The Role of Power in Deep Space Communications

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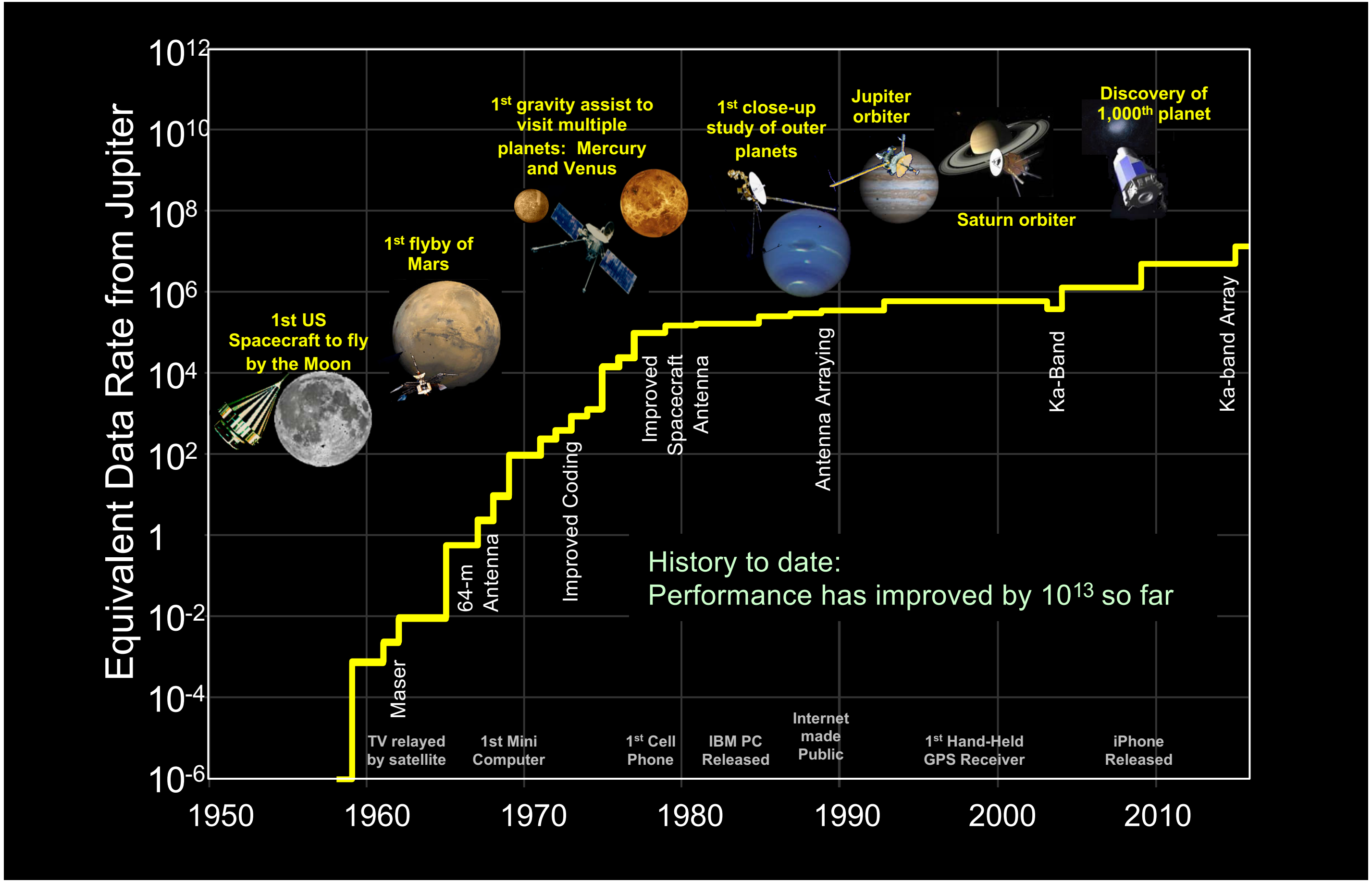
Introduction

