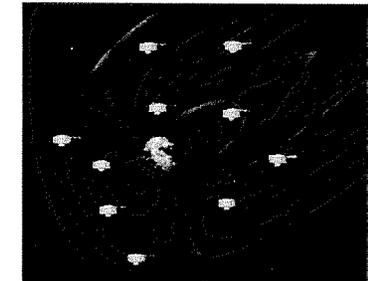
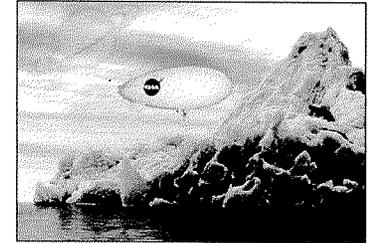
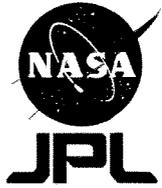


DSN Mission Demographics Projections

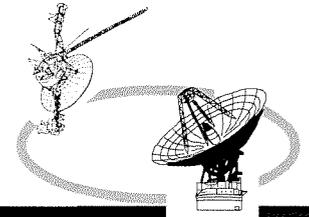
A Presentation to
Sun-Earth Connection Scientists
Goddard Space Flight Center
March 19, 2003

Doug Abraham
Jet Propulsion Laboratory





Topics

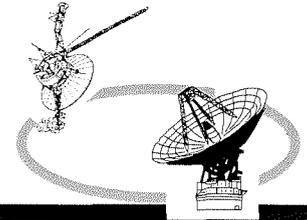


- Methodology Behind Last Year's Mission Demographics Analysis
- What Has Changed?
- General Mission Trends (10-Year View)
- Downlink Mission Trends (10-Year View)
- Uplink Mission Trends (10-Year View)
- Summary of Key Points

- Appendix A: Other Service Implications (10-Year View)
- Appendix B: 20-Year View



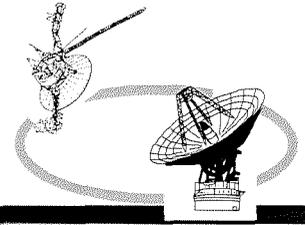
Methodology Behind Last Year's Mission Demographics Analysis



- As part of 70m Equivalent Capability Study:
 - Reviewed NASA strategic plans, roadmaps, and related NRC documents.
 - Interviewed future user community representatives.
 - Constructed extensive database on future missions and their telecommunication- related needs.
 - Used database in analysis of future mission demographics.
 - Conducted “quasi-Monte Carlo” analysis to account for future mission set uncertainties.
 - Identified time horizon applicability limits.
- To support POP-02 and various strategic initiatives:
 - Updated and expanded database a year or so ago.
 - Updated associated analyses.
- Much has changed and the mission model is once again in the process of being updated.



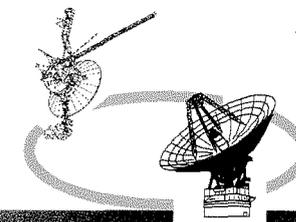
What Has Changed?



- Mission Set has changed significantly over past couple of years.
 - Financial and technical realities have pushed many missions further out in time and sometimes reduced their scope.
 - With the change in NASA Administrators, whole new strategic plans and associated Code S roadmaps have been in the making.
 - The natural maturation process for flight projects in development has led to several parameter changes within the known mission set.
- Data sources for this new mission set have become increasingly sparse.
 - Code S has moved to competitively bidding nearly all of its missions.
 - Up-to-date, on-line PSLAs no longer available for the established mission set.
- The number of potential future missions has grown huge.



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)
- MAP (O)
- INTEGRAL (O)
- ISTEP-GEOTAIL (O)
- ISTEP-WIND (O)
- ISTEP-SOHO (O)
- ISTEP-POLAR (O)
- ACE (O)
- IMAGE (O)
- IMP-8 (O)
- ISTEP-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)****
- MUSES-C (C), (F per MSD)
- MARS EXPRESS (C)
- MARS EXPLORATION ROVERS A & B (C)
- ROSETTA (C)
- DEEP IMPACT (C)
- MESSENGER (C)
- MARS RECONNAISSANCE ORBITER (C)
- DAWN (C)
- MARS SCOUT (F)
- MARS TELESAT / NET LANDERS (F)
- MARS SCIENCE LABORATORY (F)
- NEW HORIZONS (F)
- NEW FRONTIERS (F) (X)
- GRAVITY PROBE B (O)****
- 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 3/03)

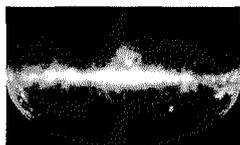
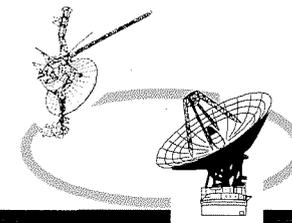
(C) = Commitment to support, but not yet operating (as of 3/03)

(F) = Future commitment to support anticipated (as of 3/03)

(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

- GAMMA-RAY LARGE AREA SPACE TELESCOPE
- GRAVITY PROBE B
- SWIFT
- SPIDR

- LISA
- INFLATION PROBE
- EXPLORER MISSIONS

- CONSTELLATION-X
- DARK ENERGY 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

- LIFE FINDER
- PLANET IMAGER
- EXPLORER MISSION
- DISCOVERY MISSION



ESS**

- DEEP IMPACT
- MESSENGER
- DAWN
- MARS SCOUT
- KUIPER BELT/PLUTO MISSION
- 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***

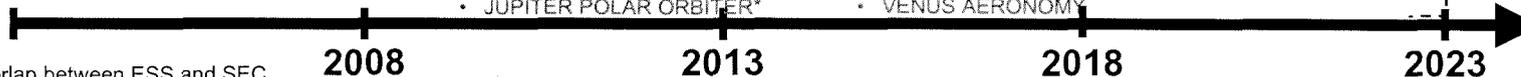
- SOLAR-TERRESTRIAL RELATIONS OBSERVATORY
- GEOSPACE ELECTRODYNAMIC CONNECTIONS
- MAGNETOSPHERIC MULTISCALE
- SOLAR PROBE
- SOLAR DYNAMICS OBSERVATORY
- RADIATION BELT STORM PROBES
- IONOSPHERE THERMOSPHERE STORM PROBES
- CINDI
- TWINS

- MAGNETOSPHERIC CONSTELLATION
- TELEMACHUS
- IONOSPHERE THERMOSPHERE MESOSPHERE WAVES COUPLER
- HELIOSPHERIC IMAGER AND GALACTIC OBSERVER
- RECONNECTION AND MICROSCALE
- INNER HELIOSPHERE SENTINELS
- SOLAR ORBITER
- 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
- DSN Support Possible
- DSN Support Unlikely

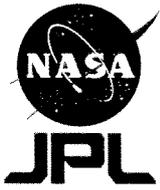


Very Approximate Launch Epoch

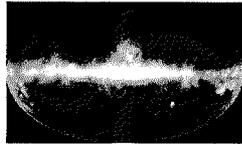
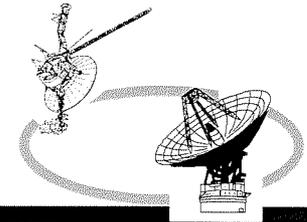
*Indicates possible overlap between ESS and SEC.

**ESS based on Planetary Decadal Survey + President's FY04 Budget; some missions may be New Frontiers missions.

***Some missions may be Explorer or Discovery.

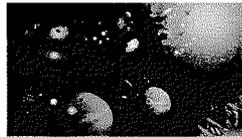


Possible Technology-Driven and Foreign-Led Missions



SEU

- HERSCHEL
- PLANCK
- RADIOASTRON



ASO

- GAIA



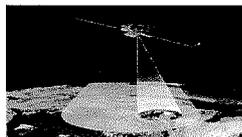
ESS**

- MARS EXPRESS
- LUNAR-A
- SELENE
- ROSETTA
- VENUS EXPRESS

- MARS TELESAT / NET LANDERS
- BEPI COLOMBO



SEC***



CROSS-CUTTING

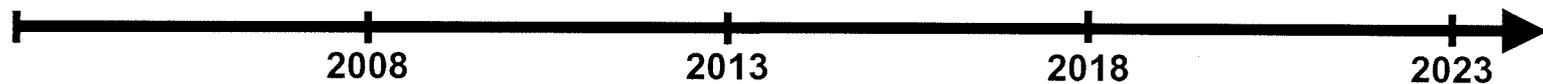
- SPACE TECHNOLOGY 5
- SPACE TECHNOLOGY 6
- SMART-2 / SPACE TECHNOLOGY 7
- SPACE TECHNOLOGY 8

- SPACE TECHNOLOGY 9

-- Work In Progress --

Key

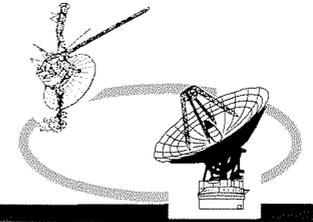
- DSN Support Likely
- DSN Support Possible
- DSN Support Unlikely



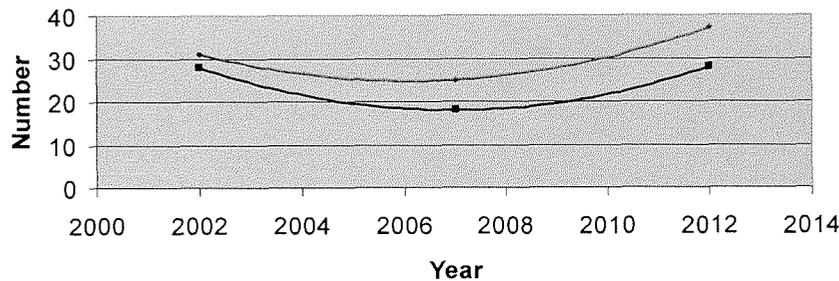
Very Approximate Launch Epoch



Last Year's Findings: General Mission Trends (10-Year View)



