National Aeronautics and Space Administration

Supply & Resource Management

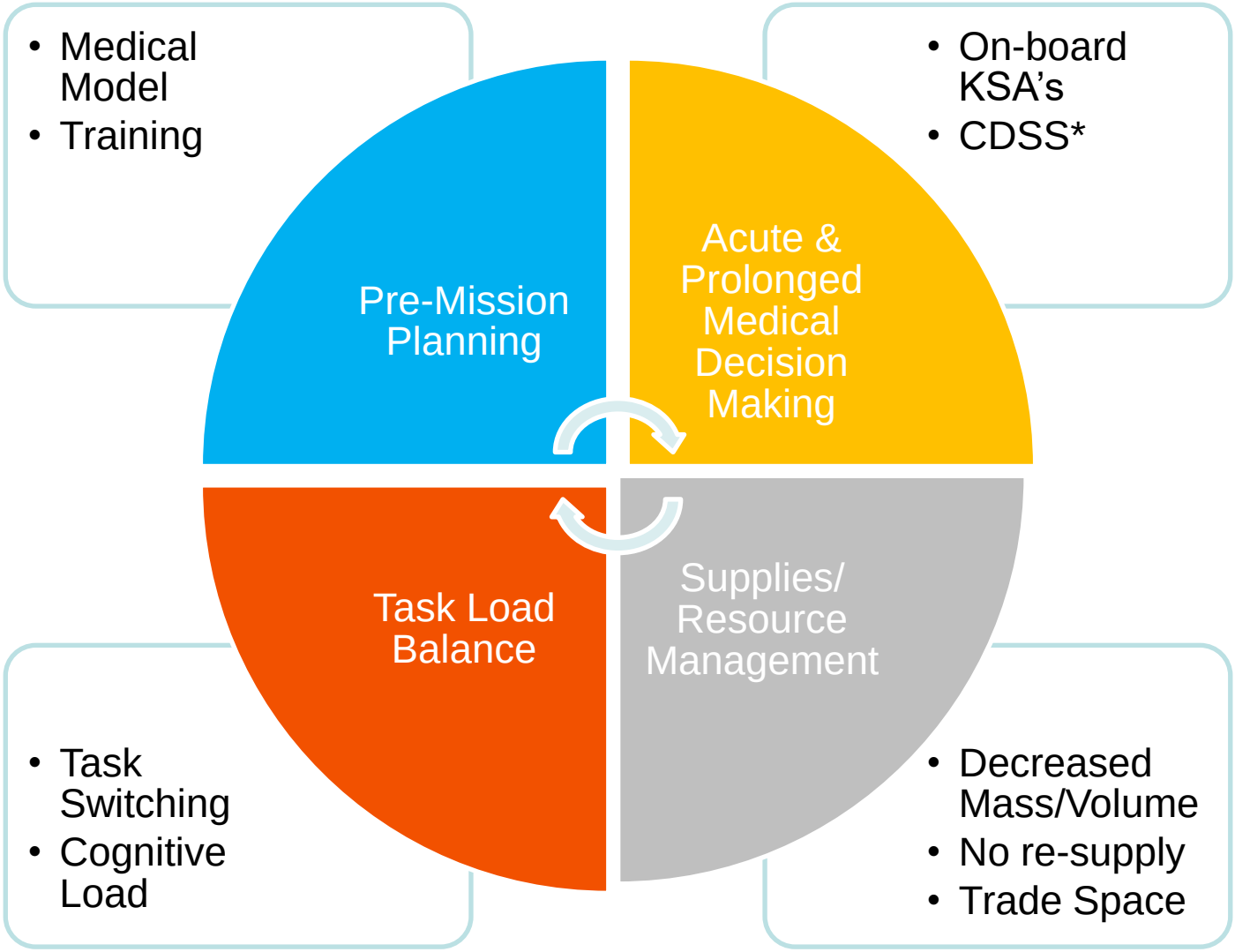
To Progressively Enable EIMO

EIMO TIM4

27 February 2024

Earth Independent Medical Operations (EIMO)

EIMO Components

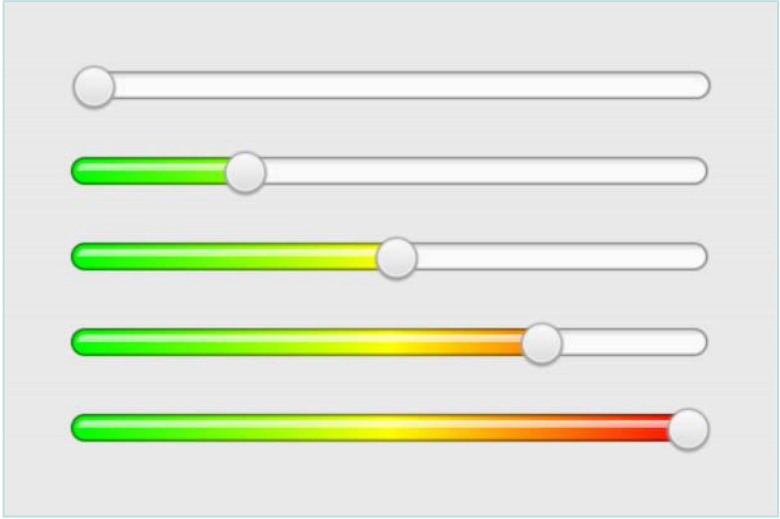


A Progressive Approach

On-board care will ***increasingly become the responsibility*** of the astronauts for primary management.

