Astronomers' Universe

Ben Moore

Elephants in Space

The Past, Present and Future of Life and the Universe

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In the memory of my father
For Mariana and Joe

Foreword

The Romance of the Universe

It is hard to think of a more romantic story than the story of our universe itself.

I realise that many will find this statement incredulous. After all, where is the sex and violence?

On a superficial level one could respond to this question quite simply: The history of life on Earth provides more examples of quirky sex than most people could imagine on their own, and nothing humans have ever invented can compare with the violence and explosive power of a supernova, the most brilliant cosmic fireworks in the sky.

But when I used the word romance here, I was referring more to the romance of science itself. It is perhaps not properly appreciated that what drives most scientists to spend the better part of their intellectual lives pursuing sometimes seemingly esoteric questions is not to the desire to save humanity, or even the natural human capacity self-aggrandisement. It is instead a love affair with the universe: the desire to understand something that no one before has understood; to push the frontiers forward so that new questions can be asked about phenomena that may have been previously invisible; to understand how it is that we came to where we are; and to comprehend realistically what the future might bring.

It is this love affair that Ben Moore captures in this book about the history of the universe. Ben has spent the better part of his career exploring the incredibly complex gravitational interplay of objects to form the structures that we know and love as we look out with our telescopes, from galaxies and clusters of galaxies, to stars and planets. When the resources didn't exist, he built his own supercomputer to help carry out the complicated numerical algorithms necessary to explore questions that are simply too complex to handle analytically with standard mathematical formulations. What has characterised his theoretical efforts, in my experience as a collaborator, observer, and friend, is a sense of adventure and fun that permeates much of what he does in his life, and that permeates this enjoyable volume. I encourage you to jump in headfirst. Don't be afraid. You will be delighted and enlightened.

Tempe, AZ Lawrence M. Krauss
2014

Preface

My father was a forester and spent much of his life immersed in nature from sunrise to sunset. During the school holidays I would join him as he worked tirelessly and thought constantly. He instilled in me his love of the natural world and his wonder in its origins. What are all those ants thinking? How do trees defy gravity and suck water from their roots into such high canopies? Why does the Earth spin and orbit the Sun like some kind of mechanised clock? What is the nature of light? Can black holes really exist? Are we alone in this vast universe or is it filled with life?

This book is written in the memory of my father, who encouraged me to go to university to find some of the answers to the questions we discussed. It is for anyone who wonders about the world around them and who is interested in its origins. It is for my children to read, to inspire them in the same way as my father inspired me. It is something I would like to leave behind in this short but incredible life.

I want to tell the story of the history and future of life and the universe at a level that anybody who is interested in it can understand and enjoy. I will start at the beginning and end at the end, describing our place in time and space, how we got here and where we are going. I will take you on a journey from the beginning of time to the end of the universe to uncover our origins and glimpse at our destiny.

It is a journey of science fiction proportions but based on 3,000 years of scientific findings. I will explain how we acquired this knowledge, beginning with the ancient Greeks who pioneered the art of scientific investigation. This takes us on a remarkable path of discovery from the origin of atoms to dark matter and dark energy, from ants and elephants to space travel and life beyond our solar system.

The following is a true story based on actual events that took place. It's a good time to tell it, since in the last decade astrophysicists have collected new observational data that allow us to understand in detail the history of our universe and how all of its contents emerged. I have spent the last 25 years carrying out research on many of these topics and I would like to explain to you all of these developments using simple and friendly non-technical language. You may encounter some concepts that are difficult to understand—don't worry, some are rather tricky to explain. There is still a lot to learn and in Chap. 10 I will be honest about what we don't understand.

I have always been curious as to the lack of evidence for intelligent life elsewhere in the cosmos. There seems to be nothing special about our star, the Sun. There are billions of similar stars within the Milky Way, itself one of countless other galaxies. The goal of one of our most exciting research projects is to understand the origin of planetary systems and to determine whether habitable planets are abundant or rare. Our supercomputer simulations predicted that 'Earth-like' planets around stars similar to the Sun should indeed be very common. In the past few years very exciting observations have emerged from the Kepler space satellite that is discovering vast numbers of distant new worlds. I wonder how many of these have atmospheres and climates suitable for the emergence of life? How many of those worlds have civilisations more advanced than our own and have already begun to explore the galaxy?

