The Expanding Reach of Artificial Intelligence in Space Exploration

Steve Chien Jet Propulsion Laboratory California Institute of Technology

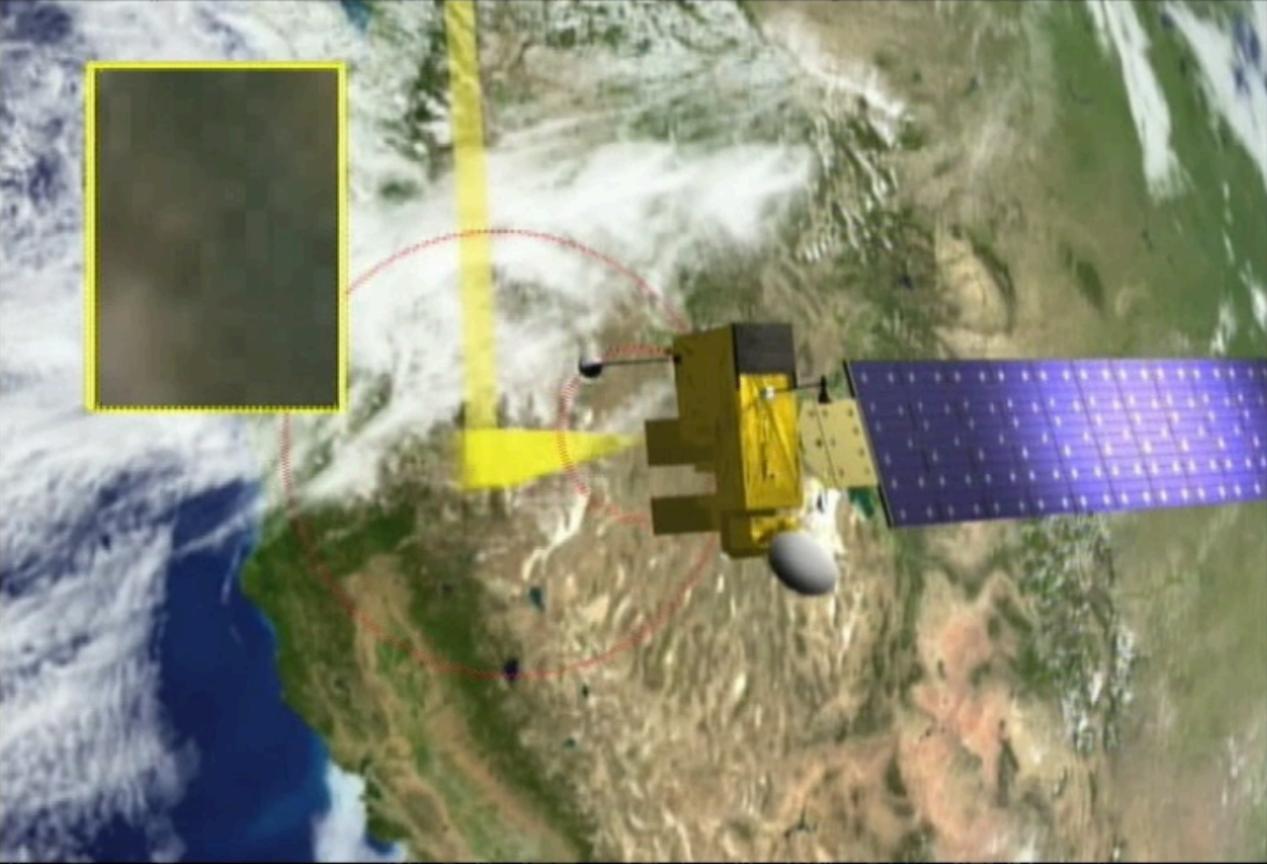
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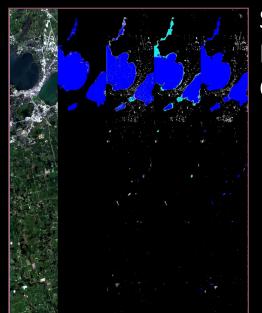
In 2004, AI in Space becomes a reality

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





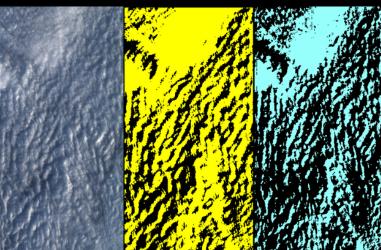
Simultaneously the Earth Observing Sensorweb links together scores of spacecraft, ground observatories, and air and marine assets to monitor volcanos, flooding, wildfires and more, acquiring thousands of images without any human intervention!

