Electrochemical Life Detection Methods for Ocean World Exploration

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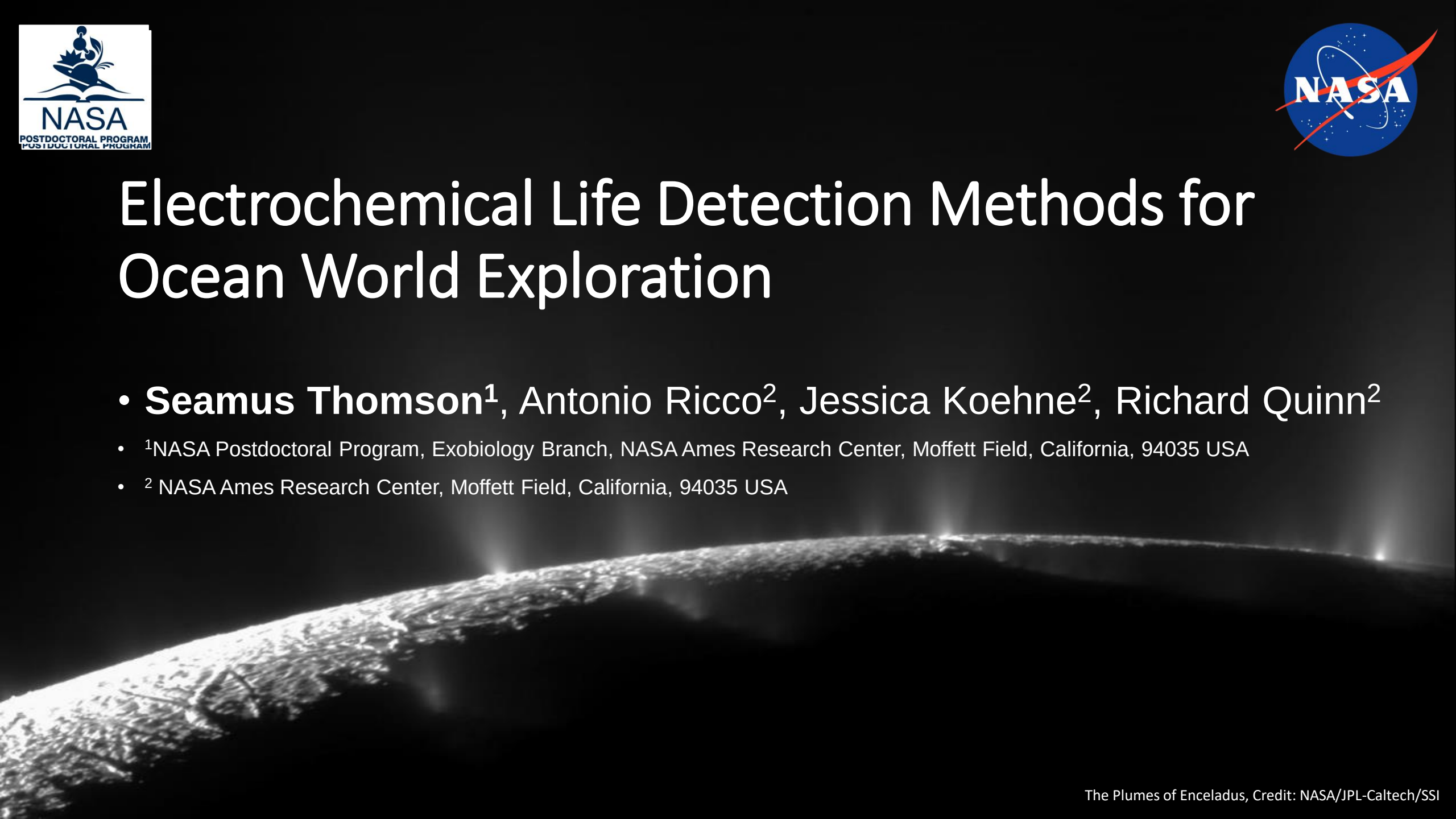


