Radar Revolution

Space-based radar operating from a microsatellite cluster will provide new military capabilities.

With all its awesome capabilities, radar based on satellites orbiting Earth does not yet detect moving targets on the planet.

But researchers in the sensing community are working to develop a space-based radar system with such capabilities, though they face challenges in deploying antenna systems large enough to detect moving targets.

A virtual antenna array, composed of multiple satellites sharing information, is one solution, and engineers at the Georgia Tech Research Institute (GTRI) have studied this approach. For the past three years, they have identified problems, developed solutions and ultimately concluded — along with other research teams elsewhere — that the concept has merit.

Now, the U.S. Air Force Research Laboratory (AFRL) is planning a flight experiment, dubbed TechSat 21 and scheduled for launch in 2006, to demonstrate a formation of three lightweight, high-performance microsatellites. The formation will operate together as a "virtual satellite" with a single, large radar-antenna aperture.

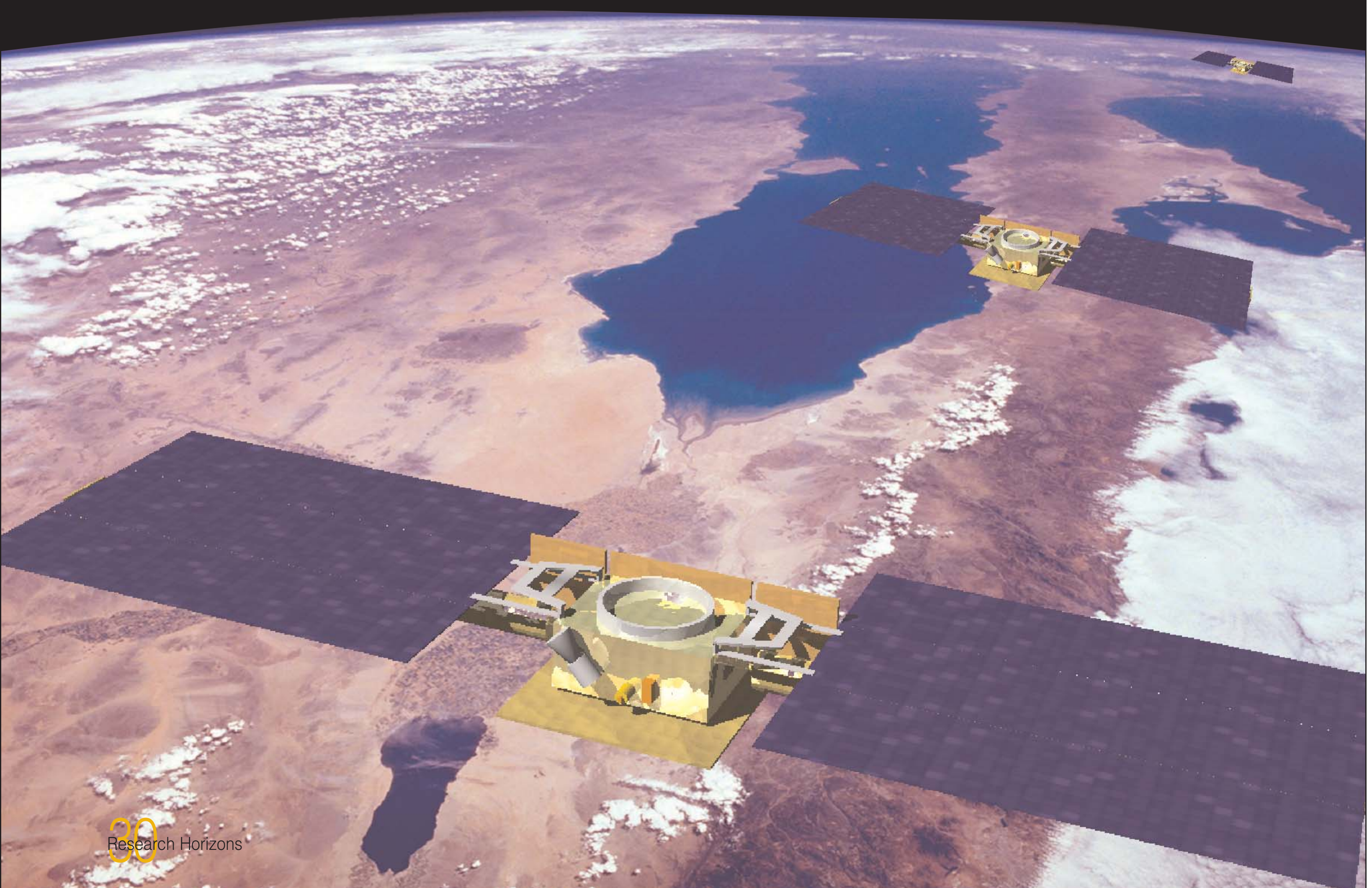


IMAGE COURTESY OF U.S. AIR FORCE RESEARCH LABORATORY

Not only will the microsatellite formation find ground-based, moving targets, it can be configured for a variety of imaging, sensing and communications missions – something not possible with a single, large satellite. Missions include: precision geolocating; single-pass, digital terrain elevation data collection; electronic protection; single-pass, synthetic aperture radar imaging; and high data-rate, secure communications. The benefits of a microsatellite formation also include unlimited aperture size, greater launch flexibility, higher system reliability, easier system upgrade and low-cost mass production.

"If this system works, it will be unique," says lead researcher Bill Melvin, a senior research engineer in GTRI's Sensors and Electromagnetic Applications Laboratory. "There is no other concept like this. If it is cost-effective and the Defense Department can implement it, it will have a dramatic impact on sensing."

While the concept has merit, TechSat 21 is still facing a number of hurdles, including properly timed wireless linking between the microsatellites, methods for calibrating system errors and reliable signal processing. A team of four GTRI engineers, including Melvin and senior research engineer Daniel Leatherwood, continues to address these issues with algorithm development and modeling and simulation studies funded by AFRL. They are also helping with plans for experiments when the trio of microsatellites is launched in 2006.

