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Variable Neutrino Mass, Supernovae, and Accelerated Decay

Eugene F. Chaffin*

Abstract

The antineutrino flux from radioactive uranium, thorium, potassium-40, etc. on the earth's surface is of the order of 10^6 antineutrinos per square centimeter per second. The flux of neutrinos from the sun is four orders of magnitude larger. Larger than that would be the cosmic background of neutrinos and the possibility of a nearby supernova. Recent physics literature contains theories in which the neutrino mass is coupled to the neutrino density via a so-called acceleron field. This acceleron field is hypothesized to resemble the Higgs field, and to change strength due to neutrino couplings and variation in neutrino density. The radiocarbon evidence for a nearby supernova is discussed and related to the possibility that such a supernova showered the earth at the time of Noah's Flood. This would contribute to accelerated decay and provide evidence that radioisotope data can be consistent with a biblical timescale.

Introduction

The RATE project (Vardiman, Snelling, and Chaffin, 2005) identified accelerated decay as a likely contributor to reconciling radioisotope data with a biblical timescale. For some time, possibly at the onset of the Deluge, or Noah's Flood, decay rates were greater than those directly measured in laboratories today. A possible mechanism involves a change in the strong nuclear force, the weak force, or both. Recent physics literature includes studies of the possible variation of the neutrino mass over cosmological time (Fardon et al., 2004; Brookfield et al., 2006a). The variation of the neutrino mass will be related in this paper to the fraction of the decay energy carried away into space by the neutrinos and to possible changes in modes or types of radioisotope decay. Also, Fardon et al. (2004) related the neutrino mass to a hypothetical field called the acceleron field, and this to the neutrino density. If we explore this possibility, it leads us to consider a nearby supernova as a cause for a sizeable increase in neutrino density, and thus to a change in the neutrino mass and furthermore to a change in decay parameters. The neutrino burst from a nearby supernova may have reached Earth at the onset of accelerated decay episodes. In fact, we will see that the radiocarbon record provides evidence for these nearby supernovae (Firestone, 2014).

* Eugene F. Chaffin, Simpsonville, SC, ChaffinEF@aol.com
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Mass of a Particle: Partial Origin from the Weak Force?

English physicist J. J. Thomson (1881) is often credited with the discovery of the electron because of his extensive experiments with beams in cathode ray tubes. Thomson hypothesized the existence of the so-called "electromagnetic mass." As the electron moves through space, it would experience a nondissipative resistance due to the electric and magnetic fields bound up with it. Thomson described this as a contribution to the mass similar to the resistance felt by a sphere moving through a frictionless fluid. Figure 1 shows a cannon being fired underwater. In pushing the water out of the way, the cannonball has inertia that would be experienced even if there were no fluid friction (viscosity). In modern times, we also associate the weak force, the force that causes beta decay, with the electron. Weinberg (1972, p. 388) discussed the electromagnetic mass, stating:

> The idea that electromagnetism is responsible for mass differences within isotopic multiplets, and possibly also for the whole mass of the electron, has historically proved very attractive but not very fruitful.

He went on to discuss the failure of this approach to explain any real data. He stressed that the lesson that emerges from this work is that it is pointless to try to evaluate electromagnetic mass differences without taking weak interactions into account.

Another Nobel Prize winner, Wilczek (2000, p. 13), noted that protons and neutrons are the major contributors to the mass of everyday objects (basketballs, apples, etc.) and that "most of the mass of ordinary matter arises from the energy associated with quark motion and color gluon fields." However, Wilczek agreed with Weinberg that the weak force is also a contributor:

> Most of the mass of ordinary matter, for sure, is the pure energy of moving quarks and gluons. The remainder, a quantitatively small but qualitatively crucial remainder—it includes the mass of electrons- is all ascribed to the confounding influence of a pervasive medium, the Higgs field condensate. (Wilczek, 2000, p. 14)

Wilczek (2006, p. 709) went on to discuss a simplified theory in which heavy quarks are ignored in deference to the lighter "up" and "down" quarks:

> QCD Lite is cooked up from massless gluons, massless u and d quarks, and nothing else. (Now you can fully appreciate the wit of the name.) If we use this idealization as the basis for our calculation, we get the proton mass low by about 10%.
>
> Full-Bodied QCD differs from QCD Lite in two ways. First, it contains four additional flavors of quarks. These do not appear directly in the proton, but they do have some effect as virtual particles. Second, it allows for non-zero masses of the u and d quarks. The realistic value of these masses, though, turns out to be small, just a few percent of the proton mass. Each of these corrections changes the predicted mass of the proton by about 5%, as we pass from QCD Lite to Full-Bodied QCD. So we find that 90% of the proton (and neutron) mass, and therefore 90% of the mass of ordinary matter, emerges from an idealized theory whose ingredients are entirely massless.

Here QCD stands for "Quantum Chromodynamics," the explanation of matter in terms of quarks and gluons, and including a property called "color" because of cogent analogy with the properties familiar to painters. After the discovery of the Higgs boson, credence was given to the idea of the Higgs field pervading all space and to an explanation of mass due to the necessity for particles to move through the Higgs field. However, Wilczek points out that the proton and neutron masses are more due to gluon/quark fields than to the Higgs (see Raya, 2009; Wilczek, 2008). Nevertheless, the weak force does contribute a small amount to the masses of quarks, electrons, and neutrinos. We shall discuss possible variation of the neutrino mass over cosmological time below and shall note that the associated changes in the weak force could also slightly affect the neutron and proton masses.

