FOCUS

UAH Research Magazine // Spring 2016

UAH'S ADDITIVE ADVANTAGE

SURGING WITH A RAPIDLY DEVELOPING TECHNOLOGY

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The Historical Legacy of UAH

Welcome to this edition of FOCUS, UAH's research magazine. This issue highlights many accomplishments of our faculty, students and staff. We are extremely proud of the work that this university does for our customers and for the advancement of science, engineering, education, business administration and the humanities. Given the size of UAH, our research productivity is quite amazing when compared against much larger universities, which I attribute to a very hard-working faculty and staff as well as a historical partnership we have with our community.

We are fairly young, having been established as an autonomous university in 1969. Our roots, however, run much deeper than that and can be traced back to 1949, when the visionary leaders of Huntsville were successful in their campaign to establish an extension center of the University of Alabama in what was West Huntsville High School and later became Stone Middle School. Ten freshman level classes were offered to 137 students (most of them veterans of World War II) at a cost of $4 per credit hour. Success was instant, and soon 83 acres of the current campus were acquired by the city to foster the university's development. That coincided with the arrival of Dr. Wernher von Braun and his team of scientists, and an instant synergistic relationship between the academic efforts underway and the von Braun team developed.

Dr. von Braun saw the need for a partnership, and when speaking with the Alabama Legislature, he commented, "The top people in government and industry today like to improve themselves. They like flourishing research institutions. They thrive on them. If they have a bachelor's degree, they want a master's. If they have a master's, they want a Ph.D. And if they have a Ph.D., they want to teach and do research. So our young engineers with bachelor's degrees are not satisfied. If they could get advanced degrees and remain near an academic environment, they would stay with us. Lacking such opportunities they want to move to California and Massachusetts."

Throughout the ensuing years this relationship grew, with UAH always focused on our primary customers – Redstone Arsenal and NASA's Marshall Space Flight Center. Our initial mission statement from 1961 as a research institute speaks to this commitment – "The primary mission of the institute will be to provide basic research in problem areas encountered at the Marshall Space Flight Center and the U.S. Army Ordnance Missile Command."

Dr. von Braun also proved to be quite a visionary himself and reminded the Alabama Legislature in 1961 that the research institute they established in Huntsville had another purpose when he said, "As this institute grows, large corporations will be encouraged to establish research organizations nearby to form an industrial research park as part of the university complex, which in turn will give birth to major new industries throughout the State." Today, UAH is the anchor tenant of the Cummings Research Park, the second largest research park in the nation.

This university prides itself on its unique history and its strong relationship with its primary customers, the Dept. of Defense and NASA. We always have been and continue to be a very applied research university with major contributions to science and engineering. I hope you will take time to look through this issue of FOCUS magazine, which highlights many of our research contributions as well as our alumni and student successes. My office is available to provide information on the efforts featured in this magazine or any other research project ongoing at UAH. ■

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COVER: Dr. Judith Schneider's additive manufacturing research involves ensuring that printed parts can be made with a high degree of predictability about their inner structure and longevity.

UAH RANKS AMONG THE NATION'S BEST in research productivity, according to the National Science Foundation – **28TH** nationally in research expenditures per faculty and research staff.

IN ALABAMA

1ST

IN ALABAMA in expenditures in the environmental sciences including atmospheric sciences

1ST

IN ALABAMA in federally funded engineering research expenditures

NATIONALLY

5TH Federally financed aeronautical/astronautical engineering research

11TH Federally financed atmospheric sciences research expenditures

12TH Federally financed computer sciences research expenditures

13TH NASA R&D expenditures

16TH Federally financed business and management research

17TH Federally financed Astronomy research expenditures

19TH Department of Defense R&D expenditures

RESEARCH

$437 million
Five-year contract and grant research total

$97 million
Fiscal 2015 research total

$5 million
Five-year license and royalty total

PATENT TOTAL – 59

SOURCE: UAH Office of the Vice President for Research and Economic Development

THE ADDITIVE ADVANTAGE

UAH surfing the swell of a powerful future R&D wave

▲ UAH additive manufacturing researchers, from left: Front – Judith Schneider, mechanical and aerospace engineering (MAE); Phil Farrington, industrial & systems engineering and engineering management (ISEEM); Sherri Messimer, ISEEM. Back – Tom Stockan, MAE; Ken Zou, MAE; Ben Beeker, MAE; Mike Banish, chemical and materials engineering; Justin Sweitzer, MAE.

The many advantages of additive manufacturing, including cost control and precision, are pushing the adoption of the technique in plastics and metals in the automotive and manufacturing industry, as well as at NASA and in the U.S. military.

It's one thing to be able to print parts that were formerly cast and machined, but it's another to say that you have confidence in the reliability of those printed parts. To do that, you must have a high degree of confidence in the raw materials being used, in the formulas involved in their combination if more than one material is used, and in your understanding of the microstructures being formed in the finished product, as well as in the processes and systems used during manufacturing.

Scientists and engineers at The University of Alabama in Huntsville (UAH) are exploring all these areas in the rapidly evolving field.

"Now, it's all about using these processes to create new structures with unique properties in a greatly compressed timeframe, but the quality control people are saying, 'Wait a minute, will it last?'" according to Dr. Judith Schneider, a professor of mechanical engineering who works with manufacturers and the government to research the effect of temperature and strain on the microstructures of metals used in additive manufacturing printing.

▲ **Dr. Judith Schneider**, professor of mechanical engineering.

That's something she says is crucial to ensuring that printed parts can be made with a high degree of predictability about their underlying microstructure and longevity.

"Additive manufacturing is being fueled by the advances in computers and computational abilities and the advent of new alloys that can be combined in new ways," she says. "The promise of additive manufacturing is that you're no longer confined to a monolithic material with monolithic properties, so now you can design structures with varying properties."

Currently, additive manufacturing is following a two-track course similar to one Dr. Schneider says she experienced when NASA implemented the relatively new friction stir welding process in 1995. Because that process was superior, it began being used almost immediately while at the same time the fundamentals of what was occurring in the process were being studied. As that knowledge increased, so did confidence in the products of the process.

"With additive manufacturing, we are now in the process of establishing the guidelines and the practices to increase our confidence," she says. "We don't understand yet the cause and effect of the variables of the materials and the manufacturing processes. We're just in the infancy of knowing what the flaws are, and as we get new and different materials, there are going to be additional problems to study."

New applications ranging from printing spare parts for spacecraft in space to printing battlefield replacement parts for soldiers seem to be on the horizon, yet the promise of additive manufacturing is tempered by the field's infancy.

Cast and machined parts have the benefit of hundreds or even thousands of years of accumulated knowledge, providing a high degree of confidence in their performance. The additive manufacturing of metals is a completely different technology that results from metal being instantaneously cooled in a process that Dr. Schneider says is similar to "splat cooling." That rapid cooling creates much different micro-structures in metal parts than in conventional cast or machined parts. The structures formed and strains placed in the microstructures of printed metals are not yet well understood.

"If we can understand fundamentally how these materials behave in an additive manufacturing environment, then we won't have to test those materials anymore," she says. "I look at how materials behave in extreme conditions." Her past research has examined material responses to cryogenic temperatures and also high-strain rate conditions.

Bimetallic printing – the ability to co-print disparate metals in a single part - is seen as one of the great potentials for additive manufacturing, and Dr. Schneider is exploring the nature of the microstructural bonds between various metals to unlock fundamental understanding of the interaction of these materials and how they best can be combined in the printing process to form a strong bond.

"We're not there yet, but that's the promise," she says of bimetallic printing. "That's the holy grail of additive manufacturing."

COLLABORATIVE BONDS

Dr. Phillip Farrington, professor of industrial and systems engineering, reaches out to defense, industry, private foundations and professors in other disciplines on the UAH campus in a quest to understand and perfect bimetallic additive manufacturing, a process that could save myriad machining steps if understood.

"The primary question we are trying to address is, can we bond dissimilar materials together using additive manufacturing technologies," says Dr. Farrington. "There has been some limited success bonding copper and Inconel, so we hope to build on that earlier work to advance our research."