Elephants are amongst the most intelligent creatures on Earth. They love, they mourn, they are social and fun, and their brains have a larger computational capacity than does the human brain. Without our Moon, life on Earth might have evolved rather differently, and elephants not at all; I will explain why later. I have recently given many popular and research talks entitled 'The frequency of elephants in the galaxy' which tie together all of these topics. Our latest research suggests that our galaxy alone hosts at least a billion planetary systems suitable for the development of intelligent life. I suspect that there are many other planets with wonderful thinking creatures like elephants; we just haven't looked in the right way or in the right places.

Our Earth has made over four and a half billion orbits around the Sun. If we can avoid self-extinction and collisions with giant asteroids, we can survive literally for billions of years as a species. Indeed, whilst humans have developed the frightening capability to cause mass extinction events, the same technology will be necessary to protect our planet from the inevitable impact of a rogue asteroid. Such random catastrophic events are rather like the random walks that our lives seem to follow—a journey during which apparently haphazard occurrences can dramatically alter our path. Just spend a few moments in contemplation after reading these words, and the future of your life could be very different.

Our brief time of consciousness is very special, but ultimately, we face the realisation that nothing lasts forever. The most recent observations from our great observatories, together with the theoretical work of my cosmologist colleagues, enable me to discuss the future of the universe. As time ticks on, and the stars begin to fade away and stop shining, can life continue for eternity or will the future be eternally dark? And what is the purpose of it all anyway?!

Zürich, Switzerland Ben Moore

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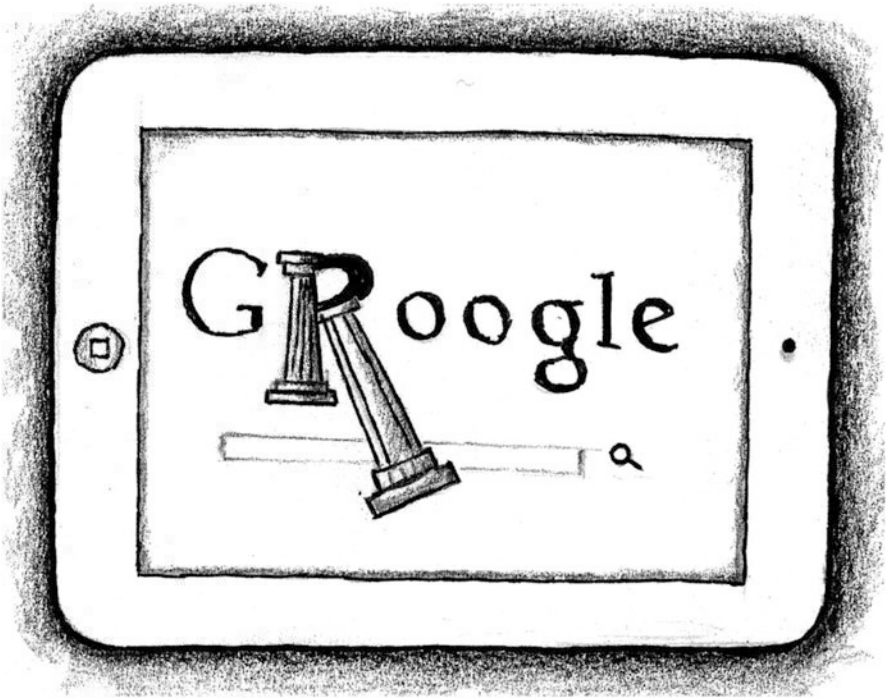
Chapter 1
A Brief History of Human Knowledge and Discovery



B. Moore, *Elephants in Space*, Astronomers' Universe,
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The sky appeared as if it had been painted a dazzling crimson as the Sun sank below the forested skyline. A line of posts stretched into the distance following the curves of the ancient glaciated valley. The post driver lay on the floor, a primitive, hand-welded iron cylinder used to manually pound fence poles into the ground. Two pairs of bare hands gripped the cold handles and, in synchronised action, lifted the weight high above the wooden post then brought it smashing down. The ground shook and the iron resonated like a church bell, until the next blow struck three seconds later. With each stroke, the splintered wooden post sank a little further into the Earth. As my father and I worked, our minds were elsewhere. We were contemplating the strange duality of light, the bizarre fact that the behaviour of photons could only be understood if they existed simultaneously as both waves and particles. We had reached this question after discussing the reason why molecules in the air preferentially scattered blue light, resulting in our evening's spectacular red sky.

