Deep Space Communication

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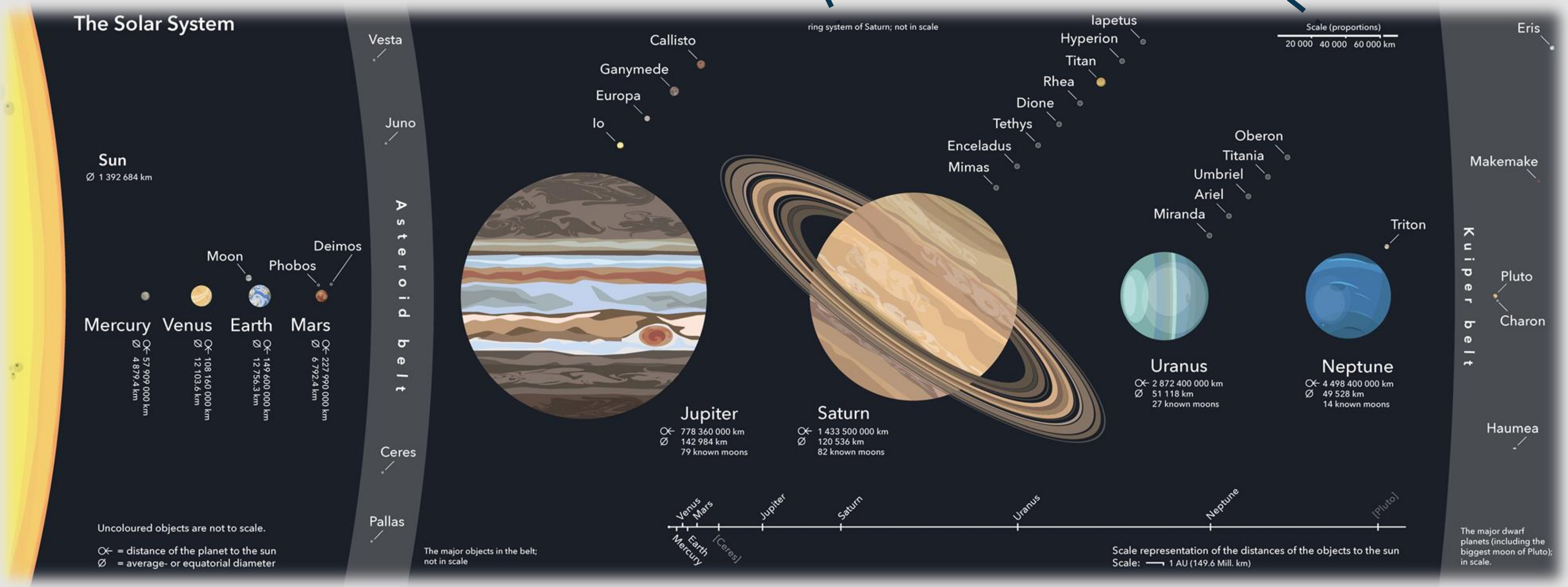
HelioSphere

0.0016 ly

8 planets



Solar System

1.5 ly
8 planets

Milkyway Galaxy

1e5 ly
~400e9 starts

Observable universe

46e9 ly
~100e9 galaxies

Pale Blue Dot

A perspective on humanity’s place in the universe

- Taken on Feb. 14, 1990, by the Voyager 1 space probe
- A record distance of about 6 billion km, or equivalently 40.5 AU
- 1-pixel apparent for the Earth

