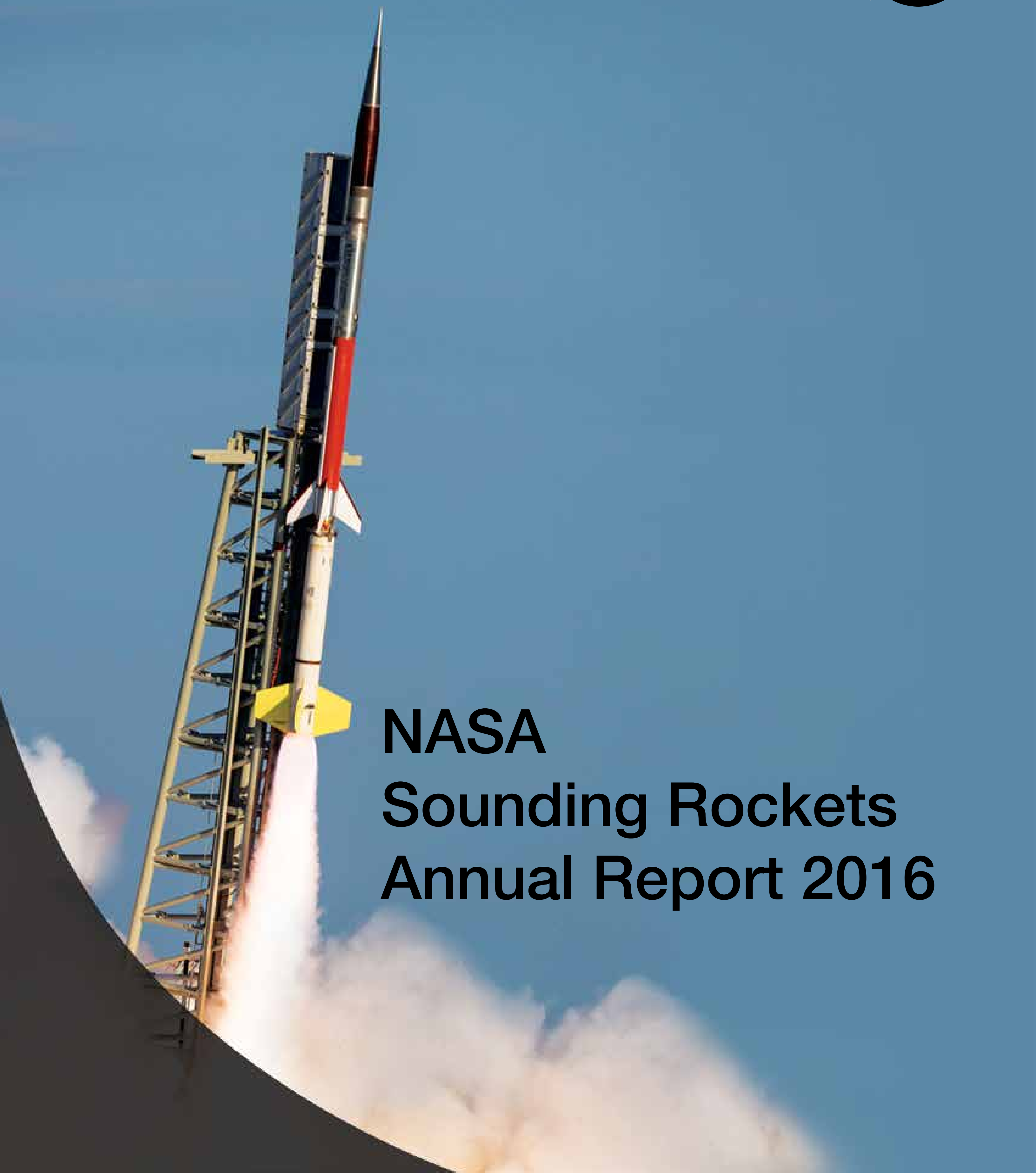
National Aeronautics and Space Administration



NASA Sounding Rockets Annual Report 2016

Message from the Chief

Phil Eberspeaker
Chief, Sounding Rockets Program Office

Another year has passed, and the NASA Sounding Rockets Program has once again completed a wide variety of impressive scientific, educational, and technology demonstration missions. We launched eight missions from sites in Norway, New Mexico and Virginia that carried science payloads to study the Earth's near space environment, deep space objects, and our own local star, the sun. We also supported two student flight missions and three technology test flights to flight qualify new components and support systems offered to our customers. These new components and systems will enhance scientific return on future missions.

The missions we supported continue our long tradition of training the next generation of engineers and scientists. The instruments that were flown on our missions collected important scientific data that will help us better understand the Earth, the solar system, and the universe we live in. Our missions helped develop new detectors and instruments that will be applied to larger more sophisticated NASA missions. As an example, the Johns Hopkins Far-Ultraviolet Off-Rowland Telescope for Imaging and Spectroscopy (FORTIS) payload, which has also flown in previous years, validated the performance of a Micro Shutter Array (MSA) to be used on the massive James Webb Telescope, and the NextGenFORTIS instrument is currently under development and will test an even more advanced MSA with electronic shutters and other new technologies for future telescopes. Sounding rockets are the ultimate platforms for these types of continuous improvement projects, leading to overall efficiencies in the Nation's space program.

The Sounding Rockets Program also made world-class science discoveries over the past year. Our geospace missions continued to collect data to better understand the Sun-Earth interaction and space weather. The University of Miami Diffuse X-ray emission from the Local Galaxy (DXL) mission collected critical data that has helped scientists solve the questions of the origins on X-rays emanating in the Local Hot Bubble (LHB) that was generated by multiple, ancient supernova explosions that occurred in our region of space.

The program once again push the boundaries of technology, not only for the program itself, but also for NASA as a whole. For example, we flew several technology demonstration experiments for NASA's Space Technology Mission Directorate (STMD) Flight Opportunities Program (FOP). This included the RadPC, a computer system that uses a novel architecture and off-the-shelf parts to increase flight computer reliability in the presence of high-energy radiation at a fraction of the cost of existing rad-hard computer systems. Another technology involved the VIP, a vibration isolation platform which will be used to reduce spacecraft disturbances during microgravity. We engaged in numerous other technology development efforts to enhance data transmission rates, more precisely deploy sub-payloads, enable long range water recovery, and enable higher altitude flights.

The program also continued its long tradition of training undergraduate and graduate students on our core science missions. Sounding rockets continue to be excellent platforms upon which graduate students can earn their PhD's by participating as critical members of the PI's science teams. Sounding rockets continue to serve as the perfect tool for teaching STEM education to undergraduates and other students. We once again flew two university level RockOn and RockSat-X missions which hosted over 100 student experimenters. We also continued our tradition of K-12 STEM education by offering multifaceted hands-on teacher workshops, lectures, school visits, and tours of our facilities. As I look back on our accomplishments over the past year I am once again impressed by the creativeness, dedication, and quality of our personnel. This not only includes technical staff, but also the business and administrative staff that make the program run so well and efficiently.

I am once again proud to lead this organization in providing NASA and the nation with low-cost, flexible access to space and I look forward to many more years of the Sounding Rockets Program serving the nation.

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TECHNOLOGY

Vacuum Doors

Side-opening vacuum doors have been developed and tested to accommodate very large detectors requiring vacuum sealing for cleanliness.

Clam Shell Skin

Load bearing clamshell skin have been developed and flown. The new design is intended as a replacement for both long skirts and large deployable doors. By replacing a conventional skirt, the clamshell skin removes the chance of the skin touching the structure as it deploys. When used to replace a large blow-off door, the clamshell provides the structural support of a skin while allowing the same working volume as a blow-off door system.

Sub-Payload Development for Swarms

New sub-payload systems have been developed for distributed measurements in space. To enable data collection over a larger area (volume) small rocket propelled sub-payloads are deployed to distances as far as 20 km from the main payload.

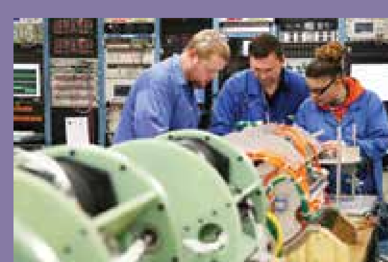
Water Recovery

Telescope instruments are frequently reused after flight and to facilitate launches over water a new vacuum shutter door has been developed and tested. The new door will protect the instrument from saltwater after impact.

Mobile Launcher

The Medium Mobile Launcher (MML) is the first launcher to be developed in-house by NSROC and is designed to launch vehicles as large as a Black Brant X (Terrier-Black Brant-Nihka) with a 1,000 pound payload.

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




Thirteen missions from three different launch sites, covering seven disciplines, were conducted in Fiscal Year 2016.

Manufacturing

Automated Inspection

Automated inspection of electrical components verifies assembly of circuits prior to utilization in payloads.

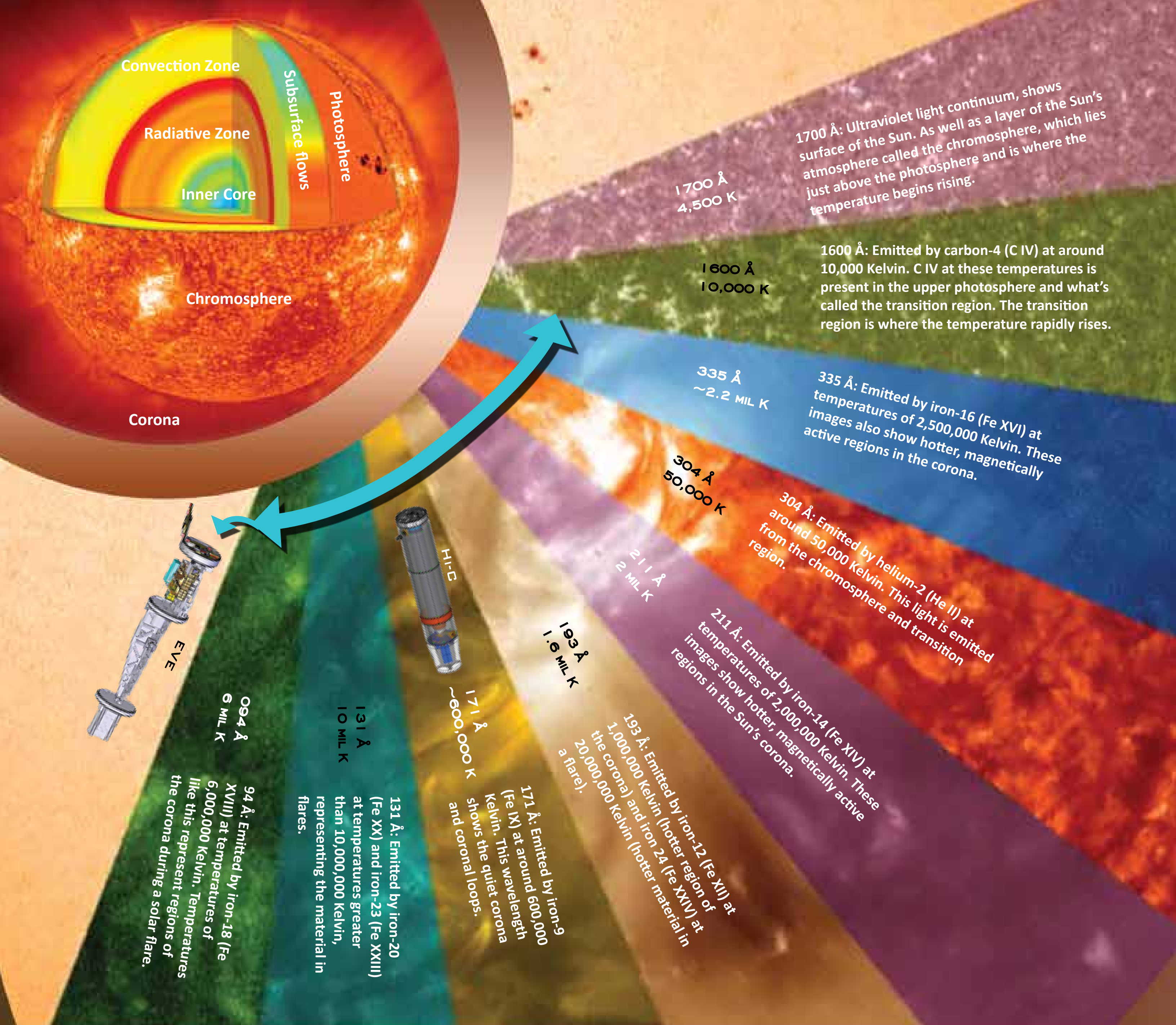
Manufacturing Cells

The custom manufacturing required for sounding rockets is enabled by state of the art machines and tooling. Efficiencies and throughput have been increased through the creation of manufacturing cells. This allows one machinist to operated several Computer Neumatic Control (CNC) machines simultaneously.

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 2016 approximately twenty payloads were integrated and tested for flight.



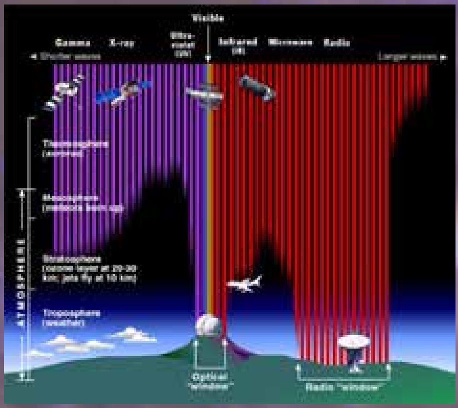


Solar Physics Missions 2016

The 2016 Solar Physics Sounding Rocket missions focused on studying the sun in the Extreme Ultraviolet (EUV) part of the spectrum. The two missions included EUV Variability Experiment (EVE) and High Resolution Coronal Imager (HI-C). Extreme Ultraviolet radiation is created by very energetic processes occurring in several layers of the Sun. The Hi-C mission focused on the corona and the EVE mission was an underflight calibration of NASA's Solar Dynamics Observatory (SDO) spacecraft.

Credit: Multispectral background image NASA/SDO/
GSFC Visualization Studio

Electromagnetic Radiation

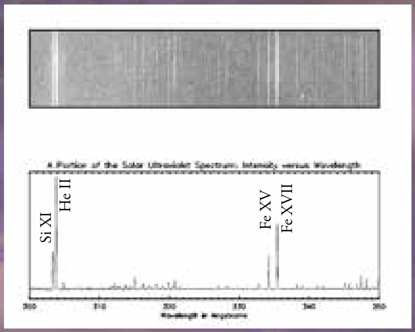


Most of the radiation emitted by the Sun is blocked by the Earth's atmosphere. In order to study the Sun at these wavelengths, instruments have to be placed in space. Spacecraft such as the Solar Dynamics Observatory (SDO) include multispectral instruments and have mission durations of several years. Sounding rockets are used for both fundamental science exploration and development of future technologies for spacecraft. With short mission lead times and lower cost, sounding rockets enable world class science discovery.

Instruments for Solar Physics

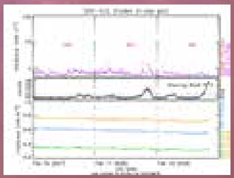
Spectrographs are commonly used instruments for solar physics. A spectrograph measures radiation intensity as a function of wavelength. All elements in the periodic table have associated characteristic spectra. When energy is added to an element, i.e., when electrons in an atom are excited and then transition 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, to ionize iron, which in its neutral state has 26 electrons (Fe I), temperatures around one million Kelvin are required. When the iron atoms encounter these temperatures eight or nine of the electrons are freed and ions of Fe IX and Fe X are created and EUV radiation at a wavelength of 171 Å is emitted.



Credit: Dr. Jeffrey Brosius/NASA GSFC

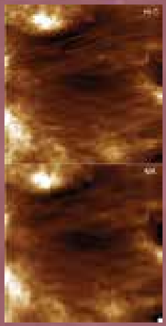
Part of a solar ultraviolet emission line spectrum was obtained with NASA's Solar Extreme-ultraviolet Research Telescope and Spectrograph (SERTS) sounding rocket experiment. Wavelength increases from 300 Å on the far left to 350 Å on the far right. The graph in the bottom frame is a different way to show how bright the lines are at each different wavelength. Intensity, how bright the line is, in the y-axis, and wavelength is in the x-axis. The most prominent lines are labelled with their respective elements.



