SETI AND MUON COLLIDER

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Intense neutrino beams that accompany muon colliders can be used for interstellar communications. The presence of multi-TeV extraterrestrial muon collider at several light-years distance can be detected after one year run of IceCube type neutrino telescopes, if the neutrino beam is directed towards the Earth. This opens a new avenue in SETI: search for extraterrestrial muon colliders.

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Are we alone in the immensely large universe? This is one of fundamental questions steering the interest of broad public to SETI — the Search for Extra-Terrestrial Intelligence. "It is to everyone's benefit to nurture this interest in the real science of SETI rather than in the pseudoscience that preys on the public's credulity" [1]. The theme of extraterrestrial creatures was always popular in human history and still abounds in popular culture. However, the real scientific SETI begins from the paper of Cocconi and Morrison some 50 years ago [2], followed by the Project Ozma [3], the first dedicated search of extraterrestrial radio signals from two nearby Sun-like stars. Ever since it was usually assumed that the centimeter wavelength electromagnetic signals are the best choice for interstellar communications. Here we question this old wisdom and argue that the muon collider, certainly in reach of modern day technology [4], provides a far more unique marker of civilizations like our own (type I in Kardashev's classification [5]). Muon colliders are accompanied by a very intense and collimated high-energy neutrino beam which can be readily detected even at astronomical distances.

Muon collider was first suggested by Budker forty years ago [6]. Ionization cooling, the idea that dates back to O'Neill [7], provides the possibility to make very bright muon beams [8]. Muons are unstable particles and their decays produce neutrinos. Therefore, high-luminosity muon collider with long straight sections is also a neutrino factory producing the thin pencil beams of neutrinos [9]. The expected neutrino intensities are so huge that even constitute a considerable radiation hazard in the neighborhood of the collider [10]. Nevertheless, the present day technology is mature enough to make the construction of muon collider and hence neutrino factory quite realistic [4, 11]. We may wonder whether extraterrestrial civilizations also built muon colliders and are illuminating us by accompanying neutrino beams. Can we detect these neutrinos from the alleged extraterrestrial muon colliders?

Due to relativistic kinematics, all neutrinos emitted by an ultra-relativistic muon in the forward hemisphere in the muon rest frame will be boosted, in the laboratory frame, into a very narrow cone with an opening half-angle,

$$\theta \approx \frac{1}{\gamma} \approx \frac{10^{-4}}{E_\mu[\text{TeV}]}\,,$$

where γ is the relativistic boost factor of the muon and E_μ is its energy.

Therefore, $E_\mu = 200$ TeV extraterrestrial muon collider operating at the $L = 20$ light-years distance will illuminate with neutrinos a disk of radius $R \approx L\theta \approx 10^8$ km, which is somewhat smaller than the Earth's orbital radius. The neutrino flux on the Earth, assuming the Earth is inside of the neutrino disk, will be $\Phi_\nu \approx 10^5$ year^{-1} km^{-2}, if the neutrino beam intensity at the muon collider is $N_\nu = 3 \times 10^{21}$ year^{-1}.

The main difficulty in neutrino detection is that neutrinos are very weakly interacting elusive particles. One of methods of high-energy neutrino detection is to look for muons generated in charged-current interactions of neutrinos in the rock below the detector [12]. The muon should be generated within the muon range in the rock (about one kilometer for TeV muons) to reach the detector and produce observable signal through the Cherenkov radiation. The probability that a neutrino of energy E_ν will produce a muon within the muon range from the detector is approximately $P_{\nu\to\mu} = 1.7 \times 10^{-6} E_\nu^{0.8}$ for multi-TeV neutrinos [12, 13]. For $E_\nu = 100$ TeV this gives $P_{\nu\to\mu} \approx 7 \times 10^{-5}$.

The similar conclusion $P_{\nu\to\mu} \approx 10^{-4}$ can be reached from estimates of the probability of neutrino interaction in the effective detector volume, after penetrating through Earth from the gamma-ray burst in the northern hemisphere, in a km deep under-ice detector at the South Pole [14].

Therefore, for $S = 1$ km^2 area neutrino detectors, such as IceCube at the South Pole [15] the expected rate of neutrino events from the hypothetical extraterrestrial muon collider is

$$R = \Phi_\nu S P_{\nu\to\mu} \approx 7 - 10 \text{ year}^{-1} . \quad (1)$$

Cosmic-ray induced background for IceCube detector is about 0.08 neutrino events with $E_\nu > 10$ TeV per year per square degree [16]. In light of IceCube's very good angular resolution (better than 1° [15]), we conclude that detection of point-like multi-TeV neutrino sources is essentially background free for such type of neutrino detectors and, therefore, (1) constitutes a significant signal allowing to detect the presence of extraterrestrial muon collider at 20 light-years distance after one year run.

Note that the parameters of the muon collider we have assumed ($E_\mu = 200$ TeV, $N_\nu = 3\times10^{21}$ year^{-1}), although challenging for modern-day technology, are likely to be within its reach, at least for single-pass muon colliders [17]. Therefore, (1) should be considered as a lower bound for advanced civilizations. For example, a futuristic 10^3 TeV muon collider was suggested [18] to use the accompanying ultra high-energy neutrino beam for destruction of terrorist's concealed nuclear warheads. We hope that advanced civilizations capable to develop the necessary technology are already free from such nasty problems. However, we may imaging various peaceful applications of the high-energy neutrino beams, for example, for the study of the inner structure of the host planet [19].

There have been proposals to use collimated neutrino beams for telecommunications [20, 21], including even interstellar communications [22, 23]. However, only now, on the eve of muon collider era, this fantastic idea acquires a realistic shape.

