Changes in Chemical Composition of ISS Archive Water Samples from Collection to Analysis

William T. Wallace[1], Edgar K. Hudson[2], Brandon J. Dunbar[3], Tanner S. Hamilton[2], Sarah L. Wallace[4], and Daniel B. Gazda[4]

[1]KBR, Houston, TX 77058

[2]JES Tech, Houston, TX 77058

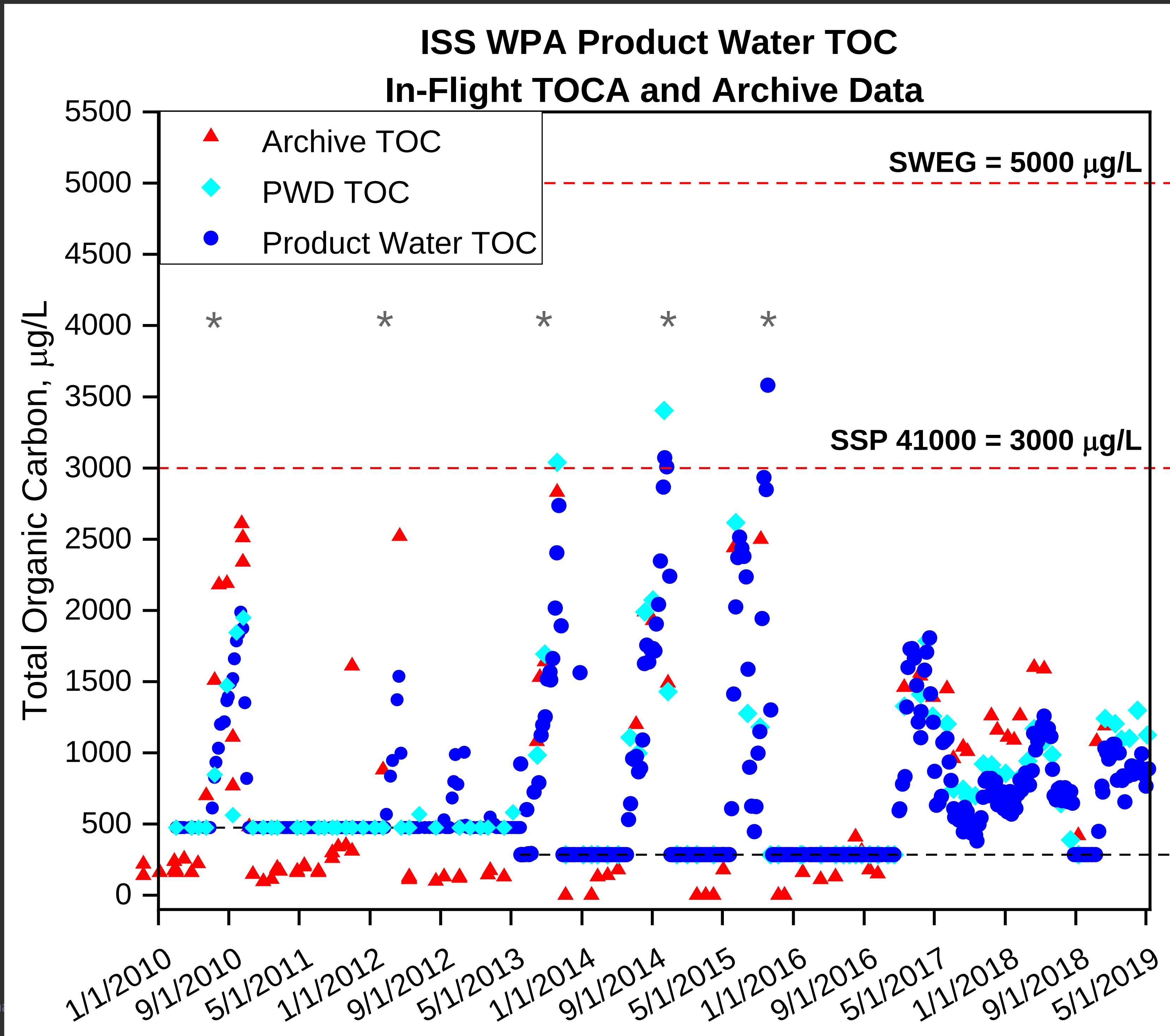
[3]GeoControl Systems, Houston, TX 77087

[4]NASA Lyndon B. Johnson Space Center, Houston, TX 77058

Outline

- Background
  - TOC increase and MF Bed replacement
  - SpaceX-12
    - Acetate and Bicarbonate?
  - SpaceX-14
    - Teflon v/s Mylar/Teflon
- Methods and Experimental Results
- Newer archival results
- Non-potable samples

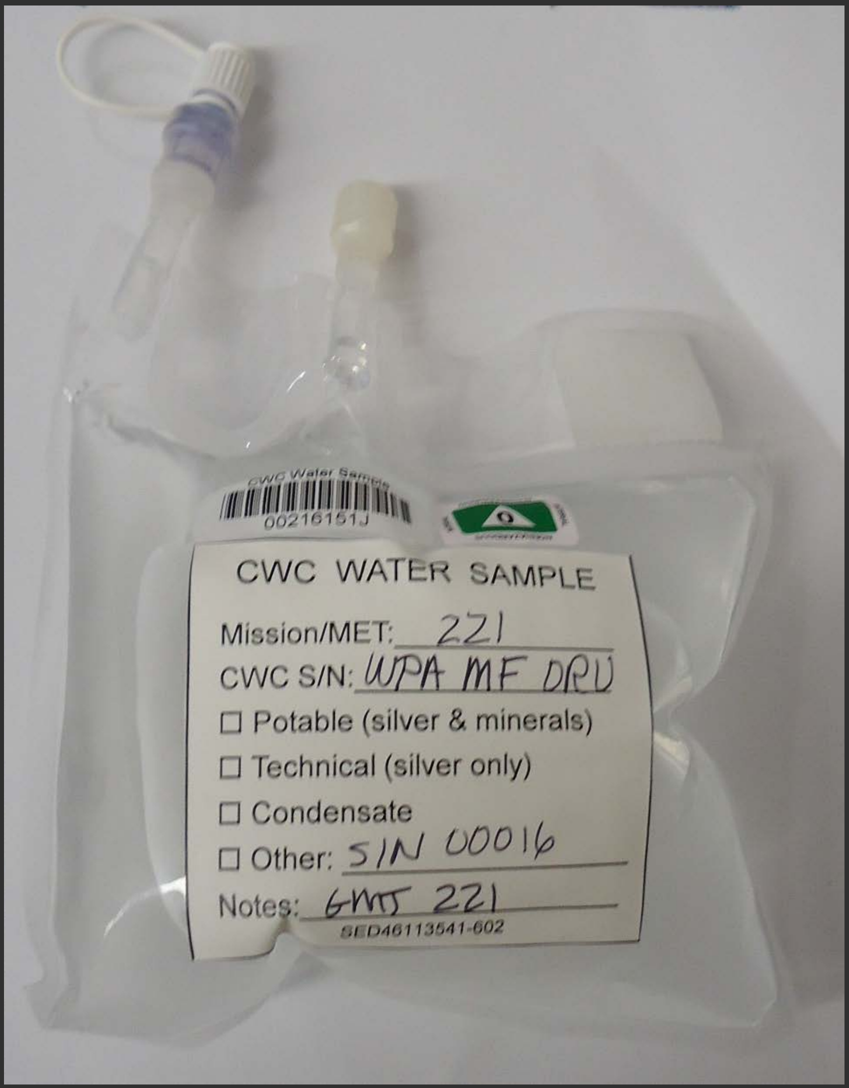
TOC Increases



Multifiltration Bed Extension

- Extended TOC trend provided opportunity to extend the life of the MF beds
- Ionic breakthrough of bed #2 would previously have resulted in replacement of the beds
- Ground testing showed that initial breakthrough contaminants could be processed by the Catalytic Reactor
    - 1) bicarbonate, 2) acetate, 3) ammonium
- Product water TOC has been unaffected by additional load
- Samples of the effluent from both beds collected and returned on SpaceX-12

