The cosmic neutrino background

Ripples in the sands of time

Cosmologists find hints of an elusive relic of the universe's beginning

Contrary to popular opinion, empty space is not actually empty—it positively buzzes with subatomic particles. Many of these are photons, the particles of which electromagnetic radiation (light, microwaves, radio waves and so on) is composed. And most of those photons are part of a relic known as the cosmic microwave background (CMB).

The CMB is made up of photons that began their journey 300,000 years after the Big Bang that marks the beginning of the universe. By analysing ripples imprinted on the CMB, cosmologists can see a picture of the universe as it then was. This has allowed them to infer its shape, and what sorts of matter and energy populated it, with great precision.

Nevertheless, 300,000 years is not exactly an eyeblink, even in cosmological terms. What cosmologists would really like to know is the nature of the universe just a second or two after its beginning. And it now seems as if they are tantalisingly close to getting a glimpse of this, by following the goings-on of a second sort of particle that permeates otherwise empty space—the neutrino.

Standard cosmological models predict that neutrinos, a type of elementary particle with no electric charge and very little mass, were created in large numbers in the Big Bang. Cosmologists therefore have good reason to believe that relic neutrinos permeate today's universe, forming a cosmic neutrino background (CMB) that parallels the CMB. Any ripples in this background would carry information about the universe as it was an instant after the moment of creation.

Neutrinos, however, are extremely hard to detect, so looking for these ripples directly does not seem feasible. But it might be possible to see them indirectly. And on June 15th, Roberto Trotta of Oxford University and Alessandro Melchiorri of the University of Rome, La Sapienza, announced that they had done just that.

Background information

In its infancy, the universe was a hot, dense ball of energy and elementary particles. The different types of particles in it interacted with each other through the fundamental forces of nature, thus maintaining a sort of equilibrium. As the universe expanded and cooled, however, it became more and more difficult to maintain this equilibrium. If the universe was expanding more quickly than a particular type of particle was able to interact with the other types, that particular type of particle would lose touch with the rest. Its distribution in the universe would then reflect the moment that this loss of touch happened.

Neutrinos interact with other particles through what is known as the weak nuclear force. As its name implies, this force is indeed feeble. Consequently, neutrinos fell out of the rankings early on. A mere one or two seconds after the Big Bang they were running away from one another so quickly that the weak force could not keep them in touch with the rest of the universe. Once this happened, they went merrily on their way, streaming through space for ever afterwards. These relic neutrinos form the neutrino background.

It is the weakness of the weak nuclear force that makes neutrinos so hard to detect individually, even today. Indeed, in the time that it takes you to read this article, around 10 million billion of them will have passed directly through your body without causing any effect. But they also interact via the force of gravity, and in particles that interaction could be detectable. This is what Dr Trotta and Dr Melchiorri have focused on. Their paper, which will be published in Physical Review Letters, reports what they believe is the gravitational effect of the CMB on the CMB.

The CMB was formed at the point, 300,000 years after the beginning, when the universe was cool enough for atoms of hydrogen and helium to form. The universe's primordial photons, which had previously been scattering chaotically off the electrically charged protons, electrons and alpha particles now imprisoned in the newly formed atoms, were thereby set free. The microwave background has been measured with exquisite precision by satellite and balloon-borne experiments.

In 1995 Wayne Hu, a physicist who now works at the University of Chicago, speculated that gravitational effects caused by fluctuations in the neutrino background might be visible in the much more easily detectable fluctuations in the microwave background. They might also be visible in the way that galaxies are distributed, since that distribution, too, reflects conditions early on.

Using a sophisticated computer model...
of the early universe, Dr Trotta and Dr Melchiorri have now put his idea to the test. They did so by varying the model’s parameters—particularly the amount of ripple in the neutrino background—and comparing the outcome with data on the microwave background and the large-scale distribution of galaxies. They found, as they had hoped, that the model universes in which most resembled the real one were those in which the CMB most resembled what cosmologists predict that it should look like. The signature of the CMB does, in other words, appear to be there.

