Using a Superfluid for Dark-State Atomic Cooling

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"We are reviving key ideas used 15 years ago in the context of laser cooling and quantum optics and putting them in a completely new context," Peter Zoller tells *PhysOrg.com*. Zoller, a professor at the University of Innsbruck in Austria, describes a new cooling method by which atoms in an optical lattice could reach temperatures much lower than what be achieved now.

Zoller is also affiliated with the Austrian Academy of Sciences in Innsbruck, and his team includes physicists from Oxford as well as from the University of Innsbruck and the Austrian Academy of Sciences. The findings of the team are published on *Physical Review Letters* in a Letter titled "Dark-State Cooling of Atoms by Superfluid Immersion."

The study of cold atoms is one that opens the door to a variety of applications, especially on the quantum level. Zoller and collaborators are especially interested in the impact his work could have on building quantum simulators for condensed matter physics. "It is hard to solve complicated many-particle systems right now," he explains. "But with cold atoms we could build quantum simulators that would help us study these more complex condensed matter systems."

Andrew Daley, post-doctorate researcher on the team, agrees that working toward a quantum simulator is important. "We need to find ways to reach much lower temperatures in the laboratory for quantum simulators. These simulators in turn can help with activities that are harder to achieve: modeling different states and using atoms in a lattice to simulate more complicated systems."

Zoller's team works from a foundation laid before dark-state laser cooling. "While these are old ideas," he says, "we are using them in a completely different context to create a novel system."

Daley explains that, "The superfluid immersion idea here is that we have atoms in an optical lattice and then you have this background reservoir of BEC of different species of atom. The basic process occurs because of collisional interaction between lattice and reservoir, and what this can do is that when atoms collide energy from lattice can be transferred to reservoir, and this happens in particular way. The atoms are then cooled from excited to ground motional states."

The idea is that "hot" atoms in the lowest Bloch band are excited to a higher band, while "cold" atoms with momentum near zero are left in the lowest band (they are in a "dark state"). Atoms are then recycled by the emission of a phonon, caused by collisions between the atoms and the reservoir. As this process is repeated, atoms then collect in the "cold" dark state region. Inspiration comes from subrecoil laser cooling, but in the Innsbruck and Oxford version, photons are replaced by the phonons and internal atomic states are replaced by the Bloch band excitations.

Both Zoller and Daley point out that right now this idea is a theory. But, Zoller insists, experiments are likely in the near future. "We are very close. It will take some time to really try to do this in the lab, but different groups are interested in trying the idea. I think a timescale of maybe the next two years. This is interesting enough that other groups may try something like it, and maybe even improve upon it."

"This is a breakthrough in the context of cold atoms," continues Zoller. "This could allow for us to maybe see condensed matter phases we don't understand, or see a new class of phase transitions. This might open some new doors."