National Aeronautics and Space Administration

Deep Space Mission Trend Analyses: A Briefing to the Next Generation EBRE Study Team

Douglas S. Abraham
IND Architecture, Strategic Planning, & System Engineering Office
Jet Propulsion Laboratory
California Institute of Technology

Keeping the universe connected.

August 8, 2012

www.nasa.gov

Presentation Purpose

- To facilitate the Next Generation EBRE Study Team's identification of potential deep space stakeholder needs by:
  - Familiarizing the team with the techniques currently used for DSE long-range planning, and
  - Briefing the team on the results from last year's analyses.

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Methodology Overview

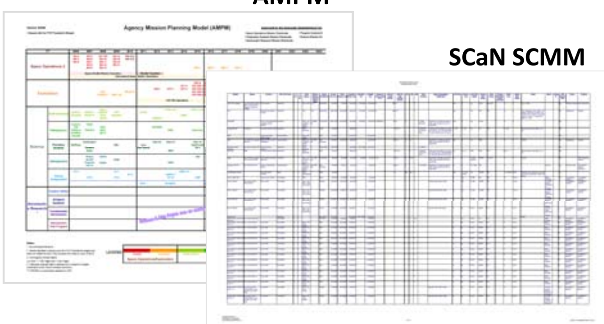
Overall approach is two-pronged:

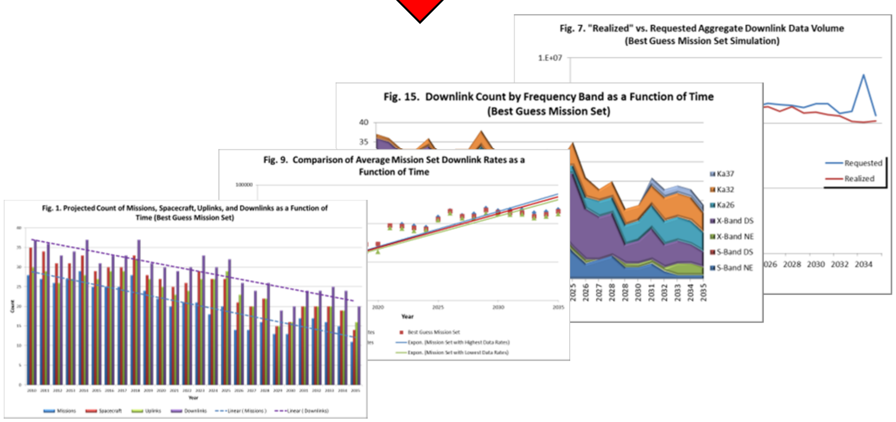
Mission Set Analysis

(What is the future mission demand?)

AMPM

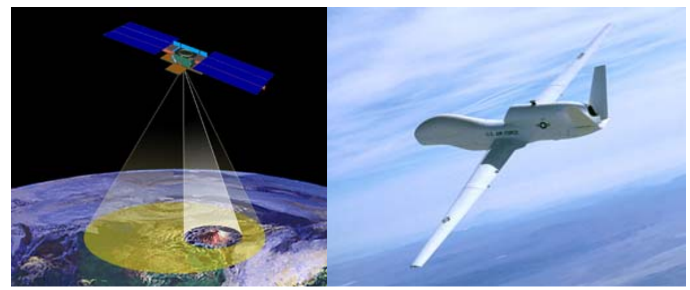
SCaN SCMM

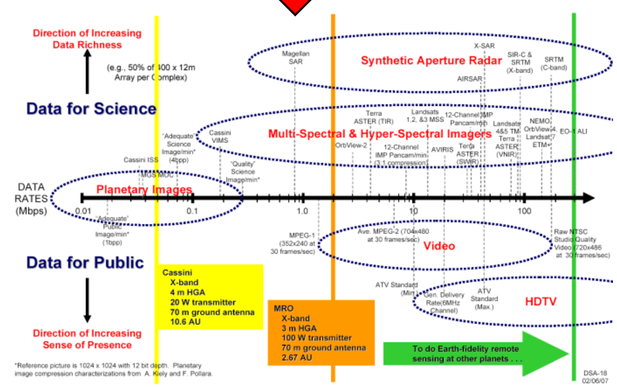




Earth-Based Analogies

(What do capabilities at Earth suggest mission proposers will eventually want at other planets?)

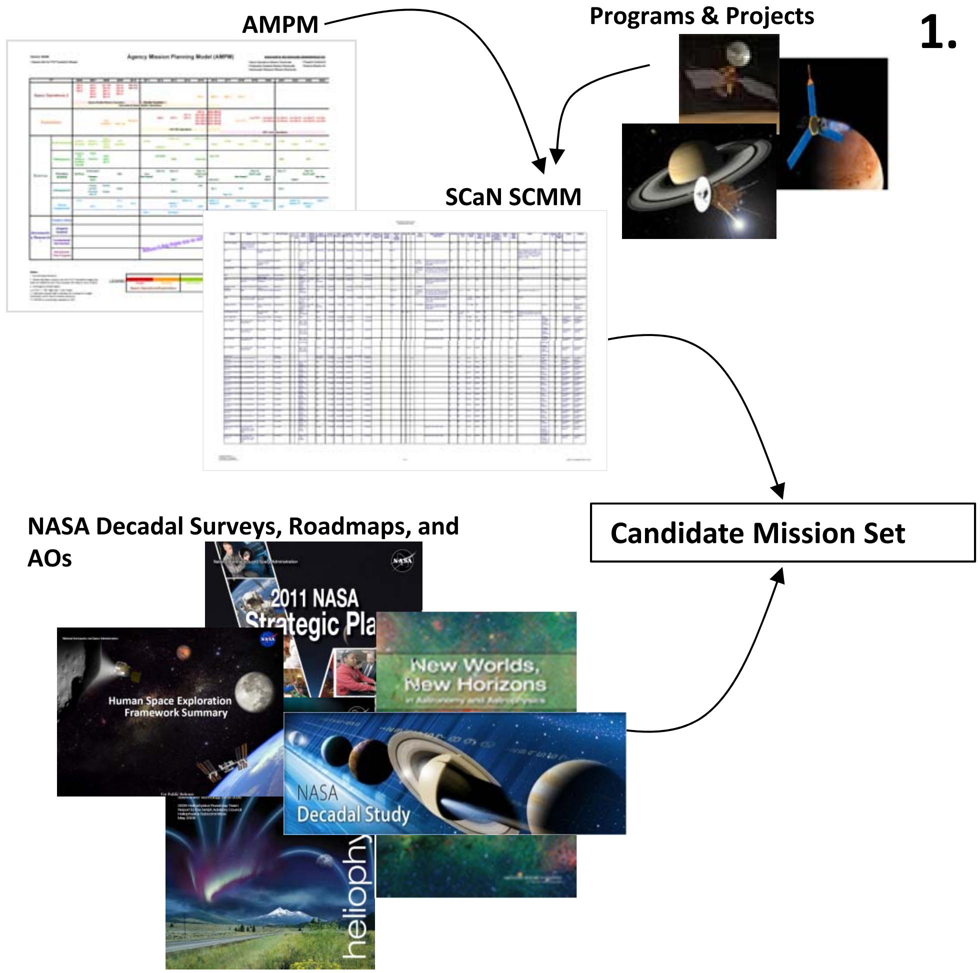




Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Mission Set Analysis Approach (1/8)



1. Identify the candidate missions.

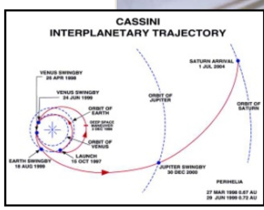
- Mission set is always changing.
- Program & Project sources supply nearer-term future mission data.
- Agency Mission Planning Manifest (AMPM) contains 20-year mission horizon that mission directorates sign off on.
- Space Communications Mission Model (SCMM) combines these sources and provides additional basic parameter data, establishing an agreed upon baseline within SCaN.
- NASA Decadal Surveys, Roadmaps, and AOs suggest candidates for generic or competitively-bid program lines.

Mission Set Analysis Approach (2/8)

Document Research: PSLAs, DSAs, Network Ops Plans, Team-X Studies, Other Mission Concept Studies

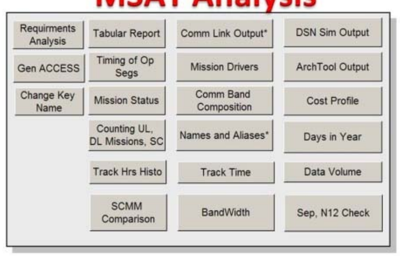
$$P_r = \frac{P_t A_t A_r f^2}{R^2 c^2}$$

Parameters Supporting Generation of Link Budgets, Spectrum Bandwidth Requirements, etc.

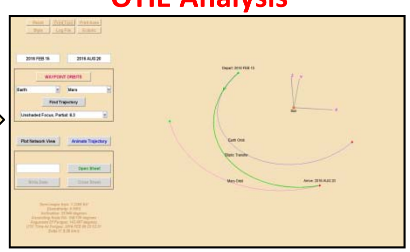


Established Tool/System Output Research: HORIZONS & NAIF trajectory files
Document Research: Study parameters supporting trajectory file generation

MSAT Analysis



OTIE Analysis



2. Research and collect data on each of the candidate missions.

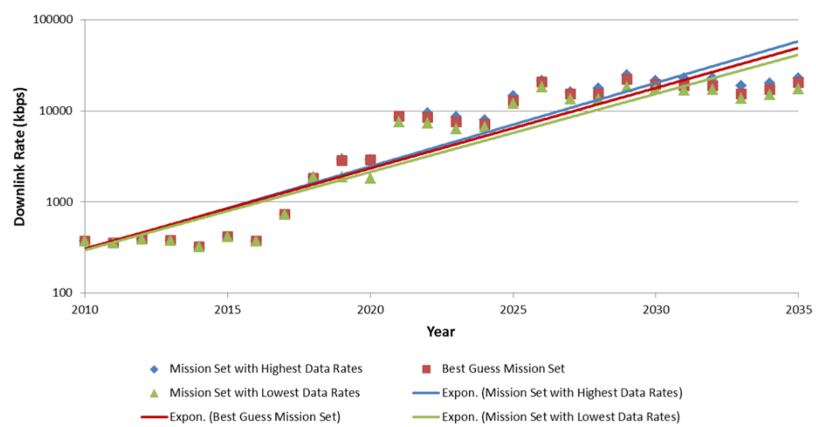
- Focus on each mission's fundamental telecom, trajectory, and tracking parameters for each operational segment within the mission.
- Candidate mission parameters entered into:
  - Mission Set Analysis Tool (MSAT) for telecom trend analyses, automated link budget calculations, and associated bandwidth, G/T, and EIRP requirements generation.
  - Orbital Trajectory Inference Engine (OTIE) for automated generation of spacecraft trajectory and/or associated visibility files.

Data collection is probably the least appreciated, yet most important, aspect of the analysis.

Mission Set Analysis Approach (3/8)

Fig. 2. Comparison of Total Potential Downlinks as a Function of Time

Fig. 9. Comparison of Average Mission Set Downlink Rates as a Function of Time

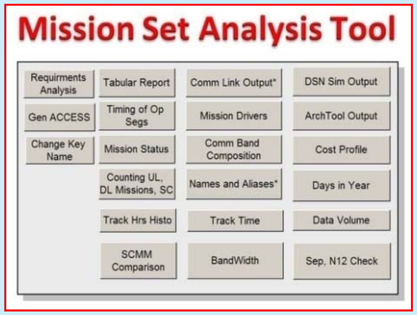


3. Analyze the data.

- For competitively-bid mission opportunities, it is extremely difficult to "divine" which mission candidate will fly in which opportunity.
- Hence, for each parameter of interest, conduct analysis with 3 different candidate mission sets:
  - "Best guess" mission set
  - Mission set that maximizes the parameter of interest
  - Mission set that minimizes the parameter of interest
- Use the SCMM Analysis Tool Suite to conduct analysis.

Mission Set Analysis Approach (4/8)

3. Analyze the data. (Continued…)



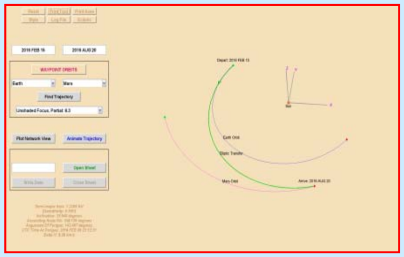
- Mission Set Analysis Tool (MSAT)
  - “Houses” all the mission data via an accompanying database.
  - Conducts link budget analysis on all of the missions.
  - Analyzes mission trends.

