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IN ADVANCE OF THE LAUNCH OF TACSAT-4

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OF SPECTRA FEATURING THE TACSAT-4
LAUNCH ON THE COVER

SPACE SCIENCE

WISPR
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STEREO

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The U.S. Naval Research Laboratory (NRL) is approaching the launch of its 100th satellite into Earth orbit: Tactical Satellite 4 (TacSat-4). This issue of SPECTRA celebrates this milestone by focusing several articles on NRL's space research activities and contributions to the Department of Defense space program.

NRL's pioneering and fruitful space-based research program got its start some 65 years ago with the launch of experiments on captured German V-2 rockets to monitor the Sun's behavior and its effect on naval communications. The Laboratory also conducted America's first satellite program by directing the Vanguard project and developing the world's first satellite tracking system, and later the Naval Space Surveillance System. Soon after Vanguard, the Laboratory launched the first intelligence satellite, GRAB I, which had a profound impact on intelligence gathering capabilities and national security decision making, particularly with regard to the deterrence of nuclear war. In another early program, NRL formulated the original concepts and developed the satellite prototypes for the NAVSTAR Global Positioning System, which earned NRL the coveted Collier Trophy. The military and commercial applications of GPS are revolutionary and pervasive.

Today, NRL's space activities continue to range from basic and applied research through advanced development and support to the warfighter. NRL conducts research in atmospheric physics, solar physics, solar-terrestrial relations, and high-energy astrophysics. We develop spacecraft, systems using these spacecraft, and ground command and control stations. From envisioning a concept to operating a platform, NRL's scientists and engineers conduct a vibrant and important space program.

We hope you enjoy SPECTRA and share it with others. To request additional copies or more information, please email spectra@nrl.navy.mil.

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AN EXPLORER IN SPACE

This issue of Spectra showcases the past, present, and future of the Naval Research Laboratory's space program. For more than six decades, NRL has been exploring space in fundamental

scientific investigations and for military applications, as the timeline starting on page 6 details. It is one of a handful of laboratories with this legacy and with the wide range of capabilities needed for both basic and applied defense research in space. NRL is known as one of the most successful designers and builders of spacecraft in the United States and has been called on to develop many hundreds of space instruments and subsystems – which is why it is designated the Navy's lead laboratory in space systems research.

Building on the multidisciplinary nature of NRL's mission, the space program integrates the science and engineering expertise found all across the Lab to advance our knowledge of the space domain and hone our ability to understand and predict its impacts on critical Department of Defense operations. Communications, surveillance, precision navigation and timing, battlespace and maritime domain awareness, orbital tracking, space weather prediction – these are just a few of the functions that NRL's space research contributes to in innovative and world-leading ways.

As we depend more and more on space-based systems, NRL continues to explore the space environment, from Earth's atmosphere to the far reaches of the Universe, to expand our knowledge of this awe-inspiring realm.

NRL

A YEAR OF LAUNCHES

Every year, the Naval Research Laboratory leads or participates in numerous space projects in various stages of development. Normally, these culminate in a launch every few years, or perhaps a launch or two in a single year. This year, for example, the TacSat-4 satellite is ready for launch (see page 20), and two NRL experiments were transported to the International Space Station on Space Shuttle Endeavour. But two years ago, 2009 saw the successful launch and deployment of ten space projects spearheaded by NRL researchers. Dr. Jill Dahlburg, superintendent of NRL's Space Science Division, noted, "2009 was a banner year for NRL space science and technology. The creativity, dedication, and perseverance of our space researchers throughout the Laboratory made this remarkable multitude of achievements possible."

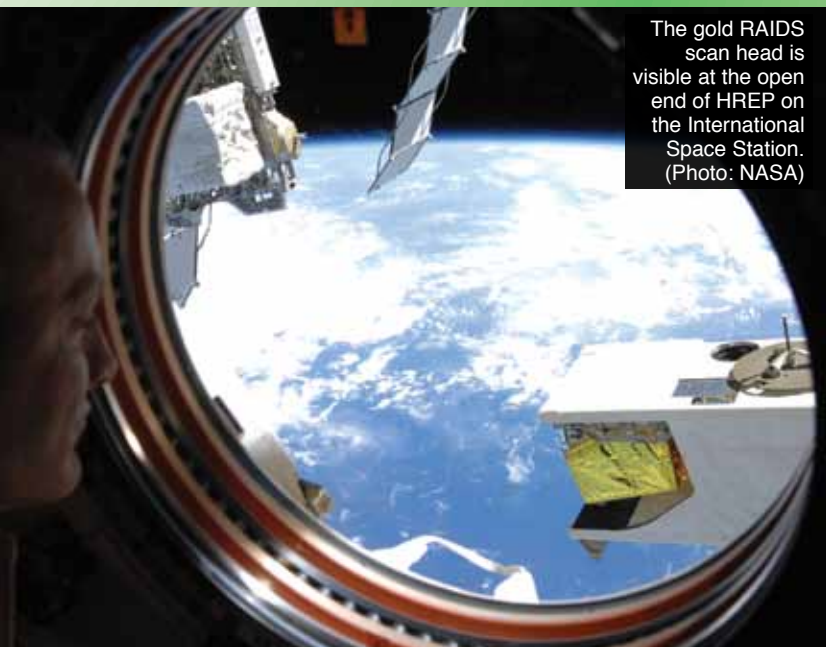
Between March and November 2009, eight militarily relevant experiments of high technical value were integrated, launched, deployed, and operated

by the Department of Defense (DoD) Space Test Program (STP); one cutting-edge instrument suite (HERSCHEL) was launched by NASA; and one transitioning operational capability (SSULI) was launched by the Defense Meteorological Satellite Program (DMSP).

Six of these missions are detailed in this feature. These six space activities scientifically encompass a wide range of investigations and applications typical of the breadth of NRL's space program: hyperspectral spaceborne remote sensing of the Earth's coastal regions, in situ monitoring of materials and components exposed to the extreme space environment, measurements of the Earth's thermosphere and ionosphere for validating and improving space weather models, and imaging of the Sun's corona for increased predictive understanding of the solar wind and space weather.

Operational sensor SSULI launched by the Defense Meteorological Satellite Program.

NRL's Special Sensor Ultraviolet Limb Imager (SSULI) was launched October 18, 2009, on the DMSP F18 satellite. SSULI cleanly measures vertical profiles of natural airglow radiation from atoms, molecules, and ions in the upper atmosphere and ionosphere by passively scanning the Earth's limb in the extreme ultraviolet (EUV) to far ultraviolet (FUV) wavelength ranges, to provide space environmental data in support of military and civilian systems. SSULI is the first operational atmospheric sensor to exploit the EUV spectrum. DMSP F18 SSULI data products, once calibrated and validated, will be used operationally at the Air Force Weather Agency to support the warfighter. The DMSP is a



The gold RAIDS scan head is visible at the open end of HREP on the International Space Station. (Photo: NASA)

RIGHT This HICO image over a coastal region of the South China Sea near Hong Kong, China, was taken October 2, 2009. The image is approximately 43 km wide and 190 km long centered upon 22°5'N, 114°18'E, oriented from SW at the bottom to NE at the top.



DoD environmental monitoring spacecraft program led by the U.S. Air Force Space and Missile Systems Center.

HREP, HICO, and RAIDS launched aboard the Japanese H-II Transfer Vehicle. The HICO/RAIDS Experiment Payload (HREP) launched September 10, 2009, from Tanegashima Launch Center aboard the inaugural flight of the Japanese Aerospace Exploration Agency (JAXA) H-II Transfer Vehicle. HREP is the first U.S. payload on the Japanese Experiment Module-Exposed Facility (JEM-EF), a component of the International Space Station (ISS). HREP provides all structural support and attitude knowledge to the HICO and RAIDS hyperspectral sensors, and serves as the control interface to the JEM-EF for HICO and RAIDS communication, data handling, monitoring, and power.

From its vantage point on the ISS, NRL's Hyperspectral Imager for the Coastal Ocean (HICO) is collecting high-fidelity hyperspectral images of land and coastal scenes and is using this information to derive important environmental data products such as bathymetry and water clarity. Under the Office of Naval Research Innovative Naval Prototype program, HICO is successfully demonstrating the viability of

operating a commercial off-the-shelf (COTS)-based system in space for littoral environmental imaging relevant to Navy and Marine Corps operations.

The Remote Atmospheric and Ionospheric Detection System (RAIDS) is a hyperspectral sensor suite studying the upper atmosphere with eight optical limb-scanning sensors that range from EUV to near-infrared wavelengths. RAIDS collects the temperature and composition of the lower thermosphere and retrieves ionospheric electron densities. The new high-resolution results are being compared with predictions from global assimilative models for improved forecasting of satellite drag, specification of the ionosphere, and investigation of the surprisingly strong relationship between atmospheric dynamic processes and global-scale ionospheric morphology. RAIDS was built and is operating in a collaboration between NRL and The Aerospace Corporation. HICO/RAIDS was integrated and flown under the auspices of the DoD STP.

MISSE-7 launched by Space Shuttle Atlantis to the International Space Station. The 7th Materials on the International Space Station Experiment (MISSE-7) was transported to the ISS by Space Shuttle Atlantis, launched November 16, 2009. The numerous

individual experiments on MISSE-7 include in situ monitoring of materials sensitivities to the harsh space environment. These experiments provide a better understanding of the durability of advanced materials and electronics exposed to vacuum, solar radiation, atomic oxygen, and extremes of heat and cold. MISSE-7 returned to Earth on NASA's STS-134 mission (the final flight of Space Shuttle Endeavour, launched May 2011) and was replaced by MISSE-8, which will remain in orbit until at least 2013. After MISSE-7 components are evaluated, the technology readiness of successful experimental components will increase to the operational prototype level. MISSE-7 and MISSE-8 were integrated and flown under the auspices of the DoD STP.

ANDE-2 microsatellites launched by Space Shuttle Endeavour. The NRL ANDE-2 twin experimental microsatellites deployed on July 30, 2009, from Space Shuttle Endeavour under the auspices of the DoD STP. The two spherical microsatellites have the same size and drag coefficient but different masses, and are slowly separating into lead-trail orbits. ANDE-2 is providing a direct opportunity to study small-scale spatial and temporal variations in drag associated with geomagnetic activity. The ANDE research products are being used to improve methods for the precision orbit determination of space objects and to calibrate the Space Fence, a radar system of the U.S. Air Force 20th Space Control Squadron that tracks low-Earth-orbiting space objects. The ANDE project is also advancing miniaturization of sensor technologies that are pivotal for multi-point, in situ space weather ensing.

CARE-I launched by DoD STP sounding rocket. The Charged Aerosol Release Experiment I (CARE-I) was launched by the DoD STP from the NASA Wallops Flight Facility at dusk on September 19, 2009, to investigate



The NRL ANDE-2 spacecraft, Castor and Pollux, shortly after deployment, as photographed by the crew of Endeavour. (Photo: NASA)

properties of charged dust in the ionosphere. The bright optical CARE-I upper atmospheric display, easily seen from the ground along the East Coast of the United States, was produced by sunlight scattered by concentrated rocket exhaust that was released at 290 km altitude by a delayed firing of the sounding rocket fourth stage. The exhaust material, composed of 1/3 aluminum oxide particles and 2/3 combustion product molecules, interacted with the ionosphere to create a dusty plasma with high-speed pick-up ions. Ground-based radars tracked the effects of CARE-I on the ionosphere for more than four hours, producing valuable data about how rocket motors affect ionospheric densities. CARE-I also provided a simulation of natural disturbances in the Earth's upper atmosphere.

HERSCHEL launched by NASA sounding rocket. The NASA-sponsored Helium Resonance Scattering in the Corona and Heliosphere (HERSCHEL) suborbital sounding rocket launched successfully on September 14, 2009, from the White Sands Missile Range. This joint mission with the NASA Living With a Star program, NRL, and multiple institutions in Italy,

France, and the United Kingdom, provided the first global images for the two most abundant elements of the solar corona, hydrogen and helium. HERSCHEL achieved three first-time measurements: simultaneous global imaging of the extended corona in EUV, ultraviolet, and visible light; global measurement of the ratio of helium to hydrogen in the corona; and global maps of solar wind outflow. Determination of the processes that generate and drive the solar wind will provide a fundamental advance in our understanding and forecasting of space weather effects at Earth. 🌈



CARE

The CARE-I dust cloud release was the brightest object in the sky over NRL as viewed from Alexandria, Virginia, six minutes after launch. The release was produced by a solid rocket motor that remained at a fixed altitude of 290 km during the rocket engine burn.

NRL

Jupiter

65 years in space

A TIMELINE

The Naval Research Laboratory entered the realm of space soon after American forces entered Germany in 1945 and captured the huge underground factory for V-2 rocket production at Nordhausen. The Americans confiscated about one hundred rockets and shipped them to the White Sands Missile Range in New Mexico, where the Army set about studying the propulsion system. The first American-launched V-2 flew from White Sands on April 16, 1946.

Seeing the opportunities for upper atmosphere research and solar astronomy, NRL took the lead in the Navy for conducting rocket research. The V-2 Rocket Panel was formed with membership from NRL, APL (Applied Physics Laboratory), California Institute of Technology, Harvard University, University of Michigan, and other organizations to oversee the allocation of space on V-2 rockets for high-altitude research, with NRL's Ernst Krause as the first chair. The research goals included radio and sound propagation in the atmosphere, properties of the atmosphere, cosmic rays, solar ultraviolet radiation, and various biological investigations.

NRL's V-2 experiments in 1946 and 1949 marked the beginning of a major space science program at the Lab.

Within a decade, NRL had developed a base of rocket science that had formed into two distinct branches: one related to applications, including the development of scientific payloads; the other, the development of rocket technology.

