Constraints on extragalactic point source flux from diffuse neutrino limits

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We constrain the maximum flux from extragalactic neutrino point sources by using diffuse neutrino flux limits. We show that the maximum flux from extragalactic point sources is $E^2(dN_\nu/dE) \leq 1.4 \times 10^{-9}(L_\nu/2 \times 10^{43}\ \text{erg/s})^{1/3}\ \text{GeV}\,\text{cm}^{-2}\,\text{s}^{-1}$ from individual point sources with average neutrino luminosity per decade, L_ν. It depends only slightly on factors such as the inhomogeneous matter density distribution in the local universe, the luminosity distribution, and the assumed spectral index. The derived constraints are at least 1 order of magnitude below the current experimental limits from direct searches. Significant constraints are also derived on the number density of neutrino sources and on the total neutrino power density.

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The origin of ultra high energy cosmic rays (UHECR), is still unknown. Active galactic nuclei (AGN), gamma-ray bursts (GRBs), or processes beyond the standard model have been hypothesized to be the sources of UHECRs. If nearby AGN are the sources of the highest energy cosmic rays [1], and if AGN emit neutrinos in addition to photons, protons and other charged particles at comparable fluxes, then individual AGN may be observable by current generation of neutrino detectors. However, only the nearest sources would be detectable as point sources, while the contribution of an ensemble of unresolved extragalactic sources would generate a diffuse flux of neutrinos. There are plausible but speculative reasons to expect a correlation between sources of cosmic rays and sources of neutrinos. Several models predict a diffuse neutrino flux from AGN, in particular, neutrino production has been predicted from the core of radio-quite AGN [2,3], and from AGN jets and radio lobes [4–6]. Direct searches for diffuse [7] and point flux [8] by current telescopes have set the most stringent upper limits, but generally have not reached the sensitivity required, and the models suggest that challenges exist even for next generation telescopes. One of the primary motivations for the construction of neutrino telescopes is to search for unexpected sources with no obvious connection to the power emitted in the electromagnetic band.

We show in this paper that the ν flux from extragalactic point sources can be constrained by the measured diffuse ν-flux limits, and we also use these results to constrain the neutrino intensity predicted in models from individual sources. The derived constraints are 1 order of magnitude below current experimental limits from direct searches for energies between TeV–PeV, and below current limits and sensitivities of km^3 neutrino telescopes, such as IceCube, for energies between PeV–EeV. Since, the constraints scale with the power of 2/3 of the measured diffuse flux, an expected factor three improvement in the diffuse flux sensitivity for 1 year of IceCube [9] data improves the constraints by another factor two.

Point sources of neutrinos are observed when several neutrinos originate from the same direction, and in the context of this study, only the very nearest of an ensemble of extragalactic sources are detectable as point sources. The number of detectable (or resolvable) point sources, N_s, presented in [10], is determined for a given diffuse ν-flux limit and point source sensitivity. The N_s calculation is based on three assumptions: (1) the sources are extragalactic and uniformly distributed in space; (2) the neutrino luminosity follows a power law or broken power law distribution; (3) the sources are assumed to emit neutrinos with an E^{-2} energy spectrum. Later, we discuss the robustness of the constraint by investigating the validity and caveats of the assumptions.

The number of resolvable sources N_s for a distribution of luminosities L_ν per decade in energy is given by

$$N_s \simeq \frac{\sqrt{4\pi}}{3} \frac{1}{\sqrt{\ln(\frac{E_{\max}}{E_{\min}})}} \frac{H_0}{c} \frac{K_{\text{diff}}}{(C_{\text{point}})^{3/2}} \frac{\langle L_\nu^{3/2}\rangle}{\langle L_\nu\rangle} \frac{1}{\xi}, \qquad (1)$$

where the parameter ξ which is close to unity, depends on cosmology and source evolution as described in [10]. The neutrino luminosity of the source L_ν has units of (erg/s), and $(E_{\min}, E_{\max})$ defines the energy range of the flux sensitivity, where $E_{\max} = 10^3 E_{\min}$ for a typical experimental condition. For canonical energy spectrum proportional to E^{-2}, we use the ultra high energy (UHE) results for all-flavor diffuse flux limits from AMANDA [7] to obtain the diffuse ν_μ flux, $K_{\text{diff}} \equiv E^2\Phi_{\nu_\mu} = (1/3) * E^2\Phi_{\nu_{\text{all}}} = (1/3) * 8.4 \times 10^{-8}\ \text{GeV}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1} = 2.8 \times 10^{-8}\ \text{GeV}\,\text{cm}^{-2} \times \text{s}^{-1}\,\text{sr}^{-1}$, valid for the energy interval of 1.6 PeV $< E <$ 6.3 EeV. This is the energy interval of interest for cosmic ray interaction with energies above the ankle. For neutrinos at the very high energy (VHE), we also use limits from AMANDA [11], $K_{\text{diff}} < 7.4 \times 10^{-8}\ \text{GeV}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$, valid between 16 TeV to 2.5 PeV. So, similar diffuse flux limits exist for the entire interval from TeV to EeV ener-