We live in a unique era in the history of humankind. We believe that we have accurately determined our place in the universe, in both time and space. We have realised our insignificance as we gaze out on 100 billion galaxies similar to our own, each containing billions of stars like our Sun. We have measured the size of our universe and determined its age. We know when our Sun started to shine and when it will die. We have found that our universe is expanding; the space between the galaxies is growing, and its rate of expansion is rapidly increasing. We have measured the tiny irregularities in the very early universe, like the ripples on the surface of a lake—the initial conditions from which all the stars and galaxies that we see have slowly emerged over cosmic time. It is a remarkable accomplishment of the human species that we have a good understanding of the history of our universe all the way back to one millionth of a second after it came into existence. At that moment, our entire visible universe and everything in it, all of its matter and energy, was squeezed into a region the size of a football stadium. That sounds amazing, and it really is.

Over the past four hundred years there has been an explosion of knowledge and understanding. It should have begun two thousand years ago. We have come a long way, yet I believe that we could have gone much further. Many important and fundamental aspects of our universe remain a complete mystery. If I could have the answer to one and only one question, it would be, What happened in the first millionth of a second after the big bang? From this knowledge I would surely gain insight into why and how our universe came to be. Our understanding is lacking, not because the question is too difficult to answer but because our current knowledge is limited. It might not even be possible to answer the question with any certainty since we cannot test our theories with observations or experiments prior to that extraordinary event. But we should certainly continue our quest to understand more about our physical universe, our origins and our destiny.

What cosmology has taught us over the past hundred years, and in particular over the last decade, has allowed us for the first time in history to predict how our universe will evolve in the future. Philosophers have long struggled to explain the meaning and purpose of life. I would like to consider this topic within a broad scientific context that encompasses some of our collective global knowledge, from physics and cosmology to neuroscience and biology. I want to take you on a remarkable journey of discovery that allows us to understand our place in the universe, how the universe evolved to yield conditions hospitable for the development of life, and how those conditions are becoming ever harsher and more inimical to life, until ultimately... well, at this point I refer you to the latter part of this book, which deals with our future.

The long-term survival of the human race rests on a systematic quest for knowledge and discovery especially during the next few hundred years. I can only dream of the findings that will emerge over the next millennium, let alone over longer reaches of time. It is, in principle, possible for our species to survive and to continue living on Earth for about another billion years. Probably no longer than this, though, for reasons that will become clear after I explain how the Sun evolves with time and eventually dies.

What is left to be learned to enable us ultimately to answer the question, Why? We can describe matter and energy, gravity, space and time with equations, yet at the deepest level, our understanding of all of these fundamental components of our universe is rather limited. I would like to illustrate one of the pinnacles of human achievement with a one-sentence summary of the theory of general relativity by Albert Einstein: "Time and space and gravitation have no separate existence from matter." What an insight, a unified description of gravity as a geometric property of four-dimensional space-time—the brain child of perhaps the greatest scientist in history. But there are still some fundamental things left to understand. For example, the description of how particles behave in time and space is given by the theory of quantum mechanics, about which American physicist Richard Feynman said, equally succinctly, "I think I can safely say that nobody understands quantum mechanics." Quantum mechanics and general relativity are separate theories that describe the very small and the very large. During the early universe, everything was squeezed into a tiny volume, and under these conditions quantum mechanics and gravity were important on the same scale. Thus, if we are to understand further back in time towards the instant the universe appeared, we will need a "grand unified theory" that combines all the fundamental forces of nature, including a unification of quantum mechanics and gravitation.

Before going any further into the workings of our universe as we understand it at this moment, let me digress into the story of human history that shows the path by which we accumulated that knowledge. The timeline of evolution and comparison to other species will reveal our place in the scheme of things on Earth. I will also lay the foundations for perceiving what our civilisation and our minds might truly be capable of. Let us take a look at how we got this far. How did we manage to figure out that the world could be comprehended? At what point did some people begin to discard mysticism, gods and spirits and to explain natural phenomena as a consequence of cause and effect?

