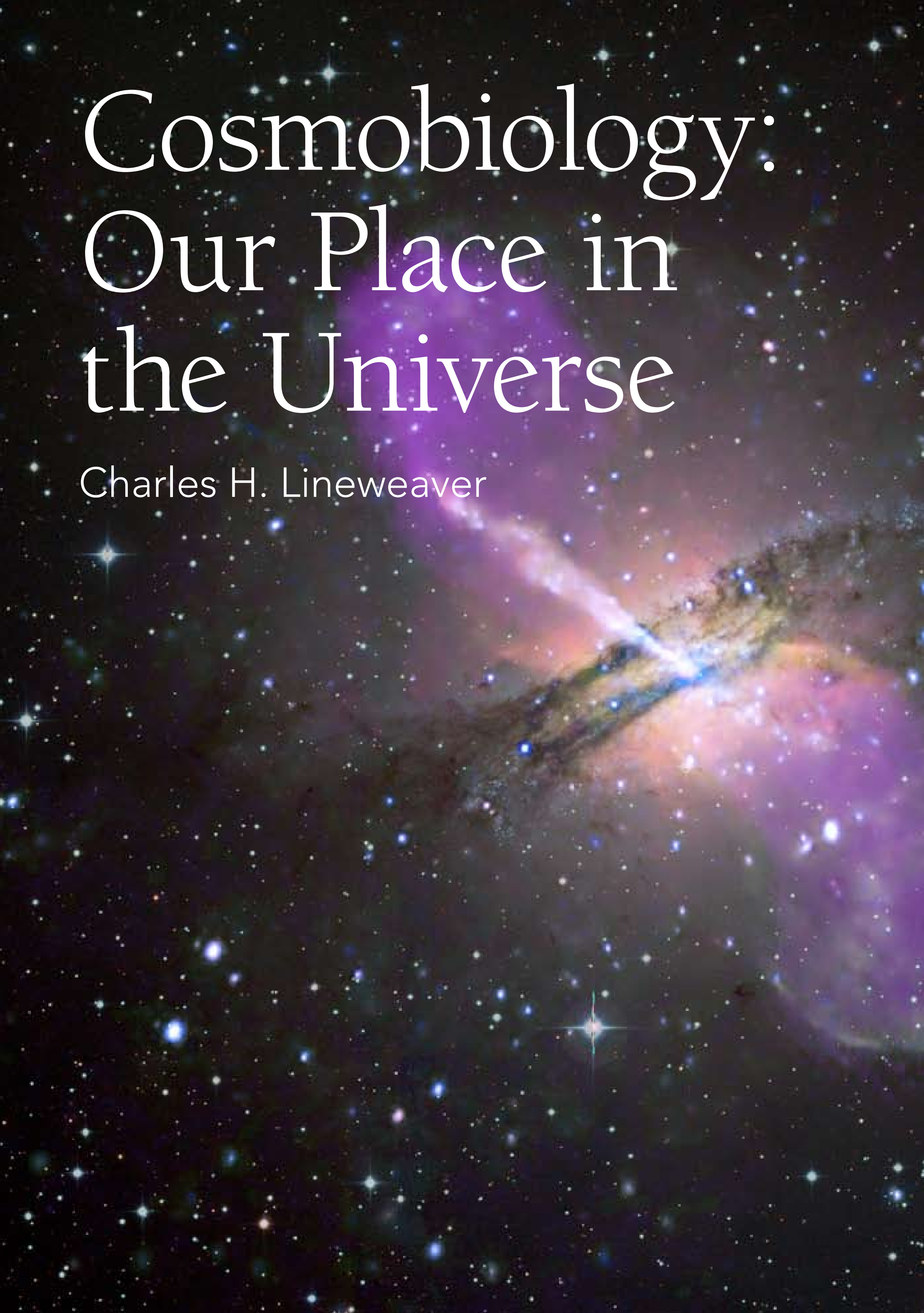
Cosmobiology: Our Place in the Universe

Charles H. Lineweaver



Here we sit on a ball of silicate with beating hearts, opposable thumbs and curious minds. How did we get here? How did the evolution of non-living things, such as galaxies, stars and planets, create the ingredients and the conditions for the emergence of life? Which aspects of this evolution are unique to the Earth and which are common in the universe? Are we alone? These cosmobiological questions are sharpened and partially answered by the overview presented here.

How in the universe did we get here?

In the fictional story "Hitchhikers Guide to the Galaxy", the Improbability Drive called into existence a sperm whale several miles above the surface of an alien planet (Adams, 1999). As it falls through the atmosphere:

"this poor innocent creature had very little time to come to terms with its identity as a whale before it then had to come to terms with not being a whale anymore… Ah….!

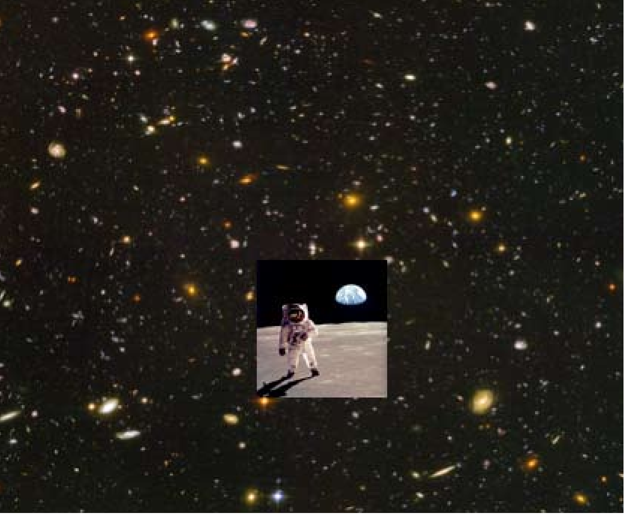


Figure 1: How did we get here? This deep image of a tiny fraction of the sky (~ 10^{-7}) shows ~ 10^{4} of the ~10^{11} galaxies in the observable universe. The square insert is a detail from one of the galaxies, showing an aerobic bipedal encephalated mammal on a moon, breathing oxygen imported from the blue planet in the background. We find ourselves on that blue planet 13.7 billion years after the Big Bang, falling at ~400 kilometers per second through an almost empty and possibly infinite universe. How in the universe did we get to be in such an unlikely situation? Images: NASA Hubble Ultra Deep Field and NASA 68-H-1401 and AS11-40-5903.
NASA/STScI

What's happening? It thought. Er, excuse me, who am I? Hello? Why am I here? What's my purpose in life? What do I mean by who am I? Calm down, get a grip now…And wow! Hey! What's this thing suddenly coming toward me very fast? Very, very fast. So big and flat and round, it needs a big wide-sounding name like…ow…ound…round…ground! That's it! That's a good name – ground! I wonder if it will be friends with me? And the rest, after a sudden wet thud, was silence."

