National Aeronautics and Space Administration

NASA Sounding Rockets Annual Report 2017

Message from the Chief

Phil Eberspeaker
Chief, Sounding Rockets Program Office

From studies of star birth regions in the Milky Way to our atmosphere and near space environment, sounding rockets enable science and technology advancement in a relatively low cost and fast turnaround fashion. An important hallmark of the program is its ability to conduct launch operations from locations around the world. These remote campaigns allow scientists to "go to where the science occurs, when it occurs". The Sounding Rockets Program's mobile capability, coupled with the unique ability to collect in-situ measurements at specific altitudes of interest, continues to make the program an important element of NASA's research activities.

Two geospace campaigns were conducted in 2017. The Poker Flat Research Range campaign involved a total of five rockets. Four of the rockets were launched to study the high latitude ionosphere, and specifically different aspects of auroral dynamics. The fifth rocket gathered data on nitric oxide and its link to ozone destruction at high latitudes. The equatorial campaign was conducted from the Kwajalein Atoll, Marshall Islands in September. This campaign involved two rockets designed to discover details about the formation of a phenomenon called Equatorial Spread F (ESF). Data from these missions, in conjunction with data from numerous missions over the years, are helping scientists better understand space weather and how it impacts our lives here on earth.

In addition to the two remote campaigns, the program also supported Solar and Astrophysics research, as well as, education and technology development activities. The Rapid Acquisition Imaging Spectrograph Experiment (RAISE) obtained the highest sequence of UV spectra of the Sun taken to date! RAISE studies the Solar Corona, Chromosphere, and the Transition region between the two layers. Moving further out in the Universe, the Colorado High-resolution Echelle Stellar Spectrograph (CHESS) enables scientists to study regions of star and planet formation in the Milky Way. CHESS was launched successfully for the third time in 2017. These missions help us better understand our local solar system and the evolution and dynamics of the universe as a whole.

One of the on-going goals of the program is to enable new science missions in order to expand scientific return. This activity involves the development of higher data collection rates, expansion of scientific observation times, and creation of new techniques to collect unique science. The program completed the development effort for the rocket propelled ampoule system which represents a new means for measuring high altitude particle dynamics over a large volume of space. This technology is also being applied to small instrumented subpayloads to enable simultaneous multi-point electric field and particle energy measurements. Where once five or six free flying subpayloads were possible, now twenty or more are feasible.

Astrophysicists are always wanting to collect more photons to enhance scientific return. This dictates a need for either larger diameter payloads to accommodate larger mirrors, or longer observation times – and usually both. Astrophysics missions have, to a large extent, been limited to flying from White Sands Missile Range in New Mexico due to the requirement to recover the instruments for re-flight. Longer flights require higher apogees, which generally dictate the need for ranges with larger impact areas. Larger launch ranges usually require flight over the ocean. The program is developing new water recovery technologies to enable such missions at a cost that is commensurate with the low-cost nature of the program. The new system includes a hydrodynamic wedge to reduce impact loads and sealed sections to protect the science instruments and expensive support systems such as telemetry and attitude control systems. The trick is, each of these systems needs to have some sort of exposure to the outside environment during the scientific data period, yet be sealed when they impact the ocean. While ocean recovery has been done for essentially the entire life of the program, it has involved relatively basic systems that offered few engineering challenges. Now telescopes, telemetry systems, attitude controls systems, and even the recovery systems themselves need to be protected so they can be reflow on future missions. The end result of these developmental activities will be expanded science and vehicle options for future scientific missions. The first operational missions for this new system will be two Astrophysics flights from the Kwajalein Atoll in the Marshall Islands in 2018. While the program is moving towards higher flights on select missions, it goes without saying that the varying mission requirements will require the continued need for White Sands operations.

Sounding rockets have always been platforms that merge leading edge science and education. Undergraduate and graduate students continue to work alongside Principal Investigators who are renowned scientists in their respective fields. Not only do the students collect the data necessary for their theses, they also obtain unique hands-on experience as they prepare the instruments for flight. Students work closely with sounding rocket engineers to ensure requirements are met and usually travel to the field to support launch operations. Sounding rockets are arguably the best means for students to get critical real-world experience in a short amount of time - experience that makes them better engineers and scientists. The Sounding Rockets Program also continued to offer internship opportunities for undergraduate students through the NASA Sounding Rockets Operations Contract, currently managed by Orbital ATK. The interns work with engineers and other professionals, and are engaged in mission critical tasks. This activity allows students to hone critical skills that make them more attractive to perspective employers. In many cases, they return to the program as experienced employees, ready to hit the road running.

The program continued to offer the RockOn! and RockSat-X student experiment opportunity through its collaboration with the Colorado and Virginia Space Grant organizations. This year represented the tenth successful RockOn! mission and the fifth RockSat-X mission. Under this program, the students built, tested, and flew experiments with various levels of complexity. The Sounding Rocket Program Office once again offered the Wallops Rocketry Academy for Teachers and Students (WRATS). This was the seventh year for this unique teacher training program where high school teachers spend a week leaning about rocket physics, building and launching model rockets and electronic payloads, and learning about the Wallops mission.

Once again, it has been a pleasure to have the opportunity to lead this fantastic team of dedicated professionals, who will always give their very best to complete our mission.

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Technology

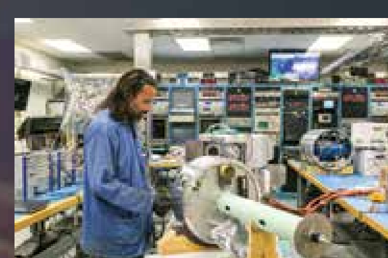
Water Recovery

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

NSROC Forward Ogive Recovery System (N-FORSe)

N-FORSe is a new recovery system assembly housed inside the ogive front end of a payload. Built with modern components N-FORSe is faster to assemble, lighter weight, and more cost effective than older systems.

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.



Missions

By Discipline

Sounding Rockets Overview

Manufacturing

The Lagun GBR5 is a Moving Table Machining Center. With an X axis travel of 197” Y axis travel 47” and Z travel 59” this is the largest milling machine in the shop. The GBR5 has a CNC controlled rotary table for doing large skin sections and will complement the Anayak milling center for the majority of the mission manifest. The machine also allows for longer launch rail sections to be milled in one set-up while maintaining tolerances.

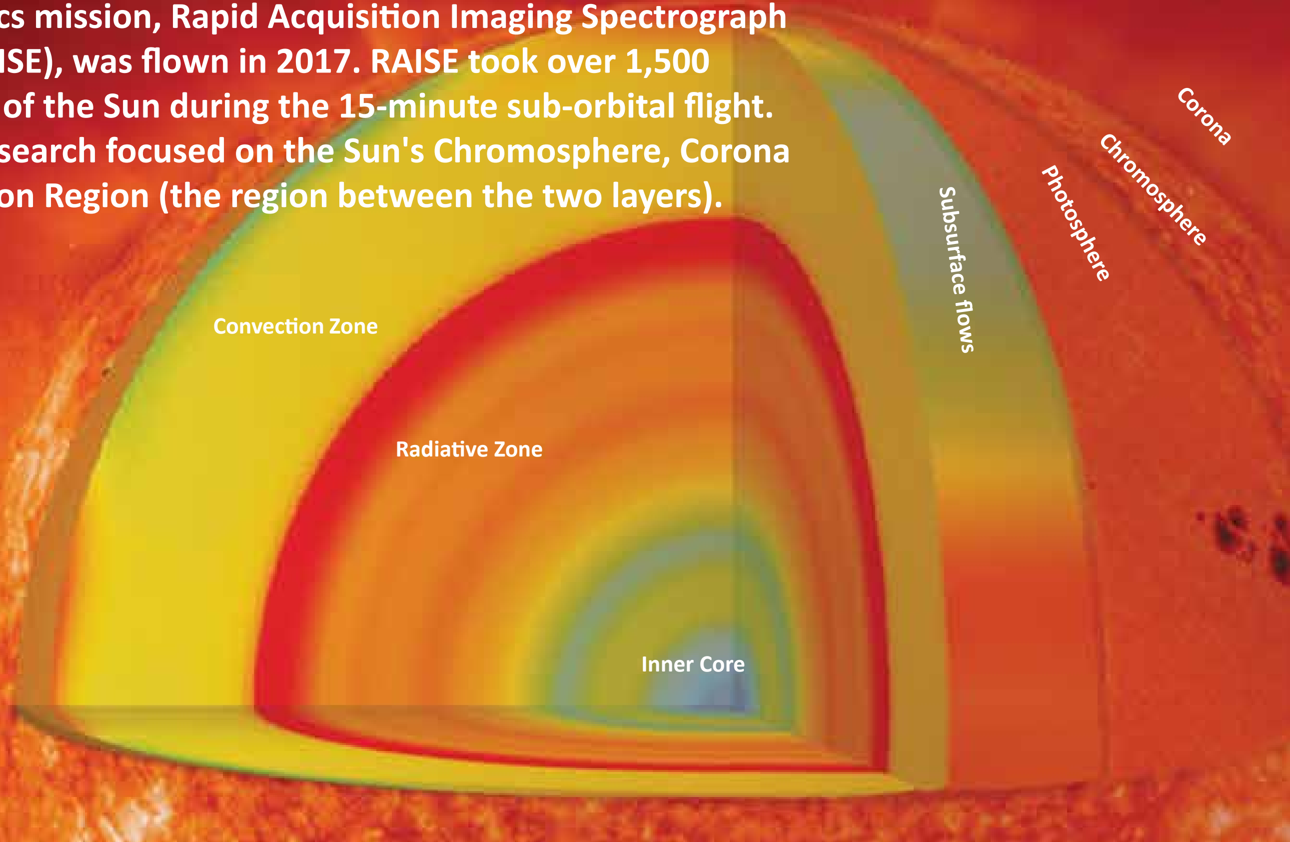
The large table on the OMAX 80X Water Jet Machining Center allows cutting of eight foot by twelve foot sheets of raw material up to six inches thick. The additional OMAX Water Jet creates another “Machine Cell” where one operator keeps two machines running concurrently. This efficiency drives an increase of production output.

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 2017 approximately twenty payloads were integrated and tested for flight.

SOLAR PHYSICS MISSIONS 2017

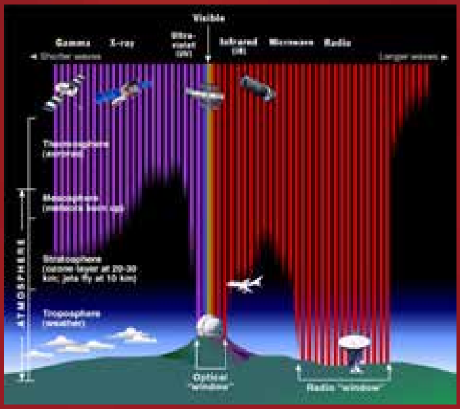
One Solar Physics mission, Rapid Acquisition Imaging Spectrograph Experiment (RAISE), was flown in 2017. RAISE took over 1,500 spectral images of the Sun during the 15-minute sub-orbital flight. The scientific research focused on the Sun's Chromosphere, Corona and the Transition Region (the region between the two layers).



Coronal loops are bright, curving structures that appear as arcs above the Sun's surface. Hot plasma causes these loops to glow. The electrified plasma flows along the curving lines of powerful magnetic fields, giving the coronal loops their characteristic shapes. Imaged by the TRACE spacecraft.

Jets, known as spicules, were captured in a Solar Dynamics Observatory (SDO) image on April 25, 2010. Spicules are short-lived jets of hot gas that shoot into the corona at more than 100,000 km per hour from the chromosphere below. Alfvénic waves have been discovered at extreme ultraviolet (EUV) and X-ray wavelengths in the spicules. The waves are more than 100 times more intense than those previously measured, and could further our understanding of coronal heating.

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, development of future technologies for spacecraft. Additionally an instrument can be launched at a predetermined time and location, as demonstrated with the RAISE mission that coordinated observations with the SDO. This type of coordination can augment and or calibrate satellite research. With short mission lead times and lower cost, sounding rockets enable world class science discovery.

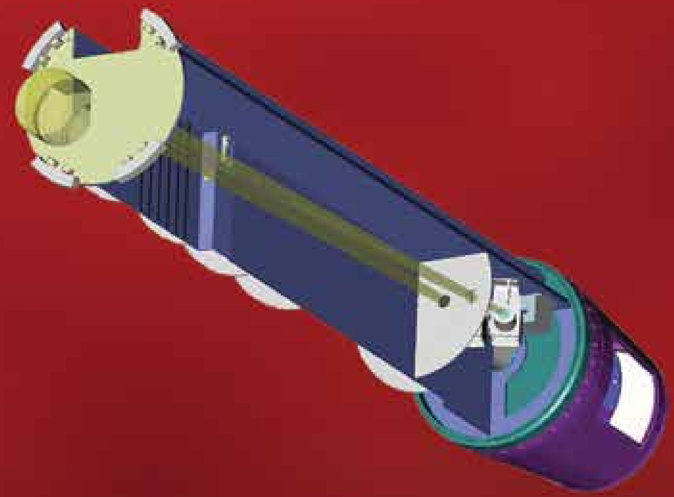
Instruments for Solar Physics

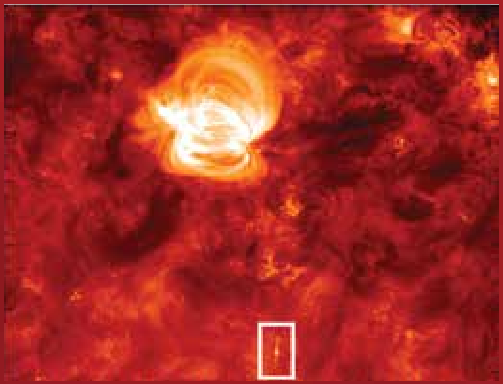
Spectrographs are commonly used instruments for solar physics. A spectrograph measures radiation intensity as a function of wavelength. All elements in the periodic table have associated characteristic spectra. When energy is added to an element, i.e., when electrons in an atom are excited and then transition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

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

Rapid Acquisition Imaging Spectrograph Experiment (RAISE)

The primary scientific objectives of the RAISE experiment focus on three areas; small-scale dynamics of coronal loops, the nature of high-frequency waves in the solar atmosphere and the nature of transient brightenings in the solar network. Each of these objectives are important to our understanding of the mechanisms of energy conversion in the solar atmosphere. RAISE images two different spectral bands in the Extreme Ultraviolet, 1st-order 1205-1243 Å and 1526-1564 Å, onto two intensified Active Pixel Sensor (APS) detectors. Examples of emission lines in these bands are H I Lyman α emitting at 1215.7 Å and Si II, silicon with one electron freed, emitting at 1533 Å.





