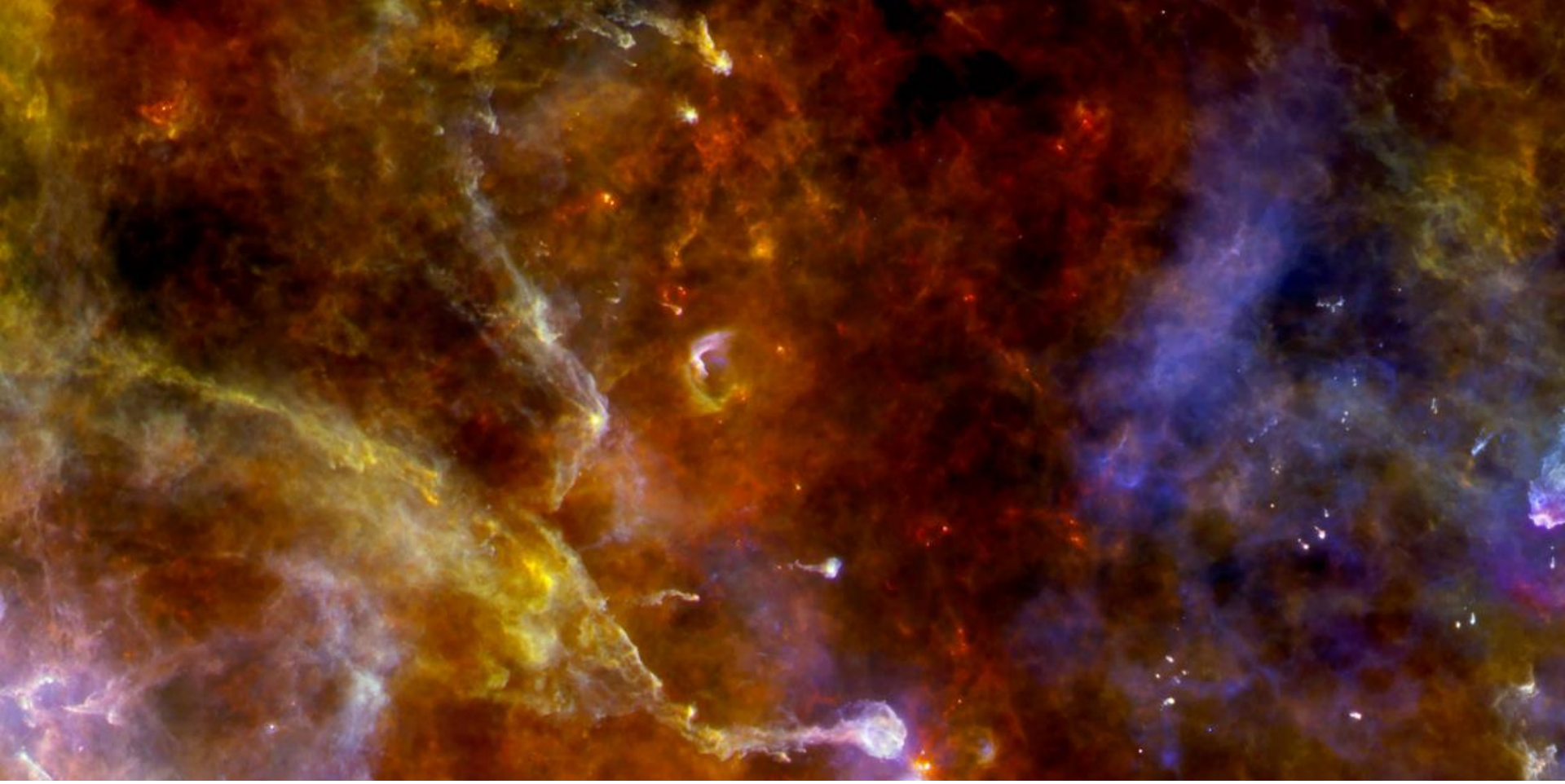

The Evolution of Planetary Protection Implementation for Mars Landed Missions

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Beginnings of Planetary Protection

