

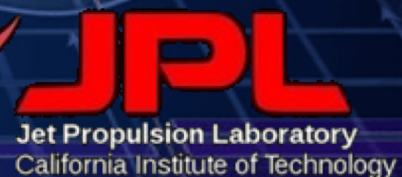
Autonomy for Space Exploration

A Consumer's Guide

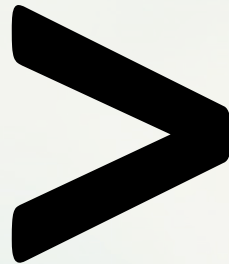
Dr. Lukas Mandrake (JPL 39, 8x/NSTA)

Jet Propulsion Laboratory, California Institute of Technology

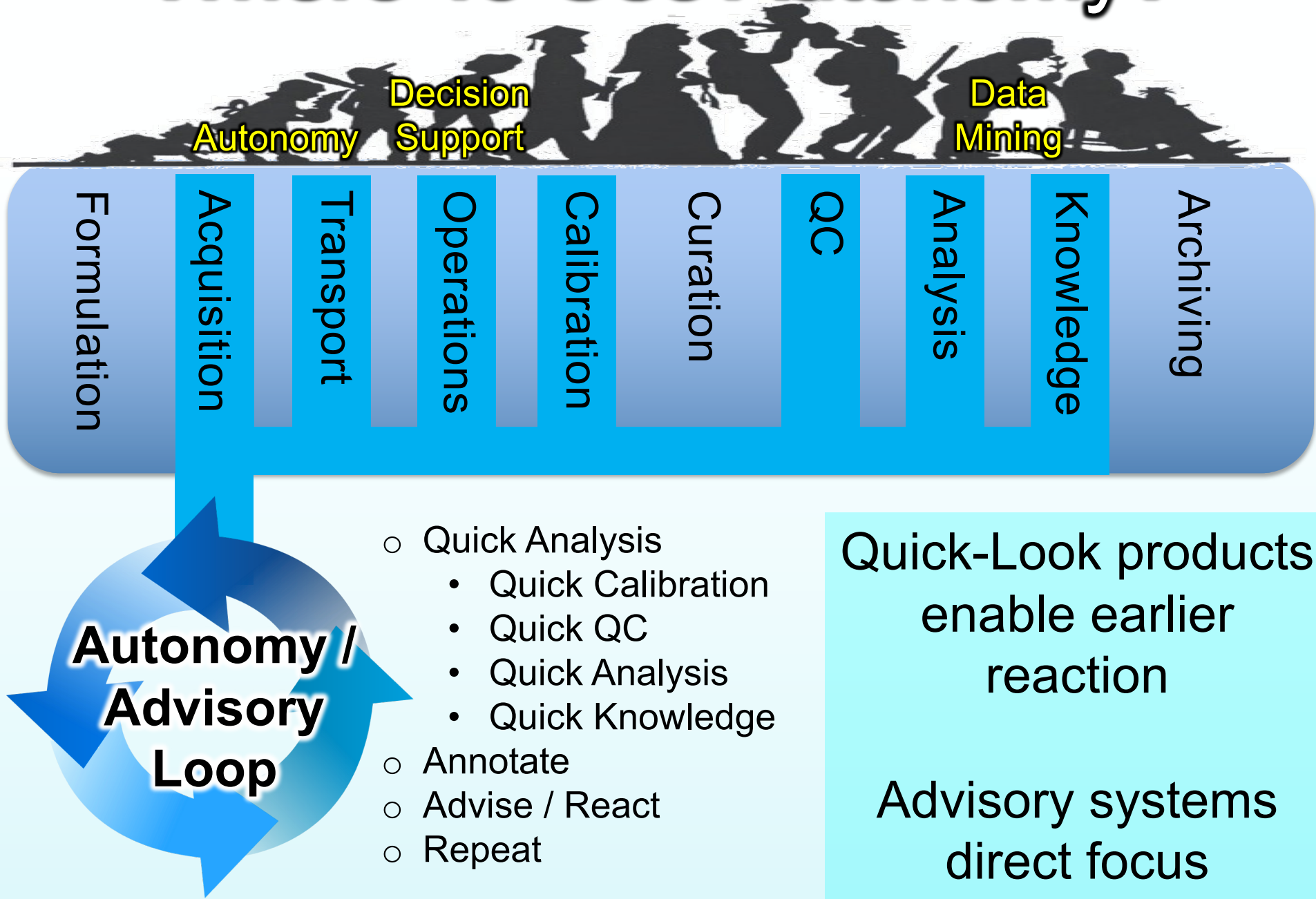
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When to Use Autonomy?



