Towards a History of Plasma-Universe Theory

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It is demonstrated that plasma-universe theory boasts a respectable pedigree in the history of science. Ideas concerning a fourth or fundamental state of matter or a pivotal role for electromagnetic forces in the physics of the polar aurora, the sun, the zodiacal light, comets and indeed the entire universe circulated long before the possibility of *in situ* measurements in space arose. An attempt is made to explain why such notions became anathema to the mainstream of astrophysics long before the Space Age provided means to test their accuracy.

1. Introduction

The 20th century has seen the growth and maturation of plasma-universe theory. In its purest form, plasma-universe theory is a paradigm within physics and chemistry, centred on the study of the plasma state of matter. It has become increasingly clear, however, that plasmas are not confined to space or the atmosphere of our own planet, but also play a role in geological and biological phenomena. For this reason, the plasma universe in its fullest form reveals itself as a full-blown system of thought about the entire knowable universe – a cosmology in its own right, which one might call 'plasma cosmology'. Unfortunately, scholars employ the term 'cosmology' in different ways; whereas some use it in the sense of an all-encompassing theory or philosophy of the universe, as I do, others restrict it to the nature and origin of deep space only. To avoid this confusion, I prefer to speak of 'plasma-universe theory' or, more succinctly, of 'the plasma universe'.

To date, the significant role of plasma-universe theory in the history of science has not received wide acclaim. Although the physics of plasma are not in dispute, it is not widely realized that an understanding of plasma on all levels provokes an intellectual revolution. An excellent way to demonstrate the profoundness of the plasma universe is to contemplate the role of electromagnetism in the cosmos. A plasma is characterized by partial ionization of its particles, making it strongly responsive to electromagnetic forces. Plasma-physical models of the formation of galaxies, the origin of planets, or the orbital dynamics of planets are markedly different from the gravity-based models that dominated the 20th century. Electromagnetism and gravity operate side by side, but the history of modern science is exposed as a struggle to recognize the importance of electromagnetism. From a historical point of view, plasma-universe theory has vied with cosmologies grounded in Newton's theory of gravity and it is instructive to chart the history of this competition. The history of plasma-universe theory as a school of thought is a fertile field for exploration. In this presentation I will demonstrate that plasma-universe theory is not a recent addition to the scientific spectrum, but has quite a long pedigree.

The history of plasma-universe theory is really the history of three separate fields. The fundamental unity of the electromagnetic field force was not recognised until the work of Michael Faraday, Benjamin Franklin and James Clerk Maxwell. Prior to the period between 1820 and 1860, electricity and magnetism were simply regarded as two distinct forces. Likewise, the relationship between these two and the plasma state was not obvious from the start; the sun and other stars, lightning and the polar aurora are plasmas that were pondered long before the involvement of any electromagnetic aspects was recognized in them. Thus, it makes sense to treat the historical study of magnetism, of electricity, and of plasma as three distinct fields that eventually converged to different degrees. This convergence occurred roughly between 1820 and 1870.

The history of the study of magnetism and, to a lesser extent, of electricity are fairly well known and well covered in scientific textbooks, except where speculations on these entities in space are concerned. The history of plasma theory, by contrast, has not at all been charted to a satisfactory depth. In a preliminary attempt to fill this gap, I offer the following selection of milestones.

2. Four States of Matter in Classical Antiquity

Perhaps the earliest acknowledgement of plasma as a separate state is found in the classical theory of the four elements – earth, water, air, and fire. From the early Greek discourses on these elements, it is clear that these were not perceived as elements in the modern chemical sense of the term, but as states of aggregation. Much Pre-Socratic speculation was concerned with the transformations of matter as they passed from one of these states into another [1]. It is only since the modern recognition of plasma as a fourth state that we can really appreciate the wisdom of the Greek scheme: 'earth' corresponds to solids, 'water' to liquids, 'air' to gases, and 'fire' to plasmas.

