ORDEM 3.0 AND MASTER-2009 POPULATIONS COMPARISON (with preliminary SRM slag study)

P.H. Krisko, S. Flegel, M.J. Matney, D. Jarkey, V. Braun, P.D. Anz-Meador, Y.-L. Xu, A. Davis, W. Davidson, J. Hyde, M. Bjorkman, D.K. Ross, S. Hornung, D. Lukco, A. Avishai

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Presentation in 3 sections

1. "ORDEM 3.0 and MASTER-2009 modeled debris population environment " P.H. Krisko, S. Flegel, M.J. Matney, D.R. Jarkey, V. Braun, presented at 65th IAC, Toronto, Canada by Sven Flegel, edited and published in Acta Astronautica Vol………

2. Disparities in population organization for ORDEM 3.0 are material density, for MASTER-2009, as well as modeling techniques

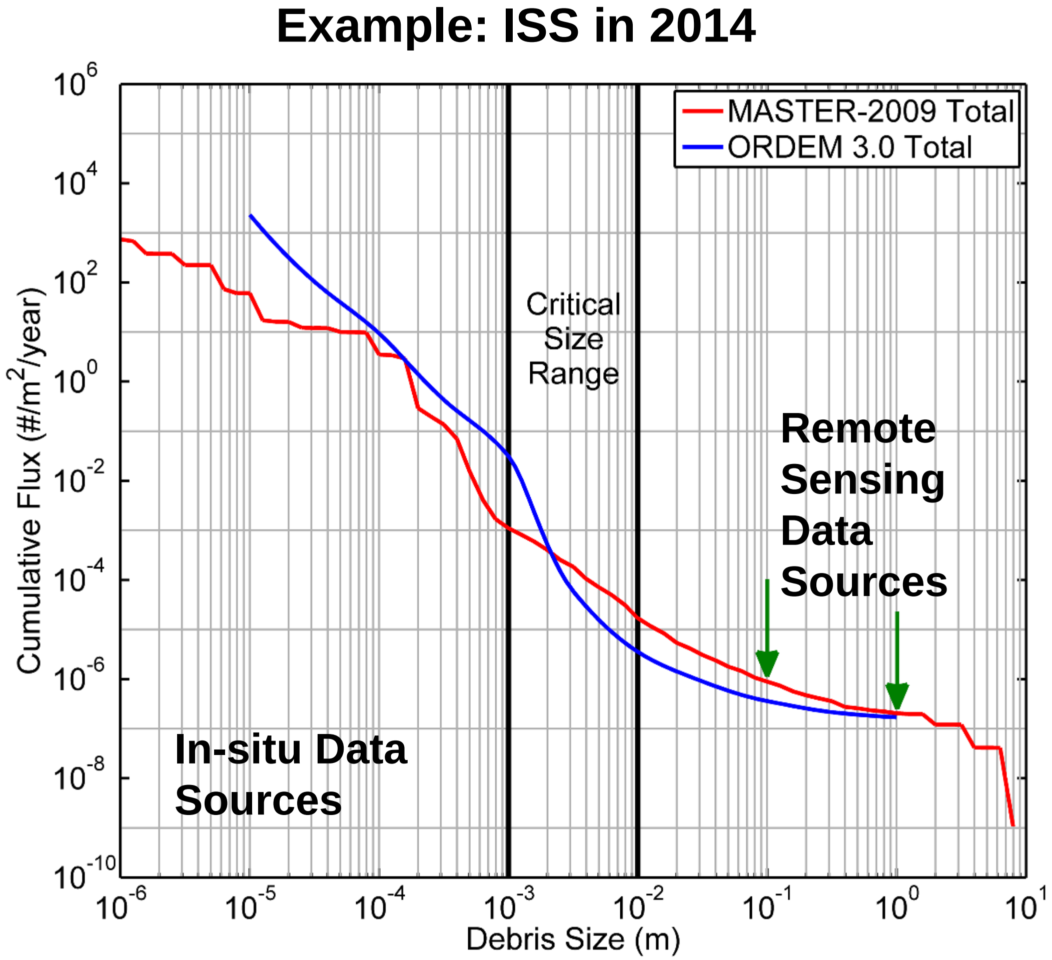
3. Aluminum (Al) and aluminum oxide (Al_2O_3) identification studies at the OPDO

ORDEM 3.0 and MASTER-2009

- **"ORDEM 3.0 and MASTER-2009 modeled debris population environment "**
- **Four test case orbits presented**
  - All Spacecraft Mode
  - All uncontrolled