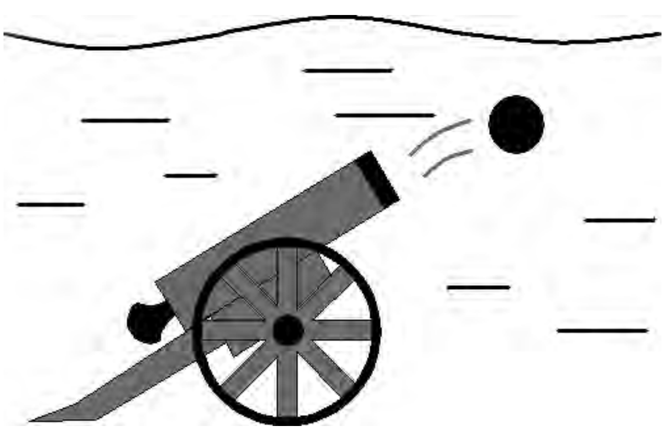

Figure 1. Firing a cannon under water causes a cannon ball to appear to have a greater inertia than in air. Even if the water had zero viscosity, there would be greater "INERTIA." The Higgs field is postulated to have a non-zero value, even in the vacuum of space far out between the stars. This plays the role of a "perfect fluid." The Higgs particle is an excitation in the Higgs field. It gives mass to other particles.

What if the Nuclear Mass Changed?

These slight changes in particle masses could have very important consequences. What if, during accelerated decay, the U-238 beta-minus half-life were to become close to or greater than the alpha decay half-life? Figure 2 shows the nuclei near U-238, in a plot of proton number Z versus neutron number N, illustrating the possible changes. As the proton number Z

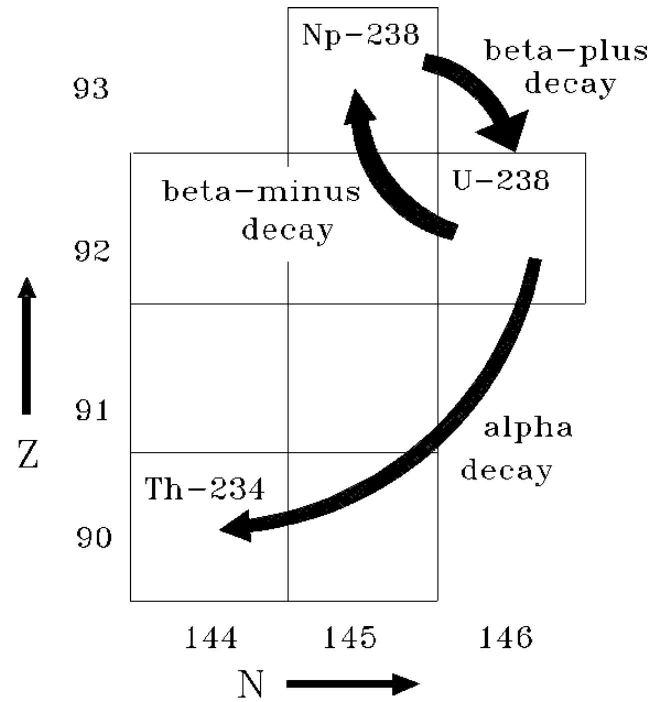

Figure 2. A portion of the chart of the nuclides, showing the possible decays connecting to U-238. An alpha decay removes an alpha particle, made of two neutrons and two protons, producing Thorium-234. If the U-238 were to undergo beta-minus decay, it would produce Neptunium-238, which has one more proton than U-238 but one less neutron.

is changed from 92 to 93 to 94, we transition from uranium to neptunium to plutonium. A neutron is changed into a proton, keeping the total particle number at 238. Then an alpha decay of plutonium-238 would change Pu-238 to U-234. Thus, if U-238 were to undergo beta-minus decay, the beta-decay branch would be:

U-238 → Np-238 → Pu-238 → U-234

At this point, the normal decay chain is joined, and the resulting isotopic abundances would be substantially as usual. Uranium-238 is under normal circumstances found to undergo alpha decay, leading to the sequence:

U-238 → Th-234 → Pa-234 → U-234

Thus we end up with U-234, joining the usual decay chain, the same as in the other scenario.

The mass of Np-238 can be deduced from that of Pu-238 given the Np-238 decay energy E = 1.292 MeV (Parrington, et al., 1996).

$$M_{Np\text{-}238} = M_{Pu\text{-}238} + E/c^2$$
$$= 238.049553 + 1.292/(931.5)$$
$$= 238.049553 + 0.00138701$$
$$= 238.05094 \text{ MeV} \qquad (1)$$

This is slightly greater than the U-238 mass of 238.050785, making beta-decay of U-238 impossible at present (but double beta decay has been seen in data). Energy cannot be created by a spontaneous decay, so U-238 cannot undergo beta-minus decay, at least at present. Accelerated decay might reverse this. The mass of U-238 is less than the mass of Np-238 by 0.000158 atomic mass units. Using $E = mc^2$, this converts to 0.148 MeV, which is very small.

