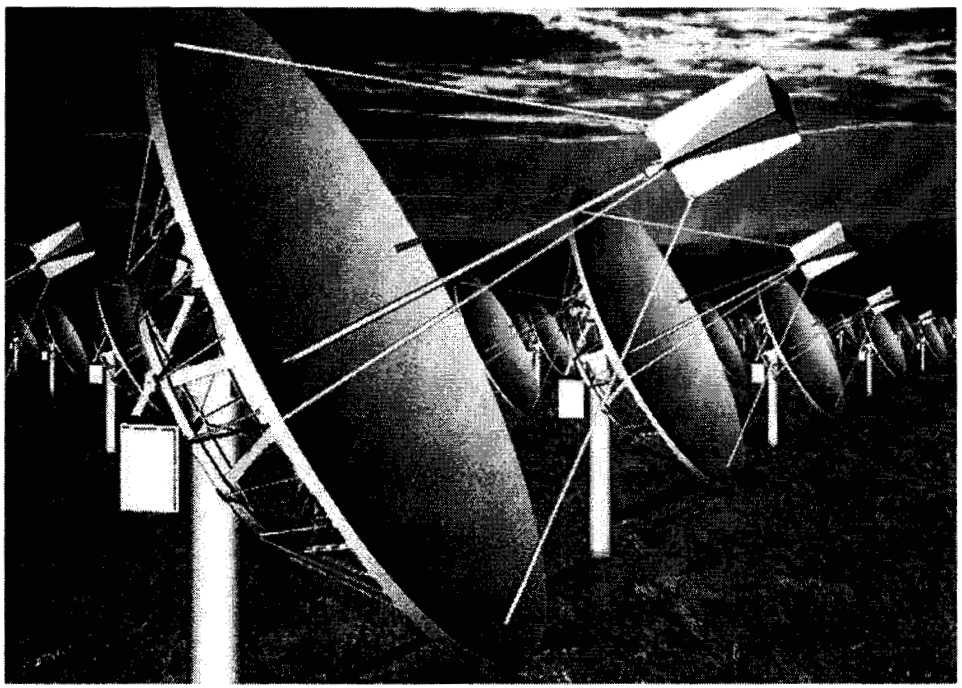
Interplanetary Network and Information Systems Directorate

Greatly Enhanced Deep Space Mission Data Return Using Very Large DSN Arrays



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by

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Outline

I. Purpose of Array System

II. Deep Space Mission Data Return Needs

III. System Description

IV. Performance

V. Cost and Return on Investment

VI. Concluding Remarks

I: Purpose of Array System

- The purposes of the Array System are:
  - To fulfill the mission needs for higher data rates in the post-2010 era
  - Reduce the cost per data bit by two orders of magnitude.
- Specific Goal:
  - Achieve a factor of 10 increase in DSN reception capability per decade from 2012 through 2027 (an average of 1 dB per year).
- Status: Development is beginning of an Operational Prototype Array System, to be completed in 2008. The prototype will have up to 100 12-m antennas, with performance up to that of up to 2.8 70-m antennas. The prototype will be used to validate performance, implementation and operations costs, and the operations concept.

II. Deep Space Mission Data Return Needs

- The science data return from deep space missions is now severely limited by the capability of the downlink communications system
  - Planetary mapping missions can return high resolution maps of only 1 to 5 percent of the planet
  - The Mars Reconnaissance Orbiter (MRO), which will be launched in 2005, will return only about one percent of the possible data from its two main mapping instruments
- New mission concepts are limited by communications capability. Increase ground system capability would enable:
  - Smaller and lower-power spacecraft
  - New instruments. High resolution, multispectral imaging
  - High data rates from Saturn, Pluto and beyond. What a shame it would be to send a mission to Pluto, and to be data-limited by the ground system.