This timeline highlights some milestones in NRL's space program as it developed from those post-World War II years to the present, when NRL is about to launch its 100th satellite and is the Navy's lead laboratory for space systems research.

1946 NRL IN SPACE



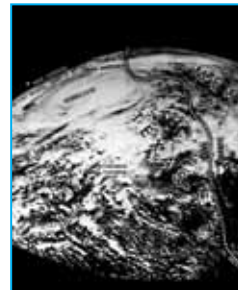
Richard Tousey's first V-2 rocket flight measured solar ultraviolet radiation.



1949 Herbert Friedman's first V-2 rocket flight measured solar X-radiation. Friedman later made the first positive identification of stellar X-rays in 1963.



1949 First flight of NRL's Viking rocket, designed to replace the V-2 for scientific missions that required higher altitudes and pointing stability.



1954 NRL's photograph of a hurricane from an Aerobee rocket was the first time a major weather feature was seen from space and a convincing argu-



ment that space cloud imagery could be a valuable tool for meteorologists.

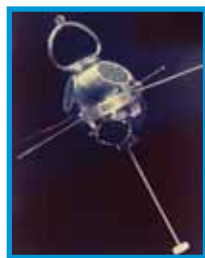
1958 Vanguard I, the oldest man-made satellite in orbit, launched on St. Patrick's Day.

NRL conducted Project Vanguard for the International Geophysical Year of 1957–1958. NRL designed and developed the three-stage rocket, the grapefruit-sized satellite, and the Mini-track network that tracked the satellite using radio interferometry. The Vanguard team was transferred in October 1958 to the new National Aeronautics and Space Administration (NASA).

1958–1964 Extending the Mini-track concept, NRL developed the Naval Space Surveillance System (NAVSPASUR).

1960 Launch of GRAB, the first U.S. "spy" satellite, along with SolRad which monitored solar X-radiation.

The month after a U-2 aircraft was lost on a reconnaissance mission over Soviet territory, GRAB I was launched and began transponding intercepted electronic intelligence signals to ground stations. GRAB demonstrated the value and viability of space-based intelligence platforms. The SolRad series of satellites studied the Sun's effects on Earth on missions from 1960 to 1979.



1961 First launch of the Low Frequency Trans-Ionospheric (LOFTI) radio satellite to study the propagation of radio waves through the ionosphere.

1965 Launch of OSO-2, first in a series of Orbiting Solar Observatory missions for which NRL developed solar physics instrumentation.

1967 Launch of the first of four Timation (time and navigation) satellites, which demonstrated NRL's new navigation concept that became GPS. Followed by Timation II (1969), Timation IIIA/Navigation Technology Satellite (NTS)-1 (1974), and Timation IV/NTS-2 (1977).



1971 First observation of a coronal mass ejection (CME) from space, by an NRL coronagraph on board OSO-7.

1972 NRL's Lunar Surface Camera operated on the Moon during the Apollo 16 mission, obtaining images of the Earth and celestial objects.

1973 NRL solar spectrometers operated on Skylab, America's first space station.

1976 First launch of the Multiple Satellite Dispenser (MSD), an upper stage for the Atlas F booster, which carried multiple satellites into precise orbits.

1979 Launch of the SolWind Coronagraph on a DoD satellite to monitor the solar corona and catalog CMEs. First observation of a CME headed toward Earth, a so-called halo CME.

1982

The first of five Space Shuttle flights of NRL's Solar Ultraviolet Spectral



Irradiance Monitor (SUSIM) which measured absolute solar UV irradiance and examined the impact of solar variability on the Earth's ionosphere and climate. SUSIM also flew on the Upper Atmosphere Research Satellite (UARS) (1991–2005) and produced the longest continuous absolute measurement of solar UV irradiance to date.

1983 Launch of Living Plume Shield II (LIPS II) to demonstrate direct downlink of tactical data from a low Earth orbiting spacecraft.

1985 NRL scientist Dr. John David Bartoe flew on the Space Shuttle as payload specialist for NRL's High Resolution Telescope and Spectrograph that recorded UV spectra of the Sun.

1987 The first Special Sensor Microwave Imager (SSM/I) was flown in DoD's Defense Meteorological Satellite Program (DMSP) to map water vapor and ocean wind speed. NRL pioneered this technique.

1987 Launch of LIPS III provided a test bed for new space power sources.

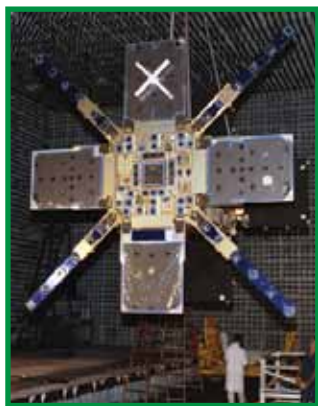


1990 NASA's Compton Gamma Ray Observatory containing NRL's Oriented Scintillation Spectrometer Experiment

(OSSE) was put in orbit from the Space Shuttle. It operated for 10 years.

1990

Launch of the Low-Power Atmospheric Compensation Experiment (LACE), a spaceborne target with sensors to characterize a laser beam emitted from a ground-based laser site.



1991 Launch of the Japanese Yohkoh solar observatory with NRL instrumentation on board to measure high-energy solar phenomena. Yohkoh provided the first definitive observations connecting solar flares to the breaking and reconnection of magnetic fields.

1993 NRL's Polar Ozone and Aerosol Measurement (POAM) instrument was launched on the French Space Agency SPOT remote sensing satellite.

1994 First flight of NRL's Middle Atmosphere High Resolution Spectrometer Instrument (MAHRSI) on the German Space Agency's Shuttle Pallet Atmosphere Satellite (SPAS) to make global measurements of OH in the mesosphere and upper stratosphere.

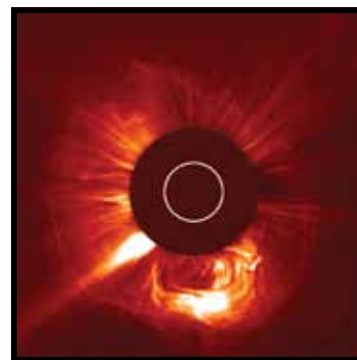


1994 The DoD-NASA Clementine satellite, developed by NRL under the mantra of "faster, better, cheaper," was launched to test lightweight miniature sensors and advanced spacecraft components, and to map the entire lunar surface.



1995 NRL's Large Angle and Spectrometric Coronagraph (LASCO) and Extreme Ultraviolet Imaging Telescope (EIT) launched on the ESA/NASA Solar

and Heliospheric Observatory (SOHO). These instruments help to understand the mechanisms that form CMEs



and drive the solar wind, providing a genuine basis for predicting geomagnetic storms on Earth.

1999 The ARGOS satellite contained five NRL instruments to measure the upper atmosphere, conduct astronomy experiments, and test new technology.

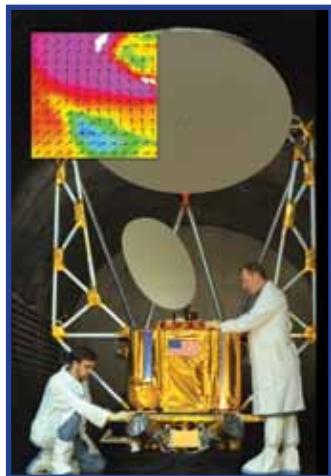
1999 First launch in Project Starshine, a science education project for measuring variations in the density of Earth's



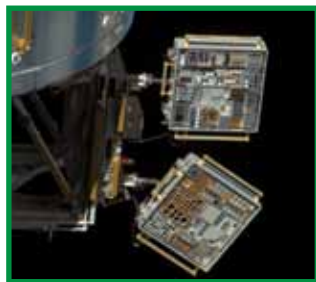
upper atmosphere during solar storms. Students from all over the world helped to build the satellites and collected data from them.

2003 The first in a series of NRL's Special Sensor Ultraviolet Limb Imagers (SSULI) flew on a DMSP satellite, providing operational environmental data for the warfighter.

2003 WindSat, the first space-borne polarimetric microwave radiometer, launched on the NOAA/DoD/NASA Coriolis spacecraft to measure wind speed and direction at the ocean surface.



2005 MISSE-5 launched to the International Space Station. The suitcase-sized experiment exposed hundreds of samples of materials and components to the harsh space environment for later analysis of the effects. Followed by MISSE-6 (2008), MISSE-7 (2009) and MISSE-8 (2011).



2006 Launch of TacSat-2, part of the Operationally Responsive Space initiative to bring tactical capability to the warfighter rapidly, without the decade of development normally associated with operational military satellites.

2006 Launch of NASA's STEREO (Solar TERrestrial Relations Observatory). NRL's SECCHI telescopes provide 3-D observations of CMEs

as they form at the Sun and traverse interplanetary space to Earth.



2006 Atmospheric Neutral Density Experiment (ANDE) microsattellites deployed to monitor atmospheric density for improved orbit determination of space objects. ANDE-2 was launched in 2009.

2006 Launch of the Taiwan-U.S. COSMIC/FORMOSAT3 mission with NRL's Tiny Ionospheric Photometer (TIP) compact far-UV sensors on board to study Earth's night-side ionosphere.

2006 Launch of the Microsatellite Technology Experiment (MiTeX), with NRL's Upper Stage, to test and evaluate small satellite technologies.

2006 Launch of the Japanese Hinode solar observatory with NRL's Extreme-ultraviolet Imaging Spectrometer (EIS) to measure temperature, density, and dynamics of the solar corona.



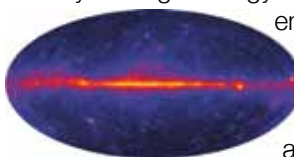
2007 Launch of STPSat-1 carrying SHIMMER and CITRUS. SHIMMER measured OH in the middle atmosphere, and demonstrated spatial heterodyne spectroscopy for space-based remote sensing. CITRIS detected when and where scintillation and refraction adversely affect radio propagation, and provided global maps of ionospheric densities.



2008 Launch of the ESA Herschel Space Observatory that measures

terahertz radiation from astronomical and planetary objects. NRL contributed to the optical system of the 3.5-meter-diameter silicon carbide Cassegrain telescope.

2008 Launch of the Fermi Gamma-ray Space Telescope to survey the high-energy space environment. NRL led the team that designed and manufactured the Large Area Telescope (LAT) calorimeter, which measures the energies of gamma rays from astronomical objects and the Sun.



2009 HICO/RAIDS launched to the International Space Station. The Hyperspectral Imager for the Coastal Ocean and Remote Atmospheric and Ionospheric Detection System collect useful environmental data for military and civilian systems.



2011 Scheduled launch of TacSat-4 with its COMMx payload to support



communications-on-the-move, data exfiltration, and Blue Force Tracking. It is designed to be reallocated rapidly to different theaters worldwide. ♦

NRL's WIDE-FIELD IMAGER selected for the SOLAR PROBE PLUS MISSION

NASA has chosen the Naval Research Laboratory's Wide-field Imager to be part of the Solar Probe Plus mission slated for launch no later than 2018. The Solar Probe Plus, a spacecraft the size of a small car, will plunge directly into the Sun's atmosphere, getting as close as four million miles from the star's surface. It will explore a region no other spacecraft ever has encountered in an effort to unlock the Sun's biggest mysteries.

For decades, scientists have known that the solar corona, or the Sun's outer atmosphere, is several hundred times hotter than the visible solar surface and that the solar wind accelerates up to supersonic speeds as it travels through the corona. In the Solar Probe Plus mission, scientists hope to find answers to the questions: Why is the solar corona so much hotter than the photosphere (the visible surface)? And how is the solar wind accelerated? The answers to these questions can be obtained only through in situ measurements of the solar wind down in the corona.

NRL's Wide-field Imager for Solar Probe (WISPR) is one of five science investigations selected by NASA for this mission. It is the only optical investigation because the solar environment is so hot the instruments need to be tucked behind a heat shield. NRL's Dr. Russell Howard, the principal investigator, says, "This is an extremely exciting mission — no other spacecraft has ever gone this close — it is like the early voyagers of the Earth, we don't really know what to expect, but we know, whatever it is, it is going to be spectacular."

The imager is a telescope that looks off to the side of the heat shield and will make 2-D images of the Sun's corona

as the spacecraft flies through. But like a medical CAT scan, the orbit of the spacecraft through the corona will enable 3-D images and a determination of the 3-D structure of the corona. The experiment actually will see the solar wind and provide 3-D images of clouds and shocks as they approach and pass the spacecraft.

"We'll be flying through the structures that we've only seen from 100 million miles away. We'll be able to see all the phenomena — mass ejections, streamers, shocks, comets, and dust — up close. Other instruments will be able to measure the magnetic and electric fields and the plasma itself," explains

Howard. This investigation complements other instruments on the spacecraft by providing direct measurements of the plasma far away from as well as near the spacecraft — the same plasma the other instruments sample.

