IOAG Lunar/Mars Missions Coordination Team -- Findings, Observations, & Issues –

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IOAG Lunar/Mars Mission Coordination Team Composition

- The IOAG Lunar/Mars mission coordination team members:
  - ASI: F. D'Amico
  - CSA: S. Beaudry
  - CNES: J. M. Soula
  - CNSA: Huang Yonghui, He Shanbao
  - DLR: R. Kozlowski
  - ESA: G.P. Calzolari, K. Nergaard
  - KARI: S. Ahn
  - JAXA: Takahiro Yamada
  - NASA: W. Tai, D. Israel
  - UKSA: M. Cosby

  Chair: W. Tai; Co-Chair: K. Nergaard

Lunar/Mars Mission Coordination Team Work Statements

- Scope of the team activity
- Identifying specific problems the IOAG should consider to solve:
  - Need to come up with specific problem statements.
- Recommendations on activities moving forward. Possibilities are as follows:
  - No problems at all or problems that will easily be resolved by the coordination team.
  - Solutions to the problems that will have to be undertaken by the CCSDS.
  - Solutions to the problems that will have to be undertaken by the IOAG.
  - Solutions to the problems that will have to be undertaken by organizations other than the CCSDS and IOAG.

Origin of this team activity: A request from the CMC to the IOAG via the CCSDS liaison dated 11/2015 -

- CMC-A-2015-11-13: "The CMC instructed the CCSDS liaison to the IOAG to propose a small working group within the IOAG to discuss and coordinate lunar and Mars missions in the early 2020s."
- IOAG decided to form a coordination team to understand the need for such a working group [3/10/2016].

Lunar/Mars Mission Coordination Work Statements – The Scope

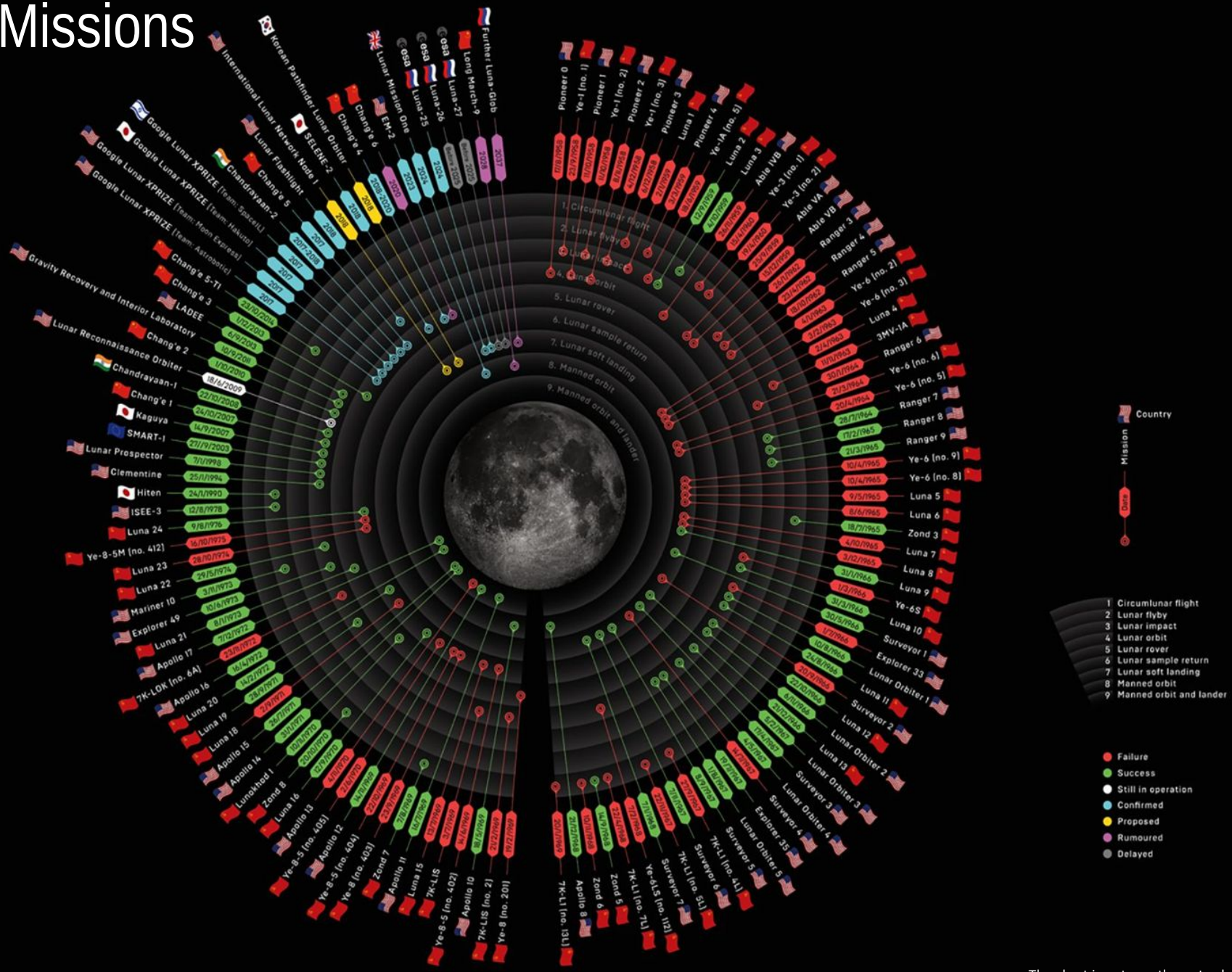
- The coordination team is to undertake some initial activity only, i.e., to understand and assess the problem space. It is not the actual working group.
  - Depending on the findings and problems identified by the coordination team, the IOAG "… might decide at a later stage to establish a formal WG with the task of creating a formal report" (quoting the words of the IOAG Chair).
- By "mission coordination", we mean the focus will be on space communications and navigation, not mission planning/design, science observation, or spacecraft.
  - How about mission operations?
- The potential areas of interest in mission coordination may be:
  - Cross support and interoperability between agencies for these missions,
  - Identification of missing standards,
  - Infusion of new standards, CCSDS or those from other standardization bodies, by these missions,
  - Identification of capability gaps

