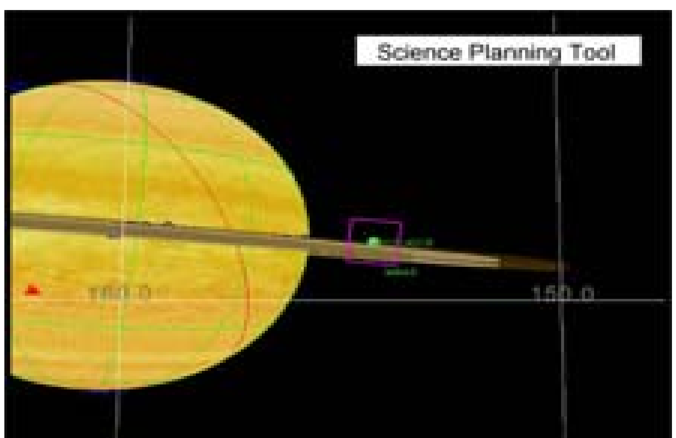
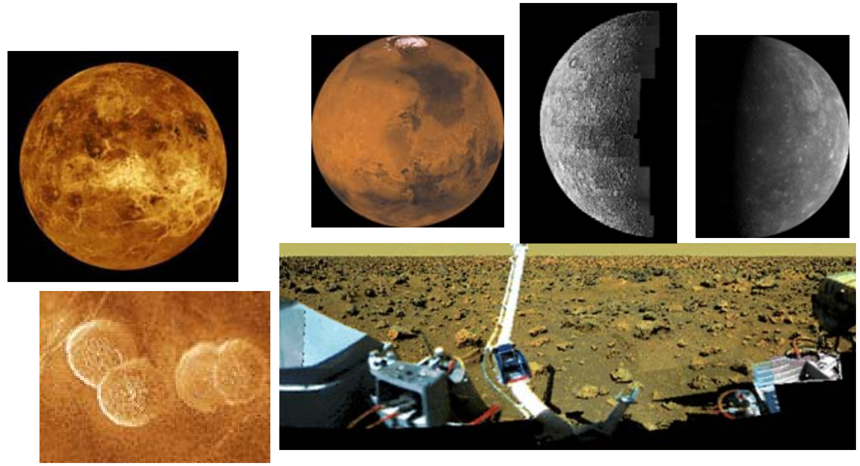
Interplanetary Network

Bill Weber
Director, Interplanetary Network Directorate



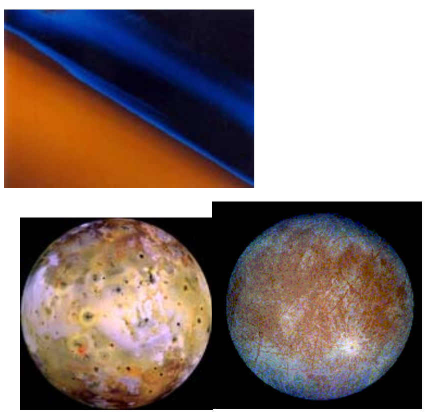
Forty Years of Exploration

Asteroids

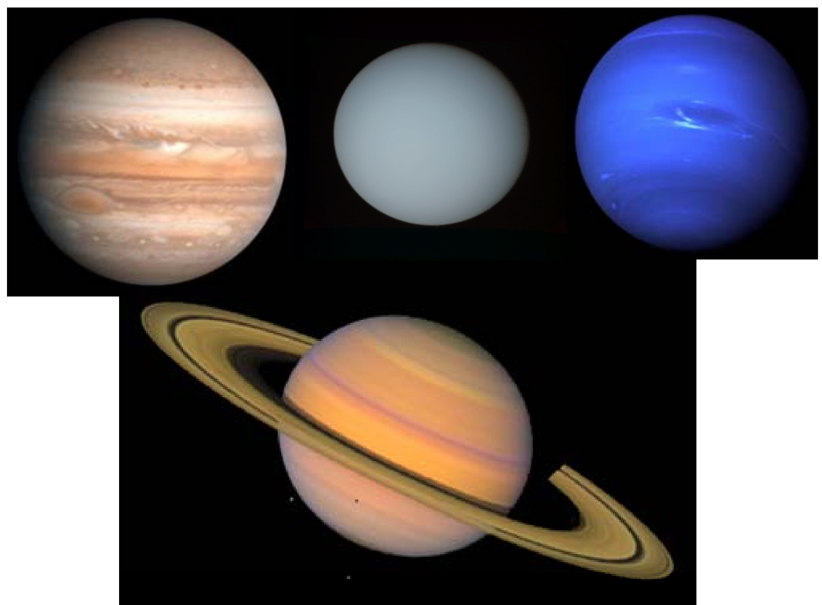


Terrestrial Planets

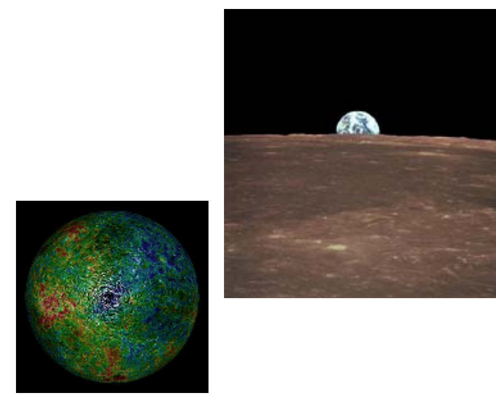
Comets



Planetary Satellites

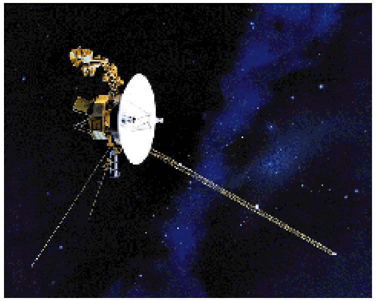


Giant Planets

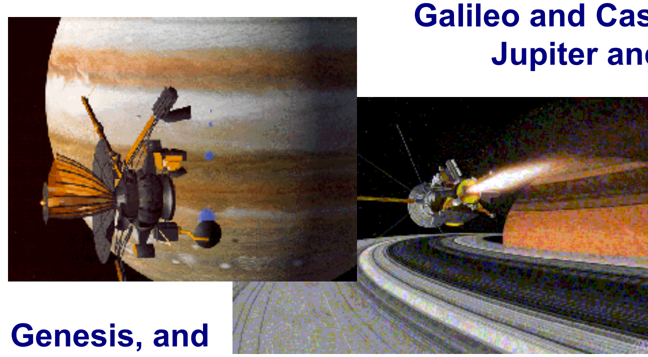


The Moon

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

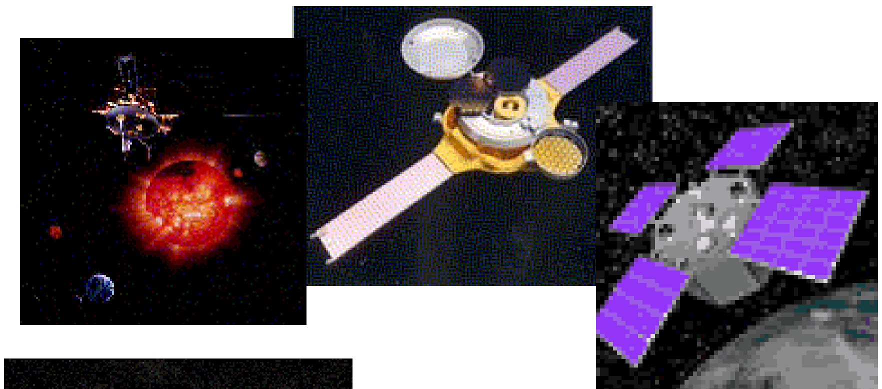


Two Voyagers on an interstellar mission

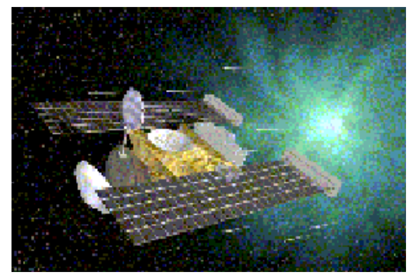


Galileo and Cassini studying Jupiter and Saturn

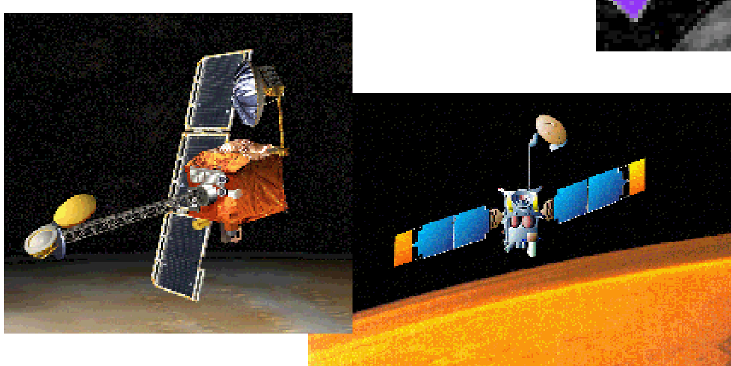
GALEX studying UV universe



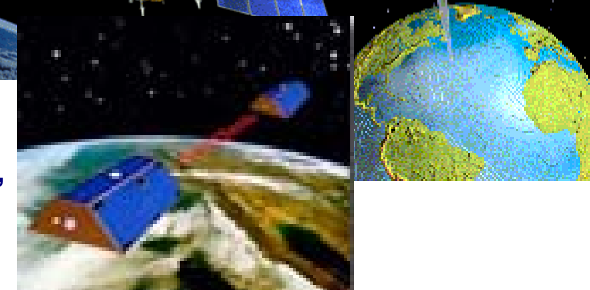
Ulysses, Genesis, and ACRIMSAT studying the sun



