National Aeronautics and
Space Administration

Mars Campaign Office
Life Support Systems

Spacecraft Water Impurity Monitor, a System for Water Quality Analysis on Exploration Missions Beyond Low Earth Orbit

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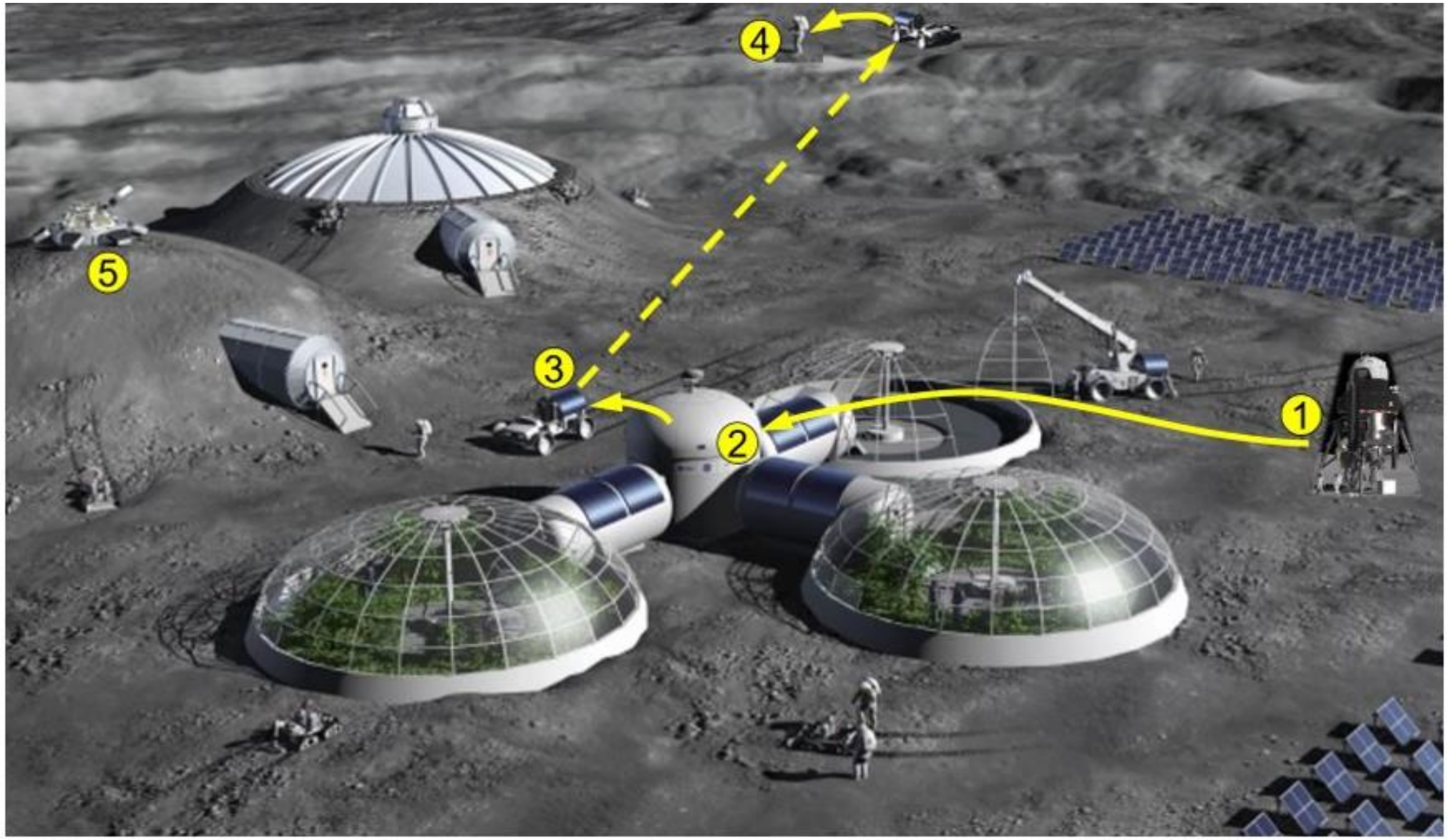
Water Quality Monitoring for Exploration

- **Exploration missions beyond low-earth orbit (LEO) will require water monitoring and will require instrumentation more advanced than a total organic carbon (TOC) analyzer and individual physical properties sensors.**

Potential Sampling Points

1. Landed water
2. Regen ECLSS water in Hab
3. Water in pressurized rover
4. Water in/to suit
5. ISRU water



Need for water quality monitoring and State-of-the-Art (SOA)

- **Ensuring that potable water is safe for crew to drink on ISS is achieved through monitoring of water quality on orbit and analysis of returned samples.**
- **Organic contamination level of potable water is monitored on-orbit on ISS using the Total Organic Carbon Analyzer (TOCA), which provides a sum-total number for organic carbon present in the water.**
- **Typical TOC monitoring cadence is every two weeks, rotating between PWD, xPWD, and WPA.**
- **Inorganic contamination levels are monitored on-orbit on ISS using environmental control and life support system (ECLSS) sensors, such as conductivity sensors.**
- **Potable water and system water is also sent as returned samples to be analyzed at the Environmental Chemistry Laboratory (ECL) at JSC.**
  - The ECL utilizes many different techniques to develop a “total water quality picture” for samples that are measured.
  - Air and water quality reports are published regularly and available publicly: Toxicology Analysis of Spacecraft Air – NASA
  - Historical detailed analysis cadence is approximately quarterly but can be more frequent if anomalies in TOC occur.

