SPACE COMMUNICATIONS
&
THE INTERPLANETARY INTERNET

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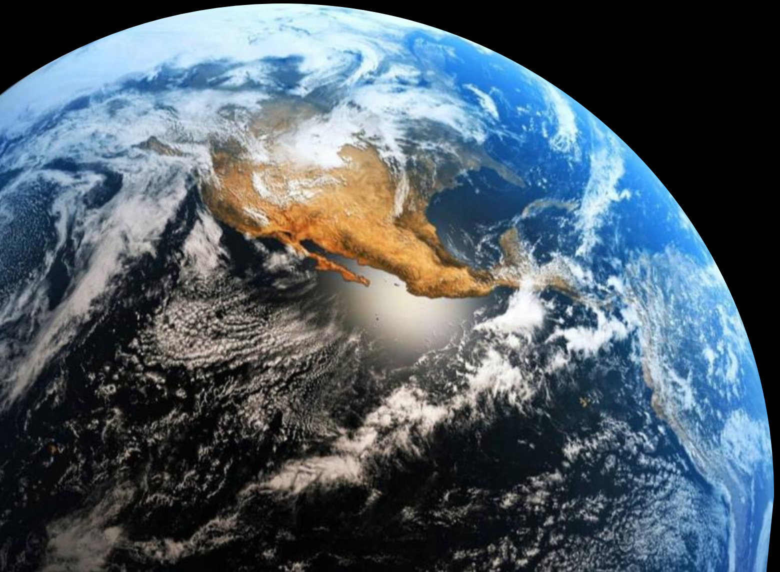


IPNSIG ACADEMY KEYNOTE – DEC 2024

About the speaker

Dr. Alberto Montilla

CEO Spatiam Corporation: Creating the Interplanetary Internet

Board Member Interplanetary Networking Special Interest Group

25 years of experience in Communications and Networking Services

Former Assistant Professor of Radiation and Propagation,
Engineering School URBE (Venezuela)

Dr. Networking Engineering, UC3M

MBA from IEB - Spain.

AGENDA

Space Communications 101

Towards the Interplanetary Internet

From Space Exploration to the Space Economy

SPACE COMMUNICATIONS 101

Voyager 1 – An extreme example of Space Communications

The first human-made object reaching interstellar space

- Launched September 5 1977
- Reached interstellar space in 2012

PHYSICAL
Distance from Earth 15.4 Billion Miles (166 AU)
Speed 30,026 miles per hour
One-Way Light Time (OWLT) 23 hours, 03 min, 17 s

COMMS
DL Frequency X-band (8 GHz) On (S-band OFF)
Signal level received on Earth 1×10^{-18} watt
Current bitrate 160 bit per second

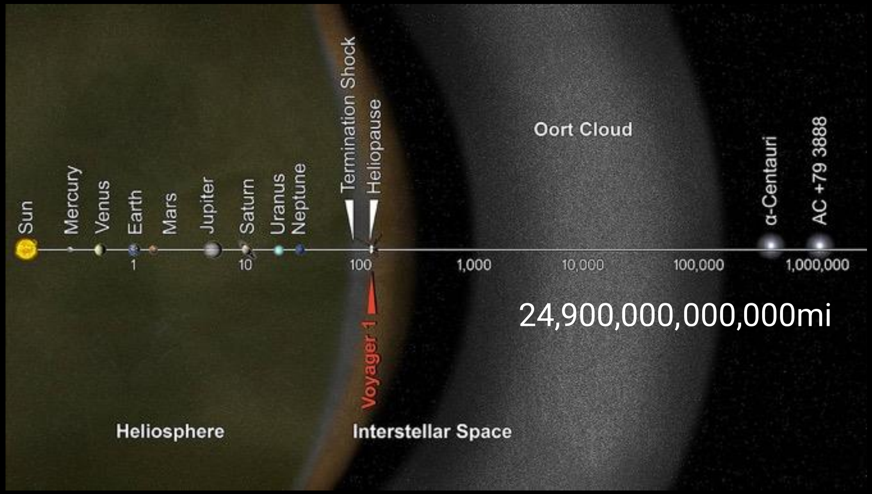
For more info https://voyager.jpl.nasa.gov/

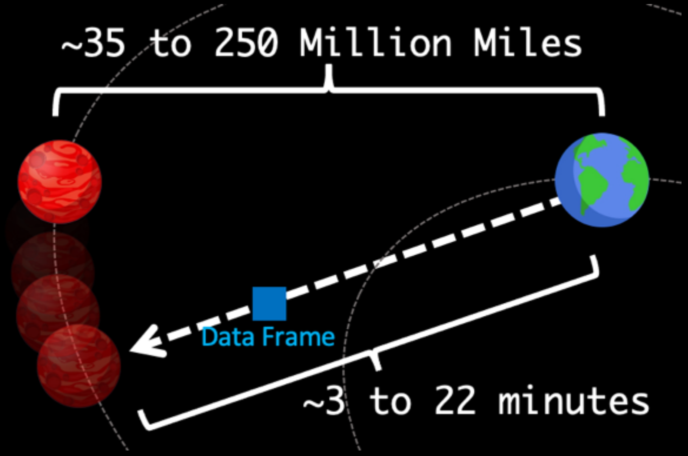
EFFECTS OF DISTANCE IN SPACE COMMUNICATIONS

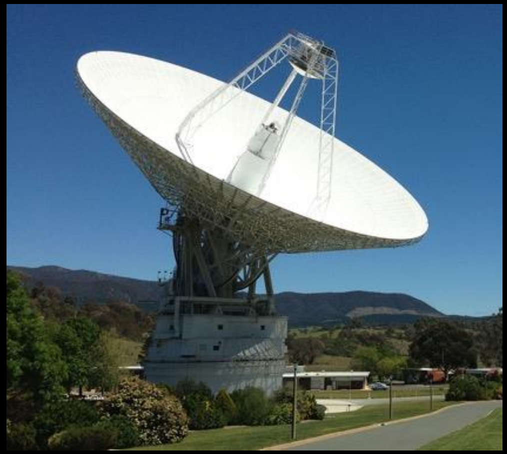
DISTANCE	**COMMUNICATIONS DELAY**	**+ SIGNAL LOSS** (frequency x distance^2)
Earth Orbit →	Milliseconds to hundreds of milliseconds	150 dB a 230 dB (x10^{-16} – x10^{-23})
• International Space Station: 250 miles		
• Geostationary Orbit: 22,236 miles		
Solar System →	Seconds to hours	282 dB (x10^{-29})
• Moon: 238,900 miles		
• Mars: 35 to 250 million miles		
Interstellar Space →	Days to Years	376 dB (10^{-38})
• Proxima Centauri: 24.9 trillion miles (4.3 light years)		

¡Real time communications is not possible!

Bigger dishes, better electronics - $$$$







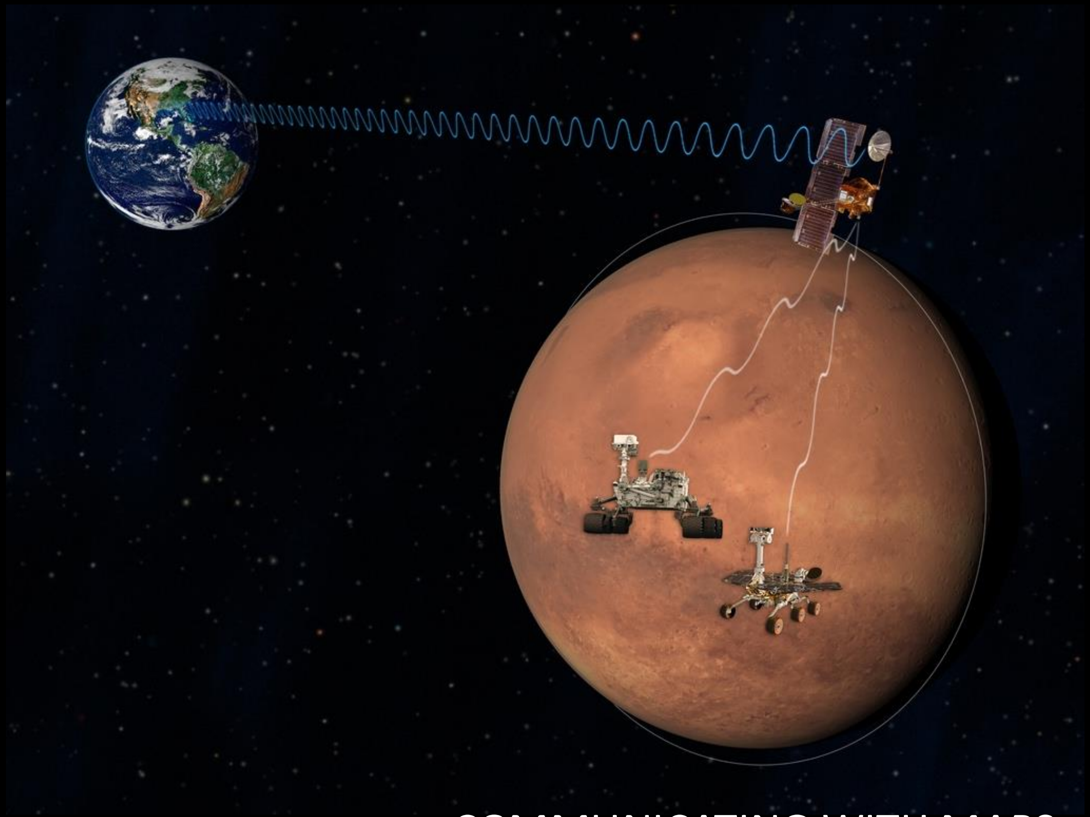
DISRUPTIONS IN SPACE COMMUNICATIONS

CELESTIAL MECHANICS
Relative rotation, translations, conjunctions.

