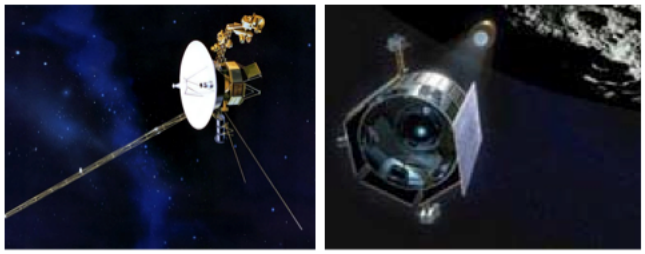
DSN 50th Anniversary

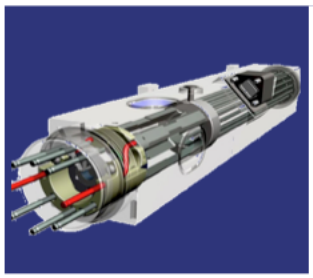
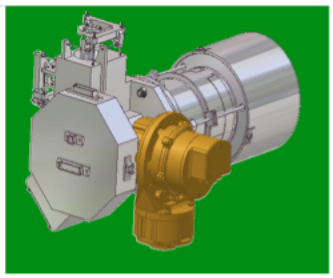
February 20, 2014

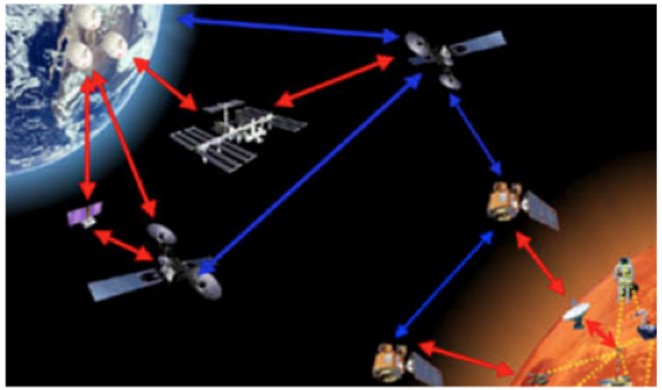
DSN 50th Celebration Symposium

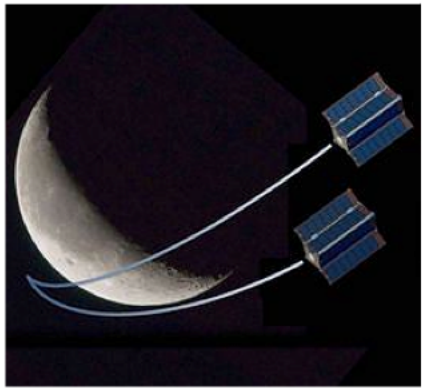
DSN: Past, Present, and Future

February 20 , 2014 1pm – 5pm
von Karman Auditorium
Jet Propulsion Laboratory
Pasadena, California, USA







Program

1:00 – 1:05 pm	**Welcome**, Les Deutsch, Chair
1:05 – 1:25 pm	**Key Note Speech**, Charles Elachi
1:25 – 1:30 pm	**IEEE Awards Presentation**, Charles Elachi
1:30 – 2:00 pm	**The First 50 Years: A Historical Perspective**, Doug Mudgway, Pat Beyer, Michael Rodrigues, and Jim Hodder
2:00 – 2:10 pm	**Introduction to the DSN and its Operations**, Al Bhanji, Wayne Sible and Jeff Berner
2:10 – 2:20 pm	**The Madrid Deep Space Communications Complex**, Pablo Perez
2:20 – 2:30 pm	**The View from Down Under**, Ed Kruzins
2:30 – 2:40 pm	**The Goldstone Deep Space Communications Complex**, Michael Clements
2:40 – 3:10 pm	**The DSN: The Most Important Science Tool of the last 50 Years?**, Joseph Lazio, Les Deutsch
3:10 – 3:25 pm	Break
3:25 – 3:55 pm	**How DSN Technology Changed the World**, Laif Swanson
3:55 – 5:00 pm	**DSN's Future: Panel Interactive Discussions with the Audience**, Bill Weber (moderator), Phil Liebrecht , Les Deutsch, Joseph Lazio, Steve Townes, and Chad Edwards

Reading Reference Sheet

Mudgeway, Douglas J., “Uplink-Downlink: A History of the Deep Space Network 1957-1997”, SP 2001-4227, NASA, Washington, D.C. 2001.

Mudgeway, Douglas J., “Big Dish: Building America’s Deep Space Connection to the Planets”, University Press of Florida, Gainesville, 2005.

Urech Ribera, Jose Manuel, “NASA Stations near Madrid: Forty-five years of history (1963-2008)”, INTA, 2011.

Yuen, Joseph H. (Ed.), “Deep Space Telecommunications Systems Engineering”, JPL 82-76, Jet Propulsion Laboratory, Pasadena, 1982.

Mudgeway, Douglas J., “William H Pickering: America’s Deep Space Pioneer”, NASA, SP 2007-4113, Washington, D.C. 2007.

Koppes, Clayton R., “JPL and the American Space Program: A History of the Jet Propulsion Laboratory”, Yale University Press, New Haven and London, 1982.

Organizing Committee

Symposium Organizing Committee:

Al Bhanjin

Les Deutsh

Joseph Lazio

Mike Rodrigues

Wayne Sible

Steve Townes

Bill Weber

Joe Yuen (Chair)

Jet Propulsion Laboratory
California Institute of Technology

DEEP SPACE NETWORK

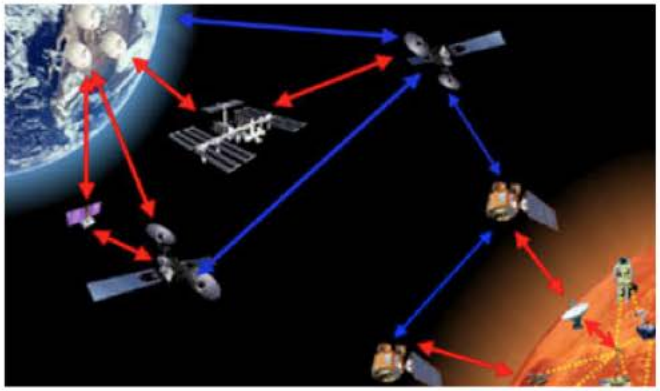
DON’T LEAVE EARTH WITHOUT IT

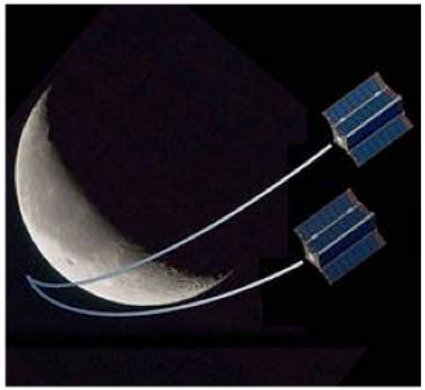
The First 50 Years: A Historical Perspective

Deep Space Network

Doug Mudgway
Pat Beyer
Michael Rodrigues
Jim Hodder

Deep Space Network, Service Management Office



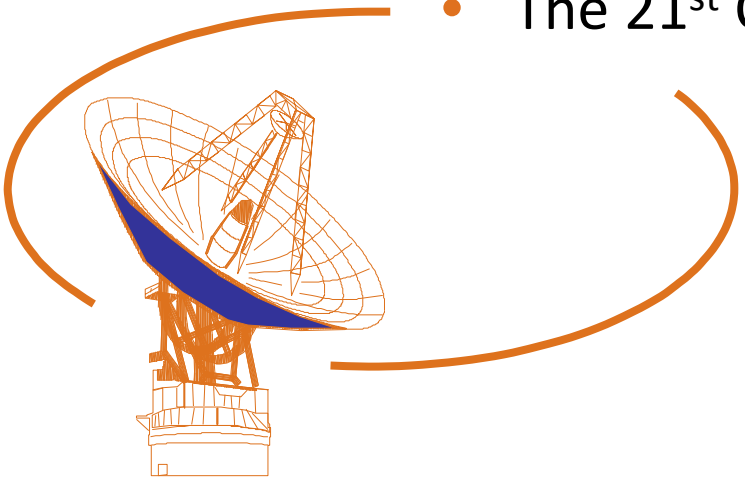


This document has been reviewed and determined not to contain export controlled technical data.

Jet Propulsion Laboratory
California Institute of Technology

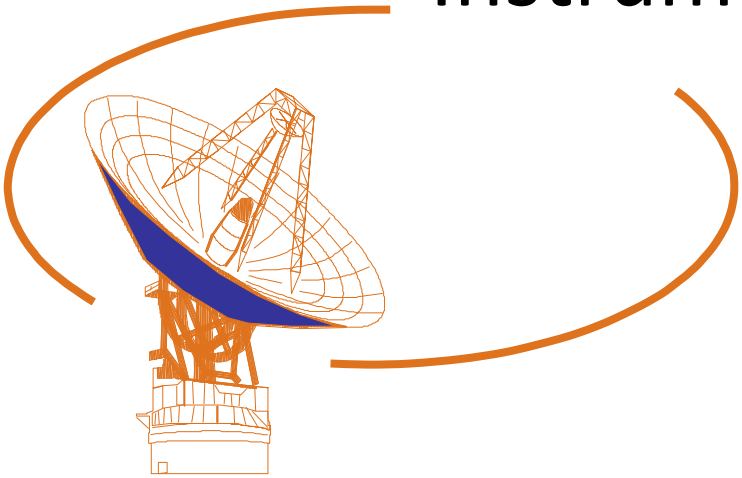
Agenda

- Deep Space Instrumentation Facility (DSIF)
- The Early Years of the DSN
- The 80's and 90's
- The 21st Century



Jet Propulsion Laboratory
California Institute of Technology

The Deep Space Instrumentation Facility (DSIF)



Deep Space Instrumentation Facility (DSIF)

The Original 26m Antennas

- DSS-11, Pioneer, Goldstone, California
- DSS-41, Woomera, Australia
- DSS-51, Hartebeestpoort, South Africa

DSS-11

DSS-41

DSS-51

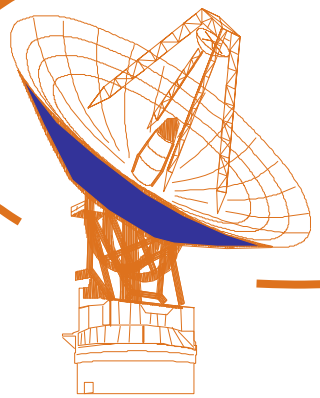
Jet Propulsion Laboratory
California Institute of Technology

Deep Space Instrumentation Facility (DSIF)

DSIF Control Center 1962

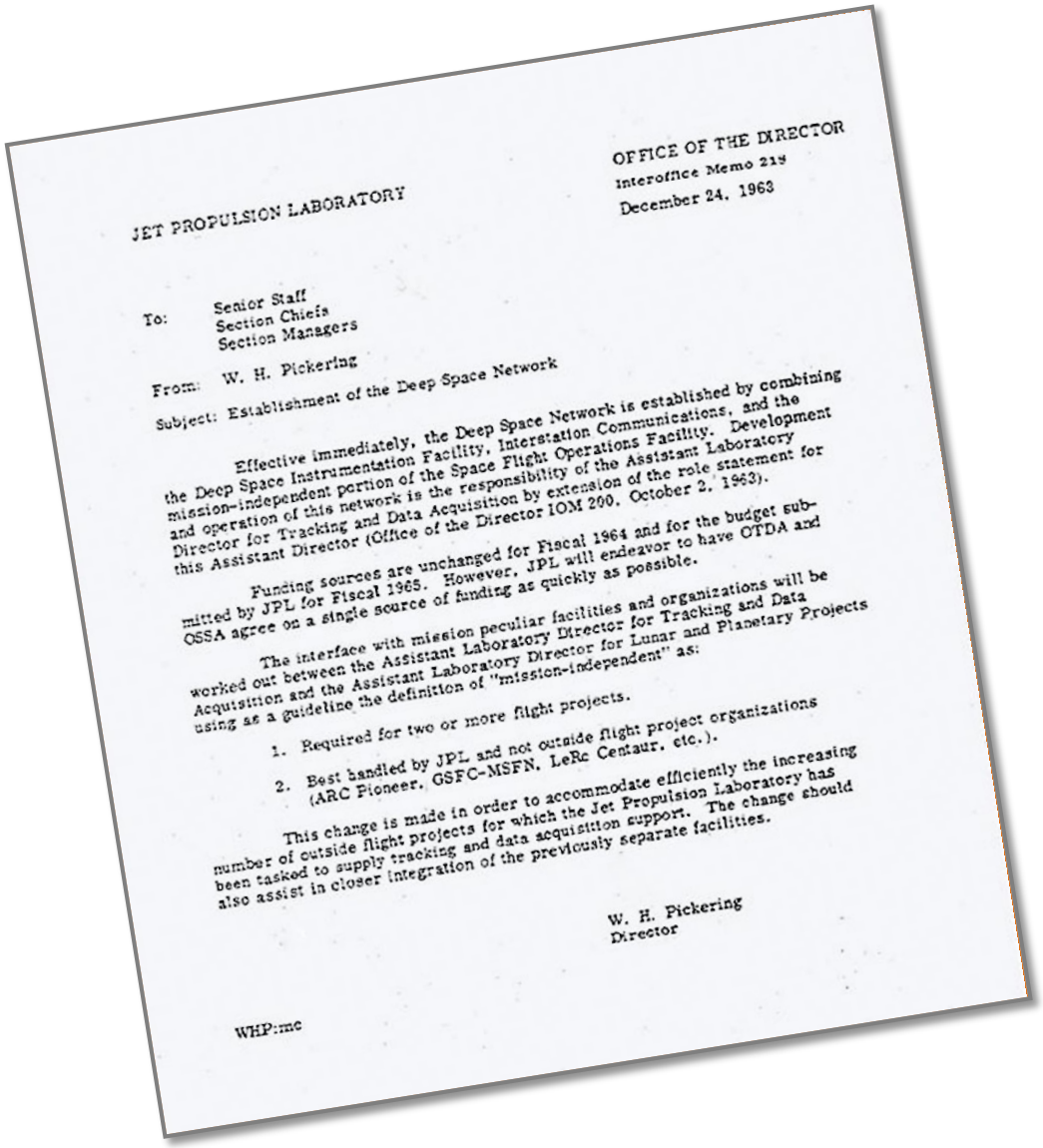
Jet Propulsion Laboratory
California Institute of Technology

The Early Years of the DSN



Jet Propulsion Laboratory
California Institute of Technology

The Early Years



JET PROPULSION LABORATORY

OFFICE OF THE DIRECTOR
Interoffice Memo 219
December 24, 1963

To: Senior Staff
Section Chiefs
Section Managers

From: W. H. Pickering

Subject: Establishment of the Deep Space Network

Effective immediately, the Deep Space Network is established by combining the Deep Space Instrumentation Facility, Interstation Communications, and the mission-independent portion of the Space Flight Operations Facility. Development and operation of this network is the responsibility of the Assistant Laboratory Director for Tracking and Data Acquisition by extension of the role statement for this Assistant Director (Office of the Director IOM 200, October 2, 1963).

Funding sources are unchanged for Fiscal 1964 and for the budget submitted by JPL for Fiscal 1965. However, JPL will endeavor to have OTDA and OSSA agree on a single source of funding as quickly as possible.

The interface with mission peculiar facilities and organizations will be worked out between the Assistant Laboratory Director for Tracking and Data Acquisition and the Assistant Laboratory Director for Lunar and Planetary Projects using as a guideline the definition of "mission-independent" as:

1. Required for two or more flight projects.
2. Best handled by JPL and not outside flight project organizations (ARC Pioneer, GSFC-MSFN, LeRc Centaur, etc.).

This change is made in order to accommodate efficiently the increasing number of outside flight projects for which the Jet Propulsion Laboratory has been tasked to supply tracking and data acquisition support. The change should also assist in closer integration of the previously separate facilities.

W. H. Pickering
Director

WHP:mc

Establishment of the Deep Space Network

W. H. Pickering

December 24, 1963

Jet Propulsion Laboratory
California Institute of Technology

The Early Years

JPL Space Flight Operations Facility (SFOF) - 1964

Jet Propulsion Laboratory
California Institute of Technology

The Early Years

JPL Space Flight
Operations
Facility
Darkroom

- 1964

Jet Propulsion Laboratory
California Institute of Technology

The Early Years

DSS-14 – 64m – Goldstone, CA

26M antennas (Operational in 1965) – "Second Network"

- DSS-12
- DSS-42
- DSS-61

64M antennas

- DSS-14 (Operational in March 1966)
- DSS 43 (Operational in April 1973)
- DSS-63 (Operational in September 1973)

Jet Propulsion Laboratory
California Institute of Technology

The Early Years

Goldstone, California – 1964

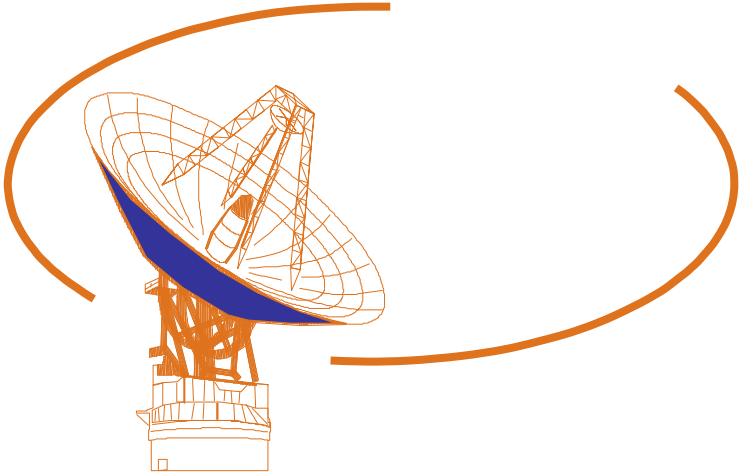
Jet Propulsion Laboratory
California Institute of Technology

The Early Years

JPL SFOF Darkroom - 1969

Jet Propulsion Laboratory
California Institute of Technology

The 80's and 90's



Jet Propulsion Laboratory
California Institute of Technology

The 80's and 90's

DSS-12 – 34m – Goldstone, CA

- 26M upgrade to 34M and retrofitted with X-band receivers (November 1978 – April 1980)
- MKIVA Upgrade 1981-1985
- 34M High Efficiency Antennas (first X-band Uplink) for Voyager Uranus Encounter (1984-1987)

Jet Propulsion Laboratory
California Institute of Technology

The 80's and 90's

DSS-14 – 70m – Goldstone, CA

- 64M upgrade to 70M (1987-88) for Voyager Neptune Encounter
- 34M Beam Waveguide Antennas (February 1995 – October 1997)
- Block V Receiver
- DSN special development for the Galileo Low Gain Antenna Mission
  - First inter-continental arraying
  - First full-spectrum combining
  - The "Ultracone"

Jet Propulsion Laboratory
California Institute of Technology

The 80's and 90's

Apollo Valley
Goldstone, CA

USA

Jet Propulsion Laboratory
California Institute of Technology

The 80's and 90's

Madrid
Deep Space
Communications
Complex

Spain

Jet Propulsion Laboratory
California Institute of Technology

The 80's and 90's

Canberra
Deep Space
Communications
Complex

Australia

Jet Propulsion Laboratory
California Institute of Technology

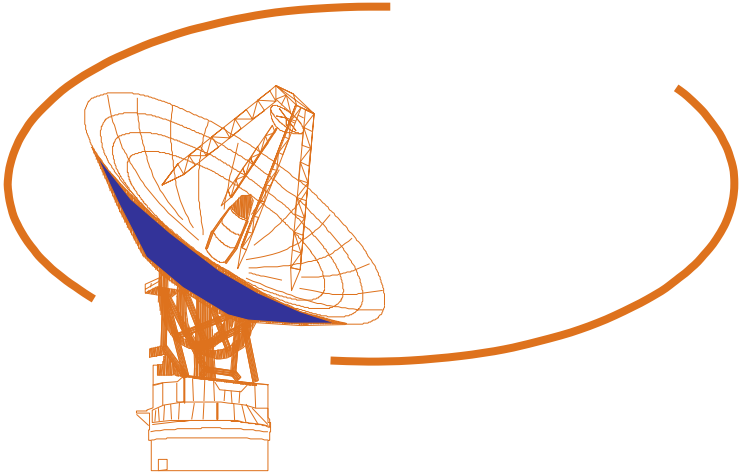
The 80's and 90's

JPL SFOF Darkroom – 1997

JPL SFOF Designated a United States National Historic Landmark in 1985

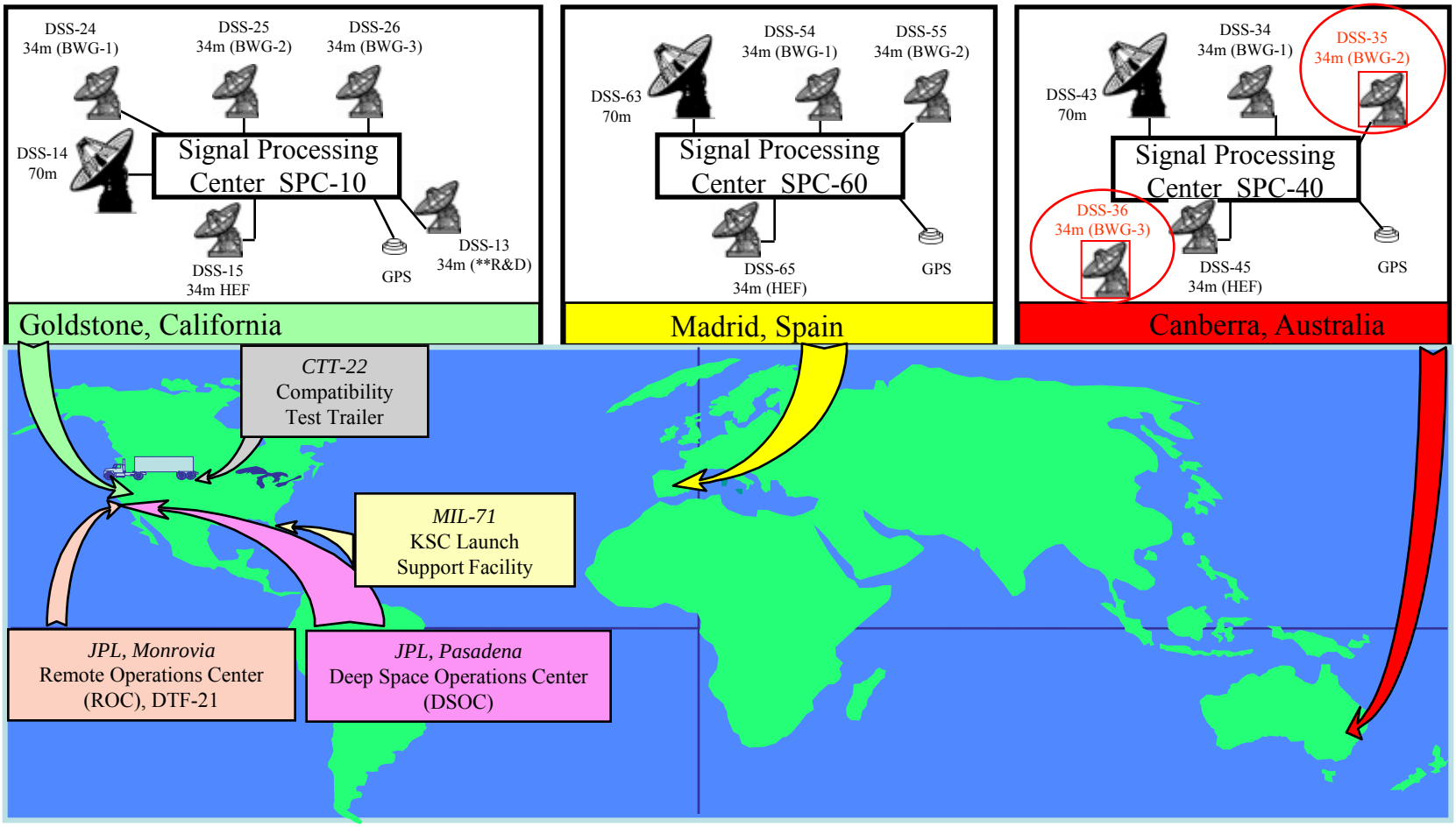
Jet Propulsion Laboratory
California Institute of Technology

The 21st Century



Jet Propulsion Laboratory
California Institute of Technology

The 21st Century



DSN Facilities 2014

Jet Propulsion Laboratory
California Institute of Technology

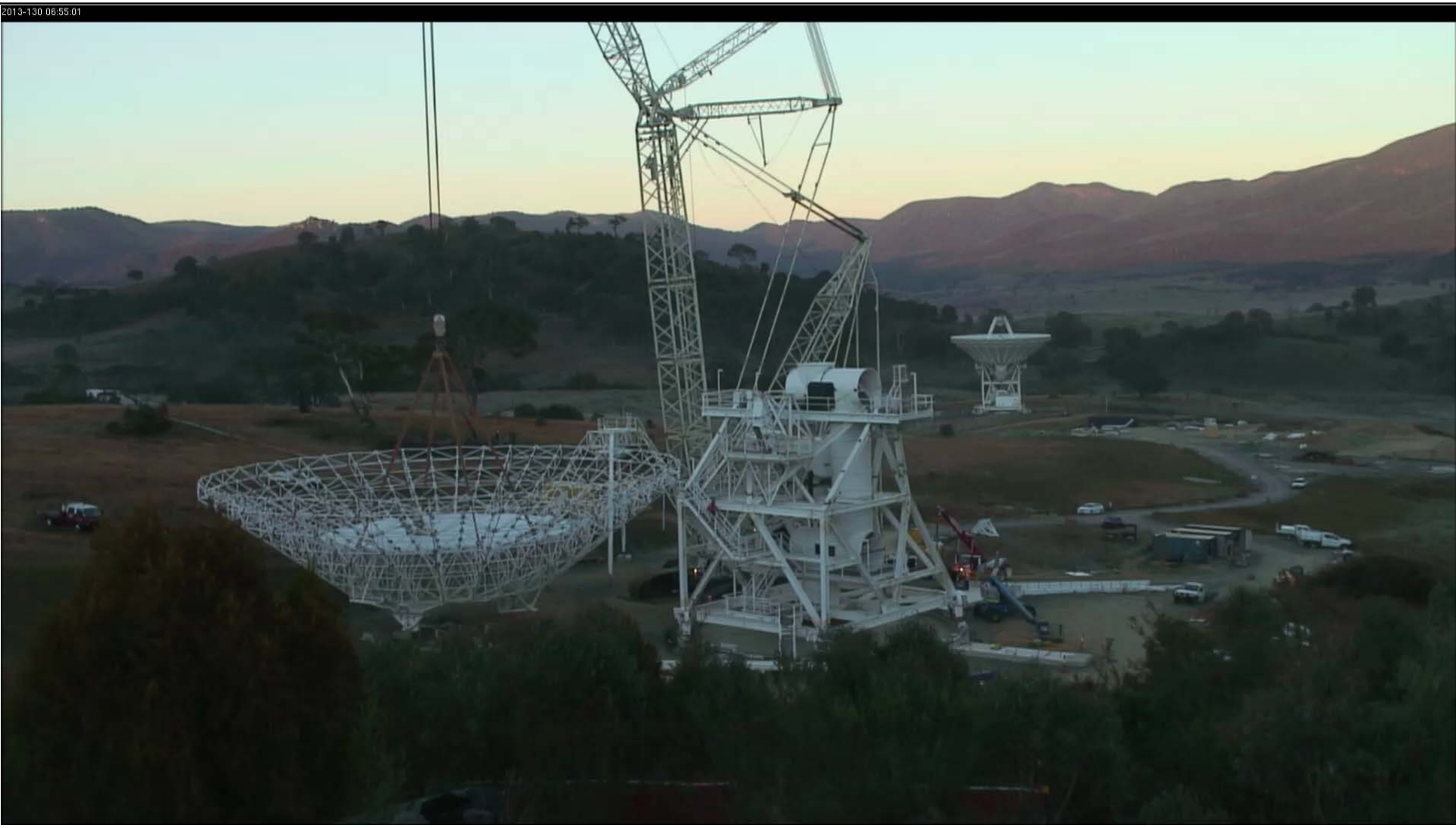
The 21st Century

JPL SFOF Darkroom - 2014

- Network Simplification Project (NSP)
- 2003/04 and 2011 Asset (Antenna) Contention Periods
- K and Ka -band implementation

Jet Propulsion Laboratory
California Institute of Technology

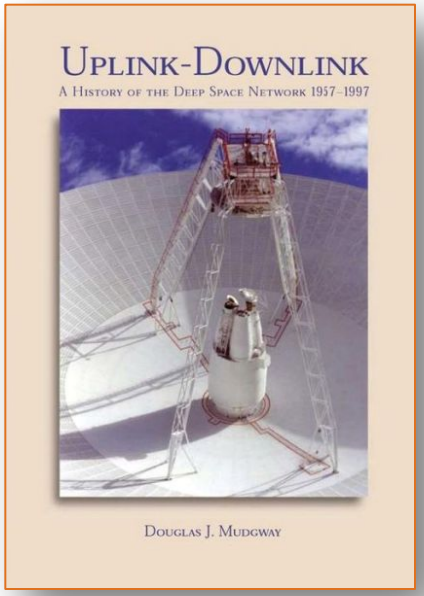
The 21st Century



Film of DSS-35 Dish Lift

Jet Propulsion Laboratory
California Institute of Technology

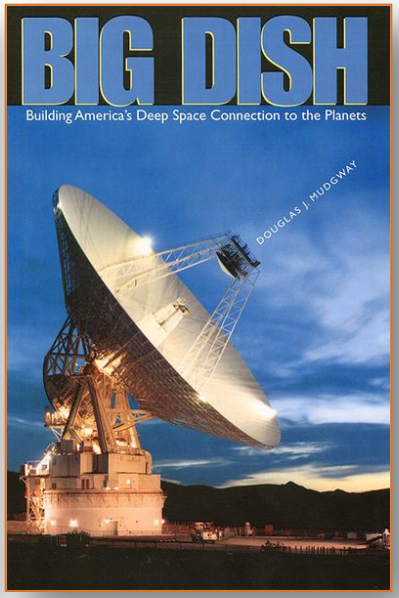
References for Further Reading



Uplink-Downlink

A History of the Deep Space Network 1957-1997

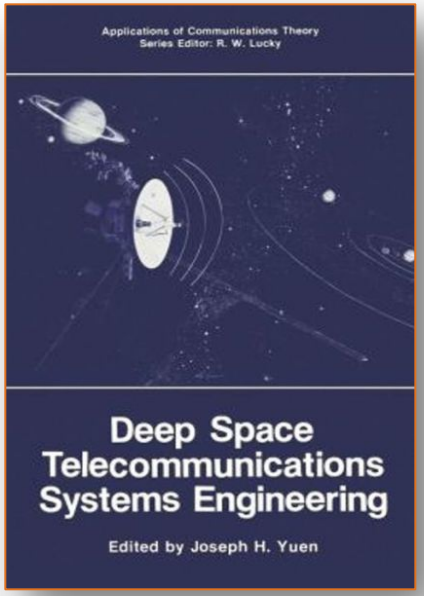
Douglas J. Mudgway



Big Dish

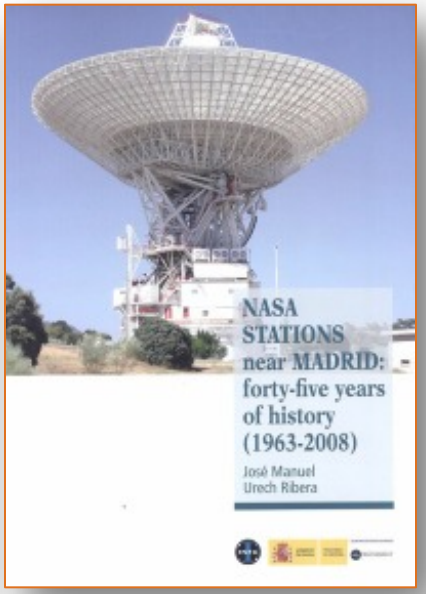
Building America's Deep Space Connection to the Planets

Douglas J. Mudgway



Deep Space Telecommunications Systems Engineering

Joseph H. Yuen (Ed.)



NASA Stations Near Madrid: Forty Five Years of History (1963 – 2008)

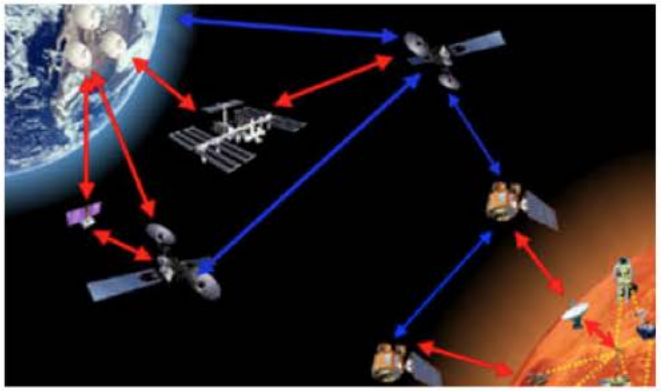
Jose Manuel, Urech Ribera

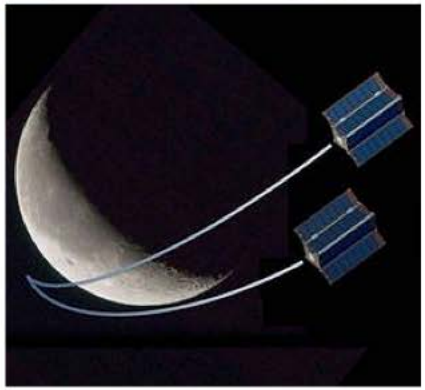
Introduction to the DSN and its Operations

Al Bhanji
DSN Project Manager

Wayne Sible
DSN Deputy Project Manager

Jeff Berner
DSN Chief Engineer





This document has been reviewed and determined not to contain export controlled technical data

Jet Propulsion Laboratory
California Institute of Technology

Agenda

- DSN Overview
- The Future
- Short Video on the “Day in the life of the DSN”

This document has been reviewed and determined not to contain export controlled technical data

Jet Propulsion Laboratory
California Institute of Technology

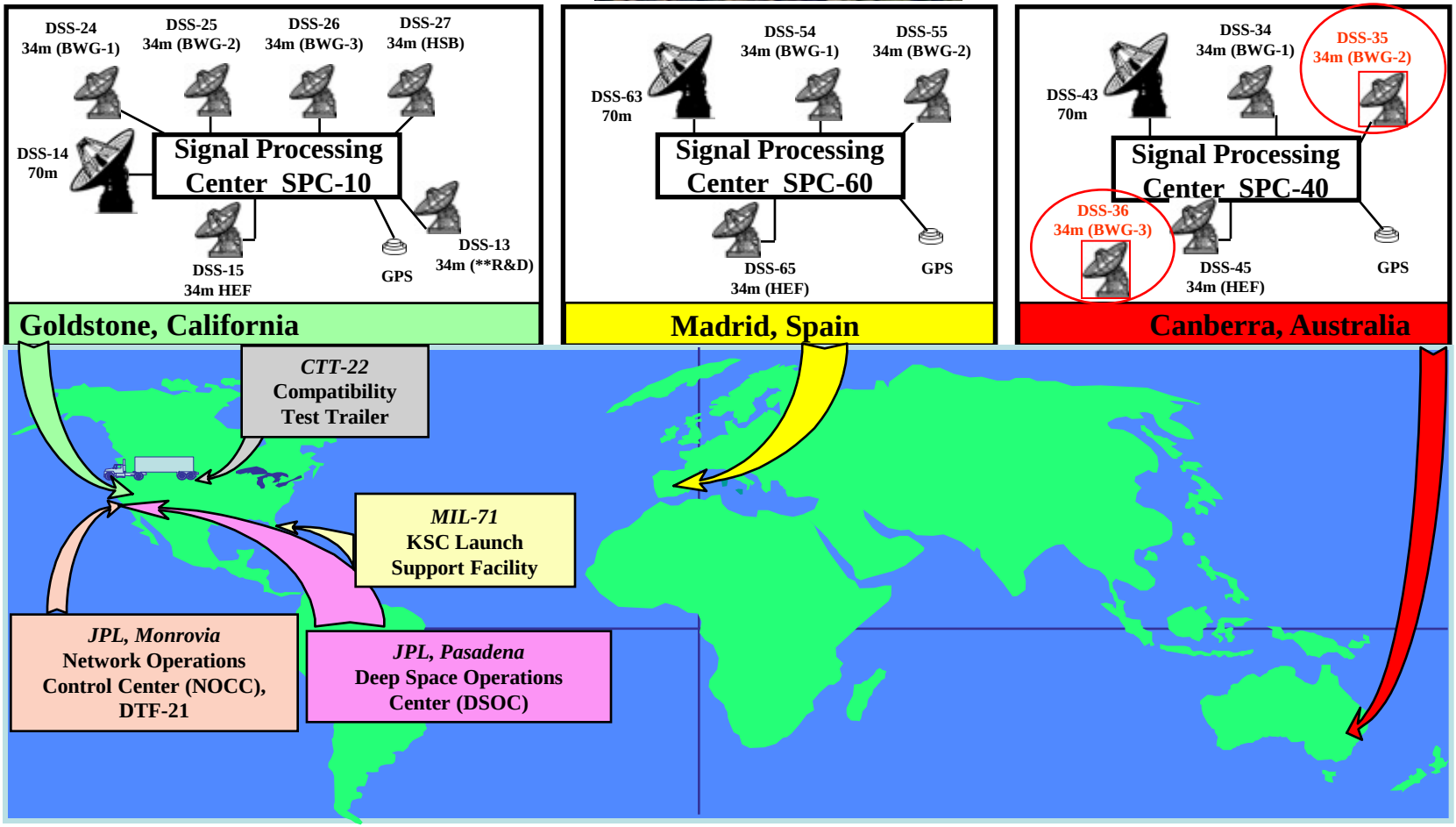
The Deep Space Network

- NASA's Deep Space Network (DSN) was established in December 1963 (50 years ago!) to provide a communications infrastructure for all of NASA's robotic missions beyond geostationary orbit. It is the largest and most sensitive scientific telecommunication system in the world. Some of the missions supported includes:
  - FOR NASA: Surveyor, Ranger, Mariner, Pioneer, Viking, Voyager, Magellan, Galileo, Mars Pathfinder, Cassini, Deep Space 1, MER, MGS, Mars Odyssey, Spitzer, Stardust, MRO, Phoenix, Deep Impact, MSL, JUNO, DAWN
  - FOR OTHER SPACE AGENCIES: Ulysses, SOHO, Planet-C, Mars Express, Rosetta, MOM
- Besides DSN's prime responsibility of telecommunications for NASA and international Missions, it also supports scientific investigations through radio astronomy, radio science, and radar activities
- The Deep Space Network Project Office at JPL handles programmatic management of the DSN and is also responsible for the engineering and operations of the DSN

This document has been reviewed and determined not to contain export controlled technical data

Jet Propulsion Laboratory
California Institute of Technology

DSN Facilities



This document has been reviewed and determined not to contain export controlled technical data

Jet Propulsion Laboratory
California Institute of Technology

International Partnerships

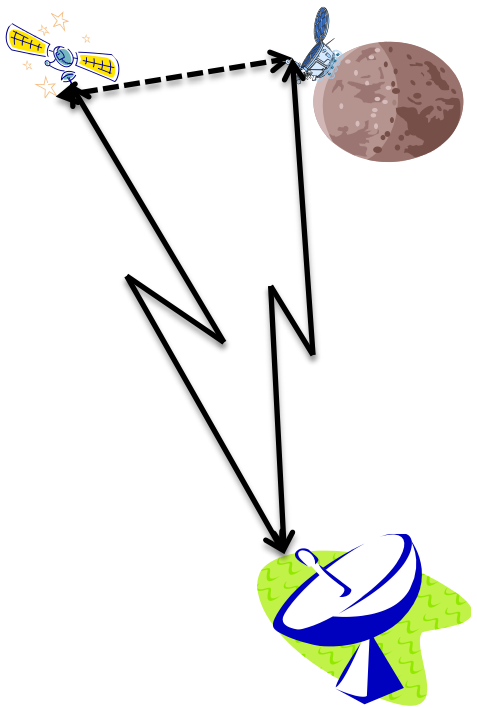
- **NASA/JPL depends upon international partnerships and contracts to successfully operate the DSN worldwide.**
  - **Goldstone and Pasadena Operations are contracted to ITT Exelis**
  - **Canberra is managed by the Commonwealth Scientific Industrial Research Organization (CSIRO)**
  - **Madrid is managed by the Instituto Nacional de Tecnica Aeroespacial (INTA) who in turn contract to Ingeniería de Sistemas para la Defensa de España (ISDEFE)**

This document has been reviewed and determined not to contain export controlled technical data

