
An earlier version of this article was posted to the newsgroup talk.origins. (http://www.dejanews.com/getdoc.xp?AN=274975926&fmt=raw) This is still a preliminary draft, and will be revised — possibly extensively. Comments and constructive criticism are welcome. Flames and spam go to the bit-bucket.

1 Introduction

The “Anthropic Principle” claim has come under considerable discussion recently. Scientists of the Christian persuasion have argued that life would not be possible if certain parameters in the universe were even slightly different from their actual values. Those scientists argue that it would have been extremely unlikely for those parameters to take on by chance just the right values to allow life. There had to be a designer who created the universe. Those scientists have identified the designer as the Judeo-Christian God of the Bible.

Astronomer Hugh Ross has formed an organization, Reasons to Believe, to promote those ideas. Their website, http://www.reasons.org/, carries a number of position papers, including Ross’s “Design and the Anthropic Principle,” the subject of this article.

In that article, under “The Universe as a Fit Habitat,” Ross claims that sixteen parameters have to be finely tuned to allow life in the universe:

1. Gravitational force coupling constant
2. Strong force coupling constant
3. Weak force coupling constant
4. Electromagnetic force coupling constant
5. Proton-electron mass ratio
6. Age of the universe
7. Expansion rate of the universe
8. Entropy of the universe
9. Total mass of the universe
10. Uniformity of the universe
11. Stability of the proton
12. Electromagnetic fine structure constant
13. Speed of light
14. Nuclear energy levels of certain nuclei
15. Distance between stars
16. Rate of luminosity increase of stars

Ross’s paper has several other sections discussing quantum theory, “The Earth as a Fit Habitat”, “Man the Creator?”, and other issues.

Several people have taken issue with the Anthropic Principle, including Victor J. Stenger in “Intelligent Design: Humans, Cockroaches, and the Laws of Physics,” (http://www.talkorigins.org/faqs/cosmo.html). In the summer of 1997, Michael Ikeda and Bill Jefferys posted a proposed FAQ to the newsgroup talk.origins, arguing that the observed life-friendliness of the universe does not require a designer, but instead suggests the opposite.

In this paper, I examine Ross’s sixteen claims, and demonstrate that they are unwarranted and in some cases patently false.

It is important to note that Ross aims his arguments not at the physics community or the science community in general, but at the general populace and the Christian populace in particular. His ideas appear in science textbooks aimed at freshmen and sophomores in Christian colleges. None of these targets have the necessary background and expertise to verify or refute his claims. There is serious danger of someone making patently false claims and pulling something over his audience. I believe that Ross has committed precisely that sin.

There may be issues I have not considered, and it may turn out that some of these parameters in reality need to be fine-tuned to support life. If so, Ross has presented his claims with utmost obscurity, making it impossible to evaluate them objectively. Ross should argue clearly and in sufficient depth to convince an expert in the immediate field. The expert must be able to reproduce and test the argument himself. “Extraordinary claims require extraordinary proof.”

Two months before my first posting of this article on talk.origins in September 1997, I gave Ross and his group a chance to explain and defend their assertions. They did not. I submitted a question to the service on the Reasons to Believe website, asking for an explanation of items two and four in particular
from Ross’s paper. I got no response from them, but I did receive a response when I sent the question to someone who works with them two weeks later. He was not able to answer the question, which was not a problem as his field was biology. However, his reply suggested that he did not quite understand what was meant by an explanation. I followed up with a short summary of my position on those items. He said he contacted a physicist in the group, who replied (to him) suggesting that I consider changes on “a broader basis.”

I heard nothing further until I posted the earlier draft of this article to talk.origins. Upon that posting, the biologist, Richard Deem, replied that the service at Reasons to Believe had a three-month backlog. (http://www.dejanews.com/getdoc.xp?AN=274948313&fmt=raw) A month after posting the article, consistent with the three-month backlog, I received a brief reply to my question, pointing me to Ross’s books *The Creator and the Cosmos* and *The Fingerprint of God*. Deem never mentioned the backlog at my first query.

2 Parameters and Interrelationships

Ross’s thesis is that certain parameters are fine-tuned to allow for life. If any of those parameters differed by even a small amount, the universe as a whole would be very different and life would be impossible.

It should be clear that in general, a tiny change has a tiny effect. While this is the general rule, there are exceptions; there are times when a tiny change has an enormous effect. A tiny initial effect may build up over a very long time to give a huge result. Similarly, a tiny change multiplied by a large number might be appreciable. In either case, one could argue that the true measure of the variation is not the tiny change itself, but the tiny change combined with the large number — that is, an appreciable number. In chaotic phenomena, a tiny change in the initial conditions of the system completely alters the future behavior of the system. Other small changes might result in a bound state of an atom (or molecule or nucleus) becoming an unbound resonance, or might change a net attraction to a net repulsion.

We must not consider the change of a single parameter in isolation. Several parameters can effect a certain phenomenon. A variation in one parameter may oppose the variation in another parameter to cancel the effects. As a hypothetical example, suppose we are told that the expansion rate of the early universe is fine-tuned: if too fast, the universe would spread out too soon for galaxies to form; if too slow, matter would coalesce too much (due to gravity) and we would have nothing but a universe of black holes. Later, we are told that the initial fluctuations in the almost-perfectly-smooth mass distribution of the early universe is also fine-tuned: If too much fluctuation, mass would collapse quickly resulting in nothing but black holes; if too little fluctuation, the mass would not collapse sufficiently to form galaxies.
But both parameters can change. We can increase one of them (such as the expansion rate) arbitrarily. Then we can increase the other (the initial degree of fluctuation) and fine-tune it to cancel the effect on the formation of galaxies. This means that the ability of galaxies to form depends only on one of the parameters. Only one parameter need be fine-tuned; the other can be chosen arbitrarily.

