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Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

NASA/JPL Future Computing Needs

Frontiers of Extreme Computing 2007
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Introduction

- **Challenges of Space (Systems & Environment)**
- **Spaceborne Computing**
- **Ground-based Computing (specific to NASA/JPL needs)**
- **Spaceborne Computing Path**

1958
First U.S. satellite

Explorer 1

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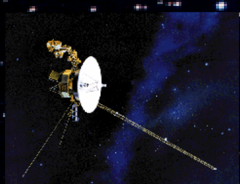
Where are we now?

NASA has more than 50 missions exploring our solar system (some examples)

Spitzer studying stars and galaxies in the infrared

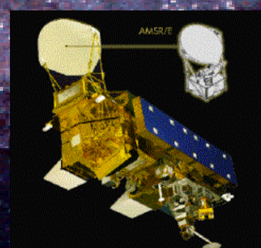
GALEX surveying galaxies in the ultraviolet



Two Voyagers on an interstellar mission

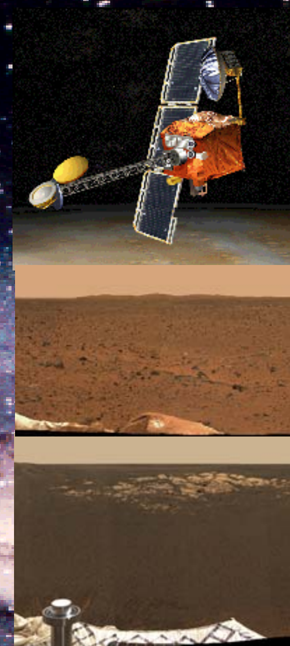
Chandra studying the x-ray universe

Ulysses studying the sun



Aqua studying Earth's oceans

Aura studying Earth's atmosphere

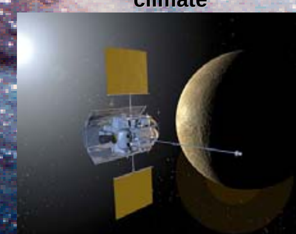


Mars Odyssey, rovers "Spirit" and "Opportunity" studying Mars

Hubble studying the universe

Cassini studying Saturn

CALIPSO studying Earth's climate



MESSENGER on its way to Mercury

New Horizons on its way to Pluto

QuikScat, Jason 1, CloudSat, and GRACE (plus ASTER, MISR, AIRS, MLS and TES instruments) monitoring Earth.

Space Challenges
Environment

- **High Radiation**
  - Total dose (>mega rads for some missions)
  - SEU
- **Temperature**
  - Wide range (-270 deg F on Europa to >900 deg F on Venus)
  - Rapid cycling (>1000 cycles of 100 deg on MER)
- **Vibration**
  - Launch
  - Planetary Entry, Descent, Landing

…. These present severe constraints to the compute hardware

Space Challenges

Communications and Guidance

- Bandwidth
  - 6 Mbit/s max (modulator limit)
  - Typically much less based on SNR (100 bits/sec)
  - Spacecraft transmitter power typically less than light bulb in your refrigerator
- Latency (one-way)
  - 20 min to Mars
  - 13 hr to Voyager 1
- Navigation
  - Positional accuracy for critical events
  - Velocity determination (continuous)

… These present severe constraints to mission operations

Space Challenges
Engineering

- Only flight qualified parts are typically used
  - Systems are >5 yrs out of date when launched (two generations behind commercial art)
- Several Power and Mass Restrictions
  - 20-30 W for a flight computer
- Often can't test final system until its flown
  - Importance of modeling and simulation
- Long mission duration challenges maintainability of ground assets in operations phase
  - Voyager is based on customer flight computer designed with MSI parts and ferrite core memory of the late 1960's (programmed in assembler)
    - Ground computers based on Univac 1100 series

… <u>Silver lining: software is about the only thing that can be changed after launch</u>

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Agenda

- Challenges of Space (Systems & Environment)
- **Spaceborne Computing**
- Ground-based Computing (specific to NASA/JPL needs)
- Future Spacecraft Computing Directions