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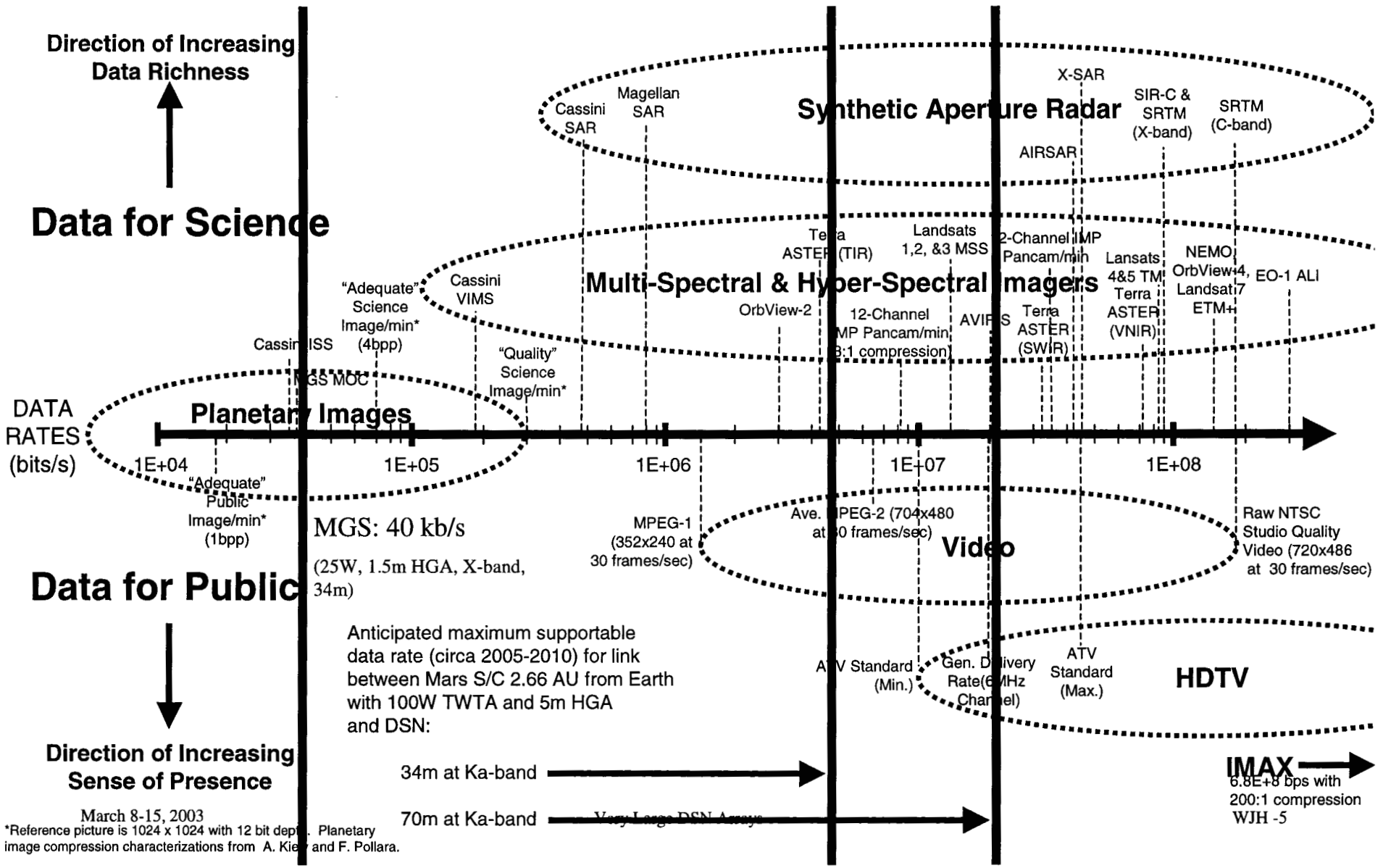
2.7 AU Mars Orbiter/Relay Scenario (~2012)

