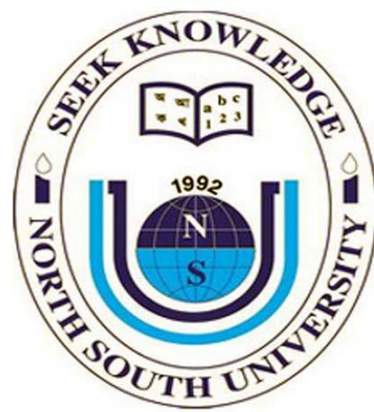




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Deep Space Communication and Exploration of Solar System through Inter-Lagrangian Data Relay Satellite Constellation

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Presented By-

Monirul Islam

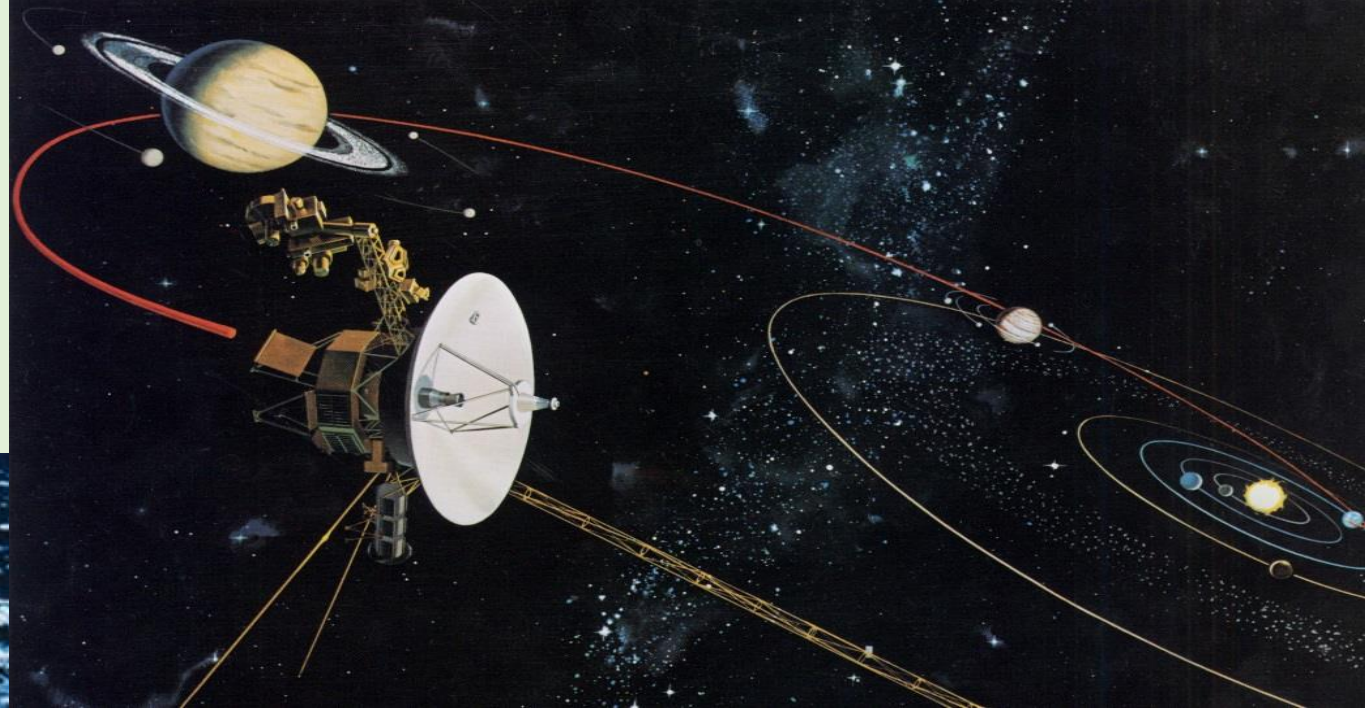
Introduction

- Proposed System for Future Interplanetary Communication
- Cluster Based Data Relay Satellite Network
- Split the Direct to Earth (DTE) communication system into multiple Relay Satellites
- Based on Lagrangian/Libration Orbit Constellation
- To ensure Continuous communications
- Reduce size of the space spacecrafts
- To Increase the data transfer rate
- Allow CubeSat missions throughout the Solar System
- Future deep space missions, human colonization, asteroid mining, exploration of inner and outer solar system
- **Communicate with any Planet any time from anywhere**

Overview of Deep Space Missions

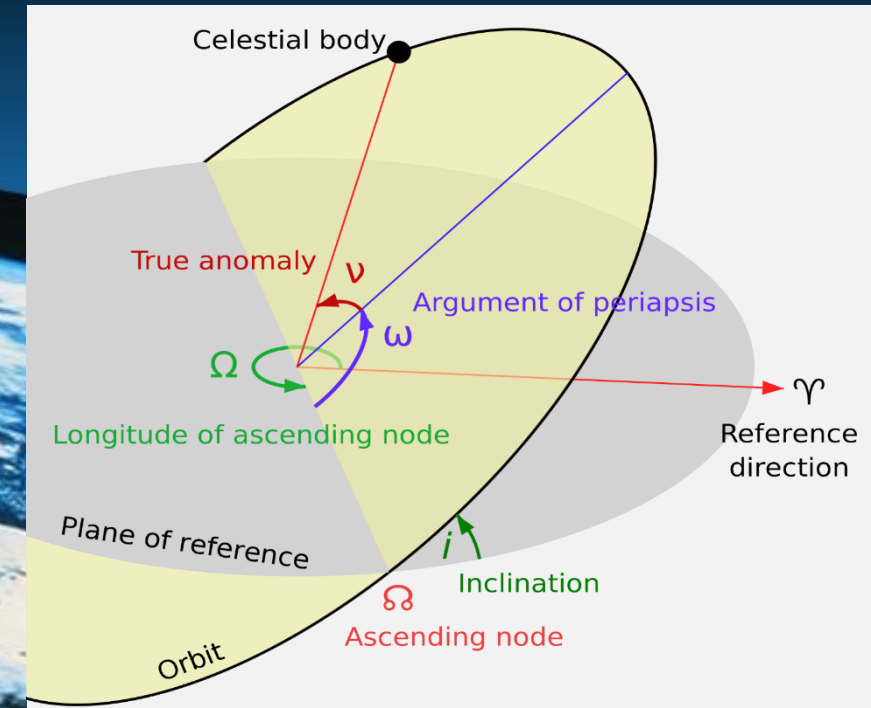
- Planetary Observation Missions
- Inner Solar System Exploration Missions
- Outer Planets and Small bodies Missions
- Outer Solar System Exploration Missions

CONTINUOUS COMMUNICATIONS SINCE 1983 ... A HISTORY OF NASA'S SPACE NETWORK



Required Orbits

- Synchronous or Stationary Orbit
- Lagrangian or Libration Point Orbit



- i. a , Semi-major axis
- ii. e , Eccentricity
- iii. i , Inclination
- iv. Ω , Longitude of the ascending node
- v. ω , Argument of periapsis
- vi. v , True anomaly

Planetary Synchronous orbits

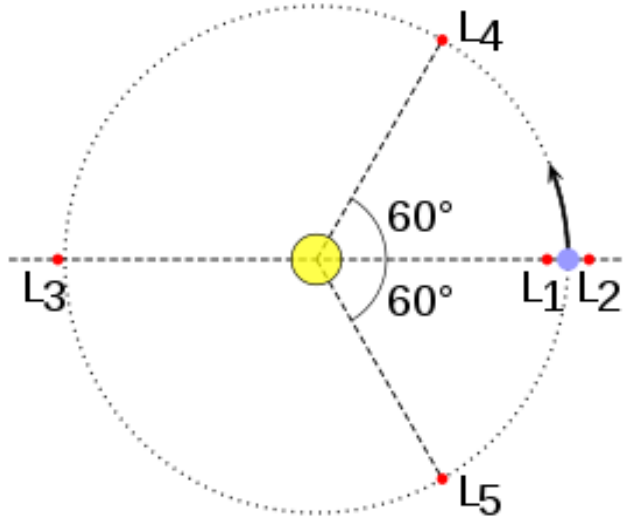
$$r_{geo} = \sqrt[3]{\frac{\mu}{4 \times \pi^2 \times \omega^2}} - r_{planet}$$

Where $\mu (= GM)$; Gravitational mass constant
 ω ; Revolutions per second

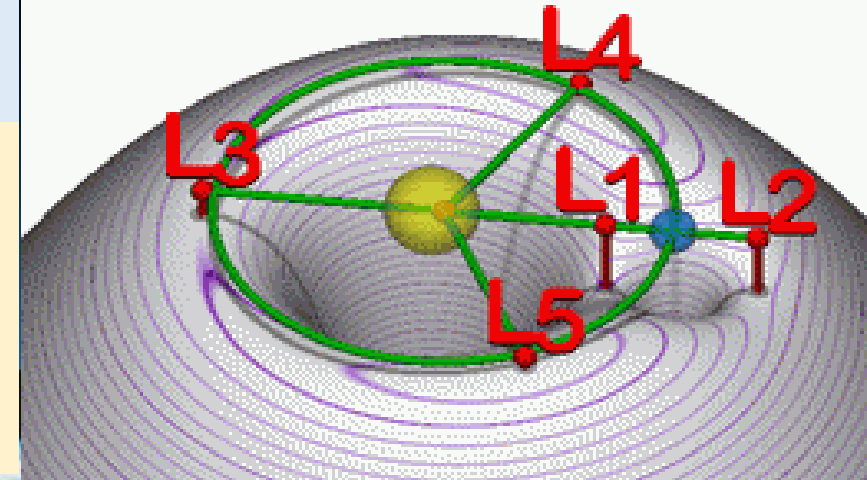
- Synchronous Orbit of Mercury and Venus not Practically Feasible
- Primary Concern is up to Saturn

Planet	μ -km ³ /sec ²	ω -rev/sec	r_{geo} -km
Mercury	2.23×10^4	1.98×10^{-7}	241,323
Venus	3.26×10^5	-4.76×10^{-8}	1,531,611
Earth	3.99×10^5	1.17×10^{-5}	35,581
Mars	4.31×10^4	1.12×10^{-5}	17,137
Jupiter	1.27×10^8	2.82×10^{-5}	87,772
Saturn	3.80×10^7	2.57×10^{-5}	52,867
Uranus	5.82×10^6	-1.61×10^{-5}	59,408
Neptune	6.90×10^6	1.73×10^{-5}	61,331

Concept of Lagrangian orbits



- Joseph-Louis Lagrange in 1772
- Three Body Problem
- 5 Lagrangian Points
- Lagrangian Orbits