Moreover, Greek philosophers correctly stated that 'fire' preponderates in the higher regions above the earth, while being comparatively rare on the surface. They rightly classified lightning, meteors, comets, aurorae and of course fire as forms of the element of fire – or 'plasma' [2]. Anaxagoras, Plato, his followers and the Stoics included the stars and the sun among the celestial fire, called 'ether' [3], while Aristotle and his movement defined 'ether' as a fifth element, even more ethereal than 'fire' [4]. Thus Aristotle:

> "We maintain that the celestial region as far down as the moon is occupied by a body which is different from air and from fire, but which varies in purity and freedom from admixture, and is not uniform in quality, especially when it borders on the air and the terrestrial region. Now this primary substance and the bodies set in it as they move in a circle set on fire and dissolve by their motion that part of the lower region which is closest to them and generates heat therein …"

3. Experimental Foundations

Moving to the roots of modern science, the groundwork for modern plasma-universe theory was laid in laboratory experiments beginning in the early 17th century.

Between circa 1600 and 1900, many insights were gained using *terrellae* or 'earthlets'. These were small magnetized spheres representing the earth. In his ground-breaking study *De Magnete* (1600 CE), the English physician and scientist, William Gilbert (1544-1603), proved that the earth is magnetic and launched the terms 'electric' and 'electricity' for static electricity. More than a century on, in the years following 1706, the English physicist and instrument-maker, Francis Hauksbee the Elder (±1666-1713), employed terrellae for his pioneering electrical experiments, in which he explored the luminescent properties of electrical discharge. He invented the 'Influence Machine', an electrostatic glass-globe friction machine capable of producing a purple, flickering light when evacuated and rubbed.

In 1753, the invention of the discharge tube enabled further penetrative research into electrical discharges in rarefied gases. The *z*-pinch of modern plasma physics is the direct descendant of these early 'electrified gases'. Perhaps preceded by the little-known French physicist, Jérémie Joseph Benoît Abria (1811-1892) in 1843 [5, p. 478], the Welsh judge and physicist, Sir William Robert Grove (1811-1896), first discovered striation in sustained discharges in 1852 [6, pp. 155-156 note †]. In 1878, Warren de la Rue (1815-1889) and Hugo W. Müller produced many other forms familiar today as plasma toroids and instabilities, including so-called 'sausage instabilities', 'kink instabilities' and 'Peratt Instabilities' [6]. Thus, James Clerk Maxwell (1831-1879) was right when he observed in 1873:

> "These, and many other phenomena of electrical discharge, are exceedingly important, and when they are better understood they will probably throw great light on the nature of electricity as well as on the nature of gases *and of the medium pervading space*." [7, p. 56, emphasis added]

4. Recognition of Plasma

One line of research led from early experiments in electromagnetism to the recognition of a fourth state of matter. The English scientist, Michael Faraday (1791-1867), was arguably the first to conceive of a state displaying a structurally different behavior than other known gases or 'airs'. In a lecture given in 1816, he called this "radiant matter", refraining from relating it directly to electricity:

> "If now we conceive a change as far beyond vaporisation as that is above fluidity, and then take into account also the proportional increased extent of alteration as the changes rise, we shall perhaps, if we can form any conception at all, not fall far short of radiant matter; and as in the last conversion many qualities were lost, so here also many more would disappear. … The simplicity of such a system is singularly beautiful, the idea grand, and worthy of Newton's approbation." [8, pp. 195-196]

In another speech, delivered in 1819, Faraday more explicitly offered the suggestion of "Matter classed into four states – solid, liquid, gaseous, and radiant – which depend upon differences in the essential properties"; the radiant state was declared to be as yet "Purely hypothetical" [9, pp. 268-269, cf. 270] and no pronouncements were made on the nature of heat, electricity and other forces in relation to matter. Sixty years later again, it was

Faraday's compatriot, Sir William Crookes (1832-1919), who followed up Faraday's suggestion in earnest, discussing at some length the effects of magnetism on 'radiant matter' [10, p. 2]. With remarkable prescience, Crookes foresaw the immense scientific potential of the 'radiant' state as early as 1879:

> "In studying this Fourth state of Matter we seem at length to have within our grasp and obedient to our control the little indivisible particles which with good warrant are supposed to constitute the physical basis of the universe… We have actually touched the border land where Matter and Force seem to merge into one another, the shadowy realm between Known and Unknown which for me has always had peculiar temptations. I venture to think that the greatest scientific problems of the future will find their solution in this Border Land, and even beyond…" [10, pp. 29-30]

In 1928, the Nobel-prize winning American chemist and physicist, Irving Langmuir (1861-1957), first employed the term *plasma* for these partly ionised gases: "We shall use the name *plasma* to describe this region containing balanced charges of ions and electrons." [11, p. 628] It is somewhat unclear whether he selected this term because of a perceived analogy with blood plasma, because of plasma's capacity to carry particles, or because plasma – from a Greek word for 'moulded' – moulds itself to the shape of its container [12, p. 989]. At any rate, as plasma is now estimated to account for some 99.9% of the interplanetary medium, as well as the universe in general, Crookes was quite right in expecting it to become the "physical basis" of cosmology.