At the moment, Dr Trotta and Dr Melchiorri have done little more than prove the point. But that could change quite fast. With better CMB data from new satellites, this approach should allow cosmologists to decide which, if any, of the various exotic theories about the very early universe is actually true. For instance, they have recently come to believe that the universe is dominated by a mysterious phenomenon that they have dubbed “dark energy”. If neutrinos interacted with this dark energy a few seconds after the Big Bang, it might have produced a detectable effect on the ripples in the neutrino background. These would give clues about what it really is.

That alone would be a prize worth having. But besides any scientific importance, the idea of seeing a snapshot of the universe not merely as an infant, but as the cosmological equivalent of a newly fertilised egg, has a glory all of its own.

Combating cancer

Networking

Picking the best treatments for cancer patients

WHILE particle physics can be esoteric, its practitioners are keen to show it has practical applications. They invented the world wide web. They also contributed to a number of advances in medicine, among them positron-emission tomography, a body-scanning technique. Now, as if to strengthen the case, a group of particle physicists led by Robin Marshall of the University of Manchester, in Britain, has applied its knowledge of information technology to show how computer programs known as neural networks can help doctors to choose the best treatments for people with cancer.

Unlike a conventional computer, which takes data, processes it using an algorithm and generates a definite answer, a neural network learns to create a range of answers from a range of inputs. To do this, it is “taught” by being fed a series of training inputs and then told what the answer should be in each case. The network adjusts the weighting of its internal connections to try to retain the correct matches as far as possible. Once the teaching process is complete, the network can be used to calculate answers from new inputs.

Like many in his field, Dr Marshall uses neural networks to discard the huge amounts of boring data produced in particle collisions and to identify the interesting events. The network learns to associate a particular range of inputs with interesting collisions and to ditch the rest. He has now turned this expertise to the medical field, following a chance meeting with Sir Alfred Cuschieri, an oncologist at Ninewells Hospital in Dundee.

Ninewells has detailed records on thousands of patients with colorectal cancer. These records contain a wide range of information such as each patient’s age, sex, type of treatment, size of tumour and eventual fate. Dr Marshall realised that a neural network could be trained with this information to calculate the survival chances of other people with the same condition. The machine would learn to associate certain ranges of patient profiles with particular survival probabilities.

Dr Marshall and Sir Alfred, together with some colleagues from Manchester and Dundee universities, selected those records that contained enough data to create a detailed profile of a patient at the beginning of his treatment, and to follow his progress over the subsequent five years. They then used 1,558 of these records to train a neural network. In each case, the input was 16 pieces of data that defined the state of the patient. The output (i.e., what the network was trying to learn to predict) was the patient’s fate—in other words, whether he died over the course of the five years and, if so, when.

The researchers, who will publish their work in a forthcoming issue of *Concurrency and Computation: Practice and Experience*, then tested the trained network by using the same 16 parameters from each of the remaining 1,232 records as the input, while withholding information about the survival of the patient. They found that, in 90% of cases, the time at which the neural network predicted that a patient’s chances of survival would fall below 40% was within three months of the actual time of death of that patient.

According to Sir Alfred, this system is ideally suited to predicting the survival chances of individuals. He says that the statistical techniques currently used by doctors to calculate a person’s chances of surviving a disease such as cancer are a blunt instrument. By contrast, the neural network created at Manchester enables them to give individual prognoses, so they do not have to rely on crudely defined average chances of survival.

Once the project’s researchers have verified the reliability of their neural network, they intend to make it accessible over the internet. Doctors will be able to enter their patients’ parameters and generate prognoses. More importantly, they will be able to compare the effects of different treatments by varying the relevant inputs.

The researchers also believe that their system could be applied to the treatment of a variety of other chronic disorders, such as heart disease and diabetes. That would create further evidence that particle physicists do live in the real world, at least some of the time.

Simian economics

Monkey business-sense

Monkeys show the same “irrational” aversion to risks as humans

ECONOMISTS often like to speak of Homo economicus—a rational economic man. In practice, human economic behaviour is not quite as rational as the relentless logic of theoretical economics suggests it ought to be. When buying things in a straight exchange of money for goods, people often respond to changes in price in exactly the way that theoretical economics predicts. But when faced with an exchange whose outcome is predictable only on average, most people prefer to avoid the risk of making a loss than to take the chance of making a gain in circumstances when the average expected outcome of the two actions would be the same.

There has been a lot of discussion about this discrepancy in the economic literature—in particular, about whether it is the product of cultural experience or is a...