Some additive manufacturing technologies, such as Laser Engineered Net Shaping (LENS) or welding-based additive manufacturing processes, present the possibility of creating bimetallic parts in one or possibly two steps, an achievement Dr. Farrington says could substantially reduce production time and costs.

"Both NASA and the U.S. Army are interested in this type of application because they have systems that would benefit from the ability to create bimetallic joints," he says.

A multidisciplinary UAH Additive Manufacturing Research Team has received a grant from the Presto Foundation to study the use of additive manufacturing technologies in the development of Dept. of Defense systems.

"When the opportunity to submit this proposal to the Presto Foundation came about, Dr. Sherri Messimer and I discussed other faculty who had the background to support the research, and as a result Dr. R. Michael Banish, an associate professor from the Department of Chemical and Materials Engineering, and Dr. Qiuhai "Ken" Zuo, an associate professor from the Department of Mechanical and Aerospace Engineering, joined the team," says Dr. Farrington.

"Dr. Messimer developed and teaches a course on additive manufacturing for the Industrial & Systems Engineering and Engineering Management Department (ISEEM)," he says. "Dr. Schneider was invited to join the team as soon as we got word she was coming to UAH because of her extensive work on additive manufacturing."

The team knew that the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMR-DEC) and Marshall Space Flight Center (MSFC) were both using additive manufacturing technologies.

"We invited them to help us refine the question we were addressing, and they both indicated interest in using additive manufacturing technologies to produce bimetallic joints," Dr. Farrington says. "Also, MSFC has provided material to an additive manufacturing equipment manufacturer that has agreed to produce test articles for our study, at no cost to UAH."

That alliance has allowed the UAH team to expand and augment its base study.

"Beyond advancing the use of additive manufacturing for creating bimetallic joints, my personal goal for this project is to enhance further collaboration on additive manufacturing research between UAH, MSFC and AMRDEC," says Dr. Farrington.

There could be wide-ranging impacts. Additive manufacturing processes are a key research focus of the Southern Alliance for Advanced Vehicle (SAAV) Manufacturing Center, which promotes greater research and development ties between vehicle manufacturers and its academic partners. SAAV began in 2014 a partnership between UAH, Auburn University and Tennessee Technological University and was funded by a National Science Foundation grant.

▲ **Dr. Paul Collopy**, chair of UAH's Industrial & Systems Engineering and Engineering Management Department.

"We have potential member organizations interested in joining the center who are interested in this research," Dr. Farrington says.

SYSTEMIC APPROACH

Dr. Paul Collopy, ISEEM's chair, looks at the field with a systems engineering approach.

"What I'm looking at is how the additive manufacturing process fits the bigger picture, as far as making rockets and jet engines and more complicated systems like that," says Dr. Collopy, who formerly worked for the National Science Foundation as director for the Engineering Systems Design and Systems Science programs.

"The fastest growing modern firms, like Google, Cisco and Twitter, all have a core competence of developing systems out of software," he says.

"In software development, you can try daring things, and if they don't work, you say, 'Well, I lost a day.' The neat thing about additive manufacturing is, you can experiment on a similar cycle: think up a daring design, push a button and you get your part out so you can test it."

Additive manufacturing has the ability to take months and even years off the time between design and physical part testing, and Dr. Collopy says that is liberating for engineers working with complex cutting-edge technologies.

Build and break testing is immediately rewarding, he says.

"We love the idea of testing in software simulation, but every real engineer who is working with a complex system or a complicated problem, they want to get hardware and break it," says Dr. Collopy. "Then you really know the design's abilities, its durability and its capabilities."

"When you are engineering technically challenging hardware, you really want to get to hardware fast," Dr. Collopy says, and that's where the materials, structural and process knowledge all come together in a systems engineering approach. "However, building things fast really doesn't work if what you build is not quality, and that is the current research frontier in additive manufacturing."

Rapid production capability for numerous variations on a design removes limits to engineering that are present because of subtractive manufacturing processes previously used. In subtractive manufacturing, raw materials are shaped and removed rather than added and formed to achieve a product.

> "Additive manufacturing is being fueled by the advances in computers and computational abilities and the advent of new alloys that can be combined in new ways. The promise of additive manufacturing is that you're no longer confined to a monolithic material with monolithic properties, so now you can design structures with varying properties."
>
> – Dr. Judith Schneider

"What you design is shaped by your manufacturing processes," says Dr. Collopy. "Additive manufacturing is a completely different process that allows you to do things you couldn't do before."

He points to work by Jonathan E. Jones with NASA's NanoLaunch effort at MSFC, which is using additive manufacturing to create scaled test vehicles that have the potential to propel programs across the "valley of death" between laboratory demonstrations and actual in-flight environments.

"He's trying to explore a completely different way of making rockets," Dr. Collopy says. "He doesn't have to wait around on a lengthy procurement process. He can go right down to the NASA Marshall Space Flight Center 3-D printing shop and print what he needs in an afternoon. If you go over to NASA to look at what they've got, they've got a room full of 3-D printing machines on a large scale."

Speaking of scale, Dr. Collopy notes that ISEEM's Dr. Messimer has studied larger-scale additive manufacturing at Penn State, the home of a facility full of additive manufacturing machinery "that is very nearly on a large manufacturing level."

And in a new twist at UAH's Manned/Unmanned Collaborative Systems Integration Laboratory in Olin B. King Technology Hall – a collaboration with the U.S. Army's Research, Development and Engineering Command (RDECOM) at the U.S. Army Research Laboratory – students working with autonomous systems in a gaming environment now have access to a 3-D printer, as well.

"This takes it out of the software-only design and testing setting into a new area," Dr. Collopy says. "Our vision is that a student designs an autonomous tracked vehicle in simulation using the software and then can 3-D print the structure for it right there. We then add the electronics, motors and other hardware to that to get a working model. It adds a new dimension to what they are doing."

Additive manufacturing is experiencing exponential growth that is in its own way additive, Dr. Collopy says, though he notes that the human mind favors identifying linear growth but has difficulty perceiving the exponential kind. Exponential growth builds on prior pillars of knowledge and experience, so that initially the curve may look flat but then it takes a sudden upward turn that is very similar to the shape of an ocean wave. UAH is riding that swell.

"For example, for additive manufacturing to grow, you have to have people experienced in additive manufacturing," Dr. Collopy says. "But you can't get those and you can't get that experience until you have scaled up to the kinds of larger manufacturing environments that can provide them. Once those are in place, things can move quickly. That's just one example of how things must grow exponentially, building on what we have and what we learn."

Some projections show that a matured additive manufacturing field may still only account for 2 percent of all parts made, Dr. Collopy says, but if most of those parts are made to telescope development times, that will free engineers to cheaply test a myriad of approaches to any one problem rather than singling out only a few possible solutions due to time and cost constraints.

"For testing purposes, it's going to change how we make complex systems." ■

THE SYSTEM IS THE SOLUTION

For Dr. L. Dale Thomas, the system is the solution and systems engineering is how you get it to work. "It's about how you get all the pieces of a complete system to work together so you can get them to do what you want them to do," he says. The work of the eminent scholar and professor of systems engineering in the Industrial and Systems Engineering and Engineering Management Department might be compared to a watchmaker with the goal of engineering everything to tick. But there's an important difference. "All systems are ultimately operated or controlled by people, so you have to take that into account," he says. "Even the so-called 'autonomous systems' are ultimately used by people." He's had plenty of experience taking the human element into consideration under a variety of conditions as the associate center director (technical) for the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center, as the NASA Constellation program manager and as the deputy program manager from 2007-2010, providing leadership for the Constellation Program Office at Johnson Space Center in Houston, Texas. His research focuses on systems engineering theory, both from a scientific and a practical perspective. "Most engineers are at heart realists," he says. "Once in the middle of attempting to solve a very complex technical issue for the Ares launch vehicle, I reminded a colleague that the payload that was launched aboard that rocket was people. He later thanked me, acknowledging that he was too narrowly focused on his part of the rocket. " His research areas include systems complexity, systems integration, technical performance measurement and systems engineering planning and management. He has authored numerous technical papers and chapters in two textbooks, and served as editor for the systems engineering textbook "Applied Space Systems Engineering." He co-chaired the Space Systems Committee of the International Astronautical Federation, and is a member of the American Institute of Aeronautics and Astronautics (AIAA) and the International Council on Systems Engineering (INCOSE). ■

DEFENDING THE UNITED STATES

As deputy to the commander for the U.S. Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT), Julie Schumacher provides leadership to an organization charged with defending the United States against ballistic missile attack and providing data gathered from space to users in organizations across the Dept. of Defense.

