KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2021 "for groundbreaking contributions to our understanding of complex physical systems" with one half jointly to **Syukuro Manabe** and **Klaus Hasselmann** "for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming" and the other half to **Giorgio Parisi** "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales".

The Nobel Prize 2021 **in Physics**

Physics for climate and other complex phenomena

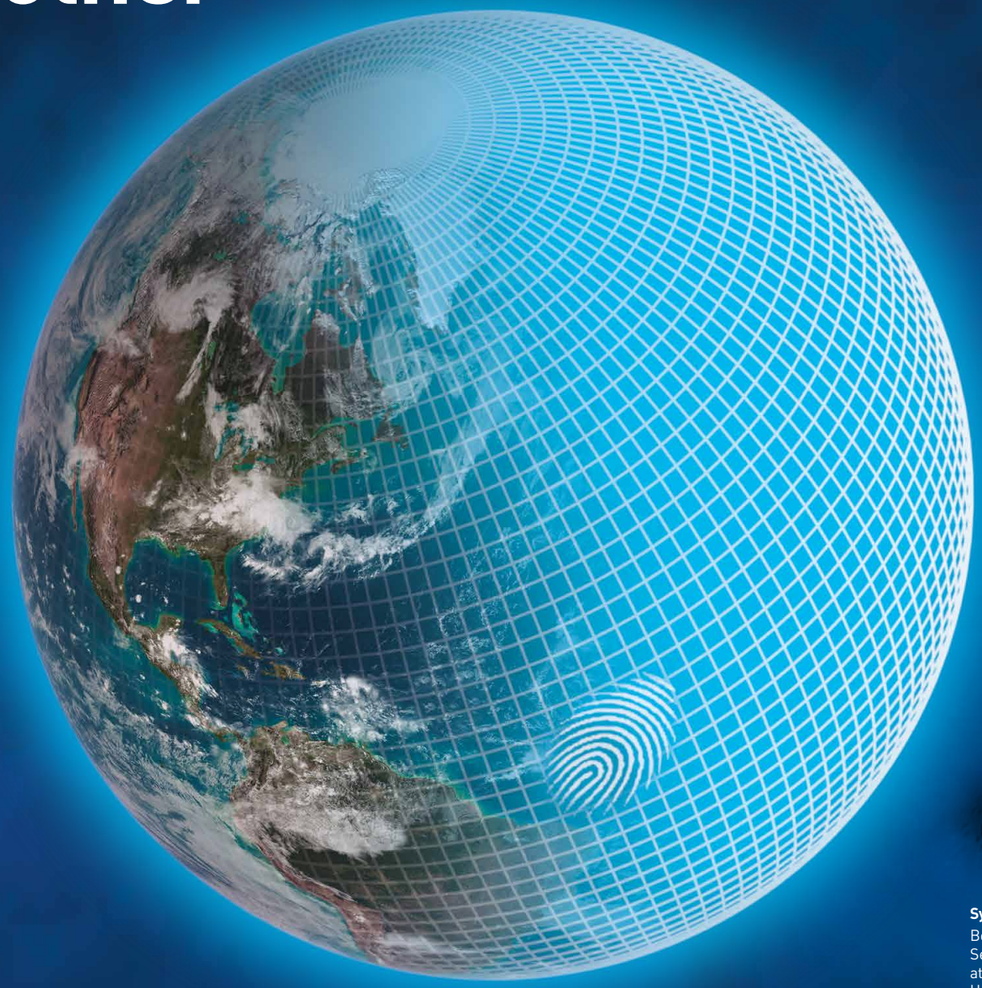
Three Laureates share this year's Nobel Prize in Physics for their studies of chaotic and apparently random phenomena. Syukuro Manabe and Klaus Hasselmann laid the foundation of our knowledge of the Earth's climate and how humanity influences it. Giorgio Parisi is rewarded for his revolutionary contributions to the theory of disordered materials and random processes.

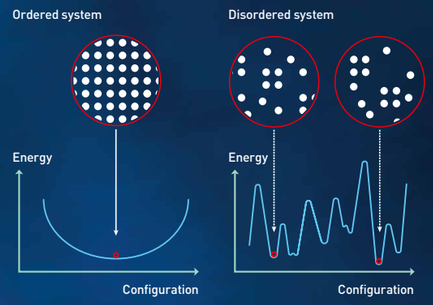
All complex systems consist of many different interacting parts. They have been studied by physicists for a long time, and are difficult to describe mathematically – they may have an enormous number of components or be governed by chance. They could also be chaotic, like weather, where small deviations in initial values result in huge differences at a later stage. This year's Laureates have all contributed to us gaining greater knowledge of such systems and their long-term behaviour.

