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MLI Blanket Effective Emittance Variance and its Effect on Spacecraft Propellant Line Thermal Control

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Outline

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- Introduction
- Case Studies
  - Mars Pathfinder
  - Mars Exploration Rovers
  - Mars Science Laboratory/Mars 2020
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- Conclusion

Motivation

Is a system thermal test required?

↓

Is the design repeatable?

↓

Is the implementation repeatable?

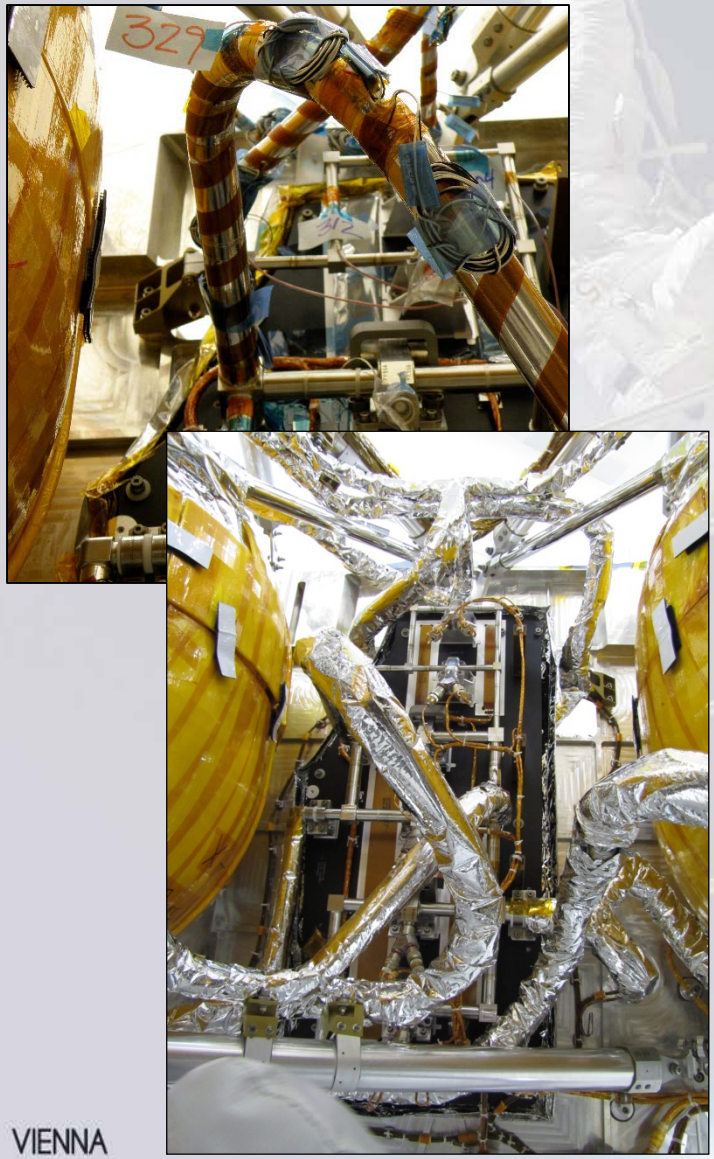
↓

What information is needed to safely fly the spacecraft?

↓

Can the problem we bounded by analysis alone?

