Cover Page

White Paper NAS: State of the Profession Considerations.
Astronomy and Astrophysics.
And for publication in the Bulletin of the American Astronomical Society (BAAS).

Problems in Neutrinos and Intergalactic Communication

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Contents. (Fulfills format requirements – text fewer than 10 pages).

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1. Abstract (overview and impact)

One of the central difficulties in neutrino astrophysics is the problem of identifying and classifying their flavors, energies, masses, relativistic effects, interactions with Standard Model particles, trans-Standard Model particles (e.g. SuperSymmetry), and Dark Matter. Moreover, neutrinos that arrive at the Earth are omnidirectional and it is a fundamental goal to resolve their possible signal profiles and signatures from background. However, neutrino technology is rapidly advancing and progressively solving these problems.

Consequently, an increased ability is anticipated to evaluate neutrino sources and identify possible artificial sources of neutrinos, a prime goal of searches for extraterrestrial intelligence (SETI). An example - case in point - is that Kardashev-Dyson advanced technology civilizations, expending the power needed to accomplish large scale planetary modifications and maneuvers, could likely utilize energy sources that release large numbers of neutrinos, with specific identifiable signatures or profiles.

Consequently, the goal of detecting possible neutrino signatures, impacts directly on both a deeper understanding of neutrino physics as well as on the assessments of possible communications from advanced technological civilizations. However, on this note, it is also relevant to point out that there are differing opinions – and caveats - as to the advisability of possible indiscriminate communication transmissions from the Earth. *Au contraire*, advanced civilizations may select cautious choices, if at all, to do so. Furthermore, some advanced civilizations may reject communications and select to remain hidden for security and well-being. Others may establish confidential interstellar communities and avoid haphazard broadcasts. In any case, communications, such as may exist, may well be difficult to distinguish and could be hidden under several codes, layers, or covert veiled wraps. [6-9, 19, 26, 28, 34, 48]

2. Issues

Here, we briefly review a few problems in neutrino research and the possible use of neutrinos for interstellar and intergalactic communications. The issue is the search for extraterrestrial intelligence by neutrino communication reception. Several well-known milestones paved the way for this goal, including work involving photons by Cocconi and Morrison in 1959, Drake in 1965, Tarter in 2001, as well as many others. [11, 18, 26, 45, 48, 60, 66, 72]

3. Neutrinos

The three flavors of neutrinos (lepton Fermions) are electron, muon, and tau neutrinos. Additional types of neutrinos may include sterile and heavy neutrinos. Some neutrinos are remnants of the Big Bang (approximately 14 billion years ago) and may differ from neutrinos produced by nuclear (bomb) explosions, radioactive decay, atmospheric impact by cosmic rays and solar wind, particle accelerators, nuclear reactors, stars, supernovae, quasars, black holes, neutron stars, and red dwarfs. Neutrinos are products of the Weak force charge or neutral currents (W^-, W^+, and Z^0 Bosons), crisscross the universe, and rarely interact with matter.[1]

For example, neutrinos can be produced by nuclear beta decay [55] and in the following case, an anti-neutrino is produced:

$$(Z, N) \rightarrow (Z+1, N-1) + e^- + \bar{\nu}_e \ (\beta^- \ decay)$$

Another example is the reaction producing positrons, neutrinos, and energy in stars (via the carbon cycle):

$p + p + p + p \Rightarrow He^4 + e^+ + e^+ + \nu_e + \nu_e + 26.7$ MeV

Seventy billion per cm^2 per sec of these ν_e's should be detected at the Earth. However, 1/3 of these are detected and this is due to neutrino flavor changes, termed neutrino oscillation. Through oscillations, the three neutrino flavors transform among one another, while traversing various distances, and they have internal 'clocks', governing when to transform. The following are the 6 leptons of the Standard Model. [2]

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

Flavor transfiguration from one neutrino to another of the three is an oscillatory event, embodied by functions of neutrino wave travel-distance. This neutrino-traversed oscillation distance is inversely proportional to the difference between each neutrino mass squared and proportional to the average neutrino energy. Moreover, superposition of mass eigenstate mixing coefficients control the overall probability. Unitary 3x3 matrix equations are produced by the mixing coefficients.

