National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Strategic Technologies

Lifecycle Modeling and Simulation
and
Data Pipelines, Distribution and Analysis

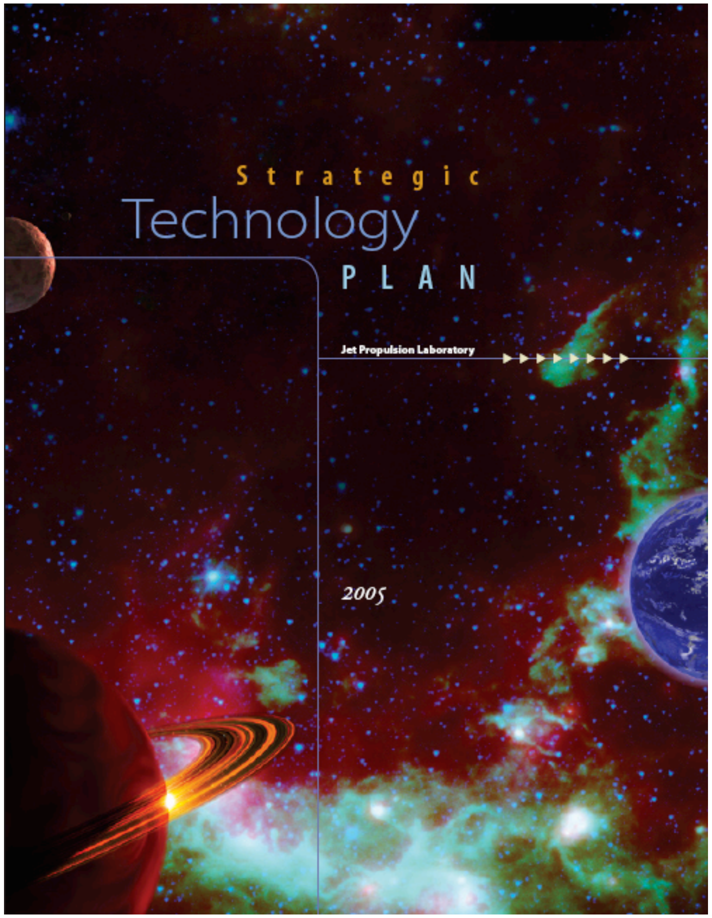
Tom Cwik
Associate Chief Technologist
JPL
May 14 2009

GRITS 2009

JPL Strategic Technologies

- **JPL maintains and monitors a set of *Strategic Technologies* managed by the Chief Technologist**
  - Critical to JPL's ability to successfully contribute to NASA's exploration goals and responding to NASA's science questions
  - Areas where JPL makes a unique or distinguishing contribution, bestowing competitive advantages
  - Require overt JPL or NASA management action to nurture and sustain their development

✷ **Important part of the JPL brand**



Strategic
Technology
PLAN

Jet Propulsion Laboratory

2005

1. Large aperture systems

1.1 Lightweight apertures

1.2 Lightweight precision-controlled structures

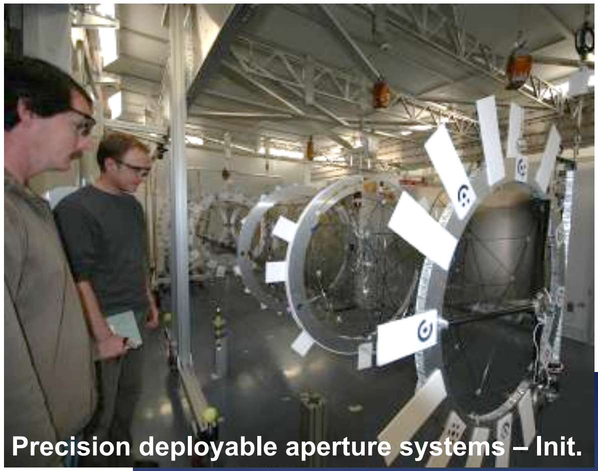
1.3 Integrated low-temperature thermal control

1.4 Advanced metrology

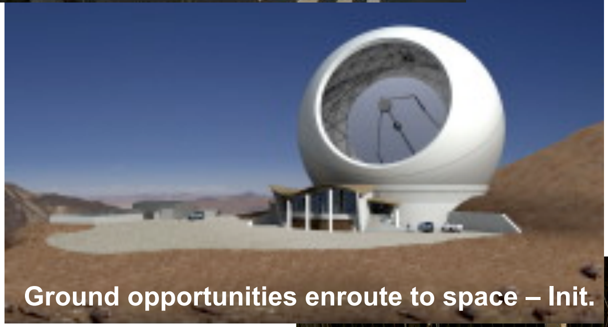
1.5 Wavefront Sensing and Control

Investment or other-support examples

- **Short-term**
  - J. Zmuidzinas (FY07 Initiative): *Ground opportunities enroute to space*
- **Long-term**
  - J. Dooley (FY09 Topic): *KISS Large space-apertures program*
  - L. Armus (R&TD Facility): *Coronagraph upgrades*
- **NASA, reimbursable, and SBIR projects**
  - *JWST support by JPL*
- **Caltech KISS Study on Large Apertures**



Precision deployable aperture systems – Init.



Ground opportunities enroute to space – Init.

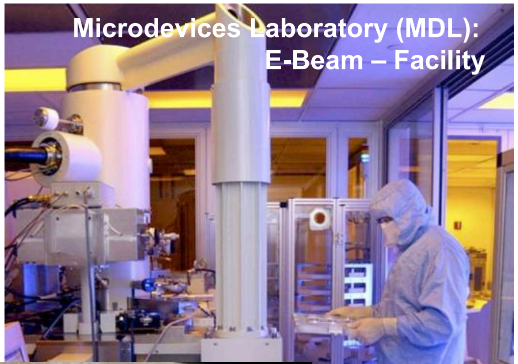
Mesh reflector in 25ft chamber - SBIR

2. Instrument and detector systems

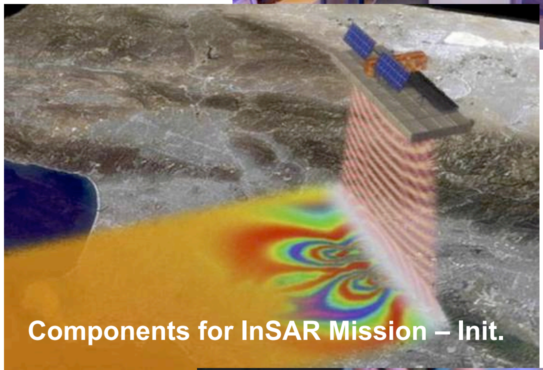
2.1 Detector and focal-plane systems
2.2 Active remote sensing
2.3 Passive remote sensing
2.4 In-situ sensing
2.5 Detector and instrument cooling

Investment/other-support examples

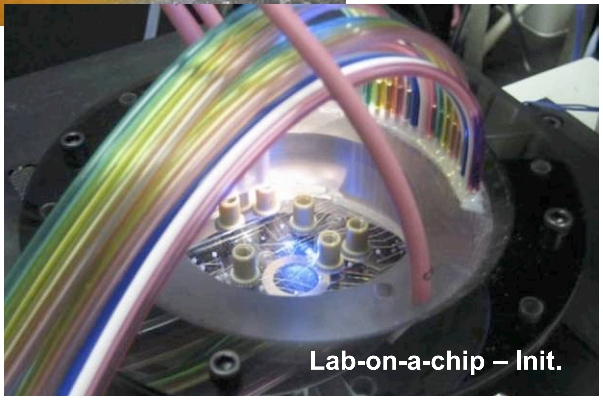
- **Short-term**
  - W. Edelstein (FY07 Initiative): *Miniaturization of Active Sensors*
  - E. Kay-Im (FY08 Initiative): *Sharable Components for Instruments*
- **Long-term**
  - A. Lange (FY09 Initiative): *Large-format, mm/submm wave detector arrays*
  - W. Traub (FY08 Initiative): *Exoplanet Science and Instrumentation*
- **NASA reimbursable projects**
- **JPL Microdevices Lab (MDL) is key to these technologies**
  - *Sustained R&TD (Facility) support*



Microdevices Laboratory (MDL): E-Beam – Facility

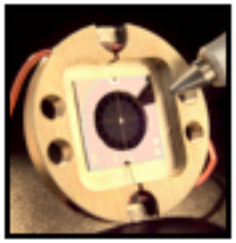


Components for InSAR Mission – Init.