→

DISRUPTIONS (No line of sight!)
Loss of Signal (Communications)

DARK SIDE OF THE MOON



COMMUNICATING WITH MARS

What's a relay satellite

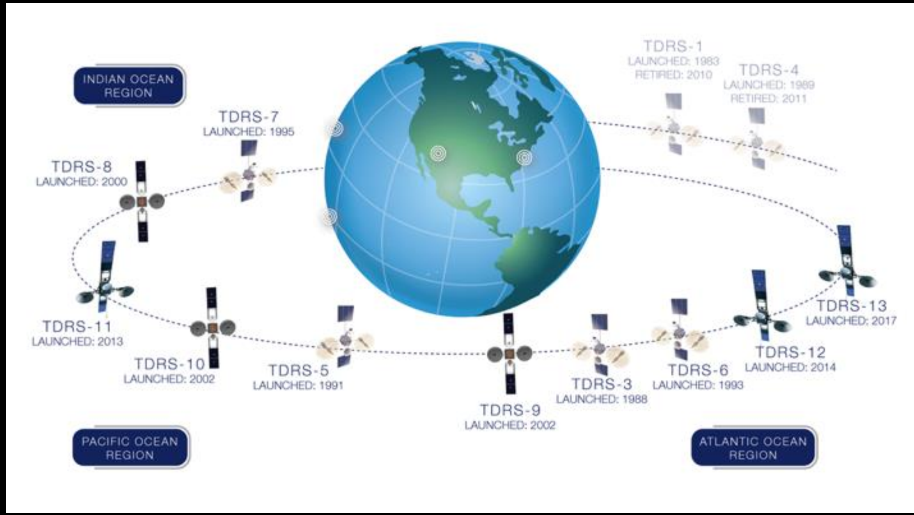
An example – NASA TDRS (Tracking and Data Relay Satellite)

Connects two moving elements, e.g.

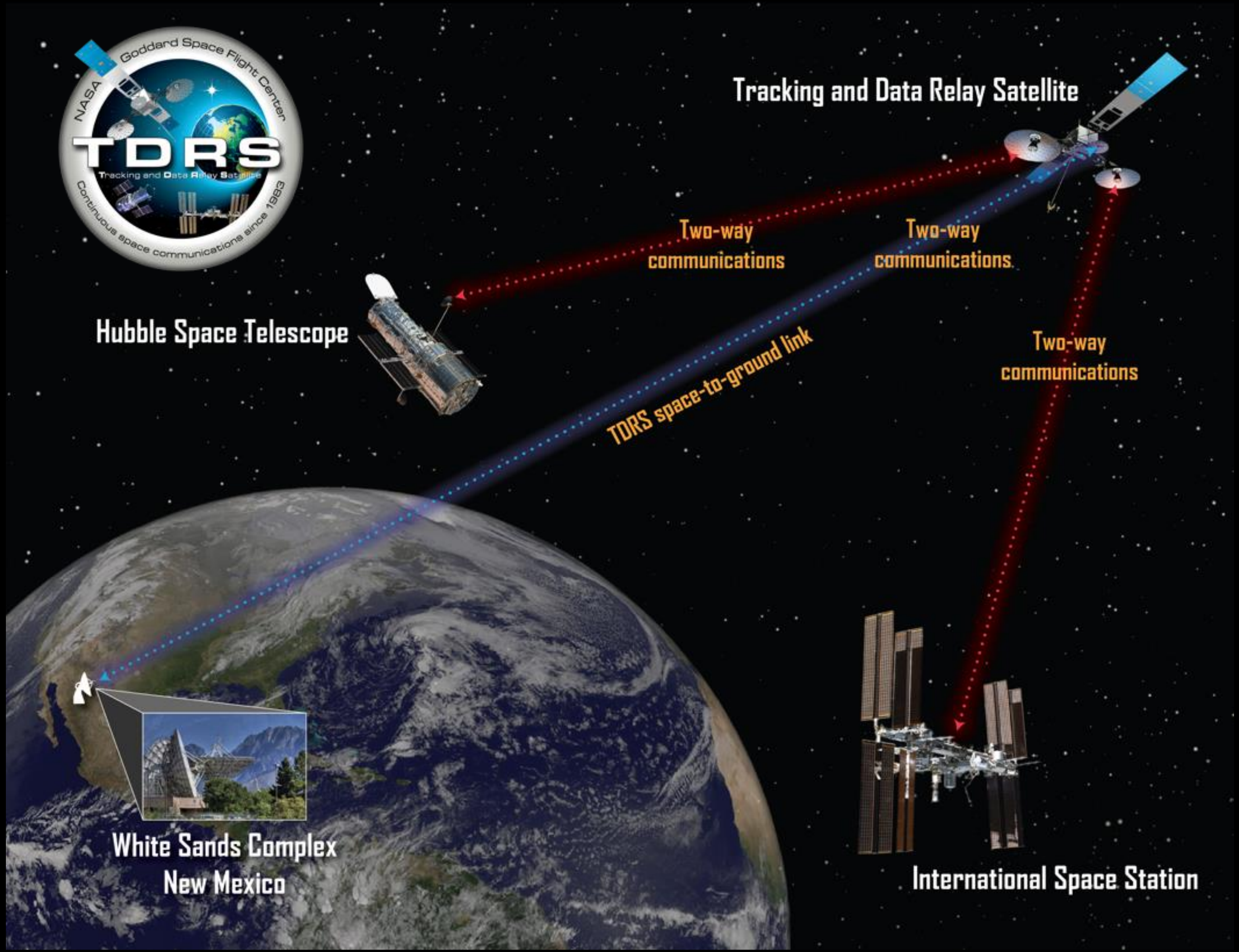
- Earth Ground Station
- Spacecraft
- Planetary surface

