Today's Deep Space Communications System: The Earth-based Elements

Dr. Les Deutsch

Deputy Director, Interplanetary Network Directorate

Jet Propulsion Laboratory
California Institute of Technology

Goal of Short Course

Provide a common understanding of the current system, providing a baseline from which we can start

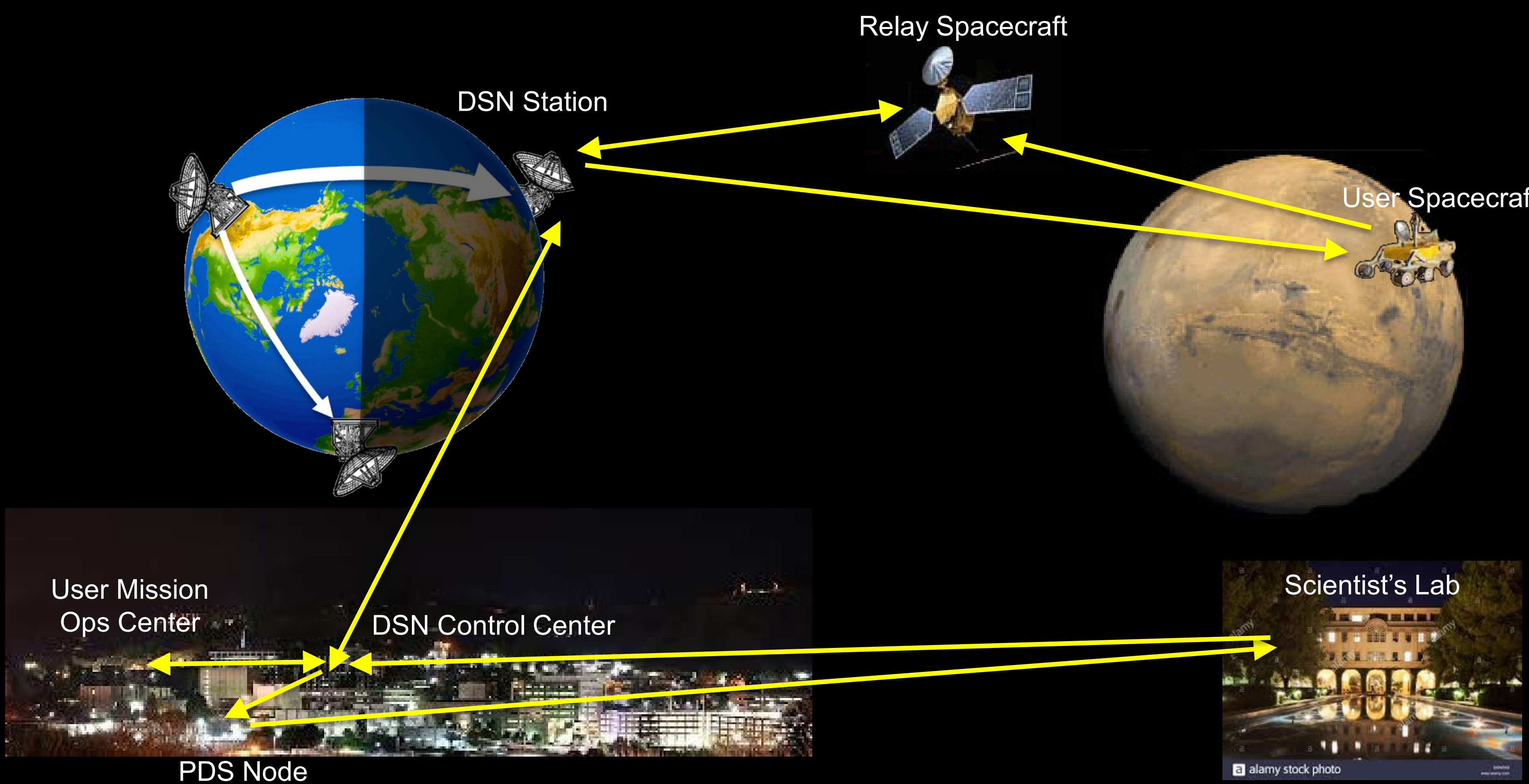
This is not meant to teach you how to design, build, and operate ground systems

We will describe the important (relevant to this study) aspects common to such systems today

After this, you can forget everything and tell me how these systems should be built in the future

The deep space communications system

This is a JPL-centric example – all JPL facilities



What are the Earth elements of the system?

