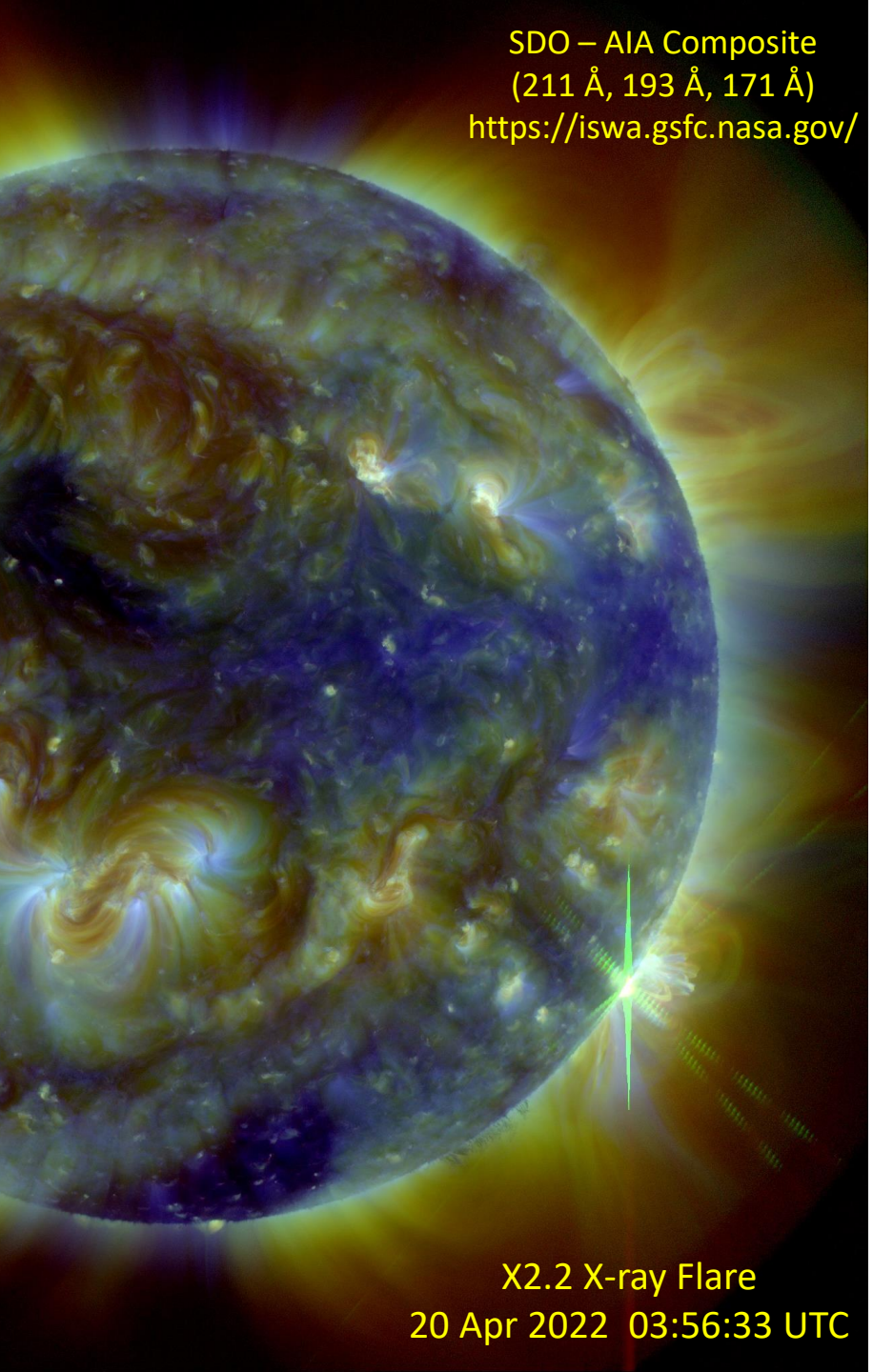

NASA Use of Charged Particle Environments and Effects Engineering Tools

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Space Environmental Effects and Science Applications Workshop
JHU/APL, Laurel, MD
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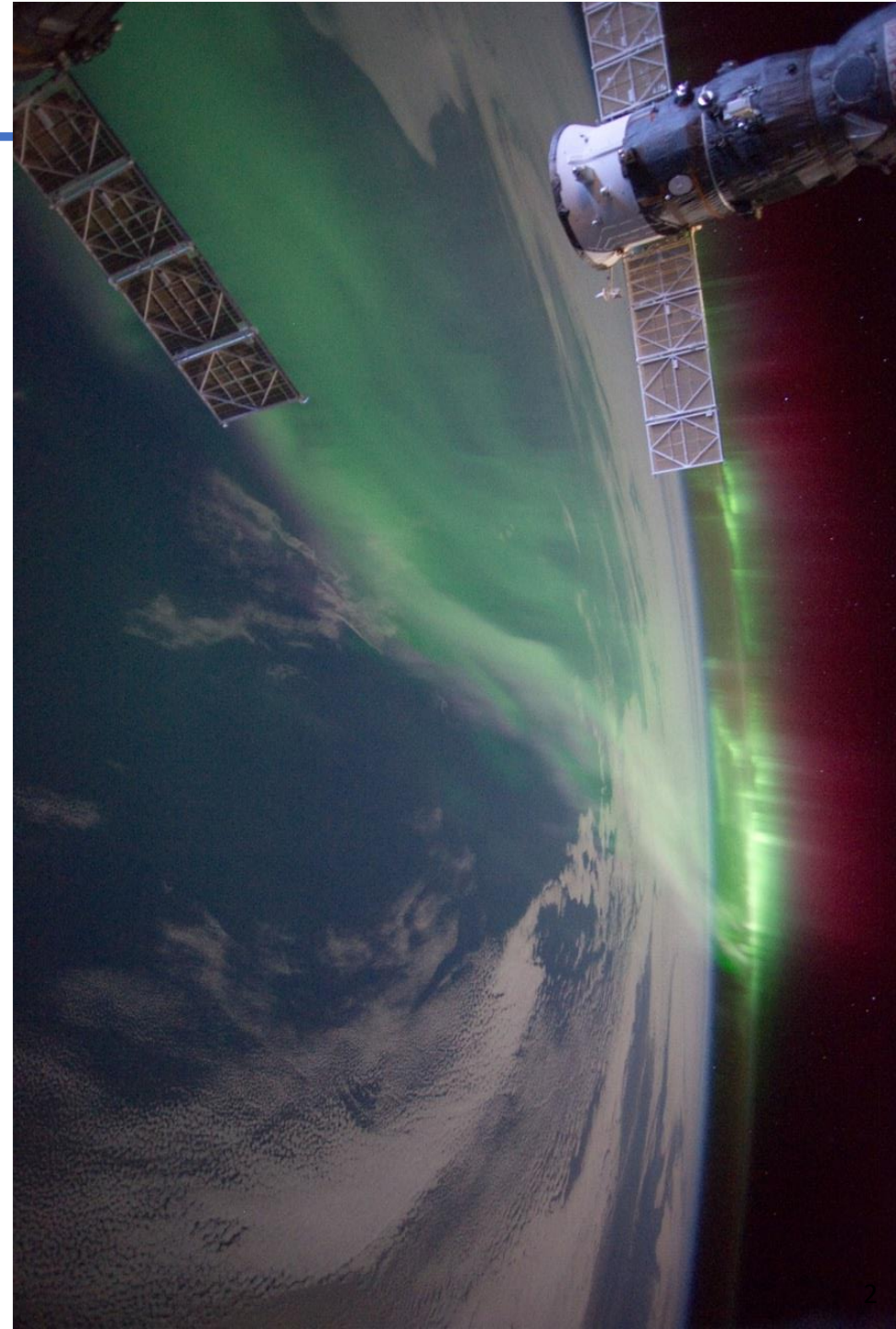
NASA Space Environments Discipline Scope

Space environments and their effects that impact the design, construction, and operation of NASA's human and robotic space systems and health of the crew

- Ionizing radiation, neutral energetic particles
- Meteoroids and orbital debris, hypervelocity impact
- Gravitational fields, microgravity
- Magnetic, electric fields and currents
- Space plasma, spacecraft charging
- Neutral atmosphere, vacuum, atomic oxygen
- Photons (IR, visible, UV/EUV, x-ray, gamma-ray)
- Applied space climate and space weather
- Planetary and interplanetary dust



