Autonomous Targeting of Geochemical Measurements on Mars

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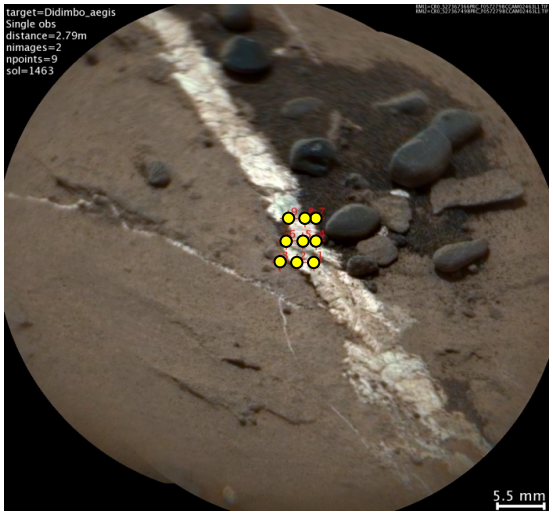
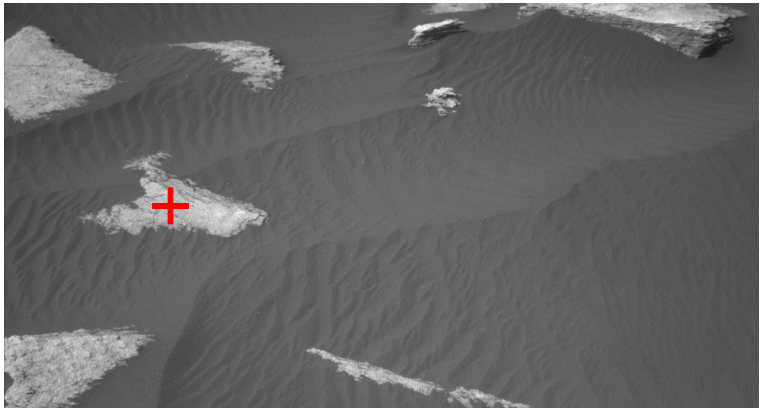
Introduction to AEGIS

AEGIS is:

- An **intelligent software** system
- Running since 2016 **on-board** the *Curiosity* rover
- **Autonomously choosing science targets** and measuring them with the ChemCam laser spectrometer instrument
- Favoring targets based on **scientists' preferences**
- Regularly, reliably interpreting **complex natural scenes**
- **Consistently performing well** even in unexplored terrain



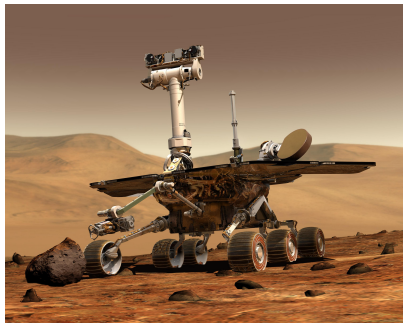


AEGIS Intelligent Targeting System

"Automated Exploration for Gathering Increased Science"

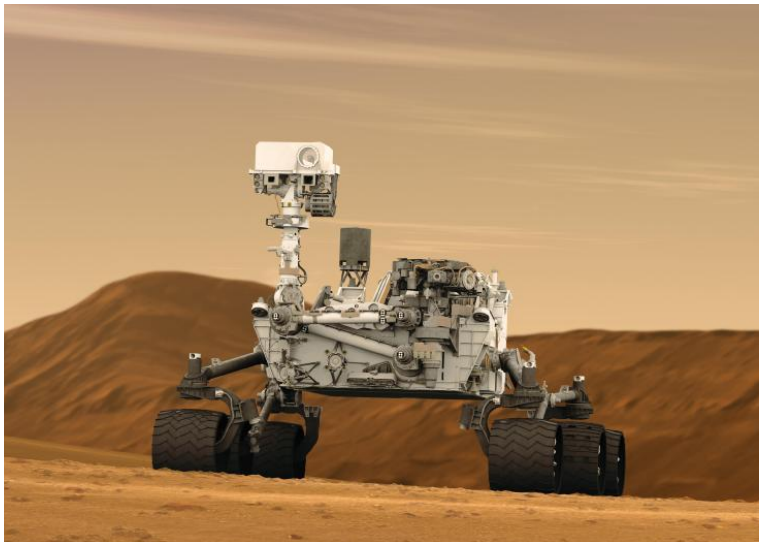
AEGIS was first flown on MER Opportunity in 2010

- Autonomous target selection for PanCam

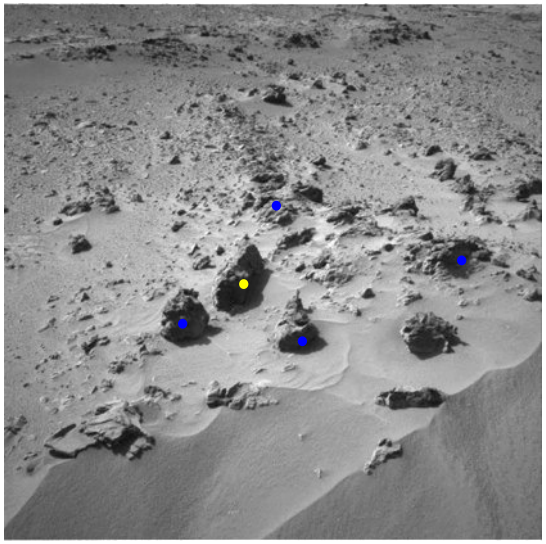


Now in use for ChemCam on MSL since 2016

- Autonomous target selection in NavCam images for ChemCam

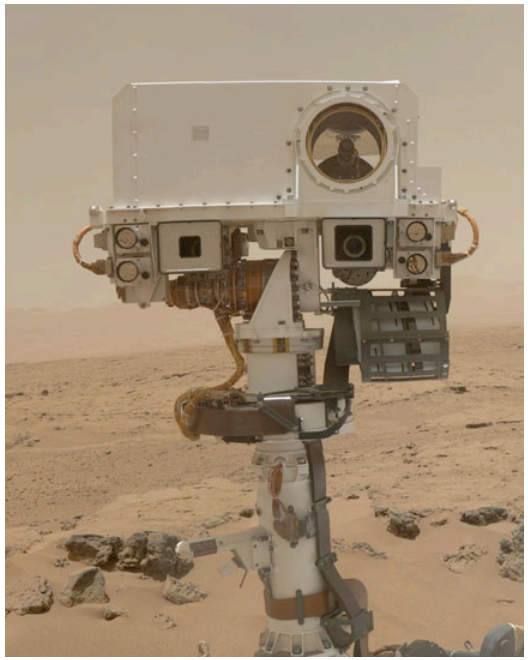


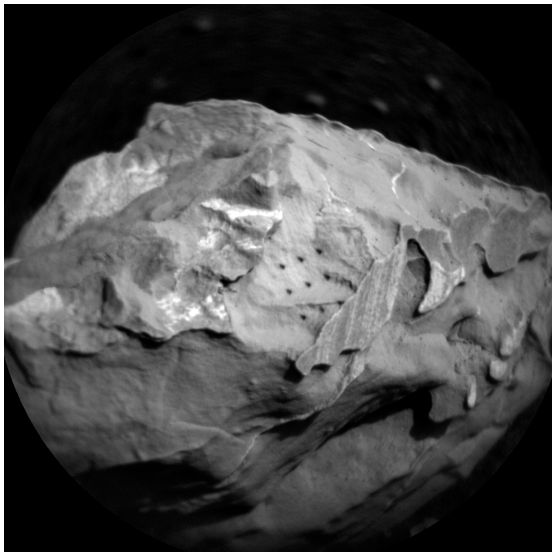
NavCam



ChemCam Instrument

- Laser-Induced Breakdown Spectrometer (LIBS) with Remote Micro-Imager (RMI)
- Gives geochemical composition of rock targets at ranges up to 7 meters
- Over 600,000 measurements on 1700 targets on Mars since 2012
- Joint development of
  - Los Alamos National Laboratory (LANL, Los Alamos)
  - Institut de Recherche en Astrophysique et Planétologie (IRAP, Toulouse)

