Jet Propulsion Laboratory
California Institute of Technology

The Technology Challenges of Space Science

Jonas Zmuidzinas,Chief Technologist
Jet Propulsion Laboratory
California Institute of Technology

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August 2011

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From Caltech students testing rockets to exploring the planets

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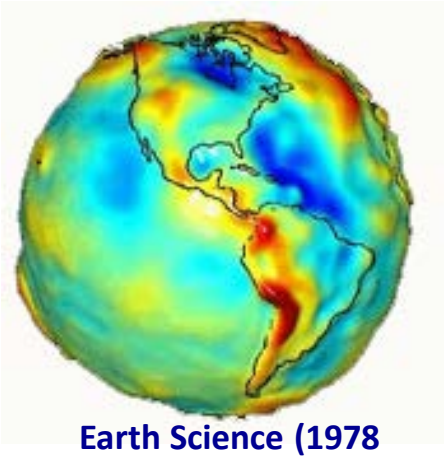
Caltech students (1936)

Missiles (1940s)

Explorer 1 (1958)

Mars Exploration Rovers (2004 – present)

Spitzer Space Telescope (2004 – present)

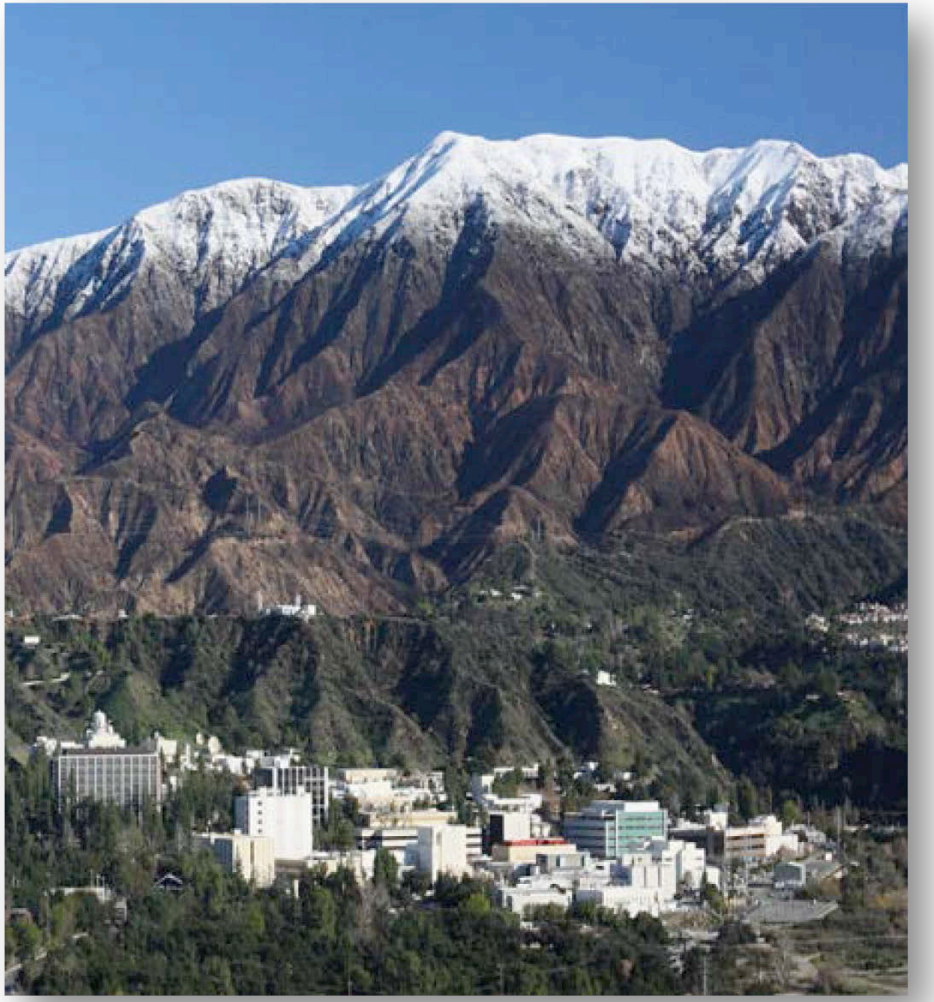


Earth Science (1978 – now)

JPL is part of NASA and Caltech

Jet Propulsion Laboratory
California Institute of Technology

- **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)**



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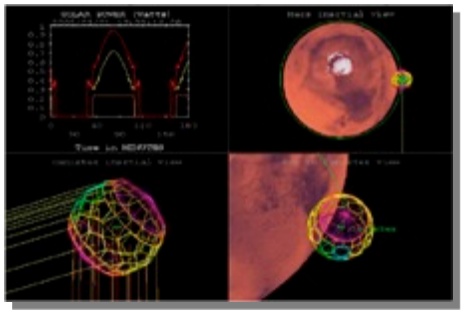
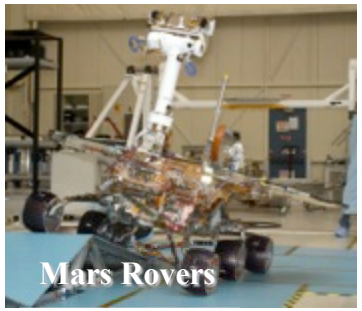
Pasadena, California

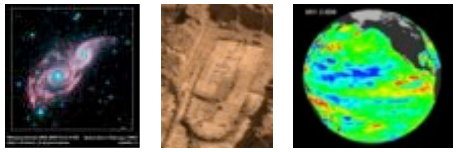
End-to-end capabilities needed to implement missions

Project Formulation - Team X

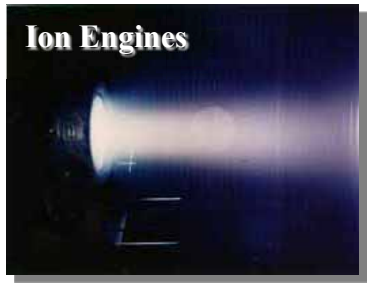


Mission Design

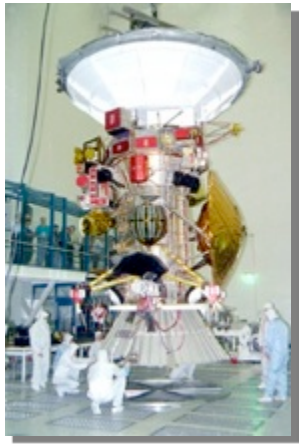




Scientific Research



Spacecraft Development



Integration and Test

Environmental Test

Real Time Operations

24 Spacecraft and 10 Instruments Across the Solar System and Beyond

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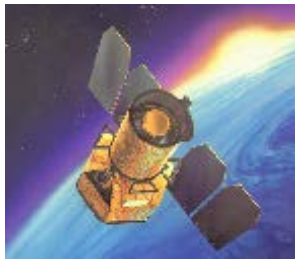
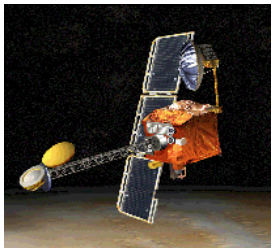
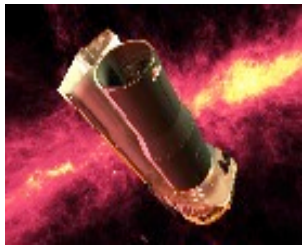