- Search for Life
  - Prevent cross-contamination of organic material (“life”) between stellar bodies
  - Protect science by avoiding cross-contamination
- International Forum
  - Planetary Protection (PP) Policies
    - National Academy of Sciences ➔ Committee on Space Research (COSPAR)
    - National Academy of Sciences ➔ Space Science Board (SSB)
  - International Treaty
    - 1967 Outer Space Treaty, Article IX
  - NASA Policy
    - Biological Contamination Control for Outbound and Inbound Planetary Spacecraft, NPD 8020.7G
    - Planetary Protection Provisions for Robotic Extraterrestrial Missions, NPR 8020.12D.

Mission Implementation: Decisions and Paths Forward

- Mission PP Requirements are a combination of detailed specifications imposed by
  - NASA Procedural Requirements (NPR) 8020.12
    - Categorization based on
      - Target Body
      - Type of Mission
  - PP Categorization Letter
  - NASA Level 1 Requirements

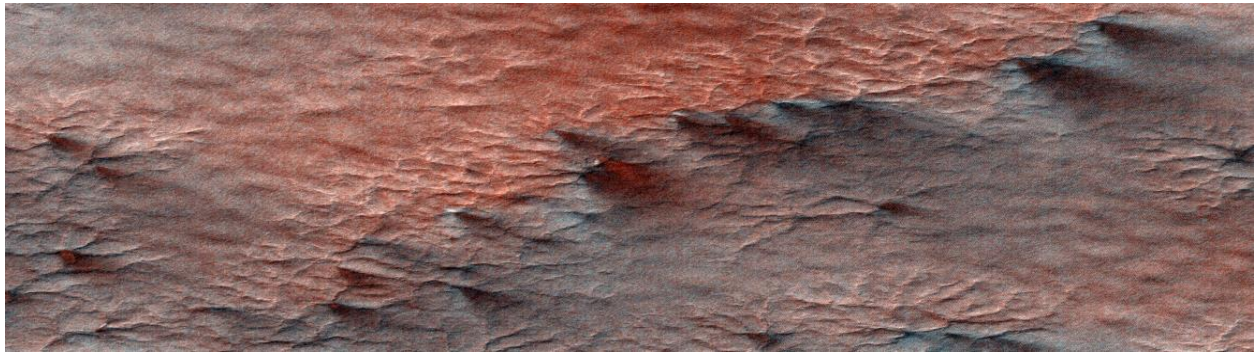
- Generally
  - PP Implementation approach is defined by Mission Body / Type, which
  - Flows into the Project System Engineering requirements system, which
  - Defines the PP approach in the Project PP Plan

Planetary Protection Mission Categories and Associated Implementation

Planet Priorities	Planetary Target Priority	Mission Type	Examples of Advisory Target Bodies	Mission Category	Example of Implementation Approach
A	Not of direct interest for understanding the process of chemical evolution or where exploration will not be jeopardized by terrestrial contamination.	Any	Undifferentiated, metamorphosed asteroids, Io	I	Documentation Only
B	Of significant interest relative to the process of chemical evolution but only a remote chance that contamination by spacecraft could compromise future investigations.	Any	Venus, Moon, Comets, Asteroids, Jupiter, Jovian Satellites except Io, Ganymede, and Europa. Saturn, etc.	II	Documentation Only
C	Of significant interest relative to the process of chemical evolution and/or the origin of life and for which scientific opinion provides a significant chance that contamination by spacecraft could compromise future investigations.	Flyby, Orbiter	Mars, Europa, Enceladus, others TBD	III	Impact avoidance and/or contamination control including: cleanroom assembly, microbial reduction, trajectory biasing, organics archiving.
		Lander, Probe	Mars	Mars IVa - Lander system NOT carrying instruments for investigation for extant life	Impact avoidance and contamination control including: cleanroom assembly, microbial reduction, trajectory biasing, organics archiving
				Mars IVb – Lander systems designed to investigate extant Martian Life	
				Mars IVc – Missions investigating Martian special regions	
			Europa, Enceladus, others TBD	IV	Impact avoidance and contamination control including: cleanroom assembly, microbial reduction, trajectory biasing, organics archiving
All	Any solar system mission	Any	Venus, Moon, others TBD	V Unrestricted Earth Return	As appropriate for the specified PP category of the outbound mission. No inbound PP requirements.
			Mars, Europa, Enceladus, others TBD	V Restricted Earth Return	IV + breaking chain of contact with target planet, sample containment and biohazard testing in receiving lab