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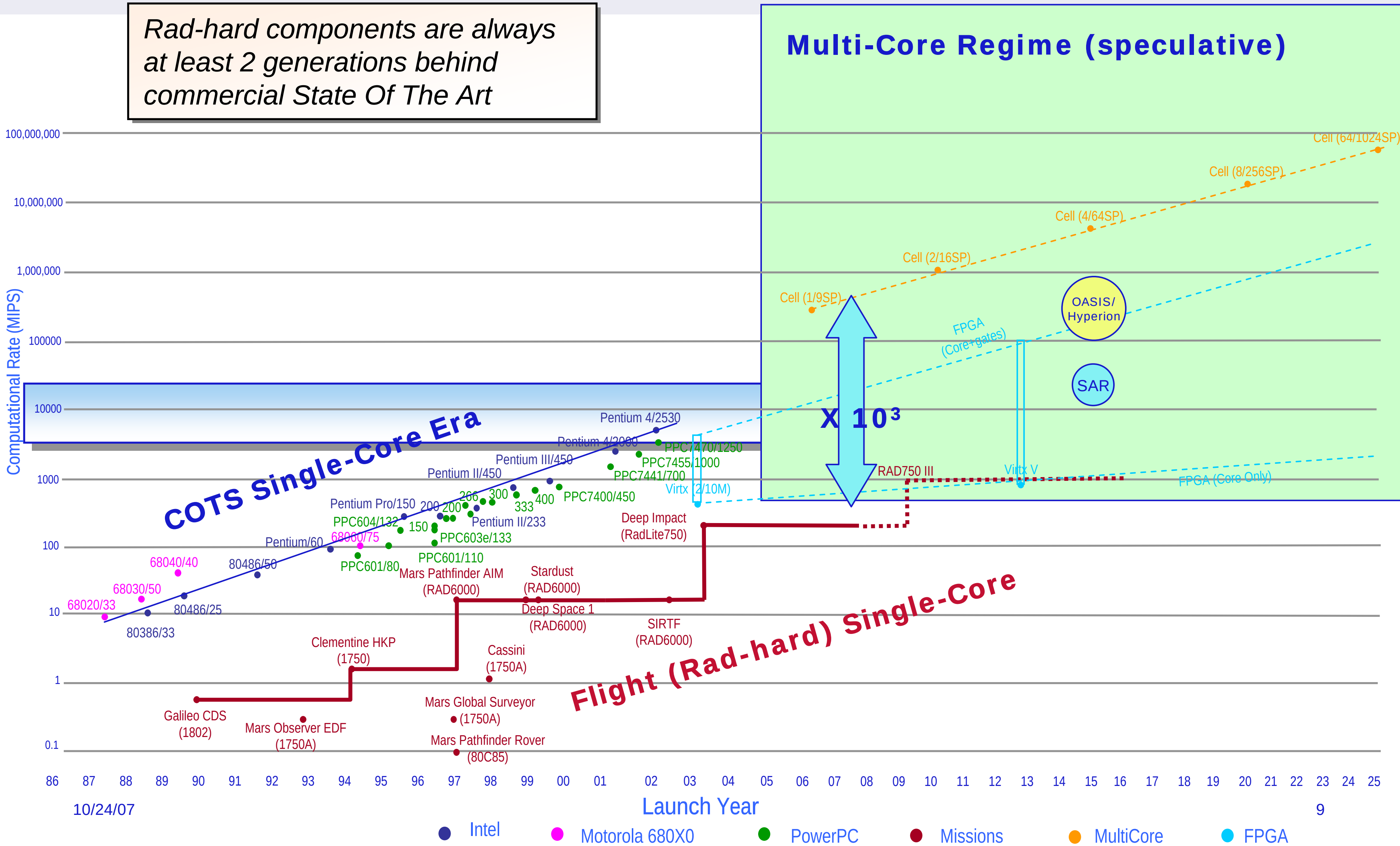
Space Flight Avionics & Microcomputer Processor History

Rad-hard components are always at least 2 generations behind commercial State Of The Art



Future Mission Applications

New Types of Science

- Event detection
- Opportunistic science (eg dust devils detectors)
- Model based autonomous mission planning
- Multiple platform cooperative missions (fleets, swarms…)
- Smart high resolution sensors (eg., gigapixel, SAR, ..)

Entry Descent & Landing

- Flight control thru disparate flight regimes
- Landing zone identification
- Hazard avoidance
- Soft touchdown

Surface Mobility

- Terrain traversal
- Obstacle avoidance
- Science Target identification
- Image/video Compression

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Data Mining of Image and Time-series Data

Capability

Recognize events & trends

- machine-assisted discovery

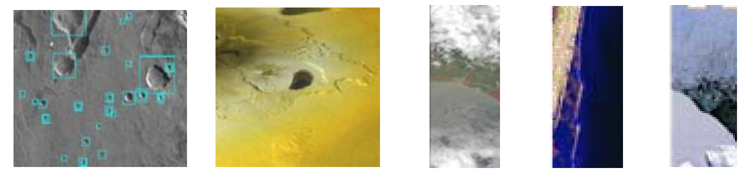
- automatically generate catalogs, summaries

