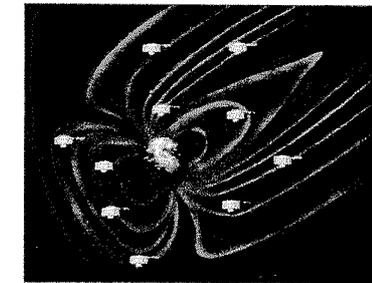
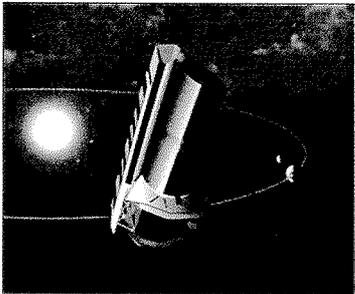
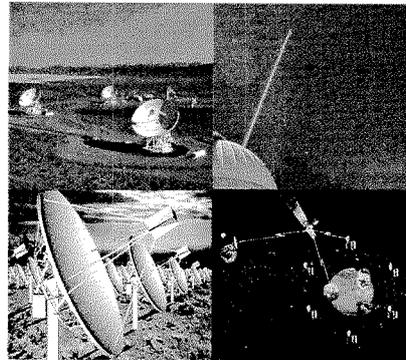
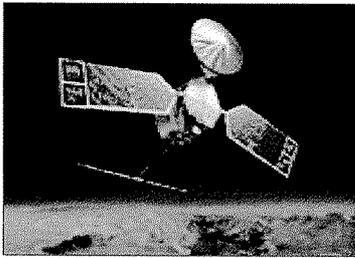
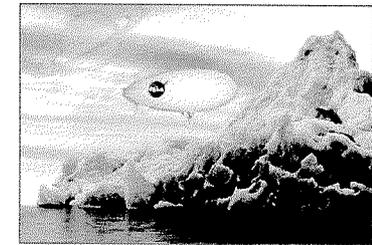
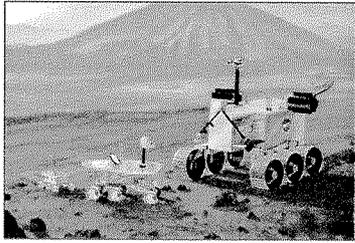


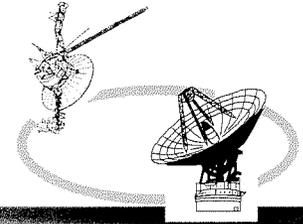
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Identifying Future Mission Drivers on the Deep Space Network



by
Douglas S. Abraham
Jet Propulsion Laboratory

Space Ops 2002
Houston, TX
October 9-12, 2002

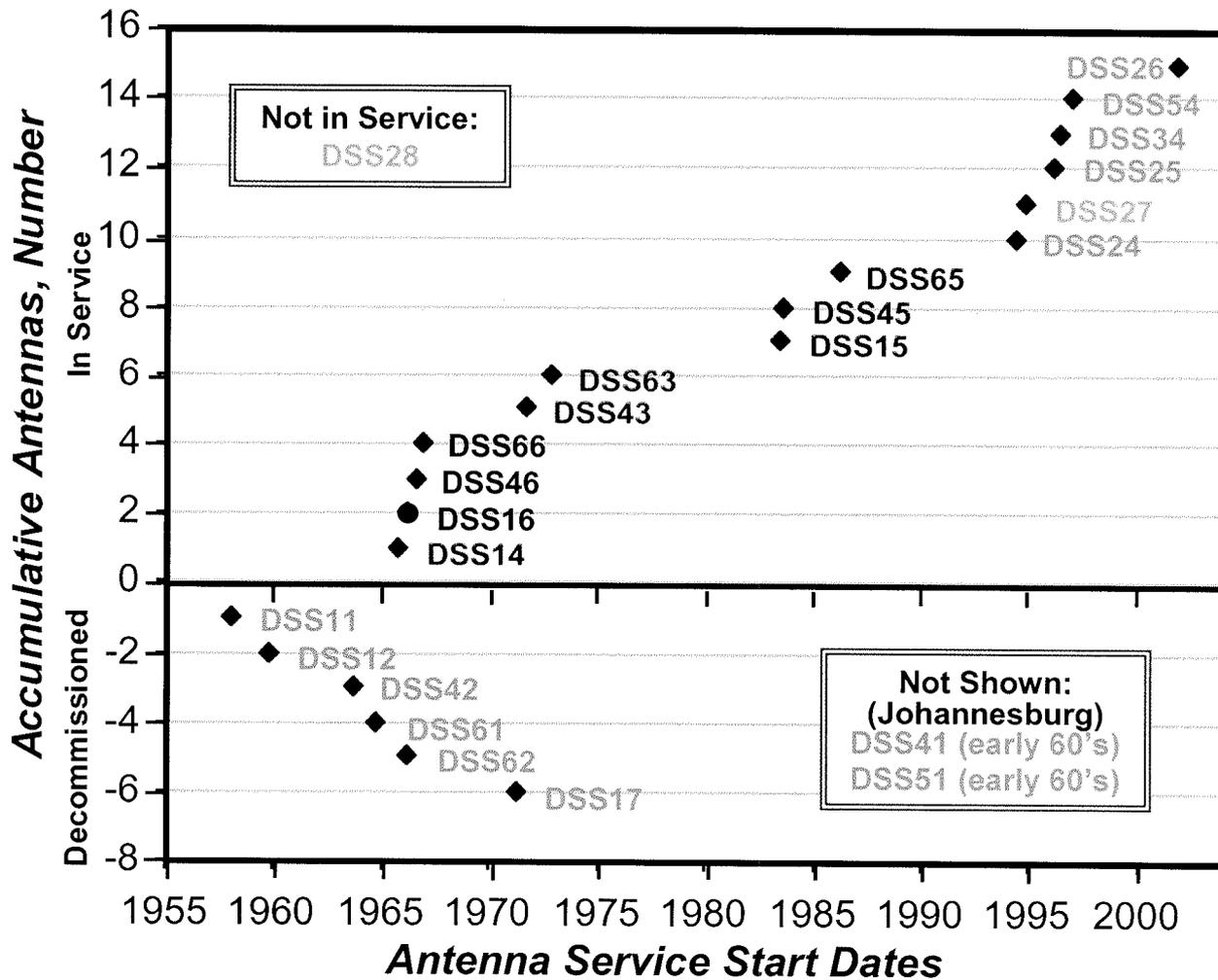
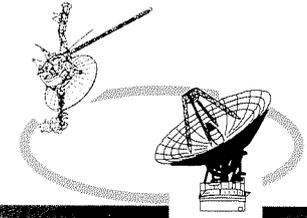


