Cosmological Immortality:
How to Eliminate Aging on a Universal Scale

(v2.0)

Clément Vidal
Center Leo Apostel
Global Brain Institute
Evolution, Complexity and Cognition research group
Vrije Universiteit Brussel (Free University of Brussels)
Krijgskundestraat 33, 1160 Brussels, Belgium
Phone +32-2-640 67 37 | Fax +32-2-6440744
http://clement.vidal.philosophons.com
clement.vidal@philosophons.com

Abstract: The death of our universe is as certain as our individual death. Some cosmologists have elaborated models which would make the cosmos immortal. In this paper, I examine them as cosmological extrapolations of immortality narratives that civilizations have developed to face death anxiety. I first show why cosmological death should be a worry, then I briefly examine scenarios involving the notion of soul or resurrection on a cosmological scale. I discuss in how far an intelligent civilization could stay alive by engaging in stellar, galactic and universal rejuvenation. Finally, I argue that leaving a cosmological legacy via universe making is an inspiring and promising narrative to achieve cosmological immortality.

1 - Introduction

The fear of death generates a huge cognitive bias, as psychologists have extensively shown (see e.g. Burke, Martens, and Faucher 2010). It is thus not surprising that even scientists are prone to this bias, and are often overly optimistic regarding achieving indefinite long lifespans. Overstatements or overoptimism of futurists in this area have been criticized (see e.g. Proudfoot 2012). The modern hopes to achieve radical life extension via mind uploading, nanotechnologies or modern medicine arguably rehash the hopes of alchemists, Taoists and other cultural traditions which have attempted to find an elixir against death (Cave 2012). The will to immortality remains constant, only the means to achieve it change (Haycock 2008).

Even if individual indefinite longevity would be *possible*, I have many reservations regarding its *desirability* (see Vidal 2014, sec. 10.4 for some counterarguments). In this paper, I focus on literally universal aspects of extremely long life spans. I first grant the premise that it is possible to achieve radical life extension. I mean that individuals would live hundreds, thousands or even millions of years.

Once we really live for extremely long life spans, we will also need to secure the broader context which allows such a new lifestyle. Ultimately, the context of all life we know is the universe. If one is seriously concerned about living a radically extended life, then the question becomes: How can the universe be immortal? Of course, the issue of motivation should be addressed: Why should we care about cosmological death? Imagine that you are truly immortal. Your ethics broadens radically, because the time scope of life has changed accordingly. Then it really makes sense to care about far future issues, such as climate change, the red giant phase of our Sun, or the heath death of the universe, because you know that sooner or later those issues will affect you.

Here I explore the four immortality narratives of soul, resurrection, survival and legacy that Stephen Cave (2012) studied, but on a cosmological scale. In this paper, I thus look into the far-future, and review some proposals to aim at *cosmological immortality*.

Instead of studying the universe only with physical theories such as relativity theories or thermodynamics, my colleague John Smart and I have advocated a biological, evolutionary-developmental view of the universe (Smart 2009; Vidal et al. 2009; Vidal 2014). The 'Evo Devo Universe' community we co-founded is meant to stimulate research within this framework. In this research context, I draw inspiration from approaches against biological aging, to tackle the inevitable aging of the cosmos.

If a cosmological immortality could be secured, it would provide the foundations of all other longings for immortality. The situation bears resemblance with the difference between potential and actual infinite in mathematics. Georg Cantor (1932, 393), founder of modern mathematics and theoretician of infinity, argued that every potential infinite requires an actual infinite. The potential infinite cannot be thought without the secure existence of the actual infinite onto which it implicitly relies. Similarly, cosmological immortality aims to provide the secure path on which other immortality longings can flow.

2 - The road to care for universal sustainability

Who cares about death beyond planet Earth? How often do you worry about the predictable death of our Sun, which will already make our oceans boil in one billion years? And why stay centered on our solar system? What about other stars? And the health of the galaxy? And the ultimate death of our universe? Almost nobody cares about that, only a tiny percentage of researchers that I can count on my fingers. Yet, the universe is almost certainly going to die…

Let us see some intermediate steps on the road to care about universal sustainability. If we care about extreme longevity for ourselves, we also ought to worry about distant long-term existential threats. This worry can seriously rise in two cases. First, if we believe in the success of current life extension medicine and research, and thus that our generation will live for a very long time. Then caring for the effects of climate change or a possible asteroid collision in 120 years makes sense, because it will affect us directly. Second, for the more skeptical, this long-term worry will only emerge once extremely long life spans are effectively achieved due to some proven radical life extension strategies. In the best case, this might take one generation time.

