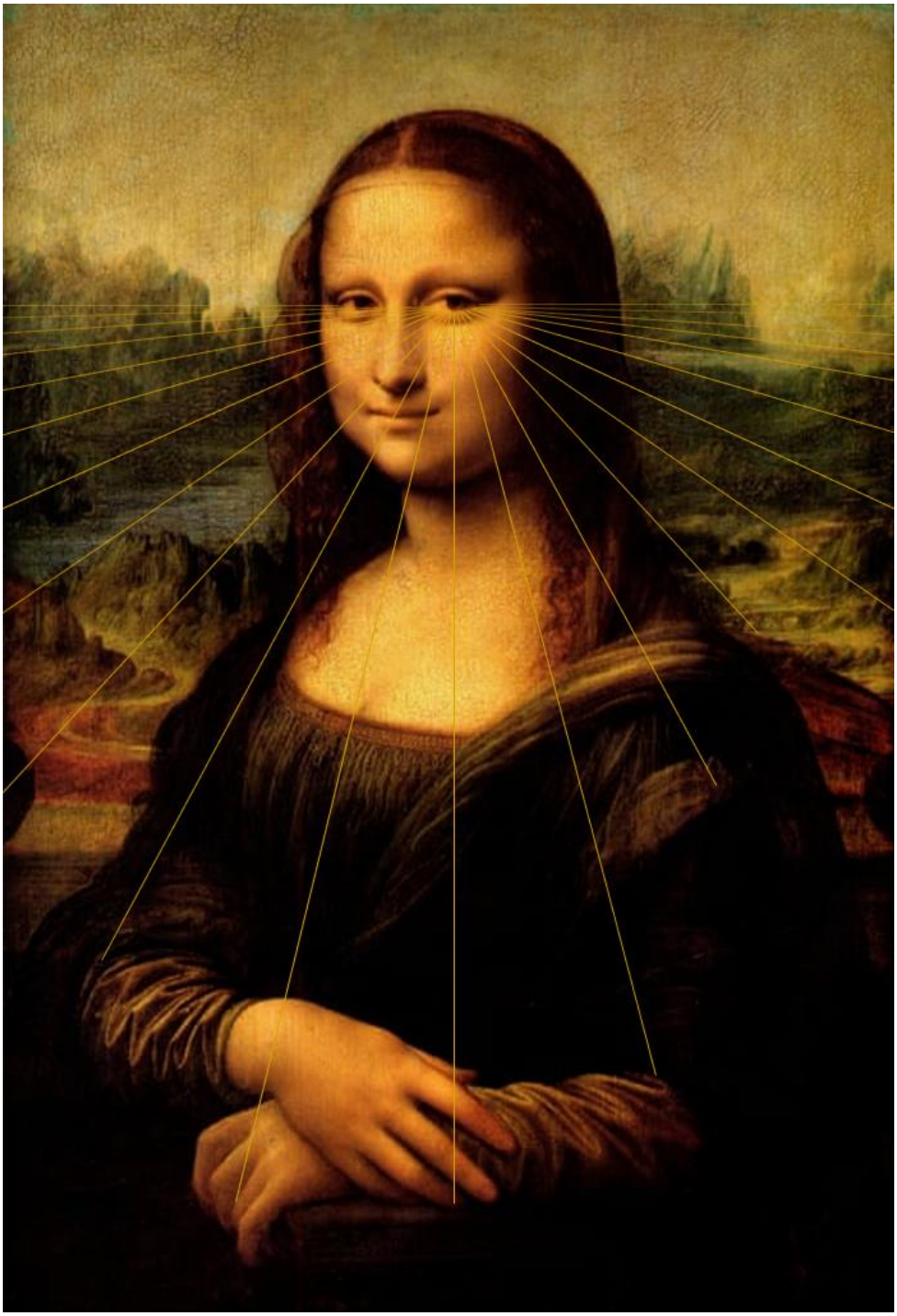
The Vanishing Skylines of Quantum Cosmology

A Holographic Astronomy of the Atom, the Multiverse, and the Mind

M Gaelen Evans



Your Horizon is Here ... and also Here ...

We live in a universe of beauty and terror. The endless detail and colour of every place and moment, our entire existence, are reflected in a distant physical illusion, a holographic image of local life in natural perspective on the cosmological horizon. Yet this too-incredible idealised reality seems to be tearing itself apart, everywhere diminishing ultimately to nothing – no meaning or resolution, just a relative end of time hidden by dark energy and negative gravitation at a crumbling edge.

Or worse yet, as the incomplete theory may still tell us.

How can we understand this? To visualise these dangerous concepts from first principles, we can 'see' almost everything from the subatomic to the cosmic via the strange and beautiful imagery of quantum gravity, an emerging science that builds a wave-particle explanation for the cosmos partly by erasing space and time. In the resulting probability of vacuum, the energies are enormous and destructive.

This must be the profile of a fragile, unstable world. Its true genius is the hologram, which replaces spacetime with constructive wave effects that simulate the entire scenery on an imaginary plane. Viewpoints onto the horizon loosely project every possible action in time, distance and direction: sound and light, covariant gravity, entangled fields, as much as the relative depth impressions inside our heads.

That's not just metaphor, it's a realistic picture of an uncertain universe at the correct scale in a personal edge of your future, and a primer by illustration of this advanced theoretical panorama. The cosmos emerges in outline as a relatably fallible mirage fragmented in a prism, the laws of physics in descent from a family of broken anti-symmetries, and the incomplete world falling to a horizon that can be accurately imagined by the harmonic illusions of perspective.

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The Vanishing Skylines of Quantum Cosmology
- a visualisation from many directions

It's a surprising fact that you can see, hear and feel the laws of physics by their role in visual perspective, harmony and balance – understood since the Renaissance as realistic optical and immersive illusions of depth. Without over-thinking it, these sensory impressions of geometry are almost all you need to view the frontier high point of science through one of its earliest ideas: the modern *Holographic Principle* and the ancient *Continuity Principle*, which tend to telescope the present to a future event horizon and back to an idea of the human mind entangled in the spatial illusions of a hologram. Here the most cosmic experiences are also the most familiar.

How, and why? Atoms and planets obey nearly identical rules of presence and absence, fading with distance and orientation along converging lines. Gravity falls away on the same diminishing curvature as light, sound, profile area or, in the complete 360-degree travelling visual experience, folds of countryside that bend into view like warped spacetime. Likewise the fuzziness of an atom is a visual system of subtle depths that project in dynamic arrows from a clock's face. 'Reality' at all scales can be re-imagined as a multi-dimensional landscape or cityscape of effects, with light and colour, direction and size as per normal sight and sound, mixed with the experiences of movement and self-weight. This natural picture extends your physical experience to the future event horizon's strangest feature, the corresponding hologram, a bizarre idea carrying a particle theory of gravity by projecting the local spacetime onto infinity, at least in a mathematical sense.

Physical perspective geometry is an old yet not quite forgotten idea. It's a beautiful paradigm, one that chimes with all the other beautiful objects of art and science, and a powerful learning tool that places the reader at the centre of their own senses. What's new here, with newly observable consequences, is a sharp and holistic science which tends to take very seriously the profound ideas and perceptions that can be found along the open bounds of a horizon, in particular the oddly flat skyscapes of our universe. At those dark edges, unveiled as you reconsider the sky, you may not be surprised to see yourself and your world distorted at the limits of the observable.

Front Cover: Leonardo da Vinci's La Gioconda *with one element of a hologram in the distance. Every point in the immediate scenery lies on one of many parallel lines in the direction of any point on the horizon. Every distant point then refers to every local point by its direction; a type of natural hologram.*

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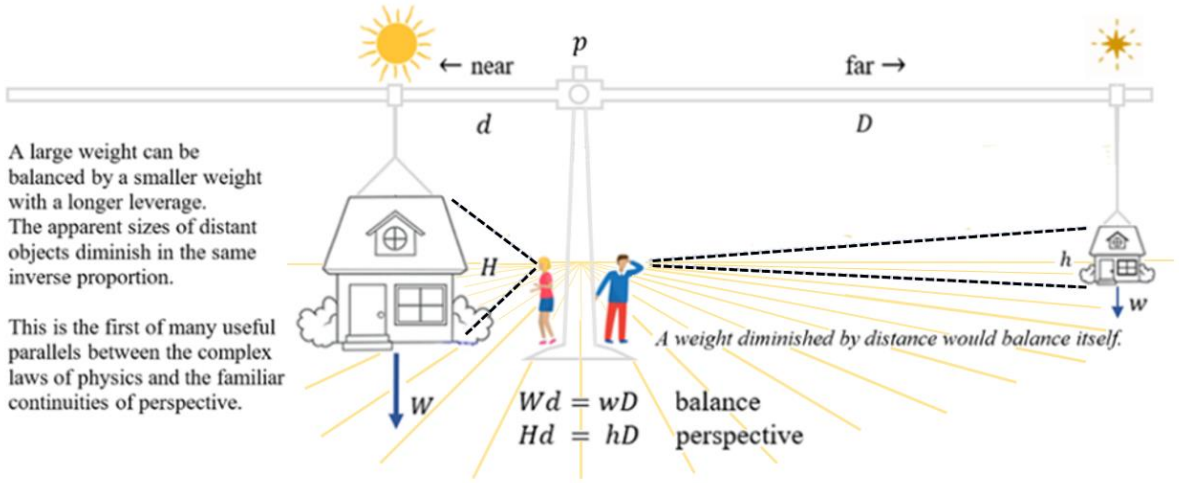
The End is Near … and yet Far …

To visualise this we don't need to see it. Horizons of all kinds share the properties of an edge that diminishes to zero, a step beyond microscopic or subatomic. Equally it is all here, as light is received from stars at distances that stretch out to a limit. Regardless of distance, the sense of it is immediate, rays of starlight being the optima of an action that is everywhere here and now. We can 'look' at it from real and imaginary viewpoints, and overlap many unique layers.

That's not just bold rhetoric, it's an outline of the as-yet unresolved theoretical technique, in the most basic terms. This is *quantum gravity*, literally a complex map of vanishing spacetime, and the most blue-sky, cutting edge of all the sciences in question. To build a concept here entails an open account of almost everything, or nothing less than a tale that begins – and ends – everywhere.

M Gaelen Evans PhD is a scientific generalist and multimedia artist, a keen observer and good storyteller, and rarely an Australian symbolist of Welsh-Dutch descent. So you are in good hands.

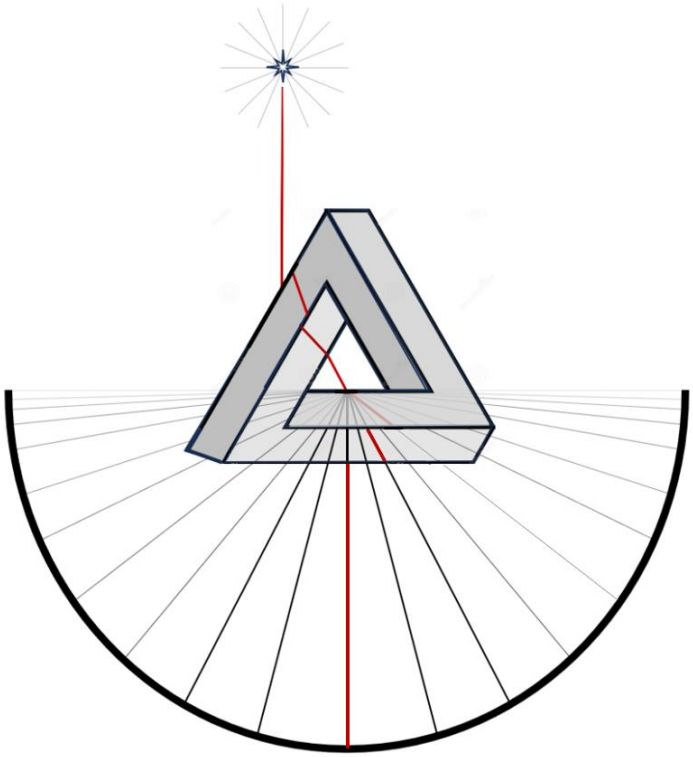
This book is an illustrated and animated reconstruction of modern physical cosmology, drawn from first principles and in beginner-intermediate language, with advanced conclusions on the harmonic geometry of this beautiful science. The idea is to see the relativistic particle basis of large-scale astrophysics, with a sensory experience of the mathematics – so far as is possible – by its musical likeness to the rules of perspective and balance that we naturally observe all around us.



Author Background:
https://michaelgifans.com/science/the-vanishing-skylines-of-quantum-cosmology/

The Vanishing Skylines of Quantum Cosmology

or: A Universe Half-Full



For Ronan,

who keeps asking the big ones

Outline of Contents

Preface

Visualising Physics: a dangerous science re-imagined in the harmonic illusions of space and time.

Chapter 1: Vanishing Points and Particle Physics

A brief history of physics and technology in visual and aural terms. Stone tools depend on the spatial-visual concepts of foreshortening and diminishment, which relate to visual and musical art forms as geometries aligned with harmony. These continuity laws of physics are essential factors in practical technology and art, the material and cultural basis of civilisation from the Pyramids to the Greek atom to quantum mechanics. Matching continuity with visual perspective and its harmonic waveform, the modern atomic descendants are uncertainties and exclusions in wave-particle-field theory, built on mythic and modern Action Principles, to Bayesian probability and entanglement with indications of quantum gravity.