Topics

- Motivation
- Methodology
- Findings
 - Downlink Trends
 - Uplink Trends
- The Changing Operations Paradigm & Future Questions



Motivation #1: The Deep Space Network's Aging Assets

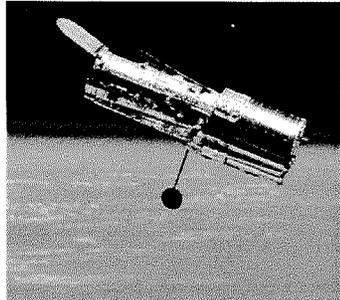
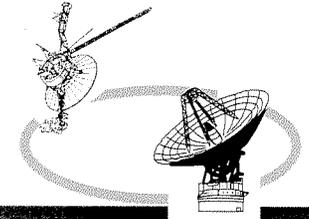


- Which current assets will still be needed in the future?
- What new assets will be needed?
- What will be the appropriate asset mix?

(Graph compliments of R. C. Hastrup and R. J. Cesarone, JPL)



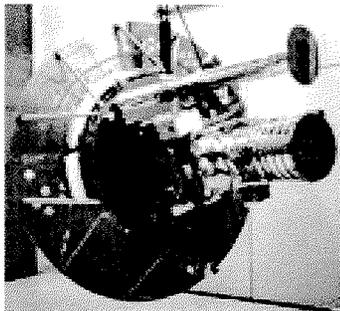
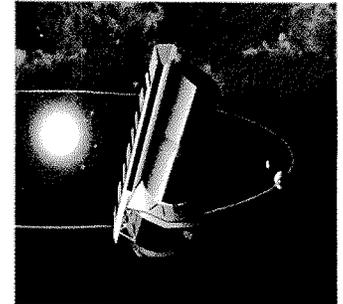
Motivation #2: The Changing Robotic Space Exploration Paradigm



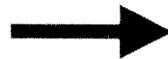
Low-Earth-orbit solar and astrophysical observatories.



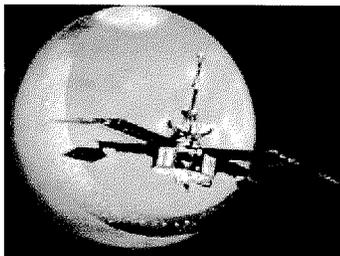
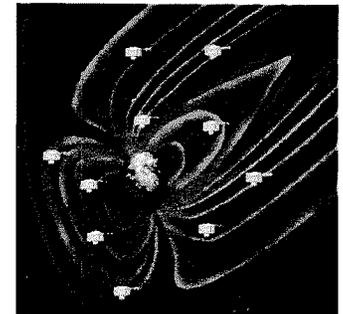
Observatories located further from Earth.



Single, large spacecraft for solar and astrophysical observations.



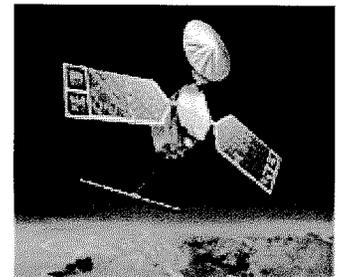
Constellations of small, low-cost spacecraft.



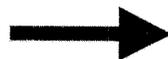
Preliminary solar system reconnaissance via brief flybys.



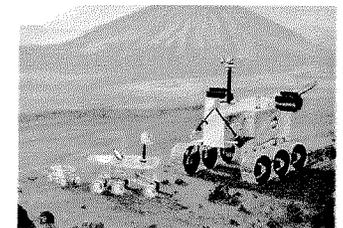
Detailed Orbital Remote Sensing.

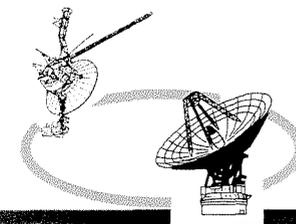


In situ exploration via short-lived probes.



In situ exploration via long-lived mobile elements.



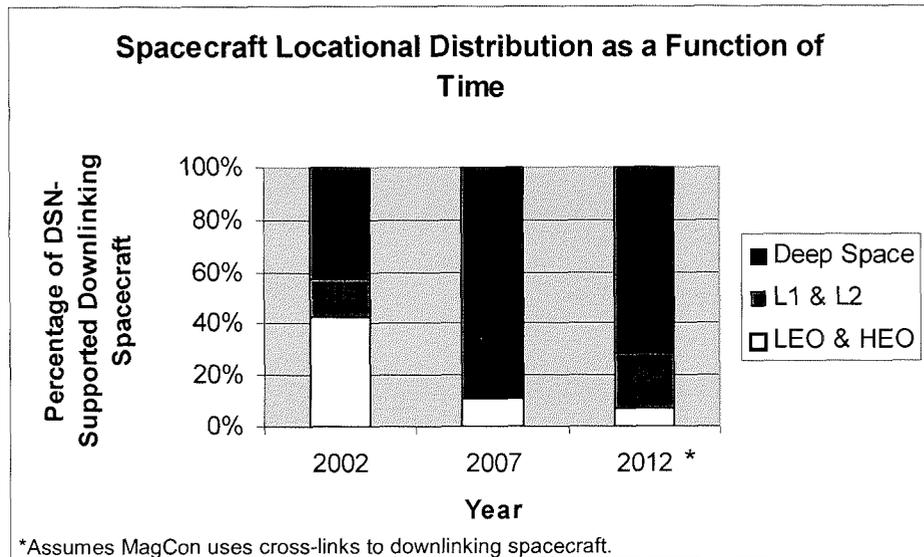
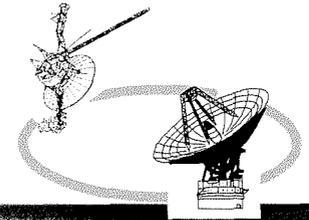