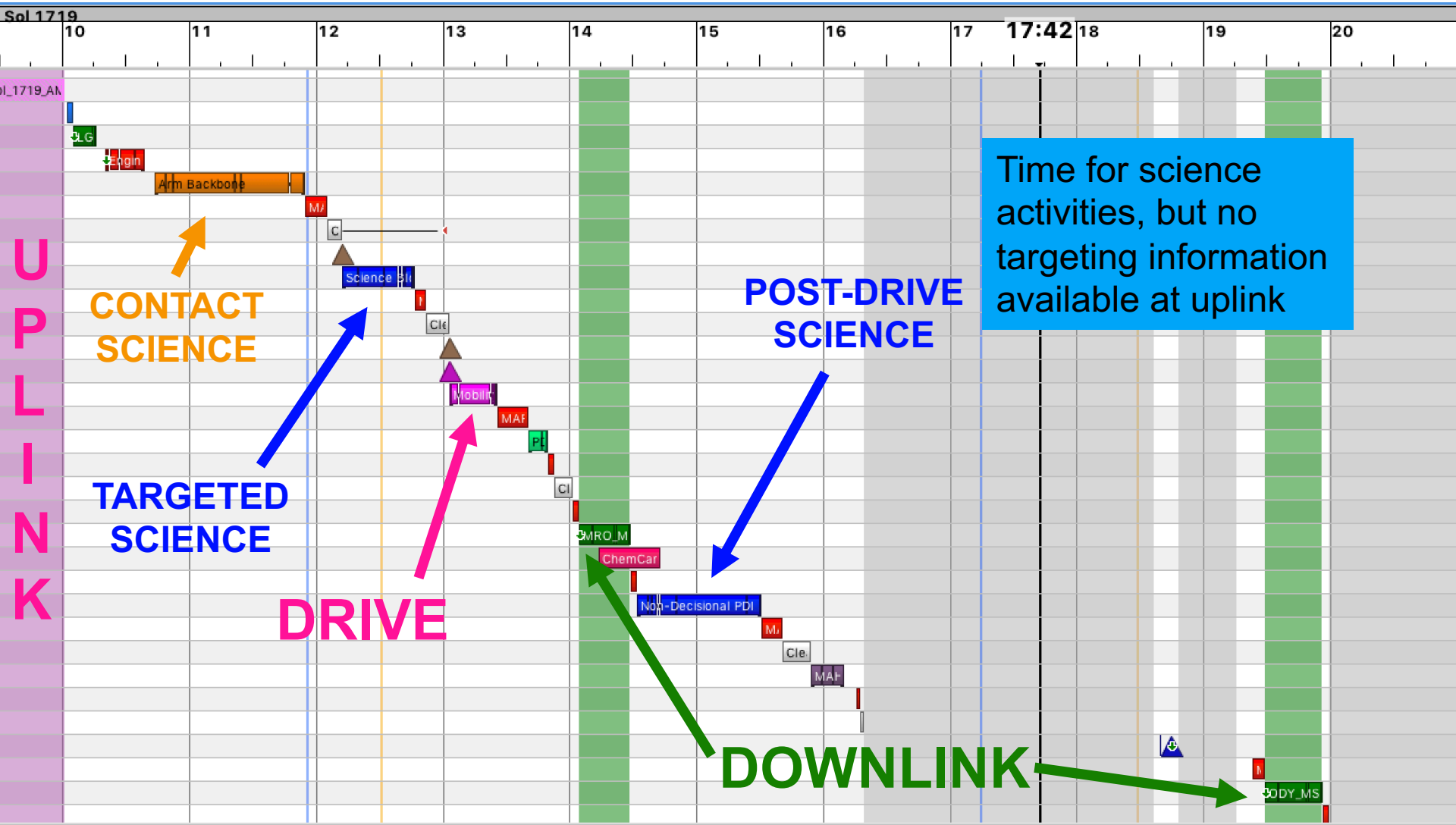




Why do we need autonomous targeting?

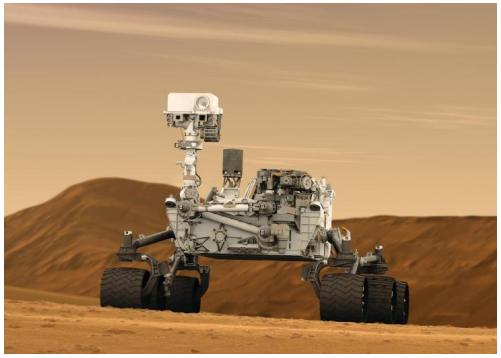
A (simplified) typical day on Mars

Sol 1719: Planned on 6 June 2017



Deployment Challenges

- *Curiosity* hardware and software complexity



- New safety constraints compared to MER
  - Sun-Safety (“Don’t look at the sun!”)
  - Collision (“Don’t shoot the rover!”)
- Limited onboard memory
  - 256 MB of DRAM, 128 MB of RAM – AEGIS limited to 16MB
- Flight processor: RAD750 @ 133 MHz
  - AEGIS runtime: 2-5 minutes
  - Stereo information on targets is time consuming

AEGIS deployment & Ops team

AEGIS deployment relied on AEGIS, MSL, and ChemCam teams:

- **AEGIS**
- Tara Estlin (AEGIS PI)
- Daniel Gaines
- Raymond Francis
- Gary Doran
- Vandi Verma
- Benjamin Bornstein
- Michael Burl

- **And of course:**
- Larger AEGIS development team
- ChemCam ops personnel
- MSL engineering ops team
- MSL science ops team

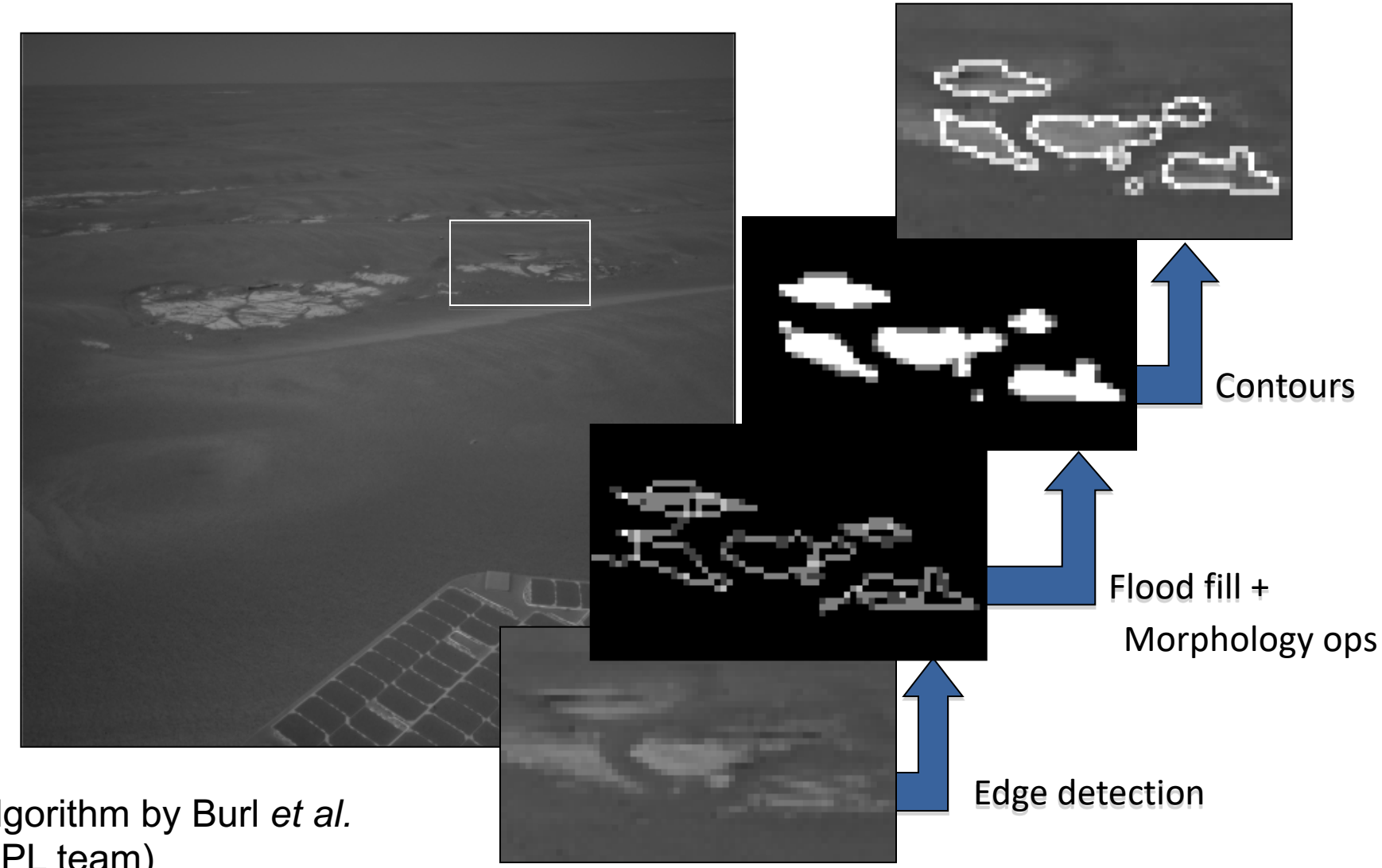
ChemCam

Roger Wiens (ChemCam PI)
Steven Johnstone
Suzi Montaño
Olivier Gasnault
Laurent Peret
Eric Lorigny
Diana Blaney
Jens Frydenvang
Valérie Mousset

MSL

Deb Chattopadhyay
Betina Pavri

AEGIS Target Detection using ROCKSTER

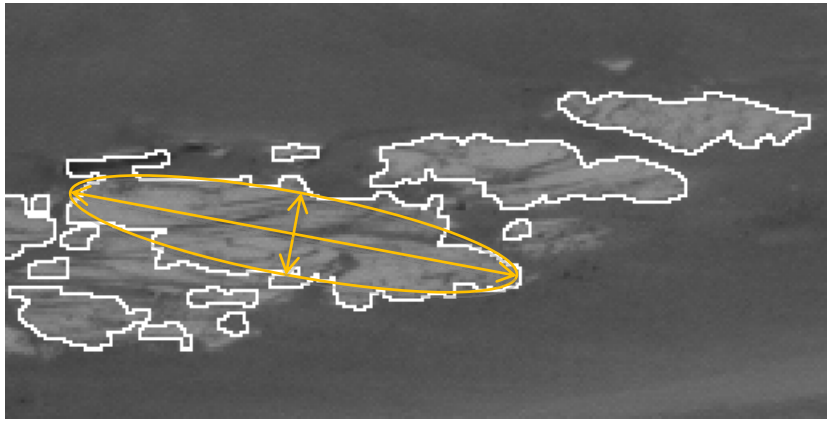


Algorithm by Burl *et al.*
(JPL team)

