Meteorology in Hamburg, Germany, built on this work to create a model linking weather and climate.

Gabriele Hegerl, a climate modeller at the University of Edinburgh, UK, who worked with Hasselmann as a postdoctoral researcher, says he was a "fantastic" mentor and supervisor, who was "full of ideas and enthusiasm".

"I am really pleased that Suki and Klaus were chosen together, as they both contributed hugely in different ways and are two giants of climate science," she adds.

Manabe was "gobsmacked" when he heard he had won the prize, said John Wettlaufer, an Earth and planetary scientist at Yale University in New Haven, Connecticut, and a member of the physics Nobel committee. "He said, 'But I'm just a climatologist.'"

Hidden order

Parisi started his career in particle physics, but his research has since touched many other subfields. In the late 1970s, he switched his attention to the theory of complex systems, where he discovered a hidden and counter-intuitive type of order in the interactions of many objects (G. J. Parisi *Phys. A. Math. Gen.* **13**, 1101; 1980). In some systems — such as magnetic materials, for example — atoms tend to align parallel to their neighbours, but complex systems are less predictable. Still, Parisi discovered that they satisfy a kind of symmetry that is noticeable only when comparing how the individual atoms arrange over different scales, says physicist Federico Ricci-Tersenghi at Sapienza.

"He opened up a way to see and interpret complex phenomena that until then had been missed," says Ricci-Tersenghi, who is a former student and long-time collaborator of Parisi's. The theory turned out to be useful even for systems that at first sight seem to be completely random, such as the structure of glass, he adds.

Parisi's research looks at underlying disorder and fluctuations and predicts emerging behaviour, said Wettlaufer. The link between his work and that of Manabe and Hasselmann is that fluctuations are key for predictability, he said. "We're recognizing that emerging phenomena sometimes require you to look at all the individual complicated physical mechanisms and knit them together to make a prediction."

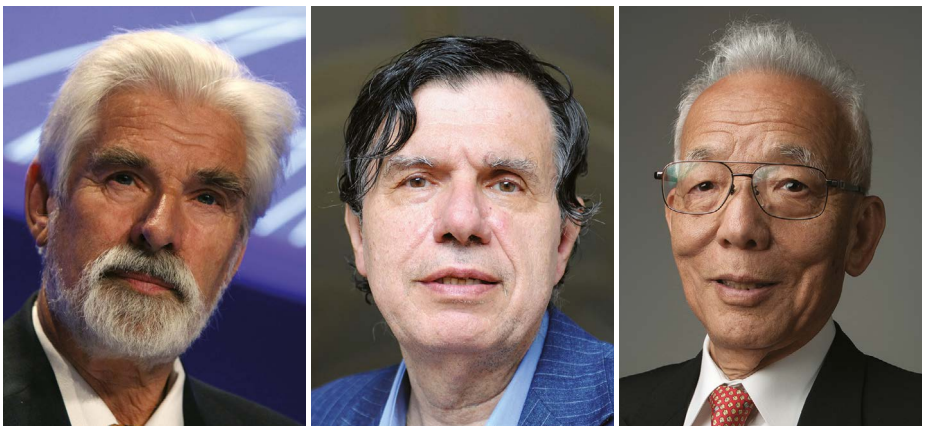
Parisi fosters a "happy environment" in his research group, Ricci-Tersenghi says, and has always encouraged those he mentors to follow their curiosity and intellectual interests.

Reacting to news of his Nobel win, Parisi told reporters during the announcement: "I was very happy and I was not really expecting it." He continued: "But I knew I had some chance — so I kept the telephone near me."

The award comes before a pivotal climate meeting — the 26th United Nations Climate Change Conference, due to take place in Glasgow, UK, in November.

Asked if the Nobel committee was sending a message to world leaders with the award, Göran Hansson, secretary-general of the Royal Swedish Academy of Sciences in Stockholm, said: "What we are saying is that the modelling climate is solidly based in physical theory and solid physics." He added: "Global warming is resting on solid science. That is the message."

