National Aeronautics and Space Administration

NASA
Sounding Rockets
Annual Report 2018

Message from the Chief

Giovanni Rosanova
Chief, Sounding Rockets Program Office

It has been an eventful year for the Sounding Rockets Program, starting with the retirement of the longtime Chief, Phil Eberspeaker and Assistant Chief, Tripp Ransone. They left the program well positioned for a smooth transition by establishing a succession plan well before departing, and I am eternally grateful for their mentorship. To complete the transition, I am happy to welcome John Hickman to the position of Assistant Chief. His tenured experience in multiple areas of the Program is invaluable to help guide us into the future.

We have again turned our eyes toward the stars, including the Sun, studied noctilucent cloud formation, flown parachutes for Mars 2020, and inspired hundreds of future scientists and engineers through student flight opportunities.

Missions were flown from our local range on Wallops Island, VA and across the globe, including, White Sands Missile Range, NM, Poker Flat Research Range, AK, and the Marshall Islands. Two rockets staged at the Andoya Space Center in Norway, ready to study neutral winds in the ionosphere, were not launched due unfavorable science and weather conditions. The mission has been re-scheduled for 2019.

Support of scientific discovery, as always, was our primary goal in 2018. Several Astrophysics missions were flown aiming to study features in our galaxy in the Extreme Ultraviolet and X-ray parts of the spectrum. Two missions, the Colorado High-resolution Echelle Stellar Spectrograph-4 (CHESS) and Water Recovery X-ray Rocket (WRX-R), launched from the Kwajalein Atoll, Marshall Islands, were the first to demonstrate successful recovery of evacuated telescope payloads from the water. The Dual-channel Extreme Ultraviolet Continuum Spectrograph (DEUCE) and Micro-X, and X-ray microcalorimeter, missions were both launched from White Sands, NM. The Diffuse X-ray emission from the Local galaxy (DXL) launched from Poker Flat Research Range in Alaska, studied the heliospheric Solar Wind Charge eXchange (SWCX) and Local Hot Bubble (LHB). Instruments to the study the Sun have evolved in the many decades of solar physics missions conducted with sounding rockets, and are now at the forefront of science discovery. This year's missions included the High-resolution Coronal Imager (Hi-C), Focusing Optics X-ray Solar Imager (FOXSI) 3, and EUV Variability Experiment (EVE). FOXSI is the first instrument to detect evidence of X-ray emission from nanoflares on the Sun. Data from Hi-C will aid in solving the "coronal heating problem", and EVE, flown for the 7th time, calibrates several EUV imagers onboard NASA and international satellites. Nearer to the Earth, the SuperSoaker mission, launched from Poker Flat Research Range, attempted to create artificial noctilucent clouds.

Sounding rockets supported NASA JPL's Mars 2020 parachute developement effort with three launches of the Advanced Supersonic Parachute Inflation Research and Experiments (ASPIRE). The ASPIRE missions all achieved comprehensive success, with all three parachutes recovered successfully off the coast of Wallops Island. Data from these missions will be used to advance models of supersonic parachute inflation, and will inform decisions on parachutes selection for future missions to Mars.

STEM enrichment to enhance the capabilities of the nation's future scientists and engineers has always been one of the main attributes of the Sounding Rockets Program. Students participate in many of the science missions as graduate and undergraduate students under the tutelage of the PIs and Co-Is. Additionally, three dedicated student missions were flown in 2018. First off the pad in March 2018 was the University Student Instrument Program (USIP), a student flight opportunity funded by NASA's Office of Education and Science Mission Directorate. Four student teams were selected from 47 applications to fly their experiments on a Terrier-Improved Malemute sounding rocket. We continued to support the RockOn/RockSat-C and RockSat-X missions. RockOn saw its 11th flight and RockSat-X, the more advanced opportunity, its 7th. Over 200 University students built experiments for these missions. Younger students participate in RockOn through the Cubes-in-Space program, and create experiments to fly in a self-contained structure inside the nosecone of the RockOn payload. Since 2011, the Wallops Rocketry Academy for Teachers and Students (WRATS) has been conducted by the Sounding Rockets Program. This year, 20 teachers attended the one-week workshop in June and learned about rocketry through hands-on experiments, demonstrations, and flying their own model rocket. Additionally, they attended the RockOn launch on Wallops Island.

New remote campaigns are on the horizon; Marshall Islands and Norway in 2018/2019 and Australia in 2020. The Norway campaign, called the Grand Challenge – CUSP Initiative, involves international partners from both Norway and Japan and is focused on studies of the Cusp region of the Earth's magnetic field. Seven NASA missions, comprising 11 payloads, will be launched in 2018 and 2019. We are returning to Kwajalein, Marshall Islands, in 2019 to launch two payloads to study the equatorial ionosphere. Four astrophysics payloads are slated for launch from Australia in 2020, allowing scientists access to the southern sky with new opportunities to study targets not otherwise visible.

The first year as Chief of the Sounding Rockets Program has been very rewarding. As a team, we have grown with the successes, as well as the challenges, and look to the future with enthusiasm. It is an honor and a privilege to lead such an accomplished team of technical and professional experts. Together we will continue supporting NASA's science priorities and develop sounding rocket capabilities to meet the growing science, technology and educational needs of the agency and the nation.

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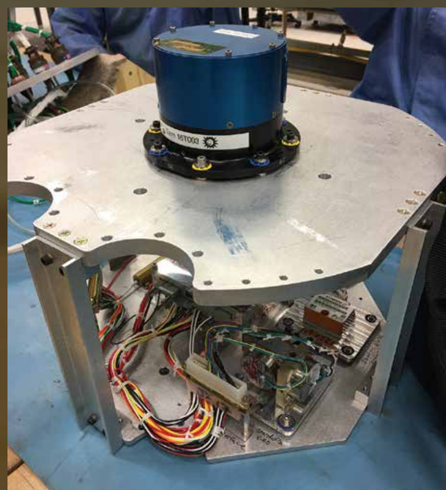
Technology Highlights

TERN Inertial Navigation System

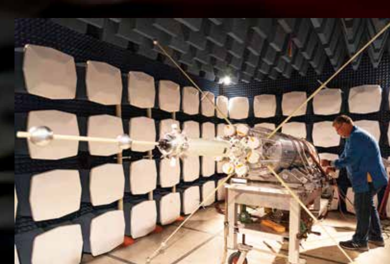


The NSROC developed Tern INS was flown operationally for the first time on 46.021 UO in 2018. The system is designed to generate high quality, reliable body rate and acceleration measurements, attitude propagation, and navigation solutions.

Low-light Camera

A new low-light camera, Standard Photonics Inc. XR/M-WFF, will replace the Xybion. Imagery from the low-light camera is used to make real-time attitude corrections on celestial attitude based telescope missions.

The Sounding Rockets Program Office (SRPO) and the NASA Sounding Rocket Operations Contract (NSROC) carry out NASA's sub-orbital rocket program. A fleet of vehicles acquired from military surplus or purchased commercially is used to carry scientific and technology payloads to altitudes between 50 and 1,500 kilometers. All payload support systems, such as Telemetry, Attitude Control, and Recovery are designed and fabricated by NSROC machinists, technicians and engineers. Launch operations are conducted worldwide to facilitate science requirements, for example Geospace research is often conducted in the arctic from launch sites in Norway and Alaska. Increasing mission complexities are addressed through continuous improvement in systems design and development.



Sounding Rockets Overview

Missions By Discipline 2018

Infrastructure

Several next generation instruments and detectors require significant LN2 for cooling prior to launch. In many of the remote launch areas, supply chain logistics makes delivery difficult, expensive, or impractical. To facilitate payload cooling requirements, SRPO invested in a mobile LN2 plant.

The LN2 plant supported launches in Kwajalein, Marshall Islands in March/April 2018 and is planned for use in Svalbard, Norway in Fall 2018 for the Grand Challenge missions, and the Australia 2020 Camapign.

Integration and testing

The increasing complexity of sounding rocket mission profiles and payload support system requirements leads to increasingly complex integration and testing processes. Mission profiles can involve deploying sub-payloads at specific intervals in specific directions at varying velocities. Payloads with multiple science instruments may require multiple Telemetry and Attitude Control Systems. In 2018 approximately twenty payloads were integrated and tested for flight.

SOLAR PHYSICS

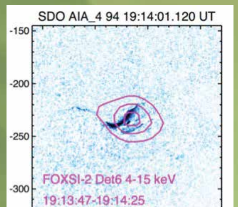
Three Solar Physics mission, High-resolution Coronal Imager (Hi-C) 2 and EUV Variability Experiment (EVE), and Focusing Optics X-ray Solar Imager (FOXSI) were flown in 2018.

Hi-C researches the connections between the solar corona and the cooler chromosphere and transition region.

The EUV Variability Experiment (EVE) provided underflight calibration for several NASA and international satellites.

FOXSI studied the solar corona in the X-ray spectrum, at energies at 4 - 20 keV.

Credit: Multispectral background image NASA/SDO/GSFC Visualization Studio
X-ray background slice from NuSTAR, Hinode and SDO.

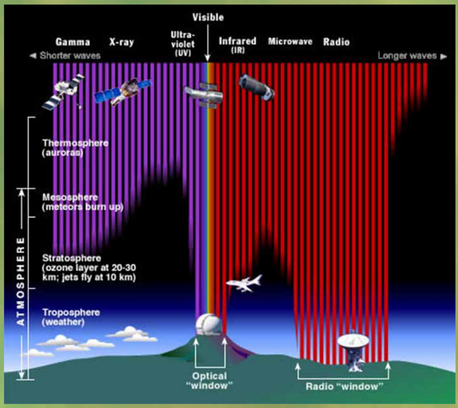


Data from the second FOXSI flight in 2014 overlaid on an image from SDO.

Focusing Optics X-ray Solar Imager-3 (FOXSI)

FOXSI is designed to investigate "nanoflares," which are much smaller than large solar flares but which occur far more frequently. These nanoflares may be responsible for coronal heating and also might serve as the seeds for the cascades that result in much larger flares. Since nanoflares are too small to be observed individually with today's technology, FOXSI looks for the combined effects of thousands or millions of nanoflares occurring nearly at the same time.

Electromagnetic Radiation



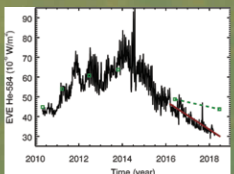
Most of the radiation emitted by the Sun is blocked by the Earth's atmosphere. In order to study the Sun at these wavelengths, instruments have to be placed in space. Spacecraft such as the SDO and IRIS include multispectral instruments and have mission durations of several years. Sounding rockets are used for both fundamental science exploration and development of future technologies for spacecraft. Additionally an instrument can be launched at a predetermined time and location, as demonstrated with the EVE mission that coordinated observations with the SDO. This type of coordination can augment and or calibrate satellite research. With short mission lead times and lower cost, sounding rockets enable world class science discovery.

Instruments for Solar Physics

Spectrographs are commonly used instruments for solar physics. A spectrograph measures radiation intensity as a function of wavelength. All elements in the periodic table have associated characteristic spectra. When energy is added to an element, i.e., when electrons in an atom are excited and then transition back from this excited state to their ground energy levels, they emit radiation at specific wavelengths. Scientists have cataloged spectral wavelengths of the elements and use that information to determine the presence of these elements in the Sun and other stars. Elements found on the Sun, using spectroscopy, include hydrogen and helium with smaller amounts of other elements such as carbon, nitrogen, oxygen, neon, magnesium, silicone, sulfur, and iron.

Knowing which elements are present, and their ionization temperatures, allows scientists to determine the temperature of the various regions of the Sun. To ionize an atom enough energy has to be added to free electron(s) from the atom. For example iron, which in its neutral state has 26 electrons (Fe I), temperatures around 600,000 Kelvin create ions of Fe IX where eight electrons are freed. This process emits EUV radiation at a wavelength of 171 Å.

Missions 2018



SDO EVE measurement of the He I 584 Å emission is shown in black. The calibration rocket flights are shown as green squares, and the trend between the last calibration in 2016 to this new one in 2018 provides the correct trend for solar cycle variability.

Extreme ultraviolet Variability Experiment (EVE)

The EVE sounding rocket instrument is used for calibrating a similar instrument onboard the SDO and other spacecraft. The EVE sounding rocket is launched annually to enable correction of the satellite data.

A subset of the Hi–C 2.1 field of view of the Sun from the 2018 flight.

High Resolution Coronal Imager (Hi-C)

The main objective of the Hi-C 2.1 investigation was to trace the flow of energy and mass between the Sun's corona and the turbulent lower-layers of the Sun's atmosphere, the chromosphere and transition region.

High-resolution Coronal Imager (Hi-C)

The High-resolution Coronal Imager (Hi-C) is designed to place significant new limits on theories of coronal heating and dynamics by measuring the structures at size scales relevant to reconnection physics. Hi-C was flown successfully in 2012 and collected the highest resolution (~0.3 arcsec) images of the solar atmosphere, or corona, in a passband sensitive to 1.5 million degree plasma.

The goal of the second flight was to trace the flow of energy and mass between the Sun's corona and the turbulent lower-layers of the Sun's atmosphere, the chromosphere and transition region. To achieve this goal, the passband of Hi-C was changed to be sensitive to lower temperature plasma (roughly 1 million degrees) and coordination with the Interface Region Imaging Spectrograph (IRIS) was planned. IRIS images the Sun's chromosphere and transition region at roughly the same resolution as Hi-C. Additionally, the original Hi-C camera was changed to a NASA Marshall Space Flight Center (MSFC)-developed low-noise camera. As a tradeoff for markedly improved read noise (~10 electrons RMS), the second flight had a smaller field of view (~260 arcsec) due to a reduced detector size (4k x4k to 2k x 2k).