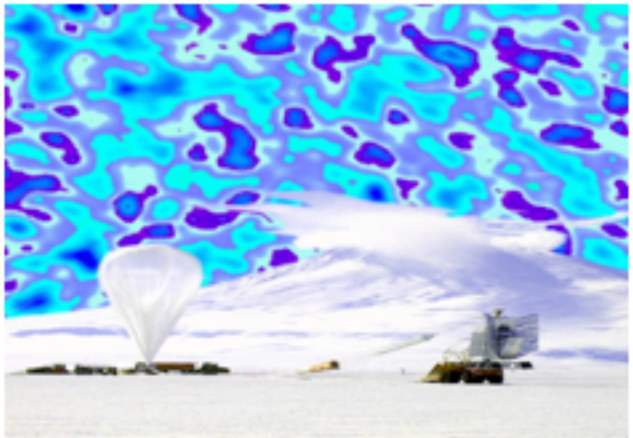


Lab-on-a-chip – Init.

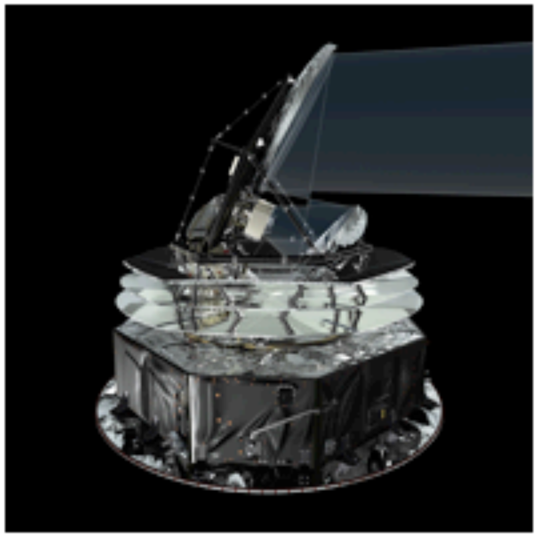
Spider web Bolometer



1995

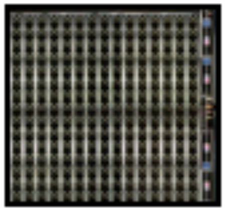


BOOMERanG 1998

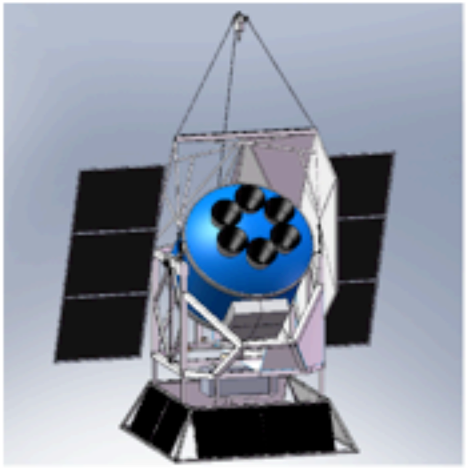


Plank 2009

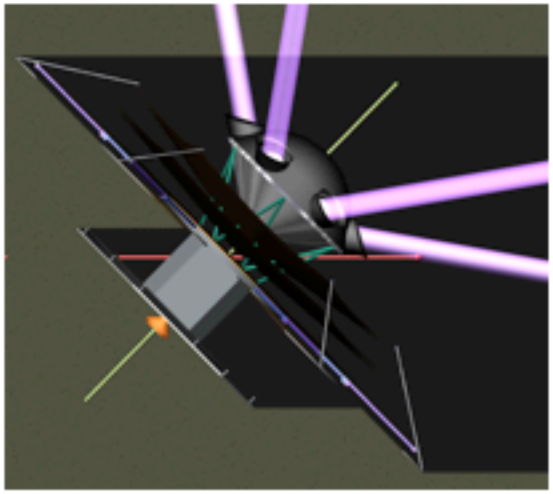
Antenna-coupled TES



2007



SPIDER 2010



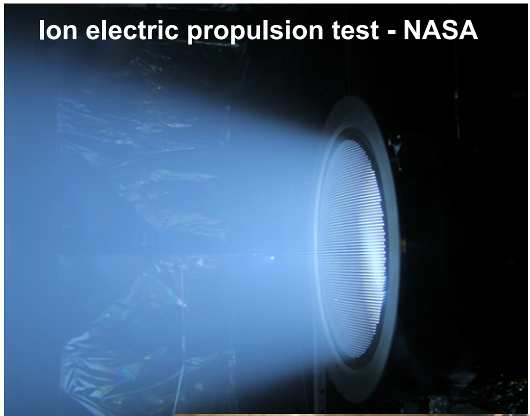
EPIC 2021

3. Advanced propulsion and power

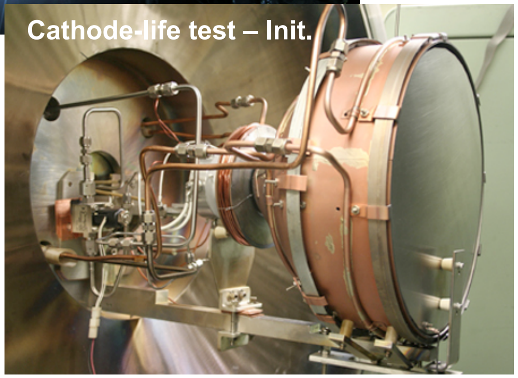
- 3.1 Advanced electric propulsion
- 3.2 Advanced chemical propulsion
- 3.3 Precision micro-/nano-propulsion
- 3.4 Power sources for deep-space missions
- 3.5 Energy sources for deep-space missions

Investment/other-support examples

- **Short-term**
  - T. O'Donnel (FY07 Initiative): *Solar Electric Propulsion*
- **Long-term**
  - W. West (FY09 Topic): *Non-radioisotope power for Europa and Titan landers*
  - E. Brandon (FY09 Topic): *High power density supercapacitor cells for low-temperature energy storage*
- **Some NASA support**

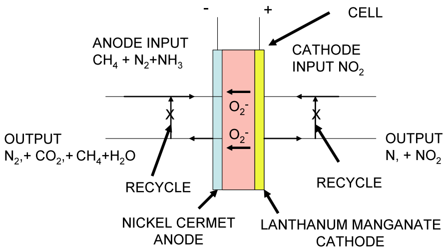


Ion electric propulsion test - NASA



Cathode-life test – Init.

