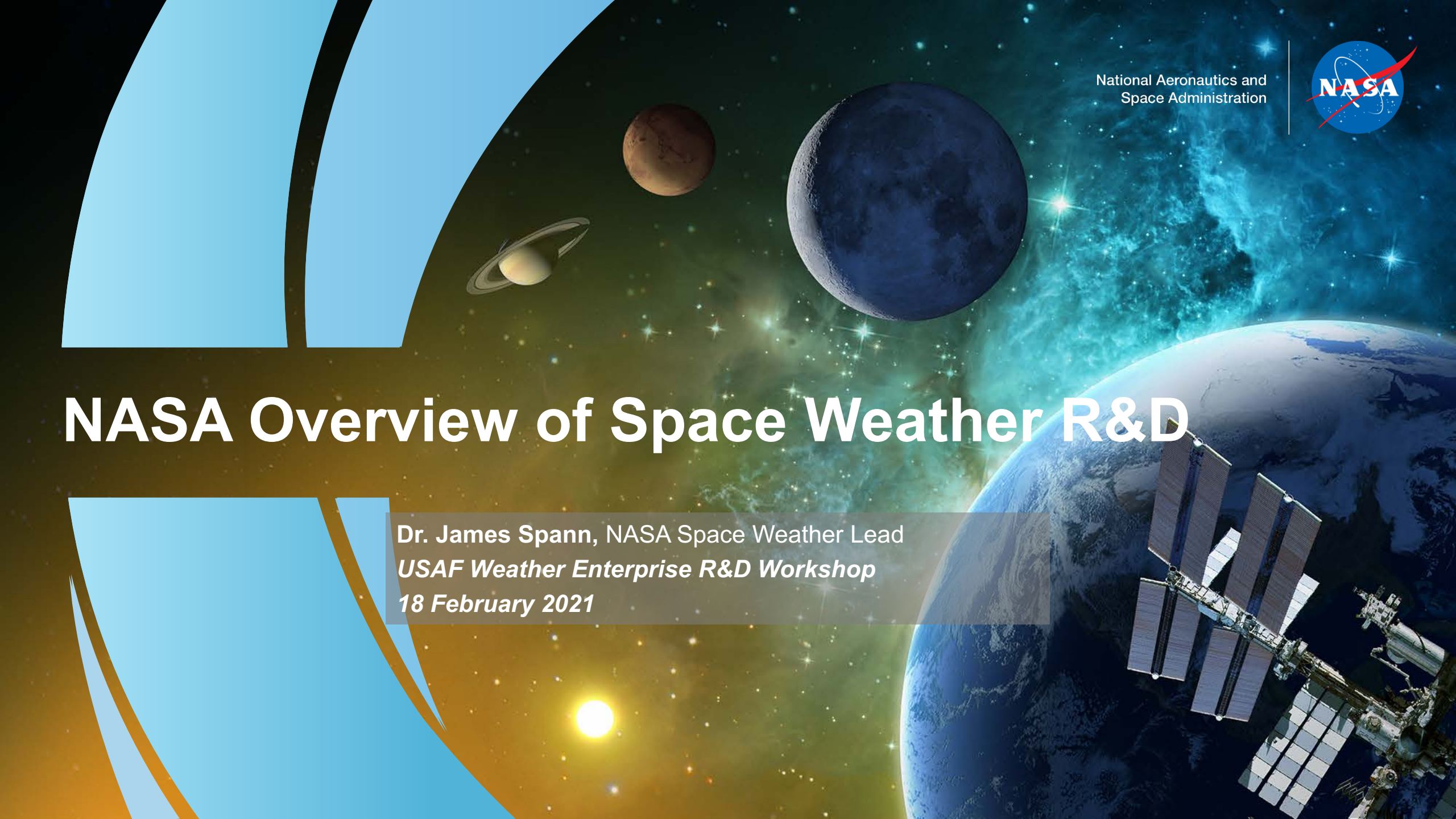


NASA Overview of Space Weather R&D

Dr. James Spann, NASA Space Weather Lead

USAF Weather Enterprise R&D Workshop

18 February 2021

NASA Space Weather Strategy

Vision: Advance the science of space weather to empower a technological society safely thriving on Earth and expanding into space.

Mission: Establish a preeminent space weather capability that supports robotic and human space exploration and meets national, international, and societal needs by advancing measurement and analysis techniques, and by expanding knowledge and understanding for transitioning into improved operational space weather forecasts and nowcasts.

