Einstein and the Revolution in Science

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On the 7th of November 1919, *The Times* of London displayed a dramatic headline: **Revolution in Science.** *New Theory of the Universe; Newtonian ideas overthrown.*[1] The previous day, about 150 scientists, mathematicians and philosophers had crammed into an extraordinary meeting of the Royal Society in Piccadilly. There they waited for Arthur Eddington, one of the world's foremost astronomers, to announce the results of an experiment which took place the previous May. Eddington and his colleagues, in two teams, had travelled to Sobral, Brazil and the island of Principe off the west coast of Africa. Both sites were in the path of totality of a solar eclipse. The goal of the expedition was to observe how light rays from distant stars behave as they pass close to the sun. This involved photographing stars near the sun's edge; something requiring eclipse conditions. After months of careful analysis, Eddington and his team announced to the world that the presence of a massive body like the sun does indeed cause light rays to bend. Or to put it another way: light has weight! Thus, the radical prediction of a Berlin physicist called Albert Einstein was confirmed.

Einstein, though well respected in his field, was hardly famous. Eddington's announcement and the media circus which followed rapidly turned him into an international superstar. Indeed, some say that Einstein was one of the first truly global celebrities. His picture appeared in newspapers all over the world. Letters from adoring fans came pouring in and everywhere he went, Einstein was feted. His Theory of Relativity, which predicted the observed bending of light rays, was now on everybody's lips. What was this mysterious theory, shrouded in formidable Mathematics, all about? What did it mean to say that "space is curved", "light has weight" or that "there is no absolute space and time"? Against a backdrop of widespread hunger, disease and discontent – the great war having only recently concluded – the story captured the public imagination.

Einstein's fame was complex. Some in the German scientific establishment tried to present his achievement as a victory for `German science', something which displeased Einstein immensely. Worse, following the murderous defeat of the left in the German revolution earlier that year, far right forces were on the rise. Einstein, a "Jewish internationalist with liberal views" was the perfect target. Anti-Relativity events and rallies were held, sometimes masquerading as scientific conferences, promoting crackpot anti-Semitic conspiracy theories. For many though, yearning for a better world, Einstein represented hope and the best of the human spirit. After all, Einstein's `German Theory' had been confirmed by a British team. Only days before the 1st anniversary of the 1918 armistice, this seemingly small act of cooperation had great symbolic value.

Unlike most of their scientific colleagues, Einstein and Eddington had both stood against the patriotic tide and strongly opposed the war. Einstein was an internationalist, a socialist and an anti-authoritarian. His revolutionary theory, overturning as it did the old scientific orthodoxy, had come at a time of tremendous upheaval: political, social and cultural. In the decades leading up to the war, the world was transforming at a scale and a pace unprecedented in human history. There were amazing new technologies: the internal combustion engine, the radio and the airplane. Radical new innovations, by figures like Picasso and Joyce, were driving revolutions within art, literature and music. The modern world was being born. While old empires clung on, new ambitious nation states were waiting to take their place. By the end of the Great War, the old order was in disarray and much of Europe was in the grips of political revolution. Amidst this turmoil Einstein became a heroic figure for much of the world.

Some saw Einstein's theory of relativity as a direct contribution to that political revolution, something Einstein strongly rejected:

> "*This world is a strange madhouse. Currently, every coachman and every waiter is debating whether Relativity Theory is correct. Belief in the matter depends on party political affiliation.*"[2]

While it would be incorrect to say that scientific theories cannot be political (there are certainly examples in the realms of biology and psychology), describing a theory like relativity, concerning as it does space, time and motion, as a left wing theory is clearly absurd. At the same time, science is a human process and takes place amid a social context. Though a scientific revolution is not the same as a political revolution, the two are not unconnected. It is not a coincidence for example, that the origins of modern science in the 16th and 17th centuries, what is commonly called The Scientific Revolution, occurred alongside (and helped create) the transformation from feudal to capitalist societies. Understanding this relationship is a deep and difficult problem and something of which, in an article such as this, we can only skim the surface. That said, we will try in describing Einstein's revolutionary science to tease out some connections with wider revolutionary ideas.

What do we mean by Science?