Bright point (boxed) captured by the AIA instrument onboard the SDO spacecraft at 171 Å. Solar atmospheric coronal and transition region bright points (BPs) are compact features overlying strong concentrations of magnetic flux. These bright points are thought to contribute to coronal heating from cooler atmospheric layers, as they may provide injection of mass, energy, and rotation into the heliosphere.

Rapid Acquisition Imaging Spectrograph Experiment (RAISE)

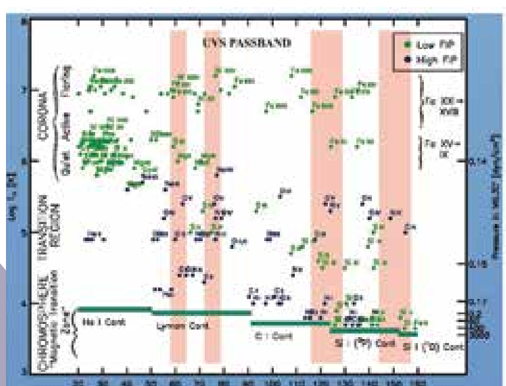
RAISE at Whte Sands Missile Range, NM before flight.

The primary scientific objectives of the experiment focus on three areas that are accessible only with the instrument's unique capabilities and can be advanced with a single flight with six minutes of observation time: Small-scale dynamics of coronal loops, the nature of high-frequency waves in the solar atmosphere and the nature of transient brightenings in the solar network. Each of these objectives is intended to answer specific questions that are important to our understanding of the mechanisms of energy conversion in the solar atmosphere. For example, how are temperature and velocity related in hot loop structures? And are there high-frequency waves in the solar atmosphere with sufficient energy to heat the corona or accelerate the solar wind?

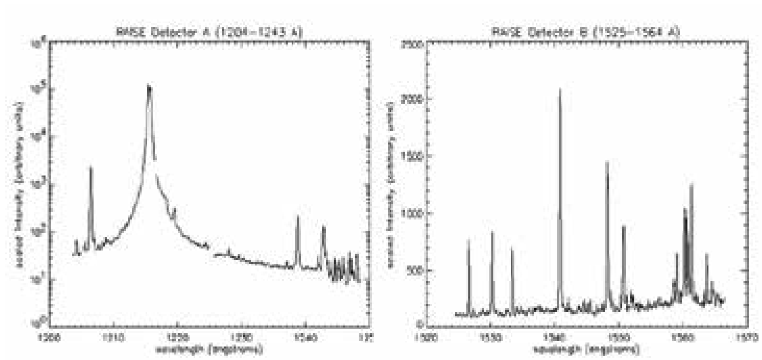
Specific science questions for flight 36.309 US were:

- Multi-Thermal Plasma Dynamics
  - How are temperature and velocity linked in active region and quiet sun loops?
  - Dynamics of ubiquitous helical loop structures?
- High Frequency Waves in the Lower Solar Atmosphere
  - How do high-frequency Alfven and magneto-acoustic waves relate to magnetic structure?
- Magnetic Carpet and Small Scale Energy Release in Solar Network
  - What drives small scale energy release in the sun? What are the observed small scale jet-like motions: shocks or jets?

RAISE imaged two different spectral bands in the Extreme Ultraviolet, 1st-order 1205-1243 Å and 1526-1564 Å, onto two intensified Active Pixel Sensor (APS) detectors. The telescope and grating are coated with B4C, boron carbide, to enhance short wavelength (2nd order) reflectance enabling the instrument to record the brightest lines between 602-622 Å and 761-780 Å at the same time.



UV/EUV lines and continuum as a function of wavelength and formation temperature. Shaded region shows the RAISE spectrograph wavelength coverage.



RAISE Spectral Coverage

Principal Investigator: *Dr. Donald Hassler/SWRI* • ***Mission Number(s):*** *36.309 US*
Launch site: *White Sands Missile Range, NM* • ***Launch date:*** *May 5, 2017*

Strong emission lines for elements in the RAISE spectral bands:

H I Ly α 1215.7 Å

Fe II 1563.8 Å

Si II 1533.4 Å

Si III 1206.5 Å

C IV 1548.2 Å

N IV 765.1 Å

N V 1238.8 Å

Ne VIII 770.4 Å

Mg X 609.8 Å

Fe XII 1242.1 Å

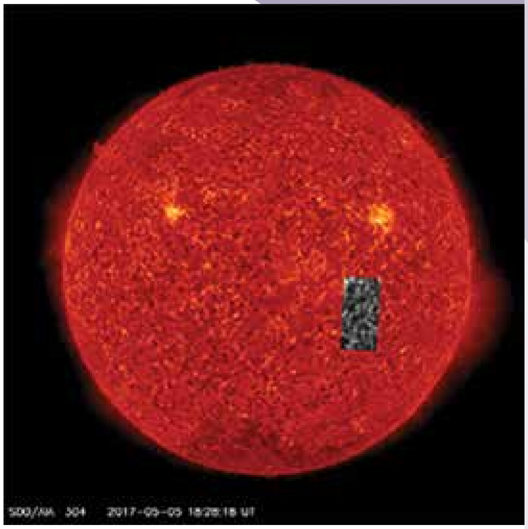


Figure 1: Sample RAISE Ly– wide–scan spectroheliogram taken at 18:31 UT overlayed onto co–temporal SDO/AIA 304Å full–disk image (18:28:18 UT).

During flight, manual uplink commands were used to independently select both the SPARCS scan type (3 arcmin wide scan, 45 arcsec narrow scan field-of-views, or fixed slit), as well as observing cadences (1, 5 and 8 Hz). Figure 1 shows the wide scan FOV superposed on an SDO/AIA 304 image taken roughly 3 minutes before launch. Although there was an alignment shift during launch, which resulted in a pointing offset away from the target Active Region (AR12654), Quiet Sun data is adequate for our science objectives. The spectra obtained from this flight are the highest cadence UV spectra of the Sun taken to date!

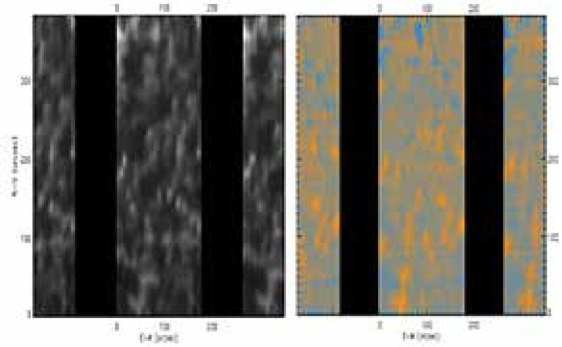


Figure 2: RAISE Spectroheliogram (left) and Dopplergram (right) from multiple Ly– wide raster scans. Dark regions separate scans.

Spectroheliograms and Dopplergrams

A reconstructed spectroheliogram of a portion of the Ly-α wide scan data is shown in Figure 2 (right). The intensity of each raster position is represented by each column in the image. The 180 position image was generated from 36 seconds of RAISE rasters and is the fastest solar UV spectroheliogram acquired to date. Further analysis of the flight data, including spectroheliograms of the Si II and other (weaker) lines, as well as even higher cadence narrow scan data (9 second scans) is ongoing.

Fixed-slit observations

Sixty-seven (67) seconds of the RAISE 36.309 flight data were taken while the SPARCS pointing system was in a fixed-slit observing mode. These data will be used primarily for the analysis of the high-frequency wave spectrum in the solar chromosphere and transition region.

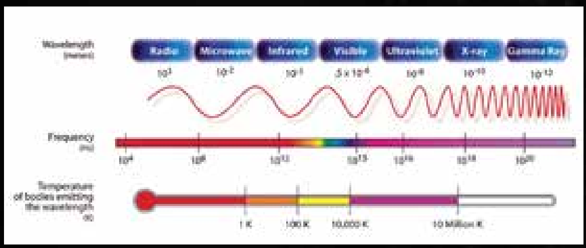
Complete data reduction, analysis and publication of the results is ongoing.

Astrophysics Missions 2017

Astrophysics seeks to understand the universe and our place in it and aims to discover how the universe works, explore how it began and evolved, and search for life on planets around other stars. In 2017 one Astrophysics mission, Colorado High-resolution Echelle Stellar Spectrograph (CHESS) 3, was flown. This was the third flight for CHESS.

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

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



Electromagnetic Radiation

Continuos spectra are created by hot opaque objects.

Hydrogen absorption spectra in visible wavelengths.

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

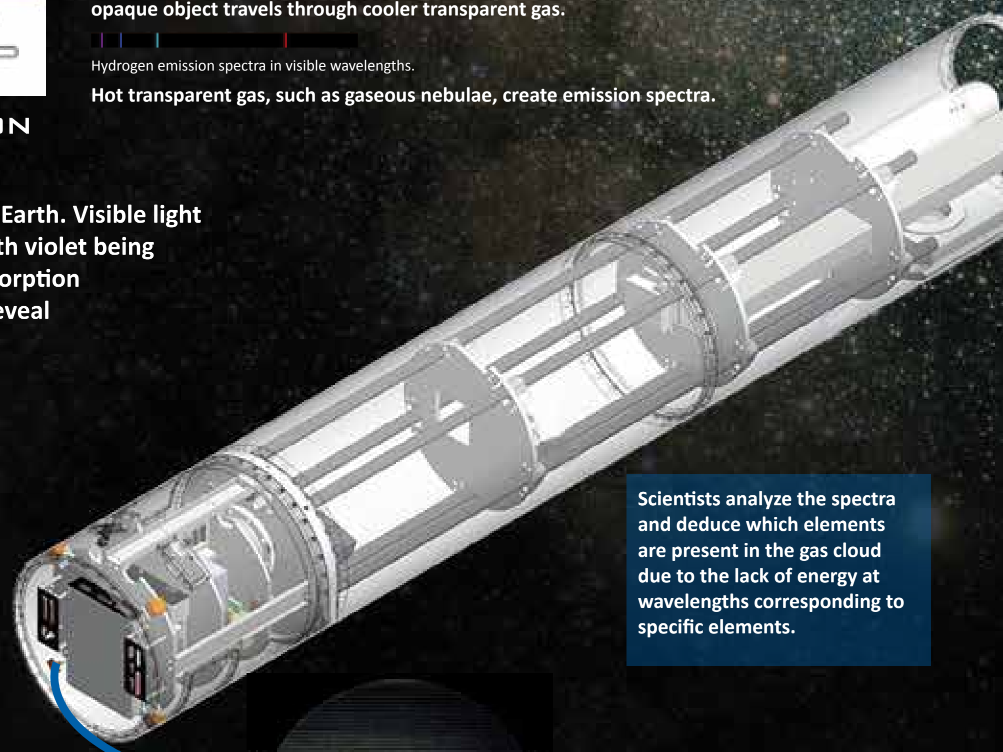
Hydrogen emission spectra in visible wavelengths.

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

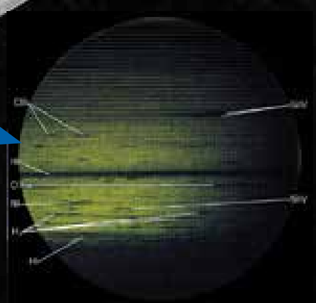
Visible light is what we are most familiar with on Earth. Visible light ranges in wavelength from 400 nm to 700 nm, with violet being the shortest wavelength and red the longest. Absorption and emission spectra of objects in the Universe reveal information about the elements present, the temperature,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

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

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

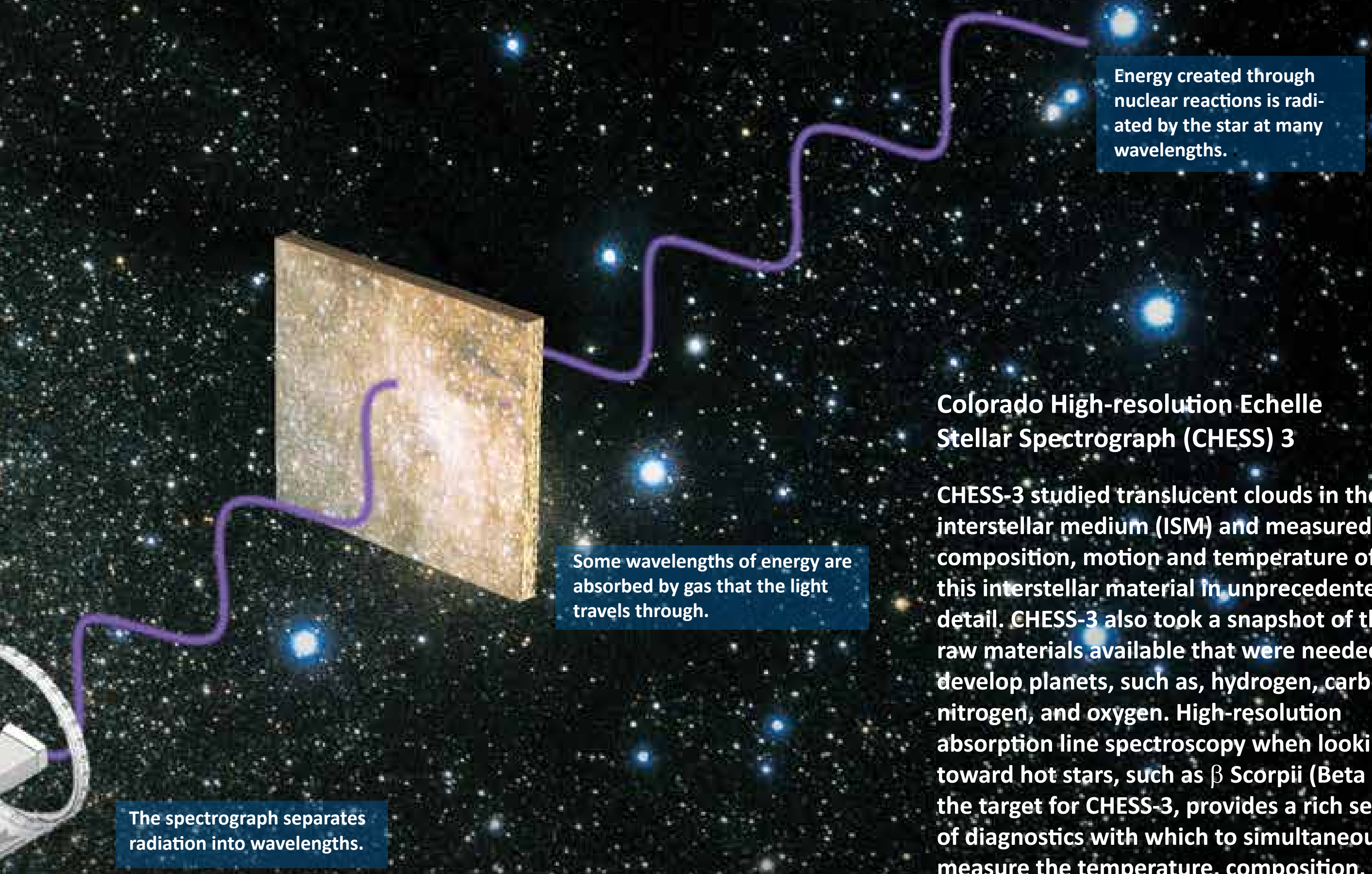


Scientists analyze the spectra and deduce which elements are present in the gas cloud due to the lack of energy at wavelengths corresponding to specific elements.



