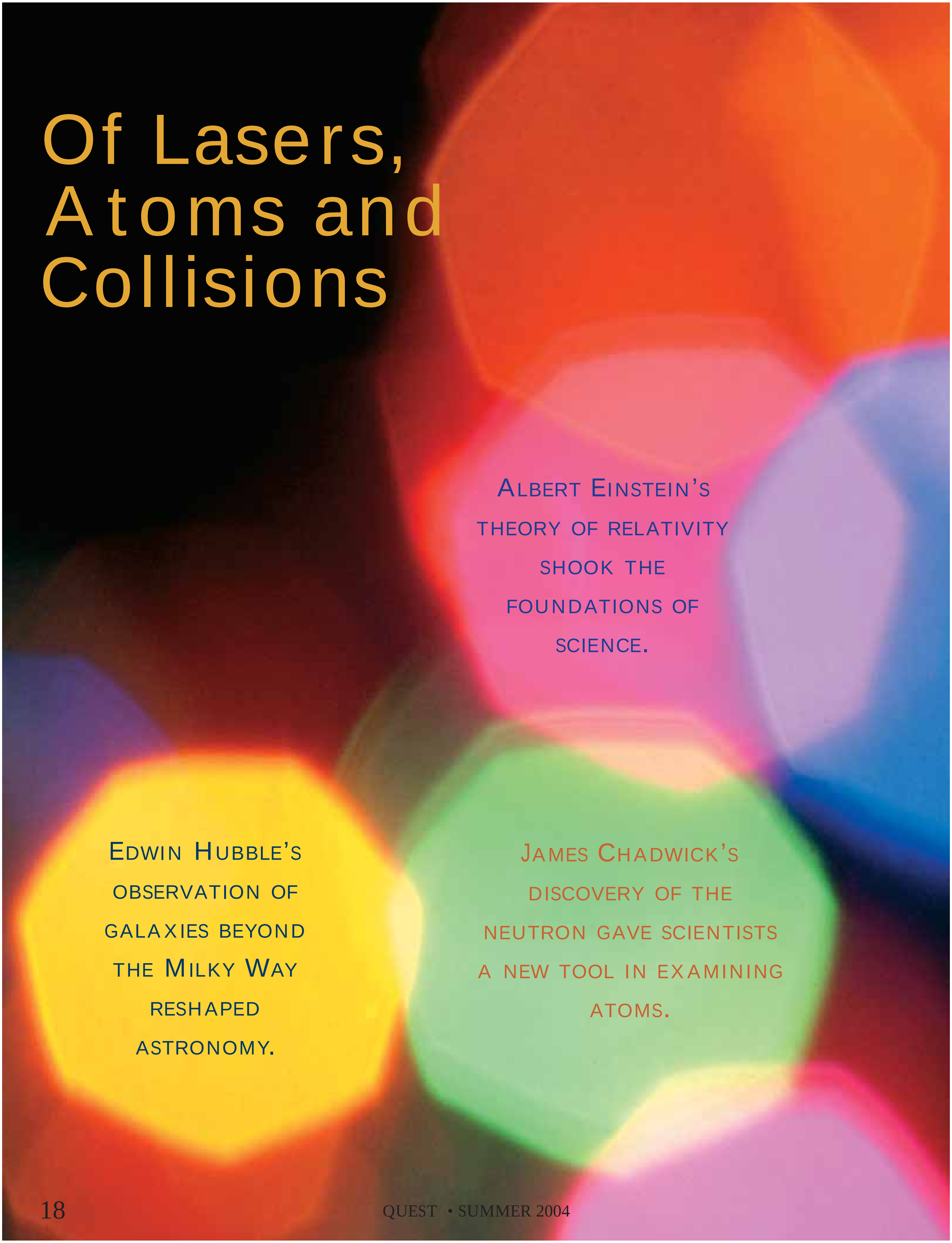


Of Lasers, Atoms and Collisions

ALBERT EINSTEIN'S THEORY OF RELATIVITY SHOOK THE FOUNDATIONS OF SCIENCE.

EDWIN HUBBLE'S OBSERVATION OF GALAXIES BEYOND THE MILKY WAY RESHAPED ASTRONOMY.

JAMES CHADWICK'S DISCOVERY OF THE NEUTRON GAVE SCIENTISTS A NEW TOOL IN EXAMINING ATOMS.

PHYSICS PROFESSOR SHINES LIGHT ON ULTRACOLD MOLECULES

BY ELIZABETH O. COOPER

Today, an Old Dominion University professor is also delving into uncharted territory by exploring ultracold molecular physics with the goal of launching new applications in physics, astrophysics and chemistry. His research could ultimately assist in the production of the next generation of computers and navigational sensors.

Rubidium and Argon combined for the First Time

"This is a new regime," says Charles I. Sukenik, associate professor and undergraduate program director of physics, who is heading an Old Dominion research group that transforms cold atoms into cold molecules. "A lot of work has been done in cold atom physics over the last 20 years, but there has not been the same level of work done in making cold molecules because molecules are a lot more complicated than atoms."