NASA is in the process of developing an implementation plan.

https://science.nasa.gov/heliophysics/space-weather

1. Observe
- Advance observation techniques, technology, and capability

2. Analyze
- Advance research, analysis and modeling capability

3. Predict
- Improve space weather forecast and nowcast capabilities

4. Transition
- Transition capabilities to operational environments

5. Support
- Support Robotic and Human Exploration

6. Partner
- Meet National, International, and societal needs consistent with Government directives

Details of Goals in back up slides

Current Space Weather Activities

Some of the steps already underway at NASA that are in line with responsibilities delineated in the PROSWIFT act include:

- Strengthening our partnership with ESA and other international and interagency partners to ensure maintained operations of the SOHO/LASCO satellite, and other space weather monitoring satellites still in operations, including the ACE, DSCOVR, GOES, SDO, STEREO, and Wind observatories;
- Planning for space weather monitoring capability on future NASA missions including the Geospace Dynamics Constellation;
- Working with other federal agencies including NOAA and DOD to build new space-based monitoring missions, like the NOAA-NASA SWFO-L1 mission (currently in development) and assessment of a ground-based continuous broadband solar radio telescope (SHAARC), to ensure the government has backup capability among our observatories to sufficiently maintain space weather forecasts;
- Carrying out basic research in solar and space physics, and space weather, including a number of joint interagency research and modeling solicitations with NSF and NOAA - *60 efforts funded in 4 years, 37%;*
- Developing a robust partnership with NOAA, NSF, and DOD to establish an interagency framework for supporting the transition of federally funded space weather research into benefit for operational and applied use, and to ensure that the insights garnered from operations and applications in turn are informing the future direction of NASA-sponsored research;
- Supporting competitively awarded grants for multidisciplinary science centers, like the DRIVE Centers based as research institutions, for the purpose of advancing solar and space physics and space weather research-to-operations.

International Collaborations

ESA L5 Mission

- ESA/NASA in discussions about providing science instrument(s) that complements the current payload and provide operational and science data, as well as possible support for a sub-system.

CSA Arctic Observing Mission (AOM)

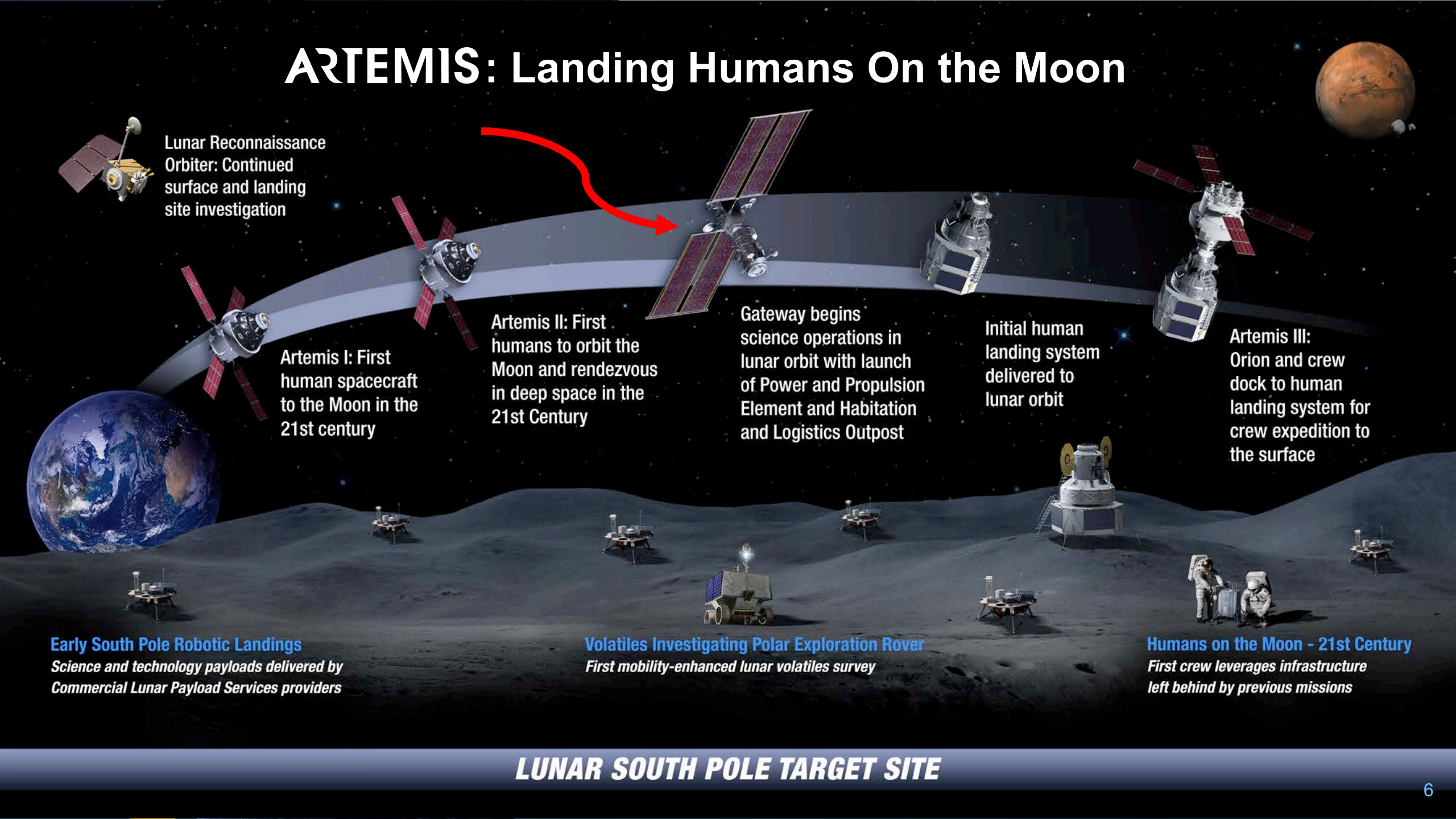
- The mission is proposed by Canada as an international collaboration to collect data on weather, greenhouse gases, air quality and space weather over the Arctic.
- The mission concept study for the AOM mission is led by Environment & Climate Change Canada (ECCC) and the Canadian Space Agency.
- CSA has expressed an interest in NASA ultimately supplying a dedicated space weather payload to the mission.
- HPD finds value participating in AOM because of the potential heliophysics investigations that are made possible with remote and in situ instruments from the AOM platform at high latitude and altitude.