CHESS raw data is downlinked to the groundstation through telemetry. During the flight, graduate students monitor the data and uplink final pointing commands to the payload.

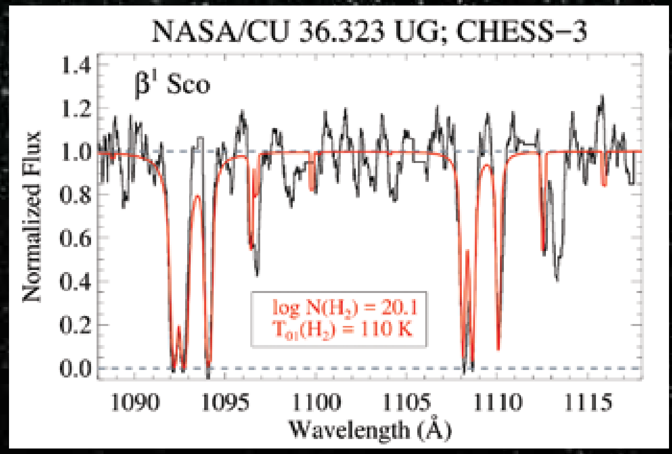
ß Scorpii



Colorado High-resolution Echelle Stellar Spectrograph (CHESS) 3

CHESS-3 studied translucent clouds in the interstellar medium (ISM) and measured the composition, motion and temperature of this interstellar material in unprecedented detail. CHESS-3 also took a snapshot of the raw materials available that were needed to develop planets, such as, hydrogen, carbon, nitrogen, and oxygen. High-resolution absorption line spectroscopy when looking toward hot stars, such as β Scorpii (Beta Scorpii) the target for CHESS-3, provides a rich set of diagnostics with which to simultaneously measure the temperature, composition, and velocity fields of the solar neighborhood.

Absorption spectra are created when radiation from an object travels through a gas, such as a nebula, or in the case of CHESS, a translucent cloud in the ISM. The gas absorbs some of the wavelenghts of energy leading to dark bands in the spectrum. For example, molecular hydrogen (H2) has a system of absorption lines near 1100 Å (110 nm), a wavelength where the Hubble Space Telescope does not have high-resolution spectroscopic capability. H2 traces cool molecular material (100 K), and makes up 99.99% of the total molecular gas in the Galaxy. If H2 is present in the cloud that the starlight passes through, the spectrograph will show less energy at wavelengths near 1100 Å. The CHESS spectrograph measures energies in the Far-Ultraviolet part of the spectrum, 1000 - 1600 Angstrom. This covers wavelengths of, for example, Oxygen VI, H2, several levels of ionized Carbon, Fe II and Mg II (once ionized Iron and Magnesium). These spectral features tell us about the physical and chemical state of the ISM and provide the initial conditions for future generations of star and planet formation.



This spectrum extracted from raw CHESS flight data shows interstellar absorption features of molecular Hydrogen (red line in the graph).

Colorado High-resolution Echelle Stellar Spectrograph - 3 (CHESS)

NASA and the University of Colorado at Boulder collaborated to launch an astrophysics experiment into Earth's near-space environment in order to study the life-cycle of stars in our Milky Way galaxy. The NASA/CU 36.323 UG – France mission launched off of the Athena launcher at Launch Complex 36, White Sands Missile Range, 05:10 Z, 27 June 2017. The CHESS-3 instrument acquired data on sightline to the hot star Beta Scorpii. The payload was successfully recovered. Comprehensive success was achieved for 36.323 UG.

Colorado University science team at White Sands Missile Range.

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 Beta Scorpii, in the constellation Scorpius. 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 hydrogen, 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. 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).

During this flight two 160 second science images were taken during the CHESS-3 mission. Additionally, a bias frame exposure, directly after payload de-spin and separation, and a 160 second dark image, after the shutter door closure, were made.

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 exoplanet/cosmic origins mission, Large UV/Optical/IR Surveyor (LUVOIR), currently under study. The LUVOIR Ultraviolet Multi-Object Spectrograph (LUMOS) is being led by Dr. France's team at the University of Colorado and would address topics ranging from characterizing the composition and structure of planet-forming disks to the feedback of matter between galaxies and the intergalactic medium.
[Link: http://cos.colorado.edu/~kevinf/](http://cos.colorado.edu/~kevinf/)

CHESS payload with recovery team after flight.

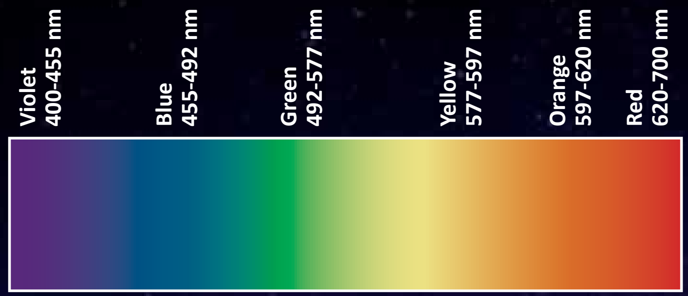
Principal Investigator: *Dr. Kevin France/University of Colorado* - ***Mission Number(s):*** *36.323 UG*
Launch site: *White Sands Missile Range, NM* - ***Launch date:*** *June 27, 2017*

CHESS-3 ready to launch at White Sands Missile Range, NM.

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 sun and 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 direct measurements in focused events, such as the aurora, regions of space above thunderstorms, ionospheric turbulence, noctilucent clouds, and the cusp, to name a few. In addition, sounding rockets are the only means to gather direct measurements in the region of space between roughly 40-150 km which is too high for balloon and too low for satellite direct measurements.

The aurora borealis, or northern lights, created when charged particles are accelerated in the magnetosphere by solar wind driven electric fields, are frequently studied with sounding rockets. Near the geomagnetic poles, the near vertical magnetic field lines extend upwards, through the upper atmosphere, allowing the downcoming energetic particles to interact with the neutral atoms of mostly oxygen and nitrogen. The energetic 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 its electron transits back to its initial level, a photon is emitted, causing the auroral light show. High energy electrons cause oxygen to emit green light, while lower energy electrons cause a red light emission. Nitrogen generally gives off a violet-blue light.



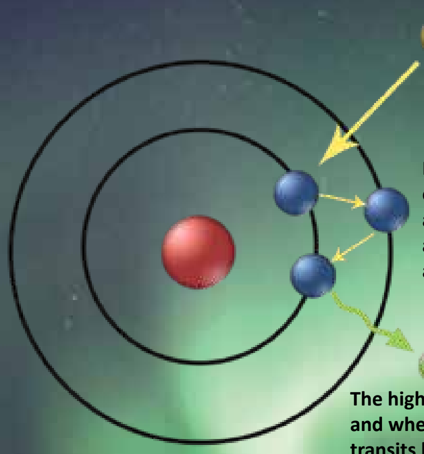
Violet-Blue Aurora emitted by nitrogen at 427.8 nm.

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

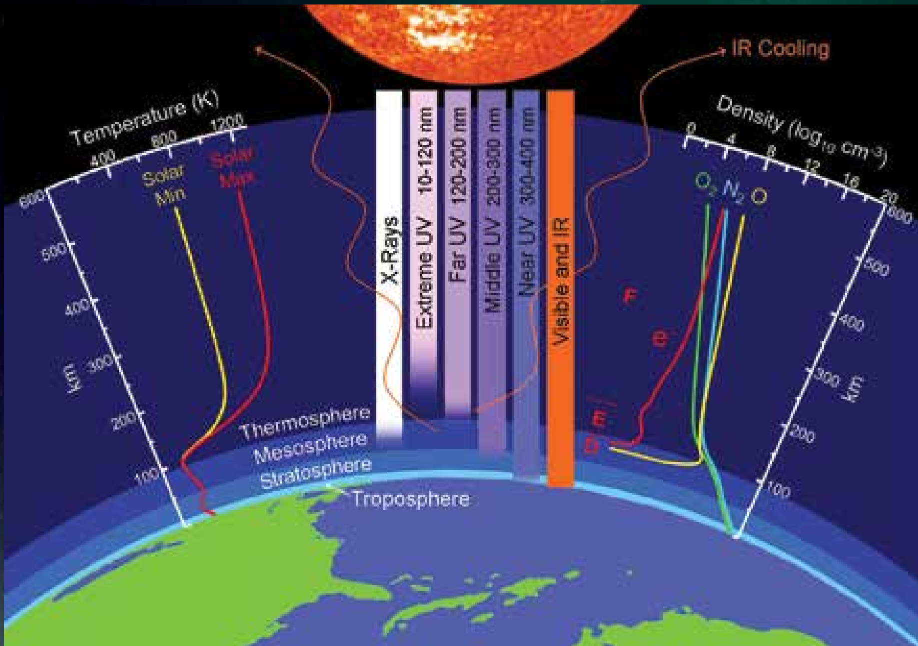
The higher level is unstable and when the electron transits back it releases energy by emitting a photon, thus creating the auroral light.

Polar Night Nitric Oxide (POLARNOX)

The overall goal of PolarNOx was to determine the altitude profile of nitric oxide (NO) in the polar night. NO is created by aurora. In a sunlit atmosphere, NO would be destroyed in about one day. But in the polar night it is expected that the NO abundance can grow to large values. Nitric oxide under appropriate conditions can be transported to the stratosphere where it will catalytically destroy ozone. Those changes in ozone can lead to changes in stratospheric temperature and wind and may even impact the circulation at the Earth's surface.

Ionospheric Structuring: In Situ and Ground based Low Altitude StudieS (ISINGLASS)

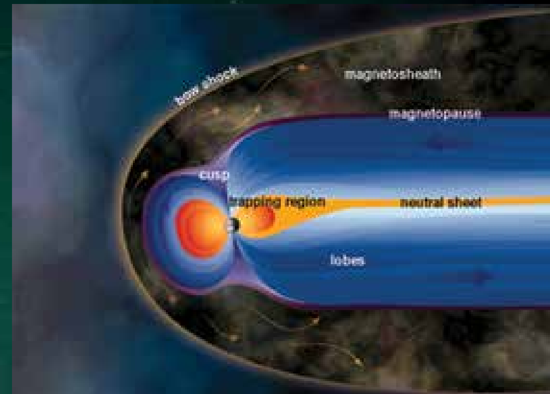
The visible light produced in the atmosphere as aurora is the last step of a chain of processes connecting the solar wind to the atmosphere. The data collected with the ISINGLASS mission will aid in understanding what structure in these visible signatures can tell us about the electrodynamics of processes higher up.



The graphic shows Earth's atmosphere layers and types of solar radiation as well as the altitudes where the various energies are absorbed. On the right is a depiction of the daytime ionosphere (in red) and chemical composition (in yellow, green, and blue) of the principal components of the neutral upper atmosphere, which is primarily composed of molecular oxygen, nitrogen, and atomic oxygen. This region of the upper atmosphere attains high temperatures, as shown on the left hand side, and is called the thermosphere.

The ionosphere is created by the ionization of the neutral atoms and molecules of the upper atmosphere which results from the Sun's extreme ultraviolet light. This extreme ultraviolet light knocks electrons off the gas atoms and molecules, leading to a gas of electrically charged particles of ions and electrons, which exist in the same volume as the thermosphere above about 100 km altitude.

Sounding rockets enable detailed studies of the ionosphere/thermosphere. This region is absolutely critical for understanding our planet and the space surrounding it.



In addition to the Sun's radiation, the Sun also send particles and fields toward the Earth which compose the solar wind, a stream of electrically charged particles (mostly protons and electrons) flowing out, away from the Sun. The Earth's magnetic field forms the magnetosphere envelope which deflects most of this stream of solar wind particles and energy. The solar wind/magnetosphere interaction does set up large electric fields which accelerate particles which are generally guided along the magnetic field from the nightside of the magnetosphere into the upper atmosphere at high latitudes where they produce the visible aurora. A different type of aurora, the cusp aurora, is produced when energetic particles directly from the solar wind are accelerated downward into the upper atmosphere on the dayside near the poles.

Geospace Missions 2017

Neutral Jets Associated with Auroral Arcs

The Auroral Jets experiment investigated whether the increased plasma density along an auroral arc undergoes enhanced collisions with the neutral atmosphere such that the magnetospheric electric fields which drive the plasma flow might also create discrete neutral streams or "jets" along the auroral "ribbon" or arc. These rockets were launched over a discrete auroral arc and recorded clear neutral "jets" by both the neutral wind insruments on the rockets and the vapor trail experiment. The combined, comprehensive data sets thus enable an in-depth study of a fundamental natural process involving the localized response of the earth's upper atmosphere to the aurora and its associated driving DC electric fields and energetic particles originating in the magnetosphere.

Waves and Instabilities from a Neutral Dynamo (WINDY)

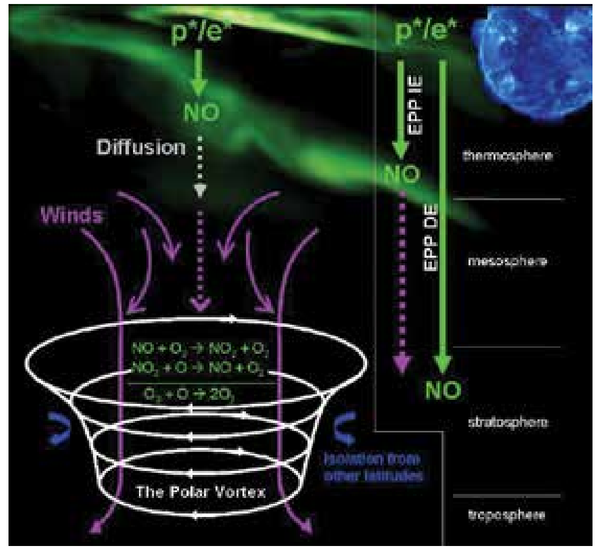
Two rockets were part of the Waves and Instabilities from a Neutral Dynamo (WINDY) mission. WINDY was designed to study a phenomenon referred to as equatorial spread F (ESF). ESF disturbances occur in the F region of the ionosphere post sunset at latitudes near the equator. ESF disturbances interfere with radio communication, navigation, and imaging systems and pose a hazard to technology and a society that depends on it.

