Science Series: Science in the Cross Hairs

There's much to be embarrassed about in the continuing acrimonious debate between some in the religious and science communities. Too often these squabbles degenerate into debates where scoring points trump listening and learning from others with differing perspectives. This divide was never more on show than with the highly public debates and campaigns led by Richard Dawkins and his ilk on one side and some in religious communities who see science as an invasive species of ideas, which threaten their beliefs. For those looking for that kind of debate, this is the wrong series for you.

This series represents a highly selective look at Science – in six one-hour sessions. That's enough time to highlight hot topics in Science and Engineering (Science's partner) such as (1) ***Ripples in Space-Time: Chirps from the Merger of Black Holes***, (2) ***Artificial Intelligence (AI): Implications for Health Care, Government, Science and the Arts***, (3) ***Gene Editing: Upending Natural Selection***, (4) ***The Effects of Emotional Deprivation, and Starvation on the Development of the Brain***, (5) ***The Origins of Humans: Fossil and DNA evidence***, and lastly (6) ***The Origins of Cognition and Altruism: A continuum from animals to humans***.

What I hope to bring to this series is a better understanding of how science and engineering work, what constitutes evidence and when and how science sometimes gets it wrong: the last for which recent highly publicized studies on gravitational waves serves as a poster child. The series works better in a seminar format rather than a series of lectures. That's why the sessions were designed to use a table around which everyone can be part of the conversation. The material will be posted on the parish website a week before each upcoming session and will include a short summary at the beginning and a series of short essays to flesh the material out. A few excellent, short videos from the New York Times may help to illustrate some phenomena such as gravitational waves and black holes.

The series poses important implications for faith communities and the wider community, as well as for most scientists who, because of the very nature of their work, live in narrow ideological and cultural silos, as indeed the rest of us do, within our communities. Here a little perspective helps: We live on one ordinary planet, in one of billions of solar systems within one galaxy, itself one of trillions of galaxies, in one universe, which might well turn out be one of many universes. That perspective, and the whole notion that 4 billion years of natural selection (and sexual selection) as the engine of evolution, might be up-ended by one species, us, in this century, are staggering perspectives, and food for thought.

This series is designed to expand our horizons, help us understand the implications of recent scientific discoveries and how science works, and among its many triumphs, sometimes stumbles big-time. It's all food for thought and worth a moment to talk about.

The series begins on Tuesday, April 17 at 2pm in the Niagara on the Lake Library and continues for the following five Tuesdays
William F. Brown

Introduction to the Science Series 2018

The idea for this short series on Science in a small-group format designed for the public has been one of my goals for several years. Why? Because despite widespread interest in science and engineering triumphs such as landing rovers on Mars, new fossils found which might fill in a few gaps in our history as a species or ringing alarm bells about potentially lethal new viruses or superbugs, there's little public interest and literacy in Science among the public. There are many reasons for this gap between Science and the public but for starters, lets begin with the scientists.

By nature and training most scientists are poor publicists for their own work, never mind Science. With the exception of some of the fossil hunters, most seem congenitally unable to explain the '*why, how and significance of their work'* in language, which catches the imagination and interest of the public. One look at the publications they write to satisfy their peers and editors, and the reason is obvious.

Most high-profile science articles are barely decipherable to all but those few scientists working within a relatively narrowly defined field within Science. Try browsing through original articles in high profile journals such as Science or Nature these days – and they're the good ones – and you'll get my point. It's not simply that scientists often employ terms and manners of expressing themselves, which are unfamiliar to the general reader, even to those with a background in science, but the composers of those articles and their journal editors assume their readers have at least a passing familiarity with the subject. That may have been true in Charles Darwin's day, when most general readers would have understood much of what he wrote, but is certainly not the case with modern day scientists working in physics, especially particle physics, chemistry and much of modern day molecular biology and genetics.

Einstein may have been the most iconic and well-known scientist of the 20th century, but even Einstein had trouble explaining special and general relativity to the public and more than a few scientists – even in physics! The same holds true for that other physics icon of the twentieth century – Stephen Hawking – who in a series of cleverly written books for the general public, tried to educate his many lay fans and admirers who simply couldn't get their heads around concepts such as 'space-time' and black holes – this despite his many artful illustrations and his simplistic analogies, I suspect that most of those books were never read, or read, were dropped after a few pages and relegated to the pile of, 'it would be really nice to understand this stuff – just not today'. To which impulse I often subscribe, because without understanding the underlying mathematics, its really very difficult to grasp the concept of general generality and nearly impossible to understand particle physics and its many mysterious particles and bizarre phenomena such as the fact that particles millions of light years away from one another appear to be in lock-step or 'entangled', as the physicists put it, with one another. Sometimes headlines in leading newspapers and programs such as CNN highlight an advance in science such as the moment two years ago when Professor Higgs's elusive particle – the so-called god particle – was finally shown to exist forty years after he suggested it should.

But understanding how the Higgs particle was found and the significance of the finding are whole other matters. The task involved accelerating invisible particles around a gigantic particle accelerator at near light speed, smashing them in to one another millions of times and analyzing the results with the aid of artificial intelligence (AI) computer systems employing complex algorithms to catch the ephemeral Higgs particle, before they morphed in trillionths of a second, into other particles. This success story in particle physics was a triumph of a gigantic machine – the multibillion dollar Hadron particle accelerator in Switzerland – the hard work of teams of hundreds and even thousands of physicists, engineers, mathematicians, statisticians and others from around the world – and a computer smart and fast enough to spot the fleeting event enough times to convince everyone involved that the Higgs particle must indeed exist.

Just describing their achievement in a few words is exhausting but also bewildering to the lay public, unfamiliar with the underlying principles and tools used to spot the particle. Some wondered what the whole exercise was about – given the billions of dollars required to carry out these studies. Yet physicists tell us that without these particles and the mass they impart to other particles, there would be no universe, and no us! Here is the perfect illustration of the dilemma – we have to believe that Higgs and his many colleagues in particle physics were correct in their hypothesis and the subsequent findings, which supported the hypothesis. But no layman to the disciplines involved can hope to understand how they got there except in the most general way – and that includes me. So there is an element, if you like, of trust that what scientists tell us is true.

The scope of the series

In such a short series such as this it's obviously impossible to cover Science – Science is far too broad for that. It would take a whole undergraduate course to cover Science in any meaningful way. And in any case, I'm hardly qualified to speak for Science as a whole. What I've chosen to do rather is to hone in on a few selected topics, which in my opinion stand out, either because they pose important issues for the public, now or if not just now, the near future. Those topics include gene editing, and artificial intelligence or AI, as it is more popularly known. Other topics include perennial favorites such as the story of how humans evolved and social intelligence in apes and humans. Yet others are interesting for their own sake such as using genomic data to track human migrations. In each case I intend to use at least one primary source to give participants a feel for how scientists go about their business. In the later choice, I've taken a page from my Oxford days when I served as an advisor for a unique undergraduate course in Physiology. Unlike most undergraduate courses in other universities, which tried to cover everything, this one focused on the hundred most influential papers of the last fifty years. So the students were in at the deep end right off but soon learned from the very best mentors, the authors of those original papers, what went into their work – the questions asked, the methods chosen to answer the questions and the analysis and critique of the results – topped off by replicating the original studies in the laboratory to give participants a real sense of the technological challenges faced by the original investigators and the limitations of their methods. Of course replicating studies was possible in only about a third of the studies. But by the end of the year the students had acquired an unrivaled grasp of the most influential key studies in neurophysiology – a much better experience than working through information gleaned from lectures, texts and reviews. It was an approach I tried to continue with postgraduate students throughout my career. Oxford had one important advantage, there was a very good chance that the students would have the opportunity to meet and more importantly question those key authors – such was the traffic of high quality scientists through Oxford in those days. Well we can't do that, nor can we replicate any of the studies we're about to examine, but I hope that at the end of this series everyone will have acquired a better feel for the nature of Science, some of the key players and an appreciation for what we don't know as much as what we do know.

References and sources

With a few exceptions, most of the primary references I've used for this series came from the journals, *Nature* and *Science*, two of the leading journals, which continue to cover a wide swath of disciplines in science. These two journals have what's been called a high impact factor – that is material published in these two journals is amongst the widest read and highest standard in the world of science. However even these two Journals cannot begin to keep up with the volume of high quality material published these days and the splintering of science into so many special disciplines served these days by their own specialty journals.

For the lay public and not a few scientists, articles published by *The New York Times* are a very helpful way to stay up to date with areas covering everything from biology to astrophysics. The articles written by science writers of the Times are of an especially high standard because the writers highlight important new developments, sometimes before the original articles in high impact journals hit the press and the writers consult the authors as well as other highly respected scientists in the field to get a feel for the significance of the new study, including any reservations or contrary opinions concerning the study. Other helpful sources for a lay public include *Scientific American* whose articles are usually authored by highly qualified scientists aided by the editorial staff of Scientific American. Yet other very useful sources include books written by experienced science writers, or better yet the scientists themselves for the general public. The latter are especially useful because the books provide the author with the space to expand on their work and the work of others in the field.

Good ideas, not so good ideas and reproducibility in Science

John Kirwan (2017) ***It's good to have lots of bad ideas: Science is all about sorting the wheat from the chaff says John Kirwan***, Nature, 548, 24 August, Page 491

This article in Nature (2017) goes a long way to explaining the challenges and missteps in Science. *John Kirwan* is professor Emeritus at Bristol University in the UK and an experienced rheumatologist and scientist, many of whose articles were widely cited. He recounts a dictum attributed to the two-time Nobel Laureate, *Linus Pauling*, by *Francis Crick*, which states, "that if you want to have good ideas, you must have lots of ideas and learn to throw away the bad ones." *Professor Kirwan* went on test the dictum by reexamining his own career record. What he found was that he, "had spent about two-thirds of my effort on projects that never produced a published paper" … " And, "of all the project ideas I started, only 25% ended up with one (or more) publications."

"It was a relief to find that, on average, I had spent more time working on each of the ideas that turned out to be publishable than on those that were not. It became clear that once I did have a good idea, I worked on it a lot. Indeed, the correlation between the output from a project idea and the proportion of work I put into the project was high, at 0.73, which did not reflect my good intentions. But it was a surprise to find out how long it took for some of these papers to hit the press: for half the projects, there was a gap of more than 4 years between the idea and the publication of the first paper. For some, the interval was 8 or 9 years. … It looks like Linus Pauling was correct. Thinking and testing ideas that do not work out is not a waste of time and effort – it is an integral and necessary part of successful research. "

J. Lithgow, Monica Driscoll and Patrick Phillips (2017) ***A long journey to reproducible results***, Nature, 548, 24 August, Pages 387-388

This paper chronicles the difficulties different laboratories experience in coming up with the same results even though they supposedly used the same methods. However the devil is usually in the details; even the tiniest differences in methodology often make all the difference. This was never more obvious than with the long list of trials purporting to show that one or other natural product extended the lifetimes of life forms as diverse as nematodes and mice.

On a more humorous note, *Frans de Waal*, a primatologist, pointed out that in one study of cognition in chimpanzee, the results seemed to vary without rhyme or reason. That is until the investigators noticed that the results were fairly predictable on all days except one, the day when one particular technologist was in charge. It turned out that she constantly fidgeted and played with her hair, behaviors which distracted the chimpanzees from their task. When someone less distracting replaced her, the chimps' performances became highly predictable, every day!

Scientific American (2017) ***Reason on the Ropes***, October Issue

> Katharine Hayhoe, as told to Jen Schwartz, ***The Roots of Science Denial: It has nothing to do with science***, Pages 66-68
> Brooke Borel, ***Message Control: Scientists are trying new ways to win over a skeptical public***, Pages 68-70

Perspectives

Middle Land: Michael Shermer, Richard Dawkins – and Bill Brown

My book, *Perspectives*, was intended to expand our horizons about how we see the world we live in. Among the hurdles of coming to a larger understanding of where we fit in the world is the issue of scale. *Richard Dawkins* and *Michael Shermer* expressed the challenge this way.