Chapter 2: The Spacetime Illusions of Light and Gravity

Continues the history in the second main branch of physics, relativity – or perspective in motion – from Galileo to Newton to Einstein and the recent giant steps of quantum gravity. Collates the longer historical debate on the nature of time, and by its natural equivalence, geometric space. Reverses time to understand antimatter, partially linking relativity with quantum theories. Continues collating spatial evidence for perspective-continuity interpretations of harmonic energy and matter mechanics, with powerful holographic edges to the experience of falling and hence the curvatures of spacetime geometry. Loops back to quantum gravity and gravitational entanglement.

Chapter 3: Mind, Language and Paradox

Follows the evidence for actions of the mind in a decision process leading to the development of science via creativity. Takes the view that reality is both mind and nature, our perceptions mediated by senses into the open environment of a holographic neurophysical system that remains unexplained in modern science and all of philosophy. Follows the entanglement-mediated collapse and persistence of wave functions as a gravity mechanism of quantum intelligence. Reflects on the nature of a universe dominated by holograms at key horizons, singularities and in our own minds, without falling for the social error of solipsism.

Chapter 4: The Here-and-Now Quantum Cosmos

Cosmology in not-quite textbook style, most recent discoveries first, telling the history in reverse to make better sense of the concepts. Quantum effects in a dual and multiple entangled universe, expanding in open comoving coordinates to a decreasing scale factor in the same past-oriented direction as an anti-history. Alternative geometries as inversions of energy with curvature, lead to the possibility of multiple projections in different views. The harmonic alternative is followed into cosmological laws of continuity. A wavelike holographic principle unites local and global spaces at quantum-cosmological scales.

Chapter 5: A Clockwork Hologram

A Toy Universe is defined and analysed on a wavelike manifold, consisting of the clock-like numbers of quantum particles, with a perspective model of special and general relativity. You could read this chapter by looking at the picture captions and fitting your own sense of scale and depth as an ‘observer’ in the present. The resulting arc-physical geometry produces energies in the same known proportions as the dark E and M components, with apparent accelerations as dilations that are in the same range as LCDM, at a density identical to the Friedmann critical density, reaching to a unique horizon for any observer, where the horizon is as compact as a hologram. And it’s still just a toy universe.

Chapter 6: The Serene and Eternal Multiverse

This indefinite universe is a kind of music eclipsed by itself, a first effect of perspective. Life and complexity arise from physical principles that defy conception but are nevertheless visible and accessible to experience. A multiverse has all possible outcomes, from a riptide of destruction to eternally evolving higher entropy states that may in time bring forth every possible form of life. Admittedly most of the alternatives lead to destruction, but there is at least one harmonic endgame where the event horizon is always exactly twice the present age. We may remain in a universe half-full, so we need not worry.

Acknowledgements, Further Reading and Journal References

Preface

We could hope, in a world full of life and movement, enriched with music and art, science and poetry, that a promising real future would come more naturally to the human imagination. The view into our world is incredible, an inspiring paradox of illusions that can be imagined in any open window, tangled up in the trees and sky. Yet we exist behind an eclipse, captive to powers that could obliterate everything.

Physics, the study of matter/energy in action and the only science to necessarily question the word 'real', is lost in a crisis that partly explains the calamity threatening to engulf this world. Since the stone age or earlier, the ideas of physics have guided the search for technology and insights into natural law, the language of the actual trees and stones as much as the sky. So it is perilously wrong, a cosmic joke that we can't take too seriously, that this ancient ideal is now answerable, not just for the Earth's own doomsday clock but also for a darkness in the future of any planet.

This is the science that built the fossil fuel engines of the industrial revolution, the same science embedded in all forms of weapons research. It's the ultimate triple-blinded juggernaut, grinding towards the quantum re-boot of artificial intelligence in an existential risk to work and creativity, the twin cores of human identity other than a sense of humour. Beyond all known vacuum the galaxies accelerate outwards, giving pause to a future while the foundations of science remain mired in contradictions.

Which is not to attack or deny the science, but to experience it with proper scepticism as well as a sense of how it might affect you personally, which can make for a very wild and enjoyable-terrifying ride.

This book draws a line from the hard geometric ideas of physics to the related physical sensations of sight, sound and depth, which we recognise also through the feelings of weight and movement. Not to say that anything in physics is real, it remains true that we experience the laws of physics directly, even if we don't and genuinely can't understand them. Subatomic, local, stellar, intergalactic and cosmological scales are accessible to your visual imagination by their common holographic geometry, following the same laws of continuity as perspective, balance and the amplifiers of force. The cosmic horizon is as apparent to you as the sky, and its geometry looks very much like the Renaissance rules of landscape.

The illusion of reality emerging across these levels is so strange, and so relevant to the physical and perceptual makeup of human observers, that a cautious reader will need to balance curiosity and visual thinking with profound scepticism, avoiding definite mental images at all costs. This can seem impossible. Science does not operate to artistic standards of truth or possibility, but of evidence, and physics is the most stringent science, often allowing no more than a one in a billion chance that these frankly unbelievable observational facts could be wrong. A holographic *to be or not to be* time horizon, the end of the world and its surviving contradiction, are visual ideas that can co-exist in one field of view.

To anyone brave enough to want to understand this, the reassuring and somewhat surprising news is that physics lends itself to essentially all of the different sensory and hands-on learning styles of ordinary people. Visual, auditory, text and kinaesthetic (doing) experiences convey the subject by stages to any interested reader, and there is a well-understood physical principle that explains why: the laws of physics correspond exactly to physical experiences, in particular visual experiences, which hide a deep mathematical precision in childhood games and sports, then work and creativity, with our often very acute sensory skills.

The first part of this concept is almost obvious, if hard to get until you do get it: Perspective, as in artwork or holography, is essential to the human idea of an open 'real' world out there; as much indeed as geometry is essential to theoretical physics. Our senses (here) perceive events or objects 'over there' to be diminished and softened by the effect of distance, and also foreshortened by orientation as they face directly or obliquely to the view. Gravity, starlight, electromagnetic field, even quantum probabilities fall off into distance in exactly the same way, in inverse proportion to the view-field area at any scale. Interactions and effects, including their amplitude and probability density, are deflected and dilated just as profiles are foreshortened and shadows are lengthened when we observe or measure events at wide or shallow angles.

The flight of a ball or javelin has a visceral rightness that athletes recognise immediately. The inverse square law and sine projection are visible in any art or architecture that seeks a true representation of space and proportion, which are in no way superior to the abstract arts that most resemble particle physics. In the same spaces the wavelike impacts and dazzling energies of anything from atoms to black holes correspond to musical harmonies, with the powerful result that any wavelike signal can be represented as sound; for

example the collision of two enormous beasts of gravity producing a rising crisis of spacetime that chirps like a bird or a whale depending on where you pitch it. All this is to exact geometric and harmonic laws, mathematics that sidestep possibility with evidence to find a universal science in individual viewpoints.

Why should the natural world behave in this brilliantly outlined artistic and sensory way? We have to realise that space, time and stuff like ourselves are more akin to ideas or illusions than the 'real' dimensional distances, intervals and bodies that we normally imagine. Experiences and the mental structures we build from them are central to this once-removed better concept of reality. We acquire a pretty good grasp of the machinery of physics by participating in it, with a stake of fun or profit in the outcome. The aim of this book is to re-imagine it in visual and auditory concepts, and so make an attempt to *see* and *hear* it.

We don't need to unlearn the plain language of time and distance even if they reduce to nothing. It's possible to use the same ideas of immediacy and proximity in a more subtle concept whereby objects and events are separated not by space/time but by their own measurements at scale, such as how many of our own step and heart rate fit in the space of a room and a particular set of events, such as a meal. They are not necessarily dimensional in their natural geometry. They're just numbers, not necessarily a number line. You don't need an axis to draw and animate a heart, and there is no single 'distance' or 'period' in an absolute sense.

Distant particles are not separate, but are held together by non-local connections and communicable limits due to light-speed, light being a wave-particle whose proper existence sits at zero in an unchanging moment, neither space nor time from one lifetime to the next. This seems to make a myth of reality, yet it is the basis of all the definitions in spacetime and by extension gravity, as a matter of geometry. Beyond extension and duration there is no certain dimensional space and/or time, but definite and indefinite energies plus momenta in a maze of material particles that diminish and foreshorten by the same rules as sight.

For example, the gravity of a lightly warped spacetime connection in a typical solar system can be measured by a transparent grid on an astronaut's porthole, the view of a distant or nearby moon echoing the sensations in their inner ear and gut. This at-a-glance check of the ship's sensors from free-fall to hover is a good guess of the curved geometry around a gravitating energy-mass: as a planet/star or massive energy looms larger in apparent visible area, in the same squared proportion its gravity dilates.

For another, more practical and terrestrial example: the leverage of a weight can be levelled on a scale by balancing a smaller weight at a larger distance. In the same proportion, the apparent visible size of an object diminishes with distance, so a distant weight reduced in direct proportion to its apparent size would balance its own natural weight. Gravity works in the same way, squaring the apparent size or inverting the area of the view field at that distance. At the scale of a particle, quantum probability amplitudes diminish and foreshorten like apparent lengths by distance and angle – and again, to find the actual probability you square the amplitude. We see important effects arrayed on areas at distances, or 'squared' fields of view.

This can be no coincidence, but even if it is, it should matter to us that the structure of physics is a familiar sentient experience, the bias of perspective, which is not just an aspect of normal sight because it can be heard or felt and generally appreciated by anyone with localised senses and a body of experience. So it seems that, buried in the most arcane science, there are universal perceptions that illustrate and to some extent 'explain' it, or at least give it a sensory familiarity.

Also surprisingly, physicists only occasionally make use of visual/sensory descriptions of nature. It comes up mainly in high school or first-year university teaching, where it provides illustrations of physics concepts via thought experiment, such as 'looking' at a sloping plane in the horizontal direction to visualise the triangles of a sliding block or 'feeling' (imagining) the centrifugal acceleration as you go around a bend in a fast car. Serious lecturers abandon analogies as soon as possible to encourage abstract reasoning, so their most dedicated physics majors may not realise, or only peripherally, that perspective illustrates large parts of the whole field. Interpretations are not needed, and I would tend to agree if not for the missed opportunity – that this is not just analogy but exact correspondence, supported by useful principles.

Perspective provides a range of different ways of looking at a situation to decide what matters. Who knew what, and when, depends on where they are standing, near or far in the picture. There are curvatures due to viewpoint of common scenery, sunlight and starlight bending across the sky to opposite vanishing points, which allow us to imagine the cosmos in view of a spherical horizon. The key sciences, quantum mechanics and relativity, are deep studies of perspective-like continuities. The familiar, illusory picture of the local landscape experienced in ordinary perspective extends out into multiple co-existing future horizons with

distinct harmonics. The vanishing point, where our local size becomes too small to see at a distance of perhaps only a few kilometres away, fills the sky as a field of parallel lines in every direction, that we can imagine as a spherical surface. Every point in your local space maps to every point on the horizon, as conceptual holograms parallel to the coherence and interference effects that we know from laser technology.

Clearly perspective has powerful moving parts, in particular where the lines of sight correspond to recent holographic concepts in neuroscience, quantum mechanics and cosmology. This may be the largest possible horizon, the convergence of these advanced physical and neurophysical theories on a corresponding mirage. Perspective in turn is a form of holographic sensory faculty that communicates with the working of the human brain to create an open world inside your head. Our minds process external and internal realities by a coordinated firing of many neurons, each of which carries a variation of an impression of the moment in a multi-layered mental state. A thought, emotion or decision activates the entire central nervous system in a way that makes it impossible to identify a fixed centre of consciousness, as though the entire thought is everywhere throughout your brain. Parts of a brain can die or be injured and whole images can still be formed, up to serious degrees of impairment.

The basic rule of a hologram is that it projects a whole scene onto every grain of an image, so an entire picture is everywhere within the image, seen in many directions. If you cut off a corner, the image remains whole, but dimmed. A mind likewise activates a huge volume of space at the small scale of its own cellular cortex, in re-expressions of sensory input. The links to quantum observation, where an observer influences observations due to the same irreducible connections, are enough to support a credible hypothesis that the universe, as a hologram, *is* a mind. We should probably remain sceptical on this point, bearing in mind that such an 'actual' mind need not be 'real' to be taken seriously in an abstract theory that gets good answers.

The principles underlying reality, questionable as they are, are not perfect and do not lead to a single fixed or monolithic truth. Instead there is an ever-changing system of partial outlines, of which the mind and its search pattern are essential components. Experience leads us into a three-dimensional, locally limited sub-reality, when the deeper truth must be more than four-dimensional and empowered far beyond our bas-relief view. The link between your local view and the farthest future horizon is one of the deepest ideas, the *Holographic Principle*, which projects our illusion of a three-dimensional world in volume onto a two-dimensional surface like a black hole at the edge of time: a geometrically flat and energetically balanced, well-formed and in-depth frame that inverts the closed shape of a planet into the open shape of a universe.

Out there, among the grandest illusions of spacetime, the ultimate view is both awe-inspiring and terrifying. In simplest terms the indefinite conclusion of the cosmological theory made possible by physical science is a shifting conundrum of relative time; one might say *Eternity, Soon*. At this decaying edge you will need a quiet steadiness or even courage to look out upon the end, and no consolation if you carelessly think of it as the sole truth of our future. It's a necessary fact that you cannot see it – rather the futures see you, in the same perspective, and may be just as real, which at the level of mind is an even more questionable word.