Target Property Evaluation

Size

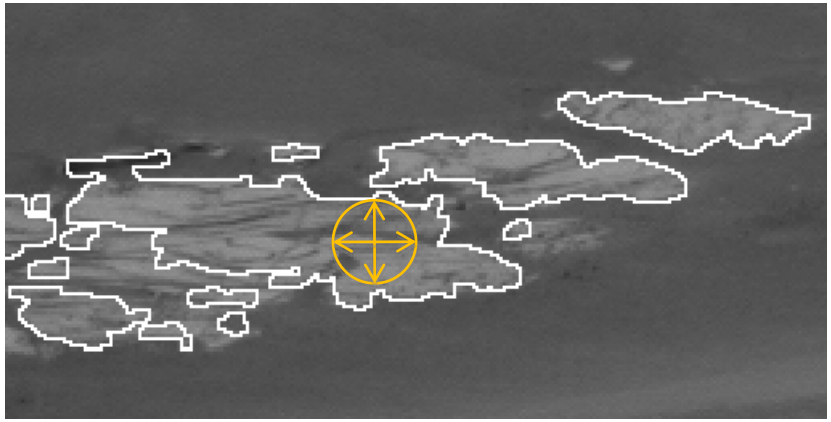
- Number of pixels
- 3D estimate (from stereo)
- Ellipse semi-major axis
- Ellipse semi-minor axis



Ellipse fit example

Position

- Distance from rover
- Inscribed circle x, y
- Site x, y, z
- Site az, el



Inscribed circle example

Target Property Evaluation

Intensity

- Mean
- Variance

Light **Dark**

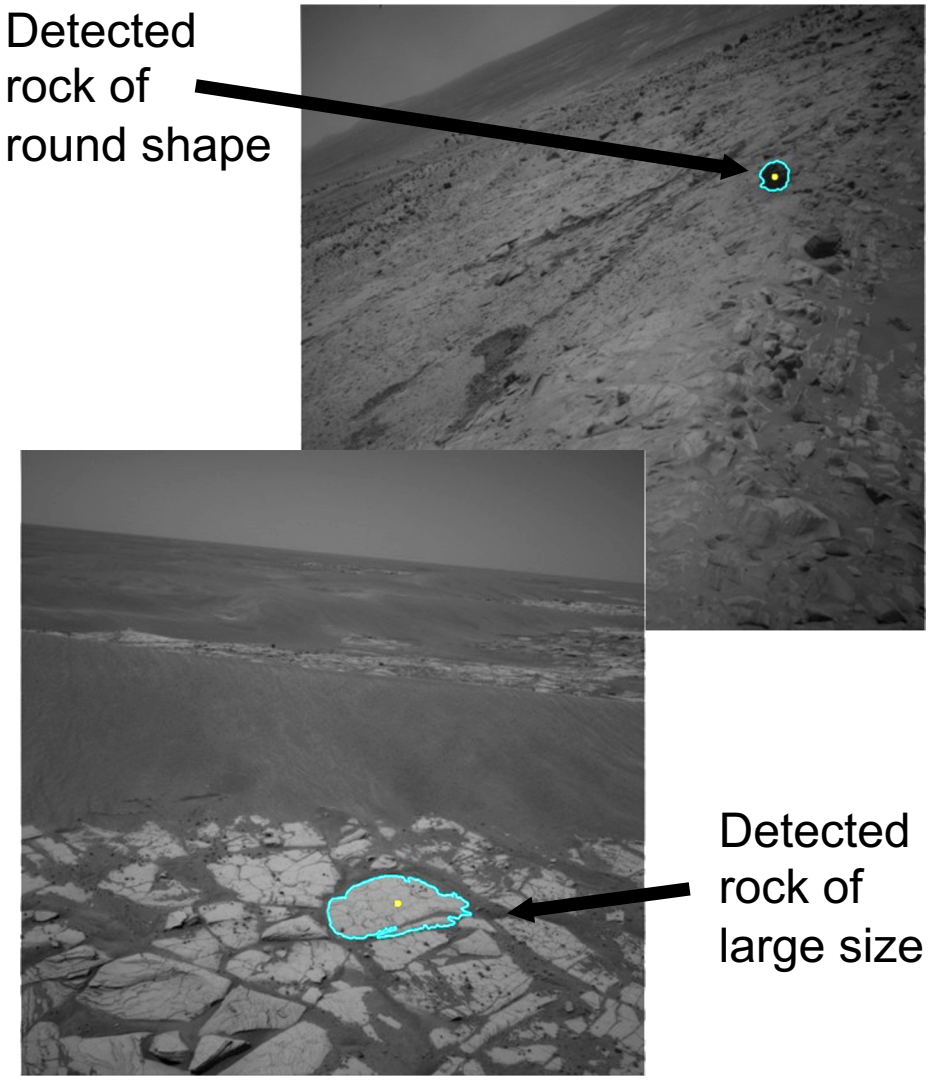
Shape

- Eccentricity
- Ellipse fit error
- Ruggedness
- Orientation

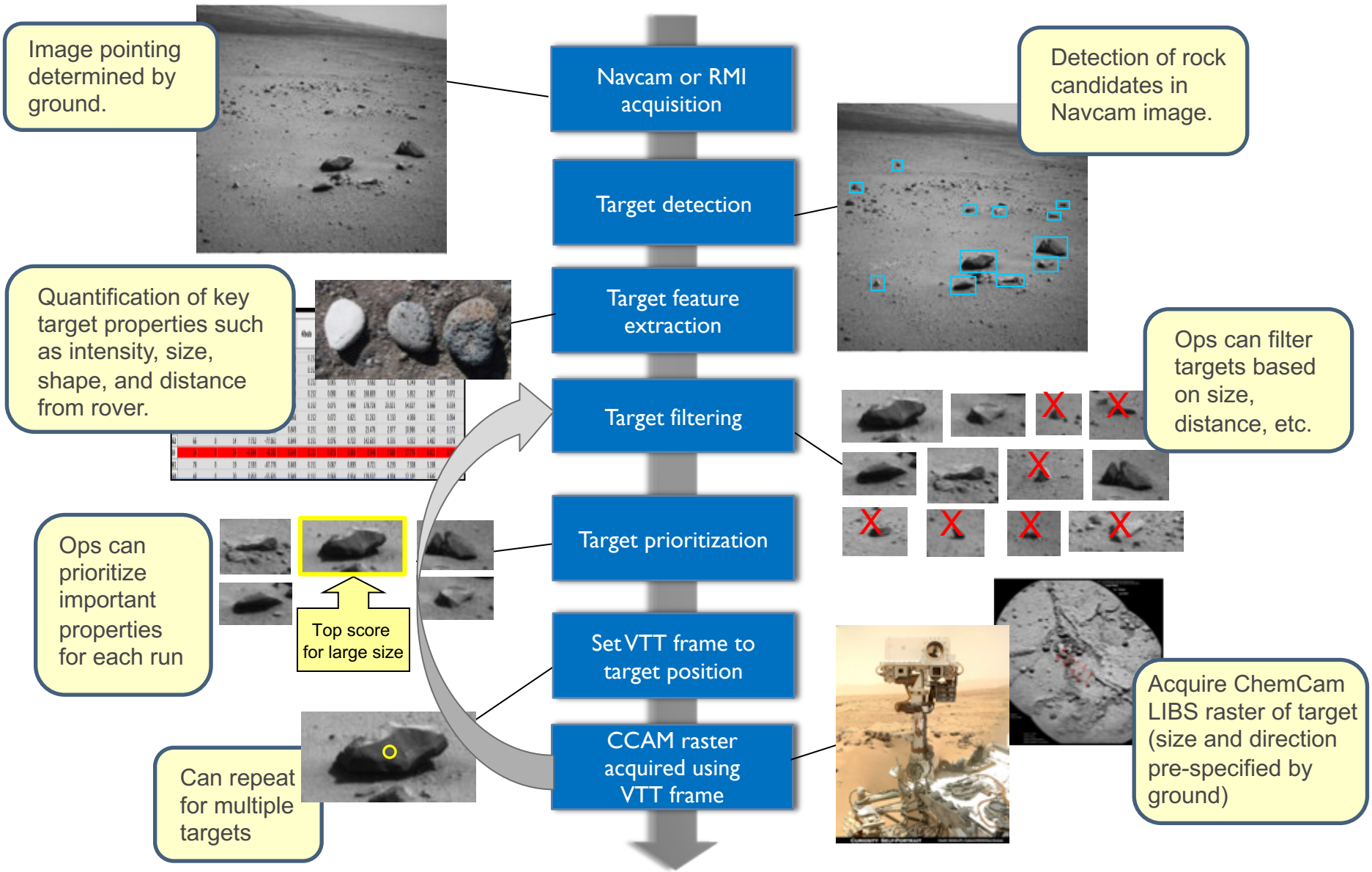
Rounded **Angular**

Target Prioritization

- Scientists can prioritize different property values
  - Single or combinations
  - e.g., prefer large, high albedo rocks
- Property setting is done at command sequencing
- Can be easily changed as rover enters different terrain areas
- Can support specific mission campaigns
  - e.g., cobble finder, outcrop finder



