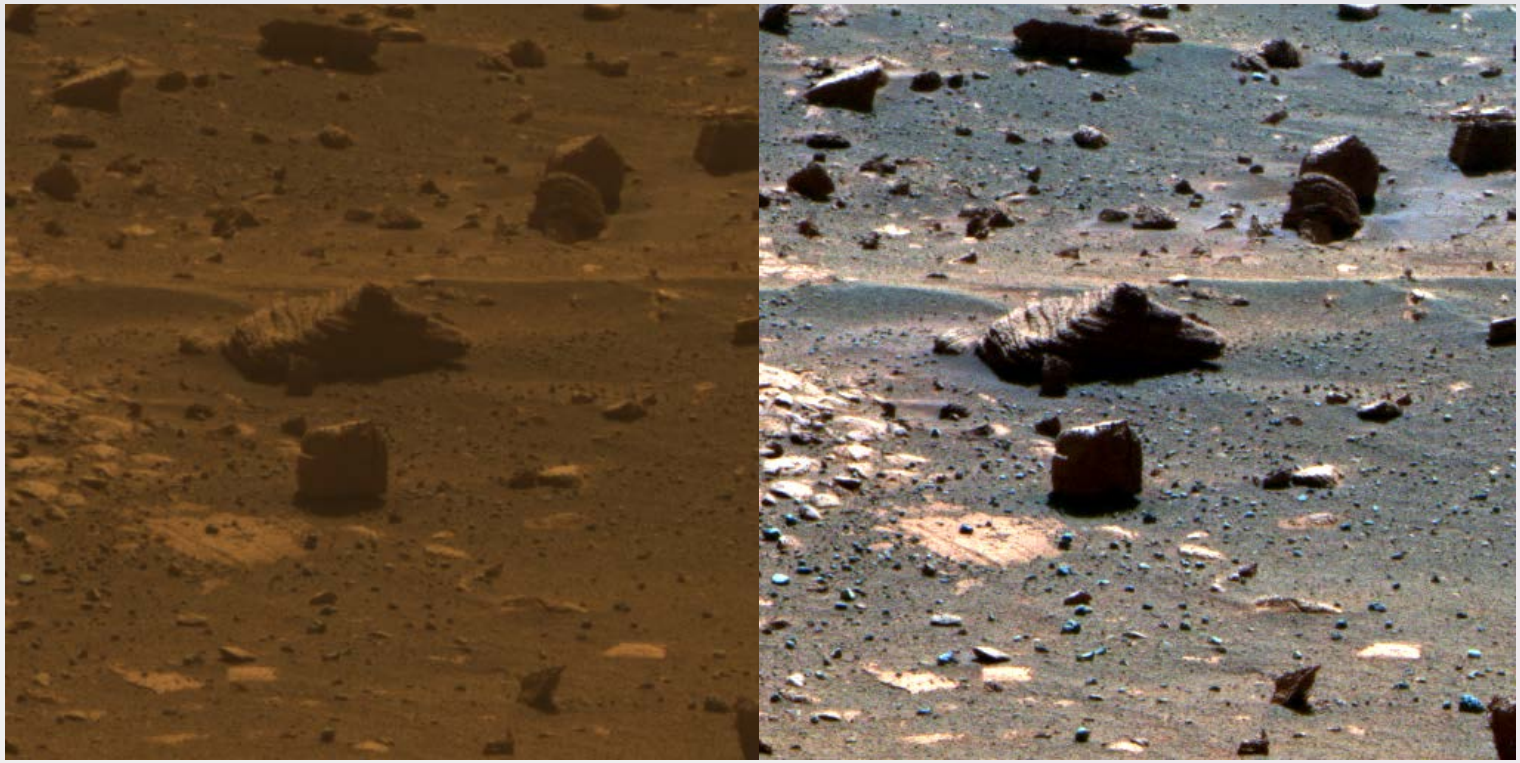
Contact: Tara Estlin

AEGIS Result from MER B Sol 2172



Analysis of Navcam image (after drive). Targets are prioritized by size and low albedo/reflectance. Shown are top ten targets in blue and top target in yellow.

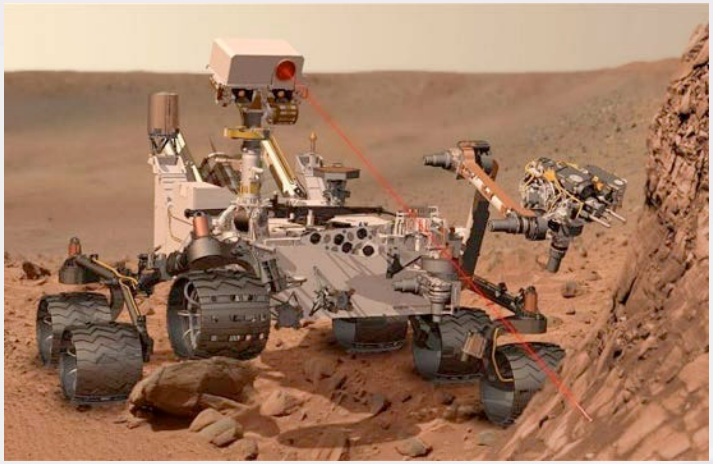
AEGIS Result from MER B Sol 2172



Final Pancams of top target (quarter-frame, 13F)

Application to MSL Curiosity Rover Mission

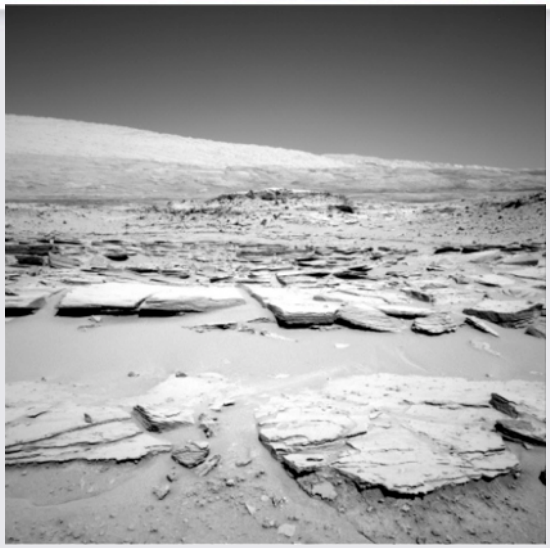
- Requested by MSL ChemCam team to support intelligent targeting onboard MSL
- ChemCam is a Laser-Induced Breakdown Spectrometer (LIBS)
  - Samples rocks from a distance of 1 to 7 meters
  - Able to rapidly identify rock elemental composition
- AEGIS will enable multiple autonomously targeted ChemCam measurements throughout the day