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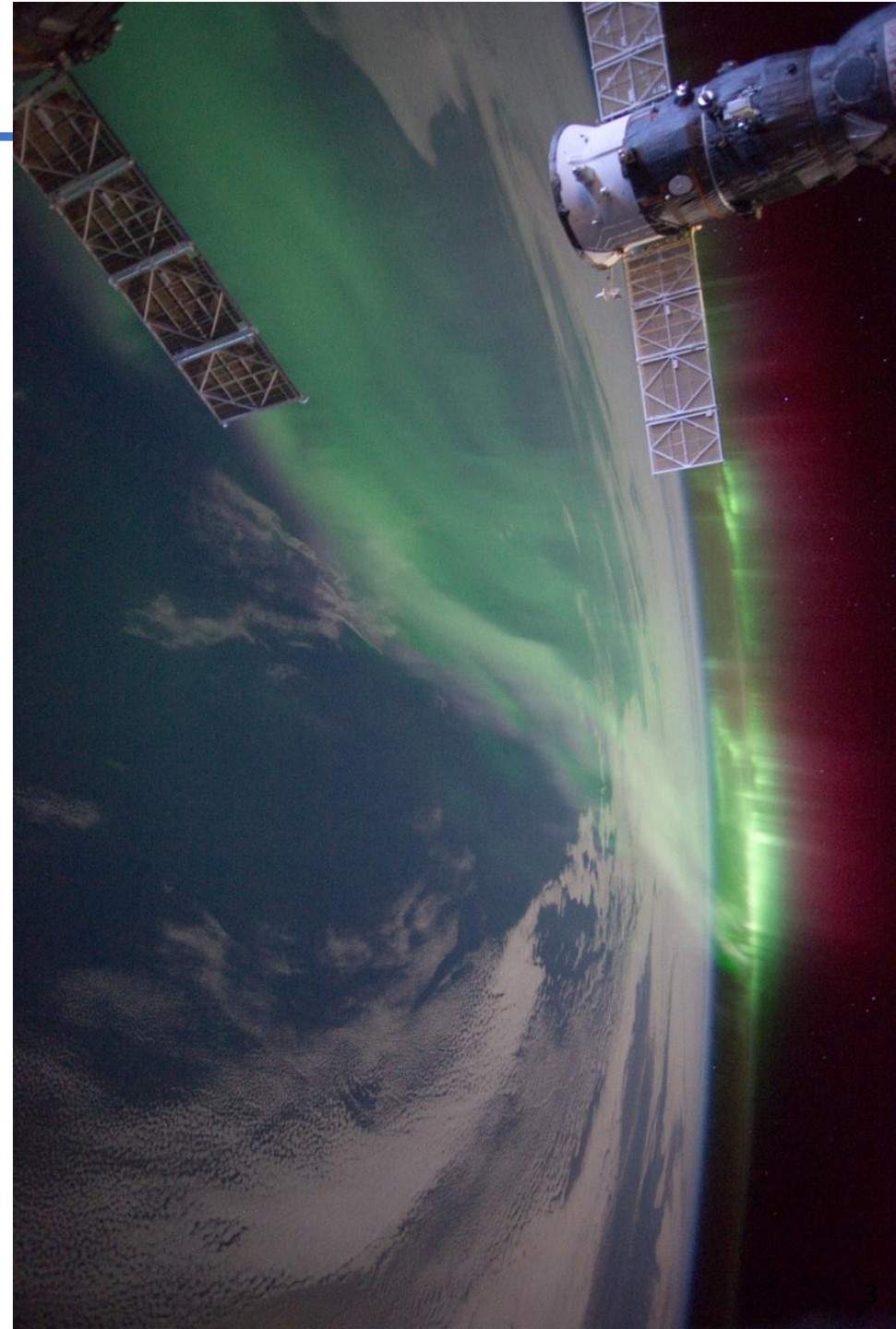
SEESAW focus is primarily charged particle environments and their contributions to total dose, single event effects, surface charging, and internal charging so these models and tools will be the topic of this presentation



NASA Use of Radiation, Charging Models

- NASA utilizes a variety of engineering models to specify space radiation and plasma environments and evaluate their effects on space systems

- Models are developed in-house at NASA Centers or obtained from other agencies, private industry, and foreign sources where appropriate including
  - Tools developed by government agencies or under contract to the government
  - Commercial products

- Environment models are used to
  - Specify the space radiation and space plasma environment for mission design
  - Evaluate on-orbit environments for operations support
  - Best estimate of on-orbit environment for anomaly investigations

- Effects models are used to evaluate the impact of the space radiation and plasma environments on hardware and humans including
  - Total ionizing dose, displacement damage dose, single event effects, sputtering, photovoltaic array degradation
  - Surface charging, internal charging, plasma interactions with photovoltaic systems
  - Biological effects of radiation on crew

