Afterglow of Creation

Decoding the Message from the Beginning of Time

MARCUS CHOWN

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faber and faber

Prologue: The World through Microwave Eyes

It is a crystal-clear night far away from the bright lights of a big city. A luminous full Moon is pulling itself free of the treetops. Against the velvet-black sky stars are winking like diamonds.

But the night sky is not all it seems . . .

The visible light our eyes see makes up only a vanishingly small portion of all the light that is streaming through the Universe. Raining down on the Earth from space is a ceaseless torrent of invisible 'light'.

For most of human history we have been entirely blind to this light. But in recent years astronomers have opened up our eyes. New telescopes have been built which can see X-rays, infrared, radio waves and every other kind of invisible light. Now, for the first time, we can behold the greater glories of the Universe.

Imagine that you can see what the astronomers see simply by putting on a pair of 'magic' glasses. To 'tune' them to different types of light you need only twiddle a knob on the frame. No longer are you almost blind. Now you can have infrared eyes, radio eyes, eyes that see ultraviolet light, gamma rays or X-rays.[1]

What can you see with these impressively enhanced lenses?

At first, nothing appears to be changing. Then you realise that the Moon is fading. So, too, are most of the stars. Soon the Moon is hardly visible and the stars have begun to wink out one by one. But as the stars disappear new ones pop into view in places where no stars were visible before. Some of the new stars are shrouded in clouds of misty white.

This is the ultraviolet sky. Your glasses are registering the kind of invisible light that causes sunburn when you lie too long on a beach. Only the very hottest stars shine brightly with ultraviolet light.

Twiddle on.

The stars change again. Now there are no familiar signposts in the heavens. The intensely bright pinpricks that dot the sky mark places where stars are cannibalising other stars and where blisteringly hot gas is plunging headlong into black holes. Wherever matter is heated to hundreds of thousands of degrees it shines brightly with X-rays.

Keep twiddling.

Everything is fading now. We have come to gamma rays, the most energetic light in the Universe, created by the most violent events imaginable. Now the sky looks utterly black.

But there is a tiny, brilliant flash of light. You turn your head to stare. But there is nothing to see. The black sky is utterly empty. But if you were very patient indeed and watched the gamma-ray sky for a few days at a stretch you would see another brilliant flash from an entirely different part of the sky. And after a few more days you would see another. Astronomers call these 'gamma-ray bursters'. They are the most powerful explosions in the Universe and we are seeing them at the very edge of the Universe. No one is completely sure what they are, but they may be the birth cries of black holes.

There is nothing more to see by tuning any further – except darkness and yet more darkness. Turn the knob back the other way, through the X-ray and ultraviolet skies to the familiar visible sky with its full Moon and familiar stars. But don't stop. Keep going. Keep tuning.

You are now seeing infrared light. Instead of the Universe's hot bodies, you are seeing relatively cool ones. Even human beings give out infrared. It's the same kind of light earthquake-rescue teams use to detect people trapped beneath rubble.

The Moon has reappeared in the sky. But instead of shining brightly from reflected sunlight, it is glowing dully from its own meagre internal heat. The sky is full of unfamiliar stars. Cold stellar embers. There are bloated red giants in their death throes and stars so new that they are still swathed in the shimmering gas out of which they were formed.

But now you have left even the infrared sky behind. You are seeing microwaves, the same type of light used for radar and for heating food in the ubiquitous ovens. Now if our glasses are working, something very odd will begin to happen: the sky will light up. Not just a part of it – all of it.

The whole sky, from horizon to horizon, is glowing a uniform pearly white. You tune further into the microwave region but the sky simply gets brighter. The whole of space seems to be glowing. It is as though you are inside a giant light bulb. And what you are seeing is quite real. It is the relic of the Big Bang, the titanic fireball in which the Universe was born. Incredibly, it still permeates every pore of space 13.7 billion years after the event.

There is more energy tied up in this universal 'cosmic microwave background' than there is in the visible light of all the stars put together. In fact, the Big Bang radiation accounts for 99.9 per cent of all the particles of light streaming through the Universe at this moment.

Yet although the technology to detect microwaves was developed for radar during the Second World War, remarkably it was not until 1965 that anyone noticed this 'afterglow of creation'. And even then it was noticed only by accident. The two astronomers who stumbled on it carried off the Nobel Prize for Physics despite not believing in the cosmic origin of what they had found for at least a year after their discovery, and despite initially mistaking it for the microwave glow of pigeon droppings.

