



# Information Technology at JPL

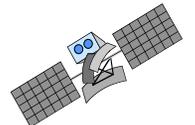
## Challenges and Opportunities

**Dr. Richard J. Doyle**

**Manager, Information Technology Program Office**  
**Leader, Center for Space Mission Information and**  
**Software Systems (CSMISS)**

**April 1, 2003**

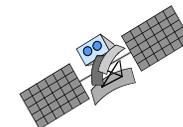
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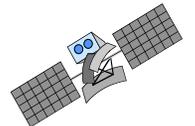
# Ten-Year Vision

- Mission software is reliable and reusable, with predictable effort and cost, and managed risk
- Software-based capabilities enable space platforms with new onboard functions and long-term survivability
- The Interplanetary Network is achieved, with routine robust access to space information products by PI's and the general public, as well as information sharing among space assets
- The role of software engineering, information technology and computer science in JPL mission success is known and valued
- JPL Project Managers routinely come from IT backgrounds as well as traditional engineering backgrounds





# Software Engineering

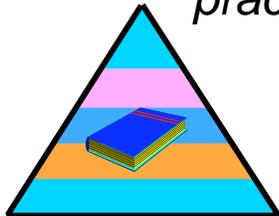




# SQL Project Thrust Areas

## Process & Product Definition (PPD)

*Capture, define, and refine repeatable processes and a set of engineering practices for project use*



## Measurement & Benchmarking (M&B)

*Provide measurement infrastructure for projects, conduct empirical analyses, and package experiences for future use*



## Project Engineering

*Provide overall technical infrastructure and thrust integration*

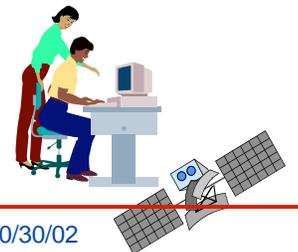
## Software Technology Infusion (STI)

*Identify, evaluate, and support software tools and techniques to facilitate process and product improvement*



## Deployment

*Infuse practices into project use; provide training, products, mentoring and consulting for projects*





# FY03 Plans in Brief



- Define and measure success criteria
- Define, collect, and analyze measurements of current practices, products, and SQI asset utilization
- Work with senior management to plan & implement new improvement opportunities

**Primary focus is on mission-critical software – others supported as resources permit**

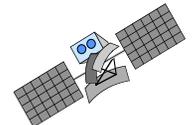
**Improvement Planning and Analysis**

**Asset Development and Deployment**



**Project Support**

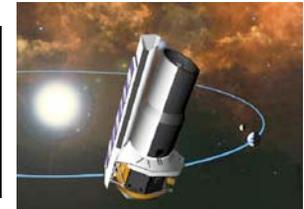
- Provide consultation on project planning (e.g., cost estimation; metrics definition, collection & analysis)
- Operate focus groups to support practitioners
- Provide training and consultation on use of SQI produced artifacts and services
- Collect cost data and establish cost data base
- Complete a set of SW engineering models that support project planning
- Deliver training to support new institutional requirements (e.g., SDR)
- Produce additional document templates & handbooks, based on needs
- Expand SW tools services
- Operate JPL SW website





# Core Functionality for Space Exploration

If these projects had been developed as MDS adaptations ...



Creation of **mission-specific** or adapted software at this level completes a given mission's functionality

**Mission-Specific Functionality**

- Stereo Processing
- Traverse Planning
- Instrument Placement

- Station Keeping
- Coordinated Observation Planning

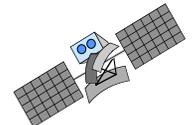
- Observatory Planning and Scheduling
- Precision Instrument Pointing

**Reusable software** at this level provides each mission with a head start on its software development

**Core Functionality**

- System-level Fault Protection
- Command & Telemetry Processing
- Space Platform System-level Control
- Resource Management
- Data Management & Transport

↑  
**Mission Data System**  
provides





# Unifying Systems Engineering and Software Engineering



Systems engineers follow a disciplined "state analysis", asking & answering questions such as these:

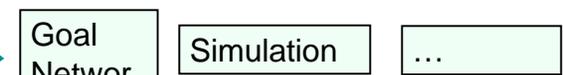
The state architecture bridges the gap through a shared set of architectural elements

Software engineers build the software system by adapting frameworks having the same architectural elements

What do you want to achieve?

*Move rover to rock.*

**Goal**



What's the state to be controlled?

*Rover position relative to rock.*

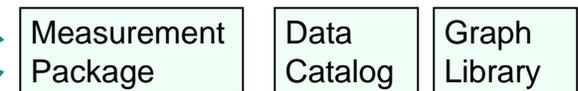
**State Variable**



How do you know what that is?

*Measure relative position with stereo camera.*

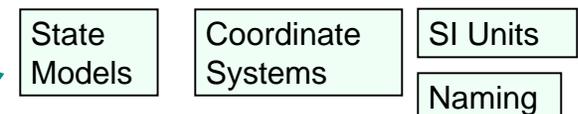
**Measurement**



What does the stereo camera measure?

*Distance to terrain features, light level, camera power (on/off), camera health.*

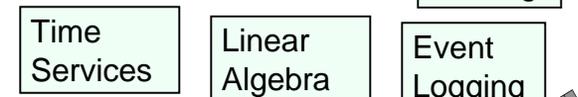
**Measurement Model**



How do you control light level?

*Wait until the sun is up.*

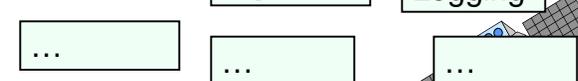
**State Model**



Where is sun relative to horizon?

...

**Etc.**





# Goal- and State-based Architecture

Estimators interpret measurement and command evidence to estimate state

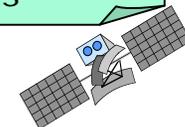
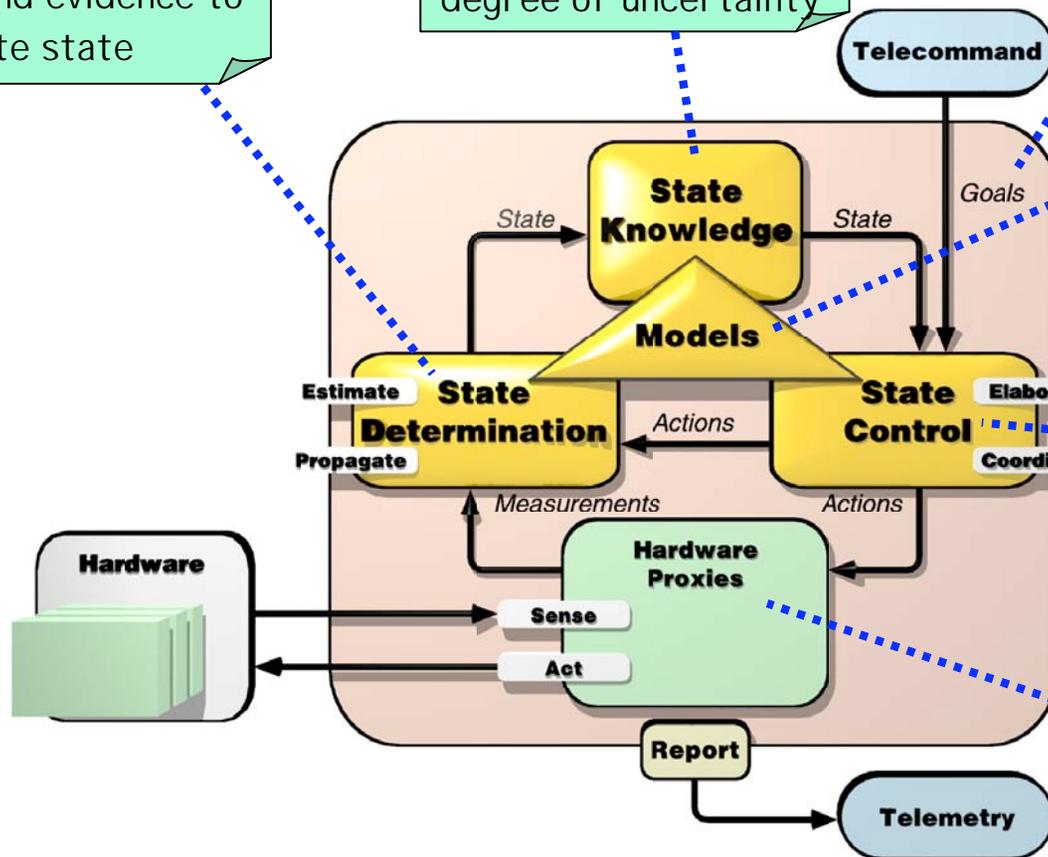
State variables hold state values, including degree of uncertainty