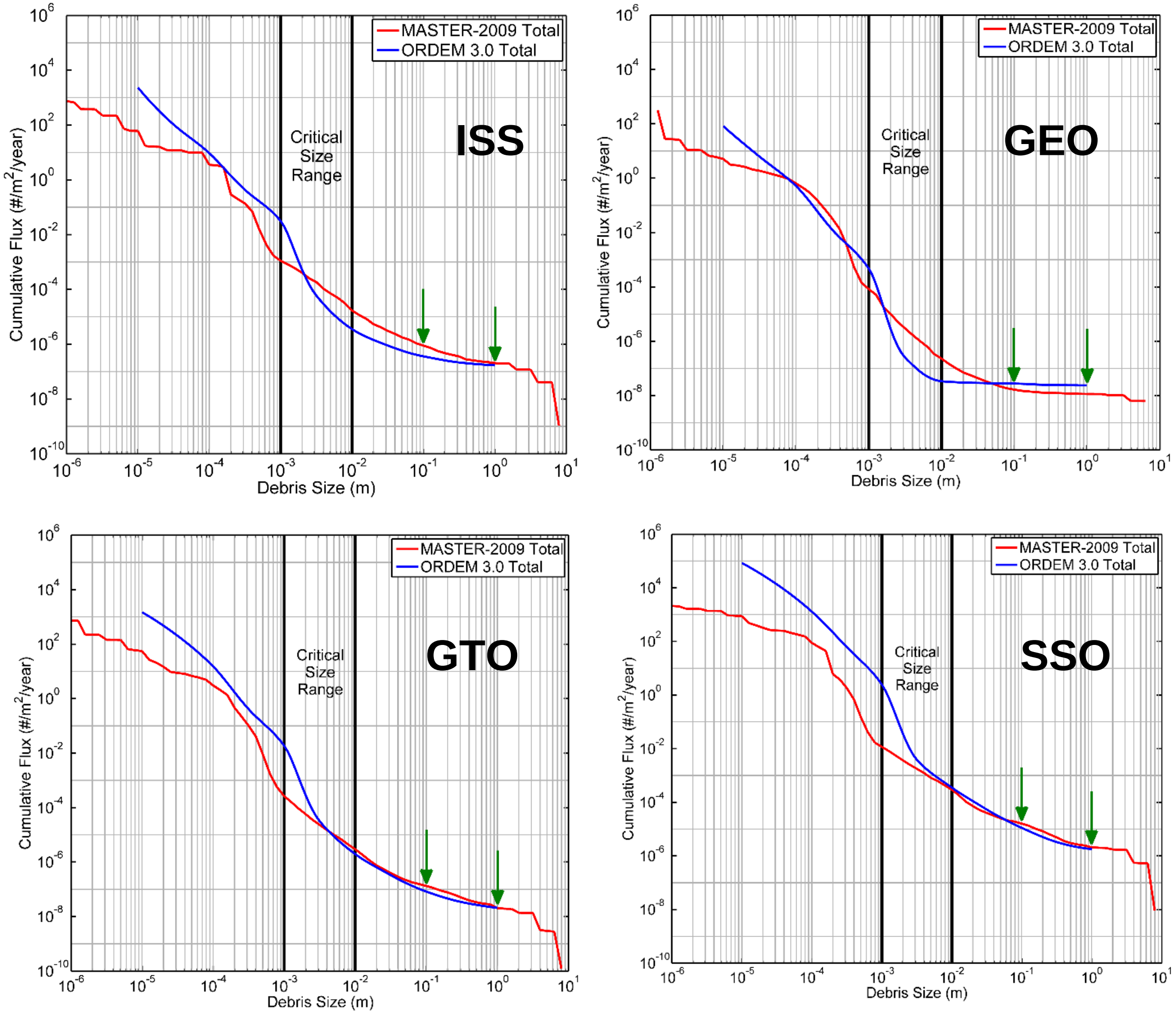
Orbit Type	Sample Satellite	NORAD ID	Ha/Hp [km]	Inc [deg]
ISS	ISS	25544	419 / 414	51.65
SSO	DMSP 5D-3 F19 (USA 249)	39630	855 / 838	98.84
GTO	CRRES	20712	33444 / 317	18.16
GEO	Raduga 1M-3	39375	35797 / 35775	0.004