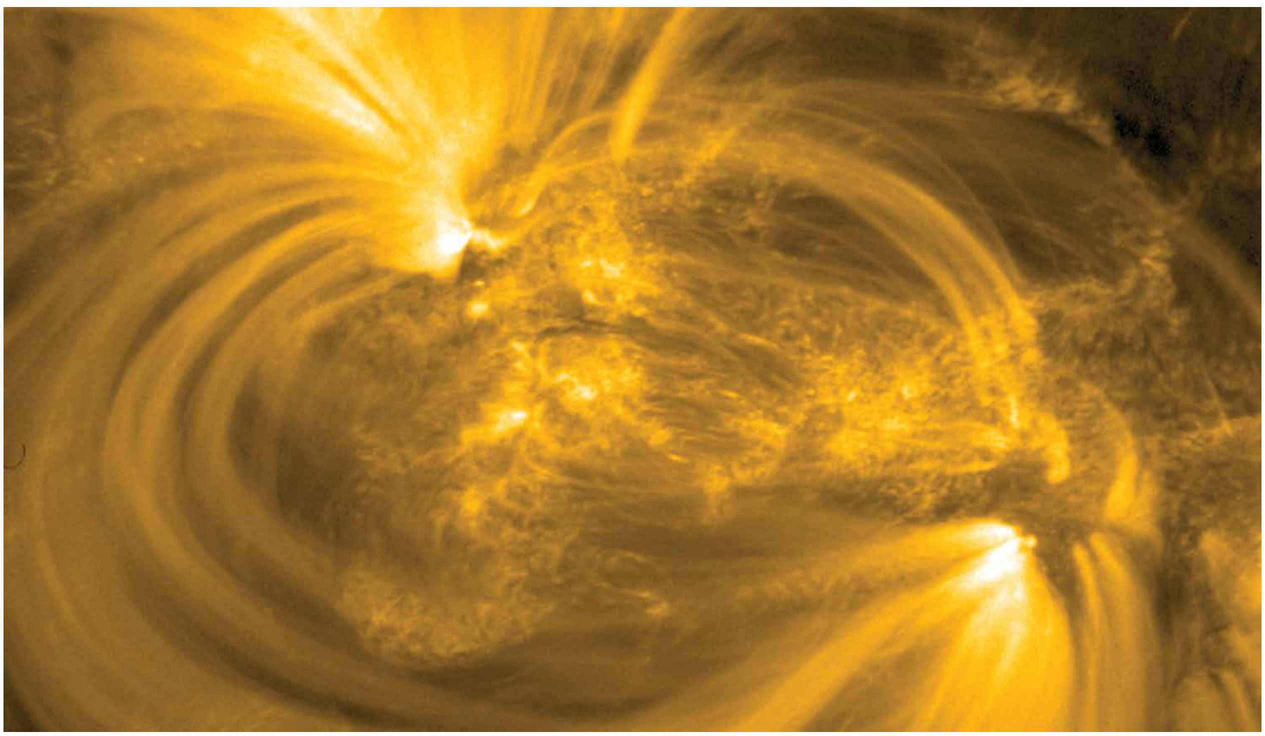


Figure 1. Hi–C 2.1 captured the highest resolution images of the Sun's 1 million degree atmosphere. A subset of the Hi–C 2.1 field of view is shown. This data, when combined with supporting data sets, will allow scientists to trace mass and energy through the Sun's lower atmosphere.

The initial flight in this new configuration (Hi-C 2) was conducted in 2016, but due to an instrument shutter failure no scientific data was collected. Another attempt in this configuration was proposed in 2017 and awarded in 2018. On May, 29, 2018, only 3.5 months after Authority to Proceed, Hi-C flew a third time (called Hi-C 2.1) and successfully collected science data. An example of the Hi-C data is shown in Figure 1.

Principal Investigator: *Dr. Amy Winebarger/NASA MSFC* • ***Mission Number(s):*** *36.342 NS*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *May 29, 2018*

Along with IRIS, several additional satellite and ground-based observatories supported the flight, including Hinode, the Nuclear Spectroscopic Telescope Array (NuSTAR), National Solar Observatory's Interferometric BIdimensional Spectrapolarimeter (IBIS), Big Bear Solar Observatory, Owens Valley Radio Observatory, and the Swedish Solar Telescope. Combing these data sets will allow the Hi-C data to be used to address a broad spectrum of science questions far beyond its initial goal.

MSFC/NASA led the mission with partners including the Smithsonian Astrophysical Observatory, the University of Central Lancashire, and Lockheed Martin Solar and Astrophysical Laboratory.

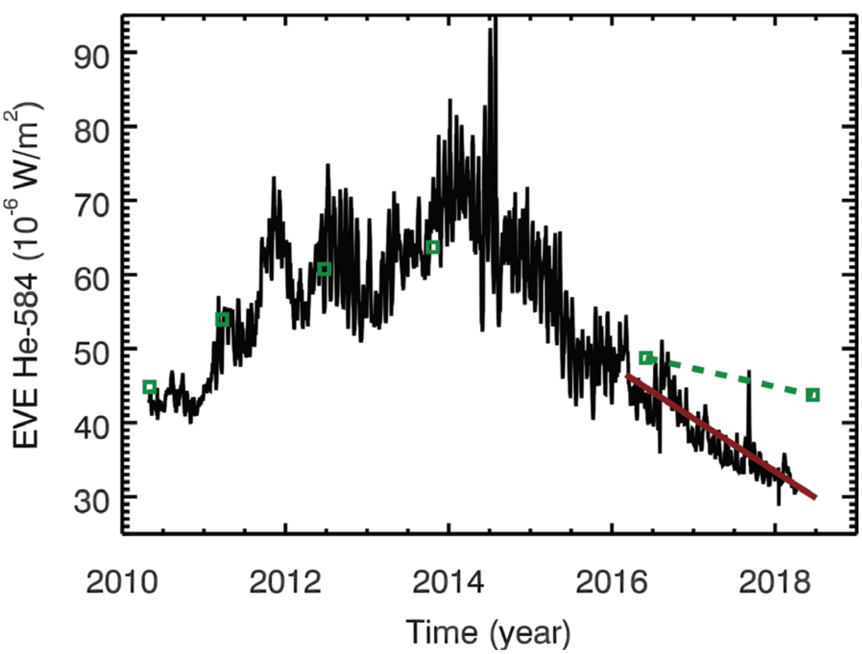
Hi–C 2.1 Science Team

Hi–C 2.1 Payload Team

EUV Variability Experiment (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. The EVE program provides solar EUV irradiance (the power per unit area (W/m^2) produced by the Sun in the form of electromagnetic radiation) data for NASA's Living With the Star (LWS) program, including near real-time data products for use in space weather operations, such as input for atmospheric models that specify the space environment. Physics based solar models are also used to advance the understanding of irradiance variations based on the activity of the solar magnetic features. EVE measures spectral irradiance at wavelengths of 1 - 1216 Å with 1 Å resolution at most wavelengths.

NASA 36.336, with its launch on June 18, 2018, provides the seventh underflight calibration for the EVE aboard the SDO satellite. Prior calibration missions have been flown on May 3, 2010, March 23, 2011, June 23, 2012, October 21, 2013, May 21, 2015 (LV failure), and June 1, 2016. This mission also provided underflight calibrations for solar EUV imagers aboard SDO, Solar and Heliospheric Observatory (SOHO), NOAA Geostationary Operational Environmental Satellites (GOES), Proba2, Hinode, and for full-disk irradiance instruments aboard Solar Radiation and Climate Experiment (SORCE), Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED), Mars Atmosphere and Volatile EvolutioN (MAVEN), and SOHO. These underflight calibration experiments are critical for maintaining high-accuracy, long-term records of the solar EUV variability as illustrated for the SDO EVE data for the He emission at 584 Å. This shows how much EVE has degraded from its last calibration in 2016 to 2018; that degradation trend (red line) will be corrected in the next EVE data product release using this rocket flight calibration.



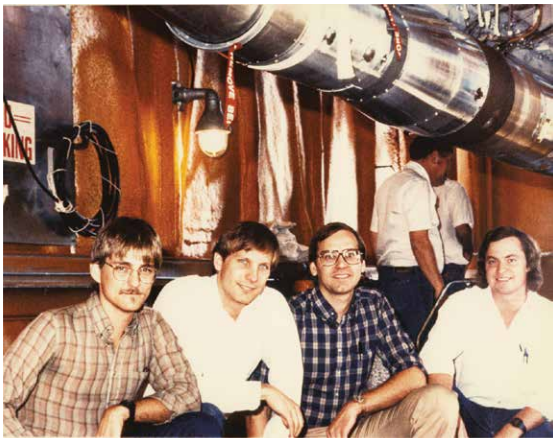
SDO EVE measurement of the He 584 Å emission is shown in black. The calibration rocket flights are shown as green squares, and the trend between the last calibration in 2016 to this new one in 2018 provides the correct trend for solar cycle variability.

Principal Investigator: *Dr. Thomas Woods/University of Colorado* ***Mission Number(s):*** *36.336 UE*
Launch site: *White Sands Missile Range, NM -* ***Launch date:*** *June 18, 2018*

NASA 36.336 also offered the opportunity to fly new technology to provide additional calibrations in other wavelengths. A new instrument, Compact SOLSTICE (CSOL), is a solar FUV-MUV spectrograph (1150-3200 Å) that was developed by the NASA SORCE project. CSOL was added to this flight to provide a final calibration for the SORCE solar ultraviolet spectral irradiance instruments before SORCE will be decommissioned in June 2019. A second new-technology instrument is the next generation solar X-ray spectrometer that is a modified version of the Amptek X123 spectrometer with dual apertures to better measure the solar X-ray range from 1 to 25 Å with higher spectral resolution. This X-ray spectrometer provides calibrations for SDO EVE and is supported by the MinXSS CubeSat project.

This flight was also a historical moment for Greg Ucker, Rick Kohnert, and Tom Woods to celebrate 30 years of calibration rocket flights for solar EUV satellite instruments. Their first calibration rocket NASA 21.101 was developed quickly in August-October 1988 to provide an urgently needed underflight calibration for the German solar EUV instrument aboard the San Marco satellite, and it was a successful flight on November 11, 1988, just in time before San Marco re-entered in December 1988. Since then they have had another 18 solar EUV calibration flights over the past three decades with five flown for calibrating TIMED Solar EUV Experiment (SEE) and seven flown for calibrating SDO EVE.

Thirty-Year Celebration of Calibrating Solar EUV Satellite Instruments.

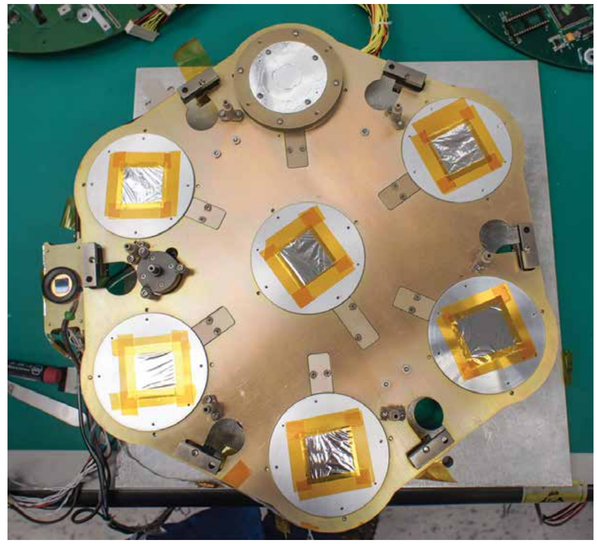


1988, left–to–right: Greg Ucker, Rick Kohnert, Tom Woods, Peter Seidl (German engineer).

2018, left–to–right: Greg, Rick, Tom, and Michael Klapetzky (LASP rocket manager).

Focusing Optics X-ray Solar Imager (FOXSI) 3

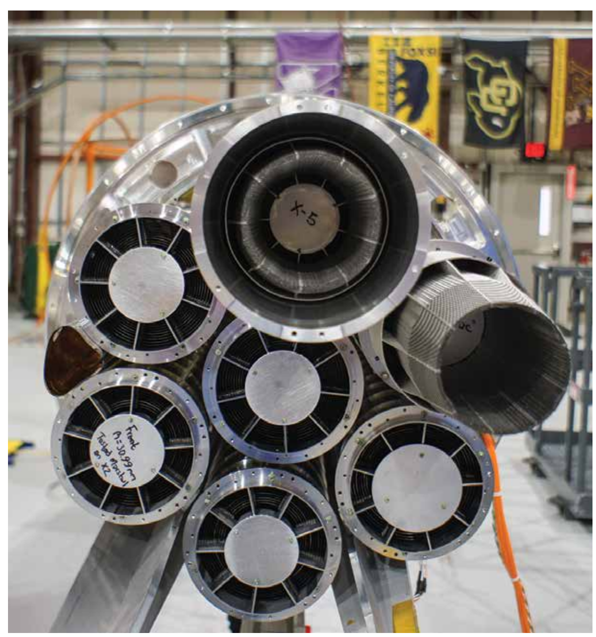
The outer layer of the Sun (known as the corona) has a temperature of over one million degrees Kelvin (K) while the visible surface of the Sun, the photosphere, is a mere 6,000 deg K. This is not what one would expect from thermodynamics unless some extraordinary energy source continually heats the corona – this phenomenon is known as the “coronal heating problem.” The mechanisms that heat up and maintain the corona are currently not understood, and solving this mystery will reveal some of the fundamental physics at work in our nearest star. Exploring coronal heating is one of the primary purposes of the Focusing Optics X-ray Solar Imager (FOXSI) experiment.



The focal plane structure holding 7 X–ray cameras. The thin (square) filters that protect each hard X–ray camera are visible, along with a photocell used for alignment (at left). The soft X–ray camera (at top) has a special, circular filter that is much thinner than the others to allow the transmission of low–energy X–rays.

FOXSI is designed to investigate “nanoflares,” which are much smaller than large solar flares but which occur far more frequently. These nanoflares may be responsible for coronal heating and also might serve as the seeds for the cascades that result in much larger flares. Since nanoflares are too small to be observed individually with today’s technology, FOXSI looks for the combined effects of thousands or millions of nanoflares occurring nearly at the same time. Together, these little bursts of energy can produce superheated plasma and particle acceleration that could be seen by FOXSI. To observe these nanoflare signatures, FOXSI employs focusing optics – a direct, high-sensitivity method only newly available in the hard X-ray regime.

This was the third flight of FOXSI. The first flight in November 2012 observed a single flare in progress, resulting in the first-ever focused images of the Sun at hard X-ray energies (see Krucker et al., The Astrophysical Journal Letters, 2014). FOXSI-2, flown in December 2014, detected emission above 7 keV from an active region of the Sun with no obvious individual X-ray flare emission, providing the most direct evidence to date of X-ray emission from tiny nanoflare populations (see Ishikawa et al., Nature Astronomy, 2017).



Front view of the 7 FOXSI–3 optics modules. Note the addition of collimators in front of two modules. These collimators are 3D printed with a fine honeycomb structure to block stray light.

FOXSI-3 flew successfully for a 6-minute observation on September 7, 2018, and included several new components. Upgrades included adding more mirrors to the optics modules to increase the collecting area; new fine-pitch CdTe X-ray detectors sensitive to higher energies; and a higher-resolution

Principal Investigator: *Dr. Lindsay Glesener/University of Minnesota* • ***Mission Number(s):*** *36.325 US*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *September 7, 2018*

optical camera for context. In addition, some entirely new components were debuted: collimators were added before the optics modules to eliminate a source of instrumental background known as "ghost rays," and a new soft X-ray telescope was included that measures low-energy X-rays with both spatial and spectral resolution.


El Zorrito – FOXSI team member.

All systems on the experiment and the rocket performed well during the flight, including the upgrades and the new components. The quickly declining solar cycle did not offer much activity, giving FOXSI-3 a clear shot at measuring nanoflaring activity in the quiet Sun. In addition, a decaying/aged active region presented enough hot plasma for distinct, rich X-ray images and spectra to be made. Data for the decaying region and quiet-Sun targets were successfully obtained from all instruments. Several observatories coordinated with FOXSI-3, including the NuSTAR, Hinode, and IRIS spacecraft as well as radio and microwave observatories on the ground. The payload was successfully recovered immediately following the flight, with all systems intact and functional. Data from this flight are being analyzed and will be presented for the first time at the American Geophysical Union Fall Meeting in Washington, D.C., in December 2018.

FOXSI-3 is a collaboration between the University of Minnesota, University of California Berkeley, NASA/Marshall, NASA/Goddard, University of Tokyo/Kavli IPMU, Nagoya University, Tokyo University of Science, JAXA/ISAS, and the National Astronomical Observatory of Japan.

More information is available at foxsi.umn.edu.


Team photo, including members of the FOXSI–3 experiment team, NSROC teams, and Navy.