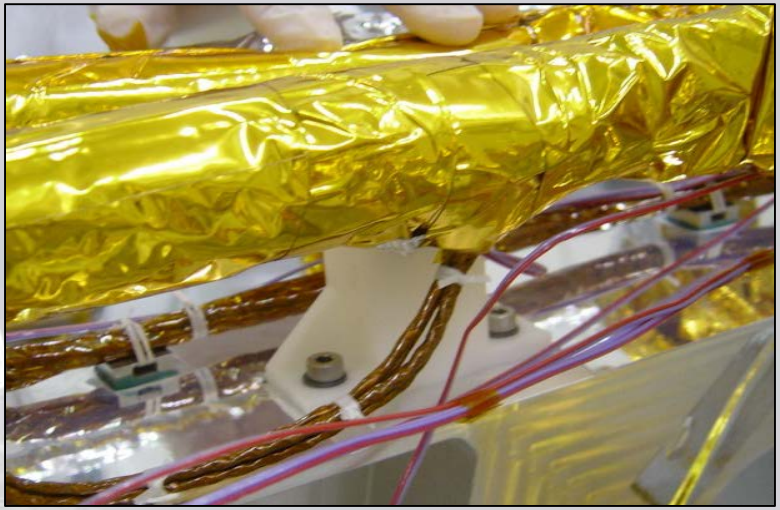
Introduction

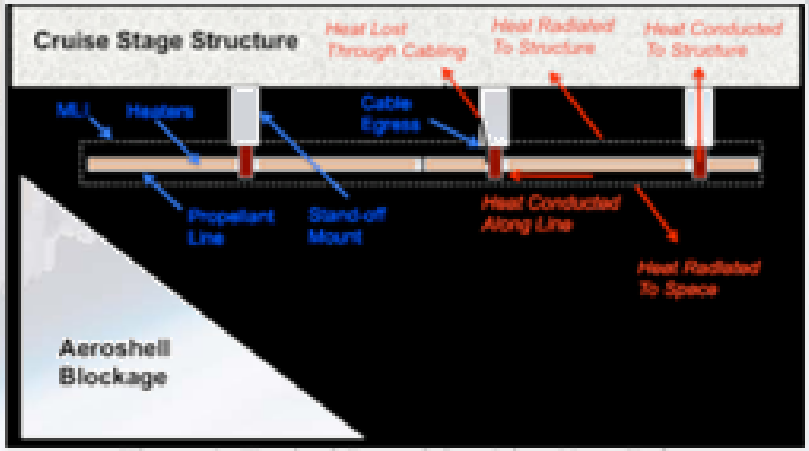


- A large portion of the CEDL thermal design and resource pool is dedicated to the propulsion system
- Hydrazine freezes at 1.8^{o}C
- Overheating may cause damage to thermal hardware and/or decrease in propulsion performance
- Propulsion system must be ready to respond to requests for planned and unplanned maneuvers
- Limited telemetry exists in flight and the thermal model is an important tool to understand temperatures

Propulsion Line Thermal Control

- Typical JPL thermal control relies on a milliwatt heat balance:
  - Conductive isolation
  - Radiative isolation (low emittance or MLI surfaces)
  - Localized heating
- MLI relies heavily on workmanship and is not repeatable





Impact of MLI Variance

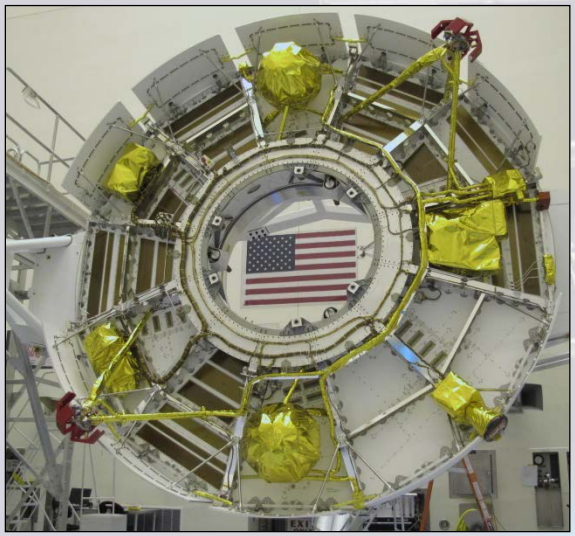
Case	T_{sink}	control ε_1*	ε_2*	control T_1	T_2
1	-30°C	0.02	0.02	25°C	25°C
2	-30°C	0.02	0.10	25°C	-16°C
3	-30°C	0.10	0.02	25°C	127°C

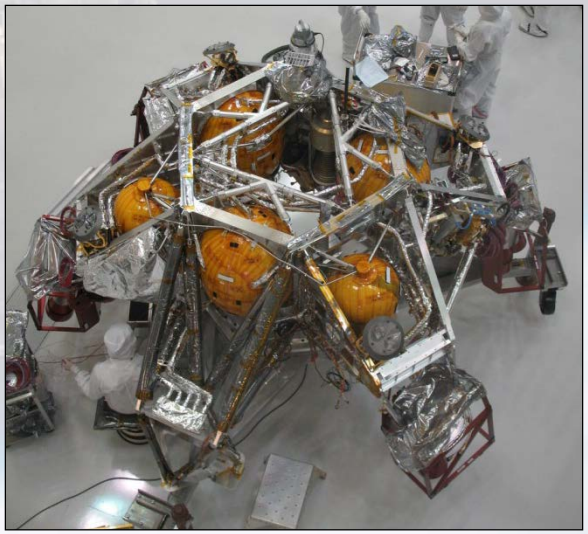
Hand calculation assumes local radiation only