  And, perhaps, the Lunar/Mars space communications architecture(s) that could potentially guide the missions and be driven by these missions.

Lunar/Mars Mission Coordination
Work Statements – Identify Specific Problems

- Understand the Lunar/Mars mission sets.
  - Identify the agencies involved in each mission and the degree of inter-agency cooperation.
  - Identify the cross-support services and the standards to be applied by each mission.
  - Identify the communications assets employed by each mission for cross support.
- Identify the standards that are currently available, but have not been infused (or are not in the plan for infusion) by these missions and relevant communications assets.
- Identify the capabilities, that exist or are in the plan for infusion by these missions, but are not currently in the form of “standards”.
- Identify the capabilities, that will be needed by Lunar/Mars missions, but are not currently in the form of “standards”.
- Determine the potential relay services needed by these missions.
- Assess whether we need a Lunar/Mars space communications architecture.
- Generate specific problem statements, if any.

Lunar Missions



The chart is not exactly up-to-da

Mars Missions

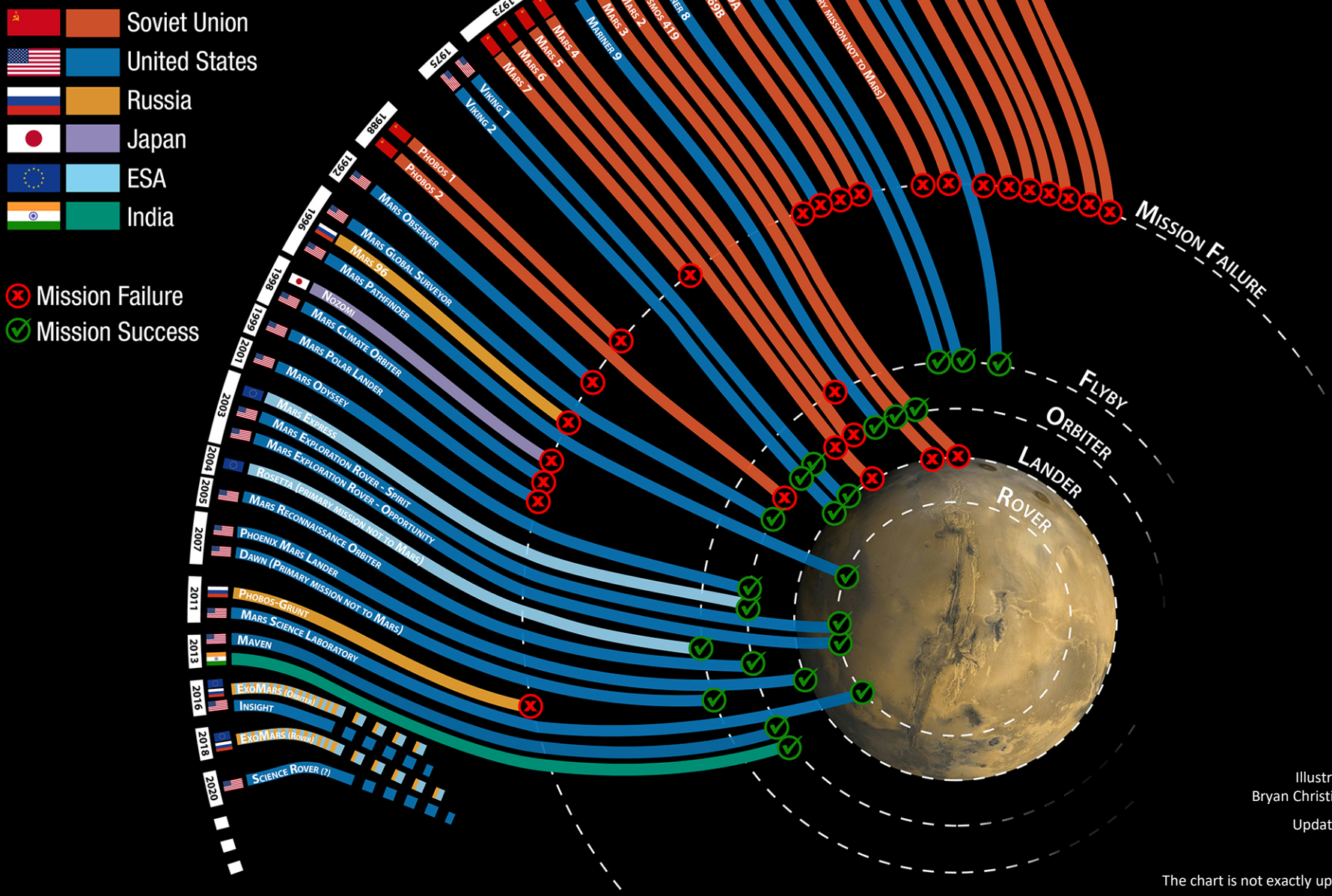


Illustration by:
Bryan Christie Design

Updated: 2015

The chart is not exactly up-to-date.

Current Lunar/Mars Missions

Lunar/Mars Missions that are currently in operational phase:

Lunar Mission	Launch Year	Agency	# of Vehicles	Mission Type
Lunar Reconnaissance Orbiter (LRO)	2009	NASA	1	Orbiter
Chang'e 3	2013	CNSA	2	Lander/rover
Mars Mission	**Launch Year**	**Agency**	**# of Vehicles**	**Mission Type**
Mars Odyssey	2001	NASA	1	Orbiter
Mars Express	2003	ESA	1	Orbiter
Mars Exploration Rover (MER) - Opportunity	2003	NASA	1	Rover
Mars Reconnaissance Orbiter (MRO)	2005	NASA	1	Orbiter
Mars Science Laboratory (MSL) - Curiocity	2011	NASA	1	Rover
Mars Orbiter Mission-1 (MOM-1) - Mangalyaan	2013	ISRO	1	Orbiter
Mars Atmosphere and Volatile EvolutioN (MAVEN)	2013	NASA	1	Orbiter
ExoMars Trace Gas Orbiter (Exo-TGO)	2016	ESA	2	Orbiter/Lander

Lunar Missions To Be Launched During The Decade 2016 -2025

Mission	Launch Year	Agency	# of Vehicles	Mission Type
Chandrayaan-2	2017	ISRO	3	Orbiter/lander/rover
Chang'e 4	2018	CNSA	2	Lander/rover
Chang'e 5	2017	CNSA	2	Orbiter/rover for sample return
Chang'e 6	2020	CNSA	2	Orbiter/rover for sample return
KPLO	2018	KARI	1	Orbiter
Korean Lunar Mission	2021	KARI	3	Orbiter/lander/rover
Luna 25	2024	RFSA	1	Lander
Luna 27	2020	RFSA	1	Rover
Luna 26	2020	RFSA	1	Orbiter
SLIM	2020	JAXA	1	Lander
Resource Prospector*	2020	NASA	2	Lander/rover
Lunar Communications Pathfinder*	2020s	ESA	1	Relay Orbiter
Cislunar Transit Habitat*	2022	NASA	1	Orbiter
International Lunar* Exploration Precursor mission	2024	ESA	3	Lander/Rover/Ascender
International Human Lunar Surface Architecture*	2028	ESA	3	Lander/Rover/Ascender

