GRAND NARRATIVE

How could the initial conditions created by the cataclysmic Big Bang have given rise to large-scale structures, and to life on Earth? These weighty issues will be addressed by a new research network based in Munich and Garching.

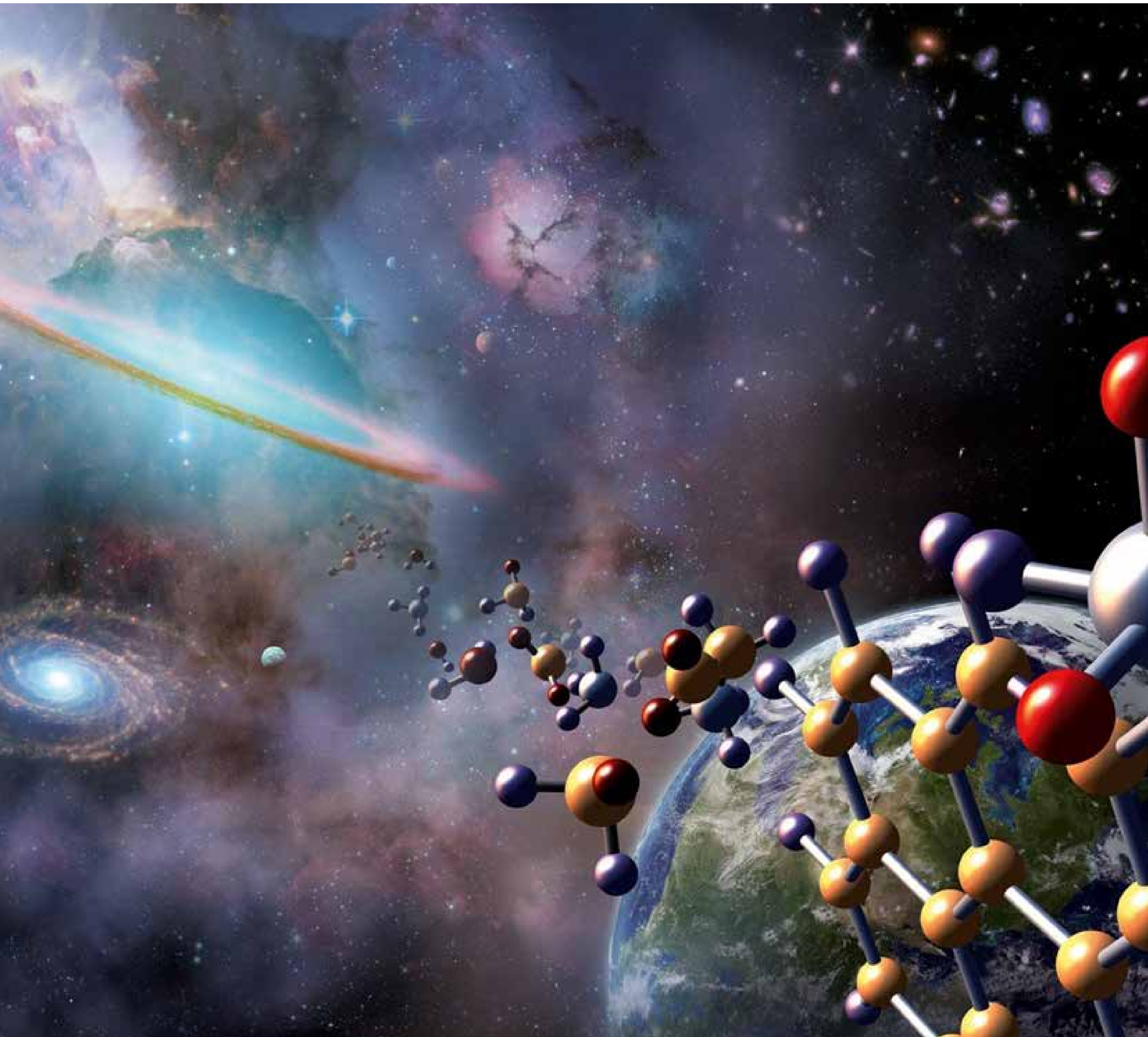

Photo: Astrid Eckert

Photo: Andreas Heddergott

PROF. DR. ANDREAS BURKERT PROF. DR. STEPHAN PAUL

Coordinators of the Excellence Cluster Origins: "From the Origin of the Universe to the First Building Blocks of Life"