Functions of the Deep Space Network

Jet Propulsion Laboratory
California Institute of Technology

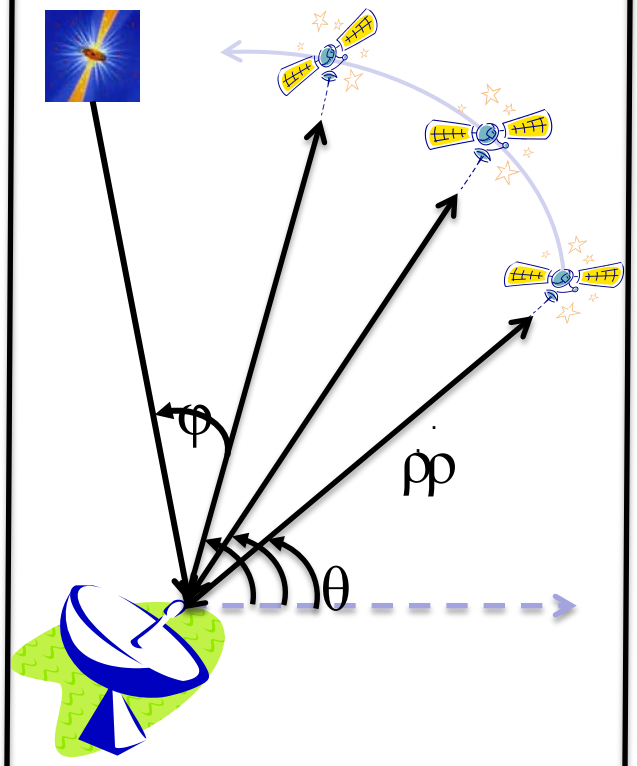
Telecommunication



Uplink (Command): 20KW Transmitters; S-band (2 GHz) and X-band (8 GHz); Data Rates from 10 bps to 10 Kbps

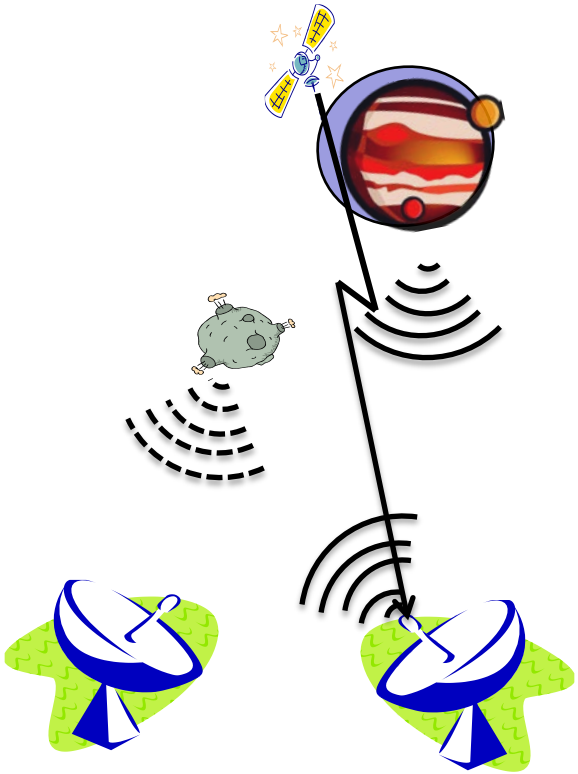
Downlink (Telemetry): S-band (2 GHz), X-band (8 GHz), Ka-band (26 or 32 GHz); Data Rates from 10 bps to 6.6 Mbps

Tracking



Collect multiple data types used for orbit determination:
- Range
- Doppler
- Angles
- Delta-DOR
- Very Long Baseline Interferometry (VLBI)

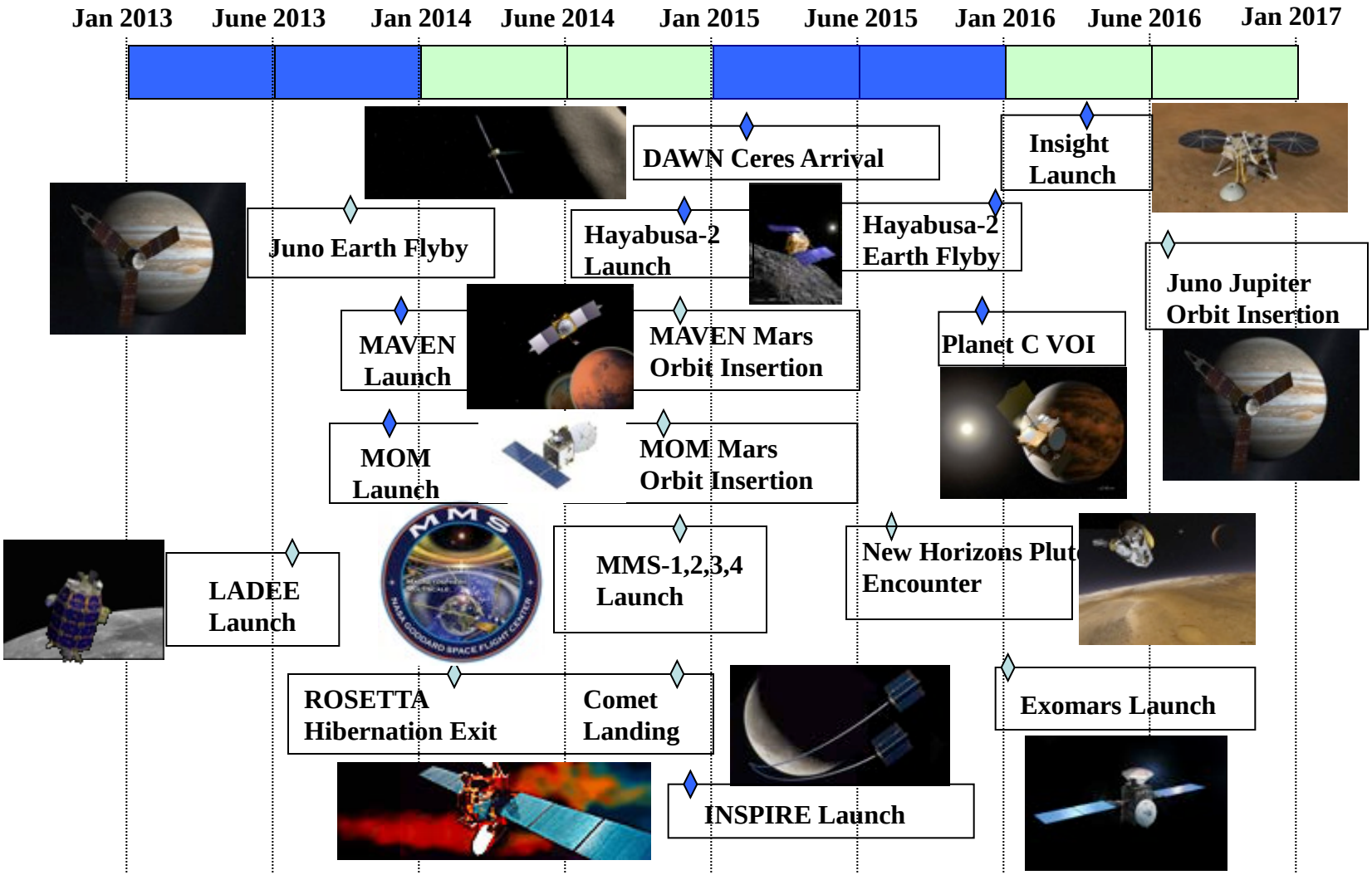
Science



Radar: Bouncing a radio signal off a celestial body and processing the received reflected signal
Radio Science: Observations of changes in a spacecraft radio signal as it passes through a planetary atmosphere
Radio Astronomy: Observations of naturally occurring radio emissions

This document has been reviewed and determined not to contain export controlled technical data

Major Upcoming Mission Events



This document has been reviewed and determined not to contain export controlled technical data

Jet Propulsion Laboratory
California Institute of Technology

The Future

What plans and challenges are ahead?

Reducing costs:

- One operator controlling multiple antennas
- Standardized maintenance across the world
- Web based data interfaces

Improving performance:

- Higher data rates for both uplink and downlink
- Error correcting coding for the uplink
- New error correcting codes for the downlink
- New antennas, operated singly or as an array

Adding new capabilities:

- Higher frequency bands
- Wider bandwidth RADAR capability
- Optical data downlinks (using RF antenna)

For half a century the DSN has been a cornerstone of deep space scientific achievement and has been an enabler of new technology and capabilities…that has also changed our daily lives on Earth!!!

This document has been reviewed and determined not to contain export controlled technical data

A day in the life of DSN….enjoy!!!

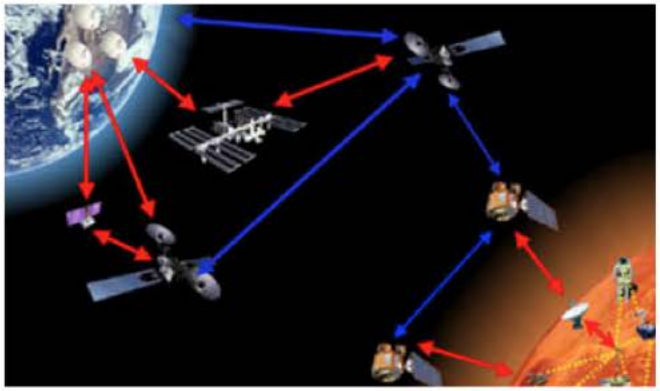
Jet Propulsion Laboratory
California Institute of Technology

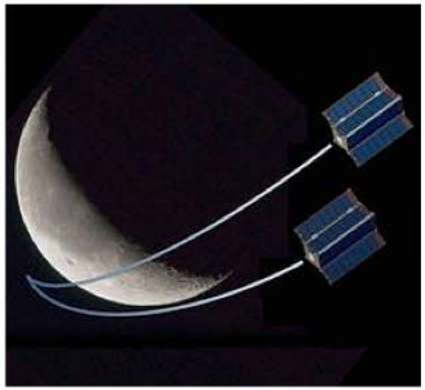
A Short Video…

This document has been reviewed and determined not to contain export controlled technical data

The Madrid Deep Space Communications Complex

Pablo Perez
MDSCC Director





MDSCC

This document has been reviewed and determined not to contain export controlled technical data

MDSCC OVERVIEW

GENERAL DATA

Located about 55km west of Madrid
104 employees
124 acres
6 antennas: 4 operational
1 RA educational
26m decommitted Oct 08
29 buildings
Power Plant

This document has been reviewed and determined not to contain export controlled technical data

MDSCC OVERVIEW

OPERATIONAL ANTENNAS

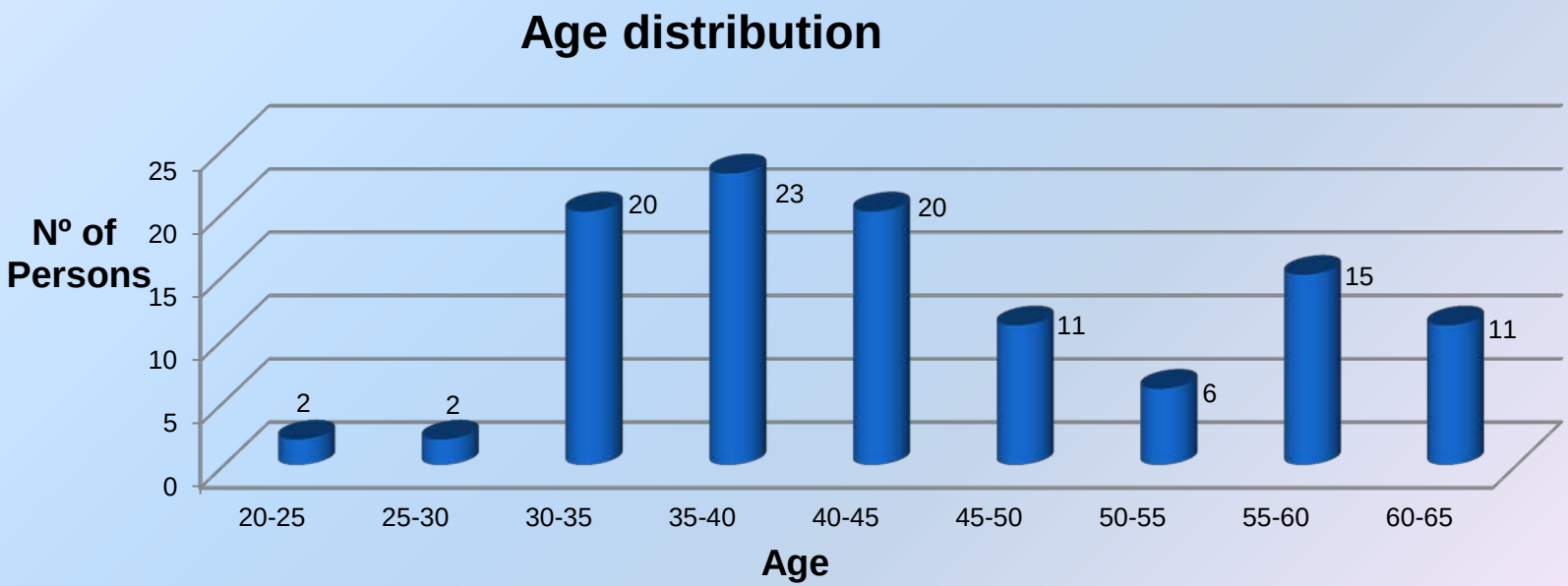
DSS-54 & 55: 34 mts – BWG type
DSS-65: 34 mts – HEF type
DSS-63: 70 mts

Station	S Band		X Band			Ka Band		Ka2	Q
	↓	↑	↓	↑	Acq	↓	↑	↓	↓
DSS54	✓	✓	✓	✓	✓	✓	No	✓	✓
DSS55	No	No	✓	✓	No	✓	No	No	No
DSS63*	✓	✓	✓	✓	No	RA	No	No	No
DSS65	✓	✓	✓	✓	No	No	No	No	No

This document has been reviewed and determined not to contain export controlled technical data

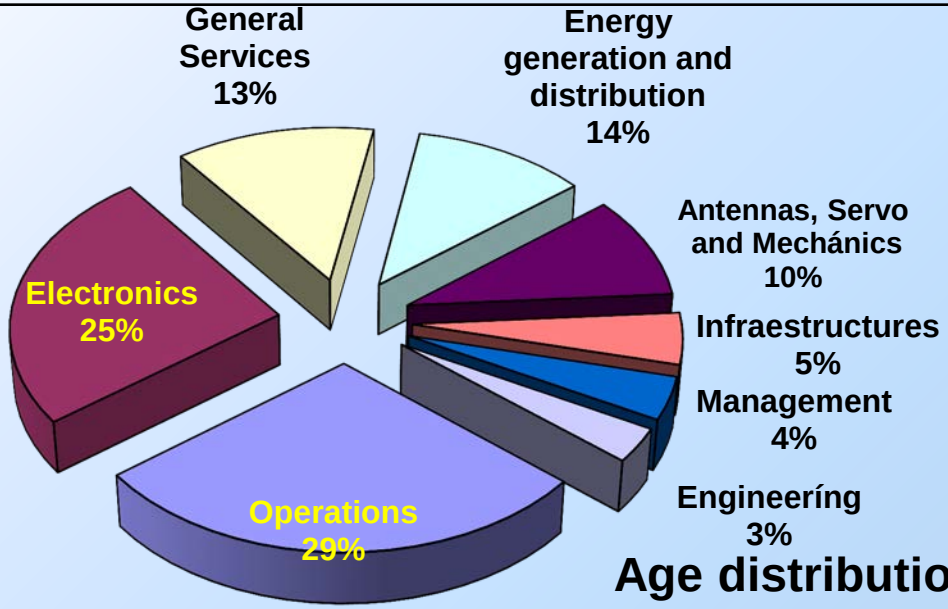
HUMAN RESOURCES

Workforce has decreased from 147 to 104 in the last 8 years
Increasing efficiency
And decreasing average employee age

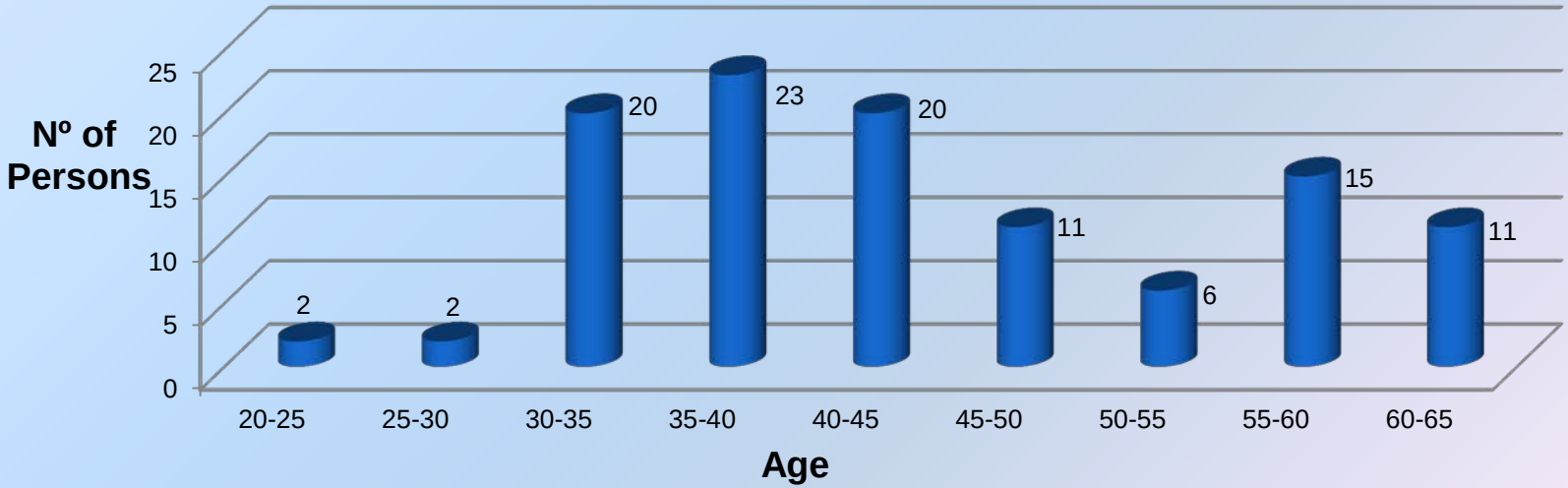


This document has been reviewed and determined not to contain export controlled technical data

MDSCC OVERVIEW



Age distribution



This document has been reviewed and determined not to contain export controlled technical data

MDSCC ROLES

FACILITIES:

- Energy efficiency program
- Environmental code compliance
- Continuous improvement

OPERATIONS:

- 24x365 operative
- 99.8% Data delivery
- 7000 tracks per year

MAINTENANCE:

- Cost effective maintenance
- Preventive maintenance versus total maintenance ratio, 64%
- Less than1% critical corrective maintenance

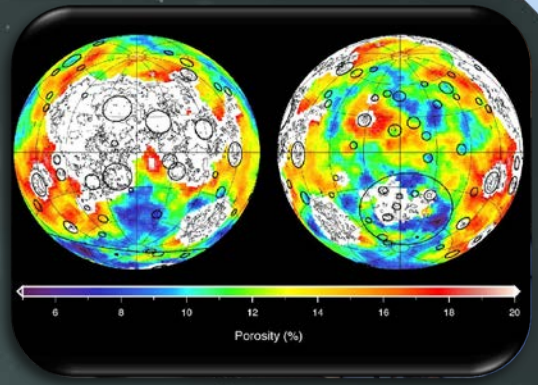
This document has been reviewed and determined not to contain export controlled technical data

OPERATIONS

ALWAYS LOOKING AT SPACE

OVER 30 ACTIVE MISSIONS.

24 x 365 DSN always on
GRAIL support on 2011 December 31st
and 2012 January 1st



LADEE launch & orbital insertion (Oct, 2013)

•MOM launch. DSN cooperation with other space agencies (Nov, 2013)

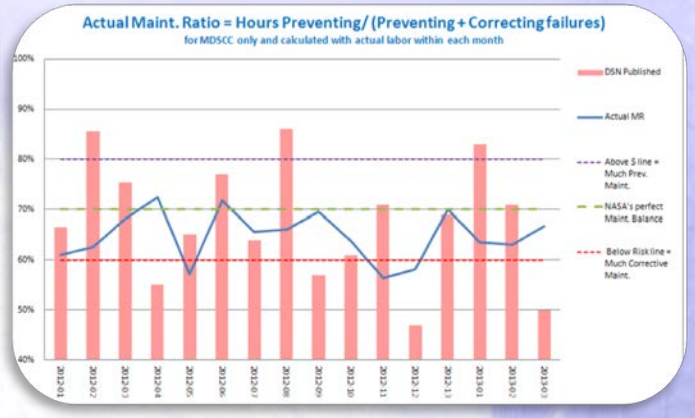
This document has been reviewed and determined not to contain export controlled technical data

MAINTENANCE

FAILURE IS NOT AN OPTION

IMPLEMENTING BEST PRACTICES MAINTENANCE PROGRAM

- Adopting US and local codes
- Standardizing maintenance across the network

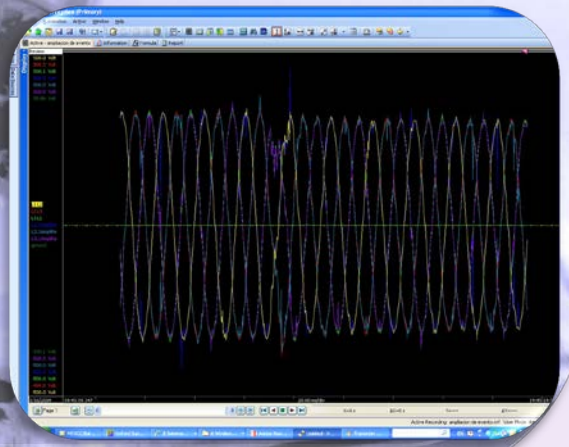


COMPLYING WITH NASA RECOMMENDED MAINTENANCE RATIO

- 64% ratio PM/(CM+PM)

AUTONOMOUS QUICK RESPONSE ON CONTINGENCIES

- Technical expertise personnel is self contained within the complex



This document has been reviewed and determined not to contain export controlled technical data

NEW ACHIEVEMENTS

This document has been reviewed and determined not to contain export controlled technical data

NEW ACHIEVEMENTS

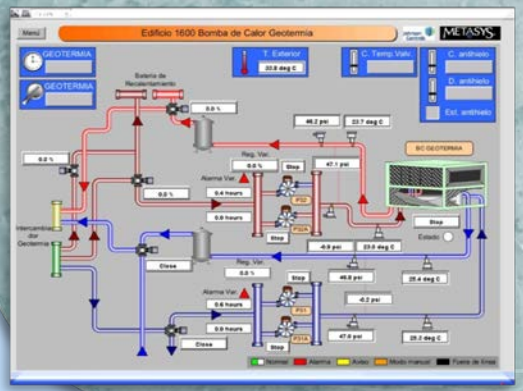
MOVING FORWARD TO IMPROVE

COMMERCIAL POWER

- 14 km 20 kV line
- 50% energy saving cost
- Power source diversification
- Reducing emissions

FPS UPGRADE (2012)

- 2.8 km new pipe
- Over 1000 detection elements
- Increase MDSCC safety



GREEN PROGRAM

- Geothermal, solar, VFD, etc.
- Optimize energy consumption
- Reduce the cost
- Reduce environmental impact

This document has been reviewed and determined not to contain export controlled technical data

ANTENNAS

WORKING AS PART OF DSN TEAM

MANUFACTURED LOCALLY DELIVERY OVERSEAS

- 2 tracks already in operation
- 1 track pending to be shipped
- 2 tracks in project
- Cost saving 40%

UNEXPECTED DSS-54 PEDESTAL REPARATION

- ASR detection

DSS-63 BEARING REPLACEMENT

- Manufacturing time near to one year
- An example of team work

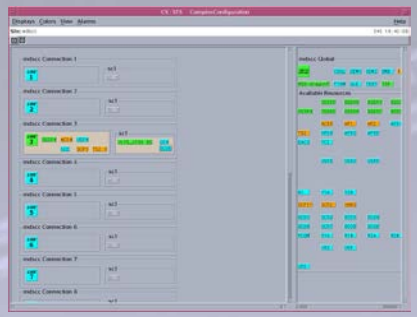
This document has been reviewed and determined not to contain export controlled technical data

MDSCC DEVELOPEMENTS

ADDING VALUE

COMPLEX SUPERVISOR

- Version 2.0.3.
- Working at DSN from 2001



ASSET MANAGER DEVELOPEMENT

- Used at complexes to control DSN assets

ANTENNA CALIBRATION MONITORING EQUIPMENT

- Standard tool for antenna DSN calibration

This document has been reviewed and determined not to contain export controlled technical data

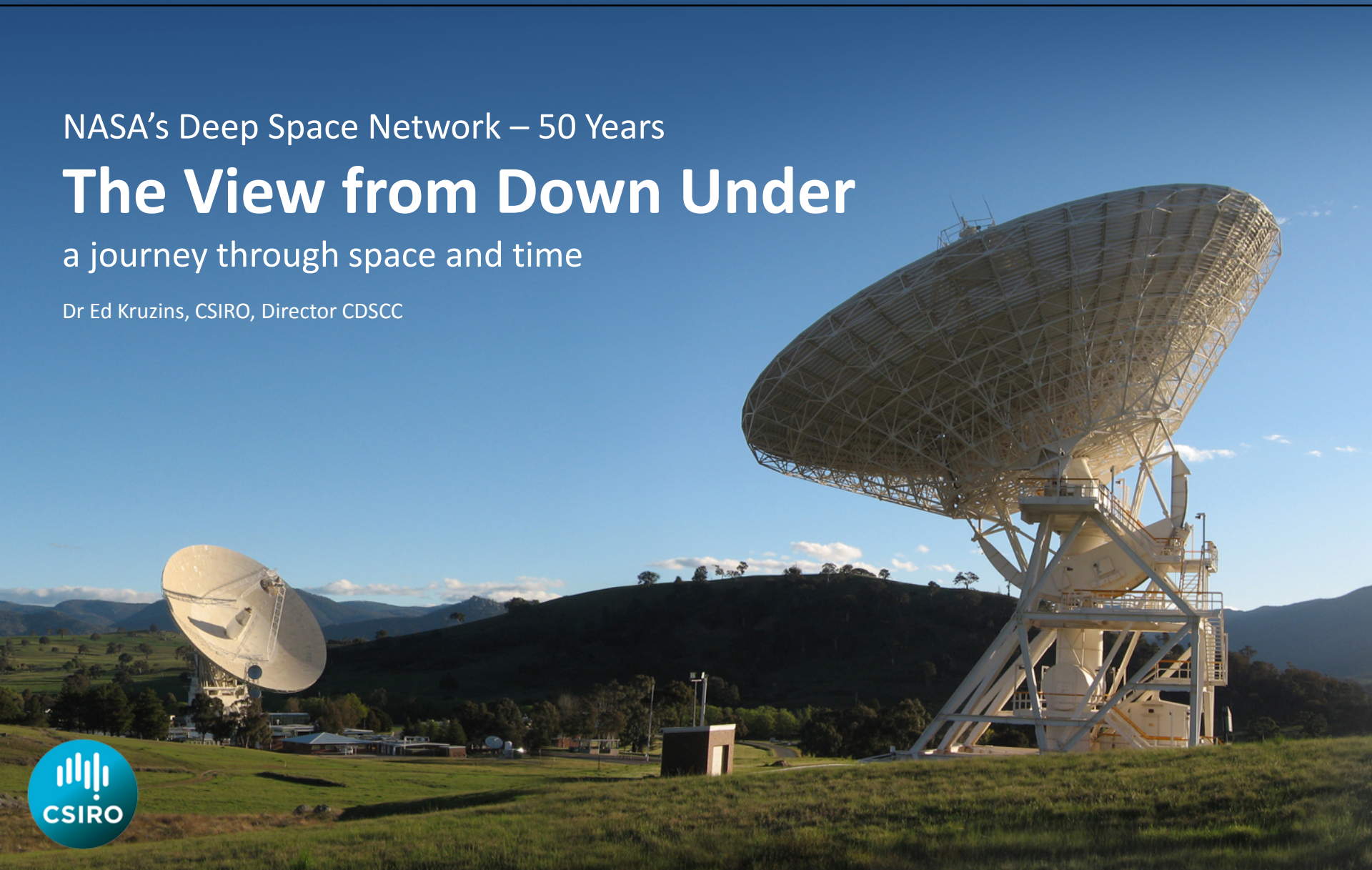
Jet Propulsion Laboratory
California Institute of Technology

NASA's Deep Space Network – 50 Years

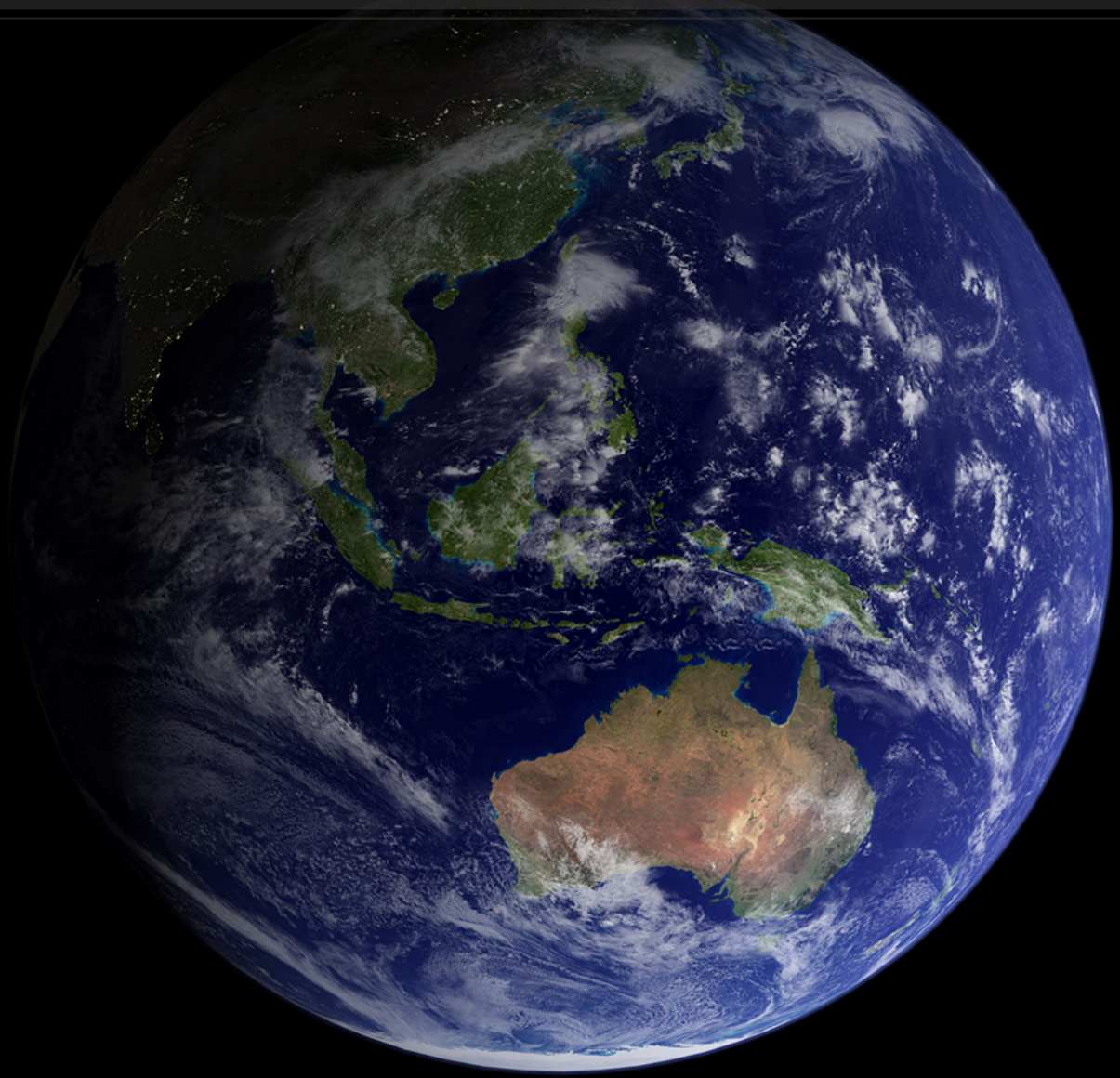
The View from Down Under

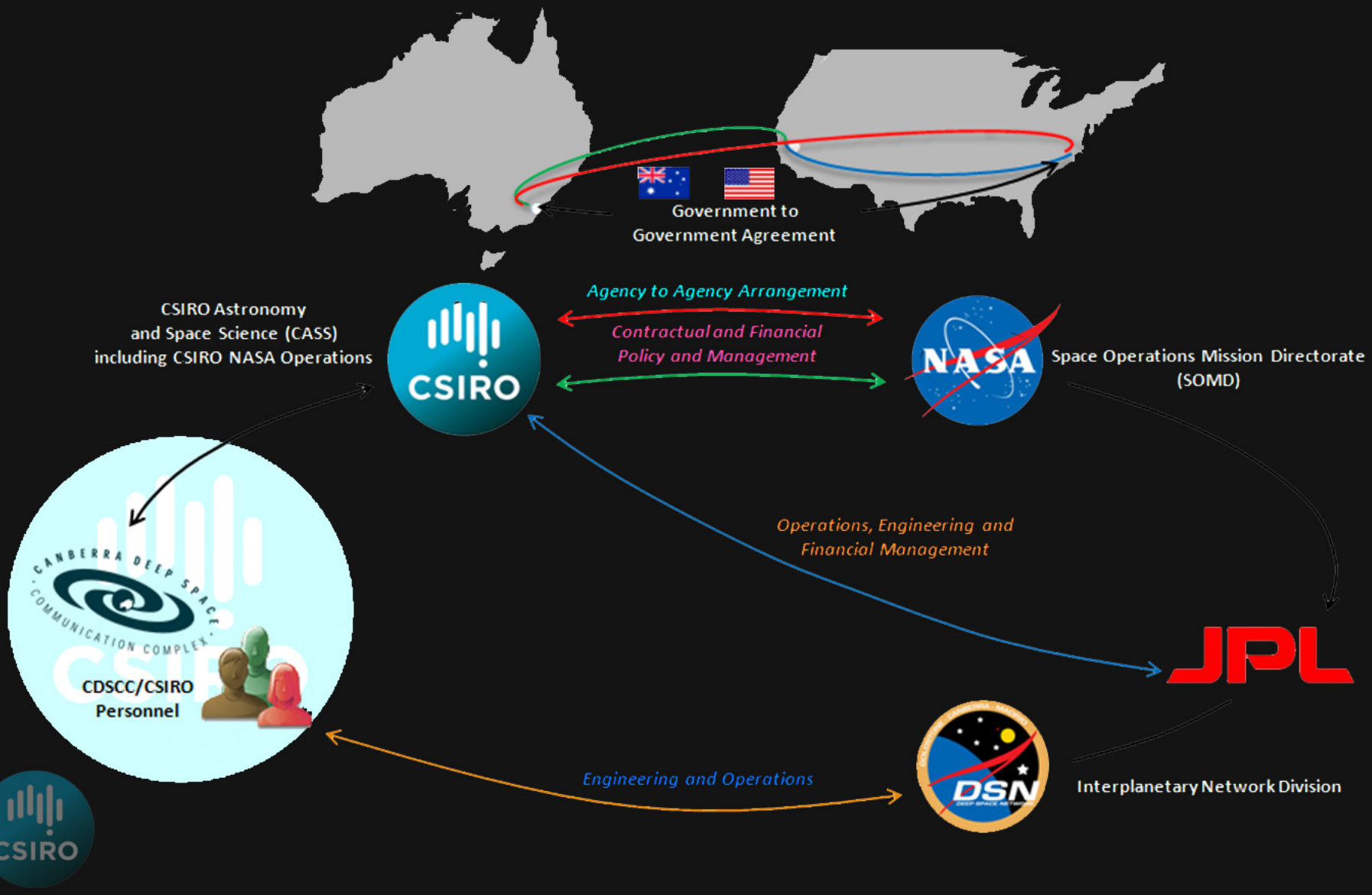
a journey through space and time

Dr Ed Kruzins, CSIRO, Director CDSCC



Jet Propulsion Laboratory
California Institute of Technology




Government to
Government Agreement
CSIRO Astronomy
and Space Science (CASS)
including CSIRO NASA Operations
CSIRO
Agency to Agency Arrangement
Contractual and Financial
Policy and Management
NASA
Space Operations Mission Directorate
(SOMD)
Operations, Engineering and
Financial Management
CANBERRA DEEP SPACE
COMMUNICATION COMPLEX
CDSCC/CSIRO
Personnel
JPL
Engineering and Operations
DSN
Interplanetary Network Division
CSIRO

Red Lake

STOP
RADIATION HAZARDS
DO NOT LOOK AT AERIALS
DO NOT LOITER IN AREA

Muchea

Jet Propulsion Laboratory
California Institute of Technology

Perth

Jet Propulsion Laboratory
California Institute of Technology

Island Lagoon

Jet Propulsion Laboratory
California Institute of Technology

Carnarvon

Jet Propulsion Laboratory
California Institute of Technology

Skylab

CSIRO

Jet Propulsion Laboratory
California Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology

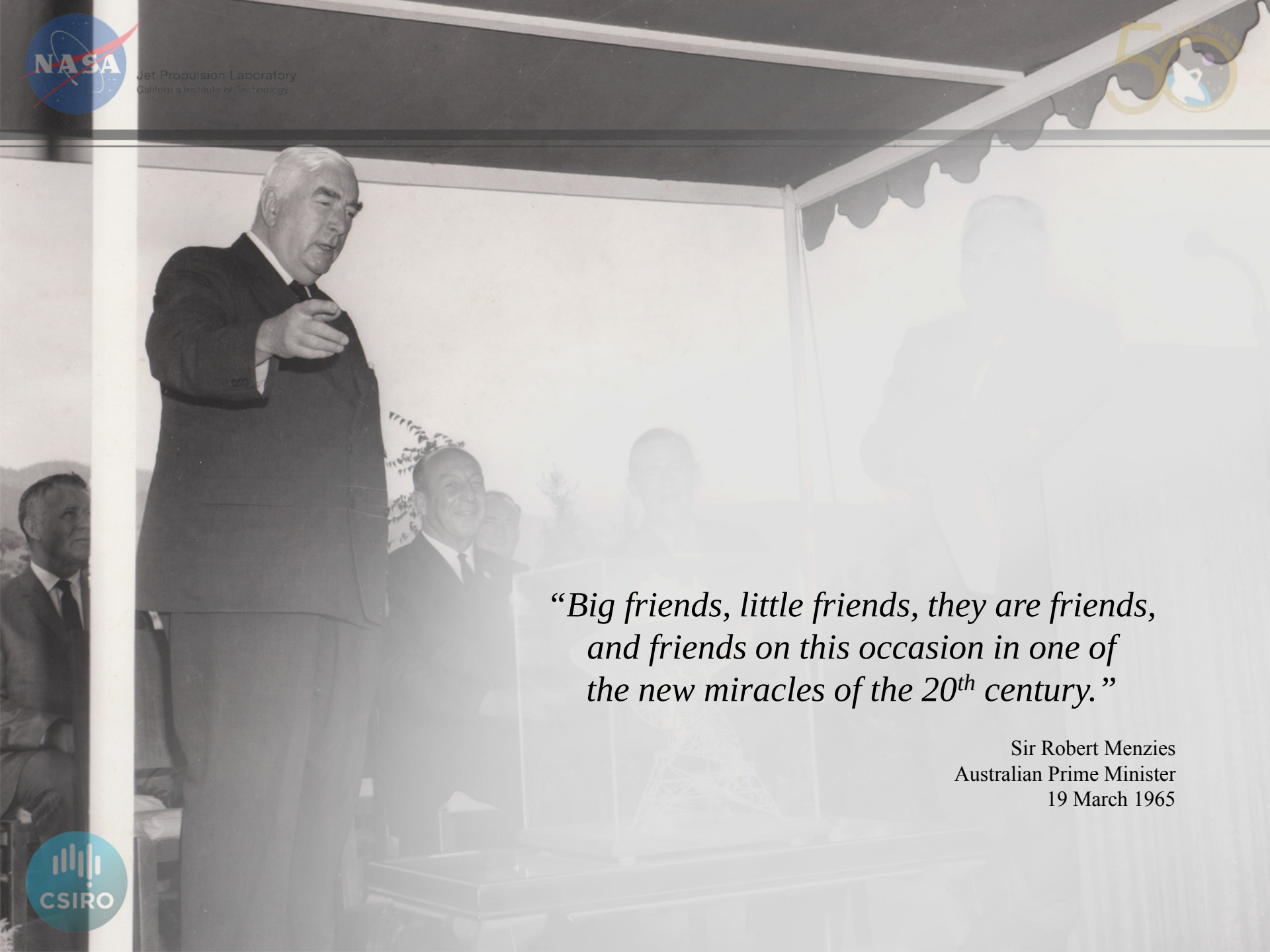
Jet Propulsion Laboratory
California Institute of Technology

19 March 1965

Jet Propulsion Laboratory
California Institute of Technology

19 March 1965

CSIRO



"Big friends, little friends, they are friends, and friends on this occasion in one of the new miracles of the 20th century."