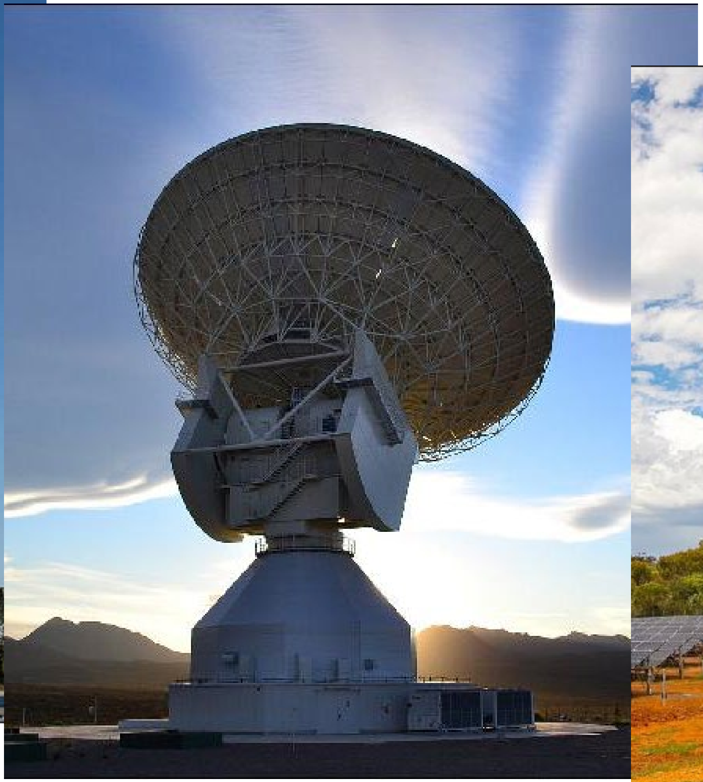
- A bunch of very large antennas
  - Perhaps, some smaller ones that we can array
- Geographic locations to “see” the user spacecraft as needed
- High power transmitters to provide uplink
- Sensitive receivers to detect downlink
- Frequency assignments so we don’t interfere with others
- “Extra” signal processing to allow detection of very weak signals
  - Error-correcting codes
  - Data compression
- Data repositories that scientists can use to find the bits
- A “scheduling system” that puts the various elements together into “links” as needed – and allows them to be reused
- People: operators, maintenance, schedulers, managers …

The Deep Space Network
NASA's Connection to the Moon, Planets, & Beyond

- Large antennas at three global sites: California, Madrid, Canberra
- Captures all information from our spacecraft
  - Most sensitive receivers
- Sends all instructions to them
  - Most powerful transmitters
- Provides most of the navigation
  - Most stable clocks and best algorithms
- Enabling more than 30 spacecraft in flight today