The Plumes of Enceladus, Credit: NASA/JPL-Caltech/SSI

Ocean Worlds and Future Proposed Missions

Enceladus: Cassini Image Sequence

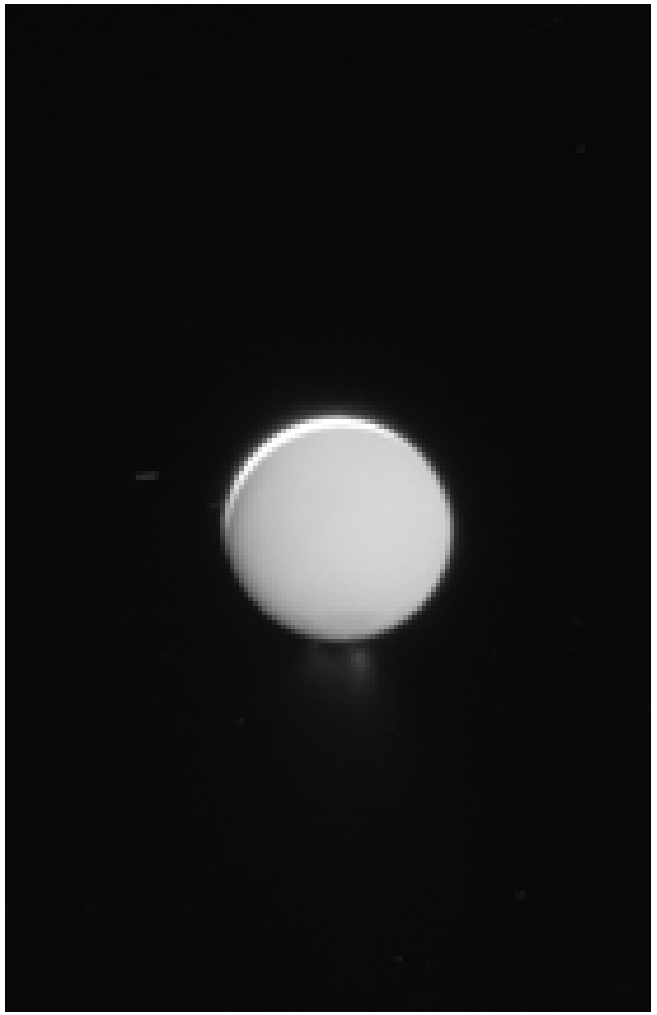


Image Credit: NASA/JPL-Caltech/Space Science Institute

Europa Lander Mission Concept

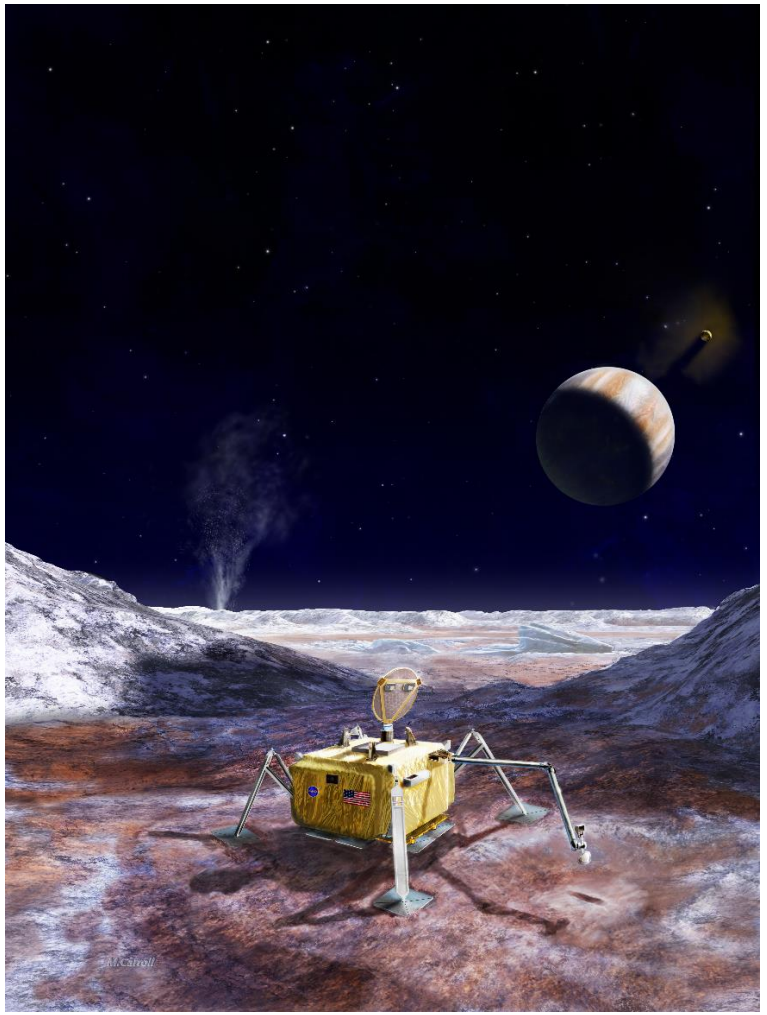
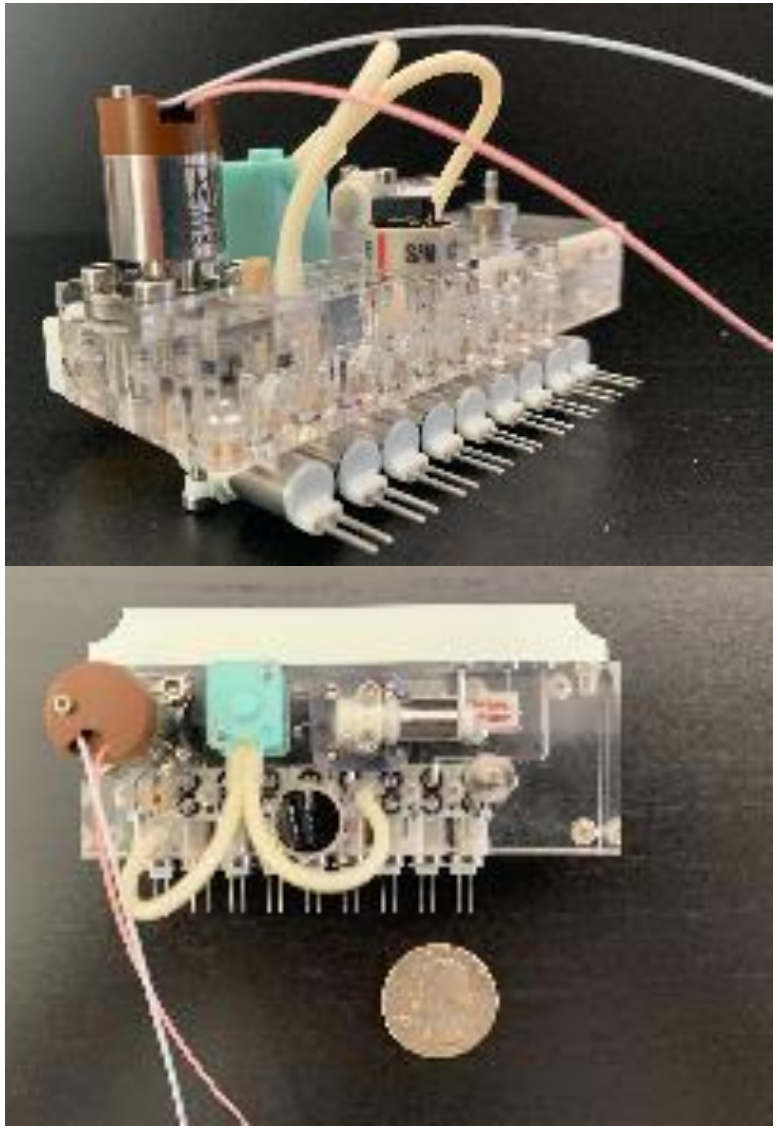


Image Credit: NASA/JPL-Caltech

Electrochemical Sensors in Planetary Exploration Applications



Microfluidic Icy-World Chemistry Analyzer (MICA)

Principal Investigator: Antonio Ricco[1]

Team: Samuel P. Kounaves[2], Aaron C. Noell[3], Richard C. Quinn[1], Jed D. Harrison[4], Michael H. Hecht[5], Jessica E. Koehne[1], Peter A. Willis[3], Kris Zacny[6], and the ARC BioMicroFluidics Engineering Team[1]

[1]NASA Ames Research Center, [2]Tufts University, [3]NASA Jet Propulsion Laboratory, [4]University of Alberta, [5]Massachusetts Institute of Technology, [6]Honeybee Robotics, Inc.