Typically operates in multiple frequencies

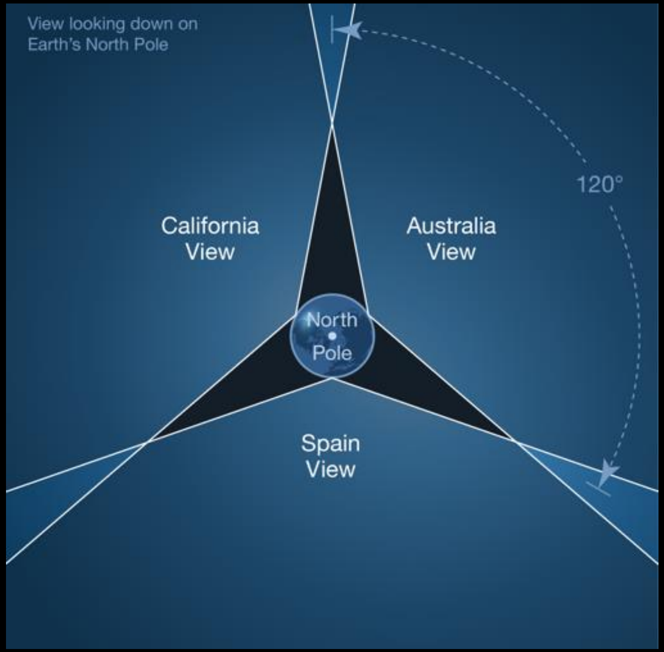
Can operate in any orbit



TDRS operates in Geostationary (GEO) orbit



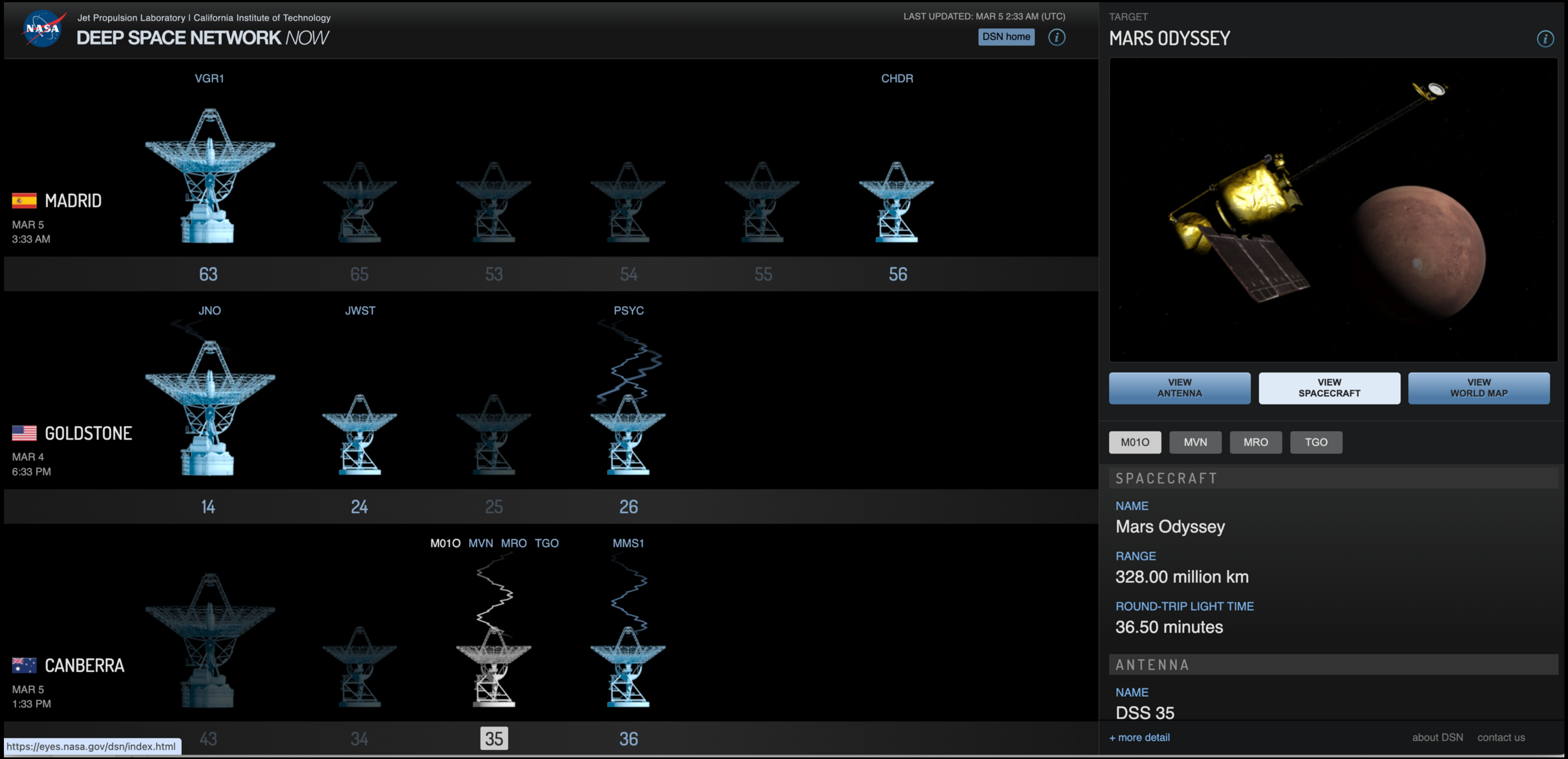
MINIMIZING DISRUPTIONS IN SPACE COMMUNICATIONS



On Earth
Ground station antennas (min 3) around the world.120 degrees of separation

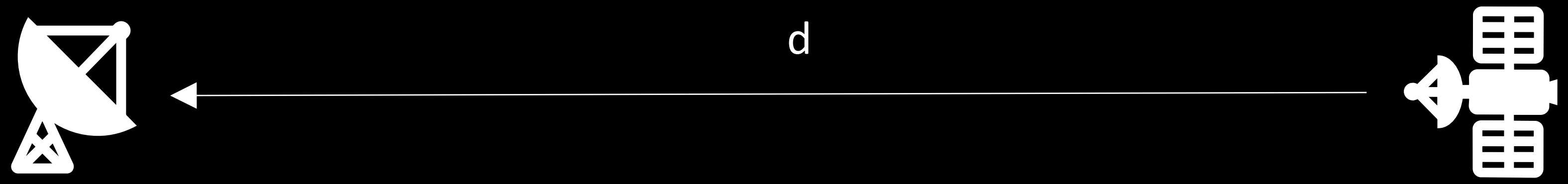
Earth vicinity
Satellite networks
Multiple types of orbit possible

NASA DEEP SPACE NETWORK



Building a space network

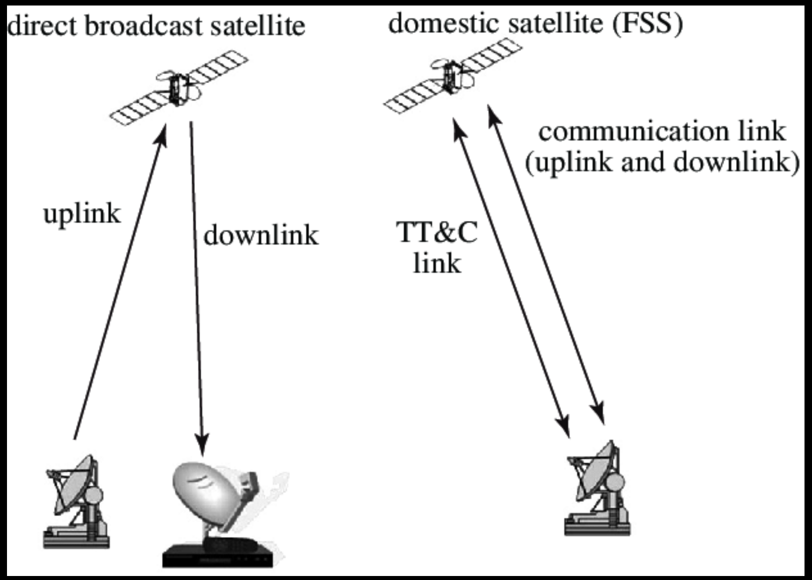
Space (PHY) Link



$$Power_{Rx} = \frac{Power_{Tx} \times Antenna\_Gain_{Tx} \times Antenna\_Gain_{Rx}}{Free_{Space_{Loss}(d,f)} \times Transmitter\_Loss \times Misc\_Loss}$$

There is a minimum signal level (Power) to be received for the system to be able to demodulate the signal.
This depends on the specific modulation/encoding used.

Transmitter Loss: Cables, connectors, splitters, etc.
Miscellaneous Loss: Polarization, fading, etc.

