Extraterrestrial Solar Neutrino Physics

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Abstract

We examine the scope of extraterrestrial solar neutrino physics, i.e. solar neutrino physics that could be carried out outside the Earth. We find that, among others, the reactions induced by the \(^8\)B solar neutrinos, in view of the sole high energy nature \((E_{\nu}^{\max} = 14.03\,\text{MeV})\), are most interesting in the solar environment. Two types of experiments are considered - the chemical compositions of the geology type and the matter-enhanced oscillations when the Sun-Venus-Earth eclipse, or the Sun-Mercury-Earth eclipse, occurs or the Satellite experiments (likely to be different from the "day-night" effect on the Earth). These experiments are not beyond current technology limits. In view of the weak-interaction nature, they are likely to be the precision experiments of the next generation or even beyond.

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1 Introduction

When we look at the eight major planets of our solar system, we cannot stop being curious by many questions - and many puzzles to ask. From inside out, the Mercury, the Venus, the Earth, and the Mars, these might look like the earthlings, and then the Jupiter and the Saturn might be mini-Suns, the other two we don’t really know. The fact that all eight planets fall in the same plane with the same direction might indicate that they might form in similar or related times. For those earthlings, the Mercury, the Venus, the Earth, and the Mars, why only on Earth are there living things?

The Sun provides the energy resources of all kind - the light, the electromagnetic waves of different frequencies, the neutrinos, and the cosmic-ray particles of all kinds - the main provider of the extraterrestrial origin. Besides the light, solar neutrinos, which come from the nuclear reactions in the core of the Sun, also carry away a huge amount of energy. Differing from the light, solar neutrinos, once produced, would travel up to the astronomical distance without suffering second (weak) interactions.

Solar neutrinos and all other neutrinos would be the thing that would "shine" the dark world, after all the lights cease to ignite - another life of the Universe if the Universe ceases to expand or start to contract. Thus, it would be a lot more interesting to look at neutrinos and antineutrinos more intimately, even though they involve weak interactions or something weaker.

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2 Solar Neutrinos

When the Sun is shining on us, a significant amount of the solar energy get carried away by neutrinos. Solar neutrinos are elusive because they only participate weak interactions - so almost all of them pass away by us without being noticed. In fact, solar neutrinos are even more elusive than, e.g., antineutrinos because charged weak interactions do not operate between solar neutrinos and the ordinary low-$Z$ matter, i.e. break-up of light nuclei by solar neutrinos being negligible (to the first sight or to the first guess; see below) - they are made of from the matter rather than the antimatter.

Solar neutrinos come from the most important reactions in the so-called $pp$-I chain,[1]

\[ p + p \rightarrow D + e^+ + \nu_e, \quad (E_{\nu}^{\text{max}} = 0.42 \text{ MeV} : \phi_{\nu} = 6.0 \times 10^{10} \text{ cm}^{-2} \text{ sec}^{-1}), \]  

\[ p + p + e^- \rightarrow D + \nu_e, \quad (E_{\nu} = 1.44 : \phi_{\nu} = 1.5 \times 10^8), \]  

or from the $pp$-II chain,

\[ ^7Be + e^- \rightarrow ^7Li + \nu_e, \quad (E_{\nu} = 0.86 \text{ MeV} : \phi_{\nu} = 2.7 \times 10^9; \quad E_{\nu} = 0.38 : 3.0 \times 10^8), \]  

or from the $pp$-III chain,

\[ ^8B \rightarrow ^8Be^* + e^+ + \nu_e, \quad (E_{\nu}^{\text{max}} = 14.06; \phi_{\nu} = 3.0 \times 10^6), \]  

or from the C-N-O cycle,

\[ ^{13}N \rightarrow ^{13}C + e^+ + \nu_e, \quad (E = 1.19 : 3.0 \times 10^8), \]  

\[ ^{15}O \rightarrow ^{15}N + e^+ + \nu_e, \quad (E = 1.70 : 2.0 \times 10^8). \]  

Here the neutrino fluxes $\phi_{\nu}$ are measured at the sea level on Earth, in units of $\text{cm}^{-2}\text{ sec}^{-1}$. Note that the $^8B$ neutrino flux has been updated[2] to $(5.69 \pm 0.91) \times 10^6 \text{ cm}^{-2}\text{ sec}^{-1}$ (theoretically) or $(4.94 \pm 0.21(\text{stat})^{+0.38}_{-0.34}(\text{syst})) \times 10^6 \text{ cm}^{-2}\text{ sec}^{-1}$ (experimentally).

Of course, the electron-like neutrinos may oscillate into muon-like or tau-like specifies but fortunately neutral weak interactions do not differentiate among them; other types of neutrino oscillations, so far less likely, could be relevant though.

The average distance of the planet Jupiter from the Sun is 5.203 $a.u.$ with the Jupiter year 11.9 our years. The radius of the Jupiter is 71,398 km, much bigger than the Earth’s 6,378 km. In terms of the mass, the Jupiter’s $1.901 \times 10^{27} \text{ Kg}$ is about 300 times than the Earth’s $5.974 \times 10^{24} \text{ Kg}$. It is believed that the composition of the Jupiter is similar to our Sun, mostly the hydrogen plus a certain fraction of the helium.

Therefore, when solar neutrinos encounter the Jupiter, we anticipate that the following weak interactions will dominate:

\[ \nu + p \rightarrow \nu + p, \quad \nu + ^4He \rightarrow \nu + ^4He, \]  

while the reaction $\nu + e^- \rightarrow \nu + e^-$ would serve as a small correction.
3 Estimate of the Mean Free Paths

For the neutral-current weak reaction induced by solar neutrinos on the protons,

$$\nu(p_\nu) + p(p) \rightarrow \nu(p'_\nu) + p(p'),$$

the transition amplitude is given by[3]

$$T = \frac{G}{\sqrt{2}} i\bar{u}(p'_\nu)\gamma_\lambda(1 + \gamma_5) u(p_\nu) \cdot \langle p(p') \mid N_\lambda \mid p(p) \rangle.$$  

We may proceed to parameterize the neutral-current matrix element as follows[3]:

$$< p(p') \mid N_\lambda(0) \mid p(p) > \equiv i\bar{u}(p')\{\gamma_\lambda f_N^V(q^2) - \frac{q_\mu q_\nu}{2m_p} f_N^M(q^2) + \gamma_\lambda \gamma_5 f_N^A(q^2) + \frac{i2Mq_\nu q_\mu}{m_p^2} f_P^N(q^2)\}u(p),$$

with $q^2 \equiv q'^2 - q_0^2$, $q_0 = (p' - p)_0$, and $2M = m_p + m_n$. Here $f_N^V(q^2)$, $f_M^N(q^2)$, $f_A^N(q^2)$, and $f_P^N(q^2)$, respectively, the (neutral-current) vector, weak magnetism, axial, and pseudoscalar form factors. The differential cross section is given by

$$\frac{d\sigma}{d\Omega}(\nu + p \rightarrow \nu + p) = \frac{G^2(E^\nu)^2 E_\nu'}{2\pi^2 \cdot E_\nu'} \{(f_N^V(q^2))^2 + (f_M^N(q^2))^2 \frac{q^2}{4m_p^2} + (f_A^N(q^2))^2\cos^2\theta_W \}
+ 2[(f_N^V(q^2) + f_M^N(q^2))^2 \frac{q^2}{4m_p^2} + (f_A^N(q^2))^2(1 + \frac{q^2}{4m_p^2})]
+ 4\frac{E_\nu'}{m_p}(1 + \frac{E_\nu'}{m_p} \sin^2\theta_W)\frac{1}{2}(f_N^V(q^2)(f_N^V(q^2) + f_M^N(q^2))]\sin^2\theta_W\}.$$  