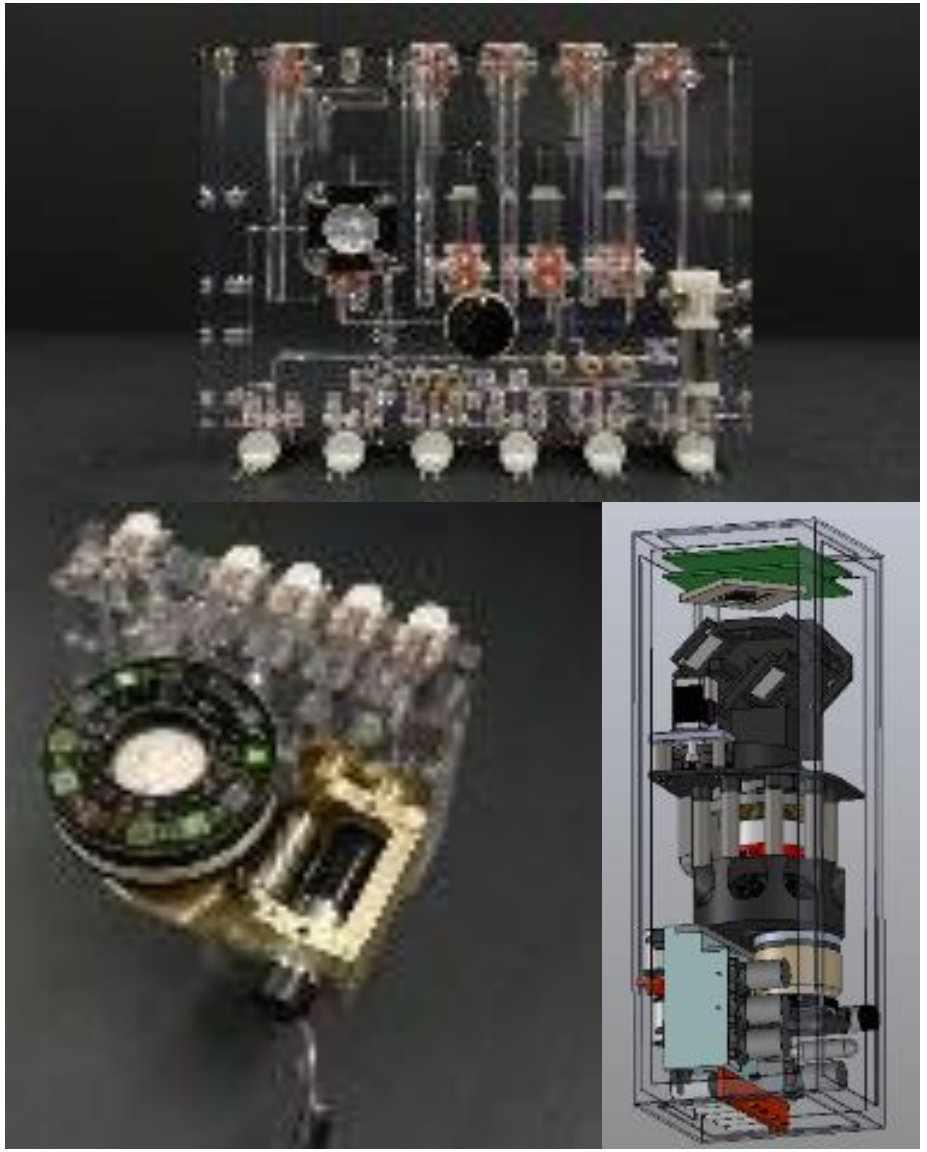
Acknowledgments: NASA Science Mission Directorate, Instrument Concepts for Europa Exploration (ICEE) 2 Program

Electrochemical Sensors in Planetary Exploration Applications

Europa Luminescence Microscope (ELM)

Principal Investigator: Richard Quinn[1]

Team: Antonio Ricco[1], Joshua Forgione[1], Linda Timucin[1], Nathan Bramall[2], Kris Zacny[3], Jay Nadeau[4], Niki Parenteau[1]



[1]NASA Ames Research Center, [2]Leiden Measurement Technology, LLC, [3]Honeybee Robotics, LLC, [4]Portland State University

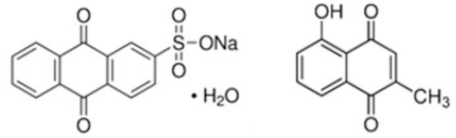
Acknowledgments: NASA Science Mission Directorate, Instrument Concepts for Europa Exploration (ICEE) 2 Program

Biological Redox Molecules

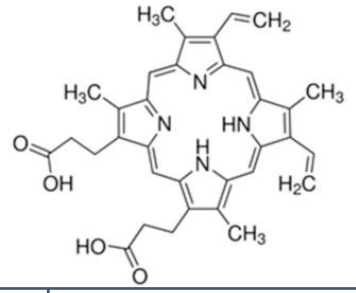
- **Redox molecules mediate the movement of electrons**
- **Four key classes of naturally-occurring redox molecules**