That is, in an indefinite set of possible futures, many later observers at intergalactic and cosmic distances may look back in time to past events including ourselves. Because they see us, they exist to us, and our fates in the physics of their universe are in an equally indeterminate state of consideration by perspective. This is an extremely difficult and elusive idea at first, but the more you think about it, the more you realise it has to mean that we ourselves are a multitude of alternative views, which would work like a hologram.

This is not new physics. The same laws of the hard sciences still apply, with metrics that measure the light-distances between correlated particle actions. Geometry has the same strong generality that mathematicians have been working on for millennia. Nevertheless this new connection to unique perspectives in the context of a holographic universe offers a modulation that can be imagined on any starry night. Once you've seen it, you can't unsee the depth and dynamism of the spangled expanse that we usually conceive of as smooth, the sky inside an inverted bowl. It is of course immeasurably deep and built on an architecture of profound illusions. If you pick up a measuring rod while stargazing, to measure the angles between stars, the only way to get a true reading is to bend it into an arc of radius one arm's length, so every degree on the scale is the same distance from your eye. That easy curvature echoes the gravitational field, parallels the cosmological horizon, and derives as much in your nature as a finite being with weak eyes.

My point, then, is to revisit these abstract and dangerous concepts of physics in a naturally accessible way. Energies and effects, read as sight or sound, can be felt and imagined. Simultaneous realities of open and

closed observable event horizons are identical to aspects of individual fields of view that most people learn by sight as children, and which can be demonstrated to anyone by examples using touch, sound, and other sensory impressions such as your own step. If none of it is real, we approach the significance of myth.

In any case, the future need not be a life-or-death question. Mortality is a blessing that gives us all a chance to make our stand against the darkness, and fight the good fight to a noble end. It may be the same for the course of life in total, to a final end that is as right for the universe as for any child. So I don't want to take anything too seriously. As well as the myths and music there will be some funny moments, with passages approaching a kind of Zen satori that I will try to balance with scepticism and awe; and most importantly, sequences of incredible physics that I have worked on like a Formula 1 mechanic, seeking the best possible gain in understanding with the lightest possible fuel. I'll step through the deep mysteries of quantum mechanics from the wave-particle duality to cosmic entanglement in the modern ideas of matter, then explore the vast theories of special and general relativity with exotic new concepts of space and time.

As these ideas sink in, you'll realise that questions regarding the nature of consciousness and intelligence, with creativity if not necessarily free will, become important, and I won't shy away nor yet take those ideas too seriously. These three chapters then inform an adventurous vision outwards into the physical cosmos via the process of expansion, with luminous and dark components leading to alternative theories of the future of the universe, one of which I bring into focus for no better reason than that it is optimistic and open-ended; apart from the other good reason that it works.

This book may jump around a little, following a roughly historical course but more importantly getting the concepts in the right order for mental structures to crystallise. I will rely on few equations except for one chapter where I make novel science proposals, and in that chapter alone I hope you will join me in revelling in the enigmatic beauty of mathematics, as richly suggestive on the page as musical notation. Mathematical physics is an art as much as a science; although guided by the truth of observation it seeks to find sharp symmetries and pure harmonies. I plan to showcase the craft of derivation, the formal step-wise proof of physical law, in the startup sequences of the powerful engine I've re-built in words as well as symbols.

The oldest science is a very big picture. It is not dominated by any single interpretation or even set of interpretations. I have not tried to bend it to fit a worldview, but sought to show where that view aligns naturally with the science, and then filled in some of the background with the best explanations I have found or discovered for myself through long years of working with students and coal-face researchers. The resulting book is a primer on an advanced subject, which extends some significant new ideas that will be of interest to practitioners as well as the general public. In particular, people concerned with the crisis of outlook predicted by physics, especially those who are concerned that the shared value of knowledge of natural science has gone out of reach of non-specialists. Hope, made realistic by scientific evidence, is of great importance to public discourse. This book seeks to play the universe in terms that anyone can enjoy.

I'll explain as I go along my focus on mythical and musical ideas. A sceptical reader should take every novel concept initially as a soundboard of nonsense. But science is above all poetic, a system of echoes from one idea to another, from the very small to the very large. Science is the telling of a great and highly coherent story, an epic of heroic minds in search of truth; but those truths are contingent and transient, being always eventually found to be wrong, merely stories that fit a time and its common-sense. The art of derivation has been called a construction of myth, the legend on a map of spoken and mathematical reasoning. It's a fair departure to demonstrate with a fragment of poetry that tries to unite these worlds, by Canberra poet David Campbell, who in *The Heart of the Matter* seeks a true unison of life with the cosmos:

> *Stars and the singing birds rejoice*
> *In their courses with one voice*
> *And from the dreaming atom grows*
> *The chain-reaction of the rose.*

We live in a universe of calm and danger, of beauty and terror. We can choose to live in fear or hope. To begin to understand these contradictions, we need to go back to the foundations of science, to the first rational enquiries, even to the echoes of oral traditions that preceded history. There is a grand consilience of science and art, from great artworks to world-changing discoveries to statesmanship and technology, yet it is a dangerous place. To see the danger and the hope, you need to see that your mind is part of it, in either a spiritual or a scientific way, since these world-views tend to converge at that distant natural limit.

Chapter 1: Vanishing Points and Particle Physics

Dreaming again of flight between galaxies, a child of the Empyrean old kingdom finally begins to understand the burden of void space and learns, by senses similar to touch, how stars are made: it's the same echoing mist as their own hands, over deep falls of a half-seen idea that feels like proximity interlaced with distance. The entire dream-reality becomes a star looking inwards, the child filling the sky in parallel at every point, vanishing into radiation and pain…

It may be the strangest truth that we are made, not only of star-dust, but also the hidden potential of vacuum. The dust has evolved over aeons since the beginning, while the glue holding it together remains ephemeral, ghostly, a network of transient particles that seem to glance out from vantage points. The same kind of observant pattern occurs at the cosmic scale, entangling every moment with a horizon. Matter and effects like life emerge from nothing and recur at an edge, where we find a literally imaginary reality whose deep roots in emptiness are closely aligned with our own.

Maybe indeed. So when a child asks "what am I made of ?" rather than *geometry* you may just as well continue to say *sugar and spice*, *slugs and snails*, and other tangibly sticky things.

Yoda gets it almost right: *Luminous beings are we, not this crude matter*. Crude we surely are, but matter is luminous in only its smallest parts, say 5% of the total mass. We are mostly dark and dubious, heavy and mysterious, caught in an even more vast, intractable yet energetic web of vacuum that spans time and space, to and beyond the cosmological horizons. In this dappled impasto universe the particle and the horizon are holistic mirror images projected away at enormous distances across time, reflecting our own existence down to the finest minute detail in every direction to the past and future; though we are not pre-determined, or even presently determined: from the smallest to the largest scales we may remain forever unresolved.

This is all true, and great in theory. Yet there remain deep questions as to whether any of these objectified ideas are 'real' or 'separate', if even space and time are real, or if anything so indefinite can exist with the durability we need to believe in an open future. Mind and matter may be variations of emptiness in action, of everything from nothing, having only the least or luckiest capacity to move ahead by necessity of change, and not distinct from each other or from the immensity of the cosmos.

It's an intriguing and treacherous worldview, without exaggeration a realm of principles that are impossible in their own right. Building on these ideas we find a disturbing cosmological forecast: an *inflationary* process that might determine the end of the universe in a vast rip that returns to the conditions that preceded our birth, but in reverse; an unlikely, unstable emptiness collapsing from nothing to something and back again, everything vanishing into red-black and inflating forever out of sight. This is not easy or comforting to grasp: it is hard and strange, the sleight of truth behind the illusion of reality. Nor is it fully resolved, since the universe it describes is inside-out on the other side of an implausibly hyperbolic mirror, a threat to our sense of a future that itself has errors.

Modern cosmology seems determined to steal the title of *dismal science* from economics. Instead of *The Tragedy of the Commons*, an inexorable monetary inflation with environmental collapse, we face innumerable disasters due to the fragility of essential physical parameters that require fine-tuning or uncanny coincidence to produce a universe capable of sustaining life. Astrophysicist Katie Mack at *The End of Everything* cheerfully sets out the general consensus of science on the almost certain death of the universe in any one of several cosmic catastrophes, from the mundane heat death expected in any closed system, to bizarre possibilities like the decay of a false vacuum into true vacuum that would switch off our existence like a blown light bulb. In recent decades the dangers have mounted to include the apparent acceleration of the cosmos due to an accumulating vacuum energy, the ominous dark energy, which leads to a universe so stressed by inflationary

redshift as to recede entirely from view, or worse, to tear itself apart at the local seams and decay into nothing. The evidence for all the scenarios is compelling, if you ignore the contradiction that they can't all be right, which would miss not just the funny side but the open meaning of a future.

Most of these end-games will not develop until many times the present age of the universe, so they are not immediate threats to life or to our even more fragile civilisation on this planet. The false vacuum disaster is different: it could happen anytime if it can happen at all, but it's hard to take it seriously as a threat since its approach at lightspeed is instantaneous, without warning, and I wouldn't write a screenplay on the circular existential questions that this might raise. I'm more worried by the threat of inflationary scenarios to young people, who while faced with immense environmental and political challenges in the 21st century are also confronted with the science that it is all ultimately pointless. There are too many reasons for future generations to have no children of their own. It's especially hard to be forced to disbelieve the real evidence of love, life and happiness, as if all our striving will lead to nothing, that life reborn is not a natural law.

Is it clutching at straws to make the point that these terminating conclusions are only arguable on interpretations of the incomplete evidence? What would it take to re-found the science on open-ended possibilities, supported by the best data? Is there a chink in the brick wall ahead?

In fact there is more than a chink, it's more like an entire section of missing bricks, including several 'holy grails' of science, along with cold fusion and a cure for old age. I'm talking about *Quantum Gravity*, and with it *Quantum Cosmology*, the synthesis of the wave-particle detail of reality with the large-scale systems that must universally support life and opportunity: the stars, galaxies and intergalactic structures that lead us out into the unimaginable yet probably finite scale of our cosmos. All the known dangers, other than the truly inevitable heat death, are due to failures of quantum mechanics at the large scale. If the universe is to fall and die, like any organism it will be because its sub-microscopic parts have failed to integrate into survival as a live system.

It's not hard at all to build a path to a viable quantum cosmology that side-steps inflation while confirming the holographic principle. In a sense you can keep the beauty while losing the terror, again not counting the heat death. A low-heat death is not really a problem: it is so far off in the future, and such a gentle continuation of the evolutionary process, that it would not offend nature for the universe to fade out that way. It may even give us time to learn to live within our means. Cosmological acceleration is more frighteningly strange, but there is at least one inversion of quantum relativity that avoids it, and coexists with all the other solutions like a wave-tossed Ark.

It is almost conventional in cosmology that there must be a universal wave function that we can imagine as a rolling landscape of *one* wave-particle at the cosmological scale. Professional cosmologists will rightly object to the over-simplicity of that image, and I totally agree we need to be careful with language. It's a simile to convey the depth of unity, the ultimate top-down framework recently explored by particle physicist Heinrich Päs in his book *The One*. Established waveforms tend to operate at constant velocity: they don't usually accelerate due to their own cumulative energy. When there is a gradient, waveforms tend to evolve into wakes and harmonics. There are very few exceptions[1], and it's hard to tell exactly what they mean at this point in history.

The genius guidepost to this rule of thumb is the invariant speed of light, a brilliantly resolved paradox of modern science. Cosmological waves can rise in the same sense, rolling with no break-point even when energies accumulate and violate all the older laws. The resulting universe has limits and connections that produce a naturally holographic horizon, at a depth that is a direct result of the wavy dynamics of particles. For this reason it matters to ask, what are we made of?

[1] Koivurova, Robson and Ornigotti, M. 2023. "Time-varying media, relativity, and the arrow of time" arXiv:2304.08108

Uniting the wavelike radiating properties of matter there is light and gravity, whose alternate ray-like properties are as much electromagnetism and nuclear reaction as the continuity of perspective, which makes a near-complete map of the human condition in nature. We are limited beings, but by existing in the light of a star on our planet we share a grand illusion of centrality that successive waves of scientific, artistic and cultural revolution have painfully superseded over long centuries.

We are not the centre of the universe, but we seem to be, and we keep discovering new ways in which this appears to be true. Important effects tend to be the same at any given distance in all directions, like the radius of an endlessly repeated spherical pattern with ourselves at the centre. Objects seen at common distances in any direction appear smaller in the same proportion, but typically larger than ourselves – houses, mountains, the moon, the planets, sun, stars, galaxies, etc. The planets and stars do not revolve or centre on us, yet all motion is relative to each observer, as though you alone are stationary and everything else is in motion around you. The distant universe appears to be expanding directly away from *us*, as if our local space was once its own big bang. This is true for anywhere in the universe, indeed for any creature gazing outward in awakening wonder that they can blot out half the sky with one paw, tentacle, fin, articulator or hand.

The rules of perspective are present in every branch of physics, if not usually recognised as such since they are just geometry measured from particular centres of effect. That is, the directional effects of physical variables such as force, velocity, acceleration etc, are constructed on geometric arrows that point in/out and to/from specific subjects and objects. These effects and the objects themselves obey the illusions of visual perspective due to distance and obliqueness, as well as a surprisingly powerful if shadowy limitation, the eclipsing of a thing's profile behind other things and itself. Matter and energy are wavelike directions that interact, modify and obscure each other according to the same rules as sight in local space.