GALEX

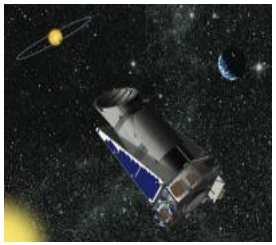
ACRIMSAT

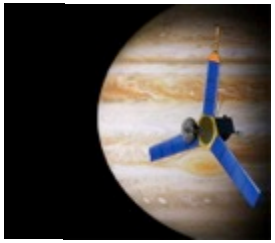

Mars Odyssey

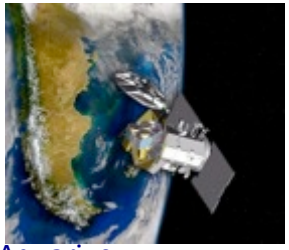
Cassini

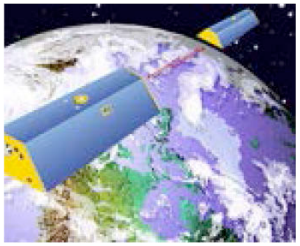
CloudSat

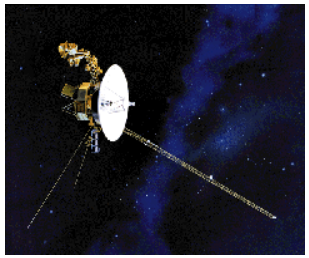

Spitzer


Kepler

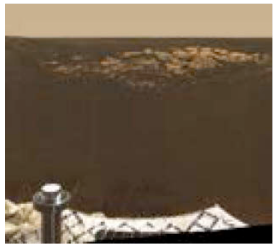

Juno

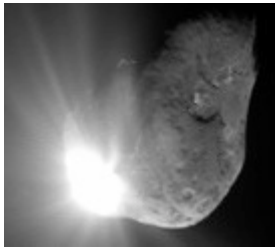

Aquarius

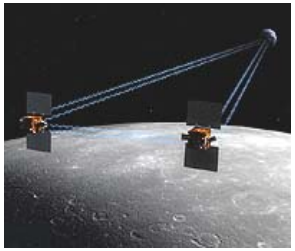

GRACE


Two Voyagers

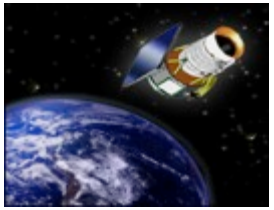
Dawn


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)

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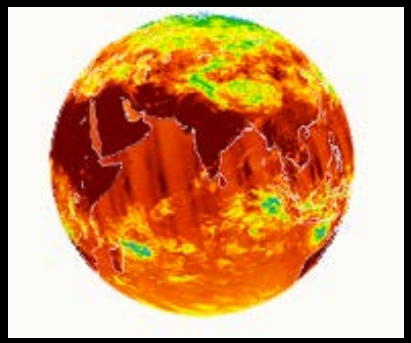
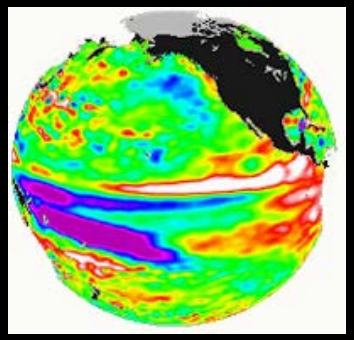
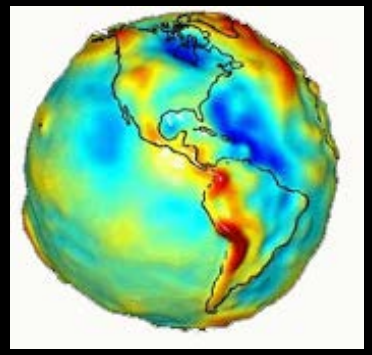