From the 20th century on, the physics of ionised gases has been known as 'plasma physics'.

5. Newton's Electrical 'Spirit'

In a separate development, various adventurous minds in the golden age of scientific speculation extrapolated from experiments in electromagnetism to the observed reality in the earth's atmosphere and in space – as should be done in sound science. Sir Isaac Newton (1643-1727) was a close collaborator of Francis Hauksbee. It was almost certainly because of Hauksbee's experiments with the *terrella* that this spiritual father of gravitational theory expressed a note of optimism that electricity may unlock a number of enigmas, including gravity [13, p. 285; cf. 14, p. 290]. Towards the very end of his *Principia*, and only in the second edition, published in 1713, Newton let his hair down writing:

> *Hactenus Phænomena cœlorum & maris nostri per Vim gravitatis exposui, sed causam Gravitatis nondum assignavi. … Rationem vero harum Gravitatis proprietatum ex Phænomenis nondum potui deducere, & Hypotheses non fingo. … Adjicere jam liceret nonnulla de Spiritu quodam subtilissimo corpora crassa pervadente, & in iisdem latente; cujus vi & actionibus particulæ corporum ad minimas distantias se mutuo attrahunt, & contiguæ factæ cohærent; & corpora Electrica agunt ad distantias majores, tam repellendo quam attrahendo corpuscula vicina; & Lux emittitur, reflectitur, refringitur, inflectitur, & corpora calefacit …* [15, pp. 483-484]
>
> That is:
>
> "Thus far I have explained the phenomena of the heavens and of our sea by the force of gravity, but I have not yet assigned a cause to gravity… I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses… A few things could now be added concerning a certain very subtle spirit pervading gross bodies and lying hidden in them; by its force and actions, the particles of bodies attract one another at very small distances and cohere when they become contiguous; and electrical [i.e., electrified] bodies act at greater distances, repelling as well as attracting neighboring corpuscles; and light is emitted, reflected, refracted, inflected, and heats bodies…" [13, pp. 943-944]

Yet Newton realized that the state of technology in his day fell far short of the capacity to delineate the role of electricity in the universe: *Sed hæc paucis exponi non possunt; neque adest sufficiens copia Experimentorum, quibus leges actionum hujus Spiritus accurate determinari & monstrari debent.* [15, p. 484] Or: "But these things cannot be explained in a few words; furthermore, there is not a sufficient number of experiments to determine and demonstrate accurately the laws governing the actions of this spirit." [13, p. 944] Newton's personal interleaved copy of the second edition of the **Principia** contained a proposed emendation, eventually rejected, in which this *Spiritus* or "spirit" was qualified by the adjectives "electric and elastic" [13, pp. 282, 944 note pp]. Various drafts Newton composed of a proposed conclusion of the book illustrate "the importance of electrical phenomena in his thinking about gravity during the years 1711-1713", though "sometime after 1713 Newton lost his enthusiasm for electricity as a possible agent in gravitation." [13, p. 944 note pp]. In one passage, Newton expressed his conviction that this 'electric spirit' permeates "all bodies" and therefore, presumably, the entire universe:

> "For the electric spirit, which seems to pervade the pores of all bodies, receives vibratory motion very easily and conserves it for a very long time, and does so in the most hard and most dense bodies as well as in the most fluid and most rare, because this spirit must be more abundant in denser bodies, and its vibrations must be propagated through the total uniform spirit as far as the surface of the body, and there not to cease but be reflected and again be propagated through the whole and be reflected and to do this very often." [14, pp. 291-292]

While Newton's theory of gravity went on to provoke a scientific revolution, his suggestion that electricity might be important fell by the wayside, presumably because investigations into the properties of electricity remained focused on static electricity until the early 19th century and accordingly prevented significant progress in atmospheric and astronomical applications. Newton's conception of the 'electric spirit' as a sort of *plenum* pervading all matter was likewise consigned to the doldrums. From a historical perspective, its significance is considerable, however. Insofar as Newton related his 'electric spirit' to emissions of light and suspected it to permeate space, he actually foresaw the modern understanding of cosmic plasma.