A goal is a constraint on the value of a state variable over a time interval

Models express mission-specific relations among states, commands, and measurements

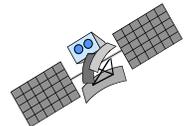
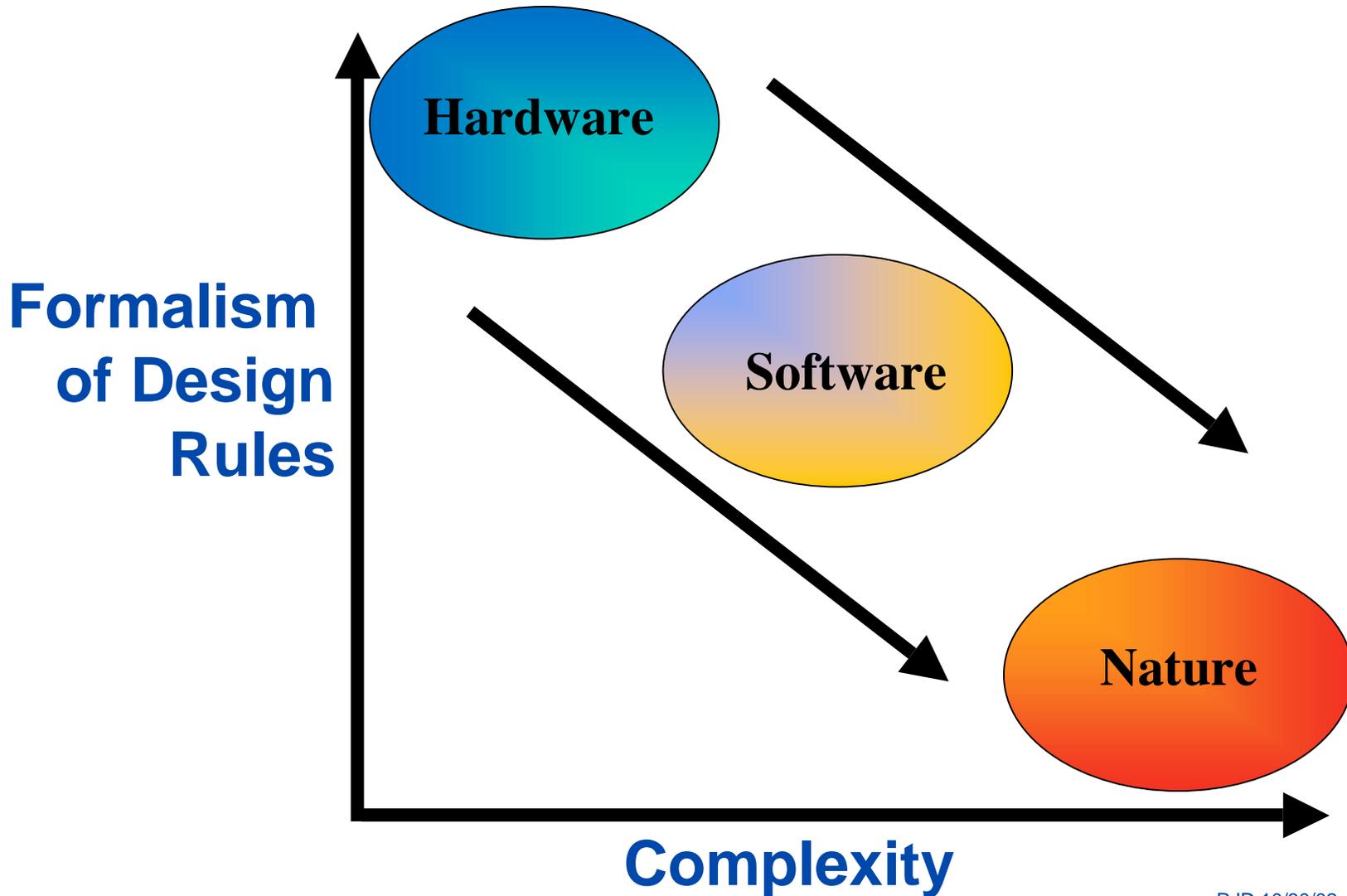
Controllers issue commands, striving to achieve goals