Mission Set Analysis Approach (5/8)

3. Analyze the data. (Continued…)

- Orbital Trajectory Inference Engine (OTIE)
  - Ingests trajectory files and converts them into visibility files for over 60 different ground stations.
  - Where trajectory data are scant, infers and generates the required trajectory file.
  - Optimizes gravity assist trajectories for launch date changes.
  - Analyzes aggregate mission geometry characteristics.

Orbital Trajectory Inference Engine



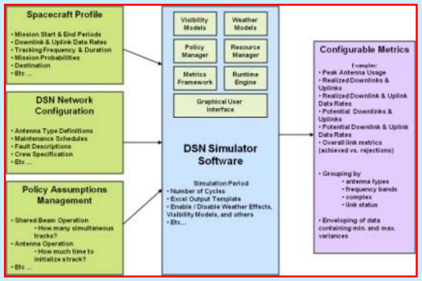
Because deep space missions undergo significant changes in Earth-spacecraft range distance and sky location as a function of time, trajectory and view period specification play an essential role in developing telecom and tracking requirement projections.

Mission Set Analysis Approach (6/8)

3. Analyze the data. (Continued…)

- Architecture Loading Analysis Tool (ALAT)
  - Simulates any desired antenna architecture (including the current DSE) as a function of time.
  - Shows how a particular candidate mission set will load up on it given the link budget and tracking requirements from MSAT and the spacecraft visibility files for each station from OTIE.
  - Analyzes various “requested” vs. “realized” metrics (e.g., tracking hours, data volume, etc.) for a given architecture.
  - Enables relative loading performance comparisons between alternative antenna architectures.

Architecture Loading Analysis Tool



Mission Set Analysis Approach (7/8)

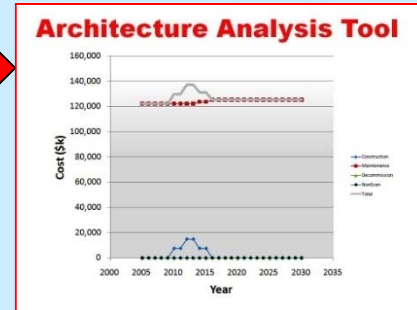
3. Analyze the data. (Continued…)

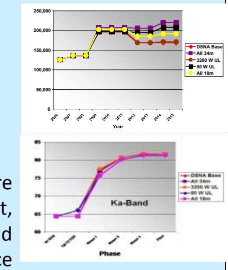
The true power of the tools comes from their synergistic application as a suite.

Study Architecture Parameters & Associated Cost & Schedule Data

Detailed Spacecraft Telecom & Tracking Requirement Data

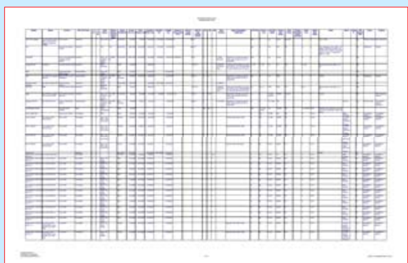
Architecture Analysis Tool





Architecture Cost, Schedule, and Performance

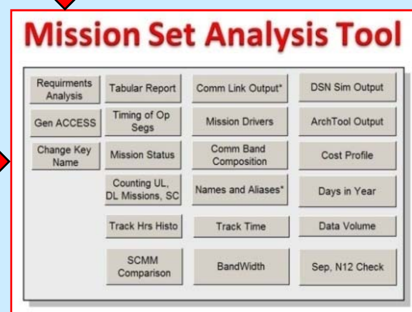
SCMM



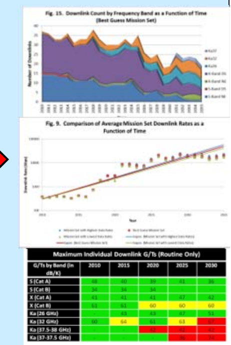
Official SCaN Mission Data

Official SCaN Mission Data

Mission Set Analysis Tool



Spacecraft Equivalent Aperture & Tracking Time Requirements & Data Rates

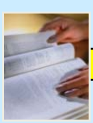


Aggregate Mission Set Trends & Requirements

Spacecraft Range Distances as a Function of Time

Spacecraft Equivalent Aperture & Tracking Time Requirements

Orbital Trajectory Inference Engine

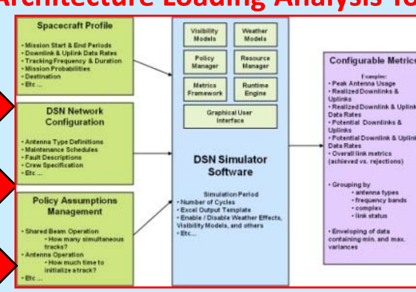


Inferential Spacecraft Trajectory Information, Trajectory Parameters, and/or Partial or Complete Trajectory Files

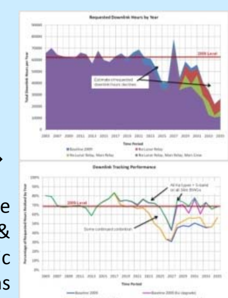
Spacecraft Rise & Set Sheets

Aggregate Mission Set Geometry Analyses

Architecture Loading Analysis Tool



Network Architecture & Ground Station Parameters; Planetary Ephemeris Data

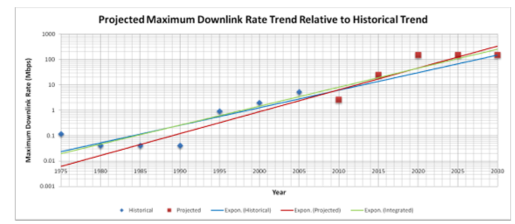


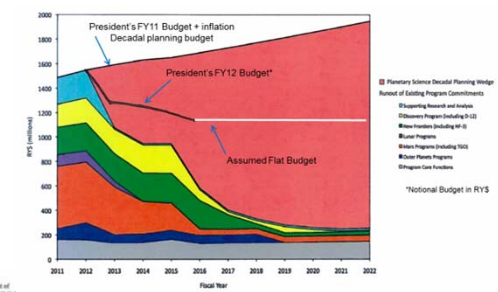
Architecture Loading & Data Traffic Implications

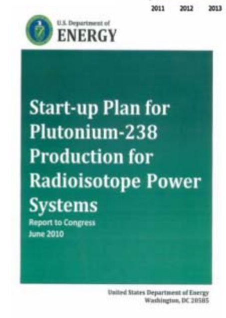
Mission Set Analysis Approach (8/8)

4. Interpret the results.

- Perform "sanity" checks.
  - Compare analysis results to historical trends and past projections.
  - Explore impacts of different future scenarios.
  - Perform sensitivity analyses.
- Provide context.
  - Fiscal environment
  - Policy environment
  - Technology issues or developments
  - Other emerging developments
- Make recommendations.







Results won't have impact unless presented in context and used to suggest a course of action.

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Last Year's Mission Set Analysis

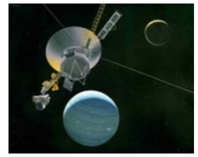
- This year's future mission set analysis is currently in work.
- Changes from last year may occur due to:
  - The evolving articulation of human exploration plans
  - Changes to Mars Exploration plans
  - Results of the Senior Review for Planetary Science
  - The impending release of the Heliophysics Decadal Survey
  - Other emerging developments
- Nonetheless, the following overview of last year's analysis results may help gauge the relevance of DSE drivers to EBRE and provide an indication of the types of information available.
  - Additional detail at the G/T, EIRP, etc. level exists behind the trend data in this overview.

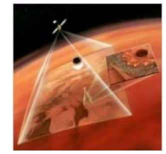
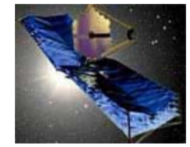
Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Long-Term Context (1/2)

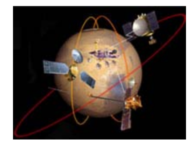
(1) Planetary remote sensing and astrophysics missions observe at increasingly higher temporal, spatial, and spectral resolutions.



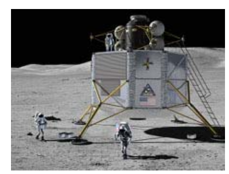
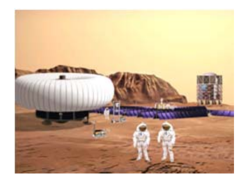



(2) Missions increasingly rely on multiple spacecraft/elements to conduct in situ exploration and synthesize more capable astrophysics and heliophysics observatories.






(3) Human exploration plans entail targets increasingly far from Earth.

(4) Missions generally increase in system complexity and cost.


Long-Term Context (2/2)

Consequences:

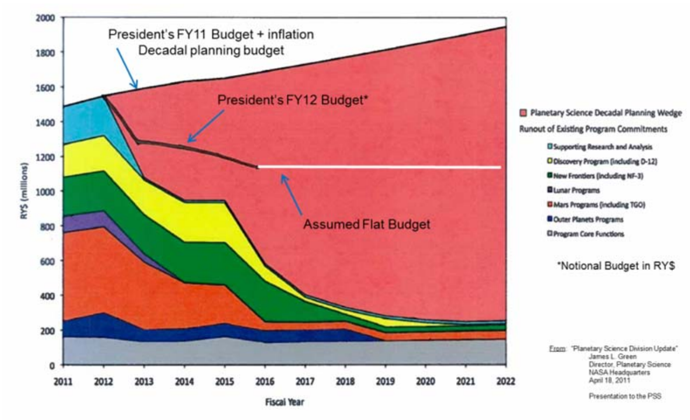
- Given increasing mission cost and complexity, somewhat fewer, but much more capable, missions.
  - Some involving significantly higher data volumes.
  - Some involving significantly more challenging operations.
- Due to the multi-spacecraft/element nature of these missions, the number of spacecraft or exploration elements (e.g., landers, rovers, etc.) does not necessarily decline with the reduction in mission numbers.
- And, multi-spacecraft operations and operational dependencies between otherwise dissimilar missions will likely present growing challenges.
- To the extent human exploration remains targeted at NEOs and Mars, this exploration will fall squarely in the deep space domain.

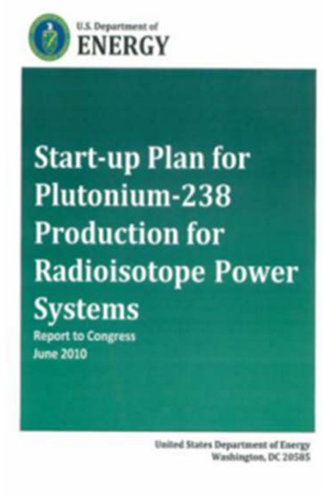
But, NASA's near-term environment complicates the picture...

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Near-Term Context (1/2)



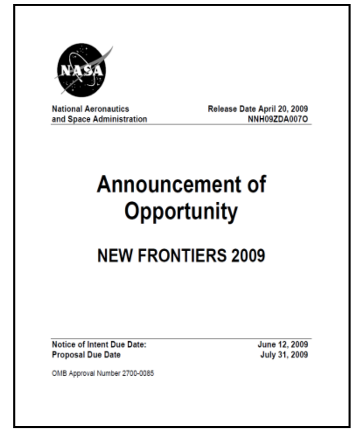


U.S. Department of
ENERGY

Start-up Plan for Plutonium-238 Production for Radioisotope Power Systems

Report to Congress
June 2010

United States Department of Energy
Washington, DC 20585



National Aeronautics and Space Administration

Release Date April 20, 2009
NNH09ZDA007O

Announcement of Opportunity

NEW FRONTIERS 2009

Notice of Intent Due Date: June 12, 2009
Proposal Due Date July 31, 2009

OMB Approval Number 2700-0085

1. Significantly less available budget coupled with NASA's increasing reliance on competitively-bid missions.
2. Nearly depleted Pu-238 supplies for powering outer-planet and dark-side missions – with resumption of steady state Pu-238 production within 5-7 years of starting.
3. SMD policy in AO's and high-visibility studies limiting missions to only a single 34m antenna for normal operations.

