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Opinion paper

Physics as Pilgrimage

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Abstract: *Pilgrimage* typically refers to a religious quest or journey. Can science ever be viewed as a sort of pilgrimage, even retaining some of the religious hallmarks thereof? Employing the views of Joseph Campbell, a widely-known religious thinker, and Albert Einstein, creator of the special and general theories of relativity, I so argue for the case of theoretical physics—the most basic and fundamental physical science. I then sketch the centuries-long (and still ongoing) development of physical ideas of space from Newton to Einstein. These ideas, while relatively accessible to non-physicists, are of the most profound physical significance, determining the large-scale behavior of not only Earth, but the cosmos itself. I argue how their development may, in consonance with Campbell and Einstein, be viewed as a sort of pilgrimage.

Keywords: pilgrimage; Albert Einstein; Joseph Campbell; cosmic religion; space; Newtonian mechanics; special relativity; general relativity

1. Introduction

The Shorter Oxford English Dictionary defines *pilgrimage* as, in part: “A journey made by a pilgrim; a journey made to a sacred place as an act of religious devotion.” We typically take the aim of a pilgrimage to be some great goal—perhaps a wish to be granted by a deity, a religious revelation, or a transformation of the pilgrim into a less imperfect being. We recognize, too, that the pilgrim’s journey may be metaphorical rather than physical.

What might the notion of pilgrimage have to do with science? There is, of course, a plausible connection to the Earth sciences, since a pilgrimage in the traditional sense involves an earthly journey to an earthly place. But a connection between pilgrimage and theoretical physics, that most basic and abstract of scientific disciplines, seems strained. I argue herein, though, that the distance between pilgrimage and science, and in particular between it and theoretical physics, is not so great as imagined.

Though my background is in theoretical physics, and I will draw upon that field, I hope to render the argument accessible in the main to people from a wide variety of scientific fields—even to thoughtful non-scientists.

In Section 2 I briefly discuss the religious views of two influential thinkers: Albert Einstein and Joseph Campbell. Einstein, perhaps the greatest theoretical physicist of the 20th century, wrote considerably on religion. Campbell was a well known and popular (but serious) expositor of history of religions, and while he likely knew little physics, he found important lessons for religion in modern physics.

Section 3 focuses on physical ideas of space, from Newton's classical mechanics to Einstein's special and general theories of relativity. Throughout, I hope to illustrate that as a deeper, more cohesive, and more unified picture of the physical world emerged, that picture became more subtle, nuanced, and difficult to comprehend, even while it arguably became more elegant and beautiful. Much as the traditional pilgrim's religious journey might cross boundaries in space, seeking a transformation of the pilgrim, the journey of physics crosses boundaries far transcending those on Earth, encompassing eventually the entire cosmos, and in so doing transforming humanity's view not only of the physical reality in which it abides, but of itself.

Section 4 reconnects with the notion of science, particularly theoretical physics, as a sort of pilgrimage—considered now in the light of the views of Einstein and Campbell, and the evolution of concepts of space in physics.

2. Einstein and Campbell

Albert Einstein (1879–1955) laid out what he saw as the three progressive stages of religion. The first and most primitive stage is a religion of fear. The second stage is moral religion (which presumably includes the major contemporary western religions). In these first two stages, God has human attributes.

Einstein himself professed to a third stage: "*cosmic religion*," or "*cosmic religious feeling*." Therein he rejected a God with human attributes, an anthropomorphic God, instead finding God (whatever that word now means) manifest in the cosmos itself. "The individual feels the futility of human desires and aims and the sublimity and marvelous order which reveal themselves both in nature and in the world of thought. Individual existence impresses him as a sort of prison and he wants to experience the universe as a single significant whole."[1] This is often construed as pantheism—a literal *identification* of God with nature—though I believe that undervalues the depths of Einstein's views [2].