The DSN is not alone
Here is ESA's ESTRACK network
There are others …

Spain



Argentina

Australia

Constraints – it's different in deep space

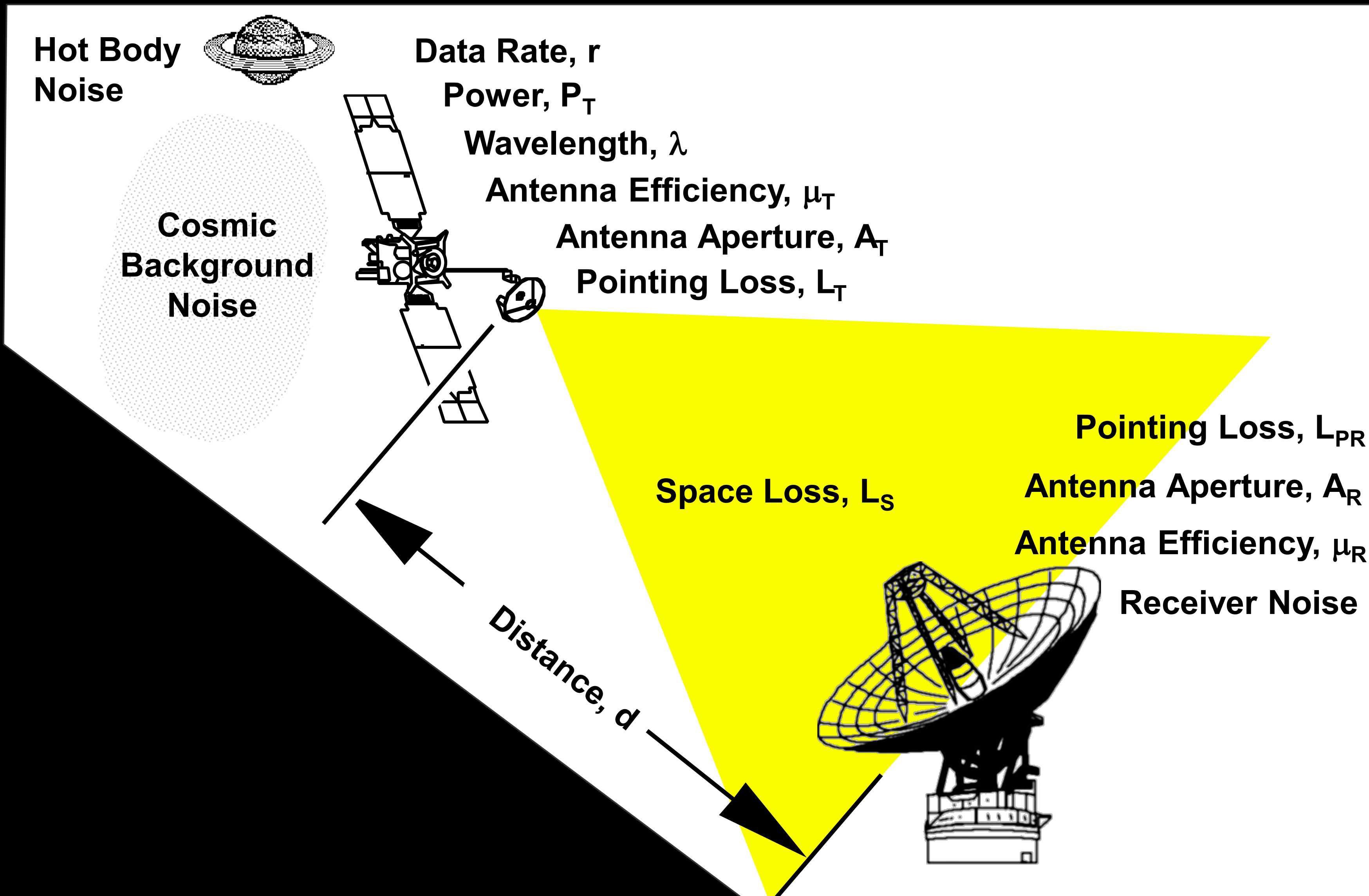
On Earth, communications is usually limited by

- Bandwidth – simply getting a big enough pipe, or
- Cost – competing with others to buy the pipe we want

The connection between Earth and deep space is limited by power – or something related to power

Since uplink is typically low-rate for deep space, I will concentrate on discussing downlink in this talk