Near-Term Context (2/2)

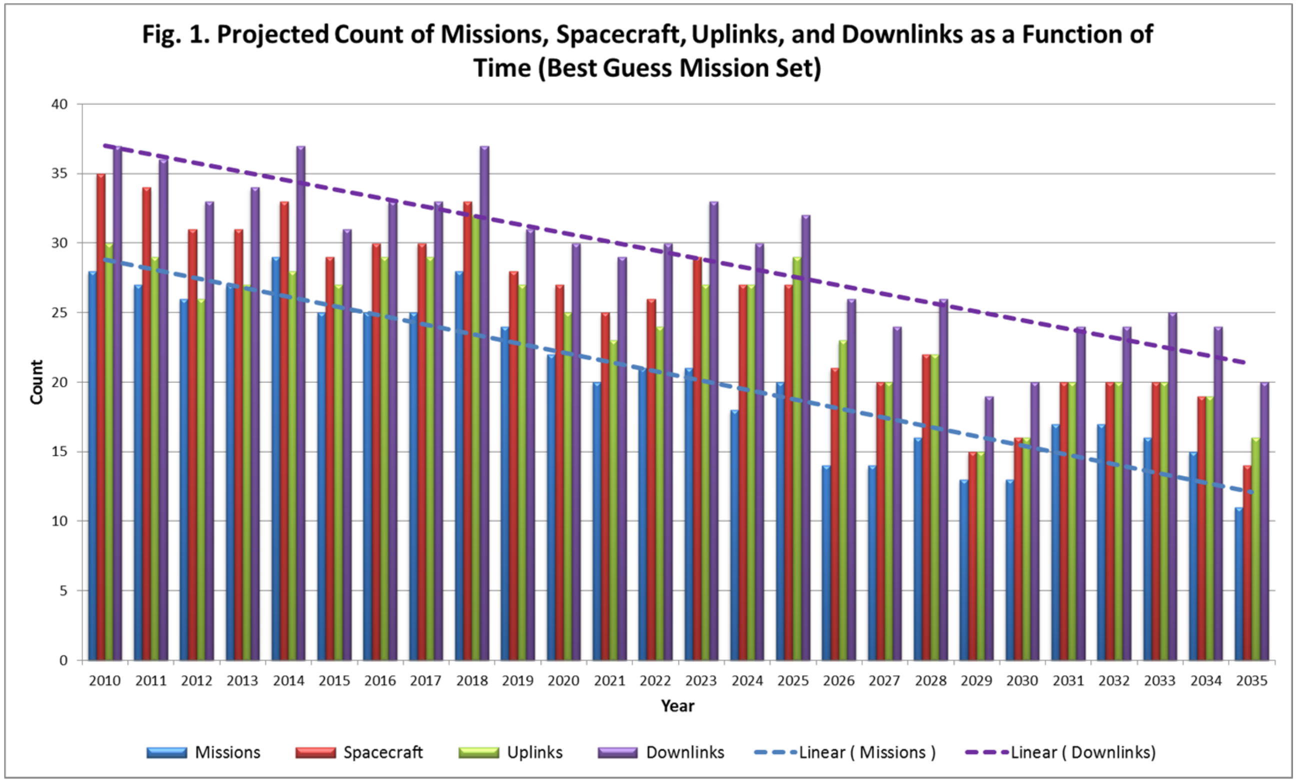
Consequences:

- Budget pressures are driving down planned mission numbers over time.
- Cost is driving PI's and mission concept designers to pursue:
  - Science questions that can be answered with less observation time & fidelity
  - Simpler mission designs involving smaller launch vehicles and spacecraft with fewer instruments
  - Reduced operational timeframes, particularly for prime science, and associated tracking for telecommunications.
  - International partners to share the cost burden
- Cost is also driving more operational mission extensions.
  - Roughly ¾ of the current deep space spacecraft are in extended mission.
  - Tight budgets are forcing SMD to trade between building new missions and operating existing ones.
- Pu-238 shortage has the potential to restrict the practical range at which missions can occur (i.e., where solar power can be used) and the environment in which they can occur (i.e., no long lunar nights, cold Martian winters, etc.).
- SMD's "single 34m" policy is discouraging high-data-rate missions at planetary distances.

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

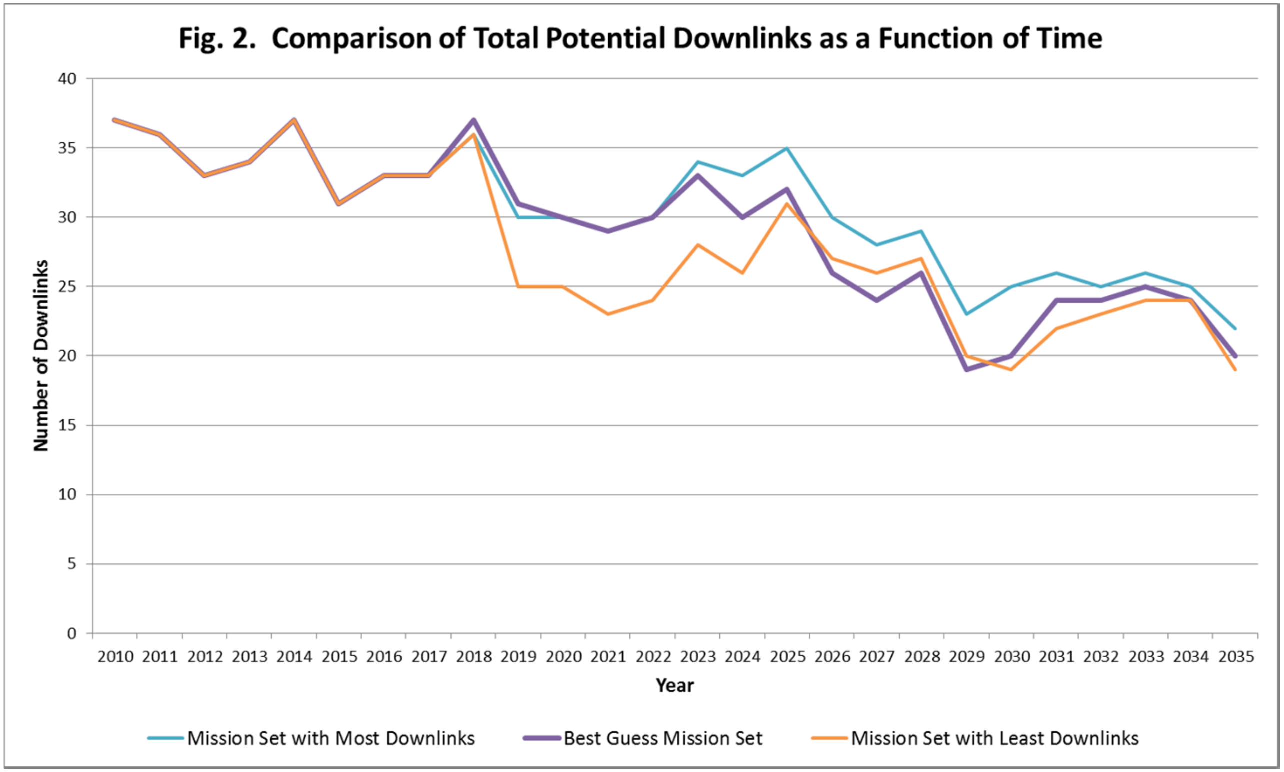
Number of Customers (1/2)



Projected decline in customer base reflects NASA's more conservative future mission plans.

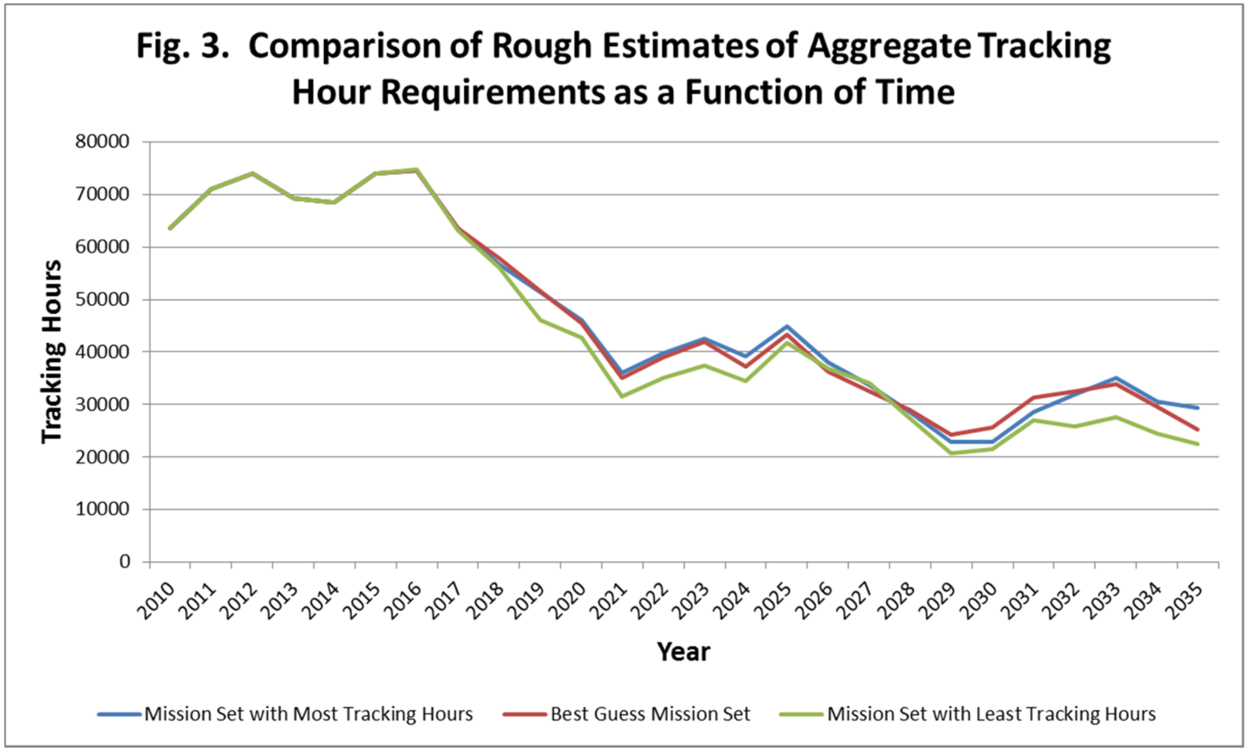
- *Driven largely by the near-term budget environment.*
- *Also driven to a much lesser extent by the long-term mission trend toward greater system complexity and associated cost.*

Number of Customers (2/2)



Regardless of which candidate mission set is selected, the same general downlink number trend holds true.

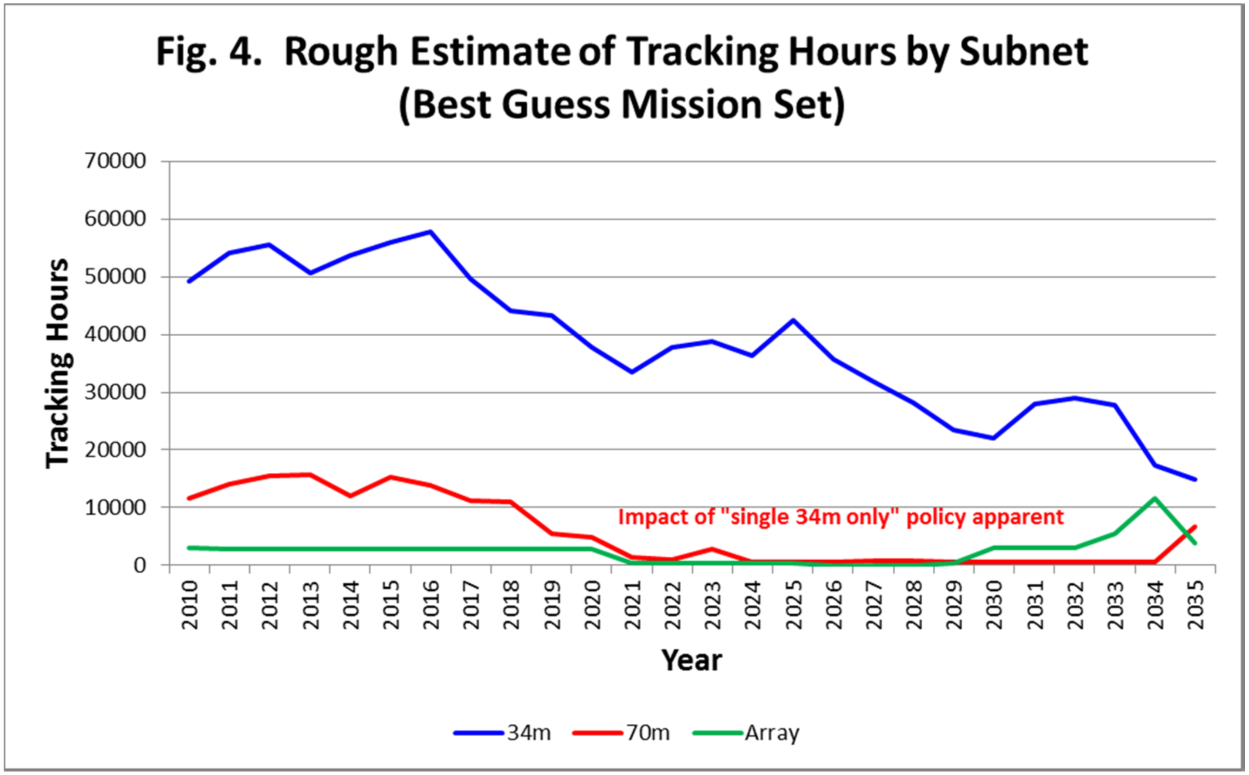
“Requested” Tracking Hours



“Average” tracking load, regardless of candidate mission set, may be lighter in the future.