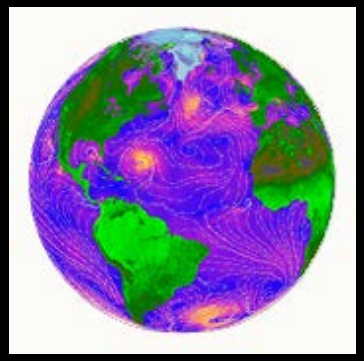
AIRS – atmospheric temperature



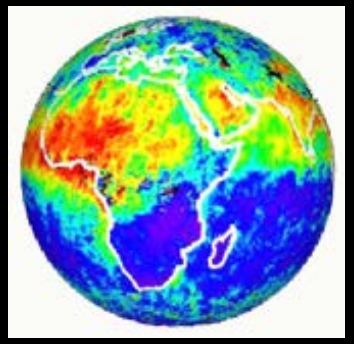
JASON – sea surface height



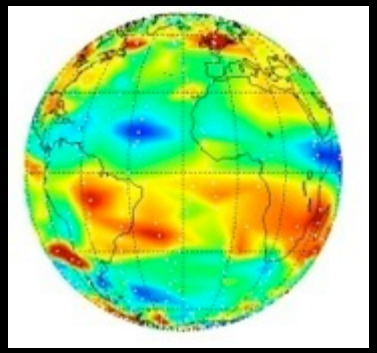
GRACE – gravity



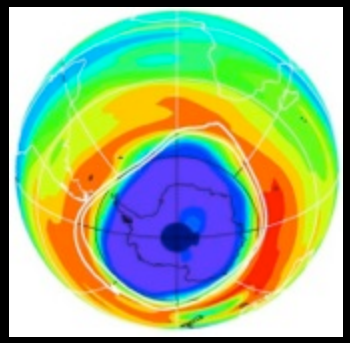
QUIKSCAT – wind



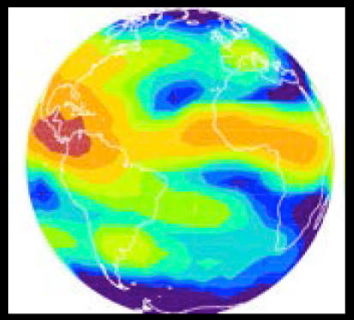
MISR - aerosols



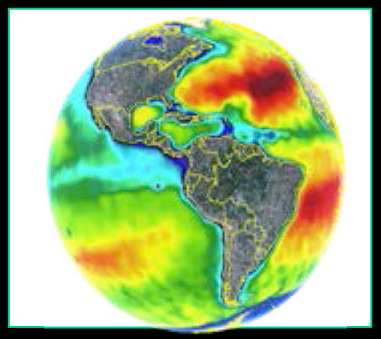
TES – trace gas



MLS – ozone layer



CLOUDSAT – water content



Aquarius - sea surface salinity

Multiple ways to look at a changing Earth

JPL's mission for NASA is *robotic* space exploration

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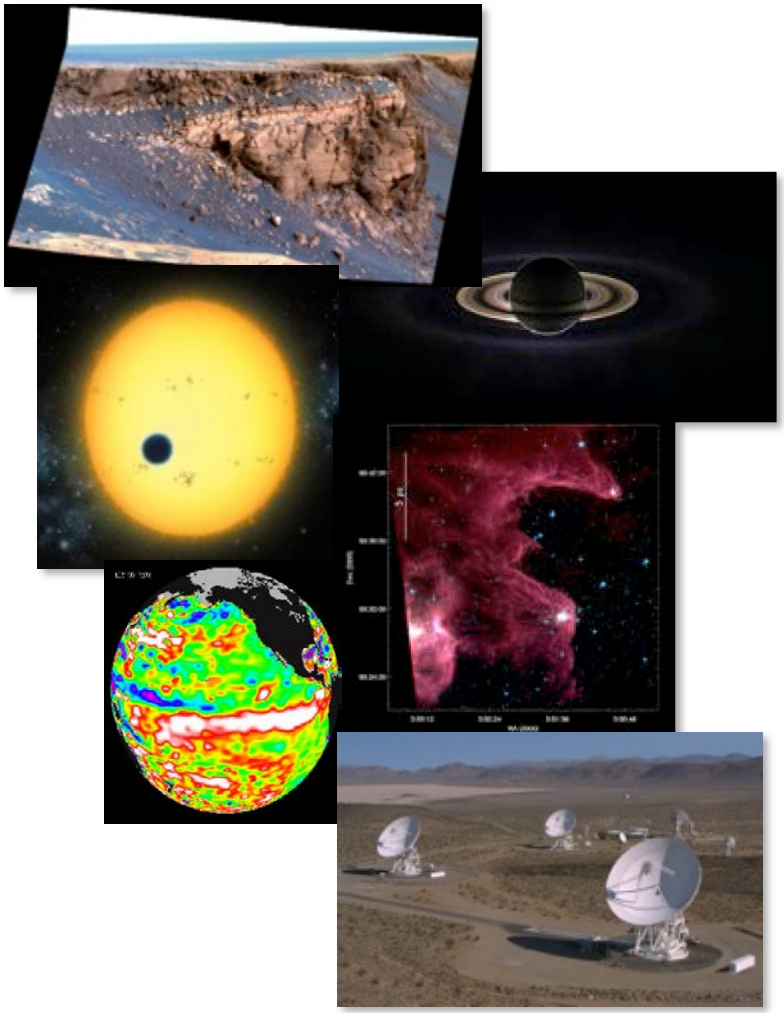
- **Mars**
- **Solar system**
- **Exoplanets**
- **Astrophysics**
- **Earth Science**
- **Interplanetary network**



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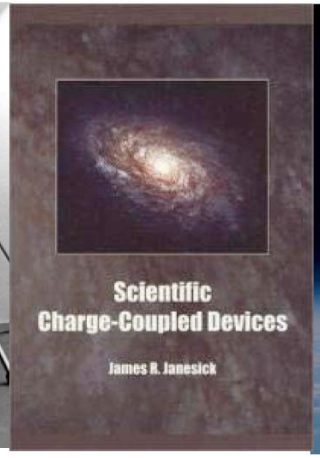
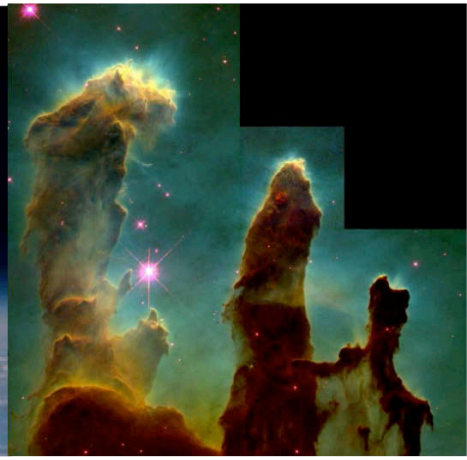
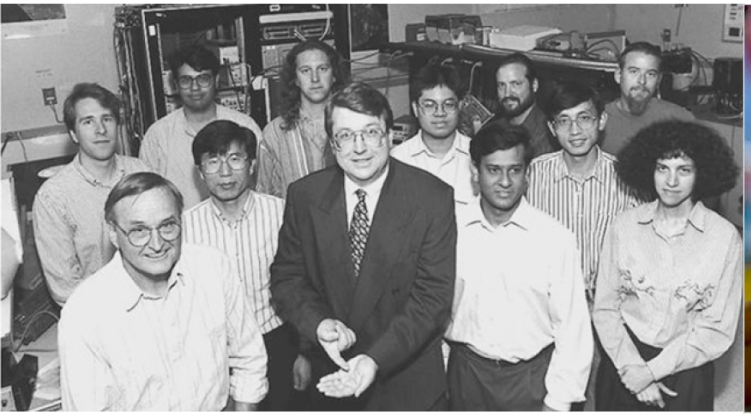
Invention of the CMOS Imager

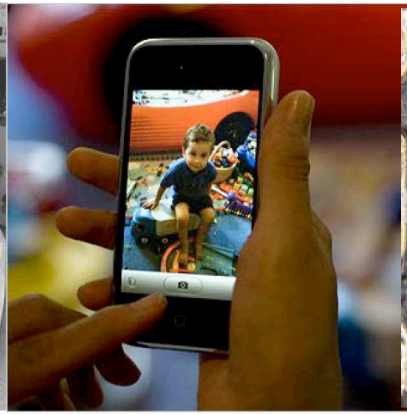


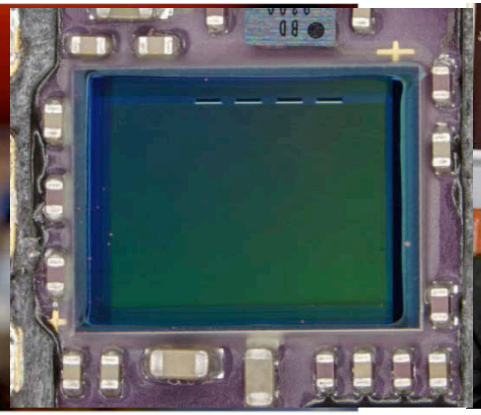


Willard Boyle & George Smith
Invent CCD at Bell Labs in 1969
Win Nobel Prize in Physics, 2009

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

The First Flyby of Mars
Mariner 4, 1965

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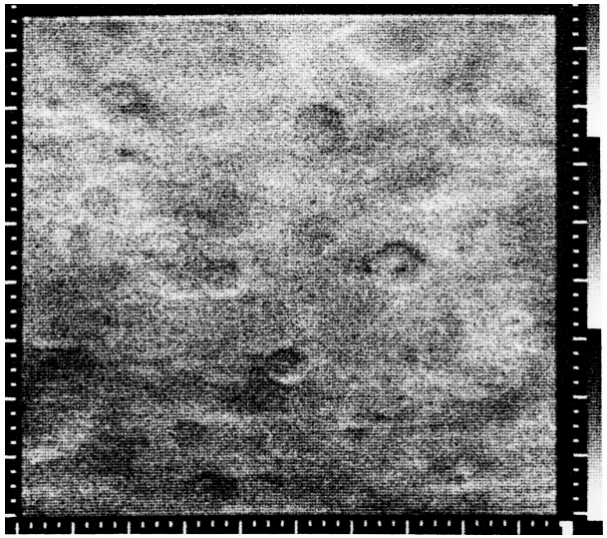

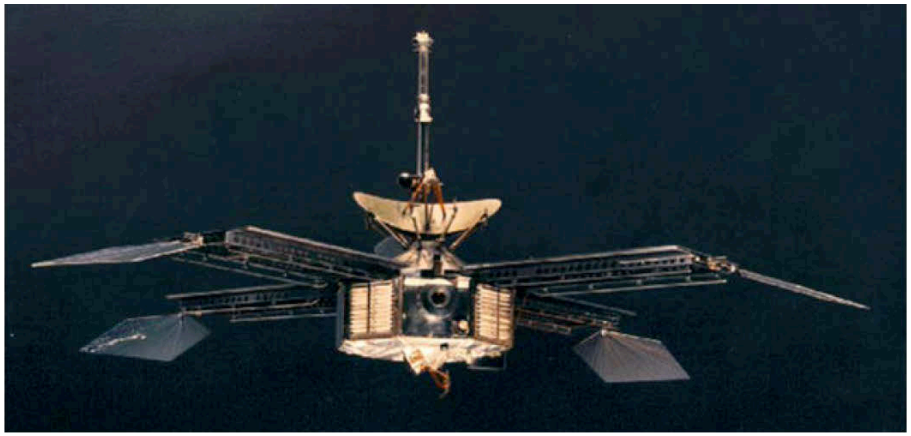

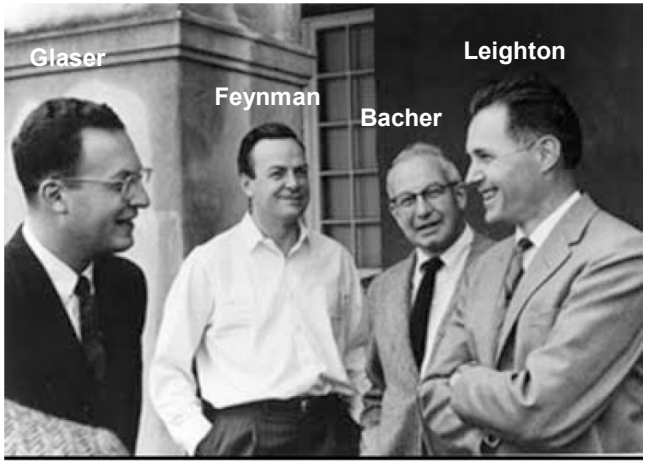

Mariner 4's famous picture Number 11, revealed large impact craters and other topographical features of Mars, July 1965