Classes of Energy Transport Molecules

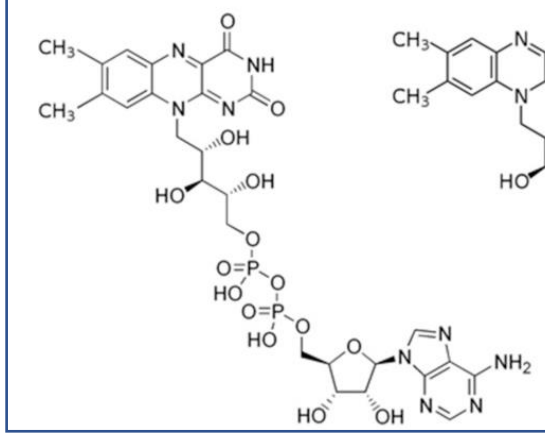
Quinones



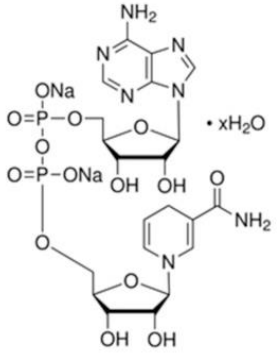
Porphyrins



Flavins

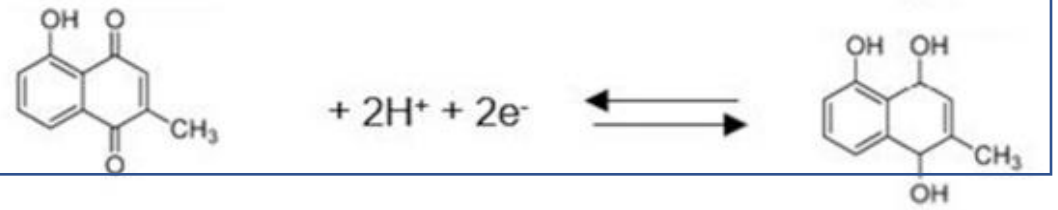


Nicotinamides



Electrochemical Reversibility

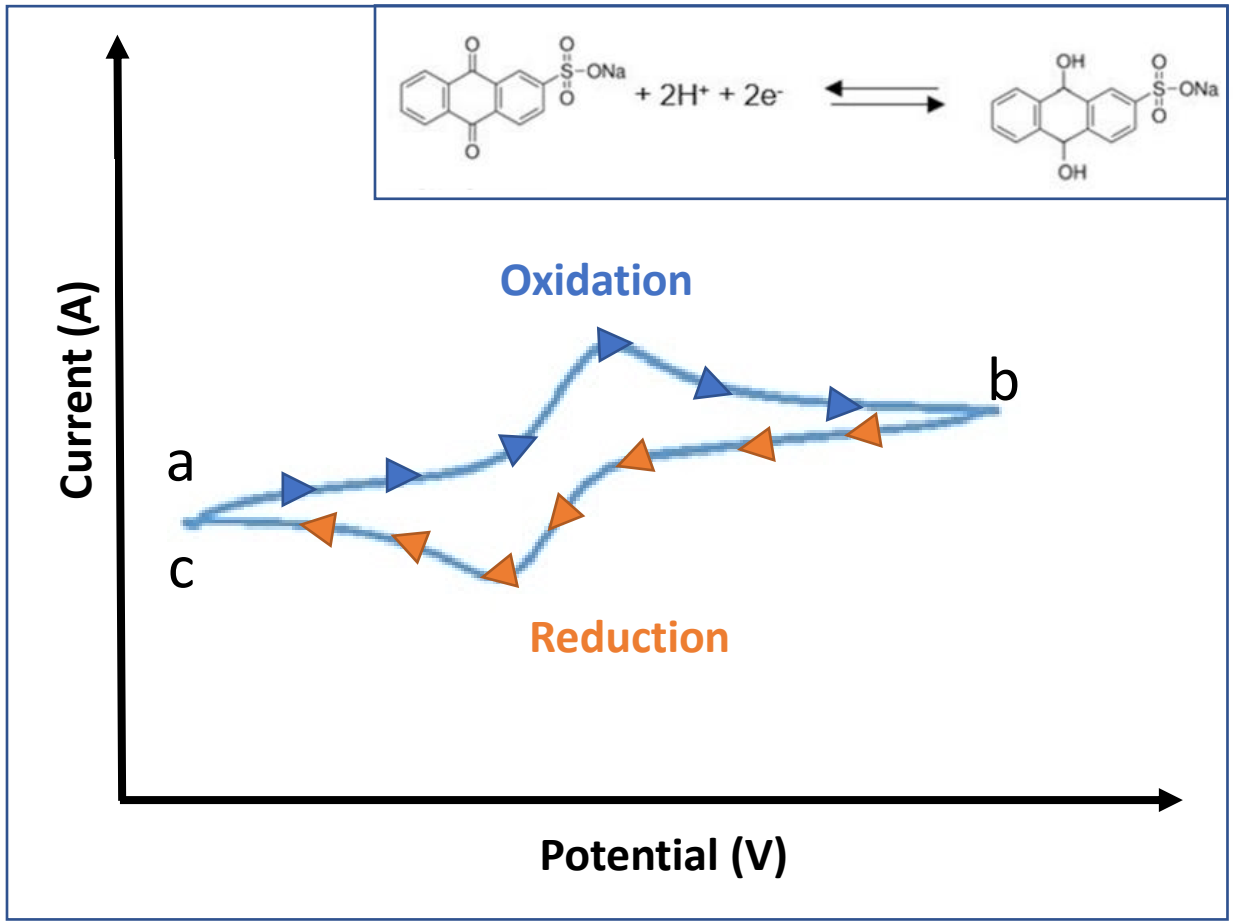
Quinone (Plumbagin)



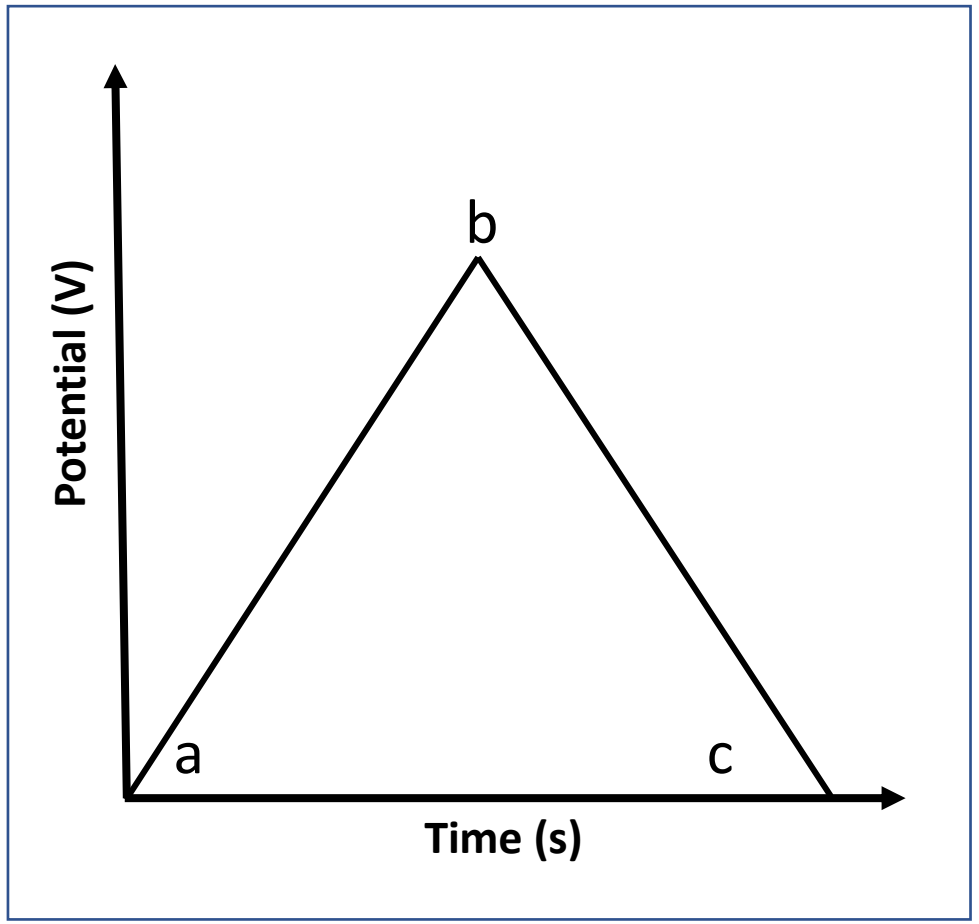
Redox Measurement Approach

- **Cyclic Voltammetry: an electrochemical technique that sweeps across a potential range and measures electron flow**