"One of the reasons human perceptions so often prove wrong is that we evolved in what evolutionary biologist Richard Dawkins called *Middle World* – a land midway between short and long, small and large, slow and fast, young and old. Out of alliterative preference, *Michael Shermer* called it *Middle Land*. In the *Middle Land of space* our senses evolved for perceiving objects of middling size – between say, grains of sand and mountain ranges. We are not equipped to perceive atoms and germs, on one end of the scale, or galaxies and expanding universes, on the other end. In the *Middle Land of speed*, we can detect objects moving at a walking or running pace, but the glacially slow movement of continents (and glaciers) and the bogglingly fast speed of light are literally impenetrable. Our *Middle Land Time scales* range from the psychological 'now' of a few seconds in duration to the few decades of a human lifetime, far too short to witness evolution, continental drift, or long-term environmental changes. Our *Middle Land numeracy* leads us to pay attention to and remember short-term trends, meaningful coincidences and personal anecdotes. The result is that we don't see the stuff off the scales of our perceptions. For the everyday, we focus on what we can see with our eyes, hear with our ears and feel with our touch. But much beyond the limits of our eyes, ears and touch, we're literally 'out of touch'. And making things worse, in the forth dimension – time – we're preoccupied with the present moment. Even the immediate past of minutes and hours ago, tends to fade quickly from view and memory - the more so as we age."

My Comments

Unlike other species we have options, which allow us to expand our reach beyond what we see with our eyes, hear without our ears and touch what is at hand. For example, by employing sophisticated telescopes such as the *Hubble telescope* and Hubble's land and space-based successors, it's possible to see back to within the a few hundred thousand years of the Big Bang 13.8 billion years ago. But there's a catch: the *cosmic background radiation* left over from the Big Bang blocks light and other wavelengths in the electromagnetic spectrum, effectively cloaking events from our eyes, from immediately following the Big Bang to approximately three hundred and eighty thousand years ago.

That was until recently. Building on Einstein's speculation that anything as large as the Big Bang must have created ripples (waves of expansion and contraction) in space-time, scientists set out to build a device sensitive enough to pick up those *Gravitational Waves (GW)* ripples in space-time created by, for example, black holes. They succeeded. Late last year (2015) those scientists were rewarded by unambiguous evidence that showed that the merger of two black holes over one billion years ago created GWs that were detectible by Earth based devices. Hopefully in the near future, similar

GWs dating back to the Big Bang will be detectible. Such work would open the door to discovering just what happened in those first few, incredibly violent, trillionths of a second following the Big Bang, and possibly what might have generated the Big Bang in the first place.

Then on the altogether different scale of subatomic particles, the Higgs particle speculated to exist by *Professor Peter W. Higgs* over forty years ago was conclusively proven to exist by a huge international team of scientists employing the giant particle accelerator at CERN in Switzerland. Without the Higgs particle, no mass in the universe, and without mass, no Universe and no life – that's how key that discovery was. For this work Higgs and *Francois Englert* shared the Nobel Prize in 2013. Then just last year, *Arthur McDonald and Takaaki Kajita* showed that the neutrino, a tiny ephemeral particle, countless numbers of which pass through us, and everything around us, every second, had mass, albeit very little. Their work led to the awarding of the *Nobel Prize in physics in 2015* to both men. These triumphs in astronomy and physics illustrate the power of humans to extend the range of what we can see at the cosmic and subatomic particle levels, well beyond our senses.

Remember a century ago, we thought the Milky Way was all there was, only to find out there were billions of galaxies out there, some very much larger than our Milky Way and that the Universe was far from a static unchanging affair, but expanding rapidly under the influence of dark energy. Then there's the very recent evidence from the Britain that there might be trillions, not billions of galaxies out there. Such a finding raises the odds of life somewhere else in the Universe considerably and well beyond the several thousand potentially habitable planets found so far. All that in one century!

There's the whole question of time to deal with; is time fixed or relative? In the world we inhabit day-to-day, time marches forward in a highly predictable fashion measured out by the wristwatches we wear and the clocks in our homes, offices and cars. And so it was in Newton's world. But everything changed in 1905 when *Einstein* made the startlingly proposal that although the speed of light was fixed, time was not. He showed that counter to all our experience and intuition, time was anything but fixed – time was relative to the speed with which we're traveling. True, whirling about the earth at thousands of miles an hour in the space station for several weeks might shave a few seconds off your time relative your earth-bound colleagues but there's so sense such a miniscule change might be important in our daily life. We would be wrong. The fact that time is relative to speed (and mass) is important for those of us who use GPS navigation systems where precision depends on taking account of the relative speeds and timing of signals from the several satellites on which those GPS calculations depend on for their accuracy.

Beyond the dazzling world of physics and astronomy these days is the even more intriguing and complex world of molecular biology, genetics, and evolution. Life on Earth may have begun a little more than 3.8 billion years ago: hatched perhaps in deep-sea vents by mineral-rich waters percolating through myriads of crevices in the nearby rock to which natural proton pumps may have provided the energy to make organic compounds including the earliest self-replicating molecules such as RNA and other building blocks for life. Metals embedded in the rock such as iron and nickel may have served to catalyze the whole process. Later those prototype rock-bound cells, acquired membranes and the where-with-all to maintain a stable environment within their cell walls. And once those early membrane-bound cells formed, they were free to move beyond their rocky hatching grounds and evolve into single cells such as Achaea and bacteria.

But don't be fooled. Those simple looking living Achaea and bacteria or their fossils, which we peer at under the microscope today or embedded in ancient rock, may look simple but they're highly evolved. Despite similarities in their appearance, the genomes of these two families of single cells differ widely from one another. Yet it took the two families, Achaea and bacteria, working together, to launch complex single cells over a billion years ago and later, assemblies of those evolved complex cells to form into multicellular organisms eight hundred million years ago. The whole scientific story of the emergence of life and subsequent evolution into extraordinary complexity and diversity and the relatedness of all life, so evident at the genetic level, is incredible and a story scarcely hinted at less than two centuries ago.

For the most part humans live in the present – preoccupied with the events and demands of the day and less often, what's coming. Its true that we sometimes fret about the future and ruminate about the past but for most of our time we're preoccupied, like other mammalian species with the here and now. On a longer scale we behave as if our species is fated to continue much as it has in the past and that even if, as individuals, we may not be immortal, our species is.

Here the archeological and more recently genetic records, suggest a very different future for our species. Looking back, the archeological record strongly suggests that modern humans were preceded by a complex array of closely related ancestors, whose specific anatomical and cognitive traits evolved in response to environmental changes. All but one, Homo sapiens, is long gone. The last of our archaic ancestors to depart the scene was *Homo neanderthalensis* 30,000 years ago, and 17,000 years ago *Homo floresiensis* (*hobbit man*). Looking forward its hard for this writer to think that our species will prove any longer lasting that our ancestors, given that evolution based on natural selection continues to mold our species in response to environmental factors and gene editing is in the wings.

Looking beyond natural selection, the recent introduction of precise gene editing techniques such as *CRISPR-Cas9* and its analogues promises to shakeup evolution. The latter makes engineering the human genome a certainty within this decade, whatever the angst shared by many over the potential risks associated with the technology and however many and passionate the demands may be to rein in the technology. For beyond commendable efforts to engineer fixes for many genetically transmitted diseases lies the prospect of changing human traits such as height, physique, and especially and most alarming to many, cognition.

Cognition and behavior are complex and probably depend on the interplay of hundreds, if not thousands of genes. That very complexity poses a hurdle, if not an insurmountable one, to gene editing. Working out which genes play key roles in cognition and behavior is the first hurdle. The second is to edit the genome to incorporate those genes in their right places to effect the desired cognitive and behavioral traits. *CRISPR-Cas9* may work well for editing single genes but inserting hundreds of genes poses a challenge on an entirely different level. Its not as simple as inserting the desired genes because some genes have multiple functions and insertion of those genes might well be associated with unanticipated and undesirable consequences as might be other surprises awaiting those determined to alter the genomes of humans and other life forms.

Adding to the complexity of cognition and behavior is the fact that the development of the brain is also powerfully influenced by culture and education, especially early in life. The underlying mechanisms may involve epigenetic changes to the genome such as methylation of bases, which may turn some genes on and others off during development or later in life, and alter behavior and cognition without changing the base sequence. Recent evidence suggests that these epigenetic changes may be heritable. If so, we can now add epigenetic influences to changes to the genome itself, as possible avenues for changing traits.

It won't be easy to change cognitive powers as expressed by social intelligence, learning, reasoning, mathematics, imagination, creativity, language and artistic talents to name but a few interrelated cognitive traits. But given the trajectory of brain research and genetics these days, the barriers to changing such complex cognitive powers will likely be surmounted in this century or the next at the latest. Genetic engineering puts humans in charge the genomes of all other creatures from single cell organisms, to viruses, complex highly developed animals, and humans, and as such, is the first major threat to evolution by natural selection since life began.

The revolution in genetics returns us to the question of whether the human species will continue as is, or morph into other species, possibly genetically engineered to possess certain desirable physical and cognitive traits. Based on the past record of relentless evolution of our ancient ancestors, evidence of continued and possibly even accelerated evolution in the last 50,000 years or so and the potential for human tinkering with our genome, it's entirely possible that our species will evolve into recognizably different species within the next several hundred thousand years and maybe, with the advent of gene editing, much earlier. This poses another issue. Will our successors prove to be much brighter and creative than our species and if so, will any of the best of our best works in the arts and sciences look like child's play to our descendants? Probably.

Often older folk, and I include myself in that age group, tend to look back, more comfortable with old assumptions and content with 'as is' or better 'as was'. But I think it's better and a lot more fun to look forward, to focus on our grandchildren, and wonder about the world our great grandchildren and their descendants will inherit and create. Aside from the inconvenience and possible suffering associated with death, my biggest regret over dying is that I won't see how it all turns out a hundred, a thousand, ten-thousand, a hundred-thousand, million, billion and yes, even trillion years from now. My generation was lucky. So much has been learned in the last hundred or so years that it's hard not to imagine that trajectory continuing. Wouldn't it be great to see what's coming? Unfortunately that's not possible. But we were very lucky to be born, when we were born and in the people we've met along the way. It's been a great trip – it's just that I'd like it to continue, at least in my imagination.

Dawkins and *Shermer* were right to draw our attention to the limits of the human perspective, if we are to gain any insight about what's important beyond the momentary slice of the life we live in. That's where science comes in because in the last century, we've learned that the cosmos is far larger than we ever suspected, life probably exists in many places in that expanded universe, our time as a species is limited and most important of all - we are a part of a very much larger scheme, of which we are but a bit player and not a very important one at that. Hopefully the last perspective will temper our hubris and overreach as a species and help us to see ourselves as part of life's ecosystem, not the boss. If so, our role is to fit in, not destroy the system on which we depend for our very life.

William Brown October 15 2016, May 2017

Cosmic and Biological Themes April 30 2017

Change, creative destruction and relatedness are recurring themes in the cosmic and biological worlds from the beginning of the known universe, through to the creation of trillions of galaxies, countless planets and other heavenly bodies and all of biology.

Creative Destruction in the Cosmic World

In the cosmic world, the universe began with what's been famously called the 'Big Bang' in which, in less than a second, the universe expanded faster than the speed of light and all the elementary forces and particles, known and yet to be discovered, came into being. In short order, the simplest atomic nuclei formed after which it took more than three hundred thousand years before the expanding universe cooled sufficiently for stable combinations of electrons and nuclei to form hydrogen, helium and a tiny bit of lithium atoms.

Cosmically speaking, within the short time of a further several hundred thousand years, those very early gaseous clouds comprised mostly of hydrogen, were shaped by gravity into swirling masses and later into the earliest galaxies stuffed with stars. Many of the earliest stars were gargantuan in size – dwarfing our sun – and massive. And because of all that mass, enormous gravitational forces developed, which in turn created extraordinarily high temperatures – much hotter than our sun – enough to fuse massive amounts of hydrogen nuclei into helium nuclei and in the process generate enormous energy and yet more heat. The result was that those giant suns burned through most of their hydrogen in short order and much earlier than smaller cooler stars – before, in most cases, collapsing in on themselves under yet stronger gravitational forces and finally exploding in super novae.