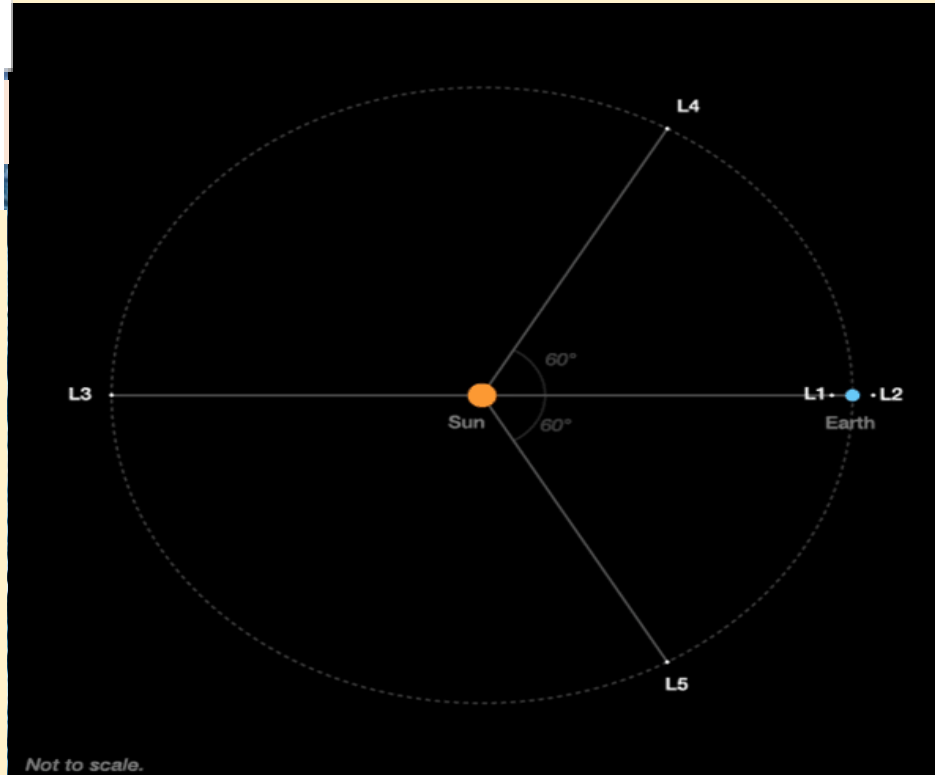


- **3 Unstable Orbits**
L1, L2 & L3

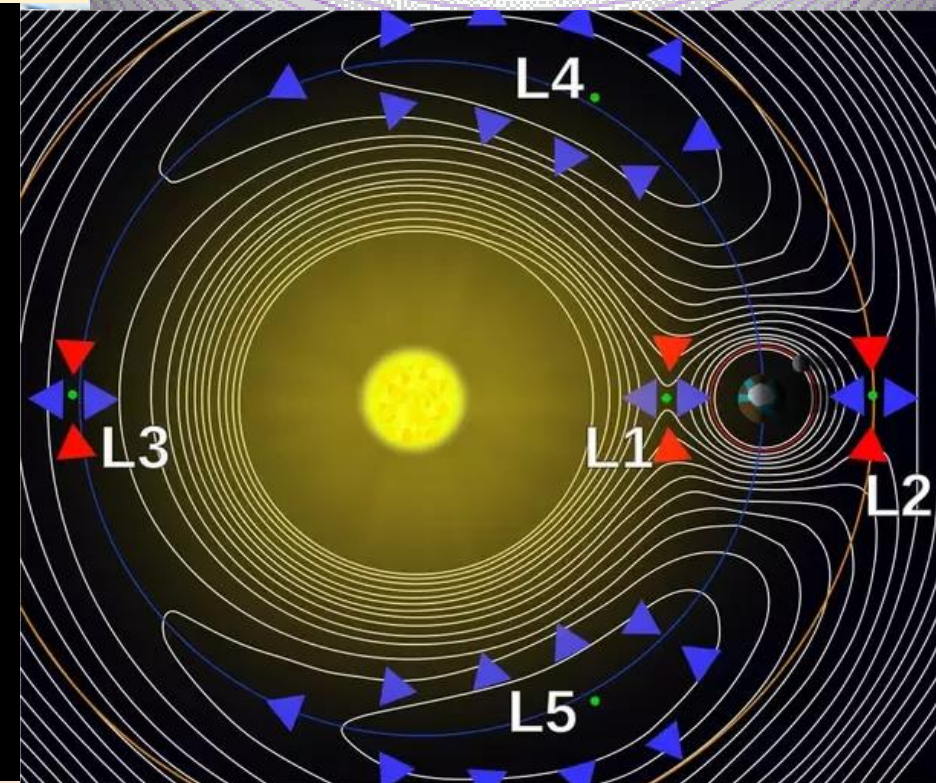
➤ Correspond to saddles

- **2 Stable Orbits** L4 & L5

➤ The Coriolis force



Lagrangian Points



Contour plot of Lagrangian Points

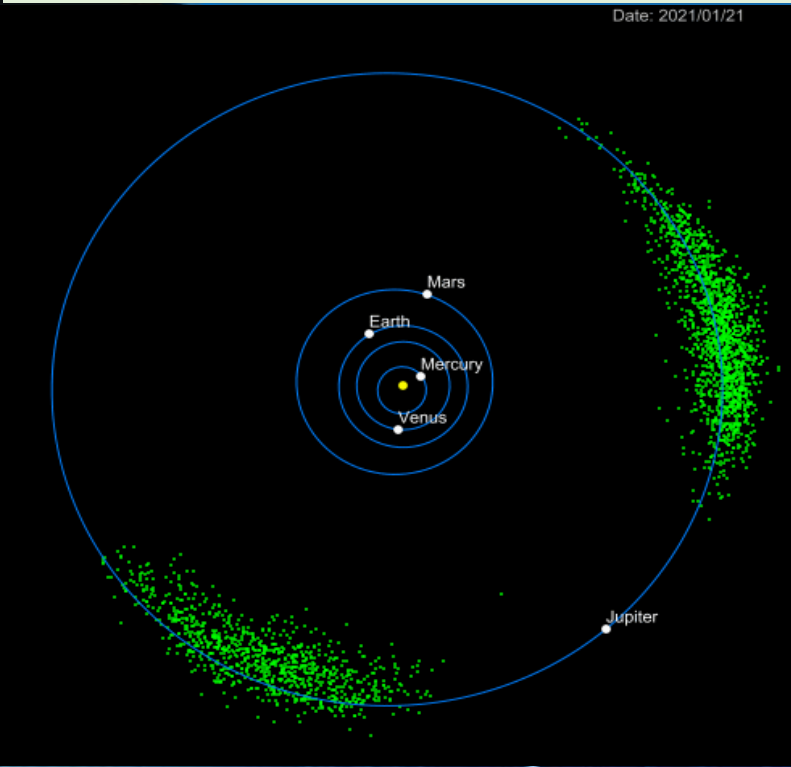
Recommendation of Orbits

Planet	Synchronous Orbit	Lagrangian Points
Mercury	N/A	L ₂
Venus	N/A	L ₄
Earth	3	L ₄ & L ₅
Mars	3	L ₄ & L ₅
Jupiter	3	L ₄ / L ₁
Saturn	3	L ₄
Uranus	3	L ₄
Neptune	3	L ₄
Moon	N/A	L ₃ , L ₄ & L ₅

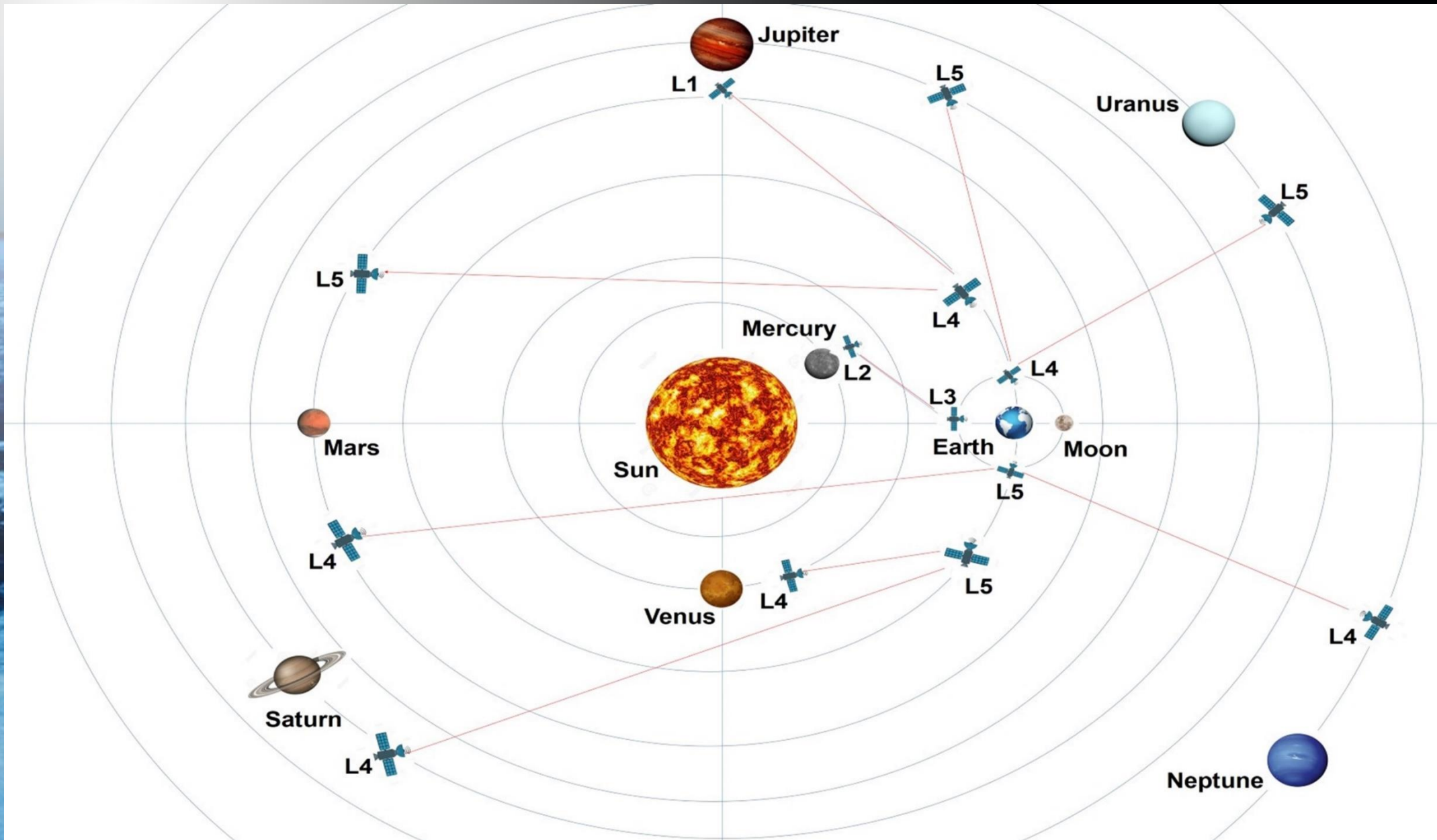
The recommended orbits for Relay Satellites

- Synchronous Orbit of **Mercury** and **Venus** not Feasible
- Mercury Orbit under Sun Radiation Belt
 - **Need to use L₂**
- Jupiter have Trojan Asteroids
 - **Recommended Orbit L₁**
- Satellites in **Uranus** and **Neptune** Orbit depends on Future Requirements