Hardware proxies provide access to hardware busses, devices, instruments



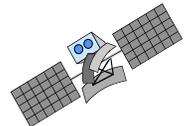


# Design Rules and Complexity



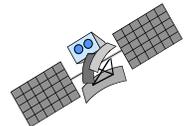
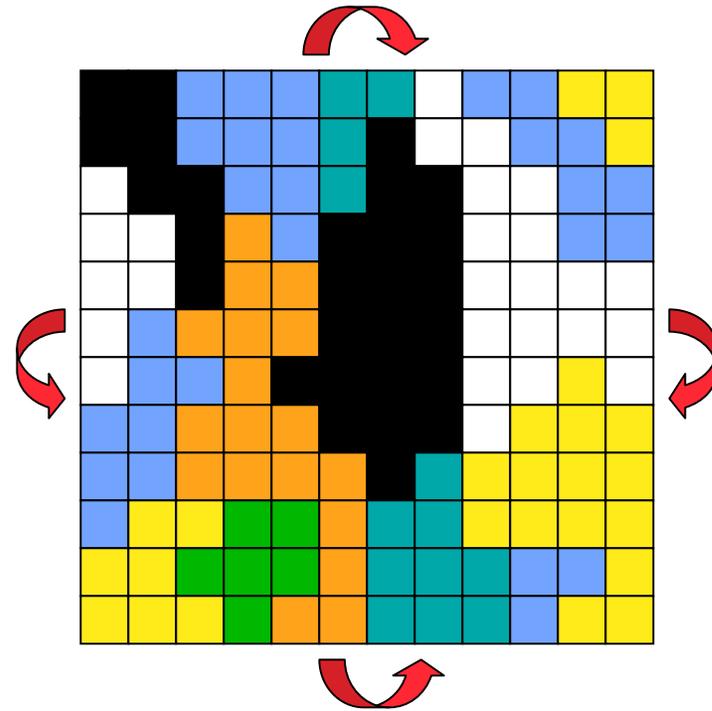
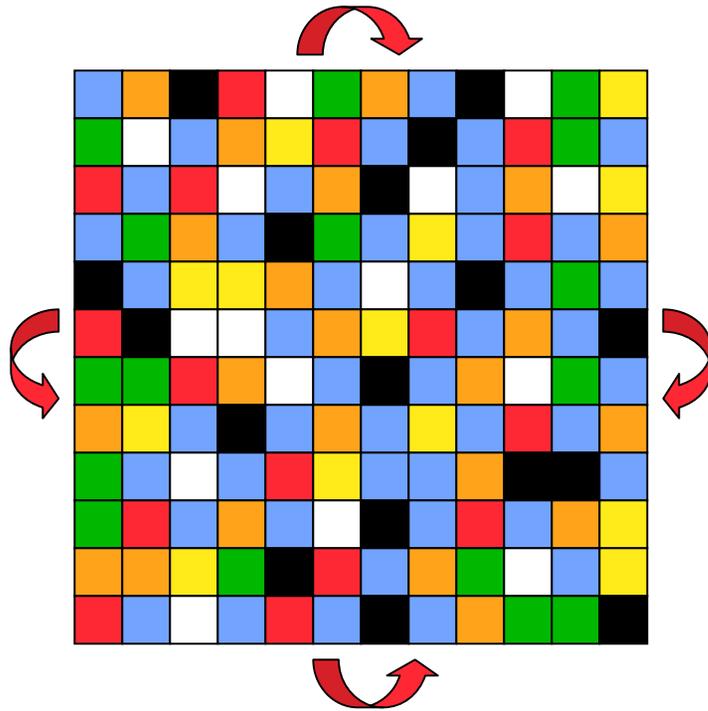


# Evolutionary Computation





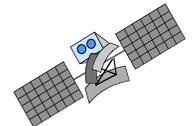
# Genetic Algorithms





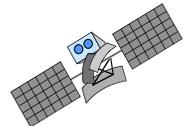
# Advantages of Evolutionary Approaches to Software

- Enables broad and systematic exploration of space of possible software designs
  - Human-generated design as starting point
  - Variations derived via evolutionary mechanisms
- Design, testing and validation are combined under a single approach
  - Avoid curtailed testing/validation due to schedule pressures
- Target applications
  - Power management
  - Robotic arm control





# Autonomous Space Systems

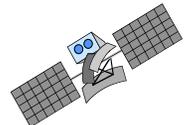




# Mars Exploration Rover



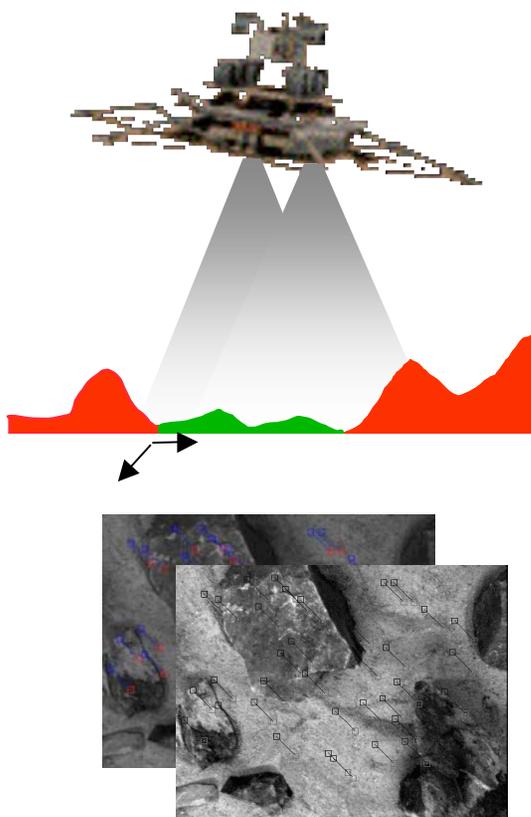
- Place two landed mobile science platforms on Mars
- Significantly upgraded science payloads
- Up to 100m traverse per sol
- 90-sol nominal mission
- Desire to command mobility at a high level and to maximize science throughput via ground-based planning tools





# DIMES Motion Estimator

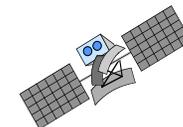
**DIMES will compute lateral motion of the Mars 2003 lander by tracking visual features during its descent.**



Mars had unexpected need to know lateral motion of the lander to 5 m/s.

Solution had to fit within tight mass and computational margins. Existing technologies were either too heavy or too inaccurate.

Visual motion estimation adapted from algorithms developed under the IS program has enabled MER to compute lateral motion to 3-5 m/s accuracy with the addition of a 0.25 kg CCD camera.

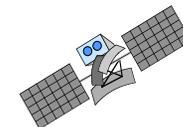




# Mars Science Laboratory



- Safe and precise landing
- Single-command-cycle traverse over the visible horizon
- Single-command-cycle robust instrument placement
- Onboard planning, scheduling and resource management
- Opportunistic science during traverse



