Communication and Navigation

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Moon Communications

- Options

System Element	Related Parameters	Trade Off considerations
• Relay Spacecraft	• Number of spacecraft (at least 2?) • Spacecraft orbit (LLO / L2) • Comms payload parameters – • *Optical or radio links?* • Platform parameters	• *number of spacecraft affects coverage (revisit time, link availability)* • *affects s/c design; Nearside vs. Farside positions?* • onboard data storage (*real time applications?*); frequency bands used; data protocols to deal with propagation delays • *Emission requirements from ITU-R regulations (Radio astronomy non-interference)* • *LEOP mission profile effects on s/c design*
• Relay Spacecraft downlink parameters	• Earth (frequency band / range/power/coverage) • Moon (frequency band/ range/power/coverage)	• *locations affect coverage and propagation (weather)* • *locations affect coverage (esp. Polar region or rough terrain)*

Moon Communications

- Options

System Element	Related Parameters	Trade Off considerations
• Relay Spacecraft uplink parameters	• Earth (frequency band/ range/power/coverage) • Moon (frequency band/ range/power/coverage)	• *assume relay is continuously visible from Earth* • From Moon – *power limitations on surface (esp. if solar power is used); dust and other environmental factors on ground terminals (e.g optical)* • Moon infrastructure: *relay link to all terminals or to centralised hub? (what on-surface comms will be used?)*
• Ground infrastructure parameters	• Location (lunar nearside or farside; equatorial or polar) • Earth (Number, size, sensitivity of ground stations) • Moon (Number, size, sensitivity of ground stations) • Relay from in-orbit spacecraft? (especially on farside)	• In-orbit lunar relay – *will require relay on lunar farside to be continuously visible (esp. For manned missions)*
• Input / output initial analysis	•	• Data rate, total data load per day, coverage

Moon Communications

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- Communications Architecture
  - Initial phase would be a single communications system provided by the scientific Orbiter, allowing relay of data to Earth from the near side or far side.
  - The second phase would launch two relay spacecraft which will orbit the Earth Moon L1 and L2 points.
  - In the third phase additional spacecraft would be launched to provide redundant communication capability prior to human exploration.
  - Only single channel communications via a relay to Earth from the farside are foreseen; However from the nearside, direct multichannel communications to the Earth are possible.
  - The ITU regulations suggest that high frequency (e.g. Ka Band) may be suitable for uplinks from the lunar farside; S-Band communications are specifically prohibited.