SOLID OXIDE FUEL CELL
OPERATING ON ROCKET PROPELLANT AND NITROGEN
TETROXIDE DECOMPOSITION PRODUCTS (Year 1)



Fuel-cell development - Topic

4. In situ planetary exploration systems

4.1 EDL, precision landing, and hazard avoidance

4.2 Atmospheric, surface and subsurface mobility

4.3 Sample acquisition and handling

4.4 Autonomous orbiting sample retrieval, capture, and return

4.5 Planetary protection

Investment/other-support examples

- **Short-term**
  - D. Bayard (FY08 Initiative): *Comet Sample Return*
- **Long-term**
  - J. Hall (FY09 Initiative): *Planetary Aerial & Surface Access System*
  - G. Brown (FY 09 Initiative): *Planetary Geophysics and Sampling Systems*
- **NASA and reimbursable projects**

ATHLETE : Lunar Mobility – NASA Direct

Venus Prototype Balloon – Init.

Surface Access Tripod – Init.

5. Survivable systems for extreme environments

5.1 Survival in high-radiation environments

5.2 Survival in particulate environments

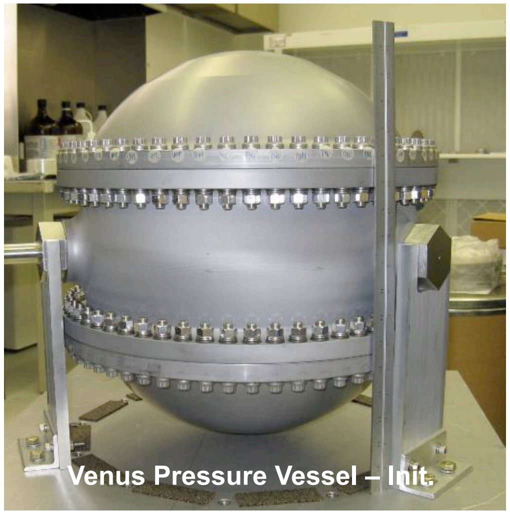
5.3 Electronics and mechanical systems for extreme temperatures and pressure

5.4 Reliability systems for extended lifetimes

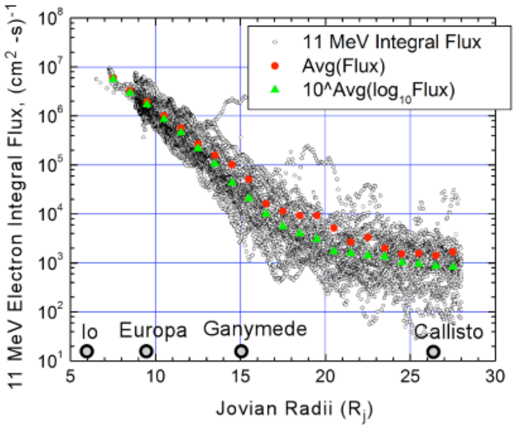
5.5 Space radiation modeling

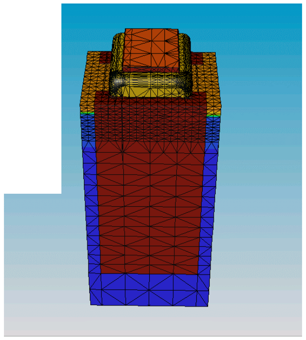
Investment/other-support examples

- **Short-term**
  - J. Polk (FY08 Initiative): *Venus Extreme Environment*
  - T. Larson (FY09 Initiative): *Space Environment Monitor*
- **Long-term**
  - G. Bolotin (FY08 Initiative): *Radiation-tolerant devices for highly ionizing environments*
  - A. Kaul (FY09 Topic): *Carbon nanotube switches for extreme environment space electronics*



Venus Pressure Vessel – Init.





Electronics Model and Measurement – Init.

6. Deep space navigation

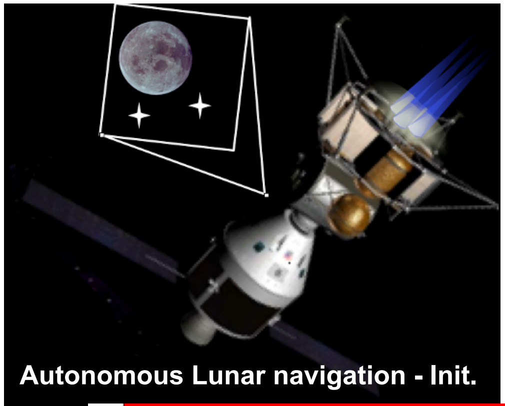
6.1 Mission Design and Navigation Methods

6.2 Precision Tracking and Guidance

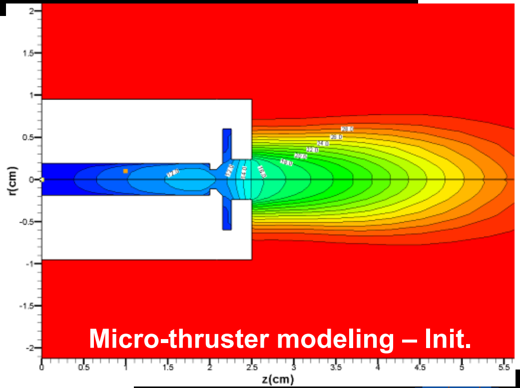
6.3 On-Board Autonomous Navigation

Investment/other-support examples

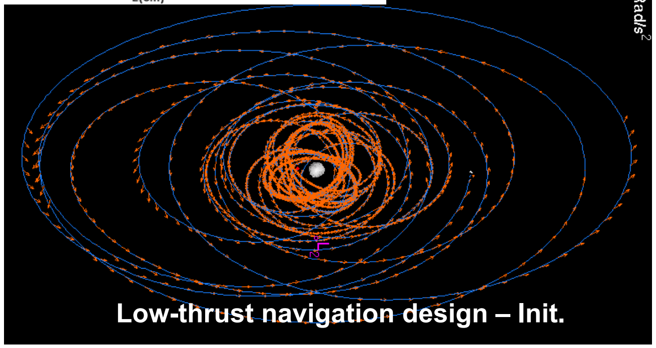
- **Short-term**
  - T. Ely (FY08 Initiative): *Lunar mission design, and Guidance, Navigation, and Control*
  - T. O'Donnell (FY07 Initiative): *Solar Electric Propulsion*
- **Long-term**
  - C. Villalpando (FY09 Topic): *Advanced imaging processor for pinpoint landing and stereo vision-based autonomous navigation applications.*
- **Also NASA/JPL Dawn mission**



Autonomous Lunar navigation - Init.



Micro-thruster modeling – Init.



Low-thrust navigation design – Init.