ORDEM 3.0 and MASTER-2009



ORDEM and MASTER charts courtesy D. Jarkey

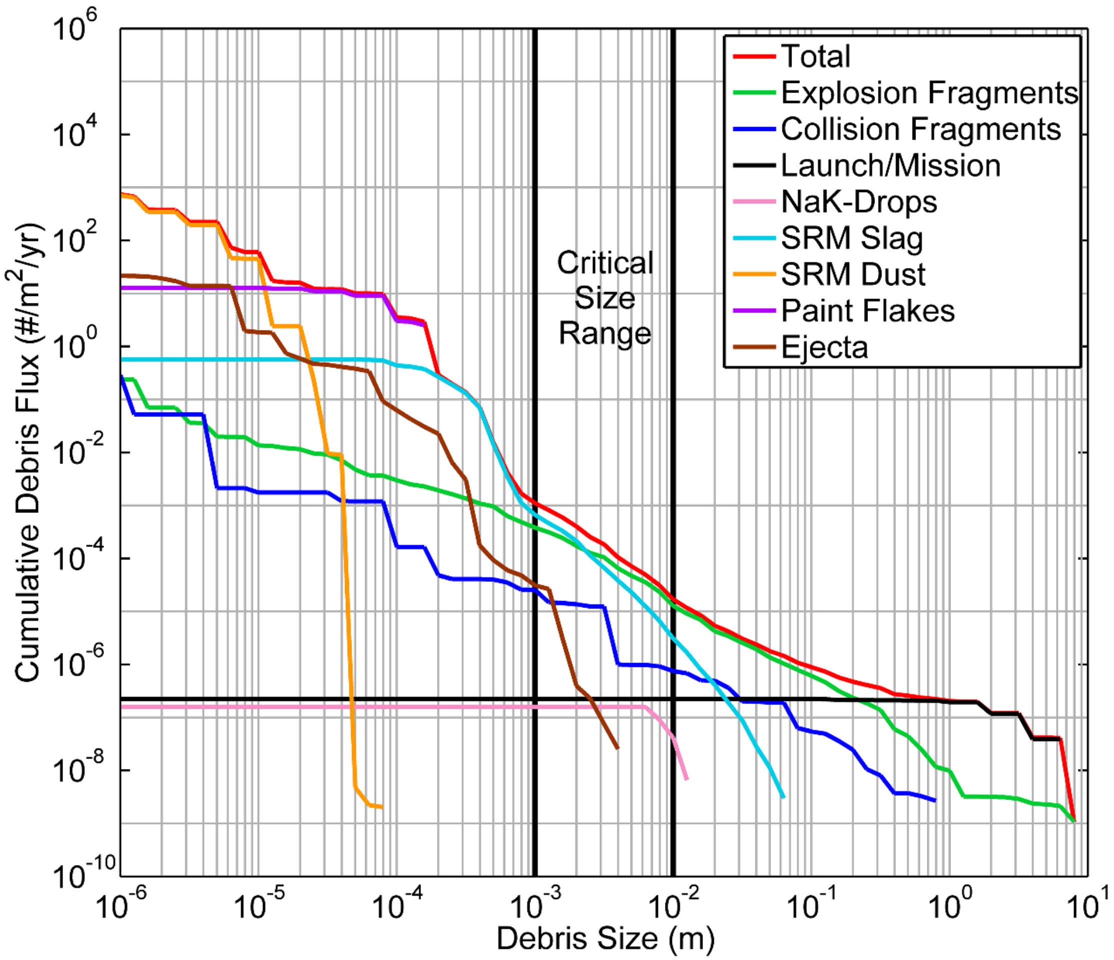
ORDEM 3.0 and MASTER-2009 test cases



- **GEO**
  - ORDEM includes GEO flux of objects larger than 10 cm, and GTO flux of objects from 10 μm to 1 m
  - Investigation underway
- **Non-GEO**
  - 1 m fluxes match well in all three cases (cataloged objects)
  - MASTER 10 cm fluxes exceed those of ORDEM in all three cases
  - **ORDEM overtakes MASTER in the low end of the critical size range in all non-GEO cases**
  - **True for ORDEM 2.0 and MASTER-2005**

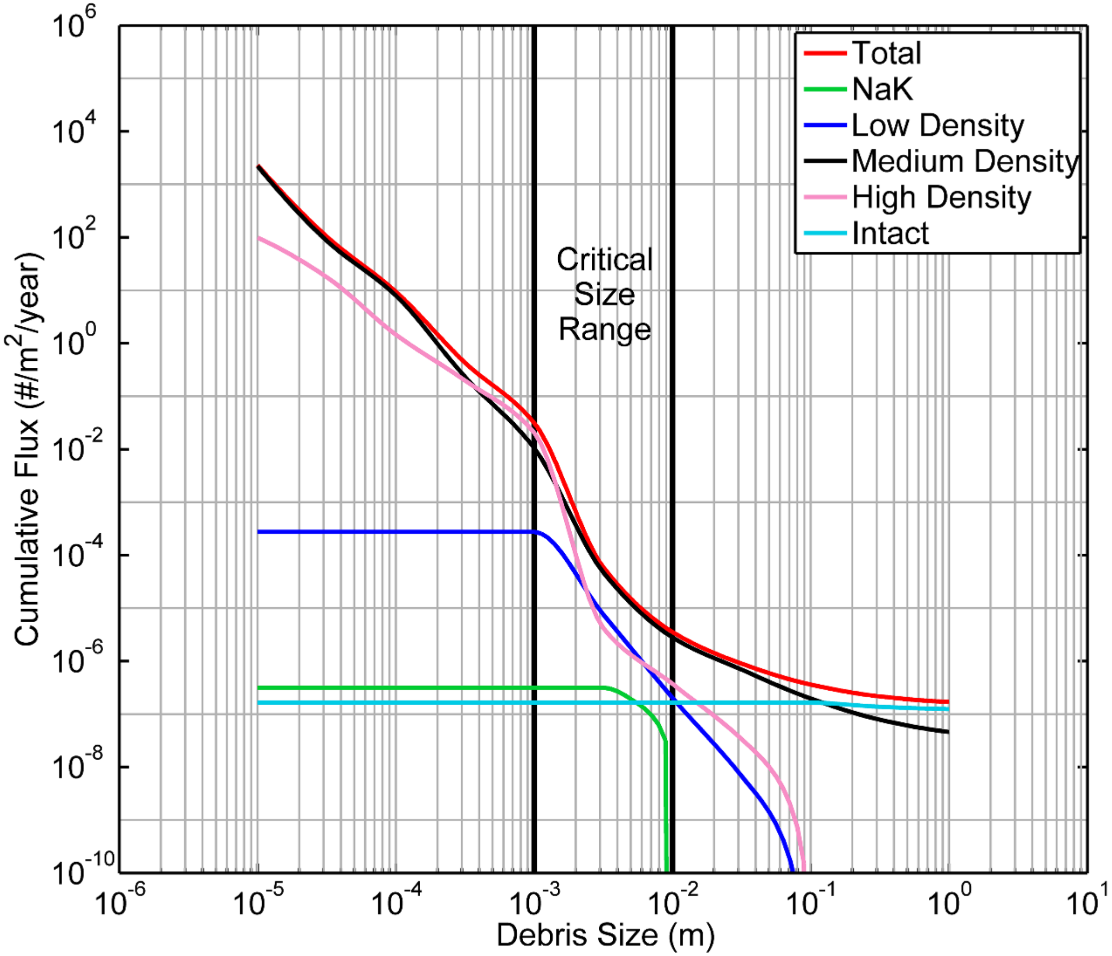
MASTER-2009 source populations for ISS 2014

