The Expanding Reach of Artificial Intelligence in Space Exploration

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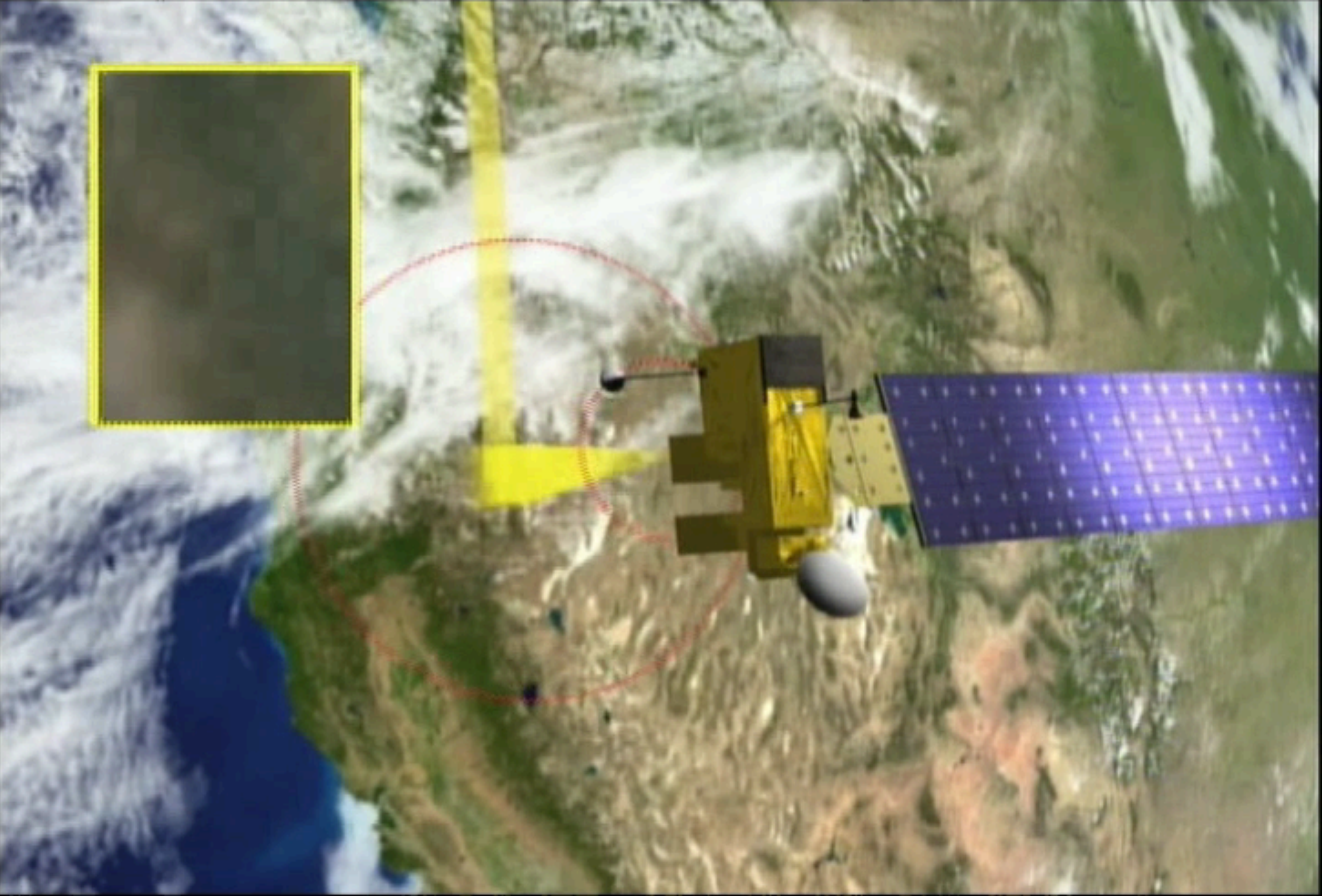
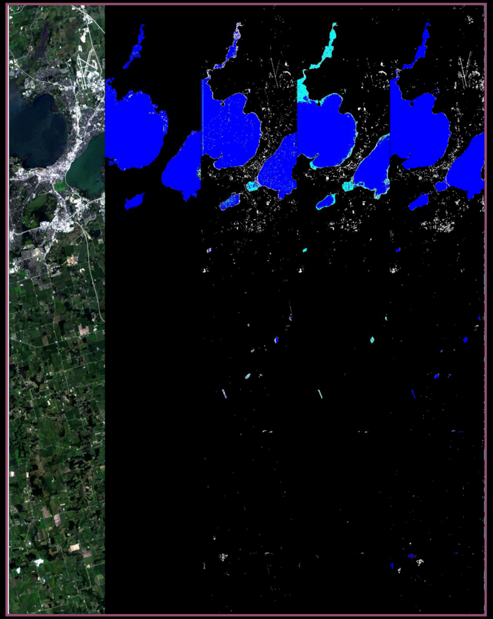
In 2004, AI in Space becomes a reality

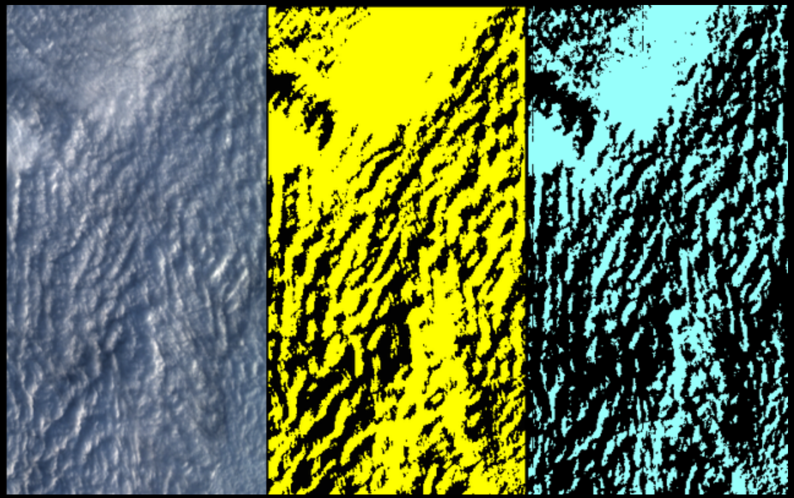
Autonomous Scienceraft AI Software operates the EO-1 spacecraft for over a dozen years, acquiring over 60,000 images, issuing almost $3 million commands



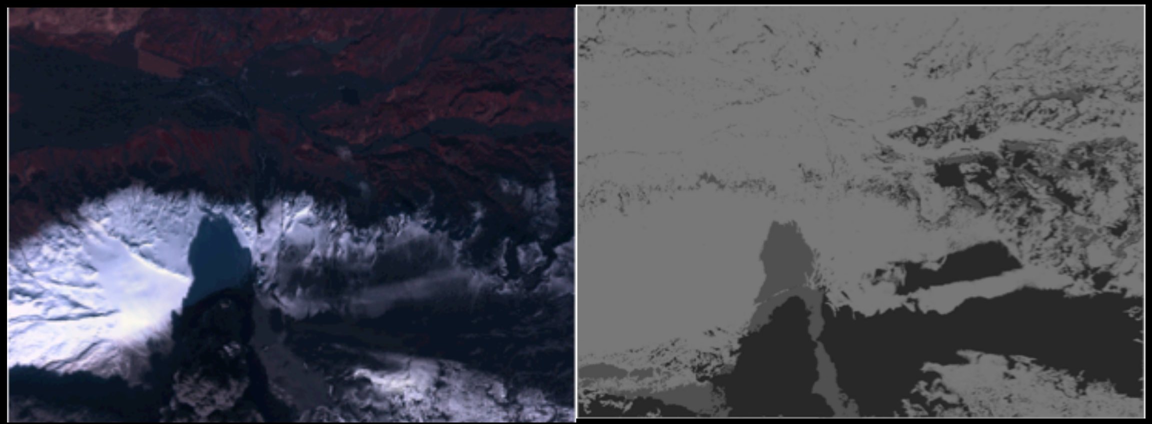
Simultaneously the Earth Observing Sensorweb links together scores of spacecraft, ground observatories, and air and marine assets to monitor volcanos, flooding, wildfires and more, acquiring thousands of images without any human intervention!