PP Implementation Approaches: Viking to MPF

- Re-evaluated PP Policy post-Viking
- Terminal sterilization not possible
  - Material incompatibility issues post Viking
  - Instrument complexity & sensitivity
- Microbial bioburden specification defined for future missions
  - ≤300 spores/m^2 of lander surfaces
  - ≤3 x 10^5 total on lander at launch
  - ≤5 x 10^5 total on combined lander / aeroshell at launch

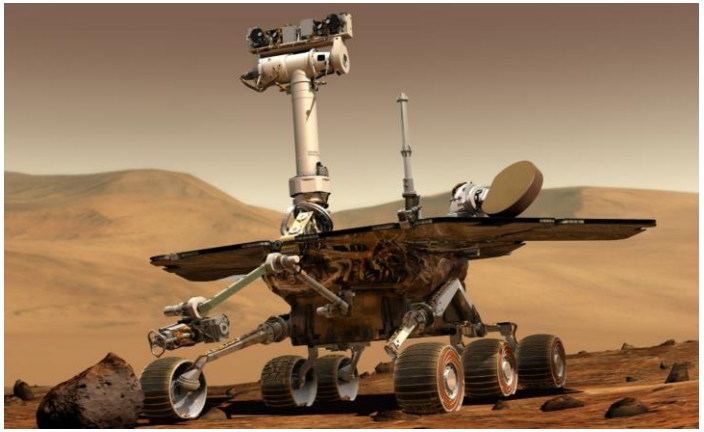


Mars Pathfinder (MPF): PP Implementation Approach

- Categorization IVa
  - Rover: No life-detection instrumentation
  - No Science Instrumentation
- Unchanged:
  - 100,000 cleanroom
  - Standard alcohol cleaning
- *New:*
  - *No terminal sterilization needed*
  - *Dry Heat Microbial Reduction (DHMR)*
  - *Microbial burden specifications*
  - *Use of High-Efficiency Particulate Arresting (HEPA) filtration for Electronic modules*

Mars Exploration Rovers (MER): PP Implementation Approaches

- Categorization IVa
  - Rovers: No life-detection instrumentation
    - *Capability of organic molecule detection*
    - *Implications for life-detection in future missions*
- Unchanged:
  - 100,000 cleanroom
  - Standard alcohol cleaning
  - No terminal sterilization needed
  - DHMR
  - Microbial burden specifications
  - HEPA filtration for electronic modules



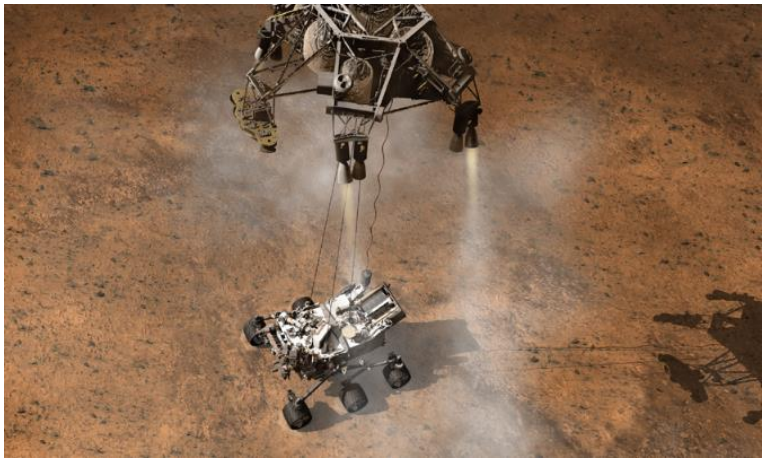
- *New:*
  - *Instrumentation Integrity driven PP requirements*
  - *PP requirements expanded to Spacecraft (S/C) Assembly, Test and Launch Operations (ATLO) associated environments*
  - *Further processes used for microbial reduction*
  - *Integrated use of Planetary Protection Equipment List (PPEL)*
  - *Development of the PP Barcode Program*

