Future ground systems for scientific spacecraft

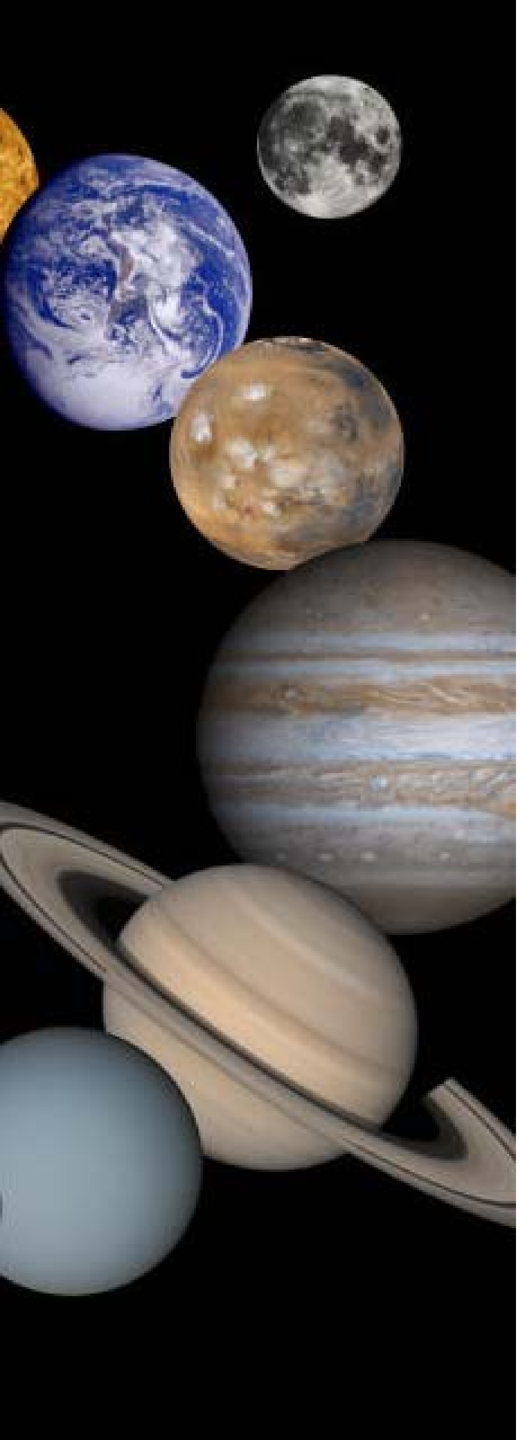
for

Ground System Architectures Workshop (GSAW2003)
Manhattan Beach, California
March 4, 2003

Gen. Eugene Tattini
Deputy Director, Jet Propulsion Laboratory
California Institute of Technology

Agenda

- Ground systems; current situation
- JPL overview
- Future vision



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Solar system distance scales

- To reach Voyager 1 at 12.5 billion km, it would take:
  - Lewis & Clark: 3.8 million years
  - JPL Director's 260Z: 14 thousand years
  - Chuck Yeager's X-1: 1500 years
  - John Glenn in the ISS: 54 years
- For Columbus to have reached Mars by today, he should have left Spain when it was populated by Neanderthals (60,000 years ago).
- Alternatively, if Earth were the size of a golf ball (and humans were the size of large protein molecules), distances to other objects would be:
  - Sun: 1600 feet (and 16 feet in diameter)
  - Mars from Sun: 2600 feet
  - Jupiter: 1.6 miles
  - Neptune: 10 miles
  - Voyager 1: 26 miles

Ground System Comparisons:
Factors Affecting Complexity

Some Factors Affecting GS Complexity	Example Systems				
	Commercial	DOD	NOAA	NASA Earth Orbiters	NASA Deep Space
Mission Customers	Mission Families	Mission Families	Mission Families	One-of-a-Kind Missions	One-of-a-Kind Missions
End-Data Access	Proprietary	Secure	Public	Public	Public
Cooperative Use of Ground Assets	Inter-Business	Inter-Service; Inter-Agency	Inter-Agency	Inter-Agency; International	Inter-Agency; International
Typical Link Distance	<40,000 km	<40,000 km	<40,000 km	<2,000,000 km	>>2,000,000 km
Typical S/C Contact Frequency	Cyclic or Continuous	Cyclic or Continuous	Cyclic or Continuous	Cyclic or Continuous	Variable
Two-Way Light Time Between S/C & GND	Nearly Instantaneous	Nearly Instantaneous	Nearly Instantaneous	Nearly Instantaneous	Seconds to Hours
Data Rates	<1 Gbps	< 1Gbps	< 1Gbps	< 1Gbps	< 10 Mbps
Tracking / Nav	Ranging, Doppler, GPS	Ranging, Doppler, GPS	Ranging, Doppler, GPS	Ranging, Doppler, GPS	Ranging,Doppler VLBI, Optical

Ground System Comparisons:

Some Cost Perspectives

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Location	Near Earth			Deep Space	
Mission	ALEXIS	Clementine**	SAMPEX	CASSINI	Mars Odyssey
Agency	DOE	BMDO	NASA	NASA	NASA
Non-recurrent GS costs as a % of total mission dev. cost*	~2%	~2%	~10%	~5%	~3%
Total MO&DA costs as a % of total mission cost*	~10%	~13%***	~15%	~26%	~25%

*Near-Earth mission numbers derived from James R. Wertz and Wiley J. Larson, eds., *Reducing Space Mission Cost* (Torrance, California: Microcosm Press and Kluwer Academic Publishers, 1996), pp. 198-199, and 439.
**Clementine received TT&C support from NASA's Deep Space Network.
*** MO&DA percentage corresponds to planned cost – mission cut short by on-orbit software glitch.

- Despite the challenges confronting these deep space missions, their non-recurrent ground system costs, as a % of their total mission development costs, are similar to that of the near-Earth missions.
- Deep space MO&DA costs as a % of total mission cost, however, tend to run higher than their near-Earth counterparts – due in large part to the increased complexity and longer duration of the missions.