Full On-board Process

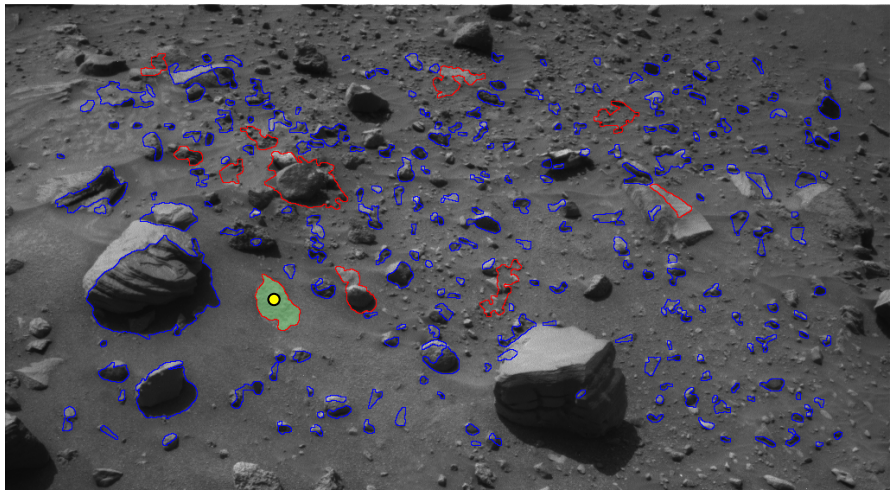


Results: Target selection

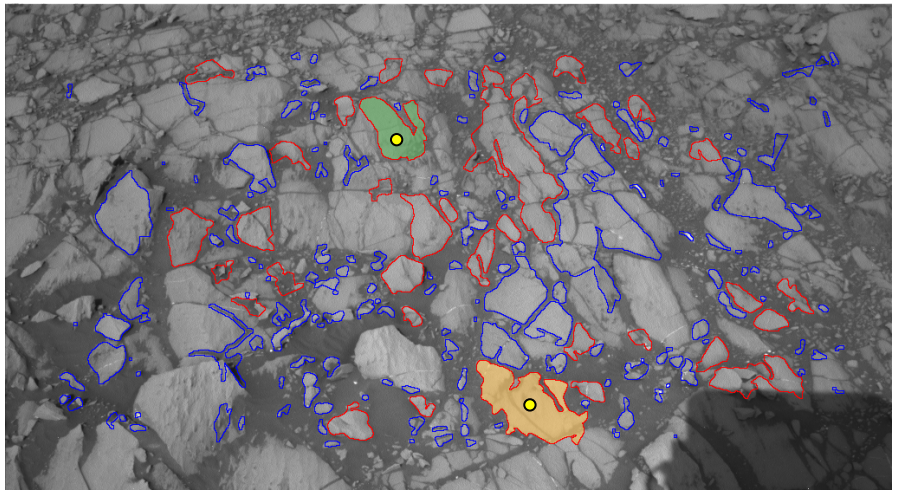
Examples from the NavCam runs on the following slides…

- Legend
  - Top target colored in **green**
  - 2nd-ranked target colored **orange** if observed
  - Targets retained after filtering: **red** outline
  - Targets found but filtered out: **blue** outline
    - Poor stereo range estimate, sun-safety, collision, outside ChemCam range, very small, very large
- **Keep in mind**
  - AEGIS' target-finding algorithm is searching for closed contours
  - **What matters most is**:
    - Which target was picked?
    - Where did the LIBS shots end up?

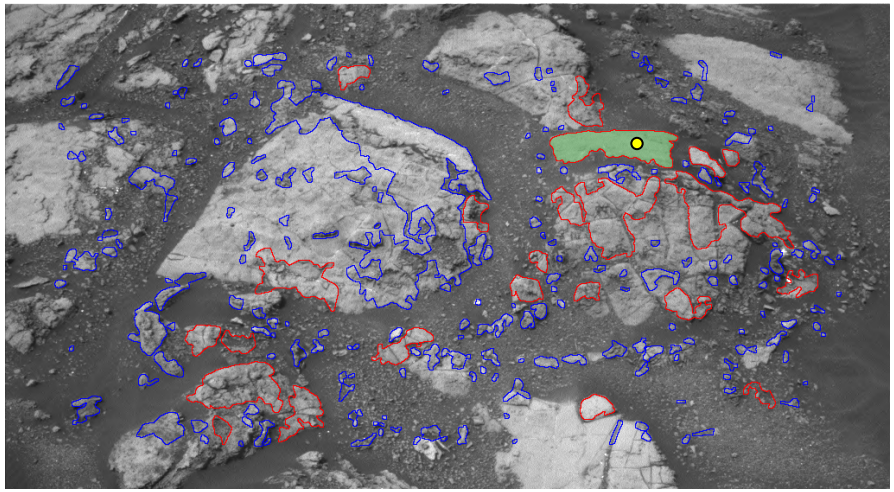
Results: Target selection



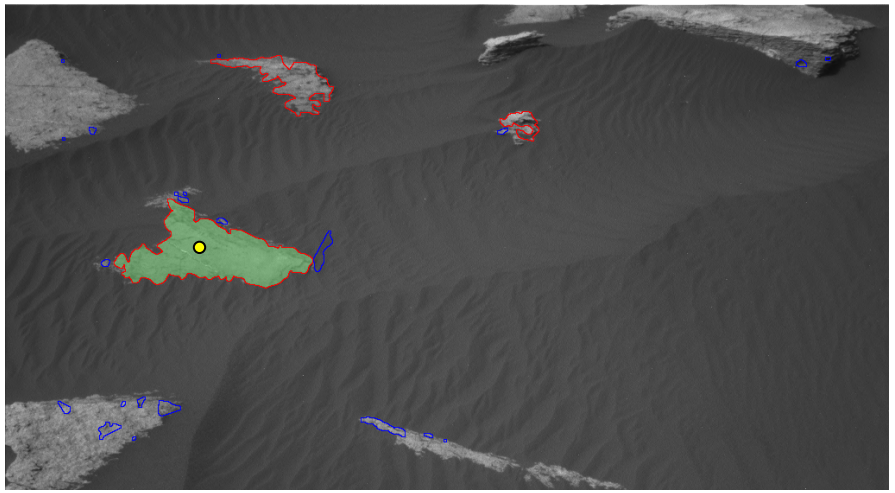
Sol 1400



Sol 1417



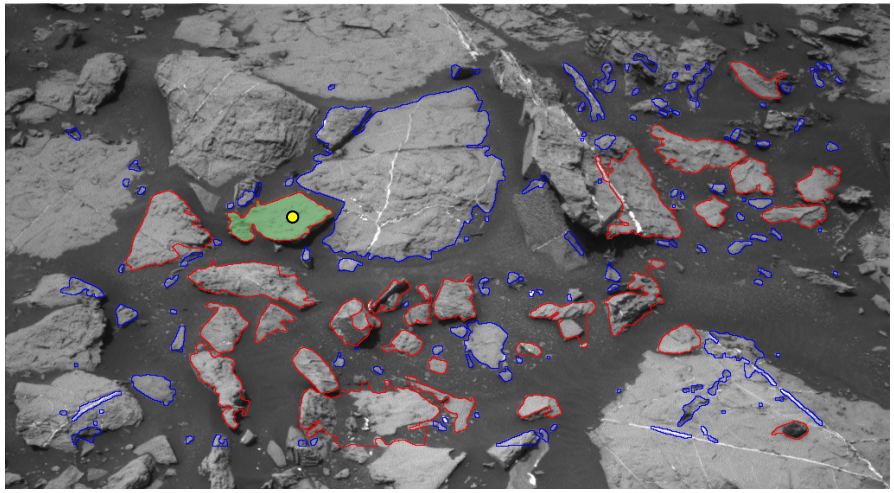
Sol 1481



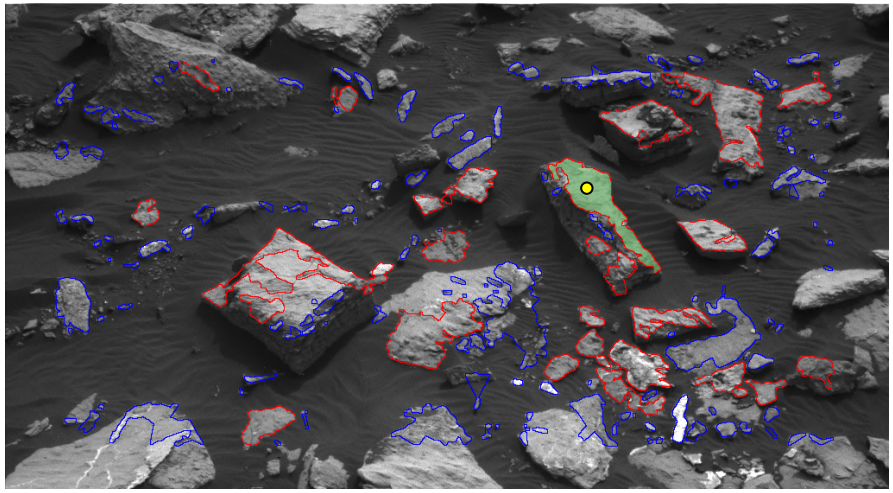
Sol 1636

("Sol" = Martian Day)