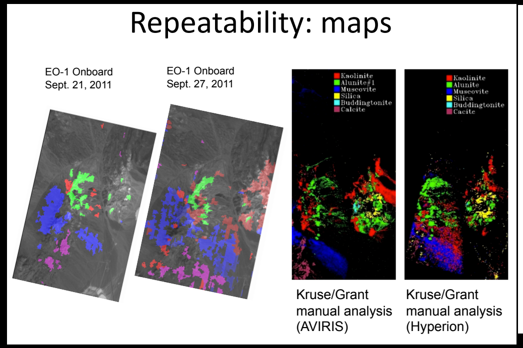
Support Vector Machine Learning Cryosphere

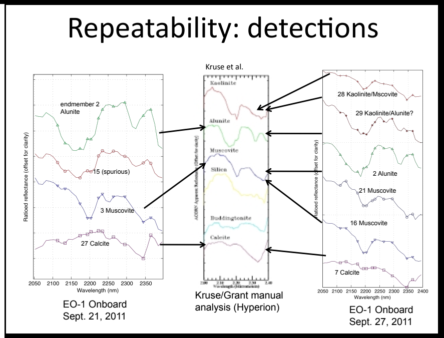


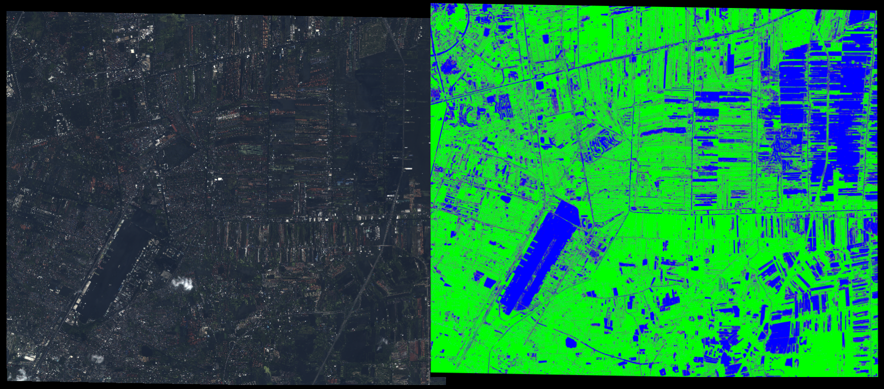
Bayesian Thresholding and Random Decision Forest: Cloud Detection



