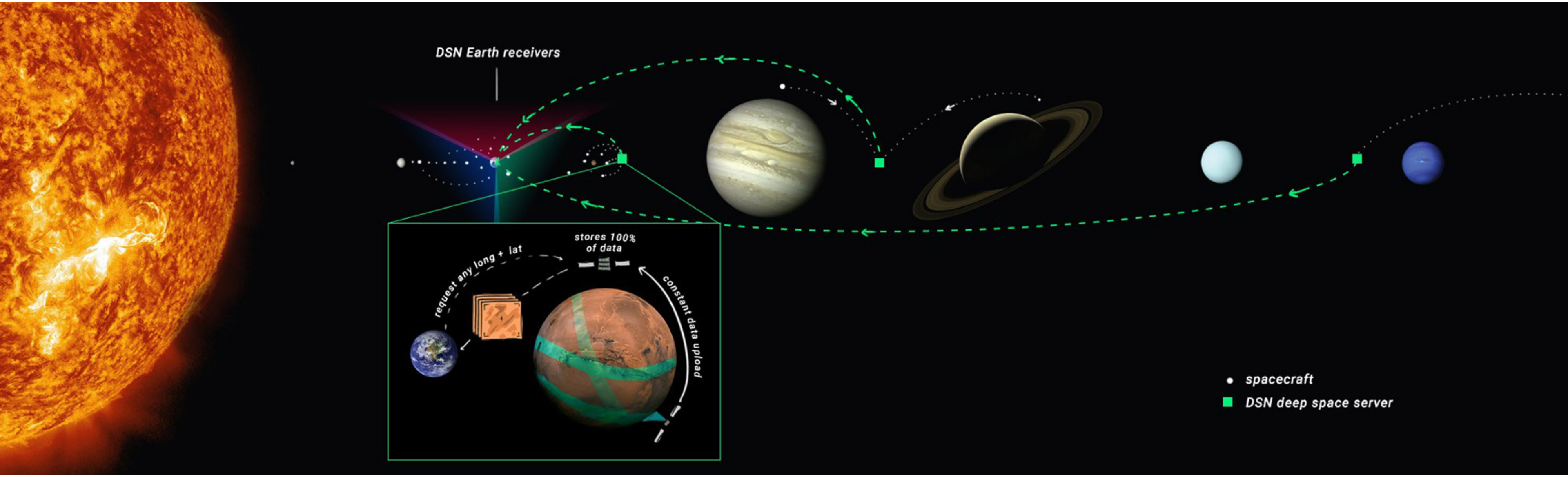

Virtual Research Presentation Conference

Mars On Site Shared Analytics Information and Computing (MOSAIC)

Principal Investigator: Joshua Vander Hook 397 (hook@jpl.nasa.gov)
Co Investigators: many (see next slide)
Program: Strategic Initiative

Assigned Presentation # RPC-132

Jet Propulsion Labo ory
California Institute of Techn ogy

Tutorial Introduction

Abstract

What new capabilities and mission concepts are enabled by next generation spaceflight computing?

Three tasks: COSMIC (Orbiter), MAARS (Rover), MOSAIC (Constellations & Networked Systems)

MOSAIC:

On-site computing infrastructure that can help with optimized **data routing**, **computation tasks**, and **observation plans**, with a **delay-tolerant network** of observers.

Key scheduler: Integer Linear Program

Target Applications: Dedicated support "servers", multi-spacecraft networked missions, orbit+lander opportunistic comms or compute, and ground networks of robots.

Works in ROS, f-prime, integrated with ION/DTN

Team (all years)	
Tiago Vaquero	397
Federico Rossi	347
Marc Sanchez-Net	332
Robyn Woollands	392
Maira Saboia Da Silva	347
Steve Chien	397
Martina Troesch	397
Josh Schoolcraft	389
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Tara Estlin	398
Ingrid Daubar	394
Mike Mischna	322
Valerie Fox	U of MN
Jay Dickson	Caltech
Jay Gao	332

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Keck INSTITUTE FOR SPACE STUDIES

Background

a) DTN and Next-Gen Computing are coming

b) Missions are downlink constrained -- to the point that mission concepts are artificially limited

c) Even without autonomous targeting or interpretation, computing and reliable networking can have a massive increase in science discovery

d) But infrastructure + intelligence has the most potential

Methodology

a) Focus on **on-site processing, storage, and analytics infrastructure**, and evaluate mission operations *change and impact*

b) Along the way, develop new technology for operating that infrastructure

c) Test in medium fidelity simulations and field trials that establish first-cut science traceability

Results

Intended results

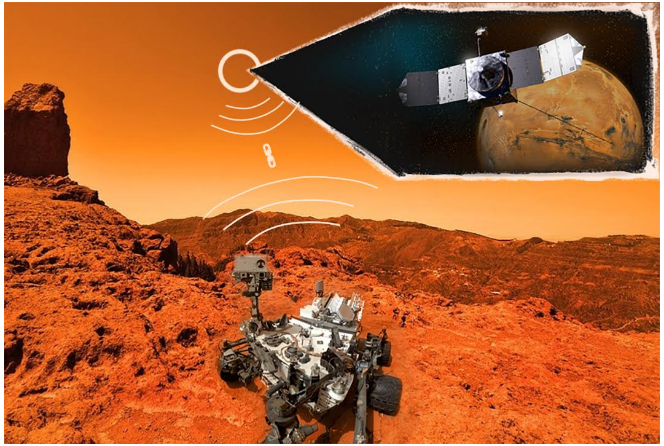
A **scheduling algorithm** that handles:

- Shared computing resources for “traditional” missions
- Distributed computing for multi-agent systems
- Observation and communications planning to enhance return of proposed mission concepts
  - Including Venus Balloon concept

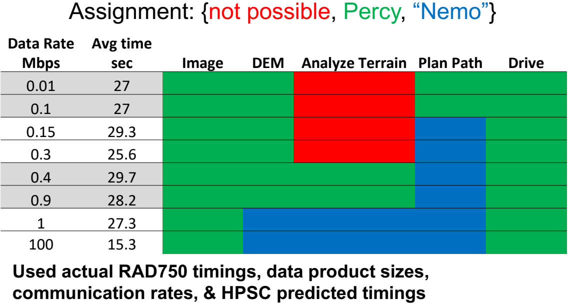
Unintended results

- High throughput *data mules* can boost mission throughput 1000x compared to MRO
- Everything is in place for a mission focused on global mapping and change detection
- Decadal whitepaper supporting onboard data fusion

Making Mars 2020 15% faster



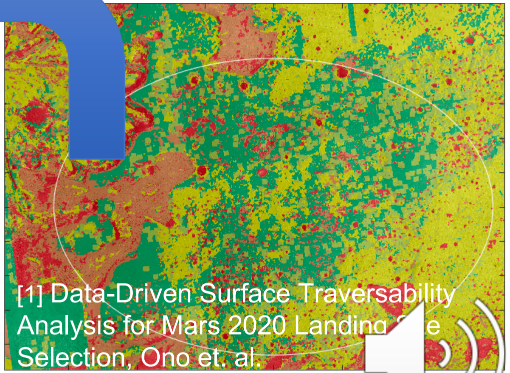
The four different computing regimes raced



Assignment: {not possible, Percy, “Nemo”}

Data Rate Mbps	Avg time sec	Image	DEM	Analyze Terrain	Plan Path	Drive
0.01	27	🟩	🟩	🟥	🟩	🟩
0.1	27	🟩	🟩	🟥	🟩	🟩
0.15	29.3	🟩	🟩	🟥	🟦	🟩
0.3	25.6	🟩	🟩	🟥	🟦	🟩
0.4	29.7	🟩	🟩	🟩	🟦	🟩
0.9	28.2	🟩	🟩	🟩	🟦	🟩
1	27.3	🟩	🟦	🟦	🟦	🟩
100	15.3	🟩	🟦	🟦	🟦	🟩

Used actual RAD750 timings, data product sizes, communication rates, & HPSC predicted timings

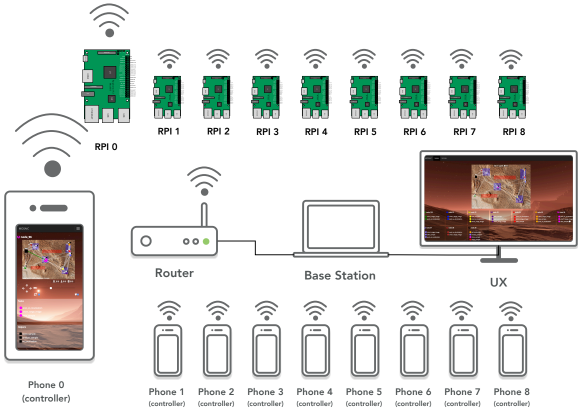


[1] Data-Driven Surface Traversability Analysis for Mars 2020 Landing [illegible]e Selection, Ono et. al.

Percy crossed Jezero Crater up to 15% faster by making use of nearby compute resources, and with no change to onboard compute

Used “drive plan as a service” from the orbiter, simulated with realistic communications & processing times

Network of small rovers



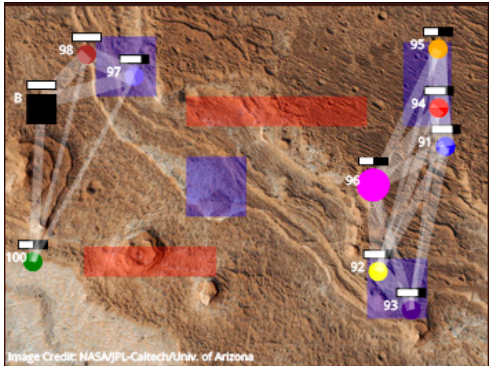
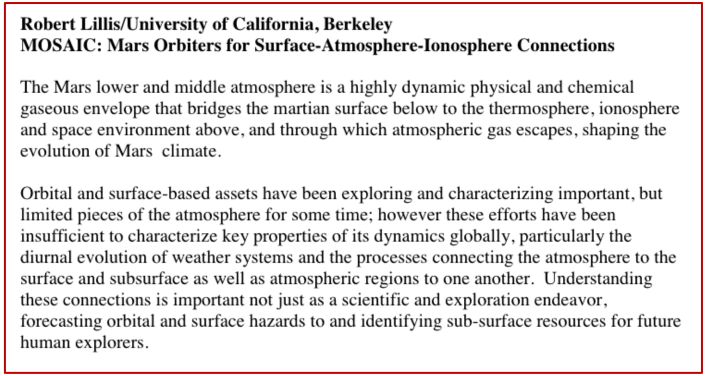