Polar Night Nitric Oxide (POLARNOX)

The overall goal of PolarNOx was to determine the altitude profile of nitric oxide (NO) in the polar night. NO is created by aurora. In a sunlit atmosphere, NO would be destroyed in about one day. But in the polar night it is expected that the NO abundance can grow to large values.

At present we a have a poor understanding of how much NO is produced in the aurora and how it is distributed in altitude. We know that in some years, the polar night NO is transported to lower altitudes where it catalytically (i.e. very efficiently) destroys ozone. When this happens, the effects are significant as the temperature at that altitude is increased and the circulation can be altered. Thus we have a need to understand NO, its abundance, and its altitude distribution. We measure that by using a star as a light source and observing attenuation of the star light by NO. A rocket is needed because NO absorbs only ultraviolet light, which does not travel through air near the surface, so the measurement must be made from space.

The PolarNOx investigation was launched on Terrier-Brant rocket 36.302 on January 27, 2017 to an altitude of 283 km.



NO can under appropriate conditions be transported to the stratosphere where it will catalytically destroy ozone.

PolarNOx instrument alignment.

Principal Investigator: *Dr. Scott Bailey/Virginia Tech* • ***Mission Number(s):*** *36.302 UE*
Launch site: *Poker Flat Research Range, Alaska* • ***Launch date:*** *January 27, 2017*

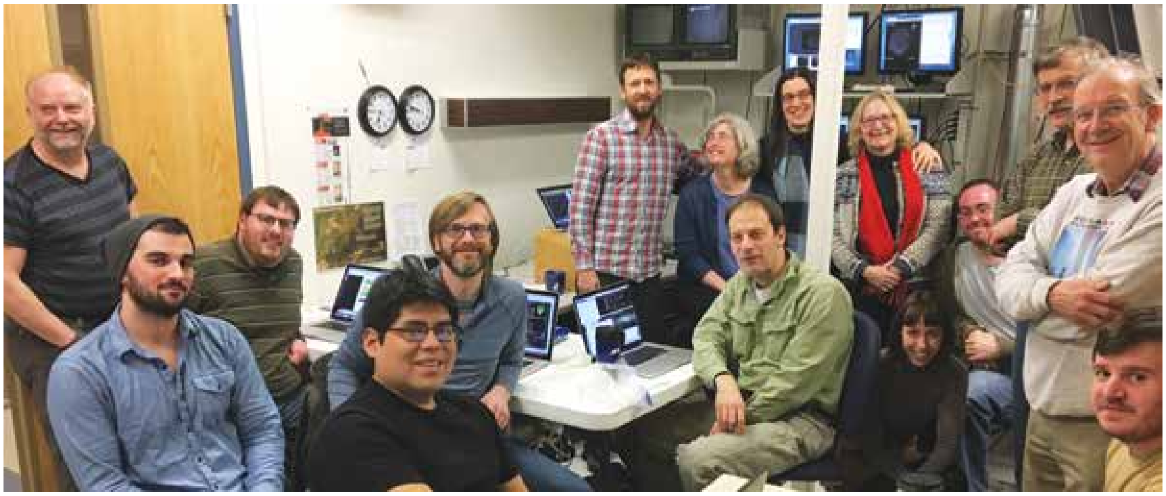
Ionospheric Structuring: In Situ and Ground based Low Altitude StudieS (ISINGLASS)

The ISINGLASS sounding rocket mission was designed to sample multiple locations simultaneously in the auroral ionosphere to measure the ionospheric plasma flow field. Two identical rockets were flown into two separate auroral events; each rocket carried a large sub-payload, and four small deployable payloads called Bobs. A door malfunction on the first flight prevented the Bob deployment; on the second flight, the four Bobs deployed cleanly and returned science data throughout the flight.


Deployment testing of sub–payloads.

The in situ measurements of ionospheric plasma from multiple locations will be stitched together using ground based measurements and data assimilation. The information gained in this process is also being applied to a CubeSat swarm mission design concept, to sample the aurora via localized multipoint measurements on orbital spacecraft in the context of ground based observations.

For ISINGLASS the multipoint auroral measurements were made using the Petite Ion Probe (PIP) retarding potential analyzer sensor. The PIPs were carried by four deployable payloads known as Bobs. The Bob payloads ejected from the (second) main payload with springs. Data from the separable payloads were transmitted back to the Bob-mains onboard the main payload. In addition, six PIPs were carried by each main payload, and their data stream passed to Wallops TM through onboard Arduinos and the Dartmouth-student-designed "Bob-shield" boards. The main payload also carried an auroral precipitation sensor Acute Precipitating Electron Spectrometer (APES), a scientific magnetometer, and a thermal electron plasma sensor, Electron Retarding Potential Analyzer (ERPA). A Cornell COWBOY electric field payload completed each array. A significant ground-based sensor array, including the use of PFISR, and filtered ground cameras at various sites, and a modelling/ assimilation analysis, completed the mission.


The ISINGLASS science team in the Science Operations Center (SOC) at Poker Flat Rocket Range, during the campaign.

Principal Investigator: *Dr. Kristina Lynch/Dartmouth College* • ***Mission Number(s):*** *36.303 & 36.304 UE*
Launch site: *Poker Flat Research Range, Alaska* • ***Launch date(s):*** *February 22 & March 1, 2017*

Neutral Jets Associated with Auroral Arcs

Background and Scientific Motivation

At high latitudes, energy and momentum from the very high altitude magnetosphere is guided down to lower altitudes by the earth's magnetic field where they "impinge" on the ionosphere/upper atmosphere, often with profound effects. In particular, electric fields and energetic electrons respectively set the ionosphere in motion and interact with the neutral gases creating the aurora and subsequent layers of enhanced ionospheric density or "thermal plasma". These ionosphere movements or drifts, in turn, set the neutral gases in motion via collisions between the ion and neutral gases which occupy the same volume.

When these two phenomena -- enhanced ionospheric motions and auroral arcs -- occur in the same location for an extended period of time, scientists have theorized that neutral streams or "jets" might be set up along the auroral arcs (Figure 1.) The idea is that the regions of increased plasma density along the auroral arc will undergo enhanced collisions with the neutral atmosphere and since that plasma density is set in motion by the electric fields, it would be expected to subsequently set up discrete motions of neutral gas along the auroral "ribbon".

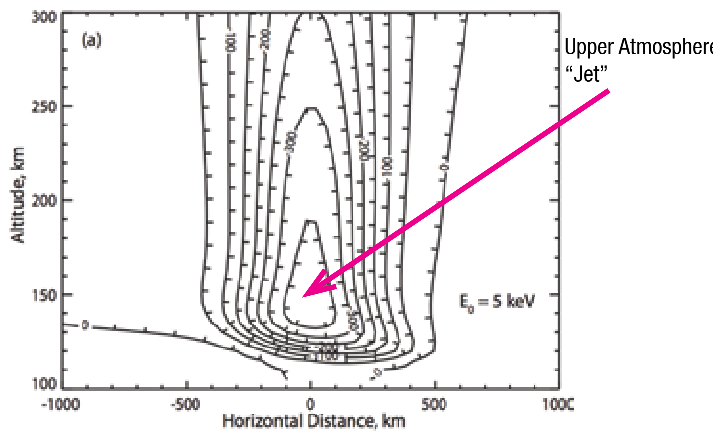


Figure 1: Computer simulation of atmospheric "winds" along an auroral arc.[Model by R. Walterscheid, Aerospace Corp.]

With this hypothesis as motivation, the main objective of the Auroral Jets investigation is to understand the height dependent coupling processes associated with auroral arcs and to determine if these processes create localized neutral "jets" in the upper atmosphere associated with the aurora. In turn, the rocket instrumentation will determine their driving conditions and associated heating and neutral structuring.

Experiment

The auroral neutral jets experiments consisted of two rockets launched nearly simultaneously to different altitudes over a stable auroral arc. The high and low altitude platforms were designed to determine the auroral jet characteristics, the background conditions and the driving electric field and particle input.

Each rocket was instrumented with plasma and neutral gas detectors as well as electric field and magnetic field detectors (Figure 2). Furthermore, the low flyer rocket released a vapor trail which was used to reveal the motions of the ambient neutral atmosphere along the rocket trajectory. Variations of these motions within the auroral arc region would thus show definitive evidence of the neutral "jets".

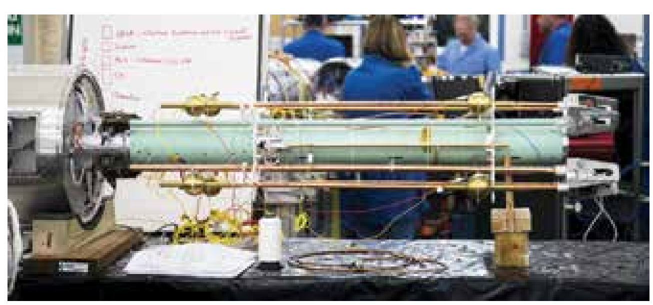


Figure 2: Auroral Jets electric field experiments are checked out at Poker Flat prior to put on the rail

Principal Investigator: *Dr. Robert Pfaff/NASA Goddard Space Flight Center* • ***Mission Number(s):*** *36.301 & 36.306 GE*
Launch site: *Poker Flat Research Range, Alaska* • ***Launch date:*** *March 1, 2017*

Finally, the experiment was carried out in conjunction with simultaneous measurements by a ground-based imaging Fabry-Perot system provided and operated by the University of Alaska, Fairbanks, which was used to determine the large scale neutral winds downrange from Poker Flat where the rockets flew, thus providing the background conditions and helping to determine the decision to launch the rockets.

Figure 3: Two Auroral Jets rocket launched 90 seconds apart over an auroral arc

The Auroral Jets Rocket Launches and Initial Results

With clear skies and good auroral conditions, NASA successfully launched the two Auroral jets sounding rockets from Poker Flat, Alaska on March 2, 2017 within 90 seconds of each other (Figure 3). The rockets were launched over an auroral arc, which was relatively stable for about 30 minutes, as measured by ground-based all sky cameras located at Poker Flat and downrange at Ft. Yukon.

The high flyer rocket, Terrier-Black Brant 36.301, achieved an apogee of 331 km and the low flyer rocket, Terrier-Black Brant 36.306, achieved an apogee of 190 km. Both rocket vehicles, the payload sub-systems, and the scientific instruments all worked flawlessly.

Figure 4: Neutral Flow from TMA Trail –– Shows auroral "jet" and aurora. Exposure at 05:49:20 U.T. Data from Prof. M. Larsen, Clemson University

The vapor trails, provided by Clemson University, revealed very clear evidence of the neutral winds and "jet" associated with the auroral arc (Figure 4). Triangulation from various camera sites set up at Poker Flat and downrange permit detailed, accurate measurements of the time history of the winds from photographs such as this one.

Furthermore, wind profiles were also measured in situ using instruments on the rocket payloads provided by the Aerospace Corporation which also revealed enhanced atmospheric motions or jets associated with the auroral arc on both the upleg and downleg (Figure 5). These measurements are being analyzed in conjunction with the detailed electric field, energetic particle, and magnetic field current measurements gathered on both rockets.

The combined, comprehensive data sets thus enable an in-depth study of a fundamental natural process involving the localized response of the earth's upper atmosphere to the aurora and its associated driving DC electric fields and energetic particles originating in the magnetosphere.

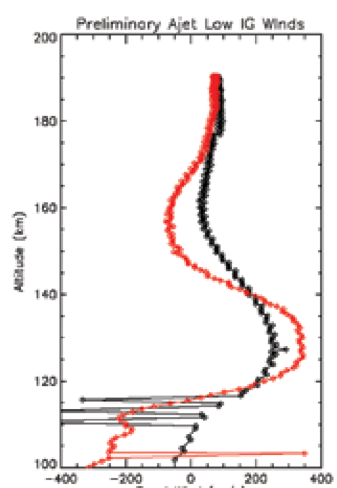


Figure 5: Neutral winds measured along upleg and downleg show "Jet" where arc was located. Data from instruments on the low flyer rocket provided by the Aerospace Corp.

Waves and Instabilities from a Neutral Dynamo (WINDY)


Payload preparation in Kwajalein.

Two rockets were part of the Waves and Instabilities from a Neutral Dynamo (WINDY) mission. The Black Brant IX sounding rocket was successfully launched at 7:34 a.m. EDT (11:34 p.m. local time) on September 9 and was followed five minutes later by a Terrier-Improved Malemute rocket. The first rocket flew to approximately 254-miles altitude and released its tri-methyl aluminum (TMA) and lithium, forming vapors to allow scientists to measure the winds and energetic particles that are in motion in the upper atmosphere.

The second rocket, carrying instruments to measure densities and electric and magnetic fields in the ionospheric disturbance, did not obtain useful data.

WINDY was designed to study a phenomenon referred to as equatorial spread F (ESF). ESF disturbances occur in the F region of the ionosphere post sunset at latitudes near the equator. ESF disturbances interfere with radio communication, navigation, and imaging systems and pose a hazard to technology and a society that depends on it.


Black Brant IX launches from Roi Namur.

The ionosphere is defined as the layer of the Earth's atmosphere that is ionized by solar and cosmic radiation. Ionization occurs when incoming energetic radiation strips electrons from atoms and molecules, creating temporarily charged particles. The nighttime ionosphere has two layers, E and F. Disturbances in the F layer, the layer studied by WINDY, degrade radio and radar signals at low magnetic latitudes. Predicting when these disturbances will occur would improve the reliability of space-borne and ground-based communication systems. WINDY will attempt to answer questions about the origin, i.e. the events preceding a disturbance, of ESF by measuring the influence of horizontal thermospheric winds on the formation of ESF, as well as, taking measurements of ionospheric densities and electric and magnetic fields.

Principal Investigator: *Dr. Hysell/Cornell University* • ***Mission Number(s):*** *29.042 & 36.321 UE*
Launch site: *Kwajalein, Marshall Islands* • ***Launch date(s):*** *September 9, 2017*

An important element of these experiments involves measurements of the atmospheric winds at high altitudes. Just as on the ground, winds at very high altitudes carry a tremendous amount of energy and are known to have a direct effect on the ionospheric disruptions that are the focus of WINDY. Wind measurements at these altitudes are difficult because of the very low atmospheric density. Over the past five decades, several tracer techniques have been perfected to accomplish this by optical tracking of visible gases released from the rockets. Lithium vapor and trimethyl aluminum (TMA) gas have been particularly effective. TMA reacts spontaneously on contact with oxygen to produce a pale white glow visible from the ground. For the WINDY mission, sunlight reflected by the Moon will illuminate the lithium, producing an emission that can be detected with cameras equipped with narrow-band filters. Using moonlight for illumination allows the launches to occur later in the evening, when the critical ESF conditions occur. Both gases, which are harmless when released at these altitudes, move with the background atmosphere and can therefore be used to determine the wind speeds and direction over the height ranges where the releases occur. Both clouds remained in the night sky for approximately 30 minutes after launch.