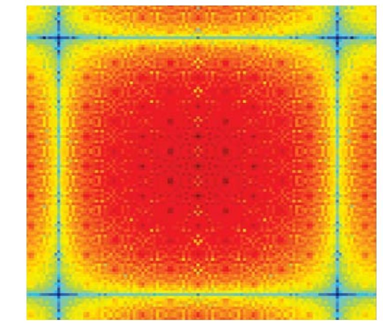
AFRL researchers will gather data, including measurements to predict the system's performance using simulation code developed by GTRI engineers. Also, GTRI researchers are developing algorithms for processing that data, either in space or on the ground.

"The experiments will give us an opportunity to collect data for an extended period of time, not just for one day or one week," Melvin says. TechSat 21 will provide enough data to determine the data-sharing coherence between satellites, the timing requirements for communication and target detection capability, he predicts.

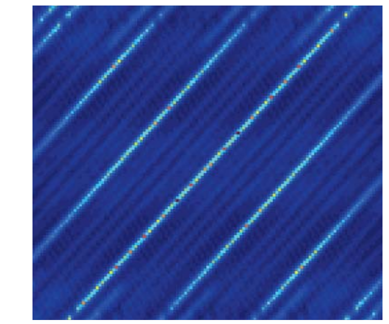
"Whether there is a residual military value from this experimental system will be revealed during the experiments," he adds. "Pressing needs may affect its missions."

Experimental systems have been deployed in the past when military needs arose. For example, during the Gulf War, the U.S. Department of Defense deployed JointSTARS, an airborne battle management system to conduct ground surveillance and support attack operations. JointSTARS detected the famous Iraqi retreat and guided the response of military commanders in the field.

IMAGES COURTESY OF BILL MELVIN



This figure shows the antenna pattern for a nine-microsatellite constellation in a spoke-like configuration.



This figure represents a super-resolution image of ground-clutter response for a nine-microsatellite spoke configuration.

A hypothetical scenario for TechSat 21 could go as follows, Melvin says: The microsatellite configuration is operating in a passive mode. Then it receives a signal, which it analyzes and determines to be a target of interest on the ground. The target, an enemy missile launcher, for example, is stationary at the time and then begins to move. A central operations site is notified, and the satellite configuration then automatically switches to a moving target indicator mode and tracks the missile launcher. Eventually, the system hands off its target information to other sensors and/or platforms. From the central operations site, a decision is made to send a fighter jet to engage the missile launcher.

"We want to automate as many processes as possible because the system will be gathering so much information," Melvin explains. "Certainly, the detection stage and switching between modes will be automated. Of course, the user could override the system."

Various technological improvements are making these and other TechSat21 capabilities possible. Advances in sensor technology, antennas, satellites, electronics and digital computing, as well as lighter-weight and more durable components, are contributing.