Like this discombobulated sperm whale, many of us are trying to come to terms with our identities as life forms, before not being life forms anymore. We are hopeful that a scientific understanding of how we fit into the universe can help combobulate us.

Our scientific discombobulation begins with the origin of the universe. Our best ideas about

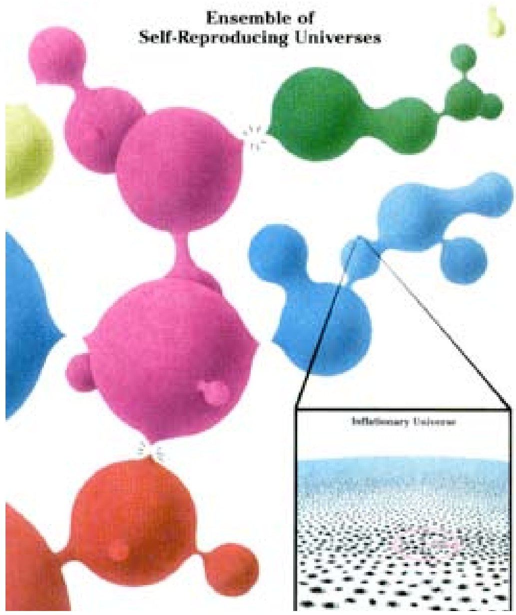


Figure 2: On the largest scales we will always be lost. This image represents the possible multiverse. Each bubble is a separate universe that was born from its mother universe and which, in turn can give birth to baby universes. Our universe may have been born as some random fluctuation of a patch of space-time foam in our mother universe that went through a process called inflation. In this diagram, our three dimensional universe is flattened into two dimensions and is represented by the surface of one of the small blue bubbles. In the square box, each black smudge represents a galaxy. The entire box full of galaxies shows only a small portion of our universe. The pink circle inside the box shows the extent of our observable universe, which is only an infinitesimally small part of the entire universe (i.e., of our blue bubble). We are in the centre of our observable universe. Figure 1 shows us the galaxies between us and the edge of our observable universe along one line of sight. Figure 3 is an image of the surface of our observable universe (the pink circle) 13.7 billion years ago when our entire universe was filled with a hot plasma rather than galaxies. Unlike the finite surface of the blue bubble shown here, our universe may be spatially infinite.

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the very earliest moments of the Big Bang come from a combination of cosmology and quantum mechanics called quantum cosmology. In quantum cosmology, there is no place for unique, one-off events — rather there are ensembles and probability distributions. Thus, quantum cosmology suggests that the event that we call the origin of our universe is not a unique event. It is one of many. Quantum cosmology suggests that our universe is just one of a possibly infinite number of other universes, which together we call the multiverse (Figure 2). We don't know how the universes in the multiverse are connected to each other or whether we can ever find evidence for their existence in our universe. Some cosmologists speculate that these disconnected universes have different laws of physics or possibly the same laws but with different constants, i.e. different values for "c", the speed of light or for "G", the strength of gravity. One thing seems clear though, despite our increasing understanding of our surroundings, our observations or our universe and others will always be limited. Thus, on the very largest scales we are and always will be lost, like that sperm whale falling through the atmosphere of an alien planet.

How did our universe begin?

The expansion and cooling of the universe is the basis of modern cosmology and a prerequisite for life. In the beginning, at the Big Bang, 13.7 billion years ago, the universe was very hot. There was no life and there were no structures in the universe. The matter, subatomic particles, atoms and molecules that we now take for granted did not exist. As the hot Big Bang cooled, matter came into existence, probably about 10^{-33} seconds after the Big Bang. We aren't sure how this happened, but according to inflationary models, the most dramatic events occurred in the first fractions of a second after the Big Bang, during a period at the end of inflation called "reheating". Vacuum potential energy of a scalar field became the tangible and clumpable energy and matter that we are more familiar with. Poorly understood symmetry violations (Sahkarov 1967) led to an excess of matter over anti-matter and a universe

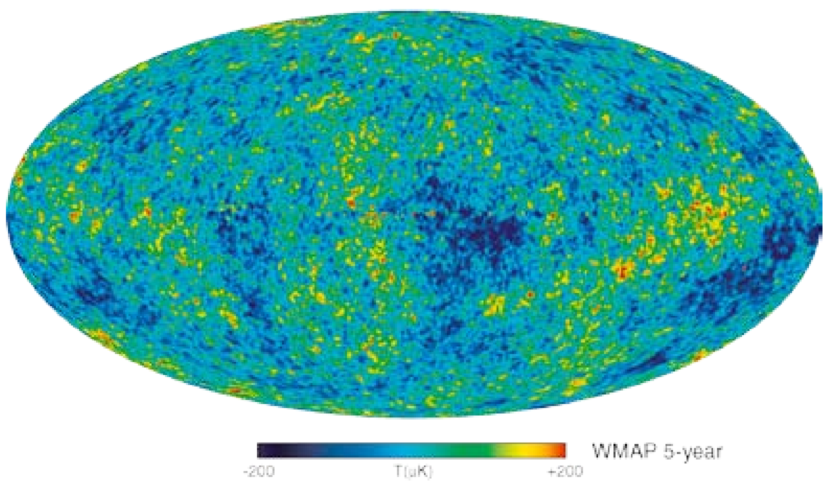

Figure 3: The best photo ever taken of the Big Bang. The photons detected to make this map travelled for 13.7 billion years and are the oldest photons we can detect. They were emitted from the surface of last scattering at the edge of our observable universe when the universe was about 380,000 years old and had a temperature of ~3000 K. As the universe expanded, these 3000 K photons became redshifted and cooled to the 3K photons we now observe. The pattern of hot (red) and cool (dark blue) spots has been used to obtain the most accurate estimates of the contents, age and size of the universe. *Image: NASA/WMAP Science Team.*