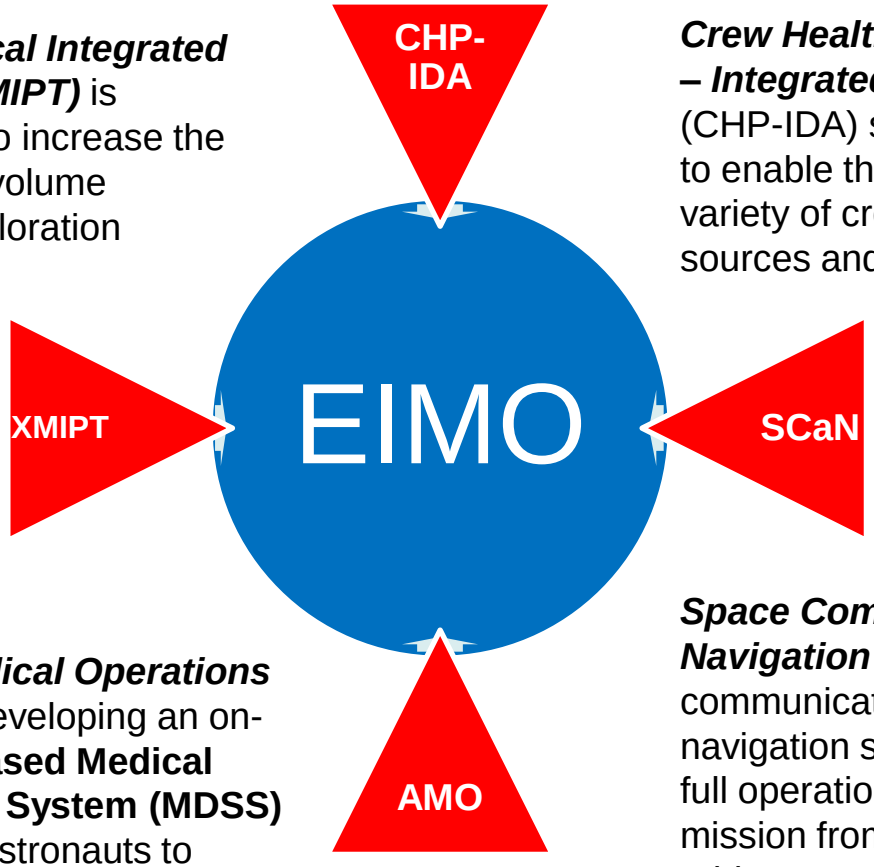
Terrestrial assets will continue to be paramount in pre-mission screening and planning, as well as health maintenance and prevention activities.

New capabilities and systems that enable progressively more robust and resilient systems and crews will ***reduce risk and increase probability*** **of deep space exploration mission *success***.



EIMO Intersects Within NASA

Exploration Medical Integrated Product Team (XMIPT) is seeking solutions to increase the mass, power, and volume efficiency of its exploration medical system.



Crew Health and Performance – Integrated Data Architecture (CHP-IDA) system as a platform to enable the amalgamation of a variety of crew-relevant data sources and applications.

Autonomous Medical Operations (AMO) project is developing an on-board **software-based Medical Decision Support System (MDSS)** which will enable astronauts to diagnose and treat emergent conditions in a timely manner.

Space Communication and Navigation (SCaN) provides communications and navigation services over the full operational life cycle of a mission from launch to de-orbit.

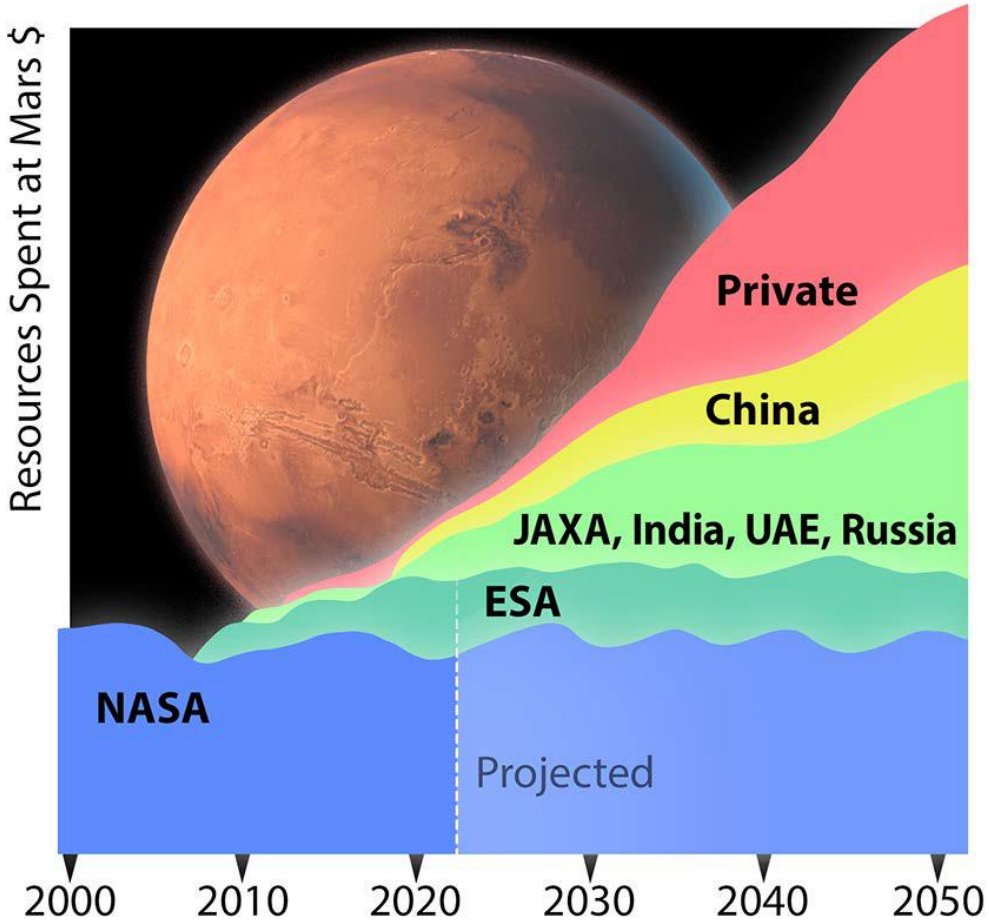
Purpose

The purpose of the TIM is to identify, prioritize and plan forward work on EIMO

From the perspective of potential stakeholders, what are key considerations pertaining to supply and resource management needed to **enable EIMO**?