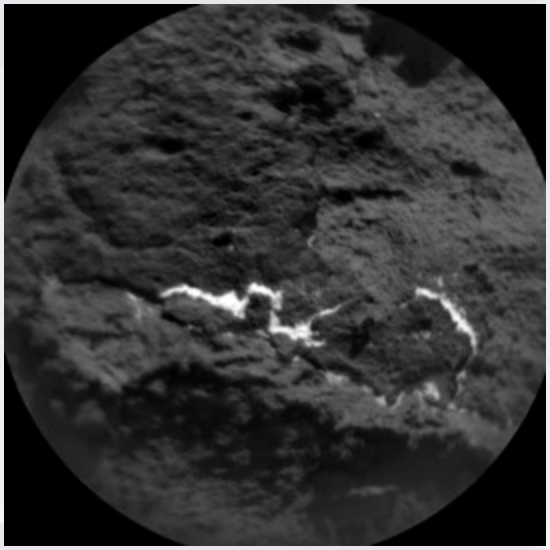
Application for MSL ChemCam

Two ChemCam applications

- Automated targeting using MSL Navcams
  - AEGIS analyzes Navcam for potential targets after or in middle of drive
  - Acquires LIBS raster on top N targets found
- Pointing refinement for small targets identified in Remote Micro Imager (RMI)
  - Small target (e.g., vein, concretion, grain) identified by ground camera
  - Ground points RMI
  - AEGIS refines pointing to ensure LIBS raster hits target on first attempt
  - Can acquire LIBS raster on top N targets found

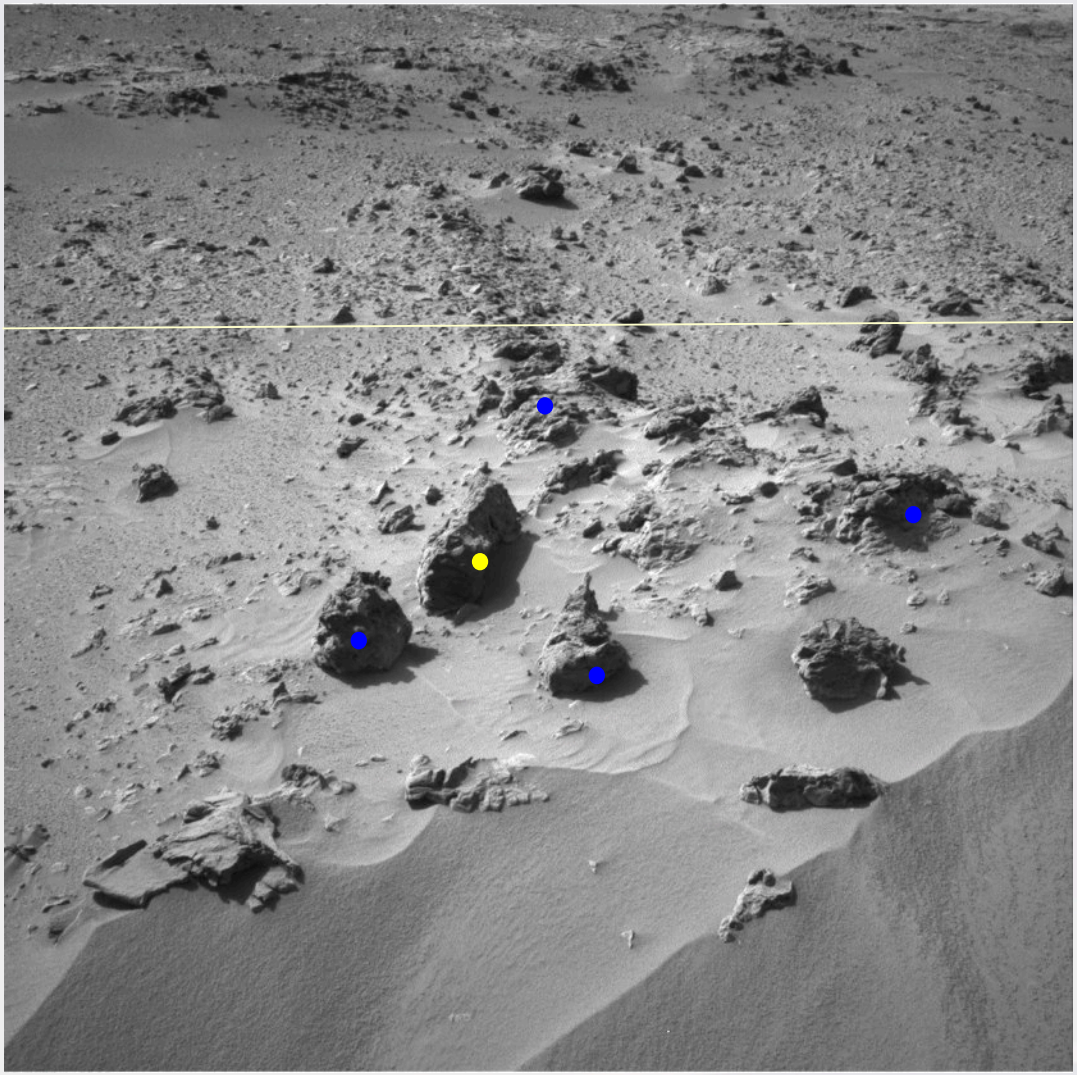


Sol 548 Navcam



Sol 530 RMI (FOV 15 cm)