- Earth-Moon Lagrangian Orbit L₃, L₄ & L₅



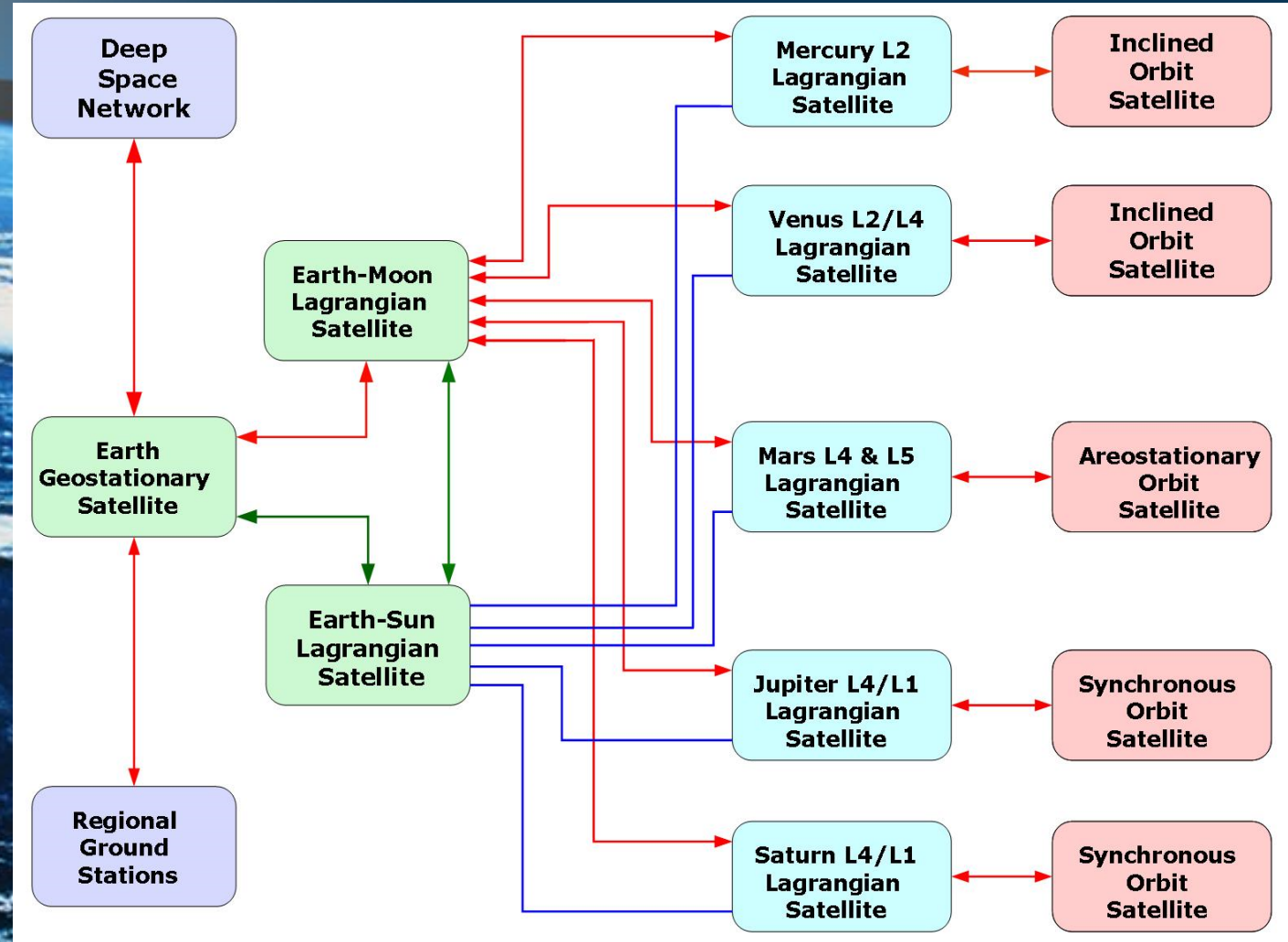
Trojan Asteroids in Jupiter's L4 & L5 Orbits



Overview Of the Complete System

System Architecture

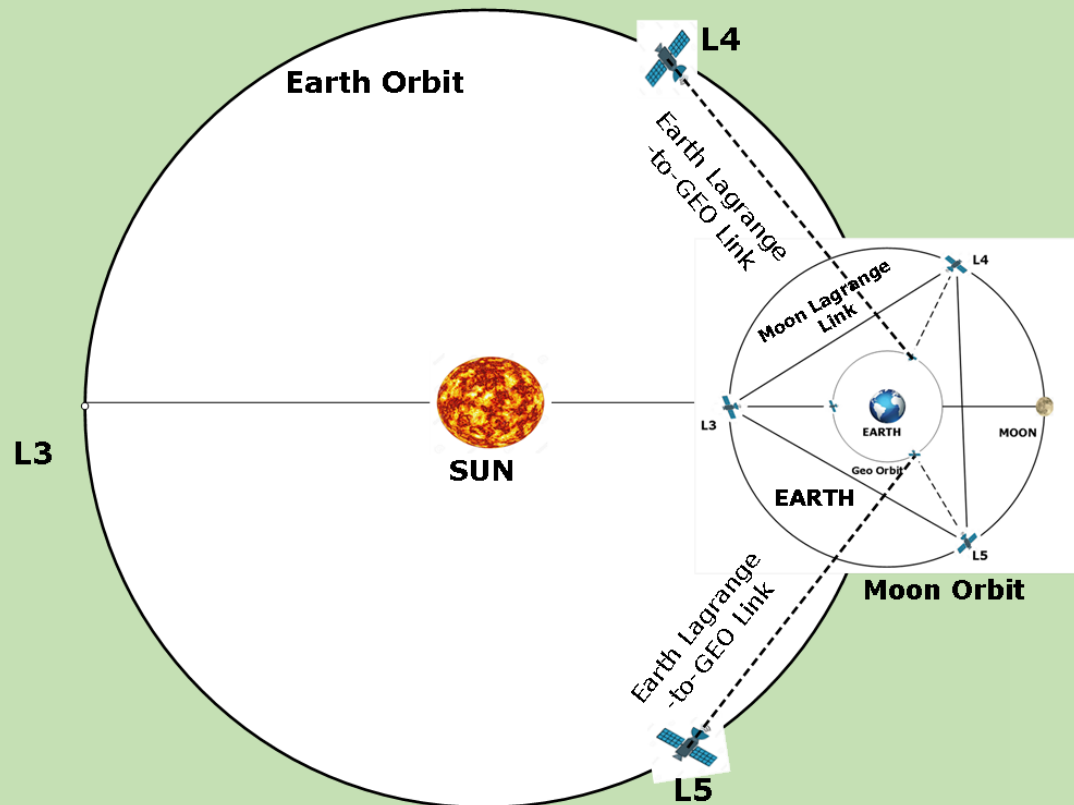
- Ground Station Network
 - Deep space network
 - Regional Ground Stations
- Earth Geostationary constellation
- Earth Lagrangian Constellation
 - Earth-Moon Lagrangian constellation
 - Earth-Sun Lagrangian constellation
- Planetary Lagrangian Constellation
- Planetary Synchronous Orbit Constellation



Satellite Constellations

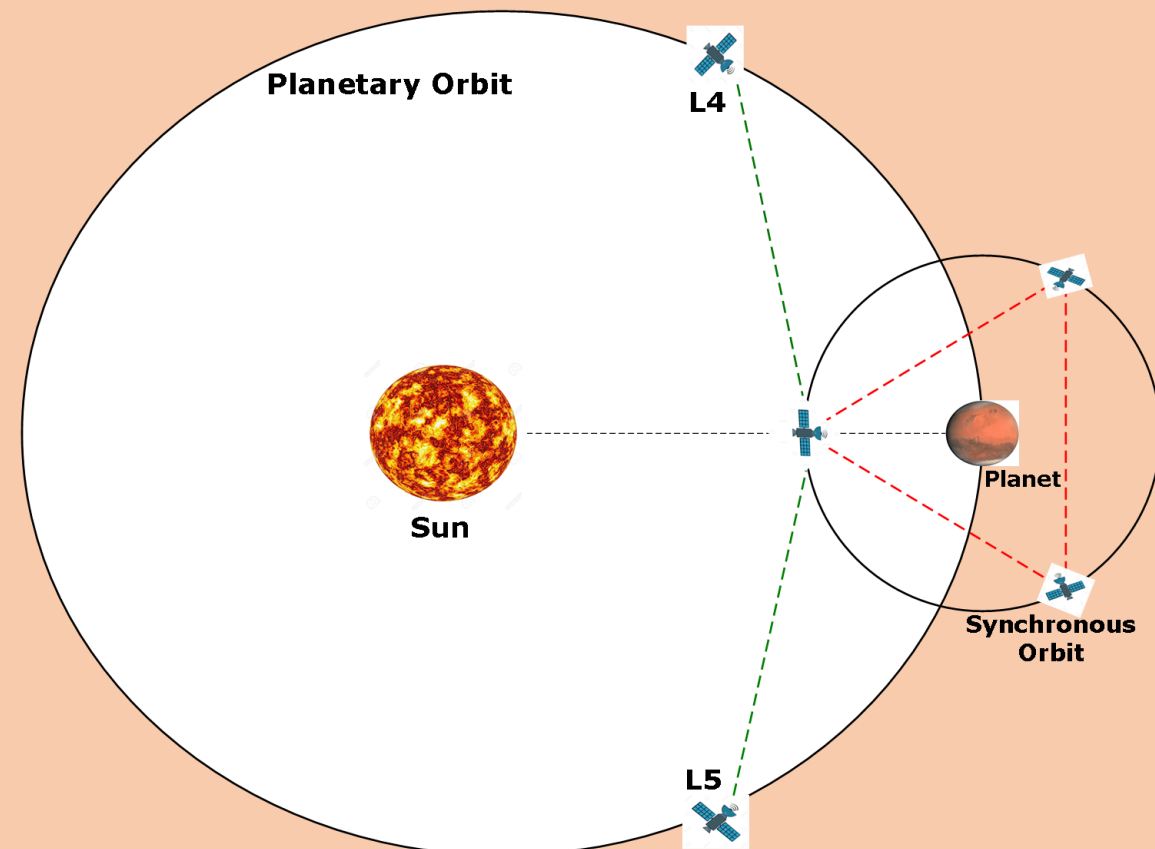
Earth Satellite Network Cluster

- Earth Geostationary Satellite Constellation
- Earth-Moon Lagrangian Satellite Constellation
- Earth-Sun Lagrangian Satellite Constellation



Planetary Satellite Network Cluster

- Planetary Lagrangian Satellite Constellation
- Planetary Synchronous Satellite Constellation



