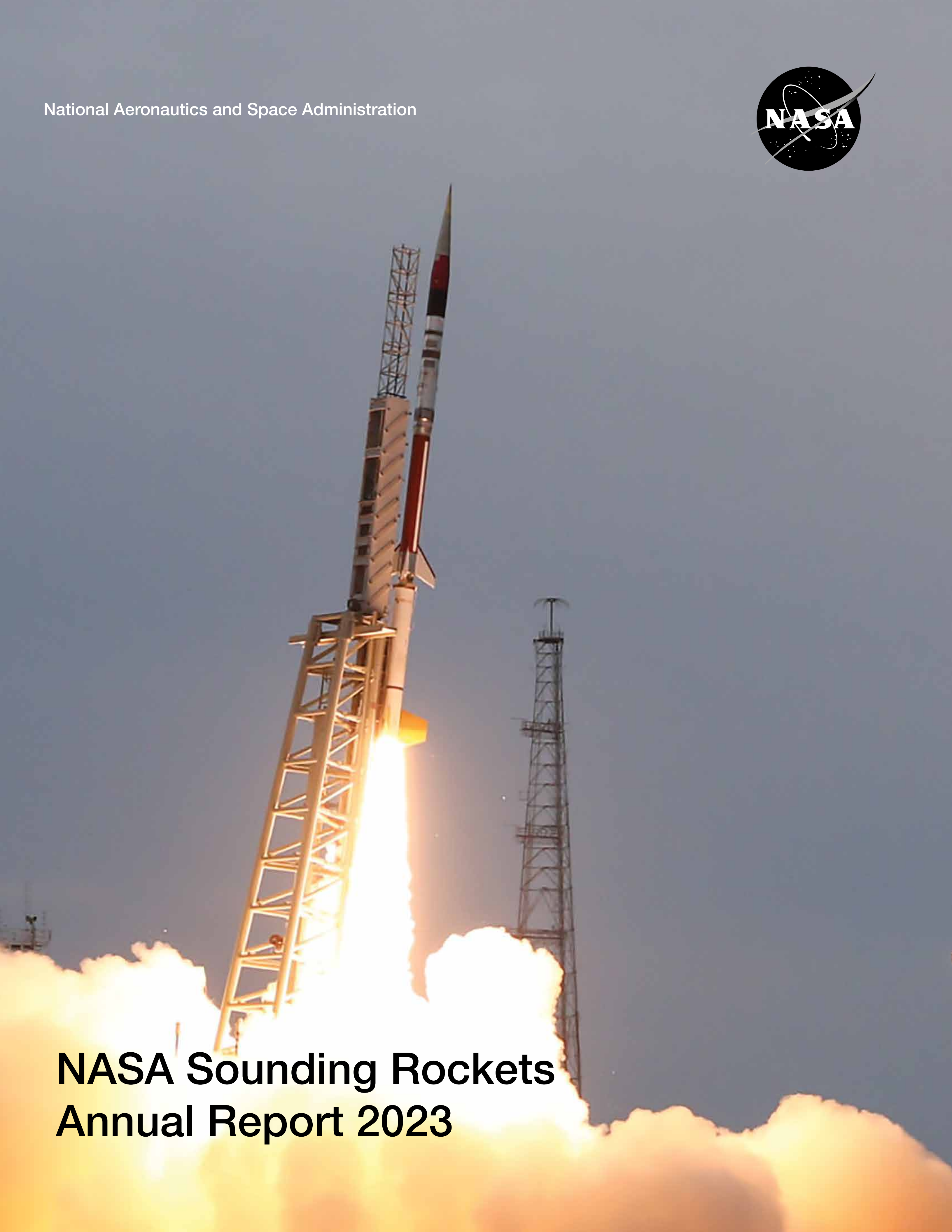
National Aeronautics and Space Administration



NASA Sounding Rockets Annual Report 2023

Message from the Chief

Giovanni Rosanova, Jr.
Chief, Sounding Rockets Program Office

At the end of each fiscal year, I have the great honor and pleasure to share with you our successes of the past year and our future plans. The rest of this report outlines in more detail what I synopsize here.

The Sounding Rockets Program launched 11 missions in FY 2023, covering five disciplines (Solar Physics, Geospace Sciences, Technology, Student Outreach, and Astrophysics) and three launch sites. FY 2023 started with 22 missions manifested in October 2022. Due to supply chain issues remaining after the Covid pandemic and some technical challenges, the actual flight rate ended up being significantly lower. The success rate for the year of 82%, slightly lower than the 85% we aim for. Two mission failures were the cause of the lower success rate.

The Solar Dynamics Observatory - EUV Variability Experiment (SDO-EVE) mission for University of Colorado flew successfully for the 10th time. SDO-EVE provides underflight calibration for the EUV Variability Experiment (EVE) aboard the NASA Solar Dynamics Observatory (SDO) satellite. Additional underflight calibrations are provided for several solar EUV imagers aboard orbiting observatories.

The Aurora Current and Electrodynamics Structure (ACES) 2 and the Vorticity Experiment (VortEx) for Iowa State University and Clemson University, respectively, took our teams to Andoya Space, in Norway. A total of four rockets were launched, two for each mission, in November 2022 and March 2023. All flights were successful. Originally the VortEx mission included four rockets and payloads, but due to weather impacts, only two were launched. The remaining two are scheduled for flight in October 2024.

Three Technology Development flights were conducted in FY 2023. Two were test rounds for a new mesospheric vehicle, the MesOrion, based on a single stage Orion motor, and two variations of a light weight, small diameter payload. Both flights were successful and reached the goal of apogees between 70 and 125 km. SubTEC-9, with various experiments developed by internal and external stakeholders was successfully launched on a Terrier-Improved Malemute. The primary objective of this mission was to the test a new C-band telemetry capability.

Two Student Outreach missions were flown, RockOn/RockSat-C and RockSat-X. These programs are now under the leadership of the Wallops Education Office and are executed in collaboration with the Sounding Rockets Program Office (SRPO). RockOn is the first step in introducing College and University students to build experiments for space flight, and includes a hands-on workshop where students build an experiment from a kit. RockSat-C is the second level of the program where students design and build their own experiments. RockOn and RockSat-C share space on a Terrier-Improved Orion vehicle. RockSat-X is the most advanced opportunity for student-built experiments and allows exposure to the space environment and provides support systems such as Telemetry, Attitude Control, Power and Recovery. About 200 students attended the launch on Wallops Island, VA in August 2023.

The Cosmic Infrared Background Experiment (CIBER) 2 experienced a flight failure when the vehicle was terminated at White Sands Missile Range (WSMR), NM shortly after lift-off. This mission is scheduled for a re-flight in 2024. The second failure occurred on the RockSat-X student mission, where the Terrier-Improved Malemute experienced anomalous flight dynamics. A review is ongoing and will likely lead to modifications of this vehicle.

The program has been extremely busy integrating missions for FY 2024, with total of 23 missions currently manifested for the year. Of particular note is our participation in the Heliophysics Big Year, starting with the Atmospheric Perturbations around Eclipse Path (APEP) mission from WSMR during the Annular Eclipse on October 14, 2023. Three payloads will be launched approximately 30-minutes before, during, and 30-minutes after, the peak eclipse. Additionally, three APEP payloads will be flown from Wallops Island, VA, during the Total Eclipse, on April 8, 2024. Other Solar Year launches include the Solar Flare campaign scheduled for Poker Flat Research Range (PFRR), AK in March 2024. Three payloads will be launched to study several aspects of the dynamic Sun, including, nanoflares, spicules, and Rapid Blue-shifted Excursions (RBEs), large solar flares, and high temperature flare lines. Additional Solar Physics missions include Full-sun Ultraviolet SpecTrograph (FURST) for Montana State University, HElium Resonance Scatter in the Corona and HELiosphere (HERSCHEL) 3 for the Naval Research Laboratory, and Marshall Grazing Incidence X-ray Spectrometer for NASA Marshall Space Flight Center.

Several Geospace Science missions are scheduled from four different launch ranges, including, PFRR, WSMR, Wallops Island, and Kwajalein, and two Astrophysics missions are scheduled to fly from WSMR.

The NSROC IV contract was awarded to Peraton, Inc. with a contract start date of October 1, 2023. This is a 5-year contract for Engineering and Manufacturing support for the Sounding Rockets Program. Changes from the previous, NSROC III, contract are being implemented and include the Mission Management function moving to Civil Service staff. Several new staff members are being recruited.

With the busy outlook for FY 2024 I'm thankful to have such a dedicated and inspired team of Civil Servants and Contractors working toward our common goal of supporting NASA's and the nation's space program. Individual and collective efforts matter, not just to me, but the entire space program. Our staff travel the world as ambassadors for the agency and the United States, launching rockets sometimes under less-than-optimal conditions. Heat, cold, rain, snow, hail, thunder, we've been there and still managed to successfully support tight launch windows. That is the spirit of Sounding Rocketeers!

We Fly for Science!

Giovanni Rosanova, Jr.

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Cover photo: SubTEC-9 launches from Wallops Island, VA on April 25, 2023.

Credit: NASA Wallops Imaging Lab

Sounding Rockets Overview

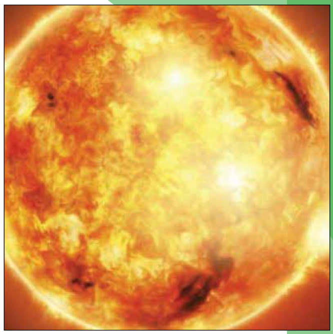
The Sounding Rockets Program supports the NASA Science Mission Directorate's strategic vision and goals for Earth Science, Heliophysics and Astrophysics. The 20+ suborbital missions flown annually by the program provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world-class scientific research. Coupled with a hands-on approach to instrument design, integration and flight, the short mission life-cycle helps ensure that the next generation of space scientists receive the training and experience necessary to move on to NASA's larger, more complex space science missions. The cost structure and risk posture under which the program is managed stimulates innovation and technology maturation and enables rapid response to scientific events.

With the capability to fly higher than many low Earth orbiting satellites and the ability to launch on demand, sounding rockets offer, in many instances, the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments onboard most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the program enables researchers to conduct missions from strategic vantage points worldwide.

Telescopes and spectrometers to study Solar and Astrophysics are flown on sounding rockets to collect unique science data and to test prototype instruments for future satellite missions. The program's rapid response capability enabled scientists to study the Supernova 1987A before it faded from view. Currently, new detectors, expected to revolutionize X-ray astronomy, are under development and have been successfully tested on sounding rocket flights. An important aspect of most satellite missions is calibration of the space based sensors.

Science with Sounding Rockets

In 1957 scientists participating in the International Geophysical Year (IGY) had available to them rockets as research tools for the first time in history. They took full advantage of these new assets, and launched a total of 210 rockets from 7 different sites as part of the United States contribution to the IGY. The research ranged from atmospheric sciences to astronomy. Ionospheric soundings included direct electron density measurements and detailed mapping of the E and F regions.



IGY 1957 firmly established sounding rockets as viable tools for science and proved their utility for in-situ measurements, quick response, and temporal and geographic mobility. The utilization of sounding rockets for science has continued with undiminished importance.

Heliophysics, Astrophysics, Geospace science and Aeronautics benefit from sounding rockets. Advantages such as the quick response to scientific events, low cost, and mobile operations provide researchers with opportunities to conduct world class science.

Some of the highest resolution spectral data of the Sun are recorded with telescope payloads flying on sounding rockets. Payload recovery yields significant cost savings by ensuring that sensors, one-of-a-kind telescopes, cameras and recorders are available for reflight on future missions.