Lunar Missions To Be Launched During The Decade 2016 -2025

Mission	Launch Year	Agency	# of Vehicles	Mission Type
EM-1**	2018	NASA	1	Orbiter
EM-2**	2020	NASA	1	Orbiter
Lunar Flashlight	2018	NASA	1	CubeSat Orbiter
Lunar IceCube	2018	NASA	1	CubeSat Orbiter
Lunar H-Mapper	2018	NASA	1	CubeSat Orbiter
ArgoMoon	2018	ASI	1	CubeSat Orbiter
Omotenashi	2018	JAXA	1	CubeSat Lander
EQULLEUS	2018	JAXA	1	CubeSat Orbiter

Note:

- *Proposed mission or mission concept in planning
- ** Not exactly a lunar mission; rendezvous to the Distant Retrograde Obit (DRO)

Pre-Decisional Information -- For Planning and Discussion Purposes Only

Lunar Missions (2016-2025)
Findings & Observations – Number of Missions

First, a few observations on the figures:

- Unprecedented number of lunar missions and space vehicles in the history of space exploration.
- Among all the missions that have decided on their cross support status, a very high percentage (~93%) of lunar missions requires cross support. Only one mission has ruled out the need for cross support by other agencies.

IOAG Agency ->		ASI	CNSA	ESA	ISRO	JAXA	KARI	NASA	RFSA	TOTAL
No. of Missions		1	3	3	1	3	2	7	3	**23**
No. of Vehicles		1	6	7	3	3	4	8	3	**35**
No. of Cross-Supported Missions	Yes	1	2	2	1	2	1	7		**16**
	No					1				**1**
	TBD		1	1			1		3	**6**

Pre-Decisional Information -- For Planning and Discussion Purposes Only

Lunar Missions (2016-2025)
Findings & Observations – The Links

- At physical layer, X-band is gaining popularity among lunar missions.
- No Ka-band and/or optical links for Earth-Moon high-rate data return – no mission requirements.
- At least 5 missions will provide relay capability. However, the frequency band(s) for proximity links are yet to converge.
- No frequency band planned for high-rate proximity link by any lunar mission – no mission requirements.

	Earth-Moon Uplink	Earth-Moon Dowlink	Moon Orbit-to-Surface Link
X-Band	12	16	
S-Band	6	6	1
Ka-Band			1
Ku-Band			1
UHF-Band	1	1	2
TBD	4	4	8
None			9

Lunar Missions (2016-2025)
Findings & Observations – Coding & Modulation

- Modulation schemes are all CCSDS-compliant and largely consistent with the "IOAG Report on Preferred Coding and Modulation Schemes".
  - Bandwidth efficient modulation, e.g., GMSK, has not been planned by any mission. Perhaps, this is because none of them is “high-rate” mission demanding high spectral efficiency.
- Coding schemes are more confined to the traditional codes:
  - Reed-Solomon/Convolutional/Concatenated code for downlink
  - BCH code for uplink
- LDPC and Turbo codes are emerging for lunar communications.
- The use of Forward Error Correction (FEC) codes for Moon-Earth uplink is happening.
- The use of high-performance Forward Error Correction (FEC) for proximity link is not imminent.

	Reed-Solomon only	Convolutional Code only	Concatenated (RS+Conv)	Turbo	LDPC	BCH	TBD	N/A
Downlink	1		8	3	3		9	
Uplink					2	9	12	
Proximity Link		2					11	10

Lunar Missions (2016-2025)
Findings & Observations - Services

- The use of standard services per IOAG Service Catalog -1 v2.0 (except Relay Services) for inter-agency cross support purpose is universally accepted by all lunar missions.
- The provision of relay services (i.e. using TM/TC/AOS for the long haul and Proximity-1 for the Moon vicinity) remains to be realized.
  - Among the 5 missions offering relay links, with the exception of Lunar Communications Pathfinder, no relay services are explicitly planned for inter-agency cross support purpose.
  - Proximity-1 protocol is yet to gain wide acceptance by lunar missions for implementing relay services.
- No obvious Lunar Network is imminent during this decade.
  - Lunar Communications Pathfinder may be a start.