Earth Satellite Network Cluster

- Earth Geostationary constellation

 - ✓ TDRS or EDRS

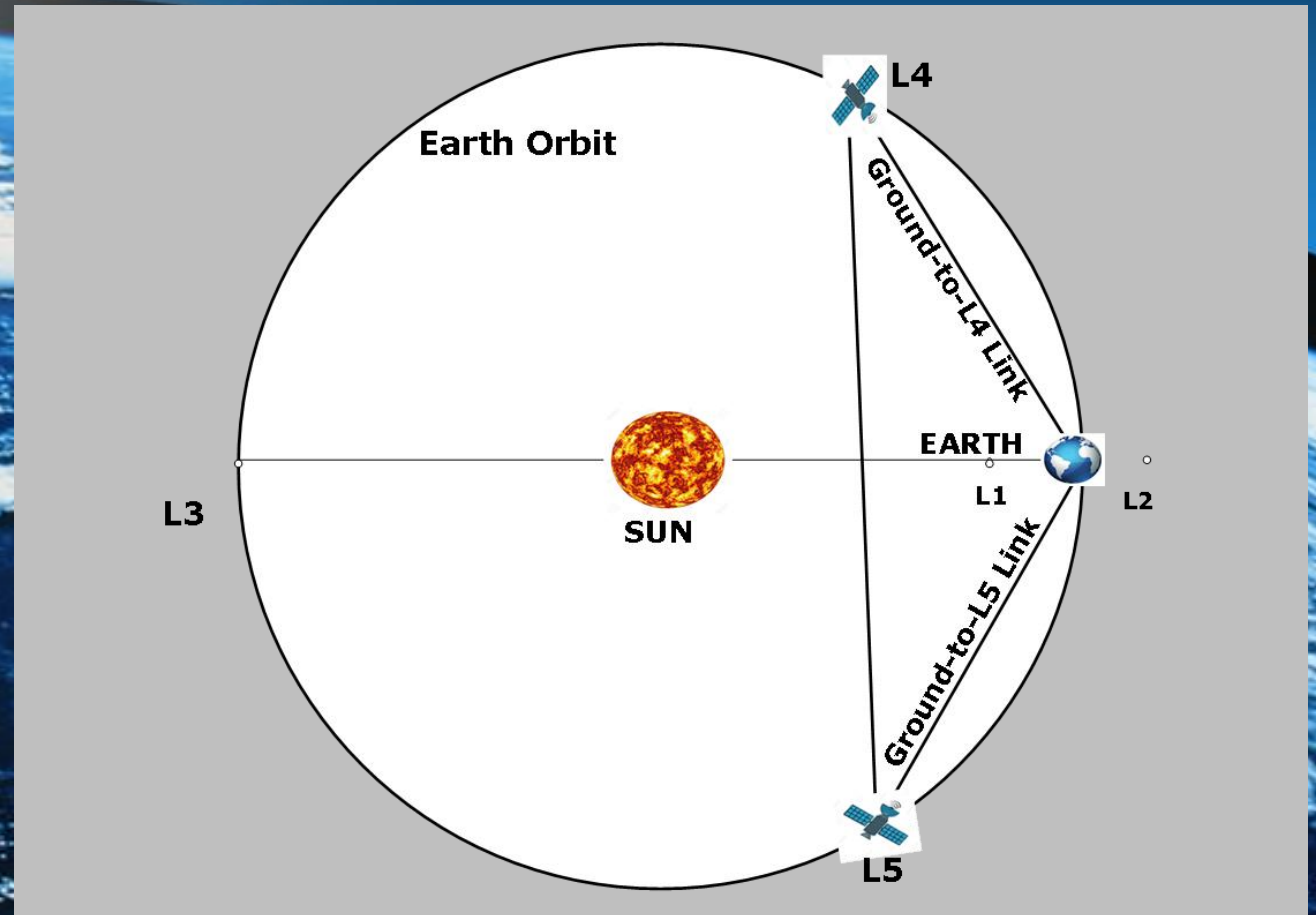
- Earth Lagrangian constellation

 - Earth-Moon Lagrangian Constellation

 - ✓ Primary Communication Hub

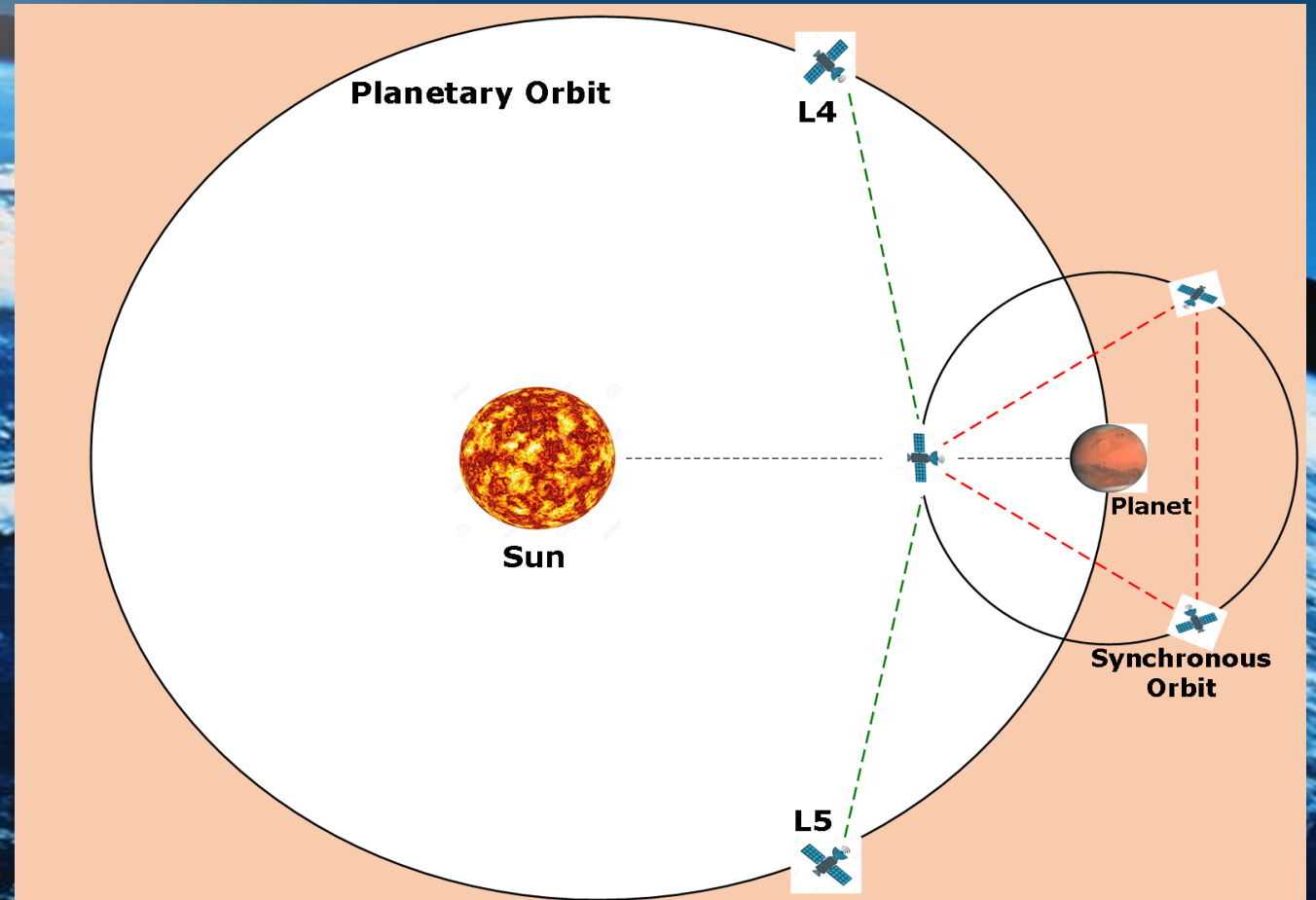
 - Earth-Sun Lagrangian Constellation

 - ✓ Alternative Communication



Planetary Satellite Network Cluster

- Planetary Lagrangian Constellation
- Planetary Synchronous Constellation
 - Equatorial Stationary Orbit Satellite (except Mercury and Venus)
 - Inclined Orbit Satellite (for Mercury and Venus)



Design of the Relay Satellites

■ Communication Sub-system

■ Software Defined Radio (SDR)

- Telemetry
 - UHF
- Data Channel
 - X-Band
 - Ka Band

■ Antenna

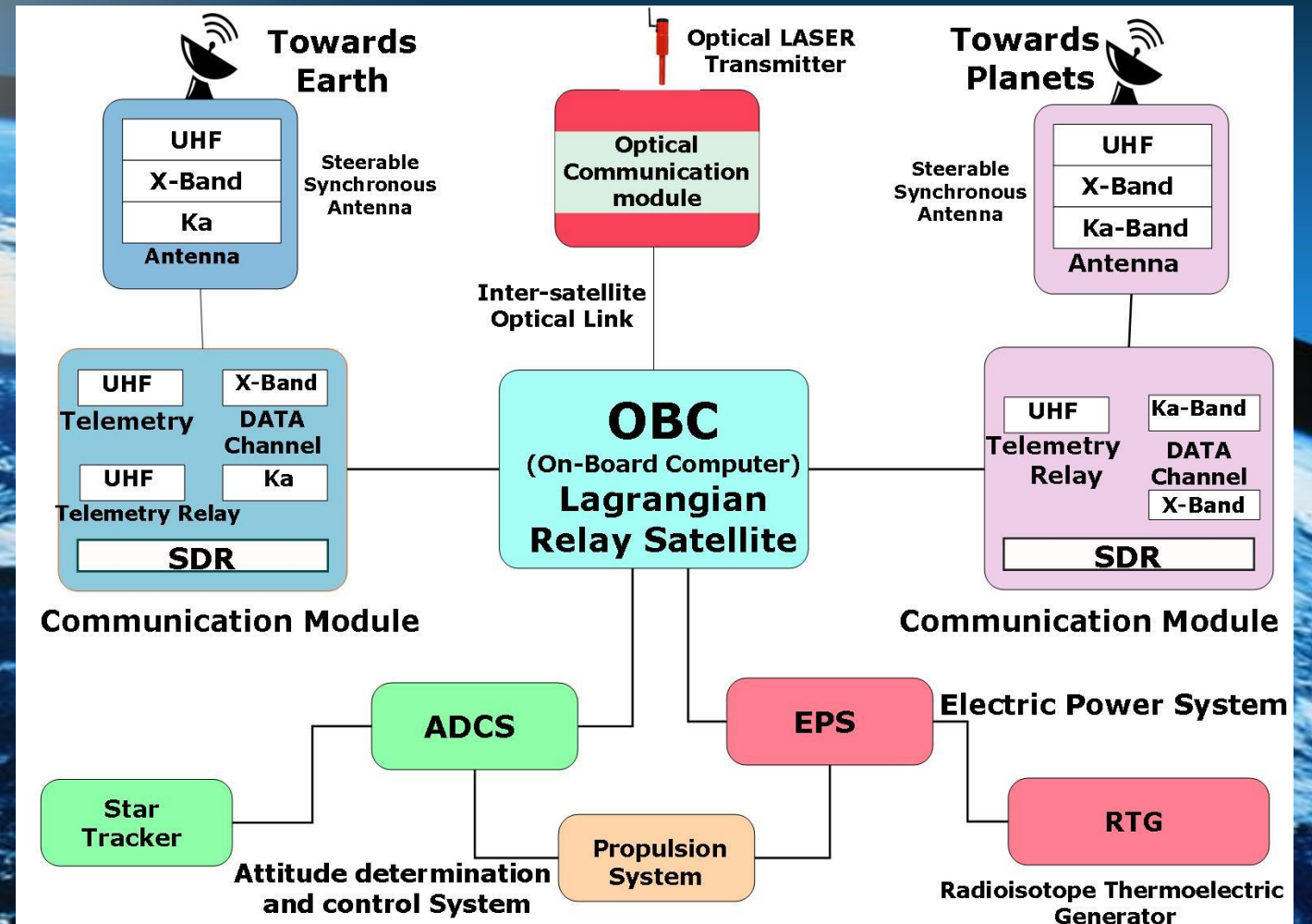
- UHF
- X-Band
- Ka Band

■ Optical Communication Module

■ Attitude Determination and Control Sub-system

■ Electric Power System

- Large Solar Array
- Radioisotope Thermoelectric Generator
- Small Nuclear Power Reactor