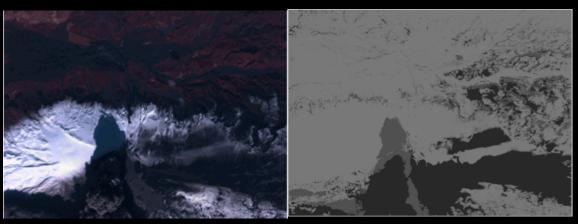


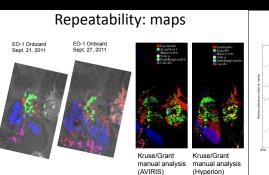
Support Vector Machine Learning Cryosphere

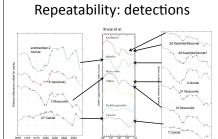
> **Bayesian Thresholding** and Random Decision Forest: Cloud Detection

> > EO-1 Onboard Sept. 27, 2011

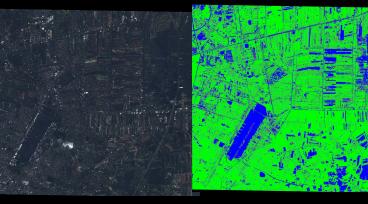




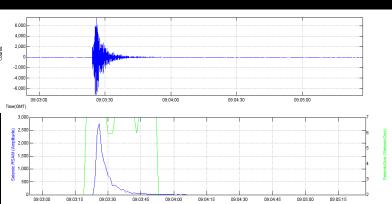




EO-1 Onboan Sept. 21, 201



Support Vector Machine: Flood Detection





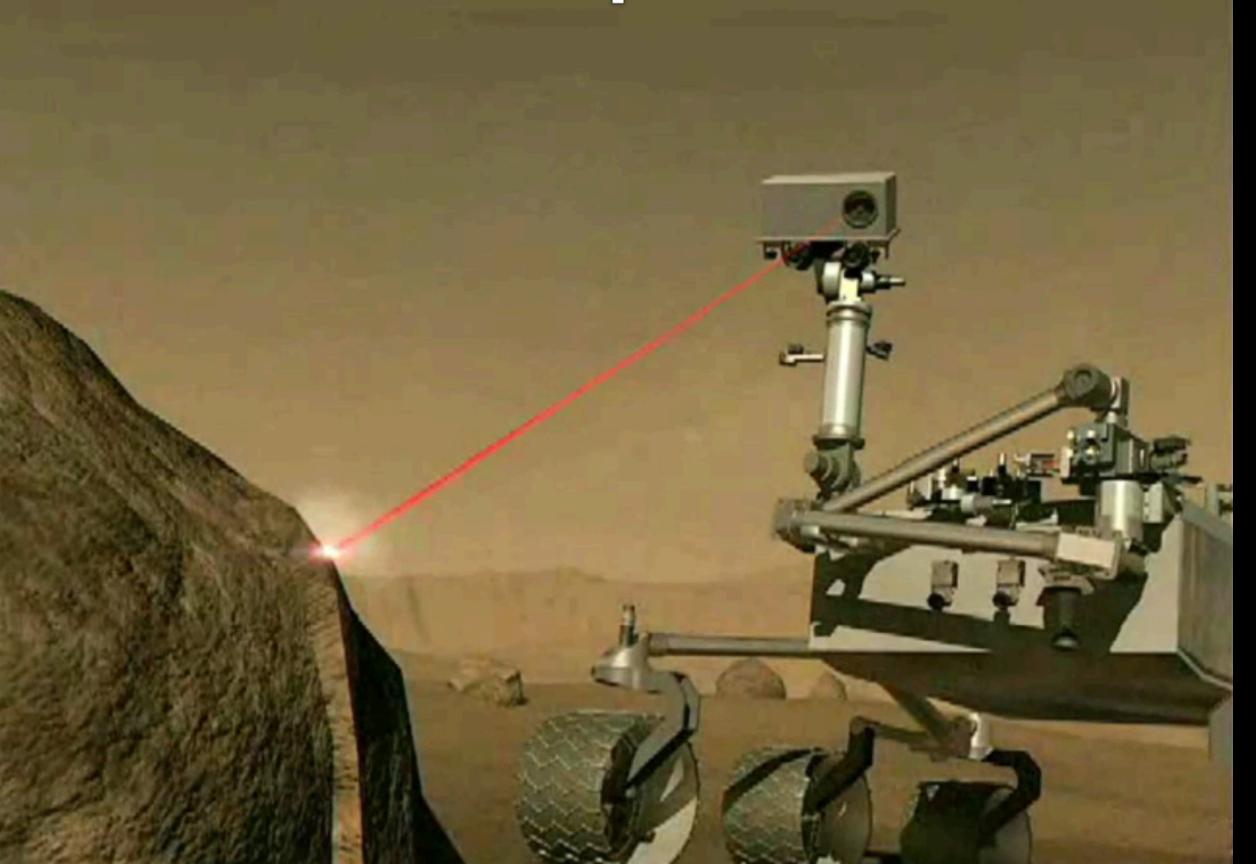
Unsupervised – Visual Salience – Building Detection