- Watch data streams and send alerts

Technologies

- *Scale and orientation invariant template matching*
- *Time-series analysis*
- *Texture recognition*
- *Data fusion – correlate data from several sources to improve accuracy.*

Features

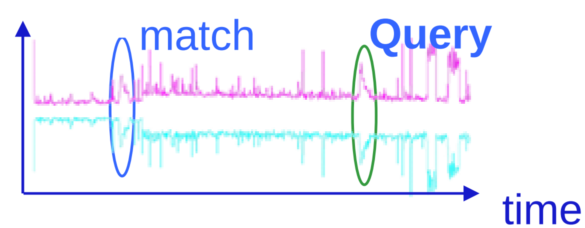


craters **volcanoes** **clouds** **floods** **ice**

Multi-Source Triggers

Cloud-cover (GOES) — infrared — Ground sensors

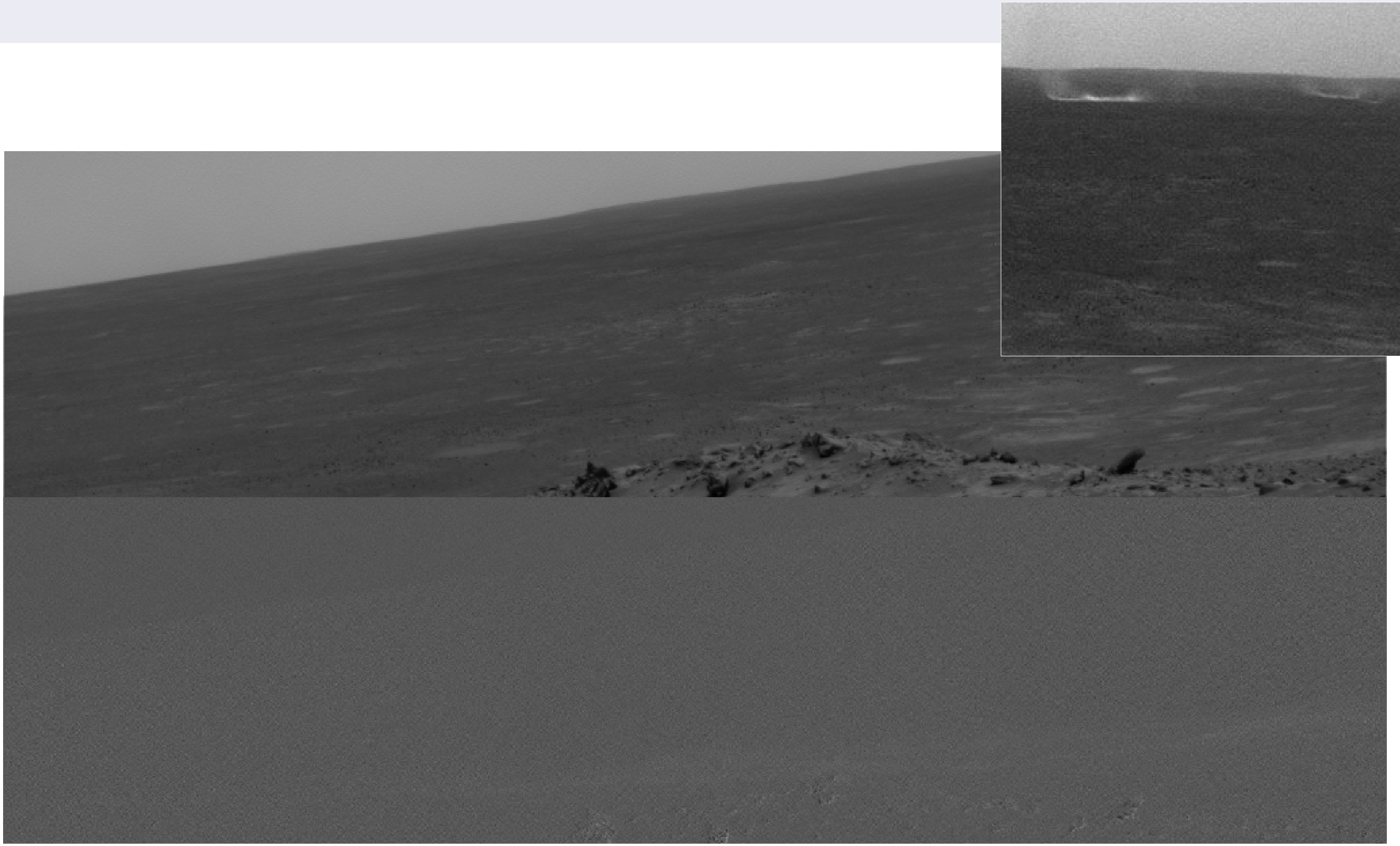
Time Series



Novelty & Changes

Mars Dust Devils

Mars Dust Devils



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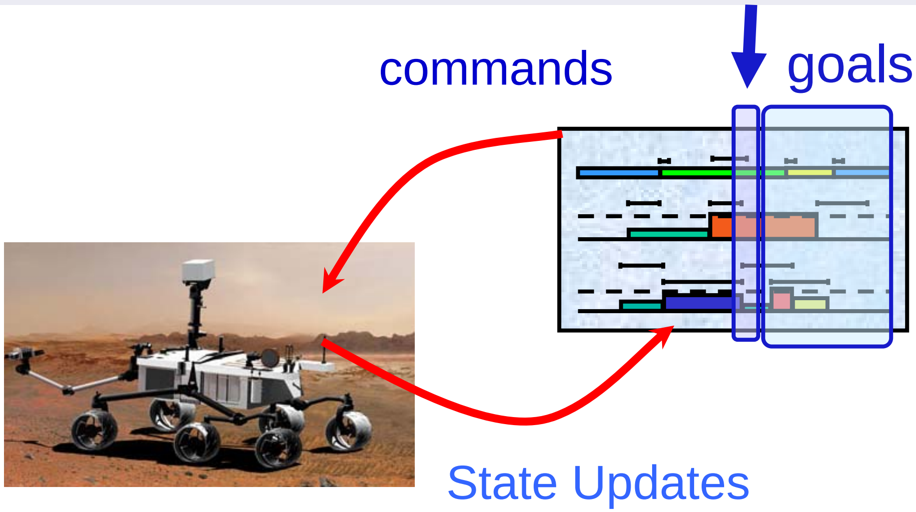
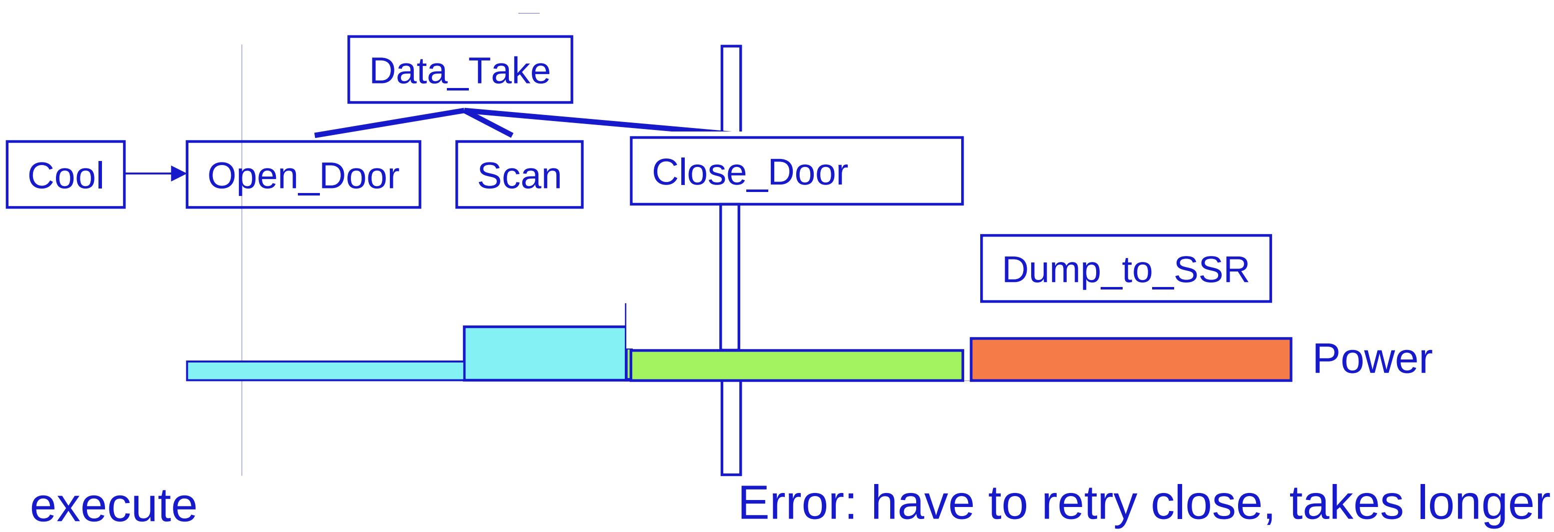
Planning and Scheduling



- Automatically generate plan of action that achieves goals while obeying resource & operations constraints.
- Continuously revises plan in response to events (~10s)



