Interdisciplinary Science for Eclipse Program
Abstracts of Selected Proposals
(NNH21ZDA001N-ISE)

Below are the abstracts of proposals selected for funding for the Interdisciplinary Science for Eclipse Program (ISE) Program. Principal Investigator (PI) name, institution, and proposal title are also included. Twelve (12) proposals were received in response to this opportunity. On July 13, 2021, six (6) proposals were selected for funding.

Xinzhao Chu/University Of Colorado, Boulder
Observations of 2021 Antarctic Solar Eclipse from McMurdo Station for Study of the Ionosphere-Thermosphere-Mesosphere Coupling

The 4 December 2021 solar eclipse will be visible only from Antarctica and the Southern Ocean. Therefore, this eclipse will be logistically challenging to observe. We propose a unique study to observe the solar eclipse and its impacts on the meteoric metal layers in the ionosphere, thermosphere, and mesosphere (ITM) with two sophisticated Na Doppler and Fe Boltzmann lidars that have been installed and running at McMurdo Station (77.84ºS, 166.67ºE) in Antarctica. These, along with numerical simulations of the metal layers, satellite observations, and other ionospheric and magnetospheric measurements, make this solar eclipse a unique opportunity to advance the understanding of ITM coupling and meteoric metal sciences.

Permanent neutral metal layers of Fe and Na species in the upper atmosphere (~80-110 km) originate from meteoric ablation and sputtering. Thermosphere-ionosphere metal (TIMt) neutral layers above the permanent metal layers, in the altitude range from ~110 to 200 km, were discovered only 10 years ago in Antarctica and are produced from the neutralization of metal ions. These metal layers provide unique tracers for studying the solar-space-atmosphere interactions during the Dec 2021 solar eclipse event. This proposal is focused on addressing the overarching science question, Does the solar eclipse produce statistically significant variations in the Fe and Na metal layers and impact the plasma-neutral coupling in the ITM system? We will combine multi-instrument observations from McMurdo, Antarctica with numerical simulations to investigate the presence/absence of three potential impacts of the solar eclipse: 1) Solar effects on the bottom sides of Fe and Na layers that have different responses to photochemistry, 2) TIMt layer changes caused by the solar-eclipse-induced sudden and large changes in the electron and ion concentrations and plasma drift via plasma-neutral coupling, and 3) variations in the permanent Fe/Na layers and temperatures due to the changes of gravity waves induced by the supersonic motion of the Moon s shadow. Our primary datasets are data from two resonance-fluorescence lidars at McMurdo,

SuperDARN, ionosonde, magnetometer, and output from WACCM-X simulations supplemented with satellite measurements of atmospheric minor species, solar winds, etc.

By comparing the observations and simulations surrounding the Dec 4 2021 solar eclipse event with 10-years of observations at McMurdo, the proposed study will provide critical new information about the photochemistry and plasma-neutral coupling in the D and E regions of the Antarctic ionosphere. We will take a novel and interdisciplinary approach for this research by using the metal layers as unique tracers. The proposed research will integrate historical lidar data, lidar data captured during the 2021 eclipse, and various other ionosphere-magnetosphere measurements to study chemistry, neutral dynamics, and electrodynamics in the mesosphere and lower thermosphere. This is a step forward towards a grand understanding of meteoric metal layers and how they provide a unique way of exploring the connection between the Sun and Earth s atmosphere, as well as the coupling in the ITM system.

Our science objectives are highly relevant to the NASA eclipse science and to the high-level Heliophysics decadal survey goals, Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs , and Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe . The proposed study will use the eclipse as a point-response function of solar energy input to verify several important and interdisciplinary ideas regarding the photochemistry of metal species, ITM coupling, and their response to the solar and terrestrial inputs. It helps address the Heliophysics objective of understanding atmosphere-ionosphere coupling.