The successful recovery of the FOXSI–3 payload

Astrophysics Missions 2018

Astrophysics seeks to understand the universe and our place in it and aims to discover how the universe works, explore how it began and evolved, and search for life on planets around other stars. In 2018 four Astrophysics missions, studying various aspects of our Galaxy in the Ultraviolet and X-ray parts of the spectrum, were flown.

Spectrometers and telescopes are frequently flown onboard sounding rockets for Astrophysics research. Telescopes focus the incoming radiation from a target object and spectrometers spread light out into specific wavelengths creating a spectra.

All atoms and molecules have characteristic spectra that produce absorption or emission lines at specific wavelengths. This allows scientists to extract information about composition, temperature, and other variables of the astronomical target of their study. Emission line spectra are created when an electron drops down to a lower orbit around the nucleus of an atom and loses energy. Absorption line spectra occur when electrons move to a higher orbit by absorbing energy.

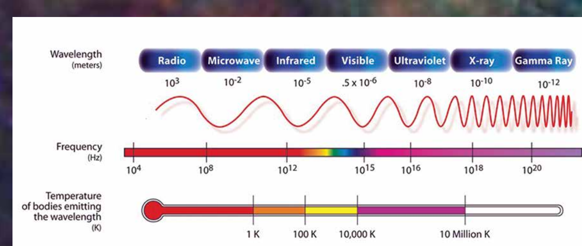
Micro-X

Micro-X combines a high-energy-resolution X-ray microcalorimeter with an imaging mirror to obtain an imaging X-ray microcalorimeter spectra from an astronomical source. The first flight of Micro-X was designed to investigate the plasma conditions (such as temperature, electron density and ionization) and the velocity structure of the Cassiopeia A Supernova remnant (SNR).

Visible light **is what we are most familiar with on Earth. Visible light ranges in wavelength from 400 nm to 700 nm, with violet being the shortest wavelength and red the longest. Absorption and emission spectra of objects in the Universe reveal information about the elements present, the temperature, and density of those elements and the presence of a magnetic field and many other variables.**

High energy and high temperature processes in the Universe radiate in the *Ultraviolet (UV)* part of the spectrum. Knowledge of star formation and evolution, growth of structure in the Universe, physics of jet phenomena on many scales, aurora on and atmospheric composition of the gas giant planets, and of the physics of protoplanetary disks, has been expanded through UV observations.

To emit *X-rays,* gas must be under extreme conditions, such as temperatures of millions of degrees, superstrong magnetic fields, or electrons must be moving at nearly the speed of light. Extreme conditions can be found in disks of matter orbiting black holes or in supernova remnants. X-rays are classified into two types: soft X-rays and hard X-rays. Soft X-rays fall in the range of the EM spectrum between UV light and Gamma Rays. Hard X-rays are very close to gamma-rays. The only difference between them is their source: hard X-rays are produced by accelerating electrons, while Gamma Rays are produced by atomic nuclei.



Electromagnetic Radiation

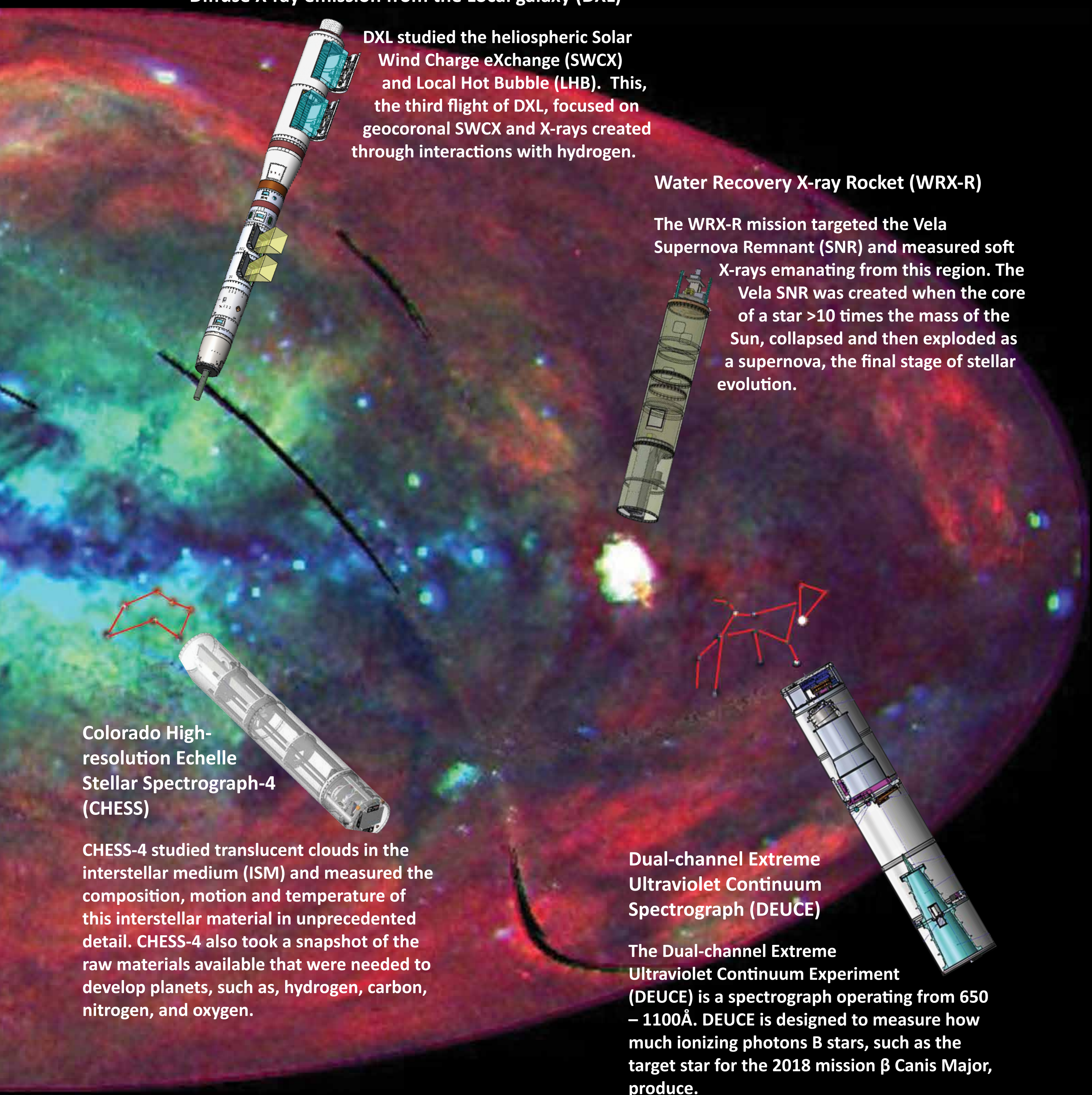
Continuos spectra are created by hot opaque objects.

Hydrogen absorption spectra in visible wavelengths.

An absorption spectrum is created when energy from a hot opaque object travels through cooler transparent gas.

Hydrogen emission spectra in visible wavelengths.

Hot transparent gas, such as gaseous nebulae, create emission spectra.



Diffuse X-ray emission from the Local galaxy (DXL)

DXL studied the heliospheric Solar Wind Charge eXchange (SWCX) and Local Hot Bubble (LHB). This, the third flight of DXL, focused on geocoronal SWCX and X-rays created through interactions with hydrogen.

Water Recovery X-ray Rocket (WRX-R)

The WRX-R mission targeted the Vela Supernova Remnant (SNR) and measured soft X-rays emanating from this region. The Vela SNR was created when the core of a star >10 times the mass of the Sun, collapsed and then exploded as a supernova, the final stage of stellar evolution.

Colorado High-resolution Echelle Stellar Spectrograph-4 (CHESS)

CHESS-4 studied translucent clouds in the interstellar medium (ISM) and measured the composition, motion and temperature of this interstellar material in unprecedented detail. CHESS-4 also took a snapshot of the raw materials available that were needed to develop planets, such as, hydrogen, carbon, nitrogen, and oxygen.

Dual-channel Extreme Ultraviolet Continuum Spectrograph (DEUCE)

The Dual-channel Extreme Ultraviolet Continuum Experiment (DEUCE) is a spectrograph operating from 650 – 1100Å. DEUCE is designed to measure how much ionizing photons B stars, such as the target star for the 2018 mission β Canis Major, produce.

Dual-channel Extreme Ultraviolet Continuum Spectrograph (DEUCE)

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DEUCE integration at White Sands Missile Range.

DEUCE has two modes; a low resolution, high throughput mode operating from 650 – 890 Å, and a high resolution, low throughput channel from 650 – 1100 Å. The stellar brightness changes dramatically above 912 Å and below 912 Å and therefore the two modes are necessary. The change in intensity is unknown, and may range from 10/1 to 10,000/1. DEUCE was designed to measure the flux of local, bright, hot stars that have very little intervening absorbing material in the interstellar medium. Only two such stars exist, β and ε Canis Major.

The target object, β Canis Major, was not acquired due to an Attitude Control System (ASC) anomaly, and science data was not obtained. All other payload systems operated nominally, including the detector, which returned data as expected from an empty target field. Post-recovery testing of the payload shows that all systems continued to function within specification, and that the optical alignment was maintained through launch and recovery.

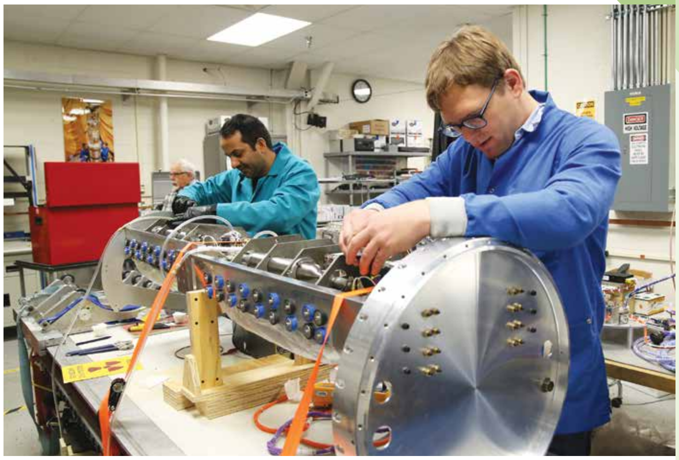
DEUCE team with rocket.

A second DEUCE flight, scheduled for December 2018, will target ε Canis Major. There are no preexisting measurements of the flux of these types of stars in the critical 700 – 900 Å regime, and the fundamental objective of DEUCE is to understand how bright these types of stars are in the 700 – 900 Å regime.

Principal Investigator: *Dr. James Green/University of Colorado* • ***Mission Number(s):*** *36.311 UG*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *October 30, 2017*

Diffuse X-ray emission from the Local galaxy (DXL)

NASA astrophysics research includes studies of our space environment in all wavelengths of the electromagnetic spectrum. Space based instruments are used for studies in the high energy range of the spectrum, such as X-rays, because these energies are blocked by the Earth's atmosphere. One such instrument is NASA's Diffuse X-Ray emission from the Local galaxy (DXL), which flew onboard a sounding rocket. DXL was launched from Poker Flat Research Range, AK in January 2018. The mission studied what proportion of X-rays are emitted from the Local Hot Bubble (LHB) versus the Solar Wind Charge eXchange (SWCX). Data from DXL enhances our understanding of the area of our galaxy close to the Sun, and can be used as a foundation for future models of the galaxy structure.



DXL integration at Wallops Flight Facility.

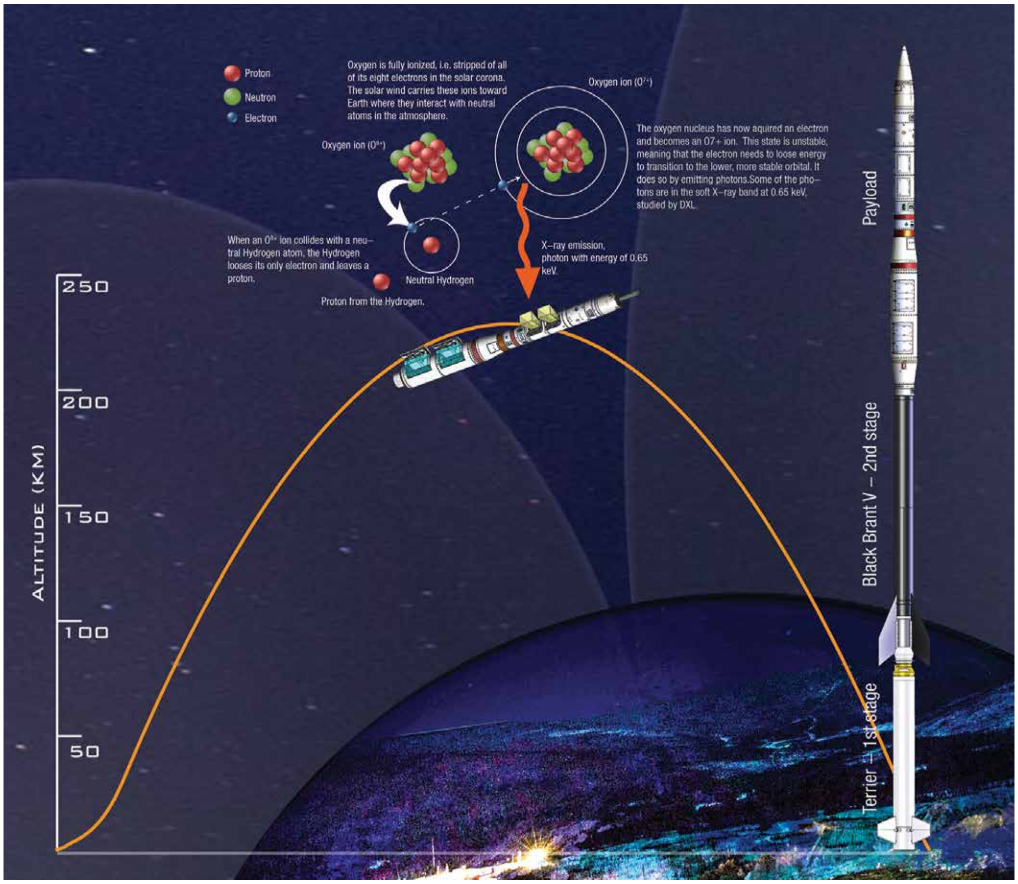
The DXL mission was designed as a multi-year campaign with a total of three sounding rocket flights. The first flight was designed to quantify the contribution of LHB and SWCX to the soft X-ray background and was launched from White Sands Missile Range (WSMR), NM in December 2012. The second mission, also from WSMR, was launched in December 2015, while the third launch was in January 2018 from Poker Flat Research Range in Alaska. The purpose of the two latter flights is to better understand the nature and characteristics of LHB and SWCX. Flight 2 investigated X-rays created through SWCX interactions with helium. Flight three focused on geocoronal SWCX and X-rays created through interactions with hydrogen.

DXL launch from Poker Flat Research Range, AK.

X-rays in the Universe are created when particles have been energized or raised to high temperatures by gigantic explosions or intense gravitational fields. These conditions exist all around the Universe from neutron stars, black holes, to the LHB. The LHB is a cavity of very low density hydrogen and hot plasma in our galaxy, thought to have been created by supernovae explosions, between a few hundred thousand and a few million years ago. This very hot plasma (material so hot that electrons are no longer bound to individual nuclei and is electrically conducting) emits soft x-rays. Soft x-rays are categorized as having energy levels below 5 kilo electron Volts, keV. X-rays are also created as the electrically-charged solar wind comes into contact with a neutral gas. The solar wind can steal electrons from this gas, resulting in an X-ray glow.