We begin with phosphorus. Why? Because phosphorus is the vital chemical link that connects the subunits in RNA and DNA polymers, whose sequences encode the hereditary information in biological organisms. The element is also an essential component of ATP, the universal energy carrier in biological systems. All organisms need phosphorus in order to store biological information and energy. Life is inconceivable without it, as biologists know. But for an astrophysicist like Andreas Burkert, this fact poses a new and interesting problem: Where did phosphorus, which plays such an important role in the origin and evolution of living systems on Earth, come from? "Astrophysicists haven't really thought much about where in the interiors of stars phosphorus is synthesized," he admits.

Burkert and his colleagues have now put the question on the list of problems set for the new Cluster of Excellence entitled simply "Origins". "Origins" is a collaborative project conceived by researchers based at LMU and the Technical University of Munich (TUM), to which specialists at the Max Planck Institutes for Physics, Plasma Physics, Astrophysics, Extraterrestrial Physics, and Biochemistry, the European Southern Observatory, the Leibniz Supercomputing Center and the Deutsche Museum will also contribute. Burkert, who holds a Chair in Theoretical and Computational Astrophysics at LMU, is one of the venture's two Coordinators. The new network builds on the work of the highly successful "Universe" Cluster, which has been funded since it was selected in the first round of the Excellence Initiative in 2006.

"DRIVEN BY NATURE" IS THE LEITMOTIF OF THE TALE

The new project will add several chapters to the grand narrative explored by its predecessor. It takes the story "From the Origin of the Universe to the First Building Blocks of Life", to quote its subtitle. "We want to show that life is a perfectly natural phenomenon, which is part of the evolution of the Universe – and can be understood as a natural outcome of the initial conditions set in place by the Big Bang, based on the laws of physics and chemistry, says Burkert. "Driven by Nature" is the leitmotif of this tale.

And indeed, the tale is truly epic in scale. It extends from the first instants of the Big Bang to the Universe as we – thanks to space missions and observational surveys – know it today, some 13.8 billion years later. The story takes in the tiniest hypothetical particles and the largest mega- and metastructure discovered in space – the cosmic web. The difference in scale corresponds to 60 orders of magnitude. It encompasses elementary particles and the forces that act on them, the enigmatic dark matter which structures the large-scale entities in the Universe, and the equally mysterious dark energy, which is thought to be responsible for accelerating the rate of expansion of the Universe. More specifically, the scientists will be looking at the roles of the neutrino, the source(s) of high-energy cosmic rays and the origin of the asymmetry between matter and antimatter. The project sets out to probe a dense mesh of complex and tightly knit processes and structures that are linked by a plethora of interactions and forces – and will require close interactions between theory and experiment. “Munich is unique, certainly in Germany and perhaps even in Europe, in providing the necessary research environment,” says Burkert. The Cluster brings particle physicists and astrophysicists together with biophysicists who study the origin of life.

The biophysicists will not study organismic evolution, the genealogy of microorganisms, animals and plants on Earth. They are concerned with the origins of the first molecules that were capable of self-replication and could therefore transmit biological information. These must have been produced in a ‘prebiotic’ phase of molecular evolution, during which they were assembled from much simpler starting components.

MYRIADS OF WATER-FILLED PORES

Where on Earth might have such processes taken place? Researchers believe that hydrothermal fields on the seafloor, in which hot gases bubble out of pores in the sediment, or volcanic formations through which hot fluids percolate, represent a possible setting for prebiotic evolution. Geothermal fields provide myriads of water-filled pores, within which temperatures vary widely. In such temperature gradients the larger molecules congregate in the colder zones, which would facilitate polymerization reactions. Polymer interactions and aggregation into networks would further promote their growth. This kind of scenario could have led to the prebiotic synthesis of RNA. The composition of the primordial soup needed to realize such a scheme is one of the questions to be addressed in the context of the Cluster. Indeed, the plan is to set up a laboratory in which the biophysicists will attempt to experimentally initiate the chemical evolution of simple informational molecules that can self-replicate, i.e. are able to transmit their subunit sequences to the next ‘generation’.