In the tree approximation in the standard model of particle physics, we have

$$N_\lambda = (1 - 2\sin^2\theta_W) f_V^\lambda - \sin^2\theta_W Y_\lambda + f_A^{3(5)} - \frac{1}{2} Y_A^{3} - \frac{1}{2} Y_A^{5},$$

so that, for example,

$$f_N^V(q^2) = (1 - 2\sin^2\theta_W) \cdot \frac{1}{2}(e_p(q^2) - e_n(q^2)) - \sin^2\theta_W \cdot (e_p(q^2) + e_n(q^2)) - \frac{1}{2} f_V^S(q^2).$$

$$f_M^N(q^2) = (1 - 2\sin^2\theta_W) \cdot \frac{1}{2}(\mu_p(q^2) - \mu_n(q^2)) - \sin^2\theta_W \cdot (\mu_p(q^2) - \mu_n(q^2)) - \frac{1}{2} f_M^S(q^2).$$

$$f_A^N(q^2) = \frac{1}{2} f_A^V(q^2) - \frac{1}{2} f_A^S(q^2).$$

As a reasonable estimate, we could use $q^2 \approx 0$ and neglect all terms higher order in $q^2/m_p^2$ and $E_\nu/(2m_p)$. The integration over $d\Omega$ yields

$$\sigma \approx \frac{G^2 E^\nu_\nu}{\pi} \cdot \{(\bar{f}_V^2 + f_A^2 + ...) (1 + \frac{2E_\nu^\nu}{m_p})^{-1} \}
+ (2\bar{f}_A^2 + ...) (1 + \frac{2E_\nu^\nu}{m_p})^{-2}\}
\approx 1.686 \times 10^{-20} \cdot (\bar{f}_V^2 + 3f_A^2) \cdot (\frac{E_\nu}{1\text{MeV}})^2 \cdot \text{barn},$$

3
where \( \overline{f}_V \) and \( \overline{f}_A \) are suitable averages of \( f^N(q^2) \) and \( f^N(q^2) \), respectively. Our formulas indicate that \( (\overline{f}_V^2 + 3(\overline{f}_A)^2) \approx O(1) \).

The neutrinos could come from either the three-body modes (i.e. the \( \beta^+ \) decays) or the two-body modes (such as the \( \beta^+ \) capture reactions). For the three-body modes, we could use the phase factors to do very good estimates for the neutrino spectra; we adopt this approximation in this paper.

Our estimate, from Eqs. (1)-(6), for the average flux times the cross section, \( \phi_\nu \sigma \), is given by

\[
\phi_\nu \sigma = 4.838 \times 10^{-36}(\overline{f}_V^2 + 3\overline{f}_A^2) \text{sec}^{-1}.
\]  

(17)

The average density of the Jupiter is 1.2469 \( \text{gm/cm}^3 \). The inverse of the mean free path \( n\sigma \) is given by

\[
n\sigma = 2.102 \times 10^{-36}(\overline{f}_V^2 + 3\overline{f}_A^2) \text{cm}^{-1}.
\]  

(18)

The neutrino flux suitably weighted by the energy factor, measured on the surface of the Jupiter, is

\[
\phi_\nu = 2.869 \times 10^8 \text{cm}^{-2}\text{sec}^{-1}.
\]  

(19)

This factor is already used before, calculated from from Eqs. (1)-(6) adjusted by the distance from the Jupiter and the Sun.

As another estimate, we could compare how much energy the solar neutrinos deposit in the Jupiter to that in the Earth,

\[
\left(\frac{1}{5.203}\right)^2 \times \left(\frac{71,398 \text{km}}{6,378 \text{km}}\right)^3 = 51.82,
\]  

(20)

modulated by small difference in the densities.

The stopping power can be calculated below:

\[
\frac{4\pi}{3} R^3 \cdot n \cdot \sigma \cdot \phi_\nu \cdot c^2 = 8.848 \times 10^8 \text{Joule/sec}.
\]  

(21)

A large amount but distributed over the hugh volume (of the entire Jupiter) - maybe leaving no trace at all.

4 Importance of \(^8\text{B}\) Solar Neutrinos

There are several reasons why \(^8\text{B}\) solar neutrinos are of special importance. First, the energies of these neutrinos are higher than the other neutrinos by a factor of ten. We know that the weak-reaction cross sections in these energies are proportional to \( E^2 \). Second, the binding energies of the nuclei are so arranged that it matches up with solar neutrinos with marvelus results. For example, the first few "deeply-bound" nuclei, \(^4\text{He} \) (or \( \alpha \)), \(^{12}\text{C} \), \(^{16}\text{O} \), etc. can only connect through the neutral-current weak reaction induced by \(^8\text{B}\) solar neutrinos, \( \nu +^{12}\text{C} \rightarrow \nu +^{8}\text{Be} + \alpha \) (\(^{8}\text{Be} \) is effectively two \( \alpha \)) and \( \nu +^{16}\text{O} \rightarrow \nu +^{12}\text{C} + \alpha \). (To be elaborate in the next section, this is a deep statement but it turns out to be true.)

If we look up at the nuclear table with the binding energies, we would realize immediately that these can categorize into the deeply bound nuclei, with B.E. per nucleon more that 7 MeV, and those with the "last" nucleon of much less binding energy. The deeply bound
nuclei are also those naturally abundant elements - with most of the abundance ratios assumed to be constants\[4\]. In fact, all these change slowly with \(^8B\) solar neutrinos, in fact, only with \(^8B\) solar neutrinos.

To see all these, consider\[5\] for example \(^{14}N\), virtually all the weak reactions could be induced by solar neutrinos such as \(\nu_e + ^{14}N \rightarrow e^- + ^{14}O\), \(\nu + ^{14}N \rightarrow \nu + ^{13}C + p\), \(\nu + ^{14}N \rightarrow \nu + ^{13}N + n\), \(\nu + ^{14}N \rightarrow \nu + ^{12}C + d\), \(\nu + ^{14}N \rightarrow \nu + ^{10}B + \alpha\), \(\nu + ^{14}N \rightarrow e^- + ^{13}N + p\), ... all by \(^8B\) solar neutrinos. In comparison, only \(\nu + ^{12}C \rightarrow \nu + ^8Be + \alpha\) by \(^8B\) solar neutrinos is allowed. So as mentioned for \(^{16}O\). See the next section for estimates of the cross sections.

At this juncture, we may introduce a new field - the "Solar Neutrino Induced Nuclear Chemistry" (SNiNC), which would deal with the various nuclear chemistry. For instance, how many \(^4He, ^{12}C, ^{16}O, ...\), \(^2H(d), ^3He, ...\), \(^{14}N, ...\), which ones would stabilize under the Sun, ... a lot of interesting questions to ask. This has nothing to do with ”extraterrestrial”. Many aspects, mentioned briefly in this section and also in the next two sections, are subjects of SNiNC, which remain to be investigated.

5 Significance of Neutral Weak Interactions

The solar neutrinos, apart from \(^8B\) solar neutrinos with energies as high as 14.06 MeV, have the energies at most around 1 MeV and would not induce any nuclear weak reactions for the most stable nuclei including \(p, ^4He, ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si,\) and \(^{40}Ca\). They are also relevant abundant in the solar system\[4\]. \(p\) and \(^4He\) are "absolutely stable under solar neutrinos" while \(^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si,\) and \(^{40}Ca\) are "\(\beta\)-decay stable under \(^8B\) solar neutrinos"\[5\]. In other words, \(\nu_e + ^{12}C \rightarrow e^- + ^{12}N\) does not have enough energy to proceed for solar neutrinos (\(E \leq 14.06 MeV\)); the same for \(^{16}O\), etc. only a few of them. Why not all the other nuclei?

In fact, the upper limit of 14.06 MeV means that \(p\) and \(^4He\) would not disapper but would accumulate because of solar neutrinos. \(^{12}C\) has one channel \(\nu + ^{12}C \rightarrow ^8Be + \alpha + \nu\) (\(^8Be\) looks like two alpha's). \(^{16}O\) has two channels, \(\nu + ^{16}O \rightarrow ^{12}C + \alpha + \nu\) and \(\nu + ^{16}O \rightarrow ^{15}N + p + \nu\). \(^{20}Ne\) has three channels, \(\nu + ^{20}Ne \rightarrow ^{16}O + \alpha + \nu\), \(\nu + ^{20}Ne \rightarrow ^{19}F + p + \nu\), and \(\nu + ^{20}Ne \rightarrow ^{12}C + ^8Be + \nu\). Let’s continue. \(^{24}Mg\) has four channels, \(\nu + ^{24}Mg \rightarrow ^{20}Ne + \alpha + \nu, \nu + ^{24}Mg \rightarrow ^{23}Na + p + \nu, \nu + ^{24}Mg \rightarrow ^{16}O + ^8Be + \nu,\) and \(\nu + ^{24}Mg \rightarrow ^{12}C + ^{12}C + \nu,\) etc. etc. All neutral weak interactions!! Charge weak reactions, such as beta decays, exist but elsewhere, not here. The energy conservation plus solar neutrino energies gives us the miracle.