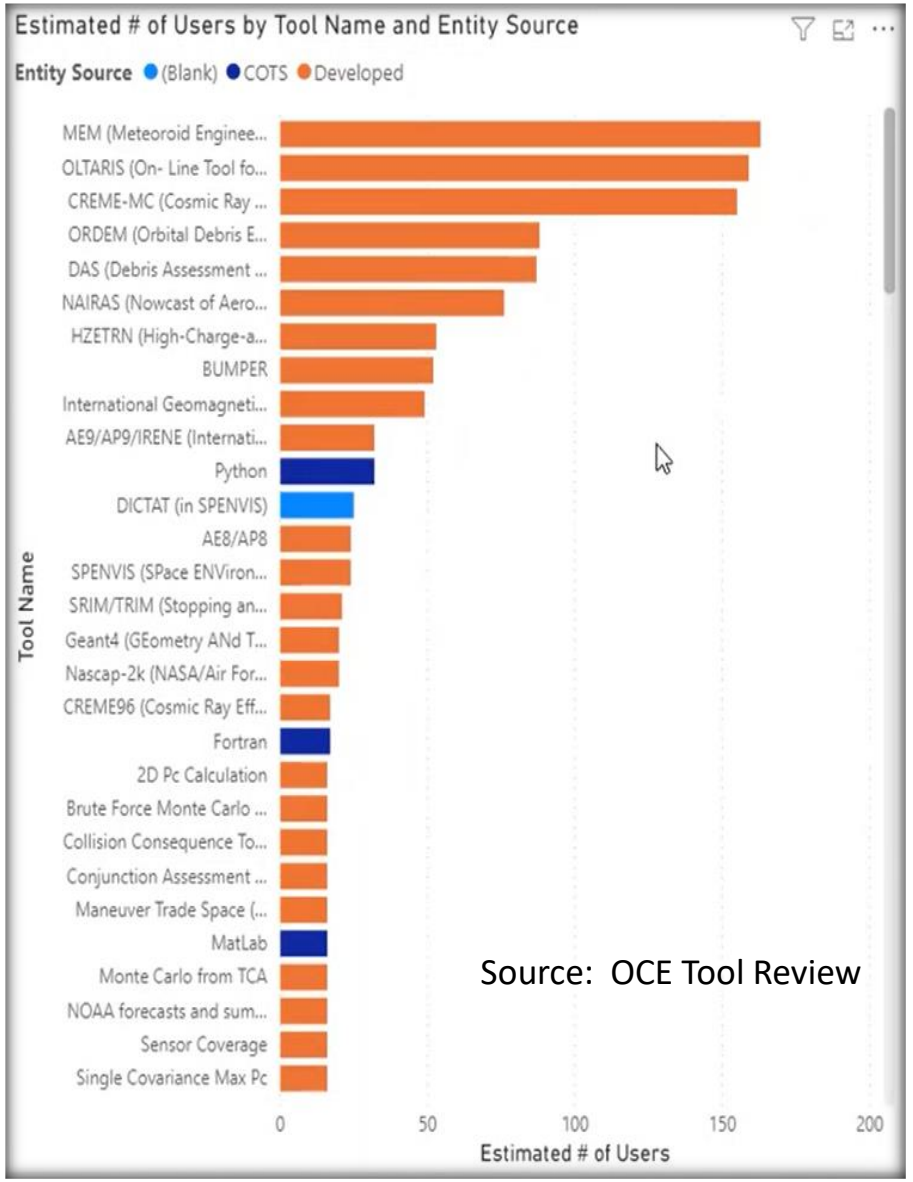
Space Environments Models and Tools: Data Sources

- NASA Engineering and Safety Center (NESC) Technical Discipline Teams (TDT) tracks engineering model and tool use within the NASA technical disciplines
  - Space Environments TDT assembled first space environment tool inventory when conducting baseline study of discipline in 2016
  - Continue to monitor status of tools, needs, and updates on an annual basis for the State-of-the-Discipline reports provided to NASA management

- NASA Office of the Chief Engineer (OCE) established a review team in 2020 to evaluate Agency use of engineering models and tools
  - Discipline interviews and data collection completed in spring 2022
  - Final report with findings and recommendations to NASA management in progress, release to technical community anticipated in late 2022

- Preliminary results from these sources indicate:
  - Space environments discipline utilizes 214+ software tools (of all kinds, not just radiation and charging) in support of NASA programs
  - Majority of tools are non-commercial codes developed in-house, at universities, by other government agencies, or open source (77%)
  - Commercial tools are widely used where appropriate (23%)