- In the Interplanetary Network Directorate we like to say that one cannot do a deep space mission without us—no communication, no mission
- However, there is no communication without power

PIF—Power Is Fundamental
(but not the whole story)

A History of Improving Deep Space Communications



Improvements follow technology trends

- Larger launch vehicles and spacecraft
- More spacecraft prime power
- Power amplifier output power and efficiency improvements
- Larger antennas—both flight and ground
- Moving up in frequency—optical is next

Plenty of room to continue to improve. We haven't hit our "Moore's Law" limit yet

The Link Equation—focus on the downlink power

- The data rate supported by the link is a function of the received signal power, P_r

$$P_r = P_t G_t L_t L_{fs} G_r L_r$$

$$L_{fs} = \left(\frac{c}{4\pi d f}\right)^2, \; G_t = 4\pi A_t \left(\frac{f}{c}\right)^2, \; G_r = 4\pi A_r \left(\frac{f}{c}\right)^2$$

and with a little math-magic

$$P_r = P_t A_t L_t \left(\frac{f}{cd}\right)^2 A_r L_r$$

  - Note that all things being equal, higher frequency is better!

(*it's never that easy*)

- $L_{fs} = free\ space\ loss$
- $P_t = transmiter\ output\ power\ (W)$
- $G_t = transmit\ antenna\ gain$
- $L_t = transmit\ losses$
- $G_r = recieve\ antenna\ gain$
- $L_r = receive\ losses$
- $A_t = effective\ transmit\ antenna\ area\ (m^2)$
- $A_r = effective\ receive\ antenna\ area\ (m^2)$
- $c = speed\ of\ light\ (m/s)$
- $d = distance\ between\ transmitter\ and\ receiver\ \ (m)$
- $f = frequency\ (Hz)$

The Link Equation—focus on noise

- The downlink power has to "overcome" the noise at the receiver so we can extract the information
- Noise at the receiver can be caused by many factors
  - One is the inherent noise in the electronics
    - The electronics noise in bandwidth B (Hz) is

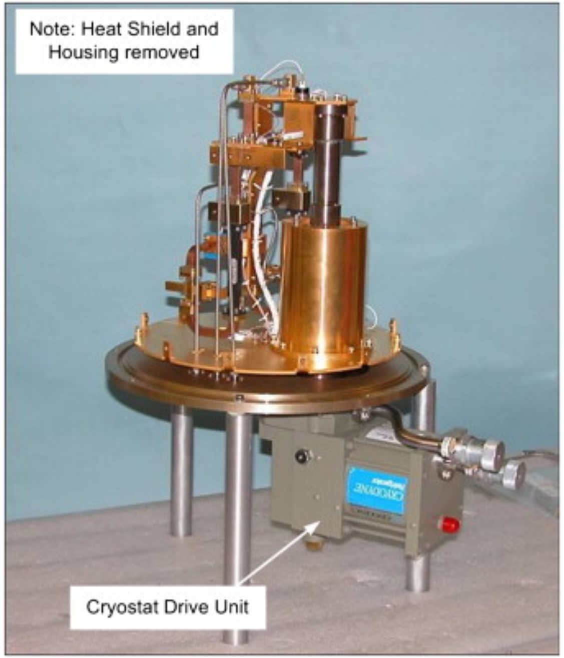
$$P_N = N_0 B = kTB$$

N_0 is the noise power spectral density (W/Hz)

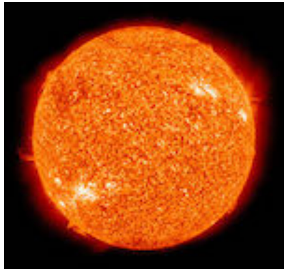
k is Boltzmann's constant $1.38 \text{ x } 10^{-23}$ $(W/K\ Hz)$