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



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

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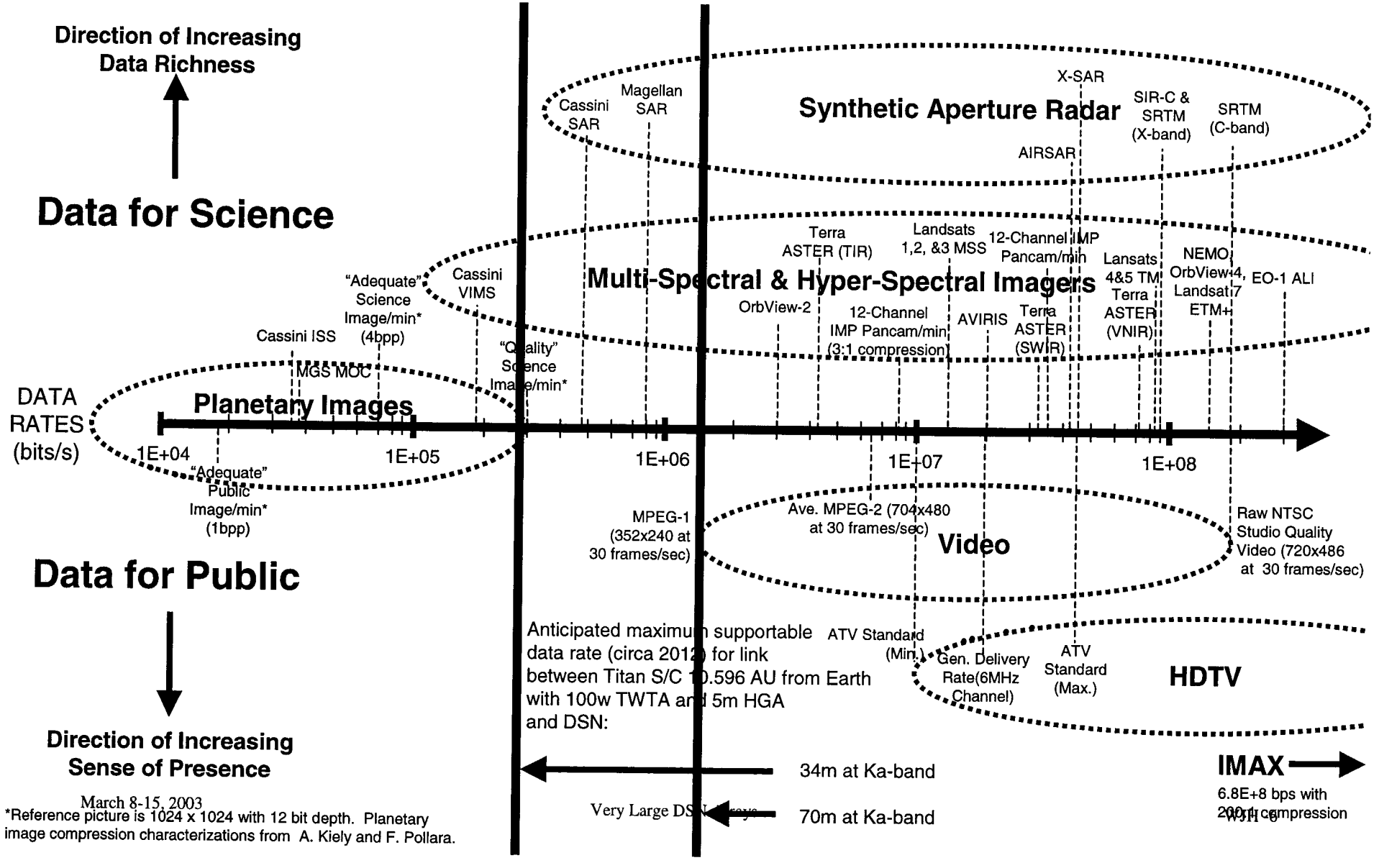
10.6 AU Titan Orbiter/Relay Scenario (~2012)

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



March 8-15, 2003

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

II: Deep Space Mission Data Return Needs

Data Needs Summary

- With today's systems, we have three order's of magnitude lower data rate from Mars than desired for SAR and hyperspectral imaging.
- Even with Ka-band on 70-m antennas, and major spacecraft improvements (100 kW Ka-band transmitter and 5-m antenna), capability would be one order of magnitude less than desired.
- For Saturn distances, such as for a Titan orbiter, the shortfall in capability is two-to three orders-of magnitude.
- A DSN vision of increasing capability by one order of magnitude per decade is well supported by these science needs.
- It clearly makes more sense to return a lot of data from one mission than to send many missions to the same target, with each mission limited to today's data rates.