NASA Space Weather Funded R&D

Year	Solicitation	# NASA funded	# Total funded	# submitted
2017	O2R	8	10	22
2018	O2R	9	9	19
	O2Ra	7	7	12
	SBIR Phase I	4	4	
	SBIR Phase II	2	2	
2019	O2R	17	17	48
	SBIR Phase I	4	4	
2020	SBIR Phase I	6	6	
	SWQU (NSF)	3	6	24
	O2R			
TOTAL		60	65	

Listing of funded efforts in back up slides

ARTEMIS: Landing Humans On the Moon



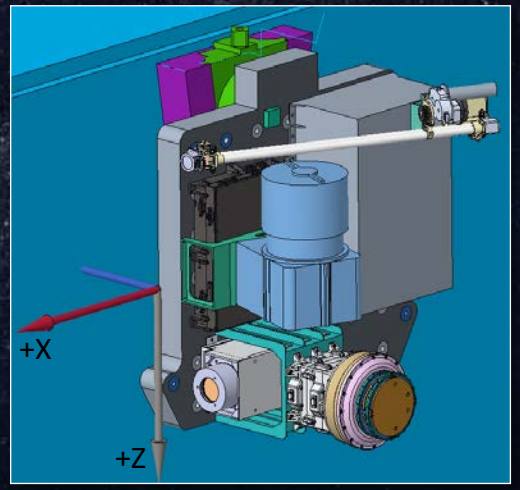
Gateway

Initial Gateway Modules
LRD NET late 2023

Power and Propulsion Element (PPE)

Habitation and Logistics Outpost (HALO)

HERMES (Heliophysics Environmental and Radiation Measurement Experiment Suite)



Instrument	Measurement	PI
EEA, Electron Spectrometer (low energy electrons)	Electrons < 30 KeV Flux, Density, Speed, Temperature	D. Gershman, GSFC
SPAN-i, Ion Spectrometer (low energy ions)	Ions < 40 KeV Flux, Density, Speed, Temperature, Species	R. Livi, UC Berkeley
MERiT, Ion and Electron Telescope (energetic particles)	0.3 – 9 MeV Electrons, 1 – 190 MeV Ions Flux	S. Kanekal, GSFC
Fluxgate and Magneto-Inductive Magnetometers	Magnetic Field Vector	E. Zesta, GSFC; M. Moldwin, U. Michigan