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gies. $C_{\rm point}$ is the experimental sensitivity to ν fluxes from point sources for an E^{-2} spectrum, where the sensitivity from AMANDA [8] is $C_{\rm point} = E^2(dN_\nu/dE) < 2.5 \times 10^{-8}$ GeV cm^{-2} s^{-1}.

The diffuse flux $K_{\rm diff}$ parameter and the point flux sensitivity $C_{\rm point}$ are linearly correlated by the following equation:

$$4\pi K_{\rm diff} = \left[3\left(\frac{c}{H_0}\right)\frac{1}{r_{\rm max}}N_s\right] \times C_{\rm point}, \tag{2}$$

where (c/H_0) represents the Hubble distance given by $c/H_0 = 3 \times 10^5$ (km s^{-1})/77 (km s^{-1} Mpc^{-1}) ~ 4 Gpc. For the case of $N_s < 1$ the distance ratio $(c/H_0)/r_{\rm max} > 1$, which occurs for sources well within the Hubble distance. The parameter $r_{\rm max}$ defines the maximum observable distance for a point source of luminosity L_ν, which is given by

$$r_{\rm max} = \left[\frac{L_\nu}{4\pi \ln(E_{\rm max}/E_{\rm min})C_{\rm point}}\right]^{1/2}. \tag{3}$$

The constraint also holds for time variable sources, since it depends only on the observed luminosity and is independent of the duration of the variability [12]. Similarly, it holds for beamed sources, such as GRBs. However for luminosities of the order of 10^{51} erg/s typical of GRB emission, a dedicated search for GRBs leads to more restrictive limits [13].

We derive an upper limit on the maximum neutrino power density $\mathcal{P}_\nu^{\mathcal{C}}$ independently of the number density of sources, given by

$$\mathcal{P}_\nu^{C} \le 4\pi\frac{H_0}{c}\ln\left(\frac{E_{\rm max}}{E_{\rm min}}\right)K_{\rm diff} = 3.4 \times 10^{45}\ \frac{\rm erg/s}{\rm Gpc^3} \tag{4}$$

which is 1 order of magnitude below the power required to generate the energy density of the observed extragalactic cosmic rays [14].

A numerical value for N_s can be estimated by incorporating the diffuse ν-flux limit and the sensitivity to point sources in Eq. (1): $N_s \simeq (3.7 \cdot 10^{-29}\ {\rm cm}^{-1}) \times (K_{\rm diff}) \times (C_{\rm point})^{-3/2} \times (L_{\rm AGN})^{1/2} \times 1/\xi \simeq 10^{-3}$, computed assuming $L_{\rm AGN} = 2 \times 10^{43}$ erg/s. We chose to scale the value for the neutrino luminosity $L_{\rm AGN} = \mathcal{P}_\nu^{\mathcal{C}}/n_s = 2 \times 10^{43}$ erg/s for a number density of $n_s \sim 10^2$ Gpc^{-3} characteristic of AGN sources. The parameter $\xi = \xi_{\rm AGN} \simeq 2.2$ accounts for the effects due to cosmology and source evolution that follows AGN [10]. The estimate for $N_s \simeq 10^{-3}$, which is compatible with the nondetection of any point sources. The constraint on ν flux is determined by resolving at least one source, i.e. by setting $N_s = 1$ and inverting Eq. (1) to solve for $C_{\rm point}$:

$$E^2\frac{dN_\nu}{dE} \le \left[\frac{\sqrt{4\pi}}{3}\frac{1}{\sqrt{\ln(\frac{E_{\rm max}}{E_{\rm min}})}}\frac{H_0}{c}\cdot K_{\rm diff}\sqrt{L_\nu}\cdot\frac{1}{\xi}\right]^{2/3},$$
$$E^2\frac{dN_\nu}{dE} \le 1.4 \times 10^{-9}\left(\frac{L_\nu}{2 \times 10^{43}\ {\rm erg/s}}\right)^{1/3}\left(\frac{\rm GeV}{\rm cm^2\ s}\right), \tag{5}$$