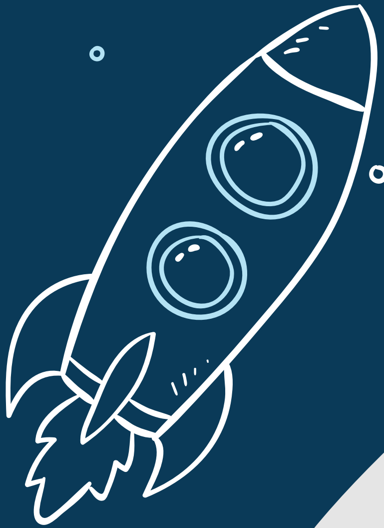
Deep Space

NASA: Any distance further than the moon which is roughly 384,000 km

ESA: Any distance greater than 2,000,000 km from the earth

Deep Space Communication

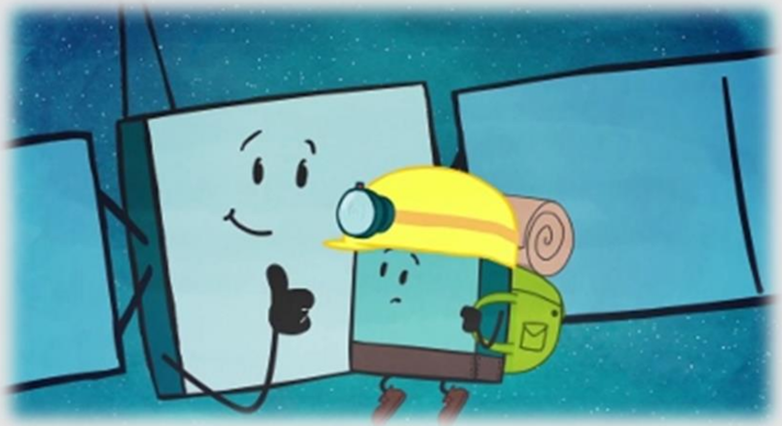
Reliable communication with a spacecraft located in deep space, to send commands or software updates, track location and receive telemetry, images, and scientific data



01.

Challenges

Strange Numbers



	Operator	Weight	Power	Distance	RTT	Rate
Rosetta	ESA (04-16)	1230 kg	850 W	4.66 AU	77.81 min	~100 kb/s
Cassini	NASA/ESA (97-17)	2523 kg	885 W	9.13 AU	2.54 h	~20 kb/s
Voyager 2	NASA (77-21)	721 kg	470 W	152.08 AU	1.76 d	~20 b/s

Deep space communication capability will need to grow by nearly a factor of 10 during each of the coming three decades.

Stringent Requirements

Low-mass

Strict size and weight constraints
Usually, some kilograms for telecommunication
44 kg for radio frequency subsystem in Voyager
4.2 kg for modem subsystem in Voyager
50 kg for antenna subsystem in Voyager

Low-power

Solar power vs radioisotope thermoelectric generator
360 W for telecommunication in Voyager

Sensitive

Sensitive equipment for signal manipulation
High tolerance manufacturing and design
15 K low noise receiver in Voyager's ground station
70 m diameter 3850 m^2 dish with 1 cm accuracy
Dish positioning with <0.001/s accuracy