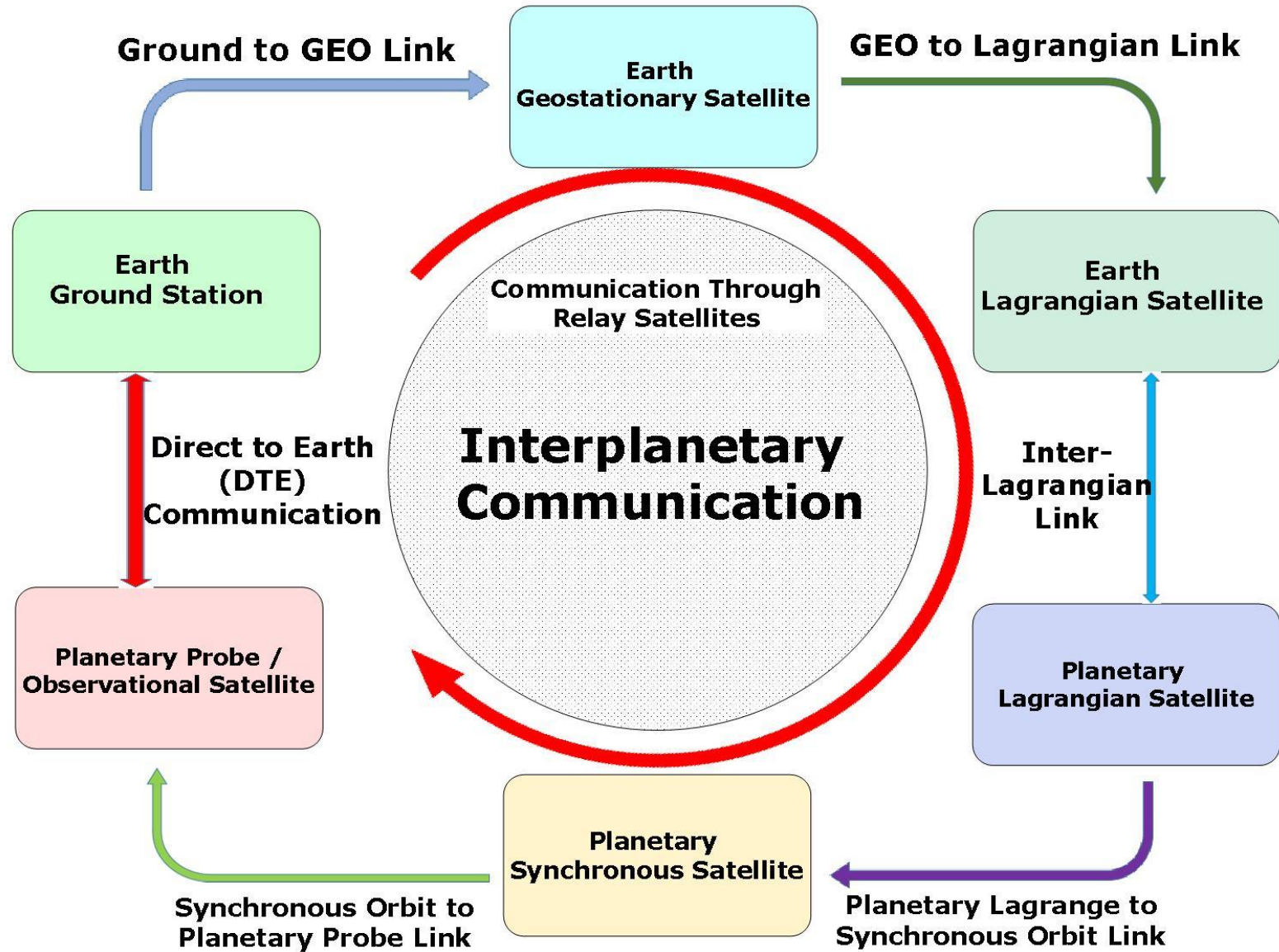
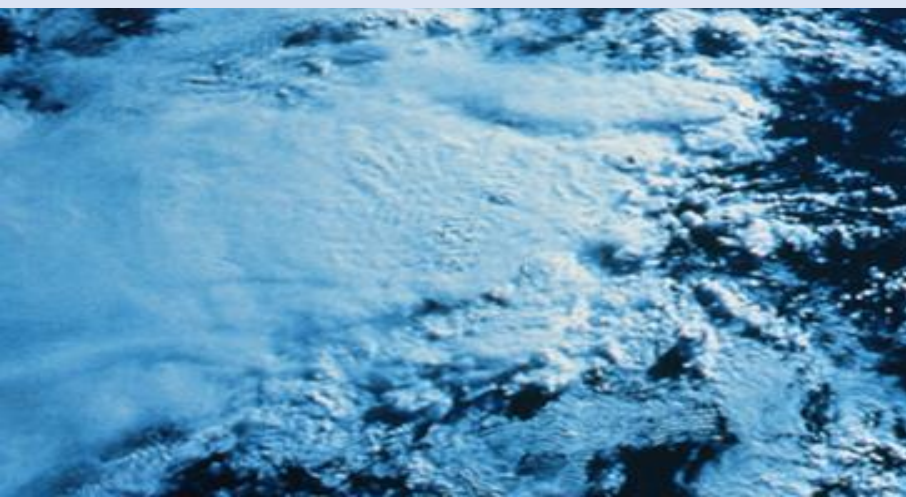


Interplanetary Communication



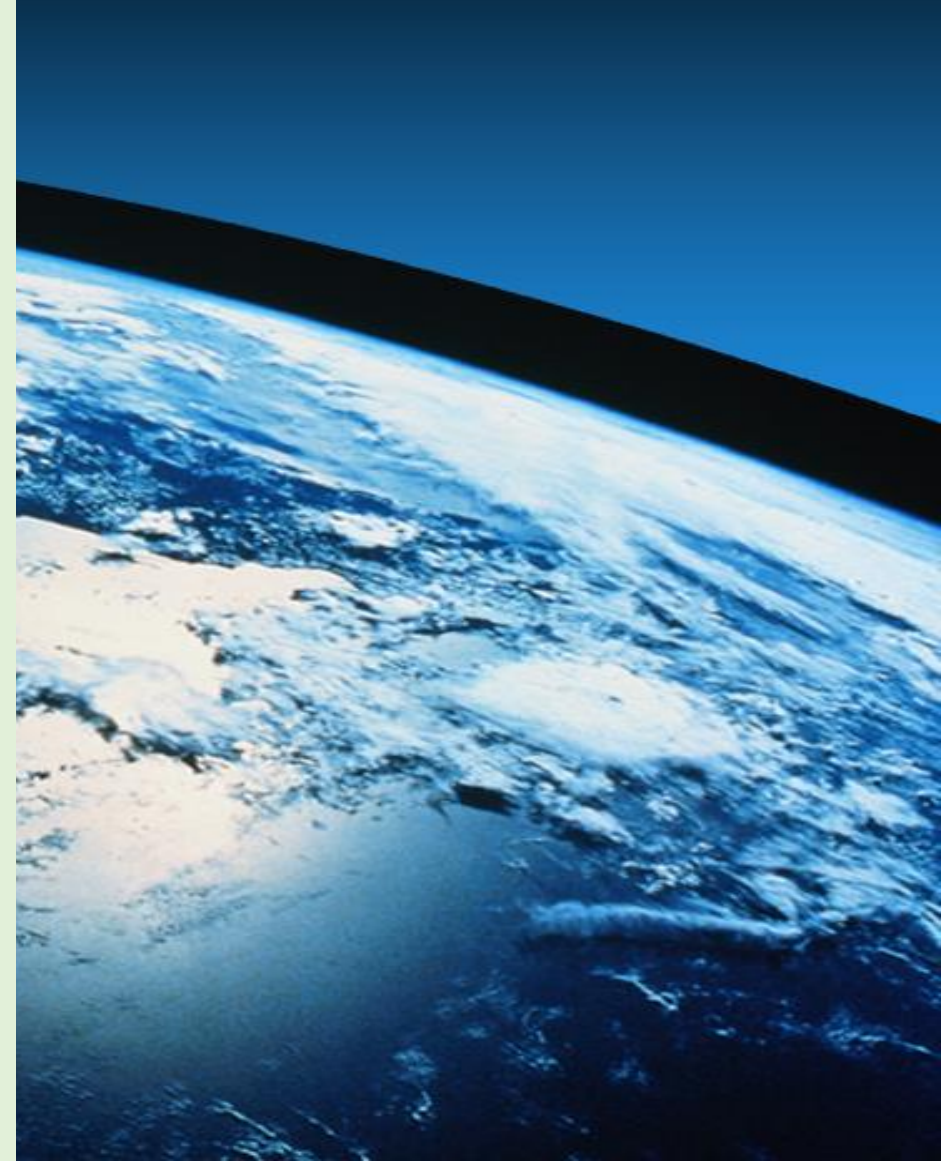
i. **Direct to Earth (DTE)** communication

ii. Communication through **Planetary Relay Satellites**



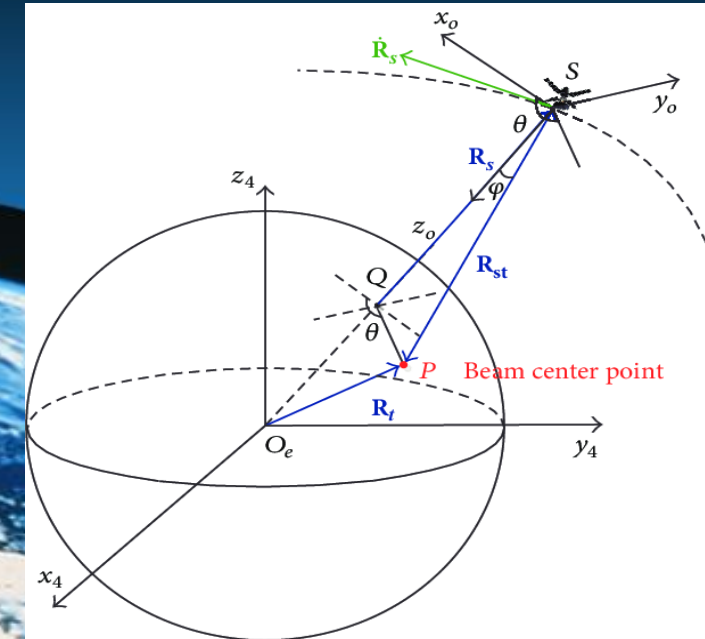
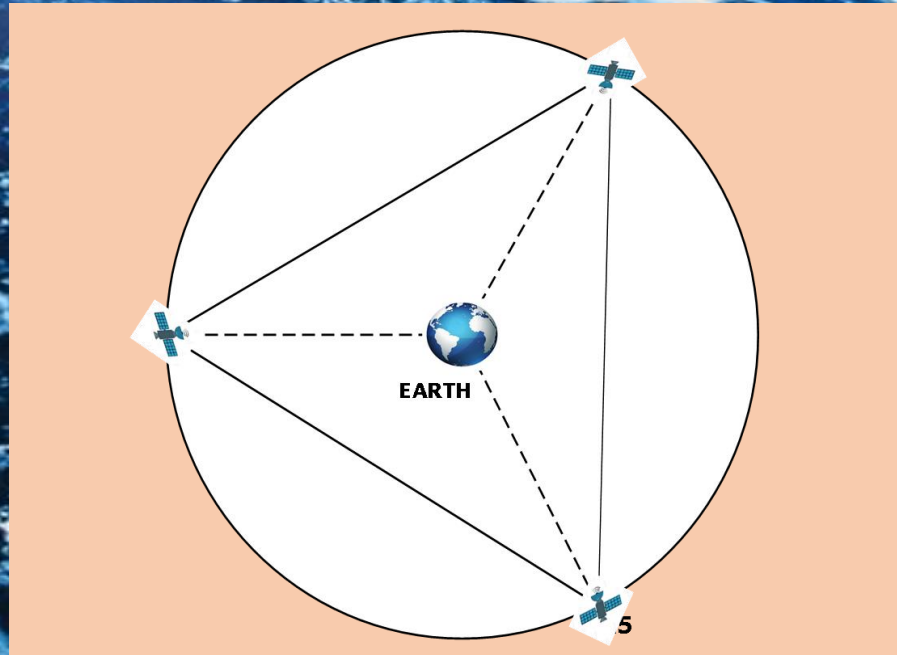
Interplanetary Relay Communication Links

- Geostationary Satellite Links
- Earth-Moon Lagrangian Orbit links
- Geostationary to Earth-Sun Lagrange Link
- Inter-Lagrangian Communication Links
- Planetary Lagrangian Orbit Links
- Planetary Synchronous orbit links