T is the system temperature (K)

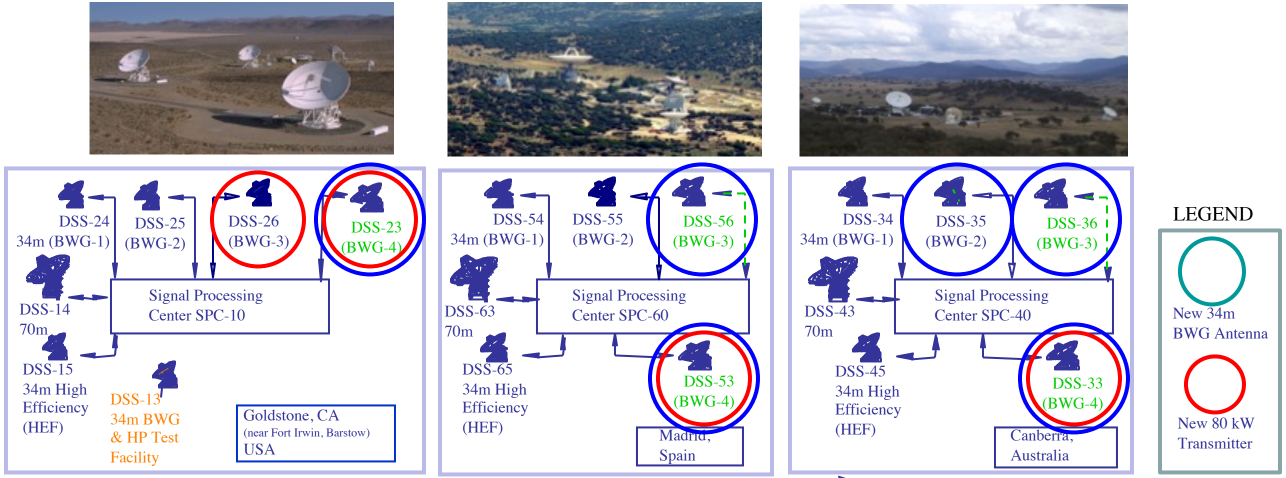
    - We use cryogenically cooled amplifiers to keep T down
- And there are other noise sources to take into account

