Excerpts from Masters Proposal 1

Research Project

The primary goal of astrobiology is to answer fundamental questions regarding the origin, evolution, existence, and future of life in the Universe. Mars is the current focus of NASA's astrobiology endeavors: the geochemical climate of Mars is very similar to the environment of several subterranean and extreme ecosystems on Earth, and its chemical composition is potentially favorable to the development of chemolithoautrophic microbial life. On Earth, this includes several groups of microorganisms that utilize a variety of available redox couples within rock to support carbon fixation and ATP generation. Biogeochemical cycling within cave systems and the physical transition from a surface to subsurface based ecosystem are often cited as reasons that astrobiologists have recognized caves as an ideal Earth-based analog for the study of the types of microbial communities that are likely to exist on Mars and for the identification of the biosignatures of these communities.

My current research involves a comprehensive investigation of the geomicrobiology of ferromanganous deposits in Tennessee cave systems, merging the fields of geology and microbiology by examining microbe-mineral interactions. Over the past year, I have utilized both culture-dependent and independent techniques to evaluate microbial diversity, and I have been involved in the process of developing a novel peptide-probing technique as a molecular method of querying metal-oxidizing communities. My proposed research will supplement current knowledge of these systems through a comprehensive study aimed at the identification of novel organisms involved in the cycling of methane and the signatures of biogenically produced mineral deposits. I will be working closely with Dr. Suzanna Brauer (Appalachian State University, Biology) and Dr. Sarah Carmichael (Appalachian State University, Geology) and anticipate completing the project by August 2011.

The first aspect of my research, conducted in conjunction with Dr. Suzanna Brauer and ongoing throughout the summer, focuses on culture-dependent methods. There is mounting evidence in scientific literature that fluxes of hydrogen, sulfur, and methane occur on Mars. It is currently unclear whether the cycling of these compounds is purely abiotic. Several researchers have suggested the potential of microbial involvement in the cycling of these elements as all three chemicals have been linked to methane-based metabolisms. I plan to develop novel culture media targeting the cultivation of cave methanogens (anaerobic archaea that generate methane through chemolithoautotrophic processes) and methanotrophs (bacteria that metabolize methane as their sole source of carbon and energy). An attempt will be made to supplement some culture media with Mn(II), as preliminary evidence from our lab suggests the existence of a novel group of organisms that are methanotrophic Mn(II) oxidizers. Expanding the scientific community's knowledge of microbes involved in the cycling of methane, and other elements linked to this biogeochemical cycle, will better elucidate the groups of organisms which are likely to be present in the current environmental conditions of Mars that are favorable for the microbial metabolic transformation of methane.

A second goal of my work this summer is related to the mineralogy of biogenic Mn(IV) oxides. I plan to work closely with Dr. Sarah Carmichael to complete mineralogical studies of biogenic oxides produced by cultivated microbes. Due to the amorphous crystal structure of biogenic Mn(IV) oxides, a variety of techniques, such as XRD, SEM-EDS, and FT-IR must be utilized to successfully identify mineral phases. The oxidation of Mn(II) produces over 30 known Mn(IV) minerals. Common manganese minerals in caves include todorokite (Mn(II)), buserite, and birnessite (Mn(IV)), all of which have been implicated as having a biogenic origin. Mineralogical studies of actively-oxidizing cave isolates will allow for the identification of in vivo, biogenically produced Mn minerals, thus better elucidating our understanding of which Mn minerals are attributed to biological activity. If these minerals are identified in samples from Mars, it would provide further evidence for the potential existence of life on the red planet.

My research within the field of cave geomicrobiology supports NASA's Mars missions because results from the proposed studies will provide the scientific community with further insight into the geomicrobiology of cave mineral deposits. A greater understanding of these analogous biogeochemically mediated systems on Earth will allow researchers to hypothesize about what is likely to exist in similar extraterrestrial environments and better define the search for life throughout the Universe.