In Solar Wind Charge eXchange (SWCX), highly ionized ions, such as O^{8+} or fully ionized Oxygen, in the solar wind collide with neutral atoms, such as hydrogen, picking up an electron in an excited state. The electron then

Principal Investigator: *Dr. Massimiliano Galeazzi/University of Miami* • ***Mission Number(s):*** *36.329 UH*
Launch site: *Poker Flat Research Range, AK* • ***Launch date:*** *January 19, 2018*



DXL mission overview.

decays producing Ultraviolet (UV) and X-ray emission. The Geocorona is the luminous part of Earth's exosphere. The exosphere is about 1,000 km above the Earth's surface. SWCX in the Geocorona is produced in the Magnetosheath, the region where the solar magnetic field collides with the Earth's magnetic field, producing a classical shock in the solar wind. When the solar wind increases, the Magnetosheath moves closer to the Earth, and deeper into the exosphere, producing greater SWCX. The fields at the Earth's magnetic poles guide solar wind ions even deeper into the atmosphere, where the neutral densities are even higher, producing strong, localized SWCX. DXL will scan the sky from as close to the cusp as possible at night and down the gradient (i.e. to the part of the Magnetosheath that is faint) to achieve a large a dynamic range from the sheath. The stronger the solar wind the better, as it increases both the absolute strength and the contrast.

DXL's main instruments were X-ray proportional counters. DXL studies X-rays with energies between 0.1 and 2 keV. Two of the four counters were filled with a gas mixture of 90% argon and 10% methane, while the other two where filled with 100% methane. Incoming X-rays enter the chamber through a window specially coated to let through only particles of certain energies. The incoming particles collide with the atoms inside, ionizing them and producing ion pairs (one electron and one positively charged ion). The electrons produced are attracted to the positive anode of the counter, creating a cascade of additional electrons that then produces a charge on the anode that is measured. The amount of charge is proportional to the energy of the X-rays that entered the detector. During flight, the payload is slowly rotated, pointing the counters toward different parts of the sky and producing spatial maps of the X-ray distribution. As LHB and SWCX emissions have different spatial distribution they can be separated, and studied individually.

Water Recovery X-ray Rocket (WRXR)

The WRXR mission, launched from Roi Namur, Kwajalein Atoll, Marshall Islands, in April 2018 and targeted the Vela Supernova Remnant (SNR) with a goal of measuring soft X-rays emanating from this region.

The Vela SNR was created when the core of a star >10 times the mass of the Sun, collapsed and then exploded as a supernova, the final stage of stellar evolution. Supernova explosions are one of the most energetic events in the Universe, and play a role in recycling material within galaxies. They are responsible for the creation and distribution of elements such as, oxygen, silicon, neon, iron, nickel, and magnesium among others, into the interstellar medium, thereby providing source material for the next generation of stars, planets, and even organic chemistry. Evidence of the supernova explosions are left behind as SNRs. Ejected material from the explosion travels at high speeds and the shockwave sweeps up interstellar material along the way, continuing to heat it to temperatures as high as 10 million Kelvin. These hot temperatures lead to the emission of high energy electromagnetic radiation, such as X-rays, from the SNR.

WRXR science team in the block house on Roi–Namur following the launch.

WRXR ready for the rail on Roi Namur, Kwajalein Atoll.

WRXR is sensitive to soft X-rays with an energy range of 0.25 - 0.8 keV focusing on emission lines for ions of $Oxygen^{6+}$, $Oxygen^{7+}$ and $Carbon^{5+}$. The data will show how much of each constituent is present, and allow scientists to derive information about the conditions in the Vela SNR such as the temperature, density, chemical composition, and ionization state. Using these characteristics they will also be able to estimate the shock velocity near the SNR limb, the age and type of the SNR, the energy of the supernova, and the mass of the progenitor.

The mission accomplished many logistical achievements while proving several technologies. This was the first astronomical payload to be water recovered at Kwajalein Atoll. This was also the first flight of X-ray hybrid-CMOS detectors and an aligned array of large-format X-ray diffraction gratings. Furthermore, this was the first flight of the water recovery shutter door, sealed telemetry system, sealed Celestial Attitude Control System (CACS), and a new NSROC Forward Ogive Recovery System (N-FORSe) with Iridium/GPS beacons and strobe lights. The payload was successfully recovered and data analysis is ongoing.

Principal Investigator: *Dr. Randall McEntaffer/Penn State University* • ***Mission Number(s):*** *36.330 UH*
Launch site: *Kwajalein Atoll, Marshall Islands* • ***Launch date:*** *April 4, 2018*

Colorado High-resolution Echelle Stellar Spectrograph - 4 (CHESS)

NASA and the University of Colorado at Boulder collaborated to launch an astrophysics experiment into Earth's near-space environment in order to study the life-cycle of stars in our Milky Way galaxy. The NASA/CU 36.333 UG – France mission launched from Roi Namur, Kwajalein Atoll, Marshall Islands, on April 16, 2018. The CHESS-4 instrument acquired data on sightline to the hot star Gamma Ara. The payload was successfully recovered and comprehensive success was achieved for 36.333 UG.

CHESS–4 science team and payload during integration at Wallops.

CHESS was designed to study the interstellar medium (ISM), the matter between stars, and specifically translucent clouds of gas which provide fundamental building blocks for star and planet formation. These clouds have very low densities and the only way to study them is to measure absorption spectra of light from stars passing through the cloud. CHESS was pointed at the star Gamma Ara, in the constellation Ara. When radiation from this star travels through the cloud some wavelenghts of energy are absorbed by the cloud. The absorbed wavelengths indicate the presence of specific elements, all of which have their unique spectral signatures. For example, molecular hydrogen (H2) has a system of absorption lines near 1100 Å (110 nm). H2 traces cool molecular material (50 – 100 Kelvin), and makes up 99.99% of the total molecular gas in the Galaxy. If H2 is present in the cloud that the starlight passes through, the spectrograph will show less energy at wavelengths near 1100 Å.

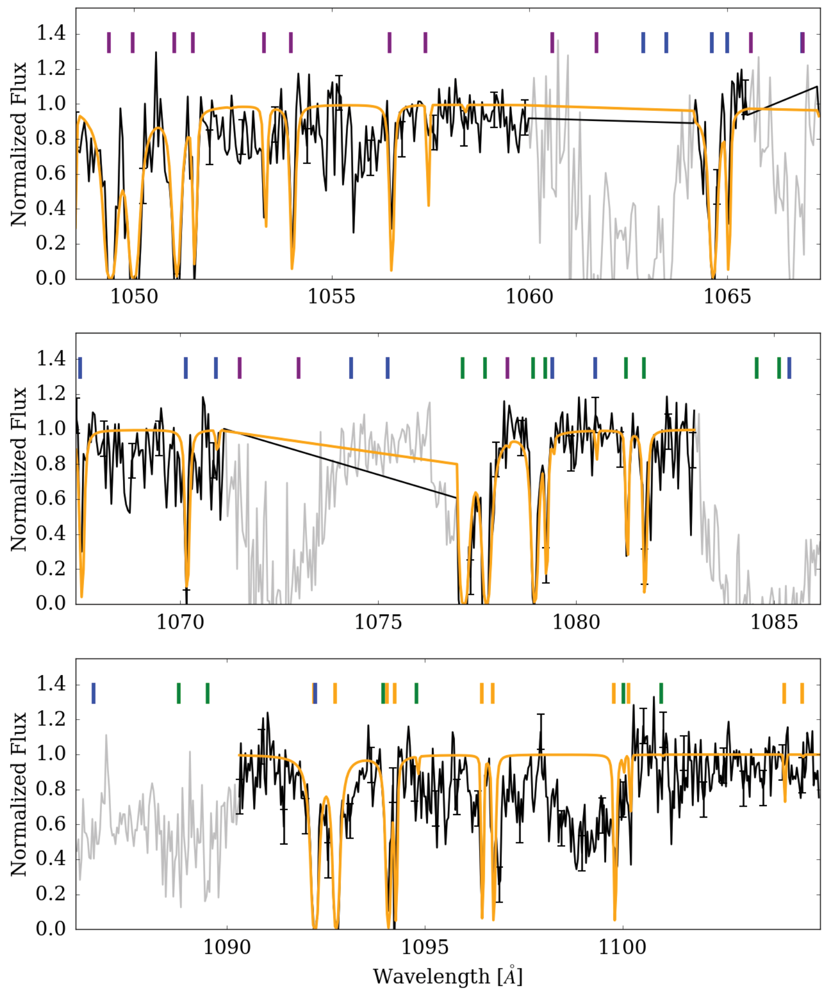
CHESS–4 launches from Roi Namur, Kwajalein.

Gamma Ara displays an unusually powerful stellar wind; CHESS studied the interaction of this stellar wind with the surrounding ISM to examine the excitation of atoms and molecules in the interface region.This allows the CHESS team to investigate the catalysts of Galactic chemistry and the raw materials for future generations of stars and planets, as well as, quantify the temperature and motions of the clouds along the line of sight.

CHESS and the follow on mission under development, Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet host stars (SISTINE), also are pathfinders and technology demonstrators

Principal Investigator: *Dr. Kevin France/University of Colorado* • ***Mission Number(s):*** *36.333 UG*
Launch site: *Kwajalein Atoll, Marshall Islands* • ***Launch date:*** *April 16, 2018*

for an ultraviolet spectrograph for the NASA exoplanet/cosmic origins mission concept, Large UV/Optical/IR Surveyor (LUVOIR), currently under study. The LUVOIR Ultraviolet Multi-Object Spectrograph (LUMOS) is being led by Dr. France's team at the University of Colorado and would address topics ranging from characterizing the composition and structure of planet-forming disks to the feedback of matter between galaxies and the intergalactic medium. SISTINE is scheduled for the first flight in 2019 from White Sands Missile Range in New Mexico, and a second flight from Australia in 2020.



CHESS–4 flight data from 36.333 UG is shown as the black line. Prominent H2 absorption features are noted with the color tick marks and a spectral synthesis model of the interstellar cloud on the gamma Ara sightline is shown in orange. Echelle order overlap regions are shown in gray and are excluded from the spectral fit. This spectral reduction is courtesy of Nick Kruczek, the lead graduate student on the CHESS–4 mission. This flight data will form a key component of his Ph.D. dissertation research.

Link: http://cos.colorado.edu/~kevinf/

Micro-X

Micro-X combines a high-energy-resolution X-ray microcalorimeter with an imaging mirror to obtain the first imaging X-ray microcalorimeter spectra from an astronomical source. As a photon is absorbed in a microcalorimeter and its energy converted to heat, the resulting temperature rise can be measured by the resistance change of a Transition Edge Sensor (TES). These microcalorimeters need to be cooled to temperatures of about a hundredth of a degree above absolute zero to function properly.

Science team working on Micro–X at Wallops Flight Facility.

This, the first flight of Micro-X, was designed to investigate the plasma conditions (such as temperature, electron density and ionization) and the velocity structure of the Cassiopeia A Supernova remnant (SNR). The high-resolution X-ray spectra (14,000 counts collected in 326 seconds at 6-10 eV resolution across the 0.2 - 2.5 keV band) that Micro-X is developed to measure, will help to ascertain the temperature and ionization state of the X-ray emitting gas in Cas A, as well as study individual bright plasma knots within the remnant.

Micro–X on the vibration table during pre–flight testing.

In addition to performing the first scientific observation with TES microcalorimeters in space, the Micro-X program also aids in the understanding and development of future flight qualified microcalorimeter systems for larger orbiting missions.

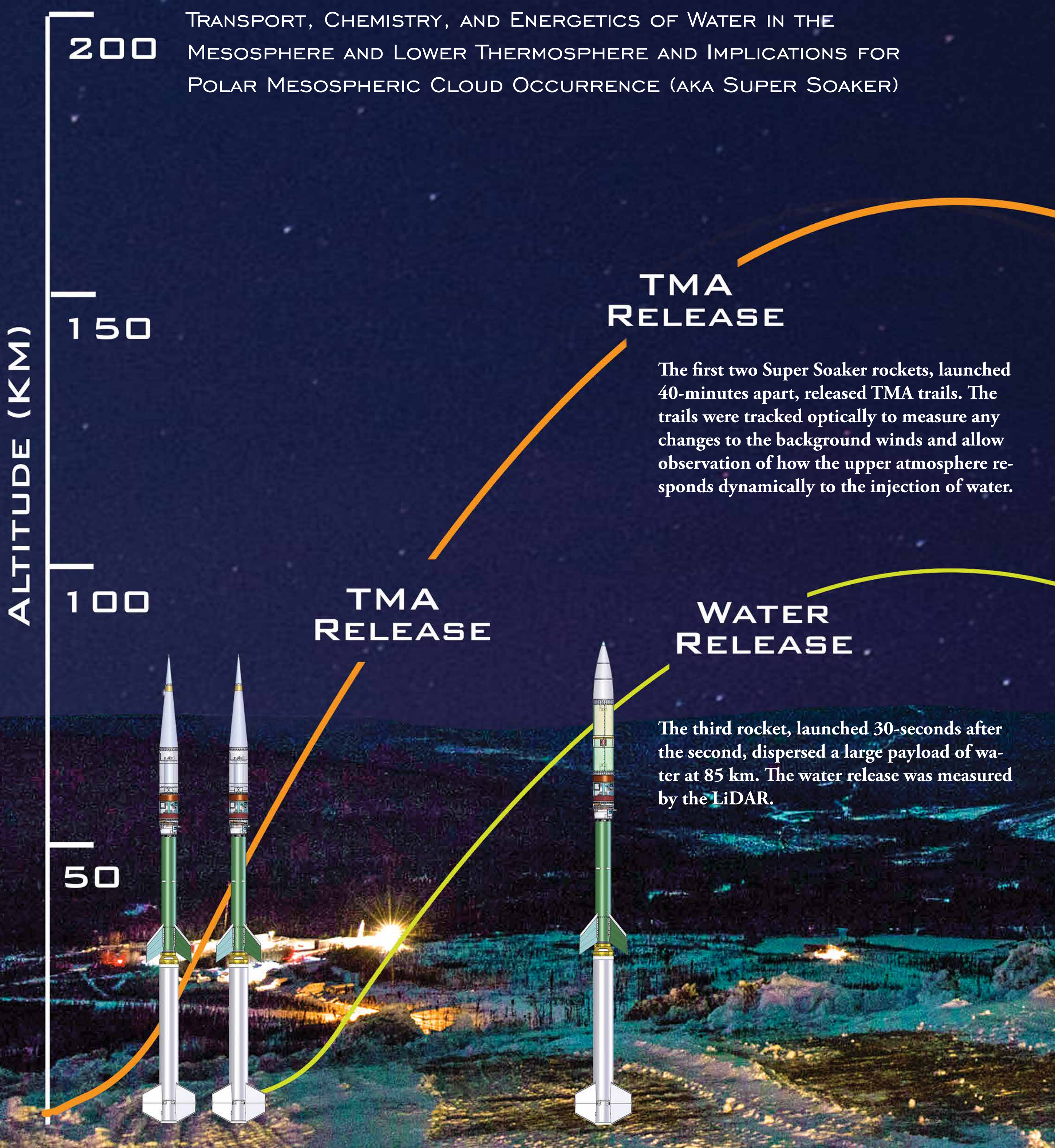
Due to an Attitude Control System anomaly, data from the target SNR was not received. However, the Micro-X instrument did perform as expected.