$|\nu_f\rangle = U_{fj} |\nu_j\rangle$

[1] For example, there are 300-400 neutrinos per cubic centimeter and trillions of neutrinos traverse the human frame per second. [42]

[2] However, neutrino mass and oscillation contribute to amending physics beyond the Standard Model.

U_{fj} is a unitary matrix; ν_f represents the three neutrino flavors (eigen states), ν_e, ν_μ, and ν_τ. In addition, ν_j represents the three putative neutrino masses, ν_1, ν_2, and ν_3. The values in the unitary matrix are based on four parameters: a phase and three angles, which are determined by oscillation experiments as well as from various models for neutrino production.[3]

In vacuo, the complete equation of neutrino oscillations (flavor change) is:

$$P(\nu_\alpha \rightarrow \nu_\beta) = \delta_{\alpha\beta} - 4\Sigma_{k>j}\mathrm{Re}(U^{+}_{\alpha k}U_{bk}U_{\alpha j}U_{pj})\sin^2(\Delta m_{kj}^2 L/4E) + 2\Sigma_{k>j}\mathrm{im}(U+_{\alpha k}U_{bk}U_{\alpha j}U_{pj})\sin(\Delta m_{kj}^2 L/4E)$$

However, for neutrinos traveling through matter, the flavor change probability equation is:

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2(\mathrm{theta})_M \sin^2 (\Delta m_M^2 x/4E)$$

Much effort is being invested to decide neutrino masses; among many, one remote possibility, proposed by Williams in 2001, is to produce a very high intensity yield muon source on the Moon (thereby reducing environmental and other radiation toxicity dangers) and then measure neutrinos directed to the Earth.

Among many complications, advanced civilizations will have to deal with difficulties of neutrinos traversing large distances, at times traversing stars, various interstellar and intergalactic media, Dark Matter, as well as relativistic and QCD upshots. [2, 14-17, 20-25, 29, 32, 33, 40-44, 46, 54-56, 58, 70, 78]

4. Neutrinos and Intergalactic Communication.

The problem that remains after many decades of the detection of extraterrestrial intelligence using photons is the lack of signal detection. In 1977, Saenz and colleagues proposed to use beams of neutrinos (energy range 1-100 GeV to produce communications on a global distance scale). At the time, such beams could be produced from proton accelerators. Next, in 1979, Pasachoff and colleagues proposed that advanced civilizations may utilize neutrino production for communication, which we may detect on the Earth. The authors presented several advantages of neutrino transmission as a message carrier: neutrino penetrability; the universal reception of neutrino signal from the full 4π spherical area; possibility of narrow foci of neutrino beams in order to improve chances of signal reception at great distances; and broad ranges of energies to select amongst. The same year, Subotowicz published on the use

[3] In contrast to P.A.M. Dirac, E. Majorana proposed different types of fundamental particles with unanticipated concepts that revolutionized ideas of matter that composes the universe. Thus, particles such as neutrinos that have no charge, can be their own anti-particles, according to Majorana. [40] Accordingly, double beta decay experiments are underway, for which there should be the absence of neutrino detection – a matter for experiment and debate.

of neutrino beams for interstellar communications and included calculations for 10 and 1,000 light year distances. [38, 47, 59, 69]

In 1994, Learned, Pakvasa, and colleagues analyzed the problem of transmission of timed data across interstellar distances. Since photons do not measure up to the requirements for interstellar communication, synthetic non-natural neutrino pulses may be useful. Timing marker pulses are required for clock synchronization across distance and are more difficult for greater distances. This requires ultrasensitive brief standards of time intervals (standard pulses as narrow as 10^{-21} sec across interstellar distances. Synchronization methods are required due to (general and special) relativistic effects across such distances. Learned *et al* discuss an example of a 20 million light year distance for which the loss of precision would range from the order of 10^{-14} to 10^{-23} sec year^{-1}. [37]

Chaos factors in multiple body motions set the stage for refinement of clock synchronization methods. Learned *et al* point out that in the local frame, the best basis for synchronization at the time was the Josephson junction, which was stable to 3 parts in 10^{-19}. The problem of relativistic corrections is significant, especially due to neutrino oscillation, speed, and masses. [35, 37] (Additionally, it may be pointed out that these evaluations do not include the possible effects of Dark Matter and Dark Energy.)