Cyclic Voltammogram of Anthraquinone-2-sulfonic Acid

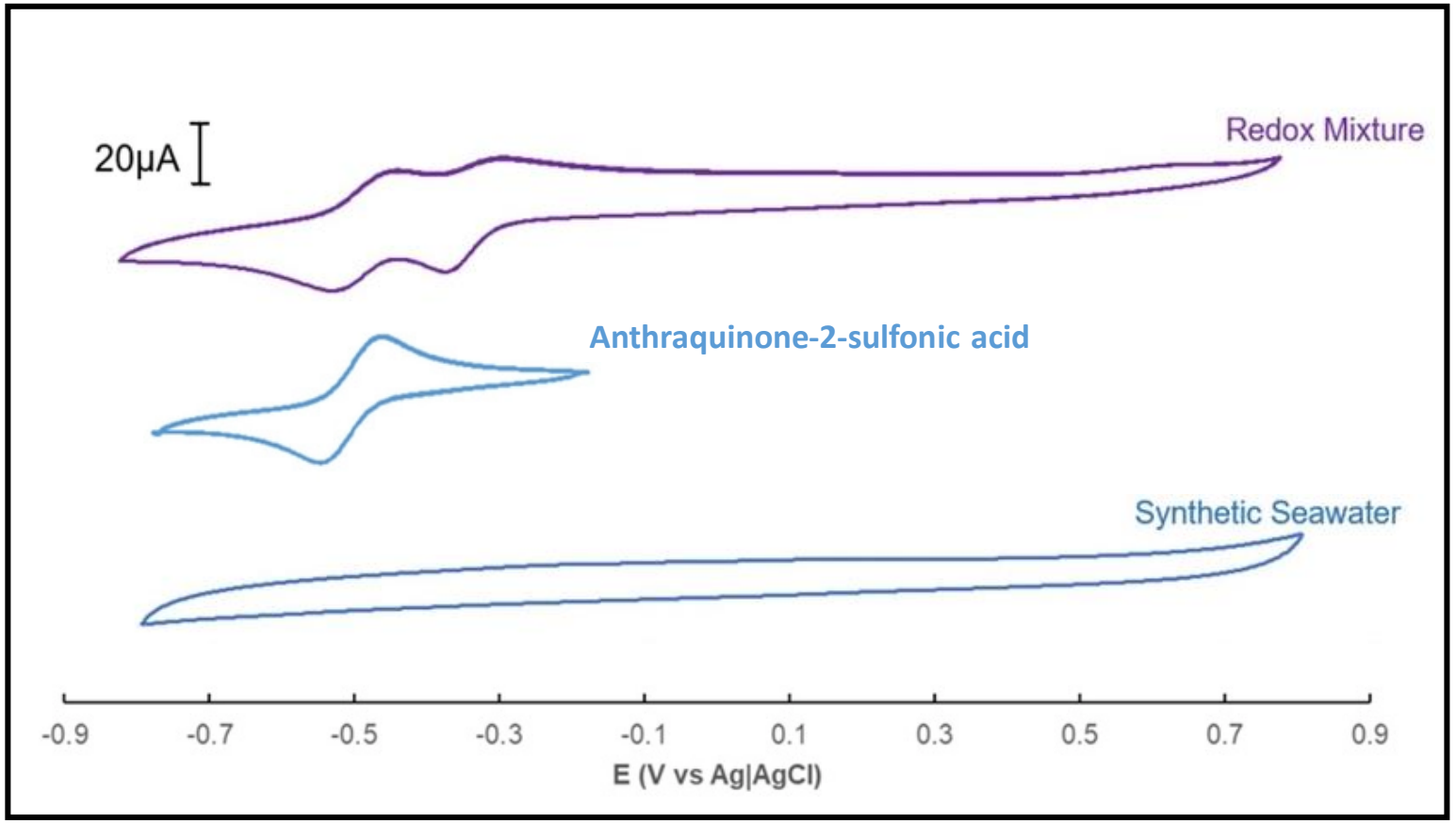


Cyclic Voltammetry Potential Waveform



Electrochemical Redox Signatures

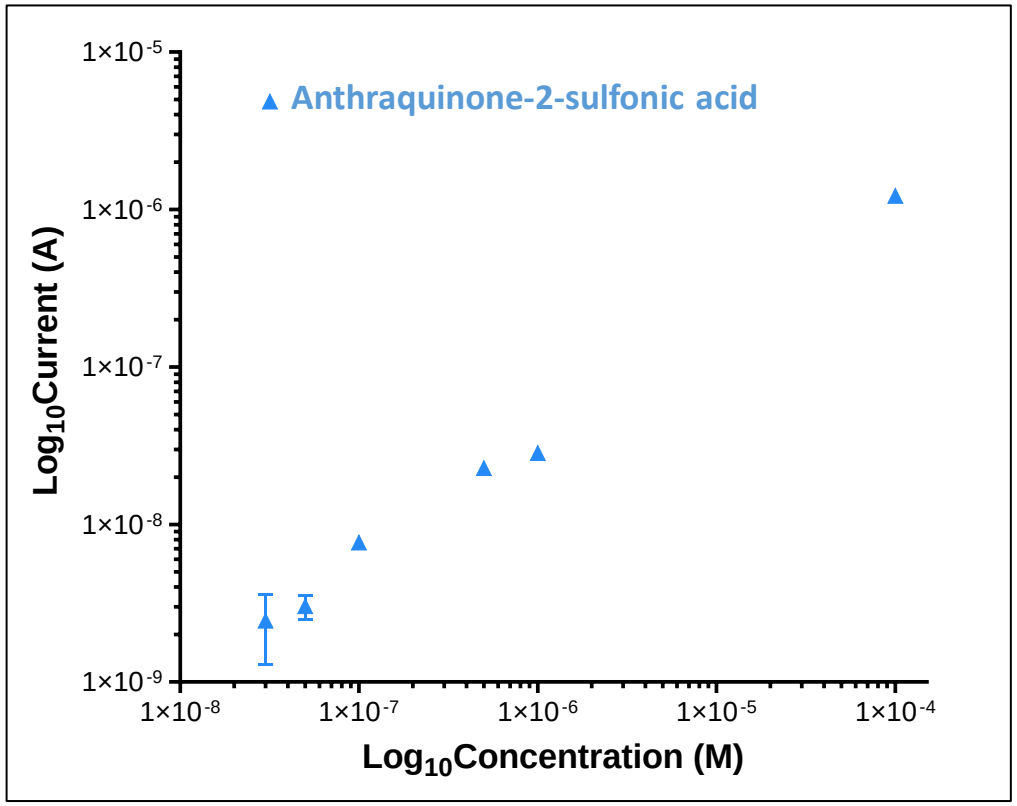
- **No observable redox couples in synthetic seawater standard**
- **In mixture containing multiple classes of redox molecules, multiple redox couples observed**



Concentration Response and Limits of Detection

- **Voltammetry current response is proportional to concentration**
- **Improved limits of detection using other voltammetry techniques such as differential pulse voltammetry**