Data from the ARPA Long-Range Tracking and Instrumentation Radar (ALTAIR) was used to monitor the state of the upper atmosphere/ionosphere in order to determine when the large-scale disruptions occur and thus when to launch the rockets. ALTAIR was also be used to monitor the evolution of the ESF after the launches.

Education Missions 2017

Level 1 RockOn!

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

Level 2 RockSat-C

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

Level 3 RockSat-X

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

RockOn! & RockSat-C

The RockOn! workshop was held at NASA Wallops Flight Facility, June 17 - 22, 2017. Seventy-one students and faculty members participated in this year's workshop, which was the tenth since the inception of the program in 2008. RockSat-C experiments are flown in the same rocket as the workshop experiments but are more advanced and completely designed and fabricated by the students. Ninty-three students participated in the RockSat-C flight opportunity.

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 decks are stacked on an internal structure that accommodates five decks.
4. Experiment stacks are housed in canisters (RockOn!). RockSat-C experiments are not board based but are also housed in canisters.
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.

Principal Investigator: *Mr. Chris Koehler/Colorado Space Grant Consortium* • ***Mission Number(s):*** *41.121 UO*
Launch site: *Wallops Island, VA* • ***Launch date:*** *June 22, 2017*

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.

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.

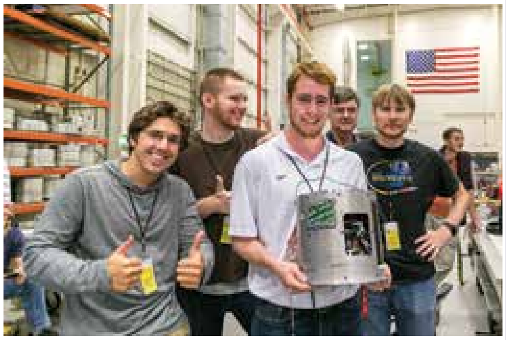
The following schools and experiments flew on RockSat-C in 2017:

Carthage College (Wisconsin)

The experiment objective was to observe very low frequency (VLF) electromagnetic (EM) waves that come from natural lightning discharges as a function of altitude.

Hobart and William Smith Colleges (New York)

The experiment objective was to measure the visible light spectrum, the efficiency of various shielding materials at attenuating radiation, and the muon flux at different levels of the atmosphere. Additionally the team managed an outreach program for students at the high school/middle school level to promote interest in STEM.



Old Dominion University (Virginia)

Monarch-3 sought to cap-off all lessons learned from the prior two years through successful pressure data gathering at the rocket boundary layer and transmission from above Wallops to ODU in Norfolk.

Oregon Institute of Technology

GRASP's goal for this project was to measure the electromagnetic (EM) exposure and solar behavior of a solar cell in the mesosphere and thermosphere.

Stevens Institute of Technology (New Jersey)

The experiment objective was to test the effects of high G's and microgravity on 3D prints, and to build on the experiences of last year's experiment and to create a system to record and reduce vibrations occurring in a payload during launch for sensitive electronics and other equipment. Additionally the experiment measured High-Speed Boundary Layer transitions from laminar to turbulent pressure waves using a high and low frequency pressure sensor combination mounted in a custom window on the skin of the rocket.

Temple University (Pennsylvania)

The experiment objective was to measure radiation levels and atmospheric ionization levels at different altitudes and compare them to find correlations between radiation and ionization. Secondary mission was to transmit this data in real time to a ground station using satellite communication.

University of Wisconsin Sheboygan

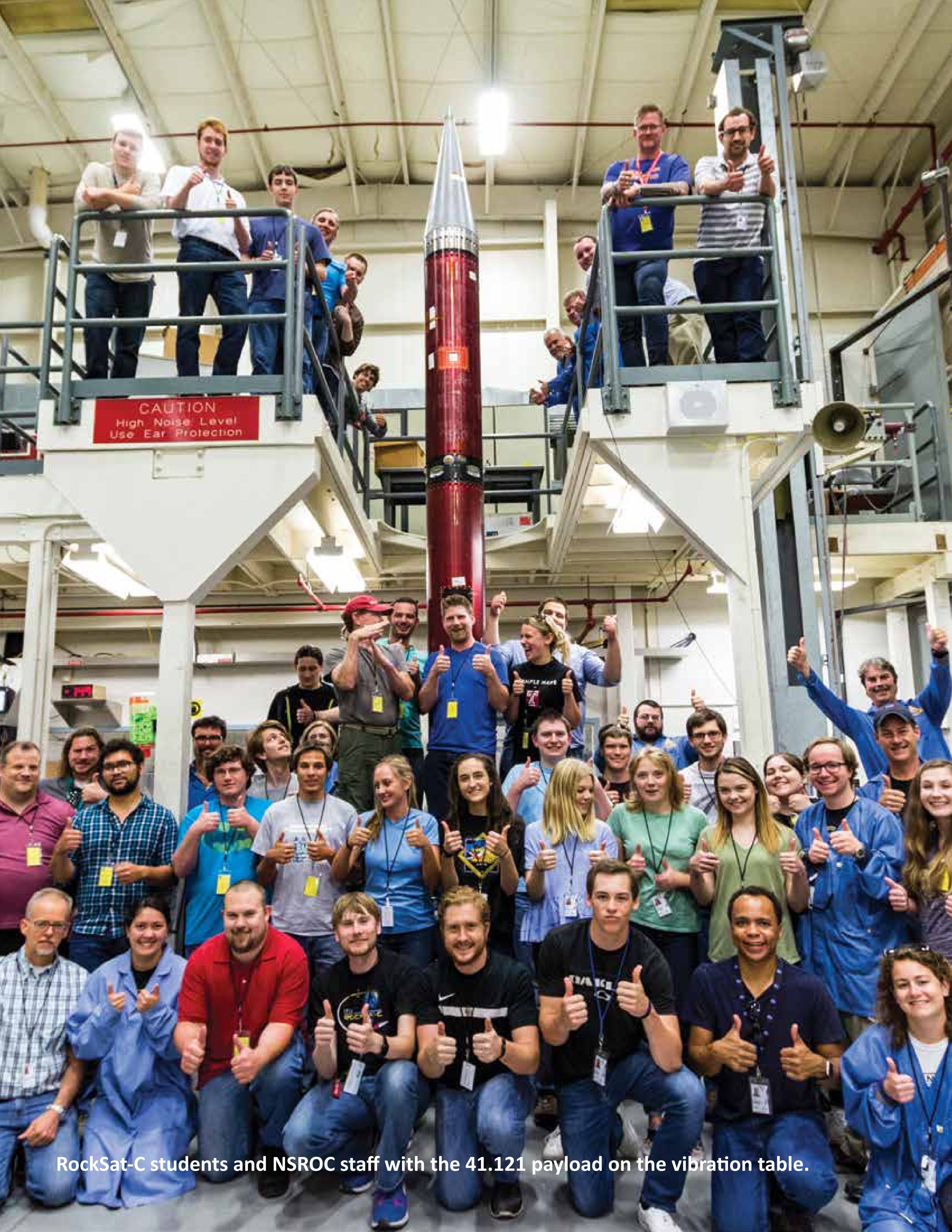
The experiment objective was to observe the effects of rocket flight to the lower atmosphere on bacterial DNA using multiple sensors to measure conditions during the flight.

West Virginia Collaboration (8 schools)

The objectives for this experiment were both to encourage collaboration between colleges in West Virginia and to develop science and engineering experiments for space flight. The experiments captured and stored real-time data to show flight path of the rocket, performed a stress test on materials in space, measured vibration environment onboard the rocket with piezoelectric gneerators, and measured plasma density in the upper atmosphere.

Cubes in Space is a program for middle school students that allows them the opportunity to design an experiment that fits in a 40 x 40 x 40 mm cube. The cubes 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 41.121 payload on the vibration table.

RockSat-X

RockSat-X was successfully launched from Wallops Island, VA on August 13, 2017. 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 experiments are fully exposed to the space environment above the atmosphere. Power and telemetry were provided to each experiment deck. Additionally, this payload included an Attitude Control System (ACS) for alignment of the payload. These amenities allow experimenters to spend more time on experiment design and less on power and data storage systems.

The following experiments were flown on RockSat-X in 2017:

University Of Hawai'i Community College System

Four community colleges in Hawaii teamed up to encourage students to explore STEM-based careers. The objective was to demonstrate proof of concept for multiple experiments. The primary experiment was to eject a naphthalene sublimation rocket and capture images of this deployment. The secondary experiments onboard evaluated a 9-axis IMU motion tracking device and take distance data of the sublimation rocket using an infrared rangefinder

University of Kentucky

This team's experiment was to increase the technology readiness level of a small entry spacecraft by demonstrating data acquisition, communication, and thermal protection system designs. Their experiment deployed a re-entry capsule to record and transmit temperature data in order to test the thermal protection system on the re-entry probe. The experiment also tested and verified their deployment method and release mechanism in the space environment. The team recorded video of the deployment to verify this aspect.

Deployable small spacecraft is ejected from the payload.

***Principal Investigator:** Mr. Chris Koehler/Colorado Space Grant Consortium* • ***Mission Number(s):** 46.017 UO*
***Launch site:** Wallops Island, VA* • ***Launch date:** August 13, 2017*

Capitol Technology University (Maryland) & University of Maryland

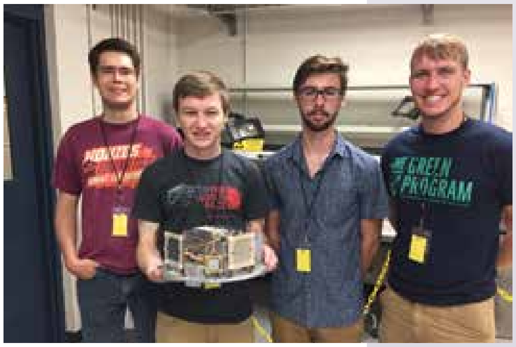
Two universities shared the experiment space in this canister. CTU used this RockSat-X mission as a proof of concept for a 1U CubeSat. Their experiment demonstrated the functionality of Iridium 9603 SBD and recorded video during flight using a VR camera. The University of Maryland's portion of the experiment collected experimental data to validate computational tribocharging models of grain interactions.

Oregon State University

Oregon State University tested a concept for an autonomous robotic arm. Their arm deployed and made contact with predetermined targets around the payload in microgravity conditions. They also recorded video of this function. The team hoped to demonstrate the ability for robotic arms to create assemblies, autonomous repairs, and preforming experiments in space.

Virginia Tech

The Virginia Tech team demonstrated the compatibility of software defined radio on different communication frequencies. The experiment received ADS-B and AIS transmissions from aircraft and boats to show that it is a more flexible and efficient system than radar tracking. The team also transmitted the received data to a mobile ground station at the launch site as well as a ground station located at their campus in Blacksburg.



West Virginia Space Collaboration

There were five different individual experiments from this team. One experiment captured near-infrared and long-wave infrared imaging of Earth's surface to distinguish landmass and potentially work as a vegetation health assessment. The second experiment was a re-entry probe that deployed and transmitted acceleration, temperature, and rotation data back to the main experiment sections. The third experiment detected ionized particles. The fourth experiment detected high energy particles and observed space effects on DNA, and studied ozone during re-entry. The fifth experiment tested an autonomous pointing determination and target acquisition system.

University of Colorado Boulder

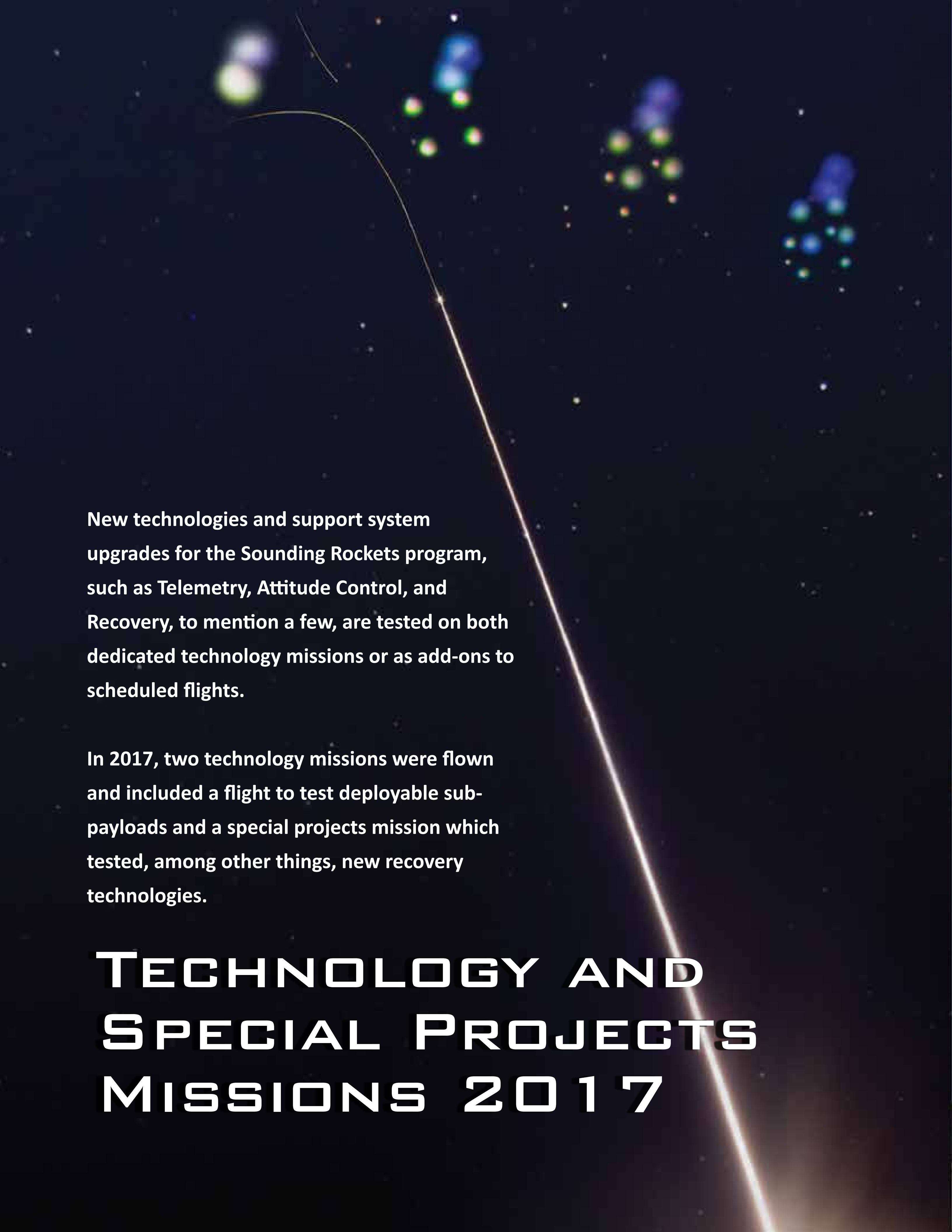
The University of Colorado Boulder Rapid EXpandable Boom or REX-B team's mission was to characterize the deployment of a slit-tube, strain energy deployment boom in a microgravity environment. The mission collected data on the temperature and humidity conditions of the boom prior to its deployment as well as acceleration, pressure, and temperature data throughout the flight. The team also took two high resolution videos using two GoPros and various low-resolution pictures at various points during the flight. The team's goal was to collect useful data for their industry partner to help them in the development of future deployable booms for future space applications.