Additional reporting by Quirin Schiermeier, Tosin Thompson and Emma Stoye.



2021 Physics Nobel laureates Klaus Hasselmann, Giorgio Parisi and Syukuro Manabe.

J. J. GUILLEN/EPA/SHUTTERSTOCK; TANIA/CONTRASTO/EYEVINE; MARKUS MARCETIC/THE ROYAL SWEDISH ACADEMY OF SCIENCES

'TRULY ELEGANT' CATALYSTS SCOOP CHEMISTRY NOBEL

Benjamin List and David MacMillan share the award for developing cheap, sustainable catalysts.

By Davide Castelvecchi & Emma Stoye

Two researchers who developed techniques to speed up and control chemical reactions have won the 2021 Nobel Prize in Chemistry.

Benjamin List and David MacMillan separately developed a new type of catalysis in the 1990s. The technique — called asymmetric organocatalysis — is widely used today for the production of drugs and other chemicals. Crucially, the catalysts that the pair developed can distinguish left from right, synthesizing molecules that are different from their mirror image.

David MacMillan (L) and Benjamin List (R), recipients of the 2021 chemistry Nobel prize.

PRINCETON UNIV./OFFICE OF COMMUNICATIONS/D. APPLEWHITE; D. AUSSERHOFER/MAX PLANCK SOCIETY/DPI/SHUTTERSTOCK

The pair developed "a truly elegant tool for making molecules — simpler than one could ever imagine", said chemistry Nobel committee member Pernilla Wittung-Stafshede at the prize announcement. "Until the year 2000, we only knew about two forms of catalysts. But then everything changed. Benjamin List and David MacMillan independently reported that you can use small organic molecules to do the same job as big enzymes and metal catalysts in reactions that are precise, cheap, fast and environmentally friendly."

Catalysts, substances that accelerate reactions without being used up, are fundamental tools for chemists. List, who is based at the Max Planck Institute for Coal Research in Mülheim an der Ruhr, Germany, and MacMillan, at Princeton University in New Jersey, developed catalysts that can drive asymmetric catalysis, in which a reaction produces more of the left-handed version of a molecule than the right-handed one, or vice versa.

In 2000, List showed that the amino acid proline could act as a catalyst in an aldol reaction, in which carbon atoms from two different molecules are bonded together, and that it could drive asymmetric catalysis (B. List *et al. J. Am. Chem. Soc.* **122**, 2395–2396; 2000). Around the same time, MacMillan designed small organic molecules that can provide or accept electrons and therefore efficiently catalyse reactions (K. A. Ahrendt *et al. J. Am. Chem. Soc.* **122**, 4243–4244; 2000).

Until their breakthroughs, the common wisdom among chemists was that a catalyst that synthesizes chiral molecules (those of a particular handedness) had to either be an enzyme or contain a transition metal such as iron. "It was a conceptual shift," says chemist Cathleen Crudden at Queen's University in Kingston, Canada. "For a long time, people thought that metals and enzymes were the only ones."

The 'organocatalysts' developed by List, MacMillan and their collaborators had no metals. And unlike enzymes — typically large complexes made of proteins — they were small, organic molecules. Organocatalysts are cheaper to produce, and more sustainable, than those containing metals, and interest in the field has exploded since their discovery.

"I absolutely didn't expect this huge surprise — you really made my day today," List told reporters at a press conference after the announcement. "When I [first] did this experiment, I didn't know what would happen and I thought maybe it's a stupid idea, or somebody has tried it already. When I saw it worked, I did feel that this could be something big."

He added that receiving the Nobel prize would allow him even greater freedom to pursue new ideas in his research. "I hope I live up to this recognition and continue discovering amazing things."

Additional reporting by Tosin Thompson.

WHY COVID VACCINES DIDN'T WIN A SCIENCE NOBEL THIS YEAR

Insiders and observers say timing and politics meant vaccine technology was an unlikely winner.