valid for the same energy range 1.6 PeV $< E <$ 6.3 EeV of the diffuse flux limit $K_{\rm diff}$. This result defines a benchmark flux constraint $\Phi_C \equiv E^2(dN_\nu/dE) \le 1.4 \times 10^{-9}$ GeV cm^{-2} s^{-1} on neutrino fluxes from individual extragalactic point sources that produce the power required to generate the neutrino flux with $L_\nu = 2 \times 10^{43}$ erg/s. The benchmark flux constraint Φ_C is 1 order of magnitude lower than present experimental limits from direct searches, and strengthen for ensemble of sources that generate less power. These results show that the likelihood of detecting neutrino signal from AGN sources will be a challenge for next generation km-scale neutrino telescopes.

Figure 1 shows the benchmark constraint on extragalactic point source fluxes derived from the UHE and VHE diffuse flux limits. Models are shown with an energy spectrum proportional to E^{-2} (or approximately proportional over the UHE and VHE energy interval). The model predictions can be compared to the derived benchmark constraint, Φ_C, by assuming that the specific prediction characterizes the mean flux $\Phi_\nu^{\rm model}$, and energy distribution from an ensemble of sources. By computing the ratio $\mathcal{R} = \Phi_C/\Phi_\nu^{\rm model}$, models are constrained if $\mathcal{R} < 1$. The results from the constraint Φ_C compared to a number of models of neutrino point fluxes from extragalactic sources are summarized in Table I.

Models shown in Fig. 2 strongly deviate from an E^{-2} spectrum and in this class of models a direct comparison with the benchmark flux Φ_C is less straightforward. For the models [2,26–28], the predicted energy spectra are integrated over the UHE (VHE) energy interval to obtain the total number of neutrinos for the given model. The result is compared to the integrated neutrino events N_C determined by the benchmark flux Φ_C and by the detector neutrino effective area $A_{\rm eff}$:

$$N_C = t_{\rm live}\int_{E_{\rm min}}^{E_{\rm max}} \Phi_C A_{\rm eff}(E_\nu)dE. \tag{6}$$

Similarly, the number of neutrino events expected from a given model, $N_{\rm model}$, is computed by substituting the predicted energy spectrum for Φ_C in Eq. (6). The ratio $N_C/N_{\rm model}$ is found to be 0.07, 0.2, 0.03, and 0.17 for [NGC4151] [2], [3C273] [26], [GeV blazar] [27], and [Cen A] [28], respectively.

The maximum number density of extragalactic sources n_s can be expressed in terms of the neutrino luminosity L_ν, using the relation [12]

$$n_s \le 4\pi\frac{H_0}{c}\ln\left(\frac{E_{\rm max}}{E_{\rm min}}\right) \times \frac{K_{\rm diff}}{L_\nu}. \tag{7}$$