The latter explosions scattered the products of the giant's nuclear-fusion furnace, including heavier elements such as carbon and iron, throughout the neighborhood of the former giant star. And in recurring similar cycles of creative destruction, successive generations of stars and some of their associated planets incorporated yet heavier elements such as gold. Recent analyses of the makeup of our sun suggest that it and our solar system are probably the product of three such cycles of creative destruction since the first stars were born in our neighborhood of what became the Milky Way with which we're now familiar.

The preceding highly-simplified overview of the life-history of the universe from the Big Bang to the present time in our neighborhood of the Milky Way illustrates two of the three recurring themes – first change and second, the recurring cycles of creative destruction in cosmos with which we're familiar. These cosmic events provide the backdrop for a similar overview of biology from the beginnings of life to the present.

Creative Destruction in the Biological World

In the biological world the equivalent to cosmic creative destruction on a giant scale are the major extinctions, the most recent of which was the impact of the giant asteroid or comet that struck just off the Yucatan peninsula in Mexico sixty five million years ago. Following which impact, roughly seventy five percent of animal and plant species were lost, including, the dinosaurs (some of which like the fearsome Tyrannosaurus Rex in museums and movies, continue to capture human imaginations). There have been several major extinctions, in the wake of the worst of which, close to ninety-five percent of species were lost. But as devastating as extinctions may be for some species – especially the most complex life forms of their day, such as the dinosaurs in their day and mammals including humans in our day – those massive extinctions also open up evolutionary niches for thousands of species who survived the extinction and were well placed to capitalize on the opportunities. Such was the case for primates who flourished not long after dinosaurs' exited evolution's stage.

Not all extinctions are major – many have been far more targeted; as happened to the North American chestnut tree in the face of the chestnut blight, an Asian bark fungus, to which the North American species of the chestnut tree proved, unlike its Asian relatives, to be very susceptible. Few original chestnut trees survive today but the introduction of genetically engineered variants, resistant to the fungus, offer hope for returning these magnificent trees to their former range, with the caveat that climate change and other environmental challenges may influence whether and to what extent, such an experiment succeeds.

Creative Destruction in the Story of Human Origins

On a larger scale, and certainly the story that captures the imaginations of humans, is the story of how we came to be as a species. It's a story of many transitional species, some of which overlapped with one another in time and even location. The story began with the common ancestor six to seven million years ago to what would become, on the one hand, modern apes, and on the other hand, anatomically and later behaviorally modern humans. Along the way there were more than twenty named species strung out over several million years whose skeletal features were sufficiently distinctive from one another for anthropologists to consider them as separate species – each one of which lasted a few hundred thousand years to, or in the case of Homo erectus, almost two million years.

The many transitional species began with small-brained, tree-climbing and dwelling creatures with limbs best adapted for life in the trees, with only the occasional foray on the ground. Later, several species variants emerged whose hip and knee joints, and foot structure were better adapted for walking and running on their hind limbs and whose shoulders, arms and hands reflected evolutionary pressures for grasping and manipulating stone tools - especially with the advent of longer, more powerful, opposable thumbs. However the brains of these otherwise skeletally evolved and varied species, remained small chimpanzee-sized affairs. Such were the Australopithecines.

Then beginning a little over two million years ago the size of the brain began to increase through a series of transitional and often overlapping species: initially by a few hundred cubic centimeters two million years ago, to sizes approximating those of modern humans several hundred thousand years ago. Along the way, other traits evolved including an increase in length of the legs, hands and forelimbs better adapted for highly skilled tasks such as creating finely tooled weapons, musical instruments such as flutes at least thirty thousand years ago and of course creation of exquisite cave art dating back at least forty thousand years in Europe and Indonesia. The latter achievements, in what in modern times we would characterize as 'the arts', strongly suggests that the requisite neural underpinnings for sophisticated symbolic oral language and thinking, and a sense of the spiritual and perhaps an afterlife, were well in place by the time of those early cave paintings and perhaps, much earlier in Africa.

Thus the whole course of human evolution beginning five to six million years ago was marked by the appearance of a variety of species, each of whose skeletal traits such as the relative robustness of their jaws and jaw muscles, the size of their molars and incisor teeth, the relative heftiness or leanness of the body build and bones and the size, and more importantly – the organization of the brain including the degree to which the two hemispheres became specialized, the relative increase in size of the frontal and temporal lobes and those regions related to language – all reflected differing selective pressures imposed by diet, environmental challenges and the growing need for enhanced social intelligence and cohesion to navigate larger social groups. And all but one of those transitional species – Homo sapiens - became extinct, as we too are slated to do if our past history is prologue to our future. Of course its entirely possible that our species, like so many before us, might evolve into yet other species shaped in turn as our ancestors were, by natural selection (and sexual selection) and for the first time in human history, by selective gene editing – all questions for the future. But whatever happens in times to come, change and creative destruction associated with the extinction of many species along the way were the order of the day throughout pre-human history. And this holds true for other species from single cells, to complex multicellular organisms such as plants and animals, and indeed all life.

Relatedness in the Cosmos and Biology

What about the other theme – relatedness – in the cosmos and biology? When I was a university student in the 1960's, physics including particle physics and Newtonian physics, organic chemistry and biochemistry seemed to live in entirely different worlds, taught by different faculties with rarely a mention of the others. These days the ice is breaking. For it has become increasingly and abundantly clear that it's hard to explain how nucleic acids, and other organic compounds relate to one another without understanding how their three-dimensional shapes and the resulting exposure or hiding of active sites, affect their interactions with other organic compounds – all of which brings biochemists into the worlds of chemistry and even physics. Of course intuitively we always knew that the separation of the various disciplines was arbitrary and that at some level, they were tightly and seamlessly related. It's just that these days, understanding those relationships has become critical to understanding biology.

Well before Charles Darwin and Alfred Russell Wallace advanced their theory of evolution by natural selection and accurate means for dating fossils were available, geological studies had already made it abundantly clear that the order of appearance of various types of fossils in ancient sea beds was practically identical around the world and that more complex fossils were among the later additions to the ancient record for life on earth. So even if the precise times various fossils appeared couldn't be pinpointed, the sequence with which they appeared was similar worldwide. Since then, highly accurate methods for dating fossils have been developed, many of which use the rates with which radioactive isotopes decay, to date the fossils or the sediments in which they were found, and for the first time offer an accurate means for pinpointing the age of fossils.

In the mid 19th century, Gregor Mendel's work on how traits such as the height and color of plants were passed on from generation to generation provided an early glimpse into what would become the molecular basis for heredity. By the late l9th and early 20th centuries heredity was linked to chromosomes. Then in the mid twentieth century Watson and Crick (and Franklin) unraveled the mystery of how information was coded in the sequence of complementary base pairs, which were at the core of that elegant double-stranded helical structure of DNA they revealed in 1953 in what was surely one of the shortest and most important papers in all of science. Others went on to show how that coded information was translated, through a series of molecular events beginning in the nucleus and later in the cytoplasm, into functioning proteins within cells.

Later studies showed when and how selected genes were turned on or off during the elaborately orchestrated sequence of development, which begins with a single cell after fertilization, and leads through a series of cell divisions and migrations, into what will eventually become hundreds of distinctive cells in complex multicellular organisms, each cell with its own job to do. Still later studies showed that environmental and cultural influences can alter the expression of genes and hence which the traits might be favored, by methylation and other means, of selected bases in genes – all without changing the underlying genome. Some of these epigenetic changes turn out to be heritable from generation to generation – again without changing the genome.

Then there are comparative analyses of ancient and modern DNA within lineages such as the last several hundred thousand years of archaic and modern human history, which helped reveal which genes might have played pivotal roles in human evolution. Yet other studies search for similarities (and differences) between the DNA of widely different life forms such as worms, fruit flies, mice and humans, and provide extraordinary insights into the surprisingly deep-relatedness of all life, the genetic-distance between different species, and how much different species share similar molecular hardware and genes required to live and pass on their genetic where-with-all to later generations, whatever their often widely differing appearances.

The foregoing studies barely hint at the pace and enormous progress of the last two centuries in understanding the relatedness of all life including the similarities among genes that govern energy metabolism, the manufacture of proteins and cellular structures, signaling between cells and protection from pathogens, however simple or complex and different their parent life forms may appear.

It turns out that on Earth at least, life probably had a common root origin and through varying combinations of chance and natural selection (and sometimes sexual selection) evolved over four billion years into the riot of life forms from single-celled organisms such as bacteria to highly complex creatures such as mammals. It is the enormous progress in genetics and molecular biology which provides the strongest common thread through this labyrinth of life – and the message is clear at the molecular - if not so much the morphological level – that all life is deeply related – it's all just a matter of successive common ancestors and shared genetic and other molecular building blocks accompanied by a series evolutionary wrinkles along the way.

Cosmic and Biological Constants

While it is true that that change and creative destruction are recurring themes in the cosmic and biological worlds, so are certain constants. Elements may yet be discovered to fill out the periodic table but there's no evidence and no reason to expect that the atomic building blocks and their underlying particles or the constants, which govern our universe will change or differs anywhere in the universe, as we know it. All bets are off of course when it comes to the possibility of other universes and the possibility that the universal constants which govern them might differ from those operating in our universe - should there turn out to be other universes, as some theoretical physicists suggest. But at least in this universe some fundamental things remain the same with the exception of the earliest moments in the creation of our universe before those elementary forces and particles came into being – although what was present before that Big Bang is a total mystery.

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The Limits of Science

In my early days in neurophysiology, budgets were small. Many worthwhile projects were carried out on shoestring budgets by today's standards, including Nobel Prize winning efforts such as *Hodgkin and Huxley's* studies on conduction of the nerve impulse and *Watson and Crick's* work on the structure of DNA, arguably the most influential study in biology in the twentieth century. Much was to change in the next few decades.

The new norm in astronomy, particle physics, and neuroscience has become very expensive, collaborative and often, international projects involving multiple complementary disciplines and many scientists. We have only to look at the search for the Higgs boson to see how expensive these projects can be. Hundreds of scientists and engineers from around the world were involved in the design, construction, and operation of the *Hadron particle accelerator in Switzerland*. Other examples include the *Kepler telescope*, which among other things was tasked with looking for planets that might meet the conditions for the emergence of life, and the network of land based radio telescopes under construction in South America and the Antarctic designed to look back to the origins of the universe. In neuroscience, huge projects touted to have the potential for finally understanding how the brain might work and costing hundreds of billions of dollars were recently launched in Europe and the United States. Long gone are the days when a few investigators, working with limited budgets and tools they often built themselves, were capable of mounting and sustaining major scientific projects. But there is a cost to bigness. However worthy and necessary those big expensive projects may be, they tend to drain resources from promising young scientists with innovative hypotheses but without the clout to secure the support they need.

There are other problems with modern science. In some areas such as particle physics, the low-lying fruit of major discoveries on shoestring budgets such as most of Einstein's work may be gone and further discoveries of similar value and impact may be much harder to achieve without the commitment of massive resources. There is another problem especially with cosmology and astrophysics that's potentially more serious for the credibility of both and science in general. That is the tendency these days to make startling public claims based on incomplete data and before there has been rigorous peer review. *Jan Conrad* reminds us that this happened recently with the claim that neutrinos exceeded the speed of light, claims about the nature of dark matter and most dramatic of all, the claim that evidence for gravitational waves dating back to the *Big Bang*, has been found in the pattern of the *Cosmic Background Radiation* (Conrad J (2015) *Don't cry wolf* Nature 523, 2 July Pages 27-28). All proved to be false or at the least with respect to the gravitational waves, unverifiable because the data on which the claim was based on artifact. This tendency to premature claims and public hype reflects the high stakes game that some areas of science have become.

Yet another serious problem, looms over the future of physics and by extension, the rest of Science. Up to now, scientists have insisted that every theory must be verifiable by experiment. That's why so much attention was given to experimental challenges to Einstein's theory of relativity over the last century. After all, his equations led to some startling predictions. They predicted that gravity could bend light waves and so doing, could act as a gravitational lens to see galaxies hidden behind other galaxies, that the universe was expanding and must therefore have begun in a singularity (though Einstein was slow to acknowledge) and that ripples in the fabric of space-time (*gravitational waves*) would exist. Each of those predictions has been tested and, based on experimental evidence, has been proven correct or very likely true. These days however we may be at a threshold, where experimental confirmation of theories such as *Supersymmetry* by which theoretical physicists predict that all particles have a partner, effectively doubling the number of particles, may be extremely difficult, if not impossible to prove with the Hadron collider or any up scaled successor, because the particles are too small.[1] Similar thresholds may exist for brain research where because of the number of nerve cells and their connections are so huge, working out how the brain thinks and feels may be beyond the talents of any group of neuroscientists, however clever they may be.