Every parallel line in your view converges to a single point on that line of sight, a natural symmetry that has been standard practice in art and architecture since the Renaissance, and before that the Greeks and ancient Indo-Chinese. In the modern era, we can see those lines as a holistic map from every point in your local space to the entire field of view at any sufficiently large distance, in an effect that mirrors the holographic principle while remaining a simple fact of centre-like eyes.

A hologram encodes a volume onto a surface, the 3D shape of the image in the picture plane. It is not hard to imagine this as a scene in a field of view. If distance can be flattened onto a 3D image, then everything we observe might well be on the same horizon at a common distance that is not actual space, but a more subtle comparison. We can in effect see, or imagine by senses parallel to sight, the most profound conclusion of modern physics in all the needed dimensions – that there is no depth, indeed no fundamental time or space. On Earth, the converging parallel lines of an open, level plain stretching to a blue horizon are the central illusion of visual depth perception, and in the same flat geometry an expression of the vanishing, expanding universe, as I hope to explain.

This common or universal illusion is an important control on how we can choose to map the universe, both in the ordinary sense of a map for navigation and in the deeper conventions of General Relativity, where *mappings* are mathematical connections between the bizarrely curved reality and the flat impressions we make on paper. The laws of perspective discovered in the Renaissance allow us to draw any scene onto a page or canvas plane. GR extends this facility to project a multidimensional spacetime into any other coordinates with a frame of conceptual axes.

Relativity is of course the genius guidepost referred to above, and the genius himself none other than Albert Einstein, who gave humanity the theoretical tool we must operate to understand space and time in their most natural partnership. We will go there, in words that any limited being can relate to in intuitive ways.

In doing this I hope to continue the humanisation of scientific concepts, to find our perceptual limits in the significance of physical law, to re-imagine jargon like *diffraction* in the quantum flicker-show of wave-particles. I'm pretty sure this side-project would meet with the approval of many scientists, in particular Richard Feynman, reputedly the most dangerous scientist of that era (according to de-classified security assessments) but certainly the most articulate physicist of the mid-20th century. Feynman was a big personality of the type not easily forgiven in the post-#MeToo era. It's my hope that it was his personal tragedy, the early death of his first wife to tuberculous, that drove the sexism he later tried to deconstruct in himself. The clock in her room stopped at the moment she died, so you could argue on a number of grounds that Feynman is the right man to front the rehabilitation of this hazardous science. Science history has few such heroes. A themed cross-section like this can find and introduce only the most outstanding.

In this opening chapter we look at matter perspectives at the particle level, in Quantum Mechanics. This subject can be complex or simple depending on how you look at it. Visual diminishment and foreshortening of probability amplitudes occur by a wide variety of comparisons in fuzzy and polarised particle distributions. These non-real idealisations present themselves to measurement as macroscopic or large-scale distributions of chance built on wavelike orientations and spacings, which are then subject to the same laws of distance and obliqueness as normal sight. Under observation, a particle distribution reduces to the actual probability (amplitude squared) of a particle appearing somewhere, at some speed. The point-particle eclipses every other possibility of the distribution in a kind of close-up. The square of the amplitude is the old trick of squaring and summing two sides of a hypotenuse, which is the flip-side of the triangular and circular geometry in use for perspective and particle physics alike. Squared lengths, or areas, are ubiquitously constant among the complex comparisons found at all levels of science and art.

As to the so-called *laws of perspective*, there is no official canon but a fair count from historic and prehistoric sources reveals just five or six points that we need to go through. It's a bit like Euclid's five postulates of geometry with a useful re-visualisation, in the sense that all 5+ reveal space in directed lines. I intend to take as a criteria for inclusion in the canon that such laws can be explained to someone who has been blind since birth, including all of geometry and to some extent colour.

One particular choice of mapping centres exactly on any point of perspective and also invokes directly the unexpected evidence that the universe as a whole is flat, with parallel lines that remain parallel at all distances to the cosmological horizons. It is known as an *equidistant projection* because it correctly projects curved distances by pursuing the distortion from spherical to flat. This is the same technique that we use to map the North and South Poles, by simply rolling the globe onto a flat sheet and tracing out the outline of seas and continents as they then press onto the page. This mapping when applied to the entire cosmos allows radial lines of sight to extend to a dilated horizon in such a way that the universe is spherical *and* flat, and generates massive energies that are in the right cosmic proportions, and seem to accelerate. The fact that this arises from the same fundamental collective illusion of all locally sapient life-forms can be no ordinary coincidence. It's a holistic bridge of mind to reality, with a vanishing point anywhere that an observer looks.

Re-set in the simplest open frame, this inverted worldview works out nicely, not as the fatally accelerating 'Big Rip' but as a perspective or continuity scaling that looks exactly like it. The hopeful result is a safer universe for children, if not a kind of miracle that the same solution is a theoretical form of life: a growing, evolving mind. Even deeper, and I promise no deeper than this, without falling into philosophy the nature of matter-energy is itself locked in the same dance of the mind in its physical environs. To go further we need to go back to the beginnings, at least most recently of the pre-scientific mind, and re-understand what we mean by the myth of matter.

Early human societies had very different concepts of time and space, of substance, cause and effect, of life, the world and the sky, and indeed of most phenomena whose practical scientific explanation we now understand and take for granted. Myth, passed down in spoken words and crafted images, provided the origin stories of peoples, the tools and witchcraft of hunting and survival that meant most to large families in ever-present danger, but also told of the monsters and spirits that haunted their dreams and moved invisibly in their breath. The urge to tell stories goes deeper than practical lore; we can imagine it lived as mature yet innocent legend, which we still have in the Dreamtime or *Tjukurrpa* of the Australian First Nations, the oldest surviving linguistic culture where the actual words and stories, and not just the ochre images on cave walls, still live.

The first musical forms appeared in the early stone-age, so far as we can tell. Simple hand tools make sound, as do dry skins and stretched thongs. Voices can soar and whisper in the telling of stories. Harmonies and disharmonies are discovered as voices join. There are forces and powers at work, depths of the imagination plumbed by unison, major thirds, perfect fifths. Hundreds of thousands of years before music theory we could find these by accident like kids in a band.

If ancient peoples had a mythology of matter at all, it would have been to understand the stuff they found and worked with, their tools, the grain of stone and wood, and then the stuff they consumed: water, animal and vegetable fibres, which only the unusually curious would need to understand more deeply, perhaps to wonder what *flavour* is, and *temperature*. They must have wondered at the invisibility of the wind and of the vital act of breathing, but would they have needed to know what the air is made of? Outside of ordinary experience, perhaps gazing at the moon and stars, their myths could not have sung of those mysterious lights and giant motions literally in the same flesh and blood as themselves, or the same earth that they walked on, but rather why they moved in the ways that they did; questions of substance being beside the point, which then and now really is more about how they worked.

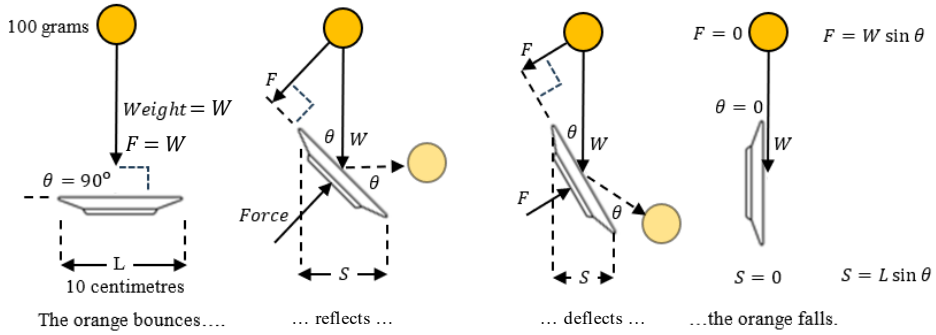
A spear has no moving parts; it *is* a moving part, the first essential technology that was originally just a heavy bent stick, then a straight, sharp one whose main task is to silently foreshorten to a point coinciding with some vital point on a target animal, and not a point on your own body in view of an attacking enemy. This required an evolution in our visual imagination, to think of a simple tool like a line approaching a point, not yet as geometry but rather a simple mechanical pattern of momentum and position. Animals using their beaks and claws know it as well as we do.

Stone and wood hand-tools, used to sharpen spears and perform many other tasks, were developed by collision mechanics rooted in the same idea of foreshortening. Glancing and direct blows produce sharp and rounded edges, and cross-cuts followed by planing and shearing actions shape and smooth a tool's working surfaces. The line of a blade is shortened to a point when you look along it for imperfections, and sharpened when you knapp a stick across it. So this, leading us to the point of a spear, would be the *first idea of perspective*; that shapes *and* effects are altered in different directions and have ideal directions that can be sharp or blunt:



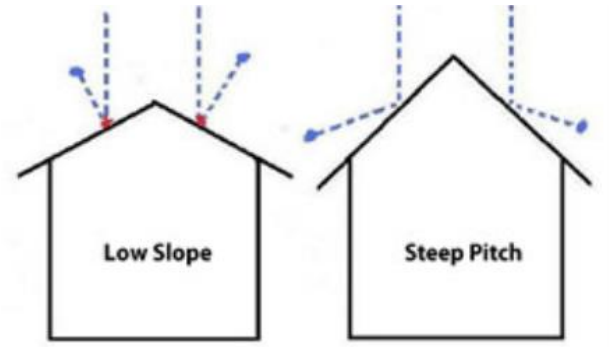
First idea of perspective: glancing blows shear the stone and sharpen it, while direct blows crush the stone and blunt it. Shear effects follow the geometry of a shallow view of the stone, with critical angles in many types of mechanical and optical effects. Adapted from https://au.pinterest.com/pin/372954412901685642/

A vertical blow, or a force due to gravity for example, points straight down at right angles to the horizontal plane. At any other angle, the resulting forces and motions occur in other directions, reflecting or projecting by foreshortening on the triangular geometries of *sines* and *cosines*. If you've ever fiddled with a calculator and wondered what sin and cos do, the trick is to see that lengths cast shadows of different lengths. If you were to tabulate the angle of a shadow or a deflected force against the proper length of an object or its weight, you'd have a table of cosines.



A weight W projects a force F in every direction other than horizontal, by foreshortening. The effect is a sine *projection, calculated as* $F = W \sin\theta$. *The length L of the plate projects a shadow S by the same rule, that is the force you can feel striking the plate decreases in the same proportion as the foreshortening shadow. The weight projects force as though visually reflected and eclipsed in various directions.*

The sine-cosine idea is exactly as you see and feel it, the measurable proportions of effects that are real or imagined lengths viewed in different directions. Any number can be thought of as a length, and so it seems any number as a physical value may project in other directions. You just decide which directions are useful, such as along the path of a moving ball, and calculate the effect in that direction with the idea of a projected shadow in the back of your mind to orient the calculation.



Direct and glancing collisions with dynamic shearing effects occur in many different branches of physics. There is a critical angle at which direct crushing and cracking blows become shearing actions that usually do less damage. There are many, many effects of orientation. http://www.roof-advisors.com/hail_damage



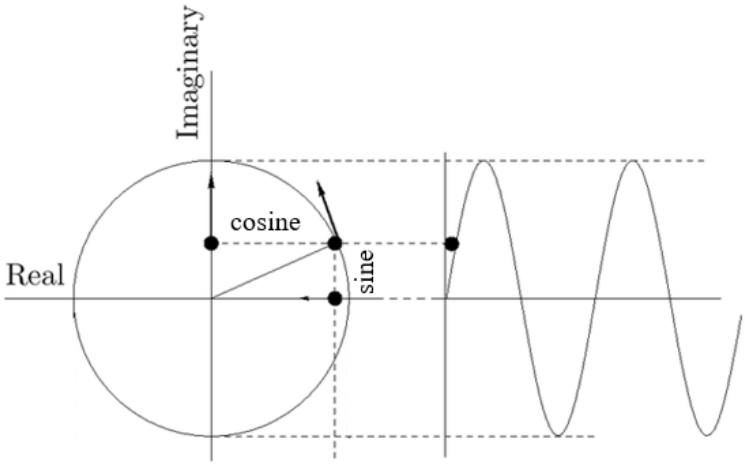
There is a similar critical angle in the behaviour of light. Here the circular edge is the angle at which submerged light 'ricochets' (reflects and refracts by orientation) into a line of sight, simulating light as a kind of particle. Photo Credit: Ranier von Brandis https://www.istockphoto.com/photo/boat-from-beneath

You could be forgiven for failing to see the point in comparing visual and ergonomic effects along the lineations of a common trigonometric function. Like OK, so there are triangles in oblique lines of sight and the natural deflections of force. So what?

Mathematicians I have known are seldom poetic in their view of the world. Even the mildest are not exactly hard-nosed but certainly practical-realist and very sharp in their recognition and dismissal of trivia. A universal exception to this firmly grounded view is the sheer poetry of their understanding of trigonometric laws, which unite entire branches of thought under one umbrella.

The idea of a sine or cosine function is that it is a projection of effects around a complete circle of 360 degrees, the original idea of a wheel, with consistent signs and rotations that apply in almost every branch of practical mathematics. The circular origins of trigonometry are a mechanism of almost universal application to everything from the impacts of force to the fluctuations of seasonal climate, profoundly rooted in one of the most central ideas in physical and natural law: a wave.

