Melting and solidification are transitions between structurally ordered and disordered states of matter. On melting, a crystal in which atoms are arranged in a regular pattern, transforms into a liquid in which the arrangement is disordered. Solidification (or crystallization) is a reverse, disorder-to-order transition. Both processes have been extensively studied by physicists and are widespread in daily life: melting of ice and crystallization of water are both a part of our everyday experience. They are also of fundamental importance for materials science and engineering since they underlie important technological processes like casting or welding. The common knowledge is that melting and freezing occur at the same temperature. When air temperature falls below 0 deg. C ice may form on the road, but the ice will melt when it warms up to above 0 deg. C. In more general case however, the actual melting and freezing temperatures are not equal. For example, some types of high-altitude clouds are composed of liquid water droplets at temperature as low as -15 deg. C. The phenomenon of existence of a liquid below its nominal freezing point is known as supercooling and is a common feature of virtually all liquids. The reverse event – superheating of a solid is much more rare. To be achieved, superheating requires heating the material extremely rapidly, fast enough to outrun melting. In fact, under normal, slow heating conditions "premelting" of solids is observed rather than overheating. It's well known that crystals start to melt from the surface even below the melting temperature. This peculiar asymmetry between melting and solidification originates from different microscopic mechanisms of the solid-liquid and liquid-solid transition. Those mechanisms are fairly well understood when temperature does not change rapidly and melting or solidification proceeds slowly. Yet, when high heating and cooling rates are involved and transformation proceeds in a superheated or a supercooled regime, the theoretical predictions cannot be easily verified. This is because of the characteristic timescale of the transformation which is extremely short and for which the relevant time unit is a picosecond – one millionth of one millionth of a second. For such short times, the conventional experimental techniques which typically require seconds or even hours to perform a single measurement, remain completely useless. In this project we aim to bypass this timescale limitation by employing state-of-the art experimental techniques involving the so-called "pump-probe" approach to study ultrafast melting and solidification of selected pure metals. The key feature of this approach is ultrafast heating of metallic thin (tens of billionth of meter) film with extremely short (shorter than a picosecond) pulses of laser emitting visible light. When metal is irradiated ("pumped") with such a short pulse, it heats at an enormous rate of 10^{14} (hundred trillion) Kelvin per second and subsequently cools down at 10^{12} (trillion) Kelvin per second. We will probe the atomic structure of the film by irradiating it with a second ultrashort pulse, this time of X-rays or electrons. The second pulse will be delayed with respect to the first one so it hits the sample during heating or cooling. By acquiring snapshots of the X-rays or electrons scattered by the film at different delay times we will capture its atomic arrangement and observe the details of ultrafast melting and solidification. In particular, we will establish the limits of superheating and supercooling and measure the velocity of propagation of the melting/solidification front deeply in the superheated/supercooled regime. By investigating pure metals with different crystalline structure, we will correlate this structure with the mechanism and rate of melting and solidification. For this purpose we will compare our experimental data with computer simulations carried out by means of, so called, molecular dynamics. Molecular dynamics models the movements of atoms caused by their mutual interactions and thus allows to study the changes of atomic structures of materials. The simulations will be carried out for systems with the characteristic dimension corresponding to the thickness of the studies samples consisting of approx. millions of atoms and at the time scale of the experimentally studied processes, i.e. from pico to nanoseconds. We anticipate that those results will shed new light on extremes of common phenomena of melting and solidification.