Methodology

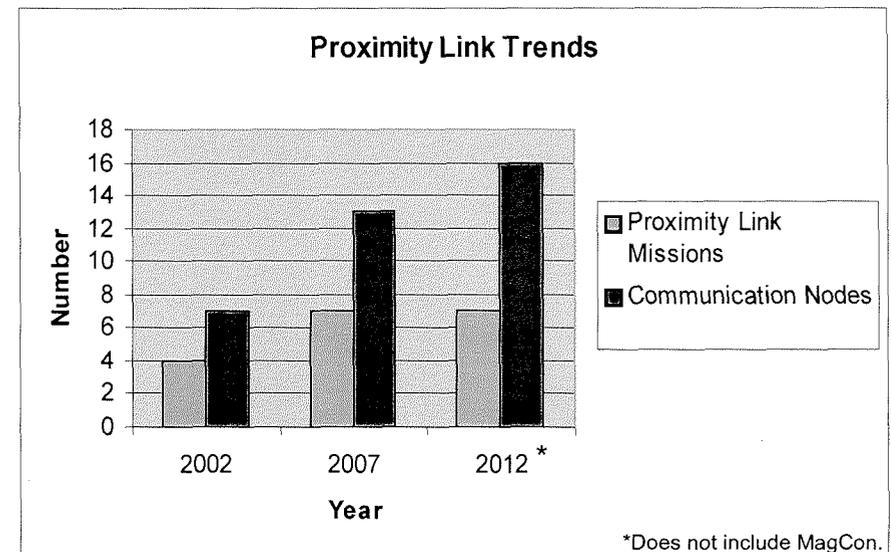
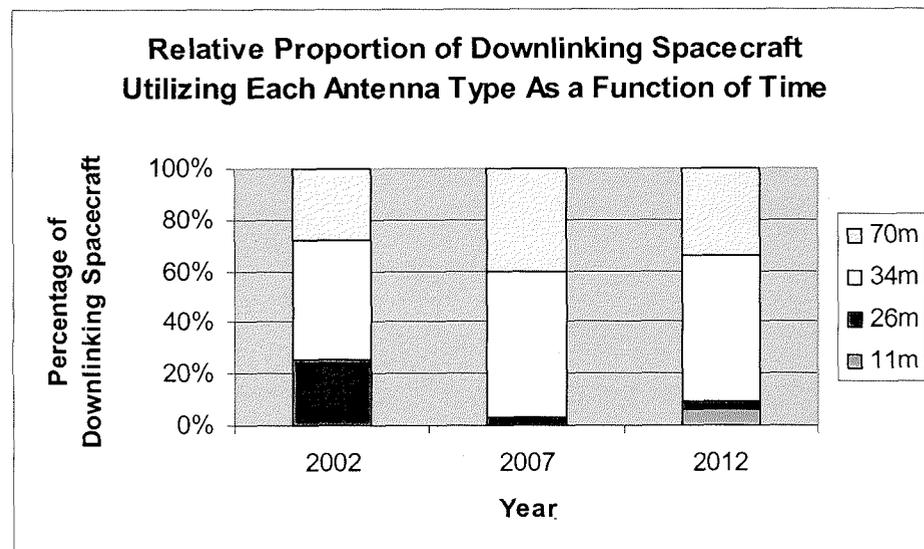
- Reviewed NASA strategic plans, roadmaps, and related NRC documents.
- Interviewed future user community representatives.
- Constructed extensive database on future missions and their telecommunication-related needs.
- Used database in analysis of future mission demographics.
 - Conducted “quasi-Monte Carlo” analysis to account for future mission set uncertainties.
 - Identified time horizon applicability limits.
- Employed analogies to Earth-based capabilities to extrapolate trends beyond demographic time horizon applicability limits.
- Identified key drivers on long-haul communications to and from Earth.
- Held a “Science & Future Mission Workshop” where preliminary results of these efforts were vetted.

