# 2021 Nobel Prize in Physics

### by Abhigyan Ray - Saturday, October 09, 2021

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The Nobel Prize in Physics 2021 was awarded "***for groundbreaking contributions to our understanding of complex systems***" with one half jointly to **Syukuro Manabe and Klaus Hasselmann** "*for the physical modeling of the Earth's climate, quantifying variability and reliably predicting global warmin*g" 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*."

Syukuro Manabe received his Ph.D. at the University of Tokyo in 1958. He then headed to the U.S. to work at the U.S. Weather Bureau until 1997. He moved back to Japan to work at the Frontier Research System for Global Change, serving as director of the Global Warming Research Division, and in 2002 he returned to the U.S. to Princeton University, where he is currently a senior meteorologist. Klaus Hasselmann completed his Ph.D. in physics from the University of Göttingen in 1957. Next, he moved to the Institute of Naval Architecture at the University of Hamburg, where he remained until 1961. He then went to the U.S. to work at the Scripps Institution of Oceanography before moving back in 1964 to the University of Hamburg. In 1975 he became a director of the Max-Planck Institute of Meteorology in Hamburg, eventually retiring in 1999. Giorgio Parisi graduated in 1970 with a Ph.D. in high-energy physics from La Sapienza University. He worked at the Laboratori Nazionali di Frascati and the University of Rome Tor Vergata before returning in 1992 to La Sapienza, where he serves as a Professor.

This year's Nobel Prize in Physics focuses upon the complexity of physical systems, from the largest scales experienced by humans, such as earth's climate, down to the microscopic structure and dynamics of mysterious and yet commonplace materials, such as glass.

During the 1950s, with the advent of modern-day computing, large-scale numerical weather forecasting originated at the Institute for Advanced Study in Princeton, led by the legendary John von Neumann himself. The study of theoretical and experimental aspects of atmospheric and oceanic dynamics (geophysical fluid dynamics–GFD) was carried out in parallel. Numerous pioneers were recruited, including Syukuro Manabe in 1959 by Joseph Smagorinsky, head of the U.S. Weather Bureau's General Circulation Research Laboratory, which later moved to Princeton to become the Geophysical Fluid Dynamics Laboratory. Over half a century earlier, another Nobel laureate, Svante Arrhenius, had conceptualized the concept of warming of the earth's atmosphere through the greenhouse effect. It built the scientific edifice central to the atmospheric column models used in successively more complex treatments that have developed since then.

In 1967 Syukuro Manabe and Richard Wetherald published the first computer model of climate sensitivity to fluctuating atmospheric carbon dioxide levels. To approximate the climate, they simulated a single column of air and looked at how convection told the story of varying temperatures. Manabe resoundingly demonstrated how increased levels of carbon dioxide in the atmosphere lead to increased temperatures at the earth's surface and was the first person to explore the interaction between radiation balance and the vertical transport of air masses. Manabe helped showcase that the observations show relatively slight seasonal variation in the climatological latitudinal relative humidity profiles in the northern hemisphere. In contrast, the absolute humidity (saturation vapor pressure) will depend sensitively on temperature, leading to the critical result of Manabe and Wetherald, their calculation of climate sensitivity of 2.3 degrees Celsius warming.

A decade later, in 1976, Klaus Hasselmann demonstrated that the climate responded to random variability by creating a model that linked together weather and climate, thus answering the question of why climate models can be reliable despite weather being changeable and chaotic. Hasselmann creatively utilized fundamental physics concepts to quantify the surface ocean wave spectra. Building on basic concepts in turbulence and Lorenz's work on chaos, he derived a generalizable stochastic description of ocean climate in which the "noise" is associated with the "weather." Hasselman also developed methods for identifying specific signals, fingerprints that natural phenomena and human activities imprint in the climate, helping climate scientists characterize how much warming was truly anthropogenic. Hasselmann provided a statistical roadmap for hundreds of subsequent climate change detection and attribution studies that eventually provided solid scientific support for the stark conclusion reached by the IPCC in 2013: "***It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.***"

Giorgio Parisi is a true giant of theoretical physics who has been honored for his groundbreaking work in the area of complex and disordered systems and their related fluctuations. During the early 1970s, Parisi began to work on the theory of phase transitions within solids, mainly focussing on the usage of field theory techniques from high-energy physics to condensed-matter physics. He conceptualized some of the most potent theoretical machinery for understanding the behavior of spin glasses and other complex systems. Spin glasses are disordered magnetic systems that appear to have a phase transition to a state where each magnetic atom is stably aligned. Still, the alignment direction varies randomly between atoms, resulting in "frustrated" interactions due to a disorder, which gives them a rich set of behaviors. Parisi realized that in contrast to ferromagnets which have only two "pure states" (up/down) in the ordered phase, there must be an infinite number within the ordered phase of the spin glass, thereby not only providing the solution but opening up a rich array of extensions to a wide range of spin-glass and other systems. Wielding advanced mathematics, he thus solved the problem of replica symmetry breaking. Later, Parisi with Mezard and Virasoro significantly clarified the physical meaning of the mysterious mathematics involved in this scheme in terms of the probability distribution of overlaps and the ultrametric structure of the configuration space.