Shadia Habbal/University of Hawaii, Honolulu
Quantifying the plasma properties of the coronal sources of different solar wind streams with multi-wavelength observations during the 2021 December 4 total solar eclipse

Science Goals and Objectives: Total solar eclipses provide unique opportunities to explore the inner corona in an uninterrupted heliocentric distance of 1 to 5 solar radii (Rs), with an angular resolution of 1- 4 . Through multiwavelength imaging and spectroscopy, capitalizing on the outstanding diagnostic capabilities of coronal emission lines in the 350 to 1100 nm range, the basic parameters of coronal species, namely their density, electronic and ionic temperature, relative ionic abundance, outflows through Doppler shifts, as well as magnetic field topology, can be inferred over a radial span where their most pronounced evolution occurs. Not only do these parameters dictate the evolution of distinct solar wind streams starting from their sources, but are critical for space weather forecasting, and for guiding models and their validation. Total solar eclipse observations thus yield key plasma parameters in the spatial gap of existing instrumentation on ground- and space-based platforms. The goal of this proposal is to capitalize on the proven diagnostic capabilities of white light and ionic emission to

characterize the plasma properties of the sources of quiescent and dynamic solar wind streams during the 2021 December 4 total solar eclipse. The objectives are to (1) link the inner corona to in situ measurements of the solar wind to be acquired by the Parker Solar Probe (PSP) and Solar Orbiter (SolO) during their close approaches to the Sun, coupled with model studies, (2) provide precursor coronal insight for the geographically optimal 2024 total solar eclipse, (3) test seaborne equipment for eclipse observations, and (4) provide eclipse science to the widest audience possible.
Methodology: The seaborne multi-wavelength imaging and spectroscopic observations of the 2021 December 4 total solar eclipse over Antarctica will be achieved by operating our proven heritage instrumentation with stabilizing platforms, such as gimbals and hexapods, together with proven image alignment and processing tools. To infer the plasma parameters of the inner corona, the instrumentation consists of: (1) White light imagers of the inner corona yielding an angular resolution of 1 < 1.5 Rs, and 5 up to 10 Rs. (2) Multi-wavelength imaging with three pairs of identical scientific-grade CMOS cameras outfitted with 300 mm lenses, and narrow (0.5 nm) band-pass filters centered on Fe X (637.4 nm), Fe XI (789.2 nm) and Fe XIV (530.3 nm). For each pair, one element is centered on the line, while the other is centered on the neighboring continuum, shifted by 1.0 to 3.0 nm from the line-center. Operated simultaneously, subtraction of the continuum for each line pair then yields the coronal line emission. (3) Two partially-multiplexed imaging spectrometers acquiring the rich coronal spectrum over a 4 Rs slit-length in the N-S direction, with a wavelength range of 350 to 1100 nm at each pixel along the slit. The dual channel spectrometer covers the 550 640 nm and 660 1100 nm wavelength ranges, while the UV spectrometer covers 350 to 550 nm. The motion of the slit during the ~ 2 mins of totality will yield spectra over an area of ~ 4Rs x2Rs off the limb. With a spectral resolution < 0.03 nm, Doppler shifts and Doppler broadenings of 20 km/s and ~ 0.3 MK respectively, can be measured with both spectrometers. The link between these data products and in situ observations from PSP and SolO will be verified by forward modeling the identified coronal sources using fluid and kinetic plasma simulations.
Relevance to Heliophysics: The proposed eclipse observations address NASA s Heliophysics goal to understand the Sun and its interactions with the Earth and the Solar System, including space weather , and objectives to: Explore and characterize the physical processes in the space environment from the Sun to the heliopause and throughout the Universe. It will also support Investigations of the origin and behavior of the solar wind and transient structures.