HERMES Goals

Goal A: Determine mechanisms of solar wind mass and energy transport

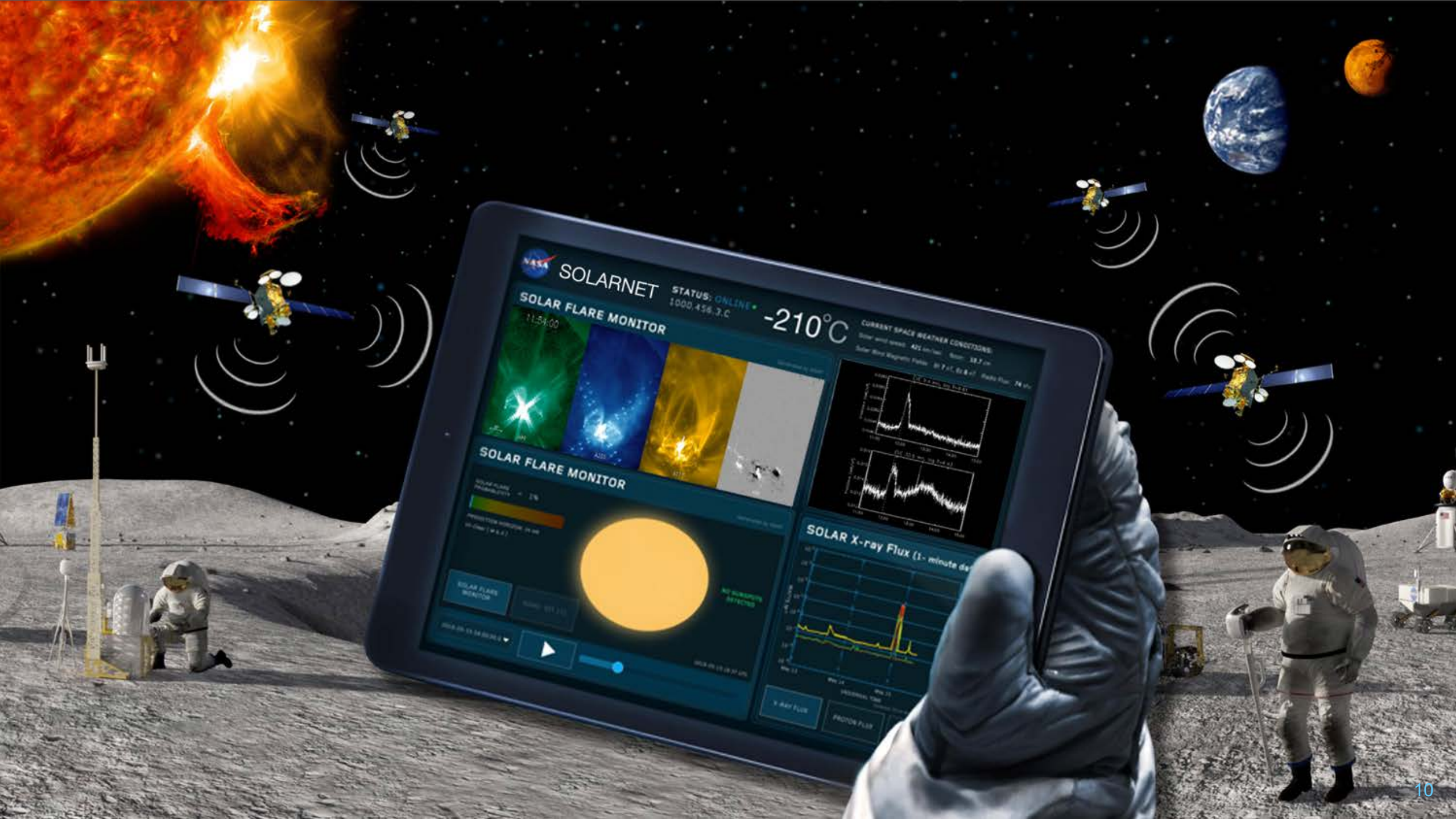
Goal B: Characterize energy, topology, and ion composition in the deep magnetotail.

Goal C: Establish observational capabilities of an on-board pathfinder payload measuring local space weather to support deep-space and long-term human exploration.

In coordination with the Heliophysics two-spacecraft mission THEMIS/ARTEMIS already in lunar orbit, the Gateway observations will initiate a heliophysics lunar constellation to conduct science investigations into what drives change in our near-Earth space environment that have never before been possible.

Heliophysics Division is poised like never before to:

- Capitalize on our unique opportunity to study the Sun and its effects throughout the Heliosphere in partnership with the solar and space physics community around the globe
- Fulfill our responsibility for the Nation enabling advances in space weather in coordination with our sister agencies
- Play a critical role in Exploration supporting the Artemis mission in partnership with HEOMD, to develop Earth-independent observational and model assessment capabilities needed for on-board space environment forecasting, for long-duration deep-space exploration missions.


SOLARNET
STATUS: ONLINE
-210°C
SOLAR FLARE MONITOR
SOLAR FLARE MONITOR
SOLAR X-ray Flux

BACKUP

PROSWIFT and NASA

- On Oct. 21, 2020 the President signed the PROSWIFT Act, which codifies ongoing efforts across the government, including interagency efforts, on space weather observations, research, modeling, operational forecasting, and applications.
- Allows NASA to focus on what NASA does best in space weather: Pushing the limits of our understanding the Sun-Earth system including space weather phenomena, and leading the evolution of the space-based network of heliophysics observatories, and the science behind them, through new missions, technology development, and cutting-edge research and modeling.
- This bill helps ensure that the United States has the forum to prepare for an increase in both human and robotic activity across the solar system and key efforts to help protect infrastructure and activities vital to national security and the economy of the United States.
- This coordination also ensures the advancement of the NASA space weather capability that is a cornerstone of the National Space Weather Strategy and Action Plan.

Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act (PROSWIFT)

Space Weather Science Application (SWxSA) Team

- SWxSA is a NASA capability and leverages the expertise across the Agency
- Serves as an internal sounding board for HPD for Space Weather ideas and actions

Space Weather Council (SWC)

- The Space Weather Council (SWC) is established to secure the counsel of community experts across diverse areas, on matters relevant to space weather in support of the NASA Heliophysics Division (HPD).
- The SWC serves as a community-based, interdisciplinary forum for soliciting and coordinating community analysis and input and providing advice. It provides advice to the Heliophysics Advisory Committee (HPAC) of the NASA Heliophysics Division (HPD).

Space Weather Instruments and Missions for Science RFI

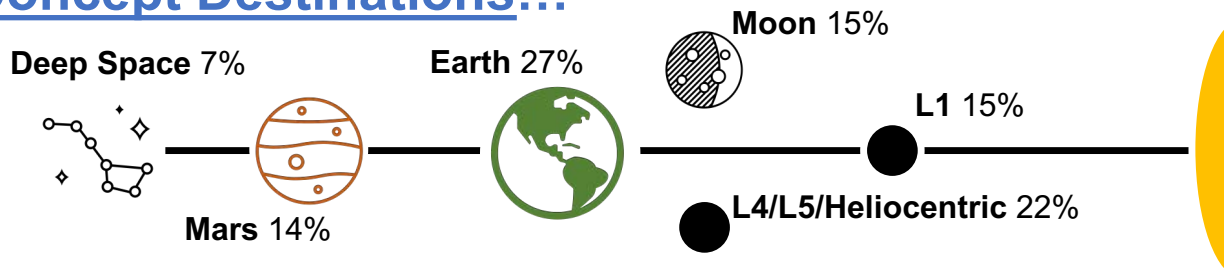
54

TOTAL SUBMISSIONS

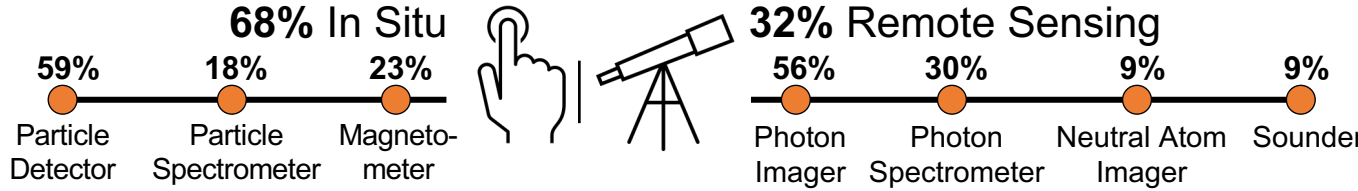
Types of Institutions that Responded…

- 25% Academic Institution
- 23% University-Affiliated Research Center
- 25% Federal Laboratory
- 9% Independent Laboratory
- 19% Commercial Organization

Concept Destinations…



Instrument Types…



Submission Categories…

NASA Space Weather Strategy Details

SWxSA Strategy by Goal		
Theme	**Goal**	**Objective**
1. Observe	Advance observation techniques, technology, and capability	1.1 Identify technologies and techniques for which enhanced or future investments would produce results that significantly and positively impact space weather understanding and prediction 1.2 Create opportunities to develop observation techniques and instrumentation 1.3 Establish and sustain recurrent flight cadence and supporting infrastructure opportunities for space weather instrumentation and missions 1.4 Identify and implement the capability to ensure that real-time and latent data streams for space weather-relevant space observations are available
2. Analyze	Advance research, analysis and modeling capability	2.1 Identify analysis capabilities that advance space weather understanding and prediction 2.2 Establish opportunities to support the develop improved data analysis and modeling capabilities 2.3 Work with NSF and other Federal agencies to advance research and analysis capabilities relevant to space weather
3. Predict	Improve space weather forecast and nowcast capabilities	3.1 Develop a structure and process that funnels basic research information to an applied focus
4. Transition	Transition capabilities to operational environments	4.1 Create a pipeline that conveys the results and outputs of the NASA Heliophysics research and technology programs to a space weather proving ground environment where models and techniques are assessed 4.2 In coordination with NOAA, establish a testbed capability to transition forecasting and nowcasting models (SWPC) and transition observations and data streams (NESDIS). 4.3 Establish formal relationships between NASA and DoD to exchange data and observation capabilities, and effectively transition data, improved forecasting and nowcasting capabilities, and improved observation techniques.
5. Support	Support Robotic and Human Exploration	5.1 Advance the partnership between the Heliophysics Division and the Human Exploration and Operations Mission Directorate (HEOMD) to provide expertise on space environment conditions that enable the health and safety of astronauts beyond low-earth orbit 5.2 Provide key real-time data streams to the Agency for forecasting, nowcasting, and anomaly resolution for robotic and crewed missions
6. Partner	Meet National, International, and societal needs consistent with Government directives	6.1 Secure the counsel of space weather expertise within the government, academia, commercial and private sector 6.2 Provide key real-time data streams to sister agencies for forecasting, nowcasting, and anomaly resolution 6.3 Continue active participation at the Executive level with OSTP 6.4 Represent the U.S. in international space weather research fora to advance the global capability and enhance U.S. ability to meet its space weather needs