Table I shows the beta-minus half-life and decay energy for the lightest isotope of each element that undergoes beta-minus decay. The average decay energy of these nuclei is 2.13 MeV, so the 0.148 MeV figure mentioned above is small compared to the average nucleus in Table I. This makes it seem likely that a change in the neutrino mass, and the associated change in the weak force, might alter the masses of neutrons and protons, and thus of U-238, and lead to beta-minus decay of U-238.

The value above is confirmed by a Japanese web site: http://wwwndc.jaea.go.jp/cgi-bin/nucltab14?92

93-Neptunium

Np-238	238.050947876 ± 0.000001983	2^+
U-238	238.050789466 ± 0.000002047	0^+
Pu-238	238.049561412 ± 0.000001977	0^+

The ground state of U-238 has nuclear spin 0^+, and Np-238 2^+. Np-238 undergoes beta-minus decay with a half-life of 2.117 days, and decay energy E = 0.144 MeV. This means that the hypothesized decay of U-238 would be first forbidden just like that of Np-238 and that the half-life should be of the same order of magnitude.

The idea of a forbidden decay was discussed before (Chaffin, 2005, pp. 563–567; Chaffin, 2008, pp. 179–180), and the above change from 0^+ to 2^+ or vice versa is a nuclear spin change of 2, signaling a forbidden transition. If the half-life for U-238 decay were to become of the order of two days, that would be long compared to many cases, but still small compared to the nominal alpha decay of U-238 with half-life of 4.47 billion years. Thus a small change in nuclear masses could be equivalent to accelerated decay for U-238.

Nucleus	beta-minus half-life	Decay Energy (MeV)
Tritium	12.32 y	0.019
He-6	807ms	3.508
Li-8	0.840 s	16.004
Be-10	1.5x106 y	0.556
B-12	20.20 ms	13.369
C-14	5715 y	0.156
N-16	7.13 s	10.419
O-19	26.9 s	4.82
F-20	11.0 s	7.025
Ne-23	37.2 s	4.376
Na-24	14.95 h	5.516
Mg-27	9.45 m	2.610
Al-28	2.25 m	4.643
Si-31	2.02 h	1.492
P-32	14.28 d	1.711
S-35	87.2 d	0.167
Cl-38	37.2 m	4.917
Ar-41	1.83 h	2.492
K-42	12.360 h	3.525
Ca-45	162.7 d	0.257
Sc-46	83.81 d	2.367
Ti-51	5.76 m	2.471
V-52	3.76 m	3.976
Cr-55	3.497 m	2.603
Mn-56	2.578 h	3.695
Fe-59	44.5 d	1.565
Co-60	5.271 y	2.824
Ni-65	2.517 h	2.137
Cu-66	5.10 m	2.642
Zn-69	56 m	0.905
Ga-70	21.14 m	1.656
Ge-75	1.380 h	1.177
As-76	26.3 h	2.962
Se-79	<6.5x105 y	0.151
Br-82	1.471 d	3.09
Kr-85	10.76 y	0.687
Rb-88	17.7 m	5.316
Sr-89	50.52 d	1.497
Y-90	2.67 d	2.282
Zr-93	1.5x106 y	0.091
Nb-94	2.0x104 y	2.045
Mo-99	2.7476 d	1.357
Tc-98	4.2x106 y	1.8
Ru-103	39.27 d	0.763
Rh-104	42.3 s	2.441
Pd-107	6.5x106 y	0.033
Ag-108	2.29 m	1.65
Cd-113	9x1015 y	0.316
In-112	14.4 m	0.663
Sn-121	1.128 d	0.388
Sb-122	2.72 d	1.978
Te-127	9.4 h	0.698
I-128	25.00 m	2.118
Xe-133	5.243 d	0.427
Cs-134	2.065 y	2.059
Ba-139	1.396 h	2.317
La-140	1.678 d	3.762
Ce-143	1.377 d	1.462
Pr-142	19.12 h	2.162
Nd-149	1.73 h	1.691
Pm-147	2.6234 y	0.224
Sm-153	1.928 d	0.808
Eu-154	8.593 y	1.968
Gd-159	18.5 h	0.971
Tb-160	72.3 d	1.835
Dy-165	2.33 h	1.286
Ho-166	1.118 d	1.855
Er-169	9.40 d	0.351
Tm-170	128.6 d	0.968
Yb-175	4.185 d	0.47
Lu-176	3.78x1010 y	1.192
Hf-181	42.4 d	1.027
Ta-182	114.43 d	1.814
W-185	74.8 d	0.433
Re-186	3.718 d	1.07
Os-191	15.4 d	0.314
Ir-192	73.83 d	1.46
Pt-197	18.3 h	0.719
Au-198	2.6952 d	1.372
Hg-203	46.61 d	0.492
Tl-204	3.78 y	0.763
Pb-209	3.25 h	0.644
Bi-210	5.01 d	1.163
Rn-221	25 m	1.2
Fr-222	14.3 m	2.03
Ra-227	42 m	1.325
Ac-226	1.224 d	1.116
Th-231	1.063 d	0.39
Pa-232	1.31 d	1.35
U-237	6.75 d	0.519
Np-238	2.117 d	1.292
		2.13

Table I. This table shows the lightest isotope that undergoes beta-minus decay for most of the known nuclei. The half-life and decay energy released are shown in columns two and three.