Let us divide human history into several eras based on the rate of acquisition of knowledge, perhaps the most important trait and commodity of an advanced civilisation. The first phase of human history lasted for several million years in which our ancestors spent most of their time as hunter-gatherers. The second great era began around 30000 BC, when art and music appeared and modern *Homo sapiens* started to explore the world both physically and mentally. Agriculture and settlements proliferated from about 10000 BC. The first burst of scientific discovery followed, beginning in earnest with the ancient Greek philosophers and scientists in 1000 BC and culminating in a million scrolls of knowledge shelved in the great libraries of Alexandria. This first remarkable period of intellectual innovation ended with the beginning of the Roman Empire around 100 BC, at which point a long period of scientific listlessness set in. Human attention turned instead to conquest and battle, and law and order. Religious idealism flourished. Interest in the physical world was crushed and suppressed, only to be awakened in another burst of brilliance in the seventeenth century, which constituted the second age of scientific discovery.

Twilight: 3 Million–30000 BC

The first evidence that our distant ape-like ancestors walked upright on two feet can be seen in bipedal footprints preserved in volcanic ash in Kenya. These steps were taken several million years ago by the Australopithecines. The hominid species had emerged and was similar in physical form and appearance to modern humans. It slowly evolved and branched into distinct but closely related subclasses over time, including *Homo neanderthalensis* and, finally, *Homo sapiens*. One of the first Neanderthal skulls to be discovered was found in the Neanderthal valley near Dusseldorf, just three years before Charles Darwin, in 1859, published *The Origin of Species by Means of Natural Selection* (alternately titled *Preservation of Favoured Races in the Struggle for Life*).

In this famous study Darwin wrote "Although much remains obscure, and will long remain obscure, I can entertain no doubt…, that the view which most naturalists entertain, and which I formally entertained—namely, that each species has been independently created—is erroneous." Darwin goes on, species by species, to discuss his ideas and thoughts. His book reveals that his ideas stemmed from the complex interrelationships that he observed between species. He writes about pigeons and domestic animals, of plants and flowers. The idea of evolution by natural selection was profound. Curiously, Darwin avoids discussing the origin of humans in this book but treats the topic at length in *The Descent of Man* (1870), a two-volume work in which he proposes that man may have evolved from apes.

At that time, the lineage of missing links—that is, the fossil record—had not been discovered. In fact, Darwin's ideas were based on speculation, not evidence, and were far from a complete or proven theory. Much of his evidence for man's descent from apes was complete nonsense and based on the differences between Europeans and the "savages" of Africa and Australasia who "could not count above four". In *The Descent of Man* he wrote: "Judging from the hideous ornaments, and the equally hideous music admired by most savages, it might be urged that their aesthetic faculty was not so highly developed as in certain animals, for instance, as in birds." He would, he noted, "rather be descended from monkeys than the barbarian savages of Africa and Australasia." However, his instinct was correct:

the final words of his book read: "Man still bears in his bodily frame the indelible stamp of his lowly origin."

Around 200,000 years ago, *Homo sapiens* appeared in Africa and began to diverge rapidly from the rest of the animal world. All of the branches that led to our species became extinct, except for modern humans, who are left as the only living species in the *Homo* genus of bipedal primates in Hominidae—the great ape family. The human DNA record shows that we actually diverged from Neanderthals almost half a million years ago. Nevertheless, *Homo neanderthalensis* and *Homo sapiens* did interbreed shortly before Neanderthals disappeared (just before the end of the last period of great glaciations, between the Palaeolithic and Mesolithic eras), and a small percentage of the genetic record of Europeans and Asians was contributed by Neanderthal relatives. Interestingly, Neanderthals were taller, stronger and had larger brains than early *Homo sapiens*, yet they developed very little advanced behaviour beyond tool making and were not a communal species.

The first renaissance in human intelligence began around 30000 BC, at which time something happened to make humans start to use their brains and begin to think. The rate at which they acquired skills and knowledge exceeded that of any other life form on Earth. Art, music, social order, agriculture, writing, science, philosophy and engineering all developed at a breathtaking pace, culminating with the work of the Greek philosophers, who questioned the origins of life, the atomic structure of matter and even the nature of stars and civilisations beyond their own. The foundations of modern humans had truly begun.

Why at that time? Why *Homo sapiens*? Throughout its 4.5-billion-year history, Earth has experienced numerous cataclysmic events, such as giant asteroid impacts and dramatic climate changes. But there have also been long periods of climate stability lasting millions of years. Many species have been present on Earth for much longer periods than *Homo sapiens*, yet they did not develop our mental skills. The other extant great apes, our genetically close relatives, show many traits of human intelligence, such as the use of tools and symbols, mourning and ritual, empathy and self-awareness. But we are alone in our ability to understand the natural world and to exploit its natural resources to benefit our existence and to propagate our species. What was it that led to the rapid creative development of our species? The answer is as yet unknown. Evolution appears to halt once a species finds a stable niche. Ants provide a telling example. Millions of years ago, they developed skills similar to those of early humans, such as farming, social order and communication. Yet they have barely evolved since.