Phoenix (PHX): PP Implementation Approaches

- Categorization IVc
  - Lander: special regions (polar region, water ice)
    - Capability of organic molecule detection; implications for life-detection
- Unchanged:
  - 100,000 cleanroom
  - Standard alcohol cleaning
  - No terminal sterilization needed
  - DHMR
  - Microbial burden specifications
  - HEPA filtration for electronic modules
  - PP requirements implemented on S/C ATLO
  - PPEL
  - Instrumentation integrity driven PP requirements
  - Microbial reduction to ≤300 spores/m^2
- *New:*
  - *Recontamination prevention post microbial reduction*
    - *Biobarrier on Robotic arm subsystem*

Mars Science Laboratory (MSL): PP Implementation Approaches

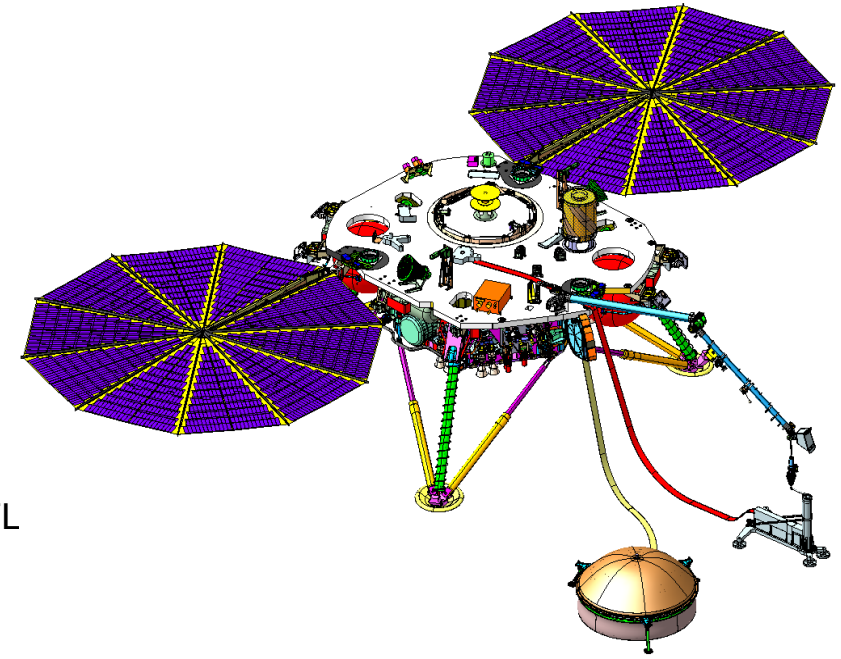
- Categorization IVa
  - Rover
    - Capability of organic molecule detection
    - Implications for life-detection in future missions
- Unchanged:
  - 100,000 cleanroom
  - Standard alcohol cleaning
  - No terminal sterilization needed
  - DHMR
  - Microbial burden specifications
  - HEPA filtration for electronic modules
  - PP requirements implemented on S/C ATLO
  - PPEL
  - Barcode Program
  - Instrumentation integrity driven PP requirements
  - Microbial reduction to ≤300 spores/m^2
  - Recontamination prevention



- *New:*
  - *Barcode Analysis program used an an accounting system for bioburden statistical analyses*
  - *Precision cleaning utilized as a standard engineering practice to clean hardware*
  - *Increased utilization of embedded processing specifications*
  - *Mandatory PP ATLO training for engineers*
  - *New definition of IVc for Special Regions approved by COSPAR*