Fortunately there is another reason why we ought to worry about distant threats, namely, if we care for others. Back in 1892, Lecky (1890, 1:101) argued that historically, the circle of benevolent actions keeps on expanding:

> At one time the benevolent affections embrace merely the family, soon the circle expanding includes first a class, then a nation, then a coalition of nations, then all humanity, and finally, its influence is felt in the dealings of man with the animal world.

Can we be sure that the harmony of humanity with the animal world is the limit? Consequent with his argumentation, Peter Singer (2011, 73) raised doubts whether "the boundary of our species marks a defensible limit to the protected circle." I claim that our species is very far from the limit of the possible circle of compassion.

Indeed, once we understand that the survival of future people is conditioned by the survival of other systems, such as the existence of ecological equilibrium, biodiversity, or of the Sun, then we can also start to care about them, progressively with as much care as we would care for ourselves or for our loved ones.

Arguably, as we grow psychologically, our awareness and compassion for larger and larger systems grows accordingly. For example, nowadays more and more people, associations, institutions and nations care about global economical, ecological or ethical issues. I have argued that our rising awareness of limited free energy, in the Sun, in galaxies, and generally in an expanding universe will trigger new levels of compassion (Vidal 2014, chap. 10). The awareness of cosmic doom scenarios such as heat death, big crunch, big rip, big bounce (Vaas 2006) makes the cosmological context particularly worrying.

If possible, how is the universe going to survive? I will first explore the two religiously inspired narratives of soul and resurrection, and how they could be applied to the universe via *cosmological soul* or *cosmological resurrection* scenarios. Back to biology, there are two ways to perpetuate life, either by survival or by reproduction. The former leads to *cosmological survival* scenarios, while the latter gives birth to a *cosmological legacy.*

3 - Cosmological Soul

The notion of the soul plays a major role in many religions. In its Christian version spread by Dante in the *Divine Comedy*, the soul is separated from the body at the time of death, and travels towards God.

If we turn to physics, assuming that Everett's (1973) many-worlds interpretation of quantum physics would be correct, our universe keeps branching into parallel universes. Those parallel universes are not accessible to us, and continue a life on their own. The belief of such parallel universes could be interpreted in a similar way as the belief that the soul can separate from the body and survive after physical death. But this many-worlds interpretation of quantum mechanics remains very controversial, and the scenario brings no knowledge, and thus no comfort, regarding what those parallel universes might be like and what might emerge in them.

4 - Cosmological Resurrection

The resurrection story is also widely spread in human cultures and religions. But techno-religious trends also hope for such resurrection. Indeed, in cryonics or plastination (see e.g. Olson 1988), the philosophy is to conserve the body now, and pray that future science will be able to resurrect it later.

Turning to cosmology, many cosmological models are cyclical, such as Tolman’s (1934), the phoenix universe (Lemaître 1933; Dicke and Peebles 1979), Smolin's (1992) cosmological natural selection, the famous chaotic inflation scenario (Linde 1990), Steinhardt and Turok's (2002) epykrotic model or Penrose’s (2011) conformal cyclical cosmology. In these cases, a cosmological cycle goes on, even if each particular universe can not harbor life indefinitely. Note that life and intelligence play no role in the cycle, but each particular universe could continue to form energy gradients and be able to sustain life.

The idea of eternal return, ubiquitous in world religions, civilizations and myths (Eliade 1959) is also extensively discussed in modern cosmology (Ellis and Brundrit 1979; Tipler 1980; Garriga and Vilenkin 2001; Knobe, Olum, and Vilenkin 2006; Vilenkin 2006). However, I have argued with logical, thermodynamic, and cosmological arguments that the scenario is unconvincing (Vidal 2014, sec. 4.3.4).