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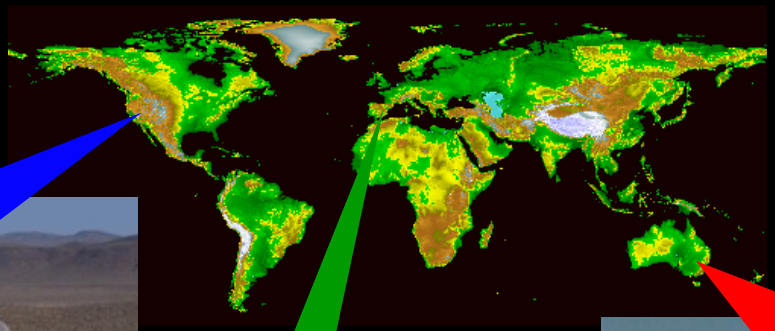
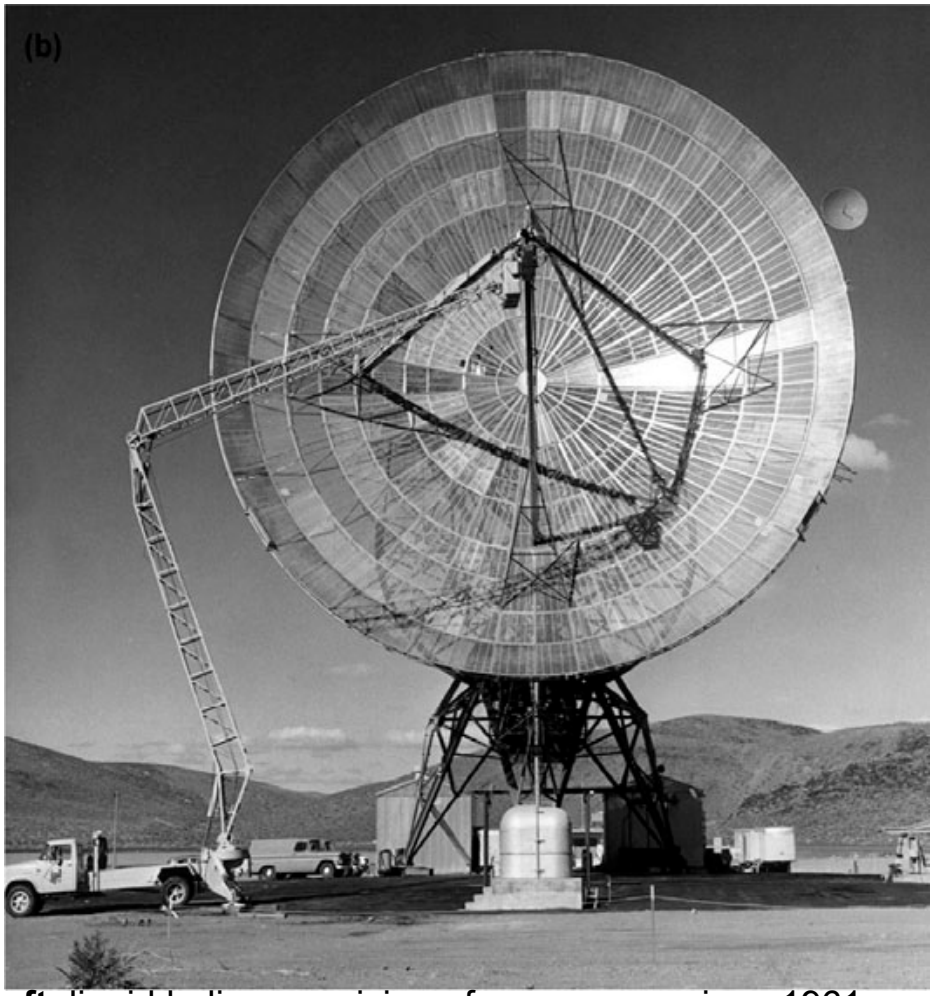
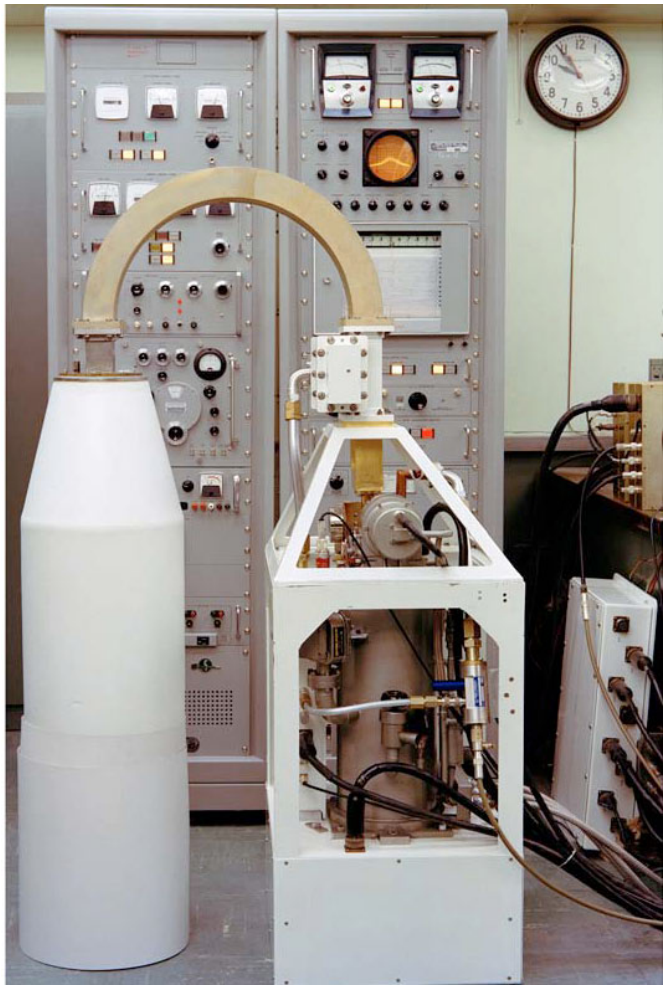
Deep space exploration enabled by NASA's Deep Space Network (DSN)



Madrid

DSN: The early years





Left: liquid helium servicing of a maser receiver, 1961.
Right: Block I S-band maser receiver of the type user for Mariner 4, with closed-cycle JT refrigerator, circa 1965.

