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TUM Succeeds with Four Clusters of Excellence

TUM has got off to another successful start in the extremely competitive Excellence Initiative organized by the German government and federal states. Over the next seven years, four research clusters run by TUM and its cooperation partners will each receive up to 50 million euros in funding. Contributing to this great start was the outstanding quality of the TUM researchers and the successful collaboration between different disciplines and various partner institutions.

e-conversion

The e-conversion Cluster of Excellence focuses on the energy conversion processes of different technologies in the sustainable energy ecosystem – from photovoltaics through (photo-)electrocatalysis to batteries. This cluster uses experimental research to study the underlying mechanisms of energy conversion with a time resolution in the femtosecond range.

MCQST

The objective of the Munich Center for Quantum Science and Technology (MCQST) is to gain a comprehensive understanding of quantum mechanics phenomena and thus advance basic building blocks, materials and concepts for quantum technologies. Interdisciplinary research extends from the analysis of entanglement in multiparticle systems to quantum chemistry, cosmology and precision metrology.

ORIGINS

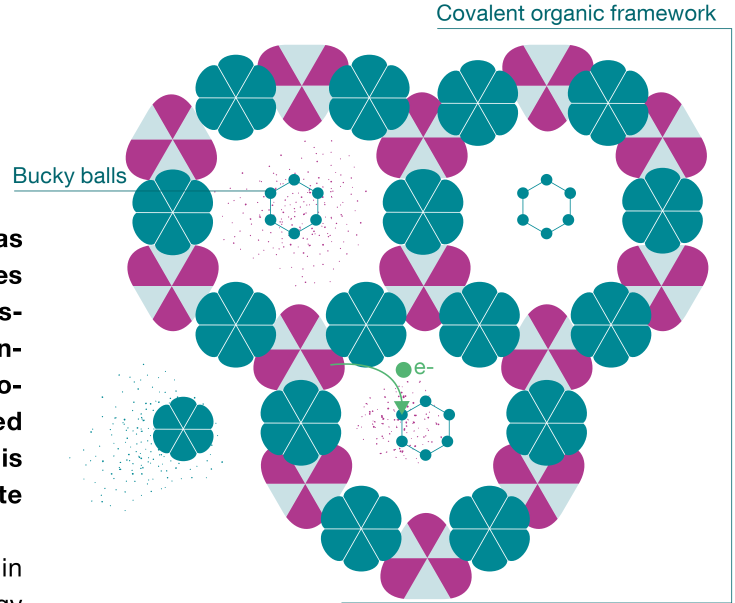
This cluster investigates the innermost structure of the universe and the origins of life. It brings together scientists from the fields of astrophysics, astrobiology, biophysics and particle physics to collaboratively explore, for instance, the connection between planet formation and the emergence of the first molecules that may have been the precursors of living cells.

SyNergy

The Munich Cluster for Systems Neurology (SyNergy) studies the onset of neurological diseases such as multiple sclerosis and Alzheimer's. Given the highly complex nature of the human nervous system, numerous processes interact in the development of these degenerative neurological conditions. At the heart of this Munich-based research engagement lies a whole new interdisciplinary field of science: systems neurology.

Graphics: ediundsepp

e-conversion – Close-up on Materials for Energy Conversion



Capturing energy from sustainable sources such as solar power calls for completely different technologies compared to those used with conventional combustion power plants. The focus here lies on energy conversion and storage methods, all based on atomic processes at tailored interfaces between engineered materials. The e-conversion Cluster of Excellence is taking an interdisciplinary approach to investigate these mechanisms.

Although the world has seen significant progress in the move towards more sustainable forms of energy through the growing adoption of renewables in recent decades, there are still major gaps in our understanding of the underlying atomic processes. In many cases, we have not even determined the basic properties affecting the nanoscale, femtosecond processes that take place at battery, fuel cell and solar cell interfaces. The effects can reduce the efficiency of the devices they power or compromise stable long-term operation.