The term Science is exceedingly difficult to define. Clifford D Conner in his superb book *A People's History of Science,* regards it simply as: *knowledge about nature and the associated knowledge producing activities*. Science in this sense is a fundamental part of the human condition. As Conner argues:

> "*It [Science] originated with the people closest to nature: hunter-gatherers, peasant farmers, sailors, miners, blacksmiths, folk healers and others forced by the conditions of their lives to wrest the means of their survival from an encounter with nature on a daily basis.*"[3]

Conner cites numerous examples: the domestication of plant and animal species by preliterate ancient peoples; the development of chemistry, metallurgy and the materials sciences from the knowledge obtained by ancient miners, smiths and potters; the debt owed by mathematics to surveyors, merchants and mechanics. Regarding the development of what we call modern science, he points out:

> "*The empirical method that characterised the scientific revolution of the 16th and 17th centuries emerged from the workshops of European artisans.*"[4]

In discussing Einstein's scientific contributions then, it is important to remember that he stood not only on the shoulders of other giants (Newton, Gallileo etc) but on a mountain of knowledge gathered incrementally over millenia by massed ranks of labourers, craftsmen, miners, potters, artisans and `low mechaniks'.

An Example from Antiquity

Nature is mysterious. Moreover, human intuition is often a poor guide to understanding. If this were not so, there would be no need for science. One obvious example is the problem of understanding the shape of our world. The fact that we live on a round ball was known since at least the time of Pythagoras (about 500 BCE).[5] It is fair to say however that local intuition (common sense) would suggest that, ignoring hills and valleys, the Earth is overall flat; something many of our ancestors believed. (Such a belief still begs the question of whether the Earth is an infinite plane or a finite disk.) For most people, belief that the Earth was flat was inconsequential. However, there were various clues that the flat Earth hypothesis was incorrect. One of these was the fact that a ship coming over the horizon would display initially only its mast, the hull appearing later. Probably the most compelling argument was that the shadow cast by the Earth on the moon during a lunar eclipse is always round. Around 300 BCE, the chief librarian at Alexandria, Eratosthenes, observed that lengths of shadows cast by vertical poles (of the same height and at the same time) varied depending on their latitude. This only made sense on a curved Earth. In what must rank as one of the most elegant geometric calculations ever made, Eratosthenes correctly deduced by comparing the lengths of two such shadows, one in Alexandria and one in Cyene (about 800 kilometres south), that the circumference of the Earth is about 40,000 km.[6]

The above story demonstrates a number of important scientific principles, ones which have parallels in Einstein's work. Firstly, drawing global conclusions from local intuition is often problematic. This does not mean that our intuition is universally bad, only that it can let us down. Secondly, we see the use of *hypothesis*. Notice that at no stage did anyone actually *prove* that the Earth was round or display the sort of evidence (photographs from space etc) that we can avail of today. Observational evidence undermined the old flat Earth hypothesis. The extra information lead to a new hypothesis: the Earth is a round ball but sufficiently large so as to appear locally flat. This hypothesis is consistent with all earlier observations and the new ones. Notice also that the observations about ships coming over the horizon and shadow lengths of vertical poles showed only local curvature. Perhaps these observations were made on the "curved part" of the Earth, a sort of "round bump" which flattened out elsewhere? Or perhaps the Earth was curved in a more complicated way: a torus (bagel shape)? Even the lunar eclipse observation could be made fit this hypothesis if such eclipses only happened in certain directions. So why assume the spherical hypothesis? It is here we stumble on a third principle: *parsimony*. Most famously espoused by the English Franciscan friar, William of Occam it is commonly paraphrased as "the simplest solution is usually the correct one." Given the possibilities, the simplest (and most symmetric) shape which explains the observed phenomena and the one requiring the fewest additional assumptions, is the sphere.

Despite overcoming the limits of local intuition to deduce the shape of the Earth, the prevailing view of our place in the universe was still in its infancy. Although Aristarchus of Samos[7] is credited with proposing a heliocentric (sun-centred) model, the standard view was the Aristotelian geocentric (Earth-centred) one. Thus, the Earth was at the centre of a collection of nested translucent spheres on which orbited the heavenly bodies in perfectly circular motions. Based on our intuition, this was not unreasonable, although even then the assumed circular motions did not quite correspond to the centuries of observations made by Greek, Babylonian and Egyptian Astronomers.[8] This system was later rigourised by Claudius Ptolemy, in his highly sophisticated *Almagest*, to create a mathematically complete geocentric model. Although, Ptolemy's model successfully incorporated the available astronomical data, it required all sorts of complicated assumptions about the motions of the planets. Viewing the Earth as a fixed point while the rest of the universe moved around it was far from parsimonious. Ptolemy's Almagest was subsequently lost to Christian culture for centuries (though it survived in the Islamic world). In its place, a version of the Aristotelian model, modified by Thomas Acquinas to incorporate Christian theology, held sway in Europe until the 16th century.

