Surveys of Returned ISS Hardware for MMOD Impacts

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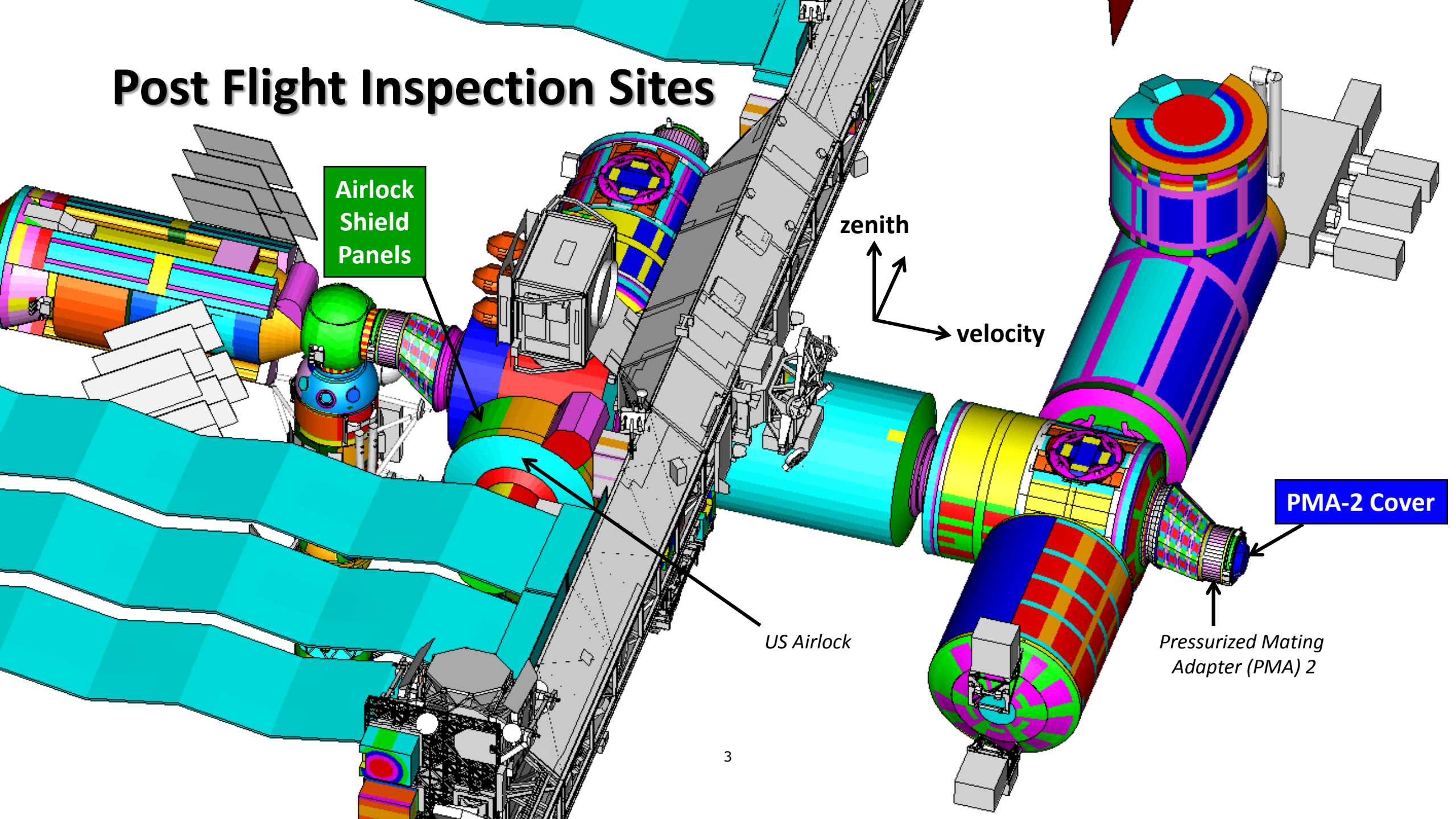
Introduction

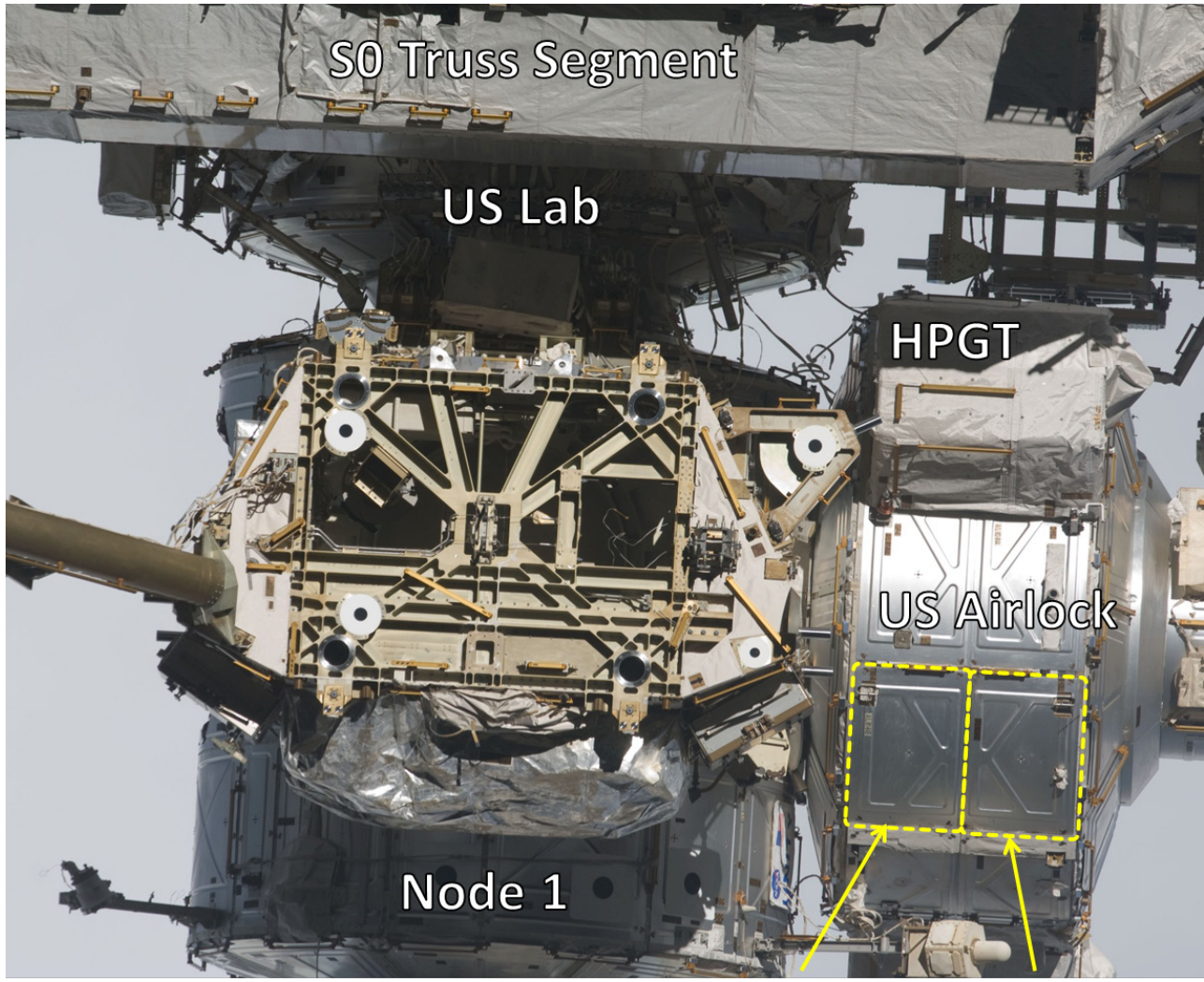
- Comparison of observed hypervelocity impact features with Bumper 3 results using ORDEM 3.0 and MEM-R2
- Post flight MMOD inspection – damage site measurements
- Sampling of impact sites
- SEM analysis – projectile characterization
- Bumper 3 calculations

