COSMOLOGY, DOOM, AND GLOOM:

Some Copernican, Anthropic, and Malthusian Musings

by David Garfinkle

In antiquity, models of the cosmos placed the Earth at the center. All other celestial bodies, moon, sun, stars, and planets, were thought to revolve around the Earth. These models were supplanted through the work of Copernicus, Galileo, Kepler, and Newton in the 16th and 17th centuries. Copernicus noted that the motions of celestial objects could be much more simply accounted for by assuming that the Earth rotated once a day, and that Earth and the planets revolved around the Sun. Galileo postulated that we don't feel this motion of the Earth because only relative motion is noticeable (this "principle of relativity" is often associated with Einstein, but Einstein rightly attributed it to Galileo). Kepler produced a more sophisticated version of the Copernican model, with the orbits of the planets being ellipses rather than circles and the planets moving faster when they are closer to the Sun. He then showed that this more sophisticated Copernican model is more accurate than the models of antiquity. Newton found laws of motion and a universal law of gravity that account for the orbits of the Earth and planets (including all the features of Kepler's model) as well as the fall of an apple.

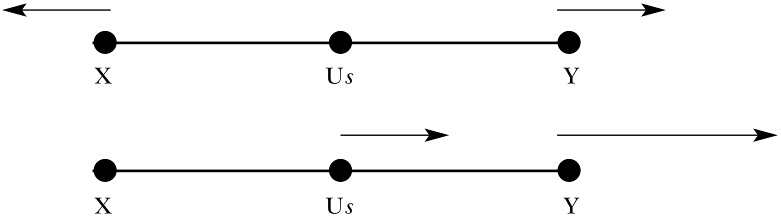
The work of Copernicus had implications beyond astronomy: Copernicus removed the Earth from the center of the cosmos. In medieval Europe, the center of the universe was thought of as the lowest and worst part. Thus, Copernicus' model can be thought of as a promotion of the status of the Earth. However, the Copernican idea did not sit well with the centrality of Earth in medieval and renaissance sensibilities; nor did it fit with a literal reading of certain passages of scripture. Because of this, Martin Luther rebuked Copernicus as an "upstart astrologer" and the Catholic Church forced Galileo to recant his defense of Copernicus' ideas.[1] Nonetheless, eventually the Copernican worldview prevailed, including the removal of Earth from its privileged place at the center of the universe. Furthermore, Newton by showing that the same universal law accounted for both the fall of an apple and the motion of the planets made the study of the cosmos much less mysterious and much more connected to the study of objects on Earth.

In contemporary astronomy and cosmology, one often refers to the "Copernican principle" that the Earth has no privileged position in the cosmos. Put this way, the Copernican principle sounds somewhat odd. However, it is really just a special case of the notion that scientific models should be made as simple as possible, and that to the extent possible they should not have unexplained coincidences: a model giving the Earth a special position is a model with a large unexplained coincidence: namely, how is it that the particular place where we are happens to be at this special position? In this article, I will present some of the implications of the Copernican principle in contemporary cosmology (the study of the universe as a whole). I will then end with a much more speculative idea that comes from attempting to apply the Copernican principle to other fields of study.

Two key observations in cosmology seem at first to violate the Copernican principle, but on closer inspection are found to be compatible with it. These observations are the Hubble law and the cosmic microwave background. The Hubble law has to do with the motion of galaxies. Stars are not spread uniformly through space, but instead are clumped in huge collections of billions of stars called galaxies. Our own galaxy, the Milky Way, is an enormous disk (about one hundred thousand light years across) with a round bulge in the middle and spiral arms in the disk. Our sun is a fairly ordinary star in one of the spiral arms of the Milky Way.

The distances and speeds of galaxies were first measured in the 1920s by Edwin Hubble (the man after whom the Hubble Space Telescope is named). Hubble found a strange result: the galaxies are moving away from us, and the farther they are away the faster they are moving. More precisely, Hubble's law says that the speed is proportional to the distance, so that a galaxy that is twice as far away is moving away from us twice as fast. At first sight, Hubble's law seems like a blatant violation of the Copernican principle. How does it happen that we live in precisely that galaxy that all the other galaxies are moving away from? What exceptional quality could the Milky Way galaxy have that could possibly account for this behavior?

