Physical Eschatology

The subject of physical eschatology is in its infancy. While popular books about the Big Bang and the cosmological origins of life have inundated bookshops during the past couple of decades, it is only in the past few years that a trickle of books about the distant future and the probable cosmological extinction of life has appeared. Moreover, this disproportion is also apparent in the technical, scientific literature: there have only been a handful of serious studies of far distant cosmological futures. Perhaps some of this relative neglect can be attributed to the more speculative nature of eschatology—and perhaps more can be attributed to the psychological discomfort to which serious study of the future of the universe seems apt to give rise—but, whatever the reasons, it seems that we are currently seeing some redressing of this imbalance. In particular, the work of Adams and Laughlin (1997) serves as a useful benchmark for progress in this area.

I shall begin with the assumption that the causally connected universe is all the universe that there is, i.e. I shall begin with the assumption that there are no causally disconnected regions. Under this assumption, I shall explore the likely future of the universe under the further assumption that the currently observable universe is representative of the universe as a whole. Since the current best opinion is that the currently observable universe is open, this means that in this most likely future, the universe itself is open, and 'exists forever'. The future of open universes much like our own is the topic of Section 1 of this paper.

If we give up the assumption that the currently observable universe is representative of the universe as a whole—but while still holding on to the assumption that there are no causally disconnected regions of the universe—then it is possible to suppose that the universe is closed. If we suppose that the universe is closed, then we can explore its likely future as it journeys towards the Big Crunch. The future of closed universes much like our own is the topic of Section 2 of this paper.

If we give up the assumption that there are no causally disconnected regions—i.e. if we allow that there are, or might be, regions of the universe with which our region of the universe shall never be in causal contact—then all kinds of speculative possibilities emerge. We shall canvass a few of these possibilities, without making any attempt to assign a value to their likelihood. These speculations are the topic of Section 3 of this paper.

One main focus of interest in the future of the universe concerns the future of human beings, life, intelligent entities, and the like. What does the future hold for us, and those like us? In Section 4 of this paper, we shall look at some suggestions about the likely fate of our descendants in each of the kinds of scenarios discussed in the first three sections of the paper.

In the final section of the paper, we shall ask some questions about the significance of the answers to—and the significance of the activity of seeking answers to—the questions which are the topic of investigation in Section 4. Since the middle of the nineteenth century, the 'Heat Death of the Universe' has exercised a considerable grip on the popular imagination—and on the imagination of scientists as well—but is there really any good reason for this obsession? Since this is a vast—and interesting—topic, the remarks to be made in this final section are preliminary at best.

In this paper, I shall assume that some kind of Big Bang theory is correct, i.e. that the currently observable universe evolved from a superdense state over a period of ten to twenty billion years. While this is clearly the view which is best supported by the current evidence, there are still supporters of various kinds of Steady State theories, which hold that the resources of the universe are continually replenished by the spontaneous creation of matter and energy to fill the space created by expansion. On these kinds of views, there is in principle no reason why there couldn't be galaxies existing indefinitely into the future: some galaxies would die, collapsing into black holes which then evaporate away via Hawking radiation; but new galaxies would continue to form, and the process of forming stars and planets would continue forever. No doubt, there are difficulties in getting the spontaneous creation of matter and energy to happen in the right way to ensure that there will be new galaxies: but I shall leave these matters to enthusiasts of steady state theories.

1. The Future in an Open Universe

If we suppose that the currently observable universe is representative of the universe as a whole, and if we suppose that there is no dramatically new physics which remains to be discovered, then we can give a fairly detailed description of the large–scale structure of the universe from the far–distant past into the far–distant future.

The very earliest stages of the universe—including and prior to the period of inflation—are shrouded in mystery. However, from the time of quark confinement and baryogenesis, we have at least a general qualitative understanding of the evolution of the universe.

Very early in the history of the universe—within what is conventionally called the first microsecond—nucleosynthesis produces some small nucleii: helium nucleii, deuterium nucleii, lithium nucleii, and the like. After about 300, 000 years, the expansion of the universe reduces the energy of the sea of photons which bathes the primordial universe to the stage at which they no longer prevent the formation of atoms. (These photons—which constitute the cosmic microwave background radiation—provide some of the best current evidence for the theory which is here described.) Vast amounts of hydrogen and helium are formed—particularly the former—and, under the influence of gravitational attraction, these hydrogen and helium atoms aggregate into large molecular clouds which are somewhat denser than the surrounding interstellar gas. Within these molecular clouds, stars and planetary systems form. Thus, from the very beginning, the universe has a clumpy appearance: clusters of galaxies are spatially separated, and the expansion of the universe drives them further apart.

Galaxies exhibit complex structure and behaviour. At the core of each galaxy is a large black hole, a superdense region from which (almost) no radiation escapes. Surrounding the galaxy is a massive halo, which contains some kind of exotic dark matter. Most galaxies rotate, hence the familiar disk–like structures which they exhibit. Apart from dark matter, galaxies contain a range of inhabitants, including brown dwarfs—failed stars which did not manage to accumulate sufficient mass to initiate nuclear reactions; red dwarfs—small stars, which burn slowly and not very brightly; medium stars like our sun; large unstable stars, which typically explode or collapse; red giants—a late phase of medium stars, in which they grow to a much larger size; white dwarfs—small, extremely dense stars, which constitute the cores of red giants, and which can arise from a variety of evolutionary processes; neutron stars—even more dense bodies, in which all of the constituent matter takes the form of neutrons; and black holes—the most dense cosmological bodies. As already intimated, these galactic inhabitants have typical evolutionary trajectories: depending largely upon their size, stars can undergo collapse into states of ever–increasing density, or they can explode, or they can simply and quietly radiate away.