One of the central claims of science has always been that findings can be replicated using the same or better methods. But who has the resources or time to mount serious challenges to evidence that required so much investment in time and money in the first place? Who is going to build another collider on the scale of the European one anytime soon?

There may also be limits to human imagination, innovation, and cognitive powers, which, without enhancements to the human brain, may limit our capacity to solve problems in science. The Nobel laureate in physics, Steven Weinberg suggested just such a stumbling block:

[1] Frank A, Gleiser M (2015) *A Crisis at the Ede of Physics* The New York Times, June 7, Page SR5

"We may… run out of intellectual resources—humans may not be smart enough to understand the really fundamental laws of physics. Or we may encounter phenomena that in principle cannot be brought into a unified framework for all science."[2]

Given the interdisciplinary nature of science these days, any personal limits in training and perspective might well be offset by collaboratively working with others with differing but complementary skills. Even so, there must be limits to the capacity of humans to solve nature's mysteries. Perhaps we're seeing such a roadblock in our inability to resolve the physics of Newton and Einstein with the quantum physics of Planck, Bohr, and Heisenberg.[3]

Science is becoming more specialized and that presents other problems. For example, in the 1980s when I was in London, Canada, several of us with an interest in neuromuscular disease attempted to put together a study group on the nervous system and muscle. They included clinicians who regularly saw patients with various neuromuscular disorders, exercise physiologists, pathologists, anatomists, and physiologists with an interest in how the brain initiated and controlled movement. We hoped that participants would be interested in what others with differing backgrounds and perspective were doing, given that we shared interests in muscle and the nervous system. We could not have been more wrong. Each published their work in their own subspecialty journals where similarly blinkered individuals vetted their work. The only one in the group able to bridge the gaps between the various interest groups was a senior neurophysiologist old enough to remember a time before the field began to split into its various sub-disciplines. The situation is much worse now. It's akin to people walking in one of those formal gardens with high hedges that divide them from one another. They might well share similar interests and questions, but unable to see each other's perspective because of the hedges that divide them, they pass by one another, unaware that someone nearby might be able to help them solve a problem they've been wrestling with. They might even have the answer to someone else's question.

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[2] Weinberg S (2015) *To Explain the World: The Discovery of Modern Science.* Harper Collins, Page 268

[3] Crease RP, Goldhaber AS (2014) *The Quantum Moment: How Planck, Bohr, Einstein, and Heisenberg Taught Us to Love Uncertainty.* W.W. Norton & Company New York

Sometimes reputations are made and other times broken. Debates within the scientific community can be bitter, but in the end, the only thing that counts is the evidence. Should cracks appear in the hypotheses, it's time to regroup, rethink, and start over. Perhaps new and better tools emerge, for example more refined methods for measuring the age of fossils or better telescopes, and science must be rewritten. *Steven Weinberg* reminds us that science depends on verifying theories with "impartial experimental tests of their predictions" and that "science is cumulative, each new theory incorporates successful earlier theories as approximations, and even explains why these approximations work, when they do work."[4] In these few words, *Weinberg* gets to the heart of science. Scientists must subject their ideas and hypotheses to rigorous testing. If a hypothesis should stumble in the face of strong evidence to the contrary, it's time to rework or even ditch it. This is what sets the scientific mythology apart from so many other creation mythologies.

Science doesn't live in laboratories, but in every human's experience. Any time a human imagines an idea, whether it's space-time or a better arrowhead, in the end it is the fieldwork and the evidence that counts. That is what sets science apart from other human endeavors such as religion and philosophy, which seldom subject themselves to the same kind of rigorous review. The scientific mythology will certainly change, perhaps even dramatically, in the coming decades, but the underlying method that made it possible will remain unchanged. What's distressing to many is that the scientific mythology, while offering stunningly beautiful and awe inspiring views of the cosmos and life, offers little personal comfort to those in personal need. In its stead, the modern cosmic mythology suggests that all life on Earth will be extinguished in a few billion years and billions of years later, the rest of our galaxy and others will follow suit. The idea that we are a very small part of the universe is hard for most of us to grasp or accept. Weinberg's perspective is that, "*We simply do not find anything in the laws of nature that in any way corresponds to ideas of goodness, justice, love, or strife, and we cannot rely on philosophy as a reliable guide to scientific explanation*."[5]

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[4] Weinberg S (2015) *To Explain the World: The Discovery of Modern Science.* Harper, An imprint of HarperCollinsPublishers, Page xiv and xv

[5] Weinberg S (2015) *To Explain the World: The Discovery of Modern Science* Harper, An imprint of HarperCollinsPublishers, Page 45

Gravitational Waves August 31, 2017

Two Perspectives

"What science tells us is that we are but one of hundreds of millions of species that evolved over the course of 3 and ½ billion years on a tiny planet among many orbiting an ordinary star, itself one of possibly billions of solar systems in an ordinary galaxy that contains hundreds of billions of stars, itself located in a cluster of galaxies not so different from millions of other galaxies in an expanding cosmic bubble universe that very possibly is only one among a near infinite number of bubble universes"

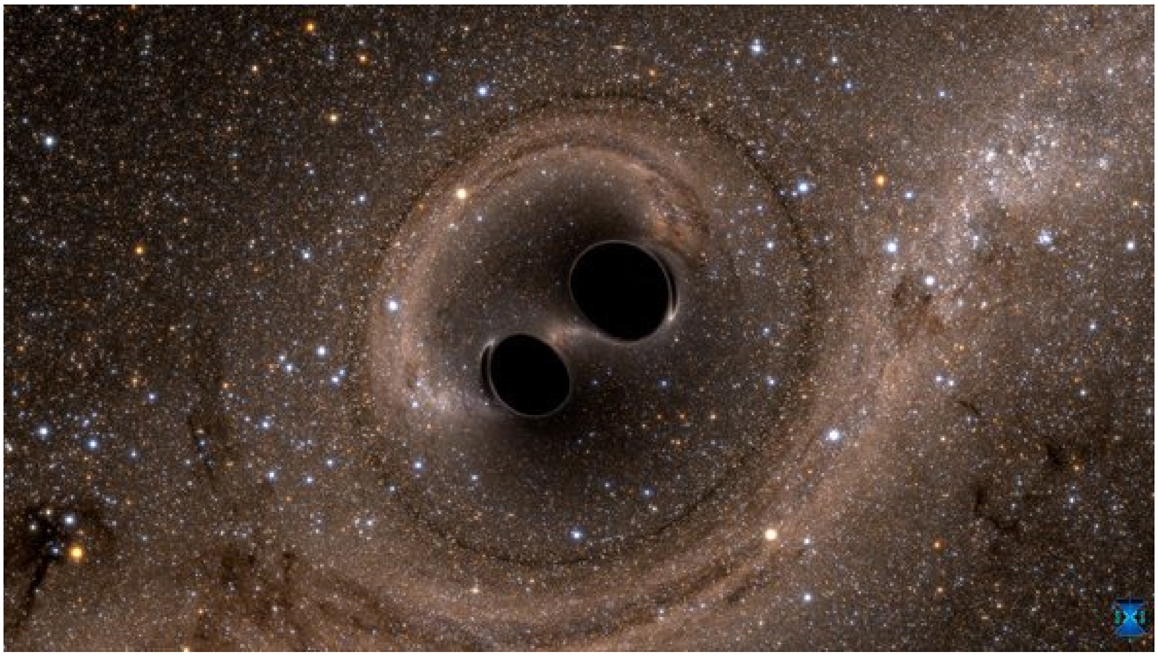
Michael Shermer from "*Why Darwin Matters*"

"One of the most poetic facts I know about the universe is that essentially every atom in your body was once inside a star that exploded. Moreover, the atoms in your left hand probably came from a different star than did those in your right hand. We are all, literally, star children, and our bodies are made of star dust."

Lawrence M. Krauss from "*A Universe From Nothing*"

Forward

Einstein's equations governing his crowning achievements in physics – first ***Special Relativity*** in 1905 and ten years later ***General Relativity***, incorporating gravity and the effects of acceleration into relativity – were gifts that kept giving for the next hundred years and beyond. Why? Because in 2015, the merger of two nearby black holes one billion years ago, each with a mass many times that of our sun, generated ***gravitational waves (GW)*** which though weakened by time, were still detectible by devices designed to be sensitive enough to pickup those faint ripples, while isolating the devices from any earth-made vibrations to avoid artifacts.



Merger of two black holes – NYT 2017

That's stunning if only because nothing like ***black holes*** were imagined in 1915, and gravity was very much thought of as an attractive force - much as we think about and experience gravity every day on Earth and Newtonian physics describes. However through a series of now famous thought experiments, Einstein reimagined gravity and specifically gravity's relationship to space and time. It took ten years of exhausting work, some mistakes along the way, and struggles with mathematics before he managed to put together a coherent series of equations to express in mathematical terms his concepts of gravity and space-time.

In Einstein's cosmos, space and time were linked as ***space-time***. In his model of the universe, masses such as our Sun, warp space-time, through which in the case of our solar system, planetary bodies such as Earth fall and rotate about the Sun: while maintaining their orbits through frictionless space by maintaining angular velocities sufficient to keep them from falling into the Sun. No need for an invisible gravitational force here, orbits and apparent attractions between heavenly bodies simply reflected mass induced changes in the shape of space-time and all else literally fell into line. The hypothesis was elegant, the equations to those who understand the math, beautiful, and the results stunning.

Even so, Newtonian physics is sufficiently accurate to land rovers on Mars and send satellites deeply into space to orbit planets in the outer reaches of our solar system. It's when speeds approach light speed that Newton's predictions break down in weird ways. For example in Einstein's world of general relativity, the faster we go in a space ship, the slower clocks run relative to home base and the greater the mass of the space ship and everyone on it become. Indeed the increase in mass becomes so massive that travel faster than the speed of light becomes impossible. But perhaps what puzzles and fascinates most people about relativity, is that time itself, is relative and influenced by mass and speed – indeed time stops at light speed in an imagined space ship. That may not be an everyday issue on Earth but differences between clock-speeds in satellites and earth-based devices must be taken into account in calculating GPS coordinates or those coordinates might be off by as much as several miles. That's a big error and a cogent reminder that time is indeed relative!

That mass was capable of bending light was clearly shown by ***Sir Arthur Stanley Eddington*****,** whose observations of a total eclipse of the Sun in 1919 revealed that light emanating from stars behind the sun were bent around the Sun to the precise degree predicted by Einstein's equations for general relativity. His evidence that Einstein was right after all caught headlines around the world and cemented Einstein's growing reputation as a genius. Further proof came later in the late twentieth and early twenty-first century when images taken by satellites such as the Hubble telescope revealed that, because of the 'lensing effect' of massive galaxies, sometimes its possible to see light emanating from star systems and galaxies otherwise hidden from our eyes by those intervening massive galaxies. Stellar lensing was yet another of Einstein's predictions, based on relativity, which, like GWs, were shown to be true, long after Einstein's death in 1955.

Gravitational Waves

Einstein's equations for general relativity, suggest that major events such as the collapse of giant stars into ***supernovas*, **their much bigger cousins called ***kilonovas***, produced by collisions between two *black holes* or possibly between *neutron stars*, and of course the ***Big Bang*** itself, may trigger a series of waves of expansion and contraction in space-time – or what's been called Gravitational Waves (GWs). The trick was to develop devices sensitive enough to reliably detect those waves billions of years later. For several decades physicists and engineers wrestled with the challenge without much success – that was until last late 2015, when two complementary detectors, one stationed in ***Hartford, Washington*** and the other in ***Livingston Louisiana*** finally detected the 'chirp' associated with the passage of a GW passing through each of those detectors.