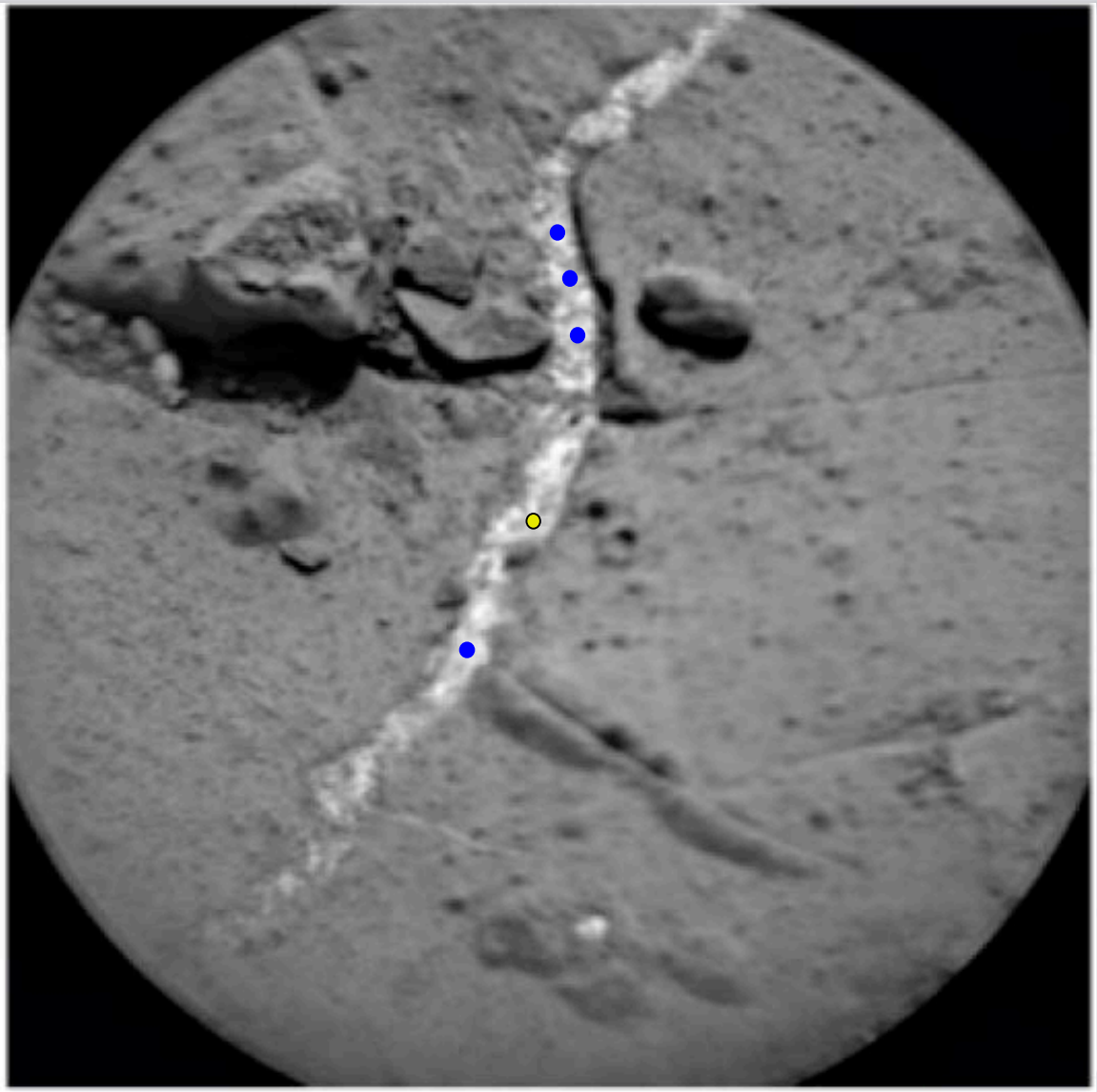
AEGIS analysis of MSL Navcam (sol 59)



7m range

Using rock size

AEGIS Analysis of MSL RMI (sol 165)



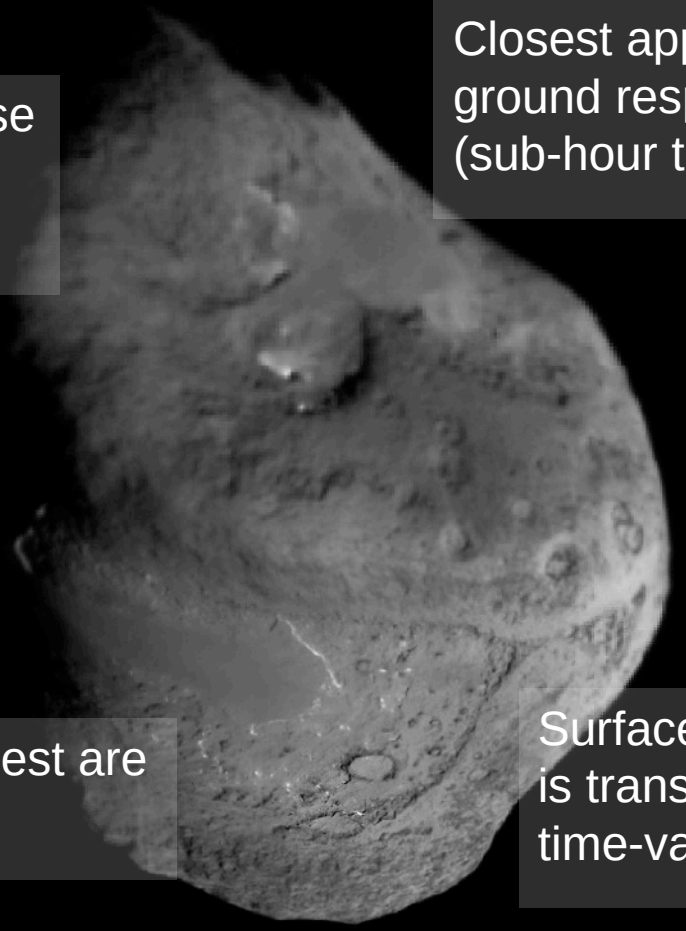
Using albedo

Agile Science Operations:
A new approach for primitive bodies exploration

Challenges of collecting data on primitive bodies:

Closest approach too fast for ground responses (sub-hour timescales)

Targets have diverse morphologies, compositions



Geometry and illumination constraints

Target locations are not known in advance

Surface activity is transient, time-variable

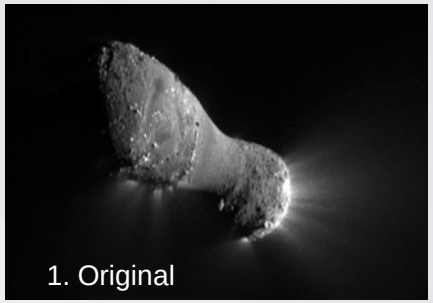
Features of interest are highly localized

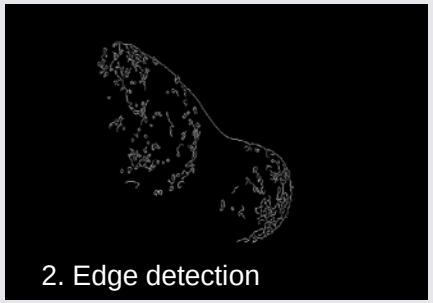
Images: Tempel 1 (Deep Impact) PIA 02142, NASA/JPL/UMD

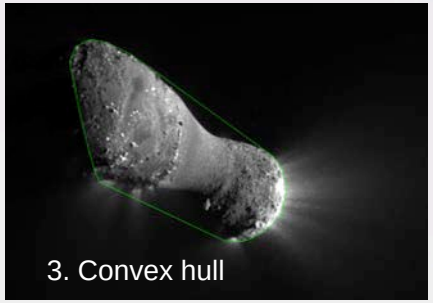
Contacts: David R. Thompson, Brian Bue

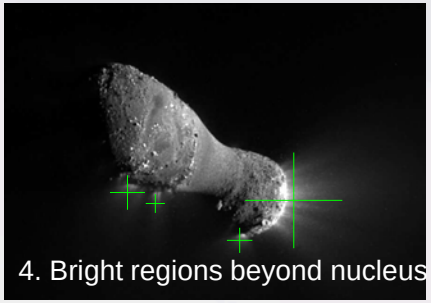
Onboard automated plume detection

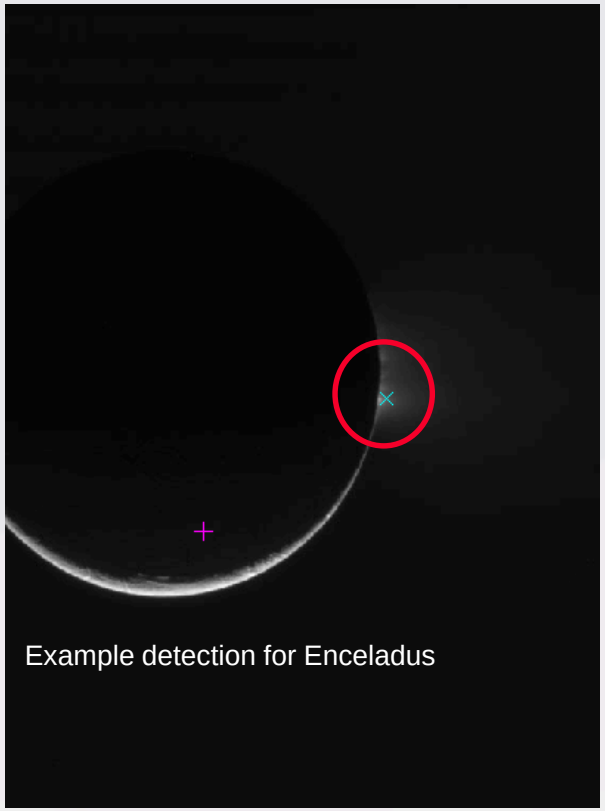
Typical performance is 70-100% recall with zero false positives (Hartley2, Enceladus)


