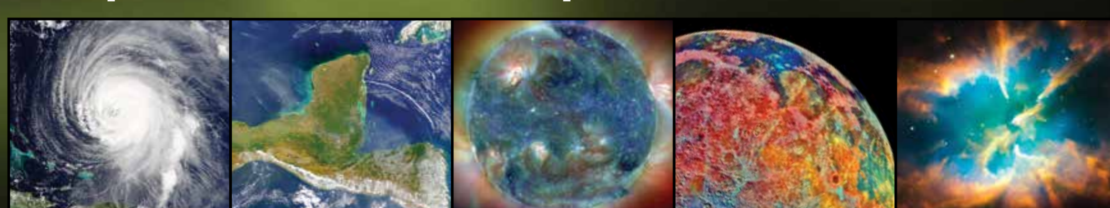
National Aeronautics and
Space Administration

Science Research Office 2012 Capabilities Report



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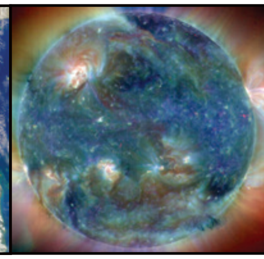

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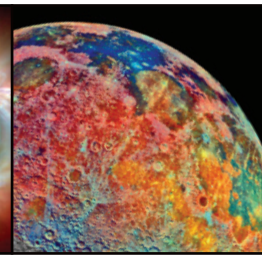

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Introduction to the Science Research Office

Office Overview

Who We Are

The Science Research Office is the primary science organization at NASA Marshall Space Flight Center. We are comprised of NASA civil servants, colleagues, and supporting personnel. The Science Research Office mission is to provide continued support to the Nation and NASA through research and development efforts, in order to expand scientific knowledge and exploration of the Earth and its universe.

We develop scientific instruments that lead to space-flight missions and train the next generation of scientists and engineers. We use space, airborne, and ground-based observations to meet our basic scientific goals and better understand our home planet and its space environment to help society cope with our changing local and global environment. We do this in alliance with academia, other federal agencies, and international partners.

The Science Research Office conducts research and development efforts in the following selected research focus areas of space and Earth science.

- Earth Science Research and Analysis
- Earth Science Applications
- Heliophysics and Space Weather
- Astrophysics
- Planetary Science

The Science Research Office has achieved a great deal of success in these disciplines. Performing at the highest levels, we are internationally recognized, advance the state of knowledge, and are leaders in cutting-edge technologies relevant to NASA's mission. As such, we believe the key to our success has been and will continue to be NASA's investments in its people, facilities, infrastructure, and key partnerships in order to shape the workforce so that NASA can maintain and expand its excellence.

Our Goals

Through these disciplines and relevant capabilities, the Science Research Office is able to directly contribute to the fulfillment of three NASA strategic goals as well as our own.

NASA's Strategic Goals	Science Research Office Goals
• Expand scientific understanding of the Earth and the universe in which we live. • Create the new and innovative space technologies for our exploration, science, and economic future. • Enable program and institutional capabilities to conduct NASA's aeronautics and space activities.	• To sustain, nurture and build new areas of excellence in Space and Earth science, and relevant technologies that support and advance NASA objectives; • To provide a consistent, coordinated, and professional science interface between MSFC and NASA headquarters, the science community, and other agencies and organizations; • To coordinate activities and strategies with partners in order to take advantage of and leverage opportunities we choose to pursue; and • To develop a coherent long-term strategy that results in competitive wins of investigations and missions.

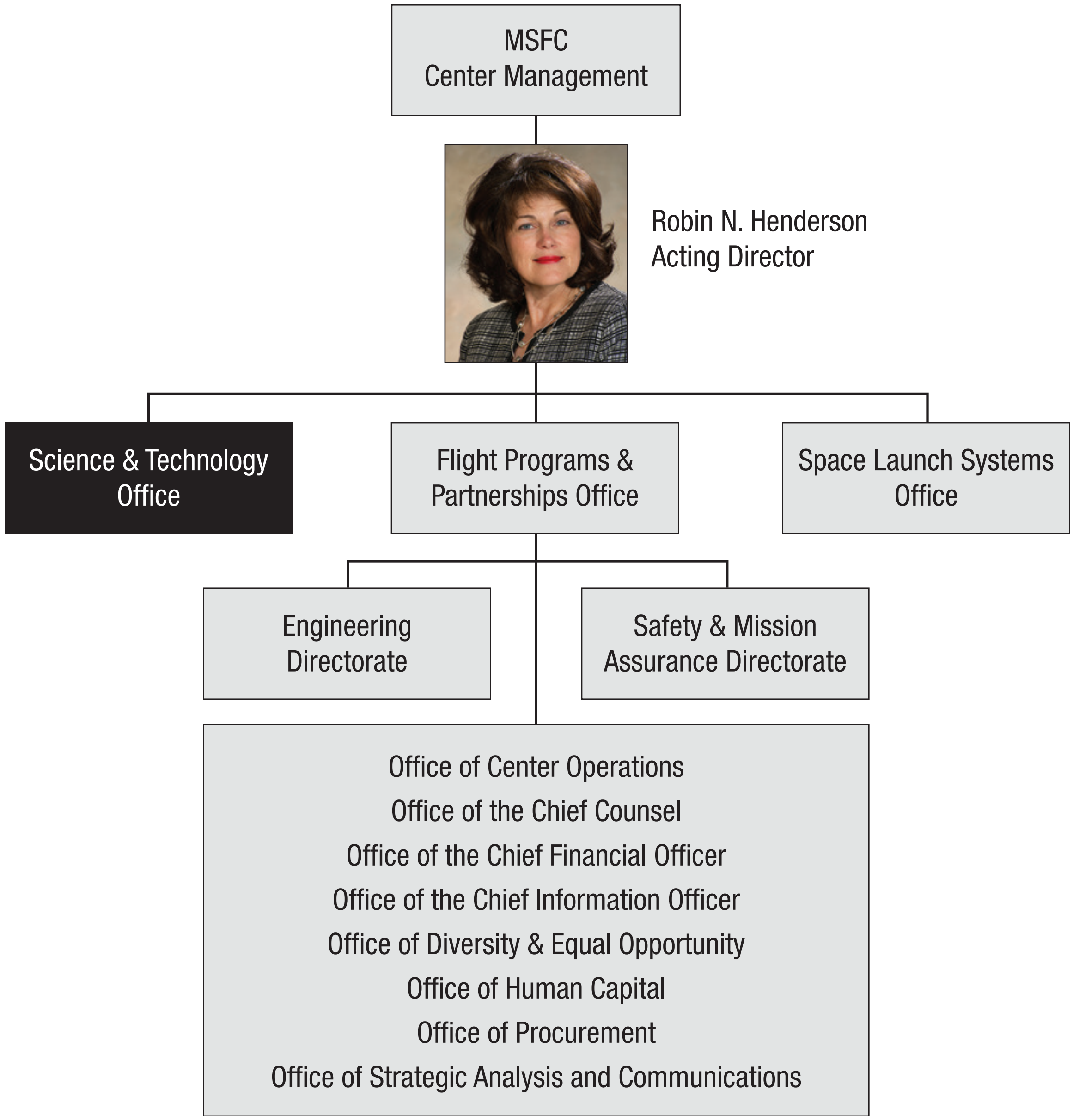
At the MSFC Science Research Office we don't investigate everything, but what we choose to pursue, we do extremely well to the benefit of NASA, the Nation, and humanity.

Enjoy,

James F. Spann

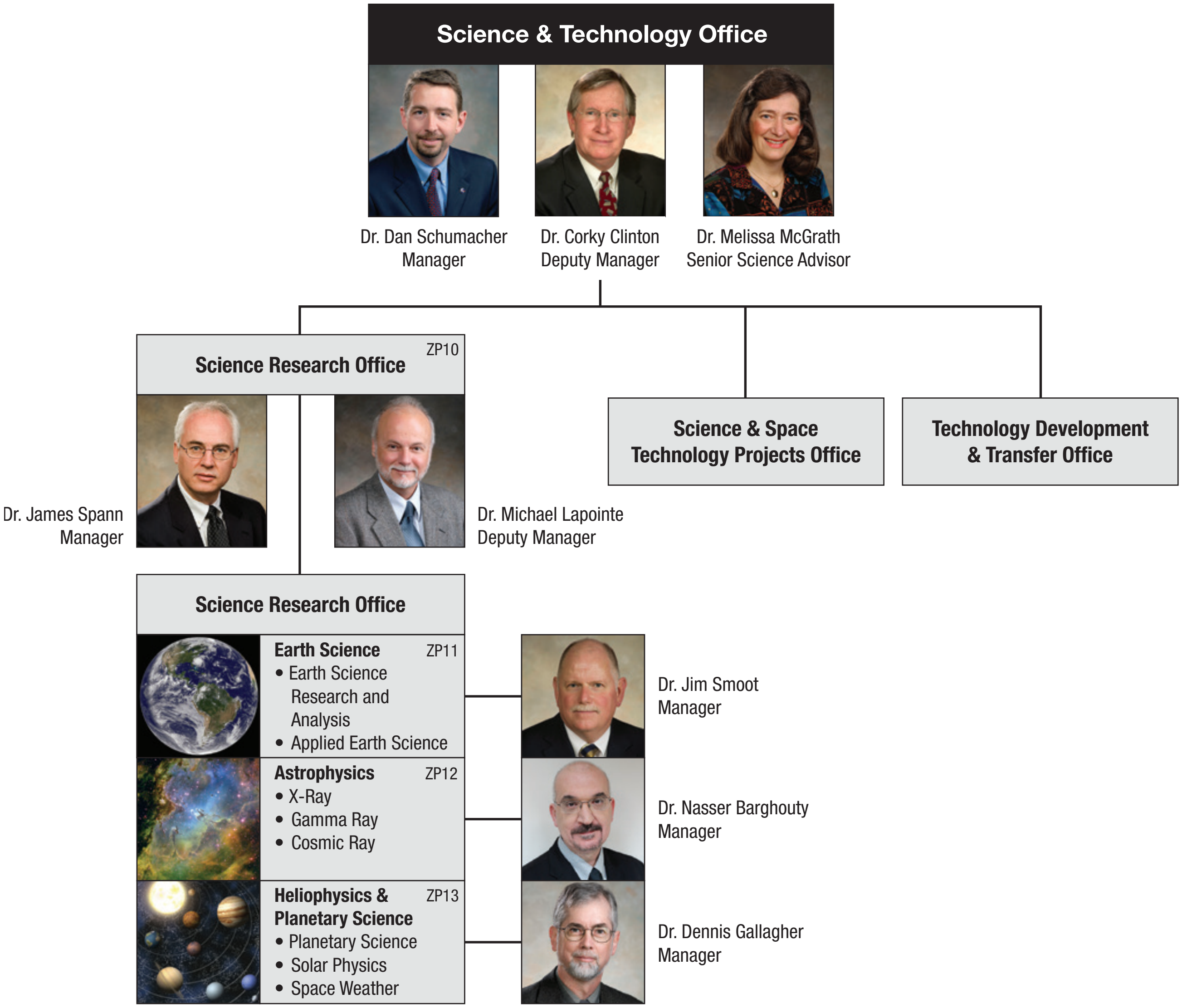
James F. Spann
Manager, Science Research Office

Organization Structure



NASA's Marshall Space Flight Center is located in Huntsville, AL, where the Nation's journey to space began more than a half-century ago. Now, a dedicated group of engineers, scientists and business professionals lead the development and testing of tomorrow's flagship space vehicles, space systems and rocket engines. We pursue cutting-edge scientific discoveries that improve and protect lives on Earth. We work to discover the secrets of the universe and our place in it.

Marshall became a NASA field center on July 1, 1960. Today, it remains a vital resource for NASA and the Nation, with unique capabilities that are essential to the exploration of space. Together with our partners across NASA and around the world, we are engaged in a large part of the agency's work, especially propulsion and space transportation, engineering, science, space systems and space operations, and project and program management. With our highly skilled and diverse workforce, proven technical and scientific experience, and state-of-the-art laboratories and test facilities, Marshall stands at the intersection of science and exploration—delivering safe, affordable and sustainable solutions that will change our world.



The Science Research Office is a part of Marshall's Science and Technology Office, whose mission is to apply advanced concepts and capabilities to researching, developing, and managing NASA's science and exploration programs, projects, and activities that fall at the very intersection of science and exploration.

Earth Science Office

The Earth Science Office focuses on researching and analyzing the Earth as a system with a focus on its climate and energy and water cycles. This Office applies NASA's Earth observations, models, technologies, and expertise to provide vital data and analyses in various ways that benefit society.

Astrophysics Office

The Astrophysics Office is charged with peering back to the earliest epochs of the Universe to unravel its mysteries and studying the most violent explosions in space in our galaxy and beyond.

Heliophysics & Planetary Science Office

The Heliophysics & Planetary Science Office is committed to studying the coupled Sun-Earth system and our solar system. The focus is on the genesis and evolution of the inner solar system bodies, and investigating what triggers space storms and their effect on the near-Earth space environment.

Collaborative Research Environment

The Science Research Office is co-located with some of our primary partners at the National Space Science and Technology Center (NSSTC) in Huntsville, AL. The NSSTC is a facility that houses the collaborative research and education initiative between MSFC, academia, and industry. The NSSTC has several laboratories and groups that are focused on specific scientific disciplines and programs.

The Science and Research Center's Primary Partnerships	
University of Alabama in Huntsville (UAHuntsville)	UAHuntsville is a public co-educational, state-supported research university within The University of Alabama System. UAHuntsville was founded as part of the University of Alabama in 1950 and became an autonomous campus within the UA System in 1969. Research at UAHuntsville is conducted within the individual colleges or through 15 independent research centers, laboratories, and institutes. Major interdisciplinary research thrusts include: applied optics; earth system science; information technology; management of science and technology; mechanical and aerospace engineering; modeling and simulation; nano devices; space plasmas and astrophysics; space propulsion; structural biology; systems engineering; and robotics.
Center for Space Plasma and Aeronomic Research (CSPAR) at The University of Alabama in Huntsville	CSPAR is dedicated to developing world-class research and providing outstanding graduate education opportunities in the physics of plasmas found in natural environments throughout the universe. This includes the Sun, the interplanetary medium, the Earth's upper atmosphere, other solar system bodies and extrasolar planets and planetary formation, stellar environments, the interstellar medium, and the basic physical processes and complex coupling that occur in these environments. To understand highly complex systems that possess multiple scales and coupled physical processes, CSPAR employs advanced theory, comprehensive modeling, and instrument development programs for both remote sensing and in situ observations.
UAHuntsville Atmospheric Science Department	From global warming to severe weather forecasting and atmospheric chemistry, the Atmospheric Science Department at the UAHuntsville is a nationally recognized academic organization working with a unique combination of partners. The faculty and students of the Department are co-located with and closely tied to UAHuntsville's Earth System Science Center.
Universities Space Research Association (USRA)	Founded in 1969, USRA is an independent research corporation with competencies that span space, Earth, and life sciences, along with related disciplines. USRA supports multiple research and technology development projects at the NSSTC that are designed to help others understand the origin, structure, evolution, and destiny of the universe; and the Sun and its effects on the Earth and the solar system. Additional fields of study include gamma-ray astronomy, x-ray astronomy, cosmic ray physics, and solar and space physics.
Von Braun Center for Science & Innovation	VCSI was established in 2006 by a group of Huntsville businessmen and university officials. VCSI's mission is to provide innovative engineering solutions and science applications for NASA, DoD, and other government agencies. VCSI provides technical solutions to vital government clients in an efficient, cost-effective, and timely manner. VCSI enables the government, industry, and academic communities in the Huntsville region to better compete for critical NASA and DoD R&D functions and activities, many of which are currently outsourced to other regions of the United States.
National Weather Service (NWS)	In 2003, the NWS opened its Huntsville Weather Forecast Office (WFO) to serve 11 counties in northern Alabama and 3 in southern Tennessee. The Huntsville WFO uses NWS resources to complete weather forecast and warning services for the citizens of Lauderdale, Limestone, Madison, Jackson, Colbert, Franklin, Lawrence, Morgan, Marshall, DeKalb, and Cullman counties in Alabama and Lincoln, Franklin, and Moore counties in southern Tennessee. Regarded as the most advanced weather monitoring, forecasting, and warning system in the world, the NWS disseminates vital weather information, forecasts, and warnings for the United States and its territories.

Earth Science Research and Analysis

Overview

Part of NASA's charter is to perform research to improve our understanding of our home planet and to develop technologies to better observe the Earth system and to transition them to operational agencies such as the National Oceanic and Atmospheric Administration (NOAA). From the early days of the Agency, NASA has shown that one of the most fascinating and useful applications of space technologies is the study of Earth's weather and climate system, and ongoing activities have further shown the importance of space-based observations of the entire Earth system.

The Earth Science Research and Analysis (R&A) team is part of Marshall's Earth Science Office. The R&A team develops and uses new technologies unique to NASA. Through the use of new observing capabilities from space, the R&A team makes significant contributions toward developing a better understanding of the intricacies of the Earth system and addressing such important questions as the reliability of future climate and weather predictions on both global and regional scales. Through its efforts, the R&A team is able to further define the requirements for new observational capabilities to address questions that arise as our study of the Earth-atmospheric system evolves.

Another focus of the R&A team is transitioning technologies (both observational and analytical) that are developed by NASA to further improve the capabilities and offerings of the Nation's vital public health and safety organizations such as the National Weather Service.

Rather than focus on the entire Earth system, the R&A team chooses to specialize in areas of expertise and of significant concern to the Nation. Specializations include observations of lightning and atmospheric convection, microwave remote sensing, studies of climate dynamics, and enabling use of NASA observations and modeling capabilities by the National Weather Service.

Short-term Prediction Research and Transition Center

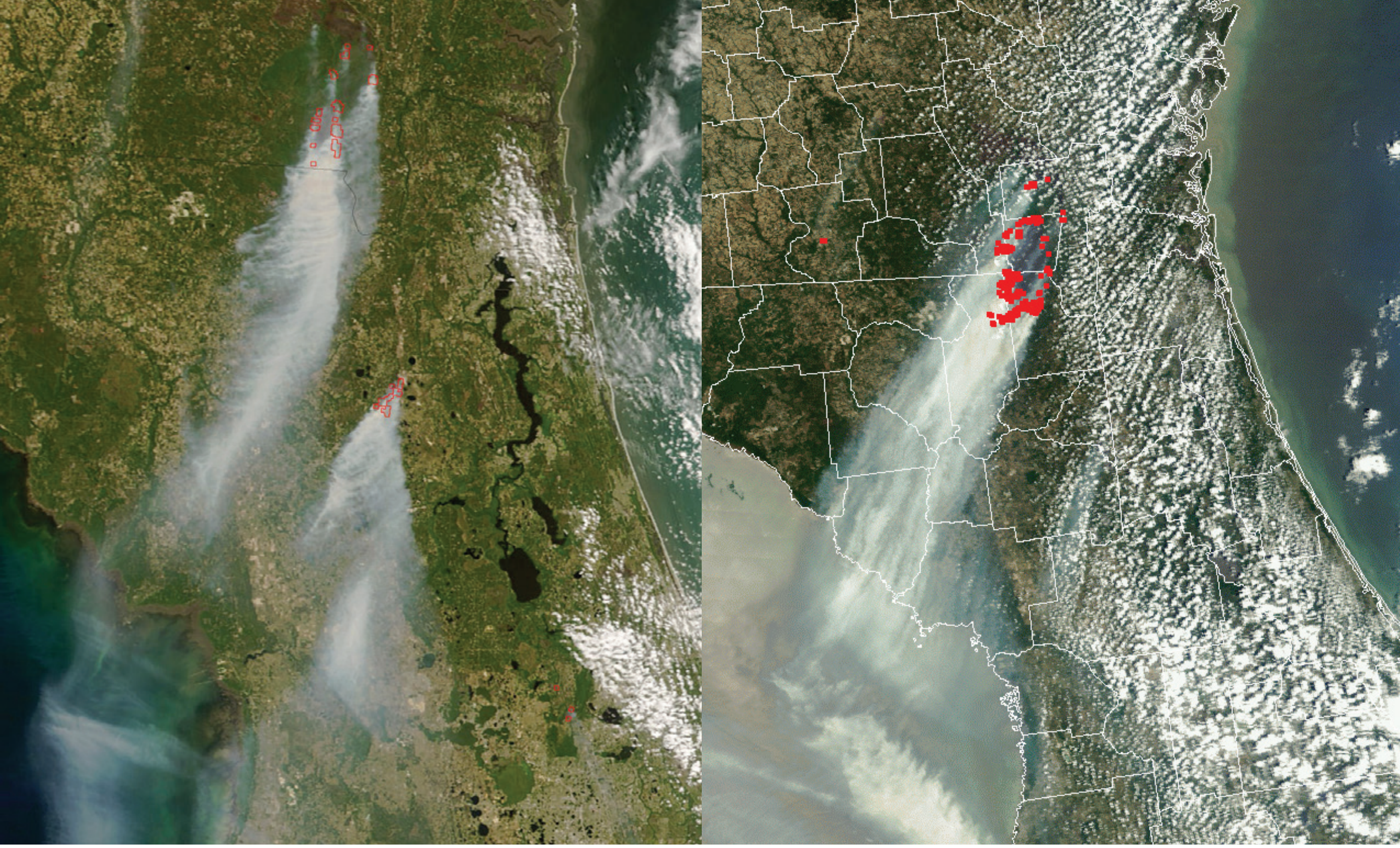
Gary Jedlovec, Brad Zavodsky, and Andrew Molthan

The National Weather Service (NWS) delivers weather forecasts to American communities through its 122 Weather Forecast Offices (WFOs). The forecasting effectiveness of each WFO depends upon the ability to collect atmospheric observations, assimilate observations into numerical models, convert model analyses into national environmental information, and provide local warning and forecast services to affected communities. NASA's Short-term Prediction Research and Transition (SPoRT) Center accelerates the infusion of NASA's Earth science observations, data assimilation, and modeling research into the regional and local NWS forecasting and decision-making process. SPoRT's experimental products focus on the regional scale and emphasize forecast improvements on a 0 to 48 hour time scale. This activity complements NOAA's Joint Center for Satellite Data Assimilation (JCSDA), which focuses on the larger, global scale and long-term forecast problems (2 to 10 days).

SPoRT works closely with the NWS forecasters at 24 local and regional WFOs and five National Centers for Environmental Prediction across the country to identify forecast problems and address them using timely, high-resolution NASA observations and unique research capabilities. The team develops novel data analysis and forecasting techniques and integrates them into a test bed environment to demonstrate their operational feasibility. Promising data and forecast approaches are then integrated into current NWS decision support systems such as the Advanced Weather Interactive Processing System (AWIPS). Weather forecasters are able to easily access and display the gathered observations due to their seamless integration with their standard product suite in order to generate weather guidance and advanced forecasts.

This partnership has afforded SPoRT and NWS WFOs the opportunity to train its team members on new data, products, and/or capabilities in the form of science sharing sessions, informative presentations, and special training modules. Additionally, SPoRT's and NWS WFOs are able to provide useful feedback about current and future tools for generating more accurate weather forecasting to the Nation.

SPoRT also works collaboratively with other federal agencies, universities, and private sector partners. In the future, SPoRT will work vigorously to continue its efforts to provide a means for effectively transitioning Earth science observations and research capabilities into NWS and private sector operations, and decision makers at the regional and local levels. Transitioning emerging experimental data and products into operations through the SPoRT infrastructure will help NASA foster and accelerate this Earth science strategy over the coming years and move future operational sensors into mainstream operations.



SPoRT provides high-resolution satellite imagery from MODIS to identify wildfires (red), smoke and impacts on public health and visibility.

Some of the key forecast problems the SPoRT team focuses on include:

- Correct diagnosis of cloud cover, fog, and visibility (particularly at night).
- Night-time minimum temperature forecasts.
- Precipitation including areal coverage, amount, and timing of precipitation.
- Improved accuracy and advanced warning/lead time for severe weather including hail, high winds, lightning, and tornados.
- Identifying the location of convective activity.
- Diagnosis of atmospheric moisture variability as it relates to minimum temperatures, clouds, and precipitation.
- Diagnosis and prediction of atmospheric stability and winds at the regional and local scales.
- Data voids (i.e., Gulf of Mexico, Mexico, and ocean regions) that contribute to forecast errors in cloud coverage, precipitation, and basic state parameters.
- Land breeze/sea breeze weather.
- Accurate marine weather forecasts.

SPoRT scientists train forecasters on the use of NASA satellite data.

Climate Dynamics

Franklin Robertson and Brent Roberts

Over the past three decades, remote sensing from space has enabled NASA and the Earth Science community to assemble an unprecedented record of the mean state of the Earth System, to identify its modes of variability, and to characterize the physical processes involved. At the same time, leaps in computational power have supported the development of comprehensive global modeling strategies. Combining these observational and computational resources has provided the means for testing specific, detailed hypotheses about past and future climate system behavior.

A primary focus of our NASA-supported climate research is to better characterize variability in the Earth energy and water cycles. Diverse exchanges of water and energy between the ocean, atmosphere, land/biosphere, and cryosphere characterize climate and its variability. These exchanges vary with time. Current research efforts within MSFC's Earth Science Office directly support the investigation of these interactions, particularly through the NASA Energy and Water Cycle Study. Satellite-based estimates of radiative and turbulent moisture and heat fluxes that transfer energy are critical to providing a standard by which the veracity of global climate model simulations can be tested. Estimating the turbulent fluxes from satellite requires accurate retrievals of sea surface temperature, near-surface wind speed, air temperature, and moisture content. Research at MSFC has contributed to improved retrieval of these variables using remotely sensed passive microwave observations and innovative nonlinear neural net algorithms. These improved retrievals lead directly to better estimates of the surface energy and moisture fluxes that are critical to modeling ocean and atmospheric variability.

MSFC's Earth Science Office is engaged in these research efforts with a specific focus on the following:

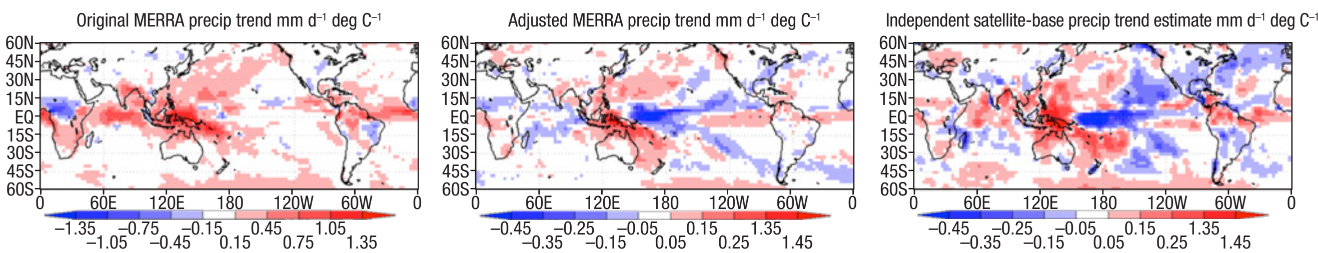
1. Apply NASA's unique observations of the Earth system in studies to advance understanding of climate variability on intraseasonal (20–90 day) to near-decadal scales
2. Evaluate and help improve NASA climate model performance in quantifying and predicting these variations. Support for these efforts comes from NASA Earth Science Division programs for precipitation science; modeling, analysis and prediction; and the NASA Energy and Water Cycle Study.