Example of water quality results for organics (Increment 71)

Data on this slide from “Toxicological Assessment of ISS Air and Water Quality: March 26, 2024 to September 23, 2024 (Increment 71) Including NG-21 Ingress and Boeing-CFT Ascent,” E.S. Williams, Memo TOX-SW-2025-02. https://www.nasa.gov/wp-content/uploads/2025/12/increment-71-report-including-ng-21-ingress-final.pdf retrieved June, 2026.

A wide variety of organic compounds are present in recovered water on ISS. Verifying water is processed to safe organic levels is the purpose of monitoring.

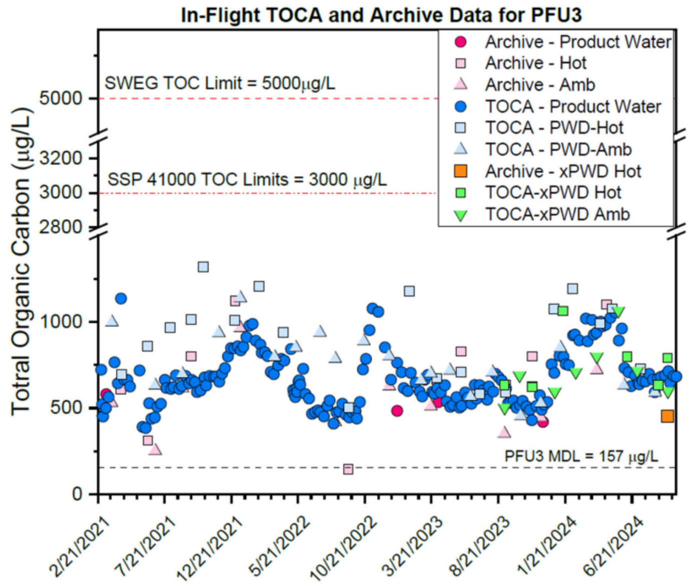
Compound	Condensate (mg/L)		Historical average (mg/L)
	April 18, 2024	July 2, 2024	
Ethanol	40	7.7	49
Acetate	17.6	<1	39.0
Methanol	6.2	3.6	4.9
1,2-propanediol	5.7	1.71	26.4
Dimethylsilanediol	5.2	6.8	33.6
Acetone	5.0	2.7	2.0
1,2-ethanediol	2.6	<1	5.4
Glycolate	1.2	3.8	<RL
2-propanol	1.0	1.8	1.4

Humidity Condensate

WPA

Table 3A. Analytical Summary of ISS Water Analyses for CHeCS Samples (Increment 71)

Return Mission	Sample Location	Sample Date	TOC (mg/L)	DMSD (mg/L)	Methyl Sulfone (mg/L)	Conductivity (µS/cm)	Total Iodine (mg/L)
SpX-30	xPWD Ambient	4/2/2024	0.7	<1	0.1	<1	0.05
SpX-30	PWD Hot	4/24/2024	1.1	<1	0.2	1	<0.05
Crew-8	xPWD Hot	9/10/2024	0.5	<1	0.2	1	<0.05



Potable Water

Example of water quality results for inorganics (Increment 69)

Data on this slide derived from "Toxicological Assessment of ISS Air and Water Quality: March 28, 2023-September 27, 2023 (Increment 69)," E.S. Williams, Memo TOX-SW-2024-02. https://www.nasa.gov/wp-content/uploads/2024/07/increment-69-report-including-ax2-spx28-ng19-ingress-final.pdf retrieved June, 2025.

Compound	microgram/L (average)
aluminum	6
barium	4
boron	20
copper	2
nickel	221
zinc	4800
silver	12
manganese	20
ammonium	10,000

Unprocessed / Recovered Water

WPA

Compound	microgram/L (average)
aluminum	1
barium	<1
boron	1
copper	<1
nickel	5
zinc	1

Compounds found in processed water not listed in potable water were not detected.

Potable Water

<u>Need</u> for water quality monitoring and State-of-the-Art (SOA)

- **Ensuring that potable water is safe for crew to drink is achieved through monitoring of water quality on orbit and analysis of down-mass samples.**
- **Water quality determined from samples collected at various points of the water recovery system informs system health / performance.**
- **EVA suits need clean water because some components are more sensitive than others to contaminants, such as the sublimator.**

Verifying whether water is not toxic for crew to drink, or that it is within specification for processing hardware, can only be done through monitoring activities using instrumentation.