6. Theories of Electromagnetic Forces within the Atmosphere

One area in which the *terrella* experiments did prove influential during the 18th century was the scientific study of the aurora. Newton aside, Hauksbee's work also fired the imagination of Sir Edmond Halley (1656-1742), who seized upon the same findings to propose an electromagnetic explanation for the aurorae in 1717:

> "… this subtile Matter… may now and then, by the Concourse of several Causes very rarely coincident, and to us as yet unknown, be capable of producing a small Degree of Light… after the same manner as we see the *Effluvia* of *Electrick* Bodies by a strong and quick Friction emit Light in the Dark: to which sort of Light this seems to have a great Affinity. This being allowed me, I think we may readily assign a Cause for many of the strange Appearances we have been treating of, and for some of the most difficult to account for otherwise; as why these Lights are rarely seen anywhere else but in the North and never, that we hear of, near the Equator … I assume the *Effluvia* of the Magnetical Matter for this purpose, which in certain Cases may themselves become luminous, or rather may sometimes carry with them out of the Bowels of the Earth a sort of Atoms proper to produce Light in the Ether…" [16, pp. 421, 423, 427]

Halley's "Ether" corresponds to the plasma contained in the ionosphere.

In 1751, the Danish bishop and historian, Erik Pontoppidan (1698-1764), replicated the *terrella* experiment, consciously likening the globe to the earth and resuscitating Halley's magnetic theory of the aurorae [17, p. 67].

And in the late 19th century, the Norwegian scientist and explorer, Kristian Birkeland (1867-1917 CE), picked up on this work to advance an electrical theory of the aurora: he reasoned that streams of electrons – called 'cathode rays' – travel from the sun towards the earth, where the geomagnetic field steers them towards the polar regions [18].

7. Theories of Electromagnetic Forces within the Solar System

Other inquisitive minds suspected an electric nature of the sun, the zodiacal light or comets. Writing to Faraday in 1852, Sir John Herschel (1792-1871), wondered if the sun could not owe its brightness to "Cosmical electric currents traversing space":

> "If all this be not premature we stand on the verge of a vast cosmical discovery such as nothing hitherto imagined can compare with. Confer what I have said about the exciting cause of the Solar light – referring it to Cosmical electric currents traversing space and finding in the upper regions of the Suns atmosphere matter in a fit state of tenuity to be *auroralized* by them…" [19, p. 443]

Writing in 1868, the American mathematician, Elias Loomis (1811-1889), proposed "that there are circulating round the sun powerful electric currents, which may possibly be the source of the sun's light; these currents may act upon the planets, developing in them electric currents; and the currents circulating round the planets may react upon the solar currents with a force varying with their distances and relative positions, exhibiting periods corresponding to the times of revolution of the planets. These disturbances of the solar currents may be one cause of the solar spots, and an unusual disturbance of the solar currents may cause a disturbance of the currents of the earth's surface, giving rise to unusual displays of the aurora." [20, pp. 198-199]

As late as 1885, the open intellectual climate still allowed the English astronomer, Sir William Huggins (1824-1910), to present the Royal Society of London with his electrical model of the sun:

> "The grandest displays of terrestrial electrical disturbance must be altogether insignificant in comparison with the electrical changes which must accompany the ceaseless and fearful activity of the photosphere… Surely it is not too much to say that our terrestrial experience of lightning and of auroræ fails to supply us with any adequate basis for a true conception of the electric forces in action on the sun." [21, pp. 125-126 = 22, p. 156]

Huggins argued that "the corona" may "have been still faintly visible in the earliest ages of the human race" [21, p. 134], that the zodiacal light may be a function of coronal activity [21, p. 134], that Mercury and Venus "are permanently charged with electricity of the other name to that of the sun", as do "the more distant planets" [21, p. 126 note *], and that comets may be electric; speaking of the "luminous streamers and rifts and curved rays" seen in cometary comas, Huggins wrote:

> "… the only theory upon which they can be satisfactorily explained, and *which now seems on the way to become generally accepted*, attributes them to electrical disturbances, and especially to a repulsive force acting from the sun, probably electrical, which varies at the surface, and not like gravity, as the mass. A force of this nature in the case of highly attenuated matter can easily master the force of gravity, and as we see in the tails of comets, blow away this thin kind of matter to enormous distances in the very teeth of gravity." [21, p. 124 = 22, p. 156, emphasis added]

Kristian Birkeland, though now mostly remembered for his contribution to auroral studies, also adduced experimental work with the *terrella* in order to explain the zodiacal light, cometary tails, and the rings of Saturn [18, pp. 611-624, 641-647; compare 23, pp. 220-225].