Recently, MSFC's Earth Science Office has been focused on ways to overcome challenges in space-based measurements. A major constraint with space-based measurements of temperature, precipitation, wind, and other variables is that they are not gathered uniformly in space or in time. Data synthesis efforts that use physically-based models to integrate and interpolate satellite measurements, i.e., "reanalyses," have become a mainstay of the climate community for diagnostic purposes and for driving offline ocean and land process models. However, continual but discrete changes in the evolving observational system, particularly from satellite sensors, may also introduce artifacts in the time series of quantities such as precipitation or atmospheric radiation.

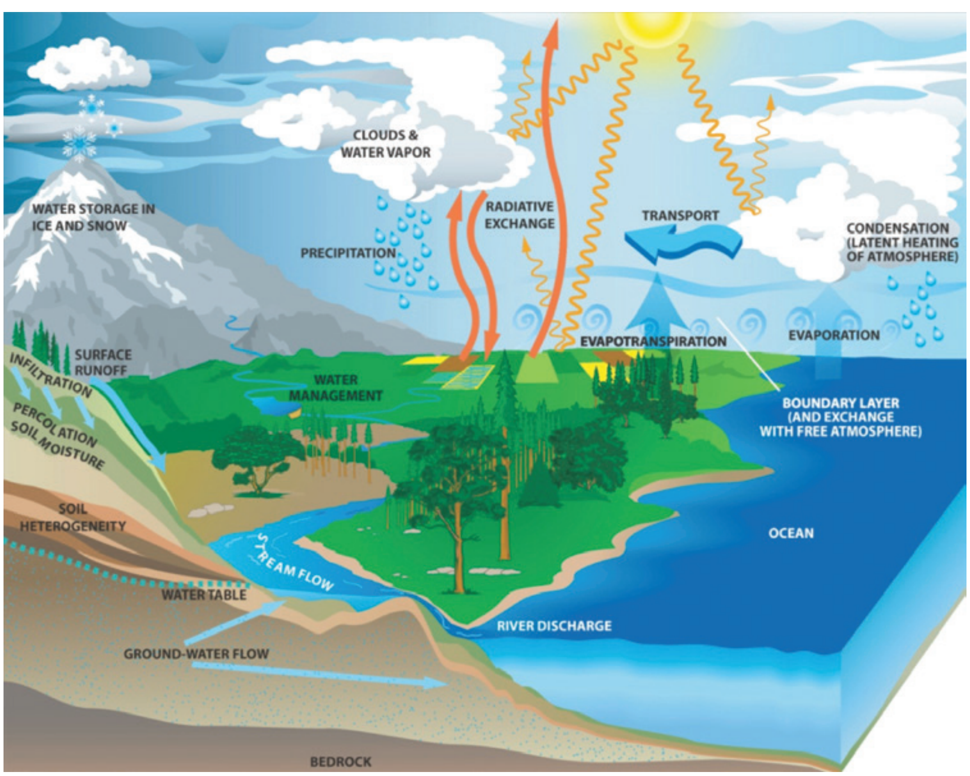
In partnership with the NASA Global Modeling and Assimilation Office (GMAO) and Goddard Space Flight Center we have recently quantified the effects of satellite observing system changes on NASA's latest reanalysis known as Modern-Era Retrospective analysis for Research and Applications (MERRA). Sudden changes in the time series of surface evaporation, precipitation, and radiative fluxes detected in MERRA have been traced to the onset of observations from the Advanced Microwave Sounding Unit-A, AMSU-A, a new instrument series on polar orbiting spacecraft that became available in 1998 and continues to the present. New moisture sensitive instrument channels on AMSU-A used a different scanning strategy from previous observations and thus changed the error properties of moisture data ingested into the MERRA reanalysis. This new data interacted with the moist physics of the MERRA assimilation model, resulting in spurious changes in the time series of energy fluxes. These artifacts potentially degrade the utility of MERRA data for climate studies.

A statistical regression methodology based on Principal Component Analysis was developed at MSFC to isolate and remove these non-physical signals in the physical flux terms (e.g., precipitation or radiation). The following chart shows how a spurious precipitation trend over the period 1979 to 2010 induced by observing system changes is removed, leaving a physical signal of regional, decadal trend. The adjusted data compares favorably with precipitation trends found in the satellite-based Global Precipitation Climatology Project data—an independent precipitation estimate that has its own uncertainties and error properties.

The arena of data fusion — the combining of data from different sensors — is an increasingly important sector of research. The advent of satellite constellation strategies such as the A-Train (a sequence of sensor platforms orbiting Earth but spaced minutes apart in orbit) are resulting in the potential to combine information from multiple frequencies, look angles, and vertical resolution. Extending the nonlinear retrievals algorithms developed at MSFC to the use of multiple sensors is currently being undertaken. In particular, combining measurements from the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) together with the AMSU-A sensor provides a unique combination of direct surface and lower atmospheric thermodynamic information. Improvements in moisture and energy flux estimates from multiple satellites result in the ability to create long-term climate data records from observations that can be used to investigate climate variability across a range of spatial and temporal scales. These records directly support the climate science community at large through multi-national programs such as the Global Energy and Water Cycle Experiment that is supported through the World Climate Research Program.



Regional precipitation trends relative to global ocean surface temperature changes: (top) original MERRA data, (middle) adjusted MERRA data, (bottom) independent GPCP satellite estimate.



Depiction of the water, heat, and radiative exchanges between oceans, land, and atmosphere that are critical to the Earth's energy and water cycles.

Real Time Mission Monitoring and Data Mining

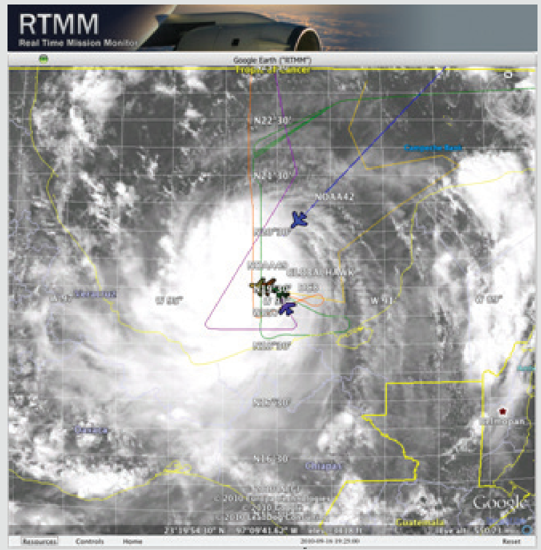
Michael Goodman, Richard Blakeslee, and Paul Meyer

The NASA Real Time Mission Monitor (RTMM) is an interactive visualization application that provides situational awareness and science asset management to enable adaptive and strategic decision-making during airborne field experiments. RTMM integrates satellite imagery, radar, surface and airborne instrument data sets, model output parameters, lightning location observations, aircraft navigation data, soundings, and other applicable Earth science data sets. The integration and delivery of this information is made possible through data acquisition systems, network communication links, and network server resources. RTMM uses either the Google Earth web plug-in or World Wind application for the user visualization display.

RTMM is a powerful science decision-making tool, built upon a service oriented architecture that seamlessly integrates multiple applications for facilitating the monitoring and management of airborne assets in NASA Earth science ground validation and field campaigns. RTMM operates from a web browser utilizing applications on a common framework for science data visualization and planning. RTMM system provides mission planners and airborne scientists with enhanced tools and capabilities to more efficiently plan, prepare and execute missions, as well as to playback and review past mission data.

The RTMM was originally developed by the Earth Science Office at MSFC (http://rtmm.nsstc.nasa.gov) to track and monitor assets during Earth science research airborne field deployments. It grew out of a requirement to chart the position and manage the flights of an Altus uninhabited aerial vehicle but has rapidly expanded to include well over a dozen manned and unmanned aircraft. RTMM has been used in a wide range of airborne science experiments including hurricane flights in the U.S. and Cape Verde, arctic tundra fires in northern Alaska and Canada, soil moisture observations in Oklahoma, lake effect snow storms in Ontario, Canada, rainfall in Finland, and monitoring and measuring the spread of the oil from the BP Deepwater Horizon oil rig in the Gulf of Mexico.

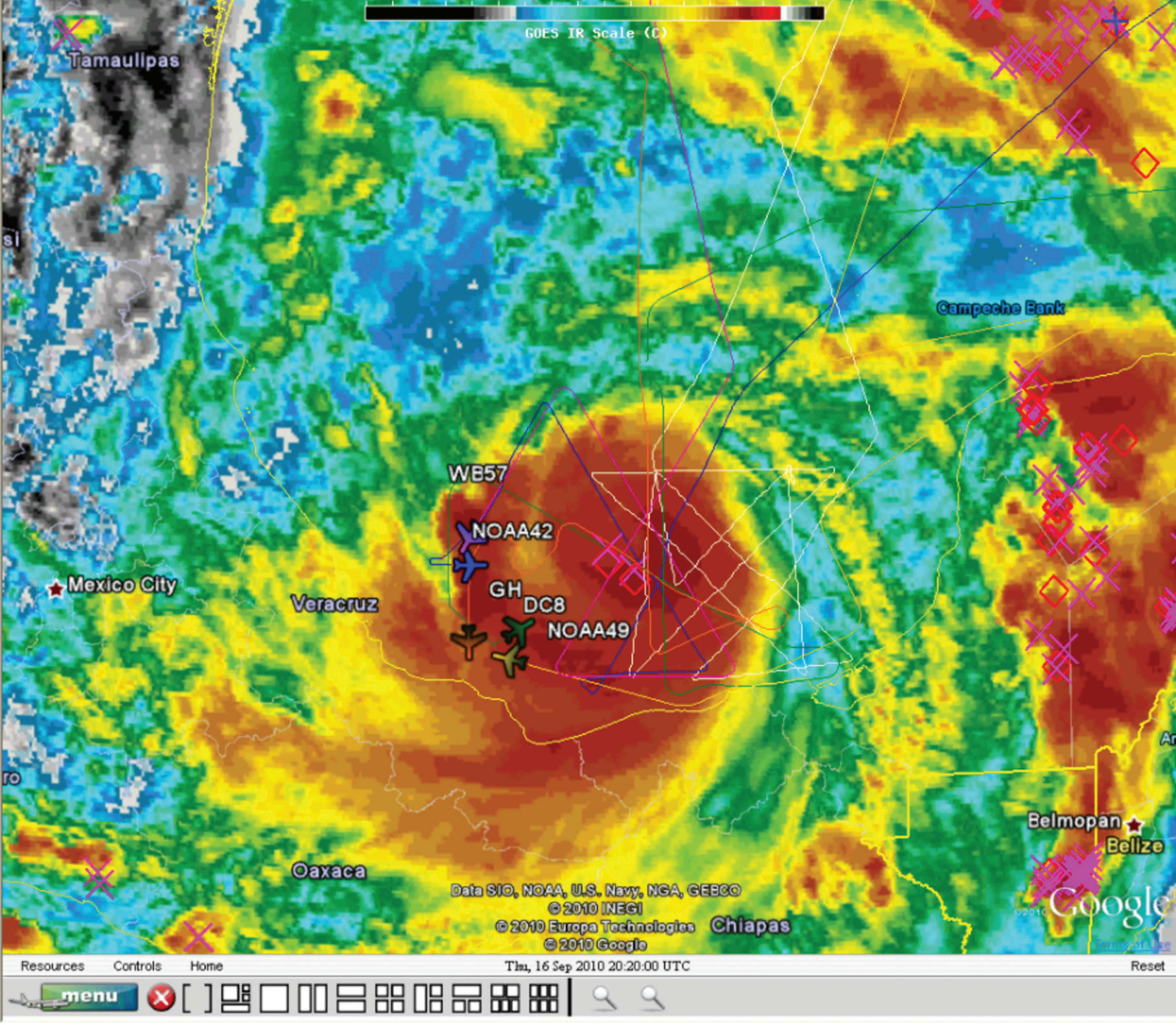
RTMM supported hurricane research flights of the NASA unmanned high-altitude Global Hawk, the NASA DC-8, and NASA WB-57 during the Genesis and Rapid Intensification Processes (GRIP) tropical cyclone field experiment. During the six week GRIP campaign, the RTMM tracked and displayed current weather conditions for multiple aircraft (three NASA, three NOAA, one National Center for Atmospheric Research (NCAR), and several Air Force Reserve), including the NASA unmanned Global Hawk at NASA Dryden Flight Research Facility, CA, the NASA WB-57 at NASA Johnson Space Center, TX, and the DC-8 at Fort Lauderdale, FL.



RTMM captures the well-coordinated flights of a combined five NASA, NOAA and Air Force aircraft over Hurricane Karl on 16 September 2010 of the coast of Mexico.

Ancillary applications, such as the integrated multiple window display of model and forecast parameter fields, interactive instant texting capability, and the Waypoint Planning Tool proved to be invaluable to science situational awareness and further contributed to mission success. In addition, feedback from users in the field was beneficial for driving new requirements and charting the course for future development. Close pre-mission coordination with the Global Hawk flight team led to using the RTMM in their operations center, which resulted in RTMM being poised to capture the maiden voyage of NASA's new asset flying over the eye of Hurricane Karl.

Tracking these planes is relatively easy; RTMM ingests the real-time navigation data as it is transmitted from the aircraft to a central data server at NASA Ames Research Center. What RTMM uniquely provides to the scientist is the ability to integrate many other ancillary data sets and do it seamlessly with multiple independent user window configurations. For example, we routinely ingest real-time NOAA Geostationary Operational Environmental Satellite (GOES) visible, infrared, and water vapor images and animate the last few hours of data. The GOES data are useful for experiments over the United States, but for the



RTMM captures of Hurricane Karl just off the Yucatan Peninsula in the Gulf of Mexico on September 16, 2010. The image captures the flight tracks of a combined five NASA (WB-57, DC-8 and Global Hawk) and NOAA (NOAA 42 and NOAA 49) research aircraft as they approach the eye of Karl. The satellite image is a colorized infrared image. Red diamonds and magenta "x"s indicate the recent lightning strikes within a minute of the image.

European-based experiments RTMM also ingests the Meteosat Second Generation (MSG), which is the geostationary satellite for views of nascent tropical disturbances emerging off of North Africa. Similarly, for experiments over the Pacific or Asia, we ingest, display, and animate the Japanese Geostationary Meteorological Satellite (GMS) imagery.

Displaying the aircraft track over animated real-time satellite images is useful, but RTMM also provides the flexibility to add combinations of NWS Next Generation Radar (NEXRAD) reflectivity images, research radar reflectivities, multiple lightning strike surface networks, real-time satellite positions, satellite predictions, hurricane tracks, aircraft altitude and pitch and roll, radiosonde and dropsonde observations, aircraft nadir camera pictures, other experiment specific data sets (e.g., buoy reports), and even weather forecast products.

This software application has become a staple of many NASA airborne science missions. The ability to "see" the plane's location, view real-time data streams and simultaneously communicate with remotely located science team members is the key to what makes the RTMM system a powerful tool for conducting airborne science.

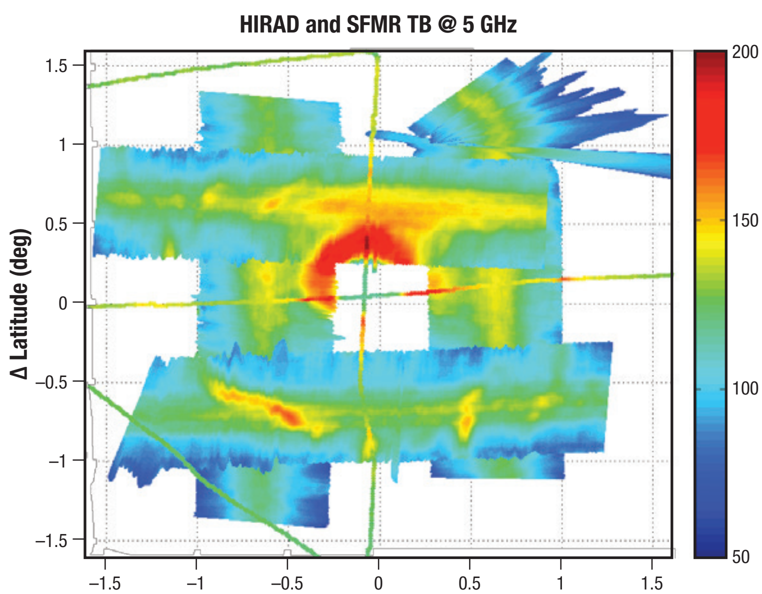
Hurricane Imaging Radiometer

Tim Miller and Brent Roberts

NASA addresses the challenge of developing new technologies to better understand and forecast severe weather, and then transfers those technologies to operational agencies (primarily NOAA) for implementation. The use of airborne science platforms is a major component of this research. NASA has conducted airborne flight campaigns over many years to study tropical cyclone development, including the most recent one in 2010. The Genesis and Rapid Intensification Processes (GRIP) experiment used three NASA aircraft, one of which was an Unmanned Aerial System (UAS), i.e., piloted from a workstation on the ground. This aircraft (Global Hawk) flew over storms at a high altitude (~60,000 feet), and carried several science instruments, including the Lightning Instrument Package (LIP), described in another section of this document. Another (inhabited) aircraft, the WB-57, also flew over storms at similar altitudes, and it carried the new MSFC instrument Hurricane Imaging Radiometer (HIRAD).

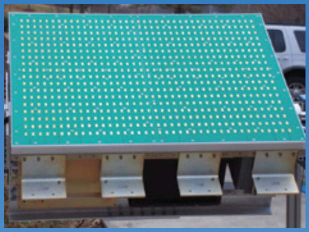
HIRAD is an innovative technology development that makes unique remotely sensed observations of extreme wind and strong precipitation in oceanic storms. MSFC partnered with NOAA's Hurricane Research Division (HRD), University of Michigan, and University of Central Florida for both science and engineering efforts, with most of the fabrication and system integration performed in-house. The instrument technique is similar to that of the airborne Stepped Frequency Microwave Radiometer (SFMR), which is a proven and operational aircraft remote sensing technique for observing tropical cyclone ocean surface wind speeds and rain rates, including those of major hurricane intensity.

The HIRAD instrument advances beyond the current nadir viewing SFMR to an equivalent wide-swath imager using passive microwave synthetic thinned aperture radiometer technology. This sensor operates over 4-6.6 GHz (C-band frequencies) where the required tropical cyclone remote sensing physics has been validated by both SFMR and WindSat radiometers. HIRAD is a compact, lightweight, low-power instrument with no moving parts that produces wide-swath imagery of ocean vector winds and rain during hurricane conditions where existing microwave sensors (radiometers or scatterometers) are hindered. In the GRIP campaign, HIRAD flew over hurricanes Earl (in the Atlantic) and Karl (in the Caribbean Sea and Bay of Campeche). Data acquired from HIRAD will be used to develop techniques to more accurately analyze and forecast the intensity and structure of the inner storm vortex. HIRAD will join several other instruments in flying on the Global Hawk on the Venture-class mission Hurricane and Severe Storm Sentinel (HS3) during the storm seasons of 2012, 2013, and 2014.

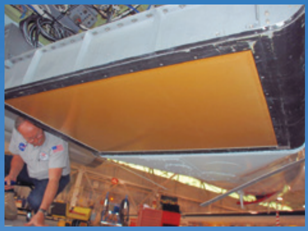


HIRAD-derived brightness temperature at 5 GHz over Earl on September 1, 2010. The coordinate system is storm-relative; i.e., the storm movement has been removed so that the swaths can be matched up, relative to the storm features. The thin line shows actual measurements from SFMR, and agreement with HIRAD is expected only in the center of the HIRAD swaths where the viewing geometries are identical..

The HIRAD instrument as it is being prepared for flight in the WB-57 pallet.



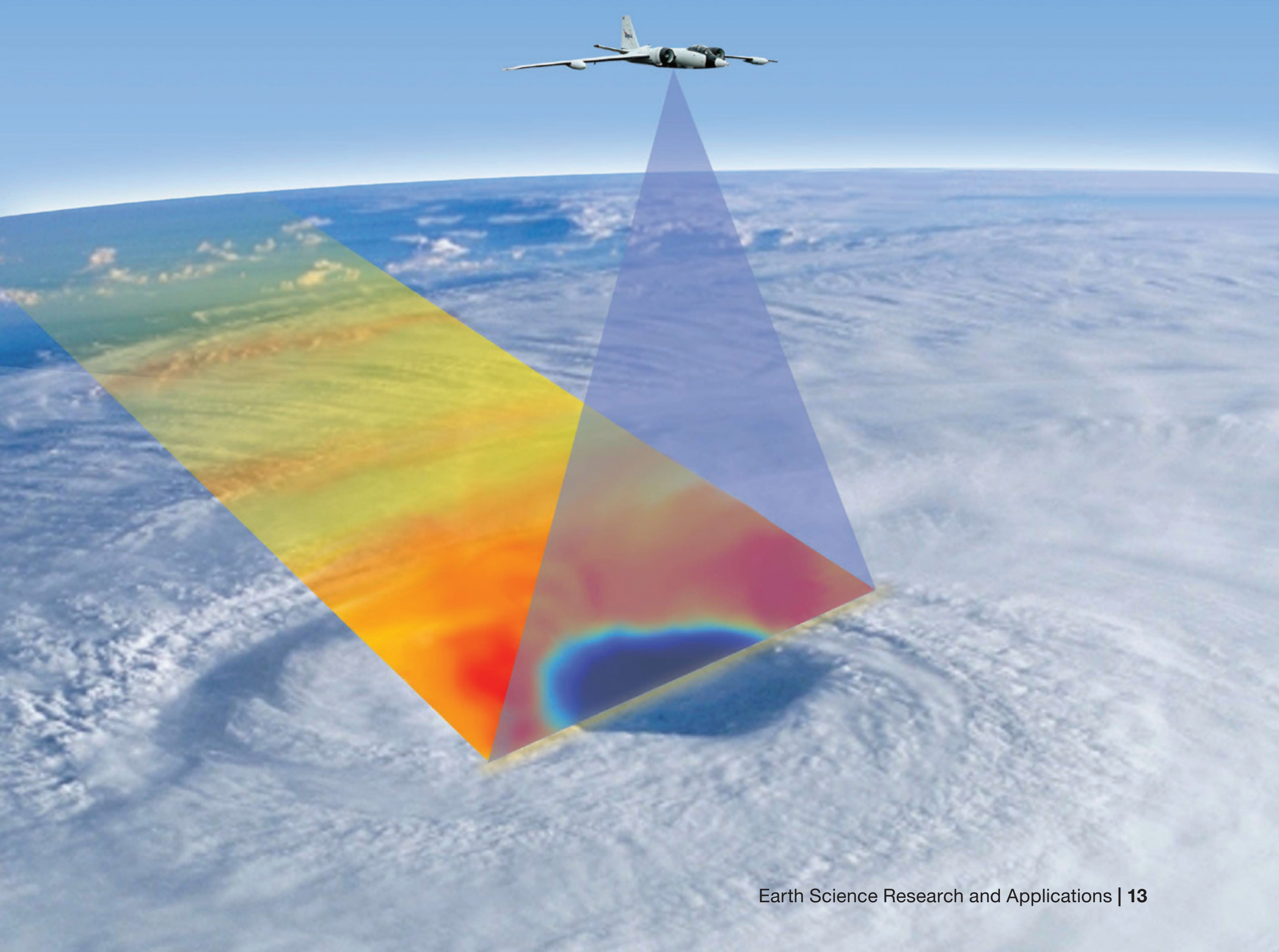
The HIRAD instrument antenna pointed at the sky, for engineering tests.



The HIRAD pallet installed in the payload bay of the WB-57, showing the protective radome (orange).

HIRAD and other personnel, including the pilots wearing their flight suits, as the WB-57 is readying for a test flight.

Artist's depiction of HIRAD flying above a tropical cyclone, obtaining an image of wind speed at the ocean surface.



Soil Moisture Remote Sensing

Charles Laymon and Ashutosh Limaye

Within the Water and Energy Cycle focus area, the global soil moisture mission element addresses the following two questions:

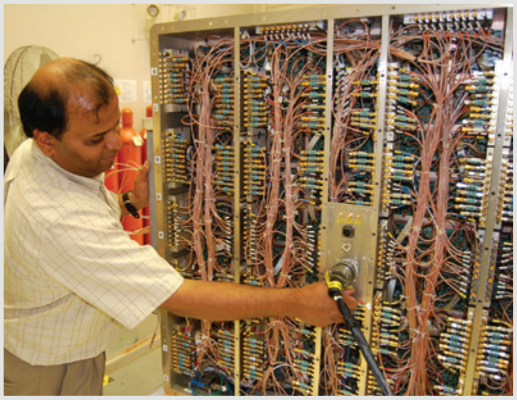
1. How will water cycle dynamics change in the future?
2. How are the variations in local water resources related to global climate variation?

Soil moisture estimates over the Earth's land surface help determine the amount of water that is stored in and moved through the top layers of soil. This information is critical to a host of scientific processes and can lead to improvements in weather prediction and have practical applications for agriculture, water resource planning, disaster management, and for military trafficability determination.

The NSSTC team of scientists has developed a suite of models and analytical tools pertinent to soil moisture observations, modeling, and analysis. The team has utilized radio brightness models ranging from simple (single-layer) Fresnel reflectance models to the coherent wave radiative transfer model for a layered soil medium. For example, the team has long used the standard single frequency/single polarization retrieval schemes as well as multi-polarization, multi-angle optimization/polarization ratio-based retrieval schemes. NSSTC hydrologists recently developed a combined passive and active retrieval scheme that solves for multiple parameters using optimization. It also has developed an optimal deconvolution (ODC) model that uses a sensors response function to more accurately assign observations made by microwave instruments to an Earth grid. This algorithm utilizes over-sampling of remote observations to enhance the resolution of brightness temperature observations or soil moisture products.

Complementing skills in soil moisture retrieval, the team has 20 years' experience with the land surface hydrology model Simulator for Hydrology and Energy Exchange at the Land Surface (SHEELS) developed at MSFC and coupled with a forward radiobrightness model and an ensemble Kalman filter for soil moisture modeling and remote sensing data assimilation. SHEELS was recently implemented within the NASA Land Information System (LIS) modeling framework, enabling us to use ensemble Kalman filter tools to extend our data assimilation abilities to regional, continental, and global scales. Assimilation experiments using microwave satellite data are ongoing with SHEELS, in off-line mode and coupled with the Weather Research and Forecasting (WRF) mesoscale meteorological model.