Space Environment Tools



Source: OCE Tool Review

Radiation (and Plasma) Environments

Model	Environment/ Effect	Source	Comments
AE8/AP8	Earth, trapped radiation	NASA GSFC, https://ccmc.gsfc.nasa.gov/pub/modelweb/radiation_belt/radbelt/	NASA standard Earth radiation belt energetic electrons, ions
AE9/AP9/SPM (International Radiation Environment-Near Earth)	Earth, trapped radiation, plasma, dose	https://www.vdl.afrl.af.mil/programs/ae9ap9/	New generation Earth radiation belt energetic electrons, ions, plasma
CRÈME-MC (CREME96, CREME84)	GCR, SPE, trapped protons	https://creme.isde.vanderbilt.edu/CREME-MC	Single event effect rate predictions and radiation environments
ESP (Emission of Solar Protons)	SPE protons	NASA GSFC (M. Xapsos), SPENVIS	Statistical solar proton fluence
PSYCHIC (Prediction of Solar particle Yields for Characterizing Integrated Circuits)	SPE heavy ions	NASA GSFC (M. Xapsos), SPENVIS	Statistical solar heavy ion fluence
JPL-91	SPE protons	NASA JPL (J. Feynman), SPENVIS	Solar proton fluence
King 1972	SPE protons	King (1974), SPENVIS	Solar proton fluence, basis for NASA crew dose analysis
SAPPHIRE (Solar Accumulated and Peak Proton and Heavy Ion Radiation Environment)	Solar protons	ESA (P. Jiggens)	
PROTEST (“Proton Test”)	GCR,SPE,trapped protons	NASA JSC (P. O’Neill, B. Reddell)	Scale laboratory proton upset rates to on-orbit proton and heavy ion rates

Radiation Environments

Model	Environment/ Effect	Source	Comments
CREME96 GCR	GCR protons	Nymmik et al, (1992), CREME96, SPENVIS	Solar max, min GCR
Badhwar-O'Neill	GCR	NASA JSC (P. O'Neill, B. Reddell)	Z=1 to 92 from 50 meV/n-20 GeV/n
Badhwar-O'Neill 2020	GCR (updated)	NASA LaRC (T. Slaba, K. Whitman) https://software.nasa.gov/software/MSC-26835-1	
SINP (Skobeltsyn Institute of Nuclear Physics) 2016 GCR	GCR		
NAIRAS (Nowcast of Aerospace Ionizing Radiation System)	SPE, GCR in LEO and atmosphere; dosimetric quantities	NASA LaRC (Mertens), http://sol.spacenvironment.net/~nairas/	Global, real-time, data-driven predictive system needed to assess biologically harmful radiation exposure levels for aviation
NAIRAS Version 2.0	SPE, GCR, Trapped in LEO and atmosphere; dosimetric quantities, proton energy spectra, LET spectra	NASA CCMC https://iswa.gsfc.nasa.gov/	Real-time and run-on-request (in work) versions running on CCMC server since 2020
CARI-7 (Civil Aviation Research Institute)	FAA civil aerospace radiation tool	https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari7/	
GIRE3 (Galileo Interim Radiation Model))	Jovian trapped protons, electrons, heavy ions	NASA JPL (H. Garrett, I. Jun)	JPL developed models of the Jovian trapped radiation and plasma
GRID3	Jovian radiation environments optimized for orbital analyses	NASA JPL (H. Garrett, I. Jun)	JPL developed codes for using JPL Jovian radiation models
SATRAD, UMOD	Saturn, Uranus trapped radiation	NASA JPL (H. Garrett, I. Jun)	JPL developed models of outer planet radiation belts
EQFLUX	Solar cell radiation (JPL method	SPENVIS	
SCREAM (Solar Cell Radiation Environment Analysis Models	Solar cell radiation (NRL method)	SPENVIS	

Plasma Environments

Model	Environment/ Effect	Source	Comments
IRI (International Reference Ionosphere)	Ionosphere Ne, Te, Ni, Ti , ion composition, vertical drift, TEC	https://irimodel.org/	Ionosphere climatology model
Statistical IRI	Ne, Te variability in ionosphere	NASA (J. Minow)	Statistical Ne, Te variability about IRI output
IRTAM (IRI Real-Time Assimilative Mapping)	Ne, foF2, hmF2	University of Massachusetts Lowell http://giro.uml.edu/IRTAM/	Assimilative ionosphere model
CTIPe (Coupled thermosphere Ionosphere Plasmasphere Electrodynamics) Model	Ne, Ni, Te, Ni and other parameters	https://ccmc.gsfc.nasa.gov/models/CTIPe~4.1/	Physics-based coupled thermosphere-ionosphere-plasmasphere model
CRM (Chandra Radiation Model)	Ring current protons at 100's keV	MSFC/EV44 or J. Minow	Empirical ring current model developed for Chandra program for use in radiation mitigation program
L2-CPE (L2 Charged Particle Environment) Model	Low energy and non-thermal (eV to MeV) plasma environments of Earth's magnetotail	MSFC/EV44 or J. Minow	Originally developed for James Webb Space Telescope design work, can be used for other magnetotail, magnetosheath, and solar wind applications