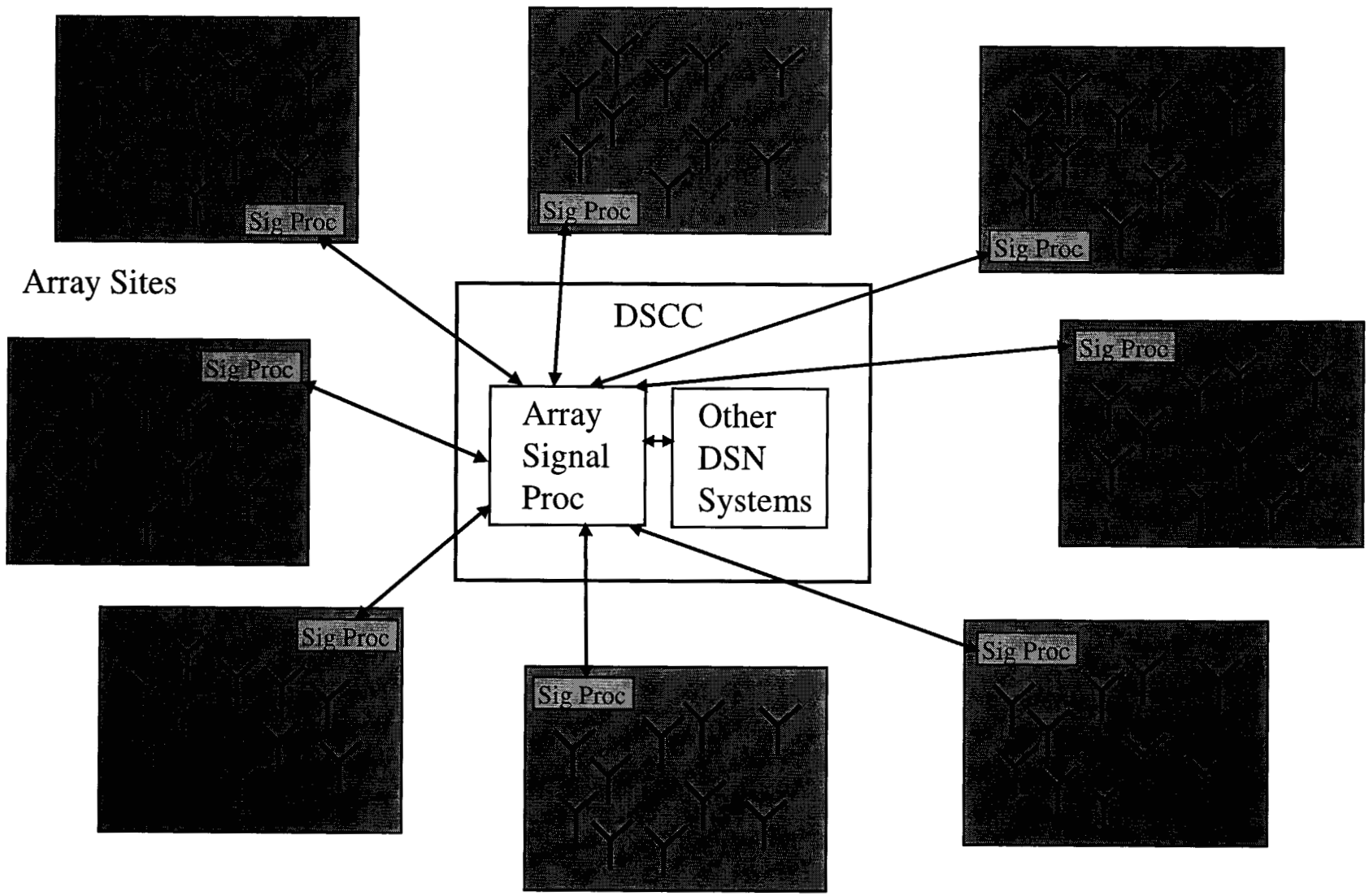
Reference: Douglas S. Abraham, "Identifying Future Mission Drivers on the Deep Space Network", SpaceOps02

III: System Description

- The key elements of the Array System are shown on the next slide.
- Baseline design:
  - A large number (~3600) of small (~12m) antennas, approximately equally distributed at approximately eight sites on each of three continents.
- Performance goal:
  - The G/T goal is the equivalent of 100 70-m antennas, with reception at X-band and Ka-band

III: System Description

Array System Pictorial



III: System Description

Key Features of Array System

- Performs all signal reception functions of the DSN.
- Can track many spacecraft and other targets simultaneously
  - Divide array into subarrays pointing in different directions
  - Each subarray can receive signals from multiple sources simultaneously.
- Site Diversity Provides:
  - Ka-band Weather Diversity
  - Delta DOR and VLBI
  - High Availability
    - Services will not be interrupted if one or even two sites have failures.