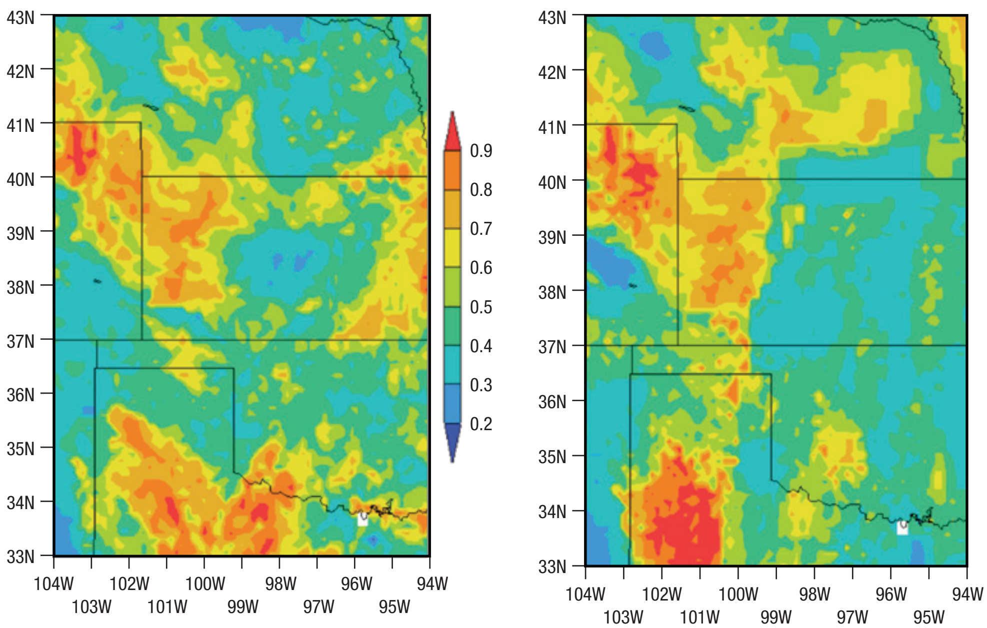
In addition to the science modeling tools, the Observing Microwave Emissions for Geophysical Applications (OMEGA) team has been developing instruments to facilitate soil moisture research and validation of space borne sensors. The OMEGA team is developing a truck-mounted active and passive system comprised of an L-band fully polarimetric radar (1.26 GHz) and radiometer (1.413 GHz) for use in validating airborne and space-borne observations and for



MAPIR antenna assembly showing the back (left) and front (right, without radome) sides.

MAPIR integrated into the belly of the NASA P-3B Orion (right) and UTSI Piper Navajo.

detailed studies of soil moisture processes. The team has completed an engineering model of the Marshall Airborne Polarimetric Imaging Radiometer (MAPIR), a fully polarimetric airborne phased array radiometer. The digital back end to the MAPIR radiometers was developed by the University of Michigan and has implemented the Agile Digital Detector (ADD) for detection and mitigation of radiofrequency interference. A spectrum analyzer also allows us to record and characterize the spectral characteristics of Radio Frequency Interference (RFI). MAPIR has been integrated into two very different aircraft, NASA's P-3B Orion and the University of Tennessee Space Institute's (UTSI) Piper Navajo PA-31. MAPIR flew eight missions in October 2008 as part of the Soil Moisture Active Passive Verification Experiment 2008 (SMAP-VEX '08), four missions in Fall 2009 for a study with Tennessee Valley Authority and five missions in collaboration with NOAA Atmospheric Turbulence and Diffusion Division. In May 2011, MAPIR supported the Mid-latitude Continental Convective Clouds Experiment in central Oklahoma.

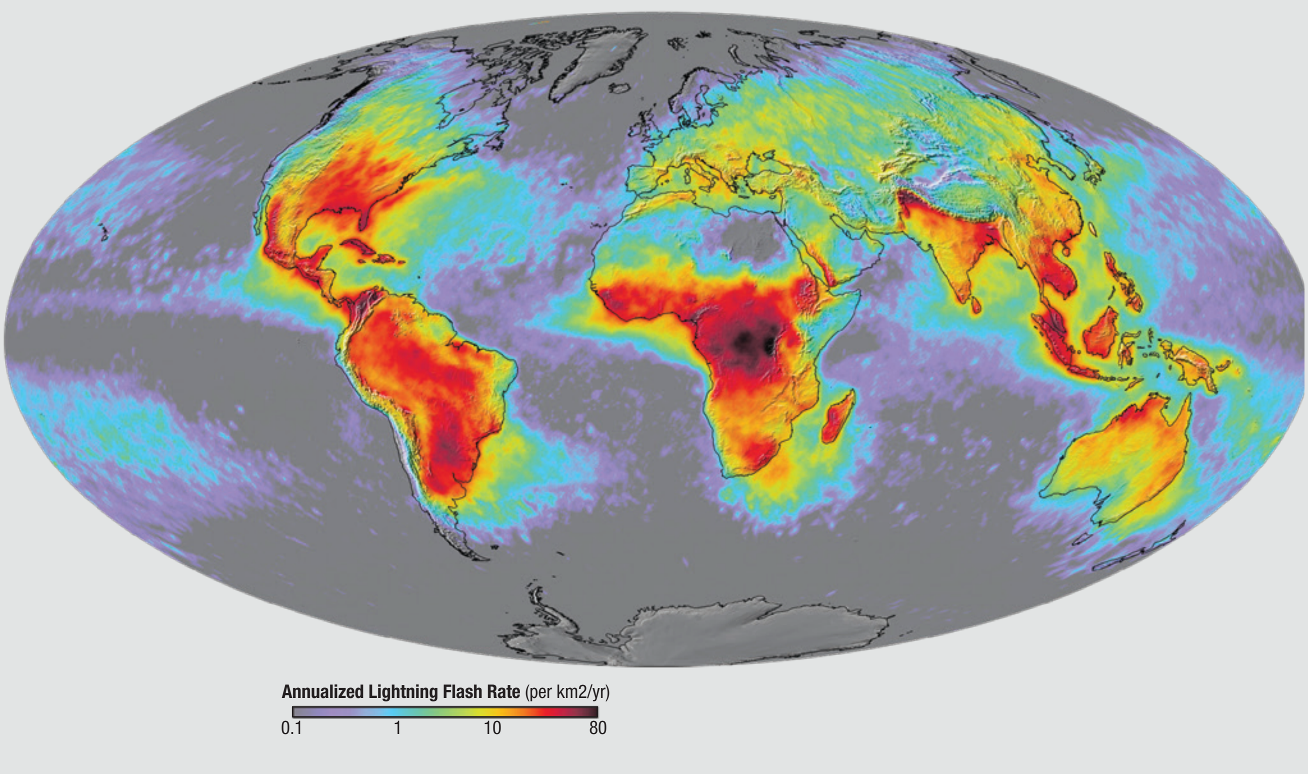


Comparison showing SHEELS-modeled fractional soil moisture in the upper layer (0–5 cm) over the Central U.S. on 7 June 2003 with and without assimilation of remote sensing data. Map on the left is without remote sensing data input, whereas the map on the right is with assimilation of AMSR-E soil moisture data using an ensemble Kalman filter.

Lightning Research

Richard Blakeslee and Bill Koshak

The lightning research program at MSFC traces back to a NASA Headquarters-sponsored workshop in 1979 on the need for space-based lightning observations during which top atmospheric electricity and weather experts advised that making lightning observations from space was a goal well worth pursuing. Since that time, the research activity has grown into a comprehensive investigation of thunderstorms, lightning, and fair-weather atmospheric electricity using a wide range of ground, in-situ airborne, and space-based observation systems as well as a sophisticated array of modeling and remote sensing algorithms. Over the past 30 years, emphasis has been placed on developing and fully exploiting the benefits of space-based lightning observations. Starting with the Optical Transient Detector (OTD) in April 1995, and continuing with the Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM) in November 1997, we have been monitoring global lightning activity with high detection efficiencies from low Earth orbit for over 17 years. The central research focus is determining how data from these sensors can improve severe weather forecasting and global chemistry/climate modeling. The OTD/LIS missions also served as the science and technology pathfinder for the GOES-R Geostationary Lightning Mapper (GLM), planned for launch in 2015. Risk reduction and algorithm development activities are ongoing in preparation for the future GOES-R GLM. The NASA MSFC lightning group actively participates in the NASA SPoRT Center which seeks to accelerate the infusion of NASA Earth Science observations, data assimilation, and modeling research into NWS forecast operations and decision-making at the regional and local level. Data from the North Alabama, Washington DC, and other Lightning Mapping Array (LMA) networks are cooperatively analyzed by our lightning group and NWS forecasters to optimize the use of lightning data in real-time severe weather warning situations. In addition, GLM proxy data derived from the LMA and other lightning networks are being developed and used to prepare users for GOES-R data and to create and test algorithms for generating higher-level lightning products. A Lightning Instrument Package (LIP), flown on a variety of airborne platforms, serves as a major research tool to better understand and quantify lightning-severe weather relationships, and to validate the space-based observations. Another important activity of the lightning research program is to support NASA launch operations, including protecting personnel and property, through the development of Lighting Launch Commit Criteria.



Advanced Microwave Precipitation Radiometer

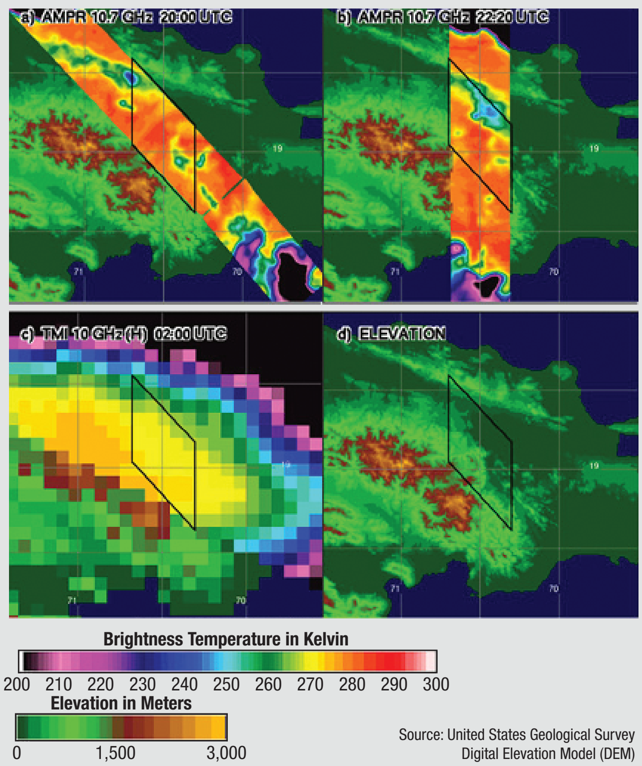
Brent Roberts

The Advanced Microwave Precipitation Radiometer (AMPR) is a cross-track scanning passive microwave radiometer developed and built in cooperation between MSFC and the George Tech Research Institute (GTRI) during the late 1980s to provide measurements of important geophysical parameters from an airborne platform. The instrument observes microwave radiation at frequencies of 10, 19, 37, and 85 GHz and is able to provide information on surface and atmospheric parameters including precipitation over ocean and land surfaces, ocean surface temperature and near-surface wind speed, soil moisture, and sea ice. Standard Level 2 products include the observed brightness temperatures and a precipitation index. Recent investigations have shown AMPR observations to be potentially useful in other applications such as flood detection.

The design of the AMPR feedhorn for the three highest frequencies is a copy of the feedhorn used aboard the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), while the 10-GHz feedhorn has been separately developed by GTRI. The use of similar frequencies as those of the SSM/I, the TRMM Microwave Imager (TMI), and other current passive microwave sensors makes AMPR an attractive instrument for use in airborne calibration/validation activities.

The original design of AMPR results in a varying polarization across-track from purely vertical polarization at 45 degrees left of nadir to purely horizontal polarization 45 degrees to the right of nadir. Recent investment through the MSFC Technology Investment Program (TIP) has resulted in a dual-polarization upgrade to the instrument. AMPR now measures fully horizontal and vertical polarization at the scan edges and a mixture across track as the instrument scans. The additional information should lead to improved geophysical retrievals over both ocean and land surfaces.

The AMPR instrument has served in more than 15 major airborne field campaigns since 1990. It has been integrated on two aircraft — the DC-8 and the ER-2. Since its dual-polarization modernization in 2010, AMPR has contributed to the Midlatitude Continental and Convective Clouds Experiment (MC3E) field campaign as a part of a larger programmatic effort to provide support of calibration/validation activities for the Global Precipitation Measurement (GPM) mission. AMPR is currently being readied for the GPM Convective and Orographic Precipitation and Hydrology Experiment (COPrHEx) to be flown in 2014, where it will provide quantitative information on precipitation processes.



Observations at 10.7 GHz from AMPR show a clear signature of surface water and potential flooding over the Dominican Republic during the CAMEX-3 field campaign. Overlapping passes of AMPR (about 2 hours apart) highlight a low-elevation region where heavy rains would likely have pooled as Hurricane Georges made landfall.

Earth Science Applications

Overview

NASA Earth Science data, research, and applications are being used to help make decisions in our lives and those of our friends, neighbors, fellow Americans and people around the world. Sometimes these decisions are direct and personal, such as "What is the chance of my having a problem with pollen today?" or "Should I take shelter from the storm?" Sometimes the decisions are at the national scale, such as impact of hurricanes, drought, earthquakes, and other disasters. And then at the largest scale there are the long-term and global impacts of climate change.

While the potential usefulness of a data set or knowledge base might seem apparent, the actual application to a specific problem may be very difficult. As a result it takes time and effort to convert potential capability to actual utility. The Applied Sciences Program provides the institutional framework for this type of work to happen. It is the objective of the program to match significant problems with appropriate, existing NASA assets to provide additional societal benefits to the Nation and to the international community.

The MSFC Earth Science Office has a long and highly successful record of Earth Science applications work. Currently the Earth Science Office is the largest single center of work applying NASA assets to problems in public health. In addition, the SERVIR project, which has received numerous national and international accolades, is a major part of the Earth Science Applications research done at MSFC. With an international venue, SERVIR brings satellite-driven technologies to provide societal benefits addressing the problems of disaster mitigation, ecosystems, biodiversity, weather, water resources, climate change, health, and agriculture to the people in Central America, East Africa and Hindu-Kush Himalaya. An international focus is not unique to just SERVIR, as many of the Applied Science projects are implemented across global venues. Other efforts that look internationally include work in Mexico, global disaster management, analysis of urban morphology for energy and climate modeling, and the Arctic. Other areas of current applications work include education and student development through the NASA Science Mission Directorate Applied Sciences Training and Development Program (DEVELOP) and hydrologic modeling of coastal estuaries. A measure of the Earth Science Office's success in applications work is the diversity of the funding sources, which besides NASA include the Centers for Disease Control and Prevention (CDC), the National Institutes of Health, Department of Defense, NOAA, the World Bank, and the U.S. Agency for International Development.

In all of these projects, the goal is to bring NASA capabilities, assets, and information to bear on significant problems that must be addressed by decision-makers at all levels of society.

Public Health

Sue Estes, Jeff Luvall, and Dale Quattrochi

The Public Health Applications area at the Earth Science Office, in collaboration with our colleagues at NSSTC promotes uses of Earth observations for public health and safety, particularly regarding infectious disease and environmental health issues. Our NSSTC team members continue to develop critical relationships beyond the existing norms for a science organization. The Public Health team of scientists has developed or has experience in the use of a suite of models and analytical tools pertinent to public health remote sensing.

The team has successfully built cooperative partnerships with several institutions not normally associated with NASA-related work, for example the CDC, the U.S. Geological Survey, Pan-American Health Organization (PAHO), New Mexico Department of Public Health, and academic partners within the United States and in Mexico.

The public health program has hosted sessions, presented papers and posters at the American Public Health Association, American Meteorological Society, American Society of Tropical Medicine and Hygiene, American Thoracic Society, and other public health events.

Public Health Projects

1. Heat Vulnerability and Climate Change
   Dale Quattrochi

   The MSFC Public Health team and the CDC are studying public health and heat vulnerability and identifying geographic locations of the most vulnerable populations. By developing a model using information from the Earth Observing System, Census data, and National Center for Health Statistics, a better understanding of geographic vulnerability of the U.S. population can be achieved.

2. REGARDS
   Dale Quattrochi, Bill Crosson, Mohammad Al-Hamdan, Maury Estes, and Sue Estes

   REasons for **G**eographic **A**nd **R**acial **D**ifferences in **S**troke is a NIH funded study of 30,000 volunteers run by the University of Alabama in Birmingham (UAB) School of Public Health. The Public Health team and UAB are studying the effects of air quality, temperature, and land use on cognitive function and blood pressure. Information gathered is provided to the CDC.

3. Environmental Public Health Tracking
   Dale Quattrochi, Bill Crosson, Mohammad Al-Hamdan, Maury Estes, and Sue Estes

   The Public Health team tests the use of satellite aerosol remote sensing and satellite-derived air quality estimates to extend air quality coverage in the CDC's National Environmental Public Health Tracking Network.

4. Improvements for Dengue Viruses Via Remote Sensing Information
   Dale Quattrochi, Bill Crosson, Mohammad Al-Hamdan, Maury Estes, Sue Estes, and Max Moreno-Madrinan

   Dengue (Break Bone) viruses are carried by mosquitoes in tropical and subtropical areas. MSFC, NCAR and the University of Veracruz are integrating environmental observations, including weather, land use/land change, and mosquito vectors with human health investigations in order to provide end users in Mexico access to remotely sensed data that will aid them in predicting the outbreak of Dengue Fever.

5. Phenology and Pollen Transport
   Jeff Luvall

   The Public Health team is using NASA-MODIS data to identify the pollen producing periods of certain Juniper species throughout the U.S. southwest, Texas and Oklahoma. Information gathered is then provided to the New Mexico Environmental Public Health Tracking System to provide early warning to pollen events, which may trigger allergic and asthma respiratory events.

6. Asthma and Air Quality in the Presence of Fires — A Foundation for Public Health Policy in Florida
   Sue Estes, Jeff Luvall, Bill Crosson, and Mohammad Al-Hamdan

   In this university/multi-agency project, asthma hospital/emergency room (patient) data serves as the foundation for creating a health outcome indicator of human response to environmental air quality. The Public Health team combines these data with environmental data from satellite measurements and models, with special attention being given to the effect of wildfires and prescribed burns on particulate matter. All of this information is used by the Florida Department of Health (FDOH) and the surrounding medical community stakeholders to establish a protocol with triggers for issuing public health advisories/alerts based on the developed and validated health outcome indicators.

7. DEVELOP
   Jeff Luvall

   NASA Science Mission Directorate Applied Sciences Training and Development Program (DEVELOP) is a NASA training and development program for students and young professionals working on Earth Science research projects. At Marshall, DEVELOP students are using NASA earth observation systems in public health projects to study lyme and other tick-borne diseases in Alabama. Additionally students are researching a predictive model for West Nile virus (mosquito vector) in Alabama.

SERVIR

Dan Irwin, Ashutosh Limaye, and Jason Kessler

SERVIR — the Regional Visualization and Monitoring System — is a joint venture between NASA's Applied Sciences Program and the U.S. Agency for International Development (USAID) that helps government officials, scientists, and researchers make better decisions by providing Earth observations and predictive models based on data from Earth-orbiting satellites.

The SERVIR system helps nations in Central America, East Africa, and the Himalayan regions cope with eight areas of societal benefit identified by the international Group on Earth Observations: disasters, ecosystems, biodiversity, weather, water, climate, health, and agriculture.

SERVIR has active hubs in Kenya and Nepal, with additional hubs to be started this year; operations for Central America are planned to continue this year as well. The hubs provide the infrastructure and subject matter experts in remote sensing and geographic information systems to develop new information or convert existing information into a useful form for government officials, scientists, and researchers. In addition, to advance its mission of helping improve environmental awareness and decision making, SERVIR has developed, modified, or advanced several models and technologies.

Working closely with the Kenya Meteorological Department (KMD), SERVIR has been incorporating local weather observations and forecasts as well as data from NASA's TRMM satellite into the Coupled Routing and Excess Storage (CREST) hydrology model, which tracks and forecasts water flow. This combination of local and NASA knowledge is helping KMD better understand historical and present potentials for drought and flooding, both of which pose a threat to the region. SERVIR is working in close collaboration with Kenya's Department of Water Resources to calibrate and validate model products using in-situ streamflow observations. With the calibrated model, SERVIR intends to foray into the seasonal forecasts, of critical importance to the agricultural productivity estimates in East Africa.

SERVIR has also been working with MSFC's SPoRT Center to improve numerical weather forecasts in Central America using the Weather Research and Forecasting (WRF) model. The goal of this effort is to make WRF-based forecasts available to governments in the developing world for improved weather forecasting and early warning of extreme events.

In addition to analytical models, SERVIR has been improving access to space-based Earth observation information that assists critical decision making during and after natural disasters. On January 9, 2012, the International Space Station (ISS)/SERVIR Environmental Research and Visualization System (ISERV) was delivered to the Space Vehicle Mockup Facility at Johnson Space Center in Houston, Texas. ISERV was launched on July 20, 2012 from Vandenberg AFB and is expected to go operational on the ISS later in 2012. The ISERV camera, looking through the Destiny module's Earth-facing window, will receive commands from Earth and acquire image data of specific areas on the Earth the next time ISS passes over the region.

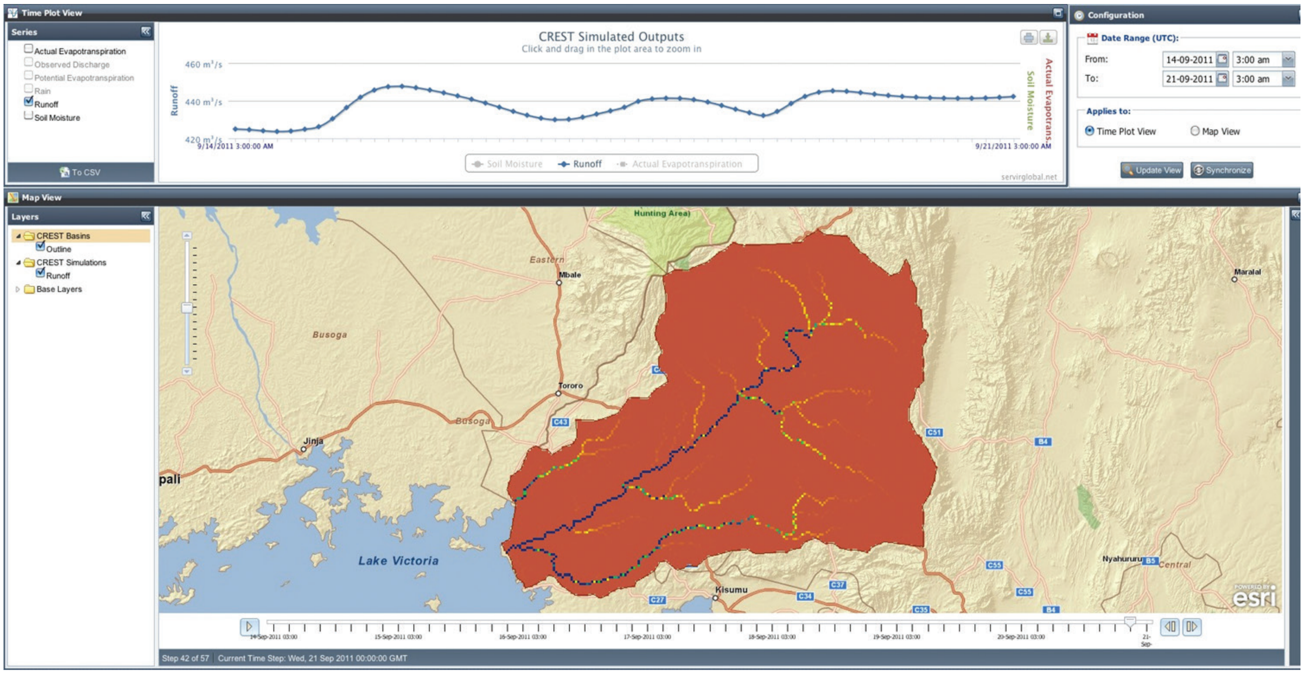
In addition to collecting data from space, SERVIR is working to develop autonomous, ground-based wireless sensor networks that collect data about soil moisture, temperature, and precipitation as well as provide more immediate data for real-time monitoring of landslides or floods. These sensors can work in concert with other data sources (weather forecasts, satellite imagery) to monitor or provide early warnings for natural disasters. SERVIR is running test systems for these networks now and hopes to apply them in multiple areas and applications.

To broaden the scientific application base, NASA Headquarters included a Research Opportunities in Space and Earth Science (ROSES) call for proposals to form a SERVIR Applied Sciences Team. The Team will infuse new ideas from a broad range of the commercial and academic communities that would leverage the program's existing science applications and product portfolio.

The future of SERVIR is expected to be one of expanded geographical reach, broader scientific capabilities and improved technological capabilities as it seeks to use space technology to directly improve life on Earth.

For more information about SERVIR, visit <www.servirglobal.net>.

Project Director Dan Irwin explains SERVIR to interns from NASA's Undergraduate Student Research Program.



Online interface of the CREST model, showing time, water level, and geographic information for a primary Lake Victoria watershed.

Urban Remote Sensing Analysis

Dale Quattrochi, Mohammad Al-Hamdan, Bill Crosson, Jeff Luvall, and Maury Estes

We live in a rapidly urbanizing world where the majority of the earth's population lives in urban areas. In 1950, less than 30 percent of the world's population lived in cities. This number grew to 47 percent in the year 2000 (2.8 billion people), and it is expected to grow to 60 percent by the year 2025, with so called 'megacities'—those cities with populations of 10 million or more—growing from 15 today to 25 by 2025. In the United States, urban/suburban population has increased from 28 percent in 1928 to 84 percent in 2010.

Researchers at the NSSTC have been working on the application of remote sensing data to observe, measure, and model urban landscape characteristics to assist decision and policy makers, and the general public in understanding the impacts that cities have on the environment, and to develop means to improve the livability of urban areas in the future. A major focus of research by the team has been the analysis of the 'Urban Heat Island' Effect (UHI), which exists as a 'dome' of elevated surface temperatures over cities caused by replacing the natural landscape (e.g., trees, vegetation) or pervious surfaces, with buildings, roads and parking lots, or impervious surfaces. Satellite and aircraft data are used to evaluate the pattern, arrangement, and extent of pervious versus impervious surfaces across urban landscape, and to relate these land covers with surface temperatures that emanate up from these surfaces, as a means for observing and measuring characteristics of the UHI. Urban land covers and land uses are derived from multispectral remote sensing data collected over different time intervals to assess the changes that have occurred as cities have grown through time. In turn, thermal remote sensing data that are obtained in sequence with the multispectral data are used to measure land surface temperatures (LSTs) for these land covers to evaluate how LSTs vary across the urban landscape, and how they change through time as a function of urban growth.