Image Credit: NASA/JPL-Caltech/Univ. of Arizona

- Hours uninterrupted operation
- “Adversarial” humans (conference crowd)
- Load balanced observations and analysis processing steps to save energy and time
- ROS and DTN integration! https://github.com/nasa/mosaic
- 3X throughput of science data (more obs, better comms paths, load balancing)

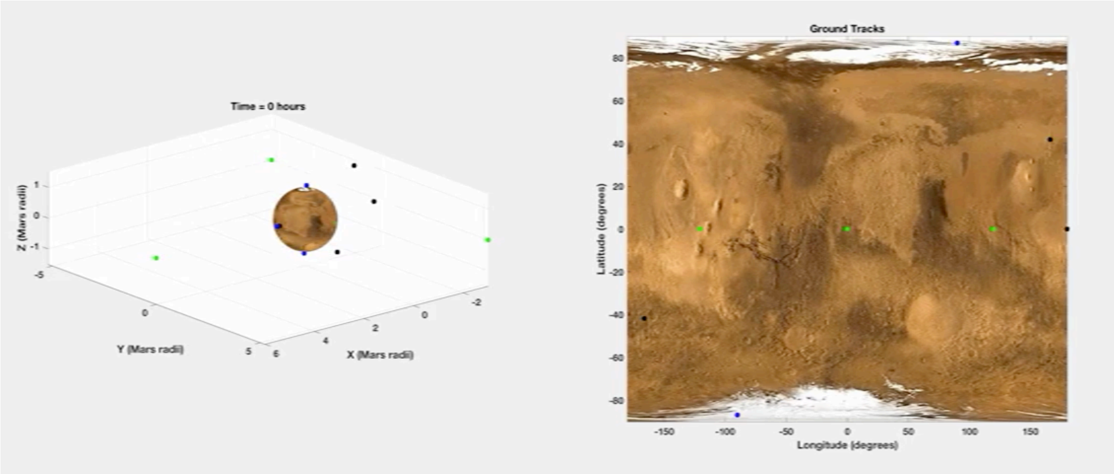
Planetary Mission Concepts Study



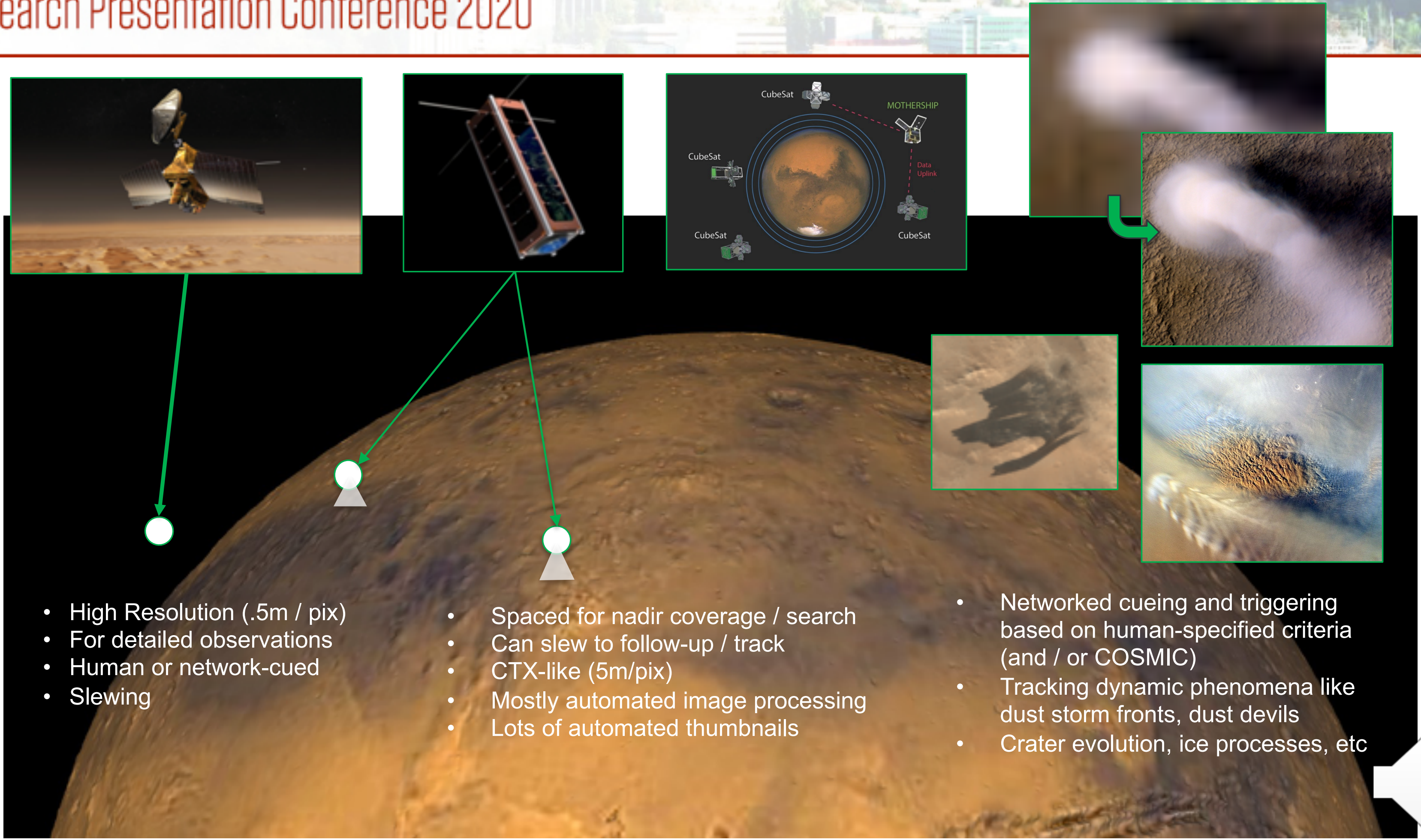
Robert Lillis/University of California, Berkeley
MOSAIC: Mars Orbiters for Surface-Atmosphere-Ionosphere Connections