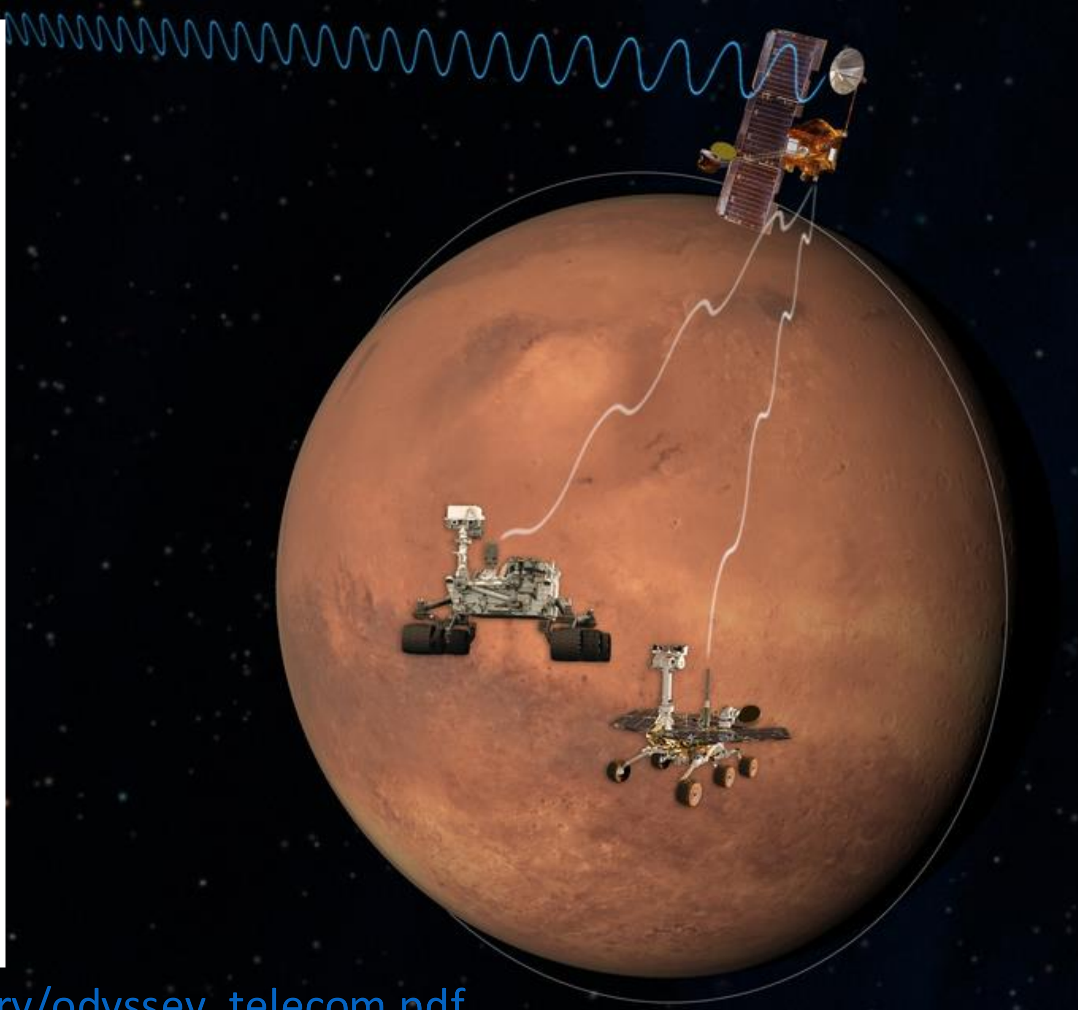


Space Link Application

Mars Odyssey Orbiter (UHF link, PSK modulation)

Table 5-5. Link budget for forward link (Odyssey transmits).

Observation Date	6/6/01					6/8/01	6/21/01
Observation Time [ERT]	07:00 UTC					07:00 UTC	04:50 UTC
Transmission Station (Odyssey)	**Nominal**	**Fav**	**Adv**	**Avg**	**Var**	**Nominal**	**Nominal**
Frequency [Hz]	437100000.0						
Wavelength [m]	0.6859						
Modulation	**CW**						
Transmit Power [W]	12.0						
Transmit Power [dBm]	40.8	0.50	–0.5	40.8	0.083		
Circuit Losses [dB]	–1.0	0.2	–0.2	–1.0	0.013		
Antenna Gain [dBi]	4.8	1.0	–1.0	4.8	0.333		
EIRP [dBm]	*44.6*			*44.6*			
Range [m]	2.02E+10					2.11E+10	2.82E+10
Space Losses [dB]	–231.4	0.0	0.0	–231.4	0.000	–231.8	–234.3
Atmospheric Losses [dB]							
Receiving Station (Stanford)							
Antenna Diameter [m]	45.7						
System Efficiency	0.60						
Antenna Effective Area [m2]	985.0						
Antenna Gain [dB]	44.2	0.3	–0.3	44.2	0.030		
Feed Losses [dB]	–0.7	0.1	–0.1	–0.7	0.003		
Polarization Losses [dB]	–0.1	0.1	–0.1	–0.1	0.003		
Misc Losses [dB]	–0.2	0.1	–0.1	–0.2	0.003		
Received Power [dBm]	*–143.6*			*–143.6*		*–144.1*	*–146.5*
System Temperature [K]	110.0	–55	55	110.0			
Sky Temperature [K]	70.0	–14	14	70.0			
Noise Density No[dBm/Hz]	*–177.0*	*–2.4*	*1.5*	*–177.4*	*1.313*		
Expected Pt/No [dB-Hz]	**33.4**			**33.9**	**1.783**	**32.9**	**30.4**
Sigma [dB]				1.3			
2*Sigma [dB]				2.7			
Expected Pt/No - 2*Sigma [dB-Hz]				**32.2**			

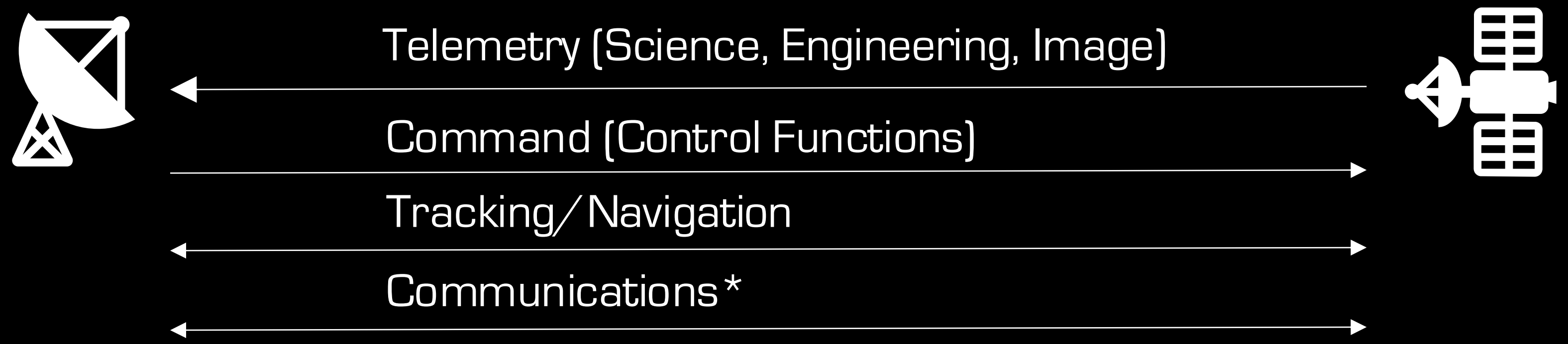


https://descanso.jpl.nasa.gov/DPSummary/odyssey_telecom.pdf

TOWARDS THE INTERPLANETARY INTERNET

Building a space network

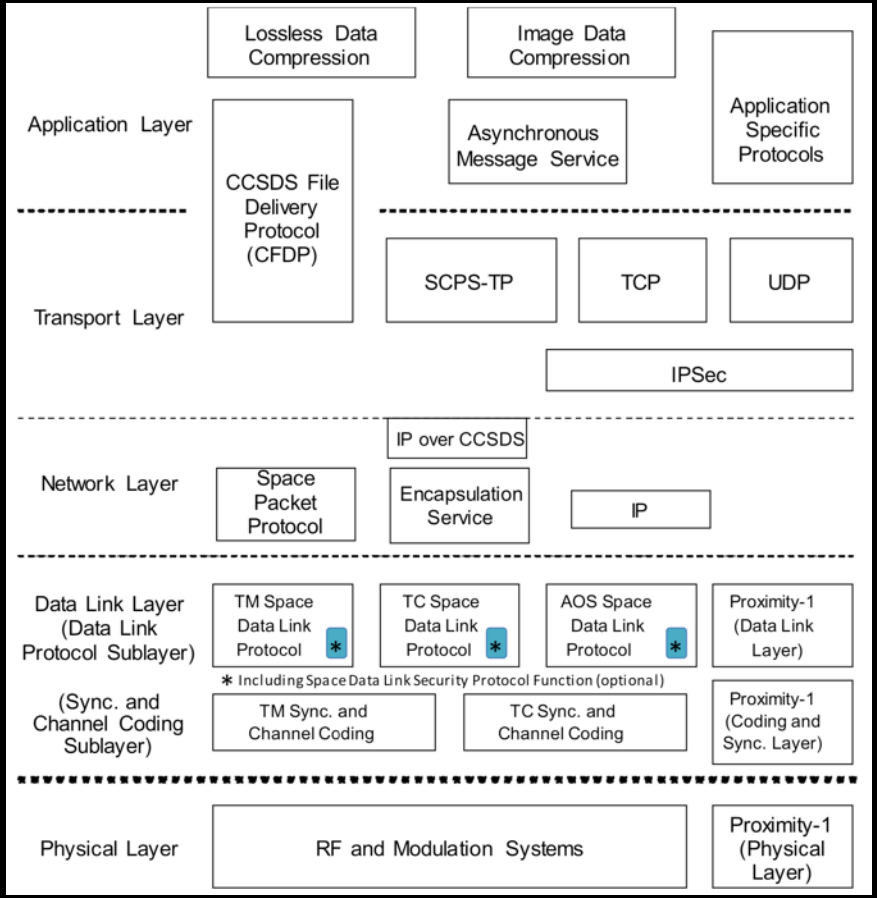
Data Transfer in Space



Type	Direction	Volume	Quality requirements	Applications
Telemetry	Downlink	Moderate to High	High to very high	• Sensor data • Sensor status • Imaging
Command	Uplink	Low	Very high	• Controlling spacecraft • Controlling sensors
Tracking/Navigation	Uplink, Downlink or bi-directional	Very Low	Very high accuracy	• Positioning and Navigation of spacecraft
Communications* for spacecraft delivering comms services	Bidirectional	High to very high	Very high	• Relays

