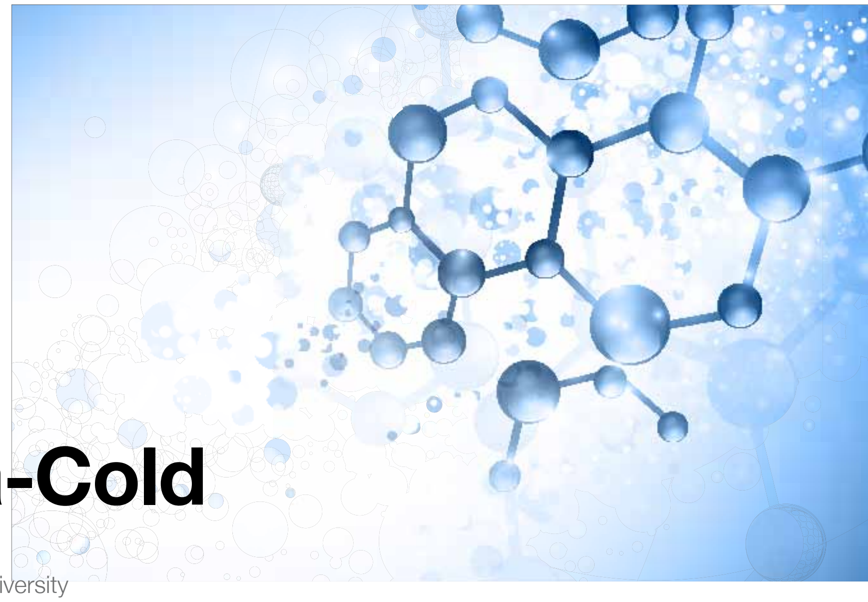

Research on ultra-cold atomic systems allow for the creation of complex but yet very accessible and well controlled many-body quantum systems, and will have a huge impact on our future technology.

Mastering the **Ultra-Cold**

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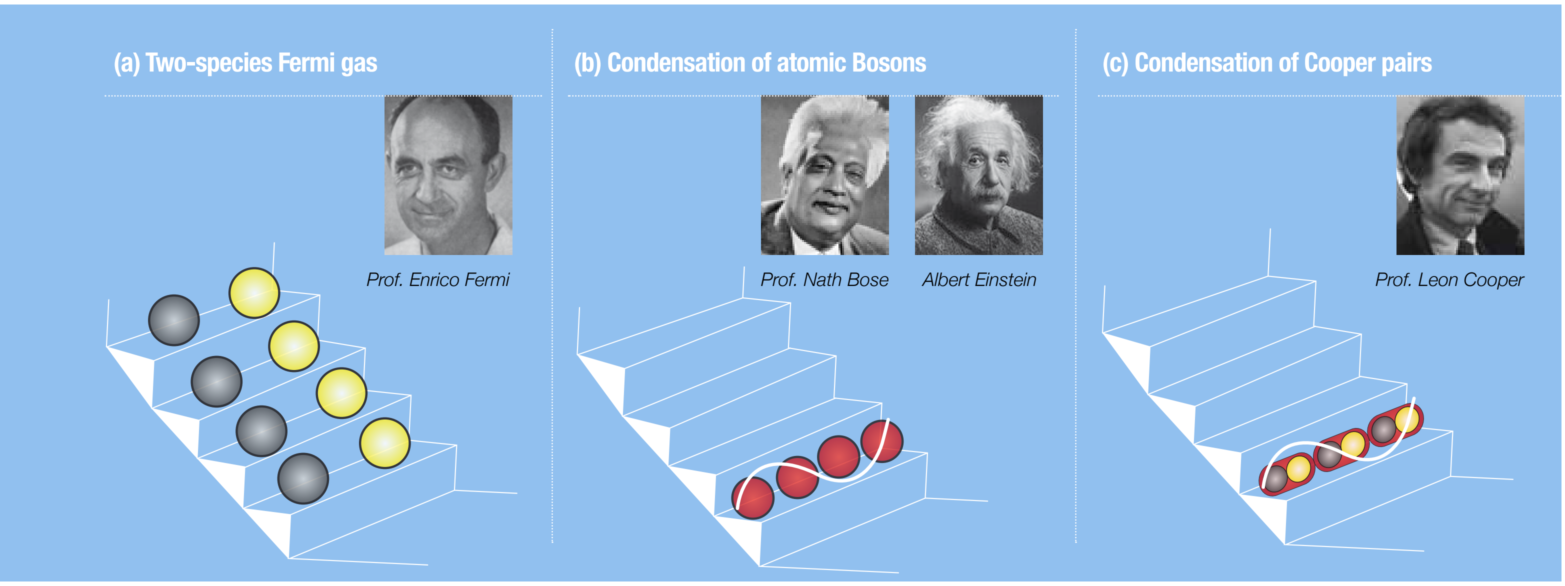
You may think that the coldest places in the universe are millions of kilometers away from us in the outer space but they are right here on Earth, created and destroyed routinely in a number of atomic Physics laboratories everyday. The atomic physicists have been trying to master the ultra-cold since the 1980s, and thanks to the laser cooling technology, they nowadays can cool a few million atoms to just a few nano degrees (billionth of a degree) above the absolute zero temperature. Here, the term absolute zero temperature (-273.15 Celsius) refers to the minimum temperature any material would have, after all of its energy content including the motion of all of its microscopic constituents (molecules, atoms and electrons) is removed. To appreciate how remarkable this achievement is compare it with the temperature of the coldest places in the outer space (around -270 Celsius), as set by the background radiation left over from the Big Bang.