A controversial resurrection scenario is the omega point theory by Frank Tipler (1997). Most of the scenario is motivated by a theological agenda, because Tipler's focus is not so much the resurrection of the universe, but the resurrection of human souls via computer simulations. However, the immortality of human souls still requires energy, and Tipler is aware of that. Although the scenario only works with a closed universe, which is not supported by current empirical observations of a universe in accelerating expansion (Riess et al. 1998), here is the general idea. Tipler first supposes that life has engulfed the universe. Then, if the universe collapses, in most cases it would do so at different rates in different directions. This create an energy gradient, which living entities would want to maintain, because it could be used as a source of free energy.

5 - Cosmological Survival

If we take the very general definition of life as a thermodynamically open system, there is no necessity for a living system to die, as long as it can process an energy flow and extrude waste products. Within these limits, the prospect of indefinite lifespan for individuals is real.

The same holds for the universe, as long as we can find free energy in the universe, we can hope to live forever. Tipler speculated about this, but this requires a collapsing universe. However, according to modern physical eschatology (Ćirković 2003) and the second law of thermodynamics, the universe is bound to dissipate energy.

What will happen to the Earth and the Sun in the far future? The story developed by modern science is a gloomy one. In about 5 billion years, our solar system will meet its end, with our Sun turning into a red giant star, making the surface of Earth much too hot for the continuation of life as we know it. The solution then appears to be easy: migration. But even if life were to colonize other solar systems, there will be a creeping death of all stars in galaxies. Once stars have converted the available supply of hydrogen into heavier elements, new star formation will come to an end in the galaxy. In fact, the problem is worse. It is estimated that even very massive objects such as black holes will evaporate in about 10^{98} years (Adams and Laughlin 1997).

The steady state cosmological model was first developed by Sir James Jeans (1928), and then in greater detail by Hermann Bondi, Thomas Gold, Fred Hoyle, and Jayant Narlikar. It assumes the universe remains unchanged, with no cycle, no beginning and no end. It thus seems to provide a never-aging cosmos. Even if galaxies age and die, new galaxies are born to replace them. In the steady-state universe, the universe as a whole never gets old. Of course, there is a catch, which is the issue of how new galaxies appear. Paul Davies (1994, 152) remarks that such a process would require the addition of 10^{50} tons of matter to the universe every few billion years! In addition, big bang models are now favored over steady state models.

A major strategy to increase human lifespan is *rejuvenation*. Let us see in how far this strategy could be applied in a stellar, galactic and universal context.

On the time scale of the solar system, the first death civilization will need to care about – if it avoids self-destruction – is the Sun. Astrophysics has very well established that the Sun will eventually burn all its nuclear fuel, and will turn to a red giant star (Sackmann, Boothroyd, and Kraemer 1993). Visionary proposals have been made to rejuvenate the Sun in order to postpone this red giant phase (Criswell 1985; Beech 2008). According to Criswell (1985, 83), modifying actively a star can considerably extend a civilization's lifetime. Assuming the civilization keeps its energy consumption at our level, it could live as much as 2 million times the present age of the universe! Beech discusses various astroengineering processes such as mass reduction, non-thermal pressure support, increasing opacity or mixing the different stellar layers. Of course, such astroengineering remains a challenge to be worked out in the details, but it is already spectacular that we can conceive plans to use stellar energy very efficiently. However this should not surprise us because the Sun is actually a very simple system compared to a biological organism. Despite its huge extension, it might be easier to manipulate its lifetime than the one of a living system. This prospect raises an interesting question of long-term policy to sustain life in the universe. Shouldn't we invest massively in stellar engineering, if this could really ensure the sustainability and continuation of life for billions of years?

Let us go one step further, and speak about about galactic rejuvenation. I mentioned the issue that new star formation will come to an end in the galaxy. I am not aware of any work suggesting how to sustain or improve the rate of star formation in the galaxy. However, a first step to take care about the galaxy is to model it as an ecosystem (Smolin 1997), rather than a physical system. Indeed, the death of stars via supernovae replenish the interstellar medium and in turn allow the formation of new stars. How, if, and why an intelligent civilization would engage in enhancing or better managing the galactic ecosystem remains largely to be investigated. The topic is already much more speculative than stellar rejuvenation, but some actions might be taken, although it might require galactic coordination.