Sir Robert Menzies
Australian Prime Minister
19 March 1965

Head of State

Don Gray

Jet Propulsion Laboratory
California Institute of Technology

Miracle workers

Miracle workers

Jet Propulsion Laboratory
California Institute of Technology
Miracle workers
CSIRO

Miracle workers

Jet Propulsion Laboratory
California Institute of Technology

Miracle workers

CSIRO

Jet Propulsion Laboratory
California Institute of Technology

History makers

CSIRO

Jet Propulsion Laboratory
California Institute of Technology

History makers

CSIRO

Jet Propulsion Laboratory
California Institute of Technology
History makers
CSIRO

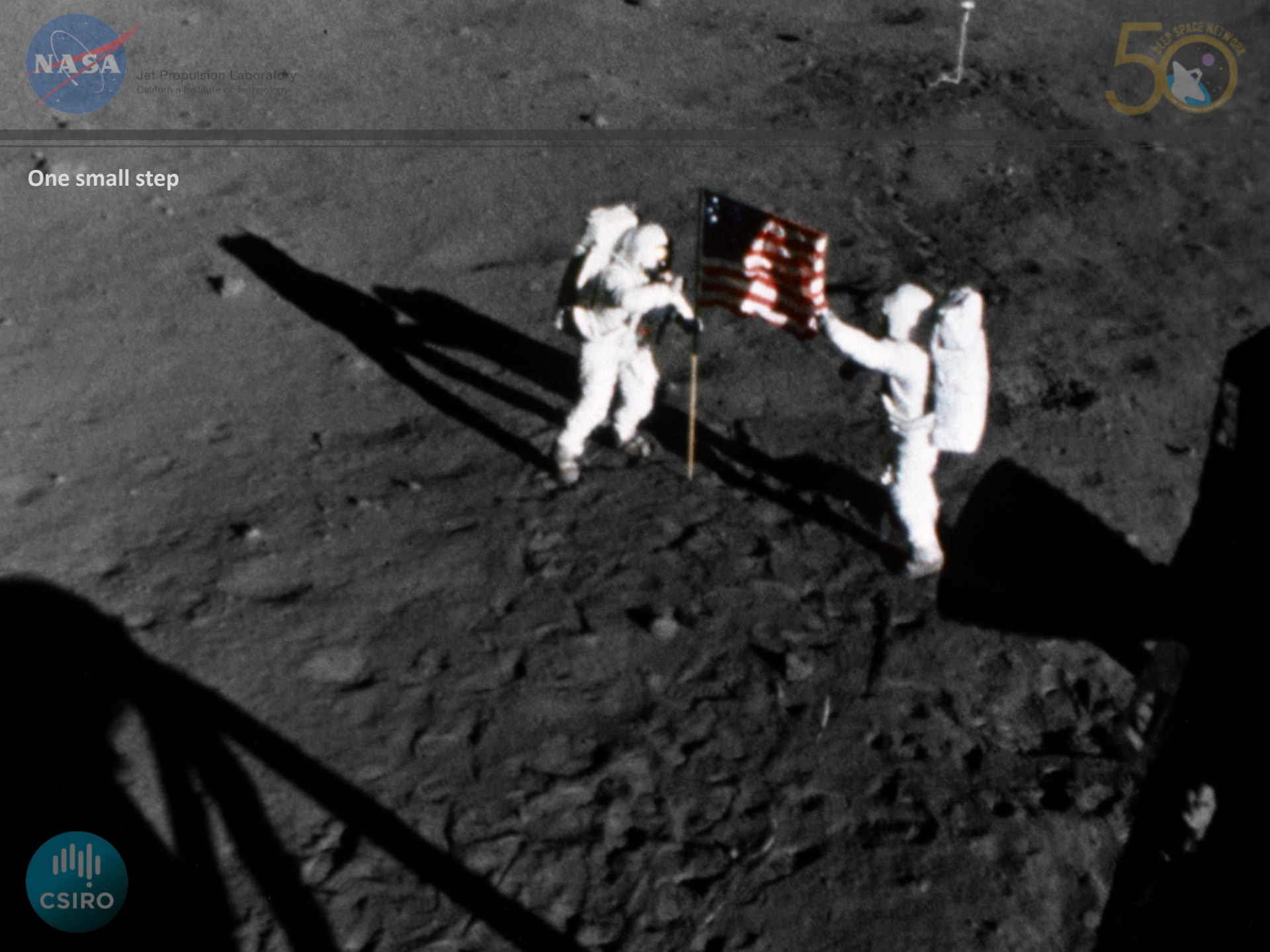
Jet Propulsion Laboratory
California Institute of Technology

DSS46

Honeysuckle Creek

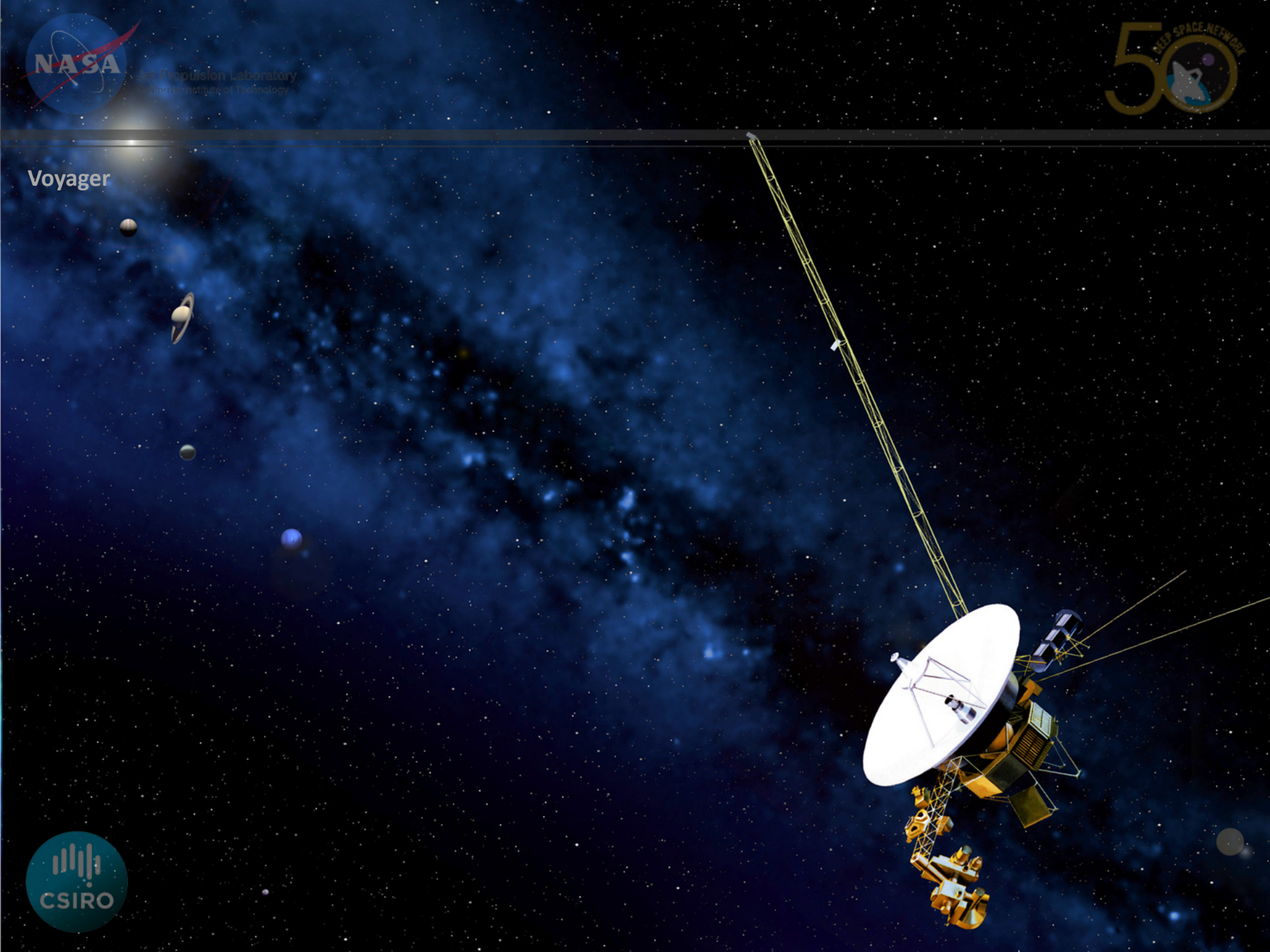
Jet Propulsion Laboratory
California Institute of Technology

One small step



Jet Propulsion Laboratory
California Institute of Technology

DSS43


Voyager

Jet Propulsion Laboratory
California Institute of Technology

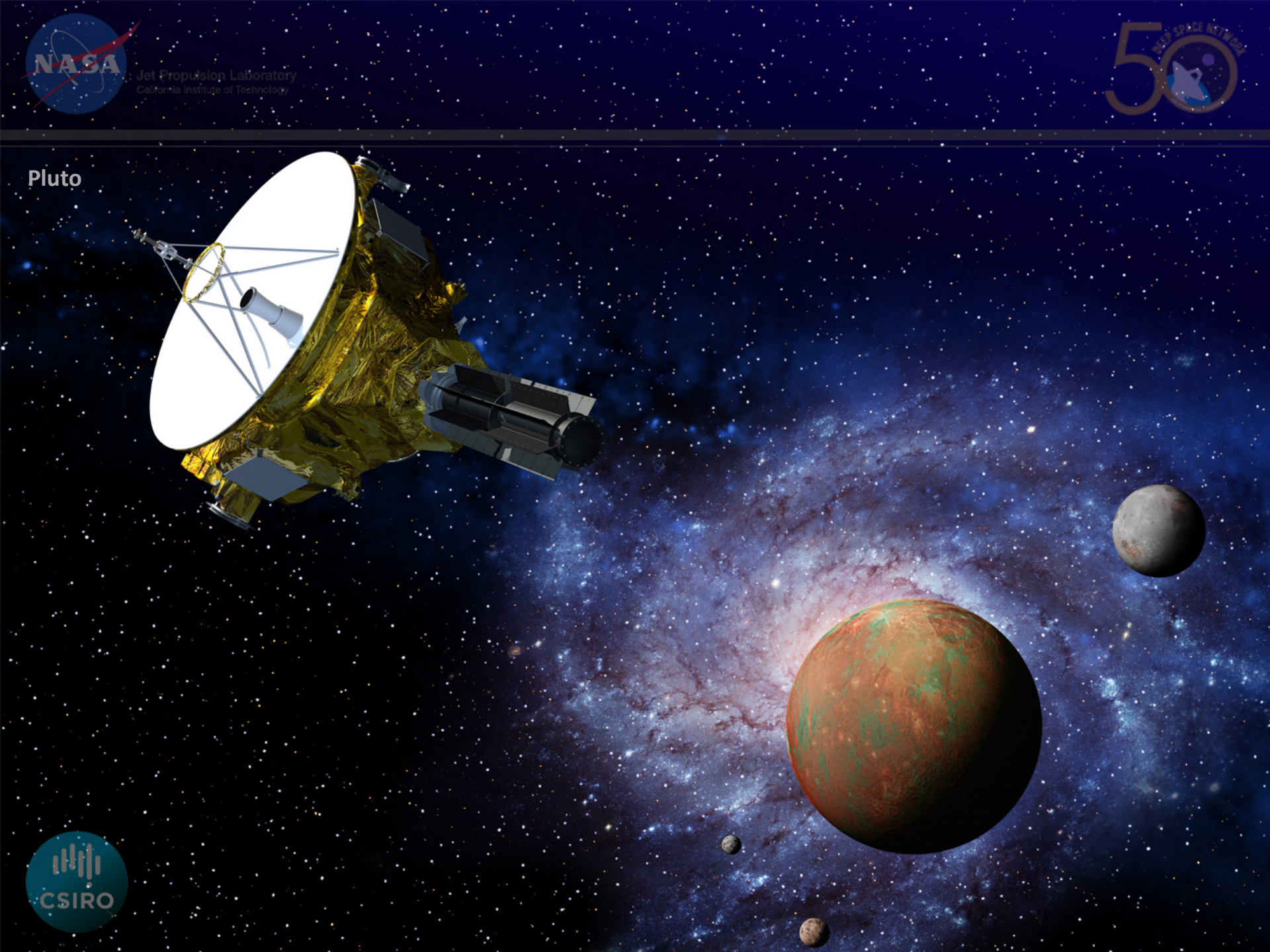
DSSs 34/45/43

The day

NASA
Jet Propulsion Laboratory
California Institute of Technology
CSIRO

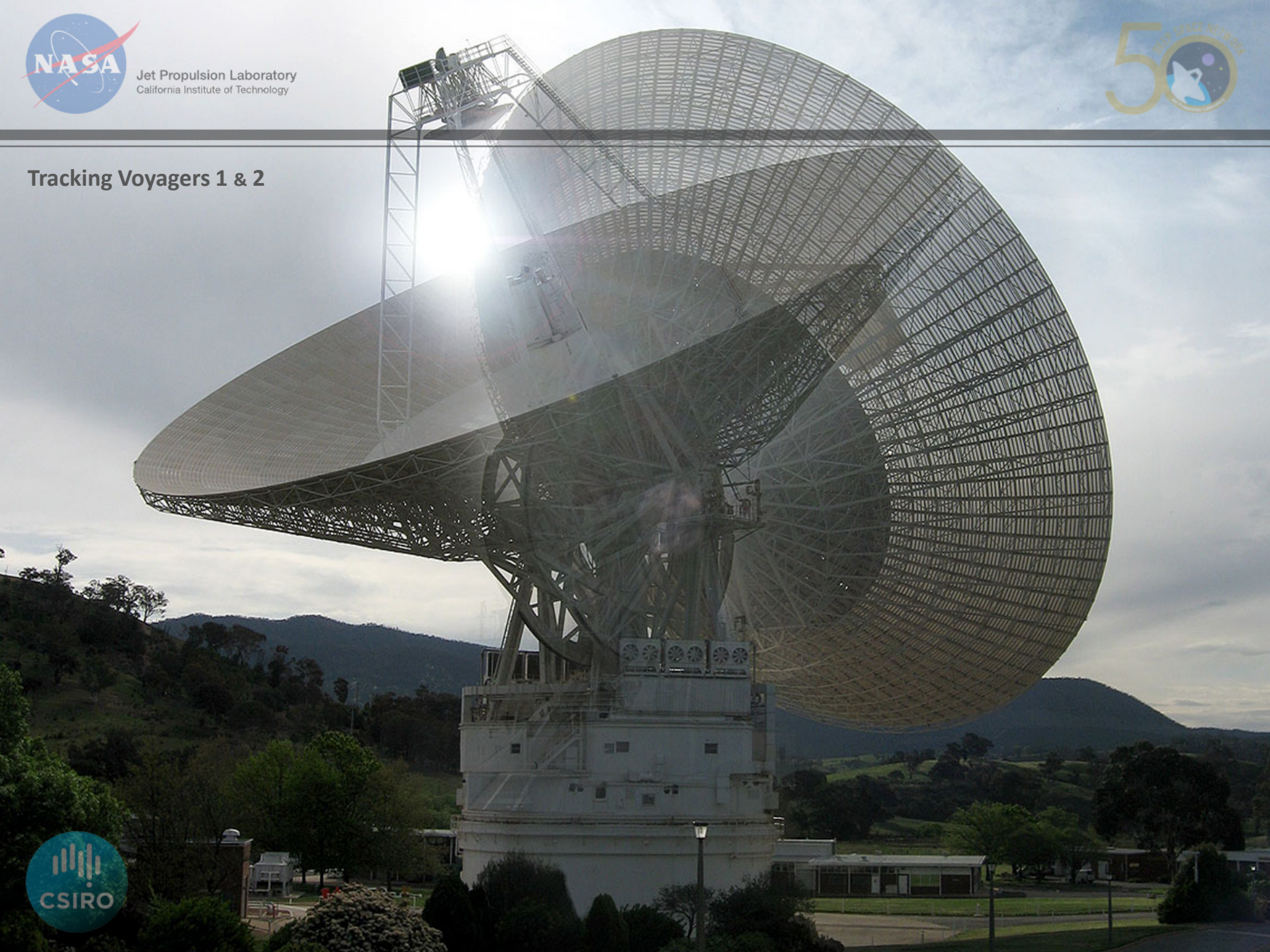
Data Management
CSIRO

Jet Propulsion Laboratory
California Institute of Technology
DSS 35
CSIRO


Jet Propulsion Laboratory
California Institute of Technology
Pluto
CSIRO

Jet Propulsion Laboratory
California Institute of Technology

Tracking Voyagers 1 & 2



The future

Jet Propulsion Laboratory
California Institute of Technology

More to come

Jet Propulsion Laboratory
California Institute of Technology

Looking bright

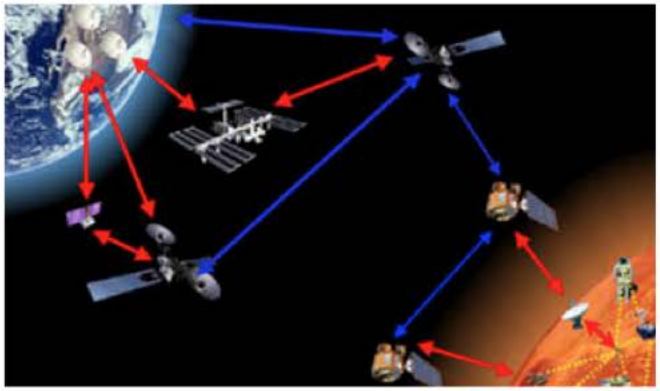
Jet Propulsion Laboratory
California Institute of Technology

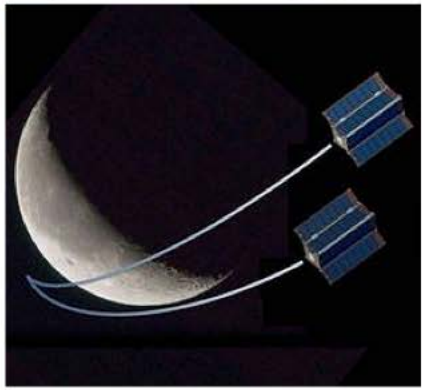
NASA's Deep Space Network – 50 Years

Thank you

The Goldstone Deep Space Communications Complex

Michael Clements
Goldstone Complex Manager



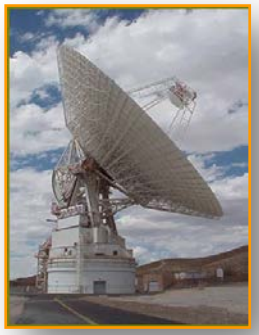


This document has been reviewed and determined not to contain export controlled technical data

The Goldstone Deep Space Communications Complex

The Antennas

- Goldstone Consists of 8 Operational Deep Space Stations (DSS)
- Antenna Sizes Range from 34 Meters to 70 Meters in Diameter
  - DSS-13 (34m BWG: R&D)
  - DSS-14 (70m)
  - DSS-15 (34m HEF)
  - DSS-24, 25 & 26 (34m BWG)
  - DSS-28 (34m HSB: GAVRT)



The Complex

- Approximately 45 miles NW of Barstow, CA & 155 miles from JPL
- Goldstone covers ~52 square miles of Territory & is located on Fort Irwin Military Reservation
- 5 Primary Sites (Echo, Mars, Apollo, Venus & Gemini)
- Centralized Control of Assets at the Signal Processing Center (SPC-10) located at Mars Site

The People

- ~ 160 Personnel Operate/Maintain all Aspects of Complex Functions
- Very Diverse Skill-Sets
  - Spacecraft Communication Operators
  - Electronic/Digital, RF, Communications, Hydro-Mechanical Technicians & Field Engineers
  - Electrical, HVAC, System Controls, Fire Protection, Facility Maintenance Technicians & Field Engineers
  - Finance, Logistics, Business & Armed Security Support Staff
  - Outreach

This document has been reviewed and determined not to contain export controlled technical data

The Goldstone Deep Space Communications Complex

The Environment

- Vast Array of Wildlife
- Goldstone is home to wide variety of flora & fauna, two endangered species & some dangerous species
- Temperatures Range from Below Zero to +120° F

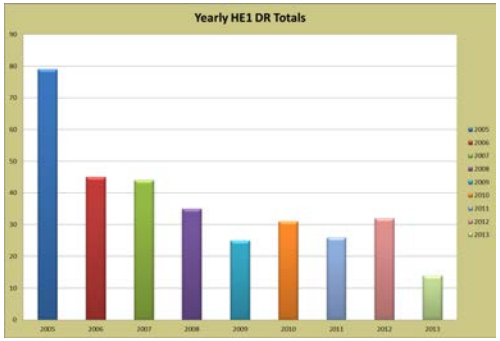
This document has been reviewed and determined not to contain export controlled technical data

GDSCC
Recent Accomplishments

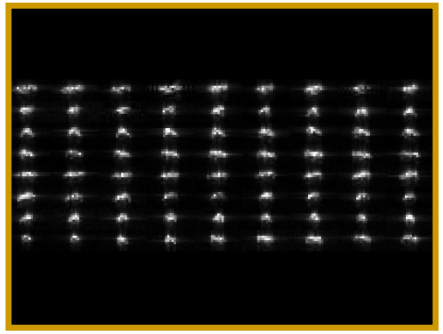
Operational Efficiency

- High Power Radiation Clearance Process
- Improved Workstations
- 2-Links per Operator

Significant Reduction of Human Errors

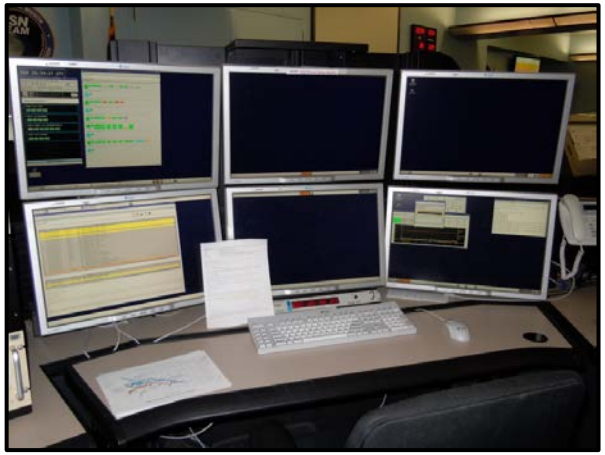


- Increasing Demand on Goldstone High Power Radar



72 individual radar-generated images of asteroid 2012 DA14 created using data from NASA's 70m DSN antenna at Goldstone

Goldstone Radiation Avoidance Map (GRAM)



Workstation Upgrades

This document has been reviewed and determined not to contain export controlled technical data

GDSCC
Recent Accomplishments

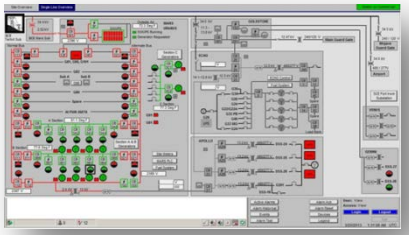
Reliability Improvements

- Site-Wide Uninterruptible Power Supply (SWUPS)
- Vast Infrastructure Upgrades
- Extensive Expansion of Infrared & Predictive Technologies
- DSS-14 70m DLM – Life Extension

4MW SWUPS

DSS-14 (70M) Suspended on 3 Sets of Legs

IR 'Find' Capture



FAC VLAN Implementation

HVAC Upgrades

This document has been reviewed and determined not to contain export controlled technical data

DSS-14: 70M Antenna Life Extension Tasks

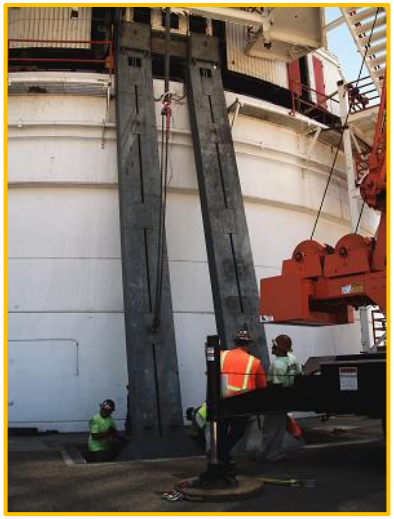
- Painting
- Hoists
- Azimuth Gearbox Support
- Azimuth Databoxes
- Hydrostatic Bearing
- Servo-Hydraulics
- Reservoir Walls Replace Runner
- Elevation Databoxes
- Elevation Drive Struts
- Master Equatorial
- Antenna Power Modernization
- Radial Bearing Wear Strips
- HVAC Mods
- Pedestal Study

This document has been reviewed and determined not to contain export controlled technical data

DSS-14: 70M Antenna Life Extension Tasks

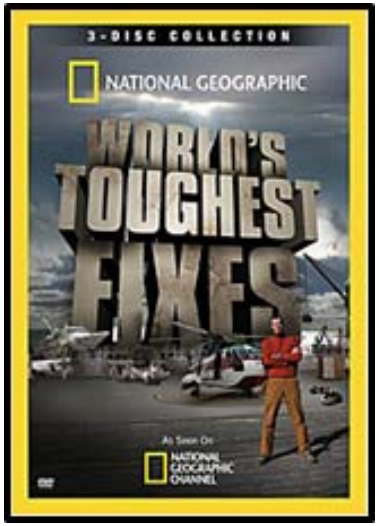
Epoxy Grout Pour

Alignment of Runner Segments



Rotating Structure Support Installation

El Bearing Replacement



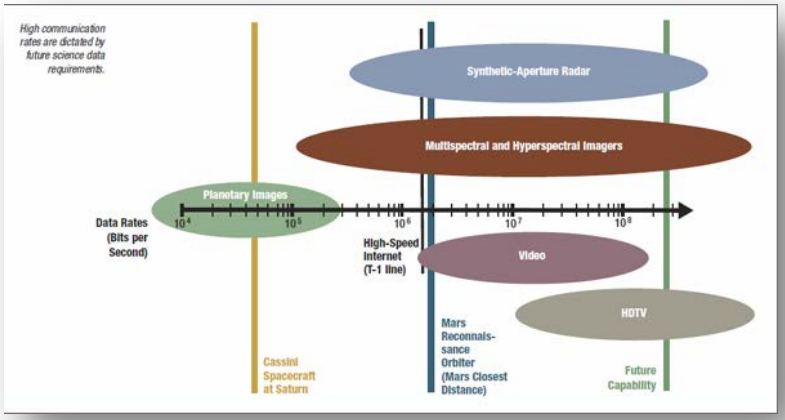
Removal of Pad

Future Upgrades & Initiatives

- 80kW Transmitter
- Addition of 4th 34m BWG Antenna
- Automated Link Builder (ALB)
- Consolidating Footprint
- Optical Communication

100kW Klystron under Test

Apollo Valley



High Communication Rates are Dictated by Future Science Data Requirements

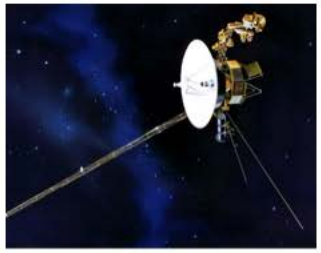
The Deep Space Network

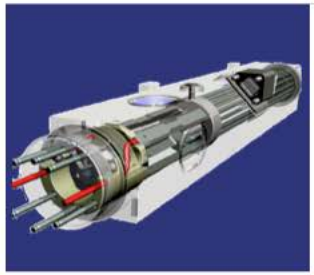
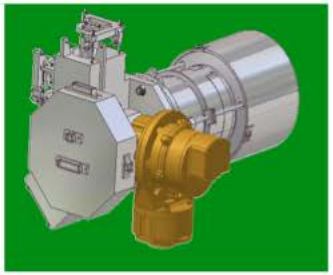
GDSCC In Action

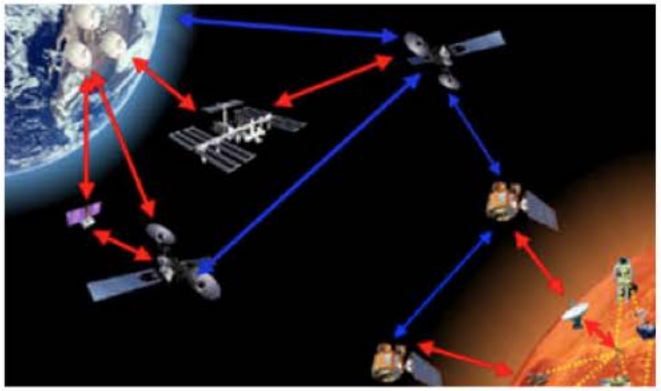
This document has been reviewed and determined not to contain export controlled technical data

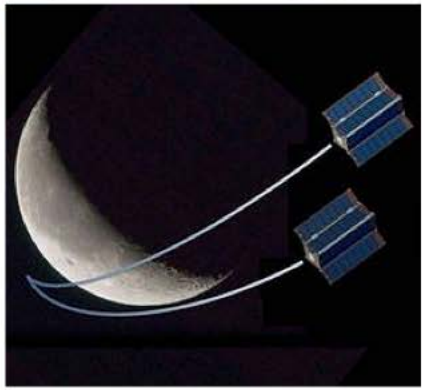
The Deep Space Network
The Most Important Science Tool of the Last 50 Years?

Joseph Lazio
Chief Scientist
Interplanetary Network Directorate
Les Deutsch
Deputy Director For
Interplanetary Network Directorate







50 Years of Science

The 20th century saw enormous strides in science & engineering

Took only 66 years to progress from first human powered flight to landing humans on the Moon

How can we begin to grasp scientific progress during lifetime of the DSN?

Council for the Advancement of Science Writing represents science journalists who serve as bridge between scientists and public

- Published a "Top 50 List" – starting from 1957
- Pretty close to first 50 years of the DSN!

50 Years of Science

Of top 50 science advances, the Deep Space Network was intimately involved with 22!

Not a bad record

Probably as good as any other scientific instrument

Let's examine the list and the role the DSN has played in advancing science in its first 50 years …

1. Satellites

Sputnik 1 launched in 1957, shocking the world

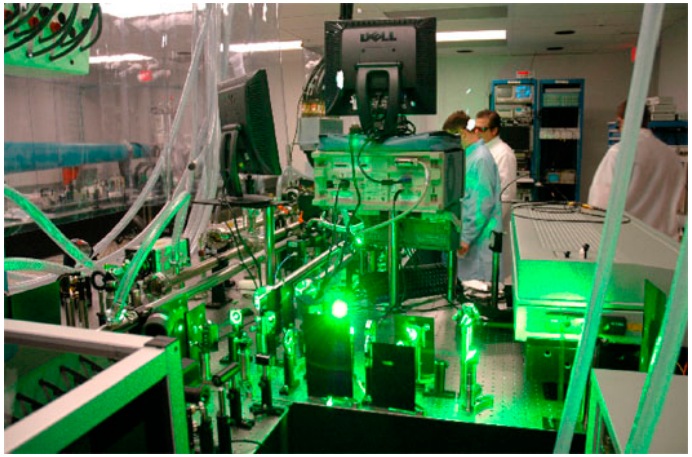
The DSN was built soon after, to enable much more capable satellites

Communicating with satellites was critical – as was navigating them on their journeys, particularly as they left the "safe" low Earth orbit pioneered by the Sputniks

Without the DSN, we would not have had spacecraft to the Moon and, later, to other planets

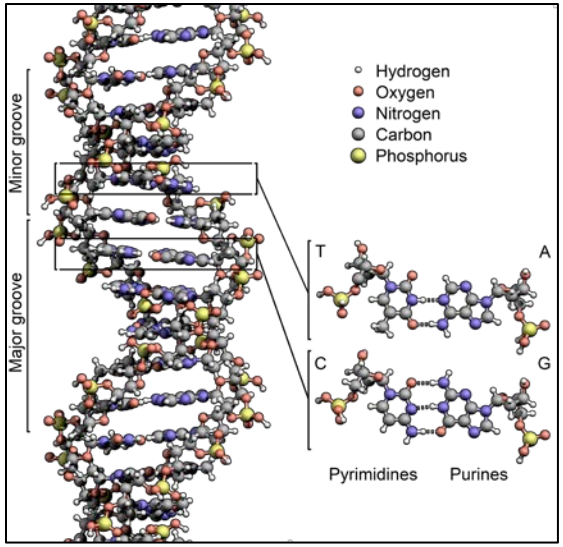
Some non-DSN Science

2. 1960 – The Pill



3. 1960 – Lasers

(remember these …)



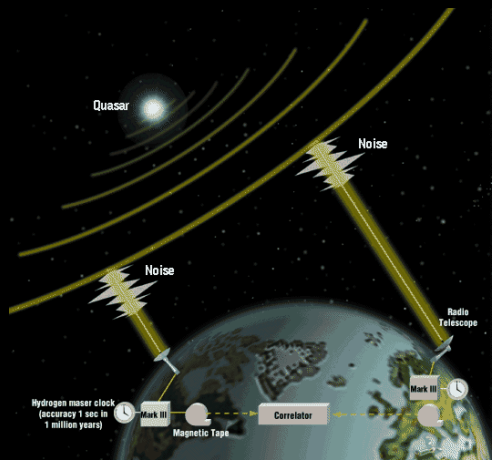
4. 1961 – DNA Code

5. Plate Tectonics

In 1961, model of plate tectonics came into prominence, explaining the observed spreading of the sea floor and uplifting of mountain ranges

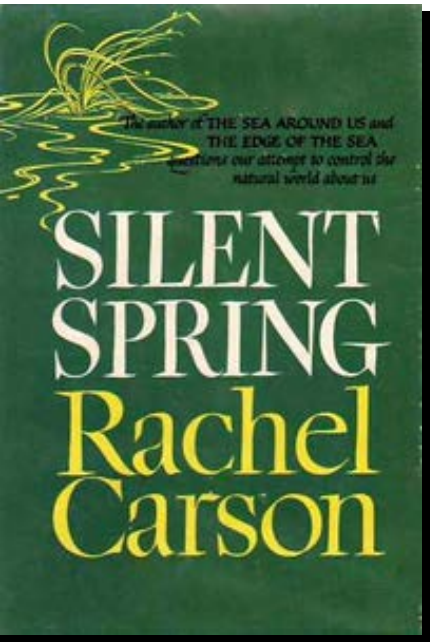
Precise measurement was critical to providing the evidence --- accomplished by observing space radio sources with pairs of antennas on different plates.

The DSN was ideally suited to this task and provided much of the data required to hone this new model



6. Environmental Movement

Jet Propulsion Laboratory
California Institute of Technology



The 1962 book Silent Spring *is credited with starting American environmental movement, leading in turn to global awareness.*

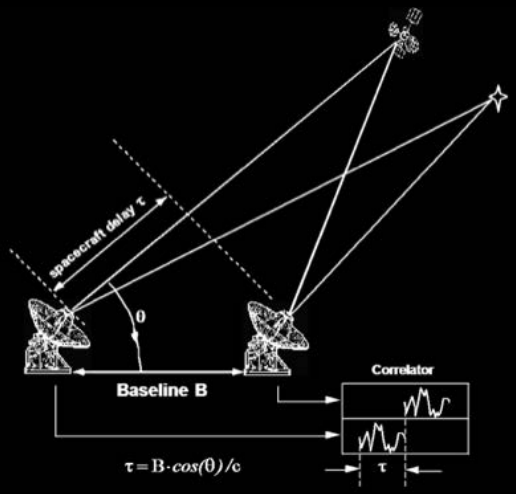
Most scientists also recognize the contributions of "Earthrise" photo, snapped by Apollo 8 astronauts and returned by the DSN.

7. Quasars

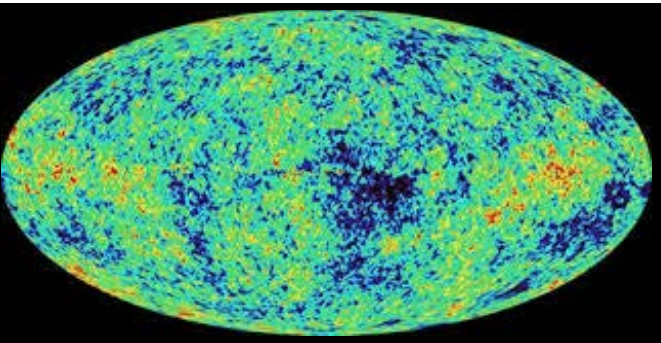
Quasars, energetic galactic nuclei, were discovered in 1963. Unlike other radio emissions from deep space, quasars behave like point sources

Quasars make ideal signposts in deep space because of their stability and the fact that they emit radio waves that can be observed by the DSN.

The DSN has cataloged these sources and uses them for navigating spacecraft in deep space



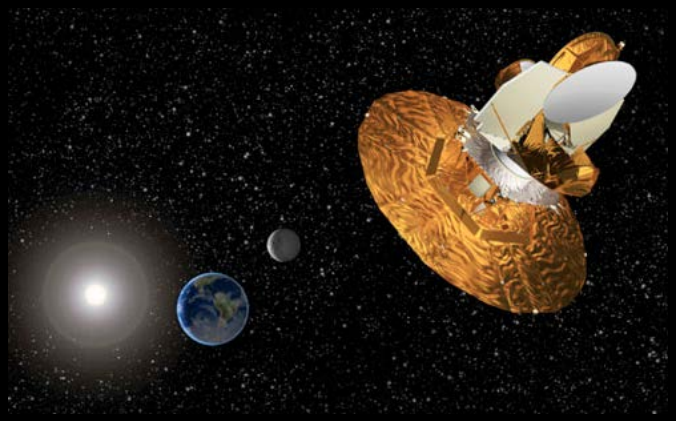
9. Cosmic Background
25. Cosmic Inflation
39. Dark Energy
43. Age of the Universe



Cosmic Microwave Background, a remnant of the Big Bang, discovered in 1964

Much of what we know today about the early Universe, and its subsequent evolution, is from deep-space spacecraft studying the CMB.

The DSN is so sensitive that spacecraft engineers have to account for the power contributed by the Cosmic Microwave Background



11. Moon Landing

In 1969 Neil Armstrong became first human to step onto the Moon. The Apollo Program spurred a host of new technologies to benefit all of us.

The DSN supported all the Apollo missions, providing communications and tracking.

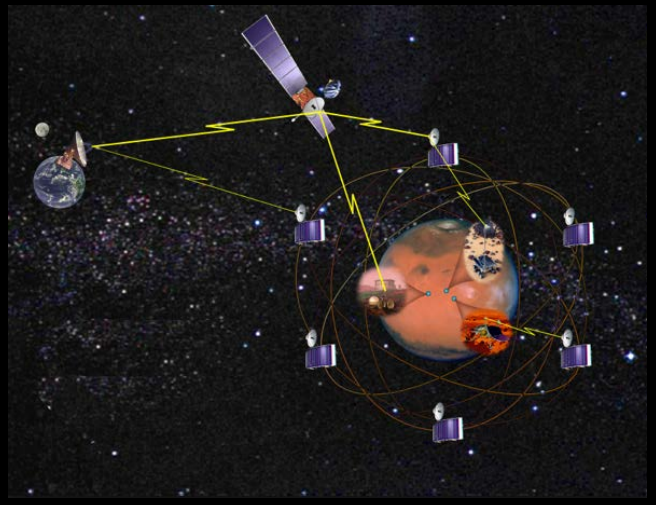
The DSN relayed the video of Armstrong's first steps on the lunar surface

12. Internet

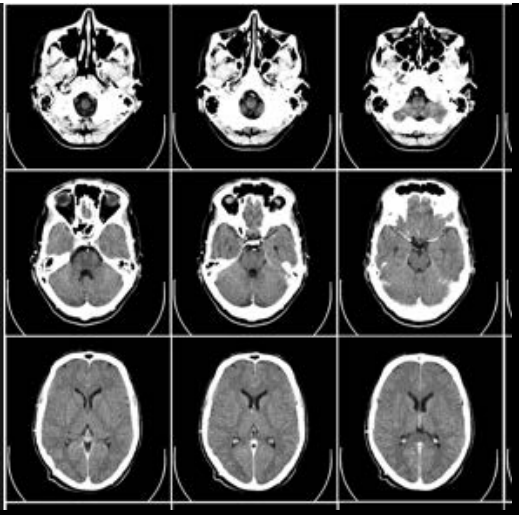
ARPANET was established in 1969 – precursor to today's Internet. Essential to the Internet is a protocol for exchanging information among nodes, accounting for delays and disruptions

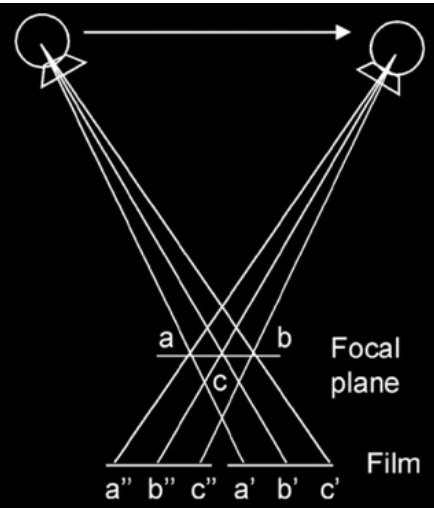
Today, the DSN is working to extend the Internet across the solar system – allowing a virtual presence wherever we are exploring.

DSN scientists are deploying Disruption Tolerant Networking, a new set of protocols that enable robust communications over planetary distances



14. Medical Scanners

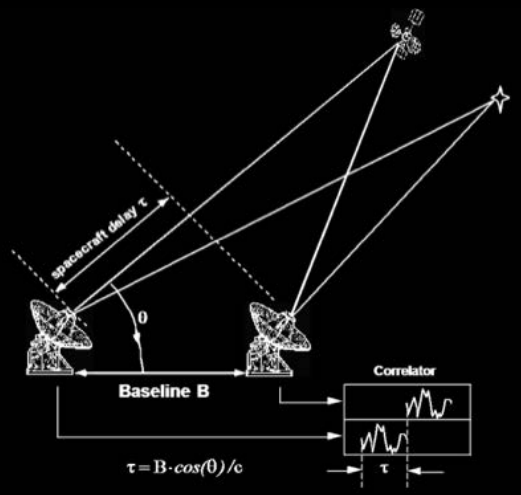




In 1972 Godfrey Hounsfield invented "computer tomography." CT scans revolutionized medical science.

Where have we seen this diagram before?

Mathematics of CT processing derives from the algorithms used for space navigation and radio science. DSN researchers contributed to emerging field of medical scanning in the 1980s.