All of these things determine the received power

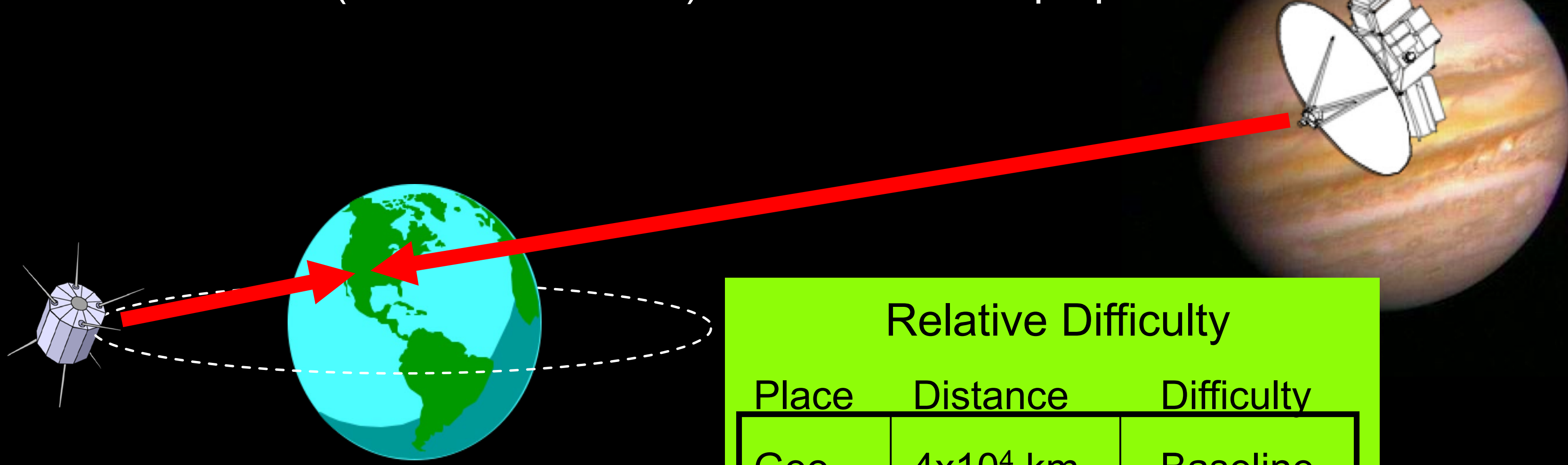


Why is Deep Space Comm Difficult?

Communications performance decreases as the square of the distance.

Jupiter is nearly 1 *billion* km away, while a GEO Earth communications satellite is only about 40 *thousand* km away

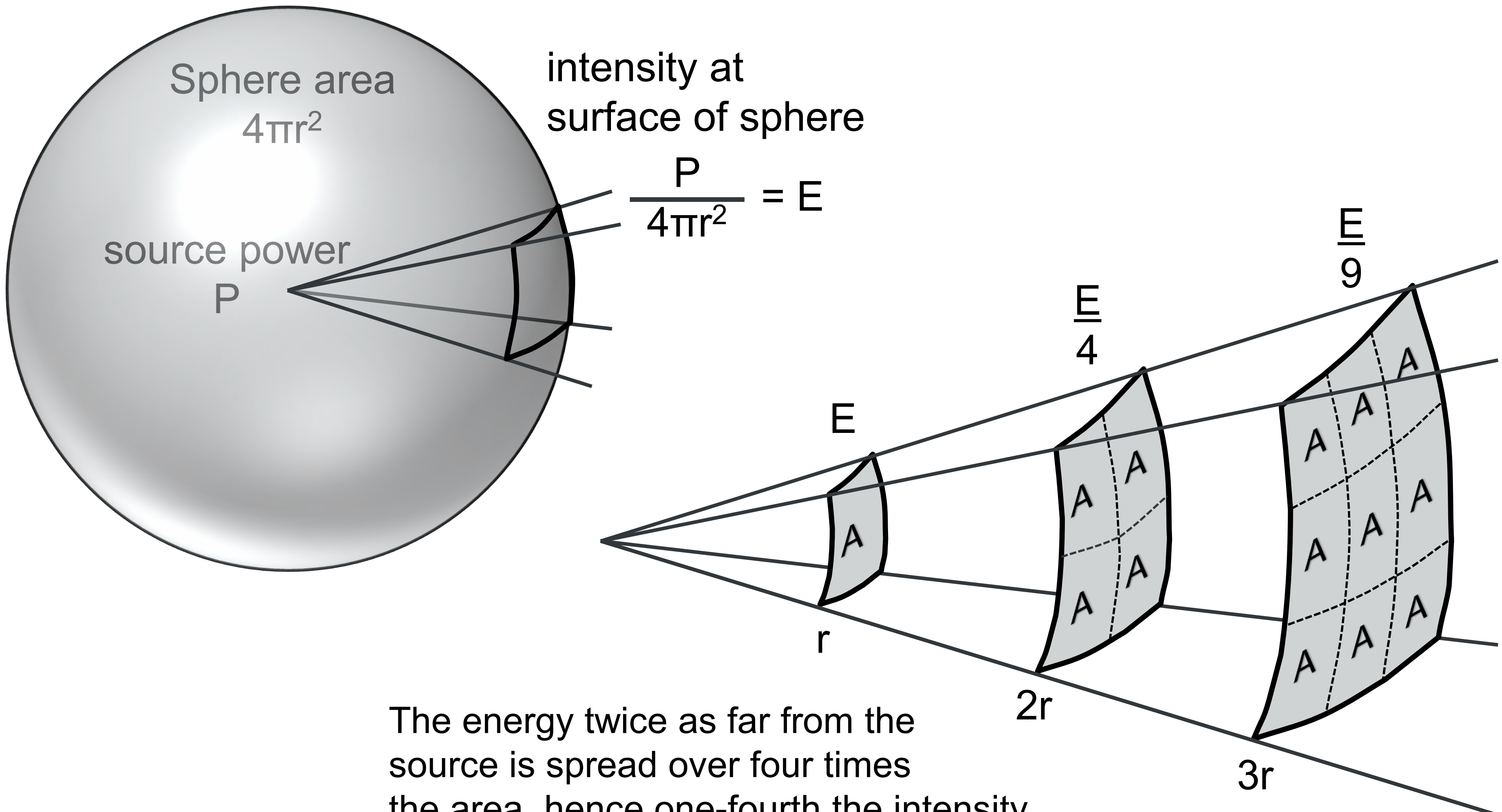
- It's about 87 dB (~1/2 billion times) harder from deep space!



