The Technology Challenges of Space Science

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California Institute of Technology
From Caltech students testing rockets to exploring the planets

Caltech students (1936)
Missiles (1940s)
Explorer 1 (1958)
Mars Exploration Rovers (2004 – present)
Spitzer Space Telescope (2004 – present)
Earth Science (1978 – now)
JPL is part of NASA and Caltech

- Federally-funded (NASA-owned) Research and Development Center (FFRDC)
- University Operated (Caltech)
- $1.5B Business Base
- 5,000 Employees
- 177 Acres (includes 22 acres leased for parking)
- 139 Buildings; 36 Trailers
- 673,000 Net Square Feet of Office Space
- 906,000 Net Square Feet of Non-Office Space (e.g., Labs)
End-to-end capabilities needed to implement missions

Project Formulation - Team X
Scientific Research
Real Time Operations
Mission Design
Environmental Test
Integration and Test
Spacecraft Development

Mars Rovers
Large Structures - SRTM
Ion Engines

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Zmuidzinas - SEMWO 2012
24 Spacecraft and 10 Instruments
Across the Solar System and Beyond

- GALEX
- ACRIMSAT
- Mars Odyssey
- Cassini
- CloudSat
- Spitzer
- Kepler
- Juno
- Aquarius
- GRACE
- Two Voyagers
- Dawn
- Opportunity
- EPOXI-Deep Impact
- GRAIL
- Mars Science Laboratory
- Wide-field Infrared Survey Explorer (WISE)
- Mars Reconnaissance Orbiter
- Jason 1 and Jason 2
- Nuclear Spectroscopic Telescope Array (NuSTAR)
Multiple ways to look at a changing Earth
JPL’s mission for NASA is *robotic* space exploration

- Mars
- Solar system
- Exoplanets
- Astrophysics
- Earth Science
- Interplanetary network
Invention of the CMOS Imager

Willard Boyle & George Smith Invent CCD at Bell Labs in 1969 Win Nobel Prize in Physics, 2009

Early 1970s: James Janesick starts JPL CCD effort
1990-93: HST launched; CCDs used in JPL’s WF/PC and WF/PC 2
JPL’s Jim Janesick writes “the book” on scientific CCDs

1989: Eric Fossum visits JPL as DVS
1990-92: joins JPL, invents CMOS APS

1995: Photobit (spinoff), Micron Technology, Aptina…
2011 (May); Fossum inducted into National Inventor’s Hall of Fame
Mariner 4's famous picture Number 11, revealed large impact craters and other topographical features of Mars, July 1965
Deep space exploration enabled by NASA’s Deep Space Network (DSN)
Right: Block I S-band maser receiver of the type user for Mariner 4, with closed-cycle JT refrigerator, circa 1965.
Mariner 4 Occultation Experiment

Occultation Experiment: Results of the First Direct Measurement of Mars’s Atmosphere and Ionosphere

<table>
<thead>
<tr>
<th>Atmosphere</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface refractivity</td>
<td>$3.6 \pm 0.2 \ N$ units</td>
</tr>
<tr>
<td>Scale height</td>
<td>8 to 10 km</td>
</tr>
<tr>
<td>Surface number density</td>
<td>1.9 $\pm 0.1 \times 10^{17}$ mol/cm$^3$</td>
</tr>
<tr>
<td>Up to 20% A or N$_2$, or a mixture</td>
<td>2.1 $\pm 0.2 \times 10^{17}$ mol/cm$^3$</td>
</tr>
<tr>
<td>50% A</td>
<td>2.5 $\pm 0.15 \times 10^{17}$ mol/cm$^3$</td>
</tr>
<tr>
<td>Surface mass density</td>
<td>1.43 $\pm 0.1 \times 10^{-2}$ g/cm$^3$</td>
</tr>
<tr>
<td>Up to 20% A or N$_2$, or a mixture</td>
<td>1.5 $\pm 0.15 \times 10^{-2}$ g/cm$^3$</td>
</tr>
<tr>
<td>50% A</td>
<td>1.75 $\pm 0.10 \times 10^{-2}$ g/cm$^3$</td>
</tr>
<tr>
<td>Temperature</td>
<td>$180 \pm 20^\circ$ K</td>
</tr>
<tr>
<td>Up to 20% A or N$_2$, or a mixture</td>
<td>$175 \pm 25^\circ$ K</td>
</tr>
<tr>
<td>50% A</td>
<td>$170 \pm 20^\circ$ K</td>
</tr>
</tbody>
</table>

Surface pressure

| 100% CO$_2$                         | 4.1 to 5.7 mb                        |
| Up to 20% A or N$_2$, or a mixture   | 4.1 to 6.2 mb                        |
| 50% A                               | 5.0 to 7.0 mb                        |

~0.5% of Earth

Ionosphere

| Maximum electron density ($\chi = 70^\circ$) | $9 \pm 1.0 \times 10^4$ el/cm$^3$ |
| Altitude of maximum                    | 120 to 125 km                     |
| Electron scale height above maximum    | 20 to 25 km                       |
| Temperature                            | $< 200^\circ$ K at 120 to 200 km   |

Switched off. This signal component can be seen at 2900 cy/sec. After the one-way signal disappeared, the two-way signal was recorded at an audio frequency of 1900 cy/sec. The phase modulation sidebands at $\pm 150 \text{cy/sec}$ can be seen on both signals.

It should again be pointed out that these numbers are the results of less than 1 month’s analysis with relatively crude techniques. As the analysis proceeds, the results will be refined, taking into account additional data as well as...
The 1st Spacecraft to Orbit Mars
Mariner 9 - 1971

Arthur C. Clarke, Ray Bradbury, Walter Sullivan, Carl Sagan and Bruce Murray
On Stage at Beckman Auditorium
JPL Memorialized on MARS

J .---
P .--.
L .--.

Morse Code

CURiosity
Curiosity’s Science Payload
The conglomerate “Link” with associated loose, rounded pebbles
A scoop full of Mars sand
Probing Mars’ Atmosphere
TLS: Tunable Laser Spectrometer
C. Webster, TLS PI

- **1980s**
  - Liquid helium-cooled lasers

- **1990s**
  - Liquid nitrogen-cooled lasers

- **2000s**
  - Thermoelectrically cooled lasers

**Atmospheric Gases**
- O$_2$
- HCl
- CO$_2$
- H$_2$O
- CH$_4$
- NH$_3$
- NO$_2$
- HNO$_3$
- O$_3$
- ClO

**Planetary Gases**
- CO$_2$
- H$_2$O
- CO
- CH$_4$
- HCN
- C$_2$H$_2$
- DCN

**Types of Lasers**
- InP/InGaAsP
- GaSb/InGaAsSb
- GaAs/AlGaAs

**Wavelength (µm)**
- 20
High-temperature and low-threshold midinfrared interband cascade lasers

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