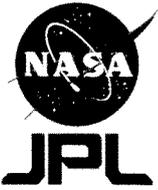


Findings: Downlink Circa ~2010



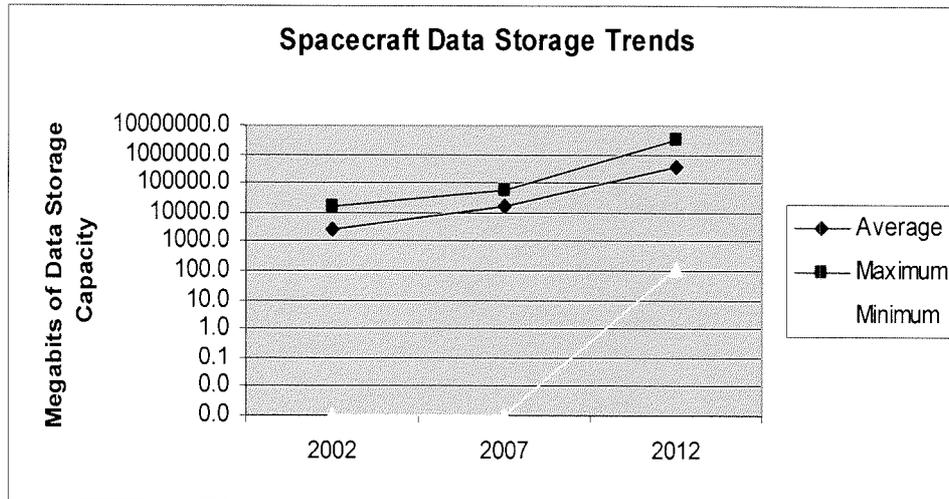
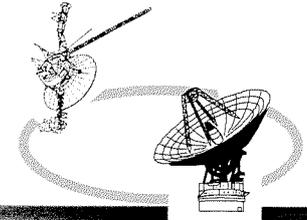
- Mission set is migrating into deep space.
- Some high data volume observatory-class missions at L1& L2 also drive DSN support.
- This move to greater distances, coupled with higher data rates & frequencies, is driving growing reliance on 34m & 70m antennas and diminishing TT&C reliance on 26m antennas.
- A growing proportion of the mission set is also serving a relay function for a growing number of locally “networked” exploration elements within each mission (e.g., probes, rovers, etc.).



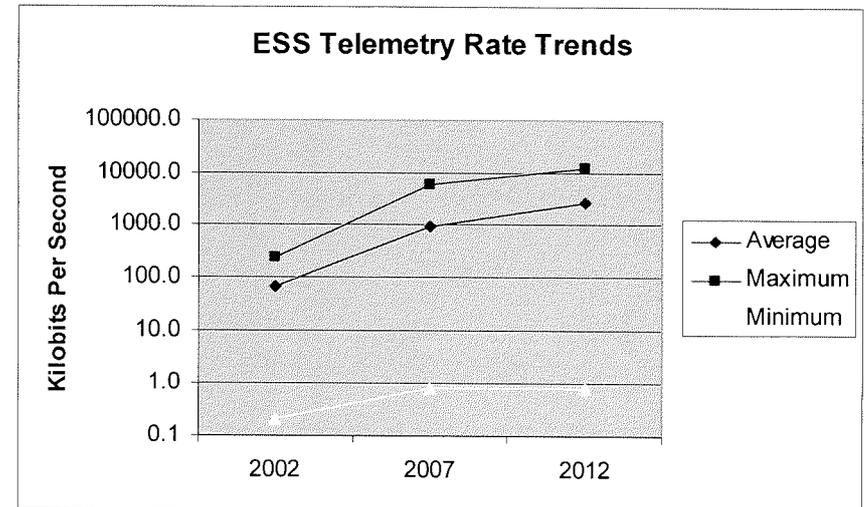
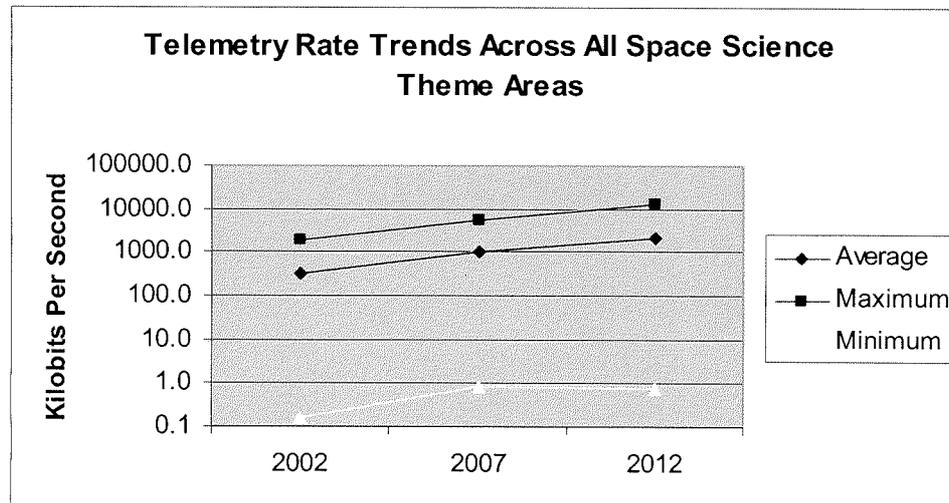


Findings: Downlink Circa ~2010

(Continued...)

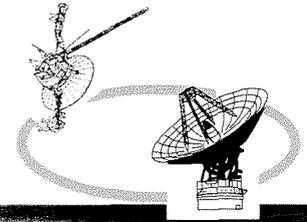


- Missions appear to be collecting 1-2 orders of magnitude more data over next 10 years.
- Similarly, mission data rates appear to be increasing ~10x in 10 years.
- Peak downlink data rates are driven by ESS missions -- largely by those at Mars.
- Mars orbiter data rates increase by almost 2 orders of magnitude in 10 years due to high-resolution spatial, spectral, and radar imaging.