This plot of SDO EVE data shows time series of 5 strong EUV emission lines. Also shown is a Dark value, which is a detector that is blocked from seeing the Sun, which shows energetic particles from the Sun that can penetrate the EVE instrument and cause false counts. This Dark diode will increase during solar storms

Extreme ultraviolet Variability Experiment (EVE)

The EVE sounding rocket instrument is used for calibrating a similar instrument onboard the SDO spacecraft. The EVE sounding rocket is launched annually to enable correction of the satellite data. The SDO mission provides measurements and models of solar magnetic fields, active region dynamics, and the solar extreme ultraviolet (EUV) radiation that can dramatically disturb Earth's space weather environment. EVE measures the solar EUV irradiance, the power per unit area (mW/m2), produced by the Sun in the form of electromagnetic radiation. Physics based models are used to advance the understanding of irradiance variations based on the activity of the solar magnetic features. EVE measures spectral irradiance at wavelengths of 0.1 - 1216 Å.



Top – HI–C image from the 2012 sounding rocket flight. Bottom – the same region imaged with SDO Atmospheric Imaging Assembly.

High Resolution Coronal Imager (Hi-C)

The main objective of the Hi-C investigation was to determine the geometric configuration and topology of the structures making up the inner corona. The mission was designed to study the mechanisms for growth, diffusion, and reconnection of magnetic fields, and the coupling of small-scale dynamic and eruptive processes to large-scale dynamics. Hi-C observations were coordinated with several NASA spacecraft. The scientific objectives of Hi-C are central to the goal of understanding the Sun's activity and its effects on the terrestrial environment, by providing unique and unprecedented views of the dynamic activity in the solar atmosphere. Hi-C studied the sun at the 171 Å wavelength.

NASA successfully launched a Black Brant IX sounding rocket at 1 p.m. MDT on June 1, 2016 from the White Sands Missile Range, NM, carrying instrumentation to support the calibration of the extreme ultraviolet (EUV) solar instruments aboard the Solar Dynamics Observatory, or SDO, satellite. The rocket payload from the University of Colorado (CU) and University of Southern California (USC) includes the EUV Variability Experiment (EVE) that measures the energetic EUV emissions from the sun. These observations by the rocket EVE and flight SDO EVE are full-disk spectra, or irradiance, over the EUV range from 0.1 nm to 122 nm. Because of the on-going degradation of the SDO EVE and Atmospheric Imaging Assembly (AIA) instruments since the SDO launch in February 2010, these rocket EVE solar measurements are important for providing an accurate calibration for the SDO satellite instruments. This was the fifth under-flight calibration for the SDO instruments, and it was highly anticipated because the previous flight in May 21, 2015 (NASA 36.300) was not successful due to a boost guidance system gyro anomaly and the last successful flight was almost three years ago on October 21, 2013 (NASA 36.290). With this successful flight this June, the next under-flight calibration for the EVE instrument is planned for June 2018 with the intention of an under-flight rocket calibration every two years during the SDO mission.

Figure 1. The NASA 36.318 rocket for calibrating the Solar Dynamics Observatory solar extreme ultraviolet instruments had a very successful flight on June 1, 2016 from the White Sands Missile Range.

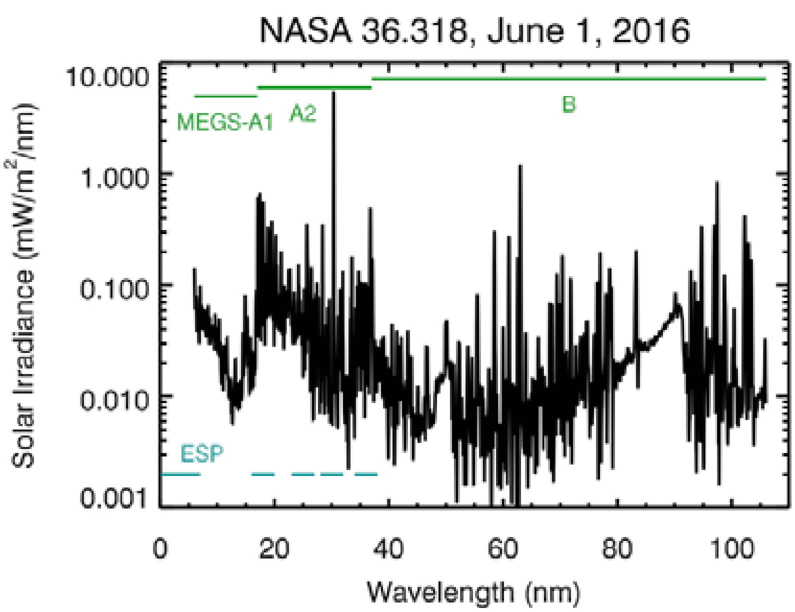


Figure 2. The solar extreme ultraviolet spectrum from the NASA 36.318 flight is provided from several different channels of the rocket EVE instrument: Multiple EUV Grating Spectrograph (MEGS) channels A1, A2, and B with 0.1 nm spectral resolution and the EUV SpectroPhotometer (ESP) five broadband channels. The solar EUV spectrum is rich with hundreds of emission lines from the chromosphere, transition region, and corona layers of the solar atmosphere.

Principal Investigator: *Dr. Thomas Woods/University of Colorado* • ***Mission Number(s):*** *36.318 UE*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *June 1, 2016*

The mission principal investigator Tom Woods, from the University of Colorado at Boulder, reports that these under-flight data are excellent and are one of the highest quality measurements due to lower noise from the cooled CCD sensors than previous flights. The solar EUV irradiance spectrum from this flight is shown in Figure 2. In addition to updating the calibration for the SDO satellite instruments, this rocket measurement is also valuable for the broader solar international community because this rocket measurement will validate solar EUV observations from NASA Solar Terrestrial Relations Observatory (STEREO), NASA Solar Radiation and Climate Experiment (SORCE), NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED), NASA/ESA Solar and Heliospheric Observatory (SOHO), NASA/JAXA Hinode, NOAA Geostationary Operational Environmental Satellites (GOES), and ESA Proba2 missions.

The web links for SDO EVE and LASP rocket programs are:

http://lasp.colorado.edu/home/eve/

http://lasp.colorado.edu/home/missions-projects/lasp-rockets/current-launch-status/

The High-resolution Coronal Imager (Hi-C) mission flew for the second time in 2016. Hi-C is designed to capture the highest-resolution images of the sun's million-degree atmosphere, called the corona, in the extreme ultraviolet wavelength. This higher energy wavelength of light is optimal for viewing the hot solar corona.

Patrick Champey (University of Alabama – Huntsville graduate student), Richard Gates and William Podgorski (Smithsonian Astrophysical Observatory) complete an alignment procedure on the Hi–C instrument in a clean room at the National Space Science Technology Center in Huntsville, Alabama, prior to shipping to White Sands Missile Range in New Mexico for its July 19, 2016, launch.

The science goal of the second flight was to identify the connection between the solar chromosphere, transition region, and corona in the hottest and most active regions of the corona. To meet this science goal, the high resolution coronal images from Hi-C would be combined with data from the Interface Region Imaging Spectrograph (IRIS), the Solar Dynamics Observatory Atmospheric Imaging Array (AIA) and Helioseismic Magnetic Imager (HMI) and the instruments on the Hinode spacecraft. Additionally, the mission was designed to study the mechanisms for growth, diffusion, and reconnection of magnetic fields of the corona, and to help understand the coupling of small-scale dynamic and eruptive processes to large scale dynamics.

Hi-C was a pathfinder mission designed to place significant new limits on theories of coronal heating and dynamics by measuring the structures at size scales relevant to reconnection physics. The Hi-C instrument used normal-incidence EUV multilayer technology, as developed in the Normal Incidence X-ray Telescope (NIXT) and Transition Region And Coronal Explorer (TRACE) programs. A dual-channel long focal-length telescope and large format back-illuminated CCD camera provided spectroscopic imaging of the corona at 0.3 arcsec resolution.

Due to a failed electrical connection, the instrument shutter did not open in flight and science data was not collected.

Principal Investigator: *Dr. Jonathan Cirtain/NASA Marshall Space Flight Center* • ***Mission Number(s):*** *36.314 NS*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *July 27, 2016*

Setting up to align the Solar Pointing Attitude Rocket Control System (SPARCS).

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.

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 get 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.

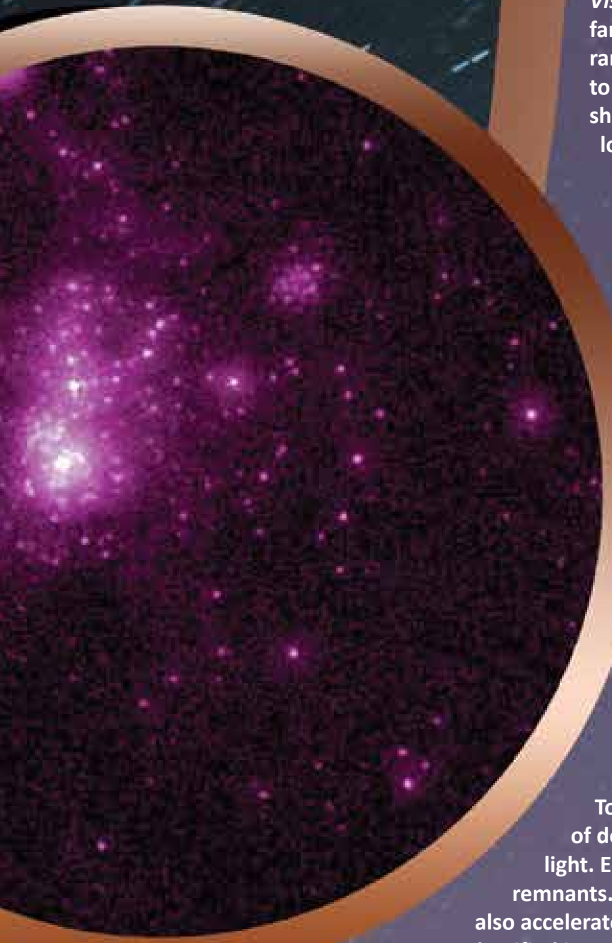
Astrophysics Missions 2016

The Far-Ultraviolet Off-Rowland Telescope for Imaging and Spectroscopy (FORTIS)

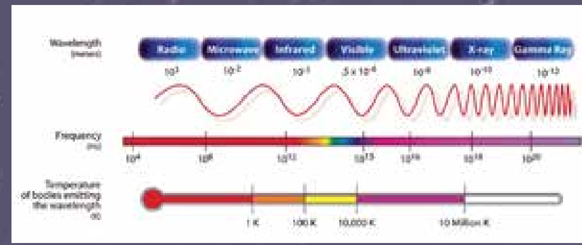
FORTIS is an innovative, multi-object, far-Ultraviolet (UV) spectro/telescope that splits the light from the target galaxy into its composite wavelengths. How much of each wavelength is present holds clues to the atoms present in the space through which the light is traveling. Scientists studied the wavelengths of energy emitted and absorbed by different types of hydrogen to quantify how much material is flowing in and out of the target galaxy NGC 1365, the Great Barred Spiral Galaxy.

Planet Imaging Concept Testbed Using a Rocket Experiment (PICTURE)

The goal of this mission was to obtain a direct image of a planetary environment around another star, Epsilon Eridani (ε Eri). ε Eri contains at least one planet and a substantial dust disk, discovered around the star in 1998. The primary goal of PICTURE was to directly image this inner 3 AU dust belt in reflected visible light. This would provide a measurement of the dusty background to help guide future attempts to image the planet.



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.



ELECTROMAGNETIC RADIATION

Continuos spectra are created by hot opaque objects.

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

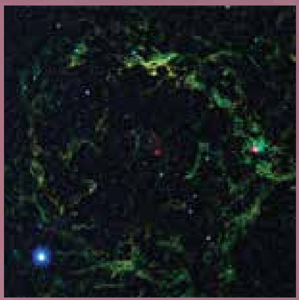
Hydrogen absorption spectra in visible wavelengths.

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

Hydrogen emission spectra in visible wavelengths.

High energy and high temperature processes in the Universe radiate in the *Ultraviolet* 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. Strong magnetic fields, like those created in the wake of a supernova explosion, can also accelerate fast moving ions in spirals around the field lines to the point of X-ray emission. 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. Soft X-rays have relatively short wavelengths — about 10 nanometers (nm), to about 100 picometers (pm). Hard X-rays have wavelengths of about 100 pm to about 1 pm and are very close to gamma-rays. The only difference between them is their source: X-rays are produced by accelerating electrons, while gamma-rays are produced by atomic nuclei.



Colorado High-resolution Echelle Stellar Spectrograph (CHESS) 2

CHESS studied translucent clouds in the interstellar medium (ISM). CHESS allowed measurement of the composition, motion and temperature of this interstellar material in unprecedented detail. CHESS also took a snapshot of the raw materials available that were needed to develop planets, such as, carbon, nitrogen, and oxygen. High-resolution absorption line spectroscopy when looking toward hot stars, such as ε Persei (epsilon Persei) the target for CHESS, provides a rich set of diagnostics with which to simultaneously measure the temperature, composition, and velocity fields of the solar neighborhood.

Diffuse X-rays from the Local Galaxy (DXL)

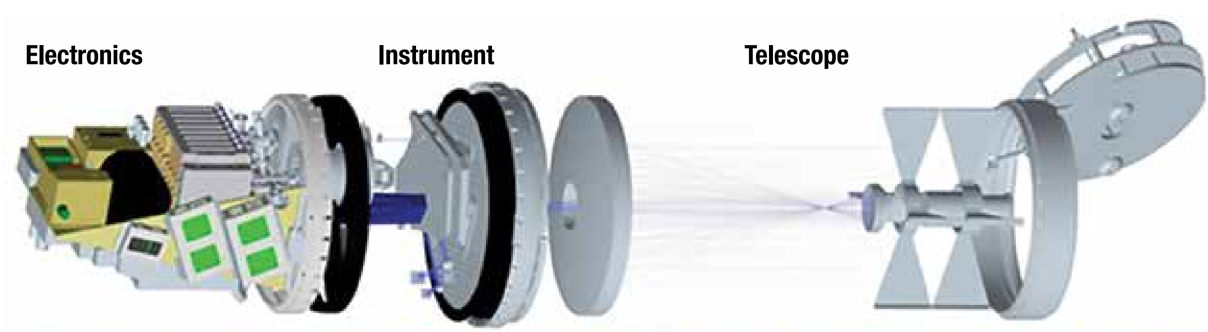
DXL studied the irregularly shaped cavity, the Local Hot Bubble (LHB) filled with X-ray-emitting hot gas. These X-ray emissions have long been thought to originate from remnants of supernovae which formed the local hot bubble. The first flight of DXL, in 2012, found that around 40 percent of this radiation is a result of the Solar Wind Charge Exchange (SWCX) i.e. solar wind stripping away electrons from neutral gas in space and emitting X-rays. The purpose of the 2016 flight was to better understand the nature and characteristics of the local hot bubble, the solar wind charge exchange, and their fundamental physics. Results from this flight will improve modeling capability of X-ray data for past, present, and future missions.

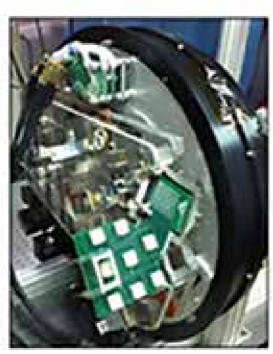
Planet Imaging Coronagraphic Technology Using a Reconfigurable Experimental Base (PICTURE-B)

The PICTURE-B (36.293) sounding rocket mission was designed to directly image the exozodiacal dust and debris disk around the Sun-like star Epsilon Eridani. In addition to the science contributions of PICTURE-B, the mission also matured essential technology for the detection and characterization of visible light from exoplanets for future larger missions currently being imagined. These technologies include: an ultralight-weight 0.5 m diameter silicon carbide primary mirror, a wavefront control system that uses a 32x32 element MEMS deformable mirror (DM), a milliarcsecond pointing control system, and the heart of the PICTURE instrument, the Visible Nulling Coronagraph (VNC, nuller). The VNC attenuates the overwhelmingly bright light from a star, while enabling dim light from material around the star (dust and planets) to reach the science camera. The electronics section on PICTURE-B includes three networked computers controlling the nuller, the science and wavefront sensing cameras, and the fine pointing system.

The experiment was launched from the White Sands Missile Range in New Mexico on November 24, 2015 and demonstrated the first space operation of a nulling coronagraph and a deformable mirror. Regrettably, the experiment did not achieve null due to a slight shift in the deformable mirror position on launch. Because of this, it did not return any science results. The fine pointing system performed extremely well, optically stabilizing the pointing to between 3 and 5 milliarcseconds. The wavefront control system successfully sensed the wavefront at the required precision of 1 nm RMS.

The next generation PICTURE-C mission has been selected by NASA to fly aboard a high-altitude balloon in 2017 and 2019.