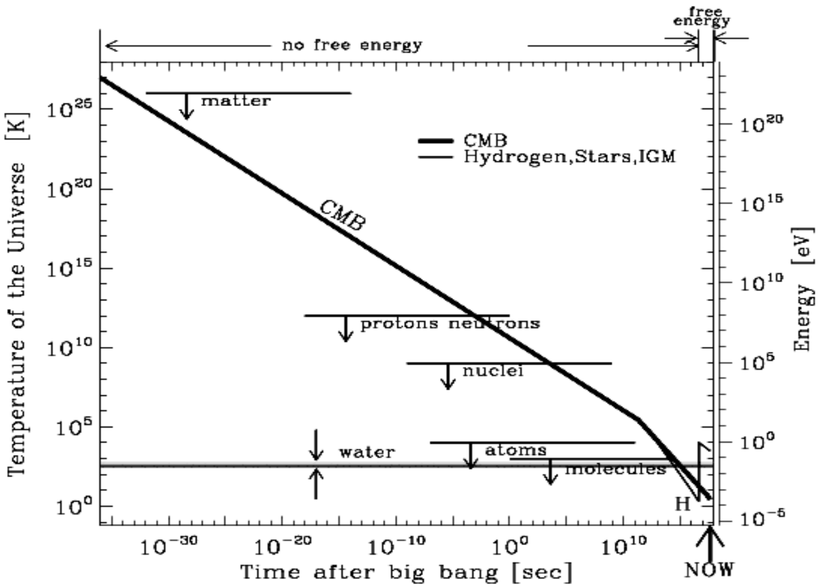

Figure 4: As the universe expands and cools, structures freeze out of the undifferentiated vacuum energy and quark-gluon plasma, like snowflakes from a cooling cloud. Structures that freeze out include, first matter at very high energies, then protons and neutrons, then nuclei, atoms and molecules. The thick diagonal line labeled "CMB" is the temperature of the cosmic microwave background, which is the temperature of the universe. The universe became transparent when it cooled down to about 3000 K and atoms (mostly hydrogen) formed out of the cooling plasma of electrons and protons (see the horizontal line labeled "atoms"). Figure 3 is an image of the CMB at that time. See Lineweaver and Schwartzman (2004) for details.

dominated by matter. Then at 10^{-3} seconds after the Big Bang, matter – in the form of a quark-gluon plasma – cooled and condensed into protons and neutrons. Within three minutes these particles had condensed into light nuclei during a period called "Big Bang nucleosynthesis". As the universe continued to cool, atoms formed for the first time about half a million years after the Big Bang. The universe was a thermal heat bath of photons and atoms in chemical equilibrium. Figure 3 is a full-sky map of the cosmic microwave background radiation. It shows the thermal heat bath of the universe 380,000 years after the Big Bang. There were no stars or galaxies. Life is not possible in such an environment. In thermal and chemical equilibrium, no free energy is available, and free energy, not just energy, is what life requires (Lineweaver & Egan 2008).

During the 13.7 billion years since the Big Bang, the universe expanded, the heat bath cooled and life (at least on Earth) emerged. Life did not emerge simply because the universe cooled down to have the right temperature for H_2O to be a liquid. Life needed a source of free energy unavailable from an environment in chemical and thermal equilibrium. The origin of all sources of free energy can be traced back to the initial low gravitational entropy of the unclumped matter in the universe (e.g., Lineweaver & Egan 2008). The gravitational collapse of this matter produced galaxies, stars and planets and is the source of all dissipative structures and activities, (including life) in the universe. Notice in the upper right of Figure 4 the small interval of logarithmic time during which free energy from stars has been available to power life in the universe. The first stars formed about 200 million years after the Big

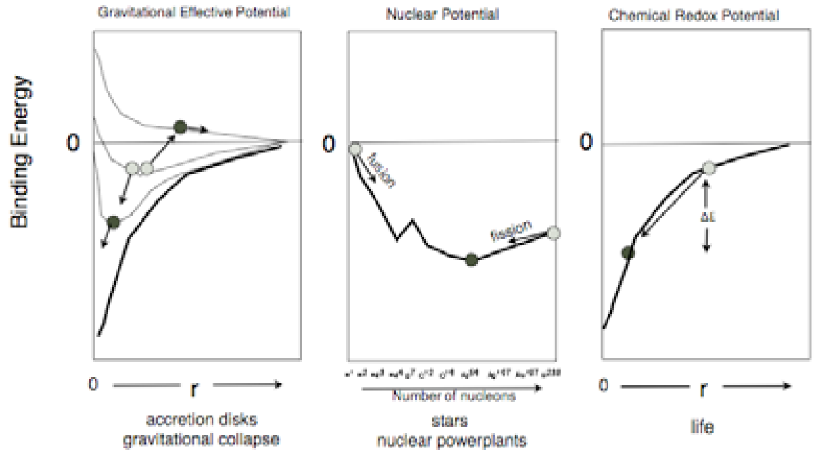

Figure 5: Any life forms in the universe depend on sources of free energy in the universe. These sources come in three kinds: gravitational (left), nuclear (middle) and chemical (right). Left panel: dissipation in an accretion disk leads to angular momentum exchange between two small masses (two light greyballs). The mass that loses angular momentum falls in. The one that gains momentum is expelled. Accretion disks are dissipative structures which, like more traditional life forms, must be fed – must have a source of free energy – to maintain their structure. Middle panel: the binding energy per nucleon due to the strong nuclear force provides the gradient that makes fusion and fission drive nuclei towards iron. Right panel: the energy that heterotrophic life (like ourselves) extracts from organic compounds, or that chemotrophic life extracts from inorganic compounds, can be understood as electrons sinking deeper into electrostatic potential wells. In every redox pair, the electron starts out high in the electron donor (light grey ball) and ends up (black ball) lower in the potential of the electron acceptor (cf. Nealson and Conrad 1999, their Figure. 3). These three sources of free energy are not independent of each other. For example, gravitational collapse (left) enables solar fusion (middle) which powers life on Earth (right). *Image from Lineweaver and Egan (2008).*

Bang (~ 10^{16} seconds) when hydrogen cooled down to 50 – 100 K. Before this time there were no stars and therefore no free energy to drive life. There was also no oxygen to make H_2O until several million years after the first generation of massive stars.