In modern physics we don't use the sine or cosine function alone as a table or calculator function. It's easier and simpler to do the whole thing in an entirely new domain of reality where numbers exist not on a line or axis, but a plane of two axes at right angles. In this *complex* plane the numbers have a natural freedom to move in circular motion like the hands of a clock, with the complete expression of a wave undulating around the centre of the plane. It's a strange fact that circular motion in this sense produces the exact mathematics of wave motion as measured in sound and light, tying together the ideas of impact and perception with the deep harmonic idea of change and recurrence, the original possibility that much later in history became a wave that is also a particle:



The rotation of a point on a circle in a Real/Imaginary or complex *number plane defines a natural sine-cosine wave. https://ccrma.stanford.edu/~jos/fp/Plotting_Complex_Sinusoids_Circular.html*

The sine wave, as it is known, is *linear*, in the sense that sound and light and other sine waveforms can be neatly added together to make a clean mix of primary, secondary and tertiary colours, or the harmonies of music, or a well-tuned engine, or a fair seasonal climate. Linear waves are a common feature of phenomena that turn out to be useful or aesthetically pleasing for the tidy summation from simple to complex. They stand in contrast with non-linear waves, such as ocean waves, that add together with a much less predictable complexity, a turbulence of rogue waves and undertows. Fortunately the linear wave is by far more common, so unless you're interested in complex fluid actions such as the surf or the tides, you can live without knowing much about it.

Linear waves are in fact so ubiquitous in nature and so central to mathematics that there would have been a problem if physics, the most mathematical of all sciences, had *not* eventually discovered that particles are also necessarily sine waves or their sums. This is a long way ahead of stone-age technology, but it is an awesomely deep principle that the same ideas of force and direction lead to the ideas of music and colour, all of them founded on the idea of the wheel. The real and imaginary split focus of the complex number plane is very profound, as we will see.

The wheel was not so much invented as discovered. It must have been obvious to anyone working hard enough to survive that large round stones were much easier to move than even small square ones. To roll a smoothed log as a primitive wheel was a necessary precursor step before we could up-scale the stone industry to architecture, but the properties of the circle, independently developed in Sumeria, India and China on this ubiquitous symmetry, were endlessly varied and powerfully useful: smoothed stones, cut logs, dried clay and leather balls, icons and toys and weapons that could be rolled downhill, before being reinvented in wood and yoked on an axle to make a carrier.

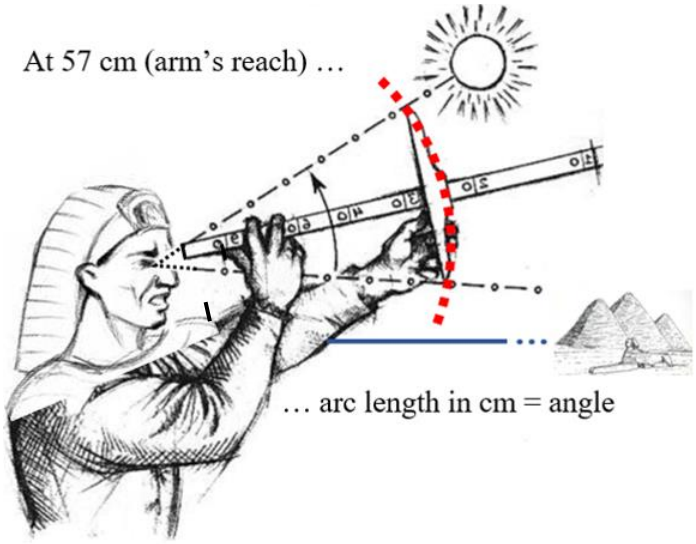
Stone-age crafters definitely did not need to invent the idea of a circle, it was visible in nature. The droplet, the rainbow, the full moon above the horizon or the horizon itself, the limit of a complete view on a grassy plain or Polynesian canoe. Not only in sight but in dynamics, the rolling action being one of the fundamental symmetries of nature, the physical *arc length* that is measurable with a land-measuring wheel, or a circular device to eyeball angles between stars. The wheel was thus the *second idea* of perspective, the uniform action and concentric common element of a view in every direction, when circles and straight lines became the first organised archetypes of geometry:



View of a circle and its centre, then of the circle seen from *its centre. The circle, now a horizon, continues on into your periphery, and can only be seen by engaging with the local space, that is by* turning around. *It's a usefully simple experiment to place a ruler against an open sea horizon and decide if it is straight.*



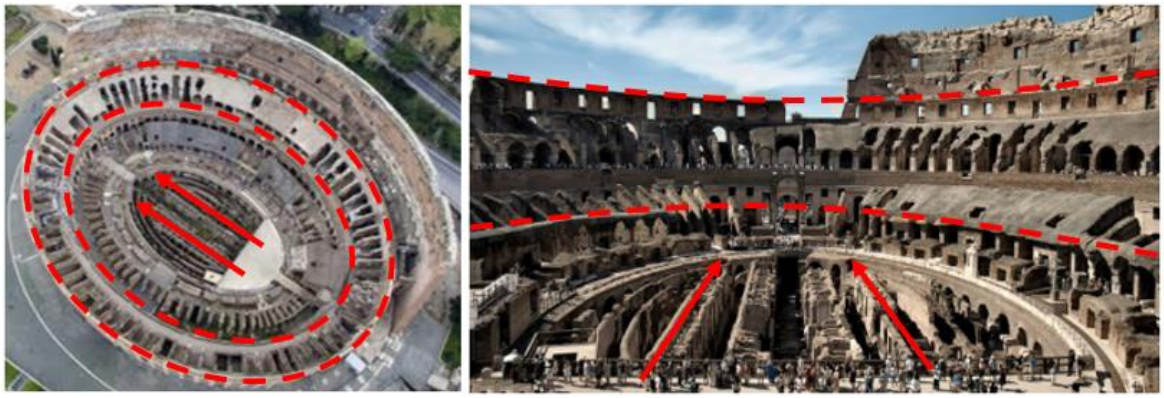
A surveyor's wheel measures a true distance *by riding smoothly over the landscape (radius ≤ curvature). Wenzel Hollar (1607–1677) - Detail from Ogilby,* Britannia Vol I (1675) *Frontispiece.*



An astronomer's staff when set to 57 cm *measures a true angle along the arc length of a circle, giving a reading in cm as the angle in degrees.* 57 *is the conversion from degrees to radians, the physical angle as we see it within a typical arm's reach. Adapted from* https://ym-ocean.com/2025/02/10/the-jacobs-staff...

These first technologies used angular effects around complete circular profiles. Not all stones can be usefully worked from every direction, but it's interesting to try for the same curvature – what

you get is a sphere, like a jewel previously seen only in droplets; or cutting a log to make a wheel, like nothing in nature and so incredibly useful it became the most abundant artefact in the human world. Craftsmen are the parents of technology, and hence physics, which emerged as an ideal of the wheeled cart industry and also by every experience of circular and spherical effects all around:



Spherical distortions of a point of view due to obliqueness of the view are a common visual experience. *https://www.rome.info/attractions/colosseum/*

As stone-age groups settled into the agricultural societies made possible by the wheel, along with the mill and the animal-drawn plough, hot furnaces and metals, their mythologies matured to become cosmogonic answers to questions their forebears had asked of the spirits. The first large-scale structures emerged with sufficient understanding of materials such as granite, ivory and marble to balance fine or gross forces and build civic and religious frames; yet there are no records or evidence that any thought was given to the nature of matter, though it's certain that we were obsessed with the view and especially the ideas of direction and distance. Building materials were solids with plain and practical internal textures, more importantly arranged on the large scale to align with the movement of the heavens and its changes through the seasons.

Art during this era was monumental but also regimental, and flat in many ways, with no sense of depth. The first hieroglyphic languages crystallised stone-age cave art into representative figures with inherited meanings but very simple stylistic laws, stick figures ideal for symbolic patterns. The expressive anatomy of Greek sculpture and design were yet to come, along with alphabetic written language systems that began evolving much earlier, and became simpler and more flexible as well as more expressive. Mathematics progressed beyond counting tallies into ways of adding them into namelike signs, ordinary letters of the alphabet, a clever trick that cuts down the number of marks you need to transfer across. The need at that time to solve the solutions of roots, like the lengths of diagonals in a building structure, was hampered by the arbitrary character of tally names. Machines like the abacus came to the idea of decimals, the reduced marks recurring in the same 10s as our hands, and the mathematical solutions for many complicated problems began to emerge.

Musical forms evolved into sophisticated instruments, lyres and horns, that were typically played either solo as single melodies rather than chords, or in unison on the same melody line, with few attempts at harmony other than ritual mixtures like call and reply. Drums remained, and are the first root of harmony that we keep rediscovering and misunderstanding by accident. We know this because it is the most natural progression from simple to complex as we learn how music works.

Likewise architecture and the monumental culture of the built environment, its culvert sewers and amphitheatres, were still simple though better than monolithic, and evolving. The rising–setting of the sun/stars provides the best alignment of houses, constructively indicating east and west at 90-degree angles from north-south, the direction of the highs and lows of the sky. The sun, solstice and circling stars, on a luminous surface that is curiously both spherical on the large scale yet flat wherever you look, became architectural guides to the placement of ritual altars in Stonehenge and spirit windows in the Pyramids. The earliest civilisations continued this pragmatism in the

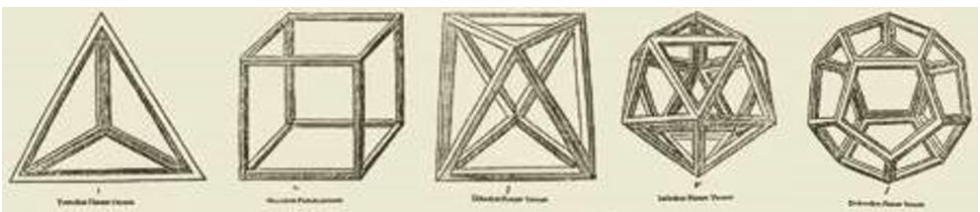
utilitarian designs of gates, palaces, hanging gardens and towers, with little thought given to questions as to the *why* or *what* of the materials themselves. *Stone is stone*, they would have said; an attitude that persisted for hundreds of millennia and might have continued into the present age were it not for the awakening curiosity of one particular tribe of farmers and sailors whose empire-building was delayed in favour of schools and marketplaces for free people.

A blink of the eye ago in the timeline of human evolution and myth, the Greek philosophers were the first to think about the nature of matter, and to come essentially to the correct modern idea.

The Greeks by no coincide also first explained the laws of harmony, by the work of the school of Pythagoras in the foundations of geometry. The rule is simple: waves harmonise if they are whole multiples of each other's frequency. Physical instruments such as plucked strings produce wavy harmonic sounds as pressure and tension effects inversely proportional to their lengths in multiple ratios, much like the as-yet unrealised proportions of distance and apparent size that later became evident in visual perspective. Pythagoras intuitively realised the depth of this idea and regarded musical harmonics as the deepest of all mysteries, the *Music of the Spheres* as he or others like him called it, and he swore his scholars to secrecy, a massive setback for public science. These simple ratios of lengths and energies eventually became models of wave structure in particle physics, although the injunctions of the school hampered early realisation of that very deep truth.

The Greeks were also the first to propose rational laws of cause and effect, with real things existing like stones effecting each other at all scales, and as a result imagined matter as divisible into lumps: analytically soluble, but not infinitely so. Just as you cannot slice a block of cheese into arbitrarily small slices, which is exactly the logical and to some extent experimental route they took, the Greeks more or less *had to agree* with Democritus (c. 380 BCE) that there is a limit to how small the smallest stone can be. It must be so small as to be invisible, but still there; a puzzle that could be partly understood by salt crystals dissolving into heavier water. We can still imagine these tiny, hard bodies, which they called *atoms* and enlarged as an idea to propose definite properties, with spiky or smooth geometries that explain the sour or sweet substances that are made from them.

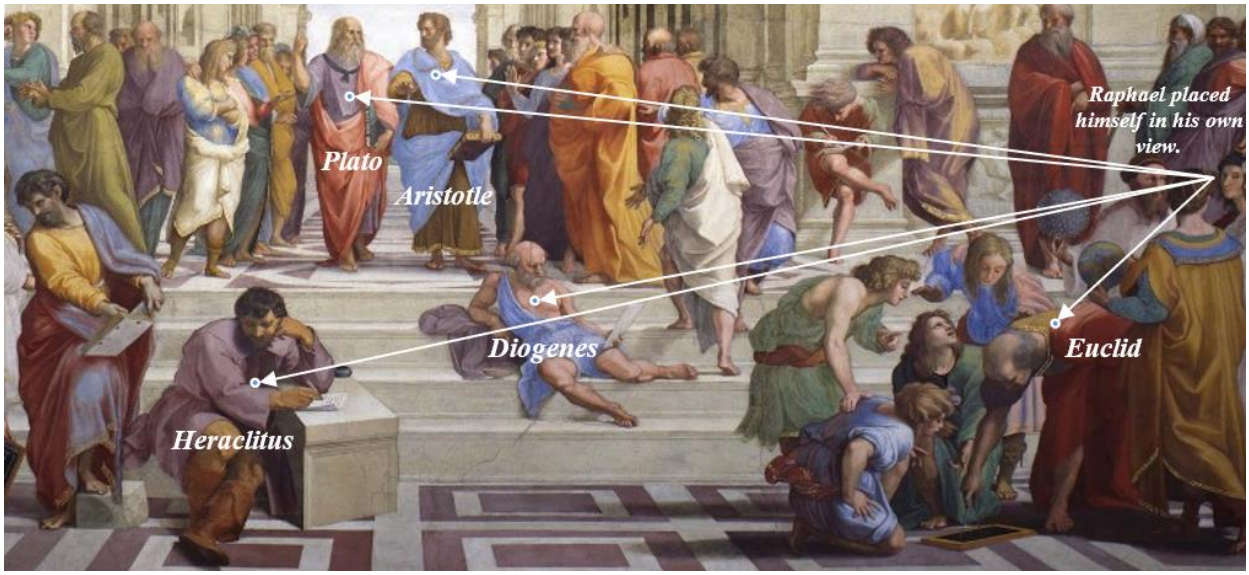
So, reasoning by intellectual argument alone on the finest divisions of matter that did not trigger useless argument about the arbitrary limits of nothing (due mainly to Zeno, surely the coolest of all philosophers), these original thinkers argued that *a-toms* are *not-divisible* but move about in an empty space called the *void* (ominously, to a modern mind), and they showed by the ideal shapes of diamonds and droplets how these rigid idealisations could come together in different combinations to make the stuff we know of: earth, water, air, fire, and the purest ethereal emptiness. These deep geometries became cosmologies, theories of musical harmony and of the human soul, auguries for confused kings, and lodestones for all the things we could not understand.