Micro–X team with 36.245 UH on the launcher.

Principal Investigator: *Dr. Enectali Figueroa/Northwestern University* • ***Mission Number(s):*** *36.245 UH*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *July 23, 2018*

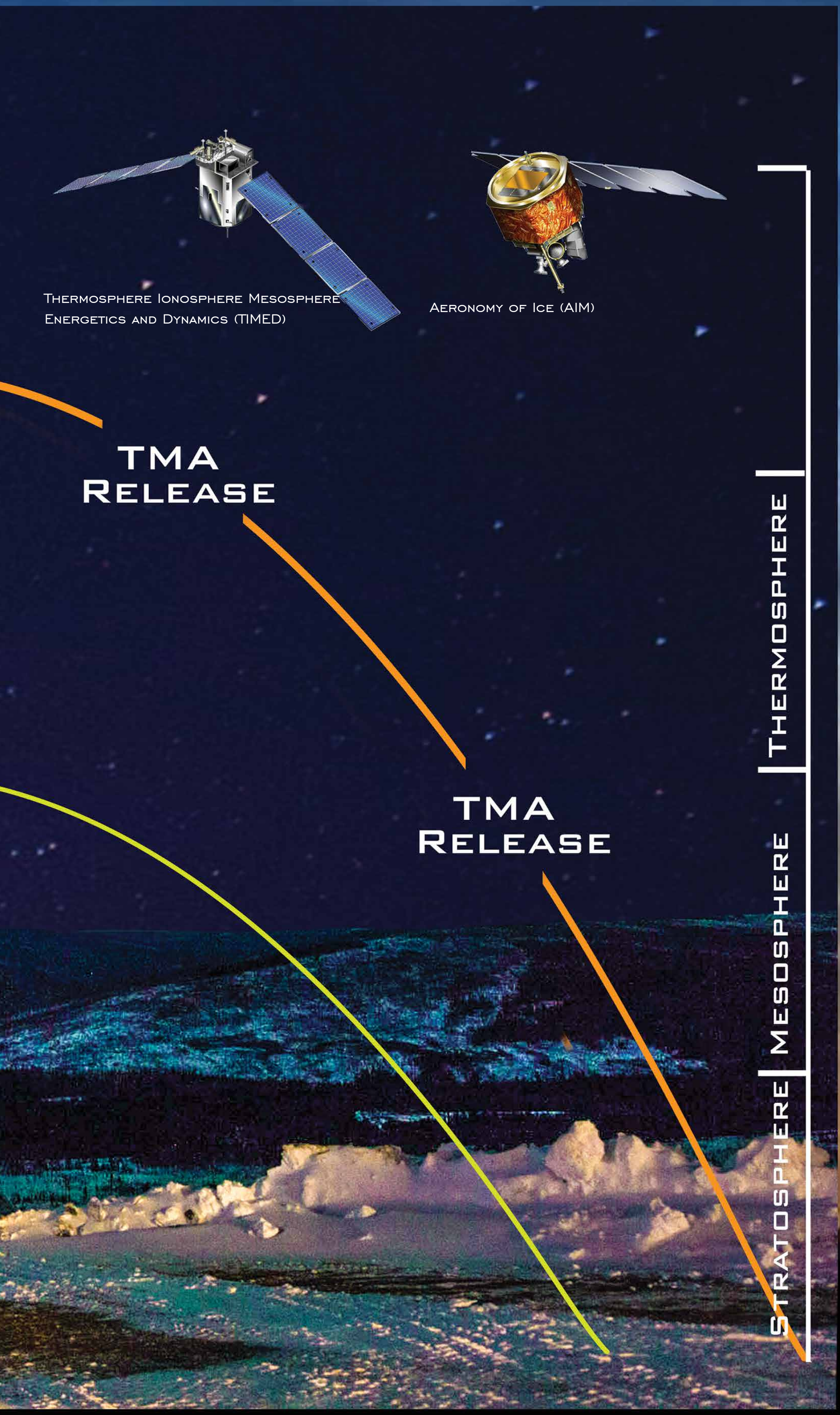
Micro-X on the vibration table at NASA GSFC Wallops Flight Facility.

Transport, Chemistry, and Energetics of Water in the Mesosphere and Lower Thermosphere and Implications for Polar Mesospheric Cloud Occurrence (aka Super Soaker)



The first two Super Soaker rockets, launched 40-minutes apart, released TMA trails. The trails were tracked optically to measure any changes to the background winds and allow observation of how the upper atmosphere responds dynamically to the injection of water.

The third rocket, launched 30-seconds after the second, dispersed a large payload of water at 85 km. The water release was measured by the LiDAR.

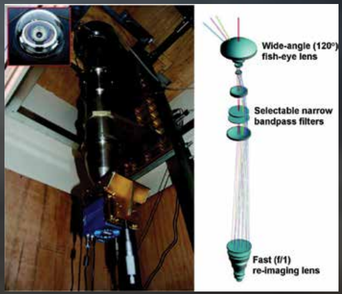


Three Terrier-Orion sounding rockets were launched from Poker Flat Research Range in Alaska in January 2018, as part of the Transport, Chemistry, and Energetics of Water in the Mesosphere and Lower Thermosphere and Implications for Polar Mesospheric Cloud Occurrence mission, also referred to as the Super Soaker mission.

Ground based instrumentation used for this mission included:

Poker Flat Rayleigh Lidar

This Rayleigh LiDAR system measures aerosols and atmospheric temperature and density profiles in the upper atmosphere (?40–100km). For Super Soaker the LiDAR was upgraded with a new beam steering mirror to allow the laser beam to point along the Super Soaker rocket trajectory.



Advanced Mesospheric Temperature Mapper (AMTM)

The AMTM is an infrared digital imaging system that measures selected emission lines in the mesospheric Hydroxyl (OH) (3,1) band (at approximately 1.5 µm) to create intensity and temperature maps of the mesosphere around 87 km.

Poker flat Incoherent Scatter Radar (PFISR)

Incoherent Scatter Radars measure parameters needed to describe the state and energy balance of the plasma in the ionosphere e.g. electron number density, electron and ion temperatures, bulk ion motion, ion masses, ion-neutral collision frequency.

Transport, Chemistry, and Energetics of Water in the Mesosphere and Lower Thermosphere and Implications for Polar Mesospheric Cloud Occurrence (aka Super Soaker)

Composite time–lapse photograph of the three Super Soaker rockets launched from the Poker Flat Rocket Range in Alaska on January 26, 2018. The green line in the upper right is the Rayleigh lidar beam. The bright white feature is part of the TMA tracer trail.

Three Terrier-Orion sounding rockets were launched from Poker Flat Research Range in Alaska in January 2018, as part of the Transport, Chemistry, and Energetics of Water in the Mesosphere and Lower Thermosphere (MLT) and Implications for Polar Mesospheric Cloud Occurrence mission, hereafter referred to as Super Soaker. The science goal of Super Soaker was to study the impact of a locally concentrated plume of water vapor on temperature and ice cloud formation in the mesosphere and lower thermosphere. Water vapor can radiatively cool the MLT region and drive the temperatures down to the water frost point if present in large enough concentrations. The Super Soaker mission released 200 kg of water vapor at 85 km altitude and then used a coordinated suite of ground-based instruments to measure mesospheric clouds, temperature, and wind changes in response to the water vapor release.

Water ice clouds occurring naturally in the polar summer mesopause region, between 80 and 90 km altitudes (the coldest part of the Earth's atmosphere), are called Polar Mesospheric Clouds (PMC) or Noctilucent Clouds (NLC). PMC are very sensitive to changes in their formation environment, and thus have been implicated as possible indicators of long-term climate change in the upper atmosphere, although this link is both controversial and complex. Water vapor is a common exhaust product of liquid fueled launch vehicles and it has been shown that several different space shuttle launches have led to bursts of PMC both in the Arctic and the Antarctic several days after launch. However, the contribution of space traffic exhaust to PMC climatology has not yet been quantified and the role of radiative cooling from water vapor plumes in the upper atmosphere to PMC formation has not been experimentally corroborated. To better understand how concentrated water vapor parcels lead to PMC formation, the Super Soaker mission performed a controlled release of a water payload and used ground-based instruments to isolate the response of the local atmosphere from ambient environmental conditions. The January 2018 launch window was selected to ensure clear mesospheric air before the release and to test the hypothesis that concentrated water vapor parcels can drive mesospheric temperatures down to the water frost point.

The first two Super Soaker rockets, launched 40-minutes apart, used a Trimethyl Aluminum (TMA) tracer to track the winds. The third rocket, launched 30-seconds after the second rocket, released the water payload at 85 km altitude. The response of the atmosphere was observed from a suite of ground-based instruments that included a Rayleigh lidar, an Advanced Mesospheric Temperature Mapper (AMTM), and photographic cameras

Principal Investigator: *Dr. Irfan Azeem/ASTRA* • ***Mission Number(s):*** *41.119, 120 & 122 CE*
Launch site: *Poker Flat Research Range, Alaska* • ***Launch date:*** *January 26, 2018*

for tracking the TMA trails. The evolution of MLT temperatures before, during and after the water release and any formation of ice clouds were studied using a Rayleigh lidar. The AMTM instrument imaged mesopause (~87 km) temperatures above the launch site before, during, and after the water release to provide quantitative information on the prevailing wave activity and changes in temperatures. Due to an earlier than anticipated launch time, with no sunlight reaching the water release altitude, PMC formation was not imaged. The Super Soaker mission provided critical data for validating predictions of a numerical model of PMC formation due to the cooling from water vapor. Together with the numerical model, Super Soaker will provide new insights into the role of concentrated plumes of water vapor in driving MLT energetics and PMC formation.

Super Soaker TMA tracer trail and the Rayleigh lidar beam.

Education Missions 2018

Level 1 RockOn!

RockOn! is the first level student sounding rocket experiment. Teams of students and faculty experience first hand the full scope of a sounding rocket mission, all accomplished during a one week workshop. Participants build, test, and integrate sensors, and program an Arduino based datalogger. Students attend the launch of their experiments before the end of the workshop.

Level 2 RockSat-C

RockSat-C and RockOn! experiments share payload space, but RockSat-C experiments are designed and built by students at their home institutions and brought to Wallops for integration with the payload. Students participate in payload integration and testing activities and view the launch of their payload on Wallops Island.

Level 3 RockSat-X

The most advanced of the student flight opportunities, RockSat-X offers sounding rocket payload support systems, such as power, telemetry, de-spin, attitude control, and deployable skins to expose the experiments to the space environment. Students are responsible for completing the design and construction of their experiment and attend integration, testing and launch activities at Wallops.

University Student Instrument Program (USIP)

NASA seeks to build science, technical, leadership and project skills among undergraduate students by offering them real-world experience in developing and flying science or technology experiments by participating in USIP.

University Student Instrument Program (USIP)

NASA seeks to build science, technical, leadership and project skills among undergraduate students by offering them real-world experience in developing and flying science or technology experiments by participating in USIP. By offering real-world experiences, with the goal of developing students' skills and capabilities in science, technology, engineering and math, NASA invests in a STEM-literate workforce and achieving the nation's exploration goals. NASA GSFC's Wallops Flight Facility, in Wallops Island, Virginia, manages USIP for the agency's Office of Education and Science Mission Directorate.

In 2016 eighty-nine proposals were received in response to a joint solicitation from NASA's Office of Education, working through the National Space Grant College and Fellowship Program, and the agency's Science Mission Directorate (SMD) in Washington. Of the 47 selected projects, 4 flew onboard the USIP sounding rocket in 2018.

Participating universities and their projects were:

Florida Institute of Technology, Melbourne: The experiment tested a new wire insulation repair material in a microgravity, near vacuum environment. The test samples were subjected to a series of tests after retrieval to inspect the material and verify effectiveness in the space environment.

University of Kentucky, Lexington: A small entry spacecraft was deployed during flight to test and demonstrate a communications system, release mechanism and thermal protection system design for application in future research.

Utah State University, Logan: The experiment tested an arc-ignition, green propellant CubeSat thruster system. During the flight test, measurements were gathered in order to assess the potentially harmful effects of plume contamination on spacecraft optical sensors, external electronics and solar panels.

University of Nebraska - Lincoln: Partnering with NASA's Langley Research Center in Hampton, Virginia, the team tested a deployable and retractable boom and solar blanket for space applications, including sounding rockets, CubeSats and small satellites.

The mission was completed successfully. The payload was recovered and the experiments returned to the students.

Principal Investigator: *Mr. Jack Vieria* • ***Mission Number(s):*** *46.019 UO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *March 25, 2018*

RockOn! & RockSat-C

The RockOn! workshop was held at NASA Wallops Flight Facility, June 16 - 21, 2018. Ninety-four students and faculty members participated in this year's workshop, which was the 11th 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. Approximately 95 students participated in the RockSat-C flight opportunity.

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 week, 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.

Cubes in Space is a program for middle school students that allows them the opportunity 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. Seventy-five middle school experiments, with approximately 375 participating students, were flown on the RockOn! mission.

RockOn website: https://spacegrant.colorado.edu/national-programs/rockon-2018-home

RockSat-C website: https://spacegrant.colorado.edu/national-programs/rs-c-home

Principal Investigator: *Mr. Chris Koehler/Colorado Space Grant Consortium* • ***Mission Number(s):*** *41.125 UO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *June 21, 2018*

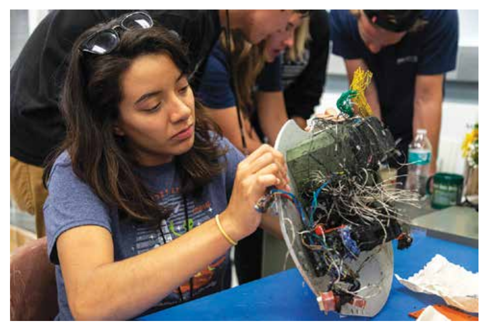
RockSat-X

RockSat-X was successfully launched from Wallops Island, VA on August 14, 2018. 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.

The following experiments were flown on RockSat-X in 2018:

Community Colleges of Colorado

The Orbital Scrap Capture and Reclamation (OSCAR) project is a collaboration between three community colleges in Colorado -- Arapahoe Community College in Littleton, Community College of Aurora, and Red Rocks Community College in Lakewood. The purpose of this experiment was to develop a cost effective method to alter the trajectory of space debris in suborbital flight.



Capitol Technology University

The goal of Project Janus was to demonstrate the use of a laser distancing system to measure the speed of CubeSats within constellation during flight.

Temple University

Temple University's mission was to detect flux and angular distribution of cosmic radiation as a function of altitude.

University of Colorado Boulder

The purpose of the Measuring Emitting Ground stations using Antennas Listening for Oscillating Doppler Outputs from NEXRAD (MEGALODON) experiment was to use passive RF technology to characterize the local NexRad Doppler Radar network.

University of Maryland

This payload included two different experiments from the University of Maryland. The Stratification and Tribocharging Analysis of Regolith (STAR) experiment studied the effects of tribocharging on extra-terrestrial

Principal Investigator: *Mr. Chris Koehler/Colorado Space Grant Consortium* • ***Mission Number(s):*** *46.021 UO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *August 14, 2018*

regolith simulant. The Space Characterization and Assessment of Manipulator Performance (SCAMP) project flew a functional robotic manipulator component in a microgravity environment to test contact stability on both hard and soft contacts.

