Have you ever wondered how bosons behave when they have to move in total chaos and disorder? We have.

Bosons are, apart from fermions, one of the two types of particles found in the universe. Examples of bosons are photons, nuclei of some elements or Cooper pairs, i.e., pairs of electrons responsible for superconductivity (technically not a particle, but a *quasiparticle*, i.e., a system behaving like a particle). Two fermions can not exist in the same quantum state (i.e., in the same place, with identical momenta, energies, etc.), but bosons do not have this limitation, so it is possible to obtain a system in which they are all in the same state. To achieve this, very low temperature and strong interaction between particles are needed. The effect can be, for example, superconductivity, if the particles are said Cooper pairs or superfluidity, when they are the nuclei of the ^{4}He helium isotope. Such states have amazing properties: no resistance in the case of superconductivity or no viscosity in a superfluid state. In both cases, therefore, once the particles are in motion, there are no losses and one does not need to perform any work to maintain their movement.
Even a small amount of disorder, i.e., randomness in the system, can cause surprisingly big changes. Echo in a forest is the result of the chaotic arrangement of trees. In quantum systems, the disorder leads to localization of the particles (e.g., electrons). In an ordered system, electrons are "spread" throughout the entire system, while the introduction of disorder makes them stay where they were placed, even though there is no force that would keep them there.
An interesting example of a disordered system are spin glasses. They are systems in which auxiliary magnetic particles are randomly distributed, and it can be assumed that the interaction between them is random. The name comes from this random placement: a glass is an amorphous material in which atoms are randomly arranged, while spin is the source of magnetism. Although the spin glasses themselves were not widely applied, the theory developed for their description turns out to be useful in other areas, even as distant as neural networks or biology.

In this project, we plan to combine these two topics and describe theoretically strongly interacting bosons with the disorder like in spin glasses. For this purpose, we will write the so-called free energy of the system, and then make a series of calculations to find when its value is the smallest. This is because physical systems "choose" precisely those states in which energy is the smallest. the whole nature is somewhat lazy. This problem most likely can not be fully solved analytically, therefore, at some stage of the calculation, we will transfer the equations to a computer program and examine the properties of the system numerically.

As we mentioned, the usefulness of the system in question lies mainly in the fact that it allows us to notice extremely interesting behavior of quantum particles, and in the possibility of transferring results to other fields science. Spin glasses turned out to belong to the class of so-called *complex systems*, i.e., systems in which the structure emerges seemingly "out of nowhere", as the original description of the system had none. Many of the complex systems have a lot in common, so understanding one can help to understand others. One of the examples is the problem of protein folding. Proteins, or chains of amino acids, have some fixed composition. However, the arrangement of those amino acids in space is not unique and may depend at least on the temperature or pH of the surroundings. Under fixed conditions, a certain geometric configuration will have the lowest energy, so the protein will tend to fold this way. However, before this will happen, the protein will go through other configurations and only after some time it will "find" the right one. It turns out that the time needed for this is either much larger or much smaller than what simple theoretical models predict, while the use of analogy to the dynamics of spin glasses gives satisfactory results.
Considerations on spin glass began over 30 years ago, but with time the interest decreased, possibly because of the lack of new ideas. Returning to this research can be motivated by the emergence of *quantum simulators*. They are physical systems that simulate other systems, but allow a lot greater control of their parameters and features. Investigation of a spin-glass-like system using such a simulator can bring many answers that were impossible to obtain earlier. In particular, systems of bosons with disorder like in spin glasses never existed, while quantum simulators can mimic them as well. It seems that we even have an idea how such a system should look like.