Schumacher, the senior civilian in the three-star command, manages more than 3,700 space and missile defense professionals conducting operational missions, developing future capabilities, and conducting scientific research and technology development.

"We perform highly specialized and technical missions for both the Army, the U.S. Strategic Command and a host of other national organizations globally across 11 different time zones."

The command manages the Ronald Reagan Ballistic Missile Defense Test Site in the Marshall Islands. Missile tests are controlled remotely from the facility shown in this photo – in close proximity to UAH.

"From over 6,500 miles away, our team operates a suite of world-class radars and optical platforms located at Kwajalein. Our instrumentation, facilities and test team provide a one-of-a-kind capability for our nation."

Schumacher initially received a Bachelor of Science in education from the University of Alabama. After teaching high school band for a year, she caught the engineering bug and decided to pursue a Master of Science in industrial and systems engineering at UAH.

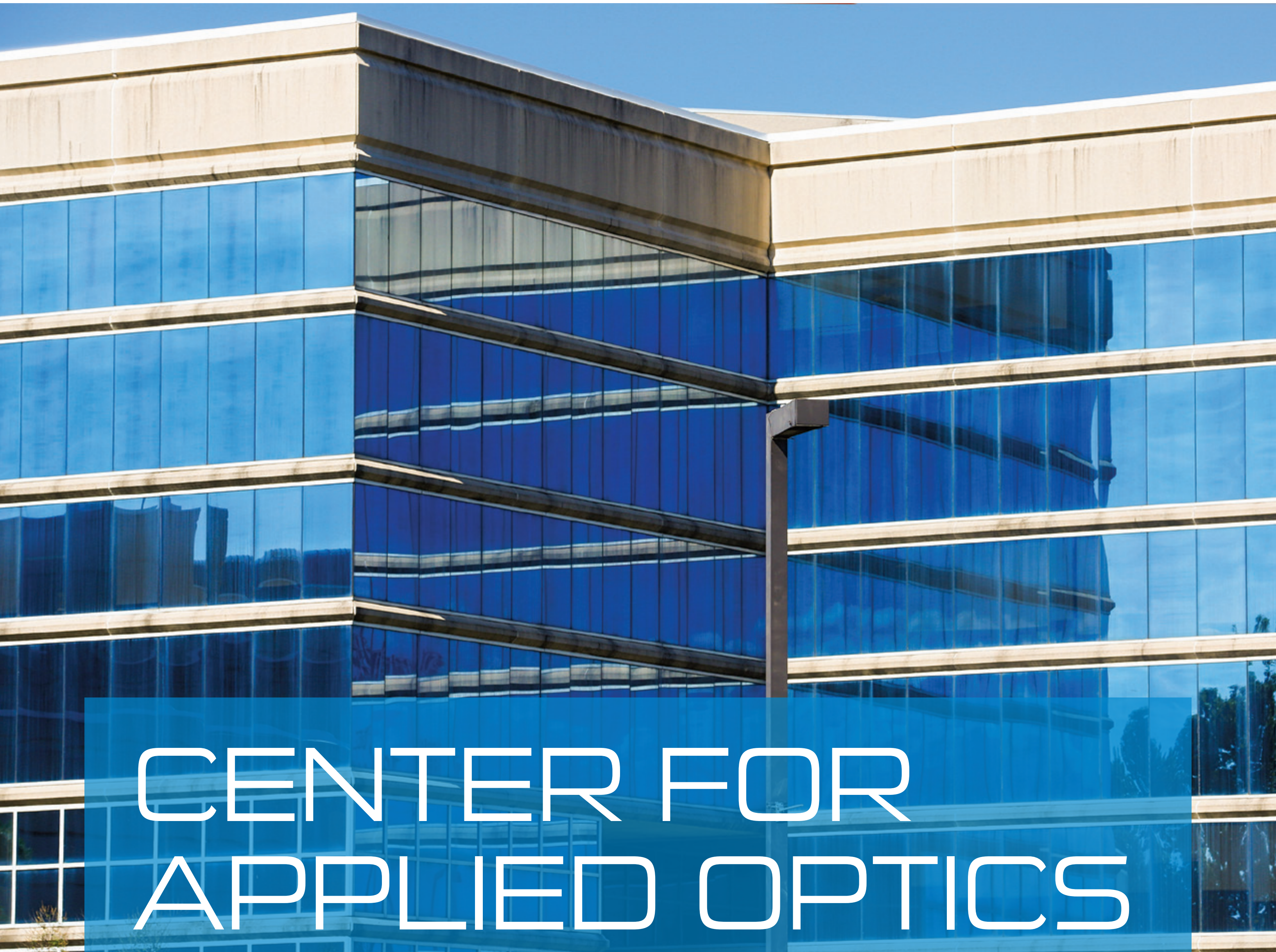
"Going from a bachelor's in music education to a master's in engineering required many prerequisites and raised quite a few eyebrows. However, my advisor at UAH, Dr. Dick Wyskida, was supportive. He knew I was determined and laid out a path for me to get there."

Schumacher served in engineering, test and program manager roles across the Dept. of Defense and industry. She was selected for the Senior Executive Service at the Missile Defense Agency as the deputy director for Test, and she served as director of the Technical Center at USASMDC/ARSTRAT before assuming her current role as deputy to the commander.

"We have many UAH graduates and students on staff and also faculty involved in our programs. Having a research institution so close to Redstone Arsenal really enhances the support we can provide to the warfighter. UAH is a great partner and I'm proud to be a UAH alumnus." ■