As research tools, sounding rockets are key to the study of the near Earth space environment; in fact, they are the only means of collecting in-situ data in the ionosphere. Several launch sites in the arctic region enable studies of phenomena such as magnetic re-connection, ion outflows and the effects of Joule heating. Understanding the fundamental processes that govern the Sun-Earth space environment will enhance our ability to more accurately predict the solar storms that can disrupt power grids and satellite-based information systems on Earth.

In the high energy and the ultraviolet and visible parts of the spectrum, Astrophysics uses sounding rockets to test new instruments on unique scientific missions. Subsystems, developed by NASA, provide unprecedented pointing accuracy for stellar targeting, yielding high resolution spectra and potentially leading to new ground breaking discoveries about our own galaxy. Sounding rockets offer calibration and validation flights for many space missions, particularly solar observatories such as the Thermosphere-Ionosphere-Mesosphere-Energetics-Dynamics (TIMED) satellite, the Solar Heliospheric Observer and the future Solar Dynamics Observatory (SDO).

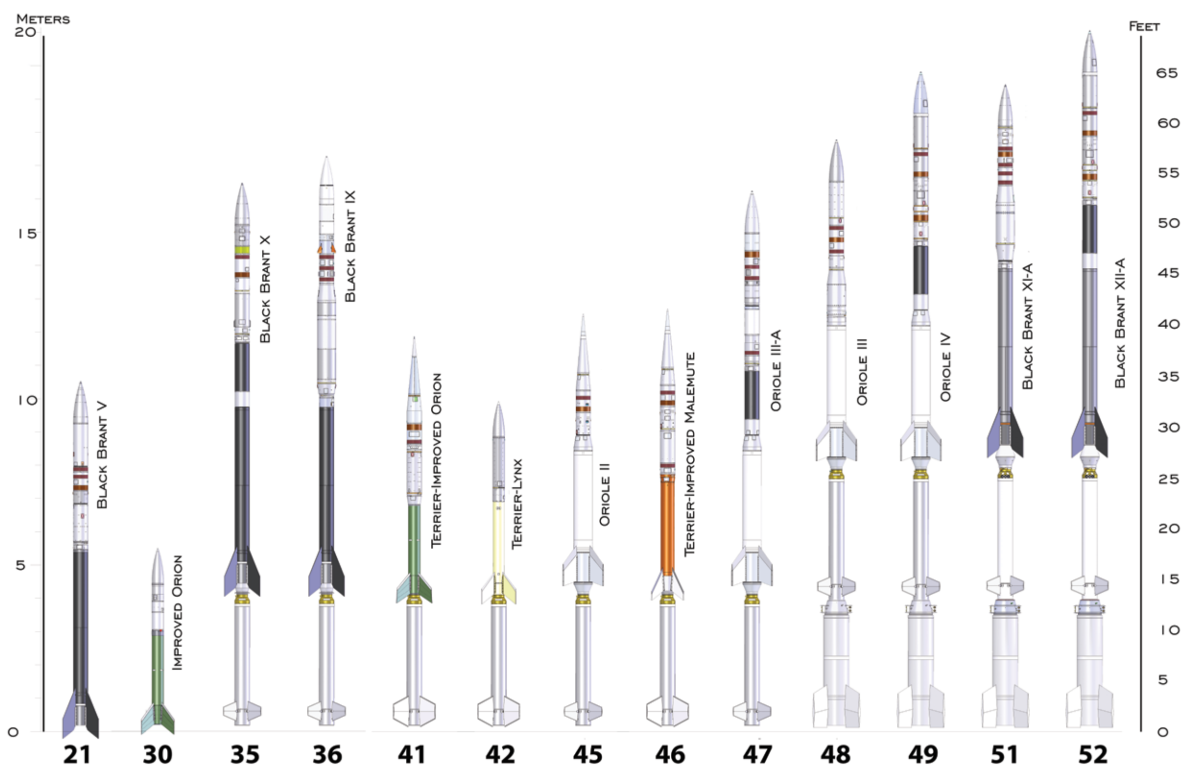
Additionally, sounding rockets are well suited for testing new technologies for future space missions. For example, parachute technologies for the Mars 2020 mission were tested on sounding rockets.

End-to-End Mission Support

The NASA Sounding Rocket Program provides comprehensive mission support and management services from concept through post flight data distribution. This end-to-end support capability enables the Principal Investigator (PI) to focus on the research aspect of the mission.

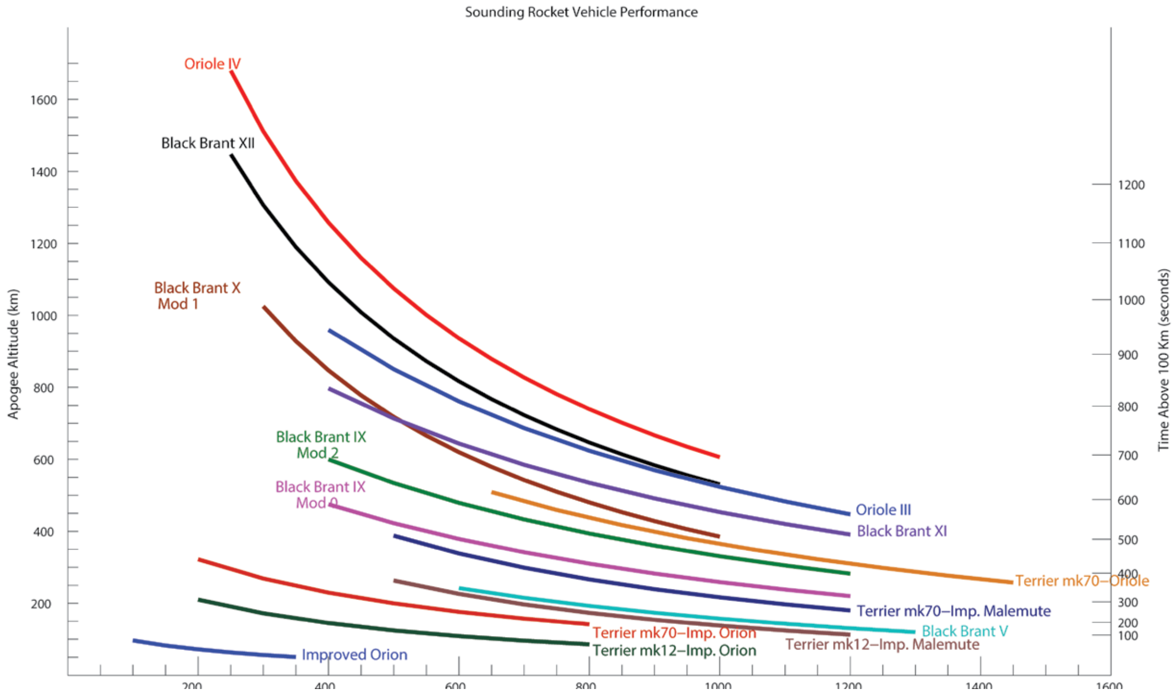
Extensive experience, over 2,500 missions flown, has lead to streamlined processes and efficient design, manufacturing and assembly techniques. Management and technical support is provided for all facets of a mission and includes engineering design, manufacturing, integration, and testing and evaluation. Periodic reviews are conducted to ensure mission requirements are being met on time and on budget.

Launch Vehicles



Sounding Rocket Vehicles
By NSROC Mechanical Section

The Sounding Rocket Program offers multiple proven launch vehicles to meet the needs of most researchers. New vehicles are brought online periodically to meet customer requirements and enhance capability. Currently, 13 vehicles are provided "off-the-shelf" and range in performance from a single stage Orion to a four stage Black Brant XII-A and Oriole IV.

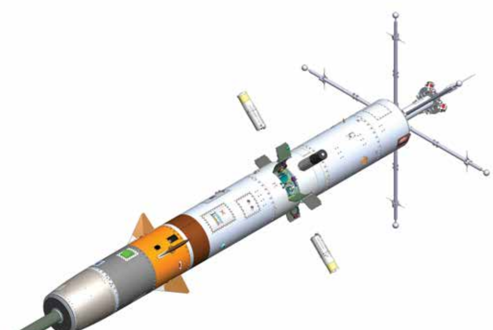


Sounding Rocket Vehicle Performance
By NSROC Flight Performance

Payload Design

The payload design process begins immediately after the Mission Initiation Conference (MIC) is completed. Initial flight requirements and schedules are discussed at the MIC.

All payload components, mechanical and electrical systems, telemetry, recovery and other sub-systems are designed using state-of-the-art software, modelling and analysis tools. 3-D visualization tools facilitate the iterative design process by allowing flexibility in design updates and changes. The integrated multi-disciplinary design methods are effective in meeting the needs of the PI.



3D model of payload.
Credit: Graham Taylor/NSROC
Mechanical Engineering

Manufacturing

Extensive in-house manufacturing capability is vital in a program with many customization requirements. The machine shop includes a vast assortment of machinery such as Computer Numerical Controlled (CNC) milling machines, lathes, welders, sheet metal breaks/shears/rollers and additional tools/processes to support the mechanical needs of the program. A waterjet cutting machine enables fast manufacturing of small parts in large quantities.

Machine shop in Building F–10 at Wallops Flight Facility.
Photos by: Berit Bland/NSROC

Assembly

Payload electrical and mechanical assembly begins with decks, longerons and electrical wiring and ends with the integration of all sub-systems and science instruments. Electrical and mechanical technicians are assigned to a mission at the MIC and, to the extent possible, stay with the assigment through flight, contributing greatly to a responsive and customer focused program.

Payload assemblies during integration.
NASA Photo/Berit Bland

Sub-systems

The Sounding Rocket Program provides standard sub-systems such as recovery, ACS, and the S-19 boost guidance system as required by the mission profile. Custom systems such as telemetry, based on heritage components, are also available.

The boost guidance system controls the path of the rocket during the initial 20 seconds of flight where air density is adequate to permit course correction by means of movable fins. The vehicle pitch and yaw angles are detected by a gyro platform which produces corresponding output signals; the signals are processed in an autopilot and, after roll resolution, are used as servo command signals.

Several types of sensors are used, singly or in combination to provide payload attitude information. They include Magnetometers, Gyroscopes, Solar/Lunar Sensors, Horizon Sensors, Television Cameras, and Film Cameras. The Attitude Control System positions the payload as required using

Magnetic Attitude Control Systems testing.
NASA Photo/Berit Bland

compressed gas that is released through small nozzles located on the payload skin.

Electrically operated vacuum doors are available for most telescope payloads.

Deployment mechanisms actuated by pyrotechnic, electric or mechanical means are available for doors, booms, shutters, etc.

Open shutter door with instrument visible during testing at Wallops.
NASA Photo/Berit Bland

In instances where missions require measurements from multiple widely spaced platforms a special payload is created to permit separation into several sub-payloads. Each sub-payload has it's own Telemetry link to transmit all science and housekeeping data for that section.

Telemetry systems are designed to support the requirements of a mission and the configuration is determined by the complexity of the experiment, the configuration of the detectors, and the size of the rocket. Systems vary in complexity from a single link with no command or trajectory equipment to systems containing as many as eight downlinks, and complex command and trajectory hardware.

When payload recovery is required, flight performance engineers predict the radius within which the payload will land; the re-entry path is tracked by radar and the recovery achieved by parachuting the payload to a land or water landing. Recovery is accomplished by boat, helicopter or land vehicle. Additionally, payloads may be designed with gas or liquid tight bulkheads fitted with sealed passages for electrical wiring or piping.

Payload recovery at White Sands Missile Range, NM. Photo by: Visual Information Branch/WSMR.

Testing and Evaluation

The launch and flight phases of a sounding rocket mission are stressful events for the scientific payload. The sum of the stressful elements to which such a payload is exposed is called the "payload environment." A rigorous environmental test plan helps to ensure that a payload will survive this hostile environment and continue working through the successful completion of its mission.