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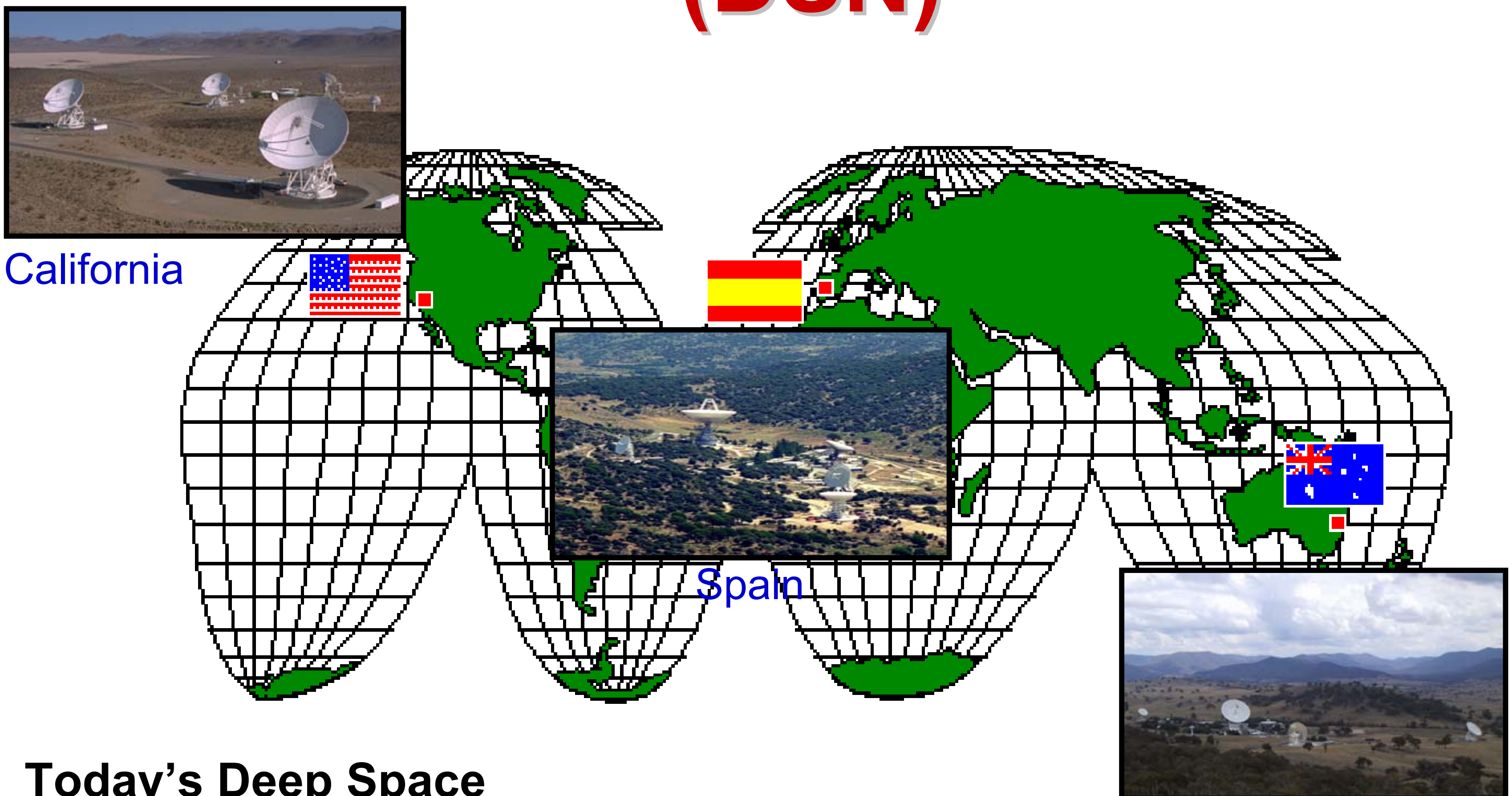
Deep Space Network (DSN)



Today's Deep Space Communications Complexes (DSCCs)

Serving Scientists and the Public

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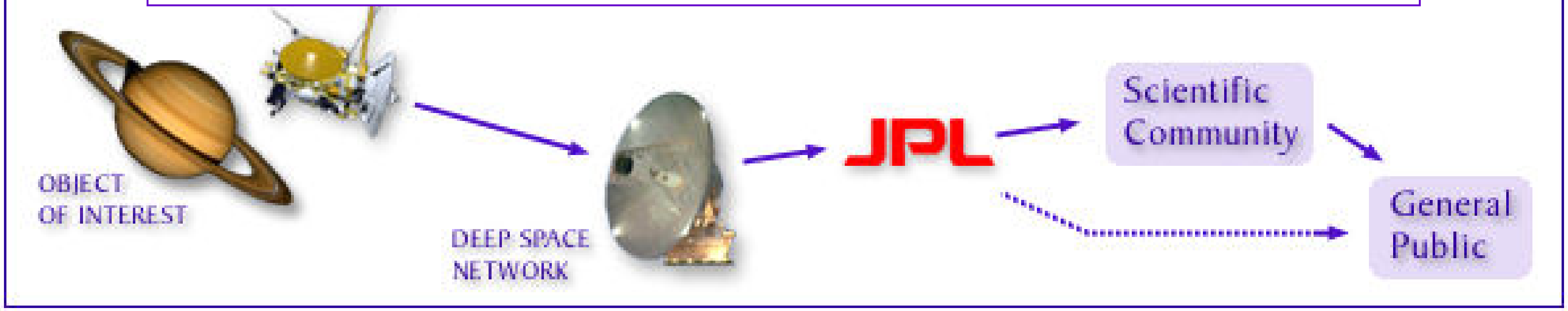
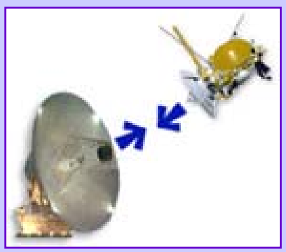
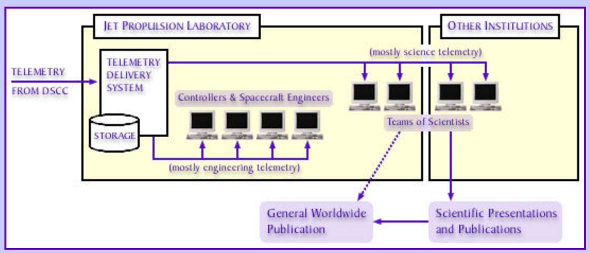
What the Network Enables: Bringing Sensors to the Scientists and the Planets to the Public



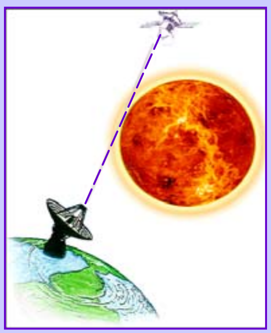
How the Network Enables It: Multi-mission Services & Tools



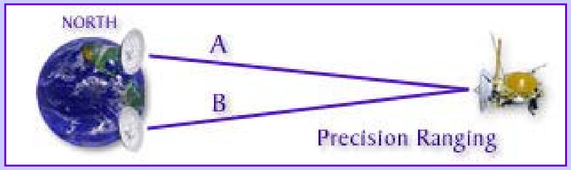
Telemetry & Command



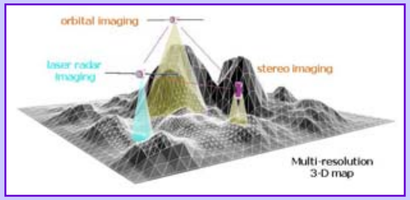
Ground Communications & Mission Data Management



