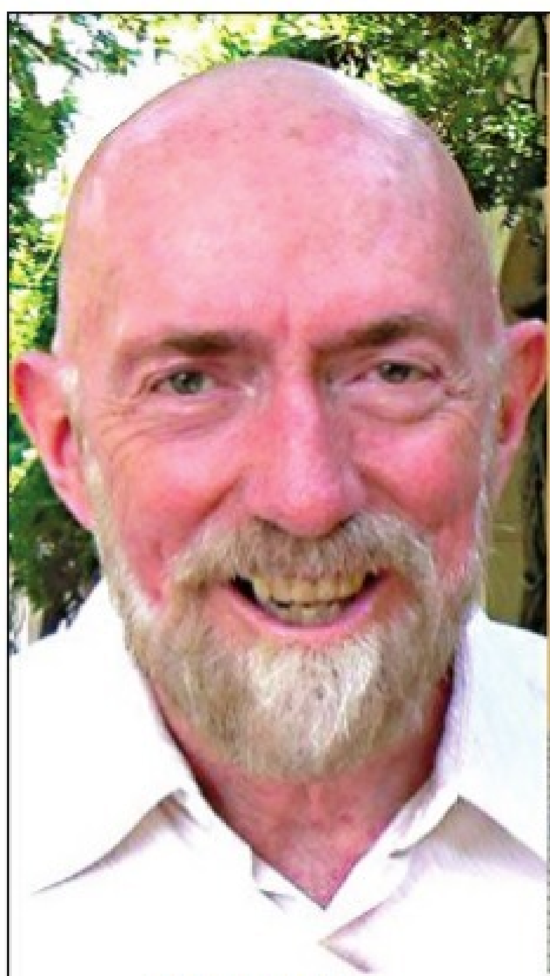
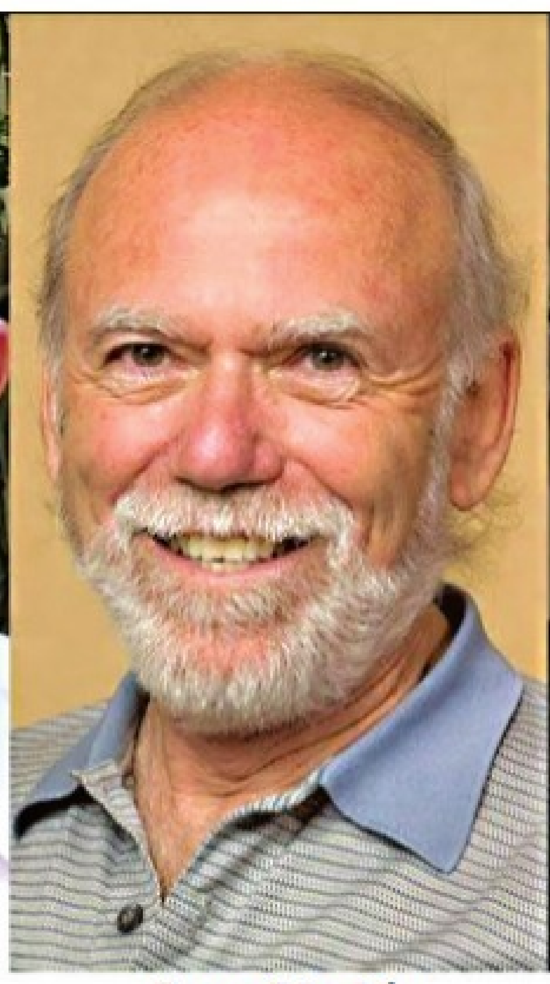
# Retelling the gravity story

## Gravity is perhaps the first sensation that a newborn becomes aware of

The Ligo site in Louisiana, US



Kip S Thorne



Barry C Barish

Rainer Weiss

S ANANTHANARAYANAN

After a tranquil nine months of suspension in the placental fluid, the new-born experiences the sensation of up and down. But it took many centuries for humans to formulate gravity as not just a feeling but a force that acted between things that had mass. A first triumph of classical physics was to recognise that it was this same mass, which gave rise to gravity, that gave an object its inertia and was the basis of the laws of motion.

The Nobel Prize for physics for 2017, to Rainer Weiss, emeritus physicist at MIT and Barry Barish and Kip Thorne, from Caltech, is for their role in the Ligo experiment, which has detected waves of gravity — very faint emissions from cataclysmic events 1.3 billion light years away. While the prize has gone to three persons who played major roles in the actual detection in 2015, the work itself was the culmination of many who participated in the quest set off by Albert Einstein's General Theory of Relativity a century earlier.