Random Decision Forest: Ash Plume Detection

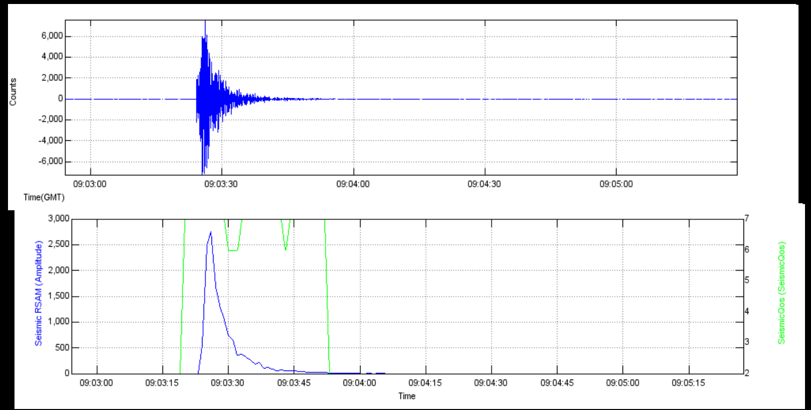


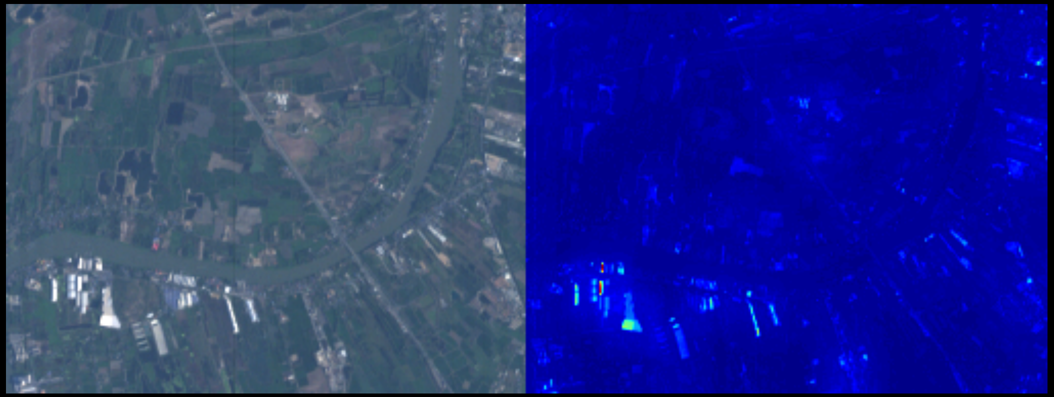




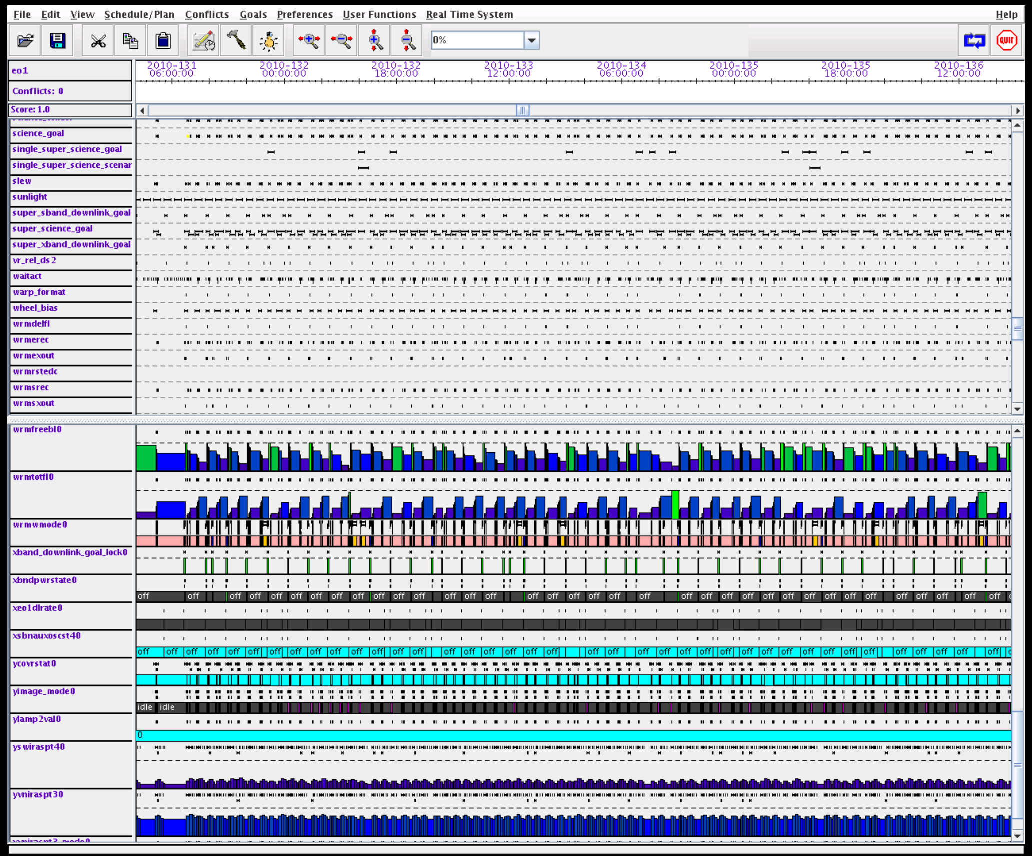
Support Vector Machine: Flood Detection

Timeseries Seismic Event Detection

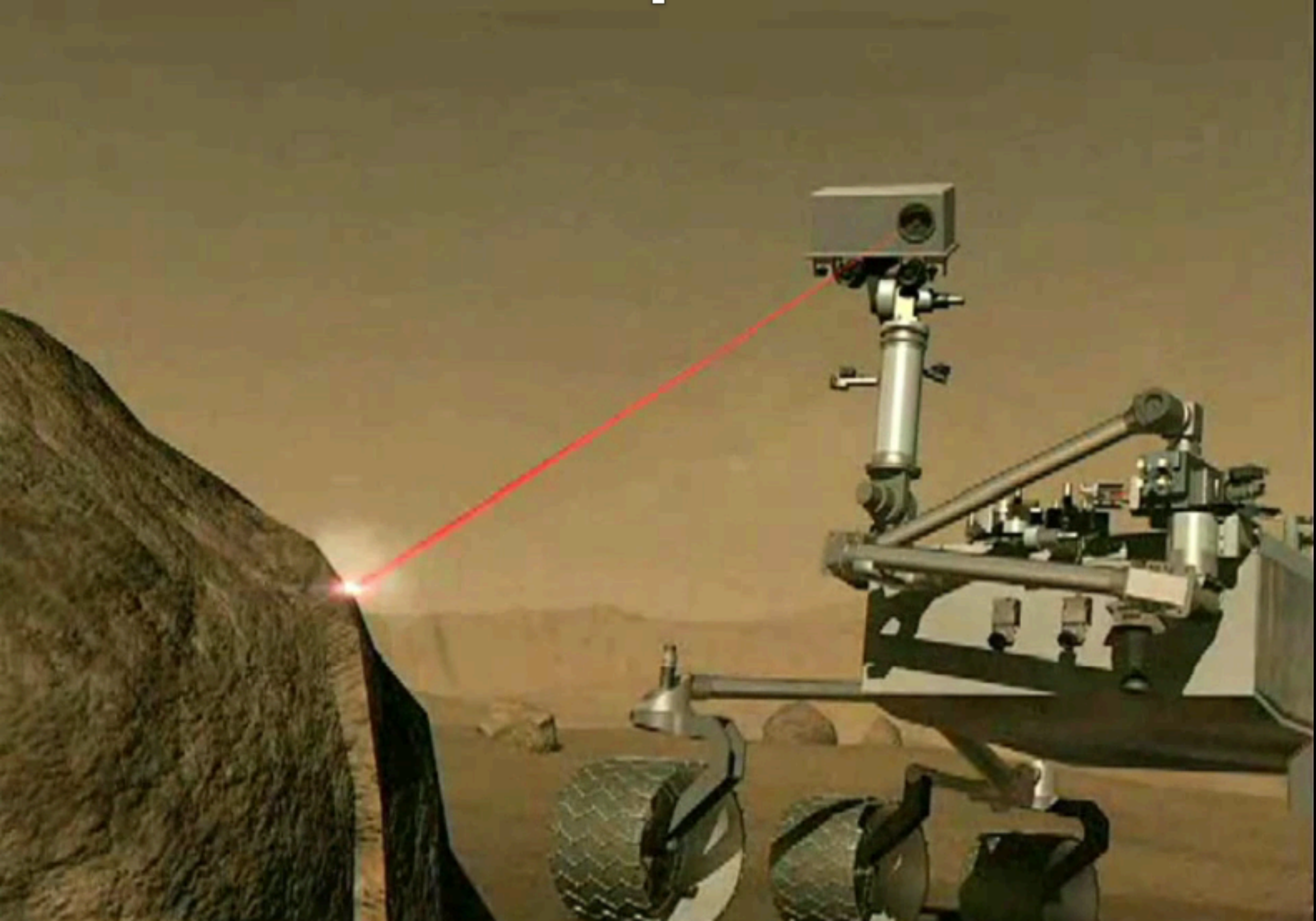




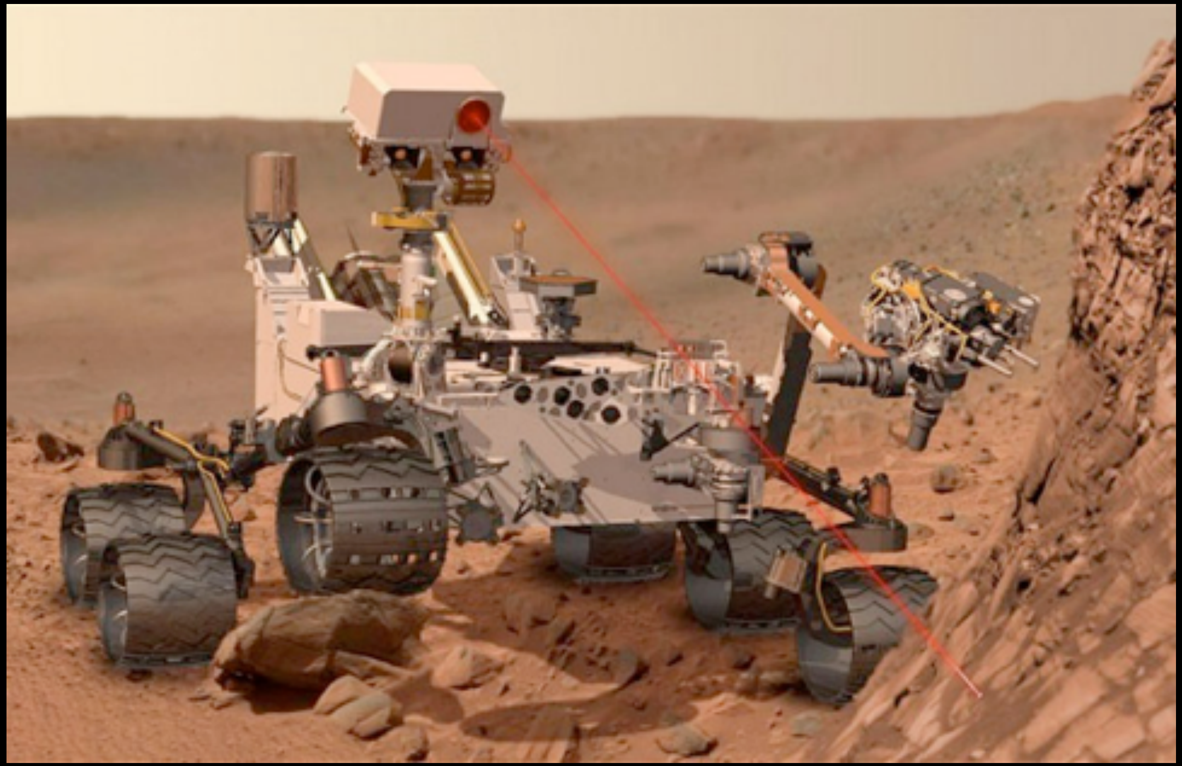
Unsupervised – Visual Salience – Building Detection