The other four investigations chosen for the Solar Probe Plus mission are:

The Solar Wind Electrons Alphas and Protons Investigation will specifically count the most abundant particles in the solar wind — electrons, protons, and helium ions — and measure their properties. The investigation also is designed to catch some of the particles in a special cup for direct analysis. (Smithsonian Astrophysical Observatory, Cambridge, Massachusetts)

The Fields Experiment will make direct measurements of electric and magnetic fields, radio emissions, and shock waves that course through the Sun's atmospheric plasma. The experiment also serves as a giant dust detector, registering voltage signatures when specks of space dust hit the spacecraft's antenna. (University of California Space Sciences Laboratory, Berkeley, California)



Artist's concept of the Solar Probe Plus approaching the Sun. (Credit: NASA)

The Integrated Science Investigation of the Sun consists of two instruments that will take an inventory of elements in the Sun's atmosphere using a mass spectrometer to weigh and sort ions in the vicinity of the spacecraft. (Southwest Research Institute, San Antonio, Texas)

The Heliospheric Origins with Solar Probe Plus is led by Dr. Marco Velli who is the mission's observatory scientist, responsible for overseeing assembly of the spacecraft. He will ensure adjacent

instruments do not interfere with one another and guide the overall science investigations after the probe enters the Sun's atmosphere. (NASA's Jet Propulsion Laboratory, Pasadena, California)

The Solar Probe Plus mission is part of NASA's Living With a Star Program. The program is designed to understand aspects of the Sun and Earth's space environment that affect life and society. The program is managed by NASA's Goddard Space Flight Center with

oversight from NASA's Science Mission Directorate's Heliophysics Division. The Johns Hopkins University Applied Physics Laboratory is the prime contractor for the spacecraft. 🌈

Learn more online at
<http://solarprobe.gsfc.nasa.gov>
<http://solarprobe.jhuapl.edu>



SOHO

In the 15 years since it launched in December 1995, the SOHO spacecraft has seen twice the number of comets as were sighted in the previous three hundred years. (Credit: NASA/ESA/Alex Lutkus)

spots 2000th COMET

In December 2010, as people on Earth celebrated the holidays and prepared to ring in the New Year, a European Space Agency (ESA)/NASA spacecraft quietly reached its own milestone: on December 26, the Solar and Heliospheric Observatory (SOHO) discovered its 2000th comet.

Drawing on help from citizen scientists around the world, SOHO has become the single greatest comet finder of all time. This is all the more impressive since SOHO was not designed to find comets, but to monitor the Sun.

"Since it launched on December 2, 1995, to observe the Sun, SOHO has more than doubled the number of comets for which orbits have been determined over the last three hundred years," says Joe Gurman, the U.S. project scientist for SOHO at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Of course, it is not SOHO itself that discovers the comets — that is the province of the dozens of amateur astronomer volunteers who daily pore over the images produced by SOHO's LASCO (or Large Angle and Spectrometric Coronagraph) cameras. More than 70 people representing 18 different countries have helped spot comets over

the last 15 years by searching through the publicly available SOHO/LASCO images online. The 1999th and 2000th comets were both discovered by an astronomy student at the Jagiellonian University in Krakow, Poland.

"There's an ever-growing community of amateur astronomers who contribute to this project," says Karl Battams, who has been in charge of running the SOHO comet-sighting web site since 2003 for the Naval Research Laboratory, where he does software development, data processing, and visualization work for NRL's solar physics missions. "These volunteers are absolutely fundamental to the success of this program. Without them, most of this tremendously valuable astronomical data would never see the light of day."

Battams receives reports from people when they find a feature in SOHO's LASCO images that has the correct location, brightness, speed, morphology, and other characteristics to be a comet. He confirms the finding, gives each

comet an unofficial number, and sends the information off to the Minor Planet Center in Cambridge, Massachusetts, which categorizes small astronomical bodies and their orbits.

It took SOHO ten years to spot its first thousand comets, but only five more to find the next thousand. That is due partly to increased participation from comet hunters and work done to optimize the images for comet-sighting, but also due to an unexplained systematic increase in the number of comets around the Sun. December 2010 saw an unprecedented 40 new comets spotted. During one short period, the rate of discoveries was so great as to be labeled a "comet storm." "The storm began on December 13 and ended on the 22nd," explains Battams. "During that time, SOHO detected 25 comets diving into the Sun. It was crazy!"

LASCO was not designed to spot comets. The LASCO camera blocks out the brightest part of the Sun in order to better watch emissions in the much fainter outer atmosphere, or

corona. LASCO's comet finding skills are a natural side effect — with the Sun blocked, it's also much easier to see dimmer objects such as comets.

"There is a significant science return from these 'sungrazer' comets," says Battams, "as they can be considered probes of solar wind conditions near the Sun. One of the main objectives of the SOHO/LASCO mission is to investigate the solar wind and its acceleration processes." (See page 14 for more on LASCO.)

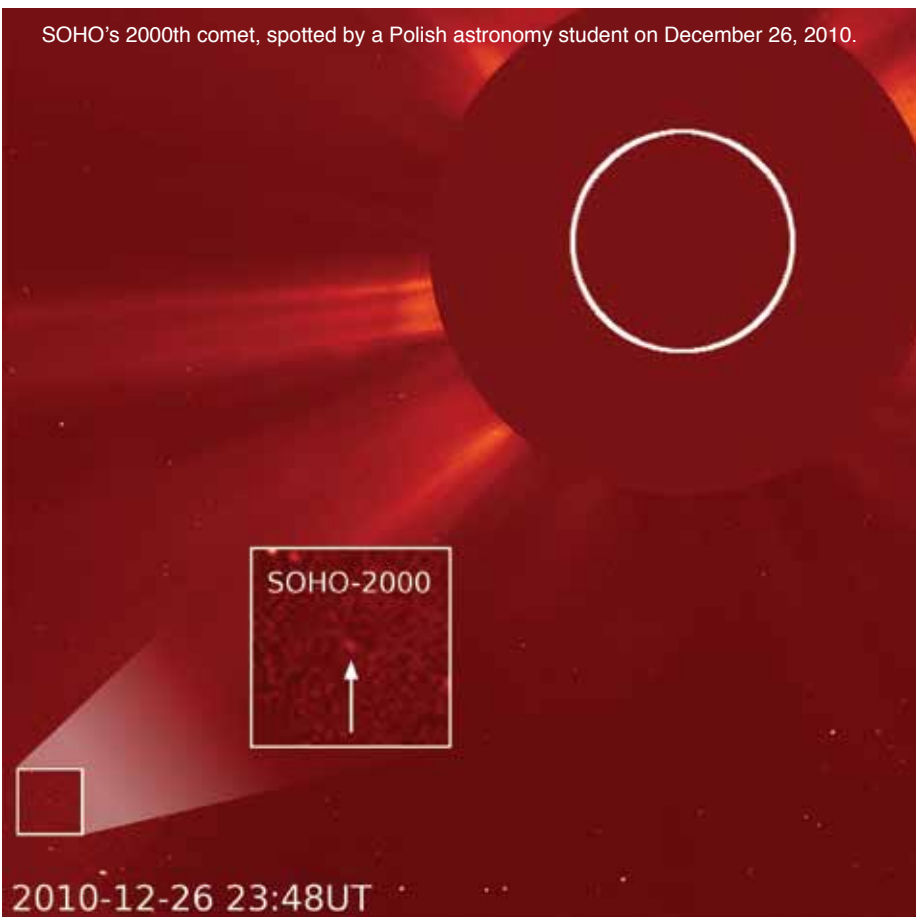
"Also," continues Battams, "now we know there are far more comets in the inner solar system than we were previously aware of, and this can tell us a lot about how they're formed and how they break up. We can tell that many of these comets have a common origin." Indeed, a full 85% of the comets discovered with LASCO are thought to come from a single group known as the Kreutz family, believed to be the remnants of a single large comet that broke up several hundred years ago.

Sungrazers like the Kreutz family comets approach so near the Sun that most are vaporized within hours of discovery. But many of the other LASCO comets boomerang around the Sun and return periodically. One frequent visitor is comet 96P Machholz; orbiting the Sun approximately every six years, it has now been seen by SOHO three times.

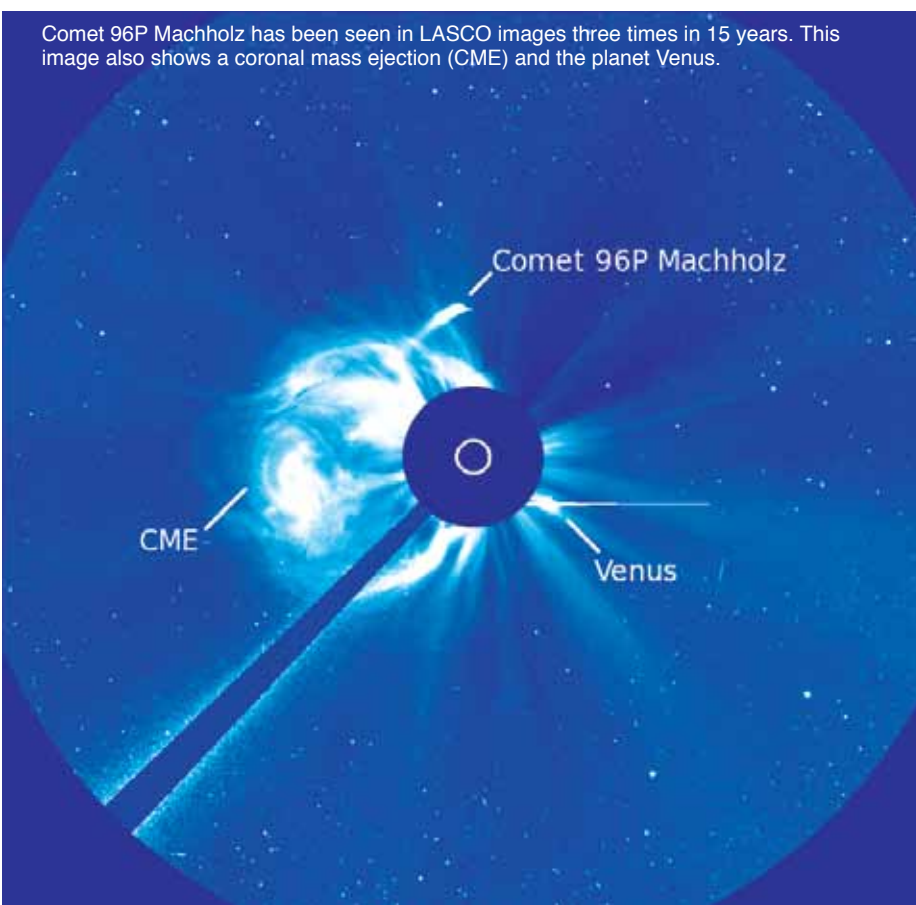
SOHO is a cooperative project between ESA and NASA. The spacecraft was built in Europe for ESA and equipped with instruments by teams of scientists in Europe and the USA. NRL's Dr. Russell Howard was principal investigator for the LASCO instrument. (Credit: NASA and NRL) 🌈

Learn how to find your own comet at <http://sungrazer.nrl.navy.mil>.

SOHO's 2000th comet, spotted by a Polish astronomy student on December 26, 2010.



Comet 96P Machholz has been seen in LASCO images three times in 15 years. This image also shows a coronal mass ejection (CME) and the planet Venus.



LASCO

13,587 CMEs and Counting

Coronagraphs Obtain the First Complete Solar Cycle Set of Coronal Mass Ejection Observations

Naval Research Laboratory scientists have developed the first comprehensive analysis of the size, speed, mass, and kinetic energy of solar coronal mass ejections (CMEs). CMEs are the most energetic phenomena in the solar system and the major drivers of geomagnetic storms. They were first observed from space in 1971 by an NRL coronagraph on board the Seventh Orbiting Solar Observatory (OSO-7). NRL's subsequent sustained basic and applied research on CMEs and their effects on the ionosphere, thermosphere, and the nation's space assets led to a progressively fuller physics-based understanding of space weather phenomena and contributed materially to the space weather forecasting capabilities used by the Air Force Weather Agency to support U.S. warfighters.

This recent study of CMEs has been enabled by the uniquely long-term and

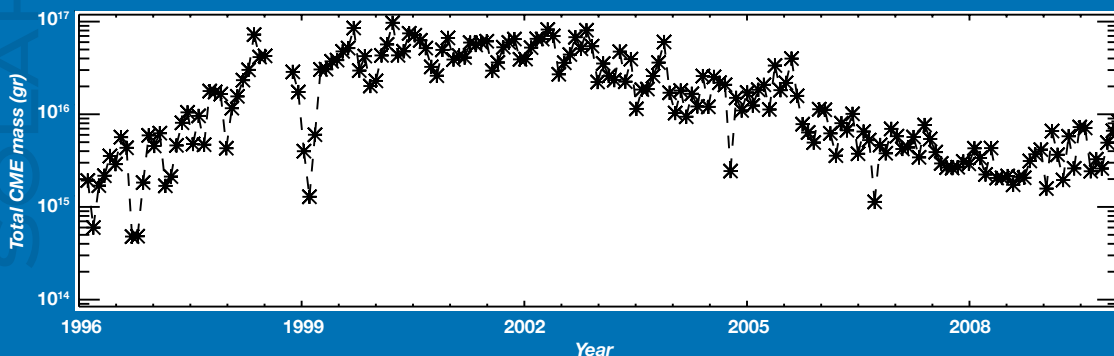
comprehensive observations obtained by the Large Angle and Spectrometric Coronagraph (LASCO) aboard the European Space Agency (ESA)/NASA Solar and Heliospheric Observatory (SOHO) mission. LASCO was developed and is operated by NRL's Space Science Division (SSD).

The continuous operation of the LASCO coronagraph suite since 1996 has resulted in the longest and most complete database of CME properties ever assembled. SSD researchers Drs. Angelos Vourlidas and Russell Howard, together with outside collaborators, have measured and catalogued the properties of 13,587 CMEs (as of December 2009) from 130,000 calibrated LASCO images. Their data analysis, reported in the *Astrophysical Journal*, provides a robust understanding of the dynamic properties of CMEs and their long-term trends, information important

for understanding the geoeffective potential of CMEs and improving space weather forecasting capabilities.

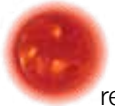
Among the most important results of the study are: (1) CMEs become fully developed only at solar distances of about 10 to 15 solar radii; this provides the field of view (FOV) specification for future operational coronagraphs used for space weather forecasting. (2) Not every solar plasma ejection qualifies as a CME; a large number of ejections disappear within the LASCO field of view (30 solar radii), possibly leading to misidentifications with in situ observations at Earth. (3) There is a rapid drop in the average CME mass and CME ejection rate by a factor of six within four months in mid-2003. When compared with similar, but intermittent, observations in previous solar cycles, the average CME mass seems to exhibit a downward trend beginning in the mid-1970s.