Einstein refined the understanding of the laws of motion with a revolutionary re-interpretation of the nature of space and time. While this led to the equivalence of mass and energy, Einstein went on to relate the acceleration that objects feel when they attract each other to a curvature of the space itself in the vicinity of massive objects. The body attracted was thus reacting to the geometry of its local space, rather than an object at a distance.

Einstein's first formulation, published in 1905, was about the motion of objects without considering the effect of gravity. The work was hence called the Special Theory of Relativity. The theory brings out that when speeds are comparable to that of light, speeds do not add up in the way that we are familiar with, but always to a little less, and the total can never equal the speed of light.

A well-known observation at the time was that although Earth is hurtling through space at the speed of 30 kms a second, the speed of light stayed the same in all directions. Einstein shows that this is because the measurement of lengths and time are observer- dependent, whose effects become appreciable when the observer is moving fast enough.

This strange effect of a thing not going sufficiently faster although pushed by a strong force dovetails with the apparent mass of a moving object being more than the mass of a stationary one. The work done by the push then gets accounted for in the greater energy of a heavier body in motion. This idea, of energy and mass being the same thing but from different viewpoints, gets formalised into the energy content of space and time and a different geometry of space when a massive body is present.

This view of gravity was published as the General Theory of Relativity, in a celebrated paper of 1915, which used the ideas to reconcile a nagging problem of the time, of anomalies in the orbit of the planet Mercury, as observed and as worked out by the conventional laws of motion. The revolutionary ideas of relativity, packaged with a solution to a flesh and blood problem that had puzzled astronomers, took the scientific world by storm. Despite the paper being written in German, and during World War I, an expedition to verify the theory was organised just after the war ended.

That massive objects would bend the fabric of space implied that straight lines should curve towards the object when they went past. Specifically, starlight shining past a large object should get bent around the star, and deviate. A total solar eclipse had been forecast for May 1919 and that was an opportunity to test the idea. If space were bent near the sun, then stars that were normally hidden should become visible at the moment of totality. English astronomers Sir Arthur Eddington and Sir Frank Dyson led expeditions to South Africa and Brazil to photograph the star field during the eclipse and sure enough, images of stars that should have been hidden sprang into view.

The properties of electric and magnetic forces, which grew, like gravity, weaker by the square of the distance, had been elegantly described by the laws of electromagnetism.

There were electrical forces from isolated charges, magnetic effects of moving charges and currents of charges set in motion by changing magnetic fields. And in consequence, acceleration of a charge or a magnet gave rise to a series of reciprocal effects, in the form of an electromagnetic wave, which carried energy away from the accelerated system.

As positive and negative gravitational charges were not known, the forces of gravity could not be described in the same way. For all that, the mathematics with which Einstein had treated the energy associated with a gravitational field, allowed for energy in rapid acceleration of masses to propagate in the form of waves.

Electric and magnetic forces are comparatively strong forces and the forces between the smallest electric charges can very strongly bind the lightweight particles found inside the atom. The forces can similarly be harnessed to generate power to light cities or run heavy machinery.

In contrast, gravitational forces are millions of times weaker. While, it is true that gravitational forces keep the planets in orbit around the sun and the stars, the force of gravity between objects of everyday use is infinitesimal. The strength of gravity waves, which would manifest as some minuscule and instantaneous variation in the dimensions of space, is hence unimaginably feeble. The equations of Einstein did say that such waves could exist, and would travel with the speed of light, but nobody imagined that they would ever be found!

This was till the discoveries of exceedingly dense objects in the cosmos, like pulsars and black holes. The force of gravity at the surface of a black hole bends space in such a way that light itself cannot escape. The first evidence for the existence of gravity waves was found in 1978, when a pair of neutron stars orbiting each other was found to be losing energy and spiralling in. The rate of slowing was exactly what it should be if they were radiating gravity waves.

The drive to detect gravity waves has been with the experiment, Ligo (laser Interferometer Gravitational-wave Observatory), a pair of L-shaped, four-kilometre-long light paths, one in Louisiana and one in Washington. A laser beam is shone, with the help of a beam splitter, down each of the L-shaped arms of the arrangement, and reflected back and forth, 280 times, to increase the effective length, before the beams are brought together. As the arms are of equal length, the beams should travel for the same time and there should be no interference or creation of dark and light fringes when the beams are received in a telescope.

If a gravity wave were to pass through Earth, however, one of the arms of the L is going to get just a little shorter, while the other gets longer, for just an instant. When this happens, the light paths will not be equal and the arrangement will detect the difference in the times of arrival of the laser beams.