The origins of modern science

The first serious blow to the Aristotelian picture, was a new heliocentric model put forward by Nicolas Copernicus in 1543. Placing the sun at the centre made for a far more elegant picture. It was revolutionary in two ways. Firstly, it challenged the widely held intuitive model. For example, the idea that the Earth was rotating or moving rapidly through space was extremely difficult for many to accept. Given that most people's experience of speed in those days was travel by horse (and so anything but smooth), it was difficult for people to imagine that the rapid motion of the Earth could pass undetected. Secondly, Copernicus challenged the established religious dogma which put man and Earth at the centre. Later Johannes Kepler, refined the model replacing the circular planetary trajectories with elliptical ones, breaking still further with the traditional view. More upheaval was to follow when Galileo, with the newly invented telescope, showed that Jupiter (and not just the Earth) had moons while the supposedly pristine surface of the sun contained dark spots.[9]

Galileo further dismantled Aristotelian physics with his experiments on motion, testing and often debunking preconceived intuitive notions. The idea of testing hypotheses, rather than simply interpreting the writings of the old masters, was in itself a radical departure from the scholastic tradition which had held sway for centuries. Following on from Galileo's work, Issac Newton, formulated a coherent set of laws concerning motion and gravitation. From these simple principles could be deduced everything from Kepler's elliptical planetary orbits, to the movement of Earthly tides, to the falling of apples from trees. The crowning scientific achievement of this age was the invention by Newton (and independently by Gottfried Leibniz) of Calculus, a powerful mathematical language for describing continuous change. All motion, it seemed, could be understood by Newton's elegant theory.

The Scientific Revolution of the 16th and 17th centuries was deeply connected with a more general revolutionary process. This was the rise of a new capitalist class and its eventual defeat of the old feudal order. Friedrich Engels, one of the most insightful thinkers on the role of science in human history, regarded this revolutionary process as:

> "*the greatest progressive revolution that mankind has so far experienced. … Natural science developed in the midst of the general revolution and was itself thoroughly revolutionary.*" [10]

On the one hand, great thinkers such as Galileo and Newton were surely motivated by a deep curiousity about the natural world. It is hard to imagine how anyone could achieve such insights without this. At the same time, their interests and the problems they worked on were also motivated by the needs of the day: improving navigation (Newton was particularly interested in the problem of computing longitude at sea, a problem that was solved by the clockmaker John Harrison[11]) or optimising the effectiveness of canon. Such concerns in turn arose in a world in which a rising capitalist class was expanding its wealth and power. New methods of production and the exploration (and exploitation) of new territories, were providing a powerful stimulus for scientific discovery. In turn developments in science were influencing this productive process. The scientific revolution instilled tremendous confidence in the rising bourgeois class. The success of theories such as Newton's were proof that nature could be understood and controlled. Ironically, given the tremendous changes which had taken place, the Newtonian view which came to dominate scientific thought was that of an unchanging clockwork universe. In the background space and time were fixed and absolute, while life played out in a predictable immutable style.

Einstein's early life

Albert Einstein was born in Ulm, Germany in 1879, although at an early age moved to Munich when the family business failed. Germany at the time had recently been unified and under the chancellorship of Otto van Bismarck was undergoing a period of intense industrialisation. Britain and France were still the world's foremost imperial powers and the German ruling classes were eager to compete. The ubiquitous militarism of the period was something that, even as a child, disturbed Einstein greatly. Albert's father, Hermann Einstein along with his brother Jacob, ran a small electrical business, manufacturing dynamos and electrical arc-lights. The experience of tinkering with such equipment and pondering the mysteries of electricity and magnetism left an indelible mark on Einstein.