Most certainly, our descendants will pay attention to our galactic neighborhood, since in about 4 billion years our galaxy will predictably merge with the nearby galaxies Andromeda and M33 (Marel et al. 2012). In this predictable cosmic event, the fate of our solar system is not certain, but possible outcomes include an ejection further away from the Milky Way's center, or a gravitational binding with the Andromeda galaxy (Cox and Loeb 2008).

What about universal rejuvenation? Even with the best intentions and the best technologies, it will prove very difficult. The life colonization of the whole universe proposed by Tipler is only possible in a collapsing universe. However, even by sending colonizing seeds *at the speed of light*, an intelligent civilization in our galaxy could “only” reach 6 billion galaxies (Armstrong and Sandberg 2013). Taking into account the 170 billion galaxies estimated to exist (Gott et al. 2005), it means only reaching 3.5% of all galaxies. Universal influence of intelligence is thus highly unlikely in an expanding universe. At least if the universe continues to expand, there is no hope for intelligence to gain control of the whole universe, as we can hope to have control over an individual organism. The sheer immense distances and the finiteness of the speed of light make it simply impossible. Intelligent life is more likely to continue its road towards manufacturing and controlling smaller and smaller scales (Barrow 1998; Smart 2012; Vidal 2014).

Even if the universe continues to evolve towards a heat death, or maximum entropy, there is an option for life to survive forever. The answer is hibernation, and the scenario was articulated in a landmark article about the future of civilization by Dyson (1979). Dyson shows that even assuming a finite supply of energy, it would be possible for a civilization to live forever. An advanced civilization would hibernate longer and longer and thus use less and less energy. Despite a finite energy source, by hibernating longer and longer, and thus using less and less energy, a civilization would be able, in the limit, to live for as long as it wants in its subjective time. Of course, ‘‘life’’ is defined here not in terms of DNA and biochemistry, but as a more general information processing capability. However, this scenario does not work if the universe continues its accelerated expansion (Dyson 2004, 15). A very stimulating debate arose between Dyson and Krauss and Starkman (2000). In their article ‘‘Life, the universe, and nothing: life and death in an ever-expanding universe’’, Krauss and Starkman criticized Dyson’s proposal and showed that eternal life in our universe is impossible. In a sophisticated response, Dyson showed that the core argument can be maintained if we replace digital computers by analog ones (Dyson 2007).

An other promising road for a civilization to endure forever is *reversible computation*. Landauer (1961) proved the theoretical possibility of logic gates that consume no energy. Given a computer built out of such gates, a possible solution to the problem of an ever-expanding and slowly dying universe would be to simulate a new universe on a collection of matter that would forever float into emptier and emptier space. Krauss and Starkman, although recognizing the theoretical possibility of this scenario, criticized it. They argued that ‘‘no finite system can perform an infinite number of computations with finite energy’’ if it is to host evolved information processing. Why not? The main reason is that reversible computation is not possible for the operation of erasure. Deleting information has a thermodynamic cost, and the authors argue that consciousness or sophisticated information processing will certainly need to erase information (see also Zenil 2012).

The reversible computation scenario is certainly one to keep in mind for the extremely far future, but as long as billions of stars are shining in billions of galaxies, there is really no reason for an intelligent civilization to go on such a drastic energy diet. Rejuvenation is certainly crucial to keep in mind to ensure that our descendant will have enough free energy. However, in contrast to using less and less energy to endure forever, which is biologically a strategy of delaying senescence, biology has a more radical solution. It is to replicate and start anew. Reproduction is a highly successful strategy that evolution uses to maintain and adapt living systems to their environment. Ashby's (1981, 80) analysis showed that ‘‘reproduction is not something that belongs to living organisms by some miraculous linkage, but is simply a specialized means of adaptation of a specialized class of disturbances''. Let us now see how we could aim for replication on a cosmic scale.