To continue with our hypothetical example, suppose now we were given a third parameter, the strength of the gravitational force. This affects both the expansion of the universe and the ability of mass to collapse and form galaxies. Again, too strong and the mass collapses to nothing but black holes; too week, the universe expands too much for the mass to collapse and form galaxies. But if we consider this with the other two parameters, only one of them has to be fine-tuned. We can pick two of them arbitrarily, and then fine-tune the third to give us galaxies.

Clearly, if we can reduce the number of parameters that need to be fine-tuned, we increase greatly the overall possibility of life being allowed in a universe formed by chance.

Dimensioned numbers (numbers with units, such as distance, time, and mass) are particularly susceptible to this issue. Units are a purely human convention, and Nature pays no attention to our choice of units. The numerical values associated with dimensioned numbers varies freely with our choice of units. For example, the speed of light \( c \) is:

\[
c = 300,000 \text{ km/sec} \\
= 3.00 \cdot 10^8 \text{ m/sec} \\
= 186,000 \text{ miles/sec} \\
= 1 \text{ light-year/year} \\
= 1
\]

That last value (one) deserves particular note. In relativity and high energy physics, it is conventional to set the speed of light exactly equal to one. All relativistic equations can be put in the form where time always appears in the form \( ct \), mass in the form \( mc^2 \), momentum in the form \( pc \), and velocity in the form \( v/c \). Taking \( c = 1 \) simplifies the equations; it does not contradict any of the other values. In this case, one second equals 300,000 kilometers. We need only assume one thing: the speed of light is constant.

We also often take Planck’s constant \( \hbar \) and the Coulomb force constant \( k \) both equal to one. This leaves the universe with only one remaining unit, which we can choose as length. In general relativity, Newton’s gravitational constant \( G \) is also often taken equal to one. This along with the others turns all dimensioned quantities into dimensionless quantities, with the Planck mass and Planck length \( (10^{-35} \text{ meters}) \) being one. This appears to alleviate the problem of dealing with dimensioned parameters, but it does not really. It only
works if someone attempts to argue that the value of the parameter relative to the Planck scale has to be fine-tuned. Ross has made no such argument, and so far the Planck scale appears to have no effect on the physical world.

An example of a dimensionless number is the (electromagnetic) fine structure constant ($\alpha$), based on the magnitude of the charge of an electron ($e$):

$$\alpha = \frac{ke^2}{\hbar c} = \frac{1}{137}$$

The electron's charge is actually negative: $-e$. The other quantities in the equation are defined above. If our units are chosen with $e = \hbar = k = 1$, then the fine structure constant is simply the square of the electric charge.

Mass ratios are also dimensionless numbers. In general, all physics results can be expressed in terms of dimensionless numbers. Nature pays no attention to mere human choice of units. Any argument that the universe is fine-tuned to support life has to be based on dimensionless quantities. However, one may be able to get around this requirement by specifying a fractional change or percent change in the parameter. The fractional change is specified by dividing the change in the parameter by the original value of the parameter, and is always dimensionless.

A list of parameters need not be independent. In the list of Ross's claims, number four is the electromagnetic coupling constant (otherwise known as the electric charge) and number twelve is the electromagnetic fine structure constant. But the fine structure constant is simply the square of the charge. If one is fixed to satisfy one fine-tuning requirement, then the other is automatically fixed, period. Ross's argument is then that in order for life to exist, the parameter is required to be fine-tuned at precisely the point where the parameter has to be. In other words, the universe is designed to require fine-tuning of the parameter to where the parameter is. This sounds awfully bizarre, and suggests that possibly the universe does not really require that parameter to be fine-tuned.

More generally, some of Ross's parameters are fixed by the laws of physics. It is likely that the energy levels in beryllium, carbon, and oxygen that he cites in item 14 are fixed by nuclear physics. Once nuclear physics is fixed to produce nucleons and combine nucleons into deuterium but not helium-2, the energy states of complex nuclei may be completely determined.

If we consider only sufficiently tiny changes, it does not matter how many parameters we have. An arbitrary (but sufficiently tiny) change in any number of parameters will have a tiny effect on the suitability of the universe for life, and is just as likely to increase as decrease the suitability. Think of the parameters forming a high dimensional vector space, and the suitability as a scalar function defined on the vector space. Current configuration is a point in the vector space. The suitability function can be expressed as a Taylor series about the point, and "sufficiently tiny" means that quadratic and higher terms can be ignored in the expansion. The change in the function can be taken as linear in the change in
parameters. A change in parameters can go in any direction, and the change in suitability is simply the projection of the parameter change on the gradient of the suitability. Whether the suitability increases or decreases depends on the sign of the projection.

3 Ross’s Claim’s of a Fit Universe

Before discussing Ross’s specific claims, I would like to point out that some of his claims are obscure. Sometimes he does not say what would happen if the parameter in question changed, other than that life would be impossible. Nor does he say, except in one of his items, how much of a change is considered a small change.

As an example of his obscurity, Ross cites Paul Dirac and Robert Dicke, and says that the number of baryons in the universe equals the square of both the gravitational constant and the age of the universe, expressed as dimensionless numbers.

It is not easy to figure out what Ross claims without actually going to the references Ross cites. In standard units, neither the gravitational constant nor the age of the universe is dimensionless. As noted above, one often sets Newton’s gravitational constant equal to one (dimensionless) in general relativity. But the universe has more than one baryon. Clearly, this does not reflect Ross’s claim.

Several sources, including Ross at the end of his paper, have claimed that the universe has approximately $10^{80}$ baryons. The ratio of the age of the universe to the time for light to travel the diameter of a baryon is about $10^{40}$. For two electrons, the ratio of the electric force to the gravitational force between them is also about $10^{40}$. Square this number, and you get $10^{80}$. This is probably Ross’s claim, although he gets it wrong for the case of the electrons’ forces because the gravitational force is the denominator of the ratio.