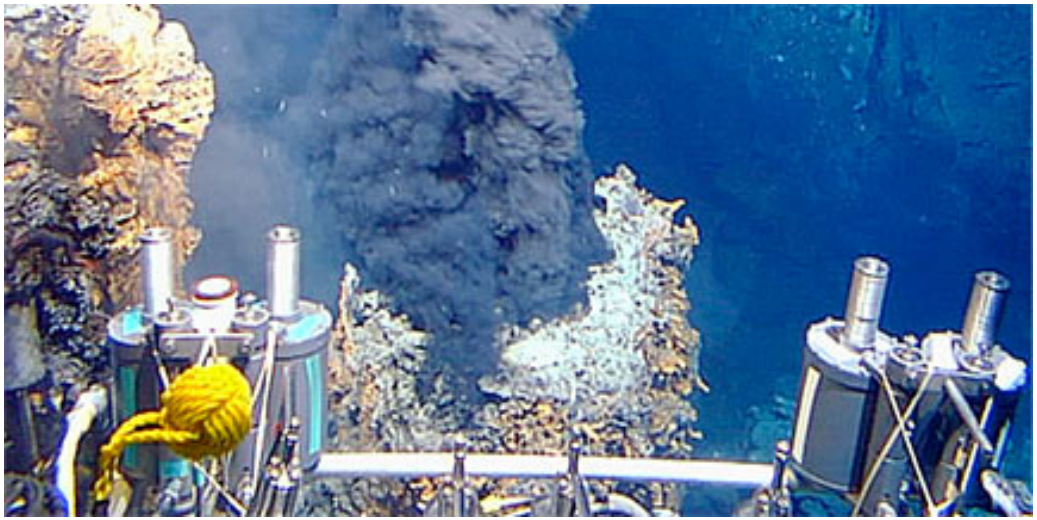
18. Pictures From Other Planets

Jet Propulsion Laboratory
California Institute of Technology

In 1976, NASA Viking landers sent back first pictures from the surface of another planet: Mars

The DSN has brought back photos, and other information, from all the planets in the solar system. The dwarf planet Pluto will be visited in 2015.

Non-DSN Science?



19. 1977 – Deep-Sea Life

Honorable mention:

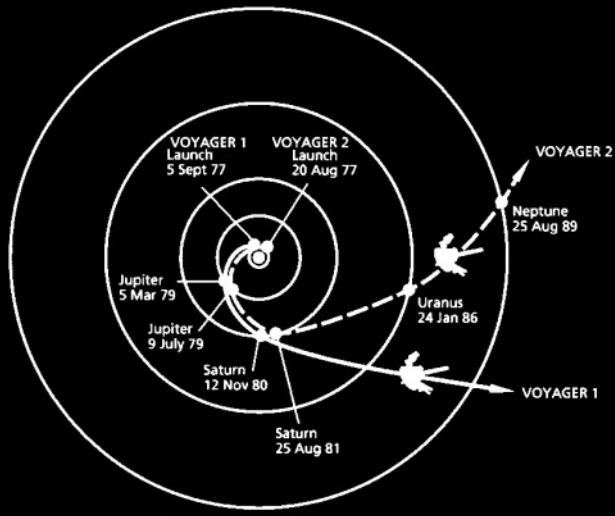
When John Delaney was forming UW's Neptune Project to study life around thermal vents on the ocean floor, he contacted JPL's DSN engineers because their expertise in communicating in hostile environments.

20. Farthest Frontier

In 1977, NASA launched the two Voyager spacecraft to study Jupiter and Saturn

In order to "keep up" with the Voyagers – which went on to visit Uranus and Neptune, the DSN made extensive upgrades and developed substantial new communications technology

Now that Voyager 1 has left the Solar System, every day sets a new distance record with the DSN

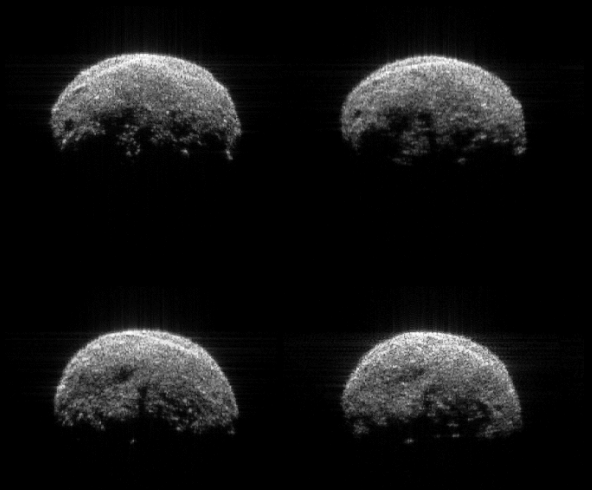


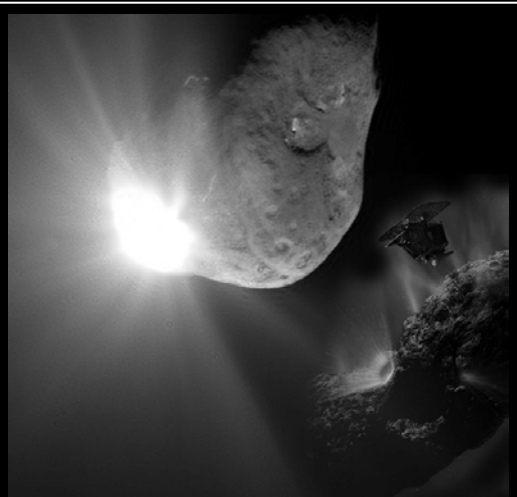
24. Killer Asteroids
31. Catching Up With Comets
33. Witnessing a Cosmic Crash

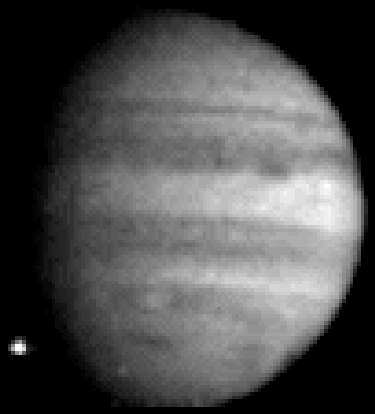
Major collision with an asteroid or comet killed off the dinosaurs proposed in 1980.

Could we be next?

Asteroid and comet chasing, deep space trajectories, radar studies of asteroids and comets --- all have benefited from the DSN and DSN researchers







36. Alien Planets
46. Planets Realigned

In 1995, first definitive discovery of a planet orbiting another "normal" star announced

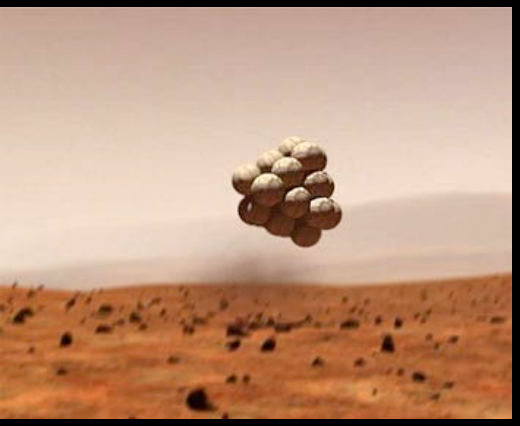
In 2006, "planet" officially defined, and Pluto re-christened as "dwarf planet."

Spacecraft supported by the DSN, primarily Kepler*, have increased the number of known planets from 9 to more than 3500 in the last 50 years.*

Planetary orbits were a consideration in the re-definition of Pluto.

CREDIT: PHL @ UPR Arecibo (phl.upr.edu) April, 2013

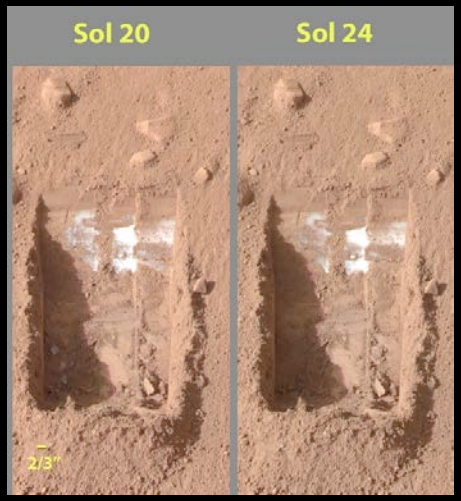
38. Big Bounce on Mars
49. Tasting Martian Water



1997 saw new start for Mars exploration with landing of Mars Pathfinder *and its rover,* Sojourner

Rovers offered potential for more detailed exploration

Succession of ever more capable rovers and landers, following the water, and setting up a Mars relay network with the orbiters

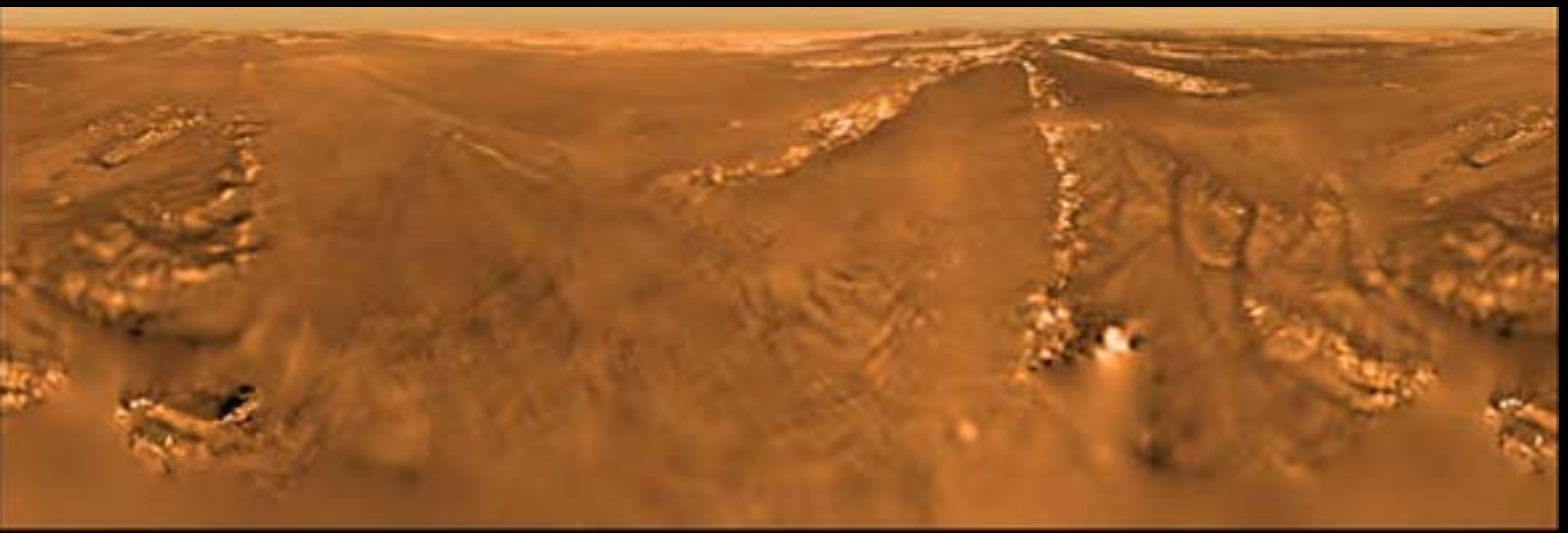


45. Titan Revealed

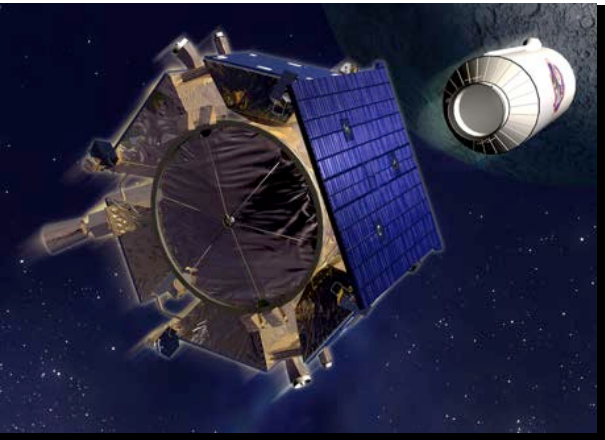
In 2005, Huygens *probe released from* Cassini *and parachuted to surface of Saturn's moon, Titan*

Hidden under perpetual clouds, the only previous images of Titan's surface came from the DSN radar.

A little-known fact is that the Huygens mission was saved through a joint effort of DSN and ESA engineers to work around anomaly discovered after launch



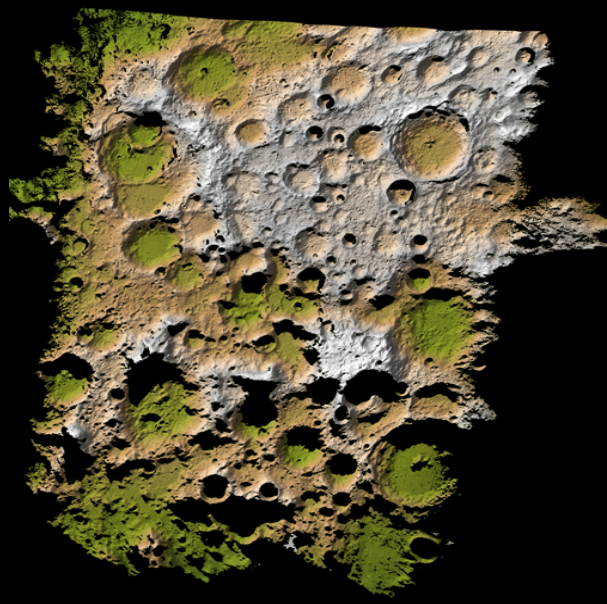
50. Water on the Moon



In 2009, NASA's LCROSS spacecraft was intentionally crashed into the Moon. Water was observed in its plume.

Long suspected that water can exist on the Moon (and Mercury) in areas that are in permanent shadow

First evidence of water on the Moon provided by radar observations – from Arecibo and the DSN. The DSN continues to study these regions on the Moon in support of future human exploration.



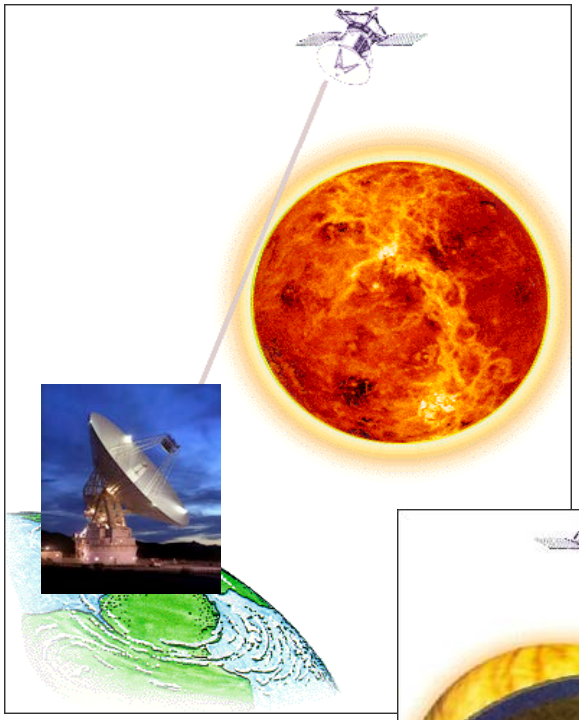
Next 50 Years?

Radio Link Science

Apparent even with early missions that occultations by planetary atmospheres affects quality of radio communications

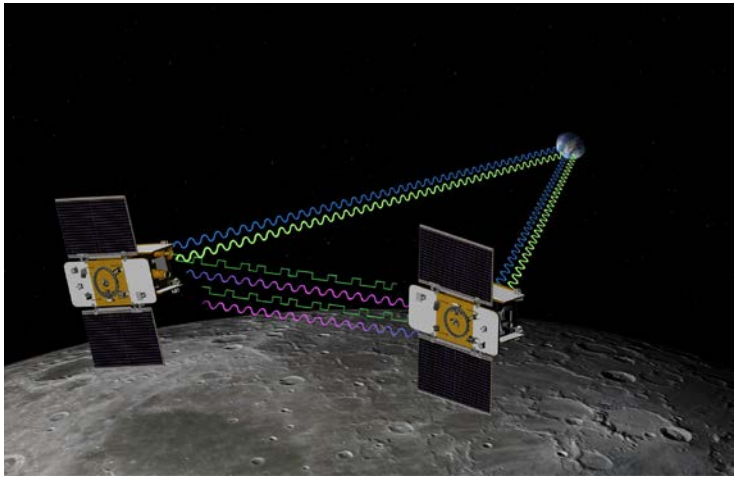
- **Mon dieu! Tragedy!**
- **Or … one person's annoyance is another's data --- Study the atmospheric properties!**
- **Can also study planetary interior!**

➢ **Turn the DSN+spacecraft into one giant science instrument**

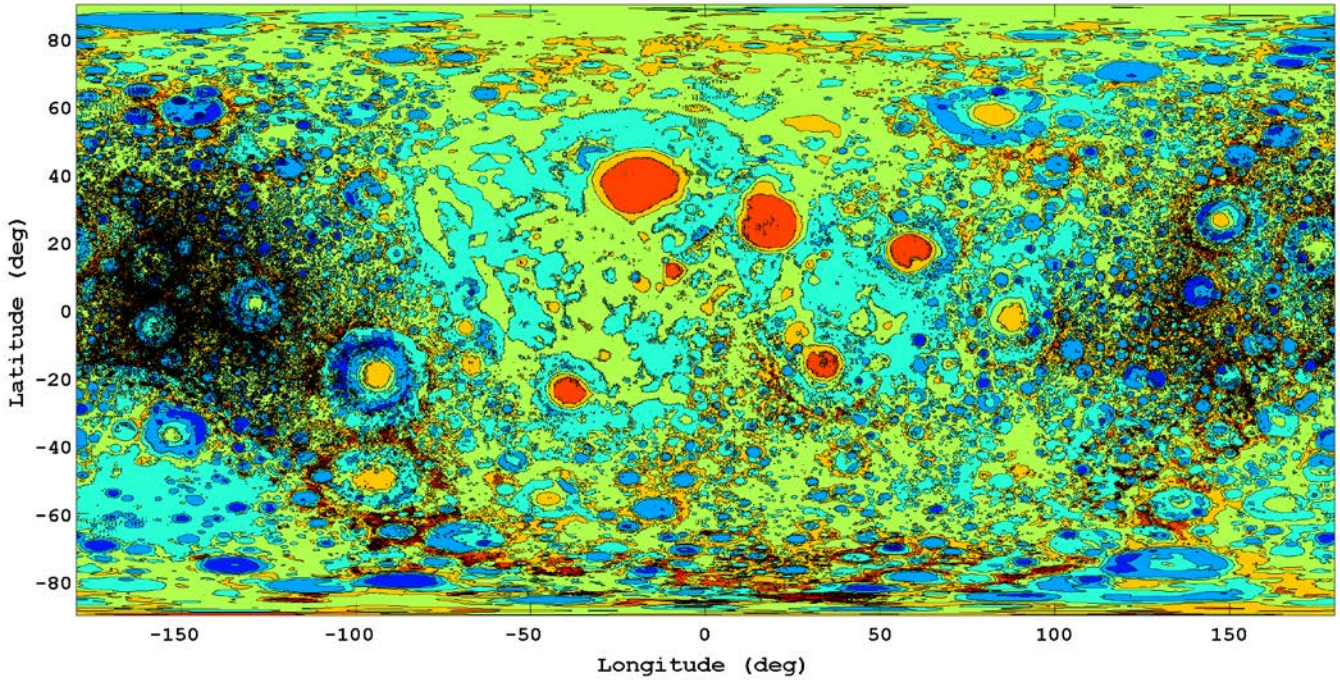


GRAIL Revealing Lunar Interior

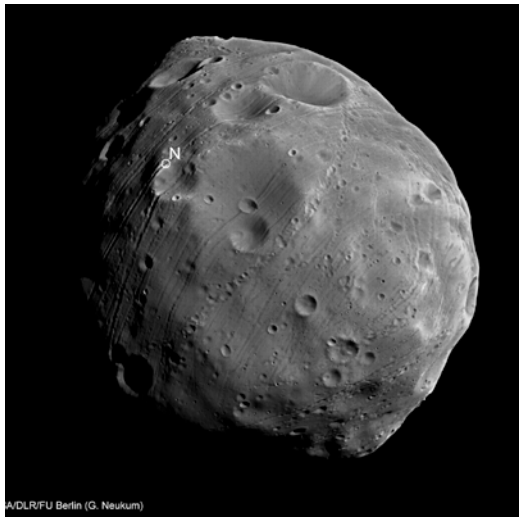
- GRAIL mission made precise measurements of separation between two spacecraft orbiting the Moon
- Changes in separation due to acceleration of one of the spacecraft
- Changes in acceleration result from changes in mass along spacecraft trajectory …



Construct map of local mass enhancements and deficits



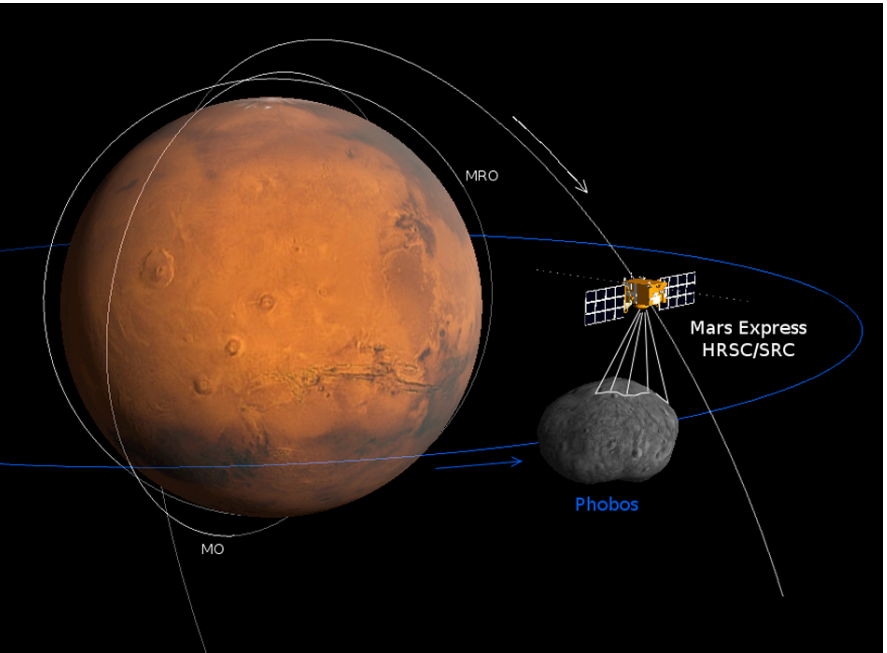
Link Science
Phobos



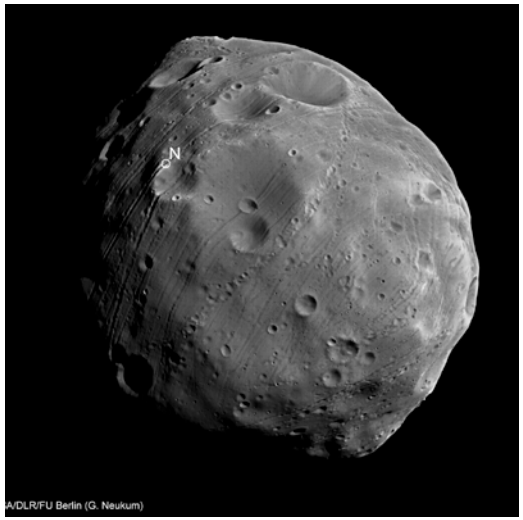
DSN radio science measurements with ESA Mars Express fly-by

- **Determine mass and bulk density**

  $\rho_{bulk} = 1862 \pm 20\ kg/m^3$



Link Science
Origin of Phobos

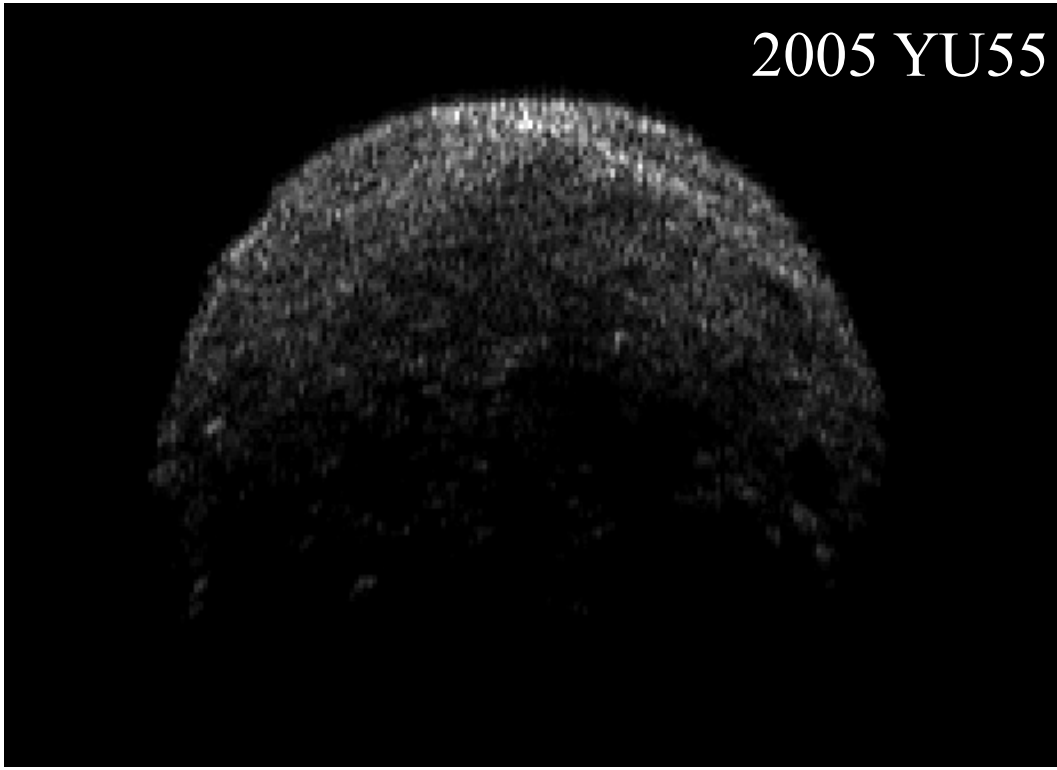


DSN radio science measurements with ESA Mars Express fly-by

- **Bulk density (considerably) lower than "solid" bodies**
- **Has lots of "gaps" inside (a.k.a. "high porosity")**

Phobos re-accreted in place! (?)

Solar System Radar



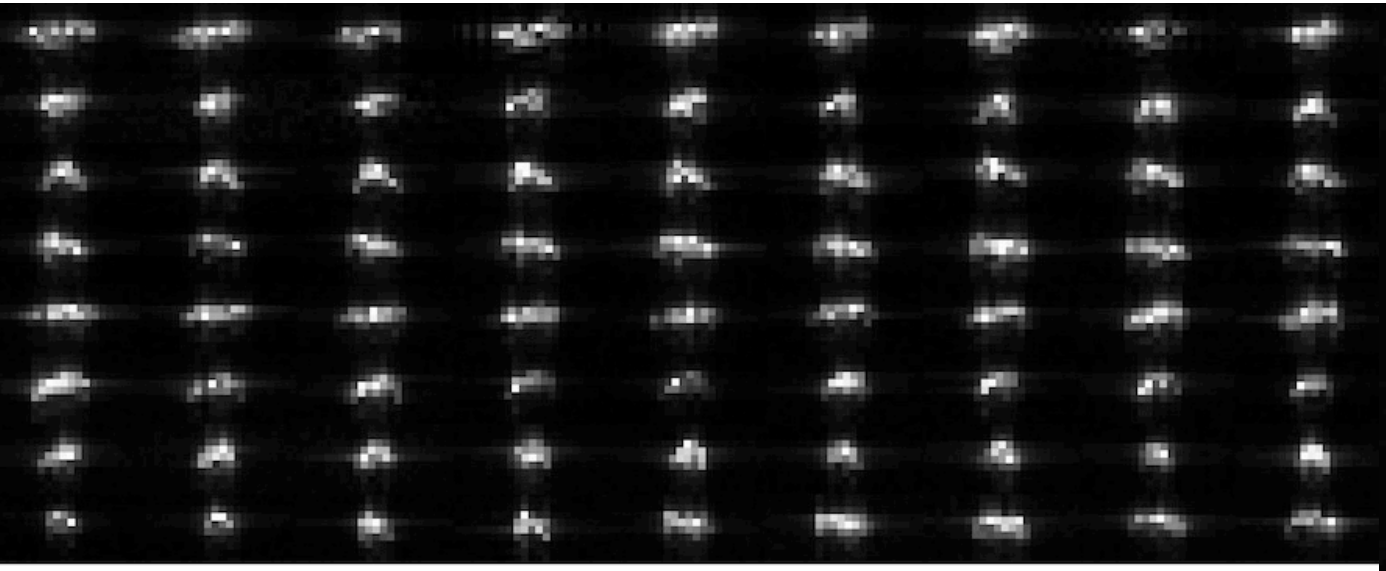
Goldstone Solar System Radar is world-leading facility

- Precise orbital determination
- Rotation periods
- Surface features, with encounter-quality 3.7 m resolution imaging
- Mass, shape, and density

Solar System Radar

Goldstone Radar Images of 2012 DA14

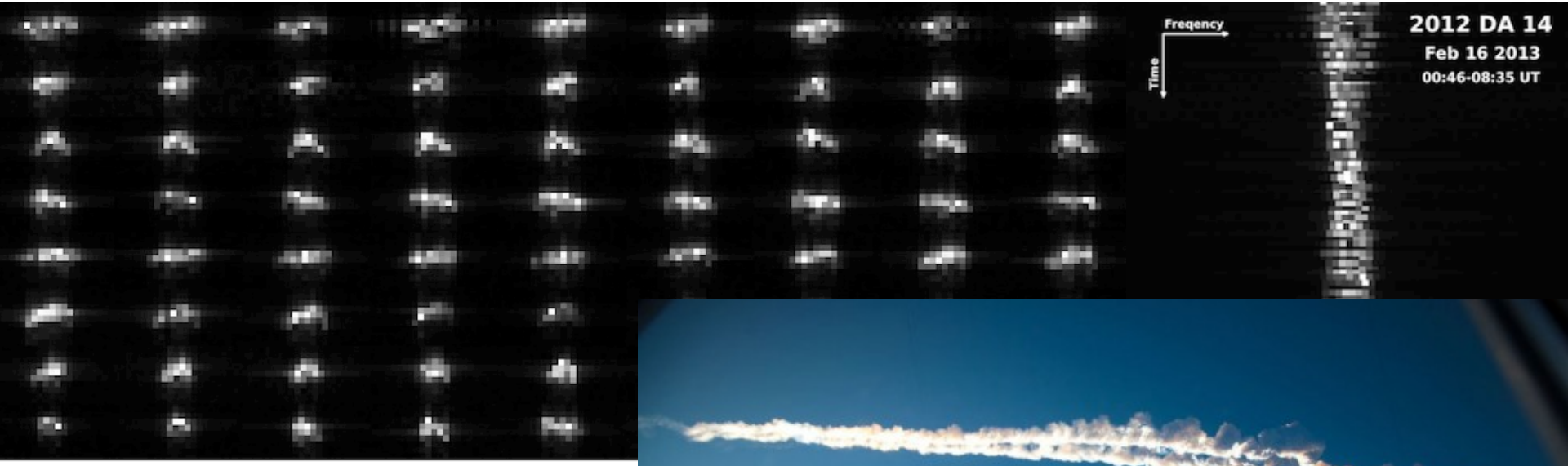
2013 Feb 16



- Elongated object: ~ 40 m x 20 m
- P > 8 h
- Earth torques may have changed the spin state.

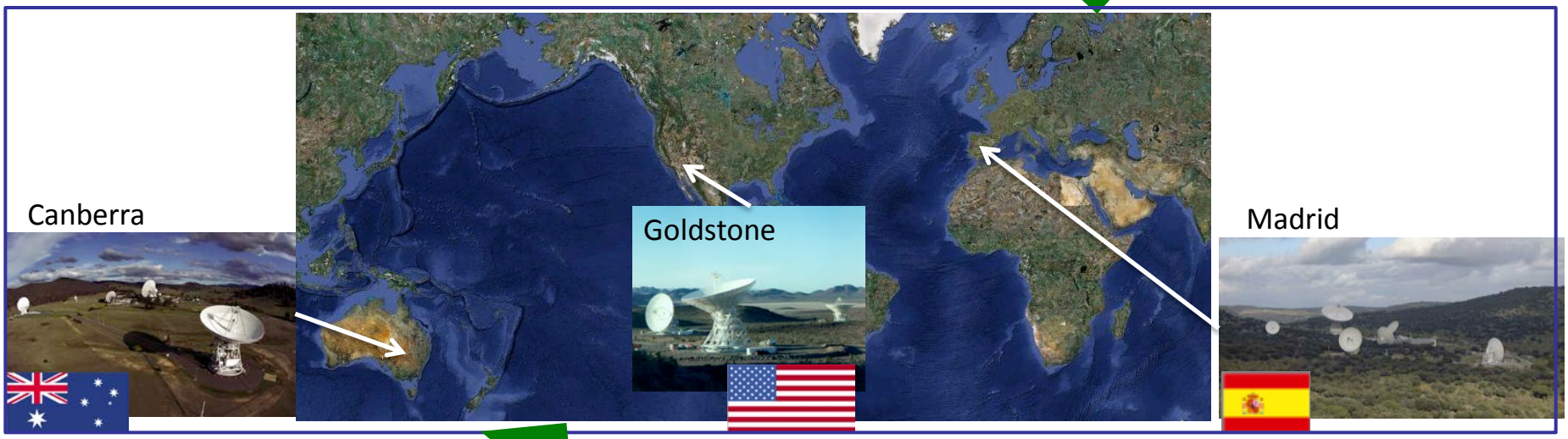
Goldstone Radar Images of 2012 DA14

2013 Feb 16



- Elongated obje
- P > 8 h
- Earth torques the spin state.

Deep Space Network



50 years of enabling solar system-class (and beyond!) science

Benefits to science and society beyond simply transmitting data

Let's keep opening frontiers

Deep Space Network

- Three major tracking sites around the globe, with 16 large antennas, provide continuous communication and navigation support for the world's deep space missions
- Currently services ~ 35 spacecraft both for NASA and foreign agencies
- Spigot for science data from most spacecraft instruments exploring the solar system
- $2B infrastructure that has been critical to the support of 10's of $B of NASA spacecraft engaged in scientific exploration over the last few decades

Deep Space Network

- Three major tracking sites around the globe, with 16 large antennas, provide continuous communication and navigation support for the world's deep space missions
- Currently services foreign agencies
- Spigot for science ents exploring the solar system
- $2B infrastructure t of 10's of $B of NASA spacecraft e r the last few decades

Canberra

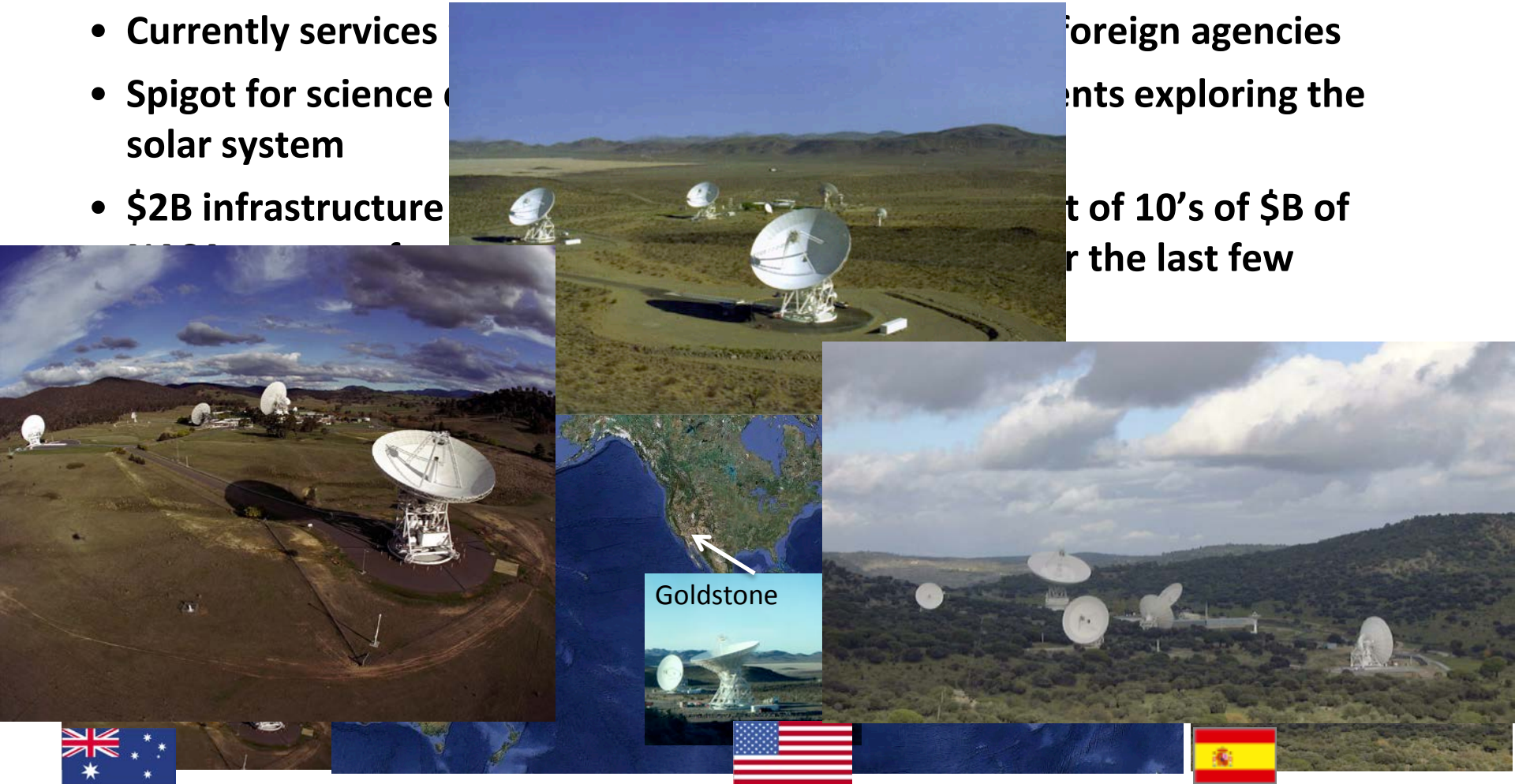
Madrid

Deep Space Network

- Three major tracking sites around the globe, with 16 large antennas, provide continuous communication and navigation support for the world's deep space missions
- Currently services foreign agencies
- Spigot for science ents exploring the solar system
- $2B infrastructure t of 10's of $B of r the last few

Deep Space Network

- Three major tracking sites around the globe, with 16 large antennas, provide continuous communication and navigation support for the world's deep space missions
- Currently services foreign agencies
- Spigot for science nts exploring the solar system
- $2B infrastructure t of 10's of $B of r the last few



Next 50 Years?