Post Flight Inspection Sites



Airlock Shield Panels

- Airlock launched July 2001
- Installed on ISS Node 1 starboard
- Originally equipped with 4 high pressure gas tanks (HPGT)
- Airlock shield panels 01-04B & 02-04B removed November 2009 to allow for the installation of a 5th HPGT
- Panels returned April 2010
- Exposure time = 8.75 years



01-04B 02-04B

Airlock Shield Panels

- Airlock pressure walls are protected by aluminum panels (Whipple Shield)
- Shield panel is 2 mm thick aluminum, with overall dimensions of 1.30 x 0.84 m

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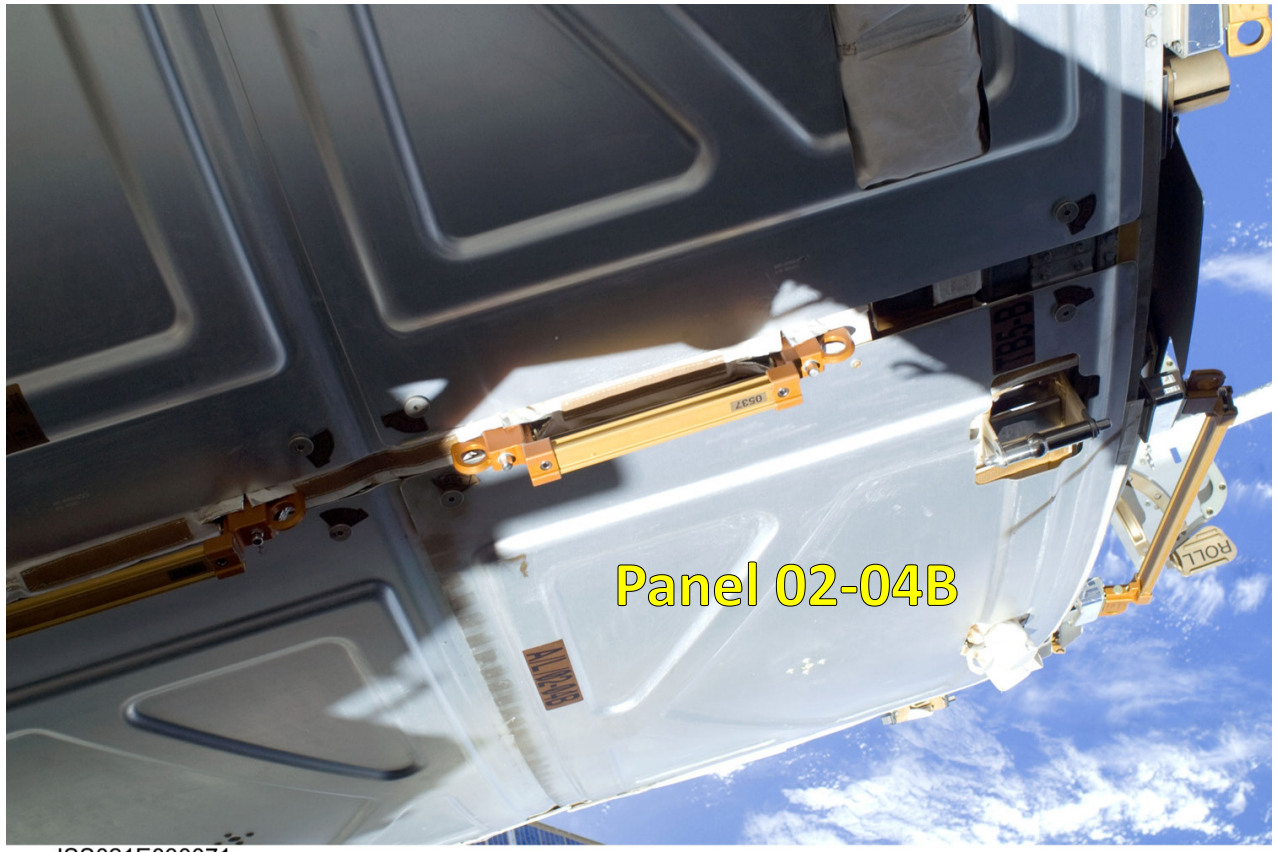