1. **Observe:** Advance observation techniques, technology, and capability

1.1 Identify technologies and techniques for which enhanced or future investments would produce results that significantly and positively impact space weather understanding and prediction

1.2 Create opportunities to develop observation techniques and instrumentation

1.3 Establish and sustain recurrent flight cadence and supporting infrastructure opportunities for space weather instrumentation and missions

a. Develop and launch a NASA-led pathfinder mission that contributes significantly to the National space weather enterprise

1.4 Identify and implement the capability to ensure that real-time and latent data streams for space weather-relevant space observations are available

2. **Analyze:** Advance research, analysis and modeling capability

2.1 Identify analysis capabilities that would advance space weather understanding and prediction

2.2 Establish opportunities to support the develop improved data analysis and modeling capabilities

2.3 Work with NSF and other Federal agencies, and with international space agencies to advance research and analysis capabilities relevant to space weather

3. Predict: Improve space weather forecast and nowcast capabilities

3.1 Develop a structure and process that funnels basic research information to an applied focus

a. Create opportunities to use existing and past observations to develop improved forecast and nowcast capability

b. Create opportunities for the scientific community and the GSFC Community Coordinated Modeling Center to test and validate forecast and nowcast models that show promise for operational environments

c. Periodically assess the opportunity to capture new discoveries into forecasting and nowcasting models

4. Transition: Transition capabilities to operational environments

4.1 Create a pipeline that conveys the results and outputs of the NASA Heliophysics research and technology programs to a space weather proving ground environment where models and techniques are assessed

4.2 In coordination with NOAA, establish a testbed capability to transition forecasting and nowcasting models (SWPC) and transition observations and data streams (NESDIS)

4.3 Establish formal relationships between NASA and DoD, and with international space agencies, to exchange data and observation capabilities, and effectively transition data, improved forecasting and nowcasting capabilities, and improved observation techniques

5. Support: Support Robotic and Human Exploration

5.1 Advance the partnership between the Heliophysics Division and the Human Exploration and Operations Mission Directorate (HEOMD) to provide expertise on space environment conditions that enable the health and safety of astronauts beyond low-earth orbit

- a. Develop Earth-independent observational and model assessment capabilities needed for on-board space environment forecasting on long-duration crewed missions
- b. Identify opportunities to manifest space observation capability to improve forecasting of space environment in support of space exploration
  - i. Deliver Gateway HERMES payload and establish a Science Operation Center
  - ii. Establish a competed HERMES science team to conduct science investigations

5.2 Provide key real-time data streams to the Agency for forecasting, nowcasting, and anomaly resolution for robotic and crewed missions

6. Partner: Meet National and International needs consistent with U.S. Government directives

6.1 Secure the counsel of space weather expertise within the government, academia, commercial and private sector

- a. Seek advice of the NASA Heliophysics Advisory Committee (HPAC) on matters relevant to space weather
- b. Secure the results of a NASA focused gap analysis of space weather knowledge, observational and data capability, and forecasting and nowcasting capability
- c. Engage NASEM on matters relevant to space weather

6.2 Provide key real-time data streams to sister agencies for forecasting, nowcasting, and anomaly resolution

6.3 Continue active participation at the Executive level with OSTP

- a. Partner with other Federal Agencies to achieve the objectives of the National Space Weather Strategy and Action plan

6.4 Represent the U.S. in international space weather research fora to advance the global capability and enhance U.S. ability to meet its space weather needs

- a. Provide leadership to the UN COPUOS space weather activities
- b. Partner with international agencies to further the capability of space weather forecasting/nowcasting
  - i. Coordinate with ESA for NASA participation in the Lagrange Mission
  - ii. Coordinate with CSA for NASA participation in the Arctic Observation Mission
  - iii. Coordinate with other space agencies as the opportunity arises and is appropriate, to include the establishment of an International Agency Space Weather Coordination Group