- **At 1 m and 10 cm the dominant population fluxes are due to explosion and collision fragments and launch/mission objects.**
- **Within the critical size range (1 cm to 1 mm) Solid Rocket Motor (SRM) slag, explosion and collision fragments are dominant.**
    - Ejecta debris is also present with significant populations within the sub-millimeter sizes, but decreases in flux more rapidly with increased size then the other major constituents

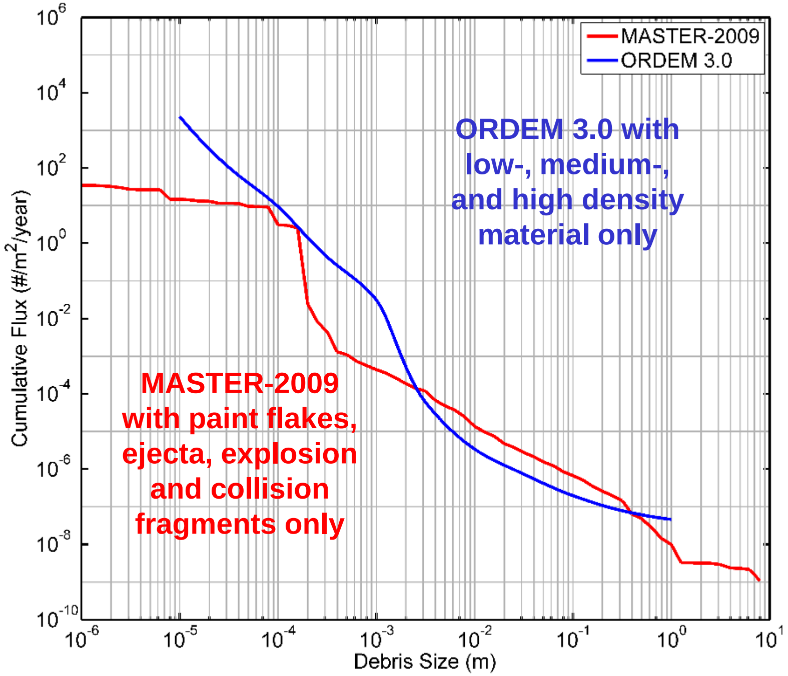


ORDEM 3.0 material density populations for ISS 2014

- **At 1 m and 10 cm the dominant population fluxes are due to medium density objects and Intact objects.**
- **Within the critical size range (1 cm to 1 mm) medium and high density material dominate with minor low density material populations.**