Evolution together with natural selection through inheritance of favourable traits has given rise to an extremely diverse assortment of life on the planet that is interdependent in many different ways. However, the average lifetime of a mammalian species is only about one million years. Entire genetic lines disappear when they become unable to adapt to changing conditions or lose out in the competition for resources with another fitter and better-adapted species. Of all the species that have ever existed on Earth, it is estimated that over 99 percent are extinct. Indeed, evolution follows a haphazard and non-optimal path. Each step in the chain is based on small differences from the previous step while at the same time incorporating the legacy design of parents. Eventually, a species can become so different that it bears little physical resemblance to its distant ancestors. But its architecture still contains remnants of its distant past.

The evolutionary biologist Richard Dawkins describes the laryngeal nerve of the giraffe as a striking example to show that animals still exhibit remarkable evidence that they (and we) descended from fish. This particular nerve connects the larynx to the brain and controls the breathing and swallowing of all animals as well as the sounds that they make. In a giraffe the nerve stretches all the way down its long neck, around its heart and back up to its throat. This is a four metre journey that could be made in a few centimetres by simply travelling directly from the larynx to the brain. Similarly, in humans this nerve passes from the brain all the way down to the chest and back up to the throat. The reason for this unnecessarily long path is because the nerve originally evolved in fish. It took the shortest journey from their brains to their gills, and their gills lie near their hearts. As species evolved, necks became longer and so did the nerve, but it still took the long route around the heart. An intelligent designer would at some point have stopped and rethought this scheme to optimise it. There would have been no need to design a nerve ten times longer than it needed to be. The laryngeal nerve shows how evolution must deal with the body plans left behind by previous generations.

Evolution thus does not necessarily represent the optimum path for the survival and advancement of life. Species evolve in a fashion similar to new releases of a computer program, which has to maintain and provide support for older versions. Computer operating systems often become clumsy and slow because they are overloaded with outdated support for old components that are rarely used and have been superseded. Life evolves step by slow step, generation by generation, striving to improve its design for survival and reproduction while at the same time maintaining support for body parts that may have been essential in the past. It cannot just start afresh. Most new branches of life die out; others may survive for millions of years. Sometimes, legacy products are just partitioned off, such as the appendix, which has no apparent use nowadays and is thought to be a relic of a digestive tract. Other body parts can be put to alternative use, such as a penguin's wings, which are no longer used for flight but instead have slowly evolved to aid underwater swimming. An advantage of artificial life over biological life is that it could optimally design and construct its next-generation state. It could start afresh and fill each new machine with a completely original operating system specifically designed for its brand new host.

So why have humans developed so far and not dinosaurs, dolphins, ants or elephants? Did humans just get lucky?

From what we know of evolution, it is not surprising that we share much of our genetic composition with other animals; over 90 percent of our DNA is identical to that of a chimpanzee. However, the small difference in DNA compared to the large difference in our mental capabilities appears to be extraordinary. As our distant ancestors moved from the trees to the plains and developed a diverse and easy-to-acquire diet, for millennia humans evolved as nomadic hunter-gatherers. They began to use their brains beyond the day-to-day tasks of survival, eating and reproduction. They developed the capacity to communicate more efficiently, to plan in advance, to see the benefits of social organisation, to co-operate and to solve problems.

Some information for the basic behaviour of animals is thought to be passed down genetically since brains seem to emerge with pre-encoded algorithms that keep hearts beating and tell lungs to breathe. However, most of our skills and actions are based on knowledge that we must learn, beginning with our time in the womb and for many years after we are born. Our advancement owes itself to our brains being able not only to store and process our learned knowledge but also to think creatively and come up with new ideas and insights. Those rare inventions and ideas that change society and the course of human history often originate with a solitary individual. If we look back over the past 3,000 years, for which we have a good documented record of human achievement, we find that it is the steady accumulation of knowledge combined with the exceptional insight of one person that leads to sudden important advances in culture or scientific understanding. A genius can change the course of history much more than the actions of the average masses. A list of unique people would include household names from among the ancient Greeks—Archimedes, Aristotle, Democritus and Euclid—continuing with great intellects from the seventeenth century onwards, such as René Descartes, Galileo Galilei, Isaac Newton and Einstein. Such people are extremely unusual.