An example of how urban land cover/land use changes and their affect on the UHI can be observed and measured using remote sensing is given for the Huntsville, AL area, specifically for the MSFC (Figure 1). Figure 2 shows Landsat satellite images of Land Cover/Land Use Changes (LCLU) for MSFC in1992 and 2001. Significant changes in LCLU have occurred between these two dates as can be

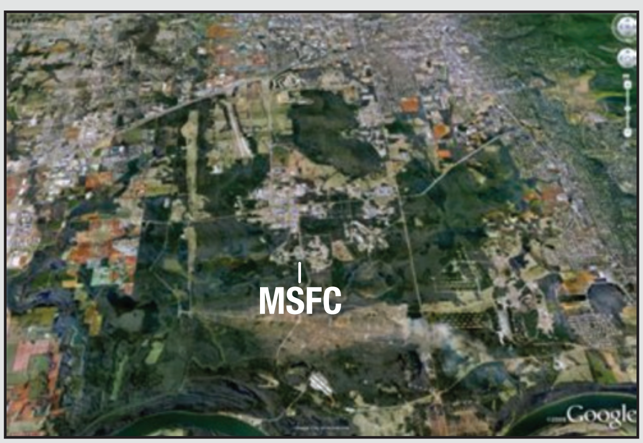


Figure 1. Image of MSFC and surrounding LCLU.

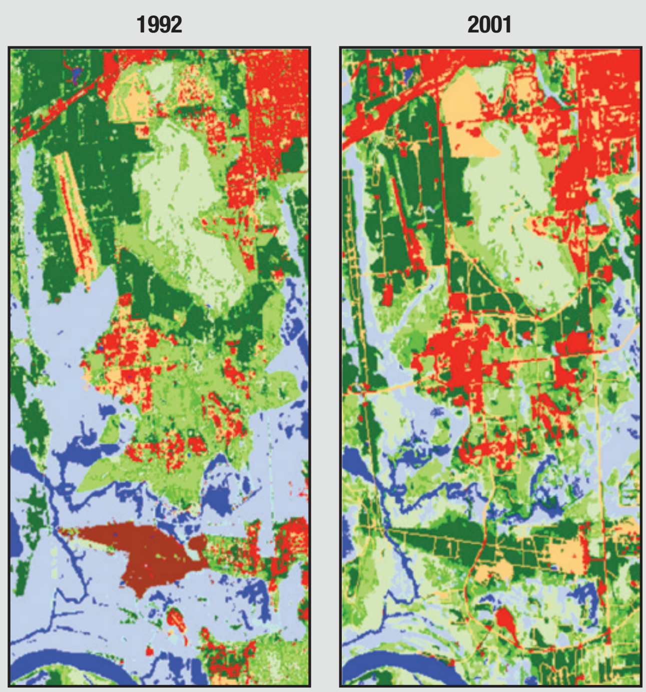


Figure 2. LCLU classification for MSFC in 1992 versus 2001.

identified in the imagery, and are even more evident when these changes are presented in graph format (Figure 3). Of particular note are changes in the Developed Open Space/Recreational Grasses and Residential/Commercial LCLU denoting there has been a substantial increase in urban or "built up" land cover between 1992 and 2001. Correspondingly, there has been a significant change in LSTs in this time period within MSFC and the surrounding area (Figure 4; 314 °K = 106 °F). These changes are further elucidated as graphed data in Figure 5.

Thus, remote sensing data are a powerful tool for the measurement and analysis of changes in LCLU and LSTs that provide observational and quantitative insight into how transition from pervious to impervious surfaces as a result of urbanization affect the characteristics of the UHI. These data are also highly useful for illustrating to policy and decision makers, urban planners, and the public, how urbanization impacts the local and regional environment to better facilitate the implementation of UHI mitigation practices (e.g., tree planting) for making cities more sustainable in the future.

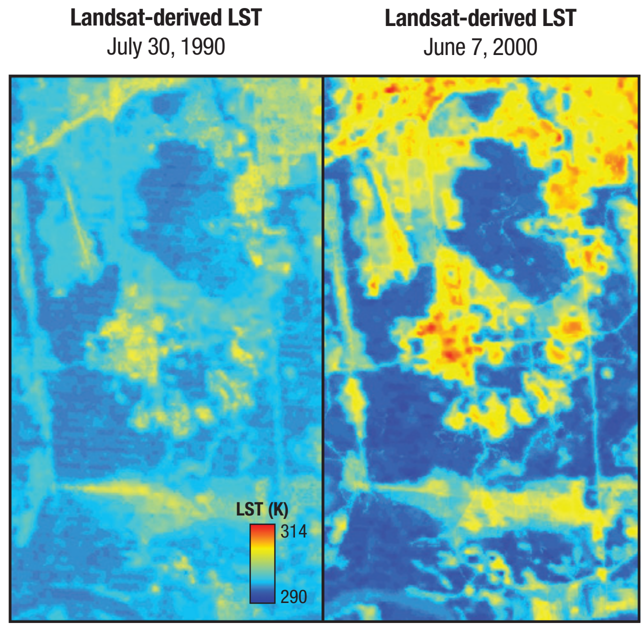


Figure 4. Changes in LSTs for the MSFC area between 1990 and 2000.

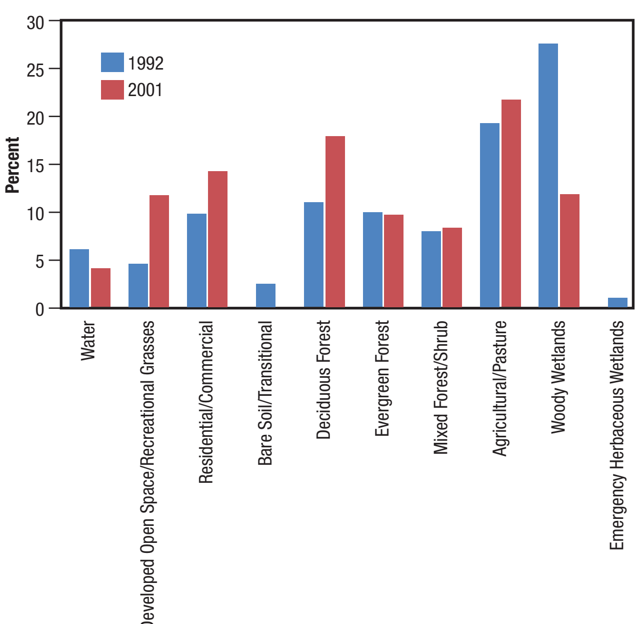


Figure 3. Comparison of LCLU changes for MSFC and environs from 1992–2001.

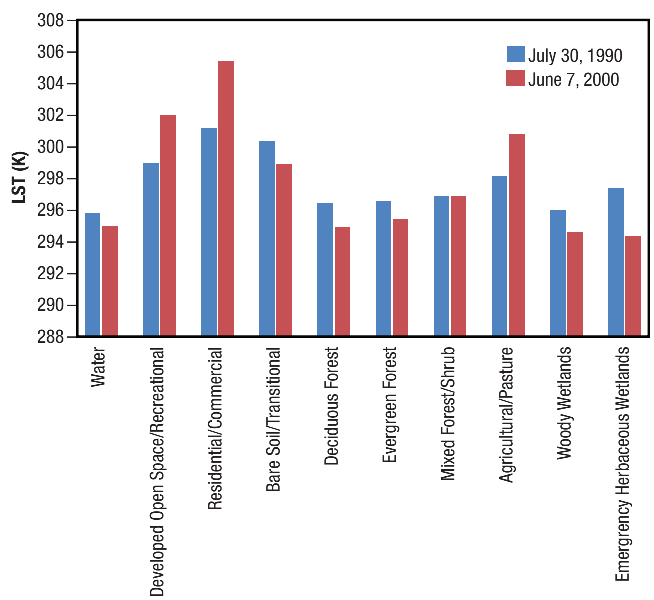


Figure 5. Comparison of changes in LSTs for the MSFC area between 1990 and 2000.

Coastal Science and Ecological Forecasting

Dale Quattrochi, Maury Estes, and Mohammad Al-Hamdan

Researchers at the NSSTC are supporting the Gulf of Mexico Initiative in the Applied Sciences Program. The effects of rapid urbanization in the coastal environment and climate change effects on coastal estuaries are being evaluated with hydrologic models. Partners at Battelle Pacific Northwest National Laboratory and on the Gulf coast are working with NSSTC researchers to determine how physical environmental changes are impacting aquatic ecosystems. Land use changes add to sediment loads in the streams and rivers discharging in to the Mobile Bay estuary and climate variation impact both temperature and salinity levels in the estuary. These impacts affect the available habitat for seagrasses critical to Gulf fisheries. Additional work ongoing is simulating future climate based on IPCC scenarios and using these data as input to the hydrologic models.

Physical land use and climate changes are being simulated with watershed and hydrodynamic models. Landsat derived National Land Cover Data in 1992 and 2001 is being used as model input for the watershed model. The Prescott Spatial Growth Model is being used to project future land use changes to 2030 and 2050 (Estes et al., 2010).

The Loading Simulation Program in C++ (LSPC) model (U.S. EPA) was used for simulating hydrology and sediments at the watershed scale (Bicknell et al., 1996). The model outputs provide data on changes in flow, temperature, sediments, and general water quality for the rivers discharging into the Mobile Bay estuary. The watershed model results are input for a hydrodynamic model, Environmental Fluid Dynamics Code (EFDC), which provides data on changes in temperature, salinity, and sediment concentrations on a grid with four vertical profiles throughout the Bay's aquatic ecosystems (Hamrick 1992; Hamrick and Wu 1997; Park et al., 1995).

Science and student team members involved in Gulf of Mexico coastal research.

Battelle Pacific Northwest National Laboratory collaborates with NSSTC researchers to determine the effect of land use and climate changes on seagrass habitat. Results indicate that a drier future climate will reduce freshwater discharge and mixing in the estuary, which may lead to changes in seagrass species habitat. Rapid urbanization is increasing sediment loads in the estuary and reducing water clarity, which limits available habitat for seagrasses. The research team is working with the Mobile Bay National Estuary Program, Alabama Department of Natural Resources, Weeks Bay Foundation, and industry partners to utilize research results and products to make decisions on seagrass restoration and other priorities.

PEOPLE/ACE

Paul Meyer, Charles Laymon, Joseph Casas, and Gina Wade

The Arctic Collaborative Environment (ACE) project is a new international partnership for information sharing to meet the challenges of addressing the Arctic. The goal of ACE is to create an open source, web-based, multi-national monitoring, analysis, and visualization decision-support system for Arctic environmental assessment, management, and sustainability. ACE was initiated with funding from the U.S. government and is managed by NASA MSFC in a joint venture with the Von Braun Center for Science and Innovation and the Department of Defense through Joint Capability Technology Demonstration funding.

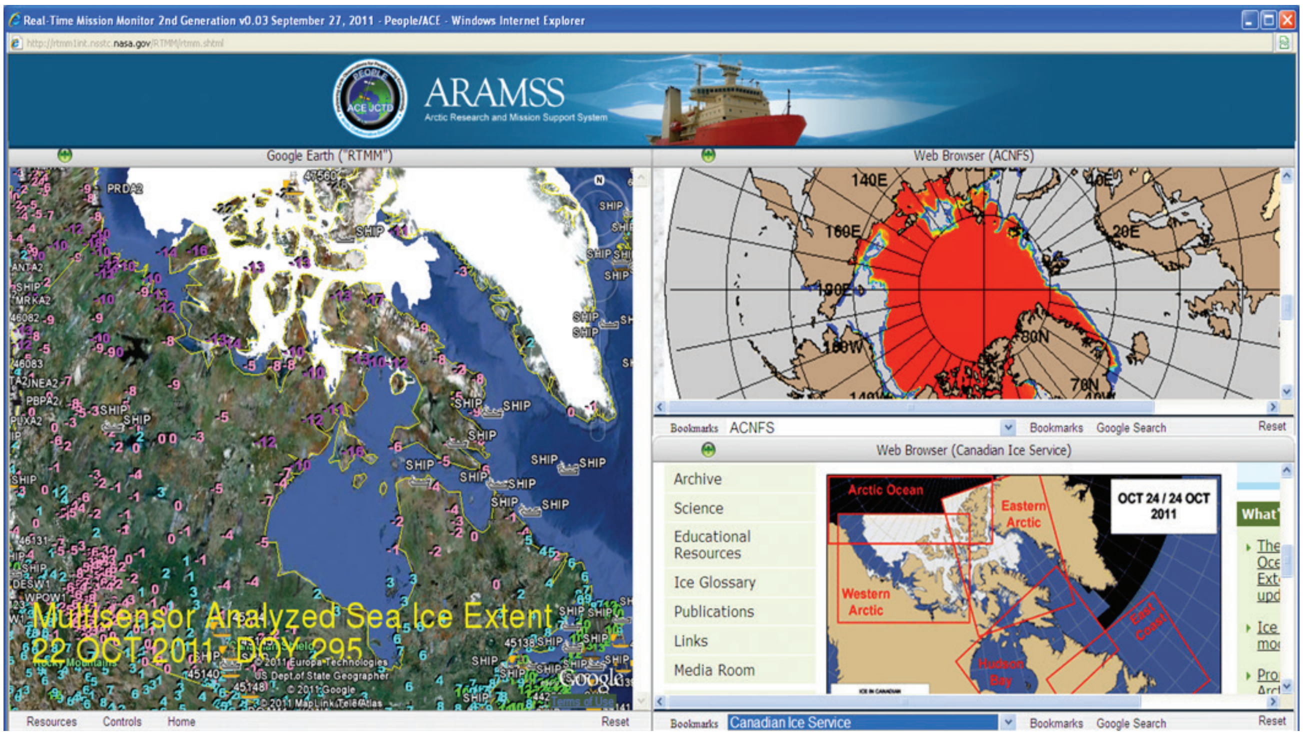
The Earth's ice cover exhibits an enormous influence on global climate through the regulation of energy and moisture exchanges between the ocean, atmosphere, and land; and through the potential of the great ice sheets to raise sea level dramatically. History and projections of global climate suggest that the high-latitude ice-covered regions of the Earth, particularly the Arctic, have high sensitivity to climate change. The polar regions of Earth have been experiencing rapid change. In some parts of the Arctic, wintertime average temperatures have climbed as much as 4 °C since the 1950s, several times greater than the average global pace. Extensive melting and dynamic thinning has been observed off the Greenland ice sheet. Much of the permafrost present for centuries appears to be thawing releasing methane and other gases. The Arctic Basin is ice-free for longer periods each year and on average sea ice is 15 percent thinner than 50 years ago. Taken together, these data suggest a faster-than-expected response to global warming.

Under the auspices of the 2007–2008 International Polar Year (IPY), Arctic nations have made key investments in monitoring the Arctic region to enhance understanding of this rapidly changing region. As a result of the IPY activities, there is strong interest in improving data sets, models, and decision-making tools related to key scientific processes and management of assets of the Arctic region. Deficiencies in these areas contribute to slower than acceptable pace of equipping and training partner nations to address environmental and resource management issues in the Arctic. Further, this results in partnership operational shortfalls and inconsistent regional and national institutionalization/utilization of data products and model outputs. The ACE project is addressing the challenge of establishing international partnerships for information needs at the appropriate spatial and temporal scales. Monitoring and predicting change in sea ice extent and condition and for improved monitoring of real-time changes in the permafrost and the associated release of methane are two high priority topics.

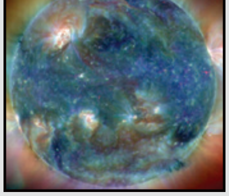
ACE is modeled after SERVIR and the Real Time Mission Monitor (RTMM). SERVIR, features web-based access to satellite imagery, decision-support tools, and interactive visualization capabilities, and puts previously inaccessible information into the hands of scientists, environmental managers, and decision-makers. The Earth observation information is used to address threats related to climate change, biodiversity and extreme events such as flooding, forest fires, and storms. RTMM is a situational awareness tool that integrates satellite, airborne, and surface data sets; weather information; model and forecast outputs; and vehicle state data for field experiment science optimization and operational logistics decision support. Likewise, ACE will enable scientists and educators at partner nations with Arctic interests with improved ability to study the Arctic's response to climate change and to enable project managers and policy implementers better response to a range of issues including transportation and mobility, emergency management, construction of off-shore oil rigs or pipelines, and identification of optimal conditions and routes for Inuit hunting and fishing.

A Science Modeling and System Administration Node is under development and will temporarily be housed at the NSSTC in Huntsville, Alabama. User Requirements and Product Development Working Groups have provided guiding definition to ACE. The team already has several international partners and is working to secure participation of Canada (Canadian Ice Service), Russia, Norway, and other Arctic nations. The ACE team has socialized these activities with the NOAA and the U.S. Coast Guard, to name a few. An alpha-level test was conducted with the U.S. Coast Guard in Alaska in February 2012. The ACE project team has identified a broad set of users including National Navies and Coast Guards; regional, national, and local governments with territorial claims in the Arctic region; Inuit and Aleut tribes and local jurisdictions; commercial shipping; and the arctic science research community. The initial set of common functions executed by these groups include maritime safety; maritime and on-ice search and rescue; Economic Exclusion Zone management; strategic movement; in-situ mobility; infrastructure design and development; coastal zone mapping; hydrographic surveys; environmental management; inter-agency and international cooperation; and scientific research. Based on preliminary inputs from these groups, two topics have emerged as high priorities: sea ice and permafrost.

In late 2012, ACE will conduct an operational demonstration of its developing capabilities. At the conclusion of this activity, the NSSTC Node will be relocated to the National Ice Center in Suitland, MD, which is a collaboration between NOAA, U.S. Navy, and U.S. Coast Guard. The node at the NSSTC will remain the foci for developing and prototyping additional capabilities.



The ACE open-source data exchange tool to address Arctic environmental management and sustainability. Example ACE display is shown with multiple disparate data sets available for intercomparison and analysis.



Heliophysics and Space Weather

Overview

The United States launched its first orbiting satellite, Explorer 1, on February 1958 and with it opened a new window on the environments of space near Earth and beyond. In the years since, NASA's mission to understand the space environments of the Sun and planets has revealed a rich tapestry of natural processes involving electric and magnetic fields in a medium of highly ionized gas, otherwise known as a plasma. NASA's Heliophysics Research Program of the Science Mission Directorate is to understand the origin and nature of solar activity and its effect on the space environment of the Earth. The involved physical processes relate to the formation and evolution of planetary systems everywhere and to the conditions within their atmospheres. As humans extend their reach into space to explore and to make use of its resources, this developing knowledge of the space environment becomes critical for the operation of both robotic and manned systems.

The Heliophysics and Space Weather research being performed at MSFC supports NASA's mission through the conduct of an experimental program of solar and magnetospheric physics research, through theory and modeling, and through the analysis of old and new measurements acquired on the ground and in space. This research seeks to expand our understanding of the basic physical processes shaping the heliospheric space environment and to enable the prediction of its conditions, space weather, for use in protecting the Agency's mission of exploration and utilization of space.

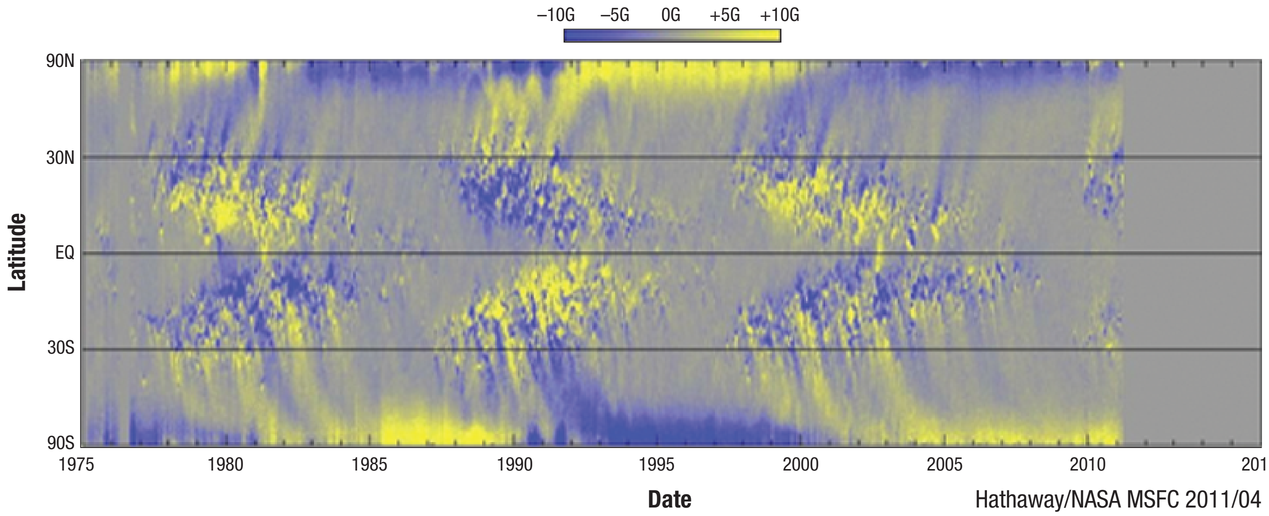
Research is organized into three primary themes: the Sun and the heliosphere, the terrestrial magnetosphere and ionosphere, and space weather. Of primary interest at the Sun is its internal processing of magnetic fields that leads to a periodic cycle of activity and the dynamics of the extended magnetic field into the corona where energy is irregularly released in tremendous eruptions of particle and electromagnetic energy. The response of the Earth's magnetic environment to solar activity is the focus of magnetospheric research. Thermal plasma in the ionosphere and its extension into the magnetosphere play important roles influencing the propagation of waves and the transport of energy and particles through the magnetospheric system. Both of these research areas lead to the bridging activity of space weather where the derived knowledge of processes taking place at the Sun and its extended plasma environment are needed to characterize the climate in space and predict its dynamic conditions or weather.

Study of the Solar Photosphere, Chromosphere, and Corona

Jonathan Cirtain, Mitzi Adams, David Hathaway, Ron Moore, Ed West, and Amy Winebarger

The Hinode observatory ("sunrise" in Japanese) is a three-instrument observatory in a sun-synchronous polar orbit. The three instruments collect imaging and spectroscopic data on the solar photosphere magnetic field, the ultraviolet chromosphere, and the extreme-ultraviolet and x-ray corona. Hinode is providing cutting-edge understanding of the interaction between convection and the solar-magnetic fields, helping reveal the source of high-energy particles and hard X-rays in large solar flares, and creating major new insights into the mechanisms that heat the solar atmosphere and produce the UV and x-ray emission.

By the early Nineties it was apparent that vector field measurements in the upper chromosphere and transition region were needed, even though this was viewed as a difficult if not impossible task. The Ultraviolet Spectrometer and Polarimeter (UVSP) instrument on board the Solar Maximum Mission (SMM, 1980) was the first space-based instrument to try to map and understand polarization in the transition region. The UVSP observations of MgII suggested that this line was a potential candidate for the upper chromosphere. Although UVSP attempted measurements of the CIV line, poor photon statistics and the loss of the ability to observe the CIV lines early in the mission resulted in a failure to produce convincing evidence that this measurement was possible. While the scientific value of these observations has been acknowledged, the measurements are difficult because they are in the vacuum ultraviolet (VUV) wavelength range where the optical efficiency of standard optics is low. The SUMI sounding rocket program was born from development programs to improve the overall wavelength and polarization efficiency for the CIV (155 nm) measurement while including the MgII measurements in its observing program. While these development programs were successful, accommodating the dual-line instrument in a sounding rocket envelope has been challenging.



The Sun's magnetic field averaged over longitude for each 27-day rotation of the Sun since 1975. Magnetic field emerges from the solar interior in sunspots located in two butterfly shaped bands on either side of the equator. These magnetic fields are transported in both longitude (not shown here) and latitude across the surface of the Sun. This transport reverses the Sun's polar magnetic fields and helps predict future sunspot cycle activity.

CIV has always been the driving force in the development of SUMI. This line is formed in the relatively thin transition region which simplifies its interpretation. However the magnetic sensitivity, $\lambda^2 g$, where λ is the wavelength and g is the Landé g factor, is low compared to lines in the visible and infrared. Table 1 compares the SUMI lines with lines that are being used in photospheric and low chromospheric magnetographs. Certainly the results from SUMI will impact future missions as scientist try to understand the 3-D structure of the Sun's magnetic field.

The SUMI development began as a set of programs to improve the efficiency of polarization measurements in the ultraviolet. As demonstrated by Table 1, polarization measurements in the ultraviolet require high spectral resolution due to the small magnetic sensitivity. Higher spectral resolution is required to resolve the Zeeman splitting. Therefore, to reduce the length of the telescope allowing a longer spectrograph (with improved resolution), a cold mirror Ritchey-Chretien telescope was chosen over a traditional Gregorian telescope. To improve the photon and polarization efficiency, a MgF2 double Wollaston polarizer was selected as the analyzer so that simultaneous measurements of orthogonal polarizations could be made. Ideally, full Stokes polarization measurements, [I, Q, U, V], should be made but photon statistics make CIV linear polarization measurements (Q and U) difficult with the limited observing time of a sounding rocket.

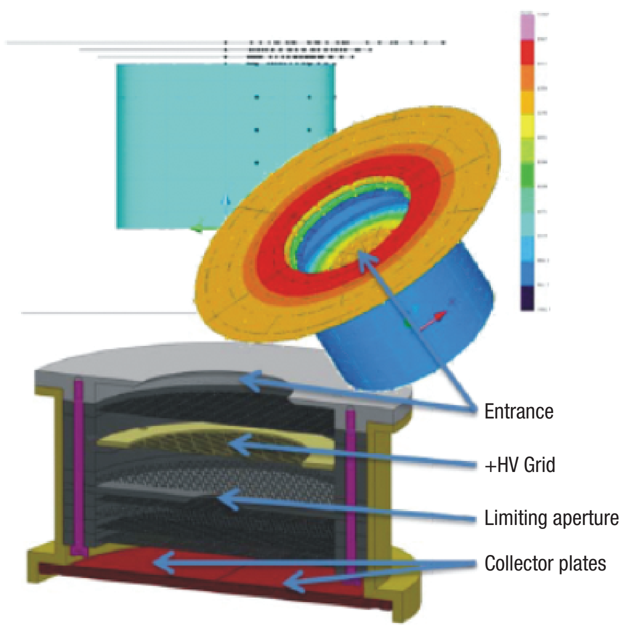
The Sun's global magnetic field is produced by the emergence at the surface of magnetic loops in sunspots. These magnetic field elements are transported across the solar surface by turbulent plasma flows. This global magnetic field serves as the ultimate source of space weather.

Table 1. Comparison of candidate lines that are being developed for current and future space-based photospheric, chromospheric and transition region vector magnetic field measurements.