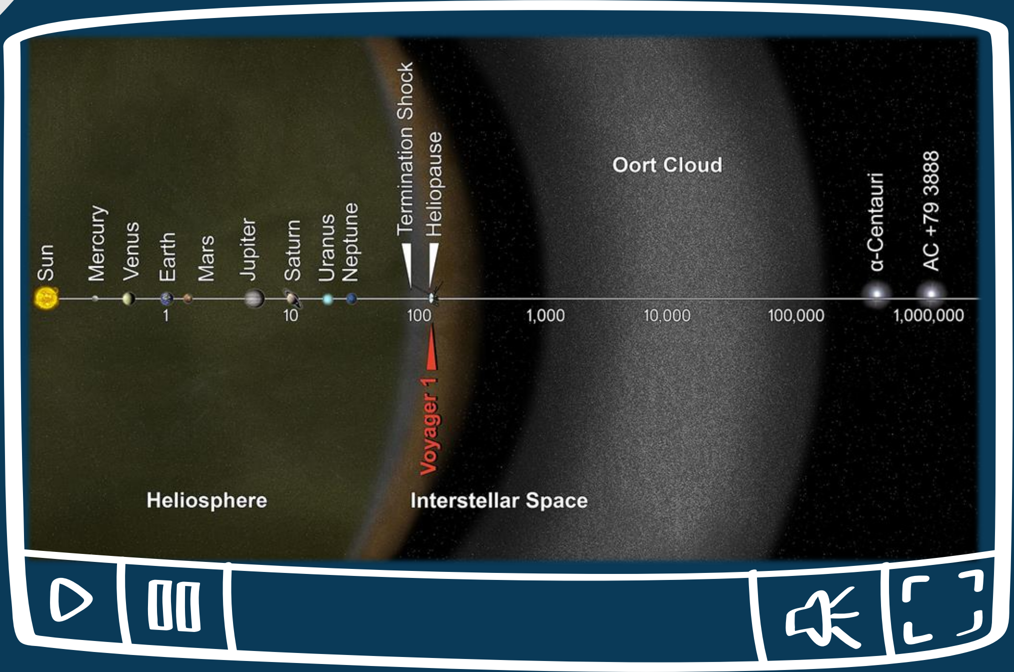
Reliable

No physical maintenance
Travels usually longer than 10 years
43-year lifetime of Voyager
Galileo's high gain antenna failure
Phobos-Grunt's control lost

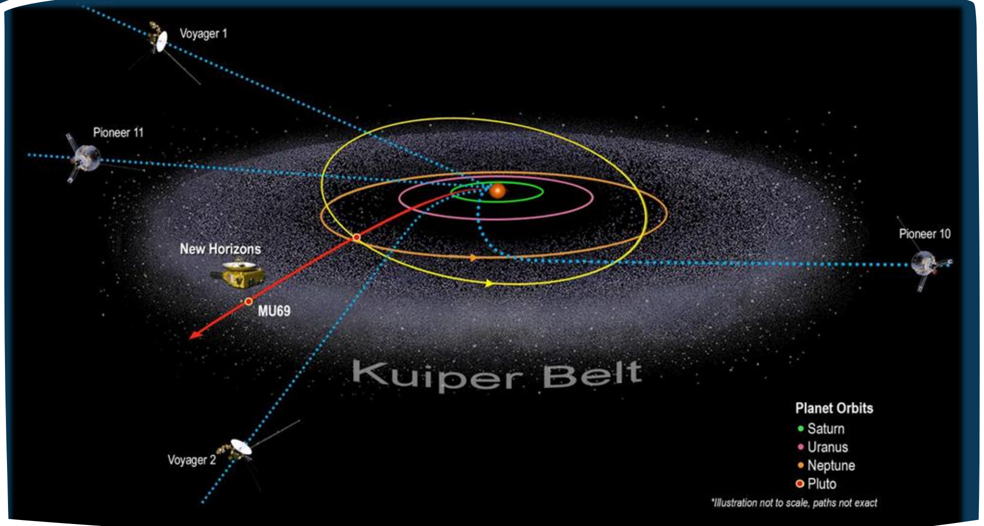
02.