Note that these numbers, $10^{80}$ and $10^{40}$, are very approximate. The estimated number of baryons is uncertain to at least an order of magnitude (because of the dark matter problem, if for no other reason). There is probably no cosmological significance to be derived from these numbers. This is just a numbers game. There is no significance if the height of a certain Egyptian pyramid (in meters) just happens to be very close to seven orders of magnitude smaller than the distance to the sun (in miles). Likewise there is no significance that one year just happens to be very close to $\pi \cdot 10^{7}$ seconds. There are an infinite number of numbers, so there are infinity-squared pairs of numbers that can be compared, and so many of them will give you whatever ratio you wish.

Now let’s discuss Ross’s claims.
3.1 Gravitational Force Coupling Constant

Ross claims that if the gravitational force were slightly stronger, all stars would have at least 1.4 times the mass of the sun. If the force were slightly weaker, all stars have less than 0.8 times the mass. The heavy stars are needed to form and distribute the heavier elements. The light stars, long-lived and stable, are needed to support life. Without both, life could not exist.

Ross is correct in identifying the necessary roles played by heavy and light stars in the support of life. However, is it really true that a slight increase in gravity’s strength would lead to all stars being 1.4 times the sun’s mass, or heavier? Where does he get the factor of 1.4? One possibility is that it’s the square root of two. The other, more likely, possibility is that it is the Chandrasekhar limit, the mass beyond which a star will collapse to form a neutron star after it finishes burning. All neutron stars which have been measured have measured masses equal to that result, even though the limit is only an inequality. Note also that this is precisely the process — collapse to neutron star accompanied by supernova explosion — that distributes the heavy elements into space.

With the current value of the gravitational constant, stars (and would-be stars) range in mass from brown dwarfs and gas giant planets which are so light that fusion never gets started, to the very heaviest stars which eventually collapse not to neutron stars but to black holes. A slight increase in the gravitational constant may mean that a star would suck in a little more mass and might burn a little faster, or might start burning whereas it currently doesn’t. Perhaps a red dwarf might go so far as to become yellow. But you don’t get a brown dwarf turning suddenly to a massive blue giant. The same applies in the opposite direction if the gravitational constant decreases slightly.

The principle given in the introduction holds here: Tiny changes have tiny effects.

3.2 Strong Force Coupling Constant

According to Ross, if the nuclear force were only slightly weaker, nucleons would not bind to form nuclei; only hydrogen would exist. On the other hand, if the nuclear force were slightly stronger, hydrogen would be rare in the universe and elements heavier than iron needed for life would not likely be formed. Ross adds in a footnote that if the strong force were two percent stronger, quarks would never combine to form nucleons; if it were two percent weaker, heavy nuclei would be unstable.

The footnote is the easiest to deal with, so I shall dispatch that first. It is fairly well established that quarks are described by the theory of Quantum Chromodynamics (QCD). The families of particles and their approximate masses are predicted by the quark model, and perturbative QCD agrees with high energy experiments. However, actually calculating anything in QCD other than perturbatively has been extremely difficult. Perturbative calculations only apply
in high energy regime, where asymptotic freedom holds. For three quarks combining to form one proton or one neutron, the calculation is non-perturbative, and has not been done to nearly the precision and confidence necessary to make any claim whatsoever about a two-percent increase or decrease in the strength of the nuclear force. The indications are that confinement holds regardless of what the QCD coupling constant is.

The two-percent claim has to have been fabricated out of whole cloth. He made his claim as early as 1990, just after a speech he gave at MIT. A couple years later, a researcher gave a talk at MIT, and said that his group was able to estimate the QCD coupling constant to around ten percent uncertainty. Frampston in *Gauge Field Theories* says that experimental confirmation of perturbative QCD is approximately at the ten-percent level.

Originally, at the posting of the first version of this article, I'd thought that Ross had simply made up this claim. I had seen the claim nowhere else, and Ross had cited no source. Since then, I learned of another reference making essentially the same claim: J. D. Barrow and J. Silk, *Scientific American* 242 No. 4 (1980), pp. 127-8, cited in “Scientific Evidence for the Existence of God” by Walter Bradley ([http://www.origins.org/real/ri9403/evidence.html](http://www.origins.org/real/ri9403/evidence.html)). Like Ross, the authors of the *Scientific American* article simply made the bald assertion, without citing any source for the claim or any indication of how the authors found out.

Ross’s main claim, apart from the footnote, has some validity. I will not talk in terms of the coupling constant itself, but rather the observed phenomena. The discussion of this section is long, but the results are that there would be no bar to life if the nuclear force were a little lighter. If the nuclear force were a little heavier, it is an open question.

Deuterium is chemically a form of hydrogen. The nucleus consists of one proton and one neutron, in contrast with regular hydrogen whose nucleus consists only of a single proton. The deuteron is loosely bound; the average separation between the two nucleons is considerably greater than in other nuclei. The deuteron (deuteron nucleus) binding energy is 2.2 MeV compared with 26 MeV for helium-4, a tightly-bound nucleus. (The proper comparison may be the binding energy per nucleon, 1.1 MeV vs. 6.5 MeV, or the binding energy per pair of nucleons, 2.2 MeV vs. 4.3 MeV.) Tritium and helium-3 are bound more tightly than the deuteron, but less than helium-4.

Helium-2, consisting of two protons bound together, does not exist. Proton-proton scattering experiments exhibit a resonance with energy just slightly greater than zero. All indications are that if the nuclear force were a little bit stronger, helium-2 would exist as well as deuterium. If the nuclear force were a little bit weaker, deuterium would not exist. However tritium, helium-3, and helium-4 would still exist.

The effects would be seen both in the burning of stars and in the initial cooling of the universe just after the Big Bang. In that cooling period, protons and neutrons combine to form helium-4. Other neutrons decay. After that short
period of fusion and decay, the universe consists of three-fourths hydrogen, one-fourth helium-4, and traces of deuterium and helium-3.

A star (or would-be star) is formed when hydrogen gas condenses from its own gravity. As the gas falls inward, the atoms move faster and the gas gets hotter. (Potential energy is converted into kinetic energy.) Once the gas starts falling inward, it will continue to fall in ever faster until a force stops the inward fall. The force could be one of several things. If the would-be star is sufficiently light, the ordinary gas pressure will eventually stop the inward fall. We get a gas giant planet, something like Jupiter.