Spectral lines	λ (nm)	g	$\lambda^2 \times g \times 10^4$	Height (km)	Remarks
Transition Region					
CIV	155.0	1.2	2.9	2,200	SUMI
MgII	280.0	1.2	9.4	2,000	SUMI
Chromosphere					
CaII	854.2	1.1	80.2	1,319	
NaI	589.5	1.3	45.1	700	
Photosphere					
FeI	630.2	2.5	99.2	250	Hinode

The evolution of this field determines the coronal and solar wind structures through which disturbances must propagate and in which solar energetic particles are accelerated and propagate. Producing magnetic maps which best represent the actual field configuration at any instant requires measuring the magnetic field over the observed hemisphere and determining the flows that transport this magnetic field. Within the Heliophysics and Space Weather group we have the capability to acquire the magnetic field from satellite observations, determine the detailed structure of the flows that transport the field, and predict future field configurations. Short-term (hours to weeks) predictions provide key information concerning the Sun's explosive events—flares and coronal mass ejections. Long-term (months to years) predictions provide estimates of the level of solar activity over each 11-year sunspot cycle.

Several instrumentation programs are in various stages of development in the Heliophysics group. The Solar Wind Electrons, Alphas, and Protons (SWEAP) instrument on the Solar Probe + mission will be tested at MSFC, and components of the Faraday cup will be fabricated by MSFC. The Faraday cup will be mounted near the sun shade for the spacecraft and must operate at temperatures in excess of 1,500 K during close approach to the Sun. Technology development at MSFC has enabled new composite materials for this instrument.

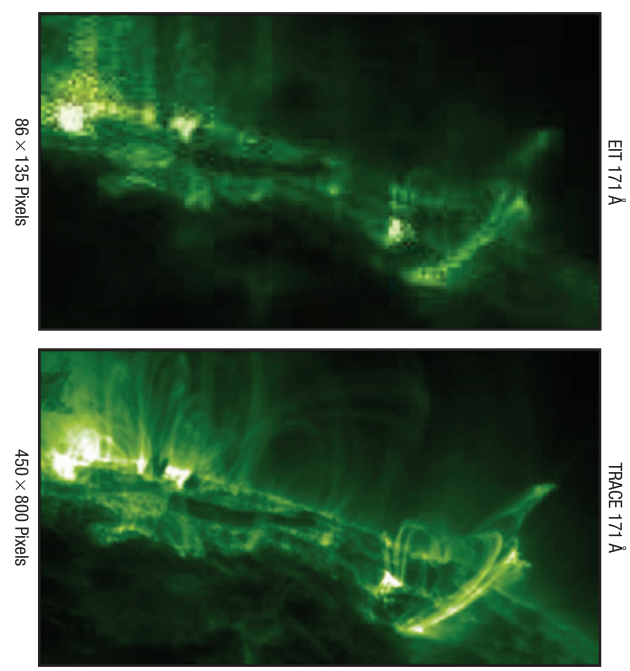


The SWEAP Faraday Cup will be mounted on the front of the spacecraft and will have a direct view of the Sun during 20+ solar encounters. The instrument will be performance and survivability tested at MSFC. Launch is expected in 2018.

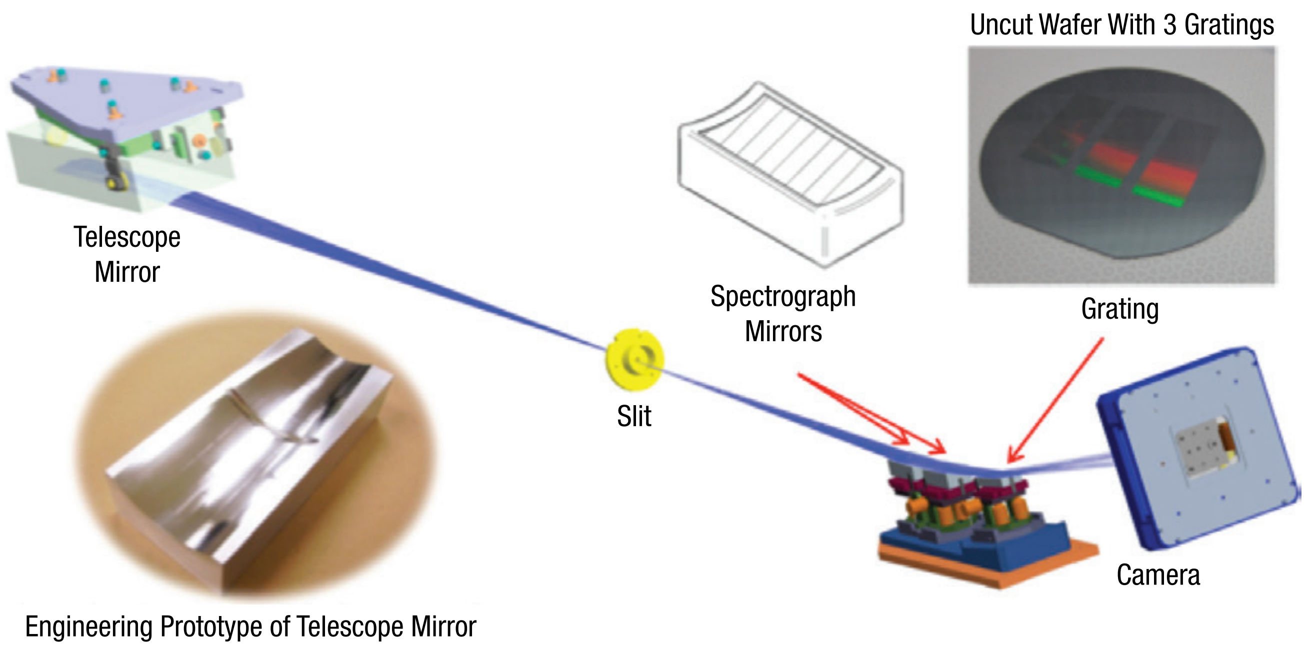
The High-resolution Coronal Imager (Hi-C) is an extreme ultra-violet imaging telescope designed to produce the highest spatially resolved images of the solar million-degree corona to date. Hi-C will be 10 times higher resolution than the TRACE and AIA instruments, and will launch in 2012. The camera and the mirror systems will be built by MSFC, and the full payload is being developed in partnership with the Harvard-Smithsonian Center for Astrophysics.

The Marshall Grazing Incidence X-ray Spectrograph (MaGIXS) is a stigmatic grazing-incidence spectrograph experiment designed to observe spatially resolved soft x-ray spectra of the solar corona for the first time. The instrument consists of a Wolter Type-1 sector telescope and a slit spectrograph. The telescope mirror pair is a monolithic Zerodur mirror with both the parabolic and hyperbolic surfaces. The spectrograph comprises a pair of paraboloid mirrors acting as a collimator and re-imaging mirror, and a planar varied-line-space grating, with reflective surfaces operate at a graze angle of 2 degrees. This produces a flat spectrum on a detector covering a wavelength range of 0.6 to 2.4 nm (0.5 to 2.0 keV). The design achieves 1.5-pm spectral resolution and 5-arcsec spatial resolution (2.5-arcsec/pixel) over an 8-arcminute long slit.

The spectrograph is currently being fabricated as a laboratory prototype. A flight candidate telescope mirror is also under development. The entire experiment is designed to fit a NASA sounding rocket payload, and is being proposed for flight.



The value of improved spatial resolution is shown by comparing simultaneous images from EIT (2.5 arsec pixels) and TRACE (0.5 arcsec pixels). The Hi-C spatial resolution will be a similar improvement.



Telescope	
Type	Wolter Type-I Sector
Mirror Substrate	Zerodur
Graze Angle	1.0°
Radius of Curvature of Aperture	75 mm
Sector Size	34°
Aperture (Geometric Area)	96 mm^2
Effective Focal Length	1,090 mm

Slit	
Width × Length	13.5 µm × 2.6 mm (2.5 in × 8.0 ft)

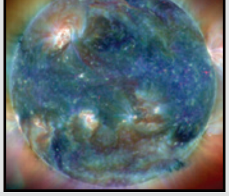
Spectrograph Specifications	
Passband	6.0 – 23.0 Å (0.5 – 2.0 keV)
Resolution	20 mÅ (wavelength) 5 arcsec (spatial)
Plate scale	10 mÅ/pixel (wavelength) 2.5 arcsec (spatial)

Spectrograph Specifications	
Type	Parabolic sector mirrors (matched pair)
Graze Angle	2.0°
Size	45 × 25 mm (tangential × saggital)
Focal Length	597 mm
Curvature	40.6 mm (sagittal radius)

Grating	
Type	Planar Varied Line Space
Size	64 × 25 mm (tangential × saggital)
Material	Silicon wafer
Ruling	2149–2709 lines/mm UV photolithography + ion etched

Camera	
Detector	Back-illuminated CCD
Pixel size	135 µm
Format	2048 × 512

Shown in the upper section of the figure is the optical layout of MaGIXS. The telescope is a sector of a Wolter Type-I telescope, matching the beam shape and F number of the spectrograph. The spectrograph mirrors are a pair of identical paraboloid sectors, acting as a collimator and reimaging mirror respectively. The grating is a planar VLS design with 2,400 lines/mm central groove density. The lower portion of the Figure provide the instrument technical details.



Space Weather Data Mining

Linda Krause

As the demand for space weather forecasting models grows, so does the need for accurate models of the near-Earth space environment. Space-based and ground-based data sources from all over the world are used to construct these models. However, with such a large amount of data comes a need to organize those data in a way such that trends within the data are easily discernible. This can be tricky due to the interaction between physical processes that lead to partial correlation of variables or multiple interacting sources of causality.

With the suite of Exploratory Data Analysis (EDA) data mining codes available at MSFC, we have the capability to analyze large, complex data sets and quantitatively identify fundamentally independent effects from consequential or derived effects. We have used these techniques to examine the accuracy of ionospheric climate models with respect to trends in ionospheric parameters and space weather effects. In particular, we have employed these techniques to:

1. Discern the underlying "latent" variables which share common sources of causality
2. Establish a new set of basis vectors by computing Empirical Orthogonal Functions (EOFs) which represent the maximum amount of variance for each principal component.

The analysis of seven days of 15-minute Jicamarca ionospheric density profiles were analyzed to derive the fundamental altitude profile shape (EOF Mode 1) and the first order correction (EOF Mode 2) illustrated in the left-most graph of Figure 1. The corresponding time series of the EOF Mode coefficients appears on the right, where we can see the day-night modulation in Mode 1 and the importance of the first-order correction near sunrise and sunset. Figure 2 shows a comparison of the original ionospheric data set on the left, where the color bars represent the plasma density in standardized units, and the reconstructed data set on the left, effectively resulting in an 82-to-3 compression ratio. Figure 3 illustrates the residuals when the reconstructed ionosphere is subtracted from the original. Figure 4 shows how the residuals do not depend systematically on the plasma frequency/density (top plot), but there is a distinct trend for the residuals to peak during times near sunrise and sunset. This indicates that perhaps it would be beneficial to adopt an optimization technique in which the baseline ionosphere can be represented with a few principal components, and the twilight hours require more sophisticated representation to maximize accuracy while minimizing the model's computational cost.

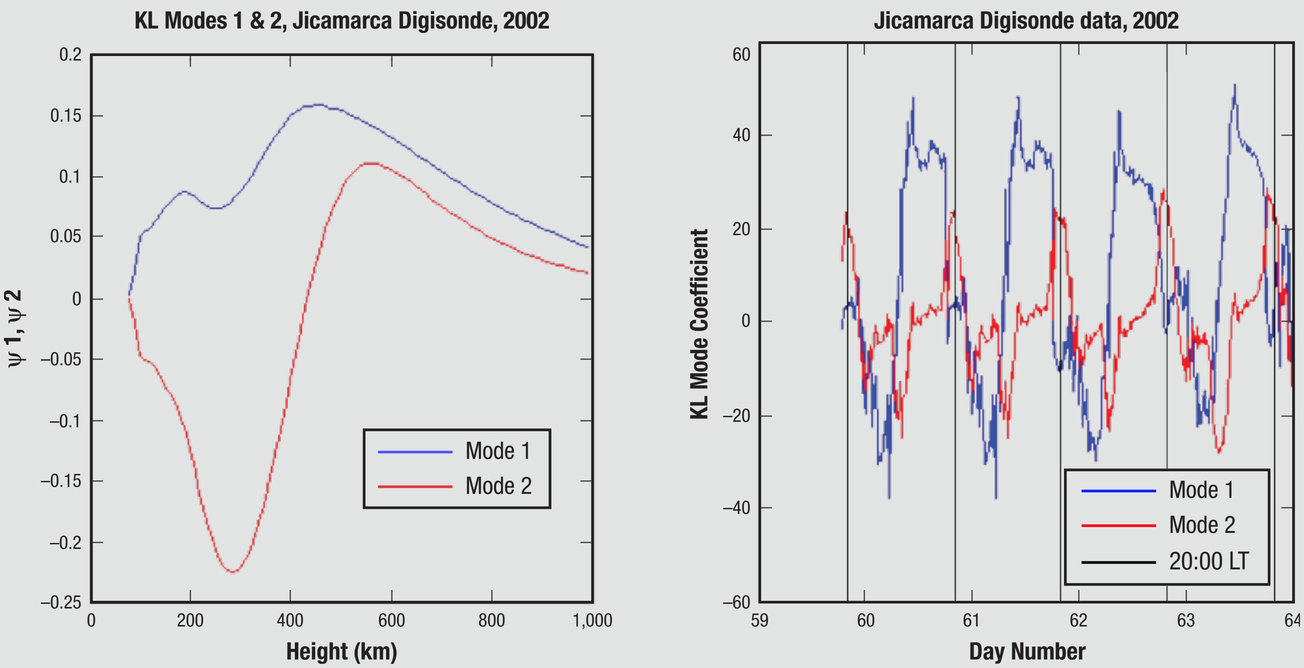


Figure 1

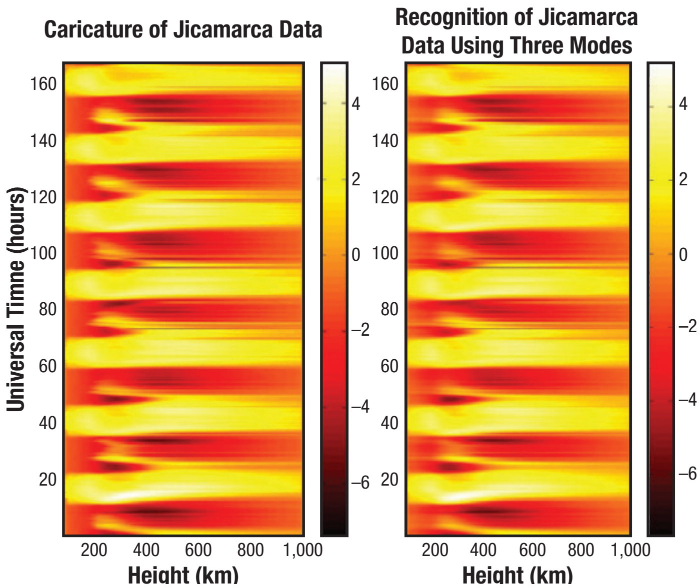


Figure 2

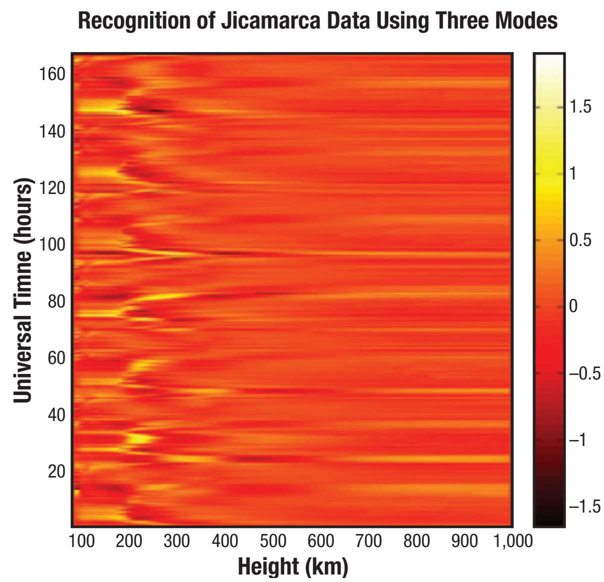


Figure 3

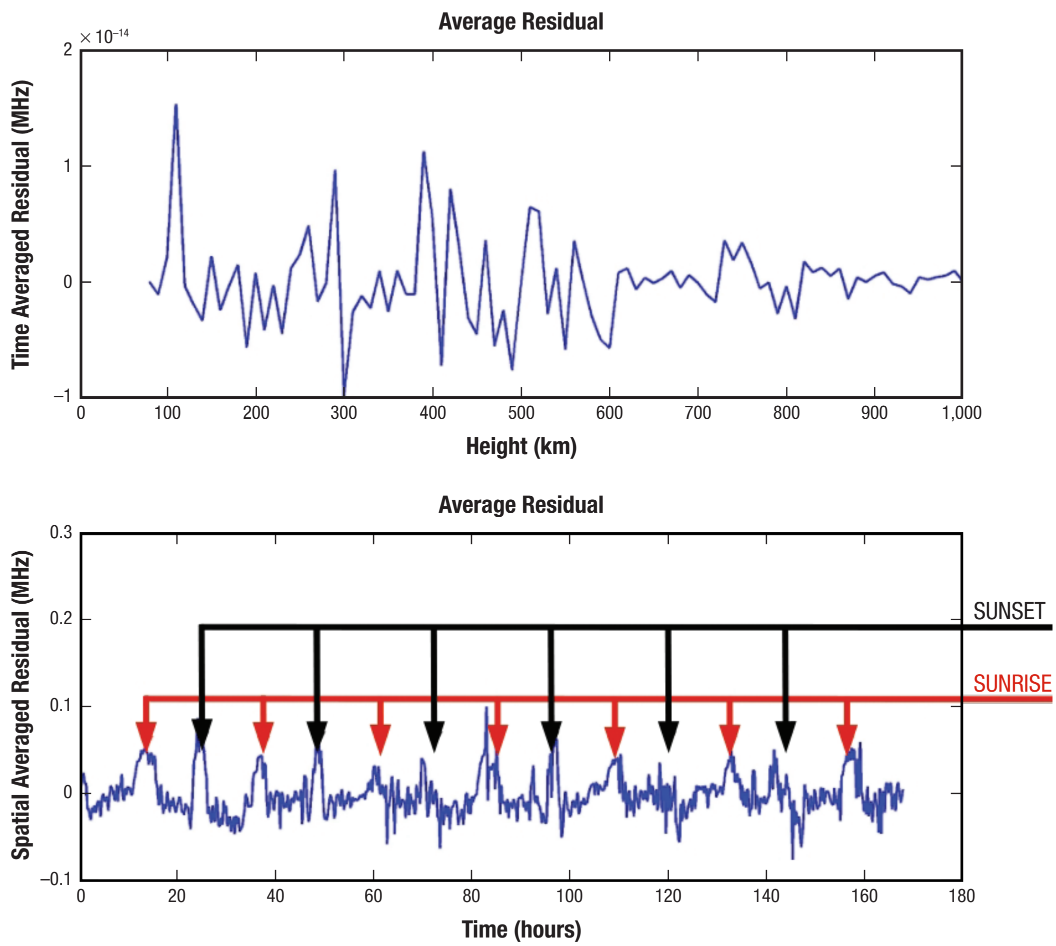
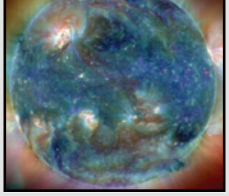


Figure 4



Space Radiation Environment and Effects

Nasser Barghouty and Mark Christl

The Cosmic-ray group at MSFC is actively engaged in a number of basic and applied research projects of direct relevance to space radiation, from protection to characterization to forecasting.

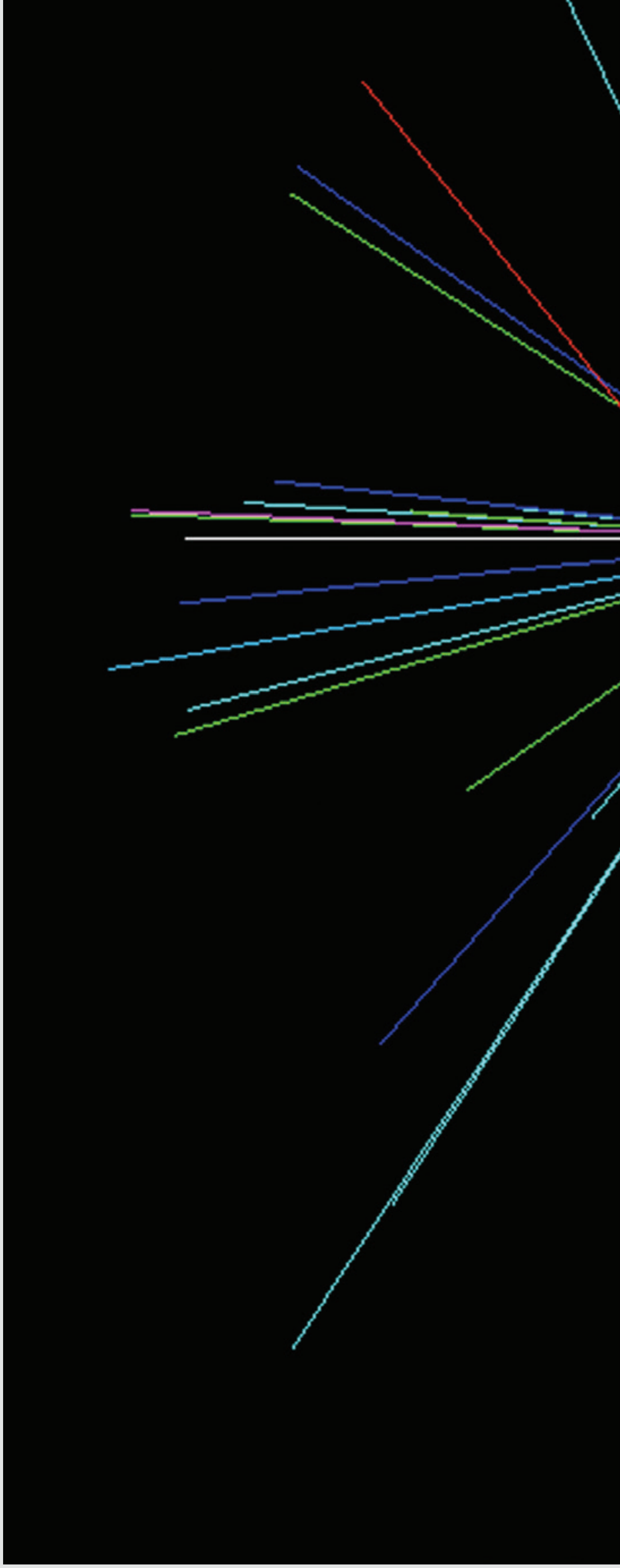
The group collaborates with other NASA centers, academia, and the private sector to design, model, and fabricate radiation shielding materials. The group is also currently helping to develop a comprehensive database of current and emerging radiation shielding materials including their structural and mechanical attributes, as well as radiation shielding properties.

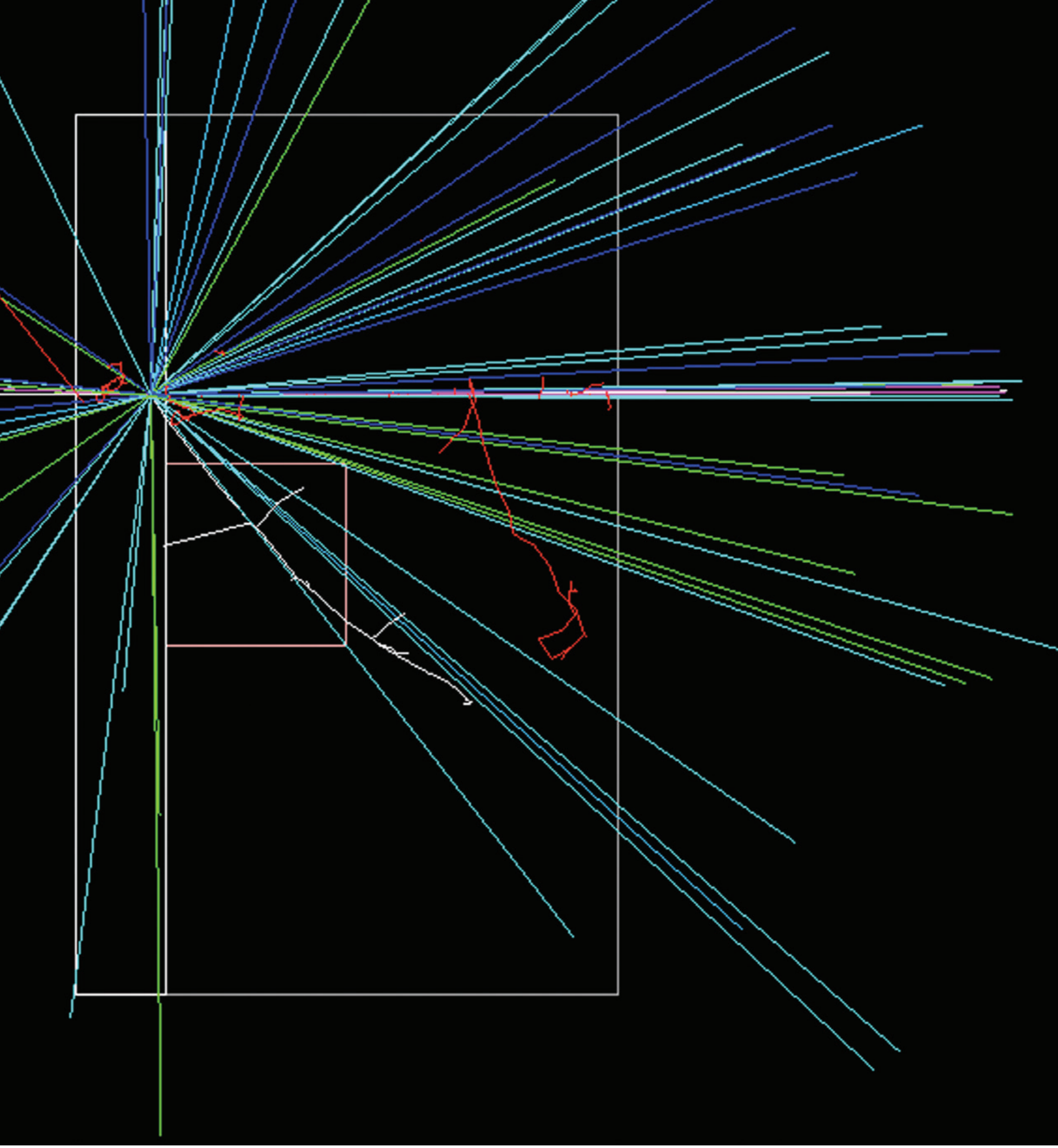
The group has collaborated with the Institute for Space and Defense Electronics (ISDE) at Vanderbilt University to develop the next generation of the widely used CREME96 model, a radiation effects on electronics simulation toolkit called Crème <https://creme.isde.vanderbilt.edu/>. Crème is the current state-of-the art tool for SEE rate prediction.