- *“Fall off” is steeper than that associated with the number of downlinks.*
- *Slope may be exaggerated by an underestimate of out-year tracking requirements due to mission concept studies only sizing for science downlink (not TT&C, nav-only passes, etc.).*
- *Some mission concepts may be postulating tracking efficiencies through the adoption of Ka-band.*

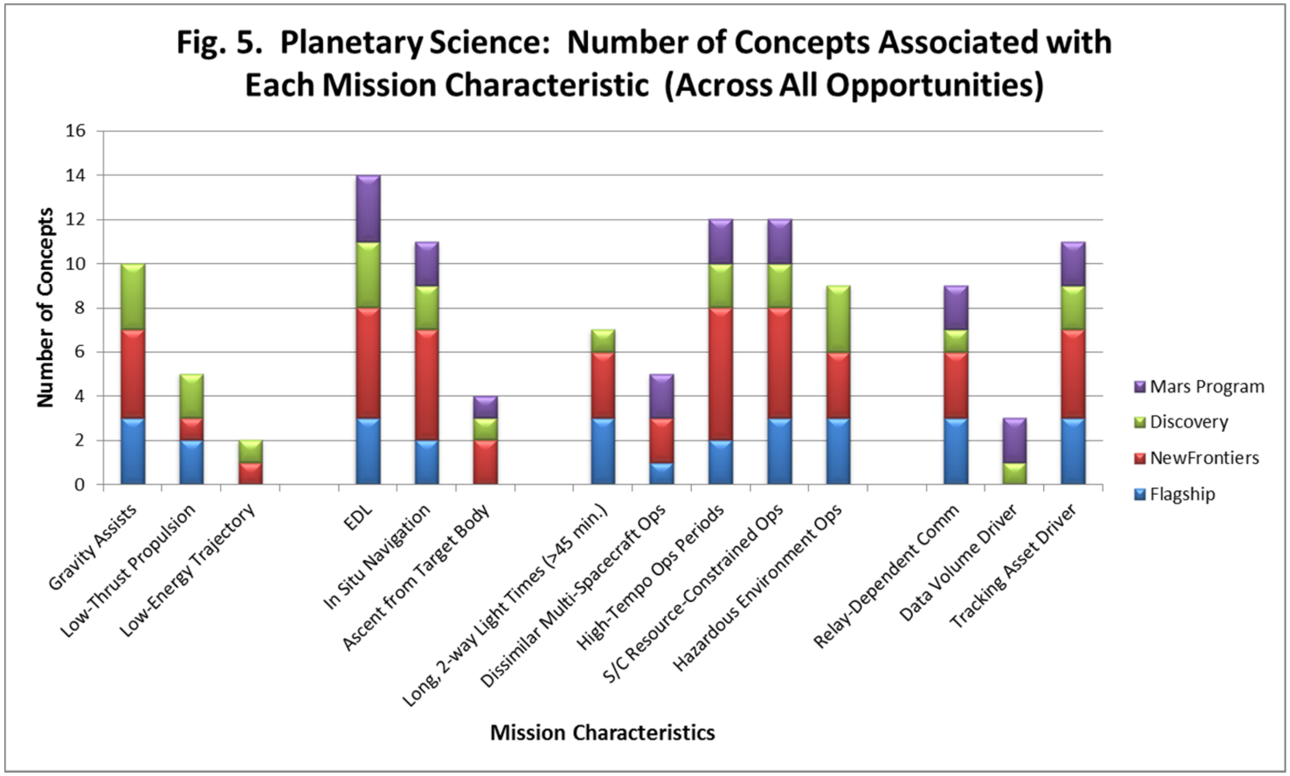
Requested Tracking Hours by Subnet



The projected post-2018 drop-off in 70m and arrayed 34m demand for science data return may largely be a product of SMD's "single 34m only" policy.

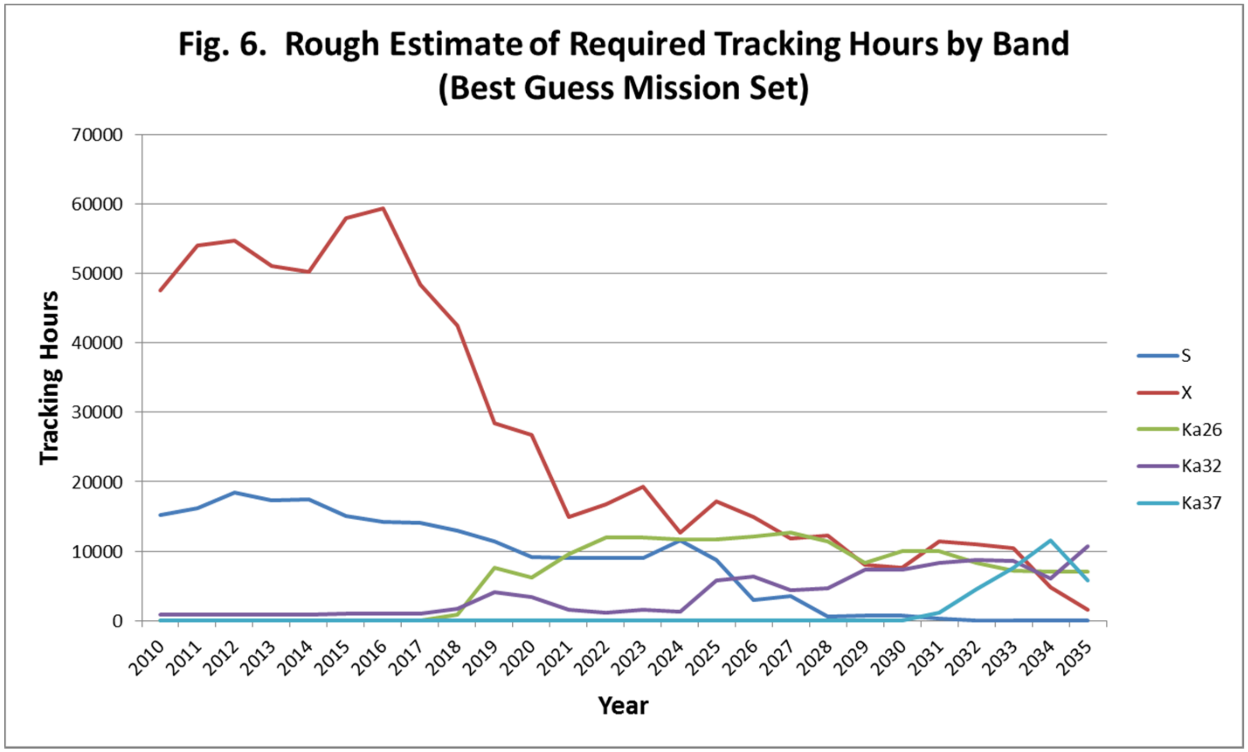
- *Pu-238 shortage may also contribute by reducing number of outer planet missions.*
- *Most legacy outer planet missions requiring more than a single 34m antenna cease operations around 2020.*
- *Note that deep space missions will still need 70m and/or arrayed 34m antennas for critical events in which their HGAs go off earth-point and in the case of spacecraft emergencies. These types of demand are not shown.*

Mission Set Ops Characteristics



The prevalence of mission concepts with landings and "high-tempo" ops periods suggest that asset contention will still occur, but driven by "peak" demands that are hard to predict until detailed mission science plans have been developed.

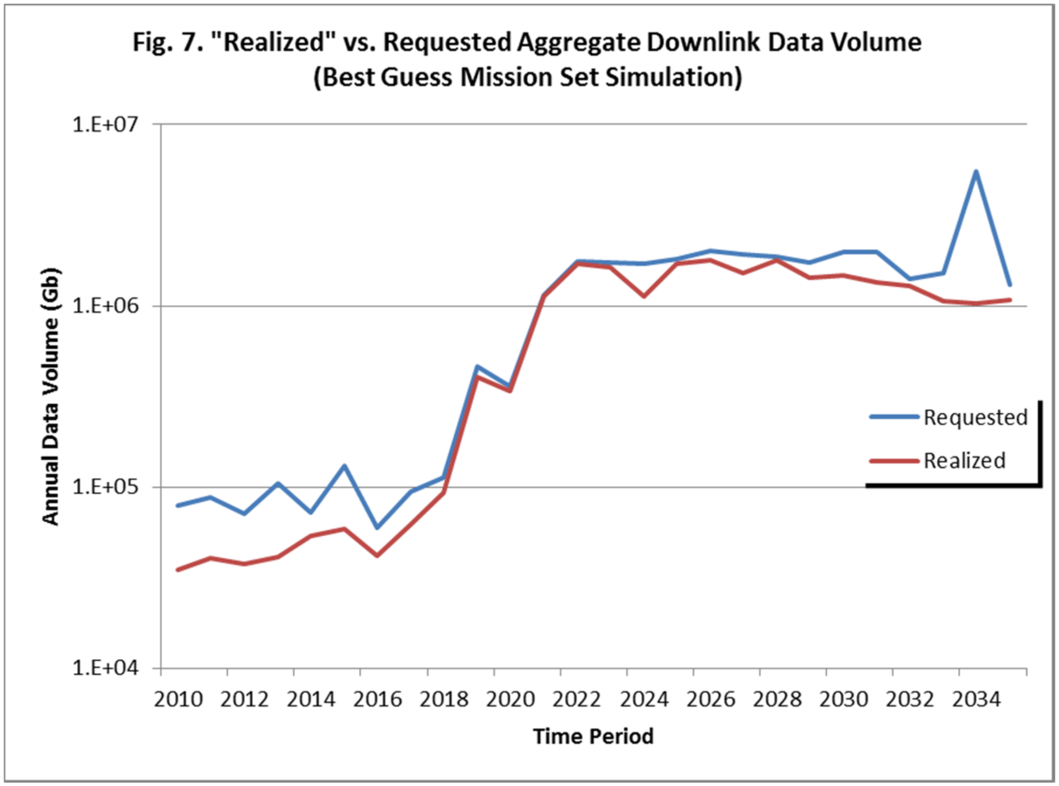
"Requested" Tracking Hours by Band



The sparse availability of Ka 26 GHz and near-Earth S-band equipped assets may also drive asset contention in the next decade.

- *More telescope-type missions (astrophysics & planetary science)*
- *Exact nature and timing of astrophysics contribution will depend on what happens with JWST.*

“Requested” vs. “Realized” Data Volumes

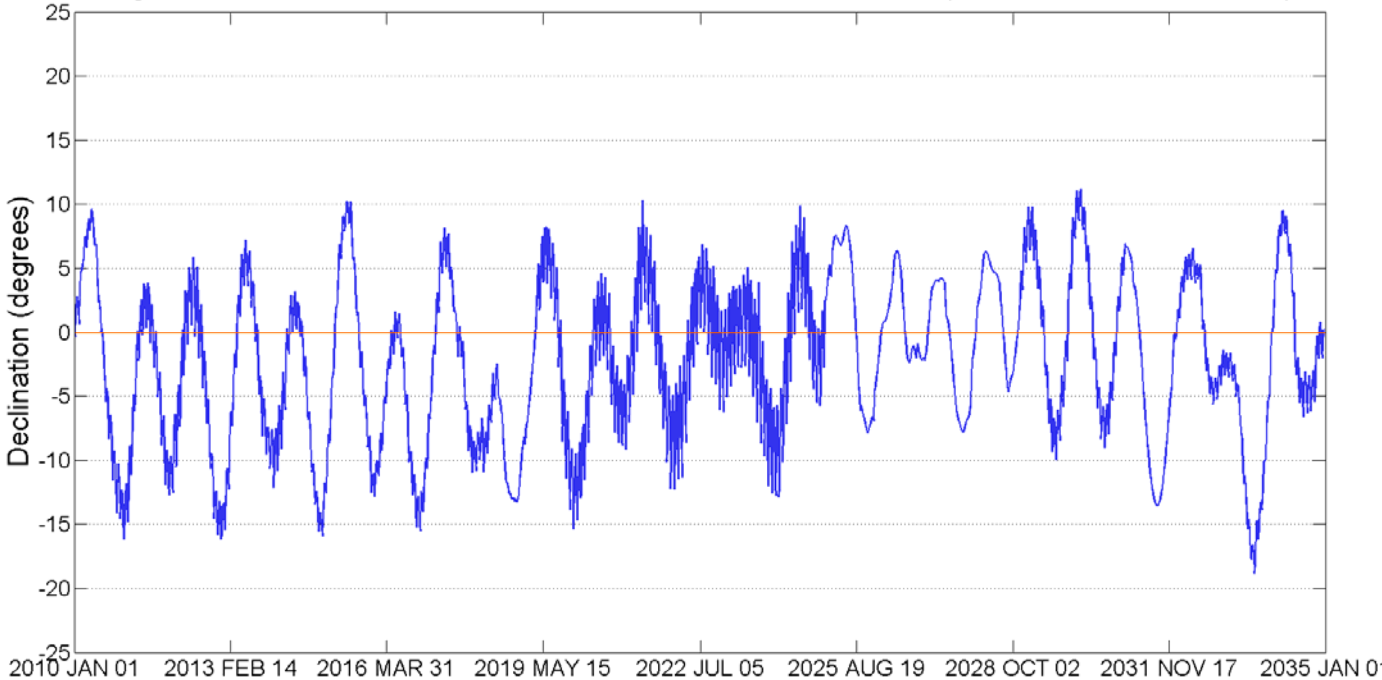


Simulations reinforce the projection on the previous slide.