Relative Difficulty

Place	Distance	Difficulty
Geo	$4x10^{4}$ km	Baseline
Moon	$4x10^{5}$ km	100
Mars	$3x10^{8}$ km	$5.6x10^{7}$
Jupiter	$8x10^{8}$ km	$4.0x10^{8}$
Pluto	$5x10^{9}$ km	$1.6x10^{10}$

Inverse Square Loss



The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity

But other things count too: Why Ka-Band is not an 11.6 dB improvement

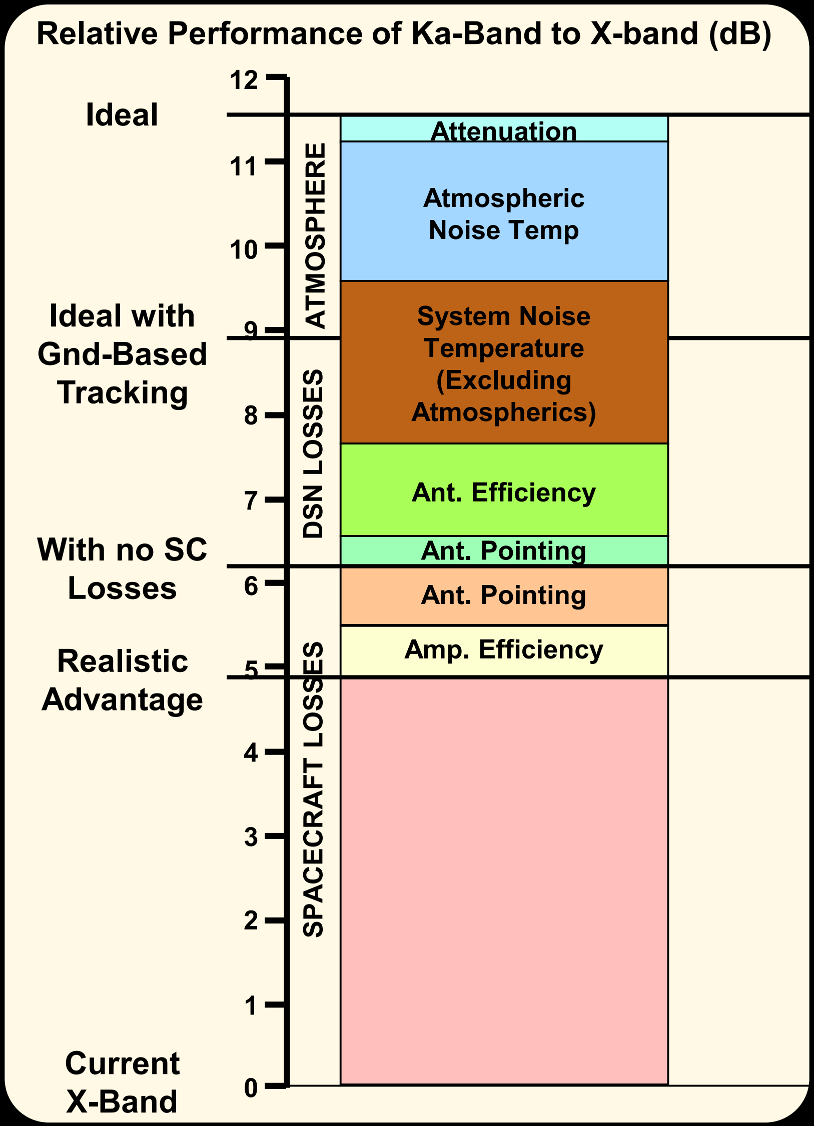
We would expect an 11.6 dB advantage over X-band based on the square of the ratio of frequencies