The Acceleron Field

A scalar field is a quantity that is defined and may vary from point to point in spacetime, which has no direction. Temperature is an example. Temperature can be negative on some scales but has no direction such as up, down, north, south, east, or west. An electric field is a vector field as opposed to a scalar field, having direction. The electric field is in the direction of the force on a small positive test charge at that point.

The acceleron field is the scalar field discussed by Fardon et al. (2004) and is similar but not the same as the Higgs field as interpreted in inflationary cosmology. It is also not the same as the "quintessence" field used to explain the observed acceleration of the expansion rate of the universe (Caldwell, Dave, and Steinhardt, 1998). The quintessence field is hypothesized to exist everywhere in our universe and to change with position and time in such a way to accelerate the expansion of the universe. It provides a form of so-called "dark energy." The acceleron field, on the other hand, couples to neutrinos and leads to variation of the neutrino mass with position and time.

In discussing a version of inflationary cosmology, Linde (1984) incorporated spontaneous symmetry breaking in gauge theories due to a scalar field, the Higgs field. The potential energy associated with the Higgs field is hypothesized to have a minimum for the case where the Higgs field is nonzero in empty space. The universe is hypothesized to begin with zero Higgs field but to transition to a phase where the Higgs field is nonzero in empty space. This new condition is called the "Higgs condensate." Neutrino physics is drastically changed when this condensate changes. All particles besides the Higgs particle that interact with the Higgs field also change their masses after the symmetry breaking. (See Linde's [1984] equations 2.4, 2.5, 2.6, and following.) Their masses depend on a proportionality constant, called their Yukawa coupling, and would change accordingly if the Higgs field changed.

Peebles (1993, p. 394) discussed the changes that inflationary cosmology has gone through:

> Guth (1981) produced the first fully assembled physical picture for inflation, though his version was imperfect because it assumed inflation ends with a first-order phase transition that creates entropy we observe in the thermal cosmic background radiation (while the CBR in turn produced the baryons). As Sato (1981b) anticipated, this has the problem that the nucleation rate is estimated to be too slow to allow inflation to end, because regions that have completed the phase transition grow in size more slowly than they move apart. This was soon remedied in the pictures developed by Linde (1982, 1983) and Albrecht and Steinhardt (1982), in which the transition from the inflation epoch to the classical Friedmann-Lemaitre model is continuous but rapid enough to produce the necessary entropy.

Ostriker and Steinhardt (2000) discussed the "quintessence" hypothesis, which introduces a quintessence field to explain why the expansion of the universe is accelerating. Quintessence may be translated from Greek as "fifth element." In the ancient Greek philosophy of Aristotle and others, it was suggested that the universe is composed of earth, air, fire, and water, plus an ephemeral substance that prevents the moon and planets from falling to the center of the celestial sphere. Aristotle also wrote many pages about the human soul as being a substance, but that is not our subject here. The term quintessence was reintroduced to refer to a changeable field, not unlike an electrical or magnetic field, that gravitationally repels and thus leads to an acceletated expansion of the universe.

One might ask why these scalar fields should exist? Douglas and Kachru (2007) pointed to the so-called moduli of the compactified extra dimensions of string theory as giving rise to scalar fields. Moduli are parameters present in the description of a shape, whether it be a surface in three dimensions or a collection of connected objects in a multidimensional space. The term "moduli" was introduced by Riemann in the 1850s (Riemann, 1857). A simple example of a modulus would be the radius R of the fifth dimension in Kaluza-Klein theory, discussed by the author in a previous paper

Figure 3. The Vela supernova remnant. Picture by Harel Boren (Creative Commons Attribution-ShareAlike 4.0).

(Chaffin, 2000). It is possible for a modulus to vary between different points of spacetime, and such variations are described as a scalar field. Thus, this line of reasoning provides one idea of why there might be scalar fields in physics.

Fardon et al. (2004) adopted an earlier idea of Kawasaki et al. (1991), which considered the neutrino mass as fixed by a Yukawa-type coupling to an extremely light scalar field, the "acceleron field." In their scenario, the neutrino mass would be density dependent. Fardon et al. consider the possibility of "neutrino clouds" inside which the mass of neutrinos would be different. They wrote:

> We consider regions of high neutrino density and find that the most likely place today to find neutrino masses which are significantly different from the neutrino masses in our solar system is in a supernova. The possibility of different neutrino mass in different regions of the galaxy and the local group could be significant for Z-burst models of ultra-high energy cosmic rays. (Fardon et al., 2004, p. 005)

Equations were developed giving the contribution of a neutrino background to the energy density and the dependence of the mass of the neutrino on the density of neutrinos plus antineutrinos. Under some assumptions about the energy density in the universe, the neutrino mass is inversely proportional to the neutrino density. That is, the neutrino mass decreases as the neutrino density increases. Absolute measurement of neutrino masses has yet to be made, but values in energy units of about 0.1 eV have not been ruled out. Fardon et al. (2004) considered the decrease in density that occurs as the universe expands and discussed a scenario in which the neutrino mass is about 0.6 eV at a redshift of about z=1 and 0.15 eV in our local group of galaxies. The neutrino density should decrease due to expansion by a factor of about 8 between z=1 and Earth, but they assumed an overdensity of neutrinos of about 30 in the local group. Other authors (Brookfield et al.,2006a, 2006b; Kawasaki et al., 1991) have considered models in which the neutrino mass *increases* with density, but the Fardon et al. model is more suited to our purposes. In this paper, contrary to the outlook of Fardon et al., we are not particularly interested in whether dark energy exists or not but whether variation of the neutrino mass and neutrino density could lead to accelerated nuclear decay on earth.