Services ->	Forward Data: FCLTU	Return Data: RAF/RCF	Radiometric Data: Validated	Delta DOR	Relay Services	
					Relay Link	Proximity-1
Compliant	13	13	9	2	5	2
TBD	8	8	10		8	8
None	1	1	2	21	10	10
Other	1	1			0	3

Lunar Missions
Some Issues Relevant to IOAG

Potential IOAG issues	Remarks
Convergence of frequency bands, by future lunar missions, for lunar proximity links: low-rate TT&C links	The divergence of frequency bands for for lunar proximity links is already a phenomenon. While it does not pose a problem for cross support now, the IOAG may want to take a pro-active role to prevent it from becoming a problem in the future.
Convergence of frequency bands, by future lunar missions, for lunar proximity links: high-rate RF links	Looking ahead for future high-rate lunar missions, the IOAG may want to contain the multiplicity of frequency bands (SFCG guidelines allow multiple choices) for better interoperability and cross support.
Advocacy of “standard” relay services	Standard relay services may also cover among others: (1) demand-access & multiple access modes; (2) position determination, both over the proximity link.
Advocacy of space internetworking services per DTN	Looking ahead for the future Lunar Network, network layer capabilities are an essential element for the Network.
Advocacy of Cross Support Service Management (CSSM)	As CSSM standards are gradually defined, IOAG may want to undertake a coordination role to plan for the implementation of CSSM, starting with the Simple Schedule Format.
Advocacy of optical communications	Looking ahead for future high-rate lunar missions, the IOAG may want to undertake a coordination role to plan for the implementation and sharing of optical assets.

Mars Missions To Be Launched During The Decade 2016 -2025

Mission	Launch Year	Agency	# of Vehicles	Mission Type
ExoMars TGO	2016	ESA	2	Orbiter/Lander
Insight	2018	NASA	1	Lander
MarCO	2018	NASA	2	CubeSat Orbiter
Red Dragon	2018	NASA/SpaceX	1	Lander
ExoMars Rover	2018	ESA	2	Rover
MOM-2	2020	ISRO	1	Orbiter
Mars Mission 2020	2020	CNSA	3	Orbiter/Lander/Rover
Emirates Mars Mission	2020	UAE Space	1	Orbiter
Mars 2020	2020	NASA	1	Rover
NeMO*	2022	NASA	1	Orbiter
Phobos-Grunt 2	2020	RFSA	1	Phobos sample return
HSF Pathfinder*	2024	NASA	1	Orbiter
MSR-O*	2024	NASA	2	Orbiter/SmallSat
MSR-L*	2028	NASA	2	Orbiter/SmallSat
Mars Moon eXploration (MMX)*	2022	JAXA	2	Phobos sample return

Note: *Proposed mission or mission concept in planning

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Mars Missions (2016-2025)
Findings & Observations – Number of Missions

First, a few observations on the figures:

- Unprecedented number of Mars missions and space vehicles in the history of space exploration.
- Among all the missions that have decided on their cross support status, a very high percentage (~90%) of Mars missions requires cross support. Only one mission has ruled out the need for cross support by other agencies.

IOAG Agency ->		CNSA	ESA	ISRO	JAXA	NASA	RFSA	UAE	TOTAL
No. of Missions		1	2	1	1	8	1	1	**15**
No. of Vehicles		3	4	1	2	11	1	1	**23**
No. of Cross-Supported Missions	Yes		2	1	1	4	1	1	**10**
	No					1			**1**
	TBD	1				3			**4**

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Mars Missions (2016-2025)
Findings & Observations – The Links

- At physical layer, deep space X-band is the dominant band for Mars DTE/DFE links.
- Ka-band and/or optical links are emerging as the high-rate Mars-to-Earth links.
- At least 8 missions will provide or use proximity link.
- UHF-band is the dominant band(s) for proximity links, i.e., for low-rate TT&C.
- X-band and/or optical links are emerging as the high-rate Mars proximity links.

	Earth-Mars Uplink	Earth-Mars Dowlink	Mars Orbit-to-Surface Link
X-Band	9	9	1
S-Band	1	1	
Ka-Band		2	
Optical		1	1
UHF-Band			8
TBD	5	5	5
None			2

Mars Missions (2016-2025)
Findings & Observations – Coding & Modulation

- Modulation schemes are all CCSDS-compliant and largely consistent with the "IOAG Report on Preferred Coding and Modulation Schemes".
  - Significant use of bandwidth efficient modulation, i.e., GMSK, by some Mars missions.
- Coding schemes are more confined to the traditional codes:
  - Reed-Solomon/Convolutional/Concatenated code for downlink
  - BCH code for uplink
- Significant use of Turbo code for return link.
- LDPC is yet to be used as a major code for Mars communications.
- High-performance forward error correction (FEC) code is rarely applied for Mars proximity link.
  - Only 1 Mars mission plans to use LDPC for proximity links; both return and forward.
- The use of FEC code for Mars-Earth uplink is not imminent.

