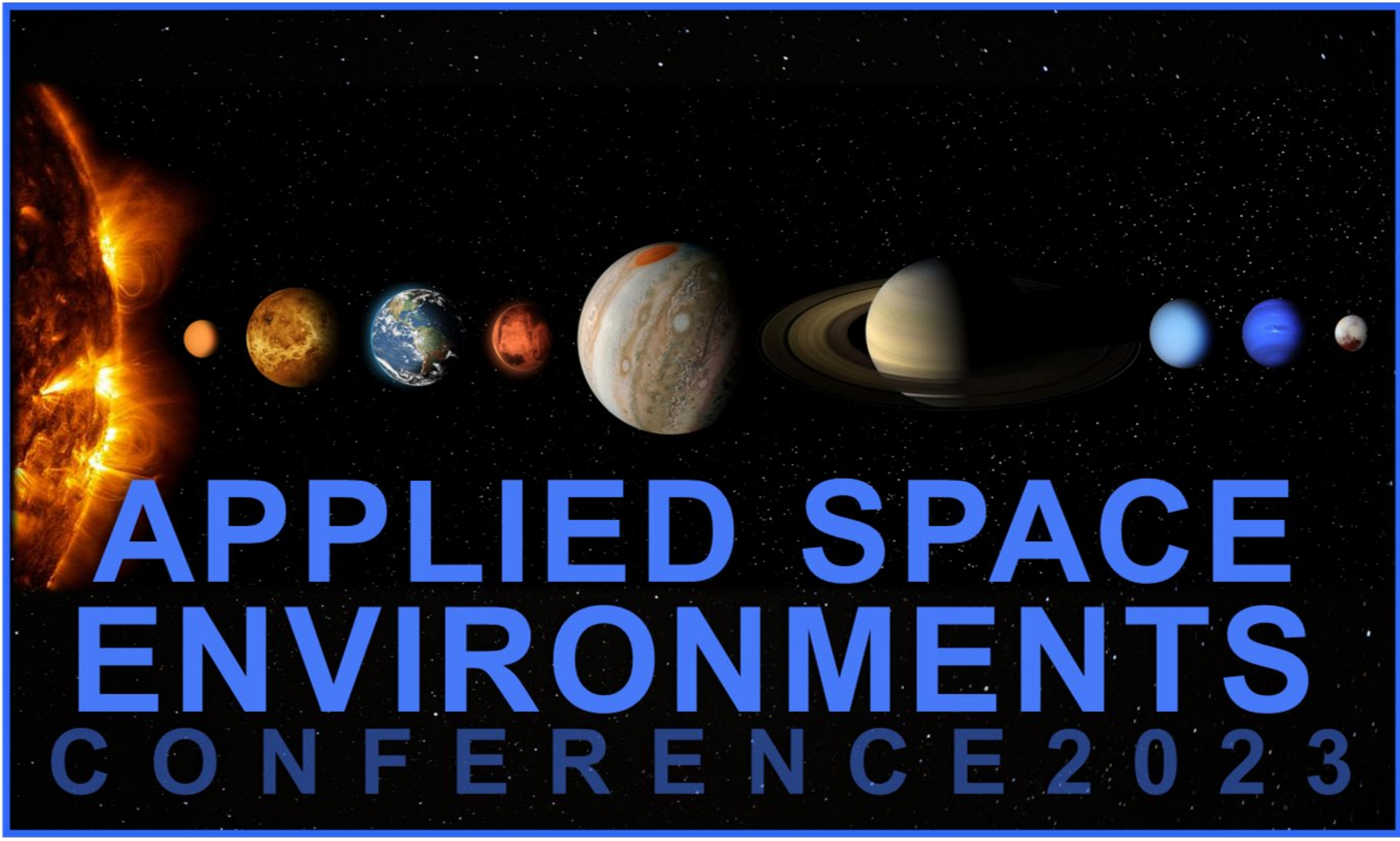


ASEC2023 Book of Abstracts

Monday, October 9

Session: Welcome and Keynote

KEYNOTE: NASA s Space Weather Program

Mr. Jamie Favors, NASA Headquarters

NASA's Heliophysics Division focuses on studying the nature of the Sun, and how it influences the very nature of space throughout the solar system and interactions with Earth and other planetary bodies. The NASA Space Weather Program, as part of the Heliophysics Division, expands the role of NASA in space weather science and application through applied research activities, flight missions, and space weather analysis for operational uses. This presentation will review the NASA Space Weather Program and highlight key activities of interest to the space environment engineering and applied space science community.

Session: Lunar Environments I

Lunar Gateway Charging and Effects on Low-Energy Electron Measurements

Dr. Miles Bengtson, Aurora Engineering, Dr. Alex Barrie, Aurora Engineering,
and Dr. Dan Gershman, NASA GSFC

The Electron Electrostatic Analyzer (EEA) is part of the HERMES instrument suite on Lunar Gateway and is designed to measure electrons in the energy range from 1 eV to 18 keV. Electrons in this range can be deflected or blocked from entering a detector by electric fields from a charged spacecraft platform, so many heliophysics missions (MMS., Cluster, etc.) use active potential control to minimize stray electric fields which would corrupt low-energy plasma measurements. Gateway, however, does not have such capabilities so the surface charging effects will influence the electron data. Further, some elements of Gateway partially block the instrument s field of view to space. The effects of the Gateway platform on the low-energy electron population must be understood to maximize the accuracy of the EEA data.

To investigate the electrostatic environment near Gateway and its effects on the EEA measurements, we use Nascap-2K to model the expected charging of Gateway under representative solar wind, magnetosheathic, and magnetospheric conditions. Next, we use the potential and electric field outputs from Nascap-2K along with in-house particle tracing codes to investigate how low-energy electrons are perturbed, blocked, or deflected by the spacecraft. We discuss how these perturbations impact the plasma moments computed from the EEA data and possible approaches for correcting the charging effects. In addition to electrons from the space environment being influenced by the electrostatic environment around Gateway, photoelectrons generated on Gateway surfaces will also be measured by EEA. We are investigating how knowledge of the potentials of various Gateway surfaces can be extracted from these measured photoelectrons using advanced numerical modeling and analysis. Such information would be valuable for validating charging models and planning mission operations around the platform.

Finally, we discuss how the specific workflow developed for Gateway can be extended to a generalized process that is applicable to other future missions. As the space industry prepares for human exploration beyond low-Earth orbit, the need to obtain accurate space weather data from rideshare science payloads is critical. Our process for removing platform effects from the science data serves as a pathfinder for leveraging advanced simulations to maximize science returns and ensure the safety and success of future crewed missions.

Lunar Electrostatics and Dust Mitigation Tool

Dr. Charles R. Buhler[1], Mr. Jerry J. Wang[1], Mr. Aaron B. Curry[2], and Mr. James R. Phillips III[1]
[1]Electrostatics and Surface Physics Laboratory, NASA Kennedy Space Center,
[2]Amentum Aerospace

Electrically charged and chemically reactive lunar dust can cause serious problems to spacecraft, surface equipment, and astronaut health, so understanding its interaction with and transport through the lunar plasma environment is important to dust mitigation efforts. We explore the charging of granular material in the natural environment of the Moon, recreate those conditions in the laboratory under high vacuum, and examine dust transport and charge neutralization for application in future lunar missions.

Phenomena such as charge deposition via electron and ion beams, photoionization through ultraviolet light exposure, neutralization of charge through impingement by an ionized compressed gas, and tribocharging during dust liberation from surfaces will be presented. Surface materials of interest such as floating/grounded conductors and orthofabric for spacesuits are the preliminary focus of this effort. An electrometer is used to characterize currents interacting with the surfaces in the case of the electron/ion/UV source exposure, an electrostatic voltmeter is used to measure the potential on the surfaces without inadvertently discharging them, and a charge plate monitor is used to verify the efficiency of discharging the surfaces via ionized gas impingement.

After setup of the initial charge conditions on the surfaces, a quick burst of high-pressure gas is used to overcome adhesion forces and initially dislodge the dust from the surfaces, followed by a low flow of gas that is ionized via application of a strong electric field. The gas is released in a high vacuum environment so as the pressure drops from the initial compressed state through to the vacuum state, the mean free path reaches a point where ionization can occur before all the gas disperses into the vacuum. This ionized gas can then neutralize both the dust and the surface to ensure minimal resettling. Several parameters such as gas composition, electrode geometry, high voltage waveform shape/polarity, and pulse timing have been explored and will be presented here.

Modelling and ground testing of lunar dust simulant electrostatic charging under VUV irradiation

Dr. Rémi Pacaud[1], Dr. Jean-Charles Matéo Vélez[1], Dr. Sylvain Ranvier[2], Mr. Martin Spohr[1],
Dr. Paul-Quentin Elias[1], Mr. François Issac[1], and Mr. Gael Murat[1]
[1]ONERA -The French Aerospace Lab, [2]BIRA-IASB

Committed for nearly 10 years to the study of electrostatic charging and adhesion of dust in space, ONERA conducts several studies with ESA and the EU through dedicated experimental facilities.

Apollo missions revealed how much dust is problematic, making the safety of future long-term lunar activities a difficult challenge. The absence of atmosphere and the constant ionizing radiation favors a very strong electric charge and a chemical reactivity that make dust stick to almost everything. To protect and preserve the mechanisms, optics, thermal control coatings, sealing and health of astronauts, it is of paramount importance to understand the underlying charging mechanisms of dust under a representative environment, both numerically and experimentally.

ONERA has developed characterization means in order to tackle the problem from several angles. The DROP platform, located in Toulouse, houses a vacuum chamber (under 10^{-6} mbar) that reproduces the lunar radiative environment (VUV and electron irradiation), a centrifuge for adhesion characterization and a dust deposition chamber with controlled uniformity and coverage rate, validated on a series of powders simulating lunar regolith. This platform is useful to investigate several questions, from the charging behavior of lunar dust simulants under VUV/electron beam to the adhesion forces on technical space-grade materials.

The upcoming lunar missions offer unique opportunities for in-situ characterization of the charging mechanisms. ONERA is currently involved in the design and testing of a compact multisensor instrument for in situ analysis of lunar dust properties in the frame of an EU-funded project led by BIRA-IASB in Belgium. The goal is to develop by the end of 2024 a sensor package, which will include a dust charge detector, a Langmuir and an E-field probe, for charge and size measurements of single dust particles. Our study focuses on the charge detector which is a polarized Faraday cup connected to a transimpedance amplifier (10^{11} V/A gain, 200 Hz bandwidth) and a digitization stage. Measurements are done with a 6 mm thick layer of JSC-1A. The background noise is low enough to measure charges of dust particles on a regolith surface after VUV irradiation with a precision of the order of 1 fC. The time evolution of the signal is compared to numerical models in order to estimate the velocity and mass of dust particles, which could give valuable information about the charge over mass ratio. Additional cross-comparisons with numerical simulations obtained with SPIS-DUST, a 3D numerical tool developed at ONERA, are in qualitatively good agreement with the experimental data: we show that both positively and negatively charged particles are measured after VUV irradiation, which was not observed in previous experimental studies. This study thus paves the way for future lunar exploration missions that will require accurate measurements of the electrostatic properties of the lunar ground and allow us to define better safety margins.

Knowledge Gaps for Human Lunar Exploration Design Environments

Dr. Robert Suggs and Dr. Emily Willis
NASA Marshall Space Flight Center

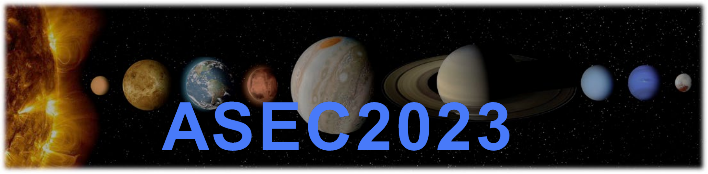
The Cross-Program Design Specification for Natural Environments (DSNE SLS-SPEC-159) specifies the natural environments which must be designed for by Artemis Programs which includes Human Landing System, EVA and Human Surface Mobility Program (EHP, spacesuits and rovers). It is a compendium of information gleaned from Apollo and various unmanned lunar programs. There are a number of technical areas where insufficient measurements were made during the previous missions and our design environments are based on modeling and hence are very uncertain. This talk will describe those environments where further measurements and modeling are needed such as lunar surface plasma and electrostatic environments (including during the lunar night), some regolith geotechnical properties, and meteoroid ejecta characteristics.

Session 3: Radiation I

INVITED: LRO CRaTER and the Radiation Environment Measured near the Moon

Dr. Harlan Spence and Ms. Sonya Smith
University of New Hampshire

NASA established the Lunar Reconnaissance Orbiter (LRO) mission's initial goals to be responsive to the NASA Authorization Act of 2005 and to NASA s 21st Century Vision for Space Exploration (VSE), namely, to enable a safe return of humans to the Moon. LRO s science payload consists of seven instruments designed to quantify various aspects of the lunar terrain and environment needed for human exploration of the Moon. One of those instruments, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), characterizes the radiation environment principally owing to energetic charged particles. In operation since 2009, LRO and the CRaTER instrument continue to support needs of the space exploration community as well as to provide novel measurements fueling planetary and space science discovery. We describe how CRaTER measures the linear energy transfer (LET) of energetic particles traversing the instrument, a quantity that describes the rate at which particles lose kinetic energy as they pass through matter. A significant portion of the kinetic energy converts into deleterious ionizing radiation through the interactions with matter, thus posing a radiation risk for human and robotic space explorers subjected to deep space energetic particles. CRaTER employs strategically placed solid-state detectors and tissue equivalent plastic (TEP), a synthetic analog for human tissue, to quantify radiation effects pertinent to astronaut safety. These same measurements also enable rich opportunities for science studies. We present a retrospective of measurements of and findings about the radiation environment in low-altitude lunar orbit during its more than 14 years in operation. This time period covers nearly one and a half solar cycles, providing not only a comprehensive views of impulsive solar particle events, but also trends in galactic cosmic rays modulated by longer-term solar variability. We review a number of emerging synergies between how exploration enables science and how science enables exploration from the point-of-view of space radiation. The physics, chemistry, and biology of ionizing radiation caused when energetic particles pass through matter remains one of the most significant risks to human exploration. The processes which accelerate and transport these charged particles remains a vibrant topic of study in space plasma physics. The role that these particles play in modifying the surfaces of solar system bodies has emerged as an important new area in planetary science. Through related studies since LRO s launch, we demonstrate how these intertwined topics are driven by exploration needs, which in turn have fueled scientific discovery in multiple parts of the scientific community. CRaTER results discussed include: depth-specific dose and dose rates from both galactic cosmic ray, solar particles, and lunar particle "albedo"; estimates of permissible mission duration for human safety; and multiple consequences of space radiation in modifying the lunar surface environment.