A Nearby Supernova

A nearby supernova decreases the neutrino rest mass by a process described by Fardon et al. (2004). According to this scenario, an increase in neutrino density causes a change in the neutrino mass, which then may lead to further effects. We will explore this possibility below, looking for evidence from the radiocarbon record that energy from a nearby supernova may have reached Earth at the onset of the Genesis Flood. Figure 4 shows an outgoing shell of energy originating from the explosion site shown in part a of the figure. On Earth we do not see or detect the explosion until the expanding shell has time to reach us. In God's plan, accelerated decay may have been triggered by the supernova, or by supernovae if there was more than one. First, however, let us mention another puzzle that may relate to variable neutrino mass.

Decay Heat

As noted in the RATE book (Vardiman, Snelling, and Chaffin, 2005), the accelerated decay hypothesis suffers from a heat problem. Producing a large amount of radioactive decay in a short time releases enough energy to endanger any life carried on the ark. Humphreys in his chapter provided a mechanism, rapid expansion of space, which serves as a secondary hypothesis for removing decay energy. However, if the uranium were to temporarily switch to beta-minus decay as discussed earlier and the neutrino mass were to decrease, the antineutrinos released in beta-minus decay could carry away a large fraction of the decay energy.

According to Wasserburg et al. (1964, p. 465),

> Data from a wide variety of igneous rock types show that the ratio of potassium to uranium is approximately 1×10^4. This suggests that the value of K/U ~ 1×10^4 is characteristic of terrestrial materials and is distinct from the value of 8×10^4 found in chondrites. In a model earth with K/U ~ 10^4, uranium and thorium are the dominant sources of radioactive heat at the present time.

The fraction of the decay heat carried off by the antineutrinos increases as a result of a decrease in neutrino mass. The heat problem is ameliorated. When we consider for simplicity a beta-minus decay in which the electron and antineutrino are emitted in opposite directions, momentum and energy con-

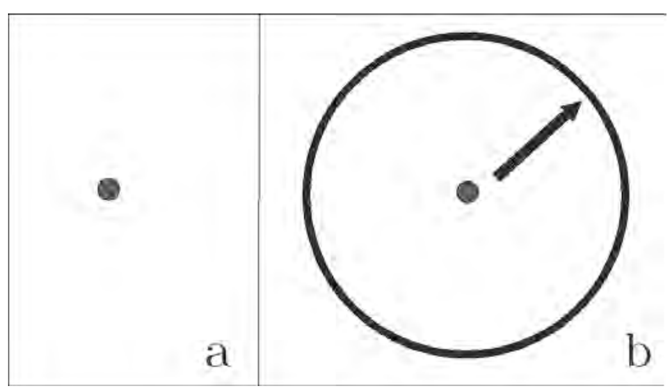

Figure 4. In part a, the star explodes at some date in prehistory. In part b, the expanding sphere of light and neutrinos has traveled many light-years and eventually reaches Earth.

servation can be used to show that the ratio of kinetic energies of the antineutrino to the electron is given by the ratio of the electron mass divided by the antineutrino rest mass. Hence, if the antineutrino mass decreases, then the antineutrino carries off more of the decay energy. Since antineutrinos have such small likelihoods of interaction, a large amount of the decay energy is carried off into space. Nuclei like U-238, which are alpha emitters, may become beta-decay nuclei during the accelerated decay. Acceleration of alpha decay may, in part, seem to occur when actually a branching to beta-decay was the actual reason, and as a by-product antineutrinos can carry off a large amount of decay heat.

The Fardon *et al.* Theory

Fardon et al. (2004, p. 005) wrote:

> We derive a model independent relation between the neutrino mass and the equation of state parameter of the neutrino dark energy, which is applicable for general theories of mass varying particles. *The neutrino mass depends on the local neutrino density.* (Italics added)
>
> We also consider the cosmology of and the constraints on the "acceleron", the scalar field which is responsible for the varying neutrino mass.

They cite a paper by G. W. Anderson and S. M. Carroll (1997), which attempted to match the ages of globular clusters with the age of the universe using time-dependent mass. In discussing this scenario, Anderson and Carroll (1997, page 1) wrote:

> The particle mass is generated by the expectation value of a scalar field which does not have a stable vacuum state, but which is effectively stabilized by the rest energy of the ambient particles. As the universe expands, the density of particles decreases, leading to an increase in the vacuum expectation value of the scalar (and hence the mass of the particle). The energy density of the coupled system of variable-mass particles ("vamps") redshifts more slowly than that of ordinary matter. Consequently, the age of the universe is larger than in conventional scenarios.

Fardon et al. (2004) developed equations for the contribution of a neutrino background to the energy density and for the dependence of the mass of the neutrino on the density of neutrinos plus antineutrinos. Under certain assumptions, they found that the neutrino mass is simply inversely proportional to the neutrino density. In their theory, there is background of neutrinos left over from the big bang. Since the density cannot be lower than that of the background, neutrinos in a region dominated by this background have the heaviest mass possible. Thus, the presence of a uniform neutrino background density will lead to an effective potential that prevents the neutrino mass from becoming too large, leaving a homogeneous negative pressure fluid in the universe, a form of dark energy. Fardon et al. (2004) used the concept of a "sterile neutrino," a neutrino that interacts with ordinary matter only through gravity and makes itself known by oscillating (changing) into the ordinary electron, muon, and tau neutrinos. However, it is not necessary to follow their scenario in that respect, since they were concerned with explaining "dark energy" and we are not.