Joseph Campbell (1904–1987) was well known for his popular 1988 PBS series, *The Power of Myth*. But Campbell was an accomplished scholar of religious ideas—or perhaps more accurately, philosophical, mythological, and anthropological ideas—in historical and geographical context.

In his 1986 book *The Inner Reaches of Outer Space*, Campbell illustrates how there are "two aspects, a universal and a local, in the constitution of religions everywhere."[3] The latter is, much as Einstein might have argued, focused on the group, the tribe, those at the center of a particular mythology; the former, unrestricted to locality or group, leads to ideas and experiences shared by humanity largely irrespective of location or time.

For Campbell, *religion* is nearly synonymous with mythology. But *mythology* is to be understood here not as mere fantasy, a collection of deceptions, but rather as "an organization of metaphorical figures connotative of states of mind that are not finally of this or that place and time."[4]

The local aspect of a religion is that in which its mythology may be taken as literally true, where metaphors are indeed taken as "of this or that place and time." This local aspect functions to serve the group at the religion's center, by promoting order, harmony, etc. But this aspect is in itself devoid of connection with deeper, universal ideas, ideas characteristic of humanity as a whole rather than merely some segment thereof that is localized in space and time.

Evidently for Campbell (as for Einstein), a religion that has no universal aspect, that is only local in nature, is stunted. In the same spirit as Einstein's third stage of religious development (cosmic religion), Campbell predicts that a new mythology is bound to soon emerge, and that it cannot be based on old, crumbling, local *mythologies*. Any new mythology must incorporate our new *cosmology*, that of "an inconceivable immensity of galaxies, clusters of galaxies, and clusters of clusters (superclusters) of galaxies, speeding apart into expanding distance, with humanity as a kind of recently developed scurf on the epidermis of one of the lesser satellites of a minor star in the outer arm of an average galaxy, amidst one of the lesser clusters among the thousands, catapulting apart, which took form some fifteen billion years ago as a consequence of an inconceivable preternatural event."[5]

Campbell argues compellingly that our present knowledge of the universe, and of the physics that governs it, renders much of the extant mythologies literally unbelievable. For example, the biblical, heaven-bound journeys of Jesus and Elijah, interpreted literally, are clearly physically impossible. In fact, says Campbell, "what is connoted by such metaphorical voyages is the possibility of a return of the mind in spirit," that is, a journey "not into outer space, but into inner space."[6]

Thus the current western mythologies (religions), in their present forms, still suffer from localism. "And so throughout the complex of mythologies now operative in the West... the reaches of outer space to which the religious mind is formally directed are not cosmic, but geographical, and defined in terms, moreover, of dark and light... prayers still being addressed in all seriousness to a named and defined masculine personality inhabiting a local piece of sky a short flight beyond the moon."[7]

Campbell was not a physicist, which may be why he seized on the *scope* and *scale* of the universe. Einstein (very much a physicist!) focused instead on the *concepts* and *physical laws* which govern the universe, and which appear to be at least largely discoverable by humans, even if a deep understanding of those laws proves elusive.

From the perspective of Einstein's cosmic religion, or Campbell's yet undiscovered new mythology, what could *pilgrimage* even mean? Because the religious vision is now truly cosmic, it would likely not refer to a journey to a physical place—a journey which, now possibly on a cosmic scale, is likely to be impossible. After all, if physical law is the manifestation of cosmic religion, and if all the cosmos is governed by the same physical laws, can it make sense for one place to be "more sacred" than another?

Perhaps not. Still, one might argue that those places and those times where the cosmos and its laws are most spectacularly displayed could be the legitimate goal of a "cosmic pilgrimage". And is not Earth just such a place? Here we find life in overwhelming diversity. Complex chemistry abounds. We have, at a distance convenient for observation, a robust nuclear furnace. We have also a stage well-set for witnessing gravity. Indeed, our present understanding of the cosmos is dependent on the fact that we have all been born into a world remarkably well suited for developing just such an understanding!