University of Puerto Rico

The University of Puerto Rico's mission was to collect micrometeorites in the Meteor Trail at altitudes of 49 – 68 miles (80-110 km) in order to gather organic molecules for complete DNA, RNA, and Nucleic Acids.

Virginia Tech

Virginia Tech's mission was to support STEM education and outreach by utilizing the ThinSat platform that allows high school and university students to test their own experiment in a space environment.

West Virginia Collaboration

The Hobart and William Smith Colleges attempted to measure the temperature and vibration of their payload throughout the rocket's flight. Marshall University's experiment used an automated target acquisition system to take pictures of target stars and assess the effectiveness of astronomy.net for target acquisition during flight. West Virginia State University prepared for future CubeSat missions by comparing different equipment designs and testing the feasibility of a Michelson Interferometer. West Virginia University evaluated the capabilities of a jettisoned capsule to project individual experiments in future missions and design an ultra-compact plasma spectrometer with reduced mass, volume, and high voltage requirements and comparing it to identical instruments. West Virginia Wesleyan College's experiment was to compare the effectiveness of a thermionic converter to a solar panel in space and to prove NOAA magnetometer data

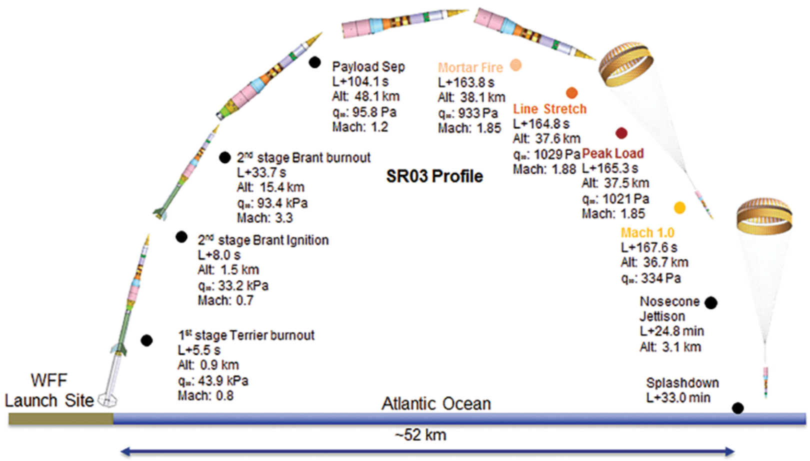
RockSat-X website: https://spacegrant.colorado.edu/rs-x-home/rs-x-2018-home

Three missions were flown for NASA's Jet Propulsion Laboratory (JPL) to support parachute development for Mars 2020.

Test and Support Missions 2018

Advanced Supersonic Parachute Inflation Research and Experiments (ASPIRE)

The Advanced Supersonic Parachute Inflation Research and Experiments (ASPIRE) project investigated the supersonic deployment, inflation, and aerodynamics of Disk-Gap-Band (DGB) parachutes in the wake of a slender body. The parachutes were full-scale versions of the DGBs used by the Mars Science Laboratory in 2012 and planned for NASA's Mars 2020 project and were delivered to targeted deployment conditions representative of flight at Mars by sounding rockets launched from NASA GSFC's Wallops Flight Facility launch range on Wallops Island, VA. The primary objective of these missions was to expose parachute designs to a supersonic inflation environment and acquire sufficient data to characterize the flight environment, loads, performance of the parachute. The flight data from the sounding rocket missions will also aid in the development of models to predict parachute performance on Mars.



Flight profile for ASPIRE SR03.

Three flights, using two-stage Terrier-Black Brant vehicles, were conducted during FY 2018. The parachute inflation loads were increased successively, starting with 35,000 lbf and ending with nearly 70,000 lbf.

Flight 1, 36.326 NR - MSL Build-to-Print Chute at 35,000 lbf launched October 4, 2017 (SR01)

The primary objectives of this test were to conduct a shake-out of the sounding rocket test architecture, to deploy Mars 2020's build-to-print parachute design in a low-density supersonic test environment, and to acquire sufficient test data to characterize the flight environments, loads, and performance of the parachute. SR01 was completed successfully on the first launch attempt. The experiment was delivered to the desired test conditions by the launch vehicle, the build-to-print DGB was deployed

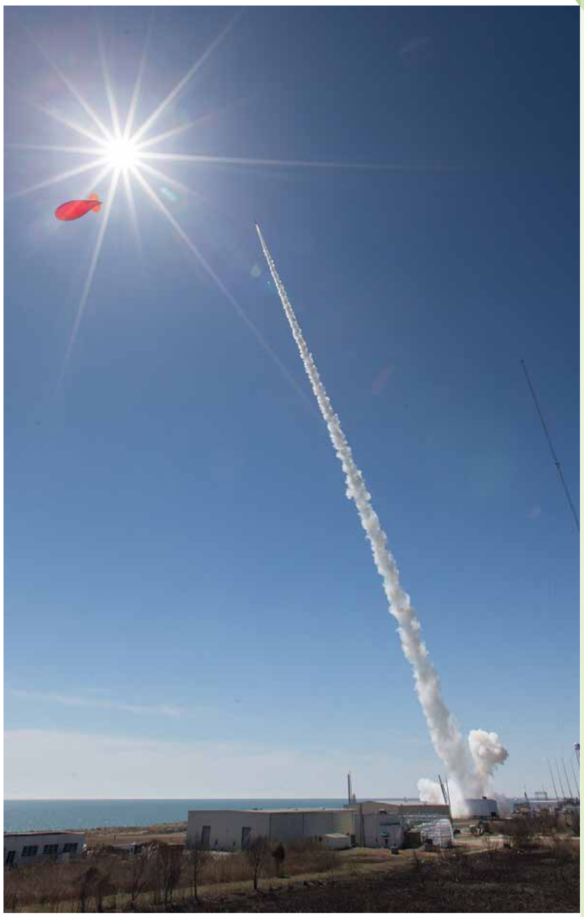
ASPIRE SR01 being prepared for flight at Wallops.

Principal Investigator: *Dr. Ian Clark/NASA JPL* • ***Mission Number(s):*** *36.326, 327 & 328 NR*
Launch site: *Wallops Island, VA* • ***Launch dates:*** *October 4, 2017, Marh 31 & September 7, 2018*

successfully at a Mach number of 1.77 and a dynamic pressure of 452 Pa, the parachute and payload were recovered from the ocean, and the required test data was collected. The parachute produced a peak measured load of 32.4 klbf.

Flight 2, 36.327 NR - Strengthened Chute at 47,000 lbf launched March 31, 2018 (SR02)

The second supersonic test flight, SR02, took place on March 31, 2018. The launch vehicle, test platform, instrumentation, mission operations, and test methodologies were nearly identical to SR01. However, the SR02 test article was a strengthened version of the MSL parachute with the same geometry but different materials and construction. The parachute successfully inflated and produced a peak measured load of 56.0 klbf at about Mach 2.


ASPIRE SR02 launch from Wallops Island.

Flight 3, 36.328 NR Strengthened Chute at 70,000 lbf launched September 7, 2018 (SR03)

The third supersonic test flight, SR03, took place on September 7, 2018. The launch vehicle, test platform, instrumentation, mission operations, and test methodologies were nearly identical to SR01 & SR02. The SR03 test article was similar to the SR02 strengthened parachute, but incorporated a change in materials for the vehicle attachment bridles. The SR03 parachute inflated in 0.410 seconds and survived a peak inflation load of 67.3 klbf at Mach 1.85.

All three flights met their comprehensive success criteria.


ASPIRE SR03 in flight after deployment from sounding rocket.


ASPIRE SR01 parachute landing in the Atlantic ocean off the coast of Wallops Island.

STEM Engagement

The Sounding Rockets Program Office (SRPO) and NASA Sounding Rocket Operations Contract (NSROC) offer opportunities for teachers and students to participate in rocketry related activities.

The Wallops Rocketry Academy for Teachers and Students (WRATS) workshop is offered annually to High School teachers interested in incorporating rocketry activities in their teaching.

NSROC and SRPO staff visit schools to give lectures, arrange rocketry activities and judge science fairs. Additionally, tours are given to groups of all ages of the payload manufacturing and testing areas.

NSROC manages the internship program and recruits about 10 - 15 interns annually from Universities and Colleges. The interns work with technicians and engineers on rocket missions and gain invaluable work experience.

The Wallops Rocketry Academy for Teachers and Students (WRATS) workshop is hosted by the Sounding Rockets Program Office and NSROC with support from the Wallops Education Office. 2018 was the 7th year of the workshop with 20 teachers selected from over 60 applicants. Participating educators teach STEM topics at the High School or Middle School level.

WRATS offers a unique, in-depth, learning experience where teachers get hands-on practice building rockets and payloads, Presentation topics such as aerodynamics, propulsion, recovery system design, and trajectory simulations are covered.

WRATS starts with overviews of the Sounding Rockets Program and model rocketry, followed by construction of an E-powered model rocket. Tours of sounding rocket Testing and Evaluation facilities and a visit with the RockOn! workshop students are also included. By the end of the first day, all teachers have a flyable model rocket.

On the second day, teachers build an electronic payload to measure acceleration, temperature. and pressure during flight. The payload is based on the Arduino microprocessor and inexpensive sensors. Recovery system design and construction are also completed. Once all the construction activities are completed, the models are launched and recovered at Wallops Flight Facility. Flight data is then plotted and analyzed.

The week ends with the launch of the RockOn! mission from Wallops Island and tours of Wallops Flight Facility.

Internships

Over 200 students have participated in the internship program managed for the Sounding Rockets Program Office by NSROC. The program, now in its 18th year, provides internships and co-op opportunities for students studying engineering, computer science, electrical or mechanical technology, as well as business disciplines. Students work side-by-side with experienced engineers and managers to perform significant, valuable tasks, leading to a better understanding of the work in a highly technical environment. Almost 90 percent of undergraduate students who intern or participate in the co-op program return for additional employment. Several participants in the program have gone on to pursue higher education in the engineering and science fields.

In 2018, NSROC provided opportunities for nine internships involving all engineering disciplines.

NSROC Testing and Evaluation Lab intern with an ASPIRE payload on the balancing table.

Outreach

Throughout the year, SRPO and NSROC personnel supported local schools by providing speakers, judging science fairs, and conducting special programs. Additionally, speakers were provided upon request to local civic organizations through the NASA Office of Communications. Tours of sounding rocket facilities were conducted for both school and civic groups throughout the year.

NSROC and SRPO staff supported the NASA Community College Aerospace Scholars (NCAS) with mentors, presentations and facility tours. NCAS is a national STEM focused program where community college students interested in NASA related careers participate in a five-week online learning experience. Top scoring scholars are invited to participate in a 3-day workshop. This year's workshop was held at Wallops and was lead by the Education Office.

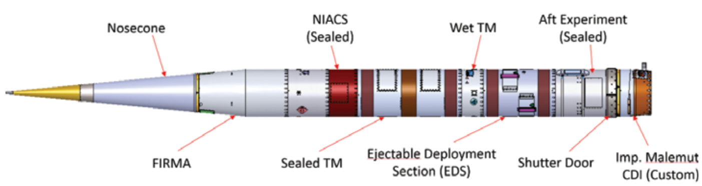
Virginia Space Flight Academy students tour the Machine Shop.

Technology Development

The SRPO and NSROC are actively engaged in upgrading and developing new technologies for the program. New emerging technologies, to be tested in the coming year include Swarm Communications. Additionally, component level improvements are developed continuously and flown on either dedicated missions or on a space available basis on manifested flights.

The NASA Sounding Rocket Program (NSRP) continues to assess new technologies in order to expand the capabilities for our science and technology customers, address obsolescence, and to improve efficiency. The major initiatives of the NSRP technology roadmap continue to focus on (1) providing increased scientific observation time for Solar and Astrophysics missions, (2) increasing the telemetry data rates from the current capability of 10 to 20 Mbps to systems with rates ranging from 40 to ~400 Mbps, and (3) developing free-flying sub-payload technologies. The NSRP leverages resources from NSROC, the NASA Engineering and Technology Directorate (ETD), the WFF Technology Investment Board, Small Business Innovative Research (SBIR), and Internal Research and Development (IRAD) programs to meet our growing technology needs.

In 2018 the NSRP has been busy preparing experiments for the upcoming 46.020 Hesh (Sub-TEC 8) technology demonstration mission that is launching in 2019. The mission will feature 15 experiments from NASA and NSROC designed to test sounding rocket development components and subsystems. The mission objectives include: (1) demonstrate swarm sub-payload to main payload telemetry communication, (2) provide an observation opportunity for two prototype star trackers and low light camera, (3) demonstrate a 40 Mbps telemetry encoder; and (4) provide a test flight opportunity for several sounding rocket development components and subsystems. Planned experiments from NASA ETD include: swarm communication, low cost star tracker, airborne power supply unit (APSU), autonomous rocket tracker (ART), solid state altimeter, and a low cost GPS experiment with patch antennas. Planned experiments from NSROC include: 40 Mbps high data rate encoder, wideband S-band/GPS high temperature combo antenna, new spin motors, SPI low light camera, ST5000 Mk IV star tracker, GNC integrated power system, and the NIACS with Tern INS controlling.



Sub–TEC 8 Payload

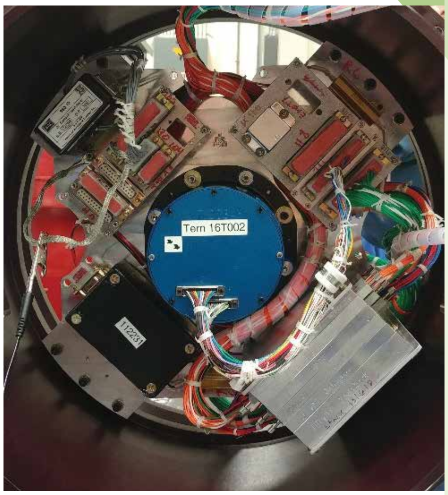
Liquid Nitrogen Plant

NSRP took delivery on a new mini liquid nitrogen (LN2) plant in late 2017 that was deployed in the 2018 Kwajalein campaign to support instruments and detectors that required LN2 for cooling prior to launch. The system was developed for use on remote campaigns where supply chain logistics makes delivery of LN2 difficult, expensive, or impractical. The LN2 plant can produce 50 liters of LN2 per day and can store up to 540 liters. The LN2 plant is fully automated and can self-govern production, shutting on/off as appropriate. The LN2 plant is fully integrated into a sea container for shipment and adheres to NASA cryogenic requirements.