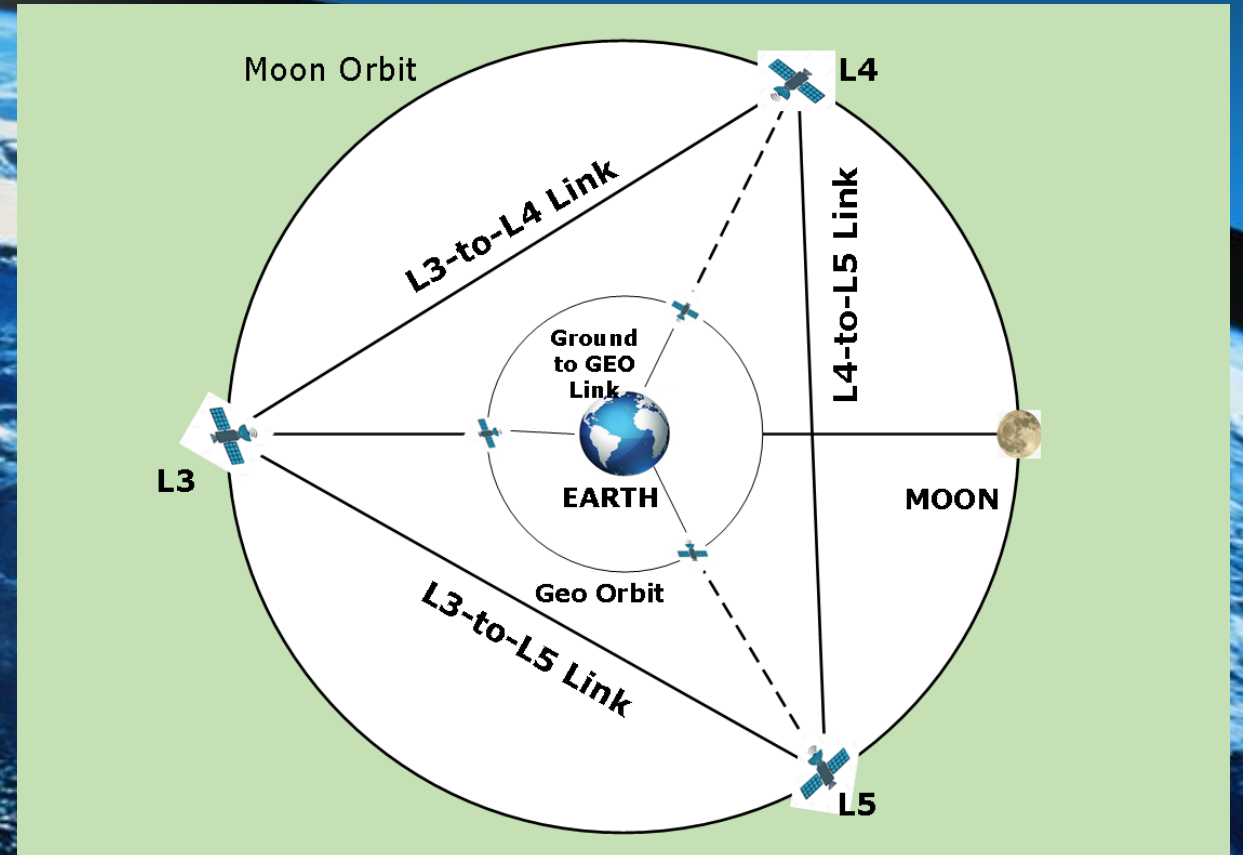
Geostationary Satellite Links

- Ground to GEO Link
 - Link Distance: 35,581 km
- GEO to GEO Link
 - Link Distance: 72,675 km
 - Free Space Optical Link
- GEO to Moon Lagrange Link
 - Link Distance: 348,419 km
- GEO to Earth Lagrange Link
 - Link Distance: 149.6×10^6 km



Earth-Moon Lagrangian Orbit links

Links	Distance (km)	Delay (sec)
L4-to-L5	665,800	2.220
L3-to-L4/L5	667,487	2.226
L4/L5-to-Geo	348,419	1.162
L3-to-Geo	382,776	1.276



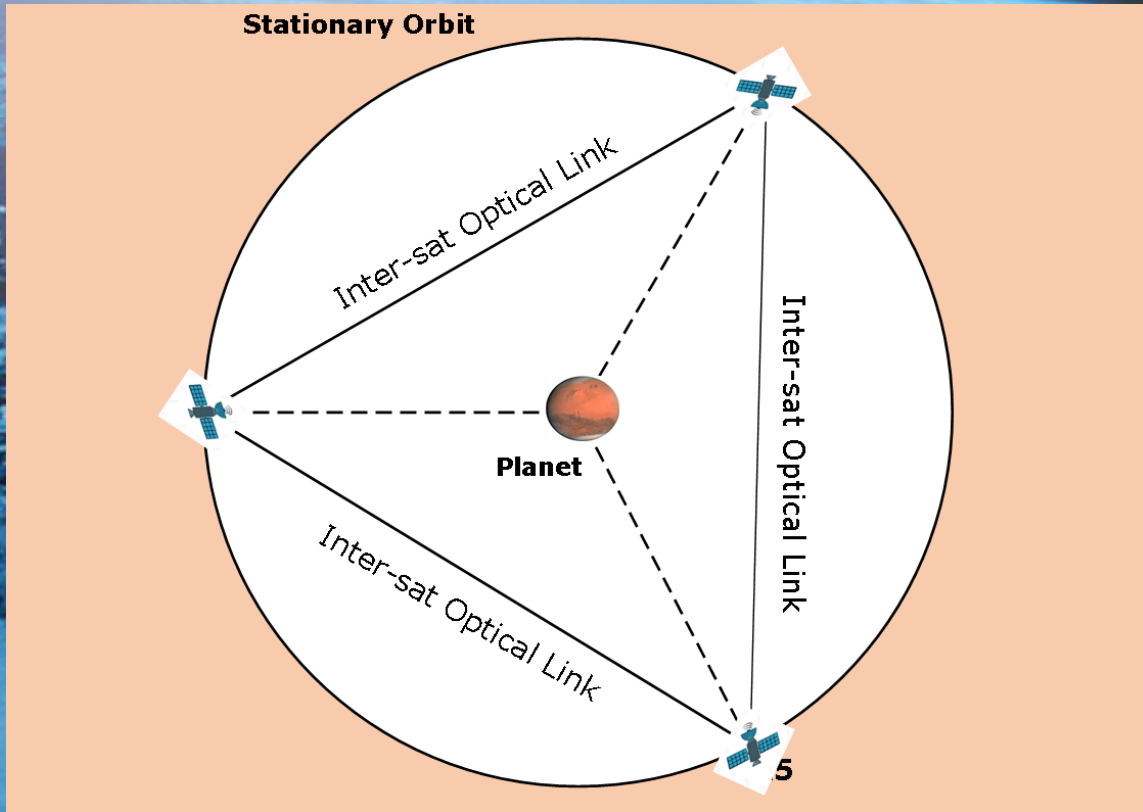
Interplanetary Link Distances, Propagation delay & Solar Conjunction Availability

Planet	Distance from Earth (10^8 km)		Propagation Delay (sec)		Solar Conjunction Availability		Solar Conjunction Blocking	
	Max	Min	Max	Min	Max	Min	Max	Min
Mercury	2.17	0.773	740	258	0.918377	0.879918	0.120082	0.081623
Venus	2.60	0.382	871	127	0.946626	0.945923	0.054077	0.053374
Mars	3.96	0.546	1339	182	0.961282	0.96002	0.03998	0.038718
Jupiter	9.63	5.89	3229	1964	0.961282	0.96002	0.03998	0.038718
Saturn	16.5	12.0	5514	3987	0.961282	0.96002	0.03998	0.038718
Uranus	31.8	25.8	10623	8619	0.961282	0.96002	0.03998	0.038718
Neptune	46.8	43.4	15638	14473	0.961282	0.96002	0.03998	0.038718

Planetary Lagrangian Orbit Links

Planet	L1/L2-to-Planet		L4/L5-to-Planet	
	Distance (10^6 km)	Delay (sec)	Distance (10^6 km)	Delay (sec)
Mercury	0.2203	0.7348	57.91	193.16
Venus	1.0109	3.3720	108.2	360.91
Earth	1.4962	4.9907	149.6	449.01
Mars	1.0822	3.6098	227.9	760.19
Jupiter	26.5264	88.4826	778.9	2598.13
Saturn	65.4695	218.3830	1434	4783.31
Uranus	70.0860	233.7820	2871	9576.63
Neptune	115.914	386.7381	4495	14993.73

Planetary Synchronous orbit links



Planet	GEO Orbit Height (km)	Delay (ms)	GEO-to-GEO Distance (km)	Delay (ms)
Mercury	241,323	804	422,208	1408
Venus	1,531,611	5108	2,663,310	8883
Earth	35,581	118	72,675	242
Mars	17,137	57	35,564	118
Jupiter	87,772	292	275,853	920
Saturn	52,867	176	195,955	653
Uranus	59,408	198	146,826	489
Neptune	61,331	204	148,875	496

Direct to Earth Communication (DTE)

DTE Links	Distance (km)		
Ground-to-GEO	35,581		
Ground-to-Moon L3	386,347		
Ground-to-Moon L4/L5	382,776		
Ground-to-Earth-Sun L4/L5	149.6 million		
Earth-to-Moon	382,776		
Ground-to-Planetary Satellites	Planet	Max (km)	Min (km)
	Mercury	2.17E+8	7.73E+7
	Venus	2.60E+8	3.82E+7
	Mars	3.96E+8	5.46E+7
	Jupiter	9.63E+8	5.89E+8
	Saturn	1.65E+9	1.20E+9
	Uranus	3.18E+9	2.58E+9
	Neptune	4.68E+9	4.34E+9

- Deep Space Networks
- For Mission Critical Data and Emergency Communication
- Low Data Transfer rate
- Proven and Stable Communication



Concept of Operation

- Split Direct to Earth (DTE) links into Multiple Data Relay Satellites
- GEO-to-GEO Optical Link
- Earth-Moon Lagrangian Satellites with Inter-satellite Optical link
- During solar conjunction, Communication through Earth-Sun Lagrangian Satellites
- Inter Lagrangian Communication
- Planetary Synchronous Orbit Satellites with Inter-satellite Optical Links
- Communication with Orbiter, Lander, Rover and Probes
- Interplanetary Communication Links
 - X-Band (Live Communication)
 - Ka Band (Data Communication)
 - Optical LASER (Inter-sat Link)
 - UHF
 - Telemetry
 - Telemetry Relay
- Path Define
- Machine Learning based Advance Control System
- Increase Data Transmission rate
- Stationkeeping
 - Unstable Orbit (L1, L2 & L3)
 - Stable Orbit (L4 & L5)

We can communicate any time from anywhere of the Earth to almost any location of any planet of the entire Solar System

Conclusion

- Lagrangian orbit Satellite based Interplanetary communication
- Reduce size of the Spacecrafts with Communication modules
- Make CubeSat Operational throughout the Solar System
- Supports future Interplanetary and Exploration missions
- Human Colonization of Mars and Moon
- Asteroid Mining

- Required precise orbital mechanics of Lagrangian orbits around the planets
- Require high efficiency Steerable Antenna with relatively smaller size
- Require Inter-Lagrangian Optical Link
- Require detail about Outer planet Radiation Environment
- Recommended Small Nuclear Power Reactor or Radioisotope Thermoelectric Generator as power source



Thank You

ANY QUESTIONS?