NASA Space Weather Funded Proposals

2017 O2R - Focus: Improve predictions of background solar wind, solar wind structures, and CMEs

NOAA Selections

No.	PI/ Institution	Title
21	Riley/Predictive Science Inc.	Metric-Based Assessment of a New Ambient Solar Wind Forecast Model incorporating Data Assimilation
4	Zhao/Stanford	Reliably Inferring the Sun's Far-Side Magnetic Flux for Operations Using Time-Distance Helioseismic Imaging

NASA Selections

No.	PI/ Institution	Title
7	Hickman/LANL	Optimizing the Source Surface and Interface Radii in WSA using Data Assimilation
5	Wang/NRL	Using Magnetograms and Coronal Imaging Observations to Improve Space Weather Predictions
8	Odstrcil/GMU	Improving the Prediction Accuracy of CME Arrivals in the WSA-ENLIL-Cone Model
2	Kirk/Catholic Univ	Evaluating and Validating Heliospheric Models Against Data and Each Other
14	Merkin/JHU	Data-driven Time-Dependent Model of the Inner Heliosphere
18	Barnes/NRA	Global Boundary Magnetic Field Optimization to Improve Solar Wind Model Predictions
11	Berger/CU	Improving Magnetic Field Boundary Conditions for Solar Wind Forecast Models
19	Kim/Univ. of Alabama	A Higher-Accuracy Model of the Heliosphere with Improved Background Solar Wind and Coronal Mass Ejections

2018 O2R - Focus: Improve specifications and forecasts of the energetic particle and plasma encountered by spacecraft

No.	PI/ Institution	Title
3	Li/UC Boulder	Quantitative forecasts and specifications of outer radiation belt electrons based on solar wind conditions
4	Green/Space Hazards	Specifying High-altitude Electrons using Low-altitude LEO Systems
6	Chen/LANL	A Neural Network Based Predictive Model for MeV Electrons inside Earths Outer Radiation Belt
7	Bortnik/UCLA	A machine learning based specification and forecast model of the inner magnetospheric radiation environment
8	Jordanova/LANL	Data-driven Specification of the Near-Earth Space Environment
10	Murphy/UMD College Park	An ARIMAX model of radial diffusion for space weather forecasting
13	Sorathia/APL	Data-Augmented Forecasting Model for near-Earth Relativistic Electron Intensities
16	Fok/GSFC	Advanced Particle and Plasma Environment Specification Model for Spacecraft Impacts
19	Sazykin/Rice	Development of a Predictive Inner Magnetosphere Model for Space Weather

2018b O2R - Focus: Improve forecasts of solar energetic particles and heavy ions

Proposal	PI/Institution	Title
3	Falconer/University of Alabama, Huntsville	Automated All-Clear Forecasting of Fast-Rising SPEs
5	Dayeh/Southwest Research Institute	Forecasting energetic particle and heavy-ion enhancements at 1 AU: A machine-learning, data intensive approach
7	Linker/Predictive Science	Integrated MHD-Focused Transport Modeling of Solar Particle Events
8	Zhang/Florida Institute of Technology	Prediction of Solar Energetic Particle Radiation Based on Measurements of Solar Eruption and Photospheric Magnetic Field
10	Szabo/NASA Goddard Space Flight Center	Solar Energetic Particles and Interplanetary Type III Bursts
11	Nitta/Lookheed Martin Advanced	Building a Solar Energetic Particle Forecast Model Using Spatial Properties of Solar Eruptions
12	Engell/NextGen Federal System	Forecasting solar particle events with SPRINTS

2019 O2R - Focus: open call

Proposal	PI/Institution	Title
21	Peck/ University of Colorado, Boulder	Improving the EUVS Spectral Model Through Physics-Based Differential Emission Techniques
53	Berger/ University of Colorado, Boulder	Application of Topological Data Analysis and Computational Geometry to Recurrent Deep Learning Algorithms for Solar Eruption Prediction
52	Riley/ Predictive Science Inc.	The Rise of SunRunner: A New Model for Predicting the Properties of Interplanetary Coronal Mass Ejections at 1 AU
28	Mertens/ NASA Langley Research Center	NAIRAS Operational Improvements to SEP Aviation Radiation Dose Predictions
32	Pankratz/ University of Colorado, Boulder	Next Generation 3D Solar Wind Interactive Data Visualizations
25	Ngwira/ Atmospheric & Space Technology Research Associates	Enhancing Geomagnetically Induced Current Understanding and Prediction over Continental United States
39	Marshall/ University of Colorado, Boulder	Quantifying the Contributions of Radiation Belt Precipitation to the Effective Radiation Dose at Spacecraft and Aviation Altitudes
17	Zou/ Universtiy of Alabama, Huntsville	Specifying near-Earth solar wind conditions: a novel model for propagating solar wind values and uncertainties