Relevance to NASA Mission Directorates

My research in cave geomicrobiology will support NASA's Science Mission Directorate, which encompasses research on the Earth, Heliophysics, Planets, and Astrophysics. Within the Science Mission Directorate, Astrobiology integrates knowledge from all four areas to answer fundamental questions concerning the origin, limits, and future of both terrestrial and extraterrestrial life. It is widely recognized that the search for extraterrestrial life starts on Earth in systems that are analogous to Mars. Insight into the current limits of life on Earth and the biosignatures of the microbial life that inhabit these environments is the keystone in answering fundamental questions concerning the origin, existence, and future of life in the Universe. Caves provide an ideal milieu in which to study these questions as they represent a transition zone from surface to subsurface based ecosystems and contain biogeochemical cycles similar to those hypothesized to occur on Mars. My work this summer will focus on the investigation of novel groups of microorganisms, the development of methods to enrich and identify metal-oxidizing species which play an integral role in biogeochemical cycling, and identification of the signatures of biogenically produced mineral deposits. Further elucidating the scientific community's knowledge of extant life in Earth's analogs to Mars will aid in the development of analytical techniques to detect and assess extraterrestrial biosignatures and allow astrobiologists to better hypothesize about what life forms are likely to exist in extraterrestrial environments, thus providing a focal point in the search for life throughout the Universe.

Excerpts from Masters Proposal 2

Research Project

My thesis research will focus on the mobilization and transport of dissolved and particulate material from the land to coastal waters following major flood events. This research will integrate field measurements, remotely sensed images, and numerical model results. The study site will include the Tar-Pamlico River, a portion of Pamlico Sound, and adjacent continental shelf of North Carolina. This research is relevant to climate change, global warming, and sea level rise as carbon is transported from the land to the ocean carbon pool. Here, processes such as bacterial remineralization can act to release carbon dioxide, a major greenhouse gas.

Currently, my research plan includes establishing a series of monitoring stations throughout the Tar-Pamlico River system where I will collect seasonal water samples for analysis of total suspended matter (TSM) and colored dissolved organic matter (CDOM) concentration. I will also collect ancillary field data such as temperature, salinity, and turbidity. Results of the TSM field samples will be used to develop a remote sensing algorithm to relate reflectance from the 250 m red band (band 1) of the Moderate Resolution Imaging Spectroradiometer (MODIS) to TSM concentration in the water column. MODIS images are critical to my project as field sampling in such a large area as Pamlico Sound is not practical and clearly shows the major use of NASA products in my research. I will also use MODIS images to develop land cover and land use maps of the areas drainage basins to relate the amount of dissolved and particulate matter delivered to the coastal waters from different land cover and land use practices.

A series of TSM and CDOM images made from MODIS data will also be used as a tracer to calibrate and validate a numerical model, DELFT3D. Remotely sensed images show complex patterns of sediment and CDOM transport and should hopefully provide a better understanding of how these transport patterns assist in hydrodynamic modeling studies performed in this field area. In addition to MODIS data, several remote sensing instruments such as FORMOSAT-2, Landsat thematic mapper, and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) will be used to examine a broader range of spatial, spectral, and revisit characteristics to better characterize changes in TSM and CDOM.

Specific objectives for my research include: 1) Determine the amount of dissolved and particulate material transported from specific drainage basins; 2) Determine the land use and land cover attributes for these drainage basins, and 3) Observe the transport of this material to the Pamlico Sound. I hypothesize that changes in land use and land cover will result in changes in the amount of dissolved and particulate matter that is mobilized and transported during flooding events.

The research is being conducted in partial fulfillment for the degree of Master of Science from East Carolina University. I expect to complete my research by the fall semester of 2012. My research advisor, Dr. Miller, also serves as my major advisor on my graduate committee. Dr. Miller and I have an active working relationship where we are continually discussing the design of the project. Weekly meetings have already been conducted and will continue throughout the completion of my research. These meetings serve as a review of the work that has been done as well as a discussion of the next steps that need to be taken in order to complete the project in the allotted time. Dr. Miller and I also often discuss the science and different research technologies that are part of my proposed research.

Relevance to NASA Mission Directorates

My research will support the NASA Earth Science Program of the Earth Science Mission Directorate. The focus of my research is related to the Carbon Cycle and Ecosystems Focus Area. Also, my research will contribute to the NASA Biogeochemistry and Applied Science Programs. I think that my research project will help advance the understanding of human-ecosystem-climate interactions that can be applied to numerous goals contained within this NASA Focus Area.