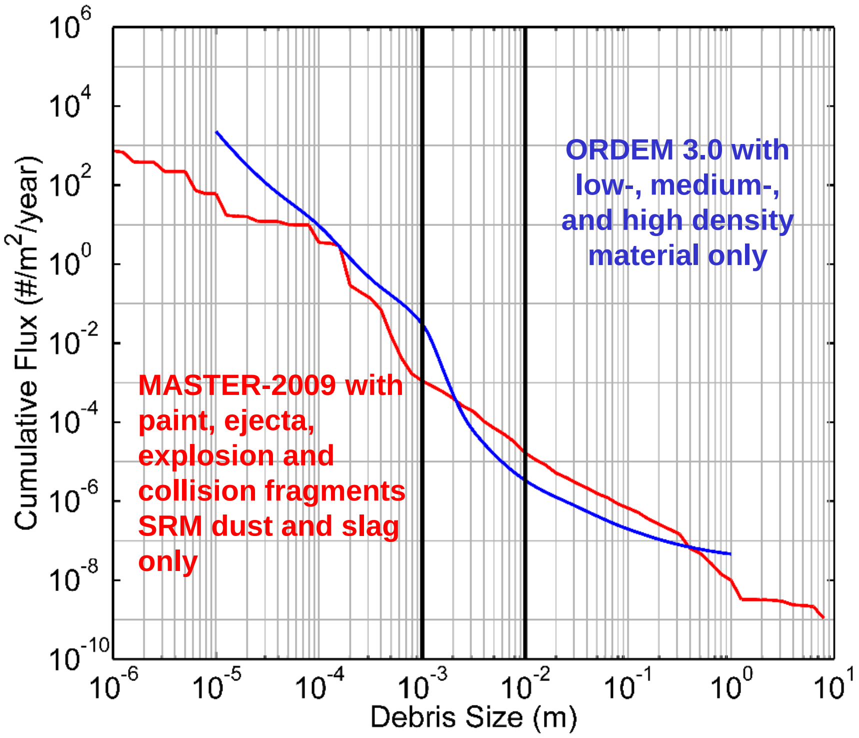


Initial Population Comparisons



ORDEM 3.0 with low-, medium-, and high density material only

MASTER-2009 with paint flakes, ejecta, explosion and collision fragments only

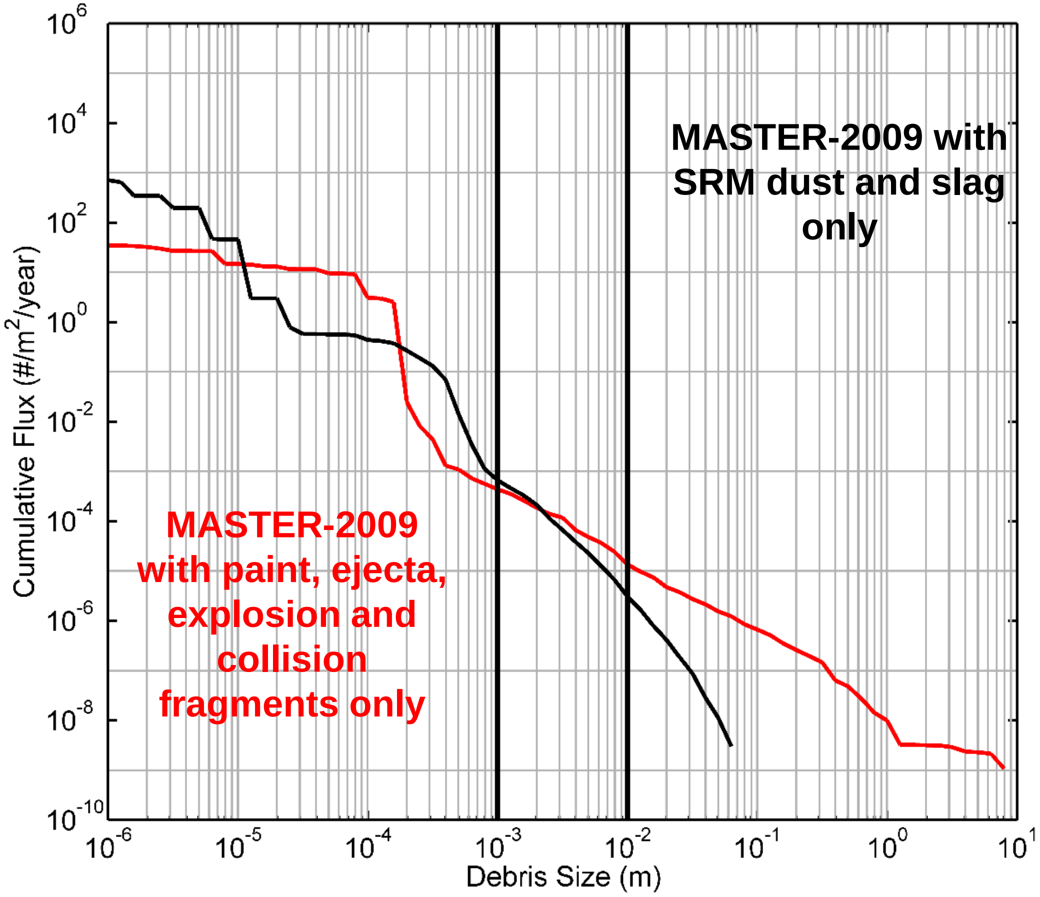


ORDEM 3.0 with low-, medium-, and high density material only

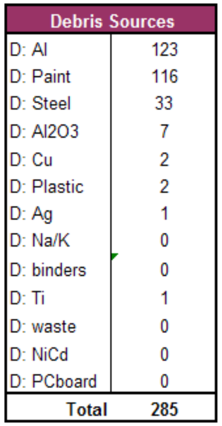
MASTER-2009 with paint, ejecta, explosion and collision fragments SRM dust and slag only

Initial Population Comparisons

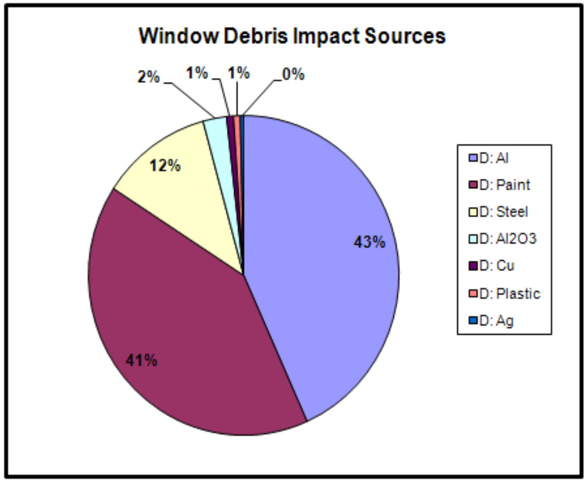
- **In ORDEM there is no SRM slag population. It is not identified in any ODPO source database.**
- **In MASTER the SRM dust and slag rival the sum of all other debris in the critical size range and below.**



Is SRM slag in the orbital environment?

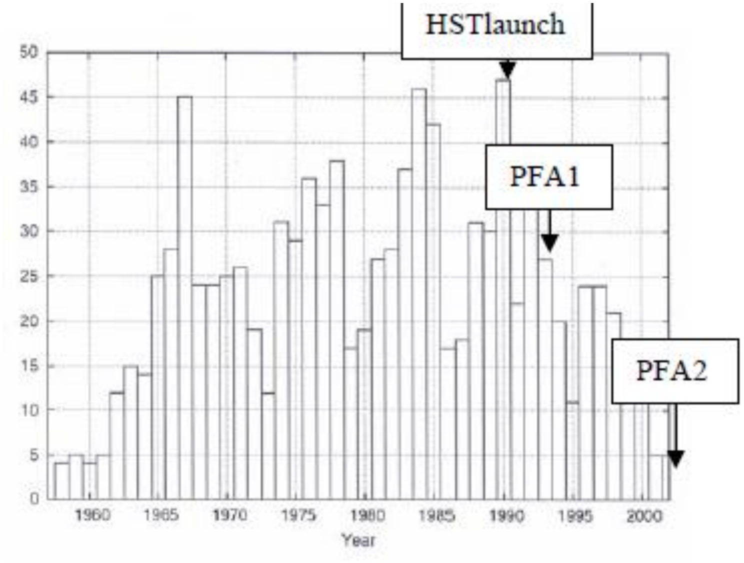


Debris Sources	
D: Al	123
D: Paint	116
D: Steel	33
D: Al2O3	7
D: Cu	2
D: Plastic	2
D: Ag	1
D: Na/K	0
D: binders	0
D: Ti	1
D: waste	0
D: NiCd	0
D: PCboard	0
Total	285



HVIT database of aluminum impactors on STS 71-135 (mid- 1990's to 2012) includes ~ 2% aluminum oxide particles.