Could it be that in cosmic religion, in the new mythology, the end goal of a pilgrimage would be to figuratively escape the bonds of the home planet, to see the inescapable unity of physical reality—but then to return home, as does the pilgrim, with new eyes. Could the real place of pilgrimage be our own cosmic home?

3. Space from Newton to Einstein

Let us consider the development of ideas of space, beginning with Isaac Newton, and then moving on to Einstein's special and general theories of relativity. What follows is a scientifically accurate but non-rigorous sketch of these topics in historical context. [i]

Before turning to Sir Isaac's physics, consider briefly the Aristotelian physical worldview that preceded it. Therein, Earth was the realm of the mundane, the human, the imperfect, the corruptible. The heavens were not merely an extension of this Earthly realm—they were fundamentally and deeply different, for the Aristotelian heavens were perfect, ideal, incorruptible. Given this, it would clearly have seemed a fool's errand to seek to understand Earth's behavior in terms of that of the heavens, or vice versa. But that is what Newton did.

3.1. Newtonian Space

In 1687, Isaac Newton published his *Principia*, which from its outset posited three *laws of motion*, thus forming the foundation of classical mechanics [8]. These laws, Newton proposed, governed the motion of physical objects. The most important is the second law:

$$\vec{F}_{net} = m\vec{a} \quad (1)$$

where $\vec{F}_{net}$ is the net external force on the object of interest,[ii] m is the object's mass,[iii] and $\vec{a}$ its acceleration.[iv] The acceleration includes both the common use of that term, in the sense of a "speeding up" or "slowing down", but also a change in the *direction* of motion—this being implicit in the fact that $\vec{a}$ is a *vector* quantity.

Because $\vec{a}$ is the second-order time derivative of the object's position function (the quantity we typically wish to solve for in mechanics), Eq. (1) is actually a second-order, ordinary differential equation. Thus, while seemingly simple, Eq. (1) is in fact incredibly rich: since $\vec{F}_{net}$ can take on an unlimited array of forms, one could regard Eq. (1) as an infinite set of differential equations.

Already two great divides arise with Aristotelian physics. First, Aristotelian physics sought to *explain* the physical world in terms of *philosophical* "causes." In contrast, Newton's mechanics is about *mathematical description* rather than *philosophical explanation*. Newton's laws set down a conceptual, mathematical dynamics, a means of predicting motion—or more precisely, acceleration, and thus change in motion—for a physical object. Second, this precise, mathematical description renders a general, qualitative "explanation" of physical behavior, such as Aristotle engaged in, inadequate—in its place we have a vast landscape of possible mathematical cases and results.

But Newton's mechanics also entailed profound *conceptual* consequences. Perhaps the most notable is that while Aristotle's universe is divided into Earth and heavens, Newton's universe is, for the first time, *universal*: the laws of mechanics are taken to apply at all times, and everywhere.

Although the second law's mathematical form is clear, fundamental physical questions remain unresolved. Though forces now cause acceleration,[v] that can seem little more than a definition, essentially devoid of physical meaning. Could we not as easily define something that "causes" velocity, or position? And while mass appears in the second law, we are given no hint of what mass *is*, other than the "stuff" that determines the degree to which force causes acceleration. Evidently the second law, confronted on fundamental terms, is not so trivial as it might appear.

But it is another and perhaps deeper question that concerns us now: What, at the most fundamental level, must we assume such that Eq. (1) can even make sense? Restated, what do we mean by *acceleration*? Acceleration, after all, must be defined *with respect to something*, or more precisely, with respect to some frame of reference.[vi]

If we consider only motion on or near Earth's surface, and regard Earth as an unaccelerated frame of reference—what physicists call an *inertial* frame—against which to reckon acceleration, then Newton's laws typically work very well. But when considering gravitation in celestial problems (as did Newton in the *Principia*), what serves as the inertial frame, and why?