Parisi is a legendary theorist whose work has had a tremendous impact on various other fields, including particle physics, theoretical computer science, quantum field theory, neuroscience, evolutionary biology, immunology, and statistical mechanics. Alongside the replica method for analyzing the Sherrington-Kirkpatrick model, Parisi has made uniquely wide-ranging contributions to many areas of physics and other sciences that have impacted and inspired generations of scientists. They include the study of scaling violations in deep inelastic processes (Altarelli-Parisi equations), the proposal of the superconductor's flux confinement model as a mechanism for quark confinement enabling very large-scale simulations of QCD, the use of supersymmetry in classical statistical systems, the introduction of multifractals in turbulence, the study of idiotypic network theory for antibodies in theoretical immunology, the stochastic differential equation for growth models for random aggregation (the Kardar-Parisi-Zhang model), scale-free correlations in starling flocks, random constraint satisfaction problems, identifying universal behavior in the dynamics of how people register for conferences.

With Parisi, the Physics Nobel Committee seems to be continuing its recent tradition of honoring a great theorist alongside two experimentalists as the examples of Peebles and Penrose in the preceding year's showcase. It is a much welcome change for an institution that never really gave theorists their fair share until late. As arguably the most well-known scientific prize that enraptures the attention of a worldwide audience, allowing legendary theorists on the bully pulpit helps drive attention to their pivotal role in germinating ideas that go on to revolutionize their fields and world at large. This is vital at a time when myopic governments and incompetent administrators, in their quest to focus on next generation technologies, quixotically end up shutting down pure mathematics and theoretical physics departments, unable to grasp their fundamental importance in seeding the basic science behind those revolutionary technologies. As Manabe proclaimed about the grim impacts of climate change that are coming to fruition now, "I did these experiments out of pure scientific curiosity. I never realized that it would become a problem of such wide-ranging concern for all of human society."

One of the biggest pantomimes of science is that it is apolitical. This ridiculous notion has been debunked time and time again, yet it continues to persist in some form or the other. The pandemic has expressly showcased how science can be misused, with terrible consequences, by politicians to further their divisive agenda during a public health crisis. Moreover, the past few decades have further displayed how politicians and groups with vested interests have been in cahoots to play down the devastating effects of climate change and global warming by resorting to spurious arguments like the science not being perfect and decisive. As the world faces a reckoning moment, with most of the dire predictions transpiring sooner than later, the Nobel committee decided to take the bull by its horns and brushed aside these fallacious arguments when announcing this year's prize.

Thors Hans Hansson, chair of the Nobel Committee for Physics, vociferously thundered during the announcement, "*The discoveries being recognized this year demonstrate that our knowledge about the climate rests on a solid scientific foundation, based on rigorous analysis of observations. This year's*

*Laureates have all contributed to us gaining deeper insight into the properties and evolution of complex physical systems." Asked during the press conference if the Nobel committee was sending a message to world leaders with the award, Göran Hansson, secretary-general of the prize-awarding Royal Swedish Academy of Sciences, emphatically replied: "What we are saying is that the modeling climate is solidly based in physical theory and solid physics. Global warming is resting on solid science. That is the message." And the great Parisi, no stranger to calling out lackluster funding of basic research, earnestly insisted that in the upcoming 26th United Nations Climate Change Conference at Glasgow in November, "It's very urgent that we take a very strong decision and move at a very strong pace. We are in a situation where we have positive feedback and an accelerating increase of temperature. For the future generations, we have to act now in a very fast way*."

Finally, for a world that has developed a very vague understanding of scientific models during the pandemic, the Nobel committee presciently observed, "Recognizing the work of this troika reflects the importance of understanding that no single prediction of anything can be taken as inviolable truth, and that without soberly probing the origins of variability we cannot understand the behavior of any system. Therefore, only after having considered these origins do we understand that global warming is real and attributable to our own activities, that a vast array of the phenomena we observe in nature emerge from an underlying disorder, and that embracing the noise and uncertainty is an essential step on the road towards predictability." In these wise words lies the true essence of science.

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