6 - Cosmological Legacy

The disposable soma theory (e.g. Kirkwood 1999; Kirkwood and Austad 2000) says that it is more efficient to invest energy in reproduction than in indefinite upkeep of the organism. Once the best chances for reproduction are used, thus ensuring the survival of the almost immortal genes (germline), the mortal body (soma) can be disposed of. Futurist Smart (2009, 224–226) speculated that this theory may also apply to the universe. The soma is analogous to the constituents of the universe, with its mortal galaxies, stars, and planets, while the germline is analogous to free parameters that determine immortal physical laws. If we take seriously this fundamental trade-off in energy expenditure between soma and germline, the death of the ‘‘universe's soma'' may indeed be inevitable. But its germline, its most delicate physical structure, may be saved if universes are replicable.

The last few years, I have developed the scenario of cosmological artificial selection, which links the beginning and the end of the universe, and offers a meaning for life and intelligence (Vidal 2014, chap. 8). If the scenario holds, intelligent civilizations will devote much energy to preparing and making universes, and less energy in maintaining our disposable universe. The artificial selection of universes would be made by computer simulations, selecting only complex universes able to harbor life and reproduce. Cosmological immortality via cosmological artificial selection is analogous to biological immortality through a chain of reproducing universes instead of a chain of living entities.

Another argument for this biological view concerns the energetics of our universe. John Smart (2009) conjectured that the cosmological energy density trend (Chaisson 2001) through time would be a U-shaped curve, with extremely high energy densities at the Big Bang era that decrease as the universe cools down. Locally, the energy rate density then starts to grow exponentially with the appearance of life (Aunger 2007). This energy pattern bears a striking resemblance to the energy pattern of a living organism's life cycle. The energy rate density is decreasing globally, both as the universe expands, and as an organisms senesces inevitably towards death. But, according to the disposable soma theory, organisms invest energy not only for maintenance but also for reproduction. In this context, the origin of life triggering the growth of energy rate density could be interpreted as a maturation phase, towards universe reproduction (Gardner 2003, 127). Age patterns of mortality and fertility vary greatly in the tree of life (Jones et al.

2013), so the putative life-history of the universe is largely unknown and remains to be written.

Despite the speculative nature of these ideas, they can lead to non-trivial predictions. Indeed, such considerations lead me to formulate the starivore hypothesis (see Vidal 2014, chap. 9), which states that advanced extraterrestrial life feeds actively on stars. This is testable, because it requires no new *observation*, but a *reinterpretation* of some known binary star systems. If this would be true, there is already a huge amount of energy invested towards securing the germline of our universe.

Stephen Cave argued that the narrative of passing on a legacy is commonly found in human cultures to resolve the fear of death. The legacy can be biological (having children), creative (e.g. a work of art, a scientific theory), or indeed, in the extreme, cosmological (making a universe). As Cave (2012, 249) speculated: “Perhaps one day we – or some far more evolved successor – will be able to seed new universes that are fit for life. Indeed, perhaps we are already in one, seeded by some earlier civilization.”

7 - Conclusion

In this paper, I started by assuming that as we care today for the sustainability of planet Earth, our descendants will care about the sustainability of the universe. I reviewed scenarios and models which could lead to an immortal cosmos. I classified them using the four narratives that human civilizations have used to deal with the fear of individual death. I critically reviewed how the soul, resurrection, survival or legacy narrative transpire in cosmological models. But this should not surprise us. Cosmology and cosmogonies before 1900 were in the realm of mythology, not science. We are gradually replacing myths with scientific models, but these models are still influenced by myths, implicitly or explicitly. The will to immortality thus still impacts the construction of cosmological models, for the better or for the worse.

I argued that stellar and galactic rejuvenation are physically possible, and could buy intelligent life billion years of survival. Universal rejuvenation is however unlikely to be possible at all. Inspired by a biological view on the universe, I argued that intelligent life leaving a cosmic progeny is a promising option. This universe making task lies in the far-future, but could already inform and guide us today. A famous maxim by La Rochefoucauld (1868) says that neither the Sun nor death can be looked at steadily. If we want have a cosmological legacy, we need to defy the maxim. First looking steadily at the death of our universe and then looking as steadily at our Sun and other stars, to see them as energy bounties necessary to the daring task of universe making.