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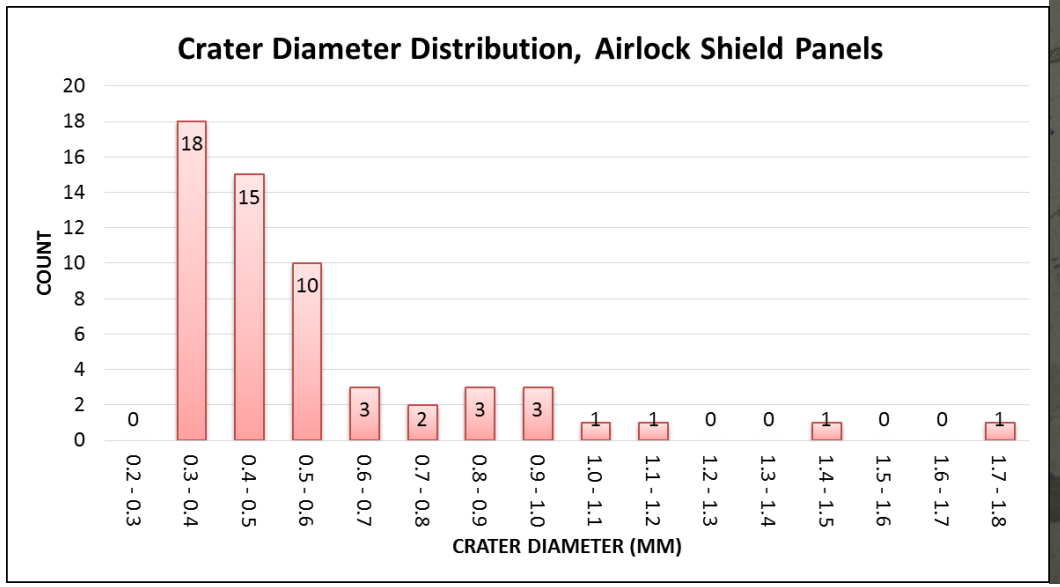
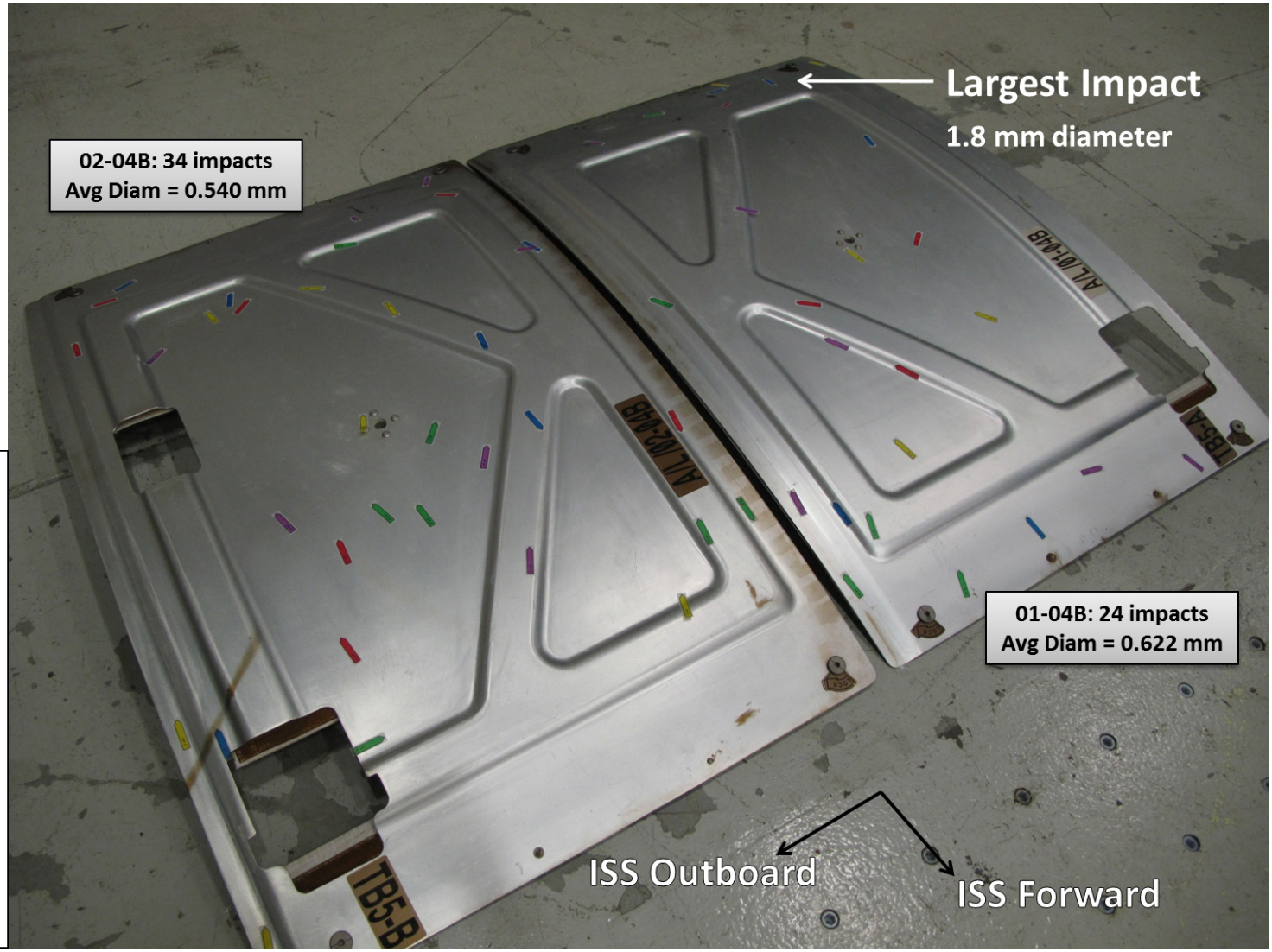
Post Flight Inspection Results

