convened by leading US and UK scientific societies concluded again that the technology is not ready for use in human embryos that are destined for implantation.

The work also sparked a fierce patent battle — mainly between the Broad Institute and Berkeley — that rumbles on to this day over who owns the lucrative intellectual-property rights to CRISPR–Cas9 genome editing.

Still, Church agrees with how the award was divvied up. Although he is proud of the work in his lab and in Zhang's — which adapted the system to work in mammalian cells, opening the door to modelling and potentially treating human diseases — Church says that this work could be classified as engineering and invention, rather than scientific discovery. "I think it's a great choice," he says.

It is always difficult to single out a discovery for a prize, says geneticist Francis Collins, head of the US National Institutes of Health in Bethesda, Maryland. But one unique aspect of CRISPR–Cas9 genome editing has been the ease and versatility of the technique, he adds. "There is no molecular-biology laboratory that I know of that hasn't started to work with CRISPR–Cas."

PHYSICISTS WIN NOBEL PRIZE FOR BLACK-HOLE DISCOVERIES

Mathematical physicist Roger Penrose shares award with astronomers Andrea Ghez and Reinhard Genzel.

By Elizabeth Gibney & Davide Castelvecchi

A mathematical physicist and two astronomers have won the 2020 Nobel Prize in Physics for discoveries relating to the most massive and mysterious objects in the Universe — black holes.

British mathematical physicist Roger Penrose receives half the prize for theoretical work that showed how Albert Einstein's general theory of relativity should result in black holes.

US astronomer Andrea Ghez and German astronomer Reinhard Genzel, share the other half of the 10-million-Swedish-kronor (US$1.1-million) award for discovering the Universe's most famous black hole — the supermassive object at the centre of the Milky Way.

Since the 1990s, Ghez and Genzel have each led groups that have mapped the orbits of stars close to the Galactic Centre. These studies led them to conclude that an extremely massive, invisible object must be dictating the stars' frantic movements. The object, known as Sagittarius A*, is the most convincing evidence yet of a supermassive black hole at the centre of the Milky Way, said the Royal Swedish Academy of Sciences, which awards the prize.


DAVID LEVENSON/GETTY, CHRISTOPHER DIBBLE, ESO/M. ZAMANI

Roger Penrose, Andrea Ghez and Reinhard Genzel (left to right) received the 2020 Nobel physics prize for their research on black holes.

Astrophysicist Monica Colpi at the University of Milan Bicocca in Italy says the prizes are highly deserved. "The observational data by Genzel and Ghez are splendid and truly unique in their ability to monitor star motions around this object."

Penrose, meanwhile, is "a giant in theoretical physics", who has influenced generations of scientists, says Carole Mundell, an astrophysicist at the University of Bath, UK. He is "a genuinely creative thinker with immense imagination, sense of fun and a passion for curiosity in everything he does", she adds.

General relativity to geometry

In a seminal 1965 paper, Penrose demonstrated how, according to general relativity, black holes could form given the right conditions — the formation of a surface that traps light (R. Penrose *Phys. Rev. Lett.* **14**, 57; 1965). Inside this surface, mass enters an irreversible gravitational collapse, producing a region of infinitely dense energy called a singularity. Previous researchers had demonstrated this inevitability only under conditions that were considered physically unrealistic.

Penrose's contributions span many areas of mathematics and physics. He communicated with the graphic artist M. C. Escher and inspired some of his drawings of impossible geometrical objects. In the 1970s, he developed a geometrical theory: a non-repeating 2D pattern now called Penrose tilings. These patterns occur in nature in 'quasicrystals', which were the subject of the 2011 Nobel Prize in Chemistry.

Penrose introduced sophisticated mathematical techniques into several branches of physics, says Matilde Marcolli, a mathematical physicist at the California Institute of Technology in Pasadena. "It was a completely new way of thinking," she says.

Whereas Penrose laid the theoretical foundations for the existence of black holes, Ghez and Genzel's teams produced powerful evidence that such a void sits at our Galaxy's heart.

Since the 1960s, astronomers had suspected that a supermassive black hole — with a mass more than one million times that of the Sun — might lie at the centre of most galaxies. The Milky Way was a prime candidate: radio observations had revealed energetic emissions from its centre. But peering closely was a challenge, because gas and dust obscured emissions from the stars. Beginning in the 1990s, rival teams led by Ghez and Genzel used some of the world's biggest telescopes — the Keck Observatory on Mauna Kea, Hawaii, and the Very Large Telescope on Cerro Paranal, Chile, respectively — and cutting-edge observational techniques, to overcome this challenge.

Crucial to their work was finding ways to boost resolution and sensitivity to the faint light, says Andreas Eckart, an astrophysicist at the University of Cologne in Germany and former member of Genzel's team at the Max Planck Institute for Extraterrestrial Physics in Garching. Using a technique known as speckle imaging, the groups took data in snapshots to avoid blurring caused by the turbulence in Earth's atmosphere. Later, both teams used adaptive optics, which uses a mirror to correct for the distortion. This allowed for longer exposures, to capture more light and boost sensitivity, also allowing them to track the motion of stars in three dimensions. The conclusion that there is a supermassive black hole at the Milky Way's centre was the culmination of team efforts and "many papers and many projects", says Eckart.

Genzel is known for being a hard worker, says Eckart, who still collaborates with the laureate. "He's very concise, and a very good scientist," he says. Ghez, he adds, is "a very focused person who goes at the problems in a very direct way".