These considerations should give a new beginning for the Solar-Neutrino-induced Nuclear Chemistry (SNiNC again!!).

The cross sections can easily be calculated, because almost all of the initial and final nuclei are spin zero and isospin zero. Our estimate for \(\nu + ^{12}C \rightarrow ^8Be + \alpha + \nu\) (Energy Difference = 7.3666 MeV) is

\[
\sigma \approx \frac{G^2(E_\nu')^2}{2\pi} \sin^4 \theta_W \cdot \rho \approx 8.4303 \times \left(\frac{E_\nu}{10 MeV}\right)^2 \times 10^{-17} \cdot \sin^4 \theta_W \cdot \rho \cdot fm^2. \tag{22}
\]

Here \(\rho\) some overlap integral squared and \(O(1)\).
6 The Composition of the Jupiter and of the Venus as the Geology Survey

Let’s assume that the Jupiter was formed approximately at the same time as the Sun. We also take the assumption that the Sun is the first-generation star - to be consist primarily of the hydrogen and the helium. In other words, Big-Bang Nucleosynthesis (BBN)\cite{6} would provide the material for the Sun. Provided that there was no major accident till the beginning of the Sun, the chemical composition at the beginning was not far from the BBN’s:

\[
\begin{align*}
4He : \frac{Y_p}{n} &= \frac{2(n/p)}{1 + (n/p)} \approx 0.25 \\
3He/p &\approx 10^{-5} \\
2D/p &= (2.78 \pm 0.29) \times 10^{-5} \\
7Li/p &= (1.7 \pm 0.02^{+1.1}_{-0.0}) \times 10^{-10}.
\end{align*}
\]

(23)

To begin with, the Jupiter and the Sun would assume the same set of values as BBN’s. As time went by, the chemical composition in the Jupiter would gradually change due to the \( ^8B \) solar neutrinos (the only “high energy” solar neutrino, \( E_{\nu}^{\text{max}} = 14.06 \text{MeV} \) - see Eqs. (1)-(6)). In fact, the amount of \( ^3He \) and \( ^2D \) in the Jupiter would be depleted unless there would be some supply from outside the Jupiter. Similar arguments could be developed for \( ^7Li \) with some modifications.

Can the chemical composition of the Jupiter be measured eventually? We think that this is an interesting question. Some day a space mission could help to go to the Jupiter to get a sample for experimentation. Before that, we think that the chemical composition of the Jupiter may well be determined in a spectrum experiment on the Earth, provided that some genius design is involved. In other words, using BBN as a benchmark, the chemical composition of the Jupiter would be very telling.

According to our previous discussions, the following reactions from \( ^4He \) (with a large binding energy) are forbidden:

\[
\begin{align*}
\nu + ^4He &\to \nu + ^3He + n \\
&\to \nu + ^3H + p \\
\nu_\ell + ^4He &\to e^- + ^3He + p \\
&\to e^- + d + p + p \\
&\to e^- + n + p + p + p \\
\nu + ^4He &\to \nu + d + p + n \\
&\to \nu + n + n + p + p,
\end{align*}
\]

(24)

while the following reactions are possible:

\[
\begin{align*}
\nu + ^3He &\to \nu + ^2D + p \\
&\to \nu + n + p + p \\
\nu_\ell + ^3He &\to e^- + p + p + p,
\end{align*}
\]

(25)
\[ \nu + ^2 D \rightarrow \nu + n + p \]
\[ \nu_e + ^2 D \rightarrow e^- + p + p. \] (26)

In terms of binding energies, we have
\[ B(^4\text{He}) = 28.2956\text{ MeV}, \]
\[ B(^3\text{He}) = 7.718\text{ MeV}, \]
\[ B(^2\text{D}) = 2.2245\text{ MeV}, \]
thus ruling out the possibilities for \(^4\text{He}\) but keeping the reactions on \(^3\text{He}\) and \(^2\text{D}\). Of course, the intermediate \(n\) and \(^3\text{H}\) would decay \( (\beta\text{-decay}) \).

Here we could use the closure approximation to estimate the cross sections:

\[ \sigma(\nu + A \rightarrow \nu + X) \approx \frac{1}{2\pi^2} \left( \frac{G}{\sqrt{2}} \right)^2 4\pi < E'_{\nu} >^2 \cdot \{ G^2_V [(1 - 2\sin^2 \theta_W)^2 + 4\sin^4 \theta_W] + ... + G^2_A + ... \} \]
\[ \approx 1.686 \times 10^{-20} \cdot (\frac{< E_{\nu} >}{1\text{MeV}})^2 \cdot 0.6041 \cdot \text{barn.} \] (27)

\[ \sigma(\nu_e + A \rightarrow e^- + X) \approx \frac{1}{2\pi^2} \left( \frac{G}{\sqrt{2}} \right)^2 4\pi < E_e >^2 \cdot \{ F^2_V + ... + F^2_A + ... \} \]
\[ \approx 1.686 \times 10^{-20} \cdot (\frac{< E_{e} >}{1\text{MeV}})^2 \cdot 2.6116 \cdot \text{barn.} \] (28)

Looking into neutrino energies, the overall effects are to be dominated by the \(^8B\) neutrinos. It follows that different numbers can then be estimated easily. We think that the scenario reached here is very interesting indeed.

Maybe we could divide the planets into two categories: (Category I:) those similar to the Jupiter as mini-Suns and (Category II:) those similar to the Earth, having the elements greater than or equal to \(A=12\). For Category I, the discussion could stop here.

For the Venus (or planets in Category II), our other important example, the composition is largely unknown - maybe we could take the Earth as the profile. In the presence of the \(^8B\) neutrinos, the \(^{12}\text{C}\) nucleus can change into \(^8\text{Be}\) and \(\alpha\), or three \(\alpha\) nuclei. This turns out to be the most important reaction. If there are \(^{16}\text{O}\) nuclei in abundance, the \(^8B\) neutrinos will change \(^{16}\text{O}\) into \(^{12}\text{C}\) and \(\alpha\) nuclei. If we consider these \(\alpha\)-stable nuclei, the \(^8B\) neutrinos provide reactions in the anti-chain order - but slowly, more slowly than the lifetime of the planets, but to be detectible.

At the surface of the Venus (like the Earth), there are plenty of cosmic rays from the Sun. For example, at the surface of the Earth, we have the intensity of nucleons from a few GeV up to above 100 TeV,

\[ I_N(E) \approx 1.8E^\alpha \frac{\text{nucleons}}{\text{cm}^2 \cdot \text{sec} \cdot \text{Sr} \cdot \text{GeV}}, \] (29)

with \(\alpha = \gamma + 1 \approx 2.7\). Among these, \(79\%\) are free protons and \(70\%\) of the rest are nucleons bound in helium nuclei. This is another major source of nuclear reactions which we can
think of. Of course, there are some meteorites bombarding the Earth’s surface. Without some reliable estimates of these numbers, the present paper can be safely referred to “the inside of the Venus, and etc.”.

Cosmic rays would be another sources, similar to solar neutrinos, that would induce change in nuclear chemistry. Meteorites, asteroids, and comets would be the other. Maybe, to the first approximation, we could neglect all these.

To make the discussions easier, we may introduce two "units":

\[ T_0 = \frac{1}{2} \text{ billion yr} = 4.32 \times 10^{13} \text{ sec}; \]

\[ \Gamma_0 = 1 \text{ mole} \times 10^{-42} \text{ cm}^2 \cdot \Phi = 3.011 \times 10^{-12} \text{ sec}^{-1}, \]

with \( \Phi = 5 \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1} \). For example, one mole (about 1 cm\(^3\)) of material on the Earth would be bombarded by \( ^8 \text{B} \) solar neutrinos with \( \Gamma_0 \) interactions per second. During the Earth’s life, it would be \( T_0 \Gamma_0 = 130 \) interactions.