Sebastijan Mrak/Boston University
The impacts of abrupt changes in photoionization on high-latitude electrodynamics

The high-latitude ionosphere is electromagnetically coupled with the magnetosphere, allowing magnetospheric currents to close, while the ionospheric conductivity controls how the currents are closed and how much energy is dissipated. One of the primary sources of the high-latitude plasma   hence conductance   is solar photoionization. A solar eclipse is a natural event that could be utilized as a laboratory experiment for studying how changing ionospheric conductivity impacts high-latitude electrodynamics and the resulting interhemispheric asymmetries. In particular, we will study the effects of abrupt spatiotemporal changes in the solar X-ray and Extreme Ultra Violet (XUV) irradiance within a penumbra. These transition regions of steep XUV changes are a projection of solar active regions on the Earth s atmosphere. The XUV energy deposition peaks in the E-region where the dissociative recombination of nitride oxide and molecular oxygen has characteristic lifetimes in the order of minutes. Thereby, the conductivity, which peaks in the E-region, changes rapidly following the trend of the XUV irradiance. The 4 December 2021 eclipse is unique in the sense it covers the whole southern polar region, so it provides an opportunity to investigate how high-latitude electrodynamics is affected by a large-scale XUV reduction and sudden XUV gradients. During the 2017 total solar eclipse, we have shown that the XUV transition regions had cross-sections in the order of 500 kilometers, where the XUV irradiance changes by 10-20%. The effects of these transition regions were measured by Global Navigation Satellite Systems (GNSS) and Defense Meteorological Satellite Program (DMSP).

The proposed research will utilize modeling frameworks, whose results will be compared against the ground- and space-based observations of plasma parameters, derived ionospheric conductivity, particle precipitation, and field-aligned currents. We will focus our efforts on one specific scientific objective: What are the impacts of steep changes in EUV irradiance on high-latitude electrodynamics and particle precipitation, and what are the resulting conjugate effects.

We will compute the eclipse occultation mask utilizing XUV images taken by Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA). The resulting eclipse occultation factors are computed as a function of geographic latitude, longitude, altitude. We will model the ionosphere-thermosphere (IT) response to the eclipse using Global Ionosphere Thermosphere Model (GITM). GITM will provide a critical diagnostic tool to determine the effects of the steep XUV changes on the IT system. GITM will provide three solutions: (1) Baseline run without any modification, (2) response to an idealized eclipse, (3) response to the eclipse using the 4D SDO-XUV mask. By comparing the three results, we will isolate contributions of the transition XUV regions.

We will compare the modeling results with ground-based Total Electron Content derived from GNSS networks in Antarctica and Northern America and in-situ satellite observations. Conjugate effects will be studied with Millstone Hill Incoherent Scatter Radar at mid-latitudes, while All-Sky Cameras will provide proxies for precipitation and conductivities. In-situ measurements using DMSP and POES will be used to measure particle precipitation, while DMSP and Swarm constellations will be used to measure plasma parameters, derived field-aligned currents, and neutral density.

This proposed study will evaluate fundamental plasma density structures in the ionosphere, thus addresses LWS program objective #1 "Understand solar variability and its effects on the space and Earth environments with an ultimate goal of a reliable predictive capability of solar variability and response", and Decadal Survey goals #2

"Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs".

Gareth Perry/New Jersey Institute Of Technology
An e-POP investigation of the ionosphere-thermosphere system's regional response to the December 4, 2021 solar eclipse

The December 4, 2021 total solar eclipse presents a unique opportunity to measure and assess the response characteristics of the Earth s coupled ionosphere-thermosphere (IT) system to an impulse-like event. The trajectory of the eclipse s umbra and penumbra, and the state of the COVID-19 pandemic make this eclipse particularly difficult for deploying and operating ground-based sensors to assess the IT system s response to the event. To overcome these challenges, we propose to use the Enhanced Polar Outflow Probe (e-POP) payload onboard the Cascade Smallsat and Ionospheric Polar Explorer (CASSIOPE) spacecraft to carry-out a one-month long campaign to investigate the IT system s regional response to the eclipse from low-Earth orbit.