Trend in Total Numbers: Space Science Exploration Elements and Subset Downlinking to Earth*

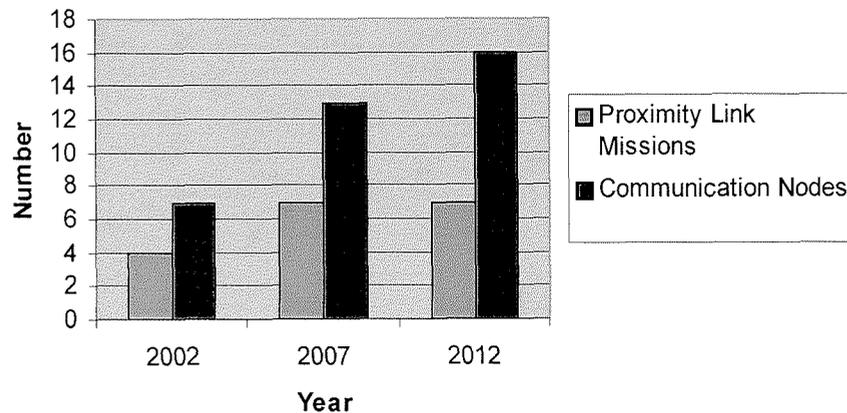


*Does not include MagCon.

- Total Number of Exploration Elements
- Number of Elements Actually Downlinking to Earth

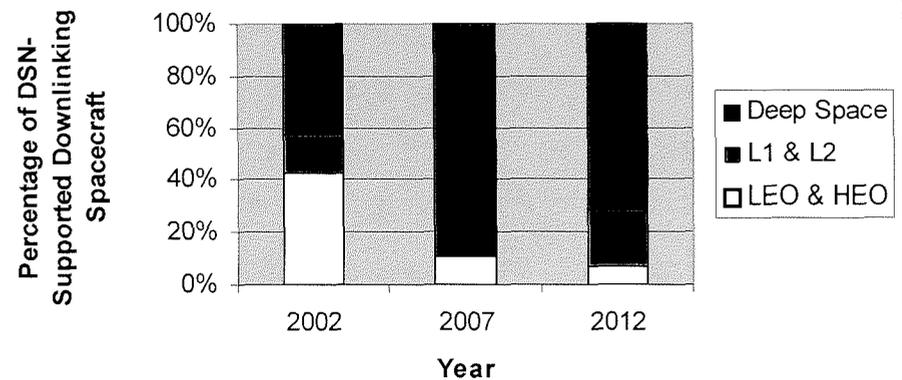
- Number of spacecraft downlinks not significantly increasing above current levels over next 10 years.
- But, more of these downlinks will serve as relays for missions with multiple elements that utilize proximity links.
 - Hence, potentially greater data loading on ~ same number of spacecraft downlinks.
- Number of LEO & HEO supports decreasing; deep space & Lagrange Pt. Supports increasing.
 - Hence, downlinks will occur over > link distances.

Proximity Link Trends*



*Does not include MagCon.

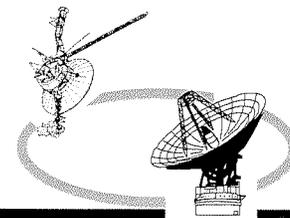
Spacecraft Locational Distribution as a Function of Time*



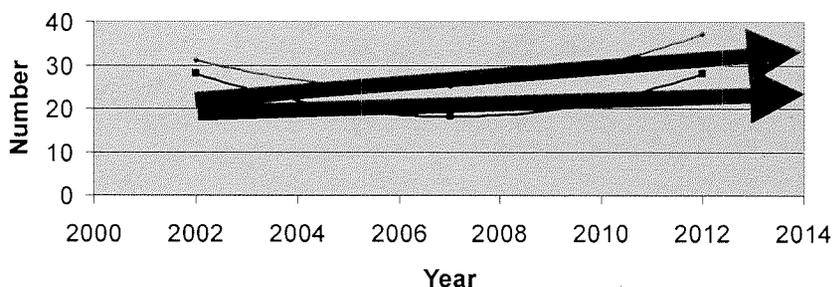
*Assumes MagCon uses cross-links to downlinking spacecraft.



Predictions Pending New Update: General Mission Trends (10-Year View)



Trend in Total Numbers: Space Science Exploration Elements and Subset Downlinking to Earth*



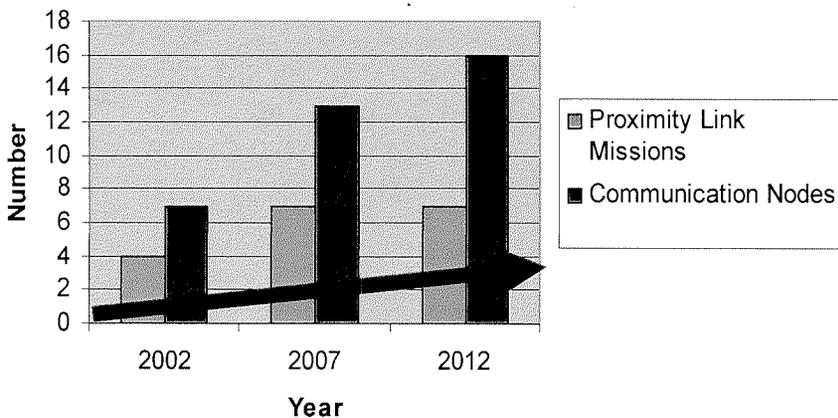
*Does not include MagCon.

- Total Number of Exploration Elements
- Number of Elements Actually Downlinking to Earth

• Last year's trends remain, but are stretched out over longer time period.

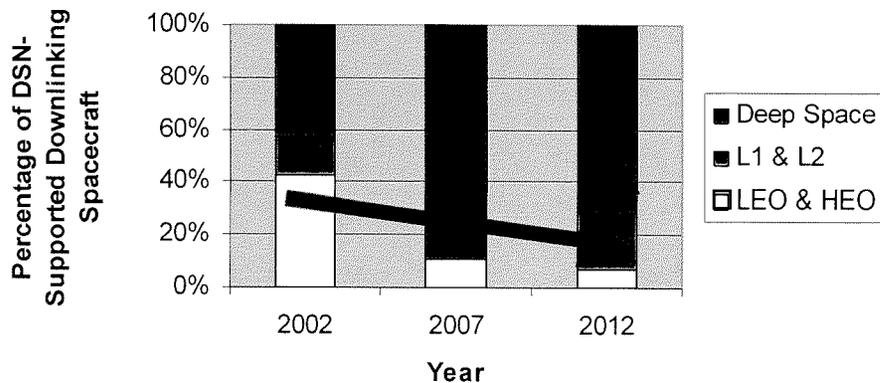
- Mission reliance on proximity links will occur more slowly due to Mars mission deferrals and constrained development budgets.
- Similarly, constellation missions will, in some cases, opt for D-T-E communication from each individual spacecraft.
- Somewhat larger proportion of distant HEO, L1 & L2 mission relative to deep space.

Proximity Link Trends*



*Does not include MagCon.

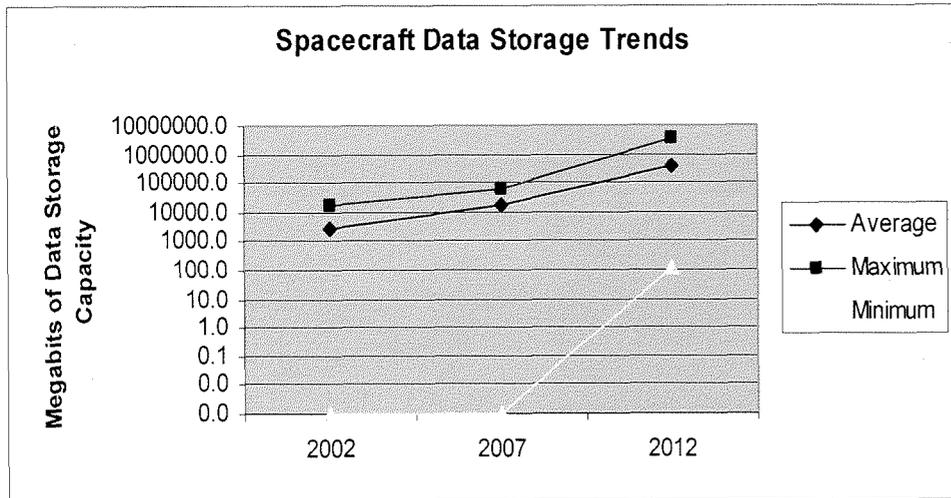
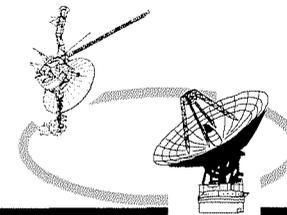
Spacecraft Locational Distribution as a Function of Time*