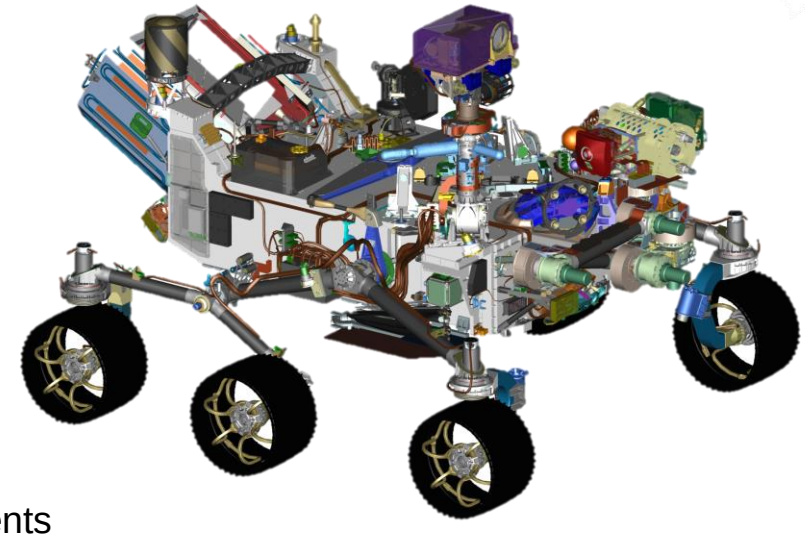
Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport Mission (InSight): PP Implementation Approaches

- Categorization IVa
  - Lander: Geological exploration
- Unchanged:
  - 100,000 cleanroom
  - Standard alcohol cleaning
  - No terminal sterilization needed
  - DHMR
  - Microbial burden specifications
  - HEPA filtration for electronic modules
  - PP requirements implemented on S/C ATL
  - PPEL
  - Barcode Program
  - Instrumentation integrity driven PP requirements
  - Microbial reduction to ≤300 spores/m^2
  - Recontamination prevention post microbial reduction
- *New:*
  - *Launch from VAFB, not KSC – 4m Atlas V rocket*
  - *Detailed launch vehicle requirements to capture environmental launch parameters*
  - *Adoption of systems engineering approach for PP requirements*
  - *Adoption of extended heat microbial reduction (HMR) specifications – due to hardy microbe resistance to standardized exposures*
  - *PP requirements matrix to capture flight system requirements*



Mars 2020: PP Implementation Approaches

- Categorization V Restricted Earth Return
  - Rover
    - Capability of organic molecule detection
    - Implications for sample caching system for potential, future Earth-Return mission
- Unchanged:
  - 100,000 cleanroom
  - Standard alcohol cleaning
  - No terminal sterilization needed
  - DHMR
  - Microbial burden specifications
  - HEPA filtration for electronic modules
  - PP requirements implemented on S/C ATLO
  - PPEL
  - Barcode Program
  - Instrumentation integrity driven PP requirements
  - Microbial reduction to ≤300 spores/m^2
  - Systems engineering approach for PP requirements
  - Recontamination prevention post microbial reduction
  - Hardy HMR specifications
- *New:*
  - *Joint PP/CC Requirements Table*
  - *PP/CC Working Group and Dedicated PP/CC Design Team meetings*