Verifying that water which has been stored for long periods of time is still acceptable would be performed using instrumentation.

Water quality monitoring State-of-the-Art (SOA)

In-Flight

- **Organic monitoring Flight Instrumentation:**
  - Total Organic Carbon Analyzer, TOCA (Crit-1SR, operational for ISS. Onboard monitoring).
  - Miniature Total Organic Carbon Analyzer, MiniTOCA (exploration forward, Crit 3 Tech demo. Features reduced mass, volume, consumables relative to TOCA).
- **Inorganic monitoring flight instrumentation:**
  - pH sensors, conductivity sensors

Ground

- **Ground Analysis Techniques, ECL:**

Table 2. Methods for Water Analysis in TEC Laboratory

	Method	Parameter
inorganic	Potentiometric	pH and conductivity
	Gravimetric	Total Solids
	Nephelometric	Turbidity
	Leuco crystal violet (LCV)	Iodine and iodide
	Inductively coupled plasma/mass spectrometry (ICP/MS)	Metals/Minerals
	Ion chromatography (IC)	Inorganic anions & cations, organic acids and amines
organic	Ultraviolet or heated persulfate oxidation	Total organic carbon (TOC)
	Direct injection gas chromatography/mass spectrometry (GC/MS)	Alcohols and glycols
	GC/MS with a purge and trap concentrator	Volatile organics
	GC/MS after liquid/liquid extraction	Semi-volatile organics
	Liquid chromatography (LC) with UV diode array detector	Urea/Caprolactam
	GC/MS after derivatization and extraction	Formaldehyde
	LC with refractive index detector	Silanols (dimethylsilanediol and monomethylsilanetriol)

Table 2 from Straub, J.E.; *et al* “ISS Potable Water Sampling and Chemical Analysis Results for 2016,” 47th ICES, Charleston, SC

Mismatch: State-of-the-Art vs. Need

- **We already have good capability for on-orbit monitoring of TOC and some physical properties**
- **Do not have ability to determine which organics or inorganics are present and contributing to trends**
- **Detailed determination of water quality composition is currently performed using returned samples (JSC Environmental Chemistry Laboratory).**

<u>however,</u>

- **Down mass (mass of returned samples) for water samples <u>must</u> go to zero!**
  - Not just a KPP "goal," to not have to down mass; will not be able to return samples and run analysis operations on the correct time scale when at Mars or farther.
  - 7-9 months is the fastest transit time of spacecraft from Earth to Mars; that time scale (6-12 months) is too slow to make actionable decisions related to water systems that are in use.
  - *<u>Must have monitoring / analysis capability at your location.</u>*
  - To achieve the required cadence for routine and detailed water analysis, new instrumentation is necessary for exploration.
- **SWIM addresses the need for on-orbit / at location monitoring of impurities in water.**

positive

challenge

SWIM Mission Primary Goal

- **SWIM project completed a system requirements review (SRR) in September 2025 and established a goal and set of objectives for the project.**
- **SWIM Mission Goal:** Demonstrate a viable solution for water quality verification in down-mass-inhibited exploration missions.
- Return mass from a Mars transit vehicle, or Moon Base, or Mars Base, will be limited.