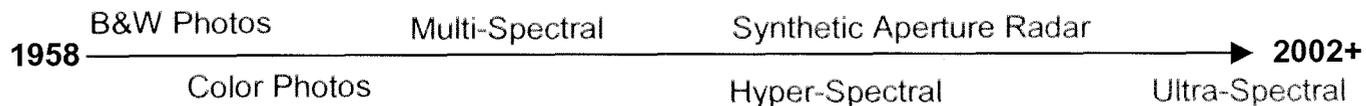


Downlink: Looking Beyond 2010

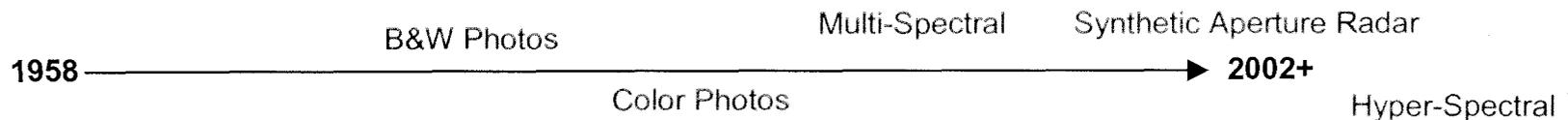


- Problem: Mission concepts more than 10 years out exhibit a heavy bias towards today's technologies.
- What We Know: Scientists want to be able to carry out science investigations at other planets with same ease, precision, and resolution as they can on Earth.
- Solution: Use current Earth-based capabilities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

Earth Remote Sensing:



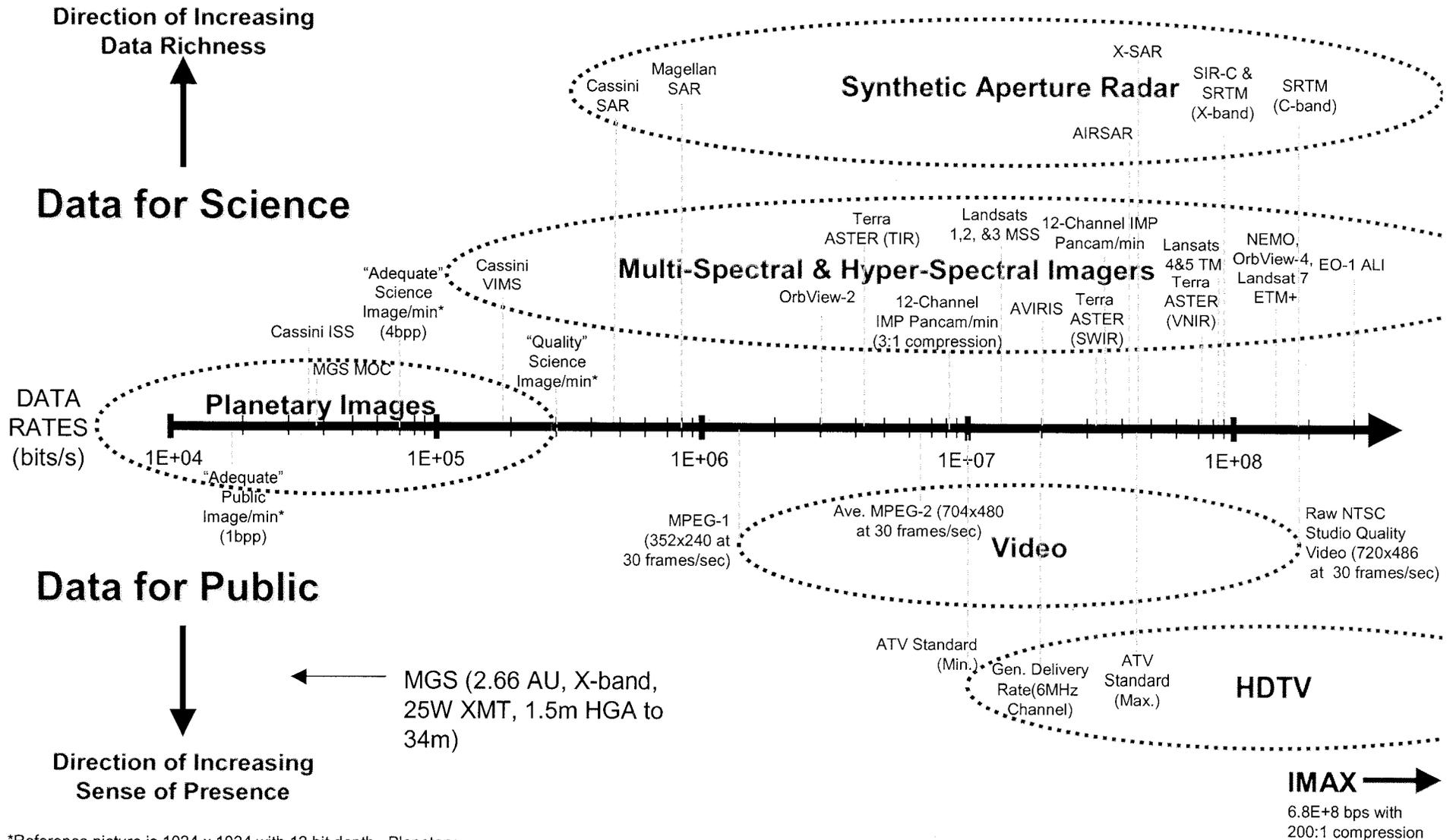
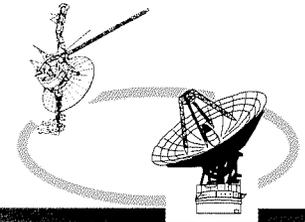
Remote Sensing at Other Planets:



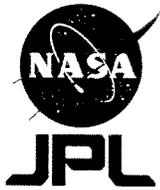


Downlink: Looking Beyond 2010

(Continued...)