Voyager Communication

Interstellar Probe



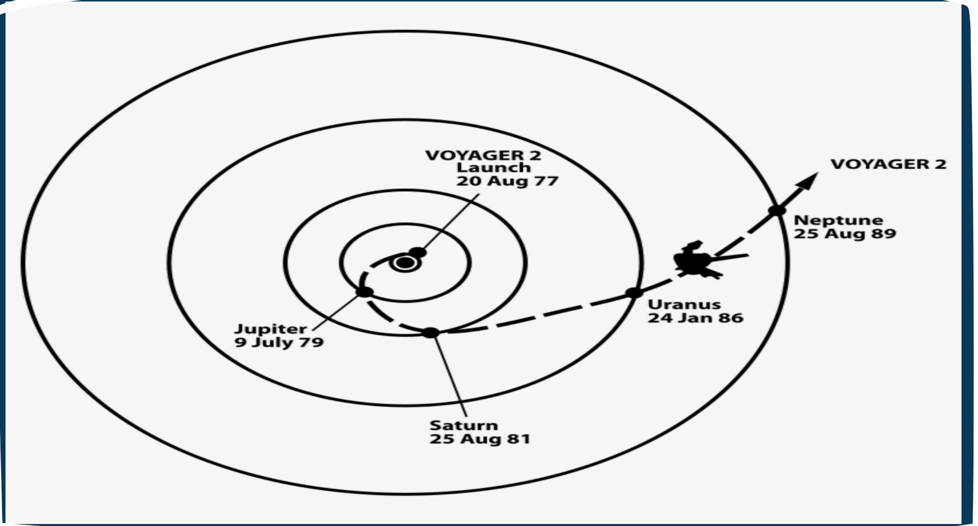
Interstellar Probe



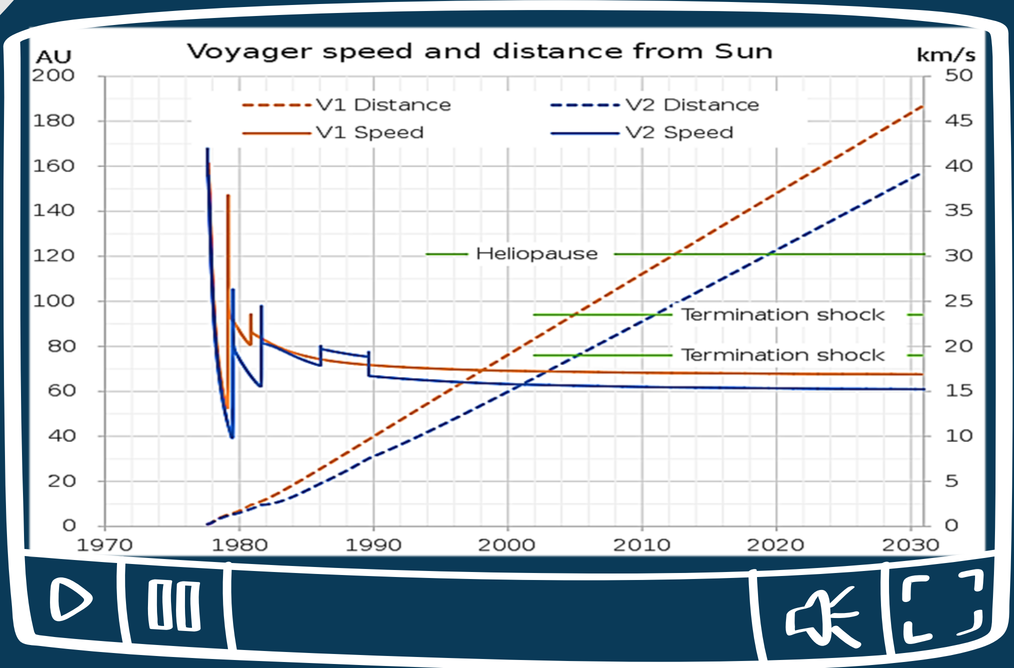
03.