IV: Performance

- Performance Compared to One 70-m Antenna
  - The collecting area of 36 12-m antennas is slightly greater (5.8 %) than one 70-m antenna.
  - Ka-band performance of 36 12-m antennas will be 4 to 5 times the X-band performance of one 70-m antenna
  - A full array of 3600 12-m antennas will have a Ka-band performance 400 to 500 times the current X-band performance of one 70-m antenna.
- Full DSN Capacity Comparison
  - The full system of 3600 antennas at each of three longitudes will have a capacity of 1200 to 1500 X-band 70-m antennas.
  - Today we have total aperture approximately equivalent to five 70-m antennas.
  - The Array System total capacity will be 240 to 300 times today's X-band capacity.

V: Cost and Return on Investment

- Operations cost is critical
  - Operations cost will place a limit on total array size, because there is no point in building a system that we cannot afford to operate and maintain.
  - The dominant operations cost will be maintenance, because of the large number of antennas.
- The biggest development challenge is cost
  - We know that the desired performance can be achieved.
  - The big challenge is to design the system to achieve low implementation, operations and maintenance cost

V: Cost and Return on Investment

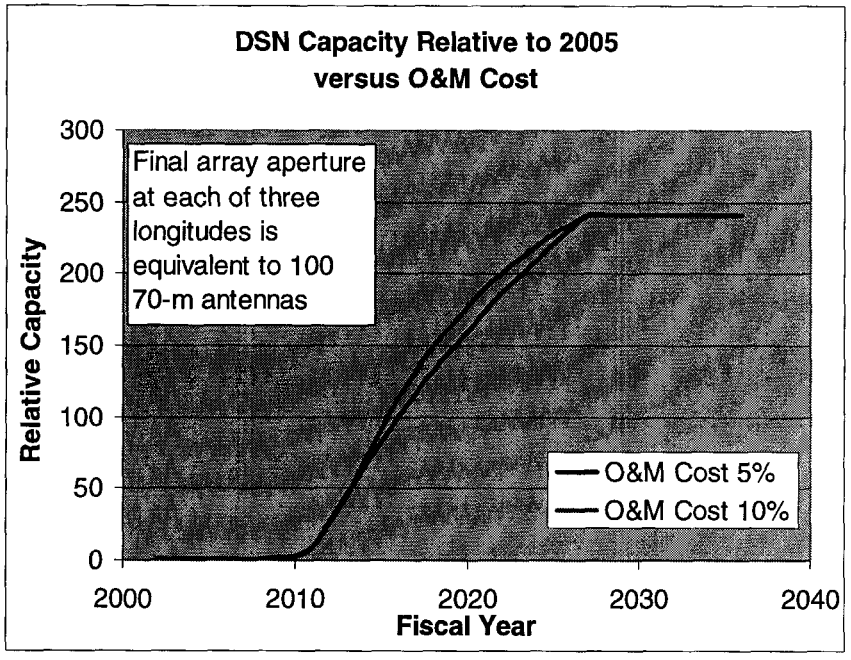
Cost Model

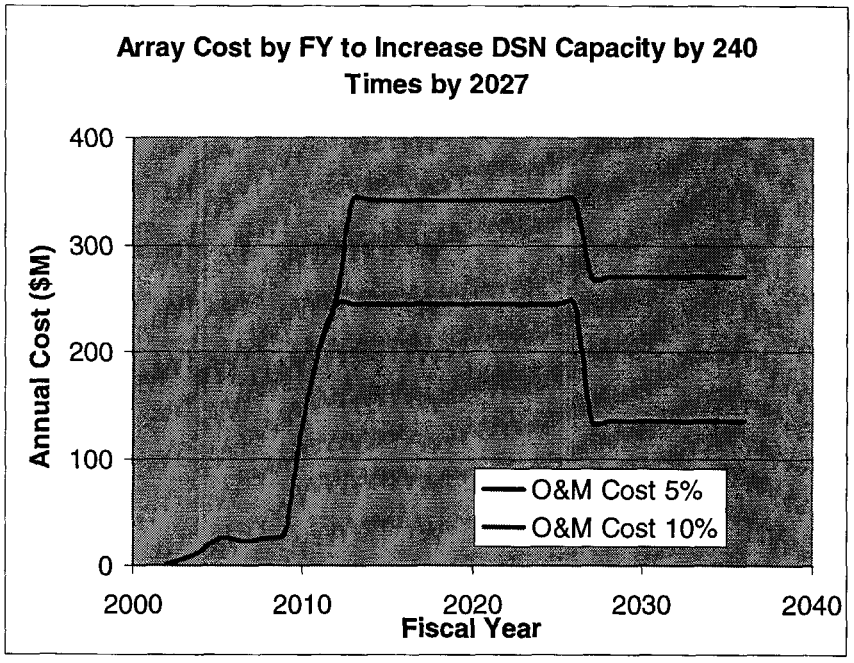
- Cost estimate profiles have been modeled to achieve the full desired array by 2027.
- Profiles shown for O&M costs of 5 and 10 percent per year of production cost to date.
- Annual funding during production phase is assumed to be constant.
  - Each year, compared to the previous year, more is spent on operations, leaving less for production.