However, appearances can be (and in this case are) deceiving. To see this, begin by putting the Hubble law in mathematical form: Hubble's law says that there is a number H (called the Hubble parameter) such that a galaxy at a distance d from us is moving at a speed Hd away from us (and a galaxy a distance 2d from us is moving at a speed of 2Hd away from us, etc.). Let's consider three galaxies on a line, our galaxy in the middle, a galaxy at a distance d from us on the left (call it galaxy X) and a galaxy at a distance d from us on the right (call it galaxy Y). Hubble's law tells us that galaxy X is moving to the left at a speed Hd and galaxy Y is moving to the right at a speed of Hd. OK, that's how it looks to us; how does it look to galaxy X? Since galaxy X is moving relative to us at a speed of Hd to the left, it follows that galaxy X sees *us* moving at a speed of Hd to the right. In other words galaxy X sees a galaxy (us) a distance of d to the right (of it) moving to the right at a speed of Hd. Furthermore, since galaxy Y is a distance of d to the right of us, it is at a distance of 2d to the right of galaxy X. And since galaxy Y is moving at a speed of Hd (relative to us) to the right and we are moving at a speed of Hd relative to galaxy X, it follows that galaxy Y is moving at a speed of 2Hd to the right relative to galaxy X. The upshot of all this is that observations made from galaxy X yield the same Hubble law: all the galaxies appear to be moving away from galaxy X where the speed of a galaxy at distance d is Hd.



Since the Hubble law tells us that each galaxy sees all the others moving away from it, we would like to have a formulation of the Hubble law that does not depend on the point of view of any particular galaxy. Such a form is provided by Einstein's general theory of relativity. General relativity tells us that the geometric properties of space and time are not fixed (as they told us in high school geometry class) but instead can change, and furthermore that the phenomena that we usually refer to as gravity are simply effects of this exotic geometry. In particular, general relativity tells us that space can expand and that the Hubble law is simply a consequence of the expansion of space. In fact the Russian mathematician Alexander Friedmann found a solution of the equations of general relativity describing the expanding universe a few years before Hubble performed his observations. Furthermore, Friedmann found his solution simply by asking what a solution of general relativity that satisfied the Copernican principle would be like. Thus we see that far from being a violation of the Copernican principle, the Hubble law is a spectacular confirmation of it.

Another cosmological observation that at first sight might seem to violate the Copernican principle is the cosmic microwave background. In the 1960s, while testing an antenna for use in communicating with satellites, two scientists at Bell

Labs, Penzias and Wilson, observed microwaves coming at us from all directions in space. This might also seem like a violation of the Copernican principle (why are all the microwaves directed at us?), but it turns out that it isn't. The microwaves are actually a consequence of the Hubble law and the expansion of the universe. If a galaxy at some distance d from us is moving away from us at a speed of Hd, then it follows that that galaxy was at the same position as our galaxy at a time 1/H ago. Since this is true no matter what distance d we use, it follows that all the matter in the universe was at the same place a time 1/H ago. In other words, at that time the universe had an extremely high density. Since compressing objects tends to heat them, it follows that the universe at that time also had an extremely high temperature. Since the universe expanded from that extremely hot and dense state to its present state, this means that the universe resembles the aftermath of a gigantic explosion, a "Big Bang," and indeed this is the name used by cosmologists for the explosive beginning of the universe. How long ago was the Big Bang? Since astronomers can measure the speeds and distances of galaxies, they can calculate the Hubble parameter and thus calculate the time 1/H since the Big Bang. From these observations and calculations, it is known that the Big Bang happened about 14 billion years ago (13.7 billion years using the most precise current measurements). Since the Big Bang was very hot, and since hot objects give off light (think of the burner on an electric stove or the filament of an incandescent light bulb), it follows that at the time of the Big Bang the universe was filled with light. What happened to that light? It is still there, but its wavelength has changed. Light is made up of waves of electric and magnetic field, just as sound is made up of waves of air pressure. We distinguish sound waves by their pitch with shorter wavelengths corresponding to higher pitch and longer wavelengths corresponding to lower pitch. For light, wavelength corresponds to color, with red the longest wavelength of visible light and violet the shortest. At first, the phrase "visible light" sounds redundant, but it isn't. Just as there are sounds so high pitched that the human ear cannot hear them, so there is light whose wavelength is so short or so long that the human eye cannot see it. Depending on the wavelength, such light is called ultraviolet, X-rays or gamma rays, for the light with wavelengths too short to see, and infrared, microwave, or radio wave for the light with wavelengths too long to see. Since the expansion of the universe is an expansion of space, it stretches the wavelength of light. The light produced in the Big Bang has had its wavelength stretched so much that it is now in the microwave range. Thus the microwave background discovered by Penzias and Wilson is simply the light from the Big Bang explosion, stretched into microwaves by the expansion of the universe.