Science Services
- Radar
- Radio Astronomy
- Radio Science
- VLBI



Tracking & Navigation



Experiment Data Product Generation & Science Visualization

Ground Systems Overview

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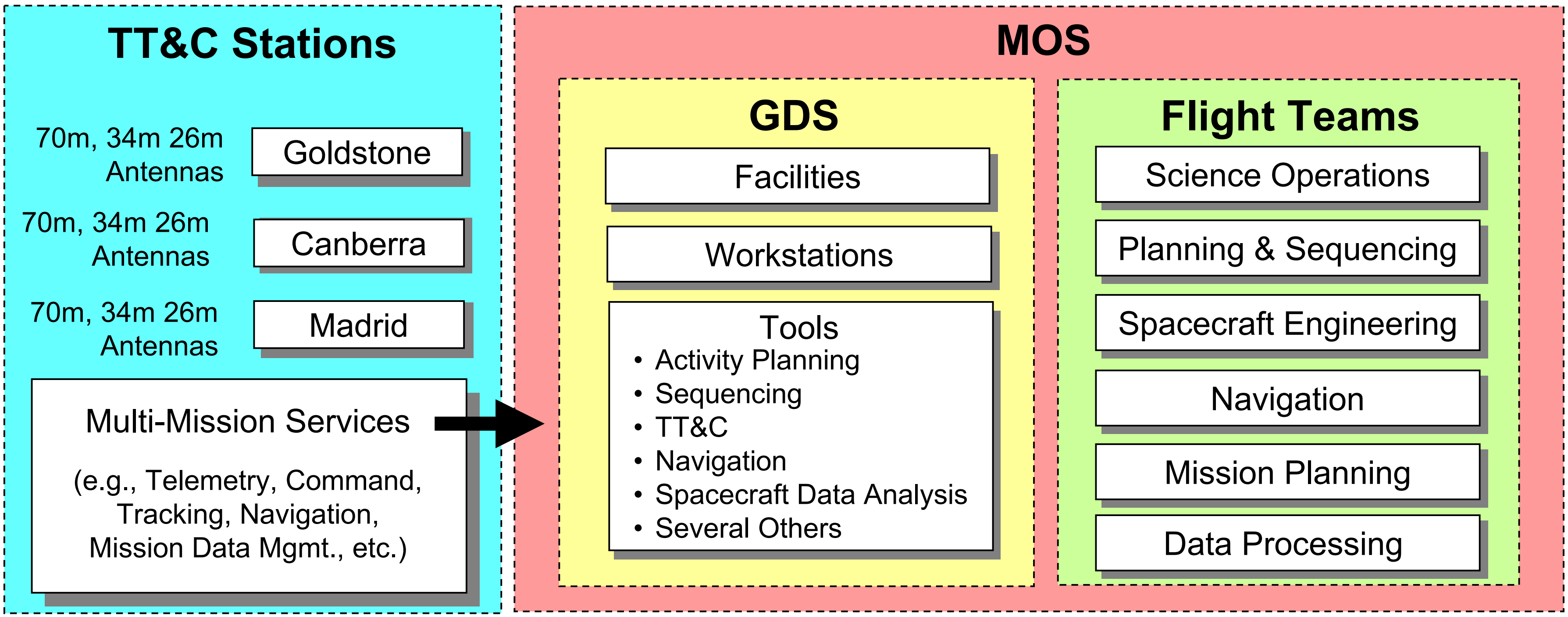
JPL Deep Space Definition:

Ground System = TT&C Stations + MOS

MOS = GDS + Flight Teams

TT&C = Tracking, Telemetry, & Command
GDS = Ground Data System
MOS = Mission Operations System



Some key differences from other ground systems:

- Distributed operations (e.g., spacecraft ops, science ops, data acquisition, etc.)
- Each mission is unique, requiring unique tool adaptations
- Interoperability with international mission GDS's and tracking assets
- Signal-to-Noise-Ratio-constrained TT&C; long two-way light times
- Exotic tracking & navigation techniques; no GPS
- Integrated suite of multi-mission tools and services

NASA Vision and Mission

- ***NASA Vision:***
  - To improve life here;
  - To extend life to there;
  - To find life beyond.
- ***NASA Mission:***
  - To understand and protect our home planet;
  - To explore the universe and search for life;
  - To inspire the next generation of explorers as only NASA can.

The Jet Propulsion Laboratory:

- **Has a dual character:**
  - **A unit of Caltech, staffed with Caltech employees;**
  - **A Federally-Funded Research and Development Center (FFRDC) under NASA sponsorship;**
- **Is a major national research and development (R&D) capability supporting:**
  - **NASA programs;**
  - **Defense programs;**
  - **Civil programs of national importance compatible with JPL capabilities.**

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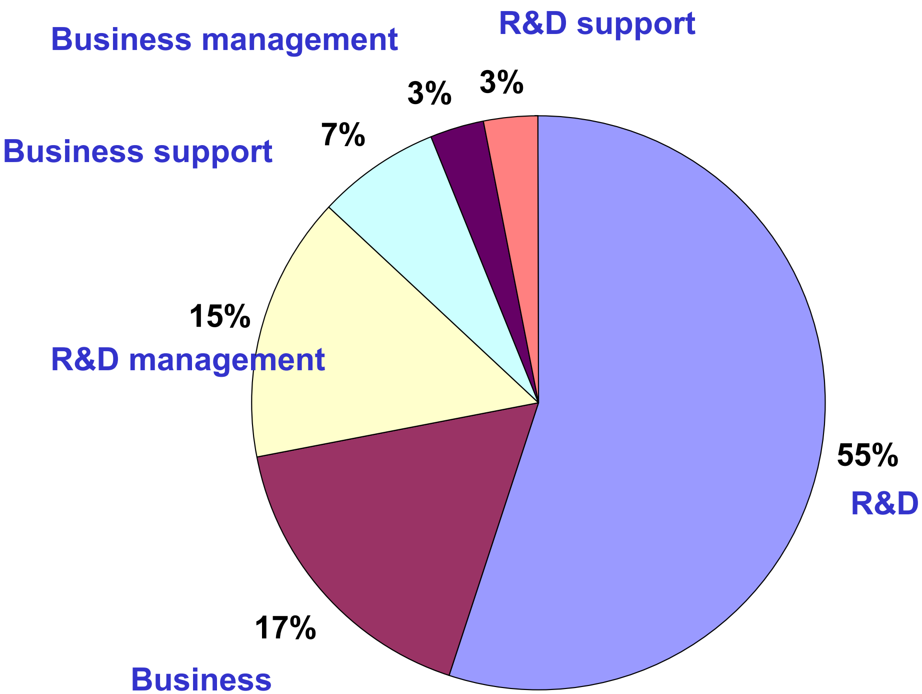
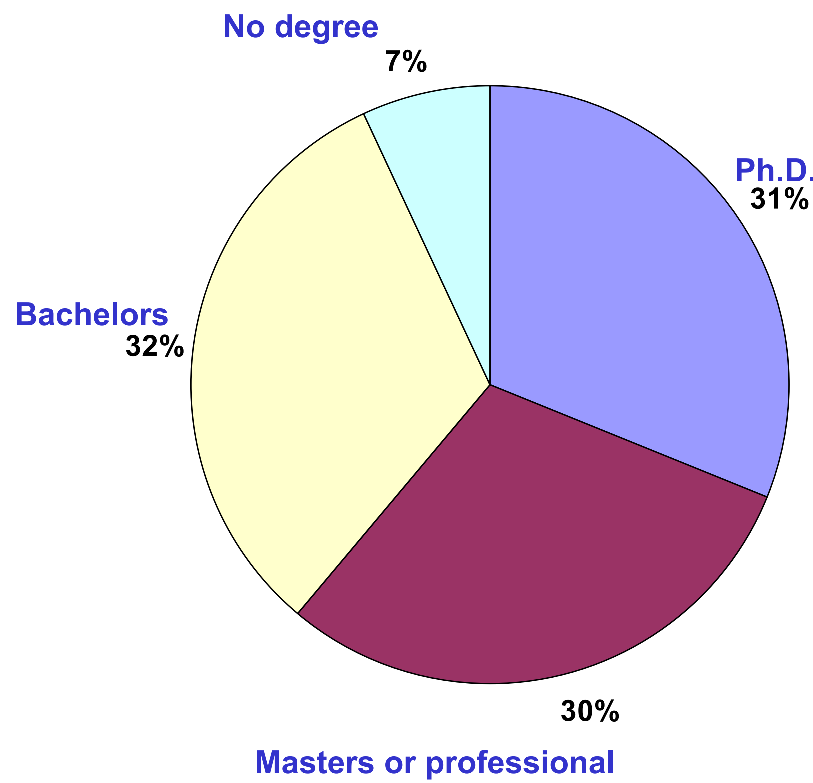
JPL staff composition by job classification and academic degree in FY2002