Ghez, now at the University of California, Los Angeles, is just the fourth woman to win the physics prize — the Nobel award with the fewest female winners. In 2018, laser physicist Donna Strickland ended a 55-year drought when she became the third woman to win it.

"I take very seriously the responsibility associated with being the fourth woman to win the Nobel [physics] prize," Ghez said at a press conference following the announcement. "I hope I can inspire other young women into the field."

Additional reporting by Nisha Gaind and Holly Else.

VIROLOGISTS WHO DISCOVERED HEPATITIS C WIN MEDICINE NOBEL

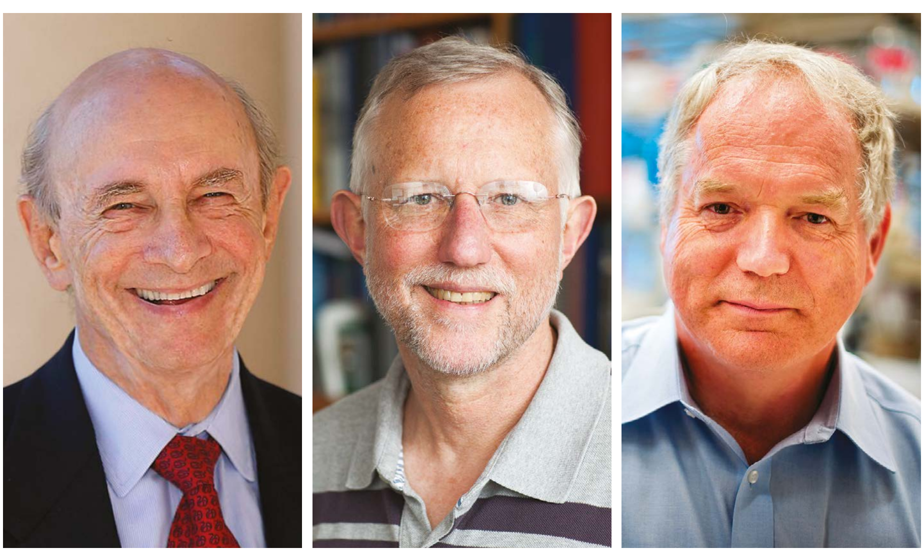
Harvey Alter, Charles Rice and Michael Houghton share the award for research on a deadly virus.

By Ewen Callaway & Heidi Ledford

A trio of scientists who identified the virus responsible for many cases of hepatitis and liver disease — hepatitis C — have won the 2020 Nobel Prize in Physiology or Medicine.

The winners are Harvey Alter at the US National Institutes of Health in Bethesda, Maryland; Michael Houghton, now at the University of Alberta in Edmonton, Canada; and Charles Rice, now at the Rockefeller University in New York City. Their work on the hepatitis C virus paved the way for effective treatments for the infection that are now available.

The World Health Organization (WHO) estimates that 71 million people worldwide are chronically infected with hepatitis C, which causes nearly 400,000 deaths per year, mostly from cirrhosis and liver cancer.



Harvey Alter, Charles Rice and Michael Houghton (left to right) won the 2020 Nobel prize in medicine for their research on the hepatitis C virus.

NIH HISTORY OFFICE; JOHN ABBOTT/ROCKEFELLER UNIV.; RICHARD SIEMENS/UNIV. ALBERTA

The prize is well deserved, says Ellie Barnes, who studies liver medicine and immunology at the University of Oxford, UK. "It stands out as an emblem of great science," she says. "We've got to a point where we can cure most people who are infected." The prizewinners will share an award of 10 million Swedish kronor (US$1.1 million).

Blood-borne pathogen

In the 1970s, Alter studied the transmission of hepatitis, or liver inflammation, as a result of blood transfusions. Earlier work had identified the hepatitis A and B viruses, but Alter showed that a third, blood-borne viral pathogen could transmit the disease to chimpanzees.

Houghton, then working at Chiron Corporation in Emeryville, California, and his colleagues identified the virus on the basis of genetic material from infected chimpanzees, showing that it was a new kind of RNA virus that belonged to the Flaviviridae family. They named it hepatitis C virus.

A team led by Rice, then based at Washington University in St. Louis, Missouri, used genetic-engineering techniques to characterize a portion of the hepatitis C genome that is responsible for viral replication, demonstrating its role in causing liver disease.

At a press conference, Alter noted that it took researchers at Chiron six years to clone a tiny fragment of the hepatitis C viral genome, and expressed doubt that such painstaking research would be carried out today. "Nowadays, if you don't have an immediate endpoint it's hard to get funding," he said. "It's much more difficult for people now — especially young people — to pursue research."

The results of research by the prizewinners and others has led to significant improvements in hepatitis testing and treatment. In the past decade, harsh and poorly effective treatments for the infection have been replaced by drugs that directly block the virus. These medicines have the potential to cure the vast majority of hepatitis C infections, but their high cost has limited access in many countries.

The WHO has set a goal of eradicating the hepatitis C virus by 2030, which Barnes says could be achievable. But to do so, she adds, might require a vaccine. Progress on developing such a vaccine has been slow, owing in part to the wily nature of the virus. The genetics of each strain of hepatitis C virus differ drastically: Barnes estimates that hepatitis C is ten times more diverse than is HIV, and "infinitely" more so than the coronavirus that causes COVID-19. And it is difficult to conduct clinical trials in the populations most vulnerable to the hepatitis C virus.

None of these problems is insurmountable, Barnes says. "The virus was discovered 30 years ago and we still don't have a vaccine," she adds. "We still have people infected and dying of hepatitis C. From that point of view, the story's not over."