A normal explosion has a center. But in the Big Bang all points of space participate in the explosion in the same way. In fact observations of the microwave background show that in the early universe (i.e. the universe shortly after the Big Bang) all points in space had almost exactly the same density and temperature. In other words, the early universe was an exemplar of the Copernican principle: there were no special positions. In the present universe, the aftermath of the Big Bang is seen in the same way from all points in space. That is, every observer would see himself as in the middle of a bath of microwaves. Thus like the Hubble law, the cosmic microwave background is compatible with the Copernican principle.

The early universe satisfied the Copernican principle because the conditions (temperature, density, etc.) at all points in space were more or less the same. However, the present universe is very different. This raises another challenge to the Copernican principle that comes from the vastness of interstellar space compared to the size of the Earth. To get an idea of the sizes involved, consider that light can go around the Earth seven times in one second, but takes eight minutes to get from the sun to the Earth, and takes years to get from even the nearest stars to the Earth. This means that space is mostly empty and therefore that conditions here on Earth differ markedly from those of a "typical" point of space. As the philosopher Pascal put it “The eternal silence of these infinite spaces frightens me.”[2] Or, as the poet Auden said, [3]

> . . . the miracle
> that we’re here to shiver, that a Thingummy
> so addicted to lethal violence
> should have somehow secreted a placid
> tump with exactly the right ingredients
> to start and cocker Life . . .

Thus our “far from typical” point of space seems to be a challenge to the Copernican principle. In this case, the Copernican principle is rescued by another principle called the anthropic principle. This principle states that when asking about a “typical” point in space for an observer, one should not treat all points in space but only those points where the conditions are sufficiently hospitable that life had a reasonable chance of developing there. In other words, one need not consider those points of space that abound in “lethal violence,” like the cold emptiness of interstellar space, or the multimillion degree temperature at the core of a star.

Life as we know it depends on chemistry, which in turn depends on atoms combining to form molecules. The formation of molecules happens only when matter is sufficiently dense (so that the atoms are near enough each other to combine) and sufficiently cold (so that high temperatures don’t tear molecules apart). The “sufficiently dense” part rules out interstellar space, and the “sufficiently cold” part rules out stars. What is left are planets. Thus, though Earth is not a typical part of the universe, it may well be typical of those parts of the universe that support life. The anthropic principle in this case rescues the Copernican principle by refining our notion of what it means to be typical.

Nonetheless, the anthropic principle was invented not to assuage the discomfort of Pascal and Auden, but instead came about through the work of two physicists named Dirac and Dicke. Dirac posed a conundrum involving extremely large numbers that come about in studies of fundamental physics,[4] and Dicke invented the anthropic principle to solve Dirac's conundrum.[5] I will now take a diversion to explain this large number problem and how the anthropic principle solves it. One difficult aspect of physics is that it deals with both objects that are extremely large compared to the human scale (like stars) and objects that are extremely small compared to the human scale (like atoms). However, since stars are made of atoms, this means there must be a truly staggeringly large number of atoms in a star. And indeed this is the case: the number of atoms in a star is about 10^{57} (that is, a one with 57 zeros after it). Is there any explanation for such a huge number? As it turns out, the answer is yes: the large number of atoms in a star can be explained in terms of the weakness of the gravitational force. In daily life we don't think of gravity as an extremely weak force, since it is gravity that keeps us in our chairs (as opposed to flying off into space). But consider what happens when you use a magnet to pick up a nail: the entire Earth is pulling the nail with its gravitational force, while the magnet is pulling the nail with its magnetic force; and yet the tiny magnet wins! To be more precise about this question, we could consider a single atom, comprised of a nucleus and electrons. The nucleus attracts the electrons through both electric forces and gravitational forces, but which is stronger and by how much? It turns out that in an atom the electric forces are stronger by a factor of about 10^{40} (a one with forty zeros after it). If gravity is so weak, then how do we notice it at all? The answer comes from the fact that gravity is always attractive, but the electric force isn't: like electric charges repel while opposite electric charges attract. Since atoms have equal numbers of positive and negative charges, for a large collection of atoms like the Earth, the electric forces mostly cancel each other out, while the combined gravitational forces of the atoms finally add up to something appreciable.