The materials from which the galactic inhabitants are constituted are partially recycled: when stars die, some of their mass is returned to the interstellar medium. However, the galactic supply of gas and dust is gradually depleted, so that, after about 10^{14} years, conventional galactic formation of stars ceases. Moreover, since larger stars burn more quickly, it happens that luminous stars disappear first—within say 2 x 10^{14} years at the latest. From this time on, the principle major bodies in the galaxies are brown dwarfs, white dwarfs, neutron stars, black holes and the remains of planets. While brown dwarfs, white dwarfs, and neutron stars continue on their evolutionary paths, the galaxies begin to break up: as a result of collisions between galaxies, and of scattering of stars within galaxies, a process of galactic relaxation leads to the ejection of the vast majority of stars into intergalactic space—and the remaining low–energy stars are absorbed by the central galactic black holes. These same processes also bring about the break–up of planetary systems, so that planets are also forced off into the depths of interstellar space.

Up until about 10^{20} years, there may still be new stars and planets formed, particularly in the aftermath of collisions between brown dwarfs, and more rarely, in the aftermath of collisions between white dwarfs. However, after this time, the only important things which grow are black holes; just about everything else is subject to decay. The dark matter particles in galactic haloes annihilate, and some of this matter is accreted by white dwarfs. Black holes continue to accrete stars, and then, after about 10^{37} years—on current estimates—protons decay. This decay marks the demise of white dwarfs, neutron stars and planets—though the final phases of existence are different in each case.

The universe is now dominated by black holes, but it continues to 'run down', due to the dissipative effects of gravitational radiation—which drives the decay of binary black hole systems—and then to the effects of Hawking radiation, which leads to the decay of the black holes themselves. At some time between 10^{100} years and 10^{130} years, the decay of the final (enormous) black hole is complete, and the universe is reduced to an enormously dilute gas of the smallest types of elementary particles and very low–energy radiation. In this final phase, which Davies calls 'eternal death', particle annihilation continues, but at an ever–decreasing rate. In the relatively early stages—say, from 10^{70} years—positronium formation is one of the most important of these processes; even though positronium takes about 10^{145} years to decay, this process is eventually exhausted. While not quite the 'Heat Death' which perturbed the nineteenth century, the distant future is 'asymptotically close to it'.

The above account contains various controversial assumptions. For example, the decay of protons has not yet been experimentally confirmed, and nor has the decay of black holes as a result of Hawking radiation. However, as Adams and Laughlin (1999) urge, the above account is the one which you get by taking what seems to be the currently most plausible option at each point. There is no doubt that it could be wrong in ever so many places; but there is no more plausible story to put in its place. For example, even though it might be that, at some time in the future, the universe will go through another phase transition—like the one supposed to have occurred at the time of the separation of the strong and electroweak forces—with entirely unpredictable consequences, there is no good reason to predict that this will happen (and certainly no good reason to predict that this will happen at any particular time). Moreover, there seems to be little reason to doubt that the state of 'eternal death' is the most likely outcome for the universe: in the battle between gravity, expansion, and entropy, it is entropy which will be the final victor.

It should be noted that the above account is premised on the assumption that the universe is open. If the universe is flat—i.e. if the density of the universe is exactly the critical value—then it might be that black holes will survive indefinitely, because the rate at which they merge and expand exceeds the rate at which they are depleted by Hawking radiation. It should also be noted that the above, highly schematic account of the future of the universe can be filled out in much greater detail, and that the major claims upon which it depends can be supported by appeal to the evidence of particle physics, astrophysics, quantum mechanics, general relativity, and so forth. However, to do all this would require a book length treatment by experts in the field—cf. Adams and Laughlin (1999).

2. The Future in a Closed Universe

If we suppose that the currently observable universe is not representative of the future observable universe—i.e. if the causally connected universe has a density which is greater than the currently observable universe—then it is possible that the universe (or our region thereof) is closed, and that it will end in a Big Crunch. Because nearby variations in the density of the universe would create ripples in the cosmic microwave background radiation, and because such ripples are not observed, we can calculate that, if our universe is to end in a Big Crunch, this will not be for a reasonably long time: at least 5×10^{10}

years. Since, in principle, recollapse could happen at any time after this, there are many vastly different scenarios which could arise for a recollapsing universe: at the point of greatest expansion, the universe could be populated with brightly burning stars, or with degenerate stellar remnants, or with black holes, or with a thin soup of elementary particles and attenuated radiation. However, the final moments of the universe will be the same in every case, and will more or less play out in reverse the initial moments of the Big Bang.

Suppose, for example, that the turnaround occurs at the earliest possible time, i.e. when the universe is about 3×10^{10} years old. By this time, the earth and sun will have long since perished, but the large–scale appearance of the universe will be much as it is now: large amounts of empty space interspersed with clusters of galaxies made up of more or less brightly shining stars, and the other galactic inhabitants mentioned in the previous section. Since, at this time, the universe will be twice as large as it is now, the temperature of the cosmic microwave background radiation will be half of its present value, i.e. about 1.4 ^{o}K. Over the next 2×10^{10} years, as the universe collapses back to its present size, the only significant large–scale change in the appearance of the universe will be that this temperature will return to its present value. (Observers would also note that the light from distant galaxies is blue–shifted, evidence of the global contraction of the universe.)

As the universe continues to contract, the space between the galaxies disappears and the universe becomes, first, one giant cluster of galaxies and then, as the contraction continues further, a single galaxy filled with stars. At this point, the universe is about one hundred times smaller than it is today, and the temperature of the cosmic background radiation has risen to 274 ^{o}K, i.e. roughly the freezing point for water. With about 10^7 years left, the universe is now about to become a rather inhospitable place. The temperature continues to rise steadily until, with about $6x10^6$ years left, the temperature of the cosmic background radiation rises above the boiling point for water. As the universe contracts and the temperature rises, there is a race to see which factor leads to the destruction of the stars: rising temperature triumphs, and, when there is less than 10^6 years left, the stellar surfaces are radiated away by the background radiation field before the stars can collide under the influence of gravitational collapse. The remaining stellar materials—brown dwarfs, white dwarfs, planets, etc.—either evaporate or else contribute fuel to the seething nuclear cauldron. During the final few thousand years, the background radiation becomes so intense that it breaks atoms apart into their constituent nucleii and electrons, and matter and radiation once again become closely coupled (as they were when the universe was 300, 000 years old). With 10, 000 years remaining, the density of radiation surpasses the density of matter. With three minutes remaining, in a frenzy of antinucleosynthesis, the atomic nucleii begin to break apart. All of the varieties of atomic nucleii are present, but even the most stable succumb to the intense heat so that, with about one second to go, none of the elements remain, and protons and neutrons exist independently. With about one microsecond to go, the protons and neutrons themselves break apart, and become free quarks. From this point, the collapse is just like the beginning run in reverse, except for the presence of coalescing black holes. The universe goes through several phase transitions, at the points at which the various forces are unified, and the remaining history escapes our present understanding.