Analysis and chart courtesy E. Christiansen, D. Lear, J. Hyde, M. Bjorkman

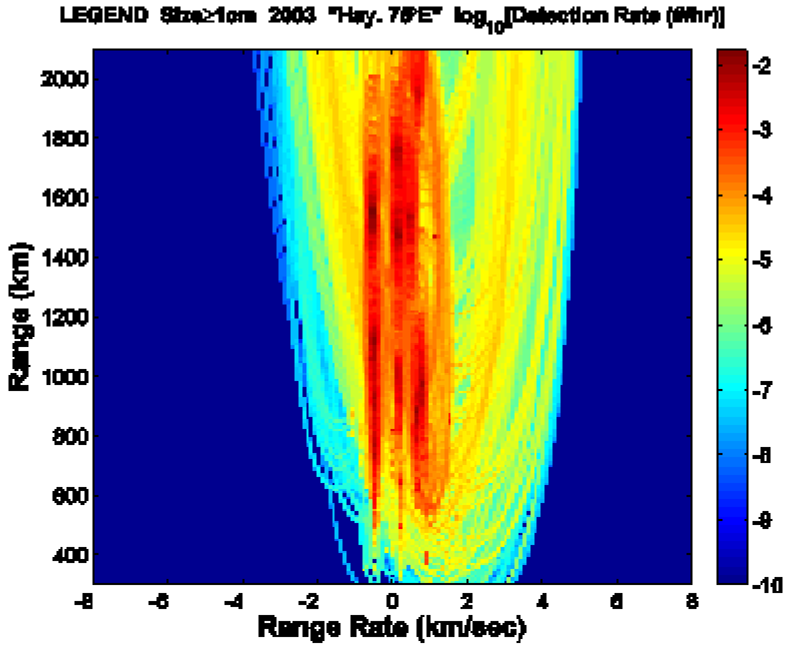


SRM usage continues to decline since the 1990s

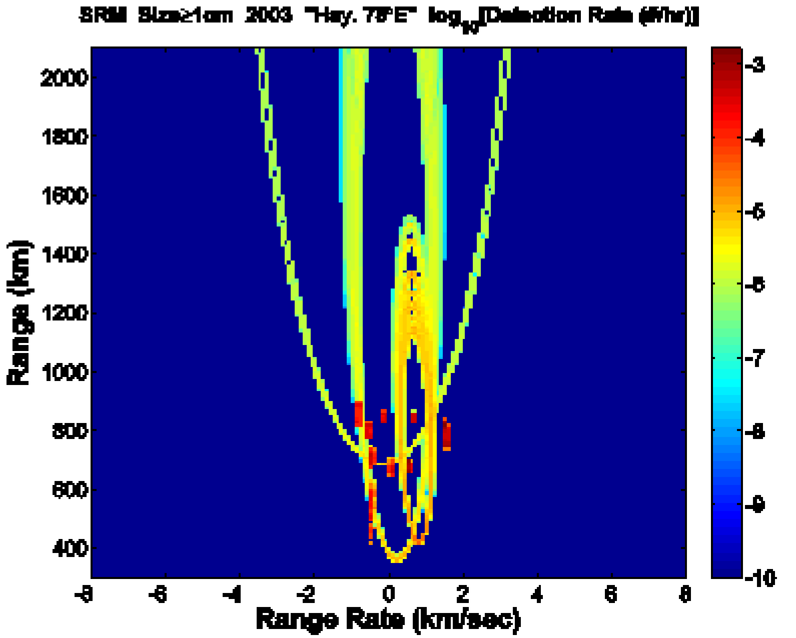
Chart courtesy P.D. Anz-Meador

Is SRM slag in the orbital environment?

LEGEND model (excludes SRM slag)



SRM slag model

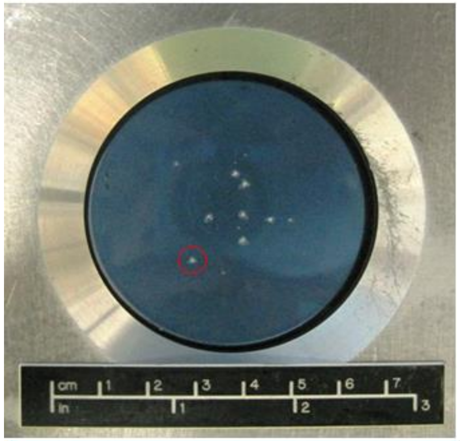


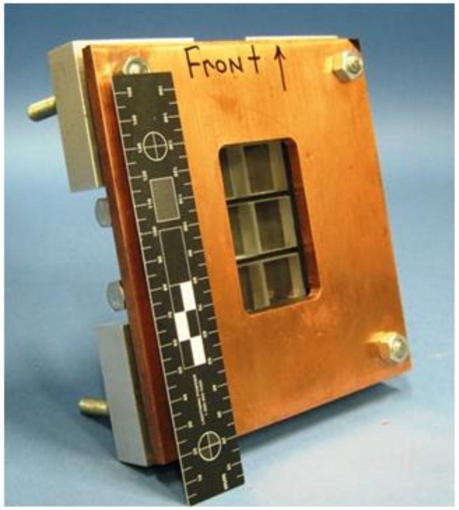
Range vs. range rate calculation courtesy Y.-L. Xu