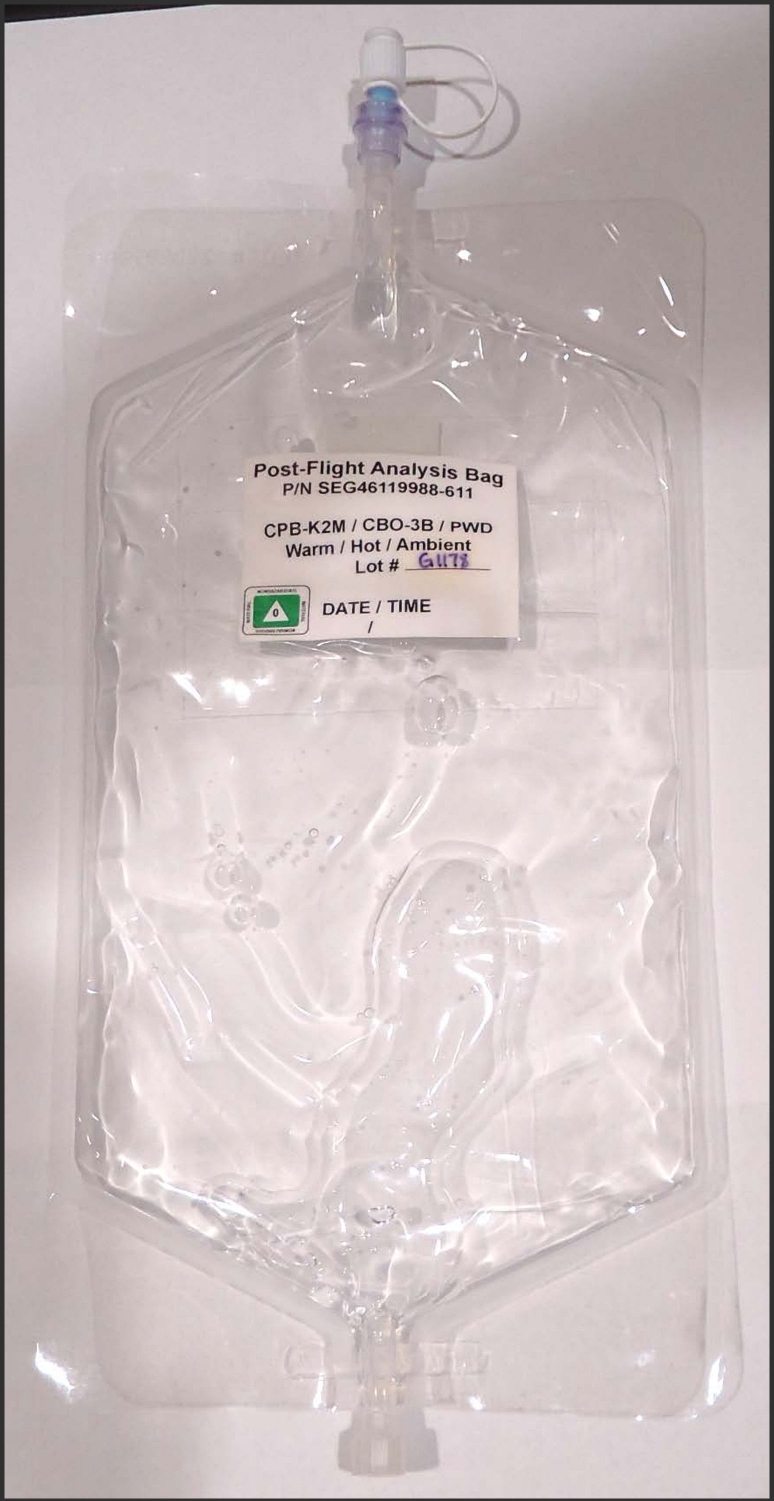
SpaceX-12 Return

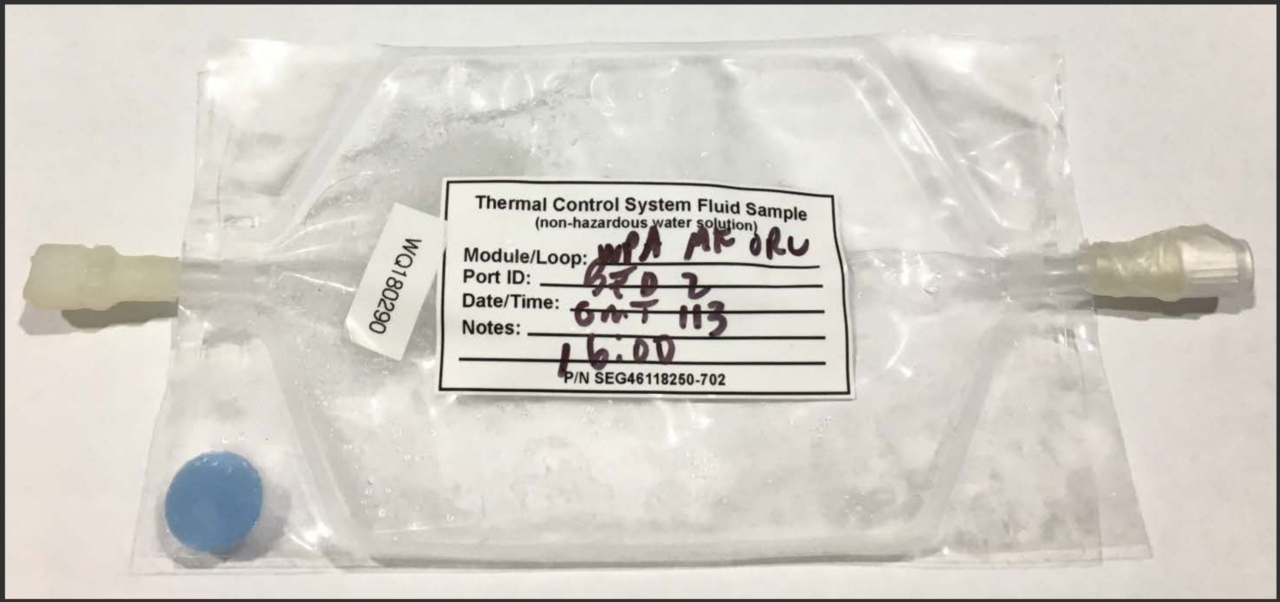


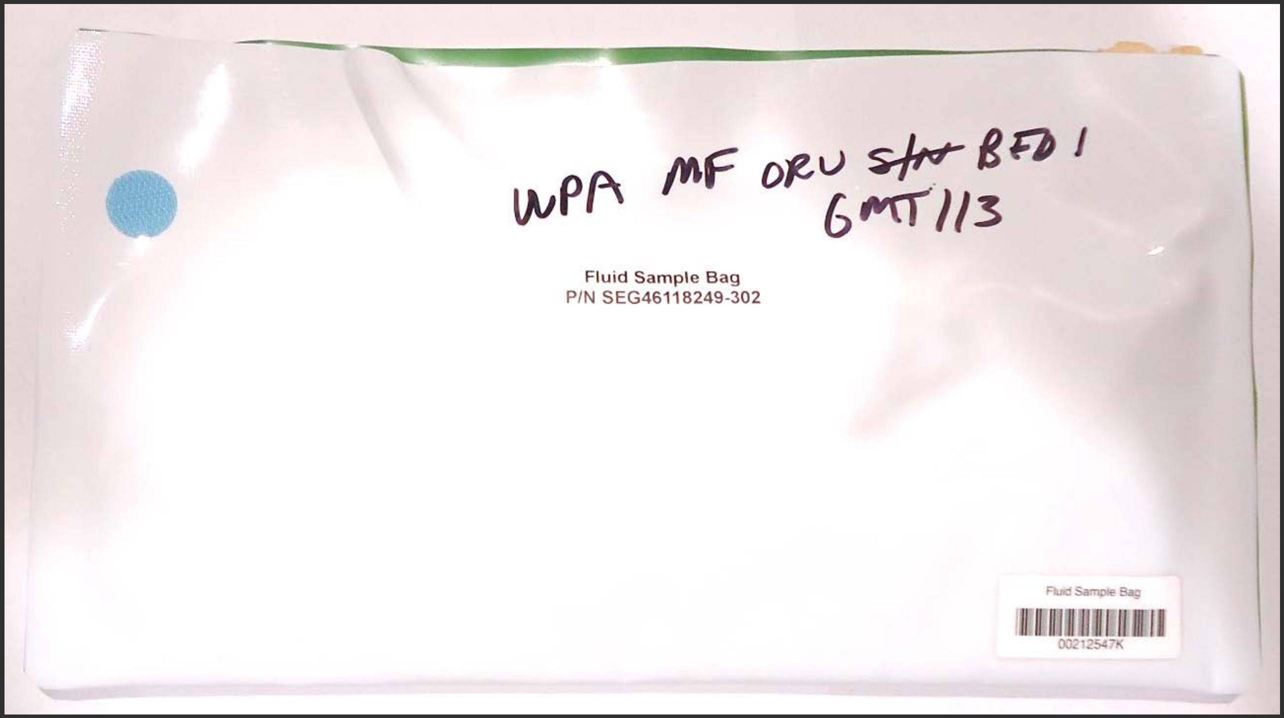
Mission		SpX-12	
Sample Location		WPA MF Bed ORU S/N 00016	WPA MF Bed ORU S/N 00017
Sample Description		WPA MF Bed Effluent, Teflon Bag	WPA MF Bed Effluent, Teflon Bag
Sample Date		8/9/2017	8/9/2017
	Units		
Cations			
Ammonium	mg/L	<0.25	<0.25
Total Organic Carbon			
Inorganic Carbon	mg/L	<3.0	<3.0
Organic Carbon	mg/L	23.2	19.1
Volatile Organics			
Acetone	µg/L	5,300	6,020
2-Butanone (Methyl ethyl ketone)	µg/L	291	<50
Semi-volatile Organics			
Methyl sulfone	µg/L	148	<50
N,N-Dimethyl acetamide	µg/L	400	not found
N,N-Dimethylformamide	µg/L	440	not found
2-Ethoxyethanol	µg/L	280	not found
Alcohols			
Ethanol	µg/L	10,400	8,320
Methanol	µg/L	4,010	3,800
1-Propanol	µg/L	524	440
2-Propanol (Isopropanol)	µg/L	1,360	2,440
Glycols			
1,2-Ethanediol (Ethylene glycol)	µg/L	1,020	1,220
1,2-Propanediol (Propylene glycol)	µg/L	4,850	3,640
Silanols			
Dimethylsilanediol (DMSD)	µg/L	17,000	19,000
Carboxylates			
Acetate	µg/L	6,340	4,690
Propionate	µg/L	964	<500

Where is the Bicarbonate?

