A SOLAR

NJIT IS EXPANDING KNOWLEDGE OF THE SUN AND SOLAR STORMS ACROSS A UNIQUE RANGE OF RESEARCH.

SANDY?

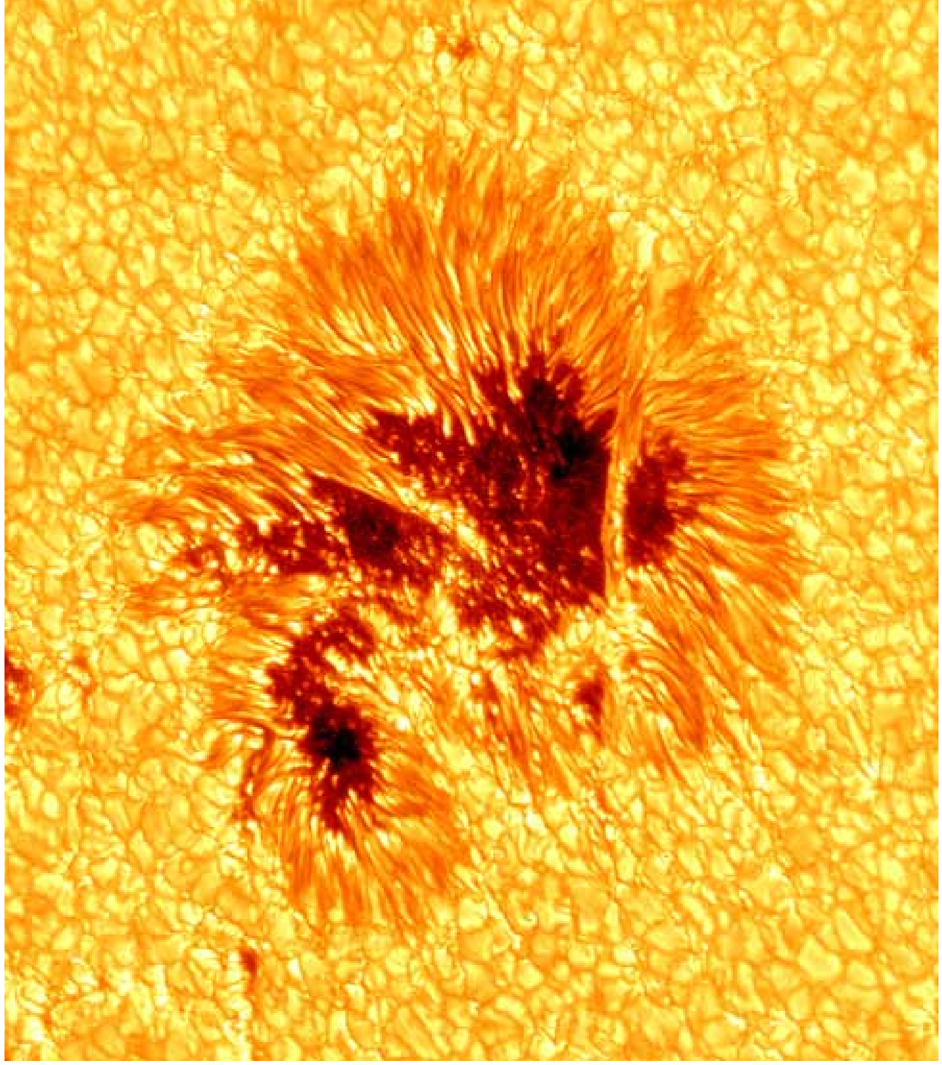
The devastation of Hurricane Sandy was a very painful reminder of our vulnerability to such violent terrestrial weather. We are equally at risk, perhaps even more so, from another type of natural threat whose source is some 93 million miles away – the Sun. While the star closest to Earth sustains all life on our planet, it also generates roiling interplanetary weather that can endanger vital infrastructure.