The group collaborates with the Space Radiation Analysis Group (SRAG) at Johnson Space Center <http://srag.jsc.nasa.gov/> and the Center for Space Plasma and Aeronomic Research (CSPAR) at The University of Alabama in Huntsville in the development of a state-of-the-art "all-clear" forecast tool, Mag4 <http://cspar.uah.edu/mag4/> for solar flares, coronal mass ejections, and solar energetic particle events based on near real-time measurements of the solar surface magnetic field. Mag4 is a first of its kind forecasting tool that is able to translate magnetic field patterns on the solar surface into operational probability measures.

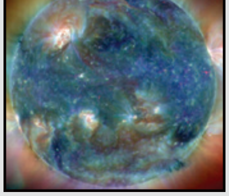
The group in collaboration with various NASA centers is helping to develop compact, low-mass, and low-power, neutron and charged particle detectors and telescopes suitable for radiation-monitoring and crew protection in space. To support these various efforts for space radiation environment characterization, its effects on crew and systems as well as its detection and monitoring, the group has a strong radiation-transport simulations capabilities based both on 3D Monte Carlo-type simulations (Geant4) as well as semi-analytical and deterministic models and codes.

The group is also collaborating with Oak Ridge National Laboratory to measure and model the potential sputtering yields of highly-charged ions impacting lunar stimulants. The potential sputtering yields of solar-wind heavy ions on oxides are poorly known but have only recently been suspected to be an important contributor to solar-wind weathering effects.





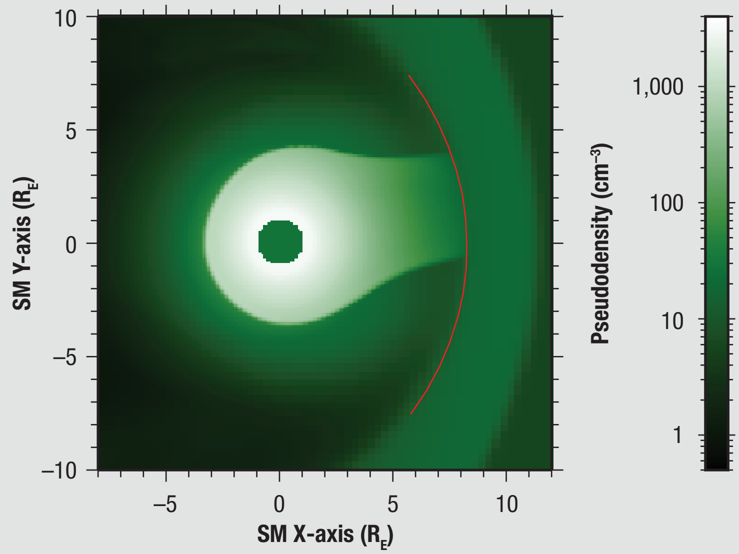
A Geant4 simulation of a ‘star event’ in a tungsten-silicon layer induced by an energetic heavy ion. Products of the nuclear event can be seen traversing a sensitive area (the smaller square in between the two layers) thought to be well protected, which can induce a number of adverse affects in the micro-electronic functions of the layer.

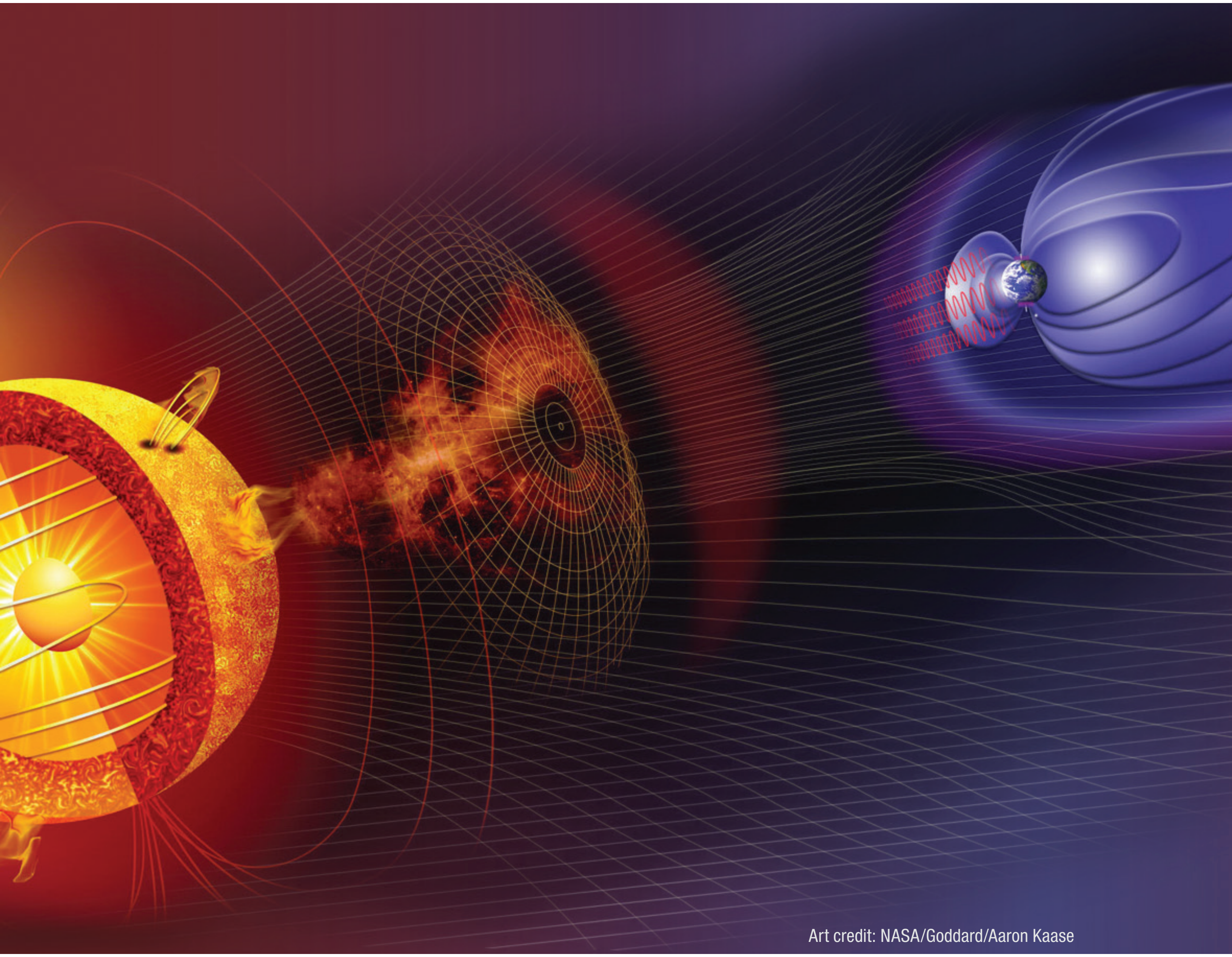


Plasmasphere Capabilities and Research

Dennis Gallagher

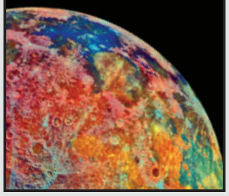
The plasmasphere is a toroidal shaped region surrounding the Earth that is the extension of the ionosphere at sub-auroral latitudes. The region is characterized by ionized gases, or plasmas, that are of much higher densities and lower energies than the radiation belts and other plasmas in near-Earth space. As a result of its properties, plasmaspheric plasma exerts a strong influence over the transport of mass and energy through space near Earth, consequently its behavior is critical to understand if we are ever to predict and protect ourselves and our machines from the damaging high-energy particles that permeate this region. The plasmasphere has been a topic of scientific research and experimental investigation at MSFC for over 35 years. This research has resulted in the development of widely used empirical and dynamic models of the plasmasphere. The empirical model characterizes typical density distributions as a function of conditions. The dynamic model describes time varying conditions as a function of externally imposed electric and magnetic fields and can be incorporated into models that describe the behavior of higher energy particle populations. Recent research has focused on the details of plasmaspheric dynamics as it affects coupling between the Sun's and Earth's magnetic fields and the coupling between near-Earth space and the ionosphere. The figure shows modeled plasmaspheric and magnetosheath densities in green, where the red line corresponds to the inner boundary of the region where Sun-Earth magnetic field coupling takes place. The magnetosheath densities and boundary are provided by the University of Michigan Bats-R-Us model available at the NASA GSFC Coordinated Community Modeling Center. Dense plasmaspheric plasma is drawn by global electric fields toward this boundary during storm times. Not yet known is whether this thermal plasma is lost into interplanetary space through the boundary where coupling between the Sun's and Earth's magnetic field lines takes place or the plasma is recirculated within the magnetosphere, perhaps to be energized and later precipitated into the atmosphere at high latitude to form auroral displays.





Earth's Magnetosphere and Plasmashere

A magnetosphere is that area of space, around a planet, that is controlled by the planet's magnetic field. The Earth's magnetosphere is a highly dynamic structure that responds dramatically to solar variations. The shape of the Earth's magnetosphere is the direct result of being blasted by solar wind. The solar wind compresses its sunward side to a distance of only 6 to 10 times the radius of the Earth. A supersonic shock wave is created sunward of Earth called the bow shock. Most of the solar wind particles are heated and slowed at the bow shock and detour around the Earth in the Magnetosheath. The solar wind drags out the night-side magnetosphere to possibly 1,000 times Earth's radius; its exact length is not known. Residing within the magnetosphere are the Van Allen Radiation Belts and the Plasmasphere.



Planetary Science

Overview

Planetary science at NASA is at the leading edge of new knowledge of our Solar System's content, origin, evolution and the potential for life elsewhere. NASA planetary science is engaged in one of the oldest of scientific pursuits: the observation and discovery of our solar system's planetary objects, using an extraordinary complement of flybys, orbiters, landers, and rovers, and an eye on returning samples from planetary bodies to state-of-the-art NASA-supported laboratories. MSFC planetary scientists are active in research and integral to projects led at the Center. Our research areas of expertise include planetary sample analysis, planetary interior modeling, and planetary atmosphere observations.

We serve as Project Scientists for the Lunar Mapping and Modeling Project (LMMP) and Robotic Lunar Lander Development Project (RLLD). LMMP is building a suite of tools and data products that support human lunar exploration activities, scientific analyses, landing site selection for robotic missions, including NASA and commercial missions, and for education and public outreach. The RLLD designs small lunar robotic landers for exploration and science missions to the Moon, Mercury, and near-Earth asteroids. We provide formal and informal scientific guidance on an as-needed basis to program-level activities such as Lunar Quest and Lunar Simulants, internal and external projects and proposals, and other related activities such as the Small Business Innovation Research in Lunar Science Instruments and Technology managed at MSFC.

We are actively involved as science team members on multiple current missions and instruments, including the Mars Exploration Rovers, the Cassini mission to Saturn, and the Gravity Recovery and Interior Laboratory (GRAIL) mission to the Moon, and have leading roles in new mission proposals.

We operate two unique laboratory facilities (the Dusty Plasma Lab and the MSFC Noble-Gas Research Lab) and we are developing a competitively-selected, nearly $1M project through the NASA Planetary Instrument Definition and Development Program (PIDDP) to begin development of the Potassium-Argon Laser Experiments (KArLE). The proposed KArLE instrument would be the first ever to yield absolute ages of rocks in situ rather than on returned samples, and is targeted for suitability on future planetary lander or rover missions to Mars, the Moon, and asteroids.

Human Mission Planning, Operations, and Field Testing

Barbara Cohen

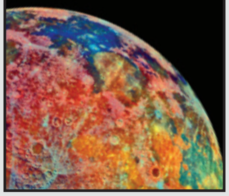
Current NASA Human Exploration planning is capability-driven, following a "flexible path" of missions with increasing capability into the inner solar system. It includes the Moon, near-Earth asteroids, and Mars, where humans will orbit planets with deep gravity wells, rendezvous with small bodies, and telerobotically explore and sample planetary surfaces. The planetary science group at MSFC provides scientific and mission-based expertise for mission planning and operations for these diverse planetary surface environments, including the Moon, Mars, and near-Earth asteroids.

MSFC Planetary scientists provide Agency expertise in planetary surface environments and mission operations. We contributed to the NASA Natural Environments Definition Document/Design Reference documents that define engineering boundary conditions for the Moon. We serve on internal NASA committees such as NASA's Optimizing Science and Exploration Working Group (OSEWG). We serve on Agency-wide teams to refine design reference missions and concepts of operation for human deep space exploration missions to Earth-Moon L2, near-Earth asteroids, and the Martian moons Phobos and Deimos in support of the ongoing Human Spaceflight Architecture Team (HAT).

Since 2009, MSFC scientists have been part of the D-RATS science team, providing geological context and traverse protocols for crew activities, as well as being part of the science backroom to integrate science observations with mission operations. The science backroom has been based both on the Apollo and Mars Exploration Rover (MER) operation models, where traverse activities are understood in real time, using suit-mounted and rover-based video streams and data. These models emphasize the need for scientists to analyze and interpret information on timescales that are unusually short (minutes to hours) by remote sensing or robotic mission standards, which presented significant challenges. Nonetheless, test metrics show that real-time data return to the backroom allows for both greatly improved field operations and scientific return.

Continued collaboration between science, engineering, and operations is crucial for future expeditions, and MSFC planetary scientists are here to support these efforts.

Dr. Barbara Cohen (second from left) served as the Science Lead in the remote science backroom at the European Space Agency for Desert-RATS 2011.



MSFC Noble-Gas Research Laboratory

Barbara Cohen

The history of a planet is told through its rocks – how the minerals are put together, what the minerals are made of, and when the rocks were formed. We use multiple analysis techniques to understand the formation, modification, and age of planetary materials to learn about their parent planets. Sample analysis of this type is well-aligned with the priorities for scientific research and analysis in the Planetary Science Division of NASA and multiple future missions are poised to provide new sample-analysis opportunities.

The MSFC Planetary group maintains our own facilities for petrographic study and imaging with three state-of-the-art Olympus microscopes and two digital cameras (2 and 12 MPx). We collaborate with other groups for sample characterization with microbeam analyses, including Washington University in St. Louis (electron microprobe and SIMS), Oregon State University (electron microprobe), National Museum of Natural History (cathodoluminescence, TOF-SIMS), and NASA Johnson Space Flight Center (TEM, FIB).

The centerpiece of the MSFC facility is the MSFC Noble Gas Research Laboratory (MNGRL), a unique facility within NASA. Noble-gas isotopes are a well-established technique for providing detailed temperature-time histories of rocks and meteorites. In the MNGRL lab we use Ar-Ar and I-Xe radioactive dating to find the formation age of rocks and meteorites, and Ar/Kr/Ne cosmic-ray exposure ages to understand when the meteorites were launched from their parent planets.

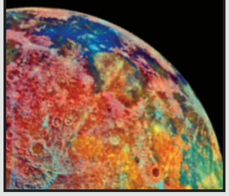
The MNGRL laboratory consists of a Nu Noblesse magnetic sector mass spectrometer with a high-voltage Nier source for high-precision isotope ratio measurements, fitted with four discrete dynode ion-counting multipliers and a Faraday cup for simultaneous counting of up to five isotopes of Ne, Ar, Kr, and Xe. The Noblesse is one of the most advanced commercially available instruments, featuring a mass resolution of 3000 and ^{40}Ar sensitivity of 6.25×10^{19} cps/mol on the multipliers. An ultra-high vacuum (UHV) noble gas extraction system, standard gas mixture pipettes, and a diode laser system with confocal optics and two-color infrared pyrometer, which allows uniform heating of the samples and enables precise temperature determination for thermochronometry and diffusion studies.

The MNGRL lab was designed to study diverse problems in planetary science. Current projects include:

1. The early impact history of the Moon through noble-gas dating of impact-melt rocks contained in lunar meteorites and Apollo breccias
2. The impact history of the asteroid belt by examination of meteorite breccias from large main-belt asteroids
3. Age limits on terrestrial impact craters
4. Ages and thermal history of unusual meteorites.

We fund the MNGRL lab and scientific projects with a diverse and sustainable portfolio of research and analysis funding.

The MSFC Noble-Gas Research Laboratory features an ultrahigh vacuum laser extraction line coupled to a multicollector noble-gas mass spectrometer for analysis of planetary microsamples.



Planetary Surface Geophysics

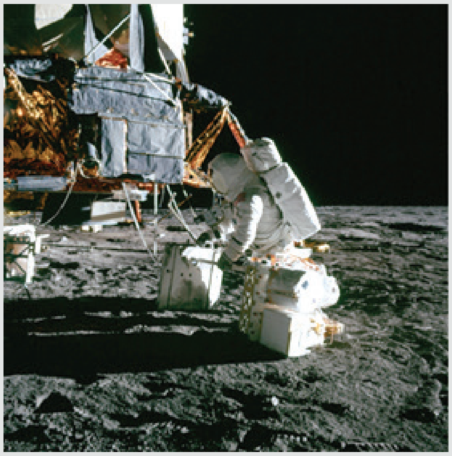
Renee Weber

The Moon has been the cornerstone of our understanding of terrestrial planet formation and early evolution since the Apollo investigations 40 years ago. Geochemical studies of returned samples combined with geophysical experiments such as laser ranging, magnetic induction, heat flow, gravity, and seismology have all contributed to the currently accepted large impact formation and subsequent magma ocean differentiation model of the Moon's earliest history. This paradigm has successfully illuminated our understanding of early planetary evolution for decades.

Of all the bodies in the solar system, the Moon is uniquely accessible for both orbit- and ground-based geophysical studies, and the recent increase in both domestic and international lunar missions emphasizes this fact. The geophysical experiments deployed on the lunar surface during Apollo remain the benchmark for ground-based studies on other planets. As such, ongoing analysis of this unique data set continues to yield new information relevant to the Moon's formation and evolution, and encourages the development of data analysis techniques that can be applied to future planetary geophysical data.

Our work focuses on the Apollo seismic data. The Apollo Passive Seismic Experiment consisted of a network of four seismometers deployed on the lunar surface between 1969 and 1972. Data from these instruments were recorded continuously until late 1977. Several types of seismic signals were recorded, including natural impacts (meteoroids), artificial impacts (booster rockets from the Apollo spacecraft, and the landers themselves), shallow moonquakes (natural events occurring in the upper 50 to 220 km of the Moon), and deep moonquakes (natural events occurring between 700 and 1000 km depth). Recently, we performed an analysis of the deep moonquake data to identify seismic energy reflecting off the Moon's core, and used this information to confirm the presence of solid, molten, and partially molten layers. The size, composition, and present state of the layers of the lunar interior are relevant to many topics concerning the formation and early evolution of the Moon. Using the core as an example, its size acts as a constraint in impact formation models. Its composition is used to infer the origin of present-day remnant magnetization observed in lunar samples (e.g. an iron core may once have provided the early dynamo necessary to support magnetic field generation). Its current state (molten vs. solid) is relevant to thermal evolution models.

Although general models of the processes that contributed to the formation of the present-day lunar interior are robust, details such as the fate of the gravitationally unstable stratification in the mantle, the origin and depth of lateral inhomogeneities, and the volatile content of the mantle remain controversial. Advancing our understanding of the Moon's interior is critical for addressing these details. The Moon's lack of Earth-like plate tectonics means that a record of early planetary differentiation has been preserved. With that in mind, future ground-based missions can build on the legacy of Apollo by designing instruments capable of addressing deficiencies in the existing lunar data.

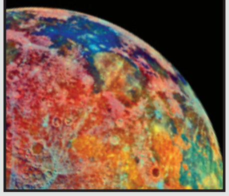


Apollo 12 astronaut Alan Bean unloads the Apollo Lunar Surface Experiments Package from the Lunar Module. Analyses of data returned by these instruments are still ongoing, and provide invaluable insight into our knowledge of the Moon's formation and evolution.

Future surface geophysical experiments can build upon Apollo's legacy to help fill in the gaps in our understanding of the Moon's interior.


Art credit: Hernán Cañellas. Source: Renee C. Weber, NASA

The lunar core is about 60 percent liquid by volume, according to a new study by MSFC's Renee Weber.



Planetary Atmospheres

Mian Abbas, Andre LeClair, and Dragana Tanksosic

Infrared Spectroscopy of Planetary Atmospheres

Infrared Radiative Transfer and Analytical Retrieval Inversion Programs

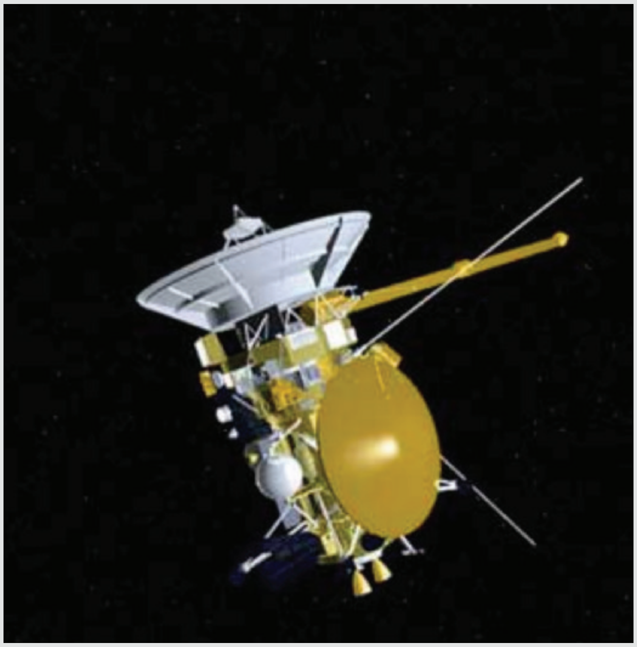
These programs have been developed over many years for remote sensing of the planetary atmosphere, with application in particular to Mars, Jupiter, Saturn and its largest satellite Titan, Uranus, and Neptune, as well as Earth. These programs have been employed for several NASA Earth and planetary atmospheric infrared spectroscopy programs with ground-based, balloon-borne instruments, as well as on Space Shuttle, and other spacecraft platforms.

Atmospheric Thermal Structure and Composition of Saturn and Titan by Cassini Infrared Observations

As a co-investigator on the Infrared instrument on the NASA-International Cassini Mission, we are focusing on infrared observation of Saturn and its largest moon with a chemically rich atmosphere Titan. The broad general objectives of the Cassini mission are exploration of the Saturn system for investigations of the origin, formation, and evolution of the solar system.

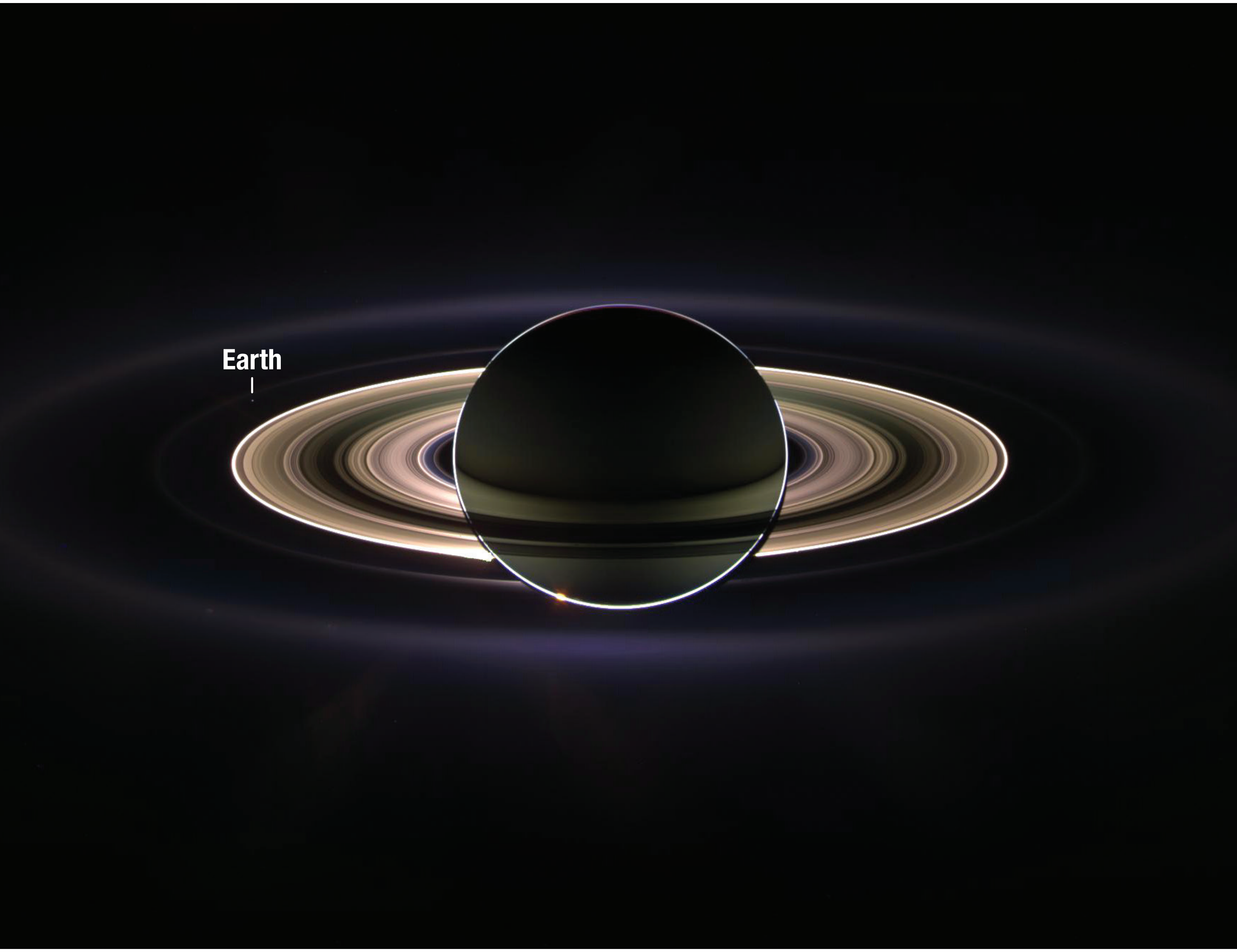
The solar system is believed to be formed in a gravitationally collapsing giant interstellar cloud of gas and dust, or proto-solar nebula, with the proto-sun formed at the core and the planets in the surrounding disc. Two current models of formation are:

1. Core accretion model: agglomeration of dust grains into pebbles, to rocks, to planetesimals, and to the formation of planets in a gaseous disc.
2. Gravitational instability model where the planets are formed directly at various distances from the sun in a proto-stellar disc. None of the two models provide satisfactory explanation of the observations.

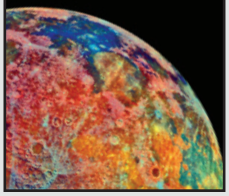


The Cassini Spacecraft was launched in 1997, inserted in Saturn's orbit in July 2004, and has been in a planned orbital tour of Saturn and its satellites since then.