SWIM Mission Objectives

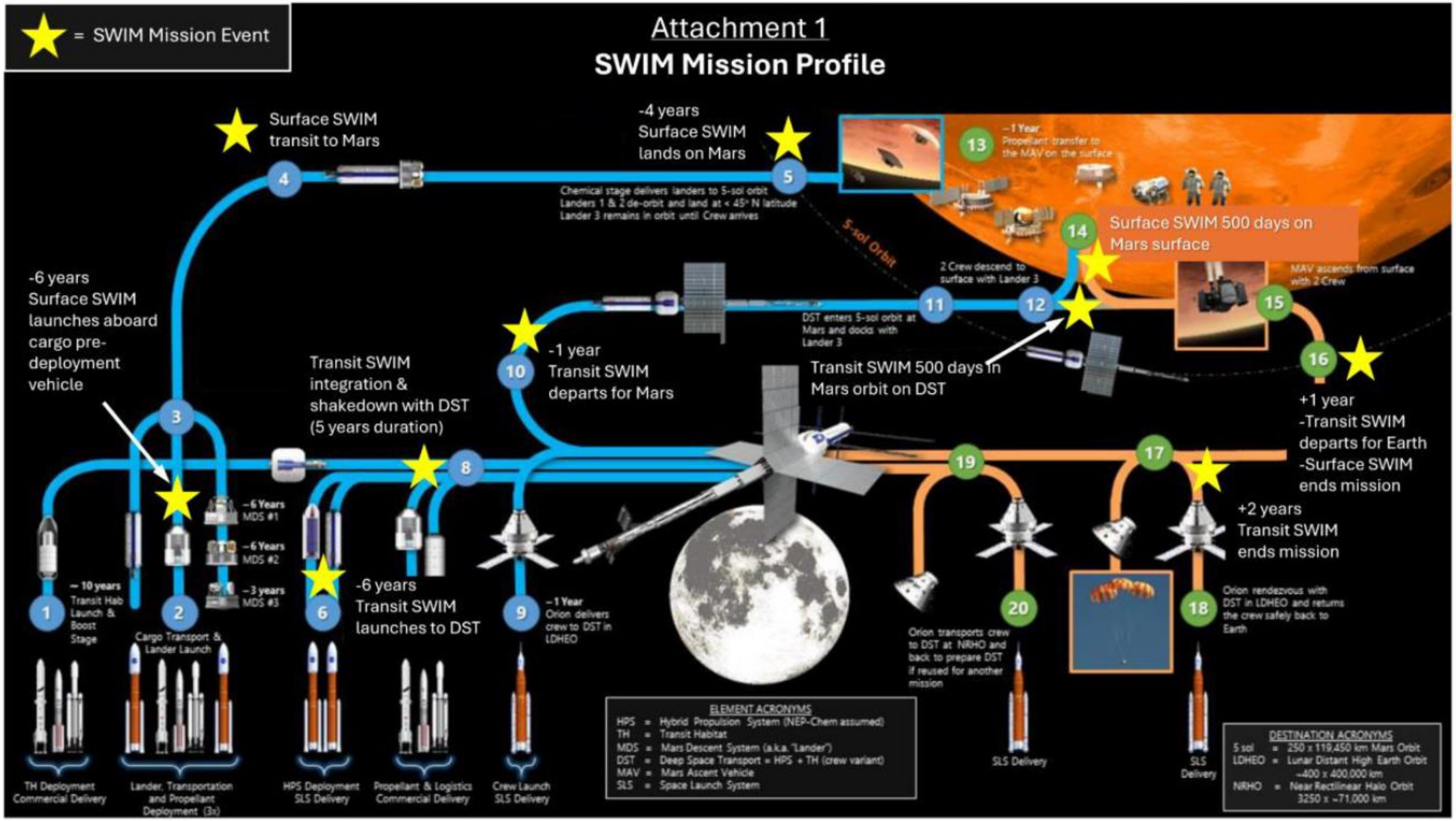
- **Objective 1:** Demonstrate a system that performs in-flight monitoring of spacecraft water. This system will be capable of performing selective identification and quantification of a broad range of organic and inorganic contaminants.
  - Selective identification and quantification means *more than* TOC, *more than* conductivity.

- **Objective 2:** Demonstrate in-flight monitoring of spacecraft water from various sources.
  - Potable water, WPA waste, suit loop, humidity condensate, water in long term storage

- **Objective 3:** Provide detailed, low-latency water quality data to stakeholders, allowing for simulation of the decision environment associated with Earth-independent operations.
  - Obtain data and transfer to ground in a timely fashion.

- **Objective 4:** Produce a flight-proven system that is ready for infusion into Moon and Mars exploration programs.
  - A tech demo would work toward achieving this objective.

Mission Profile



Graphic developed with inputs from "Reference Surface Activities for Crewed Mars Mission Systems and Utilization." Document number HEOMD-415, Version 1, National Aeronautics and Space Administration, 2022.

