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Ecology True or False: Population Changes in Bering Sea Bivalves Recorded by Death Assemblages

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Mentor(s): Professor Susan Kidwell, Geophysical Sciences; Caitlin Meadows, Geophysical Sciences

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The boundary between the Arctic and the Subarctic on the Bering continental shelf, maintained by ice-influenced bottom water, shifted northward between 1998 and 2001. The Alaskan Arctic ecosystem supports large populations of marine mammals and birds that depend on sea ice for rest and mating and on the densely productive seafloor communities for food. Seafloor biomonitoring during this time indicated a massive decline in the living abundance of the main prey bivalve species of diving sea ducks, *Nuculana radiata,* since 1985. Historically, ecologists have used living specimens to measure effects of species decline, and have not utilized death assemblages, the shelly remains of seafloor invertebrates, as an additional measurement tool. Death assemblages can provide information from many generations of individuals accumulating in the top 10 cm of the seafloor sediment; however, which individuals are preserved in the death assemblages and which individuals are lost after death is an active area of research. The potential for preservational bias against small individuals raises the question: are changes in body size distributions found in death assemblages correlated with a known ecological decline, such as in *Nuculana radiata* in the Bering Sea, or do they instead reflect a bias in preservation? To address this question, I photographed and measured the size (length, height, and mass) of each individual *Nuculana radiata* from four stations in the Bering Sea. In 2014, larger body sizes constituted a higher proportion of death assemblages than smaller body sizes. In 2015, the abundance of both living and deceased individuals declined. Here, I seek to compare the sizes of *Nuculana radiata* during the two years analyzed to determine whether the death assemblages may be used to understand changes in body size at the time of death in the presence of such a documented ecological decline. Primality results indicate that in 2015, there is a higher proportion of large bodied individuals in the death shell assemblage. This research undertakes to listen to the stories encoded within the death assemblages of the lives and environments of the bivalves as a means to understand, fundamentally, the dynamics of ecosystems today.

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Searching for Ultra-Faint Milky Way Satellites with the DELVE Survey

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We present an overview of efforts to search for ultra-faint satellites of the Milky Way with the DECam Local Volume Exploration survey (DELVE). In particular, we report the discovery of two ultra-faint stellar systems found in early data from DELVE. The first system, Centaurus I (DELVE J1238−4054), is identified as a resolved overdensity of old and metal-poor stars with a heliocentric distance of $D_{\odot} = 116.3^{+0.6}_{-0.6}$, a half-light radius of $r_h = 2.3^{+0.4}_{-0.3}$, an age of $\tau > 12.85$, a metallicity of $= 0.0002^{+0.0001}_{-0.0002}$, and an absolute magnitude of $M_V = -5.55^{+0.11}_{-0.11}$. This characterization is consistent with the population of ultra-faint satellites and confirmation of this system would make Centaurus I one of the brightest recently discovered ultra-faint dwarf galaxies. Centaurus I is detected in DR2 with a clear and distinct proper motion signal, confirming that it is a real association of stars distinct from the Milky Way foreground; this is further supported by the clustering of blue horizontal branch stars near the centroid of the system. The second system, DELVE 1 (DELVE J1630−0058), is identified as a resolved overdensity of stars with a heliocentric distance of $D_{\odot} = 19.0^{+0.5}_{-0.6}$, a half-light radius of $r_h = 0.97^{+0.24}_{-0.17}$, an age of $\tau = 12.5^{+1.0}_{-0.7}$, a metallicity of $= 0.0005^{+0.0002}_{-0.0001}$, and an absolute magnitude of $M_V = -0.2^{+0.8}_{-0.6}$, consistent with the known population of faint halo star clusters. Given the low number of probable member stars at magnitudes accessible with DR2, a proper motion signal for DELVE 1 is only marginally detected. We compare the spatial position and proper motion of both Centaurus I and DELVE 1 with simulations of the accreted satellite population of the Large Magellanic Cloud (LMC) and find that neither is likely to be associated with the LMC.