One complex system of vital importance to humankind is Earth's climate. **Syukuro Manabe** demonstrated how increased levels of carbon dioxide in the atmosphere lead to increased temperatures at the surface of the Earth. In the 1960s, he led the development of physical models of the Earth's climate and was the first person to explore the interaction between radiation balance and the vertical transport of air masses. His work laid the foundation for the development of current climate models.

About ten years later, **Klaus Hasselmann** created a model that links together weather and climate, thus answering the question of why climate models can be reliable despite weather being variable and chaotic. He also developed methods for identifying specific signals, fingerprints, that both natural phenomena and human activities imprint in the climate. His methods have been used to prove that the increased temperature in the lower atmosphere is due to human emissions of carbon dioxide.

Around 1980, **Giorgio Parisi** discovered hidden patterns in disordered complex materials. His discoveries are among the most important contributions to the theory of complex systems. They make it possible to understand and describe many different and apparently entirely random materials and phenomena, not only in physics but also in other, very different areas, such as mathematics, biology, neuroscience and machine learning.





A theory for complexity

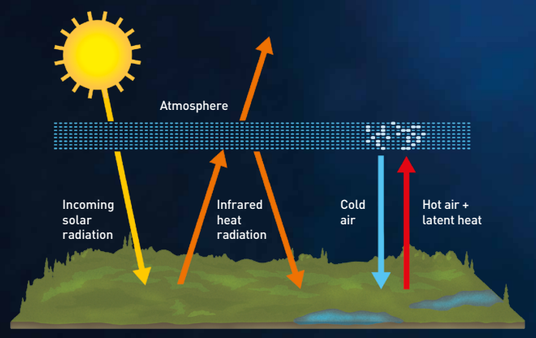
Ordered materials, such as atoms in a perfect crystal, have a simple energy landscape with just one stable energy minimum, similar to the way a marble in a round bowl can only come to rest in one place. However, the energy landscape of a disordered complex system is rugged and has different energy minima in many deep valleys. For the atoms in a glass material, this is equivalent to being able to order themselves in many different ways, but finding it hard to decide on one – the system is frustrated. Giorgio Parisi developed a mathematical description for these complex systems. This has had a great effect on many areas, even outside physics.

Parisi has also studied the patterns that occur in a murmuration of thousands of starlings, something that may appear far removed from complex materials. Still, as Giorgio Parisi has said, most of his research has examined how simple behaviours give rise to complex collective behaviours – and this applies both to disordered materials and to starlings.

Manabe's climate model

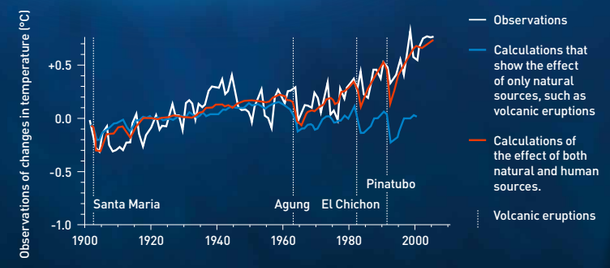
Earth's atmosphere allows shortwave solar radiation to pass through, while Earth's infrared thermal radiation is partly absorbed by the greenhouse gases in the atmosphere, primarily carbon dioxide and water vapour, warming the air and the Earth's surface. This is the principle behind the greenhouse effect.

Hot air rises due to convection, carrying water vapour (latent heat). Higher up, where the atmosphere is colder, the water vapour condenses and releases heat. Manabe was the first person to correctly include infrared radiation, convection and condensation in a model of the climate.



Fingerprints

Klaus Hasselmann developed methods for comparing measurements, observations and models, so obtaining the fingerprints that specific physical processes leave in the climate system, such as changes in solar radiation, volcanic particles or the content of greenhouse gases. These methods can also be used to identify humanity's climate fingerprints – and the results are clear: Earth is heating up, and human emissions of greenhouse gases contribute to this global warming.



Syukuro Manabe
Born 1931 in Japan. Senior Meteorologist at Princeton University, USA.

Klaus Hasselmann
Born 1931 in Germany. Professor, Max Planck Institute for Meteorology, Germany.

Giorgio Parisi
Born 1948 in Italy. Professor at Sapienza University of Rome, Italy.

Photo: Portrait of Giorgio Parisi: Francesco Maiolino; Portrait of Klaus Hasselmann: Bernie Ochs; Portrait of Syukuro Manabe: Markus Marcelic

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More information about the Nobel Prize in Physics 2021 is available at *www.kva.se/nobelphysics2021* and *www.nobelprize.org*, with video and detailed information about the Prize and the Laureates.

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