Project title: **Anomalous Collective Modes in Quantum Materials**

Project description:

Recent progress in topological quantum materials has opened a unique bridge between condensed matter physics and concepts originally developed in high-energy physics and cosmology. A well-known example is the axial anomaly, whose many-body realization in Weyl semimetals leads to experimentally observed transport phenomena such as negative magnetoresistance.
Beyond this, the same class of systems is predicted to host another, much less explored effect: the scale (or conformal) anomaly, a quantum violation of classical scale invariance. While widely discussed in particle physics, its realization in quantum materials remains largely unexplored experimentally and theoretically.
In this project, we will study collective excitations induced by the axial and scale anomalies, starting with low-dimensional (1D) systems. In reduced dimensions, the axial and scale anomalies lead to emergent bosonic modes (scalar or pseudoscalar), which dominate the long-distance behavior of correlation functions. These modes can be viewed as condensed-matter analogues of axions and dilatons, hypothetical particles discussed in high-energy physics and cosmology.
The main goal of the project is to analyze these anomaly-induced collective modes in 1D systems using effective field theory (EFT) methods. This lower-dimensional setting serves as a conceptually clean and technically accessible platform, paving the way toward more realistic (3D) materials which are actively studied in the field.
Importantly, most of the work will be performed at the effective field theory level, where calculations are largely analytical and classical in nature. This makes the project well suited for an advanced undergraduate student, while providing a direct entry point into modern research at the intersection of condensed matter and high-energy physics.

Required skills

- Basic background in quantum mechanics
- Familiarity with Lagrangian and Hamiltonian formalisms
- Interest in learning the basics of quantum field theory
- Basic knowledge of general relativity or fluid dynamics is a plus, but not required
- Motivation to engage with theoretical concepts and analytical calculations

No prior research experience in quantum field theory is required; relevant tools will be introduced during the project.
Supervision and work plan

- Supervisor: Andrey Sadofyev
- Host group: [Not sure at what level it is meant here]
- Location: UPV/EHU, Leioa
- Supervision plan:
    - Weekly meetings to discuss progress and introduce new concepts
    - Guided reading of selected review papers

- Step-by-step development of simple EFT models describing anomaly-induced modes

By the end of the internship, the student is expected to understand the physical origin of quantum anomalies in many-body systems and to present analytical results for collective modes in 2D models.