- *Telescope-type missions drive up data volumes 1-2 orders of magnitude next decade.*
- *Near-term contention in the simulation results from the sheer number of spacecraft being supported relative to the available assets (and no collaborative resource allocation process in the simulation).*

Mean Mission Set Declination

Fig. 8. Mean Mission Set Declination as a Function of Time (Best Guess Mission Set)



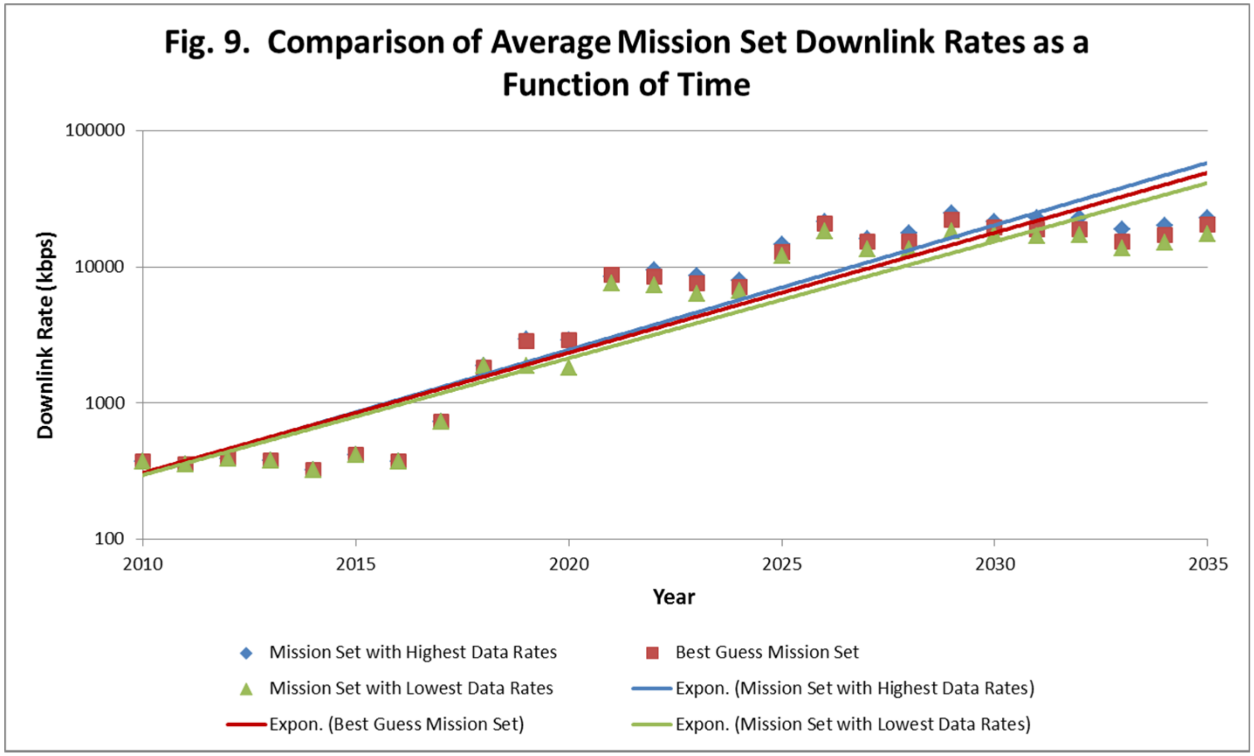
The mission set's southern declination bias underscores the need for the two additional 34m BWGs being built at Canberra.

- *Regardless of candidate mission set, southern declination bias appears through 2022.*
- *Southern declination bias reappears after 2028 for all examined candidate mission sets except the maximum tracking hour mission set which exhibits a northern declination bias (presumably due to multiple outer planet missions in that timeframe).*

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

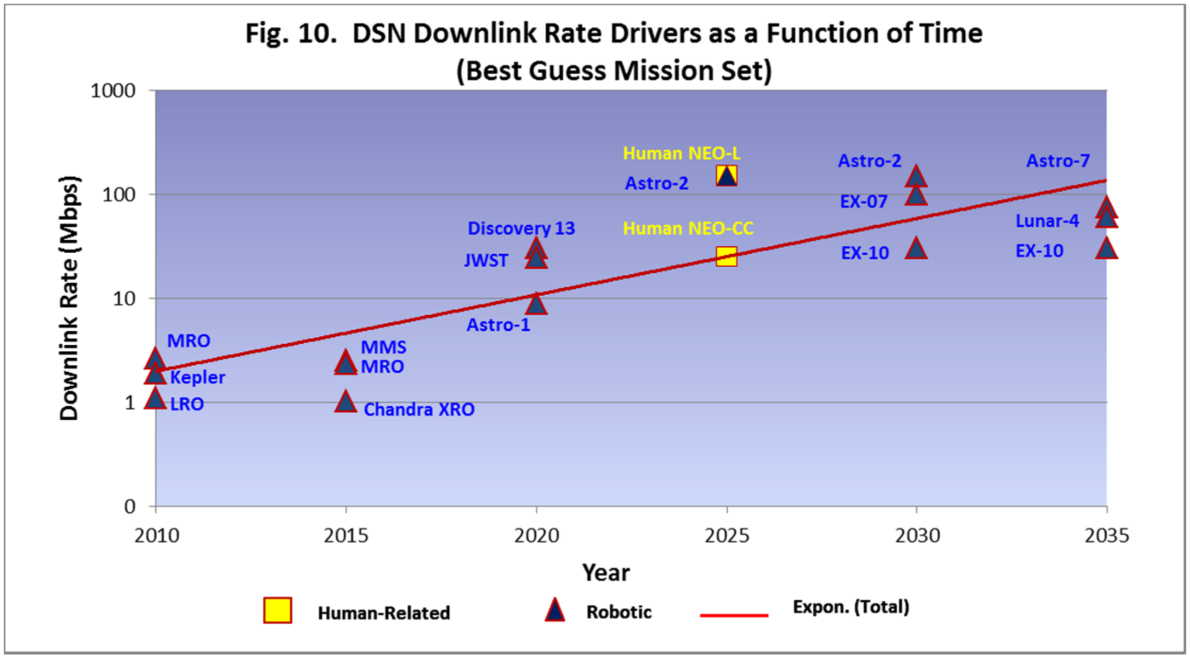
Average Downlink Rates



The average downlink rate, regardless of mission set choice, increases almost two orders of magnitude over the next 15 to 20 years.

- *Trend is consistent with the 1-to-2 order of magnitude increase in downlink data volume reported earlier during the capacity discussion.*

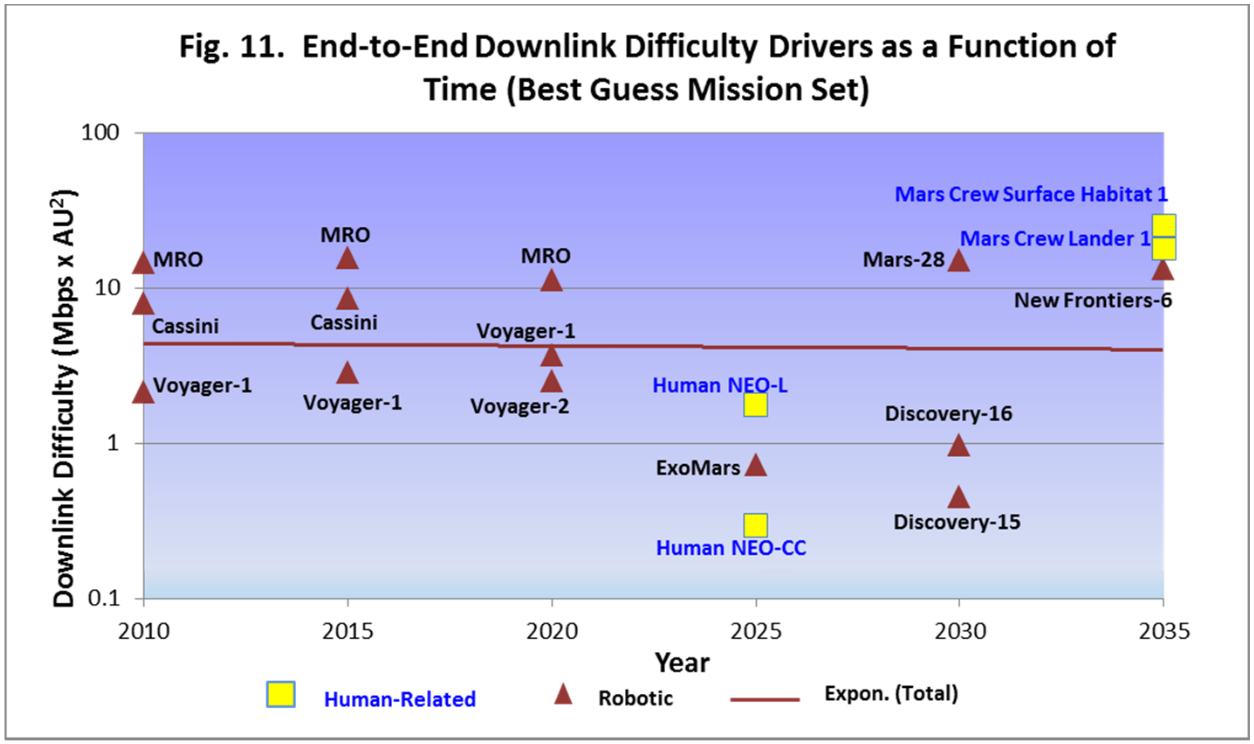
Downlink Rate Drivers



After 2015, astrophysics-related missions dominate the downlink rate drivers.