Radiation Transport Codes

Model	Environment/ Effect	Source	Comments
FLUKA (FLUktuierende Kaskade)	Radiation transport, interactions with matter	http://www.fluka.org/fluka.php	Fully integrated particle physics Monte Carlo simulation package.
Geant4 (for Geometry And Tracking)	Radiation transport, interactions with matter	http://geant4.cern.ch/	Monte Carlo toolkit for the simulation of the passage of particles through matter
HZETRN (Heavy Ion/Nucleon Transport Code)	Heavy ion/neutron transport code	NASA LaRC, OLTARIS https://software.nasa.gov/software/LAR-19979-1	A heavy ion/nucleon transport code for space radiations
ITS (Integrated Tiger Series)	Electron/photon transport code	Sandia Nat'l Laboratory, https://rsicc.ornl.gov/rsic.html	Time-independent coupled electron/ photon Monte Carlo transport codes
TRIM/SRIM (Transport of Ions in Matter/Stopping and Range of Ions in Matter)	Proton, heavy ion transport and radiation interactions	http://www.srim.org/	Collection of software packages for calculating ion transport in matter
MCNP (Monte Carlo N-Particle)	Radiation transport	Los Alamos Nat'l Laboratory https://mcnp.lanl.gov/	General-purpose Monte Carlo N-Particle code for neutron, photon, electron, or coupled neutron/photon/electron transport
Shieldose-2	1-D radiation transport	NIST, SPENVIS https://ccmc.gsfc.nasa.gov/pub/modelweb/radiation_belt/shieldose/	Dose as function of depth in Al shielding for electrons, protons
Attila4MC	Deterministic transport of photon/neutrons with CAD input capability for MCNP geometry construction.	Silver Fir Software	Complex CAD geometry import for MCNP. Accelerated transport of photons/neutrons in deep penetration shielding.
PHITS (Particle and Heavy Ion Transport code System)	Monte Carlo software for space radiation transport.	https://phits.jaea.go.jp/	

Radiation Transport Codes

Model	Environment/ Effect	Source	Comments
EGS (Electron Gamma Shower)	Electron/photon transport code	http://rcwww.kek.jp/research/egs/	
EGSnrc	Electron/photon transport code with optional graphical user interface	National Research Council of Canada https://nrc-cnrc.github.io/EGSnrc/	Permits rapid studies of electron and photon dose penetration. Fast electron transport at small scales.
Casino (monte CArlo Simulation of electron trajectory in sOlids)	Electron transport code	https://www.gel.usherbrooke.ca/casino/index.html	

Plasma, Charging Models

Model	Environment/ Effect	Source	Comments
NASCAP-2k (NASA/Air Force Spacecraft Charging Analyzer Program)	LEO, GEO, auroral, interplanetary surface charging	AFRL, NASA https://software.nasa.gov/software/MFS-32056-1	Standard US surface charging code
EMA3D Charge	3D surface and internal charging tool	Ansys https://www.ema3d.com/ema3d-charge/	Simulate electric arcing, material surface and internal charging, 3D particle transport, and dielectric breakdown
SPIS (Spacecraft Plasma Interaction System)	Spacecraft charging and plasma interactions	http://dev.spis.org/projects/spine/home/spis	Software toolkit for spacecraft-plasma interactions and spacecraft charging modelling
EQUIPOT	LEO, GEO, user defined surface charging	SPENVIS	Surface charging of patches
SOLARC	Current collection, structure potential, and material erosion of PVA in plasma environment	SPENVIS	Solar array interaction with plasma environment
NUMIT 2.0 (“Numerical Iteration”)	1-D Internal charging	NASA JPL (W. Kim)	Time dependent internal charging code
3D NUMIT	3-D internal charging	NASA JPL (W. Kim)	Time dependent 3D internal charging code
COMSOL	Spacecraft charging	https://www.comsol.com/	Electromagnetic equation solver for charging analysis
DICTAT	1-D Internal charging	SPENVIS	Time dependent internal charging code
JWST Deep Charging Tool	1-D internal charging	NASA GSFC (B. Meloy)	Internal charging analysis tool
Plasma Interaction Model (PIM)	Ionospheric plasma interaction with ISS high voltage solar arrays	NASA JSC (ISS Program)	ISS frame charging model
Interactive Spacecraft Charging Handbook	LEO, GEO surface charging	Leidos (V. Davis), NASA https://software.nasa.gov/software/MFS-31675-1	Web-based multimedia interactive spacecraft charging handbook with integrated spacecraft charging models (obsolete???)