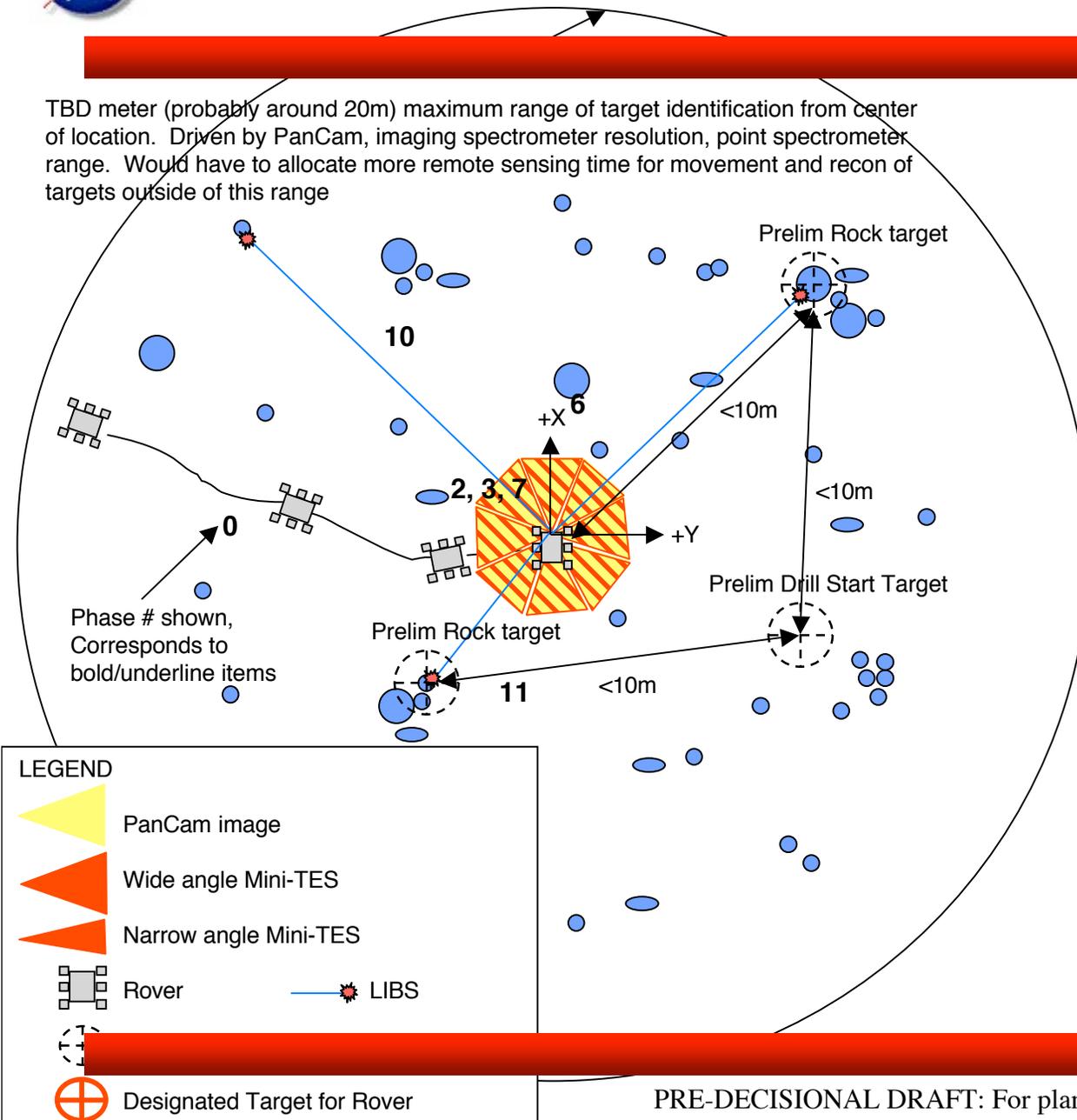


# Detail – Site Reconnaissance



## Mars Science Laboratory

TBD meter (probably around 20m) maximum range of target identification from center of location. Driven by PanCam, imaging spectrometer resolution, point spectrometer range. Would have to allocate more remote sensing time for movement and recon of targets outside of this range



### 0) Rover finishes traverse into location

#### **Sol 1**

- 1) Rover start sol at desired location
- 2) Take 360 degree panorama with Pancam (probably at least B&W and 1 color)**
- 3) Start 360 panorama with thermal emission spectrometer**
- 4) Downlink data to Earth with UHF and DTE
- 5) Ground starts figuring out which targets are interesting enough for point spectrometer (LIBS) follow up
- 6) PanCam data is used to create new coordinate frame for location specific activities**

#### **Sol 2**

- 7) Finish 360 panorama with thermal emission spectrometer**
- 8) Finish sending data to Earth with DTE and UHF

#### **Sol 3 & 4**

- 9) Ground uplinks point spectrometer (LIBS) targets to rover (possibly via feature designation, not local coordinate frame)
- 10) Rover hits targets with LIBS and returns data to Earth**

- 11) Scientists finish preliminary pick of 4 rock targets and drill hole within location (shown with cross-hairs in figure) D. Limonadi**

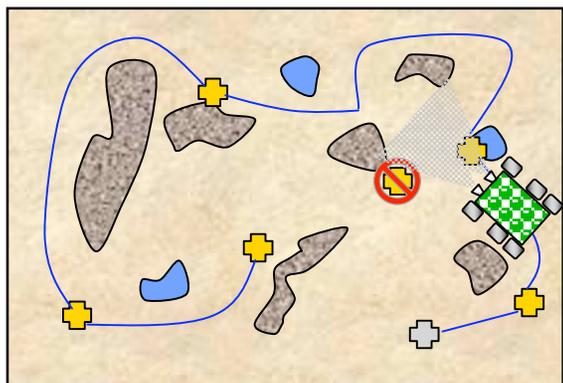
PRE-DECISIONAL DRAFT: For planning and discussion purposes only



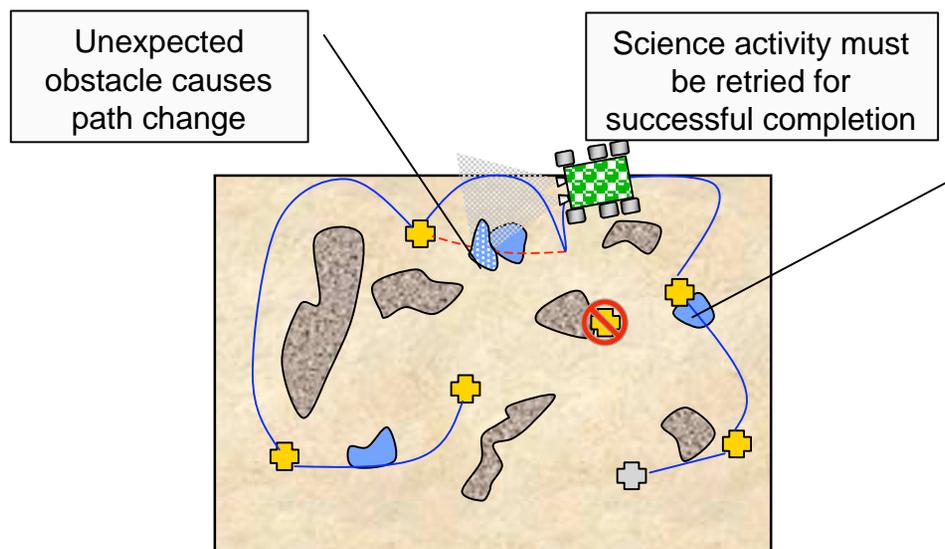
# Robust Plan Execution

(Including Handling of Unexpected Events)

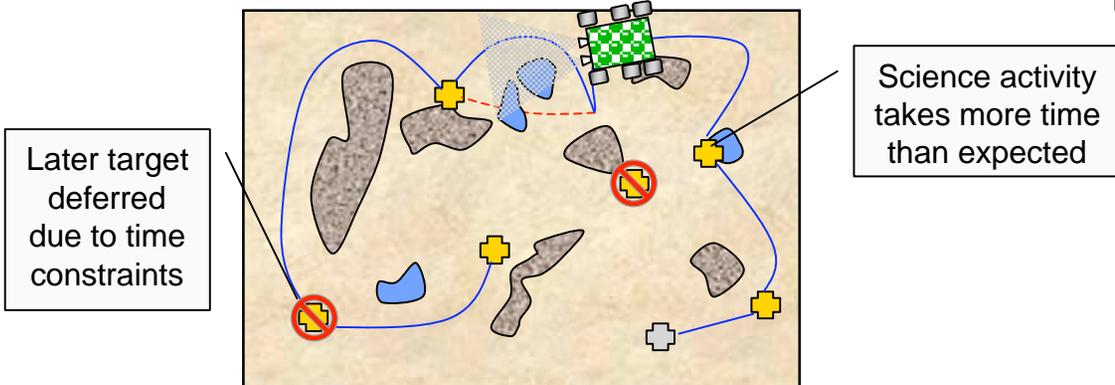
1. Execute plan commands in low-level software and receive updates on states and resources:



2. Unexpected event or failure requires quick reaction and/or global re-planning:

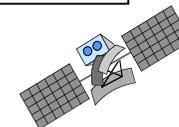


3. Schedule is shifted due to unexpected event or failure. Shift causes change in science collection (i.e., goals deferred or re-ordered):



*Technology Requirements:*

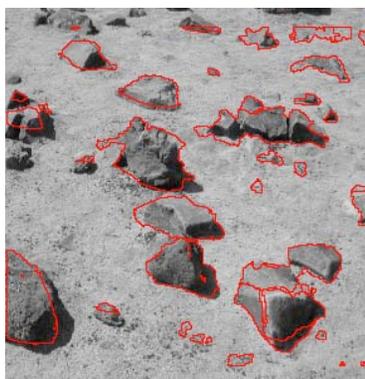
- Rover software architecture
- Integrated planning and execution
- Integrated resource management and path planning





# Traverse Science

Identify Key Targets



Identify novel objects



## Technology Capabilities:

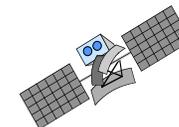
- Identify pre-specified key targets (rocks, signs of water)
- Identify novel, unexpected objects
- Catalog and summarize terrain covered
- Identify new, opportunistic science goals based on prioritization, provide goals and priorities to planner.

