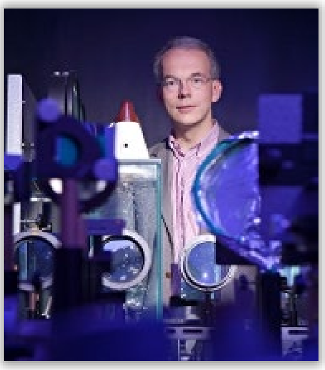
A Panorama of Scientific Challenges for 21st Century Physics

The progress we have made over the last hundred years in our understanding of the physical world is truly remarkable. However, even if we are well aware of the breakthroughs of quantum theory and relativity of the early 20th century, we rarely stop to reflect on just how much our everyday life is shaped by the advances in knowledge and technology they have brought about. When using a handheld device to navigate our way around town, we crucially rely on the physical laws of general relativity and quantum mechanics. These spectacular, early discoveries laid the basis for a golden age of uncovering new physical phenomena, from the microscopic quantum world of elementary particles to the vast expanse of our universe.

Do these successes imply that the role of physics research in the future is merely to "fill the gaps"? Far from it. We enjoy ever-increasing computational power, capabilities to handle and infer knowledge from big data, and advances in instrumentation enabling access to experimental and observational data of unprecedented precision. On the one hand, this allows us to explore extreme regimes previously out of reach, which has already produced spectacular new insights, with gravitational waves and exotic quantum matter as prominent examples. On the other hand, it brings into focus the limitations of our current physical theories and the challenges we still face in pushing their boundaries. While detailed research strategies for tackling them are formulated elsewhere , this document takes a complementary approach. By presenting a selection of such challenges, seen through the eyes of individual researchers, it aims to bring alive the beauty and richness of the subject, fueled by the drive, passion, and diversity of its practitioners. All these ingredients are essential for the Dutch physics community to continue to progress, flourish, and contribute.

Detlef Lohse finds that physics of fluids holds the key to cope with societal challenges:



Source: Wikipedia

It is nearly impossible to overestimate the relevance of fluid dynamics for mankind. Flow in the ocean or in the atmosphere determines and affects the climate. Fluid dynamics is essential for energy production, as in combustion or in the hydrogen economy or for CO_2 storage, and it plays a central role for additive manufacturing, such as in the health sector for the printing of artificial tissue or organs. Multiphase fluid dynamics governs the spreading of viruses via aerosols. I am convinced that a better understanding of fluid dynamics makes a major contribution to solving societal challenges. In fluid dynamics experiments, theory, and numerical simulations go hand-in-hand, and often only by combining these methods is it possible to solve a problem.

Erik Verlinde seeks to solve the "dark matter" mystery:

The two most challenging problems in particle physics are: Can we unify the gravitational force with all the other forces in a way that is consistent with quantum mechanics? And what is the nature of the mysterious "dark matter" in our universe? Everything we and our instruments can see accounts for only 5% of what there is; 95% is as yet invisible or "dark". I believe that bringing gravity into the fold and explaining dark matter are two closely connected questions, and am hopeful my colleagues and I will be able to find the answers within the next decade.

Source: Wikipedia

Photo: Ivar Pel

Cristiane Morais Smith explores fractional dimensions:

We are interested in quantum simulators, platforms to build matter in a bottom-up approach. We construct an electronic system atom-by-atom, to perform the tasks that we are interested in. We have recently created the first quantum fractal, a structure in which the electrons live in a dimension intermediate between the one-dimensional and two-dimensional world. We have also shown how to use this approach to construct topological insulators, materials that are insulating in the bulk but metallic at the boundaries. These could provide qubits for future quantum computers. The development of new synthetic and engineered quantum materials forms the basis for our future technology and theoretical physics will play an important role there.

Photo: Ivar Pel

Albert Polman searches for new materials:

Climate change is the largest problem that our society faces today. If we do not solve it, our society will likely become unstable (well) before the end of the century. It is a key priority for physicists to help develop the new materials and concepts needed to generate renewable energy. This requires entirely new ways to solve fundamental materials problems that we have considered too complex so far.

Bart van Wees studies matter at the atomic scale:

The European Graphene Flagship in which I participate describes graphene as “the thinnest compound known to man at one carbon atom thick, the strongest compound ever discovered, the lightest material known, and extremely flexible”. My challenge is to come up with applications that exploit these unique properties of graphene.

Credits: University of Groningen

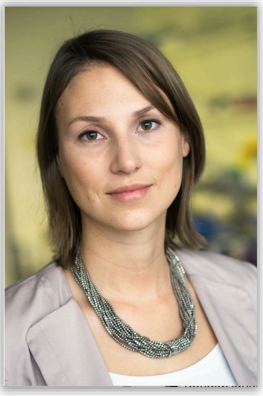


Photo: Nout Steenkamp

Daniela Kraft aims at understanding self-organisation:

Many biological systems like our body consist of a dazzling number of components, which seemingly by magic are arranged in a functional way. Identification of the organisational principles is further complicated by the complexity of the individual components. My goal is to elucidate self-organisation processes and the behaviour of their components by designing and investigating simplified model systems. Our insights not only lead to a quantitative understanding of biological self-assembly processes, but can also be exploited for the creation of new functional materials from the bottom-up.