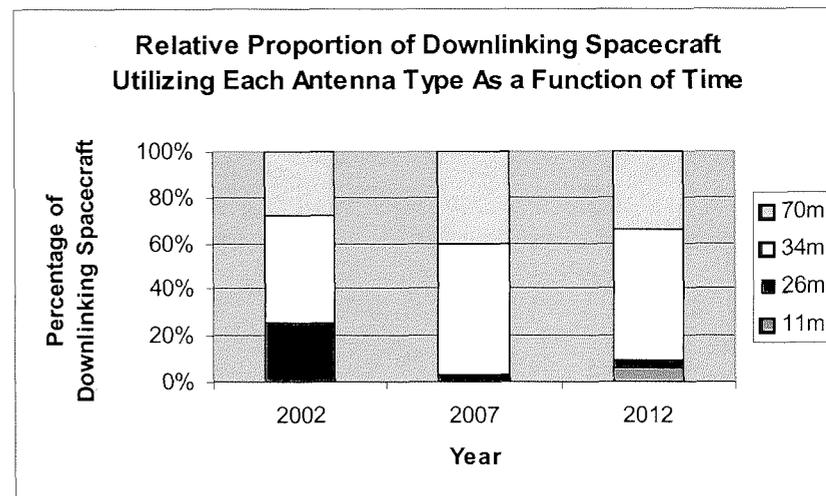
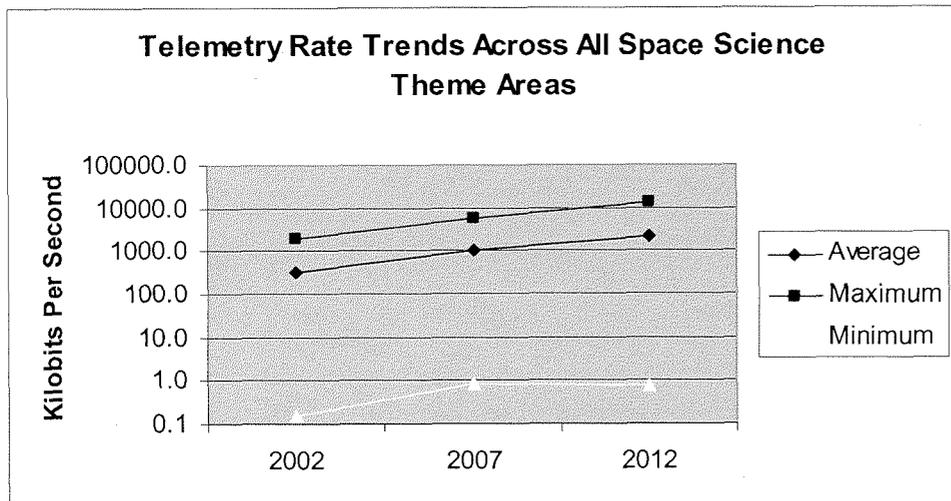
*Assumes MagCon uses cross-links to downlinking spacecraft.

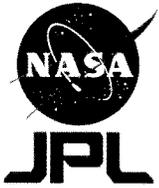


Last Year's Findings: Downlink-Specific Trends (10-Year View)

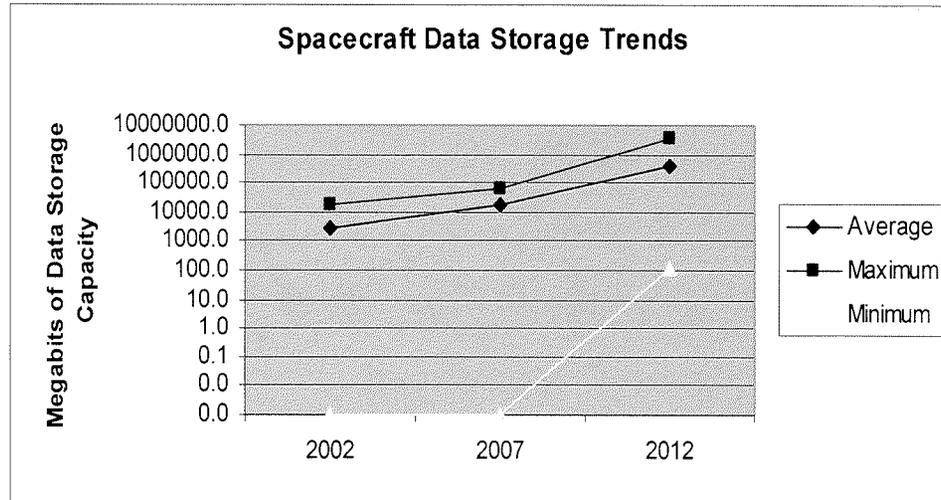
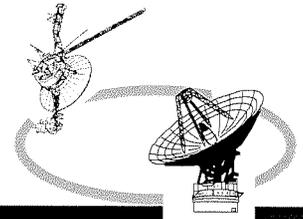


- Missions capable of collecting 1-2 orders of magnitude more data over next 10 years.
- Similarly, mission data rates appear to be increasing ~10x in 10 years.
- An increasing percentage of missions are planning on 34m & 70m equivalent aperture.
 - 26m decline partially due to mission migration from S-band to higher frequencies.
 - 11m plans for 2012 likely an artifact of earlier Lagrange point mission plans – JWST may signal change in thinking.

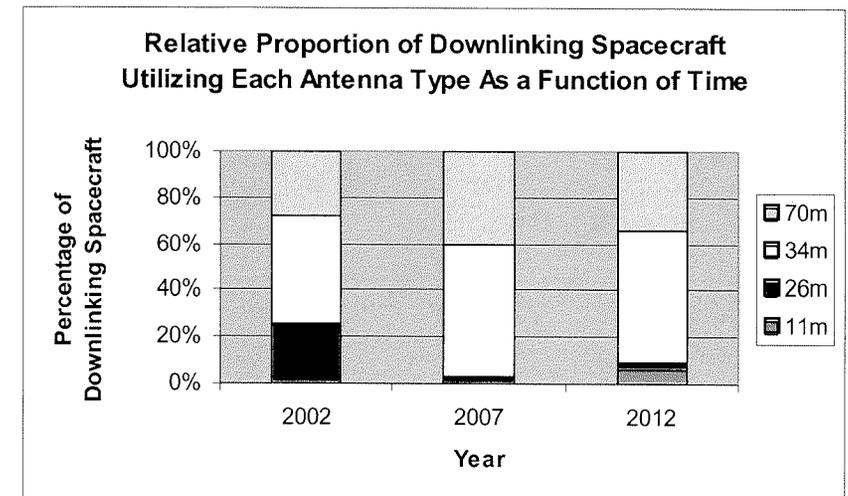
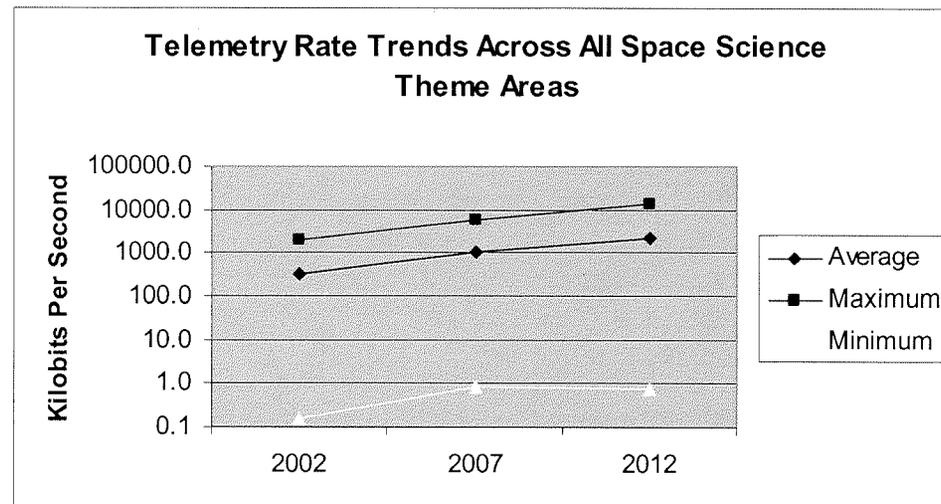




Predictions Pending New Update: Downlink-Specific Trends (10-Year View)

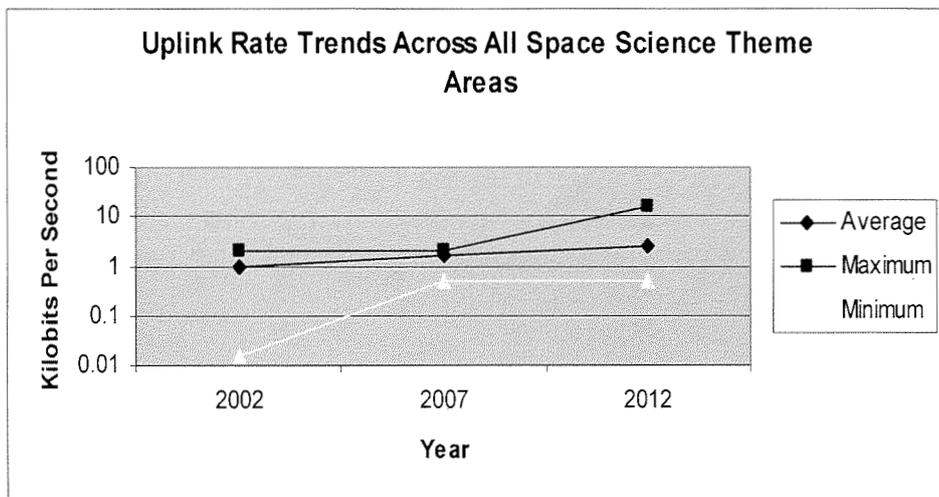
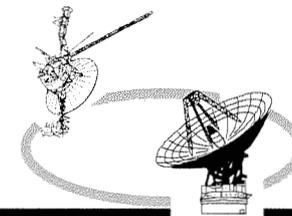