Vourlidas and his team report that there are indications for periodic variations in CME ejection rate. The discovery of such regularity in CME behavior has potentially important implications for space weather forecasting and demonstrates the importance of long-term solar activity monitoring. 



Total mass injection in the solar wind by CMEs over the last 14 years as observed by the LASCO instrument.

VIEWING THE SUN in 3-D with STEREO



In Superbowl "Sun-day,"

February 6, 2011, NASA released a video showing a full, 360-degree image of the Sun — an exciting first in solar physics. This magnificent view was sent to Earth by NASA's STEREO (Solar Terrestrial Relations Observatory) mission. STEREO consists of two spacecraft observing the Sun from two different viewpoints, in "stereo." The two spacecraft were launched together on October 25, 2006, and have been slowly drifting apart, each gathering detailed images of solar activity from different angles. Starting on February 6, the two were 180 degrees apart, each seeing half the Sun; combining the views allows the full view of the star.

A key component of the STEREO mission is the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI), a suite of five scientific telescopes built by an international consortium led by the Naval Research Laboratory. SECCHI observes the solar corona and inner heliosphere from the surface of the Sun out to the orbit of Earth. A nearly identical SECCHI suite is on each of the two solar-powered STEREO observatories, STEREO-A ahead of Earth in its orbit and STEREO-B trailing behind. The two observatories trace the flow of energy and matter from the Sun to Earth. They capture the three-dimensional structure of coronal mass ejections, the powerful eruptions of plasma and magnetic energy from the Sun's outer atmosphere, or corona.

NRL's Dr. Angelos Vourlidas, SECCHI project scientist, explains the significance of being able to map the entire solar atmosphere continuously: "For the first time, we can take snapshots of the entire atmosphere of a star. To put it in perspective, before STEREO we were like a person trying to get the pulse of a city by watching through a half-open window — not an easy task. Now, STEREO has thrown wide open the window and we can watch the Sun and its activity in its full three-dimensional glory."

Before the three-dimensional view was available, researchers had to wait until an active region of the Sun rotated to the area visible from Earth in order to study the properties. The problem of having to wait for the proper views to appear is that the corona is highly variable, filled with regions that come and go in a matter of days, and explosions that can alter the corona landscape in a matter of hours.

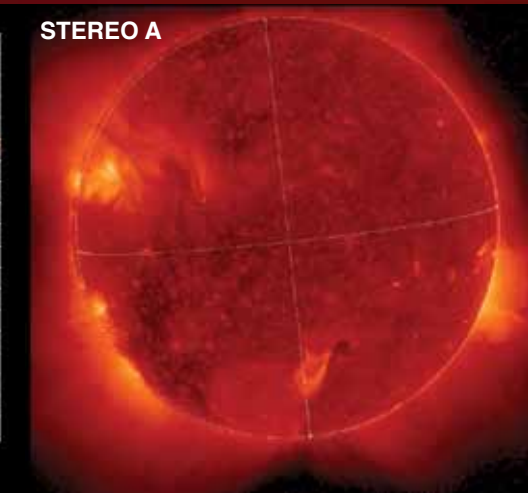
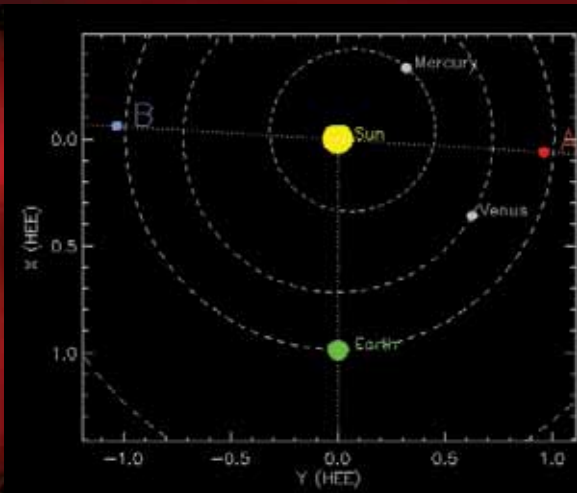
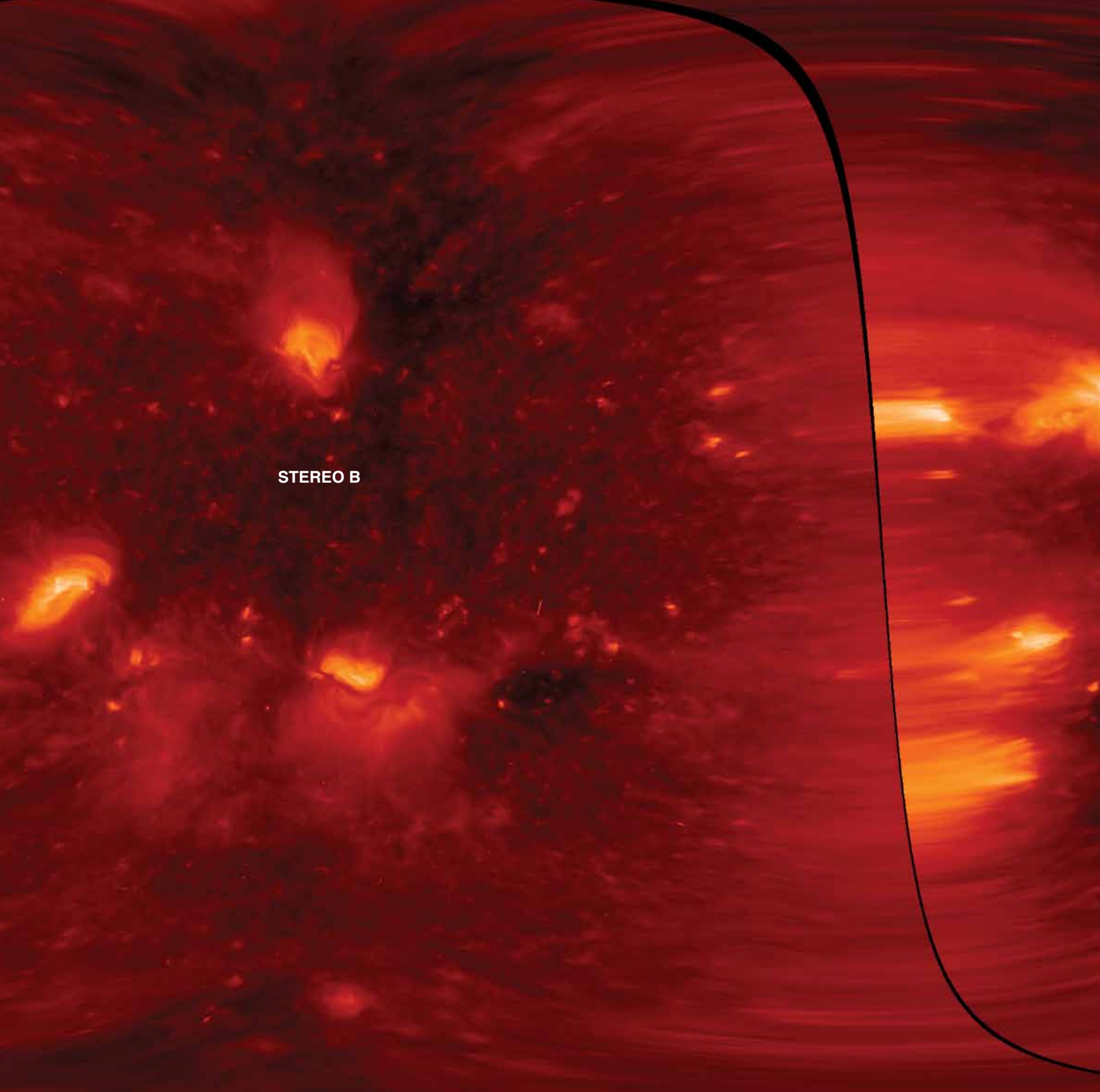
The three-dimensional view offers huge potential for advances in the field of heliophysics. "We can solve the puzzles behind the evolution and structure of the solar atmosphere, including its violent eruptions, because we will be able to observe every feature and source of activity at the same time all over the Sun, and follow their connections that can extend to large distances around the Sun," Vourlidas explains. STEREO will have the full 360-degree view for the next eight years.

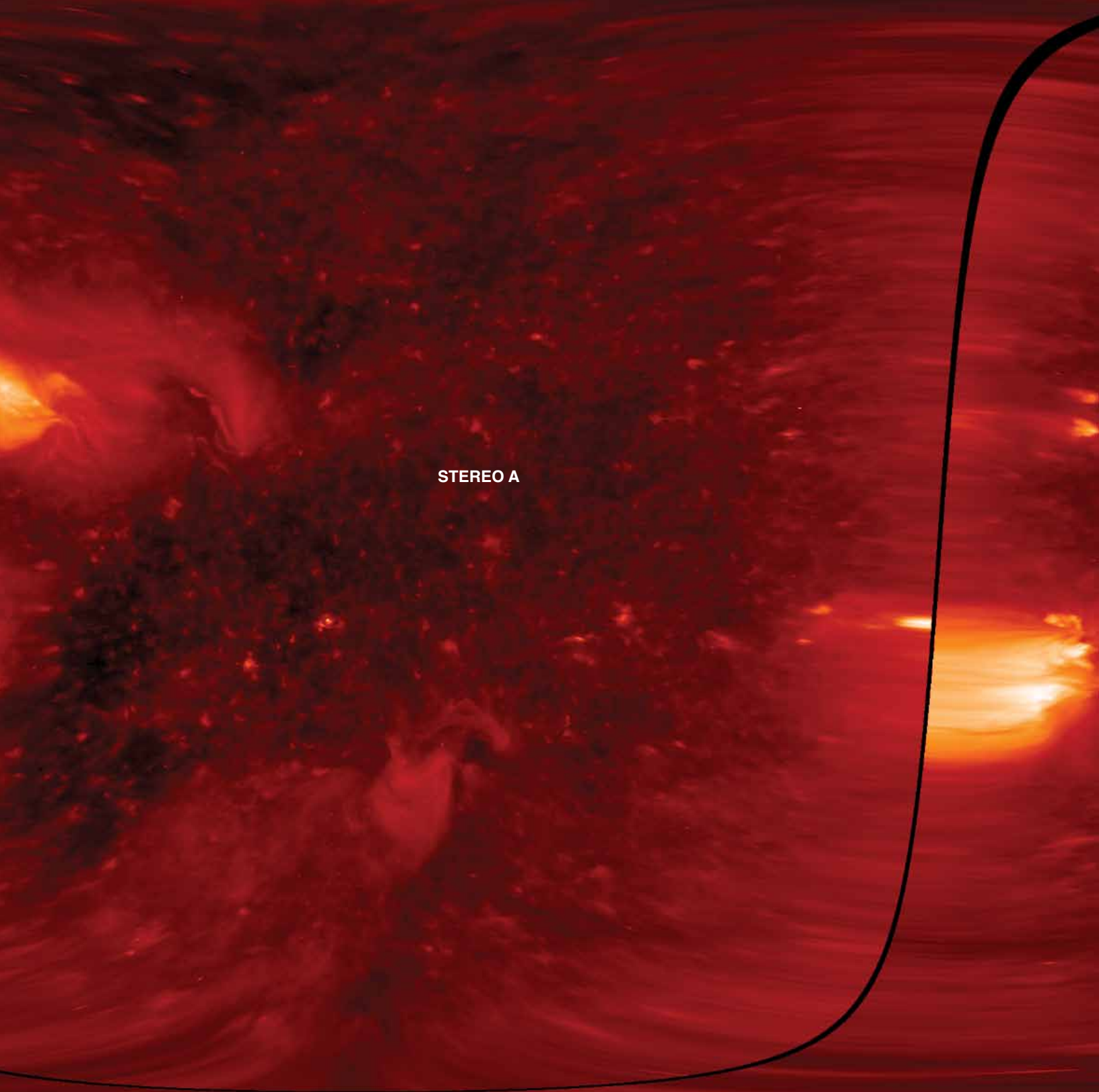
STEREO is the third mission in NASA's Solar Terrestrial Probes Program and is sponsored by NASA's Science Mission Directorate. The Goddard Science and Exploration Directorate manages the mission, instruments, and science center. The Johns Hopkins University Applied Physics Laboratory designed and built the spacecraft and is operating them for NASA during the mission. 🌈

Learn more at <http://secchi.nrl.navy.mil>.



SECCHI instrument suite in the laboratory.





Above: Cartesian projection of the entire solar atmosphere as observed by NRL's SECCHI EUV (extreme ultraviolet) telescopes at a temperature of 1.6 million degrees. The lower panels show the individual images from each telescope and the middle panel shows the geometric configuration of the STEREO spacecraft at the time the images were taken. SECCHI acquires such full maps of the Sun every 10 to 20 minutes.

NRL FEATURES

NRL LAUNCHES Nanosatellite Experimental Platforms

SPACECRAFT ENGINEERING

The Falcon 9 rocket carrying NRL's nanosatellites launched at 10:43 a.m. EST from Cape Canaveral's Launch Complex 40 on the first test flight of NASA's Commercial Orbital Transportation Services program with the Dragon capsule. (Credit: SpaceX/Chris Thompson)

SPECTRA

Two nanosatellites designed and built by NRL's Naval Center for Space Technology

were recently placed in orbit to evaluate nanosatellites as platforms for experimentation and technology development. They were launched from Cape Canaveral Air Force Station on December 8, 2010, as secondary payloads on board a Space Exploration Technologies (SpaceX), Inc., Falcon 9 launch vehicle.

NRL's nanosatellites are part of the CubeSat Experiment (QbX) of the National Reconnaissance Office (NRO). Cubesats are standardized, cube-shaped satellite platforms measuring only 10 cm (about 4 inches) on a side. NRO wants to demonstrate the feasibility of placing payloads on cubesats to accelerate technology evaluations and deploy new capabilities with markedly reduced costs over traditional satellite platforms.