- **Staff composition by job classification for 5175 employees**
- **R&D staff distribution by academic degree for 2867 employees**





JPL funding distributions for FY02
$1.391 billion business base

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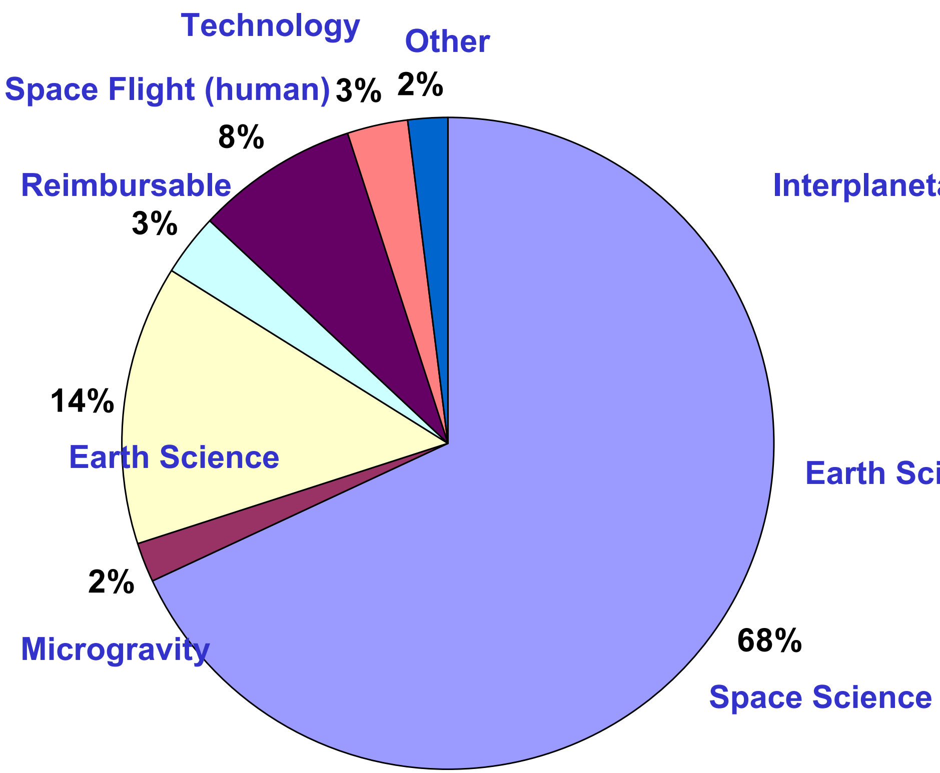
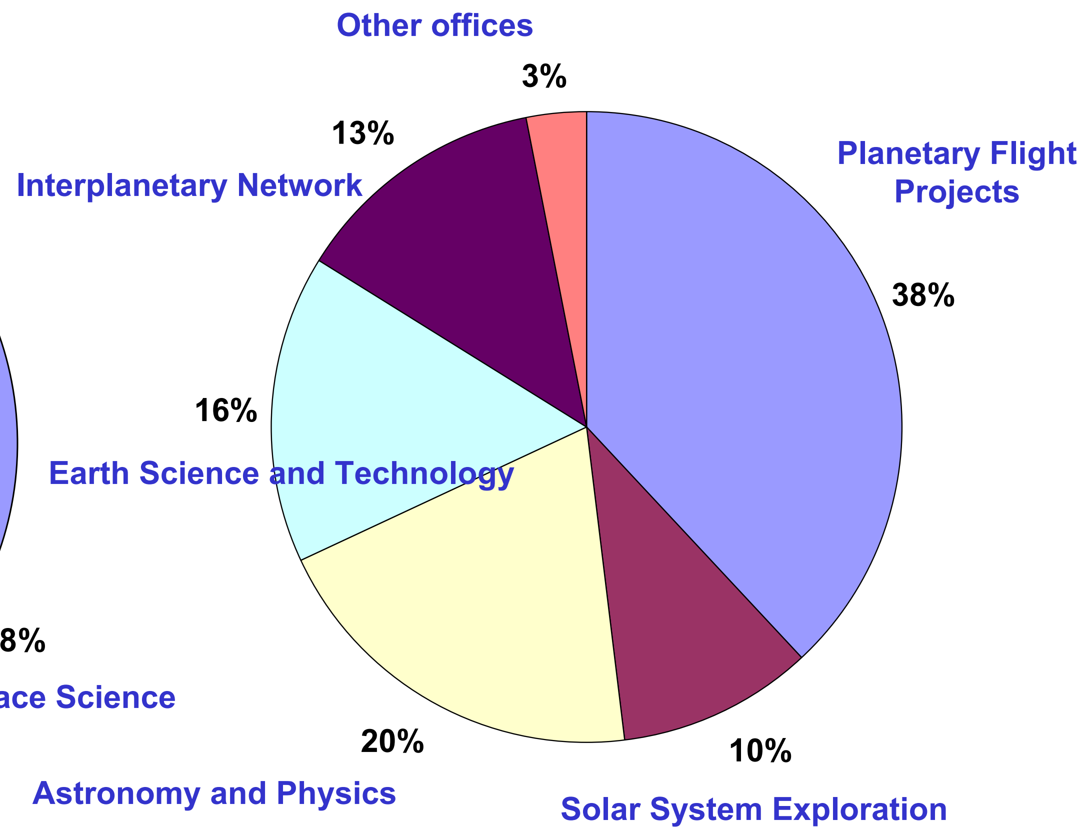
- **By NASA office or other sponsor**



- **By implementing JPL directorate**



Fourteen JPL spacecraft, and three major instruments, now operating across the solar system