The Mars lower and middle atmosphere is a highly dynamic physical and chemical gaseous envelope that bridges the martian surface below to the thermosphere, ionosphere and space environment above, and through which atmospheric gas escapes, shaping the evolution of Mars climate.

Orbital and surface-based assets have been exploring and characterizing important, but limited pieces of the atmosphere for some time; however these efforts have been insufficient to characterize key properties of its dynamics globally, particularly the diurnal evolution of weather systems and the processes connecting the atmosphere to the surface and subsurface as well as atmospheric regions to one another. Understanding these connections is important not just as a scientific and exploration endeavor, forecasting orbital and surface hazards to and identifying sub-surface resources for future human explorers.



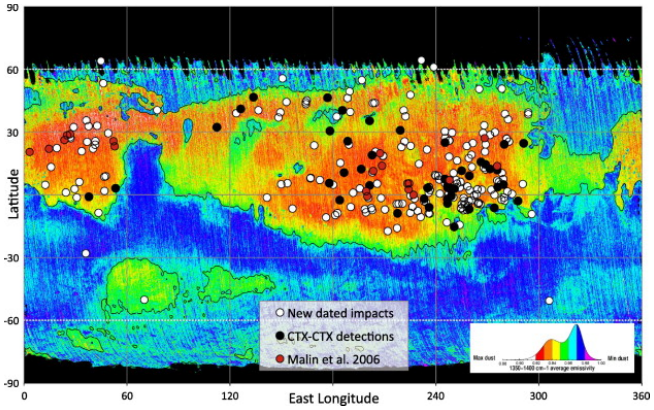
- Borrowed constellation from similarly named Planetary Mission Concept Study (naming was coincidental)
- Goal: Show how increased on-site coordination, computing, and autonomous observation could increase science throughput with minimal impact

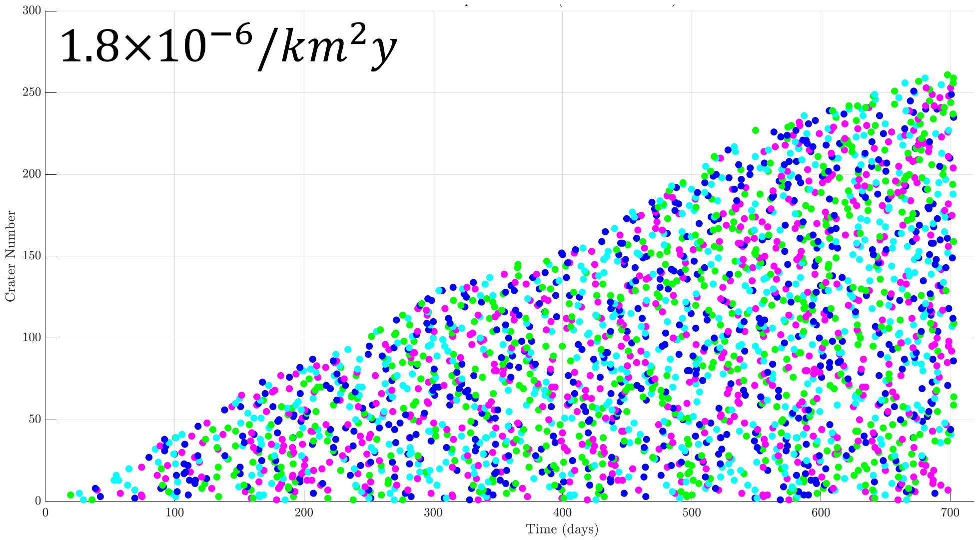


- High Resolution (.5m / pix)
- For detailed observations
- Human or network-cued
- Slewing

- Spaced for nadir coverage / search
- Can slew to follow-up / track
- CTX-like (5m/pix)
- Mostly automated image processing
- Lots of automated thumbnails

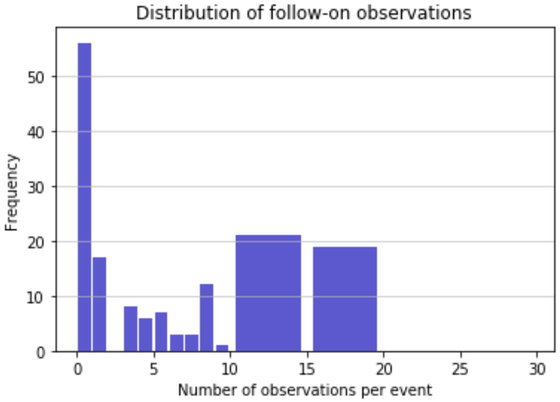
- Networked cueing and triggering based on human-specified criteria (and / or COSMIC)
- Tracking dynamic phenomena like dust storm fronts, dust devils
- Crater evolution, ice processes, etc