The *Principia* was published during an ongoing dispute as to whether space was *absolute* (independent of the bodies therein) or *relative* (defined only relative to the bodies therein). Newton argued strongly against relative space, which was unsuitable for his new mechanics, positing instead a unique, *absolute* reference frame—a universal rest frame. In fact, Newton's mechanics works not only in the postulated absolute frame, but (as Newton understood) in any frame unaccelerated with respect to it. Indeed, the absolute frame itself was *undetectable*. Still, Newton insisted upon its existence.

Finally, when Newton's mechanics is applied to gravitational forces, something remarkable occurs. To see this, consider the simplified case of gravitation near Earth's surface, where the gravitational force F_G on an object of mass m is:[vii]

$$F_G = gm \quad (2)$$

Here g is the acceleration due to gravity near Earth's surface. Assuming the object is acted on only by gravity, and substituting F_G into Eq. (1), we have:

$$F_{net} = F_G = gm = am \Rightarrow g = a \quad (3)$$

Note that the result, g = a, is independent of m. This outcome, though mathematically trivial, is remarkable; indeed, within the context of Newton's physics, it is *inexplicable*. Why?

In Eq. (2), m determines the gravitational force on the object. But in Eq. (1) m is the object's *inertia*, that is, m determines the effectiveness of a net force, $\vec{F}_{net}$, in accelerating the object. Thus, m plays entirely distinct conceptual roles in the two equations.

Given this, we could legitimately define *two* types of mass: the *inertial mass* that appears in Eq. (1), and the *gravitational mass* that appears in Eq. (2). But to what end? Since the two are numerically equivalent, we need only refer to *the mass*. This mysterious experimental result—the equivalence of inertial and gravitational mass—cannot be explained within Newton's physics.

Newton's mechanics was marvelously successful, serving as the basis for physics for more than two centuries—this despite both the *ad hoc* introduction of an absolute inertial reference frame, and the mysterious equivalence of inertial and gravitational mass.

3.2. Special Relativity

By the late 19th century, electromagnetism had been formulated in essentially finished form. With it came recognition of the existence of electromagnetic waves, and their identification as waves of *light*. This great progress came at a price, however, for the mathematical form of electromagnetic waves, light waves, posed a deep problem.

In classical physics, wave velocity must be defined with respect to some medium (e.g., the speed of sound waves is defined with respect to the body of air in which the waves propagate). In electromagnetic theory, however, wave speed was determined by physical *constants* that made no reference to a medium, suggesting that light moves at the *same* speed for *all* observers in inertial reference frames.[viii]

This appears physically implausible, if not impossible, yet it is borne out in reality. And it has profound consequences. Given this result, comparisons of simple physical situations in different inertial frames of reference quickly force us to abandon our existing Newtonian concepts of space and time. These are replaced by relativistic space and time, both of which are extraordinarily abstract and puzzling by comparison. The resulting completed theory was Einstein's *special theory of relativity*, published in 1905. Though a systematic exposition is far beyond the scope of this paper, we can still get a hint of how the theory recasts space and time.

In Newtonian physics, the length of an object is fixed, in the sense that a one meter long object is one meter long in every inertial reference frame. In special relativity this is no longer the case. Similarly, the time interval between two events now depends on the inertial frame from which we consider those events. Events that occur simultaneously in one such frame are not simultaneous in others. Indeed, even the *order* in which two events occur can be frame-dependent.[ix]

In special relativity, then, space and time are *far* more difficult to grasp than in Newtonian mechanics. They are also entwined, in a way completely foreign to Newton's physics. This is reflected in part by the fact that in special relativity the mathematical rules governing space and time are very similar (unlike in Newtonian mechanics).[x]

In fact, in special relativity clarity often eludes us unless we work with quantities that depend in some way on *both* space and time. *Relativistic invariants*, which pervade special relativity, are remarkable manifestations of the connected nature of space and time in special relativity. These quantities exhibit an immensely important and useful property: they are unchanged (invariant) with respect to change of inertial frame. But this invariance comes at a price: typically, such quantities must be composed of a piece related to time and another related to space. It is a recurring trade-off in physics: the cost of elegance is abstraction.