Three cubesats attached end to end are referred to as triple-unit (3U) platforms. On this launch, NRL deployed two 3U cubesats with Colony I buses built by Pumpkin Inc. of San Francisco, California, and provided by the NRO.

NRL's tiny 3U cubesats contained components comparable to large satellites, including command telemetry and data handling, an electrical power system with batteries and solar arrays, an attitude control system with magnetic torque coils and reaction wheels for three-axis attitude control, and a UHF radio with antenna. Each subsystem essentially fit on a 4 x 4 inch circuit board.

Engineers from the NRL Spacecraft Engineering Department tested and integrated the nanosatellites before launch, and communicated successfully with them after deployment. The

tracking, telemetry, and command (TT&C) radio was fully functional, providing reliable two-way data transfers; and the flight software, ported from previous and ongoing NRL programs to the Pumpkin Colony I processor, provided an onboard scheduler for routine vehicle control and operation.

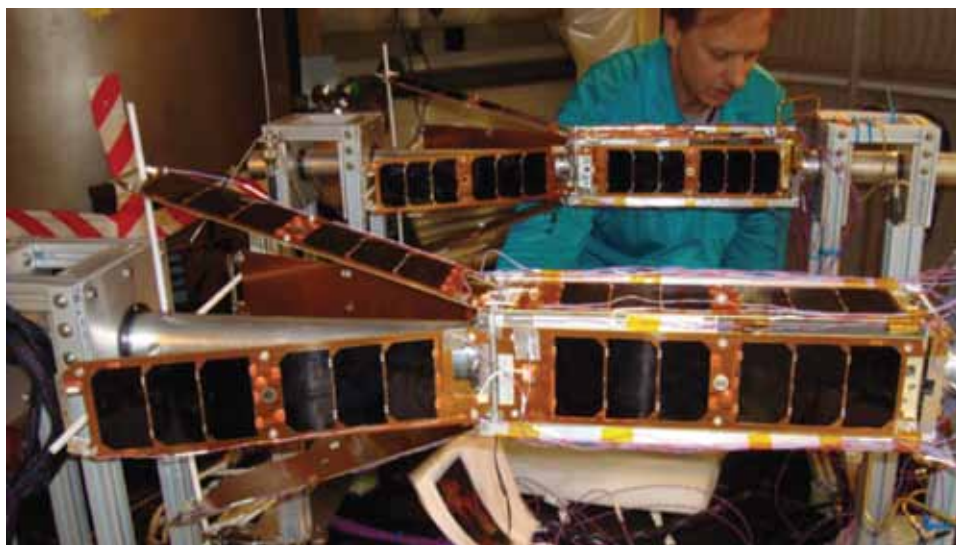
"Deployments, including arrays and antennas, were verified shortly after launch," said Dr. Stephen Arnold, a computer engineer with the Spacecraft Engineering Department. "We were able to command the satellites and receive stored and real-time telemetry from the onboard systems — in all, the spacecraft operated as expected, and the checkout and experimentation were successful."

Spacecraft attitude operated in a novel "space dart" mode, so called because of the shape and attitude of the deployed satellite. In this mode, atmospheric drag in the low orbit (300 km) provides a stabilization torque that, used with the onboard reaction wheels and torque coils, provides stable pointing to within five degrees of nadir throughout the orbit.

"It was expected that the QbX vehicles would remain in orbit for approximately 30 days," said Arnold. "In the end, one orbited for 29 days and the other for 39 days before each succumbed to the effects of atmospheric drag and was destroyed during re-entry to Earth's atmosphere."

Flight software, antennas, and the TT&C radio were designed, built, and integrated by NRL, as was the developmental communications payload. Environmental testing of the completed package was performed in NRL's extensive spacecraft testing facilities. Ground stations on the east and west coasts provided coverage for command loads and data collection, controlled via VPN from NRL's Blossom Point Satellite Tracking and Command Station in southern Maryland.

The primary payload launched aboard the SpaceX Falcon 9 was the Dragon capsule. Developed by SpaceX and sponsored by NASA's Commercial Orbital Transportation Services (COTS) program, the Dragon capsule is part of an initiative to develop private spacecraft to ferry cargo to and from the International Space Station. 🌈



Two triple-unit QbX cubesats being prepared for thermal vacuum testing at NRL's Spacecraft Checkout Facility. The "space dart" configuration of the satellites can be seen.

Ready to Deploy Virtual Mission Operations Center

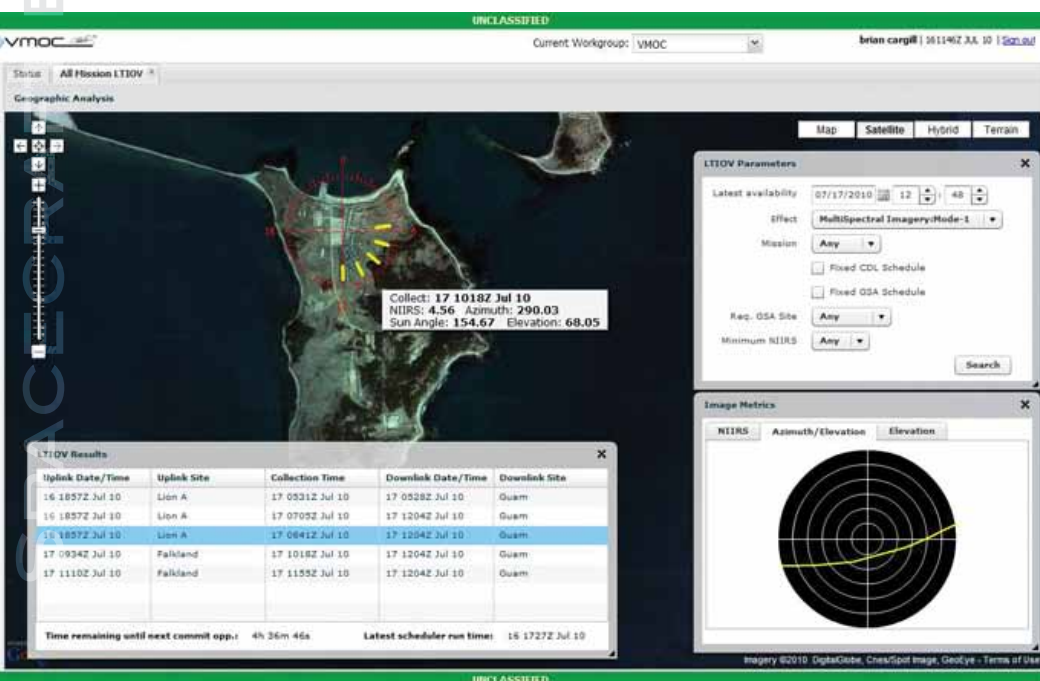
The Naval Research Laboratory is ready to deploy a remarkable capability that has been the focus of a six-year project developed in concert with numerous government and industry partners. Developed by NRL's Spacecraft Engineering Department, the Virtual Mission Operations Center (VMOC) is a web-enabled multi-application service that ushers in a new era for globally dispersed military users of Department of Defense, commercial, and civilian satellite payloads.

For the first time, requests for satellite services will be available to any approved user who has access to the Secret Internet Protocol Network (SIPRNet). By simply clicking a few selectable criteria, user requests will be immediately prioritized within VMOC based on the Operational Commander's intent, evaluated for execution based on orbital mechanics and satellite modeling data, and, if approved, autonomously loaded into a Satellite Operations Center (SOC)

upload buffer. "All of this occurs without the need for a single 'man in the loop.'" This new capability will dramatically improve satellite utilization as well as speed of command, so critical in today's dynamic battlefield," explains Joel Hicks, VMOC program manager. VMOC is accredited on SIPRNet and ready for operations today.

Specifically, VMOC is marked as the exclusive planning and tasking tool for two operational missions scheduled for launch in 2011: TacSat-4 and ORS-1. TacSat-4 is an NRL-integrated mission that provides 10 ultra high frequency (UHF) channels that can be used for myriad combinations of communications, data exfiltration, or friendly force tracking. ORS-1 will provide electro-optical/infrared capability for USCENTCOM. VMOC servers are located at NRL to support Blossom Point (Maryland) operations of TacSat-4, and at Schriever Air Force Base, Colorado, to support SOC-11 operations of ORS-1.

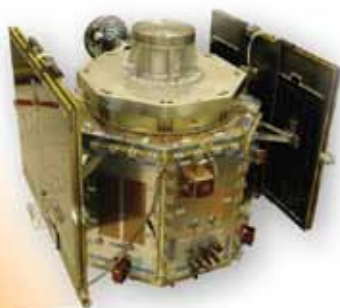
The VMOC is also providing the primary user interface for the High Integrity GPS (HIGPS) program, led at NRL. HIGPS has the ability to provide military users substantially improved capabilities for quickly locking onto and tracking a GPS signal, even while operating in restrictive



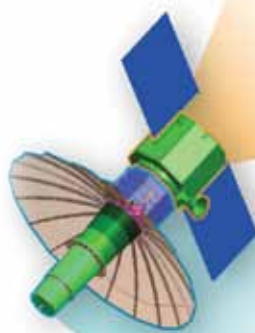
A sample Virtual Mission Operations Center screenshot.

Communication Operations Center

ORS standardized Phase 3 flight bus (solar arrays shown stowed).



TacSat-4's "COMMx" payload. 12-foot antenna with 10 channels of UHF communications.



The TacSat-4 Spacecraft

environments such as urban areas, forests, mountains, and canyons, as well as under enemy jamming attempts or amid battlefield radio frequency noise. VMOC just completed its final demonstration, of three, for the Office of the Assistant Secretary of Defense for Research and Engineering. All requirements were met and all interfaces verified. VMOC is now fully ready to support any decision to operationalize HIGPS.

The VMOC effort has been a cooperative one and has included the following agencies and companies: NASA, Air Force Research Laboratory, Space and Missile Defense Command, SAIC, Boeing, General Dynamics, Praxis, Space Ground System Solutions, PTR Group, and NRL's Information Technology Division. The primary sponsors for VMOC include the Office of Naval Research and the Operationally Responsive Space (ORS) Office. 🍀



TacSat-4, shown here in NRL's Spacecraft Test Facility, arrived at Alaska's Kodiak Launch Complex on March 1 and is undergoing final preparations for its scheduled late 2011 liftoff. VMOC will manage TacSat-4 payload tasking to provide communications management designees the ability to request satellite communications via SIPRNet and to provide dynamic channel assignments for flexible theater support. TacSat-4 is a Navy-led joint mission to augment current satellite communications capabilities and to advance Operationally Responsive Space (ORS) systems.

Project Perseus: Mission Support In Iraq

Scientists and engineers with the Naval Research Laboratory Marine Geosciences Division recently completed a 10-week deployment to help enable the safe drawdown of U.S. combat troops in Iraq. Partnering with Northrop Grumman Corp., Dr. John Brozena and Dr. Joan Gardner co-managed Project Perseus to support ground troops in counter-IED (improvised explosive device) operations, using an airborne multisensor instrumentation suite.

Incorporating the expertise of the U.S. Navy Scientific Development Squadron ONE (VXS-1), the NRL team, including project engineer Robert Liang, mission planning specialist Mike Vermillion, and data processor/analyst Dr. Andrei Abelev, installed and made mission-ready the Northrop Grumman Multi-Band Synthetic Aperture Radar (MB-SAR) aboard the squadron's NP-3D Orion research aircraft. Additional components for the MB-SAR were obtained from the Army Space Development Command and U.S. Air Force, and an MX-15 electro-optical/infrared video camera system and trackball were provided by the Office of Naval Research. The MB-SAR is a radar surveillance system with real-time onboard processing that integrates with other systems to provide tactically relevant information directly to troops on the ground.

Arriving in theater July 20, 2010, the Project Perseus team commenced the performance of 34 flights, approximately 6 to 7 hours each, under the direction of Task Force ODIN (Observe, Detect, Identify, Neutralize). MB-SAR and scene-change data were obtained along the movement routes used by the ground forces, and the images were produced on board the aircraft with the latency of only minutes. Data were collected in circular passes to illuminate objects from all directions, enhancing the ability to see objects with any orientation.

A typical circle, 20 kilometers in diameter, took about 10 minutes to fly and illuminated a 12-kilometer section of a road and its surroundings. The MB-SAR and scene change images were available 10 minutes after the completion of each circle and were exploited on board

by image analysts while the next circle was being flown. Constant imagery feeds from the MX-15 added visual situational awareness to the acquired scene change data. This flight profile was executed on each mission for more than 20 consecutive circle passes, covering up to 200 kilometers of road in a single flight.

"Missions such as these are incredibly beneficial to us as scientists and researchers," said Brozena. "Direct interface with the end-user in the environment that the technology is to be applied allows us to better understand what direction to focus research. More importantly, it gives us an awareness of what needs to be done in order to effectively transition the technology to the operational environment."

MB-SAR is a research system that has been under development for the Defense Intelligence Agency, U.S. Air Force, and NRL. It is an airborne payload that can be integrated onto a variety of platforms, and its capabilities include IED detection, foliage and building penetration, change detection, and wide area surveillance.

"We initially used MB-SAR in a sensor suite tailored for counternarcotics work in Colombia," said Gardner. "We saw its value and quickly recognized its greatest capabilities were being underutilized. We partnered with Northrop Grumman and further developed the system for specific applications such as counter-IED and counternarcotic multisensor operations."