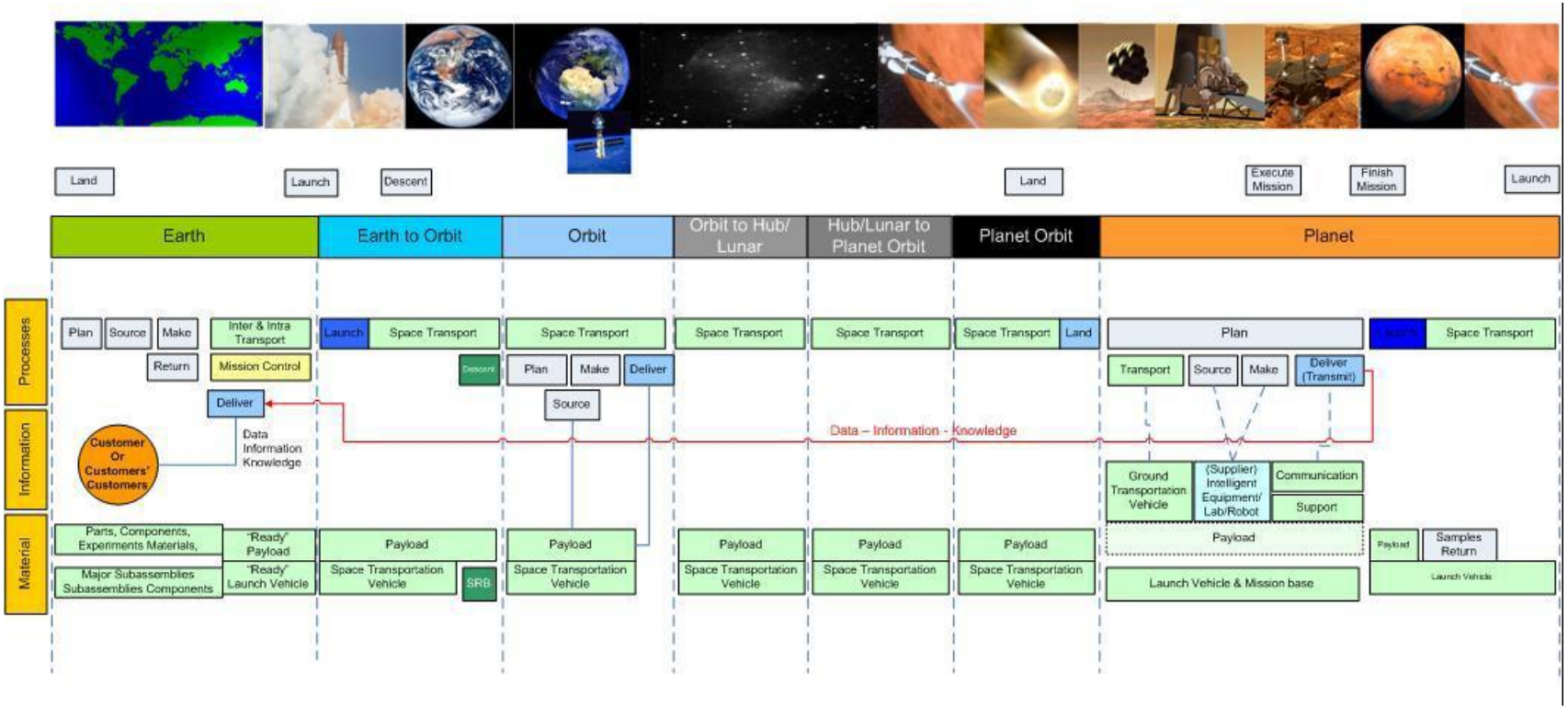
- Restrictions in mass, power, volume
- If pre-deployment, interval could exceed use life
- Environmental (elevations in temperature, humidity, oxygen)
- Radiation

Diversity of Stakeholders Investing in Mars



Keck Institute for Space Studies (KISS), 2022, Revolutionizing Access to the Mars Surface. Culbert, C.J., Ehlmann, B.L., Fraeman, A.A., editors. Final Workshop Report for the W.M. Keck Institute for Space Studies, Pasadena, CA. DOI: 10.7907/d1smmj77.

Exploration Supply Chain



Galluzzi M, et.al., Foundations of Supply Chain Management for Space Application, AIAA Space Conference, 2006.

NASA Medical Standards

LEVEL OF CARE	MISSION	CAPABILITIES
I	LEO < 8 days	Space Motion Sickness, Basic Life Support, First Aid, Private Conference, Anaphylaxis Response, Acoustic Monitor
II	LEO < 30 Days	Level I + Clinical Diagnostics, Ambulatory Care, Private Video, Private Telemedicine
III	Beyond LEO < 30 Days	Level II + Limited Advanced Life Support, Trauma Care, Limited Dental Care
IV	Lunar > 30 Days	Level III + Medical Imaging, Sustainable Advanced Life Support, Limited Surgical, Dental Care
V	Mars Expedition	Level IV + Autonomous Advanced Life Support and Ambulatory Care, Basic Surgical Care

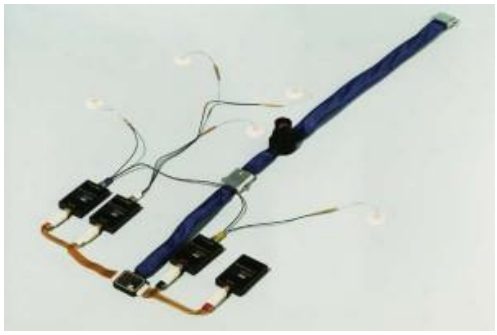
EIMO must be able to support LEVEL V NASA medical standard of care for 119 anticipated medical conditions