- As expected, breakthrough of acetate was observed in both beds
- Bicarbonate levels (as TIC) were lower than expected based on the conductivity readings, even though it was expected to break through first
- Believed that CO_2 was diffusing through the Teflon sample bag, leading to lower-than-expected TIC concentrations
- Second set of samples collected and returned on SpaceX-14
- One sample for each bed collected in normal Teflon bag and one collected in smaller ITCS bag sealed in Mylar pouch


Post-Flight Analysis Bag
P/N SEG46119988-611
CPB-K2M / CBO-3B / PWD
Warm / Hot / Ambient
Lot # G1178
DATE / TIME
/


Thermal Control System Fluid Sample
(non-hazardous water solution)
Module/Loop: WPA MF ORU
Port ID: BED 2
Date/Time: GMT 113
Notes: 16:00
P/N SEG46118250-702
WQ180290

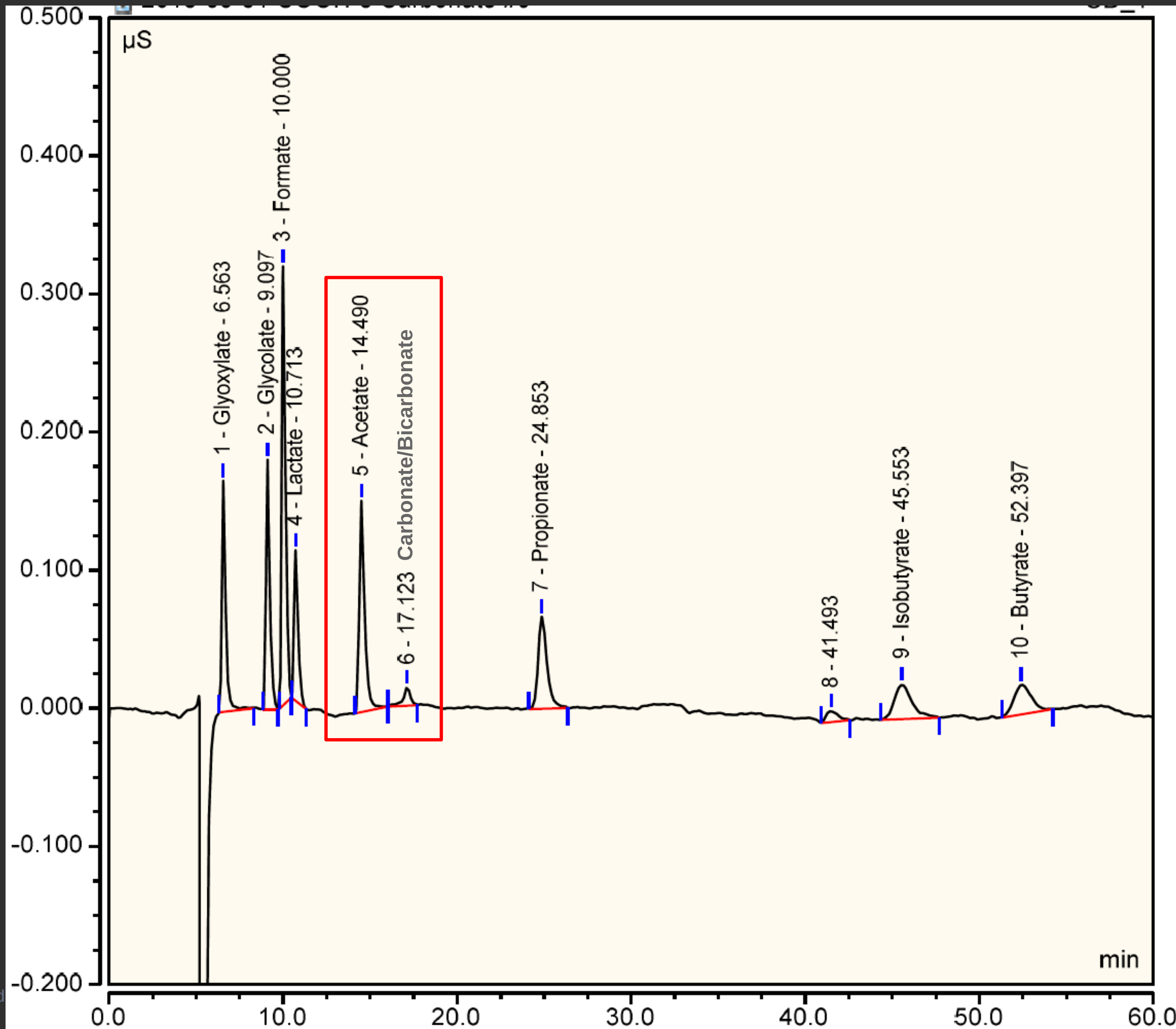

WPA MF ORU BED 1
GMT 113
Fluid Sample Bag
P/N SEG46118249-302
Fluid Sample Bag
00212547K

SpaceX-14 Return

Mission		SpaceX-14			
Sample Location		WPA MF Bed #1 ORU S/N 00016	WPA MF Bed #1 ORU S/N 00016	WPA MF Bed #2 ORU S/N 00017	WPA MF Bed #2 ORU S/N 00017
Sample Description		MF Bed Effluent, Teflon Bag	MF Bed Effluent, Teflon/Mylar Bag	MF Bed Effluent, Teflon Bag	MF Bed Effluent, Teflon/Mylar Bag
Sample Date		4/23/2018	4/23/2018	4/23/2018	4/23/2018
	Units				
Cations					
Ammonium	mg/L	<0.25	<0.25	<0.25	<0.25
Total Organic Carbon					
Inorganic Carbon	mg/L	2.51	3.23	0.70	0.63
Organic Carbon	mg/L	50.1	57.2	35.5	35.1
Volatile Organics					
Acetone	µg/L	5,550	6,610	6,160	8,010
2-Butanone (Methyl ethyl ketone)	µg/L	578	630	< 50	50
Acetaldehyde	µg/L	not found	not found	770	not found
Trimethylsilanol	µg/L	not found	60.0	not found	not found
Dimethyl sulfide	µg/L	92	110	not found	35
Semi-volatile Organics					
Methyl sulfone	µg/L	172	NA	118	NA
2-Ethoxyethanol	µg/L	230	NA	370	NA
N,N-Dimethyl acetamide	µg/L	490	NA	not found	NA
N,N-Dimethylformamide	µg/L	370	NA	390	NA
Alcohols					
Ethanol	µg/L	50,700	55,900	42,900	43,700
Methanol	µg/L	4,730	5,490	3,710	3,820
1-Propanol	µg/L	761	599	578	434
2-Propanol (Isopropanol)	µg/L	4,530	4,010	3,920	2,800
Glycols					
1,2-Propanediol (Propylene glycol)	µg/L	2,050	NA	< 1000	NA
Silanols					
Dimethylsilanediol (DMSD)	µg/L	18,000	NA	19,000	NA
Carboxylates					
Acetate	µg/L	1,970	10,200	< 500	< 500
Butyrate	µg/L	< 500	968	< 500	< 500
Propionate	µg/L	< 500	4,030	< 500	< 500

Where Did The Carboxylates Come From?