7. Precision formation flying

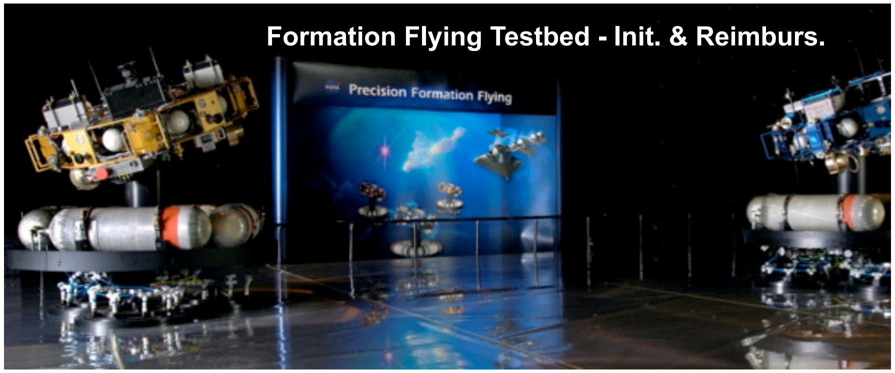
7.1 Distributed spacecraft architecture

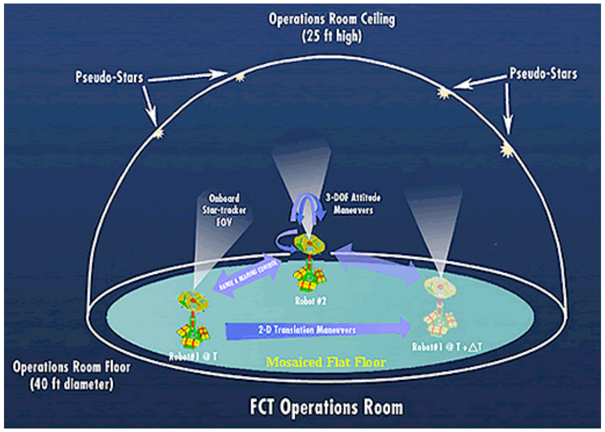
7.2 Wireless Data Transfer

7.3 Formation sensing and control

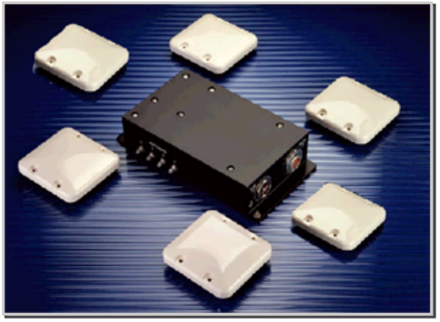
Investment/other-support examples

- **Short-term**
  - F. Hadaegh (FY08 DARPA): *Fractionated Spacecraft*
  - F. Hadaegh (FY07 Air Force): *Formation Flying InSAR*
- **Long-term**
  - D. Scharf (FY07 Initiative): *Precision Formation Flying*
- **NASA (some) and reimbursable projects**


Formation Flying Testbed - Init. & Reimburs.



Formation Flying Architecture - Init.



Flying Formation Sensor – Reimburs.

8. Deep-space communications

8.1 High-rate communications
8.2 Optical communication
8.3 Autonomous and cognitive radios
8.4 Flight transponders
8.5 DSN arraying

Investment/other-support examples

- **Short-term**
  - J. Wyatt (FY07 Initiative): *Networked Space Mission Concepts and Operations*
  - N. Lay (FY08 Initiative): *High-rate communication techniques*
- **Long-term**
  - H. Hemmati (FY07 Initiative): *Optical communications transceiver*
- **NASA and reimbursable projects**

9. Mission system software and avionics

9.1 Spaceborne computing

9.2 Mission system software

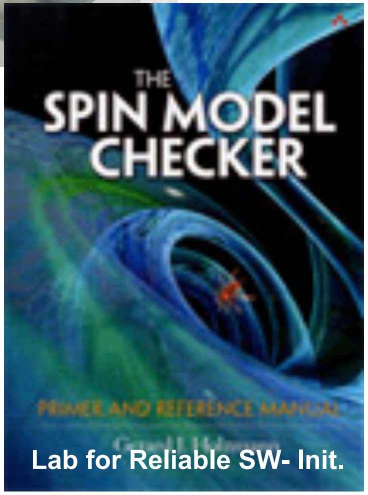
9.3 Autonomous operations

9.4 Software reliability

Internal/other-support examples

- **Short-term**
  - G. Holzmann (R&TD Center): *Laboratory for Reliable Software (LaRS)*
  - D. Bayard (FY08 R&TD Initiative): *Comet Sample Return*
- **Long-term**
  - H. Zima (FY08 Topic): *Introspection framework for fault tolerance in support of autonomous space missions*
  - R. Some (FY09 Initiative): *Advanced flight systems avionics technology*
- **NASA and reimbursable projects**

Touch-n-Go Test – Init.



Lab for Reliable SW- Init.

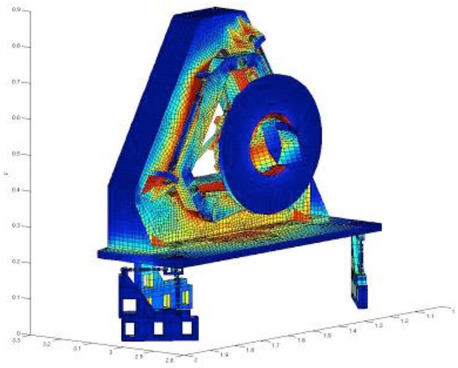
10. Lifecycle integrated modeling and simulation

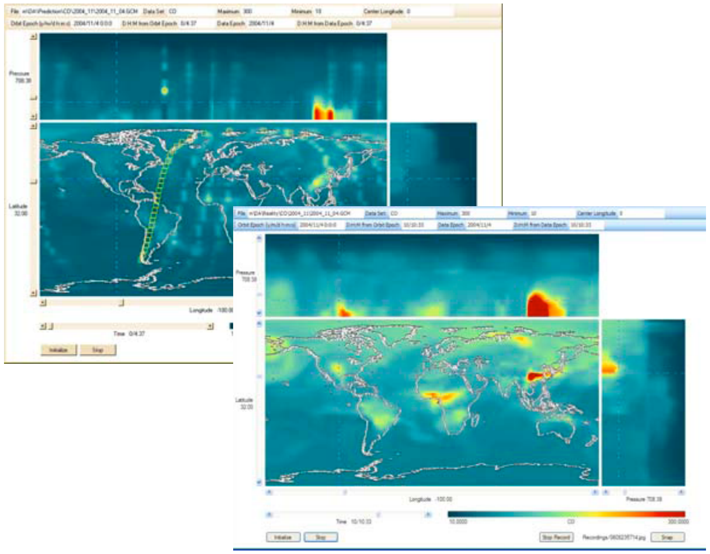
10.1 Trade space exploration
10.2 Coupled/integrated physics-based modeling
10.3 Model validation
10.4 Model integration

Investment/other-support examples

- **Short-term**
  - C. Hoff (FY07 R&TD Initiative): *Advanced Simulation and Modeling of Large Apertures with Cielo*
  - *C. Norton (FY07 R&TD Initiative): OSSE for the HyspIRI Hyperspectral Spectrometer Mission*
- **Long-term**
  - E. Larour (FY09 Topic): *Sensitivity studies for large-scale ice-flow models of Antarctica and Greenland*
  - E. Upchurch (FY08 Topic): *Heterogeneous Multi-Core Architectures for Emerging NASA Applications*
- **Lee Peterson (Jul08 Strategic Hire): Integrated modeling validation**

SIM TOM3 siderostat integrated model – Init.





Integrating instrument models and data – Init.