SRM slag model courtesy M. Horstman

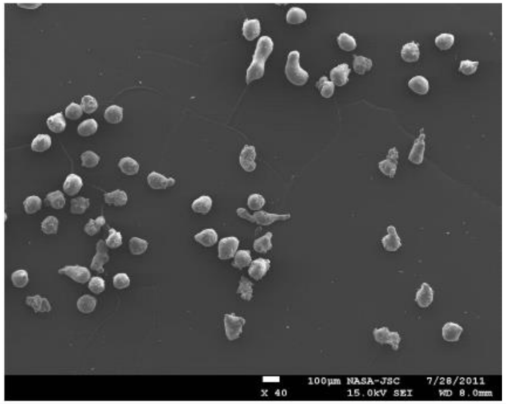
ODPO, HVIT Al vs. Al_2O_3 study

- **"Hypervelocity Impact Test Plan for Aluminum Oxide Identification Program", 10 shots completed at WSTF (White Sands Test Facility) – all samples returned to JSC in late Oct 2011.**
  - 5 shots with Al impactors on STS glass 3" pucks, 5 shots with Al_2O_3 impactors on STS 3" pucks
  - Decision: retain all glass pucks from completed test for mold samples, perform new impact tests at WSTF using precut glass cubes.
  - Multiple impactors (30-50) placed in closed sabot ('shotgun' method)
  - All targets angled at 45 deg, impactor velocities varied from ~3 to ~7 km/s
  - 2 shots unsuccessful
  - **8 impact samples analyzed in blind tests, 4 on mold (2 Al, 2 Al_2O_3), 4 on glass (2 Al, 2 Al_2O_3)**

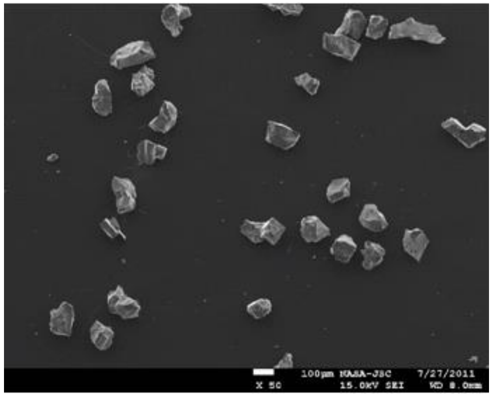




Al commercial source)



Al_2O_3(ground recovered slag



Fabrication courtesy W. Davidson

Photos courtesy A. Davis

Chemical analysis

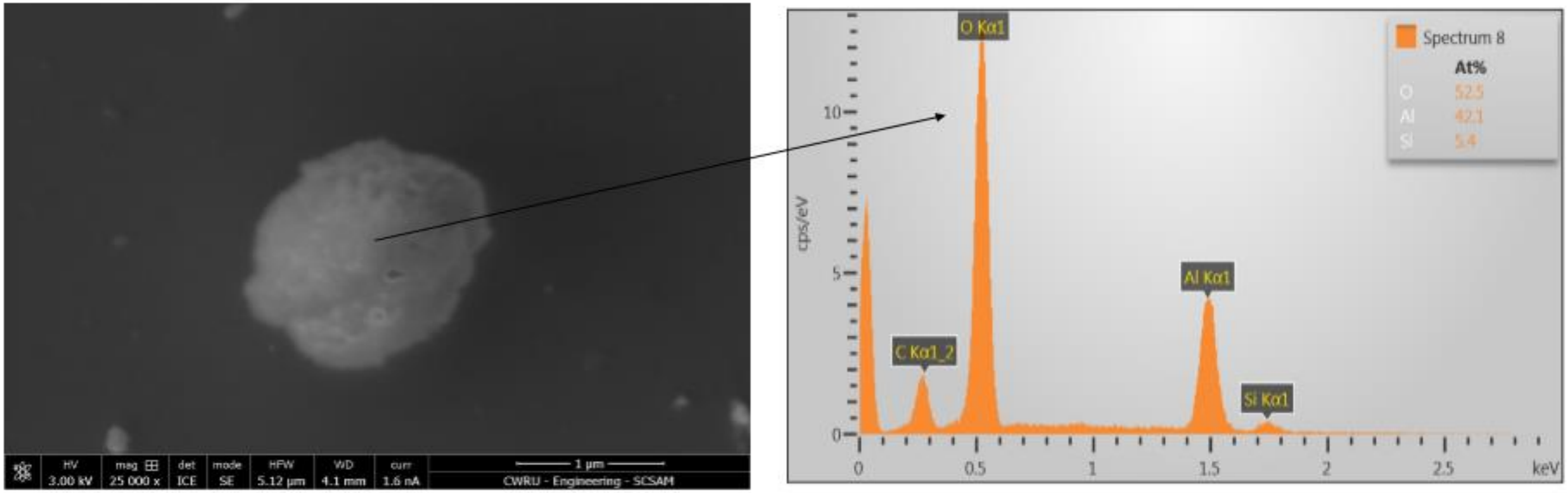
- **NASA JSC SEM/EDS analysis completed. Results are inconclusive on all 8 samples**
  - Impact remnants are sub-micron in size
    - Note: Remnant size is sub-micron in STS returned surfaces also.
  - Oxygen signal in spectra could be derived from glass, mold, or Al_2O_3.
- **The 8 samples and maps of remnant locations to WSTF for Auger analysis**
  - "Auger may have higher fidelity in this study"
- **Auger study was plagued by equipment failures and the state of the samples.**
  - Many samples had been carbon coated at JSC
- **In Sept. 2014 samples sent to GRC (Glenn Research Center)**
  - With CWRU (Case Western Reserve University), identifications of the remnants made.