8 - Acknowledgments

I thank two referees, Cadell Last and Marios Kyriazis for helpful feedback.

9 - Bibliography

Adams, F. C., and G. Laughlin. 1997. "A Dying Universe: The Long-Term Fate and Evolution of Astrophysical Objects." *Reviews of Modern Physics* 69 (2): 337–72. http://arxiv.org/abs/astro-ph/9701131.

Armstrong, Stuart, and Anders Sandberg. 2013. "Eternity in Six Hours: Intergalactic Spreading of Intelligent Life and Sharpening the Fermi Paradox." *Acta Astronautica* 89 (August): 1–13. doi:10.1016/j.actaastro.2013.04.002. http://www.fhi.ox.ac.uk/intergalactic-spreading.pdf.

Ashby, W. R. 1981. "The Self-Reproducing System." In *Mechanisms of Intelligence: Ashby's Writtings on Cybernetics*, edited by R. C Conant, Intersystems Publications, 75–84. Seaside, California. http://books.google.com/books?isbn=1127197703.

Aunger, Robert. 2007. "A Rigorous Periodization of 'Big' History." *Technological Forecasting and Social Change* 74 (8): 1164–78. doi:10.1016/j.techfore.2007.01.007.

Barrow, J. D. 1998. *Impossibility: The Limits of Science and the Science of Limits*. Oxford University Press, USA.

Beech, Martin. 2008. *Rejuvenating the Sun and Avoiding Other Global Catastrophes*. Springer.

Burke, Brian L., Andy Martens, and Erik H. Faucher. 2010. "Two Decades of Terror Management Theory: A Meta-Analysis of Mortality Salience Research." *Personality and Social Psychology Review* 14 (2): 155–95. doi:10.1177/1088868309352321. http://psr.sagepub.com/content/14/2/155.

Cantor, Georg. 1932. "Mitteilungen Zur Lehre Vom Transfiniten." In *Gesammelte Abhandlungen Mathematischen Und Philosophischen Inhalts*, edited by Ernst Zermelo, 378–439. Verlag von Julius Springer.

Cave, Stephen. 2012. *Immortality: The Quest to Live Forever and How It Drives Civilization*. New York: Crown Publishers.

Chaisson, E. J. 2001. *Cosmic Evolution: The Rise of Complexity in Nature*. Harvard University Press.

Ćirković, Milan. 2003. "Resource Letter: PEs-1: Physical Eschatology." *American Journal of Physics* 71: 122. http://mcirkovic.aob.rs/Cirkovic03_RESOURCE_LETTER.pdf.

Cox, T. J., and Abraham Loeb. 2008. "The Collision between the Milky Way and Andromeda." *Monthly Notices of the Royal Astronomical Society* 386 (1): 461–74. doi:10.1111/j.1365-2966.2008.13048.x. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2966.2008.13048.x/abstract.

Criswell, David R. 1985. "Solar System Industrialization: Implications for Interstellar Migrations." In *Interstellar Migration and the Human Experience*, edited by Ben R. Finney and Eric M. Jones, 50–87. University of California Press.

Davies, P. C. W. 1994. *The Last Three Minutes: Conjectures About the Ultimate Fate of the Universe*. Science Masters Series. New York: BasicBooks.

Dicke, R.H., and P.J.E. Peebles. 1979. "The Big Bang Cosmology-Enigmas and Nostrums." In *General Relativity: An Einstein Centenary Survey*, edited by S.W. Hawking and W. Israel, 1:504–17. Cambridge: Cambridge University Press.

Dyson, F. J. 1979. "Time Without End: Physics and Biology in an Open Universe." *Review of Modern Physics* 51: 447–60. http://siba.unipv.it/fisica/articoli/R/Review%20of%20Modern%20Physics_vol.51_no.3_1979_pp.447-460.pdf.

———. 2004. *Infinite in All Directions: Gifford Lectures Given at Aberdeen, Scotland April--November 1985*. Reprint. Harper Perennial.

———. 2007. *A Many-Colored Glass: Reflections on the Place of Life in the Universe*. University of Virginia Press.