Insight into the cycling of carbon between land and coastal ocean will be investigated. Carbon stored in the soil and plant debris can be transported to the coast via rivers after major storms and flooding events. The distribution of colored dissolved organic matter (CDOM) will be investigated in an attempt to quantify the amount of dissolved organic matter in the water. Although the effect of the dispersion of

CDOM is outside the scope of my research, it is known that CDOM can have significant effects on biological processes in aquatic ecosystems. For example, CDOM can reduce light in the water column, limiting the growth of phytoplankton. This research will help quantify carbon flux and could aid in the goal of understanding how marine ecosystems are changing.

Another aspect of my research that supports NASA is how differences in land cover and land use may affect the amount of dissolved and particulate matter transported during floods resulting from climate change. It is thought that the frequency and intensity of storms including flooding will increase in coastal ecosystems from climate change.

Excerpts from Doctorate Proposal 1

Abstract
As of February of this year, over 500 planets have been confirmed outside of our solar system, and more than 1200 that were recently detected with NASA's Kepler telescope await confirmation. Most of these systems were discovered either spectroscopically from radial velocity variations in the host star or photometrically from transit observations. These methods are biased in favor of objects with large radii and masses, and, consequently, most exoplanets found to date are gas giants resembling Jupiter. Here, we propose to utilize the remarkably stable pulsations of the often-overlooked hot subdwarf stars to search for planets down to Earth-size using the pulse-timing method. Even if no substellar companions are found, the data acquired will help us constrain the evolutionary rate of these stars, shedding light on this poorly-understood stage of stellar evolution. Our project has three main goals:
· to discover and characterize new exoplanets,
· to test the hypothesis that all hot subdwarfs have binary companions,
· and to place exquisite limits on the evolution of hot subdwarfs.

Background & Motivation
Of all the types of stars known, hot subdwarfs have remained one of the most enigmatic since they were first discovered half a century ago. They dominate surveys of faint blue objects and play crucial roles in important astronomical mysteries such as the UV-excess in elliptical galaxies and the second parameter problem in globular clusters. Models suggest they are Helium-fusing, post-giant-branch stars whose progenitors somehow lost most of their outer Hydrogen layer while a red giant. Many have shown that the angular momentum provided by an orbiting companion could expel the hydrogen envelope (Han et al. 2003), and thus it is probable that *all* hot subdwarfs are members of binaries. Soker (1998) even demonstrated that the angular momentum in an orbiting planet could accomplish the same effect. Observationally, only two-thirds of hot subdwarfs appear to be binaries. If these stars require companions in order to form, the observed binary fraction begs the question: do those subdwarfs that appear to be alone in fact have substellar or planetary companions undetectable with traditional methods?

Technique
Around 100 hot subdwarfs pulsate with periods ranging from minutes to hours, and those pulsators that have no visible companion are the perfect targets for exoplanet searches (Bear et al. 2010). The pulsational periods are stable down to 1 part in 10^{12}, and this stability allows one to measure extremely small changes in the arrival times of the pulses. Companions orbiting a pulsating star pull on it gravitationally, causing the pulsator to wobble around the system's center-of-mass. The small changes in

the light-travel distance to Earth due to the wobble result in phase shifts in the light curve: sometimes the pulses will arrive earlier than expected, sometimes later. The amplitude and period of the phase oscillation provide an estimate of the companion mass. There have only been two major attempts to apply this method to apparently single pulsating hot subdwarfs, and both revealed the presence of previously-unseen companions (Barlow et al. 2011; Silvotti et al. 2007). We note that planets located a great distance from their host stars may take several years to detect. Even if no shorter-period planets are found, our measurements will provide a strong basis from which future observers may anchor their own timing data.

Excerpts from Doctorate Proposal 2

Research Project

Gravitational accretion is one of the most ubiquitous and efficient power generation mechanisms in the universe. Hoyle-Lyttleton (HL) accretion, in which a point mass accretes matter from a uniform flow, is responsible for the behavior of a wide variety of systems on planetary to galactic scales. Despite this, there are a number of open questions regarding the time evolution and stability of HL accretion in 3D. The goal of this project is to bring together high-resolution 3D hydrodynamic simulations, cutting-edge computational techniques, and massively parallel petaflop supercomputers to investigate these fundamental questions in the context of a newly discovered sub-class of supergiant x-ray binaries (SGXRBs).