- Various degradations result in less

This old "thermometer" was a guide to technology investment

- Example of an *error budget*

Final result turned out to be 5 to 7 dB advantage, depending on scenario



DSN Scheduling

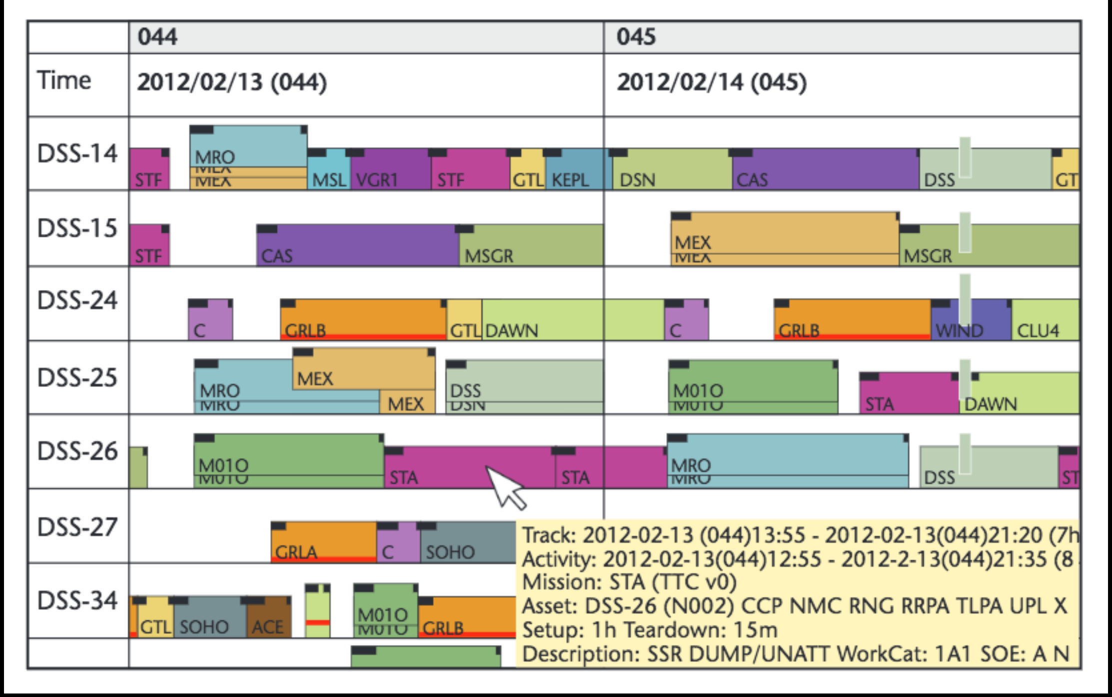
Every link using the DSN is scheduled in advance