Estimating Electron Dose in Geostationary Orbit from GOES Fluxes: an Accuracy Assessment

Dr. Juan Rodriguez[1], Dr. Michael Denton[2], and Dr. Athanasios Boudouridis[1]
[1]University of Colorado CIRES, [2]Space Science Institute

The Energetic Particle Sensors (EPS) on GOES 8-15 provided a record of the relativistic electron flux in geostationary orbit during more than two solar cycles, from January 1995 to March 2020. Although limited to three wide-field-of-view integral channels (nominally >0.6, >2 and >4 MeV), this record if properly characterized could serve as the basis for a comprehensive model of electron dose in geostationary orbit over a wide range of activity levels and solar wind drivers. Starting with GOES-16, the new radiation belt instrument, Magnetospheric Particle Sensor - High Energy (MPS-HI) includes two hemispherical dosimeters (100 and 250 mil Al shielding, respectively 0.686 and 1.72 g cm^{-2}) similar in design to those that flew on the Combined Release and Radiation Effects Satellite (CRRES), from which the CRRESRAD dose model was derived. Electrons of >1.2 and >2.8 MeV can penetrate these shielding thicknesses, and bremsstrahlung from these and lower energies also contributes to dose. MPS-HI also measures the electron energy spectrum using five solid state telescopes reporting twelve channels from 0.07 to 4.4 MeV. From mid-November 2018 to early March 2020, when its space weather monitoring role ceased, GOES-15 was separated from GOES-17 by only 9 degrees (0.6 hours in local time). This period provided an unmatched opportunity to validate dose calculations using the SHIELDOSE-2 model. Differential spectra derived from the GOES-15 EPS integral channels, and omnidirectional averages of the GOES-17 MPS-HI differential spectra, were used as input to the SHIELDOSE-2 model and the outputs compared with the GOES-17 dosimeter observations. Several conclusions can be drawn from this validation study. First, the dose under 100 mil Al is dominated by electrons that penetrate the shielding while the dose under 250 mil Al is from bremsstrahlung alone below ~3 MeV incident energy. Second, while EPS and MPS-HI report ~4 MeV electron fluxes above backgrounds infrequently, an accurate estimate of the electron spectrum up to ~4 MeV is required for an accurate dose calculation under elevated flux conditions. Third, a single relativistic Maxwellian, used in past publications to convert EPS integral electron fluxes to differential spectra, is not accurate when fluxes (and therefore dose) are highly elevated, and therefore a more complex spectral retrieval is required. When the GOES data are treated carefully based on these validation results, they may serve as the basis for an accurate electron dose model for geostationary orbit.

Space Ionizing Radiation Environment and Effects Advance Climatology (SIRE2-AC) Toolkit

Dr. Zachary Robinson[1], Dr. James Adams[1], Dr. Paul Boberg[1], Mr. Wally Westlake[1], Dr. Jonathan Fisher[1], Mr. Jonathan Fisher[1], Dr. Joseph Nonnast[1], Mr. Jeren Suzuki[1], Mrs. Haley Cole[1], Dr. Donald Smart[2], Dr. Margaret Shea[2], Mr. Zachary Lane[1], Dr. David Terry[1], Mr. David Hope[1], Dr. Robert Reed[3], Dr. Brian Sierawski[3], Dr. Vladimir Kolobov[4], Mr. Ashok Raman[4], Dr. Robert Arslanbekov[4], Mr. Jeremy Martin[4], and Mr. Carter Grimmeisen[4]

[1]Fifth Gait Technologies, Inc., [2]SSSRC, [3]Vanderbilt University, and [4]CFD Research Corporation

The Space Ionizing Radiation Environment and Effects (SIRE2) toolkit was developed to provide the space radiation environment and effects community with state-of-the-art models that can be used not just for satellites but also for arbitrary trajectories. SIRE2 Advance Climatology (SIRE2-AC) provides the space radiation community with a tool that can calculate the environment at a spacecraft that is on a trajectory in the inner Solar System. The SIRE2-AC tool utilizes the SIRE2-RISCS database of modeled SEPs to allow for environment calculations using historical SEPs as the solar radiation component of the environment.

In addition, SIRE2-AC will also include a cumulative mission fluence model that can be used for trajectories in the inner Solar System. The SIRE2-AC fluence model will provide a fluence spectrum for a user defined trajectory at a user specified confidence level. The approach used to create this model will be discussed in detail at the conference.

SIRE2-AC expands the radiation transport capabilities in SIRE2 to allow for complex shielding configurations to be specified for a calculation inside of SIRE2 to enable human dose calculations. The complex shielding configurations include multiple different shielding material layers and 3D shielding designs. The High Charge and Energy Transport (HZETRN2020) code is used inside the SIRE2-AC tool to calculate the transported radiation and the human dose.

Radiation Monitoring from the Atmosphere to the ISS - the ARMAS Radiation Database as a Global Baseline

Dr. W. Kent Tobiska, Space Environment Technologies

Radiation hazards at commercial aviation altitudes up to suborbital space have been known for decades including those from galactic cosmic rays (GCRs), solar energetic particles (SEPs), and more recently phenomena associated with radiation belt particle precipitation (RBPP). The complex radiation field that derives from these primary particle sources creates safety concerns for aerospace crew and passengers. Because of this safety hazard, the Automated Radiation Measurements for Aerospace Safety (ARMAS) program was developed to provide global aerospace radiation environment monitoring. The ARMAS operational system has now achieved monitoring from the surface of the Earth into Low Earth Orbit (LEO) with aircraft, high altitude balloon, suborbital vehicle, satellite and ISS flights over the past year. We present the latest results from i) the various flight domains (ISS in 2022 with 21 underflight aircraft conjunctions); ii) the calibrations of the ARMAS system with the Tissue Equivalent Proportional Counter (TEPC); iii) the ongoing real-time data assimilation of ARMAS data into the RADIAN system using NAIRAS v2 baseline global data and CARI-7 verifications; and iv) the development of an online ARMAS global database for scientific research. We also describe progress towards 24/7 atmospheric monitoring from both the perspective of new sensor development as well as new stratospheric monitoring platforms. We present this talk in the context of validation and performance assessment for radiation monitoring and its transition to operations.

NAIRAS Atmospheric and Space Radiation Environment Model

Dr. Christopher Mertens[1], Dr. Guillaume Gronoff[1], Dr. Yihua Zheng[2], Dr. Maksym Petrenko[2],
Dr. Daniel Phoenix[1], Dr. Janessa Buhler[3], Dr. Emily Willis[4],
Dr. Insoo Jun[5], and Dr. Joseph Minow[4]

[1]NASA Langley Research Center, [2]NASA Goddard Space Flight Center, [3]NASA KSC,
[4]NASA Marshall Space Flight Center, [5]Jet Propulsion Lab

The Nowcast of Aerospace Ionizing RAdiation System (NAIRAS) model is composed of coupled physics-based models that transport ionizing radiation through the heliosphere, Earth's magnetosphere, the neutral atmosphere, and aircraft and spacecraft shielding. The three sources of ionizing radiation included in the model are: (1) the ubiquitous galactic cosmic rays (GCR) with origins outside the solar system, (2) solar energetic particles (SEP), including heavy ions, arising from transient solar eruptive storm events, and (3) the inner radiation belt trapped protons (TRP). The transmission of GCR and SEP ions through the geomagnetic field includes the dynamical influence of the interplanetary plasma and magnetic field. The NAIRAS model predicts dosimetric quantities and differential and integral flux and fluence quantities for assessing human radiation exposure and single event effects (SEE) in vehicle electronic systems from the Earth's surface to the space environment. The recent NAIRAS version 3.0 is running at the Community Coordinated Modelling Center (CCMC), where the model now operates in two modes: (1) real-time global predictions of the atmospheric radiation environment (0-90 km), and (2) run-on-request (RoR) mode which allows the end-user to select a specific time-period for global dosimetric calculations, or to upload an aircraft, balloon, or flight trajectory file to provide predictions of dosimetric and radiation flux quantities along the flight path. NAIRAS predictions of the ionizing radiation environment are shown for various space weather conditions in the atmosphere and in low-Earth orbit (LEO), medium-Earth orbit (MEO), and cislunar orbit. NAIRAS model comparisons with dosimeter measurements are shown for commercial and high-flying aircraft, stratospheric balloons, and various spaceflight platforms.

Session 4: Charging I

INVITED: CROCUS Mission Development Status

Dr. Jean-Charles Mateo-Velez, Dr. Pierre Sarrailh, Mr. François Issac, Dr. Jean Guérard,
Mr. Vincent Lebat, Mrs. Marine Dalin, Mr. Damien Boulanger, Mr. Ratana Chhun, Dr. Julien
Jarrige, Mr. Gael Murat, Mr. Patrick Kayser, Mr. Adam Traore, Mr. Antoine Guilmain,
Dr. Ludivine Leclercq, Mr. Léon Tran, and Mr. Yoann Bernard-Gardy
ONERA -The French Aerospace Lab-

A few tens of percents of spacecraft anomalies reported in flight are attributed to electrostatic discharges (ESD) on modern spacecraft including large telecom or scientific spacecraft. The advent of nanosatellites renews the question since the design guidelines related to charging and ESDs can be more difficult to follow due to an accelerated time to market. To prepare the future, there is thus a need to improve our knowledge on the conditions leading to ESDs and of their effects on small platforms.

The ChaRging On CubeSat (CROCUS) project driven by ONERA in partnership with Centre Spatial de l Ecole Polytechnique (CSEP) prepares the flight demonstration of new generations of instruments dedicated to charging, discharging and mitigation assessment. The LEO sun-synchronous targeted orbit offers several auroral ovals crossing each day with higher probability to generate high surface charging levels.

The aim of this communication is to present the status of the CROCUS development. The Sensing Impulses and Mitigation on CubeSat (CubeSIM) payload, currently in development phase C, is composed of a series of instruments. TWIST detects the occurrence of ESDs. CPA monitors differential charging. SPARK tests TWIST by mimicking ESD transient waveforms. MISTEEC increases the probability to get high charging levels and trigger ESDs. SCAPEE alleviates spacecraft charging and reduce ESD risks. ECLAIR artificially generates high level of surface charging to test all the instruments in quiet periods of time. We will present the results of an experimental campaign conducted in the JONAS plasma chamber. We will show the global architecture of the 3U satellite bus, currently in phase B, that will integrate the payload.

A New Approach to IESD Arc Modeling: Test Data and Simulations

Mr. James Chinn, Dr. Wousik Kim, Dr. Allen Andersen,
Mr. Dennis Thorbourn, and Mr. Eduardo Martin
JPL, NASA

Internal Electrostatic Discharge, or IESD, is a radiation effect that can pose a problem for spacecraft that operate in trapped electron environments, such as those around Earth and Jupiter. Electrons trapped around these planets interact with spacecraft, depositing charge in insulating materials and electrically floating metals, in some cases even penetrating spacecraft structures to deposit charge internal to electronics boxes. If electrical charge accumulates faster than it bleeds away, then an electric field develops in the material, eventually resulting in an electrostatic discharge (ESD) if the field surpasses the material's dielectric strength. Insulating thermal control materials, wire insulation, and circuit board materials are all examples of potential IESD threats.

Evaluation of the IESD risk of any particular spacecraft component typically consists of five steps. First, a model of the radiation environment is generated for the spacecraft trajectory. Second, a radiation transport model is built to determine how the encountered radiation will propagate through the spacecraft geometry. Third, the buildup of charge over time is calculated to determine whether or not an ESD event is expected. Fourth, parameters for the ESD event are generated based on the materials and geometry. Fifth, the arc parameters are compared against the ESD sensitivity of electronic components interfaced with the arc source.

This report presents data and simulation results that support a new approach to IESD arc modelling (step 4 from the previous paragraph), leveraging advancements in internal charging modeling provided by the development of tools like 3D NUMIT (step 3), and incorporating to a greater extent the circuit modelling described in step 5. At a high level, the approach assumes an RC arc model, but does not force the component values to that of any particular standard (Human Body Model, Machine Model, etc.). The source voltage is taken from an internal charging simulation of the material (3D NUMIT) at the point the electric field surpasses the dielectric strength. For this particular investigation, the source capacitance and internal resistance were estimated for a common spacecraft geometry a wire with a conductive overwrap using test data from nine configurations: PTFE, ETFE, and PEEK wires, each with 50 Ω, 5 kΩ, and 10 MΩ terminations. Precise impedance measurements were made of the test article and measurement equipment, and the full setup was modeled as a circuit in Advanced Design System (ADS). For the most part, a circuit model was found for each test article that was consistent with the expected dielectric strength, previous estimates of wire discharge length, and the observed arc magnitude and duration for all three termination sizes.

This new approach explains some previously difficult IESD test data for high impedance terminations and promises to be a more accurate, less conservative approach to IESD modeling going forward. Future work is planned for similar tests and simulations of different materials and geometries (e.g. circuit boards).

The Knowledge Check in NASA Charging Handbook, NASA-HDBK-4002B

Dr. Wousik Kim[1], Dr. Allen Andersen[1], Mr. James Chinn[1], Dr. Henry Garrett[1],
Mr. Albert Whittlesey[1], and Mr. Frankie Wong[1]
[1]Jet Propulsion Lab, [2]Caltech

Spacecraft charging, defined as the buildup of charge in and on spacecraft materials, is a significant phenomenon for spacecraft in certain Earth and other planetary environments. Space charging effects are caused by interactions between the in-flight plasma environment (mostly electrons) and spacecraft materials and electronic subsystems. In fact, surface charging/discharging and Internal Electrostatic Discharging (IESD) have been identified as the primary causes of several spacecraft anomalies and failures. Spacecraft charging can cause disruption of or damage to subsystems (power, navigation, communications, instrumentation, etc.) because of charge buildup and electrostatic discharge. Charged surfaces can also attract contaminants, affecting thermal properties, optical instruments, and solar arrays, and can change particle trajectories, thus affecting plasma-measuring instruments.

In 2011, Henry Garrett and Albert Whittlesey merged two existing charging handbooks, (1) NASA TP2361, Design Guidelines for Assessing and Controlling Spacecraft Charging Effects (1984) for surface charging and (2) NASA-HDBK-4002, Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects (1999) for internal charging. The new combined handbook was titled NASA-HDBK-4002A, Mitigating In-space Charging Effects a Guideline. NASA-HDBK-4002A contains details of spacecraft design procedures for minimizing the detrimental effects of spacecraft charging and for limiting the effects of the resulting electrostatic discharge, and has served as the primary document for evaluating, testing, and mitigating surface and internal charging effects.

Recently (in 2022), a revised NASA charging handbook, NASA-HDBK-4002B, was published to reflect advances in electron environment definition, modeling methods, and laboratory tests that are now widely accepted. These are advances that have occurred since the last handbook revision in 2011, and have been presented in 4 major spacecraft charging conferences. There are several major updates and improvements in NASA-HDBK-4002B. Among those are Knowledge Check questions at the end of each chapter, which ask the reader to apply the general rules in the handbook to specific missions, to recall important parts of the chapter, to practice using or derive presented equations, and to understand the myriad unit conversions that still exist in the non-MKS world of spacecraft charging.

This paper presents some major examples of Knowledge Check questions and suggested solutions. The suggested solutions for most of the Knowledge Check questions will be posted in a JPL repository.

Design of the SunRISE Spacecraft and Mission for Radiation, Charging, and Upset Mitigation in Near Geosynchronous Equatorial Orbit

Mr. Ryan Martineau, Mr. Blake Rusch, Mr. Kelly Juhasz, Mr. Cameron Weston,
Mr. Craig Thompson, and Mr. Tim Neilsen
Space Dynamics Laboratory

SunRISE is a NASA Heliophysics mission using six identical 6U spacecraft in geosynchronous equatorial orbit (GEO) graveyard, about 400 kilometers above geosynchronous altitude. The six spacecraft will fly within about 10 km of each other forming a radio interferometer. SunRISE will image the Sun and inner heliosphere in a portion of the spectrum that is blocked by the ionosphere and cannot be observed from Earth (100 kHz to 23 MHz). SunRISE utilizes the GEO graveyard orbit to be well out of Earth s atmosphere, which would distort the images, and to reduce interference from Earth-based radio frequency sources.