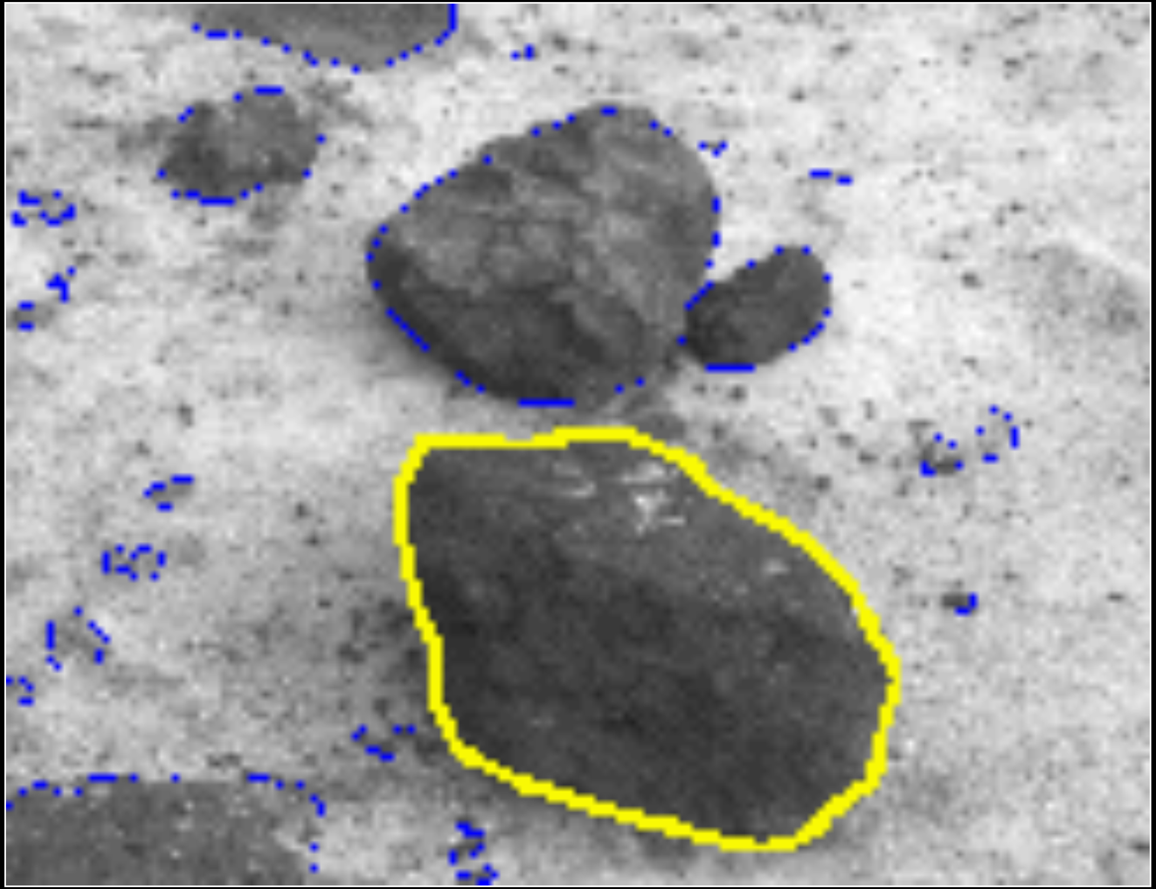


Constraint-based scheduling

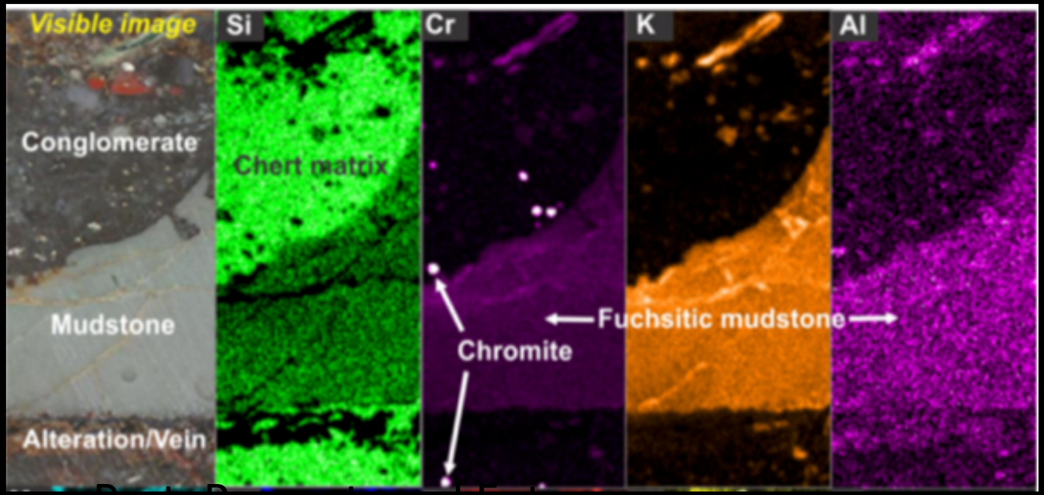


AI-based Targeting of the Chemcam laser on the Mars Science Laboratory Rover





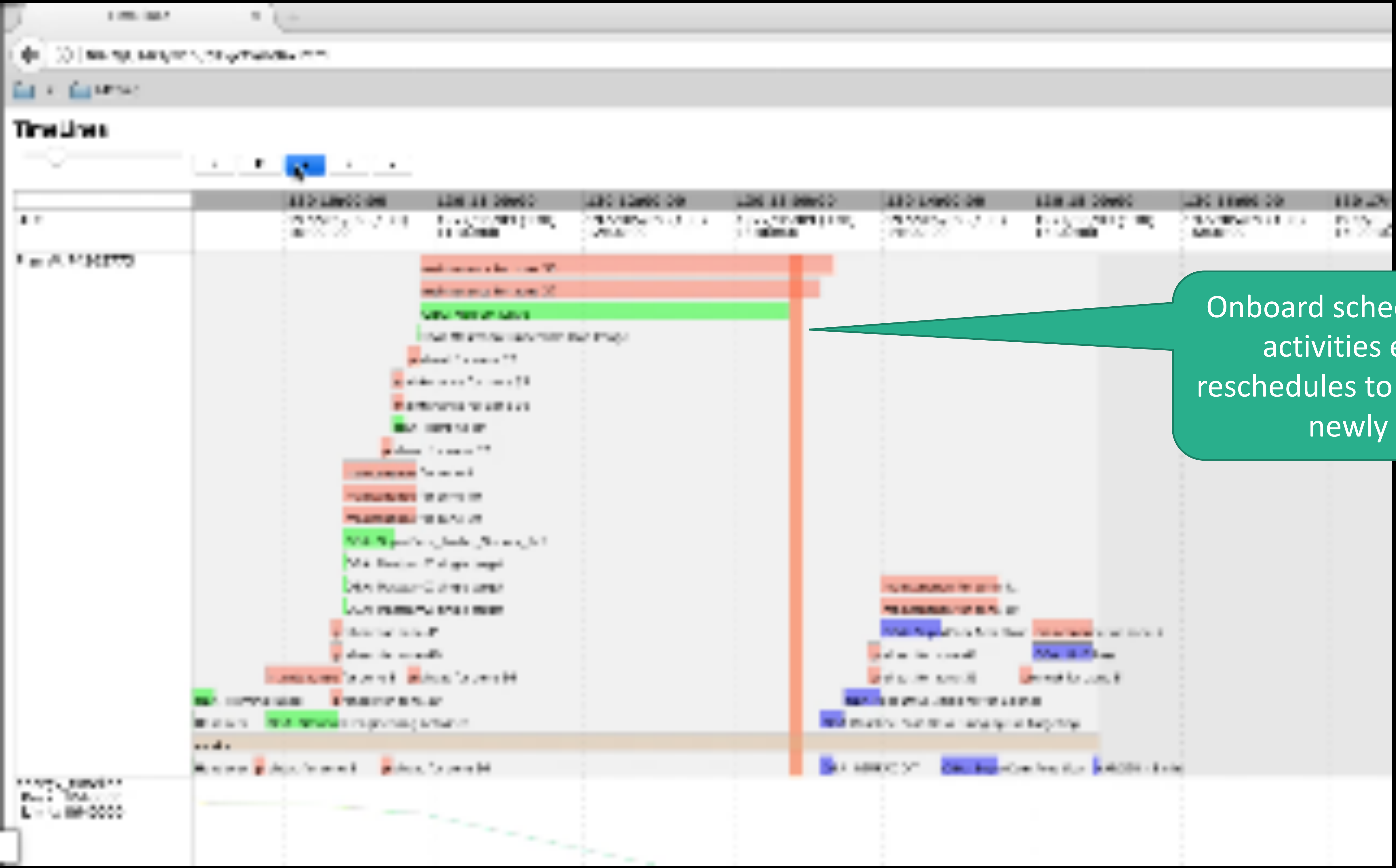
AEGIS AI Software autonomously selects and executes targets based on science provided criteria.



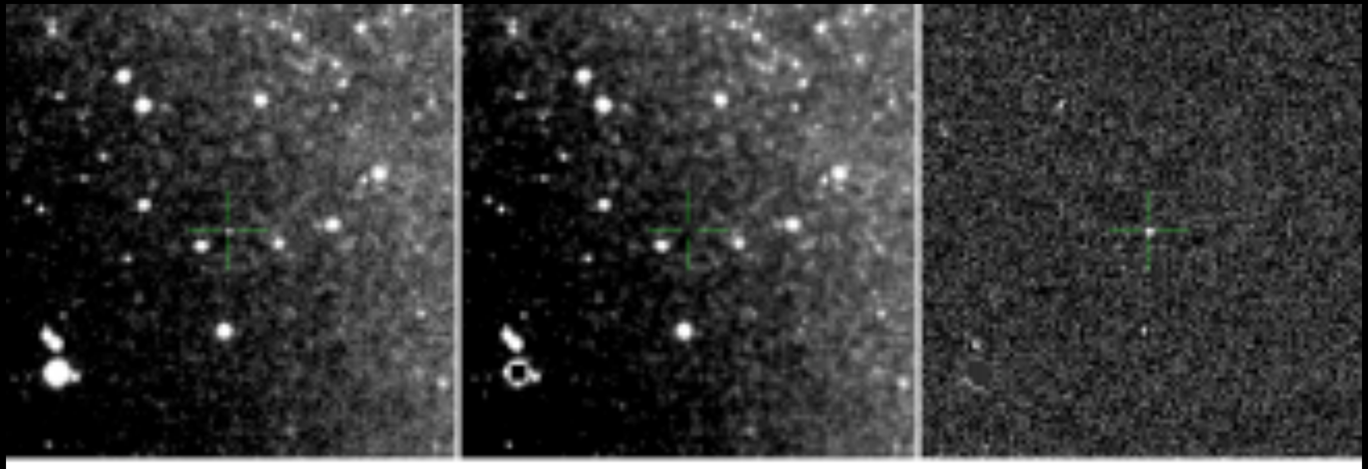
NASA’s next rover to Mars, the M2020 rover will have even more advanced AI capabilities:

- To target instruments
- To reschedule

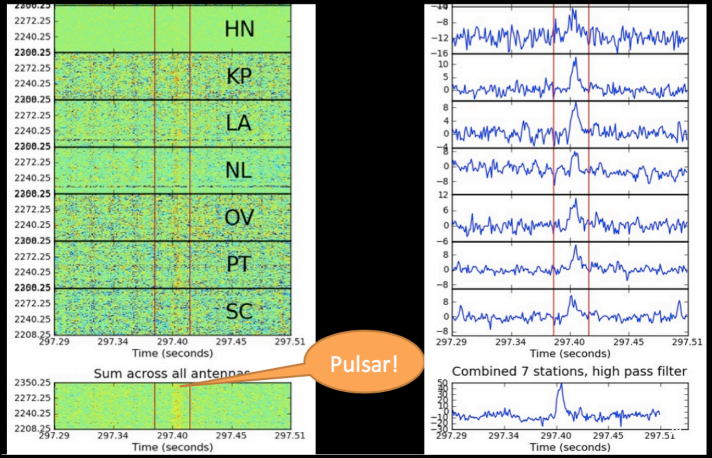
Predecisional, for planning and discussion only.