Transport of charge carriers by energetic excitation in model materials

For the researchers, three interpretations of the e in the name of the cluster are significant:
The first e stands for “energy” conversion in general. “The reason we decided to combine all the energy conversion technologies in one cluster was because we realized that we often rely on the same microscopic processes in these – previously largely separate – fields of research,” explains TUM professor Karsten Reuter. “They play a central physical role and set the limits in the current systems.”
Up to now, all these technologies further tended to rely on the same or similar materials. The interdisciplinary e-conversion cluster hopes to find synergies and analogies by bringing together researchers who had previously been working independently on different energy conversion technologies.
The second interpretation of e stands for “elementary”. The limiting microscopic processes in current energy conversion systems mostly occur at the interfaces between materials, predominantly at solid-solid, solid-liquid or solid-molecular material boundaries. So far, very little is known about these fundamental processes. More detailed findings are important, however, because during operation these processes also change these boundaries to a significant degree.
Solid-solid and solid-liquid interfaces are thereby particularly difficult to study, as unlike at a surface the boundary is then concealed within the system. The central focus of e-conversion is, therefore, to create new model systems that enable a detailed study. “The trick is not to take real systems and somehow simplify them,” TUM professor Ulrich Heiz points out. “Instead, we use the latest developments in nanotechnology to assemble artificial systems more or less atom by atom according to our specifications. Our goal is to create our own ideal models for studying the boundaries and the microscopic processes that take place there.” The researchers hope that this will improve their fundamental understanding of these molecular processes. As an additional benefit, the Cluster of Excellence will forge stronger links between the disciplines of energy research and nanoscience.
A third interpretation of the e is “excitation”. The processes in energy converters always require excitation of the atoms or molecules which form the actual basis for the energy conversion step. With renewables, the process often starts with sunlight as a sustainable source of energy. The processes involved here are also on the research agenda of the e-conversion cluster.
A thorough understanding of the mechanisms at play in the materials will provide a good springboard for work to avoid harmful effects and develop new materials that enable more efficient conversion of energy from sunlight into electricity or synthetic fuels, or lead to long-lasting and safe batteries with high storage capacities.
Alongside LMU and TUM as joint applicants, the Max Planck Institutes for Chemical Energy Conversion (Mülheim/Ruhr) and for Solid State Research (Stuttgart) are also participating in the e-conversion cluster. TUM’s spokespersons are Prof. Karsten Reuter and Prof. Ulrich Heiz (chemistry). ■

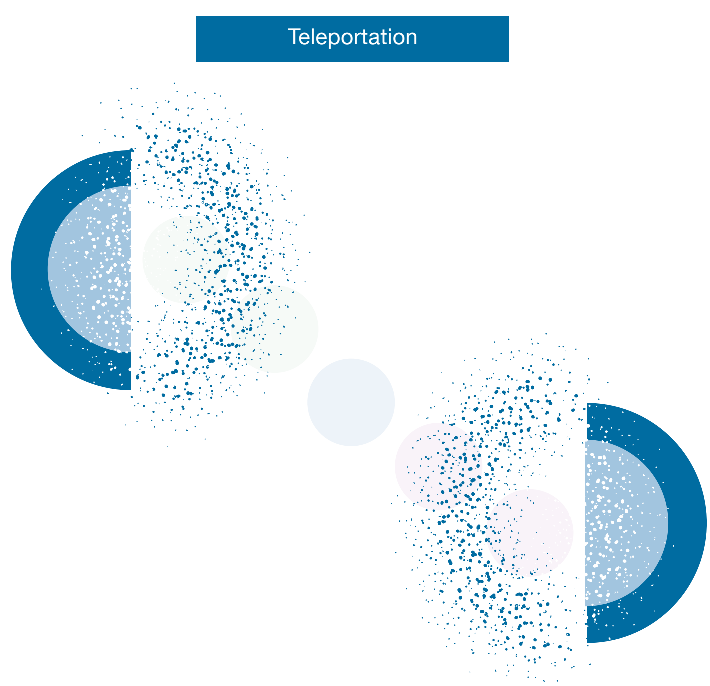
Picture credit: Wenzel Schürmann; Graphics: ediundsepp

Scientists at TUM’s neutron research source FRM II employ positrons to measure the properties of batteries. FRM II is an important research tool in the e-conversion Cluster of Excellence.