- *Finding is consistent with long-term trend toward higher spatial, spectral, and temporal resolution in telescope-type missions (e.g., astrophysics & planetary science Discovery-class telescopes).*
- *While long-duration, high-fidelity planetary remote sensing missions would also normally be drivers, SMD's "single 34m only" policy appears to be driving PI's and mission proposers to pursue science that can be achieved with lower downlink rates.*

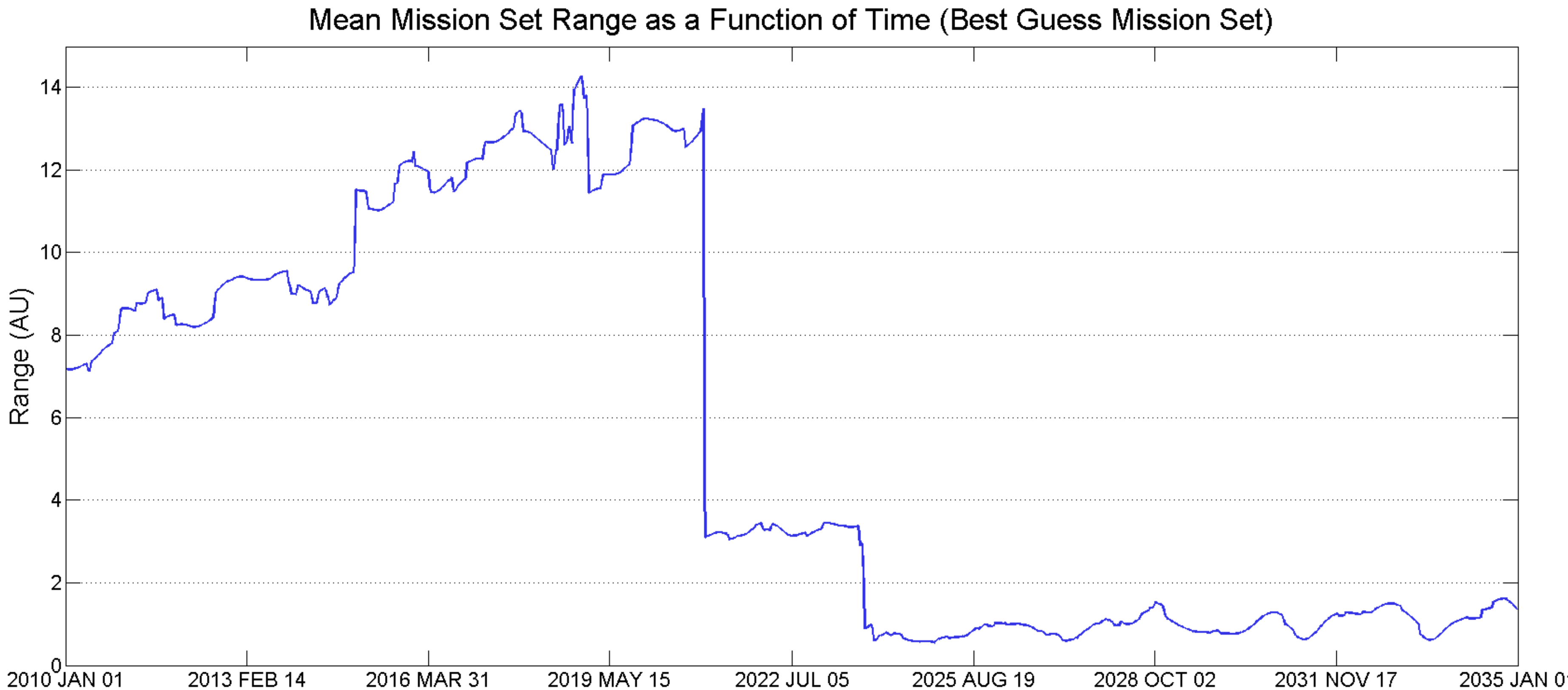
End-to-End Downlink Difficulty



The end-to-end links currently being postulated for future missions do not generally appear to be anymore challenging than today's.

- *Driven by SMD's "single 34m only policy" – keeps planetary science data rates low.*
- *Also, driven by the potential Pu-238 shortage discouraging missions to the outer planets – may keep planetary science missions closer to the Sun and, therefore, closer to Earth.*

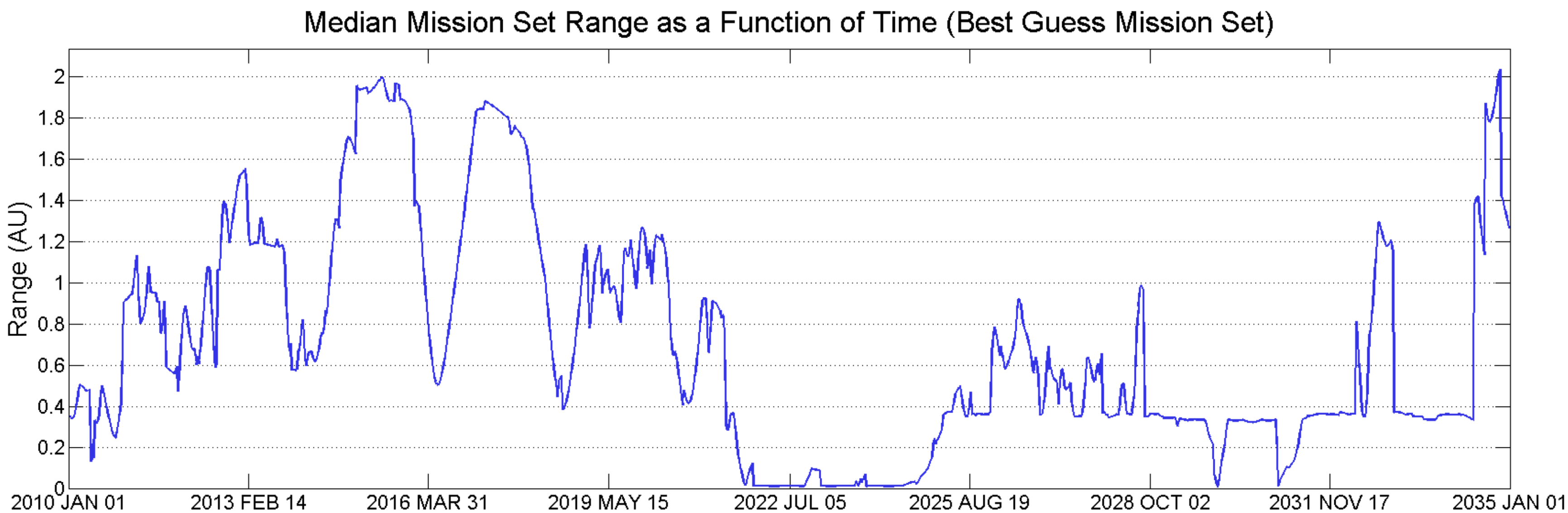
Mean Mission Set Range

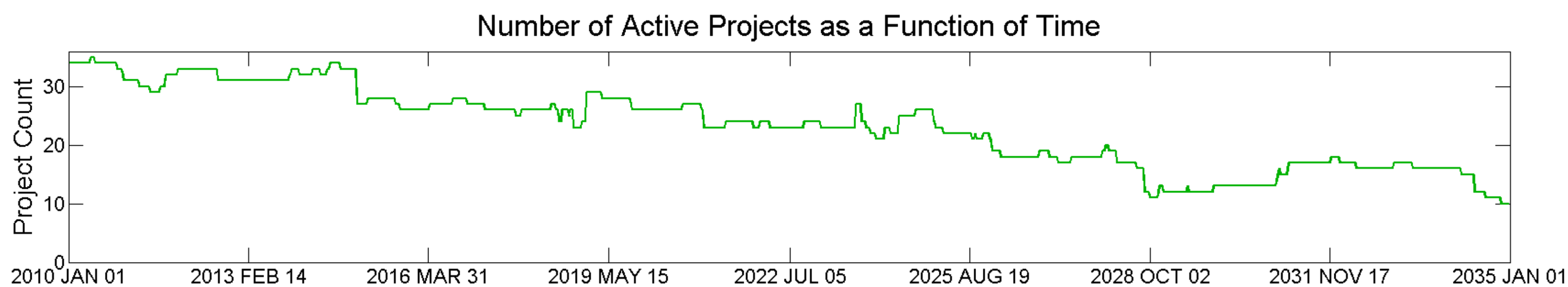


Mean range plot provides further evidence that most future missions are pursuing targets closer to Earth.

- *Potentially driven by budget and Pu-238 shortage.*
- *Mean range remains high through ~2020 due to legacy outer planet missions.*

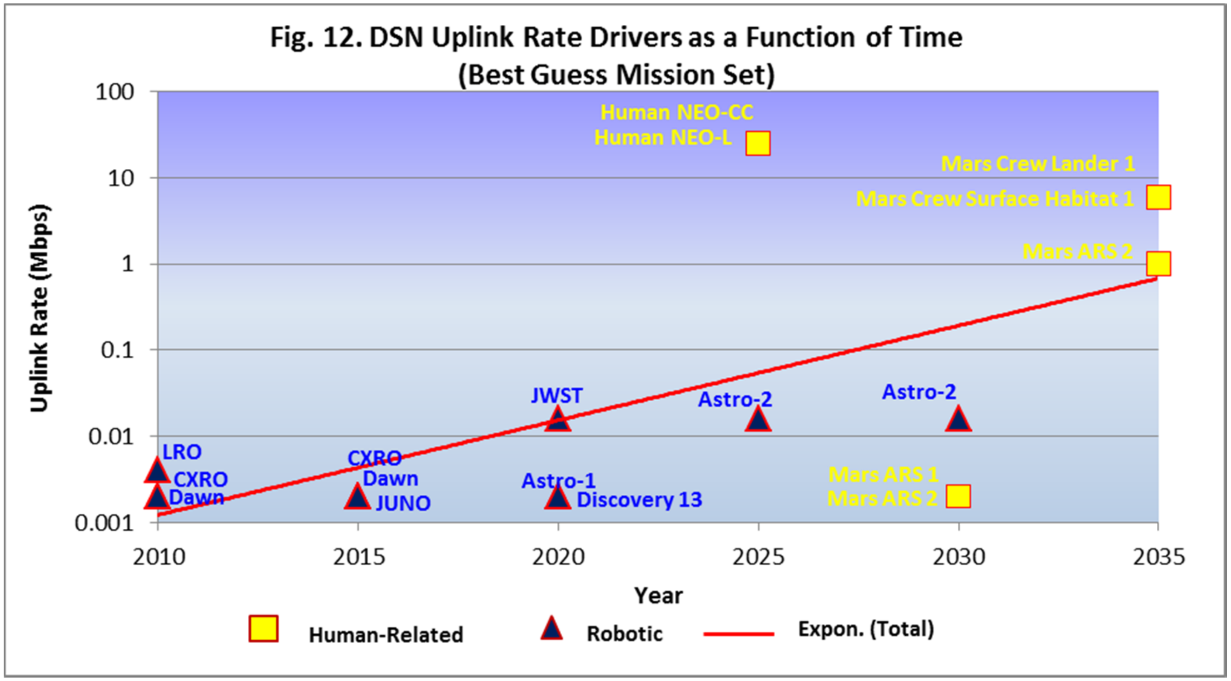
Median Mission Set Range





Median range analysis also suggests that future missions are pursuing targets closer to Earth – all while the total number of missions is decreasing.

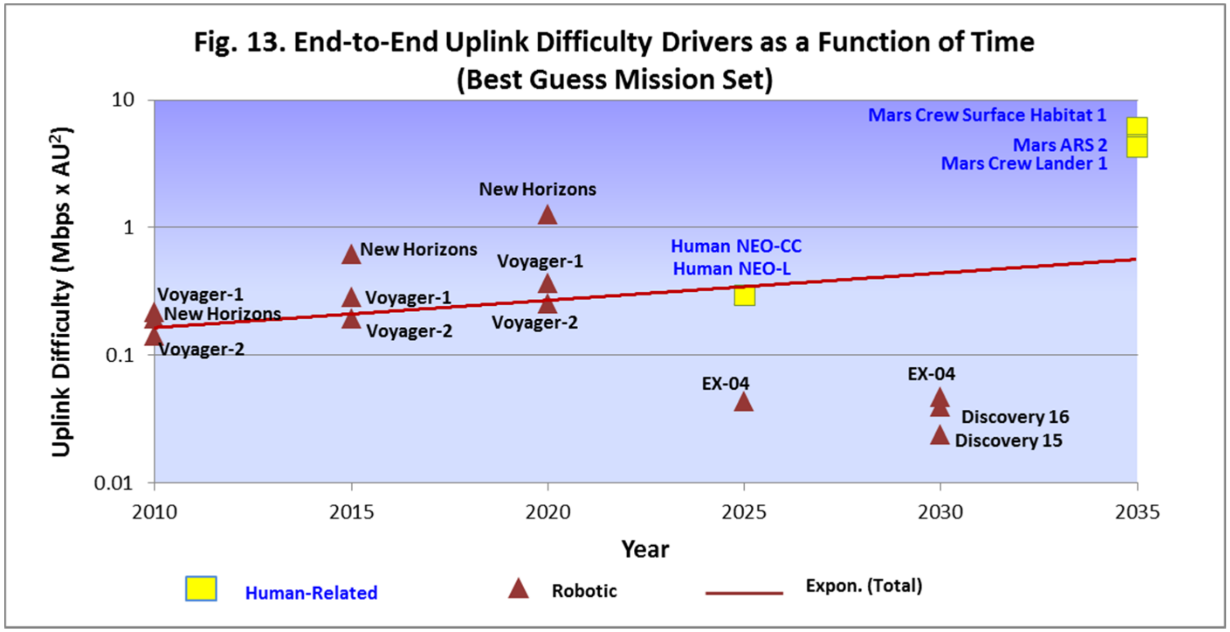
Uplink Rate Drivers



Human exploration missions drive up uplink rates by 3-to-4 orders of magnitude.