Laser communications

Interplanetary Internet

Complete catalog of NEOs

Detection of gravitational waves

[Deep space industry]

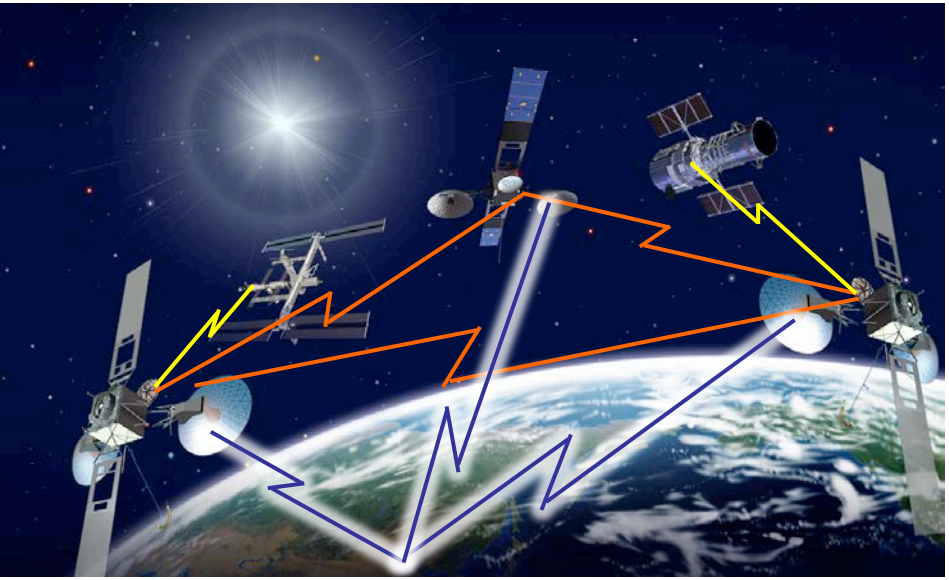
[Humans on Mars]

Extraterrestrial life

Planetary Communications Networks

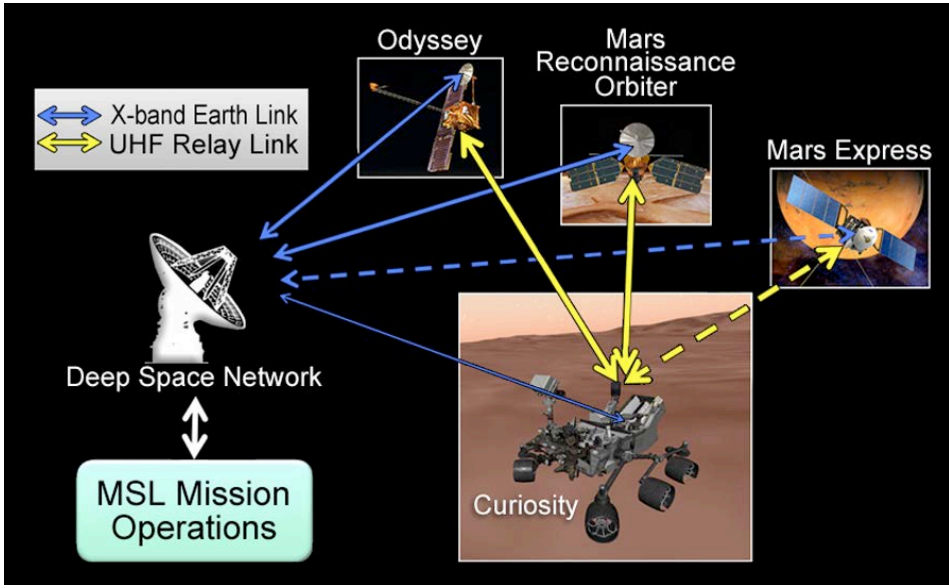
Jet Propulsion Laboratory
California Institute of Technology

Terrestrial Network



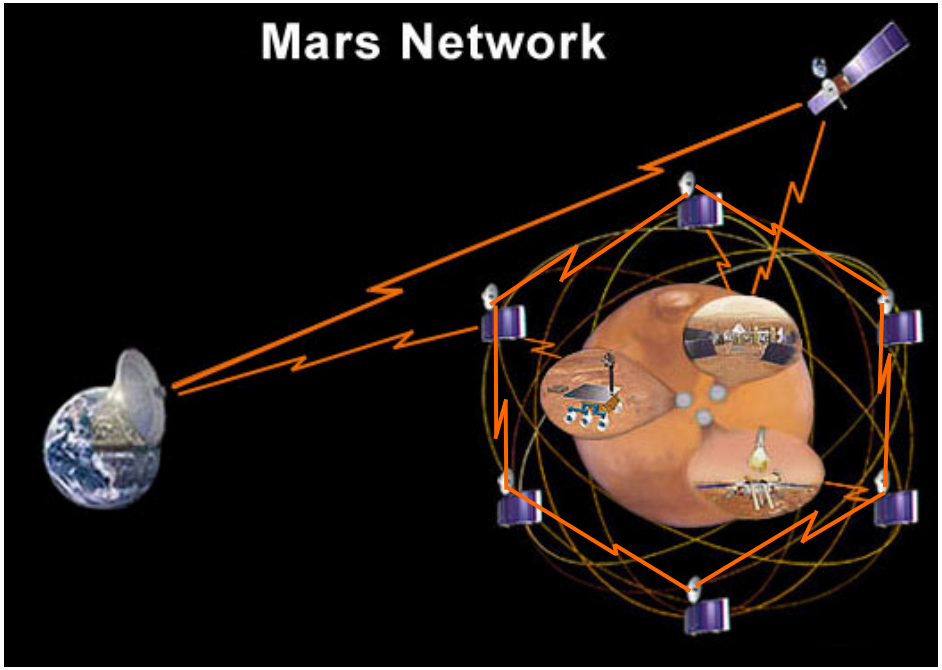
Communication flow between spacecraft, relays, and ground --- "Internet like" and robust against disruptions

Martian "Network"

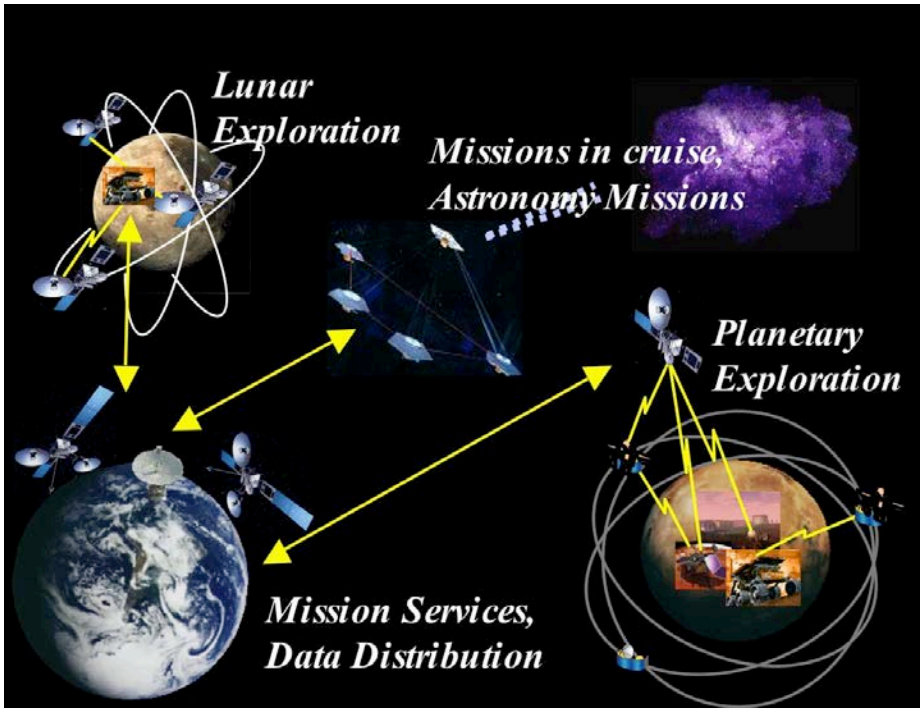


Communications between orbiters and Earth, orbiters relay communications to landers/rovers (and Curiosity can communicate directly to Earth), but …

Interplanetary Internet



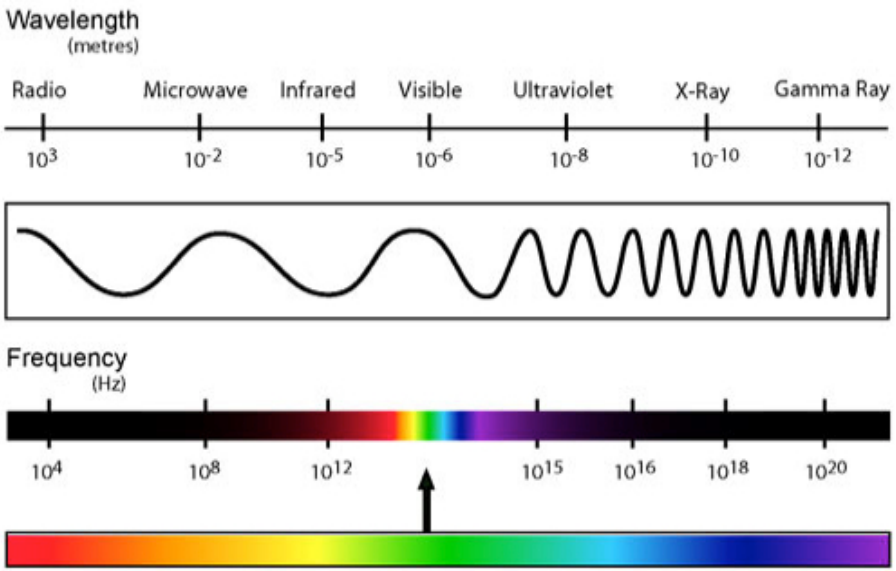
Communication flow between Earth, relays, and Mars --- "Internet like" and robust against disruptions



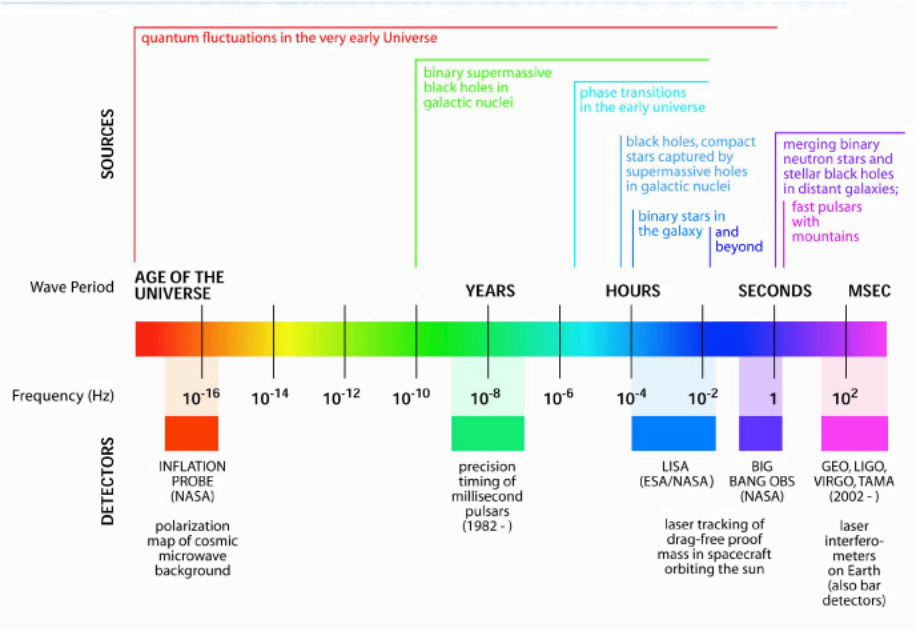
Move into the solar system --- Moon, Mars, asteroid belt, …

Gravitational Waves

Electromagnetic Spectrum



Gravitational Wave Spectrum



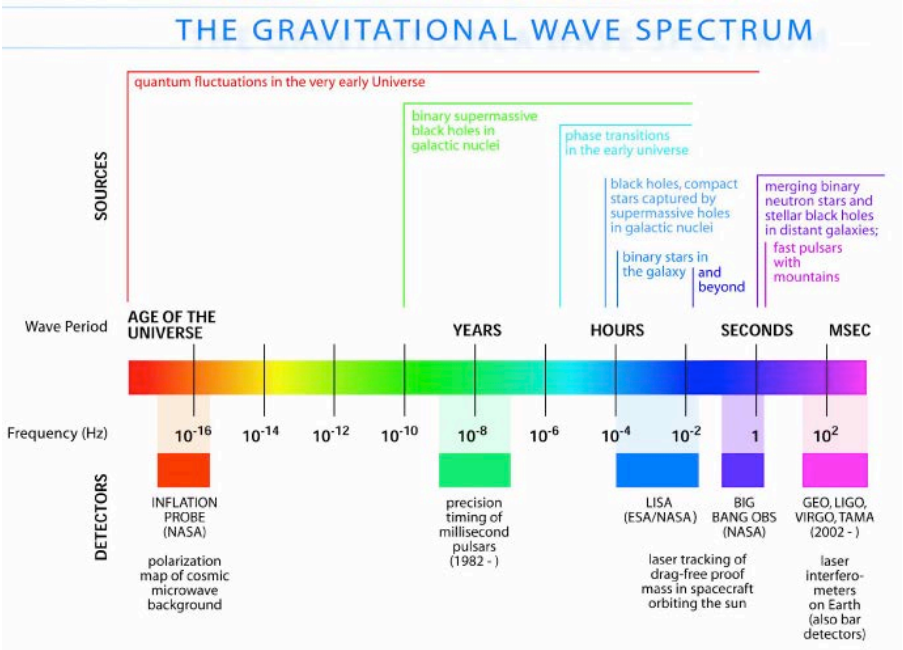
Gravitational Waves
Who Cares?

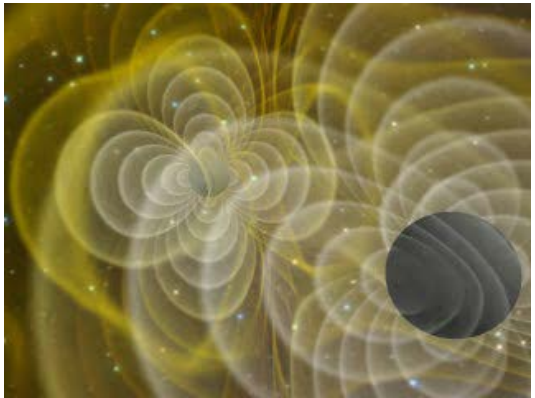
- **One of final untested predictions of Einstein's Theory of General Relativity**

  Initial work already yielded one Nobel Prize in Physics

- **Identified by U.S. astronomy community as "science frontier discovery area" *(U.S. National Academy of Sciences)***

- **Probes most extreme environments in Universe**

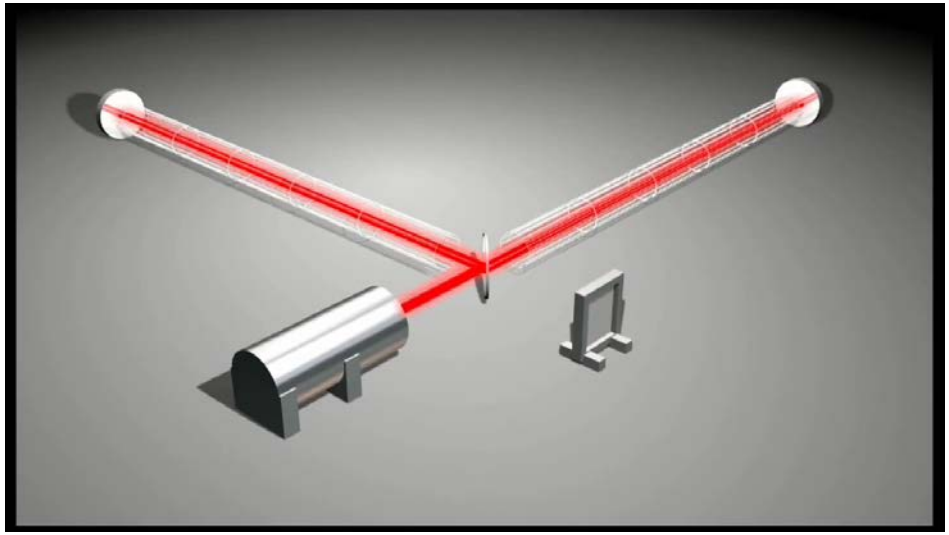


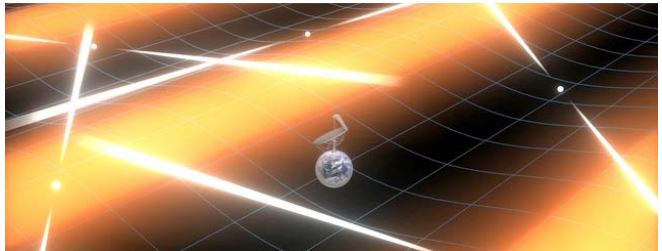


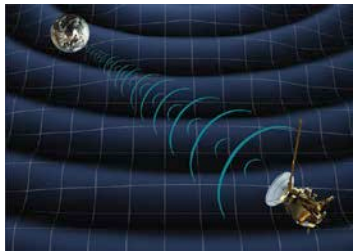
Gravitational Wave Detectors

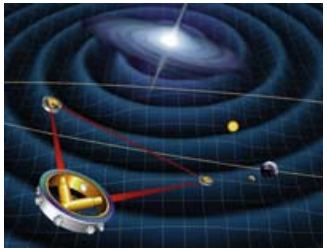
All modern gravitational wave detectors use same principle

- Gravitational wave modifies distance (a.k.a. spacetime metric)
- Measure distances between collection of objects (test masses)
- Changes result from passing gravitational waves





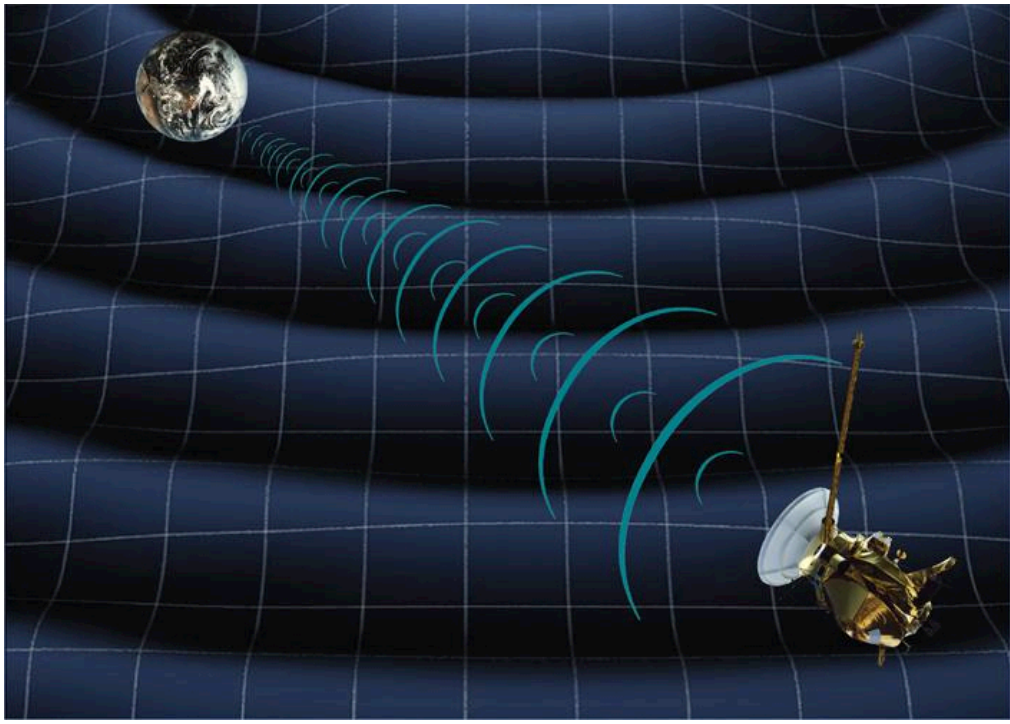




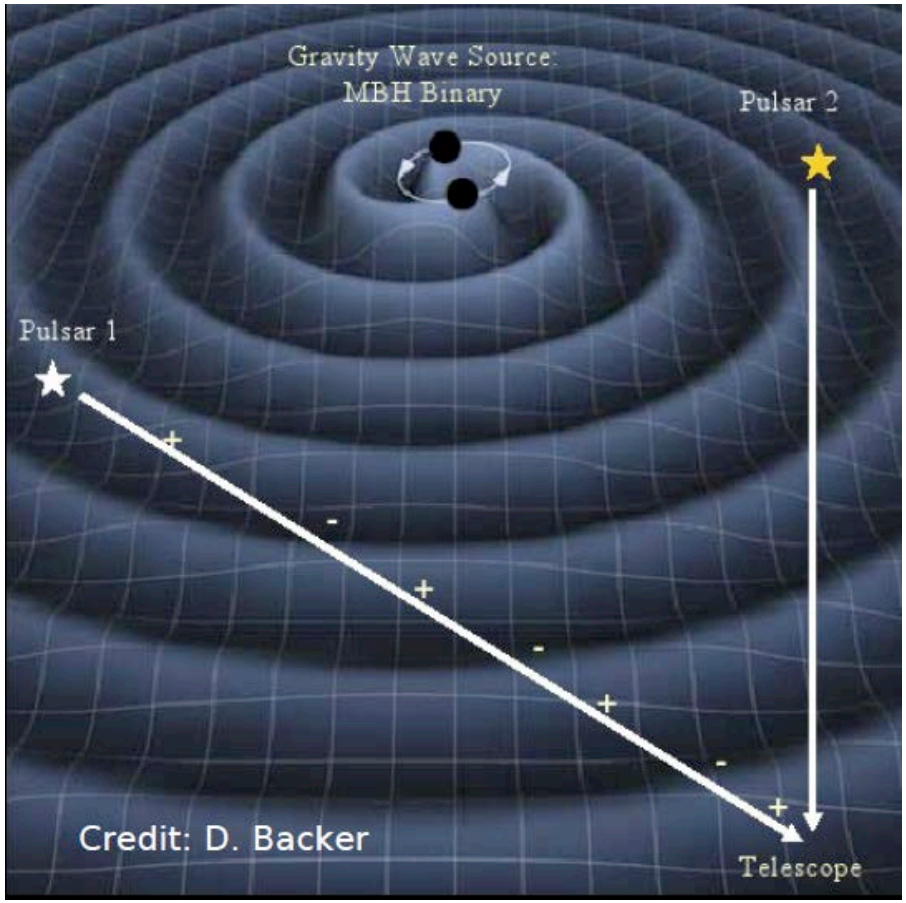
Spacecraft Tracking and Gravitational Waves

Spacecraft-Earth forms gravitational wave detector

- First suggested by Estabrook & Wahlquist (1975), both JPL
- DSN has long history --- Pioneer, Viking, *Cassini*
- DSN-*Cassini* limits ~ 1000 × better than previously obtained



Radio Pulsars, DSN, and GWs



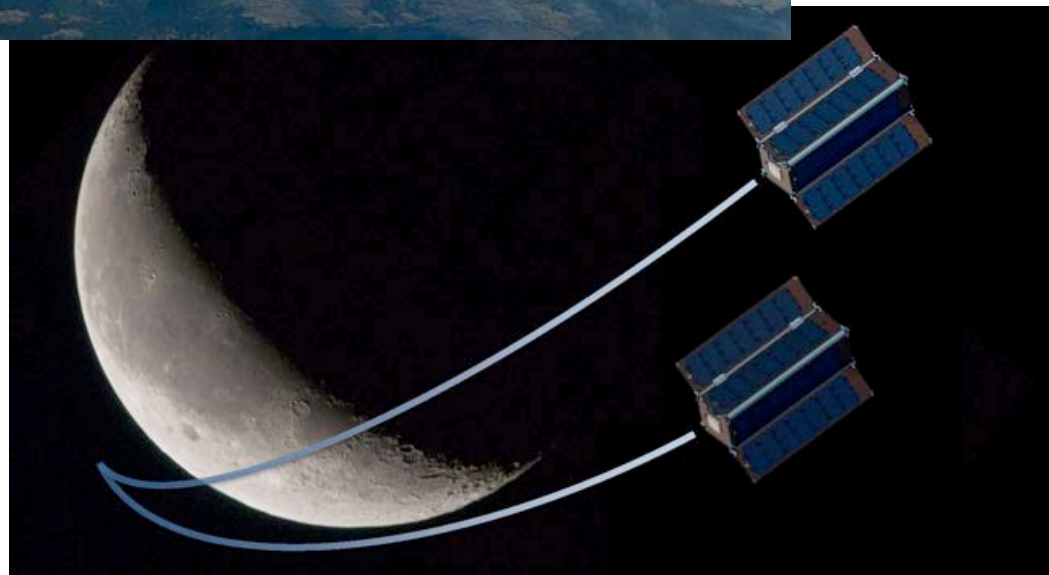
Technique first proposed by Hellings & Downs (JPL)

Searching for gravitational waves emitted by supermassive black holes at centers of galaxies as they in-spiral together ….

Deep Space SmallSat Constellations

Jet Propulsion Laboratory
California Institute of Technology

- Imagine fleets of spacecraft at other planets
- Imagine dropping many probes into a planet's atmosphere …
- May be possible with "smallsats"
- Requires whole new way to operate the DSN …



Beyond the Moon Landing

In 1969 Neil Armstrong became first human to step onto the Moon.

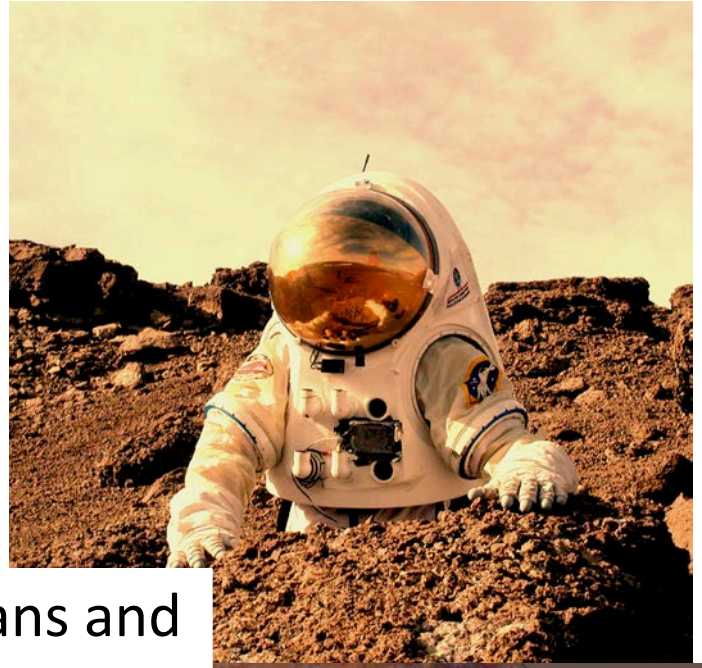
The DSN supported all the Apollo missions, providing communications and tracking.

Where next?

Beyond the Moon Landing

Deep Space Industry?

Humans on Mars?



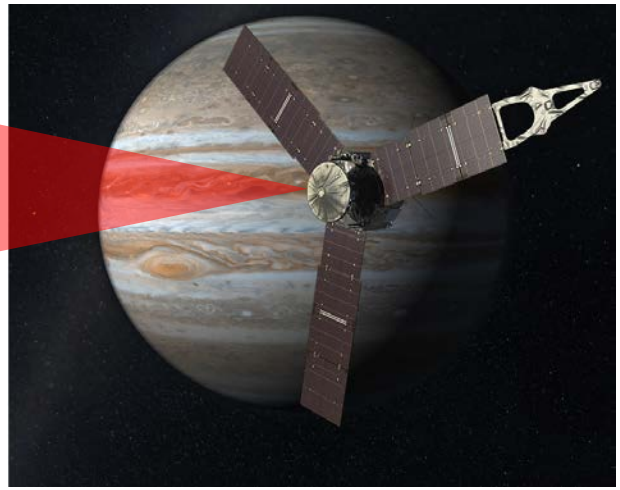
Moving humans and industry into deep space will require deep space communications support.

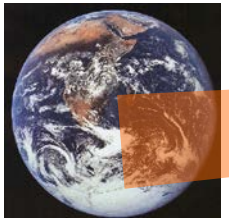
Laser Communication
Why?

Consider Juno mission at Jupiter …
(orbital insertion 2016 July 5)

0.018 Mbps
(at least)

~ 200 Earth diameters



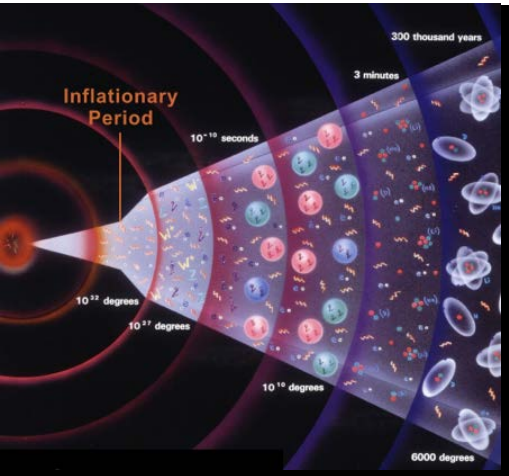


~ 2.5 Mbps (at least)

Optical Communication

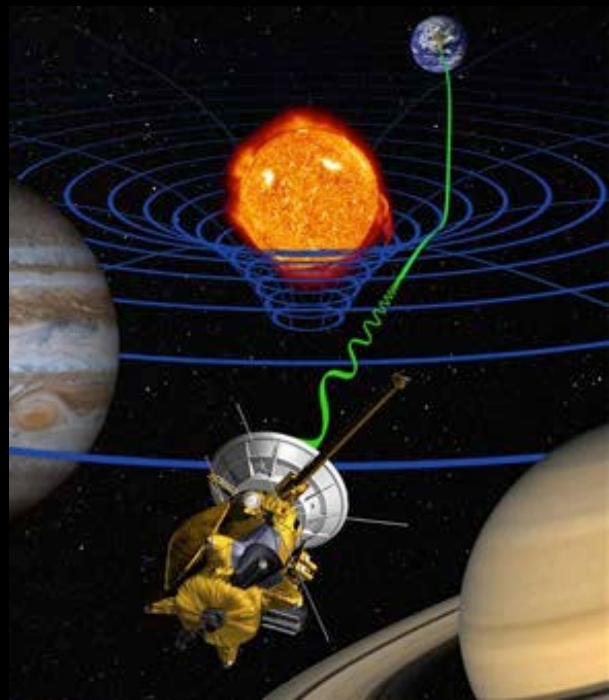
- **Lasers have the potential to offer much higher communication bandwidths, i.e., more science data!**
  - **Like fiber optics, without the fiber**
- **Already demonstrated …**
  - **… though not yet in deep space**

25. Cosmic Inflation



In 1980, inflationary big bang model is put forward, explaining the first moments of the Universe

Evidence for the model is collected by spacecraft tracked by the DSN. In addition, direct science observations by the DSN, using the Cassini *spacecraft as a radio source, provide further proof.*

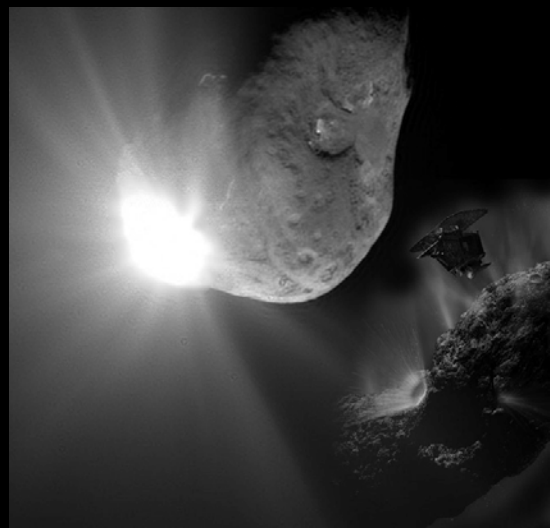


31. Catching Up With Comets

In 1984 ESA's Giotto spacecraft rendezvoused with Halley's Comet. The DSN supported the Giotto mission and returned images of the comet.

The DSN has since supported several spacecraft visiting comets, including Deep Impact and Stardust sample return mission.

A lesser-known fact is that the DSN was used to recover the Giotto spacecraft when it mistakenly turned its antenna away from, Earth. This is an example of "1,000,000 mile screwdriver."



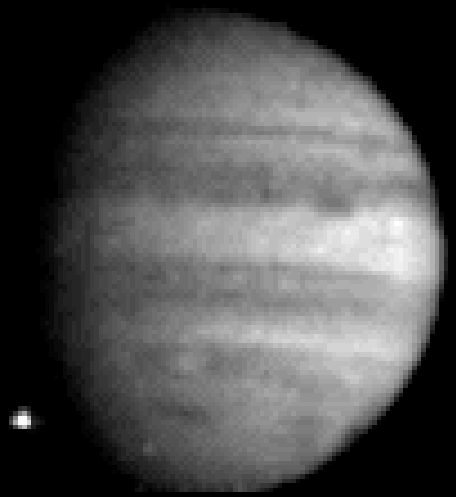
33. Witnessing a Cosmic Crash

Jet Propulsion Laboratory
California Institute of Technology

In 1994, world watched as the remnants of Comet Shoemaker-Levy 9 crashed into Jupiter –first time we saw this phenomenon

Actual impact happened on the far side of Jupiter as viewed from Earth. Only the Galileo spacecraft had a direct view!

DSN tracked the Galileo spacecraft which captured photographs of the actual collisions

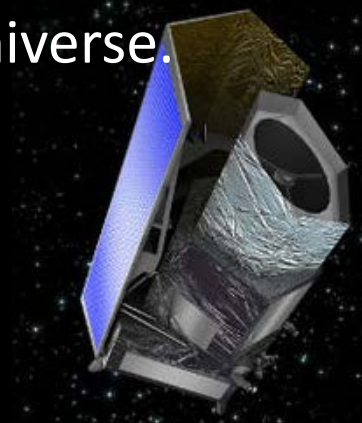


39. Dark Energy

In 1998, observations of distant exploding stars led astronomers to accept the notion of "dark energy," which is causing the expansion of the Universe to accelerate with time.

DSN support of space missions (e.g., *WMAP*, *Planck*, *Chandra*, and *Spitzer*) helped cement concept of dark energy. Their measurements also helped improve estimates of the Hubble constant, which sets the scale of the Universe.

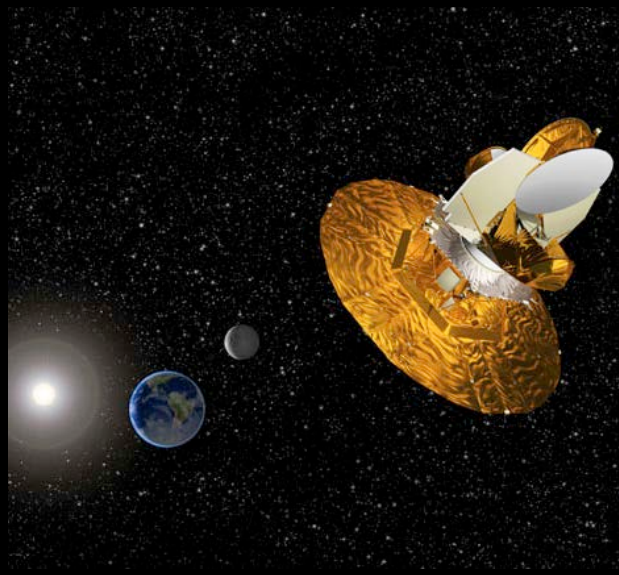
The DSN will support ESA's Euclid mission, which will be dedicated to the search for dark energy



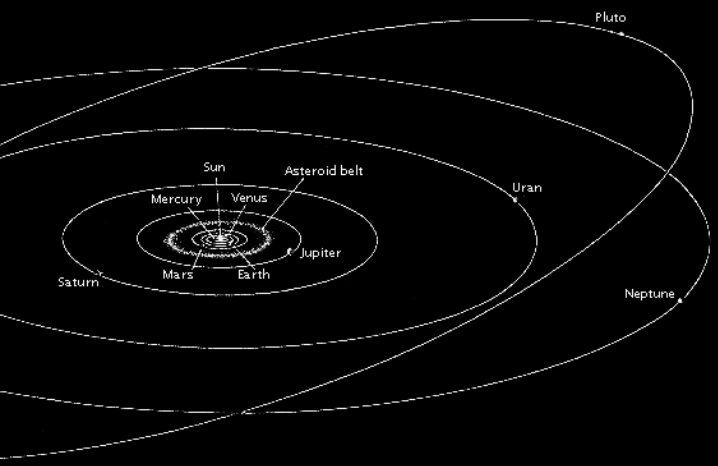
43. Age of the Universe

Estimated age of the Universe was much better determined in 2001 to be 13.7 billion years.

Best estimate uses data from NASA's WMAP and ESA's Planck *spacecrafts, supported by the DSN.*



46. Planets Realigned

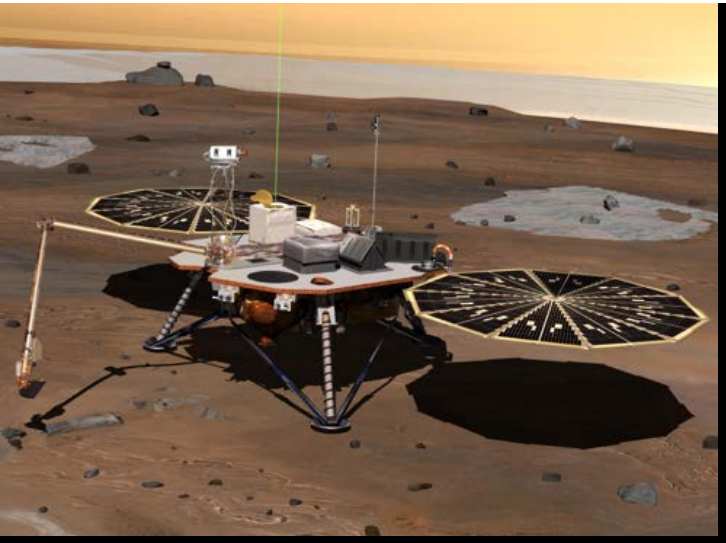


In 2005, discoveries of large Kuiper belt objects led to re-definition of a planet and Pluto as a dwarf planet

Decision to change the official definition of "planet" stems in part from the discovery of exoplanets as well as observations of comets and Kuiper belt objects.

The DSN's role comes from support of spacecraft that discover such objects and from ongoing research into planetary orbits

49. Tasting Martian Water



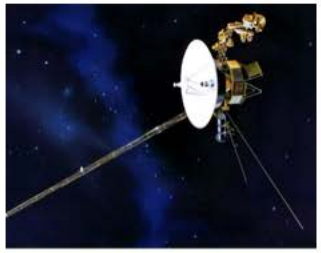
In 2008, NASA's Phoenix spacecraft lands on Mars and samples water from just under the surface.

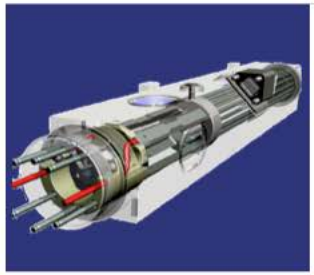
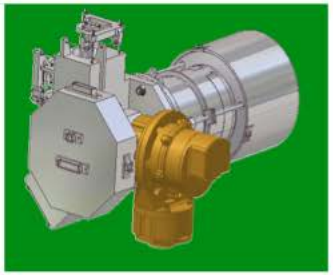
DSN supported Phoenix as well as all other spacecraft on Mars' surface.