Evolution of On-board Medical Kits

Mercury

Autoinjectors

Gemini



Biomedical Monitoring

Apollo

Therapeutics

Skylab

Physician

Shuttle

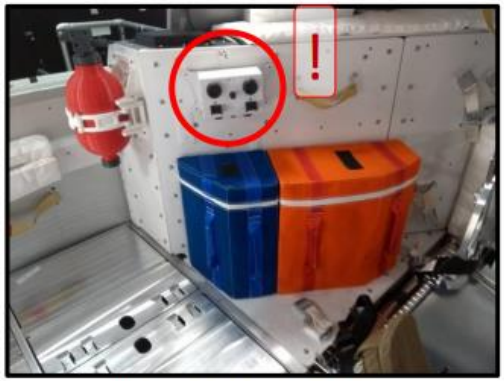
Expanded Therapeutics

ISS

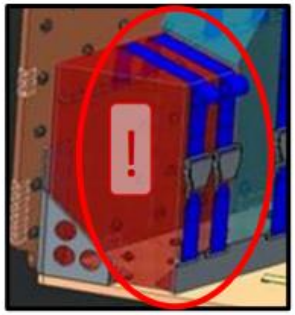
Multiple Kits

Medical Kit Design Constraints

Open Cabin Constraints



Interference Constraints



Load Constraints

Mass Allocation: 30 lbs

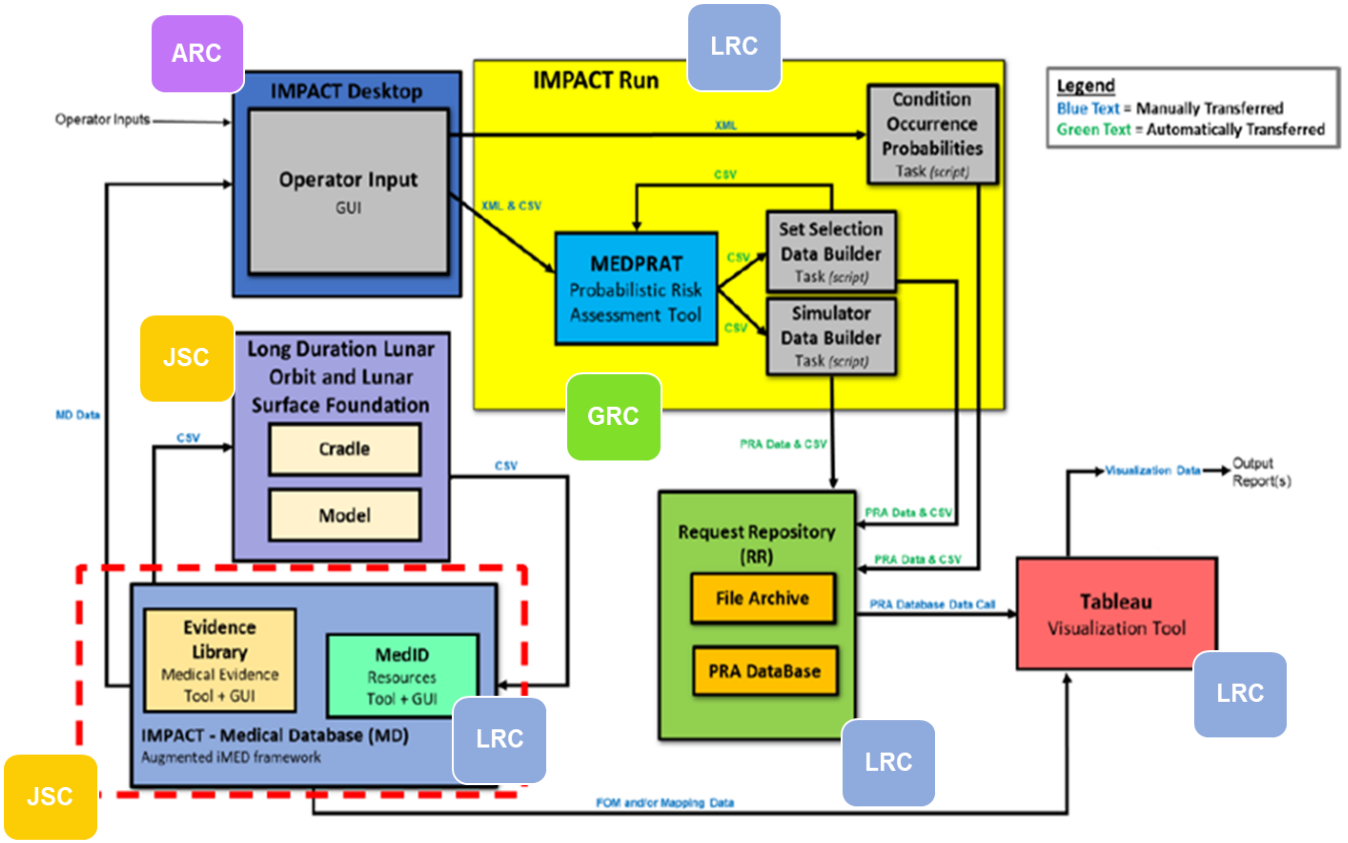
Volume Allocation: ~1,116 in³

Mass/Volume Constraints

A Semi-Quantitative Approach To Building The Orion Spacecraft Medical Kit, Rubin D, et.al., 92nd Annual Scientific Meeting, Aerospace Medical Association, Reno, Nevada May 2022.

