TRR 352 *in motion*

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TRR 352: Mathematics of Many-Body Quantum Systems and Their Collective Phenomena

TRR 352

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Welcome to the first issue of the TRR 352 Newsletter!

We're excited to bring you the latest updates from our research community. In this edition, you'll find news about recent promotions, international experiences, and career moves. Stay tuned for all the important milestones and achievements happening within our team. We hope you enjoy reading and find the updates valuable!

Recent Doctorates

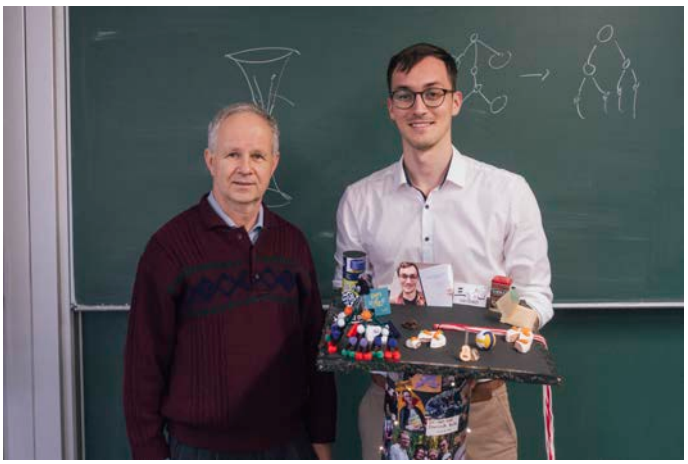
Asbjørn B. Lauritsen successfully defended his PhD thesis on September 23, 2024, at ISTA

László Erdős, Robert Seiringer, Asbjørn B. Lauritsen, Jan P. Solovej

Asbjørn's thesis, titled "*Energies of Dilute Fermi Gases and Universalities in BCS Theory*" (https://doi.org/10.15479/at:ista:18135), is divided into two main parts:
The first is about establishing asymptotic formulas for the ground state energy (and pressure) of dilute Fermi gases. Here in particular, a fermionic cluster expansion is developed and used to deal with these correlated systems.
The second is about universal properties in BCS theory, namely that (in various limits) the ratio of the energy gap and critical temperature is a universal function of the temperature, indepent of the microscopic details of the particular superconductor.

Congratulations!

On December 13, 2024, Dominik Sulz successfully completed the defense of his PhD thesis at the University of Tübingen



Christian Lubich and Dominik Sulz

Dominik's thesis "*Time Integration in Quantum Dynamics using Tree Tensor Networks*" studies the numerical solution of high-dimensional tensor differential equations. The prohibitive computational cost and memory requirements of numerically simulating such equations are often referred to as the curse of dimensionality. Such prohibitively large differential equations arise in many fields of application such as plasma physics, machine learning, radiation transport or quantum physics. Dynamical low-rank approximation offers a promising ansatz to overcome the curse by representing the highdimensional tensors in a low-rank format and solving a projected differential equation on a low-rank manifold. The low-rank manifold considered in this thesis is the manifold of tree tensor networks.

Congratulations!

International Stays

Exploring Research and Culture: My Enriching Five-Month Stay at LMU – By Lukas Junge

Lukas Junge with Emanuela Giacomelli, Arnaud Triay, Jinyeop Lee, et al. at the Oktoberfest

I had the opportunity to visit LMU for five months between March 2024 and August 2024. From the start, I was warmly welcomed by the community. My main contact, Nam, helped me settle in both academically and socially, making the transition smooth and enjoyable.

During my stay, I made progress on several research projects. I continued my work with Arnaud on the expansion of the free energy for hardcore-interacting Bosons in the thermodynamic limit. I also collaborated with François to prove Bose-Einstein condensation in 2D for trapped Bosons in the almost Gross-Pitaevskii limit. Nam introduced me to the strongest de Finetti result, which played an important role in achieving this result. I also began exploring with Florian the free energy for 2D bosons, which we hope to develop further. Additionally, I participated in summer and winter schools organized by Nam, Christian Hainzl, and Emanuela, which were valuable opportunities to exchange ideas.

I joined a reading group with Jonas, Larry, and Christian on non-linear analysis where we discussed various topics to improve base mathematical understanding.

Outside of work, I lived near Rosenheimerplatz, which gave me easy access to Munich's many attractions. I often went bouldering and took multiple hiking trips in the Bavarian Alps. The density of beer gardens made the European Championship very enjoyable and I was eager to participate with the group. Riccardo also helped me smuggle myself into football practice with the TMP students and I joined their yearly tournament, where we, unfortunately, were only able to secure second place.

From Lab to Landmarks: Four Months of Discovery in Paris – By Paul Gondolf

Spending four months in Paris – split between spring blossoms and autumn leaves – was as enriching as it was exciting. Based at Télécom Paris on the Saclay Plateau, I worked with the *Quriosity* research group alongside my supervisor, Dr. Cambyse Rouzé, and PhD student Jan Kochanowski. While my days focused on reserach, I particularly enjoyed the group's diversity: it gave me a chance to peek at the experimental side of things while I myself only moved around letters and symbols.

Living southwest of the city center meant weekends were for adventure. I wandered through the Louvre's endless galleries, stood beneath the dome of Musée d'Orsay, and paid a visit to Napoleon's tomb at Les Invalides. A trip to Versailles let me lose myself in its sprawling gardens and Marie Antoinette's quirky hamlet.