The design of ***LIGO***, the ***Laser Interferometer Gravitational Observatory***, was based on the same template at each site. Each detector was L-shaped and consisted of two arms, each 2.5 miles long enclosing a vacuum through which a laser beam was shot, beginning at the junction of the two arms, and traveled down the arm, to be reflected by a mirror at the end of the arm and return to the mirror at the hub of the two arms. If the two arms are precisely the same length, the light beams from each arm should cancel one another out when they return to the hub. However if the arms should differ in length because of the passage of a GW, even by as little as a fraction of a proton, the signals will fail to cancel one another out and some of the signal will escape to the detector.

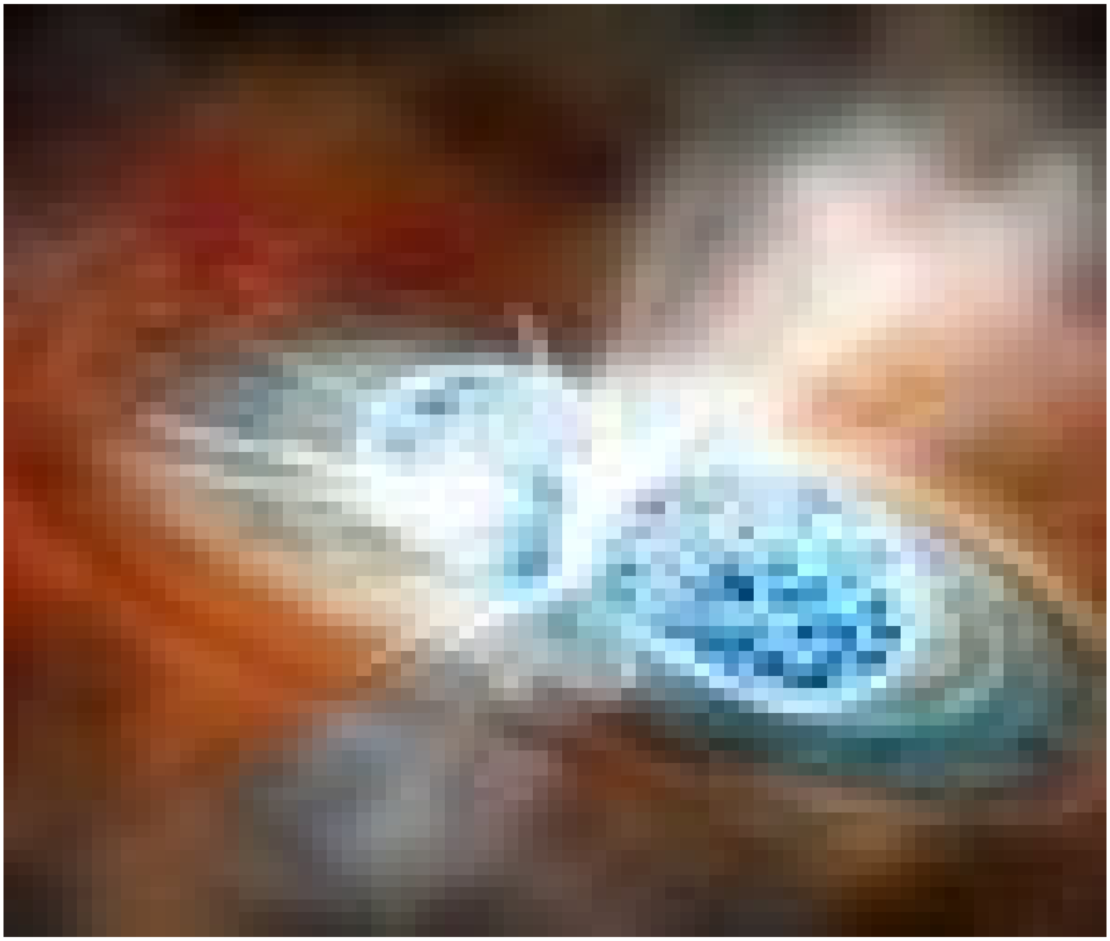
The underlying hypothesis was based on the assumption that a passing GW was likely to strike the two arms differently, lengthening one while shortening the other, and thus the reflected returning signals from the arms would fail to cancel one another out and some of the light would strike the detector and produce the signal. So it happened and such was the rigorousness with which the team weeded out false signals, that the team was able to report that they had indeed, for the first time, detected Einstein's long predicted GWs. But there remains the problem of finding the source of the GWs in the universe, given that a single detector site looks at roughly half the universe.

That's one of the reasons why two LIGO devices were dispersed, given that is was unlikely that the same GWs would strike the two sites in quite the same way. Two geographically dispersed devices provided a two-dimensional hint about where the waves might be coming from but what are really needed are three or more dispersed sites to better triangulate the source. The return of the Italian LIGO device after servicing was just in time to triangulate and locate the merger of two neutron stars (see below).

Overall the challenge was immense – to build a very sensitive device, sensitive enough to pick up what was left of gravitational waves beginning billions of years ago – but free of any earthbound sources of vibration in the system which might produce false signals. That was a huge challenge. Since then, the same *LIGO* system has detected other mergers of black holes and with upgraded sensitivity covering a much wider bandwidth should be able to pick up many more black holes in the universe.

Importance of forward planning and funding

But there was another challenge. Mounting a study such as *LIGO* requires long-term planning and steady funding from government agencies with other calls on their purse. Fortunately in this case, as the *Editorial Board of the New Times* and *Jeffrey Mervis* pointed out (see references below), *The National Science Foundation (NSF)* showed the necessary foresight for identifying worthy science projects and supporting them well into the future, beyond the serving terms of most of the decision makers. The subject matter may have been obtuse to the public and those managing the public purse, but these projects pay off in advancing the frontiers of Science well into the future and that's what *The National Science Foundation (NSF)* recognized. The same type of long term investment and imagination are key these days to other gravitational wave detectors in Italy and others under development in China, India and Europe including placing three very sensitive detectors widely separated from one another to precisely triangulate the source of the gravitational waves and give space and ground based telescopes a place to look.



Merger of Two Neutron Stars NYT 2017

Then two months ago the roof was blown off astrophysics when gravitational waves were detected, not from the collision of black holes, but the merger of *Neutron stars*, the densest bodies the universe, with densities the equivalent of the mass of Mt. Everest packed in a teaspoon (*Dennis Overbye (2017) LIGO Detects Fierce Collision of Neutron Stars for the first time, The New York Times, October 17*). This collision not only set off GWs detectable at both US sites but Italy as well and a spectacular explosion picked up by space-based Satellites including *Hubble* and other devices designed to pick up an intense burst of radiation accompanying the explosion. Stellar explosions (*kilonovas*) such as this one are of such gigantic magnitude that they can generate the fierce heat required to create some of the heaviest elements in the periodic table such as gold, silver, platinum and uranium, which then become scattered throughout that region of the universe, to be incorporated in new budding stars and planets.

The Future

GWs promise to change the face of physics. They're an idea tool for detecting black holes some of which are gigantic – possessing masses, which exceed by many millions, if not billions of times, the mass of our sun, and were born within that first second following the Big Bang. Some physicists suggest that black holes, especially the gigantic ones, because of their mass, shaped the formation of whole galaxies and collections of galaxies in the early universe and may be the missing dark matter. Maybe so – but we won't know until other, more sensitive, gravitational wave detectors come online. Its all very amazing – to me at least.

Footnote

In 2013, the *BICEP2 study group* reported that they had found evidence of gravitational waves traceable back to the Big Bang based on what they considered were telltale swirl-like ripples in the *cosmic background radiation (CBR)*. Their achievement received a lot of public attention and celebrations at such high profile institutions as *MIT* where staff and visitors speculated freely about upcoming Nobel awards in honor of the achievement. However all was for naught and had to be retracted when the *Max Planck Institute* revealed that the so-called telltale ripples were no more than 'noise' created by cosmic dust. There were plenty of red faces all around and retractions by the same editorialists in leading journals within a few months (see references below). The whole experience was a salutatory reminder that even the best scientists sometimes get ahead of themselves in their understandable enthusiasm, especially when reputations might be made.

Fortunately all may not be lost for plans are afoot by hundreds of scientists employing telescopes in Chile's Atacama desert and the South Pole, supported by the *National Science Foundation (NSA)* and the *Department of*

Energy (DOE) in the United States to reexamine the *Cosmic Background Radiation (CBR)* left over from the Big Bang looking for evidence of those telltale wiggles created by gravitational waves created by the Big Bang and evidence that the earliest universe initially expanded exponentially (cosmic inflation). Their efforts reported in 2014 failed to show such evidence because of the background noise created by stardust. However this time round they hope that by combining the findings from more telescopes located far apart from one another that they will be able to confidently detect the finger prints produced by gravitational waves in the cosmic background radiation (*Adrian Cho (2017*) *Microwave background teams mull a grand unification: United effort would aid search for signs of cosmic inflation*, Science, 357, 29 September, Page 1339). We'll see.

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How to Make a Black Hole

LIGO Hears Gravitational Waves Einstein Predicted

Peering Into a Black Hole

Black Hole Inch Ahead to Violent Cosmic Union Jan 7, 2015

Out There I Einstein's Telescope

Birth of a Star Dec 18, 2014

Out There I Raining Free

Astronomers Watch a Supernova and See Returns Mar 5, 2015

LIGO Detects Collision of Neutron Stars Oct 15,2017

The Big Bang and Evolution JULY 1, 2017

Extrapolating backward from evidence that the universe is expanding, there must have been a moment when what would become our universe, was both incredibly tiny and dense. Some physicists have likened this to a quantum singularity – without any of the elementary forces such as the weak and strong forces, the electromagnetic force, gravity, dark energy, the inflationary force, and bereft of all but the elementary particles (except possibly strings). But whatever existed before the 'Bang' must have been energy - an incredible amount of energy - equal to or exceeding all known and unknown energy sources in the universe, including Dark energy plus the energy-equivalent of all the mass in the universe. Given that Einstein showed us in that now iconic equation, $E=mc^2$, that energy and matter are interchangeable; that's a lot of energy packed into a tiny space.

Then - for reasons unknown – perhaps a moment of quantal instability – within the unimaginably brief time of trillionths of trillionths of a second – what became the universe inflated exponentially, expanding faster than the speed of light. And within those first seconds, all the elementary forces: the strong force, the weak force, the electromagnetic force and gravity appeared, accompanied by a dizzying array of particles including the building-block of atoms such as protons and neutrons (in turn made up of quarks and gluons), electrons, the Higgs particle, gravitons, and neutrinos, and whatever other particles might underlie dark matter and other particles yet to be discovered. These particles and their opposites – antiparticles - and the fabric of the universe, called space-time, all appeared in a flash and probably had their origin in some, as yet mysterious, common quantal ancestral field. It was a moment, perhaps the only moment in the Evolution of our universe, with the possible exception of black holes, when the quantal world of the 'small' and world of the large – general relativity – were probably united in a common origin.

The early universe was incredibly hot – much hotter than the core of our sun – so hot that protons couldn't capture electrons and photons of light were trapped in a highly charged sea of oppositely charged particles, unable to escape, leaving the universe dark for more than three-hundred thousand years. Toward the end of that long dark period, the expanding universe cooled sufficiently for protons to capture electrons, and form the first atoms (hydrogen and to a much smaller extent, helium and a tiny bit of lithium) and allow some of those trapped photons of light to escape and create what was discovered to be the Cosmic Background Radiation (CBR), detectible over

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thirteen billion years later as microwaves and radiating from all points in the universe to this day.

That very brief initial push from inflation insured that the universe was remarkably uniform in all directions, but fortunately for us, not completely so. Had the universe been completely uniform, there would have been no slight differences in the distribution of those primordial gases necessary for gravity to sculpt those gases in the early universe into collections of spinning gas, from which whole galaxies and stars and later planets would eventually form and without which our Milky Way, Sun, Earth, we and the rest of the universe would not be.

The inflationary period of the universe's early expansion was so violent that it created ripples in the space-time fabric of the universe. Einstein's equations for general relativity predicted that anything as violent as the Big Bang should create such ripples in space-time or what are called gravitational waves. However Einstein thought that they would be too small to detect billions of years later.