Stardust returning comet dust



Mars Global Surveyor and Mars Odyssey in orbit around Mars



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

The NASA Mission

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

To understand and protect our home planet

To explore the Universe and search for life

To inspire the next generation of explorers

…. as only NASA can

JPL's Mission Flows from the NASA Mission

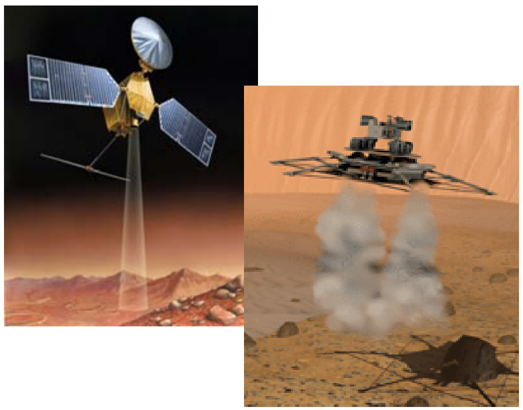
We enable the nation to explore space for the benefit of humanity.

Our Mission is :

1. *To explore our own and neighboring planetary systems*
2. *To search for life outside the Earth's confine*
3. *To further our understanding of the origins and evolution of the Universe and the laws that govern it*
4. *To make critical measurements to understand our home planet and help protect its environment*
5. ***To enable a virtual presence throughout the solar system by creating the Interplanetary Network***
6. *To apply JPL's unique skills to address problems of national significance and security*
7. *To inspire the next generation of explorers*

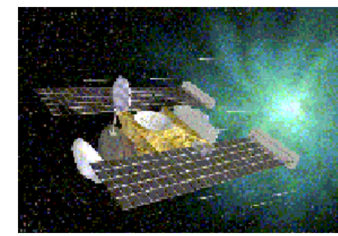
Our vision: JPL's legacy by 2020

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

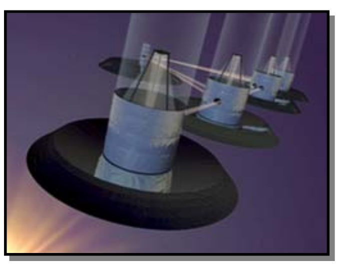


Explored the Jovian and Saturnian satellites in detail and probed their surfaces and interiors for possible pre-biotic and life-favorable environments.

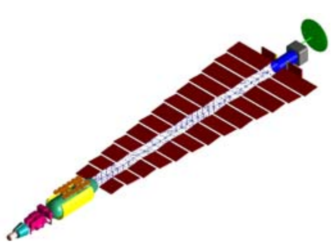
Returned first samples from other solar system bodies beyond the moon.



Began exploring neighboring solar systems.

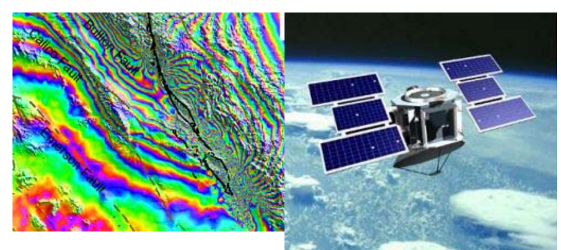


Enabled efficient access to all the bodies of the solar system



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

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



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

The Interplanetary Network

Mission Statement

Enable telescience and telepresence throughout the Solar System and beyond….

"Bringing the sensors to the scientists, and the planets to the public."

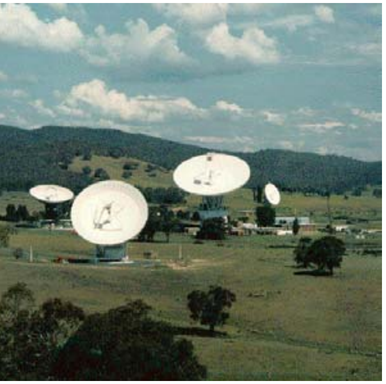
Interplanetary Network Goals

- **An integrated deep space communications network with “killer applications” for mission operations and the end users**
  - No “bottlenecks and obstacles”
  - Breakthrough communication rates on interplanetary links
  - Efficient, miniature short-range and in situ communications systems
  - Seamless end-to-end information flow across the solar system
  - Layered architecture and protocols for evolvability and interoperability
  - Integrated communications, navigation, and operations services
  - User software tools for analysis and visualization

Major Elements Start with Existing Systems

- **An integrated deep space communications network**
  - NASA's Deep Space Network and other earth-based assets
  - Mars Network and other space-to-space communications links and networks
  - Unifying network architecture, operations, standards, and protocols
- **Mission operations applications and infrastructure**
  - Advanced Multi-Mission Operations System (AMMOS)
  - Highly automated mission and network operations tools and services (invisible to the end-user)
- **End-user applications**
  - "Killer applications" for scientists and the public to take full advantage of the investments in each mission
    - Creation of "virtual observatories"

Today's Obstacles and Bottlenecks

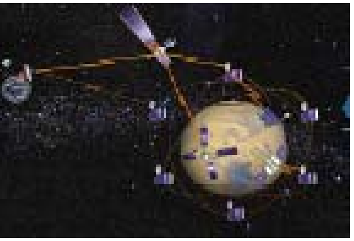


DSN Congestion/Risk

- Growing overall tracking load and number of critical events
- Contingency risks for missions (e.g., 03/04, then every two years)

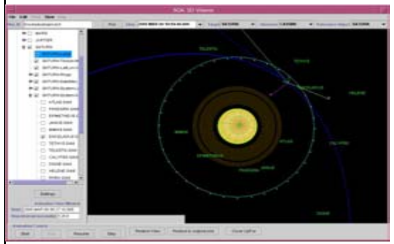
Deep Space Data Rates

- Demand for 10 times increase in next decade
- High-rate instruments currently excluded
- MGS and MRO will map ~ 1% of planet



Planetary Comm Relays

- Limited coverage during critical events
- Science orbiters provide limited data rate capability
- Relays require planning and programming each transmission



Operations and User Applications

- Deep space operations are labor-intensive
- Scientists spend too much time on operational details
- Public participation is a fraction of what it could be

More Challenges: Deep Space Missions

- **Extreme Distance**
  - Communications performance scales as $1/R^2$
  - Signals from Outer Planet mission to Neptune, Pluto are *~10 billion* times weaker than from Geostationary Earth Orbit
- **Long Round Trip Light Times**
  - Onboard autonomy required in order to close decision loops faster than a round trip light time
  - Rapid response to in situ environments and conditions
- **Wide Range of Environments**
  - Challenging thermal, radiation, shock requirements
  - Fault-tolerant hardware and software
- **Unique Navigation Scenarios**
  - Small body ops, gravity assist trajectories, aerocapture/aerobraking, SEP, libration point missions, formation flying
- **High Launch/Delivery Cost per Unit Payload Mass**
  - Drives need for low mass, low power flight systems

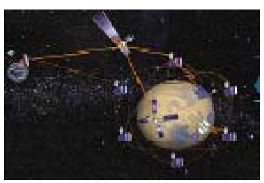
Solutions Exist….



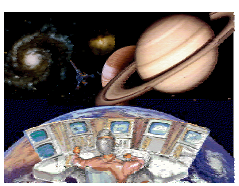
Upgrade the current DSN; advance RF flight components

Prototype large arrays of small antennas

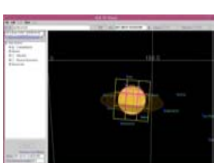
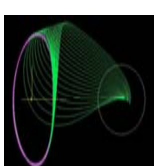

Demonstrate deep space optical communications

Expand Mars network; evolve IPN




Develop network and multi-mission operations systems and tools


Advance mission design, navigation, and science/public user tools

….but can we afford them?