NEW AUVSI PILOT CLUB PROVES POPULAR

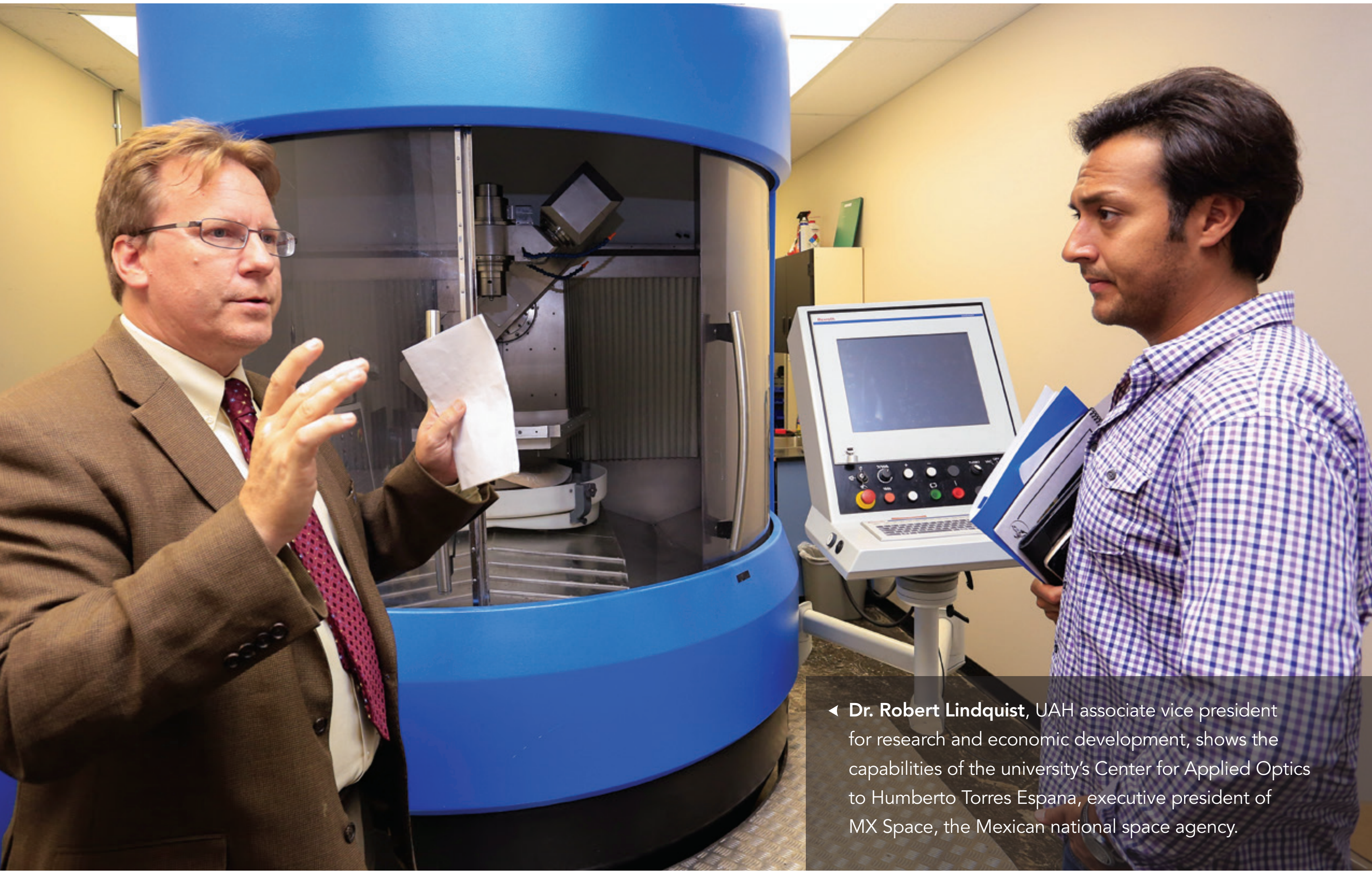
At its formation, over 80 students joined the Association of Unmanned/Vehicles Systems International (AUVSI) Pathfinder Student Club at UAH, one of just six universities involved in a national pilot program to establish the student clubs/associations. The UAH club connects students to the 7,500-member AUVSI, the world's largest organization devoted exclusively to advancing the unmanned systems and robotics community. The UAH club also connects the students with the local AUVSI Pathfinder Chapter, the largest chapter within AUVSI, with members from industry, government and academia who are experts in the field of unmanned systems. "Our student response has been tremendous," says Dave Arterburn, director of UAH's Rotorcraft Systems Engineering and Simulation Center (RSESC), who lead the establishment of the UAH club. "The UAH student club compliments the curriculum areas at UAH by providing the students with additional hands-on experience and interaction with practicing engineers and companies working on unmanned aerial systems," he says. Dr. Virginia "Suzy" Young, director of UAH's Office of Proposal Development, is a national AUVSI board member and leads the national pilot effort. "These pilot programs are establishing best practices and laying the foundation for how we can offer benefits to students and keep them involved," says Dr. Young. Club members have scholarship opportunities; increase their visibility to the unmanned systems community; are eligible for sponsorship of projects; interact with industry and government in the area; can attend conferences and symposiums; can get help with career planning and resumes; have co-op, internship and job postings opportunities; and have opportunities to present their work by speaking at meetings and conferences or at poster sessions, among other membership benefits. The UAH club is a further extension of UAH's long involvement and experience in the area of unmanned systems for both ground and air as a partner of the Army and NASA, Dr. Young says. "Populating the STEM (science, technology, engineering and mathematics) pipeline with students that have the required knowledge, hands-on skill sets and established relationships with industry and government means those students can step into these jobs upon graduation with an advantage over other university students," she says. ■



CENTER FOR APPLIED OPTICS

an innovator in large optics and nanoscale photonics

COMBINING CLASSICAL OPTICS RESEARCH WITH NANO AND MICRO DEVICES, THE UAH CENTER FOR APPLIED OPTICS (CAO) CONTINUES ITS 30-PLUS YEAR LEGACY AS A GATEWAY BETWEEN INDUSTRY AND ACADEMIA. Dr. Patrick Reardon, associate CAO director and assistant professor in the Electrical and Computer Engineering Department, says its goal is to advance optical science and engineering research and development in support of high technology educational, industrial and government programs.



Dr. Robert Lindquist, UAH associate vice president for research and economic development, shows the capabilities of the university's Center for Applied Optics to Humberto Torres Espana, executive president of MX Space, the Mexican national space agency.

"We design elements, systems, and fabricate optical elements and systems. Then we help in their deployment and operation in the field."

For example, a company approached the CAO for help after winning a proposal from the Defense Advanced Research Projects Agency (DARPA) to develop a high resolution, wide field of view persistent aerial surveillance system.

"The company's specialty was writing software that allows you to take a virtual tour of homes, and somehow they won a DARPA contract to build a camera," Dr. Reardon says. "They knew which detectors they wanted to use but needed our help to make it work. We developed optical systems that flew and provided good imagery."

The purpose, he says, was to allow a system to record a full day of video over a city at very high resolution for use as a forensic tool. If a criminal or terrorist event occurs, it can help track the offenders both before and after the event.

"The patent on it just came through," Dr. Reardon says. "Our tasks were to figure out the optics and optomechanical side, and we succeeded. We had the system completed in eight months, so it was a very quick project."

Dr. Reardon says the CAO has promoted the device as a camera system for rapid mapping.

"It can be used in defense applications, and one of the groups we've talked to is the Alabama Emergency Management Agency (AEMA). Their interest is rapidly documenting large areas of devastation from a tornado or hurricane with lots of high-quality imagery."

Dr. Reardon says it can be especially useful if several devastating storms occur within a short time period.

"AEMA needs to be able to determine which storm caused the actual damage at a site to avoid complications with federal funding," he says.

Meanwhile, at the CAO's affiliated Nano and Micro Devices Center (NMDC), research scientist Dr. Yongbin Lin is developing a supersensitive nanodevice that will provide extremely early detection of cancers and other diseases in a small package, about the size of a lunchbox.

The nanodevice holds promise for early disease detection in developing countries that can't afford elaborate equipment and offers U.S. patients the prospect of faster test results during an in-office procedure at their doctor or other point-of-care provider.

"We don't have to send your blood sample anywhere," says Dr. Lin. "We just bring this to your bedside."

The sensitivity of the equipment holds promise for finding cancer at a very early stage, even while it is at a small cluster of cells level, says Dr. Lin. "At that stage, it is easier to treat."

A nanoprobe that's 125 microns in diameter with gold nanodots on a 4-micron fiber core is at the heart of the machine. The probe is coated with a biochemical link so that specific antibodies for the particular test will attach to it.

"The Center for Applied Optics is an exciting place to work because our researchers have been developing innovative solutions in both large optics that can map the earth and space as well as photonics that can sense binding events on the nanoscale," says Dr. Robert Lindquist, UAH associate vice president for research and economic development and CAO director.

The NMDC is a national user facility that specializes in leading technology and innovation on a broad range of micro and nano projects. State-of-the-art facilities allow cutting-edge research and development of devices and components that require nano- and microfabrication.

Funded through grants and contracts ranging from small business to government, the CAO is made up of 15 faculty and staff, plus other affiliated faculty and staff from other UAH academic departments.

The CAO provides optical and optomechanical design and analysis, optical fabrication (including diamond turning and CNC polishing to make parts up to 0.3m and 0.7m diameter, respectively), optical metrology, holography, and testing and prototyping of state-of-the-art optical components and systems, in addition to its comprehensive 7,000-square-foot clean room facilities.

Dr. Reardon says that often graduate and master's level students work on Graduate Research Assistantships (GRAs) at UAH through grants from the National Science Foundation, NASA and the U.S. Army.

"Some students just like to do research projects," Dr. Reardon says. "This is how we bring students into the process. In fact, last spring, I guided a Senior Design Class team from UAH's OPE (Optical Engineering) program to create a phone app that can perform optical testing of a mirror. It was a fun project for the students, and it provided some great preliminary results on a research path I'm interested in."

The experienced faculty and laboratory resources make the CAO an ideal place for research. The UAH Optics Building was designed and built for optics research with its central core of laboratories, which are vibration isolated from the office and student spaces.