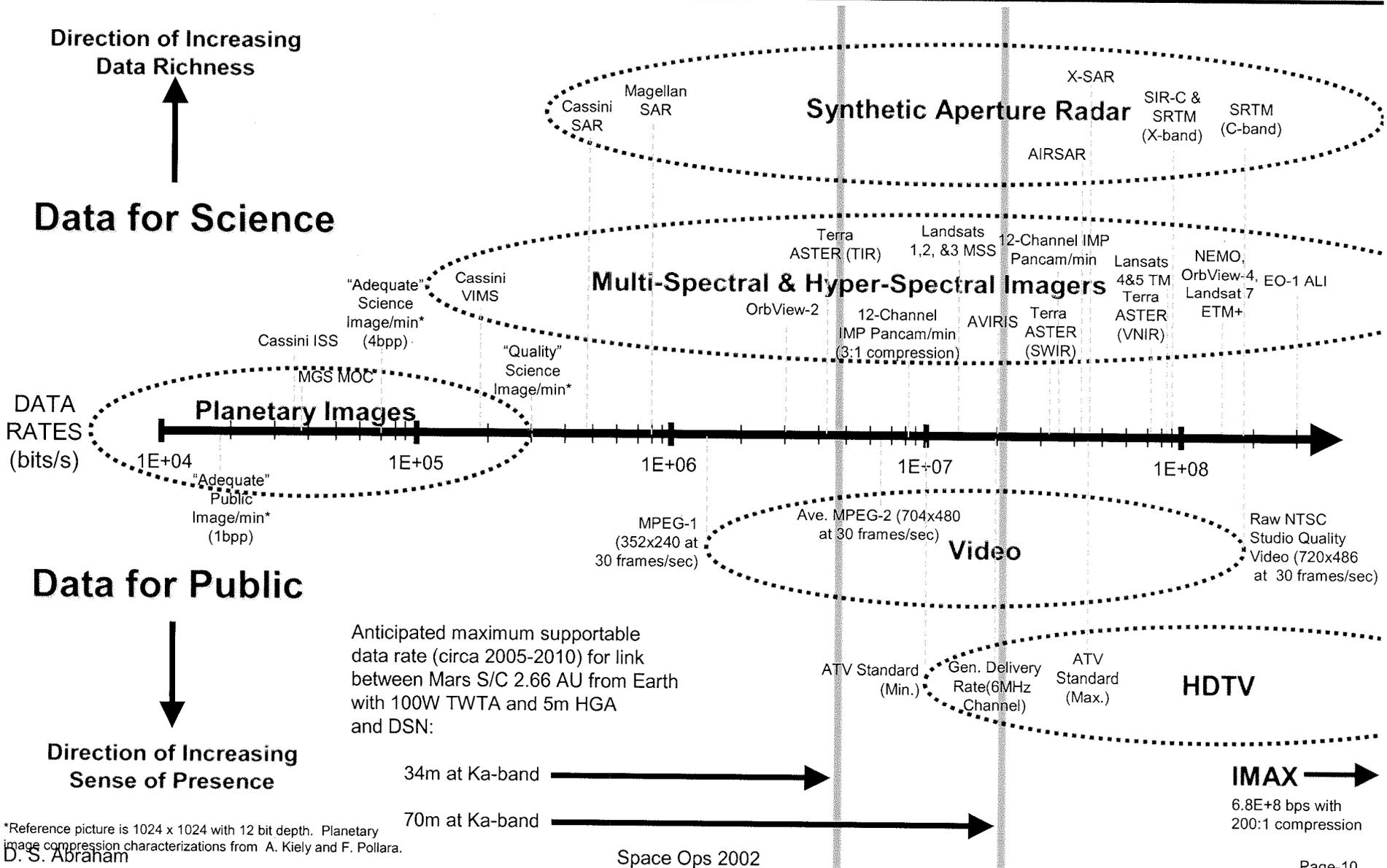
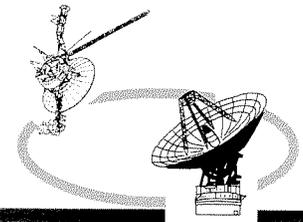
*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara. D. S. Abraham



IDENTIFYING FUTURE MISSION DRIVERS ON THE DEEP SPACE NETWORK

2.7 AU Mars Orbiter/Relay Scenario (~2012)

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

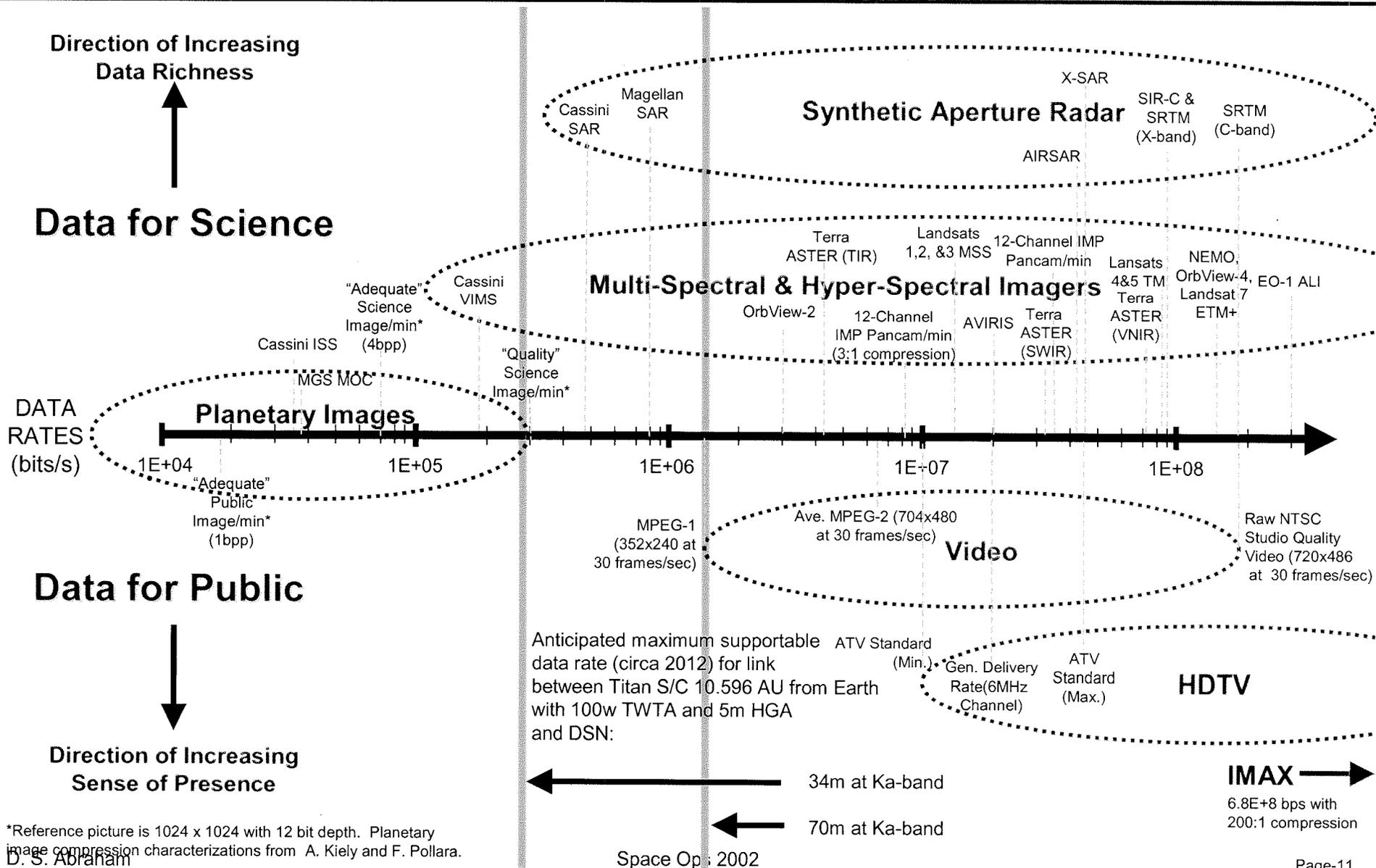
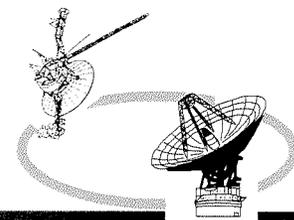


