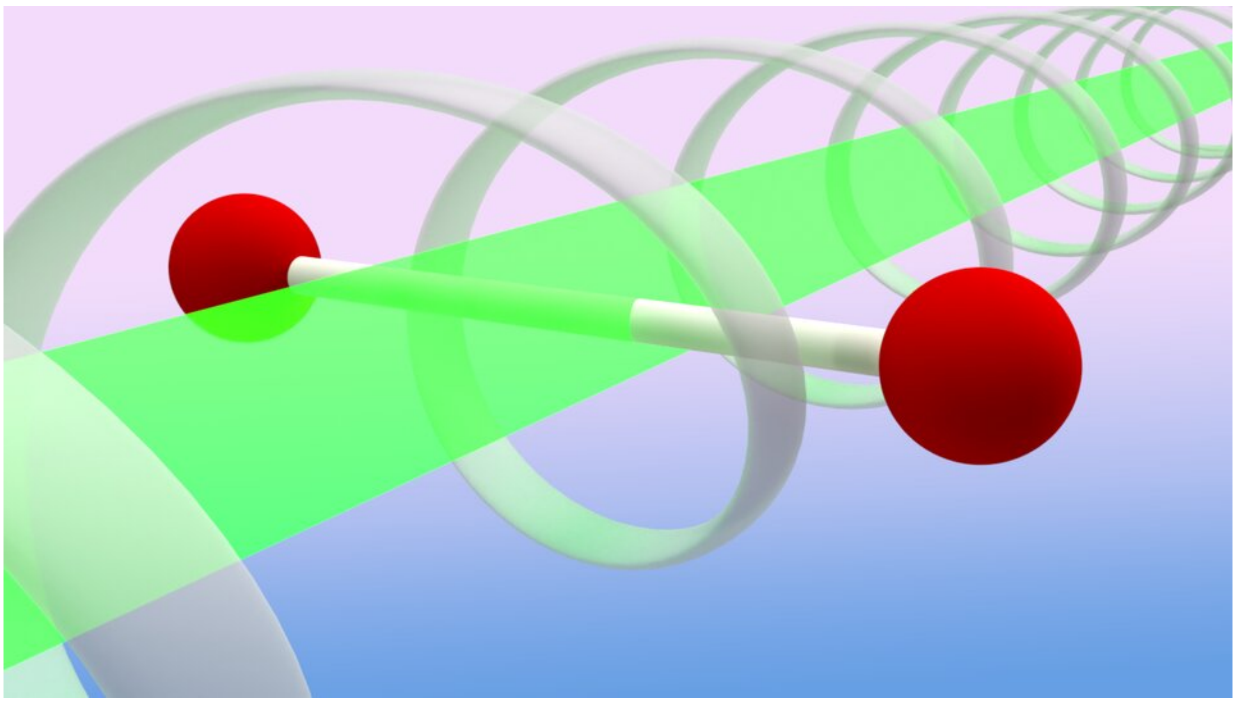
Study details final breakthroughs of late Nebraska physicist

November 25 2019, by Scott Schrage



A rendering of a laser pulse striking a molecule that consists of two bonded hydrogen atoms. The spiral surrounding the laser represents an electric field. Recent research from the late Anthony Starace and his protégé, Jean Marcel Ngoko Djiokap, has explained how the clockwise vs. counterclockwise spiraling of the electric field can influence how the laser pulse ejects electrons from the molecule. Credit: Scott Schrage | University Communication

An internationally renowned career that began in New York City and

Chicago and London before taking him, finally and for good, to Lincoln, would end on the sixth floor of the Bryan Medical Center's East Campus.

Just days earlier, the late Anthony Starace, whose pioneering research in ultra-fast laser physics earned him the rank of George Holmes University Professor at the University of Nebraska–Lincoln, had gotten word that one of his favorite journals, *Physical Review Letters*, would publish another of his papers.

Shortly after the notification, Starace began experiencing chest pains related to the sudden onset of pancreatitis that would take his life on Sept. 5.

But not before he was finished.

The journal's publisher had asked Starace to write a one-page summary of the study's findings and significance. He'd done it many times. But never from a hospital bed, between visits from his family and the colleagues who knew him as a friend and, after 46 years at Nebraska, a virtual institution unto himself.

His co-author and protégé of nine years, Jean Marcel Ngoko Djiokap, initially urged Starace to forget about the summary. Yet Ngoko Djiokap knew his mentor well enough to know better.

"Even when you are sick, you don't think about your own condition," he said of Starace's mindset. "You are always ready to give and give, to provide. I think this tells you exactly who Tony was."