If there is to be a Big Crunch, then there is not much doubt that the above story tells it more or less how it will be, at least until close to the end. However, one theoretical possibility which attracts attention from time to time is that the Big Crunch might be succeeded by a subsequent period of expansion, in which the same kind of history is played out all over again. Given that inflation happened once, why shouldn't it happen all over again? Indeed, since the very origins of the universe are shrouded in mystery, might it not be the case that there is an unending sequence of cycles of this kind stretching back into the past and forward into the future? One objection which is frequently lodged against this suggestion is that it is hard to see what kind of mechanism could reverse the collapse and produce another period of expansion. However, it is unclear that this problem is any more severe than the problem of explaining how inflation came to happen in the early history of our universe. Another observation which is often made about this kind of suggestion turns on the fact, noted above, that the collapse of the universe is not simply a reversal of the initial expansion: there is a net transfer of energy from matter to radiation during the course of history, and there are more black holes present in the contracting phase than during the expanding phase. Because of these factors, subsequent cycles must grow larger and longer, and earlier cycles must have been smaller and briefer. As the cycles grow longer, more and more of history will take place under conditions which 'asymptotically approach' the conditions of 'heat death' and—perhaps—there will eventually be a cycle in which collapse does not occur at all. However, even if this is right, these are not reasons for refusing to believe that the total universe is much larger and much longer lived than we might initially have supposed.

3. Some Speculative Possibilities

If we suppose that there are—or could be—causally disconnected regions of the universe, then many speculative possibilities about the global shape of the universe and its future emerge. In some cases, the lack of causal connection is only 'for the most part'; in others, it is total. The significant point is that we imagine exotic topological structure which extends far beyond either the currently observable universe or the largest 'regular' spacetime manifold within which it is embedded.

1. Worm Holes: Science fiction writers have often speculated about the possibility that there might be spacetime 'portals' which can be used to gain access to 'other universes', or to reduce travel times to distant parts of the observable universe. Since there seems to be nothing in GTR which rules out the possibility that there might be a multiverse of spacetimes connected by wormholes, one might be tempted to think that this kind of scenario has some credence. Moreover, if the currently observable universe does belong to a multiverse of this kind, then questions about the distant future—and perhaps the distant past—take on a quite different complexion. Perhaps our part of the multiverse is destined to collapse in a Big Crunch; or perhaps our part of the multiverse is destined to

expand into a state which approaches Heat Death—but, either way, there is no guarantee that the entire multiverse is subject to the same fate.

While the absence of evidence for wormholes might be seen as a reason for refusing to believe in their existence, the absence of evidence also means that there are few contraints on the subsequent fantasising in which it is possible to indulge. If we suppose that the laws and boundary conditions can be very different as different ends of a wormhole, then there might be other parts of the multiverse which are correctly characterised by a Steady State theory. On the other hand, if we suppose that the laws and boundary conditions must be similar at opposite ends of a wormhole, and if we suppose that all parts of the multiverse must be stepwise connected to us, then it might be that we can be fairly sure that there is no part of the multiverse which is not eventually subject to a Big Crunch or to Heat Death.

Even if there is a multiverse of the kind envisaged here, it is very hard to believe that it could be possible for large scale physical structures to travel from one part of the multiverse to another via the connecting wormholes. If there are wormholes, they will surely be something like black holes; in particular, they will surely be places where there is extreme curvature and consequent tidal forces. Thus, this kind of speculation about the existence of a multiverse provides little reason to revise our estimates about the long term future of *our* universe. Of course, this thought need not be entirely negative: if large scale physical structures cannot traverse wormholes, then there is no reason to fear that our future might be adversely affected by large scale physical structures which arrive from some other part of the multiverse.

2. Baby Universes: In the previous subsection, I did not explicitly suppose that the wormholes connecting the various parts of the multiverse have a preferred direction (and perhaps I even implicitly supposed that they do not). But suppose we add this further assumption. Suppose, for example, that it is possible for a 'mother' universe to give birth to 'baby' universes, which are initially connected to the 'mother' by wormholes which then evaporate away, leaving new and independent universes to develop on their own. Under this kind of scenario, we can impose a kind of temporal structure on the multiverse as a whole—and so make sense of the idea that the multiverse as a whole avoids the twin perils of Big Crunch and Heat Death, even if no particular universe within the multiverse succeeds in doing this.

Scenarios in which 'mother' universes give birth to 'child' universes have received intensive study. For example, much consideration has been given to the idea that a small bubble of false vacuum surrounded by true vacuum would go through inflationary expansion, but without displacing any of the volume of the true vacuum. This raises the truly bizarre possibility that it is possible, at least in principle, to create new universes in a laboratory setting: although these experiments trigger big bangs, the bangs are confined within tiny black holes which soon evaporate away without trace. (Farhi et. al. (1990).)

It hardly needs to be said that these fanciful speculations are without direct empirical foundation. Moreover, it is worth noting that, even if our descendants are able to create new 'baby' universes, there is not the slightest reason to think that large scale physical structures from our universe will be able to enter those 'baby' universes before the wormhole closes off. Apart from anything else, it is hard to believe that any kind of large scale physical structures could have survived through the inflationary expansion which characterised our early universe, or the subsequent aeons of extremely high temperature.