Life as we know it is based on molecules; clumps of atoms that froze out of the cooling universe when the temperature of the universe fell below molecular binding energies (Figure 4). Thus, the expansion and cooling of the universe has been the most basic prerequisite for the origin of molecules and molecular life. But life cannot be made out of the cooling hydrogen and helium produced in the Big Bang. Many generations of massive stars had to form and die before the ashes of nuclear fusion accumulated to contain enough oxygen, carbon, nitrogen, sulfur and phosphorus to produce watery environments and allow the chemical evolution of carbon molecules into hydrocarbons, carbohydrates and life.

Four elements make up more than 99% of the atoms in terrestrial life: hydrogen, oxygen, carbon and nitrogen or HOCN. Add seven more elements to this mix (S, P, Cl, Na, Mg, K and Ca) and we have more than 99.99% of the atoms in terrestrial life. Of all these ingredients, only hydrogen was made in the Big Bang, the rest were produced in the hot fusing cauldrons of massive stars. Their ubiquity ensures that the ingredients for life are present throughout the cosmos.

There are many reasons to believe that terrestrial planets, broadly defined, in habitable zones are ubiquitous in the Universe (Lineweaver et al 2003). For example, planets are formed in accretion disks and accretion disks are necessary ingredients in our best models of star formation. The latest observations and simulations are consistent with the possibility that rocky planets orbit the majority of stars. Even if we accept that terrestrial planets are common, in order for life to emerge and evolve into something interesting, millions or even billions of years in a clement stable aqueous environment may be required. Supernovae are the required suppliers of O, C, N, S and P but if they explode nearby they can also extinguish life. Thus, there may be a Galactic Habitable Zone close enough to the debris of supernovae to enjoy a complex chemistry but far enough away from supernovae to enjoy a clement environment for the billions(?) of years required for the biological evolution of interesting organisms (Lineweaver *et al* 2004).

Two ways to approach the origin of life

Figure 6 shows the formation of the Earth and the origin of life on Earth within the context of the history of the universe. There are two main ways to approach the origin of life on Earth. One way is to start at the initial conditions of the Big Bang at the bottom of Figure. 6 and work your way up, forward in time, through a series of evolutionary processes described by cosmology, astrophysics and chemistry including the expansion and cooling of the universe. This is described in the previous page. This chronological approach produces a rather straightforward and deterministic description of how the universe evolved and became conducive for life. This deterministic approach can explain how the ingredients of life – the elements and molecular building blocks were produced. The building blocks (or monomers) are important for understanding the origin of life because life seems to work on the Lego principle. Monomers are strung together to form polymers out of which all terrestrial life is made: amino acids are strung together to form proteins, nucleotides to form RNA, fatty acids to form lipids and monosaccharides to form carbohydrates.

However, we don't know the specific conditions of the proto-biochemistry such as the specific auto-catalytic molecular reactions that allowed the correlated polymerization of these monomers. We don't know the environments and pathways of molecular evolution that led to the origin of life. In the chronological cascade from the Big Bang to the origin of life, we are still very ignorant about the transition from the building blocks of life to the things we now recognize as "life". Our uncertainty is represented by the brown roots of the tree of life shown in Figure 6. Half a dozen good ideas are still slugging it out to explain this transition – it's a work in progress.

The other way to approach the origin of life is to start with the living organisms at the top of Figure 6, at the ends of all the branches and work your way down, backwards in time to the last universal common ancestor (LUCA) of all extant life forms. Then make some informed guesses about the origin of life on Earth, based on the characteristics of LUCA – What did it look like? How did it make a living? This procedure is similar to the way linguists use the common properties of a family of languages to make informed guesses about the extinct ancestor language which diverged to produce the family. Figures 3, 4, and 5 illustrate some of the processes of the bottom up approach, while Figures 7 and 8 are related to the top down approach.

From an aqueous environment on a rocky planet, life emerged on Earth about 4 billion years ago and branched into the three domains: Eubacteria, Archaea and Eukarya shown at the top of Figures. 6, 7 and 8. All life forms on this planet that have protein factories called ribosomes can be classified into one of these three domains. These three domains are the basic branches of the terrestrial tree of life. Figure 7 sketches the basic branches and sub-branches of life on Earth. Most of the kinds of life that you might be most familiar with (animals, plants and fungi) are just three short twigs on the tree labeled respectively "Homo", "Zea" and "Coprinus" (Figure. 7).

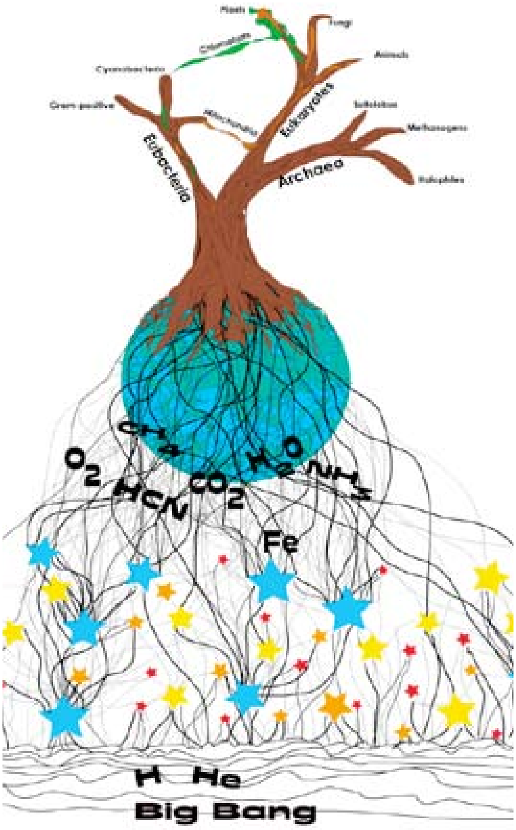

Figure 6: The history of the universe since the big bang. The hot big bang (bottom) produced hydrogen and helium (labeled "H" and "He"). Clouds of H and He gravitationally collapsed to form stars of various masses. The massive blue stars exploded after a few million years and spewed into interstellar space the ashes from the nuclei that had fused in their cores. After ~ 9 billion years of such reprocessing and accumulation, our Sun formed 4.56 billion years ago from a gravitationally collapsing cloud of molecular hydrogen contaminated with oxygen, carbon, nitrogen and other heavy elements. The Earth formed from this contamination as the accretion disk around the young Sun fragmented from lack of feeding.