The extraordinary story of the discovery of the relic radiation from the Big Bang forms the backbone of this book. With its tortuous twists and turns, accidents and missed opportunities, it provides a wonderful example of the way in which science is really carried out.

The cosmic microwave background is the oldest 'fossil' in creation. It has come to us directly from the Big Bang and has been travelling across space for 13.7 billion years. The cosmic microwave background was given out by matter cooling in the fireball, so it carries with it an imprint of the Universe as it was soon after the Big Bang. When you look at the microwave sky, you are seeing a snapshot of the Universe 13.7 billion years ago.

The early Universe must have been an extremely boring place, you think. After all, there is not a single feature anywhere in the microwave sky. However, the beauty of this featureless, uniform Universe is that it is a lot easier for scientists to understand than a complicated one. The smoothness of the cosmic microwave background is telling us that matter in the early Universe must have also been spread amazingly smoothly throughout space. And herein lies a great puzzle. Today's Universe is anything but smooth. In fact, the Universe is full of stars, and the stars are grouped together into galaxies, and these galaxies are in turn linked into great chains and clusters that snake their way across space. And between these groupings of galaxies are great voids of utterly empty space. Far from being smooth, the luminous material in today's Universe has the appearance of Swiss cheese.

So how did such an uneven and complicated universe arise from such a smooth and simple beginning?

Clearly, at some point the stuff of the Universe must have begun to clump together, like milk curdling. So, although the cosmic microwave background looks remarkably smooth, it cannot be dead smooth. If we look closely at it, we ought to be able to see signs of the first structures in the Universe beginning to clump together under gravity soon after the Big Bang.

For more than 25 years after the discovery of the cosmic microwave background astronomers peered at it closely. But, try as they might, they were unable to find any variation in the brightness of the microwave background.[2] There were no signs of the lumps of matter which would later form galaxies like our own Milky Way. The evidence of the cosmic microwave background seemed to be contradicting one of our most cherished ideas: that we and our world exist!

In 1989, NASA launched an obscure satellite called COBE (pronounced 'co-bee') into an orbit just above the Earth to study the fireball radiation. Previously, this had been difficult because the Earth's atmosphere glows brightly with microwaves.[3] COBE's sensitive instruments listened carefully for the faint whisper of the cosmic explosion which started the Universe's expansion 13.7 billion years ago. For more than two years the satellite found nothing. There were jittery mutterings among scientists.

But, in April 1992, COBE hit the jackpot. It found 'ripples in the cosmic background radiation'. In some parts of the sky the cosmic microwave background was ever so slightly brighter than in others. It was a tiny effect. The 'hot spots' in the sky were only a few parts in 100,000 hotter than the 'cold spots', but the outpouring of relief among scientists was unprecedented. 'It's like seeing the face of God,' declared one of the scientists on the COBE team. 'It's the discovery of the century, if not of all time,' declared the physicist Stephen Hawking.

Many thought these remarks a little extravagant, but the fact remained that COBE had found the 'seeds' of galaxies in the early Universe. Those regions that were slightly denser than others would grow and grow as the Universe expanded in the aftermath of the Big Bang, getting bigger as their gravity pulled in more and more matter. They would eventually become the clusters and superclusters of galaxies we see around us today. COBE had not quite seen the face of God but it had seen the largest and oldest structures in the Universe.

At the time of the discovery the world's media went wild. The story was splashed across TV screens and the front pages of newspapers all over the planet. It is probably true that no other scientific story has received such blanket coverage in the media.

Why so many people lost their heads over such an obscure and esoteric story is a bizarre tale in itself, and one that I tell later in this book. But before you can understand what all the fuss was about, you need to know a little background to the cosmic background. In particular, you need to know about the Big Bang.

The story begins in the first decades of the twentieth century, when a new generation of giant telescopes allowed astronomers to probe the remote depths of space and discover for the first time just what kind of Universe we were living in . . .

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The Big Bang

How did we come to believe in such a ridiculous idea?

In December 1924, the astronomers of the world gravitated to Washington DC for the 33rd meeting of the American Astronomical Society. It was a routine and unremarkable meeting. Some of the participants had already departed to catch their trains home when, late on the last day, one man stood up in front of a half-empty auditorium, cleared his throat and began to read out a scientific paper. It had been submitted by a 35-year-old astronomer who had been unable to make the arduous journey east from southern California.