Radiation, Plasma Analysis Packages

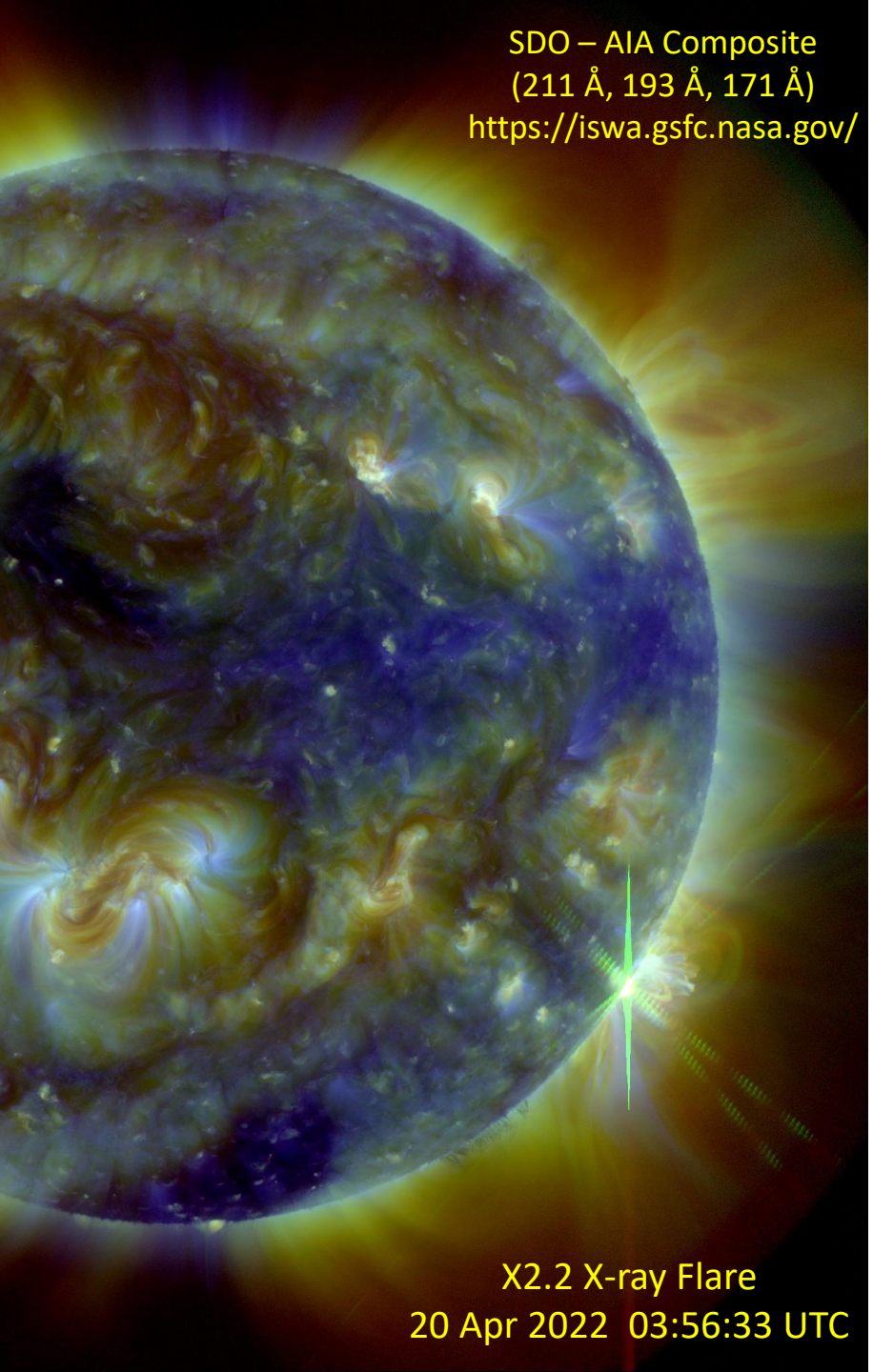
Model	Environment/ Effect	Source	Comments
NOVICE	Trapped, GCR, SPE environments; Monte Carlo radiation transport tool	https://empc.com/	3-D radiation transport and effects
SPACERAD	Multiple radiation environments and effects analysis tool	http://www.spacerad.com/	Ionizing radiation environments and effects
FASTRAD	Space radiation environment, transport analysis tool	TRAD https://www.trad.fr/en/space/fastrad-software/	
OMERE	Space radiation environment and effects freeware software package dedicated to space environment and radiation effects on electronic devices. This tool is developed by TRAD with the support of the CNES	TRAD https://www.trad.fr/en/space/omere-software/	Stand-alone tool for modeling the radiation environment of a mission, provides for use on ITAR and classified programs
SIRE2 (Space Ionizing Radiation Environments and Effect)	Radiation environments and effects on electronics	Fifth Gait Technologies https://5thgait.com/	Supports both satellite orbits and ballistic trajectories. Includes interactive and batch processing modes
OLTARIS (On- Line Tool for the Assessment of Radiation in Space)	NASA on-line tool for space radiation assessment built around HZETRN. Define SPE, GCR, LEO, and Lunar/Mars surface environments; geometry: spheres, slabs, complex raytrace; Responses: dose, dose equivalent, effecitve dose, gray equivalent, LET. Integrates human phantom models for body responses.	LaRC Space Radiation Group; https://oltaris.nasa.gov/	On-line implementation of HZETRN, focus is on human response/risk. Study the effects of space radiation on shielding materials, electronics, and biological systems