The specific objectives of the infrared observations are to measure atmospheric thermal structure, gas abundances, isotopic ratios for Saturn/Titan, wind speeds and cloud structure, Saturn's rings and its satellites. Our current focus is on analyzing the incoming infrared observations by the Cassini instrument (CIRS) for measurements of the global thermal structure and gas distributions of Saturn and Titan.



With giant Saturn hanging in the blackness and sheltering Cassini from the sun's blinding glare, the spacecraft viewed the rings as never before, revealing previously unknown faint rings and even glimpsing its home planet, Earth.



Interstellar and Planetary Dust Grains

Mian Abbas, Dragana Tankosic, and Andre LeClair

Experimental Investigations of the Physical and Optical Properties of Individual Interstellar and Planetary Dust Grains

Dust grains constitute a major component of matter in the universe. About half of all elements in the interstellar medium (ISM) heavier than helium are in the form of dust. Micron/submicron size cosmic dust grains play an important role in physical and dynamical processes in the galaxy, the ISM, and the interplanetary and planetary environments. Knowledge of the physical, optical, and charging properties of the cosmic dust provides valuable information about many issues dealing with the role of dust in astrophysical environments.

Dust in the Interstellar Medium/Cosmic Dust Cycle

Dust particles are formed in astrophysical environments by processes such as stellar outflows and supernovae. Ejected into the ISM, they lead to the formation of diffuse and dense molecular clouds of gas and dust. The gas and dust in the interstellar clouds undergo a variety of complex physical and chemical evolutionary processes leading to the formation of stars and planetary systems, forming a cosmic dust cycle.

Dust in the Interplanetary Medium

The interplanetary dust cloud (IDC) constitutes the dust in the interplanetary medium extending from the inner solar system to the asteroid belt. Zodiacal light is the visible light scattered by dust particles in the IDC. Particles in the IDC spiral towards the Sun (Poynting-Robertson effect) with lifetimes of ~10^4–10^5 years and are evaporated or driven out of the solar system. The sunlight absorbed and re-radiated in the infrared by the dust dominates the sky in the 3–70 mm spectral region.

Dust in the Lunar Environment

Astronauts found the lunar dust to be unexpectedly high in its adhesive characteristics, sticking to the suits, instruments, and the lunar rover. The lunar Surveyor spacecrafts and the Lunar Ejecta and Meteorite Experiment on Apollo 17 indicated the presence of transient dust clouds. A horizon glow over the lunar terminator and high altitude streamers were observed by the astronauts on the Apollo 17 spacecraft. The lunar dust phenomena are attributed to the electrostatic charging of the dust grains by UV photoelectric emissions on the dayside leading to positively charged grains. On the night side, the electron or ion collisions generally lead to negatively charged grains, with electrons dominating the charging process. Secondary electron emission induced by solar wind electrons with sufficiently high energy may produce positively charged grains. Measurements of the optical and physical properties of individual lunar dust grains are required to understand and mitigate the hazardous effects of the lunar dust phenomena.

Dusty Plasma Laboratory

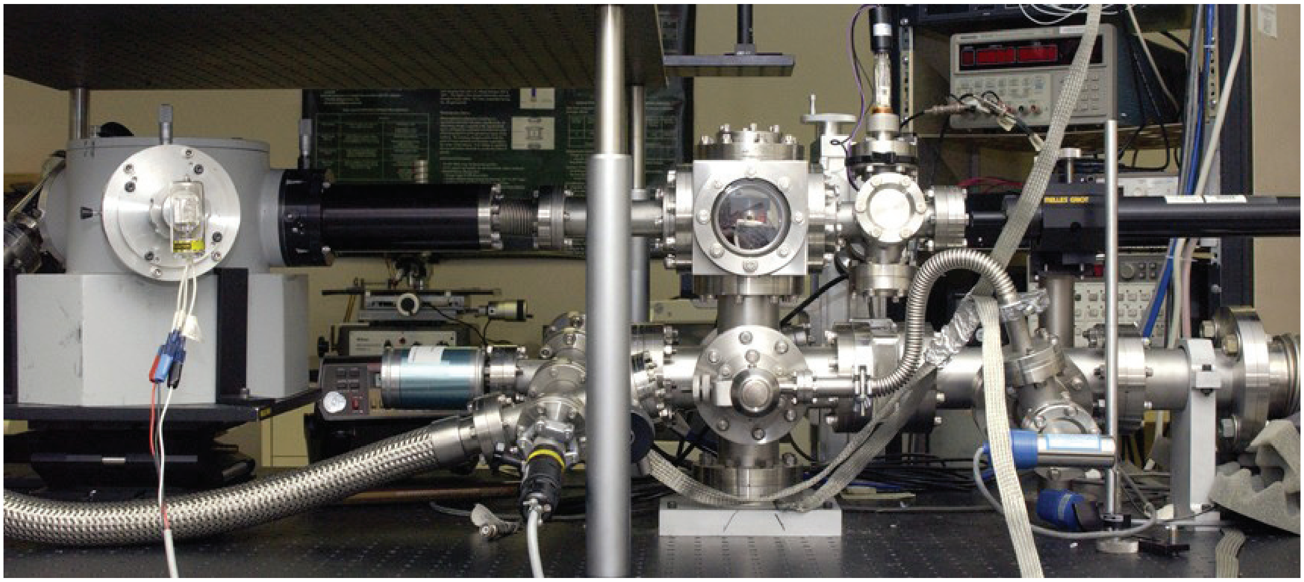
An experimental facility based on an electrodynamic balance (EDB) has been developed at MSFC for investigation of the properties of individual micron/submicron size dust grains in simulated space environments. A number of unique experiments have been conducted at this facility to investigate several different properties and processes of astrophysical interest and lunar interest.

Recent Investigations

1. First laboratory measurements of radiation pressure on individual micron size dust grains.
2. First laboratory measurements of rotation and alignment of micron size grains simulating the rotation and alignment of interstellar grains leading to the polarization of star light.
3. Laboratory measurements of the photoelectric efficiencies for charging of the analogs of individual cosmic and lunar dust grains by UV radiation. The results are found to be substantially different from the only available measurements made on bulk materials reported in the literature.
4. The current work is focusing on the charging of Apollo 11 and 17 lunar dust grains by electron impact, simulating the charging of lunar dust by the solar wind plasma.

Future Work

1. Experimental evaluation of the effect of the lunar temperature cycle (~100–400 K) on the dust charging rates and the equilibrium potentials.
2. Experiments on condensation of volatile gases on interstellar type cryogenically cooled dust grains for investigations of the formation and growth of icy mantles.
3. Measurements of the infrared optical properties in the middle- and far-infrared spectral regions (10–2,500 cm^{-1}) with the growth of icy mantles.
4. Experimental studies of rotation and alignment of dust grains by radiative torque.



A pictorial view of the experimental facility based on an electrodynamic balance for investigations of the physical and optical properties of individual micron/submicron size dust grains.

Laboratory Measurements of the Physical and Optical Properties of Individual Micron Size Dust Grains

A unique laboratory facility based on an electrodynamic balance developed at MSFC for measurements of the properties individual dust grains in space environments, has enabled us to conduct a series of first-of-its-kind measurements over the last several years, with publications in well-known journals.

These unique measurements include the following:

1. Measurements of radiation pressure efficiencies of individual micro-size dust grains in planetary/interstellar (IS) environments.
2. Rotation of individual dust grains in IS environments.
3. Measurements on charging properties of individual Lunar and analogs of Cosmic dust grains by photoelectric emissions with UV radiation, and by low-energy electron impact.
4. Future measurements and investigations currently being planned include:
   a. Infrared optical properties of individual micron size Lunar/Martian and Interstellar type dust grains in view of the substantial differences expected in planned measurements and the currently available measurements on bulk materials.
   b. Measurements and investigations of condensation processes of volatile gases on dust grains in IS dust clouds, with measurements of their IR optical properties.
   c. Laboratory measurements of discharging/charging properties of radioactive dust grains for possible developments of advanced thermonuclear propulsion systems involving dusty plasmas.

Astrophysics

Martin Weisskopf, Carolyn Atkins (UAH), Massimiliano Bonamente (UAH), Ronald Elsner, Jessica Gaskin, Mikhail Gubarev, Marshall Joy (MSFC–retired & U Chicago), Kiranmayee Kilaru (NPP), Jeffery Kolodziejczak, Stephen O'Dell, Brian Ramsey, Douglas Swartz (USRA), Allyn Tennant, and Vyacheslav Zavlin (USRA)

Overview

The X-ray Astronomy Team at MSFC is engaged in several activities in this exciting scientific field. These activities include scientific research with the Chandra X-ray Observatory; a high-energy balloon program; development of x-ray imaging detectors and x-ray focusing optics; measurements of the Sunyaev-Zel'dovitch (S-Z) effect in clusters of galaxies with a number of ground-based telescopes; development of instruments for planetary exploration; and participation in planning and technology development and testing for a number of planned and potential astrophysics missions: the Astronomical Röntgen Telescope (ART), potential substitutes for the International X-ray Observatory, and the Wide-Field X-ray Telescope Mission. The team collaborates with a large number of outside institutions such as the University of Chicago, Johns Hopkins University, the Smithsonian Astrophysical Observatory and the Center for Astrophysics, the Massachusetts Institute of Technology, Stanford University, the University of California Berkeley, the Goddard Space Flight Center, Brookhaven National Laboratory, and a number of institutions abroad. The team involves and supervises graduate students both from the local university and elsewhere.

The MSFC X-ray Astronomy Team has served as the Project Science organization throughout all phases of the Chandra X-ray Observatory, the x-ray component of NASA's Great Observatories. With over 35 years of experience in supporting Chandra and in developing x-ray optics and instruments, the team conducts technology development, builds flight hardware, and participates in concept studies for numerous planned or potential high-energy astrophysics, heliophysics, and lunar or planetary missions—ranging from balloon and rocket experiments to probe- and facility-class x-ray observatories. In support of these activities, the team conducts performance testing of x-ray optics and instruments at MSFC's 100-m x-ray test facility, both for MSFC projects and on behalf of or in collaboration with U.S. and international partners. After completion of testing of the mirrors for the James Web Space Telescope at MSFC's X-Ray and Cryogenics Facility (XRCF), the team will resume x-ray testing at that 528-m facility, which it helped to define and construct for the calibration of the Chandra X-ray observatory.

In addition to its substantial effort in developing and testing x-ray hardware, the X-ray Astronomy Team conducts basic astrophysical research on a wide range of topics including cosmology and the nature of dark energy, clusters of galaxies, source populations in nearby galaxies, neutron stars and their environments (including the Crab Pulsar and Nebula), and solar-system bodies. Much of the team's astrophysical research uses data from the Chandra X-ray Observatory won through peer-reviewed competitive processes.

Replicated Optics

Brian Ramsey and Mikhail Gubarev

In addition to its major role working with the Chandra scientists and engineers from the Smithsonian Astrophysical Observatory (SAO) in developing the Chandra optics, for the past 16 years the X-ray Astronomy Team has also been developing nickel-replicated x-ray optics both to meet the demands of future missions and for a variety of current applications. The nickel replication process, wherein nickel mirror shells are electroformed on high-precision mandrels replicating their precise figure and surface, provides full-shell optics with inherently good angular resolution.

The ART is a Russian-led instrument due to fly on the Spectrum-Röntgen-Gamma (SRG) mission in late 2013. Through an International Reimbursable Agreement, MSFC is producing mirror modules for this instrument. Each module comprises 28 nested, iridium-coated x-ray mirrors made from an in-house-developed, high-strength nickel/cobalt alloy. MSFC is responsible for the design, fabrication, testing, and delivery of the flight hardware to the Institute of Space Research of the Russian Academy of Sciences in mid 2013.

The FOcusing X-ray Solar Imager (FOXSI), is a rocket payload being developed by the University of California Berkeley that utilizes 49 x-ray mirror shells supplied by MSFC. FOXSI is designed to image high-energy x-rays from solar microflares, and will be launched in 2012 from White Sands Missile Range. A follow-on FOXSI-2 payload will include additional MSFC mirror shells to provide enhanced high-energy response and will launch approximately 2 years after FOXSI.

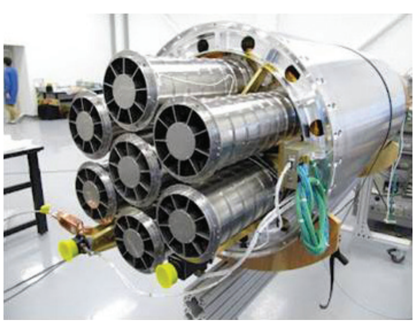
Micro-X is an MIT-led rocket payload that will use very-high-spectral resolution x-ray calorimeter detectors at the focus of MSFC-produced optics. The individual mirror shells will be 0.5 m in diameter, the largest that can be accommodated in the rocket fairing. Work on these has just begun, with a target launch date of 2014.

As an in-house test bed for MSFC optics, we have High Energy Replicated Optics (HERO), a balloon-borne x-ray telescope system. HERO currently features 110 in-house-fabricated, nickel-alloy-hard x-ray mirrors focused on to 8 custom-built focal plane detectors. The complete payload was designed and built at MSFC and recently (2011) flew from Alice Springs, Australia. The possibility of long-duration HERO flights with an enhanced payload and gondola design is currently being explored.

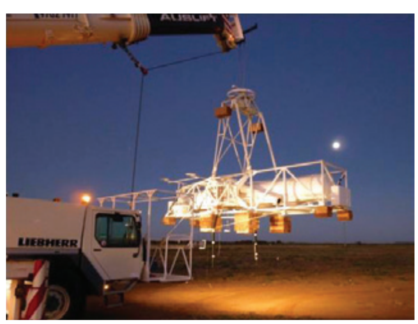
An additional application of replicated optics is for low-energy neutrons which have similar wavelengths to x-rays. The x-ray team has already demonstrated cold neutron imaging with a system of 4 nested mirror shells, under a Department of Energy-funded collaboration with MIT to develop grazing incidence optics for neutron beamlines. Possible applications are for neutron imaging, both in absorption and phase contrast; for focusing and transporting neutron beams while preserving time-of-flight information; and for scattering applications, such as Small Angle Neutron Scattering analysis. These would all take advantage of the increased neutron flux and aberration-free performance of the full-shell replicated optics.

Finally, new techniques are being explored for enhancing the angular resolution of general x-ray optics. Making use of developments for synchrotron mirrors, the team is investigating methods to precisely figure the very-thin-shell mirrors needed for the next generation of x-ray observatories. The goal of these activities is to achieve a means for sub-arc second angular resolution within realistic mirror mass and cost budgets.

A 0.5-m-diameter x-ray test mirror fabricated at MSFC.



Seven x-ray mirror modules, fabricated at MSFC, mounted in to the FOXSI rocket payload.



The HERO balloon payload, with 110 x-ray mirror shells, awaiting launch.

Replicating mandrels for the ART-XC program being polished at MSFC.

Instrumentation

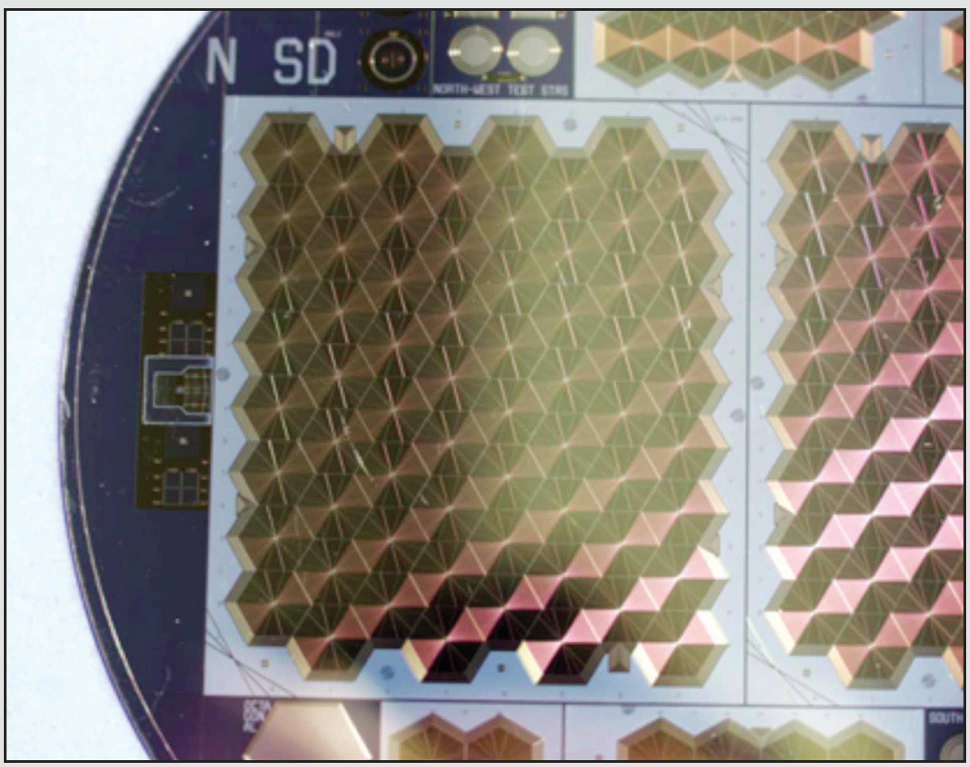
Brian Ramsey and Jessica Gaskin

The X-ray Astronomy Team also has two instrument projects related to planetary exploration. Under the NASA Planetary Instrument Definition and Development Program, the team has been collaborating with Brookhaven National Laboratory on the development of a modular X-ray Spectrometer consisting of an array of Silicon Drift Detectors (SDDs) for measuring the abundances of light surface elements (C to Fe) fluoresced by ambient radiation.

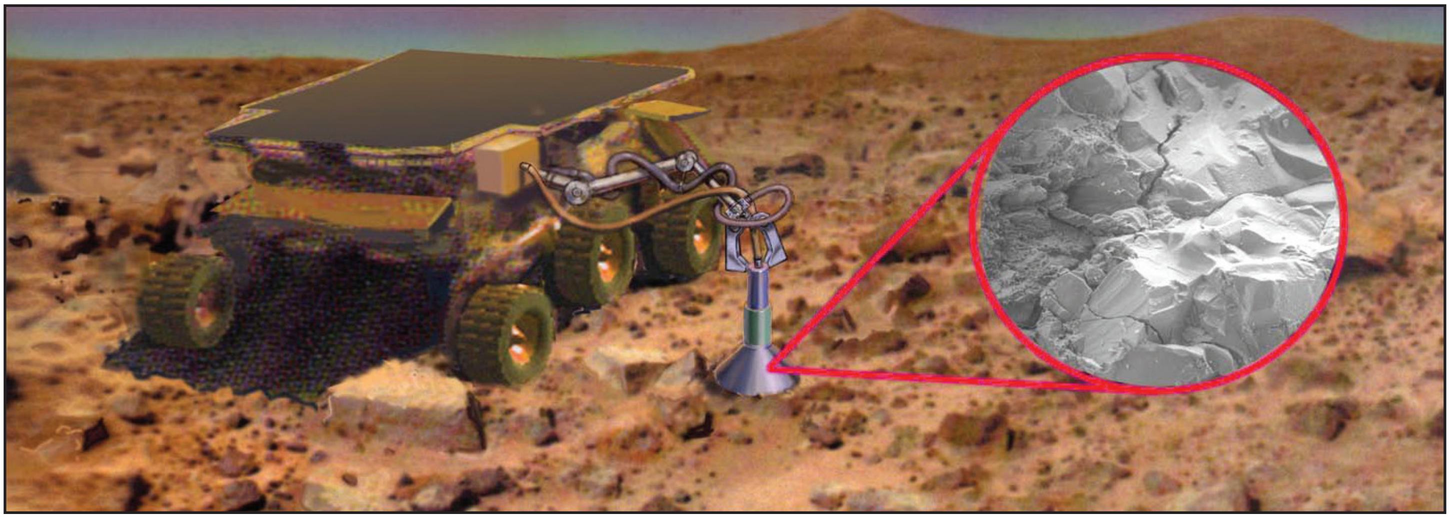
This instrument's very low power consumption compared to traditional charge coupled devices permits large collecting area and higher sensitivity. Originally developed for lunar use, the intrinsic radiation resistance of the SDD makes it applicable to other environments such as for mapping the surface elements of Jupiter's moons. Tests are currently underway to quantify the radiation hardness of SDDs specifically fabricated for such harsh environments.

The X-ray Astronomy Team is also leading an effort to develop a Miniaturized High-Vacuum Scanning Electron Microscope (mini-SEM) for in situ use in the Moon. All major proof-of-concept components have been fabricated and tested and include: a novel high-energy power supply and control system for a mini-cold field emission electron gun, a miniaturized electron focusing column with low-power operation, and a scanning and imaging system.

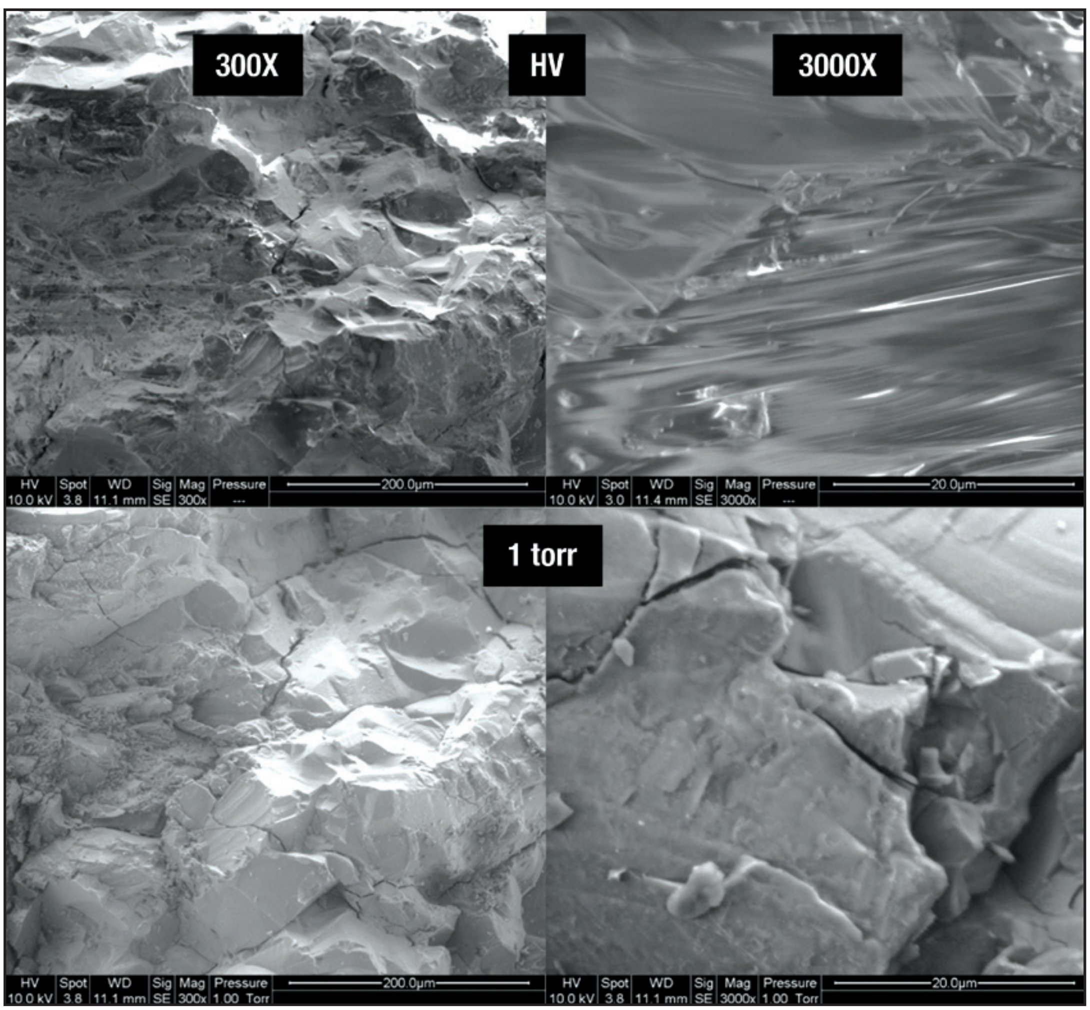
Related to the mini-SEM development, the design of a version that can be used on the surface of Mars has begun. The higher ambient pressure there calls for the use of an electron gun that can operate at High Vacuum, rather than Ultra-High Vacuum, and the presence of a CO_2-rich atmosphere also allows for the incorporation of a variable pressure system that enables the in-situ analysis of nonconductive geological specimens. Preliminary testing of Mars meteorites in a commercial Environmental SEM™ (FEI) confirms the usefulness of low-current/low-accelerating voltage imaging and highlights the advantages of using the Mars atmosphere for environmental imaging. Attached is an early concept drawing of the MVP-SEM on Mars.



64-pixel SDD array, fabricated at Brookhaven National Laboratory. 16 pixel devices were recently tested for radiation hardness at the Indiana University Cyclotron Facility. These radiation hard devices are ideal for the Jovian environment as well as for mapping the lunar surface.



Conceptualization of the MVP-SEM on the surface of Mars.



Imaging with Simulated Martian Atmosphere.