Instrument Software and Science Data Systems

- Data Distribution
- Pipeline Instrument Data Processing Systems
- Data Analysis - Machine Learning

Highly Distributed Data Intensive Systems

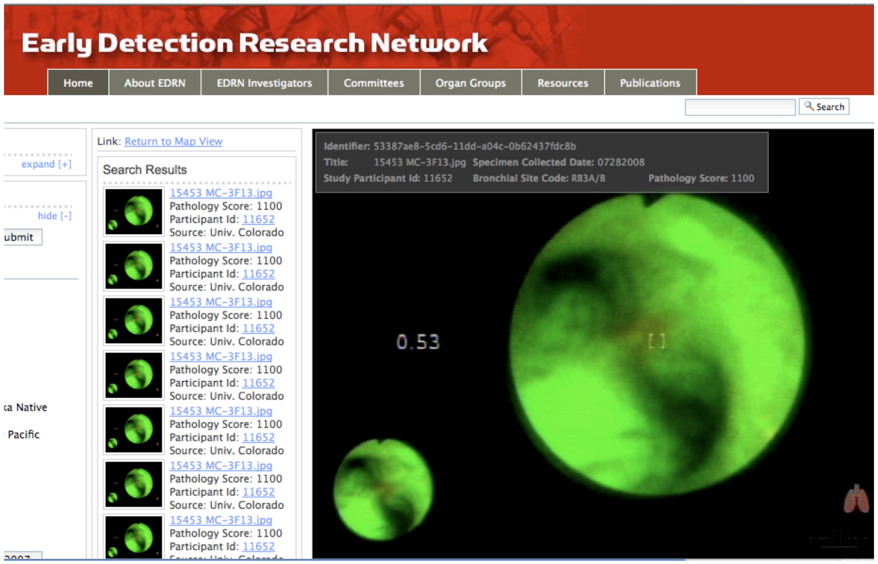
- Multiple domains
  - Planetary science
  - Earth science
  - Biomedicine

- Technology thrusts
  - Frameworks for distributed data management and computational processing
  - Ontology modeling and semantic architectures
  - Distributed search (free-text, facet and forms-based)
  - Intelligent data dissemination
  - Software architectures

- Collaborators
  - National and International Space Agencies
  - NASA, NIH, DOE, DOD, …
  - University parters (USC, UCLA, George Mason, UC Irvine, etc)

POC: Dan Crichton: Daniel.J.**Crichton@jpl.nasa.gov**

Example: Distributed Bioinformatics Grids for Cancer Biomarker Research



Link: Return to Map View

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Source: Univ. Colorado

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Source: Univ. Colorado

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Participant Id: 11652
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Source: Univ. Colorado

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Study Participant Id: 11652 Bronchial Site Code: RB3A/B Pathology Score: 1100

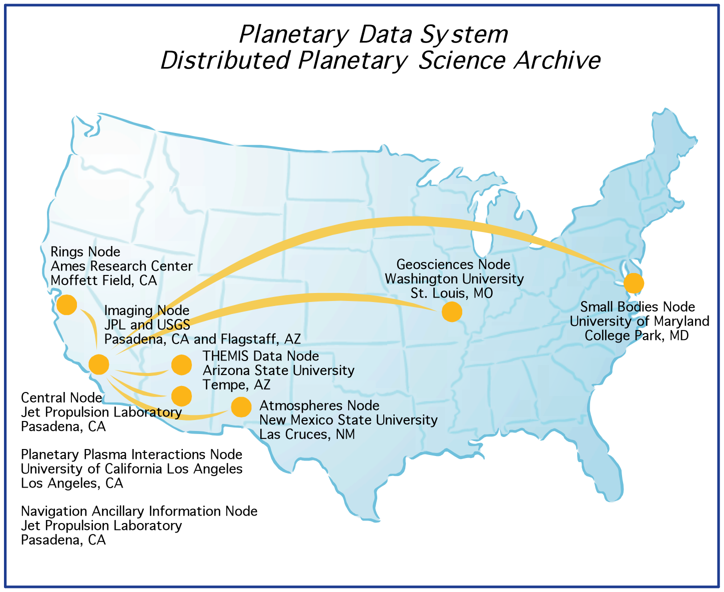
Example: Climate data exchange for models and observational data

CDX Data Wrappers Code for MLS, AIRS, MISR and NCAR CCSM.
May 08, 2009

WELCOME TO CDX

“OODT: Middleware for Metadata”

Distributed "e-science" Deployments



Planetary Data System
Distributed Planetary Science Archive

<u>Planetary Science Data System</u>

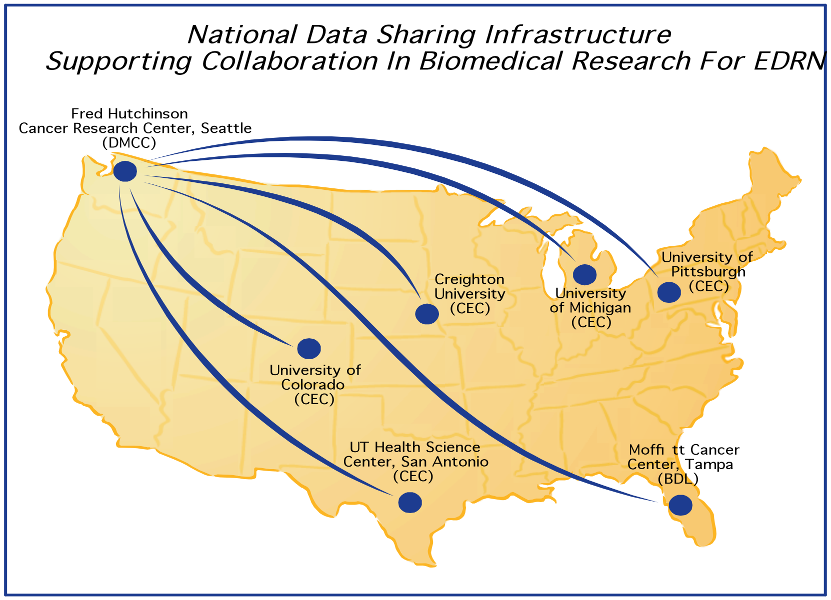
- Highly diverse (40 years of science data from NASA and Int'l missions)
- Geographically distributed; moving int'l
- New centers plugging in (i.e. data nodes)
- Multi-center data system infrastructure
- Heterogeneous nodes with common interfaces
- Integrated based on enterprise-wide data standards

- Sits on top of COTS-based middleware

<u>EDRN Cancer Research</u>

- Highly diverse (30+ centers performing parallel studies using different instruments)
- Geographically distributed
- New centers plugging in (i.e. data nodes)
- Multi-center data system infrastructure
- Heterogeneous sites with common interfaces allowing access to distributed portals
- Integrated based on common data standards
- Secure data exchange

D. Crichton, S. Kelly, C. Mattmann, Q. Xiao, J. S. Hughes, J. Oh, M. Thornquist, D. Johnsey, S. Srivastava, L. Esserman, and B. Bigbee. A Distributed Information Services Architecture to Support Biomarker Discovery in Early Detection of Cancer. In Proceedings of the 2nd IEEE International Conference on e-Science and Grid Computing, pp. 44, Amsterdam, the Netherlands, December 4th-6th, 2006.

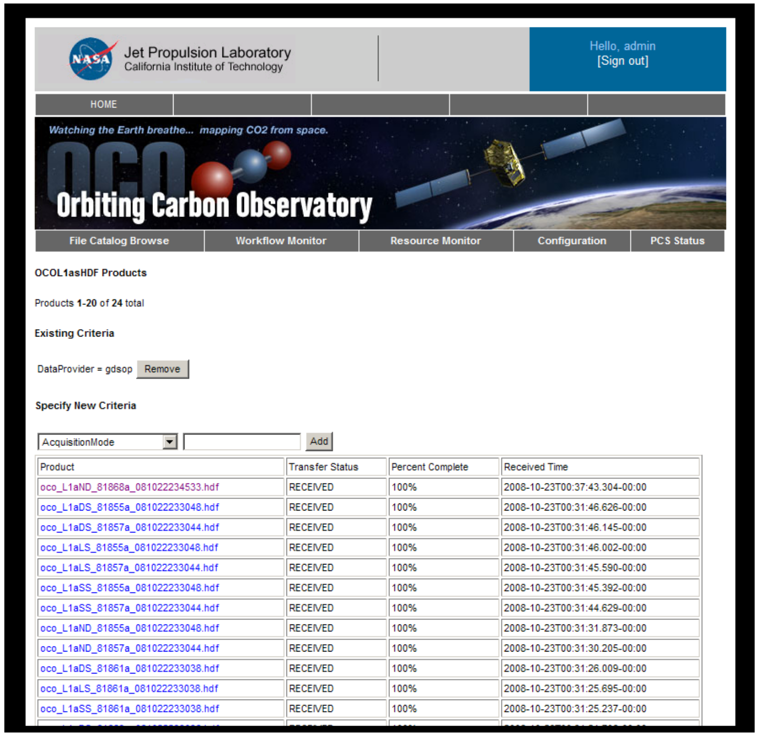


National Data Sharing Infrastructure
Supporting Collaboration In Biomedical Research For EDRN