Radiation, Plasma Analysis Packages

Model	Environment/ Effect	Source	Comments
CRÈME-MC (CREME96, CREME84)	GCR, SPE, trapped protons Proton and heavy ion single event upset rates, proton dose	Vanderbilt University https://creme.isde.vanderbilt.edu/CREME-MC	Single event effect rate predictions and radiation environments
SPENVIS (SPace ENVironment Information System)	Cosmic rays, natural radiation belts, solar energetic particles, plasmas, gases, and "micro-particles".	ESA https://www.spenvis.oma.be/	Web interface to space environment and effects models
CCMC (Community Coordinated Modeling Center)	Multiple high fidelity space environment science models	https://ccmc.gsfc.nasa.gov/	Multi-agency partnership to enable, support and perform the research and development for next-generation space science and space weather models
STK (Systems Tool Kit) SEET (Space Environment and Effects Tool)	Orbital analysis and space environments toolkit	Ansys https://www.ansys.com/products/missions/ansys-stk	
JPL Natural Space Environments Tools	Web application that integrates all environmental models and interaction tools developed and used by JPL's Natural Space Environments group	https://www.jpl.nasa.gov/site/NSET/	Includes user access to JPL outer planet radiation environments models
Environments Workbench	Multiple LEO environments and effects	Leidos (V. Davis)	Desktop, integrated analysis tool for the study of a spacecraft interactions with its environment (obsolete???)
AF-GEOSpace	Multiple LEO environments and effects	AFRL (R. Hilmer)	Air Force space environment toolset

Data Archives and Space Weather Sources

Model	Environment/ Effect	Source	Comments
NASA Space Science Data Coordinated Archive (NSSDC)	Archive of space environment data from NASA programs and other sources	NASA GSFC https://nssdc.gsfc.nasa.gov/	Includes tools for plotting and working with the data
NASA Space Physics Data Facility (SPDF)	Archive of space environment data from NASA programs and other sources	NASA GSFC https://spdf.gsfc.nasa.gov/	Includes tools for plotting and working with the data
NASA CDAWeb (Coordinated Data Analysis Web)	Archive of space environment data from NASA programs and other sources	NASA GSFC https://cdaweb.gsfc.nasa.gov/index.html/	Includes tools for plotting and working with the data
NASA OMNIWeb Plus	Magnetic field, plasma, energetic particle data relevant to heliospheric studies	NASA GSFC https://omniweb.gsfc.nasa.gov/	Includes tools for plotting and working with the data
Spacecraft Charging Materials Database	Electrical properties of materials required to evaluate surface, internal charging	NASA NESC https://maptis.ndc.nasa.gov/scmd	Contact L. Parker or J. Minow for access
iSWA (Integrated Space Weather Analysis System)	Multiple data sources and environment models	https://ccmc.gsfc.nasa.gov/tools/iSWA/	Flexible, turn-key, Web-based dissemination system for NASA-relevant space weather information
NOAA SWPC (Space Weather Prediction Center)	NOAA's real-time space environment data resources	https://www.swpc.noaa.gov/	NOAA's SWPC operates 24x7 to continually monitor and forecast space weather
ESA Space Environments and Effects	ESA space environment data and tools	https://space-env.esa.int/	ESA's Space Environments & Effects section is responsible for the analysis of space environments and their effects on space systems including the acquisition and analysis of in-flight data and the development of environment and effects models.
ESA Space Weather Portal	Current space weather conditions based on the latest products from the ESA Space Weather Service Network.	https://swe.ssa.esa.int/current-space-weather	Real time space weather products for multiple environments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Questions?