Current Response and Concentration in Synthetic Seawater



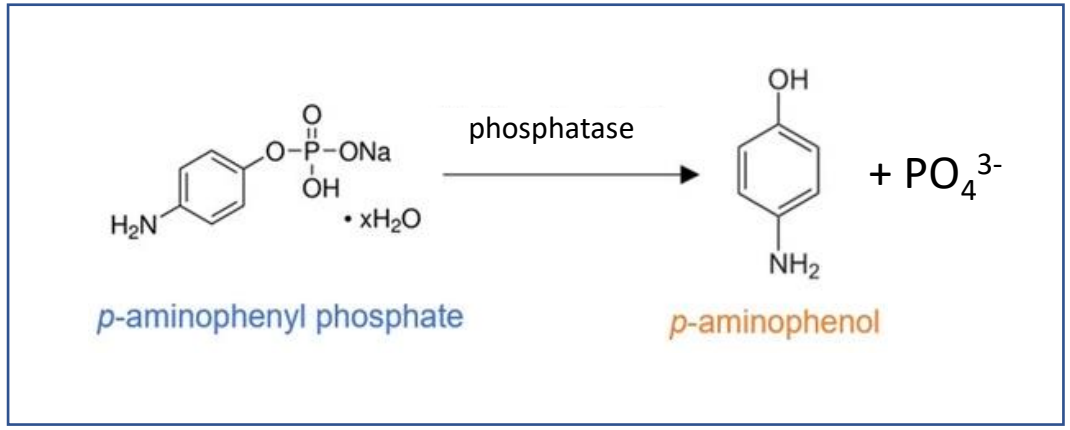
Limits of Detection Found Using Differential Pulse Voltammetry

Redox Class	Redox Molecules	Limit of Detection in Synthetic Seawater
Flavin	Flavin Adenine Dinucleotide	10 nM
Flavin	Riboflavin	30 nM
Quinone	Plumbagin	100 nM
Quinone	Anthraquinone-2-sulfonic acid	30 nM
Nicotinamide	Nicotinamide Adenine Dinucleotide	10 µM

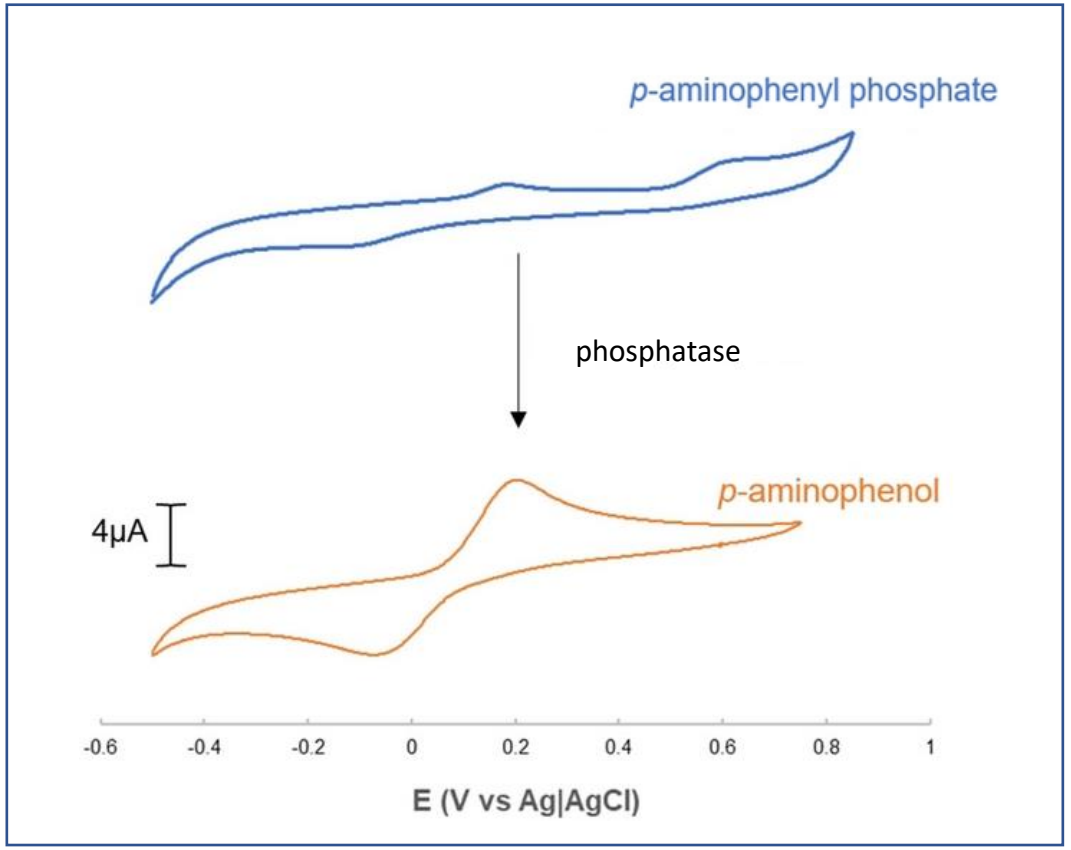
Measuring Chemical Modifications Using a Redox Marker