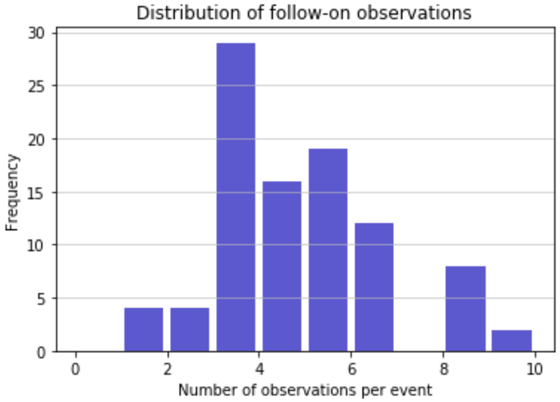
- Bland, P. A., & Smith, T. B. (2000). Meteorite accumulations on Mars. *Icarus*, *144*(1), 21-26.
- Dycus, R. D. (1969). The meteorite flux at the surface of Mars. *Publications of the Astronomical Society of the Pacific*, 399-414.
- **Daubar, I. J., et al. "The current martian cratering rate." *Icarus* 225.1 (2013): 506-516.**

Nadir only



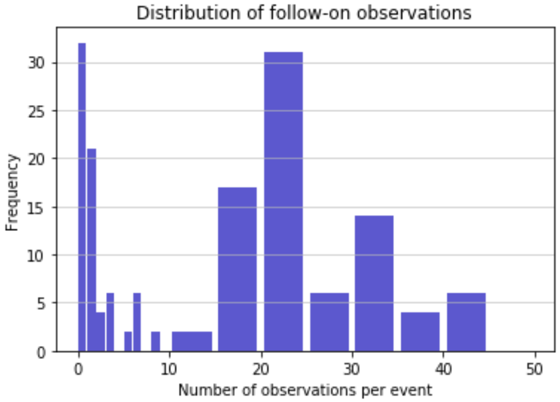
Total number of unique events observed: 114/163
Total number of observations (incl. follow-ons): 658
Maximum number of follow-on observations: 13

Realistic



Total number of unique events observed: 107/163
Total number of observations (incl. follow-ons): 1140
Maximum number of follow-on observations: 33

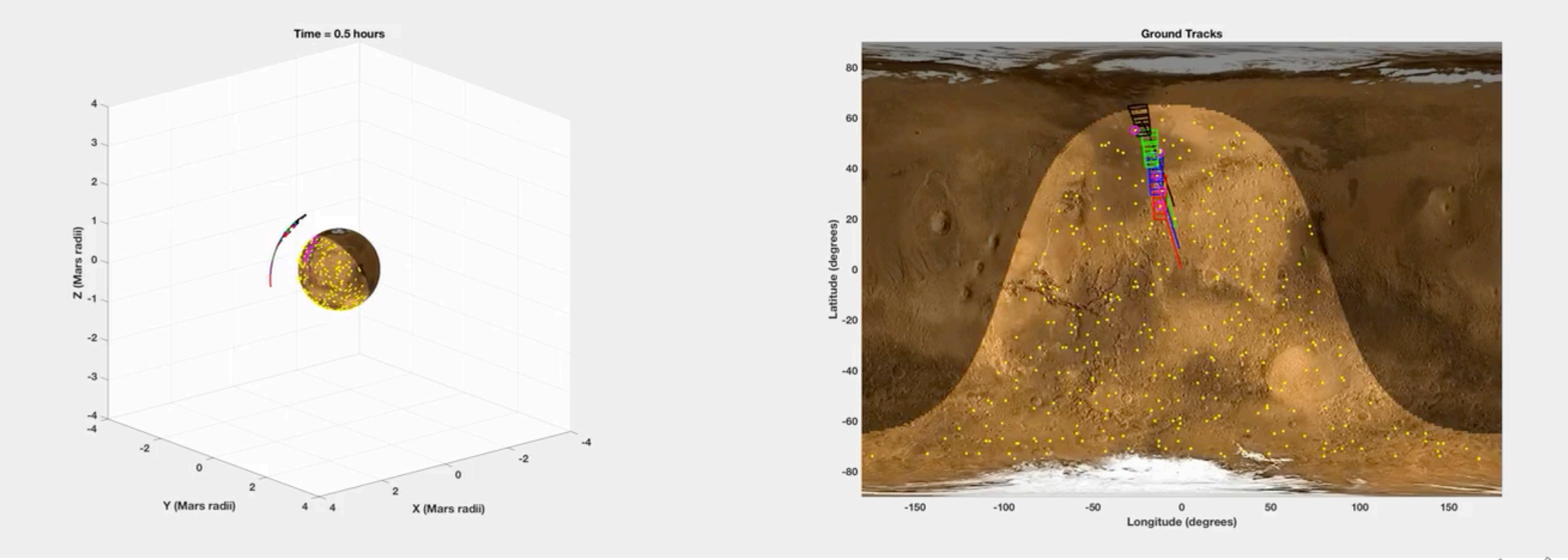
Omniscient



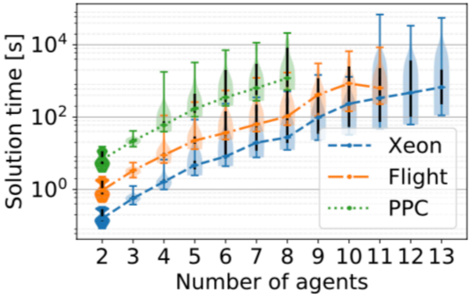
Total number of unique events observed: 131/163
Total number of observations (incl. follow-ons): 2600
Maximum number of follow-on observations: 55

When asked to follow-up, we **triple the number of follow-up observations possible** (middle). Even putting cameras on reveals 114 new fresh impacts with 13 follow-up observations (le Compare to “cued” system, right.