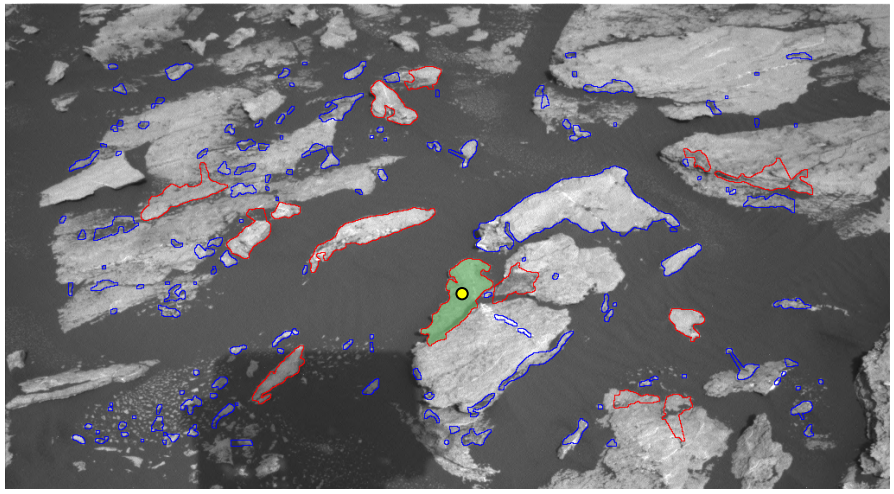
Results: Target selection



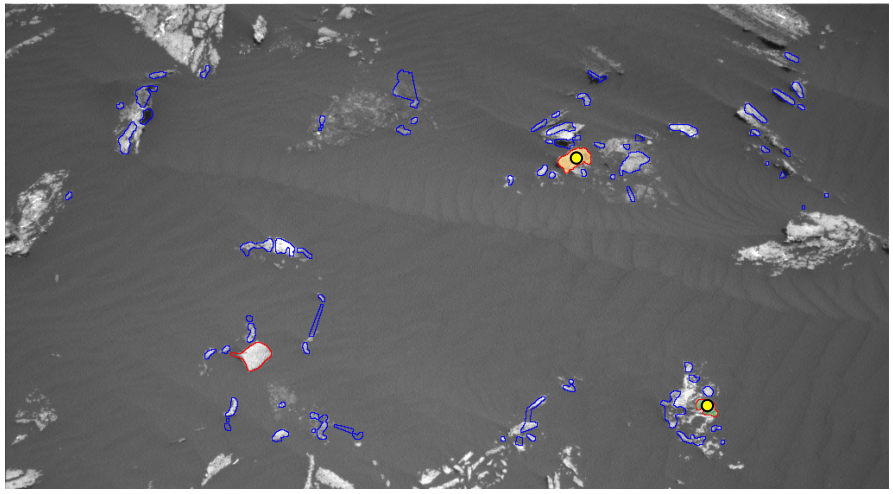
Sol 1449



Sol 1516



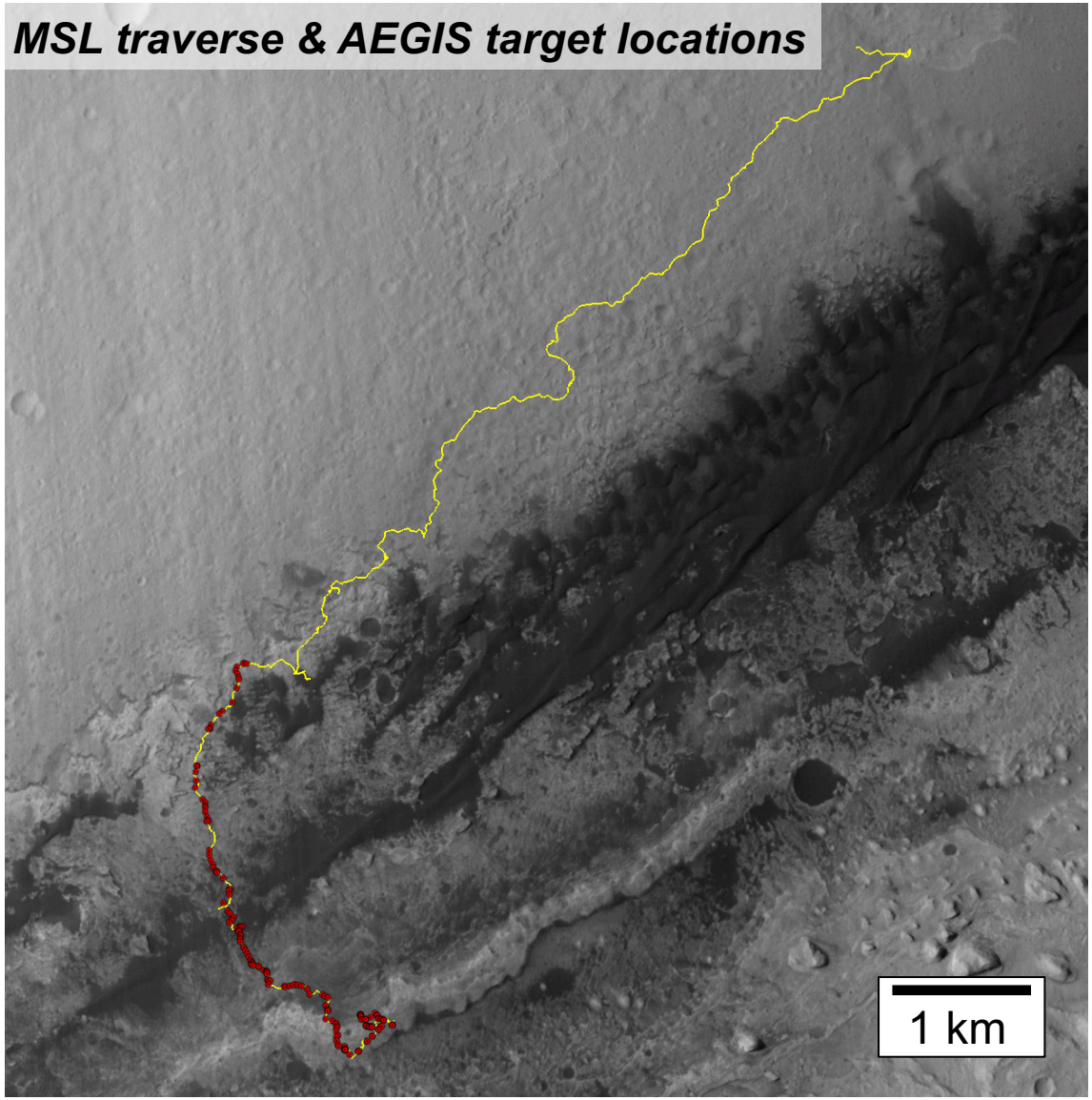
Sol 1605



Sol 1660

Use by the Science Team

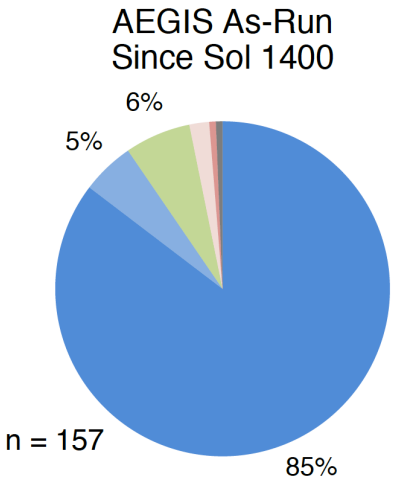
- First used sol 1343
  (planned on 13 May 2016)
- Results here as of sol 2240
  (planned 20 Nov 2018)
- Post-drive NavCam version:
  150 runs, 177 targets
- Pre-drive RMI version:
  3 runs
- Total MSL odometry since rollout: 6.859 km



Results: Target selection

For the post-drive targets…

- ChemCam on AEGIS' top-ranked target (or top 2 if time allows)
- Hits clean outcrop 85% of runs since sol 1400 parameter update



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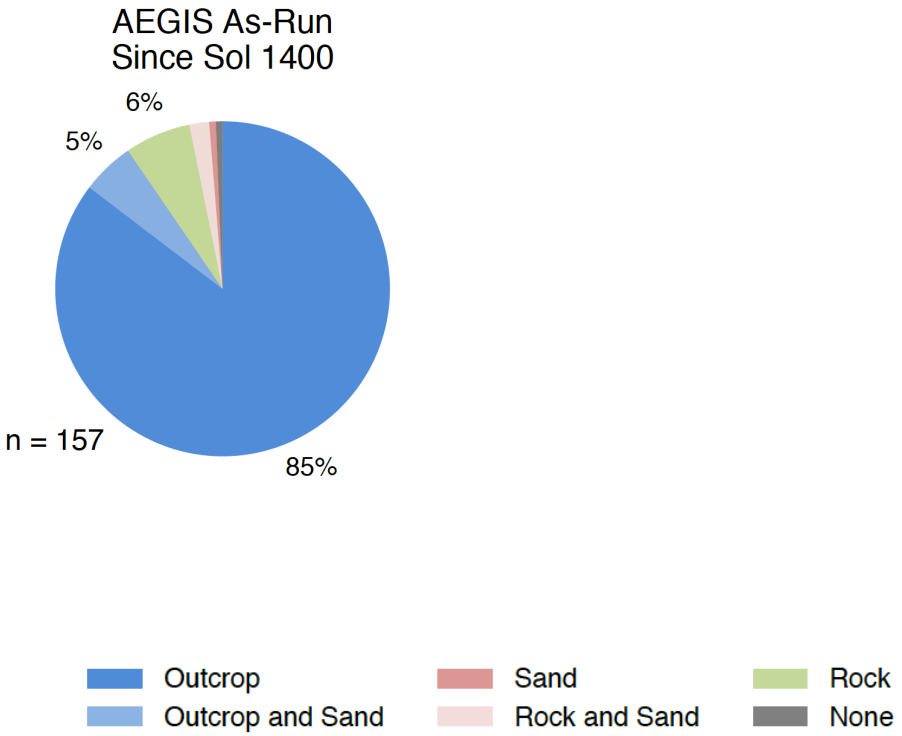
  - Chose a float rock or other material (usually when there is little outcrop in view)