Boom and spring deploying from the payload.

University of Puerto Rico

The experiment allowed the detection of high density particles found within 80-100 miles (130-165 kilometers) above Earth's sea level, in order to study their physical and chemical properties. To meet this objective, the team used UPR's 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 aforementioned particles. This year, the UPR experiment focused on cross-contamination mitigation through the use of plasma gas decontamination. They will also sequence any nucleic acids found in the collected micrometeorites.

RockSat-X students and NSROC staff with the 46.017 payload on the balancing table.



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.

In 2017, two technology missions were flown and included a flight to test deployable sub-payloads and a special projects mission which tested, among other things, new recovery technologies.

Technology and Special Projects Missions 2017

Sub-TEC 7

The two primary objectives for the 36.317 Hesh / SubTEC 7 mission were to perform water recovery on a representative Black Brant IX telescope payload as a pathfinder for future telescope payloads requiring such capability, and demonstrate the new internally designed and assembled recovery system called the NSROC Forward Ogive Recovery Section (N-FORSe). Secondary objectives for the mission were to provide test opportunities for several NASA and NSROC developed components and subsystems, as well as, technology development experiments from reimbursable partners.

The water recovery system included a water recoverable shutter door with a wedge assembly designed to survive impact loads. 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. A series of drop tests were conducted prior to this flight to evaluate the performance of the heritage shutter door assembly and the new design under conditions anticipated for a water impact.

36.317 GT launches from Wallops Island, VA.

Water wedge installed on the payload.

N–FORSe vibration testing.

First generation of the internally developed new inertial measurement unit.

Low cost star tracker designed to provide arcsecond level accuracy using commercial off the shelf components and internal labor.

GPS and Iridium based skin mounted autonomous rocket tracker that is intended to be used in Poker Flat to locate expended rocket stages.

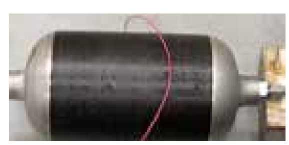
Solid state altimeter intended to replace legacy plenum chambers

Solid state lanyard to test an alternate design to legacy microswitch–based lanyard switches

Orbital ATK's LEO–2 CubeSat experiment for testing ultra–lightweight advanced materials including carbon nanotube (CNT) materials for structures and additive manufacturing.

NASA Langley's Mars Packing Efficiency Payload which is testing the development of deployable Mars rover concepts to improve lander packing efficiency and aerodynamic stability during aerocapture and EDL.

Tyvak's Nano–Launch Vehicle Avionics (NLVA) System which provides complete GNC functionality, analog sensor polling, power and telemetry distribution, and GPS metric tracking in the industry's smallest form factor. Developed under a NASA Phase II SBIR from Kennedy Space Center that ended in April 2016.



NASA Glenn's Composite Overwrap Pressure Vessel (COPV) which uses a carbon nanotube (CNT) overwrap over a metallic pressure vessel and a control system using the COPV will fire a valve to spin up the payload before re–entry

Principal Investigator: *Ms. Catherine Hesh/NASA GSFC Wallops Flight Facility* • **Mission Number(s):** *36.317 GT*
Launch site: *Wallops Island, VA* • **Launch date:** *May 16, 2017*

46.015 GP Hall

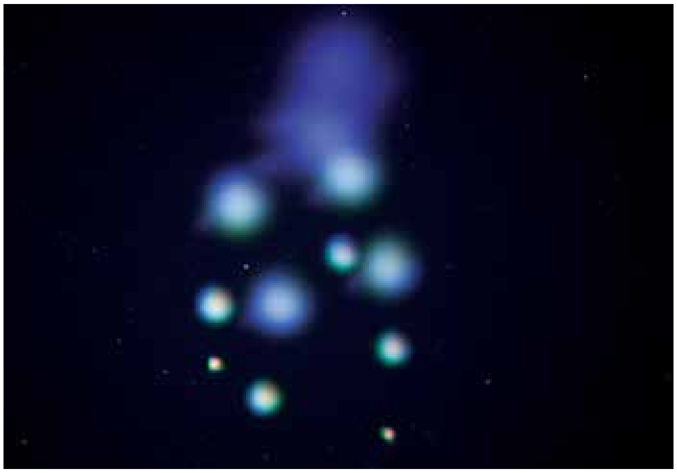
The objective of this mission was to test a deployable ampule system. The ampules, small sub-payloads carrying vapor tracer chemistry, are ejected from the main payload at various altitudes and times during the flight. Sophisticated control systems have been developed to allow autonomous operation of the ampules. The Ejectable Supervisory System (ESS) determines detonation times for the vapor tracers, collects and aggregates data from the ampules and provides the data to the Telemetry system. The ejectable portion includes the ampule with vapor tracer and initiator, Ampule Control Module (ACM), and an Off-the-Shelf rocket motor to propel the ampule. The ACM initiates the rocket motor, implements the release time from the ESS, and transmits data back to the ESS.

Preparation of the camera system to monitor deployments in flight.

A total of ten ampules were deployed during this test flight. Two additional ampules were installed in the main payload but not deployed. The deploying ampules were designed to travel between 16 and 19 km from the main payload after ejection. Deployment altitudes were between 155 and 180 km. The spread of the deployables allows distributed measurements that are important for ionospheric and auroral research. Measurements of high altitude winds often utilize vapor tracer techniques and the deployable ampule system enables measurements in a larger volume.

Payload readied for GPS testing. Ampule doors are open.

Upcoming science missions that will use the new ampule system include two sounding rocket flights from Norway in the spring of 2018.



Ten ampules deployed and two non–deployable ampules ignited.

46.015 Lift–off from Wallops Island, VA.

Principal Investigator: *Mr. Brian HallNASA GSFC Wallops Flight Facility* • ***Mission Number(s):*** *46.015 GP*
Launch site: *Wallops Island, VA* • ***Launch date:*** *June 29, 2017*


Yellow Jacket

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 & Outreach

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. 2017 was the 6th year of the workshop with 17 teachers selected from over 60 applicants. 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 18th year, provides internships and co-op opportunities for students studying engineering, computer science, electrical or mechanical technology, as well as business disciplines. Students work side-by-side with experienced engineers and managers to perform significant, valuable tasks, leading to a better understanding of the work in a highly technical environment. Almost 90 percent of undergraduate students who intern or participate in the co-op program return for additional employment. Several participants in the program have gone on to pursue higher education in the engineering and science fields.

In 2017, NSROC provided opportunities for nine internships involving all engineering disciplines.

NSROC electrical enginner intern.

NSROC Testing and Evaluation Lab intern.

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 construction and launches. Additionally, speakers are provided upon request to local civic organizations through the NASA Office of Communications. Tours of sounding rocket facilities are conducted for both school and civic groups throughout the year.

During the Kwajalein campaign staff visited the Third Island and engaged the local community in various activities. A display, describing the WINDY mission, was available to familiarize the local population with the science aspect. Supplies donated by NASA and contractor staff were also distibuted.

Tour of Sounding Rocket facilities.

Arcadia High School student preparing to launch rocket.

Kwajalein outreach program.

Technology Development

The SRPO and NSROC are actively engaged in upgrading and developing new technologies for the program. New emerging technologies, to be tested in the coming year include Swarm Communications. The Tern Inertial Navigation System (INS) was flown for the first time in 2017. Additionally, component level improvements are developed continuously and flown on either dedicated missions or on a space available basis on manifested flights.

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

In 2017 the NSRP launched its first test flight incorporating water recovery on a BBIX vehicle. The 36.317 Hesh (Sub-TEC 7) mission incorporated an enhanced shutter door design with a water wedge designed to remain sealed after water impact. In addition, NSROC has also designed a water recoverable Celestial Attitude Control System (CACS) that will be flown in 2018 from Kwajalein. The combination of the water recovery shutter door and CACS now allows the NSRP to support water recoverable Astrophysics missions from water-based ranges. The next steps in 2018 that the NSRP intends to pursue are (1) investigations into high altitude reentry heating on three and four-stage high altitude sounding rocket vehicles to enable payload recovery from larger sounding rocket vehicles; and (2) initiatives to streamline and lighten the NSRP provided sub-systems to reduce the overall payload weight to obtain increased scientific observation time for Solar and Astrophysics missions. The NSRP also continues investing in flotation technologies, over-the-horizon location aides, and alternative recovery concepts to facilitate the move to recovering payloads launched from larger vehicles.

In the avionics area, the program has continued developments aimed at increasing S-band telemetry data rates to 40 Mbps by assessing commercially available hardware as well as purpose built custom hardware. The program expects to test the first 40 Mbps S-band telemetry system on the 2019 Sub-TEC 8 technology demonstration mission. The NSRP continues to pursue development of high data rate on-board storage options as well as authorization to utilize alternate frequency bands that allow data rates up to ~400 Mbps.

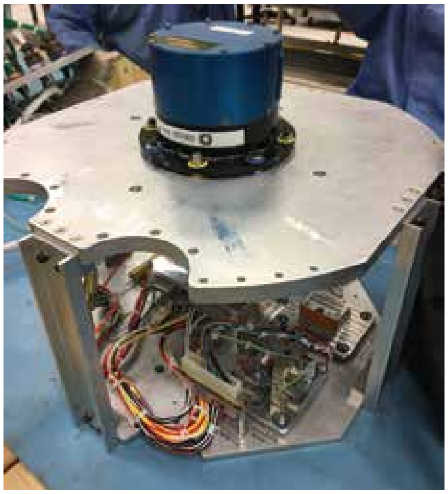
In recent years, the science community has pushed for enhance capabilities for deployable, free-flying sub-payloads capable of carrying chemical tracers or science instruments. In 2017, the NSRP underwent an extensive re-design and ground qualification test program for the igniter in the ejectable rocket motor as well as the ignition system for the chemical tracer ampule. The re-design effort culminated in a test flight on the 46.015 Hall mission in June 2017 where all 12 chemical tracer ampules onboard the demonstration flight successfully deflagrated. In 2017 and 2018 the NSRP is making steady progress towards its goal of making the deployable, free-flying sub-payloads a science platform by adding sub-payload to main-payload telemetry (called "Swarm Communication") as an additional capability. The data from the sub-payloads will be telemetered to the main payload via S-band frequencies at speeds of up to 500 kbps and separation distances up to 20 km. The Swarm Communication experiment will undergo a first flight test in 2019 on the 46.020 Hesh Sub-TEC 8 mission.

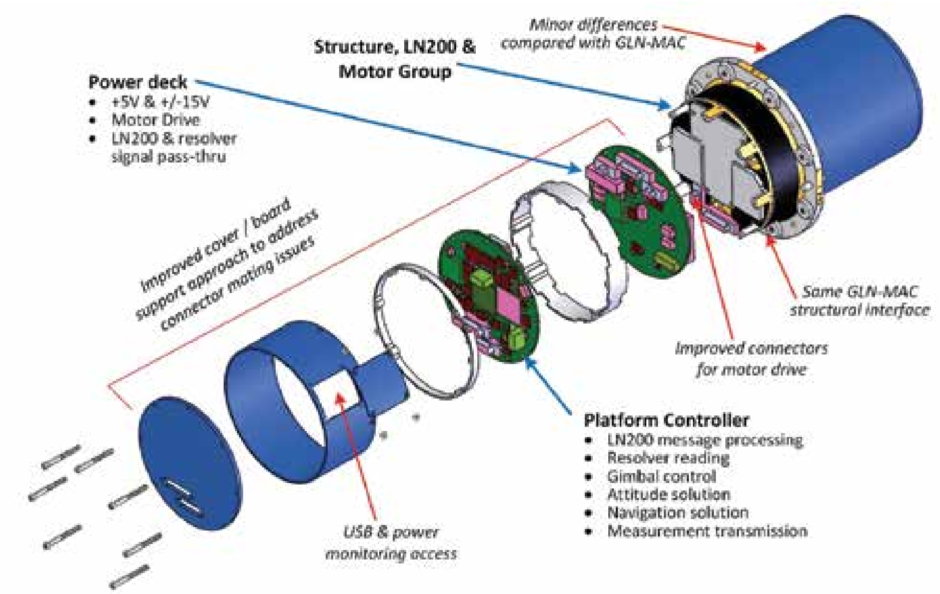
A description of two key 2017 technology developments follows.

Tern Inertial Navigation System (INS)

NSROC developed and tested a replacement Inertial Navigation System (INS) called the Tern INS that will replace the legacy GLN-MAC Inertial Measurement Unit (IMU). The Tern INS will provide enhanced capabilities and attitude solution compared to the GLN-MAC. The GLN-MAC has several performance and production limits that drive the need for a new system including Celestial Attitude Control System (CACS) performance, resolver accuracy, measurement accuracy, parts obsolescence, and component maintenance. The Tern INS is designed to generate high quality, reliable body rate and acceleration measurements, attitude propagation, and navigation solutions. Unlike the GLN-MAC, the Tern INS will not be designed to provide any application-specific flight processing support. Prototype Tern INS flew as piggyback experiments on two missions in 2017 – 36.317 Hesh, and 36.326 Clark. The flight data analyzed to date shows good performance from the prototype Tern INS.

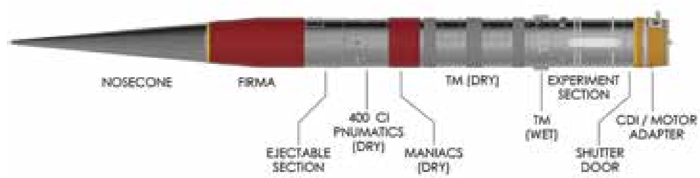
Tern INS installed in 36.317 Hesh payload structure.





Tern INS Hardware Configuration.

Swarm Communication



Sub–TEC 8 payload configuration.