Building a space network

Protocol stacks



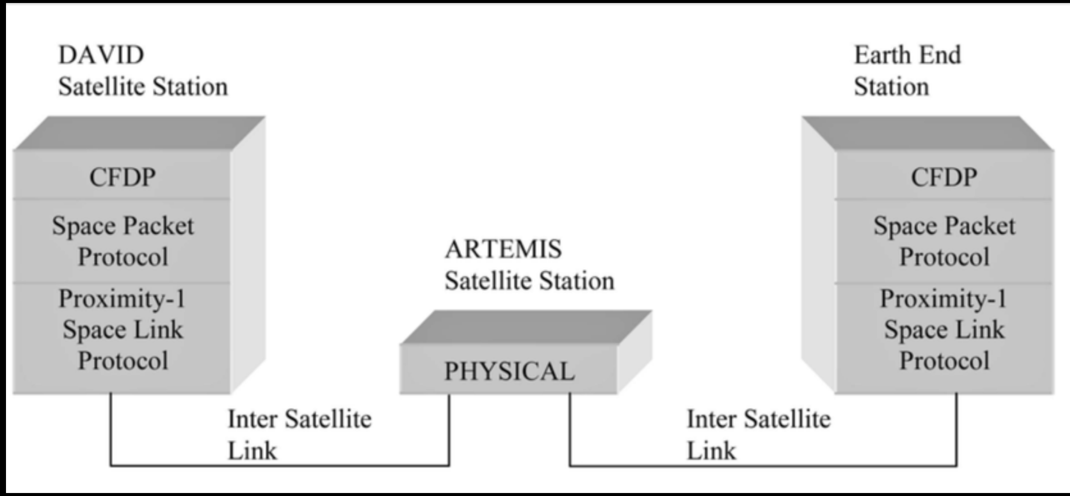
CCSDS "legacy" Space protocol stack

Popular modern protocols

CFDP: CCSDS File Delivery Protocol

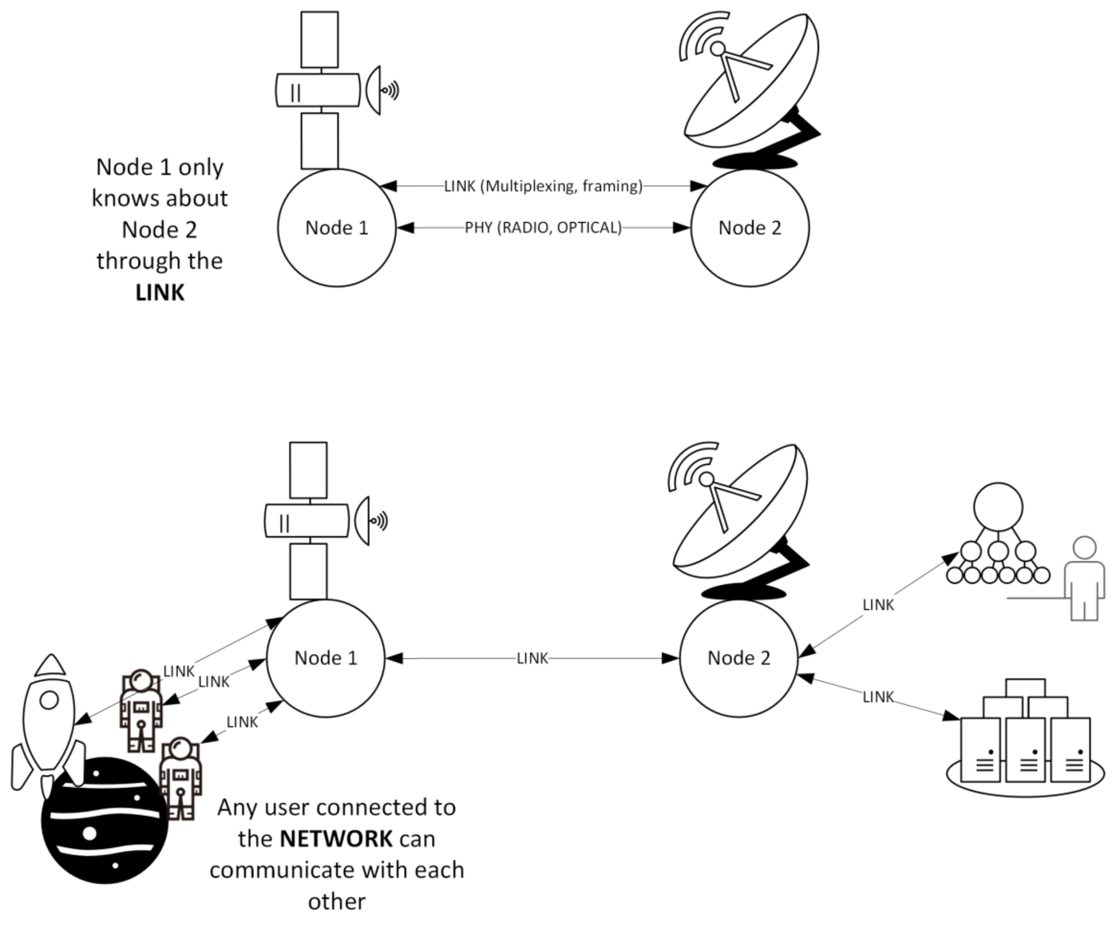
SPP: Space Packet Protocol

Proximity-1: Space Link Protocol



Building a space network

Networks – supporting communications at scale



LINKS

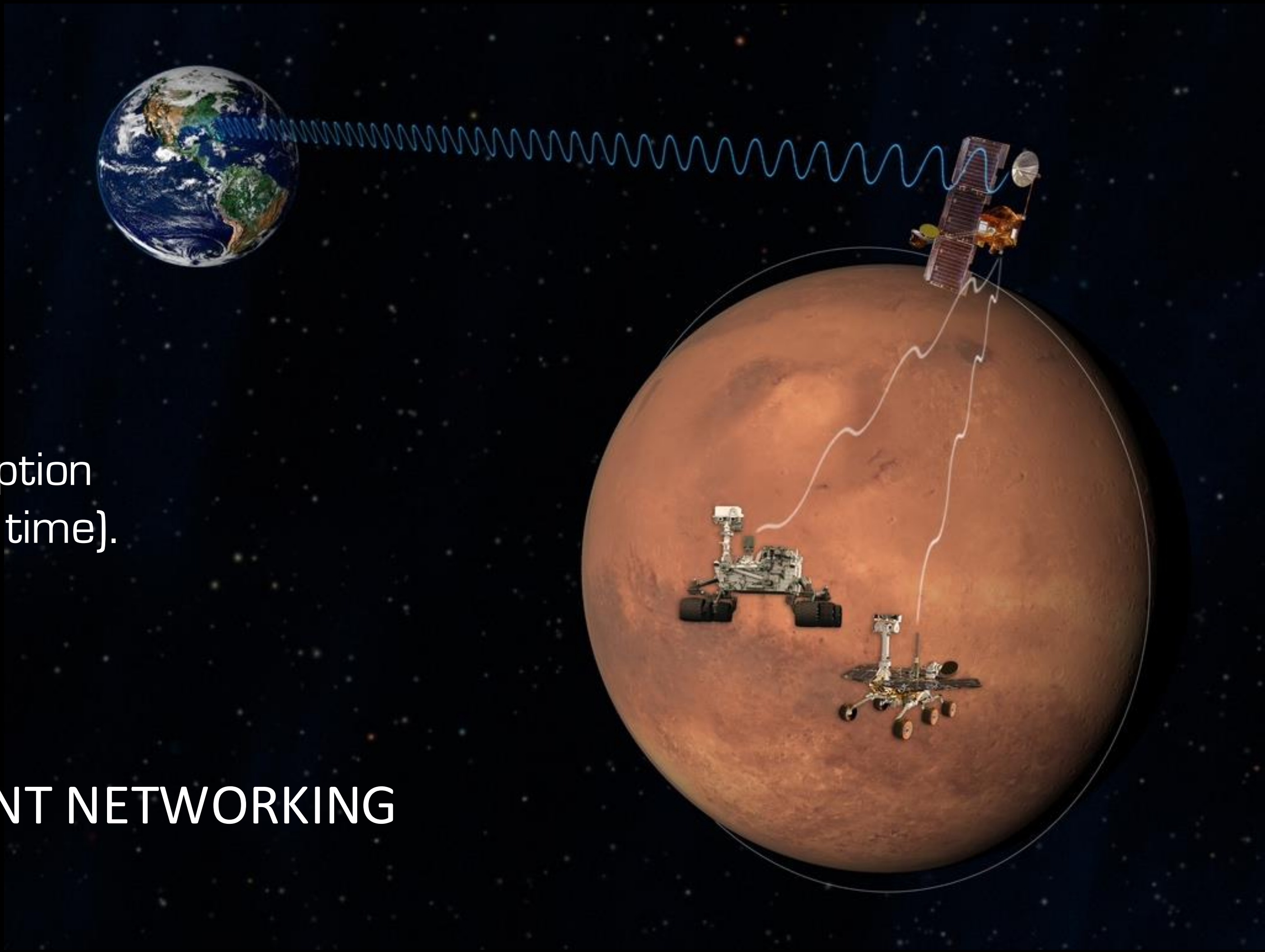
- Connect **two** nodes through a physical layer (Radio, optical) with specific link protocol for data framing, error corrections, etc.

