The first recorded instance of sound (phonons) appears in the 3rd verse of *Genesis*. The propagation of acoustic (mechanical) waves in architected matter is a generic problem that impacts telecommunication, material, and life sciences. Phonon propagation in composite structures depends on many conversational parameters (at least three per solid component), increasing further when anisotropy, confinement, and interfacial effects are included in the structure design. There is, therefore, rich, unexplored, and hardly predictable fundamental science that needs a foundation of high-frequency (GHz) phononics, enabling simultaneous manipulation of hypersonic phonons and visible light in periodic materials. The sub-micrometer organization is a ubiquitous property of soft matter that allows the fabrication of structures with manifold functionalities. Control over the phonon dispersion can impact the flow of mechanical waves, strength, toughness concomitantly, and heat transport in dielectric hybrid materials. Many essential questions in this young field of GHz phononics are being raised and require new conceptual and technical approaches to address them. This will further boost the next step of nanocrystal THz phononics, targeting the coherent management of phononic heat transport.

One-component hybrid materials exemplified by polymer grafted (inorganic core) nanoparticles (GNP), newly synthesized, are a powerful platform for self-assembly fabrication of nano-submicron periodic structures. These combine strong vibration resonant core (size and elasticity), transformative polymer conformation, and phase state depending on physical (graft length, grafting density, and bimodality) and chemical (single, diblock) parameters. The facile fabrication of tunable GNP's structures with controlled solid (core)-polymer and polymer-polymer GNP interfaces will allow phonon engineering at long and short wavelengths compared to the periodicity for scrutiny of structure-controlled nanomechanics and metamaterial properties. The thermodynamic phase diagram of the polymer grafts will be utilized for external stimulus by pressure and thermal transport. The experimental band diagram (frequency vs. phonon wave vector) will challenge theoretical predictability by employing state-of-the-art simulations.

In this project, we aim to investigate how the elasticity, photo-thermal effects, and hypersonic stopbands (all polarizations) can be tuned by architected GNP, discovering new metamaterial properties and ambient and high hydrostatic pressure. Establishing a reliable predictive power will open new application pathways of soft-matter-based high-frequency phononics.

To make this vision real, we will employ state-of-the-art GNP synthesis and experimental tools in close international and multidisciplinary collaboration between five research groups from Poland, Germany, Spain, Greece, and the United States. We will verify the research hypotheses: (i) High-frequency mechanics (elastic moduli and Poisson ratio) should deviate from a continuum-level behavior depending on graft conformation and GNP internal structure and packing. (ii) The subwavelength hypersonic stopband (hybridization) should display a complex dependence on grafting density, lattice constant, and architecture. (iii) The amplification of narrow-band metamaterial absorption in the visible light regime and modulated thermal conductivity should relate to the phoxonic features of GNPs.

The advancement of a new field creates knowledge in physics and material engineering and challenges material nanofabrication and characterization: **(1)** Strong, robust, and low-density nanostructured functional materials are of paramount importance for a wide range of applications comprising microelectronic, photonics, nano-electro-mechanical systems, nanofluidics, biomedical imaging, GHz signal processing in 5G and 6G technologies. **(2)** A detailed understanding of phonon propagation in soft nanostructures is a precondition to access fundamental concepts such as micromechanics, tunable hypersonic phononic stopbands heat management, and phonon-photon interactions. Controlling the elusive flow of heat is a complex challenge across multiple materials, length scales, and ultimately, devices. The realization of performance enhancements reducing inorganic core content in one-component hybrid materials will have an environmental (recycling) impact. **(3)** Know-how transfer between the research groups and foremost to young scientists.