Schrempp (2007, p. 39) discussed these scalar fields and how they could cause a variation in neutrino mass with position in spacetime due to the variation in the scalar field with position and time. In quantum theory, we say that the neutrino masses m_i (the index i is 1, 2, or 3, depending on which type of neutrino, electron neutrino, muon neutrino, or tau neutrino we refer to) are generated from the vacuum expectation value (which in quantum mechanics is a mathematical average obtainable if we know a particle's wave function) of the scalar field ϕ and become functions of ϕ, $m_i(\phi)$, i = 1, 2, 3. On the other hand, the dependence of m_i on ϕ turns the neutrino energy densities ρ_i into implicit functions of ϕ, since the energy densities $\rho_i(m_i(\phi))$ depend on the masses $m_i(\phi)$, i = 1, 2, 3.

On Earth, neutrinos are measured coming from the sun. The most numerous solar neutrinos are the pp neutrinos, with energies of order 0.1 MeV and a flux on Earth of 6×10^{10} cm^{-2}s^{-1} (Bahcall, 1989). Since they travel at the speed of light, we can find the density of these neutrinos as:

$$(6\text{x}10^{10}\ \text{cm}^{-2}\ \text{s}^{-1})/(3\text{x}10^{10}\ \text{cm/s}) = 2\ \text{cm}^{-3} \qquad (2)$$

This is smaller than the background density that Fardon et al. assume to be about 100 per cubic centimeter. On page 12 of their paper, Fardon et al. (2004) stated: "In core collapse supernovae, the early neutrino number density can reach 10^{35} cm^{-3}."

Gando et al. (2011) considered the antineutrinos produced by uranium, thorium, and potassium inside the earth, finding it to be around $4.3\text{x}10^6$ cm^{-2} s^{-1} and the total active geoneutrino flux including all flavors as $7.4^{+2.1}_{-1.9} \times 10^6$ cm^{-2} s^{-1}. Note that the geoneutrino flux is four orders of magnitude less than the solar neutrino flux, but this may not hold during accelerated decay.

Thus, to give a contribution to the neutrino density comparable to that of the cosmic neutrino background (100 cm^{-3}), the earth's radioactive neutrino flux at the earth's surface would have to increase to a factor of 100 more than the present solar neutrino flux and a factor of 10^6 more than the present geoneutrino flux. This is thus comparable to the increase we would expect during our hypothesized accelerated decay episode. In the RATE book (Vardiman, Snelling, and Chaffin, 2005, p. 742), it was concluded: "The physical presence of high levels of He in these U-rich zircons, given the measured He diffusion rate in zircon, is a strong argument that 1.5 billion years worth of U decay, at presently measured rates of U decay, has actually occurred within the last 6000 years." Hence the RATE findings are consistent with a significant change in neutrino masses and associated parameters and will remain so should the Fardon et al. theory survive future experimental and observational tests. However, we still need to consider whether the increased flux from a nearby supernova might also be involved. Before returning to the neutrino flux from a supernova, we first need to discuss the evidence that nearby supernovae have occurred.

Radiocarbon Evidence for a Nearby Supernova

The light from the first historically recorded supernova event arrived in AD 185 (Damon et al., 1995). However, according to Damon et al., it occurred at a distance of more than 6000 light-years. DeYoung (2008) discussed the crab nebula, the remnant of a supernova observed on Earth in AD 1054. Davies (1994, 2007) has been studying supernova remnants and relating their age to the biblical time frame. Evidence for prehistoric supernovae exists. Firestone (2014) discovered that the radiocarbon record can be used to reveal numerous other supernova candidates that occurred less than 1000 light-years from Earth.

Firestone (2014, p. 29) identified evidence:

> Four supernovae (SNe), exploding ≥ 300 pc from Earth, were recorded 44, 37, 32, and 22 kyr ago in the radiocarbon (^{14}C) record during the past 50 kyr. . . . SN22kyrBP [the supernova of 22 kiloyears Before Present], is identified as the Vela SN that exploded 250 ± 30 pc from Earth. These SN are confirmed in the ^{10}Be, ^{26}Al, ^{36}Cl, and NO−3 geologic records.

Here a parsec (pc) is 3.26 light-years.

Evidence from the radiocarbon record is as follows. Explosions of near-Earth supernovae will deposit gamma-ray energy onto Earth by producing ^{14}C and other cosmogenic isotopes that are subsequently recorded in Earth's geological record. This suggests that Earth and its atmosphere can quantitatively record the cosmic gamma ray emission following nearby supernova explosions.

Damon et al. (1995) recorded that an increase of 0.61 ± 0.16% in tree ring radiocarbon followed the explosion of SN1006, which occurred 1.56 kiloparsecs from Earth.