Cost Efficiency Themes

- **Architecture**
  - Design for multiple missions
  - Common standards and protocols
  - Interoperability
- **Use of “business cases”**
  - The real issue is return on investment; i.e., “More bang for the buck”
- **Upgrades and new equipment**
- **Equipment Designs**
  - Non-recurring engineering
  - Reusability (especially software)
  - Manufacturing
  - Operability; design for operations
  - Reliability and maintenance
- **New technological paradigms**
- **Operations**
  - Operations tools
  - Automation
  - Common displays, procedures

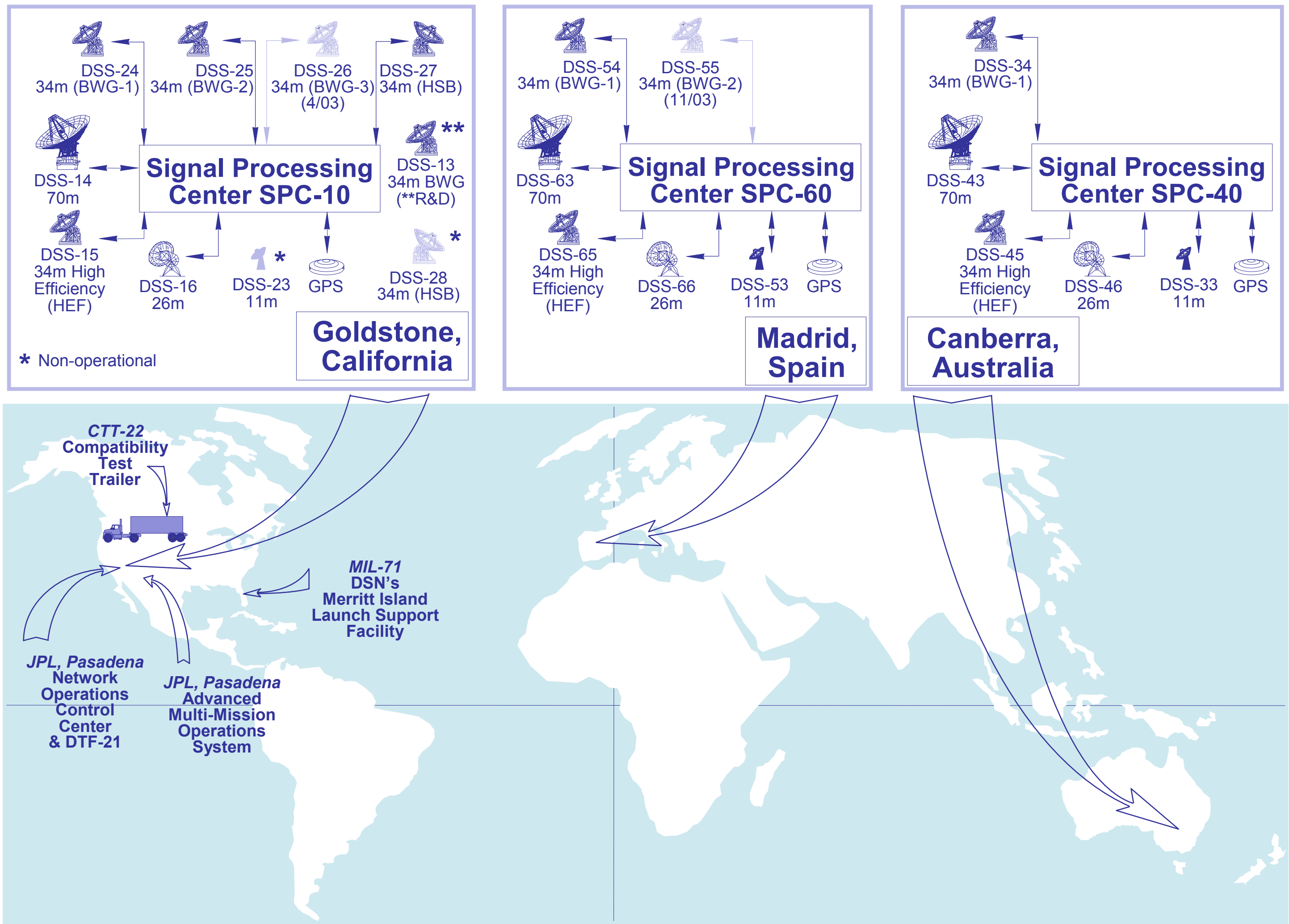
Deep Space Network

Madrid

Goldstone

Canberra

Deep Space Network Resources



Approved Mission Set: DSN Supports*

Legacy LEO

- RADARSAT (O)

LEOP**

- GOES N-P (C)
- NOAA N, N' (C)
- PROSEDS (C)
- SOLAR-B (F)

HEO, Lunar, L1 & L2

- CHANDRA (O)
- WMAP (O)
- INTEGRAL (O)
- ISTP-GEOTAIL (O)
- ISTP-WIND (O)
- ISTP-SOHO (O)
- ISTP-POLAR (O)
- ACE (O)
- IMAGE (O)
- IMP-8 (O)
- ISTP-CLUSTER II (O)
- GENESIS (O)
- LUNAR-A (F)
- ST-5 (C)

DEEP SPACE***

- GALILEO (O)
- MARS GLOBAL SURVEYOR (O)
- CASSINI (O)
- NOZOMI (O)
- STARDUST (O)
- 2001 MARS ODYSSEY (O)
- GSSR (O)****
- HAYABUSA (A.K.A., MUSES-C) (O)
- MARS EXPRESS (O)
- MARS EXPLORATION ROVERS A & B (O)
- ROSETTA (C)
- DEEP IMPACT (C)
- MESSENGER (C)
- MARS RECONNAISSANCE ORBITER (C)
- DAWN (C)
- MARS SCOUT (F)
- MARS TELESAT (F)
- MARS SCIENCE LABORATORY (F)
- NEW HORIZONS (F)
- NEW FRONTIERS (F) (X)
- JUPITER ICY MOONS ORBITER (F) (X)
- GRAVITY PROBE B (C)****
- EVN (O)****
- GBRA (O)****
- MEGA (O)****
- SIRTF (C)
- KEPLER (C)
- SIM (F)
- VOYAGERS 1 & 2 (O)
- ULYSSES (O)
- STEREO A & B (C)
- ORBITAL DEBRIS (O)
- SPACE GEODESY (O)
- DISCOVERY (F) (X)
- MIDEX (F) (X)
- NMP (F) (X)

NOTES

*~20 additional spacecraft fall under "Emergency Support Only" and are not shown.

**LEOP = Launch & Early Operations Phase; almost all DSN missions receive such support, but those listed as "LEOP" receive no other significant DSN support.

***Deep Space includes missions utilizing Earth leading and trailing orbits, since spacecraft in such orbits drift out well beyond Lagrange point distances.

****Support assumes the form of ground-based observations for mission reference ties (e.g., GP-B), VLBI co-observations, radio astronomy, solar system radar, or orbital debris.

KEY

- Structure & Evolution of Universe Theme
- Astronomical Search for Origins Theme
- Exploration of the Solar System Theme
- Sun-Earth Connection Theme
- Cross-Theme Affiliation
- Unaffiliated with Space Science Enterprise

(O) = Operating (as of 6/03)
(C) = Commitment to support, but not yet operating (as of 6/03)
(F) = Future commitment to support anticipated (as of 6/03)
(X) = Not specifically called out in Code S approved "Mission Set Database" or "Mission Set Change Log"

Future U.S.-Led Science Missions from the Code S Roadmaps**

SEU

- GLAST
- GRAVITY PROBE B
- SWIFT
- SPIDR
- EUSO
- WISE

- LISA
- DARK ENERGY PROBE
- EXPLORER MISSIONS

- CONSTELLATION-X
- INFLATION PROBE
- BLACK HOLE FINDER PROBE
- EXPLORER MISSIONS

- BIG BANG OBSERVER
- BLACK HOLE IMAGER
- EXPLORER MISSIONS

ASO

- SPACE INFRARED TELESCOPE FACILITY
- KEPLER

- SPACE INTERFEROMETRY MISSION
- JAMES WEBB SPACE TELESCOPE
- EXPLORER MISSION
- DISCOVERY MISSION

- TERRESTRIAL PLANET FINDER
- SINGLE APERTURE FAR-INFRARED OBSERVATORY
- EXPLORER MISSION
- DISCOVERY MISSION

- SPACE ULTRAVIOLET / OPTICAL TELESCOPE
- LIFE FINDER
- PLANET IMAGER
- EXPLORER MISSION
- DISCOVERY MISSION

ESS**

- DEEP IMPACT
- MESSENGER
- DAWN
- MARS SCOUT
- NEW HORIZONS
- MARS EXPLORATION ROVERS
- MARS RECONNAISSANCE ORBITER

- DISCOVERY MISSIONS
- SOUTH POLE AITKEN BASIN SAMPLE RETURN
- JUPITER ICY MOONS ORBITER*
- MARS SCOUTS
- MARS SCIENCE LABORATORY