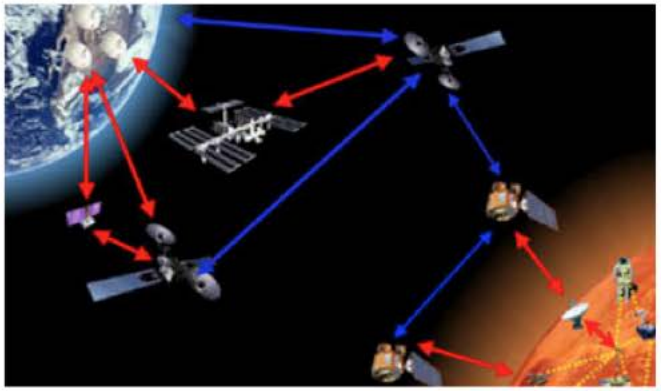
Much additional evidence for liquid water on Mars has come from studying photos from Mars orbiters showing "rivlets" that come and go with seasons

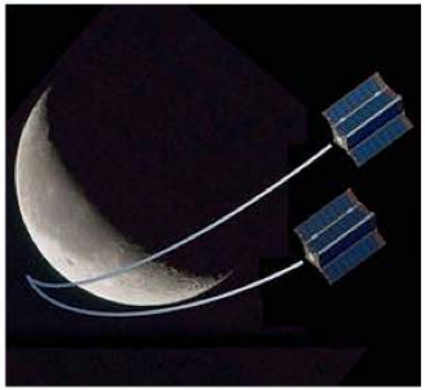
How DSN Technology Changed the World

Laif Swanson
JPL Communications Architectures & Research Section







Jet Propulsion Laboratory
California Institute of Technology

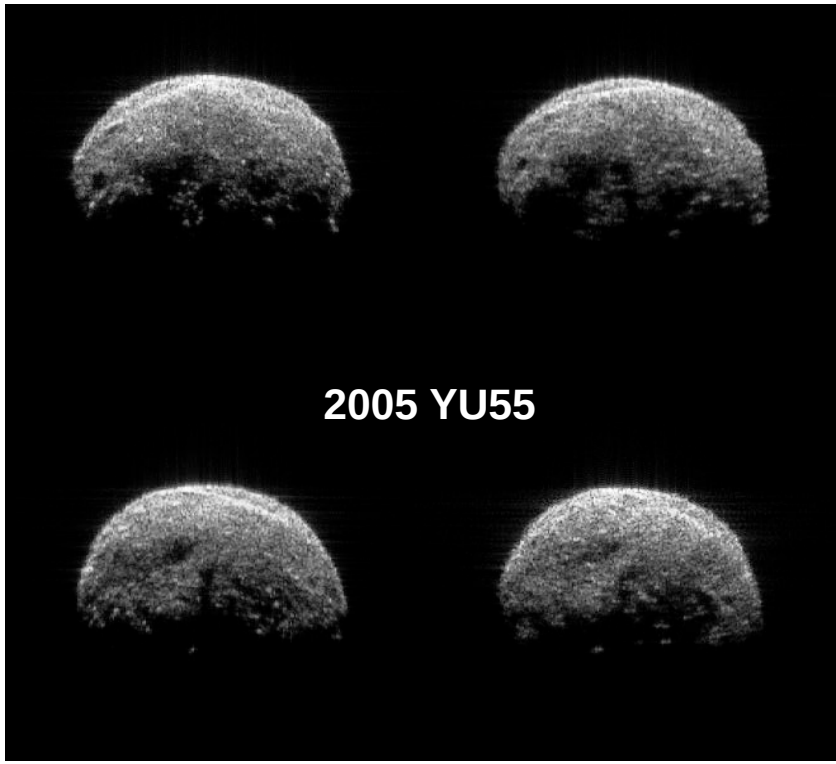
DSN Technology

- The DSN (and its predecessors) developed enormous capability
  - Active technology program
  - Excellent engineering
- Of course it has brought us planetary science
  - Pictures have become ubiquitous and almost unremarkable
  - But the technology developments have brought the world much more
- Technology developed by & for the DSN often based on others
  - Often radio astronomy
  - We usually know about this
  - When other entities use our technology, we may not know
  - These examples come from the people who have worked on them

Jet Propulsion Laboratory
California Institute of Technology

Goldstone Solar System Radar

- **Goldstone Solar System Radar is both a beneficiary and a benefactor**
  - **Has imaged many solar system objects**
  - **Advanced our knowledge of AU by two orders of magnitude**
  - **Determined good spacecraft landing sites on moon and Mars**
  - **Located SOHO when it lost lock on sun, saving mission**
  - **Served as a testing ground for new technology**



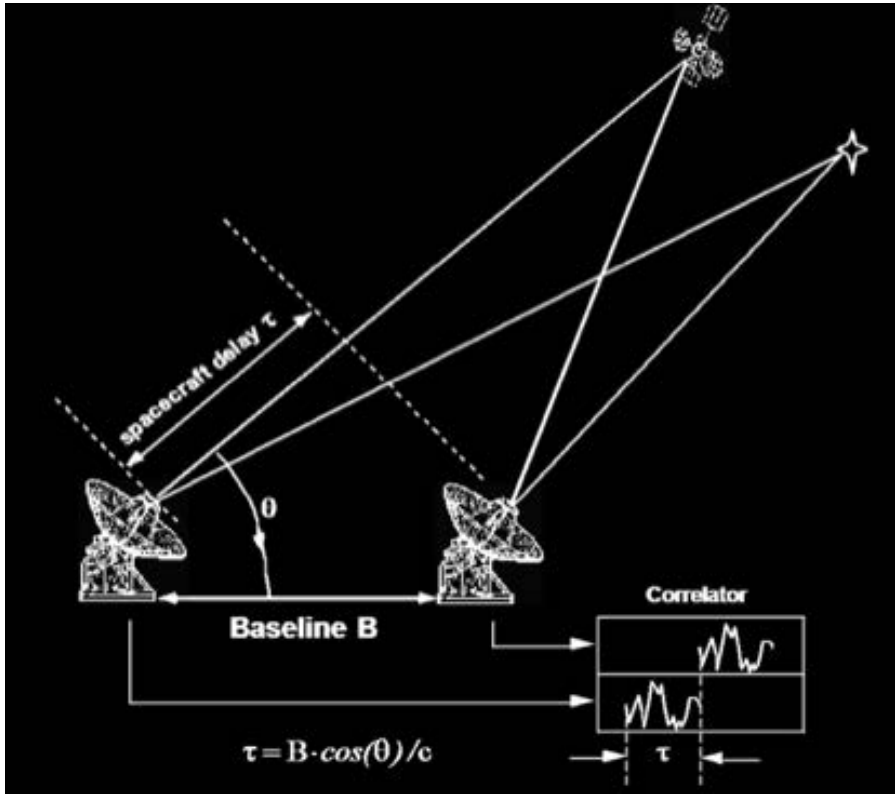
Jet Propulsion Laboratory
California Institute of Technology

Ways Others use DSN Technology

- Radio astronomy and ground stations for other agencies' space programs
  - This is the most obvious, since we have been first so often
- Spacecraft technology
- The outside world

Radio Astronomy & Ground Stations

- **VLBI**
  - **First developed for radio astronomy**
  - **DSN capability allowed collaboration**
  - **DSN developed delta DOR**
  - **Now used widely by other space agencies**



Low Noise Amplifiers

- Compact cryogenically cooled choked waveguide for low-noise input coupling into cryogenically cooled amplifier used by
  - Radio astronomers
  - SETI
  - ESA
  - CSIRO
  - DFVLR
- Reflected-Wave Maser developed in early 70s used by
  - NRAO
  - VLA
  - CSIRO
  - Max Planck
  - Caltech
  - Princeton

X-Band "ULNA"

Jet Propulsion Laboratory
California Institute of Technology

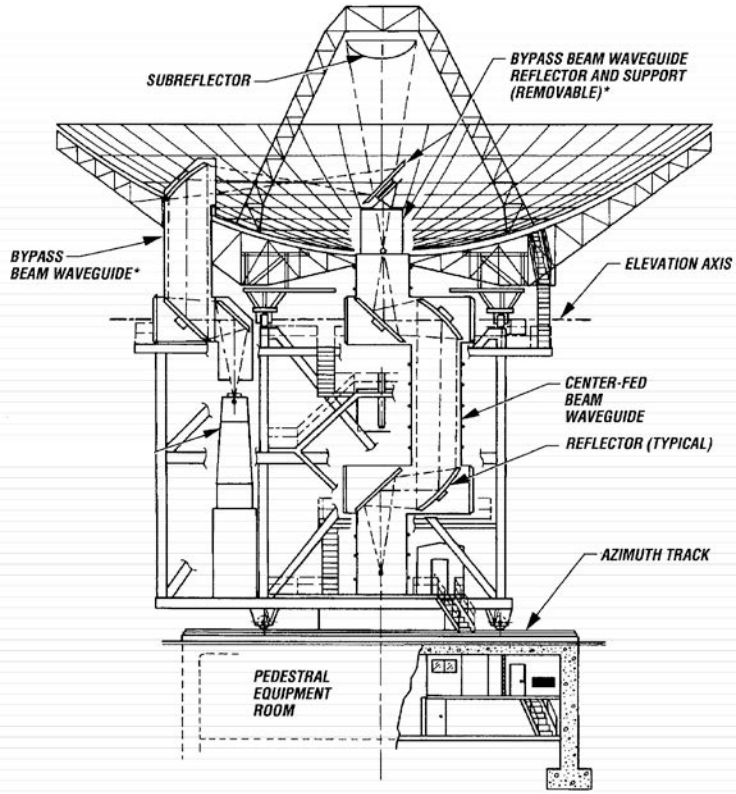
Low Noise Amplifiers (continued)

- **Cryogenically cooled traveling masers and closed-cycle refrigerator systems**
  - **Developed in the early 1960s and late 1970s**
  - **Later used at Arecibo**

Jet Propulsion Laboratory
California Institute of Technology

More Ground Station Adoptions

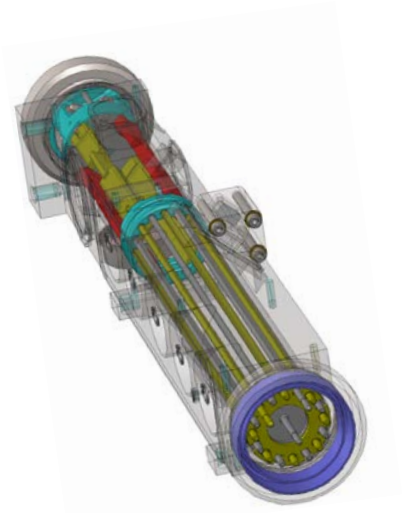
- **Beam waveguide antennas**
  - **Originally developed by the Japanese**
  - **We developed**
    - **Wideband**
    - **High-efficiency**
    - **Low noise**
    - **Electronic system below ground for ease of access and station electronic stability**
  - **Largely adopted by ESA and more recently Indian Space Research Organization**



Jet Propulsion Laboratory
California Institute of Technology

Technology Adopted by Spacecraft

- Radar Interferometry
  - NASA aircraft
  - SIR-A, SIR-C
  - ESA used on ERS1, ERS2, EnviSat
- Ferrite circulator as part of system to phase lock existing high-power Ka-band oscillator
  - In lieu of high-power amplifier
  - Being considered for use by Cloudsat
- Mercury Ion Frequency Standard
  - Being supported by NASA for spacecraft applications



Deep Space Atomic Clock

Jet Propulsion Laboratory
California Institute of Technology

Data Compression Used by Spacecraft

- The Rice Algorithm
  - "Lossless" compression
  - Developed by the Voyager Mission
  - Used by DSN Technology program as the beginning of data compression work
- Galileo S-band mission
  - Finally spacecraft teams took lossy data compression seriously
- "Icer" algorithm
  - Developed by DSN technology program to ease data volume
  - Used on spacecraft for compression of thousands of images
    - Mars Exploration Rover
    - Mars Science Laboratory
    - Solar Terrestrial Relations Observatory (STEREO)

Jet Propulsion Laboratory
California Institute of Technology

DSN Technology Used Elsewhere

- Phased Locked Loop
  - Invented elsewhere in the 30s
  - A great deal of research at JPL in the 1950's
    - Customized for new applications
    - Theory developed
  - Now used in space communications and
    - Frequency synthesis
    - Carrier synchronization
    - PN code synchronization
    - Bit synchronization
  - There are several in your smart phone

Jet Propulsion Laboratory
California Institute of Technology

Other Uses of DSN Technology

- Pseudo-Noise (PN) codes
  - First used for radio guidance systems for missiles
  - Later used for planetary radar and ranging
  - Now used in
    - GPS
    - CDMA
      - Military Communications
      - Cell phones
    - Radar ranging
- Two-way phase-coherent Doppler
  - Developed for early missile guidance
  - Then radar speed guns

Jet Propulsion Laboratory
California Institute of Technology

Frequency Standards

- Cryogenic oscillator
  - Developed for radio science
  - Used worldwide in national meteorological labs
- Opto-electronic oscillators
  - Based on JPL's Gallery Mode Oscillator
  - Adopted by DoD and flown in missiles
  - Commercialized and being pursued many places

Jet Propulsion Laboratory
California Institute of Technology

Fiber-Optic Frequency Distribution

- Developed for the DSN
- First fiber-optic system in space (SRTM)
- Basis for fiber-optic based cable TV
- Basis for distribution of optical frequency standards in Europe and Asia
- Being developed for same use in U.S.

Jet Propulsion Laboratory
California Institute of Technology

Error-Correcting Codes

- Early coding was largely a mathematical curiosity
- DSN was very early user of digital communications
- Distance and spacecraft amplifier power lead to very low signal-to-noise ratio (even after those low-noise amplifier people made the noise very small)
- Reed-Solomon code concatenated with convolutional code and Viterbi decoding
  - None of these things came from JPL
  - This particular code began with Voyager 2
  - Very popular for a lot of purposes
  - First generation DVB-S digital television broadcast standard
  - (7,1/2) convolutional code with Viterbi decoding ubiquitous in communications
  - Reed-Solomon codes ubiquitous in data storage

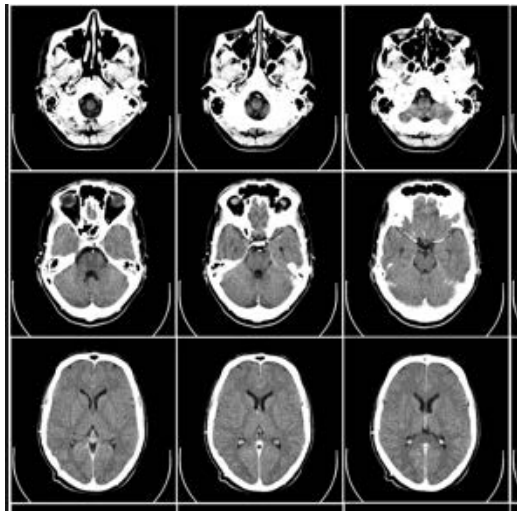
Jet Propulsion Laboratory
California Institute of Technology

Turbo Codes and LDPC Codes

- These were invented elsewhere
- Specific codes developed in the DSN Technology program are now available commercially
- 3G and 4G cellular standards use these types of (though not exactly these) codes
- “Protograph LDPC codes” enable low-complexity encoders and decoders

Other Developments

- Computer tomography can be traced to VLBI
- DSN VLBI led to the crustal dynamics program
- Shazam has roots in stellar navigation
- Chemical degradation in the pedestal of DSS-14 led to solutions that were then used to refurbish highways
- And even now – Superconducting nanowire single photon detector recently developed for the DSN is being explored in labs around the world in quantum optics and spectroscopy experiments



Some other thoughts

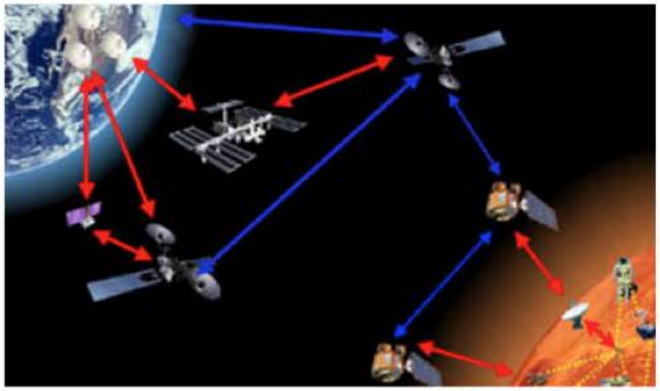
Jet Propulsion Laboratory
California Institute of Technology

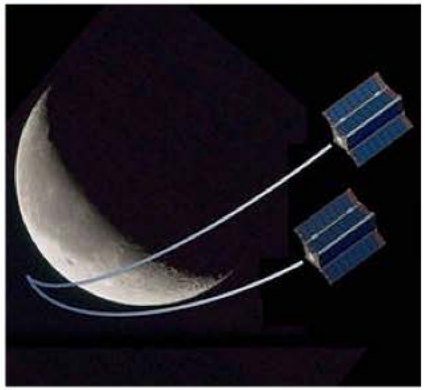
With Thanks To

- Dimitri Antsos
- Dan Bathker
- Jim Border
- Bob Clauss
- Les Deutsch
- Bill Farr
- Rick Green
- Jon Hamkins
- Dan Hoppe
- Aaron Kiely
- Pete Kinman
- Lute Maleki
- Francesco Marsili
- Dick Mathison
- Doug Mudgway
- Mac Reid
- Michael Rodrigues
- Matthew Shaw
- Marty Slade
- Charles Stelzried
- Lincoln Wood
- Joe Yuen

Panel Discussion:
DSN of the Future

Bill Weber, Moderator
Phil Liebrecht, NASA SCAN
Les Deutsch, IND
Steve Townes, IND
Joe Lazio, IND / Div 33
Chad Edwards, IND / Mars



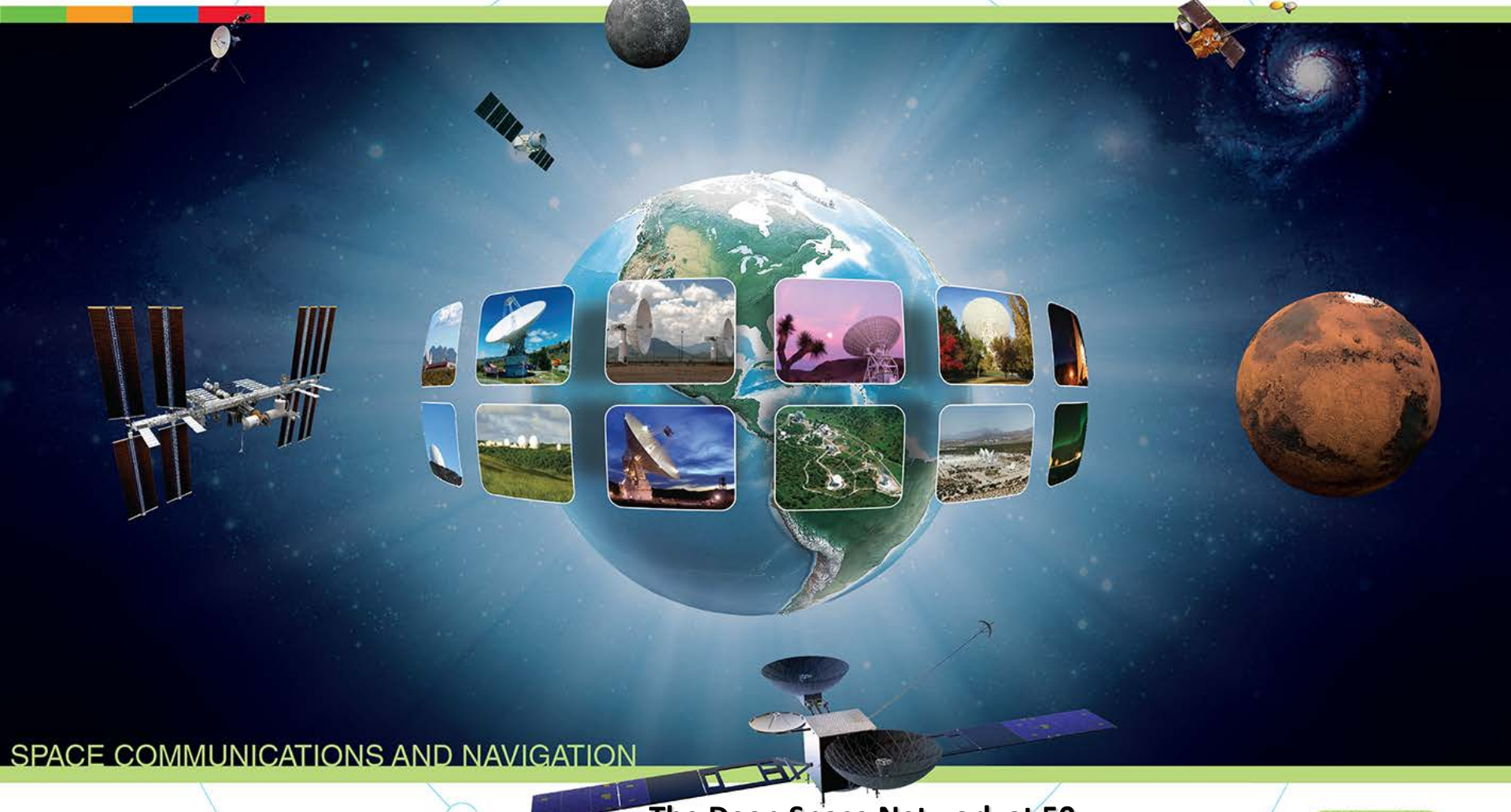


Introduction Agenda

- **Phil Liebrecht** — **NASA perspective; hi-level architecture**
- **Les Deutsch** — **DSN from the user perspective**
- **Steve Townes** — **Enabling technology**
- **Joe Lazio** — **DSN Science**
- **Chad Edwards** — **Mars Network; Interplanetary Network**

Top level Mission and Agency Drivers and Architecture Plan

National Aeronautics and Space Administration



The Deep Space Network at 50

Phil Liebrecht, Deputy Program Manager, SCaN

February 2014

www.nasa.gov

Agency and Mission Drivers

Human Exploration beyond Low Earth Orbit

- Unified interfaces for all SCaN Networks

Increasing International Collaboration

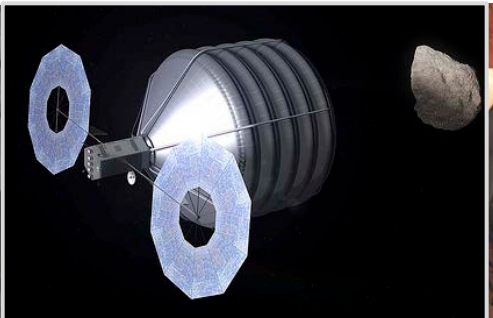
- Internationally Interoperable Standards

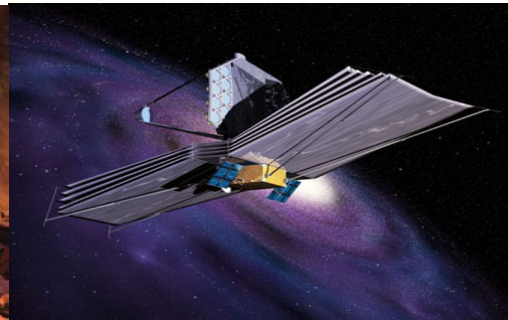
Space Internetworking

- Sensor webs & increased automation
- Seamless Human & Robotic Exploration

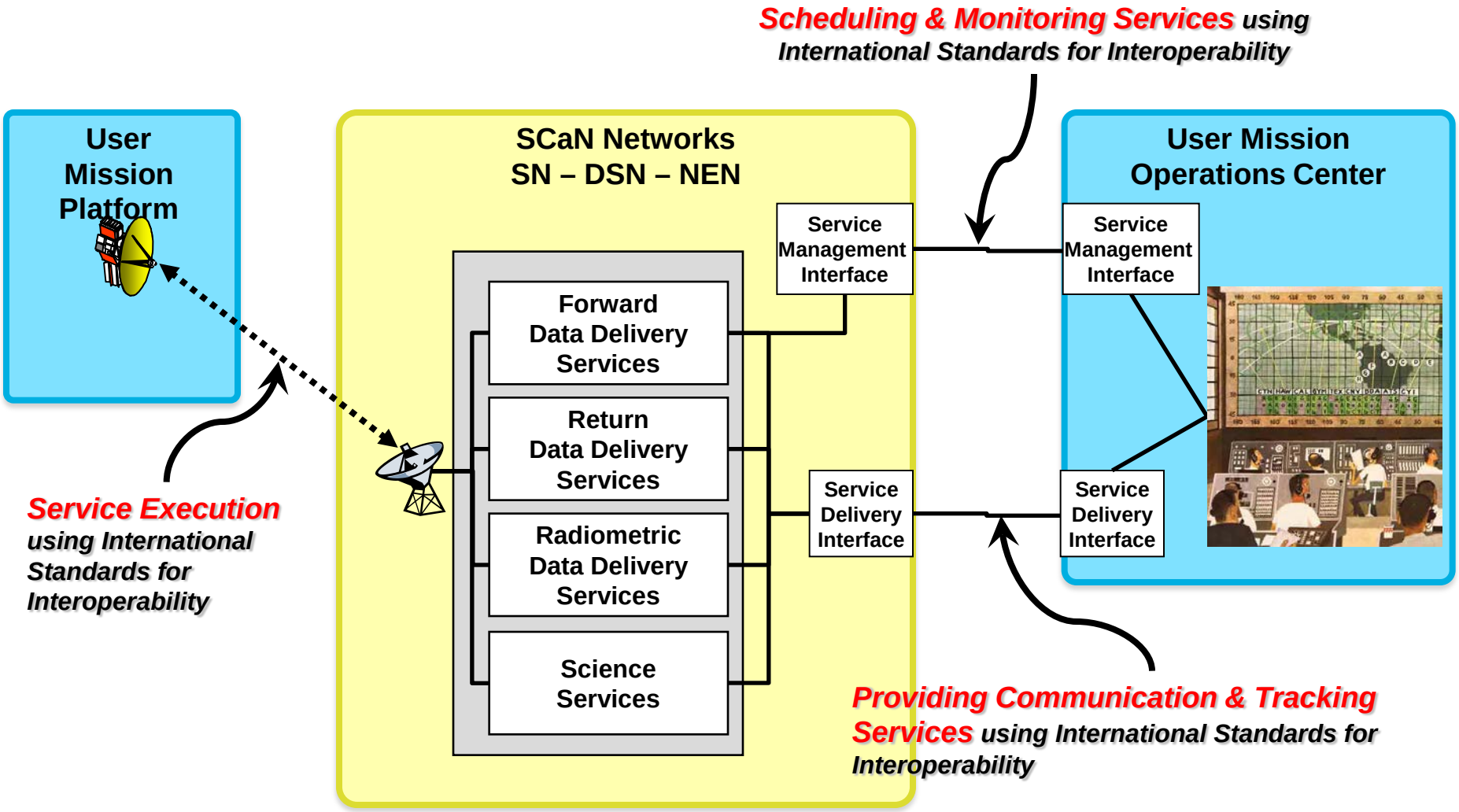
Increased data transmission

- Increased resolution & productivity
- Bring the public along for the Adventure





Unified Interfaces to Users & Internationally Interoperability



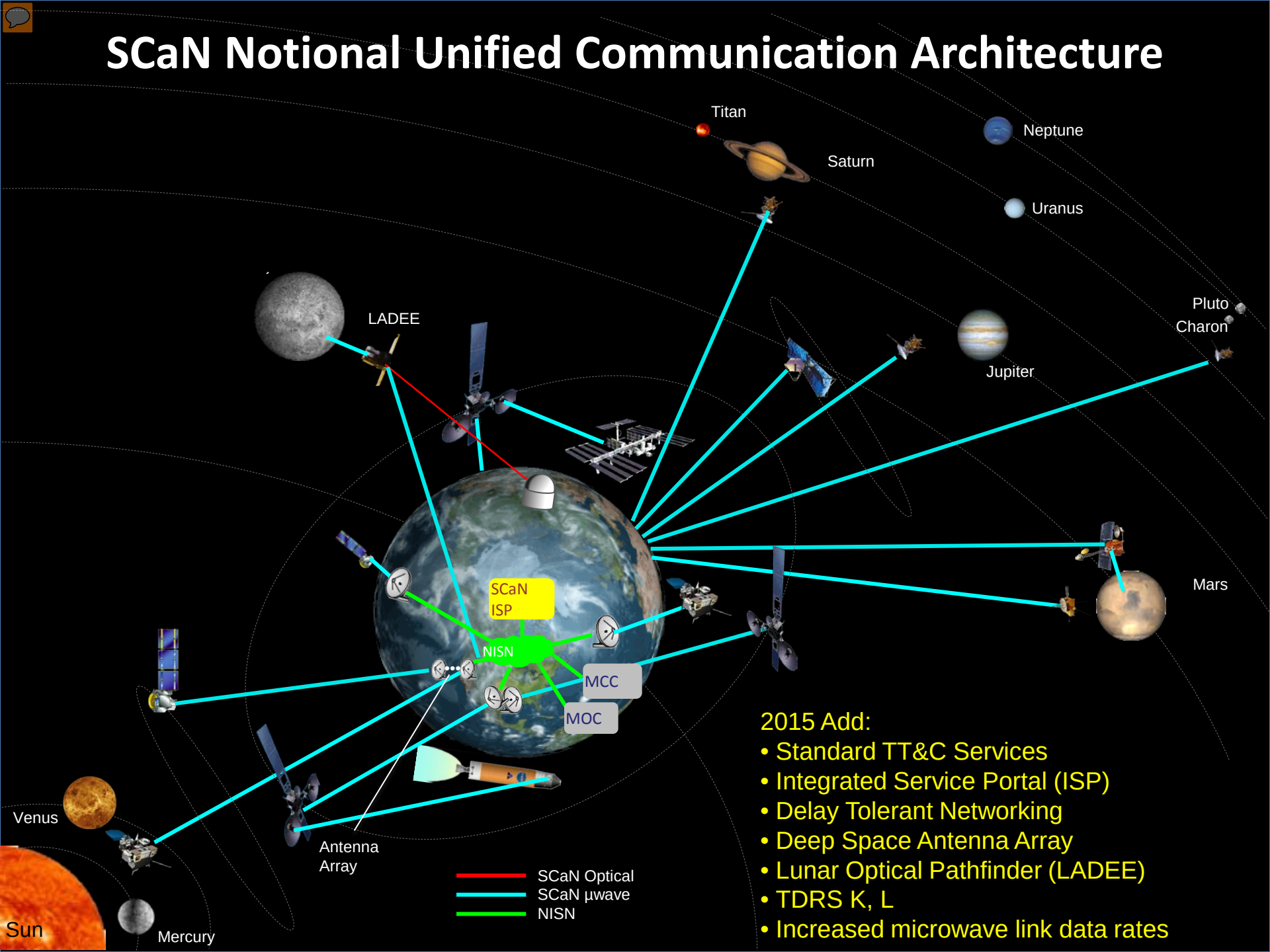
Architecture and Agency Drivers

	2010	2015	2020	2025+
Driving Requirements	Provide space communications and navigation services to existing and planned missions.	Develop a unified space communications and navigation network infrastructure Implement internationally interoperable communication protocols	Provide the highest data rates technically and financially feasible Implement a networked communication and navigation infrastructure across space	Provide communiation and navigation infrastructure and services for Lunar and Mars human missions
Mission Drivers	• Shuttle/ISS • Mars Landers • Great Observatories • Coordinated Earth Observation • LRO	• ISS • Mars – Coordinated and Complex Science Missions • SAR Earth Observation • Curiosity rover	• ISS • MPCV/Orion • SLS • Asteroid Sample Return • High Data Volume Hyper Spectral Missions	• Hyper spectral imaging at Mars and beyond • Human Near Earth Object Missions • Earth Sensor Web • Mars Exploration • Mars Sample Return
Capabilities	• Up to 300 Mps (EBRE/NEE) • Up to 6 Mbps at 1 AU (DSE) • Radiometric Services	• Up to 1.2 Gbps (EBRE) • Up to 13 Mbps at 1 AU (DSE) • Standard Services • Integrated Mission Commitment • Radiometric Enhancements	• Up to 50 Mbps at 1 AU • Integrated Network Management • Integrated Service Execution • Space Internetworking	• Up to 1.2 Gbps from the moon (optical) • Optical Communications to 100 Mbps (planetary) • Lunar far side coverage • High capacity multi-node • Inter-networking interoperability

SCaN Notional Unified Communication Architecture

2009 SCaN Architecture Baseline will transition to an Integrated Network Architecture which follows…

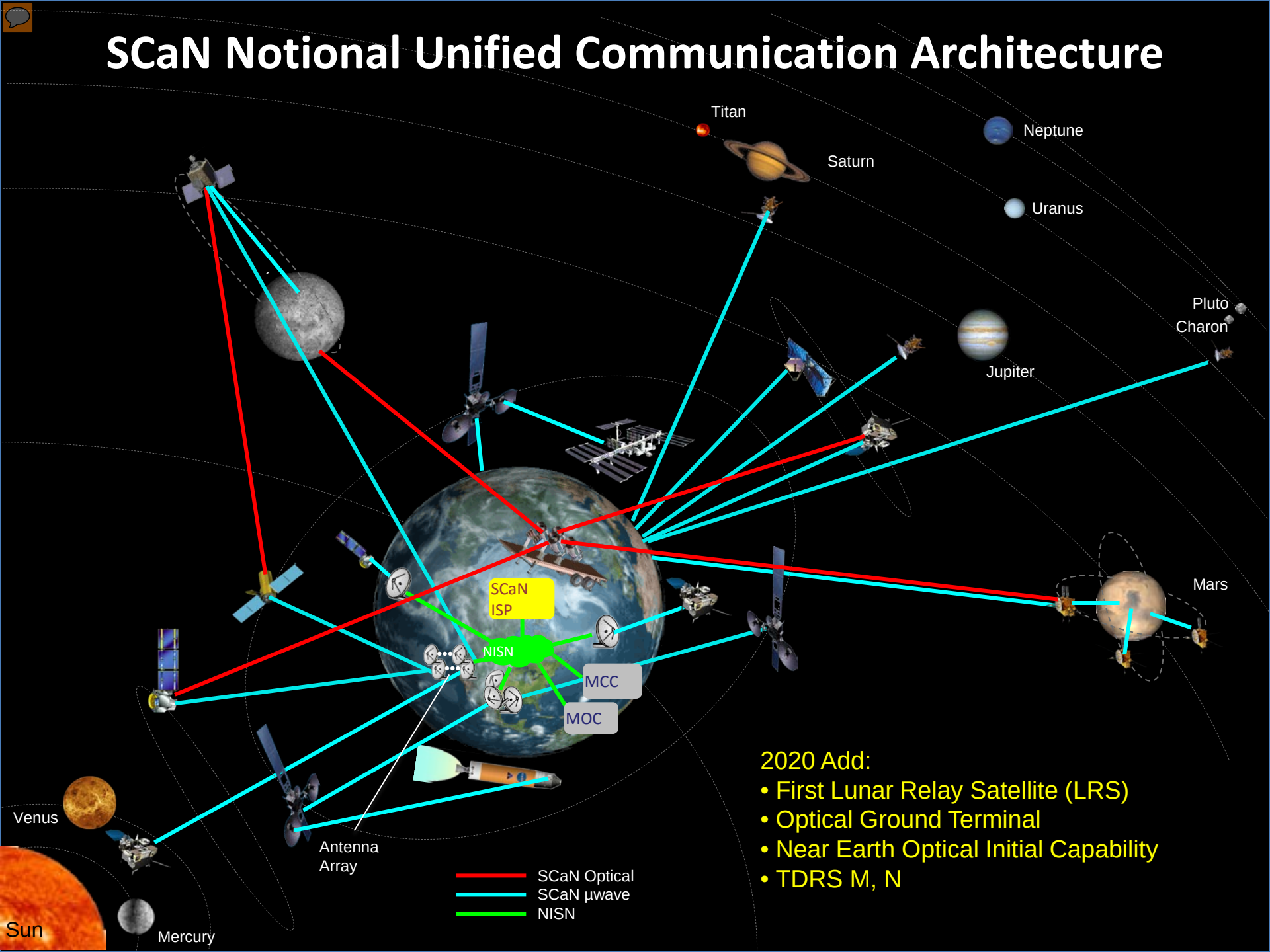
SCaN Notional Unified Communication Architecture



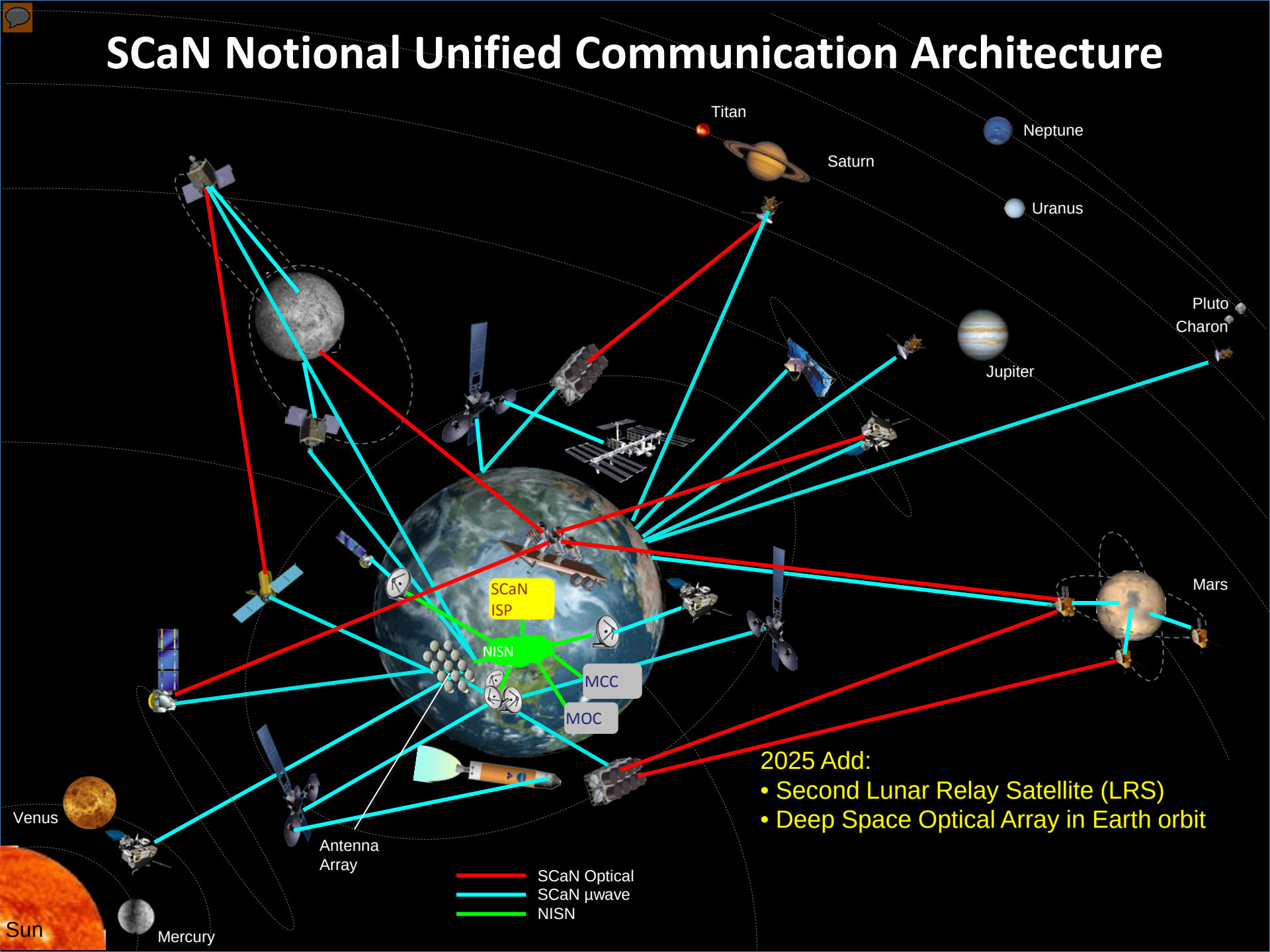
2015 Add:

- Standard TT&C Services
- Integrated Service Portal (ISP)
- Delay Tolerant Networking
- Deep Space Antenna Array
- Lunar Optical Pathfinder (LADEE)
- TDRS K, L
- Increased microwave link data rates

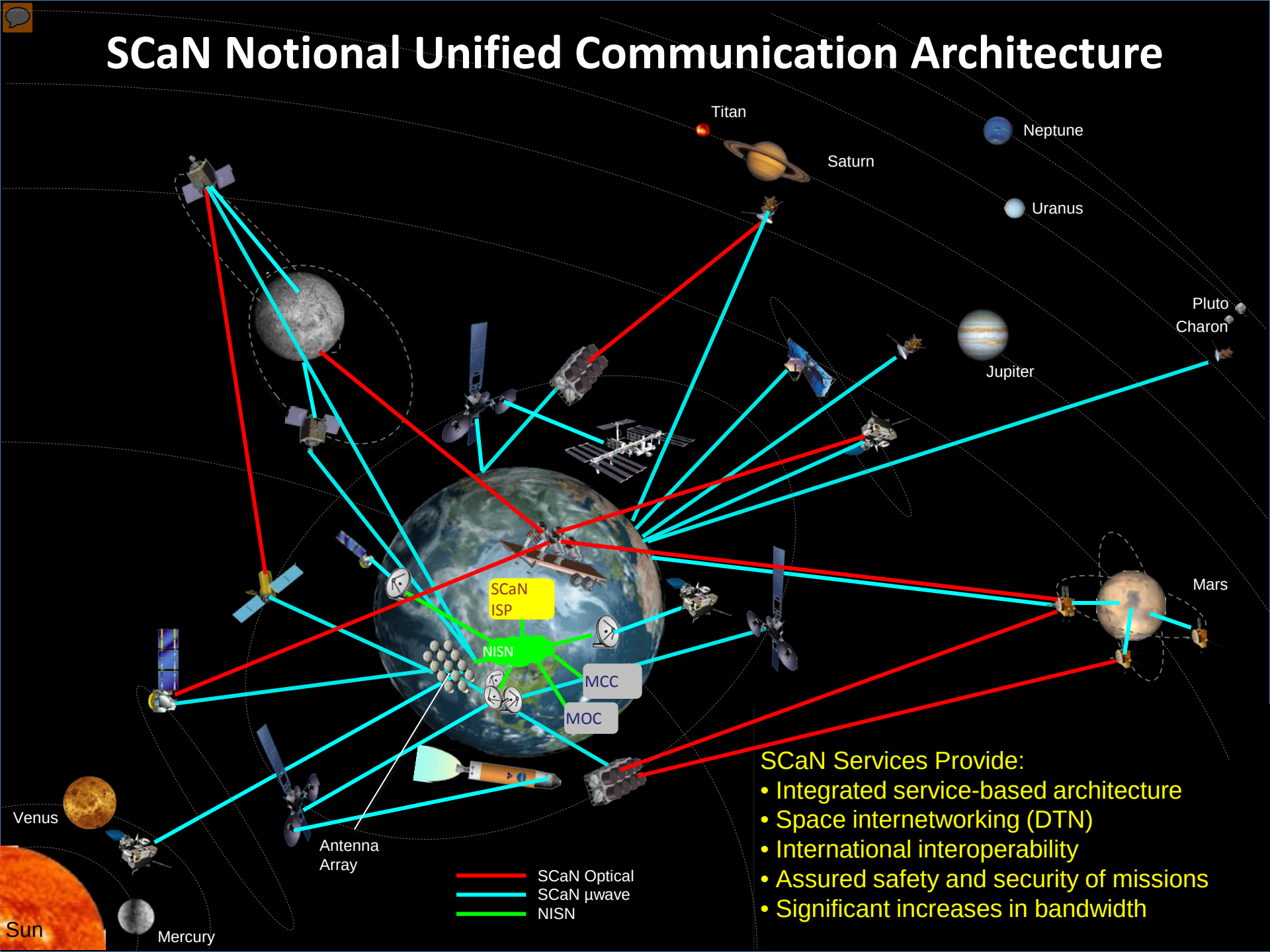
SCaN Notional Unified Communication Architecture



SCaN Notional Unified Communication Architecture



SCaN Notional Unified Communication Architecture

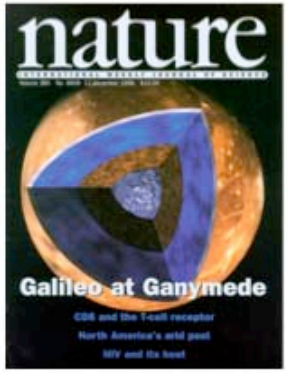


SCaN Services Provide:

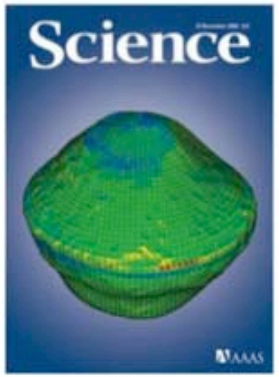
- Integrated service-based architecture
- Space internetworking (DTN)
- International interoperability
- Assured safety and security of missions
- Significant increases in bandwidth

DSN's Impact on Exploration and Science

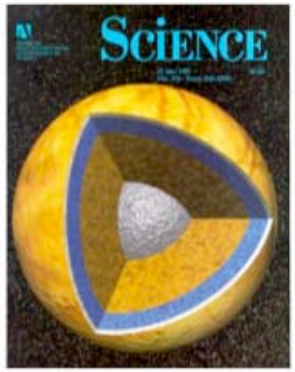
Communications and navigation support and *Radio and Radar* science has enabled a continuing torrent of forefront discoveries



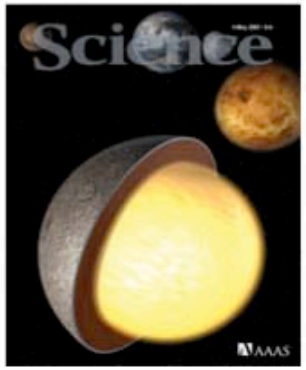
Interior of Ganymede



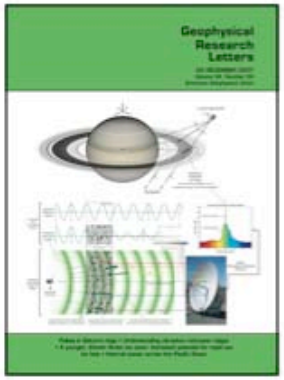
Asteroids in 3-D



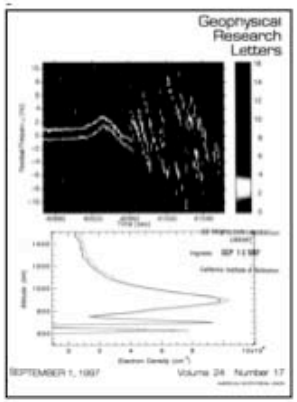
Oceans on Europa?