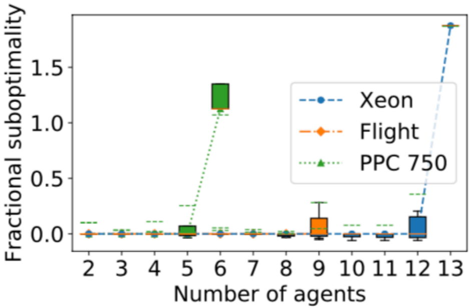
We could record movies of hundreds of dust devils per day



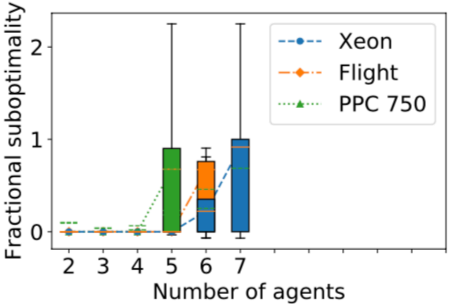
Scheduler for follow-up observations was tested using dust devil models



(a) Time required to solve Problem 2 to optimality as a function of number of agents, log scale.

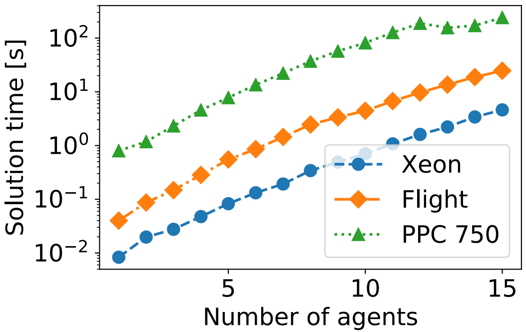


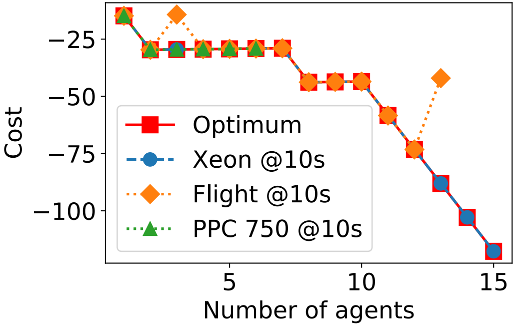
(b) Problem (2): Suboptimality as a fraction of the optimal solution after 60s of execution.

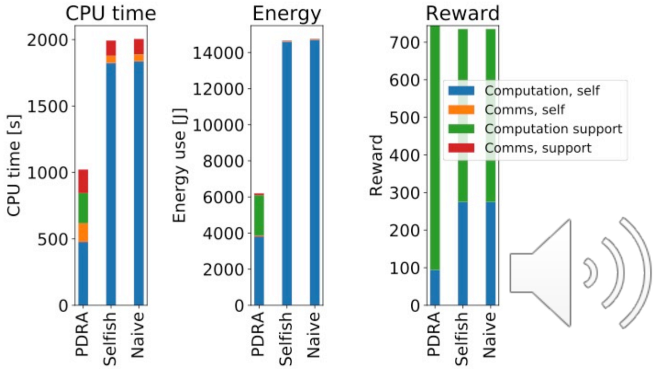


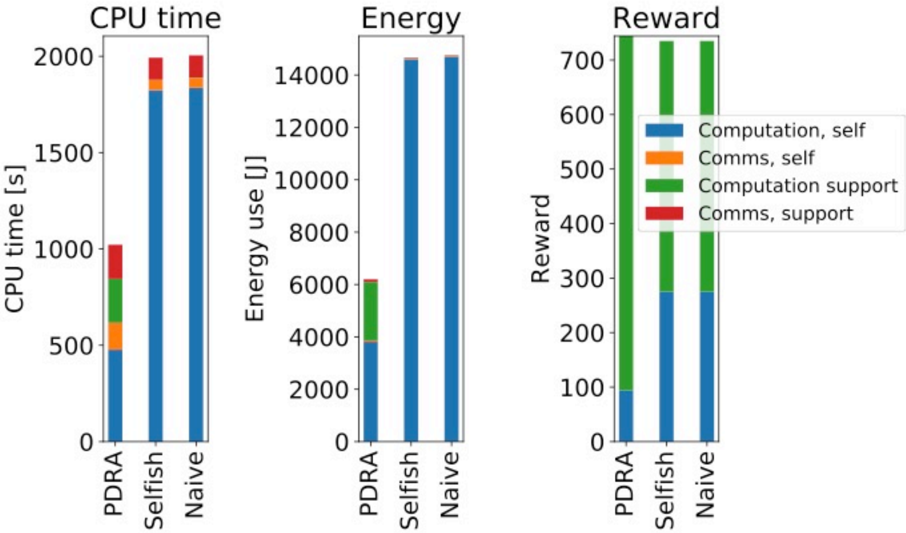
(c) OPTIC PDDL solver (Benton et al. 2012): Suboptimality as a fraction of the optimal solution after 60s of execution.