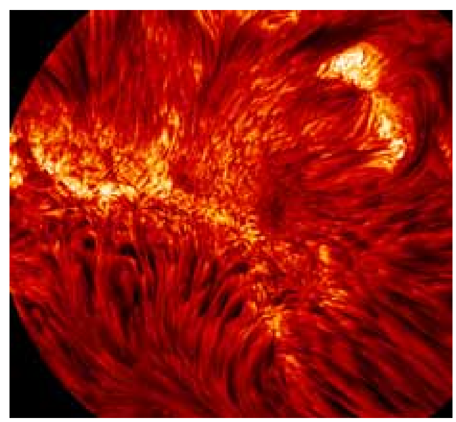
Solar flares and more powerful coronal mass ejections regularly send bursts of charged particles and high-energy radiation in our direction at nearly the speed of light. Upon initially reaching us within minutes, this inclement solar radiation can destroy the electronics in satellites essential for telecommunications, global positioning service, forecasting terrestrial weather and protecting national security. Airlines are forced to reroute flights away from the North Pole due to the disruption of high-frequency communications and the elevated radiation danger for passengers and crew members.

On the ground, effects from solar storms can destroy costly, hard-to-replace transformers in power grids, causing widespread loss of electricity. In 1989, for example, a solar storm brought down the Hydro-Quebec grid within minutes, blacking out the entire Province of Quebec and parts of the US Northeast for nine hours.

Space weather has been impacting terrestrial technology in a big way since the 19th century. An 1859 solar superstorm caused telegraph systems throughout Europe and North America to fail. It's a threat that has grown exponentially since then, as emphasized by a 2008 report from the National Academy of Sciences. The report warned of the social and economic consequences that could result from severe space weather, particularly how sudden power loss would affect financial and medical services, availability of food and water, and every other aspect of daily life dependent on electricity.

While the likelihood of dangerous space weather does tend to wax and wane over 11-year cycles related to sunspot activity, severe geomagnetic storms can develop at any time during a cycle. That's what scientists have learned by studying the historical record and geophysical evidence from the distant past as recorded in ice cores. The threat is really continuous throughout the solar cycle.





ABOVE: Acquired with the unparalleled resolution of the Big Bear telescope, this sunspot image reveals previously unknown small-scale features.
RIGHT: Research at Big Bear includes using visible-imaging spectroscopy to study the three layers of the Sun's atmosphere – the photosphere, chromosphere and corona. The ultrafine magnetic loops seen in this image originate in the Sun's surface layer, the photosphere.

COVERING ALL THE BASES

For more than a decade, NJIT has considerably expanded a range of solar research initiatives unique in the US and, arguably, internationally. It is work that receives substantial funding from the National Science Foundation, the Air Force, and the National Aeronautics and Space Administration, especially in connection with NASA's Living With a Star program.

"We cover all the bases," says Philip Goode, distinguished professor of physics and director of NJIT's Center for Solar-Terrestrial Research and the Big Bear Solar Observatory in California. "We're applying a unique set of tools to learning as much as we can about the Sun." Solar flares and the often concurrent coronal mass ejections are primary objects of study for Goode and his colleagues.

"At Big Bear over the last decade, we designed, built, and commissioned the world's most powerful optical solar telescope to observe what's happening on the surface of the Sun, and where flares are first seen in the lower part of the solar atmosphere," says Goode, who was recently named a Fellow of the American Geophysical Union for his contributions to solar physics.

Wenda Cao, associate professor of physics and the Big Bear observatory's associate director, adds that the capabilities of the 1.6-meter off-axis, clear-aperture telescope are enhanced by adaptive optics to compensate for terrestrial atmospheric distortion and state-of-the art instrumentation for acquiring

BELOW: An elevation of more than 6,000 feet and surrounding water contribute to ideal viewing conditions at NJIT's Big Bear Solar Observatory in California.
BOTTOM: Pausing in work at the Big Bear solar telescope, which has a 1.6-meter primary mirror, is Wenda Cao, associate professor of physics and the observatory's associate director.

"AT BIG BEAR…WE DESIGNED, BUILT, AND COMMISSIONED THE WORLD'S MOST POWERFUL OPTICAL SOLAR TELESCOPE TO OBSERVE WHAT'S HAPPENING ON THE SURFACE OF THE SUN."

– Philip Goode, distinguished professor of physics and director of NJIT's Center for Solar-Terrestrial Research and the Big Bear Solar Observatory

BIG BEAR PHOTOS: ALLA SHUMKO

infrared and magnetic data. "This range of capabilities enables solar physicists to attack long-standing unanswered questions about the Sun," Cao says.