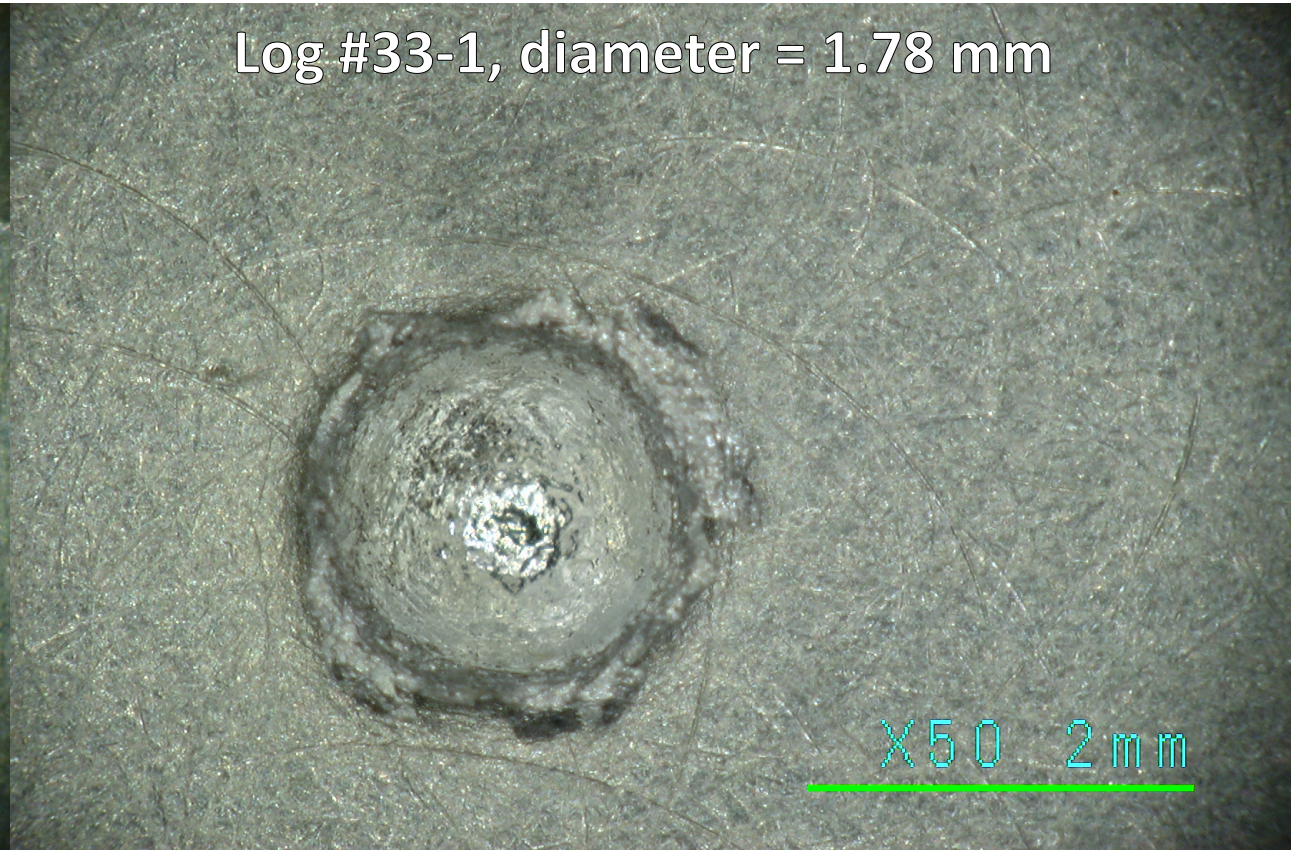
- 58 impact feature observed
- Max crater diameter = 1.78 mm
- Average crater diam. = 0.57 mm





Sampling at Impact Sites

- Intact extraction of craters was not permitted
- Portions of the raised lips at 9 craters were removed for analysis



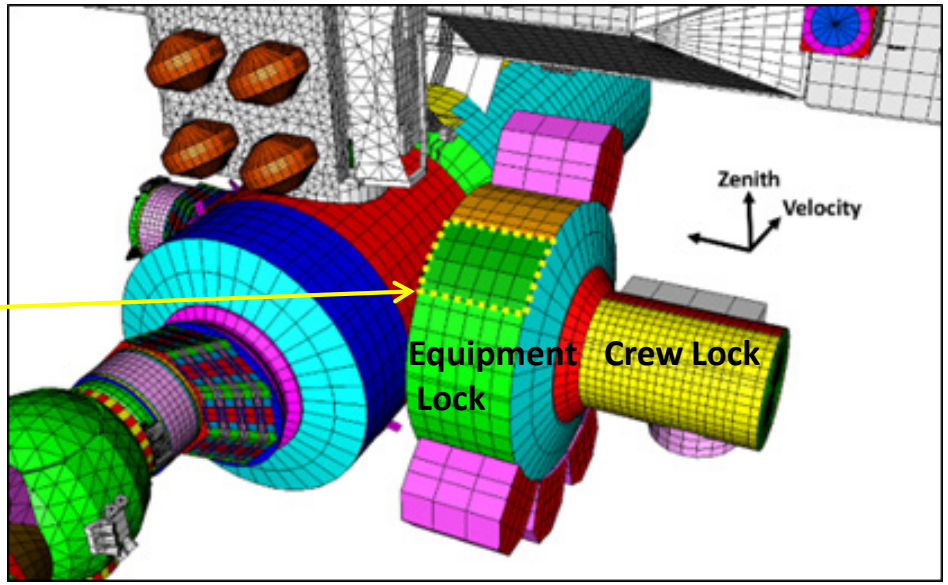
SEM/EDS Results

- SEM analysis revealed many areas with silica melted into the aluminum
- Instances of Fluorine and Carbon were also common

Impact Site	Crater Size (mm)	# of Samples	Impactor Type: Major Constituents	Possible Impactor
33-1	1.78	3	OD: SiO	Silica
33-2	1.06	1	OD: CF, Si, SiO	PTFE, Silica
33-8	1.48	1	OD: Fe, SIO, Pb, Cr, Ni, Co	Silica, paint, metal alloys
33-21	0.73	1	unknown	--
34-2	1.17	4	OD: CF, Fe	PTFE
34-8	0.42	4	OD: CF, K, Ca, Ti, SiO	PTFE, Silica
34-10	0.81	3	OD: SiO, Fe, Cu, Zn	Silica
34-11	0.91	1	OD: SiO, BaS, Cu, Zn	Silica, paint
34-14	0.85	3	OD: CF	PTFE

Comparison with Bumper 3

- Bumper 3 was used to calculate the expected number of craters on a 2 m^2 patch of the equipment lock region of the airlock
- Years = 2001 through 2010
- Time averaged altitudes
- Damage equation = Cour-Palais crater depth