NETWORKS

- Automatically connects **ANY** nodes that are connected through the network.
- Each node has one or more addresses (e.g. IP address, Bundle Protocol Node ID)
- Required when number of elements (nodes) increases

THE INTERPLANETARY INTERNET

1998



TCP/IP (Internet)
architecture and performance issues

- Centralized Infrastructure (DNS)
- Connection establishment in delay and disruption scenario (Mars - 7 to 40 minutes round trip time).
- Loss of information

SOLUTION

DTN – DELAY AND DISRUPTION TOLERANT NETWORKING

DELAY AND DISRUPTION TOLERANT NETWORKING

DTN is a digital communications networking technology that enables the reliable transfer of data across DTN network elements when the propagation delay is highly variable and/or very high.

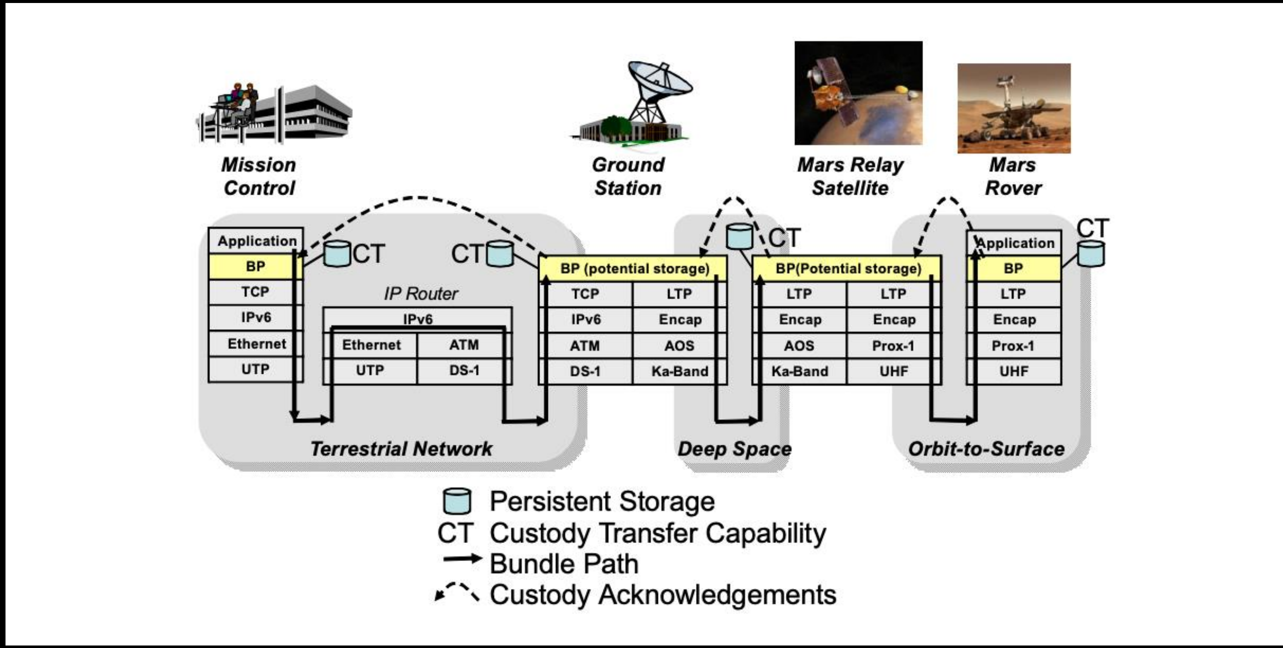
The data transmission is performed automatically, even when one or more network links are not available during long time intervals.

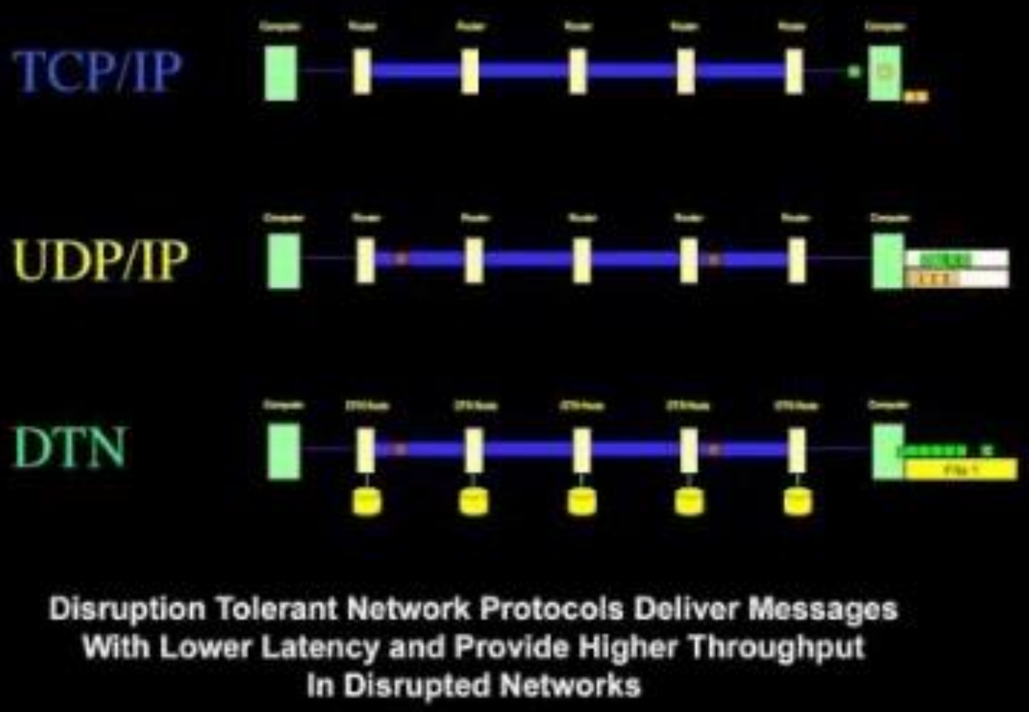
The main internetworking protocol in DTN is the Bundle Protocol (BP).

Information provided by IPNSIG

THE BUNDLE PROTOCOL [IETF RFC9171]

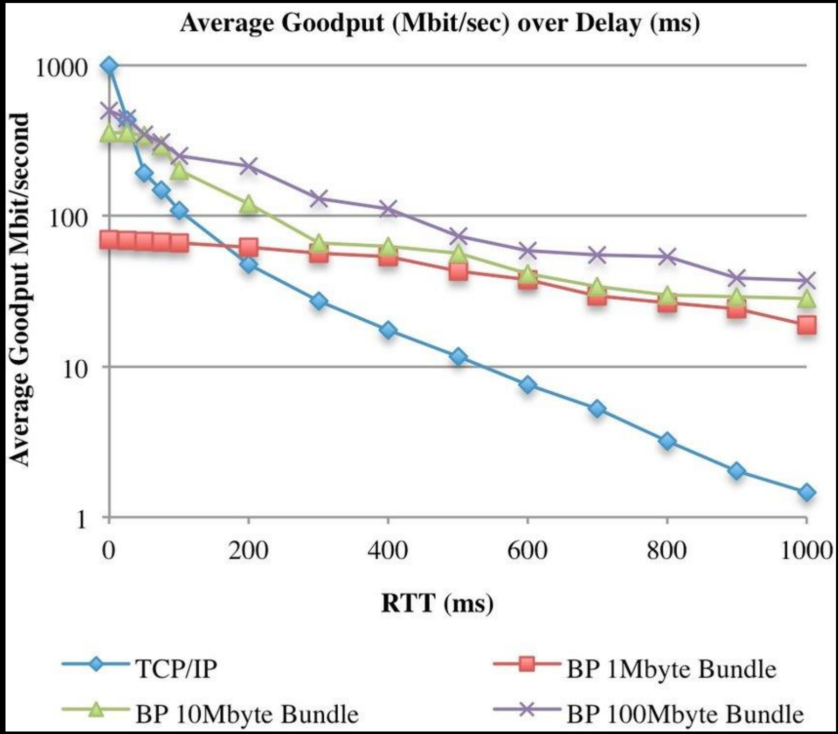
- Runs as overlay over multiple network/link technologies
- Networking with scheduled (planned) or opportunistic contacts.
- Network Store-and-forward