3. Cosmic Evolution: If 'baby' universes are—or can be—the offspring of 'mother' universes, then a question arises about the connection between the physical characteristics of the 'baby' universes and the physical characteristics of the 'mother' universe. On the one hand, it might be that there is no connection between the laws and boundary conditions in the 'mother' universe and the laws and boundary conditions in 'child' universes. On the other hand, it might be that 'child' universes must have exactly the same laws and boundary conditions as the 'mother' universe. Some physicists have speculated that the connection between 'child' universe and 'mother' universe might be typically close—almost no variation in laws and boundary conditions—except for the occasional dramatic departure. Others—in particular Smolin (1997)—have speculated that there might be a kind of Darwinian evolution in operation which indirectly favours the emergence of life and consciousness. (If we suppose that life typically develops to the stage where there are creatures who have the ability to bring about the creation of 'baby' universes in the laboratory, then this might be an additional factor in the proliferation of life–containing universes.)

Once again, it hardly needs to be said that we are far advanced into the lands of fanciful speculation here. Perhaps it isn't possible for 'baby' universes to form in the way envisaged. Perhaps it is possible, but it hasn't happened, and it never will. Perhaps it happens, but the resulting 'universes' are few in number, and do not support life. Perhaps ... we should leave all of this unconstrained speculation for some other occasion.

4. Inflating Bubbles: Since there is one spacetime–bubble which underwent inflationary expansion, it is conceivable that there is more than one. Perhaps there are many—indefinitely many, uncountably many—universes, each of which undergoes inflationary expansion from an initial tiny space–bubble. These universes may have some kind of initial connection—perhaps they all arise in some kind of ancestral spacetime foam—or it may be that they have no causal connections of any kind. Either way, we may suppose that there is no further causal interaction—i.e. these parts of the multiverse are essentially causally isolated domains.

As noted in the previous subsections, there are various different hypotheses which we might entertain about such a multiverse. It could be that some parts of the multiverse are Steady State universes; or it could be that there is asymptotic approach to Steady State universes amongst universes which are eventually subject to either Big Crunch or Heat Death; or it could be that every part of the multiverse is subject either to Big Crunch or effective Heat Death within a definite and finite length of time. Which of these outcomes is most likely depends upon the assumptions which we make about the variation in physical law and physical boundary conditions across the parts of the multiverse, and upon the assumptions which we make about the number of parts which the multiverse has.

There may be other scenarios which also make provision for causally isolated universes. Moreover, there may be some reason—given, in particular, by the fine–tuning considerations—for supposing that there must be a multiverse, or an ensemble of universes, or the like. However, we shall not attempt to follow up on these kinds of considerations here.

4. What About Us?

As I noted in my introductory remarks, one of the main foci of interest in the future of the universe concerns the future of human beings, intelligent entities, life, and the like. In this section, we shall examine some of these concerns, beginning with a look at the likely fate of the earth and sun in both open and closed universes. Given the extreme nature of the likely 'terminal' conditions in both open and closed universes, it should come as no surprise to be told that life and intelligence will ultimately disappear from the currently observable universe and from the causally connected universe. Of course, whether life and intelligence persist in other causally disconnected regions of the universe remains a far more speculative question, but one to which we shall also give brief attention.

1. Open Universes: At present, the Earth and Sun are about 4.5×10^9 years old. Barring unfortunate accidents, it should be possible for life to continue on Earth for another 2×10^9 years. By that time, the power output from the Sun will have increased considerably, leading to global warming, and then to greenhouse catastrophe. When the oceans evaporate, conditions on Earth will come to closely resemble current conditions on Venus: very hot and sterile. As more time passes, the power output from the Sun continues to increase and it swells into a red giant, perhaps engulfing Mercury and Venus. Strong solar winds carry away even more mass from the Sun and, with the reduction in gravitational attraction, the orbit of the Earth enlarges. A white dwarf forms as the central core of the Sun, and then the death throes of the dying star are played out: the helium flash, and then the slide into relative senescence. When the Milky Way and the Andromeda galaxy merge—perhaps around the time that the Sun dies—the earth is stripped from its orbit, and plunged into the depths of interstellar space. Various possible fates await: perhaps it falls into a black hole, or a white dwarf; perhaps it endures until the protons of which it is composed decay. Similarly, different possible fates await the Sun: the white dwarf which remains when all else has evaporated away may perish in a collision with another white dwarf or black hole; or it, too, may endure until the protons of which it is composed decay. Whatever happens, after no more than 10^{40} years, no trace of either remains.

Although the most probable fate for the Earth is that it is turned into a small sterile lump of rock by the increased radiative output of the Sun, there are less probable scenarios on which imminent doom is delayed. For example, it is possible that the orbit of the Earth might be disrupted by a passing star within the next $2x10^9$ years. In that case, the most likely upshot is that the Earth would be ejected from the solar system and left to wander through the depths of interstellar space. In this case, as the Earth recedes from the Sun, the temperature at the surface will drop, causing the atmosphere to condense and the entire planet to be plunged into a permanent deep freeze. However, deep inside the earth, nuclear–powered geological activity continues for billions of years, and exotic forms of life may continue—e.g. in hydrothermal vent ecosystems—provided that they evolve to cope with the dwindling oxygen supplies. Under these circumstances, it is possible that anaerobic bacteria might continue to thrive deep inside the earth for many billions of years, until the internal energy supplies of the Earth are exhausted. Thereafter, the potential futures are as described in the previous paragraph.

Of course, ever more fantastic scenarios might lead to more interesting extensions of the tenure of life on Earth. For instance, it could happen that, when the orbit of the Earth is disrupted by a passing star, the Earth then falls into a stable orbit around that star. If, for example, the Earth fell into the right kind of orbit around a red dwarf, then life could conceivably continue on Earth for around 10^{12} years or more. However, the odds against this happening are truly astronomical—and, in any case, when the red dwarfs all burn themselves out, the same scenarios which were described in the previous two paragraphs will then play themselves out. As we have already noted, the tenure of life as we know it in an open universe is limited, though, by ordinary standards, the limitations of this tenure are extraordinarily generous. In the long run, even if living creatures manage to master the immense difficulties of interstellar and intergalactic travel, there will come a time when no living creatures remain.