"Because of these advances, we can implement advanced algorithms and dream up new approaches that weren't even possible five or 10 years ago," Melvin says. "Technology is the driver of this project."

Given that, technology has placed GTRI engineers in the driver's seat. Leveraging their extensive experience in advanced signal processing

Facing page: This artist's rendering represents the U.S. Air Force Research Laboratory's proposed TechSat 21 microsatellite configuration. A virtual antenna array, composed of multiple satellites sharing information, could aid military maneuvers worldwide. Engineers at GTRI have studied the concept — along with other research teams elsewhere – and have concluded that it has merit.

and antenna modeling, they generated results for the AFRL within a year of the program's onset, and AFRL responded by increasing GTRI's role.

"We have focused on understanding the problems and developing suitable techniques to address them," Melvin explains. "Through modeling and simulation, we have determined the best possible performance for the system for ground moving target indication. So we know the concept has merit."

Only physics, not technology or research effort, will limit what TechSat 21 can do, he adds.

"TechSat 21 is a very non-traditional approach in radar," Melvin says. "There are a lot of doubting Thomases in the sensor community. So that makes it a challenge and makes it fun. We want to prove we can do it. Our task will be to convey to others that it can be done."

— Jane M. Sanders

■ For more information, you may contact Bill Melvin, Sensors and Electromagnetic Applications Laboratory, Georgia Tech Research Institute, Atlanta, GA 30332-0800. (Telephone: 770-528-3274) (E-mail: bill.melvin@gtri.gatech.edu)

Space Mysteries

Scientists' studies of grains of minerals and dust from space are revealing new hints about the mysteries of the solar system, including new insight about the origin of life on Earth. The findings were published in the journal *Nature* earlier this year.

Scientists' findings provide new insight about minerals from space, shed light on origin of life on Earth.

On May 9, researchers — including one from the Georgia Institute of Technology – reported that previously unidentified mineral grains found in abundance in space dust are an unusual form of iron sulfide. Despite the cosmic abundance of sulfur, scientists had never observed iron sulfide in space dust until now.

Scientists have long assumed that sulfur, which may be important to the origin of life on Earth, enters the solar system in a gaseous form. But this study reveals that sulfur in space exists primarily in the form of solid grains, explains John Bradley, an adjunct professor of materials science and engineering at the Georgia Institute of Technology and director of the Institute for Geophysics & Planetary Physics at Lawrence Livermore National Laboratory.

"Sulfur is really, really important in the solar system," Bradley says. "There is increasing evidence that sulfur may have played a significant role in the origin of life on Earth. This paper shows that an extraterrestrial rain of solid, sulfur-containing grains was bioavailable when an explosion of life occurred following the Pre-Cambrian period on Earth."

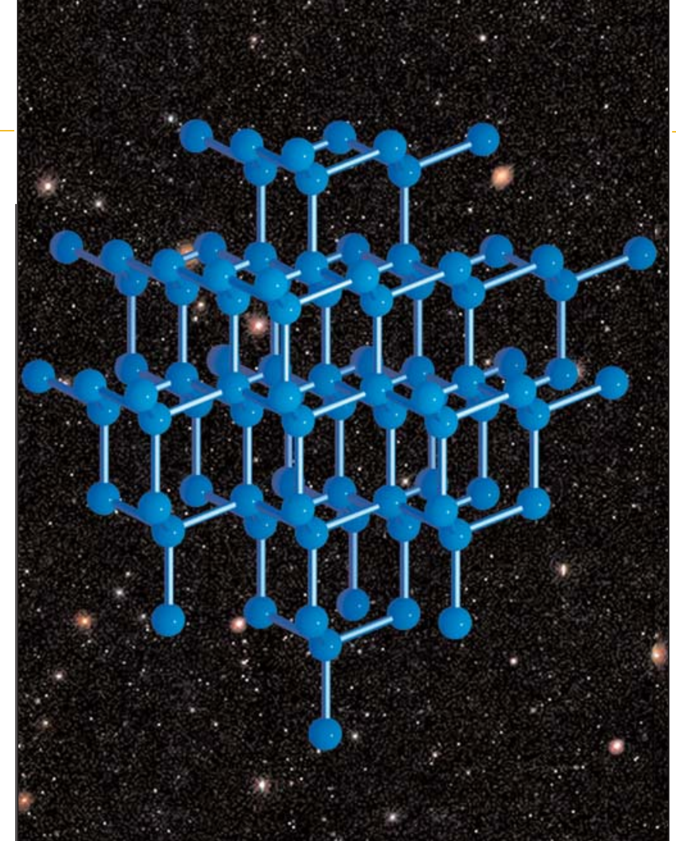


IMAGE COURTESY OF JOHN BRADLEY

This figure shows the atomic crystal structure of nanodiamonds (spheres are carbon atoms) superimposed on an image of space. An accumulating body of evidence suggests that nanodiamonds form in a variety of astrophysical environments, including the early solar system.