	Convolutional Code only	Concatenated (RS+Conv)	Turbo	LDPC	BCH	TBD	N/A
Downlink		7	5	1		7	1
Uplink					7	7	1
Proximity Link	8			1		5	2

Mars Missions (2016-2025)
Findings & Observations - Services

- The use of standard services per IOAG Service Catalog -1 v2.0 and Relay Services for inter-agency cross support purpose is universally accepted by all Mars missions.
  - Delta DOR service is widely used and always requires inter-agency cross support.
- The provision of relay services (i.e. using TM/TC/AOS for the long haul and Proximity-1 for the Mars vicinity), has led to the emergence of a "rudimentary" Mars Network, which will likely persist during the decade.
  - But some deficiencies in the implementation will have to be corrected.

Services ->	Forward Data: FCLTU	Return Data: RAF/RCF	Validated Data Radio Metric Service	Delta DOR	Relay Services	
					Relay Link	Proximity-1
Compliant	10	10	7	7	8	8
TBD	5	5	7		5	5
None			1	8	2	2
Other						

Mars Missions
Some Issues Relevant to IOAG

Potential IOAG issues	Remarks
Convergence of frequency bands, by future Mars missions, for Mars proximity links: high-rate RF links	Looking ahead for future high-rate Mars missions, the IOAG may want to contain the multiplicity of frequency bands (SFCG guidelines allow multiple choices) for better interoperability and cross support.
Advocacy of “standard” relay services	Standard relay services may also cover among others: (1) demand-access & multiple access modes; (2) position determination, both over the Mars proximity link.
Advocacy of space internetworking services per DTN	Looking ahead for the future Mars Network, network layer capabilities are an essential element for the Network.
Advocacy of Cross Support Service Management (CSSM)	As CSSM standards are gradually defined, IOAG may want to undertake a coordination role to plan for the implementation of CSSM, starting with the Simple Schedule Format.
Advocacy of optical communications	Looking ahead for future high-rate Mars missions, the IOAG may want to undertake a coordination role to plan for the implementation and sharing of optical assets.

IOAG Lunar/Mars Mission Coordination Conclusions

1. The Lunar/Mars missions of the 2020s are mostly in compliance with those Core Services defined in the IOAG Service Catalog 1. There is no interoperability issue. The CCSDS standards (either available or under development), when adopted and applied properly, are sufficient for the communication assets owned by the IOAG member agencies to cross support those missions.
2. Looking further into the era of late 2020s and early-to-mid 2030s, due to multiple choices in the standards, the selective use of standards to avoid any interoperability problems, will be important to future Lunar/Mars missions. By "selective use", it means the following:
   - Convergence of frequency bands for lunar proximity links: low-rate TT&C links
   - Convergence of frequency bands for lunar and Mars proximity links: high-rate RF links
3. In anticipating the advancement of new communication capabilities and services during the era of late 2020s and early-to-mid 2030s, there will be the need for an coordinated effort in advocating the infusion of new CCSDS standards, so that a new level of interoperability among future Lunar/Mars missions is possible. Chief among the new standards and capabilities to be infused include:
   - Space Internetworking Services per DTN
   - Cross Support Service Management (CSSM)
   - Optical communications

IOAG Lunar/Mars Mission Coordination Conclusions

4. While optical and Ka-bands (26 GHz, 32 GHz, and 34 GHz) will likely be used for high-rate Moon/Mars-to-Earth links, the use cases for other Ka-bands, i.e. Ka 21-22 GHz, Ka 37-38 GHz, and Ka 39-40 GHz, in the future remain rather unclear. Two key issues may have to be explored further by the IOAG:
   - Optical vs. RF, i.e., Ka-bands: Will optical communications be the ultimate, primary approach for high-rate links? Or both optical and Ka-band?
   - Protection of Ka-bands: If there is no future plan for using Ka 22 GHz, Ka 37-38 GHz, and Ka 39-40 GHz, how will we protect these bands, i.e., preventing them from being encroached upon by other user communities?

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