In 2009, the Marine Geosciences Division used the MB-SAR system for ice penetration and foliage penetration applications. The system was used to search for a U.S. Coast Guard Grumman Duck aircraft lost over Greenland in 1942 and believed to be buried in up to 30 meters of ice. The MB-SAR's L-band can penetrate several tens of meters of ice and can cover large areas in a small amount of time. This capability provides a cost-effective way to verify and engage in recovery operations for the downed aircraft. In the area of foliage penetration, high-quality MB-SAR data in several modes (strip-map, circle, and



The crew of Project Perseus assembled in front of VXS-1's research-modified NP-3D Orion.

spiral) were acquired over Colombia in 2009 under sponsorship of the Office of the Secretary of Defense.

The 2010 Iraq operation was not the first time NRL and VXS-1 personnel worked in an active war zone. The group deployed in 2006 and 2008 to Afghanistan for several months to conduct the Rampant Lion I and II missions. Partnering with scientists and engineers from the NRL Remote Sensing Division, Rampant Lion I collected, processed, analyzed, and interpreted data which were integrated into U.S. Geological Survey natural resource assessments. These assessments were released to the Afghanistan government, international donor organizations, private investment groups, and NGOs working on the reconstruction and economic revitalization of Afghanistan.

The collected imagery is enormously important for seismic and flood hazard analysis; development of roads, pipelines, and property boundaries; other civil infrastructure projects; and agriculture and mineral resource management.

Rampant Lion II developed new technologies for the rapid acquisition, processing, archiving, and distribution of a broad spectrum of commonly registered geospatial information, primarily to support military operations and counternarcotics objectives that also included testing the utility of new sensor systems for various applications.

Due to their success in Afghanistan and Colombia, the NRL team was chosen for the Iraq mission as a recog-

nized leader coordinating and operating a multisensor platform under hostile conditions. In 2008, Brozena, Gardner, and colleague Dr. Vicki Childers each received the Navy Superior Civilian Service Award for contributions to the Rampant Lion I mission. In 2009, Gardner was awarded the Society of American Indian Government Employees (SAIGE) Meritorious Service Award for her contributions to the global war on terrorism. 🌈

VXS-1 conducts airborne scientific experimentation and technology development missions worldwide in support of Navy and national science and technology priorities and warfighting goals. Stationed at Naval Air Station Patuxent River, Maryland, VXS-1 operates five aircraft: three research-configured NP-3D Orions and two RC-12 Guardrails.



Recent VXS-1 missions have supported NASA, DARPA, NOAA, the Missile Defense Agency, and many other agencies. Research conducted on these missions includes anti-ship missile testing, sensor development, oceanographic mapping, satellite communications, and mapping of hazardous weather events.

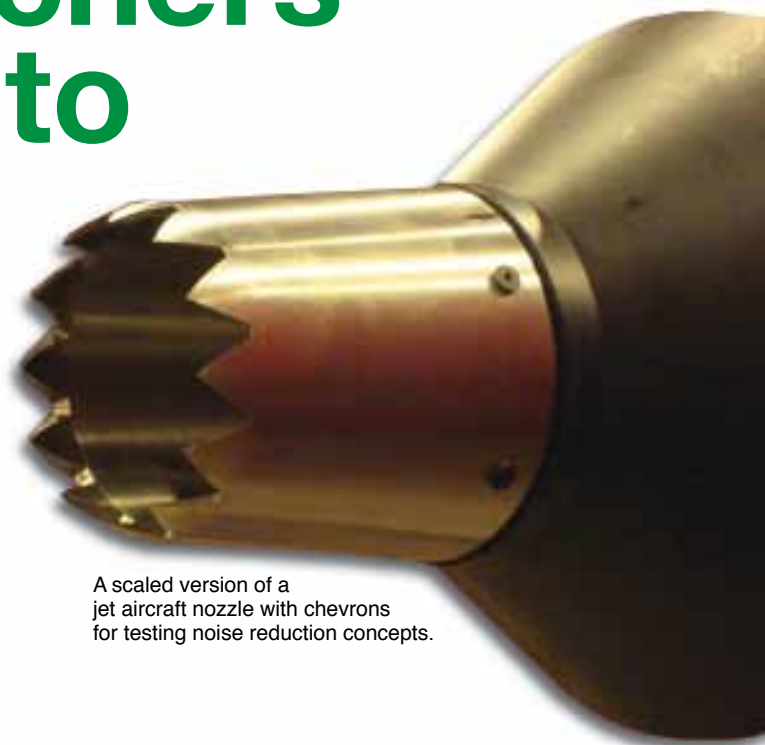
In 2010, VXS-1 became the first squadron to operationally deploy a manned Navy airship in over 45 years, first to Yuma, Arizona, then to the Gulf of Mexico to aid the Coast Guard in Deepwater Horizon operations.

NRL Researchers Study Ways to Reduce Jet Aircraft Noise

Advanced military jet aircraft have powerful engines that provide outstanding speed and maneuverability. However, with this greater power there is significant noise during takeoff and landing — noise that can impact the public and affect the health and safety of flight line workers. To confront the challenges of the noise problem, the Naval Research Laboratory collaborated with the University of Cincinnati (UC) and GE Aircraft Engines to investigate the use of mechanical chevrons (serrations at the rim of the exhaust nozzle) and fluidics technology to successfully reduce the noise from supersonic military jet aircraft.

The initial research, sponsored by the Strategic Environmental Research and Development Program (SERDP), revealed the potential for significant noise reduction of high performance jet engines without compromising performance or environmental standards. SERDP is the Department of Defense's environmental science and technology program, planned and executed in partnership with the Department of Energy and the Environmental Protection Agency. The Navy recognized this research as a Top Twenty Research Accomplishment of 2009.

Drs. Junhui Liu, Ravi Ramamurti, and Kazhikathra Kailasanath of NRL's Laboratory for Computational Physics and Fluid Dynamics performed computational analysis to characterize the flow from the nozzle exhaust of a supersonic jet engine. Their "large-eddy simulation" findings revealed that the spacing of the shock cells (one of the noise-causing components in the flow) and the length of the jet core (the central region of the flow)



A scaled version of a jet aircraft nozzle with chevrons for testing noise reduction concepts.

increased as the ratio of the pressure inside the nozzle to the pressure outside (total pressure ratio) increased. These results were confirmed by experimental data from UC, showing that computational analysis works well in assessing flow and noise characteristics. The research team published their finding in the *American Institute of Aeronautics and Astronautics Journal*.

Following the successful simulations of the jet flow and noise, the research team shifted their work to simulate and assess specific noise reduction concepts. They conducted experiments and simulations to assess the impact of the mechanical chevrons on the flow from the exhaust nozzle and the near-field noise. Their simulation results revealed that the chevrons caused the shock cells to move closer to the nozzle and also reduced the spacing between them. The chevrons also induced more spread of the jet flow (weakened the core) and decreased the strength of the shock cells. Together, these factors reduced the noise significantly, by more than 3 decibels at the locations tested.

As a next step, the researchers replaced the mechanical chevrons with fluidic injections of air at discrete locations along the jet nozzle rim. Using a 1 to 2 percent injection of air under a variety of operating conditions, the researchers achieved the same noise reduction as they



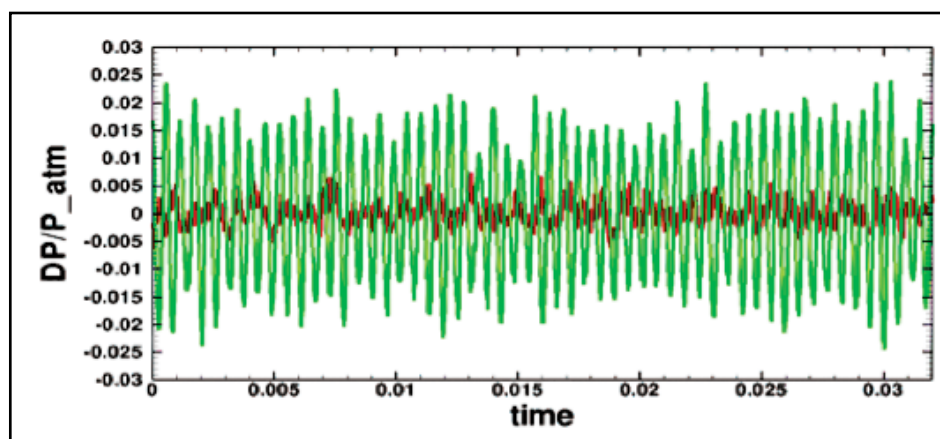
Researchers have developed new methods of reducing the noise generated by high performance supersonic military aircraft. (Photo: US Navy)

did using the mechanical chevrons. The advantage of the fluidic injection technique is that it can be easily turned on and off, for use only when needed.

The researchers then investigated a combination of mechanical chevrons and fluidics. They were able to improve the effect of the chevrons on flow modification and noise reduction by properly positioning the fluidic injections of air. They also injected air upstream of the nozzle exit, near the throat, to effectively modify the flow area. This modified the shock cell structures and reduced the noise generated.

Reduction in pressure fluctuations (and hence noise) with mechanical chevrons (brown) in comparison to the baseline case without chevrons (green) at a representative location outside but near the jet flow.

Working under the Office of Naval Research's Rapid Technology Transition program, GE researchers then tested the mechanical chevrons on a full-scale Navy engine. The tests, conducted at Naval Air Warfare Center Lakehurst, New Jersey, proved the mechanical chevrons to be effective, as predicted by the NRL simulations. Work continues on this project, using the validated computational capability, to further increase the noise reduction level and advance the technology. 🌟



Scientists Imitate Nature to Engineer Nanofilms

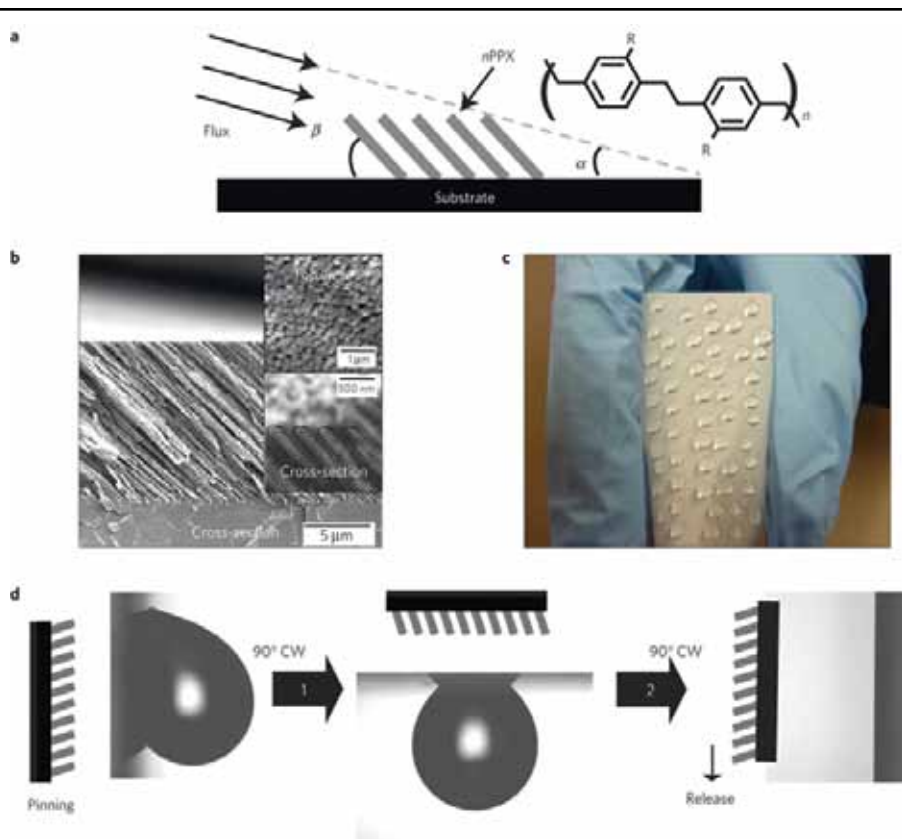
In nature, water striders can walk on water, butterflies can shed water from their wings, and plants can trap insects and pollen. Scientists at the Naval Research Laboratory are part of a research team working to engineer surfaces that imitate some of these water repellency features found in nature. This technology offers the possibility of significant advances for producing new generations of coatings that will be of great value for military, medical, and energy applications. The research, funded by the Office of Naval Research, is published in the December 2010 issue of *Nature Materials*.

Dr. Walter Dressick from NRL, Professor Melik Demirel of Penn State, and Dr. Matthew Hancock of MIT have collaborated to create an engineered water-repellent thin film. What sets this development apart from earlier technologies is that this newest film has the ability to control the directionality of liquid transport. In this system, parylene (or PPX) nanorods are deposited on the surface by a simple, straightforward vapor deposition method. The single step usually takes less than 60 minutes, compared with the more complex, multi-step lithography processes often used in previous

systems. This is the first time this kind of surface has been engineered at the nanoscale.

In the newly created surface, the nanorods that form the film are smooth on a micron scale. This size and smoothness in the posts means that when droplets are placed on the surface, they move without being distorted in any way. Also, they can be moved without pumps or optical waves. Previous systems caused the water droplets to be distorted, which could rupture, spill, or destroy the cargo in the droplet when used in medical or microassembly applications. As they continue the research, the team will focus on optimizing the droplet transport mechanism and tuning the preparation method.

Looking to the future, researchers are hopeful that this film might be used as a coating on ships' hulls where it would reduce drag and slow fouling. In industry applications, the film might have uses in directional syringes and fluid diodes, pump-free digital fluidic devices, increased efficiency of thermal cooling for microchips, and tire coatings. 🌈

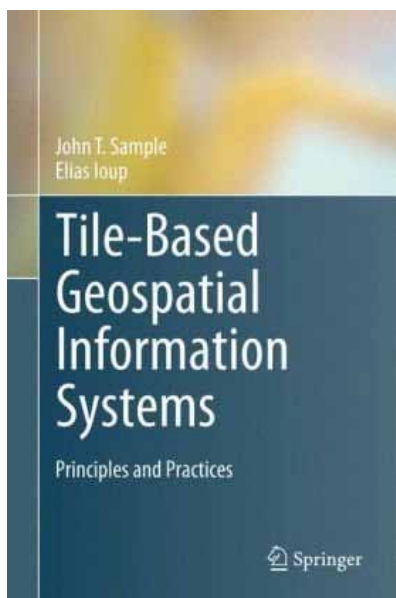


Overview of nanofilm preparation and anisotropic wetting property.