Speaking of related NJIT research, Goode says, "The Owens Valley Solar Array in California measures magnetic phenomena higher in the solar atmosphere at radio frequencies. Then there's investigation of the effect of the solar wind by NJIT instruments on NASA's dual Van Allen Probe spacecraft in Earth's magnetic field – the magnetosphere. At some point that energy gets into our atmosphere and we study the effects with ground-based instrumentation."

"It's the particles dumped directly into Earth's magnetosphere and upper atmosphere that cause all the damage," explains Professor of Physics Andrew Gerrard, the solar-terrestrial center's deputy director and leader of the Automatic Geophysical Observatory solar research program in Antarctica. "This material can generate electrical currents much stronger than transformers in power grids can handle when it hits us at the right orientation to Earth's magnetic field. You also don't want to be flying over the North Pole when that happens."

EXPECTING TO BE SURPRISED

According to Goode, integrated study of the phenomena associated with space weather is very much a matter of "who sees what when." Big Bear's unparalleled capabilities for studying the Sun's surface and lower atmosphere are complemented by NJIT radio instrumentation at the Owens Valley observatory.

NJIT owns and operates the Expanded Owens Valley Solar Array, a major part of the larger facility managed by California Institute of Technology. NJIT has installed key observing equipment and control systems, and is adding more under the direction of Distinguished Professor of Physics Dale Gary.

Three antennas of the expanded array are fully outfitted at present, and the electronics for the remaining ten antennas are in mass production. The two large, historic 27-meter-diameter antennas have been refurbished to serve as calibrating instruments. The expansion, funded in large part by the National Science Foundation, will allow imaging of the Sun at numerous frequencies over a range of 1 to 18 gigahertz.

Solar flares affect all layers of the Sun's atmosphere – the photosphere, chromosphere and corona. But it is in the corona, the outermost layer, where the bulk of flare energy can be observed, with radio imaging yielding especially significant data. "The instrumentation we're adding at Owens Valley will give us much greater ability to measure and understand processes in the region where the energy of flares increases and is released into space," Gary says.

"Our goal is to obtain new data about conditions in the corona that we can compare to current models, to what we think we know about the underlying causes of solar flares and other phenomena. We expect to be surprised."

At Owens Valley, as at Big Bear, NJIT undergraduates and graduate students share the scientific surprises with NJIT faculty. Corrado Mancini '14, who worked with Gary this past summer in California, is typical of the student researchers at the solar frontier. An electrical engineering major with a math minor, the Albert Dorman honors scholar says, "By working with Dr. Gary, I've been able to truly appreciate how complex – or sometimes simple – the process of making radio astronomy observations can be. It's been very cool to help with a project that's building a world-class facility for solar and space-weather research."

“WE EXPECT TO GAIN NEW BASIC UNDERSTANDING OF THE VAN ALLEN BELTS, AND DATA NEEDED FOR SPACECRAFT DESIGN GOING FORWARD.”

– Louis Lanzerotti, NJIT distinguished research professor of physics

BELOW: Three of the 13 2.1-meter antennas at Owens Valley dedicated to studying the Sun in the radio spectrum. In the distance is one of two 27-meter antennas that are being upgraded with cryogenic receivers for use as calibrating instruments.

PHOTO: KJELL NELIN, OWENS VALLEY SOLAR ARRAY

PROVIDING DAILY AND HISTORIC DATA

NJIT graduate students are also assisting Haimin Wang, distinguished professor of physics, with the mission of NJIT’s Space Weather Research Laboratory as they train to become future leaders in the field. Under Wang’s direction, the Newark-based laboratory gathers data from Big Bear, Owens Valley, NASA spacecraft and observatories in other countries to provide information about prevailing solar weather and what’s ahead in the near future based on current predictive capability.

Using the Global High Resolution H-alpha Network, Wang and his laboratory colleagues monitor solar activity and report space weather 24/7. In addition, they are working to further fundamental understanding of solar activity and geomagnetic effects. Better forecasting of solar events is a chief objective. Beyond NJIT, the laboratory is the lead institution in a collaborative multi-discipline initiative under NASA’s Living With a Star program to gain new knowledge about solar flares, the source of space weather, and to refine forecasting techniques.

Another project on Wang’s agenda “looks back to the future.” It involves converting images from Big Bear and other observatories archived only as photographs into more accessible digital formats. This will give all researchers investigating the solar cycle and flare activity access to high-quality data extending over a century.