Principal Investigator: *Dr. Supriya Chakrabarti/University of Massachussetts -* ***Mission Number(s):*** *36.293 UG*
Launch site: *White Sands Missile Range, NM -* ***Launch date:*** *November 25, 2015*

The Far-Ultraviolet Off-Rowland Telescope for Imaging and Spectroscopy (FORTIS 36.312) launched from the White Sands Missile Range in New Mexico to investigate the properties of galaxy NGC 1365, also known as the Great Barred Spiral Galaxy. FORTIS aimed to contribute knowledge to one of the remaining mysteries about the evolution of the universe, namely, how did it get reionized about 400 million years ago.


NGC1365 is a giant Seyfert type galaxy in Fornax with a diameter of 200,000 light years.

FORTIS has a multi-object spectroscopic capability between 800 - 2000 Å and an imaging bandpass of 1300 - 2000 Å and uses a novel prototype Micro Shutter Array (MSA) with 64 x 128 individually selectable slitlets addressed by a zero-order microshutter interface (ZOMI) module controlled by a National Instruments cRIO. cRIO selects only the brightest regions of the target galaxy in each row of microshutters for observation, resulting in 43 different spectra in each of the two redundant spectral orders.

FORTIS was designed to detect Lyman α (Lyα) escape from nearby starforming galaxies, and to serve as a pathfinder mission for enabling observations of Lyman Continuum (LyC) escape. The primary science goal was to determine the Lyα escape fraction and relate it to other observable properties, such as the gas-to-dust ratio.

The 2016 flight was an engineering success (notably successful actuation of the Microshutter Array), but did not produce actionable science, as the target was too faint to detect in the face of higher than anticipated geocoronal oxygen and hydrogen emissions. The data gathered during flight are an indispensable guide for efforts to develop a next generation FORTIS, the goal for which is to reduce the sensitivity to geocoronal emissions by a factor of ~ 200. Evaluation of new baffle materials and configurations to enable this reduction is in progress.

NextGenFORTIS will also employ two new technologies in the form of large area borosilicate microchannel plate (MCP) detectors coated with CsI (Cesium Iodide), and an advanced Microshutter Array featuring a purely electronic, pulsed actuation technique for opening the shutters; as opposed to the previous mechanical technique that employed a scanning magnet. The new MCPs have larger open area ratios and are more immune to electron gain sag, which will lead to higher quantum efficiency and provide a more linear response at higher count rates. The pulse actuated MSA assembly will be smaller, have a longer lifetime, and be simpler to operate.

Results from a previous FORTIS mission, 36.296 UG flown November 20, 2013 to study Comet ISON, were published in 2016 in *The Astronomical Journal* (152:65 (10pp), 2016 September). This flight successfully returned images from ISON of Lyman alpha emission and neutral carbon emission (see Figure 1).

Principal Investigator: *Dr. Stephan McCandliss/Johns Hopkins University* - ***Mission Number(s):*** *36.312 UG*
Launch site: *White Sands Missile Range, NM* - ***Launch date:*** *December 18, 2015*

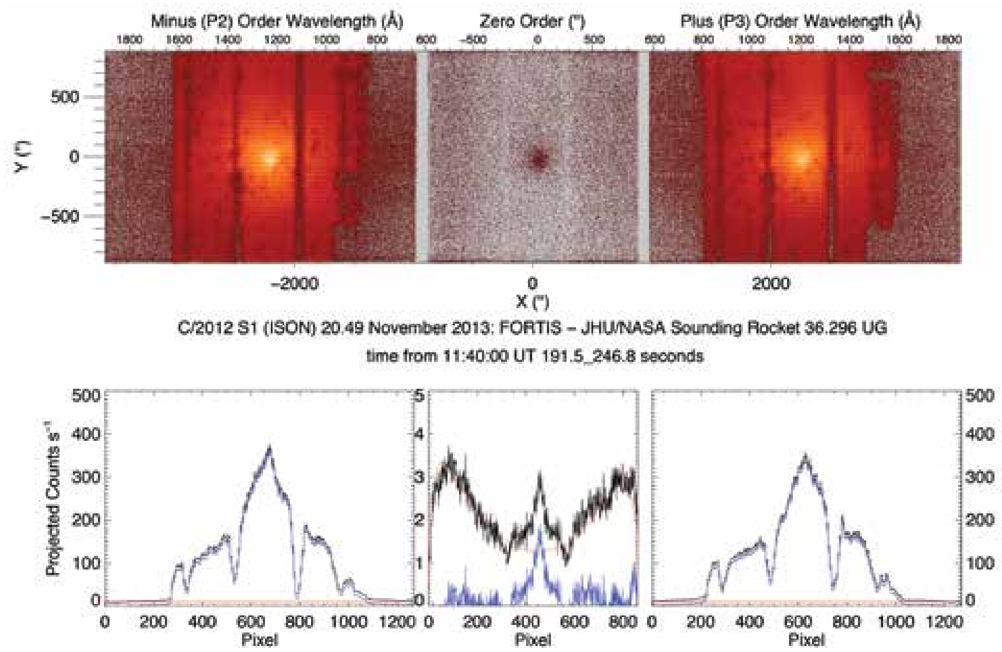


Figure 1. Images of Lyman Alpha emission and neutral carbon emission from ISON acquired by FORTIS.

Radial profiles were extracted, showing that the peak brightnesses were 625K rayleighs for Lyman alpha (Figure 2) and 27K rayleighs for carbon (Figure 3) in the 1657 Angstrom multiplet (in comparison, the night time brightness of geocoronal Lyman alpha is ~ 3K rayleighs; during the day it is a factor of 10 stronger). Water and carbon production rates were found to be Q(H2O) = 8e29/sec, Q(C)=4e28/sec. The profile of C emission was consistent with production from a parent molecule with a lifetime of less than a day, which is much shorter than the lifetime of CO ~ 15 days. An upper limit to the CO production rate of Q(CO) < 5e28/sec, yielding an upper limit to the abundance of CO relative to water of < 6%. In future work the intent is to examine the data in the context of nearly contiguous far-UV spectral observations acquired over 19 to 21 November 2013 made by Mercury Atmospheric and Surface Composition Spectrometer (MASCS) on NASA's MESSENGER spacecraft to further investigate the water production variability and to place more stringent limits on the CO production, during this extremely volatile period. These results appeared in McCandliss et al. 2016 AJ, 152, 65. Link:
http://iopscience.iop.org/article/10.3847/0004-6256/152/3/65/pdf

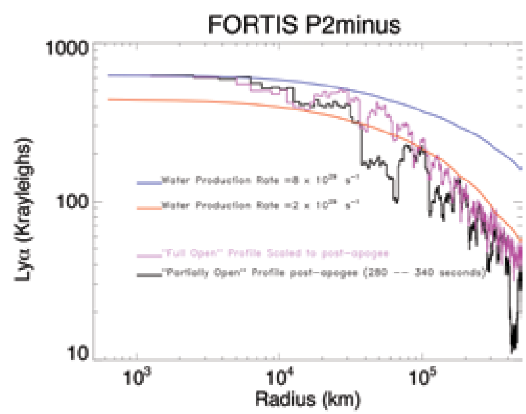


Figure 2. Radial profile for Lyman alpha.

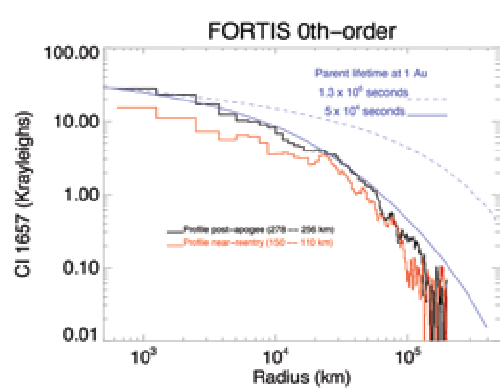
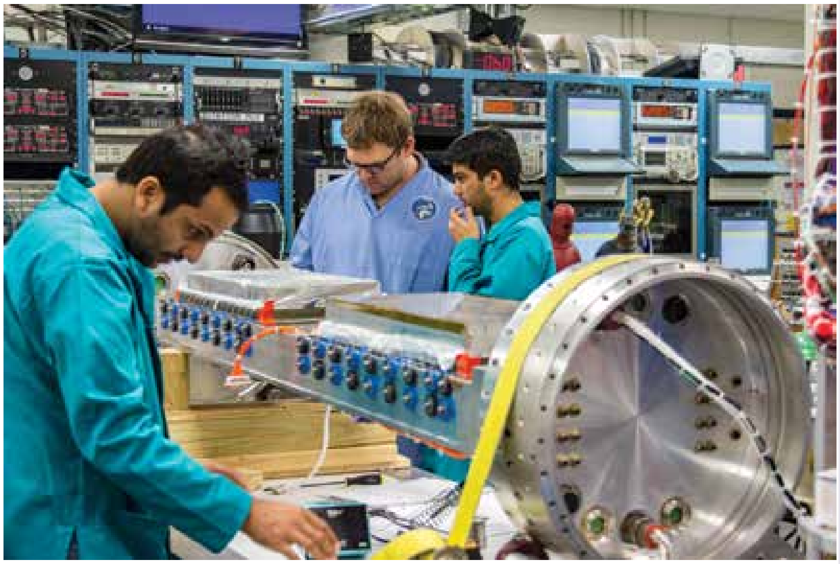


Figure 3. Radial profile for carbon.

The objective of the Diffuse X-ray emission from the Local Galaxy (DXL) sounding rocket experiment was to distinguish the soft X-ray emission (with energies of 0.12-5 keV, kilo electron Volts) emanating from the Local Hot Bubble (LHB) from those produced via Solar Wind charge exchange (SWCX). The 300 light years long bubble is filled with very thin hot gas and was formed by a cluster of supernova explosions about 10 million years ago.

The first flight of DXL in 2012 found that around 40 percent of the Diffuse X-ray emission is a result of the solar wind charge exchange, that is, solar wind taking away electrons from neutral gas in space and emitting X-rays. The purpose of the 2016 flight was to better understand the nature and characteristics of the LHB and SWCX. Additionally the flight will enhance the understanding of the fundamental physics of the LHB and SWCX and the results will improve modeling capability of X-ray data for past, present, and future missions.



DXL science team working on preparing instrument for integration and testing at NASA GSFC Wallops Flight Facility. Prior to shipment of hardware and personnel to the launch site, the payload goes through extensive testing, including vibration to flight loads, bend testing for aerodynamic integrity, balance and moments of inertia measurements to ensure the highest possible confidence in a successful flight.

DXL uses Proportional counters refurbished from Aerobee rockets in the 70s and 80s. The instrument is designed for heliophysics, astrophysics, and planetary physics applications. DXL consists of two large proportional counters refurbished from the Aerobee payload used during the Wisconsin All Sky Survey. The counters utilize P-10 fill gas (P10 is 90% argon and 10% methane) and are covered by a thin Formvar (polyvinyl formaldehyde) window with Cyasorb UV-24 additive supported on a nickel mesh. DXL also includes the Cusp Plasma Imaging Detector (CuPID) instrument. CuPID is a Soft X-ray camera that utilizes slumped micropore ('lobster-eye') optics to focus X-rays onto a position sensitive, chevron configuration micro channel plate detector. The CubeSat version of CuPID, DXL/STORM, flew successfully with DXL on the 2012 flight.

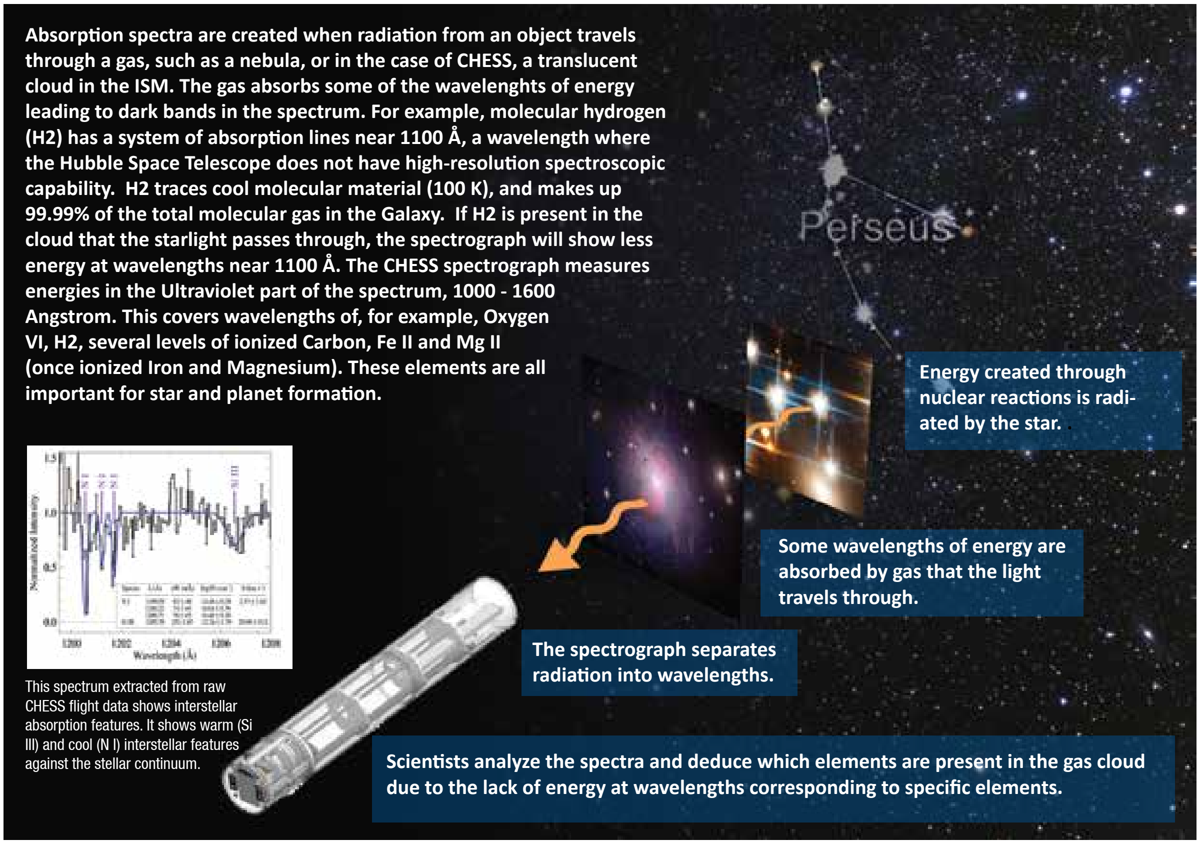
To differentiate between X-rays from the two sources DXL was launched in December when the Earth passes through the helium focusing cone, a region where neutral helium from the interstellar helium wind is concentrated by the gravitational influence of the Sun. The helium focusing cone is a strong source of interplanetary SWCX, but planets, including Earth, may have stronger emission. The X-ray glow of the helium could not account for all of the X-rays measured, leading to the conclusion that the difference is emitted by the hot gas in the LHB.

Principal Investigator: *Dr Massimiliano Galeazzi/University of Miami* - ***Mission Number(s):*** *36.305 UH*
Launch site: *White Sands Missile Range, NM* - ***Launch date:*** *December 5, 2015*

Good data was received during the flight and preliminary analysis confirms the finding from DXL 1 that the X-ray contribution from the SWCX is about forty percent in the galactic plane, and even less elsewhere, and the remaining X-rays must come from the Local Hot Bubble. DXL 2 also investigated the exact direction of the cone, which relates directly to the motion of the Sun in the Galaxy.

DXL payload sequence testing. Sequence testing involves going through all payload inflight events, such as door openings, Attitude Control Systems operations, recovery system deployments etc. as they would happen in flight. Conducting a sequence test shows that the instrument and all payload support systems are still in working condition after all other testing is complete.

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 36.297 UG – France mission launched off of the Athena launcher at Launch Complex 36, White Sands Missile Range, 21:15 MST, 21 Feb 2016. The CHESS-2 instrument acquired data on sightline to the hot star epsilon Persei for the entire 400 seconds of available observing time with detector high-voltage on. The payload was successfully recovered the following morning at ~8am; all science-critical subsystems are alive and well, and are being refurbished for the next flight of the CHESS payload. Comprehensive success was achieved for 36.297 UG.



This spectrum extracted from raw CHESS flight data shows interstellar absorption features. It shows warm (Si III) and cool (N I) interstellar features against the stellar continuum.

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 Epsilon Persei, in the constellation Perseus. 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. This allows scientists to take a snapshot of the raw materials available, such as carbon, nitrogen, and oxygen, that are needed to build future generations of stars and planets. The CHESS spectrograph enables the University of Colorado team to also quantify the temperature and motions of the clouds along the line of sight.