Even as the path difference that a gravity wave will cause is minuscule, we can imagine that an event can easily be swamped by all kinds of false signals or "noise". Ligo, which has been in development now for 30 years, incorporates all kinds of noise suppressing or compensating devices, apart from the light path being in high vacuum. The arrangement can now detect changes of one part in a thousand billion billion ($10^{21}$). And two arrangements, separated by 3,000 kilometres, are used so that only events that are reported in both are counted, to eliminate false signals in either.

A third detector, Virgo, has now been added in Italy and two more are being added, one in Japan and one in India.

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# How dinosaurs became birds

## New research shows how they suppressed their teeth and grew beaks, and then back-shifted this process from adult to embryo stage

MICHAEL J BENTON

Once you know that many dinosaurs had feathers, it seems much more obvious that they probably evolved into birds. But there's still a big question. How did a set of dinosaurian jaws with abundant teeth (think T Rex) turn into the toothless jaws of modern birds, covered by a beak? Two things had to happen in this transition, suppression of the teeth and growth of the beak. Now new fossil evidence has shown how it happened.

In a new study, Shuo Wang from the Capital Normal University of Beijing and colleagues studied a series of dinosaur and early bird fossils to see the transition. They found that some dinosaurs evolved to lose their teeth as they got older and sprouted a small beak. Over time, this process happened earlier and earlier until eventually the animals emerged from their eggs with a fully formed beak.

The oldest birds actually had reptilian-like teeth -- for example, Archaeopteryx from the late Jurassic period (150 million years ago) and Sapeornis from the early Cretaceous (125 million years ago). But other early birds had lost their teeth, such as Confuciusornis, also from the early Cretaceous.

Modern birds all lack teeth, except for the South American hoatzin, Opisthocomus, whose hatchlings have a small tooth, which they use to help them escape from their egg and then shed. Developmental experiments in the 1980s showed that modern birds could probably generate teeth if their jaw tissue was artificially stimulated with the right molecules. This suggests their ancestors at some point grew teeth naturally.

Meanwhile, many dinosaurs actually did have beaks of some kind. Beaks are composed of keratin, the tough, flexible protein that also makes fingernails and cow horns, as well as feathers and hair. We typically think of beaks as all-encompassing structures, extending from the pointed tip at the front back to the eyes, and including the nostrils in modern birds. But fossil examples show that many toothed dinosaurs actually possessed a minimal beak at the front of the snout.

To find out exactly how beaks came to replace dinosaur teeth, the researchers had to look inside the animals' jaw bones. Dinosaur bone fossils are not simply rocky casts of the original bone, but they nearly always show all the internal structure. A microscopic thin section from any dinosaur bone shows all the detail of internal canals for blood vessels and nerves, as well as pits where the bone-generating cells sat. Thin sections of fossil jaw bones show the teeth in as much detail as in any modern jaw bone.

Nowadays, bones are rarely cut up, and it is much more common to use computed tomography scanning to look inside the bones without damaging them. The CT scans are a closely spaced series of X-rays that allow researchers to construct detailed 3D models showing every fine detail within the bone.

Wang and colleagues observed that the theropod dinosaur Limusaurus, which was closely related to birds' ancestors, and the early bird Sapeornis had teeth right to the front of the jaws when they were young but lost them as they grew up. The detailed internal scans of the fossils showed adult Limusaurus had no teeth but still had tooth sockets in their lower jaws, closed off and forming a single canal. In adult Sapeornis, there were teeth at the back of the jaw but not at the front of the jaw.

An artist's impression of a Sapeornis

As modern birds develop inside their eggs, the beak keratin begins to form at the tip of the snout and then grows back to cover both upper and lower jaws. Wang and colleagues argue that the mechanisms that regulate beak growth also suppress tooth formation. This is supported by studies of the gene BMP4 that show it controls both functions in modern birds.

Using the fossils to show how the animals evolved over time suggests beaks in some dinosaurs and bird relatives originally expanded backwards as the animals grew up and tooth sockets closed off. Eventually, this process happened earlier and earlier in the developmental cycle until hatchlings emerged with beaks and no teeth. Today, the bone gene BMP4 controls aspects of beak growth and tooth suppression, and these might have been acting early in bird evolution.