PUTTING NJIT INTO ORBIT

NASA space probes are a key source of solar information for Wang, NJIT colleagues, and investigators around the world. The two Van Allen Probes launched in August 2012 were sent into orbit to study extremes of space weather and other phenomena related to the layers of charged particles named after their discoverer, James Van Allen.

Composed mainly of particles from the solar wind held in place by our planet’s magnetic field, the Van Allen radiation belts pose hazards to satellites that necessitate special shielding to protect sensitive components. There are five experiments aboard the identical Van Allen Probes, one designed under the leadership of Louis Lanzerotti, NJIT distinguished research professor of physics, in collaboration with the Johns Hopkins University Applied Physics Laboratory and Fundamental Technologies, Inc.

“The Van Allen belts have never been studied with the spatial resolution provided by the two probes,” Lanzerotti says. “Coronal mass ejections and other solar processes disturb Earth’s magnetosphere, which changes the characteristics of the radiation belts. The particle population of the belts can increase, which in turn increases the potential for radiation damage to spacecraft. We expect to gain new basic understanding of the Van Allen belts, and data needed for spacecraft design going forward.

“NJIT’s ion composition experiment is dedicated to the dominant particles in the belts – protons and electrons – and we’re measuring both over a certain energy range. It’s a range that carries a great deal of energy, enough to have undesirable terrestrial effects as well as endangering spacecraft. We’re also measuring helium and oxygen, which we believe can come from Earth’s atmosphere and the interplanetary medium. We want to learn the relative abundance of these and confirm their sources.”

Lanzerotti adds that the probes could also increase knowledge of how coronal holes on the Sun, gaps in the Sun’s magnetic field, affect Earth’s magnetosphere as the Sun rotates. This influences the magnetosphere in a different way compared to coronal mass ejections, yet still causes potentially damaging particle acceleration and greater radiation in the magnetosphere.

Lanzerotti has had a long and very distinguished career in geophysics and space science. He came to NJIT in 2003 after more than 35 years as a member of technical staff at Bell Telephone Laboratories, at about the same time that he became founding editor of the journal *Space Weather,* published by the American Geophysical Union.

In a sense, Lanzerotti’s career has come full circle with his contributions to the Van Allen Probes. As a young Bell Labs physicist in the 1960s, he helped to determine that flare-enhanced radiation in the recently discovered Van Allen belts was a primary factor in the electronic demise of the pioneering telecommunications satellite Telstar 1.

ASKING EVEN MORE SOLAR QUESTIONS

Better understanding of solar storms and improved forecasting are clearly central to investigation of the Sun at NJIT. Sufficiently forewarned of a catastrophic release of energy – perhaps a “solar Sandy” – satellites could be put into a safe mode and steps taken to protect terrestrial infrastructure. “Should we shut down now? Tomorrow? How much should we shut down? We really don’t have the ability to answer these questions with the necessary accuracy,” Gerrard says.

The answers needed could very well be forthcoming from results obtained with the tools now at the disposal of NJIT researchers, and which are shared with the international

BELOW: An illustration of the radiation belts that surround Earth with the two Van Allen probes carrying NJIT's ion composition experiment flying through them to investigate phenomena related to space weather. The graphic also shows the relative positions of the International Space Station and other satellites.