Principal Investigator: *Dr. Kevin France/University of Colorado* - ***Mission Number(s):*** *36.297 UG*
Launch site: *White Sands Missile Range, NM* - ***Launch date:*** *February 22, 2016*

Almost all of the target absorption lines were detected by the CHESS instrument, ranging from cool molecular gas (H2, T ~ 100 K) to Si IV (three times ionized silicon, T ~ 60,000 K). Figure 1 shows an echellogram; about 120 spectral orders across the 8196 pixel x 8196 pixel detector were recorded, and each spectral order is a horizontal stripe. There is a lot of data (about 5 million science counts in the flight were recorded). The two-dimensional spectrum shows several neutral and ionized species (labeled). A high-level science extraction has taken place (Figure 2), science and technical results were presented at the SPIE meeting in June 2016 and a subsequent publication led by the project's lead graduate student (Keri Hoadley) is in preparation.

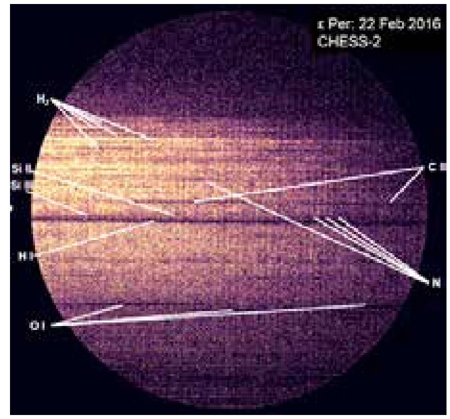


Figure 1– 36.297 CHESS flight data, full two–dimensional echellogram with relevant molecular and atomic absorption features labeled.

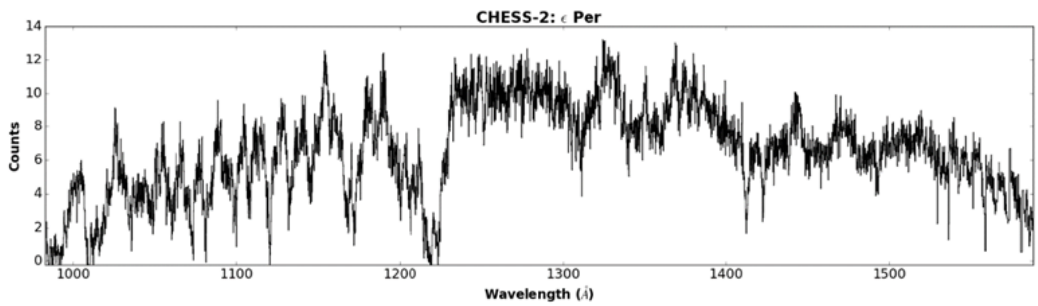


Figure 2 – 36.297 CHESS flight data, one–dimensional extraction.

The refurbished high-count rate cross-strip MCP (developed, in part, as a Strategic Astrophysics Technology program at the University of California at Berkeley, - J. Vallerga SAT program) worked beautifully in-flight, a new echelle grating provided almost 10x the collecting efficiency as CHESS-1 (Figure 3), and this mission served as the second flight of the new high data rate suborbital telemetry system. The PI and science team are very happy with the performance of the CHESS system and will continue improvements as part of their research and development program on dispersive optics, projecting another factor of ~2 increase in throughput while decreasing instrumental scatter for the next flight, CHESS-3, June 2017.

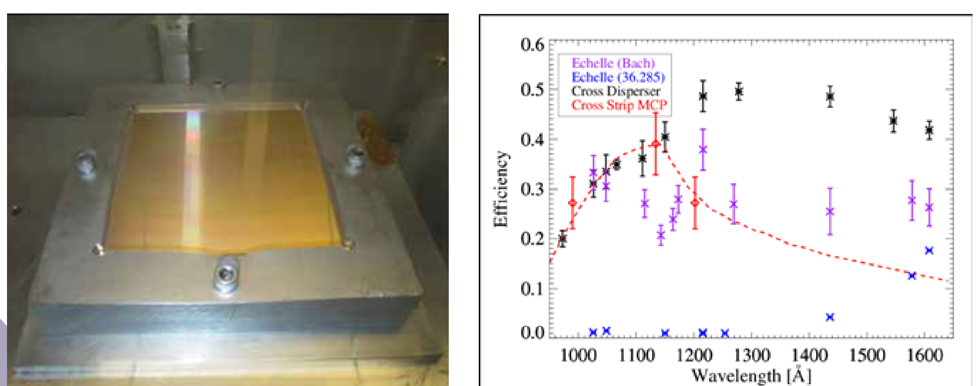


Figure 3 – Component–level research and development (diffraction grating, at left) carried out as part of the CU rocket program provided ~10x the instrumental sensitivity (at right, 36.297, pink x's) compared to CHESS–1 (36.285, blue x's).

36.297 Recovery. Left to right: Nick Kruczek (Colorado grad student), Keri Hoadley (Colorado grad student), Brian Fleming (Colorado, CHESS project scientist)

The lead graduate student, Keri Hoadley, led all phases of the build-up, calibration, and integration of the CHESS payload. She was at the command system for real-time control of the rocket during flight, "driving" the payload to center the target stars in the aperture. The CHESS project scientist, Dr. Brian Fleming, directed a significant portion of the field activities, gaining the PI-training that is one of the goals of the Colorado rocket program. The University of Colorado field team also included 3 other graduate students (Nick Kruczek, Nick Erickson, Nicholas Nell) and one undergraduate student (Jack Swanson).

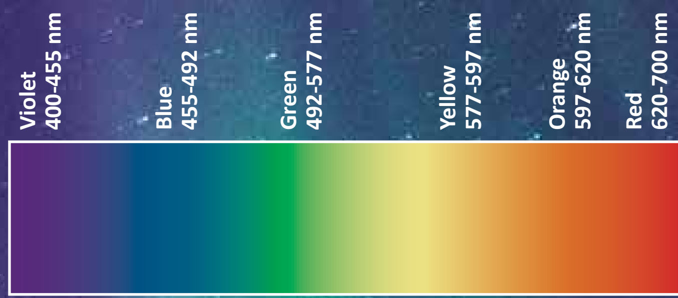
CHESS and the follow on mission under development, Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet host stars (SISTINE), also are pathfinders and technology demonstrators for an ultraviolet spectrograph for the NASA cosmic origins mission, Large UV/Optical/IR Surveyor (LUVOIR), currently under study. The Combined High-resolution and Imaging Spectrograph for the LUVOIR Surveyor (CHISL) 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.

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

Geospace science focuses on the study of interactions between Earth and the space environment surrounding our planet. Part of the broader research discipline, Heliophysics, geospace scientists study Sun-Earth connections such as effects of the solar wind on the Earth's magnetosphere and ionosphere.

Sounding rockets are uniquely suited for many geospace research applications due to their ability to take measurements in a region of space too high for balloons and too low for satellites.

The aurora borealis, or northern lights, created when charged particles from the Sun are carried to Earth with the solar wind, are frequently studied with sounding rockets. When these solar particles reach Earth, they get trapped in the magnetic field lines created by Earth's magnetic core. At the geomagnetic poles, the field lines extend through the lower atmosphere, allowing the charged particles to interact with atoms of mostly Oxygen and Nitrogen. The charged particles, mostly electrons, energize the atoms by exciting their electrons, causing them to move to a higher energy level. This higher energy level is not stable and when the electron transits back to its initial level it emits a photon, causing the auroral light show. High energy electrons cause oxygen to emit green light, while low energy electrons cause a red light. Nitrogen generally gives off a violet-blue light.



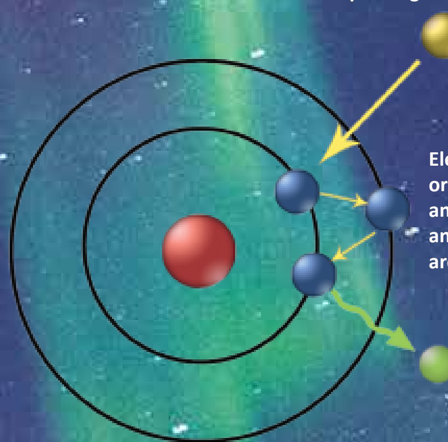
Violet-Blue Aurora emitted by nitrogen at 427.8 nm.

Green Aurora emitted by oxygen at 577.7 nm.

Red Aurora emitted by oxygen at 630 nm.

Light Emission

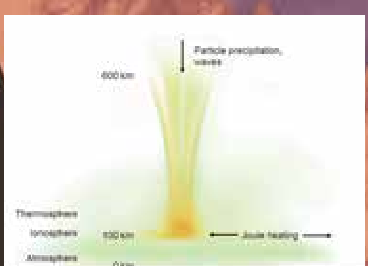
Incoming energetic particles (mostly electrons) collide with atmospheric gases.



Electrons in the gas atom or molecule (mostly oxygen and nitrogen) are energized and move to a higher level around the nucleus

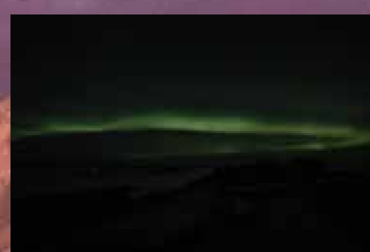
The higher level is unstable and when the electron transits back it releases energy by emitting a photon

Geospace Missions 2016



Rocket Experiment for Neutral Upwelling (RENU 2)

RENU studied the relationship between the inflow of electrons that creates the cusp aurora, electric currents flowing along magnetic field lines, and dense columns of heated neutral atoms in the upper atmosphere. The neutral upwelling was discovered when satellites travelling through the magnetic cusp experienced increased drag. When solar wind electrons collide with atmospheric electrons, they transfer some of their energy, heating the atmospheric electrons. The higher heat means the electron populations expand upward along the magnetic field lines.



Cusp Alfven and Plasma Electrodynamics Rocket (CAPER)

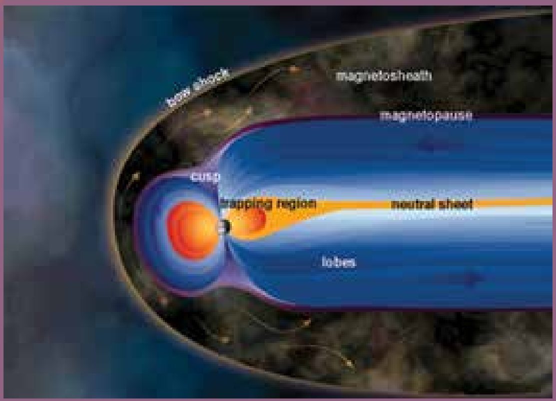
CAPER was designed to investigate electromagnetic (EM) waves that can accelerate electrons down into Earth's atmosphere or up out to space. The electrons that are accelerated downward collide with particles in the atmosphere, releasing light and creating the cusp aurora.

Complex interactions govern the Sun-Earth space environment. Coronal Mass Ejections (CME), solar flares, solar wind, and regular solar radiation influence the behavior of Earth's atmosphere. The atmosphere is divided into several layers; starting with the troposphere closest to the Earth, the stratosphere where the ozone layer is, followed by the mesosphere and thermosphere. Of particular interest, since the beginning of the space age and the use of orbiting satellites, has been the ionosphere, a layer of partially charged or ionized gas extending in altitude from about 90 km to over 500 km. The thermosphere and ionosphere almost overlap spatially, but the ionosphere can vary temporally, i.e., with time.

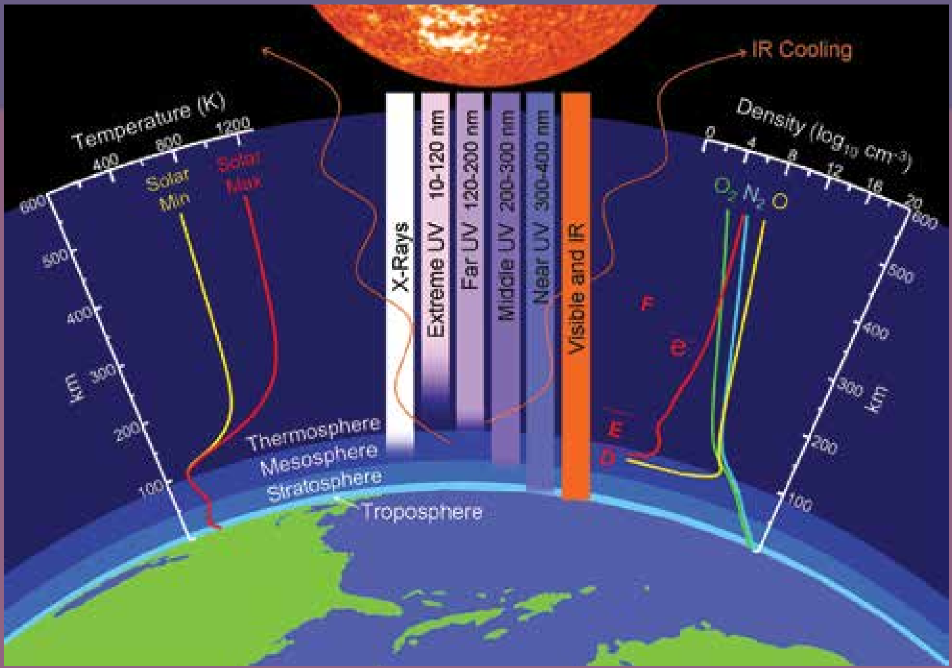
The lower ionosphere/thermosphere (90-130 km) represents a critical transition region between the neutral and ionized gas populations; this is where the two gases couple and exchange energy. This is also the region where much external energy is deposited, from above and below, producing heating and instabilities. The thermosphere/ionosphere is coupled energetically, dynamically, and chemically to the mesosphere below and the exosphere above. Atmospheric tides, gravity waves, and planetary waves propagate upward from the mesosphere. Pressure gradients resulting from temperature differences, with the absorption of solar EUV being the dominant source of heating, influence the region from above.

The ionosphere is created by the ionization of the neutral atoms and molecules of the atmosphere. This electrical charging is the result of the Sun's ultraviolet light bombarding the atmospheric gas, which is mainly oxygen and nitrogen molecules. The ultraviolet light knocks electrons off the gas molecules, leading to electrically charged particles or ions. Neutral molecules exist alongside the ions. Gases in the troposphere, where life on Earth exists, are neutral, meaning that they are not electrically charged. In a neutral gas, the number of electrons surrounding the nuclei is the same as the total number of protons in the nuclei. It is difficult to conduct large scale studies of this region, yet characterizing the ionosphere/thermosphere is important for understanding our planet and the space surrounding it.

Changes in the ionosphere caused by variations in solar activity has an impact on everyday life on Earth and in near-space. Solar storms can disrupt the ionosphere and cause communication black-outs. Availability and accuracy of GPS signals are impacted by changes in the ionosphere as are signals from other Earth orbiting satellites. Long conductors, such as power grids and overhead power lines, experience additional currents due to geomagnetic storms that create electric currents in the magnetosphere and ionosphere.



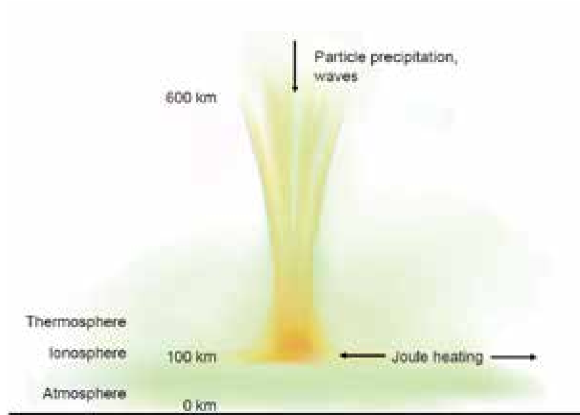
The Sun's energy is carried toward the Earth in the solar wind, a stream of electrically charged particles (mostly protons and electrons) flowing out from the Sun. The Earth's magnetic field deflects most of these particles. Most of the highly visible aurorae occur where the magnetic field guides the electrons from the tail of the magnetosphere into the atmosphere where they produce the aurora. A different type of aurora, the cusp aurora, is produced when energetic particles are accelerated downward into the atmosphere directly from the solar wind.



The graphic shows Earth's atmosphere and types of solar radiation and the altitudes at which the various energies are blocked. On the right is a depiction of the Ionosphere and chemical composition of molecular oxygen, nitrogen, and atomic oxygen.

Rocket Experiment for Neutral Upwelling 2, studied the relationship between the flowing electrons that create the cusp aurora and dense columns of neutral atoms in the upper atmosphere.

The cusp regions are the two funnel-shaped features near the Earth's magnetic poles where Earth's magnetic field lines connect with those of the sun. The cusp aurora, is produced when energetic particles are accelerated downward into the atmosphere directly from the solar wind. The density of neutral atoms, meaning they are not charged, in the atmosphere can change throughout the day because of heating by sunlight. The original understanding was that the increased density of neutral particles was driven horizontally. But satellites orbiting through Earth's magnetic cusp experienced increased drag, which indicates a small vertical slice of higher-density neutral atoms that are harder to travel through.