The above discussion is largely premised on the assumption that living creatures will be creatures like us, i.e. creatures with a carbon–water based chemistry. However, many people have been prepared to speculate about the possibility of far more exotic life forms which are capable of existing in the inhospitable conditions which lead to the extinction of familiar forms of life. For example, Dyson (1979) takes seriously the possibility that dilute assemblages of electromagnetically charged dust grains might be endowed with intelligence, and Adams and Laughlin (1999) speculate about the possibility that black holes in the black hole era might form complex living structures. However, even under the most unconstrained exercises of imagination, it seems impossible to suppose that there might be living creatures in the far distant future as the universe 'asymptotically approaches' the 'Heat Death'. (Under the most optimistic scenario which Dyson envisages, his creatures are required to endure ever lengthier periods of hibernation. Even ignoring the fact that there will be no grains of dust in the far distant future, the upshot is that the universe asymptotically approaches a state in which there is no non–hibernating life. It is unclear why this should be thought to be more desirable than a universe from which life is entirely absent.)

Of course, if the purpose of these exercises of imagination is to show that the future tenure of life and intelligence in the universe may be much greater than the maximum of $2x10^9$ years allocated to life on Earth, then we have little reason to disagree. If life as we know it is reasonably common in the universe then, without any further strong assumptions, we might reasonably expect that it will not die out entirely until the universe is 10^{20} years old. If we are prepared to make bold assumptions about the possibilities for our descendants to engage in interstellar and intergalactic travel, then it is at least possible that we might not die out entirely until the same time. If we are prepared to suppose that it is tantamount to survival if we launch self–replicating machines which can then colonise the galaxies, and which can survive in quite inhospitable conditions, then it is possible that our survival might persist until the era of proton decay, i.e. for about 10^{38} years. However, that these scenarios are conceivable is no argument at all that they are probable: there is currently considerable debate about the likelihood of independent life elsewhere in the universe; and there are enormous practical difficulties for space travel and the production of self–replicating machines. Moreover, there is a serious question whether colonisation of the galaxies by self–replicating machines is tantamount to our survival; various reasons for giving a negative answer readily spring to mind.

2. Closed Universes: As we noted in the previous section, the turnaround time in case the universe is closed could be anything greater than $2x10^{10}$ years. Under the most likely scenarios described in the previous sub–section, life on Earth will be extinguished long before the turn–around time is reached. However, if the Earth were captured by a passing red dwarf, then it could be that life on Earth persists until the final 10^6 years of the universe, at which point the escalation in temperature of the background radiation would lead to the evaporation of water, and the driving of life deep underground. As the heat continues to intensify, the rocky surface melts and the layers of liquid rock grow deep

until the entire planet is molten. The silicate atmosphere gradually bleeds off into space, and the entire planet evaporates. Of course, a similar fate befalls all of the other planets and stars before the final million years of history is played out.

It is overwhelmingly likely that the fate of life on Earth does not depend upon whether the universe is open or closed: the Earth will become uninhabitable long before the turnaround time. However, if we turn our attention to the imaginative scenarios discussed in the previous sub–section, then the timing of the turnaround could well make a significant difference. For example, if we could reasonably expect life like ours to persist for 10^{20} years in an open universe, then life on many other planets could be extinguished by the escalation of temperature of cosmic background radiation if the turnaround time is insufficiently long. Similar considerations apply if life will persist until the era of proton decay in an open universe: perhaps lots of self–replicating machines will perish in the fiery furnace as the universe collapses. Again, I make no attempt to assign likelihoods to these possible outcomes: it is very hard to say how long life is likely to endure if the universe is closed.

Not everyone agrees that life eventually dies out in a closed universe. Tipler (1995) claims that it is possible for life to persist throughout the entire future of such a universe, 'right up to the final singularity'. Critics rightly find this claim unbelievable: no structures of any kind can survive in the final few minutes before the Big Crunch. Since the only counterveiling consideration to which Tipler appeals is that it is 'simpler'—i.e. more desirable—to suppose that life does somehow survive, there seems to be no reason here to depart from the orthodox view that, in a closed universe, absolutely everything is destined to fry. Moreover, even if life did persist ‘right up to the final singularity’, it would nonetheless be the case that life comes to an end, along with the universe to which it belongs: there is no more reason to think that existence at the final singularity constitutes immortality than there is to think that existence right now does so.

3. Universe Builders: So far, we have considered the prospects for life in the causally connected universe. Of course, if there are causally disconnected regions of the universe, then these considerations say nothing about the prospects for life in those regions. If the rest of the universe has the right kind of structure, it may be that there is a sense in which life lasts forever, even though life in any particular region dies out after some finite amount of time. If there is a cycle of universes, or if universes ‘give birth’ to baby universes, then there may be no end to the occurrence of life and intelligence somewhere in the total ensemble.

Even if there is life in causally disconnected regions of the universe, it might be thought that this could be little consolation to us. In order to offer consolation for this kind of thought, some theorists have speculated that it might be possible for us to create new universes by engineering circumstances in which baby universes can develop. However, quite apart from the dangers which would be involved in this kind of activity, it is worth noting that it is unclear that there is any genuine consolation here. After all, on any plausible account, these baby universes do not remain causally connected to us—there is no possibility of transmission of information between parent universe and baby universe—and we have no control at all over the nature of the baby universe, i.e. we cannot choose any of the features which that universe is to have. Moreover, it is also worth noting that it is highly speculative to suppose that this activity of universe building is so much as possible. Given all of these considerations, it seems that we should not put much stock in the possibility that we might feel more affinity for living creatures who owe their origin to us than to living creatures which merely happen to exist in causally disconnected regions.