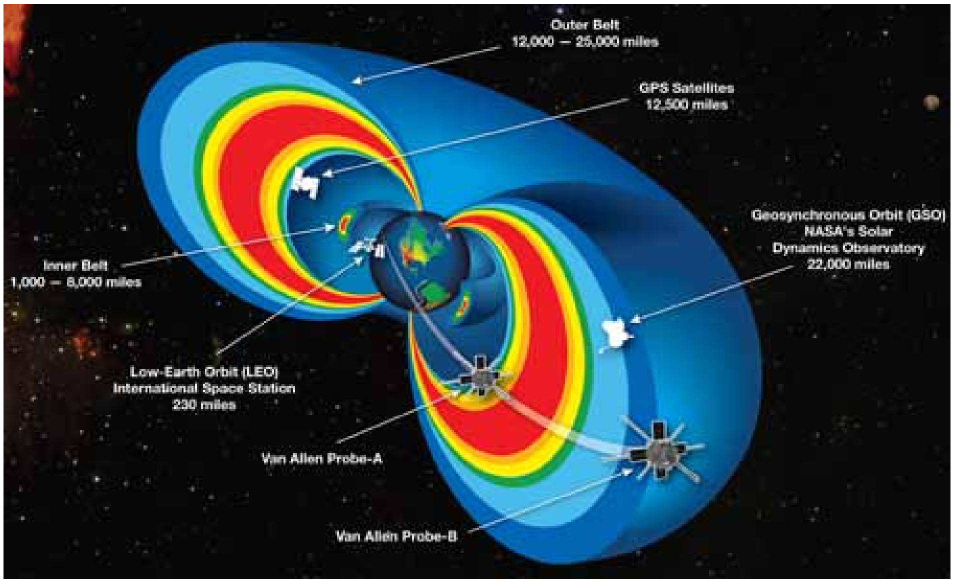


ILLUSTRATION COURTESY OF NASA

scientific community. "We are observing things in flares that are completely different from what we expected to see, and we don't understand them," Gerrard says. "We're working to understand how these observations relate to the mechanism of solar flares, how they are triggered. If we can recognize what presages a big event, we could very well be able to say that it's likely to occur in a matter of hours or even days."

New space-weather effects are still being discovered. In 2006, Gary and colleagues at Cornell, Boston University and NASA's Jet Propulsion Laboratory found that radio noise from solar bursts directly affects GPS receivers on Earth. An event occurred in December 2006 that wiped out GPS reception over Earth's entire sunlit hemisphere.

Investigation of related but poorly understood processes includes studying how the solar wind energizes Earth's magnetosphere. "We don't know how the energy deposited into the magnetosphere and Earth's upper atmosphere gets down to the surface," Gerrard admits. "We don't know the physics yet."

The essential nature of other phenomena aside from flares and coronal mass ejections is equally mysterious, and NJIT investigators are seeking to enlarge our understanding of these as part of the university's unique range of solar research. Citing one of the oldest questions about the Sun, Goode says that it's still unknown as to why the temperature at the surface of the Sun is some thousand times lower than that of the corona. However, he says, "For the first time individual heating events at the surface have been imaged by the Big Bear telescope. We can see exactly where they come from on the surface and track them all the way up to the corona."

NJIT faculty affiliated with the Center for Solar-Terrestrial Research are also working on other fundamental questions with a solar angle, among them the link between solar physics and climate change. Analysis of readily available microwave and magnetic-field data has even confirmed the presence of antimatter particles – specifically positrons – in solar flares, indicating that radio observation of the Sun and other stars can shed new light on the structure of matter at its most basic level.

"We are each working to understand a piece of a very complex puzzle and collaborating to determine how the pieces fit together," Gerrard says. "And we still don't have all parts of the puzzle. We have to work together to find the missing pieces as well." ■

Author: Dean L. Maskevich is editor of NJIT Magazine.

NJIT SOLAR SCIENCE

COMPOSING A COMPLETE SOLAR PICTURE

The Center for Solar-Terrestrial Research based on campus is the focal point of NJIT's comprehensive solar science program. The center integrates the work of NJIT researchers involved with:

- **The university's Big Bear Solar Observatory in California, the world's most powerful optical telescope dedicated to solar research**
- **Radio observation of the Sun at the Owens Valley Solar Array, also in California**
- **The Space Weather Research Laboratory headquartered in Newark, a central source of information about solar conditions kept current by data from Big Bear and Owens Valley, spacecraft, and seven other observatories around the world**
- **NJIT experiments aboard the two NASA Van Allen Probes now in orbit gauging the impact of space weather on the near-Earth radiation environment**
- **The network of Automatic Geophysical Observatory (AGO) stations managed by NJIT at the South Pole that's collecting data about the terrestrial influence of space weather, including disruptive interaction between solar phenomena and Earth's magnetic field. See "At the Edge" in the spring 2013 *NJIT Magazine* for more about the AGO program.**

Center for Solar-Terrestrial Research:
http://solar.njit.edu

Big Bear Solar Observatory:
http://bbso.njit.edu

Space Weather Research Laboratory:
http://swrl.njit.edu

NJIT ion composition Van Allen Probe experiment:
http://rbspice.ftecs.com/home.html

Automatic Geophysical Observatory network: http://antarcticgeospace.net