

**Hotwired Life: Electron Transport Across the Biotic-Abiotic Interface.** M.Y. El-Naggar<sup>1,2,3</sup>, S. Pirbadian<sup>1</sup>, H.S. Byun<sup>1</sup>, S. Xu<sup>1</sup>, Y. Jangir<sup>1</sup>, B.J. Gross<sup>1</sup>, A.R. Rowe<sup>1,4</sup>, A. Karbelkar<sup>3</sup>, G. Chong<sup>2</sup>, A. Nakano<sup>1,5</sup>, P. Subramanian<sup>6</sup>, G.J. Jensen<sup>6</sup> <sup>1</sup>Department of Physics and Astronomy, University of Southern California, <sup>2</sup>Department of Biological Sciences, University of Southern California, <sup>3</sup>Department of Chemistry, University of Southern California, <sup>4</sup>Department of Earth Sciences, University of Southern California, <sup>5</sup>Collaboratory for Advanced Computing and Simulations, University of Southern California, <sup>6</sup>Howard Hughes Medical Institute, California Institute of Technology

Life as we know it is dependent on the fundamental process of electron transfer (ET). The stepwise movement of electrons within and between molecules dictates all biological redox reactions in all three domains of life. Given this importance, the fundamentals of ET and its precise impact on bioenergetics have received considerable attention, and the broad mechanisms allowing ET over small length scales in biomolecules are now well appreciated. Coherent tunneling is a critical mechanism that allows ET between cofactors separated by nanometer length scales, while incoherent hopping describes transport across multiple cofactors distributed within membranes.

During the last few years, however, the understanding of biological ET has been challenged by studies of the biophysical and structural basis of ultra-long-distance (over micrometer length scales), fast, extracellular electron transport (EET) through the extended redox systems of environmental bacteria. These remarkable organisms have evolved direct charge transfer mechanisms to solid surfaces outside the cells, allowing them to use abundant redox-active minerals as electron acceptors for respiration, instead of oxygen or other soluble oxidants that would normally diffuse inside cells. In addition to the fundamental implications for physiology and astrobiology, where interfacial electron transport may form the basis of an extra-terrestrial metabolism on iron-rich planets, a physics-based understanding may enable the transmission and control of signals at hybrid living/synthetic interfaces [1].

Here, we take stock of where we are and where we are heading as we come to grips with the basic mechanisms and immense implications of microbial long-distance electron transport. We will focus on biophysical measurements, electron transfer simulations, and electron cryo-tomographic studies of the multiheme cytochrome conduits that perform EET in the dissimilatory iron-reducer *Shewanella oneidensis* MR-1. We show how the ET rates gleaned from single molecule conductance measurements and kinetic Monte Carlo simulations can be linked to the single cell respiration rates measured using an integrated platform that combines optical trapping and on-chip electrochemistry [2-3]. In addition, we describe our current understanding of how *Shewanella* organizes heme networks along the

filamentous membrane tubes known as ‘bacterial nanowires’ [4]. Using correlated electron cryotomography and *in vivo* fluorescence microscopy, we are gaining new insight into the near-native (vitreous ice) localization patterns and orientation of these multiheme cytochrome conduits along nanowires as well as the morphology and formation mechanism of these structures. These experimental developments are being coupled into large-scale Divide-Conquer-Recombine kinetic Monte Carlo high performance computations of transport in structures ranging from nanowires to full biofilms. Throughout, we focus on the astrobiological significance of EET as an energetic biosphere-geosphere link, and the promise of bioelectrochemical techniques to study and detect biological activity in diverse environments.

#### References:

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