Libby, the inventor of radiocarbon dating, originally assumed that the radiocarbon abundance, ^{14}C/C, in living organisms was always constant so that the age of a fossil could be calculated simply by measuring the amount of ^{14}C remaining following its death and the subsequent decay since then. It soon became apparent, when comparing with alternate dating methods such as tree rings, that ^{14}C/C was much larger in the past. Recent dates are not altered, only very old ones. To accurately date older samples required the direct determination of earlier radiocarbon abundance *calibration* data in order to accurately date fossils. Firestone (2014) cited papers published in the journal *Radiocarbon* to establish this calibration (Reimer et al., 2002, 2003, 2009).

Firestone wrote: "The higher ^{14}C/C ratio indicates that the cosmic ray rate striking the atmosphere was larger at earlier times. . . . For example, a significant increase in global radiocarbon might be expected to occur following the explosion of the Vela supernova 250 ± 30 parsecs from Earth (Cha et al. 1999)" (Firestone, 2014, p. 30). Figure 5 shows a graph of the carbon-14 excess versus the date before the present. The excess radiocarbon, Δ^{14}C(%) is the difference between the actual C-14 abundance and a standard; on the original relative normalization scale, Δ^{14}C(%) was set equal to 0.0 for 1950. The figure, drawn after Firestone's figure, has peaks on it that are interpreted as excess carbon-14 produced when gamma-rays

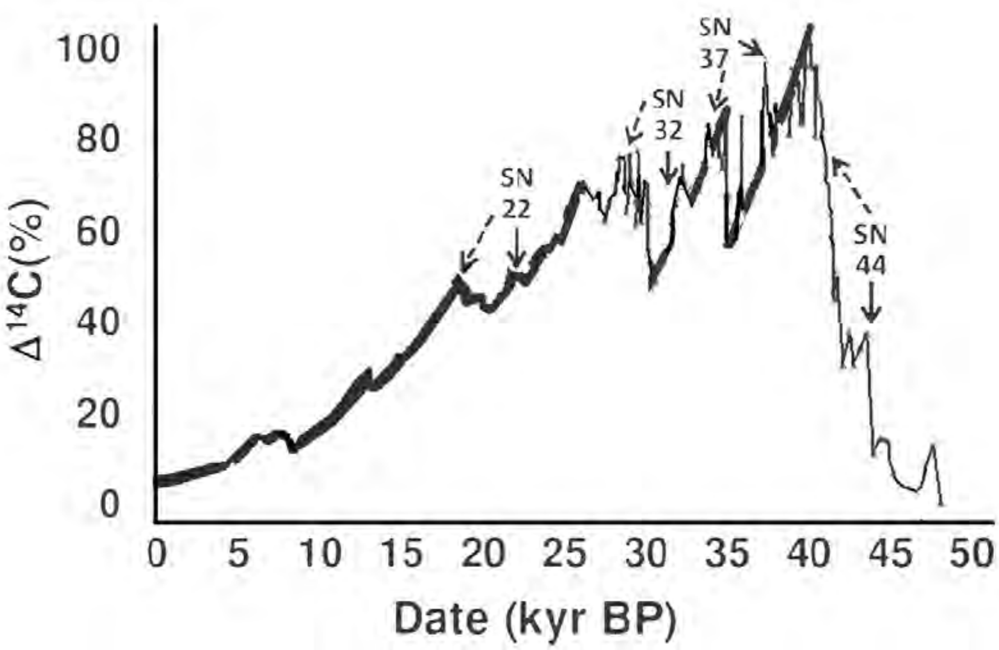

Figure 5. A graph of the excess Carbon-14 versus date before present. Drawn after Firestone (2014).

from a nearby supernova reached Earth. Firestone interpreted the 22 kiloyears before the present peak as the result of the Vela supernova. The remnant from this supernova is shown in Figure 3. However, more pronounced earlier peaks are shown at 32, 37, and 44 kiloyears before the present.

How does this fit into a young-earth scenario? Tabulated radiocarbon dates published in *Science* and *Radiocarbon* (up to 1970) led Whitelaw (1970) to a date for the Flood of about 5000 years before present (BP), corresponding to a published date of 5900 years BP. Also, published dates of 19,100 years and older would actually correspond to 6500 BP to Creation at 7000 BP, as show in the curve of Whitelaw's Figure 2. Whitelaw was professor of nuclear and mechanical engineering at Virginia Tech and a contemporary of Henry Morris.

Thus the 22,000-year date associated with the Vela supernova remnant would correspond to an actual date just over 6500 years, at least 1500 years before the Flood. However, there may be enough uncertainty in the 22,000-year date to allow it to correspond to the Flood. Also, Whitelaw did not consider the possible effects of accelerated decay in constructing the calibration curve. Hence, one does not have to accept Firestone's absolute dates. However, the relative ordering is definitely significant.

Firestone adopted the calibration of the IntCal working group (Reimer et al., 2002, 2003, 2009). He wrote, "The date of SN22kyrBP is consistent with the age of the Vela SN" (Firestone, 2014, page 31). Although there are other opinions for the Vela pulsar age present in the astronomy professional literature, we need not accept any of them since we follow Whitelaw's arguments cited above.

The data shown in Figure 5 were known to Godwin (1962) and are not new, but Firestone's interpretation in terms of nearby supernovae is new and seems to fit the facts better.