Graphic showing upwelling in the cusp region.

When solar wind electrons collide with atmospheric electrons, they transfer some of their energy, heating the atmospheric electrons. The higher heat means the electron populations expand upward along the magnetic field lines. This upward flow of negatively-charged particles creates a vertical electric field, which in turn, pulls up the positively-charged and neutral particles, increasing the atmospheric density in columns rather than horizontal layers.

RENU 2 was successfully launched on December 13, 2015 and transited the cusp region while taking measurements. Data from this flight is currently being analyzed.


RENU 2 during integration activities at NASA GSFC Wallops Flight Facility.

Principal Investigator: *Dr. Marc Lessard/Univeristy of New Hampshire* • ***Mission Number(s):*** *52.002 UE*
Launch site: *Andoya Space Center, Norway* • ***Launch date:*** *December 13, 2015*

Cusp Alfven and Plasma Electrodynamics Rocket (CAPER) was designed to investigate the interactions between electrical waves and charged particles in a region of space known as the "polar cusp." The polar cusps are structures in the Earth's magnetic field above the north and south poles, where the magnetic field lines converge in a funnel-shape. The cusps are significant because they are connected directly to the solar wind, a stream of charged particles coming out of the sun and striking the Earth's environment, giving rise to space weather effects such as loading of the radiation belts, intense auroral activity known as substorms, and strong natural electrical currents lasting several days known as geomagnetic storms. These processes can have a significant impact on ground- and space-based technical systems. By probing the cusp regions, CAPER was designed to measure particle and wave phenomena related to these processes.

CAPER in the Magnetic Calibration Facility at NASA GSFC Wallops Flight Facility.

The Earth's magnetic poles are offset from its spin axis, so that the polar cusps occur at significantly higher geographic latitudes in Europe than in North America. Furthermore, the pressure of the solar wind against the Earth's magnetic field distorts the field, shifting the polar cusps toward the dayside. Therefore, the optical auroral signatures of the cusp, which need to be observed in order to know when to launch CAPER, occur near noon local time. CAPER had to be launched from Norway, because only in the European sector is the cusp located far enough north so that it lies in darkness at noon, with cusp aurora visible, during a couple of months of the year around Winter solstice (December/January). Over North America, the cusp occurs at lower geographic latitudes and is always daylit, implying that it is impossible to observe cusp aurora from the ground at any time of year, and hence impossible to determine when to launch CAPER.

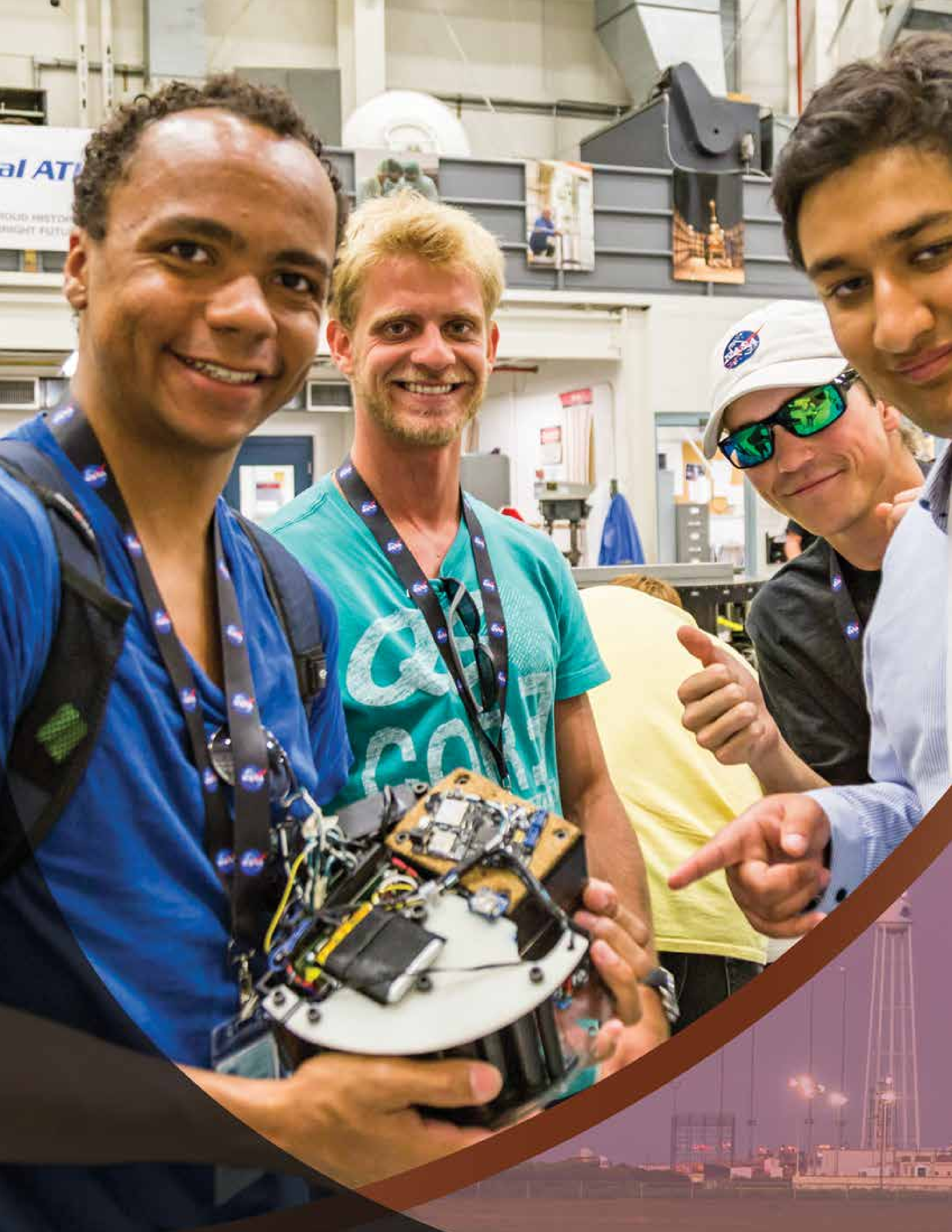
Principal Investigator: *Dr. Jim Labelle/Darthmouth College* • ***Mission Number(s):*** *49.003UE*
Launch site: *Andoya Space Center, Norway* • ***Launch date:*** *November 30, 2015*

CAPER carried multiple instruments, providing: measurements of electric and magnetic fields of low-frequency waves, measurements of electric fields of high frequency waves, and measurements of charged particles of a wide range of energies. Most importantly, CAPER included a unique instrument called a wave-particle correlator, which combines the data of the other instruments in order to measure exactly how the charged particles behave in the electric fields of the waves. This correlator, never before flown in the cusp region, was designed to reveal the detailed physics whereby the charged particles are accelerated upward or downward by the waves. The electrons, which are accelerated downward, collide with particles in the atmosphere, releasing light and creating the cusp aurora; charged particles accelerated upward may escape Earth's gravity entirely and be lost to outer space. CAPER was designed to reveal how these acceleration processes, which are highly significant but not fully understood, work in detail.

Due to an anomaly in the sequence of events during the flight, the payload did not reach its intended apogee, and no data were recorded. A re-flight "CAPER-2" is being proposed.

CAPER ready to launch from Andoya Space Center, Norway.

Eric Taylor and Walt Suplick working on CAPER at Wallops Flight Facility.



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 a datalogger, which are flown on a sounding rocket 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 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.

Education Missions 2016

RockOn!

RockSat-C

RockSat-X

The RockOn! workshop was held at NASA Wallops Flight Facility, June 18 - 24, 2016. Seventy-three students and faculty members participated in this year's workshop, which was the ninth since the inception of the program in 2008. RockSat-C experiments are flown in the same payload as the workshop experiments but are more advance and completely designed and fabricated by the students. Ninty-three students participated in the RockSat-C flight opportunity.

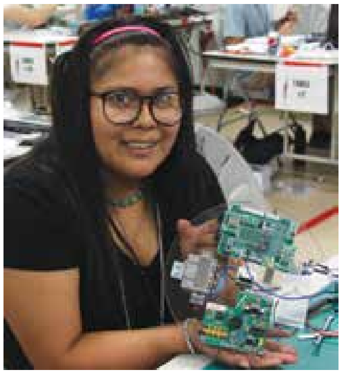
The goal of the RockOn! mission is to teach university faculty and students the basics of rocket payload construction and integration. RockOn! also acts as the first step in the RockSat series of flight opportunities, and workshop participants are encouraged to return the following year to design, build, test, and fly their own experiment. The RockOn! experiments are designed to capture and record 3-axis accelerations, humidity, pressure, temperature, and radiation counts 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.

The chart above shows the workflow for the RockOn! and RockSat-C programs.

1. RockOn! workshop participants build their experiment during the workshop.
2. All materials and instructions are provided to complete the experiment.
3. Experiment boards are stacked on an internal structure that accommodates five boards.
4. Experiment stacks are housed in canisters (RockOn!). RockSat-C experiments are not board based but are also housed in canisters.

Principal Investigator: *Mr. Chris Koehler/Colorado Space Grant Consortium* • ***Mission Number(s):*** *41.116 UO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *June 24, 2016*

5. All canisters are integrated with the payload structure.
6. Payload is tested prior to flight. Tests include Moments of Inertia measurement (roll moment measurement shown in picture), vibration, and balancing.
7. Payload is launched with a two-stage Terrier-Improved Orion sounding rocket before the end of the workshop week. Participants view the launch from Wallops Island.



RockOn! workshop participants.

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.

The following schools and experiments flew on RockSat-C in 2016:

Community Colleges of Colorado
The experiment aimed at launching an inter-school payload to: test viability of carbon fiber shielding, gather successful Cherenkov radiation data, and test durability of DNA under ascent and reentry conditions.

Eastern Shore Community College (Virginia)
The Eastern Shore Community College aims to expose local students (middle school and up) to aerospace career possibilities by involving them in a STEM based project that records and saves data from a 3-axis accelerometer on the RockSat-C 2016 Flight.

Hobart and William Smith Colleges (New York)
The purpose of this experiment was to determine the flux of muons at various levels within the atmosphere using a plastic scintillator detector with a solid state silicon photomultiplier

Old Dominion University (Virginia)

The mission of Monarch-Two was to evaluate and design a smartphone based flight system and transmitter with flight data collection capabilities

Oregon State University

This mission aimed to measure the polarization of gamma radiation coming form outside our solar system

Stevens Institute of Technology (New Jersey)

The objective of this experiment was to test the effects of high gs and microgravity on 3D prints and to measure High-Speed Boundary Layer Transitions from laminar to turbulent pressure waves using a piezoresistive and pizoelectric pressure sensor combination mounted in a custom window on the skin of the rocket.

Temple University (Pennsylvania)

The goal of this experiment was to determine the concentration of sulfate based aerosols in the troposphere and stratosphere using a series of filters and valves that were designed to open/close during the descent of the flight, and to determine the volumetric flow rate and pressure differential between the dynamic and static port of the rocket.

University of Delaware

The experiment was designed to study ionizing radiation during the rocket flight. The main goal this year was to establish a permanent RockSat team at the University of Delaware.

West Virginia University

The West Virginia University team aimed to capture near infrared Earth images from space, measure plasma density in upper atmosphere, measure atmospheric pressure and magnetic field of Earth, gather redundant flight dynamics data, determine attitude in space relative to the sun, and test the strain of ABS plastic in space

Cubes in Space is a program for middle school students that allows them the opportunity to design an experiment that fits in a 1" x 1"x 1" cube. The cubes are flown inside the nose cone of the RockOn! payload. Seventy-five middle school payloads with approximately 375 student participants were flown on the RockOn! mission.

Cubes in Space experiments.

RockSat-C students and NSROC staff with the 41.116 payload on the vibration table.

RockSat-X was successfully launched from Wallops Island, VA on August 17, 2016. RockSat-X carried student developed experiments and is the third, and most advanced, student flight opportunity. The other two student flight missions are RockOn!, an introductory workshop for building and flying experiments, and RockSat-C, which allows students to design their own experiment, but does not offer exposure to the space environment. RockSat-X had an ejectable skin and nose cone that fully exposed the experiments 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 2016:

University of Hawaii Community Colleges

Four community colleges in Hawaii teamed up to encourage students to explore STEM-based careers. The first primary experiment was to measure thermal neutron and gamma background radiation using scintillators and photomultiplier tubes. The second primary experiment deployed a naphthalene sublimation mini-rocket made from 3D printed materials and capture imagery of the sublimation rocket's release. The secondary experiments onboard were designed to evaluate a 9-axis IMU motion tracking device and wirelessly transfer video from the sublimation rocket-mounted cameras back to the experiment.

University of Nebraska Lincoln

This experiment aimed to develop and streamline the mechanism for a deployable boom and solar panel system. The deployable boom system could be used for suborbital and small satellite missions. For the 2016 flight, this experiment flew as a mechanical experiment only, in order to test the resilience of the retracted boom system.

Capitol Technology University (Maryland)

This experiment, TRAPSat, used a silica aerogel to capture micro-debris. CTU utilized this RockSat-X mission as a proof of concept both for the use of aerogel as a medium to remove debris, as well as to prove the viability of using aerogel blanketing as an alternative to Multi-Layer Insulation. A camera imaged the micro-debris and recorded data about their impact.

Principal Investigator: *Mr. Chris Koehler/Colorado Space Grant Consortium* • ***Mission Number(s):*** *46.014 UO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *August 17, 2016*

Northwest Nazarene University (Idaho)

This experiment tested flexible electronics in the space environment. Utilizing passive flexible radio frequency identification (RFID) tags, provided by American Semiconductor, temperature was recorded, transmitted, and received during the space flight. A boom extended an RFID tag away from the experiment, during which temperature and transmit power was recorded via the RFID reader powered by a smartphone. Additionally, the experiment used a microcontroller to control and sample the American Semiconductor FleX-Analog to Digital Converter (ADC) accelerometer alongside a traditional ADC to compare the use of flexible electronics in space.

Virginia Tech

This experiment demonstrated the capability of software defined radio (SDR) in spaceflight communication systems. Additionally, it tested the possibility of using economically priced SDR devices such as the Ettus E310. Data was transmitted to the Virginia Tech Ground Station using the Ettus E310 and a helical transmit antenna that deployed from the rocket and pointed in the direction of the Virginia Tech Ground Station. The transmitted packages contained gyroscope, acceleration, pressure, and temperature data.

Carthage College (Wisconsin)

The objective of this experiment was to observe very low frequency electromagnetic waves that come from lightning discharges. As the payload increased in altitude, the experiment observed the impact that the ionosphere has on these low frequency waves. This experiment utilized two electric field plate antenna pairs and three magnetic loop antennas (x,y,z-axis) to detect electromagnetic waves. The signals from the antennas were amplified and then stored onboard in an xCORE computer with microSD card.

University of Colorado Boulder

The RockSat-X High Definition video payload was intended to provide a view of the experiments from space. The system housed four HD cameras that recorded the flight and any deployments or activations on student experiments. Each camera was housed in a sealed container with a pressure and temperature sensor to give important data on the integrity of the system during the flight to space.

University of Puerto Rico

The experiment allowed the detection of high density particles found between 130-165 kilometers above sea level using the UPR early micrometeorite impact detection system, collector, and various other measuring devices. This project could aid in developing a clearer image of space particles, and potentially lead to the discovery and subsequent genome sequencing of organic materials found within the particles. The experiment utilized a Leica SL UHD 4K video camera pointed aft to record video of the flight. The Leica SL was selected as an ongoing research collaboration with Bifröst Corporation to test optical behavior and camera functionality during flight. These experiments provided data to evaluate camera performance for future missions to visualize the aurora borealis.

This flight included the first clam shell skins. The skins were successfully deployed during flight. For more information on the clam shell skin, see the Technology Development section of this report.

The payload was not recovered. Telemetered data was received as designed, but on-board recorded data was not.

John Yackanech, Nic Marks, and Ahmed Ghalib (left to right) working on RockSat-X.

Sounding rockets have served as technology test beds since the beginning of the space age. New technologies and support system upgrades for the Sounding Rockets program, such as Telemetry, Attitude Control, and Recovery, to mention a few, are tested on both dedicated technology missions or as add-ons to scheduled flights. New science instruments are tested on sounding rockets to evaluate their feasibility and functionality before committing to a longer duration spacecraft mission.

In 2016, three dedicated technology development missions were flown and included testing of deployable sub-payloads, a standard instrument carrier development mission, and a flight in support of NASA's Space Technology Mission Directorate (STMD) Flight Opportunities Program (FOP). All three missions were successfully flown from Wallops Island, VA. In addition, the new clam shell skin was tested on the RockSat-X student mission.