The ultimate success of the techniques for trapping and cooling atoms has a long history with full of exciting and Nobel prize winning discoveries, but the conquest of the cold is not the main topic here. I will instead try to convey why many physicists are interested in studying ultra-cold atomic systems, and what we expect to learn from them in the upcoming years.

Quantum mechanics tells us that all known particles of nature can be divided into two main groups: (i) publicly less familiar bosonic particles such as quanta of light (photons), sound (phonons) or spin wave (magnons), and (ii) publicly more familiar fermionic ones such as electrons, protons or neutrons. Since the fundamental difference between bosons and fermions has a quantum origin, it can only be probed at sufficiently low temperatures. For instance, as the temperature gets lower, Bose and Einstein predicted in 1920s that the bosonic particles gradually looses their individual identities and start acting collectively like a school of fish attacked by a predator. This collective behavior of bosons, the so-called Bose-Einstein condensate (BEC), is a new phase of matter, similar to the solid, liquid or gas phase, and it was only in 1995 that atomic physicists were able to create and observe it for the first time with neutral bosonic atoms. Surely, these initial experimental observations were celebrated with a Nobel prize in 2001. This new phase has many striking properties, the most important of which is the superfluidity (frictionless mass flow) of the particles involved.

Unlike bosonic particles that like to stick together and form a BEC at sufficiently low temperatures even in the absence of interparticle interactions, it was well-established in early 20th century that noninteracting fermionic particles avoid each other in space at a given time due to what is known as the Pauli exclusion principle. However, in the presence of sufficiently strong attractive interparticle interaction between fermions, it was proposed in 1950s that two fermions can bind together as a pair, and start acting effectively like



a bosonic molecule. The collective behavior for fermionic particles that is analogous to BEC for bosonic particles is the superfluidity of these fermion pairs, and it is also responsible for another superphenomenon in electronic systems, that is the so-called superconductivity (resistanceless electrical current flow) of electrons. While this pair-formation mechanism successfully explained some of the early low-temperature superconducting materials that were discovered between 1911 and 1986, a complete understanding of recently discovered high-temperature superconductors remains a puzzle even today.

Since the aforementioned superphenomena in atomic systems are very similar to the transition from normal conductor to super conductor in ordinary metals, I have been working on cold-atom systems since the early 2000s. In particular, by studying pairing mechanism in ultra-cold atoms, we have been trying to find out some clues on how and why some materials retain their superconducting properties up to relatively very high (up to -100 Celsius) temperatures. Our ultimate goal in this line of research is to discover one day a magic trick to create a room temperature superconductor, which would have profound implications in energy efficiency, by dramatically improving nearly every steps from its generation to its delivery. Although cold-atom physics has grown quite immensely over the past two decades, and we have already made a huge progress in understanding the basics of pair formation and associated superfluidity, there is a lot more to be done especially in Turkey, where this extremely exciting forefront field of Physics is barely known in public and also in the scientific community.

In short, given that the ultra-cold atomic systems allow for the creation of complex but yet very accessible and well controlled many-body quantum systems, they have emerged as a unique testing ground for many theories of exotic matter in nature ranging from superfluidity, superconductivity, and pairing in neutron stars and nuclear matter, where quantum effects play a fundamental role. Therefore, we have good reasons to believe that the implications of this basic research will go far beyond our imagination with a huge interdisciplinary impact on our future technology.

Assistant Professor Menderes Işkın received his BS degree from Bilkent in 2002 and PhD degree from GaTech in 2007, and worked 2 years as a guest researcher at NIST before joining Koç University in 2009. His research on cold-atom physics is supported by EC Marie Curie IRG (FP7-PEOPLE-IRG-2010-268239), TÜBİTAK CG (3501-110T839) and TÜBA-GEBİP, and he is the recipient of Turkish Physical Society's Prof. Dr. Şevket Erk Young Scientist and TÜBİTAK's Basic Sciences Encouragement awards in 2012.