Case Studies

Mars Pathfinder (MPF)

Mars Exploration Rovers (MER-A, MER-B)





Mars Science Laboratory (MSL) and Mars 2020

Case Studies

	MPF - Cruise Stage -	MER-A/MER-B - Cruise Stage -	MSL/Mars 2020 - Cruise Stage -	MSL/Mars 2020 - Descent Stage -
Length [m]	12	8	15	36
Line Diameter [mm]	6.35	6.35	6.35	6.35 to 25.4
Control Zones	4	8	15	21
Control Method	Mechanical Thermostat	Flight Software (2 Locations)	Flight Software (1 Location)	Flight Software (1 Location)
Correlated Model ε*	0.019 – 0.026	0.025 – 0.085	0.015 – 0.220	0.010 – 0.055

Mars Pathfinder

- Design changes implemented following thermal vacuum test chamber break and test conclusion:
  1. New 10-layer aluminized Mylar/Dacron net MLI installed (two offset blankets) with second surface aluminized Kapton overwrap replaced previous 15-layer embossed Kapton blankets. New blankets used a single seam along the length instead of seams at every edge.
  2. Blankets added to line mounts to reduce heat loss.
  3. Aluminum foil added along stainless steel lines to enhance lateral conduction.
  4. 5-mil double-aluminized Mylar, semi-cylindrical radiation shields added to reduce mechanical thermostat views to warm solar array.

Mars Pathfinder

- Lessons learned incorporated into the next mission:
  1. Lack of set point adjustability offered by mechanical thermostats.
  2. Need for more control zones
  3. Benefit of better representing view factors and sink temperatures.
  4. Blanket workmanship identified as the greatest source of uncertainty

Mars Exploration Rovers

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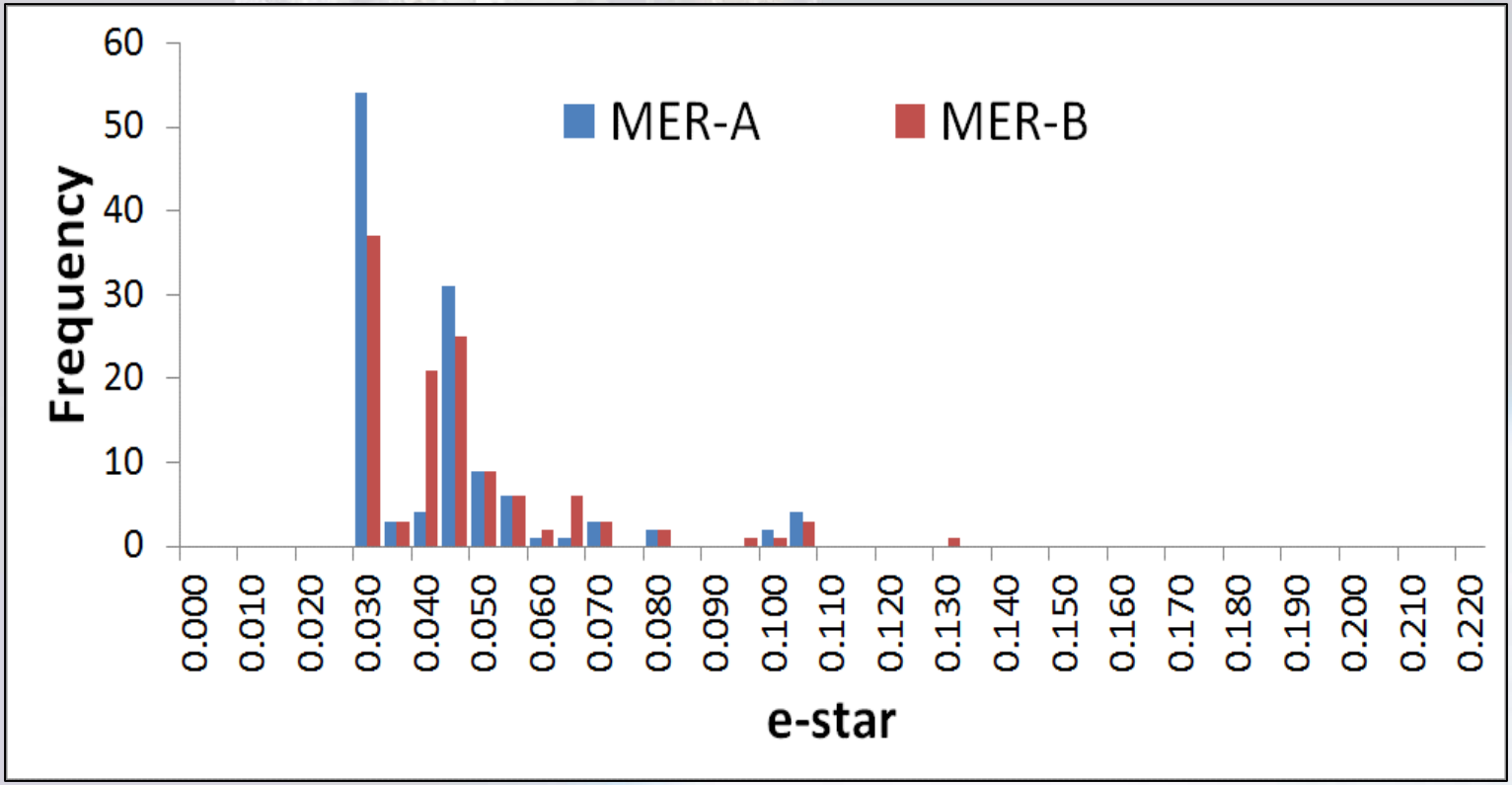
- Propulsion line set points post-test and post-correlation