*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara. D. S. Abraham

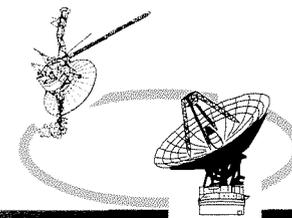


10.6 AU Titan Orbiter/Relay Scenario (~2012)

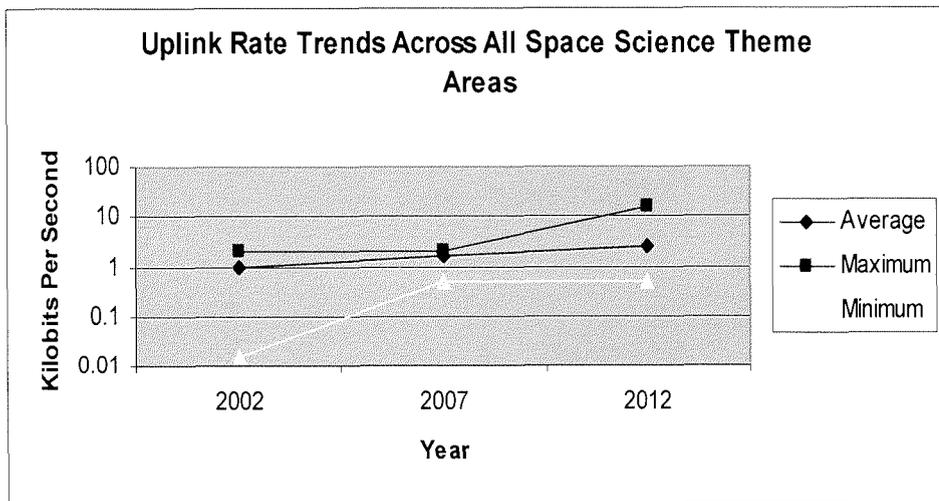
(Maximum Supportable Rates with RF Flight Hardware Improvements and Ka Ground Improvements)



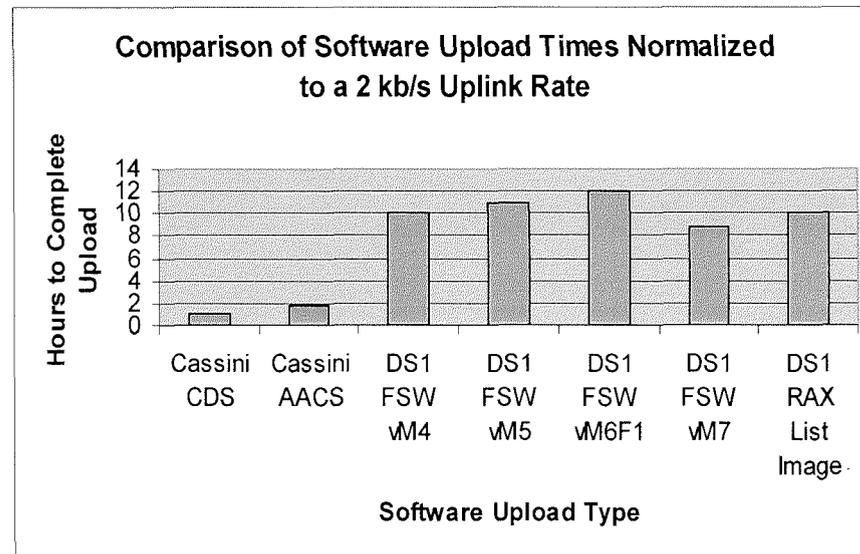
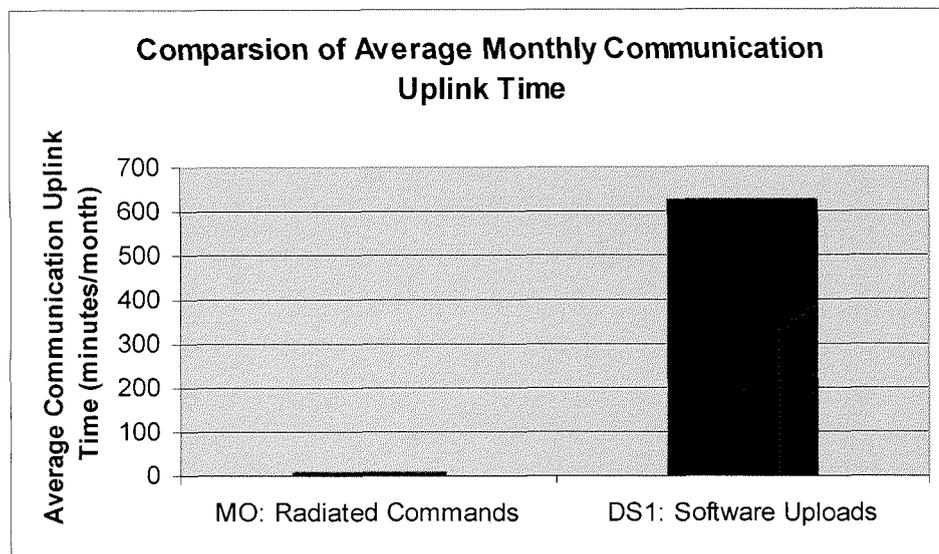
*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara. D. S. Abraham