Technology and Special Projects Missions 2016

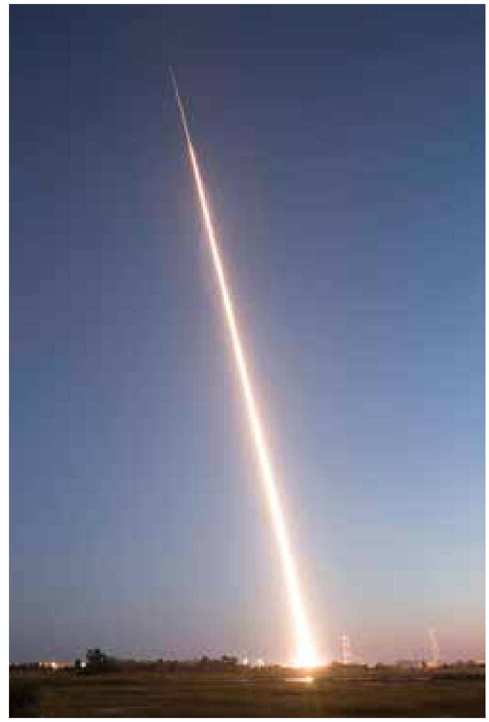
This NASA technology test mission's primary goal was to fully test and characterize the new Black Brant Mk4 motor in a sounding rocket vehicle configuration. This was be the first flight test of the next Mk4 version of the Black Brant rocket motor.

Additionally, the mission provided NASA and NSROC an opportunity to test new technology experiments, as well as, further develop rocket propelled sub-payload ejection technology for the Sounding Rockets Program.

The NSROC technologies on this mission included: HD Camera System, Quasonix transmitter SOQPSK encoding, Kulite pressure transducers, Ampule Control Module (ACM) with rocket propelled sub-payload ejection, and Vehicle diagnostics package.

Two new technologies, the Advanced Near Net Shape Technology (ANNST) experiment and a materials testing experiment with Orbital ATK, sponsored by the NASA Game Changing Office, were also onboard. The objective of the ANNST project was to develop and mature manufacturing technology to enable fabrication of single-piece, integrally-stiffened launch vehicle structures to replace expensive, heavy, and risky multi-piece welded assemblies. The novel integrally stiffened cylinder (ISC) process improves manufacturing efficiency and structural performance by producing single-piece stiffened barrels in one manufacturing process through combined spin- and flow-forming operations. Such a technique has never before been applied to launch vehicle structures. A 25" flow formed aluminum skin replaced the standard NSROC Ogive Recovery System Assembly (ORSA) adapter and was flown on this mission.

The NASA and Orbital ATK experiment consisted of advanced materials in three different designs and configurations for evaluation of radiation and thermal heat shields, ultra-lightweight structure design, and carbon based conductive wire.



36.310 GT launches from Wallops Island, VA.

Payload sequence testing. Open sub–payload doors are visible on the left.

NASA/Orbital ATK materials experiment mounted on deck.

Principal Investigator: *Ms. Catherine Hesh/NASA GSFC Wallops Flight Facility* • ***Mission Number(s):*** *36.310 GT*
Launch site: *Wallops Island, VA* • ***Launch date:*** *October 7, 2015*

The Autonomous Flight Safety System (AFSS), which also flew on this mission, is a joint effort by NASA's Wallops Flight Facility (WFF) and Kennedy Space Center (KSC) to develop an autonomous, onboard system that can augment or replace the function of the traditional ground commanded system. The AFSS is an independent, self-contained subsystem mounted onboard a launch vehicle. The system autonomously makes flight termination/destruct decisions using configurable software-based rules implemented on redundant flight processors using data from redundant GPS/IMU navigation sensors. The Low Cost Transmitter (LCT) 2 is a WFF project to enable a launch vehicle to communicate via satellite rather than line of sight TM. Although AFSS can act autonomously, it is anticipated that data to evaluate its actions will be required. LCT2 provides bi-directional communication through NASA's Tracking and Data Relay Satellite System (TDRSS) that meets suborbital and orbital launch vehicle needs for Space Based Range (SBR) communications.

NASA has long recognized the utility of sounding rockets with respect to workforce training and development. Sounding rocket mission and instrument development provide hands-on experience for technicians, engineers, and managers. Design, fabrication, and testing phases of a sounding rocket mission, while technically rigorous, are relatively fast compared with other spaceflight opportunities, with a mission completion time, from design to launch, of about 18-months.


West Virginia University students integrating their experiment.

MUSIC provided NASA Applied Engineering and Technology Directorate (AETD) personnel an opportunity to gain experience in developing sounding rocket technology, conduct systems engineering processes, and test NASA AETD experiments. This mission resulted in a standard payload carrier with predefined mechanical, telemetry, power, and attitude control capabilities to be offered to reimbursable customers and other Wallops Flight Facility organizations.

The payload carried experiments/instruments developed by AETD including, Wheel Tracker Experiment (WTE), Diminutive Assembly for Nanosatellite deploYables (DANY), GoPro camera, solid state altimeter, Temperature and Strain measurement, Strain Gauge management System (SGMS), and Iridium GPS Beacon. Some of these experiments have been improved and are considered for upcoming Sounding Rocket flights. Additional experiments from West Virginia University's Undergraduate Student Instrument Program (USIP) include instruments for Plasma Physics and Flight Dynamics with GPS and camera.

Launch occurred on Tuesday, March 1, 2016. The vehicle flew to an Apogee of 185.5 km with all payload systems performing nominally. The payload was recovered.


MUSIC team with payload during integration at Wallops Flight Facility.

Principal Investigator: *Mr. Carsell Milliner/NASA GSFC Wallops Flight Facility* • ***Mission Number(s):*** *46.011 GP*
Launch site: *Wallops Island, VA* • ***Launch date:*** *March 1, 2016*

Three new technologies sponsored by NASA's Space Technology Mission Directorate (STMD) Flight Opportunities Program (FOP) were supported by this mission. The technologies included Montana State University's RadPC, Controlled Dynamics Vibration Isolation Platform (VIP), and NASA Ames Sub-Orbital Aerodynamic Re-Entry Experiments (SOAREX-9). Sounding rockets enable rapid development and testing of new technologies, thereby increasing the Technical Readiness Level (TRL) of instruments intended for future space flight missions.

PI Mr. De Leon with the vehicle on the launcher.

The RadPC is a computer system that uses a novel architecture designed and built using off-the-shelf parts. This technology provides increased reliability in the presence of high-energy radiation at a fraction of the cost of existing rad-hard computer systems, where spare circuits are brought online to replace other circuits that may have been struck by ionizing radiation. During this test, the engineers were looking to increase the TRL by demonstrating it in increasingly challenging space environments. The system has been tested on commercial high-altitude balloons, NASA scientific balloons, and commercial suborbital rockets.

RadPC team.

The VIP, a vibration isolation platform, is used to reduce spacecraft disturbances during microgravity. VIP has also flown on developmental flights on both the space shuttle mission STS-73 and two commercial suborbital rockets. VIP provides a free-floating mounting platform that is completely isolated from the disturbances and vibrations of the host vehicle or other payloads. Non-contact isolation allows the experiment to float freely in the sway space between the host vehicle and the platform. Active stabilization allows the platform to cancel any disturbance from the experiment or connected umbilicals, and allows for precisely controlled acceleration environments uniquely tailored to the mounted payload. For optical payloads, this includes scanning and precision tracking. For g-sensitive research experiments, this includes programmable excitations designed to influence and optimize the research results.

The SOAREX-9 experiment tested several technologies for the first time, and matured other components that have evolved from a previous test flight conducted from Wallops in July 2015. Wireless Sensor Modules (WSM) are now much smaller and more capable. Also, the camera technology was improved. This was an incremental test flight, and the results are being applied to the TechEdSat 6 and TechEdSat 7 nano-sat missions which are planned to be launched from the ISS in 2017. SOAREX-9 also enabled development of techniques needed to get optical and WSM data through the downlink directly to the satellite telemetry receivers at Wallops during a TechEdSat-5 over flight.
Link: http://www.nasa.gov/directorates/spacetech/flightopportunities/index.html

SOAREX–9 team.

Principal Investigator: *Mr. Paul De Leon/NASA Ames Research Center* • ***Mission Number(s):*** *41.114 NP*
Launch site: *Wallops Island, VA* • ***Launch date:*** *March 7, 2016*


NASA
BOOM
Virginia Tech.

Educating the next generation of engineers and scientists starts with opportunities to engage in exciting projects. 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.

STEM Education

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. 2016 was the 5th year of the workshop with 20 teachers selected from over 80 applicants. Teachers came from as far away as New York state and as near as Accomack County, VA. All participating educators teach STEM topics at the High School Level.

WRATS offers a unique, in-depth learning experience where teachers not only get hands-on practice building rockets, but are exposed to rocket physics through interactive lectures conducted by Office Chief, Phil Eberspeaker. Topics such as aerodynamics, propulsion, recovery system design, and trajectory simulations are covered in detailed presentations and then put into practice with rocket and payload construction activities.

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 ended with the launch of the RockOn! mission from Wallops Island.

Internships

Over 190 students have participated in the internship program managed for the Sounding Rockets Program Office by NSROC. The program, now in its 17th 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 2016, NSROC provided opportunities for nine internships involving all engineering disciplines.

Outreach

Throughout the year, SRPO and NSROC personnel support local schools by providing speakers, judging science fairs, and conducting special programs, such as model rocket launches. Additionally, speakers are provided upon request to local civic organizations through the NASA Office of Communications.


BLOCKHOUSE 2

The SRPO and NSROC are actively engaged in upgrading and developing new technologies for the program. This year has seen several new and major initiatives to enhance program capabilities including firings of a prototype rocket motor and spin motors, a new launcher, and several payload systems upgrades.

Continuous development efforts allow new and emerging technologies to be incorporated into payload systems fairly quickly. Thorough testing ensures that these technologies are ready for operational use. In-house technology flights are often used to validate new technologies without exposing science missions to any risks that this may involve. Also, several new technologies can share a flight, reducing cost for any one system.

Technology Development

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 Applied Engineering and Technology Directorate, the WFF Technology Investment Board, Small Business Innovative Research (SBIR), and Internal Research and Development (IRAD) programs to meet our growing technology needs.

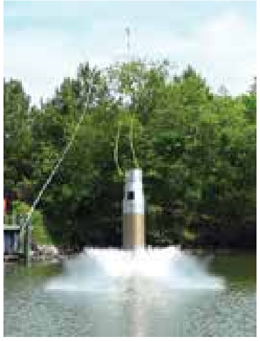
In pursuit of the initiative to increase scientific observation time, the NSRP assesses opportunities to utilize alternate surplus and commercial solid rocket motor assets, assesses alternate launch vehicle configurations utilizing the current stable of assets, and assesses alternate concepts for mission operations. One approach is to conduct missions at water-based launch ranges to address the vehicle performance limitations driven by land-based ranges. The Solar and Astrophysics sounding rocket missions are typically flown from the land-based White Sands Missile Range (WSMR). While this facilitates recovery, the relatively narrow range boundaries of WSMR limit the type of vehicle that can be launched from WSMR, consequently limiting the science observation time. Conducting such a mission from a water-based range would allow for higher performing launch vehicles and increased science data periods. However, water-based ranges come with the increase risk to recovery. In an attempt to mitigate that risk, NSROC has focused on test and evaluation of the existing vacuum shutter door and modified shutter doors. 2016 brought promising test results for the enhanced shutter door design and has led to a planned flight test on the 36.317 Hesh (SubTEC-VII) mission in the coming months. Based on analysis, ground testing, and the upcoming flight demonstration, NSRP hopes to offer this capability for water recoverable missions launching on BBIX and larger vehicles. The NSRP continues investing in flotation technologies, over-the-horizon location aides, and alternate recovery capabilities to facilitate the move to BBX and larger vehicles.

In the avionics area, the Program continues to ensure we maintain the standard systems and assess new avionics systems that can provide increased telemetry data rates, improved power density, and new avionics capabilities. The major goal of the new capabilities assessment is to increase the telemetry system data rates and to provide high data rate on-board storage. The program continues to utilize 10 and 20Mbps S-band telemetry systems to transmit data from the sounding rocket payload to the ground stations. There are ongoing efforts to significantly increase data rates, potentially up to 400 Mbps, by assessing commercially available hardware as well as purpose-built custom hardware. A portion of the currently utilized systems can be tuned to alternate bands, such as C-band, and products are available that provide dual channel (S and C-bands) or C-band capability. The Program will continue to pursue flight systems capable of providing higher data rates and alternate frequency band compatibility while we pursue the authorization to utilize alternate frequency bands and work with launch ranges to assess ground support system upgrades.

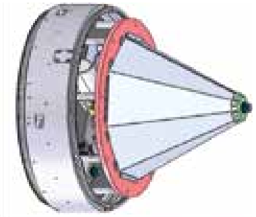
In recent years, the science community has pushed for enhance capabilities for deployable, free-flying sub-payloads capable of carrying chemical tracers or science instruments. Numerous hardware and software developments have been made to develop and enhance support systems for these ampules, including ejection systems and control logic to activate deployment and detonation (chemical tracers) to ensure science and safety criteria are met. In 2016, much focus has been on improving the ignition system for the rocket propelled ampules and enhancing the ignition system for the chemical tracer ampules. Recent activities include analysis, ground-based testing of ignition train components, ground-based testing of ignition systems, and planning for an upcoming flight test. A summary of some of the major 2016 technology activities follows.

Water Recovery Shutter Door

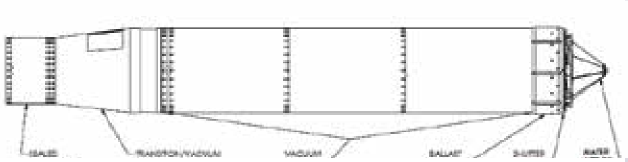
NSROC developed a modified vacuum shutter door assembly for water recovery payloads, with a goal of enabling water recovery for telescope payloads on BBIX class vehicles. The system leverages the heritage vacuum shutter door design and incorporates a water-wedge feature similar to the crushable bumper design commonly utilized for telescope payloads. NSROC conducted a series of drop tests to evaluate the performance of the heritage shutter door assembly and the new design under conditions anticipated for a water impact. The new design performed well and has been chosen to be flown on an upcoming test flight to be launched from WFF. The water recovery shutter door system is anticipated to become operational upon successful completion of the test flight.



Water recovery testing,



Engineering drawings of shutter door with water wedge and payload.

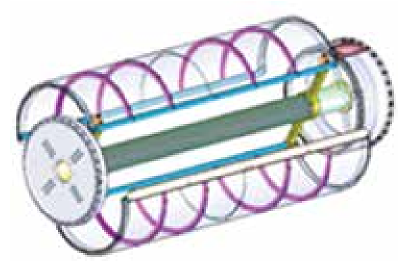


Clamshell Skin Development

NSROC continued development of a load bearing clamshell skin design which is intended as a replacement for both long skirts and large deployable doors. By replacing a conventional skirt, the clamshell skin removes the chance of the skin touching the structure as it deploys. When used to replace a large blow-off door, the clamshell provides the structural support of a skin, while allowing the same working volume as a blow-off door system. NSROC completed the initial

Clam shell skin deployment testing.

round of prototype testing in 2015 and continued into 2016 with additional structural testing and functional testing. The clamshell skin system was successfully tested on the 46.014 Koehler (RockSAT-X) mission in August of 2016.



Engineering drawing of Clam shell skin.

Free-Flying Ampule Development

The NSRP, through NSROC, AETD, industry, and the science community, has continued the development of the rocket-propelled ampule system. This design initially conceived by the science community for chemical tracer distribution also has utility for spatial distribution of small instrument packages. The NSROC team worked with vendors and industry experts to improve the reliability of ignition for the small, commercially available solid motors used to deploy the ampules. The team conducted analysis, design modifications, and ground tests in an attempt to improve the reliability for upcoming science missions.

Ampules being prepared for integration at Wallops.

High Data Rate Encoder

NSROC continues to work closely with Ulyssix to develop the 50 Mbps Phoenix PCM Encoder. In 2016, the team continued to develop and test prototype decks for this next generation encoder.

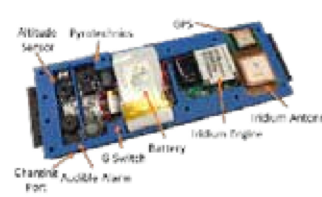
Embedded Engineering:

The NSRP has brought in dedicated engineer staff to support research and development initiatives. This staff will focus on early concept technologies for the program and work closely with other teams and programs to seek out areas for collaboration and development of cross-cutting technologies. Highlights of some of these developments are as follows.

Microcontroller Altimeter: Designed as a solid state architecture replacement to the legacy plenum chamber. The new design will increase reliability and precision as well as lower manufacturing costs.