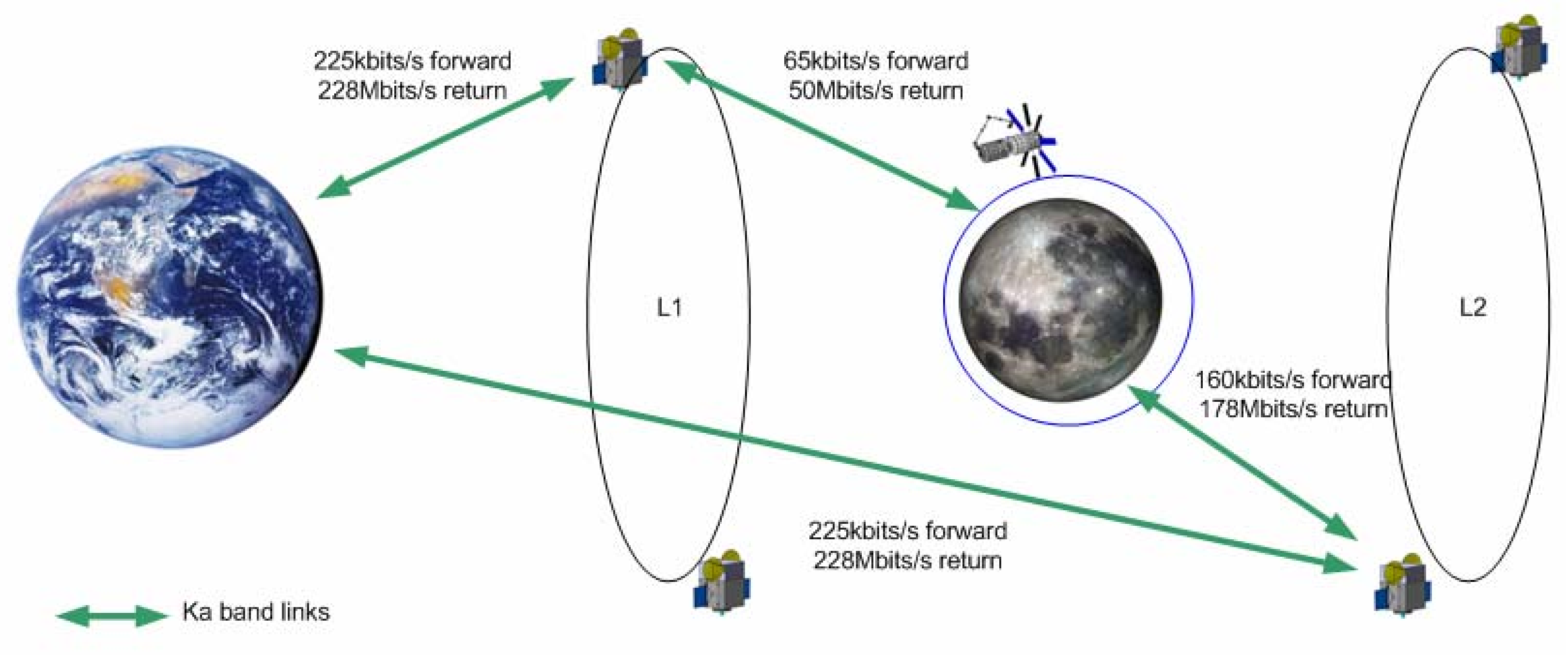
Moon Communications

- Communications Requirements: The communications relay should be compatible with the total rates presented in the table, 225kbits/s uplink and 288Mbits/s downlink from/to Earth.

Vehicle	Uplink	Dowlink
Phase 2		
Small Rover	10kbits/s	100kbits/s
Large Rover	100kbits/s	1Mbits/s
Lunar Transportation	10kbits/s	9Mbits/s
Robotic Cargo Lander	10kbits/s	9Mbits/s
Low Lunar Orbit Station	65kbits/s	110Mbits/s
Total	**195kbits/s**	**130Mbits/s**
Phase 3		
Small Rover	10kbits/s	100kbits/s
Large Rover	100kbits/s	1Mbits/s
Lunar Transportation	10kbits/s	9Mbits/s
Robotic Cargo Lander	10kbits/s	9Mbits/s
Low Lunar Orbit Station	65kbits/s	110Mbits/s
Crew Lander	10kbits/s	9Mbits/s
Lunar Base	10kbits/s	50Mbits/s
Low Frequency Telescope	10kbits/s	100Mbits/s
Total	**225kbits/s**	**288Mbits/s**

Moon Communications

- Communications Architecture (Phase 3)



Moon Communications

- Communications Payload
  - Based on the communications requirements we anticipate using something based on the HYLAS (Highly Adaptable Satellite) Generic Flexible Payload (GFP).
  - The HYLAS payload has 8 forward and 8 return link Ka-band transponders, allowing communication with the surface /moon orbit through a pattern of 7 beams and communication with the earth through the eight transponder.
  - The power and bandwidth levels are adjustable in orbit enabling the spacecraft to be flexible to user demand.