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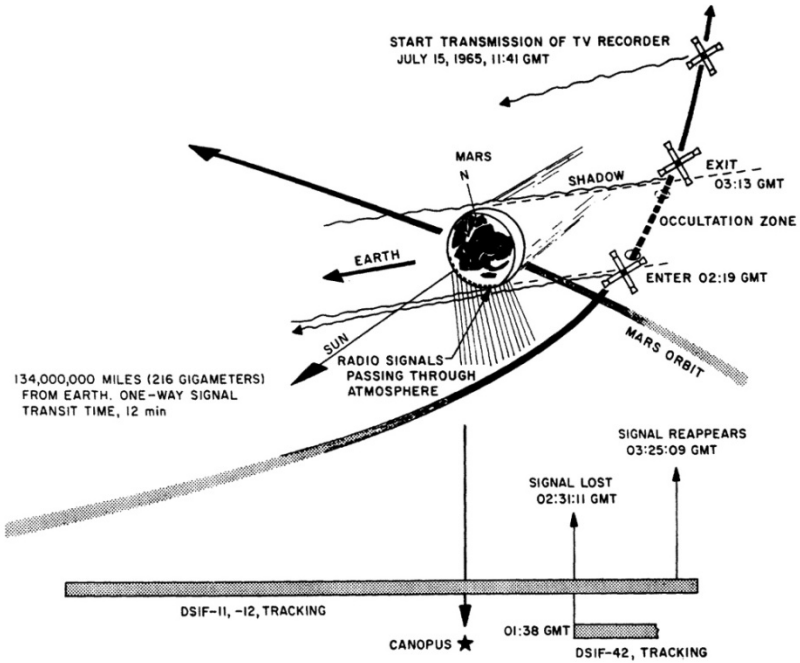
Mariner 4 Occultation Experiment



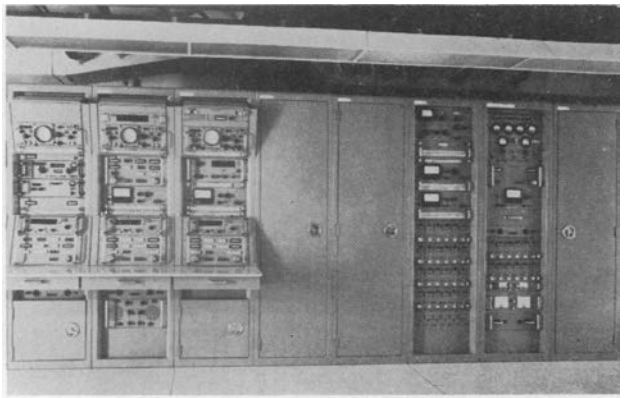


Fig. 4. DSIF phase-lock-loop receiver system.

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

Table 1. Summary of occultation experiment.

Atmosphere	
Surface refractivity	$3.6 \pm 0.2\ N$ units
Scale height	8 to 10 km
Surface number density	
100% CO_2	$1.9 \pm 0.1 \times 10^{17}$ mol/cm³
Up to 20% A or N_2, or a mixture	$2.1 \pm 0.2 \times 10^{17}$ mol/cm³
50% A	$2.5 \pm 0.15 \times 10^{17}$ mol/cm³
Surface mass density	
100% CO_2	$1.43 \pm 0.1 \times 10^{-5}$ g/cm³
Up to 20% A or N_2, or a mixture	$1.5 \pm 0.15 \times 10^{-5}$ g/cm³
50% A	$1.75 \pm 0.10 \times 10^{-5}$ g/cm³
Temperature	
100% CO_2	180 ± 20°K
Up to 20% A or N_2, or a mixture	175 ± 25°K
50% A	170 ± 20°K
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
Ionosphere	
Maximum electron density ($\chi = 70°$)	$9 \pm 1.0 \times 10^4$ el/cm³
Altitude of maximum	120 to 125 km
Electron scale height above maximum	20 to 25 km
Temperature	<200°K at 120 to 200 km

~0.5% of Earth

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 ± 150 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

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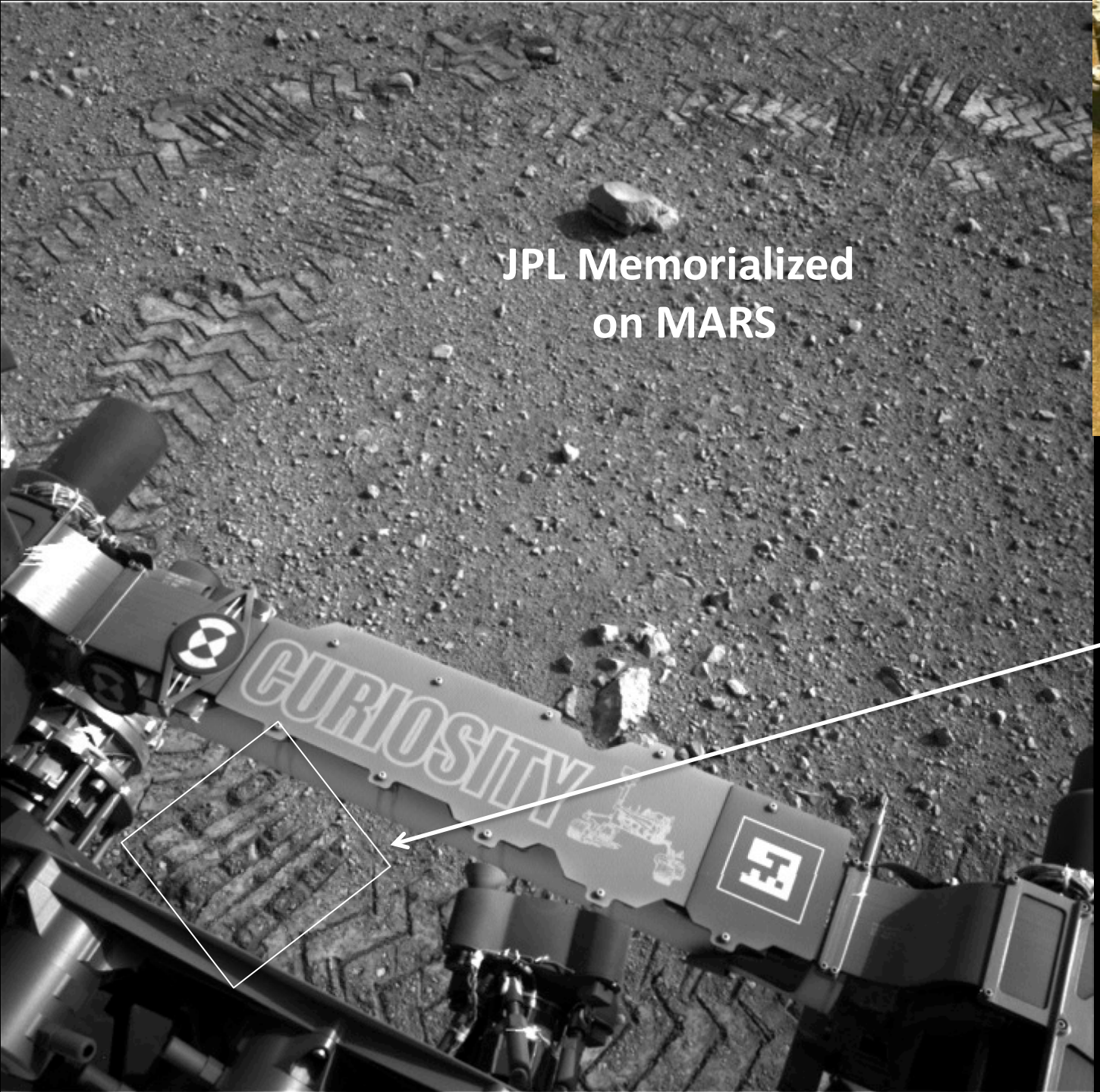
The 1st Spacecraft to Orbit Mars
Mariner 9 - 1971