- *The 2025 Human NEO mission drives most of this increase within the next 15 years.*
- *Without the human exploration drivers, uplink throughput rates remain within the DSN's current 256 kbps uplink capability for the foreseeable future.*

End-to-End Uplink Difficulty Drivers



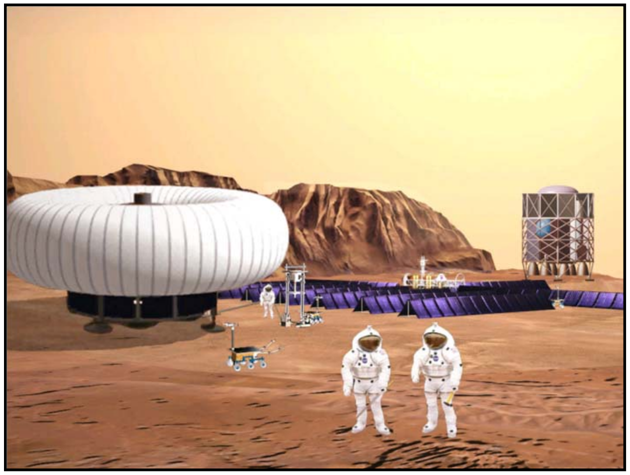
The end-to-end uplinks being postulated for future missions only grow more challenging if human Mars exploration occurs – otherwise, link difficulty actually decreases by almost an order of magnitude.

- *Up until ~2020, legacy outer planet missions drive the uplink difficulty.*
- *Subsequent drop off in robotic mission link difficulty may be driven by budget constraints and the potential Pu-238 shortage, causing mission proposers to target destinations closer to the Sun and, hence, the Earth.*

Most Challenging Uplink EIRPs

Routine Uplink to Humans on Mars

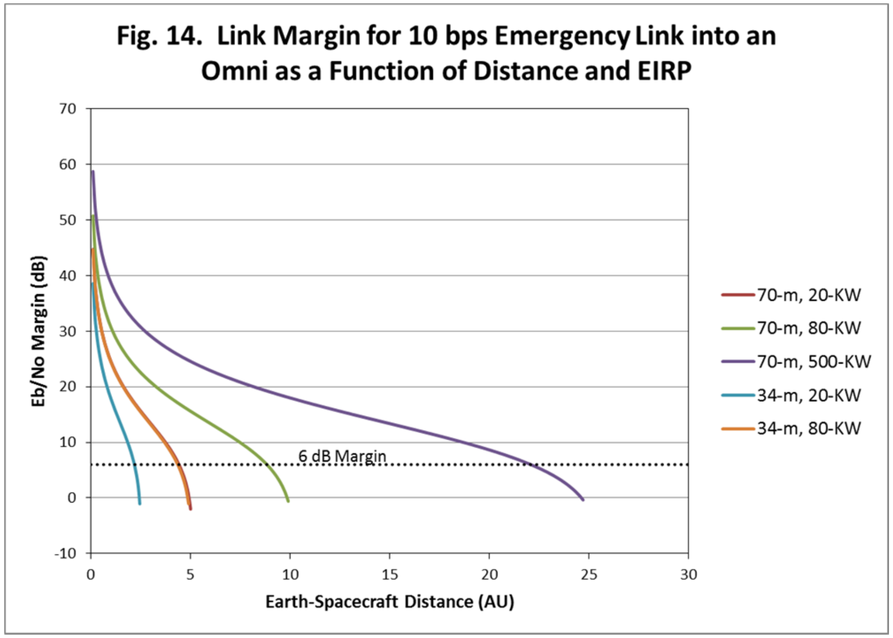
25 Mbps routine uplink to human Mars mission stresses current 70m, 20kW capability.



- Not quite a 3 dB margin with a 4m HGA.
- Doesn't account for power needed for bandwidth efficient modulation.

vs.

Emergency Uplink to Outer Planets



Credit: Shervin Shambayati, Section 332.

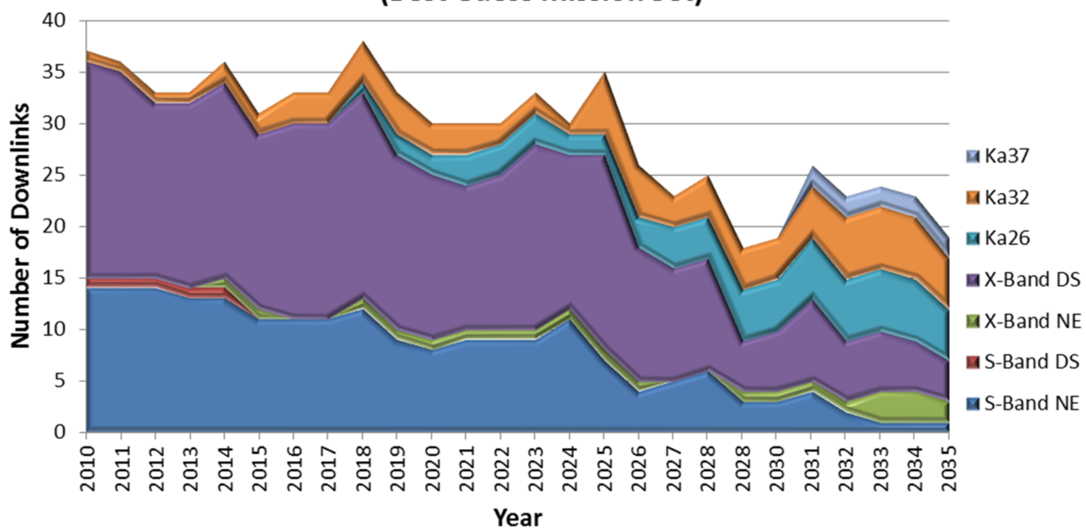
Providing sufficient EIRP for emergency uplink into an omni at the outer planets also enables reliable, high-rate uplink at Mars.

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Downlink Number by Frequency Band

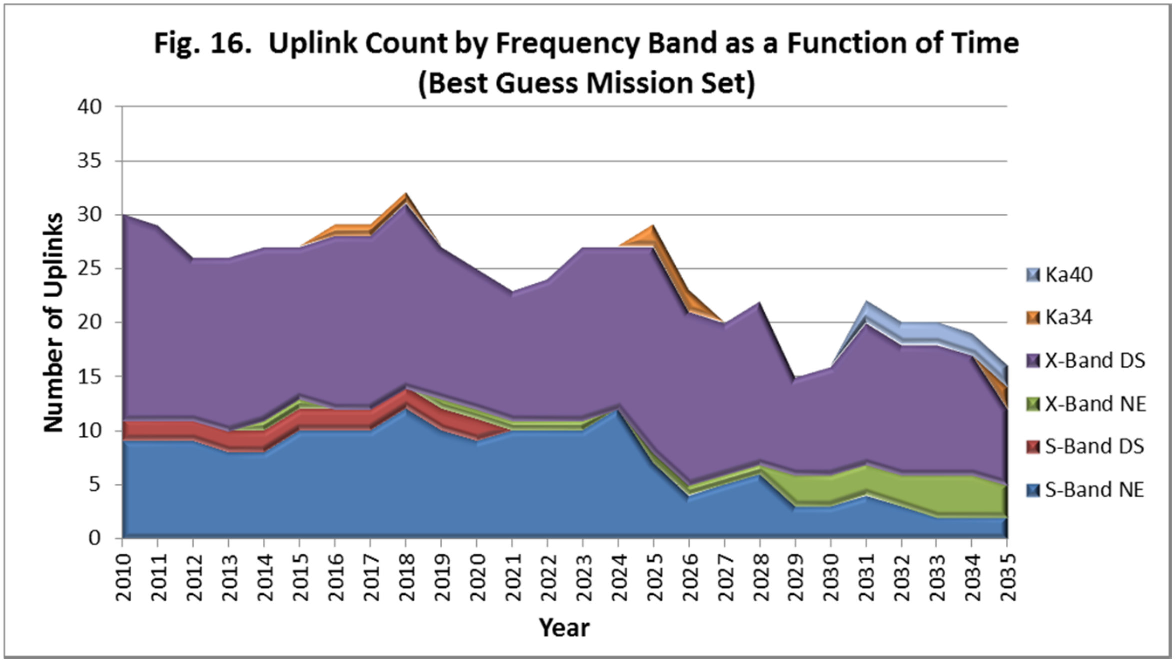
Fig. 15. Downlink Count by Frequency Band as a Function of Time (Best Guess Mission Set)



Toward the end of this decade, Ka 26 GHz and 32 GHz use emerges while deep space X-band and near-Earth S-band use remains strong.

- *Telescope-type missions drive much of this planned Ka-band use.*
- *Many of these missions use Ka 26 GHz for science return and near-Earth S-band for TT&C.*
- *Ensuring that a sufficient number of DSN assets at each complex support the requisite bands will be key to achieving efficient network loading.*

Uplink Number by Frequency Band



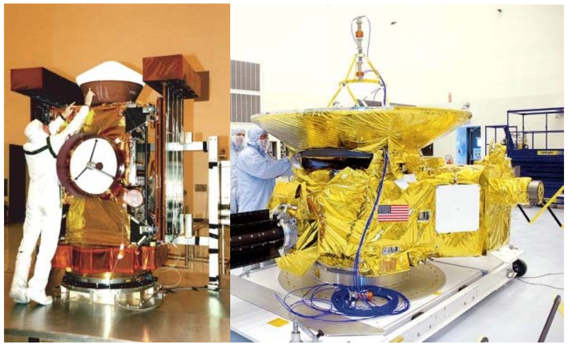
While uplink use of deep space X-band and near-Earth S-band mirrors that for downlink, use of Ka-band for uplink is much less pronounced.

- *Early 34 GHz use is radio science driven.*
- *Subsequent 34 GHz and 40 GHz use is human exploration driven.*
- *The current DSN-supported mission set does not assume any 22 GHz use, since it is not currently an allocated band; but, NASA is pursuing this band as a natural uplink counterpart to the 26 GHz downlink.*

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

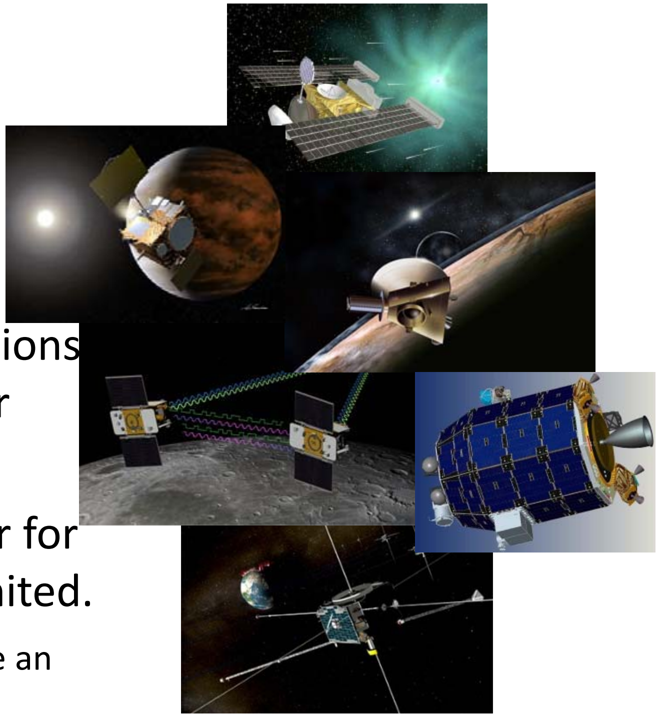
Other Emerging Developments



1. Making spacecraft smaller to save on construction and launch costs and reduce power requirements.
2. Networking small spacecraft with different specialties to achieve a greater collective capability – and, in so doing, making overall system capability upgrades and repairs cheaper.
3. Collaborating with international partners in both development and operations so as to minimize each participant’s individual expenditures.

Smallsats

- The DSE has a history of smallsat support that can be expected to continue in the future.
  - All supports fall into the "minisat" class.
  - Past examples: Stardust, Planet-C/Akatsuki
  - Current examples: ARTEMIS, New Horizons, GRAIL
  - Future example: LADEE
- Continued budget pressures may drive more future missions into the smallsat regime – and perhaps into even smaller smallsat classes.
- As this happens, available "real estate," mass, and power for the spacecraft's telecomm subsystem becomes more limited.
  - Will likely drive miniaturization of telecom components and create an impetus to move to higher frequencies.
  - More capability on the ground may be needed to compensate for the scaled-down telecom systems on the smallsats.



Smallsats may drive demand for DSN G/T and EIRP capabilities, potentially offsetting some of the decrease in network demand caused by the near-term factors discussed earlier.