Payload Elements	Weight (kg)
K band repeater	120.00
Reference and Harness	36.00
Moon facing antenna	22.00
Earth facing antenna	22.00
Total	**200.00**

Moon Communications

- Configuration
  - The L1 and L2 spacecraft are not exactly the same (antenna position, dimension, power)
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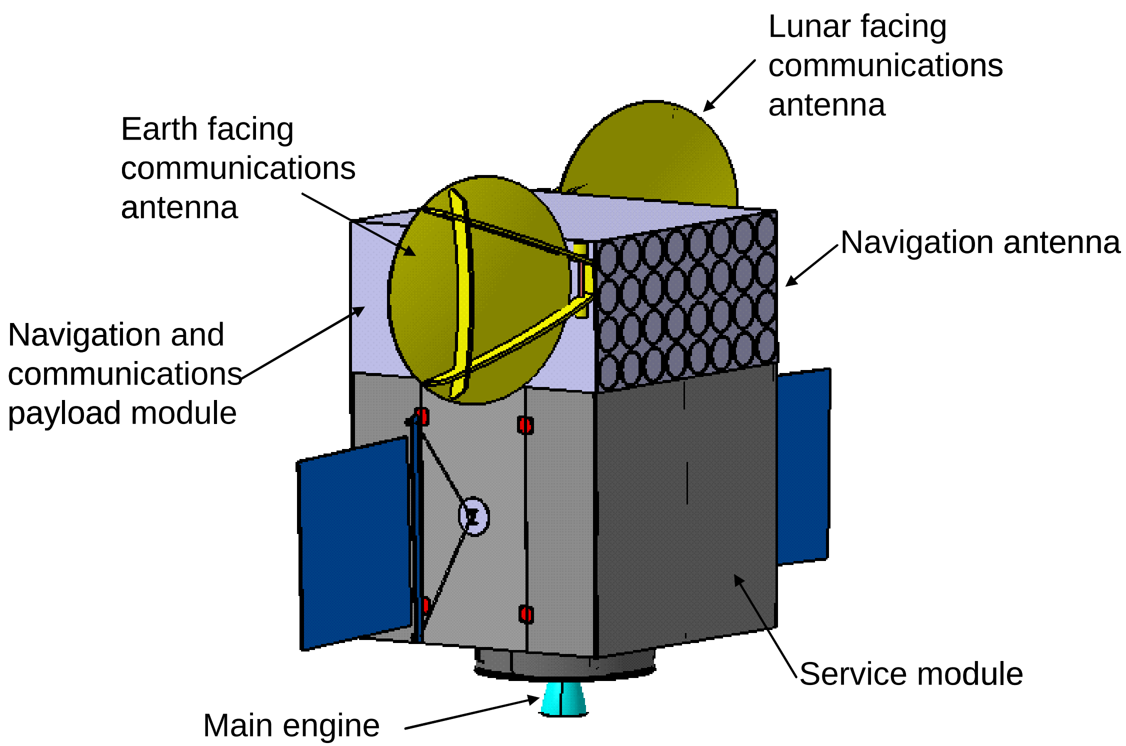

Moon Communications

- Moon Communication S/C
  - The mass budget of the Moon Telecom S/C is shown:

		Target Spacecraft Mass at Launch			3200.00	kg
		Below Mass Target by:			1644.24	kg
	Without Margin		Margin		Total	% of Total Dry
Dry mass contributions			%	kg	kg	
Structure	142.00	kg	19.26	27.35	169.35	18.73
Thermal Control	8.00	kg	17.50	1.40	9.40	1.04
Mechanisms	18.20	kg	10.11	1.84	20.04	2.22
Pyrotechnics	14.00	kg	8.21	1.15	15.15	1.68
Communications	2.80	kg	15.71	0.44	3.24	0.36
Data Handling	29.00	kg	5.00	1.45	30.45	3.37
AOCS	34.80	kg	5.00	1.74	36.54	4.04
GNC	0.00	kg	-	-	-	-
Propulsion	71.50	kg	6.24	4.46	75.96	8.40
Power	30.90	kg	10.00	3.09	33.99	3.76
Harness	25.00	kg	20.00	5.00	30.00	3.32
Instruments	400.00	kg	20.00	80.00	480.00	53.09
DLS	0.00	kg	-	-	-	-
Life support	0.00	kg	-	-	-	-
Total Dry(excl.adapter)	**776.20**				**904.12**	**kg**
System margin (excl.adapter)			**20.00**	**%**	**180.82**	**kg**
Total Dry with margin (excl.adapter)					**1084.94**	**kg**
Other contributions						
Astronauts	0.00	kg	-	-	-	
Consumables	0.00	kg	-	-	-	
Wet mass contributions						
Propellant	338.40	kg	5.00	16.92	355.32	
Adapter mass (including sep. mech.)	110.00	kg	5.00	5.50	115.50	
Total wet mass (excl.adapter)					**1440.26**	**kg**
Launch mass (including adapter)					**1555.76**	**kg**