MCQST – The Practical Applications of Quantum Physics

A new approach to the laws of the quantum realm is paving the way for completely novel technologies, such as better encryption possibilities, data teleportation and quantum computing. This new field of research, which harnesses quantum phenomena for practical use cases, is now being advanced on an interdisciplinary platform at the Munich Center for Quantum Science and Technology (MCQST). The application potential is huge.

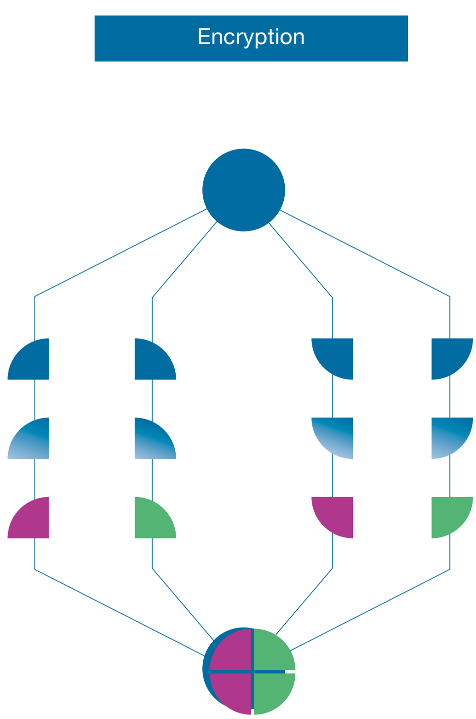
From computers through lasers to atomic clocks – technologies based on quantum mechanics have already been in use for years across many different application scenarios. This science, developed in the first three decades of the twentieth century, describes physical processes on the very smallest scale – some of which can seem truly bizarre. For a long time, the influences of quantum mechanics were seen as a disruption to classical physics, but there has since been a complete shift in perspective. Now, a new generation of physicists are applying these laws for their own aims and developing brand new applications under the Quantum 2.0 umbrella. Needless to say, the physical laws have not changed, but the way we harness them certainly has.

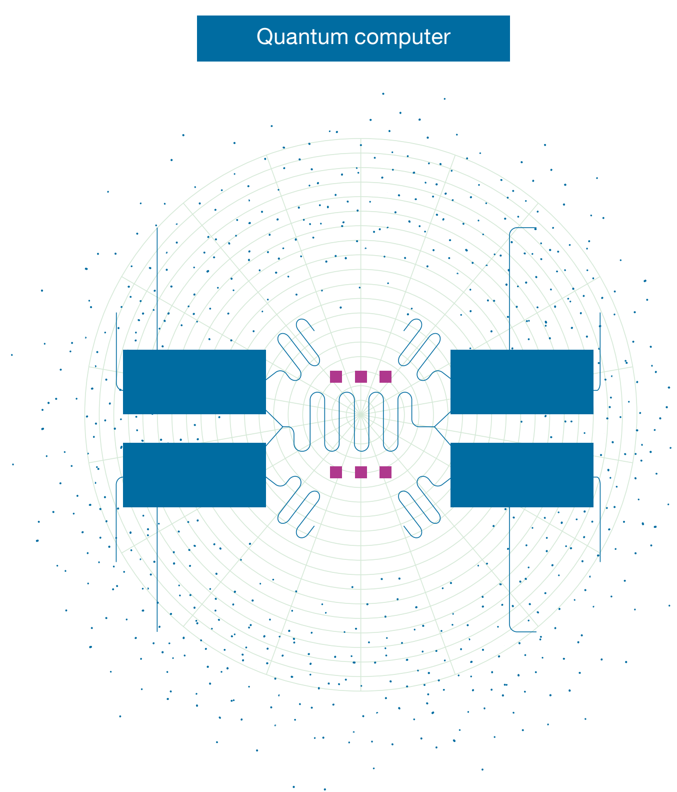


This center's work is largely based on the use of superposition, entanglement and teleportation of quantum states. Entanglement is the phenomenon described by an incredulous Albert Einstein as "spooky action at a distance". Two quantum objects that are entangled are always correlated, no matter how far apart they are from one another. If the state of one changes after being observed, the state of the other automatically does too, as though bound by telepathic connection. Harnessing this phenomenon in conjunction with teleportation has enabled the development of revolutionary methods for encrypting messages, for instance – which are now on the path to practical applications.