Solid State Lanyard: Designed as a "drop-in" replacement for the legacy mechanical lanyard switch, the solid state design seeks to improve reliability, precision, manufacturability, and cost. The new design provides the same functionality as the legacy design but increases the channel capacity.

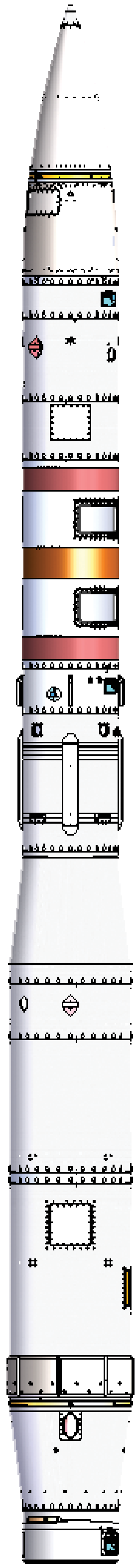
Autonomous Rocket Tracker (A.R.T.): Designed to facilitate recovery of expended solid rocket motor stages for clean-up of land-based launch range areas, this Iridium/GPS beacon is designed to mount on the exterior of a solid rocket motor, function autonomously, and survive the harsh flight and re-entry environment. This capability will aide the NSRP and launch ranges in locating and removing expended motor stages.



Upcoming Technology Development Flights

36.317 Hesh (Sub-TEC 7) – Winter 16/17 from Wallops Island, VA.

Objectives for this mission include providing NASA and NSROC an opportunity to test new technology experiments and demonstrate water recoverable vacuum shutter door. Additionally NASA's Space Technology Mission Directorate (STMD) is sponsoring experiments flying on this mission.



Planned Experiments include

Reimbursable – Sponsored by NASA STMD/Game Changing Development Office:

NASA Glenn Carbon Nanotube Composite Overwrap Pressure Vessel (CNT COPV)

Orbital ATK LEO-2 CubeSat experiment with 3D printing and nanotechnology

NASA Langley Mars Rover Packing Efficiency Experiment (self-contained)

Reimbursable – Commercial Experiments

Tyvak nano avionics experiment (NASA SBIR)

Science Flight Opportunity

RIT CSTARS Cryogenic Star Tracker (36.281 Bock)

NASA AETD Experiments:

Low cost star tracker

Autonomous rocket tracker

Microcontroller Altimeter

Solid state lanyard

NSROC Experiments:

Water Recovery Shutter Door (22")

NSROC Forward OGIVE Recovery Section (N-FORSe)

40-50 Mbps Ulyssix PCM stack

Solar sensors

Current sensor

Vacuum monitor

Power supply

Timer

Uplink stack and receiver

Transmitter

Vibrometers

Processor in a frame

Analog to Serial Board

Inertial Measurement Unit (IMU)

Peregrine Static Firing

Two static firings of the prototype Peregrine sustainer motor were conducted on Wallops Island. The firings were conducted in a purpose-built horizontal safety restraint cage. The motors were instrumented with pressure, thermal, strain, and vibration sensors. In addition, photographic, video, high speed video, and thermal imaging products were recorded to support evaluation of performance. Even though the firings resulted in anomalous insulation performance, they provided valuable design evaluation information. Data collected will be used in a NESC sponsored re-design effort.

Peregrine static firing on Wallops Island, VA.

Aerial view of test firing operation on Wallops Island, VA.

Thermal camera overlay of Peregrine plume.

Prototype Spin Motor

The first test firing of the prototype spin motor was successfully conducted. The goal of the effort is to upgrade the existing spin motor design to a safer, less restrictive propellant hazard classification. The new classification will reduce safety concerns in addition to minimizing logistical, shipping, and storage issues. Six prototype cartridge grains have been cast with the first successful static test being conducted in September 2016. The first firing was conducted in a newly designed all aluminum motor case and was very successful, verifying all new design elements of the prototype motor.

Prototype aluminum spin motor case.

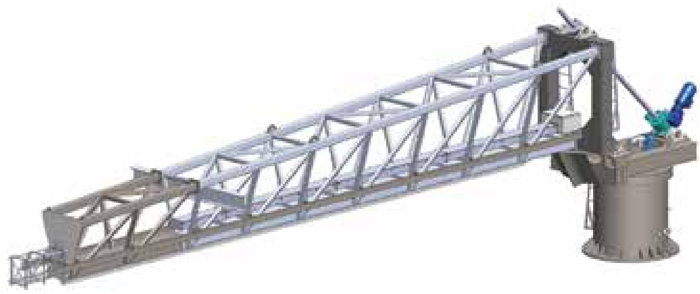
Spin motor grains.

Spin motor firing.

Medium Mobile Launcher (MML)

The Medium Mobile Launcher (MML) is the first launcher to be developed in-house by NSROC. The project began in 2014, and has progressed through design, fabrication, and testing and is nearly ready to be declared operational. The MML was designed to fill a void between the capacity of the mobile Missouri Research Laboratory (MRL) launcher and that of the semi-permanent Astro Met Laboratories (AML) 20K launcher, both already in use by SRPO. The MML is designed to launch vehicles as large as a Black Brant X (Terrier-Black Brant-Nihka) with a 1,000 pound payload. The launcher can also accommodate an extension on the forward end for umbilical rigging and for a retractable "zero-length" rail mechanism. The entire system will be stored and shipped in two standard shipping containers: one 40' long and one 20' long. The first intended use of the MML is the 2019 sounding rocket campaign in Australia.

MML launcher on Wallops Island.

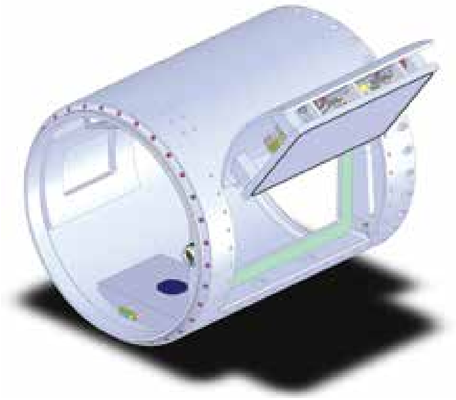


SolidWorks model of the MML.

The development of the new launcher was executed by a team of NSROC personnel from various groups. These include Launcher Systems, Mechanical, Electrical, Flight Performance, and Launch vehicle Engineering, as well as the Machine Shop, the Electrical Fabrication Shop, Safety & Mission Assurance, and Mission Management.

Side-Opening Vacuum Doors

Mission 36.305 Galeazzi featured a particularly exciting engineering and fabrication challenge for NSROC. The science instrument had five detectors that were very large and required a field of view that could only be achieved by orienting them to look out the side of the payload. Furthermore, the cleanliness requirements for the three of the five detectors necessitated a vacuum-sealed enclosure while in the Earth's atmosphere. The mission team responded by developing five large, side-opening doors, three of which were vacuum-sealed.



SolidWorks model of the Side–Opening Vacuum Door.

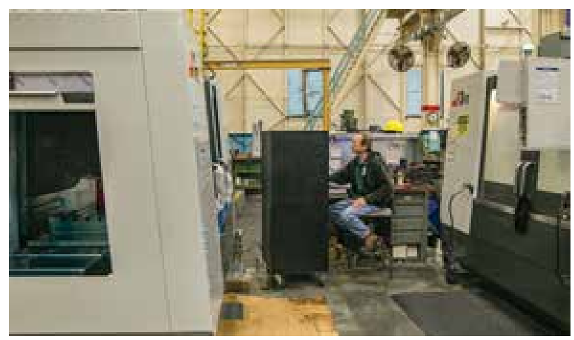
The complex nature of the doors each required multiple moving parts and fine adjustments during assembly for proper opening, closing, sealing, and locking. Furthermore, environmental testing of the fully built payload required additional effort due to the doors. For example, mass properties measurements were conducted with doors closed, and again with doors open. Also, because of the extreme length of the payload, spin balance was conducted in two separate operations.

The doors performed nominally during launch, maintaining the required vacuum level on the three vacuum-sealed doors. All five operated properly by fully opening and closing on either side of science data collection. The two non-vacuum-sealed doors experienced anomalies on re-entry, however, resulting in damage to two science detectors. In the end, the Principal Investigator received good science data.

36.305 UH Galeazzi payload with side–opening vacuum doors prior to launch at White Sands.

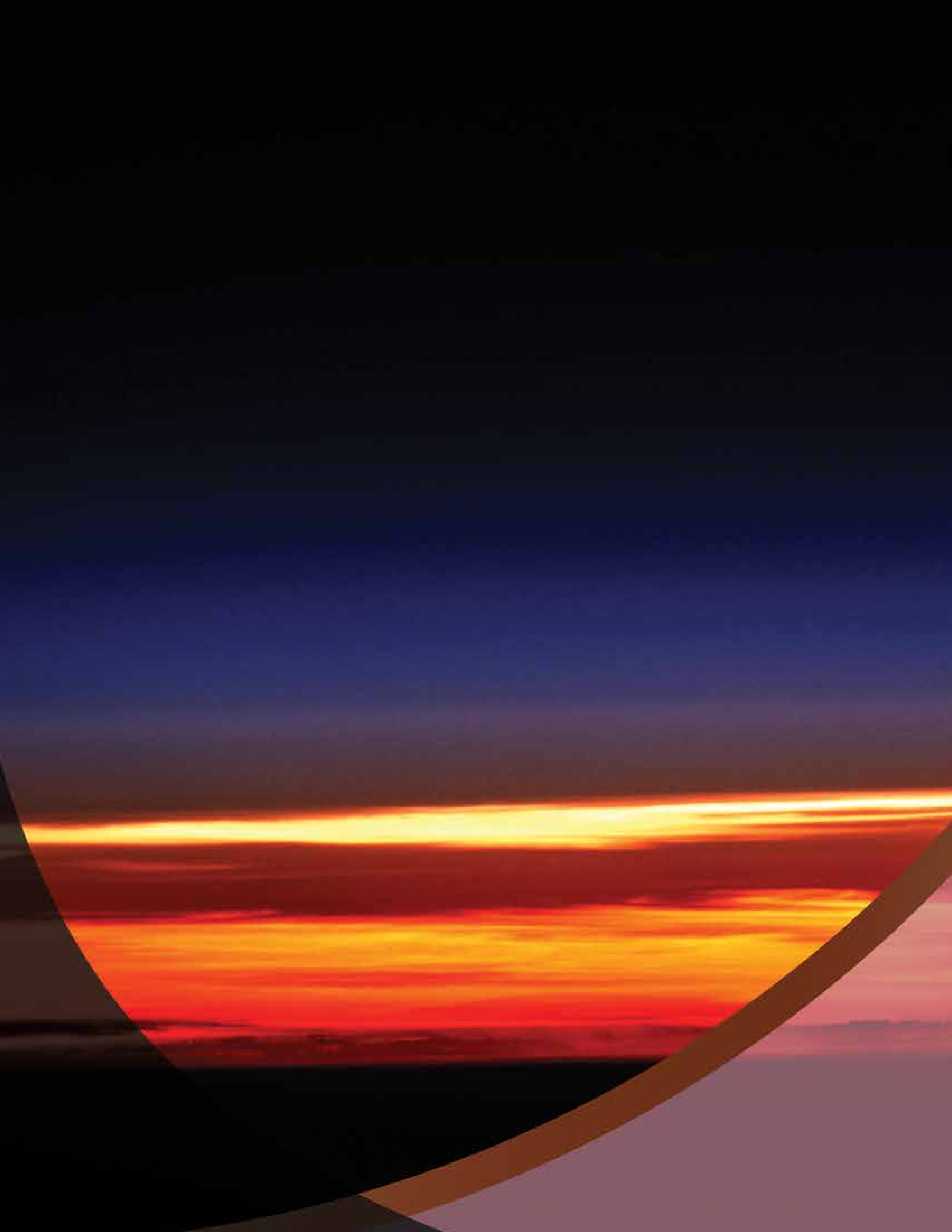
Manufacturing Cells

NSROC has implemented an approach in the Machine Shop where one machinist operates multiple machines. This has proved effective at increasing operator efficiency. One example of this approach may feature a lathe making an individual skin section and a milling machine doing high volume runs of small parts, with a single machinist setting up and operating both. This work cell implementation has resulted in an increase in overall production capacity in the Machine Shop, reducing back-log. This has also reduced the need for outsourcing, while maintaining the NSROC mission schedule. Furthermore, an overall cost reduction per part has been achieved from the improved efficiencies.



Machining cells – one machinist operating several machines.

Nate Wroblewski with the water wedge.



New opportunities to conduct science missions in the Southern Hemisphere are being developed by SRPO. Two launch sites in Australia are being evaluated for use in 2019 for Astrophysics missions.

FY 2018 will see several flights from launch sites in Norway. The campaign involves both US, Norwegian, and Japanese scientists and an international student mission. Two US science flights will launch from Svalbard and two from Andøya. The Norwegian and Japanese rockets will launch from Andøya. All missions study the polar ionosphere and Cusp region.

Additionally, SRPO is returning to the Kwajalein Atoll in 2017 to launch two rockets to study the stability of the post sunset equatorial F region ionosphere.

On the Horizon

Kwajalein 2017

The SRPO will once again be returning to the Regan Test Site (RTS) in the Kwajalein Atoll to conduct equatorial science investigations. For many years, the SRPO has been trying to provide more routine opportunities for our scientists to study the equatorial ionosphere, with this investigation we are one step closer. Dr. David Hysell of Cornell University was selected to conduct the Waves and Instabilities from a Neutral Dynamo (WINDY) from Kwajalein in late August-early September 2017.

WINDY will study the stability of the post sunset equatorial F region ionosphere and the factors that predispose it to equatorial spread F (ESF), a spectacular phenomenon characterized by broadband plasma turbulence, which degrades radio and radar signals at low magnetic latitudes. The goal of the investigation is to lay the foundation for a strategy to forecast this disruptive phenomenon. The Advanced Research Projects Agency (ARPA) Long-Range Tracking and Instrumentation Radar (ALTAIR) will be used in conjunction with other ground based instruments to monitor the state of the upper atmosphere/ionosphere and help determine if the scientific conditions are suitable for launch.

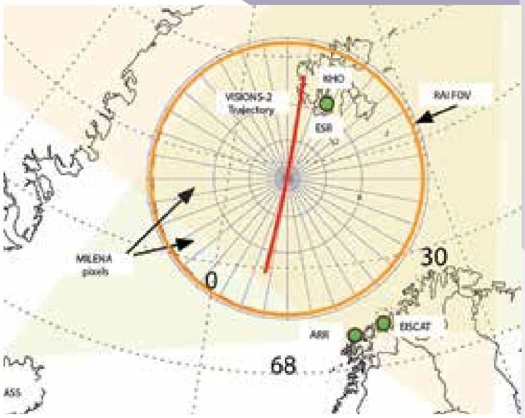
SRPO and NSROC crews are busy making launch site preparation with a service trip planned for the first of the year. SRPO is once again working with the RTS staff to make a few more permanent site improvements that should help reduce costs on future missions.

Grand Challenge (GC) - Norway FY 2018

Four science investigations and one student mission will be launched as part of the Grand Challenge (GC) – Cusp Initiative in northern Norway. The GC is a joint international science campaign being managed by the Andøya Space Center with help and assistance from NASA's SRPO. The first GC Initiative is designed to bring together an array of scientist from the radar community, scientific modeling community, and sounding rocket researchers to focus their efforts on the Cusp. At present, the NASA component includes two science investigations with four launch vehicles. Two launches will take place from Andøya Space Center and the other two from the SvalRak launch range in Ny-Ålesund, Svalbard. The Principal Investigators are Dr. Craig Kletzing, University of Iowa, and Dr. Douglas Rowland, Goddard Space Flight Center. The University of Oslo and the Japanese space agency JAXA will also be launching one investigation, both from SvalRak as part of the GC. To help inspire and train the next generation of engineers and scientists, a joint US-Norway student mission, RockSat-XN, is planned to be launched in the second phase of the GC planned for January 2019. The student mission is similar to the Colorado Space Grant Consortium RockSat-X concept and is designed to bring students from Norway and the US together in a joint international mission.

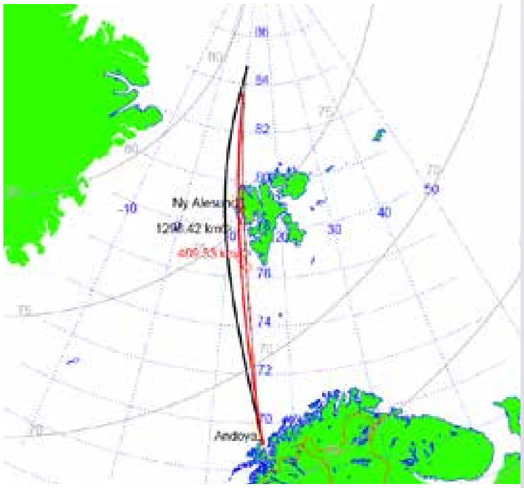
The NASA science missions, VISualizing Ion Outflow via Neutral atom imaging during a Substorm 2 (VISIONS-2) with Principal Investigator Dr. Rowland and Twin Rockets to Investigate Cusp Electrodynamics 2 (TRICE-2) with Principal Investigator Dr. Kletzing, will both study the polar ionosphere and Cusp region.