- Schematic of PPX nanofilm deposition by oblique angle polymerization.
- Electron microscope cross-section of PPX nanofilm (insets show top view and high-resolution cross-section micrographs).
- Picture of the anisotropic adhesive wetting surface with water drops.
- Water adhesion and release in three configurations of the nanofilm. Schematics illustrate the nanorod inclination at each tilt angle and correspond to photographs showing the anisotropic wetting behavior of the nanofilm.

(Credit: *Nature Materials*)

Premier Book on Tile-based GIS Published



Naval Research Laboratory computer

scientists John Sample and Elias Ioup recently had their book *Tile-Based Geospatial Information Systems* published by Springer. *Tile-Based Geospatial Information Systems* is the first published book dedicated to the subject.

Sample and Ioup present theory and provide concrete techniques to implement a tile-based online

mapping system, knowledge they honed while developing NRL's Tile Server. NRL's Tile Server is widely used across the Department of Defense for high-performance map access.

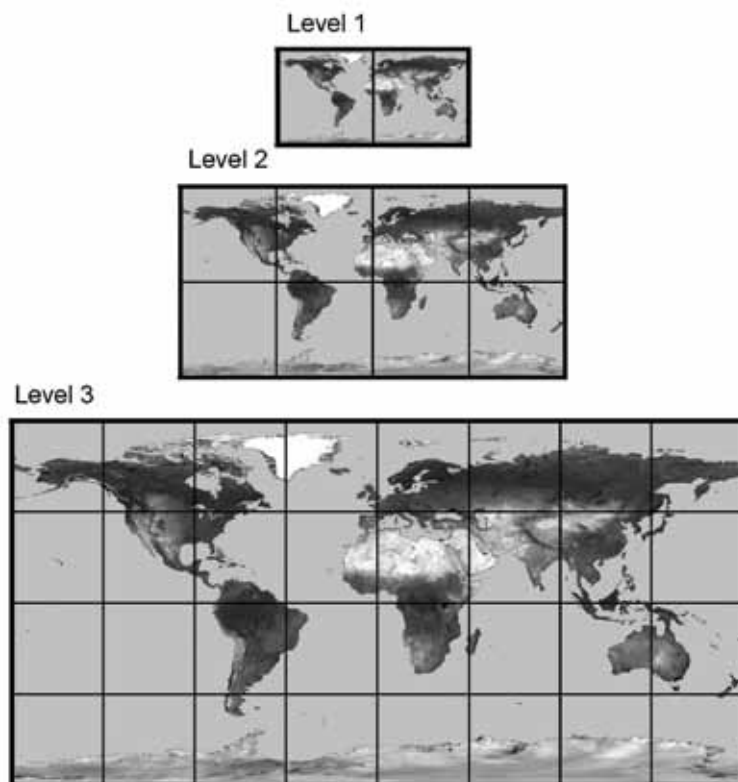
Using their experiences in the field of geospatial computing, the authors provide valuable case studies and samples of code to aid in comprehension of the topic, benefitting both the experienced professional practitioner and novice GIS student.

Because of increased loading speed and improved usability, tile-based systems have become the new standard for online mapping. Anyone who has searched for a location using Google, Yahoo, or Microsoft's online maps has interacted with a tile-based system. When a searcher's Internet speed is slower, he may notice a square of the map takes longer to load; the square is a tile. Each map tile loads simultaneously; if tiles were not used, the searcher would be forced to wait for one large image to load every last byte of data.

In addition to this relatively simple mapping interface improvement, *Tile-Based Geospatial Information Systems* discusses use of tile-based systems with 3-D mapping tools, various coordinate systems, indexing requirements, and other topics.

The authors also dedicate attention to the overall theoretical understanding and development of algorithms to maximize functionality and efficiency within a tile-based system.

Sample and Ioup both work in the Geospatial Sciences and Technology Branch at the NRL Stennis Space Center (SSC) detachment on the Mississippi Gulf Coast. NRL-SSC employs approximately 200 civilian scientists and support personnel and conducts research and development in the fields of marine geosciences, oceanography, and underwater acoustics in support of the Navy and Marine Corps. 🌐



Using multi-level tile-based systems, the clarity of an image improves as a viewer zooms because the number of tiles covering the same distance, though at different levels of detail, increases.

NRL and NASA Offer Unique Teacher Resource

The Naval Research Laboratory teamed with the NASA Education Office at NASA John C. Stennis Space Center (SSC) in December 2010 to offer a select group of science educators a unique, no-cost training opportunity — to build and operate underwater robots.

Teachers from Louisiana and Mississippi spent two days at Stennis learning how to build and use Sea Perch, a remotely operated underwater robot. The teachers now can take the Sea Perch Program back to their students, offering a hands-on activity designed to inspire continued studies in science, technology, engineering, and mathematics (STEM).

“This is an exciting program in an area of growing importance,” said Katie Wallace, director of the Stennis Education Office. “Our NASA office has been looking for opportunities to work with the Navy, and robotics is an area both of us are involved in, so it’s a natural fit. Partnering together provides us both a new way to reach teachers and students.”

The Stennis office and NRL personnel partnered earlier in the year to introduce the underwater robot to youth aged 13 to 15 attending an annual Astro STARS camp. After completing final assembly of robots, the campers had a chance to operate them in an onsite swimming pool. Response from camp participants provided the impetus to offer a pilot teacher training session.

During the December workshop, nine area teachers assembled robots from start to finish and learned how to operate them. The robots are simple underwater Sea Perch vehicles made from PVC pipe and other inexpensive, easily available materials.

The Sea Perch Program was created by the Massachusetts Institute of Technology Sea Grant College Program in 2003 to encourage underwater studies; it is funded by the National Defense Education Program. Teachers work with students to build their own Sea Perch robots and modify



David Lalejini from NRL-SSC helps a pair of teachers deploy a Sea Perch robot during workshop activities. (Photo: NASA)

them to conduct research missions in nearby bodies of water. Students then are able to enter water quality data into the Sea Perch Data Bank, an international water quality online database. Collected data are integrated into state-of-the-art GIS maps and comparative graphs, which can be accessed by students and teachers to use in classroom exercises and projects.

Scientists from Stennis Space Center are augmenting the teachers’ Sea Perch lessons in the classroom during the spring semester, providing practical applications and real-world examples of the STEM lessons they learn as part of the Sea Perch program.

“The Navy operates underwater robots every day from right here at Stennis Space Center,” said Dr. Joe Calantoni of NRL. “We want to not only excite students about STEM in general, but also to show our local students that they don’t have to leave home to study the depths of the sea or the far reaches of space.”

“Much has been said about the importance of inspiring students to pursue studies and even careers in the areas of science, technology, engineering, and math,” Wallace said. “This is exactly the kind of hands-on, interactive exercise that can provide that inspiration.” (Credit: NASA press release) 🌟

Paul Charles Recognized for Fostering STEM Education and Diversity

A Naval Research Laboratory research chemist was recognized

June 15 for his efforts to promote science and technology to minority youth.

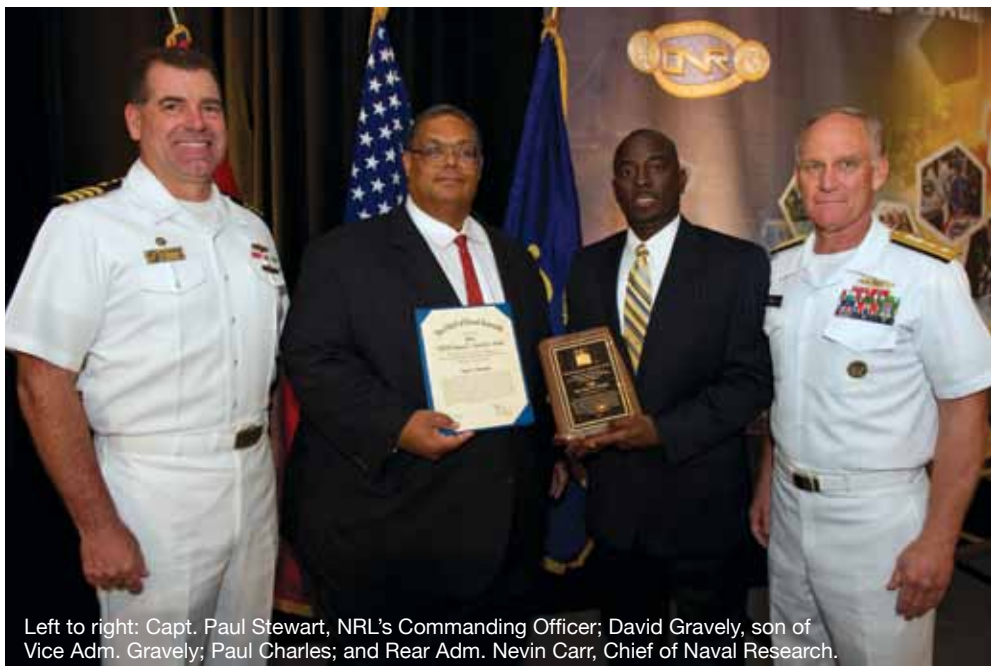
Mr. Paul Charles, of NRL's Center for Bio/Molecular Research, was honored during the 2011 Naval STEM Forum held in Alexandria, Virginia. The forum gathered more than 600 leaders in academia, business, and the government to collaborate on ways to address U.S. students' declining interest in science, technology, engineering, and math (STEM) disciplines.

According to Rear Adm. Nevin Carr, Chief of Naval Research, the STEM forum was a fitting platform to salute Charles. "Paul has played a critical role in increasing the visibility of minority scientists and encouraging minority students to pursue careers in STEM," said Carr, who presented Charles with the 2011 Vice Adm. Samuel L. Gravely Jr. Award. "We are recognizing his leadership of NRL's summer internship program for students from under-represented communities. He is a role model to fellow researchers and to inner-city students."

The Office of Naval Research (ONR) is NRL's parent organization.

ONR bestows the Gravely award to the "Champion of the Year for Excellence in STEM Education and Diversity" for excellence in fostering STEM education and diversity growth to sustain and expand future generations of students in the Naval Research Enterprise science and technology workforce.

Gravely was the first African-American to command a U.S. Navy warship, an American warship under combat conditions, and a



Left to right: Capt. Paul Stewart, NRL's Commanding Officer; David Gravely, son of Vice Adm. Gravely; Paul Charles; and Rear Adm. Nevin Carr, Chief of Naval Research.

major naval warship. He also was the first African-American admiral, vice admiral and U.S. Fleet commander. In 2009, the Navy christened an *Arleigh Burke*-class guided-missile destroyer in his name.

"Gravely's efforts to promote diversity and STEM education and to expand the Naval Research Enterprise science and technology workforce exemplified the type of leader he was," Charles said. "It's thrilling to know that I can continue his legacy and beliefs with the HBCU/MI program. I take pride in trying to provide the same opportunities to our youth so they, too, can follow in Gravely's footsteps one day and be a 'first.'"

Charles oversees the NRL summer internship program's Historically Black Colleges and Universities/Minority Institutions/Tribal Colleges and Universities component, including strategic planning, recruitment, and budget activities. To date, the program has provided training opportunities and role models for more than 200 students considering careers in STEM-related areas.

"As a nation, we have proven ourselves worldwide to be leaders in the [science and technology] field, however, we must continue to strengthen our workforce by mentoring our youth," Charles said. "Brilliant ideas can resonate from all minds, regardless of race, color, or gender. By investing in our youth today, we can remain as leaders in exploratory science and advanced technological development that is essential for the future of the Navy and Marine Corps." (Credit: Office of Naval Research) 🍀

NRL ON THE ROAD



NRL'S EXHIBIT PROGRAM

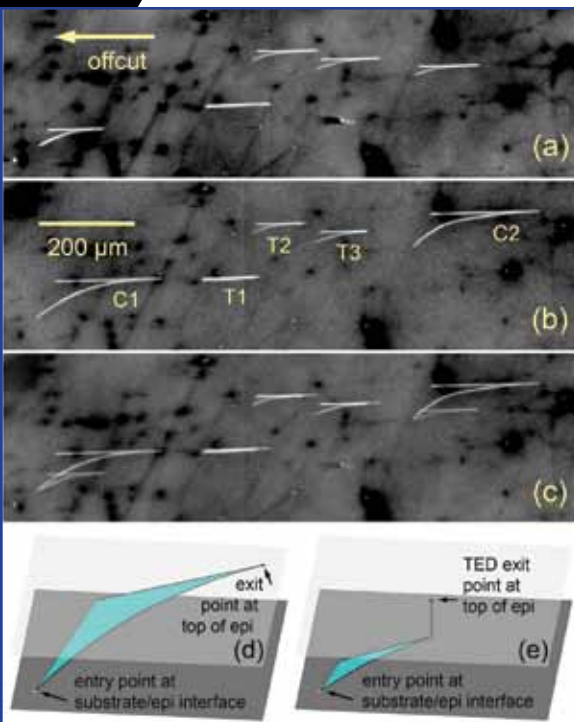
showcases a broad spectrum of NRL's technologies and achievements at specialized events and conferences nationally and internationally. The goal is to seek diverse and non-traditional audiences and excite visitors with interactive displays, models, artifacts, presentations, and participatory demonstrations.