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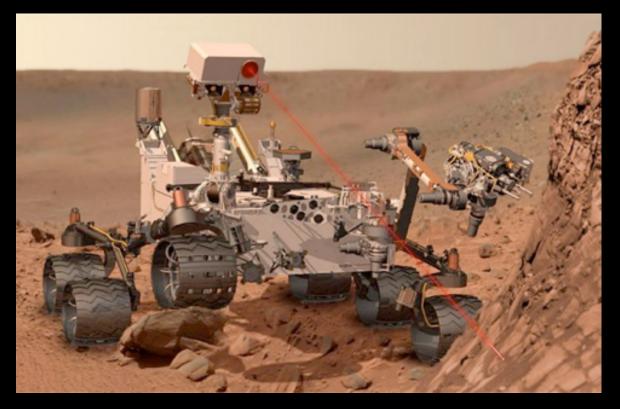
Timeseries Seismic Event Detection

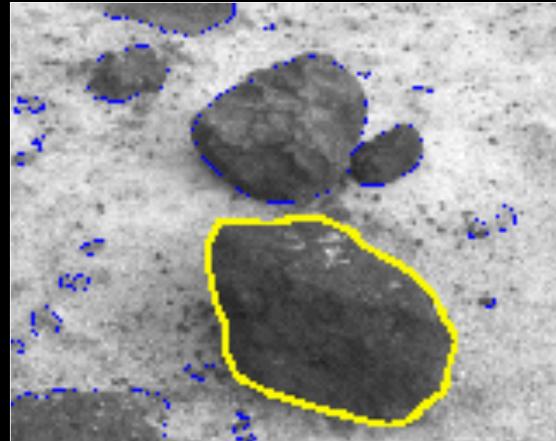
Random Decision Forest: Ash Plume Detection

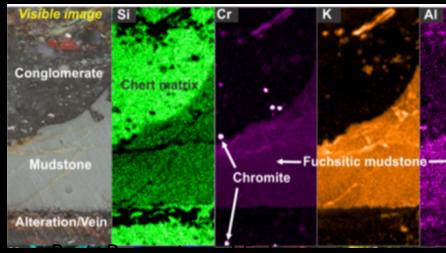
Constraint-based scheduling



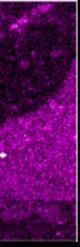
Al-based Targeting of the Chemcam laser on the Mars Science Laboratory Rover