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Understanding the Origin of Pre-solar Grains through CNO Ratios

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Mentor(s): Professor Vikram Dwarkadas, Astronomy and Astrophysics

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Pre-solar grains are solid matter that originated before the formation of the solar system. Their origin can be characterized by their C, N and O isotopic ratios. We study oxygen-rich grains through examining their O17/O16 and O18/O16 isotopic ratios, and comparing them to both the latest stellar evolution models of Ekström and our own models using the MESA stellar evolution code. The origin of these grains is purported to be from asymptotic giant branch (AGB) stars, but we find that theoretical predictions of isotopic ratios from both OB and red supergiant (RSG) stars also match those in the grains. We also compare isotopic ratios of heavier elements such as Mg, since dust containing Mg is believed to be formed around RSG stars.

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PaleoBuddy: Simulating Evolutionary Dynamics in R

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Fossil records and phylogenetic trees are important tools in paleobiology. It is through the many methods developed to analyze those tools that we are now able to gain insight into the dynamics of the tree of life. As such, it is imperative for paleobiologists to have access to a flexible and robust simulator for fossil records and phylogenies, which is useful to test such methods and to understand the consequences of certain diversification patterns, among other applications. While the field has advanced greatly in the realm of simulating evolutionary data, we have written a simulator that fills crucial capability gaps in relation to other simulators in the field. PaleoBuddy runs species birth-death simulations with flexible speciation and extinction rates, and generates fossil records and phylogenies with equally adjustable sampling rates. The package accepts any time varying function, species age dependency, dependency on an environmental variable and any combination of these for the different types of rates. Since it generates both fossil records and phylogenies from the same underlying process, it might help alleviate some of the discrepancies found in previous studies between those types of data. Furthermore, being the first package that can simulate age dependent speciation and extinction with time varying parameters makes it invaluable for the growing group of researchers interested in investigating time dependent dynamics. In short, PaleoBuddy promises to be an impactful package for those interested in simulating paleobiological data.

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Carbon Dioxide Utilization in Plastic Production: Catalyst Development

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Carbon dioxide emissions, known to exacerbate climate change, have been increasing rapidly over the past century. One strategy to alleviate this issue is carbon capture and utilization (CCU), in which some of the abundant atmospheric CO2 is used as a carbon source for the production of widely used compounds. An attractive target is sodium acrylate, the building block of superabsorbent sodium polyacrylate found in hygiene products, detergents, and many other common goods. Currently, sodium acrylate is synthesized by sequential oxidations of propylene over heavy metal catalysts at high temperatures. Researchers have instead sought a one-step process coupling CO2 and ethylene, which is more sustainable and uses much less expensive starting materials. With biologically sourced ethylene, this method could consume a large quantity of atmospheric CO2. However, the process is not spontaneous and requires a catalyst. Nickel catalysts have shown great promise for enabling this reaction, but the reported systems suffer from low efficiency, limiting their application. The main obstacle is a very stable intermediate known as a nickelalactone, which contains a rigid Ni–pre-acrylate ring that resists the release of free sodium acrylate from the catalyst. My project aims to develop a series of nickel complexes which have a bis(N-heterocyclic carbene) (bis(NHC)) as the supporting ligand. The characteristic strong electron donation and steric imposition of bis(NHC)s is expected to destabilize nickelalactones and to promote ring-opening, thereby enabling efficient catalytic production of sodium acrylate. Initial results support the instability of a simple bis(NHC) nickelalactone, and experiments testing sodium acrylate production are underway. Investigating different bis(NHC)s with varying electronic and steric effects will also help elucidate the capability of these ligands to support the target reaction. This family of ligands could be the key to efficient nickel catalysts coupling CO2 and ethylene for sodium acrylate production, thus contributing to global CCU efforts.

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Using Switchable Fluorescent Molecules to Image Track and Measure Energy of Double-Beta Decay Events in Large Liquid Detectors

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We propose the development of a new detection technique for large-volume imaging of charged particle tracks based on switchable fluorescent organic dyes. A ‘Switchillator’ is a designed mixture of substances that responds to a charged particle by switching non-fluorescent precursors into a fluorescent configuration. The image of the tracks in an event such as nuclear β-decay or the interaction of gamma ray is thus temporarily recorded in the form of active fluors, with the number of activated molecules proportional to the energy deposited. The activated molecules can repeatedly fluoresce, creating a three-dimensional image recorded by cameras. Image reconstruction of this track may allow background rejection in ββ-decay experiments, as well as improved energy resolution. There exists at least one class of well-studied molecules, the diarylethenes, which seems to meet most of the requirements, but some molecular engineering is needed to create a suitable candidate.