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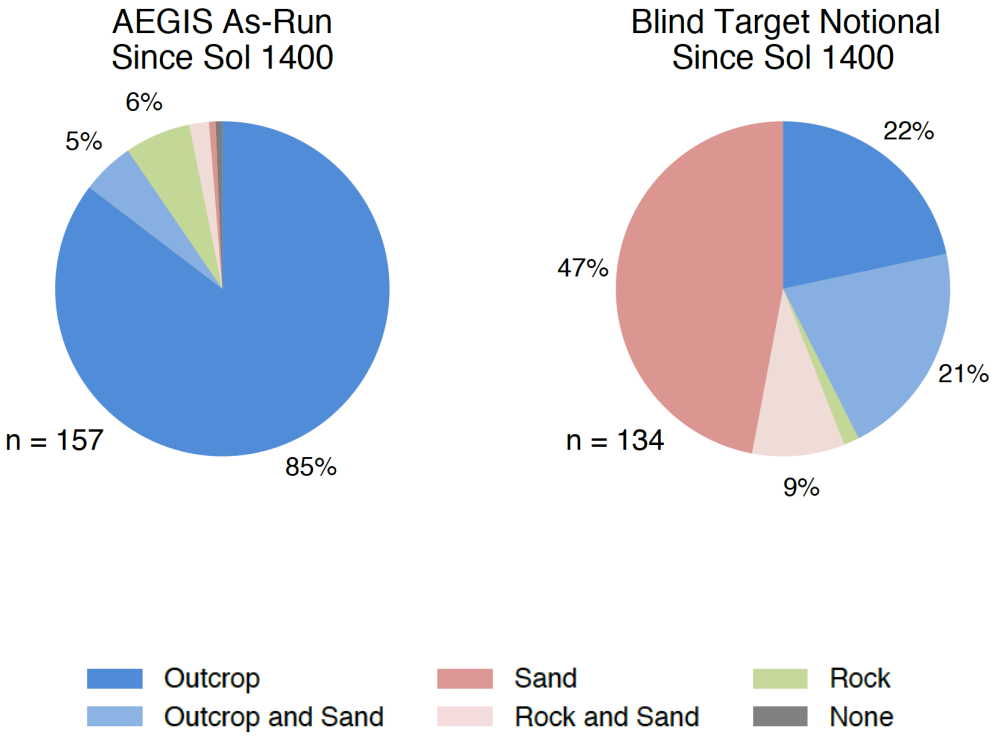
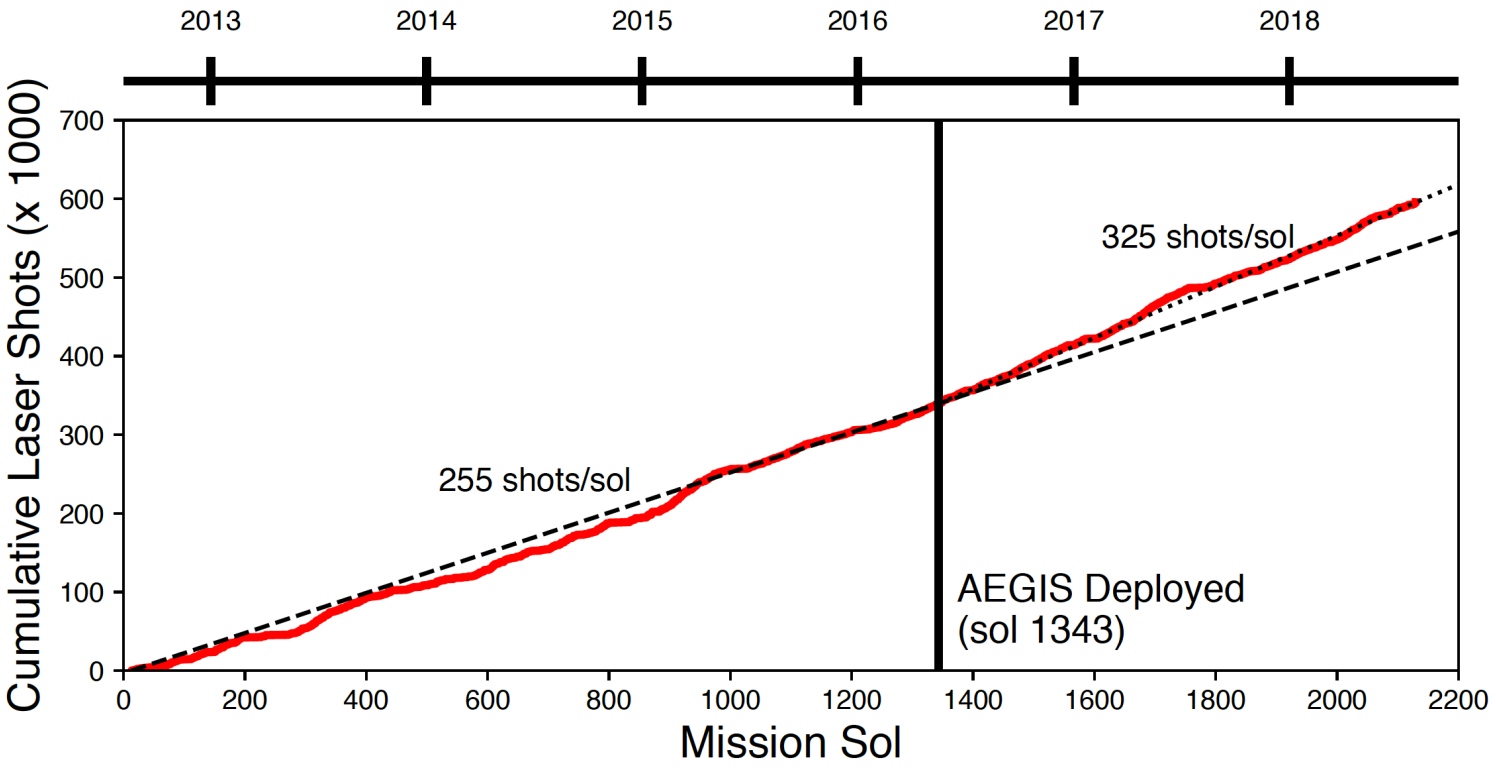
- Exceptions:
  - Chose desired outcrop unit, but some shots hit sand on top or beside the outcrop
  - Chose a float rock or other material (usually when there is little outcrop in view)
- Modeled Blind Targeting results for same sols:
  - 10x1 RLR @ standard pointing
  - Only one target



More data from ChemCam



- Significant increase in rate of data return from ChemCam
- AEGIS rollout to science team on sol 1343

Notable events

Sol 1612: Highest chlorine

Highest concentration of chlorine ever measured by ChemCam on Mars

(So high it strains the calibration)