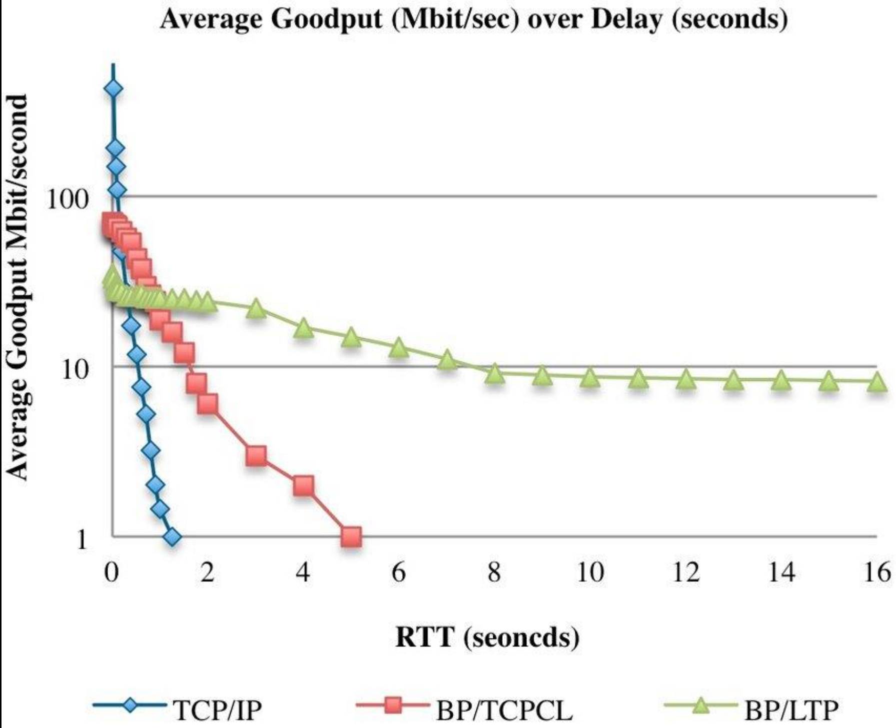




Information provided by IPNSIG

THE BUNDLE PROTOCOL
Performance examples*





* From "A performance comparison of DTN protocols for high delay optical channels". Muri and McNair. 2013

Information provided by IPNSIG

PROGRESS ON DTN AND THE INTERPLANETARY INTERNET

EXPERIMENTAL HIGHLIGHTS

2008-2011

- Successful DTN experiments onboard NASA EPOXI in deep space (81 sec delay)

2012-2016

- Successful control of robotic arm through DTN in the International Space Station, by the European Space Agency (ESA).

2016-2019

- NASA tests and setup the first DTN operational network in the International Space Station

2020

- IPNSIG PWG network – first civil open DTN ground network (in operation).

2021

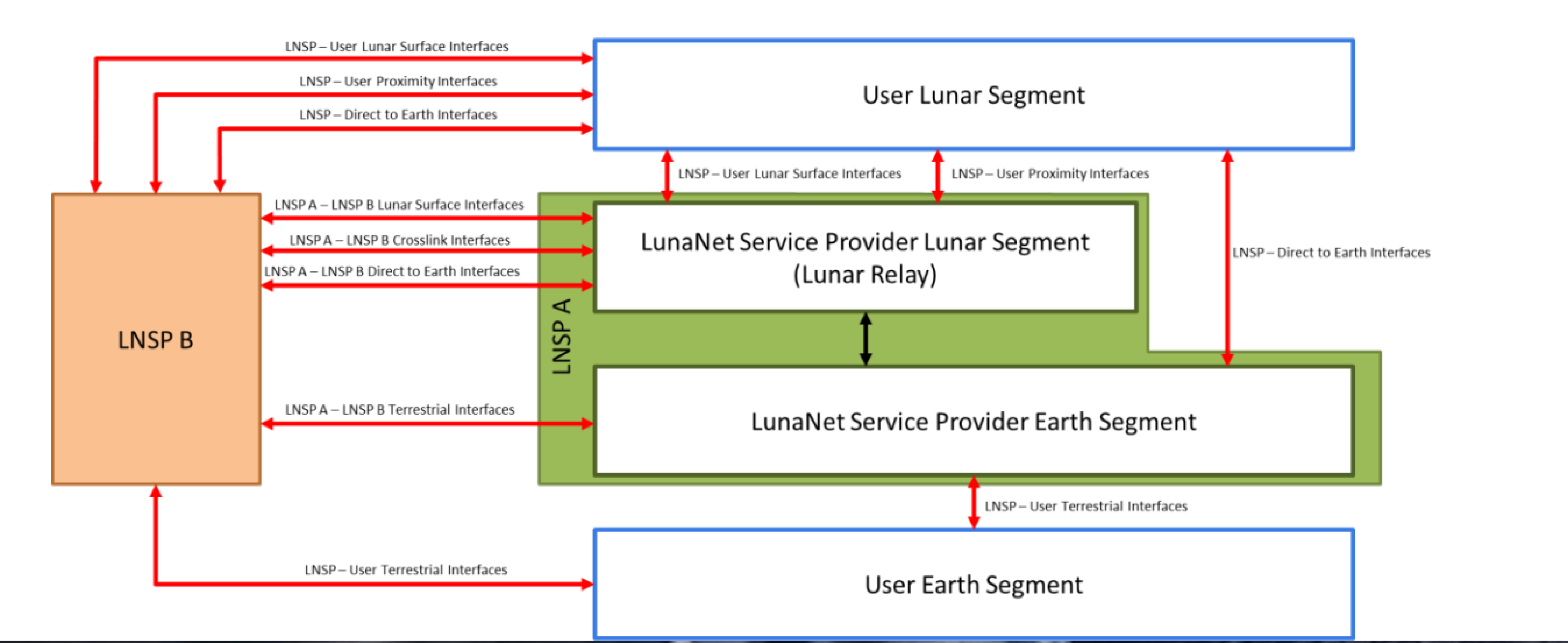
- D3TN Ring-Road DTN Network experiment in LEO with ESA OPS-SAT Satellite

2024

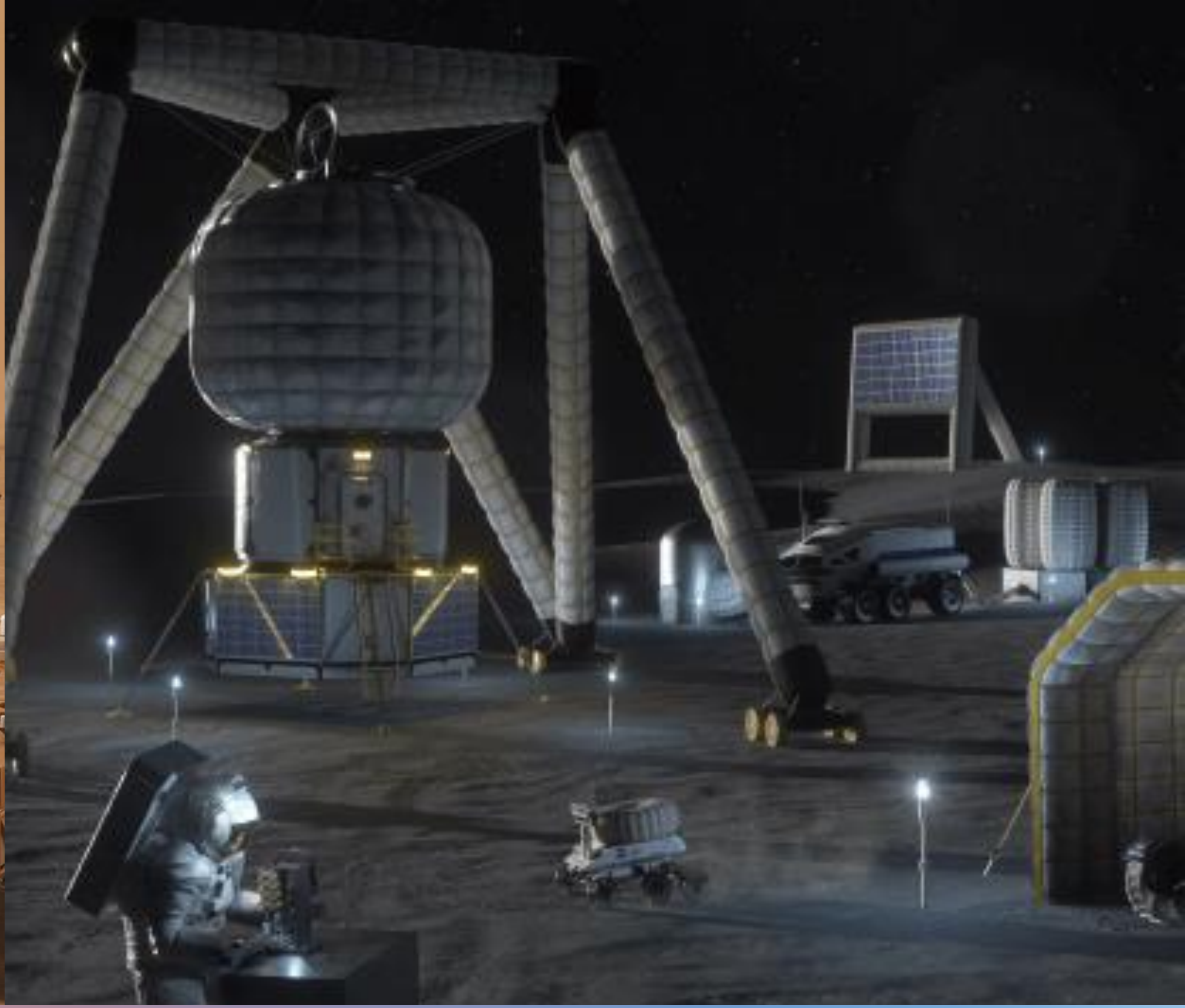
- PACE – First NASA class B mission that uses DTN operationally in a satellite.
- SPATIAM DTN Platform Technology Demonstration in the International Space Station.
- Spacely Packets – Implementation of E-mail service over Bundle Protocol.