- DISCOVERY MISSIONS
- JUPITER POLAR ORBITER/PROBES*
- VENUS IN-SITU EXPLORER
- COMET SURFACE SAMPLE RETURN
- MARS SCOUTS
- MARS LONG-LIVED LANDER NETWORK

- DISCOVERY MISSIONS
- MARS SCOUTS
- MARS UPPER ATMOSPHERE ORBITER*
- MARS SAMPLE RETURN
- EUROPA LANDER
- TITAN EXPLORER
- NEPTUNE ORBITER WITH PROBES*

SEC***

- SOLAR-TERRESTRIAL RELATIONS OBSERVATORY
- THEMIS
- GEOSPACE ELECTRODYNAMIC CONNECTIONS
- MAGNETOSPHERIC MULTISCALE
- SOLAR DYNAMICS OBSERVATORY
- RADIATION BELT STORM PROBES
- IONOSPHERE THERMOSPHERE STORM PROBES
- CINDI
- TWINS
- AIM

- MAGCON
- SOLAR PROBE
- TELEMACHUS
- IONOSPHERE THERMOSPHERE MESOSPHERE WAVES COUPLER
- HELIOSPHERIC IMAGER AND GALACTIC OBSERVER
- RECONNECTION AND MICROSCALE
- INNER HELIOSPHERE SENTINELS
- INNER MAGNETOSPHERIC CONSTELLATION
- TROPICAL ITM COUPLER
- JUPITER POLAR ORBITER*

- AURORAL MULTISCALE
- GEOSPACE SYSTEM RESPONSE IMAGER
- INTERSTELLAR PROBE
- SOLAR CONNECTIONS OBSERVATORY FOR PLANETARY ENVIRONS
- SOLAR POLAR IMAGER
- DAYSIDE BOUNDARY LAYER CONSTELLATION
- MAGNETOSPHERE-IONOSPHERE OBSERVATORY
- PARTICLE ACCELERATION SOLAR ORBITER
- L1-DIAMOND
- MAGNETIC TRANSITION REGION PROBE
- SOLAR IMAGING RADIO ARRAY
- STELLAR IMAGER
- SUN EARTH ENERGY CONNECTOR
- SUN-HELIOSPHERE-EARTH CONSTELLATION
- NEPTUNE ORBITER*
- IO ELECTRODYNAMICS
- MARS AERONOMY*
- VENUS AERONOMY

Key

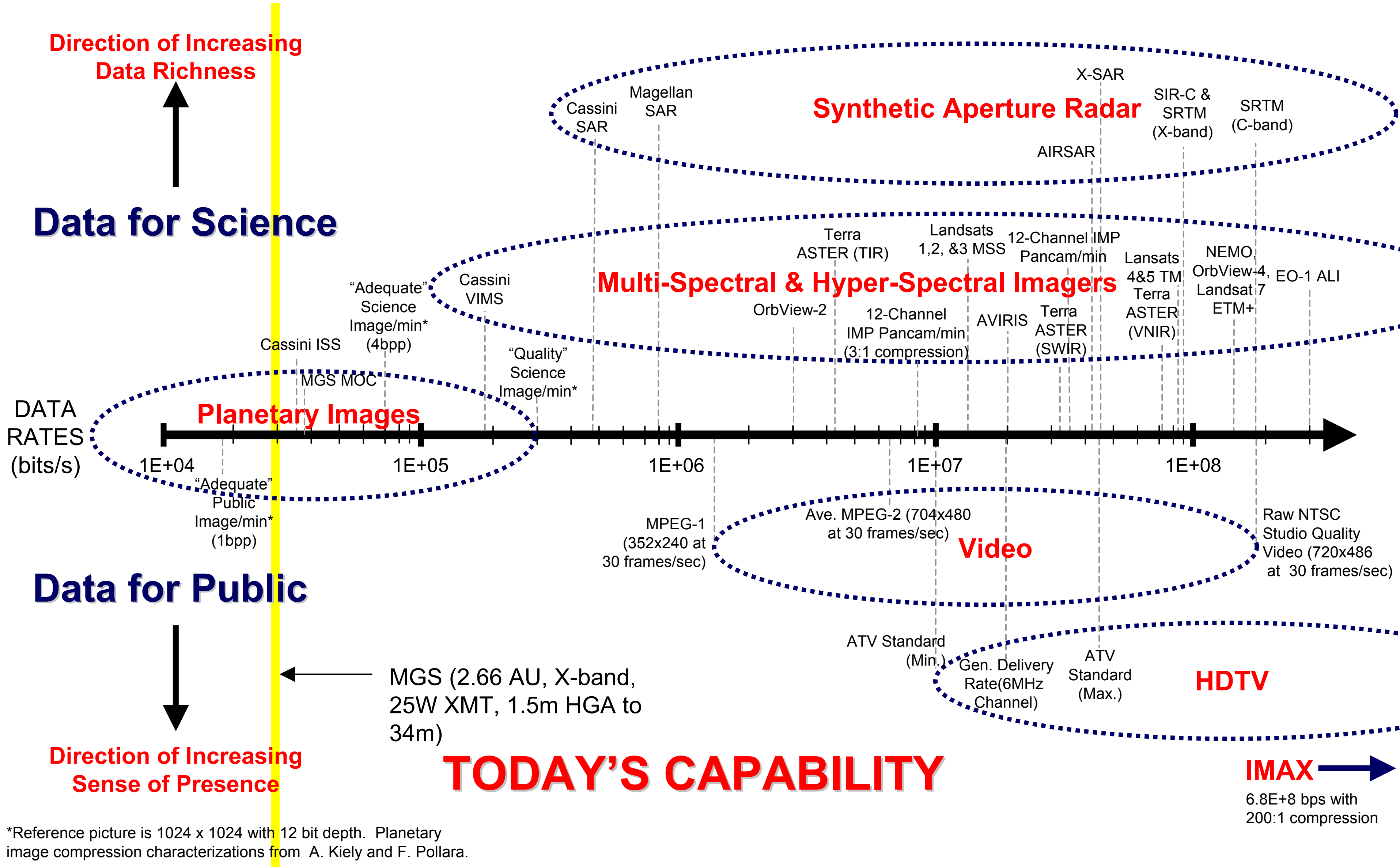
- DSN Support Likely (red)
- DSN Support Possible (blue)
- DSN Support Unlikely (black)

2008 | 2013 | 2018 | 2023

Very Approximate Launch Epoch

*Indicates possible overlap between ESS and SEC.
**ESS based on Planetary Decadal Survey + President's FY04 Budget ; some missions may be New Frontiers missions; some SEU & SEC missions derived from latest Explorer awards.
***Some missions may be Explorer or Discovery.

Downlink Trends: Looking Toward the 20-Year Horizon



*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara.