- For deep space, little change from last year's trends at the "order-of-magnitude" level.
- For distant HEO, L1, and L2 missions, a few somewhat higher data rates (between 10 to 100 Mbps)
 - Station throughput capability probably more of a concern than before.
 - Somewhat higher demand for near-Earth frequency X- and Ka-capable antennas

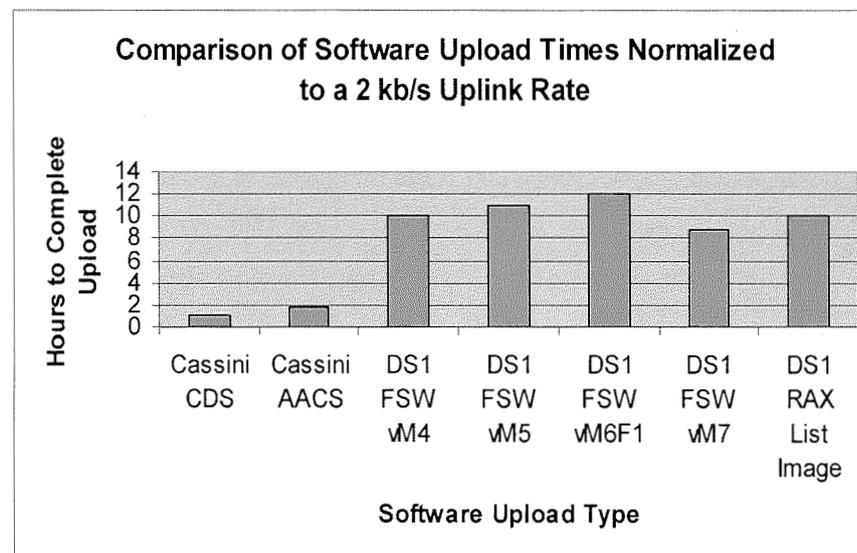
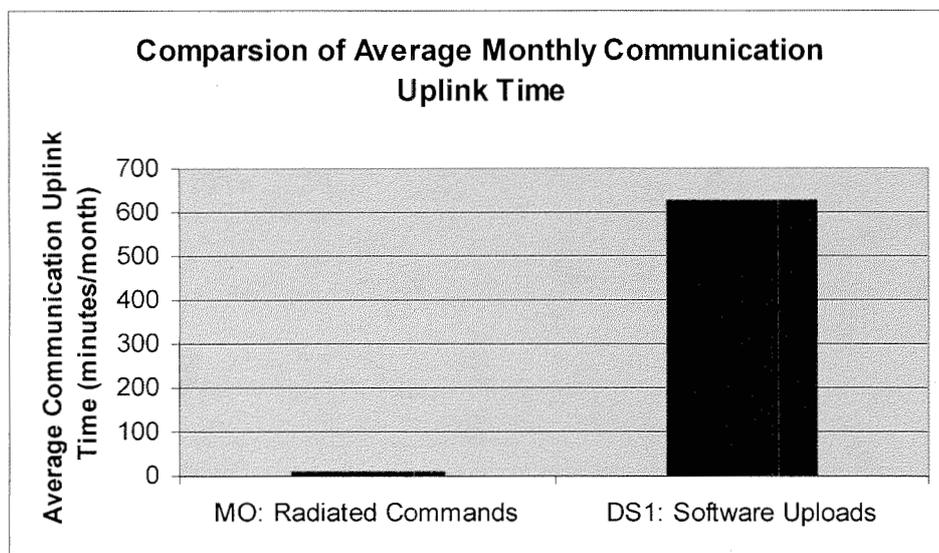




Last Year's Findings: Uplink-Specific Trends (10-Year View)

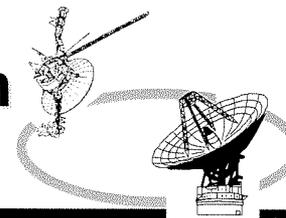


- For next 10 years, majority of space science missions planning on uplink rates of ~2 kbps.
- However, a mission emerges at end of time frame requiring an uplink rate ~10x higher – driven by upload of instrument calibration flats rather than commanding.
- Nature of uplink changing from low-level commands to software uploads -- which may be less frequent, but longer in duration.
- And, software upload durations may be increasing with increased software complexity.

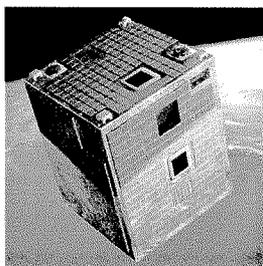




Some New Data: Non-DSN Missions with Software-Driven Uplink Requirements



PROBA



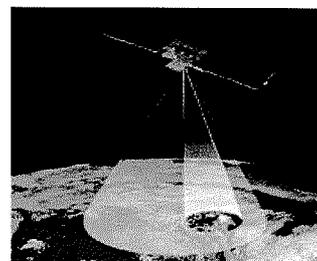
ESA's Project for On-Board Autonomy

- Onboard autonomous agent provides for routine housekeeping and resource mgmt.
- Instrument planning, scheduling, and pointing also handled autonomously
- Requires upload of target request file

Telecom Impacts:

- Reduction of downlink data associated with engineering telemetry
- 4 kbps uplink (2x > than current rate)

Space Technology 6



Autonomous "Sciencecraft" Demonstration

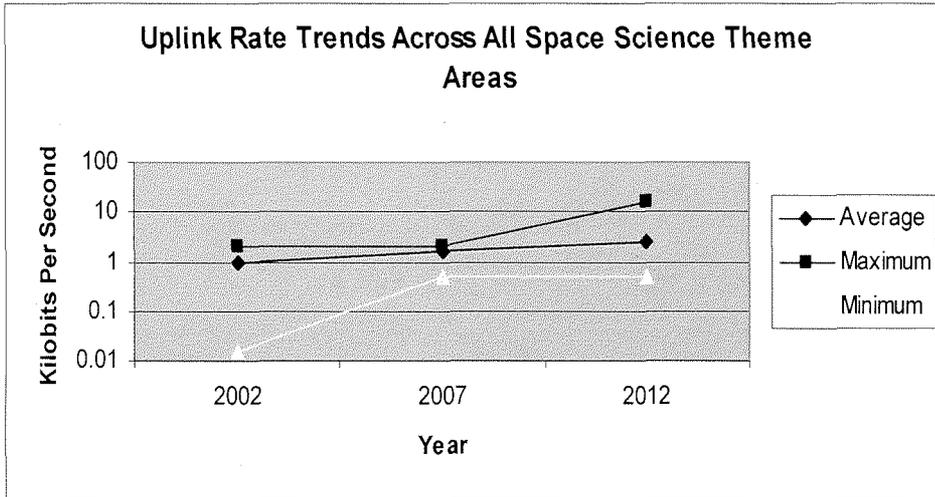
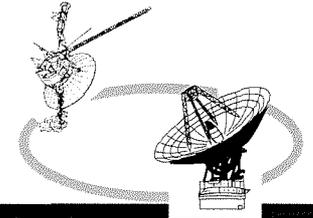
- Onboard autonomous agent selects interesting features for observation
- Data return decisions based on change criteria
- Some onboard analysis of data

Telecom Impacts:

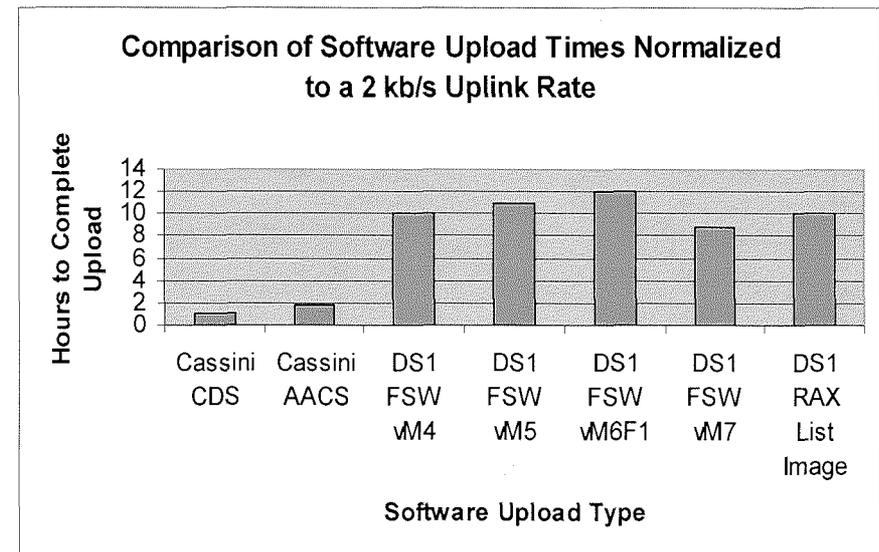
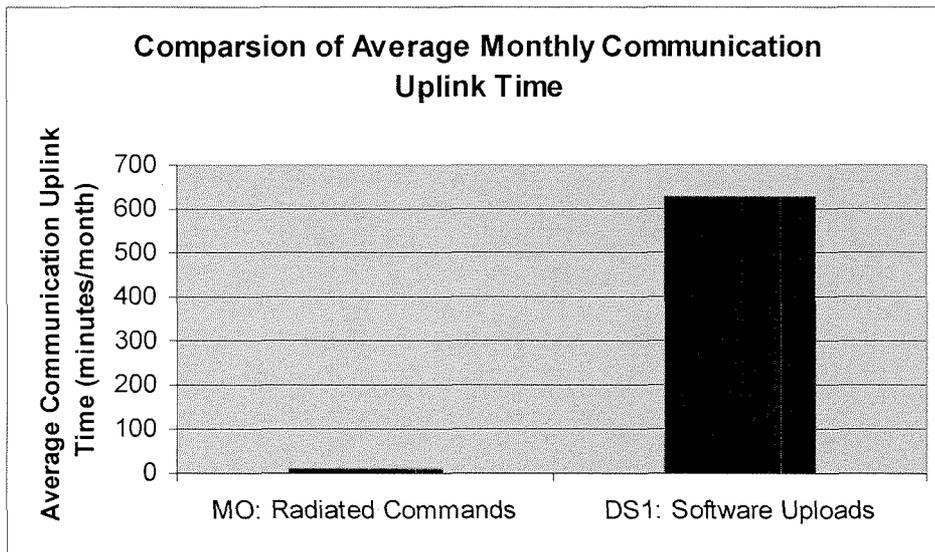
- Significant reduction of downlink data associated with science
- 50 kbps uplink (25x > than current rate)



Predictions Pending New Update: Uplink-Specific Trends (10-Year View)



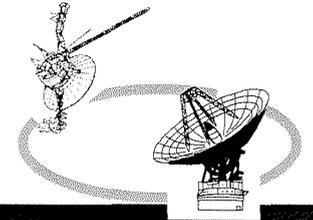
- No change in reported trends.
- The new data suggest that the available uplink “window” tends to drive the uplink rate for software uploads.
 - Deep space missions may simply stay at 2 kbps and uplink longer.
 - Uplink may start to drive antenna loading.
 - Consequent DSN overload may then drive higher uplink rates.