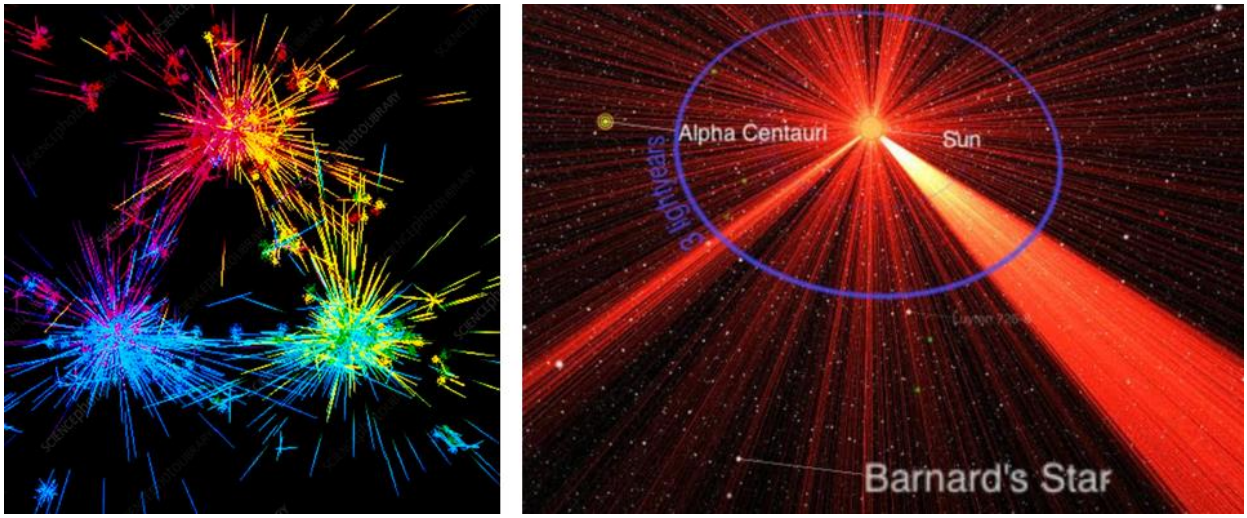
Leonardo da Vinci The Platonic solids and their elements*: Fire, Earth, Air, Water, Aether.*

Democritus probably did not realise that the atom concept was just the *third idea* of perspective, which is a point-like centre that relates by arrow-like directions to other points in a surrounding space, forming a spherical geometry and a physics at the same time. The ideal zero-dimensional point was a revolutionary realisation that everywhere or anywhere – exactly here, say – has a subtle zero-ness to it that is patently non-zero by its directional relations to other things. The first points we might notice that have this property are ourselves and our interactions, since on any scale larger than a room, a marketplace for example, we are merely approximate blobs politely observing each

other in a symmetrical space along lines of sight that are different for everyone:



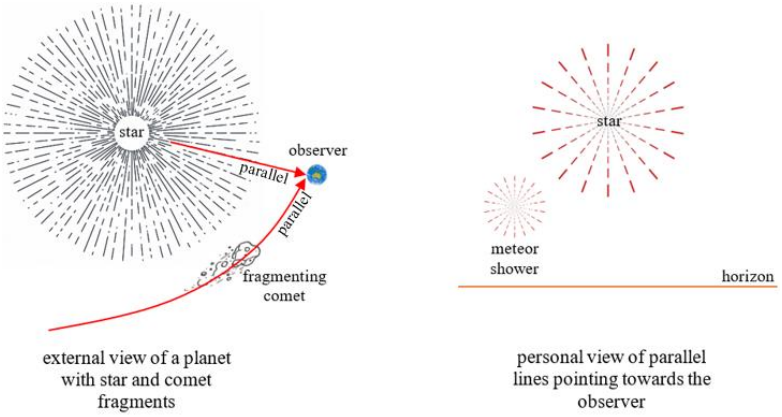
The complete view of a scene is a system of related viewpoints, equally true of atoms and stars. Detail from The School of Athens *by Raphael*



Left: Visualisation of the quark structure of a proton. https://www.sciencephoto.com/media/2092/
Right: Directions of the known exoplanets from an exo-perspective. Image: Hanno Rein "Exoplanet"

The Greeks had experimented with visual perspective as early as the fifth century BCE, first in theatrical scenery and later in the proportioning of important public buildings such as the Parthenon. They understood the foreshortening of circular shields into ovals, and of spears into the eye. They tried gradations of hue and saturation in set design that created illusions of depth, then later realised they could better reveal subtle ceremonial and architectural details by constructing in smooth curves that broke up the optical illusions of perspective that this highly aesthetic culture had noticed in large public buildings.

There are almost no straight lines or right angles in the Parthenon, and indeed the concept of a point had by then barely escaped from the arcane thoughts of Euclid and Pythagoras; yet it emerged in the atom theory as a zero-dimensional centre, as we are centred, with linear geometries that have no meaning unless connected by lines in an architecture. The straight lines of geometry would be meaningless if our cultural biology did not communicate with sound and see by light, both of which are waves that travel in straight lines radiating spherically outward from a source. Crucially, those radial axes approach the eye on nearly parallel lines, which we see as the same radial pattern:



Radiant and parallel lines. Any system of lines pointing towards an observer are perceived as a radiant pattern. The rays on the right are not actually radiating, but parallel, and fill not the sky but just the light-capture width across the pupil of the eye. Parallel rays are the basis of the sine projection.

Perspective developed independently in many cultures. Ancient Indo-Chinese and Japanese artists developed their own oblique perspective techniques from the second or first century or earlier. Arabic and Himalayan cultures tended to abstraction, with their own links to natural philosophy. In mapping the view, humans are exactly reflecting the perceptions of most mammal species, a view not far dissimilar from that of birds, reptiles and fish. We can imagine any terrestrial or even extraterrestrial species equipped with any number of eyes and a small body will see the same basis of a radiant-parallel pattern. At its deepest, it is a spherical symmetry innate to observation.

It is probably impossible to imagine life without perspective or geometry, so fundamental is it to ourselves and our surroundings as light, sound, and in the downward direction, gravity, which also connects points (planets and stars) to each other by the shortest paths even in curved space. But jumping forward several millennia to see how this is now understood, we are fortunate to have Frank Wilczek, a Nobel Prize-winning physicist whose ideas in *A Beautiful Question* provide a strong bridge between the sciences and aesthetics of nature. Wilczek almost sings it: that life responds to symmetry with a mathematical biology of ergonomics that is as inevitable as evolution. We recognise symmetry, and by it the beauty of a physical world that persists by natural selection of balance, alignment and grace as precursors to efficiency and hence survival.

These symmetric native geometries were discovered or re-invented for practical and mystical reasons, stemming from the parallel development of artistic and architectural techniques and ultimately inspiring the development of complex three-dimensional mathematics in the schools and academies under Thales and Pythagoras and many others. Purposefully enabling the cities and libraries and marble sculptures and piped sewers and all the messy, arty advances of the ages that followed, perhaps their greatest achievement was to prove that the core of human progress is idealised and insightful speculation, inspired by beauty, symmetry, harmony. It was only incidental, as an embarrassed afterthought on the limits of experiment, the slicing of a block of cheesy matter which must be a small piece of the moon and hence the stars, that the atom seemed inevitable and had to share the real natural geometry as the soul shares it with the Gods.

It's also hard at this distance to imagine the older system of thought that didn't have atoms. That alternative idea, of continuous and smoothly unbroken matter with no finest division, must have influenced the human imagination in ways that we probably cannot reconstruct from this fossilised concept. Continuities of time, space and energy seem to be natural and common-sense in the modern world, like fuel in a pipeline, but the related notion of continuous matter has been lost. It has been millennia since we last thought that way, and centuries since the new evidence for an atomic theory began to emerge. The intervening centuries have no single strand of thought, and in fact the best ideas were persecuted by dogma, driven underground, lost. It has taken us as long to re-discover that the atomic ideas were not just another ancient Greek myth.

The Middle Ages had their own tortured mythologies of matter that are as hard to understand for their magical inventiveness as for their dictatorial rigidness, further distinguished by their complete absence of evidence or even the idea that evidence should be necessary. Concepts such as the transubstantiation of consecrated bread and wine into the body and blood of Christ were accepted doctrinal truths, while the transmutation of base metals into gold, or herbs into panaceas for disease, or stone into an elixir of immortality, were suppressed. The political risk was that some commoner in a basement laboratory might invent a means to subvert power from the Church and the State by controlling the flow of money and indulgences, destroying the powerful untruths of widespread poverty and eternal hell-fire. Likewise music and art were strictly regimented and stark other than a desperate light of devotion to a fallen higher culture. The entire period is a junking of truth with lies, best ignored in a science history except to bluntly dismiss just about all of it.

Both science and art were reborn – obviously – during the Renaissance, in a parallel evolution that has recurred in many stages of history before and since. The titans of this era valued natural observation and the personal human being as much as the pure ideas of God and philosophy. Between 1415 and 1420, the Italian architect Filippo Brunelleschi developed formal techniques of linear perspective to represent three-dimensional objects on a picture plane, using vanishing points, ground planes and horizon lines that are the *fourth idea* of perspective, with diminishments that were belatedly realised as a *fifth idea* that should perhaps have been first or second. This sudden perception of smallness with distance and its expression on paper was a technical leap probably as great in the minds of the public as the 20th century hologram, but with much simpler and more publicly accessible tools. Art and science exploded in popularity, to the envy of our times.



*Domenico Veneziano c*1442 – 1445 The Annunciation *from the St Lucy Altarpiece*

It's interesting to see the early mistakes and wrong-headed simplifications that young artists (they typically did not live long) produced. You can project distance with some part of the viewpoint held constant, to make it easier to plot on a wall. Perspective representation is in some ways just a matter of taste. Since the art revolutions of the 20th century it's been possible to choose to reject perspective representations entirely, but elements of the same continuity law remain in all good abstract art. Harmonic perspective, a kind of balanced ideal, represents objects in a landscape at apparent sizes that are whole multiples of each other, a frame that genuine artists learn to recognise as children and delight in demonstrating to their friends, who wouldn't get it otherwise.

From about 1470 the extraordinary career of Leonardo da Vinci fused the principles of art, anatomy, astronomy and engineering with perspective techniques, in what was perhaps the greatest outpouring of far-sighted invention and creative mastery in history. Da Vinci's *Vitruvian Man* placed the human figure equal to geometry in an effect that he explicitly (if cryptically) intended as an intersection of the human and divine. Any child can still rediscover this as they grow into the dimensions of their own bed.

Music in the Renaissance made essentially the same discoveries in harmony, revealing the depths of polyphony and the subtle use of ephemeral meanings of musical phrases, like a hidden, half-understood language. Many voices and many more new instruments joined in multipart dramatic recreations, rose toward the sky, fell in rain, and created vistas of the imagination like ships and mountains with a powerful movement and deep immersion in the listener. To hear these new sounds after the dark ages' stodgy hypnosis would be as rock 'n roll and hip hop to our own innovating ears, but the connection of science to art is perhaps at its closest here too. We created those new sounds and the instruments to produce them out of the same exploration impulse that led from the Renaissance to the Enlightenment and beyond.

The 16th and 17th centuries continued the fusion and re-fusion of art and science. René Descartes developed algebraic geometry with architectural corners on paper, and then Christiaan Huygens, a giant of science who followed Galileo Galilei and preceded Isaac Newton, used circular geometry in collision and wave theory, and so infused in both laws the first and second ideas of perspective. We will return to Galileo and Newton in the next chapter, where we can begin to appreciate that relativity *is* perspective, and in Chapter 5 the deeper significance of Huygens.

Resurfacing after the Greek and Medieval dark ages, the atomic ideas of the Scientific Revolution started from scratch with more advanced methods of observation, experiment and analysis than the pure intellectual reasoning of Ionian philosophers or their Roman and Medieval shadows. Geometrical, ecclesiastic and alchemical myths of the atom faded with native witchcraft while the methods of algebra and logical elimination were slowly realised: the naming and ordering of elemental substances by the similarities and differences of their properties, the whole-number ratios of their mixtures, combined with increasingly sophisticated mathematics and equipment.