- Robotic Missions Communication Requirements
  - The communication link for robotic missions is assured by the Mars Scientific Orbiter

No.	Requirement text	Assumptions	Numeric Requirement
1	At least 1 HD video signal should be available from Mars to Earth	Each HD link is 8Mb/s + housekeeping	8.05 Mbps
2	For Earth to Mars, Mars Express rate as a minimum		i) 7.8125 bps ii) 15.625 bps iii) 250 bps iv) 1 kbps v) 2 kbps

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- Human Missions Communication Requirements

No.	Requirement text	Assumptions	Numeric Requirement
1	Earth should be able to receive at least 3 HD video links at the same time (i.e. 2 from exploration teams and one from surface base)	Each HD link is 8Mb/s	24Mbps
2	Independent delayed real time voice communication should be possible from Earth to all surface personnel	32 kbps per voice channel 4 surface personnel	128kbps
3	Misc. data transmission should be available (i.e. housekeeping data (Base and orbiting S/C), Logs upload/download, …)	-	10kbps
	Total downlink rate		24.138Mbps

Mars Communications

- Human Missions Communication Trades

Relay spacecraft location	Pros	Cons
Earth Sun Lagrange Points	Simple deployment of spacecraft	Long distance from surface elements to relay spacecraft Relay spacecraft not always visible from Mars surface.
Mars Synchronous Orbit	Spacecraft maintain constant contact with areas of human activity 2 spacecraft provide continuous links to Station in LMO	Medium distance from surface LMO station to relay spacecraft, moderate power needed on surface elements
Mars High Orbit	Links to s/c short minimising power and antenna size needed on surface elements	Large number of spacecraft needed to provide full continuous coverage
Highly inclined Low Mars Orbit	Short distance links	Limited time of pass Long duration between passes therefore no continuous communication, UHF hardware therefore low data rate capability
Sun-Mars Lagrange Points	2 spacecraft provide complete coverage	Long distance from surface elements to relay spacecraft Relay spacecraft not always visible from Mars surface.

Mars Communications

- Mars Communication S/C
  - The Mars stationary orbit is the preferred location for the telecoms s/c as it increases the contact time between lander and telecom s/c to 100% and has almost continuous contact with Earth.
  - 1 spacecraft is not sufficient to provide continuous communication to a manned station in low Mars orbit, therefore 2 Mars synchronous spacecraft are recommended and 3 needed for full redundancy
  - The telemetry link (surface-Relay Spacecraft) requirement of ~8 Mbits/s for robotic missions and ~24Mbits/s for human missions can be met with a moderately sized Ka-band communication system comprising a 0.5m antenna on the s/c.
  - The data downlink capability from the Mars Telecom s/c to Earth is limited and not compatible with continuous transmission of high quality video channels (3), it should therefore be included on the s/c, as a backup, a high data rate optical system.