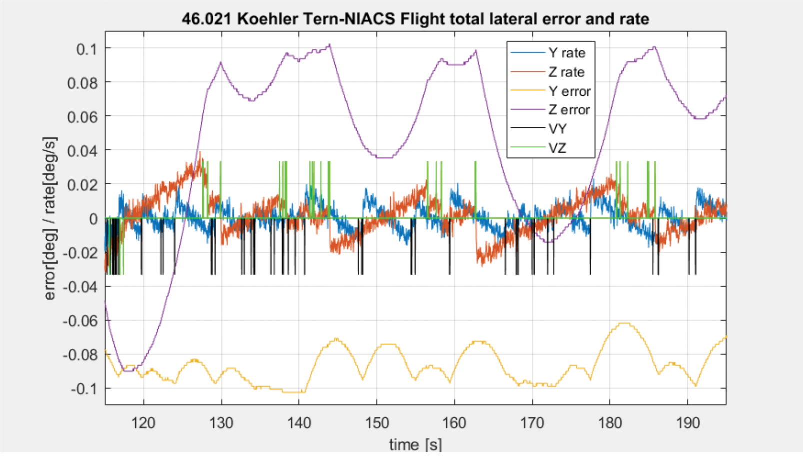
The LN2 plant will be deployed to Svalbard, Norway in Fall 2018 to support the Grand Challenge campaign and then deployed again to Australia in 2020.

Tern based NSROC Inertial Attitude Control System (NIACS):

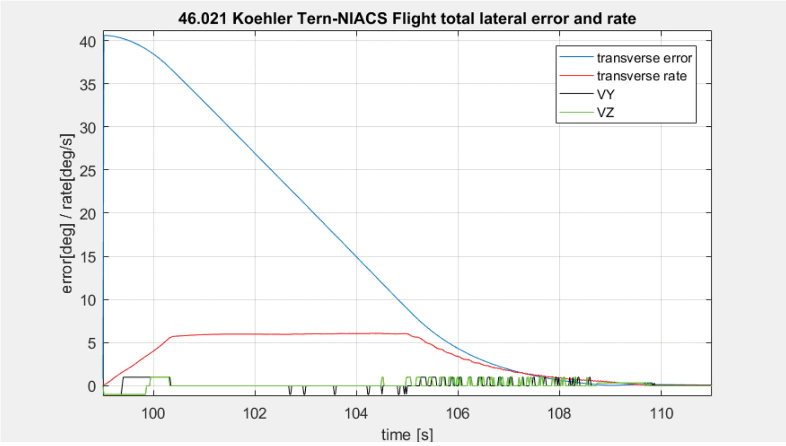
The Tern based NIACS was flown for the first time on 46.021 Koehler (RockSAT-X) in August 2018 and successfully met all mission requirements. The ACS aligned to two different inertial targets during the flight, one while spinning at 0.5Hz roll rate and the second as a three-axis stabilized target. Initial analysis of stability while on target shows equal or better performance than the previous GLNMAC based NIACS.



Tern INS installed in 46.021 Koehler NIACS.



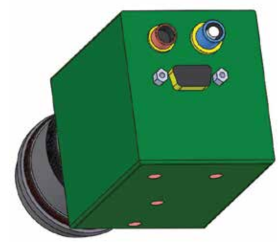
46.021 Koehler Tern based NIACS flight results

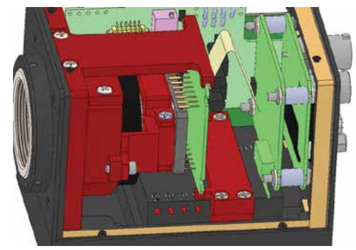


46.021 Koehler Tern based NIACS flight results

Low Light Camera (Xybion Replacement)

NSROC has selected the Stanford Photonics Inc (SPI) XR/M-WFF camera, an intensified CCD camera that is meant to replace the aging Xybion camera. The camera is used for image feedback of where the telescope is pointed, to make real-time pointing corrections in flight. The camera has a field of view of 61° (V) x 73° (H) with dimensions of 3.7"L x 2.3"W x 2.5"H and weighs less than 1.7 pounds. NSROC has received a qualification unit that will be qualified for flight in late 2018 and flown on the upcoming SubTEC 8 mission in 2019.





Stanford Photonics Inc (SPI) XR/M–WFF camera

High Data Rate Telemetry Encoder

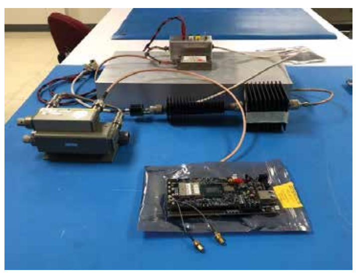
NSROC has selected Curtiss-Wright's Axon system for the high data rate telemetry encoder. Curtiss Wright currently offers a wide variety of data modules including but not limited to, analog and asynchronous with output accommodations for PCM and Ethernet with a roadmap to add additional capabilities every quarter for the foreseeable future. Curtiss Wright also offers options for development of custom modules at a rate of 1 deck per year for required sounding rocket specific data types. The Axon encoder also allows the use of satellite stacks that can be scattered throughout the payload. NSROC has received a prototype unit that will be configured and flown on the upcoming SubTEC 8 mission in 2019 with a dedicated 40 Mbps telemetry downlink.

Axon encoder

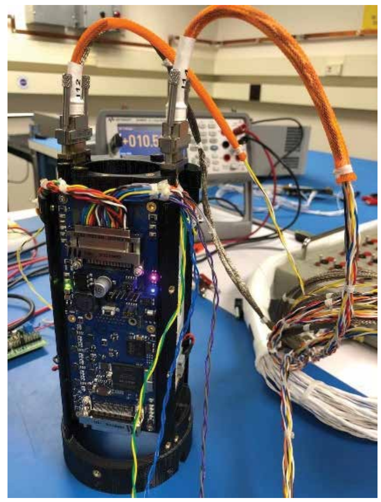
Swarm Communication

Swarm Communication is a NSRP development effort using matrixed NASA ETD engineers to design a system that telemeters data from multiple deploying sub-payloads to the main payload. The ETD design effort encompasses a sub-payload transmitting antenna, a sub-payload command and control board with embedded encoder, a main payload receive software defined radio, and a main payload receive antenna system with filter and low noise amplifier. The Swarm Communication experiment is currently undergoing bench tests in the lab and will fly for the first time in 2019 on the SubTEC 8 mission. The Sub-TEC 8 payload will deploy four sub-payloads – two via high velocity springs and two via COTS rocket motors. The data from the sub-payloads will be telemetered to the main payload via S-band frequencies at speeds of up to 1 Mbps and separation distances up to 20 km.


Swarm Ground Support Equipment (GSE)



Main payload receiver bench testing



Sub–payload control card bench testing

New opportunities to conduct science missions in the Southern Hemisphere are being developed by SRPO. In 2020 sounding rockets will return to Australia with four Astrophysics payloads.

FY 2019 will see several flights from launch sites in Norway. The missions involve US, Norwegian, and Japanese scientists and an international student mission. Additionally, a geospace science campaign is on schedule from Kwajalein, Marshall Islands in 2019.

On the Horizon

New and repeat opportunities to conduct science missions in remote locations abound within the SRPO in 2019 and beyond. A new Australian launch range continues to be pursued with a refined programmatic target date in May 2020. The program also plans to return to the middle of the Pacific Ocean to conduct an equatorial study at the Reagan Test Site (RTS) in the Kwajalein Atoll, Marshall Islands in June 2019. Though still early in formulation, the SRPO is looking to return to Punta Lobos, Peru to enable unique opportunities for studying the ionosphere near the magnetic equator.

Grand Challenge

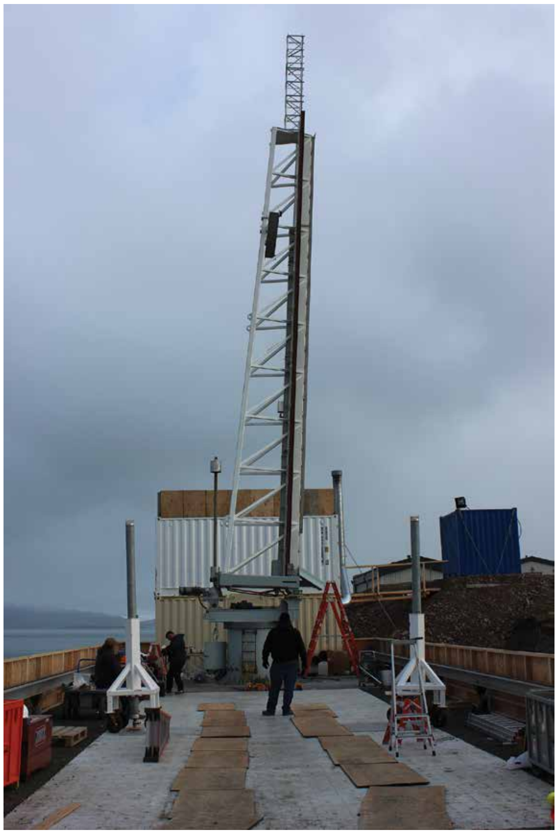
As reported in 2017, the SRPO continues to spend a large amount of time “on the road”. The two new Operations Managers and one additional Projects Manager have been fully subscribed in their duties. Many of the planned campaigns are now fully into the execution phases. In this year’s On the Horizon, we provide updates on these mobile operations and outline future opportunities for unique science missions!

A large percentage of the rocketeer workforce will be showcasing their dedication and enthusiasm for the sounding rocket program as they spend Thanksgiving and New Year’s (with a break in the middle for Christmas) in Norway. Teams will be on duty at both Andøya Space Center (ASC) and in Ny-Ålesund, to support eight sounding rockets, scheduled to launch from the two launch ranges, between December 2018 and March 2019. The Sounding Rocketeers act to keep morale high when spending holidays away from our homes and families. The below images show a previous Thanksgiving celebration at ASC with our Norwegian teammates. Similar events are planned for our teammates at both Ny-Ålesund and ASC.

The multiyear campaign at ASC and Ny-Ålesund has been coined the Grand Challenge – CUSP Initiative. This campaign is the largest deployment in recent SRPO history. The campaign kicks off with four missions: two Black Brant X’s launching south from Ny-Ålesund and two Black Brant XIIA’s launching north from ASC. These four missions are investigating similar auroral phenomenon in the Earth’s Cusp and have a shared launch window opening in December 2018. After conducting these four missions, the SRP teams will return home for the Christmas period and return to Andenes for two additional missions: a third Black Brant XIIA and an international student mission launching on a Terrier-Improved Malemute. Additional information about the Grand Challenge Initiative can be found here: http://www.grandchallenge.no/

The SRPO will use some recently acquired mobile assets in order to conduct the Grand Challenge campaign. First, coming shortly off the heels of a very successful first use at RTS (Marshall Islands) in April 2018 in support of two celestial telescopes, a mobile liquid nitrogen plant will be used in Ny-Ålesund. The mobile liquid nitrogen production plant is critical in providing the cooling needed to experiment detectors making sure they achieve the ideal temperature for science collection during the launch operation. Being able to produce LN2 locally is particularly important at remote sites, such as Kwajalein, Marshall Islands and Ny-Ålesund, where it is logistically difficult to arrange for timely delivery of liquid nitrogen.

The launches from Ny-Ålesund will also be the first to use the NSROC manufactured Medium Mobile Launcher (MML). This launcher has been specifically designed for ease of shipment and assembly. The MML is the first NASA launcher installed in Ny-Ålesund Two launchers are required to conduct the science mission from Ny-Ålesund due to the salvo launch concept i.e. the two missions will be launched near simultaneously. The two payloads will achieve different apogees in order to provide an understanding of the auroral phenomenon as it takes place over varying altitude regimes.




MML elevated in Ny-Ålesund.

Kwajalein

In Spring 2019, the SRPO will return to Reagan Test Site (RTS) at Kwajalein Atoll, Marshall Islands. The program will execute a repeat attempt of Dr. Hysell's campaign in 2017, which resulted in a failure to collect scientific data due to a vehicle anomaly. The campaign comprises two Black Brant IX vehicles. One of the vehicles will carry a chemical release experiment to measure thermospheric winds, while the second carries a suite of scientific instrumentation for in-situ measurements of the development an onset of the Spread-F phenomena.

The two payloads will launch five minutes apart to optimize science collection. A team will deploy to conduct site preparations and to setup a second launcher to augment the permanent RTS owned launcher. The launch widow for the two missions is set to open in June 2019.

Australia

The SRPO has been working for a number of years to solidify plans that would enable the astrophysics science community to have access to a launch range in the southern hemisphere that also offers up some of the capabilities of our routine launch range in White Sands, New Mexico – primarily telescope recovery. Early this year a campaign kickoff meeting was hosted at Wallops Flight Facility for all campaign and mission stakeholders. The campaign will consist of four telescope missions which are progressing through the design phase. In parallel, the program is preparing to evaluate and select from two commercial launch ranges, where the campaign will be executed. This will be NASA's first ever use of a foreign commercial launch range which, while exciting for program also introduces unique challenges. The SRPO is working closely with the NASA Office of International and Interagency Relations (OIIR) to resolve these challenges in order to bring this new approach to fruition. Similar to the Norway GCI campaign, SRPO will be taking advantage of newly obtained systems including the Liquid Nitrogen Plant as well as two MML's (a second MML build is in the works). Two launchers will be utilized for the campaign in order to minimize the teams time in the field. The launch window for the 4 missions is set to open in May 2020 and planned to span a 2 week period.

Visit to potential launch site in Australia in 2016.

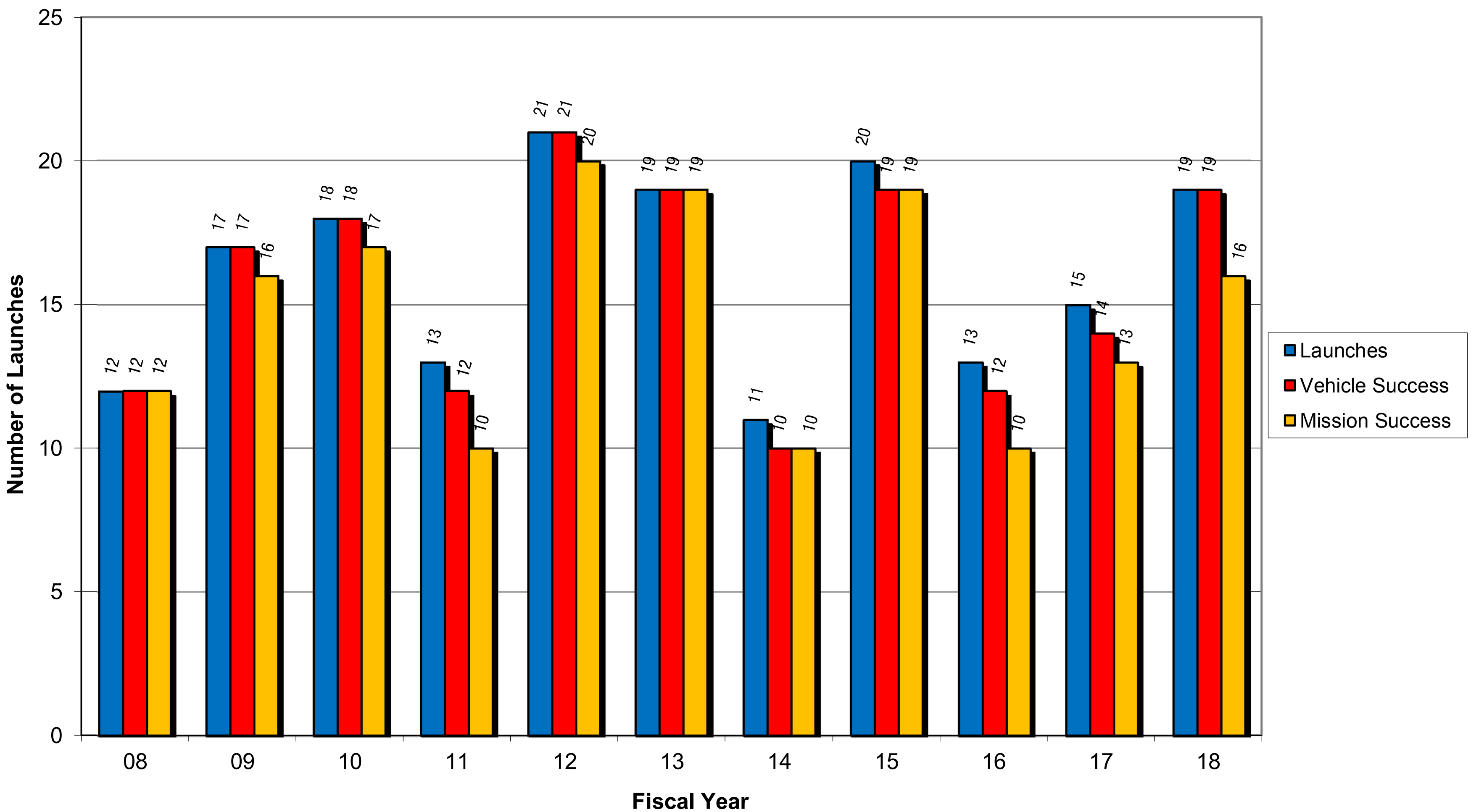
Peru

In recent years, there has been an initiative from within the geoscience community for the SRPO to identify and pursue a launch range strategically located on the Earth's magnetic equator. As a result the SRPO has opened conversations with CONIDA, the Peruvian Space Agency. A launch range does exist in Punta Lobos, Peru that is ideally located geographically and offers up a unique opportunity for partnership with a world-renowned radar asset – the Jicamarca Radio Observatory. Many hurdles are yet to be overcome and much preparation is required to augment the range infrastructure. The SRPO, however, has an optimistic outlook on conducting a campaign from Punta Lobos, Peru to unlock the opportunity for unique science collection from this ideal location in the years to come.

