Data Science and Computing on the Path to Autonomy

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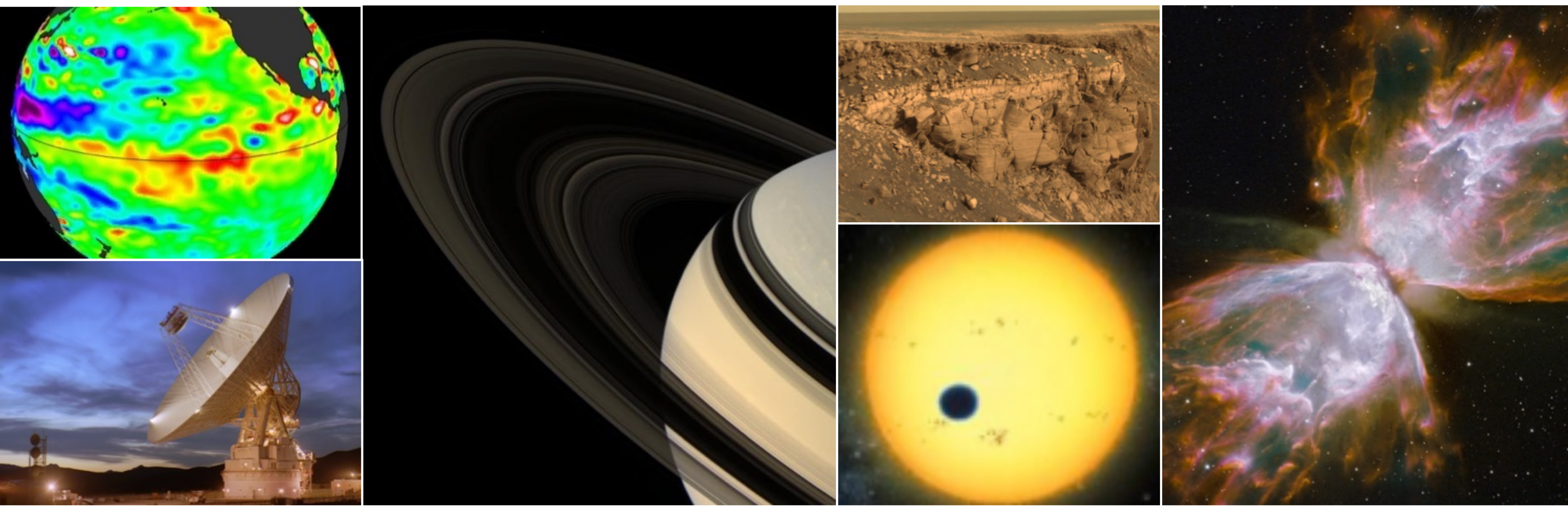
Astroinformatics 2019, Caltech, Pasadena

June 26, 2019

JPL's Mission for NASA

Robotic Space Exploration

Earth Science • Mars • Solar System • Astrophysics • Exoplanets • Interplanetary network



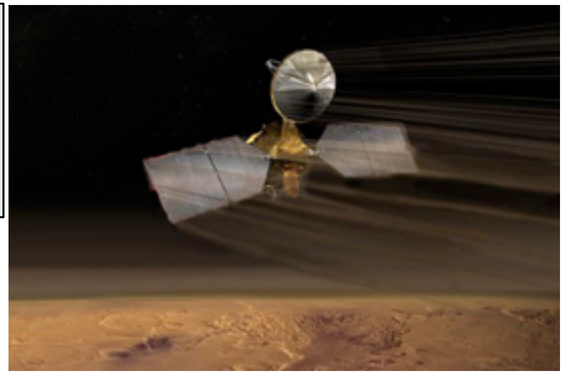
Our mission has introduced unique challenges for protecting space system assets and information

Data Challenges for Space Systems

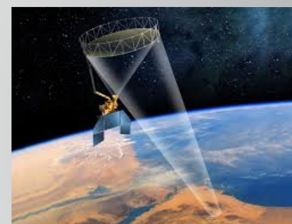
Data Lifecycle Model for NASA Missions

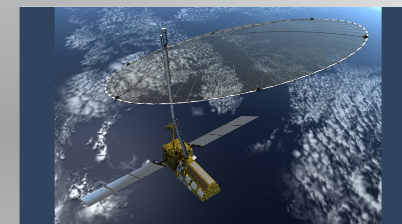
From Onboard Computing to Scalable Data Analytics

Emerging Solutions
- *Next-Generation Flight Computing*
- *Onboard Data Analytics*



Observational Platforms and Flight Computing





SMAP (Today): 485 GB/day **NISAR (2020): 86 TB/day**

Scaling Pressures Expose the Need for an Integrated End-to-End Data and Computational Architecture

Emerging Solutions
- *Intelligent Ground Stations*
- *Agile Mission Operations*

Ground-based Mission Systems

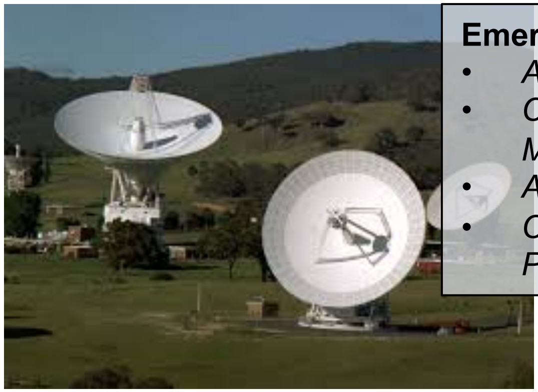
Emerging Solutions
- *Data-Driven Discovery from Archives*
- *Scalable Computation and Storage*

Interactive Analytics and Visualization and Decision Support

Interoperable Ground Data Systems and Archives

An Analytics-Driven Ground Environment

Intelligent Ground Stations



Emerging Solutions
- *Anomaly Detection*
- *Combining DSN & Mission Data*
- *Attention Focusing*
- *Controlling False Positives*

Data-Driven Discovery from Archives

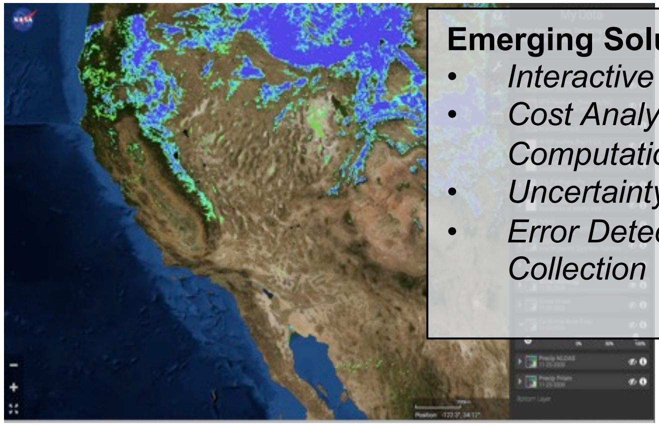
Emerging Solutions
- *Automated Machine Learning - Feature Extraction*
- *Intelligent Search*
- *Integration of disparate data*

Technologies: Machine Learning, Deep Learning, Intelligent Search, Data Fusion, Interactive Visualization and Analytics

Agile MOS-GDS

Emerging Solutions
- *Anomaly Interpretation*
- *Dashboard for Time Series Data*
- *Time-Scalable Decision Support*
- *Operator Training*

Data Analytics and Decision Support



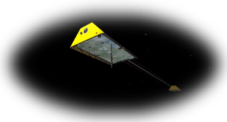
Emerging Solutions
- *Interactive Data Analytics*
- *Cost Analysis of Computation*
- *Uncertainty Quantification*
- *Error Detection in Data Collection*

Operational Recommendations for Capturing History and Infusing Data Science (ORCHIDS)

ORCHIDS aims to apply science data processing standards to engineering data streams from across the mission workflow (planning artifacts, commanding, event records, telemetry, ground station logs, etc.)