The ultimate purpose of environmental testing and evaluation is to determine if a particular payload can survive the environment specific to the vehicle configuration designated for that mission. A comprehensive preflight qualification process involves subjecting the complete payload, in its flight configuration, to a series of environmental elements such as vibration, bending, heating, spin, de-spin, and vacuum exposure.

Vibration Testing

Payload on vibration table.
NASA Photo/Berit Bland

The test specifications used for a particular payload are determined by the ignition and burn parameters of the rocket motors used for that launch. Vibration tests are performed in three payload axes - thrust and two orthogonal laterals. There are two types of vibration inputs – sine and random – for each axis. Shock pulses can also simulate motor ignition or payload separation events. A payload's response to an input vibration depends on the size, weight distribution, and harmonic frequencies of the assembly. A test is considered successful when the payload continues to perform all functions as designed after each round of vibration.

Bend Testing

Bend testing of payload.
NASA Photo/Berit Bland

The pressure effects of high velocity atmospheric flight create bending moments along the length of a payload, with the maximum moment occurring at the base where the payload attaches to the motor. The severity of this moment and the resultant payload bending are predicted during a detailed performance analysis prior to testing. Commonly, deflection is measured at the tip to determine the sum of all joint deflections under the anticipated bending moment. A test is considered successful if the total tip deflection is equal to or less than that predicted in the performance analysis, and if the deflection at an individual joint is within acceptable limits.

Spin Testing - Operational and Deployment

Payload with deployed booms and instruments.
NASA Photo/Berit Bland

Sounding rockets are spin stabilized. Motor vehicle fin cants ensure that the assembly begins to spin-up as soon as it leaves the launch rail. The amount of spin at any given time in the flight sequence is referred to as the roll rate. Payloads often use the resultant centrifugal force to deploy doors, sensors, and other devices. Some deployments increase the spin inertia and thereby decrease the roll rate. Some payloads are designed to operate at zero roll rate and de-spin weights can be deployed to achieve that effect. Roll rate gradients occur during the intervals of rate change. Maximum spin rates, maximum rate gradients, and even the entire flight sequence spin rate profile can be reproduced in the spin test bay.

Most spin deployments are performed in the same facility and photo or video data are collected. Using this optical data, in conjunction with telemetry signal data monitored during the tests, the payload team can verify that payload instruments are functioning properly throughout these events, and that the deployments can be performed successfully in flight, and/or they can identify problems which need to be addressed.

Mass Properties Measurements

A payload's mass properties – weight, center of gravity, and moments of inertia – are calculated during the design phase. These numbers are incorporated into the early performance and ACS analyses to verify flight and control stability. Design changes are incorporated to enhance stability, to incorporate customer requirement changes, and to reacquire stability in an iterative process that may continue right up to the brink of test time. Accurate mass property measurements of the launch and control configurations are used to confirm the theoretical calculations and to provide the performance and ACS analysts with data to be used in the final pre-flight performance predictions.

Payload place on mass properties measurement table.
NASA Photo/Berit Bland

Static And Dynamic Balancing

Dynamic imbalances in the launch configuration could cause an unstable flight profile such as coning, which would decrease apogee altitude and experiment data collection time. Static or dynamic imbalances in the control configuration could degrade the attitude control system's ability to align property and acquire the mission target(s). The balance facility uses technology similar to that used for automobile tires but it is more accurate. Imbalances are first detected, and adjusted using lead or brass correction weights, then re-measured to verify that the problem has been resolved. Each payload has its own imbalance limits, determined by the launch, control, and mass property parameters specific to that payload.

Payload being prepared for balancing.
NASA Photo/Berit Bland

Thermal Testing

Thermal testing verifies the ability of a payload or component to withstand elevated temperatures, caused by friction or onboard heat souces such as a transmitter. Several thermal testing chambers are available to accommodate components and systems of various sizes.

Vacuum Testing

Vacuum testing is conducted to verify that component shields and conductive heat sinks are designed such that the components will survive space conditions and function properly throughout all phases of exo-atmospheric flight. Out-gassing is a release of molecules from a material caused by exposure to vacuum and/or heat. Scientific detectors are often very sensitive to contamination and must be isolated from materials that out-gas excessively. Materials that cannot be isolated from the detectors must be thoroughly cleaned and then forced to out-gas completely by high temperature baking and other methods. Subsequent thermal vacuum testing can verify that these materials have been rendered inert.

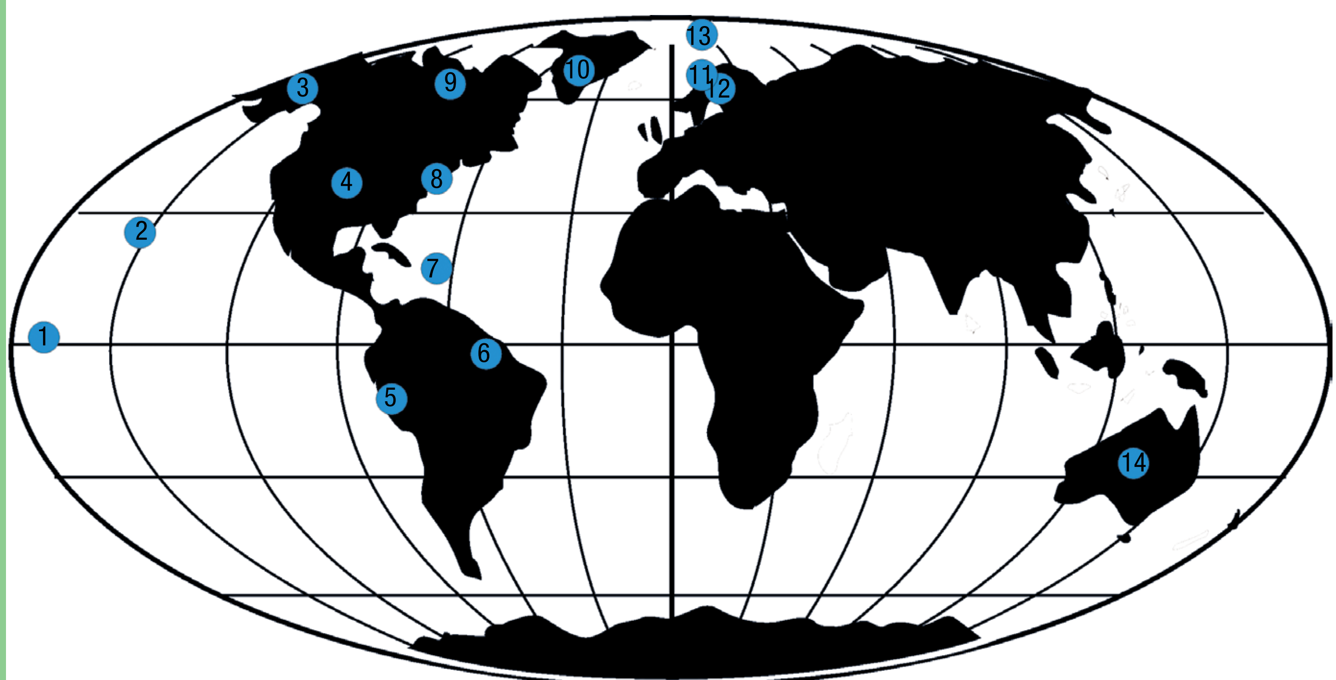
Payload ready to enter the thermal–vacuum chamber.
NASA Photo/Berit Bland

Launch operations support

Both established and temporary launch sites world wide are available to accommodate the needs of the PI. Established launch ranges exist in Alaska, New Mexico, Virginia, Norway, Sweden and Australia. Coupled with temporary sites in Greenland, Marshall Islands, Puerto Rico and Brazil, the Sounding Rockets Program provides extensive access to phenomena of interest to the science community.

The Sounding Rockets Program, in cooperation with the Wallops Range, provides all necessary personnel and equipment to conduct successful missions anywhere in the world.

Additionally, ground and flight safety analyses are provided by the NASA Safety group at Goddard Space Flight Center's Wallops Flight Facility, home of the Sounding Rockets Program.



Past and present world wide launch sites used by the Sounding Rockets Program to conduct scientific research:

1. Kwajalein Atoll, Marshall Islands
2. Barking Sands, HI
3. Poker Flat, AK
4. White Sands, NM
5. Punta Lobos, Peru *
6. Alcantara, Brazil *
7. Camp Tortuguero, Puerto Rico *
8. Wallops Island, VA
9. Fort Churchill, Canada *
10. Greenland (Thule & Sondre Stromfjord) *
11. Andøya, Norway
12. Esrange, Sweden
13. Svalbard, Norway
14. Australia (Equatorial Launch Australia (ELA) & Woomera)

* Inactive launch sites

VortEx payload integration.
Credit: NASA Photo/Berit Bland

Astrophysics Missions 2023

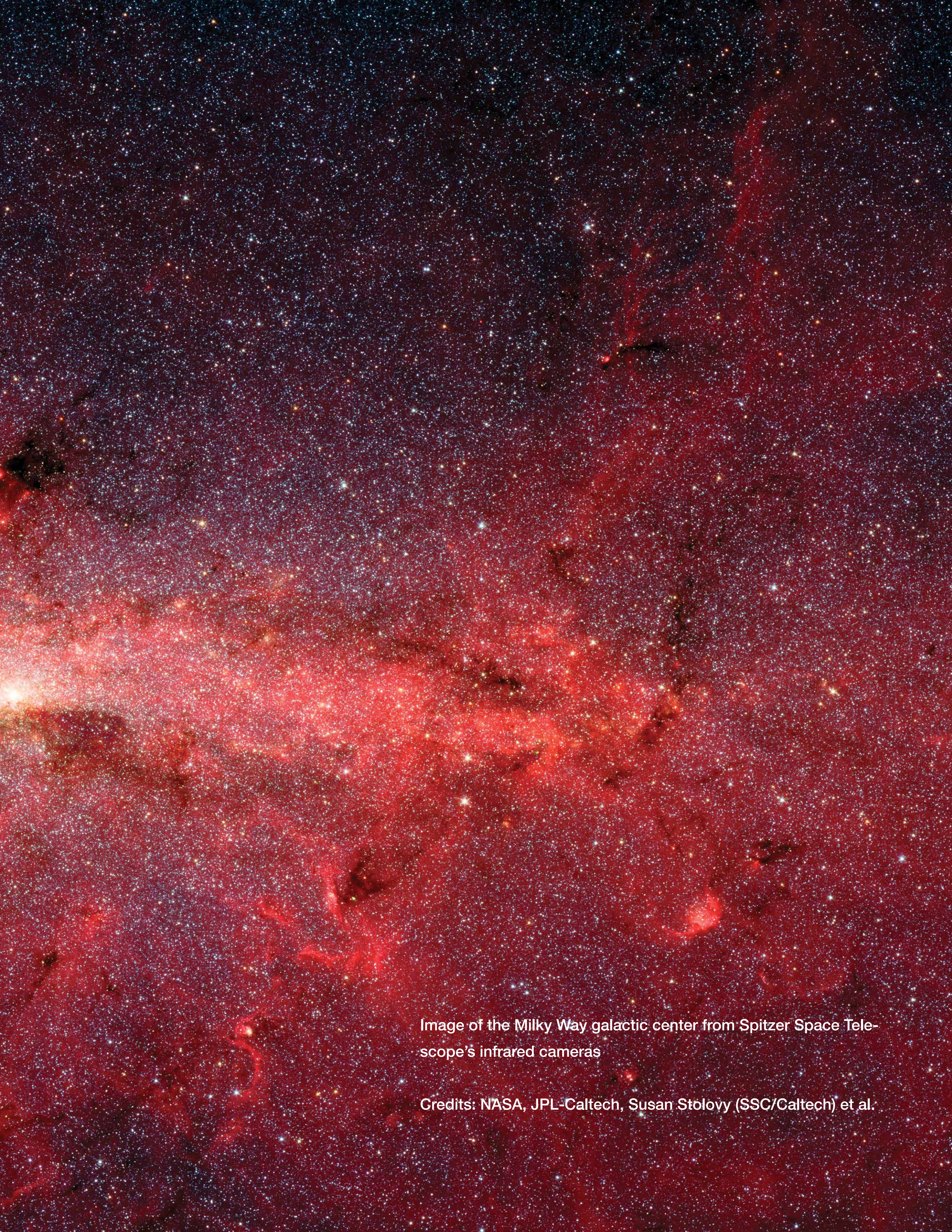


Image of the Milky Way galactic center from Spitzer Space Telescope's infrared cameras

Credits: NASA, JPL-Caltech, Susan Stolovy (SSC/Caltech) et al.