Oceans 11	September 18–23, 2011	Waikoloa, HI
International Conference on Stability, Handling, and Use of liquids	October 16–20, 2011	Sarasota, FL
IEEE Nuclear Science Symposium	October 23–29, 2011	Valencia, Spain
Association of Old Crows International Symposium	November 13–16, 2011	Washington, DC
I/ITSEC	November 28– December 1, 2011	Orlando, FL
American Geophysical Union	December 6–9, 2011	San Francisco, CA
American Meteorological Society	January 22–26, 2012	New Orleans, LA
SPIE Photonics West	January 24–26, 2012	San Francisco, CA
AGU Ocean Sciences Meeting	February 20–23, 2012	Salt Lake City, UT
National Space Symposium	April 16–19, 2012	Colorado Springs, CO
Navy League – Sea Air Space	April 16–18, 2012	National Harbor, MD
AUVSI	August 7–10, 2012	Las Vegas, NV



TECHNOLOGY TRANSFER OFFICE

NRL's Technology Transfer Office (TTO) facilitates the implementation of NRL's innovative technologies in products and services to benefit the public. Detailed here are two technologies available for licensing.



SiC EPITAXIAL LAYERS WITH LOW BASAL PLANE DISLOCATION CONCENTRATIONS

The Naval Research Laboratory has developed a process for manufacturing silicon carbide epiwafers with low basal plane dislocation (BPD) concentration that saves time and resources on the production line by relying on epitaxial growth interrupts. The reduction of BPDs relies on the conversion of BPDs to threading edge dislocations (TEDs) at each growth interrupt and the use of multiple interrupts to achieve a desired overall BPD reduction. The interrupted/modified epitaxial growth technique relies on a straightforward, in situ growth process that may be easy to implement with commercial epitaxial growth systems.

Advantages/Features

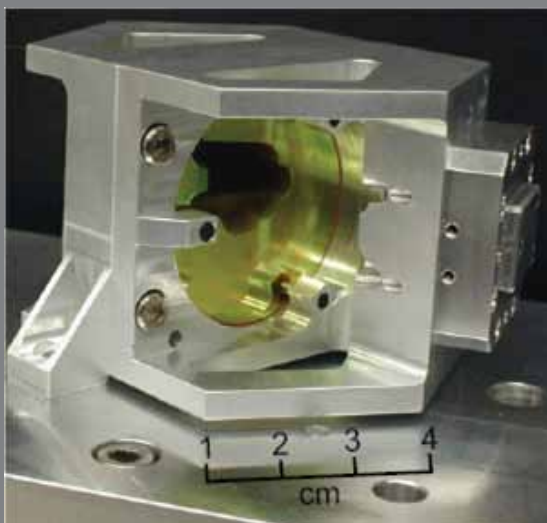
- Provides epilayers with low BPD levels ($<1 \text{ cm}^{-2}$) over large areas
- Applicable to any SiC substrate with offcuts of approximately 8 degrees
- Compatible with conventional SiC epitaxy
- More efficient than traditional BPD reduction methods

Applications

- High-voltage diodes
- High-voltage switches
- High-efficiency power electronic components and converters

PSEUDO-MONOLITHIC SPATIAL HETERODYNE SPECTROMETER INTERFEROMETER

The Naval Research Laboratory has demonstrated a passive, broadband (8.4 to 11.2 μm), LWIR spectrometer with a resolving power of ~ 500 that has no moving parts, is immune to scene changes, and has high throughput. It uses a compression assembly spatial heterodyne spectroscopy (SHS) interferometer (C-SHS) which employs precision spacers that result in a robust, self-aligning, economical assembly, and enables easy replacement of optical components. SHS is similar to Fourier-transform spectroscopy in that it also features a beamsplitter which divides the incoming signal into two interferometer arms. However, in SHS, the latter terminate at fixed, tilted gratings that impose a wavelength-dependent tilt onto the diffracted wavefronts. After recombination at the beamsplitter and imaging onto a detector array, a complete interferogram can be recorded without using any moving parts.



Advantages/Features

- Insensitive to spectral errors caused by changing scenes
- Ideal in applications where jitter is a concern (on airplanes, ground vehicles) and for imaging fast events such as combustion processes or explosions
- Reduced manufacturing cost compared to traditional monolithic SHS

Applications

- Satellite remote sensing of the Earth's atmosphere; planetary astronomy; and laboratory spectroscopy
- C-SHS in LWIR has been demonstrated in the laboratory

JOHN SCHAUB



It takes a team to get to space, and John Schaub knows that. As superintendent of the Spacecraft Engineering Department in the Naval Research Laboratory's Naval Center for Space Technology, Schaub leads a highly skilled team of engineers, scientists, and technicians in the execution of

cutting-edge spacecraft research and development programs relevant to the needs of the Department of the Navy and Department of Defense.

Schaub has more than 26 years of federal service, all of it at NRL. During these years, Schaub has contributed to the successful launch of 19 satellites or space instruments, with several more under development. He has seen the changes in the ways that systems are built.

"When I started in the mid 80's, the nation was producing very large and very capable space systems. Unfortunately these systems were also massive and therefore very costly to launch."

MEETING the CHALLENGES of **SPACECRAFT** **RESEARCH** for NRL

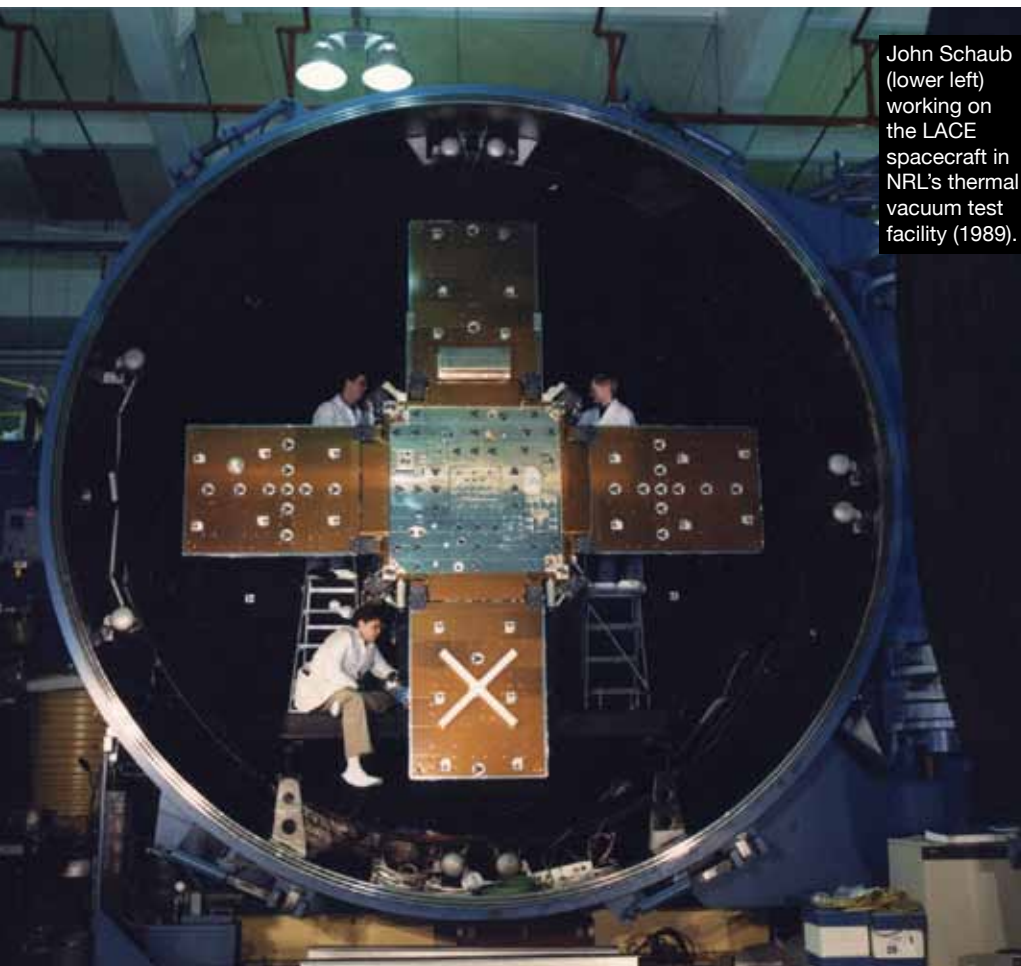
Schaub describes how NRL has made a concerted effort to drive down the size and cost of these systems. "By applying strong systems engineering principles, exploiting the commercial miniaturization of electronics, and entrusting the quality of the product that we are producing to each individual team member, we are producing today very capable systems in much smaller packages, much faster and less costly."

Before being appointed to his current position, Schaub served as associate superintendent and then acting superintendent of the Spacecraft Engineering Department from November 1998 to December 2006. On a detail to the National Reconnaissance Office, he directed the Space Technology Experiment Satellite Program Office from May 1994 to November 1998. There, he led a multi-million-dollar, "first of a kind" advanced technology demonstration space mission to accomplish challenging program objectives of national significance within severe cost and schedule constraints.

John Schaub
(lower left)
working on
the LACE
spacecraft in
NRL's thermal
vacuum test
facility (1989).

Schaub completed a dual degree program, with bachelor's degrees in mechanical engineering from the Georgia Institute of Technology and in physics with honors from the State University of New York at Oneonta.

Schaub likes to make the case for NRL being a good place to work. "NRL's retention statistics make the case that when folks come to NRL, they stay... My theory is it is because of the work. NRL offers exciting opportunities to materially contribute towards solving 'real' problems. The personal satisfaction that comes from knowing that the work that you do 'makes a difference' is underrated. I promise recruits that they will be challenged every day they come to work." ♦



FUTURE SPACE

What is the Naval Research Laboratory's future in space?

SPECTRA asked Mr. Peter Wilhelm, director of NRL's Naval Center for Space Technology, for his view on the subject.

environment
navigation
surveillance
communications
space weather



Wilhelm began his NRL career in 1959, not long after Sputnik, Explorer, and Vanguard hit the skies, and he has played a leading role in many of NRL's pioneering space achievements, from electronic intelligence gathering to GPS to tactical

microsatellites. Wilhelm singles out two technologies he thinks could be "game-changing" and that he would like to see NRL take into the future: electrodynamic propulsion systems and low-cost launch vehicles.

Electrodynamic propulsion technology exploits the Earth's magnetic field to allow a spacecraft to maneuver without expending precious fuel. "This is a revolutionary technology," explains Wilhelm, "that will enable satellites to conduct missions that cannot be done right now, including moving between significantly different orbital inclinations." NRL has already built and tested a proof-of-concept spacecraft, TEPCE (Tether Electrodynamic Propulsion Cubesat Experiment), to be launched next year. TEPCE consists of two microsatellites at the ends of a 1-km-long, conducting tether; electrons are collected at one end of the tether and emitted at the other, producing a force which changes the satellite's orbit. The force is determined by the length of the tether, the amount of current, and the strength of the earth's magnetic field.

NRL proposes to take this technology to the next step by developing a

3-km-long tether divided into three sections, each with separate control of the magnitude and direction of the current. "This allows for refined maneuvering so the spacecraft can rendezvous with other spacecraft and space objects, and then use cameras and robotic arms to 'see' and grasp them," says Wilhelm. "We envision this kind of spacecraft delivering payloads to orbiting satellites through the use of plug-in interfaces; and also servicing ailing spacecraft, and capturing and de-orbiting space debris."

Wilhelm also wants to develop small, low-cost launch vehicles: "Launch has been unpredictable and expensive since day 1 in space exploration, and there are still delays and failures. NRL and other satellite developers can now rapidly design and build small, highly capable satellites, but the holdup is still in getting the satellite into orbit." The Department of Defense is the most

likely developer of a better launch vehicle, benefiting most from the rapid deployment it will enable. Standardized spacecraft, already being built in the Operationally Responsive Space (ORS) initiative, will be assembled and launched within days to meet immediate mission needs. "I want to see NRL work with the ORS Office and the Army to make this happen."

What keeps NRL at the forefront of space research and technology for the future? Wilhelm's answer comes easily: "NRL invests in talented researchers and top-notch facilities. We have a solid and reliable base of expertise, so when we're presented with a new problem, we have the knowhow and imagination and facilities and flexibility to tackle it. This has always been our strength." 🌈

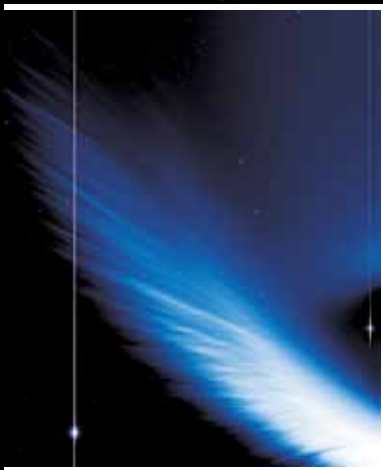


COVER STORY:

COMET MCNAUGHT

Due to a fortuitous spacecraft roll angle, COMET MCNAUGHT was the unanticipated sight captured in the *first image* taken by NRL's SECCHI/HI1 instrument on the NASA STEREO-B satellite.

Scientists in the SECCHI Payload Operations Center in NRL's Space Science Division building were initially taken aback at the brilliant streak of light that dominated the first image returned from the instrument. But when comet McNaught was recognized, concern turned to relief and then delight at both the fantastic image, and the demonstration of instrument performance: SECCHI/HI1 has since returned unprecedented views of the solar wind, coronal mass ejections, and co-rotating interaction regions.



The comet — the brightest seen in some 30 years — was subsequently observed for several days by the SECCHI/HI1 instruments on both the STEREO-A and -B spacecraft.

The spectacular image sequences and movies are available online at <http://sungrazer.nrl.navy.mil/index.php?p=mcnaught>

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NRL/PU/1000--11-558
RN: 11-1226-3322
September 2011
CAPT Paul C. Stewart
Commanding Officer



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