Apart from speculations about universe creation, some theorists also engage in speculation about universe modification. For instance Dyson (1979) asks whether, if the current density is sufficient to close the universe, it might be possible to engage in some kind of vast engineering project which blows open some part of the universe which contains us and our descendants. It seems to me that this is massively unlikely, to say the least: think of the scale on which such a project would need to be carried out, and also about the control which would be required to ensure that we and our descendants are not wiped out in the process. Moreover, the costs involved might very well make the project quite unattractive: after all, life will eventually die out in the open region which remains, so some consideration about the quality of life of those engaged in the engineering project needs to be undertaken. In any case, we are now far into the realms of fantasy, so we can afford to leave this topic here.

4. <u>Universe Hoppers</u>: Given that our universe is going to become uninhabitable, and given that we can't just build ourselves a new universe to inhabit, there is one remaining

option which some theorists have considered: perhaps we can travel to some other universe, and continue our lives there. If this can be done once, then it can be done repeatedly—and, in that case, it is possible for life to persist indefinitely. This suggestion is no less fanciful than the suggestions considered in the previous sub–section, and it also faces serious conflict with currently accepted physical theories. In particular, the reasons for thinking that there can be no transport of information between parent universe and baby universe are equally reasons for thinking that no information can be transmitted across 'wormholes' to otherwise causally disconnected universes.

Some theorists have speculated that black holes might be gateways to other universes. However, while it is true that we can't get information about what goes on behind the event horizon which surrounds black holes, we have every reason to think that tidal forces will tear apart any beings which fall into black holes. Even if matter could pass into another universe by falling into a black hole, it would not take with it any information about the universe in which it originated. Moreover—and perhaps more importantly—we don't have any good reason to think that black holes are gateways to other universes. This is not to say that it is logically impossible for spacetime manifolds to extend through singularities—as Earman (1995) argues, that all depends upon the extendibility conditions which one takes to apply at those singularities—but rather to note that it is extremely implausible to suppose that living entities could travel on trajectories which take them through such singularities unscathed.

The conclusion to be reached at the end of this section is predictable: it is pretty much certain that life and intelligence will eventually depart from the universe without trace. Whether life and intelligence are to be found in causally disconnected regions of the universe—and whether such life and intelligence will persist indefinitely—are matters about which we can do no more than speculate. Depending upon the speculations which one is prepared to countenance, one might allow that actual extinction could be deferred for a very long time—perhaps as much as 10^{40} years, a mind–boggling extent of time—but there is no plausible way of evading the conclusion that such an extinction will eventually come.

5. Dreams and Fantasies

Many physicists claim that it is 'depressing' to contemplate a future universe in which life is everywhere extinguished; others claim that, the more we find out about the large–scale cosmological features of the universe, the more 'meaningless' it appears. Some physicists are driven by these kinds of thoughts to focus attention on models of the universe in which life exists indefinitely into the future; some even take it to be a fundamental physical postulate that, once life has gained a toehold in the universe, it cannot die out, but rather must expand to fill the universe entirely. While I do not deny that it is interesting to construct models in which life survives indefinitely—just as it is interesting to construct models in which there can be time travel to the distant past, or models in which there is 'eternal return'—I am very sceptical about the reasonableness of the claims which are typically invoked prior to commencement of investigation of such models. In particular, I think that there is room for serious examination of the claim that it is depressing to contemplate a future universe in which life is everywhere extinguished.

(A caveat. It may be that it is only physicists who are drawn to write ‘pop’ physics books who are tempted by the claim which I wish to examine. While this claim does get an airing in articles in serious journals, I have only tracked it down in the works of the usual suspects: Davies, Dyson, Adams and Laughlin, Barrow and Tipler, etc. However, I have at least anecdotal evidence that the kind of attitude which I am interested in investigating is quite widespread in the general community: when I have described my current project to non–philosophers, they have almost universally expressed surprise at my claim that it is not reasonable to be depressed by the likely future fate of the universe. Consequently, I have at least some grounds for suspecting that the view is likely to be more widely spread amongst cosmologists and other kinds of physicists.)

So, why should I find it depressing to contemplate a future universe in which life is everywhere extinguished? Perhaps one might think as follows. On the most plausible future for the universe, all of the following claims are true: (1) there will be no direct traces of me and my projects; (2) there will be no indirect traces of me—no descendants, however distant, of me or my projects; (3) there will be no traces of my kind, i.e. no traces of human beings, or of living things; (4) there will be no traces of my home and habitat—no earth, no solar system, no Milky Way; (5) there will be no traces of the things I value, nor any traces of the kinds of things I value; (6) there will be no traces of valuable things. Many of these claims can be summed up in the observation that all things of value, and all information about those things, will eventually disappear from the universe. Isn't this a cause for 'depression'?

I don't see why. Of course, it is a familiar fact that we mourn death, and that we feel great sorrow at the destruction of loved objects. Moreover, it seems clear that we would be rightly depressed to learn that life on earth will be extinguished in one hundred years time (say, by a giant meteor impact). However, neither of these kinds of considerations suggests a reason for depression at the prospect of the ultimate extinction of life from the universe. On the one hand, while it is true that we often feel that we would like particulars amongst the dead and the destroyed to be returned to us, at least for a little bit longer, I do not think that we typically want these things to last forever. And I suspect that there is no one who wants all the things which exist at a particular time to last forever: we all agree that it is part of what confers meaning and value on life that there is change, birth and death, the appearance and disappearance of things and kinds of things from the universe. And, on the other hand, while it is true that we reasonably regard the extinction of life in a hundred years as grounds for depression, there are clearly special factors which apply in this case—e.g., our grandchildren would very likely be amongst those who perish in the imagined catastrophe. But there is no reason at all to think that this kind of concern can be projected across vast amounts of spacetime, to the last of the living creatures in the universe (and there are reasons for thinking that we would find it puzzling if someone were to claim to be depressed at the fate of those creatures). Moreover—a point to which we shall return—this kind of imminent extinction would be the direct result of a local catastrophe, rather than an inevitable consequence of the *kinds* of laws and boundary conditions possessed by worlds like ours in which life like ours flourishes.