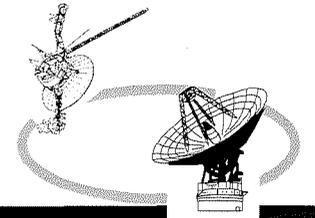


Summary of Key Points

(10-Year View)



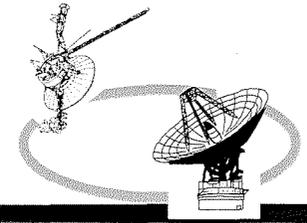
- New NASA roadmaps and strategic plans are in process of being released.
 - Impacts last year's mission model findings.
 - Competitive-bid basis for new mission set creates uncertainty about nature and timing of future missions.
- Number of missions likely to be growth limited by fiscal constraints.
 - Slight increase in number of downlinks to Earth as multi-element missions rely on multiple D-T-E links, rather than proximity links, to save development money.
 - Slower growth in proximity links than previously projected due to ESS mission deferrals and development money issues – but, still sustained growth due to transition from planetary reconnaissance to detailed in situ exploration.
- Less DSMS-supported near-Earth orbital missions, but more distant-HEO, Lagrange Pt., and deep space missions.
- More reliance on 34m and 70m equivalent aperture due to longer link distances, higher data rate demands, and diminishing reliance on S-band (e.g., increased near-Earth reliance on X and Ka).
- 10x increase in downlink telemetry rates for deep space missions, a few distant HEO and Lagrange Pt. Missions with higher data rate increases.
 - May impact station throughput and GDS capabilities.
- More software uploads due to increasing spacecraft complexity.
 - May eventually, at 2 kbps, lead to uplink-driven DSN loading issues
 - May eventually drive higher uplink rates.



Appendix A: Other Service Implications (10-Year View)

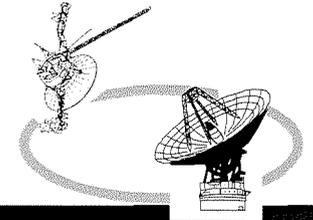


Other Service Implications

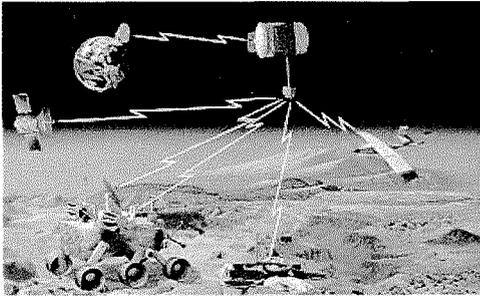


- To date, investigation of customer needs has been focused largely on DSN-user requirements for downlink and uplink.
- However, the DSMS provides mission customers with more than just telemetry and command services. Other service areas include:
 - In situ or Proximity Communications
 - Mission Data Management
 - Tracking, Navigation, and Timing
 - Flight Control
- Significant work still needs to be done to quantify the trends associated with these other service areas.
- But, we can infer some implications for each of these areas based on the information already gathered for the downlink and uplink analyses.

Other Service Implications (10-Year View)

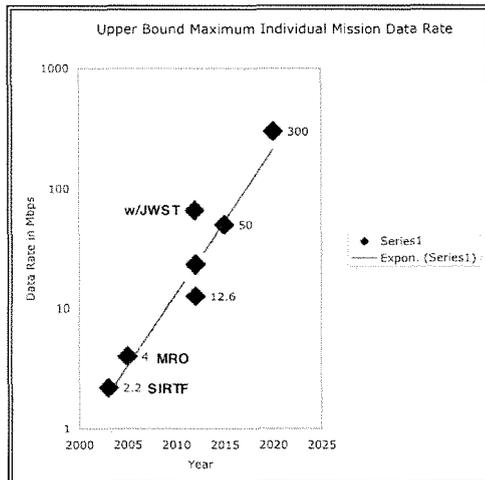


• *In situ* or Proximity Communications



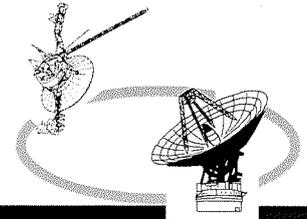
- **Observation** -- General mission trends show a gradually increasing number of proximity link missions and associated communications nodes as a function of time – both from *in situ* missions (largely at Mars) and the beginnings of formation flyer/constellation missions.
- **Implications** – Traditional telemetry and command services, as well as associated flight components, protocols, and tools, need to evolve to encompass proximity link services and the local area networking of multiple mission elements.

• Mission Data Management

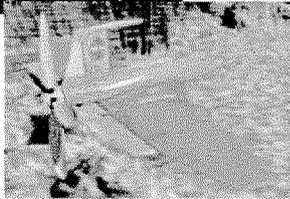
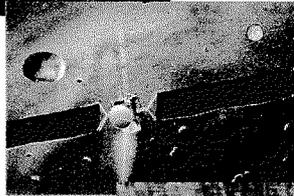
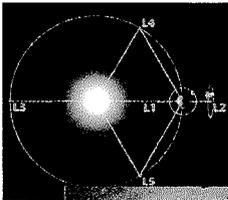


- **Observation** – Downlink trends show that data rates to Earth will likely increase by at least 10x per decade. Hence, ground data handling capabilities will likely need to be commensurate. Also, increasing multi-element mission data will lead to more complex ground data handling.
- **Implications** – The ground data system and ground communications facility will need to evolve to handle greater data throughput and routing diversity.

Other Service Implications (10-Year View Continued...)

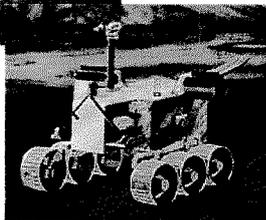
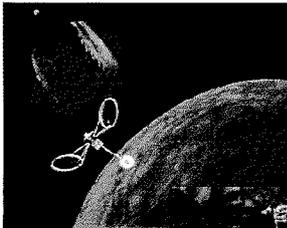


• Tracking, Navigation, and Timing

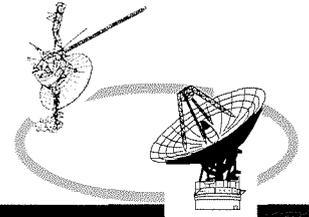


- **Observation** – NASA's future mission plans involve some very challenging mission scenarios. These scenarios include low-thrust guidance and navigation, aerocapture, precision landing, *in situ* vehicle GN&C, rendezvous & docking, flight in irregular or multi-body gravitational environments, and multi-vehicle GN&C (see next page).
- **Implications** -- Traditional tracking, navigation, and timing services, as well as their associated flight components, protocols, and tools, will need to evolve to meet these emerging navigation challenges. At the same time, this evolution will need to leverage any new frequencies, ground assets, flight components, or networked assets being emplaced for communications purposes.

• Flight Control



- **Observation** – Missions are emerging which involve two-way light times that are too long to allow timely Earth-commanded obstacle avoidance or fault response. In addition, intense budget pressures are discouraging missions from reinventing unique flight software, fielding large ground ops teams, and securing comfortable tracking allocations.
- **Implications** – New technologies and tools are needed that will facilitate onboard autonomy, minimize ground-time devoted to engineering analysis and commanding, and minimize required tracking.