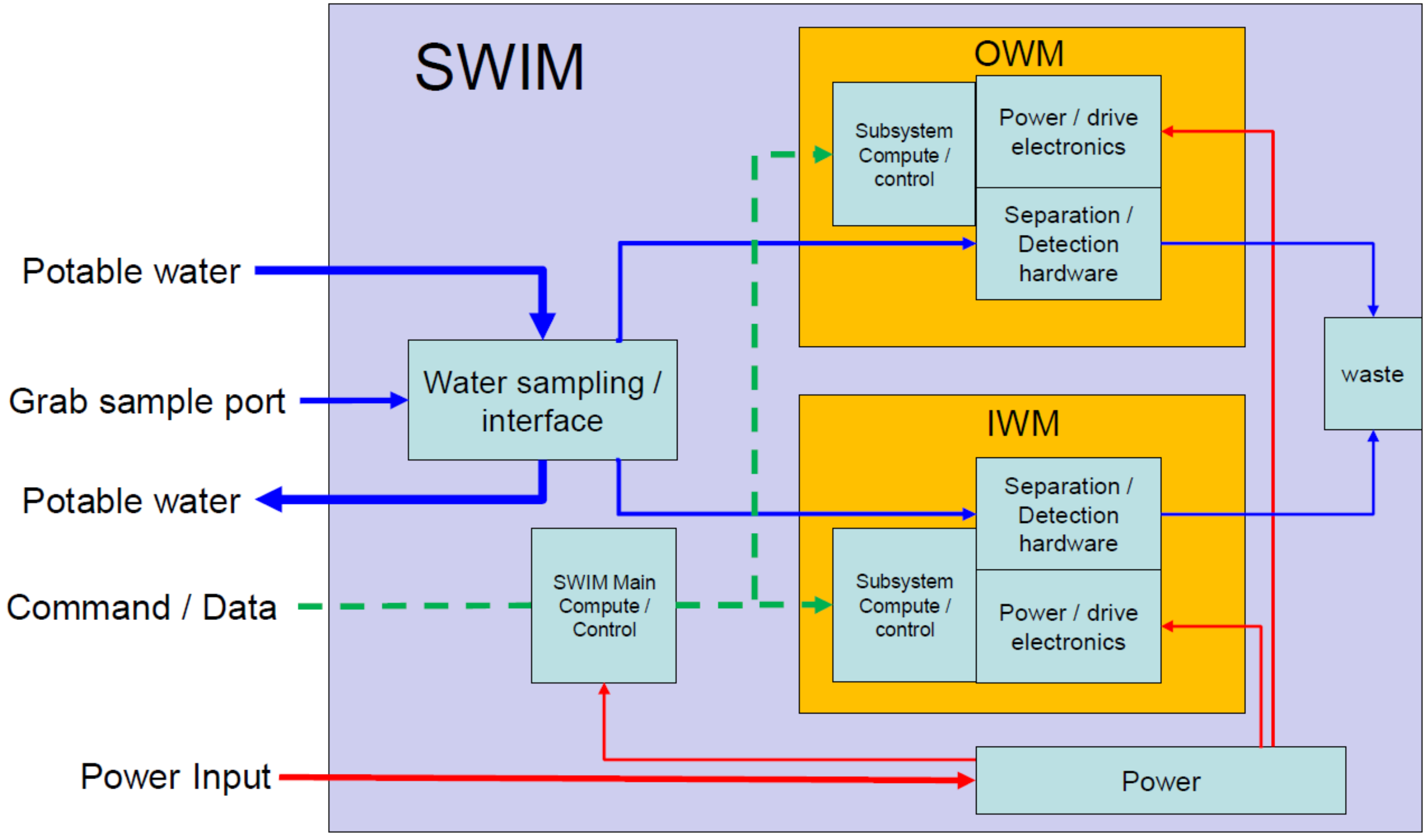
Lifetime Requirements

- **Summary of current lifetime requirements for SWIM**
- **The Mars mission profile sets the longest lifetime requirements (driving requirement)**
- **Lifetimes stated below for Mars missions are expected to be adequate for any Moon Base build as well, or lifetimes could be tailored for Moon Base mission profiles.**

	Requirement	**Notes**
Storage Life	Store for 730 days.	Maintenance permitted at 6-month or longer intervals. Maintenance includes power-on, perform built-in-test (BIT), and replacement of ORUs.
Dormant Life	1760 days after start of mission, with keep-alive power.	
Operational Life	Operate for 1600 days.	Includes 1420 days of mission ops plus 180 days of integration & test.
Cycle Life	300 analyses over operational lifetime.	Supports mission duration.