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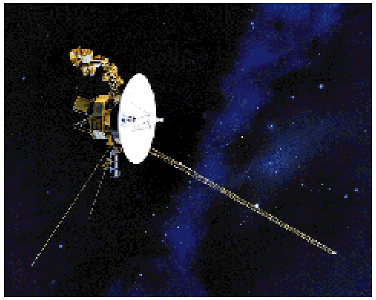
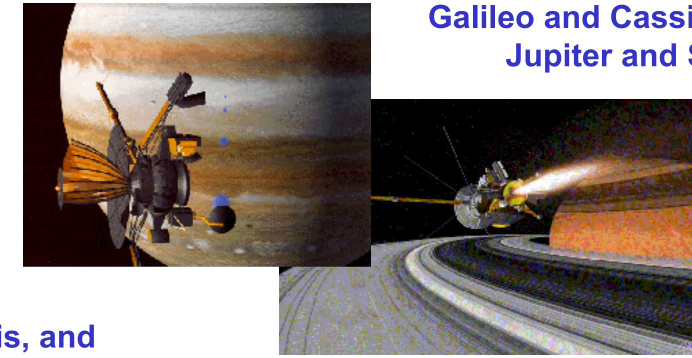
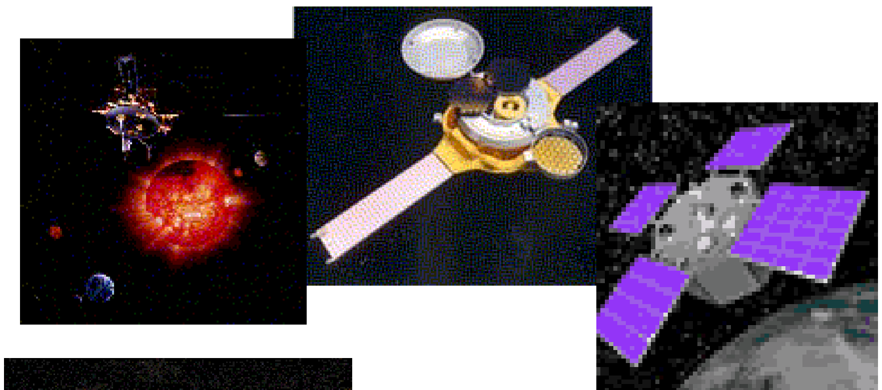


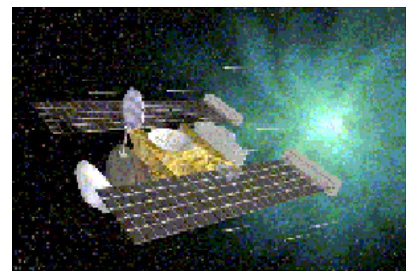
Two Voyagers on an interstellar mission



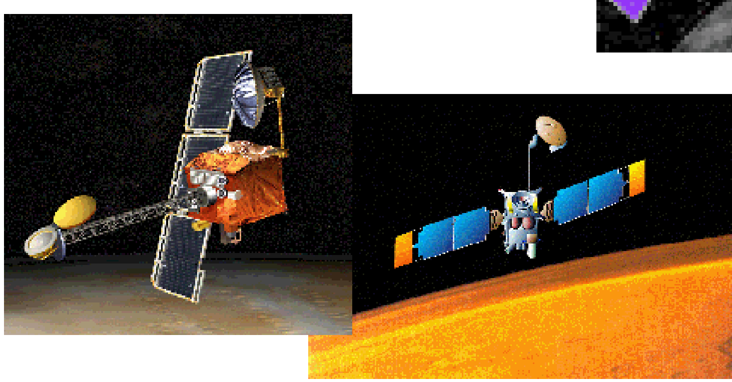
Galileo and Cassini studying Jupiter and Saturn

Ulysses, Genesis, and ACRIMSAT studying the sun





Stardust returning comet dust



Mars Global Surveyor and Mars Odyssey in orbit around Mars

Topex/Poseidon, Quickscat, Jason 1, and GRACE (plus Seawinds, MISR, and AIRS instruments) monitoring Earth

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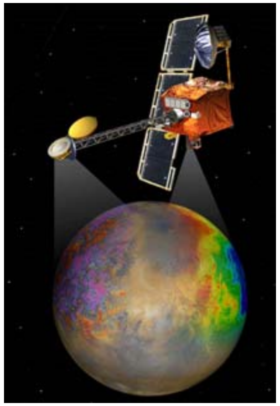
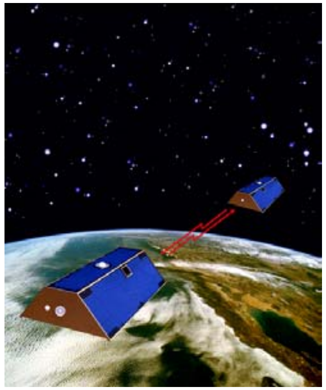
Significant recent and future events

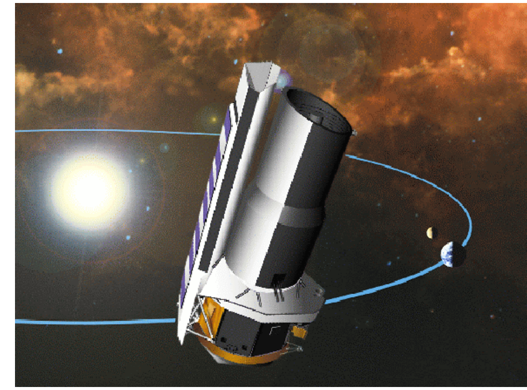


2001 Mars Odyssey began mapping February 2002

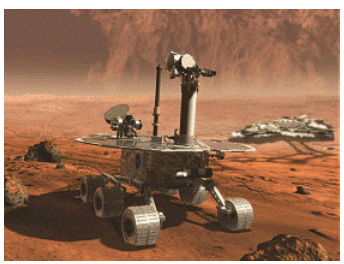


GRACE Earth gravity measuring mission launched March 17, 2002

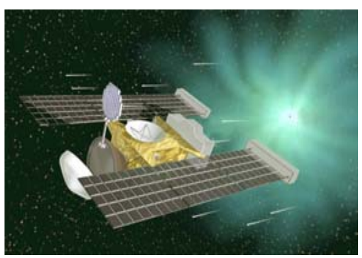
GALEX ultraviolet observatory launch in March 2003



NASA infrared great observatory SIRTF launch in April 2003

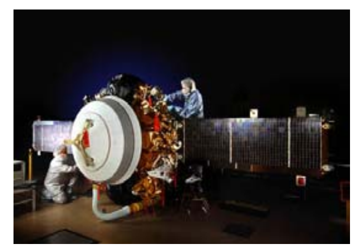


Mars Exploration Rovers launch summer 2003, arrive January 2004



Stardust captures material from Comet Wild 2 in January 2004

Cassini/Huygens arrives at Saturn July 2004



Genesis solar wind sample return September 2004

Cloudsat launch November 12, 2004

Hardware (and software) designs and implementation are verified during the assembly, test, and launch operations phase.