We do not know if such a tree of life exists on other terrestrial planets. However, we can use this tree to make better guesses about what forms of life we should expect elsewhere. For example, life forms at the root of this tree are the common ancestor of all life on Earth. They are simpler and less quirky than the life forms they evolved into and therefore these simpler organisms may be more representative of what we should expect to find at the base of alien trees of life, i.e., as far as predicting aliens goes, the smart money is on hyperthermophilic bacteria, not vertebrates.

Consider two cosmobiological facts: (1) terrestrial biogenesis occurred rapidly, i.e., life formed on Earth more than 3.5 billion years ago, probably as soon as it could have after the heavy bombardment subsided; (2) terrestrial planets are not made of anything unique–life and planet Earth are made of the most common elements available in the Universe. These facts suggest that life may be common on terrestrial planets throughout the Universe. See Lineweaver & Davis (2002) for details.

Combining our knowledge of the cooling of the universe, of the formation of stars and planets, of the composition of those planets and the earliest forms of life on Earth, is one example of how cosmobiology brings together the study of life forms and cosmic processes to help us understand how we fit into the universe and how we compare to other life forms that may inhabit the Universe.

If we consider viruses to be alive then Figure. 7 does not show all life. If viruses or bits of RNA played an important role in the origin of life, then in neglecting viruses we have thrown the baby out with the bath water. For the beginning of a viral phylogeny, see Ward (2007).

The debate about what life is, and how to recognize it, is at the heart of the question: What is our place in the universe? This is the Holy Grail of cosmobiology. To make progress, we need to explore the martian subsurface and analyze the atmospheres of the nearest 100 or 1000 terrestrial planets. NASA is preparing to build the Terrestrial Planet Finder and ESA is preparing Darwin. Both are putting their money on using interferometric infrared

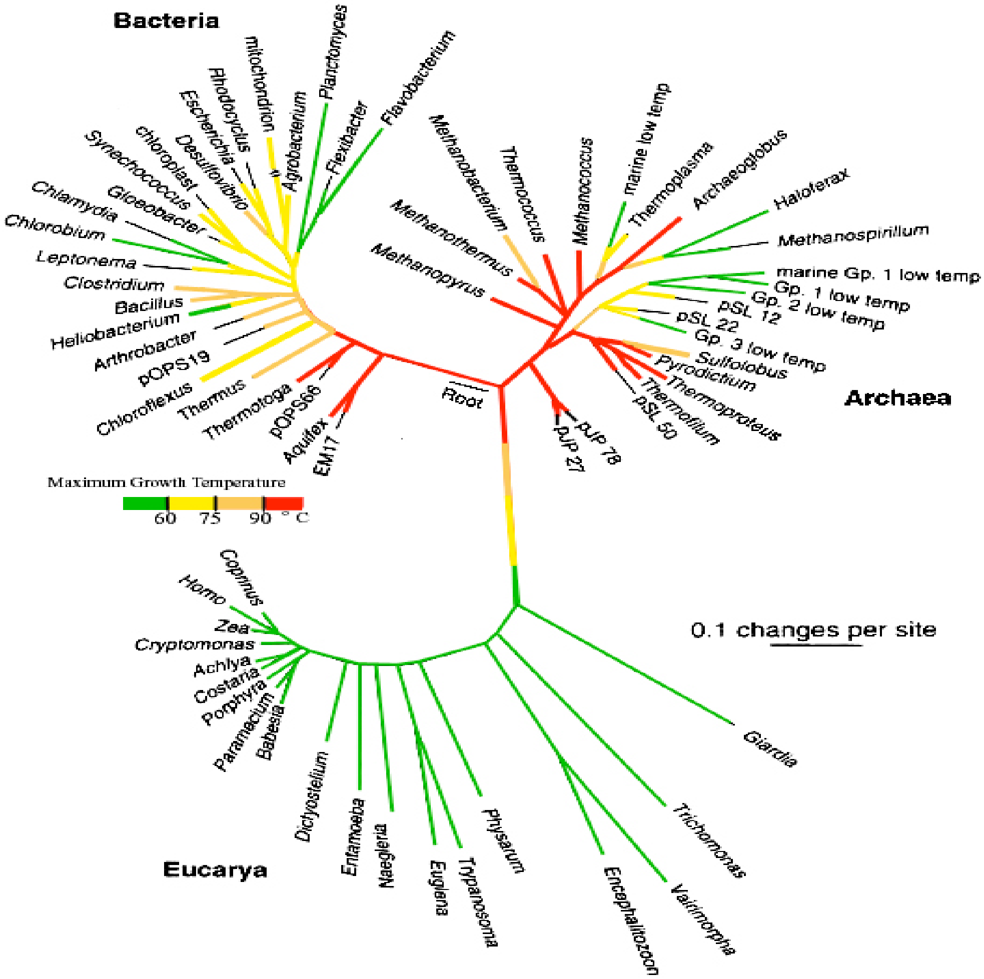

Figure 7: Phylogenic tree of terrestrial life based on the 16s subunit of ribosomal RNA. An estimate of the position of the last universal common ancestor (LUCA) of all life is at the center of the tree, labeled "Root". The deepest and shortest branches of this tree are all hyperthermophilic: organisms that can survive above 90° C. Therefore, LUCA at the root of the tree was probably hyperthermophilic. Life started as a hyperthermophilic eubacteria or archaea and branched out (see Wong 2008 but also Boussau et al 2008). Maximal growth temperatures have been used to assign colours to the branches and thus to construct this biological thermometer on billion year time scales. The distance from the root to the end of each branch corresponds to the same amount of time – roughly 3.5 or 4.0 billion years. Because the ticking of the 16s molecular clock is not exactly uniform, the distances from the root to the ends of the branches are not the same length. Among the Eucarya in the lower left are the three twigs of complex multicellular life: Coprinus (representing fungi), Homo (humans, representing animals) and Zea (corn, representing plants). The common ancestor of fungi, animals and plants lived ~1.5 billion years ago (Hedges et al 2004). The last 200 million years of vertebrate evolution corresponds to the last ~2 mm of the twig labeled "Homo". Diagram from Lineweaver and Schwartzman (2004) based on Pace (1997). Near the root, pJP27 and pJP78 are Korarcheota, the deepest and shortest branched extant organisms – presumably the extant organism that most resembles LUCA (Elkins et al 2008).