Where To Use Autonomy?



Three Operational Frameworks



Archival / Ground

Compute: **High**
 Data Volume: **High**
 Data Velocity: **Low**



Real Time / Ops / Pipelines

Compute: **High**
 Data Volume: **Med**
 Data Velocity: **High**



Onboard Autonomy

Compute: **Low ****
 Data Volume: **High**
 Data Velocity: **High**

Anomaly Detection		
Focus of Attention		
Content-based Search		
Quality Estimation		
Exploration / Mining		
Interactivity / Insight		
V & V		
Change Detection		
Triage / Prioritization		
Reactive Systems		
Knowledge Compression		
Auto-calibration		

- Support publications
- Understand data better

- Root Cause Analysis
- System trending

- Min bandwidth
- Max science return

Related and Interdependent

- Autonomy is just the march of data analysis upstream to the edge
- Con: Easier towards the ground (human in the loop)
- Pro: Unique opportunities exist with earlier insight



JPL Autonomy Examples

Is the Signal Even In The Telemetry?

DSWG Tech – ON-WATCH

Onboard Numeric Watchdog for Analysis of Telemetry Channel

Heuristics

Jack Lightholder

Different channels are manually ordered to take data at high (~1s), medium (~6s), or low (>10 s) rates.

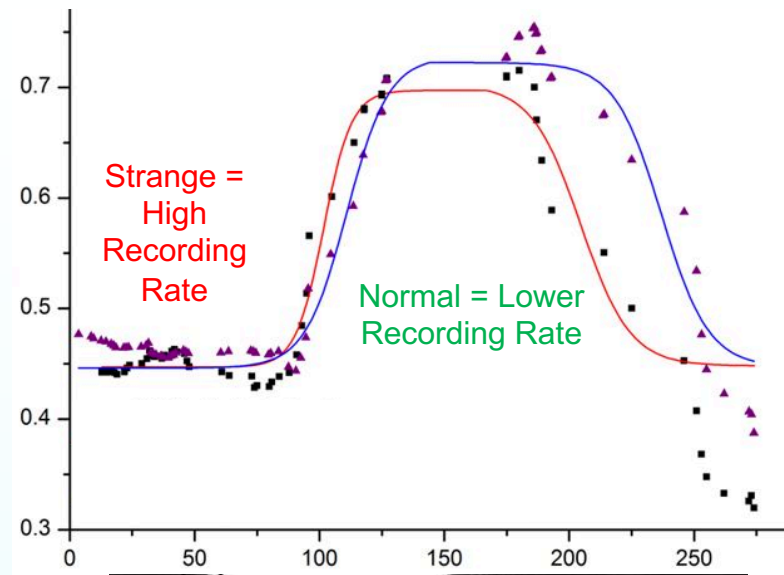
What if anomaly happens faster than you're sampling?

You miss it!