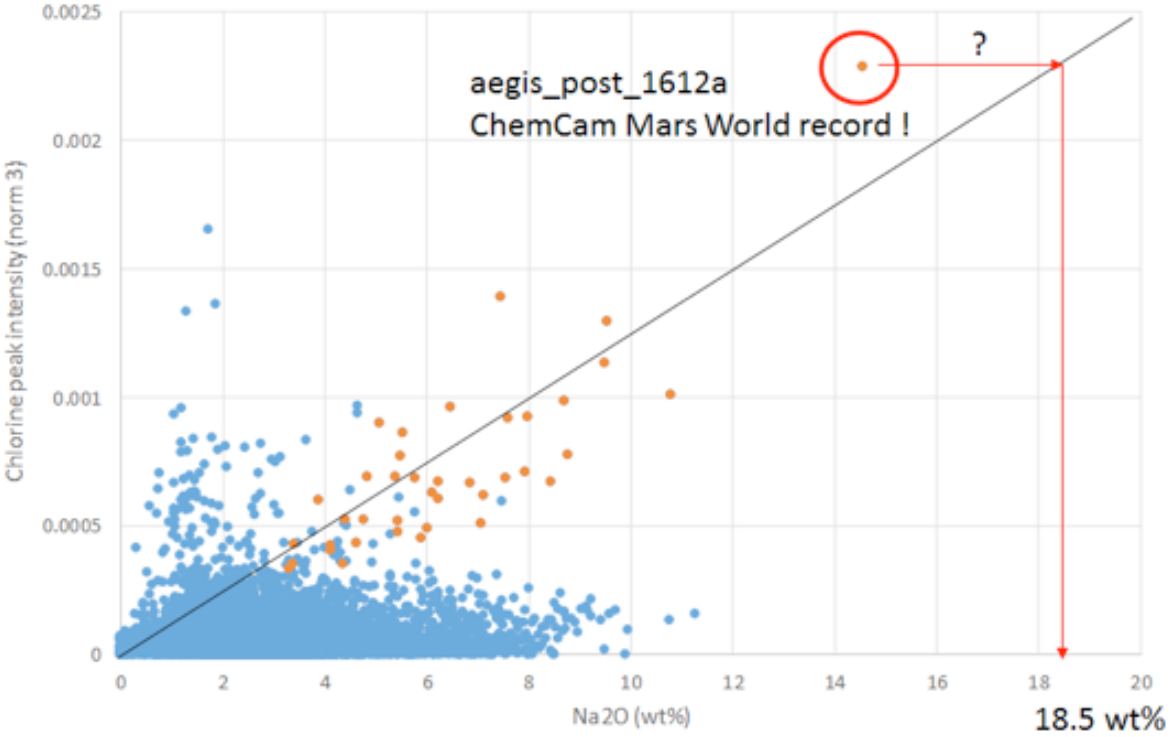


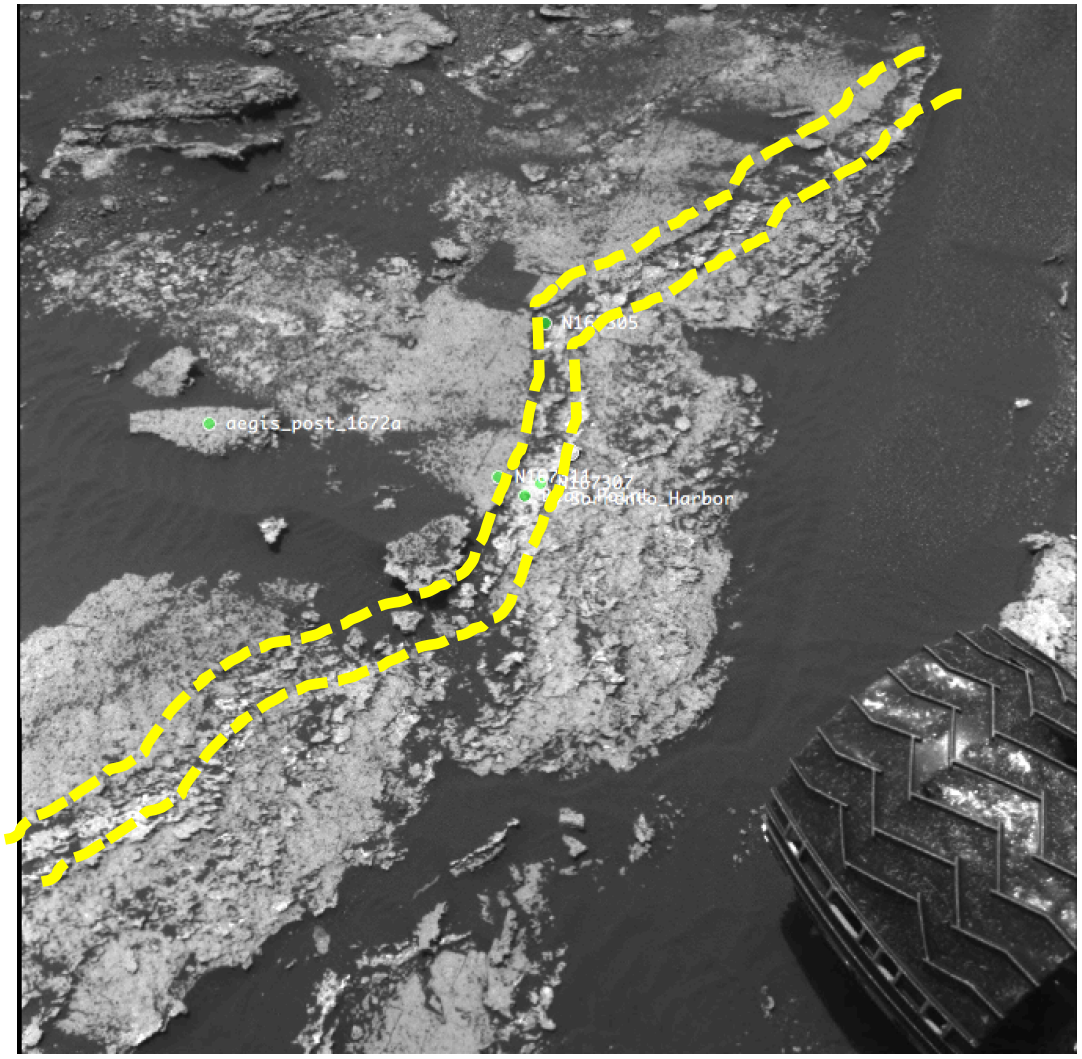
Figure from Pierre-Yves Meslin

Notable events

Sol 1673: Collect all 3

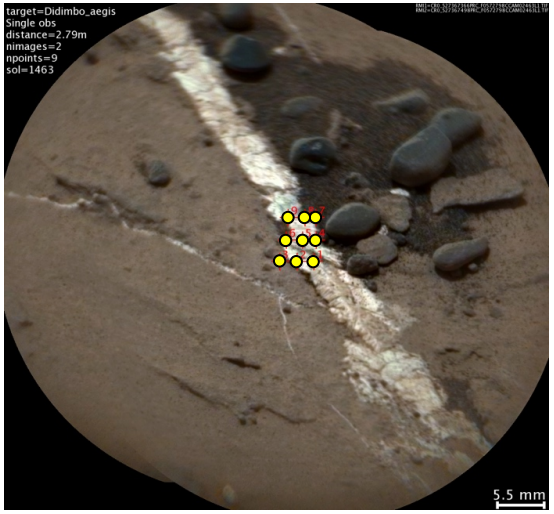
1) Upper, smooth material
2) Brighter vein
3) Lower, rough material

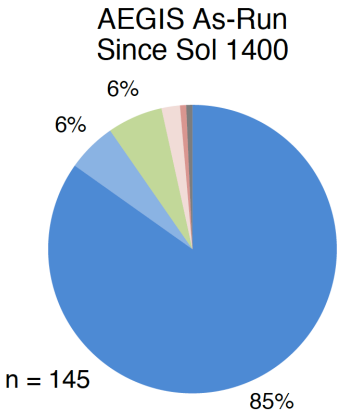
AEGIS had already measured the upper unit, allowing a complete survey with only 2 targeted measurements

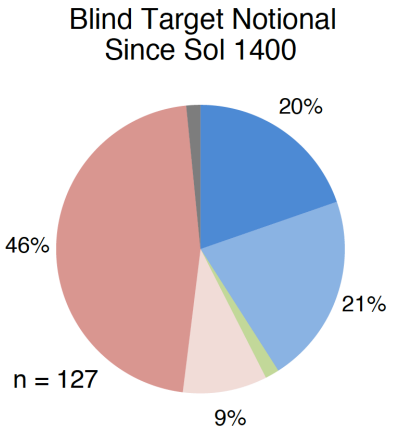


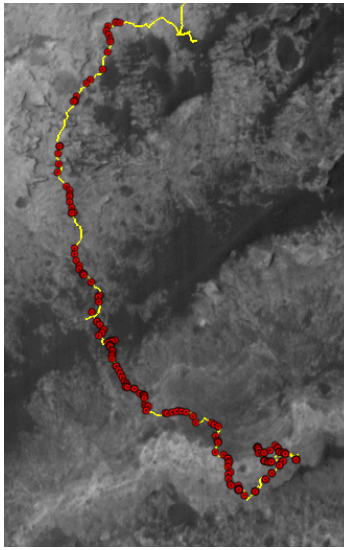
Outcomes

- AEGIS team is very pleased with system performance to date
  - Feedback from science team has been very positive
  - 177 ‘bonus observations’
  - AEGIS-guided observations often inform next sol’s tactical decisions
  - The team is learning new ways to explore



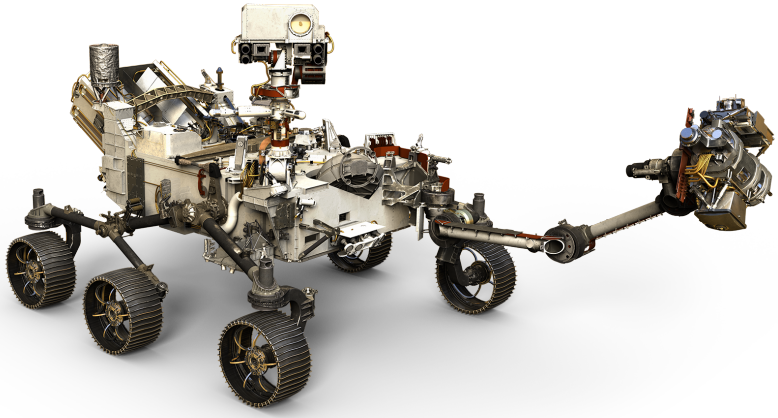






The Future of AEGIS

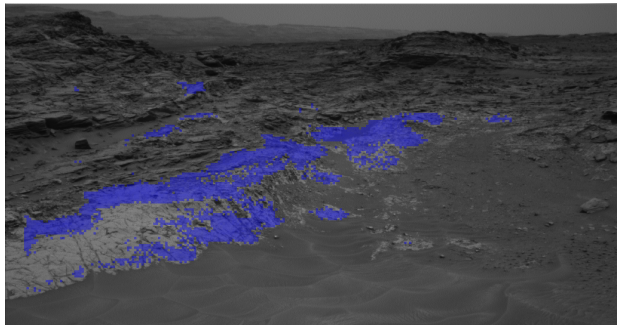
- AEGIS is baselined for Mars 2020
  - SuperCam, the successor to ChemCam
  - Other mast-mounted instruments

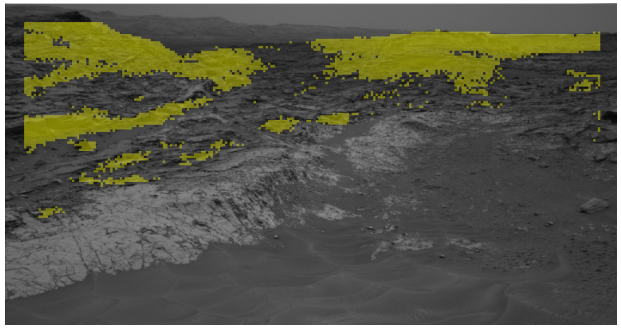


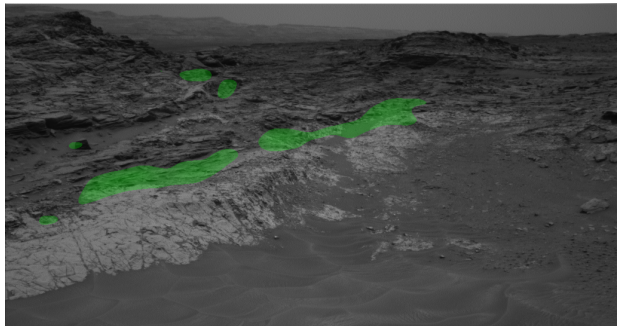
- In this case, the winning features were:
  - Demonstrated science value to Mars Science Laboratory
    → Science Office and Instrument team support
  - Projected ops efficiency savings for ambitious surface mission
    → Mission System support
  - Low development cost to adapt MSL AEGIS flight code to M2020
    → Budget acceptability

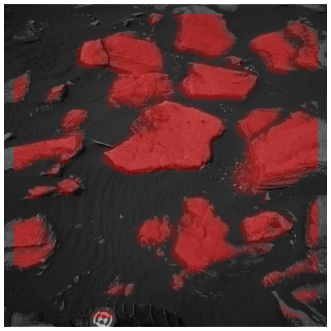
Looking Beyond 2020

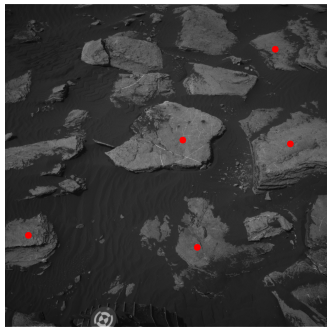
- Exploring new technologies for target detection to enable detection of new types of science targets.
- TextureCam software (Thomson et al.) uses a random forest for pixel-wise classification to directly detect rock units of interest.
- Classifier output enables finding contacts between two rock units.