V: Cost and Return on Investment

Cost to Achieve Desired Array Capacity

Cost depends strongly on O&M and sustaining costs

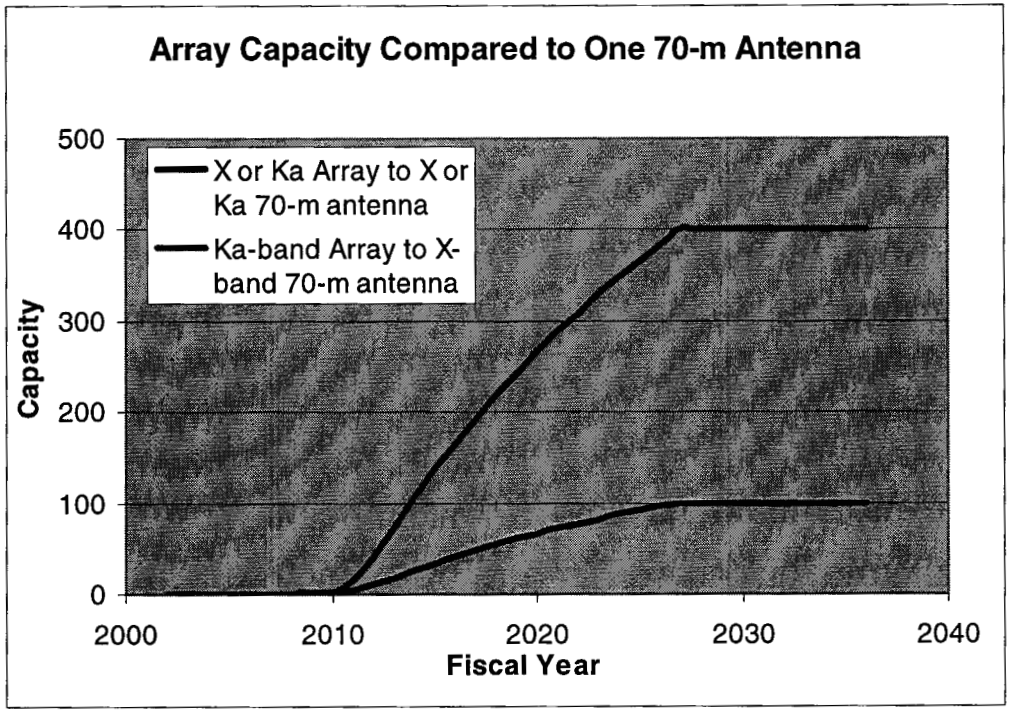




- Based upon an estimated implementation cost of $9M per 70-m equivalent aperture.
- Cost is approximately proportional to array size, after prototype and engineering costs.

V: Cost and Return on Investment

Array Peak Capacity at Each Longitude



Note: The array performances shown use the low end of the performance estimates. Actual Ka-band peak capacity will be 400 to 500 times the reference antenna. Actual total system capacity (previous slide) will be 240 to 300 times current DSN capacity.

V: Cost and Return on Investment

Return on Investment

- The current annual budget for the DSN is on the order of $200M.
- To achieve the desired array performance by 2027 is estimated to require somewhat more than doubling this budget in the production phase, and somewhat less than doubling the current budget for operations in the post-production phase.
- The performance increase is by a factor of 240 to 300 times in system capacity, and by 400 to 500 times in peak capacity.
- Cost per bit of data is decreased by more than a factor of 100.

VI: Concluding Remarks

- Very large arrays are a very promising way to obtain orders of magnitude increase in the DSN RF reception capability.
- This would greatly enhance mission science return, and reduce the cost per bit of science data reception by two orders of magnitude.
- Cost is the key challenge.
- Development of an Operational Prototype Array System is beginning.
- A fully operational Array System could be in place in about 10 years, with full capability in 25 years. This would achieve the DSN vision of improving capability by an order of magnitude each decade.