## MSL Benefits:

- Increase science return on mission by selectively transmitting the most valuable and informative data for fixed mission downlink bandwidth.
- Identify opportunistic science targets during long traverse.
- Decrease the amount of dead time needed for science observations.

- 1) Prioritize images collected during traverse for downlink
- 2) Summarize traversed region (rock types, counts, and locations)
- 3) Science alert: stop at a high-priority rock.

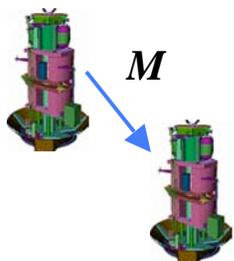
Autonomy



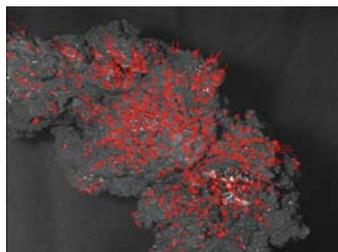


# Machine Vision for Safe and Precise Landing

## Multi-Sensor State Estimation

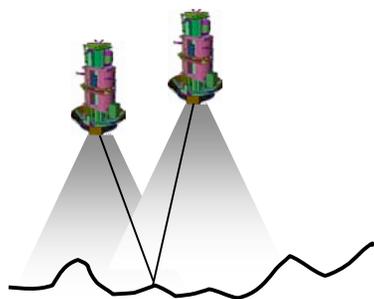


Altimetry, imagery and inertial measurements contribute to state estimation.



**FY01**

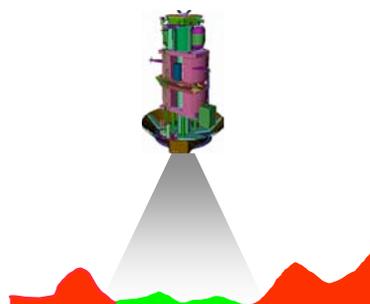
## Efficient 3-D Structure Recovery



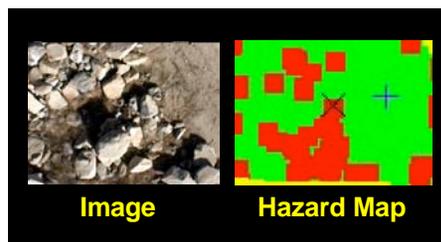
Surface reconstructed from pair of images acquired from single camera.



## Hazard Detection and Avoidance

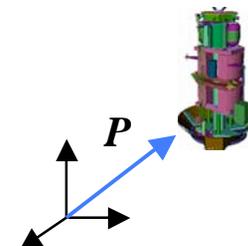


Hazards detected in terrain map generated from passive imagery (safe zones are in green.)

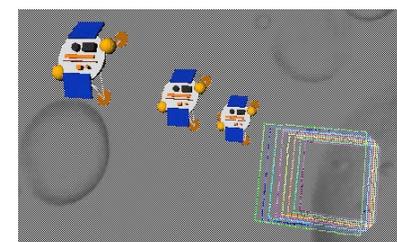


**FY02**

## Precision Landing Through Surface Tracking

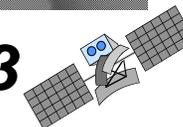


Landing site modeled as a 3-D faceted surface to allow for 6 DoF tracking.



**FY03**

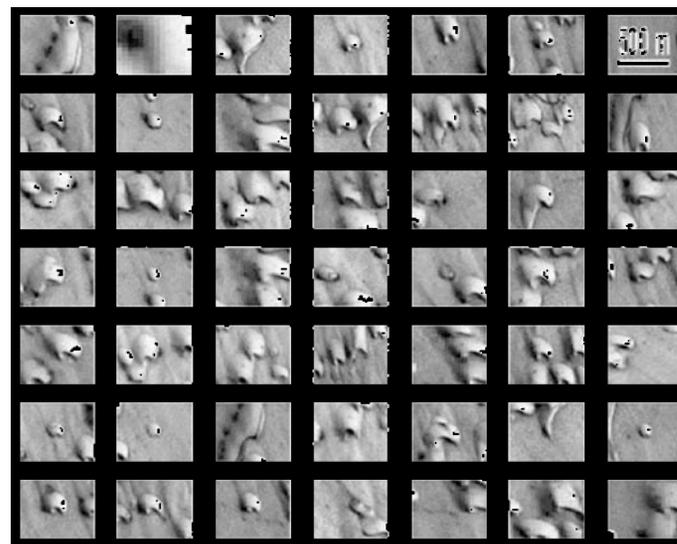
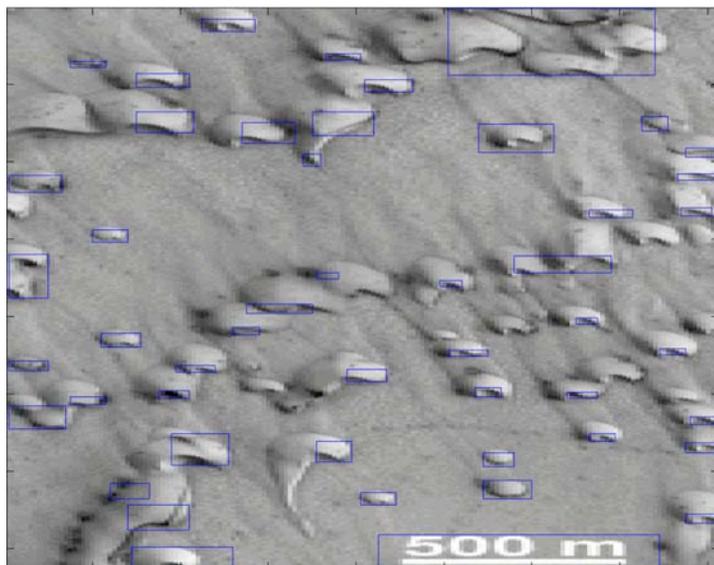
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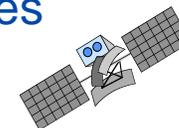


# Discovery Algorithms

- Prototype visual discovery algorithm
- Identifies regions of an image that differ significantly from the local background
- Has successfully identified impact craters, volcanoes, sand dunes, ice geysers from sample image data