The young Albert did not enjoy school, finding it stifling and regimented. He left without completing his second level education meaning he could not enter university in Germany. However, the Swiss Federal Institute of Technology (ETH) in Zurich accepted any student who could pass their entrance exam. On the second attempt, Einstein gained entrance and began studying Physics at one of the finest institutes in the world.

Einstein rarely went to lectures, having little time for formal instruction. Instead he spent his time experimenting with the cutting edge equipment in the laboratories or arguing about science, philosophy and politics with friends in local cafes. Zurich at the time was a lively place and temporary home to many exiled revolutionary figures; Lenin, Trotsky, Rosa Luxemburg and Alexandra Kollontai were all there. Albert learned about revolutionary socialism from his friend Friedrich Adler, a lecturer in Physics. In 1902, after graduating with mediocre marks, Einstein began work at the Swiss Patent Office in Bern, marrying Serbian mathematician Mileva Maric the following year. At this stage he had renounced his German citizenship and gained Swiss nationality. The position in Bern was perfect. The work was relatively easy and Einstein had a great deal of time to spend just thinking about interesting problems.

Science at the end of the 19th century

Throughout the course of the 19th century, scientific development proceeded at a tremendous pace. The Newtonian revolution had chiefly concerned the mechanics and dynamics of material bodies. Alongside this sprung up new sciences concerned with heat, electricity and magnetism. Developments in chemistry undermined the presumed gap between the organic and the inorganic. Most spectacular of all was the theory, due to Alfred Russel Wallace and Charles Darwin, that all species had evolved incrementally from common ancestors through the process of natural selection.

This theory in particular, along with the new science of geology, posed a dramatic challenge to the static world view that had held sway since Newton. The natural world was not fixed or constant but had a history. Just as the scale of the Earth had challenged early human spatial intuitions about its shape, the scale of this history had challenged our intuitions in time. After all, evolution was not something witnessed directly but deduced from evidence and brilliant insight.

By the end of the 19th century, human knowledge about the natural had grown immensely since the time of Newton. In the realm of Physics, new knowledge had brought with it a number of serious problems. Various theories, hugely successful in their own right, contradicted each other. The scientific revolutions of the early twentieth century, in which Einstein played such a fundamental role, emerged in the attempts to resolve these contradictions. The resulting new theories, Relativity and Quantum Mechanics, provided challenges to our intuition the like of which we had never seen.

Einstein's Theory

In 1905, while still working as a patent office clerk in Bern, Einstein published his Special Theory of Relativity. That same year, he published several other papers on topics such as Brownian motion and the photoelectric effect. The latter work, which actually earned him the Nobel prize in 1921, would prove to be a significant contribution to the theory of quantum mechanics. However, it is Einstein's work on Relativity that stands out as one of the most revolutionary contributions in scientific thought. In it, Einstein did away for ever with the notion of absolute space and time.

It is important to realise that, amid the myriad new scientific developments, Newton's laws of mechanics had maintained their lofty position for the best part of two centuries. Central to the Newtonian view was the idea that time and space were absolute. Thus, the passage of time was the same for every person and everything. Moreover, space was simply the background where events happened and was unaffected by the events themselves or by the presence of matter or energy. These assumptions were natural and obvious. How could things be any other way?

In the 1860's, following the work of Michael Faraday and others, James Clerk Maxwell in an analogous fashion to Newton, consolidated our knowledge of electrical and magnetic phenomena in a set of simple mathematical laws. Maxwell's Theory of Electromagnetism was an enormous breakthrough (leading for example to the development of radio) and is still a cornerstone of modern science. It should be said that much of this originated in the work of Michael Faraday. Though untrained in Mathematics, Faraday (the son of a blacksmith) developed a deep understanding of the electromagnetic force through ingenious experimentation and geometric intuition. It was Faraday who first conceived of "fields of force" to describe the effect of magnetism across space, a far more satisfying explanation of an action than the instantaneous action at a distance implicit in Newton's theory of gravity. One consequence of Maxwell's equations is that light (a form of electromagnetism) has a constant speed in empty space. This speed is approximately 300,000 km per second, but we will just abbreviate it as c.

This constancy of the speed of light, reconfirmed again and again by experiment, suggested (as we shall shortly see) a serious problem with our assumptions about space and time.