Ordinary gas pressure may not be sufficient to stop the infall. Eventually, the gas becomes so dense that a new kind of pressure called “electron degeneracy pressure” appears. Electron degeneracy pressure is a consequence of the Pauli exclusion principle: two electrons cannot occupy the same state. If you try to compress a gas too much, you force electrons into higher energy states. The work required for that results in the outward force. The resulting star is a brown dwarf.

If the star is sufficiently massive, the center will get sufficiently hot to start fusion. The star heats up further, and the resulting increased pressure stops the collapse. The star burns for millions (if the star is heavy) or billions (if the star is light) of years, going through several different forms not relevant here. But eventually, the star runs out of fuel, and cools down. The outward pressure stops and the star collapses again. If the star is not too heavy, electron degeneracy pressure eventually stops the collapse and the star becomes a white dwarf — a cooling ember radiating away the heat left over from the fusion.

If the star is too heavy — greater than the Chandrasekhar limit of 1.4 times the sun’s mass — electron degeneracy pressure will not be enough to stop the collapse. The star collapses until something else stops it, and the next possibility is a combination of neutron degeneracy pressure and the hard-core repulsive part of the nuclear force. In the process, electrons and protons combine to form neutrons (emitting copious amounts of neutrinos). The star becomes a neutron star, essentially a single giant atomic nucleus, on the order of ten kilometers across. The star may be too massive even for that, though. Then nothing stops the inward collapse. The result is a black hole.

Bear in mind, the collapse does not stop when the outward force equals the inward force of gravity. The gas continues to fall in beyond that point. Newton’s Second Law \((F = ma)\) and its relativist equivalent both say that no force means no acceleration; the gas does not slow down just yet. The outward force becomes greater than the inward gravitational force, and the gas slows down, stops, and comes back up. In short, the gas bounces.

The bounce may be minor for a star forming and just about to start burning. When a star collapses to a neutron star, however, we see the bounce as a supernova and lots of material is shot back out into space. During the collapse and bounce, all sorts of elements are formed and get shot out.

A typical star burns by combining four protons into one helium-4 nucleus.
The process takes several steps:

\[
\text{proton} + \text{proton} \rightarrow \text{deuteron} + \text{positron} + \text{neutrino}
\]

\[
\text{proton} + \text{deuteron} \rightarrow \text{helium-3}
\]

\[
\text{helium-3} + \text{helium-3} \rightarrow \text{helium-4} + \text{proton} + \text{proton}
\]

Two protons can’t just come together and stick, because the two-proton bound state doesn’t exist. Instead during the extremely short time of a proton-proton collision, one of the protons turns into a neutron, emitting a positron and a neutrino. The neutron is bound to the proton in a deuteron. This interaction uses the weak force and occurs very rarely. Consequently, this reaction limits the overall fusion rate.

The second reaction is practically instantaneous. As soon as a deuteron appears in the star, a proton will grab it. The third reaction may be comparably fast, but is limited by how much helium-3 is available. Protons apparently can’t combine with helium-3 or helium-4 nuclei, so helium-4 remains.

Another possible way for fusion to occur, called the CNO cycle, uses the following steps:

\[
\text{proton} + \text{carbon-12} \rightarrow \text{nitrogen-13}
\]

\[
\text{nitrogen-13} \rightarrow \text{carbon-13} + \text{positron} + \text{neutrino}
\]

\[
\text{proton} + \text{carbon-13} \rightarrow \text{nitrogen-14}
\]

\[
\text{proton} + \text{nitrogen-14} \rightarrow \text{oxygen-15}
\]

\[
\text{oxygen-15} \rightarrow \text{nitrogen-15} + \text{positron} + \text{neutrino}
\]

\[
\text{proton} + \text{nitrogen-15} \rightarrow \text{carbon-12} + \text{helium-4}
\]

After each cycle, the carbon nucleus remains intact. Carbon is a catalyst in this reaction. Unlike the other sequence, the weak interaction does not have to occur in the middle of a fast collision. The nucleus simply waits to decay. Consequently, we expect this fusion reaction to go much faster.

Similar reactions could go on involving heavy nuclei. Protons may keep stuffing a heavy nucleus until the nucleus can’t take it any longer. The nucleus decays weakly, converting a proton to a neutron. The nucleus then can take more protons. This occurs until the nucleus says enough, and can take neither protons or neutrons. The nucleus may break apart, or emit an helium-4 nucleus (an alpha particle).

Sufficiently hot stars can start fusion of helium. Two helium-4 nuclei can combine to form beryllium-8, but that nucleus is very short-lived; it lasts about \(2 \times 10^{-16}\) seconds, then splits apart as two helium-4 again, unless a third helium-4 hits it to form a carbon-12 nucleus. The carbon-12 nucleus just happens to have an excited state at the right energy (7.7 MeV) which added to its mass gives the mass of three helium nuclei. As a result, they will fuse more readily than otherwise. Beyond carbon-12, further fusion can occur; it occurs rather quickly before a heavy star collapses in a supernova.
Slightly Weaker Nuclear Force

Now suppose the nuclear force were slightly weaker — sufficiently so that deuterium could not form. Tritium, helium-3, and helium-4 would still exist as bound states, as would most other elements. In the cooling-off period following the big bang, very little fusion would occur — three-way collisions would be required. Three-way collisions are far rarer than straight two-way collisions, so the universe would be mostly hydrogen with traces of helium.

Proto-stars would still form the way they do now, and undergo gravitational collapse. This time, the proton-proton reaction of ordinary fusion would not occur. A star that would have started burning and stopped collapsing now continues to collapse until something stops it. If the mass is less than the Chandrasekhar limit, electron degeneracy pressure stops it and we have a brown dwarf. If the mass is greater, the star collapses to a neutron star and explodes in a supernova. All forms of matter are emitted in the process, including most likely carbon and other elements that can serve as catalysts in CNO-type processes.