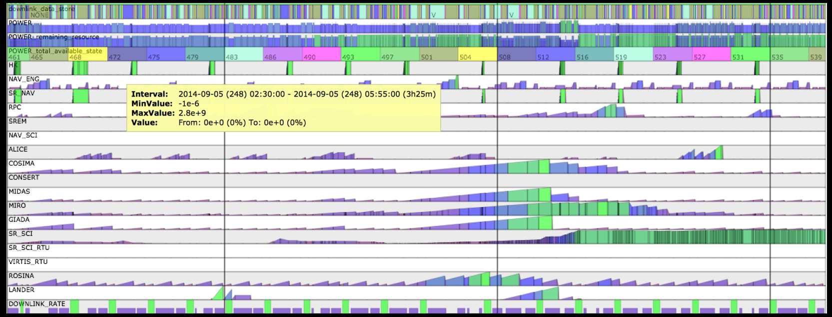
Onboard scheduler notes when activities end early and reschedules to take advantage of newly free time.



Machine Learning for
Automated Triage/detection of
Visual Transient Events



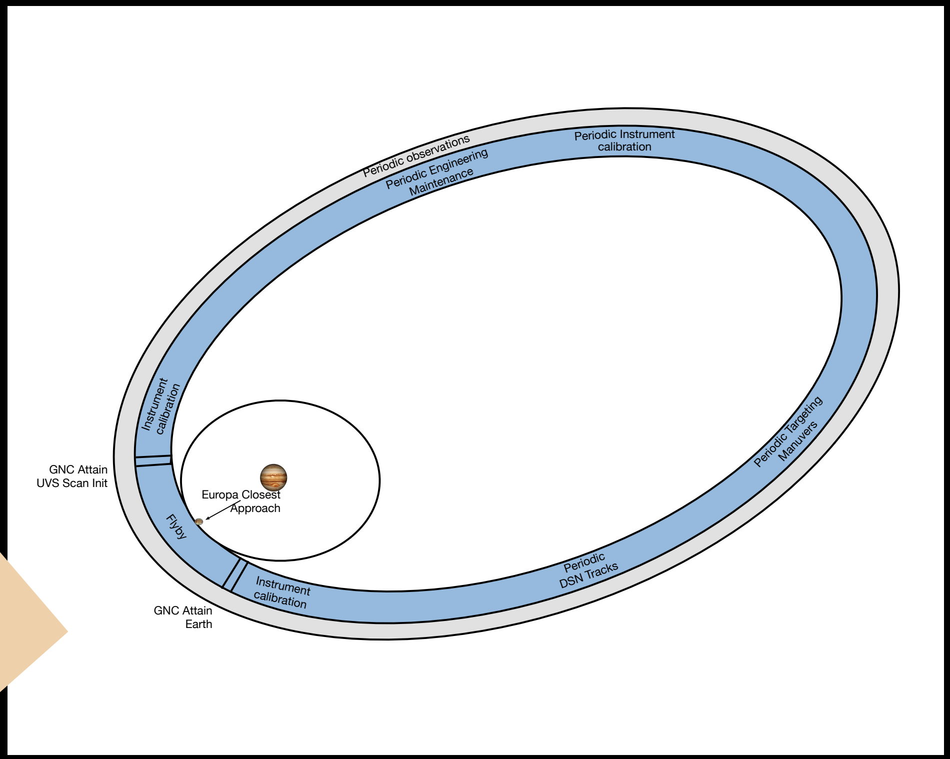
Machine Learning for
Automated Triage/classification
of Radio Transient Events



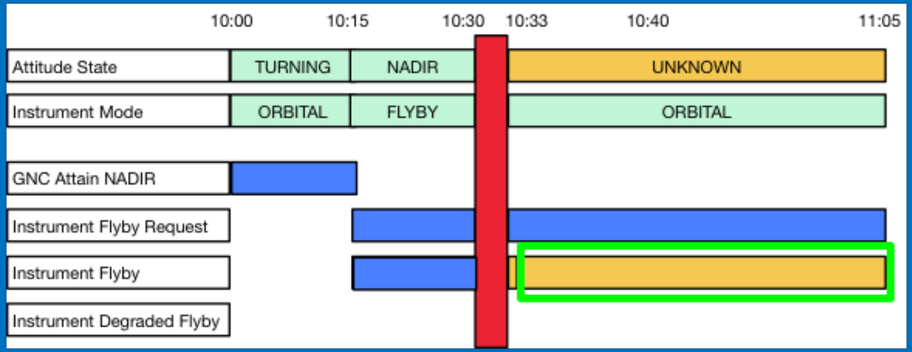
Constraint-based Scheduling
to support Rosetta Orbiter
Science Operations and Data
Management

Europa Clipper – Radiation Resets

Requirement to accommodate up to 5 radiation induced Flight Software resets per flyby



EXAMPLE: RESPONSE TO EARLY RESET



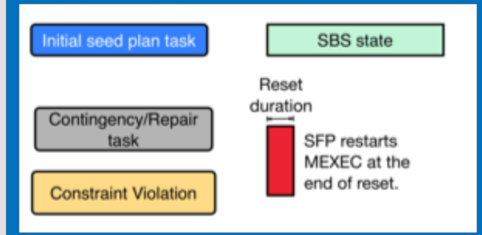
Plan loop applies contingency response
Results in conflict for Attitude

Example Task Constraints/Impacts:

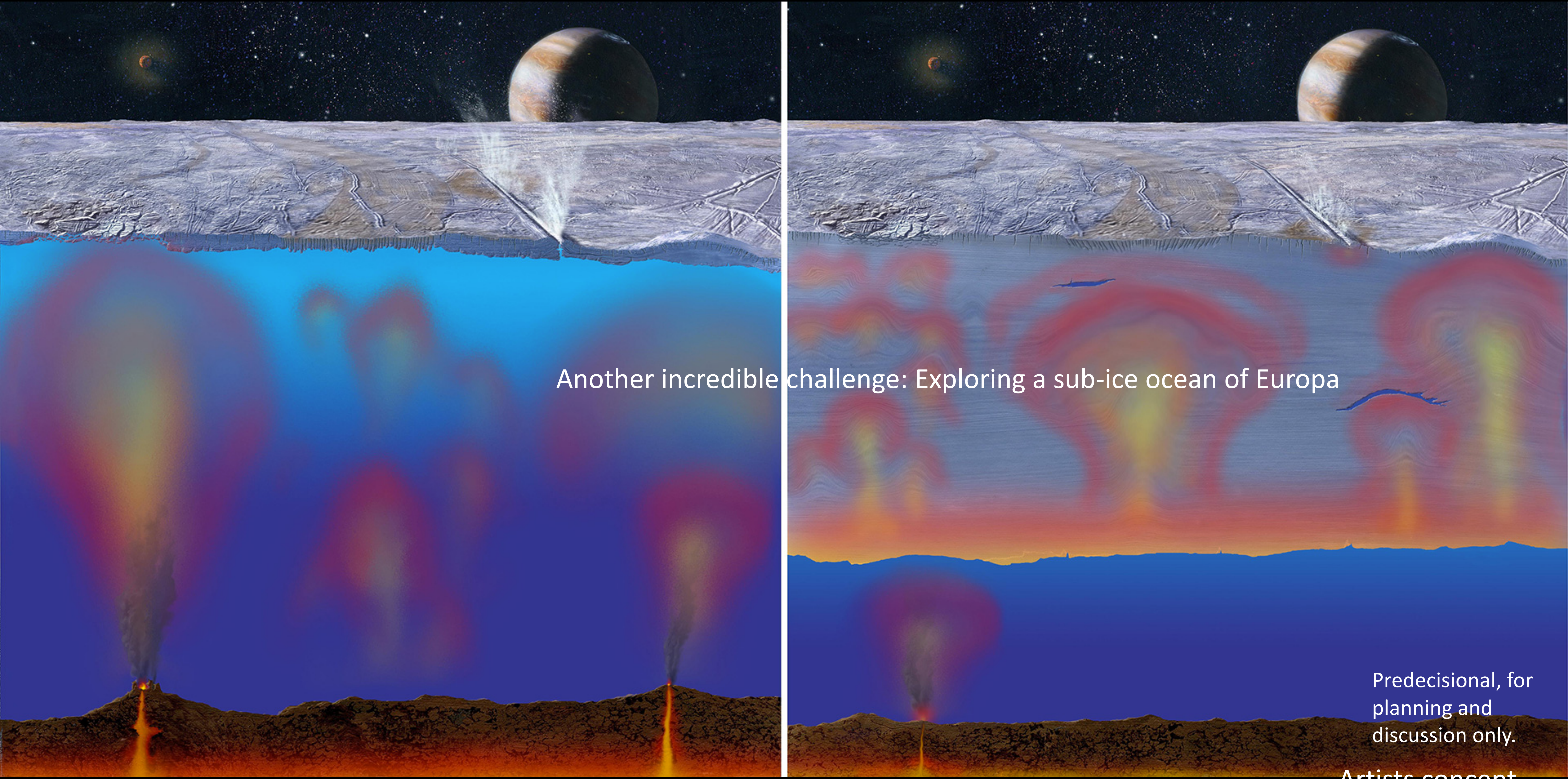
Gnc Attain NADIR:	POST IMPACT	Attitide State=NADIR
Instrument Flyby:	PRE CONSTRAINT	Attitude State = NADIR
	MAINTAIN CONSTRAINT	Attitude State = NADIR
	DURING IMPACT	Satisfies InstrumentFlybyRequest
Instrument Degraded Flyby :	DURING IMPACT	Satisfies InstrumentFlybyRequest