POC: Dan Crichton: Daniel.J.**Crichton@jpl.nasa.gov**

Pipeline Systems for Distributed Science Processing

Example: Process Control System (PCS) for OCO, NPP Sounder PEATE and SMAP



OCOL1asHDF Products

Products **1-20** of **24** total

Existing Criteria

DataProvider = gdsop

Specify New Criteria

AcquisitionMode

Product	Transfer Status	Percent Complete	Received Time
oco_L1aND_81868a_081022234533.hdf	RECEIVED	100%	2008-10-23T00:37:43.304-00:00
oco_L1aDS_81855a_081022233048.hdf	RECEIVED	100%	2008-10-23T00:31:46.626-00:00
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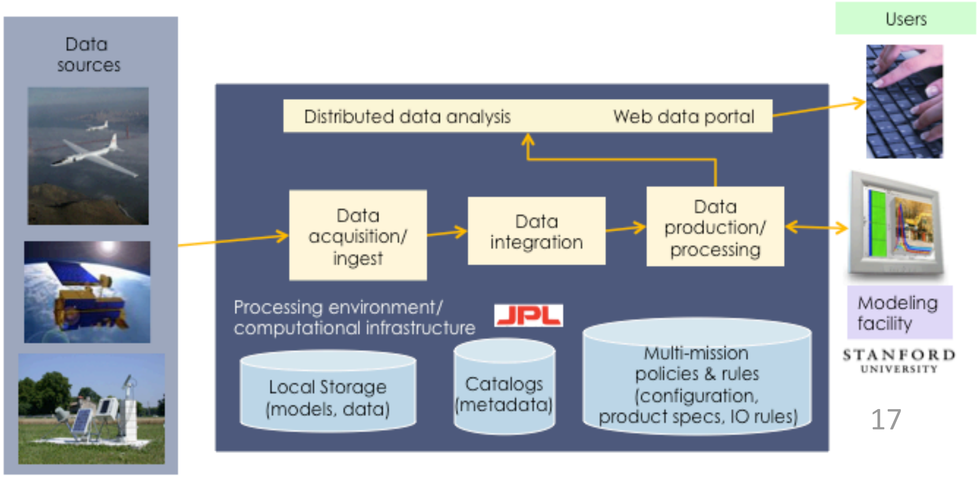
oco_L1aSS_81861a_081022233038.hdf	RECEIVED	100%	2008-10-23T00:31:25.237-00:00

- Spaceborne and Airborne Environments
- Pipeline and workflow systems
- End-to-end automation and process management
- Software architectures for process control systems
- Science data system generation, dissemination and archiving

C. Mattmann, D. Freeborn, D. Crichton, B. Foster, A. Hart, D. Woollard, S. Hardman, P. Ramirez, S. Kelly, A. Y. Chang, C. E. Miller. A Reusable Process Control System Framework for the Orbiting Carbon Observatory and NPP Sounder PEATE missions. To appear in Proceedings of the 3rd IEEE Intl' Conference on Space Mission Challenges for Information Technology July 2009

POC: Dan Crichton: Daniel.J.**Crichton@jpl.nasa.gov**

Example: Airborne Cloud Computing Environment



An Adaptable Framework for Modeling, Processing, Distribution and Analysis of Science Data

Dana Freeborn, David Woollard, Chris Mattmann, Sean Hardman, Dan Crichton, Paul Ramirez

Goal	**Reduce Cost And Risk and Deliver More Science**
Architectural Drivers	**NASA Directive - "Faster, Better Cheaper"** **Increased Technology Refresh Rate** **Increased Partnering** **Increase in Data Volumes** **Increase in Processing Complexity**

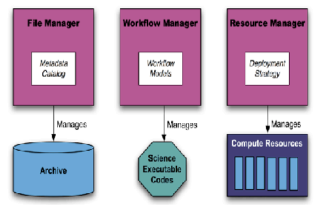


Figure 2: Refactored CAS components

Benefits	**Missions have more money to focus on science** **Risk and cost of algorithm development, integration and validation greatly reduced** **Ability to support centralized, distributed and fully gridded SDS architectures**

1998 *NASA Office of Space Science funds OODT*

1999

2002 *Seawinds infused with CAS Reference Implementation*

2002

2005 *CAS refactored for extensibility*

2006 *Common Science Data System (SDS) Architecture Initiated*

2007 *CAS Interfaces refined to support common SDS Architecture*

2009

2011

2013

Framework Evolution

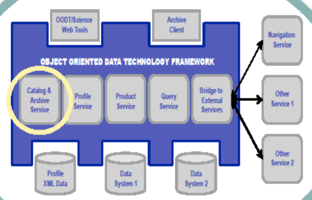


Figure 1: The OODT Framework

Results

Framework accomodates all sized missions *(scalable & re-usable)*

Hardware configuration is not driven by Framework *(hardware-independent)*

Use or selection of a database is not driven by the Framework *(database-independent)*

Plug-in capability of mission-specific processing and tools *(adaptable)*

Supports all phases of algorithm development *(one integrated system)*

Provides automated pipeline processing *(lights out operations)*

Allows data sharing across organizational boundaries for science analysis, data modeling and knowledge discovery *(interoperable)*

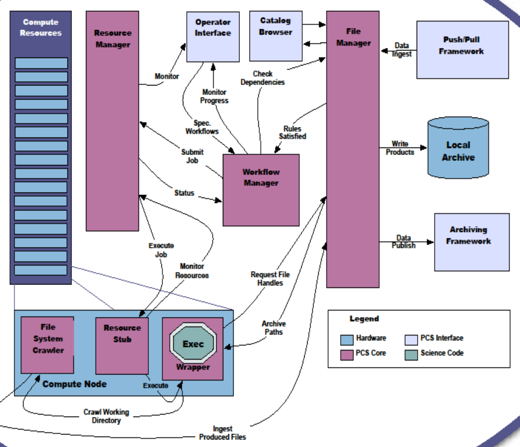


Figure 3: CAS components configured for a science data system.

POC: Dan Crichton: Daniel.J.Crichton@jpl.nasa.gov

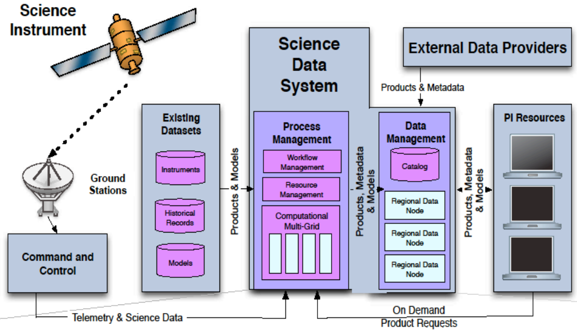
These activities were carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Science Data System Architecture

Integrating Modeling Capabilities in a Production Environment to Further Forecasting and Decision Support

David Woollard, Dana Freeborn, Dan Crichton, Charles Norton, and Elizabeth Kay-Im

Heritage and Experience Base

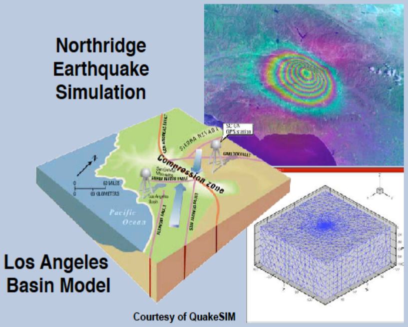


Scientist-driven SDS Requirements Trades

Our goal is to enable scientists to easily integrate and utilize science instrument data within advanced simulation models to improve forecasting and decision support capabilities. JPL will further this goal by providing a unified environment for modeling, processing, distribution, and analysis. Our SDS framework consists of validated components that can be configured to support access to disparate data resources and a highly distributed (multi-organizational) processing environment.