Initial concerns focused on potential sampling issues or interference from carbonate/bicarbonate

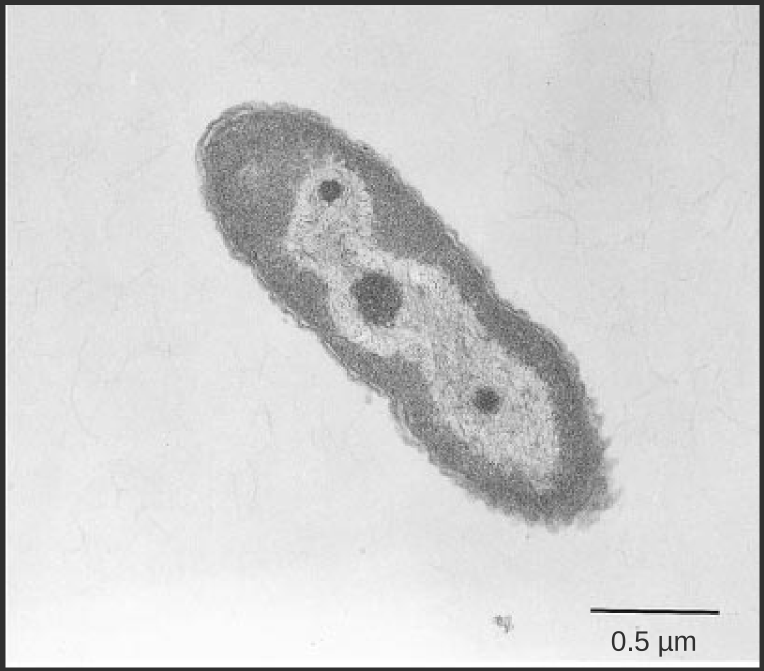


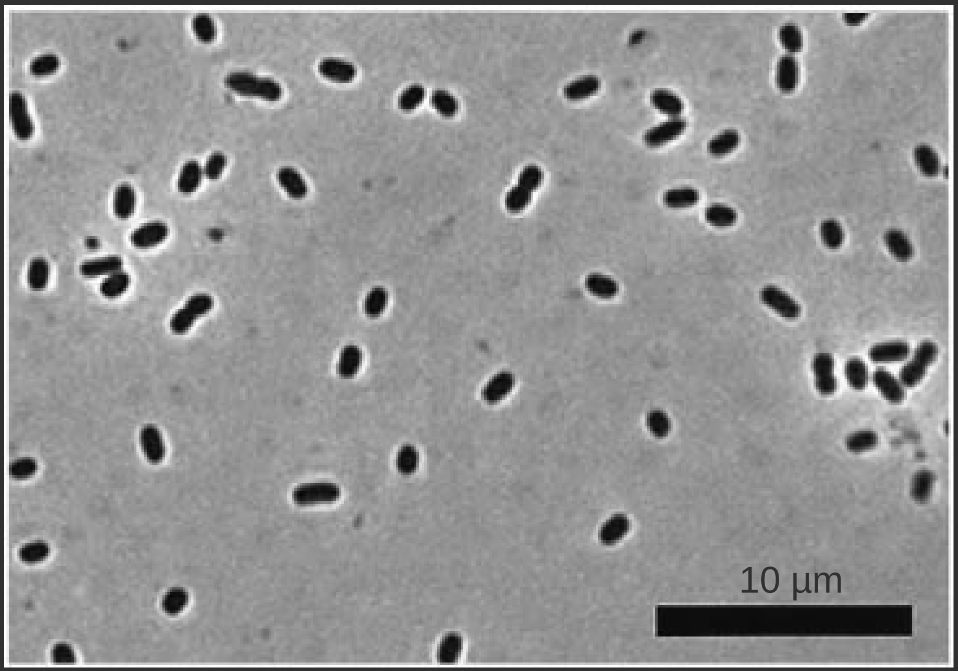
Further Testing on Teflon/Mylar Sample

	Analysis Date	5/16/2018	6/21/2018	6/21/2018	6/25/2018
		Initial aliquot	5/16/2018 aliquot, room temp.	Archived sample (4 °C, Mylar)	6/21/2018 archived aliquot, room temp.
Compound	**Units**				
Acetate	µg/L	10,200	< 500	8,500	< 500
Butyrate	µg/L	968	< 500	867	< 500
Propionate	µg/L	4,030	< 500	4,740	< 500

What is Causing the Changes?

- Gas diffusion and/or temperature-dependent mechanism





Zhang *et al.* (2000) *Int. J. Syst. Evol. Microbiol.* 50:743-749

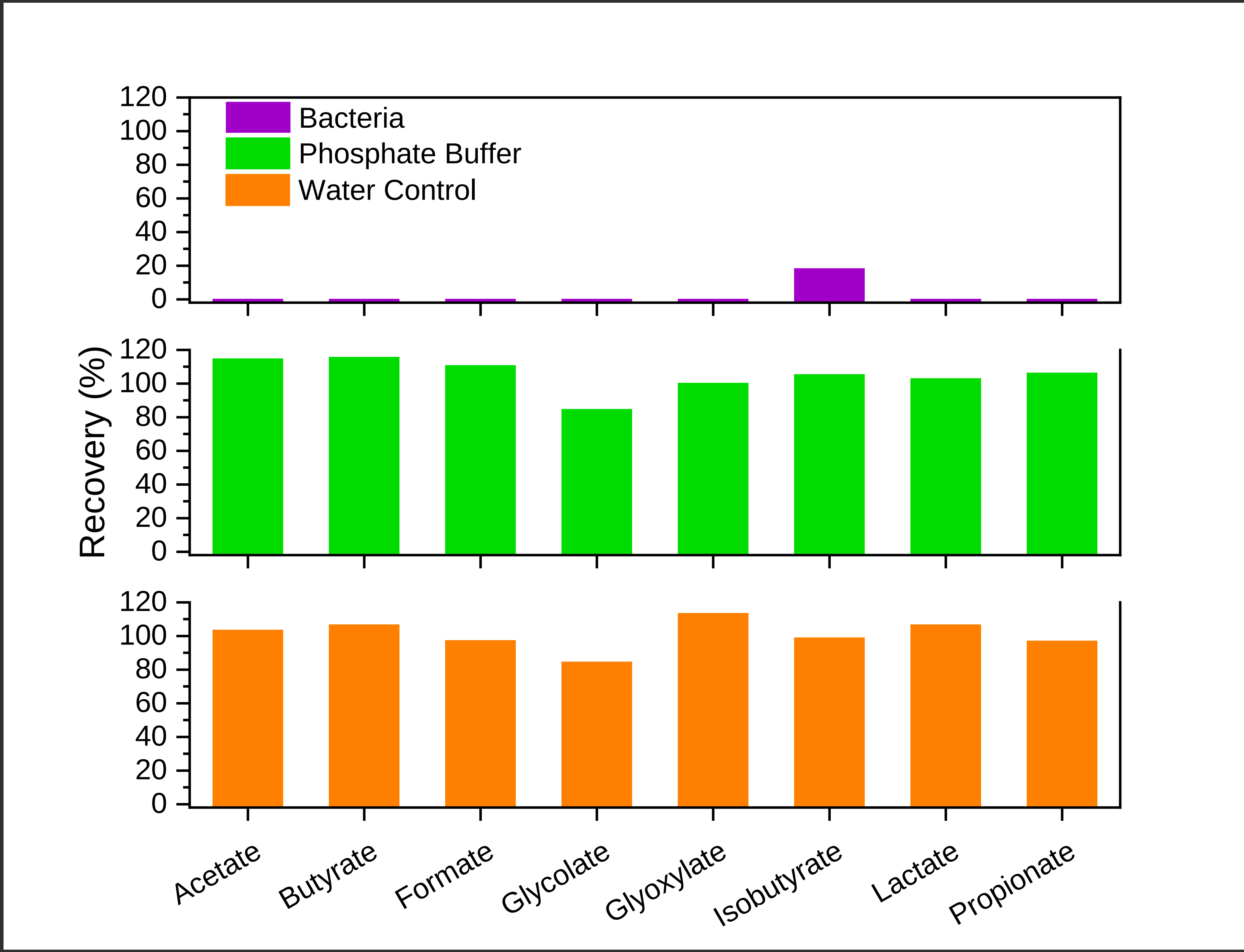
- Microbial analysis of the MF bed 00016 (bed #1) sample collected in the normal Teflon bag showed the presence of *Burkholderia* species and *Burkholderia kururiensis* at a total count of 4.1 x 10^6 CFU/mL
- Can we confirm that these bacteria were responsible for the losses?