These standard units indicate that the extraterrestrial solar neutrino physics involves the reactions fairly feeble and reactional rates fairly low. We would say that they are low-energy neutral weak interactions - slight slow than the charged weak interactions. It is very difficult but not impossible to achieve.

7 Matter-enhanced Neutrino Oscillation and the Sun-Venus-Earth Eclipse

Neutrino oscillations could happen in several ways - oscillating into different flavors but conserving the total lepton number \( (L = L_e + L_\mu + L_\tau) \), oscillating into the sterile species \((\nu_s)\), oscillating into the antineutrinos via the so-called ”see-saw” mechanism, and so on. Of course, we don’t know exactly in what way neutrino oscillations take place\(^2\) and for the sake of simplicity we assume that the Nature would prefer the simplicity and choose option (1).

Matter-enhanced neutrino oscillations is now established to be of importance in the Sun. We don’t know how big the signal when neutrinos pass through the Venus or Mercury - to eventually measure during the Sun-Venus-Earth eclipse or the Sun-Mercury-Earth eclipse. On the other hand, we could speculate that what happens in the Sun is also true in the Jupiter, the Mini-Sun, a factor of 10 smaller (in diameter). To study the effects, we imagine that some satellite is launched to circulate the Jupiter such that the Sun are in line with the Jupiter and the Satellite. Similar could be thought of the Sun and the Venus and the satellite configuration.

What is details in neutrino oscillations is in fact of importance. For instance, if solar neutrinos, as born to be electron-like, oscillate 1/3 of time into muon-like or tau-like neutrinos, in the passage of the Venus or the Earth. Note that for solar neutrinos, no decay product of \( \nu_\tau \) or of \( \nu_\mu \) is accessible energetically. (Same as that sterile.) The simplest neutrino oscillation reads\(^2\)

\[
P(\nu_\alpha \rightarrow \nu_\beta) = \delta_{\alpha\beta} - 4 \sum_{i>j} \text{Re} \{U_{\alpha i}^* U_{\beta i} U_{\beta j} U_{\beta j}^*\} \sin^2[1.27 \Delta m^2_{ij} (L/E)]
+ 2 \sum_{i>j} \text{Im} \{U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*\} \sin[2.54 \Delta m^2_{ij} (L/E)].
\]
Here $\alpha$, $\beta$ flavor indices, $i$, $j$ the mass eigenstates, $\Delta m^2_{ij} \equiv m^2_i - m^2_j$ is in eV$^2$, $L$ is in km, and $E$ is in GeV.

The situation during the Sun-Venus-Earth eclipse would be different in detail from that during the Sun-Mercury-Earth eclipse. Here we have $\Delta m^2 = 8.0 \times 10^{-5}$eV$^2$ and $\theta = 33.9^\circ$, and now use the relevant distance, of the order $10^3$km, and the neutrino energy, of a few MeV; we see that the angular factor is more than of order unity - fortunately!! It means that we can in principle measure everything.

Here we wish to point out that it’s very different from that in the so-called ”day-night” effect, done on the Earth - in terms of the phase space.

The question is whether the matter-enhanced neutrino oscillations could be studied using the Sun-Venus-Earth eclipse or the Sun-Mercury-Earth eclipse. Most of these oscillation issues might in principle be investigated in experiments on the Earth - maybe there is no need to go to the Jupiter or the Venus to enhance our knowledge.

Coming to think about it, everything presumably happens in our Sun but God forbids us from doing an experiment except just observing. Hopefully, to do experiments, not necessarily with solar neutrinos, on the Venus or the Jupiter is no longer a dream, and would be a reality fifty years from now.

On the other hand, the chemical composition of the Jupiter and of other planets, if could be measured with precision (which turns out to be very difficult), could be an important direction to go.

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Extraterrestrial Solar Neutrino Physics

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Abstract

We advocate the extraterrestrial solar neutrino physics (etSNP) as a means of investigating solar neutrino physics (SNP). As we already know, the dominant and subdominant (vacuum) oscillation lengths would be approximately one kilometer and one hundred kilometers. On the other hand, we know so far that the matter-enhanced oscillations take place only in the core of the Sun. Thus, the etSNP, i.e. solar neutrino physics that could be extracted outside the Earth, would assume a special unique role. The etSNP experiments include (1) a satellite (detector) around the Earth or around the Jupiter or others (to provide the shadow, for the matter-enhanced neutrino oscillations), (2) during the Sun-Venus-Earth eclipse or similar, and (3) the chemical compositions of the geology type (as in the Jupiter or in the Venus, to study the origins of these planets). To be specific, we note that the reactions induced by the $^8B$ solar neutrinos, in view of the sole high energy nature ($E_{\nu}^{\text{max}} = 14.03\,\text{MeV}$), would be most interesting in the solar environment. Moreover, the experiments such as the chemical compositions of the geology type (on the Venus or Jupiter) and the matter-enhanced oscillations when the Sun-Venus-Earth eclipse, or the Sun-Mercury-Earth eclipse, may also be interesting.

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1 Introduction

When we look at the eight major planets of our solar system, we cannot stop being curious by many questions - and many puzzles to ask. From inside out, the Mercury, the Venus, the Earth, and the Mars, these might look like the earthlings, and then the Jupiter and the Saturn might be mini-Suns, the other two or the so-called "ice" giant planets that we don’t really know. The fact that all eight planets fall in the same plane with the majority along the same direction might indicate that they might form in similar or related times. For those earthlings, the Mercury, the Venus, the Earth, and the Mars, why only on Earth are there living things?

The Sun provides the energy resources of all kind - the light, the electromagnetic waves of different frequencies, the neutrinos, and the cosmic-ray particles of all kinds - the main provider of the extraterrestrial origin. Besides the light, solar neutrinos, which come from the nuclear reactions in the core of the Sun, also carry away a huge amount of energy.

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Differing from the light, solar neutrinos, once produced, would travel up to the astronomical distance without suffering second (weak) interactions - lost in the vast space.

Solar neutrinos and all other neutrinos would be the thing that would "shine" the dark world, after all the lights cease to ignite - another life of the Universe if the Universe ceases to expand or start to contract, according to our current knowledge of particle physics and cosmology. Thus, it would be a lot more interesting to look at neutrinos and antineutrinos more intimately, even though they involve weak interactions or something weaker.

2 Solar Neutrinos

When the Sun is shining on us, a significant amount of the solar energy get carried away by neutrinos. Solar neutrinos are elusive because they only participate weak interactions - so almost all of them pass away by us without being noticed. In fact, solar neutrinos are even more elusive than antineutrinos because charged weak interactions do not operate between solar neutrinos and the ordinary low-Z matter, i.e. break-up of light nuclei by solar neutrinos being negligible - since these materials are made of from the matter rather than the antimatter, but solar neutrinos (before oscillation, or can't oscillate away) are also matter too.

Solar neutrinos come from the most important reactions in the so-called pp-I chain\[1, 2\],

\[
p + p \rightarrow D + e^+ + \nu_e, \quad (E^\text{max}_\nu = 0.42 \, \text{MeV} : \phi_\nu = 5.97 \times 10^{10} \, \text{cm}^{-2} \text{sec}^{-1}), \quad (1)
\]

\[
p + p + e^- \rightarrow D + \nu_e, \quad (E_\nu = 1.44 : \phi_\nu = 1.41 \times 10^8), \quad (2)
\]
or from the pp-II chain,

\[
^7Be + e^- \rightarrow ^7Li + \nu_e, \quad (E_\nu = 0.86 \, \text{MeV} : \phi_\nu = 5.07 \times 10^8; \quad E_\nu = 0.38 : 3.0 \times 10^8), \quad (3)
\]
or from the pp-III chain,

\[
^8B \rightarrow^8 Be^* + e^+ + \nu_e, \quad (E^\text{max}_\nu = 14.06; \phi_\nu = 5.94 \times 10^6), \quad (4)
\]
or from the C-N-O cycle,

\[
^{13}N \rightarrow^{13} C + e^+ + \nu_e, \quad (E = 1.19 : 2.88 \times 10^8), \quad (5)
\]

\[
^{15}O \rightarrow^{15} N + e^+ + \nu_e, \quad (E = 1.70 : 2.15 \times 10^8). \quad (6)
\]

Here the neutrino fluxes $\phi_\nu$ are measured at the sea level on Earth, in units of $\text{cm}^{-2} \text{sec}^{-1}$. Note that the $^8B$ neutrino flux has been updated\[3\] to $(5.69 \pm 0.91) \times 10^6 \, \text{cm}^{-2} \text{sec}^{-1}$ (theoretically) or $(4.94 \pm 0.21(stat)_{-0.34(syst)}^{+0.38(syst)}) \times 10^6 \, \text{cm}^{-2} \text{sec}^{-1}$ (experimentally). The quoted number is from PDG2010\[2\].