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Smoothed Particle Inference Studies of Supernova Remnant DEM L71

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Supernova explosions are caused by either the core collapse of massive stars or the thermonuclear detonation of a white dwarf in a binary system (Type Ia supernova). In both cases, the supernova creates an expanding shell of gas and dust that will form a supernova remnant (SNR) that lives for many thousands of years. Here we analyze the X-Ray emission of the supernova remnant DEM L71 using the Smoothed Particle Inference (SPI) technique. We report high Fe abundances, particularly in the central region, which appears to confirm the Type Ia origin. Our method allows us to separate the material ejected in the supernova explosion from the material swept up by the supernova shock wave. We are able to calculate the total mass of this swept up material to be about 228 ± 23 solar masses. We plot the posterior distribution for the number density parameter and create a map of the density structure within the remnant. While the observed density shows substantial variations, we find our results are generally consistent with a two-dimensional hydrodynamical model of the remnant that we have run. Assuming the ejected material arises from a Type Ia explosion, with no hydrogen present, we use the predicted yields from Type Ia models available in the literature to characterize the emitting gas. We find that the abundance of various elements match those predicted by deflagration to detonation transition (DDT) models. Our results, compatible with the Type Ia scenario, highlight the complexity of the remnant and the nature of the surrounding medium.

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Nanoscale Metal-Organic Layers for pH and Oxygen Sensing

Eric **You**, 2nd-Year, Chemistry
Mentor(s): Professor Wenbin Lin, Chemistry

Monitoring intracellular pH and oxygen levels is of great importance to understanding biological and pathobiological pathways in the body. In particular, monitoring oxygen and pH in the mitochondria and the relationship between them is crucial to understanding pathways of diseases such as cancer and diabetes. In order to study these effects, nanoscale fluorescent probes have been developed to permit the direct, label-free detection of intracellular pH and oxygen levels owing to their high sensitivity and outstanding spatiotemporal resolution. Ratiometric sensing of pH and oxygen, which compares fluorescence emission ratios between a pH/oxygen-insensitive reference probe and a pH/oxygen sensitive probe, can further increase the accuracy of measurements by compensating for external environmental disturbances. Yet, no biosensor has existed which has been able to hierarchically combine these distinct functions. Thus, we hypothesized that nanoscale Metal-Organic Layers (nMOLs), could serve as a novel mitochondria-targeting biosensor for the ratiometric sensing of both pH and oxygen levels as a highly tunable two-dimensional nanocrystalline material. In order to investigate our hypothesis, we solvothermally synthesized a cationic Hf12-Ru nMOL by laterally connecting Hf-oxo metal-based nodes with oxygen-sensitive Ru(bpy)32+-derived DBB-Ru organic ligands (bpy = 2,2′-bipyridine). Post-synthetic surface modifications further functionalized our Hf12-Ru nMOL with pH-sensitive fluorescein isothiocyanate (FITC), pH/oxygen-independent Rhodamine-B isothiocyanate (RITC) through thiourea linkages to yield Hf12-Ru-F/R. Upon construction of pH and oxygen-dependent fluorescence standard curves using confocal laser scanning microscopy (CLSM), qualitative and quantitative confirmation of selective and efficient mitochondrial uptake, and incubation studies to affirm stability, we conducted in vitro studies in anoxic, normoxic, and hypoxic conditions. Analyzing random points of interest (POIs) by CLSM, we established for the first time a positive correlation between pH and oxygen levels in the mitochondria. Moreover, we have shown nMOLs as a platform for the hierarchical assembly of a multifunctional nanoscale fluorescent probe. Applying our systematic approach using nMOLs, future steps could include investigating novel endoplasmic reticulum (ER) targeting nMOLs as a platform to analyze ER stress through the ratiometric detection of free glutathione (GSH) and oxidized glutathione disulfide (GSSG) levels, which are of vital importance to understanding the intracellular redox triangle and its role in disease pathways.