Methods

- Isolation
- Bacteria from archive water samples cultured on Reasoner's 2A (R2A) media for 48 hours
- Identified via 16S rDNA sequencing (ABI 3500 Genetic Analyzer)
- Individual isolates frozen at $^{-}80$ ^{o}C for future use
- Current Testing
- 10 µL loop of each isolate obtained from frozen stock, inoculated in R2A broth, and grown at 35 ^{o}C overnight
- Concentrations determined using serial dilution and plating methods followed by overnight culture at 35 ^{o}C
- Individual isolates centrifuged, R2A removed, and re-suspended in phosphate buffer for testing
- Chemical
- Carboxylate analysis performed using ion chromatography (Dionex ICS-5000+)

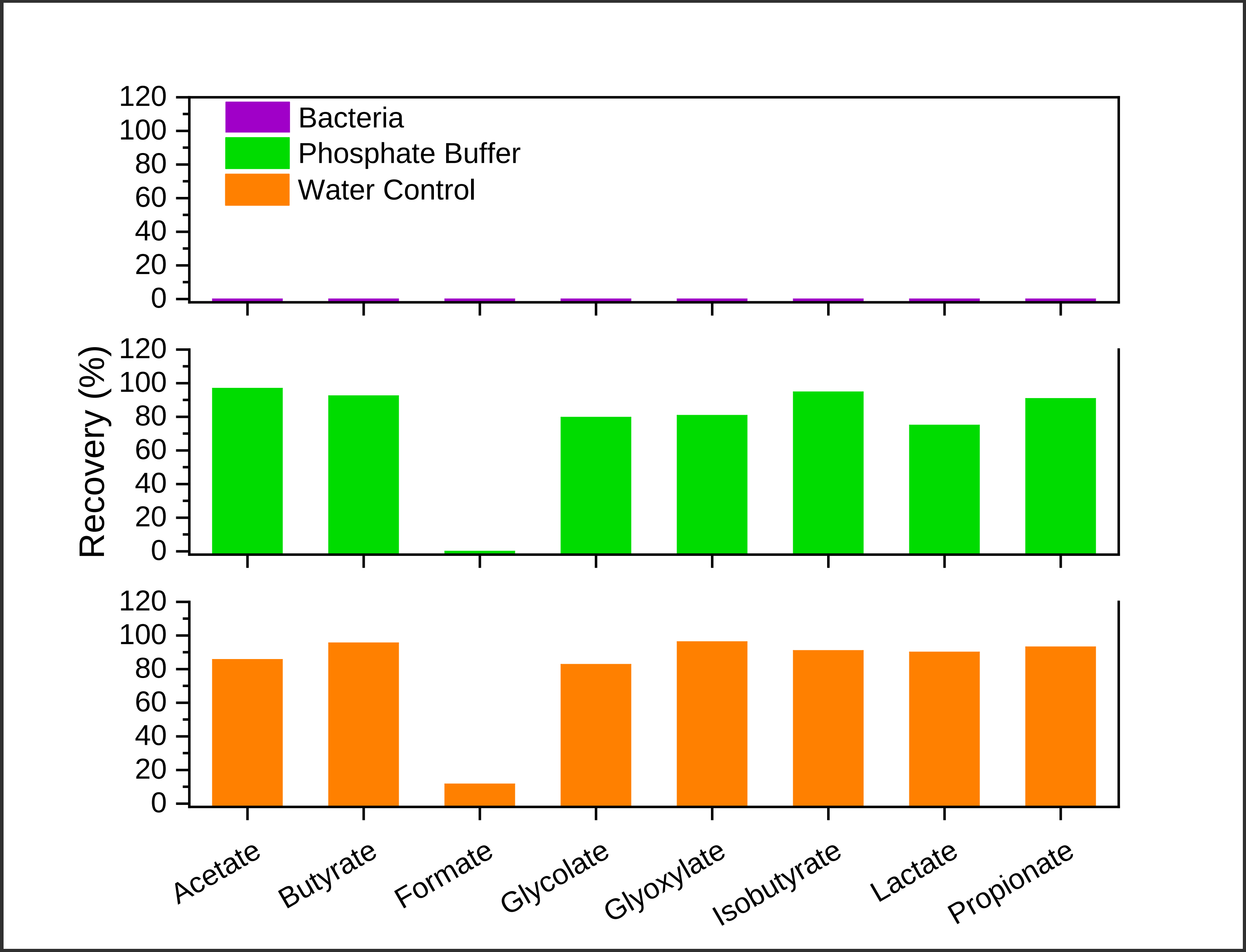
Results of 24-hour Exposure

- 2500 µg/L carboxylate standard spiked with *B.* sp. and *B. kururiensis* at a total concentration of 2.44×10^7 CFU/mL and analyzed after 24 hours



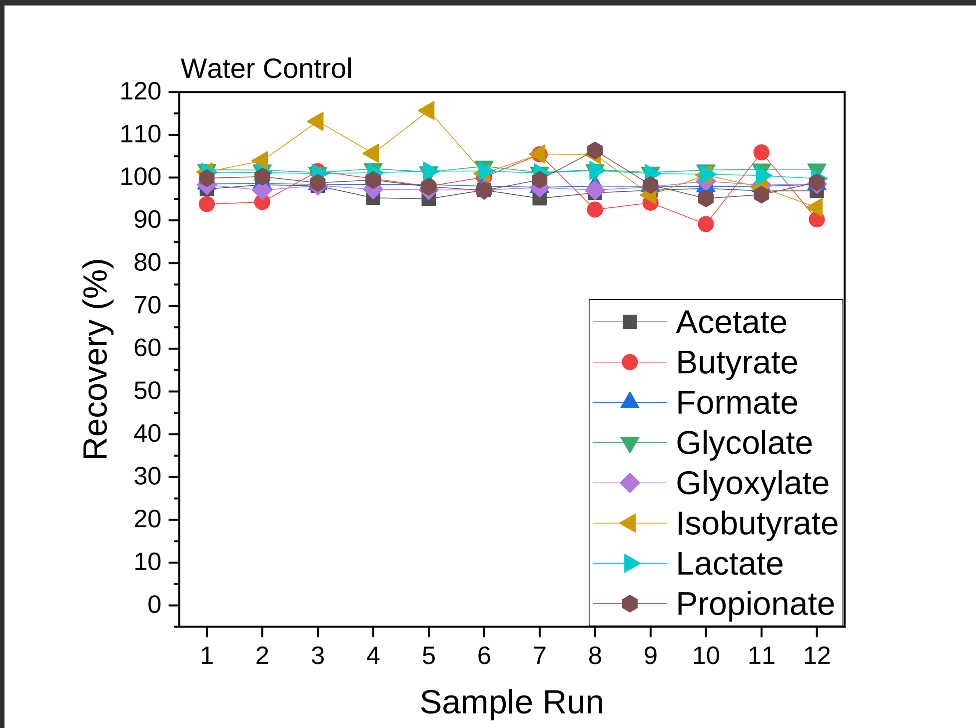
Results of 8-day Exposure

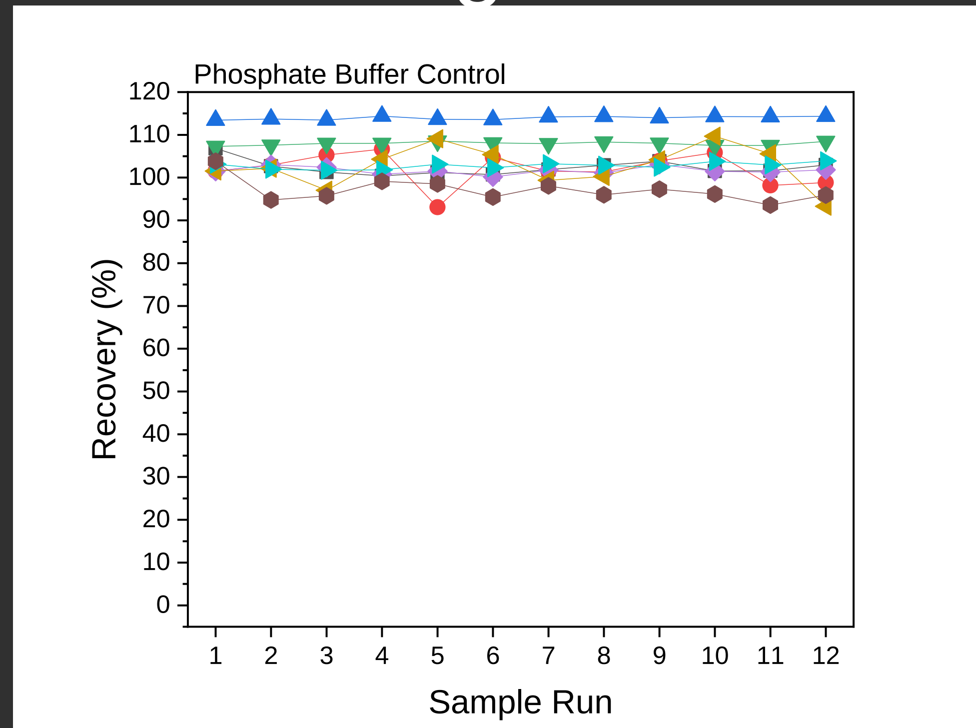
- Remaining aliquot from 24-hour test spiked with carboxylate standard to final concentration of 2500 µg/L and allowed to sit at room temperature for 8 days.