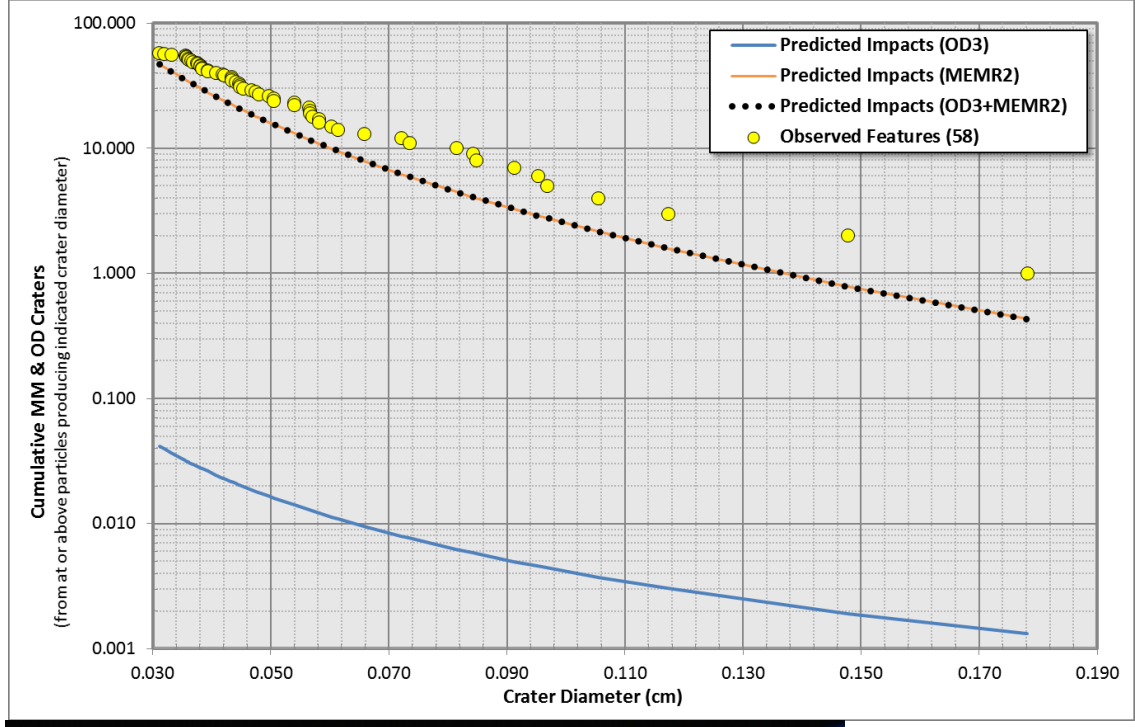


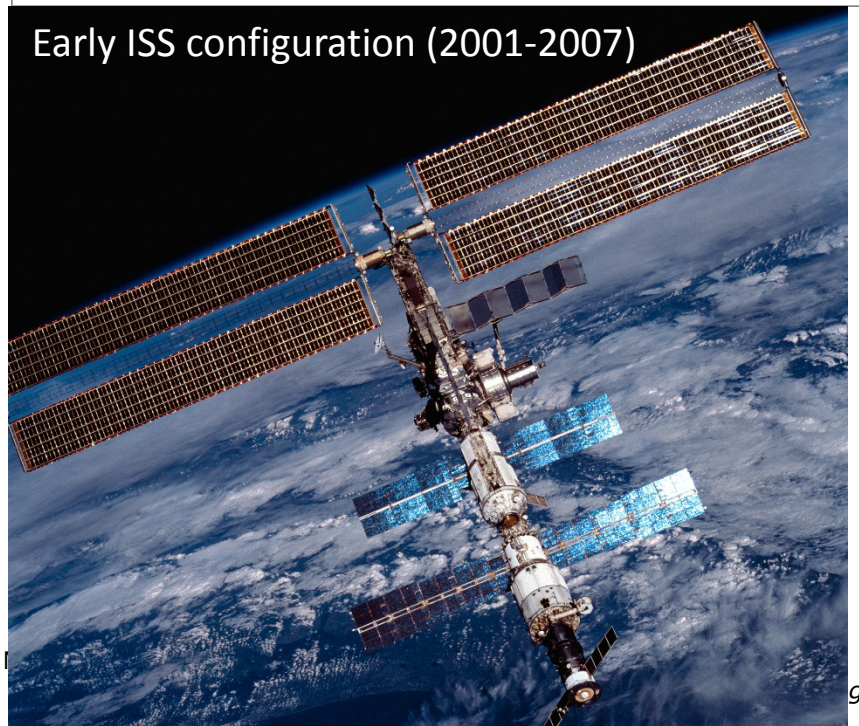
Crater Depth (cm)	Crater Diameter (cm)	MEM R2	ORDEM 3.0	MMOD TOTAL
0.02	0.04	26.955	0.026	26.980
0.04	0.08	4.726	0.006	4.732
0.06	0.12	1.467	0.003	1.470
0.08	0.16	0.605	0.002	0.607
0.10	0.20	0.297	0.001	0.298

Year	Altitude (km)	Time (year)	Event
2001	382.68	0.466	07/14/01: Airlock install
2002	390.04	1.0	
2003	384.61	1.0	
2004	361.66	1.0	
2005	352.54	1.0	
2006	342.20	1.0	
2007	337.55	1.0	10/27/07: P6 moved from Z1 to P5
2008	345.41	1.0	
2009	348.55	1.0	11/23/09: airlock shields to ESP-2
2010	349.40	0.282	04/13/10: shields retrieved from ESP-2
		8.753	

Comparison with Bumper 3

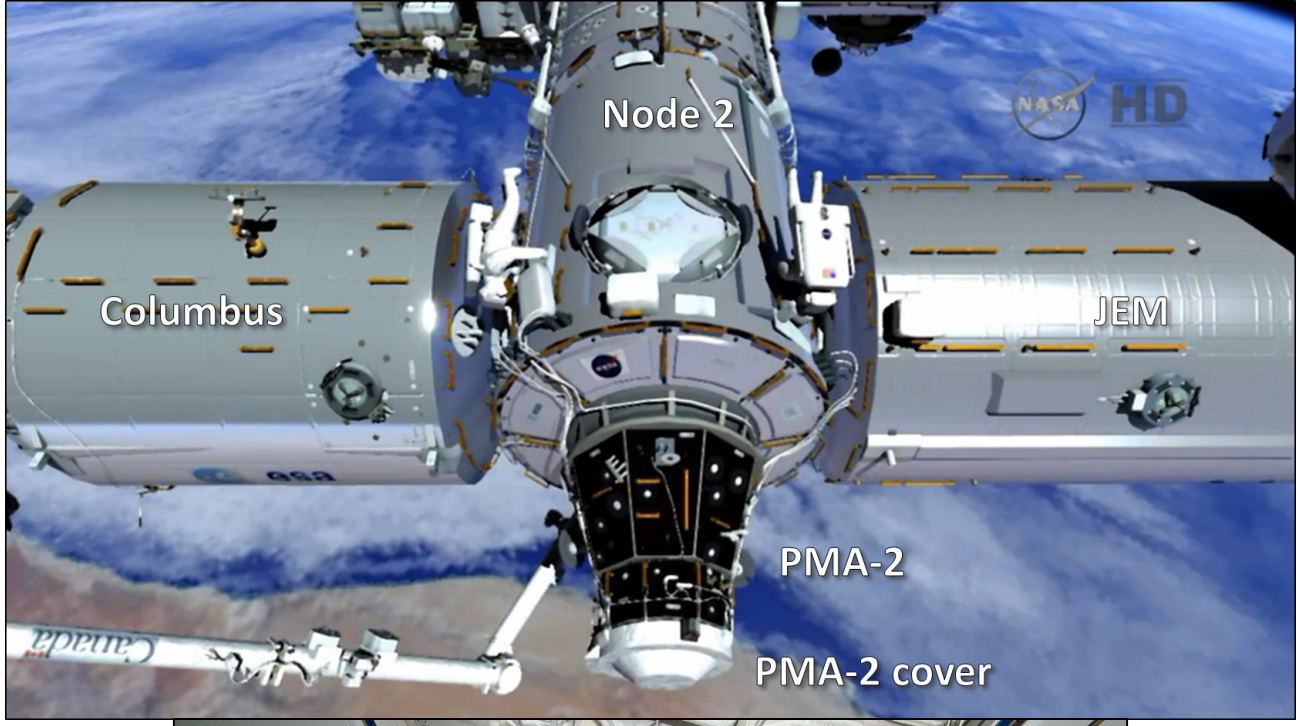
- Micrometeoroids are expected to account for nearly all of the craters
- Shield panels are oriented on the zenith/trailing side of the airlock
- The abundance of orbital debris impacts can be explained by the proximity of the ISS solar arrays wings and radiator
- Secondary debris (ejecta) from MMOD impacts on solar arrays and radiators is the suspected source
- SEM evidence supports the hypothesis, with an abundance of silica detected