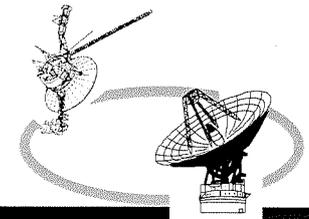


Appendix B: 20-Year View

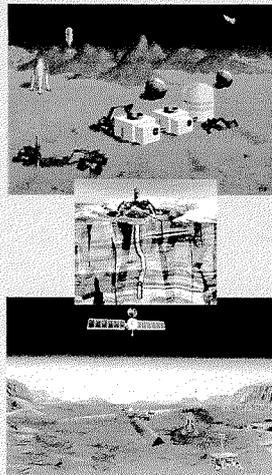


INTERPLANETARY NETWORK DIRECTORATE

General Mission Trends (20-Year View)

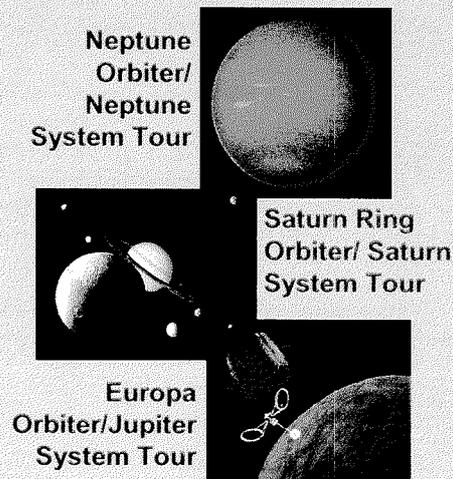


Lunar and Mars Robotic Outposts



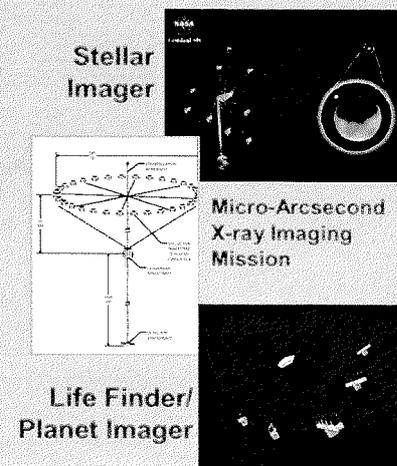
- Cooperative, multi-element operations relying on *in situ* navigation and communication

Detailed Outer Solar System Exploration Missions



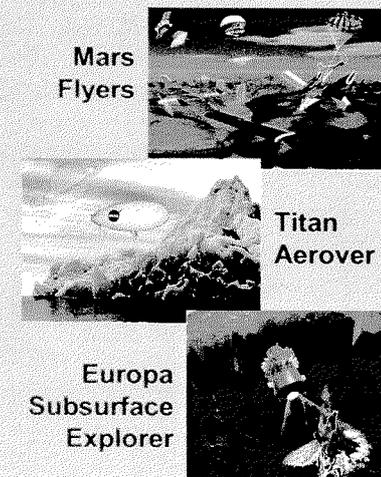
- Data-intensive, long-duration remote sensing at long link distances

Observatory Constellation Missions



- High-bandwidth, multi-element observations relying on formation flight and proximity links

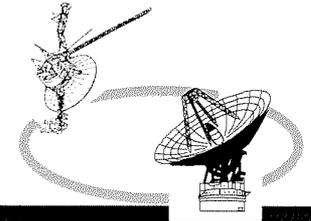
Advanced Mobility Missions



- Autonomous operations with specialized navigation and communication needs

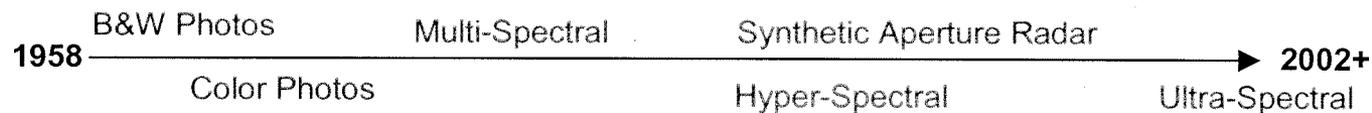


Downlink: Looking Beyond 10 Years

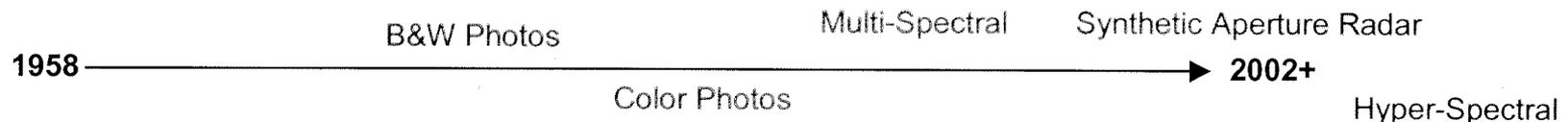


- Problem: Mission concepts more than 10 years out exhibit a heavy bias towards today's technologies.
- What We Know: Scientists want to be able to carry out science investigations at other planets with same ease, precision, and resolution as they can on Earth.
- Solution: Use current Earth-based capabilities as an indication of what will be needed for future deep-space capabilities.
- Case in point: Remote Sensing from Space

Earth Remote Sensing:

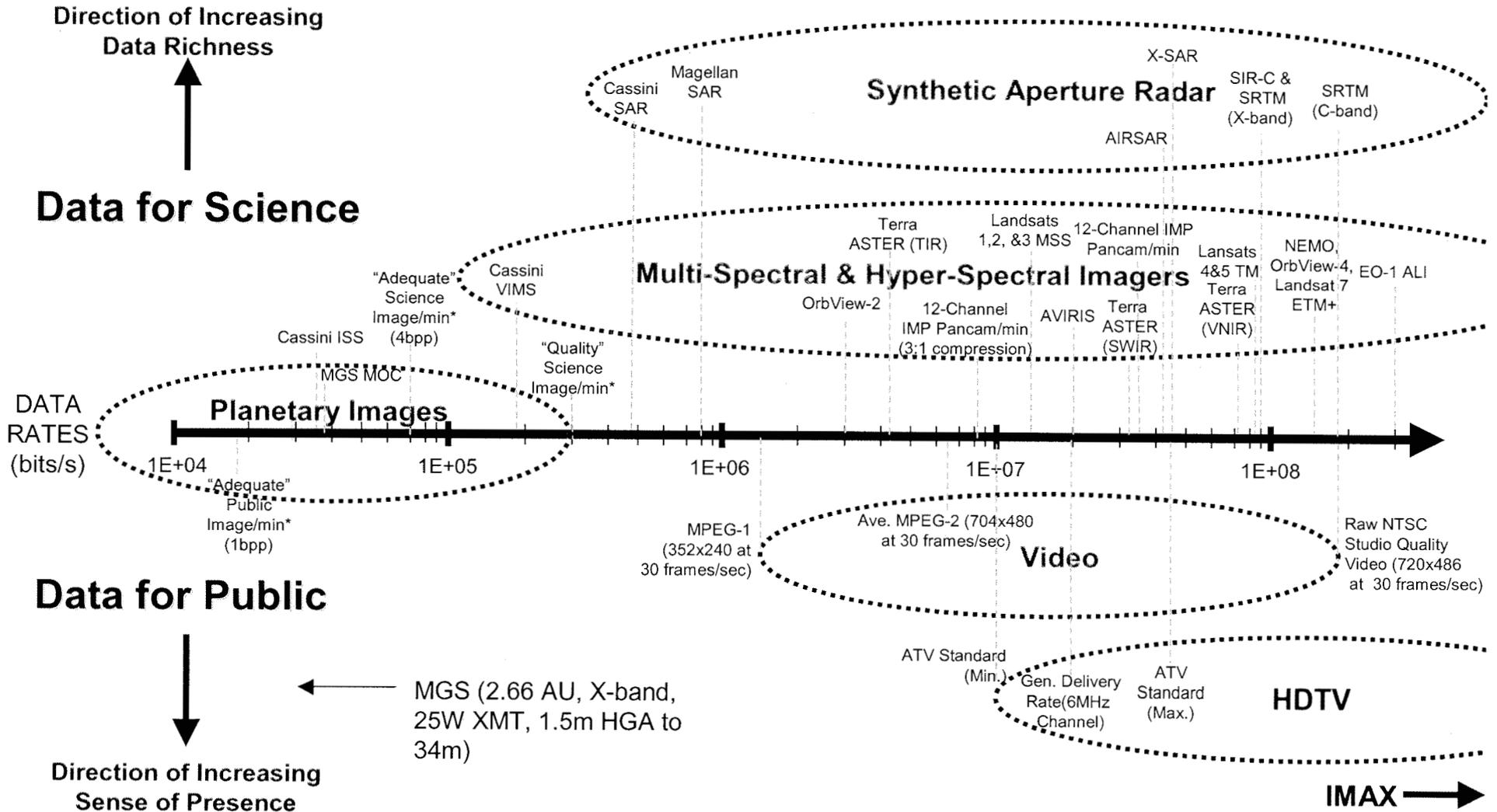
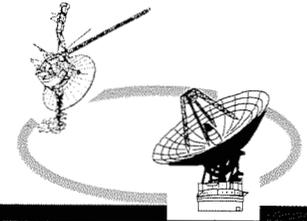


Remote Sensing at Other Planets:

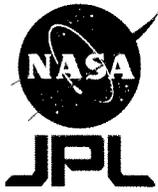




Findings: Downlink-Specific Trends (20-Year View)