8. Theories of Electromagnetic Forces on a Cosmic Scale

On an even larger scale than the solar system, some pioneers envisioned the entire universe as a playground of electromagnetic forces. As early as 1770, a humble amateur scientist – the Scottish traveller and writer, Patrick Brydone (1741-1819 CE) – expressed his conviction that "electrical causes … in future ages, I have little doubt, will be found to be as powerful an agent in regulating the universe, as gravity is in this age, or as the subtile fluid was in the last." [24, p. 89] But Brydone's remained a lone voice in the desert.

Possibly the first credentialled scientist to follow in the footsteps of the more carefully phrased suggestions of Newton, Herschel and Crookes, was Kristian Birkeland. Birkeland envisioned "one cosmogonic theory, in which solar systems and the formation of galactic systems are discussed perhaps rather more from electromagnetic points of view than from the theory of gravitation":

> "According to our manner of looking at the matter, every star in the universe would be the seat and field of activity of electric forces of a strength that no one could imagine. … It seems to be a natural consequence of our points of view to assume that the whole of space is filled with electrons and flying electric ions of all kinds." [18, pp. V, 720]

This outlook was adopted and extended by the Swedish plasma physicist, Hannes Alfvén (1908-1995), the spiritual father of 'plasma cosmology'. Alfvén expressed his conviction that, extrapolating from what is known on earth, electromagnetism holds the key to many 'black holes' in modern models of the cosmos:

> "Nearly everything we know about the celestial universe has come from applying principles we have learned in terrestrial physics. Newton's laws of motion, our studies of the spectrum of light, our explorations of the nucleus of the atom and other major discoveries in our physics laboratories have contributed to our enlightenment about the stars – their motions, their chemical composition, their temperatures and their source of energy. Yet there is one great branch of physics which up to now has told us little or nothing about astronomy. That branch is electricity… Electricity has illuminated our cities but has shed no light on stellar phenomena… there are good arguments for assuming that a weak magnetic field… pervades all of space. It is likely, therefore, that magnetohydrodynamic waves roam ceaselessly through space, generating weak but very extensive electric fields, especially near the stars." [25, pp. 74, 79]

Thanks to Alfvén's pioneering work, it is now understood that space is not a vacuum, punctuated by galaxies, but is "filled with a network of currents which transfer energy and momentum over large or very large distances. The currents often pinch to filamentary or surface currents." [26, p. 5; compare 27, p. 639] An excellent overview of Alfvén's achievements and the length of time it took for these to be accepted by the academic community is provided in [28]. Over time, however, "the idea that space is alive with networks of electrical currents and magnetic fields filled with plasma filaments was confirmed by observation and gradually accepted… The universe, thus, forms a gigantic power grid, with huge electrical currents flowing along filamentary 'wires' stretching across the cosmos." [29, pp. 45, 195]

Prior to the Space Age, there was no way such speculations could be checked against actual measurements and observations. Laboratory simulations were the closest possible approximation. When space probes did begin to relay data, the electrical nature of the aurorae, as argued by Birkeland and a host of others, was vindicated definitively. Curiously, however, speculations concerning electrical aspects of the zodiacal light, comets, the planets, the sun and other stars were never given a proper hearing. They had, in fact, been banished from mainstream astrophysical journals, conferences and curricula since the 1890s.

9. Theories of Electromagnetic Forces in Space Tabooed

It was roughly between 1890 and 1920 that discussion of electromagnetism in space, outside the earth's magnetosphere, became practically *verboten* – a taboo that is only now beginning to disintegrate, following a century of Dark Age myopia and limited progress in astronomical theory. The question is what that stigma was based on. A definitive answer is not yet available, but five likely factors can be proposed.