Dr. Reardon says researchers are discovering unique applications of optics for numerous space, military, industrial and medical uses.

Among the many projects at the center, he says, researchers are currently evaluating the characteristics of air turbulence and ways to correct it.

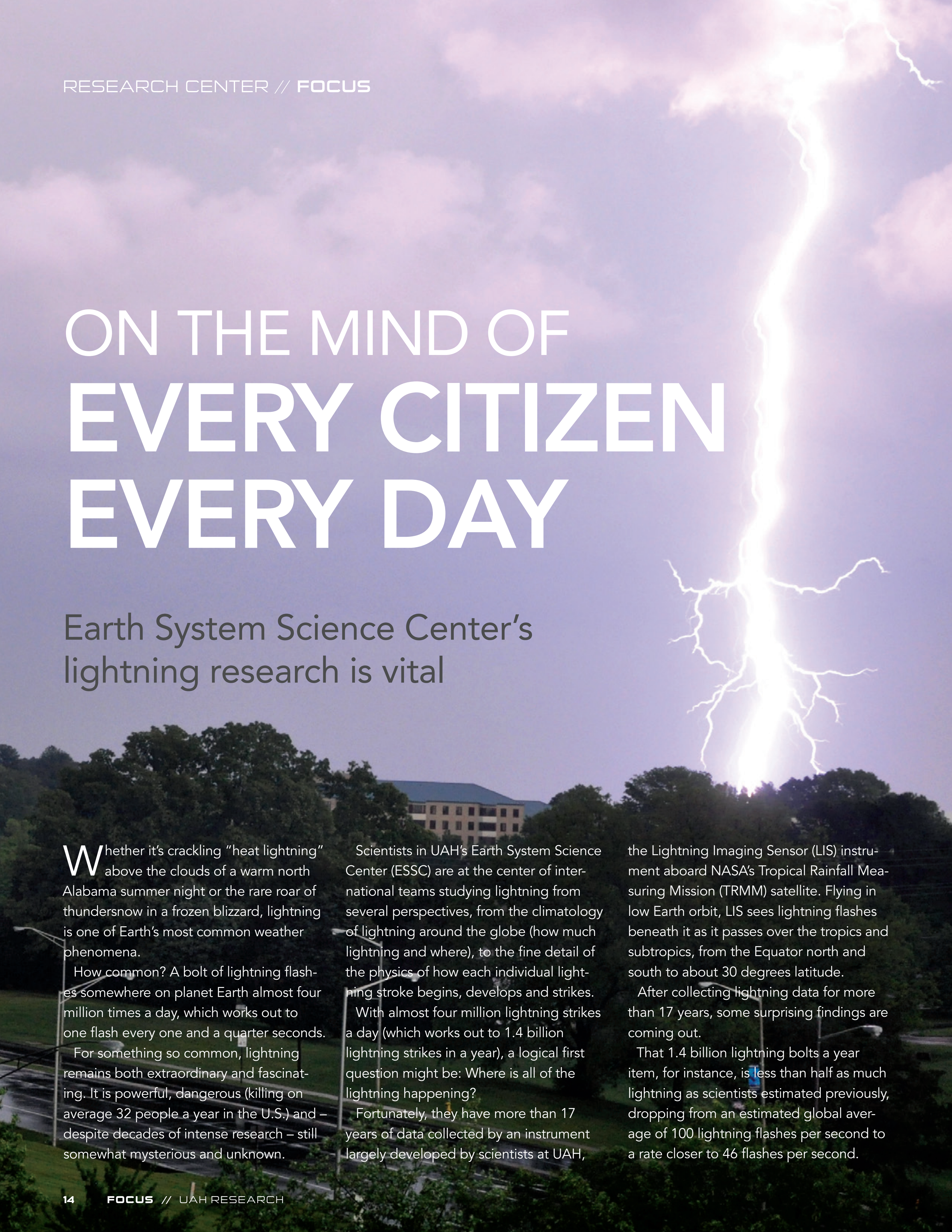
"When you look at the stars, they twinkle and it's very pretty," Dr. Reardon says. "But that twinkling causes problems for people who want to do astronomy because the atmosphere affects the propagation of light.

"Sometimes it gets to you, sometimes it goes to another location. Instead of collecting light, we want to be able to project light in optical communications and in laser weapons. If you want to direct a lot of laser energy on a target you need to be able to account for the atmosphere."

Another major project for the CAO is the optical development and testing of the 18 primary mirror segments of the NASA James Webb Telescope (JWST) to make sure the telescope sees everything it should see. The observatory is designed to look at stars and galaxies on the distant edges of the universe. It is scheduled to launch in 2018.

The mirror is made of beryllium and has to withstand the extreme cold of outer space. Getting a perfect mirror for the telescope meant testing them at their eventual operational temperature (35K or -400F) in conjunction with Marshall Space Flight Center's X-ray Calibration Facility. During testing the mirror deformed under the extreme cold conditions.

"Our job was to measure the deformation induced by the cryogenic temperatures. If a bump formed when cold, the mirror was then polished down at that spot, the opposite of the bump, so that when it gets cold in space, it cryo-deforms into the correct shape," Dr. Reardon says. "Those mirrors were completed two years ago, with the CAO's Dr. James Hadaway leading the effort. He is still working on JWST, supporting the full telescope testing in Houston."



ON THE MIND OF EVERY CITIZEN EVERY DAY

Earth System Science Center's lightning research is vital

Whether it's crackling "heat lightning" above the clouds of a warm north Alabama summer night or the rare roar of thundersnow in a frozen blizzard, lightning is one of Earth's most common weather phenomena.

How common? A bolt of lightning flashes somewhere on planet Earth almost four million times a day, which works out to one flash every one and a quarter seconds.

For something so common, lightning remains both extraordinary and fascinating. It is powerful, dangerous (killing on average 32 people a year in the U.S.) and – despite decades of intense research – still somewhat mysterious and unknown.

Scientists in UAH's Earth System Science Center (ESSC) are at the center of international teams studying lightning from several perspectives, from the climatology of lightning around the globe (how much lightning and where), to the fine detail of the physics of how each individual lightning stroke begins, develops and strikes.

With almost four million lightning strikes a day (which works out to 1.4 billion lightning strikes in a year), a logical first question might be: Where is all of the lightning happening?

Fortunately, they have more than 17 years of data collected by an instrument largely developed by scientists at UAH, the Lightning Imaging Sensor (LIS) instrument aboard NASA's Tropical Rainfall Measuring Mission (TRMM) satellite. Flying in low Earth orbit, LIS sees lightning flashes beneath it as it passes over the tropics and subtropics, from the Equator north and south to about 30 degrees latitude.

After collecting lightning data for more than 17 years, some surprising findings are coming out.

That 1.4 billion lightning bolts a year item, for instance, is less than half as much lightning as scientists estimated previously, dropping from an estimated global average of 100 lightning flashes per second to a rate closer to 46 flashes per second.

One of the discoveries was the high level of lightning activity over several large lakes, including Lake Maricaibo in Venezuela and Lake Victoria in Africa. Maracaibo earns the title of the world's lightning hotspot, with lightning occurring 297 days (or mostly nights) a year. Lightning there is so common, ancient Caribbean sailors used the flashing storms over the lake as a kind of lighthouse.

While most of Earth's lightning is during the day, when heat from the sun causes convection, Maricaibo is unique, says Dennis Buechler, an ESSC research associate who has been working with LIS data since it was launched. "One of the first things we saw, it was lighting up at night instead of during the day. It's a very warm lake and it doesn't cool at night. The wind flows converge at the surface, which causes a rising motion. And that's the recipe for lightning."

The storms that form over Lake Maricaibo aren't powerful, but are both frequent and long lasting, Buechler says. "We also found some other lakes, like Lake Victoria, where you have this warm lake where you have more lightning at night than during the day."