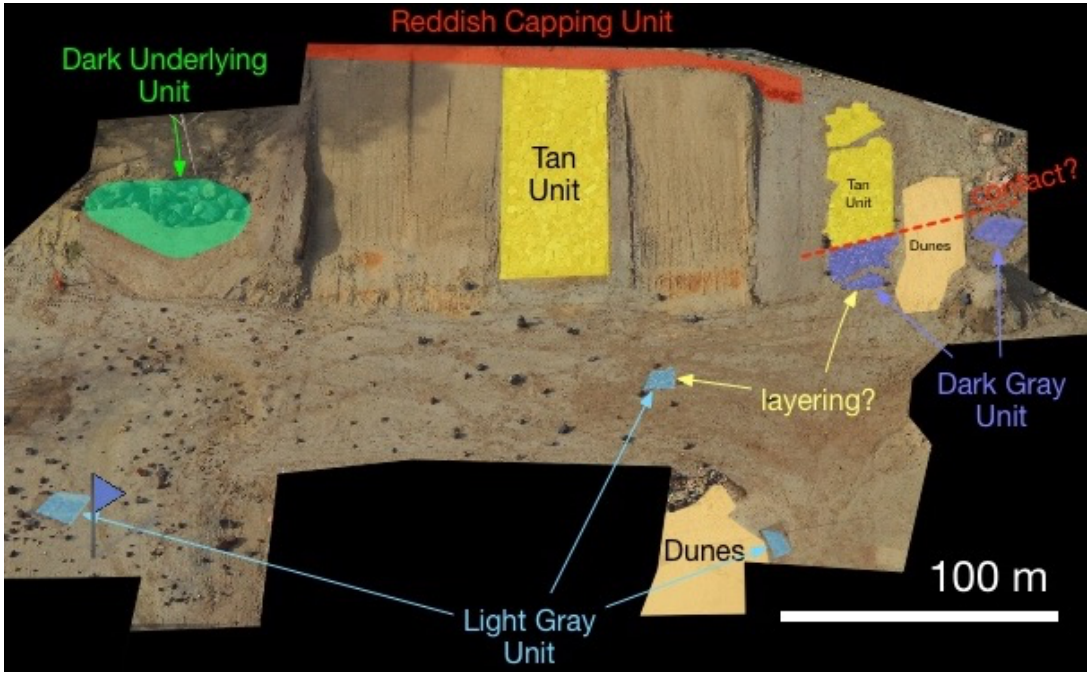


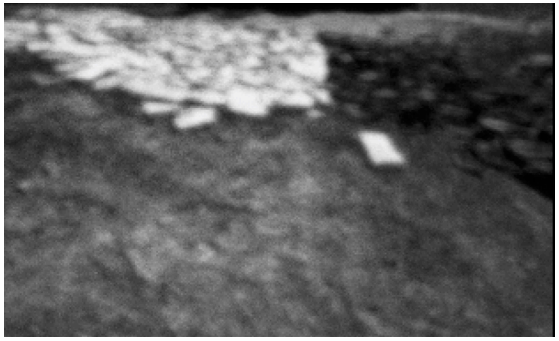


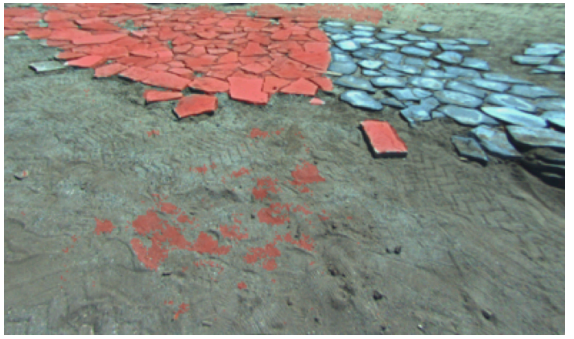




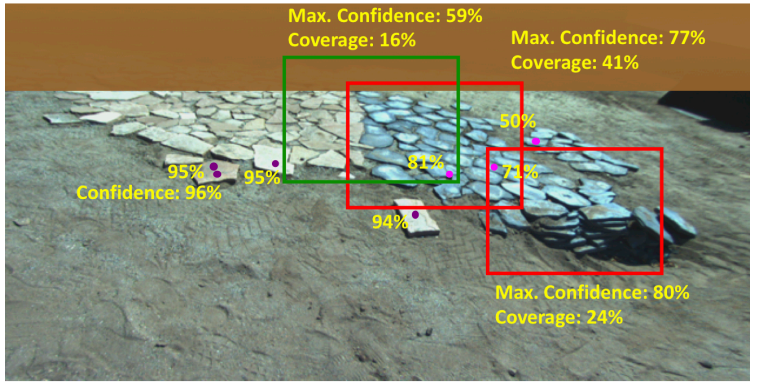
Autonomous Targeting Demo Campaign





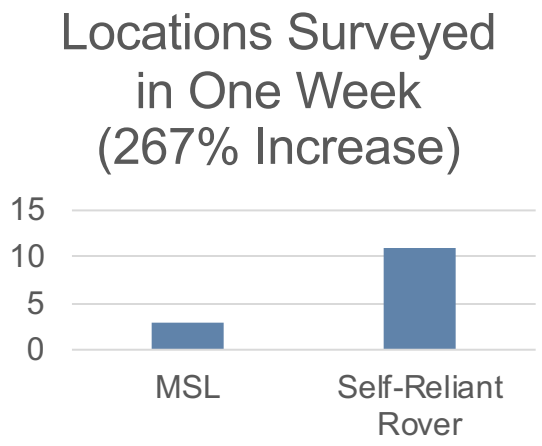


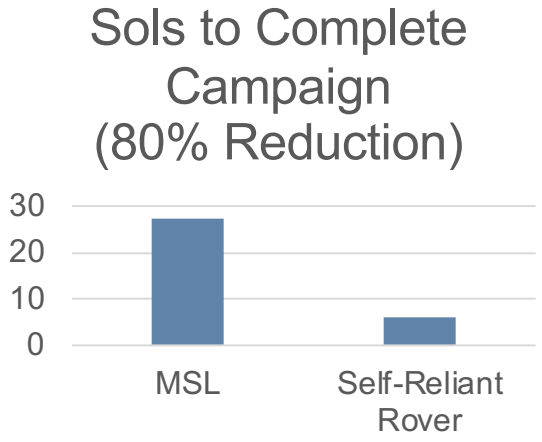
- Simulate a region of interest
- Provide science team with tools to detect geologic features
- Simulate a “walkabout” campaign with autonomous targeting



Campaign Results

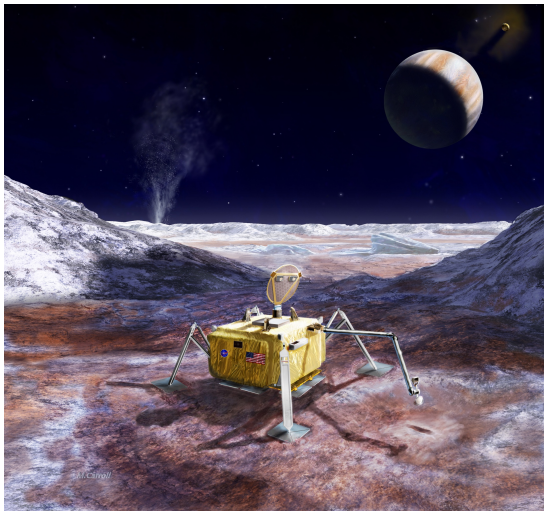
- The “Self-Reliant Rover” campaign incorporated autonomous science targeting, advanced autonomous navigation, and on-board planning.
- The new capabilities allowed scientists to plan several sols of activities at once across multiple locations between communication passes.
- Scientists judged that the autonomously acquired measurements sufficiently characterized each region.



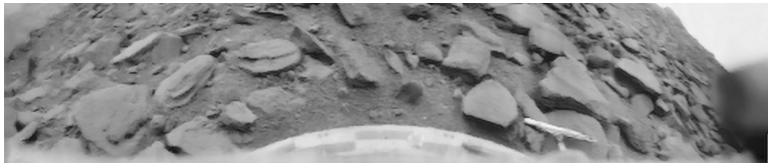


Potential Future Destinations

- Europa Lander

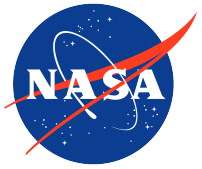


- Venus (short-duration missions require autonomy)



Credit: Ted Stryk

- Small robotic platforms, such as the “PUFFER” (Pop-Up Flat Folding Explorer Robot)



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