Finally, recall that Newton insisted on the existence of an absolute, universal, rest reference frame, even though that frame played no role in his mechanics. In special relativity that frame is at last discarded as superfluous. For purposes of doing physics, no absolute frame remains, only an infinite set of inertial reference frames, all valid for doing physics, with none inherently better than any other (apart from possible calculational benefits).

Relativistic space and time are thus far more abstruse, but also far more connected, than their Newtonian counterparts. We lose much in easy comprehensibility, but gain in generality and elegance.

3.3. General Relativity

Special relativity is a remarkable recasting of space and time, but it applies only to inertial reference frames (thus the name, special relativity). Remarkable though it is, special relativity does not address some truly fundamental issues. It says nothing about non-inertial frames, it does not explain *why* some frames are inertial, and it offers no explanation of the equivalence of inertial and gravitational mass.

As a consequence of the equivalence of inertial and gravitational mass, the behavior of any mass-possessing object in an appropriately accelerated, gravity-free reference frame is identical to its behavior due to gravity in an unaccelerated frame. [xi] This is called *the equivalence principle*.

Imagine two closed laboratories: one at rest on Earth, the other in deep space (where gravitational forces are negligible). If the deep-space laboratory is accelerated "upwards" at *g*, its inhabitants feel their feet pressed to the floor (think of an accelerating elevator)—precisely as would someone in the Earth-bound lab. Similarly, if an object is released above the floor of the accelerating deep-space lab, it is observed to accelerate towards the floor at *g*—precisely as would an object released above the Earth-bound lab's floor. The context here is that of Newtonian gravity: an external force that arises from the presence of mass in space, and acts, across a fixed backdrop of space, on (some other) mass.

Einstein postulated a simple but profound extension of the equivalence principle, thus forming the conceptual basis for his crowning achievement: *the general theory of relativity*. By positing that the equivalence principle applies also to *massless* entities (most notably light), the physics of a gravitational field (i.e., gravitational forces) and an accelerated reference frame become *completely* indistinguishable. In general relativity, then, gravity need not be—and *is* not—regarded as a force transmitted across space.

Rather, gravity is manifest as a distortion in space itself, resulting in an alteration in the path an object follows through space. What determines that path? As in ordinary Newtonian mechanics, space itself does, through that property we call mass. In what way, then, must space be distorted? Evidently so as to precisely produce the observed motion of objects due to gravity.

But what *causes* this distortion in space? Again, mass does. Mass locally distorts space, and that space then determines how mass moves within that region. Because mass distorts space, and because mass distribution is obviously dependent on where we are in the cosmos, space may now be regarded as a sort of weave, or mesh, much like a wrinkled fabric. If we examine a sufficiently small patch, or local region, of the fabric, it appears flat. But over larger scales, there is no flat, two-dimensional surface that can describe its geometry. In general relativity, if we examine a sufficiently small region of space we find Newton's laws are valid—for example, an object free of *external forces* moves in a straight line without changing speed. We call this a region of *flat space*. Inertial frames still exist, but only *locally*, within such flat space regions. Over larger scales, space is not flat, Newton's laws are violated, and objects follow curved or otherwise accelerating paths (even absent external forces).

Recall that Newton proposed a unique, absolute inertial reference frame extending throughout space—a universal rest frame. Special relativity discarded this unique frame as superfluous, replacing it with an infinite set of inertial frames, each unaccelerated with respect to all others in the set. Finally, in general relativity only local inertial frames exist; none extend throughout space, and there is *no* frame in which Newton's laws are applicable everywhere. The price of elegance, and of generality, is abstraction.