So, together, Starace and Ngoko Djiokap composed the summary—one that describes the final breakthroughs of an academic giant who rose to prominence by investigating the infinitesimal.

Eyeblink as eternity

Around the turn of the millennium, Starace delved into the emerging realm of attosecond science: striking atoms and molecules with intense laser pulses that last for an inconceivably short time. How inconceivable? The number of attoseconds that pass within one second equals the number of seconds that pass within 31 billion years—more than twice the estimated age of the universe.

By studying how those ephemeral laser pulses interact with atoms and molecules, Starace and others have peered into the once-impenetrable: the ways that electrons depart their orbits around atoms when struck by light, for instance. That knowledge, in turn, has helped other physicists better understand the rules governing the atomic or molecular dynamics they discover—and even control that behavior.

"When things happen on such fast time scales, experimentalists don't always know what they've achieved," Starace said in 2014. "They cannot 'see' how electrons make atomic and molecular transitions. So they need means to ascertain, "How did we do that?" or, "What did we have there?'"

Starace and Ngoko Djiokap had spent the past few years studying a phenomenon called dichroism—specifically, how the properties of a laser pulse change how its energy is absorbed and the probability that it will eject electrons from atoms and molecules. But this was no six-sided die of probability; it featured so many facets, with so many nonlinear edges, that Starace and Ngoko Djiokap could only begin calculating the probabilities with supercomputers and quantum mechanics.

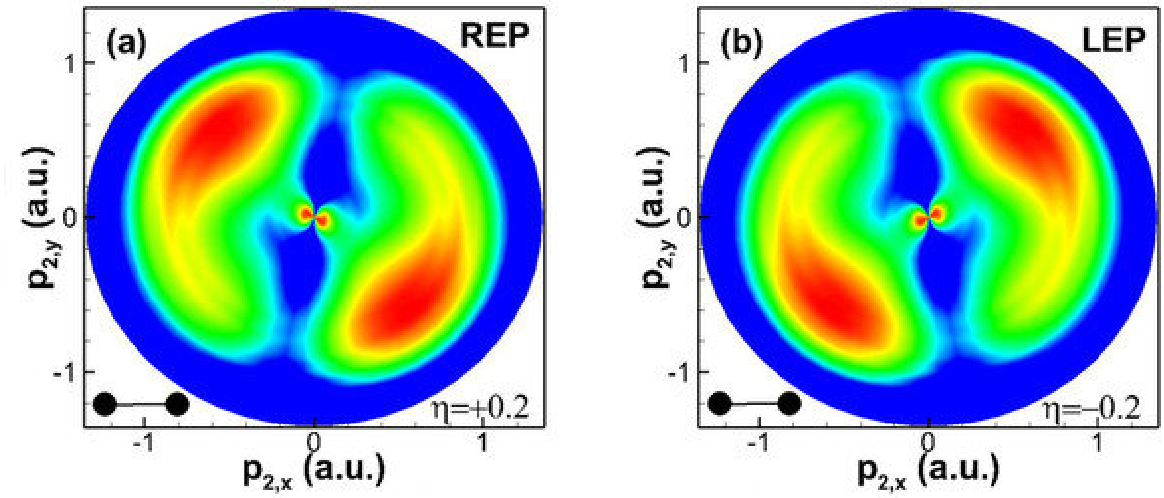
Among those probability-shifting properties were the orientation and behavior of the electric field that surrounds a laser beam. In some cases, the electric field extends only vertically or horizontally from the beam.

In others, the electric field rotates around the beam like a propeller. When it does, it can rotate either clockwise or counterclockwise and can trace the path of either a circle or an ellipse.

Back in 2014, while firing laser pulses at a helium atom, the team discovered that the clockwise vs. counterclockwise rotation of an elliptical path could influence the launch angles of the atom's two electrons. In the pages of Physical Review Letters, the duo introduced equations to characterize that influence. The laser pulses, they explained, had stimulated electron responses associated with absorbing both one vs. two particles, or photons, of light, with the interference among those dynamics—and the vanishing of the one-photon effects—driving the unusual dichroism.

This year, Starace and Ngoko Djiokap conducted a similar study but shifted their attention from an atom to a molecule: two bonded hydrogen atoms that share two electrons. When firing a one-photon laser pulse parallel to the axis of the dihydrogen molecule, they found that the effects of clockwise vs. counterclockwise rotation on the electrons' launch could be described by the same equations they derived for a helium atom.