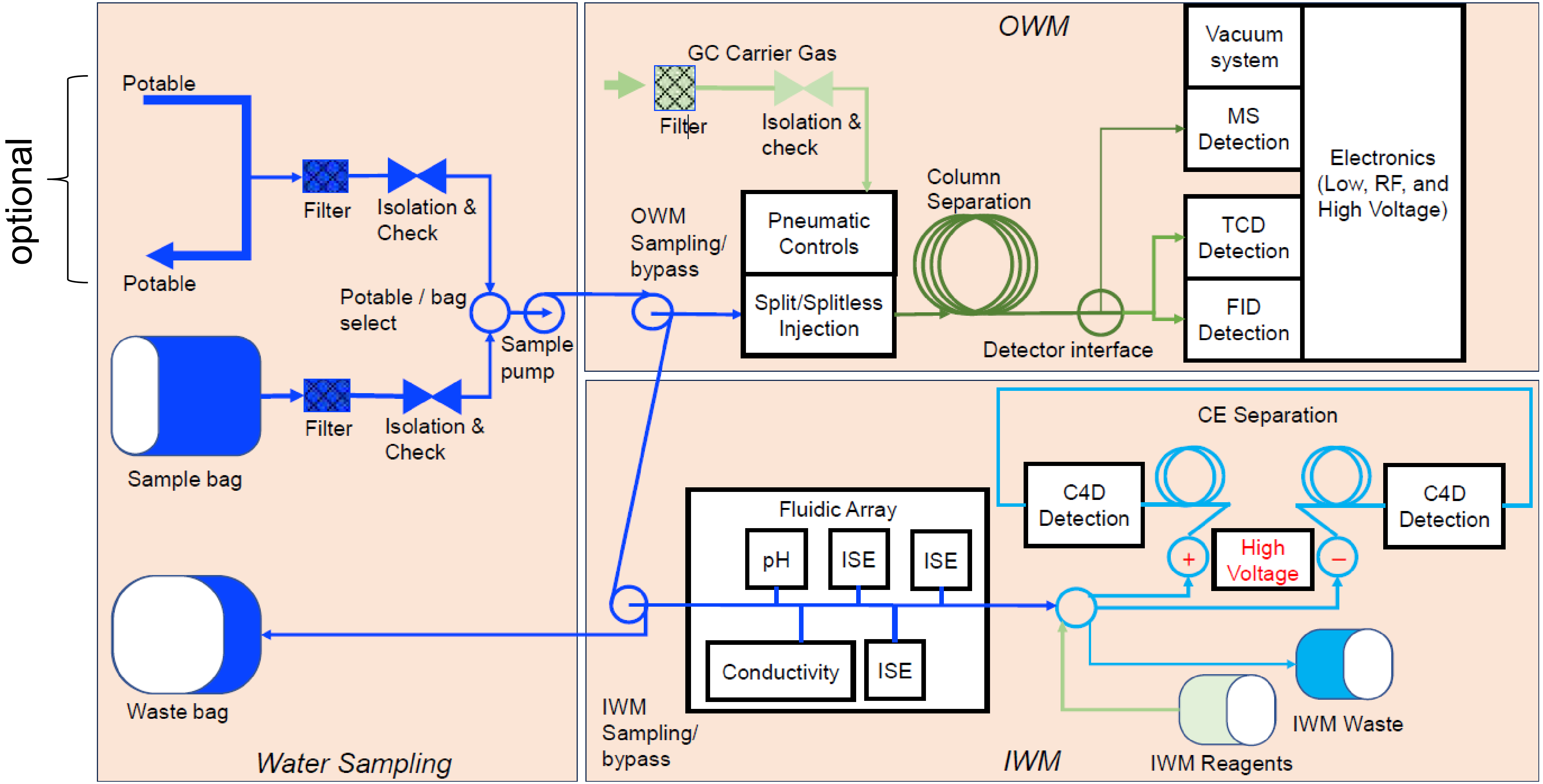
SWIM Hardware Architecture

- **SWIM is an instrument suite which can perform detailed water analysis for organic and inorganic chemicals, identifying the chemicals present and their concentrations.**



- **Organic Water Module (OWM) is a gas chromatograph mass spectrometer (GCMS).**
- **Inorganic Water Module (IWM) is a capillary electrophoresis (CE) system with capacitively coupled contactless conductivity detection (C4D) and ion-selective electrodes (ISE)**

SWIM System Generalized Schematic



- **SWIM system concept schematic showing water sampling, OWM, and IWM sections of the system.**

Chemical Target Lists

- **List of chemicals, ions, and properties required to be detected by SWIM (SRR Baseline).**

Organics	CAS Registry
Acetone	67-64-1
methyl ethyl ketone	78-93-3
methanol	67-56-1
isopropyl alcohol	67-63-0
ethanol	64-17-5
dichloromethane	75-09-2
trimethylsilanol	1066-40-6
benzene	71-43-2
chloroform	67-66-3
propylene glycol	57-55-6
ethylene glycol	107-21-1
benzyl alcohol	100-51-6
phenol	108-95-2
dimethylsilanediol (DMSD)	1066-42-8
caprolactam	105-60-2
methyl sulfone	67-71-0
o-phthalaldehyde	57-55-7
di-n-butyl-phthalate	107-21-2
2-mercaptobenzathiazole	100-51-7
n-phenyl-beta-naphthylamine	108-95-3
di(2-ethylhexyl) phthalate	1066-42-9
formaldehyde*	50-00-0

Inorganics	Detected as
potassium	K^{+}
calcium	Ca^{2+}
magnesium	Mg^{2+}
chloride	Cl^{-}
nitrate	NO_3^{-}
sulfate	SO_3^{2-}
ammonium	NH_4^{+}
barium	Ba^{2+}
manganese	Mn^{2+}
nickel	Ni^{2+}
silver	Ag^{+}
zinc	Zn^{2+}
chromium	Cr^{3+}
cadmium	Cd^{2+}
lead	Pb^{2+}
iron	Fe^{3+}
copper	Cu^{2+}
formate	HCO_2^{-}
iodide	I^{-}
carbonate*	CO_3^{2-}
bicarbonate*	HCO_3^{-}