Lineweaver and Schwartzman (2004) based on Pace (1997)

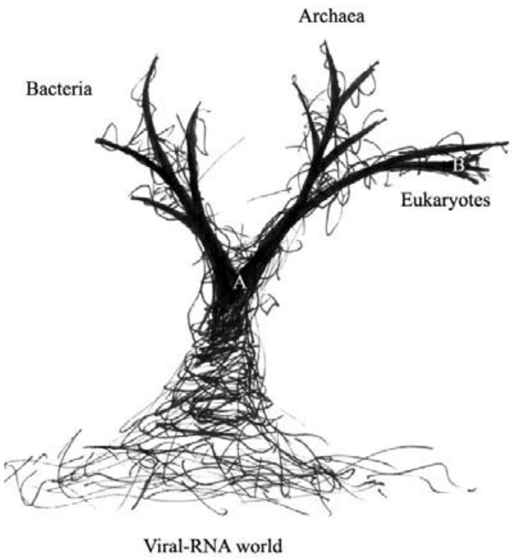

Figure 8: Tree of life emerging from roots in an RNA/Viral World. Every branch is adorned (or infected) with viruses. Viruses may well be remnants from an earlier epoch in which they were the dominant life form and no stable gene lines had yet emerged. From the viral point of view our vertically transferred genomes are frozen, hardly-evolving non-participants in the lively cut and thrust of lateral gene transfer. *Image Lineweaver 2006.*

spectroscopy to look for the traces of chemical disequilibrium as the primary biomarker (Lovelock 1979).

Are we alone?

The answer to this important question depends on what "we" means. If "Are we alone?" means "Are we, the life forms on Earth, part of a larger group of life forms out there in the universe?" then we don't know the answer. We don't know if terrestrial life is the only life in the universe…but even more problematically we're not sure what "life" in its most generic form is or how we can recognize it. For more on these doubts see Lineweaver (2006).

If "Are we alone?" means "Are we humans the only species of life in the universe?" then the answer is easy. No, we are not alone. There are millions of other species of life on Earth. If we are not alone on Earth, we can't be alone in the universe.

If "Are we alone?" means "Are we humans the only species of life in the universe with human-like intelligence?" then we have a controversial question and the topic of much debate. Many physical scientists tend to believe that we humans are members of a larger group of "functionally equivalent humans" and thus, we are not alone (Sagan 1995a,b).

Many biological scientists tend to believe that there is no evidence for such a group of "functionally equivalent humans" and that our closest relatives in the universe (chimps and other apes) are here on Earth, not in orbit around other stars. Thus, if, after examining our closest relatives, we decide there are none with human-like intelligence, then by our own self-servingly narrow definition of intelligence, we are alone (Simpson 1964, Mayr 1995ab). This last version of the question "Are we Alone?" can be sharpened and rephrased as:

Is human-like intelligence a convergent feature of evolution?

In other words, is there a tendency in evolution to evolve toward our kind of intelligence? If there is, then we are likely to find beings with human-like intelligence elsewhere in the universe. If our version of intelligence is something species-specific – something that evolved only once in the context of billions of years of evolution on Earth – we should not expect to find it on other planets.

The scientists who support Sagan's view, subscribe to what I call the Planet of the Apes Hypothesis that goes something like this: There is a "human-like intelligence" niche. There is selection pressure on other species (including our ancestors) to occupy this niche. In our absence (or on other planets) some species will evolve into that niche and develop technology. Carl Sagan has called the occupants of this niche the "functional equivalent of humans".

I call it the "human-like intelligence" niche not the "intelligence niche" because generic intelligence is poorly defined. Each animal species with a brain seems to have its own version of intelligence. It is also not clear to me that a life form must have a brain to be intelligent. All creatures that survive and reproduce could be said to be as intelligent as they need to be. Bacteria, for example, have worked out complex and simple ways of accommodating themselves to virtually every environmental condition that exists on the planet. That's pretty smart. But that's not the kind of intelligence most people hope to find elsewhere in the universe. Our human-like intelligence, unlike any other type of intelligence on Earth, has allowed us to build radio telescopes and given us the ability to hear and be heard across interstellar distances. This ability that we humans have, and that we are able to look for in others, is a "species-specific characteristic". No other species on Earth seems to have it.

Frank Drake is a physical scientist and a pioneer in the search for extraterrestrial intelligence (SETI). When I asked him what the best evidence for the existence of intelligent extraterrestrials was, he referred me to the work of Jerison shown in Figure 9 which seems to show that human-like intelligence, or at least a large brain case is a convergent feature of evolution. In this version of the evolution of human intelligence, Jerison analyzes the sizes of brain cases as a function of time and finds a trend toward bigger and bigger brains. He concludes that there is some general trend in evolution toward bigger brains. Compare this plot to my plot in Figure 10, where I trace the evolution of the nose size of the elephant. Looking back through time, it is easy to see that the ancestors of the elephant had smaller noses than the elephant. In fact, if I look at the evolution of the elephant, I can find a definite trend toward bigger noses, but it would be silly to conclude that there is a general trend in evolution toward bigger noses.