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Bradley was part of an international team of materials scientists, astronomers and astrophysicists that examined infrared data collected in space by the Infrared Space Observatory, which was launched in 1996 by a group of European countries. Researchers used the National Synchrotron Light Source at Brookhaven National Laboratory in New York and a powerful electron microscope at Georgia Tech to compare their infrared data with information gathered by other spacecraft.

"So this is one piece of a complicated jigsaw puzzle," Bradley says of the team's findings. "Not only could it have implications for the origin of life on Earth, but also for planets around other stars."

In a *Nature* paper published July 11, Georgia Tech materials scientist Zurong Dai, Bradley and their colleagues elsewhere test the theory that "nanodiamonds" found in interplanetary dust particles and meteorites are the most abundant form of pre-solar material, or "stardust."

If nanodiamonds are pre-solar stardust, they should be at least as abundant in comets as in asteroids because comets likely formed farther out in the early solar system than asteroids. And more pre-solar material should survive farther from the sun.

Testing those theories, Bradley and his colleagues compared the Murchison and Orgueil meteorites (from asteroids) with interplanetary dust particles (from comets) collected in the stratosphere. The comparison suggests that nanodiamonds are conspicuously depleted in cometary material. Bradley and his colleagues say their research may indicate that some or most nanodiamonds are not pre-solar at all, but formed in the early solar system.

"This raises all sorts of questions about the origins of our solar system," Bradley says. "Our findings are consistent with recent research that has detected nanodiamonds within the accretion discs of other young stars that are similar to our early solar system."

— Jane M. Sanders

■ For more information, contact John Bradley, c/o Institute for Geophysics & Planetary Physics, Lawrence Livermore National Laboratory, Mail Stop L-413, 7000 East Ave., Livermore, CA 94550. (E-mail: jbradley@igpp.ucllnl.org); or Zurong Dai, School of Materials Science and Engineering, Georgia Tech, Atlanta, GA 30332-0245. (Telephone: 404 385-0326)(E-mail: zurong.dai@mse.gatech.edu)

The Color of Cancer

A researcher's tiny, colored "dots" may hold the key to early detection, clinical diagnosis and treatment of cancer — and also may solve another longstanding medical mystery.

Pioneering nanotechnology research offers new ways to detect and treat cancer.

Zinc sulfide-capped cadmium selenide nanocrystals or "quantum dots" are the foundation of a novel technology developed by Shuming Nie, an associate professor in the Coulter Department of Biomedical Engineering at the Georgia Institute of Technology and Emory University. His ongoing research is funded by the Georgia Cancer Coalition (GCC), a public-private partnership established by the Georgia General Assembly in 2001.

Nie's work provides a way, in effect, to color-code biological molecules such as genes and proteins, thereby allowing doctors to view a spectrographic profile of an individual's unique body chemistry and identify the actual location and distribution of selected molecules in cells and tissues.

Applying the profiling technique to the molecules or markers associated with cancer may enable doctors to isolate the disease at its earliest stages, Nie says. The process may be useful for advancing the understanding of cancer pathology, he adds.

The technology involves embedding the fluorescent, semiconducting quantum dots inside micron-sized, polystyrene beads. Nie synthesizes the dots in different colors by varying their size. Embedding dots of different sizes and quantities gives the beads a unique optical signature.

Nie attaches biological macromolecules, such as antibodies, to the beads and applies them to cells and tissue samples in the laboratory. There, antibodies attached to the beads adhere to specific molecules, permitting identification of their location and determining the number of molecules present.

So far, Nie has produced dots with 10 levels of intensity in 10 visible colors and four colors in the near-infrared portion of the spectrum. Combining these characteristics aids identification of a nearly unlimited number of molecules simultaneously.

"There are 30,000 to 60,000 genes and maybe a million proteins, so I tell people that there's not enough biological information for this technology," he jokes.