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Mars Communications

- Mars Communication S/C
  - The mass budget of the Mars Telecom S/C (Mars Express type configuration) is shown:

				Target Spacecraft Mass at Launch			3200.00	kg
				Below Mass Target by:			1252.41	kg
	Input Mass	Input Margin	Dry mass contributions	Without Margin	Margin %	Margin kg	Total kg	% of Total Dry
linked			Structure	212.00 kg	19.50	41.35	253.35	36.10
linked			Thermal Control	8.00 kg	17.50	1.40	9.40	1.34
linked			Mechanisms	18.20 kg	8.30	1.51	19.71	2.81
linked			Pyrotechnics	14.00 kg	8.21	1.15	15.15	2.16
linked			Communications	52.00 kg	12.46	6.48	58.48	8.33
linked			Data Handling	29.00 kg	5.00	1.45	30.45	4.34
linked			AOCS	34.80 kg	5.00	1.74	36.54	5.21
linked			GNC	0.00 kg	-	-	-	-
linked			Propulsion	107.66 kg	15.93	17.15	124.81	17.78
linked			Power	30.90 kg	10.00	3.09	33.99	4.84
linked			Harness	30.00 kg	20.00	6.00	36.00	5.13
linked			Instruments	70.00 kg	20.00	14.00	84.00	11.97
linked			DLS	0.00 kg	-	-	-	-
linked			Life support	0.00 kg	-	-	-	-
			Total Dry(excl.adapter)	606.56			701.88 kg	
			System margin (excl.adapter)		20.00 %		140.38 kg	
			Total Dry with margin (excl.adapter)				842.26 kg	
			Other contributions					
linked			Astronauts	0.00 kg	-	-	-	
linked			Consumables	0.00 kg	-	-	-	
			Wet mass contributions					
linked			Propellant	942.70 kg	5.00	47.14	989.84	
linked			Adapter mass (including sep. mech.)	110.00 kg	5.00	5.50	115.50	
			Total wet mass (excl.adapter)				1832.09 kg	
			Launch mass (including adapter)				1947.59 kg	

Optical Demo Mission

- Optical Communication Demo
  - Several elements of the exploration architecture drive the need for optical communications:
    - Full deployment of Radio Telescope on the far side of the moon leads to data rates ~100Mbit/s
    - High definition video required during robotic phase of Mars Exploration (~10Mbits/s)
    - Multiple HD video channels needed for mission operations during human activity (10 Mbits/s each for Mars, up to 50 Mbits/s for the Moon base)
  - Demonstration Mission Objectives:
    - Demonstrate use of optical communications in phase 1 of the architecture deployment (Optical payload must be accommodated on lunar scientific Orbiter)
    - Demonstrate surface to Orbiter links
    - Demonstrate Orbiter to Earth links
    - Support human presence
    - Provide communication support to lunar farside if not covered by NASA constellation

Optical Demo Mission

- Scientific Orbiter with Optical Demo Payload
  - A preliminary analysis of a lunar demonstration mission has shown that the optical demo payload can be accommodated on the science Orbiter with limited design impacts and the spacecraft is still compatible with Soyuz launch capability:
    - Mass ~150kg
    - Moving mass ~75kg
    - Science Orbiter mass increases to 1882kg, still compatible with Soyuz launch (an A5 shared launch is also possible)
    - Power demand 130-220W
    - Pointing accuracy <2µrad
    - Spacecraft pointing accuracy of typical GEO sat needs (deg level), science orbiter performance should be significantly better than this
    - Operational impacts, use of telecoms payload may limit time available for science