IMPACT PRA Tool

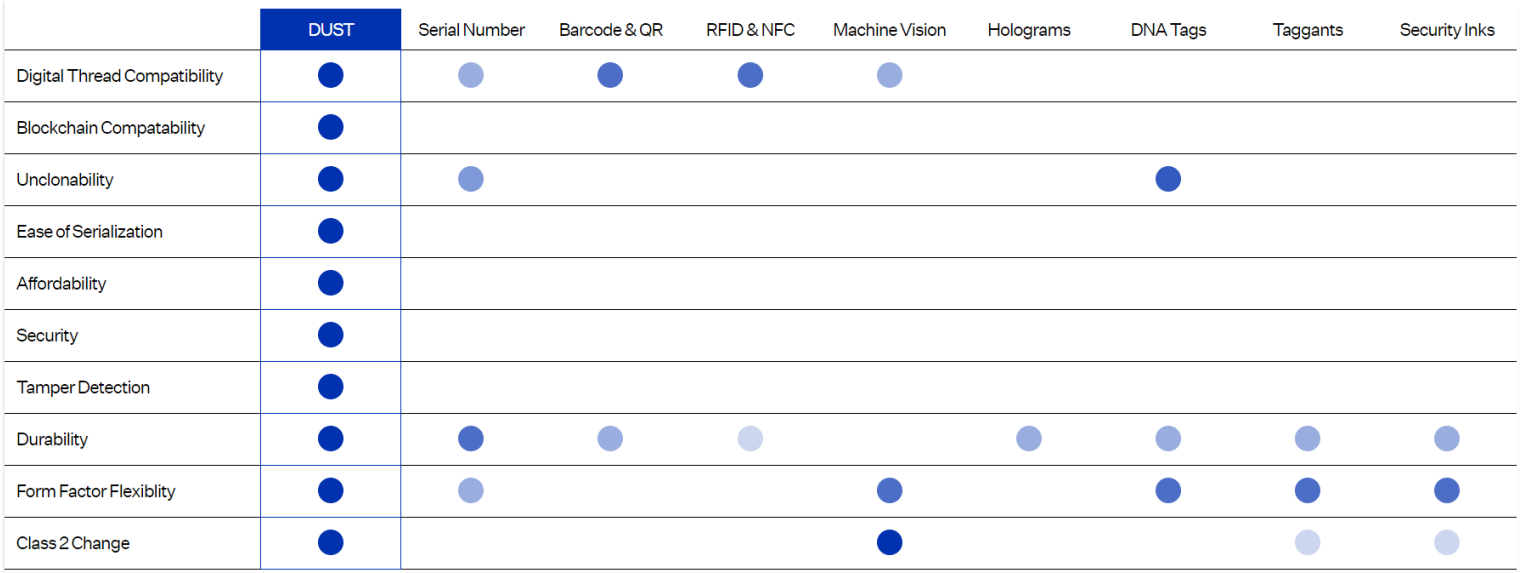
- **Informing Mission Planning via Analysis of Complex Tradespaces (IMPACT)**
  - Probabilistic Risk Assessment Tool



Resource Tracking Tools

Resource ID and Inventory Tracking

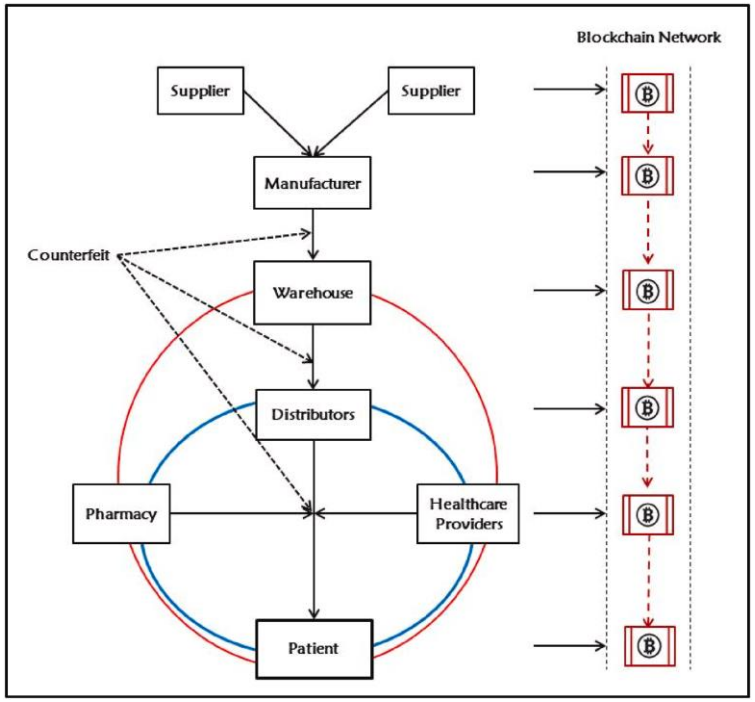
- Radio Frequency Identification (RFID) tags first evaluated for flight in 2008, proven superior to bar codes
- In 2017 RFID Enabled Autonomous Logistics Management (REALM)
- ISS has 100,000 RFID tags in use
- Diamond Dust Technology



Resource Data Management

Blockchain Solution for E2E supply chain logistics

- Immutability, decentralized, transparent, distributed ledger
- Real-time inventory, audit
- SpaceChain has deployed eight LEO nodes for commercial use



Sources: https://doi.org/10.1016/j.ssaho.2022.100328;

S&RM Topic 1

Topic 1:

It has been estimated that approximately 1.5 tons of supplies are required to support a crew member for six months of mission time in space. ExMC has developed IMPACT (Informing Mission Planning via Analysis of Complex Trade spaces), a probabilistic risk assessment tool for optimizing space medicine packs. Given mass/volume/power constraints, what are the key considerations when conducting trade space analyses for medical supplies to enable EIMO?

S&RM Topic 2

Topic 2:

Due to the extensive increased training requirements necessary to support progressively autonomous operations on exploration class missions, are multi-function medical devices (*e.g.*, TempusPro, LifeBot) a viable option to enable EIMO? Key considerations include:

- Mass/power/volume trade space
- Interoperability
- Point failure rate and loss of capability
- Repair/troubleshooting one device *vs* many

S&RM Topic 3

Topic 3:

A clinically integrated medical supply chain requires access to credible data from its procurement processes, inventory management and clinical usage of products for micro-logistics analysis. How can this be achieved and what parameters should be considered as a priority (particularly with regard to pharmaceutical products) to enable EIMO? Should blockchain distributed ledger methods be developed to track supplies from inception to consumption?

