-What's so exciting about 2D materials?

2D materials are atomically thin crystalline solids that can behave very differently from their 3D bulk counterparts. It is possible to tune the electronic properties of 2D materials relatively easily using external perturbations such as electromagnetic fields. Moreover, different types of 2D materials can be stacked together, in a very similar way as stacking toy LEGO bricks. These so-called van der Waals heterostructures can show emerging properties, such as superconductivity, correlated insulating states and even exotic forms of topology depending on how they are stacked. In the future, these artificial materials could ultimately be the main functional building blocks for truly realizing quantum electronics devices.

-What advantages are there in applying 2D materials to devices?

Devices made with 2D materials will be much smaller in size. Also, as we will have better control of their properties, these devices with run faster, consume less power and may even introduce new functionalities such as foldable, flexible and transparent electronics. Given the wide range of electronic properties that can be realized by combining vastly different 2D materials, one could dream about atomically thin units that are both capable of capturing and converting energy, in the form of light, performing demanding computations using advanced information technology and storing memory – all within a few atomic planes.

-What in particular is interesting about VSe_2?

Bulk VSe_2 is a metal and its structure changes if it is cooled below 110 K. But it behaves differently in single layer form. In this case, its structure changes twice – at about 350 K and 135 K. Interestingly single layer VSe_2 also become insulating below 135 K. There is a very large interest within the condensed matter physics research field to understand such phase transitions in general terms, as this will improve our predictive power to find new systems and ability to control such phases in real devices.

-What's a charge density wave? Can they be used for anything?

As the name suggests, a charge density wave is a phenomenon, where the conduction electron density of a material develops a periodic modulation. There can be different reasons behind it – repulsion between electrons and interactions between electron and lattice degrees of freedom in the material. The underpinning physics can be different for different materials. It is a very active field of research to obtain a coherent picture of this situation.

The metallic and insulating state of many charge density wave materials can be switched using electric fields, for example, in the form of a laser pulse. Very often these switching events take only a fraction of a pico-second to happen. These materials therefore have a potential use in ultrafast electrical switching, memory devices, photodetector and so on.

-What new information did the measurements you did on Artemis give?

At Artemis, we shined a very intense laser pulse on a single layer VSe_2 sample and observed the changes in the electron energy and momentum using a technique called angle resolved photoelectron spectroscopy. By measuring the electron energy and momentum, we were able to identify if our sample was in the metallic phase or in the insulating phase. The speciality of Artemis is that we can measure these changes very precisely with few tens of femtosecond time resolution. We find that for samples that have been cooled to the insulating phase, below 135 K, the laser pulse switches them to the metallic phase within half a picosecond. Since we can see how the quantum land-scape modifies before, during and after the excitation, we were also able to pin-down that the electron-lattice interaction is the driving force for this transition.

-You talk about understanding the interplay between electrons and the lattice. How do you study both of these things when the experiment just measures the electrons?

As the lattice is made of many nuclei that are a lot heavier than the electrons in the material, the electrons respond to any external excitation by an electric field much more rapidly than the lattice. Consequently, any process involving only electrons happens much faster than the processes involving the lattice. The time scale of purely electronic processes is typically 50 fs. Our sample took much longer to switch to the metallic phase after exciting it with the laser pulse, and the observed time scale matches with the "slow" timescale of processes involving lattice.

-What teams of people were involved in the work?

This work was a collaboration between many international groups. The samples are grown in University of Seoul, Korea and University of St Andrews, UK. The static ARPES measurements are done at University of St Andrews, UK and Maestro beamline of advanced light source, US. The time resolved measurements are performed in the Artemis facility at Rutherford Appleton Laboratory, UK. The theoretical calculations are performed in collaboration with Rutgers University, US. Planning of the experiment, co-ordination and data analysis were done by the group at Aarhus University, Denmark.