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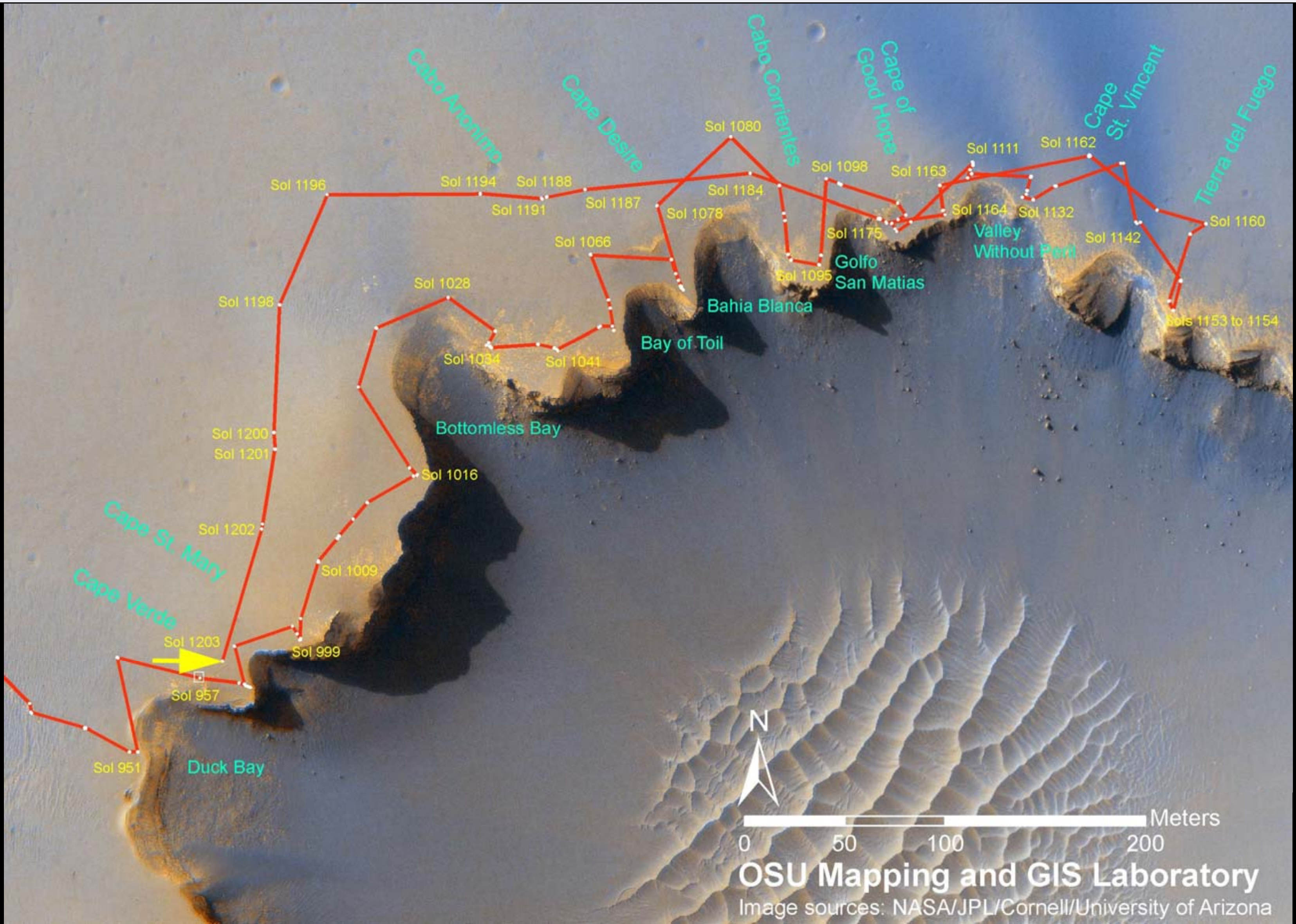
Duck Bay: Site of Opportunity's descent into Victoria Crater