Perhaps it might be said that there is just the same kind of reason for being depressed at the likely future of the universe as there is for being depressed by the fact that things age and decay. Many people do seem to be depressed by the effects which age has on their minds, their bodies, their possessions, and the things they love. However, while it seems undeniable that there can be reasonable regret that life passes by so quickly, it is far from clear that it is right to say that people are 'depressed by the fact that things age and decay'.

First, it should be noted that, when people regret the passing of earlier states, the regret in question is essentially *de se et nunc*: it is a regret that they, themselves, have reached a certain stage in their lives. That is, the regret in question is not merely a *de dicto* regret that the stages in people's lives pass by. (Cf. Prior. In fact, I think that it is highly doubtful to suppose that people do have a *de dicto* regret that the stages in people's lives pass by—more about this anon.) However, the kind of regret that is supposedly engendered by consideration of the likely future fate of the universe can only be *de dicto*: regret, say, that life will eventually be extinguished.

Second, it should be recalled that it is well-known that the universe appears to be 'fine-tuned' for life: were there small changes in the values of fundamental physical constants, there would be no life in the universe. If this claim about the appearance of fine-tuning is correct, then it seems right to say that there could only be creatures like us if the universe has a long initial period without life, and if life is eventually extinguished from the universe. Even if we agree that, other things being equal, a universe is better if it has more life—or more intelligent life, or more good and intelligent life, or whatever—it seems that we can still say that it isn't reasonable to wish that life hadn't been absent from the early part of the universe, and nor is it reasonable to wish that life not disappear from the universe—for, in universes with those kinds of properties, creatures like us simply could not exist. Once we recognise that the future of the universe is a necessary price to pay for our existence, it no longer seems reasonable to regret that the universe will pass into that future state. (Perhaps, again, we should say something similar about the stages of our own lives. Perhaps we couldn't be the kinds of creatures that we are if we didn't age in the ways that we do. But, in that case, it can hardly seem reasonable to regret that we age and change in the ways that we do.)

Perhaps it might be conceded that these is some weight in the comments which have been made thus far, but then contended that they are nonetheless inadequate. True enough, given the contingencies of existence—the laws and boundary conditions governing our universe—it is understandable that we have—and should have—patterns of valuing which are tied to these contingencies. But isn't it cause for depression that our existence is subject to these contingencies and exigencies? Isn't it cause for depression that we are the kinds of creatures that we are, rather than …? Well, rather than what? Rather than unchanging and immortal beings? Should we really want to be beings of that kind? I don't see why. And I expect that other people will share this scepticism. As I hinted earlier, there is room for thinking that we are essentially finite, mortal and changing. If so, then to wish that we be immortal and unchanging is, in effect, to wish that we do not exist. Moreover, there are clearly reasons for thinking that much of what gives meaning and value to our lives would be absent from a world without aging, decay and loss. And there are clearly interesting questions to ask about the psychology of creatures which are able to—or even which are guaranteed to—live forever. However, I shall not try to pursue any of these questions here; rather, I shall content myself with the observation that there just is no obvious reason why *de dicto* facts about our finitude and mortality should give rise to depression—and hence, there is no obvious argument to the conclusion that depression about the likely fate of the universe is similarly mandated.

Perhaps it might be said that to fail to be depressed by the likely future fate of the universe is to return a negative verdict on the things one values: if we think that life, the universe and everything have value, then surely it follows that we must want life to persist indefinitely into the future. This does not seem obviously right to me. I think that my own life has value, but I do not think that I am thereby obliged to want my life to persist indefinitely into the future. Perhaps it might be reasonable for me to wish that my life were not quite so short—so much to see and do, and so little time!—but even that wish should, I think, be tempered by the observation that knowledge of one's likely allotted span helps to give shape and structure—meaning—to one's life. Similarly, it is certainly reasonable—if not mandatory—for me to hope that life will continue on Earth, and perhaps elsewhere in the galaxies, for many years to come. Perhaps—though this is far from obvious—I might even think that 10^{10} years or so is not really long enough; but it is hard to see why I should think that a failure to want life to continue for longer indicates a negative verdict on its value. (It is worth emphasising that there has been recognisably human life on earth for no more than 10^7 years, and there have been written records kept for no more than 10^4 years. Much will happen if human life persists for another 10^{10} years!)

Perhaps it might be said that, given the likely future fate of the universe, we must inevitably be led to denials of meaning and value: (1) my life cannot have any meaning; (2) no life can have any meaning; and (3) the universe cannot have any meaning. While these views may be quite widespread, I do not think that they can have any justification. Since the matter is very complicated, the following observations are rather preliminary in nature.

First, it is worth asking whether, in the light of our own future deaths, we must inevitably be led to deny that our lives have meaning or value. On the face of it, such a denial seems far too swift. Our lives—at least when they go well—are filled with events and entities which give them both value and meaning. At least in this sense, it seems beyond dispute that our lives do—or, at any rate, can—have meaning and value, despite the fact that our lives come to an end. Moreover, in this same sense, it seems equally beyond dispute that our lives do—or, at any rate, can—have meaning and value even if life in the universe comes to an end.

Second, it is worth asking what the universe would have to be like in order for it to have value and meaning. Why should we think that there is more meaning or value in Tipler's universe than in the likely future of our universe? If the universe comes to an end, then so does the life which exists within it. Why is such a universe better—more valuable, more meaningful—if it contains life 'right up' to the end than if it fails to do this? Why should we think that there is more meaning or value in Dyson's universe than in the likely future of our universe? If the universe approaches a condition of 'Heat Death', then life does no better than approach a condition of extinction from the universe. Why is such a universe better—more valuable, more meaningful—if life is never actually extinguished from the universe than if it is extinguished from the universe?