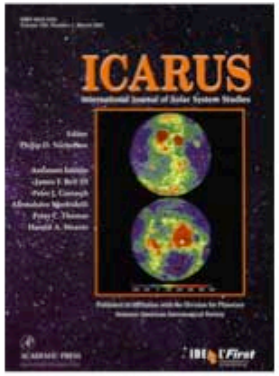
Mercury Liquid Core



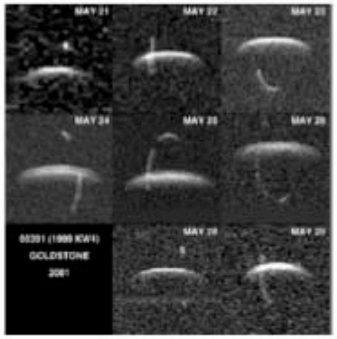
Saturn's Rings



Mars Ionosphere



Moon Gravity Field



Binary Asteroids

Student Study of Juptier Radio Emission

Saturn's Rings

For more information, visit NASA:

www.nasa.gov

or

Space Communications and Navigation (SCaN):

www.nasa.gov/scan

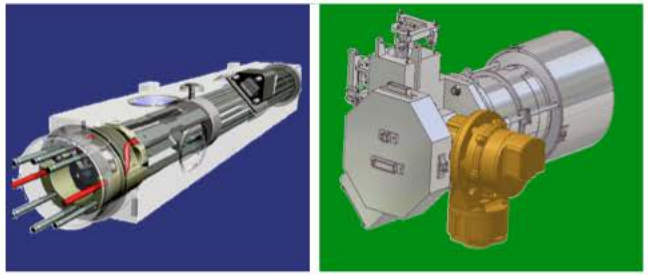
www.facebook.com/NASASCaN

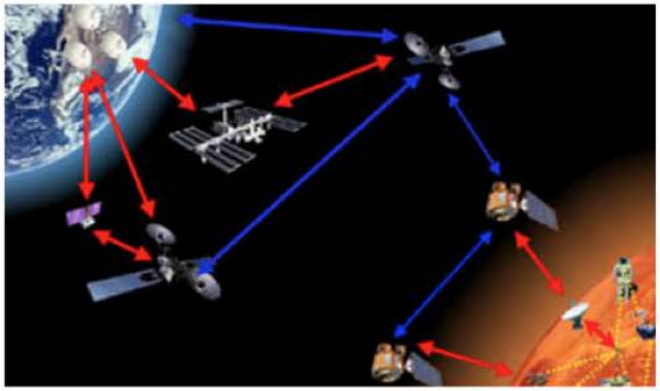
Twitter: @NASASCaN

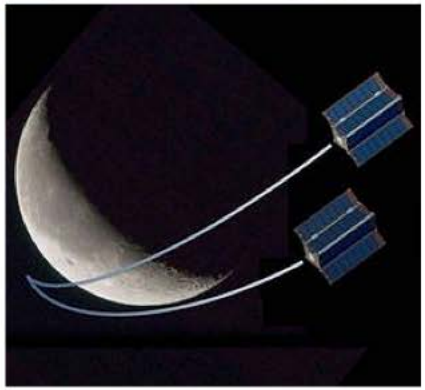
DSN Future:
A User Perspective

Dr. Les Deutsch
Deputy Director For
Interplanetary Network Directorate
Jet Propulsion Laboratory
California Institute of Technology

February 20, 2014



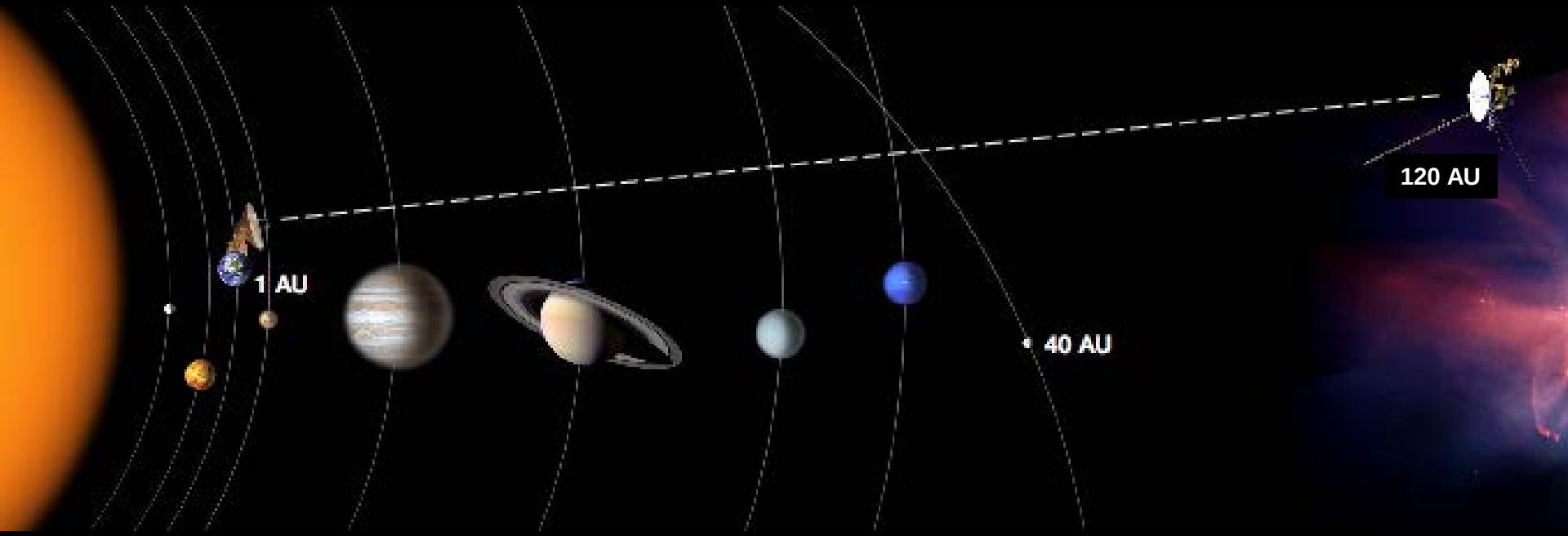




Copyright 2014 California Institute of Technology, Government sponsorship acknowledged.

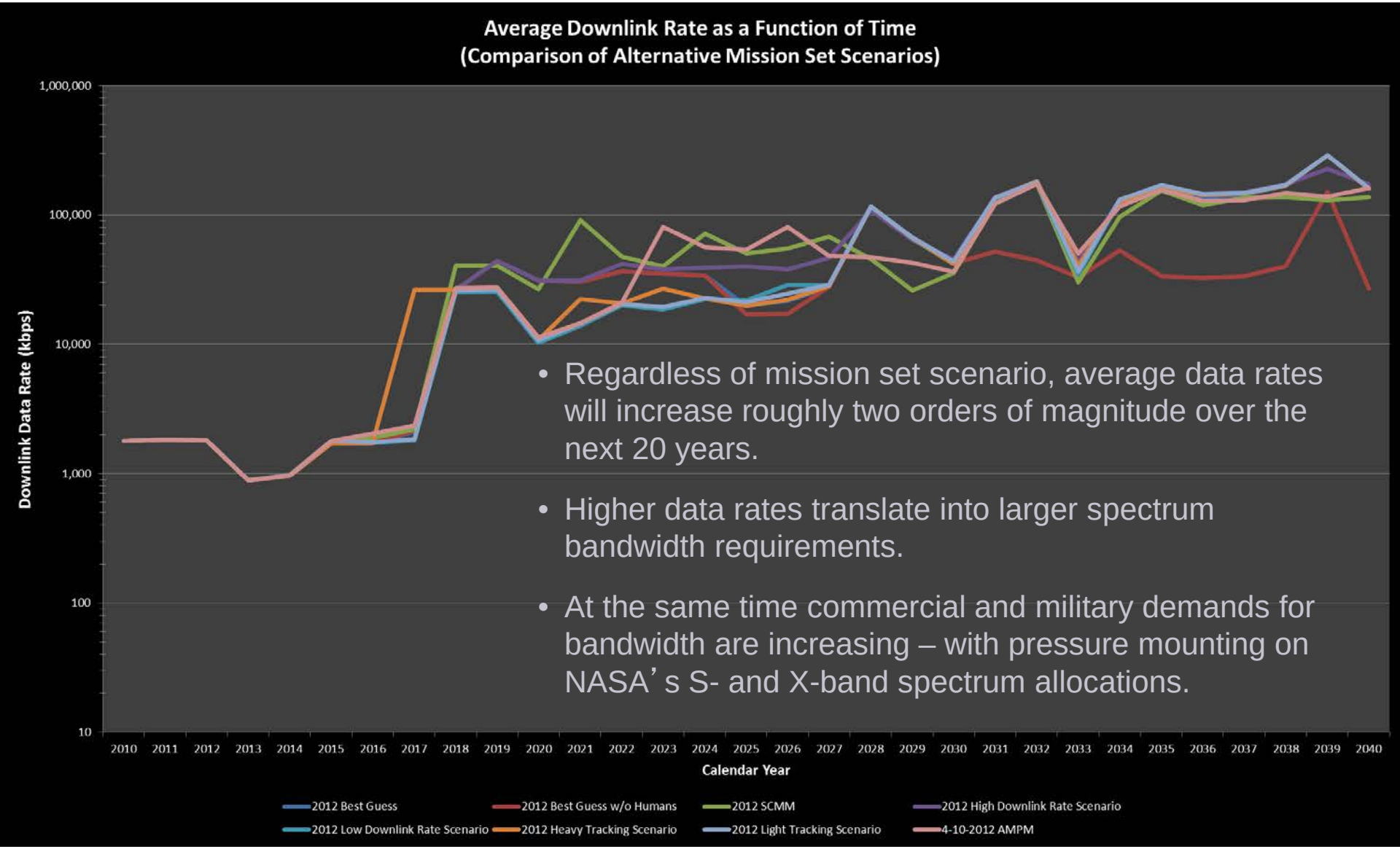
Ultimate Long Distance Carrier

Power received by 70 m DSN antenna from Voyager is so small that, if accumulated for 10 trillion years, it could power a refrigerator light bulb for one second!!!



Jet Propulsion Laboratory
California Institute of Technology

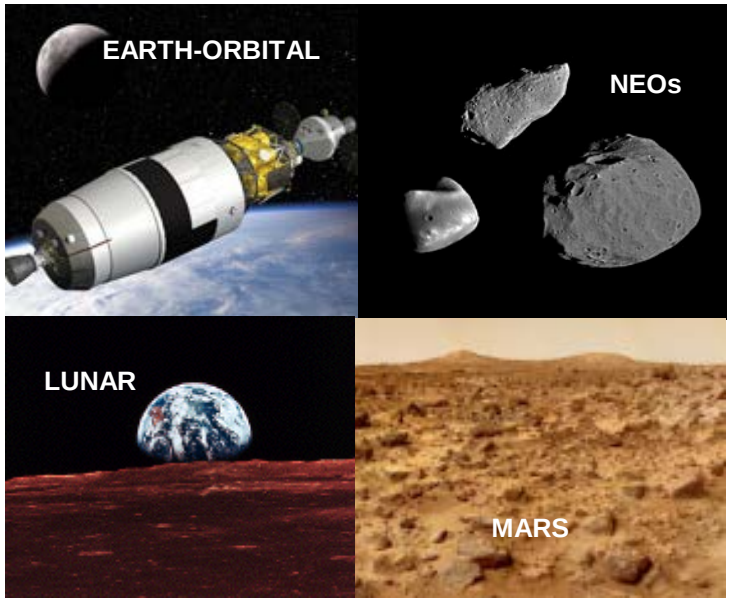
Increasing Bandwidth Demand



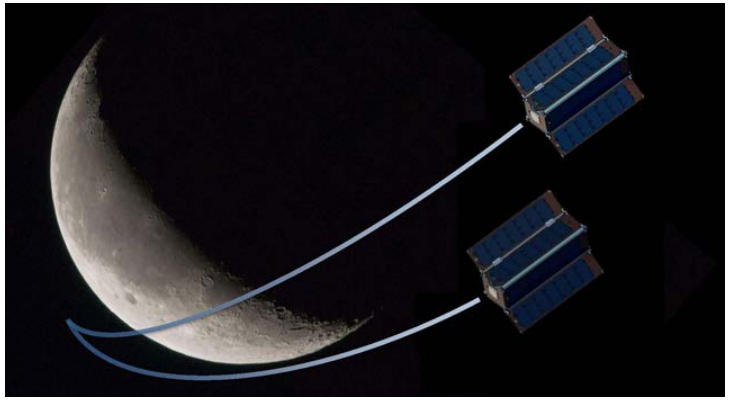
- Regardless of mission set scenario, average data rates will increase roughly two orders of magnitude over the next 20 years.
- Higher data rates translate into larger spectrum bandwidth requirements.
- At the same time commercial and military demands for bandwidth are increasing – with pressure mounting on NASA's S- and X-band spectrum allocations.

Customer Changers: Humans & Smallsats

- **The DSN enables astronauts to explore beyond low-Earth orbit**
  - Over the last two years, DSN has become a key participant in HSF planning



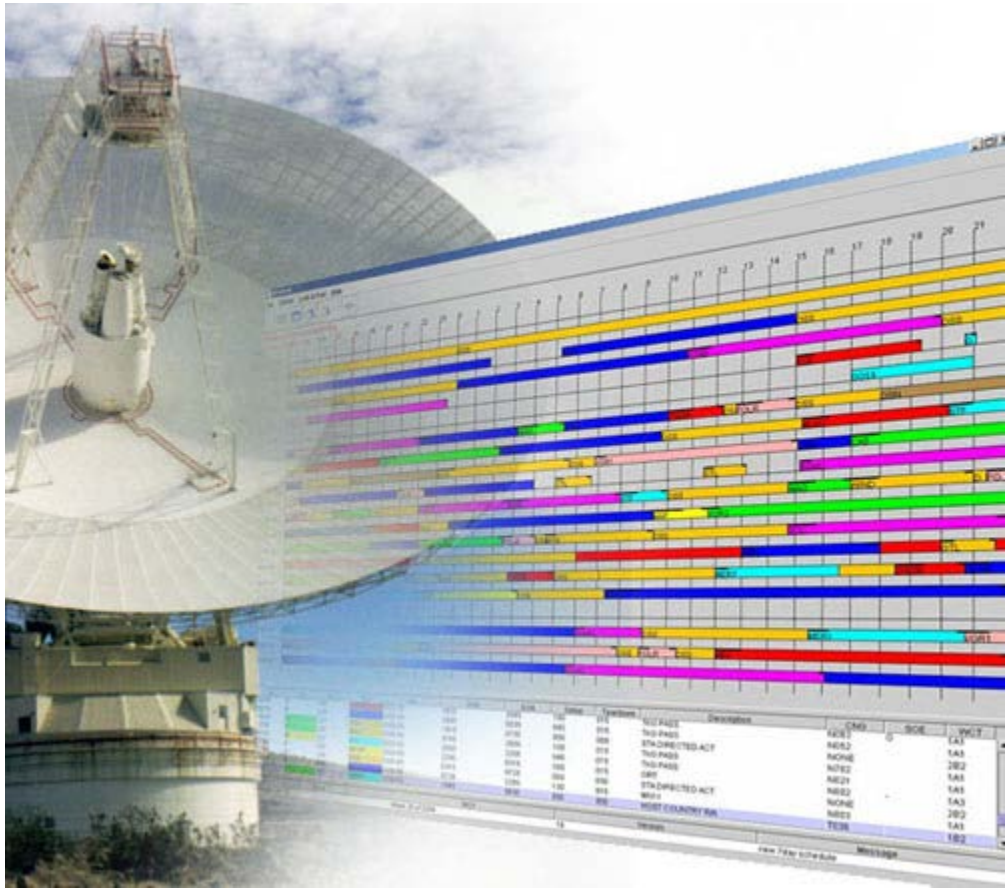
- **The DSN and AMMOS enable deep space smallsats – including CubeSats**
  - Large DSN antennas, Optical communications, Clever navigation and trajectory design, Low-cost multimission ground systems
  - New IND R&TD investments are focused on smallsats



Jet Propulsion Laboratory
California Institute of Technology

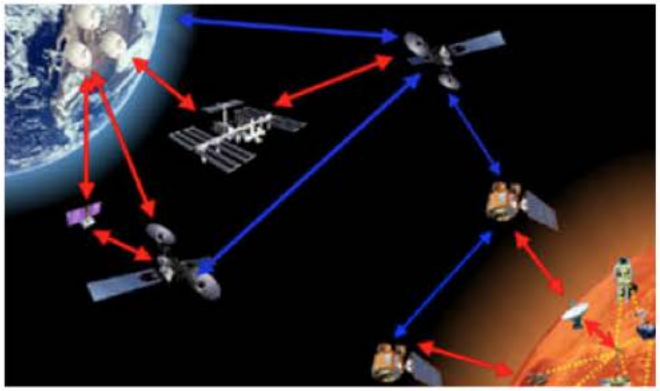
DSN in the Integrated Network Era

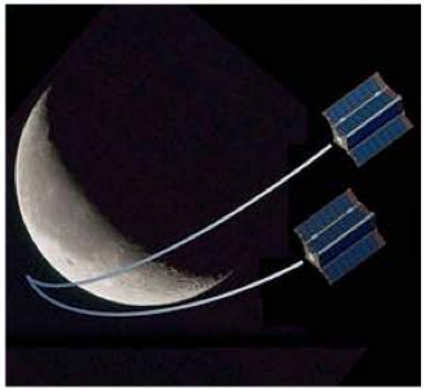
- NASA has a goal of providing missions with a user-friendly interface for services throughout the lifecycle
  - New architecture is the result of years of system studies
- DSN is working as part of a team including NASA's Space Network and Near Earth Network to make this happen – in fact, JPL is leading this effort, called "SCaN Network Integration Project" (SNIP)



Enabling Technology

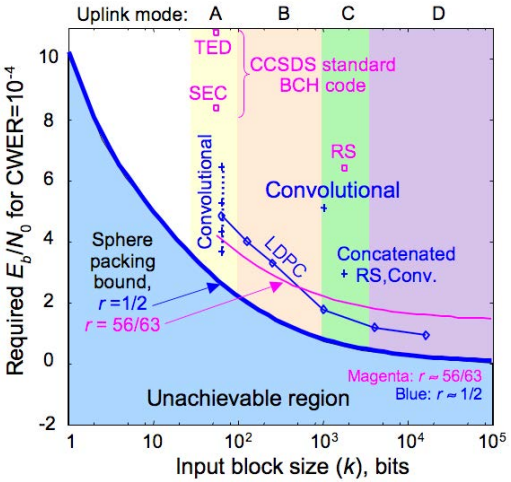
Steve Townes
Chief Technologist
Interplanetary Network Directorate





Jet Propulsion Laboratory
California Institute of Technology

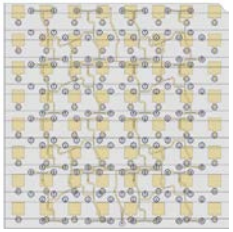
Improved Performance



Efficient Coded Up/Downlinks

Arrayed Antennas for Uplink and Downlink

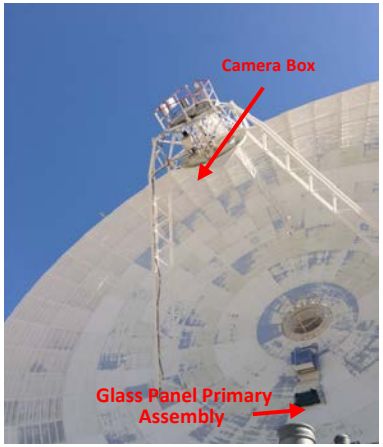
X-band and Ka-band



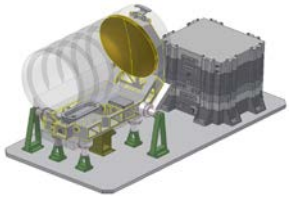
1 Kilowatt Ka-Band Solid State Amplifier Array

100 kW X-Band Klystron

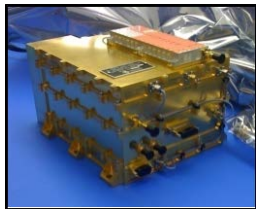
High-Power Uplinks



Combined RF/optical Ground Station



Optical Terminals

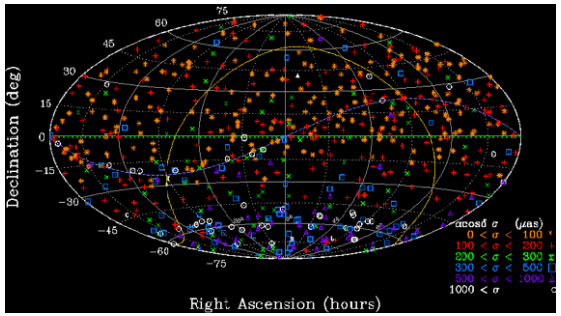


Software Defined Radios

Flight Hardware

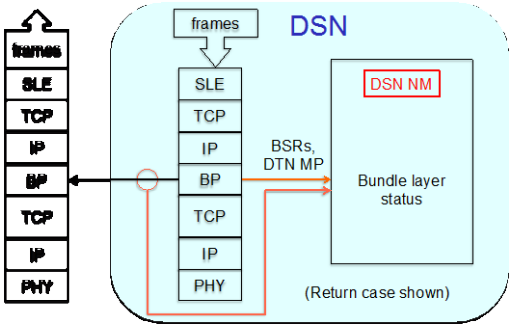
Improved Navigation

Ka-Band Quasar Reference Source Catalog—Filling in Southern Declinations



Advanced Communications Protocols Protocols

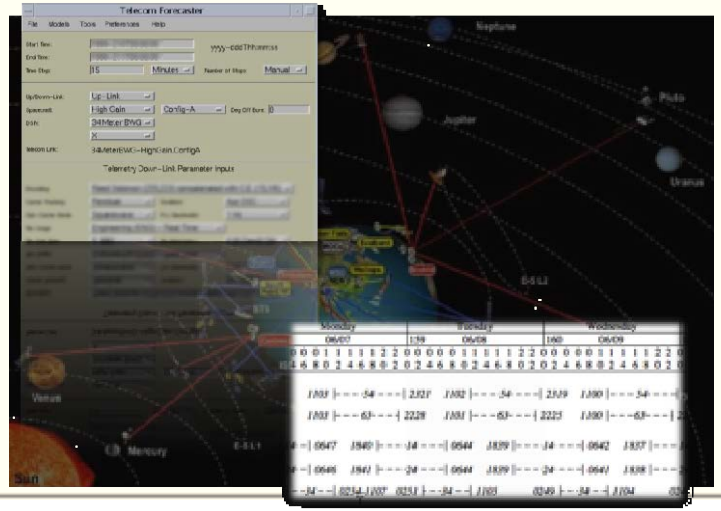
Delay Tolerant Networking



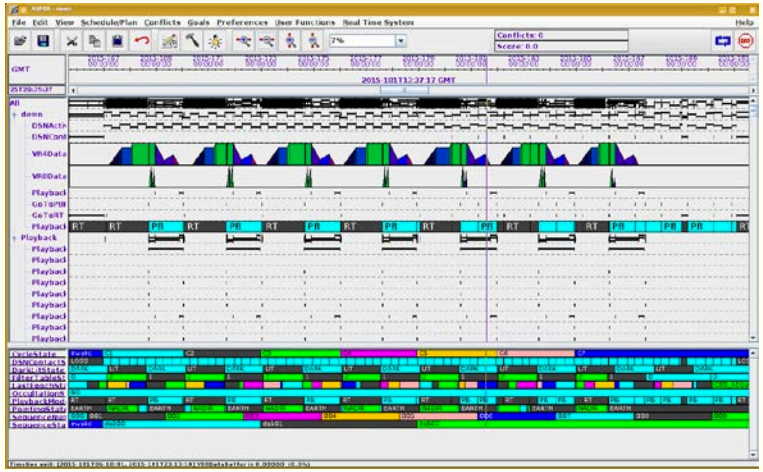
Jet Propulsion Laboratory
California Institute of Technology

Improved Operational Efficiency

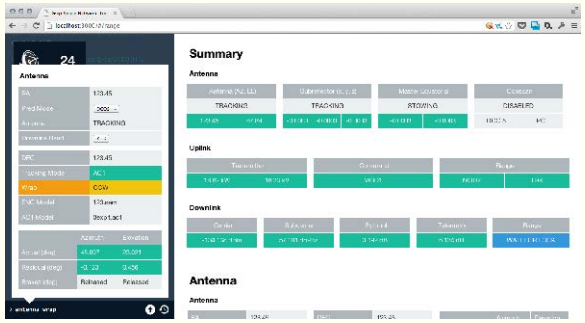
Automated DSN Scheduling



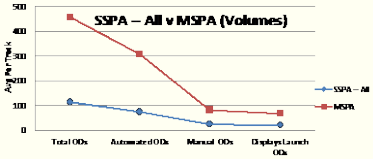
Automated Re-Scheduling



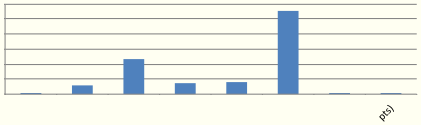
Human Computer Interaction



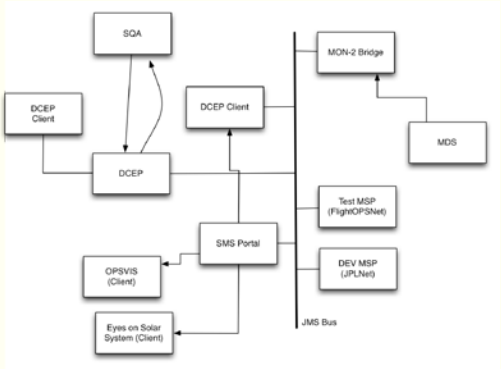
Link Complexity Optimization



Evt/Alarm Percentage Occurence -- SSPA

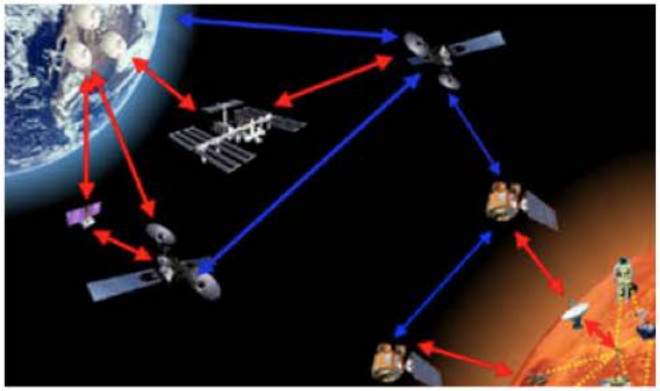


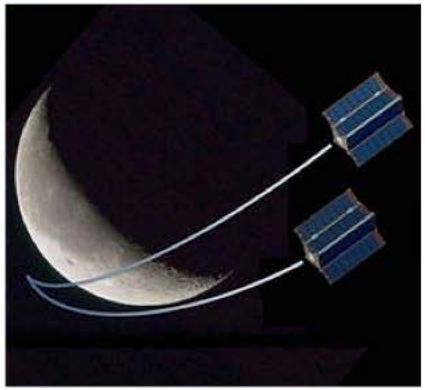
Complex Event Processing



DSN Science

Joseph Lazio
Chief Scientist
Interplanetary Network Directorate





Next 50 Years?

Complete catalog of Near Earth Objects

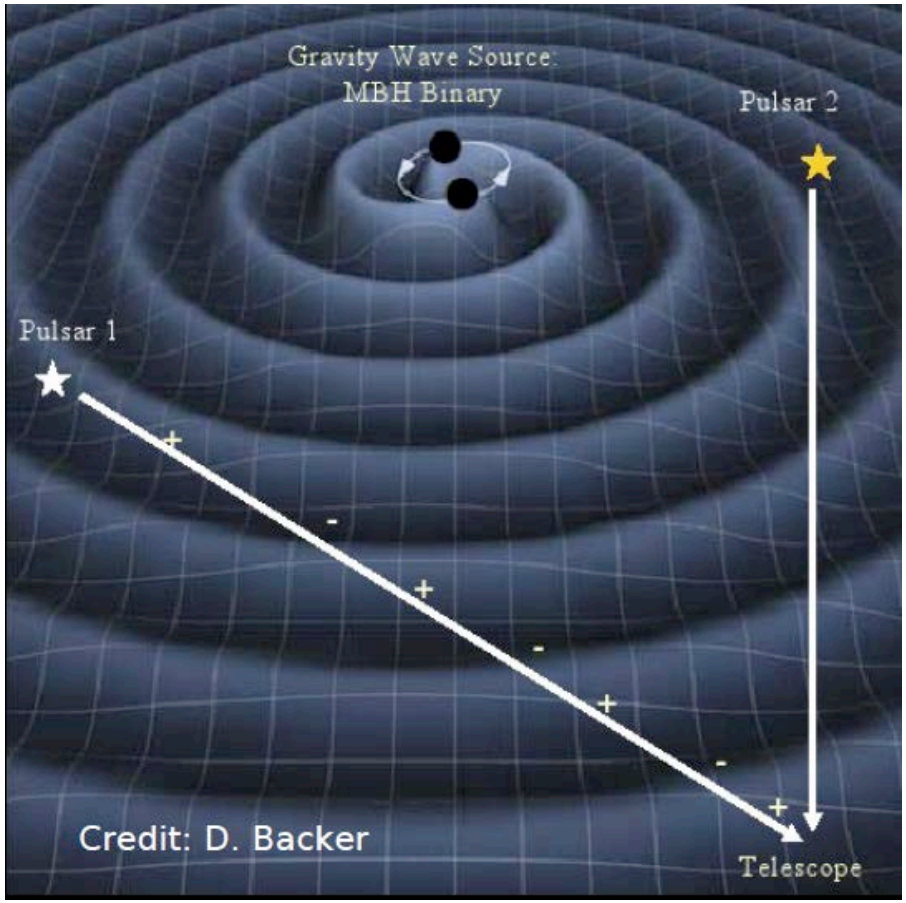
Gravitational wave astronomy

Planetary spacecraft fleets

Extrasolar planets

Extraterrestrial life

Radio Pulsars, DSN, and Gravitational Waves

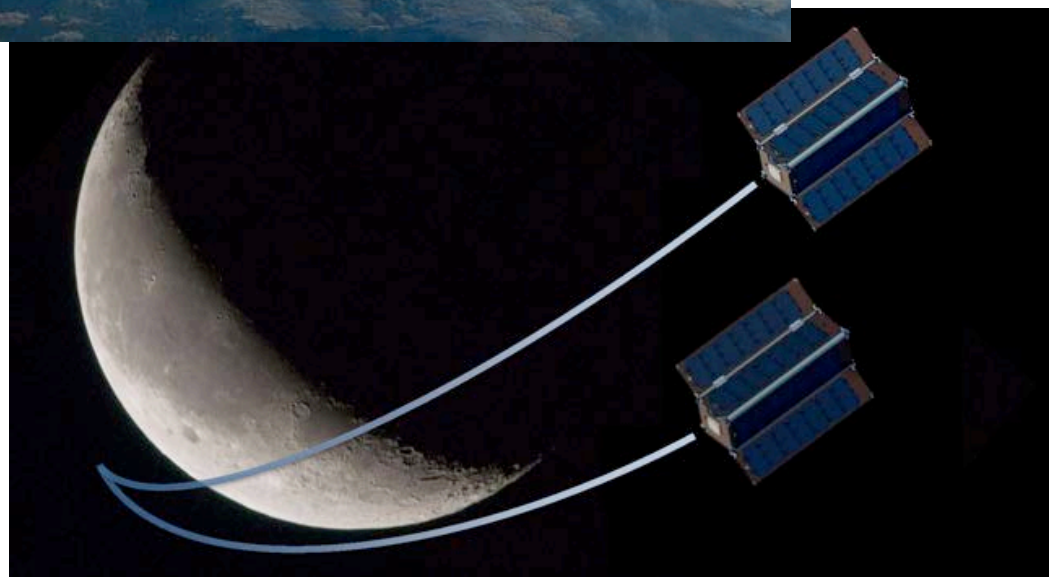


Technique first proposed by Hellings & Downs (JPL)

Searching for gravitational waves emitted by supermassive black holes at centers of galaxies as they in-spiral together ….

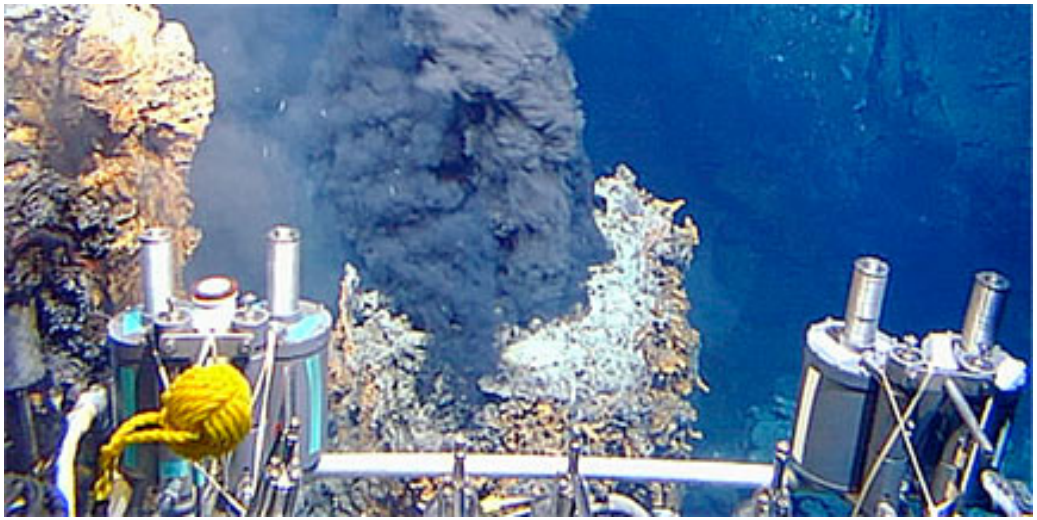
Deep Space SmallSat Constellations

- Imagine fleets of spacecraft at other planets
- Imagine dropping many probes into a planet's atmosphere …
- May be possible with "smallsats"
- Requires whole new way to operate the DSN …



BACKUP

Non-DSN Science?



19. 1977 – Deep-Sea Life

Honorable mention:

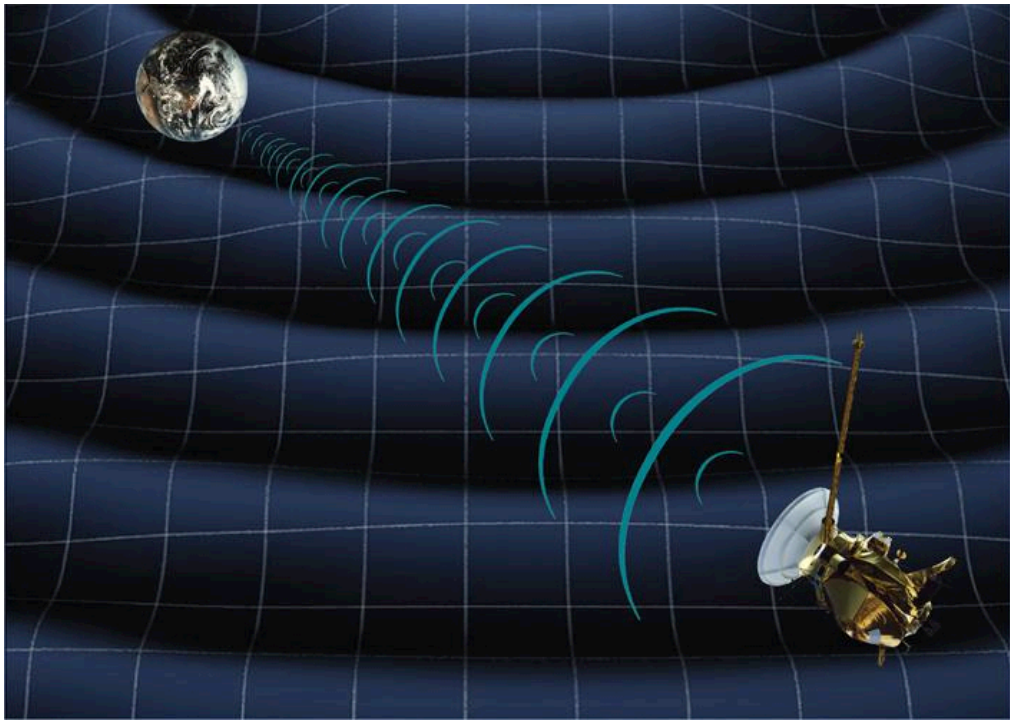
When John Delaney was forming UW's Neptune Project to study life around thermal vents on the ocean floor, he contacted JPL's DSN engineers because their expertise in communicating in hostile environments.

What about Europa?

Spacecraft Tracking and Gravitational Waves

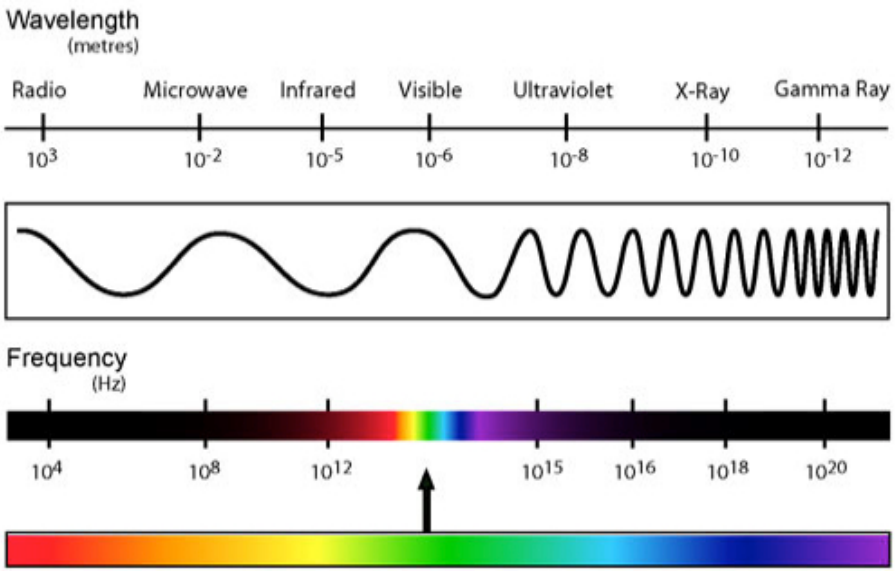
Spacecraft-Earth forms gravitational wave detector

- First suggested by Estabrook & Wahlquist (1975), both JPL
- DSN has long history --- Pioneer, Viking, *Cassini*
- DSN-*Cassini* limits ~ 1000 × better than previously obtained

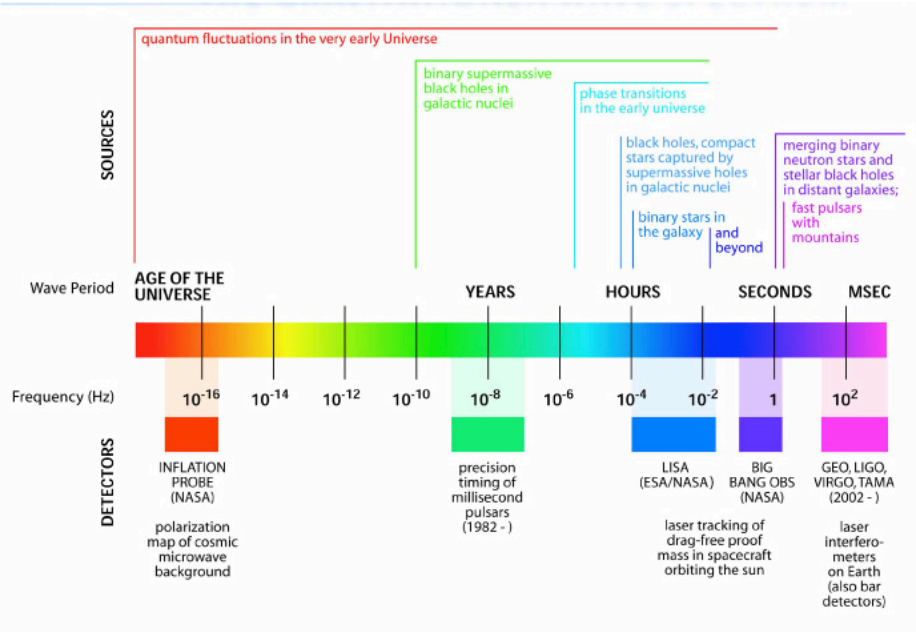


Gravitational Waves

Electromagnetic Spectrum



Gravitational Wave Spectrum



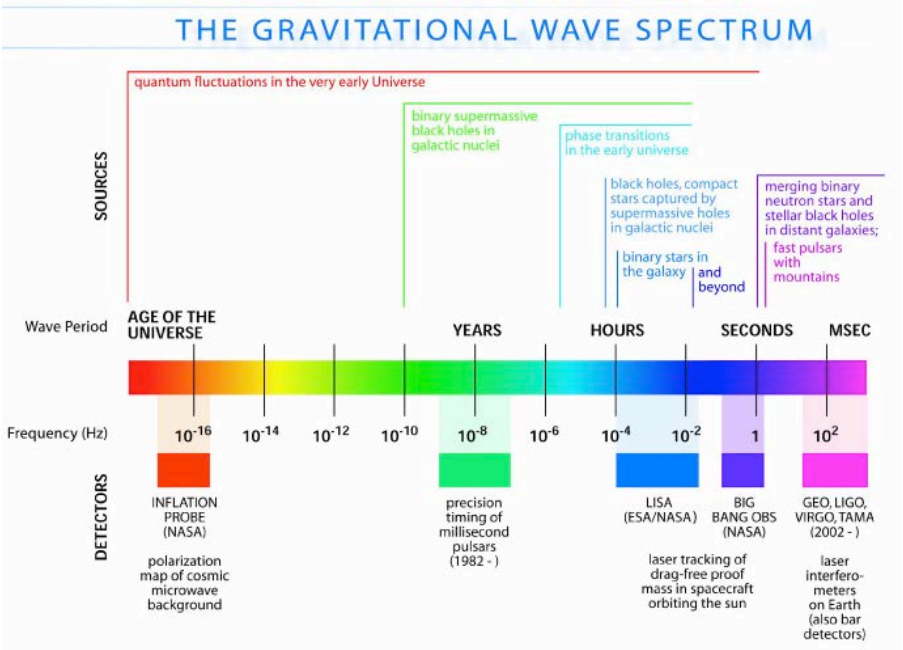
Gravitational Waves
Who Cares?