In this paper, we present SunRISE as a case study in balancing competing technical, risk, and cost constraints as a cost-capped, tailored risk Class D Mission of Opportunity subject to CubeSat volume constraints. We present the material evaluation methods used to assess the risk of destructive discharge and the design features present in the integrated spacecraft. The chosen evaluation methods and design features are implemented to mitigate charging and radiation effects by approaching best practices while minimizing the costs of mission-unique analysis and testing. We discuss the operational design and upset-tolerant approach to continuous observation through redundancy and autonomous recovery.

As of September 2023, SunRISE has completed development and is pending delivery to short-term storage awaiting launch currently scheduled for Q3 2024.

Tuesday, 10 October

Session 6: Testing and Instrumentation

Establishment of a Ground-Based Testing Facility for Simulating Space Plasma:
- Vacuum Facility Assessment

Mr. Emmanuel Kofi Asuako Wie-Addo, Mr. Jacob Ortega, and Dr. Daoru Han
Missouri University of Science and Technology

INTRODUCTION
In the past, research on plasmas in the context of space environments heavily relied on costly rocket and satellite missions such as the Magnetospheric Multiscale Mission (Sharma and Curtis, 2005) and the THEMIS mission (Angelopoulos, 2008). To Complement these in-situ space investigations, ground-based facilities, used to simulate space environment conditions have proven

to be reliable and cost effective. From small experimental facilities to very large ones, it has been possible to study the interaction of orbiting spacecraft with ionospheric plasma (Stone, 1981) (Hastings, 1995), the technological readiness of payloads (Maldonado et al.,2015), atomic oxygen-material interaction (Banks et al., 2004), and LEO electrical break-down threshold (Cho et al., 2002), to name a few.

METHODOLOGY

To assess the fidelity of Missouri S&T's vacuum facility at the Gas and Plasma dynamics Lab (GPDL), the performance of a 10 ft x 6 ft vacuum chamber has been assessed. In addition, a 3-axis moving platform has been developed for the precision translation of diagnostic probes to enable extensive characterization of the simulated plasma environment. For a preliminary test, an in-house cylindrical Langmuir probe was positioned 10 inches downstream of a magnetic filter-type low Earth orbit (LEO) plasma source. The measured plasma parameters compare very well with actual LEO conditions, guaranteeing the readiness of the vacuum facility to simulate space plasma conditions. Currently undergoing upgrades with thermal and cryogenic systems, GPDL looks forward to verifying several numerical studies as well as studying synergistic effects.

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Integrated Space Environmental Testing Facility

Mr. Matthew Beckerle[1], Mr. Ethan Kravet[1], Mr. Mohnish Umashankar[1],
Dr. Callie Zawaski[2], Dr. Michael Zugger[2], and Dr. Sven Bilén[1]

[1]The Pennsylvania State University,
[2]The Pennsylvania State University Applied Research Laboratory,

The Space Propulsion and Environments Lab (SPEL) at The Pennsylvania State University has developed an extensive suite of space environmental testing capabilities for space qualification of subsystems and small satellites, material characterization, and research on in-space propulsion systems. Current and planned testing capabilities include outgassing assessment, thermal vacuum, vibration, atomic oxygen degradation, spacecraft charging, plasma interactions, simulated orbital debris impacts, solar ultraviolet, and magnetic field interactions. Having all these capabilities in one facility provides a readily accessible hub to qualify satellites and their components for a multitude of space environmental requirements. SPEL can provide end-to-end space environments testing and analysis in-house, providing a comprehensive service for space qualification.

The lab contains small, medium, and large vacuum chambers to facilitate this testing. A large vacuum chamber (5' diameter x 8' length) houses a 20-ft^2 cold plate and is intended for thermal vacuum testing of nano- to small-sats and other large components and subsystems. An atomic oxygen (AO) source can be fitted within this chamber to enable material degradation testing. A dedicated thermal vacuum chamber (2.5' diameter x 3.25' length) is an insulated chamber with a cold plate connected to a chiller capable of -80 to +250° C with programmable temperature profiles and indefinite cycling times. A Low Earth Orbit (LEO) chamber (3' diameter x 3.5' length) has an adjustable-aperture, low-density plasma source that simulates the environment found in LEO. This allows for simulating the effects of spacecraft charging and surface erosion due to the plasma environment. The density provided in the chamber ranges from 0.07 to 2.2 x 10^{13}m^{-3}, with a nearly constant electron temperature over the density range. Also, a high-energy laser is used to simulate micrometeoroid and orbital debris (MMOD) impacts by creating craters and ejecta like traditional grain cannons. A small hypersonics chamber houses an arcjet whose high-density plasma plume is used to simulate the plasma conditions upon atmospheric reentry and hypersonic flight. These chambers can perform outgassing tests, including collected volatile condensable materials (CVCM) using a quartz crystal microbalance. Our chambers are capable of achieving pressures below 10^{-8} Torr.

SPEL also partners with Penn State's Microwave Engineering Lab, which houses an anechoic chamber suitable for testing antennas and EM components in the P, L, S, C, X, Ku, K, and Ka bands using a 4-channel VNA and various calibrated horns. The roll plate in the anechoic chamber can scan in 360° in both the azimuth and elevation, allowing for full 3D scans of the propagation patterns to be visualized with a custom data collections program. The Applied Research Laboratory houses vibration testing equipment including a shake table (2' x 2' shaker head and plate), which is capable of 12-g GEVS and similar launch profiles, as well as shocks of up to 30 g with a deflection of 1 inch.

Additional capabilities and diagnostics of SPEL include Langmuir probes, Faraday cups, high-speed camera, and retarding potential analyzer.

Characterization of Electrons in the Space Environment with X-Ray Spectroscopy

Mr. Samuel Westrick, Universities Space Research Association, Dr. Miles Bengtson, Aurora Engineering, and Mr. Ryan Hoffmann, Air Force Research Laboratory

There is a need to develop low SWaP (size, weight, and power) instrumentation to characterize the total flux and energy distribution of electrons present in the space environment. The electron flux and energy distribution vary widely over time and contribute to many spacecraft anomalies. However, the current state-of-the-art characterization of electron flux and energy relies on instrumentation that is bulky and power hungry, making it unsuitable for space architecture that has transitioned to small satellite constellations over the past decades. While conventional instruments for electron characterization have mass and size limits that prohibit them from being implemented on small satellites, gamma ray and x-ray detectors that are small and lightweight have been successfully used on CubeSats. X-ray detectors also commercially available while conventional electron instruments are uniquely designed for each satellite.

When an electron collides with a surface, an x-ray may be produced in the form of either a bremsstrahlung or characteristic x-ray. A spectrum of x-rays at varying energies will be produced with a continuous flux of electrons bombarding the surface. Using an x-ray detector to collect the produced x-rays, there is potential to deduce information of the electron environment that produced the measured x-ray spectrum.

Work is currently being done to measure the energy of electrons from the x-ray spectrum they produce. Modeling theoretical bremsstrahlung and characteristic x-ray spectra based on electron energy, flux, and material being impacted by electrons has allowed for the development of a deconvolution algorithm. The algorithm identifies the energy and flux of electrons that created the spectra via numerical differentiation and spectral subtraction. X-ray spectra collected from monoenergetic electron beams in vacuum have been combined to create a spectrum of x-rays produced from multiple discrete electron energies. The method derived from the modelled spectra is currently being tested for feasibility as well as susceptibility to noise.

Considerations for Langmuir probe operations on small spacecraft

Dr. Omar Leon, Dr. Brian Gilchrist, and Dr. Walter Hoegy
University of Michigan

When Langmuir probes (LP) operate on small spacecraft (SC) the current balance between the LP and SC can actively induce a negative charge on the SC. Active SC charging due to LP operation occurs whenever the LP collects more electron current than the SC can balance through either ion collection or electron emission. Mitigating the induced charge on the SC can be accomplished by either limiting the voltage range of an LP sweep, minimizing the collection area of the LP, or increasing the conductive area on the satellite. However, these mitigation strategies are not always possible and the active charging due to probe operation is unavoidable. Thus, to mitigate the effects of SC charging on LP current-voltage curves, the twin-probe method was developed where the SC potential is tracked during an LP sweep to correct the curves during analysis.

To understand SC charging behavior during LP operation and develop analysis techniques to maintain LP accuracy on small SC, the Plasma Spacecraft Interaction Codes (PSIC) was developed. PSIC provides an approximate estimate of the SC potential using analytic expressions for current collection of the SC and LP. We will first provide an overview of the algorithm and compare simulation results to plasma chamber measurements. From there, a discussion of instrument considerations and SC best practices, including SC to LP collection area limitation, instrument sensitivity requirements, and SC potential as a function of ram surface area is presented.

Object Relative Heading Estimation with Binary Wide Field of View X-Ray Sensing

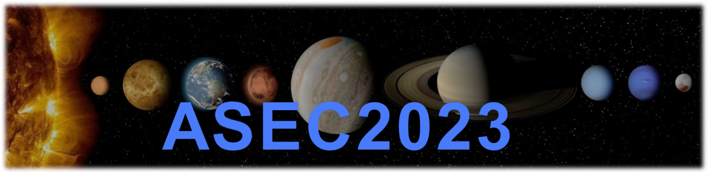
Ms. Andrea Lopez and Prof Hanspeter Schaub
University of Colorado, Boulder

On-orbit, passive detection of objects in the vicinity of a spacecraft is a desirable capability for Space Situational Awareness applications, especially in orbit regions that are not illuminated by the Sun. Ambient plasma in the space environment interacts with any object in space. When the electrons in the plasma are energetic enough (> few 100 eV), this interaction induces the release of characteristic x-rays and bremsstrahlung x-rays. These plasma conditions are present in regions such as GEO or cislunar space. This work investigates the use of a wide field of view (FOV) x-ray detection solution that exploits the natural space environment interactions to detect and track objects neighboring a spacecraft. The x-ray detection capabilities depend on local plasma properties but are not contingent on illumination conditions, which potentially presents an advantage over visible light detection methods in the Moon's shadow and Earth's eclipse regions.

The proposed x-ray instrument consists of a cluster of off-the-shelf x-ray spectrometers with Si-PIN detectors with partially overlapping FOVs, motivated by a coarse sun sensor assembly concept. The signal at each sensor is modeled as a binary signal: with a value of 0 when the target object is out of the field of view of the sensor, and a value of 1 if the target is viewed by the sensor. The trigger events of signal acquisition and loss of signal are used to estimate the line of sight unit vector, also called heading. With the objective of obtaining more of such events, the cluster is assumed to be mounted on a rotating platform, moving at a known, constant angular speed.

A number of configurations for a cluster of x-ray sensors are analyzed, comparing their performance (assuming a static target) in terms of coverage and average error in the area covered for changing values of FOV of the individual sensors and FOV overlap. An instrument concept consisting of multiple x-ray clusters is also analyzed.

In a real on-orbit scenario, encountering a target with zero relative motion with respect to the observer spacecraft is unrealistic. However, typical relative velocities are small, and the heading is expected to vary slowly in the span of minutes to tens of minutes. A batch least squares approach is followed to estimate the heading, assuming that the target heading remains constant during the collection of the considered trigger events. For a dynamic target, this assumption introduces an error that depends on the relative motion, the rotational speed of the platform, and the signal sampling frequency. This error is quantified for multiple relevant relative orbit cases.



Furthermore, this estimated heading can be used in a sequential filter to estimate the full relative orbit, in the same manner as an angles-only relative orbit estimation with camera-based measurements. The angles-only relative orbit estimation problem with linearized dynamics and measurement model is unobservable, but introducing a nonlinear model for both the dynamics and the measurement model increases the observability. The feasibility of this approach is explored using the unscented Kalman filter.

Testing of a Magnetohydrodynamic Generator System within Simulated Solar Wind/GEO and LEO Space Environments

Mr. Chris Torre[1], Mr. William Torre[1], Dr. Kenneth Wright[2], and Mr. Todd Schneider[3]
[1]Torre Space and Power Systems, [2]Universities Space Research Association/ Science and Technology Institute, and [3]NASA

This paper summarizes experimental results from testing at Marshall Space Flight Center (MSFC) to determine the proof-of-concept performance of a Magnetohydrodynamic (MHD) generator to produce electrical power for spacecraft systems in a simulated space environment that represents the interplanetary solar plasma ion flow. The test articles and the laboratory experimental method are summarized herein with a compilation of test results. Testing was conducted in a vacuum chamber at the NASA MSFC Space Environmental Effects Facility with an internal Argon ion beam plasma source that was developed for testing of Parker Solar Probe components and a hollow cathode source for LEO conditions simulated plasma to measure the MHD generator system s production of power. This work was funded by a National Science Foundation grant to Torre Space and Power Systems LLC. Test results indicate this new technology development has potential for offering an alternative electrical power generation system for spacecraft applications.

Lunar Environmental Testing Facilities at Marshall Space Flight Center

Dr. Erin Hayward, Mr. Todd Schneider, Mr. Jason Vaughn, Mr. Patrick Lynn,
Mr. Peter Berton, and Ms. Mary Nehls
NASA

Environmental testing for technologies going to the Moon requires specialized test facilities. PLANET (Planetary, Lunar, & Asteroid Natural Environment Testbed) is a new vacuum 2m diameter x 3m long chamber currently under development, and it is specifically focused on providing high-fidelity combined planetary surface environments. It will be equipped not only with high vacuum, but a cryogenic shroud, low energy charged particle radiation, ultraviolet lamps, and a large simulant bed with dust distribution. The decisions and trades that were considered when designing PLANET and common considerations for performing high-fidelity ground-based testing will be described. Marshall Space Flight Center (MS.FC) also hosts several other unique capabilities to cover the entire range of lunar technology development phases, from basic materials selection to full qualification of flight articles. This talk will detail how PLANET fits into the MS.FC Lunar Testing Ecosystem by giving a quick overview of these other facilities, including the Lunar Environment Test System (LETS), the V20 large scale dirty thermal vacuum chamber, and the Lunar Regolith Terrain (LRT) Field.

Session 7: Radiation II

INVITED: A Solar Cycle of Radiation Measurements on the Surface of Mars with RAD on the Mars Science Laboratory

Dr. Don Hassler, Southwest Research Institute

Exposure to radiation remains one of the major risks for the human exploration of space, the Moon, and Mars. To adequately protect future human explorers from potential health hazards, the Martian radiation environment must be assessed in detail, and it must be understood how Space Weather at Mars affects this environment. To do this, the Mars Science Laboratory (MSL) Radiation Assessment Detector (RAD) has been conducting detailed radiation measurements on the surface of Mars throughout the 11 year solar cycle, beginning in August 2012.

On long-term time scales the Martian radiation environment is mainly influenced by the solar modulation of the impinging Galactic Cosmic Radiation (GCR) flux. GCR intensities, and subsequently, the radiation dose on the Martian surface is highest during solar minimum, and lowest during solar maximum. On short time scales (days to weeks) the radiation field can be dominated by Solar Energetic Particles (SEPs) emitted from the sun during strong SEP events which can increase the surface radiation dose by orders of magnitude.

Here, we present an overview of existing RAD radiation measurements and show how the changing solar activity cycle affects the radiation environment on Mars and its implications for the planning and timing of future exploration missions.