- Engineering data is for "expert consumption only"
- Shallow or emergency analysis assumed
- Wake the person who understands this stuff!
- New personnel overwhelmed with missing details
- Even basic analysis is stymied, let alone data-driven science

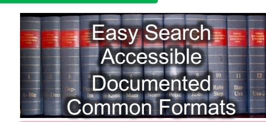
Replace nonstandard formats with a single data access point, with pre-aligned data and all metadata necessary to do data science analysis.



Operating Spacecraft

Ground Station

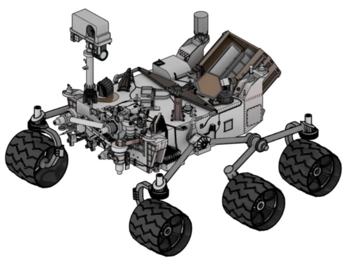
Science Data → L0 Raw Data (Wild & Wooly) → L1 Unitful Observations (Interpretable, Calibrated) → L2 Science Estimations (Usable, Traceable, Quality Assessed) → L3 Harmonized Products (Harmonized, Common Grid, Common Time, Filtered) → Standardized Archive



Engineering Data → "L0" Raw Data (Wild & Wooly) → Nonstandard Archive

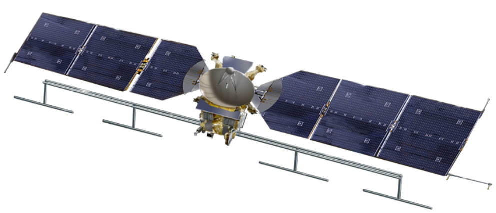
Jack Lightholder, Lukas Mandrake, Cooper Gilbert, Natalie Gallegos, Connor Francis, Ian Colwell, Brian Kahovec

ORCHIDS Infusion Pathways



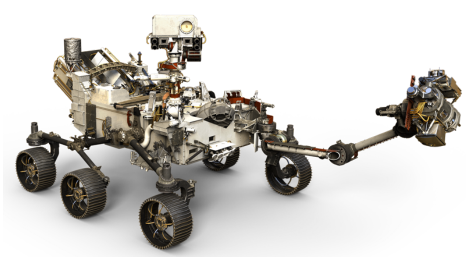
Mars Science Laboratory (MSL)

- Full engineering data system tracking
  - Commanding, telemetry, event monitoring, DSN monitoring, planning, scheduling, team staffing, vehicle parameters…
- Knowledge capture tool for human reporting
- Multi-subsystem in-flight data trending
- Anomaly investigations



Europa Clipper

- Time correlation between science and engineering products
- Human knowledge capture
- Multi-instrument anomaly investigations

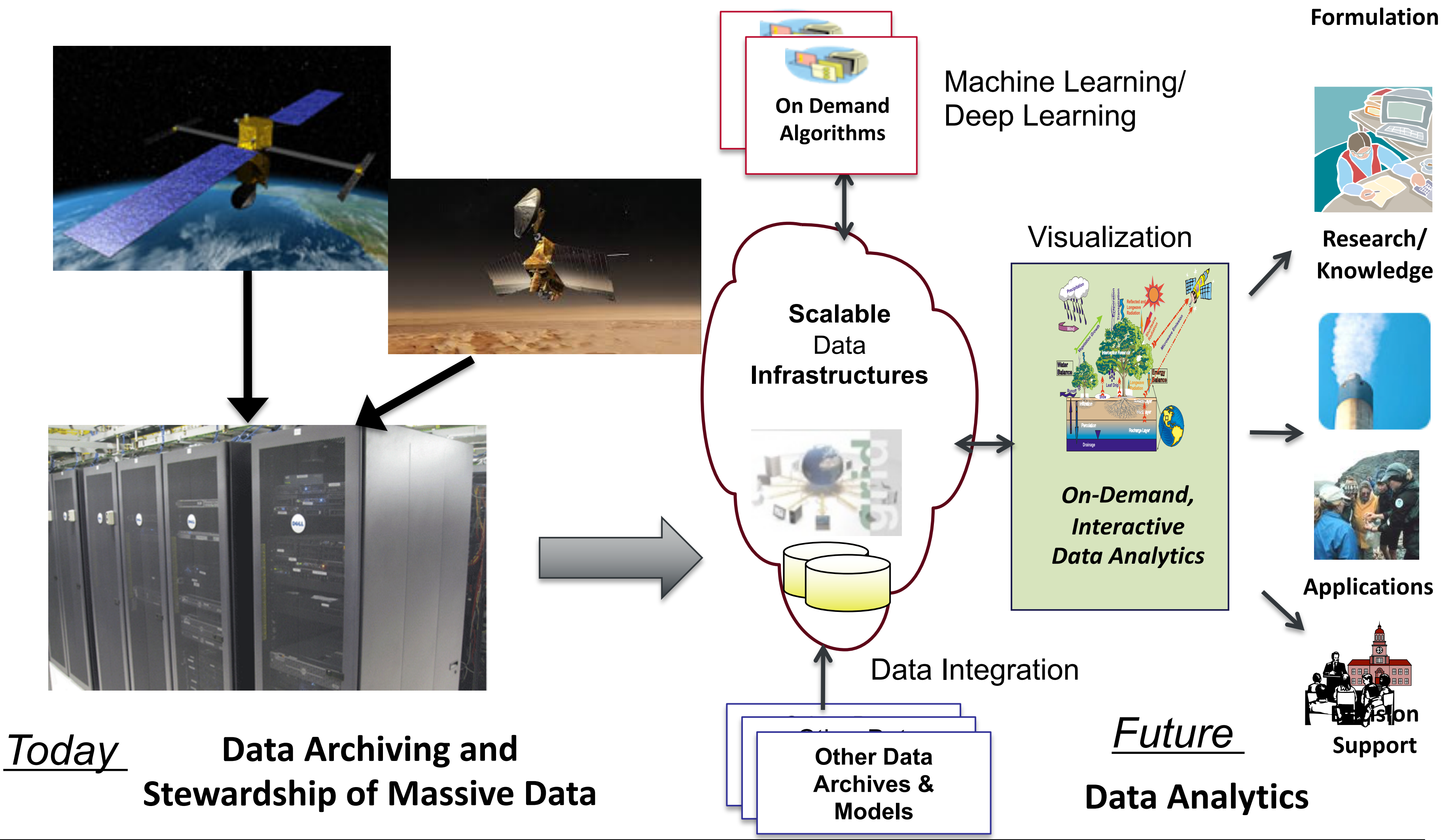


Mars 2020

- Active learning of anomalies - humans ‘on the loop’
- Increased data exploration capabilities in the mission operations environment
- Knowledge playback and training

Shifting toward Data Analytics

Expanding to Data-Driven Analytics



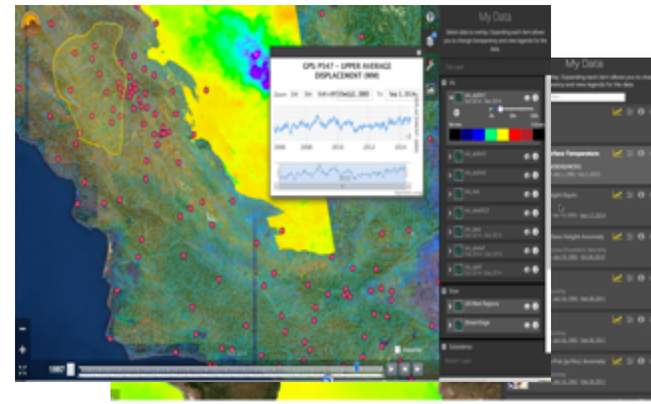
Reducing Data Wrangling: "There is a major need for the development of software components… that link high-level data analysis-specifications with low-level distributed systems architectures."
Frontiers in the Analysis of Massive Data, National Research Council, 2013.