- **Cyclic voltammetry can be used to measure chemical reactions occurring in the system**
  E.g. Enzymatic cleavage of phosphate

Phosphate Group Removal by Enzymatic Species in Solution

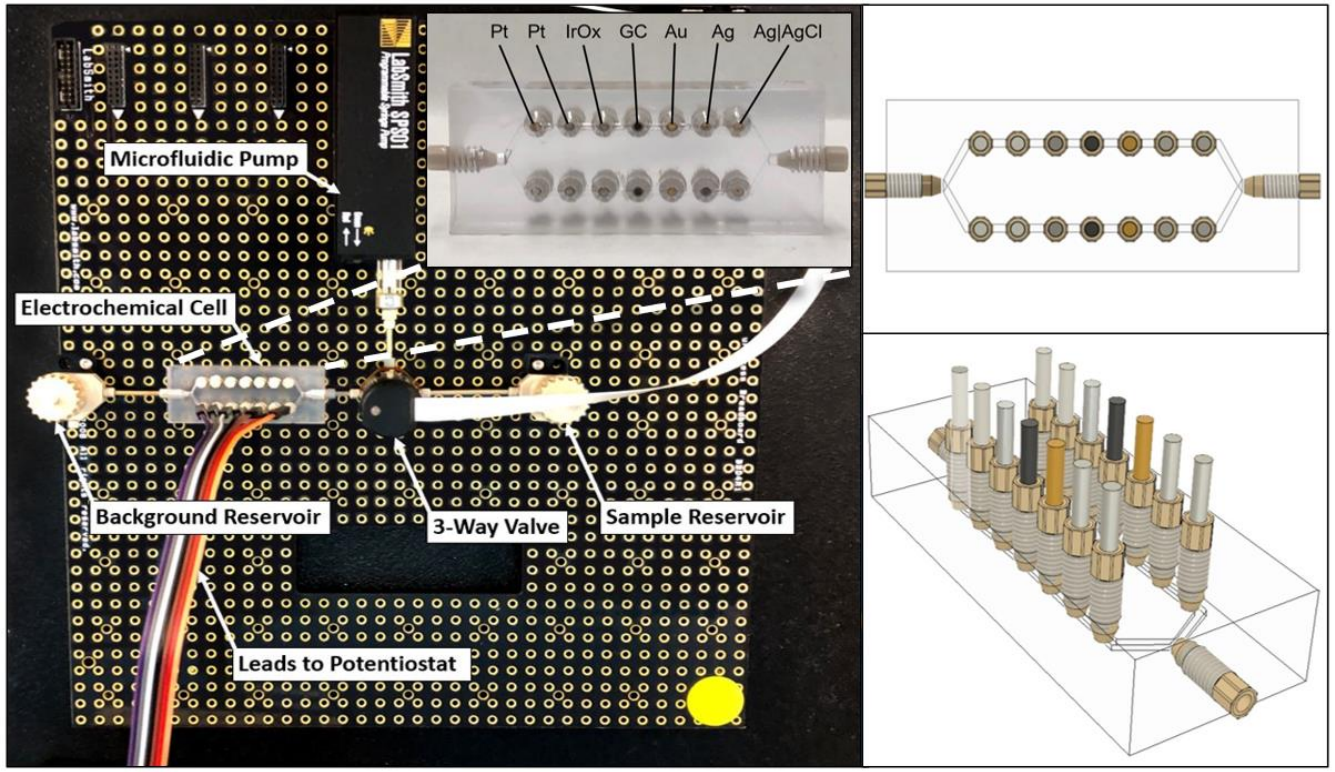


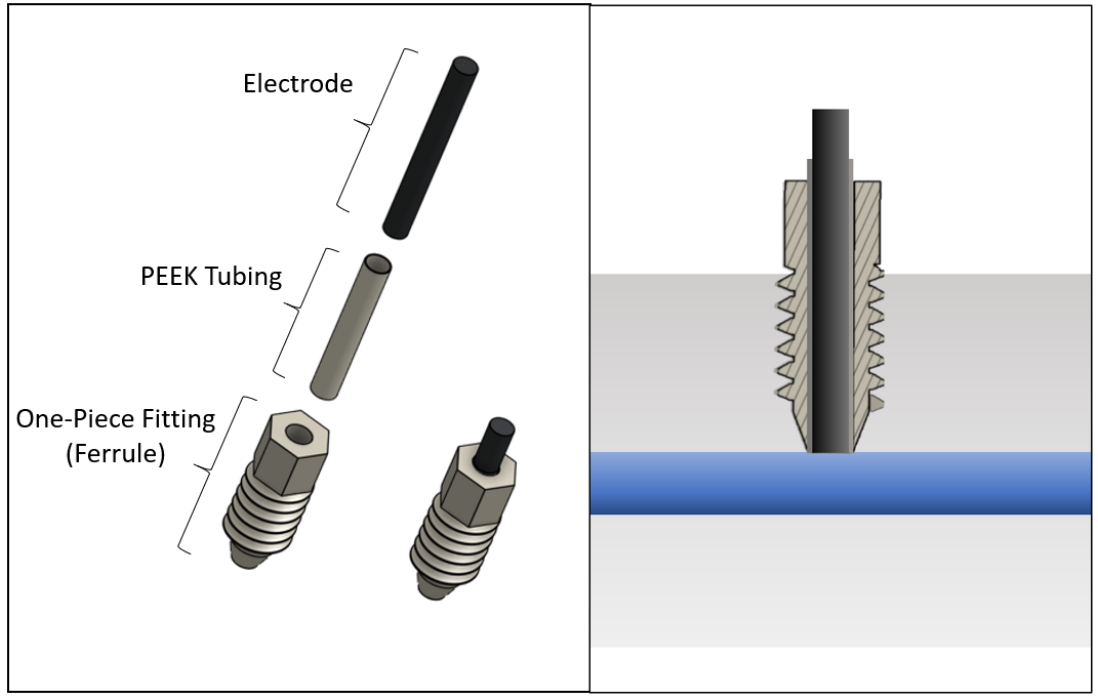
Change in Redox Signatures Following Addition of Enzyme