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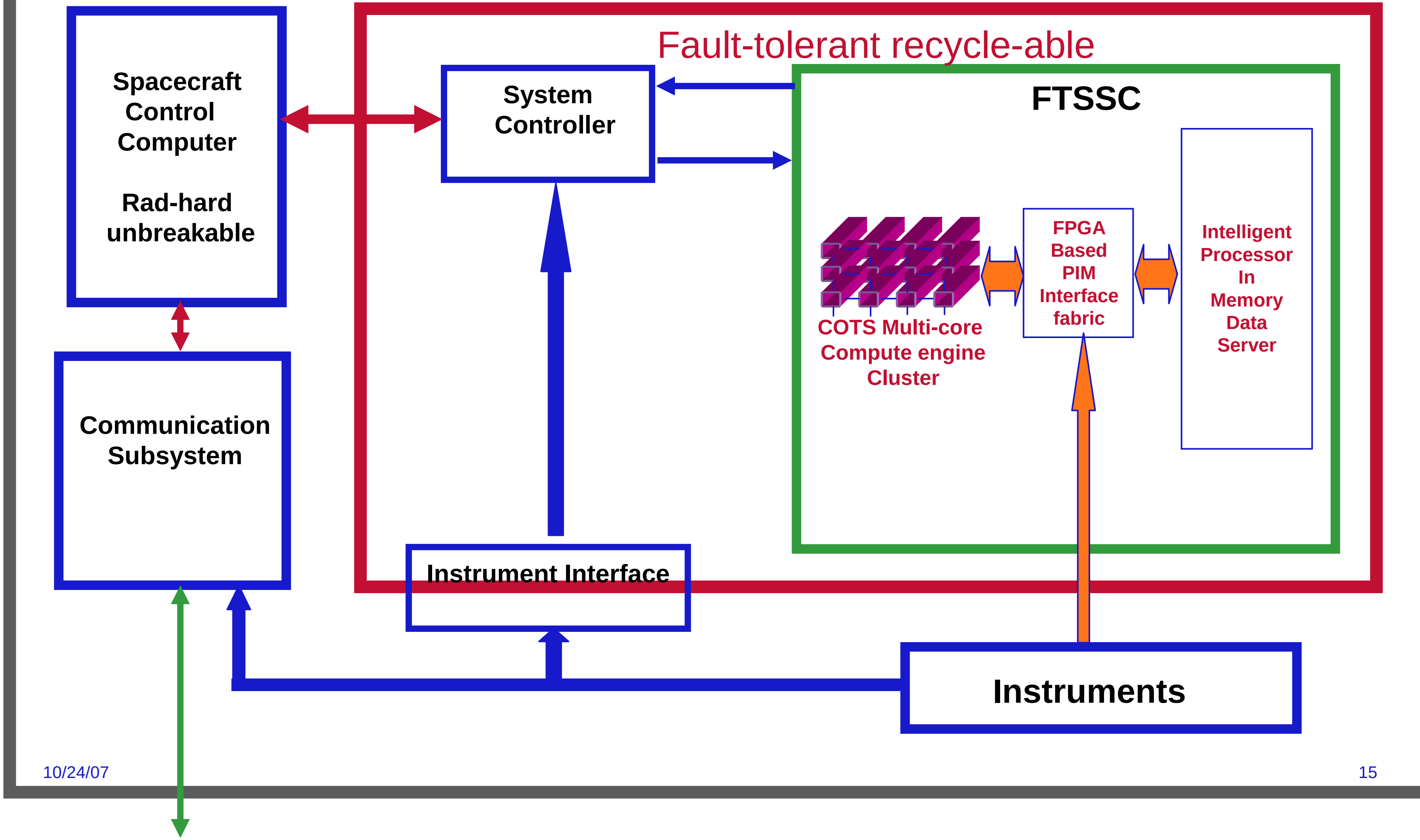
Fault Tolerant Space-Borne Scalable Computer (FTSSC)



Multi-Core Challenges for Space

General

- Programming and execution model
- Porting of legacy code
- Heterogeneous/homogeneous architectures
- Design tools, environments, libraries

Space critical

- Real-time
- Fault tolerance issues
- Testability / validation

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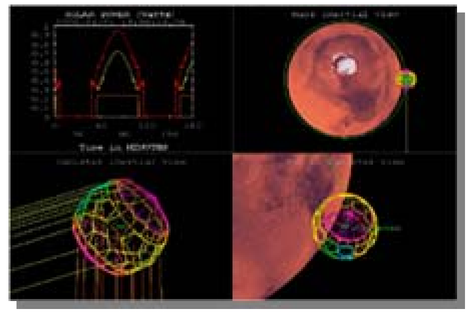
End-to-End Capabilities Needed to Implement Missions

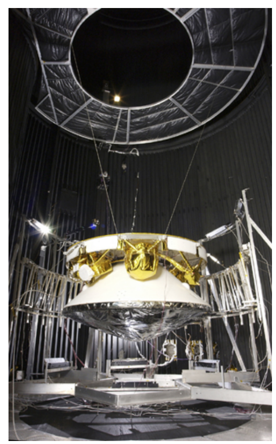
Project Formulation - Team X



Mission Design

Spacecraft Development

Integration and Test



Environmental Test

Real Time Operations

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Phoenix Mission Landing Simulation