Interactive Analytics for Data Exploration

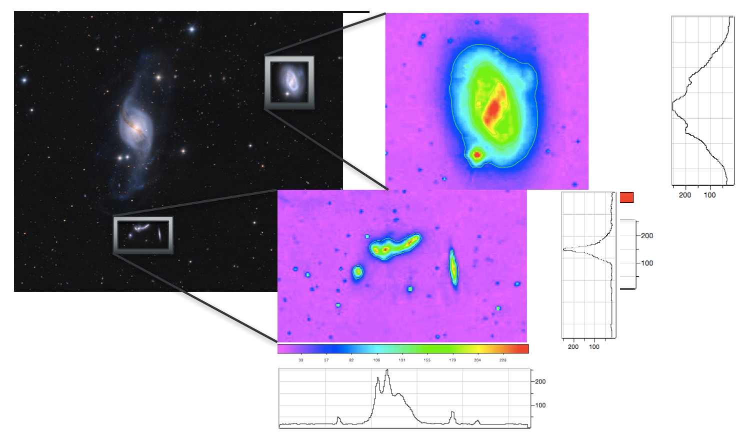
Exploration of Data from Planetary Missions

Examples: Planetary Image search, Mars and Moon surface navigation, feature extraction from Planetary images.

Examples: Hydrology and sea level rise

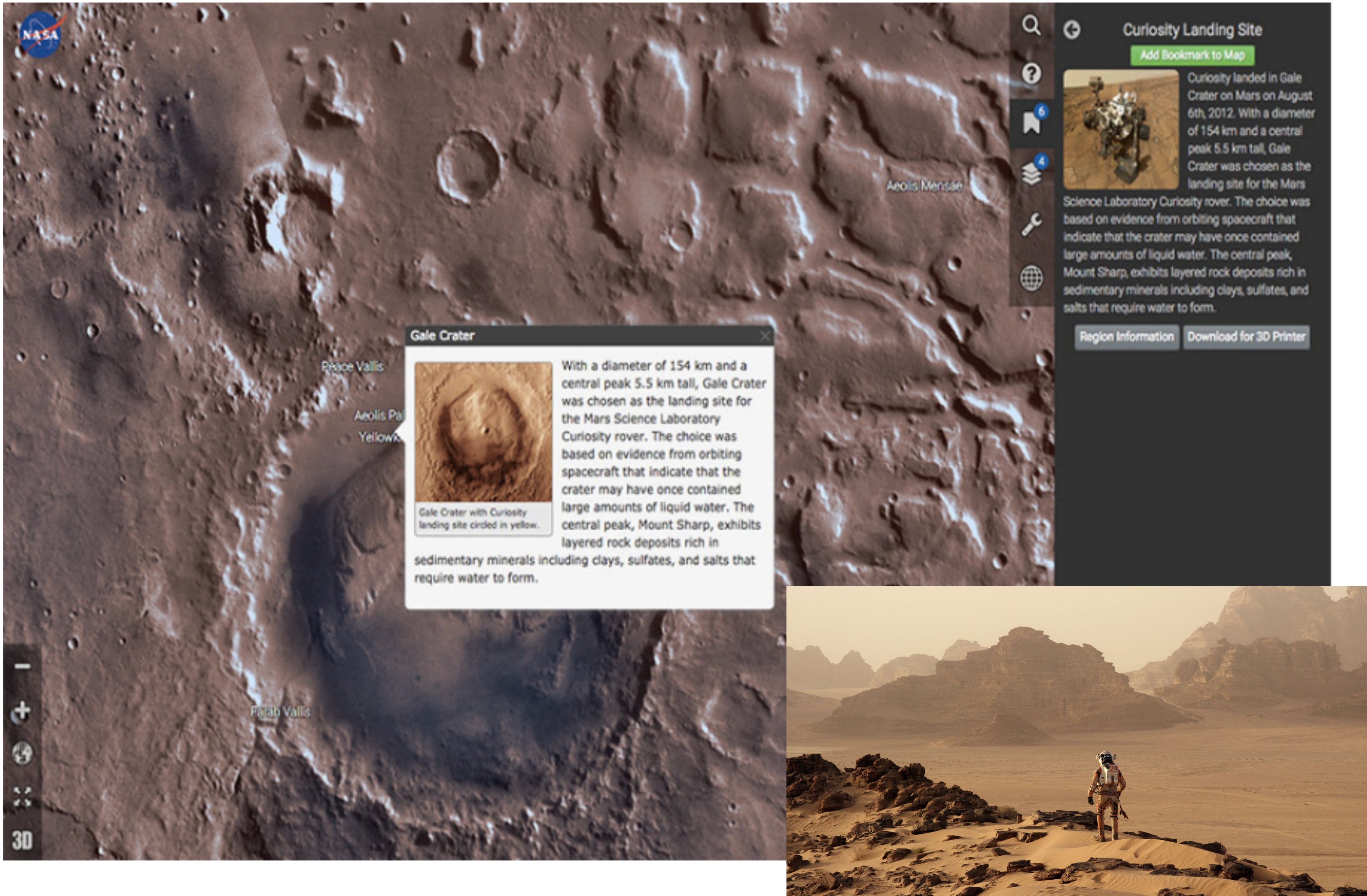


Analysis of Earth and Climate Science Observations and Models



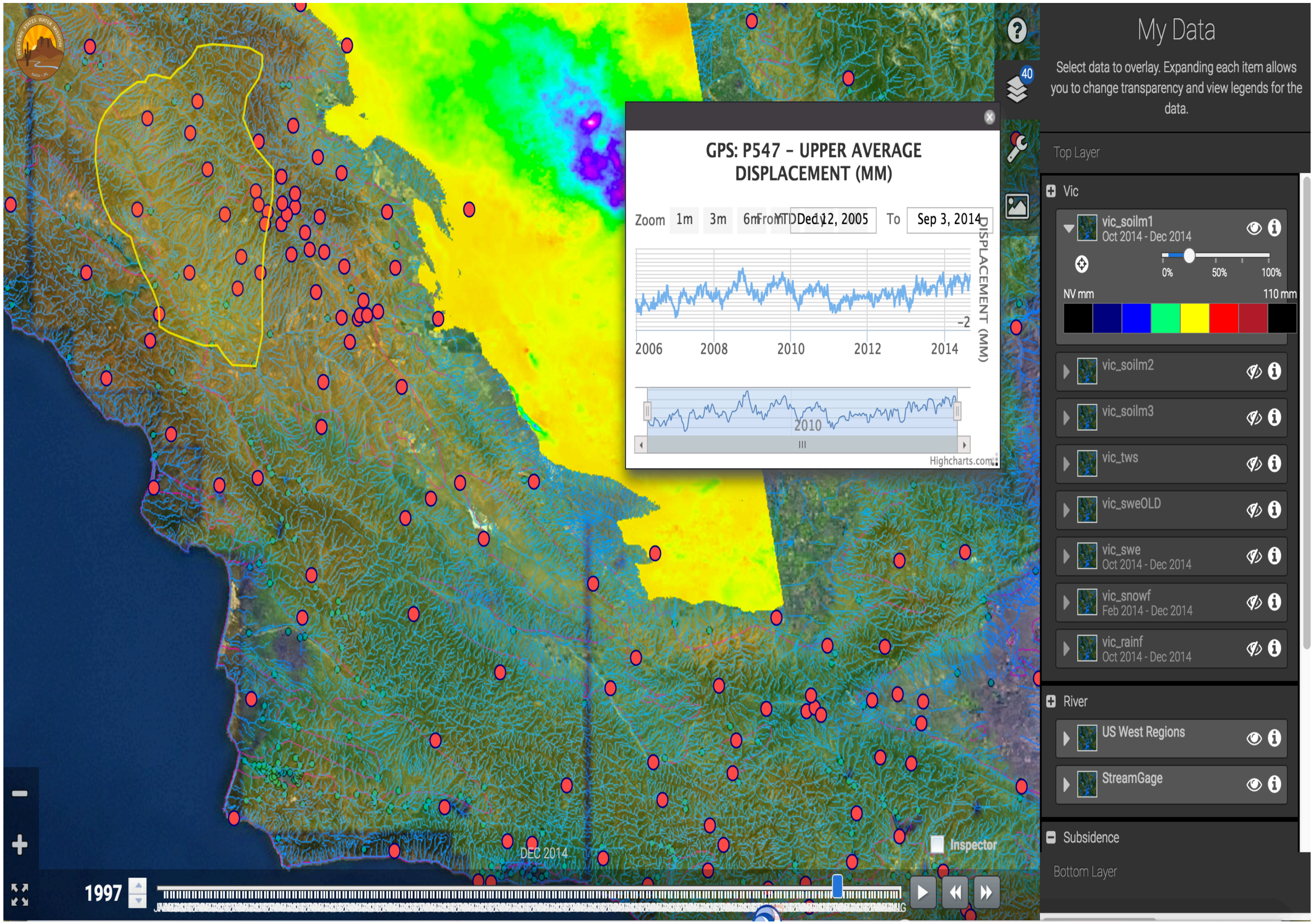
Classification and Analysis of Transient Events in Astronomy

Mars Trek: The Google Earth of Mars



Credit: Emily Law, Shan Malhotra

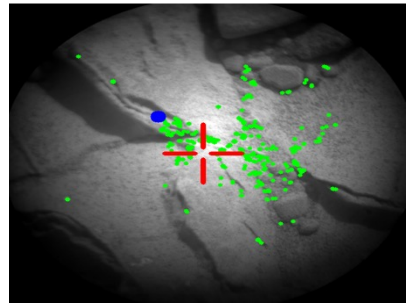
WaterTrek: Interactive Analytics for Western States Water Analysis



Credit: Jay Famiglietti, Cedric David, Shan Malhotra, D. Crichton

Computing, Autonomy and Analytics at the Far Edge

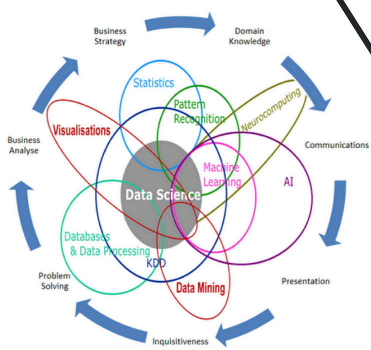
Enabling Onboard Autonomy Through Data Science and Computing



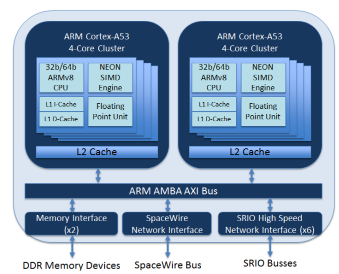
Onboard Autonomy

SPACE MISSION ARCHITECTURE