2019 O2R - Focus: open call

Proposal	PI/Institution	Title
50	Kellerman/ University of California, Los Angeles	Towards a Robust Hindcast and Forecast Framework for On-Orbit Satellite Anomaly Detection
14	Lucas/ University of Colorado, Boulder	Pushing the Frontiers of Operational Geoelectric Hazard Modeling
29	Ruohoniemi/ Virginia Polytechnic Institute & State University	Specification and Modeling of Radio Blackout Following Solar Flares
55	Groves/ Boston College	Advanced Techniques to Specify Irregularities with Ground- and Space-based Sensors
34	Sutton/ University of Colorado, Boulder	A Data-Assimilative Methodology for WAM-IPE
3	Weimer/ Virginia Polytechnic Institute & State University	Advanced prediction of upper atmospheric neutral density using measurements from solar wind sentinels
35	Elliott/ Southwest Research Institute	Extending and Improving the Wang-Sheeley-Arge Solar Wind Model
37	Thiemann/ University of Colorado, Boulder	Operational Measurements of Thermospheric Density, Composition and Temperature from GOES-R SUVI Solar Occultations
51	Jackson/ University of California, San Diego	Updates to Global Remotely-Sensed Heliospheric Modeling Using In-situ Spacecraft Measurements

Satellite Drag: Improve the specification and forecast of neutral density in the thermosphere as it pertains to satellite drag and orbital operations.

Ionospheric Disturbances: Improve forecasts and/or specifications of ionospheric disturbances that impact: 1. positioning, navigation, and timing (PNT) derived from the Global Navigation Satellite System, and/or 2. radio communication.

Small Business Innovative Research (SBIR)

Proposal	PI/Institution	Title
SBIR 2018 Phase 2	Meaghan Marsh / Predictive Science, Inc.	Interactive Tool for Modeling Multiple Solar Eruptions
SBIR 2018 Phase 2	Kent Tobiska/Space Environment Technologies, LLC	Automated Radiation Measurements for Aerospace Safety - Dual Monitor (ARMAS-DM)
SBIR 2019 Phase 1	Kent Tobiska/Space Environment Technologies, LLC	Operational Radiation Information System (ORBIS)
SBIR 2019 Phase 1	Pete Riley/Predictive Science, Inc.	An extensible tool for estimating space weather benchmarks
SBIR 2019 Phase 1	Jesse Woodroffe/Quantitative Scientific Solutions, LLC	Real-time Prediction and Forecasting of Geoelectric Fields Using Machine Learning
SBIR 2019 Phase 1	Janet Green/Space Hazards Applications, LLC	A Tool for Defining Solar Particle Access to the Magnetosphere (SPAM) for Satellite Anomaly Attribution

Small Business Innovative Research (SBIR) (cont.)

Proposal	PI/Institution	Title
SBIR 2020 Phase 1	Vladimir Kolobov / CFD Research Corporation	Space Weather Forecasting Toolset to Support Operations
SBIR 2020 Phase 1	Bodo Reinisch/Lowell Digisonde International, LLC	A CubeSat Based System for Topside Ionospheric Sounding
SBIR 2020 Phase 1	Asher Pembroke/Ensemble Government Services, LLC	Kamodo Containerized Space Weather Models
SBIR 2020 Phase 1	Henry Voss/NearSpace Launch Inc.	Space-Weather CubeSat Array for 24/7 Prompt Global Coverage Experiment (SWAP-E)
SBIR 2020 Phase 1	Kent Tobiska/Space Environment Technologies, LLC	Machine learning Enabled Thermosphere Advanced by HASDM (META-HASDM)
SBIR 2020 Phase 1	Jon Linker/Predictive Science, Inc.	Time-Dependent Connectivity Mapping of the Solar Magnetic Field

Space Weather Quantification of Uncertainties (SWQU)
NSF/NASA

Proposal Title	PI	Institution
NextGen Space Weather Modeling Framework Using Data, Physics and Uncertainty Quantification	Toth, Gabor	University of Michigan
A New-generation Software to Improve the Accuracy of Space Weather Predictions	Pogorelov, Nikolai	U of Alabama Huntsville
Composable Next Generation Software Framework for Space Weather Data Assimilation and Uncertainty Quantification	Linares, Richard	MIT
Aether: A Flexible Community-Based Upper Atmosphere Ensemble Prediction System with Quantifiable Uncertainty to Accelerate Scientific Advances and Model Improvement	Ridley, Aaron	University of Michigan
Collaborative Research: Forecasting the small-scale plasma structures in the Ionosphere-Thermosphere system	Fang, Tzu-Wei	U of Colorado Boulder
Ensemble Learning for Accurate and Reliable Uncertainty Quantification	Camporeale, Enrico	U of Colorado Boulder