Learned, Pakvasa, and Zee present their theoretical model for advance civilizations in which neutrino and anti-neutrino signals can be produced efficiently by Z^0 bosons as follows: $e^+e^- \rightarrow Z^0 \rightarrow \nu$ and anti-ν where Z^0 mass is 91.1 GeV, $E_\nu = M_Z/2 = 45.6$ GeV, the three flavors produced in equal numbers. Anti-neutrinos can be detected by W^- boson production as follows: anti-ν_e and $e^- \rightarrow W^-$ where $E_e = M_w^2/4E_\nu = 35.1$ GeV. Various additional conditions are provided to then produce neutrinos and anti-neutrinos at a high pulse rate and to detect them. Clock calibration is based on neutrino vs. anti-neutrino detection. However, timing of the transmitter neutrino vs. anti-neutrino must be known in order to calibrate the receiving clocks (with relativistic corrections across 10 kpc).[4] Next, relating current SETI (Search for Extraterrestrial Intelligence) technology to the Learned et al advanced technology, they point out that signals from the center of the galactic center would be undetectable; however, signals from a distance of 1 kpc would be possible with a 1 km^3 effective water volume instrument. It is further indicated that much work needs to be done in regard to discriminating signal from noise and signal direction.

Learned *et al* further examined the intra-galactic neutrino basis of communication. They hypothesized that creation of neutrino and anti-neutrino beams, at resonant neutrino energies near 6.3 PeV (including the Z^0 and W^- resonances), were possible, and perhaps even at 30 PeV. They further stated that such beams could be detectable by current neutrino detectors. To enable encoding information for possible communication, Learned et al also proposed the feasibility of a 'Morse code' type signaling, which may

[4] 1kpc = 3,261.564 light-years. The diameter of the Milky Way is 30 kpcs. The distance from the Earth to the galactic center is 8 kpcs.

surmount several physical and technological problems. Additionally, they pointed out that for communications within the galactic plane, photons can be readily obscured or perturbed: photon jitter and scattering decreases the signal/noise ratio of potential interstellar communications, and Einstein gravitational lensing, when asymmetric, will also contribute to clouding of any potential photon communication signals. [37, 38, 46]

Neutrinos, be they Dirac or Majorana, may additionally be subject to signal alterations as they traverse Dark Matter tufts within or outside galaxies. Even more enveloping is the preponderance of Dark Energy, which may also contribute to perturbations of neutrino travel crisscrossing intergalactic distances. In particular, there is an abundance of theories in regard to Dark Energy and Dark Matter including how they may interact with Standard Model and Supersymmetry particles. Moreover, interactions with neutrinos (Dirac, Majorana, or sterile) require much further study to describe neutrino communications across large distances. [3, 4, 40, 52, 74]

It should be noted that perhaps binary code signals are advantageous for communication for the widest possible range of audiences of sending and receiving signals at differing levels of extraterrestrial intelligence and technology. Moreover, perhaps flavor changes themselves, could someday be utilized to produce such binary signals (once the problems of dissipation are solved). The statistical approaches involved in handling entropies and signaling, range from Shannon's more deterministic approach to Kolmogorov's more intuitive approach. The influence of relativistic effects on such information/entropy and signal content requires further analysis to attempt to extricate information that may be embedded in various possible modes of neutrino signaling. Such considerations are needed, due to the large interstellar, let alone intergalactic distances, embodied in potential neutrino broadcasting. [5, 64, 65]