The principle of relativity is actually an old one, and goes back to Galileo. It states simply that there is no such thing as absolute motion, only relative motion with respect to something else. Thus, an observer in a sealed container moving at constant speed would be unable to detect movement. Notice here that the speed must be constant. A change in speed (acceleration) would be felt. Einstein extended this principle to declare that *all laws of nature should be exactly the same for all observers in relative motion.*[12] Thus, any two observers, regardless of their state of motion should measure the same value, c, for the speed of light. This has radical consequences. Einstein was a huge fan of thought experiments, so let us consider the following rather idealised scenario.

We have two observers, Karl and Rosa, both equipped with stop-clocks. Karl sits on a railway embankment observing a train pass by at, say, 100km per hour. Rosa, sitting at the back of a carriage, stands up and walks briskly to the front at, say, 10km per hour. As far as Rosa is concerned she has travelled the length of one carriage. From Karl's point of view, she has covered a good deal more ground. This makes sense. Relative to the train, she has moved at a speed of 10km per hour.

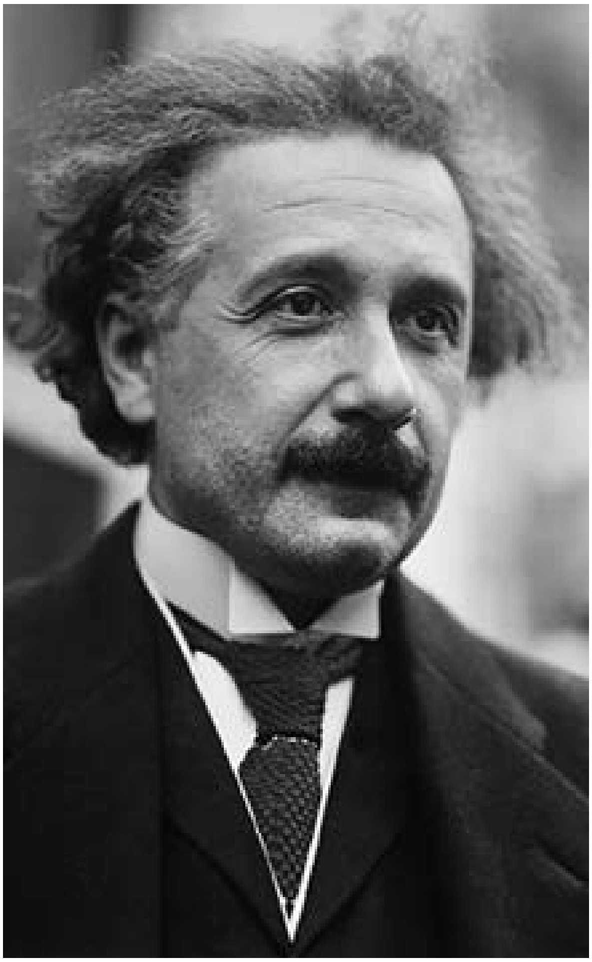
Relative to the embankment (Karl's point of view), she has travelled at 100+10=110km per hour. Moving faster, she covers more ground. Recall that as we are for simplicity assuming constant speeds, we can calculate *speed* as *distance divided by time*. Assuming that time is absolute means that both Karl and Rosa measure the same time passing for Rosa's short walk. The increase in speed (from Karl's point of view) corresponds to an increase in distance. Obviously.

Now let's suppose that instead of getting up and walking, Rosa sends a beam of light, from the back to the front of the carriage.It is tempting to think that, while Rosa will measure the speed of the light beam as c (technically this is the speed in a vacuum but it will do), Karl's measurement as he watches the train zip by will be $100+c$. However, this is not the case. It is a fact, verified by countless experiments, that all observers measure the same value c for the speed of light. Thus, Karl and Rosa both measure the speed of the light beam as c. But, fast and all as the light beam is, the movement of the train means that from Karl's point of view the light beam will cover slightly more distance than that measured by Rosa who measures it as the length of the carriage. This leads to a serious contradiction. Remember *distance covered is the product of speed and time*. If both observers measure the same speed over the same interval of time, how could they measure different distances?