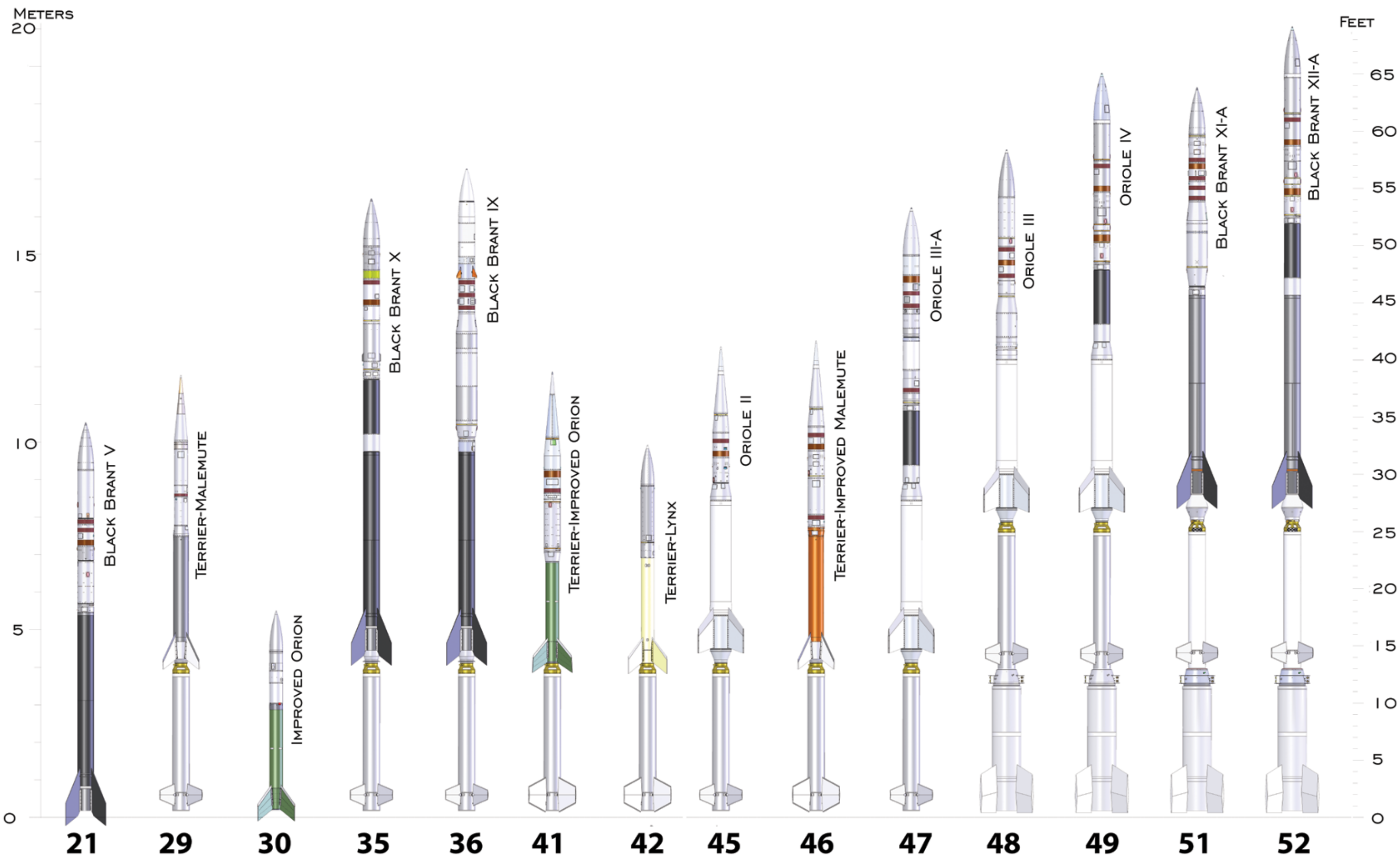
Aurora over Andoya Space Center in 2015.

Mission Success History

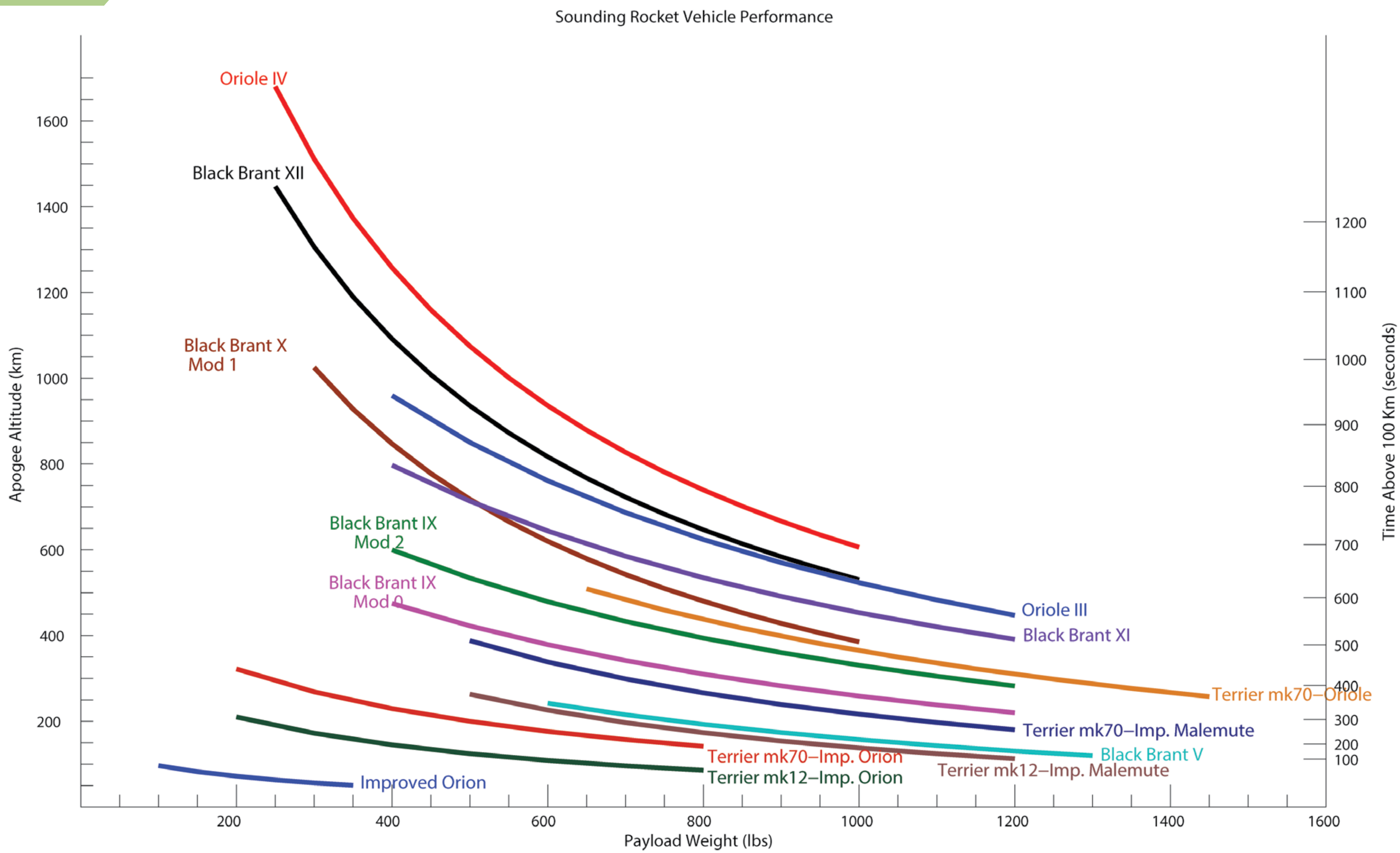
Sounding Rocket Launches
FY 2008 - 2018
Total number of launches: 178



Sounding Rocket Vehicles



Sounding Rocket Vehicle Performance



Sounding Rocket Launch Sites

Poker Flat, Alaska

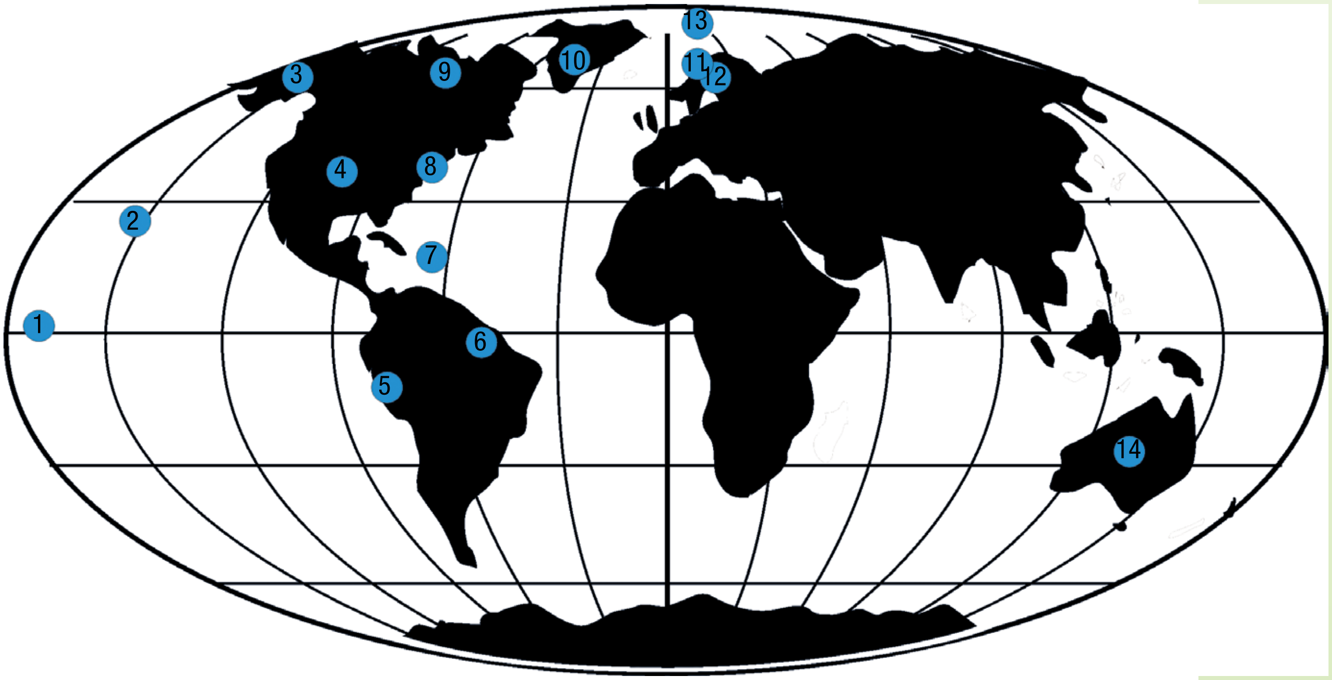
Esrange, Sweden

Kwajalein, Marshall Is.

Andøya, Norway

Woomera, 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. Woomera, Australia

* Inactive launch sites

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Safety & Mission Assurance Manager

Elizabeth West
SRPO Projects Manager

Joshua Yacobucci
Mechanical Engineering

Image Credits

1	ASPIRE launch: Berit Bland
10	EVE data plot: Dr. Woods/Univ of Colorado
11	Team photos: Courtesy of Dr. Woods/Univ of Colorado
12	Payload photos: Dr. Lindsay Glesener/Univ of Minnesota
13	Team photo: White Sands Imaging Group
13	Recovery photo: White Sands Imaging Group
15	Background image: Soft X-ray sky from ROSAT.
16	DEUCE integration: White Sands payload team
16	Team photo: White Sands Imaging Group
17	Rocket Launch image: Allison Stancil/Wallops Imaging Lab.
19	WRXR team and payload in Kwaj image: Wallops Imaging Lab
20	Rocket on Launch: Wallops Imaging Lab
22	Team Photo: White Sands Missile Range
25	Poker Flat Background Image - Wallops Imaging Lab
26	Launch image composite: Zany Roohi/Univ of Alaska
27	Vapor trail image: John Elliot/Univ of Alaska
35	ASPIRE launch: Berit Bland
36	Trajectory graphic: JPL
37	Launch image: Wallops Imaging Lab
37	ASPIRE in flight: Dr. Clark/JPL
37	Recovery image: Recovery team
42	Solidworks concept drawing - Josh Yaccobucci
45	Photos provided by Cathy Hesh/NASA SRPO
46	Photos provided by Cathy Hesh/NASA SRPO
50	Thanksgiving images - Wallops Imaging Lab
51	MML images - Henry Burth/NSROC
52	Australia site visit: Jay Scott/NSROC
53	Aurora over Andoya: Terry Zaperach/Wallops Imaging Lab
55	Vehicle stable grahic: NSROC Mechanical Engineering
56	Performance graph: NSROC Flight Performance
59	John Brinton/Berit Bland
61	Launch photo: White Sands Imaging Group
63	Kwaj team photo: Wallops Imaging Lab.

Wallops testing and integration images and report design by Berit Bland/BBCO - NSROC/SRPO support contractor.

Science mission information submitted by Principal Investigators.

FOXSI Launches from White Sands Missile Range, NM.

USIP integration.

ASPIRE integration.

ASPIRE sequence testing.

NFORSe testing for DXL.

Super Soaker integration.

Kwajalein rocket teams.

USIP payload team and students.

ASPIRE sequence testing.

Super Soaker vibration testing.

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