So how does the weakness of gravity explain the large number of atoms in a star? The answer comes from considering what a star is: a collection of atoms held together by gravity and shining through nuclear fusion. To make atoms undergo nuclear fusion, one needs an extremely high temperature (on Earth fusion is done in hydrogen bombs which need the heat of an atomic bomb just to get the fusion started). Stars are made of gas, and compressing a gas heats it up. The compression is provided by the star's own gravity. Since fusion takes a very high temperature, and since gravity is so weak, it takes an extremely large number of atoms before their gravity is large enough to make the temperature rise to that needed for fusion. No star can have a mass of less than about 1/100th that of the Sun and attain fusion. OK, so the weakness of gravity explains why stars much less massive than the Sun can't exist; what about stars much more massive than the Sun? It turns out that they can't exist either. Such a star would have such a high temperature that it would undergo fusion at such a high rate that it would blow itself apart. No star with a mass more than about 100 times the mass of the Sun can hold itself together. Thus the weakness of gravity explains the extremely large number of atoms in a star.

One might then go on to consider whether the weakness of gravity can itself be explained. This is a deep question in physics for which the answer has not yet been found. Instead, we will ask whether there are any other extremely large numbers that can be explained by the weakness of gravity. Atoms are small and the universe is large, so we could consider the extremely large number that we get when we take the ratio of the size of the universe to the size of an atom. More precisely, we don't know how large the universe is, but we can consider the size of that part of the universe that we can see and take the ratio of that size to the size of an atom. Since the universe has been around for about 14 billion years, and since we see using light, the size of that part of the universe that we can see is the distance that light can travel in 14 billion years. So how large is the ratio of the size of the universe to the size of an atom? About 10^{38}. (Equivalently we can think of this number as being the ratio of the age of the universe to the time it takes light to cross an atom). This extremely large number seems suspiciously close to the extremely large number that tells us about the weakness of gravity. So we might expect that here too the weakness of gravity explains this large number. However, there is a fundamental problem with this expectation. Unlike the number of atoms in a typical star, which is a single number, this ratio depends on the age of the universe and thus was a much smaller number at much earlier times and will be a much larger number at much later times. This then is the "large number problem" alluded to earlier. This particular large number (the ratio of the age of the universe to the light crossing time of an atom) certainly seems suspiciously as though it should have an explanation in terms of the equally large number that tells us how weak gravity is. And yet no such explanation seems possible since the number has the particular value that it has only at the present time. Dirac developed this particular paradox, and also came up with a desperate measure to solve it. Dirac supposed that gravity does not always have exactly the strength it does today, but rather that the strength of gravity depends on time in just such a way that the two large numbers (ratio of electric to gravitational strength, and ratio of age of the universe to light crossing time of an atom) should always be approximately the same.

Dirac's paradox can be viewed as another application of the Copernican principle, only this time to our time in the history of the universe rather than our position in space. This "Copernican principle in time" would then say that our time in the universe should be a typical time rather than a special time. In particular the fact that we happen to live at the time when the large number involving the age of the universe is about the same as the large number involving the weakness of gravity should be regarded as a glaring coincidence that demands some sort of explanation.

Dicke developed the anthropic principle precisely to solve Dirac's paradox without resorting to Dirac's desperate measure of making the strength of gravity depend on time. Dicke noted that the present age of the universe cannot be just any time but instead must be a time in which living creatures can exist. Living creatures are made of molecules, in particular long molecules containing atoms of carbon. Thus living creatures depend on the existence of carbon. The lightest two chemical elements, hydrogen and helium, were formed in the Big Bang. But carbon and all heavier elements are formed in stars. A star spends most of its life fusing hydrogen into helium; but then when enough helium has accumulated in its core, the star fuses helium to make carbon and oxygen. Average size stars like our Sun stop there; but large stars go on to make all the other elements of the periodic table and then die in a huge explosion called a supernova that scatters these elements into interstellar space where they can become parts of new stars and planets that form around those stars. Thus life cannot come about until at least some stars have formed, produced chemical elements, and exploded. Or to put it another way, the age of man cannot precede the age of the stars.