When the reader finished and left the podium, there must have been many in the audience who felt a sudden chill descend on the auditorium. For, at long last, the human race knew the true scale of the Universe it was lost in. And it was unimaginably more vast than anyone had ever dreamed.

The absent Californian astronomer was Edwin Hubble, an ex-athlete and ex-boxer who had given up a promising career in law to study the heavens. In 1923, he had turned the most powerful telescope in the world – the newly built 100-inch reflector on Mount Wilson above Pasadena – onto a misty white patch in the night sky known as the Great Nebula in Andromeda. What he had made out in the outskirts of the nebula, so faint that they teetered on the very edge of invisibility, were the tiny specks of individual stars.

To understand why this changed our picture of the Universe you have to realise that, at the time of Hubble's observation, most astronomers assumed that Andromeda was merely a cloud of glowing gas floating between the stars. Hubble showed this was wrong. Andromeda was no nebula. It was made of stars blurred together by sheer distance. It was a vast island of stars suspended in the depths of space.

The Mysterious Spiral Nebulae

By discovering his remote stars, Hubble had settled a fierce astronomical debate which had been raging throughout the early decades of the twentieth century. It concerned the nature of the 'spiral nebulae', of which Andromeda was the largest and so most easily studied with telescopes.

The spiral nebulae had been discovered in the eighteenth century, when the first generation of astronomers to use telescopes had seriously trained their instruments on the sky. Their passion was comet-hunting, so these early astronomers were irritated to discover that cluttering up the night sky were many fuzzy patches of light which could easily be confused with comets. In 1784, the French astronomer Charles Messier provided a valuable service to his fellow comet-hunters by publishing a catalogue of the positions of the brightest of these 'vermin of the skies'.

Messier's original catalogue contained 103 cloud-like objects, the majority of which were spiral-shaped nebulae. At number 31 in the list was the Great Nebula in Andromeda. Arguably the least comet-like of all the celestial objects in Messier's list, the nebula is easily visible to the naked eye if you know where to look: a fuzzy elongated cloud about six times as big as the Moon appears in the sky. To this day, astronomers refer to it as Messier-31, or M31 for short.

The fierce debate about the nature of the spiral nebulae was inextricably bound up with the size of the Universe, for the following reason: if the spiral nebulae were clouds of glowing gas, as most astronomers maintained, then they must be near the Earth. Glowing gas simply did not shine brightly enough to be visible at great distances.

But others argued that the spiral nebulae were great islands at enormous distances from the Earth. They appeared like clouds of glowing gas only because distance had blurred together their stars.

At the time, it was known that our Sun belonged to a large stellar swarm called the Milky Way. The Milky Way is a flattened, roundish collection of stars similar in shape to a compact disc. In the night sky it appears as a misty band stretching across the heavens, but that is only because we see it edge on from our position inside it.

In the early part of the twentieth century, many astronomers believed that the Milky Way was the entire Universe and that nothing existed beyond its limits. If the spiral nebulae were shown to be beyond the Milky Way, then this idea would be blown apart.

The moment Hubble found stars in Andromeda, it began to look as if it was indeed beyond the Milky Way. But unless he could discover its exact distance, Hubble could not tell for sure.

Fortunately, among the stars of Andromeda Hubble was able to identify were very unusual stars known as Cepheids.[1] And these enabled him to settle the question once and for all.

To an astronomer, finding Cepheids is like scouring a vast expanse of beach and stumbling on a handful of jewels sparkling in the sand. The reason is that it is always possible to determine the exact distance to a Cepheid, which is usually impossible with an ordinary star. If you see two stars and one appears brighter than the other, it is impossible to tell whether the bright one is intrinsically brighter or whether it is simply closer. But there is a way of telling how intrinsically bright Cepheids really are. So if an astronomer sees two similar Cepheids and one is brighter than the other, he can be certain that the bright one really is closer.

Building Blocks of the Universe

Hubble compared the Cepheids he had found in Andromeda with those in the Milky Way and found that they were immensely further away. Andromeda was at a truly enormous distance. It was a 'galaxy', a vast island of many billions of stars floating in space far beyond the limits of the Milky Way.