Capabilities:
- Data Analytics
- Scalable Data Services
- Data Processing
- Data Integration



Data Science

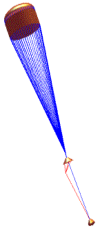
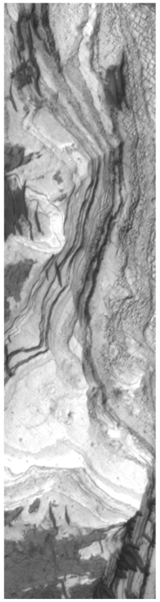
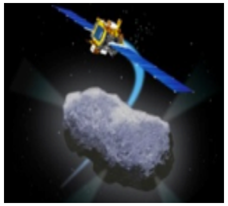
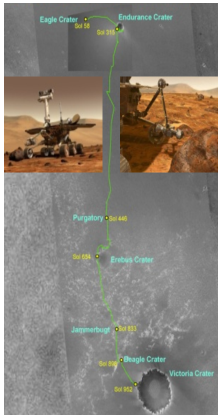


Capabilities:
- Processors
- Memory
- Energy Mgmt
- Fault Tolerance

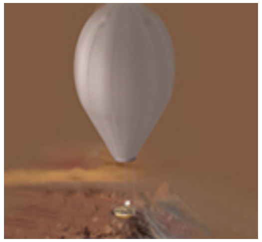
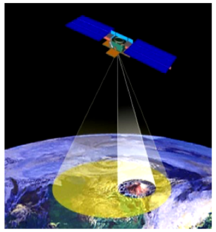
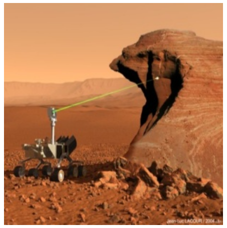
High Performance Spaceflight Computing

Future NASA Needs for Space-Based Computing

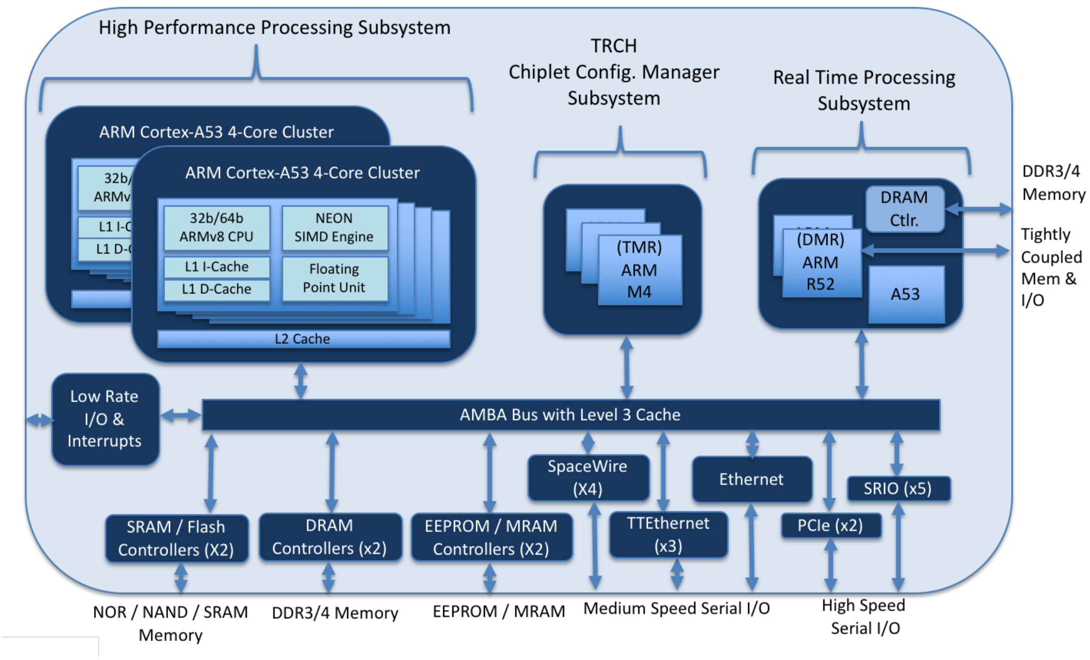
- Space-based computing has not kept up with the needs of current and future missions
- NASA has some unique requirements
  - Deep space, long duration, robotic and human missions
  - Higher performance, smaller spacecraft
    - Onboard science data processing
    - Autonomous operations
  - Extreme needs for low power and energy management, efficiency, fault tolerance and resilience