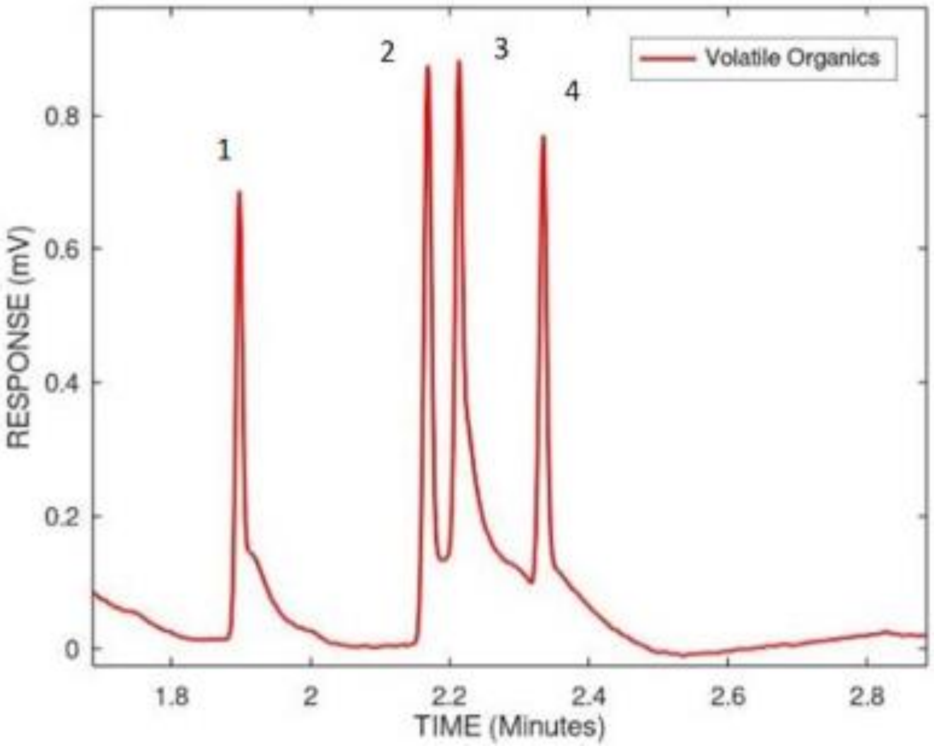
Physical properties
pH
Conductivity

***Goal: detect if possible but does not drive design**

Separation Science Enabling Detection of Unknowns

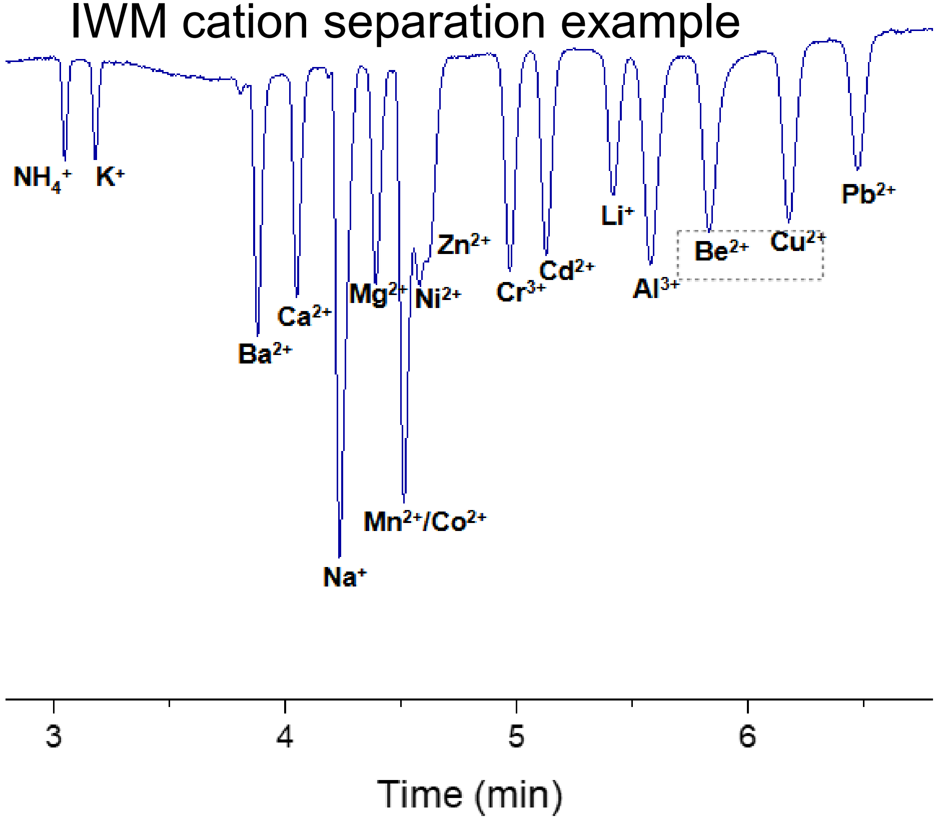
- **OWM and IWM chemical lists encompass a very large range of chemical functionalities – polarity, boiling point, ionic strength, solubility, etc.**
- **Given the wide range of the target lists, it is expected SWIM will be capable of detecting chemicals not on the list, if they occur.**
- **OWM and IWM use separation science methodologies (GC and CE) to perform mixture analysis.**