Modeling

- Supports ingest of large (near real-time and archived) data sets into high performance simulation models for solid earth, ecosystem and other science disciplines
- Enables the scientific community to interact and collaborate in development of predictive models for Earth science.
- Facilities sharing of model components and data among distributed collaborators.



Los Angeles Basin Model

Courtesy of QuakeSIM

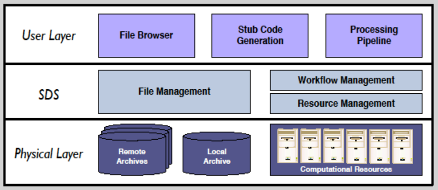
Trades:

- Data access time and volume requirements for ingest by models
- Data organization enabling simulation experiments to characterize science return

Processing

- Developed as reusable components that have been successfully deployed to manage mission processing (OCO) as well as science computing facilities (NPP Sounder PEATE).
- Easily integrates legacy science code and provides development support for scientist-developed algorithms and new executables.
- Provides workflow and resource management to effectively utilize desktop, cluster, Grid, and multi-organizational environments.

SDS Software Stack



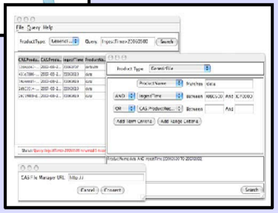
Trades:

- Centralized job queueing vs. decentralized science analysis for compute intensive processing
- Support for ongoing validation activities

Distribution

- A proven technology providing access to federated data resources on a number of projects (Planetary Data System, Early Detection Research Network).
- Virtualized access through standard web portal technologies while allowing locally autonomous data management.
- Functionality scales as the data volume grows.

PDS Node Distribution



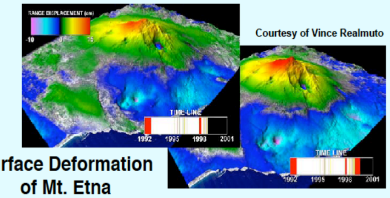
Metadata Browsing Capabilities

Trades:

- Decentralization of the archive with interoperable data based on standardized format, access, and metadata

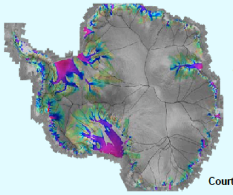
Analysis

- Facilitates ***interaction*** among scientists, pulling together data from multiple sources and driving interdisciplinary research.
- Provides infrastructure to couple simulation and observational data to characterize and understand changes in the ecosystem, cryoshere, and solid Earth.



Courtesy of Vince Realmuto

Surface Deformation of Mt. Etna



Ice Sheet Velocities in Antarctica

Courtesy of Eric Larour

Trades:

- Data retrieval/search/storage capabilities for multi-resolution analysis
- Science analysis based on data across multiple time and spatial scales

These activities were carried out at the Jet Propulsion Laboratory,
California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

POC: Dan Crichton: Daniel.J.Crichton@jpl.nasa.gov

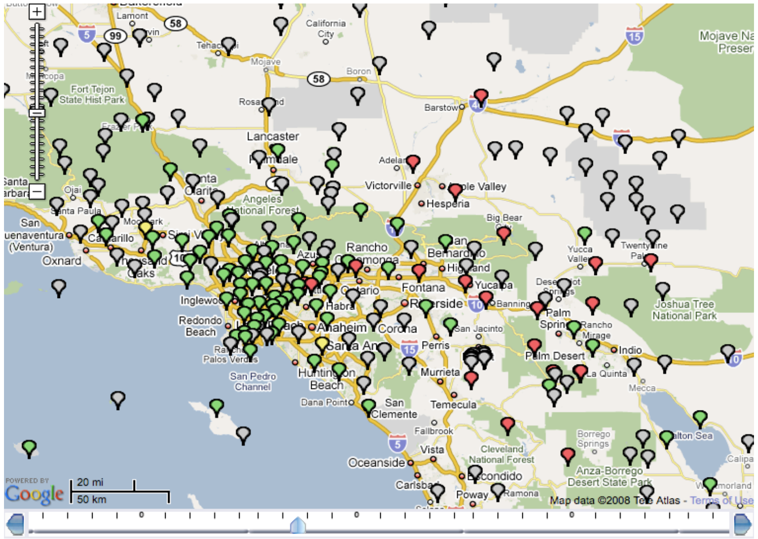
Machine Learning and Instrument Autonomy

- Goals and Objectives
  - Automated change detection
  - Identification of transient targets
  - Timely autonomous decision making
  - Efficient communication prioritization
  - Dynamic event detection
- Historical and current work with astrophysics data sets
  - Star/Galaxy separation
  - Morphological clustering of galaxies
  - Sky object identification

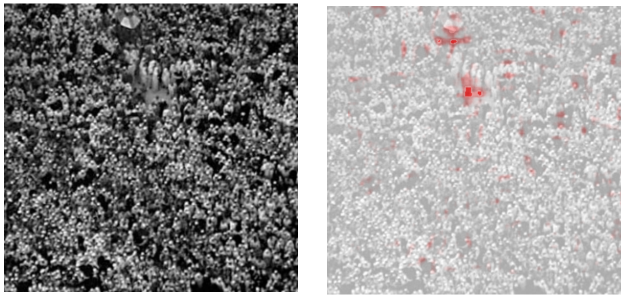
MLIA Core Technology Capabilities

- Computer vision:
  - event detection, motion estimation, object recognition, tracking
- Image analysis:
  - scene classification, change detection, anomaly detection, feature search
- Time series analysis:
  - segmentation, classification, anomaly detection, search

Signal detection in GPS networks.



Anomaly detection in crowd images.

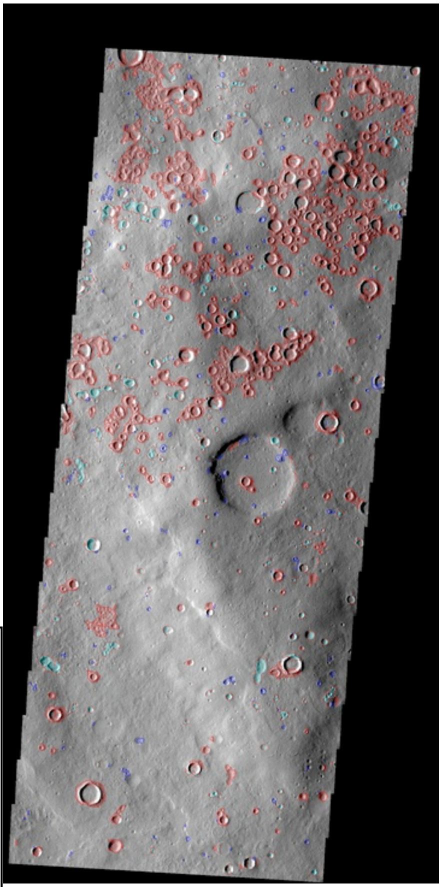


Mars crater identification.