Advancing Deep-Space-to-Earth Communications

Improve Reliability & Availability of DSN Services

- Robust HW & SW with high functional availability
- Faster fault detection, isolation, and recovery
- Reduced setup time and simplified data flow

Upgrade Current Deep Space Network Performance

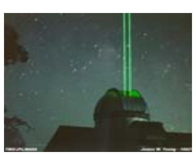
- 70m antenna refurbishment
- Migration to Ka-band
- Additional 34m antenna(s)
- Facilities improvements

Accommodate planned HEO and Lagrange Point missions

- High-Rate Telemetry Systems and protocols
- 26m Evolution / Replacement

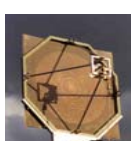
Prototype large arrays of small antennas

- Build equivalent of one or two 70 meter antennas
- Understand technology, costing, operations, extensions



Demonstrate deep space optical communications

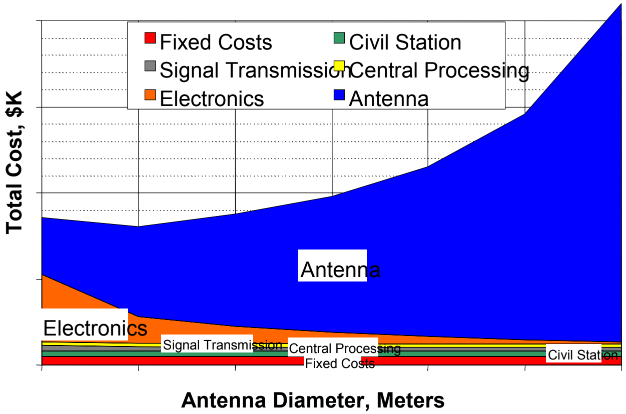
- Deep space demo with Mars Telecommunications Orbiter



Develop advanced RF flight components

- Radios
- Amplifiers
- Antennas

Arraying Technology --
Synthesizing Large Antenna Apertures



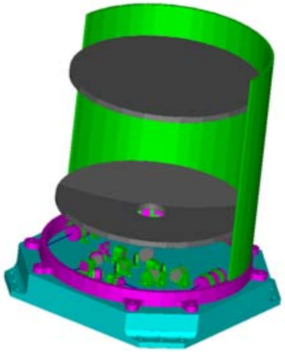
- A new paradigm for microwave, large-aperture synthesis
  – Arrays of 100's of 12 meter antennas
- Requirements:
  – Low cost, high performance antennas
  – Low cost, low noise amplifiers
  – Low cost, reliable, cryogenics
  – Mass production efficiencies
- Need for a prototype array to demonstrate technologies, costs, and operational characteristics
- **Potential for significantly lower cost than large microwave antennas**

Optical Communications

- Potential for orders of magnitude greater downlink performance
- Initial technology and demonstration steps have been taken
- Demonstration on Mars Telecommunications Orbiter (2009)
- Strong collaborations and synergy with DoD space communications efforts
- Synergism with Code Y and near-Earth, high-rate applications

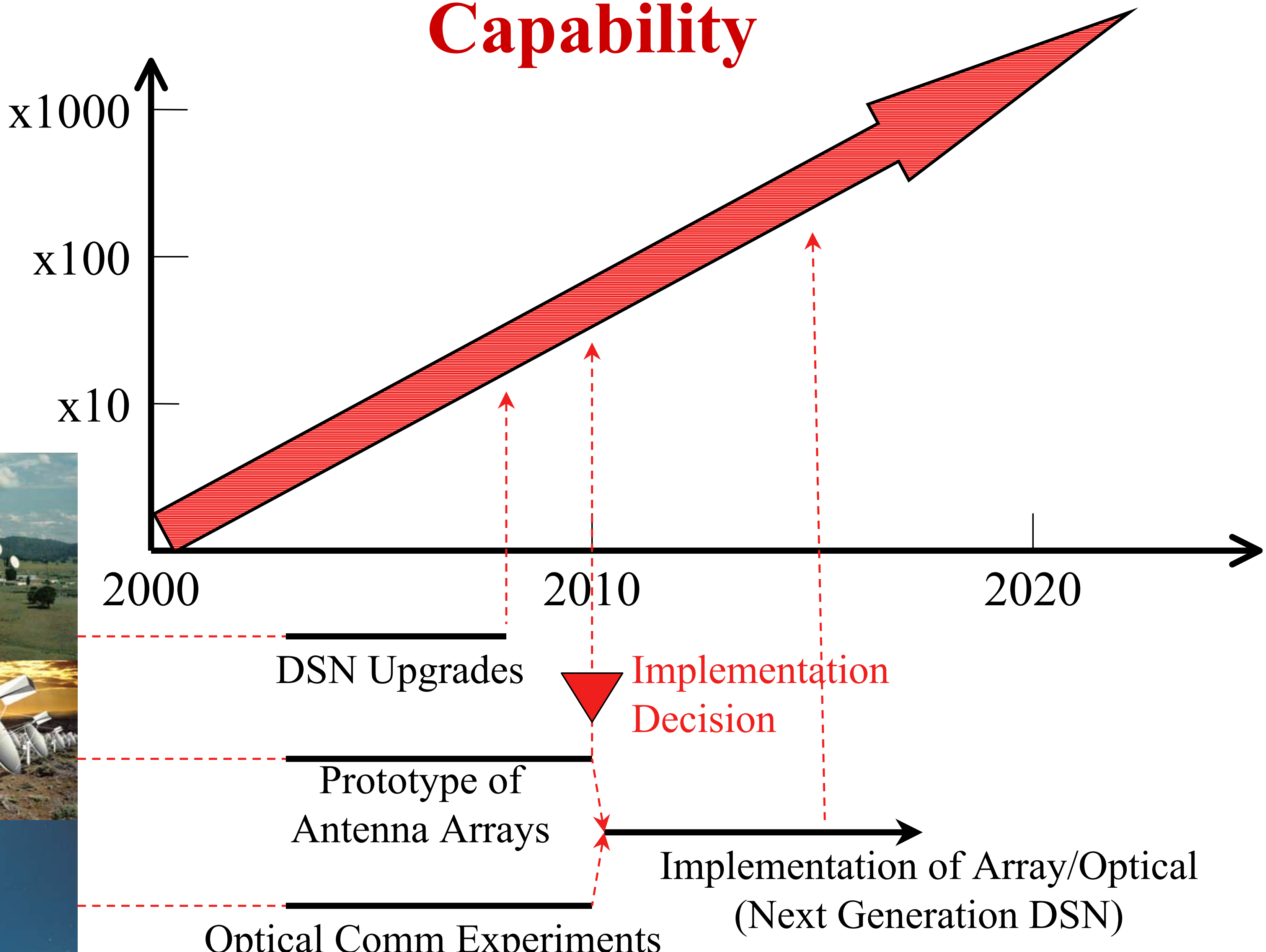
Optical Comm Demonstrator
- 10 cm telescope
- Fiber-coupled laser

1-m OCTL Facility (under construction)