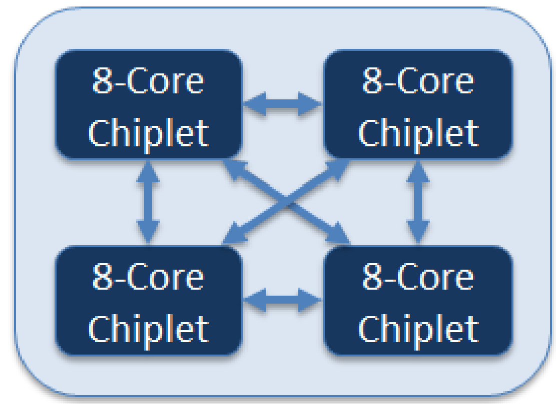







HPSC – Reinventing the Role of Computing in Space





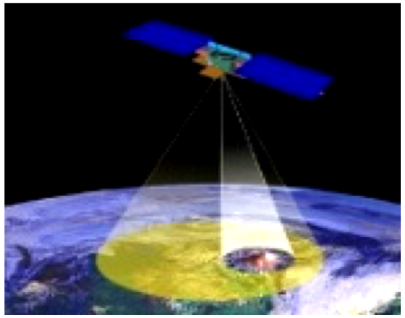
- **HPSC** offers **a new flight computing architecture** to meet the future needs of NASA missions.
- Providing on the order of **100X the computational capacity of current flight processors for the same amount of power**, the multicore architecture of the HPSC chiplet provides **unprecedented flexibility** in a flight computing system.
- By enabling the operating point to be set dynamically, **trading among needs for computational performance, energy management and fault tolerance**.
- **HPSC has been conceived to be highly extensible**. Multiple **chiplets can be cascaded together** for more capable computing, or HPSC **can be configured with specialized co-processors** to meet the needs of specific payloads and missions.
- **HPSC is a technology multiplier**, amplifying existing spacecraft capabilities and enabling new ones.
- The HPSC team anticipates that the chiplet will be **used by virtually every future space mission**, all benefiting from more capable flight computing.

HPSC – Mission Infusion Framework

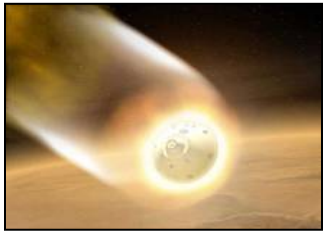
- NASA will develop HPSC-based, flight-qualified, single board computers (SBCs), ready for infusion into missions
  - Develop a NASA SBC reference design
  - Integrate the board with at least one set of flight-ready system software
  - Demonstrate flight readiness of the single board computer
  - Fund industry to develop standards-based HPSC SBCs

Deep Space

Surface Systems



High Data Rate Instruments



Landing Systems

Human Spaceflight

CubeSats, SmallSats

Entry, Descent and Landing

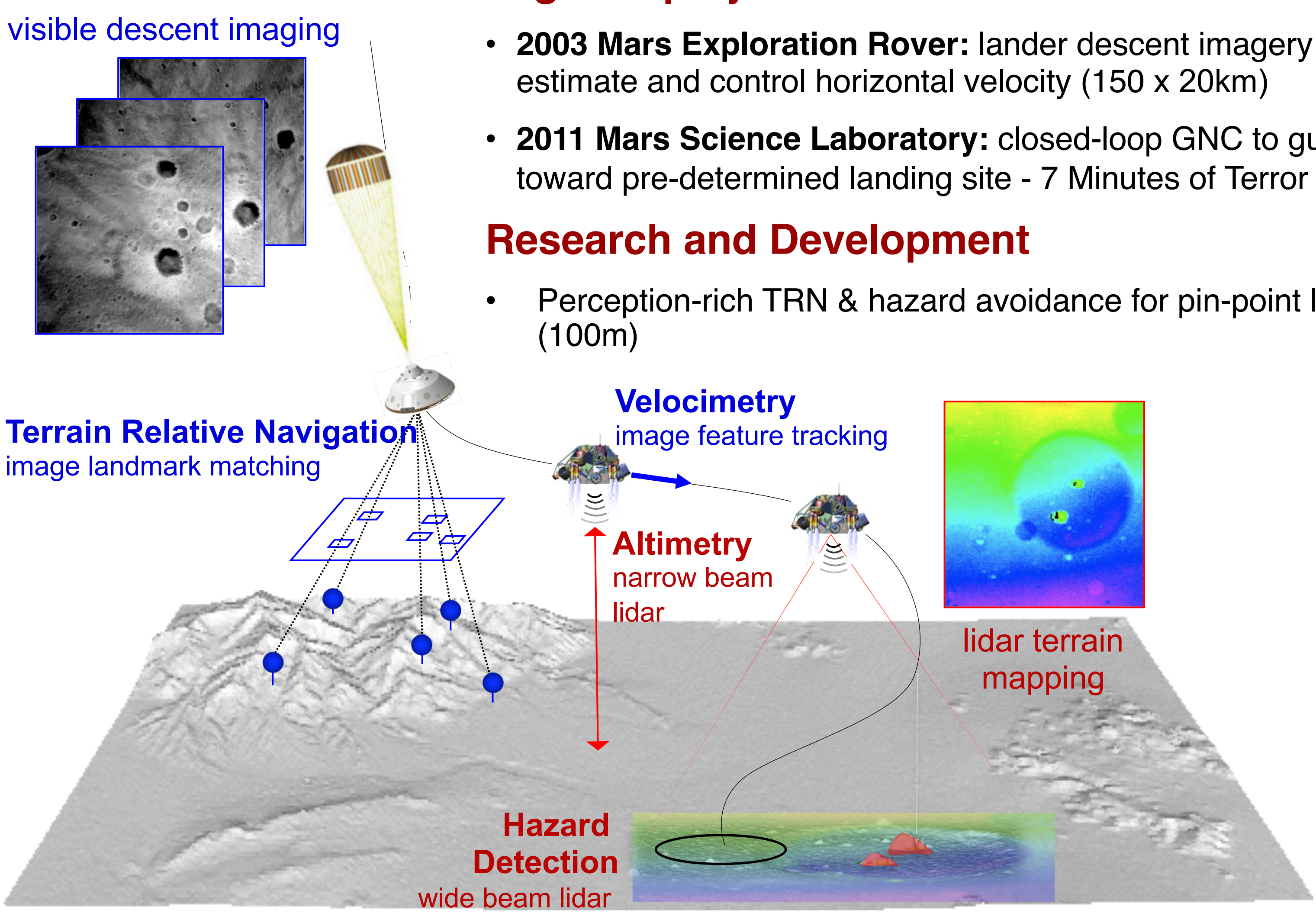
Terrain Relative Navigation and Hazard Avoidance