Mission Complexity vs PP Implementation: Chronological Display

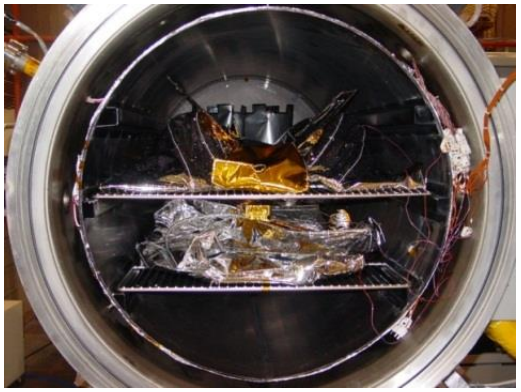
Mission	Viking	Mars Pathfinder (MPF)	Mars Exploration Rover (MER)	Phoenix (PHX)	Mars Science Laboratory (MSL)	*InSight*	*M2020*
PP Category	**IV**	**IV**	**IVa**	**IVc**	**IVa**	**IVa**	***V Restricted Earth Return***
Terminal Sterilization	✓	✗	✗	✗	✗	✗	✗
DHMR	✓	✓	✓	✓	✓	✓	✓
Microbial Bioburden Limits	30 total CFU, ≤0.03 spores/m^2	3 x 10^5 total CFU, ≤300 spores/m^2	3 x 10^5 total CFU, ≤300 spores/m^2	3 x 10^5 total CFU, ≤300 spores/m^2	3 x 10^5 total CFU, ≤300 spores/m^2	3 x 10^5 total CFU, ≤300 spores/m^2	3 x 10^5 total CFU, ≤300 spores/m^2 Sample Intimate hardware ≤0.03spores/m^2, ≤1 viable organism/sample tube
Microbial Bioburden Values (total CFU, or spore/m^2)	22-230 spores/m^2	2.9 x10^4 14.9	1 x 10^5 (Spirit) 2.1 x 10^5 (Opp) 33 (Spirit) 69 (Opportunity)	3.46 x 10^4 74	5.64 x 10^4 total 39	*In Progress*	*In Progress*
Launch Date	August, ’75 Sept, ‘75	December, ‘96	June, ‘03 July, ‘03	August, ‘07	November, ‘11	*To launch May, 2018*	*To launch July, 2020*
Landing Date	June, ‘76 July, ‘76	July, ‘97	January, ‘04 January, ‘04	May, ‘08	August, ‘12	*To land November, 2018*	*To land, Jan/Mar 2021*
# Science Instruments	1	0	3	2	5	*3*	*7*

Implementation of Systems Engineering into the ATLO Life Cycle of a Mission

- Previously
  - PP Plans document implementation processes and practices
    - Hardware engineers
      - Responsible for implementing requirements
    - Growing mission complexity – presents challenges
- Currently
  - PP team works in conjunction with project
    - Categorization
    - Requirements flow down
    - Validation & verification
    - Compliance
  - During all pre-ATLO and ATLO activities

PP Implementation Methods for Bioburden Reduction

- **Standard Methods**
  - Precision Cleaning
  - Alcohol cleaning
  - DHMR



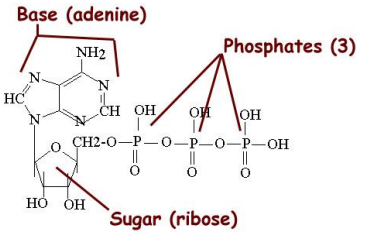
  - VHP Microbial Reduction (M2020)

- **Non-Standard Methods**
  - Liquid Boundary Layer Disruption System (NASA approved)
  - CO2 Jet Composite Cleaning (Non-NASA approved)
  - Laser Induced Plasma Shockwave Cleaning (LSC) (Non-NASA approved)

Detection Methods & Bioburden Limits

- NASA Standard Assay
  - During closeout of surfaces during integration and assembly
    - 1 CFU detection limit
    - 72 hour turnaround

- ATP Assay
  - Pre-screens hardware for cleanliness levels prior to final closeout of surfaces
    - 10^{-11} to 10^{-14} Mmol detection limits
    - 3 hour turnaround



Challenges

- Current Challenges
  - Delays & their consequences
  - Lessons Learned
  - Remote Laboratory Assembly
  - ATLO
  - Launch Vehicle
- Future Challenges
  - New Technologies for future implementation

In Conclusion

- Scientific Exploration of the Solar System is growing exponentially
  - Can habitable environments be identified?
  - Can cross-contamination be prevented?
    - Identify hitch-hikers and stragglers
    - Identify methods and technologies to document and archive isolates
- Treaties/Agreements
  - COSPAR defines PP Requirements
    - Requirements are always evolving
    - Can be challenging if implementation is not feasible
- PP Requirements and System Level flow-down
  - Evolution/adaptation of technologies for future PP implementation
    - Categorization and Type of Mission

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