Distributed Spacecraft

- There is also a growing interest in creating "fractionated" spacecraft (a.k.a "distributed" spacecraft) out of smallsats and/or hosted payloads.
  - Desired functionality comes from networking a cluster of spacecraft and/or hosted payloads to achieve a particular mission (e.g., a distributed synthetic aperture radar).
  - Smallsats and hosted payloads are cheap to build and launch relative to traditional spacecraft.
  - Fractionated spacecraft increase mission resilience to spacecraft/payload/LV malfunctions.
  - They also are readily scaled and repurposed.

- Approach is consistent with long-term trend toward using multiple spacecraft/elements to conduct in situ exploration and synthesize more capable astrophysics and heliophysics observatories.
- Fractionated spacecraft architectures figure prominently in NASA's Franklin and Edison small satellite programs.
- DARPA is working to spur progress on fractionated spacecraft through its F6 program.

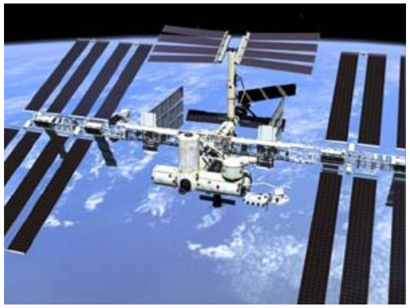
The demand pull for DTN, and space internetworking in general, may come from near-Earth distributed spacecraft applications.

Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
  - Long-Term Context
  - Near-Term Context
  - Capacity Trends
  - Capability Trends
  - Spectrum Trends
  - Other Emerging Developments
- Earth-Based Analogies Approach
  - Analogy to Earth-Based Remote Sensing
  - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Earth-Based Analogies (1/5)

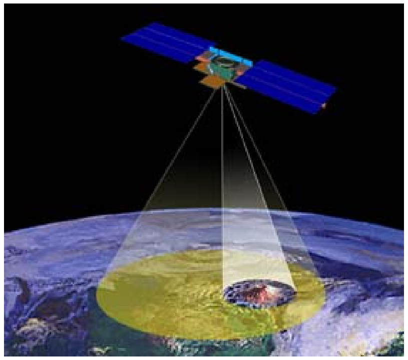
- It is inherently hard for mission concept designers to foresee and incorporate design features that exceed the current "state of the art."
- Hence, required capability projections based solely on future mission trends risk understating what will actually be needed in the far-future.
- Because technologies that are used in space are frequently used first at Earth, a particular technology's Earth-based capabilities are frequently a good indicator of what may ultimately be needed at other solar system destinations.

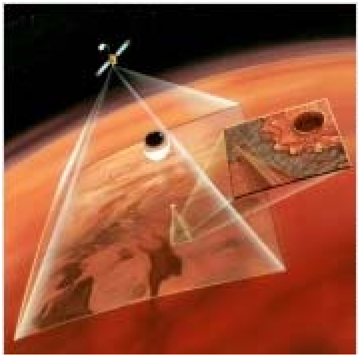


ISS was using i386 processors when the average person on the ground was using a Pentium 4 1.5 GHz processor.

Earth-Based Analogies (2/5)

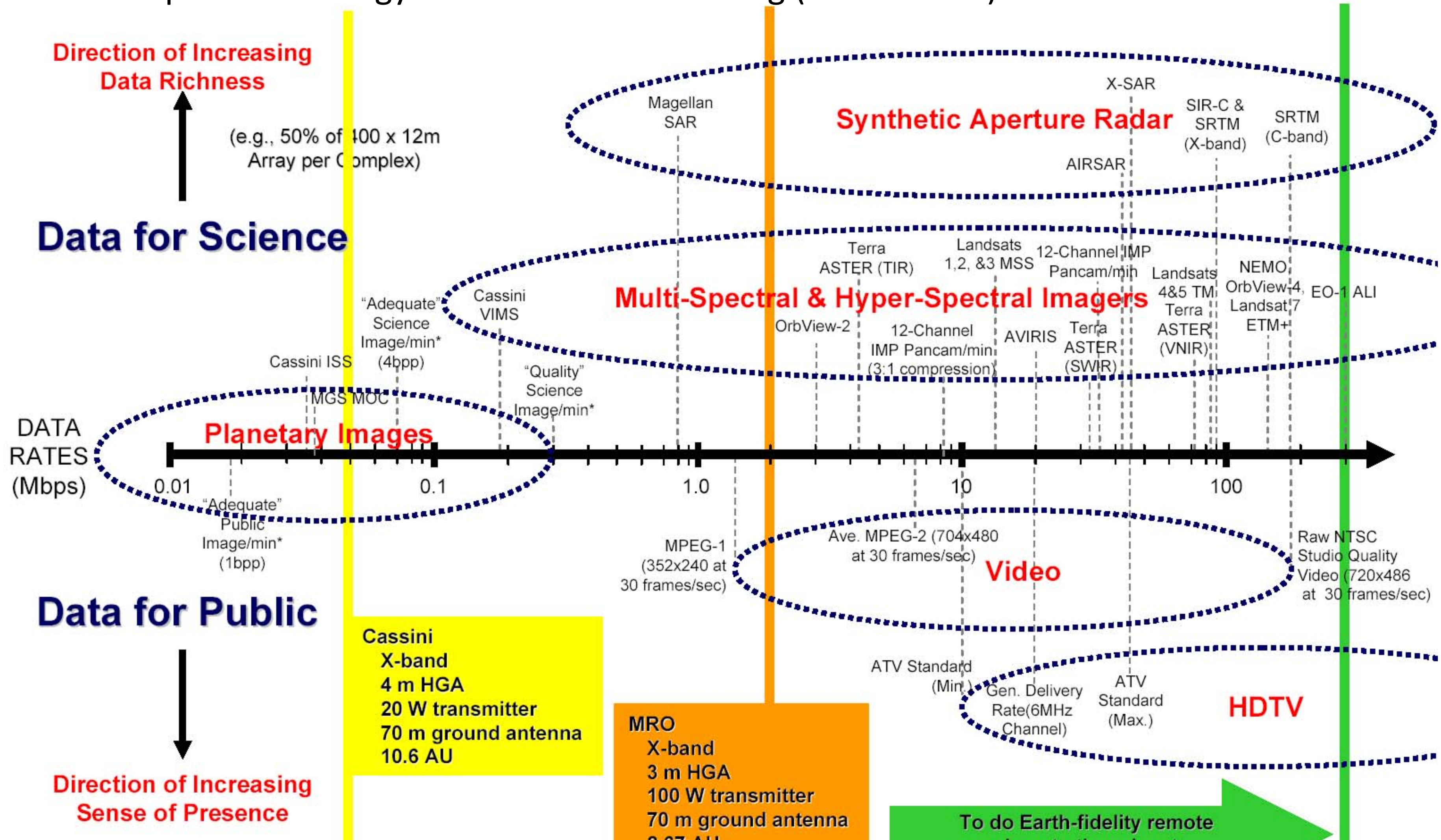
- Example #1: Analogy to Earth remote sensing
  - Remote sensing capability beyond Earth has always lagged such capability at Earth.
  - A key mission paradigm change is from preliminary reconnaissance to much higher-fidelity planetary remote sensing.
  - So, what telecommunications capability is implied by doing remote sensing at other planets with the same fidelity that we can do remote sensing at Earth today?





Earth-Based Analogies (3/5)

- Example #1: Analogy to Earth remote sensing (continued…)



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

Earth-Based Analogies (4/5)

- Example #2: Earth-based autonomous vehicle navigation and targeting data types as indicators of upload requirements for in situ exploration elements

  - *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 →

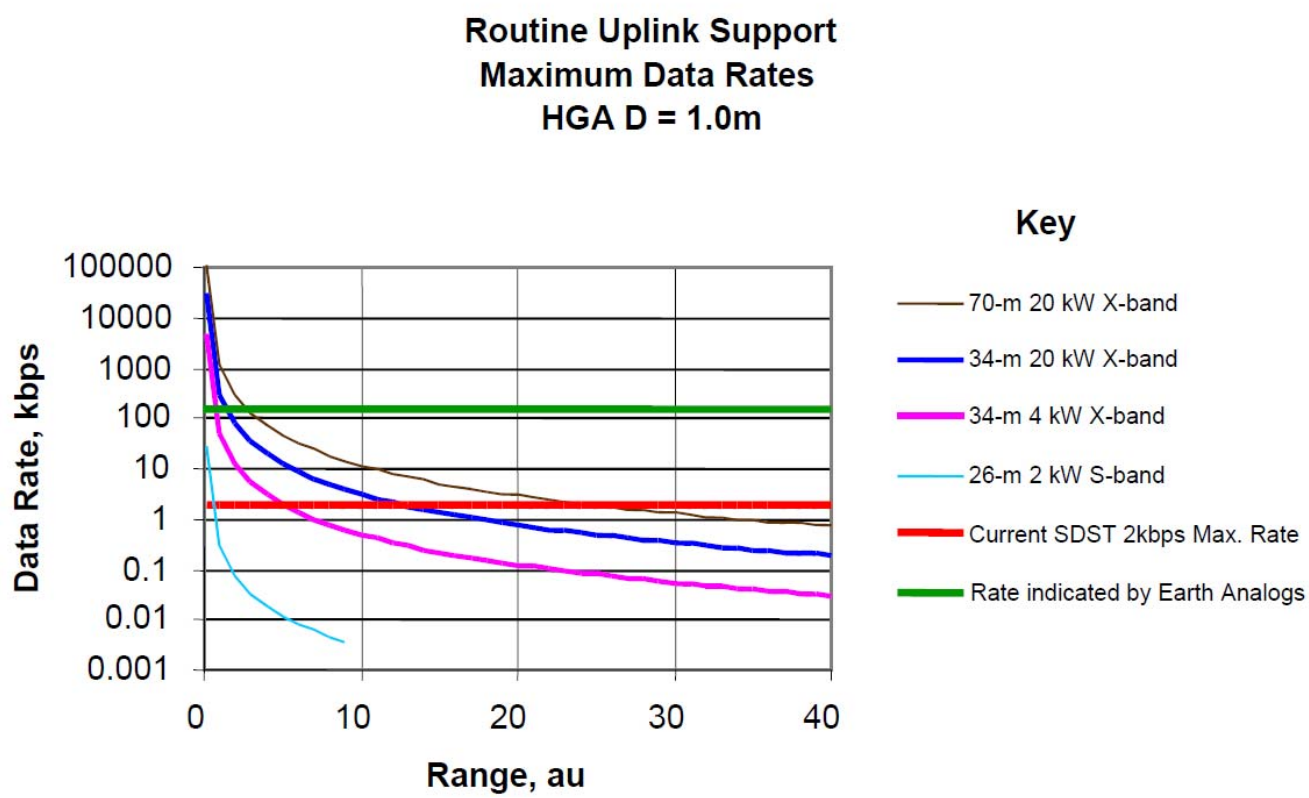
- Guidance via GPS-like beacon aids
- Targeting via hyperspectral signature

UGVs →

- Stereoscopic vision
- Multi-spectral terrain classification

Earth-Based Analogies (5/5)

- Example #2: Earth-based autonomous vehicle navigation and targeting data types as indicators of upload requirements for in situ exploration elements (continued…)



Topics

- Methodology Overview
- Mission Set Analysis Approach
- Overview of Last Year's Mission Set Analysis Results
    - Long-Term Context
    - Near-Term Context
    - Capacity Trends
    - Capability Trends
    - Spectrum Trends
    - Other Emerging Developments
- Earth-Based Analogies Approach
    - Analogy to Earth-Based Remote Sensing
    - Analogy to Earth-Based Autonomous Navigation & Targeting
- Summary

Summary

- Determination of stakeholder needs for next generation implementations necessitates a multi-pronged approach.
  - Future mission set analyses provide a lower “bound” for some of these needs.
  - Earth-based analogies provide an upper “bound” for some of these needs.
- Interpreting the results requires being mindful of both the near-term contextual factors and long-term factors that are in play.
- In the context of last year’s analyses, the current budget environment, the potential Pu-238 shortage, and SMD’s “single 34m only” policy may, collectively, create a future deep space mission set that, from a capacity and end-to-end link difficulty standpoint, is no more challenging than it is today.
- Nonetheless, data rates and volumes continue to increase, suggesting capability and spectrum challenges ahead. These results agree with the results from the Earth-based analogies.
- Emerging developments such as smallsats and distributed spacecraft could significantly change the capacity and end-to-end link difficulty picture.
- This year’s analysis is currently in work. Stay tuned.