1. Original


2. Edge detection


3. Convex hull

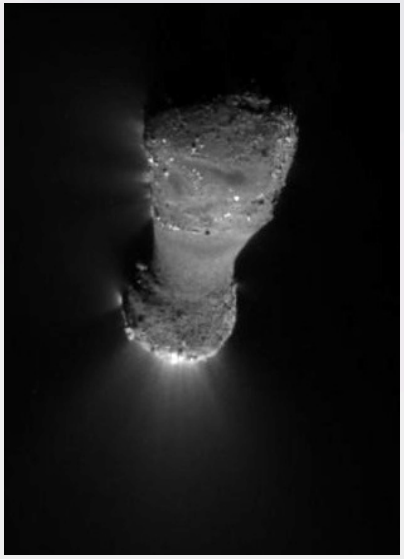

4. Bright regions beyond nucleus

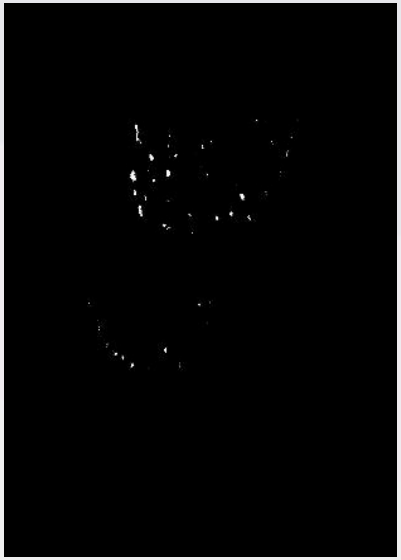

Example detection for Enceladus

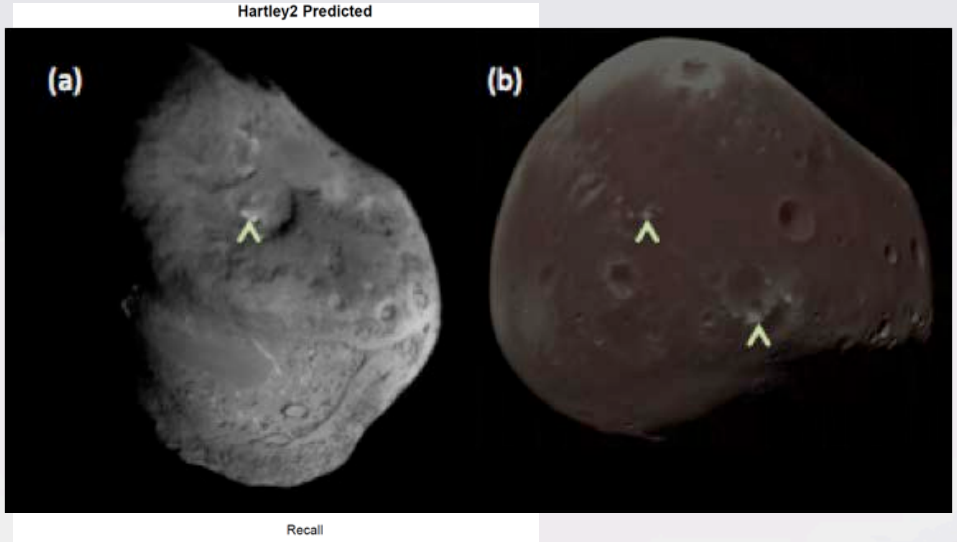
- Determine nucleus and mask out
- After edge detection find subset of of edge points that lie on exterior
- Model nucleus as conservative convex hull of edge points
- Apply 2D convex hull algorithm

Onboard detection of high albedo features

- We use a machine learning random forest classifier, trained on similar surface features, and classify each pixel independently.
- Attributes are simple arithmetic and comparison operators applied to nearby pixel intensities



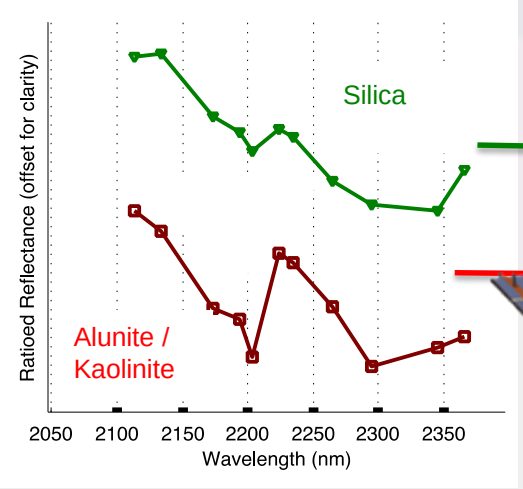




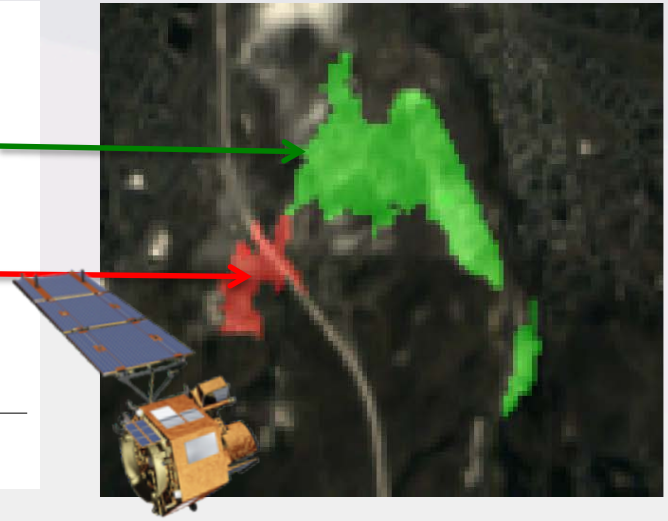
Results shown on Hartley2 comet (images taken by EPOXI mission) and Tempel1 comet (images taken by Deep Impact Mission)

EO-1 Autonomous Spectral Discovery

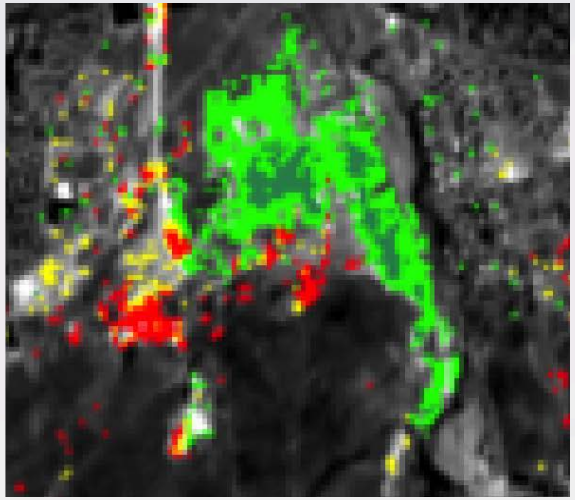
- Onboard analysis for the EO-1 Hyperion VNIR imaging spectrometer
- 220 spectral bands, 30m spatial resolution, 7.5x100km swath
- Endmembers detected and mapped onboard
- Summarizes a **250MB** data product to **20KB** for immediate downlink



Compositional map generated onboard



Authoritative version [Kruse et al., 2003]