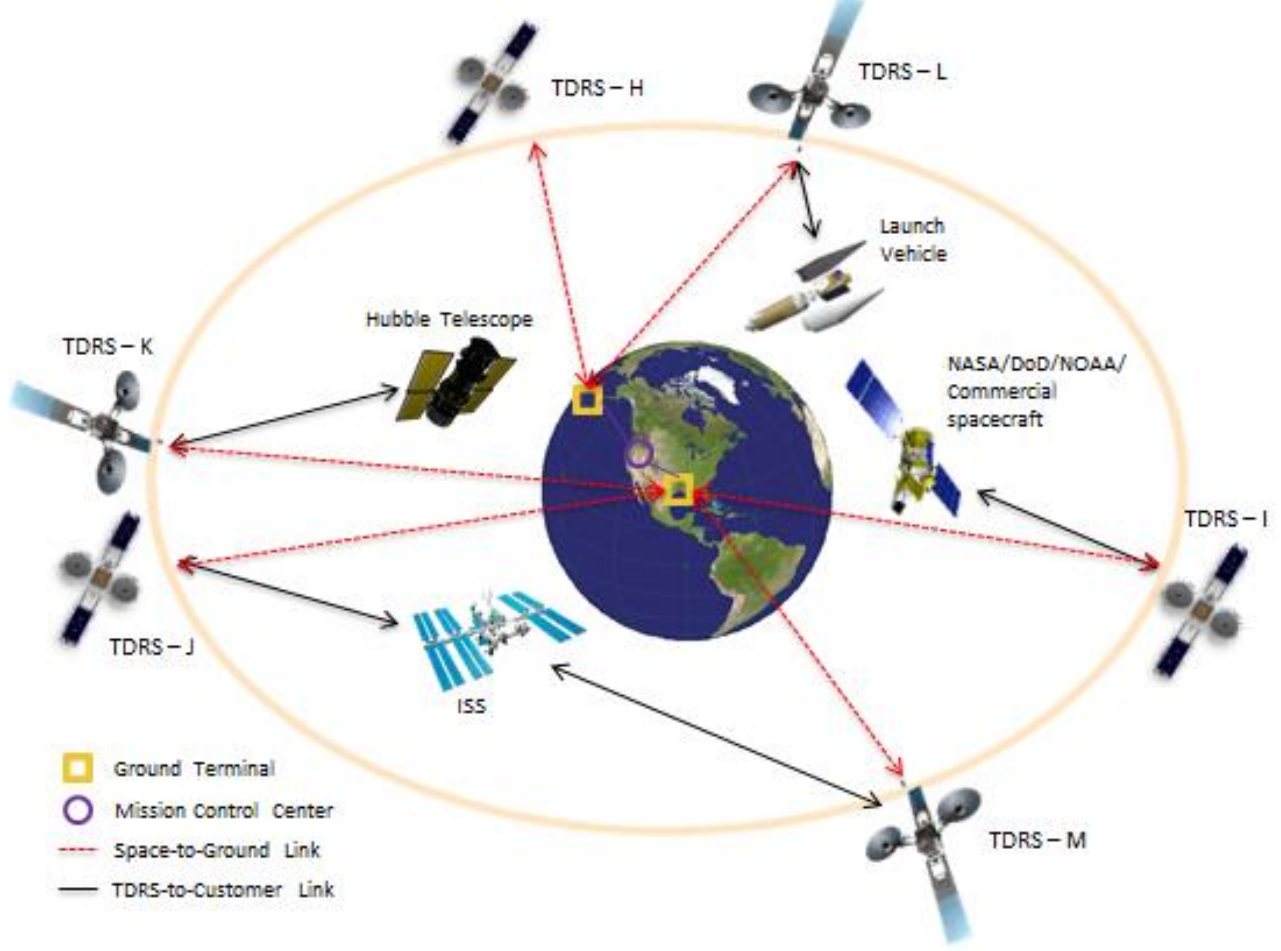
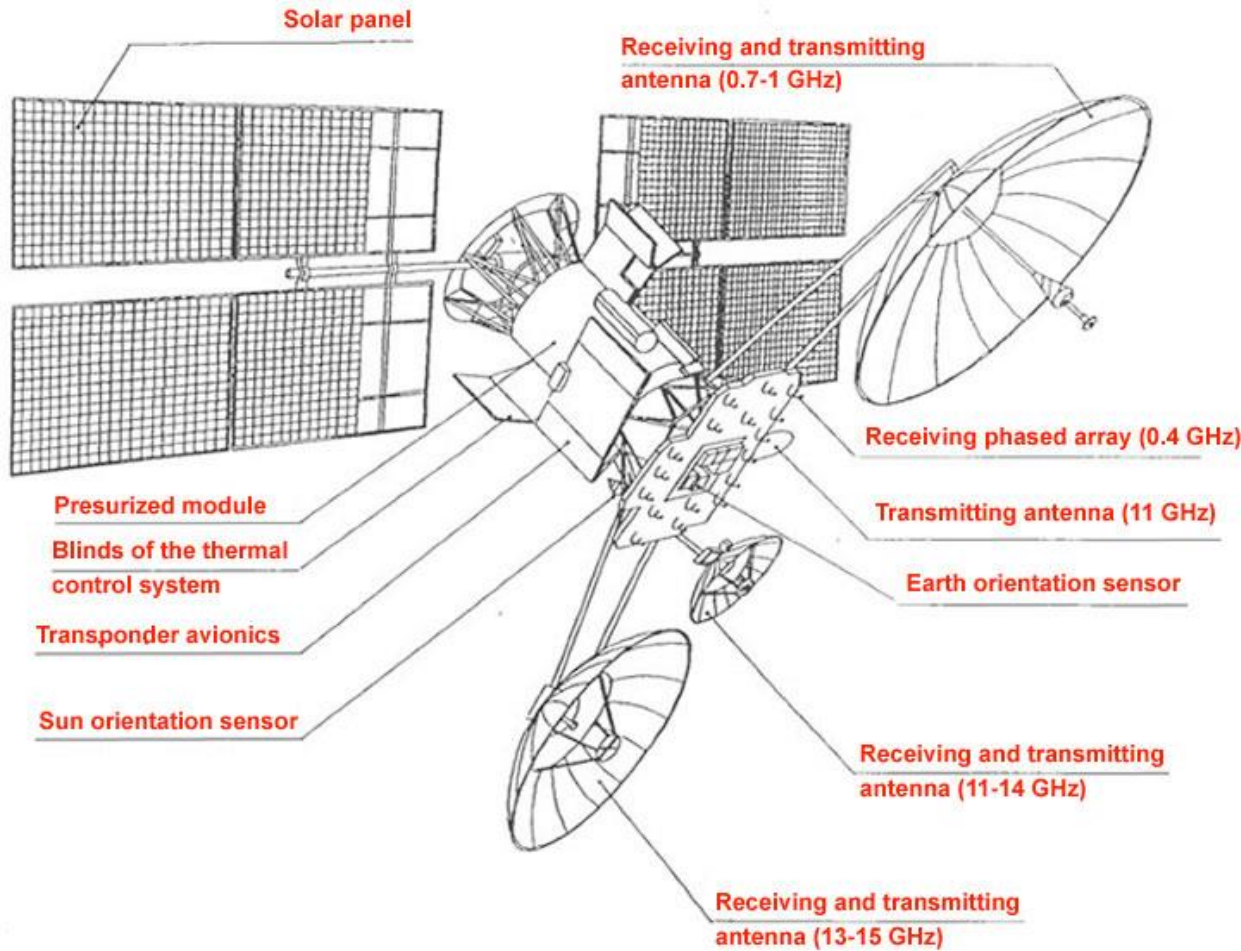


Appendix Slides

Coordinates of Lagrangian Points

Planet	L1 (10 E+6 Km)	L2 (10 E+6 Km)	L3 (10 E+6 Km)	L4 (10 E+6 Km)	L5 (10 E+6 Km)	Mass(10E +24 Kg)	Distance from Sun
Mercury	57.6897006; 0	58.1302994; 0	-57.9100039; 0	28.95499044; 50.15153113	28.95499044; -50.15153113	0.3282	57.91
Venus	107.1890523; 0	109.2109477; 0	-108.200110; 0	54.09973524; 93.70394869	54.09973524; -93.70394869	4.867	108.2
Earth	148.1037508; 0	151.0962492; 0	-149.600399; 0	74.79955098; 129.5574004	74.79955098; -129.5574004	5.97	149.6
Mars	226.8177543; 0	228.9822457; 0	-227.900030; 0	113.9499268; 197.3671895	113.9499268; -197.3671895	0.639	227.9
Jupiter	752.3735858; 0	831.6264142; 0	-778.809260; 0	388.7073996; 674.2007768	388.7073996; -674.2007768	1898.13	778.9
Saturn	1368.530567; 0	1499.469433; 0	-1434.1705; 0	716.5906086; 1241.880429	716.5906086; -1241.880429	568	1434
Uranus	2800.913972; 0	2941.086028; 0	-2871.05220; 0	1435.374701; 2486.358834	1435.374701; -2486.358834	86.81	2871
Neptune	4379.059042; 0	4610.940958; 0	-4495.09641; 0	2247.268595; 3892.78419	2247.268595; -3892.78419	102.4	4495
Moon	0.323113622; 0	0.445686377; 0	-0.38634731; 0	0.187526456; 0.332900165	0.187526456; 0.332900165	0.073476730	0.384400

Earth-Geo constellation



Structure of Data Relay Satellites

Network Structure of Tracking and Data Relay Satellite Constellation

Earth GEO Constellations



TDRSS Summary

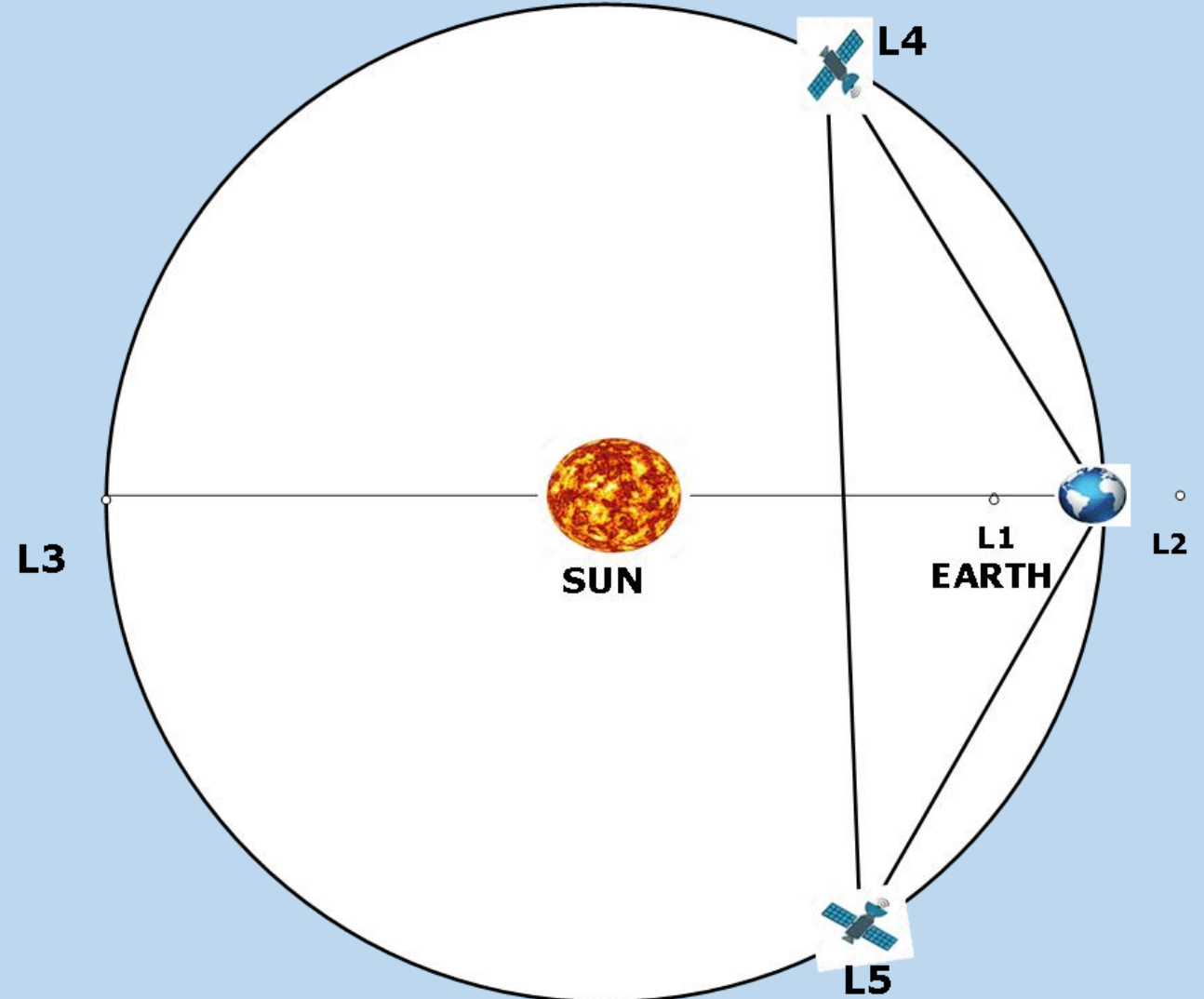
Existing, proven relay network of 9 satellites

- 6 original, 3 advance link satellites
- Peak downlink of 300 and 800 Mbps
 - Ku-band
- 13.7 - 15 GHz (225 MHz BW)
 - Ka-band
- 25.25 - 27.5 GHz (650 MHz BW)
- Used for comms. with shuttle, Hubble, and other satellites.
- GEO Coverage all the way around Earth
- US station in White Sands, NM