Mars Global Surveyor image – many of the identified regions are sand dunes

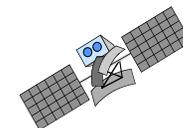
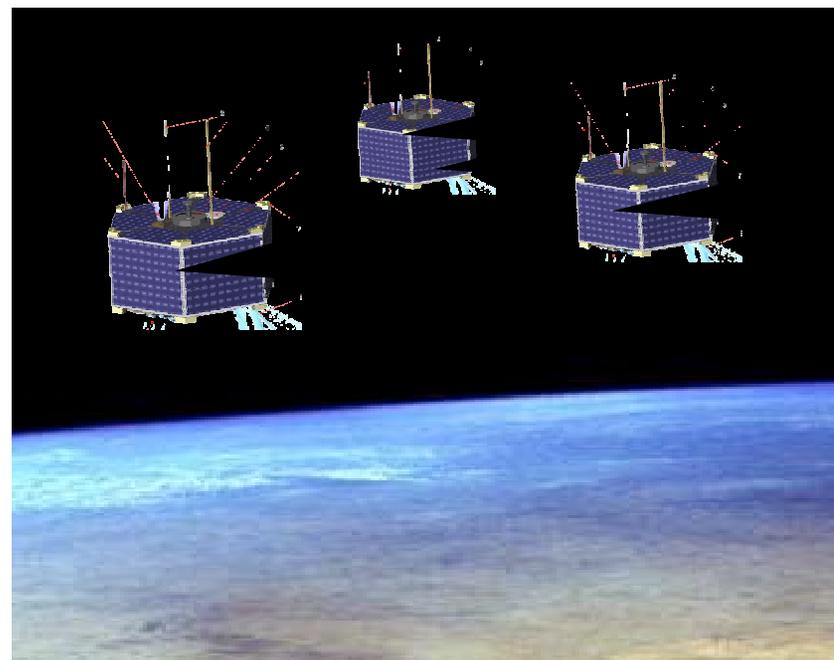




# Onboard Continuous Planning

## Delivered Onboard Planning capability to Three Corner Sat University Nano-satellite

- Onboard image analysis detects bad (cloud-obscured) images.
- CASPER continuous onboard planner discards bad images and schedules new imaging activity to replace it, while optimizing use of limited spacecraft resources.
- Increases effective science return 10x over open-loop sequencing.
- 3CS is now undergoing testing in preparation for 2003 launch.



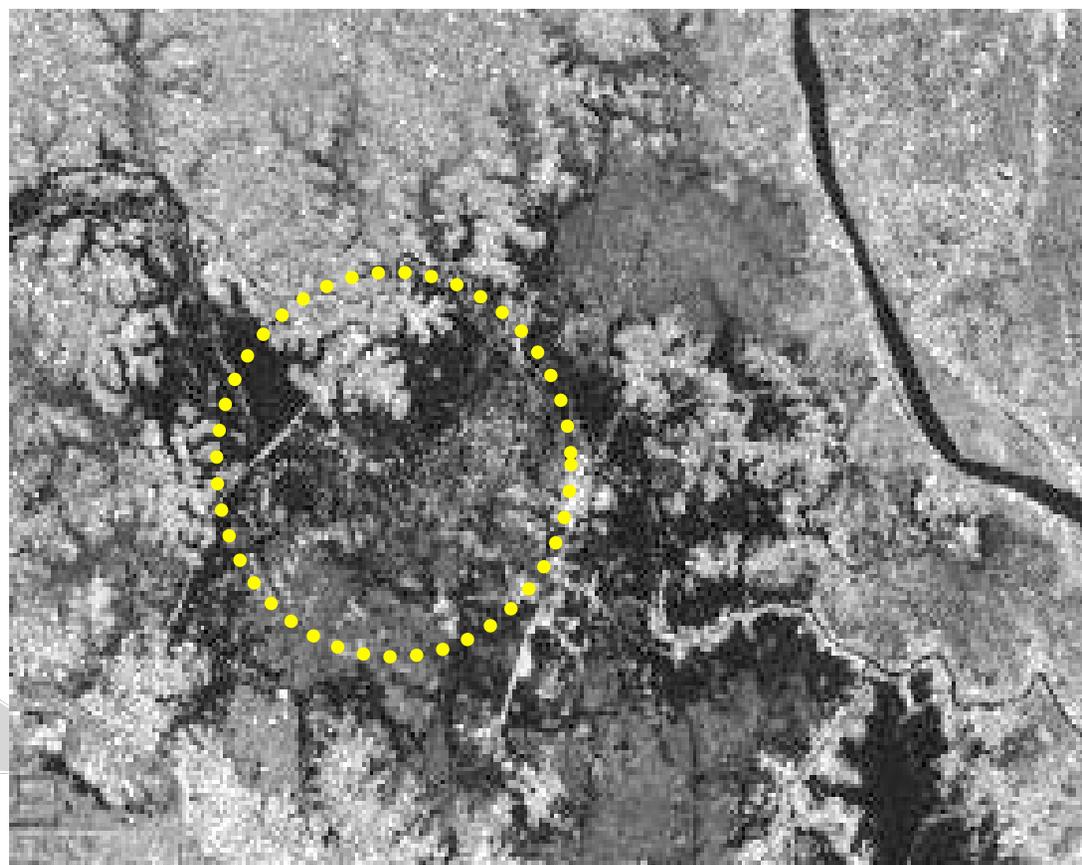
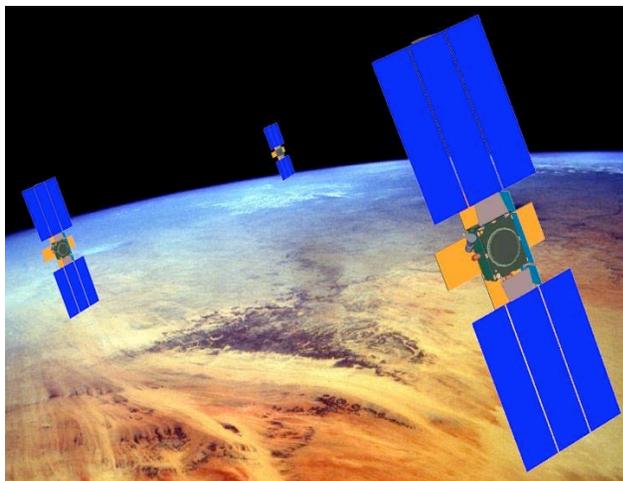


# Autonomous Sciencecraft Constellation Scenario



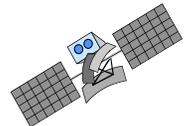
Cluster  
Management:  
Constellation  
Reconfiguration