S&RM Topic 4

Topic 4:

Pharmaceutical products are re-packaged for flight and studies are planned to evaluate the effects of the re-packaging process on product stability. What type(s) of storage/packaging solutions make the most sense to enable EIMO? Key considerations:

- Must utilize inert materials designated “generally regarded as safe” (GRAS)
- Maintenance of product stability, content uniformity
- Ease of packaging
- Label durability/longevity
- Minimize mass, volume & waste

S&RM Topic 5

Topic 5:

Management of inventory for a Mars class mission will require a robust, reliable & proven technology. RFID tags have been successfully used in LEO (ISS has in excess of 100,000) but the reliability of RFID outside of LEO is unknown and will need to be tested for compatibility with long-duration spaceflight environment.

If RFID is not suitable, what other technologies could be leveraged, *e.g.*, Diamond Dust, Near Field Communication (NFC) tags, QR codes?

S&RM Topic 6

Topic 6:

Is an analysis of the micro-logistics (stowage, usage and disposal) of medical supplies and resource packs warranted to enable EIMO? How can micro-logistics of medical supplies be optimized given the constraints expected on exploration missions?

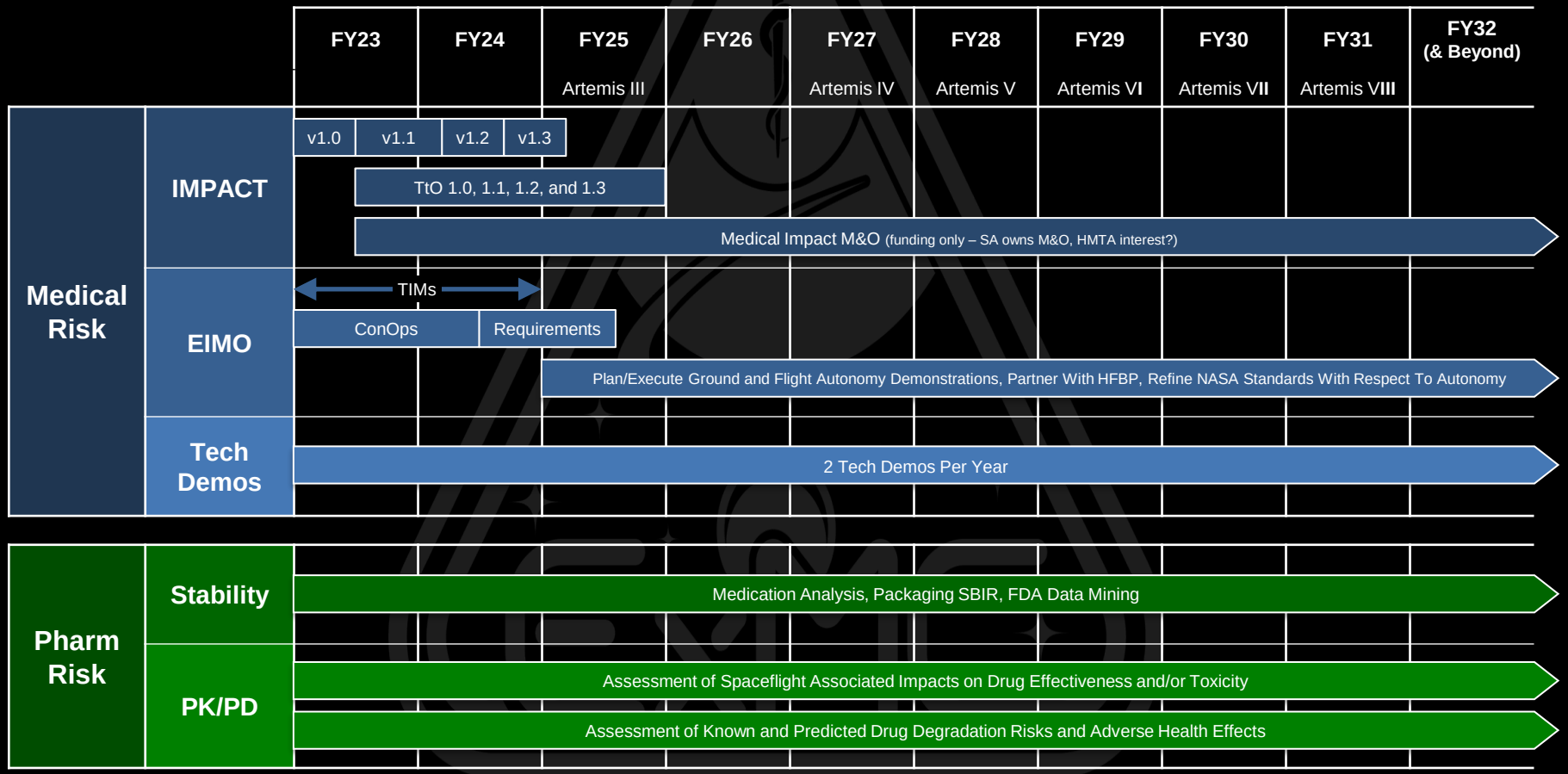
S&RM Topic 7

Topic 7:

In a tradespace analysis, is it worth bringing all the extra capacity to support additive manufacturing in-mission (*e.g.*, 3D printer) rather than just bringing more supply?