Between lab days and sightseeing, I embraced Parisian rhythms: mornings espressos and flaky croissants, evenings with lively discussions (and occasional beers) at Quriosity's casual get-togethers. The group's mix of early-career researchers sparked insightful discussions about career paths, research, and private life – whether debating proofs, sharing meals, or swapping film recommendations.
All in all, the stay was a fantastic mix of professional development and personal enjoyment. And yes, Paris in both spring *and* autumn? Absolutely worth it.

La Pyramide du Louvre, Paris

Research Experiences Across Europe: Cambridge, Paris, and Munich – By Sebastian Stengele

Sebastian Stengele

As it sometimes happens, my PhD advisors are spread across three countries: Angela Capel is in Cambridge, Cambyse Rouzé at Telecom Paris, and Simone Warzel at TUM. Although I am primarily based in Germany, I regularly travel between Germany, France, and the UK for my research, which mainly focuses on the thermalization of quantum spin systems.
My visits to Telecom Paris, located on the Plateau of Saclay south of Paris, are always rewarding. The research group is quite diverse, with people working on applied quantum information, foundational questions, and more mathematical aspects, like my advisor Cambyse. I had many valuable discussions with him, and we made good progress. Additionally, the food in the cafeteria is excellent. Some things are quite different from Germany; for instance, you need a badge to enter the building, and before the Olympics, there were even security checks. I also enjoyed exploring Paris on the weekends. In Cambridge, the entire town reminds me of scenes from a Harry Potter movie. The group there also has a wide range of research focuses, ranging from the more mathematical work of Angela to algorithm development. I enjoyed engaging with various people from different backgrounds. Working with Angela was very productive, as nothing beats discussing ideas on a blackboard. Cycling is the easiest way to get around and explore Cambridge, although staying on the left side of the road was initially confusing. These research stays have led to significant progress in my projects. I have also met many interesting people, which has been rewarding both professionally and personally. I am grateful to SFB TRR 352 for making these experiences possible and look forward to continuing my visits to both places.

Research Visit at ISTA: Exploring Thermalization in Quantum Systems and Enjoying Nature in Klosterneuburg – By Cornelia Vogel

From the beginning of March to the end of June 2024 I was visiting László Erdős at the Institute of Science and Technology Austria (ISTA) in Klosterneuburg close to Vienna. ISTA is a young research institute beautifully surrounded by woods but still close to one of the most livable cities in the world. It offers a competitive graduate program consisting of lab rotations in the first year and after a qualifying exam students conduct research for three to four years leading to their PhD. During my research visit I was able to live in one of the apartments on campus; everything was very well organized and I could reach the institute in less than five minutes.

ISTA Logo

In my PhD I am concerned with the typical macroscopic behavior of large quantum systems. For some questions it was helpful to model the system's Hamiltonian by a random matrix and use properties as the delocalization of eigenvectors of certain classes of random matrices. One topic of particular interest is the thermalization of large quantum systems. With our methods we could only obtain extremely large and physically unrealistic thermalization times (for rather arbitrary Hamiltonians) and there are also models in the literature that exhibit way too short thermalization times but the realistic regime remains to be understood. During my time at ISTA, László Erdős, Joscha Henheik and I developed a random matrix model for which we are able to prove "more realistic" thermalization times.

Besides working on this interesting research project, I was also able to attend a great variety of talks and small lectures, go to the Vienna-Budapest probability seminar in Budapest and participate in the 3rd ISTA Summer School in Analysis and Mathematical Physics.

A hare on campus

In my free time, I enjoyed going for long walks in the beautiful woods around ISTA and watching the wildlife. A large variety of insects including fireflies and many butterflies could be seen as well as hedgehogs, ducks, frogs, snakes, deers, beavers and, most importantly, many hares, which seemed to rule the campus at night.

I would like to thank László Erdős for his hospitality as well as for many interesting discussions together with Joscha Henheik, the whole mathematical physics group at ISTA and the research institute itself for making it a great time and the CRC TRR 352 and in particular my PhD supervisor Stefan Teufel for making this research visit possible!

New Career Moves

From Klosterneuburg to Paris: Research on Fermi Gas Energy Asymptotics and Time-Dependent Density Functional Theory – By Asbjørn B. Lauritsen

Asbjørn B. Lauritsen in front of the Arc de Triomphe in Paris

My PhD project with Robert Seiringer concerned the study of a spinless/spin-polarized Fermi gas and its energy asymptotics in the dilute regime, where the interparticle spacing is large compared to the lenghtscale set by the interaction. This analysis somewhat parallels the study of a dilute Bose gas, which many people are working on. We managed to prove the leading correction to that of the free gas, being the analogue of the famous order $a\rho^2$-term for the Bose gas, first proved rigorously by Dyson (upper bound) and Lieb and Yngvason (lower bound). To study such a Fermi gas, we gave in particular a rigorous implementation of a fermionic cluster expansion of Gaudin, Gillespie and Ripka, first proposed in the physics literature as a method to study such strongly correlated fermionic systems.

In Paris, I work with Mathieu Lewin on a newly started project with the goal of formulating a version of time-dependent density functional theory (TDDFT) with good properties. The project is interdisciplinary and joint with Julien Toulouse (Quantum Chemistry) and Eric Cancès (Numerical Analysis). The standard (time-independent) density functional theory (DFT), useful for studying the ground state energy of a system, can be understood as the following reformulation of the variational characterisation of the ground state energy. Minimizing the energy expectation first over all wave functions ψ giving rise to a prescribed one-particle density ρ one finds a functional of the density $F(\rho)$, whose infimum over densities ρ is the ground state energy. The usefulness of this construction then hinges on the existence of good computable approximations to the functional F. Our project works to formulate and study a time-dependent version of the functional F. Immediately one faces the difficulty of not having a simple variational principle, characterising the time evolution, as one has for the ground state energy.