Eliade, Mircea. 1959. *Cosmos and History; the Myth of the Eternal Return*. Harper Torchbooks, TB50. New York: Harper.

Ellis, G. F. R., and G. B. Brundrit. 1979. "Life in the Infinite Universe." *Quarterly Journal of the Royal Astronomical Society* 20: 37–41. http://adsabs.harvard.edu/abs/1979QJRAS..20...37E.

Everett, Hugh. 1973. "The Theory of the Universal Wave Function." In *The Many-Worlds Interpretation of Quantum Mechanics*, edited by Bryce DeWitt and Neill Graham. Princeton University Press. http://hdl.handle.net/10575/1302.

Gardner, J. N. 2003. *Biocosm. The New Scientific Theory of Evolution: Intelligent Life Is the Architect of the Universe.* Inner Ocean Publishing.

Garriga, Jaume, and Alexander Vilenkin. 2001. "Many Worlds in One." *Physical Review D* 64 (4): 043511. doi:10.1103/PhysRevD.64.043511. http://arxiv.org/abs/gr-qc/0102010.

Gott, J. Richard, M. Juric, D. Schlegel, F. Hoyle, M. Vogeley, M. Tegmark, N. Bahcall, and J. Brinkmann. 2005. "A Map of the Universe." *The Astrophysical Journal* 624: 463. http://arxiv.org/abs/astro-ph/0310571.

Haycock, David Boyd. 2008. *Mortal Coil: A Short History of Living Longer.* London: Yale University Press.

Jeans, James Hopwood. 1928. *Astronomy and Cosmogony*. Cambridge: The University Press.

Jones, Owen R., Alexander Scheuerlein, Roberto Salguero-Gómez, Carlo Giovanni Camarda, Ralf Schaible, Brenda B. Casper, Johan P. Dahlgren, et al. 2013. "Diversity of Ageing across the Tree of Life." *Nature* advance online publication (December). doi:10.1038/nature12789.

Kirkwood, T. B. L. 1999. *Time of Our Lives: The Science of Human Aging*. Oxford University Press, USA.

Kirkwood, T. B. L., and Steven N. Austad. 2000. "Why Do We Age?" *Nature* 408 (6809): 233–38. doi:10.1038/35041682.

Knobe, Joshua, Ken D. Olum, and Alexander Vilenkin. 2006. "Philosophical Implications of Inflationary Cosmology." *The British Journal for the Philosophy of Science* 57 (1): 47 –67. doi:10.1093/bjps/axi155. http://arxiv.org/abs/physics/0302071.

Krauss, L. M., and G. D. Starkman. 2000. "Life, the Universe, and Nothing: Life and Death in an Ever-Expanding Universe." *The Astrophysical Journal* 531 (1): 22–30. http://arxiv.org/pdf/astro-ph/9902189.

La Rochefoucauld, François. 1868. *Œuvres de La Rochefoucauld*. Nouv. éd. Les Grands Écrivains de La France, Pub. Sous La Direction de M.A. Regnier. Paris: L. Hachette et cie.

Landauer, R. 1961. "Irreversibility and Heat Generation in the Computing Process." *IBM Journal of Research and Development* 5 (3): 183–91. doi:10.1147/rd.53.0183.

Lecky, William Edward Hartpole. 1890. *History of European Morals: From Augustus to Charlemagne*. Vol. 1. 2 vols. Longmans, Green, and co. http://www.gutenberg.org/ebooks/39273.

Lemaître, Georges. 1933. "L'Univers En Expansion." *Annales de La Societe Scietifique de Bruxelles* 53: 51.

Linde, A. D. 1990. *Particle Physics and Inflationary Cosmology*. Harwood Academic. http://arxiv.org/abs/hep-th/0503203.

Marel, Roeland P. van der, Gurtina Besla, T. J. Cox, Sangmo Tony Sohn, and Jay Anderson. 2012. "The M31 Velocity Vector. III. Future Milky Way M31–M33 Orbital Evolution, Merging, and Fate of the Sun." *The Astrophysical Journal* 753 (1): 9. doi:10.1088/0004-637X/753/1/9. http://iopscience.iop.org/0004-637X/753/1/9.