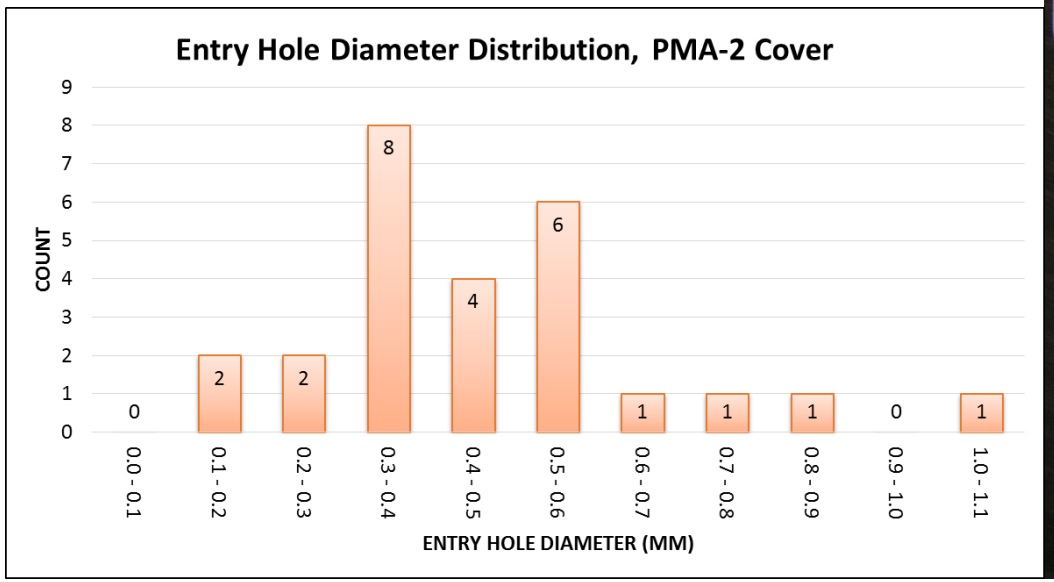
PMA-2 Cover

- Installed July 9, 2013 during US EVA 22
- Removed February 25, 2015 US EVA 30
- Returned on SpaceX CRS-6 May 2015
- Exposure time = 1.633 years
- Beta Cloth outer layer (t = 0.2 mm) with internal layers of ballistic fabric
- Overall diameter of cover = 2.0 m
- Tie down strap length = 0.6 m