With regard to SETI, Silagadze, in 2008, described an approach involving intense neutrino beams produced from muon colliders beams. They proposed that such beams at TeV power levels could be detected, if pointed at the Earth by advanced civilizations. The IceCube neutrino telescope would be an example of a detector in their proposal. The distance traversed by such neutrinos would be 20 light years and the duration to complete detection, at least a year. In support of the use of modified neutrino beams for signaling, in 2012, Stancil et al were able to detect modified neutrino signals using ground-based detection. [67, 68]

Harris in 2002, proposed that gamma-ray photons could be produced by machines powered by proton-antiproton annihilation. They analyzed data accumulated 1991-1995, in the relevant 30-928 MeV range from the EGRET experiment carried by the Compton Gamma Ray Observatory. Harris concluded that within 10 AU[5] there is no evidence for antiproton-proton annihilation machine use. However, since neutrinos are produced in proton-antiproton annihilation, it should be noted that a similar systematic search for neutrinos rather than photons could be utilized. [10, 13, 30, 31, 34, 37, 38, 47, 50, 59, 67-69, 71, 73, 79]

[5] 10 AU = 1.5×10^9 km.

As mentioned, through his Majorana neutrino concept, Majorana thereby influenced how we may approach the problem of exobiological intelligent life. This is pivotal because it points to unanticipated forms of matter that may be intimately connected with the possible detection of extraterrestrial intelligence, let alone extraterrestrial communication. What appeared anomalous and counter-intuitive, such as a particle being its own anti-particle, may become part of the signatures of advanced civilizations. [40]

Several particles and their possibly cognate supersymmetry particles are shown in Table 1. Table 2 shows several interactions among particles in the Standard Model. Indeed, several candidate particles have been discussed as present in Dark Matter including WIMPs and sterile neutrinos, whose interactions are under theoretical study to assist in experiments. Additionally, various theories are being developed as to the interactions of Supersymmetry particles. Such studies will be on firmer ground when any of the particles are identified. [1, 41, 53, 57]

Table 1. Several selected particles and their corresponding supersymmetry particles, extending the Standard Model to the Minimal Supersymmetric Standard Model. [27, 51, 61, 77]

Particle	Supersymmetry particle
Gluon	Gluino
Neutral boson	Neutralino
Charged boson	Chargino
Gauge boson	Gaugino
Lepton	Slepton
Quark	Squark
Neutrino	Sneutrino
Sterile neutrino	Sterile sneutrino
Majorana neutrino	
Majoron	
Higgs	Higgsino
Photon	Photino
Graviton	Gravitino
	Inflaton
	Chameleon

(Anti-particles are not shown.)

Table 2. Interactions of standard model particles. [12]

Particles & Interactions	γ photon	**W±** bosons	**Z** boson	**H** Higgs boson	**G** Gluon
$e^- \mu^- \tau^-$ charged leptons	yes	yes	yes	yes	
$\nu_e\ \nu_m\ \nu_t$ neutrinos		yes	yes		
u c t **d s b** quarks	yes	yes	yes	yes	yes
H		yes	yes		
W±	yes		yes		
γ		yes			

(Sterile neutrino and anti-particles are not shown.)

5. Conclusion and Future Directions

The field of production and detection of signaling by advanced civilizations is evolving from photon physics towards particle physics. Central are the greater penetrability and lower occlusion of neutrinos compared to photons in interstellar and intergalactic medium.

In future publications, we will continue to study neutrinos in terms of the growing knowledge of their fundamental properties as well as what global cosmology has to elucidate for us. To assess their use for interstellar communications by advanced civilizations, these studies include neutrino masses, energies, relativistic effects, flavors, Dirac and Majorana, interactions with Standard Model and SuperSymmetry particles, as well as Dark Matter and Energy. Coming to grips with how advanced civilizations may utilize neutrinos for communication involves understanding both neutrinos and Cosmology. The problem in neutrinos and intergalactic communication is embedded within a highly complex global background. [22, 36, 40, 75, 76]

6. Acknowledgments

G. Rajasekaran (Chennai, India), G. Baumslag (Princeton, New Jersey), C. Smith (Princeton, New Jersey), and C. Sagan (Ithaca, New York) are thanked for discussions.

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