Voyager Spacecraft

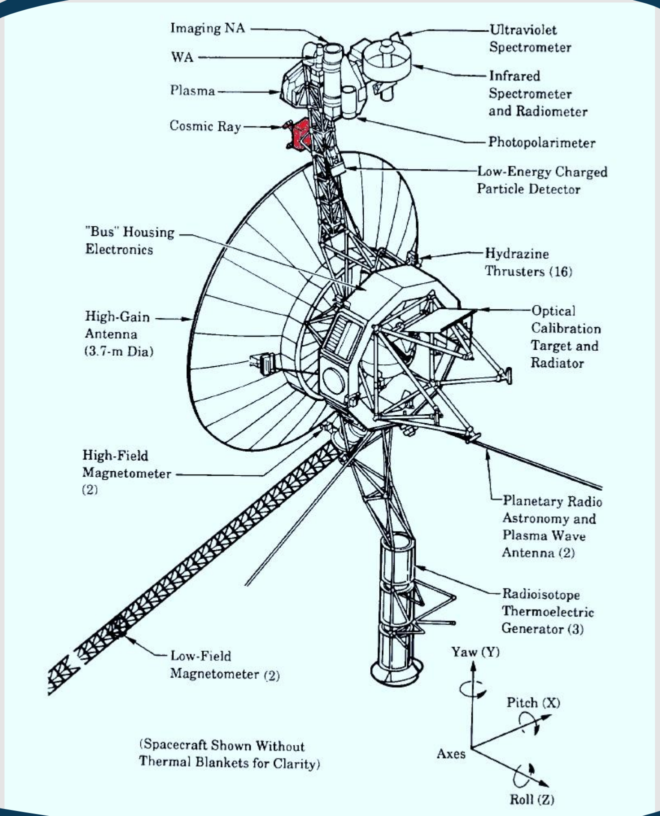
Voyager's Path



Voyager's Path

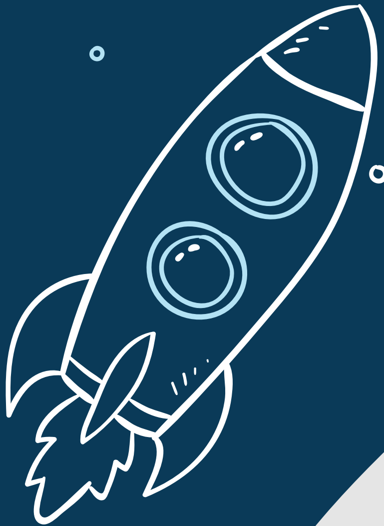


Voyager's Sub-Systems



Voyager's Sub-Systems

- Control and Communications Subsystems
  - Bus
  - High Gain Antenna (HGA)
  - Attitude Control
  - Power Subsystem
  - Data Storage Subsystem
  - Computer Command Subsystem
  - Flight Data Subsystem
- Instrument Subsystems
  - Imaging Science Subsystem (ISS)
  - Infrared Interferometer Spectrometer and Radiometer (IRIS)
  - Ultraviolet Spectrometer (UVS)
  - Photopolarimeter Subsystem (PPS)
  - Planetary Radio Astronomy (PRA)
  - Plasma Wave Subsystem (PWS)
  - Radio Science Subsystem (RSS)
  - Magnetometer (MAG)
  - Plasma Subsystem (PLS)
  - Low-Energy Charged Particle (LECP)
  - Cosmic Ray subsystem (CRS)



04.
Deep Space Network

Deep Space Network

1

DSN consists of three centers, located roughly 120 degrees apart, to provide full 24/7, 360 degree coverage as the earth rotates.

2

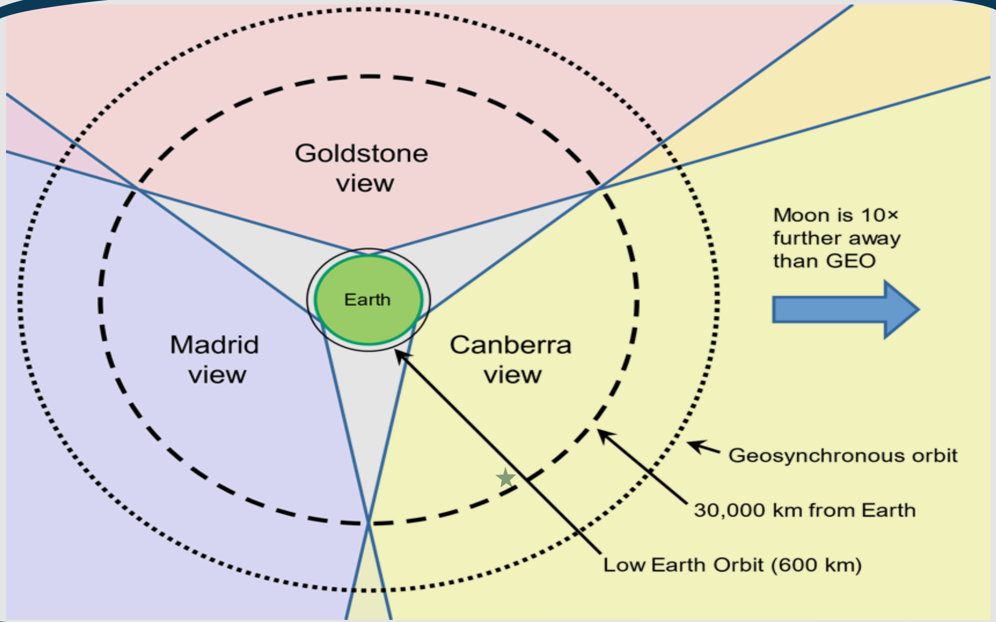
DSN has three centers in California (USA), Canberra (Australia) and Madrid (Spain), each has one 70m--diameter antenna, one 34m and one 26m antenna.