However, the creativity of such minds is based on the accumulated knowledge that is the product of generations of previous scholars. It would have been impossible for Newton to have deduced general relativity and derive the same equations as Einstein. Likewise, Einstein could hardly have conceived all the mathematics and principles of physics that he needed to formulate his theories. He made a massive leap when he linked gravity, space and time, but he could not have done it without the groundwork of earlier scientists. Prodigies, too, are constrained by their surroundings and the store of human knowledge available.

Progress also requires a critical mass of population to drive it. A few hundred or even a few thousand members of a species living together are less likely to produce and nurture a genius. Indeed, the number of cultural traits in chimpanzee communities correlates with the number of females in the population: Female chimpanzees use tools more frequently than the males, they spend more time with their young and they transfer novel cultural traits from other communities. Since new discoveries are based on older knowledge, major advances could not occur until humans ended their hunter-gatherer lifestyle and began to establish permanent settlements. Once those settlements became large enough to connect and communicate with each other, ideas and knowledge could be shared and built on. Progress is a runaway process, but it required the invention of a few basic tools. One of those was controlled fire.

The first undisputed evidence for the systematic use of fire dates back about 200,000 years, although it may be as old as a million years. Fire pits and fragments of burnt chards of bones and clay heated to over 600 degrees centigrade have been found in Africa, Europe, Asia and China, showing that the use of controlled fire was already widespread among hominids one hundred thousand years ago. Genetic change can take place on a timescale of just a few thousand years. We know this from looking at how humans have adapted to recent dietary modifications, such as the consumption of animal milk and the consequent development of lactose tolerance, and how specific genes have developed to cope with a new diet of grain resulting from agriculture. Our brain is only 2 percent of our body weight, but it uses over 20 percent of our energy resources. It has been argued that certain cooked foods were easier to digest and gave a richer source of calories, allowing the brain to develop further and increase in size.

Perhaps it was a combination of nurture and nature that led to our unique progress within the animal world. Humans developed the ability to grow food and store it through hard times, thus preventing starvation and death. They were able to pass information from parent to child, down through generations, allowing the continuation and accumulation of knowledge even through periods of harsh environmental changes or natural disasters. Climate change, giant asteroids and other extreme events wiped out entire species in a very short timescale. If a species were not completely decimated, an existing population could still be damaged to such an extent that it would revert back to instinctual knowledge alone. The difference with *Homo sapiens* was that they could maintain their societies, at least in a basic form, as well as pass on existing knowledge through periods of hardship.

The development and complexity of language points to its origin in Africa some 50,000 years ago. Most languages are formed from about 40 distinct sounds, or phonemes. However, recent research by New Zealand biologist Quentin Atkinson showed that the number of phonemes in different languages decreases the further away from South-West Africa the language is spoken, consistent with the idea that the complexity of a language correlates with its age. English has 45 phonemes, while Hawaiian (at the far end of the human migration route out of Africa) has only 13. The San bushmen of Namibia have lived as hunter-gatherers for as long as records exist, and they use over 100 distinct sounds in their language, including a variety of click noises. They are the focal point of the highest phoneme count, implying that Namibia and surrounding regions could be the place from where *Homo sapiens* migrated outward. The world map of language complexity follows the migration pattern of humans and is remarkably similar to the world map of human genetic diversity, which is also highest in South-West Africa. The DNA of the Bushmen shows a divergence from the rest of humanity that split off some 70,000 years ago.

Perhaps it was this early development of language and social organisation that enabled our species to survive through global natural disasters, such as the enormous volcanic eruption that took place 70,000 years ago at Lake Toba in Sumatra, Indonesia. The explosion had a magnitude of M8 or “mega-colossal”, which is at the top of the volcanic explosive index. It created a huge caldera larger than the area of London, and ejected 3,000 cubic kilometres of molten magma into the atmosphere, covering Asia in 15 centimetres of ash. In some places in India the ash was up to six metres deep. The resulting volcanic winter lowered the Earth’s mean surface temperature by several degrees, resulting in a 1,000-year cold period followed by the last great ice age. Evidence for these colder temperatures comes