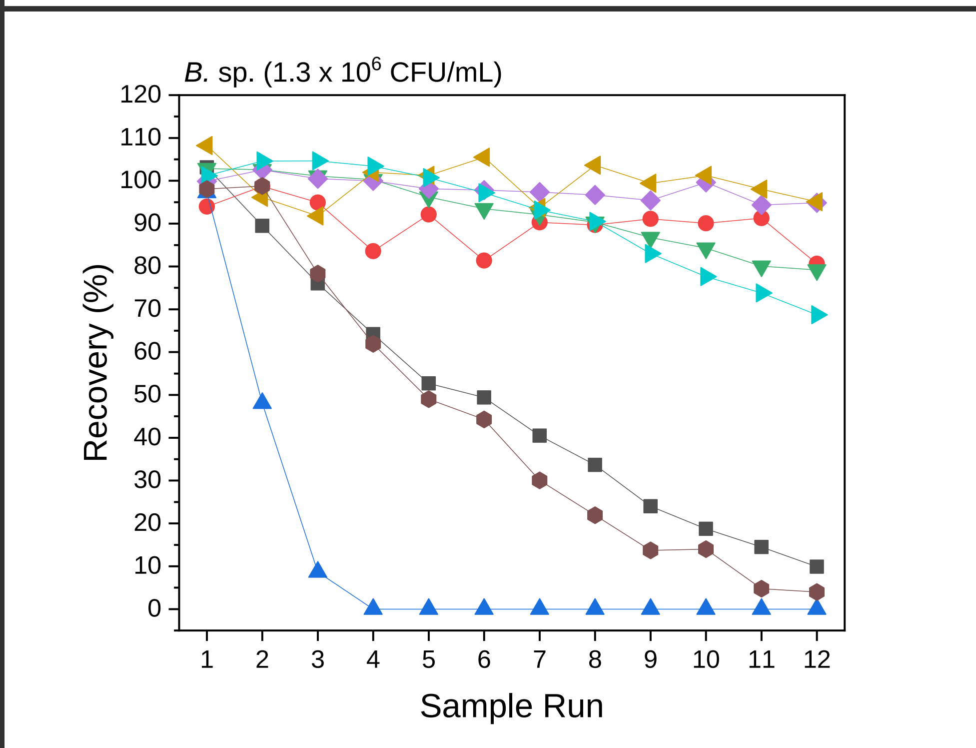


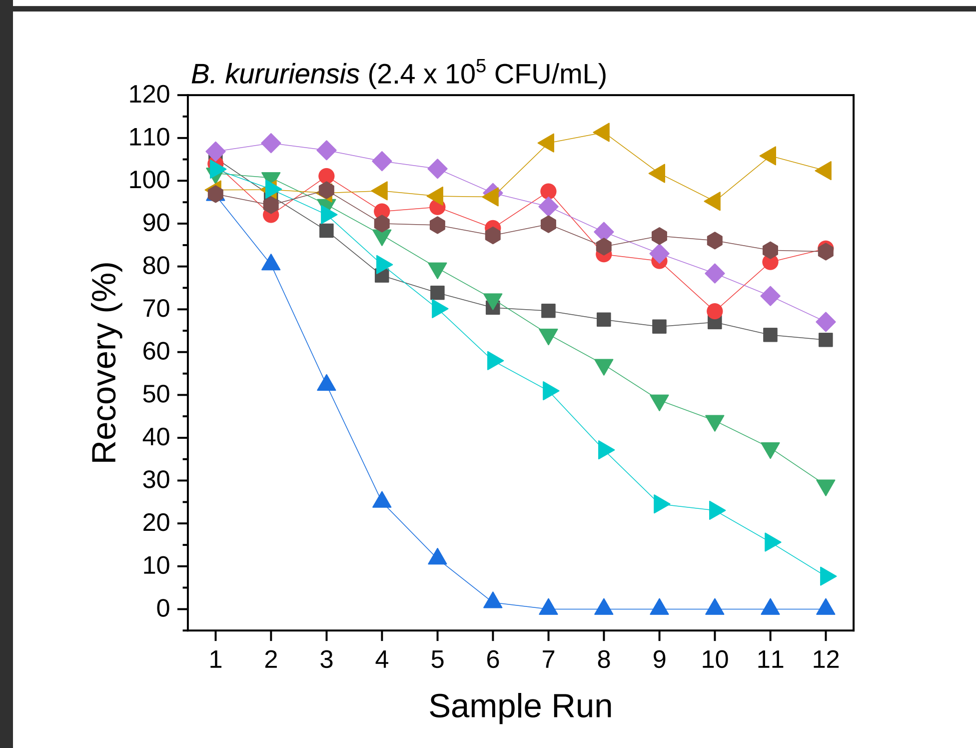
Can We Tell *Exactly* Which Bacterium Is Responsible?