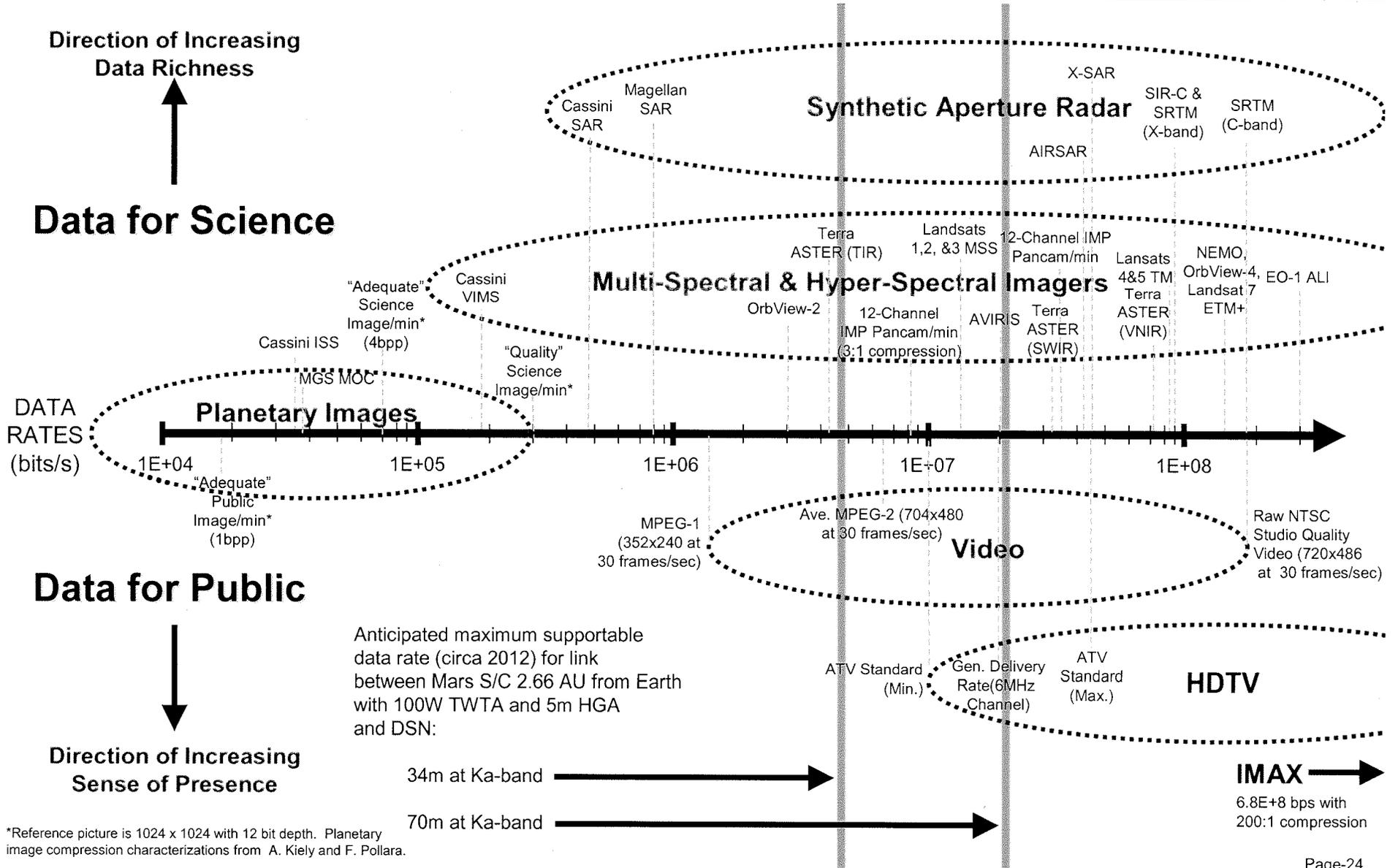
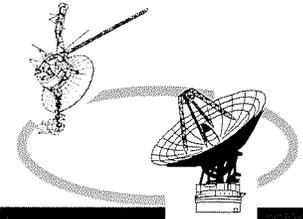


*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara.



2.7 AU Mars Orbiter/Relay Scenario (~2012)

(Maximum Supportable Rates with RF Flight Hardware Improvements and Ka Ground Improvements)

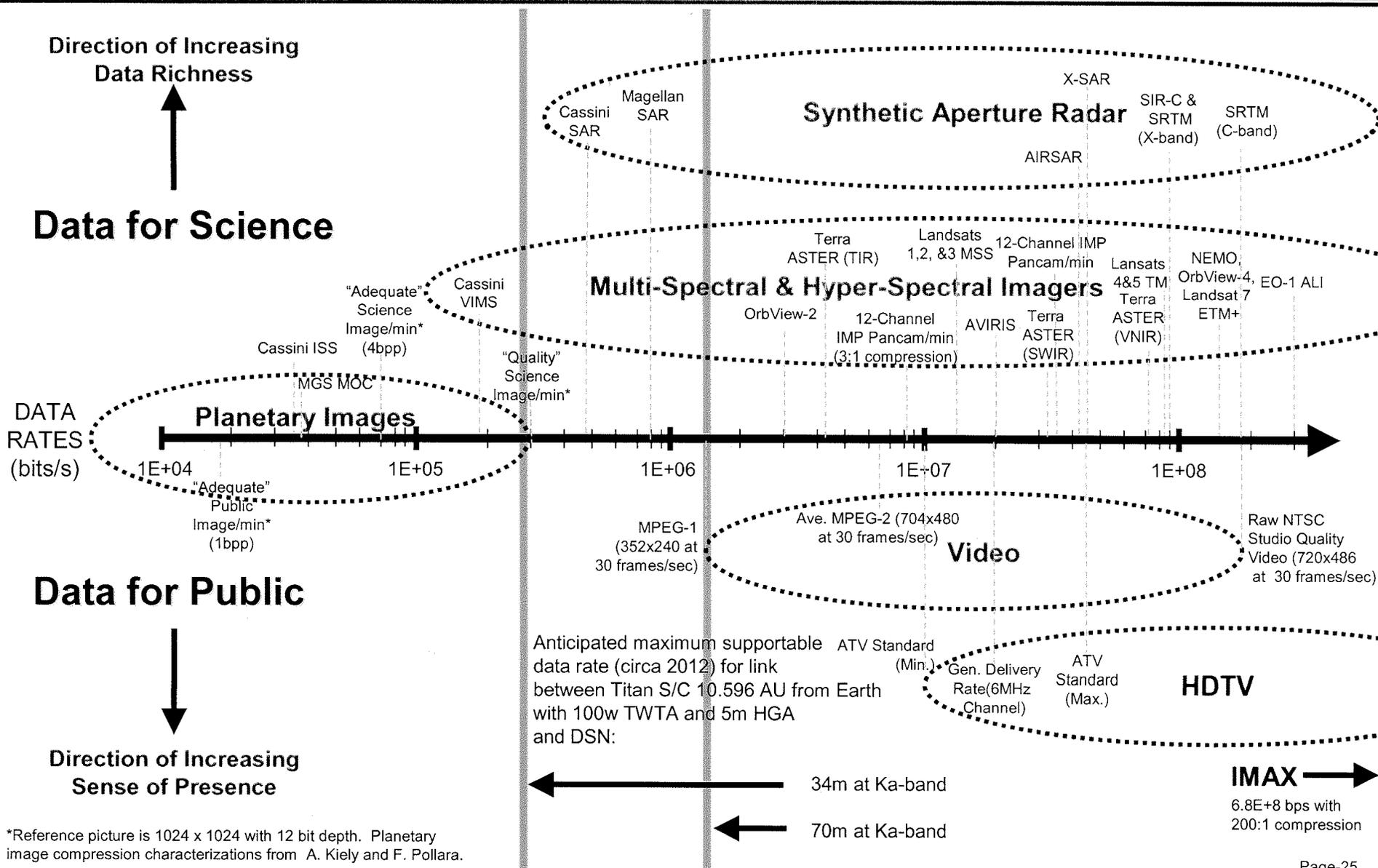
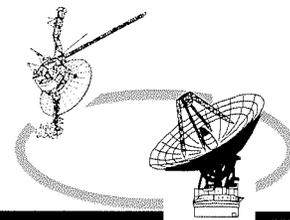


*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara.



10.6 AU Titan Orbiter/Relay Scenario (~2012)

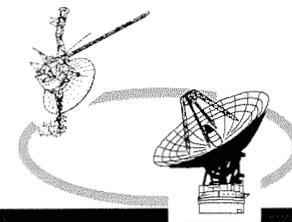
(Maximum Supportable Rates with RF Flight Hardware Improvements and Ka Ground Improvements)



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



Uplink: Looking Beyond 10 Years



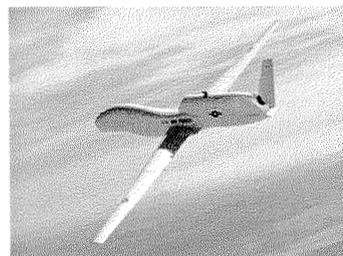
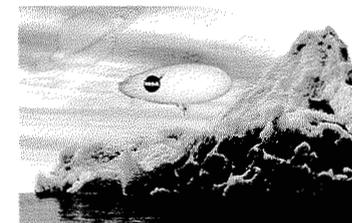
- *In situ* exploration will directly entail or depend heavily upon mobility elements.
- Intelligent use of mobility requires guidance, navigation, & control (GN&C).
- Mobility elements will have to negotiate obstacles faster than command from Earth will allow.
- Earth-based analogs suggest potential solutions that depend on onboard autonomy, in conjunction with remote sensing data product uploads, for navigation & retargeting.



Cruise Missiles



- Guidance via matching SAR data
- Targeting via digital scene matching



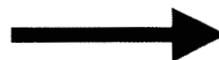
UAVs



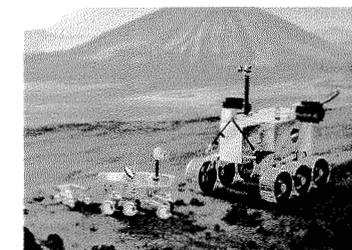
- Guidance via GPS-like beacon aids
- Targeting via hyperspectral signature



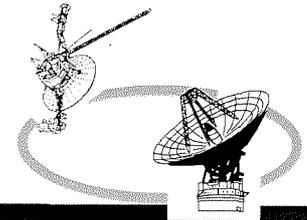
UGVs



- Stereoscopic vision
- Multi-spectral terrain classification

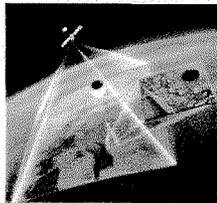
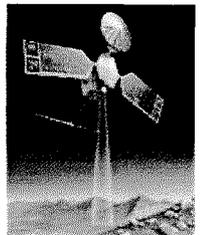


Findings: Uplink-Specific Trends (20-Year View)

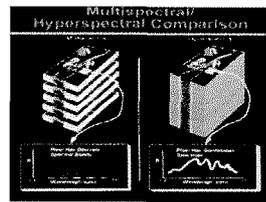


The Changing Operations Paradigm:

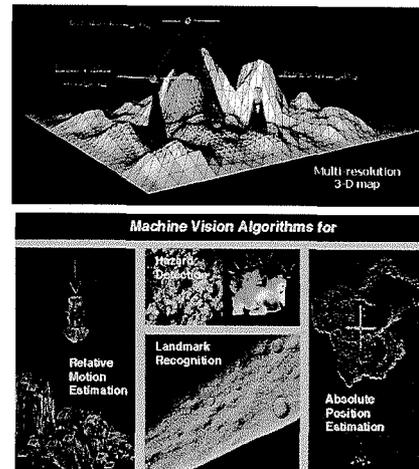
- (1) More onboard autonomy, less low-level commanding.
- (2) In situ exploration elements as consumers of orbital remote sensing data.