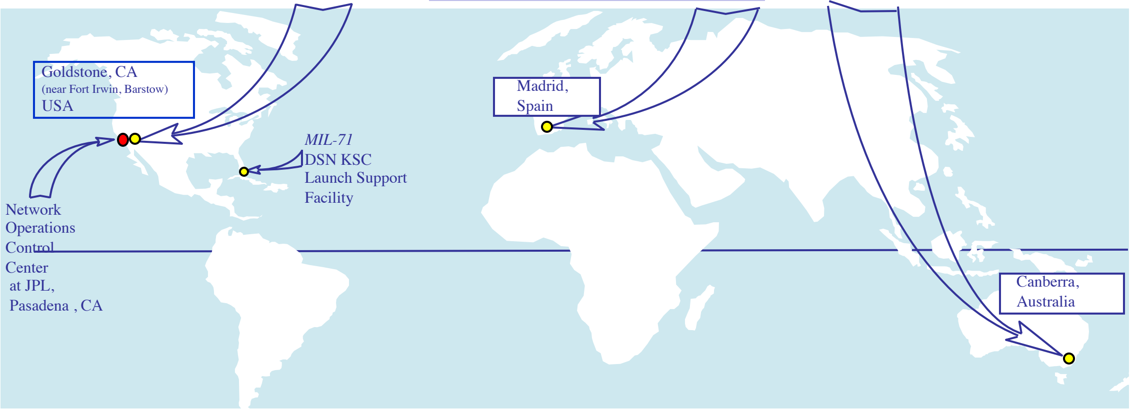


Ka-band (32 GHz) low noise amplifier



DSN Facilities by 2025





Antennas
Operational Dates

DSS-35	10/2014
DSS-36	10/2016
DSS-56	10/2019
DSS-53	10/2020
DSS-33	10/2022
DSS-23	10/2024

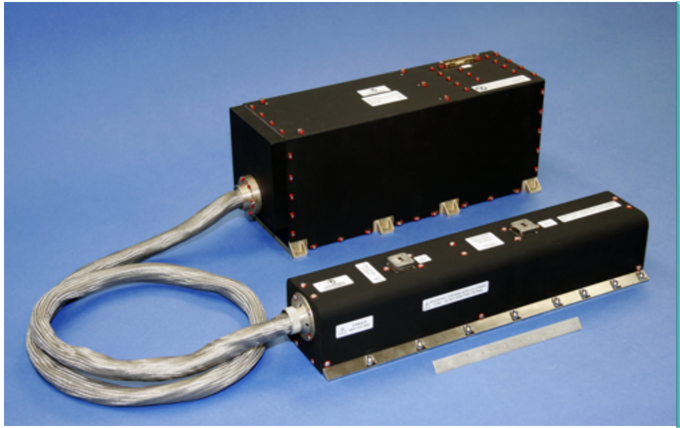
80 kW XTR
Operational Dates

DSS-26	9/2015
DSS-53	10/2020
DSS-33	10/2022
DSS-23	10/2024

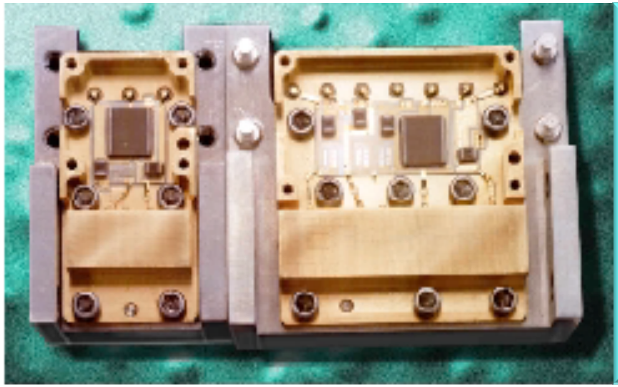
Historically we have tried to reduce the burden on the deep space missions by building large antennas on Earth

- *Receive*
  - *High gain*
  - *Low noise*
  - *Arraying*
- *Transmit*
  - *Higher output power*
  - *Arraying*
- *Support multiple missions simultaneously*

Power Amplifiers—Higher efficiency and Higher power



200 W Ka-band TWTA developed in mid 2000s but has yet to fly because no mission has, or has been willing to allocate, that sort of power to comm



2 W Lockheed Martin Ka-band SSPA developed for DS-1 late 1990s

Traveling Wave Tube Amplifiers (TWTA)

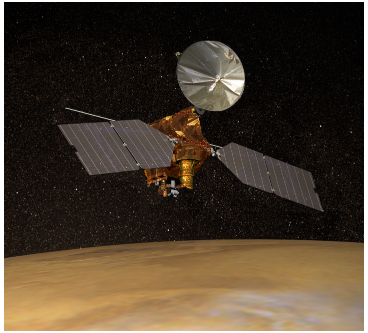
- Workhorse of deep space flight comm
- Vacuum system—somewhat of an art
- Power levels of 200 W and more at Ka-band
- Efficiency of 50%-60%--can get a bit higher
- High voltage power supplies, e.g., 350 V

Solid State Power Amplifiers (SSPA)

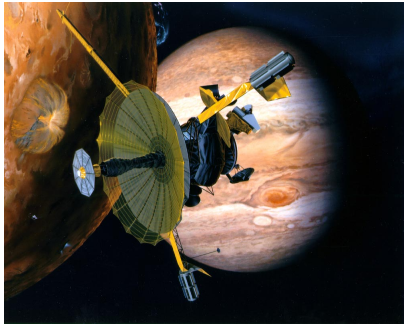
- Power levels of <10 W for Ka-band flight
- Efficiencies of 25% or less
- Goal of 10-50 W with 40%-50% efficiencies with GaN
- Expected to be smaller, lower mass, more rugged and easily manufacturable

