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**Dynamics and Thermodynamics of Many-Particle cold Atom Systems**

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<b>14. ABSTRACT</b> The proposal focuses on understanding non-equilibrium quantum systems both isolated and coupled to the environment. Three major themes of the proposed research are (i) extension of phase space methods to strongly correlated quantum systems (spins, bosons, fermions), (ii) dynamics and thermodynamics of periodically driven (Floquet) systems and (iii) dynamics of slow degrees of freedom and their connection to quantum geometry and topology. The research will focus both on fundamental questions and applications to experimentally relevant setups predominantly in cold atoms and trapped ions. (i) Phase space methods proved to be very reliable and unique tool for analyzing quantum dynamics in weakly interacting systems or the systems near classical limit. They found major applications in quantum optics, quantum chemistry, and more recently dynamics of interacting bosons in cold atoms. Following newly developed ideas we are planning to extend these methods to strongly interacting systems by introducing extra (hidden) phase space dimensions. This should allow one to simulate quantum dynamics of interacting systems without doing standard mean-field type approximations. (ii) Floquet systems found many applications in recent experiments in cold atoms, strongly correlated materials, superconducting qubits and others.			
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During the period of the grant I worked in all three key areas of the proposed research outlined in the abstract. On top of that new, previously unanticipated ideas emerged from that work and resulted in expanded scope of the work.

Below I will outline main topics and the key results. I will refer to the relevant publications, according to the bibliography.

1. **Phase space methods** [10,14, 15, 18, 23,34]: Developed new semiclassical (phase space) approach for simulating dynamics of interacting fermions and strongly correlated systems. Applied these methods to simulate such phenomena as quantum diffusion, disordered fermionic models, quantum chaotic systems like SYK or SK models.
2. **Floquet Systems** [3, 20,21,28,32,35]: Developed new replica approach for finding Floquet Hamiltonians, which allows for infinite resummation of the high frequency expansions. Formulated criteria for Integrable Floquet Dynamics, which allows one to avoid heating for infinitely long times. Showed that one can use Floquet engineering to implement local counterdiabatic protocols. Developed Fermi Golden Rule approach to Floquet systems with a large-amplitude driving.
3. **Quantum dynamics close to the adiabatic limit. Quantum geometry.** [12, 13, 19]. Published two reviews on nonadiabatic response in geometry of both standard and Floquet systems. As a part of this effort we discovered a new variational approach to counterdiabatic driving and applied it to many different setups as also outlined below. We also formulated a conjecture for the quantum speed limit (fastest time for state preparation) within a restricted space of controls (e.g. only experimentally realizable controls).
4. **Counter-diabatic driving** [2,11,17,21,22,25,29,31]. In a series of works we developed a new variational approach to counterdiabatic driving in both quantum and classical systems and analyzed various applications to fast quantum state preparation and efficient energy transfer. We also used this method to find approximate conservation laws in nonintegrable systems and to simulate their long time dynamics in the regimes where other methods fail. This variational method and its Floquet implementation are now routinely used by many different research groups.
5. **Quantum chaos through adiabatic transformations. Absence of MBL** [4,6,18, 27,30]. Another outcome of topic 3, where we realized that adiabatic transformations can serve a very sensitive probe of quantum chaos. We applied this probe to disordered systems and found no evidence of many body localization (MBL). Then we did very extensive work to critically analyze previous evidence of MBL, both analytical and numerical, and found serious errors there (both analytical mistakes and incorrect analysis of numerical data). We discovered an overlooked instability mechanism of the localized phase. We also found that classical and quantum disordered models show very similar glassy dynamics.
6. **Quantum eigenstates from classical Gibbs distributions** [9]. This is a stand alone work, where we showed that classical Gibbs distributions can be represented through discrete eigenstates and Hermitian operators showing that the whole formalism of

quantum mechanics (as we know it) is contained in the classical statistical mechanics, This work was featured by editors and in the condensed matter journal club.,

7. **Dynamical quantum phase transitions through string observables** [5,7]. We showed that dynamical quantum phase transitions encoded in the singular behavior of the Loschmidt echo can be probed using local finite length projectors. We are collaborating now with the group of Monika Aidelsburger from LMU, who are probing these strings experimentally.

Several of our papers were selected as editor's suggestions [9,21,31,36] and in addition Ref. [9] was featured in the Journal Club for Condensed Matter Physics ([https://doi.org/10.36471/JCCM\\_October\\_2020\\_01](https://doi.org/10.36471/JCCM_October_2020_01)).

The results of our work were reported in multiple (well over 100) presentations including conferences, workshops, schools, seminars and colloquia. This grant also supported travel by students/postdocs to conferences and schools.