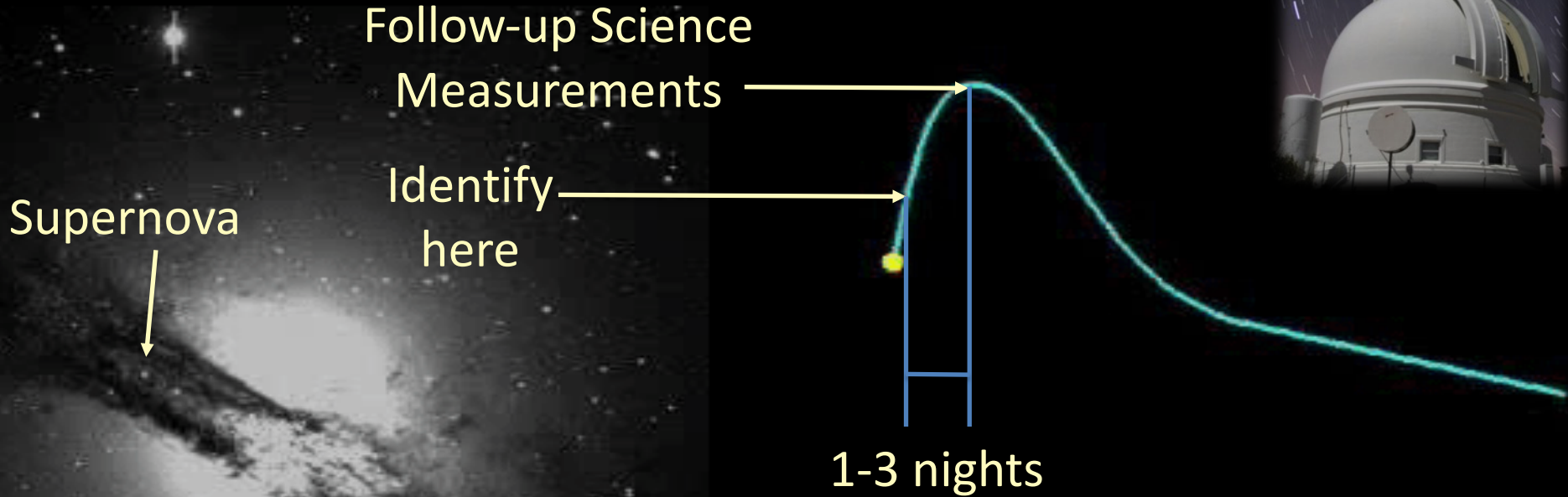
ON-WATCH automatically adjusts telemetry recording rates based on how unusual the spacecraft state.

Would already have initial guesses of when to look for anomalies based on high-resolution data!

GRACE-FO team has already said, "If our telemetry even captured the anomaly itself..."



Early Warning Systems



PTF Supernova Autonomy

Dr. Umaa Rebbapragada et al

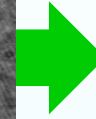
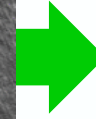
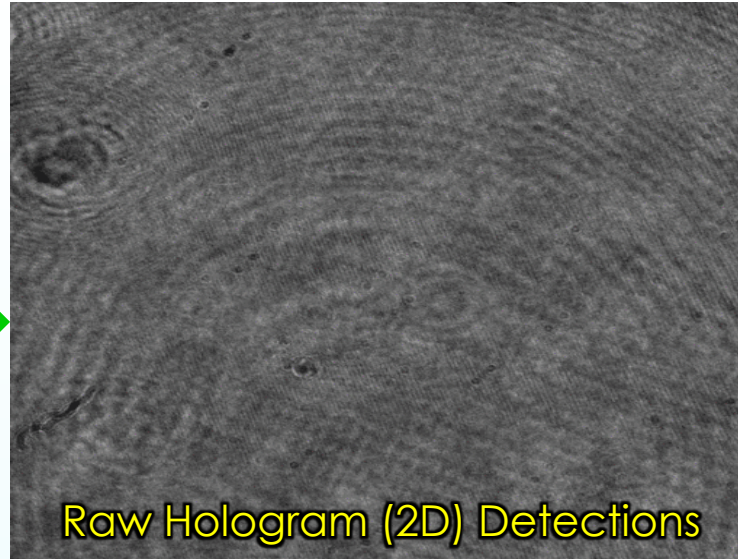


Current PTF Supernova Detector!