Swarm Communication is a NSRP development effort using matrixed NASA AETD engineers to design a system that telemeters data from multiple deploying sub-payloads to the main payload. Development of the sub-payload transceiver avionics began under a FY2017 IRAD and the main payload avionics will be completed under a FY2018 IRAD. The AETD design effort also encompasses a sub-payload deploying door for a transmitting antenna, a sub-payload command and control board, and a main payload receive antenna. The Swarm Communication experiment will undergo a first flight test in 2019 on the 46.020 Hesh Sub-TEC 8 mission. The Sub-TEC 8 payload will deploy four sub-payloads – two via high velocity springs and two via COTS rocket motors. The data from the sub-payloads will be telemetered to the main payload via S-band frequencies at speeds of up to 500 kbps and separation distances up to 20 km.

The NSRP Embedded Engineering NASA AETD staff has continued to support research and development initiatives. This staff focuses on early concept technologies for the program and works closely with other teams and programs to seek out areas for collaboration and development of cross-cutting technologies. New technologies developed in 2017 are highlighted below.

Airborne Power Supply Unit: Designed as a programmable DC/DC converter that can supply dual constant voltage or constant current outputs in a small enclosure, enabling power conditioning from a single bus to multiple outputs with differing requirements.


Airborne Power Supply Unit.

New opportunities to conduct science missions in the Southern Hemisphere are being developed by SRPO. A new launch range, Equatorial Launch Australia (ELA) will be used for several Astrophysics missions launching in 2019.

FY 2018 and 2019 will see several flights from launch sites in Norway. The missions involve US, Norwegian, German and Japanese scientists and an international student mission. Two US science flights will launch from Svalbard and three science flights and one student mission from Andøya. The Norwegian, Japanese and German rockets will launch from Andøya. The missions study the polar ionosphere, the Cusp region and Polar Mesospheric Winter Echos (PMWE).

On the Horizon

As reported in the 2016 Annual Report, the SRPO will be spending the next few years "on the road". With the addition of two new Operations Managers and an additional Projects Manager to the SRPO staff, planning for mobile range activities are now in full swing. In this year's On the Horizon we will provide updates on these mobile operations and while focusing a bit more on the many innovations being implemented to make these mobile range operations possible. Many of these innovations help keep our cost and resource conflicts under control and enable the SRPO to efficiently and effectively execute NASA's scientific research missions.

Many of our rocketeers will once again ring in the New Year in Fairbanks, Alaska. The Poker 2018 campaign, which is requiring pre and post-Christmas field operations, will kick off the new year with a bang as we prepare to launch four sounding rockets for two separate investigations. This year's mission set will once again include a telescope payload requiring clean room capabilities and winter recovery operations. A Geospace science mission will include the launch of three sounding rockets, two of which will require launch within a 90 seconds of each other. The mission window begins in mid-January and ends the last day of the month at which time our crews will be returning to Wallops to begin the next adventure.

In February of 2018, our crews will be on the road again as we take the Auroral Zone Upwelling Release Experiment (AZURE) mission to Andoya Space Center (ASC) in northern Norway. This mission consists of two Black Brant XI-A vehicles launched within five minutes of each other. These two very complex payloads will each eject 24 rocket propelled ampules to create vapor clouds to help map the 3D structure of the neutral winds in the Auroral Zone. These missions required a launch site move from Poker Flat Research Range due to safety implications associated with launching so many sub payloads from a single "mother" payload. There are two significant innovations being implemented on this mission. First, the Wallops Aircraft Office will deploy NASA 428 for use as an optical platform to help ensure we have clear optical coverage of release. The second innovation involves Telemetry coverage for the mission. Over the past several years, ASC has been acquiring newer and larger Telemetry (TM) tracking systems and this will be the first time the SRPO has launched a mission from ASC without NASA tracking assets present. These new launch operation approaches will help keep our cost down, reduce our setup and launch time, and will hopefully bode well for future missions from ASC. Upon completion of the AZURE mission, the SRP is conducting a collaborative research mission with Germany's Deutsche Zentrum fur Luft-und Raumfahrt (DLR) which is studying Polar Mesospheric Winter Echos (PMWE). This is a unique collaborative research opportunity that we hope will open the door for future collaboration and benefits to the SRP.

Near simultaneous with the AZURE mission, February will see the SRP be back at the Reagan Test Site (RTS) in the Kwajalein Atoll with the Colorado High-resolution Echelle Stellar Spectrograph (CHESS) and Water Recovery X-Ray Roclet (WRX-R) missions. These two Astrophysics missions are being flown from RTS to provide researchers with partial access to the Southern Hemisphere sky. These missions represent an innovation for the SRP as they will be the first telescope missions flown over open ocean with water recovery planned. The missions are proving to be challenging with the need to waterproof the ACS, develop enhanced recovery systems, and plan the recovery operation. Logistics is generally difficult in the remote parts of the world where we operate and Kwajalein is no exception. Faced with the logistical issues associated with an experiment which requires a significant amount of LN_2, the NASA Sounding Rockets Operations Contract (NSROC) team proposed we acquire a small mobile liquid nitrogen (LN_2) production plant. This mobile LN_2 plant will be delivered in the next few months and if it works as planned, the Program will see much benefit and future use for missions requiring this commodity.

Starting in the summer of 2018, the NSROC Launcher Systems (and mobile range) crew will travel to Svalbard to prepare for the upcoming Grand Challenge (GC) sounding rocket campaign. Part of the GC campaign will take place from the SvalRak Launch Site in Ny-Ålesund, Svalbard. Sitting at 79 degrees North latitude, our team will take advantage of the summer daylight to get as much of the outside work done as possible. The VISualizing Ion Outflow via Neutral atom Sensing – 2 (VISIONS 2) mission will be the first time two rockets have been launched near simultaneously from Ny-Ålesund. The SRP is planning to take the new in-house developed Medium Mobile Launcher (MML) to SvalRak for this mission. This will be the first mobile deployment of this new SRP asset which should see much use in the coming years. These payloads also contain instruments that require a significant amount of LN_2. So, once again, the new mobile LN_2 plant will enable a mission of this complexity to launch from such a remote region of the world.


Aerial of Ny-Ålesund.


SvalRak motor assembly building.

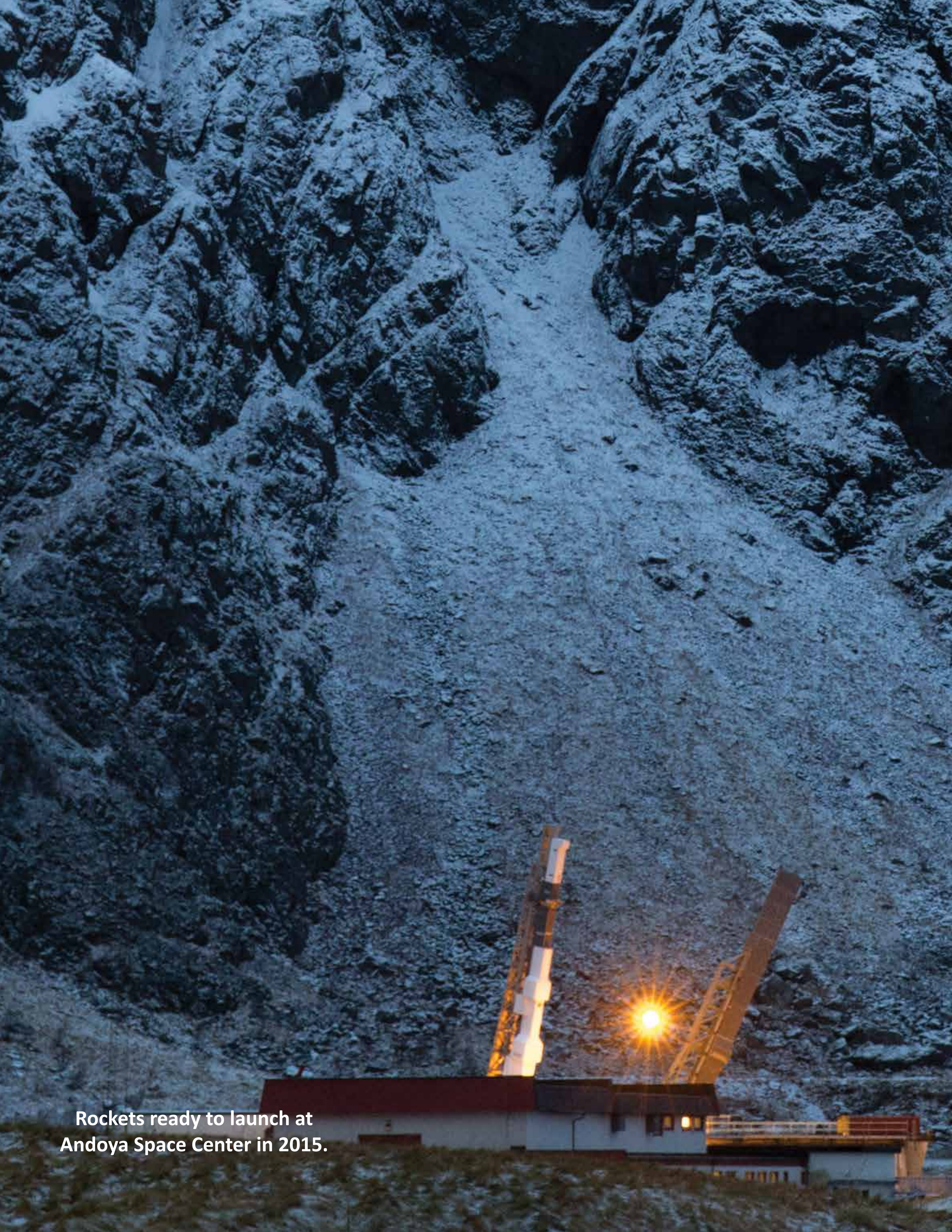

Launch shelter.

The Sounding Rocket portion of the Grand Challenge (GC) – Cusp Initiative starts in the fall of 2018 with SRP mission teams in both Ny-Ålesund and Andenes, Norway. With launches at both sites, multiple rockets will be used to study the electrodynamics of a Cusp Aurora near simultaneously. Two launch windows will be necessary to support all of the missions associated with the GC. Mission teams will arrive home just in time for Christmas after the first launch window. Then, shortly after the Christmas holiday, the teams will depart again to support the second launch window. One of the many innovations being implemented on the GC campaign is the TM tracking plan supported by the joint US/Norway GC Project Team. Mobile Range assets from the Wallops Mobile Range (Code 840 - Range and Mission Management Office) will be used in concert with TM assets from the ASC to fully instrument each launch site with redundant TM tracking resources. The concept of operations for the GC is innovative in that the Ny-Ålesund instrumentation will be supporting the ASC launches as the “down range” tracking site and vice versa. As the GC will be launching some of NASA’s largest sounding rockets, a down range tracking site is always a necessity to ensure adequate TM coverage throughout the critical data collection period of the flight. This will be one of the largest mobile sounding rocket missions the SRPO has undertaken in many years and will no doubt be one of the most “Challenging”, as the campaign name implies!!

Once the crews return home from the GC in early spring 2019, preparations will be underway for the 2019 Australia Sounding Rocket Campaign scheduled for the Fall (September/October) 2019. SRPO has recently decided to pursue the option of utilizing the newly emerging launch site known as Equatorial Launch Australia (ELA) located in Australia's Northern Territory. Two major developments over the past year have lead to the decision to use ELA. First, ELA has secured a sublease for the launch site from the Gumatj Corporation paving the way for the launch site infrastructure development. Second, recently completed safety studies have verified that typical Astrophysics missions can be safely launched and recovered from the land portion of the "Range" which is sparsely populated. We also hope this decision will open the door for higher performance missions in the future to provide more time aloft for the researchers. This will be a mobile campaign in every sense of the word and it will take the best of SRPO, NSROC, and the Wallops Range to make this campaign a reality. Many of the innovations being implemented in the preceding campaigns are coming together to make Australia 2019 a reality. The MML launcher development is the first and perhaps the most significant of these innovations. With an eye to the future, the SRPO has tasked NSROC to build a second MML which we also plan to use for this campaign. The LN_2 plant is a second and equally important innovation since the supply chain logistics are so challenging in this remote part of Australia. Another innovation that makes this campaign a reality, it the mobile command uplink needed by our researchers. The SRPO is working with the Wallops Range and NSROC to develop this mobile uplink capability for the CHESS/WRX-R missions in Kwajalein before the April 2018 launches from RTS

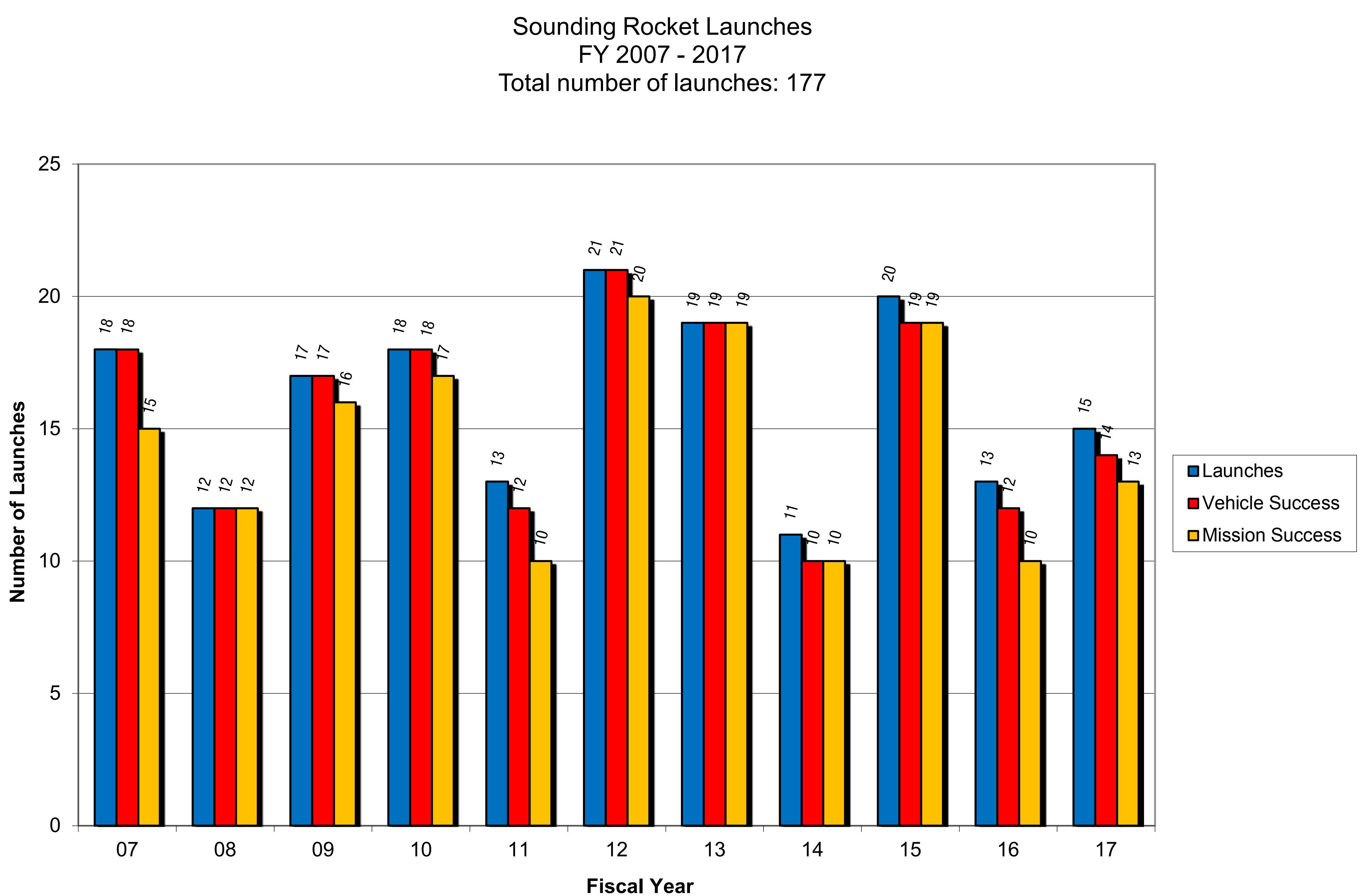
These missions and mobile range activities represent less than half of our overall mission set. We are planning all of these operations and still conducting routine missions from Poker, White Sands Missile Range (WSMR), and Wallops. Only once will we forego the typical winter campaign at Poker in 2019 due to the deployment complexities of the GC campaign. With all of these plans for future missions, it's easy to understand why everyone on the SRP team is so excited about the next few years.

