

Alumni Weekend: Session 2 Abstracts

Rhizosphere engineering of a sucrose-driven metabolic niche to direct plant carbon into microbial storage

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Mentors: José Dinneny, Jared R. Leadbetter, and Christopher Dundas

Microbial storage compounds are fundamental to soil carbon cycling, yet the ecological function of these energy-rich polymers - particularly at the plant-microbe interface - remains unclear. Polyhydroxyalkanoates (PHAs) are one such storage compound, and with well-characterized metabolic and nutrient constraints in the context of bioplastic production. Here, we develop a high-throughput microplate assay using Nile Red - a lipophilic and fluorescent dye staining intracellular storage compounds - and corroborate it with confocal microscopy of stained PHA granules to quantify polyhydroxyalkanoate (PHA) accumulation in model *Pseudomonas putida* KT2440 both *in vitro* and on plant roots. Leveraging synthetic biology, we engineer *P. putida* KT2440 strains with modified PHA metabolism to maximize accumulation. In vitro analyses across these mutants and mixtures of plant-relevant carbon sources reveal distinct metabolic interactions between plant exudates profiles and microbial PHA accumulation, highlighting the underexplored role of microbial carbon storage in shaping rhizosphere carbon flux. Additionally, we demonstrate that the introduction of sucrose catabolism to strains grown on *Arabidopsis thaliana* roots exhibiting increased sucrose exudation increases PHA accumulation - a proof-of-concept of how rhizosphere engineering on both plant and microbial sides can be used to construct a metabolic niche that sequesters photosynthetically derived carbon.

Ester accretion products from $RO_2 + RO_2$ chemistry of methyl vinyl ketone

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Mentors: Sarah E. Reisman and Kristen E. Gardner

Volatile compounds are important compounds, because they oxidize to produce organic peroxy radicals in the atmosphere. With accretion products, we focus on the study of RO_2 chemistry, because two peroxy radicals can undergo a reaction to form ROOR. The Wennberg group has studied accretion product formation of self-reacting ethene derived hydroxy peroxy radicals. These formations are interesting, because these compounds become lower in volatility and are more likely to partition in the particle phase thus providing new information aerosol formation. The principal focus on ester accretion products is that some RO_2 can react to form esters. They are similar to peroxide products, because they experience an increase mass. Additionally, these esters can be found in different aerosol samples and have the potential for possible gas phase mechanism for their formation. Herein, we focus on a synthetic plan to make potential accretion products derived from methyl vinyl ketone (MVK) to better understand if $RO_2 + RO_2$ chemistry is important for MVK and the substantial impact it can have on our environment. The synthesis plans focus on creating 3,4-dihydroxybutan-2-one, 1-hydroxy-3-oxobutan-2-yl acetate, and 2-hydroxy-3-oxobutyl acetate. Once synthesized, we will test the sensitivity of GC-CIMS of the compounds so we can know in the gas phase what concentration we are forming and if the ester accretions products formed.

Integrated entangled photon pair source on thin-film lithium niobate

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Mentors: Alireza Marandi, Rithvik Ramesh, and Thomas Zacharias

Integrated photonics has become a leading platform for quantum information processing (QIP) systems on a single chip. It provides unique advantages, including room-temperature operation, low loss, scalability, and compatibility with existing nanofabrication techniques. The development of quantum light sources, such as entangled photon pairs, is essential for achieving large-scale quantum

networks and applications like quantum sensing, metrology, communication, and computation. While significant progress has been made in developing on-chip entangled photon pair sources, most implementations still rely on bulky, table-top lasers to provide pump, preventing scalability and accessibility of QIP. This project demonstrates a compact, integrated entangled photon pair source pumped by a small diode laser. Utilizing the strong optical nonlinearities of the thin-film lithium niobate (TFLN) platform, biphotons can be generated on-chip from spontaneous parametric down-conversion (SPDC). The diode laser is butt-coupled to a TFLN waveguide-based SPDC source to produce entangled photon pairs. The biphoton quality was characterized through its coincidence-to-accidental ratio, pair generation rate, and single photon behavior. This demonstration enables a practical path toward scalable QIP.

Laboratory characterization of Snowball Earth-analog cryoconites

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Mentors: Robin Wordsworth, Heather A. Knutson, and Charlotte Minsky

Snowball Earth events were rare globally glaciated states in Earth's climate history. At least two such events – the Sturtian and Marinoan glaciations – occurred during the Neoproterozoic era, after the evolution of eukaryotic diversity. The fossil record shows that microbial diversity survived the Snowballs, while geologic evidence for post-Snowball oxygenation points to sustained primary production. However, explaining how life survived the Snowballs is a challenge: kilometer-thick ice sheets prevented Solar radiation from reaching subglacial habitats and halted the weathering processes that supply essential nutrients to the biosphere. Cryoconites – supraglacial meltwater pools supplied by nutrient-rich dust – may have provided a habitat for survival of photoautotrophs during Snowballs. In this work, we perform the first-ever experimental analog study to physically characterize cryoconite holes under controlled conditions. We establish a protocol for simulating cryoconite formation by using a solar simulator tuned to Neoproterozoic-like solar fluxes to irradiate basalt-covered ice. We use a thermocouple array to measure 3D heat distribution, and record cryoconite depth and diameter, at steady state. Future work includes simulating a 24-hour day-night freezing cycle and introducing biological cultures to assess cryoconite productivity. These experiments lay the groundwork for assessing the potential of cryoconites as viable microbial habitats during Snowball glaciations.

Treasury buybacks to improve liquidity of securities markets

Ryan J. Leal

Mentors: Darrell Duffie and Jaksa Cvitanic

The goal of this ongoing project is to model the US Treasury securities market with a focus on Treasury buybacks, which are a re-purchase of these securities by the Treasury, and reopenings, where the Treasury auctions additional amounts of security it has previously issued. Our model revolves around solutions to dealer's optimal behavior in the auction, buyback, interdealer, and customer interaction settings. These optimal behaviors, and market clearing, determine a solution to the Hamilton Jacobi Bellman equation for dealer's values of their expected future net cash flows. We optimized the model's parameters to exhibit accurate empirical moments using a variety of heuristic and computational techniques and adjusted structural details of the model until the model satisfactorily represents an abstraction from the true US Treasury securities market for a given sector. Fixing the mean path of outstanding debt, we observed a decrease in debt servicing costs and social costs when increasing buyback operations, with this effect diminishing as we increased buybacks. Similarly, introducing more reopening operations decreased debt servicing costs and social costs, with a diminishing effect.

From black hole seeds to Little Red Dots: Validating progenitors of active galactic nuclei

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Mentors: Philip F. Hopkins and Daichi Tsuna

Since it began its mission in 2021, the James Webb Space Telescope has fundamentally changed and challenged our understanding of the universe and our place in it. In the last few years JWST has identified a number of high redshift, dense objects now referred to as Little Red Dots. Their relative

abundance and compactness, coupled with their high mass/luminosity, make them good candidates for the early progenitors of current-day Active Galactic Nuclei and the SMBHs that we expect reside at their centers. Speculative work under this "dusty" AGN interpretation of LRDs has yielded interesting insights regarding the life cycle of SMBHs. Principal to our project is the work of a previous graduate student, Yanlong Shi, which suggests that a method of "seed" BH capture followed by a period of Hyper-Eddington accretion may be the mechanism responsible for the birth and growth of these SMBHs. Using a semi-analytical model in conjunction with the assumptions inherent to Shi's work, we study the population dynamics of these objects, further validating this dusty AGN hypothesis and this non-exotic method of SMBH formation.