- **NASA's 2007 Phoenix Mars Lander mission is sending a spacecraft to land in the northern polar region of Mars (launch: August 2007; land at Mars: late May 2008)**
  - **Will sample water ice and chemical content of the soil, and also measure local weather phenomena**
- **A key phase of Phoenix is the approximately six-minute traversal of the Martian atmosphere, descent on parachute, and rocket-powered landing on Mars.**
  - **This phase is commonly termed "Entry, Descent and Landing" (EDL).**
- **The Phoenix EDL team has made extensive use of the JPL advanced computing, beginning in January 2007.**
  - **Continued supercomputer usage planned through Phase E - until actual EDL**

Phoenix Mission Landing Simulation (cont'd)

- **Primary *advanced computing* usage performed sets of 2000-case Monte Carlo simulations of the Phoenix EDL event, for a range of atmospheric entry conditions**
  - **Varying location, speed and attitude at the top of the Martian atmosphere**
  - **Varying random noise effects, and injecting various error modes, in the accelerometers, gyroscopes, and radar**
  - **Varying atmospheric density, winds, terrain features of the landing site, landing thruster performance characteristics …**
- **Each individual trajectory simulation "case" takes ~ 3.5 node-hours to run (due to the high-fidelity radar model)**
- **Each 2000-case Monte Carlo batch produces ~ 25 Gbytes of raw output data (compressed) that are post-processed by the Phoenix EDL engineers**
- **This simulation campaign has logged > *1 Node-Decade* of run-time, and ~ *1 TB* of useful raw data for sensitivity analyses, statistical characterizations, and outlier analyses.**

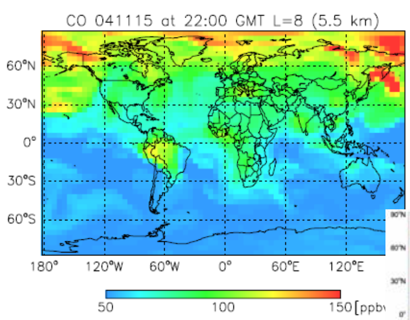
Observing Systems Simulation Experiments (OSSEs) For Instrument Design

Objective

- **Perform design trade and sensitivity studies to assess the impact of a remote sensing instrument on specific science goals.**

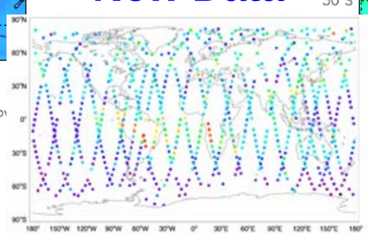
Challenges

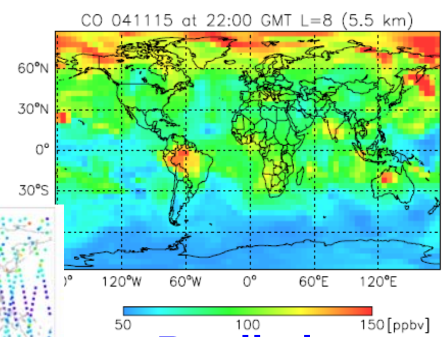
- **Building/establishing model interfaces**
- **Large-scale data assimilation**
- **High-productivity computing systems (distributed?)**
- **Validation of OSSE components**



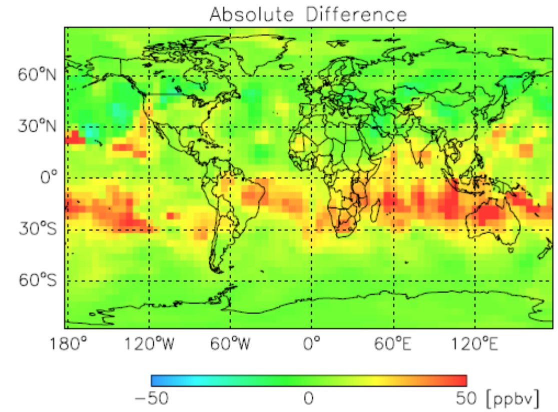
Prediction Without

New Data





Prediction With



Improvement

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Observing Systems Simulation Experiments (OSSEs) For Instrument Design (cont'd)