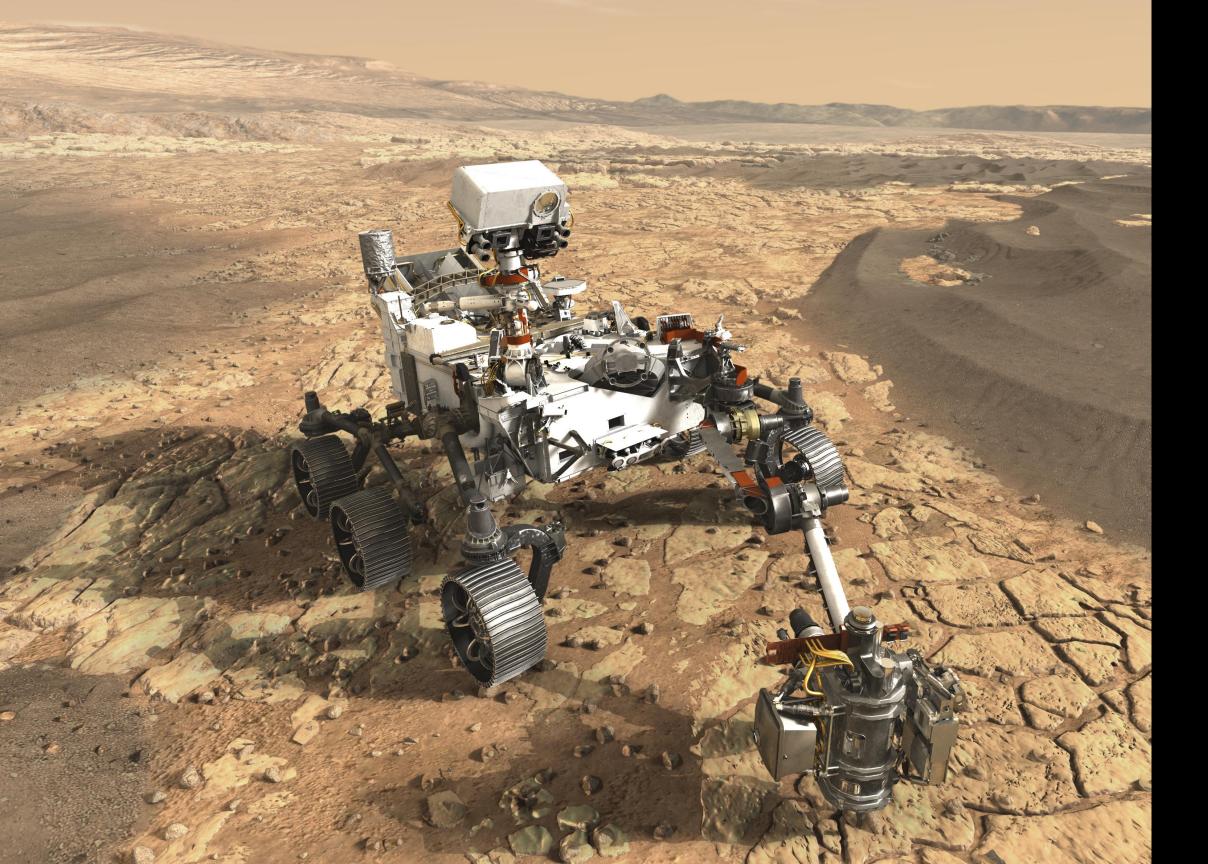




AEGIS AI Software autonomously selects and executes targets based on science provided criteria.



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

- To target instruments
- To reschedule

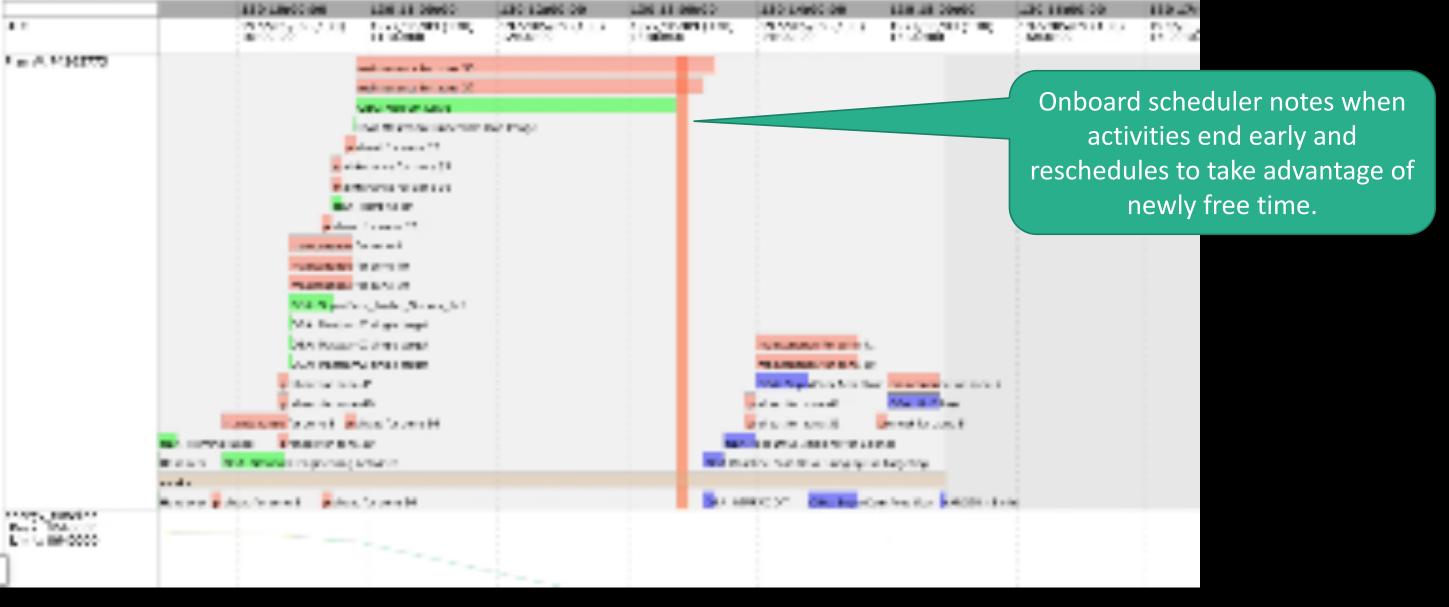
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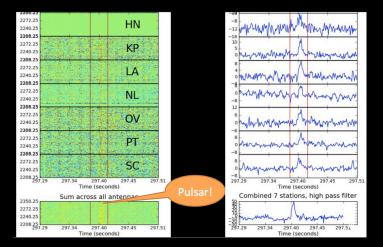