The unified dynamic and gravitational laws published by Isaac Newton in 1687 are studies in perspective. The first, second and third laws of Newton's mechanics are beautiful consequences of point-line-arrow thinking, with many deep symmetries. The inverse square law of gravity that guides the planets is equivalent to the relative profile area of a planet: force diminishes with distance as the square of apparent size, a geometric work-out that we'll come to, which in turn diminishes in the same proportion as balancing forces at those distances. The boast of Archimedes, "give me a lever and a place to stand and I will move the world" is strangely redoubled here: the leverage of a planetary machine and its gravitation at a distance are visually correlated.

Electrical effects that had been known since ancient times were measured and studied after the surprising discovery that vital shocks could be stored in jars and conducted in metals to stimulate living and dead subjects, like frogs and *salon* socialites. It was hazardous work before insulation was devised, by Benjamin Franklin when he flew a kite in a 1752 storm; the handling end of the kite-string was kept dry so that the live end could key into a Leyden jar. Charles Augustin de Coulomb in 1785 found that electric forces between charged objects diminish as the inverse square of distance, again in the same way as perspective-diminished area.

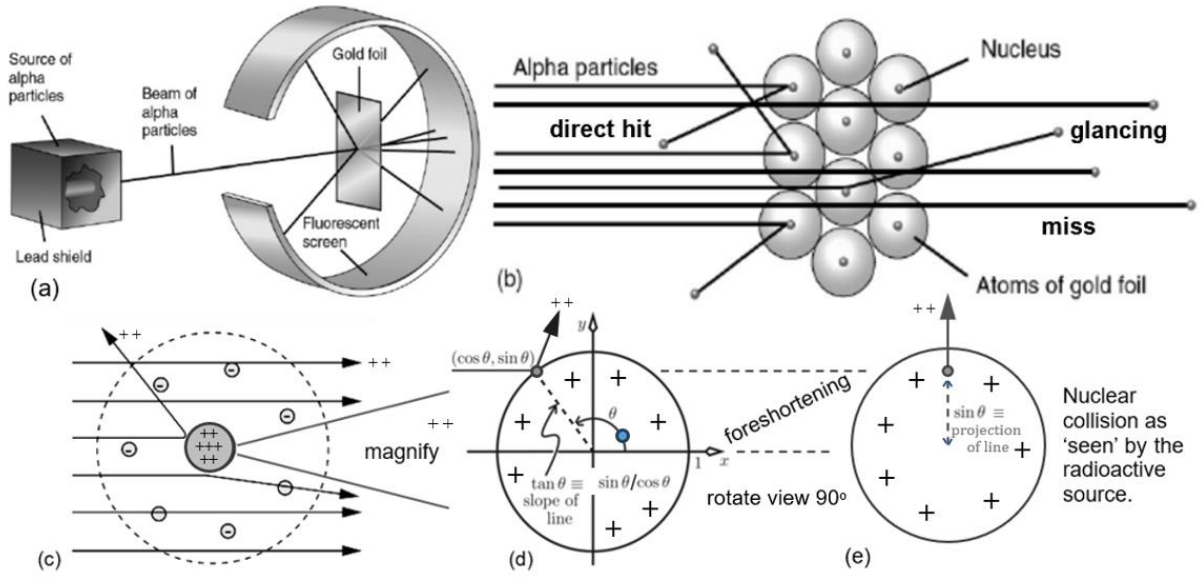
The atomic theory at this time was not thought of as anything more than a fanciful myth, which made for a pretty serious delay of several centuries before this most useful idea became accepted. In 1803 chemist John Dalton realised that the combustion of 1 part oxygen with 2 parts hydrogen to form 1 part water vapour could be explained if the parts were Greek atoms. More complex molecules did not fit the pattern, yet Ludwig Boltzmann based his 1877 statistical theory of heat on gas atoms in chaotic motion, a model that was panned so badly that in the end he killed himself. Regardless, heat and pressure were tamed by Boltzmann's *Entropy Principle*, that the total disorder of used-up waste energy in the universe can never decrease in total. There is a powerful exponent of possible arrangements of energetic particles in motion, a rule that explained not just hot gases

and fuel, but thermal and material waste. Chemistry and physics replaced alchemy and witchcraft with the periodic table of the elements and the raw principles that explain its step-like structure.

The unexpected truths of the modern era emerged in stages, in parallel with new and powerful ideas, impressively proven predictions, incredible technologies; dangerous energies, machines and medicines that defied magic and mythology. Much of it came from the emerging atomic and subatomic theories, in chemistry and electronics, in radio and radar. The atom, it seems, is essential to the advances we now know are possible. The last sceptical refuseniks of the atom theory died away in the early twentieth century, and their ideas were far from coherent, but they fought the hard fight of stubborn empirical disproof that all genuine sciences must survive.

The exploration of electricity and magnetism and their unification as electromagnetic fields in motion, not just subatomic particles but light or radiation in all possible colours, motivated a scientific culture of incredible precision, with instruments capable of probing and measuring the microscopic and then subatomic worlds. Two of the legendary narrative moments in experimental science came with J.J. Thomson's 1897 detection of the electron, followed by Ernest Rutherford's lucky accidental discovery in 1911 of the atomic nucleus. Thomson used vacuum tube technology to isolate the tiniest object known to this day in any class of experiment. Rutherford's plan went deeper into the unknown, probing gold foil with radioactive particles, in theory a gossamer web of matter, only to have it rebound against his instruments "like tissue paper deflecting an artillery shell". For that one strange moment, when Rutherford and his team must have laughed nervously, the nature of matter at the smallest and most fundamental levels seemed very surprisingly definite.

Rutherford, without performing an actual backward leap, was relying on the first stone-age concept of perspective, the idea of oblique foreshortening due to observations or interactions that occur at some acute or obtuse angle. A metre ruler looks shorter when you hold it at an angle to your eye, to a limit of zero length when it points straight at you. Rutherford realised that the very strong signals of something hard and lump-like in the imagined soft matter of a gold foil were due to collisions happening at a sharp angle as though in a direct hit, with a fuzzy range of weaker signals due to glancing hits and more often than not total misses. The same geometry, as we recall again from high school the sines and cosines of angles, applies to foreshortening and collisions, both of which had been understood centuries before Rutherford chanced upon them:



Rutherford's experiment: (a) *lab setup.* (b) *beam collision detail.* (c) *atomic environment.* (d) *nuclear trigonometry detail.* (e) *source view. Updated from Carlos Bertulani* https://www.researchgate.net/

Oblique, circular, point-line, horizontal-vertical and distance-diminishing interactions are five of a fuzzy number of ideas that link physics to perspective, which I'll try to set out systematically as

I go along. The rules or laws of perspective are seldom (if ever) organised into a textbook canon so well-ordered as the five Euclidean postulates, which are naturally arranged by the involvement of points, lines and comparisons in a mathematical progression. Perspective has always been more creative-organic than geometry, and every school of art has a different ordering of the rules of perspective. The canon I will develop is not meant to be restrictive, but ordered in a sense that I'll work out as I write them. So far it looks like it will develop as a loosely historical exercise.

Rutherford's technique of blasting known energetic particles into unknown depths to measure the resulting echoes became the basis for a deep exploration of atomic and nuclear structure. This accidental collision with the atom, like striking a hard nugget of something foretold in ancient myth, was a resounding victory for the power of both Greek philosophy and materially rational modern science, but almost immediately things became stranger: subatomic particles behaved in ways that could not be explained by the idea of lumps of matter such as sand grains or dust motes. Even before that, familiar wavelike effects such as light had been weirdly found to behave more like particles. Rather than being definite solid objects or even wavy actions, elementary waves and particles turned out to be uncertain, literally complex in all senses, and extremely difficult to understand in terms of common sense or even industrial physics at the human scale. The usual idea of a particle is that it should be simple, a small lump with no moving parts. Yet simple it ain't.

Max Planck, a mentor of Albert Einstein and the father of quantum mechanics, was in 1900 the first to realise just how catastrophic these departures were, and to understand (or at least theoretically derive from scratch) how they could be resolved. In doing so he found that many of the most fundamental aspects of nature, such as light, energy and momentum are divided into discrete smallest pieces just as matter is sliced into subatomic nucleons and electrons. Planck calculated the smallest possible quantity of *action*, the quantum factor now known as Planck's Constant, which is still the smallest natural number in common use in any branch of science.

It isn't easy to translate Planck's reluctant discovery into an explanation in plain language, with or without a diagram. Planck's focus was far from poetic. His main task was to understand the appearance of light emerging from a pinhole into a blast furnace, which has the same pattern of intensities as the light of a star. Both of these types of light sources were given the name *black bodies*, because the emission of radiation from a sufficiently pure source has the same spectrum as the absorption of radiation by an ideally black body that absorbs all frequencies of radiation that falls on it, from every direction. A normal star is not black, but it absorbs all the light that falls on it, and reflects nothing. The spectrum of a star or cavity or black body of any kind depends only on its temperature. Even black holes are black bodies, and as it turns out, extremely cold ones:



Black bodies. https://acktar.com/an-in-depth-guide-to-understanding-black-bodies/

Scientific revolutions seldom happen in isolation form the general progress of culture. The decades around the turn of the 20th century saw a parallel foment of techniques and theory in the art world. The rigid methodisms of academy had given way to impressionism and were about to be rocked by expressionism, then cubism, in a bold assault on how we see and imagine the world.

At the turn of this tide we find Paul Cézanne, the Master of Aix, whose artistic vision was matched by his ability to communicate in words what he was seeing. Cézanne explained artistic observation

in terms of experience *la sensation* realised by perception *le réalisation.* You can tell that Cézanne was seeing something else, something deeper, but rigorously true in words to what he saw, an echoing world of motifs that recurred in any scene, with subtle differences by direction and colour.

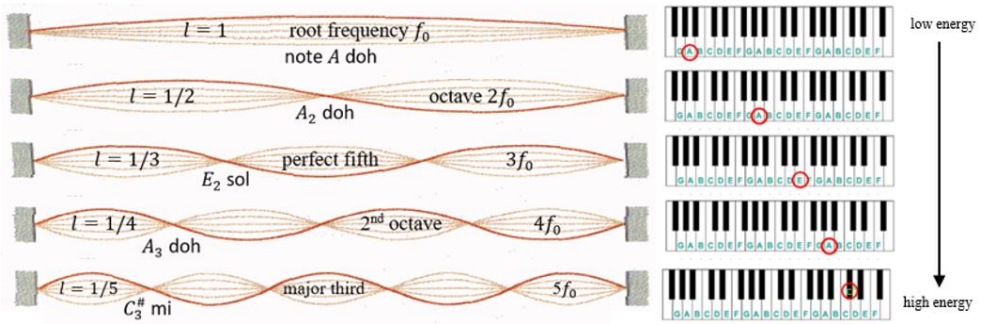
Cézanne understood best of all that continuity is a visual concept: you can't produce mature images without figuring out how to connect and unite the disparate parts of a picture, how to smooth and join an edge even when it seems as crisp and disjunct as a horizon. Cézanne was followed by artists who saw so much more by these ideas of sensation: intimate connections and fragmentations, viewed from many directions and alive with the half-seen buzz of trees and people whose rhythms are stronger in oil-canvas visualisations than silver oxide film:



Mont Sainte-Victoire, Left: *Paul Cézanne, 1885.* Right: *Marsden Hartley, 1927.*

Cézanne's concept of recurring motifs is one of the deepest secrets in art theory, not easily seen without long, intense study of nature. It is a subtle reveal of illusions, a depth contained as the nearby is figured again at distances with rules by which the motif can transfigure, sculpted in two dimensions with colours balanced by harmonies and continuities. There is a deep and simple logic that tallies in lines and planes, from the shoulder of a hill to the crook of an elbow.

This echoing of a common property by many kinds of systems is as much a hallmark of scientific as artistic discovery. We find the same rules apply, producing similar graphs like a rhyming phrase addressing love and then rivalry in the same terms. Planck found he could better understand the open surface of a star by considering the closed surface of a furnace, a cavity with a fixed internal size that limits the lengths of light waves that can fit by whole numbers of wavelengths inside that space. You can divide a cavity into halves, then thirds, quarters and so on down to whole-number billionths, corresponding to whole numbers of wavelengths that can span the cavity. This operates like a musical instrument, emitting not just notes but chords that carry the timbre of a given type of instrument, its sound, as a balanced combination of harmonic multiples of the root frequency. In the case of hot light in a furnace, the multiples go into trillions beyond ultraviolet:



Natural harmonics are simple multiples of a root note f_0. All possible harmonics exist at the same time in a vibrating instrument, body or hot cavity. A furnace contains these and many higher frequencies in diminishing ratio. https://www.researchgate.net/figure/Standing-waves-particles

If you assume that those wavelengths *are* the radiation, and the shorter waves have larger divisors in the fraction, that is larger numbers dividing the cavity into larger energies, you effectively

quantize the waves, a process that in the limit of Planck's reasoning necessarily divided it into discrete lumps of energy: photons, in the simplest model one photon at each nodal oscillation of the wave. These travel at the speed of light in streams whose energy is conveyed by the density (intensity) and frequency of collective and individual particles. Later it was realised that conditions similar to a furnace's whole wavelengths apply also in the dimensions of a star, requiring an ordering of its properties by the inconceivably huge number of wavelike electrons that a typical star contains. Each electron in a star is neatly lined up in its own unique energy level, a function of how many whole numbers of the particle's wavelength can fit into an entire star.