Interpreting Figure 9 as evidence for evolutionary convergence on bigger brains is as silly as interpreting Figure 10 as evidence for convergence on longer noses. One cannot identify a current extreme feature in a species, plot the trend with time of its ancestors and then generalize that trend to other lineages. The trend that results is specific to your ancestors – obligatorily so, since the recipe for such plots is 1) identify your species' most extreme feature (a big brain, a big nose) and make that

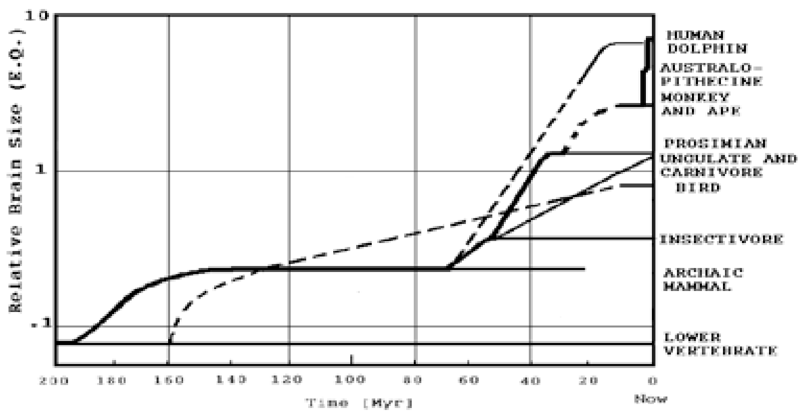

Figure 9: The Evolution of Relative Brain Size in Groups of Vertebrates Over the Past 200 Million Years (adapted and updated from Jerison 1976, p 96, Jerison 1991, Figure. 17). This plot purports to show an evolutionary trend towards increasing relative brain size (= E.Q. = Encephalization Quotient) and is probably the most well-documented evidence for such a trend. Average living mammal E.Q. is defined as 1. The broken lines indicate gaps in the fossil record. Variation within groups is not shown. The lineage that led to humans is drawn thicker than the other lineages. *Lineweaver (2008)*

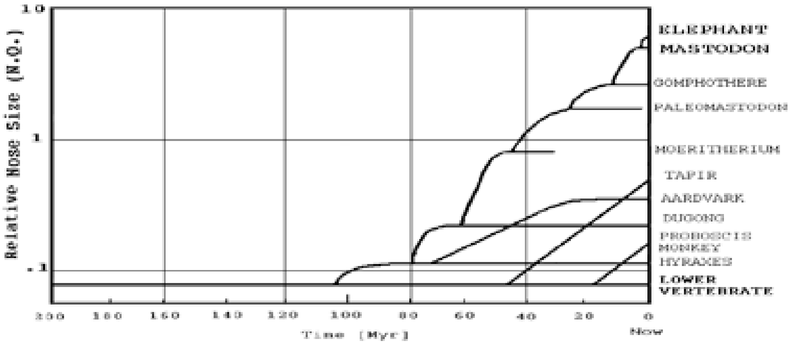

Figure 10: The Evolution of Relative Nose Size (= N.Q. =Nasalization Quotient, ratio of nose length to body length) Over the Past 200 Million Years. Notice the apparent trend in the data as, over time, N.Q. reaches its ultimate value in extant pachyderms. Notice also that once the direct lineage that led to elephants is ignored, most of the species do not have an increasing N.Q. This plot is meant to illustrate a point, and should not be taken as more than a crude representation of a specious trend in N.Q. that has been largely ignored and poorly quantified by paleontologists. *Lineweaver 2008.*

the y-axis of a plot 2) plot yourself in the upper right 3) plot your ancestors who, since you are the extreme, will fall on a descending line into the lower left. Thus Figures 9 and 10 are not evidence for any general trend toward bigger brains or noses.

In addition, heads (and therefore brains) are monophyletic: a single species diversified into all extant species with heads (brains). Not only is human-like intelligence not a convergent feature of evolution, heads are not a convergent feature of evolution. Heads were once a species-specific feature, thus, all heads and brains have diverged from a single species that had a head. Thus, heads and brains are not the generic products of evolution but are as quirky and unique as a single species.

Humans are unique, just like every other species on Earth. It makes no sense to concoct an imaginary set of which we are the only terrestrial member and then suppose that biological evolution elsewhere in the universe evolves toward this set. This concoction is The Planet of the Apes Hypothesis. It is testable. Paleoneurology does not support it.

Carl Sagan said that our evolution represents the universe becoming aware of itself (Figures. 12 and 13). If human-like intelligence were so useful, we should see many independent examples of it in biology, and we could cite many creatures that had evolved on independent continents to inhabit the “intelligence niche”. But we can’t. Human-like intelligence seems to be what its name implies – species specific. Thus, the terrestrial record suggests that we are as unlikely to find a creature with human-like intelligence elsewhere in the universe as we are to find a sulphur crested cockatoo or a naked mole rat on another planet.

Even so, I am a strong supporter of the SETI Institute, which uses radio telescopes to search for extra-terrestrial intelligence. I do not expect to find creatures on other planets that build radio telescopes, but I support the effort to keep looking. Who knows what we will find? SETI is the exploration of new parameter space with new instruments – a proven recipe for scientific discovery. However, we do not need to misinterpret the fossil record to justify continuing exploration of our universe.