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Cancer cells have certain characteristics or markers. After targeting and labeling these markers with color-coded quantum dots, Nie's computer-based algorithm converts the optical information into biological data. He then knows which markers are present, as well as their distribution over the surface of a cell. The patterns formed by the optical information may indicate the presence of cancer.

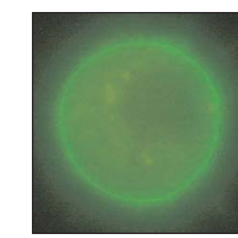
The technique allows simultaneous analysis of the markers in clinical tissue specimens, and also detects the tiniest molecular abnormalities — a tremendous step forward for early cancer detection.

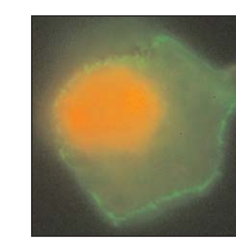
Nie likens the process to that of identifying a criminal.

"If you say only that he is 1.8 meters tall, there are too many people who fit that description," Nie explains. "Then you say he weighs 180 pounds, and that reduces the number. Say he has black hair, and you've narrowed the list of suspects further, and so on until you get an accurate description of the criminal."

The quantum-dot technology could also prove useful for developing targeted, more effective cancer treatment, Nie says. Doctors have long been puzzled by the individual patient variation in the performance of medicines. The interaction between a drug and an individual's body chemistry may hold the answer, Nie says.

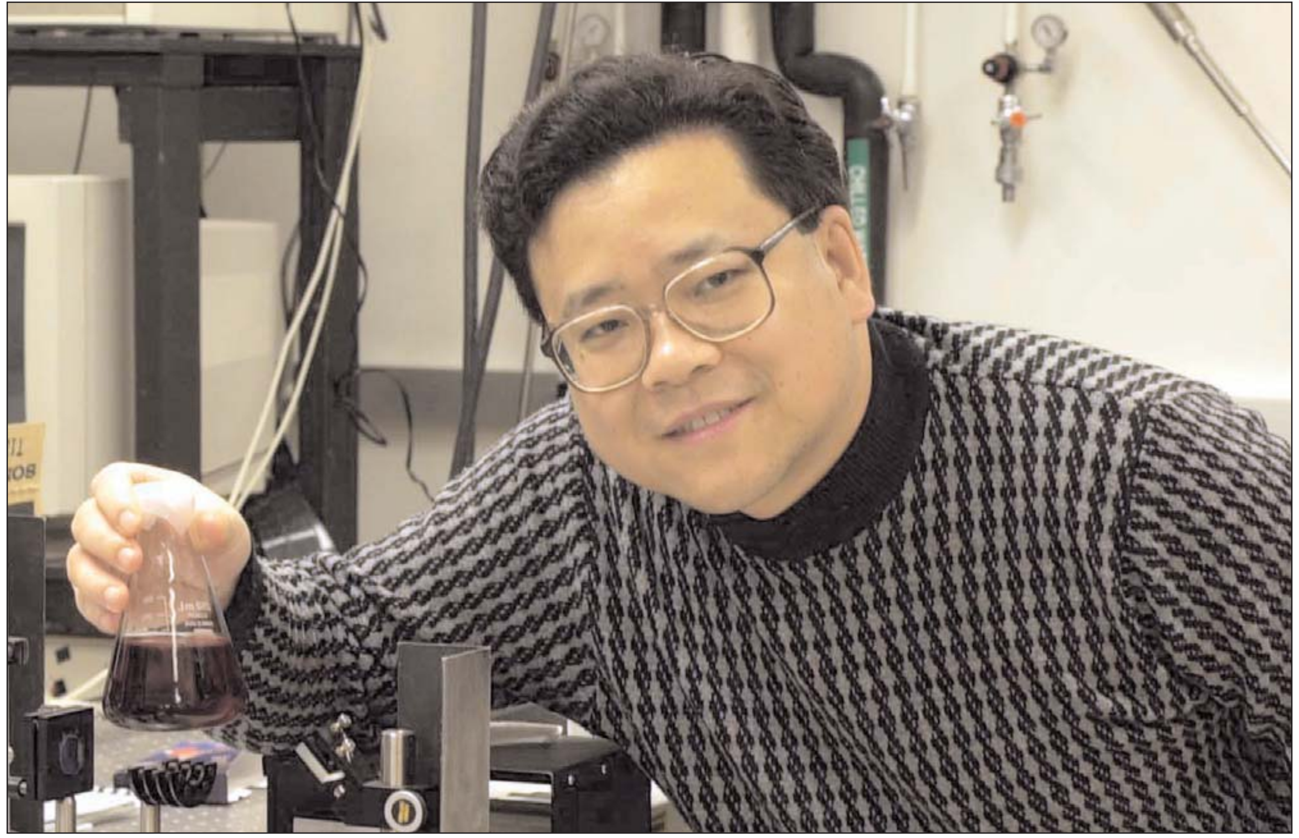
"We believe the reason why drugs work on some people and not others is because of their different molecular profiles — genes and pro-