- Millions of candidates / night
- Select 200 for manual follow up
- Better be right: sound world alert
- Launch / Detonation Detection

Holographic Life Detection

Drs. Lukas Mandrake, Gary Doran, Brian Bue

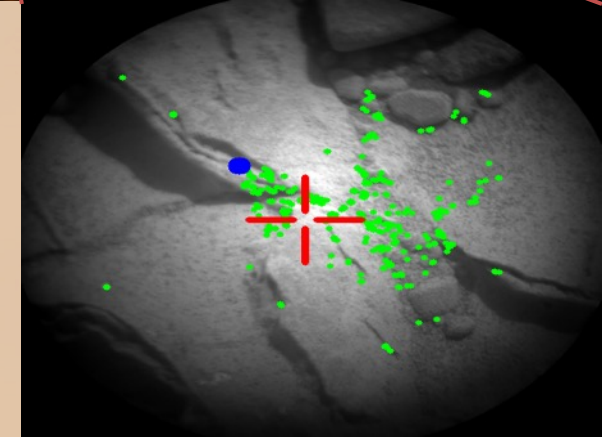
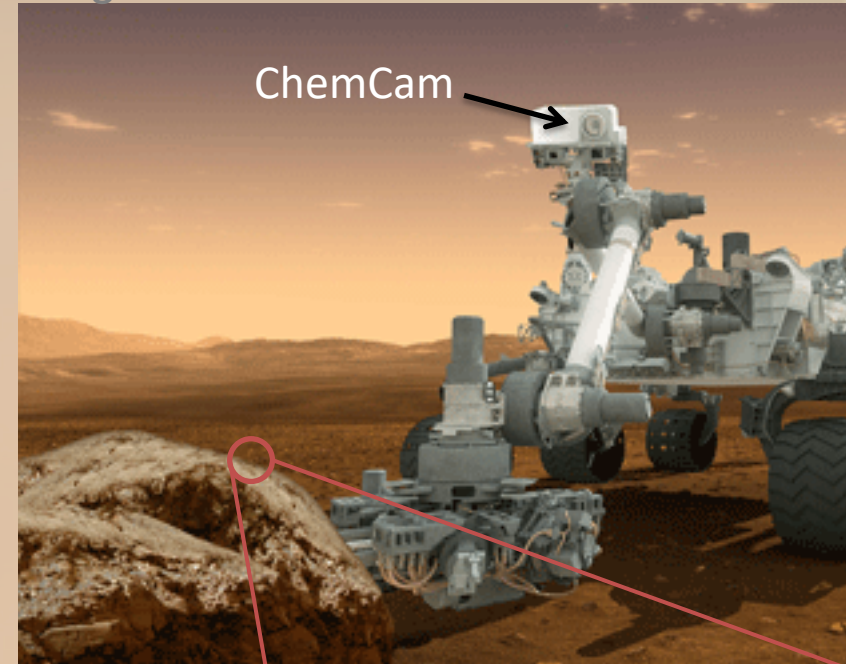


- Digital Holographic Microscopes
 - Big data (4D, ~GB/s), rare findings
- Motility ~ Life (composition agnostic!)
- HELM ML system detects, tracks, and classifies in messy, raw 2D holograms

AEGIS/ChemCam on MSL

Autonomous Exploration for Gathering Increased Science

- Target & Zap Rock
- Manually Scheduled Targets
- Round Trip Delays
- Trouble hitting 1st time
- Targeted science not possible right after drive
- Autonomy selects interesting targets
- Refines targeting automatically
- ~30-100% additional ChemCam science targets on drive sols

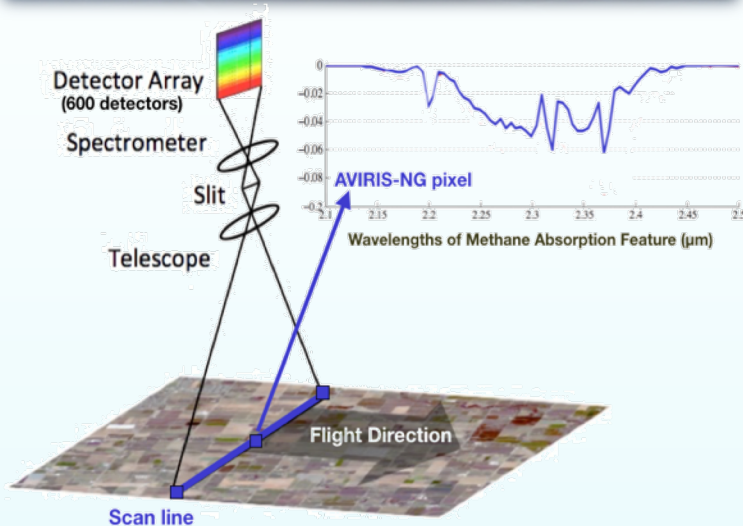


Currently on Mars for Curiosity and 2020 rovers

Drs. Tara Estlin, Dan Gaines, Gary Doran,
Raymond Francis, et al...