Flight Deployed

- **2003 Mars Exploration Rover:** lander descent imagery used to estimate and control horizontal velocity (150 x 20km)
- **2011 Mars Science Laboratory:** closed-loop GNC to guide EDL toward pre-determined landing site - 7 Minutes of Terror (20 x 7km)

Research and Development

- Perception-rich TRN & hazard avoidance for pin-point landing (100m)



Surface Mobility

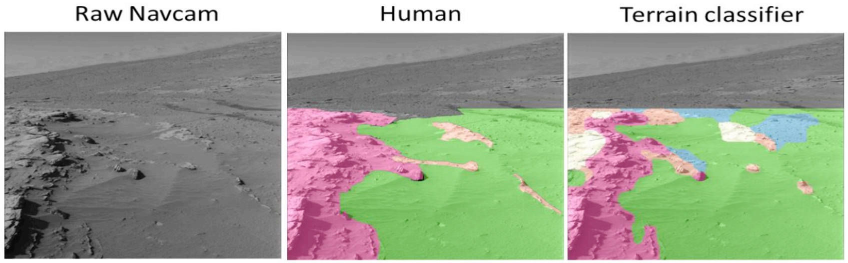
Mars Rover Navigation

Flight Deployed

- **1996 Mars Pathfinder:** obstacle avoidance with structured light
- **2003 Mars Exploration Rover:** obstacle avoidance with stereo vision; pose estimation and slip detection with visual odometry; goal tracking
- **2011 Mars Science Laboratory:** enhanced obstacle avoidance, visual odometry and goal tracking

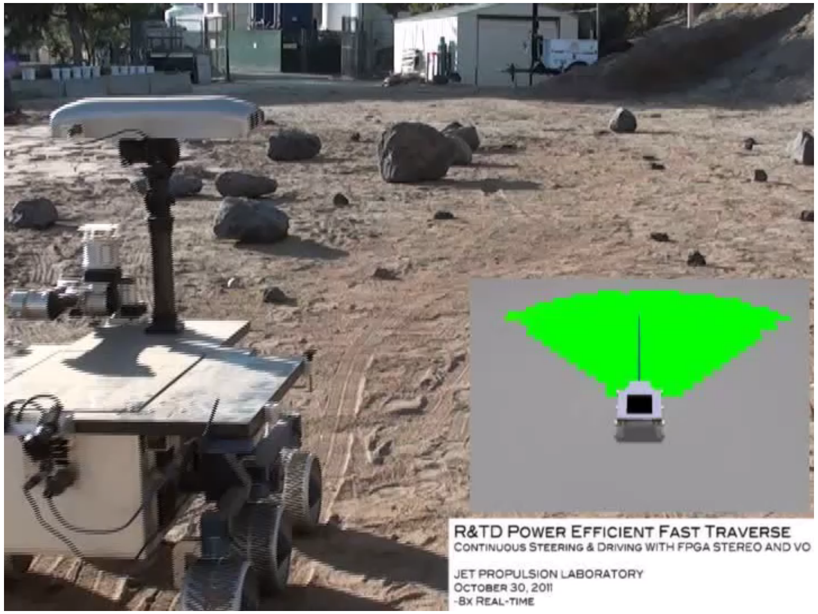
Research and Development

- Enhanced hazard detection, traversability analysis and motion planning for Mars 2020 and beyond



Terrain Classification

Athena



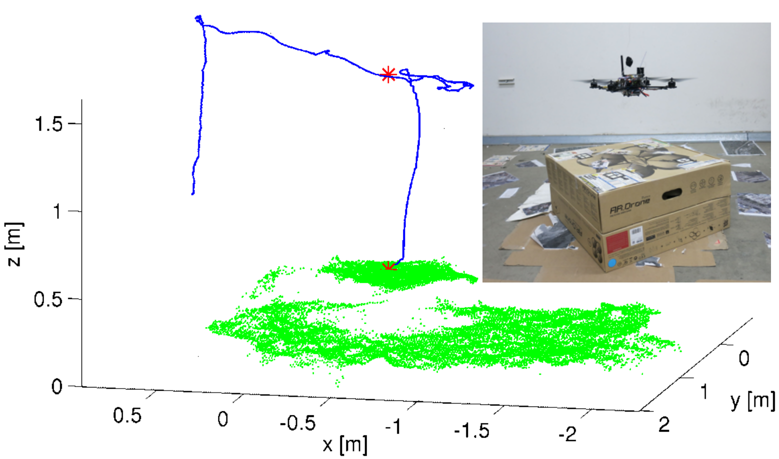
Fido

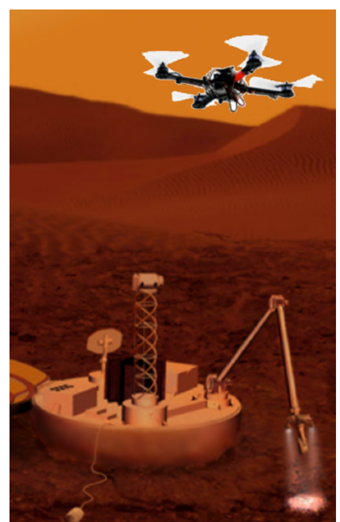
Above-Surface Mobility

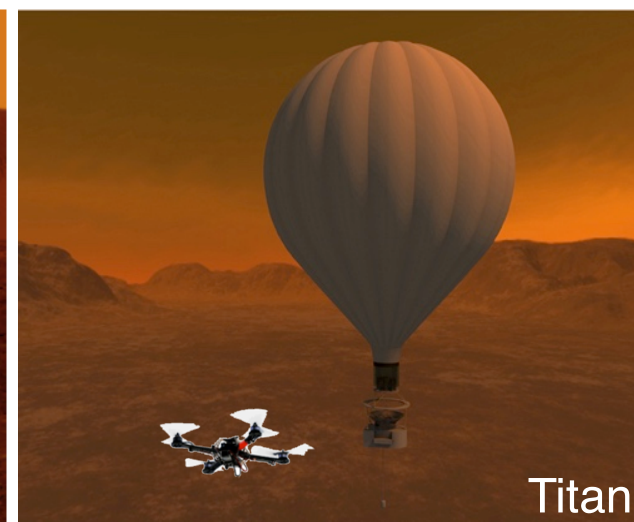
Rotorcraft and Balloon Mobility Research

Research and Development

- **Multiple applications:** (a) terrestrial (defense, intelligence, commercial, and science) and (b) planetary (Mars, Titan, and Venus)
- **Capabilities:** visual-inertial localization combines images with IMU for better estimate; autonomous landing with obstacle avoidance