Example Contingency Response:
Restart InstrumentFlyby on failure

Example Plan Modifiers to resolve violation:
Add GncAttain NADIR
Add Degraded Flyby
Remove InstrumentFlyby



Another incredible challenge: Exploring a sub-ice ocean of Europa



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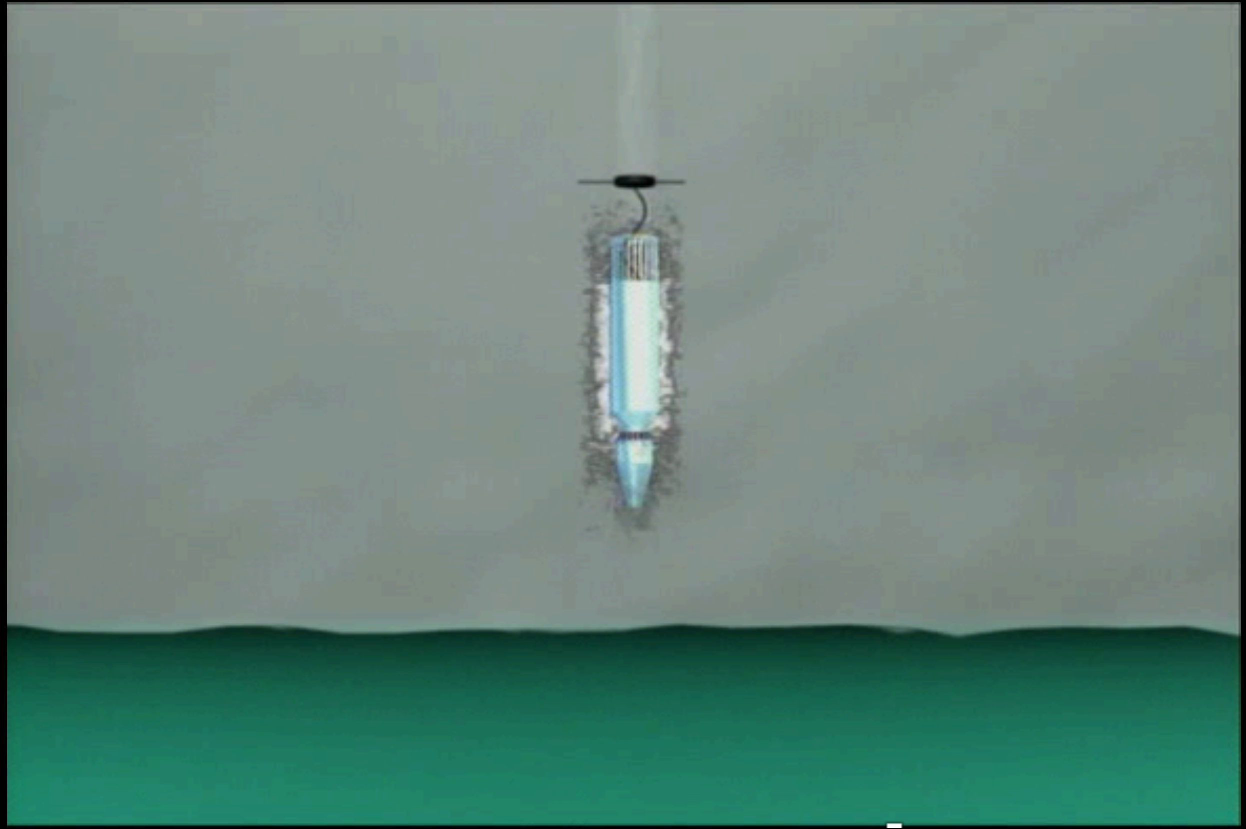
Artists concept.



- A Europa Submersible would have spend a year or even more to penetrate kilometers of ice
- Then explore autonomously for weeks to months at a time searching for life, perhaps at hydrothermal vents
- A true challenge for AI!