Maybe so in Einstein's day but recently gravitational waves created by the merger of two black holes over one billion years ago were detected in the United States. Its only a matter of time before tweaks to those gravitational wave detectors and the development of more sensitive detectors under construction in Europe, the US, India and China, should be able to detect gravitational waves dating back the first moments following the Big Bang, unlike earth and space-based telescope, which are designed to look for signals within the electromagnetic spectrum. The latter signals were unable to escape the intense heat and sea of charged particles that prevailed within the universe for the first three hundred and eighty thousand years, which followed the Big Bang – leaving a major gap in our understanding of the early universe – a gap hopefully soon to be closed by studies of gravitational waves.

But there's more to the story. Current theoretical models and evidence for the Big Bang suggest that there may have been many big bangs and many more to come, creating the theoretical, if not proven possibility that there might be many alternate universes, new universes budding from older established universes and possibly created by the quantal transformation and collapse of gigantic black holes. So, possibly, black holes or something like them might be birthing places of new universes.

Most galaxies including our own Milky Way have black holes near their center, which however large they appear, are probably much too small to spawn a new Big Bang and universe. Hypotheses suggesting that there might be multiple universes are natural predictions from Einstein's general relativity and quantum physics. Perhaps our universe began with a truly massive black hole, much larger than any black hole found so far in the universe.

Some physicists suggest that the universe and possibly other universes, go through a cycle beginning with a 'Big Bang', followed in turn by a very brief period of hyper-expansion created by inflation, followed in turn by a period of slowing up to about 10 billion years ago in the case of our galaxy after which dark energy kicks the universe into an accelerated period of expansion (the period we're in now), following in turn by a period of gradual slowing expansion and finally a trillion or so years later ending in a period of collapse in what's been called the great crunch and the possibility of the formation of another quantal singularity. And so on to the next Big Bang: maybe – but for now that's a huge guess.

Physics has come an enormous way in the last century. After all it wasn't so long ago that most thought our Milky Way was it and a very stable affair at that. But in less than a century we've come to realize that there are trillions of galaxies out there and probably trillions more, which are too far away to see because even at light speed, the light they emit moves too slowly given the enormous distance that light has to travel, for us to see - ever.

The story of the Big Bang is the cosmic equivalent in biology of searching for the common ancestor of all life, and the countless series of common ancestors for what became separate species among the kingdoms of plants and animals. Unfortunately, like our medieval ancestors who felt the earth must be at the center of the solar system and by extension the universe, as they knew it, we make the mistake of assuming that humans are the central player to which all of evolution has worked since life began. We could not be more wrong.

Like our archaic ancestors, our species time on earth is limited – perhaps two million years at best and quite possibly much shorter, to be followed by extinction of our species and with any luck the appearance of cleverer descendants. But there are no guarantees on that score. And in the shorter term, tectonic shifts, and major climate changes including repetitions of ice ages before us, will surely re-sculpt the lands and waters and profoundly change the look and feel of the world we live in, with scarcely anything we've built surviving the change.

We live on one small planet, serviced by a middle-aged and sized sun, in a universe with trillions and trillions of stars and many more planets. Some of those planets might contain intelligent life, the equivalent or possibly exceeding our own but living so far away, that short of warp-speed, they're out of reach. Recently seven rocky earth-like planets, possibly with liquid water on board, were found circling a much smaller and cooler sun compared to our sun, too far away to get to in a lifetime of travel even at light speed. Mind you some physicists believe that travel at light speed might become feasible within the next century, and if so, planets such as these are especially tantalizing, given that similar small, cool suns are far more numerous than bigger suns such as ours – making the odds that extraterrestrial life exists much higher than anyone dreamed of ten years ago.

But short of finding life within practical get-to range, for practical purposes we're stuck on our 'red dot'. This makes us uniquely responsible for looking after our habitable home in the solar system, ours and other species all that more important. That's what Pope Francis was harping about two years ago in his encyclical on the climate change what many ancient myths have been trying to tell us for much of our specie's time on earth, backed up in recent times by a wealth of knowledge in physics, chemistry, biology and other sciences. Wouldn't it make sense to listen to our ancestor's tales and the now overwhelming evidence of science?

W.F. Brown July 12, 2016

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Got gravitational waves? Thank NSF's approach to building big facilities

By Jeffrey Mervis Feb. 12, 2016 , 4:30 PM

Nobody thinks of government bureaucrats when they hail a scientific breakthrough. But **yesterday's announcement** that researchers working at the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves might never have occurred without an earlier, nonscientific development. The National Science Foundation (NSF)—a U.S. agency historically focused on funding small-scale academic research—first had to figure out how to manage the financially perilous task of building a large and costly scientific facility.

More than a quarter-century ago, physicists asked NSF to spend nearly $300 million on an instrument to measure the gravitational waves that researchers had predicted would result from a cataclysmic event in deep space, like the merger of two black holes. That was no easy sell. The project would require technological leaps and bounds that even other scientists found incredible, recalls Rainer Weiss, a physicist at the Massachusetts Institute of Technology in Cambridge, who described the original idea for LIGO in paper in 1972. "People thought we were crazy," he says.

But Weiss won the backing of long-time NSF program officer Richard Isaacson, and over the next decade the agency provided millions of dollars in research grants to advance the concept. NSF was OK with the fact that researchers didn't expect to detect such waves for more than a decade, and only after the instrument had been upgraded. But they were very concerned that LIGO, the most costly project in the agency's history, would blow a hole in the budget not just for astrophysics, but across all of NSF's physical sciences directorate and, possibly, the agency itself.

break

It wasn't an idle fear. Other federal agencies had seen the costs of big science facilities spiral out of control, wreaking havoc with their budgets, roiling researchers, and triggering harsh criticism from lawmakers.

A new account

Created in 1950, NSF had earned a stellar reputation funding basic research on university campuses. Unlike its larger government cousins, NSF didn't manage big national laboratories (like the Department of Energy), nor build costly scientific payloads for spacecraft (like NASA). But by the late 1980s some academic disciplines had begun to assert that they needed one-of-a-kind large facilities like LIGO to remain globally competitive. And they turned to NSF for help.

With a budget that stood at $2 billion in 1990, NSF had little room—and scant experience—tackling projects like LIGO. "It was crazy," then-NSF Director Neal Lane, now a university professor at Rice University in Houston, Texas, recalls about the agency's traditional approach to supporting science. "You ended up cutting grants in order to fund a big new facility."

So NSF officials conferred with their oversight body, the National Science Board, and came up with the idea of creating something new for the agency: a separate capital budget for brick-and-mortar projects. It would allow Congress to support multiyear projects without having to shrink the pot for bread-and-butter research grants. They called it the Major Research Equipment (MRE) account.

NSF sold the idea to Congress with the help of powerful legislators from states with a vested interest in LIGO—in particular Louisiana, one of two states that would host the facility, and Massachusetts, which had teamed with the California Institute of Technology (Caltech) in Pasadena to design the project.

Congress adopted the idea in 1994, just in time to handle the ramping-up of

LIGO, which was being managed by Caltech. (**Conflicts within the project's upper management** had led to a 1-year hiatus in construction, which had begun in 1992. NSF made two moves that righted the ship: approving the replacement of founding project director Rochus Vogt with Barry Barish, and appointing a new project manager at NSF to oversee operations.)
LIGO began doing science in 2002, 4 years later than initially scheduled. In 2008, NSF began building a $205 million update, called LIGO II, and completed it last year.

LIGO was the first project to benefit from the MRE account, Lane recalls. The new account also made it much easier for NSF to accommodate a 40% jump in LIGO's original cost estimate, an increase that otherwise almost certainly would have required curtailing existing programs.

LIGO's bureaucratic legacy

The MRE account has now become a fixture in NSF operations. In its early years it financed the twin 8-meter Gemini telescopes in Hawaii and Chile, a new South Pole station in Antarctica, and what eventually became a billion-dollar array of millimeter telescopes in Chile. Now, funded at a steady-state level of roughly $200 million annually, the MREFC (the words "facilities construction" were later added to its name) account this year supports work on the $344 million Daniel K. Inouye Solar Telescope, the $473 million **Large Synoptic Survey Telescope**, and the $434 million **National Ecological Observatories Network**, or NEON.

Although the account has been used mostly to build facilities in the physical sciences, the inclusion of NEON, the first project supported by NSF's biology directorate, is no accident. "The MRE account was meant to encourage disciplines to take the long-range view of what facilities they needed to stay on the cutting-edge of science," says Lane, a physicist. In 2014, for example, NSF completed construction of the $384 million **Ocean Observatories Initiative**, a global array of marine and seismic instruments. The account has also funded the recently commissioned ***Sikuliaq***, an ice-capable research vessel now working in the Arctic.

Winston Churchill's essay on alien life found

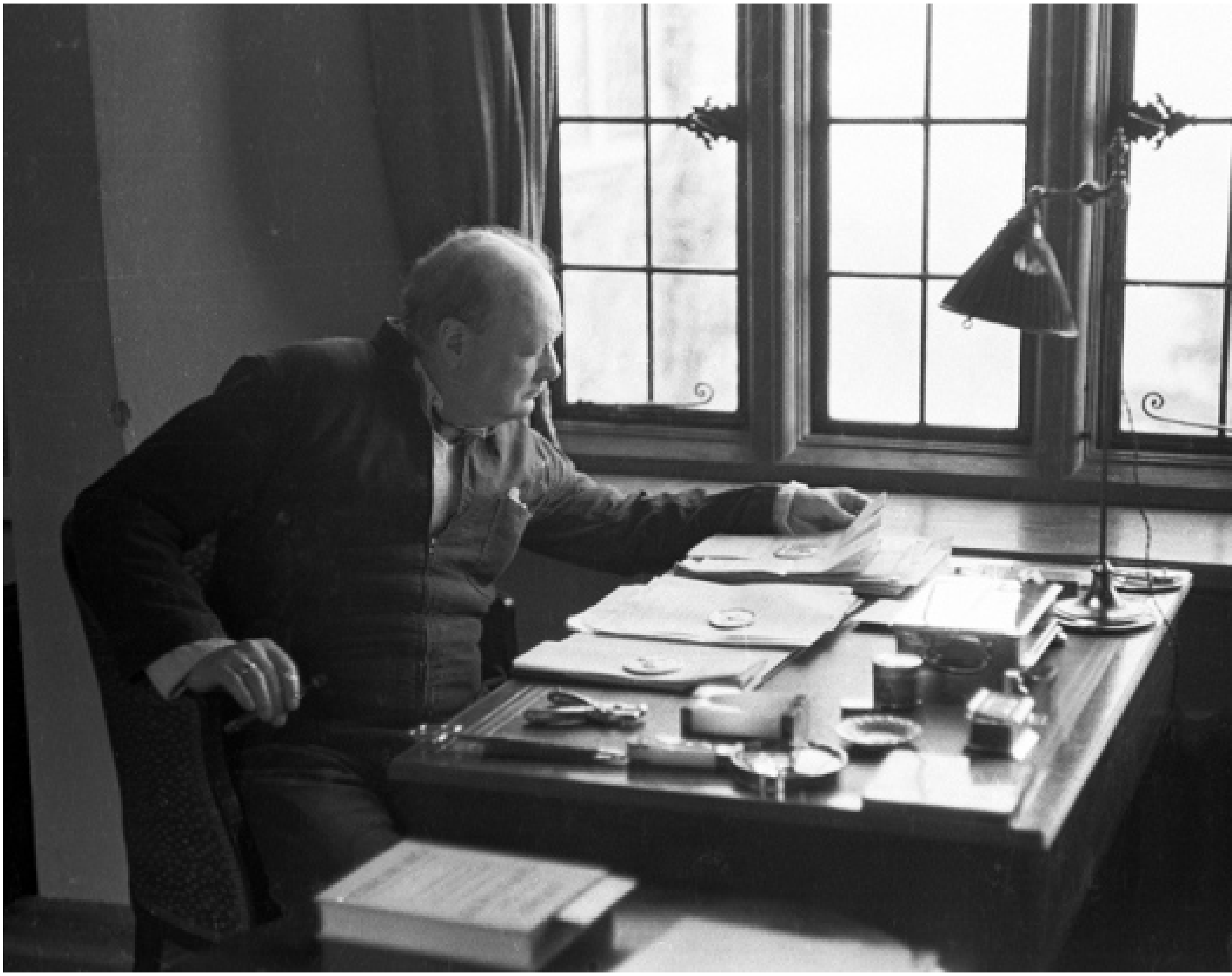
Mario Livio

Many of those projects have gone smoothly, whereas others have struggled. Just last week, a senior NSF official promised the science committee for the U.S. House of Representatives that the agency would follow recommendations in **a new report by the independent National Academy of Public Administration** detailing how NSF needs to improve its oversight of such large projects. At the same time, NSF is looking for a new team to manage NEON, which **last summer was shrunk in size and scope** after its costs soared and construction fell behind schedule.
NSF officials readily admit that building and managing large scientific facilities remains a challenge. "As we do more projects we learn," says NSF Director France Cordóva, in Arlington, Virginia.