Cosmic Infrared Background Experiment (CIBER) 2

The Cosmic Infrared Background ExpeRiment 2 (CIBER-2) is a rocket-borne instrument designed to conduct comprehensive multi-band infrared (IR) measurements of spatial fluctuations in the extragalactic background light (EBL) on a wide range of angular scales.

CIBER–2 team at WSMR.
Credit: Ryan Harty/WSMR

The EBL is the summed light produced by all emission over the Universe's history, and it encodes a great deal of information about the history of stars and the assembly of cosmic structure over time. At near-IR wavelengths, the EBL teaches us about the first objects that formed during the earliest phases of galaxy assembly all the way up to the most faint and diffuse objects in the nearby Universe. Broad-band intensity mapping is a technique in which spatial fluctuations are used to unambiguously disentangle the faint EBL from brighter foreground emission from our solar system and Milky Way galaxy. Multiple intensity mapping studies, including those by CIBER-2's predecessor rocket experiment, have found that fluctuations in the EBL significantly exceed predictions from galaxy models. What could be causing the discrepancy is unclear, and better measurements are required.

CIBER-2 is a sounding rocket experiment designed to isolate the sources of near-IR fluctuations, and testbed technologies that will be used in the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and ices Explorer (SPHEREx) Medium Explorer (MIDEX) mission. CIBER-2 comprises a 28.5-cm telescope cooled to 80 K that images to three HAWAII-2RG detectors with dual-band filters to simultaneously obtain degree-scale data over the range 0.5-2.0 μm in six bands.

CIBER-2 made a successful first flight from White Sands Missile Range in New Mexico on June 7th of 2021, and a second flight was attempted in April 2022. No science was collected due to termination of flight shortly after launch.

CIBER-2 is led by the Rochester Institute of Technology in collaboration with the California Institute of Technology, the University of California Irvine, Kwansei Gakuin Univiersity and the Kyushu Institute of Technology in Japan, and the Korea Astronomy and Space Science Institute.

CIBER-2 is scheduled for a re-flight in FY 2024.

Principal Investigator: *Dr. Zemcov/RIT* • ***Mission Number(s):*** *36.383 UG*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *April 17, 2023*

CIBER-2 ready for launch at White Sands Missile Range, NM.
Credit: Julia Rae Gallegos/WSMR.

Geospace Missions 2023

Aurora over Andoya Space, Norway with the ACES rockets on the pad.
Credit: NASA Photo/Lee Wingfield

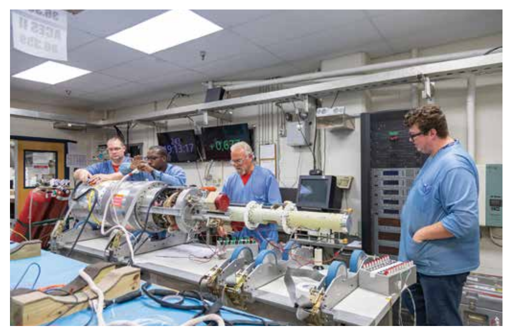
Aurora Current and Electrodynamics Structure (ACES) 2

The purpose of the Aurora Current and Electrodynamics Structures 2 mission was to:

- Determine the distribution of the ionospheric currents and the associ¬ated energy dissipation in a stable arc.
- Determine the role of the Alfvén resonator in governing the structur¬ing of current closure.

Composite image of Bounds 36.357 & 36.358 launching from Andøya, Norway.
Credit: NASA Photo/Lee Wingfield

Electrical currents are a key energy transport mechanism between the separated regions of the Earth's magnetosphere and the ionosphere. Remarkably, the currents flowing more than 100,000 km between the vast magnetosphere and the ionosphere close in a very thin altitude layer of just a few tens of km. This layer is unfortunately located at an altitude too low for satellites to make in-situ observations and too high for balloons. As a consequence, we have very few in-situ observations of the actual current closure and our understanding is largely based on simply mapping satellite observations from higher altitudes (typically ~700 km) or using ground based observations and applying various inversion techniques to determine the ionospheric current distribution. ACES 2 was designed to take a "snapshot" of the complete auroral current at one moment in time. ACES 2 included two Terrier-Black Brant rockets and payloads; a "high-flyer" that measured particles flow¬ing in and out of our atmosphere, and a "low-flyer" that, at the same time, measured the dynamic exchange in the ionosphere that keeps the auroral current flowing.



ACES 2 Integration at Wallops.
Credit: NASA Photo/Berit Bland

The high-flyer, 36.359, was launched first and reached an altitude of about 406 km, followed by the low-flyer, 36.364, one and a half minutes later, reaching an altitude of about 188 km. The low-flier being a flatter trajectory overtook the high-flyer about halfway through their parabolic trajectory. Both payloads trajectories were oriented so that they flew nearly magnetically north such that their magnetic projections were aligned as much as possible to cross the same magnetic field lines across the arc. The launch from Andøya, Norway, being close to the magnetic north pole provided the opportunity to launch in early evening into a stable auroral arc.

The nearly identical payloads consisted of energetic ion and electron spectrometers (University of Iowa), Dual Fluxgate Magnetometers (University of Iowa), Langmuir Probes (University of Iowa), Double Probe Electric Field Instrument (University of California Berkeley), Dual Electron Retarding Potential Analyzers (University of New Hampshire) and 4 Miniature Plasma Imagers (University of Calgary, low-flyer only).

Principal Investigator: *Dr. Bounds/University of Iowa* • ***Mission Number(s):*** *36.359 & 36.364 UE*
Launch site: *Andøya Space, Norway* • ***Launch date:*** *November 20, 2022*

Vorticity Experiment (VortEx)

The science objective of the Vorticity Experiment (VortEx) is to better understand nonlinear gravity wave interactions in the upper mesosphere and lower thermosphere, the formation of vortices, and the importance of mesoscale stratified turbulence.

Four vehicles/payloads were part of the VortEx mission, intended to be launched in two salvos with one each Terrier-Improved Orion and Black Brant IX. Only the first salvo was launched during this launch opportunity due to weather delays.

41.127 UE Terrier-Improved Orion was launched first on March 23rd, followed 2-minutes later by the Black Brant IX, 36.361 UE.

The first rocket carried ionization gauges and Langmuir probes to measure neutral densities and temperatures and electron and ion densities, respectively. The upper mesosphere and lower thermosphere showed a large-scale saw-tooth structure with alternating stable and less stable regions and many small-scale fluctuations.

The second rocket deployed luminescent trails on upleg and downleg to observe the wind structure, and additionally, sixteen small payloads to display the variability of wind and turbulence. The overall wind structure was dominated by tidal motions below 100 km, an unstable shear region between 100 and 110 km, and a very strong westward wind likely due to the auroral forcing in the hour before the launch. Auroral activity overhead was minimal for 50 minutes after the launches, but then picked up again and the geomagnetic storm continued through the night.

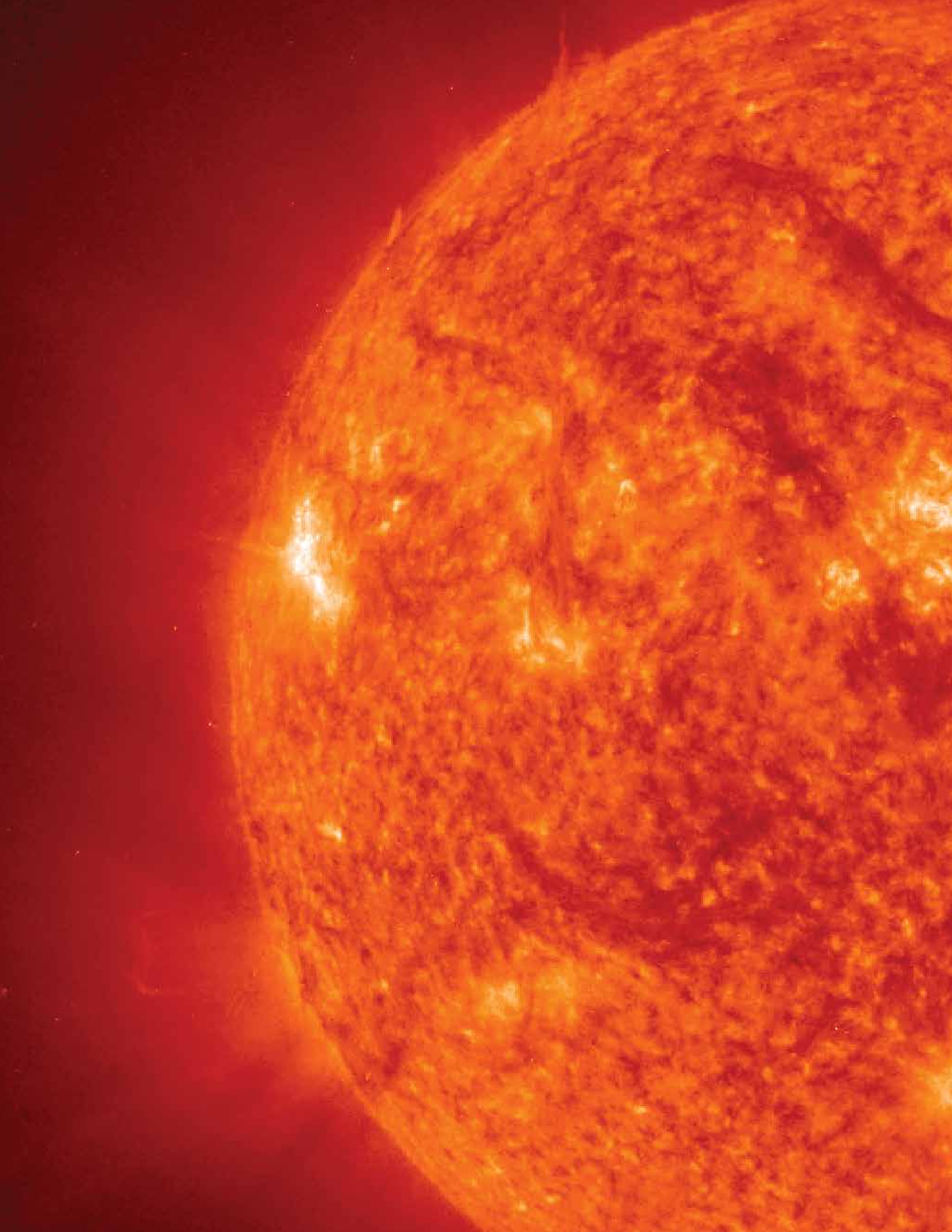
The rocket data and simultaneous ground-based radar and optical observations of winds and temperatures will be used to initialize a high-resolution regional model of the mesosphere and lower thermosphere. Comparing the wind variability and turbulent structures produced by the model with the real observations will help us understand the nonlinear interactions in this region, which mix and redistribute atmospheric constituents with effects on the upper thermosphere and ionosphere, which can last for days.