The superposition of quantum states plays an important role in constructing a quantum computer. This concept was first discussed in theory by US Nobel Prize winner Richard Feynman in 1981. In the meantime, we have progressed to initial prototypes, components and the rudiments of suitable software.

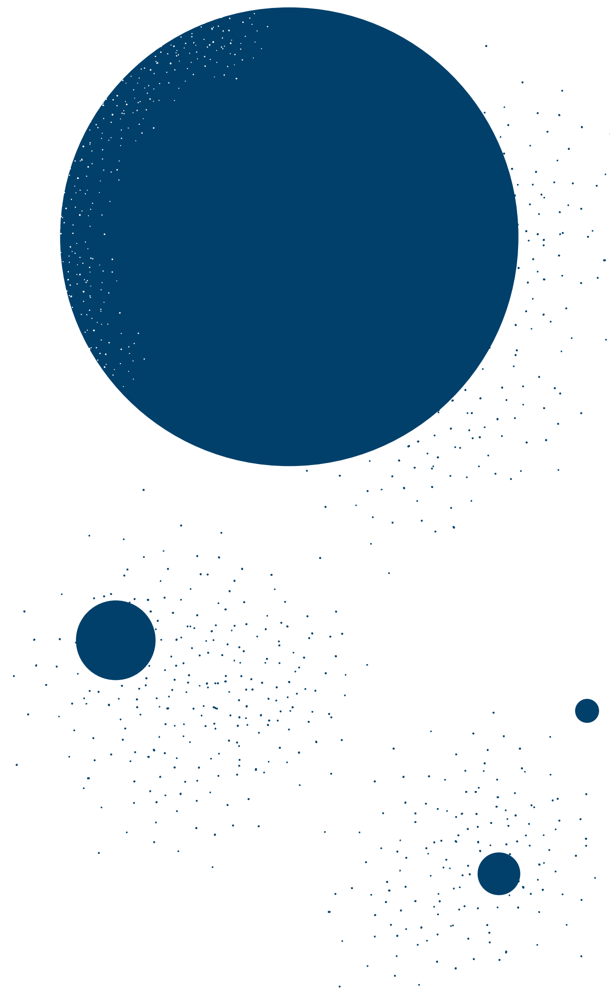
The Munich Center for Quantum Science and Technology aims to further our understanding of the principles of quantum information and to harness the effects described. Its interdisciplinary research extends from the analysis of entanglement in many-particle systems to quantum chemistry, cosmology and precision metrology. A new research building is under construction at TUM's Garching campus, jointly funded (to the tune of 40 million euros) by the federal government and the state of Bavaria. Alongside TUM and LMU as joint applicants, the Max Planck Institute of Quantum Optics, the Walther Meißner Institute of the Bavarian Academy of Sciences and Humanities, and the Deutsches Museum are involved in MCQST. TUM's spokespersons are Prof. Rudolf Gross (physics) and Prof. Ignacio Cirac (physics / MPI of Quantum Optics). ■





Graphics: ediundsepp, Christoph Hohmann (MCQST)

ORIGINS – How Did the Universe and Life Originate?