One of the most important quantities governing the behavior of accretion-driven systems is the mass accretion rate, which affects the system's luminosity and provides a link between theory and observation. Hoyle and Lyttleton (1939) were the first to calculate the mass accretion rate, but numerical simulations in the 1970s called their steady-state picture into question. One of the most dramatic examples of nonlinear behavior in 2D HL accretion occurs in the flip-flop phenomena, where the accretion wake oscillates from side to side and forms transient accretion disks between each flip. This results in the mass accretion rate varying about the HL prediction by up to an order of magnitude. Whether behavior such as this exists in 3D and how it might affect HL-driven astrophysical systems will be the core questions of our project.

Recent observations by INTEGRAL, XMM-Newton, and Swift have discovered the presence of a subclass of SGXRBs labeled supergiant fast x-ray transients (SFXTs). These systems consist of a neutron star bathed in the stellar wind of an OB giant, and display brief (on the order of hours) transient x-ray outbursts at luminosities up to four orders of magnitude higher than their quiescent phase. A popular explanation for the outbursts is the accretion of high-density clumps created by stellar wind instabilities. However, predictions from this theory are based on the 70-year-old results of HL, which neglect to account for the presence of complex hydrodynamic behavior. 2D simulations have shown that the accretion flow can be dramatically altered due to nonlinear effects, and in order to adequately explain SFXT outbursts we must move beyond the HL formula towards high-resolution 3D hydrodynamic simulations.

Computational resources have advanced to the point that a comprehensive study of 3D HL accretion at previously unattainable resolutions has become viable. We propose to answer questions regarding the stability of HL accretion and the origin of SFXT outbursts by employing the VH-1 hydrodynamics code. To ensure feasible runtimes and to avoid difficulties inherent in spherical coordinates, we implement a yin-yang overset grid. We currently have access to the resources offered by the NSF TeraGrid, and are able to accurately scale VH-1 to tens of thousands of cores. Our current 3D simulations of HL accretion utilize a spherical grid with dr/r = 0.0256, which is far superior to previous 3D simulations (dr/r=0.195, Ruffert, 1999) and comparable to that of the best 2D simulations (Blondin & Pope, 2009).

Work by an undergraduate in our group has shown that introducing high density perturbations into the system (such as those present in a clumpy wind) can cause the accretion wake to make the transition into a disk accretion mode, but whether this behavior extends to 3D is currently unknown. The results of this 2D investigation will provide a starting point for my project. Preliminary runs by our group have shown that 3D HL accretion with an adiabatic index of 5/3 (corresponding to a wind of ionized hydrogen) appears stable in time. I will investigate the stability of this model by introducing high-density clumps and monitoring their effect on the structure of the accretion flow as well as the mass and angular momentum accretion rates. This project will form the base for further research, namely the introduction of more nuanced physics, such as nonuniform winds, anisotropic winds, and x-ray heating and ionization of the stellar wind. This research will be conducted on the campus of NCSU under the supervision of Dr. John Blondin, and will begin in the Summer of 2011. We plan to complete our analysis and publish our results in the Spring of 2012.

Relevance to NASA Mission Directorates:
A primary goal of the NASA Science Mission Directorate's Astrophysics division is to investigate the evolution of stellar systems. The Astrophysics Roadmap issued by the SMD calls for projects that will 'explore the exotic objects left by dying stars' (objective 6), such as SGXRBs and SFXTs. SFXTs are one of the currently unexplained examples of extreme physics at the end of normal stellar lives (subgoal 2). Our simulations will assist in the interpretation of data from several active NASA missions, including Integral, XMM-Newton, and Swift, and will serve to guide future observations. Our research also has the unique opportunity to address deeper fundamental questions regarding HL accretion, which could have implications in other accretion-driven astrophysical systems, such as protoplanetary disk accretion and the growth of active galactic nuclei.

The SMD also calls for outreach efforts targeted at K-12 students. Our group is currently working with CEI (the makers of the EnSight visualization software) to coordinate the development of a hands-on 3D visualization station to be used in the NC Museum of Natural Science's Astronomy Days. This station will allow students to manipulate data sets produced by our simulations and will allow them to engage with cutting-edge astrophysics research in an interactive way.