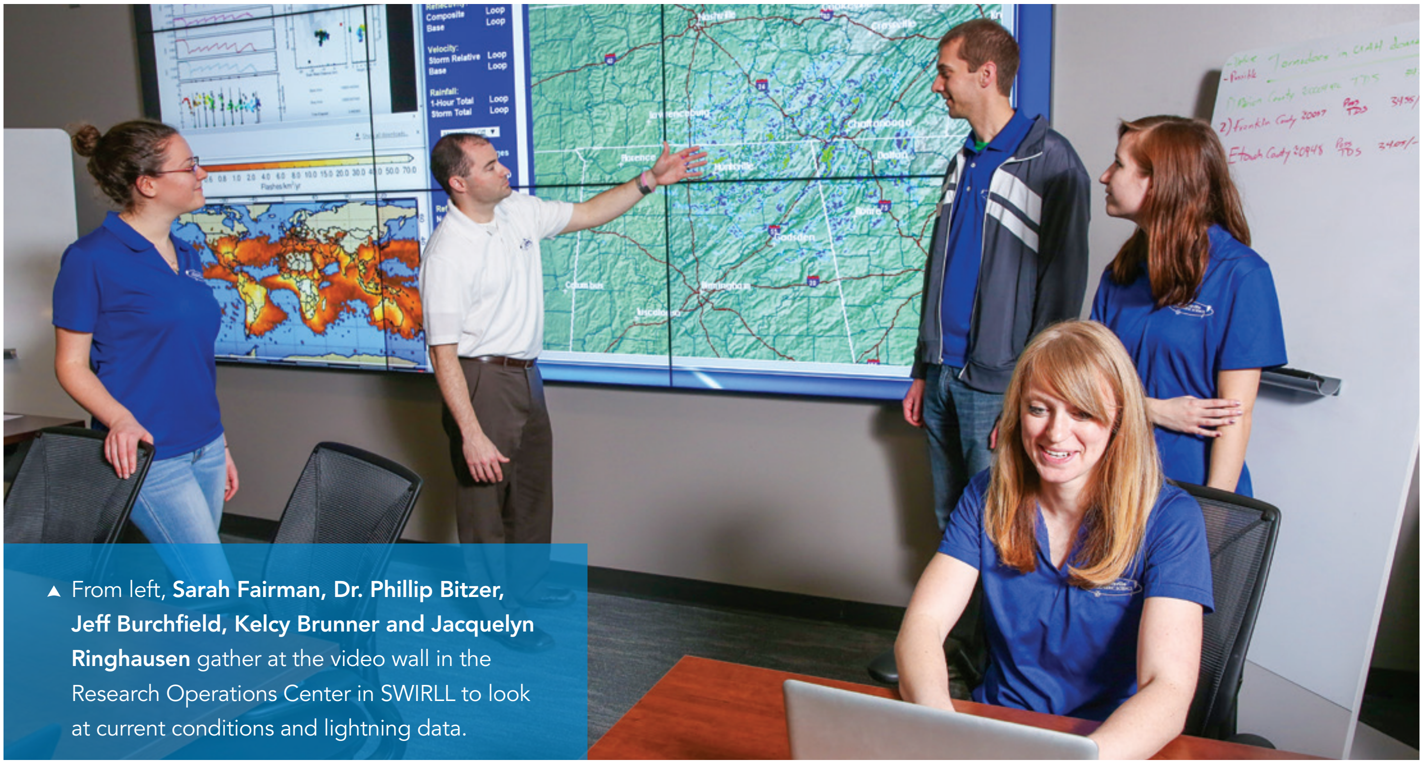
In one of the first lightning surveys done using LIS data, the Congo River basin was thought to be the hottest lightning location on Earth. But additional years of data let Buechler develop a global lightning grid with finer resolution, about one tenth of a degree per grid square instead of the earlier one half of a degree.

When a colleague at the University of Sao Paulo analyzed the new data grid, it was discovered that each square kilometer at Maracaibo had about 232.5 lightning flashes each year. The next most active spot was near Kabare, in the Democratic Republic of Congo, with 205.3 lightning flashes per kilometer each year.

By comparison, the most active lightning hotspot in the continental U.S. is over the Everglades near Ft. Myers, Fla., with a rousing 79 flashes per square kilometer every year. It ranks 122nd globally.

The lightning climatology developed using LIS will be expanded starting first in August, when a second LIS instrument largely developed and tested at UAH is scheduled to be mounted on the International Space Station, and again in October, when the Geostationary Lightning Mapper (GLM) – which UAH played a major role in developing – is launched aboard the new National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite R-Series (GOES-R) weather satellite.

And 17 years of LIS data may serve other purposes. UAH's Dr. Philip Bitzer, an assistant professor of atmospheric science,



▲ From left, **Sarah Fairman, Dr. Phillip Bitzer, Jeff Burchfield, Kelcy Brunner and Jacquelyn Ringhausen** gather at the video wall in the Research Operations Center in SWIRLL to look at current conditions and lightning data.

▲ **Jacquelyn Ringhausen** checks two cameras, one regular and one high speed, used for video of lightning and spectroscopy.

is using LIS data to learn more about lightning by breaking flashes into their smallest pieces. The goal is to find new ways to forecast severe weather using data from the GLM when it becomes available.

"Most of the research to this point focused on counting lightning flashes and trying to connect changes in the lightning numbers to severe weather events," says Dr. Bitzer. "We propose to dive down below the flash level, to look at the individual parts of the flash.

"We want to look at the more fundamental aspects, to see how lightning stroke properties change, how they evolve and how those changes relate to the parent storm, and whether we can find a way to use that information to relate back to storm dynamics a little better."

A typical cloud-to-ground lightning "flash" is made of several distinct pieces, starting with a weak, dim leader that might climb into the atmosphere in several stages until it connects the positively charged surface to the negatively charged cloud above.

"Then you will see the ground stroke flicker, and that flickering is individual strokes," Dr. Bitzer says. "All of that together becomes a flash."

Satellite instruments provide vast quantities of quality data and ground-based lightning sensor networks collect more useful data. These sensors are being used to study the relationships between lightning and powerful storms by UAH scientists.

For instance, a sudden jump in the number of lightning strikes inside a garden-variety thunderstorm might one day give forecasters a tool for predicting severe weather and issuing timely warnings.

The sudden increase in lightning is one sign a normal storm is rapidly evolving into a supercell, with a large rotating updraft (or mesocyclone) at its heart.

"Supercells are more prone to produce severe weather events, including damaging straight line winds and large hail," says Sarah Stough, a UAH graduate student in atmospheric science. "Supercells also produce the strongest and most deadly tornadoes."

Because the sudden increase in lightning strikes happens either at the same time or within minutes of a supercell forming, UAH researchers are developing algorithms that might be used by forecasters to issue timely severe weather warnings.

"We can use the lightning jump as a nowcasting tool for supercells," says Dr. Larry Carey, chairman of UAH's Atmospheric Science Department. "If the meteorology of the day suggests supercells are likely, the jump can tell us when and where that is happening."

Other ESSC scientists are using satellite instruments (not LIS) and Doppler radar to develop tools for forecasting which convective "pop up" storms might soon produce lightning, and when that lightning is likely to begin.

Severe weather research has one inherent advantage over some more esoteric fields: Everyone has to deal with the weather.

"We deal with a scientific topic that's actually on the mind of every citizen every day," says Dr. John Christy, the ESSC director. "That makes it a more exciting and purposeful field to study, because people plan their daily lives based on what the weather might do." ■

UAH SCIENTIST

AT CENTER OF ACTION UPON FIRST DETECTION OF GRAVITATIONAL WAVES

UAH's Dr. Tyson Littenberg was at the center of the action when gravitational waves were discovered in the fall by twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, La., and Hanford, Wash.

The discovery rippled through popular culture and the scientific world because it provides physical proof of gravitational waves traveling through the universe that had been predicted 100 years ago by Dr. Albert Einstein's general theory of relativity.

Involved in LIGO-related research since 2007, Dr. Littenberg helped the LIGO team to develop sophisticated computer algorithms that combed through data and extracted physical information from the detection once it was made on Sept. 14. After coming to UAH, the UAH Center for Space Plasma and Aeronomic Research (CSPAR) scientist applied for UAH to become a member of the LIGO Scientific Collaboration. UAH was accepted in 2015.

▲ **Dr. Tyson Littenberg** says the scientific world changed forever on Sept. 14.