Individual Isolate Testing

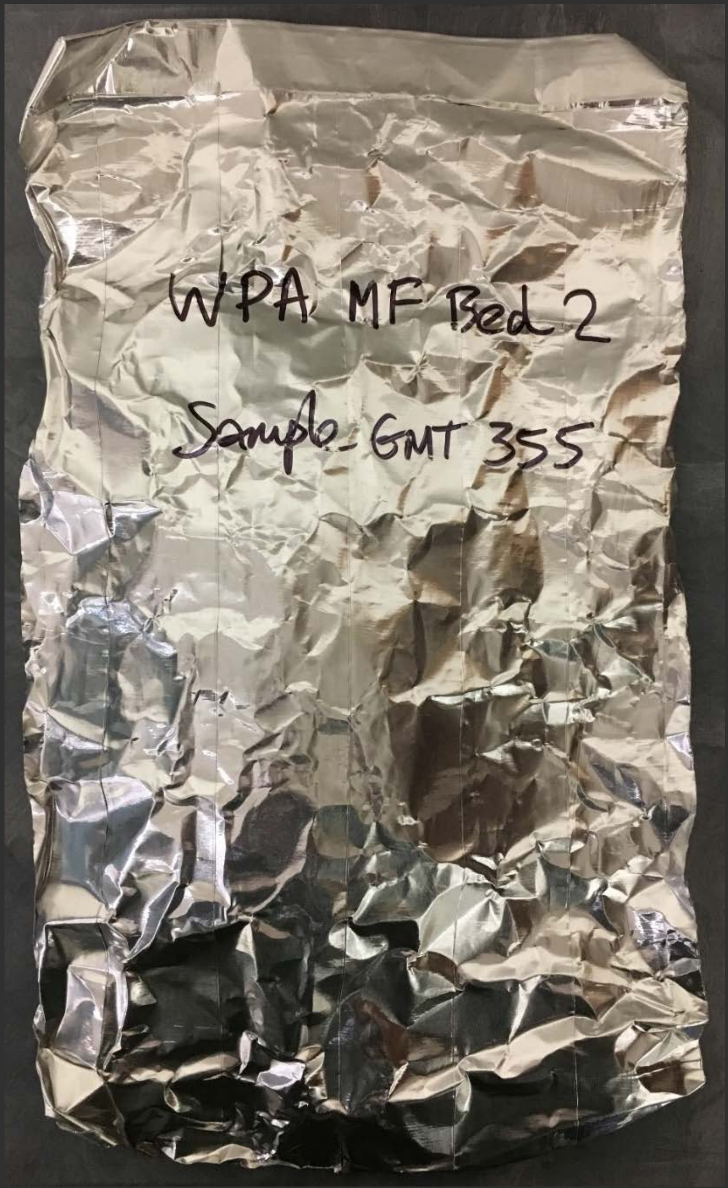








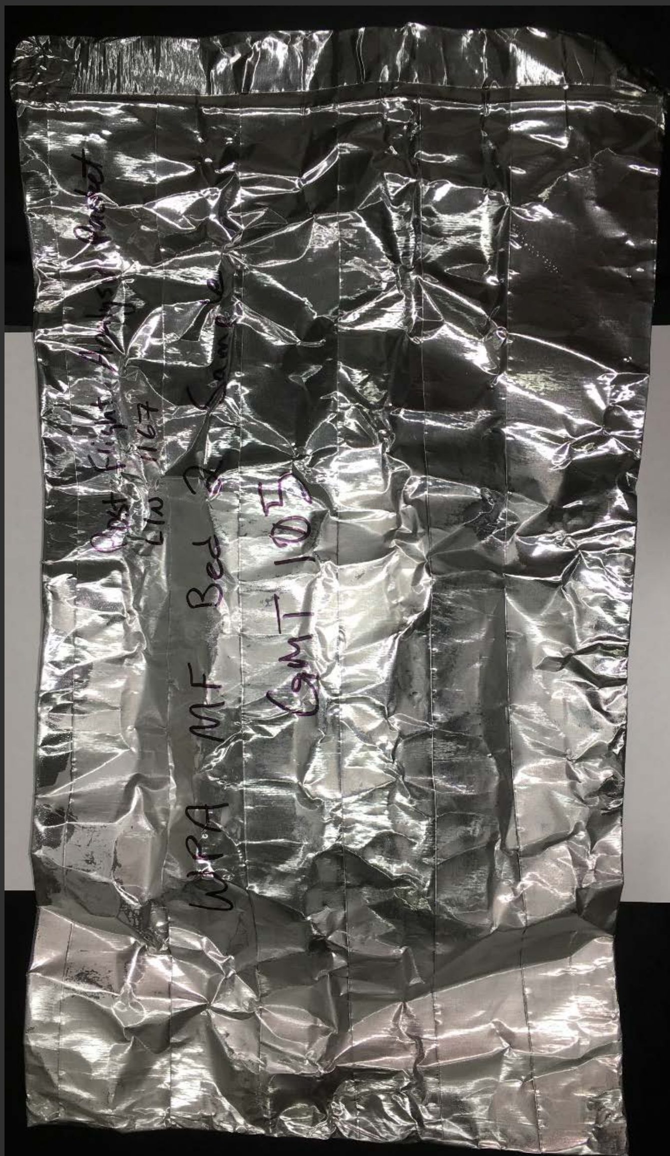
SpaceX-16 Return



Mission		SpX-16	
Sample Location		WPA MF Bed ORU S/N 00016	WPA MF Bed ORU S/N 00017
Sample Description		WPA MF Bed Effluent, Aluminum Tape-sealed Teflon Bag	WPA MF Bed Effluent, Aluminum Tape-sealed Teflon Bag
Sample Date		12/21/2018	12/21/2018
	Units		
Cations			
Ammonium	mg/L	11.1	<0.25
Total Organic Carbon			
Inorganic Carbon	mg/L	6.00	0.60
Organic Carbon	mg/L	44.2	28.9
Volatile Organics			
Acetone	µg/L	5,560	4,060
2-Butanone	µg/L	438	400
Trimethylsilanol	µg/L	330	not found
Semi-volatile Organics			
Methyl sulfone	µg/L	103	113
1-Methyl-2-pyrrolidinone	µg/L	420	not found
N,N-Dimethyl acetamide	µg/L	310	310
N,N-Dimethylformamide	µg/L	not found	200
Alcohols			
Ethanol	µg/L	36,900	44,700
Methanol	µg/L	3,970	5,210
1-Propanol	µg/L	583	402
1-Butanol	µg/L	<400	544
2-Butanol	µg/L	407	<400
2-Propanol (Isopropanol)	µg/L	3,480	4,280
Glycols			
Propylene glycol	µg/L	1,630	1,120
Silanols			
Dimethylsilanediol (DMSD)	µg/L	20,000	21,000
Carboxylates			
Acetate	µg/L	19,000	1,360
Butyrate	µg/L	1,250	<500
Propionate	µg/L	2,180	<500
Non-volatiles			
Urea	µg/L	<800	1,360

Bacterial Results	
WPA MF Bed ORU S/N 00016	WPA MF Bed ORU S/N 00017
5.2×10^5 CFU/mL	8.4×10^4 CFU/mL
Burkholderia sp.	*Burkholderia sp.*
Curvibacter lanceolatus	*Ralstonia insidiosa*
Unidentified Gram-negative rod	

SpaceX-17 Return



Mission		SpX-17
Sample Location		WPA MF Bed ORU S/N 00017
Sample Description		WPA MF Bed Effluent, Aluminum Tape-sealed Teflon Bag
Sample Date		04/15/2019
	Units	
Cations		
Ammonium	mg/L	<0.25
Total Organic Carbon		
Inorganic Carbon	mg/L	1.20
Organic Carbon	mg/L	38.2
Volatile Organics		
Acetone	µg/L	3,250
Alcohols		
Ethanol	µg/L	12,300
Methanol	µg/L	2,880
1-Propanol	µg/L	492
2-Butanol	µg/L	456
2-Propanol (Isopropanol)	µg/L	2,870
Silanols		
Dimethylsilanediol (DMSD)	µg/L	15,400
Carboxylates		
Acetate	µg/L	38,200
Propionate	µg/L	8,450

Bacterial Results
WPA MF Bed ORU S/N 00017
5.5×10^4 CFU/mL
Burkholderia sp.
B. kururiensis

Other Questions

- How might this affect some other non-potable samples?
  - Condensate
  - Wastewater
- Is this behavior specific to *Burkholderia*?
- What is the concentration dependence?

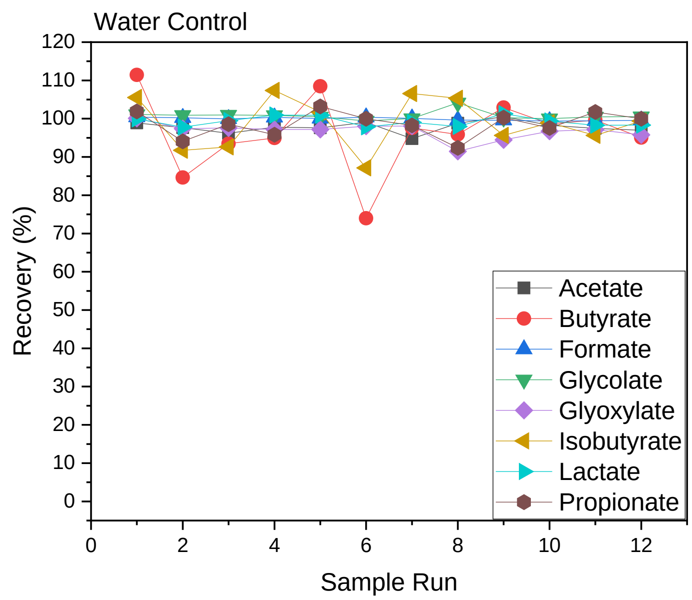
Condensate

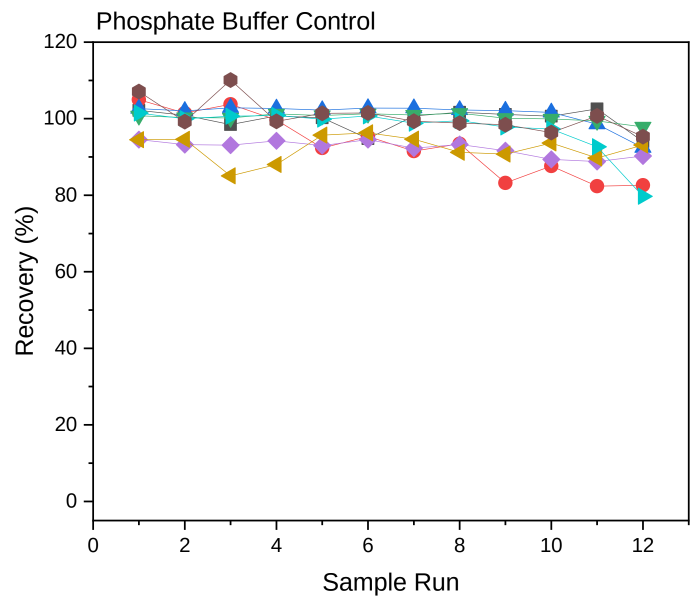
	Increment	43	45	46	47			48	50		51	52	54	54	55	58
	Return Flight	SpX-6	Soyuz 43	Soyuz 44	SpX-8			SpX-9	SpX-10		SpX-11	SpX-12	SpX-13	SpX-14	SpX-14	SpX-16
Compound																
Acetate		634	13500	42900	64300	54100	46300	60400	<500	31600	<500	9170	<500	2670	41200	39100
Butyrate		NA	<500	<500	<500	593	565	<500	<500	<500	<500	<500	<500	<500	<500	<500
Formate		<625	547	<500	2860	11400	9730	6650	<500	<500	<500	<500	<500	<500	<500	<500
Glycolate		<625	<500	<500	<5000	<5000	<5000	<1000	<1000	<1000	<1000	<5000	4840	6400	<1000	<1000
Glyoxylate		<625	<500	<500	<500	<500	<500	<500	<500	<500	<500	729	813	<500	<500	<500
Isobutyrate		NA	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	1170
Lactate		<625	<500	<500	44300	2920	2130	<500	<500	<500	<500	<500	<500	<500	23700	<500
Propionate		<625	<500	<500	1400	1730	1200	1220	<500	<500	<500	<500	<500	<500	<500	<500
Bacterial Counts		1.8×10^5	4.6×10^4	2.9×10^5	1.8×10^5			2×10^4	1.5×10^4	4.3×10^4	3.5×10^5	3.6×10^4	1.7×10^5	5.2×10^4	3.9×10^5	1.2×10^6
Bacterial ID		*Ralstonia insidiosa*	*Cupriavidus metallidurans*	*Ralstonia pickettii*	*Ralstonia insidiosa*			*Caulobacter vibrioide*	*Flexibacter* sp.	*Ralstonia insidiosa*	*Ralstonia insidiosa*	*Ralstonia insidiosa*	*Ralstonia insidiosa*	*Ralstonia insidiosa*	*Ralstonia insidiosa*	*Ralstonia insidiosa*
		Cupriavidus metallidurans	*Ralstonia insidiosa*	*Sphingobium xenophagum*	*Cupriavidus basilensis*			*Ralstonia insidiosa*	*Cupriavidus basilensis*	*Flexibacter* sp.	Unidentified Gram-negative rod	Unidentified Gram-negative rod	Unidentified Gram-negative rod	Unidentified Gram-negative rod	Unidentified Gram-negative rod	Unidentified Gram-negative rod
				Unidentified Gram-negative rod					*Cupriavidus metallidurans*							