This is a hard problem because

- There are only a ~dozen DSN antennas and ~35 operating spacecraft
- Spacecraft tend to clump in the sky – the DSN is driven by astrology
- Some links have special importance – e.g. launches, landing, and trajectory changes
- Also critical science encounters, including occultations (more astrology?)
- Deep space missions typically require things to stay unchanged for months at a time because of their own sequenced operations – hence schedules are set far in advance
- Changes in schedule (e.g. launch slips) play havoc with this

Service Scheduling Software (SSS)

SSS is a tool helps the scheduling process



It does not do this autonomously

People work the schedules – representing each user mission

In fact, every bit is scheduled
And its even worse than that …

Missions use the DSN schedule to assign data to each link to return from space

The more DSN time they can get, the more data they can return

Because the DSN time and data are both precious, missions will add “margin” to the power to ensure a high probability (say 98%) of getting all those bits back correctly

Note: This extra power is also precious and using more of it works exactly against maximizing data return

NASA's Planetary Data System: The last mile to the scientists

The repository for data from planetary missions

Serves as a model for other mission types

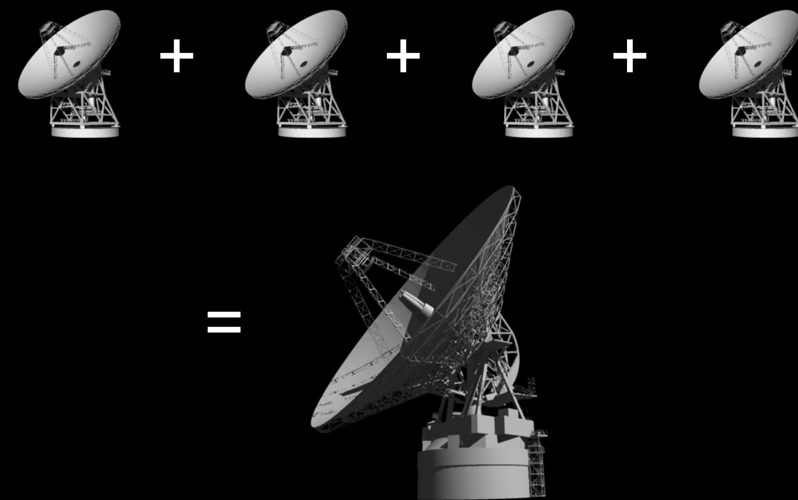
Consists of "nodes" of like-data

- Atmospheres (ATM)
- Geosciences (GEO)
- Cartography and Imaging Sciences (IMG)
- Navigational & Ancillary Information (NAIF)
- Planetary Plasma Interactions (PPI)
- Ring-Moon Systems (RMS)
- Small Bodies (SBN)

- Data ontology is well-defined and tools exist to help missions enter their data

Flexibility and Scalability

- The DSN is inherently flexible
  - All sites use same architecture and processes
  - All antennas can provide all services – mostly
  - Using CCSDS standards for communications