For the moment, however, she and other NSF officials are basking the glory of LIGO's discovery. In their minds, the detection of a gravitational wave is a ringing endorsement of their decision more than 2 decades ago to get into the construction business. "The NSF likes to think of itself as the agency that can undertake high-risk, high-reward projects," says Cordova, "and this is certainly one of them."

Reporting by Adrian Cho.

15 February 2017



Winston Churchill at his desk in 1939: a prolific writer, he covered scientific topics as diverse as evolution and fusion power.

Winston Churchill is best known as a wartime leader, one of the most influential politicians of the twentieth century, a clear-eyed historian and an eloquent orator. He was also passionate about science and technology.

Aged 22, while stationed with the British Army in India in 1896, he read Darwin's *On the Origin of Species* and a primer on physics. In the 1920s and 1930s, he wrote popular-science essays on topics such as evolution and cells in newspapers and magazines. In a 1931 article in *The Strand*

Magazine entitled 'Fifty Years Hence'[1], he described fusion power: “If the hydrogen atoms in a pound of water could be prevailed upon to combine together and form helium, they would suffice to drive a thousand-horsepower engine for a whole year.” His writing was likely to have been informed by conversations with his friend and later adviser, the physicist Frederick Lindemann.

During the Second World War, Churchill supported the development of radar and Britain's nuclear programme. He met regularly with scientists such as Bernard Lovell, the father of radio astronomy. An exchange about the use of statistics to fight German U-boats captures his attitude. Air Chief Marshal Arthur 'Bomber' Harris complained, “Are we fighting this war with weapons or slide rules?” Churchill replied, “Let's try the slide rule.”[2]

He was the first prime minister to employ a science adviser, hiring Lindemann in the early 1940s. *The science-friendly environment that Churchill created in the United Kingdom through government funding of laboratories, telescopes and technology development spawned post-war discoveries and inventions in fields from molecular genetics to X-ray crystallography*.

Despite all this, it was a great surprise last year, while I was on a visit to the US National Churchill Museum in Fulton, Missouri, when the director Timothy Riley thrust a typewritten essay by Churchill into my hands. In the 11-page article, 'Are We Alone in the Universe?', he muses presciently about the search for extraterrestrial life.

More related stories

He penned the first draft, perhaps for London's *News of the World* Sunday newspaper, in 1939 — when Europe was on the brink of war. He revised it lightly in the late 1950s while staying in the south of France at the villa of his publisher, Emery Reves. For example, he changed the title from 'Are We Alone in Space?' to 'Are We Alone in the Universe?' to reflect changes in scientific understanding and terminology. Wendy Reves, the publisher's wife, passed the manuscript to the US National Churchill Museum archives in the 1980s.

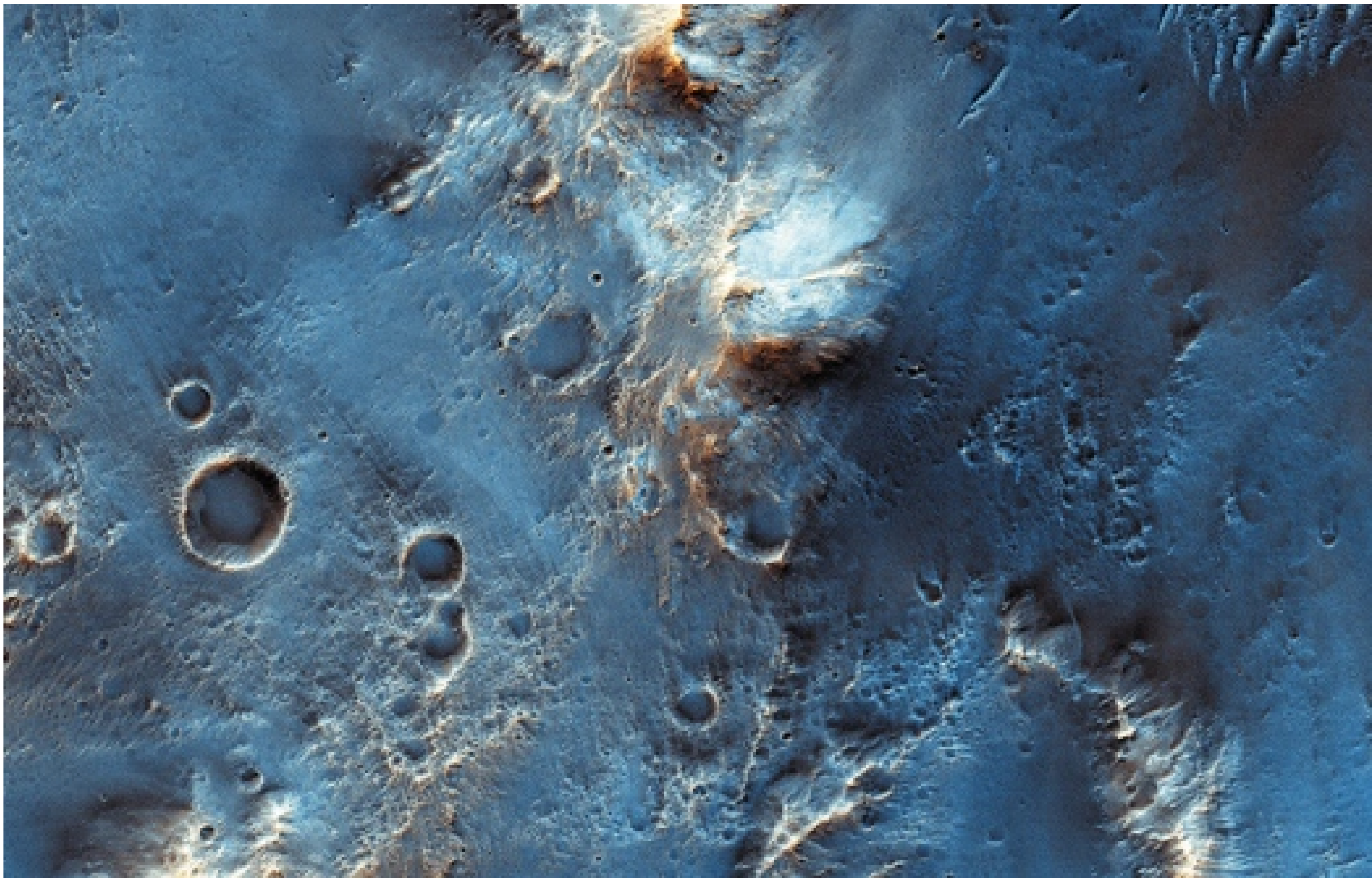
Riley, who became director of the museum in May 2016, has just rediscovered it. To the best of Riley's knowledge, the essay remained in the Reves's private collection and has never been published or subjected to scientific or academic scrutiny. Imagine my thrill that I may be the first scientist to examine this essay.

Here I outline Churchill's thinking. At a time when a number of today's politicians shun science, I find it moving to recall a leader who engaged with it so profoundly.

Modern thinking

Churchill's reasoning mirrors many modern arguments in astrobiology. In essence, he builds on the framework of the 'Copernican Principle' — the idea that, given the vastness of the Universe, it is hard to believe that humans on Earth represent something unique. He starts by defining the most important characteristic of life — in his view, the ability to "breed and multiply". After noting that some viruses can be crystallized, making them hard to categorize, he decides to concentrate on "comparatively highly-organised life", presumably multicellular life.

His first point is that "all living things of the type we know require water". Bodies and cells are largely composed of it, he notes. Other liquids cannot be ruled out but "nothing in our present knowledge entitles us to make such an assumption". The presence of water in liquid form still guides our searches for extraterrestrial life: on Mars, on the moons of Saturn and Jupiter or on extrasolar planets (beyond our Solar System). As well as being essential for the emergence of life on Earth, water is abundant in the cosmos. This wonderfully universal solvent — almost every substance can dissolve in it — can transport such chemicals as phosphates into and out of cells.



NASA/JPL/Univ. Arizona

An image taken by the Mars Reconnaissance Orbiter of the Martian surface, where the search for water is ongoing.

Churchill then defines what is known today as the habitable zone — that narrow 'Goldilocks' region around a star that is neither too cold nor too hot, so that liquid water may exist on the surface of a rocky planet. He writes that life can survive only in regions “between a few degrees of frost and the boiling point of water”. He explains how Earth's temperature is fixed by its distance from the Sun. Churchill also considers the ability of a planet to retain its atmosphere, explaining that the hotter a gas is, the faster its molecules are moving and the more easily they can escape. Consequently, stronger gravity is necessary to trap gas on a planet in the long term.

Taking all these elements together, he concludes that Mars and Venus are the only places in the Solar System other than Earth that could harbour life. He eliminates the outer planets (too cold); Mercury (too hot on the sunny side and too cold on the other); and the Moon and asteroids (their gravities are too weak to trap atmospheres).

Churchill began his essay not long after the 1938 US broadcast of the radio drama *The War of The Worlds* (an adaptation of H. G. Wells's 1898 story) had generated 'Mars fever' in the media. Speculation over the existence of life on the red planet had been going on since the late nineteenth century. In 1877, Italian astronomer Giovanni Schiaparelli described seeing linear marks on Mars (*canali*; mistranslated as canals) that were thought to be constructed by some civilization. These turned out to be optical illusions but the idea of Martians stuck. Science-fiction stories abounded, culminating with Ray Bradbury's *The Martian Chronicles* (Doubleday, 1950), published in the United Kingdom as *The Silver Locusts* (Rupert Hart-Davis, 1951).

Cosmic outlook

Churchill's essay next assesses the probability that other stars host planets. He reasons that “the sun is merely one star in our galaxy, which contains several thousand millions of others”. Churchill assumes that planets are formed from the gas that is torn off a star when another star passes close to it — a model suggested by astrophysicist James Jeans in 1917, which has since been ruled out. He infers that, because such close encounters are rare, “our sun may be indeed exceptional, and possibly unique”.

Now Churchill shines. With the healthy scepticism of a scientist, he writes: “But this speculation depends upon the hypothesis that planets were formed in this way. Perhaps they were not. We know there are millions of double stars, and if they could be formed, why not planetary systems?”

Indeed, the present-day theory of planet formation — the build up of a rocky planet's core by the accretion of many small bodies — is very different from Jeans's. Churchill writes: “I am not sufficiently conceited to think that my sun is the only one with a family of planets.”

“Churchill sees great opportunity for exploration in the Solar System.”

Thus, he concludes, a large fraction of extrasolar planets “will be the right size to keep on their surface water and possibly an atmosphere of some sort” and some will be “at the proper distance from their parent sun to maintain a suitable temperature”.

This was decades before the discoveries of thousands of extrasolar planets began in the 1990s, and years before astronomer Frank Drake presented his probabilistic argument for the rarity of communicating civilizations in the cosmos in 1961. Extrapolating data from the Kepler Space Observatory suggests that the Milky Way probably contains more than a billion Earth-size planets in the habitable zones of stars that are the size of the Sun or smaller[3].

Reflecting on the enormous distances involved, Churchill concludes that we may never know whether such planets “house living creatures, or even plants”.