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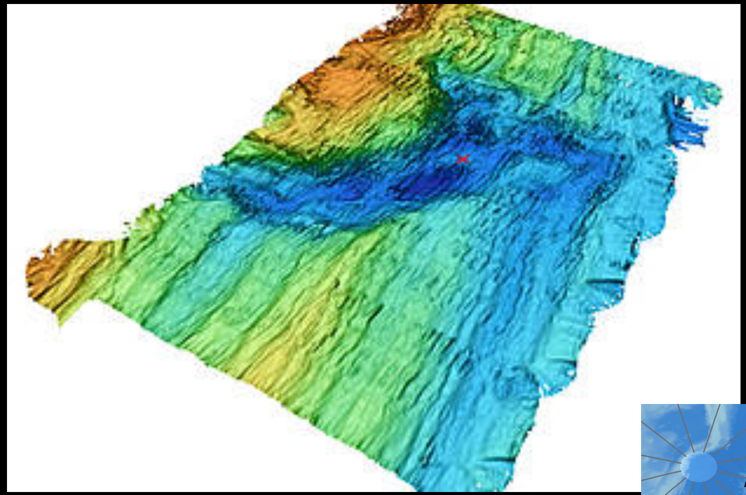
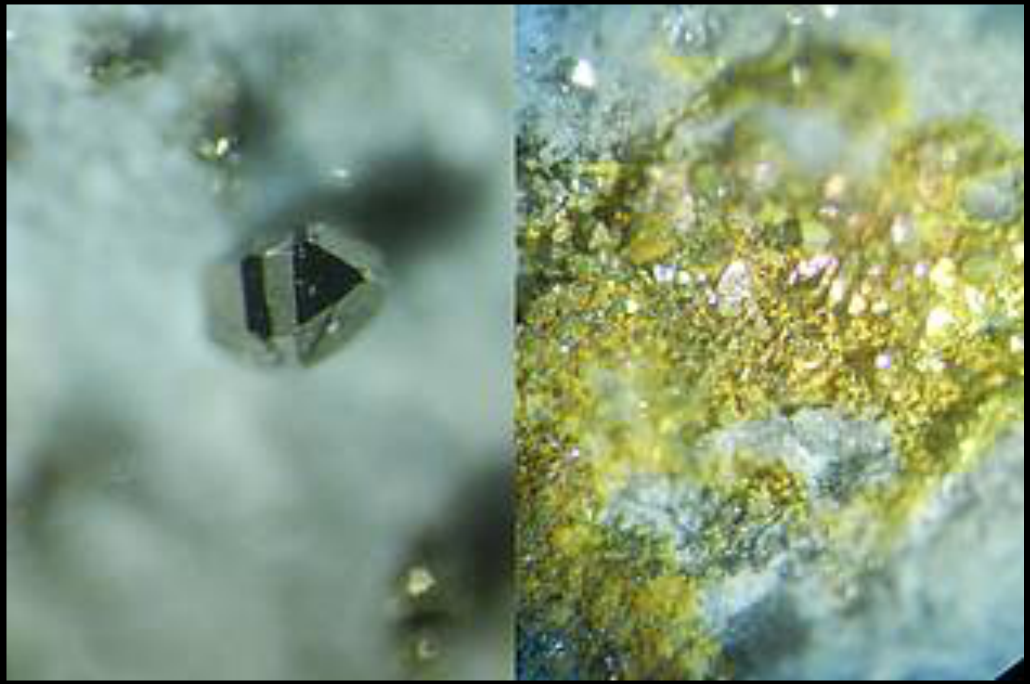
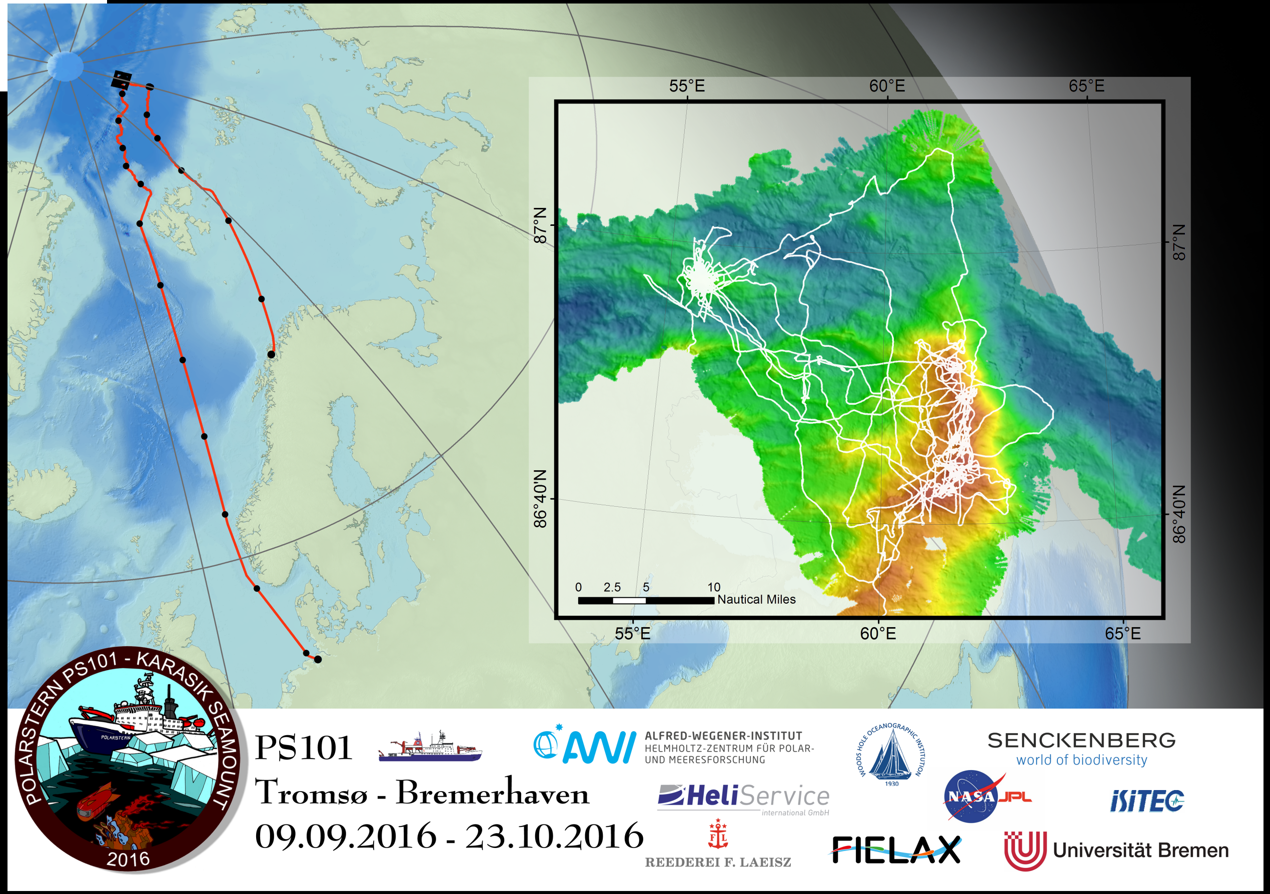
Ocean Worlds submersible concept.