IMAGES COURTESY OF SHUMING NIE

This figure shows immuno-fluorescent images of human cancer cells labeled with green quantum dots.



Professor Shuming Nie's research is funded by the Georgia Cancer Coalition, a public-private partnership established by the Georgia General Assembly in 2001.

IMAGE COURTESY OF SHUMING NIE

teins," he explains. "If you can make such a profile, you can probably determine if a drug is going to be effective for that person."

In the case of cancers, he adds, "The presence of a particular panel of markers could mean that a certain drug will work."

The applications of quantum dots in science, engineering and medicine have resulted in tremendous advances, Nie says. "People often associate nanotechnology with microelectronics or optoelectronics or memory systems," he adds, "but it has turned out that one of the first practical applications of nanotechnology is in biology and medicine."

Bioplex Corporation was founded by the technology-transfer company LaunchCyte Inc. to commercialize Nie's quantum-dot technology for human health applications, including drug discovery and clinical diagnostics. Bioplex is based in Pittsburgh, while its research and development operations are housed at Emtech Bio, an Atlanta-based, business incubator operated by Georgia Tech and Emory University.

Formerly a professor of chemistry at Indiana University at Bloomington, Nie is among the first group of researchers brought to Georgia Tech and Emory by the Georgia Cancer Coalition. Its Distinguished Cancer Clinicians and Scientists Program recruits and supports expert medical scientists who are making significant contributions leading to increased understanding of the causes and mechanisms of cancer, and to developing more effective cancer therapies. At Indiana, Nie conducted much of the research that led to his quantum-dot technology. Now headquartered at Emory, Nie is director of cancer nanotechnology at the Winship Cancer Institute and associate professor of biomedical engineering, chemistry, hematology and oncology.

In the next 10 years, the $1 billion Cancer Coalition initiative is expected to bring 150 researchers and clinicians to Georgia universities and medical centers to strengthen cancer-related programs and create new initiatives for early detection, leading-edge treatment, research, prevention and education.

—*Gary Goettling,* freelance writer

■ For more information, contact Shuming Nie, Georgia Tech / Emory Department of Biomedical Engineering and Winship Cancer Institute, 1639 Pierce Drive, Suite 2001, Atlanta, GA 30322 (Telephone: 404-712-8595) (E-mail: snie@emory.edu).

Shown here is a fluorescent image of a mixture of cadmimum selenide-zinc sulfide and quantum dot-tagged beads emitting single-color signals.

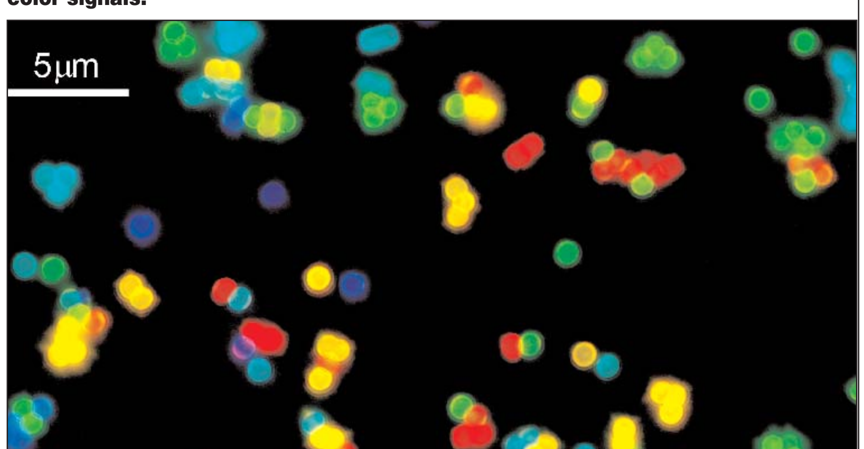


IMAGE COURTESY OF SHUMING NIE