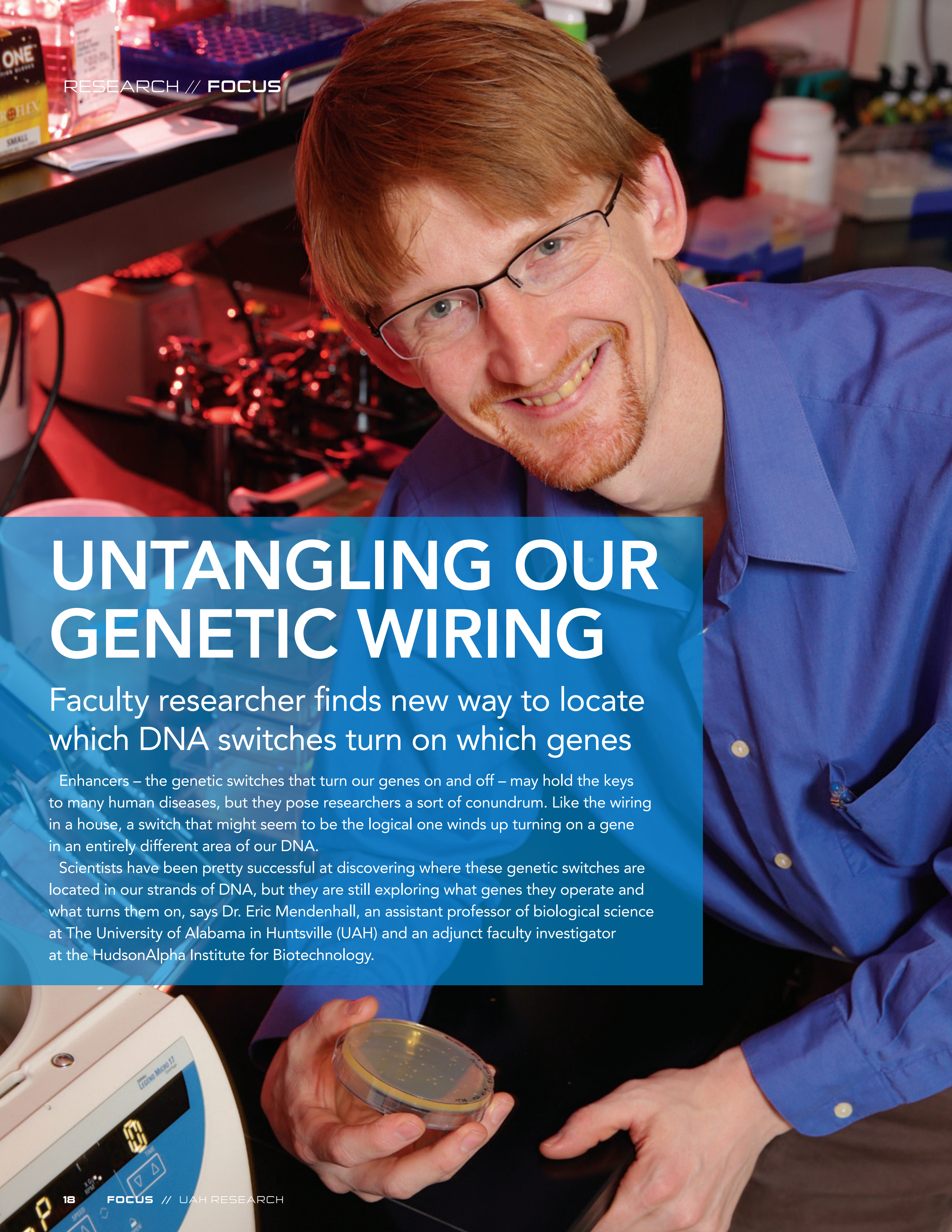
"Our job is to take a small segment of data that has been identified as being potentially interesting, and do an exhaustive analysis to figure out what the gravitational wave signal looked like in our detectors," he says. "It took months of analysis, reanalysis, checking, rechecking, and re-rechecking of the results before we were ready to say with confidence that we had something, and precisely what we had. The stakes are so high, we tried over and over again to prove ourselves wrong until, exhausted, we admitted defeat and said, 'This is really it.'"

The LIGO discovery has broad connections in the fields of fundamental physics, astrophysics and astronomy.

"The significance of this discovery cannot be overstated. Gravitational waves are the last missing confirmation of Einstein's general theory of relativity – our most fundamental understanding of how physics works in the macroscopic world," Dr. Littenberg says. "The scientific world changed forever on Sept. 14."

Gravitational waves come to us from a regime of gravity that we have never been able to test before, Dr. Littenberg says.

"Almost everything we know about the universe has come to us from light. Now that we are receiving signals from the gravitational universe, we can learn about what is going on out there with a brand new 'sense,'" he says. "Thanks to this discovery we have finally turned on the 'sound track' of the universe. With it we have impressive detail about the collision of two black holes a billion light years away and we would never have known about it from telescopes – even inconceivably futuristic ones. The thrill is that we know there will be more." ■



UNTANGLING OUR GENETIC WIRING

Faculty researcher finds new way to locate which DNA switches turn on which genes

Enhancers – the genetic switches that turn our genes on and off – may hold the keys to many human diseases, but they pose researchers a sort of conundrum. Like the wiring in a house, a switch that might seem to be the logical one winds up turning on a gene in an entirely different area of our DNA.

Scientists have been pretty successful at discovering where these genetic switches are located in our strands of DNA, but they are still exploring what genes they operate and what turns them on, says Dr. Eric Mendenhall, an assistant professor of biological science at The University of Alabama in Huntsville (UAH) and an adjunct faculty investigator at the HudsonAlpha Institute for Biotechnology.

Dr. Eric Mendenhall is part of a team that developed a new way of identifying the proteins that control our genetic switches.

"Our DNA is the worst wiring ever," Dr. Mendenhall says, "because a gene can be controlled by a switch that is far, far away."

Plus, the proteins that turn on these switches can be likened to the various residents of that house. It's not always easy to figure out which one turned on which switch.

"We were trying to identify the proteins that turn on the switches," says Dr. Mendenhall. "They're called DNA binding proteins and they bind to DNA and turn on the switch, but we could never easily identify what proteins are turning on which switch."

As part of the National Institutes of Health (NIH) funded Encyclopedia of DNA Elements (ENCODE) consortium, Dr. Mendenhall – along with Dr. Dan Savic, Kim Newberry and Dr. Chris Partridge from the Dr. Rick Myers Lab at HudsonAlpha – developed a new way of identifying the proteins that control the switches and thereby to locate by correlation the genetic switches on specific points on DNA, called enhancers, that control when a gene is turned on or off.

The team combined two separate, less efficient techniques to yield a faster and more reliable response. It began with ChIP-seq, a common method for understanding DNA binding proteins but one that works only 5 percent of the time. With it, researchers can attach antibodies to the proteins that are part of the on/off system and then use those antibodies to locate the enhancers.

Then they added CRISPR/Cas9, adapting it to place a locating beacon in the proteins that would allow them to more easily find the sites where specific transcription factor proteins were binding to the genome.

The result is CETCh-seq, which Dr. Mendenhall says should rapidly speed up the scientific understanding of both the proper functioning and the possible malfunctioning of enhancers.

The team described the CETCh-seq method in a paper published recently in the journal *Genome Research*. Co-authors of the paper include Dr. Partridge, Newberry, Sarah Meadows, Brian Roberts, Dr. Mark Mackiewicz and Dr. Myers, all of HudsonAlpha, Sophia Smith of UAH and Dr. Mendenhall.

"Our labs work really closely together on several projects and that joint effort with Eric is important to our research on transcription factors," says Dr. Myers, president and science director of HudsonAlpha and leader of the lab that collaborated with Dr. Mendenhall. "We're excited that this new technique is already looking like it's making a big difference."

The team is currently performing follow-up studies to show a causative relationship between specific switches and the genes they control. There are 2,000 of these DNA binding proteins in the human body and science only knows which switches about 300 or so of them control.