- PDDL is considered the state of the art, at least among timeline solvers

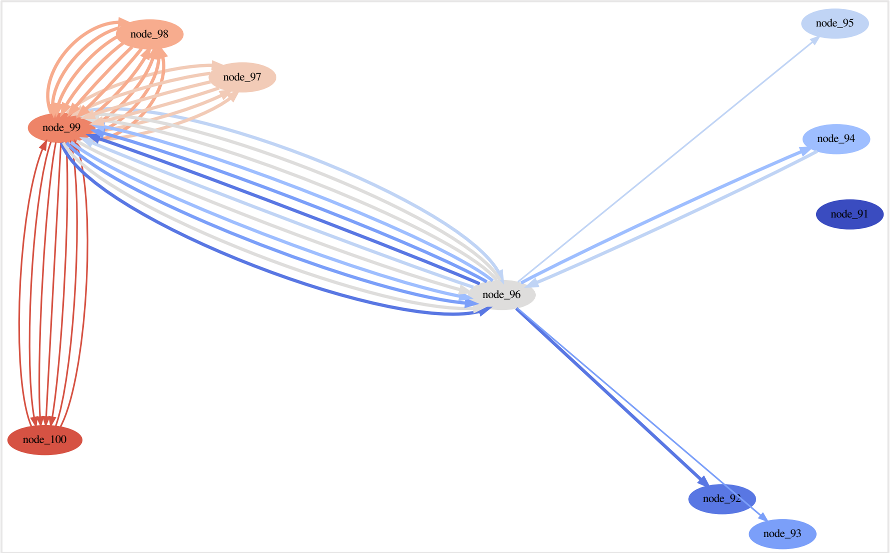




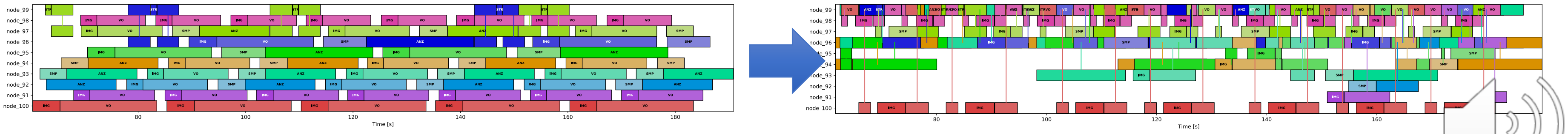




Example with "pure savings". No extra observations, significant CPU/ energy savings.

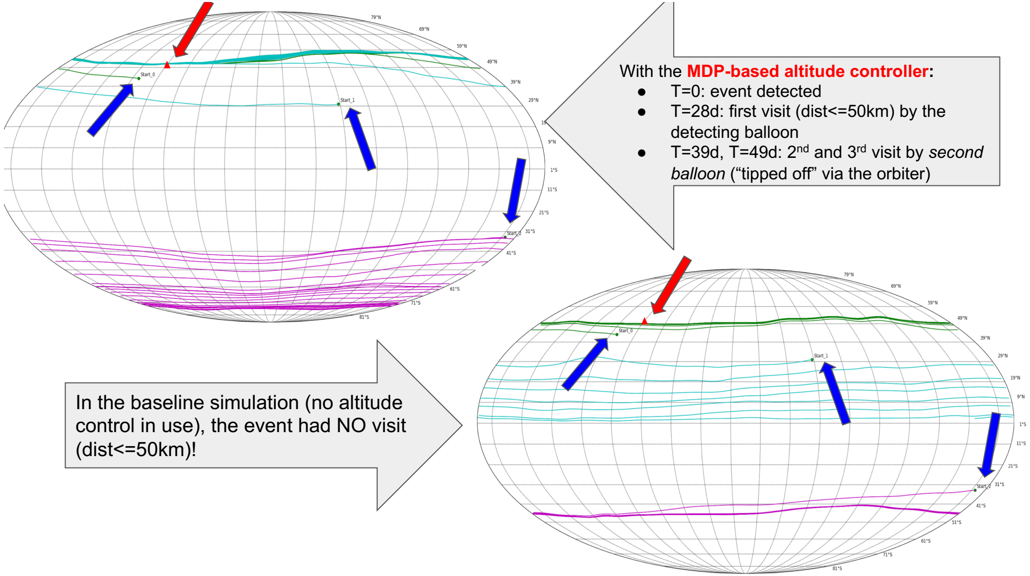


Data flows



Obligatory timelines naïve vs PDRA

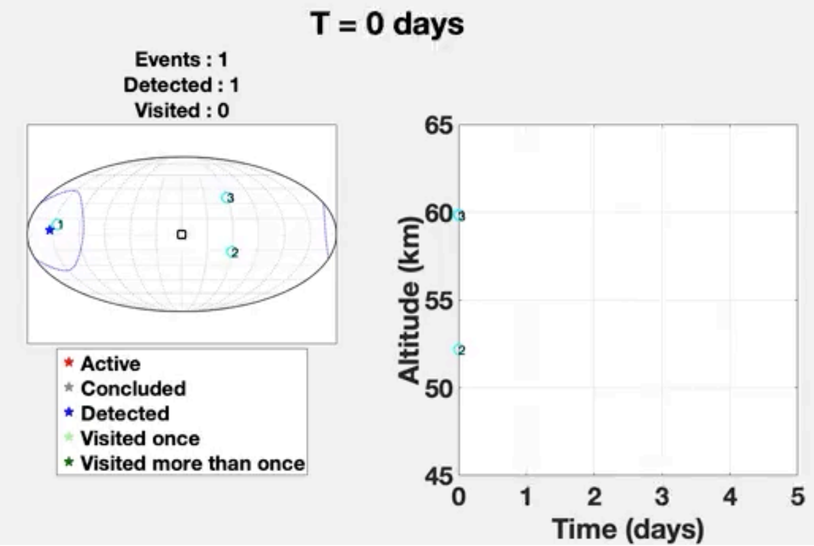
Extensions to Venus



With the **MDP-based altitude controller**:

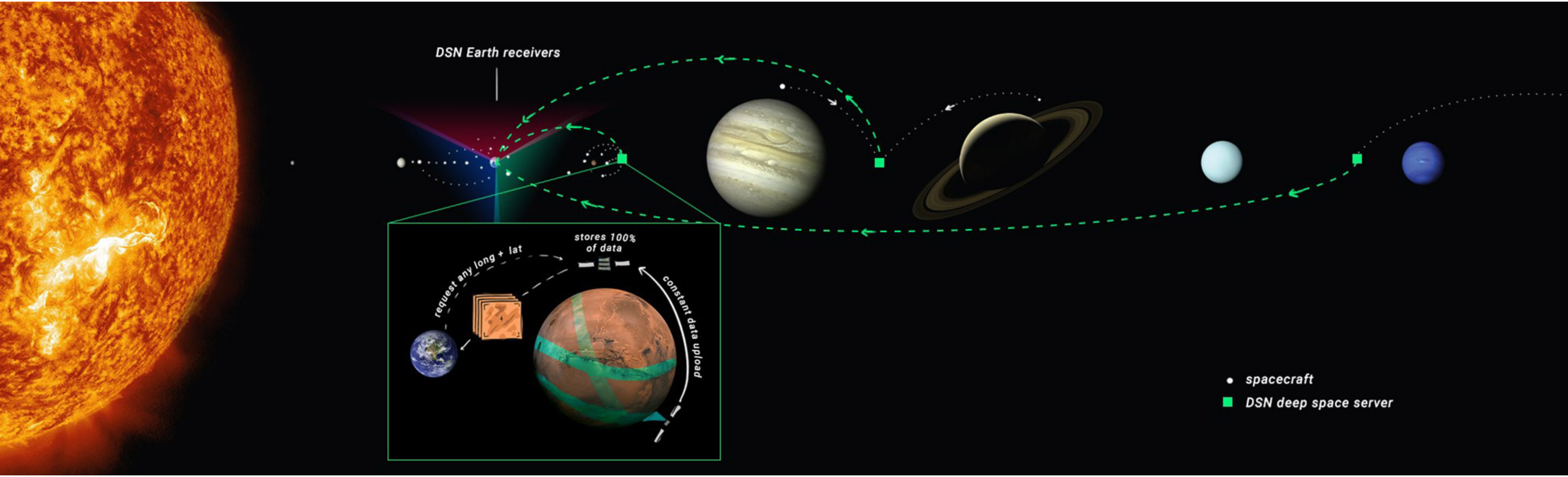
- T=0: event detected
- T=28d: first visit (dist<=50km) by the detecting balloon
- T=39d, T=49d: 2nd and 3rd visit by *second balloon* (“tipped off” via the orbiter)

In the baseline simulation (no altitude control in use), the event had NO visit (dist<=50km)!



Onboard planning increased the chances of visiting a volcano event during eruption from 0.4% to 54%

Can we do human-driven science with data we cannot downlink?



Report expected December 2020

Publications and References

CODE release and demonstrations: https://github.com/nasa/mosaic

1.The Pluggable Distributed Resource Allocator (PDRA): a Middleware for Distributed Computing in Mobile Robotic Networks
F. Rossi, T. Stegun Vaquero, M. Sanchez-Net, M. Saboia da Silva, J. Vander Hook.
Submitted to the 2020 International Conference on Intelligent Robots and Systems. Las Vegas, USA
[pdf] [bib] [github]

2.Nebulae: A Proposed Concept of Operation for Deep Space Computing Clouds
Joshua Vander Hook, Julie Castillo-Rogez, Richard Doyle, Tiago Stegun-Vaquero, Trent M. Hare, Randolf L. Kirk, Dmitriy Bekker, Alice Cocoros, Valerie Fox,
Proceedings of the IEEE Aerospace Conference. Big Sky, MT 2020.
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3.Data Mules on Cycler Orbits for High-Latency, Planetary-Scale Data Transfers
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J. VanderHook, Tiago Stegun Vaquero, Federico Rossi, Martina Troesch, Marc Sanchez-Net, Joshua Schoolcraft, Jean-Pierre de la Croix, Steve Chien
Proceedings of the International Conference on Automated Planning and Scheduling. 29 (1), pp 707-715. Berkeley, CA 2019.
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5.Dynamic Shared Computing Resources for Multi-Robot Mars Exploration
Joshua Vander Hook, Tiago Stegun Vaquero, Martina Troesch, Jean-Pierre de La Croix, Joshua Schoolcraft, Saptarshi Bandyopadhyay and Steve Chien
Workshop on Planning and Robotics in 28th International Conference on Automated Planning and Scheduling. Delft, Netherlands, 2018.
[pdf] [bib]

6.Journal papers in URS, available on request