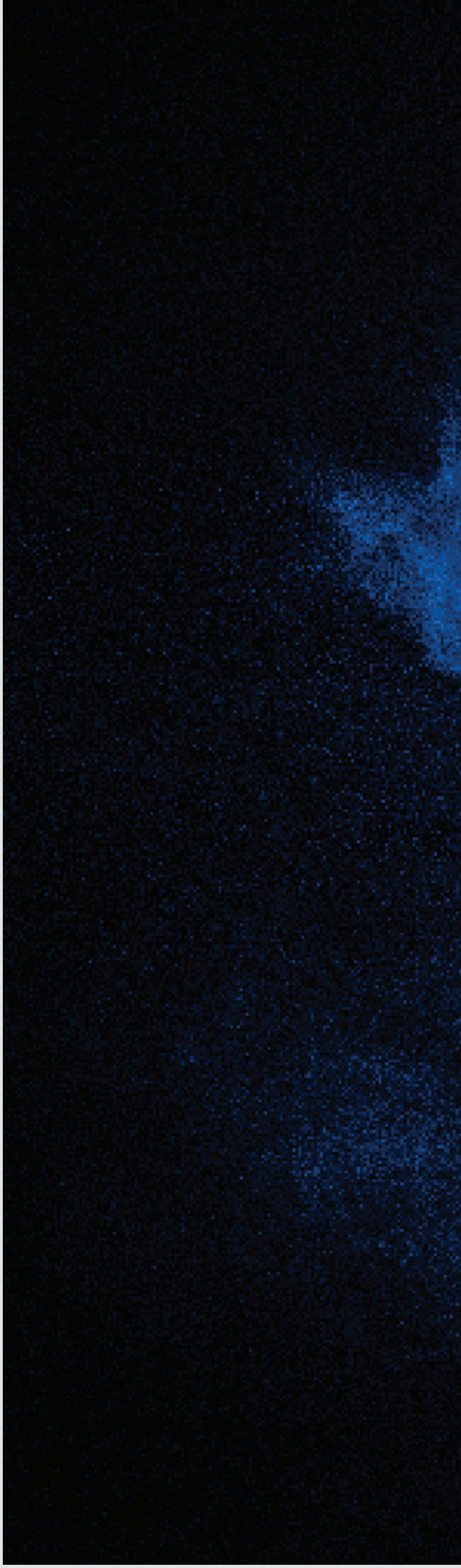
Astrophysical Research

Martin Weisskopf, Ronald Elsner, and Stephen O'Dell

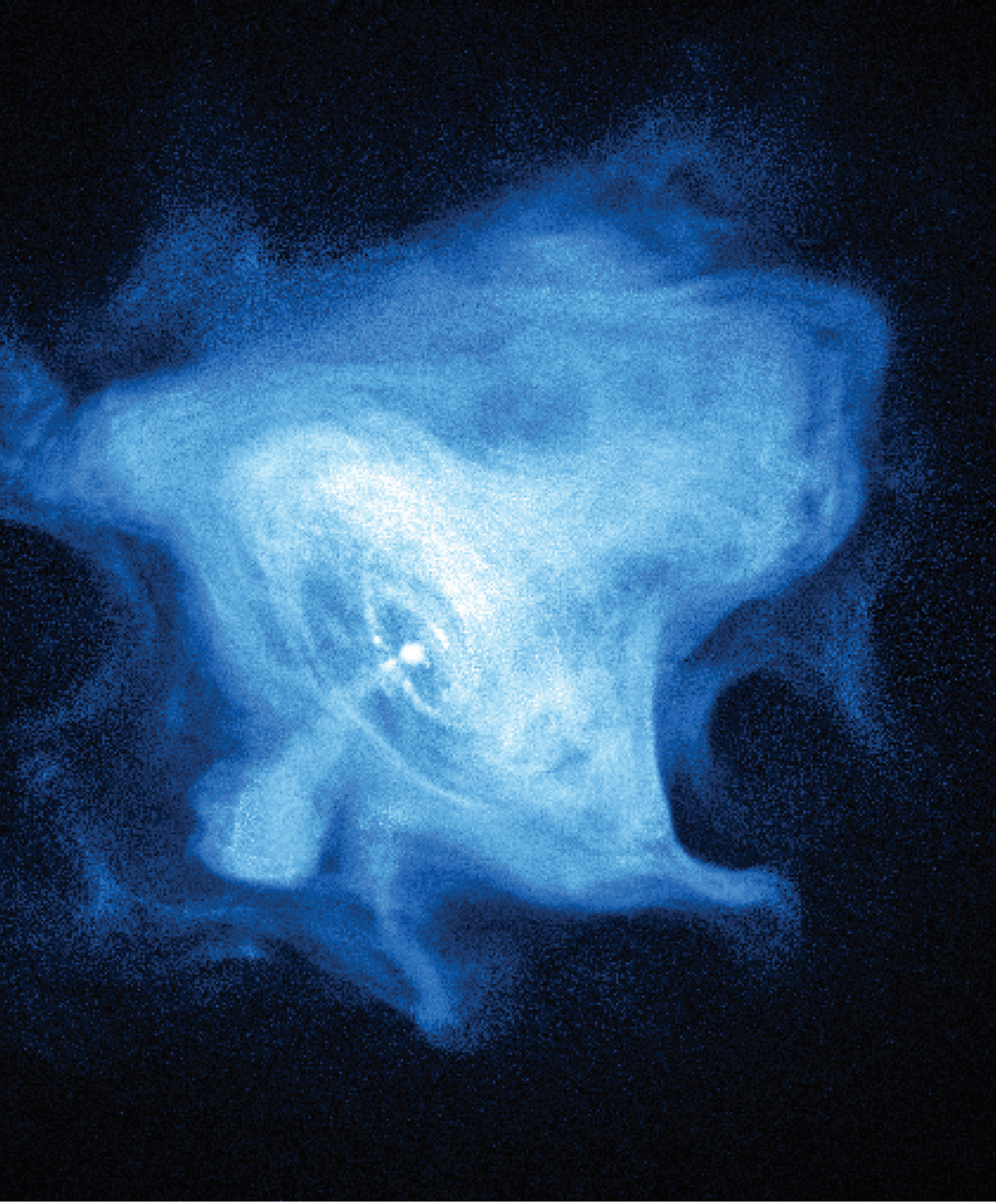
Team members conduct panchromatic studies of star forming regions and their impact on the growth and evolution of nearby galaxies. They perform statistical studies of x-ray source populations in the local universe including the enigmatic Ultraluminous X-ray sources — black holes with potential masses lying between stellar-mass black holes and supermassive galactic nuclei. The team also investigates many objects within our own Milky Way including timing and spectroscopic studies of neutron stars and white dwarfs. In particular, the team leads analysis of the dynamic behavior of the Crab Pulsar and Nebula from powerful short-lived flares detected at extremely high energies to the decades-long evolution of rings, wisps, knots, and jets in the Nebula. Members of the team recently were part of the collaboration that discovered enigmatic and possibly paradigm-shifting flaring at gamma-ray energies from the Crab Nebula and are leading an international effort using Chandra, HST, and a number of ground-based observatories to determine the site from which this flaring occurred.

Over the past three years, the X-ray Astronomy Team has published over 140 papers in SPIE Proceedings (optics and instruments) or in refereed journals (primarily astrophysical research). These include:

- 25 papers on technology advances and future mission concepts.
- 30 papers on x-ray mirror and detector design, performance, and fabrication.
- 34 papers on clusters of galaxies, including numerous South Pole Telescope results.
- 20 papers on the Crab nebula, Galactic and extra-galactic x-ray sources.



Recent Chandra x-ray image of the Crab Nebula taken as part of the campaign to locate the origin of the gamma-ray flares. The pulsar is shown at the proper location but was artificially drawn in because it is so bright it appears as a hole in the data. The image is 2.5 × 2.5 arc-minutes. The system is at a distance of ~2 kpc.



Fermi Gamma-ray Burst Monitor

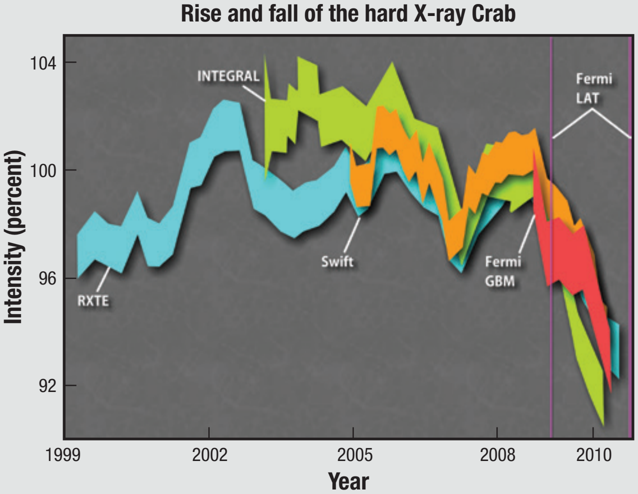
Chryssa Kouveliotou and Colleen Wilson-Hodge

The gamma-ray astronomy team at MSFC has long contributed to studies of gamma-ray bursts, now known to be the most distant and powerful explosions in the universe. The Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory made pioneering observations from 1991 until 2000, obtaining compelling evidence that the sources of gamma-ray bursts were near the edge of the observable universe. Current theories postulate that the sources represent a rare type of explosion of a massive, rapidly rotating star, or the merger of two neutron stars or of a black hole and a neutron star. These gamma-ray bursts are also used to study the properties of the most distant regions of the Universe.

Our team's current focus is the Gamma-ray Burst Monitor (GBM) on the Fermi Gamma-ray Space Telescope. Fermi is a high-energy gamma-ray observatory that was launched on June 11, 2008. Before launch, the observatory was known as the Gamma-ray Large Area Space Telescope (GLAST). The primary instrument is the Large Area Telescope (LAT), which makes observations of sources of gamma radiation above 20 MeV with unprecedented sensitivity. The GBM has augmented the science from Fermi by observing gamma-ray bursts from 10 keV to 30 MeV, covering the majority of gamma-ray burst emissions. Together, the GBM and LAT have provided gamma-ray burst observations covering over six decades of energy.

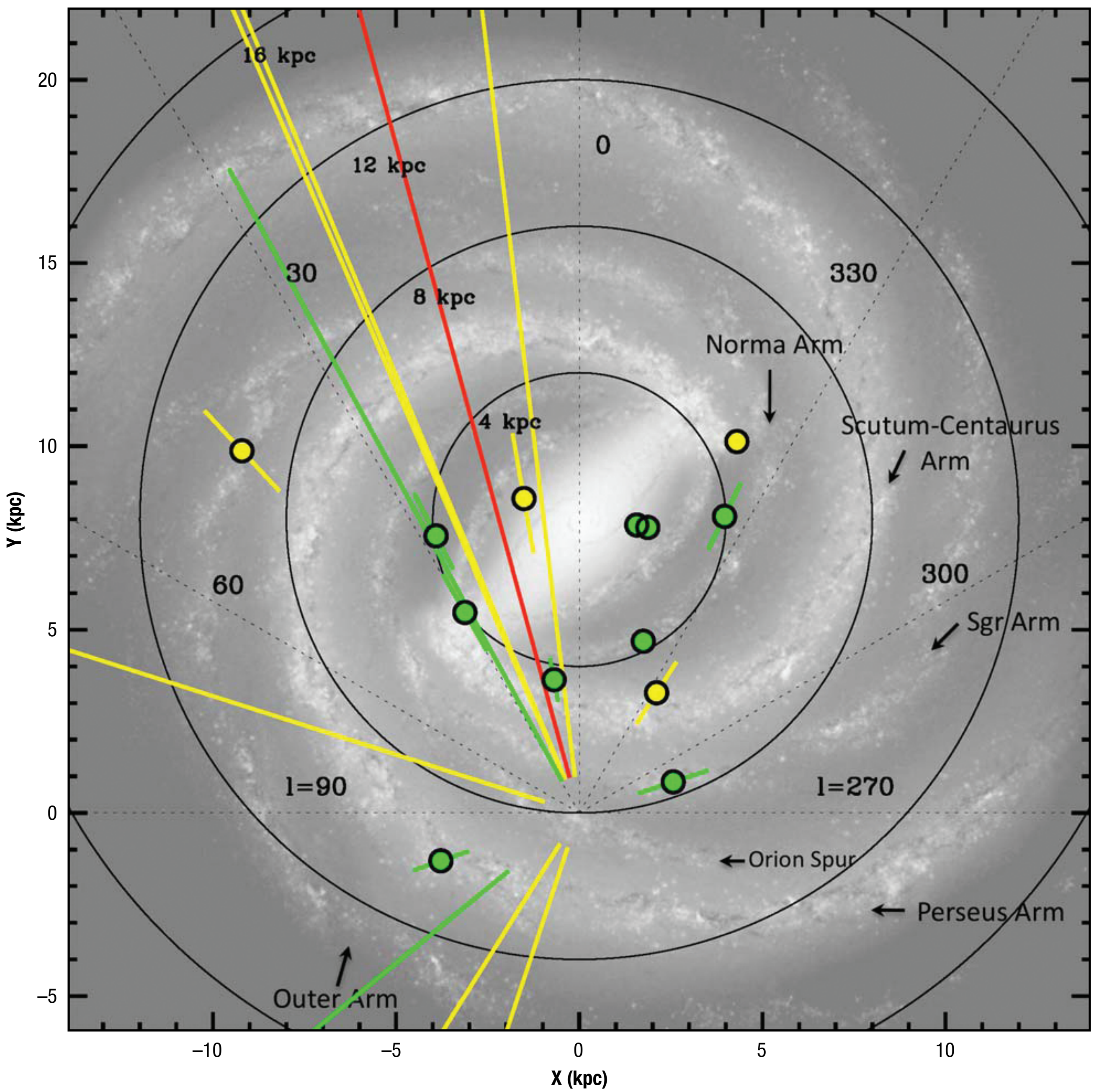
The GBM consists of twelve sodium iodide (NaI) scintillating detectors, covering the 10 keV to 1 MeV energy range, and two bismuth germanate (BGO) scintillation detectors, covering the 150 keV to 30 MeV energy range. The detectors are positioned so that any burst will illuminate at least one BGO detector and four NaI detectors. An on-board computer determines the direction to the burst using the relative count rates on the NaI detectors. For particularly intense bursts, this information is used to reorient the spacecraft to place the burst within the LAT field of view.

Fermi is now in its fourth year of orbital operations. Its wide energy coverage and high sensitivity have provided significant advancements in gamma-ray burst research. In addition, Fermi is also being used to study other high-energy objects within our galaxy, such as magnetars (soft gamma repeaters (SGRs) and anomalous x-ray pulsars (AXPs), as well as solar flares and short, intense flashes of gamma rays above terrestrial thunderstorms.



X-ray data from NASA's Fermi, RXTE, and Swift satellites and the European Space Agency's International Gamma-ray Astrophysics Laboratory (INTEGRAL) confirm that the Crab Nebula's output has declined about 7 percent in two years at energies from 15,000 to 50,000 electron volts. They also show that the Crab has brightened or faded by as much as 3.5 percent a year since 1999. Fermi's Large Area Telescope (LAT) has detected powerful gamma-ray flares (magenta lines) as well.

The Fermi satellite, shown during integration and testing in, Chandler, Arizona. The LAT is the large block-shaped instrument on the top of the satellite. Three of the twelve GBM NaI detectors are visible near the center of the picture with one of the two BGO detectors to the left of the NaI detectors.



Galactic distribution of magnetar candidate sources superposed on the Milky Way model of Churchwell et al. (2009). Circles denote sources at known distances; all others are represented as directions by lines. The red stars are the new sources detected since the *Fermi* launch using GBM, Swift and IPN data. The white stars are reactivations of old sources detected with GBM. Green color represents Soft Gamma Repeaters (SGRs) and yellow Anomalous X-ray Pulsars (AXPs). All lines start from the Solar System.

Cosmic Rays Astrophysics

Mark Christl and Nasser Barghouty

The MSFC Cosmic Ray Team has contributed to the study of cosmic rays that originate from the Sun, within the Milky Way Galaxy, and from other galaxies. The Extreme Universe Space Observatory on the Japanese Experiment Module (JEM-EUSO) is a future experiment to measure the energy and arrival direction of extreme energy cosmic rays (EECRs) by recording video clips of the extensive air showers (EASs) they create in the Earth's nighttime atmosphere. An EAS produces light by exciting nitrogen fluorescence in the atmosphere and by generating Cherenkov radiation. The EAS are analyzed to determine the energy and nature of the incident particle and to learn of its origin. At energies above 10^{20} eV the particles suffer little deflection by the weak magnetic fields in space and the EAS can point back to the particle's origin.

The JEM-EUSO mission is a pathfinder mission for the future of these extreme energy particle investigations. The technique was originally developed with large ground-base arrays of detectors covering many square kilometers: AGASA, Fly-eye, Telescope Array, and AUGER. When observing from space, Earth's entire atmosphere becomes the detector, greatly increasing our ability to study these rare events. With the launch of this international mission to the ISS, JEM-EUSO will usher in the age of Charged Particle Astronomy.

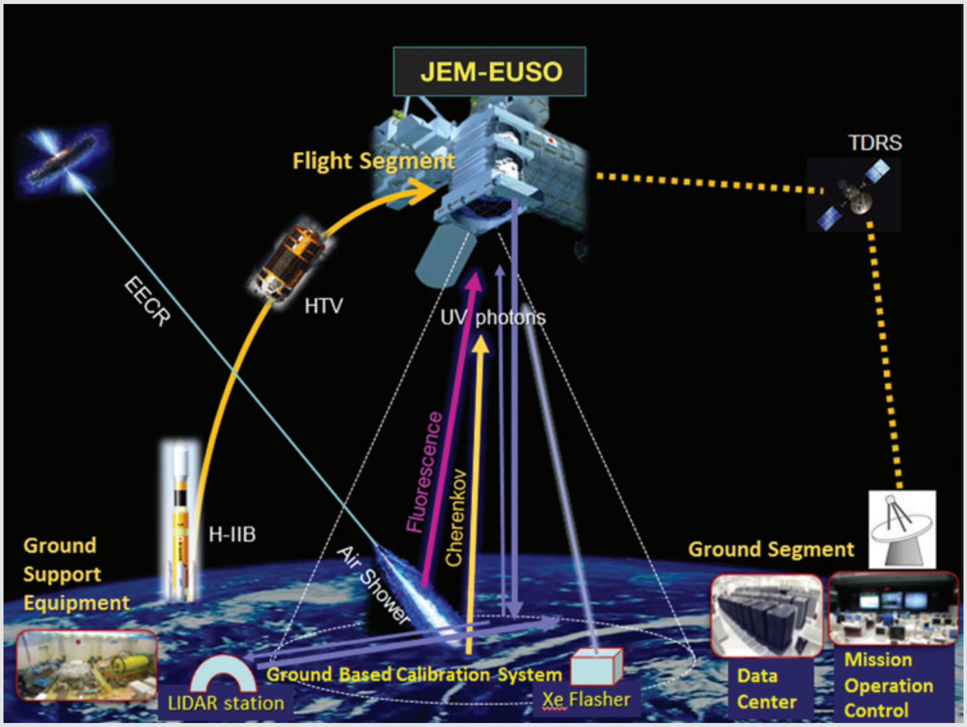
Basic Processes for Cosmic Rays Astrophysics

The Cosmic Ray group at NASA/MSFC is updating and expanding our database and modeling capabilities needed to reliably model many of the basic reaction processes known to be relevant for cosmic rays and solar energetic particles; including surface, atomic, nuclear, and very high energy reactions.

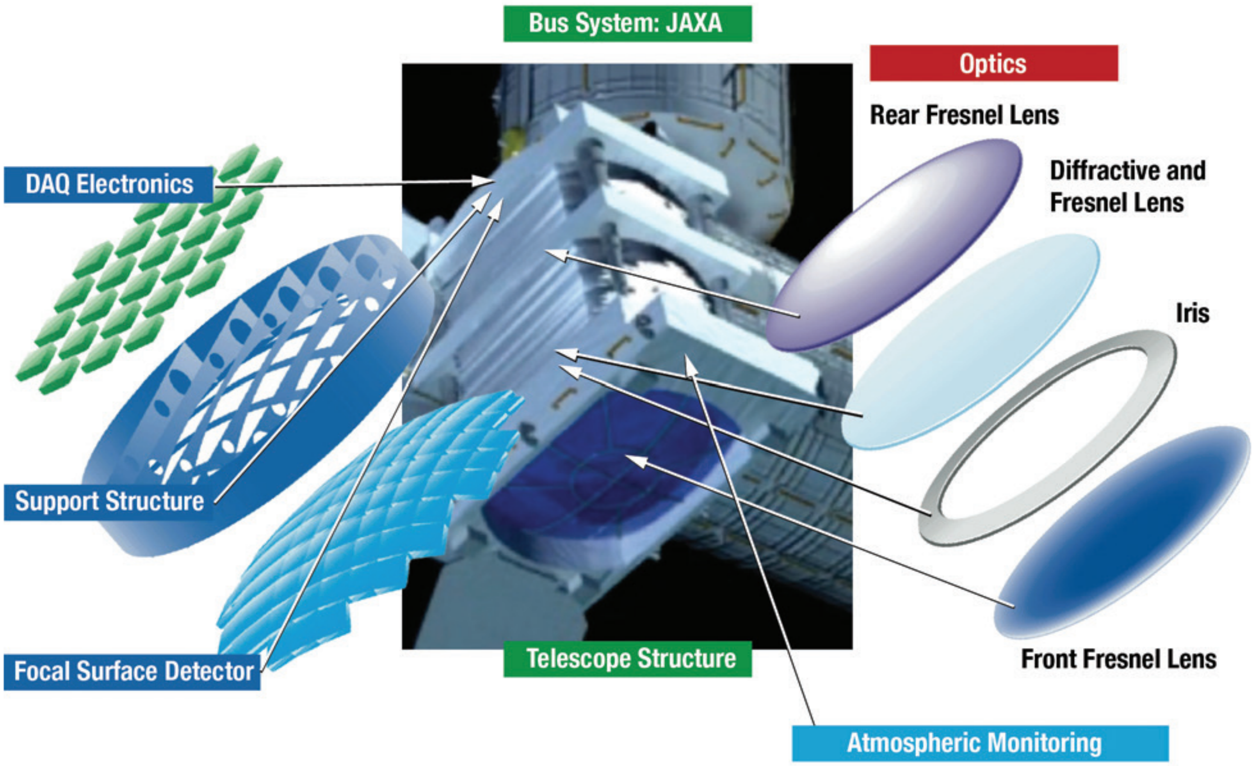
In surface reactions, the group collaborates with Oak Ridge national Laboratory's MIRF to measure the sputtering products of highly charges ions impacting oxides at around 1 keV/amu.

The group is also currently developing from first-principles estimates for the charge-exchange cross sections of MeV-protons on various solar-corona ions species for use in energetic neutral atom (ENA) modeling and detection.

We are expanding and updating the nuclear cross sections database using analytical models and Monte-Carlo based simulations. In addition we are updating the estimates used in high-energy cosmic rays involving anti-matter reactants and products and dark matter candidates.



EUSO mission overview and concept of operations



Expanded view of the EUSO subsystems

Appendix A

Abbreviations and Acronyms

ACE	Arctic Collaborative Environment
ADD	Agile Digital Detector
AGASA	Akeno Giant Air Shower Array
AMPR	Advanced Microwave Precipitation Radiometer
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
ART	Astronomical Röntgen Telescope
AWIPS	Advanced Weather Interactive Processing System
AXP	Anomalous X-ray Pulsar
BATSE	Burst and Transient Source Experiment
CAMEX	Convection and Moisture EXperiment
CDA	Confirmatory Data Analysis
CDC	Centers for Disease Control and Prevention
CREST	Coupled Routing and Excess Storage
CRÈME	Cosmic Ray Effects on MicroElectronics
CFA	Common Factor Analysis
COPrHEx	Convective and Orographic Precipitation and Hydrology Experiment
CSPAR	Center for Space Plasma and Aeronomic Research
DEVELOP	NASA Science Mission Directorate Applied Sciences Training and Development Program
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
EAS	Extensive Air Showers
EDB	Electrodynamic Balance
EDA	Exploratory Data Analysis
EECR	Extreme Energy Cosmic Ray
EFDC	Environmental Fluid Dynamics Code
ENA	Energetic Neutral Atom
EOF	Empirical Orthogonal Function
EOS	Earth Observing System
EPHT	Environmental Public Health Tracking
EUSO	Extreme Universe Space Observatory
FDA	Federal Drug Administration

FDOH	Florida Department of Health
FOXSI	Focusing X-ray Solar Imager
GBM	Gamma-ray Burst Monitor
GDML	Geometry Description Markup Language
GLAST	Gamma-ray Large Area Space Telescope
GLM	Geostationary Lightning Mapper
GMAO	Global Modeling and Assimilation Office
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GPM	Global Precipitation Measurement
GRIP	Genesis and Rapid Intensification Processes
GTRI	George Tech Research Institute
HERO	High Energy Replicated Optics
Hi-C	High-Resolution Coronal Imager
HIRAD	Hurricane Imaging Radiometer
HRD	Hurricane Research Division
HST	Hubble Space Telescope
ISM	Interstellar Medium
IDC	Interplanetary Dust Cloud
INTEGRAL	International Gamma-ray Astrophysics Laboratory
IPN	Interplanetary Network
IS	Interstellar
ISDE	Institute for Space and Defense Electronics at Vanderbilt University
ISERV	International Space Station (ISS)/SERVIR Environmental Research and Visualization System
ISS	International Space Station
JCSDA	Joint Center for Satellite Data Assimilation
JEM	Japanese Experiment Module
JEM-EUSO	Japanese Experiment Module-Extreme Universe Space Observatory
KMD	Kenya Meteorological Department
LAT	Large Area Telescope
LIP	Lightning Instrument Package
LIS	Lightning Imaging Sensor

LCLU	Land Cover/Land Use
LMA	Lightning Mapping Array
LST	Land Surface Temperature
MaGIXS	Marshall Grazing Incidence X-ray Spectrograph
MAPIR	Marshall Airborne Polarimetric Imaging Radiometer
MC3E	Midlatitude Continental and Convective Clouds Experiment
MERRA	Modern-Era analysis for Research and Applications
MIRF	Multicharged Ion Research Facility of the Oak Ridge National Laboratory
MNGRL	MSFC Noble Gas Research Laboratory
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
MVP	Mars Variable Pressure
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDVI	Normalized Difference Vegetation Index
NEXRAD	National Weather Service Next Generation Radar
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NSSTC	National Space Science and Technology Center
NWS	National Weather Service
ODC	Optimal Deconvolution
OTD	Optical Transient Detector
OMEGA	Observing Microwave Emissions for Geophysical Applications
PAHO	Prevention, the United States Geological Survey, Pan-American Health Organization
PCA	Principal Components Analysis
PEOPLE	Partnering Earth Observations for People Living Environmentally
PREAM	Pollen Regional Atmospheric Model
REGARDS	REasons for Geographic And Racial Differences
R&A	Research and Analysis
R&D	Research and Development
ROSES	Research Opportunities in Space and Earth Science
RTMM	Real Time Mission Monitor
SAO	Smithsonian Astrophysical Observatory

SEM	Scanning Electron Microscope
SERVIR	Means “To Serve”; Serves as the Regional Visualization and Monitoring System
SFMR	Stepped Frequency Microwave Radiometer
SHEELS	Simulator for Hydrology and Energy Exchange at the Land Surface
SDDs	Silicon Drift Detectors
SGR	Soft Gamma Repeater
SRAG	Space Radiation Analysis Group at Johnson Space Center
SMAP-VEX ’08	Soil Moisture Active Passive Verification Experiment 2008
SMM	Solar Maximum Mission
SRG	Spectrum-Röntgen-Gamma
SPIE	International Society for Optics and Photonics
SPoRT	Short-term Prediction Research and Transition Center
SSM/I	Special Sensor Microwave/Imager
SWEAP	Solar Wind Electrons, Alphas and Protons
S-Z	Sunyaev-Zel’dovitch
TIP	Technology Investment Program
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UAB	University of Alabama in Birmingham
UAHuntsville	University of Alabama in Huntsville
UAS	Unmanned Aerial System
UHI	Urban Heat Island
UHV	Ultra High Vacuum
USAID	U.S. Agency for International Development
USRA	Universities Space Research Association
UTSI	University of Tennessee Space Institute
UVSP	Ultraviolet Spectrometer and Polarimeter
VCSI	Von Braun Center for Science and Innovation
VUV	Vacuum Ultraviolet
WFO	Weather Forecast Office
WRF	Weather Research and Forecast
XRCF	X-ray and Cryogenics Facility

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Appendix C

2009 to Present Publications and Presentations

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