CASSIOPE (hereafter referred to as e-POP) is a spacecraft with a high-inclination orbit. Current orbit projections show that e-POP will intersect the eclipse s path of totality within 30 minutes of totality on December 4, 2021, at 888 km altitude. We will use two of e-POP s instruments, the Radio Receiver Instrument (RRI) and the Global Position System receiver-based Attitude, Position, and profiling experiment Occultation (GAP-O) instrument to investigate two signatures of the IT system s response to the eclipse. First, we will search for signatures of travelling ionospheric disturbances (TIDs) in the eclipse region. Eclipse induced TIDs is a hypothesized IT system response which lacks decisive observational evidence confirming the connection. The second IT system response signature is the transformation of the region s vertical plasma density profile during the eclipse, from depletion to recovery. The proposed investigation will examine these two distinct IT system responses using two distinct instruments and techniques and modeling an interdisciplinary science investigation for the eclipse.

The proposed team, led by PI Perry, has extensive experience planning and executing interdisciplinary observation campaigns with e-POP, including several solar eclipses, with a proven track record of high impact scientific results. The team members are well versed in solar-ionosphere-thermosphere coupling physics, possess an intimate knowledge of e-POP and its capabilities, and have strong connections with the e-POP operations team and international science community, ensuring that the proposed research will be carried-out successfully.

Kevin Pham/University Corporation For Atmospheric Research (UCAR)
Impact of Eclipse on the Magnetosphere through Magnetosphere-Ionosphere-Thermosphere Coupling

BACKGROUND/MOTIVATION:
Impact of solar eclipses on the state and evolution of the magnetosphere has not been extensively studied. However, recent works using a coupled magnetosphere-ionosphere-thermosphere model demonstrated that solar flares, which were never considered in the context of the magnetosphere, appreciably disturb the structure of the dayside magnetosphere. The solar flare caused field-aligned currents to increase in peak intensity and moved the magnetopause earthward in response. Therefore, we believe that it is worth investigating to what extent the global scale effects of eclipses on the thermosphere-ionosphere system lead to changes in the magnetosphere. The main difference being that solar flares introduce a sudden global step-function change in the conductance, while eclipse-induced changes are more progressive in time and the shadow appears in one hemisphere. The 4 December 2021 total solar eclipse occurs at high latitude where magnetosphere-ionosphere coupling is most pronounced. This eclipse also occurs in the southern hemispheric summer and near solstice when the southern hemisphere is more sunlit. These conditions provide an ideal path of totality for the eclipse to influence the geospace environment.

SCIENCE OBJECTIVES:
This study aims, for the first time, to utilize global simulations to identify and characterize the potential impacts of the eclipse on the magnetosphere. The results will provide guidance for further observational investigations to confirm the model predictions. The study addresses the following three specific science questions:
1) How do changes in the electrodynamics of the system due to the solar eclipse affect the geospace coupling?
2) How does the size of the magnetosphere, as defined by magnetopause and bow shock location, change in response?
3) How do interhemispheric asymmetries of the system change in response to the eclipse shadow in the southern hemisphere?

METHODOLOGY:
We will employ the fully coupled magnetosphere-ionosphere-thermosphere geospace model, the Multiscale Atmosphere Geospace Environment (MAGE) model, to simulate the consequence of the 4 December, 2021 eclipse on the geospace environment with an emphasis on the magnetosphere. Prior to 4 December, 2021, we simulate the eclipse using typical solar wind and solar irradiance for a moderate CME and CIR storm under solar minimum conditions. Multiple simulations will be done in which the eclipse occurs at differing times; prior to, during, and after the main phase of the storms. This provides a comprehensive analysis of how the eclipse influences the geospace system. As an observational challenge, results will be made available to the research community to aid in identifying observational priorities, especially in the magnetosphere. Virtual satellites corresponding to projected positions of THEMIS, MMS, Geotail, and GOES spacecrafts will fly through these simulations. For global coverage, AMPERE and GPS derived TEC

will be examined. Comparison of predicted measurements will determine the expected signatures of the eclipse. After 4 December 2021, we simulate the geospace environment twice using the MAGE model. The first simulation uses the observed solar wind conditions and the eclipse path. The second will be conducted with observed solar wind conditions without the eclipse. Comparisons of the two simulations will isolate the impacts driven by the solar eclipse effects.