AVIRIS-NG Hyperspectral

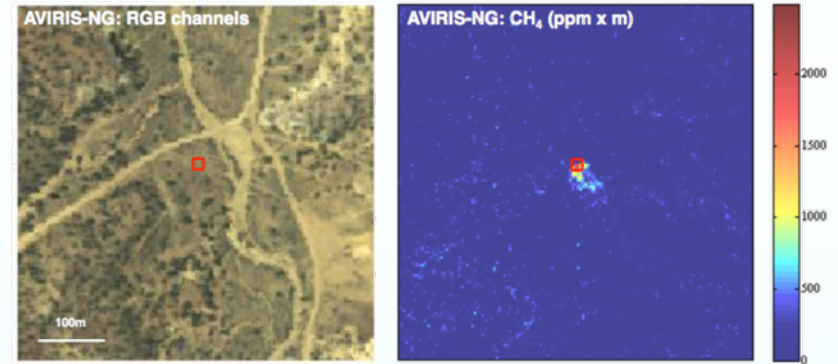
Dr. David Thompson, Dr. Brian Bue, et al



Airborne Imaging Spectrometer

Multiple gas pipelines shut down / repaired
Machine Learning "That Matters"

CH₄ detection in four corners



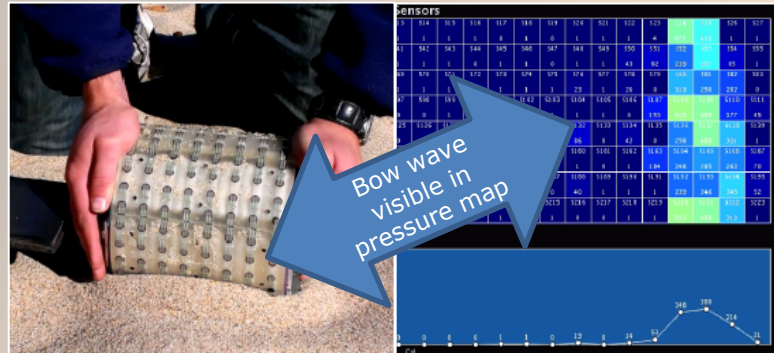
Enabled ground team to find underground pipe leaks



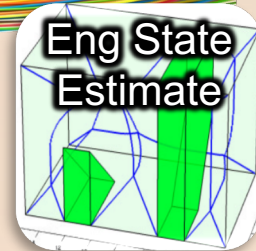
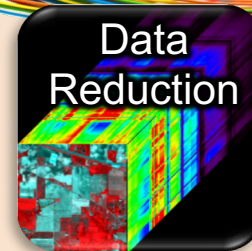
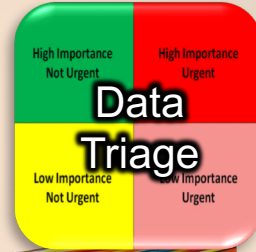


The Barefoot Rover

Jack Lightholder, Dr. Lukas Mandrake

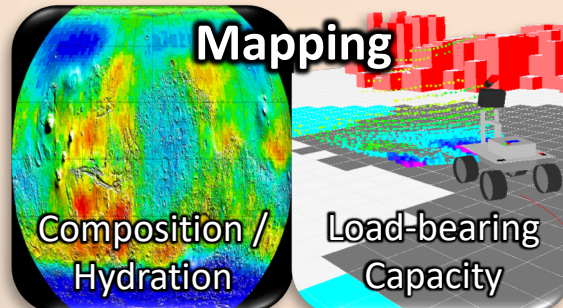


Real-Time
On-Board
Analytics

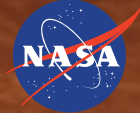


What if rover wheels could:

- Feel the ground like we use bare feet?
- Taste for specific compounds like a fly? (like water or)
- Hear the electrical properties of buried metal, or power lines?