Sukenik is studying the production of ultracold, heteronuclear molecules as a reaction product in the collisions of ultracold atoms. His research focuses on understanding the mechanics of production of the RbAr (rubidium argon) molecule, a disparate combination of an alkali metal and a noble gas. Simultaneously trapping an alkali atom (rubidium) and a noble gas atom (argon) had never been achieved before Sukenik and his group began using lasers to confine ultracold rubidium and metastable argon atoms in a specially designed magneto-optical trap.

"No one else is using a rubidium argon combination. Most others are using single atoms," Sukenik notes. "Only a handful of researchers work with noble gases. Nobody works with a combination of an alkali and a noble gas. But it's a rich and unique system for study. There are so many different things that I can look at."

To effectively study this combination, Sukenik uses lasers to cool the rubidium and argon atoms to a temperature very close to absolute zero (minus 459 degrees Fahrenheit). Laser cooling tailors the contact between atoms and light, resulting in the light carrying off energy and momentum from the atoms. Once a large flux of molecules is produced, additional lasers are used to spatially confine the ultracold molecules in a second type of trap – an optical dipole force trap. Sometimes referred to as optical tweezers, this trap can also be used to move DNA around. Designed in the mid-1980s, the magneto-optical trap is a vacuum that combines lasers, magnetic fields and atoms, forcing atoms to cool and become optically confined.

"When atoms are that cold, we can study the interactions between them and the interaction between light and atoms," he explains, adding that at cold temperatures the dynamics of the interactions are different than they are at room temperatures. Atoms move slowly when they are cold, and if they get cold enough, quantum mechanics – the wave nature description of the interaction between matter and radiation at an atomic level – must be utilized to describe their motion.

"Because atoms move very slowly, there is great promise to be able to contain chemical reactions at ultracold temperatures and we can use light to manipulate the outcomes," Sukenik says. "We're able to study the system with a high level of precision."

Atoms Respond to Specific Light Colors

Each atom interacts with only specific colors of light. "If you shine light on an atom, and it's not the right color, the light doesn't interact with the atom," he notes. "If you tune the laser to the right color, the atom slows down. Slowness corresponds to coldness. The light holds the atom in place, but if you turn the light off, the atom falls."

Sukenik decided to combine rubidium and argon in a low-energy state to form what's known as a weakly bound van der Waals molecule. Rubidium, a soft, silvery-white metallic element, is one of the most electropositive and alkaline elements. It ignites spontaneously in air and reacts violently with water. Argon, a colorless, odorless, chemical element of the noble gases, constitutes nearly 1 percent of the atmosphere and is not known to form true chemical compounds.

"These molecules have been studied in the chemistry community for decades but never at ultracold temperatures," Sukenik notes. "Right now we're searching for their molecular formation. First, we have to know something about the interaction between rubidium and argon. Preliminary results indicate the interaction is much less than expected."

Laser sources exist to produce light which interacts with rubidium in its lowest energy state. For argon, however, no such laser sources presently exist; therefore, the atom must be placed in a long-lived excited state known as a metastable state. This allows the atom to interact with light which can be produced in the lab. "You can make an atomic beam of argon and hit it with a laser light which slows it down," Sukenik explains, comparing the process to stopping a bowling ball by pelting it with pingpong balls. "If you throw a million pingpong balls, it slows the bowling ball down. It's hard to throw a million pingpong balls at a bowling ball, but it's easy to throw a million photons at argon."

Heteronuclear Studies Present Unique Challenges, Opportunities

Sukenik has previously conducted research in ultracold atomic physics, ultrafast laser science and cavity quantum electrodynamics. When he joined the Old Dominion faculty in 1997, he focused his research on problems in ultracold atomic and molecular physics. The rubidium argon molecule project was initiated in 2000. He opted to work on a heteronuclear system which is a molecule formed from two different types of atoms, a decision that has put him on the vanguard of ultracold molecular research.

"It's very interesting," he says. "It's a different system from having two atoms that are the same. There's not much work going on in this area because it's much more complicated. You need different systems to cool the different atoms. There's a tradeoff between interesting physics and a more complicated setup."