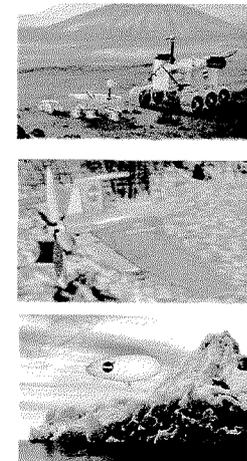
Orbital Remote Sensing



Large Downlink Data Volumes



Production of GN&C and Science Targeting Data Products

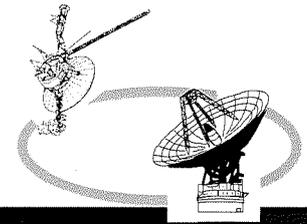


Large Software Uploads on Uplink

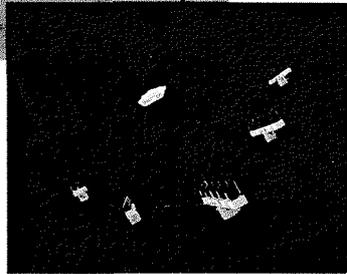
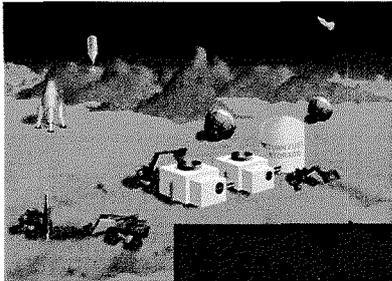
- (3) Significant increase in uplink rate to accommodate software uploads.
 - In-flight-retargetable cruise missile, UAV, and UGV analogies suggest an uplink rate of 200 kbps.
 - 100x increase over today's uplink rate.



Other Service Implications (20-Year View)



• *In situ* or Proximity Communications



- **Observation** – Future mission concepts include lunar and Mars robotic outposts as a prelude to human presence. These outposts entail a large number of robotic elements which coordinate their efforts in real time. NASA plans also call for solar and astrophysical observatory constellations that rely on many distributed elements operating together in a coordinated fashion.
- **Implications** – The need for rapid, reliable messaging within and between networks of robotic elements will become paramount. Assets and associated protocols for long-haul communications will need to interface seamlessly with those for *in situ* and proximity communications.

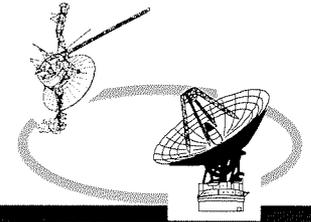
• Mission Data Management



- **Observation** – Same observation as above for *in situ* or proximity communications. In addition, the mobility elements envisioned for this time frame will need to be able to rapidly access navigation and targeting data.
- **Implications** – Ground-based mission data management services will need to evolve into ground- and space-based “information management” services with network-distributed data storage and access, as well as protocols that render the use of such services location-transparent.



Other Service Implications (20-Year View Continued...)

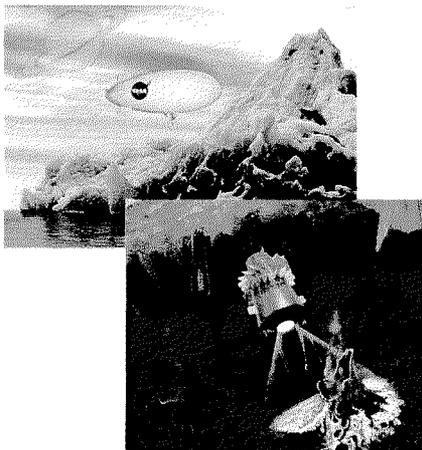


• Tracking, Navigation, and Timing



- **Observation** – As illustrated on the next page, future exploration will involve increasingly complex mission scenarios. Over the same time period, communications-driven improvements in the areas of frequency, ground assets, flight components, and networked assets will be emerging.
- **Implications** – Mission requirements, other service requirements (e.g., information management requirements), and communications-driven improvements (e.g., optical comm and local area networks at other planets) will drive higher accuracy tracking observables, spur introduction of new observables and navigation techniques, and promote more precise time synchronization between distributed assets.

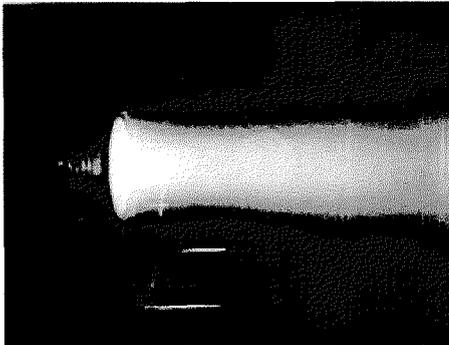
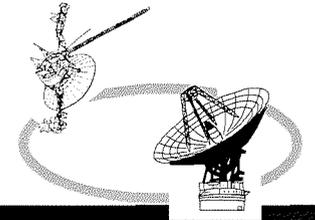
• Flight Control



- **Observation** – Most missions will involve two-way light times too long to allow Earth-commanded obstacle avoidance or fault response. Also, to realize a large fraction of the mission concepts envisioned for that time frame, the operations cost of any single mission element will have to be significantly reduced.
- **Implications** – “Fleet” operations will start to subsume “mission” operations. Individual mission elements will have to have substantially more capability to autonomously monitor and control their states, execute activities, and predict, prevent, and respond to anomalies.



Navigation: Challenging Mission Scenarios (2003-2023)



Low-Thrust Guidance & Navigation

Mercury, small body, and outer planet missions (e.g., Dawn, Bepi Colombo)



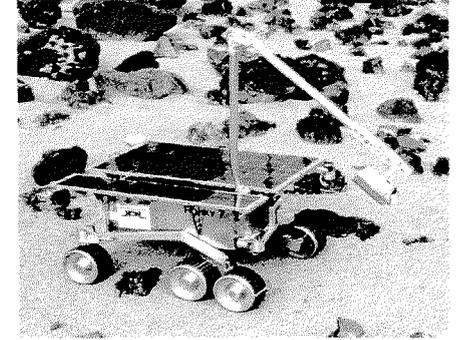
Aerocapture

Missions going into orbit about Venus, Mars, Saturn, Titan, Uranus, Neptune (e.g., Titan Explorer, VSSR)



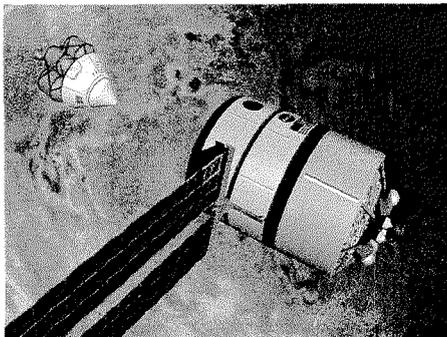
Precision Landing

Landing on small bodies, terrestrial bodies, or planetary satellites (e.g., MSL, CSSR)



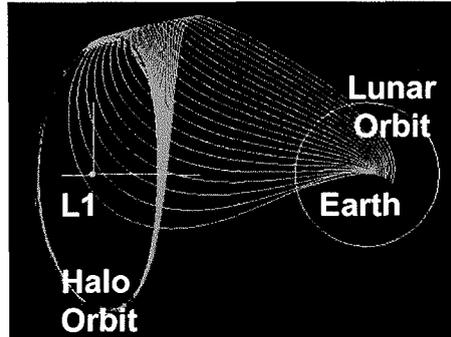
In-Situ Vehicle GN&C

Rovers, balloons, submarines, and aircraft on planets, satellites, and small bodies (e.g., MER, MSL, MSR)



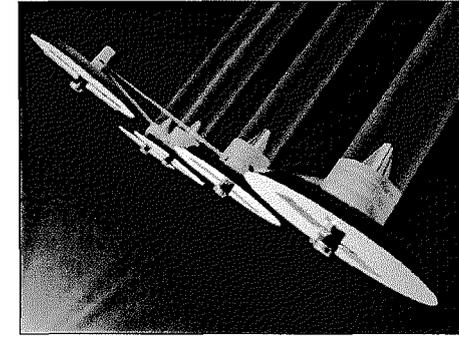
Rendezvous & Docking

Sample return missions to terrestrial planets, small bodies, and planetary satellites (e.g., MSR, CSSR)



Flight in Irregular or Multi-Body Gravitational Environments

Small body and libration point missions (e.g., JWST, Con-X, TPF, SCOPE)



Multi-Vehicle GN&C

Mars constellations, formation flying, etc. (e.g., TPF, MAXIM, Life Finder, Planet Imager)