ODPO Al vs. Al_2O_3 study conclusion

- **For glass cube remnants 3 out of 4 were correctly identified.**
- **For mold sample remnants 2 out of 4 were correctly identified.**
  - One of mold sample failures showed conflicting IDs in different regions of the mold.
  - At best 6 of 8 successes. At worst 5 of 8 successes
  - An Al_2O_3 identification requires O/Al ratio of 3/2

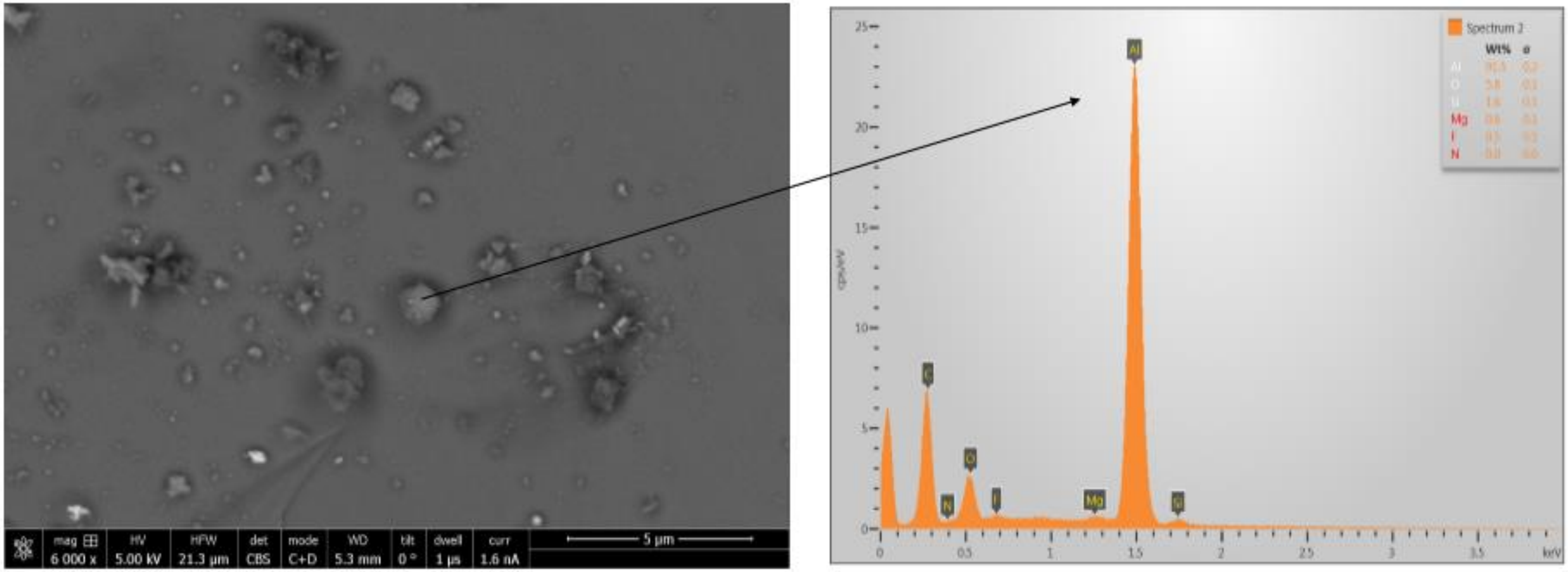
Analysis and photos courtesy D. Lukco and A. Avishai

Al_2O_3 Sample Identification



Cube 3: The particle shown above clearly stood out as aluminum oxide. Two other particles on this sample were also clearly identified as aluminum oxide.

Al Sample Identification



Cube 9: The particle shown above clearly stood out as aluminum metal. Several other aluminum containing particles were also identified.

Best Method for Distinguishing between Al and Al_2O_3 Particles on Silicone Mold Impressions from Over Ten Years ago

by D. Lukco

- **Field Emission Secondary Electron Microscopy (FE-SEM) with Energy Dispersive Spectroscopy (EDS) using low voltage (3-5 kV) would still be the best choice for characterizing these samples. If the particles were already mapped out and had only a 15-25 nm thickness of carbon coating on them, it should be possible to identify whether the particles are aluminum metal or oxide fairly quickly.**

- **If the carbon layer is too thick, a Focused Ion Beam (FIB) cross section of the particles could be obtained. Ideally, from the cross section, it would be possible to see a metal core with oxide on the outsides of the particles. If the particles are too small, a lift-out section could be prepared for Transmission Electron Microscopy (TEM) or Scanning TEM. This last method would be definitive but it also takes much longer (4-5 hours/cut, but the cuts could be across several particles at the same time).**

- **Aluminum metal always has a thin oxide coating on its surface. If the particles are large and smooth (at least > 1 µm), the oxide thickness could be 5-50 nm and should not increase over time. However, if the particles are sub-micron, then you reach a point where the oxide layer constitutes most of the sample and it would be difficult to distinguish, except maybe with TEM.**

Time of Flight- Secondary Ion Mass Spectroscopy (TOF-SIMS)

by D. Lukco

- **This technique would be a good place to start looking at samples that had not been previously analyzed before. It holds the highest chance of being able to collect data over a large area and locate where aluminum is concentrated much faster than FE-SEM. It would also simultaneously collect data on all other particles on the samples which could be then be used to identify them.**

- **The aluminum containing areas could then be lightly sputtered to remove any surface oxide and then the mass could be checked to identify either aluminum or aluminum oxide.**

- **A thick carbon coating would be problematic with this technique since it is the most surface sensitive of all analytical methods and all of the carbon would have to be sputtered away.**