VISIONS-2 is specifically designed to investigate the outflow of oxygen ions from Earth's upper atmosphere and into the magnetosphere. This mission will observe the phenomenon during the day from Earth's magnetic cusps— regions near Earth's poles where the magnetic field lines dip down toward the ground. This information will lead to a better understanding of the physics that influence the Earth's magnetosphere, the region where most space assets, including communications satellites, reside. Such satellites are sensitive to severe space weather caused by the solar wind.



Two BB X's launched to >700 km in the cusp. Measurements are taken in conjunction with EISCAT, SuperDARN, ASIs, and ground–based magnetometers.

Magnetic reconnection has emerged as a major topic of interest for both space-based and laboratory plasma physics. The process occurs in a variety of plasmas from controlled fusion devices to our near-Earth plasma environment, as well as for astrophysical plasmas, such as solar flares and stellar atmospheres. The ***TRICE-2*** scientific goals are aimed at distinguishing between signatures of pulsed reconnection versus those of steady reconnection, as well as investigating ionospheric cusp electrodynamics. By examining the evolution of stepped cusp ion dispersion along nearly identical field lines at a variety of different times, the team can determine if the stepped forms have moved due to convection as predicted by pulsed reconnection models, or if the steps are fixed in latitude as predicted by steady reconnection models. The comprehensive suite of measurements will allow a detailed study of the temporal physics of current closure, incident Poynting flux, Alfven wave occurrence, and high frequency waves.



A sample TRICE trajectory. The thin lines indicate the geodetic positioning of the payload and the thick lines indicate the magnetic foot–point track of the two payloads. The grey lines indicate the lines of magnetic latitude. NOTE: These trajectories have not been optimized for science conditions.

While this is the first GC initiative, there is hope it will lead to future collaboration on topics of scientific interest from a variety of scientific disciplines. Future missions and researchers may be added as the campaign matures. However planning is now underway for the core of the GC missions.

Australia Campaign

With a long tradition of launching sounding rockets from Australia, SRPO is once again planning to return to the "Land Down Under." While there is a long history of Sounding Rockets in Australia dating back to the 60s, it has been a while since we have launched from there. Three highly successful campaigns were conducted in 1987, 1988, and 1995 from the Woomera Test Range (WTR). The launches in 1987 studied the Supernova 1987A (a supernova in the outskirts of the Tarantula Nebula in the Large Magellanic Cloud), and were followed by another three launches in 1988 studying the same supernova. Additionally, six missions were launched in 1995 to study the Large Magellanic Cloud (LMC) in the ultraviolet and x-ray wavelengths. The LMC is only visible from the Southern Hemisphere.

SRPO is now considering two options for conducting launch operations in a Southern Hemisphere campaign: a return to WTR, or engaging a new launch range Equatorial Launch Australia (ELA). Both sites offer unique opportunities with unique challenges.

The WTR is located in South Australia and is a “trials area” for testing of defense systems. Sufficient space, facilities, and infrastructure exists to meet most of our requirements, with Wallops mobile range capabilities being utilized for telemetry, power conversion, and wind weighting. Black Brant IX class vehicles can be accommodated without waivers or range extensions.

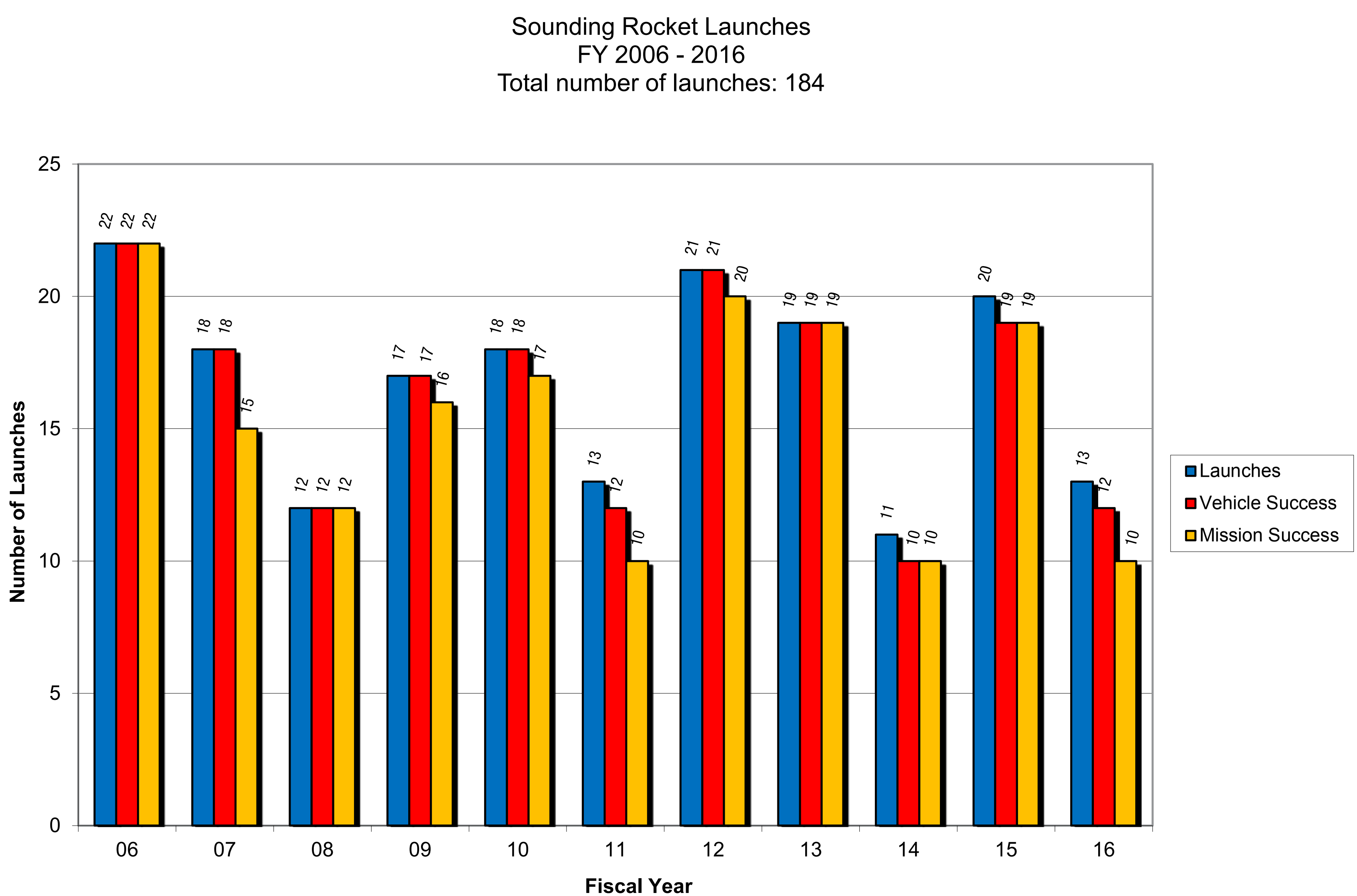
ELA is a new range under development for both sub-orbital and orbital launches from the Northern Territory. Presently, minimal infrastructure exists. However, the site has great potential due to its unique location. Extensive mobile operations support is required to enable launches from ELA, but this is not unusual for the SRPO with the remote campaigns we have conducted in the past. The large, uninhabited landing areas allow vehicles up to a Black Brant XI to be launched and recovered. This extends the capabilities for telescope missions by providing more observation time. Apogees on the order of 400 km (320 for BBIX) lead to approximately 20% more observation time above 150km.

Meeting area at the Garma Knowledge Center.

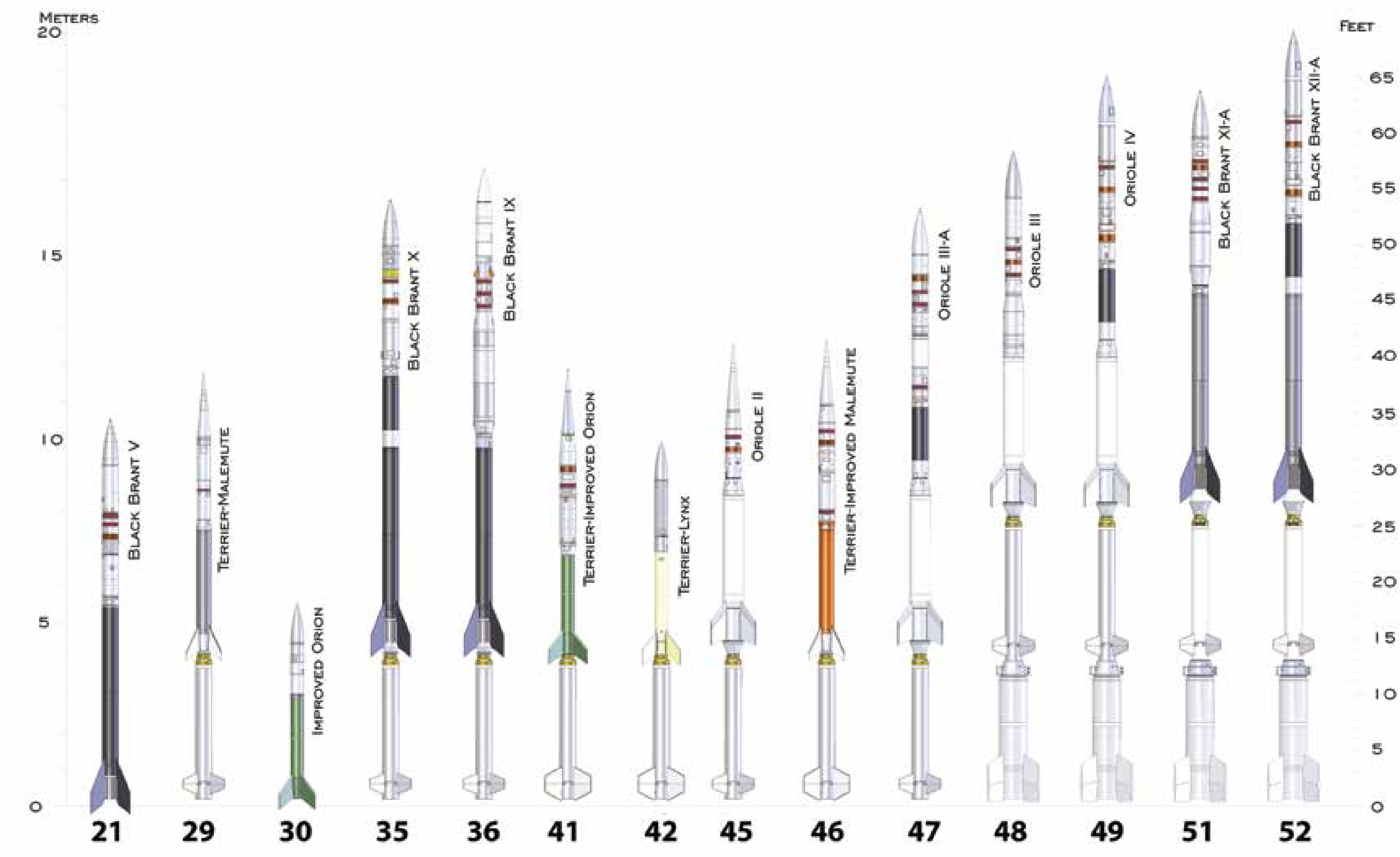
Planned launch area at ELA.

NASA team during the 2004 Kwajalein campaign.

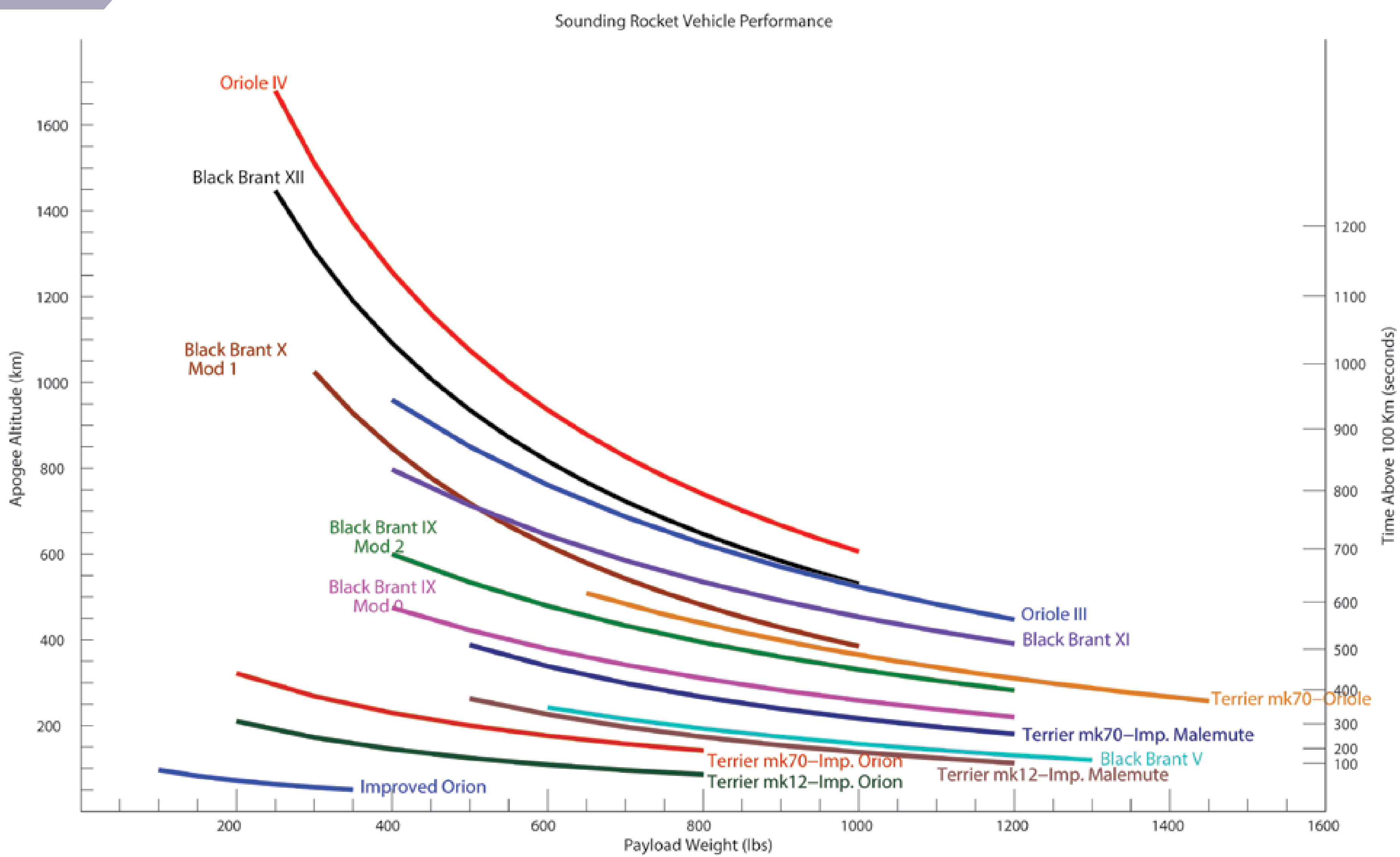
Mission Success History



Sounding Rocket Vehicles



Sounding Rocket Vehicle Performance



Sounding Rocket Launch Sites

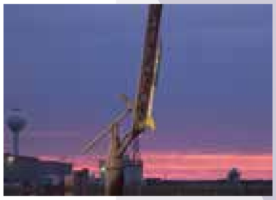

Poker Flat, Alaska


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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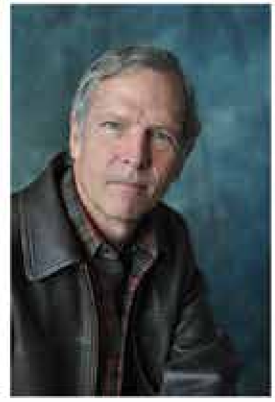
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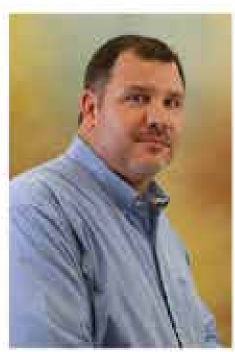
Todd Winder
Resource Analyst

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Science mission information submitted by Principal Investigators.

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