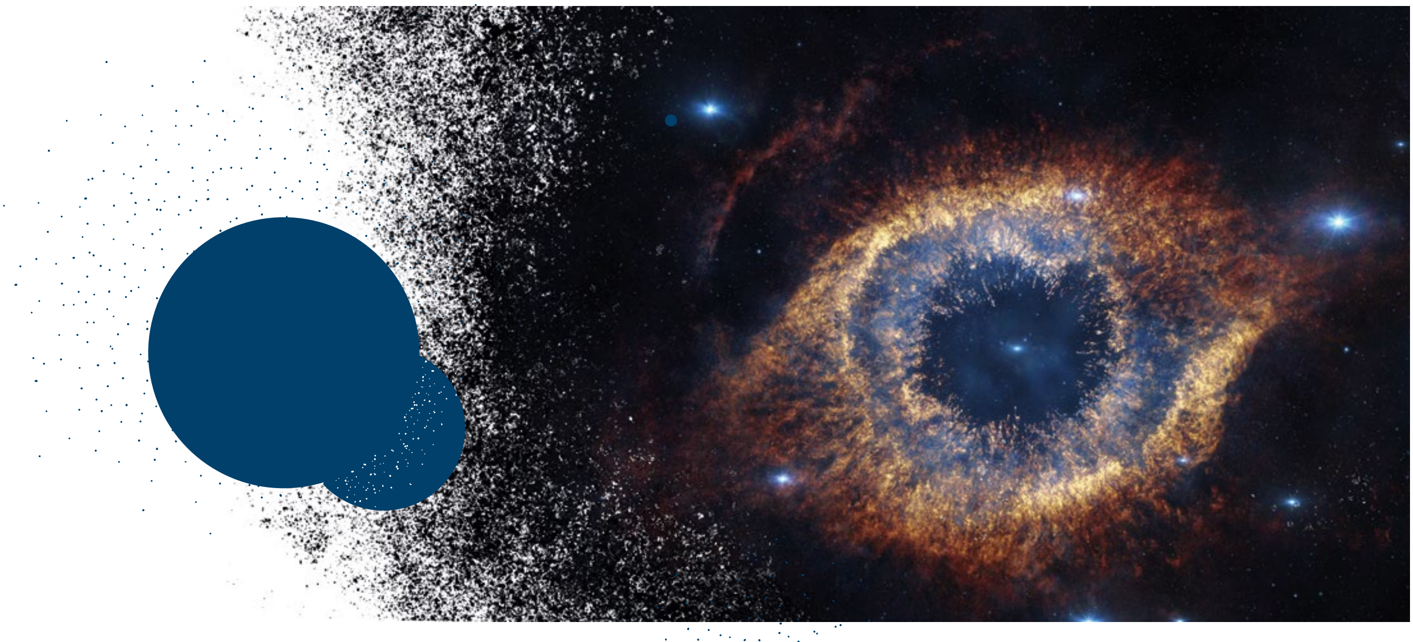
The development of the cosmos – from the Big Bang to the emergence of life – is still one of science's greatest mysteries. The ORIGINS research alliance builds on twelve successful years of work by the Universe Cluster of Excellence, which drew to a close at the end of 2018. The focus of the new cluster is on understanding the structure of the universe as well as the origin of life, on Earth and on possibly other planets.

Science has already revealed a great deal in recent decades about the origins of the universe and its development up to the present day. We now understand much better how stars and galaxies are formed from gas clouds and nebulae, and have discovered a myriad of exotic phenomena in the skies, some of which have now been explained. Nonetheless, fundamental questions remain unanswered. One of the most important is how life develops – and originally emerged – in the vastness of the universe, as well as on Earth. Closely linked to that is the search for exoplanets that could possibly be home to living structures. Researchers can get closer to the answers by investigating in retrospect what conditions were once necessary for the emergence of life on Earth.

Responding to approval by the German Research Foundation (DFG), cluster coordinators Professor Andreas Burkert (LMU) and Professor Stephan Paul (TUM) commented: "The experience of the Universe cluster gives us a platform for research into the new challenges we are tackling with ORIGINS. We are delighted to continue our devotion to fundamental questions on the emergence of the universe and extending our research to the origin of molecular life."

The research covers everything from the microscopic to the macroscopic scales. Exemplarily, the researchers are seeking to investigate the interconnection of planet formation and the emergence of the first prebiotic molecules, in order to trace the origins of life. Another key issue is the connection between the fundamental nature of dark matter and cosmic structure formation. Researchers from the fields of astrophysics, astrobiology, biophysics and particle physics will all work together in the quest for new findings.

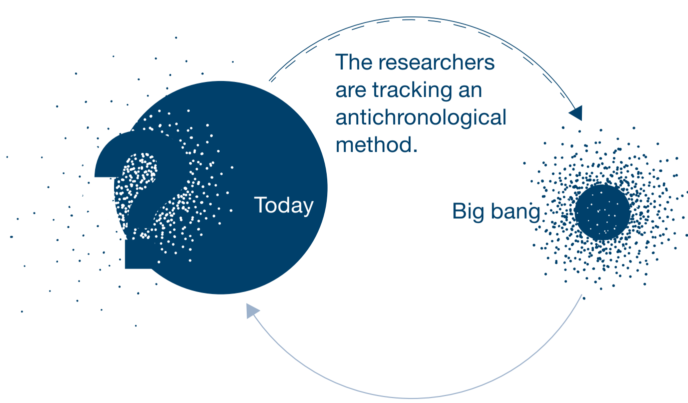
Important strands of this work will be carried out within international partnerships and involve some of the world's most prominent research institutions, such as CERN and ESO's Very Large Telescope in Chile. Laboratories established in the course of the Universe cluster will be flanked



This infrared image shows the Helix Nebula, 700 light-years away from Earth. The picture was taken by one of ESO's telescopes. ESO is one of the members of the ORIGINS Cluster of Excellence, which looks into the origins of both life and the universe itself.