Steamboat Springs, NV – Oct 2011

Contacts: David R. Thompson, Brian Bue

Extra Slides

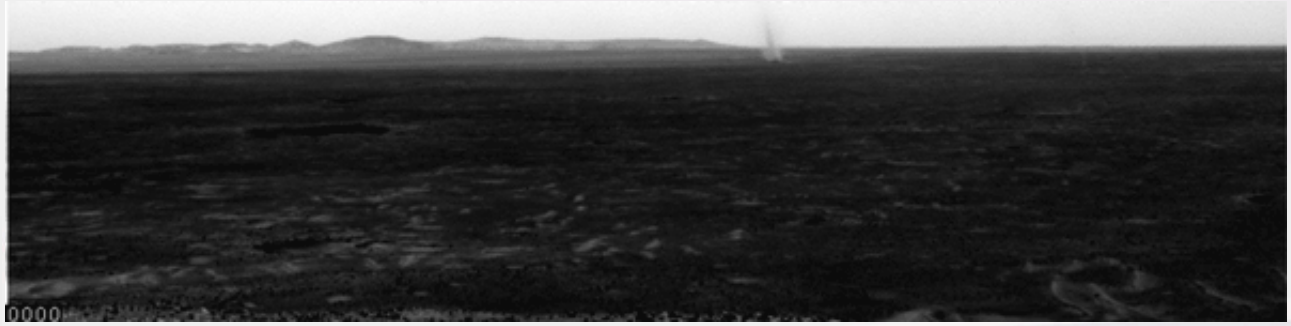
Onboard Science Autonomy

Traditional spacecraft operations:

- Select data collection opportunities on Earth
- Uplink commands to spacecraft and wait for data to be returned (often days or weeks)
- Analyze data after returned

Science autonomy enables a spacecraft to:

- Analyze science onboard and detection key signatures
- Recognize and capture dynamic or short-lived events
- Enable new science opportunities when ground communication cycle not possible
- Prioritize data onboard so critical data reaches scientists first

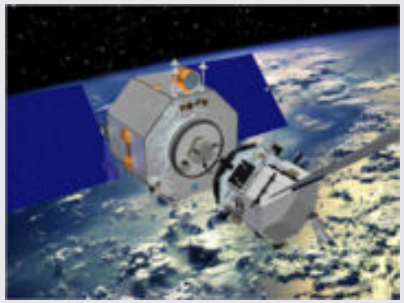


Spirit Sol 543 (July 13, 2005)

Automated Planning and Scheduling

Enables automated generation or modification of robotic command sequences

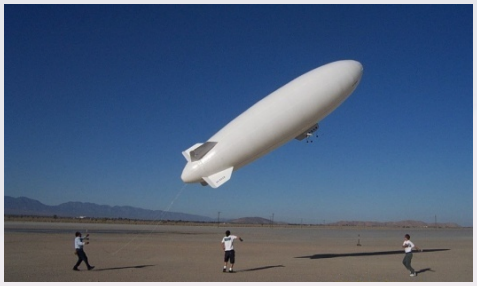
- Traditional approach has been manual, time intensive effort to create sequences by ground operators
- Instead, fast search techniques enable sequences to be created rapidly by using detailed model of vehicle



Orbital Express

Model specifies robot tasks, resources, states

- Operation rules, resource profiles, state information, time deadlines



JPL Airship

Allows ground operators to specify high-level goals vs. detailed commands

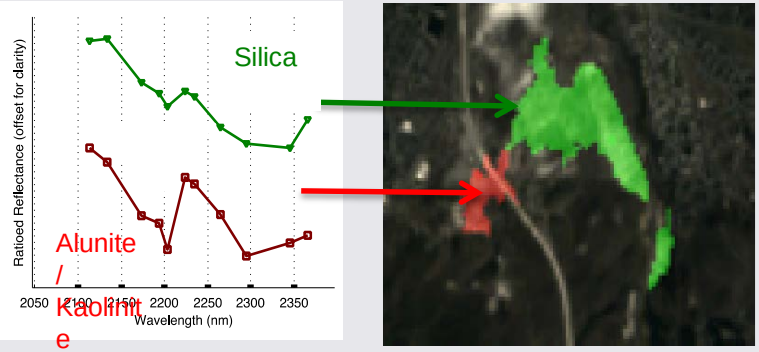
Can monitor robotic system, carrying out planned tasks and adapt tasks if necessary

Slocum glider submersible
(courtesy Rutgers University)

Onboard Data Analysis

Analyze data onboard vehicle to recognize

- Key science or target signatures
- Dynamic changes
- Outliers or novel data
- Anomalies



Analysis of Hyperion VisNIR data

Enables data to be prioritized or summarized for downlink

Enables responses to be triggered when events of interest are detected

Applicable to numerous instruments and data types (e.g., visual images, hyperspectral, infrared, seismic, radio)

Applicable to Range of Platforms and Sensors

Multi-Agent Coordination

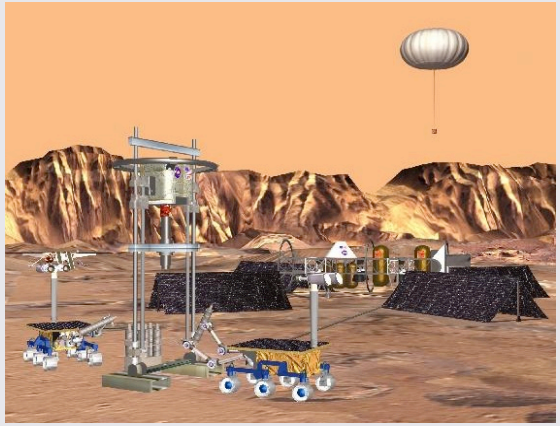
Coordinate multiple robotic agents in exploration or engineering activities

- Activities can be loosely or tightly coordinated
- Agents can be homogenous or heterogeneous robotic platforms

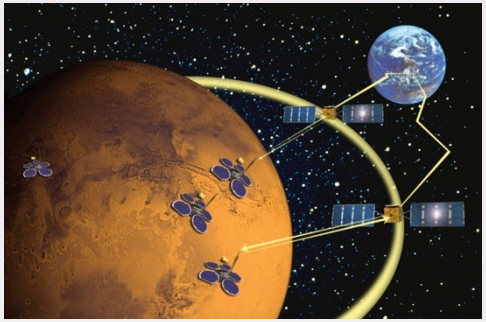
Automated task distribution based on agent capabilities

Enable robust behavior in presence of hardware failures or communication dropouts

Gathered data can be shared among platforms to guide activities and create global environment models