GLACE (Geant4 Lunar Albedo Computed Environment): A Freely-Available Model of Lunar Energetic-Particle Secondary Radiation and Its Variation with Regolith Hydrogen

Dr. Mark Looper[1], Dr. Joseph Mazur[1], Dr. Bern Blake[1], Dr. Harlan Spence[2],
Dr. Nathan Schwadron[3], Dr. Jody Wilson[3], Dr. Andrew Jordan[3], Dr. Cary Zeitlin[4], Dr. Anthony Case[5], Dr. Justin Kasper[6], Dr. Lawrence Townsend[7],
Dr. Timothy Stubbs[8], and Dr. Phillip Phipps[9]

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[3]University of New Hampshire, [4]Leidos Innovations Corporation, [5]Harvard Smithsonian Center for Astrophysics, [6]University of Michigan, [7]University of Tennessee,
[8]NASA Goddard Space Flight Center, [9]University of Maryland Baltimore County

When cosmic rays or energetic solar particles strike the lunar surface, the secondary energetic particles that escape back into space carry information about the surface composition. These albedo particles are also a source of additional radiation exposure for astronauts or hardware at or near the lunar surface, which must be understood in order to plan for survivability of space missions there.

Since the 2009 launch of the Lunar Reconnaissance Orbiter (LRO), the science team of its Cosmic Ray Telescope for the Effects of Radiation (CRaTER) sensor has used the Geant4 radiation-transport code to study this process. Using hundreds of processor-years on computer clusters, we have modeled all albedo particle species except neutrinos. We have organized our model results into JSON-formatted files and are making them available to the space science and engineering communities via the Zenodo open archive.

The distributions of albedo particles are calculated for individual energies of ion species from H to Ni arriving isotropically from space. This enables a user to convolve these response functions with any desired incident ion spectra, rather than having to choose from a limited set of spectra hard-coded into the model. We also include with the model some examples of such convolutions, so that users can check their use of the response files.

We will describe the organization of the model files, which allows users to avoid downloading portions not needed for a particular study. To demonstrate usage, we will show the modeled effects of regolith hydrogen on albedo proton and neutron distributions, including the depths probed. We will compare distributions at the surface and at 20 km altitude, to isolate the products of unstable particles that decay on the way up. And we will present the NEWT (Neutron Electron Water Tomography) technique, which can use electrons from neutron decay to probe regolith hydrogenation.

RADISH (Radiation DeflectIng Shield): Assessment of Active Magnetic Shielding for Deep Space Exploration

Ms. Paulina Umansky and Ms. Sydney Hemenway
University of California, Berkeley

Radiation in the form of energetic protons severely limits time and resources for crewed space exploration missions, constraining the science that can be conducted and limiting the effectiveness and sustainability of expensive and time-intensive missions. Earth’s magnetic field protects humans on Earth and partially protects humans on the International Space Station (ISS) from exposure to energetic protons. However, the Moon, interplanetary space, and Mars do not have magnetic fields capable of protecting humans. Since radiation exposure causes immediate and long-term adverse effects on astronaut health, deep space missions require radiation shielding.

The current State of the Art (SOA) for radiation shielding relies on polyethylene and aluminum, both of which are passive shields that produce secondary radiation. These material solutions are limited in their effectiveness, since increasing their thickness has diminishing and in some cases, even negative returns. Existing literature on active magnetic shielding concepts has examined geometries of magnetic shields that require large structures and frequently only accounts for magnetic effects.

We propose a magnetic shielding concept that is small-scale and modular, enabling construction of a variety of geometries. We assess: 1) the effectiveness of a magnetic radiation shield module, accounting for secondaries produced, and 2) the superconductive requirements for this type of shield to be practical. We use Geant4 Beamline to simulate superconducting solenoids under proton beams of 100MeV and 1GeV, accounting for both magnetic and material effects. The shielding effectiveness is determined via analysis of particle trajectories and secondaries produced. To compare with the SOA, we present a metric for one-to-one comparison and similarly simulate the effectiveness of equivalent aluminum and polyethylene blocks.

We present the required improvements in superconductor performance parameters to create effective magnetic shielding compared to the SOA. We also discuss potential implementations (e.g. distance of magnetic shield from spacecraft) that can lower the superconductive requirements, and assess the effectiveness of our concept given superconductors available today. This analysis informs the realizability of magnetic radiation shields for deep space exploration.

INVITED: Nuclear Data for Enhancing Space Exploration

Mr. Keith Jankowski, Department of Energy

Nuclear data is fundamental to all areas of basic nuclear science and applications. These data underly the modeling and simulation software of nuclear systems and, therefore, are critical to ensuring results are accurate and useful. The US Nuclear Data Program (USNDP), funded by the US Department of Energy, Office of Science/Nuclear Physics, is tasked with updating and filling gaps in these data through compilation, evaluation, and dissemination in publicly available databases hosted by Brookhaven National Laboratory’s National Nuclear Data Center (NNDC). Recent outreach to other federal programs, including NASA, has shown the continued need for improved nuclear data, including in areas related to human spaceflight, exploration, and electronics protection. This talk will highlight some of these areas, describe how interagency programs coordination on nuclear data needs, and describe potential funding opportunities for improved data.

Session 8: Charging II

Dramatic Influence of Temperature upon Charging of External Cables on a Spacecraft

Mr. Michael Bodeau, Consultant and Ms. Nina Altshuler, Northrop Grumman

Charging and discharging of cables outside of a spacecraft have been cited as the root-cause of multiple anomalies, commonly based upon correlations with peaks in the external energetic electron environment. The source of the discharges was presumed to be external cables because of the higher electron flux exposure of cables only protected by thin thermal blankets versus the reduced flux inside of the spacecraft primary structure. But this attribution of the anomalies to external versus internal cables was never supported by any analysis.

External cables are subject to much wider temperature changes than hardware located inside the thermally regulated spacecraft. Temperature affects both bulk resistivity and radiation induced conductivity (RIC), but temperature effects have typically been ignored in charging assessments and ground tests. In this paper, literature is surveyed to obtain estimates of the temperature effects on both bulk resistivity and RIC. Charging of a generic coax cable is simulated using a diurnal temperature variation for an external coax on a geosynchronous orbit satellite using an external electron environment derived from GOES detectors. The simulation shows that the coax insulators behave as perfect insulators during the cold portion of the diurnal temperature cycle (even when accounting for RIC), but the accumulated charge leaks out during the hot portion of the cycle. So, there is little to no memory or hysteresis in charge density from one day to the next. This charging behavior is very different from the behavior of materials inside the spacecraft, where low flux and stable, colder-than-room-temperature conditions lead to charging time constants ranging from weeks to months that produces a slow, stair-step increase of trapped charge levels in response to multiple electron storms. Given the short duration over which charge is accumulated, GOES flux data taken at a 5minute cadence was required for the simulation of an external coax, whereas 24hour averaged GOES flux is commonly used for simulations of charging of long time-constant materials inside a spacecraft.

Experimentally Estimating Secondary Electron Yield

Mr. James Walker, Mr. Julian Hammerl, and Prof Hanspeter Schaub
University of Colorado, Boulder

Uncertainty in secondary electron yield (SEY) models can lead to major differences in spacecraft charge modeling. Previous studies have found that SEYs vary significantly with material properties including surface roughness and contamination layers. A primary technique for determining accurate SEY models focuses on using an electron beam to excite electrons from a target and measuring the current generated on a collection surface. These methods hinge on the ability to measure all of the secondaries emitted from the target and find the ratio between the incoming and outgoing electrons. To capture all the emitted electrons, a large surface - with a small aperture for the electron beam - must be built and placed around the target. This complicates the experimental setup and requires additional equipment. Because of this, a simpler method for estimating SEY is explored and presented here. By holding the target at a constant voltage and varying the impacting electron beam energy, a retarding potential analyzer (RPA) is used to measure the flux of secondary electrons. These results are then used to determine a relationship between secondary electron yield and incident energy. The RPA does not capture all the secondary electrons, so a separate method for transforming this relative SEY curve into the actual curve is needed. Using the secondary electron method on an electrically isolated uncharged target, the floating potential of the target is measured. This floating potential occurs when the incident energy of the electrons is at E2, the second crossover point of the SEY curve, when the ratio of incoming and outgoing electrons is one. The relative SEY curve is then scaled such that the yield at the value for E2 is one, giving an approximation of the actual SEY curve. With this method, a SEY curve is generated with a simplified setup and does not rely on measuring all the generated secondary electrons. This process is explored using a gold sputter-coated copper disk and an oxidized aluminum cube with unknown surface characteristics.

Impacts of Cislunar Plasma on Electrostatic Tractor Potentials

Ms. Kaylee Champion and Prof Hanspeter Schaub
University of Colorado, Boulder

The electrostatic tractor has been investigated as a means of contactlessly maneuvering non-cooperative objects, or clients. To do so, a servicer equipped with an electron beam may emit electrons to positively charge itself and negatively charge a target through electron beam impact. The resulting attractive, electrostatic force is utilized to conduct electrostatic actuation. However, uncertainty arises as the floating potentials of the spacecraft induced by the electron beam are reliant on the beam characteristics, spacecraft shape and size, and ambient plasma properties. Previously, these induced potentials have been shown to vary on the order of kilovolts as the ambient plasma properties change in Geosynchronous (GEO) plasma. Recently, the electrostatic tractor has been proposed for use in cislunar space, which introduces environmental variations not previously encountered in GEO. The cislunar plasma environment can be divided into four regions based on the Moon's orbit through and outside of Earth's magnetosphere: solar wind, magnetosheath, magnetotail lobes, and plasma sheet. Each environment is expected to generate different servicer and client potentials for the same spacecraft and electron beam properties on a similar order of magnitude to the GEO environment. Furthermore, spacecraft wakes form in the magnetosheath and solar wind environments. When a spacecraft travels through plasma, the impacting electrons and ions are disturbed and pushed out of the way, similar to how an airplane pushes air aside as it travels. In mesothermal plasma environments, the spacecraft velocity is higher than the ion velocity and lower than the electron velocity. Therefore, the electrons catch up to the spacecraft and continue to impact from all sides, while the ions may not catch back up for several spacecraft lengths (Lai 2012). This creates a low density, ion void region on the anti-velocity side of the spacecraft with respect to the plasma. This formation does not occur in GEO, and the impact of cislunar spacecraft wakes on electrostatic actuation is a novel subject. To account for the unique cislunar plasma phenomenon, the floating potentials of a servicer and client is characterized in cislunar plasma regions and compared to previous results in GEO plasma.

Inner Magnetosphere Transport and Acceleration Model for specification of radiation environment for surface charging

Dr. Natalia Ganushkina, University of Michigan, Ann Arbor, MI

Surface charging, the process of charge deposition on covering insulating surfaces of satellites is directly linked to the space environment at a time scale of a few tens of seconds. Accurate specification of the space environment at different orbits is of a key importance. We present the operational model for low energy (< 200 keV) electrons in the inner magnetosphere, called Inner Magnetosphere Particle Transport and Acceleration model (IMPTAM). This model in its various versions has been operating online since March 2013 (imptam.engin.umich.edu) and it is driven by the real time solar wind (solar wind number density, dynamic pressure and velocity) and Interplanetary Magnetic Field (Y and Z components and total magnitude) parameters and by the real time Dst and Kp indices. The model provides the low energy electron (and proton) flux at all L-shells and at all satellite orbits, when necessary. We present several products, such as (1) 3D distributions of 1-200 keV electron fluxes (dependent on L, MLT, pitch angle and energy) inside 10 Re, (2) electron fluxes along any given satellite orbit for any given energy, (3) electron spectra at any location inside 10 Re as input to software computing potentials at satellite surfaces.

Neighboring Spacecraft Charging due to Continuous Electron Beam Emission and Impact

Mr. Julian Hammerl, Ms. Amy Haft, and Prof Hanspeter Schaub
University of Colorado, Boulder

Spacecraft charge in the space environment, which affects spaceflight in various ways. Arcing can occur between spacecraft components if the spacecraft is not fully conducting and some parts are charged to different electric potentials than other parts, referred to as differential charging. A solar panel's lifetime can be reduced significantly if arcing occurs on the panel. Two nearby spacecraft can also be subject to electrostatic discharges if they are charged to different potentials and are very close to each other, for example during docking. Additionally, even if two spacecraft in close proximity are charged to the same potential, they exert electrostatic forces on each other if the electric potentials are high enough. These forces can affect rendezvous and proximity operations, but can also be used to one's advantage for active debris removal.

Spacecraft charging has been extensively reviewed, and studied with emphasis on, among other topics, mitigation of charging, modeling of spacecraft charging, detection of discharging events and characterization of the secondary electron yield that plays an important role in spacecraft charging. Charging levels in various orbital regions have been investigated, such as Low Earth Orbit, the auroral regions, GEO and cislunar space. However, most research on spacecraft charging focuses on the effects of only the space environment, that is, how much a spacecraft charges naturally due to the ambient plasma environment. Charging induced by electron beam impact, electron beam emission, and ion beam emission is discussed relatively briefly in Chapters 9-12 of Ref. Lai2011. The coupled charging behavior of two spacecraft in close proximity, where one spacecraft emits an electron beam that hits the other spacecraft, has been studied for the application of the Electrostatic Tractor active debris removal method. These papers specifically study the effect of the charging levels on the electrostatic force magnitude between the two spacecraft, with the goal of improving the performance of the Electrostatic Tractor, as a higher force magnitude leads to a reduction of the time required to reorbit retired satellites from GEO to a graveyard orbit. The motivation of this current work, however, is to study the effect of electron beam impact on remote sensing methods that estimate the electric potential of another spacecraft.

For this analysis, we investigate the effect of electron beam emission and impact on the electric potential of a servicer and target spacecraft, respectively. With the charging models used, multiple equilibria may exist, which must be accounted for when automatically computing the equilibrium potential of interest. The range of equilibria is studied for different charging environments in geostationary orbit and cislunar space.

SpaceSuite, The self-consistent toolbox for space environment effects analysis

Mr. Julien Forest, Mr. Benjamin Jeanty-Ruard, Mr. Arnaud Trouche, and
Dr. Benoit Tezenas du Moncel
ARTENUM

SpaceSuite (www.space-suite.eu) is a self-consistent and extensive set of tools and services dedicated to the modelling of the space-environment impacts on space systems. SpaceSuite provides a global multi-models and multi-physics approach to ease to model and optimize the design of complex systems, like a spacecraft in its whole but also complex and modern instruments or subsystems, where several physics should be considered in a same time and an accurate way.

Around a rich GMDL oriented CAD tool, called EDGE, SpaceSuite provides an equally rich set of effects models, like SPIS for plasma-matter interaction analysis, including surface and internal charging, and the sector shielding analysis plugin SSAM or the Monte-Carlo based tool MoORa for radiation analysis. The interoperability between the different tools of the suite aims to ease multi-physics and multi-model analysis, as well as interface them with external simulation models.

With the integration of the SEE-U software, the SpaceSuite offer has recently been extended to the Single Events analysis, including models to evaluate the sensitivity cross-sections of technological nodes and to compute the final Software Event Rates (SER) in-situ inside the modelled satellite and for each given space environment. The development and the integration of SEE-U has been completed by an extensive validation campaign, especially regarding the computation of the sensitivity cross-sections of different electronics technologies. In addition, first application cases of in-situ SER on concrete example of cubesat have shown that the final SER may deeply impacted by the position of the component inside the spacecraft structure and to the relative shielding, especially if we take into account the angular dependency of the cross-section.