It is clear that practical realization of interstellar neutrino communications requires higher level of technology than our civilization now possesses. It was suggested that advanced civilizations may deliberately choose the neutrino channel for interstellar and intergalactic communications to shutout very young and not mature emergent civilizations like our own from the conversation [22].

Intergalactic neutrino communications will require much higher neutrino energies and intensities. Maybe type III civilizations (which have captured the power of an entire host galaxy) can produce and control neutrino beams even beyond the so called Greisen–Zatseptin–Kuzmin limit of about 10^{19} eV. Interestingly, Askaryan effect [24] allows to develop large-scale detectors to detect such ultra high-energy neutrinos through the coherent Cherenkov radio signal created by an neutrino initiated electromagnetic shower in a salt dome. Hopefully we will soon have an operating detector of this type [25].

Neutrino SETI was also proposed earlier with somewhat different perspective [26]. It was suggested that type II (which have captured all of the power from their host star) and type III civilizations, spread throughout the Galaxy, may require interstellar time standards to synchronize their clocks.

It is argued that mono-energetic 45.6 GeV neutrino pulses from the $Z^0 \to \nu\bar{\nu}$ decays produced in a futuristic dedicated electron-positron collider of huge luminosity may provide such standards. If there is an extraterrestrial civilization of this type nearer than about 1 kpc using this synchronization method, the associated neutrinos can be detected by terrestrial neutrino telescopes with an effective volume of the order of km^3 of watter [26].

An appealing feature of the neutrino SETI is that it does not require any special efforts, in contrast to the radio SETI, and can be conducted in a background regime as a by product of the conventional neutrino astrophysics. There are several neutrino telescopes under construction world wide that will allow neutrino detection in a broad energy range. We just should have in mind that some high-energy neutrino signals which will be detected by these devices might have artificial origin.

We conclude that at the jubilee of the SETI proposal by Cocconi and Morrison it is just the time to search for neutrino signals from extraterrestrial muon colliders. What is the probability of success? "The probability of success is difficult to estimate: but if we never search, the chance of success is zero" [2].

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REFERENCES

[1] J. Tarter, *Annu. Rev. Astron. Astrophys.* **39**, 511 (2001).

[2] G. Cocconi, P. Morrison, *Nature* **184**, 844 (1959).

[3] F.D. Drake, in *Current Aspects of Exobiology*, eds. G. Mamikunian, M.H. Briggs, Pergamon, New York 1965, p. 323.

[4] C.M. Ankenbrandt *et al.*, *Phys. Rev. ST Accel. Beams* **2**, 081001 (1999) [physics/9901022].

[5] N.S. Kardashev, *Sov. Astron.* **8**, 217 (1964).

[6] G.I. Budker, in Proceedings of the 7th International Conf. on High Energy Accelerators, Academy of Sciences of Armenia, Yerevan 1969, p. 33, in Russian.

[7] G.K. O'Neill, *Phys. Rev.* **102**, 1418 (1956).

[8] A.N. Skrinsky, V.V. Parkhomchuk, *Sov. J. Part. Nucl.* **12**, 223 (1981).

[9] S. Geer, *Phys. Rev.* **D57**, 6989 (1998) [Erratum, *Phys. Rev.* **D59**, 039903 (1999)] [hep-ph/9712290].

[10] B.J. King, *AIP Conf. Proc.* **530**, 165 (2000) [hep-ex/0005006].

[11] M.M. Alsharoa *et al.* [Muon Collider/Neutrino Factory Collaboration], *Phys. Rev. ST Accel. Beams* **6**, 081001 (2003) [hep-ex/0207031].

[12] T.K. Gaisser, F. Halzen, T. Stanev, *Phys. Rep.* **258**, 173 (1995) [Erratum *Phys. Rep.* **271**, 355 (1996)] [hep-ph/9410384].

[13] F. Halzen, D. Hooper, *Rep. Prog. Phys.* **65**, 1025 (2002) [astro-ph/0204527].

[14] S. Razzaque, P. Meszaros, E. Waxman, *Phys. Rev.* **D69**, 023001 (2004) [astro-ph/0308239].

[15] J. Ahrens *et al.* [IceCube Collaboration], *Astropart. Phys.* **20**, 507 (2004) [astro-ph/0305196].

[16] C.D. Dermer, *J. Phys. Conf. Ser.* **60**, 8 (2007) [astro-ph/0611191].

[17] F. Zimmermann, *AIP Conf. Proc.* **530**, 347 (2000).

[18] H. Sugawara, H. Hagura, T. Sanami, hep-ph/0305062.

[19] A. De Rujula, S.L. Glashow, R.R. Wilson, G. Charpak, *Phys. Rep.* **99**, 341 (1983).

[20] A.W. Saenz, H. Ueberall, F.J. Kelly, D.W. Padgett, N. Seeman, *Science* **198**, 295 (1977).

[21] H. Ueberall, F.J. Kelly, A.W. Saenz, *J. Wash. Acad. Sci.* **69**, 48 (1979).

[22] M. Subotowicz, *Acta Astronautica* **6**, 213 (1979).

[23] J.M. Pasachoff, M.L. Kutner, *Cosmic Search* **1N3**, 2 (1979).

[24] P.W. Gorham *et al.* [ANITA Collaboration], *Phys. Rev. Lett.* **99**, 171101 (2007) [hep-ex/0611008].

[25] K. Reil [SalSA Collaboration], *AIP Conf. Proc.* **842**, 980 (2006).

[26] J.G. Learned, S. Pakvasa, W.A. Simmons, X. Tata, *Q. J. R. Astron. Soc.* **35**, 321 (1994).