Third, it might be said that the above remarks fail to do justice to the intuition that there is a sense of value or meaning for life which is not delivered by the kind of mundane value and meaning which I mentioned a couple of paragraphs back. When people say that the universe is 'pointless'—without value, without meaning—what they typically mean is that the kind of value and meaning which we ordinarily find in love, friendship, and so forth is shown to be worthless by the observation that there is no 'grand' or 'external' meaning to life and the universe. However, there are at least two points which seem worth making in reply here. On the one hand, it is hard to see how the future of the physical universe can have any bearing on these questions about 'grand' or 'external' meaning: as I noted above, there is no more 'grand' or 'external' meaning in the universes of Tipler and Dyson than there is in the likely future universe. Moreover, there would be no more 'grand' or 'external' meaning in the universe if it and all of its contents lived forever: that we should never die—or that life should never die out—would not confer any special kind of meaning on our lives or on the universe. And, on the other hand, I don't see why we should agree that the kind of value and meaning which we ordinarily find in love, friendship, and so forth would be shown to be worthless by the truth of the observation that there is no 'grand' or 'external' meaning to life and the universe. Indeed, I suspect that to say this is to return a negative verdict on things of value: surely life, the universe, and everything have value whether or not there is any 'grand' or 'external' meaning to the universe. That our love and friendship are valuable and meaningful must surely be true quite independently of whether there is any 'grand' or 'external' meaning to the universe.

There is a kind of view of the universe—which I hope might appropriately be called a 'religious' view of the universe—according to which (1) the universe is 'for us'; (2) there is a sense in which we do not deserve the universe; and (3) the ('grand') meaning of life, the universe and everything is entirely external to the universe, i.e. it all comes from outside the universe. I am very suspicious about all of this. Although I can't argue for these claims here, I think that there is no reason to suppose that the universe was 'made' for life, or that we are unworthy recipients of an extraordinary gift. Moreover—and I will try to say something in defence of this final claim—I am sceptical that there is any way in which meaning and value could be 'grand' or 'external'.

Suppose, for example, that the traditional Christian story is right, and the universe is the result of a gratuitous whim on the part of an immensely powerful creator. How could this fact make the universe more meaningful or valuable than a brutely contingent universe?

Indeed, isn't such a universe still brutely contingent, since the creative whim is held to be brutely contingent? More generally, how could the obtaining of a relation between the universe and some entirely external entity make it the case that the universe—or life within it—is meaningful when otherwise it would not be? (Some people will want to object that the universe is not the kind of thing which could be meaningful, any more than the earth or a rock could be. However, in order to keep these comments to a reasonable compass, I don't propose to take up this issue here; rather, I shall take for granted the assumption that we can make some rough sense of the idea that the universe—or life therein—has, or lacks, meaning.)

Perhaps it might be said that it is not 'brute contingency' which is the enemy of meaningfulness: after all, many people do seem to suppose that the Christian story provides a paradigm case in which life turns out to be 'meaningful'. Furthermore, I suppose that it might also be said that there is no 'brute contingency' in the Christian story: the choices which God makes are fully explained simply because they are the free choices of a perfectly free agent. (Or, more plausibly, it might be said that this kind of 'brute contingency' is perfectly compatible with 'meaningfulness': because the choices in question are the free choices of a perfectly free agent, they can play a role in conferring 'meaning' on the universe and lives lived within it.) However, it seems to me that all of this can be contested, and that there is a kind of 'special pleading'—or perhaps 'moral schizophrenia'—which is involved in the view which says that God—an external source of 'meaning'—is required in order to make our lives meaningful.

In order to reach the conclusion that our lives do not have an intrinsic meaningfulness, one needs to take a kind of ‘external’ vantage point on them: one has to view them from the ‘standpoint of eternity’. (Else, as I noted before, it seems perfectly obvious that, at least when our lives go well, they are filled with meaning and value). When one looks from this vantage point, it is alleged that one sees that there is no ‘point’ to life, the universe and everything. However, if this were right, then exactly the same thing would be true if one were to take a kind of external vantage point on the more inclusive system consisting of God and the universe—what extra point is there to that more inclusive system of life, the universe and everything? It’s only if you think of the Christian account from a kind of ‘internal’ perspective that it can be seen to afford any extra element of meaning: otherwise, what you have is just ‘more damn stuff’, and the alleged ‘meaning’ proves no less elusive than before. For this kind of reason, it seems to me that the demand for ‘external’ meaning is unsatisfiable; and, as I hinted above, there is also room for thinking that it involves a denial of the meaning and values which actually make our lives meaningful and valuable.

As I noted earlier, there is much more to be said about the various issues that I have raised (and there are numerous relevant considerations which I have not even mentioned). Nonetheless, it seems to me to be clear that there is a serious case to be made for the view that there is nothing at all to regret in current evidence about the likely fate of life in the universe.

6. Concluding Remarks

No doubt, some people will think that the investigation of the previous section is either pointless or premature. In order to reach the conclusion that the universe is destined for 'Heat Death', we had to rely on some kind of 'Copernican Principle'—some principle to the effect that the universe which we can't observe is just like the universe which we can observe. But, it might be said, there is no reason to think that this *a priori* cosmology is likely to be more successful than the *a priori* geography which held that there must be substantial landmasses in the unobserved southern oceans because the observed northern oceans contain sizeable continents. Perhaps this is right; however, it might equally be said in reply that what we have is a straightforward case of inference to the best explanation—there is no more reason to be a counter–inductivist here than anywhere else. (Whether this is a good response may depend upon how good the 'geographical' analogy is. I don't want to take up this issue here.)

However, it seems to me that there is good reason to think about the issues which I have been examining even if there is room for doubt about the firmness of the conclusion that extinction will eventually come. Even if current theories prove not to be the last word, there is little doubt that those theories do point to the eventual extinction of life from the universe. Moreover, there is a fair bit of evidence that physicists are uncomfortable with this consequence of their theories, and, more importantly, that they are uncomfortable communicating this information to non-physicists. If I am right, then reflection on the attitudes which are appropriate here may well show that physicists need not be in the least bit apologetic about the direction in which the evidence points. (Of course, those who think that there is a non-physical afterlife will agree that there is no reason to fear physical extinction; however, it would require a much broader enquiry adequately to investigate this kind of response. My concern here has been with the kind of response which it is appropriate for those of a naturalistic bent to make to the news about the likely fate of the natural world.)[1]

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