These first results will be presented and discussed, as well the SpaceSuite tool-box in its whole.

KEYNOTE: NOAA Space Weather Prediction Center’s Operational Support for Space Missions

Dr. Howard Singer, NOAA Space Weather Prediction Center

NOAA s Space Weather Prediction Center’s (SWPC) mission is Safeguarding Society with Actionable Space Weather Information. While SWPC provides space weather information to numerous customer sectors, the focus of this presentation is on the information that benefits space missions. Over many decades, SWPC has supported robotic spaceflight, as well as human spaceflight going back to the days of the Gemini (mid-1960 s) and Apollo missions (late 1960 s). This presentation will highlight space weather impacts on past space missions, as well as the needs for space weather services for recent missions to low-Earth orbit (LEO) and future missions to other orbits, the Moon, and Mars. Recent studies and policies regarding the need for space weather support will be summarized and the process for moving new models and observations into operations will be described. The presentation will describe the importance of continuing and expanding partnerships with other government agencies, academia, the international community, and the commercial sector. In addition to discussing the source of space weather effects on space missions and the observations and models in use today, gaps in knowledge and technology needed to meet future requirements for crewed and robotic exploration and services will be presented.

Wednesday, 11 October

Session 10: Space Weather Environments

INVITED: Mitigation of environments in heritage and new designs

Ms. Catherine Keys, Ms. Shivani Parekh, Ms. Hailey Richart, Mr. Brian Watkins,
and Mrs. Nicole Pothier McGillivray
Maxar

Maxar is currently providing the Power and Propulsion Element (PPE) for the NASA lunar Gateway mission. To do this, Maxar is leveraging its highly reliable 1300 class spacecraft bus originally developed for 15 year GEO missions. Maxar has studied the similarities and differences between the typical 1300 mission and the PPE mission. When comparing the new environmental requirements of the Design Specification for Natural Environments (DSNE) in the case of PPE to the old environmental requirements of Maxar’s internal Environmental Requirements

Specification (ERS), the differences are key to consider. This paper will discuss the practical comparison of differently specified environments (radiation, EMC, etc.) and the assessment of engineering decisions based on those differing requirements. We will also discuss how the general approach for the 300 class, currently for LEO applications, differs.

SBIR Space Weather R2O2R Technology Development and Commercial Applications

Dr. Anthony DeStefano, Dr. Mitzi Adams, and Dr. Robert Loper
NASA

The Small Business Innovation Research (SBIR) Program provides U.S. small businesses of 500 or fewer employees with the opportunity for early-stage funding for research and development. Through NASA's Science Mission Directorate, the SBIR subtopic S14.01 Space Weather Research-to-Operations-to-Research (R2O2R) Technology Development and Commercial Applications supports high-priority space weather needs as outlined in the National Space Weather Strategy and Action Plan (NSWSAP). There are four focus areas for which solutions are sought; these will be discussed (in no priority order): 1) space-weather forecasting technologies, techniques, and applications, 2) commercial and decision-making applications for space weather technologies, 3) space weather advanced data-driven discovery techniques, and 4) space-weather instrumentation.

Relationship Between GOES-R Series Operational Anomalies and In-situ Electron Measurements

Dr. Brian Kress[1,2], Dr. Juan Rodriguez[1,2], Dr. Natalia Buzulukova[3], Dr. Rob Redmon[2], Dr. Janet Machol[1], Dr. John Fiorello[4], and Mr. Robert Meloy[4]

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The first two of NOAA s Geostationary Operational Environmental Satellite (GOES) -R series spacecraft, GOES-16 and GOES-17, were launched in November 2016 and March 2018 respectively. Space weather instruments on board GOES-R Series spacecraft include the low- and high-energy Magnetospheric Particle Sensors, MPS-LO and -HI. These sensors measure 30 eV to ~3 MeV electrons in 25 differential energy channels and one integral (>2 MeV) channel. Since launch, a growing catalogue of recurring GOES-R series operational anomalies has been maintained by the GOES-R program. A subset of the anomalies show a clear relation to ambient electron fluxes. These anomalies are primarily associated with the solar pointing platform instruments and their interface with the spacecraft. The list of GOES-R operational anomalies and continuous in-situ electron measurements from the same satellites provide an unsurpassed opportunity to study the interrelation between spacecraft errors and the ambient electron environment. In this work we focus on one type of spacecraft anomaly involving telemetry between the Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) and the spacecraft. It is found that these anomalies occur more frequently when ambient electron flux levels are elevated. Comparisons of full distributions of measured fluxes and distributions of fluxes preceding anomalies show that the anomaly occurrences are most well associated with the elevation of ~130 keV electrons above normal levels, implicating shallow charging by electrons in the low 100s of keV. This is confirmed by results from superposed epoch analysis showing strong peaks in MPS-HI energy channels in the low 100s of keV preceding the anomalies by ~30 minutes. Analysis of the local time dependence of the anomalies and measured fluxes reveal that there is a delay between the peak in ambient electron flux and anomaly occurrences suggesting a charging timescale of ~30 minutes to several hours.

Improving Space Weather Predictions with a New Generation Software for Modeling the Solar Atmosphere and Inner Heliosphere

Prof Nikolai Pogorelov[1], Dr. Charles N. Arge[2], Dr. Phillip Colella[3], Dr. Jon Linker[4], Dr. Brian Van Straalen[3], Dr. Lisa Upton[5], Mr. Raphael Attie[6], Dr. Ronald Caplan[4], Dr. Cooper Downs[4], Mr. Christopher Gebhart[3], Mr. Dinesha Vasanta Hegde[1], Dr. Shaella Jones[2], Dr. Tae K. Kim[7], Dr. Andrew Marble[8], Mr. Syed Raza[1], Dr. Talwinder Singh[7], Mr. Miko Stulajter[4], and Dr. James Turtle[4]

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Improving Space Weather (SWx) predictions requires, on the one hand, to recognize that we are working with an interrelated Sun-heliosphere system and, on the other hand, address the problem by systematically enhancing each component that affects the accuracy of forecasts. We describe our team efforts aimed to develop a new set of open-source software that ensures substantial improvements of SWx predictions. While focusing on the development of data-driven models, we ensure that each individual component of our software has higher accuracy with a dramatically improved performance. This is done by the application of new computational technologies and enhanced data sources. The development of such software paves way for improved SWx forecasts accompanied with an appropriate uncertainty quantification. This makes it possible to monitor hazardous SWx effects on the space-borne and ground-based technological systems, and on human health. Our models involve (1) a new, open-source solar magnetic flux model (OFT), which evolves information to the back side of the Sun and its poles, and updates the model flux with new observations using data assimilation methods; (2) a new potential field solver (POT3D) associated with the Wang-Sheeley-Arge coronal model, and (3) a new adaptive, 4-th order of accuracy solver (HelioCubed) for the Reynolds-averaged MHD equations implemented on mapped multiblock grids (cubed spheres). We describe the software and results obtained with it, including the application of machine learning to modeling coronal mass ejections, which makes it possible to improve SWx predictions by decreasing the time-of-arrival mismatch. Extensive tests show that our software is formally more accurate and performs much faster than its predecessors used for SWx predictions.

Using SPIS connection to Virtual Observatory to model the electrostatic cleanliness of science missions

Dr. Sebastien Hess[1], Dr. Ludivine Leclercq[1], Dr. Nicolas André[2], and Dr. Baptiste Cecconi[3]
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[3]LESIA, Observatoire de Paris/CNRS

Spacecraft in orbit around planet or in the interplanetary medium are immersed in plasma from which they collect charged electrons and ions leading to the electrostatic charging of the surfaces. In addition, energetic impacts of particles or UV photons may lead to the emission of secondary electrons back to the plasma. This latter effect is highly dependent on the exposure and characteristics of the surface material, leading to differential charging. The electrostatic charging can ultimately lead to electrostatic discharges onboard the spacecraft, but even in less dramatic configuration they can perturb the plasma close to the spacecraft, which impacts scientific payload studying either the plasma particles or the electromagnetic fields.

The spacecraft charging effect must be taken into account in the processing of the raw measurements from these instruments, but this task reveals itself complicated by the strong variability of the charge levels, themselves correlated to the variability of the environments. Standard methods of calibration use average charge states to process the data, and some studies use charge state estimations based on estimate of the environment parameters at the time of the measurements. However, the data processing usually require a self-consistent processing of the data, using the data themselves to estimate the environment conditions and determine the charge state. In absence of compatibility and link between the measurement databases and the spacecraft charging simulation tools, this task is tedious and limited to particular events. We present here the latest developments of the Spacecraft-Plasma Interaction Software (SPIS) to allow it to access space measurement databases using the SPASE framework to monitor the spacecraft charging effects on instrument measurements. We discuss how the SPASE formalism allows a semi-automated treatment of the database to select and process relevant data. A typical use case is presented with the simulation of the observation of a fast reverse shock in the solar wind by THEMIS.

A next step after PAGER: the Advanced Charging Risk Forecast Service

Mr. Julien Forest[1], Mr. Arnaud Trouche[1], Dr. Benoit Tezenas du Moncel[1],
Dr. Dedong Wang[2], and Prof Yuri Shprits[3]
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With more than 10,000 satellites expected in orbit in a near future, the impact of the space environment becomes a key issue for the safety of futures missions by the simple fact of statistics. Moreover, the requirements on new designs, cheaper and optimized, the choice of sensitive orbits, like PEO and EOR, and the need to consider the dynamics of the space environment with possible severe events, made a simple risk evaluation in design phase not enough anymore. A real-time prediction of the in-flight risk, based on precise space-weather forecasts, is an emerging, and soon critical, need to predict and mitigate in time the risks for space missions.

Recent observations let to think that the risks related to spacecraft charging appear as critical, especially in internal charging. Observed in-flight anomalies, possibly attributable to internal charging process, seem to be subsequent to moderated solar events but in series. The time variations of the environment seem being critical and sensitive charging scenarios must be identified to avoid issues. Simulations done with the SPIS-IC internal charging simulation software in variable environments have confirmed cumulative aspects in IC. Analyses based on a simple worst-case are not enough anymore.

Downstream from the European H2020/PAGER project, this is the aim of the SpaceSuite Advanced Charging Service proposed by Artenum with academic laboratories. This framework integrates an electrostatic charging risk prediction service, downstream to space-weather prediction environment models, able to predict in real-time the internal and surface charging risk levels for satellites in GEO and MEO. For each weather forecast, 1D and 3D charging models, including the reference charging software SPIS, are automatically run to provide in-time a charging risk indicator over up to two days. This can be dedicated mission per mission, taking into account its mission profile, its quasi-realistic geometry and its technological specificities to address needs of future commercial missions.

Environments models can be used as <<post-cast>> as-well to rebuild past environments and the charging service to reproduce observed charging events. This has been applied during the validation phase of the service, where the signature of observed past charging events on the SCATHA mission, for the surface charging, and the GIOVE-A and SURF instrument, for the internal charging, have been rebuilt. The simulations present results very close to the observations, reproducing the observed charging events and validating the framework. This confirms as well that such service might also help to understand if observed anomalies result from a platform design error or simply be at the wrong place at the wrong moment .

These first application cases will be presented and discussed in details and the Advanced Charging Risk service presented in its key functionalities and implemented models.

Radiation, Interplanetary Shocks, and Coronal Sources (RISCS) toolset for situational assessment and decision making related to space operations

Dr. Vladimir Kolobov[1], Mr. Ashok Raman[1], Mr. Carter Grimmeisen[1], Dr. Robert Arslanbekov[1],
Dr. Junxiang Hu[2], Dr. Bryan Johnson[2], and Prof Gary Zank[2]
[1]CFD Research Corporation, [2]CSPAR, The University of Alabama in Huntsville,

Space weather phenomena such as solar flares, coronal mass ejections (CMEs), and associated solar particle events (SPEs) can damage critical space-based and terrestrial infrastructure. Operators of such systems. need to forecast major space weather storms and potential effects towards risk mitigation.

CFD Research and the University of Alabama in Huntsville have developed a novel Radiation, Interplanetary Shocks, and Coronal Sources (RISCS) toolset by enhancing and integrating existing research codes into a software product for situational assessment and decision making related to space operations. The computational physics engine within RISCS is a hybrid kinetic-fluid solver. Inputs from space-based and ground-based observations drive magnetohydrodynamic (MHD) solar wind models, which feed CME-induced collisionless shock models and kinetic models of solar particle acceleration and transport to locations of interest. Key advantages include adaptive mesh and algorithm refinement techniques for numerical efficiency, heterogeneous computing, and cloud-based and local execution.

We will present key features of RISCS software, describe its current capabilities, and show sample applications for selected solar events. Details of the RISCS technology will be discussed to illustrate (i) efficient coupling between component codes that describe background solar wind, SPE-induced shock propagation, particle energization, and transport of solar energetic particles; (ii) improved numerical algorithms and physics models of component codes, and (iii) validation and integration with third-party tools for operational use.

Session 11: Meteoroids and Orbital Debris

INVITED: The four most common misconceptions concerning the meteoroid environment

Dr. William Cooke, NASA Meteoroid Environment Office

The NASA Meteoroid Environment Office has improved our understanding of the meteoroid environment in near-Earth space and other parts of the Solar System since its formation in 2004. One of our main tasks in the nearly 20-year existence of the office has been to deal with the numerous misconceptions program managers and personnel have with regard to meteoroids. In this presentation, we list and correct four of the most common misconceptions.

Meteor showers account for the bulk of the meteoroid risk to spacecraft and crews. Even though meteor showers are visually spectacular, they do not significantly increase the flux of hazardous particles. In the threat range for spacecraft and crews (0.1 to 10 mm), measurements show that the flux of the sporadic background almost always exceeds the flux of even strong meteor showers like the Geminids. The only exceptions occur during meteor shower outbursts and storms, and those periods of greatly elevated flux are brief (hours). The net upshot is that meteor showers only account for 5% or less of the total meteoroid risk to a long-term mission in Earth orbit (1).

Meteoroids are rocks. Most meteoroids in the threat regime originate from comets, and are very fragile conglomerates of ice and dust. Bulk densities are often less than 1 gram per cubic centimeter. Rocky meteoroids are much rarer, accounting for just a few percent of the environment.

Meteoroid populations at the Moon (or Earth-Sun L_1 and L_2) are distinct from those encountered in Earth orbit. Meteoroids and their parents orbit the Sun, and the environment changes across distances measured in astronomical units. The Earth-Moon separation or the 1.5 million km to L_1 or L_2 are very small in terms of Solar System distances spacecraft in these locations encounter the same comets, the same meteoroid sources, and even the same meteor showers. Therefore, the meteoroid environments at all these locations are essentially equivalent, with the only difference being the gravitational focusing or physical blocking of meteoroids by the Earth or the Moon. Both of these effects are fully accounted for in our environment models.

Meteor shower activity can always be predicted from past activity alone. The orbits of small bodies like meteoroids, asteroids, and comets are constantly being changed due to gravitation perturbations from the planets (particularly Jupiter) and non-gravitational forces. As a consequence, the distances and particle concentrations of the streams of debris that produce meteor showers change in a manner governed by celestial mechanics and not by stochastic processes. Some streams may migrate away from Earth’s orbit; others may move closer. Meteor shower forecasting requires complex dynamical simulations in which millions of particles are evolved over centuries or millennia.