Bigger picture

Churchill sees great opportunity for exploration in the Solar System. “One day, possibly even in the not very distant future, it may be possible to travel to the moon, or even to Venus or Mars,” he writes. By contrast, he notes, interstellar travel and communication are intrinsically difficult. He points out that it would take light some five years to travel even to the nearest star and back, adding that the nearest large spiral galaxy to the Milky Way (Andromeda — one of the “spiral nebulae”, as he calls them) is more than several hundred thousand times as far away as the nearest stars.

The essay finishes eagerly: “with hundreds of thousands of nebulae, each containing thousands of millions of suns, the odds are enormous that there must be immense numbers which possess planets whose circumstances would not render life impossible.” Here Churchill shows that he was familiar with the findings of astronomer Edwin Hubble in the late 1920s and early 1930s, who discovered that there are many galaxies beyond the Milky Way (about 2 trillion, according to a recent estimate[4]). Taking a bleaker turn that reflects his times, Churchill adds: “I, for one, am not so immensely impressed by the success we are making of our civilization here that I am prepared to think we are the only spot in this immense universe which contains living, thinking creatures, or that we are the highest type of mental and physical development which has ever appeared in the vast compass of space and time.”

Almost 80 years later, the question that obsessed Churchill is one of the hottest topics of scientific research. Searches for signs of subsurface life on Mars are ongoing. Simulations of Venus's climate hint that it may once have been habitable[5]. Astronomers believe that, in a few decades, we will discover some biological signatures of present or past life in the atmospheres of extrasolar planets, or at least be able to constrain its rarity[6].

Timely find

Churchill's essay is testament to how he saw the fruits of science and technology as essential for society's development. When he helped to establish Churchill College at the University of Cambridge, UK, in 1958, he wrote[7]: “It is only by leading mankind in the discovery of new worlds of science and engineering that we shall hold our position and continue to earn our livelihood.”

Yet he was also concerned that without understanding the humanities, scientists might operate in a moral vacuum. “We need scientists in the world but not a world of scientists,” he said[8]. In order for science to be “the servant and not the master of man”, he felt that appropriate policies that drew on humanistic values must be in place. As he put it in a 1949 address to the Massachusetts Institute of Technology's convocation: “If, with all the resources of modern science, we find ourselves unable to avert world famine, we shall all be to blame.”

Churchill was a science enthusiast and advocate, but he also contemplated important scientific questions in the context of human values. Particularly given today's political landscape, elected leaders should heed Churchill's example: appoint permanent science advisers and make good use of them.

Nature **542,** 289–291 (16 February 2017) doi:10.1038/542289a

Brains as Social Networks

That gelatinous mass inside our skull - our brain - is what makes us special. The rest of our body is simply the supporting cast – tasked with getting us around, implementing our intentions and impulses, keeping us in touch with the world through our eyes, ears and other sensors, providing the fuel to keep the brain going and taking out the garbage. But it is the brain that does all the really interesting and important stuff like thinking, planning, loving, communicating with others of our kind and perhaps even possessing a soul.

Brains soak up language and culture with ease from parents, family and the wider community. But our brains go further. They are uniquely gifted with imagination, a proclivity for making things up and telling stories, and a positive talent for coming up with novel solutions for unanticipated and often unique challenges. But however marvelous our brains might be working is isolation, by nature humans are social animals as David Brooks (2011) might put it. Indeed without the latter we probably would not have progressed very far (Christian, 2012).

Coming up with novel solutions is usually a social exercise. That's how science and most human endeavors usually work. Bringing complementary skills together to solve problems, whatever the inevitable clashes of personalities and controversies along the way, works. How else could the Hubble telescope have been imagined, created and used without the teams of brains with widely differing skill sets and imaginative questions working together to make it all work and worthwhile?

So we often depend on the brains of others, whether we acknowledge their contributions or not, to create everything from pies to solving the deepest and most intractable questions posed by the universe and biology. Think about it – making pies requires recipes often passed on from others, ingredients, pots and pans and ovens to name a few of the many bits and pieces we need for such a relatively simple task and we didn't make any of them and usually buy the ingredients to boot!

The extent to which we depend on one another's brains – past and present – is one of our brains most unique characteristics. More than any other species – especially in recent times, we've created an explosive increase in our 'collective intelligence' the product of the activities of an enormous web of brains with the power to transform and transcend cultures. Each of our brain's catalogue of experience and expertise acquired over a lifetime dies when we die. But to the extent that some part of us lingers on in the form of stories told about us, a few photos or some small part of the stuff of our lifetime's activities survives the inevitable clean out after we die, creates a temporary hold on mortality reaching beyond the grave for one, or tops, two or three generations. And parallels the genetic legacy we passed on to our children, then grandchildren, increasingly mixed with the genes of others in future generations to the point when within a few generations, any genetic identity solely attributable to us, will surely be lost for eternity.

The role of genes is of course critical. They set the basic ground rules governing our brains development. But the final product – our brain – is shaped powerfully by our own experience and environment, especially in early life. In the year of his death, Oliver Sachs, the famous neuroscientist, reminded us that each of us is unique; there was no one quite like us before or will be in the future. We were one of a kind. Each brain then is unique, both genetically and in the manner it was shaped by others, culture, and experiences of a lifetime.

Some genes influencing the development of our brains date back, in some recognizable form, to the very beginnings of multicellular animals which evolved nervous systems for coordinating the activities of the host's organism's increasingly differentiated cell types, each tasked with their specific, now outsourced jobs. However we're a long way from identifying most of the genes responsible for our highly evolved brains, especially those, which played a major role in the development of the brains of those primates most closely related to us such as chimpanzees and closer to home, ever more sophisticated ancestors such as homo erectus or much closer to home, those brain genes which evolved since the brains of modern humans came on stage 200,000 years ago in Africa. We may have a long way to go but at least we have better tools for tackling the job of unraveling the mysteries of the how our brain came to be including comparative studies of the genomes of modern humans, our living ape relatives and some archaic humans such as the Denisovans, Neanderthals and perhaps some day yet older archaic humans, such as Homo erectus.

Modern humans have not been around for long. For ninety-nine percent of the time we were nomadic gatherers and hunters of food, lived in extended family groups – probably numbering no more 20-30 and perhaps at the most 100 – with little distinction between the tasks and experiences among members of the group.

But over the course of time we developed a vast library of communal knowledge, which allows each of us to hone in – laser like - on some tasks while outsourcing the rest to others. Which one of us has the foggiest idea or means of building a smart phone, a computer, building and maintaining our roads, growing and delivering our food, taking away our waste or any of a host of knowledge, experience and skills possessed by other brains in our community? The list goes on.

It’s obvious that our very existence depends on others. Indeed it’s not too much of a stretch to conclude that through our shared knowledge and experience that we have become a vast powerful multi-brain organism – the next step in evolution’s unintended march to ever increasing complexity.

Perhaps we’ve learned unique skills – perhaps we’re a musician, sculptor, physician, mechanic or pilot but for most of everything else in our lives we depend on others for the rest. Most of what we take for granted was bequeathed to us by countless ancestors who through language in all its forms, were able to pass on their knowledge to others and to that exponentially or perhaps faster growing library of knowledge and experience

which is ours to tap into and use without in most instances any awareness of the authors or doers that made it all happen for us. It is that increasingly powerful social network which truly sets us apart from other species and granted us our ever-increasing dominion over other life forms and threatens in some instances not only them but also ourselves through changes in our environment rivaling the worst of natural disasters.
So what are the relative roles of genetics and culture to making us who we are and become? Or to get to the nub of the matter are Dawkin's "selfish genes" or environmental influences the more important in shaping who we are and become? Well the answer is an unequivocal both. After all we have gene directed neural platforms. But absent the stimulation provided through sight to one eye or exposure to language early in life, both may fail to develop at all or with the greatest difficulty later in development. Enrichment – whether social, cultural and linguistic – are critical and have their greatest impact early in life, Moreover patterns developed early on become fixed and hard to undo later in life. There's no surprise in this. Every culture has known at some level – get them early and you've got them for life. That's why changing people's nature – to the extent dictated by family and culture - is so difficult later in life. So nurturing seed early during a period when behavioral roots are being laid down is critical and why seeking agreement between peoples of widely dissimilar cultures and identify can be so difficult and even intractable, later in life.

For example in my decade in Boston I worked at the New England Medical Center in a period when immigration from the former Soviet Union was so common. The young assimilated the culture and language of their new country effortlessly especially those born in the USA while the middle aged and elderly struggled and often gave up all too soon and retreated into their linguistic and cultural ghettos.

In a very real sense we have become a new organism – a multi-brain organism whose singular power has been to expand by means of our language and related cognitive skills, by leaps and bounds, our capacity to share the fruits of our brains manifold achievements in so many endeavors, with so many others of our kind. That's what's made us what we are and what we've become as a species, capable of expressing our deepest feelings and understanding of ourselves and the world we live in by stories, music and art in all its forms.

We are wholly dependent on all those other brains – past and present to make our modern life possible, Without them and the countless, taken for granted tools which surround us, we would be returned to our stone age culture in a heartbeat, quite unable to make all the conveniences on which we've become so dependent and worse than that, without all the skills our stone age ancestors had acquired for living in their age.

The true power of our brain lies not simply in its unique capacity to soak up new information and solve problems for by itself it would be nearly helpless to learn language, social skills and culture. But beyond that, the real power of the brain goes beyond simply working with other brains. What sets us apart as a species is our unique ability to pass on the fruits of that knowledge – initially by gesture and example – soon by oral symbolic language, much later by written language and now of course by the wide dissemination of our knowledge through traditional libraries and especially these days by the internet and heavens knows what in the years to follow.

What was unintentionally and unanticipated by evolution is the huge game changer manifest in our species – is the unparalleled power of our species to harness thousands and millions of brains together in a huge network of information – hopefully accessible to all.

Summary

In the little more than 300,000 years that we modern humans have been around and especially in the last few hundred years, there has been a remarkable increase in our understanding of the natural world and the greater cosmos for which our brains have been the engine but which began in an age when stone tools were the order of the day.

Human brains are remarkably social and curious. They have a very strong impulse to tell stories whether mythological or scientific about the origins of the universe, life and ourselves. Beginning with the acquisition of highly sophisticated and nuanced symbolic oral languages and later transcription of those oral languages into texts, mathematical symbols and musical scores, this brain proved to be a truly astounding instrument and remarkably capable of taking on challenges their ancestors would have marveled at. It is truly astounding that this now highly evolved biologic machine could within a generation or two make the leap from stone age cultures - for example of many of the highland tribes in New Guinea – who when exposed to modern cultures of the 20th mastered the skills and knowledge of fully modern societies within a generation or two.

The brain was able to make those leaps without changing its genetic hardware – only the ways in which the hardware was used. In short the brain had the capacity all along. All it needed was the challenge and perhaps some developmental changes in its software to make the requisite changes.

So my guess is that we have a brain far more capable than perhaps we use most of the time. Clues to the latter are the remarkable skills of savants, high functioning autistic subjects and sometimes severely brain injured patients who excel well beyond our grasp in some areas of cognitive function, whatever their impairment in other areas.

The brain could not have anticipated these challenges anymore than Apple anticipated all the many ways that users used their iPhones and iPads. The brains strong impulse to look for patterns and most importantly share and pass on those understandings and mythologies to later generations, was able in a singularly exceptional manner to create shared oral and later written libraries open to their fellows. And in so doing they and later generations didn't have to reinvent the wheel. The same brain that hunted with bone and stone tools, lived in caves or other primitive dwellings had the capacity in later generations to link space time and gravity, imagine and test quantum physics, pursue molecular biology and evolution, poetry, art and music and develop societal structures for relationships and the systems of governance which now exist and who knows what in the future might be possible.

Of course there have been periodic setbacks and periods of darkness of the mind and spirit, wars and prejudice because unfortunately this same brain has shown a formidable capacity for equal measures of great mischief and evil – sometimes in the same person. Indeed one recent study suggests that most people cheat at one time or the other and knowingly fib and exaggerate. The good and bad exist in all of us - that is the great challenge - to encourage the one, while reining in the other.

And should for any reason we ever lose that great collective library of shared experience and knowledge we would be set back thousands of years and find ourselves forced to live much as our stone age hunter gatherer ancestors did without any of the tools or understanding we so depend on now and none of the tools and wisdom they had to survive.