From the Recent Polarstern Cruise, Karasik Massif 85 N

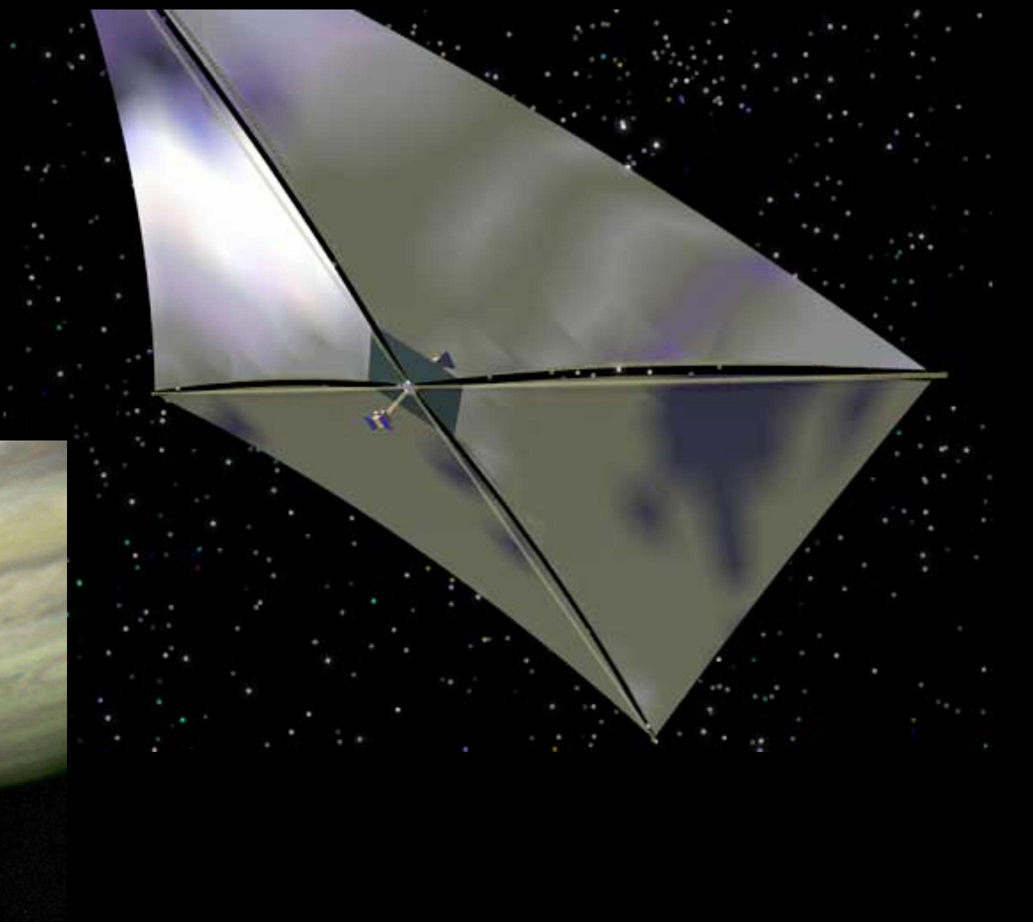


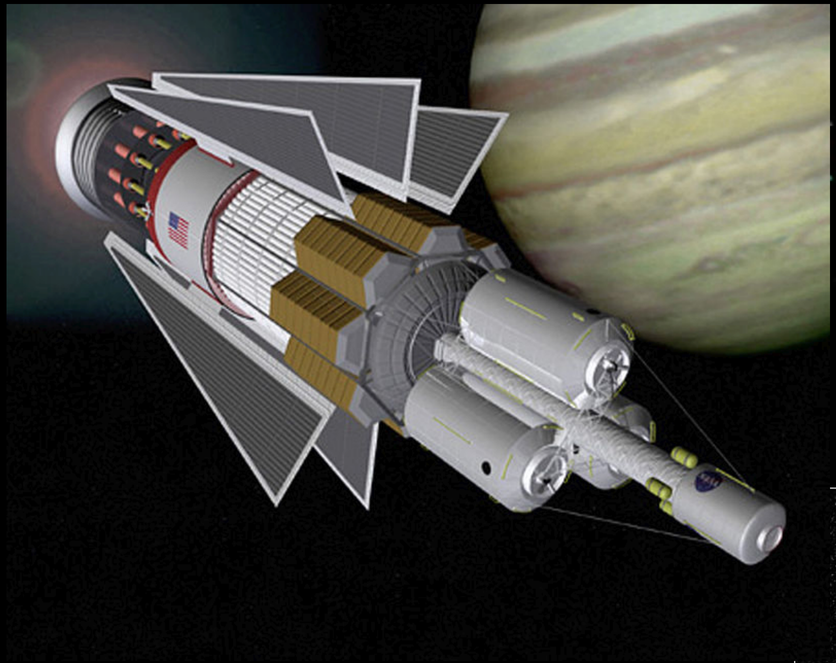




Images courtesy of A. Boetjius/AWI, C. German/WHOI, K. Hand/JPL

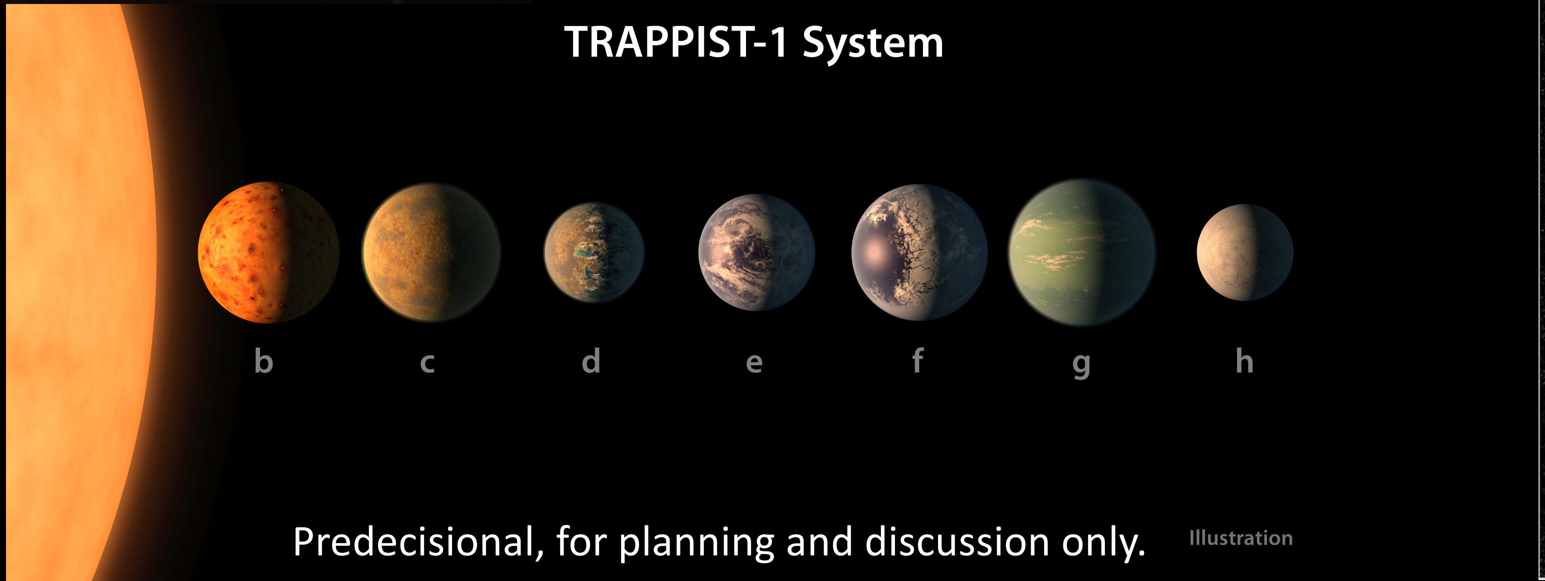
Interstellar Mission Concepts





The ultimate challenge for Space AI.
How to autonomously explore an entire solar system!

Artists concepts.



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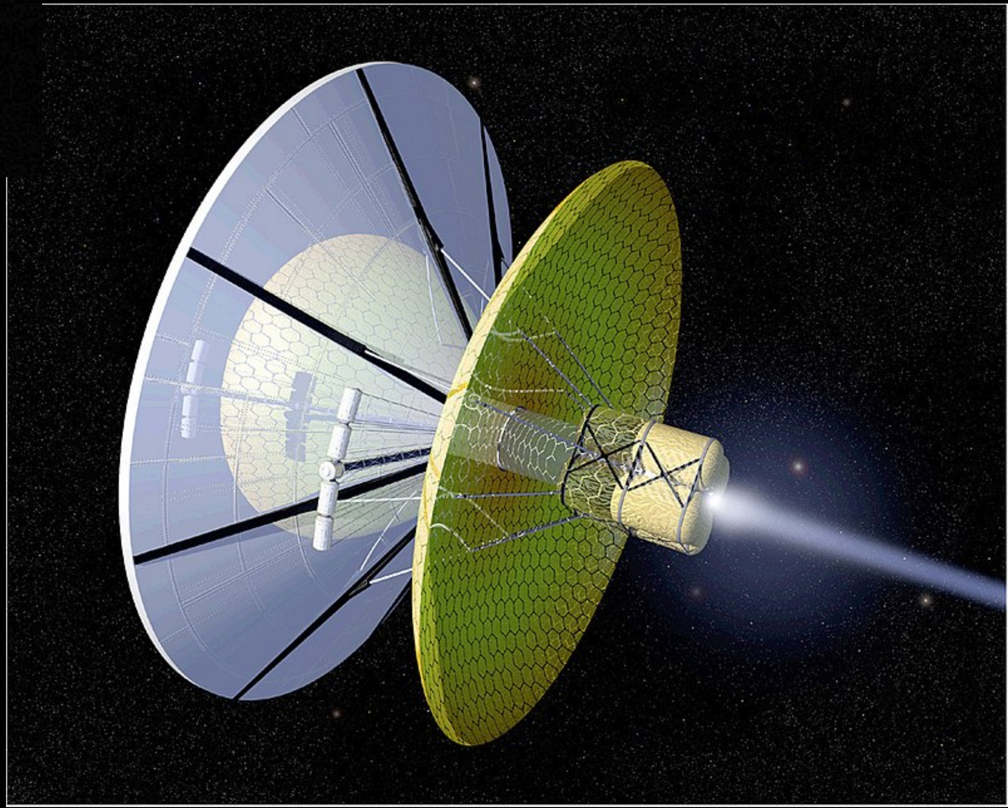

Further Information /Credits

- Autonomous Sciencecraft and Sensorweb:
  - ase.jpl.nasa.gov, sensorweb.jpl.nasa.gov, ai.jpl.nasa.gov
- Mars 2020 Rover: mars.nasa.gov
  - Aegis.jpl.nasa.gov, Rabideau et al. IWPSS 2017.
- Europa Clipper: europa.jpl.nasa.gov
  - MEXEC: Verma, Gaines et al. 2017, IWPSS.
- Cave Exploration
  - A. Husain et al, "Mapping planetary caves with an autonomous, heterogeneous robot team", IEEE Aerospace Conf, 2013.
  - A. Fraeman, E. J. Wyatt, J. Lazio, J. Castillo-Rogez, S. Chien, J. Gao, S. Herzig, F. Albay, K. Belov, D. Ellison, H. Kim, N. Guy, M. Troesch, W. Walsh, "Benefits Offered by a Networked of CubeSat-Class Platforms for Planetary Cave Exploration," Low cost planetary missions workshop, Pasadena, CA, August 2017.
- NEO 100
  - B. Ehlmann, C. Raymond, J. Sercel, "Mapping and Assaying the Near-Earth Object Population Affordably on a Decadal Timescale," KISS Study, Caltech.
  - See Made in Space Project RAMA, NIAC, 2014.
- Machine Learning for Data Triage
  - i-PTF U. Rebapragada et al.
  - V-FASTR – K. Wagstaff et al.
- Comet Hitchhiker
  - Ono M, Quadrelli M, Lantoine G, Backes P, Lopez Ortega A, Grip H, Yen CW, Jewitt D. The Hitchhiker's Guide to the Outer Solar System. In AIAA SPACE 2015 Aug 31. (2013 NIAC)
- Enceladus Vent Explorer
  - Ono M., et al. NIAC Study 2016, https://www.nasa.gov/feature/journey-to-the-center-of-icy-moons
- Ocean Worlds
  - https://www.nasa.gov/specials/ocean-worlds
  - Polarstern- A. Boetius/AWI, C> German/WHOI, K. Hand/JPL
- Interstellar Mission
  - https://en.wikipedia.org/wiki/Interstellar_probe
  - http://kiss.caltech.edu/workshops/ism/ism2.html

DARE MIGHTY THINGS

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