(1) Moorhead, Althea V.; Egal, Auriane; Brown, Peter G.; Moser, Danielle E.; Cooke, William J., Journal of Spacecraft and Rockets, Vol. 56, p. 1531-1545.

Space debris tracking, mitigation and removal innovations for a safer orbital environment

Mr. John Christy Johnson, Mr. Peter Anto Johnson, and Dr. Austin Mardon
University of Alberta

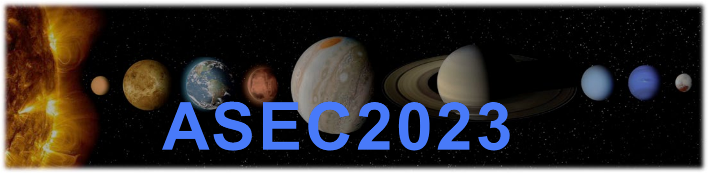
The growing presence of space debris in Earth's orbit poses a significant threat to spacecraft, satellites, and future space missions. The escalating concern for space sustainability demands innovative technologies and strategies to track, mitigate, and remove space debris, thus ensuring a safer orbital environment. This abstract outlines an advanced approach that combines cutting-edge tracking systems, efficient mitigation techniques, and novel removal methods to address the space debris challenge comprehensively.

Firstly, a state-of-the-art space debris tracking system is proposed, integrating advanced radar, optical telescopes, and data processing algorithms. This system offers improved accuracy and real-time monitoring of space debris trajectories, allowing precise predictions of potential collisions and timely alerts to spacecraft operators and mission control centers. By enhancing situational awareness, this technology reduces the risk of accidental collisions and facilitates proactive avoidance maneuvers.

Secondly, a novel approach to mitigate space debris proliferation is introduced, focusing on spacecraft design modifications and end-of-life disposal strategies. By implementing innovative materials that are designed to naturally degrade in the space environment, the generation of new debris can be mitigated. Furthermore, optimizing spacecraft design for safe and controlled deorbiting, either through propulsion or aerodynamic drag enhancement, ensures that defunct satellites and spent rocket stages can be intentionally removed from crucial orbital regions.

Lastly, the abstract presents revolutionary space debris removal methods that address the challenge of clearing existing debris from congested orbital regions. A proposed solution involves the utilization of autonomous robotic systems equipped with advanced grasping and propulsion capabilities. These robotic "debris hunters" can intercept and capture defunct satellites, spent rocket stages, and other large debris objects. Once captured, the debris hunter either deorbits the object for a controlled re-entry into Earth's atmosphere or transports it to designated disposal orbits, away from active satellite constellations.

The integration of these innovative technologies and strategies forms a comprehensive approach to tackle the space debris crisis, safeguarding vital orbital regions and ensuring the sustainability of future space endeavors. By fostering international collaboration and industry-wide adoption, this solution can effectively curb the growth of space debris, paving the way for safer and more sustainable space exploration and utilization.



Plasma signatures of small orbital debris in LEO

Dr. Pedro Alberto Resendiz Lira, Dr. Gian Luca Delzanno, Dr. Daniil Svyatsky, Dr. Oleksandr. Koshkarov, Dr. Carlos Maldonado, Dr. Gabriel Wilson, and Dr. Tatiana Espinoza
Los Alamos National Laboratory

Since the beginning of the space age, the number of orbital debris has skyrocketed to levels which seriously threaten the current and future use of space. It is estimated that ~36,500 objects greater than 10 cm and orders of magnitude more smaller objects are currently in orbit, created predominantly by collisional events. The smaller objects, with characteristic size less than ~1 cm, are extremely hard to detect and cannot be tracked with existing technology but, with typical velocities of ~10 km/s, can create significant damage upon impact. Furthermore, with the ongoing commercialization of space and constellations of thousands of satellites envisioned in the near future, the orbital debris problem is expected to become much worse and methods for detection, tracking, characterization and possibly removal are much needed.

In this presentation we will discuss the potential signatures created by the interaction with small orbital debris and the ambient plasma in low Earth orbit (LEO). First-principles debris-plasma modeling work performed with the Curvilinear Particle-In-Cell (CPIC) code will be presented, with a focus on the conditions that might lead to particular signatures that could be exploitable for detection. This includes the possible formation of non-linear coherent structures such as solitons, that have been recently proposed as a novel signature of debris-plasma interaction, as well as wake structures. Our findings highlight the importance of accurately describing debris charging and damping physics. A progress update on laboratory experiments being conducted at the Los Alamos National Laboratory to complement the modeling work will also be presented.

INVITED: An Overview of Ground-based Radar and Optical Measurements Utilized by the NASA Orbital Debris Program Office

Dr. Alyssa Manis, NASA

For over 30 years, the NASA Orbital Debris Program Office (ODPO) has led the characterization of orbital debris (OD) too small to be tracked by the U.S. Space Surveillance Network (SSN), yet which may pose the greatest threat to human spaceflight and robotic missions. Measurements from specialized sensors, including ground-based radars and telescopes capable of detecting smaller objects, provide the foundation for developing statistical models to describe the current state and future evolution of the OD environment from low Earth orbit (LEO) to geosynchronous Earth orbit (GEO). Since 1990, the ODPO has partnered with the U.S. Department of Defense and the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) to collect data using the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) formerly Haystack to characterize OD in LEO with a sensitivity of approximately 5 mm at 1000 km altitude. In addition, since 1993, the Goldstone Orbital Debris Radar, operated by NASA s Jet Propulsion Laboratory, has provided data on OD as small as approximately 2-3 mm for altitudes below 1000 km, some of the most sensitive ground-based measurements achievable at these altitudes. Recently, collaborations with the 18th Space Control Squadron of the U.S. Space Force have also provided the ODPO with special datasets from the Space Fence to extend coverage below the historical SSN limit of 10 cm and to characterize individual breakup events in LEO. For GEO altitudes, the Eugene Stansbery Meter

Class Autonomous Telescope (ES-MCAT), a joint NASA-Air Force Research Laboratory project that reached full operational capability in 2021, collects data on debris smaller than 1 m and provides coverage of debris in historically under-sampled high-altitude orbital regimes. This paper summarizes the radar and optical sensors utilized by the ODPO, their unique capabilities, and recent datasets and applications for statistical sampling of the dynamic OD environment.

Misconceptions and Reality of Orbital Debris Risk

Dr. Mark Matney, NASA

Since the formal commissioning of the NASA Orbital Debris Program Office in the 1970's, recognition of the risks of orbital debris has gradually become more widely known to the community of space experts. The subject has even entered the mainstream of popular culture (cf. the 2013 film "Gravity"). This growth in professional and public interest has unfortunately been accompanied by a growth in misconceptions concerning the nature and scope of orbital debris risks and how to fix the problem. Because dealing with orbital debris issues is both complicated and potentially expensive, and is implicitly an international issue, it is important that problem solvers and policy makers are asking the correct questions and addressing the correct problems that make the most sense in a cost/benefit analysis. This paper will identify a select number of these misconceptions and clarify and correct them.

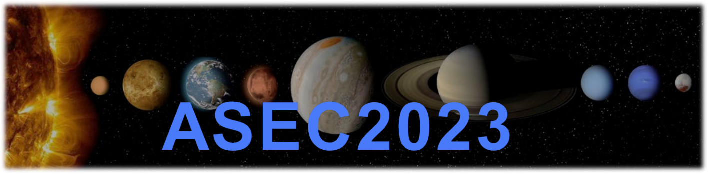
Thursday, October 12

Session 13: Lunar Environments II

KEYNOTE: Robotic and Crewed Mars Missions Increasing the Demand for Planetary Protection Technology Needs

Dr. James Benardini[1], Dr. Elaine Seasly[1], and Dr. J. Andy Spry[2]
[1]NASA Headquarters, [2]SETI Institute

Planetary protection (PP) policy seeks to avoid harmful contamination by limiting biological and relevant organic contamination from spacecraft as well as preventing adverse changes to Earth's biosphere when extraterrestrial samples are brought back to Earth. The PP policy at NASA was updated in 2021 (NPR 8715.24) and 2022 (NASA-STD-8719.27) to enable missions by expanding the decades old prescriptive requirements to allow for an option of adopting performance-based requirements that are objectives-driven, risk-informed and case-assured. In parallel, the final PP knowledge gap workshop was completed representing the international consensus on the key areas to be considered in developing crew PP policy. These knowledge gaps focused on key technology development areas in 1) microbial and human health monitoring, 2) technical and operations needed for contamination control and 3) natural transport of contamination on Mars. As robotic missions start to implement performance-based approaches and research and technology efforts commence to inform crew policy the demand for data quality driven verification and validation in relevant space environments. Examples of the types of testing that is envisioned includes test as you fly validation and verification of decontamination systems in a relevant on-orbit and Mars environment, developing lethality curves of terrestrial organisms to further our understanding of the biocidal impacts of Mars and the space environment, and particle transport model validation



and verification. Thus, the PP discipline has identified the need for ground-based space environments to perform preliminary testing as validation and verification of flight systems and to advance the technology readiness level prior to further testing on-orbit or lunar environments to prepare for Mars.

Space Environments Applied to the Gateway Program

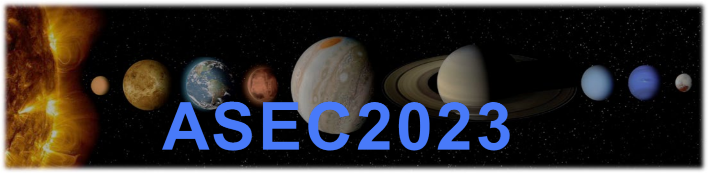
Dr. Emily Willis[1], Ms. Kristin Stillwell[2], and Dr. Alexander Henderson[3]
[1]NASA Marshall Space Flight Center, [2]Aerodyne Industries, [3]Jacobs

NASA's Gateway is a crewed space station with a planned mission duration of 15 years in lunar orbit. It is an international collaboration, including partnerships with the European Space Agency, Canadian Space Agency, Japan Aerospace Explorations Agency, and others. Additionally, the program relies on important partnerships with industry for designing and building hardware. This complex mission poses significant challenges related to space environments. Gateway s hardware will be directly exposed to the extremes of space weather posing challenges to avionics and materials as well as operations planning. The space environments are defined in the Design Specification for Natural Environments and applied through program requirements to all design partners. This presentation describes the space environments applicable to the Gateway program, the flow of the environments to system requirements, and the challenges that the program is currently facing with regards to the space environments.

Overview of NASA Gateway Lunar Dust Mitigation and Contamination Modeling and Analysis

Mr. Ronald Lee, Booz Allen Hamilton, Inc

The planned NASA Artemis campaign has several lunar surface missions in which the NASA Gateway is the waypoint between lunar orbit and the lunar surface for Human Lander System (HLS). Each of these missions is an opportunity for lunar dust to be introduced into the Gateway environment, post surface mission, potentially causing end of life (EOL) performance degradation due to lunar dust contamination of sensitive hardware and systems on the exterior of Gateway and Visiting Vehicles. The Gateway Systems Engineering and Integration (SE&I) and Induced Environments teams are addressing the challenge of lunar dust with a two-pronged approach. Characterization of the lunar dust induced environment around Gateway and contamination risk is accomplished with a comprehensive physics-based framework, the Gateway On-orbit Lunar Dust Modeling and Analysis Program (GOLDMAP), which is currently in development. Analysis results from GOLDMAP define Gateway-level induced environments requirements and are flowed to elements and subsystems. In parallel, a dust mitigation strategy is being developed with a focus on lunar dust protection, dust mitigation technologies, mitigation and testing guidance, and cross-program coordination and is informed by outputs from GOLDMAP analyses. Activities supporting both components include hardware susceptibility assessments and testing, and scientific experiments on lunar regolith.



Plume-surface interaction testing for crewed lunar lander risk reduction

Dr. Wesley Chambers, NASA Marshall Space Flight Center and
Dr. Ashley Korzun, NASA Langley Research Center

Spacecraft conducting propulsive near-surface operations such as landing or initial ascent must consider potential hazards caused by rocket exhaust interacting with planetary regolith. Gas-granular interactions can erode the surface and eject material, altering the landing site, obscuring views of the surface, and creating abrasion or impact risks. The next generation of lunar landers under development for NASA s Human Landing System program will push us outside Apollo flight experience for plume-surface interaction. Strategic knowledge gaps and poorly constrained flight data inhibit our ability to accurately and precisely predict the plume-surface interaction environment for a given flight vehicle. We present an overview of a lunar relevant, supersonic plume-surface interaction test that will be conducted in 2024 to improve our understanding of lunar PSI and reduce associated risks to the HLS program.

Electrostatic Issues in Space

Dr. Charles R. Buhler, Mr. Jerry J. Wang, Mr. James R. Phillips III, Joseph R. Toth III,
Dr. Krystal L. Acosta, Dr. Aaron D. S. Olson
Electrostatics and Surface Physics Laboratory, NASA Kennedy Space Center

An analysis of the docking currents expected during the mating of the Co-manifested Payload or Gateway with the Orion Capsule is investigation. Differential charging exists between these two vehicles due to their locations within the out Van Allen Radiation Belt and geosynchronous orbit. NASCAP has estimated that the electrostatic potentials could exceed 9 kilovolts.

The Electrostatics and Surface Physics Laboratory was tasked to measure the expected currents during the docking phase experimentally using capacitors similar those of the range of the vehicles. Tests were performed for two cases. The first case assumes that all electrostatic charging occurs on the metallic outer skin of the vehicles, while the second case assumed 100% of the deposit charged remained on the insulating surface of the spacecraft.

For the metallic case, two extreme modes were investigated to encompass the possible maximum current flows by comparing a direct short circuit to ground versus a direct short to the floating second capacitor representing the smaller Orion capsule. An exciting result for the insulating case was that the polarization of the underlying metallic frame ensures that there is no voltage difference between the vehicles upon contact. This subtly was described using COMSOL modelling which is usually ignored in electrostatics investigations.

Finally, a new approach to measurements of precipitation static or p-static testing will be presented. This includes corona charging of test samples followed by careful discharge measurements under high vacuum conditions to simulate the breakdown in air during ascent of launch vehicles.

Mesoscale Charged Dust Dynamics on Spacesuits

Ms. Elana Helou[1], Dr. Joseph Wang[1], and Dr. Lubos Brieda[2]
[1]University of Southern California, [2]Particle in Cell Consulting LLC

Lunar regolith adhesion presents several major safety and performance concerns to human exploration that must be addressed as the lunar exploration progresses. One of these challenges is the adhesion and transmission of lunar dust. This fine-grained material is expected to deposit on astronaut spacesuits, from where it may be inadvertently transported to lunar habitats or other notionally clean environments. Due to its small size and electrostatic attraction, lunar dust is particularly difficult to remove. Numerical modeling could offer a possible solution as it could be used to select mechanisms and fabric designs with low dust adhesion patterns. However, no numerical models exist to date that are capable of capturing the dynamic dust transmission at the appropriate length scales. Simulations of dust particles have historically been restricted to the scales considering entire planetary bodies or to atomic scales encompassing just a single granule. Neither scale is appropriate for the investigation of the interaction between dust grains and astronauts. For this reason, we are currently developing a numerical tool capable of simulating multiple dust grain “actors” interacting with a spacesuit fabric modeled at the mesoscale level. This model is coupled with the particle in cell method for capturing the ambient plasma, which is also used to impart charging to the surface and the grains.