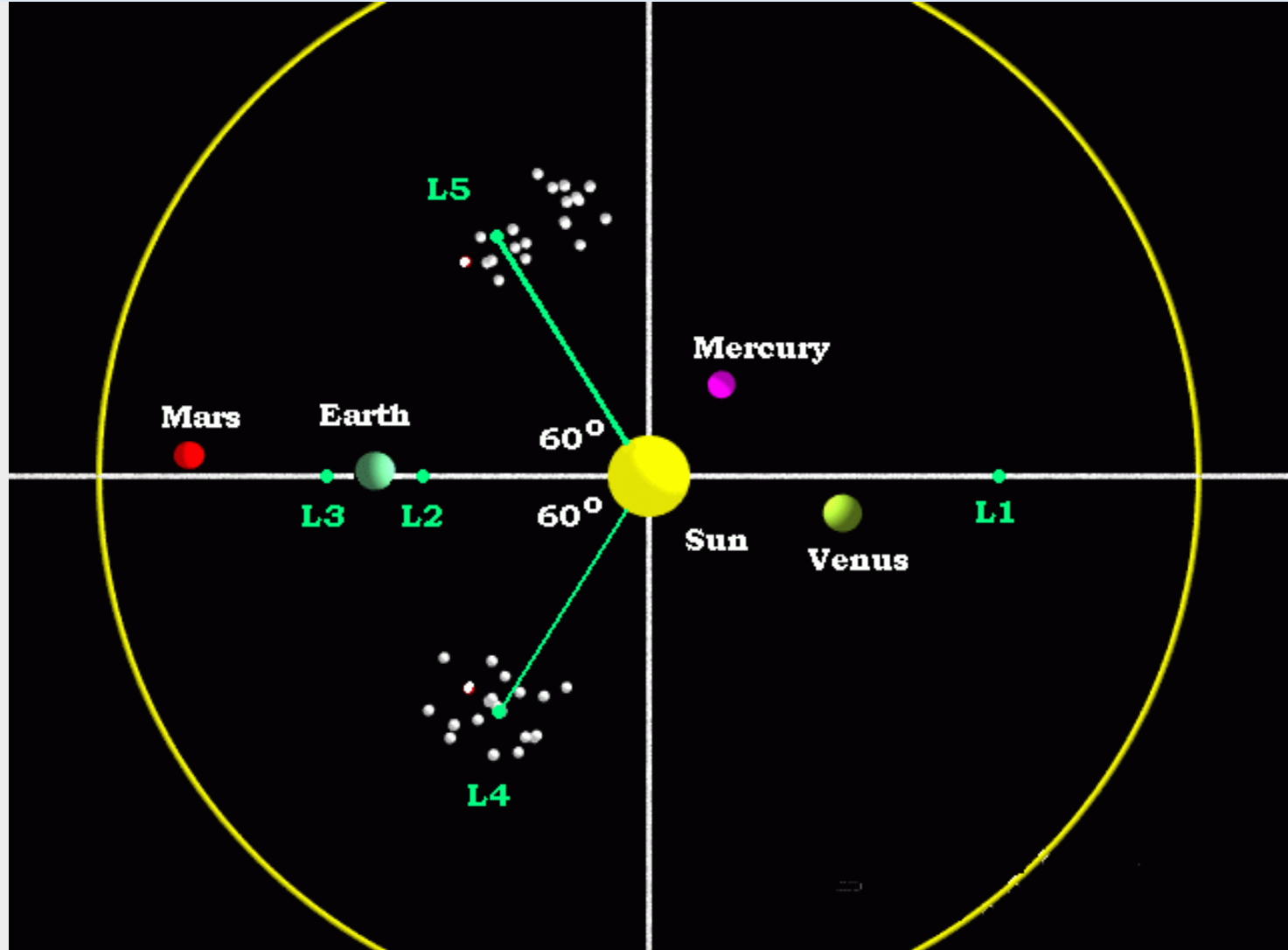
Earth-Sun Lagrangian Constellation

- Earth Lagrangian Orbit Constellation
 - L4 Satellite
 - L5 Satellite
- Secondary Communication Hub
- Distance from Earth: 149.6 million kilometer
- Larger Delay
- Reduce Solar Conjunction
- Ensure Continuous Communication



Planetary Lagrangian Constellation

- Planetary Lagrangian Orbit Satellite
 - L4 / L5 Orbit Satellite
 - Venus
 - Mars
 - Saturn
 - Uranus
 - Neptune
 - L1 Halo Orbit Satellite
 - Jupiter
 - Large number of Trojan Asteroids trapped in L4 & L5
 - L2 Halo orbit Satellite
 - Mercury



Picture: Lagrangian Points of Different Planets

Planetary Synchronous Constellation

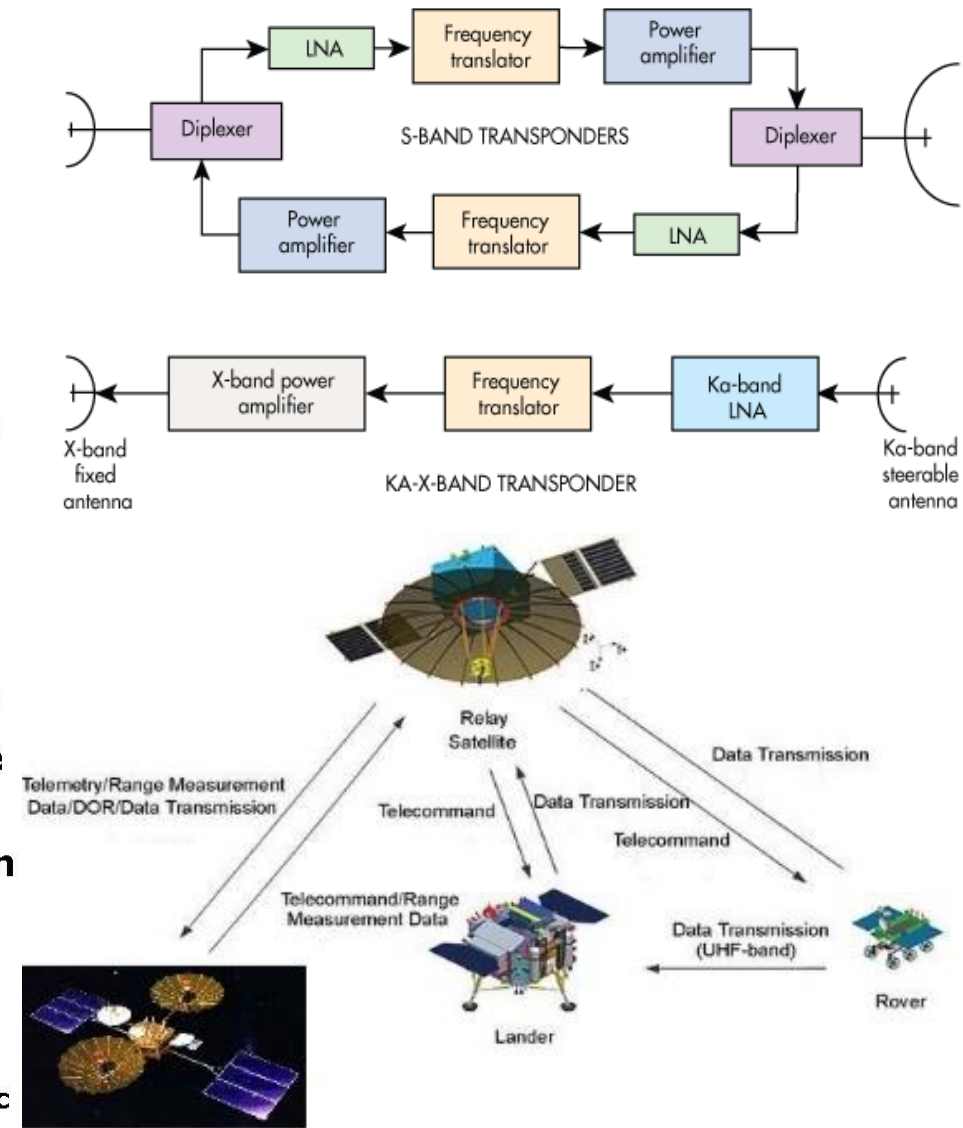
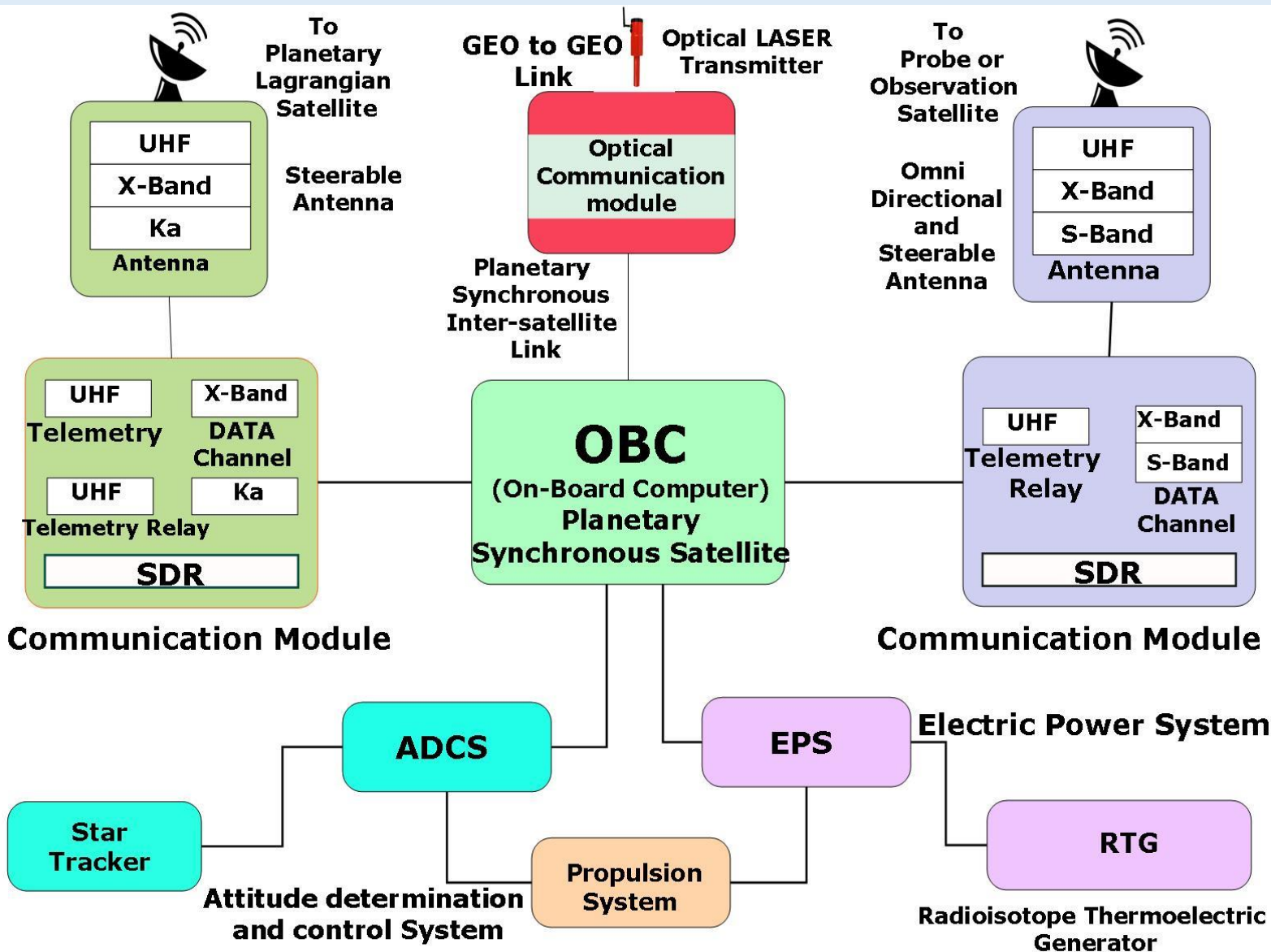


Figure: System Design Planetary Synchronous orbit Satellites

Picture: Probes to Relay Satellite Communication

Deep Space Network