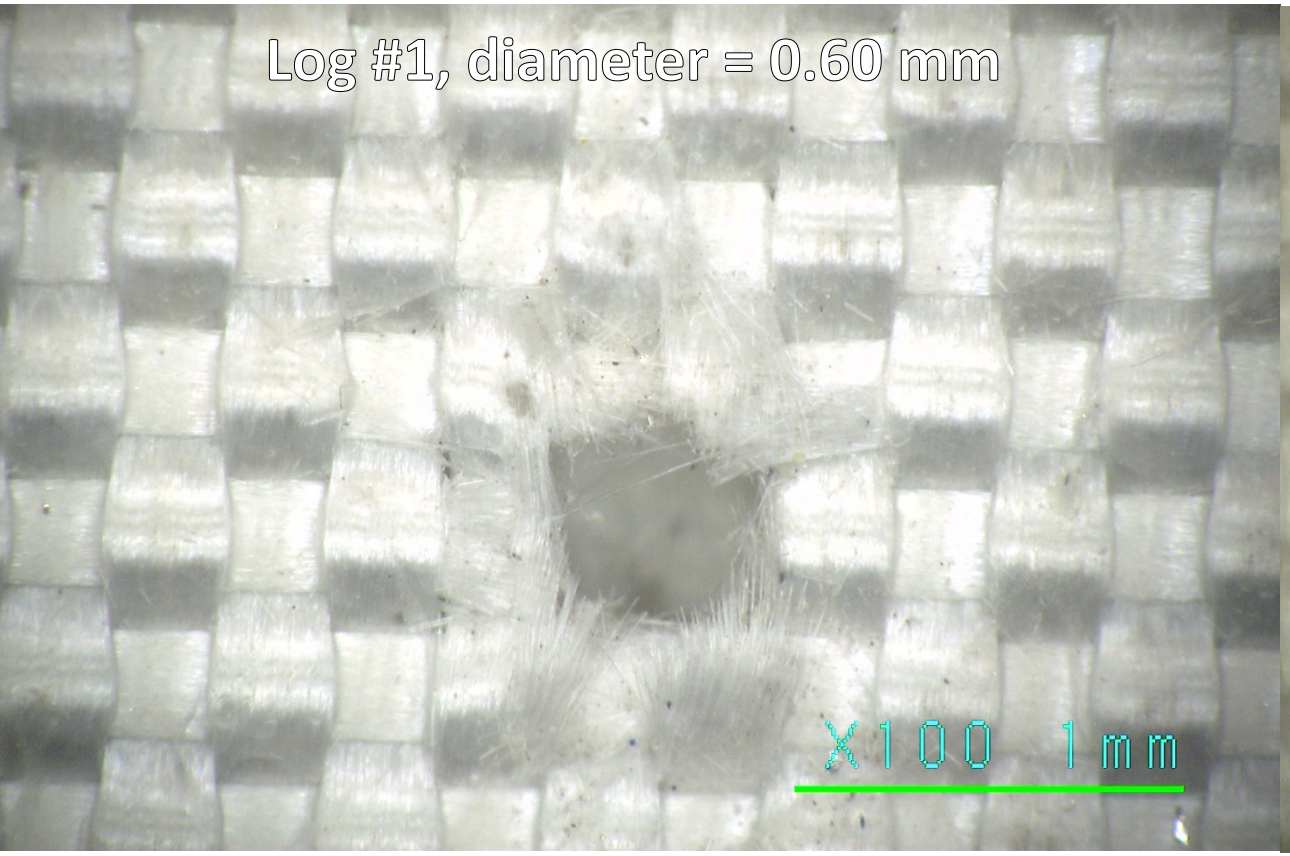
Post Flight Inspection Results

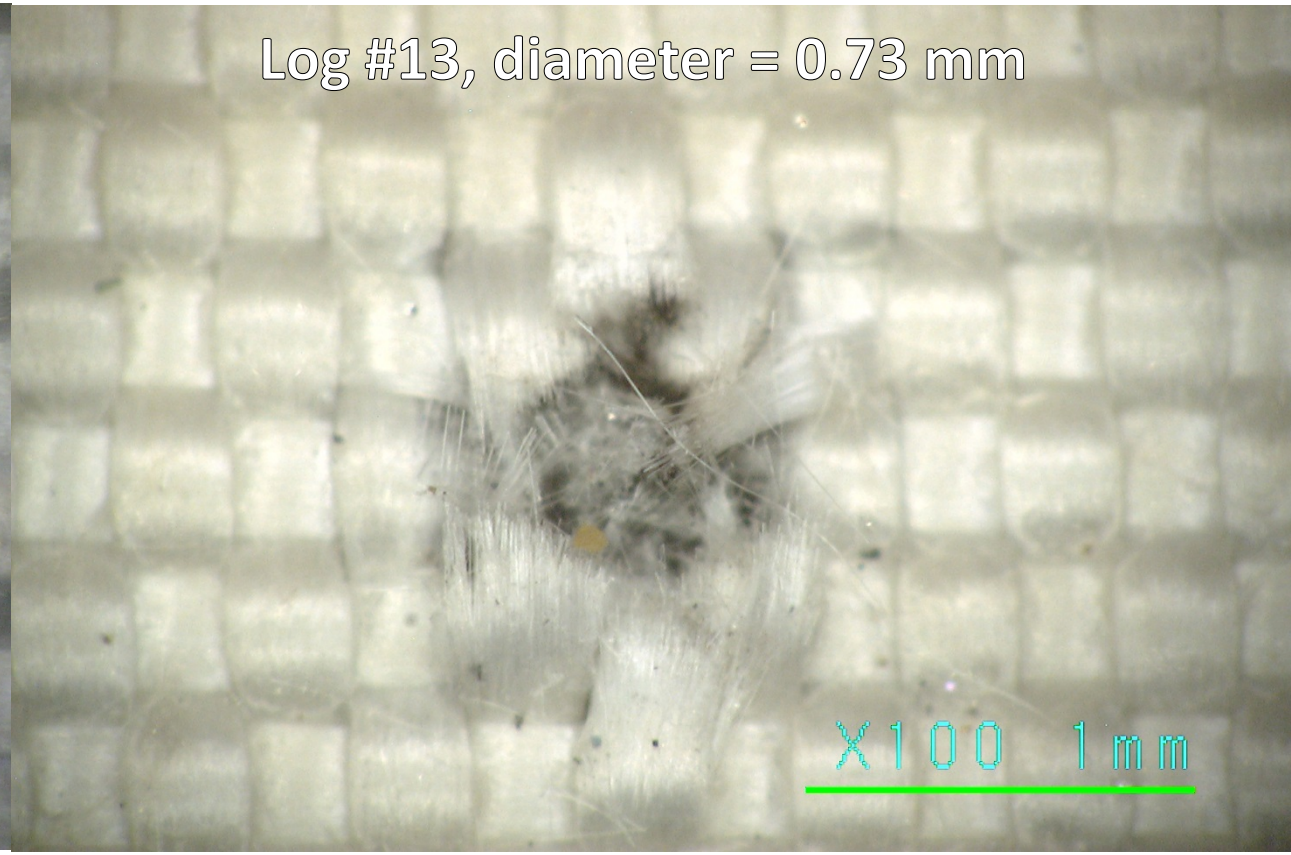
- 26 impact feature observed
- Max hole diameter = 1.01 mm
- Average crater diam. = 0.45 mm



Sampling at Impact Sites

- Six samples were extracted intact using a “hole punch” technique
- Relative orientation of internal layers was preserved





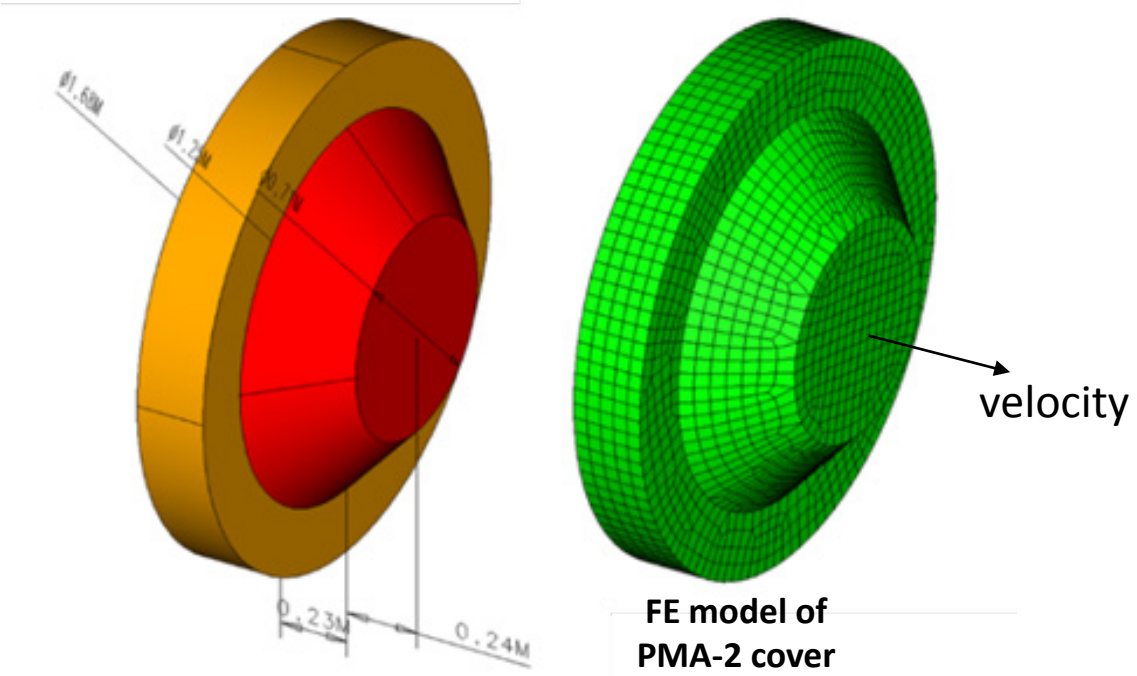
SEM/EDS Results

- Textural and compositional indications of high density orbital debris as the source in 4 of 6 samples