Consequently, second-generation stars will be able to burn even though straight proton-proton fusion cannot occur.

We would still have hydrogen and heavier elements (carbon, oxygen, etc.) for our bodies, and stars would still burn to give us heat and light. Therefore, there is no indication that if the nuclear force were too weak to produce deuterons, life would not exist as we know it.

Slightly Stronger Nuclear Force

Now suppose the nuclear force is slightly stronger, sufficiently stronger that helium-2 now exists as a bound state. Deuterium now exists both in spin-zero and spin-one states. The spin-one state was bound in the real universe, and several MeV more tightly bound in this universe. Therefore helium-2 probably decays weakly to deuterium, emitting a positron and neutrino.

Most likely, after the initial period of fusion from the Big Bang, the universe consists of helium-2 and helium-4, with or without ordinary hydrogen. The helium-2 decays to deuterium. Chemically, deuterium is hydrogen, and it can play the role that hydrogen plays for life in our regular universe.

What happens to stars now? The primary barrier to fusion no longer exists. Two particles, protons or deuterons, can combine directly. Fusion no longer requires a weak interaction to occur in the short time of a collision between two protons. The fusion reaction in a proto-star would start much sooner in the collapse, and the resulting star would be much bigger and much cooler, and more proto-stars would actually start fusing.

A steady equilibrium is determined by two conditions:

- The outward pressure balances the inward gravitational force.
• The energy radiated from the star equals the energy produced from fusion.

The pressure force is not simply the pressure, but rather related to the gradient (or spatial variation) of the pressure. If the pressure is constant, there is no force no matter how great the pressure. The force is the same on all sides, and cancels. The connection between radiation occurring at the star’s surface, and fusion occurring deep down is related to the details of the heat transport upward. This is most likely turbulent.

If fusion would occur faster or more readily, it would start a lot earlier in the star’s collapse. The star would be a lot bigger, and the pressure required to balance the gravitational force would be much lower. It’s possible, although I won’t attempt any calculation to verify this, that the star would burn slower. In any case, the actual rate of fusion would not increase the same way the readiness to fuse does.

The stars would be much bigger and be much cooler. It’s possible they would burn slower. It is possible that all stars would be a dull red (or infrared), and too cool to support life.

Note that temperature itself is not directly the problem. If one planet is too cold for life, another one will be found close to a star and warm enough. The basic reason is thermodynamical. Sunlight is needed to drive the process of life on the earth’s surface. The entropy of light radiated from a body is inversely proportional to the body’s absolute temperature. The sun’s surface temperature is 20 times the earth’s. On the average, the earth radiates the same amount of energy it absorbs as sunlight. But the entropy decrease due to the earth’s radiation is far greater than the entropy of the sunlight absorbed. The entropy of the earth’s surface can decrease greatly, and most of the sun’s energy is available to do work.

It is possible the massive stars (blue giants in our universe) would be yellow and burn a lot slower than they currently do. They might last for billions of years instead of only millions, and therefore they might actually support life. It is very uncertain whether life could exist in this alternative universe.

3.3 Weak force coupling constant

Ross does not exactly start on the right foot when he calls the weak force the “weak nuclear force.” The weak force is no more nuclear than the electromagnetic force is. They both operate inside and outside the nucleus. However, many other people call the force the “weak nuclear force” so I shall let that pass. But he is completely wrong when he calls the photon a lepton. At least he got the reaction for beta neutron decay right:

\[
\text{neutron} \rightarrow \text{proton} + \text{electron} + \text{antineutrino}
\]

Anyway, his overall claim is that if the weak force were slightly stronger neutrons would decay faster and little or no helium would be produced from the
big bang. Consequently, not enough heavy elements would be formed in stars for life. If the weak force were slightly stronger, most hydrogen would become helium and there would be too many heavy elements for life to exist.

The decay of the neutron is probably what limits the fusion just after the big bang. If the neutron does not decay, it will probably fuse. So it is correct that if you increase slightly the weak force, you decrease slightly the helium production; if you decrease the weak force slightly, you increase the helium production slightly.

The universe does not need helium from the big bang in order to produce heavy elements in stars. The helium produced in stellar fusion will serve. Therefore, a major increase in the strength of the weak force, resulting in no helium produced at the Big Bang, will have no effect on life.

A large decrease in the weak force might well prohibit life, if it resulted in all the protons of the Big Bang combining with neutrons to form helium. It would be the absence of hydrogen, not the overabundance of heavy elements, that would prevent life from forming. However, it requires a large decrease; a tiny decrease would not be sufficient. Again we have the principle that a tiny change has a tiny effect.

His second “possibly more delicate” balance is probably bogus. He claims that neutrinos are required to blow out the heavy elements in space, so that planets and life could form. If the weak force were both stronger or weaker, the neutrinos would pass through unimpeded, and not blow out the heavy elements.

While I understood that the supernova explosion is primarily due to the bounce from gravitational collapse, the outflux of neutrinos may well contribute to the explosion. The light of a supernova (generated by the collision of the outgoing matter with the interstellar medium) outshines the entire galaxy it’s in. A supernova 170,000 light years away in 1987 was visible to the naked eye in broad daylight. There’s plenty of room left to allow for a small decrease in neutrino interactions.

It is very unlikely that an increase in the strength of the weak force could result in a decrease in the interaction between the neutrinos and the envelope. Especially when the probability of interaction is very low as with the weak force, an increase in the strength of the force means an increase in the amount of interaction with the envelope. The envelope would blow off more strongly, not less.

### 3.4 Electromagnetic force coupling constant

Ross claims that if the electric coupling constant (i.e. electric charge) were just a little smaller, electrons would not be orbit around nuclei. On the other hand, he claims, if the charge were just a little larger, atoms could not share orbitals with other atoms.