Firstly, late-19th-century equivalents of 'New Age' uncritical thinking may have spoiled the field for serious investigators: the rampant popular belief in 'animal magnetism', 'vital fluids', and ectoplasm, as well as the fantasies bandied about in the theosophical oeuvre of Helena Blavatsky (1831-1891), published between 1877 and 1892, may have prompted a similar visceral repulsion as modern scientists experience upon exposure to New Age writings about healing 'vibrations' and 'energies'.

Secondly, the rise of quantum mechanics during the early 20th century, involving Max Planck, Niels Bohr, Werner Heisenberg, Albert Einstein and others may have simply diverted the attention away from electromagnetic studies; the attention span of scientists is not unlimited and the more traditional subjects of electricity and magnetism may have simply lost their appeal when quantum physics entered the scene. Especially after Dr. Einstein got involved.

Thirdly, the 19th century saw the rise of uniformitarian thought in geology, biology and palaeontology, producing further ripples in astronomy and anthropology. Whereas gravity naturally acts as a uniformitarian, highly predictable force, the almost unfathomable complexity of plasma behavior is better appreciated on a catastrophist mindset. Natural philosophers who are happy to speculate on cometary impacts, changes in planetary orbits or punctuated equilibria in evolution will be better prepared for the non-linear, chaotic regime that is so common in plasma instabilities. For those who believed that *natura non facit saltus*, the seeming capriciousness intrinsic to electromagnetism was a hard pill to swallow, best buried under a sediment of dogmatic orthodoxy.

Fourthly, the turn of the 19th century ushered in a marked preference of theory over practice, of mathematical calculations over direct observations. The seeds for that shift may have been sown in 1860, when the vacant directorship of Cambridge Observatory was not given to Richard Carrington (1826-1875), an experienced observer, but to John Couch Adams (1819-1892), who solved astronomical problems using mathematics only [30, pp. 112-115]. This love of unfettered mathematical derivation, *ins Blaue hinein*, has characterised astrophysics ever since; in 1892, Lord Kelvin – the same who in 1900 overweeningly announced that "There is nothing new to be discovered in physics now", rejected Carrington's evidence for a relation between sunspots and aurorae on the slender basis of mathematics [30, pp. 152-154]; and Sydney Chapman (1888-1970) was a prominent mathematician and geophysicist who famously refused to observe Alfvén's replication of Birkeland's *terrella* experiment when he was given the opportunity to do so; Alfvén reflected: "… he flatly refused to go down into the basement and see it … It was beneath his dignity as a mathematician to look at a piece of laboratory apparatus!" [29, p. 185].

Essentially the same conflict can be traced back to early Greek philosophy, where practical observers and experimentalists such as the Milesians Thales, Anaximander and Anaximenes formed a different school than the number-crunching Pythagoreans, of a more metaphysical bent. It is hoped that future scientists will be able to strike a balance that recognizes the importance of both.

And fifthly, perhaps in relation to the above, the devastation of the First World War (1914-1918) had a massive effect on collective psychology. In its most general form, this effect entailed a retreat from accurate and detailed observation of reality, often whimsical, into the relative safety of abstraction and neglect of details. In art, this tendency is seen in such movements as modernism, expressionism, Dadaism, surrealism, futurism, cubism and Bauhaus, continued after the Second World War (1939-1945) by the likes of pop art, minimalism, and abstract expressionalism – all of which shared an aggressive contempt for naturalistic painting, sculpture or writing. Perhaps in science the response was a similar escape from testable facts, coupled with an embrace of the magical, unthreatening world of numbers and unobservable entities – a world in which regularity, predictability and uniformity could be postulated with impunity and any form of large-scale destruction simply denied. It was this neurotic mindset, paralyzing the sciences as well as the humanities, that a Jewish-Russian maverick scholar, whose name escapes me, tried to confront in the 1950s.

Conclusion

The likes of Newton, Faraday and Herschel were open-minded enough to conduct thought-experiments concerning a fourth state of matter and electromagnetism in space – long before the technology existed to make *in situ* measurements and long before mathematical tools were sophisticated enough to model plasma behavior. Ignoring these early theories, three impatient generations have prevented much genuine progress in our understanding of the universe since the 1890s. Yet now that our computers and other requisite technology have caught up, it is our moral responsibility to continue where science left off about a century ago.

Acknowledgments

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