This example, though a little unrealistic, illustrates a serious problem if we assume that time is absolute i.e. that both Karl and Rosa measure the same time. The solution to this problem is to drop this assumption. Counterintuitive as it might feel, it is simply false to say that Karl and Rosa both measure the same time passing. In fact, Rosa will measure a slightly shorter time interval than Karl. Given that the train is only traveling at 100km per hour, the difference would be so small as to be unnoticeable. However, if we sped up the train to some significant proportion of the speed of light, Rosa's clock would run substantially slower than Karl's. For example, if the train were traveling at $0.9c$ (90% of the speed of light), Rosa's clock would be moving at less than half the rate of Karl's.[13] This is a phenomenon known as *time dilation* and is a fundamental feature of our universe. In fact, even at the speed of orbiting GPS satellites, small corrections for time dilation need to be made.[14] Of course, at everyday speeds its effects are negligible, hence it is so difficult accept. If our species had evolved moving regularly at near light speeds relative to each other, such notions would be quite mundane. Again, we see the problem with our "local" intuition.

In fact, Einstein's theory of special relativity predicted not only that time for an observer traveling at speed would slow down, but also that there would be a *spatial contraction*. More specifically, if Rosa's train were to pass Karl moving at some considerable quantity of the speed of light, Karl would notice the carriage shrink horizontally. At the same time, Rosa would see the same thing happen to Karl (traveling relatively at the same speed but in the opposite direction).[15] Thus, space in its absolute sense, as well as time, was dispensed with. Einstein, using mathematical notions developed by his friend Hendrik Lorentz, wrote down formulae for describing this new reality. This meant constructing "transformations" between the "reference frames" of different observers. The mathematics here is actually quite elegant and beautifully written. One final and radical consequence of special relativity is the equivalence of mass m, and energy E, captured in that most famous of equations: $E=mc^2$. It was well known that energy could be transformed from one form to another. Now, mass and energy could be mutually transformed. Moreover, even a small quantity of mass contained within it a staggering amount of energy, a principle that in the nuclear age we know all too well.

Einstein's Special Theory of Relativity had some serious limitations. It only applied to bodies moving relatively at fixed speeds. What happens when (as in the world) bodies accelerate? In particular, given that the force of gravity, via Newton's laws, induces an acceleration on an object, how does the theory deal with gravitation? Einstein spent the next decade on the formidable task of appropriately generalising his theory. By 1915, he had established what is now called the General Theory of Relativity. Contained within as a special case was the original theory. Unlike the special case however, the Mathematics involved is some of the most difficult ever to be applied to the natural world. Not only was space not absolute, it was no longer even Euclidean (flat). The presence of matter caused space to curve and gravitational effects were the result of this curvature.



Albert Einstein in Washington DC early 1920s

Curved space is extremely hard to visualise even for experts. At this point it is worth briefly recalling the problem of understanding the shape of our own world. At school, we learn about the geometry of 2-dimensional flat space (the Euclidean plane), often represented (a la Descartes) with horizontal and vertical (x and y) axes. In more advanced classes, students see the analogous 3-dimensional Euclidean space (this time with x, y and z axes). Both spaces are considered flat. One consequence of this is that the sum of angles on a triangle is 180 degrees. Now locally, the surface of the Earth seems like a piece of flat 2-dimensional space. Globally it is obviously not; it curves. Draw a triangle on a sphere and its angles will always sum to something greater than 180 degrees. In fact, one does not need to "go global". A roundish hill in an otherwise flat plain is a region with curvature (i.e. not flat). Such curvature in three dimensions is harder to visualise (we are inside the three dimensional space we are trying to observe!) but can be detected in various ways, such as measuring triangles. Curvature in 3-dimensional space will also cause triangles to deviate from the 180 degree rule. Another, related consequence is the problem of finding the shortest path between points (a so-called *geodesic*). In flat space this is easy. Once we introduce curvature, geodesics must curve also, often in ways which are difficult to compute.

As with any good theory, general relativity made predictions. One of these, given that rays of light should form geodesics in space, was that light should bend in the presence of gravity. Now gravity is a rather weak force and so in order to notice these effects (curving space), a large amount of matter needs to be present. Hence, even in our solar system, these effects are relatively small. However, Einstein calculated that our sun was sufficiently massive as to bend light rays passing from a nearby star system (the Hyades). It was this, and the bending arc calculations Einstein had made, that Eddington and his team successfully verified in their expedition in 1919. Since then, Einstein's theory is recognised as one of the most successful in all of science. It has been vindicated again and again; in 2015 the observed phenomenon of gravitational waves (emerging from a binary black hole system) was a prediction of general relativity.[16] Black holes themselves (places where, roughly speaking, the curvature of space has become infinite at a point) though conceived well before Einstein, were also predicted by Einstein's equations. Though relativity breaks down at the quantum scale (or inside a black hole) it forms the bedrock for modern cosmology and its attempts at understanding the origins and shape of our universe. This latter problem represents a wonderful (albeit on an immense scale) analogue of the problem our ancient ancestors faced when considering the shape of the Earth.