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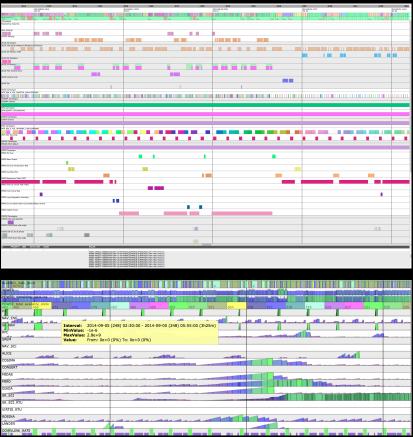




Machine Learning for Automated Triage/detection of Visual Transient Events



Machine Learning for Automated Triage/classification of Radio Transient Events





Management

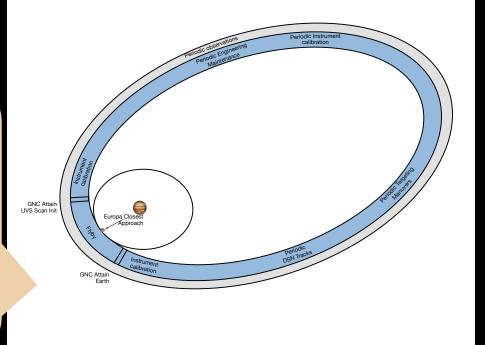
Constraint-based Scheduling to support Rosetta Orbiter Science Operations and Data

Europa Clipper – Radiation Resets

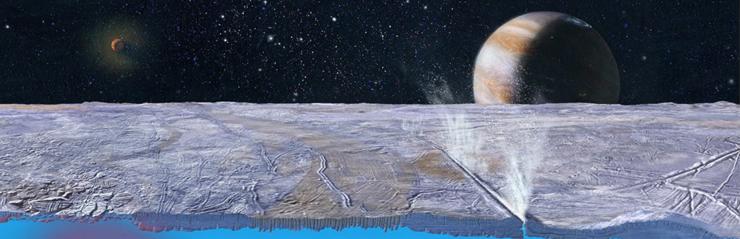
EXAMPLE: RESPONSE TO EARLY RESET

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



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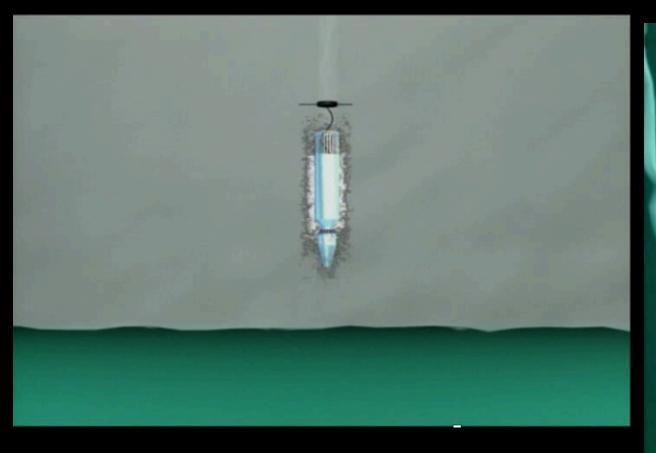


Another incredible challenge: Exploring a sub-ice ocean of Europa



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Artists concept.