Both claims are false. As long as electrons and nuclei have opposite charge, electrons can bind to nuclei in sufficient amount to neutralize the atom. The
hydrogen atom has been calculated precisely. Any decent quantum mechanics textbook (e.g. Shankar) calculates the Schrodinger Equation for the hydrogen atom. It’s energy levels go like:

\[ E_n = -\frac{me^4}{2\hbar^2 n^2} \]

where \( e \) and \( \hbar \) are the electric charge and Planck’s constant, \( m \) is the electron’s mass (more precisely, the reduced mass of the combined electron-proton system; this makes a measurable difference, and is relevant to number five in Ross’s list), and \( n \) is an integer from 1 to infinity, known as the principle quantum number. Note that this formula does not depend on the value of \( e \). Bound states exist for any value, no matter how great or small.

The chemical properties of elements depend primarily on the shape or the angular parts of the wavefunctions of the orbitals. The angular parts are given by spherical harmonics, and do not depend on \( e \), \( m \), or \( \hbar \). The size of the orbital is inversely proportional to \( m \) and \( e^2 \).

The electron charge doesn’t have to equal the nuclear charge; nothing in the solution of the Schrodinger Equation requires equality. If instead the nuclear charge is \( Ze \), we still have bound states for a single electron, and the energy levels become:

\[ E_n = -\frac{mZ^2e^4}{2\hbar^2 n^2} \]

When two or more electrons orbit a nucleus, we cannot calculate exact solutions. However, imagine starting with an overall neutral atom, and moving one electron far away (perhaps a centimeter). In that region, the laws of classical physics hold, and the electron orbits the nucleus in classical elliptical orbits. The force is the classical inverse-square Coulomb force (magnetic and other relativistic corrections would be negligible). This is still a bound state, albeit highly excited — this means that an electron in this state decays to a more deeply bound state, emitting a photon. In short, all neutral atoms would be bound no matter what the electron’s charge was, as long as the nuclear charge is opposite.

Ross’s claim that electrons couldn’t share orbitals with other atoms is equally false. If two nuclei appear a finite distance apart, the electron orbitals are automatically shared. The degree of sharing depends strongly on the separation. Two hydrogen atoms a centimeter apart can be described to high accuracy as effectively not sharing orbitals, but in the exact solution, they would not only share orbitals, but each orbital would be equally distributed about both atoms.

For a given separation between the atoms, a higher electron charge means the orbitals are smaller, so there’s less sharing. However, that simply means the two atoms can get closer. The strong repulsive force between atoms that keeps the atoms from getting too close together comes from excessive sharing of orbitals, and would be appreciable only at a smaller separation. With a greater
electric charge, atoms could get closer together and molecules would be more tightly bound.

I shall mention a couple possible effects, for completeness. If the electric charge were an order of magnitude smaller, the hydrogen energy levels would be comparable to thermal energy at current temperature, and that would forbid molecules from forming and staying together. But that does not say that life would not form at a cooler temperature.

If the electric charge were to increase greatly, it would be necessary calculate the hydrogen atom relativistically; i.e. use the Dirac Equation. Relativistic effects are actually measurable, and the Dirac hydrogen atom has been solved. See Ikzykson and Zuber, p. 75. A problem occurs when the fine structure constant becomes one; a certain parameter that has to remain real becomes imaginary. Ikzykson and Zuber express the problem in terms of \( Z \) (the number of protons) and the current value of the fine structure constant (1/137). That is, if \( Z \leq 137 \), the parameter becomes imaginary with potentially catastrophic results. However, they claim on p. 83 that if one takes account of the finite size of the nucleus, the catastrophic point increases to 175. This result is obviously unrelated to Ross’s claim.

3.5 The Electron-Proton Mass Ratio

Ross claims that the if the proton’s mass were slightly different from its actual value of 1836 times the electron mass, molecules could not form. He claims that the mass ratio determines the characteristics of electron orbits.

The existence of isotopes gives the lie to this claim. Different isotopes of the same chemical element have different numbers of neutrons in their nuclei, but they have the same number of protons. Their chemical properties are identical. The nucleus is an approximate point — its diameter is about a hundred-thousandth the size of the orbitals. Adding a neutron to the nucleus has the same effect as increasing the mass of the nucleons. Carbon-12 (for example) with the nucleon mass increased by one-sixth would be chemically identical to the present Carbon-14.

The discussion of the previous item is relevant here. For the hydrogen atom, or any interacting system of two particles, the reduced mass (which appears in the expression for the states and energy levels) is given by:

\[
\frac{1}{m} = \frac{1}{m_1} + \frac{1}{m_2}
\]

If the two masses are very far apart, the reduced mass is very close to the lighter mass. If they are equal, the reduced mass equals half of either mass. If the proton’s mass increased even to infinity, the reduced mass would only increase by one part in 1800. If the proton’s mass decreased to the electron’s mass, the reduced mass would only go down to one-half the electron’s mass.
The energy levels are proportional to the reduced mass. The size of the orbitals are inversely proportional to the reduced mass. The reduced mass has no affect on the shape (the angular part) of the wavefunction, which determine most strongly the chemical properties.

3.6 Age of the Universe

Ross claims that the “window of time during which life is possible in the universe is relatively narrow.” He specifies the window as about ten billion years wide. That is not exactly narrow. More importantly, the age of the universe is not constant. Given the other parameters of the universe, the probability that the age of the universe will fall within that window at some time is certain — in fact, it’s certain to spend ten billion years within that ten-billion-year interval.

He gives several estimates for certain required times: three billion years for the first stars to form, ten to twelve billion years for the stars to emit sufficient heavy elements for life, and a few more billion years for sun-type stars to stabilize sufficiently for life. I am not going to dispute his estimates here, but I think that they seem too long.

3.7 Expansion Rate of the Universe

Ross cites Alan Guth to the effect that the expansion rate of the universe has to be fine-tuned to one part in $10^{55}$. If slower by more than that small amount, the universe would have collapsed by now. If faster by that small amount, the universe would have spread out too much for galaxies to condense.