OSSE Framework

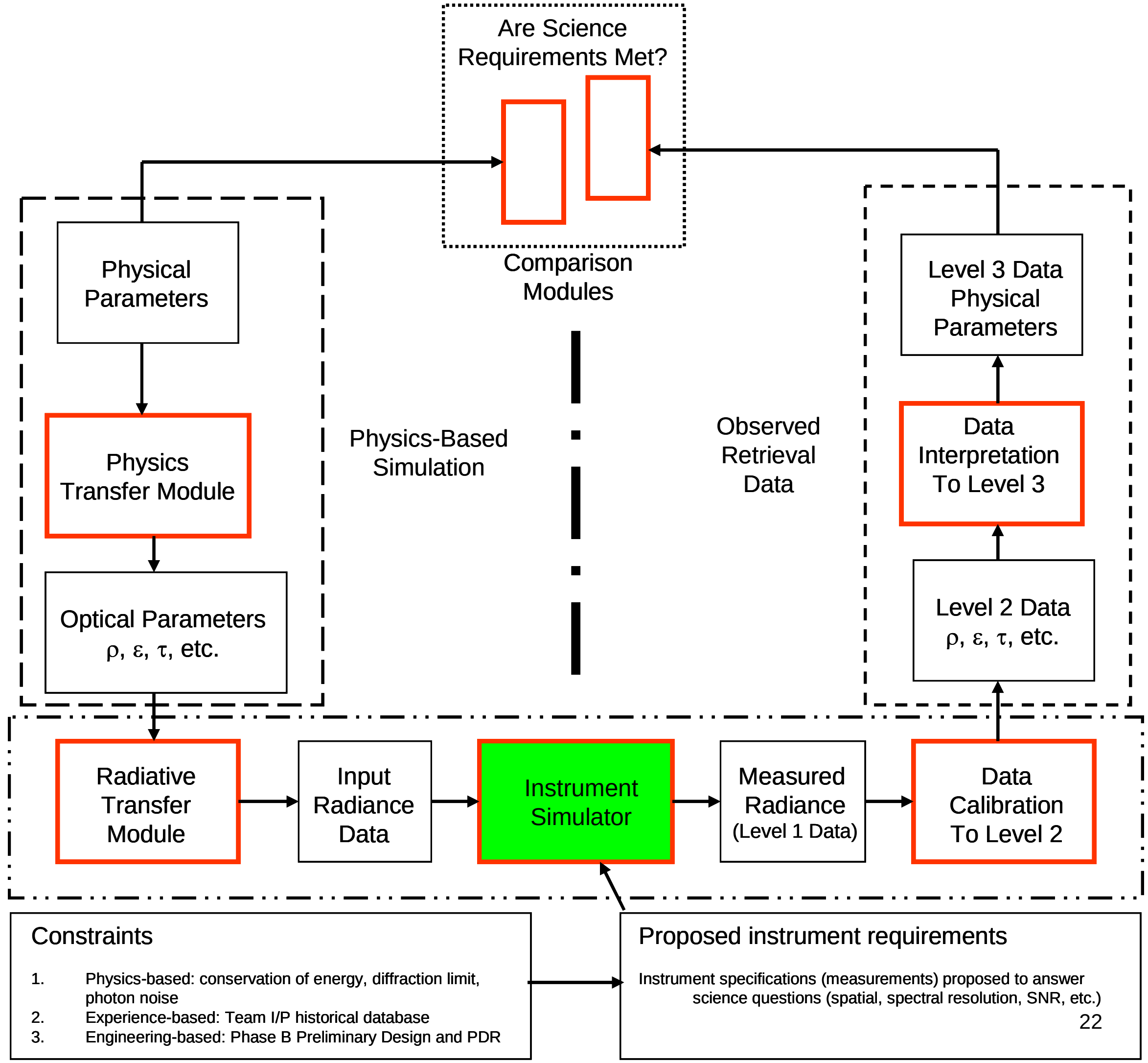
- **Models**
  - **Instrument**
  - **Forecast, retrieval, radiative transfer**
  - **Mission design**
- **Data Assimilation**
- **Integrated computational environment**

Integration of

- **Science goals**
- **Instrument development**
- **Mission design**

Assessment and sensitivity

- **Science goals to instrument and mission design**



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Spaceborne Computing Path

- Current Generation (Phoenix and Mars Science Lab -'09 Launch)
  - Single BAE Rad 750 Processor
  - 256MB of DRAM and 2 GB Flash Memory (MSL)
  - 266 MFLOPS peak, 14 Watts available power
  - 19 MFLOPS/Watt Performance
- NASA ST8 Honeywell Dependable Multiprocessor ('09 task end)
  - COTS Multi-board system with Rad Hard 603e controller
  - Fault-tolerant architecture
  - 6.4 GFLOPS peak/board & 31 Watts available power; overhead needed for FT
  - 220 MFLOPS/Watt Performance - but can scale total MFLOPS with power
  - Scalable to 20 COTS processing nodes
- Target
  - Radar Application, Large focal-plane array processing, autonomy …
  - > 1000 MFLOPS/Watt sustained performance
  - Can multi-core architectures improve power utilization?