Improving efficiency can only get us so far-> Need more prime power

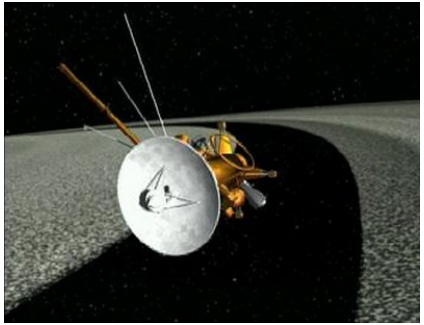
Antennas—Bigger is better



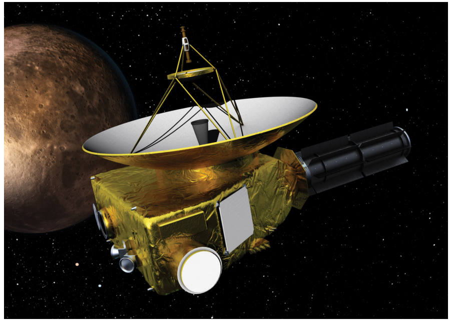
MRO X and Ka
3.0 m Solid



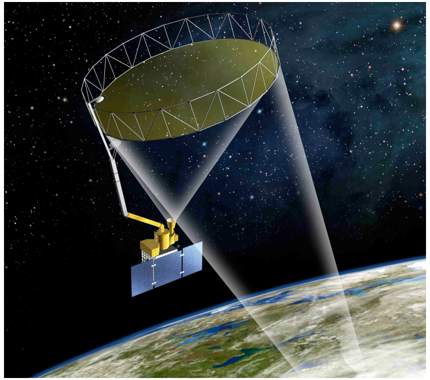
Galileo S & X-band
4.8 m Deployable (oops!)



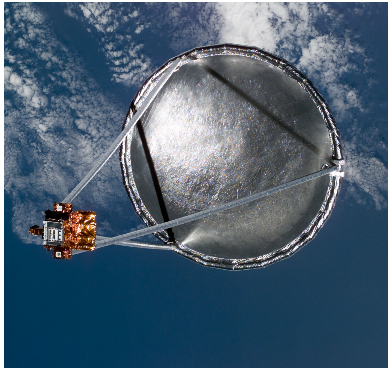
Cassini S, X and Ka-band
4.0 m Solid



New Horizons X-band
2.1 m Solid



SMAP L-Band
12.0 m Deployable

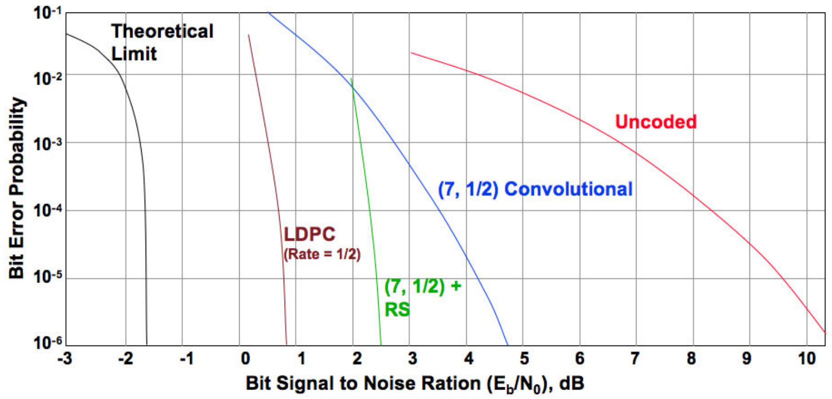


Inflatable Antenna Experiment
X-Band (?)
14.0 m Inflatable

What is wrong with this picture?