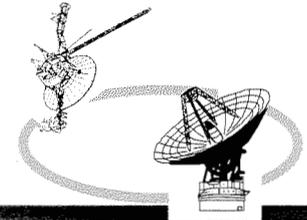
Findings: Uplink Circa ~2010



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



Uplink: Looking Beyond 2010



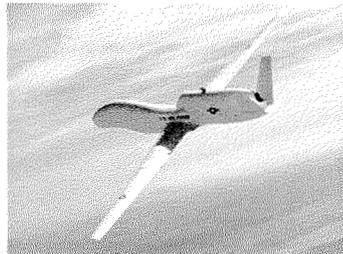
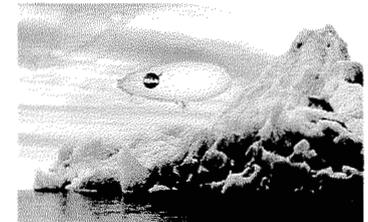
- *In situ* exploration will directly entail or depend heavily upon mobility elements.
- Intelligent use of mobility requires guidance, navigation, & control (GN&C).
- Mobility elements will have to negotiate obstacles faster than command from Earth will allow.
- Earth-based analogs suggest potential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



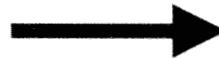
Cruise Missiles



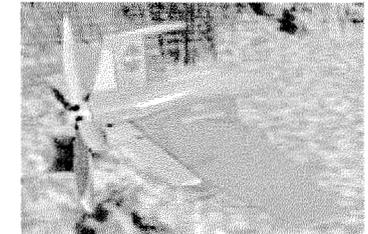
- Guidance via matching SAR data
- Targeting via digital scene matching



UAVs



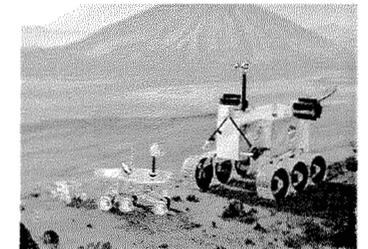
- Guidance via GPS-like beacon aids
- Targeting via hyperspectral signature



UGVs

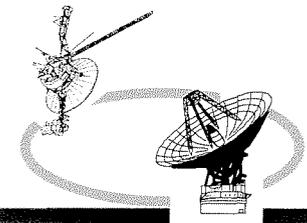


- Stereoscopic vision
- Multi-spectral terrain classification



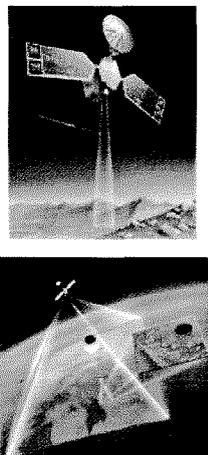


The Changing Operations Paradigm and Future Questions

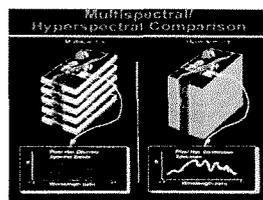


The Changing Operations Paradigm:

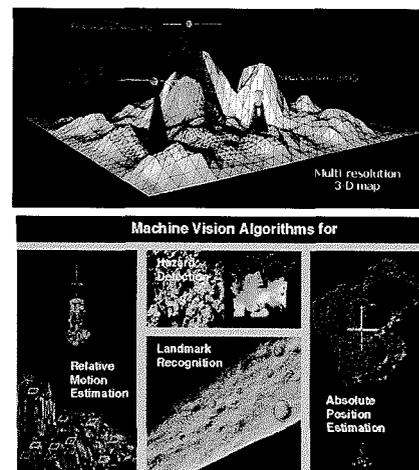
- (1) More onboard autonomy, less low-level commanding.
- (2) In situ exploration elements as consumers of orbital remote sensing data.



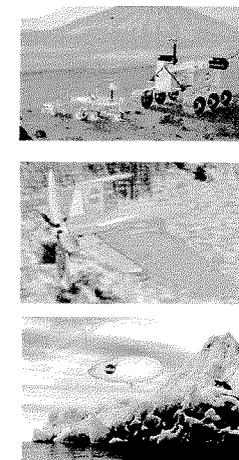
Orbital Remote Sensing



Large Downlink Data Volumes



Production of GN&C and Science Targeting Data Products



Large Software Uploads on Uplink

Future Questions:

- (1) What is the anticipated size of the uploads as a function of time?
- (2) What is the anticipated frequency of these uploads?