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Cooperation with NASA

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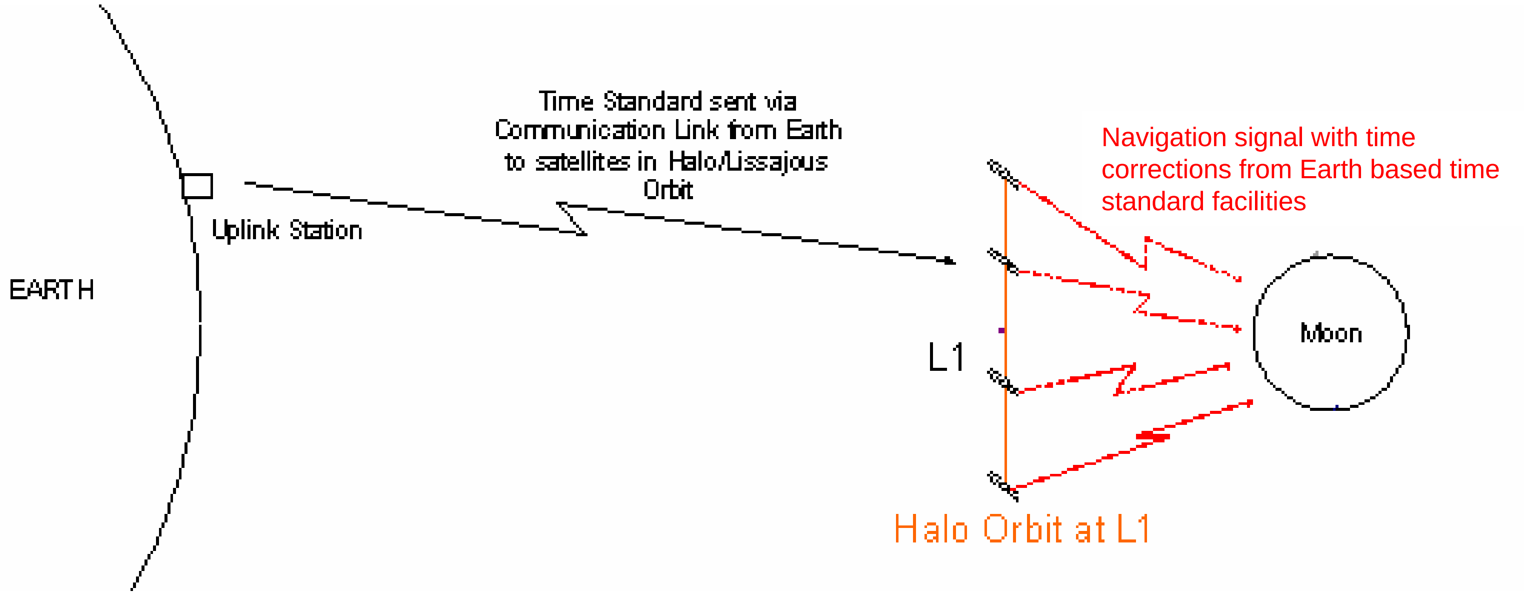
- The current NASA plan is for a Constellation of 2 spacecraft with the following orbital properties:
  - 12 hour frozen orbit
  - Semi-major axis 6142.4km
  - Inclination 57.7 deg
- There are two options for the deployment of the spacecraft:
  - Option A the spacecraft are in same orbit 180 deg phased, this option gives good coverage of one hemisphere and redundancy
  - Option B Orthogonal planes with the same inclination and opposite apolunes – provides full surface coverage but no on-orbit spare
- The ESA/RHI proposed architecture complements the NASA solution as is provides complete coverage for widely dispersed surface elements while the NASA architecture is focused on providing continuous communications to a manned outpost close to the south pole.

Moon Navigation

- The basic principle of operation is that each of the navigation satellites carry precise clocks and transmit a spread spectrum timing signal, this data includes the satellite position (ephemerides). The receiver at the surface element measures the time delay between transmission and reception (pseudoranges) from the visible satellites and derives the user X.Y,Z coordinates and deltaT, the time offset.



Moon Navigation

- With three satellites around L1 and L2, a purely space based navigation system with global coverage is realised, assuming that the User terminals are equipped with high standard frequency oscillators (e.g. atomic clocks).
- Navigation Payload Mass Budget:

Payload Elements	Weight (kg)
Atomic Clocks and Clock Monitoring and Control Unit	63.00
Payload Security Unit	12.00
Navigation Signal Generation Unit	15.00
Frequency Generation and Upconversion Unit and Test Couplers	13.00
SSPA, Splitter and Test Couplers	15.00
Navigation Output Section (including Antenna)	30.00
C-Band Section	35.00
Remote Terminal Unit	9.00
Cables and Harness	8.00
Total	**200.00**