New Science  
Images



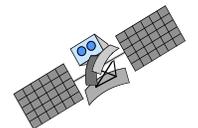
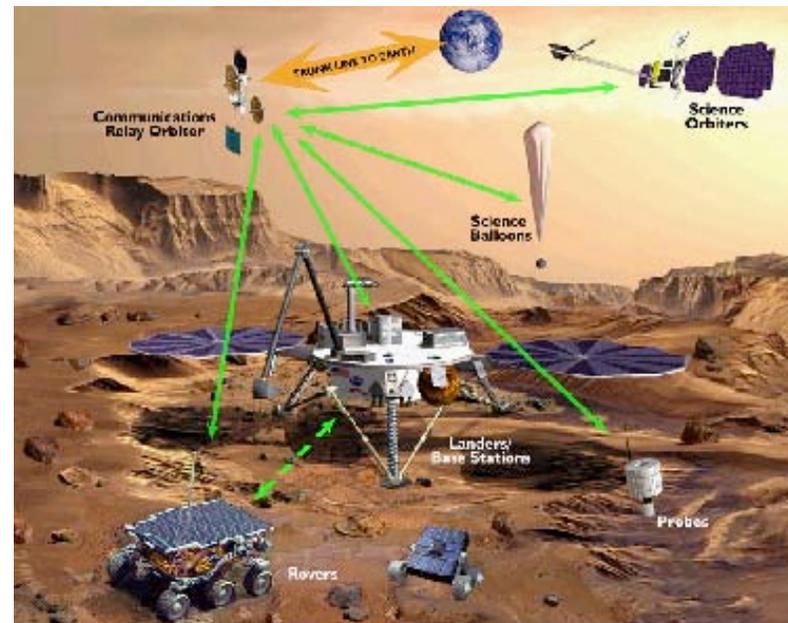
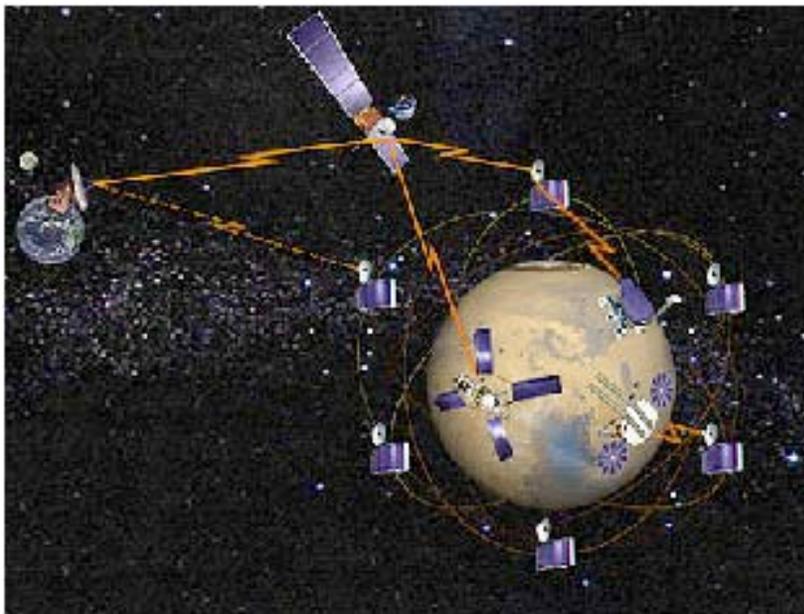


# Interplanetary Network and Virtual Environments





# Mars Network

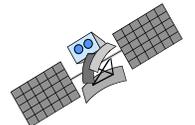




# Motivation for a Mars Network

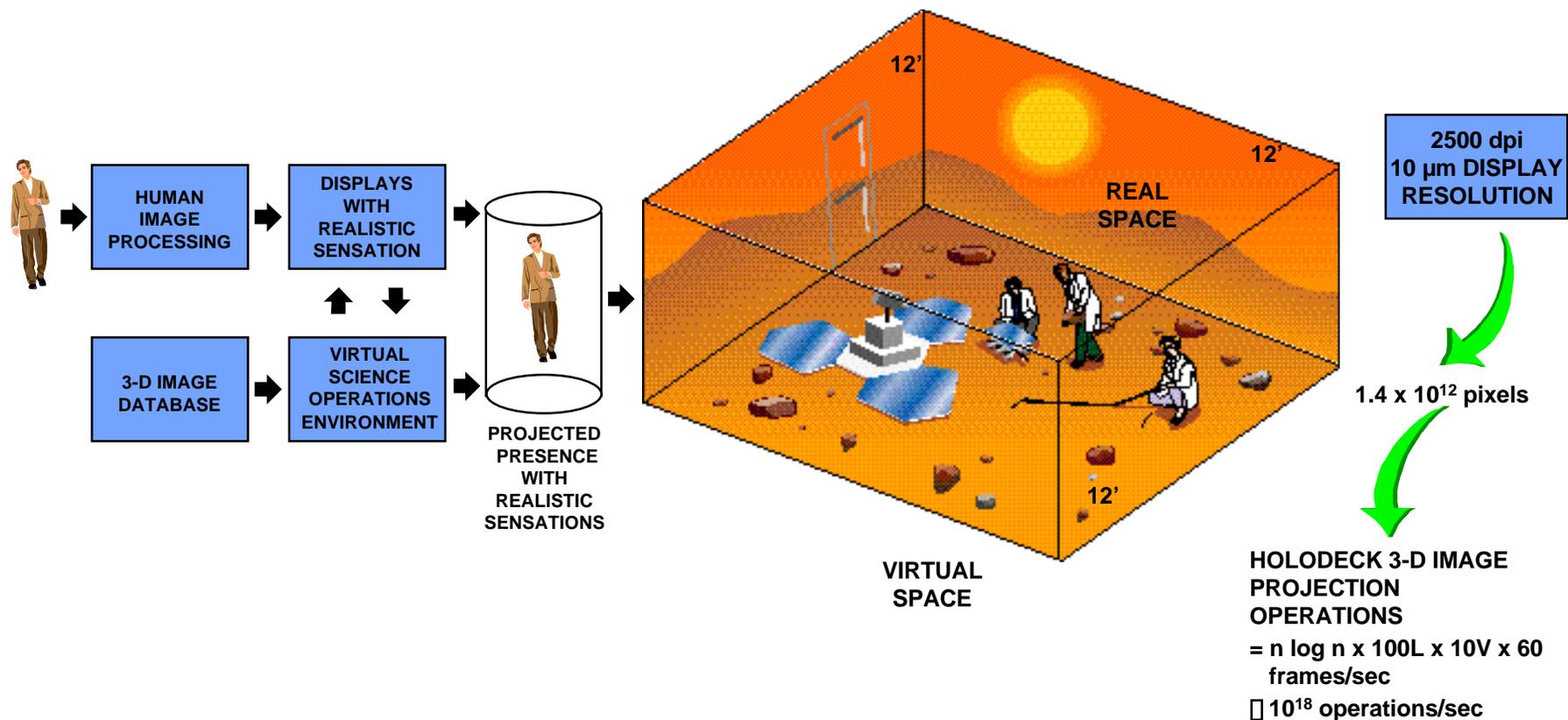
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- Real deployed infrastructure
- High-sensitivity communications relay
- Improved navigation
- Complex surface operations require more frequent connectivity
- Enable streaming video from surface (MarsCam)
- Support varied and rich information management scenarios among surface, airborne and orbital assets, cooperating to accomplish science goals
- Virtual presence requires increased data return

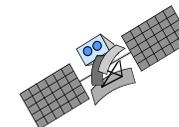




# Virtual Science Operations



- NO HEAD GEAR FOR 3-D VISUALIZATION
- PHOTOGRAPHIC PROJECTION QUALITY

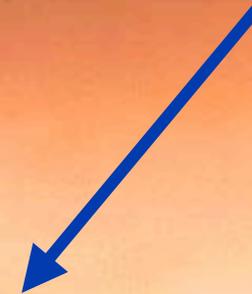




# Experiencing the Remote Environment

- Immersive Visualization
- 3-D Acoustic Imaging
- Force and Touch
- Odor Reproduction