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

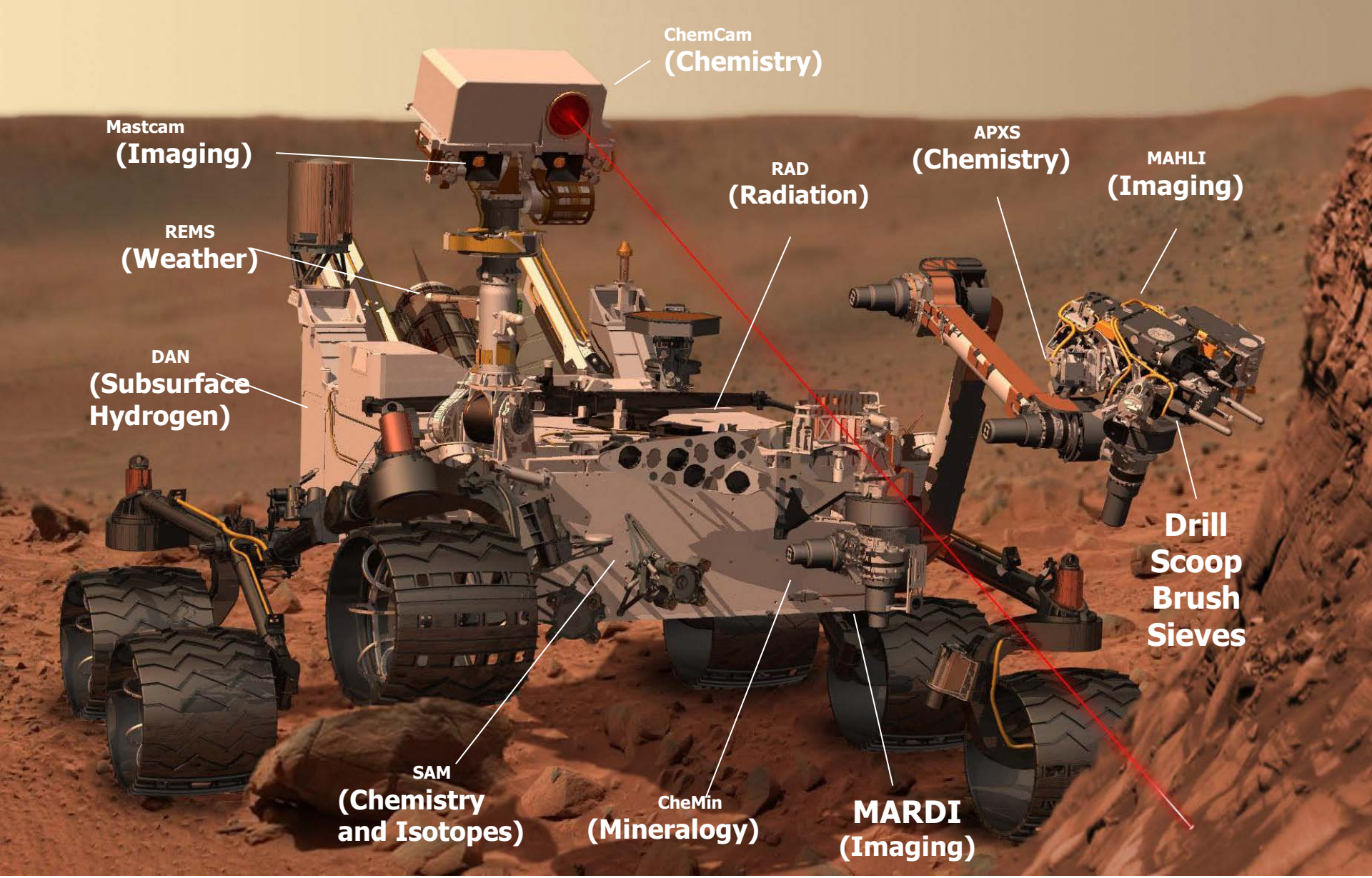


J .---

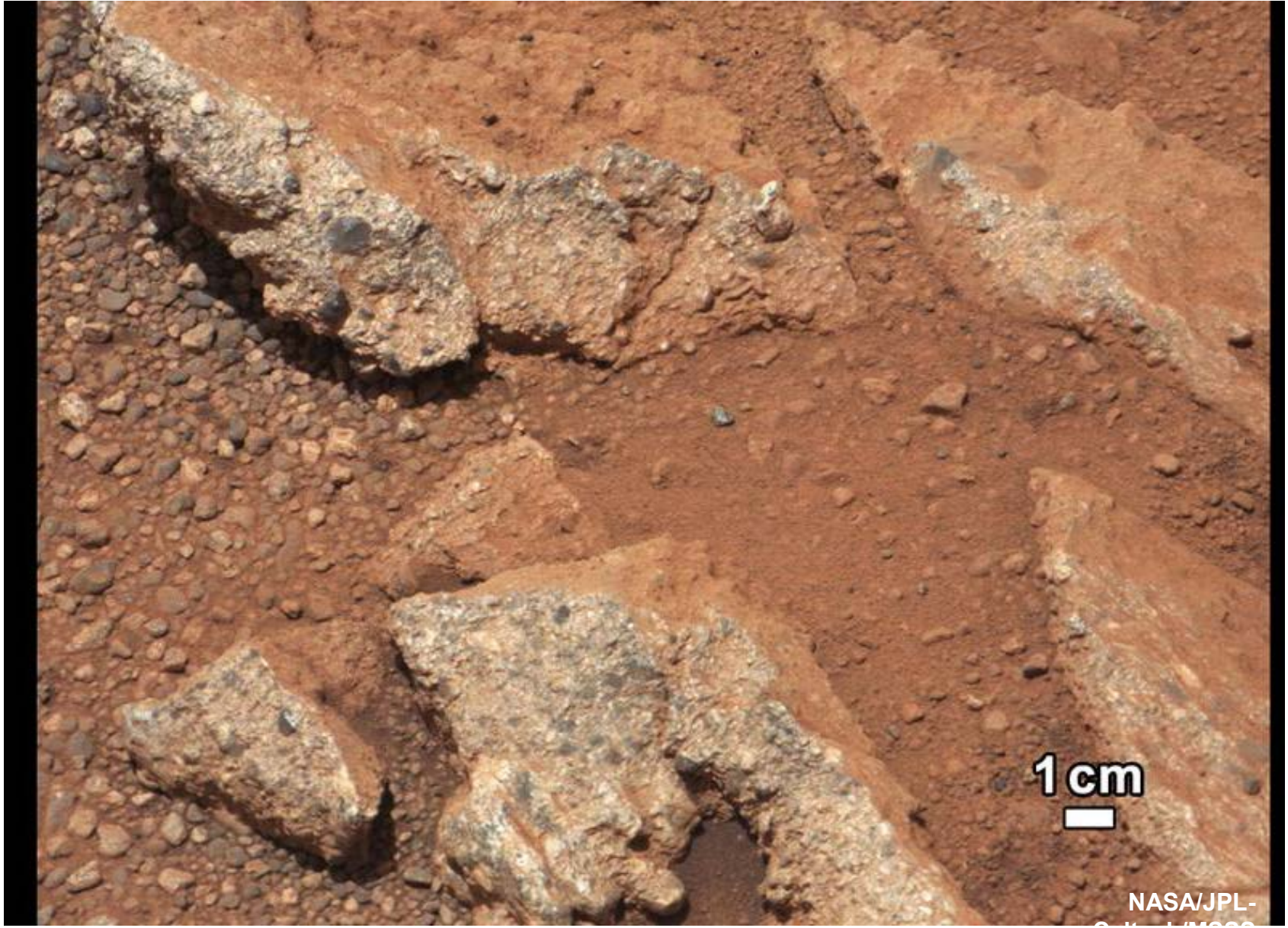
P .--.