In seeing this rhyming parallel of a furnace to a star we are trying to understand the first great revolution of modern physics, the wave-particle duality, using the word 'revolution' in multiple senses at this point. The total effect of a complete rotation of point-line and oblique interactions through 360 angular degrees – clock motion in other words – uses sine–cosine trigonometry to form a wave by projecting a clock hand's shadow onto an axis. The $9 \longleftrightarrow 3$ and $12 \uparrow\downarrow 6$ carry mobile wavelike graphs of the eclipsing shadow as the clock hand turns.

This is one of those moments in high-school maths where even if you're paying attention you have to go wait, what? It's very surprising that a set of angular projections around a full circle can be plotted as a wave shape that turns out to be *exact* at the level of particles, or point objects. This is a fairly complicated diagram even as an animation (see the hyperlinks in the appendix) so if you haven't come across this idea before you can rightly treat your incomprehension as outright utter disbelief. So it goes for the whole idea that a point-like phenomenon can be a particle and a wave.

After Planck it soon emerged that not only energy, but momentum and all the other tools of physics must come in discrete packets. This neat division into fundamental chunks of anything useful, that Einstein in 1905 named *quanta* in agreement with Planck, was unusual because by that time the alternative to atomic theory, the idea of continuity, had so thoroughly worked its way into scientific thinking that it was an essential part of the public marketplace of common sense: the idea that there is a smooth continuum of any effect, such as energy and momentum, with no atomic divisions or fundamental smallest scale. These varying quantities were thought of as continuous, that is they were supposed to be take every possible value on a complete number line. Planck concluded reluctantly, as though destroying a cherished myth, that energy comes only in discrete amounts, stepping between certain limited values on a number line that consists of only those allowable values, and nothing else. More than concluded, he *proved* it to be true.

This implies among other things that a spinning object, such as a child on a piano stool, can do so only at certain speeds, and that any transition between speeds as the stool winds down is not continuous but step-like. There is a threshold of physical effect between macroscopic and quantum levels, a ramp scaled to a stair by Planck's derived physical constant: $6.63x10^{-34}$, a 6 preceded by 34 zeroes, an immensely tiny smallest part of any effect, any trajectory or action. But think about it: as a spin winds down, each step is distinct, and there is no actual step; the child moves from one speed to the next by a *quantum jump*; a little like the infinity staircase in Norton Juster's *The Phantom Tollbooth*, where you need only keep climbing down, one step at a time, to appreciate just how enormously small everything really is: Each decimal on this number line takes you down by a factor of 10, until as though rising over a deep inner horizon the first essential non-zero number appears, outlining the shape of worlds tinier than any atom:

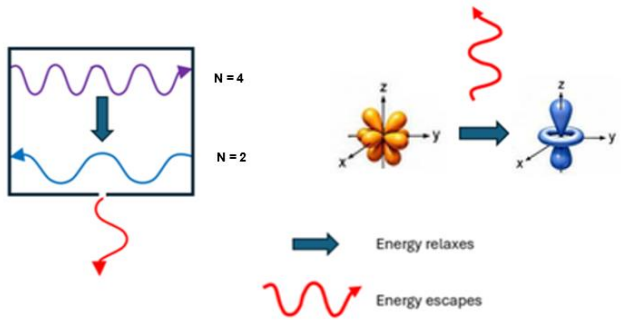
$$h = 0.00000000000000000000000000000000662607\ldots \quad \textit{Planck's Constant}$$

Perhaps more familiar to most people, neon light is a perfect illustration at the other end of an extreme of physical action. Rather than the wide spectrum of furnace radiation, in neon light (or not just neon, any suitable gaseous element will do) we see single precise colours that add up to the dynamics of multiple overlapping waves in a blast furnace, which you can almost do in your

head because the waves are linear. As the Pretenders remind us, neon light is a vivid example of a quantum process more than equal to the bedazzling of young hearts in a big city.

Cool gases that are energised in an electric circuit, or even solid elements that are heated by a flame, emit light in specific colours related to the energy of electrons that react to the stimulation and jump sharply on a staircase of atomic orbitals. Precise wavelengths of light are released from each set of steps, giving those specific romantically rich colours. The precision of the colours was hard to understand as a fringe science, because in the old idea of energy on a solid number line they were supposed to grade smoothly like rainbows and blend into white.

What we're seeing in neon light is a kind of polyphonic musical instrument of atomic energy levels collapsing and rebuilding themselves with the input electrical energy, making jumps from one energy level to another. When an electron falls to a lower energy level it releases a photon that carries the energy it has lost, so the total energy remains the same. But because electrons are only allowed at certain specific energy levels, the light is emitted at specific wavelengths, and there is no actual transition between levels: it is as though a falling electron steps directly from one layer to the next, without passing through any value of energy between layers on the way. Quantum physics at this point seems to break or violate continuity, but the continuity law is more subtle and discrete: to heat up a furnace, you have to fit more waves in a box; that is, smaller waves in larger numbers at more energetic rates. While cooling down, the waves relax in a chunky way, say from 10 waves per cm to 7, then 5, as heat escapes. The continuity is in the steps of Planck's staircase:



Energy level transitions of furnace wavelengths and atomic orbitals. Integer numbers and limiting wavelengths step between different three-dimensional waveforms, providing a quantized heat exchange.

The discrete energy levels are related to the configuration of the electrons, so the quantum jump repositions the electrons in a discrete and disjunct or sudden way. It's a shape flickering into another shape – there is a jump, not to travel but to be that way. This has continuity at a deeper level, in the linked uncertainties of where/when things are and what their momentum/energy is. So the atom, with its definite either-or choice of where/when a thing might be, has a continuity law like perspective but a totally different intuitive picture. The continuity is musical, as indeed only whole numbers of harmonic vibrations can fit into any musical or physical instrument.

Even more strangely, the mass of a neon atom depends partly on the energy of its electrons, so as an electron jumps to a lower energy and the correspondingly coloured photon is emitted, the total mass of the atom decreases by a quantum $m = E/c^2$, the original form of Einstein's most famous equation. The photon has no mass but Planck's energy $E = hf$ at a frequency f which in turn controls its colour; so we have the very strange concept that a neon colour is the exact, incredibly tiny mass loss of any individual atom, visible in a massless form which has no known purpose other than to help animals and most plants to find or create food and reproductive opportunities. These values are not neutral, but have costs like coins in transaction.

It's natural enough that quantization should separate the smallest fundamentals, not just matter in atoms. Particles can be counted, and in the same sense their properties, their mass and hence energy and momentum, are counted like cash. There is an economy-like sub-reality that has individual

actors buying and selling, sharing and exchanging, coins of energy and momentum. Electrons can be thought of as incredibly rich with photons, trading them with protons and other particles as though under pressure to do so. Electrons become in a sense further enriched with photons at smaller scales, and the closer to zero, the more intense the exchange.

It's also fairly natural that a point-like mass can't be the final explanation, since it would have properties that tend to infinity; for instance a mass like an electron crammed into a point of zero volume must have an incalculably large density. A fundamental particle with no moving parts of internal detail should have no granularity or texture, just continuous unbroken matter without limit whose intrinsic density at any point is very difficult to define. A massless particle such as a photon doesn't have this problem, which is one of the differences between matter and its flip-side, energy, but a photon is still a particle whose energy fights against confinement to zero. The upshot is that a particle's energy at any zero point would be infinite. So we need to think about how particles are distributed in spacetime, of *where* and *when* they are over a range, not a point: what matter is made of is at least partly determined by how much space and time it occupies. Space and time also exist in small packets, as quanta later discovered within Planck's constant.

Wave-particles then, which soon after Planck included light and the newly quantized electron, were found to be self-contradictory, with a dual existence in irreconcilable states, existing exactly somewhere at some specific time or loosely spread out in space with oscillations at any point for indefinite periods of time. A wave-particle can appear as one or the other depending on how we observe and measure it.

Because of this, physical effects and descriptions such as position and momentum cannot be measured or even defined with certainty at the same time. The more you know about a wave-particle's speed, the less you *can* know about its location. Likewise the energy of an interaction, how hot or fast or loud it is, is paired to how long it lasts: the more you know of a particle interaction's energy, the less you *can* know of how much time it took. Individual particles behave like a gas (of many particles) when they are compressed into a smaller space – the more precise location blurs the momentum, so the particle has more active motion. But unlike a gas, a confined particle has no extra energy; the jittery motion is unavailable or unusable, in a sense related to entropy, the decaying partner of energy as a potential for industry and biological growth.

This is a profoundly important complementarity of physical and spatial properties that can be guessed at a human scale in ordinary collisions of the dangerous kind, then quantized to fit the subatomic scale. Momentum and energy, recognisable as the difficult actions of stopping a truck and the damage you can do with it, are related to forces that apply to bodies like trucks over distances and periods of time. If you apply a force to push a heavy body such as a truck, it builds up destructive energy that could badly dent a car, and it also builds up proactive momentum that could be used to bump the car into motion. The energy builds in proportion to how far you push it, while the momentum builds in proportion to how long. These quantities are a zero-sum game – the car can acquire no more energy than you expend in pushing it, and it can pass on no more momentum than it has acquired along with the energy. The same limits apply to particles.

Quantities that can be carried forward like this, with a direct exchange of value, are said to be *conserved*. Conserved values are always found to be quantized, i.e. they come in Planck-sized fine-scale lumps, and are complementary to each other in terms of space and time. For the same force applied to an object we get an energy over distance and a momentum through time. Many other useful properties are conserved, so you know beforehand and can predict how much angular momentum for example will remain in different places after various kinds of actions.

As a wave, a particle has no specific location but a smooth variation over many ripples of different lengths that span a wide range of momentum in space and energy in time. The French word for

wave, *vague*, is a nice word in English for these effects. The fluid, wave-like aspects of momentum and energy, re-imagined by Louis de Broglie[2] in 1925, contradict the solid, definite, particle-like aspects of position and time. A waveform with a definite wavespeed, meaning definite energy and momentum, has a wide spread of ripples and no definite location in space or time.

That's a major consideration for cosmologies that hope to answer questions such as *how large is the universe*, and *how old*? Definite energies, especially large energies, must take place over more uncertain time and space ranges: the more energetic a universe is, the harder it is to locate any particular thing or location in it, by a factor of how large it is, and also the longer it must persist into a future however indefinite that might be.

This strange blurring of any selected focus of measurement in space, time, energy and momentum is so well-established as to be a principle, Heisenberg's *Uncertainty Principle*. Werner Heisenberg explained this in 1927 in terms of the evolution of wavelike effects over space and time, but also as the self-interference of modes of observation, such as light or electrons in a microscope trying to examine particles of a similarly small scale. There are fine points at which the energy of an observing wave disturbs a wavelike object so much that you have to look away and think of something else to get any information at all.

This is almost the same reasoning as the original Greek derivation of the atom: a good knife can cut thin slices of cheese, even transparently thin, but not arbitrarily or invisibly thin slices. To make a fine knife, you need very fine tools, which are made with even finer tools, for which the practical limit is the atom. To observe an electron, you need a tool finer than an electron, and it becomes physically impossible in both practical terms and in the deeper theoretical logic of proof, since an observation fundamentally disturbs the observation, much as a knife deforms a cheese.

Leonard Susskind, another outstanding scientist with a gift for language whose work we must return to, explains this deep contradiction in his book *The Black Hole War.* Susskind points out that when you are driving a car and you glance at your speedometer, you can't sense any difference in your sense of location and of course you are not at that moment looking at your location. If you glance at your GPS screen to fix your location, you can't detect any change in your speed and are in fact not just at that second watching your speed. Looking back again at the road, the distant objects of your scenery continue to move along in harmonious spacelike ways, mountains slowly unfolding as nearby trees and grass rush past.

The point is that you can't watch both measurements at the same time, and when you watch one, the other *has to be* less certain to you at that moment. In a deep principle, this is as much true of the objects of observation, and it becomes seriously problematic at the scale of a particle. The subtle measurements you would need to make to see that these complementary macroscopic observations of road and scenery do effect each other, are finer than any useful difference that you can detect when viewed on the ramp-like staircase of Planck's energy law. Yet they are as real and dual as your own split attention when you try to keep track of both momentum and position. Even with a GPS that monitors both map position and speed, the speed is calculated by the position (i.e. it doesn't try to separately measure both) and there are in any case uncertainties of at least 1 metre and 1 km/h or worse.

Heisenberg's uncertainty is a pairing of momentum and position around a constant, not so much a conserved value as its very definition, the Planck constant. It comes down to an equation, which we are now in a position to derive in detail from what we can see, regardless of our instruments.

[2] de Broglie (pronounced de BROY) went one further than Planck: if wavelike light is a particle, so the particle-like electron is a wave. After de Broglie, every wave-form has a representative particle, and every particle is a wave.

Thank you for taking a moment with *The Vanishing Skylines of Quantum Cosmology*. I hope you're as intrigued as I am. Contact me at *michaelgifans@gmail.com* if you would like to know more.

Other than direct quotes referenced in the "Turing test" interview with ChatGPT in chapter 3, no AI tools or generated text were used in the writing of this book. No permissions, rights or copyright exceptions are given or in any way implied to third party actors for purposes of AI training or anything else.

A 'Toy Universe' of Chapter 5 *is available for preview in* Desmos: *https://www.desmos.com/calculator/4eckuxvrrk*