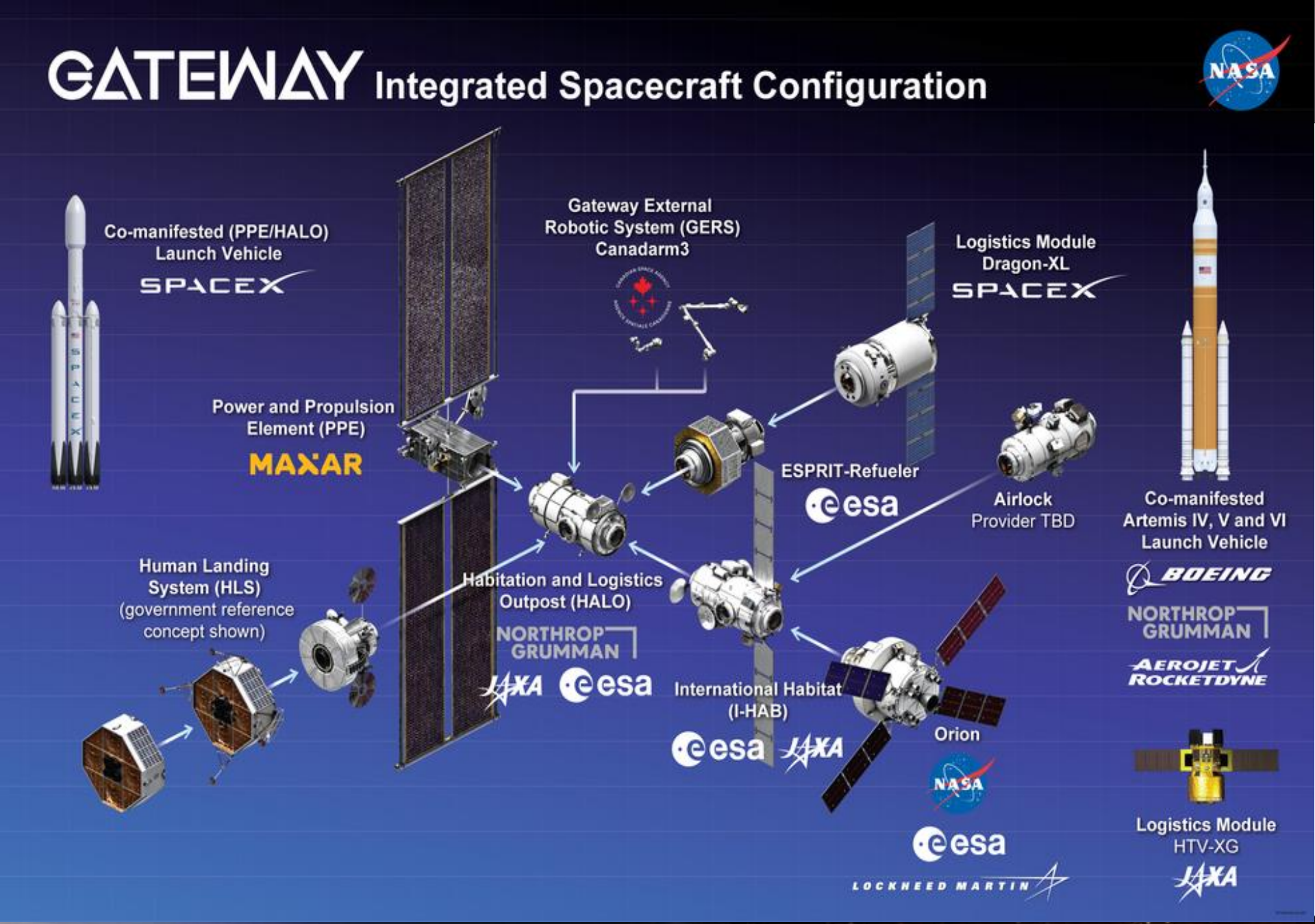
BACK-UP SLIDES

ExMC HSRB Risk Roadmap

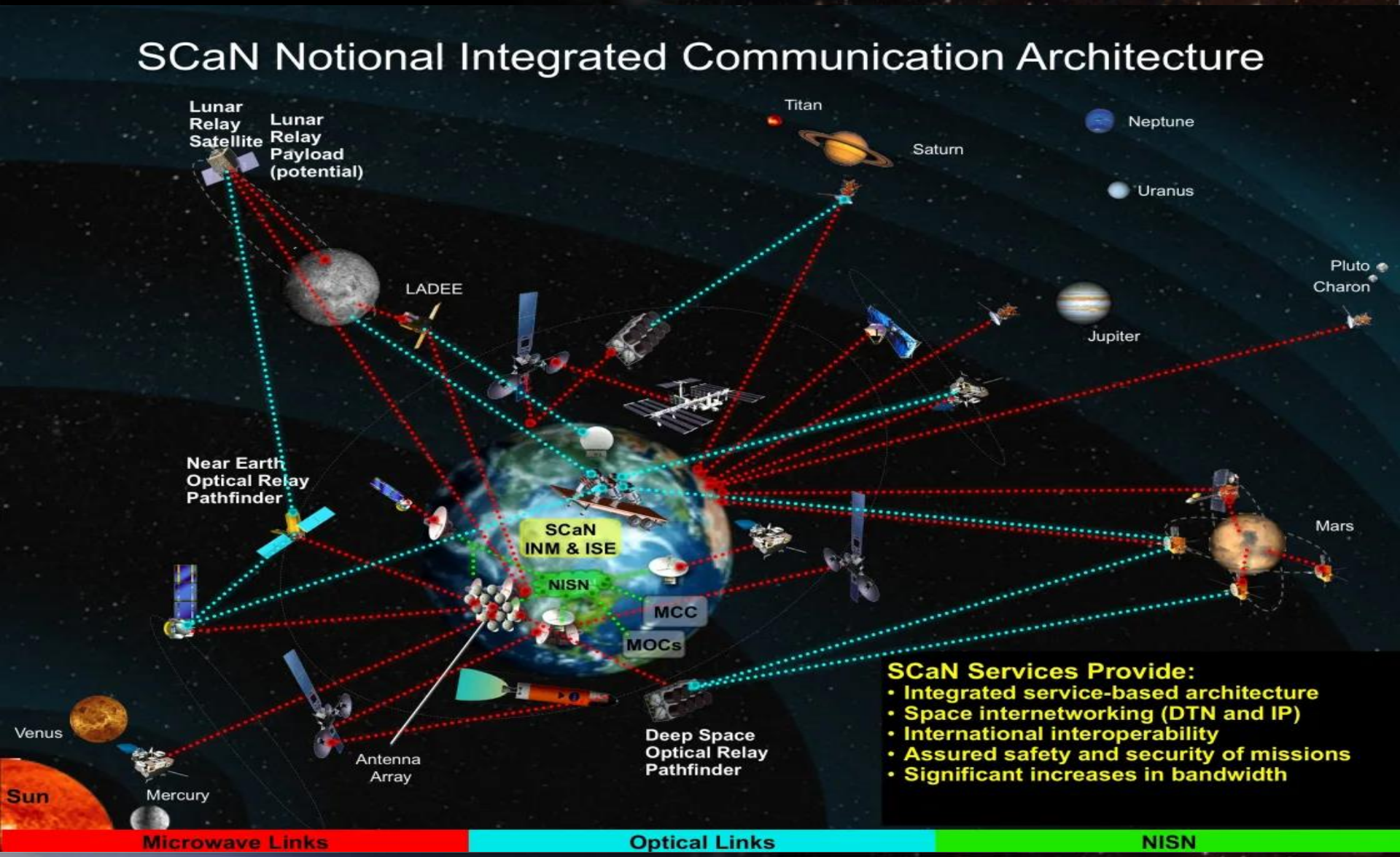


EIMO Roadmap

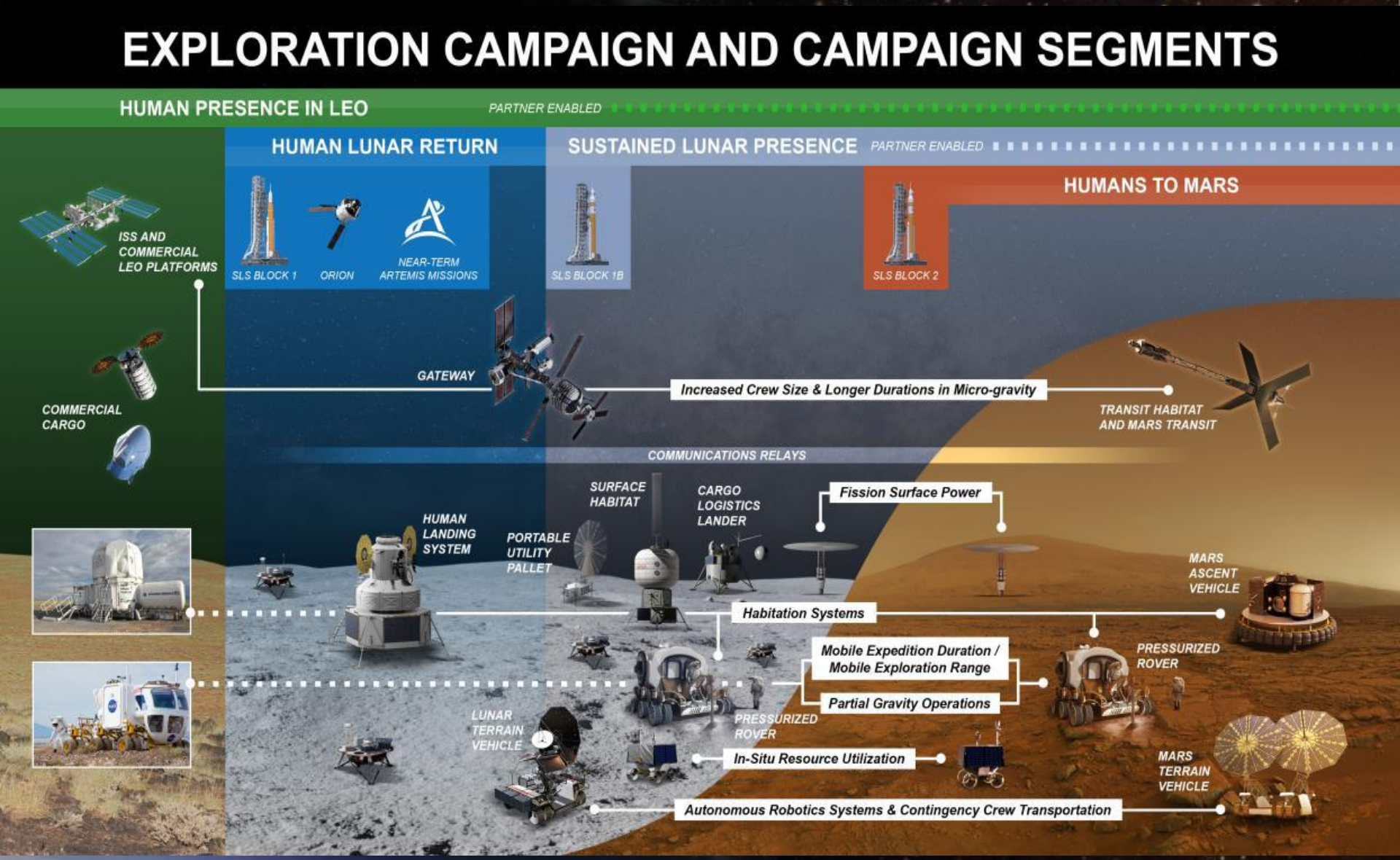
	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32 (& Beyond)
EIMO	TIMs ConOps & Requirements									
Test Environment		Build & Test Federated Labs								
Ground Analog				HERA, CHAPEA						
Flight Analog					Gateway, Artemis					


GATEWAY Integrated Spacecraft Configuration
NASA
Co-manifested (PPE/HALO)
Launch Vehicle
SPACEX
Gateway External
Robotic System (GERS)
Canadarm3
Logistics Module
Dragon-XL
SPACEX
Power and Propulsion
Element (PPE)
MAXAR
ESPRIT-Refueler
esa
Airlock
Provider TBD
Co-manifested
Artemis IV, V and VI
Launch Vehicle
BOEING
NORTHROP GRUMMAN
AEROJET ROCKETDYNE
Human Landing
System (HLS)
(government reference
concept shown)
Habitation and Logistics
Outpost (HALO)
NORTHROP GRUMMAN
JAXA
esa
International Habitat
(I-HAB)
esa
JAXA
Orion
NASA
esa
LOCKHEED MARTIN
Logistics Module
HTV-XG
JAXA

Space Communication and Navigation (SCaN)



Theaters for Exploration



Notional Human Mars Mission Overview

Short Stay, Date-Agnostic (Events = # years before Boots on Mars)