POC: Robert Granat: Robert.A.**Granat@jpl.nasa.gov**

Automated Landmark and Change Detection in Orbital Images

- Detect landmarks as statistically unusual features
  - KL divergence, entropy, covariance descriptors
- Classify landmarks using machine learning
  - Craters, dust devil tracks, dark slope streaks
  - 94% classification accuracy
- Change detection
  - Build regional landmark graph
  - Detect changes in subsequent images



THEMIS

POC: Kiri Wagstaff: Kiri.L.**Wagstaff@jpl.nasa.gov**

Kiri Wagstaff, Julian Panetta, Ron Greeley, Mary Pendleton Hoffer, Melissa Bunte, Norbert Schorghofer, and Adnan Ansar

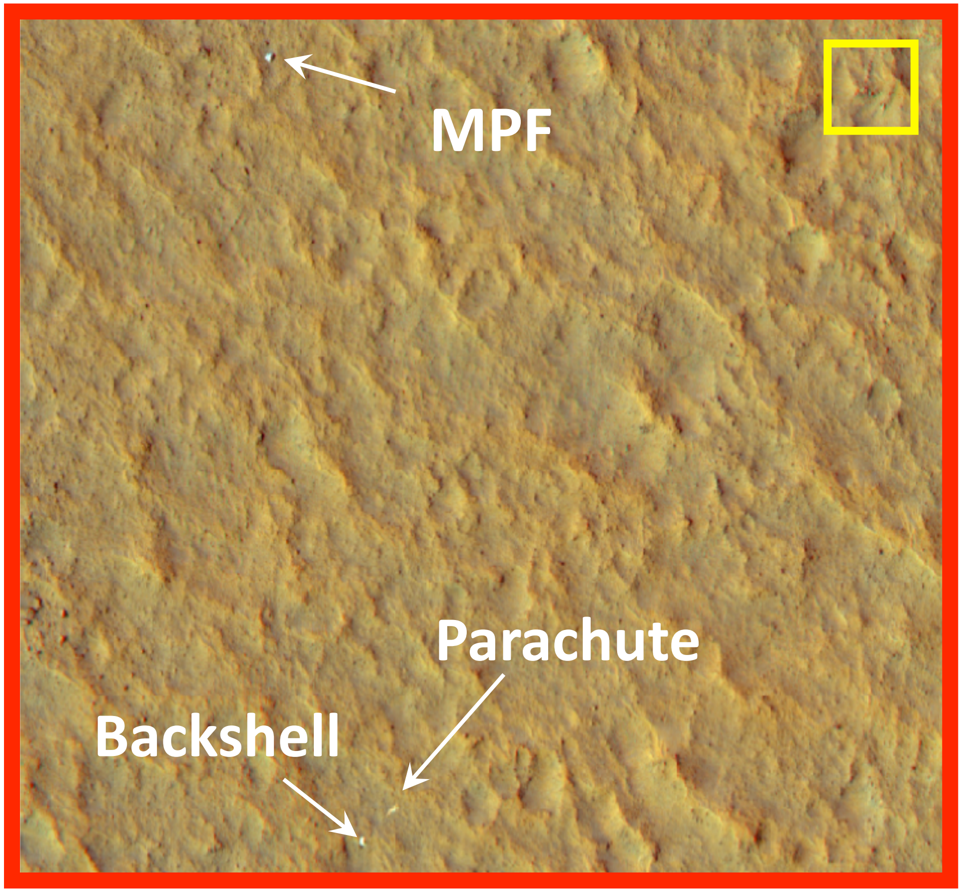
Funded by the NASA Applied Information Systems Research Program

Novelty Detection: Finding Spacecraft on Mars

- Capability
  - Demonstrated proof-of-concept system for detecting man-made objects (such as spacecraft parts) using a reformulation of existing CD technology.

- Approach
  - Compare local window statistics (covariance descriptors) to the statistics of a fixed global (larger) window designating the surrounding context. This leads to divergence values signaling "outlier-ness" of surface features in a single image.
  - Compute divergence between local windows (yellow) and the entire image (red), thus signaling statistical "outliers" throughout image

MPF site in HiRISE



"Change Detection"

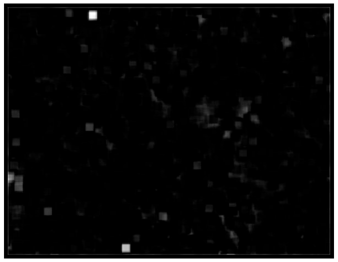
POC: Baback Moghaddam: Baback.Moghaddam@jpl.nasa.gov

Novelty Detection Example (cont)

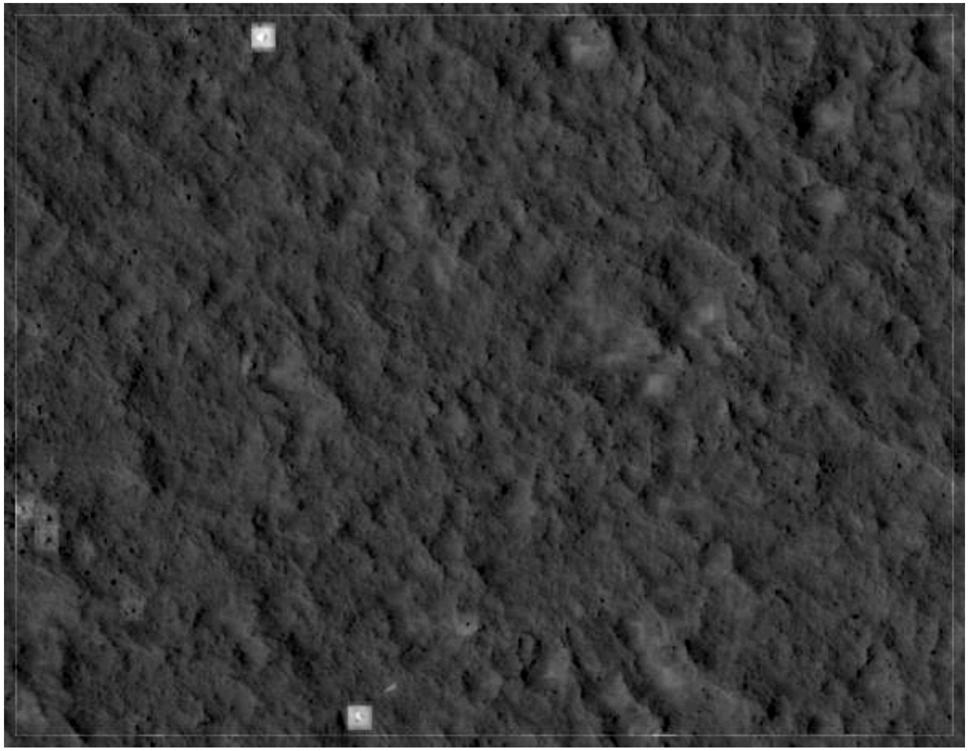
Features:

- neither color nor luminance were used as input features
- Instead our results are based on the more robust Hessian-Determinant feature which models local edge-structure.

Resulting Divergence Map



Divergence Map/Image Overlay



Example Results:

- Both MPF Lander and its Backshell are clearly detected
- The dust-covered & flat parachute structure however was not detected

POC: Baback Moghaddam: Baback.Moghaddam@jpl.nasa.gov