We would be remiss if we didn't mention the forward thinking and planning by our outgoing Chief, Mr. Phil Eberspeaker, who has enabled these plans to move forward. Under his leadership, the SRP has made strategic investments in new capabilities, developed new modes of operation, and made important additions to our staff that have allowed us to continue with these important research missions. The ability of the SRP to take missions to locations where the "science in occurring" is a hallmark of the program and without Phil's forward thinking and leadership, this would not have been possible.

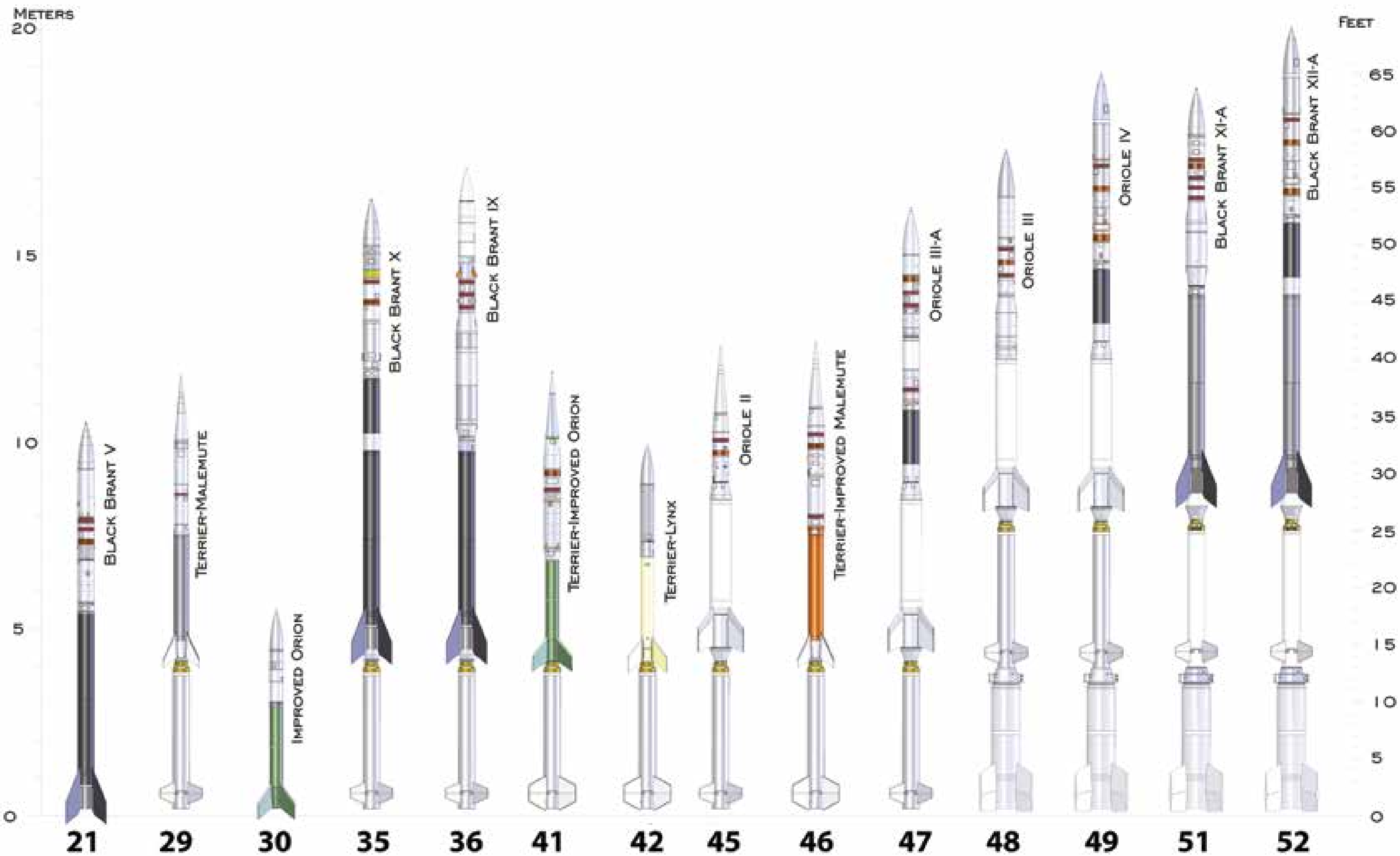


Rockets ready to launch at
Andoya Space Center in 2015.

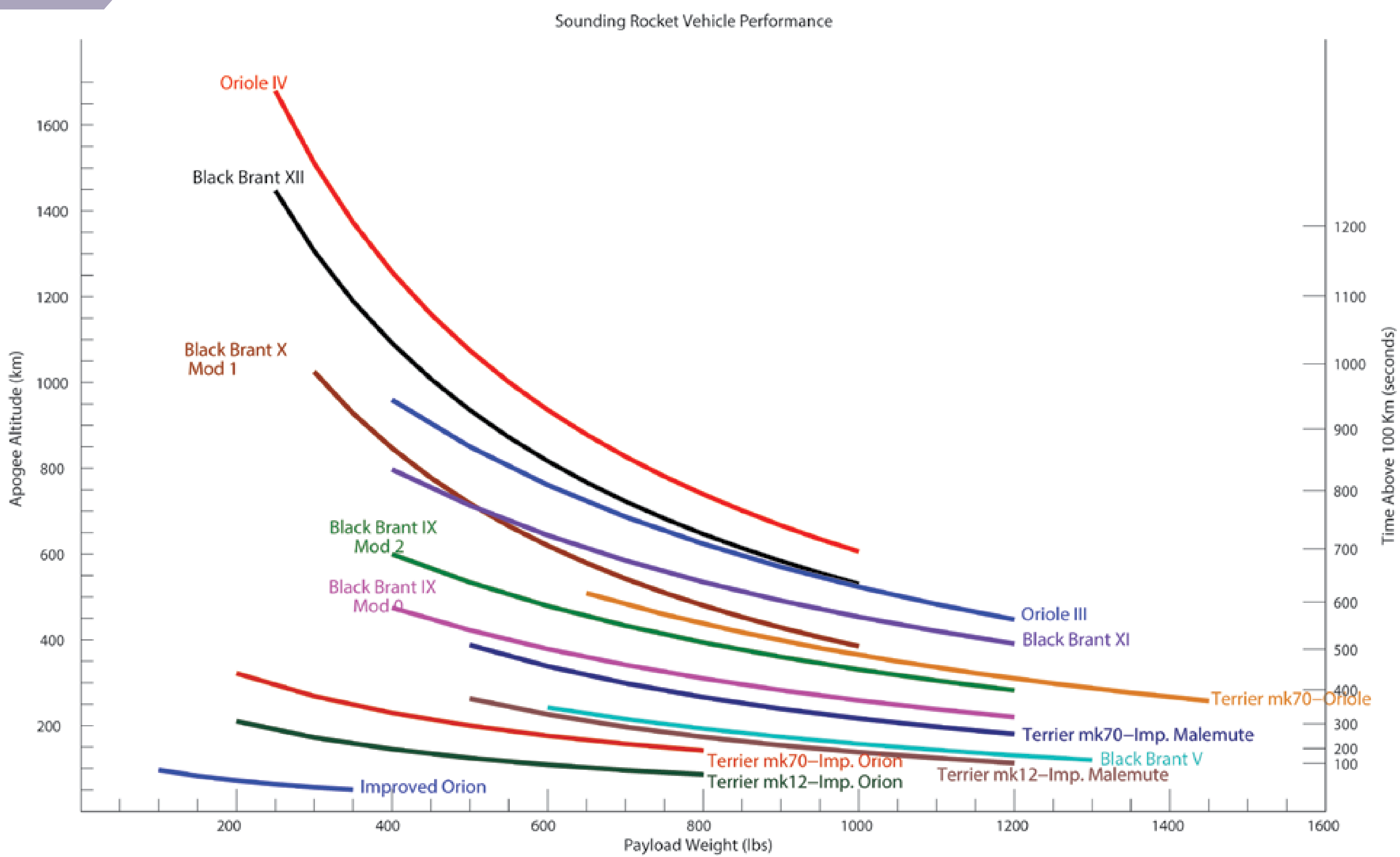
Mission Success History



Sounding Rocket Vehicles



Sounding Rocket Vehicle Performance



Sounding Rocket Launch Sites

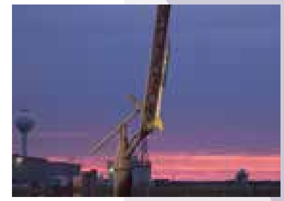

Poker Flat, Alaska


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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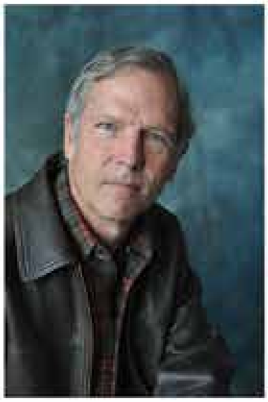
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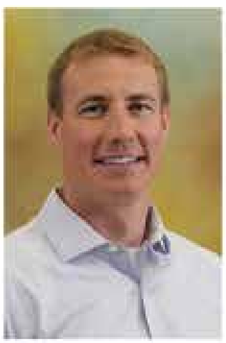
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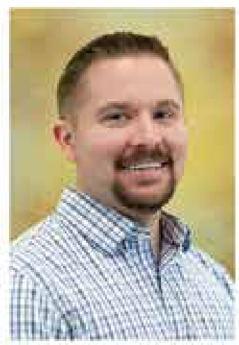
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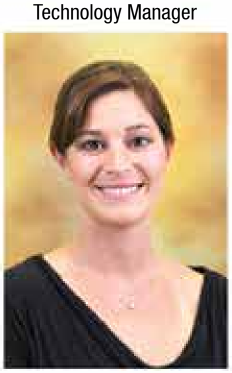
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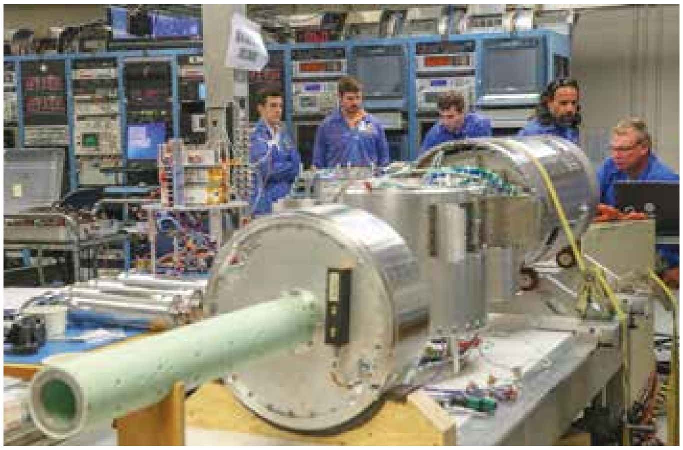
10	Scorpius background image - heic0211e scorpius Akira Fujii
11	CHESS data Dr. Kevin France
13	Rocket on Launch rail: White Sands Imaging Group
14	Aurora background image - Terry Zaperach
15	Aurora insert images - Wallops Imaging Lab
16	NO graphic: Dr. Scott Bailey/VA Tech
17	Depoyment photo: Nate Wroblewski/NSROC
17	Group photo: Dr. Lynch
18	Figure 1: Model by R. Walterscheid, Aerospace Corp
18	Figure 2: Dr. Pfaff NASA/GSFC
19	Figure 3: Terry Zaperach, Wallops Imaging Lab
19	Figure 4: Prof. M. Larsen, Clemson University
19	Figure 5: Aerospace Corp.
20	Kwaj photos: NASA/Matt Griffin
28	Team photos provided by Chris Koehler, Colorado Space Grant
28	Deployment photo: Kentucky University
29	Team photos provided by Chris Koehler, Colorado Space Grant
30	Photos provided by Chris Koehler, Colorado Space Grant
32	Launch photo - Wallops Imaging Lab/Terry Zaperach
34	Payload component photos provided by Cathy Hesh/NASA SRPO
35	Launch photo - Wallops Imaging Lab/Terry Zaperach
40	Solidworks concept drawing - Josh Yaccobucci
43	Photos provided by Cathy Hesh/NASA SRPO
44	Photos provided by Cathy Hesh/NASA SRPO
49	Svalbard images - Scott Bissett/SRPO
51	Rockets on the pad - Wallops Imaging Lab
53	Vehicle stable grahic: NSROC Mechanical Engineering
54	Performance graph: NSROC Flight Performance
57	John Brinton
59	Kwaj team photo: NASA/Matt Griffin
59	Poker Flat Range photo: Dr. Pfaff, NASA GSFC

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

Science mission information submitted by Principal Investigators.

Kwajalein rocket teams.



ISINGLASS integration activities.

PolarNOx instrument check.

Four rockets ready to launch from Poker Flat Research Range, AK.

National Aeronautics and Space Administration

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www.nasa.gov

NP-2017-11-131-WFF