(Mars Exploration Rover 2003 in vibration test)

2003 - 2004: The Busiest Period in JPL's History

March 2003	Galaxy Evolution Explorer (GALEX) launch
April 2003	Space Infrared Telescope Facility (SIRTF) launch
May 30, 2003	Mars Exploration Rover – 1 (MER-1) launch
June 25, 2003	Mars Exploration Rover – 2 (MER-2) launch
January 2, 2004	Stardust Encounter with Comet Wild-2
January 4, 2004	Mars Exploration Rover – 1 (MER-1) landing
January 25, 2004	Mars Exploration Rover – 2 (MER-2) landing
January 2004	Microwave Limb Sounder (MLS) and Tropospheric Emission Spectrometer (TES) launch on EOS-AURA
July 1, 2004	Cassini Saturn orbit insertion
September 8, 2004	Genesis solar wind sample return (first samples from beyond lunar orbit)
October 26, 2004	First Cassini images of Titan surface
November 12, 2004	Cloudsat launch
January 2005	Deep Impact Launch
January 14, 2005	Huygens probe Titan atmospheric entry

In addition to the above key events:

- 7 to 12 missions in development
- 14 missions in operations

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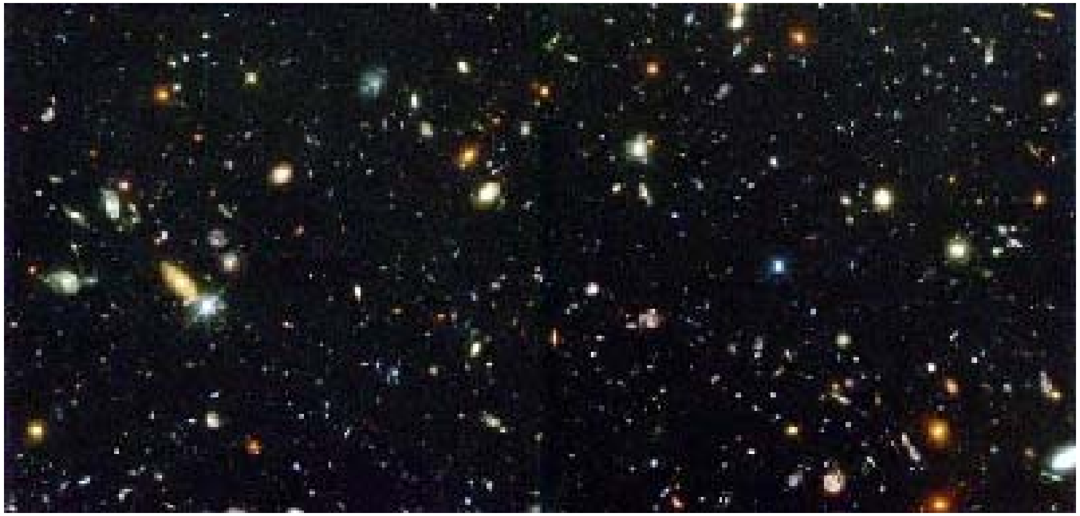
Hubble Deep Field size comparisons

- Image:
  - Image is of a sky region the size of Roosevelt's eye on a dime held at arm's length.
- Galaxies in image:
  - The smallest galaxies in the Hubble Deep Field image have a diameter seen from Earth of 1/200th the width of a hair held at arm's length.
  - Galaxies (the dots in the Hubble Deep Field image) have:
    - ~400 billion stars
    - Mass of ~1 trillion solar masses
    - Diameters of ~1 billion billion miles
    - Distances from Earth of ~1 hundred billion trillion miles



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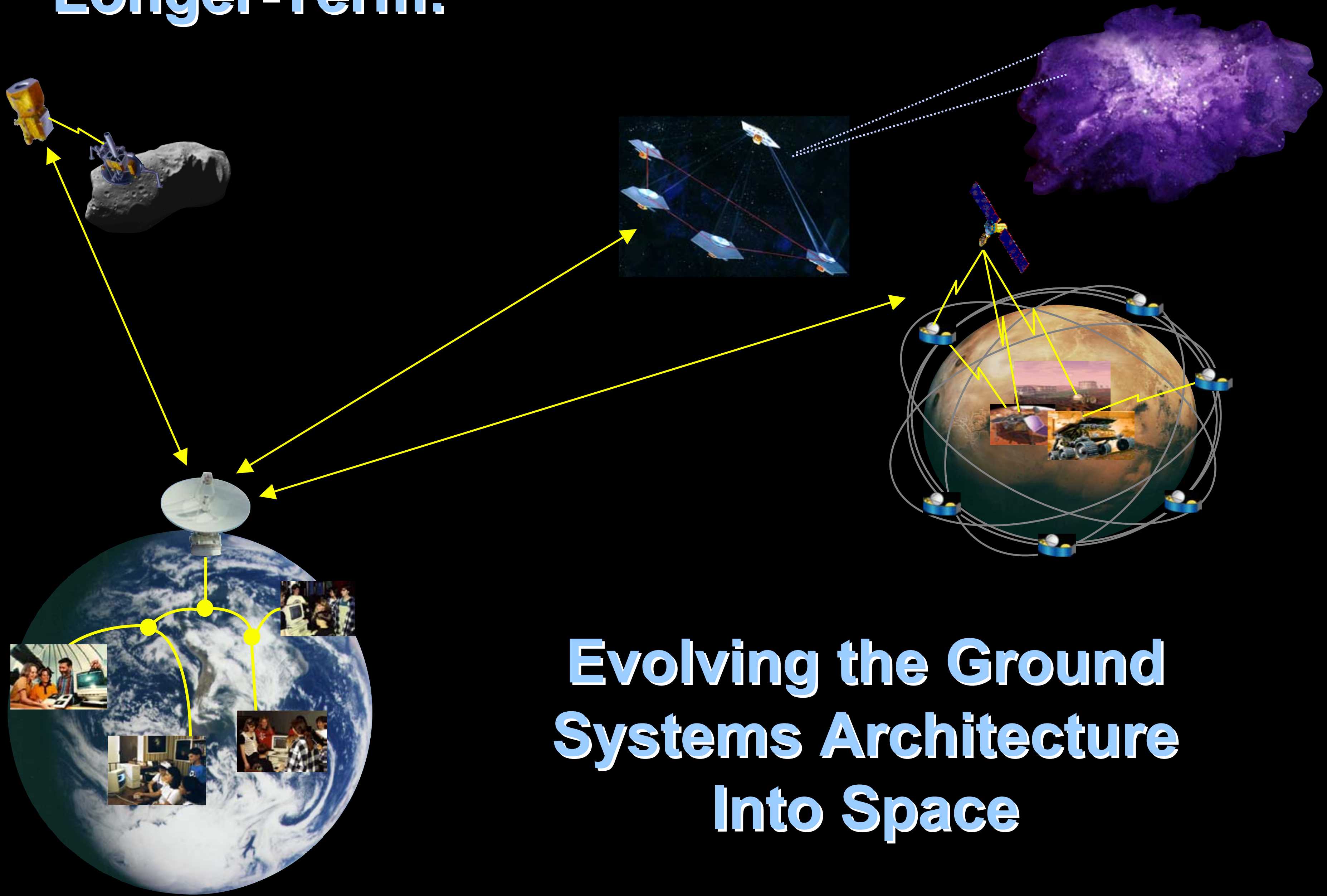
Longer-Term:



Evolving the Ground Systems Architecture Into Space

The Changing Mission Paradigm

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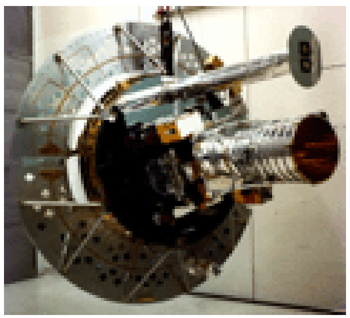
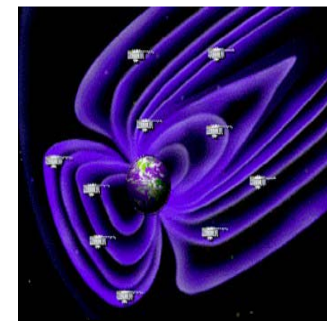
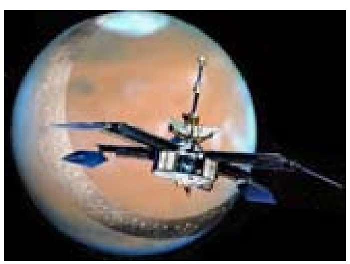
Low-Earth-orbit solar and astrophysical observatories. → Observatories located further from Earth.



Single, large spacecraft for solar and astrophysical observations. → Constellations of small, low-cost spacecraft.





Preliminary solar system reconnaissance via brief flybys. → Detailed Orbital Remote Sensing.

In situ exploration via short-lived probes. → *In situ* exploration via long-lived mobile elements.

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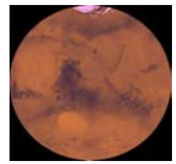
Operational Challenges

Fundamental Obstacles

- **Extreme distance** – communicating at Neptune (30 AU) is ~10 billion times more difficult than at a commercial GEO satellite distance.
- **Long Round Trip Light Times** – over 8 hours at Neptune; no "joy-sticking" possible.
- **Unique Navigation Scenarios** – small body ops, gravity assist trajectories, aerocapture/aerobraking, low-thrust propulsion, Lagrange point missions, formation flying.
- **High Launch/Delivery Cost per Unit Payload Mass** – drives need for low mass, low power flight systems.




Programmatic "Bottlenecks"

- **Deep Space Network Congestion** – compromises science return and adds risk to all missions (e.g., Mars '03-'04).
- **Limited Connectivity at Mars** – Mars science orbiters provide only limited relay communications for surface vehicles; little or no communications during many critical events.
- **Aging Assets & Insufficient Bandwidth** – ~30-year old 70m antennas; very low data rates from planets; can only map ~1% of Mars at high resolution due to data rate constraints.
- **Increasing Operations Complexity** – scientists spend more time on operations than science; more multi-element missions will increase this complexity.

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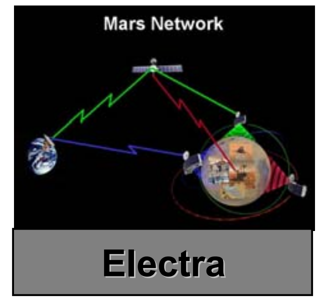
Meeting the Challenges

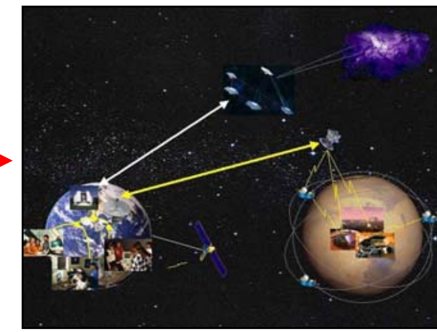
Build the Deep Space Telecom Backbone

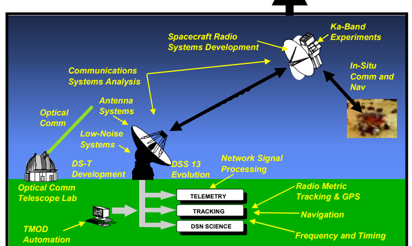
Modernize DSN & Advance RF

Pioneer Optical Comm

Network Space Comm Assets







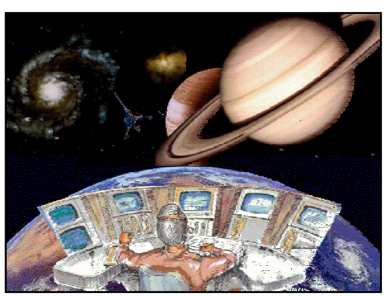
- Standards & Protocols
- S/C Comm Components
- RF & Optical Technology
- Middleware & Applications
- Mission Ops Technology

An Interplanetary Network

Sensors to the Scientists

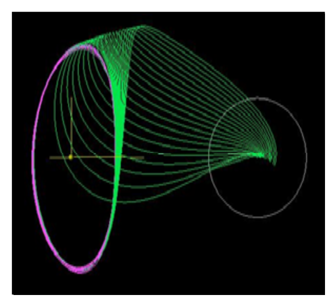
Planets to the Public

Develop the Tools & Techniques Needed to Operate with this Backbone



Provide Multi-Mission Ops Systems & Software

Revolutionize Mission Operations



Advance Mission Design & Nav

First Steps

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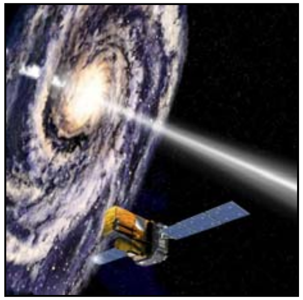
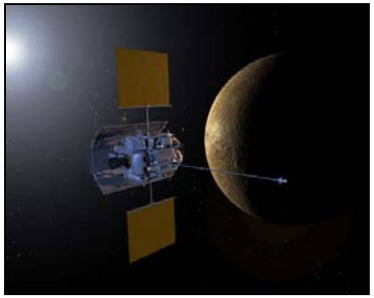
Space Link Extension



2002: INTEGRAL

Turbo Code

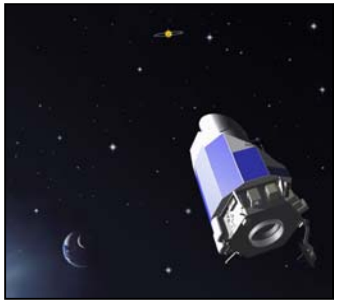


2004: MESSENGER

Ka-band (Ops Validation)

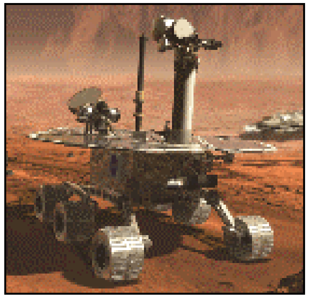
2005: MRO

Ka-band (Operational)



