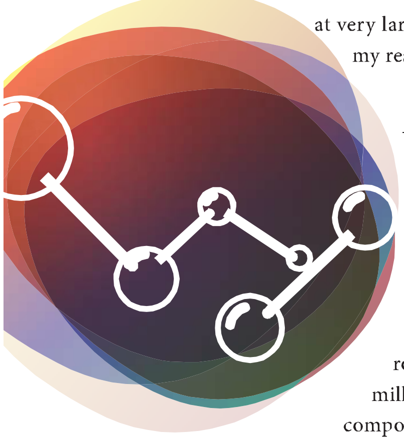
the sea or how they move with respect to one another.

In my current project, I am essentially trying to figure out how much energy it takes to separate the nucleons from a nucleus. Knowing the precise amount of energy would be useful in many applications, from simulating supernovae to engineering nuclear reactors. To answer this question, we are simplifying QCD into what is called an "effective theory." I study atomic nuclei, which have small binding and kinetic energies compared to the mass energy of most elementary particles. This means I can omit information from QCD that mostly pertains to things at very large energies without significantly affecting my results.

Some people may think that theoretical physics is all beautiful proofs and elegant theorems, but the truth is that it also entails quite a bit of hard work. It can take weeks to manipulate equations into simple forms, have computers solve them, and then check that you have done things right. After all that effort, you're not even guaranteed a result. Still, I think physics is a beautiful field, and I can't wait to see my effective theory accurately predict real nuclear-binding energies.

Cory Schillaci earned a BS in physics from the University of Washington and is now in his second year of graduate work at UC Berkeley. In addition to physics, Cory likes cooking, sailing, mountains, surreal films, and well-written books.



GOOD TIMING

BY MONIKA SCHLEIER-SMITH

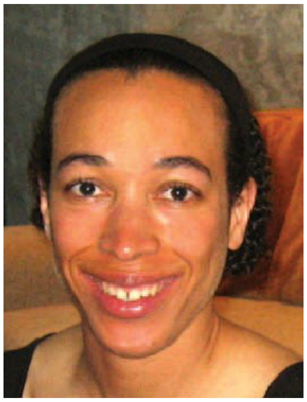
The world of atomic physics is one of extremes. Atomic gases isolated in ultra-high vacuum, manipulated with exquisite control using carefully tuned lasers, are routinely cooled to temperatures within a millionth of a degree of absolute zero. Clocks composed of laser-cooled atoms keep time with extraordinary steadfastness: the best of them, if its ticks were measured in seconds, would lose a beat less than once every billion years.

Making these atomic clocks even better could lead to advances in precision navigation (GPS satellites each carry four atomic clocks) and better monitoring of geological phenomena such as continental drift. It could also allow physicists to test whether supposed constants of nature, such as the charge of an electron or the speed of light, might actually be changing in time.

An atomic clock works by detecting regular oscillations of its atoms. The clock's precision comes from making thousands of measurements on individual atoms and averaging the results. An atomic clock composed of 10,000 atoms reads the right time on average, just as tossing 10,000 coins gives on average 5,000 heads. Yet the precise timing between the clock's ticks, like the precise count of the coin toss, fluctuates about the average.

State-of-the-art clocks operate at the so-called "standard quantum limit," the highest degree of precision that can be reached by measurements on independent, uncorrelated atoms. The goal of my PhD research was to surpass this limit by "entangling" the atoms. A pair of entangled atoms is like a pair of coins whose tumbling through the air is unpredictable but choreographed: as one coin randomly twists toward heads, the other turns toward tails to compensate.

My colleagues and I set out to improve the precision of an atomic clock by using light to choreograph the behavior of its constituent atoms. We confine the ultra-cold atoms between two highly reflective mirrors that form an optical resonator, where a laser beam passes through the atomic sample thousands of times. The laser light probes the states of all atoms on each pass and provides feedback to all the atoms on subsequent passes, coordinating the twisting and turning of the different "coins."



When we measure the oscillations of the atoms in this entangled state, the ticking of the clock is uncannily steady. Imagine tossing 10,000 coins over and over again and finding that exactly half always land heads up. Classical physics would not allow this: we have broken the standard quantum limit.

Our reduction of the clock's quantum uncertainty is so far a proof of principle. The next challenge will be to combine state-of-the art classical and quantum engineering in a single device to truly push precision metrology toward its extreme.

A CTY alumna, **Monika Schleier-Smith** earned her PhD in physics from MIT and is now a postdoctoral researcher affiliated with the LMU Munich and the Max Planck Institute for Quantum Optics. She did her undergraduate studies in chemistry, physics, and mathematics at Harvard University. In her free time, Monika enjoys spending time outdoors, especially running. She has completed the Boston Marathon six times.