	Design (Pre-Test)		MER-A (Post-Test)		MER-B (Post-Test)	
	On (°C)	Off (°C)	On (°C)	Off (°C)	On (°C)	Off (°C)
1A	30	40	30	37	28	34
2A	30	40	36	44	36	46
3A	30	40	36	44	37	43
4A	30	40	36	44	23	30
5A	30	40	36	44	34	43
6A	30	40	37	44	33	40
7A	30	40	31	40	31	40
8A	30	40	31	41	31	41
1B	27	33	38	44	31	41
2B	27	32	22	27	22	27
3B	27	32	24	30	24	30
4B	28	36	23	30	36	44
5B	28	36	23	31	23	31
6B	26	33	22	29	26	33
7B	25	35	26	35	26	35
8B	25	35	26	35	26	35

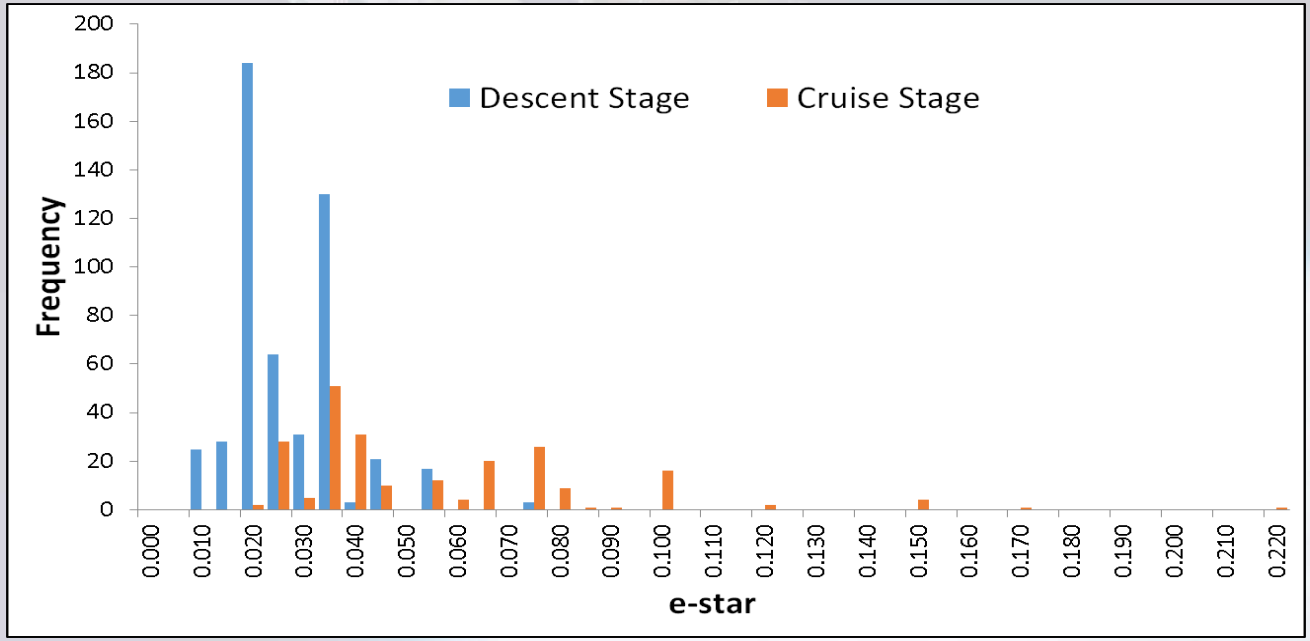
Mars Exploration Rovers

- Model correlation performed by two different engineers with MER-A the starting point
- Different propulsion line set points for each spacecraft



Mars Science Laboratory

- Model development and correlation performed by two different engineers
  - Modeling approaches vary slightly
- Larger lines present in descent stage result in a smaller overall range and lower ε* values



Mars 2020

- Mars 2020 is a build-to-print spacecraft