Guth made a credible case for essentially that claim in the reference cited by Ross, Physical Review D23, 347 (1981). The ratio of the universe mass density to the critical mass density is within an order of magnitude of one. The critical density is the lowest density at which an expanding universe will expand forever; any lower density results in the universe falling back in on itself. The problem is that the critical mass density is an unstable point. If at one point the universe starts slightly away from that point, the universe gets progressively farther away at a rapid rate later on.

Guth’s inflationary model was an attempt to avoid the required fine-tuning, to make our current universe a stable point rather than an unstable point. As a hypothetical alternative, I can imagine obtaining this point automatically by requiring the total energy of the universe (including gravitational energy) to be zero. As another possible alternative, the density of the early universe might have varied from point to point around the critical density. We just happen to find ourselves in a region of the universe that was originally almost exactly at the critical density because there is no other place where we could possibly find ourselves.
3.8 Entropy Level of the Universe

Ross claims that, with 100,000,000 photons per baryon, the universe is extremely entropic. This makes the universe a very efficient radiator and a very poor engine. Galaxies would not form if the entropy were slightly larger; if it were slightly smaller, radiation would be trapped and galaxies could not "fragment" to form stars.

I do not know how to evaluate Ross's claim.

3.9 The Mass of the Universe

Ross claims that if the mass of the universe were slightly less, no helium would be formed; the stars need helium to form the heavier elements. If the mass were slightly greater, too much deuterium would form during the fusion just after the big bang. He claims that deuterium is a catalyst for fusion in the stars, and too much deuterium would result in stars burning too rapid for life.

Deuterium is not a catalyst for fusion. It simply fuses rapidly in stars; once it fuses, it's gone. Carbon in the CNO cycle is an example of a catalyst: after each cycle, the carbon nucleus recovers intact. An increase in the amount of deuterium in the universe even by an order of magnitude would not change stellar history significantly. Deuterons would fuse away right at the start of the star's burning, or in an early part of the star's collapse, and then the star would go on unchanged.

Likewise, big-bang helium is not needed for stars to produce the heavier elements. Helium resulting from the fusion of hydrogen in stars will do perfectly fine.

Ross stated parenthetically that the parameter is actually mass plus energy of the universe, since \( E = mc^2 \). This could lead to a kind of error I've seen in other contexts. Depending how you define the mass and the energy of the universe, you may double-count. If energy equals mass, each quantity separately is the total mass or the total energy. If you add the two, you get twice the result. Notice also that Ross implicitly used the convention that \( c = 1 \) in his sentence. Also, if you include gravitational energy, the total energy might be zero.

3.10 Uniformity of the Universe

Ross claims that the universe is highly but not absolutely uniform. If the universe were slightly more uniform, galaxies and stars could not have formed; whereas if the universe were slightly less uniform, the universe would have become a bunch of black holes separated by empty space.

The uniformity of the universe that he refers to is not the current universe, but rather the very early universe that we see echoed in the cosmic microwave background radiation. With the high structure that we see in the universe today — the great wall, for example — there seems to be a fair amount of room for
the initial universe to be smoother yet still allow for galaxies to form. If the universe were somewhat less uniform, I expect that we would have seen galaxies form at the boundaries between the empty space and the black hole regions.

3.11 Stability of the Proton

Ross claims that the proton must decay. If the proton’s lifetime were greater than $10^{32}$ years, proton decay would result in radiation lethal to life. If the proton’s lifetime were less, insufficient matter would emerge from the Big Bang. He weakens his claim in a footnote by presenting results that the proton’s lifetime is greater than $10^{92}$ years.

The proton’s lifetime has to decrease by many orders of magnitude from the value of $10^{32}$ years before its radiation becomes comparable to the ground’s background radiation that we all experience, even considering that everything in our bodies would be susceptible to decay. There is no fine-tuning here.

As I understand it, Ross attempts to explain the current absence of antiprotons in the universe with proton decay. In the Big Bang, equal numbers of protons and antiprotons formed. The antiprotons decay much faster than the protons. Any antiprotons that did not decay annihilated protons, so we are left with a net surplus of protons.

His qualitative explanation may be correct, although I can think of another possible explanation. However, this effect depends primarily on the decay rate of the antiproton. The relationship between the proton and antiproton decay rates are far from understood. If CP (“C” is charge conjugation, or the operation changing a particle to an antiparticle; “P” is parity or reflection symmetry, the operation of changing a particle to opposite spin; “CP” is the combination of operations, changing a particle to an antiparticle of opposite spin) were an exact symmetry, antiprotons would decay at exactly the same rate as protons. Any difference in the decay rates is due to breaking of that symmetry. CP breaking has only been observed as far as I am aware in the kaon system, and there only to a small degree. Cornell University’s high energy facility is creating a B-factory to study properties of B-mesons. B-meson decay is expected to exhibit CP violation on the same basis the kaon.

In any case, the source of CP-violation is not established. In addition, we have no confirmed theory of proton decay. It is not established that a proton lifetime of $10^{32}$ years is any less likely than a lifetime of $10^{92}$ years to result in the current asymmetry between protons and antiprotons. Ross’s claim, given our understanding in 1990 of the relevant physical phenomena, had to have been fabricated.

3.12 The Fine Structure Constants

Ross mentions the fine structure constants for all four forces, and claims that they have even stricter constraints than the coupling constants. Focusing on
the electromagnetic fine structure constant, he claims that constant affects the opacity of stellar material. If the fine structure constant were slightly larger, all stars would be less than 0.7 times the mass of the sun; if slightly smaller, all stars would be more than 1.8 times the mass of the sun.

The discussion of item number one, the gravitational coupling constant, applies here as well: why would ALL stars, no matter how tiny or how large, be subject to those limits given a slight change in the value of the fine structure constant.

Furthermore, in units where the speed of light, Planck's constant, and the Coulomb force constant are all one, the fine structure constant is simply the square of the electronic charge (the electromagnetic coupling constant). There is no constraint whatsoever imposed by the fine structure constant that is not imposed by the charge. The electronic charge determines the fine structure constant (and vice versa, up to sign).