Microfluidic Electrochemical Cell and Breadboard Fluidic System

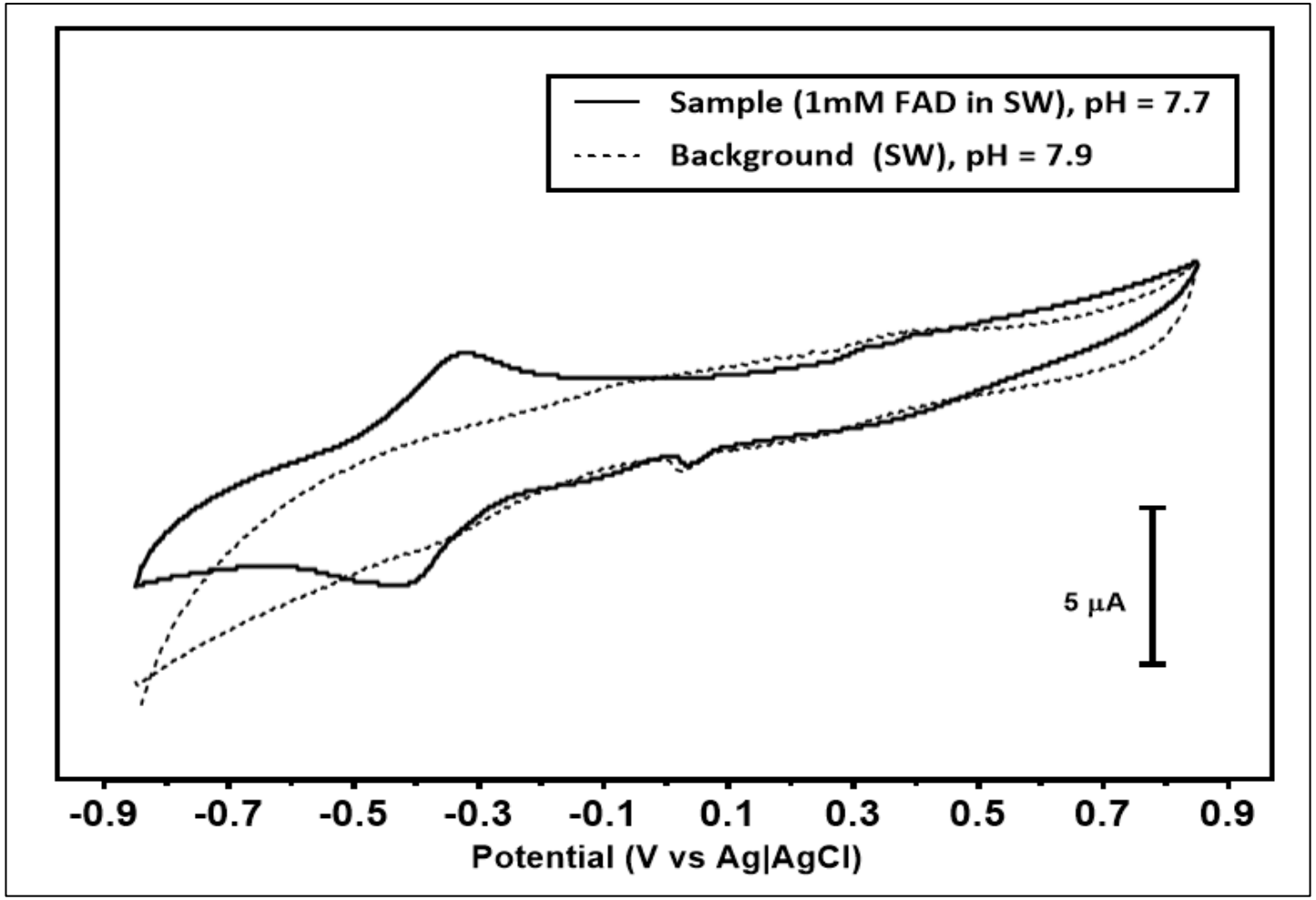
- **Performing cyclic voltammetry in a 3D-printed dual-channel microfluidic cell**
- **Autonomous background and sample delivery using fluidic breadboard approach**





Microfluidic Electrochemical Cell Results

Autonomous Fluidic Delivery and Electrochemical Measurements (CV and pH) of Background and Sample

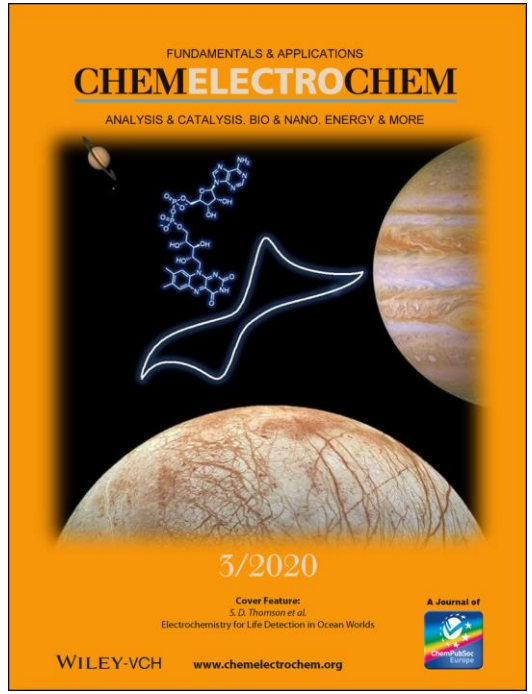


Summary

- Cyclic voltammetry can be used for:
- Identification of biological redox active molecules
- Measuring chemical reactions

- Detection limits in seawater:
- redox classes greater than **10 nM**
- enzymatic activity greater than **3.1 aM over a 60 min period**

- Microfluidic approaches coupled with cyclic voltammetry can achieve high sensitivity in very small volumes - **ideal for plume sampling**



Relevant Published Works:

Thomson, S. D., Quinn, R. C., Ricco, A. J., & Koehne, J. E. (2020). **Electrochemistry for Life Detection on Ocean Worlds**. *ChemElectroChem*, *7*(3), 614-623.

Acknowledgements

- Richard Quinn[1]
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NASA Ames Research Center, Credit: NASA

- NASA Postdoctoral Program
- Universities Space Research Association
- MICA Team
- ELM Team
- NASA Science Mission Directorate
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