So how long do stars live? Just as with the number of atoms in a star, stellar lifetimes can be calculated using the weakness of gravity, and the answer comes out to about 10^{38} times the light crossing time of an atom. In other words, the present age of the universe is about the same as the lifetime of an average star. However, this lifetime is only an average, since stars come in different sizes. A larger mass star has more fuel to consume; but due to its larger gravity it has a much higher temperature and thus consumes its fuel much faster than a smaller mass star. The upshot is that the largest stars have the shortest lifetimes and the smallest stars have the longest lifetimes. Since carbon is produced in stars, life cannot exist before the shortest lived stars have exploded. However, life on Earth runs on solar power, either directly (plants that make energy through photosynthesis) or indirectly (animals that eat those plants or eat other animals that eat the plants). Thus life needs not only a planet, but also a shining star. Therefore Dicke argued that the “age of man” coincides with the “age of the stars.” Since the time of the stars can be explained using the weakness of gravity, Dirac’s conundrum is solved without having to suppose any new laws of physics.

On a cautionary note, however, it is helpful to point out that the first part of Dicke's argument is on much more solid ground than the second part. It is clear that from just hydrogen and helium nothing as complicated as life will arise, so the formation of stars must precede the age of life. But it is not quite so clear when the age of life in the universe will end. It is conceivable that a sufficiently advanced civilization might figure out how to survive the death of the stars. And even if the death of the last star means the end of life in the universe, very low mass stars last much longer than the sun, so even if one accepts the notion that the age of life coincides with the age of the stars, one is still left with the Copernican question of why we happen to be alive so early in the age of the stars. This difficulty can be overcome by understanding the Copernican principle in time and the anthropic principle in a statistical sense: a typical place and time for life is where life is most likely to be found, not merely where life is possible. Though stars are forming even in the present day, they do so at a smaller rate than in the heyday of star formation and will do so at a slower rate as time goes on. Though very small stars last much longer than the sun, it may very well be that the planets around such small stars are less likely to bring forth life. Thus we should not be surprised to find ourselves so early in the time of the stars if such early stars are more likely to give rise to (in Auden's words) "exactly the right ingredients to start and cocker Life."

Though much of the previous discussion has used the minutiae of astrophysics and cosmology, the Copernican principle in time itself is independent of these minutiae. It depends only on having a personal time scale (in this case that of the human species) much shorter than a more universal time scale (in this case that of the universe) so that one can ask whether the position of the personal time scale is typical in that of the more universal time scale. Put that way, one can note that the lifetime of an individual human being is much shorter than the life of the human species. One can then apply the Copernican principle to ask whether "our time" meaning in this case the lifetime of those of us alive today is a typical time in the history of the human species. The rest of this article will be concerned with this somewhat speculative question.

The way that history is studied tends to discourage questions of this sort. The subject of history is balkanized with each historian tending to specialize in one geographic region for one time period. The question itself also seems on the face of it quite vague and therefore not susceptible to an analytic treatment. Nonetheless, there is a well defined sense in which our time in human history on the face of it seems to violate the Copernican principle. One can then argue that the anthropic principle may render our time typical, but only if we are on the verge of a catastrophic collapse.[6,7] Arguments of this sort are called "Doomsday Arguments." The rest of this article will be a presentation of a variation on the Doomsday Argument.

To begin with let's consider how one might make the case that we appear to live in an untypical time. The most obvious thing one might point to is the state of our technology. We have things like spaceflight, computers, cell phones, and TV that have never appeared before in human history. However, this alone is not sufficient to render us untypical in a Copernican principle violating sense. As long as there is progress, each generation has better technology than the generation before. Thus the possession of better technology than the previous generation does not by itself render our generation untypical. As an analogy with the previous treatment of cosmology, one could imagine someone saying, "of course our time in the history of the universe is untypical: due to the expansion of space, the distance between galaxies is larger than it has ever been before!" To which one could easily reply, "yes, but that statement was true a billion years ago and will also be true a billion years from now."

Instead, I will make an argument that our time appears to be untypical based on the work of Malthus.[8] Thomas Malthus wrote (several versions of) a treatise on population in the years around 1800. In particular Malthus pointed out that (a) unchecked reproduction leads to exponential growth of population, and that (b) exponential population growth cannot be maintained indefinitely because there will not be enough resources. It is customary among economists to reject the work of Malthus and to say that history has proved Malthus wrong. It is true that Malthus underestimated the effects of technological innovation and trade in increasing available resources and thus appeared to predict an immanent crisis that did not take place. However, these errors do not affect points (a) and (b) above, which I regard as the core of Malthusianism, and which will be the only part of Malthusianism used in this article. Furthermore, this core Malthusianism is one of the main ingredients of Darwin's theory of evolution and thus of modern biology. In fact, Darwin's development of the theory of evolution was influenced by Malthus' ideas. So if economists really mean to reject all of Malthus, they are also rejecting a large part of the foundation of biology.