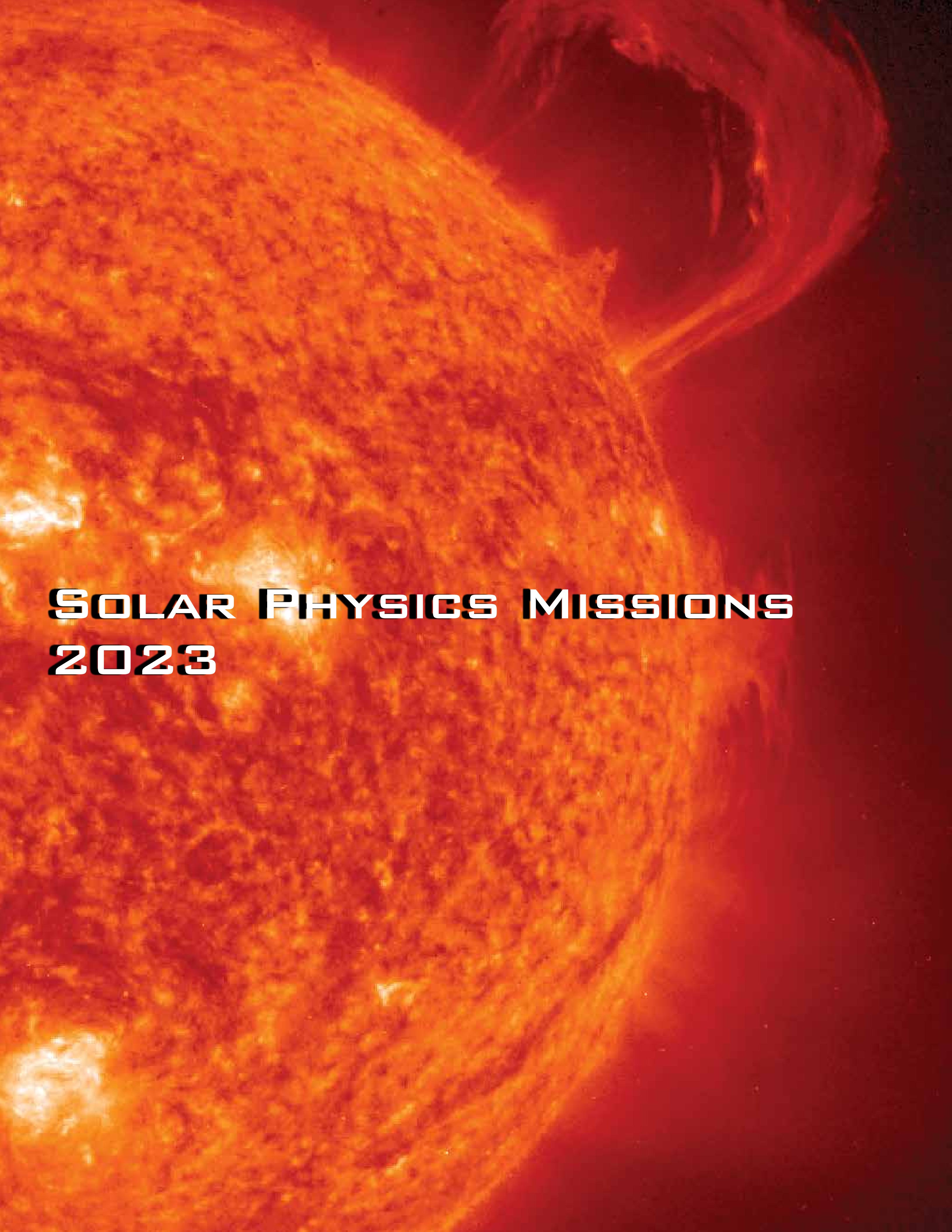
41.127 VortEx launching from Andøya Space, Norway.
Credit: NASA Photo/Danielle Johnson.

VortEx integration at NASA Wallops.
Credit: NASA Photo/Berit Bland

36.361 VortEx vapor trails.
Credit: Clemson University/ Michael Denz.

Principal Investigator: *Dr. Lehmacher/Clemson University* • ***Mission Number(s):*** *36.361 & 41.127 UE*
Launch site: *Andøya Space, Norway* • ***Launch date:*** *March 23, 2023*





Solar Physics Missions 2023

Solar Dynamics Observatory - EUV Variability Experiment (SDO-EVE)

The primary objective for this mission is to provide an underflight calibration for the EUV Variability Experiment (EVE) aboard the NASA Solar Dynamics Observatory (SDO) satellite.

EVE launch from WSMR.
Credit: WSMR.

The EVE program provides solar EUV irradiance data for NASA's Living With the Star (LWS) program, including near real-time data products for use in operational atmospheric models that specify the space environment and to assist in forecasting space weather operations.

This was the 10th underflight calibration for the EUV Variability Experiment (EVE) aboard the NASA Solar Dynamics Observatory (SDO) satellite. Prior calibration missions have been flown on October 28, 2006, April 14, 2008, May 3, 2010, March 23, 2011, June 23, 2012, October 21, 2013, May 21, 2015 (LV failure), June 1, 2016, June 18, 2018, and, September 9, 2021.

In addition to SDO this mission also provided underflight calibrations for several solar EUV imagers aboard orbiting observatories, including Solar TErrestrial RElations Observatory (STEREO), Geostationary Operational Environmental Satellite (GOES), and Hinode.

This payload, 36.389, was a re-flight of 36.353, flown on September 9, 2021.

Principal Investigator: *Dr. Woods/University of Colorado* • ***Mission Number(s):*** *36.389 US*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *May 3, 2023*

EVE team with vehicle at WSMR.
Credit: Ryan Harty/WSMR.

Technology Development Missions 2023

SubTEC-9 launching from Wallops Island, VA.
Credit: Wallops Imaging Lab

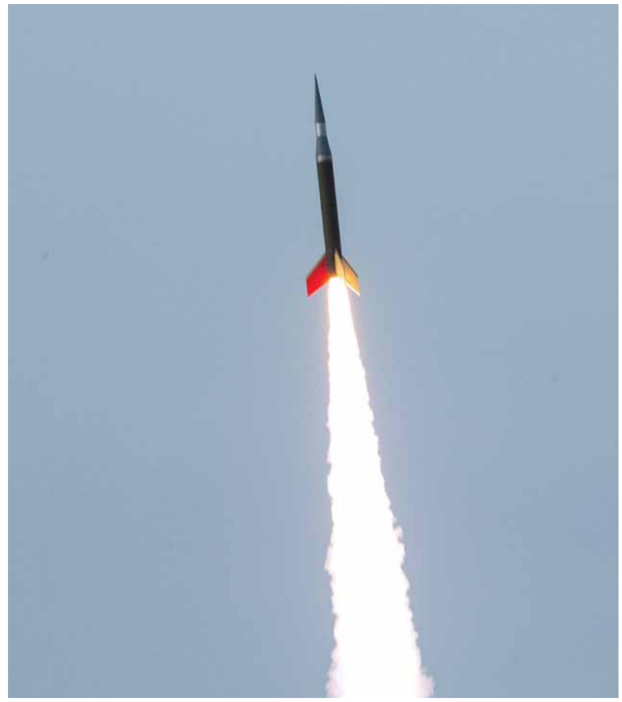
MesOrion

Two MesOrion vehicles, single stage Improved Orion vehicles with 4-inch (12.089) and 9-inch (12.090) diameter payloads were launched on February 16, 2023.

The launches were a feasibility study for using Improved Orions for mesospheric research, with simplified operational requirements and rapid launch sequences. The goal for these testflights was to reach apogees between 70 and 125 km.

Both vehicles performed well with 12.089 reaching an altitude of ~129 km, and 12.090 reaching ~125 km.

Further development will include adding instrumentation, miniaturization of payload systems and developing a nosecone separation systems. Additionally, development of rapid rail staging will continue. A two stage "small motor" vehicle is also being evaluated.



12.090 WT MesOrion launching from Wallops Island, VA
Credit: NASA Photo/Danielle Johnson.

MesOrion 9–inch payload in spin/balance facility at Wallops.
NASA Photo/Berit Bland

MesOrion 4–inch payload.
NASA Photo/Berit Bland

Principal Investigator: *Mr. Edwards/NSROC* • ***Mission Number(s):*** *12.089 & 12.090 WT*
Launch site: *Wallops Island, VA* • ***Launch date:*** *February 16, 2023*

SubTEC-9

SubTEC-9 was the ninth technology development flight and included both in-house experiments and one GSFC partnered piggy-back experiment. The primary objective of this mission was to test a new high data rate (~40 Mbps) C-band telemetry system. Additional experiments included a new star tracker as well as Ethernet cameras, a new battery system, and several other technologies.

46.032 WT Sub–TEC 9 launch from Wallops Island, VA
Credit: NASA Photo/Kyle Hoppes

List of experiments::

Wallops Integrated Star Tracker (WaIST)
High Rate C-Band Telemetry (~40 Mbps)
Haigh-Farr GPS/S-band Combo Antenna
Space Eye 320 Ethernet Cameras
Gigabit Ethernet Switch w/ Time Stamping
NSROC Ethernet Sensor Suite
Wallops Solid State Peripheral Control Relay Board (SPECTR)
Next-Gen Battery (lithium ion)
Command Uplink D/A Board Redesign
TERN-FLY
COTS Gyro
Constant Current Buck Box (C2B2)
Autonomous Rocket Tracker (ART)
Printed Hybrid Electronics (PHE) Demo

C–band telemetry testing in ground station.
Credit: NASA Photo/Berit Bland

SubTEC–9 integration activities.
Credit: NASA Photo/Berit Bland

Principal Investigator: *Ms. Hesh/Mr. Yaccobuci/NASA WFF* • ***Mission Number(s):*** *46.032 WT*
Launch site: *Wallops Island, VA* • ***Launch date:*** *April 25, 2023*

Education Missions 2023

Level 1 RockOn!

Level 2 RockSat-C

Level 3 RockSat-X

RockOn & RockSat-C

The RockOn! workshop was conducted at NASA Wallops Flight Facility in June 2023. This was the 15th RockOn workshop since the inception of the program in 2008. RockSat-C experiments are flown in the same rocket as the workshop experiments but are more advanced and completely designed and fabricated by the students.

Photos by: Chris Koehler and Berit Bland

The goal of the ***RockOn*** missions is to teach university faculty and students the basics of rocket payload construction and integration. RockOn also acts as the first step in the RockSat series of flight opportunities, and workshop participants are encouraged to return the following year to design, build, test, and fly their own experiment. The RockOn experiments are designed to capture and record 3-axis accelerations, humidity, pressure, temperature, radiation counts, and rotation rates over the course of the mission. All items and instruction necessary to complete the experiment are provided for the participants during the workshop, and teams of students and faculty work together to build their experiment. The workshop culminates with the launch of the experiments on a Terrier-Improved Orion sounding rocket.

RockSat-C offers students an opportunity to fly more complex experiments of their own design and construction. The intent is to provide hands-on experiences to students and faculty advisors to better equip them for supporting the future technical workforce needs of the United States and/or helping those students and faculty advisors become principal investigators on future NASA science missions. Teaming between educational institutions and industry or other interests is encouraged.
Participating schools for 2023 included:
Clemson University
Lincoln University
Northwestern State University
Old Dominion University
Stevens Institute of Technology
Temple University
University of Delaware

Cubes in Space, part of the RockSat-C program, is aimed at middle school students and allows them to design an experiment that fits in a 40 x 40 x 40 mm cube. The cubes were flown inside the nose cone of the RockOn payload.

Student flight opportunities website: **https://www.nasa.gov/nasa-rocksat-program/**

Principal Investigator: *Mr. Koehler/NASA Wallops Flight Facility* • ***Mission Number(s):*** *41.132 WO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *August 17, 2023*

RockSat-X

RockSat-X was launched from Wallops Island, VA on August 16, 2023. RockSat-X carried student developed experiments and is the third, and most advanced, student flight opportunity. RockSat-X experiments are fully exposed to the space environment above the atmosphere. Power and telemetry were provided to each experiment deck. Additionally, this payload included an Attitude Control System (ACS) for alignment of the payload. These amenities allow experimenters to spend more time on experiment design and less on power and data storage systems.