L .-..

Morse Code

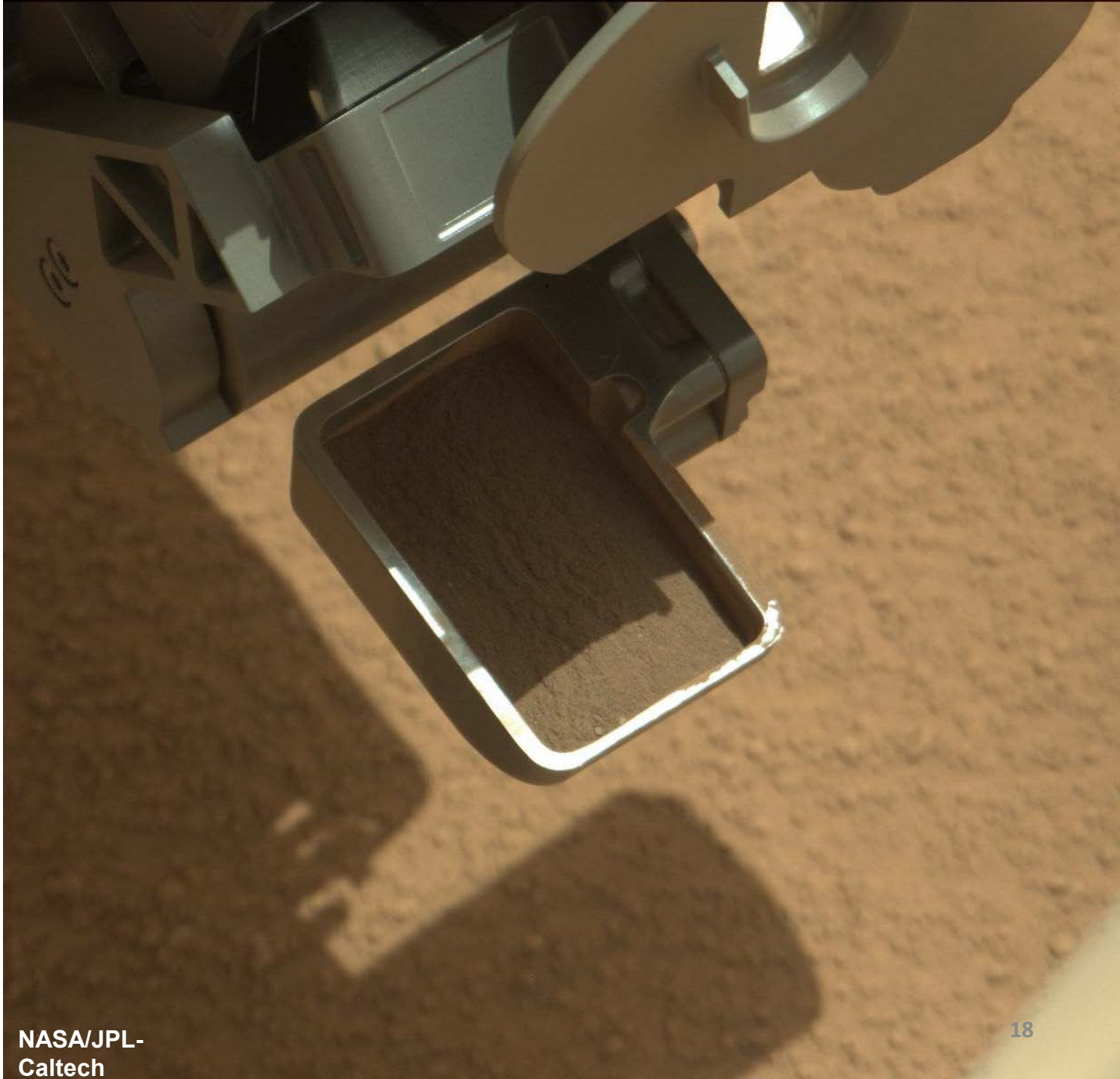


Curiosity's Science Payload



The conglomerate “Link” with associated loose, rounded pebbles

A scoop full of Mars sand



NASA/JPL-Caltech

EXOGENOUS SOURCE ?
cometary impact or meteoritic infall

UV

ATMOSPHERE

CH_4 Loss

60km

20km

oxidation and surface sinks

UV

HOTSPOT

VOLCANIC

UV interactions with near surface organics ?

Diffusion

PERMAFROST

Methane storage

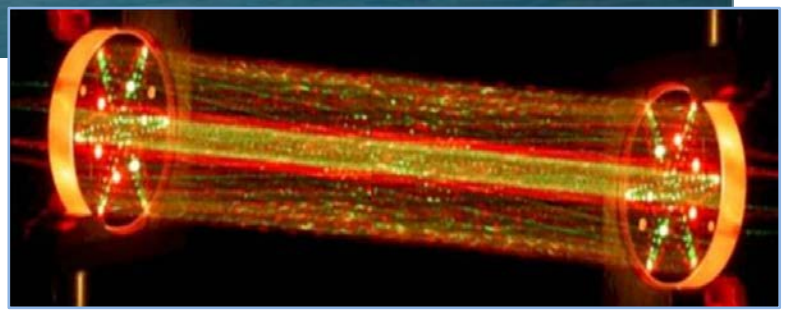
WATER

water/rock interactions ?

Methane Production

microbes ?