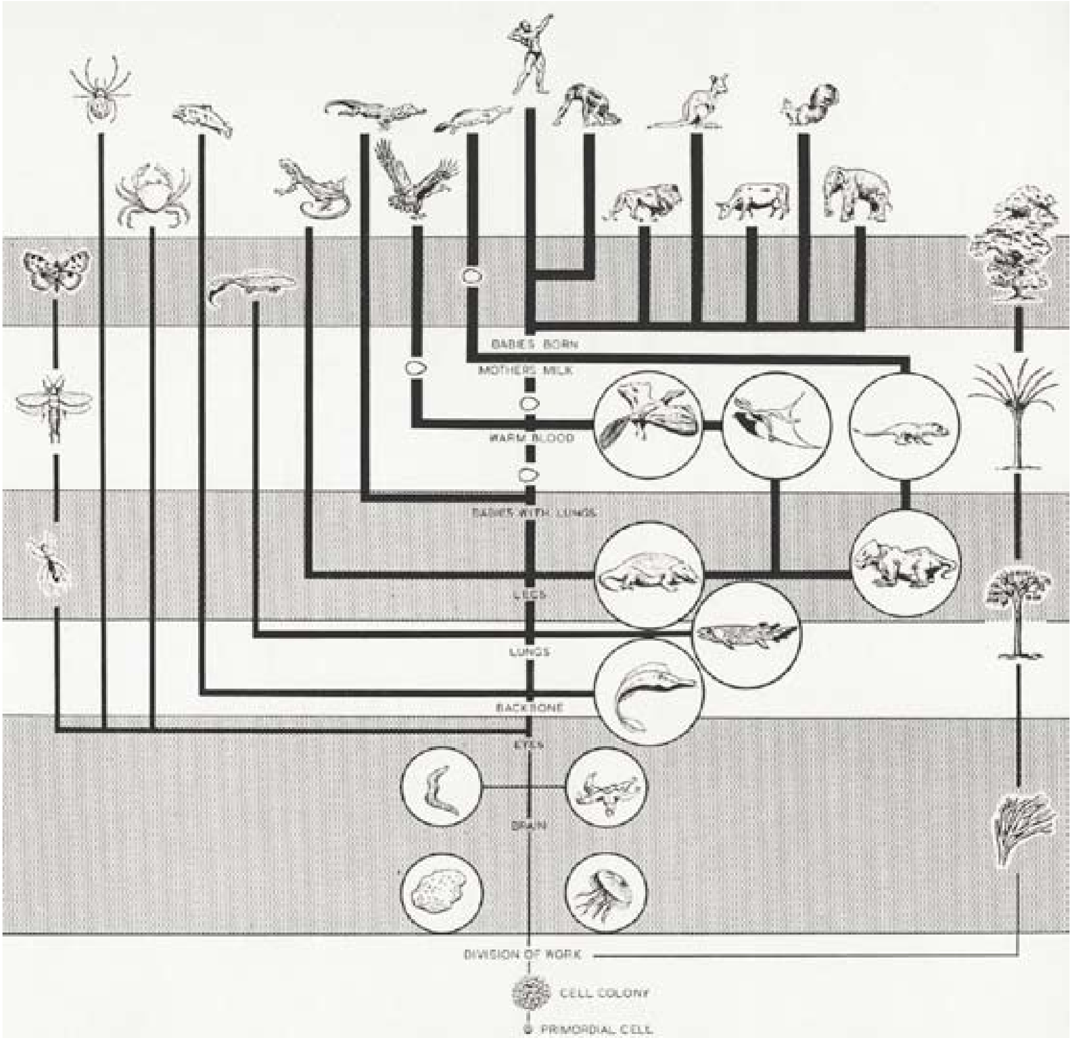

Figure 11: The Schwarzeneggerization of Life: a self-serving misinterpretation of evolution. A muscle-bound man stands as the end product of a linear progression—the Great Chain of Being – a ladder of life that leads to male Caucasian weight lifters. One can create such an apparent linear trend out of the crooked phylogenetic branch of any species. Looking back from any particular species we will find the evolution of the traits of that particular species but these traits will be different from the ones listed along the central axis here. Precisely because we can construct such a figure from the lineage of any species, a single example of such a construction should not be construed as a general linear trend applicable to all life. The simple appeal of this figure is a good example of how easy it is to be misled into believing that the important events and the major transitions in evolution that led to us, are important events for all organisms. The problems with this view are detailed in Gould (1989) but are perpetuated by Smith and Szathmary (1995). The prevalence and recurrence of this mistaken interpretation of evolution needs to be avoided as we try to use terrestrial evolution to give us hints about the evolution of extraterrestrial life. This Schwarzo-centric tree should be compared with Figure. 7 which itself, because it ignores viruses, may be guilty of a similar bias against creatures who outsourced protein production. *Gatland and Dempster (1957)*

Figure 12: Who are we? As you read this, photons are bouncing off the image and entering your eyes. The photons are producing a pattern of excited retinol molecules. This pattern is being sent from your retina through your optic nerves to the occipital lobes of your bilaterally symmetric brain, where you have a molecular model of yourself, and how you fit into the universe. Thus, patterns of molecules inside your brain are contemplating themselves, and that, of course, is what this picture illustrates. Understanding how the universe produced molecules and how these molecules acquired the ability to think about themselves may be a central thread of how we are woven into the universe. *Drawing by Victor Juhasz.*

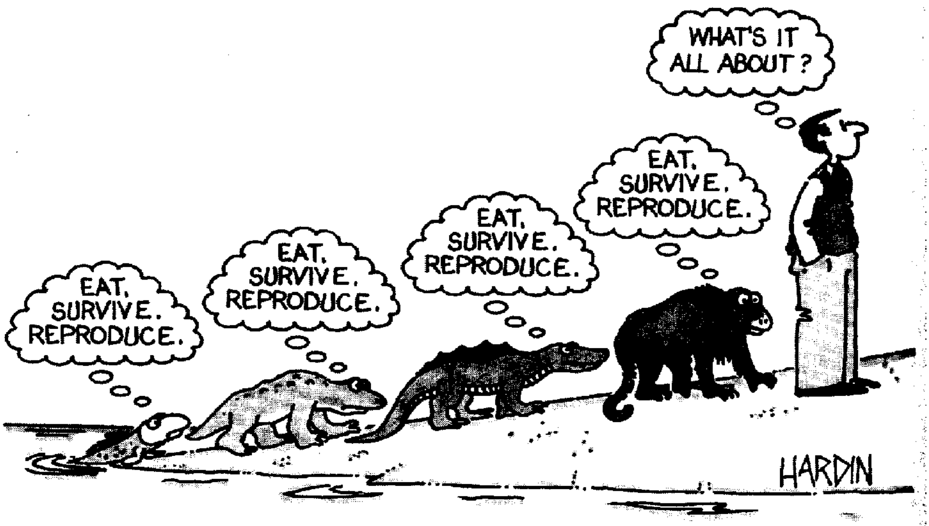

Figure 13: This cartoon captures the status of a big-brained biped. Our big brains enable us to ask important questions such as "What's it all about?", "How do I fit into the universe?" On the other hand, our brains may be too big. They deceive us with self-importance and prevent us from knowing the humble answer that every other creature seems to know: "Eat, survive, reproduce". *Image Garret Hardin.*

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