Due to a launch vehicle failure no data was received from the payload.

The following experiments were flown on RockSat-X in 2023:

University of Puerto Rico:

The team aimed to collected micrometeorite samples from the upper atmosphere and created an in-depth profile of the atmosphere to deliver environmental context for biosignature detection.

Northwest Nazarene University

This team planned to test two robotic arms that could be used to assist astronauts conducting maintenance and repairs during spacewalks.

Red Rocks and Arapahoe Community Colleges of Colorado

These two teams aimed to deploy an extendable arm system equipped with a 360-degree camera to capture video of the rocket, payloads, and a view of Earth.

Photos by: Chris Koehler

West Virginia Space Collaboration:

West Virginia University (WVU)

WVU served as the integrator for the West Virginia Space Collaboration teams, and also provided the electrical design for the experiments.

West Virginia State University (WVSU)

Several experiments were designed to measure acceleration, rotation, velocity, magnetic field, temperature, pressure and radiation levels. Lab grown Mycelium blocks, were also to be tested for structural integrity and durability during space flight.

Principal Investigator: *Mr. Koehler/NASA Wallops Flight Facility* • ***Mission Number(s):*** *46.038 WO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *August 16, 2023*

West Virginia Wesleyan College (WVWC)

The experiment was designed to control the spin of a gear motor at the same frequency but in the opposite direction of the rocket's rotation.

Blue Ridge Community and Technical College (BTCTC)

The team created and designed an Autonomous Navigational Assistant.

West Virginia University Institute of Technology (WVUIT)

The team aimed to collect data real-time data on the position, acceleration, and rotation of the rocket

Virginia Tech

This payload was designed to eject FemtoSats from the payload and investigate communication methods between the FemtoSats, the payload, and the ground. The plan also included improving upon the star-tracking instrument designed by the Virginia Tech 2022 RockSAT-X team.

University of Kentucky

The team planned to test a method of ejecting a capsule that was to collect and transmit data during the flight. The capsule ejection method is planned to be used for a future International Space Station mission.

College of the Canyons

College of the Canyons planned to simulate atmospheric data collection pods that are capable of communicating between each other and a satellite/base station. This experiment was removed from the manifest due to incomplete pre-flight testing.

Post launch exuberance.
Credit: NASA Photo/Danielle Johnson

Technology Development

Terrier-Improved Malemute launches from Wallops Island, VA.
Credit: NASA Photo/Wallops Imaging Lab

Technology development is essential for the NASA Sounding Rocket Program (NSRP), a linchpin, keeping the program relevant and enabling us to continue moving forward to achieve our science goals. The major initiatives of the current NSRP roadmap are as follows:

- Increasing data: increasing the amount of science data obtained on each flight.
- High Cadence Mesospheric Capability: leveraging sub-payload systems to develop a small, high cadence platform for mesospheric science instruments.
- Capability improvements: improving the programs current capabilities and preventing obsolescence of components and systems.

Increasing Data:

40 Mbps C-band Telemetry System, flown on SubTEC-9.
Ethernet Via Telemetry (EVTM), flown on SubTEC-9.
300-400 Mbps C-band Telemetry System, planned for SubTEC-10.
Store-and-forward capability as part of WFFCM4, planned for SubTEC-10.

C-Band telemetry allows for higher data rates and/or more downlinks and it compliments our current S-band capabilities. During the SubTEC-9 flight in April, two experimental C-band telemetry links were flown. One C-band link utilizing EVTM, and the other the Axon PCM telemetry encoder. This provided two ways of transmitting data in C-band, one as a direct ethernet stream and the other as transmitting data from a telemetry encoder. EVTM will be used on the upcoming science missions in 2024: 36.384 McCandliss and 36.385 Winebarger.

Building on the demonstration of the 40 Mbps C-band links for SubTEC-9, the program is currently developing a 300-400 Mbps C-band system that will be flight qualified on SubTEC-10 in 2025. Additionally, the development of the WFFCM4 flight computer started in 2023 with the goal of flying on SubTEC-10 and demonstrating a buffered telemetry downlink of 1 Gbps (store-and-forward) as well as a data storage capability for the retrieval of flight data after payload recovery.

High Cadence Mesospheric Capability:

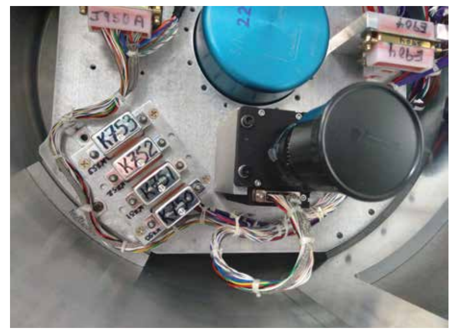
MesOrion Vehicle Pathfinder, flown as Edwards 12.089 and 12.090.
Mesospheric Payload and Systems Development, planned for a future flight in 2024/2025.
Mesospheric 2-Stage Vehicle Development, planned for a future flight in 2025/2026.

This year the program assembled, tested, and flew two single stage Orion missions from Wallops flightfacility as part of a pathfinder for the development of a vehicle that will carry high cadence payloads to study themesosphere. Engineering teams began the planning and development of the necessary payload systems for afuture flight of a mesospheric payload as well as a 2-stage mesospheric vehicle capability."

Capability improvements:

- **Flown on SubTEC-9:** Next-Gen Battery (lithium-ion), Wallops Solid State Peripheral Control Relay Board (SPECTR), and Command Uplink (CU) D/A Board Redesign.
- **Planned for SubTEC-10:** Wallops Integrated Star Tracker (WaIST), NSROC Common Ignition System (NCIS), 1500# Recovery System and CACS-GT (GIPS-Tern).
- SPARCS-8, to be flown on 36.366 Kankelborg.
- Launch Site Vacuum System (LSVS), planned for a future demonstration in 2025/26.
- Versatile Linear Shape Charge (VLSC).
- Next Generation Remote Payload Control System (RPCS).

Multiple capability improvements were demonstrated in a space environment during SubTEC-9, including: the Next-Gen Battery, SPECTR, and the Command Uplink D/A board upgrade. Unfortunately, SubTEC-9 was unable to provide a successful flight demonstration for WaIST, the intended replacement for the obsolete star tracker currently in use on the program. However, several improvements have already been incorporated into the next integration of WaIST, with the intention for a flight demonstration no later than SubTEC-10 in 2025.