Of course, the electron-like neutrinos may oscillate into muon-like or tau-like specifies but fortunately neutral weak interactions do not differentiate among them; other types of neutrino oscillations, so far less likely, could be relevant though.
If we look at different planets, for example, the average distance of the planet Jupiter from the Sun is 5.203 a.u. with the Jupiter year 11.9 our years. The radius of the Jupiter is 71,398 km, much bigger than the Earth’s 6,378 km. In terms of the mass, the Jupiter’s $1.901 \times 10^{27}$ Kg is about 300 times than the Earth’s $5.974 \times 10^{24}$ Kg. It is believed that the composition of the Jupiter is similar to our Sun, mostly the hydrogen plus a certain fraction of the helium.

Therefore, when solar neutrinos encounter the Jupiter, we anticipate that the following weak interactions will dominate:

$$\nu + p \rightarrow \nu + p, \quad \nu + ^4 He \rightarrow \nu + ^4 He,$$

while the reaction $\nu + e^- \rightarrow \nu + e^-$ would serve as a small correction. So, the solar neutrinos do stop at the different planets but only with the tiny factions.

As a suggestion, we would use the so-called ”elementary-particle treatment” (EPT)[4] to handle the neutrino-nucleus reactions such as $\nu + ^4 He \rightarrow \nu + ^4 He$. In fact, under EPT, the ”estimates” for most reactions which we are talking about could be obtained easily. As a matter of fact, our treatment for $\nu + p \rightarrow \nu + p$ is the typical EPT treatment - the elementary-particle treatment for elementary particles themselves.

### 3 Extraterrestrial Solar Neutrino Physics

We may begin with a typical estimate on a satellite (carrying a detector of $1 m^3$) orbiting the Earth (to shield the Sun) to do the solar neutrino experiments. Let’s focus on the high-energy $^8B$ solar neutrino experiments with the flux $5 \times 10^6 cm^{-2} sec^{-1}$. As seen below, typical cross sections would be $10^{-42} cm^2$. The number density is estimated to be $6.02 \times 10^{23} cm^{-3}$.

The exposure time is adjustable and is set to be one day. So, the event rate is

$$\phi_{\nu} \cdot \sigma \cdot \text{"density"} \cdot V \cdot T = 3 \times 10^{-6} \times 86400,$$

with V in $m^3$ and T in day. For example, the target would be rich in $^{37}Cl$ and after a certain days we could check how much it produce $^{37}Ar$ (an active mode of the Davis Jr. experiment). We could check how many nights (under the shadow of the Earth) and how many days (as exposed to the Sun).

There are in fact many experiments similar to the above, one (dedicated) category of extraterrestrial solar neutrino experiments, if the other experiments cannot be "complete". The idea is that the results under the shadow of the Earth ”long enough” would be different that not under the shadow - and with the time periods fully adjustable (with the target volume also adjustable to some degree).

There are satellites that carry human beings or robots which can conduct complicated experiments. In this way, the potential to do ET solar neutrino experiments would be greatly enhanced. What we have in mind is that we eventually have to understand the neutrino physics in some details, using solar neutrinos as a possible avenue.

On other hand, in an experiment during the Sun-Venus-Earth eclipse, if the change could be detectible, i.e., the volume V would be that defined by the Venus, then we get a big factor $10^{27}$. Of course, we have to think about what could be actually detected.
In many situations, we are thinking of the extraterrestrial experiments because of neutrino oscillations. Such physics, in view of its scale and strength, may take several decades (of experimentation) to complete. That is why we try to contemplate all the possibilities to map out a "complete" set of experiments.

We may examine the scales of oscillation physics - that comes from neutrino mixings and oscillations. We will find out that, for MeV neutrinos and the mass-squared differences $\Delta m^2$ in the range of $10^{-5}$ to $10^{-3}$ eV$^2$, the natural distance is about one to a hundred km. For the matter-enhanced oscillation inside the Sun[3, 2] where the electron density $N_e \approx 6 \times 10^{25}$ cm$^{-3}$ yields the interaction energy of $0.75 \times 10^{-5}$ eV$^2$/MeV, an effect which may be duplicated inside the Jupiter with considerable region (volume).

Of course, what is details in neutrino oscillations is in fact of importance. For instance, if solar neutrinos, as born to be electron-like, oscillate $1/3$ of time into muon-like or tau-like neutrinos, in the passage of the Jupiter. Note that for solar neutrinos, no decay product of $\nu_\tau$ or of $\nu_\mu$ is accessible energetically. (Same as that sterile.) The simplest neutrino oscillation reads[3]

$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4 \sum_{i>j} Re \{U^*_{\alpha i} U_{\beta j} U^*_{\beta i} \} \sin^2[1.27 \Delta m^2_{ij} (L/E)]$$

$$+ 2 \sum_{i>j} Im \{U^*_{\alpha i} U_{\beta i} U^*_{\beta j} \} \sin[2.54 \Delta m^2_{ij} (L/E)].$$

(9)

Here $\alpha, \beta$ flavor indices, $i, j$ the mass eigenstates, $\Delta m^2_{ij} \equiv m_i^2 - m_j^2$ is in eV$^2$, $L$ is in km, and $E$ is in GeV.

We note that[2]

$$| \Delta m^2_{21} | \approx 7.6 \times 10^{-5} eV^2; \quad | \Delta m^2_{31} | \approx 2.4 \times 10^{-3} eV^2; \quad | \Delta m^2_{21} | / | \Delta m^2_{31} | \approx 0.032. \quad (10)$$

So, for the solar neutrinos, the energy is of order $MeV$; $\Delta m^2$ would be of order $10^{-3}eV^2$, then oscillation length would be in the order $1 km$; $\Delta m^2$ in $10^{-5} eV^2$, the length would be in $100 km$. We may name them as "dominant oscillation length (DOL)" and "subdominant oscillation length (SDL)". These lengths justify why the "extraterrestrial solar neutrino physics (etSNP)" has the natural place.

In fact, neutrino oscillations, plus matter-enhanced oscillations, occur all the time. The question is how to observe them. The extraterrestrial solar neutrino physics offers a natural way to do it.

4 Some Calculations for the Jupiter

We turn our attention to the interaction induced by the neutrinos, which can be observed but the weak-interaction cross sections are generally too small. In what follows, we do some exercise in order to set up our "notations[5, 4]".

For the neutral-current weak reaction induced by solar neutrinos on the protons,

$$\nu(p_\nu) + p(p) \to \nu(p'_\nu) + p(p'), \quad (11)$$

the transition amplitude is given by[5]

$$T = \frac{G}{\sqrt{2}} i \bar{u}_\nu(p'_\nu) \gamma_\lambda (1 + \gamma_5) u_\nu(p_\nu) \cdot < p(p') | N_\lambda | p(p) > . \quad (12)$$
We may proceed to parameterize the neutral-current matrix element as follows[5]:

\[
\begin{align*}
< p(p') & | N_\lambda(0) | p(p) > \\
& = i\bar{u}(p')\{\gamma\lambda f^N_{V}(q^2) - \frac{\sigma_{\lambda\nu}}{2m_p} f^N_{M}(q^2) + \gamma\lambda\gamma_5 f^N_{A}(q^2) + \frac{2M_0\gamma_5}{m_\nu^2} f^N_{P}(q^2)\}u(p),
\end{align*}
\]