If Andromeda was a separate galaxy, then the implication of this was obvious to Hubble: the Milky Way must be a galaxy as well. Although it looked like a flattened disc of stars from our vantage point, it, too, was a spiral galaxy, a giant fiery pinwheel turning ponderously in space.

And if Andromeda was a galaxy, all the other spiral nebulae littering the heavens must also be galaxies, giant beacons of stars burning brightly out of the black depths of space. Far from being all of creation, the Milky Way was merely one galaxy among countless billions of others scattered throughout space. Galaxies like Andromeda, which appeared large and bright in our sky, were simply close neighbours of the Milky Way. The small and faint galaxies were at enormous distances.

Hubble had demonstrated just how large our Universe really is. He had identified the building blocks of the Universe – immense pinwheels and spheroids of stars. They crowd space all the way out to the very limits probed by the largest telescopes, dwindling finally to mere specks of light.

Today, the Universe we see with our telescopes is about a billion billion billion metres across. If that gives you a headache, try imagining the Universe as a sphere just a kilometre in radius. In this shrunken Universe, our Galaxy,[2] the Milky Way, which has about 200 billion stars, floats at the centre and is roughly the size and shape of an aspirin.

But the Milky Way is not alone in space. Galaxies tend to congregate in 'clusters', and our Milky Way is no exception. It belongs to a meagre cluster of galaxies called the Local Group. Of the cluster's couple of dozen other galaxies, only one – the Andromeda galaxy – is sizeable. Andromeda is another aspirin floating in space a little over ten centimetres away.

The nearest large cluster of galaxies to our own is the Virgo Cluster, which contains about 200 galaxies. In this Lilliputian universe, the galaxies of the Virgo Cluster occupy the volume of a football and are about three metres away.

Some other more distant clusters may contain many thousands of aspirin-sized galaxies, and these clusters may be many metres across. And clusters of galaxies in turn form clusters, which astronomers call 'superclusters'. Aspirin-sized galaxies crowd space out to the edge of the observable Universe a kilometre away.

The Fleeing Nebulae

Hubble had succeeded in identifying the major constituents of the Universe – the galaxies – and provided some sense of the vastness of the cosmos that they inhabited. But he had yet to make his greatest discovery. For his next trick, Hubble would show that the Universe had not existed for ever, as most astronomers believed, but that it had a beginning.

The man who laid the groundwork for Hubble's greatest discovery was Vesto Melvin Slipher, an astronomer at the Lowell Observatory in Flagstaff, Arizona. Ever since 1912, well before anyone knew about galaxies, Slipher had been painstakingly measuring the patterns in the light from spiral nebulae.

Just as in sunlight, the light from these nebulae was a mixture of colours. Each colour corresponded to a particular wavelength of light: the longest was red and the shortest blue.[3] With the aid of a prism – a triangular wedge of glass – it was possible to spread the colours out into an ordered sequence known as a spectrum.

In the nineteenth century, astronomers had found that the rainbow-like spectra of the Sun and the nebulae were interrupted by ugly dark lines. Colours were missing. It was soon realised that these 'missing' colours had been removed, or absorbed, by gases in their atmospheres. From the pattern of dark lines it was possible actually to identify the gases that were doing the absorbing – gases like helium or nitrogen or oxygen.

Slipher's great triumph was to perfect a technique for photographing the spectra of extremely faint objects such as spiral nebulae. By 1917, he had studied 15 of these with the telescope at Flagstaff, and what he had discovered puzzled him greatly.

In the spectra of the Sun and the stars of the Milky Way the dark lines of absorbing gases appear very close to the positions measured in laboratories on Earth when the same gases absorb light. But Slipher found that in the nebulae the lines were shifted – usually to the longer wavelength end of the spectrum, where the light was redder. In only two of his sample of 15 nebulae were the lines shifted towards the blue end of the spectrum.

Slipher interpreted the wavelength shifts as due to the Doppler effect, which is familiar to anyone who has noticed how the pitch of a police siren changes as it speeds across town, becoming higher as it approaches, then deeper as it recedes into the distance.

As a sound wave passes, the air is alternately compressed and expanded. That is all a sound wave is: a long train of alternating 'compressions' and 'rarefactions' of air. The longer the wavelength – related to the distance between one compression and the next – the deeper its pitch.