- New engineers and technicians control modifications and implementation

Are the same MSL propulsion line set points applicable?

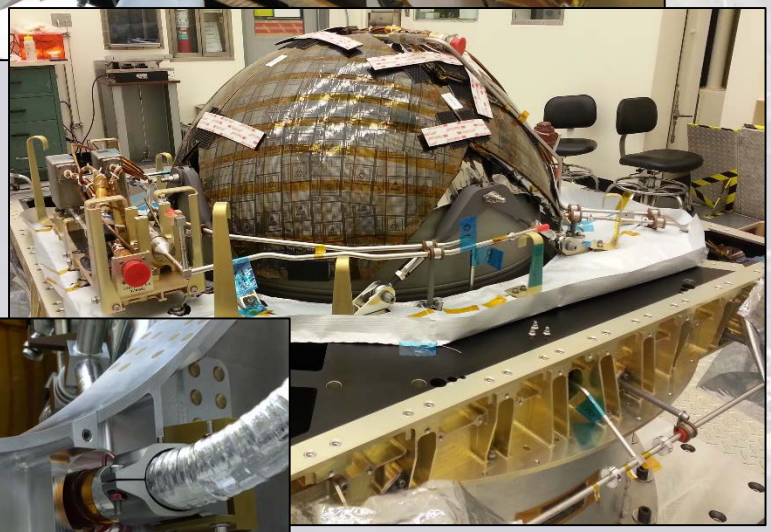
How does the team respond to fault scenarios?

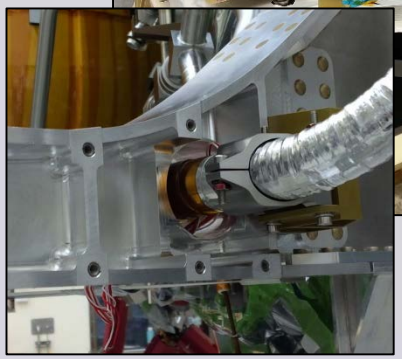
How does the team adequately bound the problem by analysis?

Is the MSL correlated thermal model still valid?

How can the team improve the design while still adhering to a build-to-print mantra?

Lessons Learned





- Change the heat balance
  - Do not depend on a milliwatt design
  - Reduce the inconsistent sinks
  - Cause conduction to play a larger role
- Increase MLI repeatability
  - Implement blanket structures
  - Improve blanket performance
  - Ensure identical mechanical configurations
- Understand the risks
  - Flight adjustability and visibility
  - Susceptibility

Reference *Robust Thermal Control of Propulsion Lines for Space Missions* by Pradeep Bhandari for alternative approaches beyond the “build to print” scope.