### 3.13 The Speed of Light

Ross claims flat-out, without any attempt to explain, that the slightest change in the velocity of light would prohibit the existence of life. I cannot conceive what he may have been thinking about.

### 3.14 The Energy Levels of Certain Nuclei

Ross gives three claims in this section. First, the lifetime of Beryllium-8 is just within the range required to allow fusion of heavier elements — if too great, fusion would go too fast and result in catastrophic stellar explosions and too little production of heavy elements; if too small, then no fusion would occur. Second, carbon-12 has an excited energy level very close to the sum of the masses of helium-4 and beryllium-8, and that is needed for helium fusion to proceed. Third, oxygen-16 has the right energy level both to prevent all carbon from turning to oxygen, yet enough to convert to produce the oxygen needed for life.

To nit-pick a little, Ross gives the lifetime of beryllium-8 as $10^{-15}$ seconds. The lifetime is actually $2 \cdot 10^{-16}$ seconds. While I would not make much of this difference, it's an order of magnitude smaller than the value Ross claims is necessary for the universe to be as it is. This point suggests that Ross determines the value that the parameter has to be fine-tuned to from its actual value, or the value Ross believes it as, rather than from an independent calculation. This in turn suggests that Ross has done no such calculation to actually show that parameter really has to be fine-tuned.

These claims are very much interrelated, and Ross is partly correct overall. The 7.7-MeV excited state of carbon-12 was predicted by astronomer Fred Hoyle as necessary to allow three helium-4 nuclei to fuse into carbon-12. It was discovered later. However, it is not necessarily true that the precise state is necessary for fusion to occur. If electron degeneracy pressure doesn't stop the
star’s contraction first (or if it doesn’t collapse to a neutron star) the star will continue to contract until fusion starts somewhere.

I expect the likelihood of helium-4 fusion to be proportional to the beryllium-8 lifetime. However, this was discussed above in item four. The star would not necessarily burn faster; instead it would start burning sooner in its collapse and be bigger.

The energy level of the excited state of carbon-12 and the lifetime of beryllium-8 are an example of the situation described in the earlier section of two supposedly fine-tuned parameters that interrelate in such a way as to require really only one parameter to be fine-tuned. If the excited energy were slightly closer to the mass of three helium-4 nuclei minus the carbon-12 ground-state mass, the lifetime of beryllium-8 could be shorter to attain the same fusion. Conversely, if the excited energy were slightly farther, a slightly longer lifetime would suffice.

I am not sufficiently familiar with oxygen nuclear energy levels, to attempt evaluate that claim. However, it’s unlikely that the absence of a state at an energy can be fine-tuned. States occur at discrete energy levels. States are absent between those energy levels, and energies with no states form a continuum between energy levels.

3.15 Distance Between Stars

Ross claims that if stars were slightly closer together in our neighborhood, the gravitational effects would distort planetary orbits so much that our planets would suffer extremes of temperature too strong for life to form. On the other hand, if stars were slightly farther apart, the heavy elements thrown out by supernovas would be distributed too thinly for earth-type planets to form.

Any gravitational effect of a nearby star (other than the sun) on our orbits can only result from the variation in gravity across our orbits. A constant gravitational field for freely falling bodies is no different from no gravitational field. The variation is inversely proportional to the cube of the distance from the star, not the square of the distance. (This result comes from the derivative of \( r^{-2} \).) The nearby stars have far less effect than planets in our solar system on our orbits. If any effect has been at all measured, I would be very surprised.

It’s very unlikely that a small reduction in the average density of heavy material would prevent earth-type planets from forming. At worst, it would take a little longer for additional material to be spewed into space by supernovas.

In any case, the separation between stars varies widely. If stars were too close together or too far apart at one spot, another spot would be satisfactory.

3.16 Rate of Luminosity Increase of Stars

Ross claims that the gradual increase in luminosity of stars is perfect for progression of primitive to advanced lifeforms on the earth. If it were slightly greater,
we would have a runaway greenhouse effect. If slightly smaller, we would have a runaway freezing effect.

A runaway freezing effect simply cannot occur. There is only so much that can freeze, and we've had ice ages where the temperature was considerably cooler than now, without runaway results. A runaway greenhouse effect is possible. Venus has been victimized by it, but that is primarily due to its slow rotation rate: The day was so much longer that Venus got so much hotter during the day, resulting in considerable carbon released to the atmosphere. Most environmental scientists are not very worried about a runaway greenhouse effect occurring on the earth due to human dumping of carbon dioxide into the atmosphere. Current global warming is a much more mild effect.

4 Conclusion

While a couple of Ross's claims have some validity, most are false, and none conclusively establish that life requires fine-tuning of any parameters. Furthermore, manifestly bogus claims — that quarks could not combine if the strong force were just two percent stronger, or that atoms could not hold electrons if the coupling constant were slightly weaker, or that atoms could not share electron orbitals if the coupling constant were slightly stronger, or that molecules would not form if protons and neutrons were slightly heavier, or that stars would distort planet orbits if distances to nearby stars were just slightly smaller — utterly damn Ross's credibility. I believe that Ross has discovered the scientific illiteracy of the general population and the Christian community, and has learned how easy it is to deceive them.

Reasons to Believe has a number of affiliated physicists and other scientists. I urge them all to critically examine claims made by Ross and Reasons to Believe, and to disassociate themselves from the more egregious falsehoods. There is no virtue in lying or self-deception, not even to promote or defend the existence of God.

5 References

I am rather sparse on references, and prefer to cite the more general references. I believe that in analysis of scientific claims, there is no genuine substitute for becoming familiar with not only the subject matter of science, but the way scientists think. By learning to think like a scientist, ie. becoming a scientist, one can evaluate the claims of other scientists, and distinguish between science and pseudoscience.

Frampton, Guage Field Theories, Frontiers in Physics No. ??? (1988?)