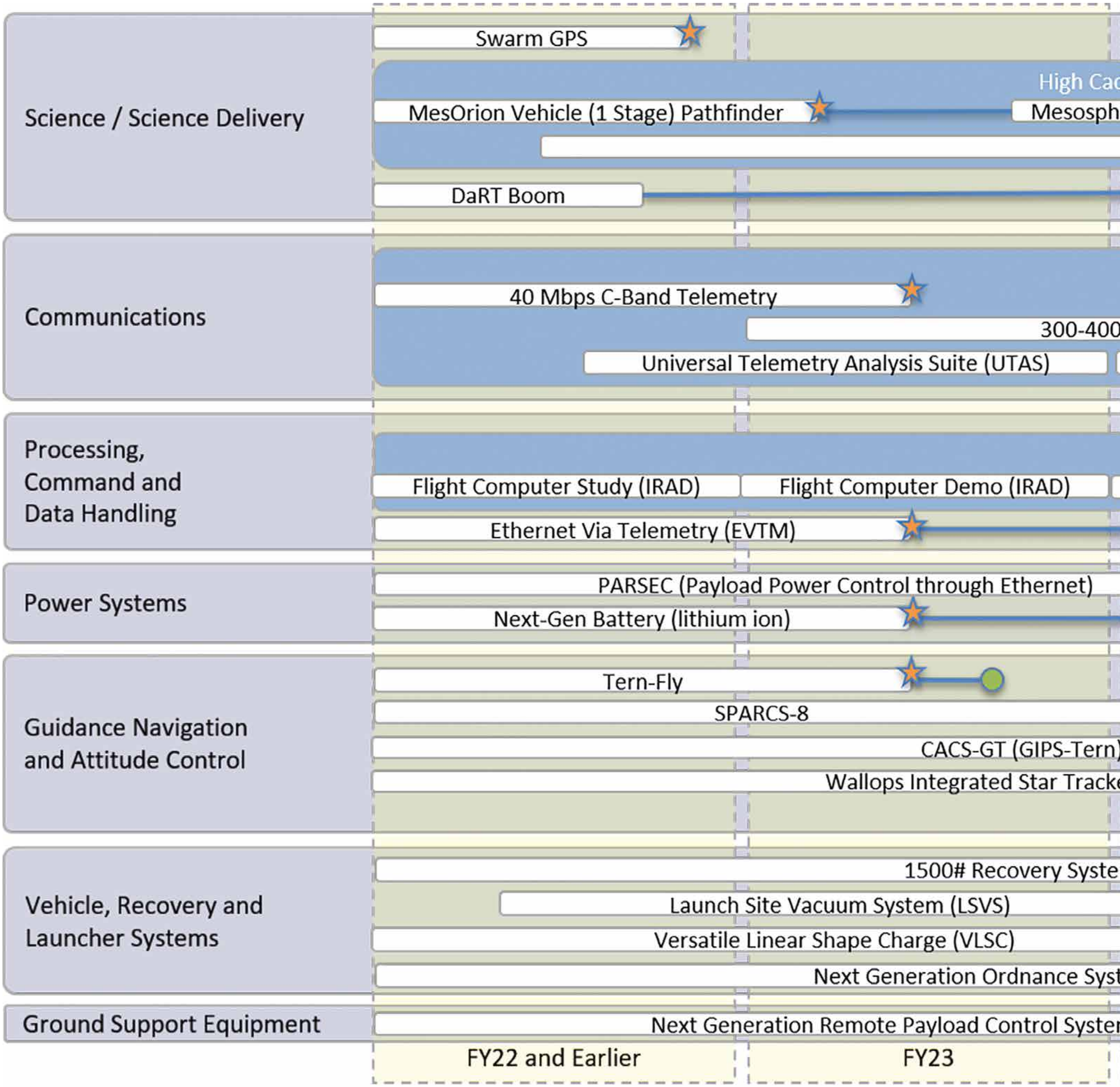


Wallops Integrated Star Tracker (WaIST)
Credit: Josh Yacobucci

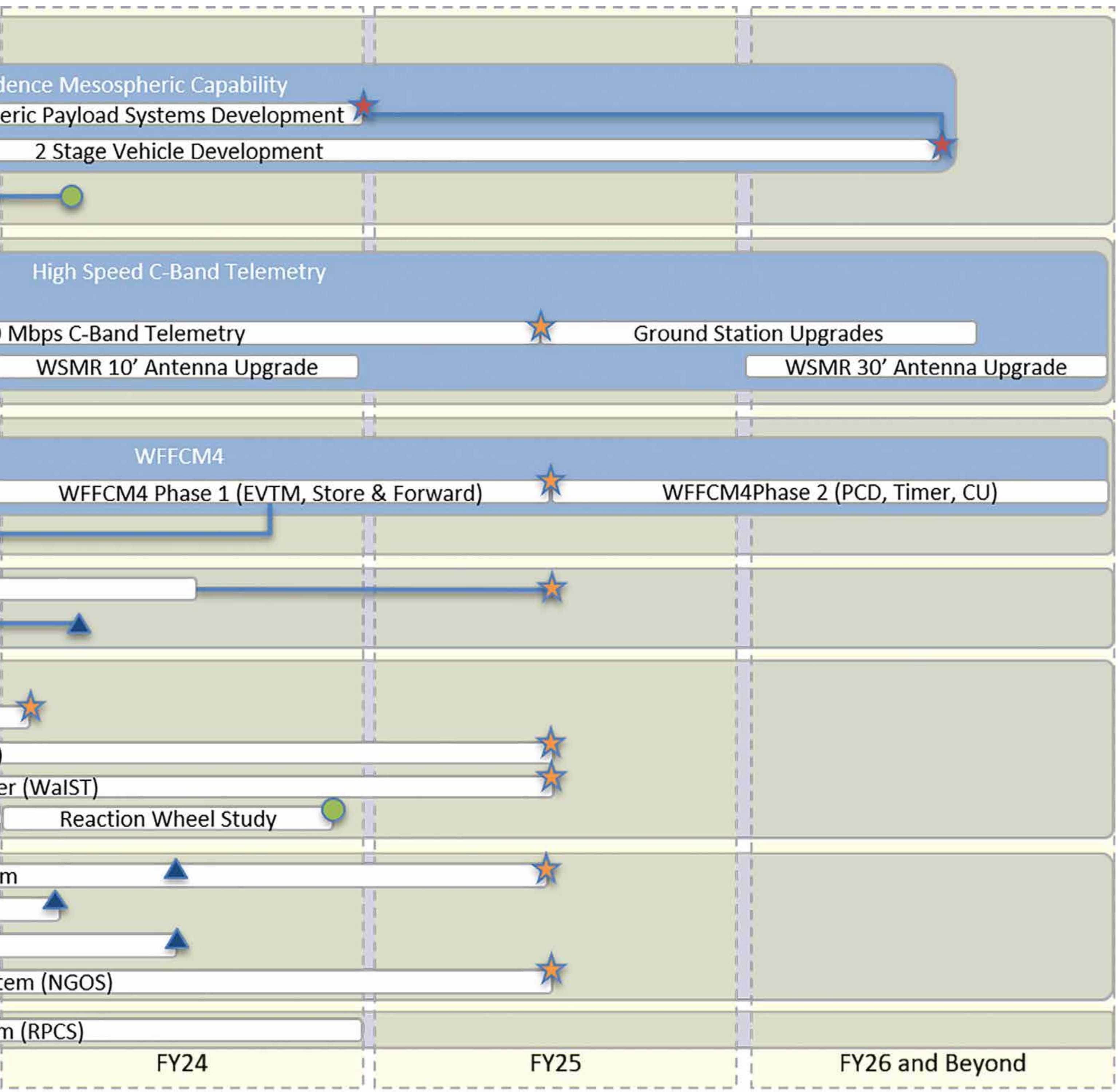
Two other significant capability improvements will be flown on SubTEC-10: the 1500# Recovery System and CACS-GT. The 1500# Recovery System, a capability increasing from #1250, will enable larger telescope payloads to be flown and recovered. Additionally, the CACS-GT will continue the program's efforts to upgrade the capabilities of attitude control systems. The first instance being the utilization of the Tern Inertial Navigation System (INS) to replace the magnetometer, coarse sun sensors, the Miniature Acquisition Sun Sensor (MASS) and the Ring Laser Gyro (RLG) as part of SPARCS-8, which will be demonstrated on the upcoming Kankelborg mission. Following that flight, the CACS-GT will be flown on SubTEC-10 and will demonstrate the new Celestial Attitude Control System (CACS). Improvements will include replacing the obsolete GLNMAC with the Tern INS and the incorporation of the new GNC Integrated Power System (GIPS).

SubTEC-9 payload testing.
Credit: NASA Photo/Berit Bland

Technology Roadmap



Planned Demonstration Flight (TRL 7)
Prospective Demonstration Flight (TRL 7)
Demonstration in Relevant Env. (TRL 6)
Decision Point



On the Horizon

In 2024 operations will continue from regularly used launch sites, Wallops Island, VA, White Sands Missile Range, NM, Poker Flat Research Range, AK, Andoya Space, Norway, and Kwajalein, Marshall Islands. Over twenty missions are manifested for flight in FY 2024.

Solar Flare Campaign 2024

This planned campaign will include three solar physics payloads, with launches taking place from Poker Flat Research Range (PFRR), AK. Two separate launch windows are scheduled for the campaign; the first, a ten day window, for Solar eruptioN Integral Field Spectrograph (SNIFS) opens mid-March, and the second, a 14-day window for Focusing Optics X-ray Solar Imager (FOXSI) 4 and High-Resolution Coronal imager (Hi-C) - Flare opens after the SNIFS launch. FOXSI 4 and Hi-C Flare are planned to launch within minutes of each other to observe the same event. Solar activity during the launch windows will be monitored by scientists using data from the NOAA operated Geostationary Operational Environmental Satellite (GOES). When data from GOES indicate a solar flare is occuring, the payloads will be launched to study the event. By analyzing previous solar cycles, scientists estimate that the opportunity of capturing a flare in progress is fairly high during the selected launch window.

Solar eruptioN Integral Field Spectrograph (SNIFS)

SNIFS is designed to study the high frequency dynamics associated with small nanoflares, spicules, and Rapid Blue-shifted Excursions (RBEs), as well as, large solar flare energy releases in the lower solar atmosphere. The Pricnipal Investigator for SNIFS is Dr. Chamberlin/University of Colorado.

Focusing Optics X-ray Solar Imager (FOXSI) 4

As part of the first solar flare campaign, FOXSI-4 will perform a triggered observation of a large flare. The Pricnipal Investigator for FOXSI-4 is Dr. Glesener/University of Minnesota.

High-Resolution Coronal imager (Hi-C) - Flare

The Hi-C instrument is optimized for detecting high temperature flare lines. The Principal Investigator for Hi-C - Flare is Dr. Savage/NASA Marshall Space Flight Center.

Atmospheric Perturbations around Eclipse Path (APEP) Sounding Rockets to study the ionosphere during Solar Eclipses

The APEP missions include launches of three Black Brant IX rockets each from WSRM, NM and Wallops Island, VA to coincide with the Annular Solar Eclipse, October 14, 2023 and the Total Solar Eclipse, April 8, 2024. APEP is designed to detect changes in the ionosphere using instruments such as Langmuir probes, electric field probes, magnetometers, ionization gauges, and accelerometers. Simultaneous multipoint measurements will be achieved by ejecting four instrumented deployables from each payload. Springs are used to deploy the ejectables at a velocity of 3 m/s and they will take data for about 7 to 8 minutes. This allows taking measurements in a larger volume of space.

The first APEP rocket, launched approximately 35 minutes before the local peak eclipse measures the ionosphere as the eclipse is starting. The second rocket is launched during the peak eclipse period when the ionosphere has the maximum shielding from solar radiation. Approximately 35 minutes after the eclipse, when solar radiation again reaches the ionosphere, the third rocket is launched.

Mars Sample Return support mission, FY 25

The Mars Sample Return (MSR) is a proposed mission to return samples from the surface of Mars to Earth. The mission would use robotic systems and a Mars ascent rocket to collect and send samples of Martian rocks, soils and atmosphere to Earth for detailed chemical and physical analysis. Two sounding rocket missions will be flown FY 2025 to test systems for the Mars Ascent Vehicle (MAV) and parachute for the Sample Retrieval Lander (SRL).

Geospace Science campaign from Peru

NASA HQ, SRPO, and other interested parties are evaluating operational options and programmatic resources for a future rocket campaign in Peru. The SRPO Operations Group conducted a preliminiary site survey trip to Peru in September 2023 and met with representatives from the US Embassy, the Peruvian space agency, CONIDA, Peruvian Air Force, Institute Geophysics Peru (IGP), and Port of Callao. The Peruvian counterparts welcomed the NASA presence in Peru and were supportive of starting campaign planning activities. Current target for a Peru campaign is 2028 with launches taking place from Punta Lobos, a range that has been used in the past.

Site visit to Punta Lobos, Peru, September 2023.
Credit: Josh Bundick


Launch pad area at Punta Lobos.
Credit: Josh Bundick

Sounding Rocket Launch Sites


Poker Flat, Alaska

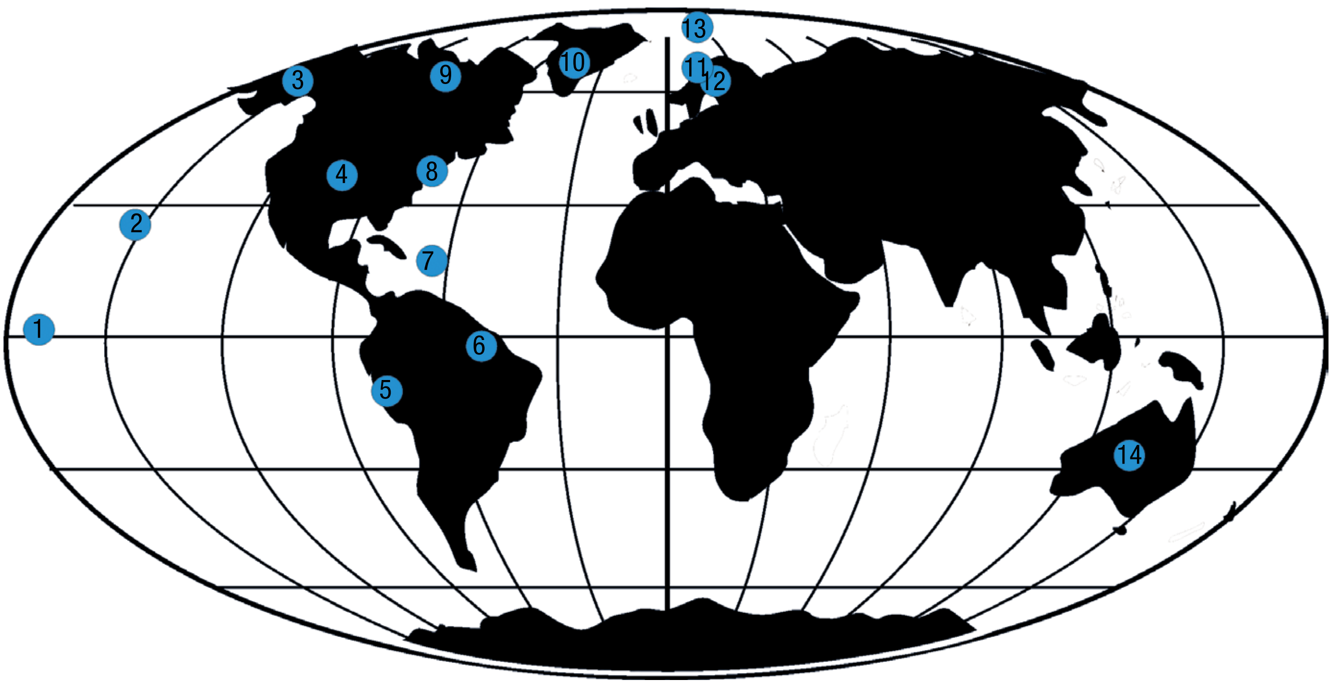

Esrange, Sweden


Kwajalein, Marshall Is.