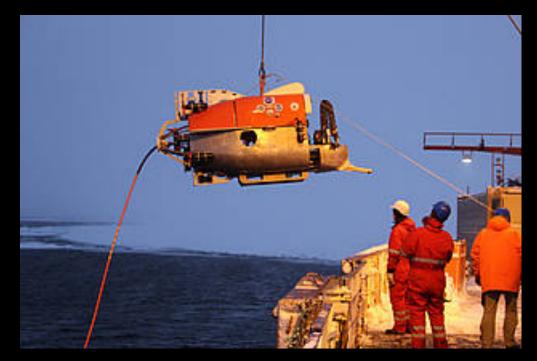
- A Europa Submersible would have spend a year or even more to penetrate kilometers of ice
- Then explore autonomously for weeks to months at a time searching for life, perhaps at hydrothermal vents
- A true challenge for AI!

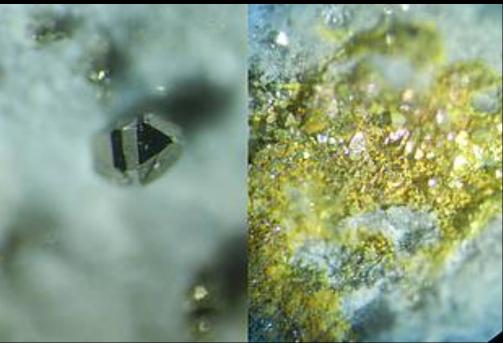


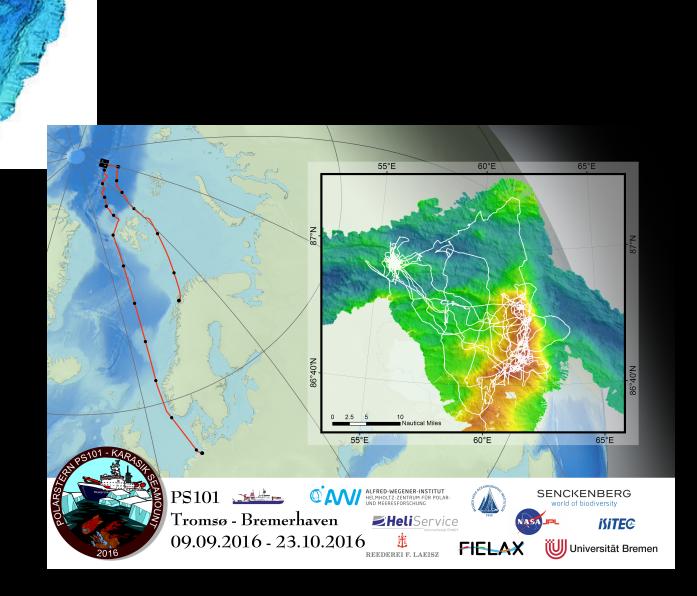
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> Ocean Worlds submersible concept.

From the Recent Polarstern Cruise, Karasik Massif 85 N







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

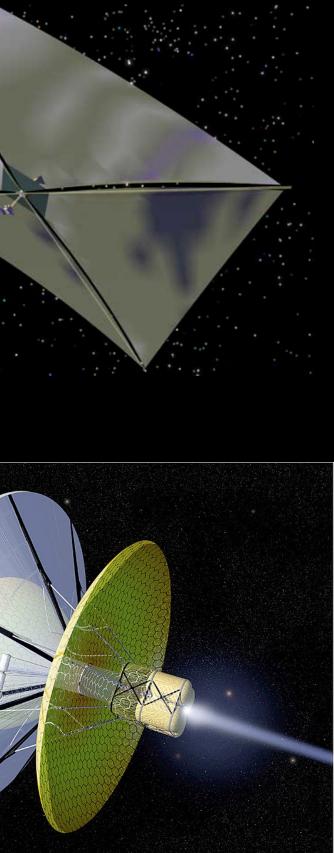
Interstellar Mission Concepts

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-icymoons
- Ocean Worlds \bullet
 - https://www.nasa.gov/specials/ocean-worlds
 - Polarstern- A. Boetius/AWI, C> German/WHOI, K. Hand/JPL
- Interstellar Mission \bullet
 - https://en.wikipedia.org/wiki/Interstellar probe
 - http://kiss.caltech.edu/workshops/ism/ism2.html \bullet

DARE MIGHTY THINGS

Jet Propulsion Laboratory California Institute of Technology