Some basic features of this scenario have been implemented experimentally. But under what conditions might the process have unfolded on the young Earth? And how did such a planet form in the first place? By exploring all the intermediate stages necessary for the evolution of living systems back to the very start, the members of the Cluster wish to show that the required preconditions arose as a logical consequence of the historical development of the Universe. “Earlier versions of this story proceeded chronologically. Today, we prefer to tell it from the other end, by reconstructing the process in reverse. We first define the preconditions that made a particular phenomenon possible. Then we ask what insights and information we need to understand how they came about. In the end, we should have a consistent picture of the whole process,” says Stephan Paul, holder of a Chair in Hadron Structure and Fundamental Symmetries at the TUM and, together with Burkert, a Coordinator of “Origins”.

NEW GENERATIONS OF STARS

In Burkert’s chronological version, everything begins with the Big Bang, or rather a fraction of an instant later. The newborn Universe undergoes an unimaginably brief phase of extremely rapid expansion, such that the energy released in the cataclysm is distributed homogeneously, apart from minuscule quantum fluctuations. The fluctuations are magnified by the continuing, somewhat more sedate expansion, and subsequently act as the seeds of all large-scale

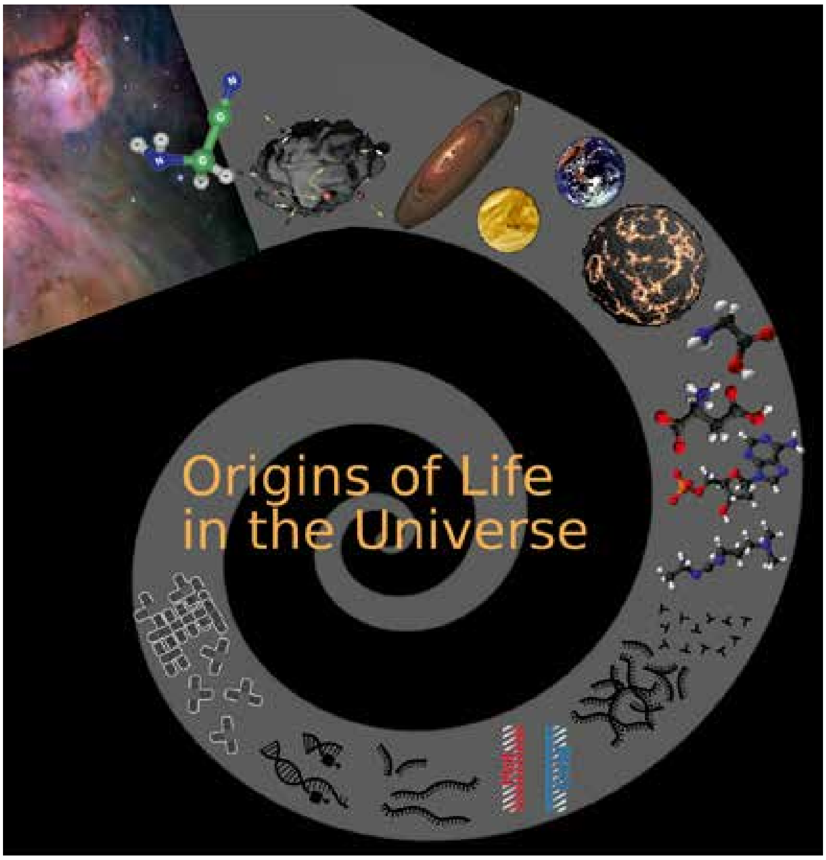

Photo: LMU / D. Braun

structures in the cosmos. They are ultimately responsible for the distribution of matter we now see. Thus, the formation of visibly structured entities is the consequence of an earlier phenomenon, while the gravitational force exerted by dark matter, whose nature remains obscure, dominates the process of structure formation in the Universe.

Dark matter shapes the giant molecular clouds that give rise to galaxies, those islands in the vast reaches of nearly empty space. Galaxies in turn give birth to stars – luminous spheres of gas, powered by the nuclear fusion of hydrogen into helium, the major elements formed in the first few minutes after the Big Bang. Virtually all of the heavier elements, including carbon, nitrogen, oxygen – and phosphorus – are produced within stars. When a star runs out of hydrogen, its core collapses, and the shock wave ejects most of the material in its outer layers into the interstellar medium. The resulting mixture of stardust and gas can then be compressed by the force of gravity, forming molecular clouds that give birth to new generations of stars. What remains in orbit around a new star forms a flat disk. In the course of billions of years and the birth and death of successive generations of stars, the concentration of dust in what is now a "protoplanetary" disk is so high that it begins to accrete to form planets. And on one such planet at least, elements produced in long dead stars provided the stuff of life. As Burkert puts it: "We are in fact all made of stardust."