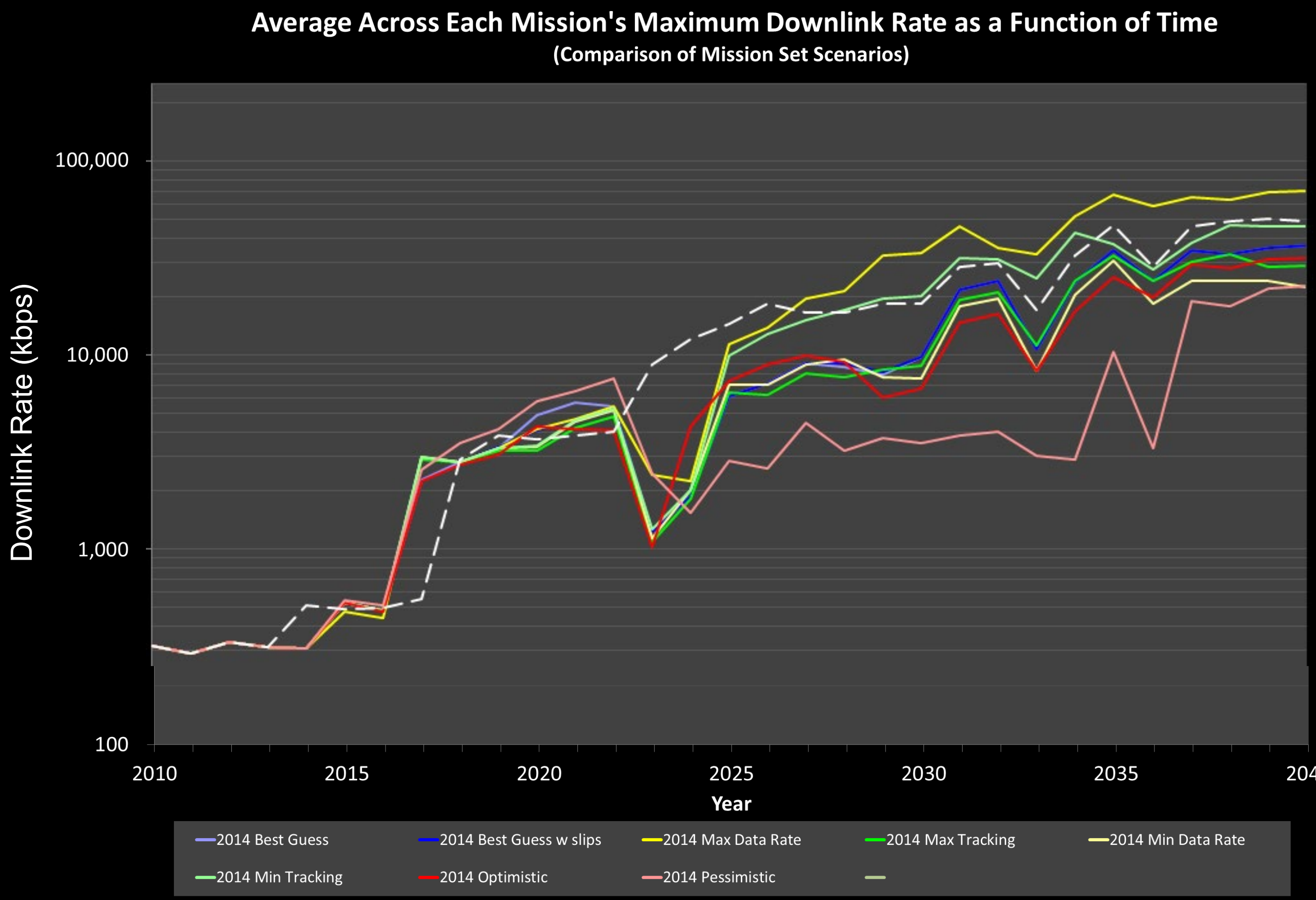


Using 34m Antenna Array to Back Up 70m

- DSN is inherently scalable
  - Can easily add or subtract antennas
  - Array antennas for more downlink performance
    - Have demonstrated uplink too – but not yet operational
- We work with our customer community to determine the needed scale and flexibility
  - We perform market research for 25 years in the future
  - We have user groups and publish our plans

Challenge: Future Missions Generate More Data

We expect data rates from deep space missions to increase 10-fold each decade for 50 years



Some things do not scale well

The scheduling process we use today is not inherently scalable

- It can break down with large number of missions or
- large numbers of links

It has also been suggested (by Vint Cerf among others) that the idea of scheduling each downlinked spacecraft bit also will not scale

- It can break down as above
- And also as the data volume in each mission grows

Technology that can help

- Disruption Tolerant Networking
  - Can automate scheduling of bits within links
  - Can reduce wasted “margin”
- Automated link scheduling
  - Can help scale up to future mission set
- Demand-Access protocols
  - Can bridge to onboard autonomy to reduce required communications links
- Data science techniques
  - Can help scientists find the data they need in the system
- Others you will hear about or maybe invent in this study

Conclusion

- Today's deep space commuinications system works well getting data between space and scientists
- However, it may be using more power than needed
- And it may not scale as needed in the future