(13)

with \(q^2 \equiv q^2 - \bar{q}^2\), \(q_\lambda = (p' - p)\), and \(2M = m_p + m_n\). Here \(f^N_{V}(q^2)\), \(f^N_{M}(q^2)\), \(f^N_{A}(q^2)\), and \(f^N_{P}(q^2)\), respectively, the (neutral-current) vector, weak magnetism, axial, and pseudoscalar form factors. The differential cross section is given by

\[
\frac{d\sigma}{d\Omega}(\nu + p \rightarrow \nu + p) = \frac{G^2(E^\nu)^2}{2\pi^2} \cdot \frac{E^\nu}{E_p} \cdot \left\{ (f^N_{V}(q^2))^2 + (f^N_{M}(q^2))^2 \frac{q^2}{4m_p^2} + (f^N_{A}(q^2))^2 \cos^2\theta_W \right. \\
+ 2[(f^N_{V}(q^2) + f^N_{M}(q^2))^2 \frac{q^2}{4m_p^2} + (f^N_{A}(q^2))^2(1 + \frac{q^2}{4m_p^2})] \\
\left. + 4\frac{E^\nu}{m_p} (1 + \frac{E^\nu}{4m_p} \sin^2\theta_W) f^N_{A}(q^2)(f^N_{V}(q^2) + f^N_{M}(q^2)) \right\} \sin^2\theta_W.
\]

(14)

In the tree approximation in the standard model of particle physics, we have

\[
N_\lambda = (1 - 2\sin^2\theta_W) I^2_\lambda - \sin^2\theta_W Y_\lambda + I^{3(5)}_\lambda - \frac{1}{2} Y_\lambda^s - \frac{1}{2} Y_\lambda^{(5)},
\]

(15)

so that, for example,

\[
f^N_{V}(q^2) = (1 - 2\sin^2\theta_W) \cdot \frac{1}{2} (e_\nu(q^2) - e_n(q^2)) - \sin^2\theta_W \cdot (e_\nu(q^2) + e_n(q^2)) - \frac{1}{2} f^S_{V}(q^2).
\]

(16)

\[
f^N_{M}(q^2) = (1 - 2\sin^2\theta_W) \cdot \frac{1}{2} (\mu_\nu(q^2) - \mu_n(q^2)) - \sin^2\theta_W \cdot (\mu_\nu(q^2) - \mu_n(q^2)) - \frac{1}{2} f^S_{M}(q^2).
\]

(17)

\[
f^N_{A}(q^2) = \frac{1}{2} f_A(q^2) - \frac{1}{2} f^S_{A}(q^2).
\]

(18)

As a reasonable estimate, we could use \(q^2 \approx 0\) and neglect all terms higher order in \(q^2/m_p^2\) and \(E_\nu/(2m_p)\). The integration over \(d\Omega\) yields

\[
\sigma \approx \frac{G^2E_\nu^2}{\pi} \cdot \left\{ (\bar{f}^2_{V} + \bar{f}^2_{A} + ...) (1 + \frac{2E_\nu}{m_p})^{-1} \\
+ (2\bar{f}^2_{A} + ...) (1 + \frac{2E_\nu}{m_p})^{-2} \right\} \\
\approx 1.686 \times 10^{-20} \cdot (\bar{f}^2_{V} + 3\bar{f}^2_{A}) \cdot \left( \frac{E_\nu}{1 MeV} \right)^2 \cdot \text{barn},
\]

(19)

where \(\bar{f}_V\) and \(\bar{f}_A\) are suitable averages of \(f^N_{V}(q^2)\) and \(f^N_{A}(q^2)\), respectively. Our formulas indicate that \((\bar{f}^2_{V} + 3(\bar{f}^2_{A}) \approx O(1)\).

The neutrinos could come from either the three-body modes (i.e. the \(\beta^+\) decays) or the two-body modes (such as the \(\beta^+\) capture reactions). For the three-body modes, we could...
use the phase factors to do very good estimates for the neutrino spectra; we adopt this approximation in this paper.

Our estimate, from Eqs. (1)-(6), for the average flux times the cross section, $\phi_{\nu} \sigma$, is given by

$$\phi_{\nu} \sigma = 4.838 \times 10^{-36} (f_V^2 + 3f_A^2) \text{sec}^{-1}. \quad (20)$$

The average density of the Jupiter is $1.2469 \text{gm/cm}^3$. Accordingly, the famous product of Eq. (8) is estimated to be

$$\phi_{\nu} \sigma'' n'' = 3.63 \times 10^{-12} (f_V^2 + 3f_A^2) \text{cm}^{-3} \text{sec}^{-1}. \quad (21)$$

The neutrino flux suitably weighted by the energy factor, measured on the surface of the Jupiter, is

$$\phi_{\nu} = 2.869 \times 10^8 \text{cm}^{-2} \text{sec}^{-1}. \quad (22)$$

This factor is already used before, calculated from from Eqs. (1)-(6) adjusted by the distance from the Jupiter and the Sun.

As another estimate, we could compare how much energy the solar neutrinos deposit in the Jupiter to that in the Earth,

$$\left(\frac{1}{5.203}\right)^2 \times \left(\frac{71,398 \text{km}}{6,378 \text{km}}\right)^3 = 51.82, \quad (23)$$

modulated by small difference in the densities.

The stopping power can be calculated below:

$$\frac{4\pi}{3} R^3 \cdot n \cdot \sigma \cdot \phi_{\nu} \cdot c^2 = 8.848 \times 10^8 \text{Joule/sec}. \quad (24)$$

A large amount but distributed over the huge volume (of the entire Jupiter) - maybe leaving no trace at all.

One may wonder that our systems (planets) could be complicated - but in fact not; that is why we introduce the EPT[4] - how to visualize the “complex” system as a simple system through the symmetries. For example, the Jupiter, to the first approximation, would consist hydrogen and helium (like the Sun). But in some calculations we could approximate the system as composed of hydrogen, bound neutrons, bound protons, and electrons - in other words, the contribution due to the small fraction of the nuclei can be reliably estimated.

The size of the Jupiter, about a part in a thousand compared to the Sun, means that the matter-enhanced oscillations could be visible through the Jupiter. Since the orbit of the Jupiter is much farther than the Earth, we imagine that the etSNP with the Jupiter could be accomplished by a satellite surrounding the Jupiter - with the detector at the Satellite and the shade of the Jupiter on/off at will. The experiments could be expensive but may be needed in a “complete” of experiments in the design.

5 The Estimates for the Venus

To look at the Venus, the twin planet of our mother Earth, we should and could do a lot of ET solar neutrino experiments - since it is inside between the Sun and the Earth. The average distance of the Venus from the Sun is 0.72333 a.u. and its radius is 6.652 km.
The estimate, when applied to the Venus, for the average flux times the cross section, \( \phi \nu \sigma \), is given by

\[
\phi \nu \sigma = 2.504 \times 10^{-34} (f'_V + 3f'_A) \text{sec}^{-1}.
\]

(25)

The average density of the Venus is 5.24 gm/cm\(^3\). Accordingly, the famous product of Eq. (8) is estimated to be

\[
\phi \nu \sigma n' = 7.8988 \times 10^{-10} (f'_V + 3f'_A) \text{cm}^{-3} \text{sec}^{-1}.
\]

(26)

The neutrino flux suitably weighted by the energy factor, measured on the surface of the Venus, is

\[
\phi \nu = 1.4849 \times 10^{10} \text{cm}^{-2} \text{sec}^{-1}.
\]

(27)

As another estimate, we could obtain how much energy the solar neutrinos deposit in the Venus. The estimate for the stopping power is

\[
\frac{4\pi}{3} R^3 \cdot n \cdot \sigma \cdot \phi \nu \cdot c^2 = 3.464 \times 10^8 \text{Joule/sec}.
\]

(28)

Also a large amount because the distance from the Sun is much closer (than the Jupiter). The volume of the Venus is \((6.652 \times 10^5 \text{cm})^3\) or \(2.943 \times 10^{26} \text{cm}^3\), so each unit volume \((1 \text{ cm}^3)\) would take \(8.496 \times 10^{17} \text{sec}\), a long time, to accumulate one Joule of neutrino energy.

The importance of the etSNP using the Venus in the eclipse configuration and thus investigating the matter-enhanced oscillations shouldn’t be underestimated. The DOL of one kilometer and the SOL of a hundred meters means that the etSNP has of the right distance to play with - if the matter-enhanced oscillations leave the marks through the Earth-Venus-Sun eclipse, however small but detectible, the story would be remarkable.