- Instrument data production rates continue to increase—no matter where in the Solar System
- As we go farther out we need larger antennas and/or more RF output power to return this data
- Large deployables—like those being used in GEO—will be needed
- Key is to keep mass low and aperture large

Be as efficient as possible when sending data



Example of near-lossless compression performance on a calibrated MaRS hyperspectral image

	File Size	Bit Rate (bits/sample)	Compression
Original image file	385 MB	16	1×
Lossless compression, δ=0	135 MB	5.6	2.9×
Near-lossless, δ=1	96 MB	4.0	4×
Near-lossless, δ=4	67 MB	2.8	5.7×

δ = maximum error in reconstructing the corresponding sample in Data Number

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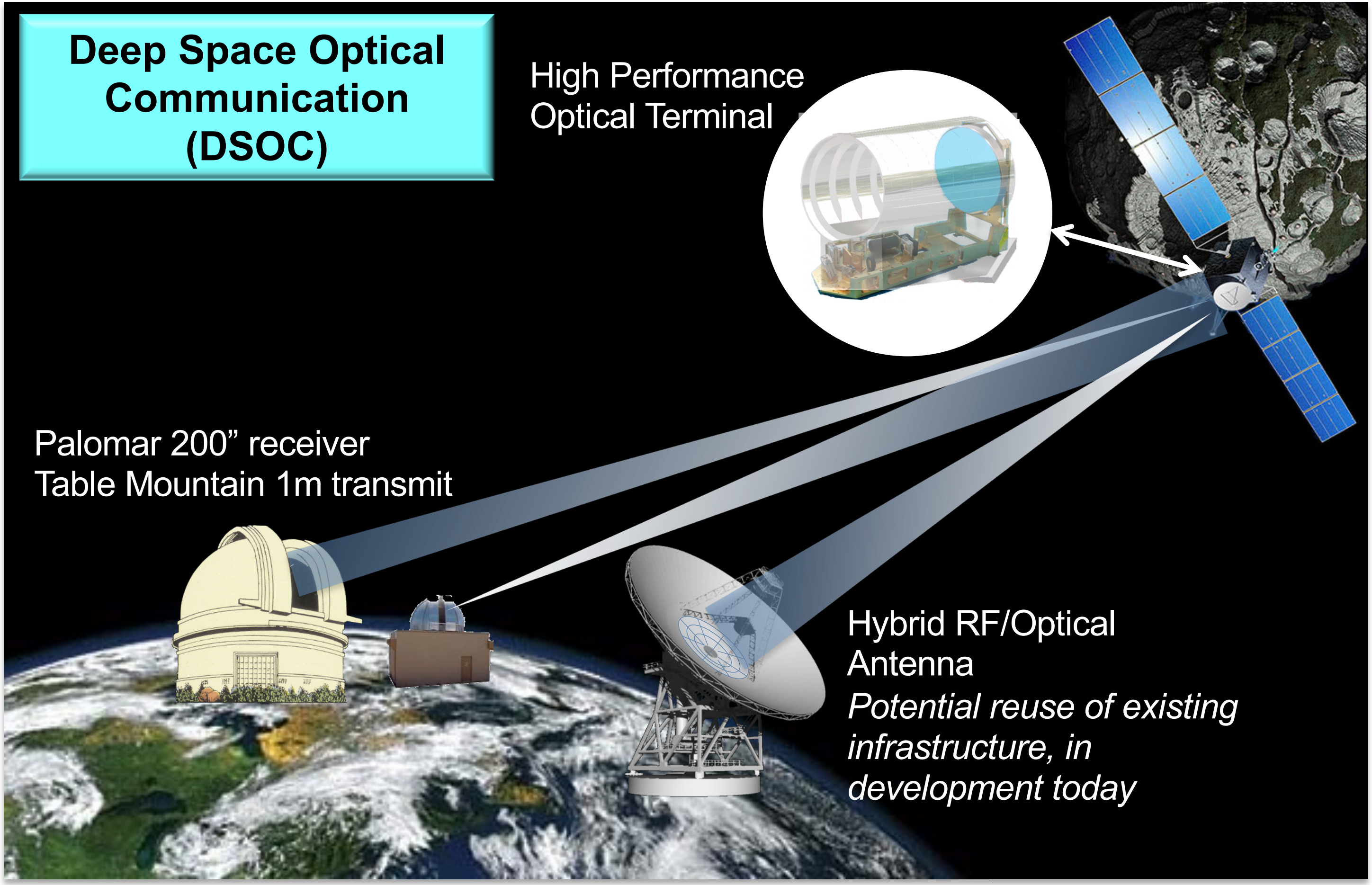
Error Correction Coding