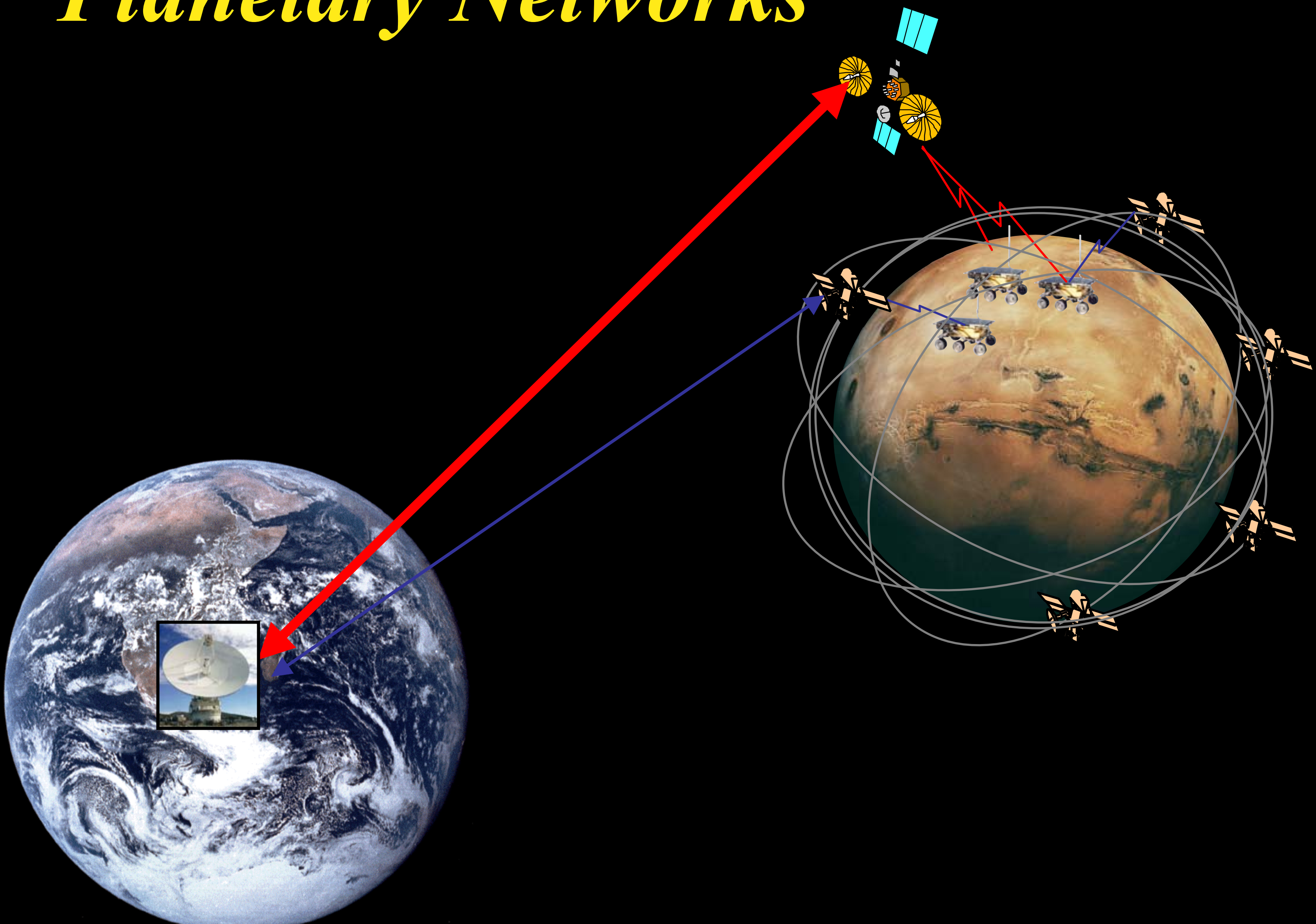


30-cm Optical Comm Terminal with Hi-Res. Imaging and Laser Altimeter

Future DSN Architecture and Capability



Planetary Networks

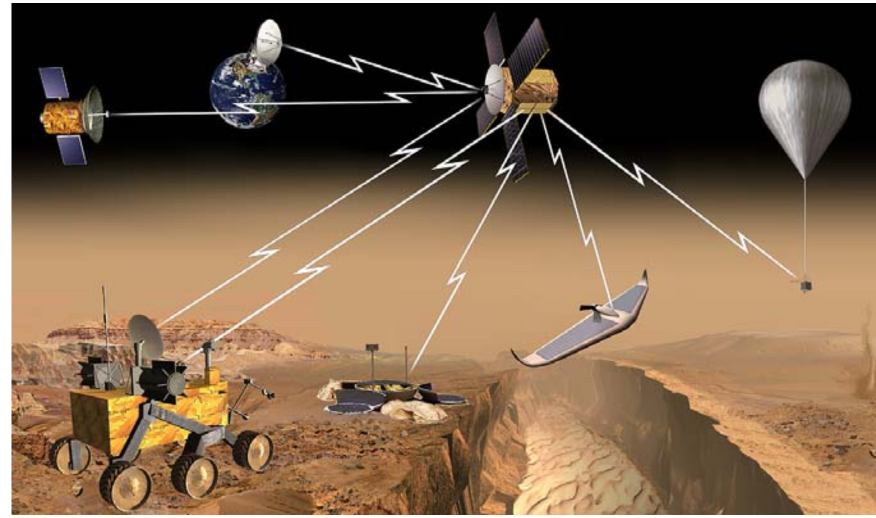


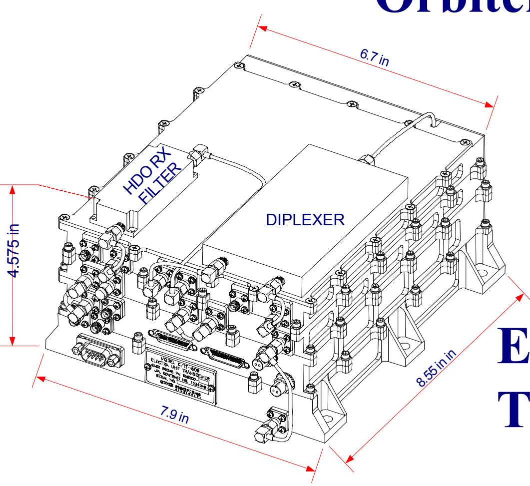
A Decade of Mars Exploration

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Mars Network

2005 Mars Reconnaissance Orbiter

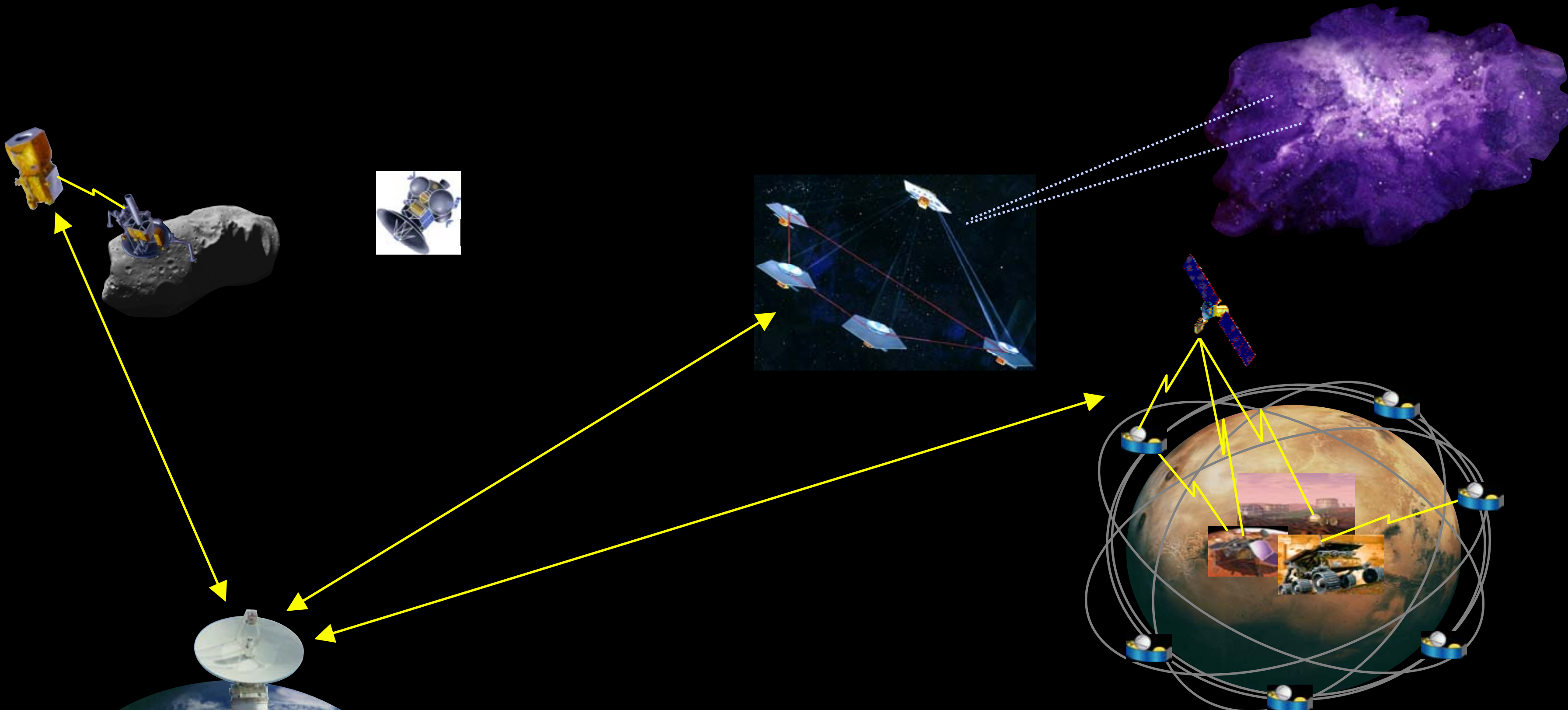




Electra UHF Transceiver

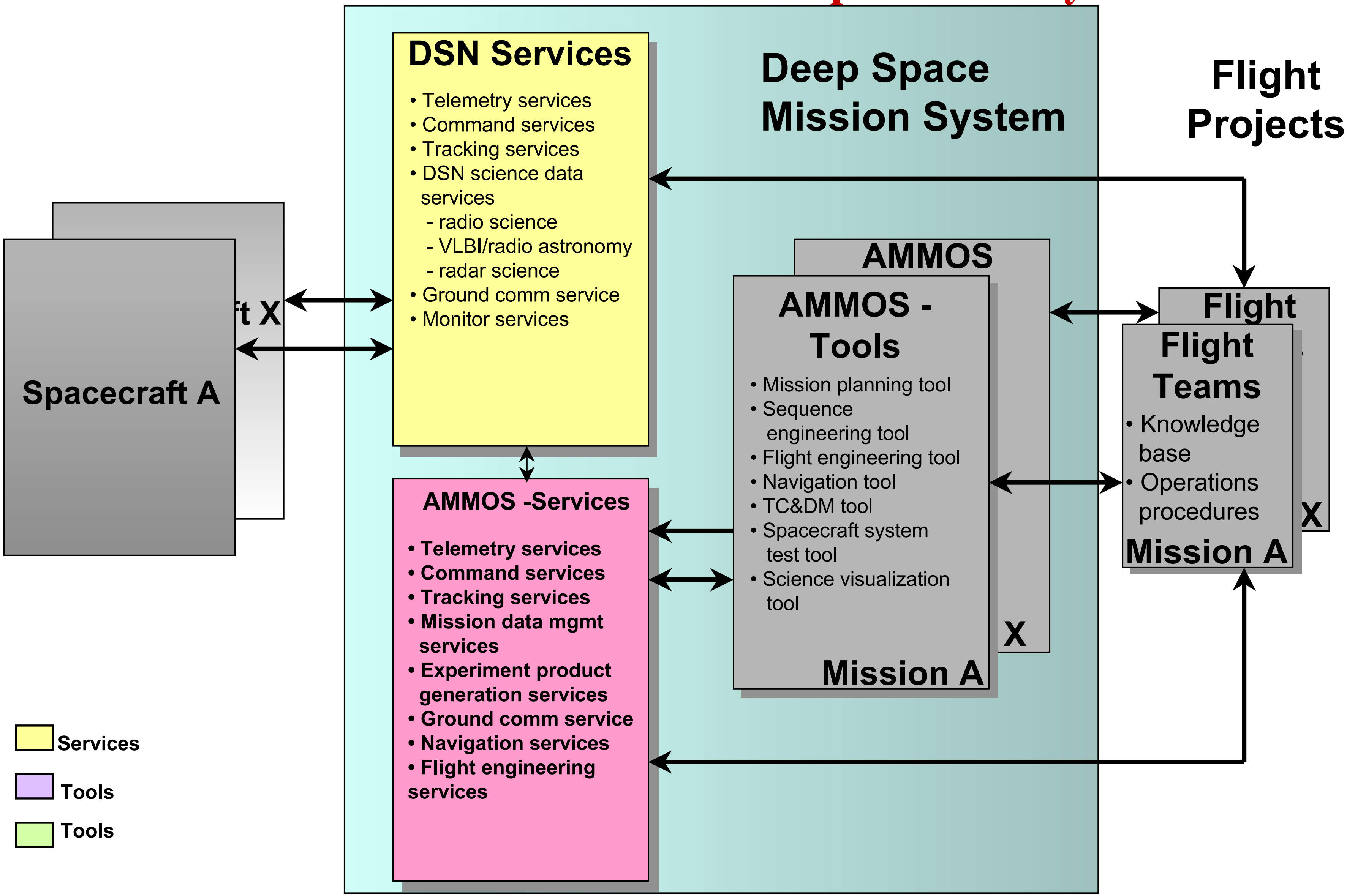
QuickTime™ and a
Video decompressor
are needed to see this picture.

Orbit options under consideration for Mars Telesat

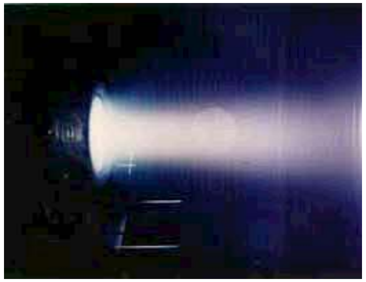


Network and Mission Operations Services

DSN and the Advanced Multi-Mission Operations System

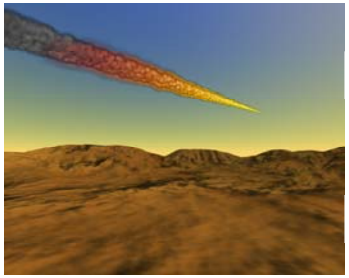


Enabling Precision Navigation