Andøya, Norway


Arnhem Space Center, Australia


Wallops Island, Virginia

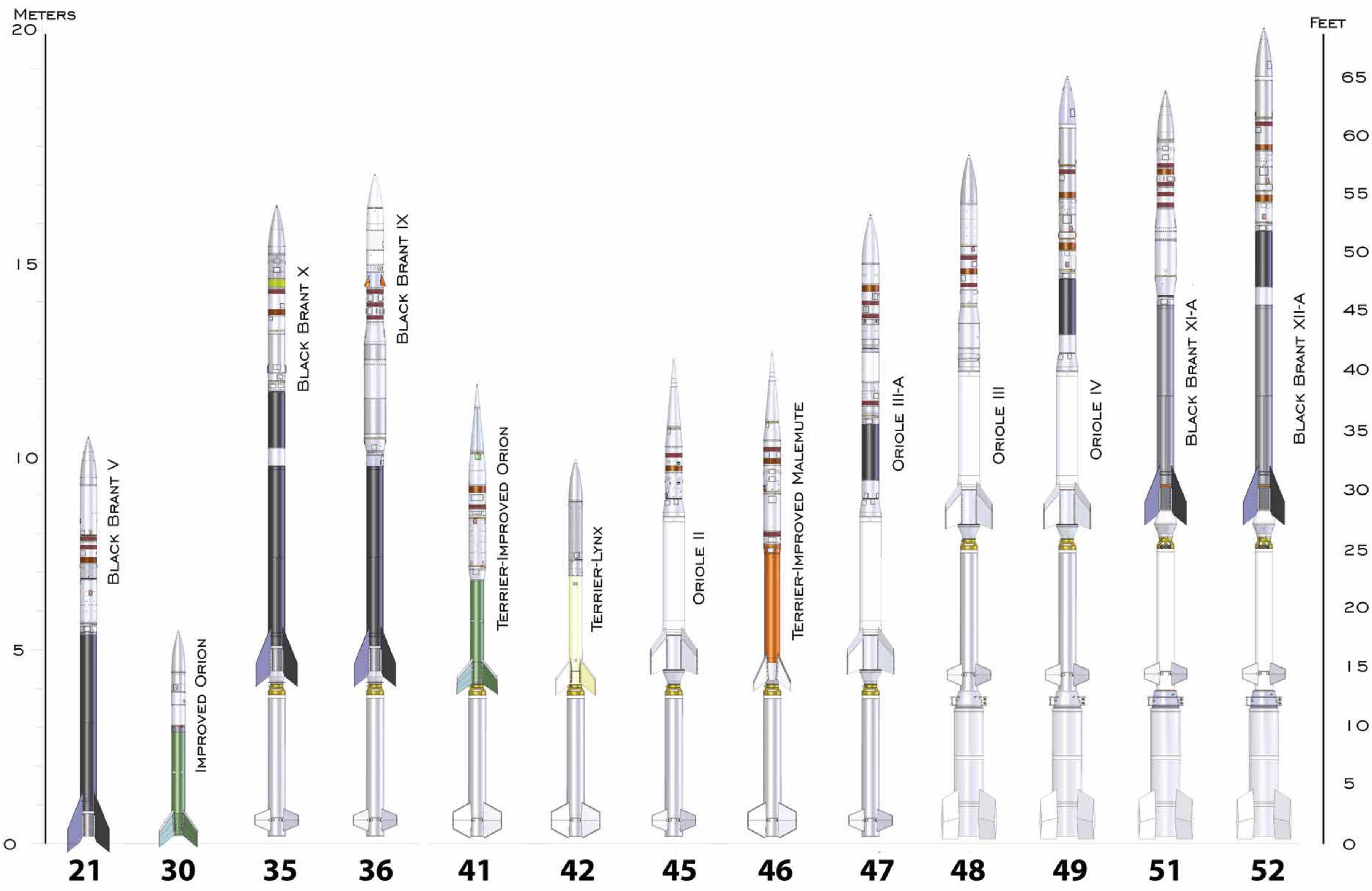


Past and present world wide launch sites used by the Sounding Rockets Program to conduct scientific research:

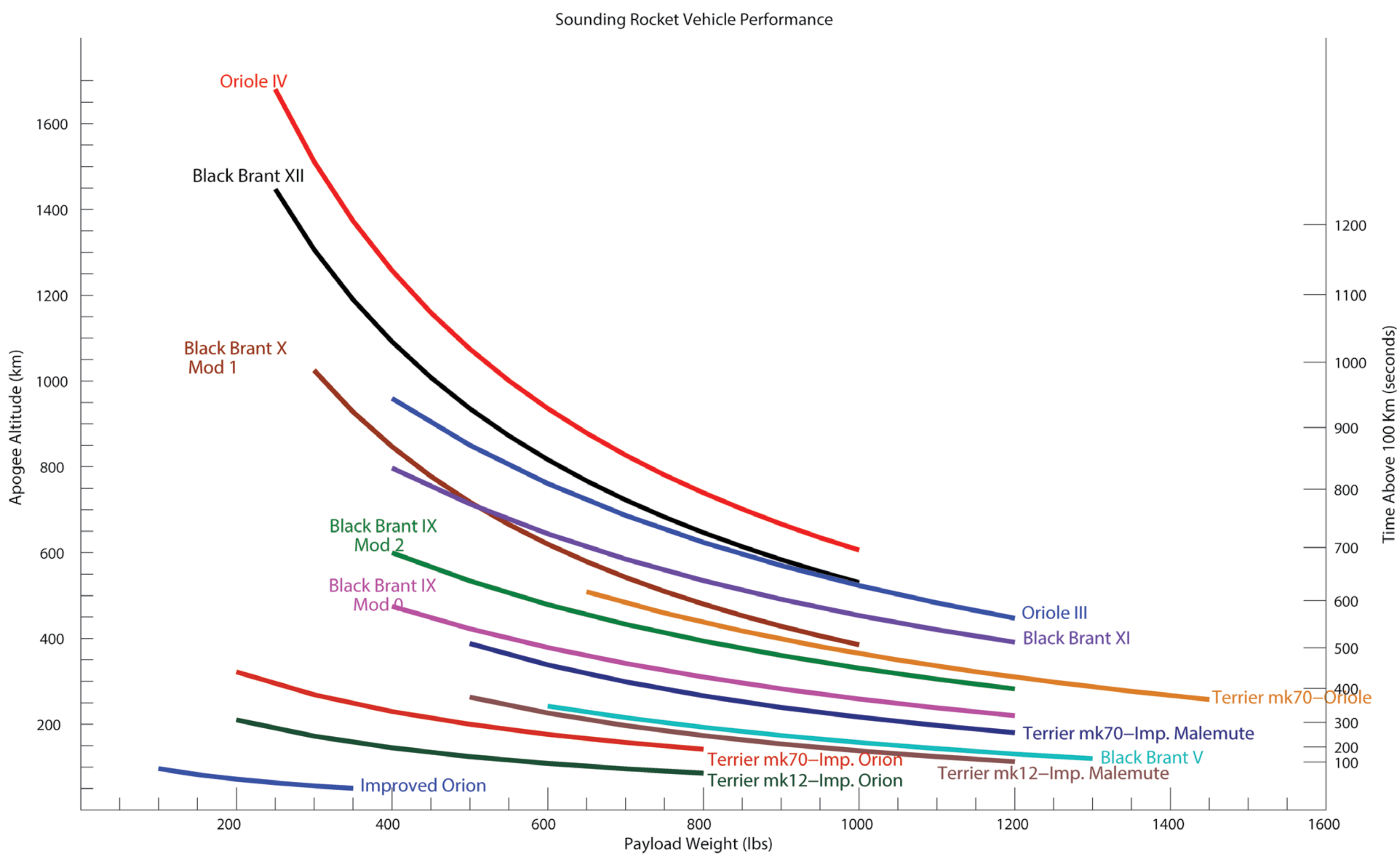
1. Kwajalein Atoll, Marshall Islands
2. Barking Sands, HI
3. Poker Flat, AK
4. White Sands, NM
5. Punta Lobos, Peru *
6. Alcantara, Brazil *
7. Camp Tortuguero, Puerto Rico *
8. Wallops Island, VA
9. Fort Churchill, Canada *
10. Greenland (Thule & Sondre Stromfjord) *
11. Andøya, Norway
12. Esrange, Sweden
13. Svalbard, Norway
14. Australia (Equatorial Launch Australia (ELA) & Woomera)

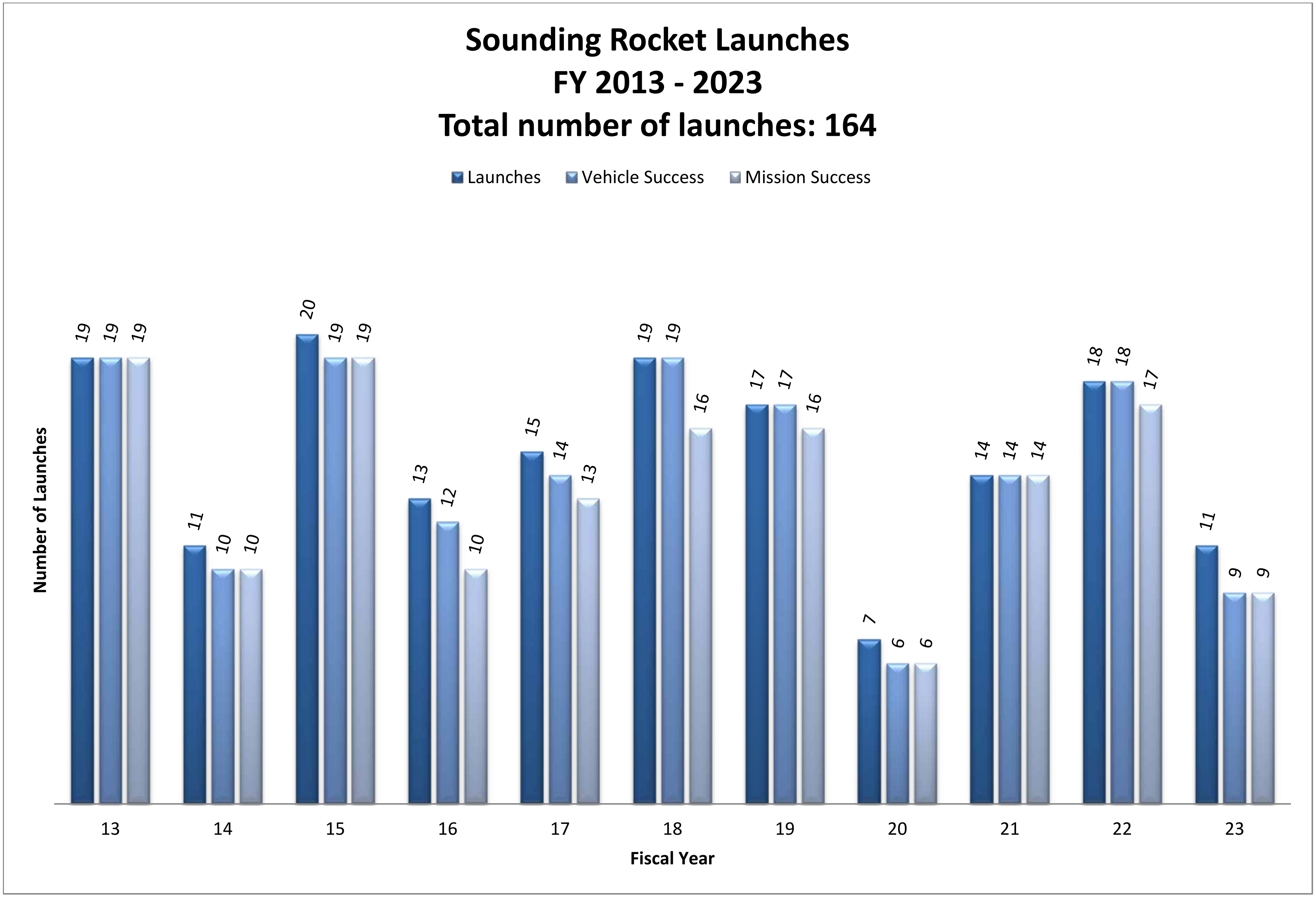
* Inactive launch sites

Sounding Rocket Vehicles



Sounding Rocket Vehicle Performance




Sounding Rocket Launches
FY 2013 - 2023
Total number of launches: 164
Launches
Vehicle Success
Mission Success
Number of Launches
19 19 19
11 10 10
20 19 19
13 12 10
15 14 13
19 19 16
17 17 16
7 6 6
14 14 14
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Fiscal Year

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