This numerical modeling is coupled with an experimental characterization of the JSC-1A lunar simulant sprinkled on a sample of Ortho-Fabric, which make the outermost layer of spacesuits. This data will be used to calibrate the model and inform the dust behavior. Ambient air experimentation shows that larger rock-like grains are easily brushed off however smaller dust-like particles settle into the space between individual threads of the fabric and are not easily removed. Dust removal from the fabric is observed using a USB microscope under different removal methods and conditions. Before and after pictures are collected to determine the response of each particle population to the removal stimulus. The first experiment considers a dusty fabric sample at atmospheric conditions that is blown with compressed air. Almost all dust particles are removed from the surface of the fabric; however, the smaller leftover particles become embedded in the fabric and buried within the threads. The second experiment considers the sample in a vacuum chamber with high density ambient glow discharge plasma. Surface charging is expected to be minimal due to experimental limitations. We suspect that the particles are lofted by a very small amount before they fall back on to the fabric, so the sample is placed vertically in the chamber to allow us to observe any particle displacement from charging. In this configuration we observe some dust removal. This work presents the details of the numerical model, the experimental setup, as well as the results to date.

Environmental conditions in the vicinity of the Apollo 17 LEAM/ALSEP package

Dr. Fabrice Cipriani, European Space Agency and
Mr. François Piette, Sirius Space Services

The Lunar Ejecta and Meteorites Experiment was part of the Apollo Lunar Surface Experiment Package deployed in the Taurus-Littrow area during the Apollo 17 mission, aiming at characterizing the cosmic dust environment at the lunar surface and the nature of lunar ejecta (Berg et al 1974). The data returned by the LEAM have been extensively analyzed. Interestingly, most of the events were detected in the terminator region, suggesting an electrostatic dust levitation mechanism.

While the LEAM was located in Taurus-Littrow valley, the local topography includes nearby hills, generating time varying shadow patterns at the LEAM location. This, combined with the varying local plasma environment encountered along the Moon s orbit, results in a complex time varying set of environmental parameters.

In the present study, we have used the Spacecraft Plasma Interaction Software to perform a parametric study accounting for the environment variability encountered during a lunation (including Sun illumination angle), lunar regolith physical properties and LEAM surface materials properties. This allows determining the LEAM local electrostatic environment possibly leading to dust mobilization and collection by the sensors and instrument surfaces. The largest electrostatic potential difference between the LEAM surface and the lunar regolith tends to be observed at low SZA (sunset / sunrise conditions). In addition, due to the low conductivity of the LEAM surface materials, strong asymmetries occur between sunlit / upstream areas and shadowed / downstream areas of the experiment. The dust dynamic is very sensitive to such in-homogeneities in the near environment of the senor. Close to sunrise and sunset, larger dust fluxes are generally observed on the illuminated side of the sensor, which fits well with the dawn flux enhancements observed by the LEAM EAST sensor. In this paper, we will describe the electrostatic environment expected at the LEAM and nearby lunar surface as a function of sun angle and plasma parameters. In a second step, we will address the dust dynamic, provide estimates of dust fluxes collected by the LEAM surfaces and especially the sensor areas, and their dependence on the environmental parameters, and discuss those in the context of LEAM observations reported in the literature.

Solar Array System Combined Environmental Effects Tests: Gateway Power and Propulsion Element

Mr. Todd Schneider[1], Mr. Jason Vaughn[1], Mr. Patrick Lynn[1], Dr. Erin Hayward[1],
Dr. Kenneth Wright[2], and Mr. Bao Hoang[3]
[1]NASA, [2]USRA, [3]Maxar

The NASA Lunar Orbital Platform-Gateway (LOP-G), a vital component of NASA s Artemis program, will serve as a multi-purpose outpost orbiting the Moon. A foundational component of LOP-G is the Power and Propulsion Element (PPE). The PPE is a high-power, +60-kilowatt solar electric propulsion spacecraft that will provide power, high-rate communications, attitude control, and orbital transfer capabilities for the Gateway. The solar array system will utilize 4-junction photovoltaic cell technology on a flexible substrate (roll-out solar array or ROSA) in combination with multiple diode assemblies to combine the power of the solar array strings. NASA s Marshall Space Flight Center, together with the PPE developer, Maxar, are in the midst of completing a rigorous combined environments test campaign of 3 solar array coupons and 1 array blocking diode board coupon. The campaign includes Ultra-Violet Radiation, Charged Particle Radiation, Ion Erosion, Thermal Cycles, and Electrostatic Discharge tests. The environments are applied in 3 separate incremental stages reflecting the various mission phases: 460 days of Earth-to-Lunar Transit, with much of that time through the Van Allen Belts, 5-years in Lunar Near-Rectilinear

Halo Orbit (NRHO) at the Moon, and finally 15-years in Lunar NRHO, which represents the end of the design life. This paper will report on the state of the testing for each coupon, and brief look at the array performance, including some unexpected sensitivities of array blocking diodes.

Session 14: Materials in Space

INVITED: Atomic Oxygen Environment, Effects and Simulation

Ms. Sharon Miller, NASA Glenn Research Center and
Mr. Bruce Banks, SAIC

Atomic oxygen is the most predominant constituent in the low Earth orbital environment between the altitudes of 180 and 650 km. It is also a major constituent of the Mars orbital environment. It is very chemically reactive and can oxidize materials on the outside of spacecraft. In many cases the reaction products are volatile which can lead to mechanical failure. Stable oxides can also form that change the optical or thermal properties of the material. The importance of understanding atomic oxygen reactions with materials has led to both flight experiments in low Earth orbit and ground-based testing in vacuum chambers containing atomic oxygen to study its effect on materials. This presentation will focus on defining atomic oxygen environments, discussing atomic oxygen effects on spacecraft materials, reviewing some methods of atomic oxygen simulation, and discussing differences in ground-based testing and space testing as well as synergistic effects.

Geographical Challenges of Acquiring Atomic Oxygen: Impact on Materials and Potential Technological Innovations for Space Missions

Mr. Peter Anto Johnson, Mr. John Christy Johnson, and Dr. Austin Mardon
University of Alberta

The acquisition of atomic oxygen poses significant geographical challenges in both Earth and Mars environments, impacting materials and requiring innovative technological solutions for successful space missions. Atomic oxygen is highly reactive and can profoundly affect various materials, including spacecraft surfaces and protective coatings. Understanding the geographical distribution, concentration, and interaction mechanisms of atomic oxygen is crucial for designing robust spacecraft and ensuring their longevity in space.

In the Earth's upper atmosphere, atomic oxygen is predominantly found in the thermosphere, where it results from the dissociation of molecular oxygen under the influence of solar radiation. Atomic oxygen poses challenges for spacecraft as it can cause erosion, corrosion, and degradation of structural materials and optical surfaces. The concentration of atomic oxygen varies with latitude, altitude, and solar activity, necessitating careful consideration when designing spacecraft for Earth-orbiting missions.

On Mars, the acquisition of atomic oxygen presents unique challenges due to the planet's thin atmosphere. While atomic oxygen is present in the Martian atmosphere, its concentration is significantly lower compared to Earth. The scarcity of atomic oxygen on Mars limits its potential for chemical reactions and material degradation. However, it also restricts opportunities for using atomic oxygen for propulsion or life support systems. Technological innovations are required to effectively harness and utilize this limited resource for future Mars missions.

To mitigate the adverse effects of atomic oxygen on spacecraft, several technological innovations are being explored. Advanced materials and coatings are being developed to provide increased resistance to atomic oxygen corrosion and erosion. Novel approaches include the use of nanostructured materials, atomic layer deposition, and multi-layered coatings that can effectively protect spacecraft surfaces. Additionally, active monitoring and predictive models are being developed to assess and manage the impact of atomic oxygen on materials throughout space missions.

In conclusion, the geographical challenges of acquiring atomic oxygen in Earth and Mars environments necessitate careful consideration in spacecraft design. Understanding the distribution and interaction mechanisms of atomic oxygen is crucial for mitigating its detrimental effects on materials. Technological innovations, such as advanced materials and coatings, active monitoring, and predictive models, offer promising solutions for enhancing spacecraft durability and performance during space missions in the presence of atomic oxygen. Future research and development efforts in this area will contribute to the success of space exploration and enable sustainable long-term missions to both Earth's orbit and other celestial bodies like Mars.

Thermal Control Coatings Flown on MISSE and METIS

Mrs. Miria Finckenor[1], Mr. Levi Leeper[2], Mr. Kenneth Jones[2],
Ms. Meghan Carrico[1], and Mr. Justin McElderry[1]
[1]NASA Marshall Space Flight Center, [2]AZ Technology,

A variety of coatings for passive thermal control were flown on the Materials on International Space Station Experiment (MISSE) 15th and 16th flights and on the Materials Exposure and Technology Innovation in Space (METIS) 1st and 2nd flights. The MISSE and METIS flights were both in low Earth orbit but had very different results. Space environmental and molecular contamination effects on optical properties are reviewed. Future experiments, including the Regolith Adherence Characterization (RAC) flight to the Moon, are discussed.

Space Environment Effects on Materials: Testing Capabilities for ESA s Challenging Missions

Dr. Julien Eck, Dr. Adrian Tighe, Dr. Agnieszka Suliga, Mr. Abel Brieva, Mr. Nuno Dias, Mr. Ricardo Martins, Mr. Bruno Bras, and Mr. Riccardo Rampini
European Space Agency

The Environmental Testing Team in ESA s Materials Physics and Chemistry Section is tasked with supporting ESA s space projects to verify the performance of exposed items. in simulated space environments. For this purpose, the group’s experimental capabilities include a wide range of radiation and environmental test facilities and associated measurement techniques, ready to adapt for new missions. Combined testing is performed to assess the impact of different environmental factors, using both simultaneous and sequential irradiations. Flight experiments are also undertaken when the opportunities are available to compare the performance of items exposed to the ground and space environment.

This presentation will provide an overview of the facilities and testing techniques available and under development within our team for future missions with challenging space environments. A focus will be made on the test campaign performed to simulate the aerobraking environment which will be encountered in the atmosphere of Venus by ESA s future Envision mission.

Exploring the Impact of High-Energy Electron Irradiation on the Properties of Space Coverglass Materials

Dr. Elena Plis[1], Dr. Jainisha Shah[2], Mr. Yassine Fouchal[3,4], Mr. Ryan Ramirez[3],
Ms. Maria Beloreshka[5], Mrs. Sydney Collman[1], Mr. Samuel Westrick[2],
Dr. Alexey Sokolovskiy[2], and Mr. Ryan Hoffmann[2]

[1]Assurance Technology Corporation, [2]Air Force Research Laboratory, [3]Georgia Institute of Technology, [4]Aerospace Systems Design Laboratory, [5]Rose-Hulman Institute of Technology

Space coverglasses play an important role in the operation and durability of space solar arrays, which are essential for providing power to spacecraft and satellites in orbit. Coverglasses provide protection from the space environment, ensure high optical transparency for efficient energy conversion, offer thermal insulation, control contamination, and enhance the longevity and durability of the solar panels. By safeguarding the integrity and performance of space solar arrays, coverglasses enable longer space missions and power various spacecraft and satellites in orbit.

Geosynchronous orbit (GEO) weathering induces differential charging of spacecraft surfaces due to the simultaneous fluxes of electrons with a wide distribution of energies interacting with spacecraft surface materials. As a result, satellite surfaces can accumulate charges of thousands of volts relative to each other, while entire satellites can accumulate charges of tens of thousands of volts negative with respect to the surrounding space plasma. These electric fields can give rise to local discharges (arcs) between different parts of the spacecraft, posing a risk to the normal operation of the satellite. In particular, radiation-induced arcing of space coverglasses may cause physical damage to the coverglass material, impair optical performance, pose risk to nearby components, threaten the safety of the mission, create debris, and reduce the mission s longevity.

This study investigates the impact of high-energy electron radiation, a prevalent phenomenon in GEO space weather, on the material properties of widely employed space solar cell coverglasses, specifically, CMO, CMX, CMG, and Corning 0214. With the aim of accurately quantifying and analyzing the structural integrity and any radiation-induced defects, the surface morphology and elemental composition of these coverglasses were examined before and after electron irradiation.

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Durability of Passive Thermal Control Materials Exposed to Low Earth Orbit Environment

Mrs. Miria Finckenor, Ms. Meghan Carrico, and Mr. Justin McElderry
NASA Marshall Space Flight Center

Spacecraft components for passive thermal control need to resist degradation in the space environment. The Materials on International Space Station Experiment (MISSE) 15th and 16th flights and the Materials Exposure and Technology Innovation in Space (METIS) 1st and 2nd flights exposed a variety of materials to the low Earth orbital environment. Materials discussed in this presentation include components for multi-layer insulation (MLI) blankets, chemical conversion coatings per MIL-DTL-5541, thermal control coatings, and multipurpose materials for both thermal control and radiation shielding. Space environmental and molecular contamination effects on optical properties are reviewed. Future MISSE and METIS experiments are discussed.

FTIR Characterization of Ground and Space-Aged Spacecraft Materials

Mr. Scott Bowman[1], Dr. Elena Plis[2], Ms. Sydney Collman[3], Dr. Jainisha Shah[3],
Dr. Alexey Sokolovskiy[3], Dr. Miles Bengtson[4], Mr. Ryan Hoffmann[3],
Mr. Samuel Westrick[1], and Ms. Maria Beloreshka[5]

[1]Universities Space Research Association, [2]Assurance Technology Corporation, [3]Air Force Research Laboratory, [4]Aurora Engineering, [5]Rose-Hulman Institute of Technology

The harsh space environment significantly impacts spacecraft materials through factors like solar radiation, extreme temperature variations, atomic oxygen exposure, and micrometeoroid damage. These conditions can lead to degradation of materials optical properties, thermal conductivity, electrical conductivity, or mechanical properties. It is important to understand and mitigate these effects to ensure spacecraft longevity, reliability, and safety during space missions. Fourier Transform Infrared (FTIR) spectroscopy measurements play a critical role in spacecraft materials characterization as they offer insights into the changes in the chemical composition of materials under the space environment. FTIR measurements can detect degradation, oxidation, and other chemical alterations that may occur due to electron irradiation, atomic oxygen exposure, thermal cycling, and other space-related factors. Through the analysis of distinctive absorption patterns in the IR region, FTIR spectroscopy enables the identification of specific functional groups and molecules present in the materials. By understanding how the chemical composition of spacecraft materials evolves in response to space conditions, scientists and engineers can make informed decisions about spacecraft material selection and design. This study presents an examination of the FTIR spectra of material samples retrieved from both wake- and ram-mounted positions during the 16th Materials International Space Station Experiment (MISSE) mission aboard the International Space Station (ISS). Furthermore, we analyze the FTIR spectra of the identical materials in situ, during electron irradiation conducted in a controlled laboratory setting. Samples were also analyzed using FTIR spectra after exposure to atomic oxygen using the FAST source.

