The objective of the project:

The main goal of the project is to describe the dynamics of the layer of compressible electrically conducting fluid in the magnetic field, due to the baroclinic and magnetorotational instability, with particular emphasis on the influence of thermal and magnetic diffusion.

The motivation to undertake planned research is one of the fundamental problems of theoretical astrophysics, which is the formation and maintenance of stellar magnetic fields. The mechanism that governs these phenomena is called the magnetohydrodynamic dynamo. The fields generated by it play a great role in various processes occurring in the universe. They also significantly influence other celestial bodies like planets. Thus, the main motivation of the research and the reference point for the obtained results will be the dynamics of the Sun's magnetic field, whose direct and indirect impact on our planet is important from the point of view of the Earth's climate, life on Earth, and even the safety of humanity in the context of the geomagnetic storms.

It is believed that among many types of instabilities occurring in solar plasma, one of the most important for the dynamo mechanism are baroclinic (disturbances of the thermal wind) and magnetorotational (associated with the solar differential rotation). They may also be responsible for the formation of the sunspots due to the release of a strong toroidal magnetic field from the Sun’s interior. The most important quantities characterizing the dynamics of these instabilities will be found in linear regime: stability criterions, dispersion relation, growth rates of the perturbations and their structure, especially spatial and temporal scales. Particular emphasis will be placed on the quantitative description of the impact of diffusion on the studied instabilities, which will allow for identify the most unstable mode, which role in the dynamics of the system is the most important. Ultimately, thanks to the results obtained, it will be possible to formulate an effective system of equations describing the evolution of the plasma and magnetic field in the studied system.

Research to be carried out:

Achieving the goals of the project is planned through simultaneous application of advanced mathematical methods in theoretical analysis and numerical simulations.

It is believed that the generation of the solar magnetic field take place primarily in the relatively thin layer inside the star, called the solar tachocline. Hence, a reasonable and common approximation when studying local properties of the similar issues is the adoption of Cartesian geometry and consideration of a plane layer of fluid with finite thickness.

The evolution of the flow and magnetic field will be described by standard magnetohydrodynamics equations. However, unlike in many previous works, the compressibility of the fluid, as well as thermal and magnetic diffusion (related to the non-zero thermal conductivity and resistivity of the medium) will be taken into account. A linear analysis of such system of equations will be possible due to the use of asymptotic methods in the limit of small diffusivity, which is motivated by the physical properties of the solar plasma. In particular, the boundary layer method and the WKB method will be used, which hopefully will allow to find asymptotic approximations of the quantities characterizing considered instabilities. Moreover, the multiple-scale analysis will be used to formulate the final system of equations describing the dynamics of plasma in the solar tachocline under adopted assumptions.

Numerical simulations will be carried out using code developed by the principal investigator in the Python programming language. With the use of appropriate methods, both the boundary value problem and the time evolution of the system will be examined, hence it will be possible to verify the results of the theoretical analysis.

Reasons for choosing the research topic:

The obtained results will help in further studies of the problem for more complex and closer to reality assumptions, such as saturation of nonlinear instabilities, turbulent flows and spherical geometry. It will be also possible to use them in studies of the evolution of magnetic fields of other astrophysical objects such as planets or accretion disks.

Obtained spatial and temporal scales of perturbations may help in research and explanation of the origin of heliophysical phenomena such as sunspots, which may be the result of development of baroclinic and magnetorotational instability in the tachocline. Moreover, the obtained effective system of equations describing the plasma in the solar tachocline will allow for a deeper understanding of the mechanism of the solar dynamo and thus may contribute to a better description of the activity of the Sun which has a fundamental impact on our planet.