RELEVANCE:
The proposed work is directly relevant to the goals of the NASA Heliophysics Decadal Survey to Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs. The study uses the latest fully coupled geospace model to examine how the eclipse effects propagate into and influence the magnetosphere from the ionosphere and thermosphere. The study also provides the context for the widely dispersed, multi-instrument measurements in geospace.

Shun-Rong Zhang/Massachusetts Institute of Technology
2021 Antarctic Solar Eclipse: Ionospheric response in the southern and northern hemispheres

The Sun provides the ultimate energy input to geospace in several forms including solar radiation. A sudden reduction in EUV flux during a solar eclipse results in sharp decreases of both photoabsorption by neutral constituents and ionospheric photoionization. Supported by the 2017 NASA ISE program and other agencies' programs, we conducted a series of eclipse studies resulting in 10+ peer-reviewed papers. Highlights include observations of eclipse-induced bow-shaped ionospheric waves, dynamic and photochemical changes in the midlatitude ionosphere over Millstone Hill (MH), conjugate effects, and studies of three recent eclipses in 2019 and 2020.

The December 2021 Antarctic eclipse will provide a very unique geographic configuration with great potentials for community understanding of ionosphere-thermosphere-plasmasphere (I-T-P) coupling during a sudden reduction in solar irradiation. The Moon's shadow path will sweep through the area containing the well-known Weddell Sea ionospheric anomaly (WSA), where diurnal maximum electron density in December (southern summer) occurs not during the day but at night even though the Sun remains above the horizon. This will provide an unprecedented opportunity to revisit a classical ionospheric mystery in the Antarctic.

The Moon's shadow will pass near Palmer on the Antarctic Peninsula, magnetically conjugate to the MH incoherent scatter radar (ISR) site near Boston. Previous MH observations have noted a predawn wintertime electron temperature (Te) enhancement, explained in terms of impact from conjugate photoelectrons originating near Palmer. The 2021 Antarctic eclipse will allow us to examine the predawn conjugate photoelectron impact, as eclipse modulations in photoelectron production due to the Moon's shadow rapidly turn the Antarctic photoelectron source on and off.

We propose to use this extremely rare observation opportunity to investigate two I-T-P coupling questions: [Q1] What are the magnetically conjugate effects of the Antarctic eclipse? In particular, [Q1.1] are there any changes in conjugate predawn Te, Langmuir mode visibility from photoelectron flux changes, and 630 nm redline brightness? [Q1.2] Are there any conjugate TEC variations? [Q2] What is the solar eclipse impact on the WSA? Can observations of eclipse ionospheric responses help understand WSA candidate driving mechanisms: zonal and meridional winds (perturbed also by the Moon's shadow) and photoionization?

We will analyze multiple observational datasets, including [1] MH ISR ionospheric altitude profiles and Langmuir mode ("plasma-line") F2 peak brightness; [2] MH FPI relative brightness; [3] GNSS TEC observations in the Antarctic region and its conjugate region; and [4] GOLD daytime O/N2 observations. A 5-day MH ISR campaign centering on the eclipse day will be conducted. These data [1-2] will be combined with historical data near sunrise to explore (Q1.1) conjugate photoelectron impact as manifested in Te, Langmuir mode brightness, and redline brightness. Data [3] will be also used to examine conjugate TEC variations (Q1.2). Data [3] will be further used for eclipse effects on WSA regional TEC (Q2). Data [4] from GOLD, related to Q2, will be used to understand neutral composition response to the eclipse and its contribution to the WSA.

This proposal directly addresses ISE 2021 program goals of connecting eclipse effects to ITM system studies, as WSA and conjugate photoelectron impacts remain active ionospheric research topics in the Heliophysics community. It addresses a key Heliophysics research objective to explore and characterize physical processes in the space environment from the Sun to the heliopause and throughout the universe.