6 Importance of \( ^8 B \) Solar Neutrinos

There are several reasons why \( ^8 B \) solar neutrinos are of special importance. First of all, the energies of these neutrinos \((E_{\nu}^\text{max} = 14.06 \text{MeV}, \text{see Eq. (4)})\) are higher than the other neutrinos by a factor of ten. We know that the weak-reaction cross sections in these energies are proportional to \(E^2\). Secondly, with these energies, many reactions among nuclei become energetically possible. Thirdly, the binding energies of the nuclei are so arranged that it matches up with solar neutrinos with marvelous results. For example, the first few "deeply-bound" nuclei, \(^4\)He (or \(\alpha\)), \(^{12}\)C, \(^{16}\)O, etc. can only connect through the neutral-current weak reaction induced by \(^8\)B solar neutrinos, \(\nu + ^{12}\text{C} \rightarrow \nu + ^8\text{Be} + \alpha \) \((^8\text{Be} \text{ is effectively two } \alpha)\) and \(\nu + ^{16}\text{O} \rightarrow \nu + ^{12}\text{C} + \alpha\). (To be elaborate in the next section, this may be a deep statement but it turns out to be true.)

If we look up at the nuclear table with the binding energies, we would realize immediately that these can categorize into the deeply bound nuclei, with B.E. per nucleon more that 7 MeV, and those with the "last" nucleon of much less binding energy. The deeply bound nuclei are also those naturally abundant elements - with most of the abundance ratios assumed to be constants[6]. In fact, all these change slowly with \(^8\)B solar neutrinos, in fact, only with \(^8\)B solar neutrinos.

To see all these, consider[7] for example \(^{14}\)N, virtually all the weak reactions could be induced by solar neutrinos such as \(\nu_e + ^{14}\text{N} \rightarrow e^- + ^{14}\text{O}, \nu + ^{14}\text{N} \rightarrow \nu + ^{13}\text{C} + p\),
\[ \nu^{+14}N \rightarrow \nu^{+13}N+n, \nu^{+14}N \rightarrow \nu^{+12}C+d, \nu^{+14}N \rightarrow \nu^{+10}B+\alpha, \nu^{+14}N \rightarrow e^-+^{13}N+p \ldots, \]

all by \( ^{8}\)\( B \) solar neutrinos. Thus, it is easy to have \( ^{14}N (A \neq 4j) \) nuclei converted eventually into \( ^{12}C (A = 4j) \) nuclei, but not vice versa.

On other hand, only \( \nu^{+12}C \rightarrow \nu^{+8}Be+\alpha \) by \( ^{8}\)\( B \) solar neutrinos is allowed. So as mentioned for \( ^{16}O \) into \( ^{12}C \), or eventually into \( ^{4}\)\( He \). (See the next section for estimates of the cross sections.) So, the net effect is to increase the \( A = 4j \) nuclei, especially the \( ^{4}\)\( He \) nuclei.

At this juncture, we may introduce a new field - the "Solar Neutrino Induced Nuclear Chemistry" (SNI\( \text{NC} \)), which would deal with the various nuclear chemistry induced by solar neutrinos. For example, how many could \( ^{4}He, ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, \) and \( ^{40}Ca \). These stable nuclei are also relevant abundant in the solar system[6]. \( p \) and \( ^{4}\)\( He \) are "absolutely stable under solar neutrinos" while \( ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, \) and \( ^{40}Ca \) are "\( \beta \)-decay stable under \( ^{8}\)\( B \) solar neutrinos"[7]. In other words, \( \nu_{e}+^{12}C \rightarrow e^-+^{12}N \) does not have enough energy to proceed for solar neutrinos \( (E \leq 14.06\, \text{MeV}) \); the same for \( ^{16}O \), etc. only a few of them. Why not all the other nuclei?

In fact, the upper limit of 14.06 MeV means that \( p \) and \( ^{4}\)\( He \) would not disappear but would accumulate because of solar neutrinos. \( ^{12}C \) has one channel \( \nu^{+12}C \rightarrow ^{8}Be+\alpha+\nu \) (\( ^{8}\)\( Be \) looks like two \( \alpha \)'s). \( ^{16}O \) has two channels, \( \nu^{+16}O \rightarrow ^{12}C+\alpha+\nu \) and \( \nu^{+16}O \rightarrow ^{15}N+p+\nu \). \( ^{20}Ne \) has three channels, \( \nu^{+20}Ne \rightarrow ^{16}O+\alpha+\nu, \nu^{+20}Ne \rightarrow ^{19}F+p+\nu, \) and \( \nu^{+20}Ne \rightarrow ^{12}C+^{8}\text{Be}+\nu \). Let's continue. \( ^{24}Mg \) has four channels, \( \nu^{+24}Mg \rightarrow ^{20}Ne+\alpha+\nu, \nu^{+24}Mg \rightarrow ^{23}Na+p+\nu, \nu^{+24}Mg \rightarrow ^{16}O+^{8}\text{Be}+\nu, \) and \( \nu^{+24}Mg \rightarrow ^{12}C+^{12}C+\nu, \) etc. All neutral weak interactions!! Charge weak reactions, such as beta decays, exist but elsewhere, not here. The energy conservation plus solar neutrino energies gives us the miracle.

These considerations should give a new beginning for the Solar-Neutrino-induced Nuclear Chemistry (SNI\( \text{NC} \) again!!).

The cross sections can easily be calculated, because almost all of the initial and final nuclei are spin zero and isospin zero. Using the EPT[4], we obtain, for \( \nu^{+12}C \rightarrow ^{8}Be+\alpha+\nu \)
(Energy Difference = 7.3666 MeV),
\[ \sigma \approx \frac{G^2 (E'^\nu)^2}{2\pi} \sin^4 \theta_W \cdot \rho \approx 8.4303 \times (E'^\nu/10 MeV)^2 \times 10^{-17} \cdot \sin^4 \theta_W \cdot \rho \cdot fm^2. \] (29)

Here \( \rho \) some overlap integral squared and of order \( O(1) \).

As a parenthetical remark, solar neutrinos never stop "shining" us; and this is a way to induce basic nuclear change, for the better or worse. This is why one of us speculate the primary source of cancers[8]. In any event, perhaps we should look into those harmful nuclear reactions would be. Sorry there is no way to escape from solar neutrinos.

8 The Composition of the Jupiter and of the Venus as the Geology Survey

Let’s assume that the Jupiter was formed approximately at the same time as the Sun. We also take the assumption that the Sun is the first-generation star - to be consist primarily of the hydrogen and the helium. In other words, Big-Bang Nucleosynthesis (BBN)[9] would provide the material for the Sun. Provided that there was no major accident till the beginning of the Sun, the chemical composition at the beginning was not far from the BBN’s:

\[
\begin{align*}
^4He : Y_p & = 2(n/p)/(1 + (n/p)) \approx 0.25 \\
^3He/p & \approx 10^{-5} \\
^2D/p & = (2.78 \pm 0.29) \times 10^{-5} \\
^7Li/p & = (1.7 \pm 0.02_{-1.1}^{+1.0}) \times 10^{-10}.
\end{align*}
\] (30)

To begin with, the Jupiter and the Sun would assume the same set of values as BBN’s. As time went by, the chemical composition in the Jupiter would gradually change due to the \( ^8B \) solar neutrinos (the only "high energy" solar neutrino, \( E'^\nu_{max} = 14.06 MeV \) - see Eqs. (1)-(6)). In fact, the amount of \( ^3He \) and \( ^2D \) in the Jupiter would be depleted unless there would be some supply from outside the Jupiter. Similar arguments could be developed for \( ^7Li \) with some modifications.

Can the chemical composition of the Jupiter be measured eventually? We think that this is an interesting question. Some day a space mission could help to go to the Jupiter to get a sample for experimentation. Before that, we think that the chemical composition of the Jupiter may well be determined in a spectrum experiment on the Earth, provided that some genius design is involved. In other words, using BBN as a benchmark, the chemical composition of the Jupiter would be very telling.

