

In 2011, the scientific community got excited with a tweet: "*It would take an elephant, balanced on a pencil, to break through a sheet of graphene the thickness of cling film.*" Since 2007, graphene has entered the collective consciousness as a wonder, super-durable material and, as a forerunner, triggered extensive research on van der Waals (vdW) materials. In the scientific community, it is evident that 2D materials will revolutionize our technology. Today, it is a question of "when" this will happen. **On the other hand, the mechanical fragility of freestanding 2D vdW materials remains the critical bottleneck for their mass fabrication and application in durable everyday devices.**

Considering state-of-the-art and forecasted cutting-edge research on vdW materials, it begs the question: **Can we create unambiguous and comprehensive empirical knowledge to reach the technological level that allows for predictive design and fabrication of mechanically robust 2D vdW structures?** Furthermore, from the point of view of common knowledge, we may ask: **What causes the discrepancy between repeatedly announced superior elastic properties of vdW materials when confronted with today's modest possibilities of mass production of durable structures?** Available experimental work on elastic features of vdW shows a vast disproportion between the number of studies devoted to 2D and bulk vdW materials. Thus, knowledge about bulk, which should be the foundation for further research, is rudimentary. Today, it is possible to piece together molecular layers in a LEGO-like approach and create stacking multifunctional vdW structures. At the same time, it is highly desired that a similar, atomically precise degree of manipulation of elastic properties be possible. The critical question arises:

Do we have experimental tools for an unambiguous and complete mechanical assessment of vdW materials from bulk to the single molecular layer and their complex nanostructures?

Based on the literature overview, we can figure out that the elasticity of bulk vdW materials remains sparsely examined experimentally compared to theoretical studies. Most standard techniques require large different-cut samples, while vdW are small, flaky crystals limited to cleavage planes and flat surfaces. In the case of single- and few-layer vdW materials, the most standard technique, i.e., atomic force microscopy (AFM), is a contact-like method inherently perturbing the measured system. Thus, the reported values do not lead to any clear consensus regarding the size dependence of the elastic features. At the same time, there is a great need for a framework combining complementary experiments and simulations supported with AI machine learning for predictive scaling of the mechanical behavior of simple and complex 2D materials. To this day, the experimental part of this story remains uncharted territory.

The project aims to pick up this gauntlet and unravel the nanomechanical properties of vdW materials from bulk to a single molecular layer utilizing state-of-the-art all-optical tools. In particular, we will focus on TMDCs and perform the first complex experimental investigation of the impact of spatial confinement, lattice twist, and intralayer coupling on the intrinsic elasticity of freestanding structures.

To address these challenges, we will develop a novel contactless experimental platform employing all-optical methods utilizing inelastic light scattering on thermal and nonthermal phonons. In this way, we will access intrinsic anisotropic elastic features of Transition Metal Dichalcogenides (TMDCs) ranging from bulk to a single molecular layer and their complex stacking heterostructures. This project outcome will gain the fundamental knowledge essential for the predictable fabrication of robust vdW molecular layers and heterostructures. **The groundbreaking nature of the project** is due to the out-of-the-box experimental platform for the elastic evaluation of bulk and 2D vdW materials. We will go beyond today's experimental routine of contact-like tools and utilize an all-optical contactless and nondestructive approach based on inelastic light scattering on phonons. In particular, we will employ Brillouin light scattering as the core part of the experimental setup, expand its capabilities to the technological limit, and measure the speed of all possible acoustic phonons needed for the complete elastic evaluation.