- Adding "parity" bits to allow detection and correction of errors
- Reduces power required to send the "information bits"
- In deep space comm, usually implies larger RF bandwidth

Data Compression

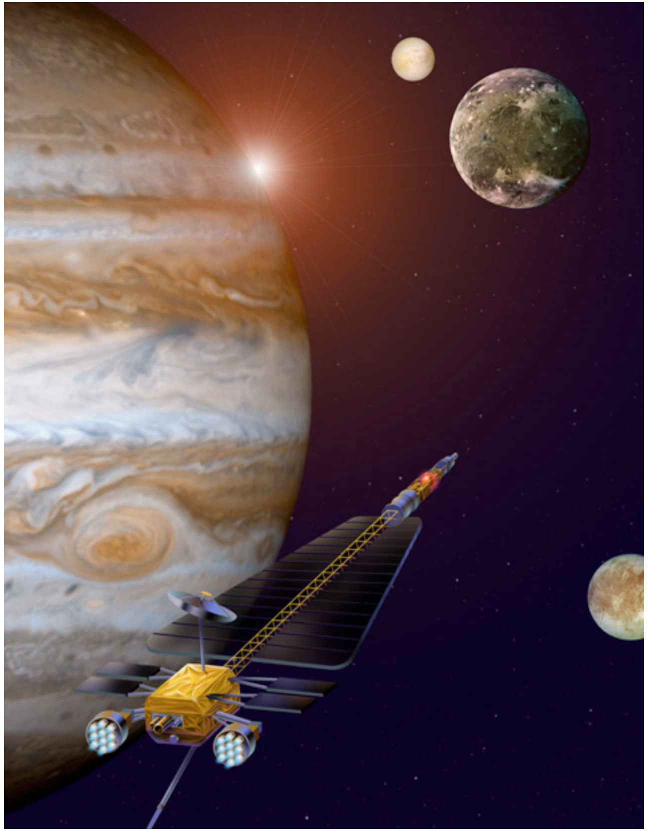
- Don't send bits that don't need to be sent
- Examples:
  - Long runs of zeros can be represented by a single number--the number of zeros
  - Frequency bands with no content don't need to be sent
  - Bit patterns that occur more often can be encoded into shorter codewords—think Morse Code

And then there's optical



- **Planned Tech Demo on Psyche**
- The equations are different but the same basic principles discussed for RF apply
  - Remember going higher in frequency helps
  - But factors like pointing and "antenna" surface quality become more problematic
- Must deal with weather and atmosphere
- Much less mature than RF so plenty of room for efficiency improvements

The Challenge—Outer Planets & Beyond



- In the inner solar system, we expect to be able to send gigabits/second of data by generating lots of power (solar or nuclear) and using large antennas (it's not cheap...)
- The Outer Planets and Beyond are more of a challenge
  - Need more power
    - Really big, efficient, solar arrays
    - Nuclear power
  - Need large flight apertures
    - RF: Large aperture, low mass, deployable antennas
    - Optical: Large aperture, low mass telescopes
  - More aperture on Earth would help

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Deep Space Link Parameters