OWM volatile organic example



1: acetone
2: methanol
3: butan-2-one
4: ethanol

IWM cation separation example

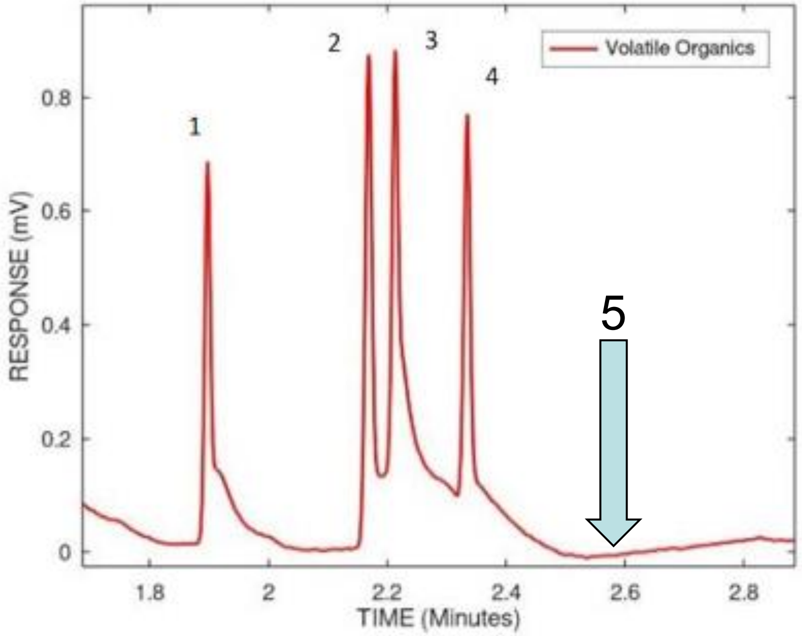


Separation Science Enabling Detection of Unknowns

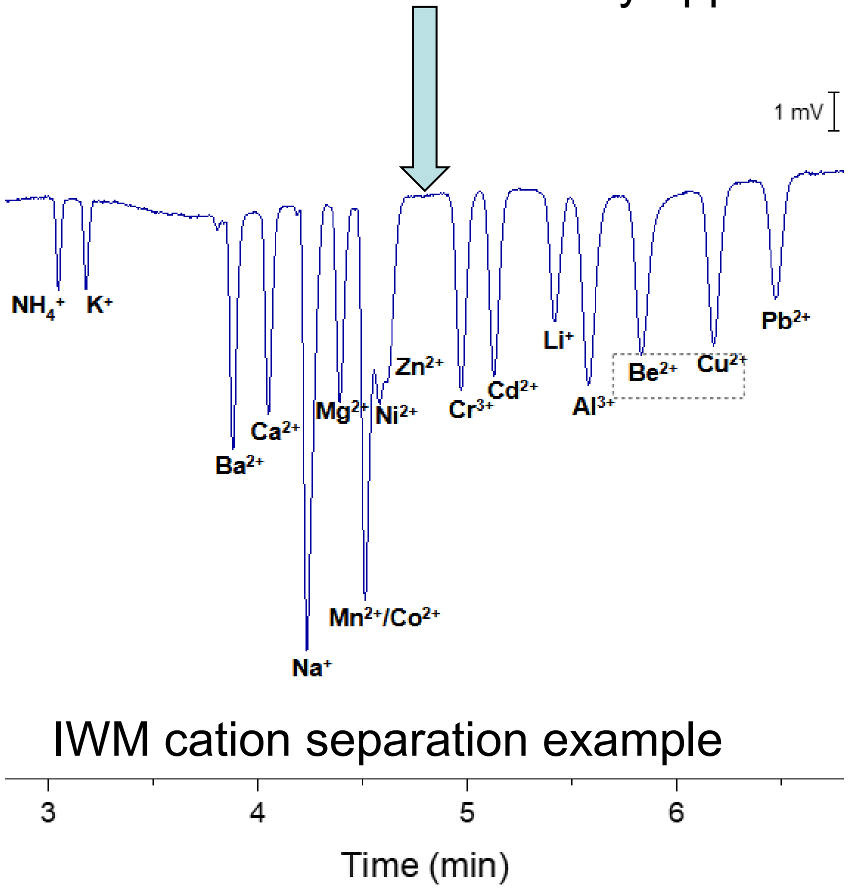
- **If a peak were to appear at the marked locations on OWM or IWM, it is a new one not on the list but due to the use of separation science techniques, SWIM can detect it.**

new cation may appear here

OWM volatile organic example



1: acetone
2: methanol
3: butan-2-one
4: ethanol
5: “new alcohol” e.g. n-propanol



SWIM Forward Work and Project Plans

- **Study radiation-tolerant electronics architectures for SWIM command and data handling (C&DH) computer**
  - Leverage work already completed at JPL for mass spectrometer controller and detector preamplifier
- **Continue subsystems maturation:**
  - OWM GC column module
  - IWM ISE stability studies
- **Continue chemical detection feasibility studies, limit-of-detection studies**
- **Conduct initial design concept studies for a packaged SWIM**

SWIM:

- **Addresses the technology gap in water monitoring that exists when returned water samples are no longer possible. TOC and conductivity, technology we have, does not provide the detailed analysis possible by a dedicated instrument or returned samples. SWIM is a new system being developed to address the need for detailed analysis.**

- **The SWIM is a system for detailed analysis of spacecraft water, providing identification and quantification of organic and inorganic impurities.**

- **The system is being designed to meet Moon Base, Mars Base, or Mars Transit mission lifetimes and environmental requirements.**

- **The list of chemicals and ions to detect results in a highly capable instrument suite. Chromatographic separation of complex mixtures (gas chromatography or capillary electrophoresis) enables detection of new unknown compounds if they appear.**

Acknowledgments

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