Information provided by IPNSIG

LunaNet – LUNAR COMMUNICATIONS, POSITIONING NAVIGATION AND TIMING NETWORK ARCHITECTURE



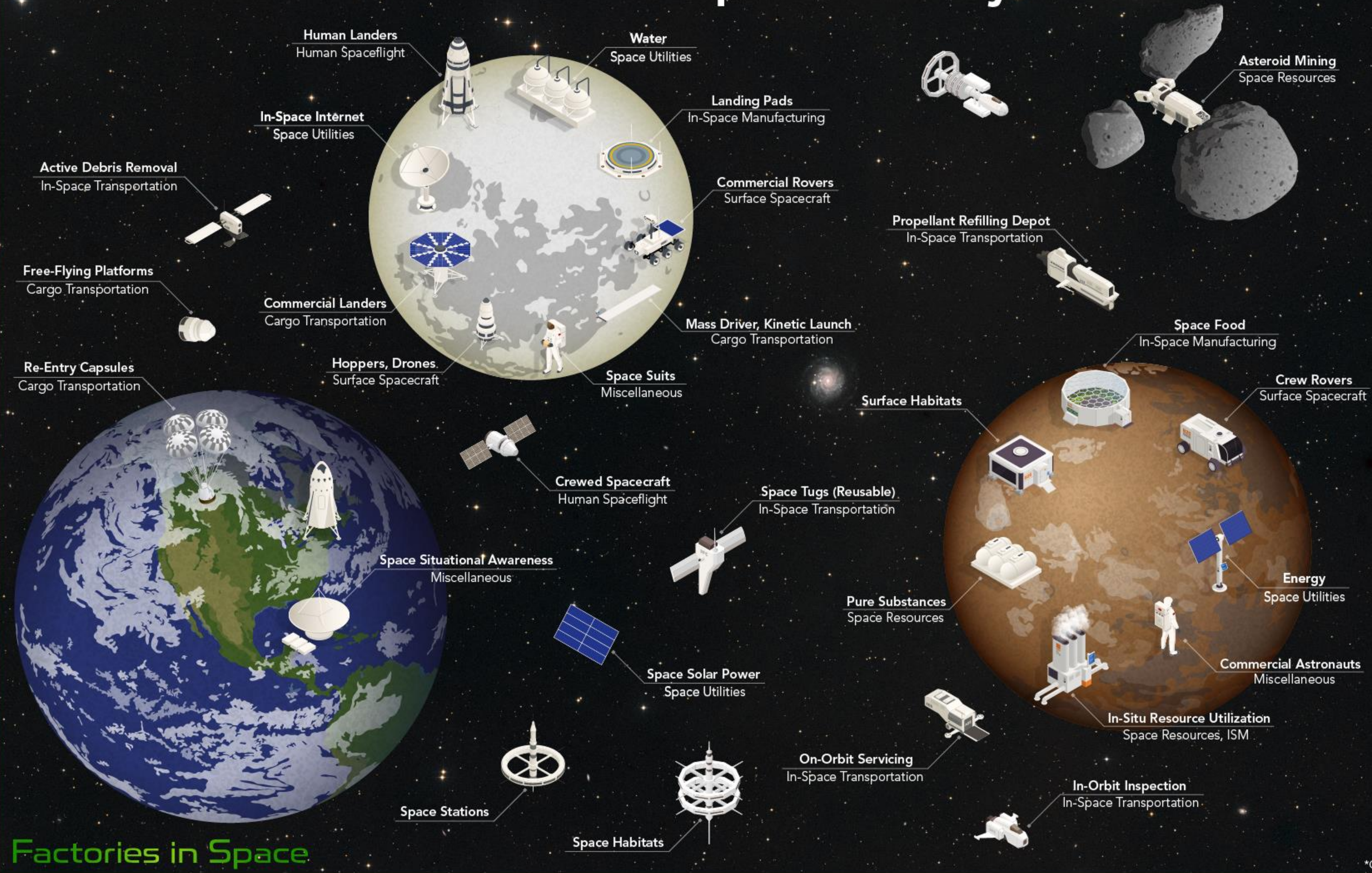
FROM SPACE EXPLORATION TO THE SPACE ECONOMY



THE SPACE ECONOMY WILL BE BASED ON DATA

In-Space Economy

factoriesinspace.com
2023-02-26



In-Space Economy Classification:

1) Human Spaceflight
   - Crewed Spaceships & Shuttles
   - Human Landers
2) Cargo Transportation & Landers
   - Robotic Landers (Moon, Mars)
   - Re-Entry Capsules (Earth, Mars)
   - Cargo Resupply
   - Reusable Satellites
3) Surface Spacecraft
   - Crew Rovers
   - Robotic Rovers
   - Drones, Hoppers
4) Space Stations & Habitats
5) Surface Habitats & Structures
6) In-Space Manufacturing (ISM)
   - In-Space Production
   - Space Food, Space Agriculture
   - Microgravity Manufacturing
   - Additive Manufacturing
   - In-Space Assembly, Construction, etc.
7) Space Resources
   - ISRU (In-Situ Resource Utilization)
   - Pure Substances (Ice, Oxygen, Metals)
   - Space, Lunar & Asteroid Mining
   - Prospecting, Processing, Recycling
8) Space Utilities
   - Energy, Power-Beaming
   - In-Space Internet, Data Relay
   - Navigation
   - Water, Propellant
9) In-Space Transportation
   - Space Tugs, Space Trucks
   - Orbital Transfer Vehicles (OTV)
   - On-Orbit Servicing, Maintenance
   - Propellant Reload Stations (Depots)
   - Active Debris Removal
   - In-Orbit Inspection
   - Space Mobility, Space Logistics
10) Miscellaneous
   - Microgravity Services
   - In-Orbit Computing, Storage
   - Space-Flown Items
   - Space Suits & Garments
   - Commercial Astronauts
   - Space Entertainment & Advertising
   - Space Traffic Management
   - Space Tourism Support, etc.

*Original creation by Erik Kulu since 2020 inspired by E2MC.

THE HUMAN NEED TO COMMUNICATE AND COLLABORATE

FROM THE MOVIE "THE MARTIAN"

WOULD YOU LIKE TO KNOW MORE?

Visit IPNSIG website

- General and technical documentation.
- IPNSIG Academy webinars
- Access to Pilot Project Working Group. Open to join our network.
- Free access!

IPNSIG – The Interplanetary Networking Special Interest Group is a chapter of the Internet Society

SPATIAM

THANK YOU!

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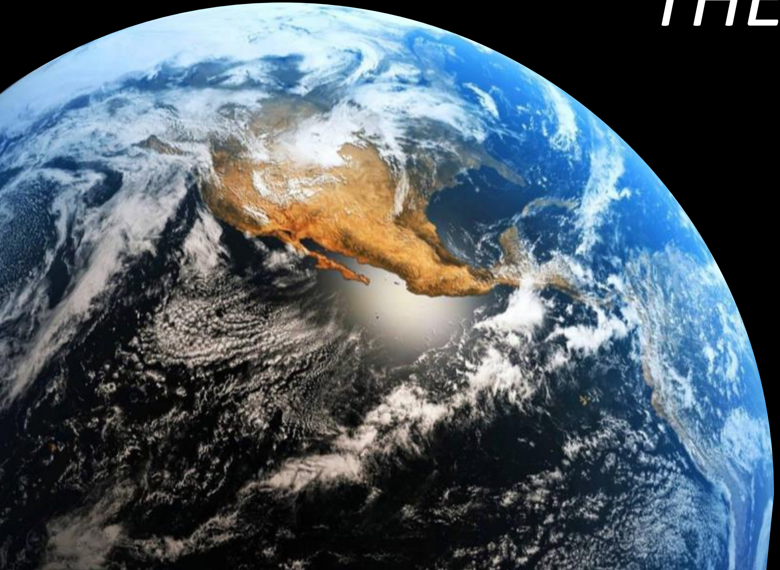

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