Ground systems in support of space exploration for
Ground Systems Architectures Workshop
April 3, 2008

Charles Elachi, Director
NASA Jet Propulsion Laboratory
California Institute of Technology
Ground systems have supported space exploration for a half century

- 1958: Explorer 1 news conference at National Academy with William Pickering, James van Allen, and Werner von Braun
Where are we now? About 58 NASA robotic explorers, plus a number of international missions (some examples)

- Spitzer studying stars and galaxies in the infrared
- Ulysses studying the sun
- ESA Venus Express orbiting Venus
- ESA Rosetta to study comet in 2014
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- Two Voyagers on an interstellar mission
- Aqua studying Earth’s oceans
- Aura studying Earth’s atmosphere
- Rovers “Spirit” and “Opportunity” studying Mars
- CALIPSO studying Earth’s climate
- MESSENGER on its way to Mercury
- Chandra studying the x-ray universe
- Japanese SELENE studying Earth’s moon
- ESA Mars Express orbiting Mars
- New Horizons on its way to Pluto
- QuickScat, Jason 1, CloudSat, and GRACE (plus ASTER, MISR, AIRS, MLS and TES instruments) monitoring Earth.
Now: A continuous robotic presence on and in orbit around Mars

“Do not go where the path may lead, go instead where there is no path and leave a trail.” Emerson.

( Opportunity’s tracks in Meridiani Planum)
Mars Reconnaissance Orbiter zooms in on Opportunity at Victoria crater
Opportunity’s reconnaissance of the cliffs of Victoria Crater
Magellan Venus radar data processed to show topography beneath clouds
Galileo catches sulfur volcano erupting on Jupiter’s moon Io
Jupiter’s ring and its halo from Galileo
Looking down on Saturn from Cassini orbiter
(1 billion miles from Earth)
Backlit Saturn from Cassini orbiter

Earth
Visions of Saturn’s rings from Cassini orbiter
(Colors indicate particle sizes)
Celestial art:
Dione, rings and Saturn from Cassini orbiter
Saturn’s “spongy” moon Hyperion from Cassini orbiter
Saturn’s moon Phoebe from Cassini orbiter
Saturn’s moon Enceladus with “tiger stripe” cracks in ice
Cassini flew within 50 km of Enceladus on March 12
Saturn’s moon Titan from Cassini orbiter
Surface of Saturn’s moon Titan from Huygens lander
Methane lakes on Saturn’s moon Titan from Cassini orbiter radar (at –300°F)
Water ice jets on Saturn’s moon Enceladus from Cassini orbiter
(At –300°F)
Ground software processes data from the most distant part of the universe

- Hubble Space Telescope deep field image
Spitzer views the star-forming “Mountains of Creation”

GL4029
IRAC [3.6][4.5]
IRAC image
Lori Allen and the IRAC team
AFGL402
A dying star from Spitzer Space Telescope
New ways to see a changing Earth with robotic remote sensing

Atmospheric Infrared Sounder (AIRS) provides monthly global temperature maps

Jason provides global sea surface height maps every 10 days

Gravity Recovery and Climate Experiment (GRACE) provides monthly maps of Earth’s gravity

QuikSCAT provides near global (90%) ocean surface wind maps every 24 hours

Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps

Tropospheric Emission Spectrometer (TES) provides monthly global maps of Ozone

Microwave Limb Sounder (MLS) provides daily maps of stratospheric chemistry

CloudSat provides monthly maps of cloud ice water content
Shuttle Radar Topography Mission (SRTM) image of Los Angeles (2000)
Ground Systems contribute to mission success during all mission life-cycle phases.
Ground system implementation challenge for JPL missions

- **Multiple one-of-a-kind missions**... each with unique challenges

- **Common** tracking, command, telemetry and data management services

- **Flexible** multi-mission operations infrastructure—processes, procedures, teams and facilities

- **Adaptable** multi-mission software systems for mission-unique requirements

- **Distributed** ground system capabilities for science and engineering interoperability
Mars Exploration Rovers: An example of an operationally responsive ground system

- Execute
- Assess and analyze
- Generate data products
- Communicate and acquire
- Prepare command products
- Plan observations and measurements
- Sequence and simulate
- Integrate activity plan

Tactical Timeline reduced from 16 hours to 8 hours with ground system improvements

NASA “Software of the Year” Maestro enables remote scientists to actively participate in rover planning activities.
Mars Science Laboratory (MSL): Infusion example of ground system software technologies

**MSLICE (MSL Operations Interface)**
- Seamless integration of cutting edge visualization and planning tools for Mars surface missions.
- Allows scientists to rapidly search spacecraft data temporally and spatially.
- Automatically validates plans against flight rules and science constraints.
- Enables collaboration by geographically distributed users.

**Mission Data Processing System**
- Multi-mission, DISA-compliant downlink processing framework.
- Event-driven capabilities enabled by component architecture.
- Supports flight system integration and test through operations, starting with flight software test bed.
JPL’s ground system is the product of a multiple systems integration activity
JPL’s Systems and Software Integrated Management and Operability

Flight and ground systems and software engineering leadership

Systems engineering
Mission system concepts
Flight software systems
Integrated ground data systems
Planning and execution systems
System verification, validation and ops

Systems & Software Division

NASA/JPL Laboratory for Reliable Software

Software Quality Improvement
Model-Based Engineering
Systems Engineering Advancement
In the end, science application and utilization is what matters.

The Ground System science data processing systems provide both science communities and the public a window into space.
Future solar system exploration: Flagship Mission Studies

Europa Explorer

Titan Explorer

Jupiter System Observer

Water, organics, and prebiotic chemistry…
the evolution of habitable environments
Future Robotic Mars Exploration: From water, to habitability, to life, and better understanding of Mars’ history

Water

Habitability

Life

Mars’ History

Early Wet Mars

Cumulative Time Available for Biological Evolution

Late Dry Mars

4.5 Ga

Martian History

Present

MSR

AFL

Urey Instrument

Phoenix

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