What appears untypical of our time then is that we are in a period of exponential population growth. Since exponential population growth cannot be sustained indefinitely, a period of exponential population growth cannot be the typical behavior. Thus, on the face of it, our time period appears to violate the Copernican principle.

Does it actually violate the Copernican principle? Or is this another of those situations where the Copernican principle is rescued by the anthropic one? The answer to this question depends on what happens next. In particular, I want to consider two possible scenarios: the best case scenario of a "soft landing" and the worst case scenario of a catastrophic collapse and the extinction of the human species. In the best case scenario, population growth slows down (as it has already done in first world countries), leading eventually to a steady world population, perhaps somewhat larger than the present number, but in any case significantly larger than say the world population in 1800. Furthermore, technological innovation and change in consumption habits leads to adequate resources for this population provided in a renewable way and without an excessive level of greenhouse gases. Wonderful as this scenario is, it is also clear that it violates the Copernican principle.

Human history in this scenario has three clearly delineated pieces: a long period of very low population, followed by a short period of exponential growth, followed by a long period of comparatively large population. Clearly, the short period of exponential growth is untypical. Furthermore, the anthropic principle is of no help here since there are far more people in the era of large population than in the era of exponential growth. Of course, there's nothing wrong with violating the Copernican principle, especially when the alternative is extinction of the human species. Nonetheless, if we do somehow achieve the best case scenario, we will have done so by participating in a truly exceptional period in history.

In contrast, consider the worst case scenario. If population growth is unchecked, or not sufficiently checked, there are any number of things that could cause a catastrophic collapse and extinction of the human species. These include (but are not limited to) worldwide famine, pandemic disease, global warming, all out nuclear war, and mass extinction of species leading to large scale collapse of ecosystems. Human history would thus consist of three periods, a long period of very low population, followed by a short period of exponential growth, followed by extinction. At first sight this scenario seems to violate the Copernican principle, as it places us squarely in the era shortly before collapse, which sounds like a very untypical time. However, oddly enough, in this case the Copernican principle is not violated due to the anthropic principle. One of the curious facts about an exponentially growing population suddenly cut off is that there are as many people in the period shortly before the cutoff as there were *in all the time before that period.* Since the statistical version of the anthropic principle teaches us to count number of observers rather than amount of time, we are left with the odd fact that the time shortly before the collapse is actually, by anthropic lights, a typical time. Thus the worst case scenario actually satisfies the Copernican principle.

What about cases that are somewhere in between best and worst cases? To be consistent with the Copernican principle a scenario requires that the number of people who live after us not be hugely greater than the number who have lived before us. Given the huge recent increase in population, the only way for future human history to be both long and Copernican is if there is soon a sharp and permanent reduction in population. Thus, for example, one could imagine a not-quite-worst-case scenario in which an ecological disaster destroys civilization but leaves the human species alive with stone age technology and stone age population numbers. But in any case one is left with the inescapable conclusion that either the Copernican principle is violated or some sort of very drastic change is going to occur relatively soon.

Of course that does not mean that the worst case scenario (or something like it) will actually happen: the Copernican principle is only a guideline for making models, not an iron law that cannot be violated. Nonetheless, because of their lack of unexplained coincidences, models that obey the Copernican principle are inherently more likely than those that violate it. This should lead us to be even more worried about ecological catastrophe than we were before. We are left with the uncomfortable conclusion that we may well live in a typical time, but only if we're doomed.

Acknowledgements

It is a pleasure to thank Alberto Rojo, Fred Adams, Sherm Folland, Sean Moran, and John Halpin for helpful discussions. Note that this acknowledgement does not imply that the above named people agree in any way whatsoever with the views expressed in this article (but they should).

REFERENCES

[1] T. Kuhn, *The Copernican Revolution,* (Harvard University Press, 1957)

[2] B. Pascal, *Pensees,* 206

[3] W. Auden, *Ode to Terminus*

[4] P. Dirac, Proc. Roy. Soc. **A 165**, 199 (1938)

[5] R. Dicke, Nature, **192**, 440 (1961)

[6] J.R. Gott, Nature, **363**, 315 (1993)

[7] H. Nielsen, Acta. Phys. Polon. **B 20**, 427 (1989)

[8] T. Malthus, *An Essay on the Principle of Population* (1798, 1803, 1806, 1817)