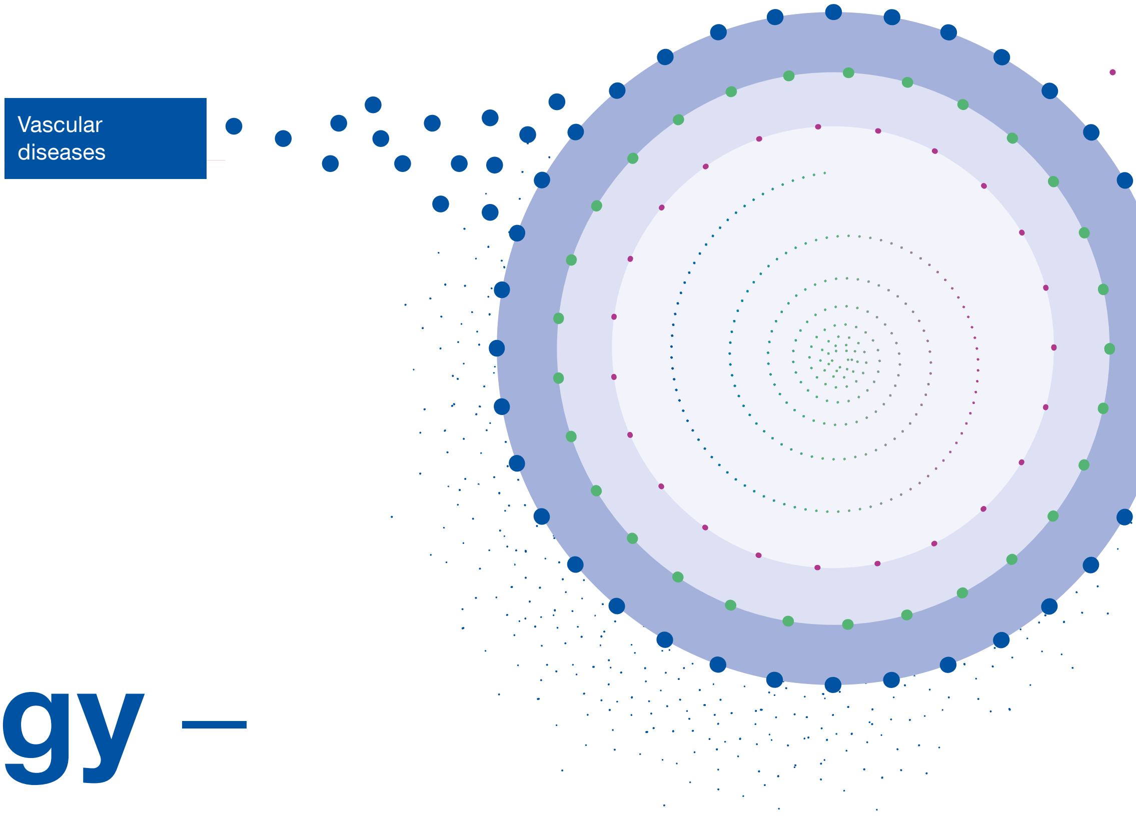
by new facilities in Munich, such as the Origins Data Science Lab (ODSL). This will bundle existing expertise in statistical data analysis and develop the next generation of numerical and statistical methods to analyze enormous and closely interlinked data sets in the future. Meanwhile, the new Ice, Dust and Sequencing Laboratory (IDSL) will help researchers reconstruct the first cycles of Darwinian molecular development in a bid to understand how living matter emerges from inanimate substances.