Surface robot coordination



Multi-spacecraft asset coordination

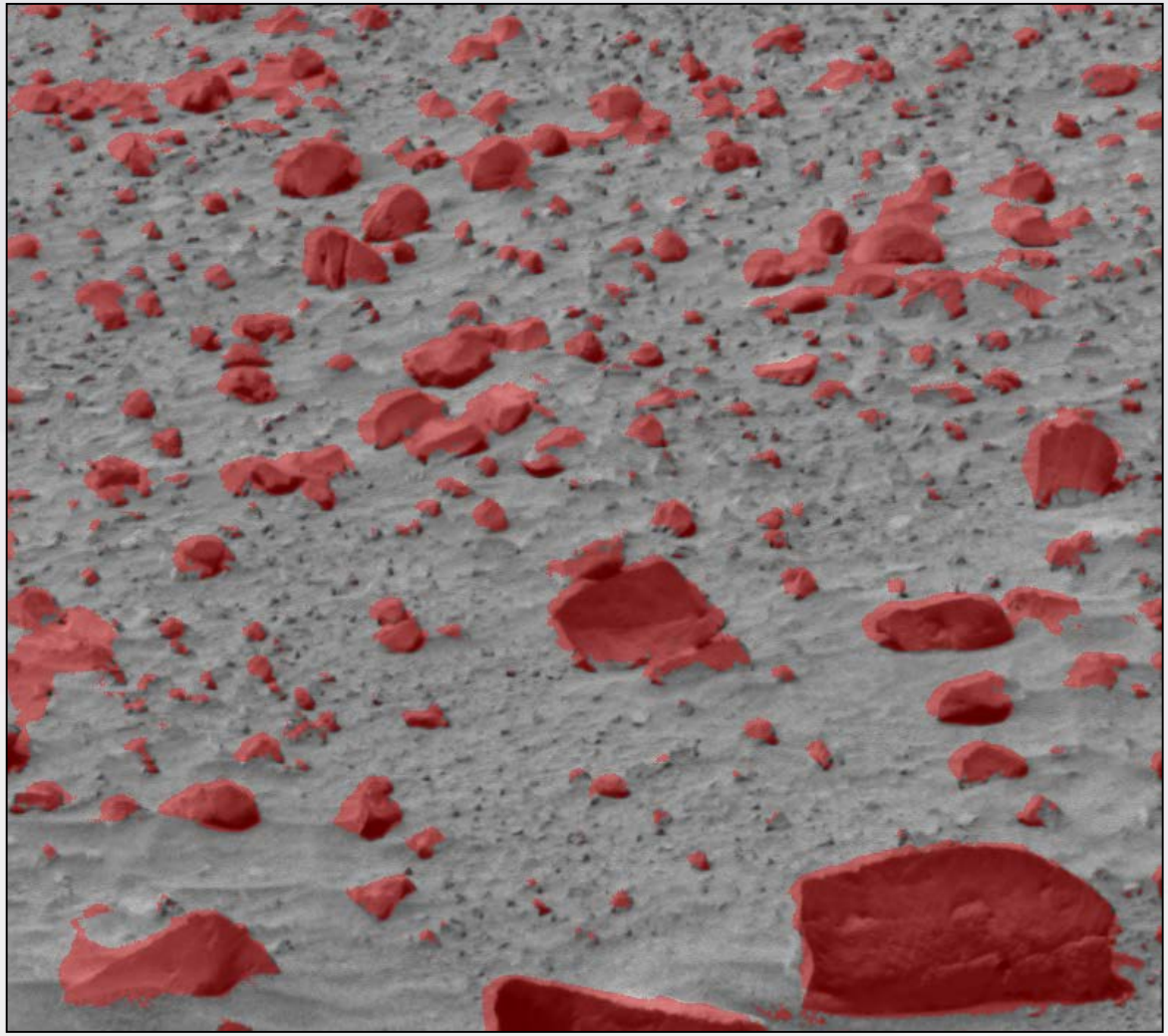
TextureCam

A Smart Camera for Astrobiology Site Survey

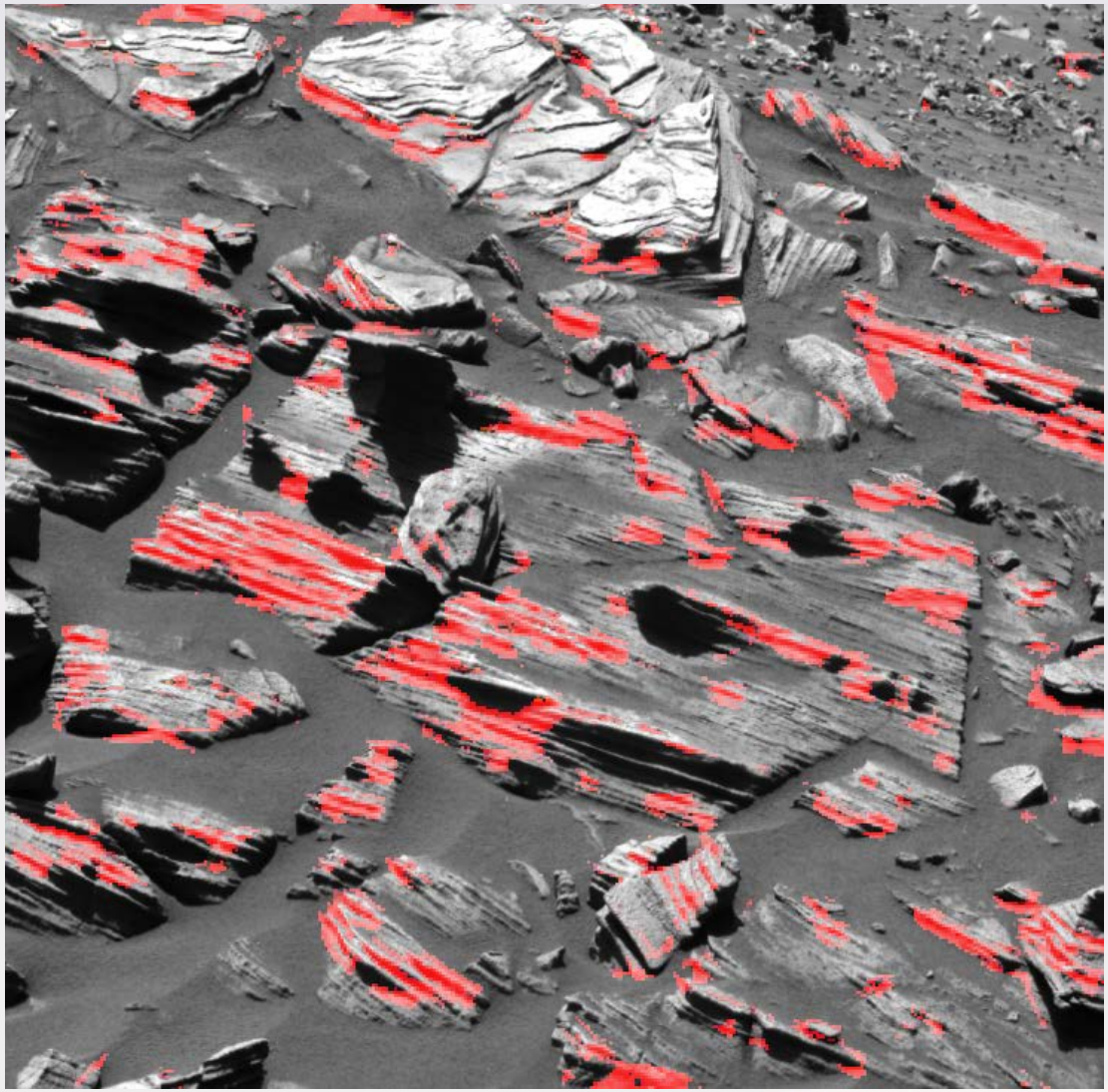
- A suite of software and algorithms for automatic classification of geologic surfaces
- Maps surfaces with texture channels which signify statistical patterns of image pixels
- To create a set of classifiers, uses a decision forest. Trees are created by training on a subset of pxels.