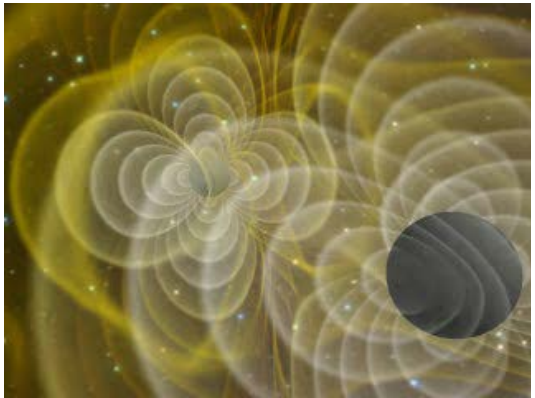
- **One of final untested predictions of Einstein's Theory of General Relativity**

  Initial work already yielded one Nobel Prize in Physics

- **Identified by U.S. astronomy community as "science frontier discovery area"** ***(U.S. National Academy of Sciences)***

- **Probes most extreme environments in Universe**

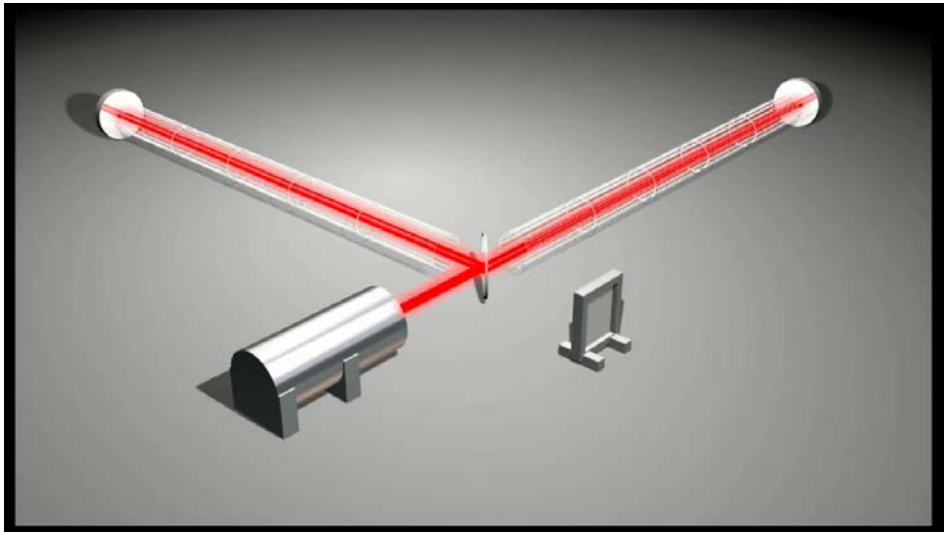


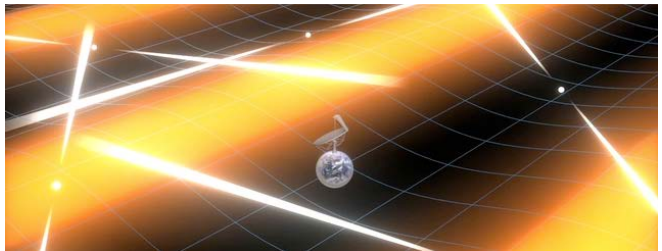


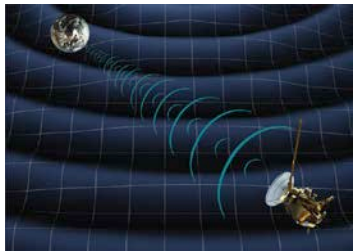
Gravitational Wave Detectors

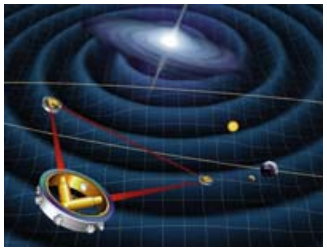
All modern gravitational wave detectors use same principle

- Gravitational wave modifies distance (a.k.a. spacetime metric)
- Measure distances between collection of objects (test masses)
- Changes result from passing gravitational waves



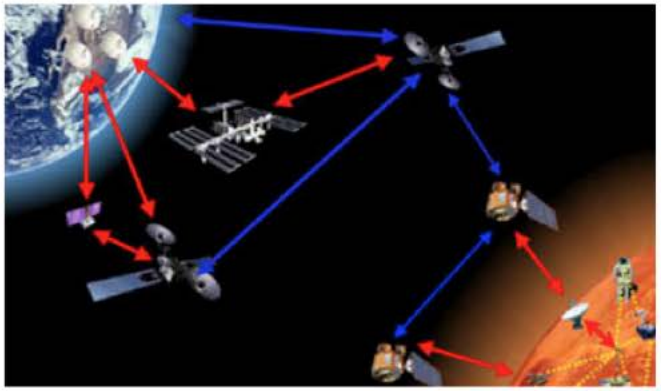


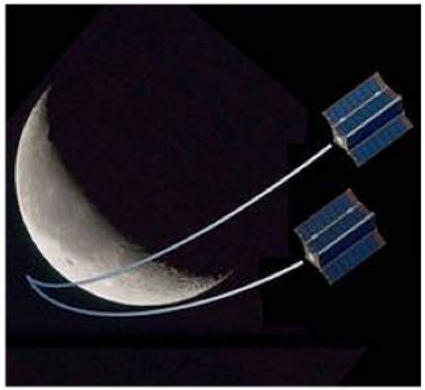




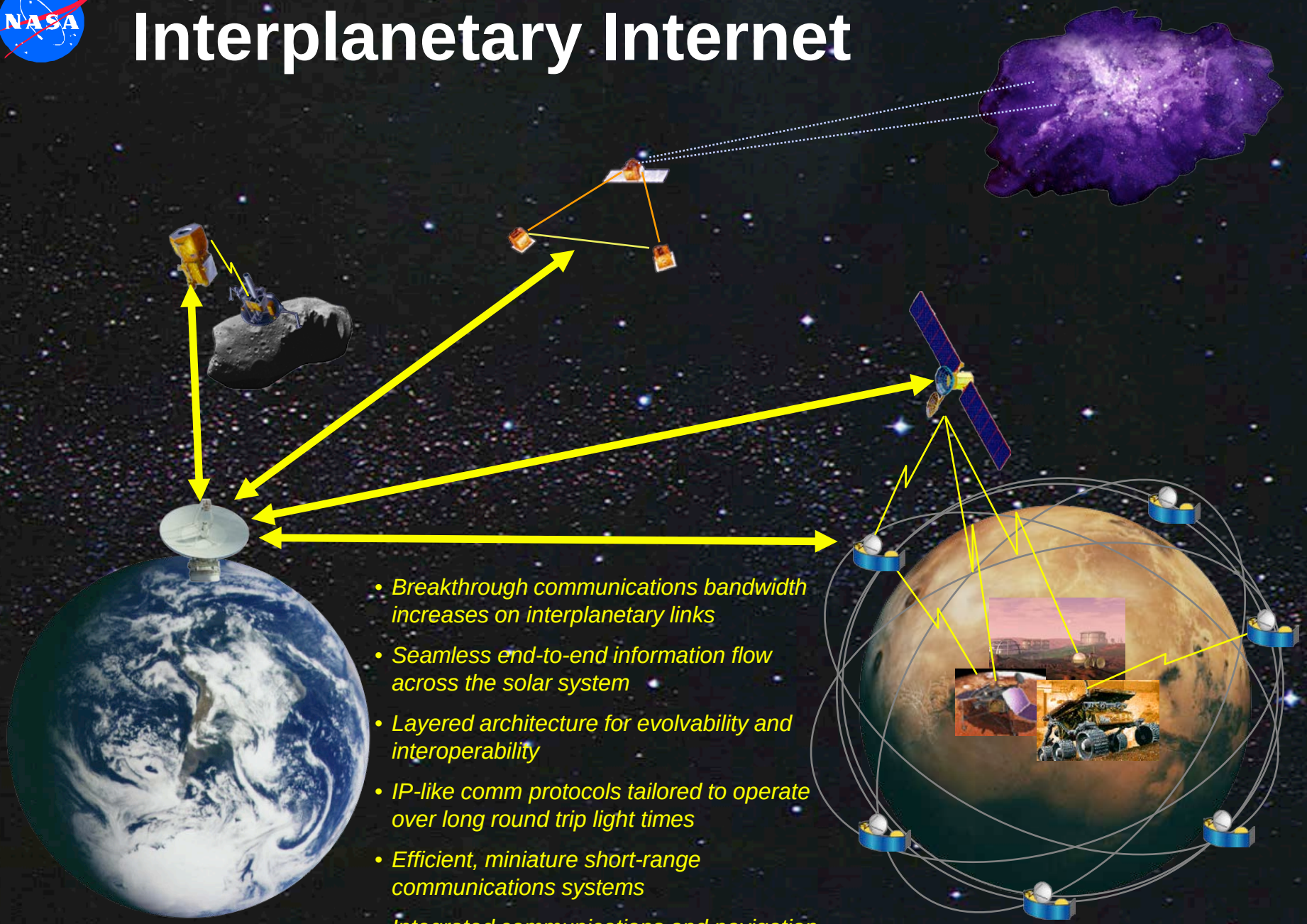
Mars Relay Network

Chad Edwards
Chief Telecommunications Engineer
Mars Exploration Directorate
Jet Propulsion Laboratory





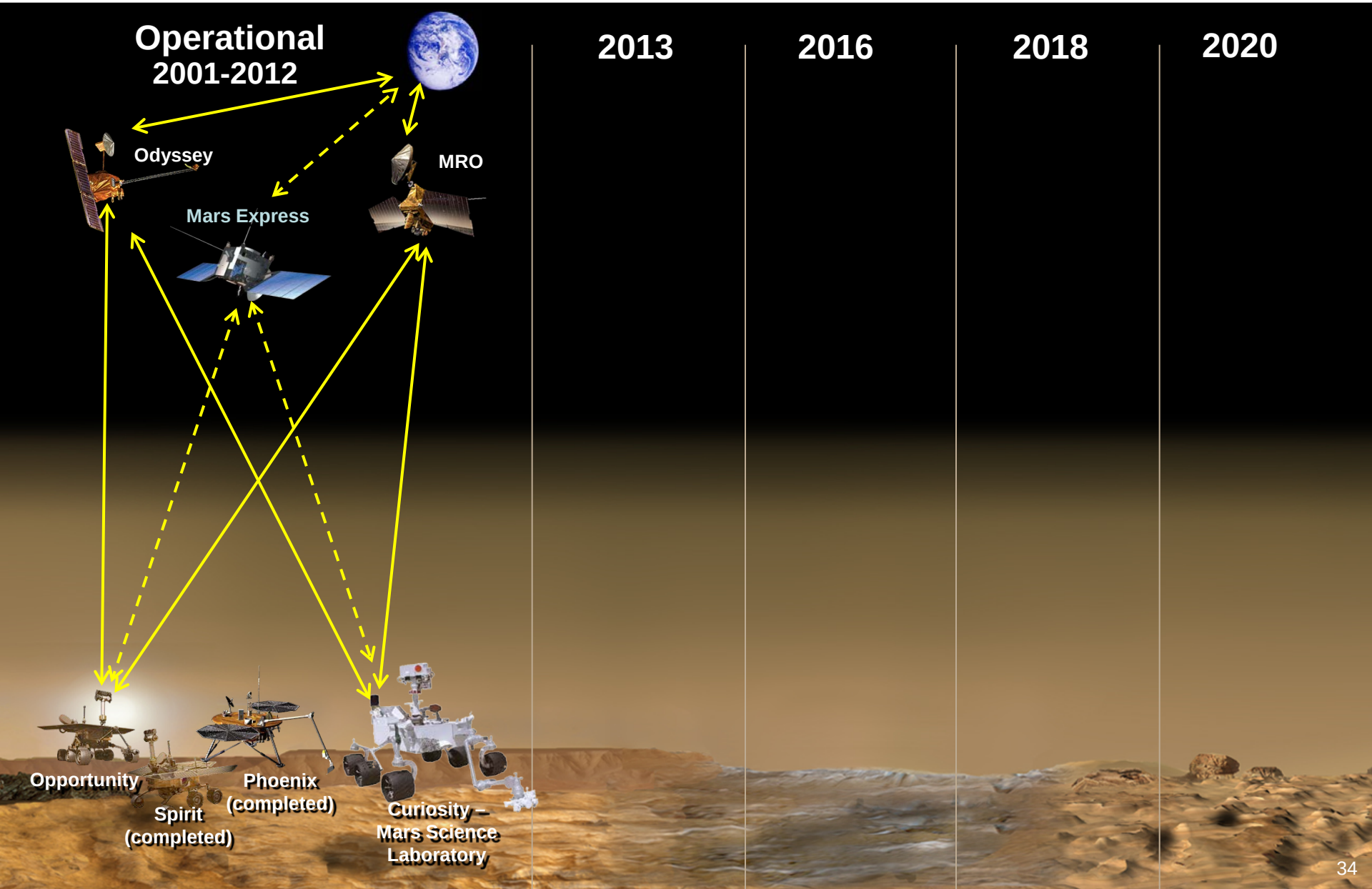
Interplanetary Internet



- *Breakthrough communications bandwidth increases on interplanetary links*
- *Seamless end-to-end information flow across the solar system*
- *Layered architecture for evolvability and interoperability*
- *IP-like comm protocols tailored to operate over long round trip light times*
- *Efficient, miniature short-range communications systems*
- *Integrated communications and navigation services*

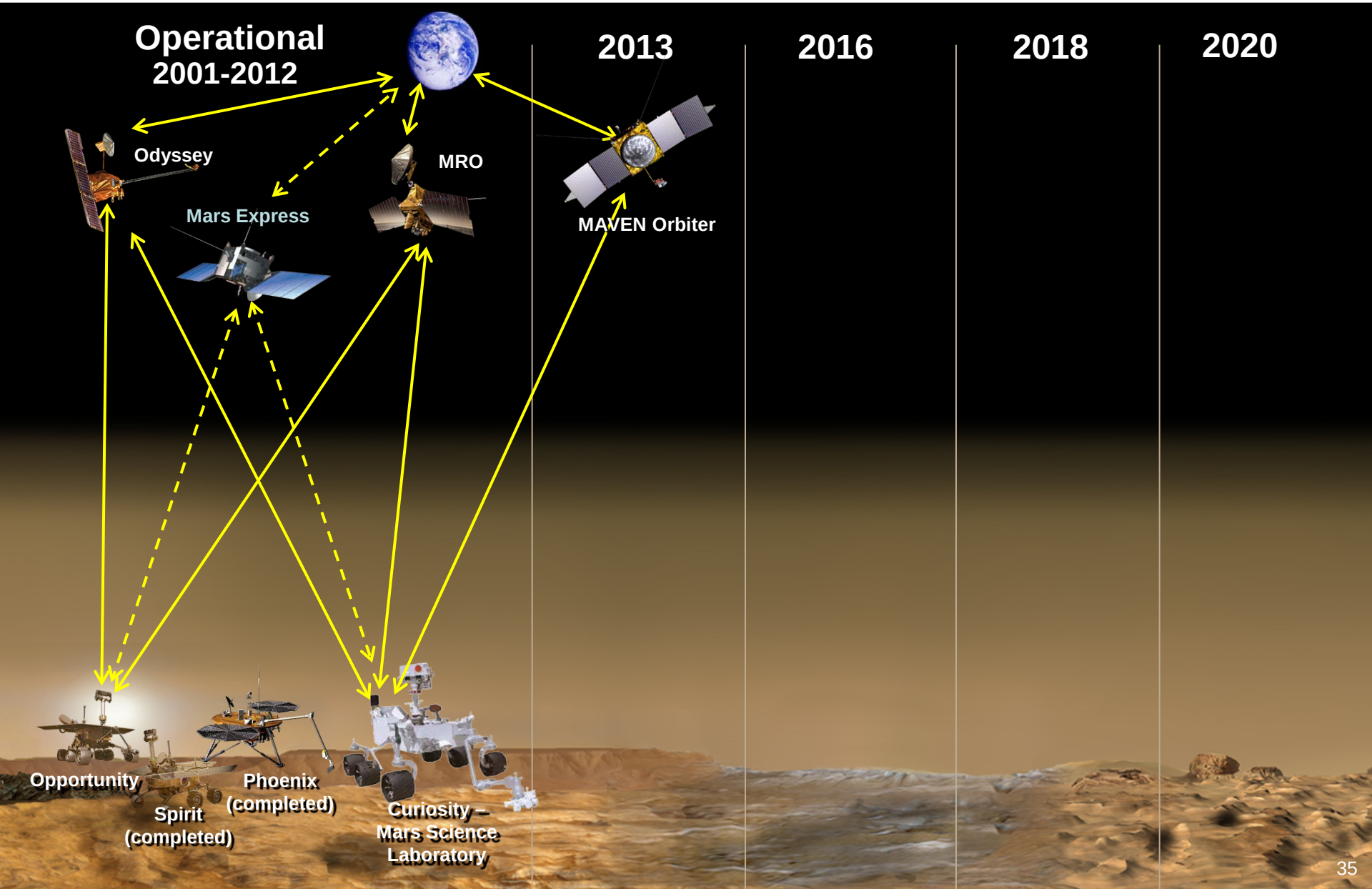
Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution



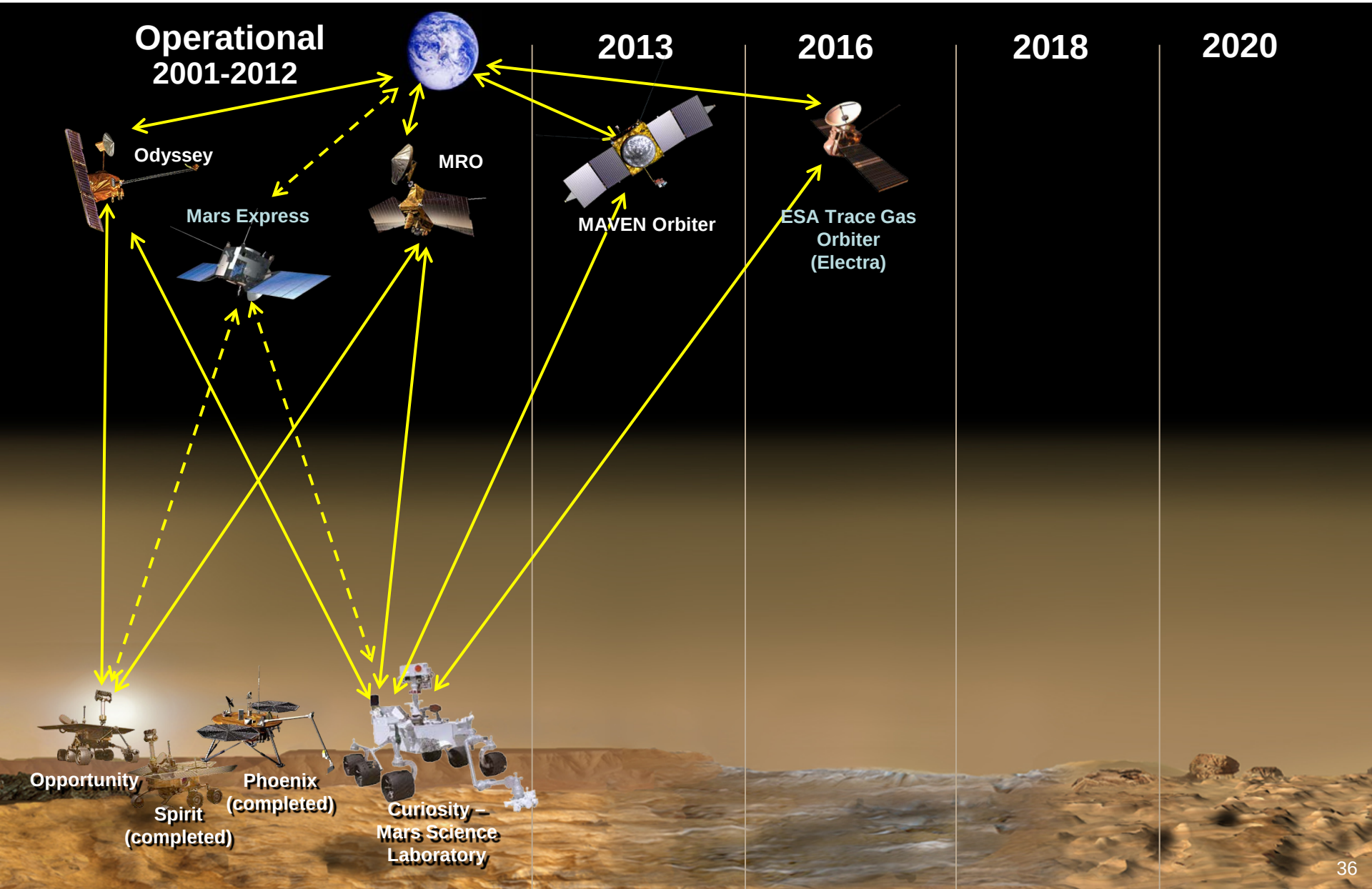
Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution



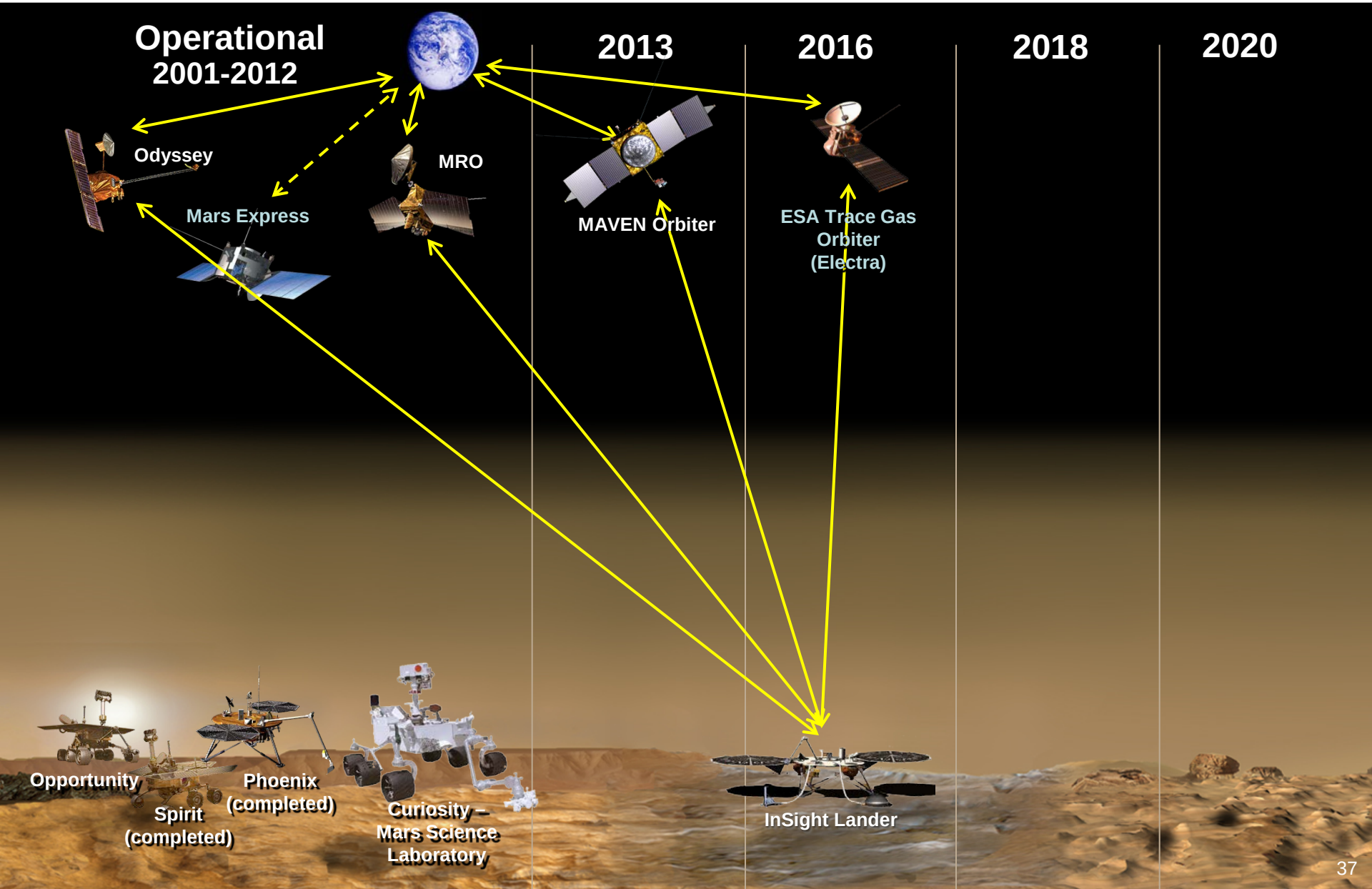
Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution



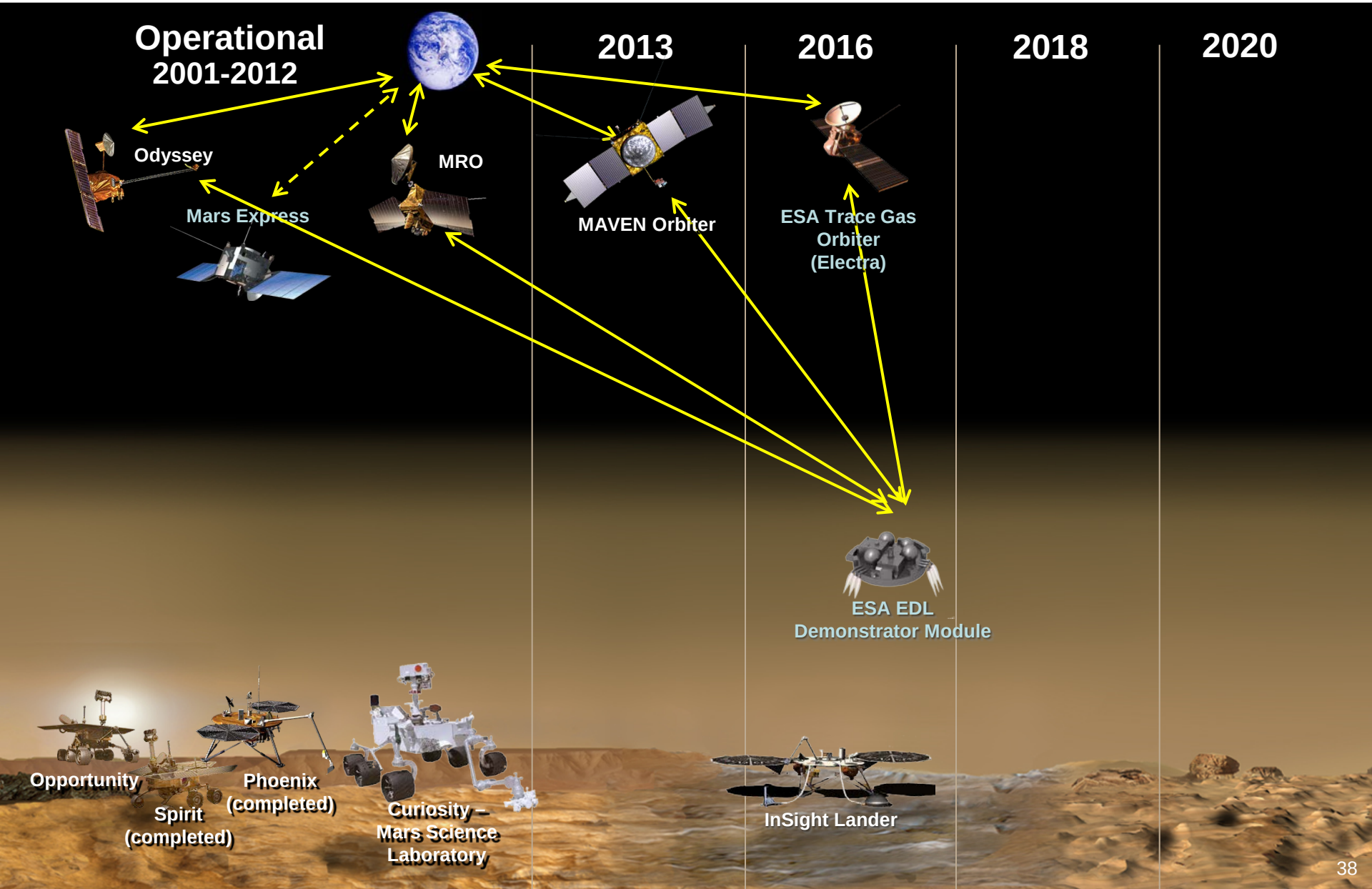
Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution



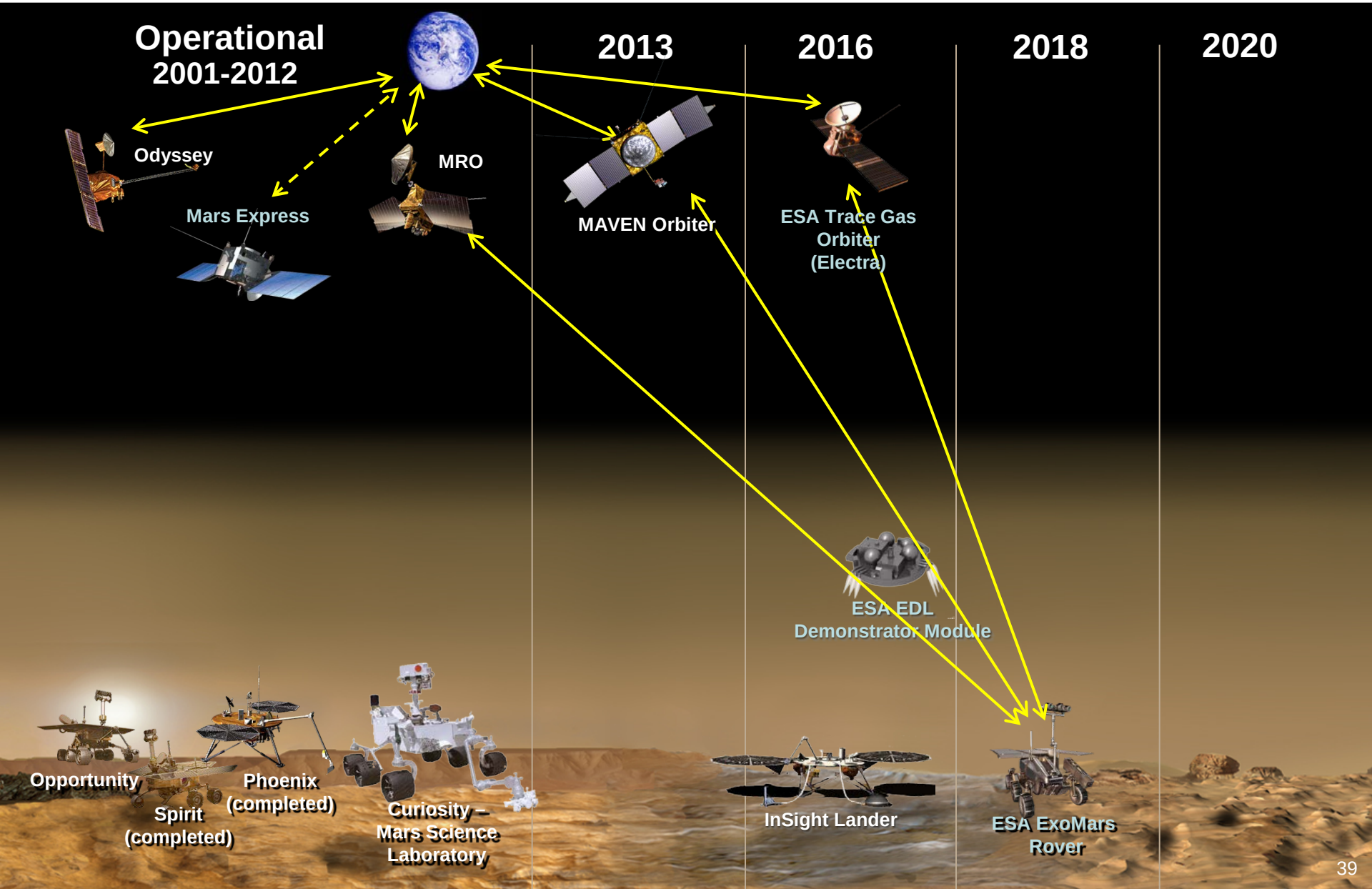
Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution



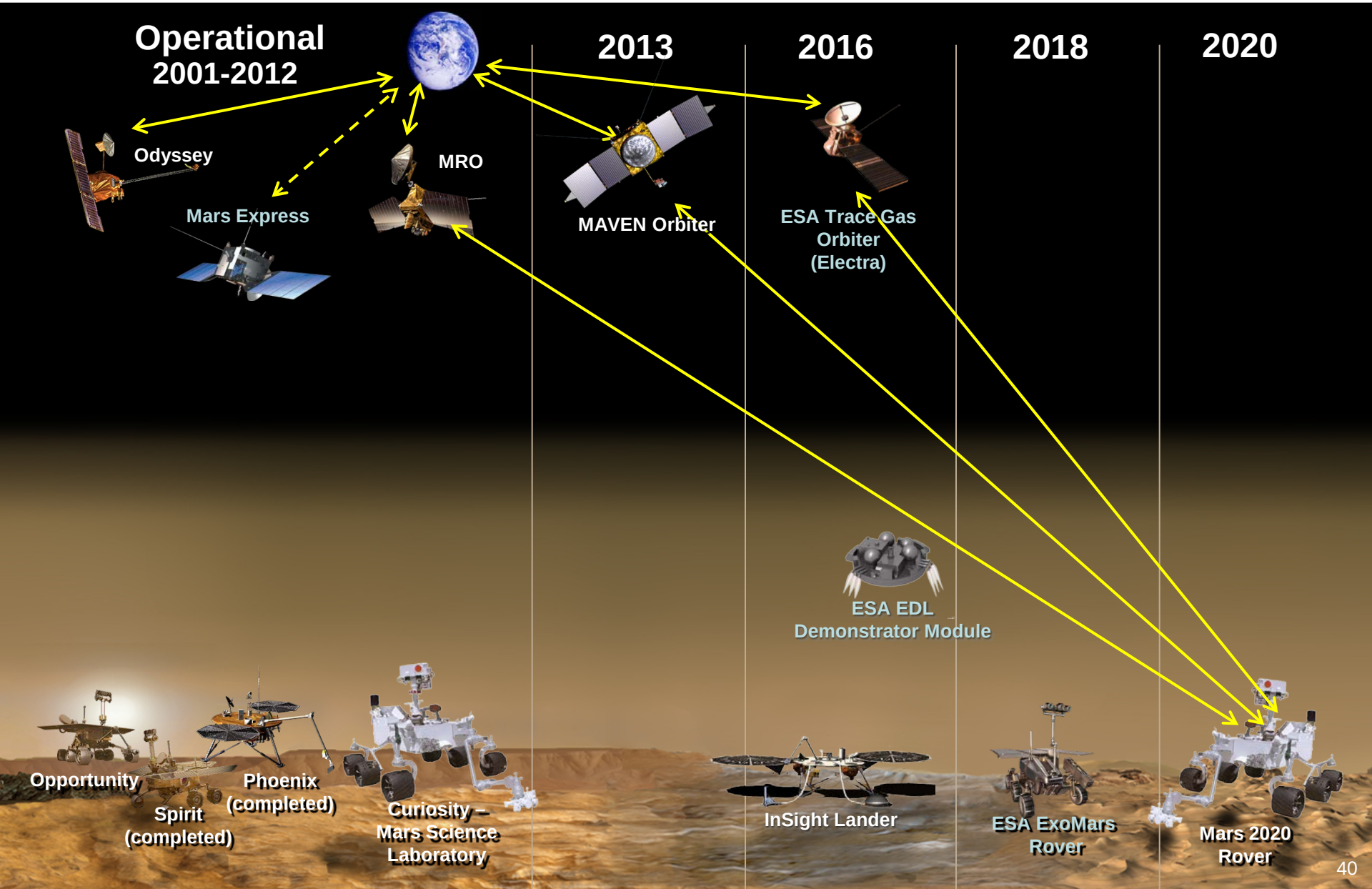
Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution

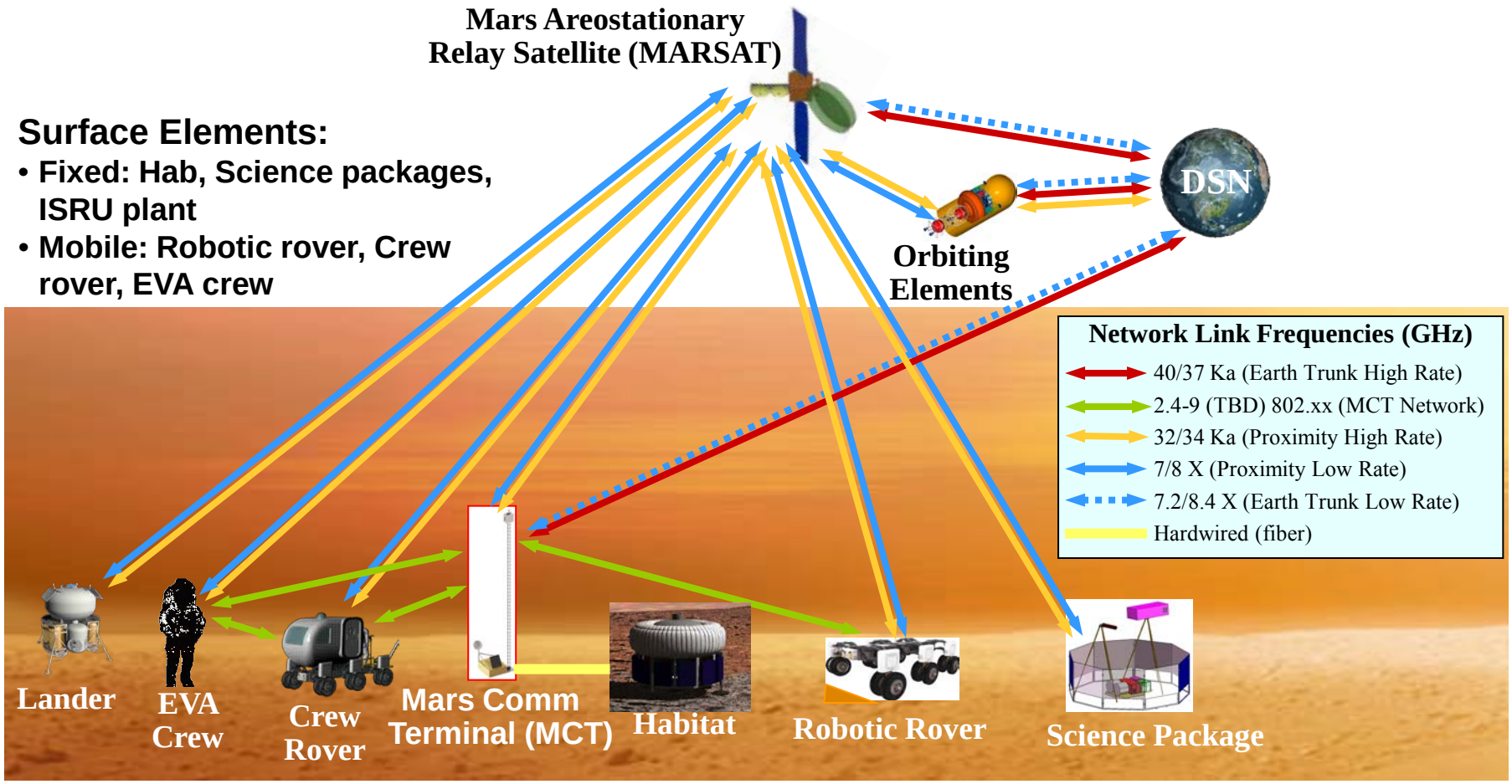


Jet Propulsion Laboratory
California Institute of Technology

Mars Relay Network Evolution



A Long-Term View: Human Mars Exploration



Surface Elements:

- Fixed: Hab, Science packages, ISRU plant
- Mobile: Robotic rover, Crew rover, EVA crew