RESEARCH LABORATORY OF ELECTRONICS AT MIT

MIT ■ HARVARD UNIVERSITY
CENTER FOR ULTRACOLD ATOMS
SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION

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To the Habilitation Committee of Dr. Igor Mekhov:

It is my great pleasure to provide a report on the Dissertation of Igor Mekhov "Quantum optics of ultracold quantum gases: open systems beyond dissipation" for the degree of Doctor of Physical and Mathematical Sciences at the Saint Petersburg State University, speciality 1.3.6. Optics. I have read his Dissertation and let me immediately state that in my view it fulfills all the requirements for a Doctor of Physical and Mathematical Sciences.

I have known Dr. Mekhov for more than ten years now, and he has impressed me as one of the most creative young theorists in the field of quantum optics, and more broadly in atomic physics. I am particularly familiar with his work that relates to my own (experimental) research in quantum cavity electrodynamics, as well as his work on many-body entanglement by measurement.

Dr. Mekhov's timely Dissertation creates a new subfield at the intersection of atomic physics and quantum optics. By considering ultracold atoms confined in standing waves of light (so-called optical lattices) inside an optical resonator, he manages to bring the quantum properties of light, as well as those of the atomic matter waves, into the problem. (There have been many experiments and much theoretical work on atoms in optical lattices, but they almost exclusively occupy a parameter regime where the strong light can be treated as a classical wave, and where the quantum nature of the light can be ignored.) However, if one places ultracold atoms inside high-finesse optical resonators, as are now experimentally available, with photons reflecting several hundred thousand times from the mirrors before they are lost, the repeated photon-atom interaction can give rise to new phenomena where even individual photons can influence the state of an atom. In particular, it is possible for a single photon to form a trapping potential that

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significantly influences the atomic motion, or a single photon, when detected, can provide information about the atomic state that effectively changes that state.

Igor Mekhov's interesting and original work takes advantage of these strong atom-photon interactions and predicts a plethora of new phenomena that have never been observed in the laboratory. These include proposals for non-destructive light probes of atomic systems that can measure multi-point density-density correlations in an atomic gas, proposals for control of the quantum feedback on the atomic gas induced by the measurement of the light field, and the prediction that feedback control can even be used to induce quantum phase transition in atomic gases. In several papers, Igor Mekhov shows that light measurements can distinguish between different states of bosons and fermions. Dr. Mekhov further proposes, in an extension of the quantum Zeno paradigm, that measurement backaction can be viewed as a physical process that competes with other orderings in an atomic gas that are induced by direct atom-atom interactions. He predicts, e.g., that antiferromagnetic order in an atomic spin system can be induced by optical measurements alone.

Dr. Mekhov is very prolific, and he has published a large number of significant papers over the past decade. What I particularly value about his work is that he keeps in mind experimental capabilities, and proposes realistic scenarios that can be implemented experimentally in the relatively near future. Among several, I point out his interesting paper "Multipartite Entangled Spatial Modes of Ultracold Atoms Generated and Controlled by Quantum Measurement," , published in Physical Review Letters in 2015, where he shows that by detecting individual photons scattered from an ensemble of trapped atoms, one can generate and control multimode entanglement in the atomic ensemble.

I first met Igor when he worked with Dr. Helmut Ritsch from the University of Innsbruck. The two worked together very successfully, and published several high-impact papers in the field of quantum optics with quantum gases. In the meantime Igor has further branched out into several different research areas. He is an independent, competent, technically strong, and very creative scientist.

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In summary, on the basis of his dissertation, I strongly recommend granting Dr. Igor Mekhov the title Doctor of Physical and Mathematical Sciences at Saint Petersburg State University.

Sincerely,