Active Development: Earth & Mars Applications 2020 timeframe



Jet Propulsion Laboratory
California Institute of Technology



Content-based On-board Summarization to Monitor Infrequent Change

PI: Dr. Lukas Mandrake

Co-I's: Dr. Kiri Wagstaff, Dr. Gary Doran, Steven Lu, Jimmie Young,
and Dr. Umaa Rebbapragada

Machine Learning and Instrument Autonomy Group

Current Operation Mode

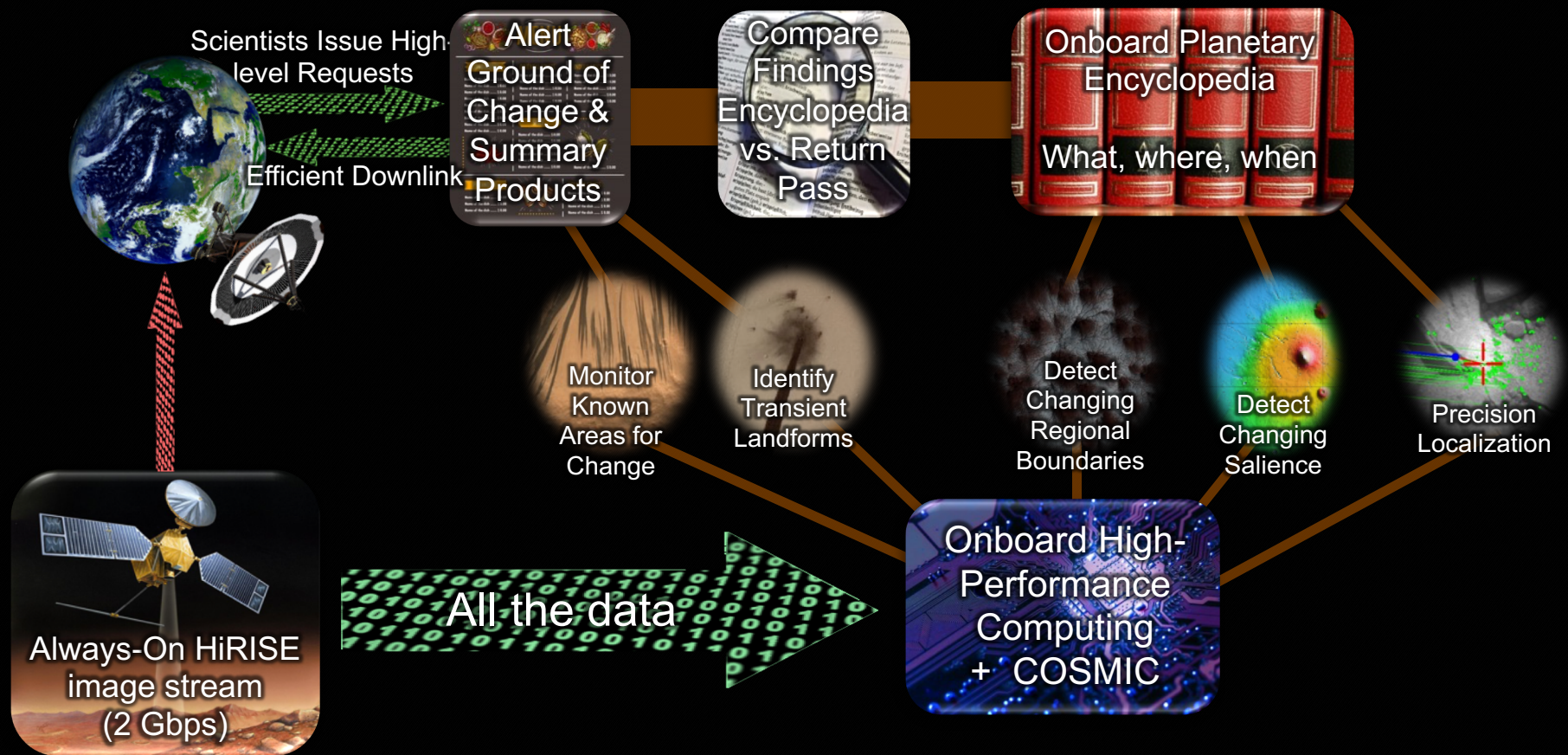


- Scientists select where and what to look for
- Spacecraft responds to commands
- Return data to ground
- Ground data analysis
- THIS WORKS! (if the target stays put)