A Revolutionary Figure

What made Einstein's work revolutionary was the fact that he was willing to put aside the most obvious, natural assumptions about the world and imagine something different. This was not done arbitrarily of course but followed deep and careful analysis. It also required courage and a rebellious attitude. This attitude transcended Einstein's scientific work. Throughout his life, Einstein never hid his political views or avoided speaking out against authority. When the first world war began, Einstein (then a professor in Berlin) proclaimed publicly his proud internationalism and opposition to war. Later, while living in the US Einstein spoke out very publicly against McCarthyism, for civil rights for black Americans (joining the Princeton chapter of the NAACP) and always against war and nationalism.[17] In 1949 he wrote a memorable piece for the magazine Monthly Review entitled '*Why Socialism?*', which spelled out has political views.[18]

Like all of us, Einstein was complicated and held positions which many on the left might disagree with. Though initially highly critical of Zionism, he came to support the creation of the state of Israel. Given his experiences as a German Jew, this is surely understandable. Moreover, given the nuanced way in which he expressed such support and the concern he showed for the implications of such a state on indigenous Palestinians, it is hard to imagine he would be anything but appalled at the subsequent behaviour of the Israeli state.[19] Fearful of the prospect of atomic weapons in fascist hands, Einstein was also one of the signatories on Leo Szilard's letter to Franklin Delano Roosevelt, urging the construction of an atomic bomb. Though he played no role in the Manhattan Project, Einstein expressed profound regret following the destruction of Hiroshima and Nagasaki.[20]

In his approach to science and the wider world, it must be said that Einstein personified some of the finest human qualities. He famously stated:

> "*Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution.*" [21]

This was a call to question authority and previously held assumptions. A call to reject petty parochial notions like nationalism. A call to be skeptical of common sense and to search for good sense. It was also a call to confidently wonder about what might be possible. For those of us wishing not simply to understand the shape of our space but to change it, this is a call we would do well to heed.

References

1. Matthew Stanley, *Einstein's War*, Penguin [2019], page 289

2. Stanley, page 312

3. Clifford D. Conner, *A People's History of Science*, Nation Books [2005], page 2, paragraph 2

4. Conner, page 3, paragraph 3

5. Kitty Ferguson, *Pythagoras*, Walker Publishing [2010], page 108

6. Carl Sagan, *Cosmos*, Random House New York [1980], pages 14-17

7. Sagan, page 20, paragraph 3

8. Sagan, pages 52, 53

9. Sagan, pages 66, 91

10. Friedrich Engels, *The Dialectics of Nature*, Engels Collected Works (MECW), Vol. 25 LondonJo [1987], page 319. See also the excellent article by Paul McGarr: *Engels and Natural Science*, International Socialism Journal Issue 65, [Winter 1994]

11. David Sobel, *Longitude*, Harper Perennial [2007]

12. Peter Coles, *Cosmology: A Short Introduction*, Oxford University [2001], page 15, paragraph 3

13. See *https://www.omnicalculator.com/physics/time-dilation*

14. See *http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit5/gps.html*

15. George Gamow, *One, Two, Three, ... Infinity*, Bantam Books New York [1967], Chapter V

16. See *https://www.ligo.caltech.edu/page/what-are-gw*

17. Ken Gewertz, *Albert Einstein, Civil Rights activist*, The Harvard Gazette [April 2007]

18. Albert Einstein, *Why Socialism?*, Monthly Review [May 1949] See *https://monthlyreview.org/2009/05/01/why-socialism/* for a reprise.

19. See *http://monthlyreview.org/2005/05/01/albert-einstein-radical-a-political-profile/*

20. Ibid

21. From an interview in 1924 with George Viereck; see *http://www.saturdayeveningpost.com/wp-content/uploads/satevepost/einstein.pdf*