3

DSN usually uses microwave spectrum divided in:
L-Band: 1.67–1.71 GHz
S-Band: 2.025–2.3 GHz
X-Band: 8-9 GHz
Ka--Band: 20--30 GHz

4

DSN commonly utilizes
- BPSK modulation
- Circular polarization
- RS and Turbo coding



Deep Space Network

Deep Space Network

05.

Communication Capacity

Power Budget

$$S = P G_T L_S L_A G_R$$

$$L_s = \left(\frac{\lambda}{4\pi D}\right)^2 = \left(\frac{c}{4\pi f D}\right)^2$$

$$G_R = \left(\frac{\pi d_R}{\lambda}\right)^2 e_R$$

$$G_T = \left(\frac{\pi d_T}{\lambda}\right)^2 e_T$$

Quantity	Name	Unit
P, S	Transmit/Receive Power	W
G_T, G_R	Transmit/Receive Antenna Gain	dB
d_T, d_R	Transmit/Receive Antenna Diameter	m
e_T, e_R	Transmit/Receive Antenna Efficiency	-
L_S, L_A	Free Space/Atmosphere Loss	dB
λ, f	Wavelength/Frequency	m
D	Communication Distance	m
c	Light Speed	m/s

Shannon Capacity

$$R = B\log_2(1 + \frac{S}{N})$$

$$R = B\log_2(1 + \frac{S}{N_0 B})$$

Quantity	Name	Unit
R	Channel Capacity	b/s
B	Channel Bandwidth	Hz
S	Receive Power	W
N	Noise Power	W
N_0	Noise Spectral Density	W/Hz

Power-limited Capacity

$$R = B\log_2\left(1+\frac{S}{N_0 B}\right)$$

$$R = \frac{B}{\ln 2}\ln\left(1+\frac{S}{N_0 B}\right)$$

$$R \approx \frac{B}{\ln 2}\frac{S}{N_0 B} = 1.44\frac{S}{N_0}$$

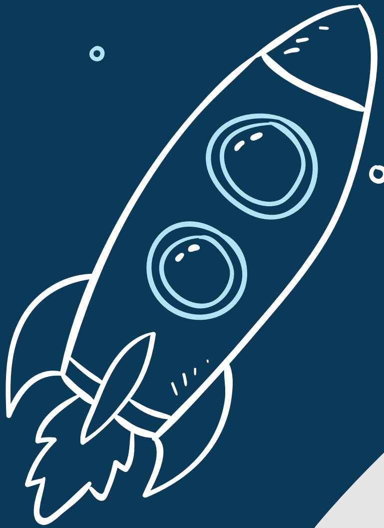
Quantity	Name	Unit
R	Channel Capacity	b/s
B	Channel Bandwidth	Hz
S	Receive Power	W
N	Noise Power	W
N_0	Noise Spectral Density	W/Hz

Deep Space Rate

$$R \approx 1.44 \frac{P G_T L_A G_R}{N_0} \left(\frac{c}{4\pi f D} \right)^2$$

$$R \propto \frac{1}{D^2}$$

Quantity	Value	Unit
c	3e8	m/s
f	8.42e9	Hz
P	12.3	W
G_T	48.2	dB
G_R	73.7	dB
L_A	-4.8	dB
N_0	2.8980e-22	W/Hz
D	2.2749e+13	m
R	487	b/s



06.

Further Reading

Interesting topics

Optical Communication

Higher bandwidth over long distances

Arraying Antenna

Larger antenna gain

Interplanetary Internet

A network of interconnected nodes on Earth, in space, and orbiting other planets

References

For more information, visit

https://voyager.jpl.nasa.gov/
https://eyes.jpl.nasa.gov/dsn/dsn.html

Thanks!

Do you have any questions?
Contact me via mohammad.hadi@sharif.edu
Visit me at room 424, EED, SHUT.