Low-Thrust Guidance & Navigation

Mercury, small body, and outer planet missions



Aerocapture

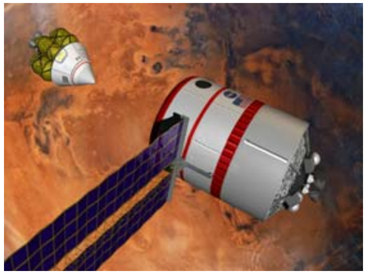
Missions going into orbit about Venus, Mars, Saturn/Titan, Uranus, Neptune

Precision Landing

Landing on small bodies, terrestrial bodies, or planetary satellites

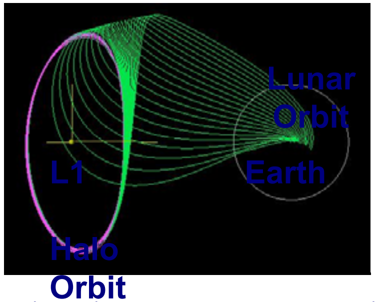
***In-Situ* Vehicle GN&C**

Rovers, balloons, submarines, and aircraft on planets, satellites, and small bodies



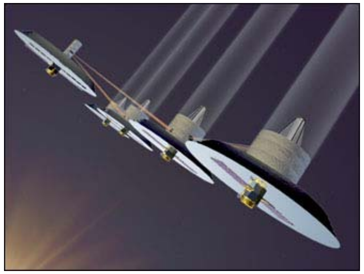
Rendezvous & Docking

Sample return missions to terrestrial planets, small bodies, and planetary satellites



Flight in Irregular or Multi-Body Gravitational Environments

Small body and libration point missions

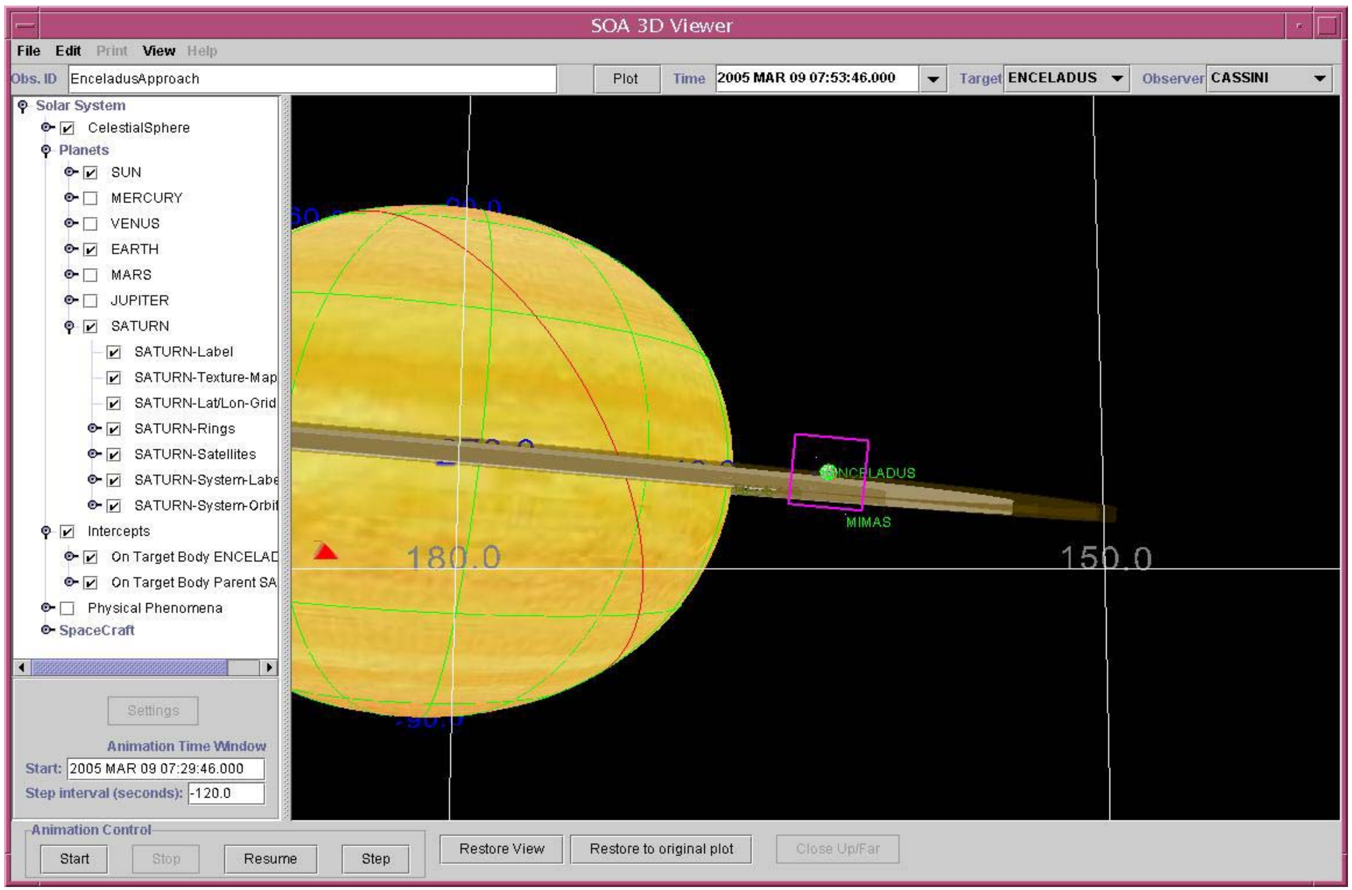


Multi-Vehicle GN&C

Terrestrial Planet Finder, constellations, etc.

