The Fine Tuned Weak Force?
(4) The Weakless Universe of Harnik, Kribs and Perez

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TRACK 1

1. Introduction

Even in the case of a reduced value for $\tilde{G}_F$, for which there would appear to be a soft lower bound, there is an interesting twist which weakens the argument. Harnik, Kribs and Perez[1] (HKP) have constructed a suitably complex, element-producing, universe with no weak force at all. Admittedly, this does not apply in our universe, in the sense that other parameters are altered in addition to $\tilde{G}_F$ to make this 'weakless' universe work. This fascinating paper deserves a section on it own. This construction serves to refute the idea that the weak force is essential. It also serves as a warning that definitive conclusions about fine-tuning cannot be drawn from varying single parameters.

2. The HKP Weakless Universe

In Section 3 we showed that reducing the value of the Fermi constant sufficiently led to a helium dominated universe. The reason is that the smaller $\tilde{G}_F$, the earlier the freeze-out of the leptonic reactions, and hence the higher the temperature, and hence the closer to equality is the density of neutrons and protons. However, we have taken for granted that the neutrons and protons achieve their thermal equilibrium densities. This will only be the case if the weak interactions are active, since this provides the mechanism for their inter-conversion. Thus, we have an entirely different situation if the weak interaction does not exist at all. In this case, the relative abundance of protons and neutrons (in the primordial universe prior to Big Bang Nucleosynthesis [BBN]) would be determined by whatever CP symmetry violating mechanisms gives rise to baryogenesis. In other words, we can presumably fix the relative neutron and proton abundance by fiat. This was the line taken by HKP. So there is no reason to assume equal numbers of protons and neutrons, and hence an all-helium universe does not result. Moreover, the same argument applies to the baryon:photon ratio, which HKP also adjusted at will.

HKP found that they could contrive a universe with a similar hydrogen:helium ratio as ours, but with about 25% of the hydrogen being deuterium rather than protons. To do so they chose a baryon:photon ratio of 4×10^{-12} (cf. about 2×10^{-9} in our universe). HKP argue that galaxies could still form despite the much reduced visible baryon density, but that the number density of stars in the galaxies would be appropriately reduced. They can also claim that stars would form, because they have taken the precaution of making the chemical composition of their universe sufficiently similar to ours, thus ensuring that there would be a cooling mechanism to permit gravitational collapse.

The main difference for stars in the HKP universe would be that the initial fusion reaction would be the formation of helium-3 from a proton and a deuteron. Note that HKP have cunningly contrived to have substantial quantities of deuterium formed

[1] "A Universe Without Weak Interactions", arXiv:hep-ph/0604027 (Apr.2006)

during BBN, so there is no need for the usual weak-force-mediated deuteron formation reaction from two protons. Since the first stellar reaction in HKP stars is very fast compared with the usual weak-mediated deuteron formation reaction, the core temperature of such stars would be lower. It has to be lower to keep the reaction rate down to a level at which the thermal power does not outstrip the available mechanisms of heat transport away from the core. The burning of deuterium would be followed by burning helium-3. HKP also argue that a greater number of nuclear isotopes would be stable, because there would be no decays via the weak force, e.g. beta decay. Hence, a sequence of element creation broadly similar to that in this universe would result, but with a richer diversity of stable isotopes. However, one weakness (no pun intended) of HKP is that Type II supernovae would not occur. To release the chemical elements into the inter-stellar material relies on Type Ia supernovae. Elements heavier than iron would not be formed in the HKP universe, but they are probably not essential for life.

Another minor observation is that radioactivity would not occur. One reason is that the heavier nuclides are not formed, but, in any case, there is no weak interaction to cause the decay. It is probably the case that radioactivity is unnecessary for the emergence of life. However, we note that without it, rocky planets like the earth could not stay hot in their interiors for the order of billions of years required for the emergence of life. In the epoch of life there would therefore be no vulcanism or plate tectonics. This does not seem particularly important. However, there are two possible reasons why it might be important. The first is if the nitrogen in the biosphere requires the geological nitrogen cycle, since the latter is driven by tectonic activity and hence relies on the weak force via radioactivity. In this respect, note that the isotopic composition of biological nitrogen and geological nitrogen are the same (Reference?). The second reason why radioactivity, and hence the weak force, might be essential to the emergence of life on earth is that life may have originated in the heat of the depths. It has been suggested that the origin of terrestrial life might have been underground or near oceanic geothermal vents[2], in which case the heat of radioactive decays might have provided the nurturing environment in lieu of sunlight.

However, the above observations seem rather specific to the particular case of terrestrial life. Overall, HKP appear to have made a credible case for a weakless universe capable of giving rise to a universe with galaxies and stars and of sufficient chemical diversity to support the emergence of life. Perhaps the weakest aspect of their case is in respect of the mechanisms for ejecting the chemical elements into the inter-stellar environment in the absence of Type II supenovae.

3. Are Supernovae Crucial Anyway?

There are at least three other mechanisms by which the elements could be ejected into the ISM:-

(1) Type Ia Supernovae: In Section 4 we were addressing only Type II supernovae. There are also Type Ia supernovae, which result from accretion of material, possibly from a binary companion. These do not need the weak interaction to make them go bang! But would they produce the full range of required elements?

[2] See, for example, "The Origin of Life" by Paul Davies (Penguin)

(2) Stellar Winds: Low and intermediate mass stars loose a lot of material from their envelopes via stellar winds, particularly during the period of thermal pulsing in the AGB. If supernovae could not occur, would stellar winds provide a sufficient mechanism for releasing life-forming elements into the ISM? The ejected material from the envelope will tend to be hydrogen rich, but possibly there might be enough heavier elements resulting from earlier dredge-ups to meet the needs of life? Need to research and add here.

(3) Don't high mass stars loose a lot of material in winds also? Gribbin & Rees suggest so, but that it's all H and He.

References

[1] Carr & Rees 1979
[2] Harnik, Kribs and Perez 2006
[3] Davies, The Origin of Life