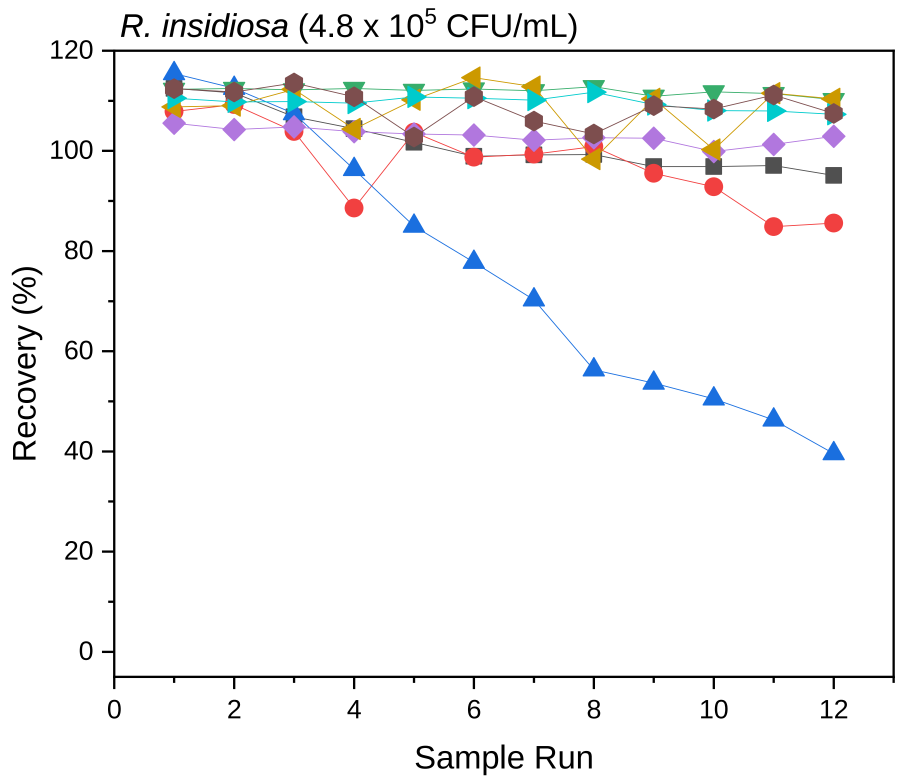
Wastewater

	Increment	43	45	46	48	50		51	52	54	54	55	58
	Return Flight	SpX-6	Soyuz 43	Soyuz 44	SpX-9	SpX-10		SpX-11	SpX-12	SpX-13	SpX-14	SpX-14	SpX-16
Compound													
Acetate		<625	1710	<500	<10000	<1000	MI	530	<500	<500	<500	<500	<500
Butyrate		NA	<500	<500	<10000	<1000	MI	<500	<500	<500	<500	<500	<500
Formate		<625	<500	<500	<10000	<1000	MI	<500	3440	<500	<500	<500	<500
Glycolate		<625	<500	<500	<20000	<2000	MI	<1000	<1000	<1000	<1000	<1000	<1000
Glyoxylate		<625	<500	<500	<10000	<1000	<1000	<500	<500	<500	<500	<500	<500
Isobutyrate		NA	<500	<500	<10000	<1000	<1000	<500	<500	<500	<500	<500	<500
Lactate		<625	<500	<500	<10000	<1000	MI	<500	<500	<500	<500	<500	<500
Propionate		<625	<500	<500	<10000	<1000	<1000	<500	<500	<500	<500	<500	<500
Bacterial Counts		$7.6x10^5$	$7.4x10^4$	$1.2x10^6$	$1.6x10^6$	$1.6x10^5$	$1.1x10^6$	$2.5x10^5$	$1x10^5$	$1.4x10^6$	$5.0x10^6$	$6.7x10^6$	$8.3x10^6$
Bacterial ID		*Cupriavidus basilensis*	*Burkholderia multivorans*	*Sphingobium xenophagum*	*Cupriavidus basilensis*	*Flexibacter sp.*	*Cupriavidus basilensis*	*Ralstonia insidiosa*	*Burkholderia multivorans*	*Ralstonia insidiosa*	Unidentified Gram-negative rod	*Ralstonia insidiosa*	*Ralstonia insidiosa*
		Cupriavidus metallidurans	*Ralstonia insidiosa*	*Sphingobium yanoikuyae*	*Ralstonia pickettii*		*Flexibacter sp.*	Unidentified Gram-negative rod		Unidentified Gram-negative rod			*Burkholderia sp.*
			Curvibacter lanceolatus	*Acidovorax temperans*	*Cupriavidus metallidurans*								Unidentified Gram-negative rod
			Novosphingobium sp.		*Burkholderia multivorans*								

Can We Account for Losses in the Wastewater?







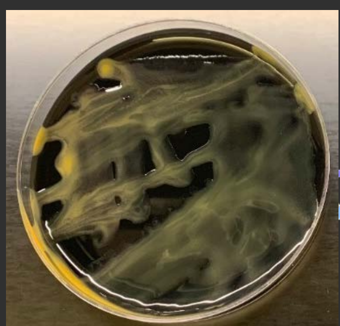
Clearly, *R. insidiosa* isn't responsible for the lack of most carboxylates in the SpaceX-13 wastewater

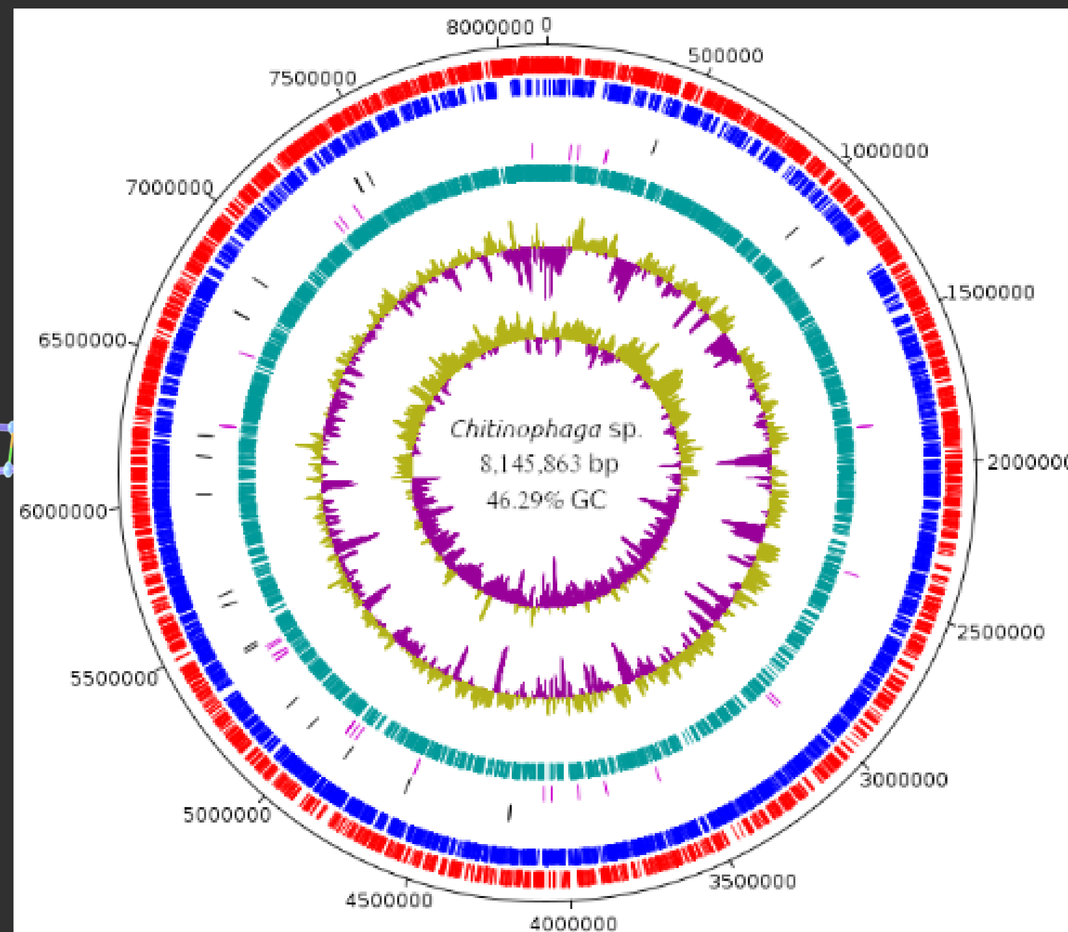
What about the Unidentified Gram-negative Rods?

- 2 morphologies actually present in the SpX-13 sample
- Identification not possible under nominal JSC Microbiology Lab procedures

Whole Genome Sequencing

Full genome sequencing with the MinION





Chitinophaga sp.

Summary

- Microbial growth can affect the chemical results obtained from ISS archival water samples
- Utilization of carbon sources for bacterial growth can be minimized by limiting the oxygen present and/or maintaining the samples at reduced temperature
- On-orbit sample processing (i.e. packaging) is one method to limit the oxygen, but this may not be realistic for all samples
- Need for this on-orbit processing depends on what information is hoped to be gained from archival sample analysis

Acknowledgements

- JSC Microbiology Lab
  - Christian Castro
  - Melanie Smith
  - Sarah Stahl

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  - Patti Cheng
  - Bruce Brown