Limitation: must know where to look to make request

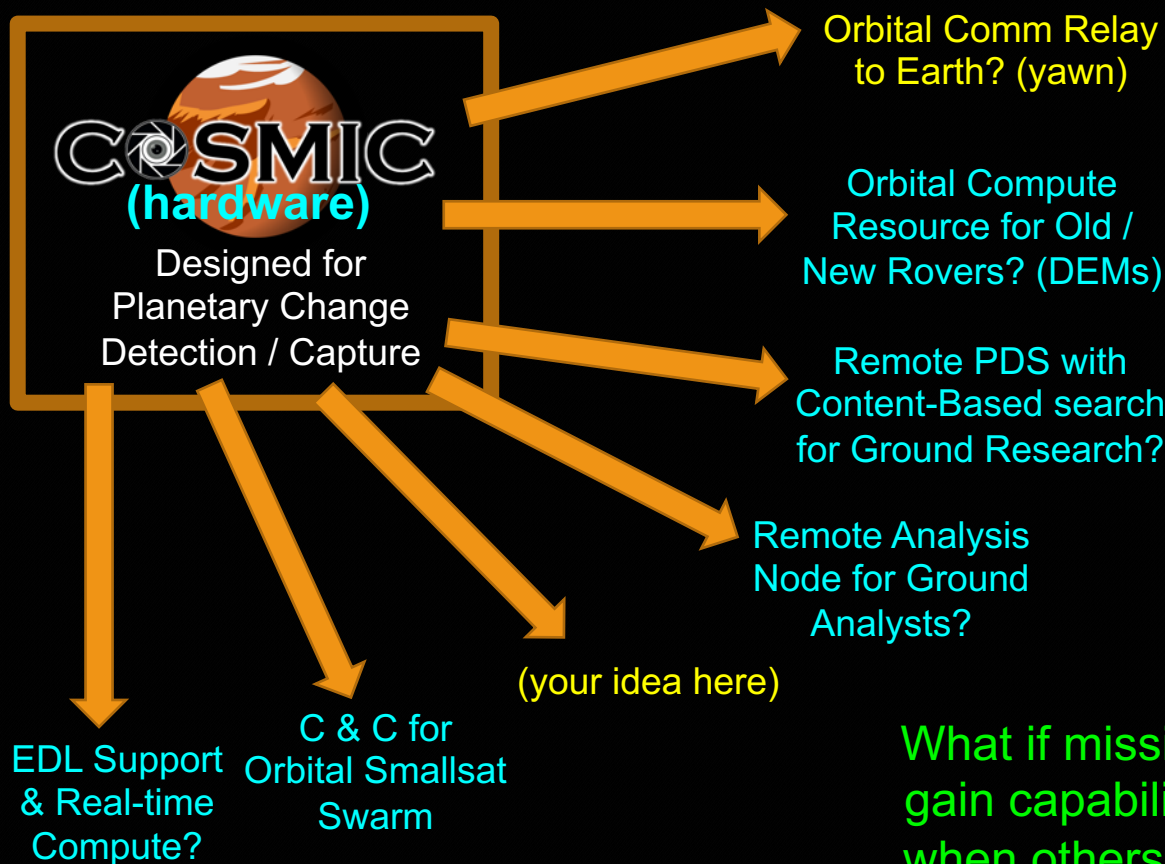
Unaddressed need: Change Detection

COSMIC-in-the-loop Operation Mode



Planetary Change Detection with minimal downlink!

Break Out of the Box – Implicit Collaboration



What if we permit craft to exchange analysis requests rather than just data?

What if we schedule planetary compute like we schedule comm passes?

What if missions gain capabilities when others are nearby?