When turning the molecule even slightly, though, they spied additional factors—a new form of dichroism—that emerges only in certain molecules. In their efforts to better understand the newfound factors, Starace and Ngoko Djiokap discovered how to orient the laser pulse and molecular axis—and how to detect the electrons—so that the atomic-like dichroism variables they uncovered in 2014 disappeared. That allowed them to isolate and measure just the molecule-specific influences, including how shifts in the energy and orbit of one laser-excited electron can interact with those of the other electron sharing its molecule.



Figures depicting the distributions of momentum values for electrons that were ejected, or ionized, from dihydrogen molecules by laser pulses whose elliptical electric fields rotated either clockwise vs. counterclockwise, resulting in a signature mirroring of the respective distributions. (Redder areas represent a higher probability of ionization, with bluer areas representing lower probability.) As one electron is detected along the direction of the laser pulse's flight — perpendicular to the molecule's axis and creating the dumbbell shape at center — the other is detected in the plane of the electric field, which contains the molecular axis and results in the vanishing of the atomic-like dichroism. The mirroring effect directly reflects the molecule-specific form of dichroism detailed in the team's new paper. Credit: Jean Marcel Ngoko Djiokap / Physical Review Letters

"The selection rules we found are very sensitive to the orientation of the molecule," said Ngoko Djiokap, research assistant professor of physics and astronomy. "So we see this new correlated molecular effect as a tool for (measuring) molecular alignment. That's very important for ultra-fast molecular imaging."

Starace and Ngoko Djiokap even found that they could control some of the molecule-specific responses by adjusting the elliptical path of the laser's electric field. The ability to predict and measure those responses could effectively act as a diagnostic for the lasers themselves, Ngoko Djiokap said.

Combined with the earlier study, the new findings could also inform future efforts to better identify an especially important characteristic of molecules, Ngoko Djiokap said. Both a helium atom and a dihydrogen molecule are non-chiral, meaning that their mirror images look identical to the originals. By contrast, chiral molecules can take two forms that, like right and left hands, are structurally identical but distinguishable from their mirrored counterparts.

And just as most people consider handedness an important distinction—having much greater coordination with one than the other—the handedness of chiral molecules can have massive consequences. Whereas a left-handed molecule might help sooth a disease, its right hand might trigger one.

Because only non-chiral molecules exhibit some of the electron-ejecting signatures that Starace, Ngoko Djiokap and their international colleagues discovered, those signatures could help researchers or others confirm which class of molecule they're working with.

"I have to do it for him'

Since Starace's passing, the Department of Physics and Astronomy has asked Ngoko Djiokap to assume leadership for most of his mentor's research projects.

Ngoko Djiokap now works from the office that Starace called his own, the journals and books piled high as Ngoko Djiokap takes a seat behind the desk that he often sat across from while meeting with Starace.

In the distance between those two seats, a mere four feet, resides the burden of expectation and legacy. Starace's own mentor, Ugo Fano, once researched under Nobel Prize winners Enrico Fermi and Werner Heisenberg.

"It's a lot of pressure," Ngoko Djiokap admits. "But I think I have to do it for him, for what he represents to me. He was the best mentor I ever had, the way that he took care not only of me but of his entire group."

Ngoko Djiokap came to Nebraska from Belgium just three days after defending his dissertation at Universite catholique de Louvain. He remembers the date: Feb. 4, 2010. He'd never been to Nebraska, knowing Starace only from a videoconference interview and the scores of research papers he'd pored through during his young career.

"He took me in like his son," Ngoko Djiokap says. "That's why I still have to cope with the grieving process. It's going to take time, but I know who he was."

Ngoko Djiokap talks of how Starace invited him to his home for Christmas dinners, of how his mind could instantly recall a great meal taken at a restaurant 10 years earlier, of how he played squash with the same enthusiasm and commitment he brought to physics.

He thinks aloud about an unlived future in which a retired Starace would have accepted the gestures of hospitality that his mentor so often bestowed.

"My only regret is that he will never see me doing this, because I think this is what he wanted—that one day, I would invite him to my home and to see how to I run my own research group," he says.

Jean Marcel Ngoko Djiokap (left) and the late Anthony Starace in 2015. Credit: Craig Chandler | University Communication

And he describes the balance of empathy and authority, of precision and open-mindedness, that earned Starace the admiration of those who worked with and knew him. If Ngoko Djiokap can emulate that, he says, maybe he'll prove himself worthy of Starace's legacy.

But that work remains unfinished.

"I have to take the driver's seat and work hard and deliver, so that he can be proud of me."

More information: J. M. Ngoko Djiokap et al. Molecular Symmetry-Mixed Dichroism in Double Photoionization of H2, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.143202

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