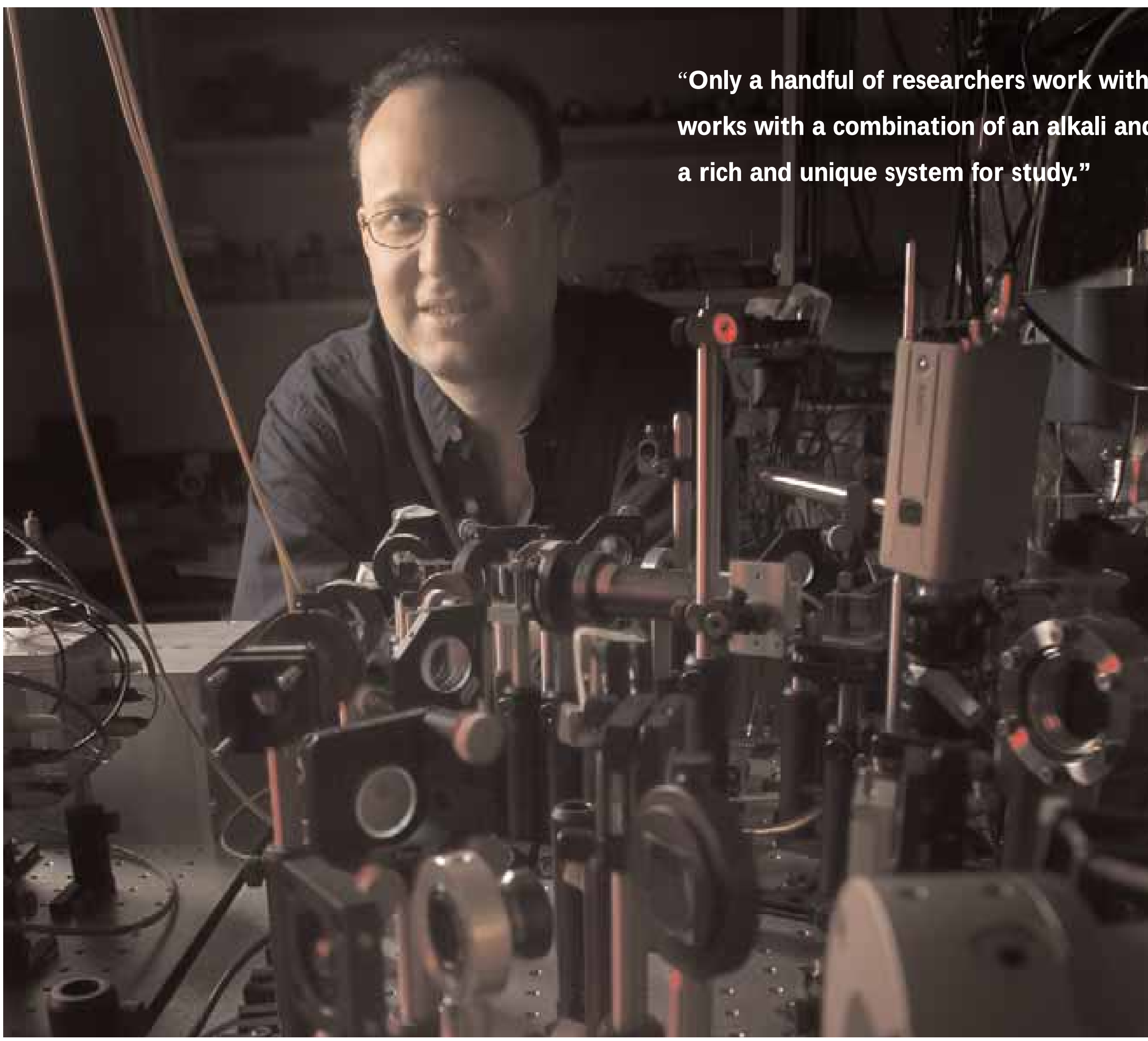
Sukenik also wanted to work with metastable noble gases in order to conduct additional studies in ionizing collision physics which would, in turn, allow him to perform experiments in both ultracold physics and ultracold chemistry. He notes that the rubidium-metastable argon combination provides researchers with a myriad of interesting ionization physics interactions. "It's one of the richest systems I could think of to study in ultracold dynamics, but it's one of the most complicated systems in the lab." He quickly realized that the physics and chemistry benefits outweighed the intricacies involved in developing the apparatus.

"Do you go with the thing that's easier to build or do you want to invest in the thing that's harder to build because the science pays off there?" Hauke Busch, a physics doctoral student, along with several undergraduate physics students, joined Sukenik in designing and building the apparatus which consists of a series of mirrors, lasers, optics, vacuum chambers and electronics.

"For this to work, every single mirror, every piece of optics has to be aligned," Sukenik says. "This is very instrumentation type of research. If one mirror is not in the right position, nothing works. You won't be able to cool atoms, and you won't be able to confine them. This is still tabletop physics. To me that's appealing because you have everything under control."

Sukenik's group has received grants from the National Science Foundation, the Office of Naval Research, the Jeffress Foundation and the ODU Research Foundation. As the only researchers combining rubidium and argon, the Old Dominion group must follow its course without the benefit of theoretical support so often used in other scientific investigations. "There's interest in the community," Sukenik says. "Theorists are excited about it, but they want more experimental data. The experiments will drive the theoretical developments."

Without theoretical support, Sukenik is left to rely on his own knowledge and instincts. "We use our judgment and measure what we think are the interesting properties, and take it from there. Sometimes we find what we expect. Sometimes we find interesting surprises. That's really how science is done."



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