NASA/JPL-Caltech,



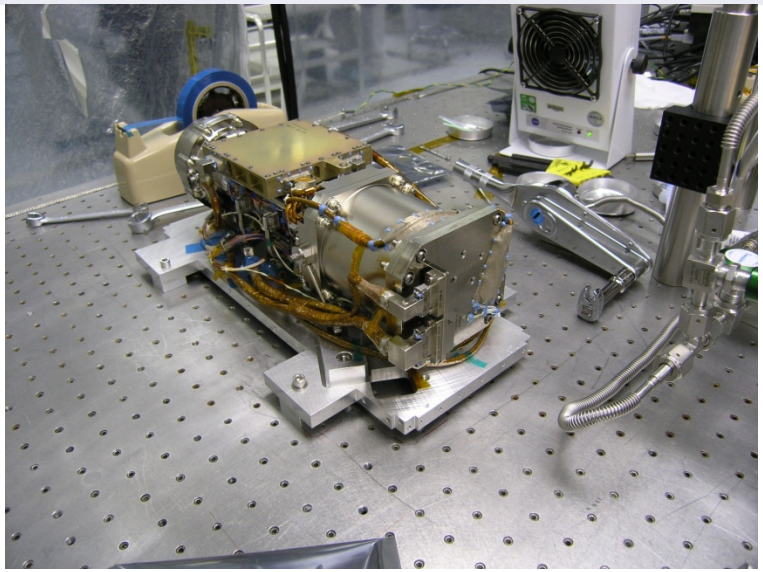
Probing Mars' Atmosphere

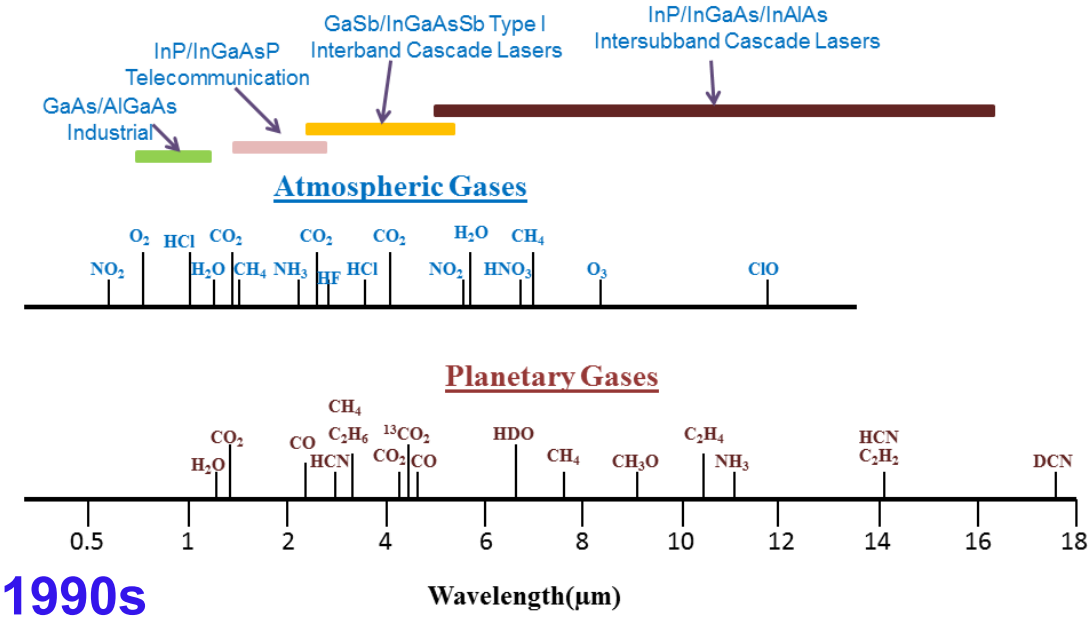
National Aeronautics and
Space Administration

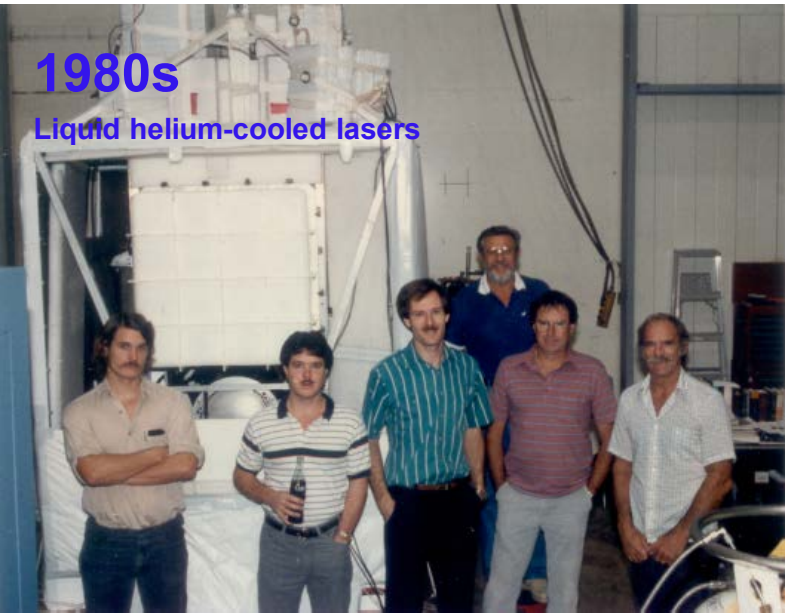
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

TLS: Tunable Laser Spectrometer

C. Webster, TLS PI







1980s

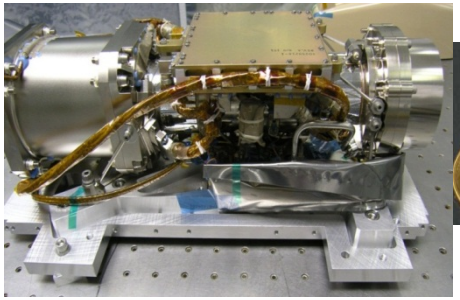
Liquid helium-cooled lasers

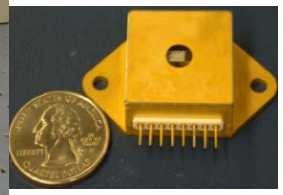
1990s

Liquid nitrogen-cooled lasers

2000s

Thermoelectrically cooled lasers





National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

TLS: Interband Cascade Laser for Methane Detection

APPLIED PHYSICS LETTERS **87**, 151109 (2005)

High-temperature and low-threshold midinfrared interband cascade lasers

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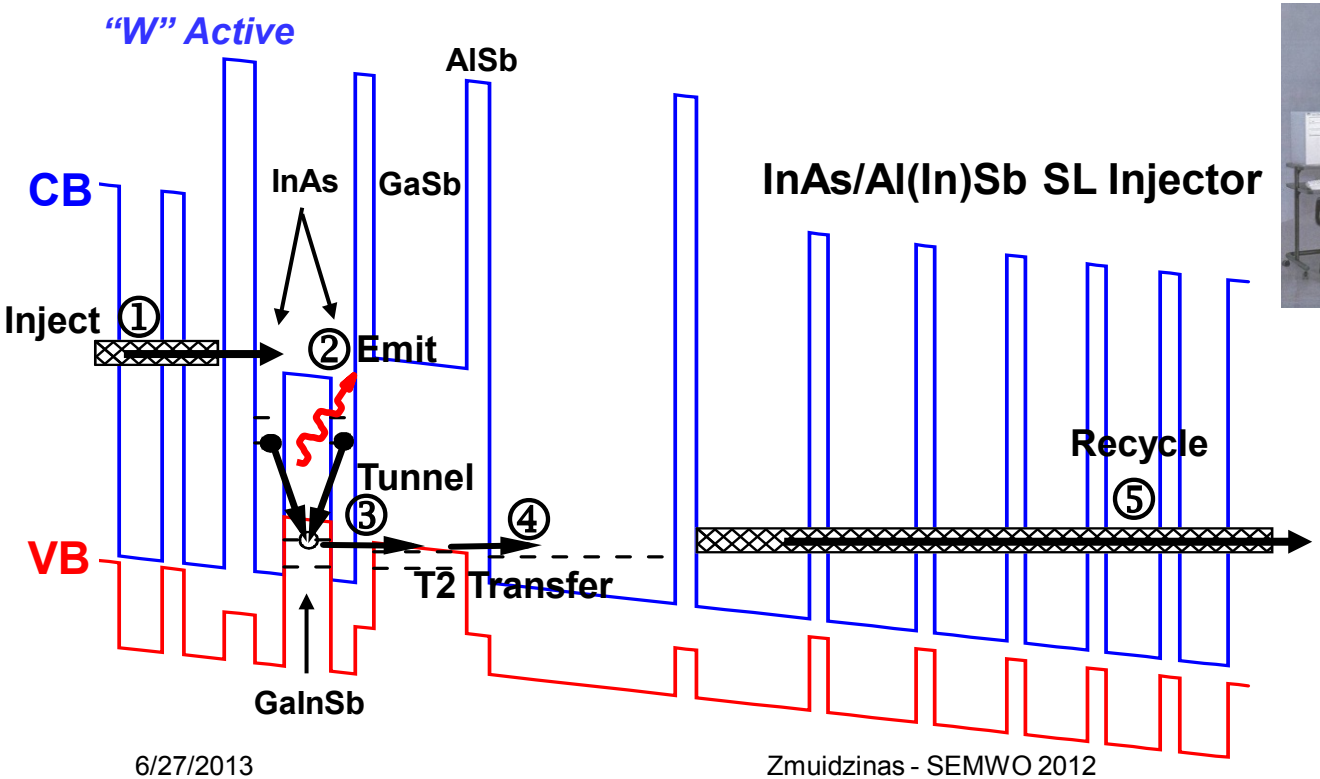

Molecular Beam Epitaxy

Electron Beam Lithography