CHaMISEn Data Management System for Material Properties

Dr. Sebastien Hess and Dr. Ludivine Leclercq
ONERA -The French Aerospace Lab-

The modeling of the various interactions of the materials on the surface of spacecraft with space environments is accessible to everyone through integrated tools such as NASCAP, SPIS, MUSCAT, COMOVA, Systema, and a few others. Depending on the physics simulated, these models require the measurements of different property sets for every material used on spacecraft in order for the software to provide the user with an accurate prediction. However, the available databanks are quite sparse and are barely sufficient to provide estimates of the level of risk undergone by the spacecraft. In order to ease the characterization of space materials, ONERA developed the characteristics of material interactions with the space environment (ChaMISEn) data management system. It is composed: of the ChaMISEn open-source data model for the description of the models, experimental setups, measurement data, and extracted material properties; of the COMPEx extraction software that performs the material property extraction using the metadata of the experimental setup, of the measurements and of the model; of distributed databases; and of libraries that allow connecting both experimental facilities and end-user software to the data system. We will present the ChaMISEn system as well as its integration into ongoing activities performed at ONERA. The capabilities of the system will be illustrated through the presentation of use cases related to spacecraft charging modeling.

Friday, October 13

Session 15: Current and Future Missions

INVITED: 24 years of Radiation Protection of the Chandra X-ray Observatory

Dr. Scott Wolk, Center for Astrophysics | Harvard & Smithsonian

I discuss the challenges and successes of radiation monitoring for the Chandra X-ray Observatory (Chandra). Now in operation for over 24 years, Chandra was originally designed with minimal concern for its space environment. However, just weeks into the mission it was discovered that the Charge Coupled Devices (CCDs) on its primary detector were vulnerable to radiation damage from low energy protons, Its highly elliptical orbit, with a 63.5 hr period, regularly takes the spacecraft through the Earth's radiation belts, the magnetosphere, the magnetosheath, and into the solar wind. Therefore, proper radiation management has been a prime concern of the Chandra team. A comprehensive approach utilizing scheduled radiation safing, in addition to both onboard autonomous radiation monitoring, manual intervention, and specific orbital modeling, has proved successful at managing further radiation damage. Owing to the tremendous success and long duration of the mission, there have been a series of challenges in all of these approaches as the orbit has evolved and the as the availability of both onboard and independent space-based monitoring has changed.

Radiation Odyssey: Navigating Material Challenges in Earth and Mars Environments with Innovative Tech-shields

Mr. Peter Anto Johnson, Mr. John Christy Johnson, and Dr. Austin Mardon
University of Alberta

Radiation poses significant geographical challenges in the environments of Earth and Mars, profoundly impacting materials and necessitating innovative technological solutions for successful and sustainable space missions. The intricate interplay between cosmic rays, solar radiation, and planetary magnetic fields contributes to a complex radiation environment that poses risks to both crewed and uncrewed missions.

In Earth's magnetosphere, the planet's magnetic field provides a protective shield against high-energy charged particles, such as cosmic rays and solar energetic particles. However, the polar regions, particularly the South Atlantic Anomaly, exhibit weaker magnetic protection, allowing higher radiation doses to affect spacecraft and satellites in low Earth orbit. Ionizing radiation can induce material degradation, electrical disruptions, and data corruption, impacting the longevity and performance of space assets.

Mars, with its tenuous atmosphere and lack of a global magnetic field, presents an even greater challenge. The Martian surface is exposed to galactic cosmic rays and solar radiation, posing significant health risks to future human missions. The radiation environment on Mars can erode materials over time and interfere with sensitive electronic components, potentially jeopardizing mission success. Effective radiation shielding and mitigation strategies are imperative to safeguard both crewed and uncrewed missions.

Technological innovations are crucial to addressing radiation challenges in space missions. Advances in material science have led to the development of radiation-resistant materials and shielding solutions. These include composite materials, hydrogels, and regolith-based shielding, which can effectively absorb or deflect ionizing radiation. Additionally, the use of artificial magnetic fields, such as superconducting magnets, could create localized magnetic protection, enhancing radiation safety for crewed missions.

Sophisticated radiation monitoring and prediction systems are also vital for space missions. Real-time data collection and analysis enable mission planners to make informed decisions about spacecraft trajectories and crew activities, minimizing radiation exposure. Furthermore, radiation-hardened electronics and fault-tolerant designs contribute to mission reliability by mitigating the impact of radiation-induced failures.

In conclusion, the geographical challenges of radiation in Earth and Mars environments necessitate comprehensive strategies to protect materials and ensure the success of space missions. Understanding the intricate radiation environment and its effects on materials is fundamental to designing robust spacecraft and equipment. Technological innovations, ranging from radiation-resistant materials to advanced shielding and prediction systems, are essential components of the toolkit to address radiation challenges and enable safe and sustainable space exploration. Continued research and development in this field will play a pivotal role in shaping the future of space missions beyond our planet.

Multifunctional Shielding Polymer for Space Applications

Prof Lembit Sihver, Cosmic Shielding Corporation, USA;
Technische Universität Wien, Austria; NPI of the CAS, Prague, Czech Republic and
Mr. Yanni Barghouty, Cosmic Shielding Corporation

To enable the planned rapid growth of both government and private operators in space, including space tourism, optical and quantum communication, surveillance, in-orbit manufacturing, manned missions to the Moon and to Mars, etc., a realistic and holistic approach to radiation risk reduction is needed. In deep space, ionizing radiation from Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs) from the sun pose a critical threat to both humans and electronic equipment. GCRs provide a chronic, slowly varying, highly energetic background source of High-Z high-Energy (HZE) particles, while the Sun's activity varies with an 11-year cycle during which the Sun produces Solar Wind (SW) at varying intensities and unpredictable bursts of Solar Particle Events (SPEs). SPEs can be a nightmare for the astronauts and cause acute radiation damage, while

GCRs can cause long term damage including cancer, cataracts, central nervous system and cardiovascular system damage, fibrosis, neurodegeneration, digestive diseases, and immunological, endocrine, hereditary effects, and cognitive impairment.

The GCRs and SPEs can also cause degradation of micro-electronics, optical components and solar cells. Commercial off-the-shelf (COTS) electronic components are especially susceptible to radiation effects that emerge from interactions with HZE particles, but highly energetic gamma photons, neutrons and protons can also damage electronical components. Since the exposure of humans and electronics to GCRs and SPEs in deep space, and on the surface of the Moon and Mars, will cause huge radiation risks, it is very important to apply the best possible protection for both humans and electronics. Currently, the only proven and practical countermeasure to reduce the exposure to GCRs and SEPs is passive shielding. It is well known that low atomic number (Z) materials are most effective for shielding in space, and liquid hydrogen has the maximum theoretical performance as a shielding material. Hydrogen is, however, not a practical shielding material, being a low temperature liquid associated with practical handling problems and explosion risks. Hydrogen concentrated in specially engineered and nanoparticle doped polymers, however, is ideal for stopping primary cosmic and solar radiation, as well as secondary neutrons, protons and heavier ions created when the primary particles are impinging on the spacecraft. Low atomic number (Z) materials also produce less electron-positron pairs and Bremsstrahlung than materials with higher Z, such as aluminum alloys, which are used in conventional satellites and spacecraft.

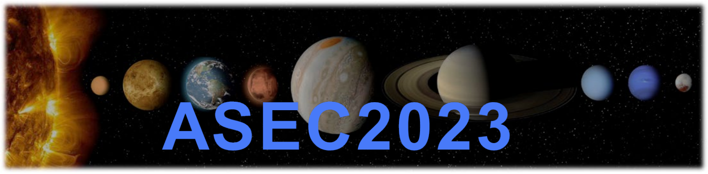
Additives can improve the flame retardancy and inhibit the release of toxic gases as well as absorption of neutrons, electrons and Bremsstrahlung created when HZE particles hit the shielding and other components of the spacecraft. Coating can also be added for protection against micrometeoroids, debris, extreme temperature variations and protection against atomic oxygen present at low Earth orbit (LEO).

We will present the basic physics behind CSC s hydrogen rich multifunctional shielding polymer (MSP), and show how it can be used as spot- and conformal shielding of electronic components, as well as a construction material for satellites, spacecraft and space habitats, and components in space intravehicular (IVA) and extravehicular (EVA) spacesuits.

IMPPACT: Invisible Magnetospheric Plasma Pathfinder with Active Charging Techniques

Dr. Gian Luca Delzanno, Los Alamos National Laboratory
On behalf of IMPPACT team

The Earth s magnetosphere comprises a variety of particle populations spanning a wide range of energies, such as the low-energy or cold (~eV) particle populations of the ionosphere and plasmasphere, the hot particle populations of the plasma sheet and ring current (~0.1-100 keV) and the radiation belts (~>MeV). These particle populations coexist and interact with a variety of plasma waves. The waves are the glue of the magnetosphere as they regulate the transport of mass and energy in the system via scattering, acceleration and losses. In all, the magnetosphere is a system of systems, i.e. a system of nonlinearly coupled, interconnected components that exhibits complex behavior that could not be predicted by looking at the individual components alone.



The cold electron and cold ion populations of the Earth s magnetosphere are often referred to as the hidden or invisible magnetosphere, to acknowledge the fact that we typically cannot measure them and hence they are very poorly characterized and very poorly understood. This is due to spacecraft charging and contamination by spacecraft-generated low-energy electrons. The lack of understanding of the cold particle populations is disabling: we cannot fully understand nor predict the behavior of a complex system of systems like the Earth s magnetosphere if we have major gaps in understanding of some of its components.

In this presentation, we will discuss a new mission concept, called Invisible Magnetospheric Plasma Pathfinder with Active Charging Techniques (IMPPACT), which uses active spacecraft potential control to perform robust in-situ measurements of the cold electron and cold ion populations of the Earth s magnetosphere. IMPPACT will shed light on the nature of the cold particle populations, their drivers, controlling factors and impacts, with a particular focus on waves, wave-particle interactions and auroral signatures of magnetosphere-ionosphere coupling.

Artemis IV Docking in Radiation Belt Charging Environment

Mr. Matt McCollum[1], Dr. Emily Willis[1], and Ms. Anne Diekmann[2]
[1]NASA Marshall Space Flight Center, [2]NASA (ESSCA)

NASA s Artemis IV mission is planned to deliver the International Habitation Module (I-Hab) to the Gateway space station in lunar orbit. The I-Hab will be launched aboard the Space Launch System (SLS) vehicle as a co-manifested payload with the Orion spacecraft. After translunar injection begins, the Orion spacecraft will separate from the SLS Exploration Upper Stage (EUS) and then dock with the I-Hab to extract it from the EUS. Because of the altitude, orientation, and time for this to occur, the vehicle-to-vehicle potential between the I-Hab/EUS vehicle and Orion spacecraft could exceed several thousand volts. The docking of these two spacecrafts with such large differential potentials presents a challenge for the vehicles. This presentation describes the space environments at the docking altitude, the calculated vehicle-to-vehicle potential, and the possible impacts of the resulting voltage and current transients occurring at first contact. Additionally, possible risk mitigation tests to demonstrate compatibility with the transient current and voltages will be presented.

Space Environment Data at NOAA NCEI: Status, Recent Advances and Upcoming Events

Dr. Juan Rodriguez[1], Dr. Christian Bethge[1], Dr. Athanasios Boudouridis[1],
Mr. Kevin Hallock[1], Dr. Brian Kress[1], Dr. Trevor Leonard[1], Dr. Paul Loto'aniu[1],
Dr. Janet Machol[1], Dr. Alessandra Pacini[2], Dr. Laurel Rachmeler[2], Dr. Rob Redmon[2],
Mr. William Rowland[2], and Dr. Donald Schmit[1]

[1]University of Colorado CIRES, [2]NOAA National Centers for Environmental Information

NOAA's National Center for Environmental Information (NCEI) in Boulder, Colorado, USA is the primary source for retrospective and scientific data from NOAA's satellite-borne space weather instruments in geostationary orbit (GEO), polar low-earth orbit (LEO), and at the first Sun-Earth Lagrange point (L1). From solar images to auroral plasmas, NCEI s space environment data are important for enabling and developing new scientific insights and applications for protecting critical infrastructure. Since 1975, eighteen Geostationary Operational Environmental Satellites

(GOES) have launched successfully. The Space Environment Monitor (SEM) that flew on Synchronous Meteorological Satellite (SMS.) 1-2 and GOES 1-15 included a Magnetometer, an Energetic Particle Sensor (EPS) suite of particle detectors, and a solar X-Ray Sensor (XRS). The later satellites also carried a Solar X-Ray Imager (SXI) (GOES 12-15) and a solar Extreme Ultraviolet Sensor (GOES 13-15). The current GOES-R-series observatories (GOES 16-18) carry completely new instruments: a Solar Ultraviolet Imager (SUVI), solar Extreme ultraviolet and X-Ray Irradiance Sensors (EXIS), two Magnetometers (MAG), and a Space Environment In-Situ Suite (SEISS) of particle detectors. In LEO, a suite of plasma and radiation detectors (SEM-1 on TIROS-N and selected NOAA 6-14; SEM-2 on NOAA 15-19 and Metop A-C) has made observations since 1978. Currently, the SEM-2 s on NOAA 15, 18, and 19 and Metop B and C are returning data. At L1, the Deep Space Climate Observatory (DSCOVR), launched in 2015, flies a 50-Hz magnetometer and a 4-Hz Faraday cup. Recent advances in NCEI s retrospective space environment data offerings include the release of GOES-18 science-quality and operational data, GOES 8-15 science-quality 2-Hz magnetic field data, reprocessed radiation belt fluxes from the pre-operational phases of the GOES 16-18 missions, and a new version of science-quality GOES 14 & 15 Lyman-alpha irradiances. Upcoming events include the launches of GOES-19 (2024) and Space Weather Follow-On Lagrange 1 (SWFO-L1) (2025). In addition to the existing instruments, GOES-19 will fly a Compact Coronagraph (CCOR-1). SWFO-L1 will fly CCOR-2, two magnetometers, a Solar Wind Plasma Sensor (SWiPS), and a SupraThermal Ion Sensor (STIS). NCEI is also involved in studies for future NOAA space weather satellite concepts, including a solar sail mission concept.

Retrospective space environment data are available at the following NCEI portal: https://www.ncei.noaa.gov/products/space-weather/satellites. NCEI is developing the SWFO Science Center portal to serve the GOES-19 CCOR and SWFO-L1 data to the public.

Space Weather Launch Constraints for JWST

Dr. Joseph Minow[1], Mr. Robert Meloy[2], Dr. Linda Neergaard Parker[3], and
Dr. Yaireska Collado-Vega[2]
[1]NASA Marshall Space Flight Center, [2]NASA Goddard Space Flight Center,
[3]Space Weather Solutions

The James Webb Space Telescope (JWST) was launched from the Guiana Space Centre in Kourou, French Guiana by an Ariane 5 rocket at 12:20 UTC on 25 December 2021. The initial flight trajectory was a direct ascent single transfer orbit through the Earth s radiation belts on the way to the spacecraft s final operational orbit about the Sun-Earth L2 point. JWST is an infrared astronomy space telescope designed for observations of the first galaxies, formation of star and planets, and investigations of exoplanet atmospheres. The largest space telescope launched to date, the high value program has an estimated value of ~$10B at time of launch and is an international collaboration of NASA, the European Space Agency, and the Canadian Space Agency. As an additional risk mitigation procedure to protect the high value spacecraft, the JWST Program used a set of space weather launch constraints to avoid extreme space environments during the initial flight operations and radiation belt transit in the hours following launch. The constraints reduced the risk of single event upsets in mission critical electronics from protons and heavy ions in a solar particle event during critical flight operations in the first 18 hours following launch and electrostatic discharge damage to spacecraft materials and avionics from surface and internal charging during transit of the Earth s radiation belts. This presentation will summarize the space weather launch constraints designed to protect the spacecraft and the space weather conditions and space weather reporting used to support the JWST launch operations.