So what makes a planet habitable? What else is required, apart from water, organic molecules and moderate temperatures? The answers to these questions determine the probability that life exists elsewhere in the Universe – and it also has a bearing on the potential diversity of extraterrestrial life forms.

"THE WHOLE UNIVERSE AS A LABORATORY"

In a transdisciplinary subproject, researchers will try to trace the origins of the chemical elements found on Earth. How were they synthesized under the extreme conditions that prevail in the interiors of stars? Specialists in particle and astrophysics, as well as biophysics and chemistry will address this issue – and perhaps their combined efforts will throw light on the source of Earth's phosphorus. Another subproject will inquire into the impact of turbulence on the evolution of structure in the Universe – at scales ranging from the formation of protoplanetary disks to molecular evolution. A further key question concerns the origin and nature of dark energy.

The participating scientists believe that such transdisciplinary approaches will significantly improve their chances of constructing a coherent picture of the emergence of structure in the Universe. In order to distill the maximum amount of insight from the masses of data, the project also envisages the establishment of a Data Science Lab, which will develop novel methods of analyzing the information collected. In addition, a Technology Center will be set up to design innovative sensors and other instruments for use on microsatellites being developed by engineers at the TUM. These and other structures within the Cluster are intended to facilitate collaboration and interactions between experts from very different backgrounds. Together with the interconnections between theorists and experimentalists, Burkert expects that the collaboration will lead to significant advances in a wide range of fields. "After all, what other project can boast of having the whole Universe as its laboratory?"

Martin Thurau / LMU

*The **Excellence Cluster Origins** will study the evolution of the cosmos – from the inception of the Universe to the First Building Blocks of Life, to cite its subtitle. Its goal is to show that life is the product of a natural process, a logical outcome of the evolution of the Universe – which can be understood based on the laws of physics and chemistry and the initial conditions created by the Big Bang.*

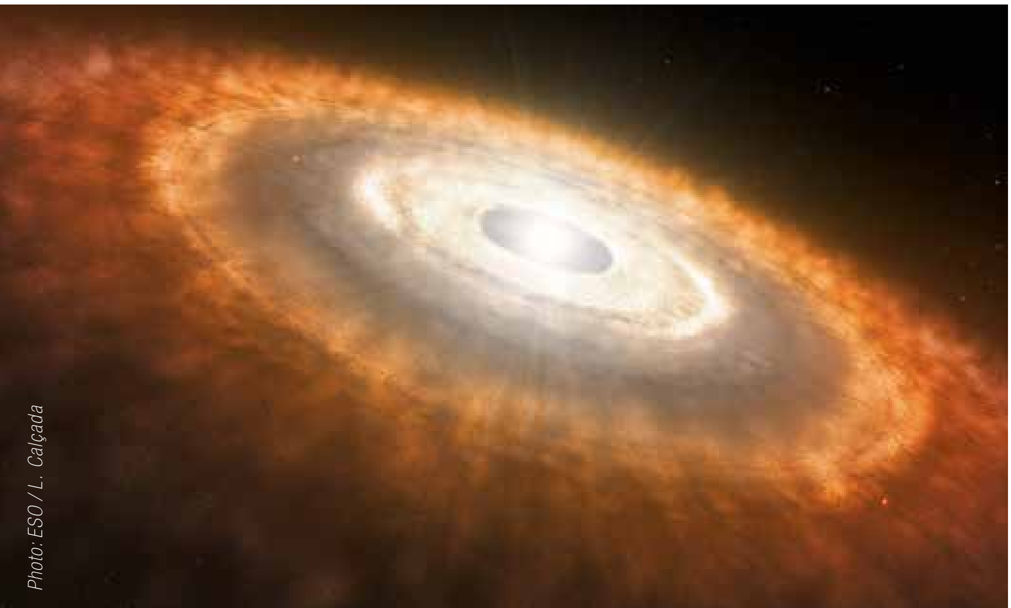

Photo: ESO / L. Calçada

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