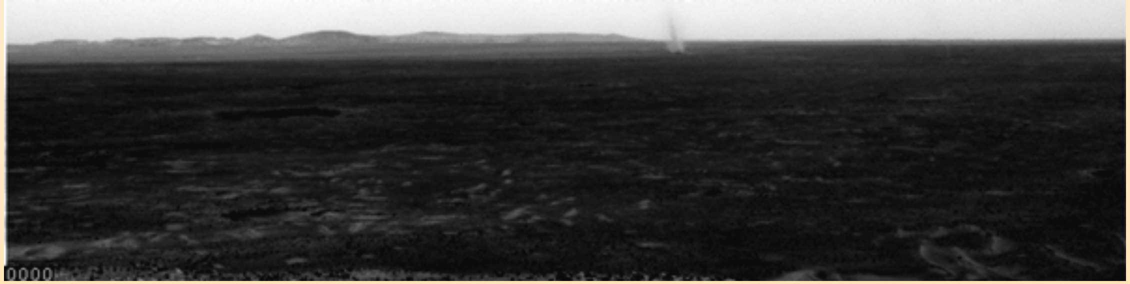


Onboard Data Product Generation

Dust Devils on Mars

Dust devils are scientific phenomena of a transient nature that occur on Mars

- They occur year-round, with seasonally variable frequency
- They are challenging to reliably capture in images due to their dynamic nature
- Scientists accepted for decades that such phenomena could not be studied in real-time



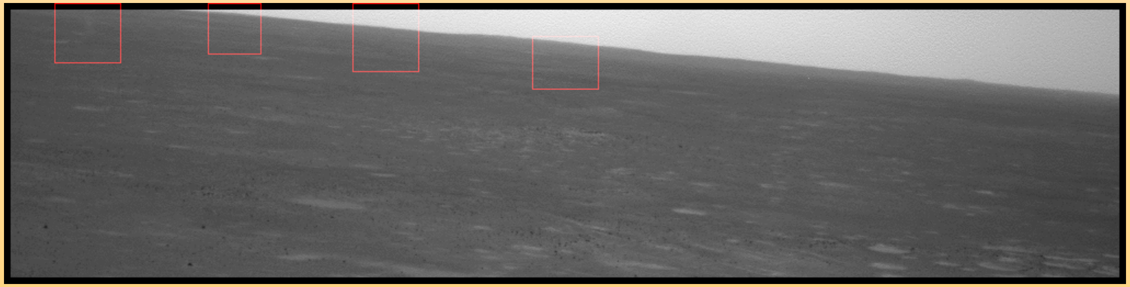
Spirit Sol 543 (July 13, 2005)

New onboard Mars rover capability (as of 2006)

- Collect images more frequently, analyze onboard to detect events, and only downlink images containing events of interest

Benefit

- < 100% accuracy can dramatically increase science event data returned to Earth
- *First notification includes a complete data product*



Credit: T. Estlin. B. Bornestein, A. Castano, J. Biesiadecki, L. Neakrase, P. Whelley, R. Greeley, M. Lemmon, R. Castano, S. Chien and MER project team

Partnering

Caltech-JPL Partnership in Data Science

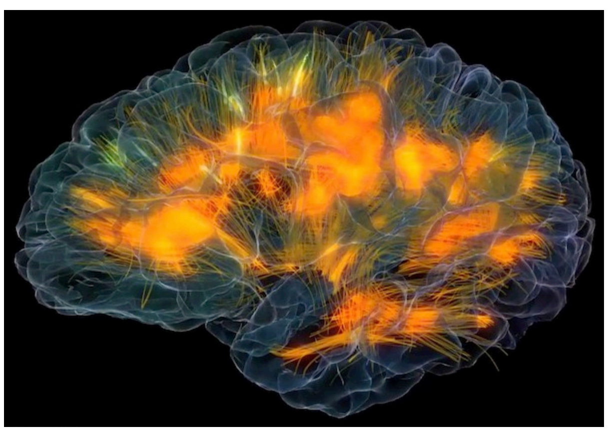
Center for Data-Driven Discovery on campus/Center for Data Science and Technology at JPL

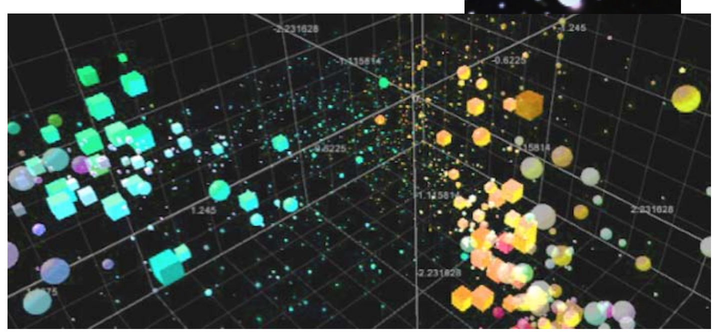
From basic research to deployed systems ~10 collaborations

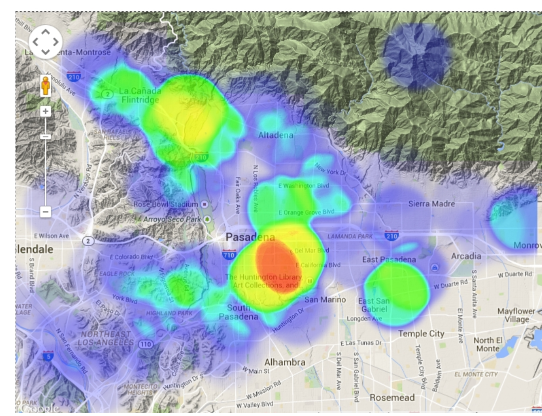
Leveraged funding from JPL to Caltech; from Caltech to JPL