Neutrino Flux from Supernovae (Again)

Neutrino fluxes from the 1987 Large Magellanic Cloud event, SN1987A, were measured by Hirata et al. (1987) and Bionta et al. (1987). SN 1987A was a supernova in the outskirts of the Tarantula Nebula in the Large Magellanic Cloud (a nearby dwarf galaxy). It occurred approximately 51.4 kiloparsecs (168,000 ly) from Earth. This was close enough that it was easily visible to the naked eye and could be seen from the Southern Hemisphere. The light from the new supernova reached Earth on February 23, 1987. As the first supernova discovered in 1987, it was labeled "1987A." It was the first opportunity for modern astronomers and experimental neutrino physicists to study the development of a supernova in great detail, and its observations have provided much insight into core-collapse supernovae. Since we have the neutrino data of Hirata et al. and Bionta et al., we do not have to concern ourselves with uncertainties in the theory, since we have observational data.

Hirata et al. (1987, p. 1493) wrote: "In supernovae of Type II almost all of the gravitational binding energy of the resultant neutron star, ~$3x10^{53}$ ergs, is radiated within a few seconds in the form of 10^{58} neutrinos of all flavors with average energy in the vicinity of 10–15 MeV."

From this we may calculate the flux at any given radius from the center, although an oversimplified assumption of isotropic emission (which does no harm for an order of magnitude calculation) is made.

$$1 \text{ light-year} = (2.9979\text{x}10^{10} \text{ cm s}^{-1})(3600\text{x}24\text{x}365.25) =$$

$$= (2.9979\text{x}10^{10} \text{ cm s}^{-1})(3.15576\text{x}10^{7} \text{ s}) = 9.46\text{x}10^{17} \text{ cm}$$

$$\text{Flux} = (10^{58} \text{ neutrinos})/[(4\pi r^2)(10 \text{ s})]$$

$$= (10^{58} \text{ neutrinos})/[(4\pi \text{ x } 8.949\text{x}10^{35} \text{ cm}^2)(10 \text{ s})]$$

$$= 8.89\text{x}10^{19} \text{ neutrinos}/(\text{cm}^2 \text{ s}) \qquad (3)$$

Bionta et al. (1987, p. 1496) wrote:

> When corrected for dead-time and trigger losses, our observation corresponds to 22 events in the 6-s interval. If we assume, for simplicity, monoenergetic 32-MeV $\bar{\nu}_e$'s interacting via inverse beta decay on free protons with a cross section of $8\text{x}10^{-41}$ cm^2, this corresponds to a total flux of $8\text{x}10^8$ cm^{-2}. The total neutrino output from the supernova is then $3\text{x}10^{56}$ corresponding to a luminosity of $\bar{\nu}_e$ of $1\text{x}10^{52}$ ergs above our threshold; the flux and luminosity have an estimated uncertainty of a factor of 2.

Bionta et al. referred to a "total flux of $8\text{x}10^8$ cm^{-2}." This is actually the flux integrated over time. The flux at Earth is thus ($8\text{x}10^8$ cm^{-2})/(6 s) = 1.3 x10^8 cm^{-2} s^{-1}

The 1987A supernova was at a distance of 168,000 light-years. Therefore, the emissions will be spread over a spherical area of $4\pi r^2$, where r is the distance.

$$(3\text{x}10^{56})/(4\pi\ (9.46\text{x}10^{17} \text{ cm})^2) = 2.66\text{x}10^{19} \text{ cm}^{-2}$$

$$(2.66\text{x}10^{19} \text{ cm}^{-2})/(6 \text{ s}) = 4.45\text{x}10^{18} \text{ cm}^{-2} \text{ s}^{-1} \qquad (4)$$

This is the flux at 1 light-year. At Earth, the inverse square law reduces this value considerably due to the huge distance involved. The flux is reduced by $(168{,}000)^2$. Thus, it is $1.58\text{x}10^8$ cm^{-2} s^{-1}. Multiplying by 6 seconds gives $9.46\text{x}10^8$ cm^{-2}, which is in substantial agreement with Bionta et al.'s $8\text{x}10^8$ cm^{-2}.

The 22 events in a 6-second interval could be consistent with this, depending on the density and cross section in the detector. Here we use cgs (centimeter-gram-second) units in order to compare with the figures given in those units in the Bionta et al. (1987) and other papers.

We have already seen earlier in this paper that the solar pp flux on earth is 6×10^{10} $cm^{-2}s^{-1}$ and that to be effective the flux on Earth must be a factor of 100 more than this, so it must be at least $6x10^{12}$ $cm^{-2}s^{-1}$. Thus Bionta et al. 's (1987) value $4.45x10^{18}$ cm^{-2} s^{-1} can be effective for a candidate supernova provided that:

$$4.45x10^{18}\ cm^{-2}\ s^{-1}/r^2 > 6x10^{12}\ cm^{-2}\ s^{-1}, \text{ thus}$$

$$r^2 < 7.42x10^5 \text{ or } r < 861 \text{ light-years}$$

$$(\text{or } 861/3.26 = 264 \text{ parsecs}). \quad (5)$$

Thus, the Vela SN that exploded 250 ± 30 pc from Earth is marginally within this limit, but a closer one (possibly SN44 kyr) would be better.

Conclusion

Thus, we find that it is possible that these few supernovae would have sent out neutrinos that reached Earth at the time of the Genesis Flood and could have triggered a change in neutrino mass. This in turn would be associated with accelerated decay. The possible change in neutrino mass still needs to be confirmed experimentally.

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