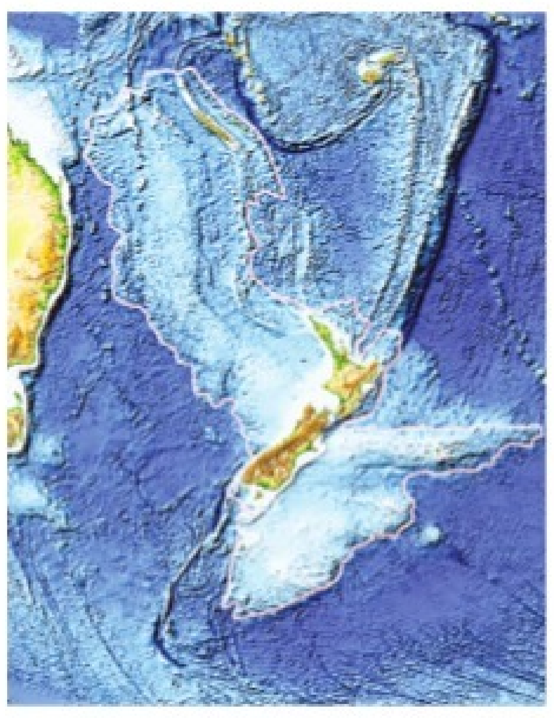
For more evidence, Wang and colleagues looked more widely across vertebrates that have lost or reduced their teeth as they evolved, including some fish, frogs, pangolins, whales and the entirely toothless turtles. In all cases, animals that had lost their teeth were associated with replacement of the teeth by a keratin beak.

These kind of developmental observations help confirm the theory that the exquisite dinosaur fossils point to. In becoming birds, dinosaurs had to change in many ways, including shrinking in size, sprouting wings, adapting feathers that were used for display and flight, improving their senses, shortening their tails, losing teeth, and many other characteristics. It is important to be able to identify plausible evidence for how each of these amazing changes happened.

The writer is a professor of vertebrate palaeontology at the University of Bristol, UK
The Independent

## PLUS POINTS

### Submerged continent



Scientists have uncovered more than 8,000 fossils during an expedition to a lost, underwater continent in the Pacific Ocean.

Drilling into the crust of Zealandia, thousands of feet below the surface, researchers discovered the remains of hundreds of species including pollen from land plants.

The land mass, on which New Zealand sits, was announced as the globe's newest continent earlier this year. It spans 5,000,000 sq km and is a distinct geological entity, a landmark study declared in the summer. Now it is believed Zealandia was once much closer to the ocean's surface and may have served as a land bridge for animals moving around the south Pacific region.

Gerald Dickens, from Rice University in the US, said after the expedition returned, "The discovery of microscopic shells of organisms that lived in warm shallow seas, and spores and pollen from land plants, reveal that the geography and climate of Zealandia was dramatically different in the past.

"The new discoveries reveal that the formation of the Pacific 'ring of fire' about 40 to 50 million years ago caused dramatic changes in ocean depth, volcanic activity, and buckled up the seabed of Zealandia,"

Rupert Sutherland, of New Zealand's University of Wellington, said the continent "probably" sank beneath the waves after it separated from Australia and Antarctica.

Jamie Allan, from the US National Science Foundation, said, "This expedition has offered insights into Earth's history, ranging from mountain-building in New Zealand, to the shifting movements of Earth's tectonic plates, to changes in ocean circulation and global climate."

The Independent

### Drugs in eggs

Japanese researchers have genetically engineered hens whose eggs contain drugs that can fight serious diseases including cancer, in a bid to dramatically reduce the cost of treatment, a report said recently.

If the scientists are able to safely produce interferon beta, a type of protein used to treat illnesses including multiple sclerosis and hepatitis, by rearing the hens, the price of the drug — currently up to 100,000 yen (S$1,211) for a few micrograms — could fall significantly, said the English edition of the Yomiuri Shimbun.

Researchers at the National Institute of Advanced Industrial Science and Technology in the Kansai region kicked off the process by introducing genes that produce interferon beta into cells that are precursors of chicken sperm, the newspaper reported.

They then used these cells to fertilise eggs and create hens that inherited those genes, meaning the birds were able to lay eggs containing the disease-fighting agent. The scientists now have three hens whose eggs contain the drug, with the birds laying eggs almost daily, the report said.

The researchers plan to sell the drug to pharmaceutical companies, halving its price, so the firms can use it first as research material, the newspaper said.

Consumers may have to wait a while, as Japan has strict regulations concerning the introduction of new or foreign pharmaceutical products, with screening processes that routinely take years to complete.

But the team hopes that the technological breakthrough will eventually help drive down the cost of the drug to 10 per cent of its current price, the newspaper reported.

The Straits Times/ANN