Conclusion

- Flight telemetry alone lacks the information needed to ensure safe propulsion system temperatures
- The correlated thermal model is only as good as the test and is truly a system model
  - Each engineer will have a different approach with different results
- A design robust to variance is the engineer's goal
  - Current JPL thermal designs are not robust to MLI variance
  - Attempts to bound the MLI variance reduce the risk
  - Test-as-you-fly is a powerful approach

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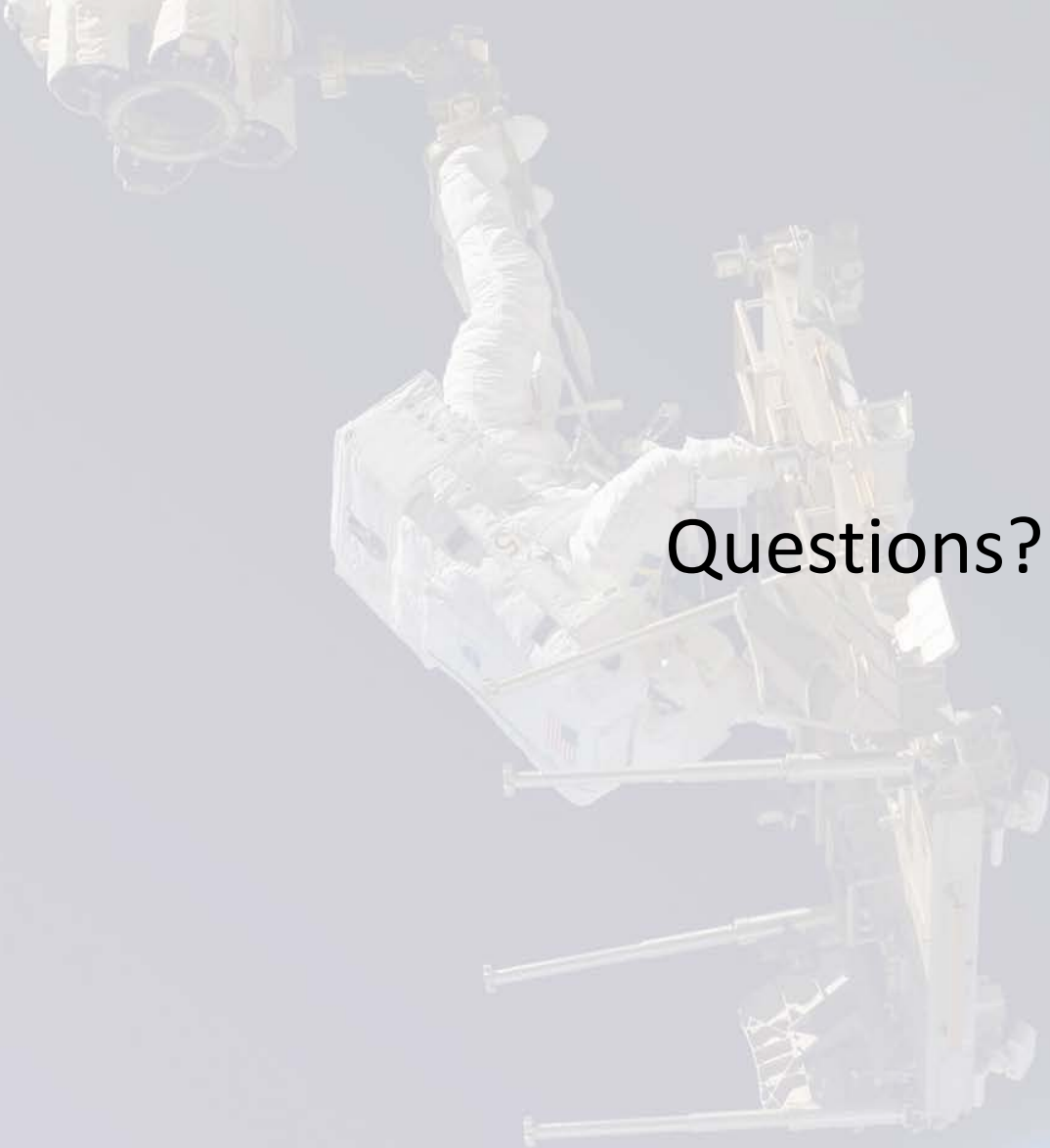

Questions?