So, what now of the mysterious equivalence of inertial and gravitational mass? Because gravity no longer refers to a force, but rather to space itself, and thus to the paths of physical entities (massive or not) in space, we are left with only *one* type of mass: the mass that both acts *on* space, determining its geometrical structure, and is guided *by* space to determine the paths of objects.[xii]

4. Physics as Pilgrimage

The preceding is in no way a systematic development of classical mechanics, special relativity, or general relativity; vast areas of each remain untouched. We sought only an overall picture of the development of space in each.

But we now see the trajectory of fundamental physics: towards greater generality, but with greater abstraction—and also, perhaps as revealed only to the true devotee, towards great simplicity. We see Newton's unique, absolute reference frame falling away in special relativity. Indeed, we see *all* universal reference frames relegated to idealization, surrendering to the intricate weave that is space in general relativity; any inertial frame is now inertial only locally. And we see the mysterious dual roles of mass become unified into something far more abstract, but also far more pleasing, than we could have imagined.

None of this physics is outwardly religious, at least not in the common sense of that word. But the progress of physics seems quite in consonance with Einstein and Campbell—with a vision that is necessarily cosmic and universal, a vision antithetical to the provincial. Theoretical physics is an attempt to grasp the cosmos not through direct experience of its scale, however vast, but instead through its governing principles, which now, more than ever before, appear fundamentally other, fundamentally foreign to our daily earthly experience.

Do we not see a sort of pilgrimage, then—a pilgrimage over more than three centuries, from the *Principia* to general relativity; a pilgrimage embarked upon not just by one individual, but by a community of scientists and searchers over many generations; a pilgrimage whose destination is no one place, but rather the *cosmos*; a pilgrimage in which we are led to a more all-embracing, more elegant, but also more abstract picture of physical reality than Aristotle or Newton could have imagined?

And in the context of Einstein's cosmic religion or Campbell's new mythology, what else *could* pilgrimage be? Presumably it would not be a physical journey to a physical location. Perhaps it would be a journey both without and within: without, to ultimate generality, to truly cosmic reality, to a world inhabited and formed not by a God made in our own image, but by some inscrutable, perhaps ultimately incomprehensible intelligence; and within—within the self, to hope to grasp that which actually exists, that which we have found "without".

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

Notes

i. Section 3 is *not* intended as a systematic development of classical mechanics, special relativity, or general relativity.

ii. That is, $\vec{F}_{net} = \sum_j \vec{F}_j$, where the $\vec{F}_j$s are the various external forces on the object.

iii. Here *mass*, or *inertia*, characterizes the degree to which the object resists a change in velocity (acceleration).

iv. Generally, the second law is $\vec{F}_{net} = \frac{d\vec{p}}{dt}$, where $\vec{p}$ is the linear momentum and t is the time. For constant m, this reduces to Eq. (1), which is adequate for our purposes. Neither form appears in the *Principia*, where the second law is stated in terms of Latin text.

v. Though Eq. (1) does not itself imply causation, that clearly was Newton's intent.

vi. To see this, consider dropping a ball to the ground. The ball "obviously" accelerates. But viewed from the frame of reference of the ball itself, it is not accelerating (or even *moving*).

vii. Because $\vec{F}_G$ acts only downwards on the object, we may ignore its vector nature and work with its magnitude, F_G.

viii. Contrast e.g., sound: the observed speed of a sound wave depends on both its speed in a medium (e.g., air) *and* the observer's velocity with respect to that medium.

ix. To make concrete the notion of a pair of events, consider, e.g., the (separate) explosions of two firecrackers.

x. Some claim the distinction between space and time *vanishes* in special relativity, with time becoming a "fourth dimension." This is, in my view, inaccurate.

xi. This is implied by Eq. (3) for the restricted case of motion near Earth's surface.

xii. If these still seem like independent roles, realize that they are connected much like charge is for the electric force: charge both *causes* electric force and is *acted on* by electric force. In the words of one well known general relativity book, "Space acts on matter, telling it how to move. In turn, matter reacts back on space, telling it how to curve."[9]

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