Science Opportunity Analyzer

Basic Functions: Opportunity Search, Observation Design, Visualization, Flight Rules, Communication with SEQ tools



Automated Spacecraft Ops Planning

- **Objective:** Automate 80-90%of science team planning and all engineering team planning for any deep space mission.
- **Significance:** Expected benefit is 50% reduction in turnaround time for sequences/ 50% reduction in mission planning effort/ 50% reduction in mission planning personnel training

Advantages of Multi-Mission Tools and Services

Shorter Time to Develop

- Reuse is the key; Adaptation versus New Development

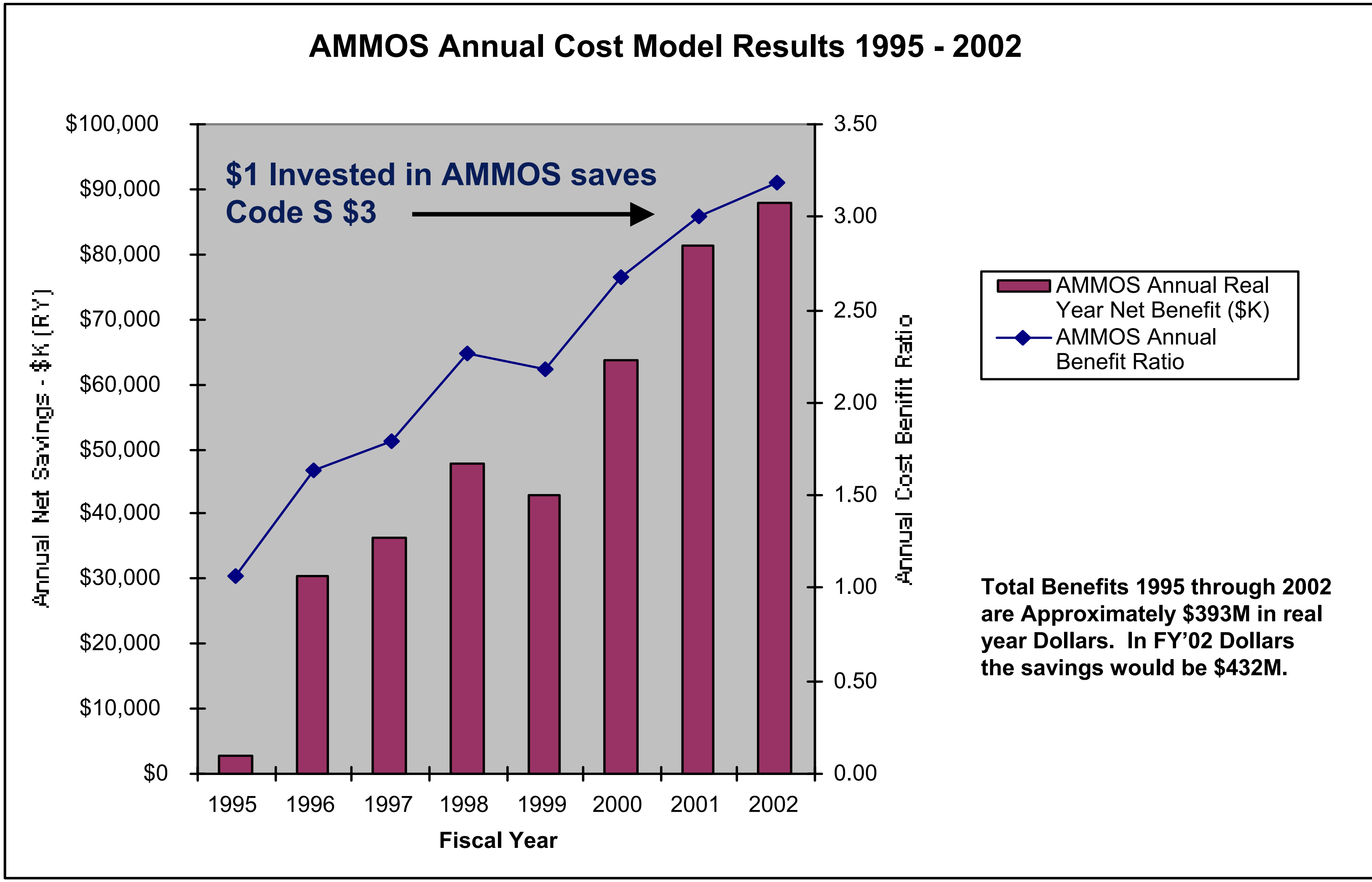
Better Product

- Continuous maintenance (bug fixing and small enhancements) results in highly reliable tools and services
- Continuous improvement results in ever increasing functionality and efficiency

Less Cost

- Mission specific adaptation costs of multi-mission tools and services are 10 to 15% of mission specific Ground Data System development costs
- Tools and services support Projects during entire life cycle -- no transition headaches between Development and Operations
- Single system to sustain rather than multiple mission specific systems
- Single system means less training and documentation

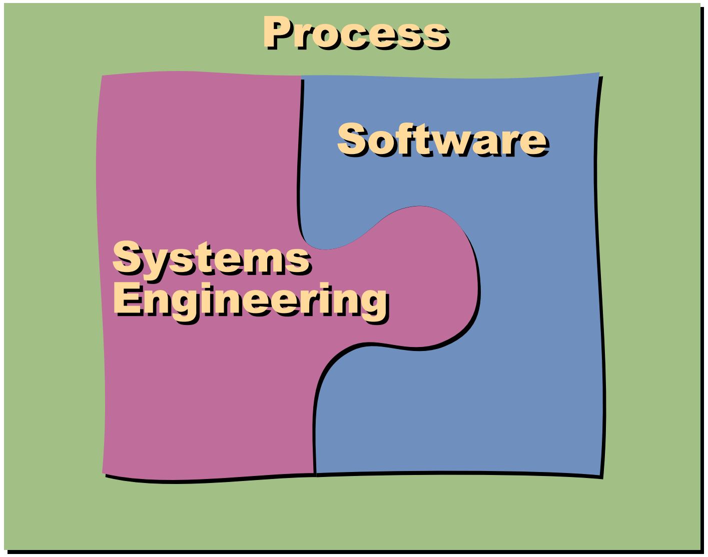
GDS Return on Investment



* Does not account for capitalization or cost savings prior to 1995

Mission Data System

A Unified Flight, Ground, &Test
Data System Architecture for Space Missions



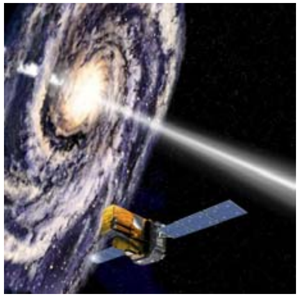
MDS provides a cradle-to-grave, end-to-end system solution

MDS Products

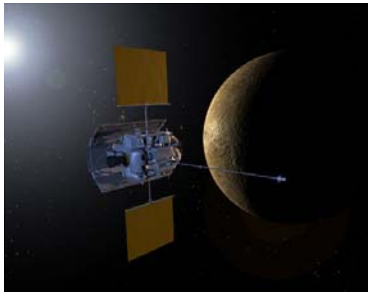
- ☑ Unified flight, ground and test architecture
- ☑ Orderly systems engineering methodology
- ☑ Frameworks
- ☑ Processes, tools, and documentation
- ☑ Examples (e.g., Mars Smart Lander)
- ☑ Reusable software

Standards

Space Link Extension

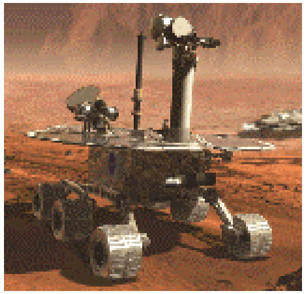


Turbo Codes

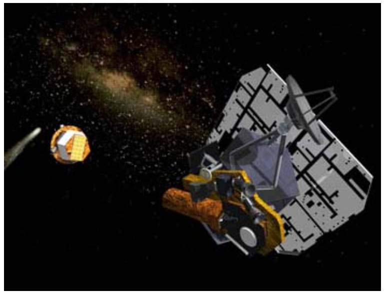


- Reduce costs
- Enable interoperability and cross-support services
- Increase reliability and reduce risks

Proximity Links at Mars



CCSDS File Delivery Protocol



The Interplanetary Network: Enabling NASA's Mission