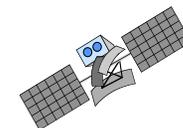
**YOU  
ARE  
HERE**





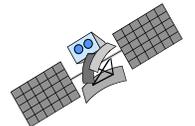
# Public Outreach Scenarios

- Look at the space system: walk, fly around it
- Look “as” the space system, be the space system, have the space system senses
- Become the space system - interactive, piloting
- What-if scenarios involving the space system moving in its environment - “What if I went this way?”
- What-if scenarios involving the environment itself - “What’s behind that ridge over there?”
- Experience weather (and other environmental conditions) at Mars, Europa, etc.
- Available on home computers and at special facilities (universities, museums)





# Future Mission Concepts

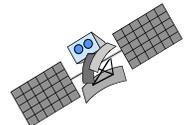




# Mars Fleets

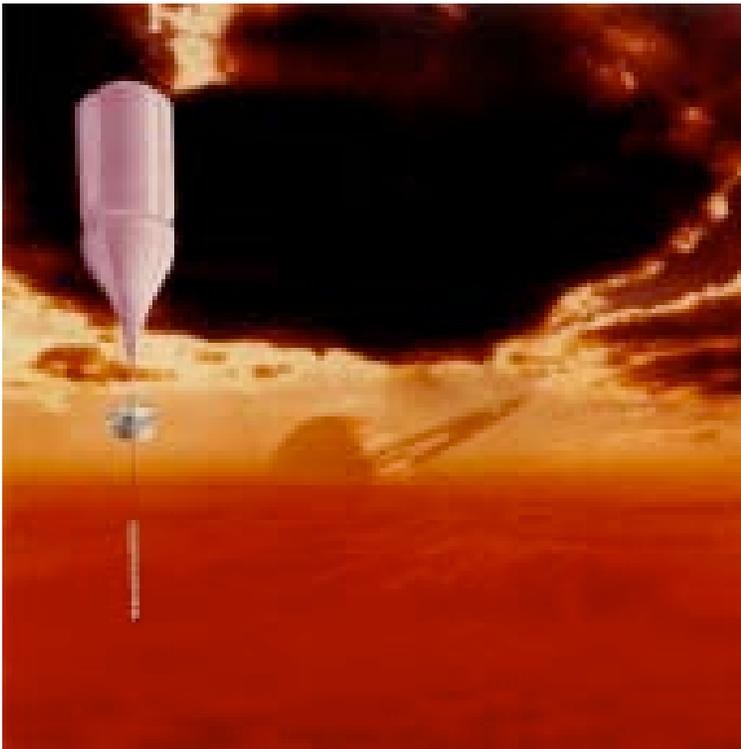


- Orbital assets
  - High-sensitivity observing instruments
- Surface assets
  - Mobile rovers
  - Science stations
- Airborne assets
  - Balloons
  - Air platforms
- How to coordinate?

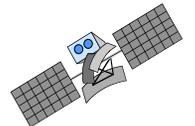




# Titan Aerobot

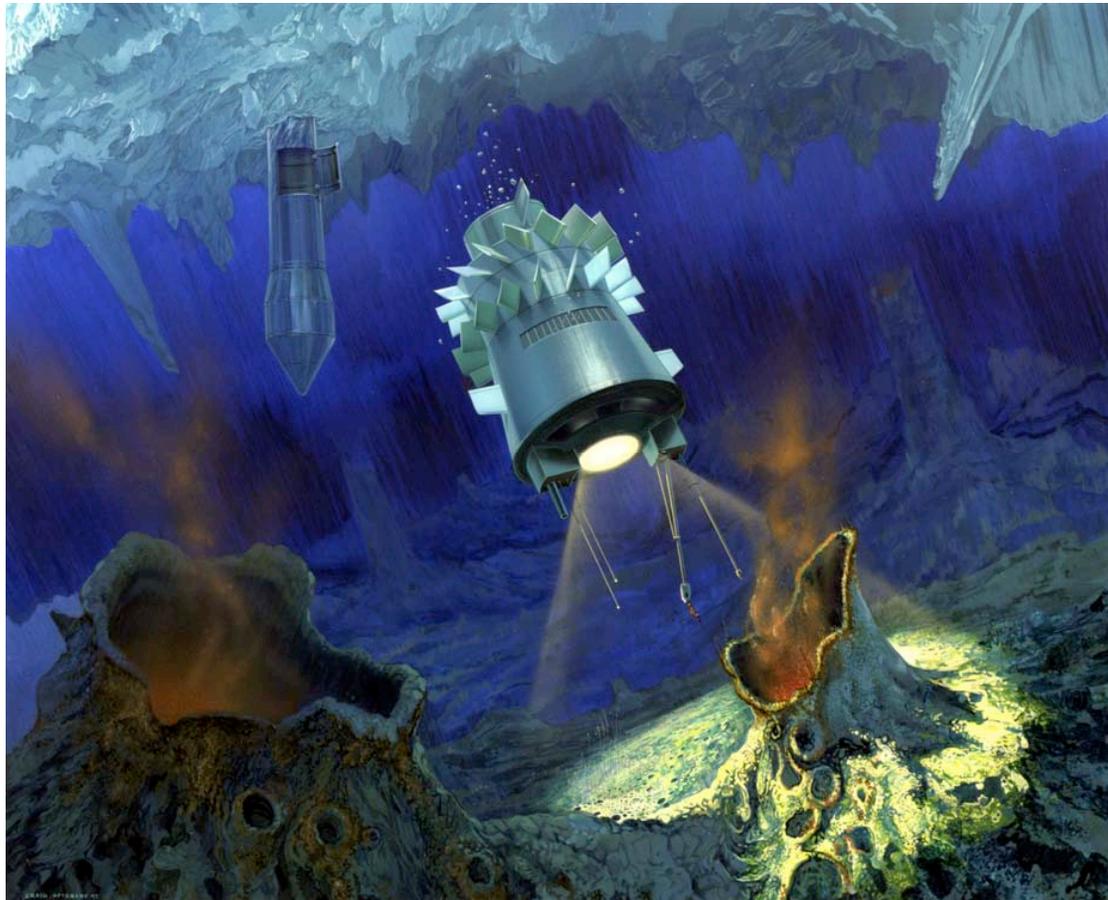


- An aerobot conducts in situ science operations when landed, and wide-area imaging when aloft
- Learned models of wind patterns may assist path planning, enabling near-returns to areas of high scientific interest
- Bio-signature detection

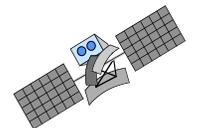




# Europa Cryobot / Hydrobot

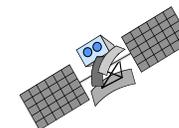


- Unattended operations
- Environment modeling
- Bio-signature detection
- Goal creation





# A Challenge for Autonomy: Europa Cryobot / Hydrobot





# Exploration at the Frontier

- Character of missions has changed: from reconnaissance to in situ exploration and multiple platform concepts
- First true off-planet infrastructure is coming
- Information technology, software engineering and computer science will make fundamental capability and infrastructure contributions to the future missions
- JPL will always need a dynamic balance between the best engineering and the boldest visions
- We must be careful and complete, not conservative