Waves from an approaching siren are 'scrunched up', shortening their wavelength and making them higher pitched, while waves from a receding siren are 'stretched out', deepening their pitch.

On the other hand, when the wavelength of light is changed, this causes a change in colour rather than a change in pitch. So, for a body coming towards us, the Doppler effect shortens the wavelength of the light, shifting its characteristic pattern of colours to the blue end of the spectrum; on the other hand, the same effect drags out and lengthens the wavelength of the light from a body moving away, causing the pattern in its spectrum to be 'red shifted'.

We are fortunate indeed that nature has created atoms which can make dark lines in spectra. If all the colours in a spectrum were simply shifted, we would never know. The spectrum would look the same. It would be like taking a sequence of numbers like 1, 2, 3, 4, 5, 6, 7, 8 . . . and shifting it one place to the right. The number 1 would replace 2, 2 would replace 3, and so on, but the sequence would still appear as 1, 2, 3, 4, 5, 6, 7, 8 . . .

But, because of spectral lines, there are distinctive patterns in any spectrum. A spectrum looks like a supermarket bar code, so it is immediately obvious if the atomic bar code has been shifted.

Because 13 of Slipher's 15 nebulae had red shifts, this meant that 13 were racing away from us, while only two were coming our way. But this seemed to defy common sense. The nebulae were in different parts of the sky and so were not connected to one another. They should therefore be moving in random directions. By the laws of chance, roughly half the nebulae should be approaching and half receding. Why should there be any pattern at all in their velocities?

There was something else peculiar about the red shifts of the receding spiral nebulae. The shifts were very large, much larger than those of ordinary stars in the Milky Way. Taken at face value, they implied that the nebulae were receding from us at enormous speeds of thousands of kilometres per second.

A partial explanation of these speeds came in 1923, when Hubble discovered that the spiral nebulae were galaxies. Since they had nothing whatsoever to do with the Milky Way, there was no reason why they should be moving like stars in the Milky Way. But though the high red shifts could be swept under the carpet, there was still no explanation of why most spiral nebulae were fleeing from us.

Hubble's assistant at Mount Wilson was a man called Milton Humason, a one-time mule driver on the mountain who had taught himself to be an astronomer. On Hubble's suggestion, Humason began to extend Slipher's pioneering work. He measured the velocities of the faintest, and therefore most distant, galaxies that could be seen with the 100-inch telescope, and very soon confirmed that Slipher was absolutely right. Every single galaxy whose spectrum he measured was receding from us, some at incredible speeds of tens of thousands of kilometres a second.

Hubble had not been idle while his assistant photographed spectra. He had been painstakingly measuring the distances to Humason's galaxies, assuming that they were all of the same brightness, so that the fainter ones really were further away than the brighter ones.

A Beginning to Time

In 1929, while staring at the data, it suddenly dawned on Hubble that the red shifts of the galaxies were not random at all. There was a pattern: the further away a galaxy, the faster it seemed to be hurtling into the void. In fact, the velocities of the galaxies increased in step with their distances. A galaxy that was twice as far away as another turned out to be receding from us at twice the velocity; a galaxy three times as far away was receding at three times the velocity.

The pattern would come to be known as Hubble's law.

The simplest and most naive explanation of what Hubble had found is that at some time in the remote past a violent explosion took place in the Universe, centred on the Earth. The galaxies were blasted outwards so that today when we observe them we quite naturally see them all racing away from the origin of the explosion. Those galaxies that came out of the explosion moving relatively slowly have covered the least distance, while those that started off fastest have receded furthest from us.

Hubble had made the outstanding astronomical discovery of the twentieth century. The entire Universe is expanding, its constituent galaxies flying apart like pieces of cosmic shrapnel. But if the Universe was expanding, then one conclusion was inescapable: it must have been smaller in the past. There must have been a moment when the headlong expansion started: the moment of the Universe's birth.

This was the real significance of Hubble's discovery. By finding that the Universe was expanding, he had found that there was a beginning to time; that although the Universe was old, it had not existed for ever. By imagining the expansion running backwards, like a movie in reverse, astronomers now deduce that the Universe came into existence in the Big Bang about 13.7 billion years ago. For the first time, scientists would be able to ask where the Universe – with its galaxies, stars and living organisms – had come from and where it was going. Cosmology – the most audacious of sciences – was born.