David R Thompson
Jet Propulsion Laboratory, California Institute of Technology

TextureCam Example



TextureCam Example



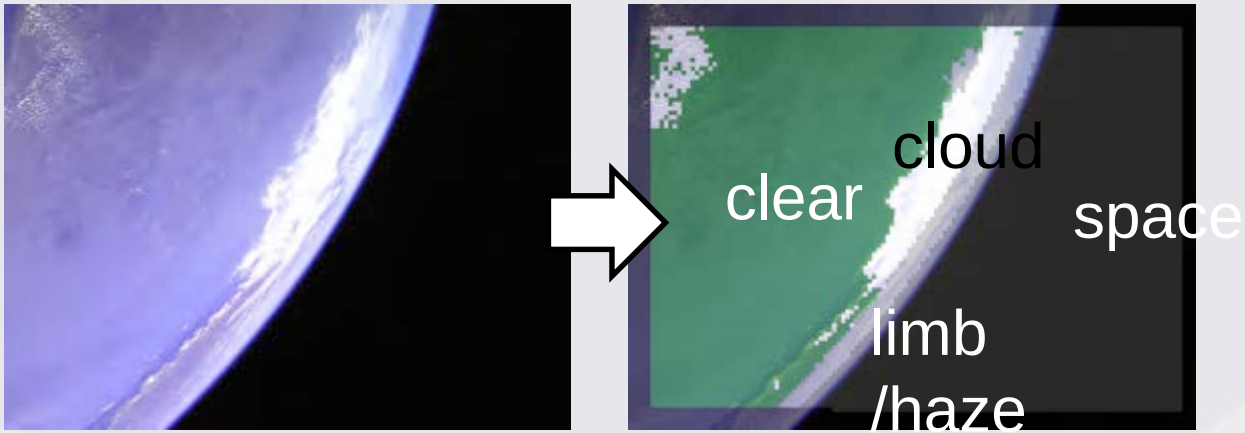
IPEX Cubesat onboard surface classification and cloud screening

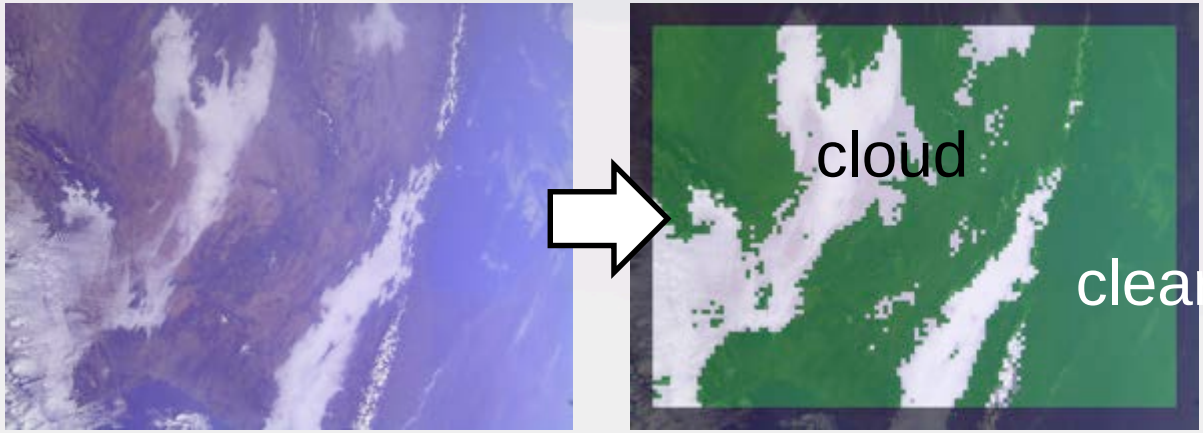
Contacts: steve.a.chien@jpl.nasa.gov, david.r.thompson@jpl.nasa.gov

We demonstrated fully-automatic image analysis onboard the IPEX spacecraft

A pattern recognition system based on the TextureCam codebase identifies surface features and excises clouds.

To date, thousands of images have been analyzed onboard





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