Olson, Charles B. 1988. "A Possible Cure for Death." *Medical Hypotheses* 26 (1): 77–84. doi:10.1016/0306-9877(88)90118-1.

Penrose, R. 2011. *Cycles of Time: An Extraordinary New View of the Universe*. Knopf.

Proudfoot, Diane. 2012. "Software Immortals: Science or Faith?" In *Singularity Hypotheses*, edited by Amnon H. Eden, James H. Moor, Johnny H. Søraker, and Eric Steinhart, 367–92. The Frontiers Collection. Springer Berlin Heidelberg.

Riess, Adam G., Alexei V. Filippenko, Peter Challis, Alejandro Clocchiatti, Alan Diercks, Peter M. Garnavich, Ron L. Gilliland, et al. 1998. "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant." *The*

Astronomical Journal 116 (3): 1009–38. doi:10.1086/300499. http://arxiv.org/abs/astroph/9805201.
Sackmann, I.-Juliana, Arnold I. Boothroyd, and Kathleen E. Kraemer. 1993. "Our Sun. III. Present and Future." *The Astrophysical Journal* 418 (November): 457. doi:10.1086/173407. http://adsabs.harvard.edu/abs/1993ApJ...418..457S.
Singer, Peter. 2011. *Practical Ethics*. 3rd ed. New York: Cambridge University Press.
Smart, J. 2009. "Evo Devo Universe? A Framework for Speculations on Cosmic Culture." In *Cosmos and Culture: Cultural Evolution in a Cosmic Context*, edited by S. J. Dick and Mark L. Lupisella, 201–95. Washington D.C.: Government Printing Office, NASA SP-2009-4802. http://accelerating.org/downloads/SmartEvoDevoUniv2008.pdf.
———. 2012. "The Transcension Hypothesis: Sufficiently Advanced Civilizations Invariably Leave Our Universe, and Implications for Meti and Seti." *Acta Astronautica*, no. 0. doi:10.1016/j.actaastro.2011.11.006. http://accelerating.org/articles/transcensionhypothesis.html.
Smolin, L. 1992. "Did the Universe Evolve?" *Classical and Quantum Gravity* 9 (1): 173–91.
———. 1997. *The Life of the Cosmos*. Oxford University Press, USA.
Steinhardt, Paul J., and Neil Turok. 2002. "Cosmic Evolution in a Cyclic Universe." *Physical Review D* 65 (12): 126003. doi:10.1103/PhysRevD.65.126003. http://arxiv.org/abs/hep-th/0111098.
Tipler, F. J. 1980. "General Relativity and the Eternal Return." In *Essays in General Relativity*, 21–37. New York: Academic Press. http://www.gravityresearchfoundation.org/pdf/awarded/1979/tipler.pdf.
———. 1997. *The Physics of Immortality: Modern Cosmology, God and the Resurrection of the Dead*. Anchor.
Tolman, Richard C. 1934. *Relativity, Thermodynamics and Cosmology*. The International Series of Monographs on Physics. Oxford: The Clarendon Press.
Vaas, Rüdiger. 2006. "Dark Energy and Life's Ultimate Future." In *The Future of Life and the Future of Our Civilization*, edited by V. Burdyuzha and G. Kohzin, 231–47. Dordrecht: Springer. http://arxiv.org/abs/physics/0703183.
Vidal, C. 2014. *The Beginning and the End - The Meaning of Life in a Cosmological Perspective*. The Frontiers Collection. Springer. http://arxiv.org/abs/1301.1648.
Vidal, C., C. Auffray, Alex H. Blin, J. Chaline, L. Crane, Thomas Durt, Börje Ekstig, et al. 2009. *The Evolution and Development of the Universe*. Edited by C. Vidal. Ecole Normale Supérieure, Paris 8-9 Oct., 2008: Special Issue of the Conference on the Evolution and Development of the Universe. http://arxiv.org/abs/0912.5508.
Vilenkin, A. 2006. *Many Worlds in One: The Search for Other Universes*. Hill and Wang.
Zenil, Hector, ed. 2012. *A Computable Universe: Understanding and Exploring Nature as Computation*. World Scientific Publishing Company.