Impact Site	Hole Size (mm)	Impactor Type: Major Constituents	Possible Impactor
1	0.60	OD: Steel, ZnS, FeO, Ti	Steel
2	1.01	OD: Steel, Nickel-Oxide	Steel
10	0.80	OD: Steel, Iron-oxide	Steel
12	0.57	MM: Ca, Mg, Fe, S, O	Chondrite
13	0.73	MM: Fe, Ni, S	metal/sulfide-rich MM
24	0.36	OD: Steel, Iron-oxide, Ti	Steel

Comparison with Bumper 3

- Bumper 3 was used to calculate the expected number of holes on a stand alone model of the PMA-2 cover
- Years = 2013 through 2015
- Time averaged altitudes
- Damage equation = beta cloth hole size

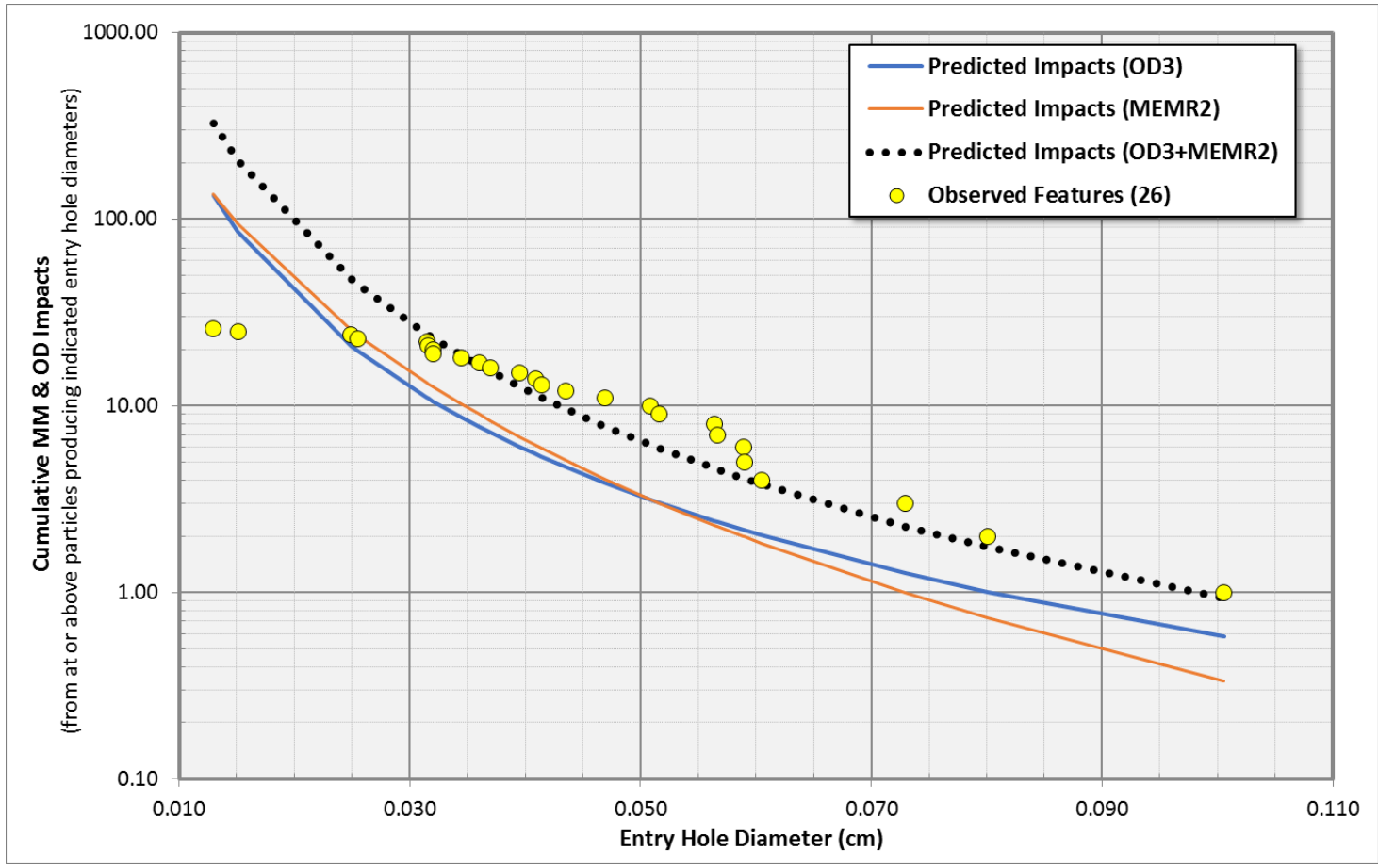


Hole Diameter (cm)	Particle Diameter (cm)	MEM R2	ORDEM 3.0	MMOD TOTAL
0.0288	0.0125	16.89	14.60	31.49
0.0460	0.020	4.40	3.87	8.27
0.0920	0.040	0.46	0.68	1.14
0.1380	0.060	0.11	0.30	0.40
0.1840	0.080	0.04	0.15	0.19
0.2300	0.100	0.02	0.08	0.10

Start Date	End Date	Days	Years	Altitude (km)
7/9/13	1/1/14	176	0.482	413.6
1/1/14	1/1/15	365	1.000	414.5
1/1/15	2/25/15	55	0.151	402.1
	Total	**596**	**1.633**	

Comparison with Bumper 3

- Bumper predictions for MM and OD are much closer to observations



Conclusions

- Damage found in post-flight inspection of the PMA-2 cover and the returned airlock bumper panels was generally consistent with Bumper code predictions using the ORDEM 3.0 debris model and MEM-R2 meteoroid model
- Excess orbital debris damage was observed on the airlock bumper panels compared to predictions, although this discrepancy is likely the result of secondary debris impacts