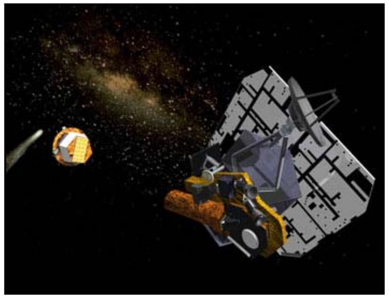
2006: Kepler

Proximity Links



2003: MER

CCSDS File Delivery Protocol



2004: Deep Impact

Higher Data Rates (>2 Mbps)

2005: MRO

Higher Data Rates (>40 Mbps)

2010: JWST (Tentative)

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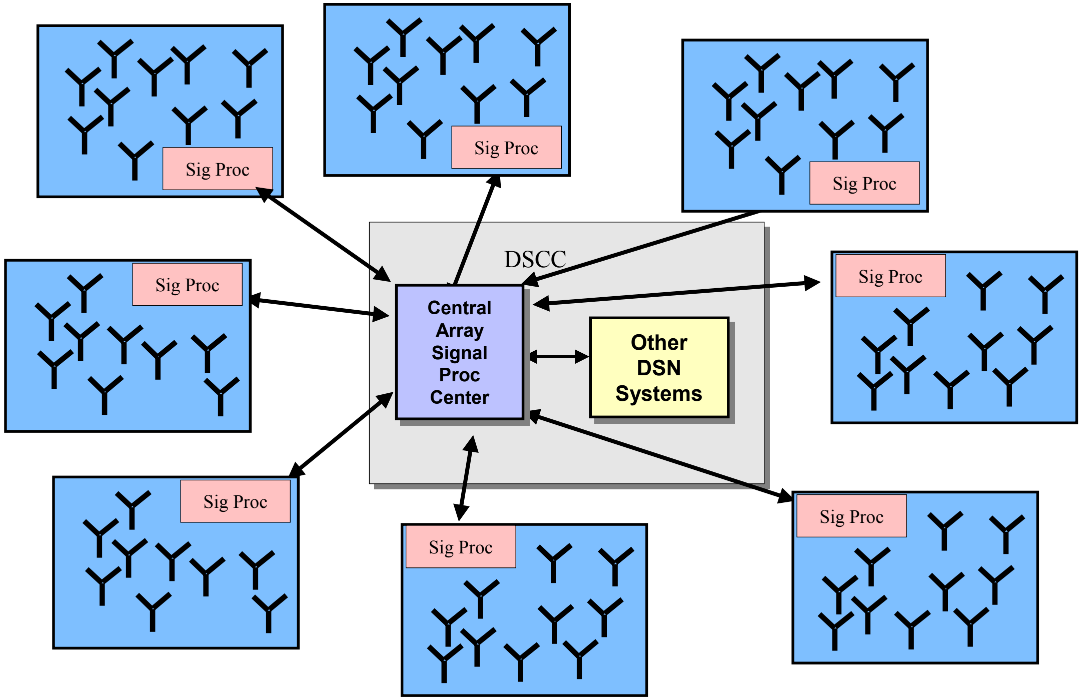
Longer-Term:
Large Arrays of Small Antennas

- Locations
  - –Large number (~3600) of small (~12m) antennas, approximately equally distributed at approximately eight sites on each of three continents.

- Processing
  - –Analog communication from multiple antennas in a cluster to a Local Signal Processing Center (LSPC).
  - –Communication from LSPC to an Array Central Signal Processing Center (ACSPC) at a DSCC.
  - –Conventional signal processing at the DSCC, with existing DSN ground communications to JPL/Customer.



Longer-Term:
Optical Networks

- Potential Locations
  - Linear Dispersed Optical Subnet (LDOS) - has seven stations equally spaced around the world.
  - Clustered Optical Subnet (COS) is a 9-station network with clusters of three stations every 120 deg longitude, say near the DSCCs.
  - Elevation may range from 1,000 to 3,000 meters to be free from dust.
  - Factors include geo-political realities. Oceans, unstable countries.
- Processing
  - Autonomous, with occasional on-site maintenance functions.
  - No foreseeable spectral bandwidth issues.
  - Since data rate is dependent on the capacity of the link, it will change with technology.
  - Recent analyses have predicted data rates in the 30-300 Mbps from Mars, depending on distance and the technology growth.
  - If technology developed more aggressively, these numbers could increase even further.

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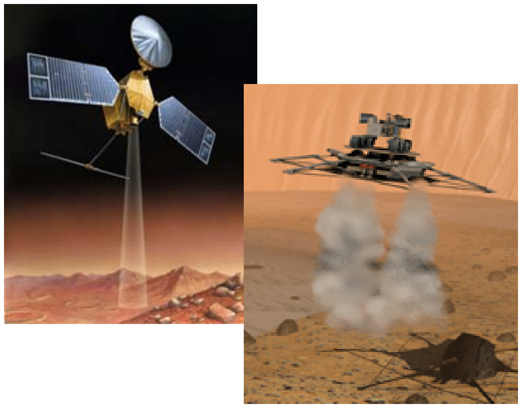
Our vision:
JPL's legacy by 2020

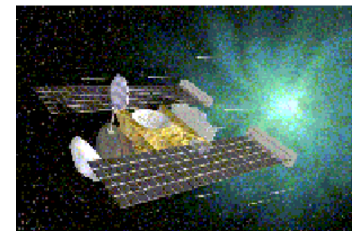
Established a continuous presence *around* and *on the surface* of Mars



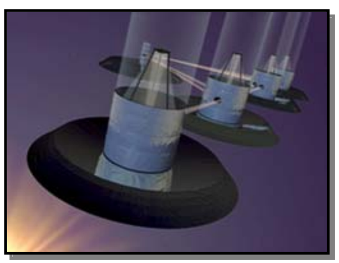
Explored Saturnian system, especially Titan, the only satellite with an organic atmosphere.

Explored Jovian satellites in detail and probed their interiors for possible life-favorable environments.

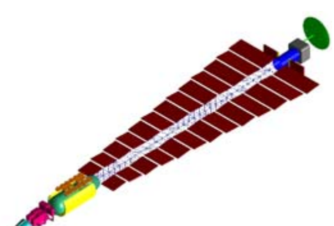
Returned first samples from other solar system bodies beyond the moon.



Began exploring neighboring solar systems.

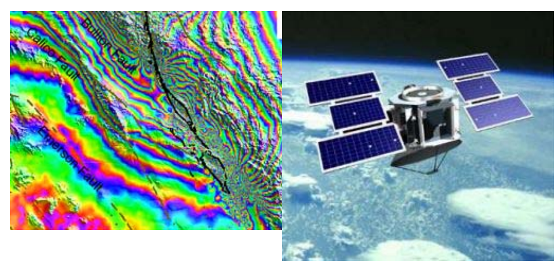


Enabled efficient access to all the bodies of the solar system



Explored the boundaries of physics to understand the forces that powered the Big Bang

Established operational capability to monitor dynamics of solid Earth and its oceans and atmosphere.



Established the Interplanetary Network, which is being commonly used by students.