CENTER FOR DATA-DRIVEN DISCOVERY

CDST







JPL Data Science Partnering Strategy

Universities

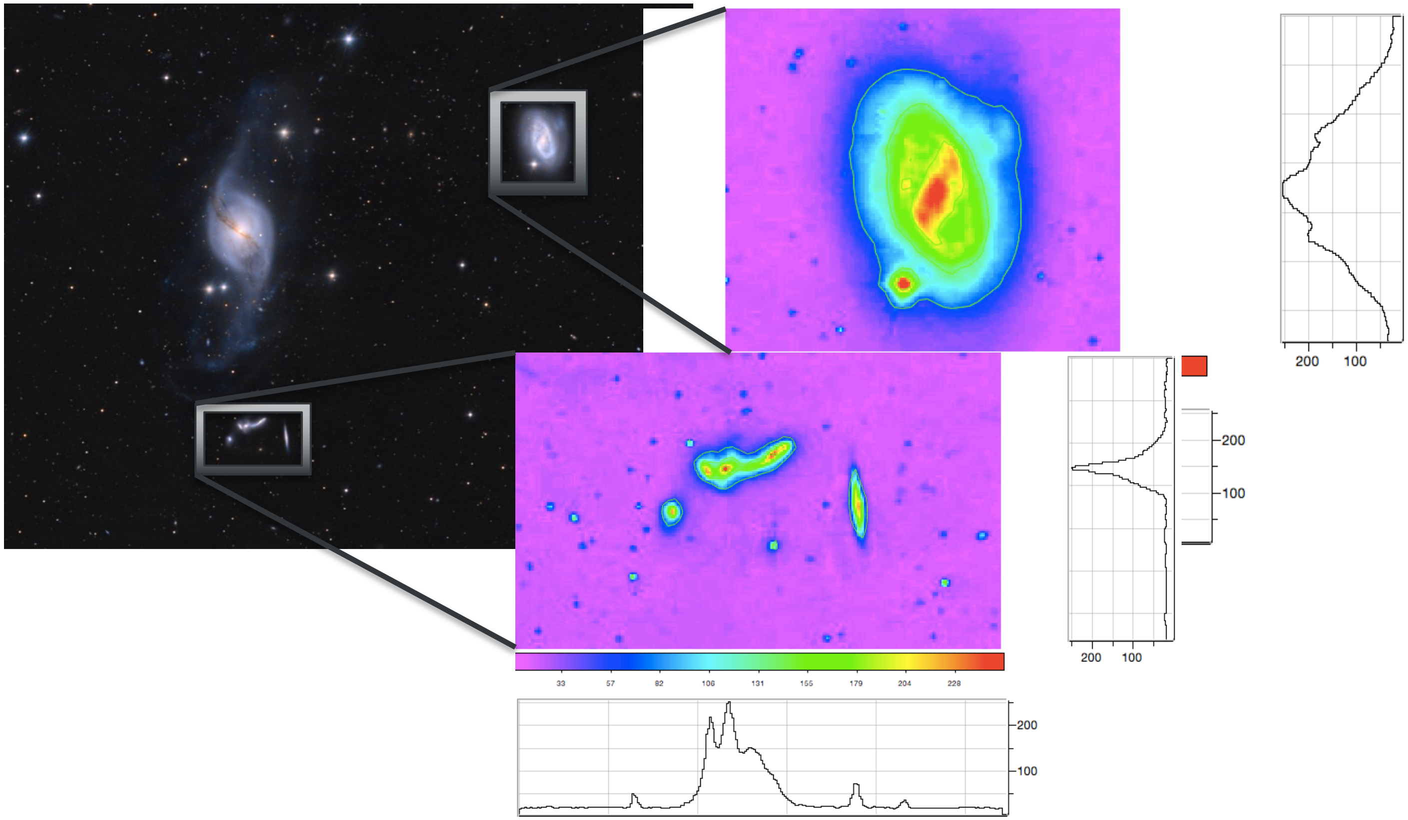
Non-NASA partnerships

Open Source

Commercial

Methodology Transfer

From Astrophysics…

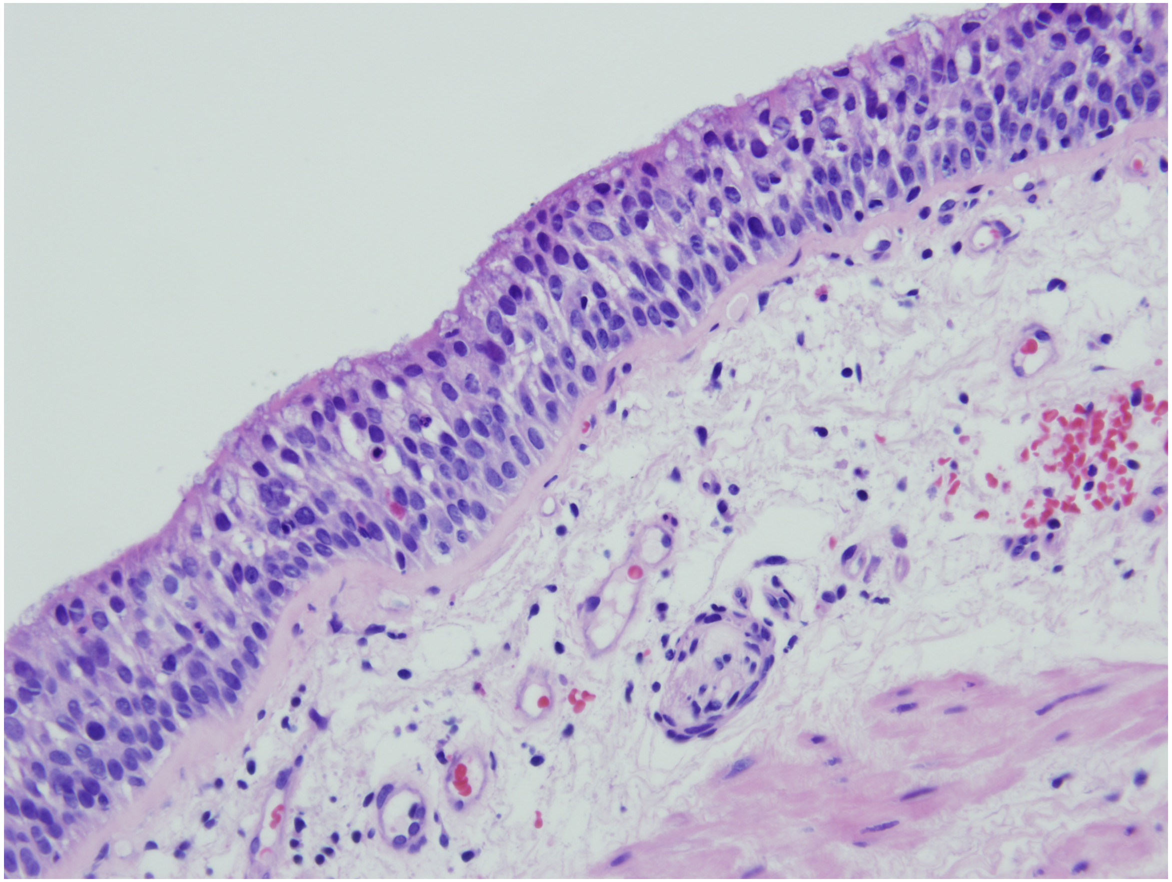


Description: Detecting objects from astronomical measurements by evaluating light measurements in pixels using intelligent software algorithms.

Image Credit: Catalina Sky Survey (CSS), of the Lunar and Planetary Laboratory, University of Arizona, and Catalina Realtime Transient Survey (CRTS), Center for Data-Driven Discovery, Caltech.

Methodology Transfer

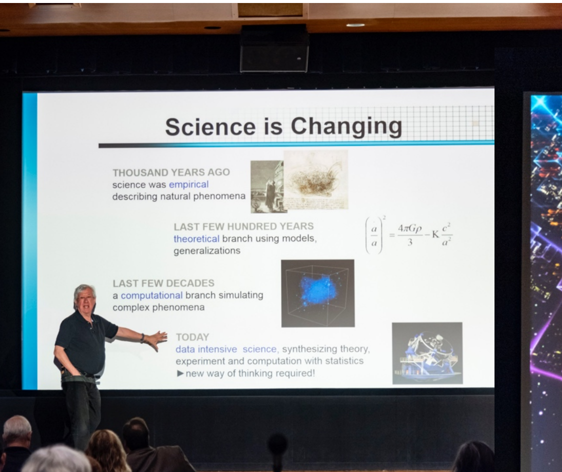
…to Biomedicine

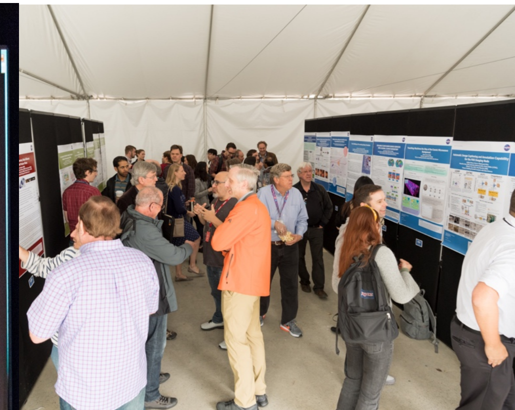


Description: Detecting objects from oncology images using intelligent software algorithms transferred to and from space science.

Image Credit: EDRN Lung Specimen Pathology image example, University of Colorado

An Emerging Community of Practice





2 Keynotes (Johns Hopkins, Caltech)
6 JPL Talks, 96 Posters, and live demos across JPL
Over 1000 attendees
…an emerging community of practice

NASA JPL Caltech