Alongside joint applicants TUM and LMU, the Max Planck Institutes of Astrophysics, Biochemistry, Extraterrestrial Physics, Physics, and Plasma Physics are all partners in the "ORIGINS – from the origins of the universe to the first building blocks of life" cluster – as are the European Southern Observatory (ESO), the Leibniz Supercomputing Center and the Deutsches Museum. TUM's spokesperson is Prof. Stephan Paul (physics). ■



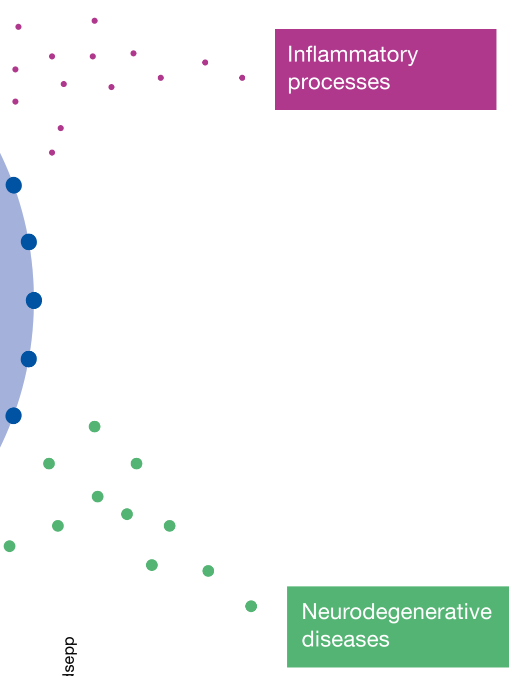
Picture credit: ESO/VISTA/J.Emerson; Graphics: ediundsepp

Professor Thomas Misgeld is a neurobiologist at TUM and the TUM spokesperson for the SyNergy Cluster of Excellence. SyNergy's research focuses on the shared pathomechanisms of neurological diseases like Alzheimer's and multiple sclerosis.



SyNergy – Holistic Research into Neurological Disease

SyNergy – Munich Cluster for Systems Neurology studies the shared pathomechanisms of neurological diseases such as multiple sclerosis and Alzheimer's. Given the highly complex nature of the nervous system, numerous processes interact in the development of these diseases, making an interdisciplinary approach to collaboration essential.



Picture credit: Magdalena Jooss; Graphics: ediundsepp

At the heart of this Cluster of Excellence lies a whole new field of science: systems neurology. This interdisciplinary concept fosters collaboration between experts in diverse fields of medical research. Their shared aim is to investigate the closely interlinked mechanisms that occur during the onset of neurological diseases. The norm to date has been separate specialists in inflammation (inflammatory processes), in the destruction of nerve cells (neurodegenerative diseases) and in blood vessels (vascular changes). In systems neurology, these experts all now work closely together, crossing the lines between their disciplines – for instance, to investigate how inflammatory responses influence neurodegenerative processes, how microvascular and degenerative damage mechanisms affect each other and how immune cells interact with the blood-brain barrier.

The SyNergy Cluster creates a scientific and structural framework to establish Munich as the European center for systems neurology. It builds a collaborative network between basic researchers, clinical scientists and leading experts in the field of systems analysis. This also involves pursuing new, interdisciplinary approaches to the analysis, modeling and modification of disease processes. To this end, tandem projects are funded, which entail two or more scientists working together. These tandems have a two-way bridging function: both horizontally, between different disease mechanisms, and vertically, between basic research and clinical application.

Additionally, a number of new SyNergy professorships have been created to bring in outstanding scientists with special expertise at the interfaces between the various fields. A new program has also been set up to train and promote young clinical scientists.

This cluster has been funded by the Excellence Initiative since 2012. The close collaboration between teams from different scientific disciplines has already yielded highly impressive results, including the discovery that catabolic products of lipid metabolism aggravate inflammation in damaged nerve fibers and prevent healing in multiple sclerosis.

Alongside TUM and LMU as joint applicants, the German Center for Neurodegenerative Diseases (federal initiative), Helmholtz Zentrum München and the Max Planck Institutes of Biochemistry, Neurobiology and Psychiatry are collaborating in SyNergy. The spokesperson for TUM is Prof. Thomas Misgeld (medicine), whose counterpart from LMU is Prof. Christian Haass. ■