"What we have made is a method to identify a lot of the remaining 1,700 or so," Dr. Mendenhall says. "We have also freely shared all the reagents for other labs to do this themselves. In the last six months there have been over 100 requests from other labs for these reagents, so we are hoping a bit of crowd-sourcing will speed up the work on these proteins as well."

Decoding these interactions is akin to an electrician supplying a wiring diagram of the switches in that house.

"There is a lot of useful information once we know the hand that is switching it," he says. "When you know what hand is switching the thing, you know where in the switch is important and we can predict a lot better which gene is being switched on and off."

Some genetic switches have dozens of proteins that are able to lend a hand in switching them on, making them more likely to be turned on than other switches. In some cases, once one switch is turned on, a feedback loop provides the ability to switch on another gene or set of genes. And some genetic switches operate in a cascading fashion. Once one is turned on, it allows for a broadening array of others to be activated.

Our cells use these processes every day as a cellular memory while they conduct the normal business of life, Dr. Mendenhall says. But when something changes in that process and the wrong switches are turned on at the wrong time, or in the wrong cell, consequences other than the normal course of events occur.

"Of these genetically-based diseases, we know of numerous ones that are caused by a defect in the switch, not in a gene," he says, citing polydactyly, a condition where humans grow six fingers, as an example.

It's still a new field filled with potential for important discoveries.

"We actually haven't been able to identify the precise gene mutations that cause disease for all that long," he says. Most of that research has only happened since the late 1980s. "Now we are sequencing patients' genomes to use genetic information for precision medicine. Knowing more about these switches will help interpret this information."

Ongoing new research could impact cancers and numerous other disorders with a genetic component, Dr. Mendenhall says.

Once scientists know which transcription factor is binding to DNA to turn on which switch, which gene that switch operates and what turning that gene on or off does, a new world of medicine may be revealed. Future therapies could include drugs that block the receptors that proteins use to turn on the switches in order to alter the course of a chronic disease or the growth of tumors.

"It is not so far-fetched," Dr. Mendenhall says. "For diseases that are going to be chronic, there is the potential to modify the behavior of the gene to affect progression." ■

The Propulsion Research Center's wind tunnel team with during its construction at Johnson Research Center. From left, graduate student **Warren Buzzard, Dr. Phillip Ligrani,** undergraduate **Daniel Corey,** undergraduate **Benjamin Shea,** undergraduate **Andrew Miller, graduate student Benjamin Lund,** undergraduate **Patrick McIntertt** and laboratory engineer **Tony Hall.**

$2 MILLION wind tunnel soon to be ready

CAPABILITIES PLACE UAH IN ELITE UNIVERSITY GROUP

A new $2 million wind tunnel system at The University of Alabama in Huntsville (UAH) is soon to be operational and involved in research.

Championed by the university's eminent scholar in propulsion, Dr. Phillip Ligrani, who also oversaw its construction, the TranSonic/SuperSonic/WindTunnel or TS/SS/WT resides in the Air Breathing Test Cell at UAH's Johnson Research Center and makes UAH one of a handful of universities nationwide with such capabilities.

"In the near future, following a couple of days of testing, we are expecting to achieve our initial goal of creating a supersonic flow at Mach 1.6, with a supersonic shock wave," Dr. Ligrani says.

Test sections of the facility reach speeds and air velocities ranging from Mach 1.6 with an airspeed of approximately 1,230 miles per hour to Mach 3 with an airspeed of about 2,300 mph, says Dr. Ligrani, the project's principal investigator and a professor of mechanical and aerospace engineering.

Test applications include supersonic engine intakes, scramjets and hybrid space vehicles and components.

"We received excellent support from UAH building services in developing and installing the various structures needed to support the wind tunnel," says Dr. Ligrani. "Piping Machine Specialties Corp. in Salt Lake City worked closely with us to manufacture various parts and components needed for the installation."

Four 14-foot-long tanks valued at $1 million and weighing 16 tons each were donated to the university by the U.S. Air Force's Arnold Engineering Development Center in Manchester, Tenn. The tanks started life as rocket fuel storage but now are used in conjunction with a fifth tank to provide 50 cubic meters of compressed air storage at supply pressures up to 2,500 pounds per square inch.

Air from the tanks is routed through pressure regulating valves to two wind tunnels that are slightly larger than washing machines, where it rushes past objects under research in the 9.6-inch by 4-inch test bed chambers and then is exhausted outdoors through a noise reduction baffle system.

"An elaborate valve system controls the flow," Dr. Ligrani says. "This will ensure high enough flow rates and pressures to reach the required supersonic speeds."

The project was awarded $249,810 by the Alabama Innovation Fund, supplemented by investment from UAH's Office of the Vice President for Research and Economic Development.

"The state of Alabama provides an excellent and unique environment for the development of advanced research efforts, which are tied to important and vital economic activities, and benefit the scientific and engineering communities, not only for the Huntsville area, but for the entire state," says Dr. Ligrani. "We are likewise very grateful to the UAH Office of Research and Economic Development for the generous supplemental support we received for this project. I am also grateful to the Propulsion Research Center and the Department of Mechanical and Aerospace Engineering for the outstanding support provided to this and to related efforts since my arrival at UAH in August of 2014."

UAH HOLDS TRUE TO ITS ORIGINAL MISSION — SUPPORTING REDSTONE

The University of Alabama in Huntsville has a past and future like few other institutions of higher learning in the nation. When state, Redstone and community officials broke ground on a Research Institute on the campus in December, 1961, an important mission for UAH was established, according to the *Marshall Star*, the official newspaper of NASA's Marshall Space Flight Center.

> *The primary mission of the institute will be to provide basic research in problem areas encountered at the Marshall Space Flight Center and the U.S. Army Ordnance Missile Command. Also, the institute will serve to expand and strengthen the university's graduate training programs.*

Since that time, UAH has worked with its partners and stakeholders to grow its strengths as a comprehensive research university, and has built nationally competitive education programs and outstanding research expertise in crucial disciplines that support America's national security and space exploration activities.

Today, U.S. News & World Report's annual ranking includes UAH as a Tier 1 national university — the 103rd best public university in the nation for 2015. According to the latest National Science Foundation federally financed research expenditure data, UAH has five research areas ranked in the top 20 universities in the nation:

- Aeronautical and astronautical engineering (5th)
- Atmospheric sciences (11th)
- Computer sciences (12th)
- Business and management (16th)
- Astronomy (17th)

These rankings demonstrate the important relationship between Redstone's federal agencies and the education and research being conducted today on UAH's campus, according to Dr. Ray Vaughn, Vice President for Research and Economic Development.

"UAH's collaboration with the agencies on the Redstone Arsenal and the technology focused corporate presence in Cummings Research Park goes back for more than a half century," Vaughn says. "This long history of cooperation really allows our university to conduct innovative research to help solve some of the toughest challenges facing our Redstone and CRP partners, and to produce graduates who are problem solvers, who have a strong work ethic, and who can make an immediate contribution to the region's advanced workforce, as well as groundbreaking research to create solutions to resolve some of the challenges facing Redstone and Cummings Research Park. The mission that existed in those early days remains largely unchanged more than 50 years later.

This special mission continues to play a key role at UAH today, and will for the foreseeable future. Expanding Horizons, the university's strategic plan led by President Robert Altenkirch, was influenced heavily by this continuing mission and its impact can be seen throughout the university's strategic priorities and future direction.

For instance, a key strategic priority within the Expanding Horizons plan includes being a recognized national leader in selected areas of education and research:

- Aerospace and Systems Engineering
- Earth, Atmospheric Science and Space Science
- Cybersecurity and Big Data
- Gaming and Entertainment Arts
- Biotechnology

All of those disciplines are crucial to the continued support of the research and technological needs of the entire community.

UAH embodies the far-sighted vision of Dr. Wernher von Braun, the father of America's space exploration program. The rocket pioneer and first director of NASA's Marshall Space Flight Center envisioned a world-class research university that would help transform Huntsville into a permanent scientific and industrial center.

In remarks to the Alabama Legislature, he stated: "It's the university climate that brings the business. Let's be honest with ourselves. It's not water, or real state, or labor or cheap taxes that brings industry to a state or city. It's brainpower."

Von Braun's prophetic words are as true today as they were when he first made them 55 years ago.

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