By Ewen Callaway

And the winner is ... not COVID-19 vaccines. Despite sky-high hopes that one of the Nobel committees would recognize research on vaccines that have saved countless lives, this year's science Nobels instead went to fundamental advances that had been tipped to win for years.

Some scientists expressed surprise and disappointment at the omission of COVID-19 vaccines, particularly those developed using messenger RNA technology, which have launched a new class of vaccine.

"The Nobel Prize folks could have done something with this year's award to directly aid global health efforts during a 100-year pandemic. And they chose not to. This is utter dereliction. It is an indefensible decision that will cost lives," Alexey Merz, a cell biologist at the University of Washington in Seattle, wrote on Twitter on 5 October, after research into the mechanisms behind senses won this year's medicine or physiology prize.

But Nobel prize insiders and watchers say that timing, technical details and politics meant that a nod this year was a long shot. However, the impact of COVID-19 vaccines — and the underlying advances — indicate that it shouldn't be long before researchers behind the work get a call from Stockholm.

"The development of mRNA vaccines is a wonderful success story that has had enormous positive consequences for humankind. And we're all very grateful to the scientists," says Göran Hansson, secretary-general of the Royal Swedish Academy of Sciences in Stockholm, which awards the prizes. "This is a kind of discovery that will receive nominations. But we need to take time."

"We want to give credit to the right people, and for the right discovery. So stay tuned."

The timing didn't work in favour of a COVID-19 Nobel this year. Nominations for this year's prizes had to be submitted by 1 February. This was more than two months after the first vaccines proved their mettle in clinical trials, but before their impact on the pandemic was fully clear, Hansson notes. "Follow-up is really still happening now."

History was also against a win for COVID-19 vaccines. The gap between a discovery and recognition with a scientific Nobel prize has grown over time, says Santo Fortunato, a physicist and director of the Indiana University Network Science Institute in Bloomington, and it now stands at an average of more than 30 years. The first experimental mRNA vaccines were tested in the mid-1990s, but key advances underlying the jabs developed by Moderna in Cambridge, Massachusetts, and by Pfizer in New York City and BioNTech in Mainz, Germany, didn't come until the 2000s. And one could argue that the technology's impact wasn't apparent until this year.

But Fortunato says that major discoveries do tend to be recognized much more quickly. One potential parallel for mRNA vaccines is the detection of gravitational waves. The existence of gravitational waves was predicted by Albert Einstein in 1915, but it took a century for researchers to develop the tools to detect them directly. Researchers announced their discovery in February 2016, and scientists behind the observations and theoretical work won the 2017 physics Nobel.

When it comes to COVID-19, Brian Uzzi, a computational scientist at Northwestern University in Evanston, Illinois, who studies scientific prizes, expects the Nobel committees to look more broadly than the development of vaccines. "They like to give prizes to people who do fundamental research that can go on and solve lots of different problems, not just one problem," he says.

Nobel harbingers

COVID-19 vaccines have already started hoovering up major scientific prizes: last month, one of the US$3-million Breakthrough prizes went to two scientists who developed modifications that silenced unwanted immune responses and were key to the Moderna and Pfizer–BioNTech vaccines. The same researchers also won one of the Lasker Foundation's annual awards (considered by some to be predictors of Nobel prizes). Uzzi expects there will be more awards for COVID-19 vaccines before Stockholm comes knocking.

If the vaccines are awarded a Nobel prize, the committee will need to make some difficult decisions about whom to recognize and for what. It's not clear-cut who the recipients should be, because the vaccines' development has deep roots in several disciplines, says Arturo Casadevall, a microbiologist at Johns Hopkins Bloomberg School of Public Health in Baltimore, Maryland. "I can imagine the committee taking its time to sort out which contributions to recognize since many fields contributed to their deployment."

Working all this out takes time, Hansson says. "We want to give credit to the right people, and for the right discovery," he says. "So stay tuned."