According to our previous discussions and the binding energies listed below, the following reactions from \( ^4He \) (with a large binding energy) are forbidden:

\[
\begin{align*}
\nu + ^4He & \rightarrow \nu + ^3He + n \\
& \rightarrow \nu + ^3H + p \\
\nu_e + ^4He & \rightarrow e^- + ^3He + p
\end{align*}
\]
\[ e^- + d + p + p \]
\[ e^- + n + p + p + p \]
\[ \nu + {}^4\text{He} \rightarrow \nu + d + p + n \]
\[ \nu + n + n + p + p, \]
\[ \nu + {}^3\text{He} \rightarrow \nu + {}^2\text{D} + p \]
\[ \nu + n + p + p \]
\[ \nu + {}^2\text{D} \rightarrow \nu + n + p \]
\[ \nu_e + {}^3\text{He} \rightarrow e^- + p + p + p, \]
\[ \nu_e + {}^2\text{D} \rightarrow e^- + p + p. \]

while the following reactions are possible:
\[ \nu + {}^3\text{He} \rightarrow \nu + {}^2\text{D} + p \]
\[ \nu_e + {}^3\text{He} \rightarrow e^- + p + p + p, \]

and
\[ \nu + {}^2\text{D} \rightarrow \nu + n + p \]
\[ \nu_e + {}^2\text{D} \rightarrow e^- + p + p. \]

In terms of binding energies, we have \[ B(4\text{He}) = 28.2956 \text{ MeV}, \]
\[ B(3\text{He}) = 7.718 \text{ MeV}, \]
and \[ B(2D) = 2.2245 \text{ MeV} \] [10], thus ruling out the possibilities for \(^4\text{He}\) but keeping the reactions on \(^3\text{He}\) and \(^2\text{D}\). Of course, the intermediate \(n\) and \(^3\text{H}\) would decay (\(\beta\)-decay).

Here, using the closure approximation, we obtain the cross sections for the involved weak reactions:

\[ \sigma(\nu + A \rightarrow \nu + X) \approx \frac{1}{2\pi^2} \left( \frac{G}{\sqrt{2}} \right)^2 4\pi < E'_\nu >^2 \cdot \left\{ G^2_V \left[ (1 - 2\sin^2\theta_W)^2 + 4\sin^4\theta_W \right] + ... + G^2_A + ... \right\} \approx 1.686 \times 10^{-20} \cdot \left( \frac{< E'_\nu >}{1 \text{ MeV}} \right)^2 \cdot 0.6041 \cdot \text{barn}. \]

\[ \sigma(\nu_e + A \rightarrow e^- + X) \approx \frac{1}{2\pi^2} \left( \frac{G}{\sqrt{2}} \right)^2 4\pi < E_e >^2 \cdot \left\{ F^2_V + ... + F^2_A + ... \right\} \approx 1.686 \times 10^{-20} \cdot \left( \frac{< E_e >}{1 \text{ MeV}} \right)^2 \cdot 2.6116 \cdot \text{barn}. \]

Looking into neutrino energies, the overall effects are to be dominated by the \(^8\text{B}\) neutrinos. It follows that different numbers can then be estimated easily. We think that the scenario reached here is very interesting indeed.

Maybe we could divide the planets into two categories: (Category I:) those similar to the Jupiter as mini-Suns and (Category II:) those similar to the Earth, having the elements greater than or equal to \(A=12\). For Category I, the discussion could stop here.

For the Venus (or planets in Category II), our other important example, the composition is largely unknown - maybe we could take the Earth as the profile. In the presence of the \(^8\text{B}\) neutrinos, the \(^{12}\text{C}\) nucleus can change into \(^8\text{Be}\) and \(\alpha\), or three \(\alpha\) nuclei. This turns out
to be the most important reaction. If there are $^{16}O$ nuclei in abundance, the $^8B$ neutrinos will change $^{16}O$ into $^{12}C$ and $^\alpha$ nuclei. If we consider these $^\alpha$-stable nuclei, the $^8B$ neutrinos provide reactions in the anti-chain order - but slowly, more slowly than the lifetime of the planets, but to be detectible.

At the surface of the Venus (like the Earth), there are plenty of cosmic rays from the Sun. For example, at the surface of the Earth, we have the intensity of nucleons from a few GeV up to above 100 TeV,

$$I_N(E) \approx 1.8E^\alpha \text{ nucleons } cm^2 \cdot sec \cdot Sr \cdot GeV,$$

with $\alpha = \gamma + 1 \approx 2.7$. Among these, 79% are free protons and 70% of the rest are nucleons bound in helium nuclei. This is another major source of nuclear reactions which we can think of. Of course, there are some meteorites bombarding the Earth’s surface. Without some reliable estimates of these numbers, the present paper can be safely referred to ”the inside of the Venus, and etc.”.

Cosmic rays would be another sources, similar to solar neutrinos, that would induce change in nuclear chemistry. Meteorites, astroids, and comets would be the other. Maybe, to the first approximation, we could neglect all these.

To make the discussions easier, we may introduce two ”units”:

$$T_0 = 1/2 \text{ billion yr} = 4.32 \times 10^{13} \text{ sec};$$

$$\Gamma_0 = 1 \text{ mole } \times 10^{-42} \text{ cm}^2 \cdot \Phi_\nu^B = 3.011 \times 10^{-12} \text{ sec}^{-1},$$

with $\Phi_\nu^B = 5 \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$. For example, one mole (about 1 cm$^3$) of material on the Earth would be bombarded by $^8B$ solar neutrinos with $\Gamma_0$ interactions per second. During the Earth’s life, it would be $T_0\Gamma_0 = 130$ interactions.

These standard units indicate that the extraterrestrial solar neutrino physics involves the reactions fairly feeble and reactional rates fairly low. We would say that they are low-energy neutral weak interactions - slight slow than the charged weak interactions. It is very difficult but not impossible to achieve.

In a satellite experiment such as the dedicated Davis Jr. experiment, we use the enriched $^{36}Cl$ as the target (on the satellite) and collect the $^{36}Ar$ after the mission. It is clear that the experiment would be feasible, using the above estimates as a guide.

9 Matter-enhanced Neutrino Oscillations

Neutrino oscillations could happen in several ways - oscillating into different flavors but conserving the total lepton number ($L = L_e + L_\mu + L_\tau$), oscillating into the sterile species ($\nu_s$), oscillating into the antineutrinos via the so-called ”see-saw” mechanism, and so on. Of course, we don’t know exactly in what way neutrino oscillations take place[3] and for the sake of simplicity we assume that the Nature would prefer the simplicity and choose the first option.

Matter-enhanced neutrino oscillations is now established to be of importance in the Sun. We don’t know how big the signal when neutrinos pass through the Venus or Mercury - to eventually measure during the Sun-Venus-Earth eclipse or the Sun-Mercury-Earth eclipse.
On the other hand, we could speculate that what happens in the Sun is also true in the Jupiter, the Mini-Sun, a factor of 10 smaller (in diameter). To study the effects, we imagine that some satellite is launched to circulate the Jupiter such that the Sun are in line with the Jupiter and the Satellite. Similar could be thought of the Sun and the Venus and the satellite configuration.

We think that the Sun-Jupiter-satellite experiments should be seriously considered mainly because all our knowledge points to the positive matter-enhanced oscillation experimental results.

The situation during the Sun-Venus-Earth eclipse would be different in detail from that during the Sun-Mercury-Earth eclipse. Here we have used $\Delta m^2 = 8.0 \times 10^{-5} eV^2$ and $\theta = 33.9^\circ$, and now use the relevant distance, of the order $10^3 km$, and the neutrino energy, of a few $MeV$; we see that the angular factor is more than of order unity - fortunately!! It means that we can in principle measure everything.

Here we wish to point out that it’s very different from that in the so-called "day-night" effect, done on the Earth - in terms of the phase space. The "day-night" effect involves a small cone of the Earth and could be very small.

The question is whether the matter-enhanced neutrino oscillations could be studied using the Sun-Venus-Earth eclipse or the Sun-Mercury-Earth eclipse. Most of these oscillation issues might in principle be investigated in experiments on the Earth - maybe there would be no need to go to the Jupiter or the Venus to enhance our knowledge.

Coming to think about it, everything presumably happens in our Sun but God forbids us from doing an experiment on the Sun except just observing. Hopefully, to do experiments, not necessarily with solar neutrinos, on the Venus or the Jupiter is no longer a dream, and would be a reality a few decades from now.

On the other hand, the chemical composition of the Jupiter and of other planets, if could be measured with precision (which turns out to be very difficult), could be another important direction to go. In particular, we may answer the questions regarding the origins of these planets.

To sum up, the future of the extraterrestrial solar neutrino physics (etSNP) seems to be very bright.

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