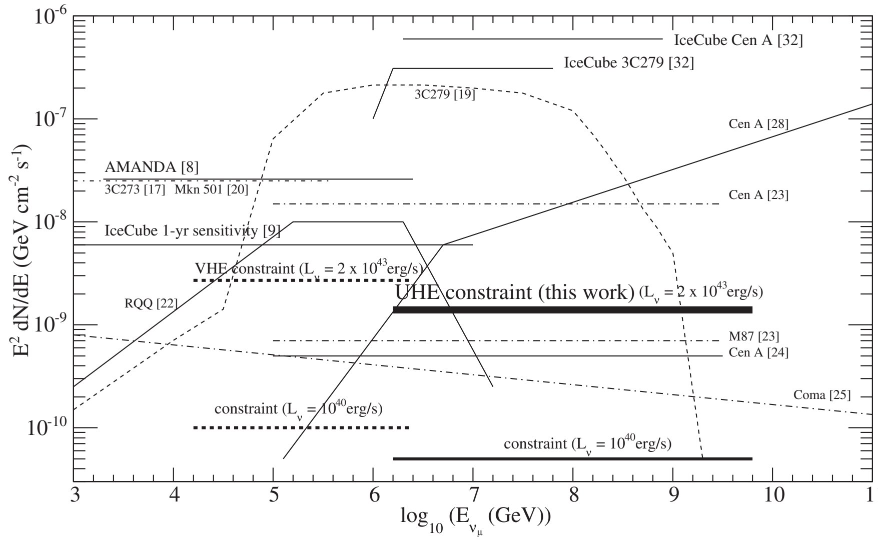

FIG. 1. Constraints on neutrino point fluxes derived from the UHE diffuse ν-flux limit [7], and from VHE limit [11], for two representative $\langle L_\nu \rangle = (10^{40}, 2 \times 10^{43})$ erg/s. Current AMANDA limit [8], IceCube sensitivity [9] to neutrino point fluxes,and IceCube limits [32] on fluxes from two individual point sources are also shown (thin solid lines). A sample of model predictions for ν_μ-point flux from extragalactic sources are displayed in thin dotted-dashed lines, which are proportional to an E^{-2} spectrum or follow a broken power law. Emission from AGN jet, calculated for a 3C279 flare of 1 day period (3C279 [19]); spectra predicted for Mkn 501 during the outburst in 1997 (Mkn 501 [20]) and core emission due to pp interactions (3C273 [17]); radio-quiet AGN (RQQ [22]); emission from Cen A as described in Cen A [23], Cen A [24], and Cen A [28]; emission from M87 (M87 [23]), and emission from Coma galaxy cluster (Coma [25]).

The number density is inversely proportional to the neutrino luminosity L_ν and scales linearly with the measured diffuse flux $K_{\rm diff}$. Therefore we can set a constraint on the number density n_s based on the measured diffuse flux limits $K_{\rm diff}$, as shown in Fig. 3. The thick solid line shows the constraint on $n_s \propto K_{\rm diff}/L_\nu$, so stronger diffuse flux limits constrain the neutrino source density n_s to lower values. The thin parallel lines beneath it correspond to improvements in the experimental diffuse limit $K_{\rm diff}$ by factor of 10 and 100, respectively. The experimental sensitivity to point flux $C_{\rm point}$ can also be expressed in terms of the number density n_s as follows:

$$n_s = 3\sqrt{4\pi}\left(\ln\frac{E_{\rm max}}{E_{\rm min}}\right)^{3/2} \times \left(\frac{C_p}{L_\nu}\right)^{3/2}. \tag{8}$$

TABLE I. Summary of models for ν_μ point flux from extragalactic sources constrained by the results from this work. The benchmark flux Φ_C defines the flux constraint for an E^{-2} spectrum, which is directly compared to the predicted neutrino flux for a given model, $\Phi_\nu^{\rm model}$. The redshift of the source is from [15], and the parameter d_s defines the distance of the source in Mpc computed according to the relation $d_s = z \times c/H_0$. The neutrino luminosity L_ν is computed from $\Phi_\nu^{\rm model}$ (see text for details). Upper bounds on the number density, n_s, are given in units of Gpc^{-3}. The ratio $\mathcal{R} = \Phi_C/\Phi_\nu^{\rm model} < 1$ determines a model constrained by this work.

Model	$\Phi_\nu^{\rm model}$ (GeV/cm^2 s)	n_s (Gpc^{-3})	Redshift z [15]	d_s (Mpc)	$\log_{10}(L_\nu)$	$\mathcal{R}$	Reference
[3C273]	1.0×10^{-8}	0.82	0.158 339	633	45.2	0.14	[16]
[3C273]	2.5×10^{-8}	0.33	0.158 339	633	45.6	0.06	[17]
[3C273]	1.0×10^{-8}	0.82	0.158 339	633	45.2	0.14	[18]
[3C279]	2.0×10^{-7}	3.6×10^{-3}	0.536 200	2145	47.6	7×10^{-3}	[19]
[NGC4151]	3.5×10^{-8}	5.3×10^{2}	0.003 319	13.3	42.4	0.04	[16]
[Mkn 421]	9.0×10^{-9}	25.3	0.030 021	120	43.8	0.16	[16]
[Mkn 501]	2.5×10^{-8}	7.2	0.033 663	135	44.3	0.06	[20]
[Mkn 501]	1.1×10^{-8}	16.4	0.033 663	135	43.9	0.13	[21]
[RQQ]	1.0×10^{-8}	8.2×10^{2}	...	20	42.2	0.14	[22]
[Cen A]	1.5×10^{-8}	3.9×10^{3}	0.001 825	7.4	41.6	0.09	[23]
[M87]	7.0×10^{-10}	1.5×10^{5}	0.004 360	17.4	41.0	2	[23]
[3C279]	6.0×10^{-10}	1.2	0.536 200	2145	45.1	2.3	[16]
[Cen A]	5.0×10^{-10}	1.2×10^{5}	0.001 825	7.4	40.1	2.8	[24]
[Coma]	2.5×10^{-10}	1.5×10^{3}	0.023 100	92	42.0	5.6	[25]

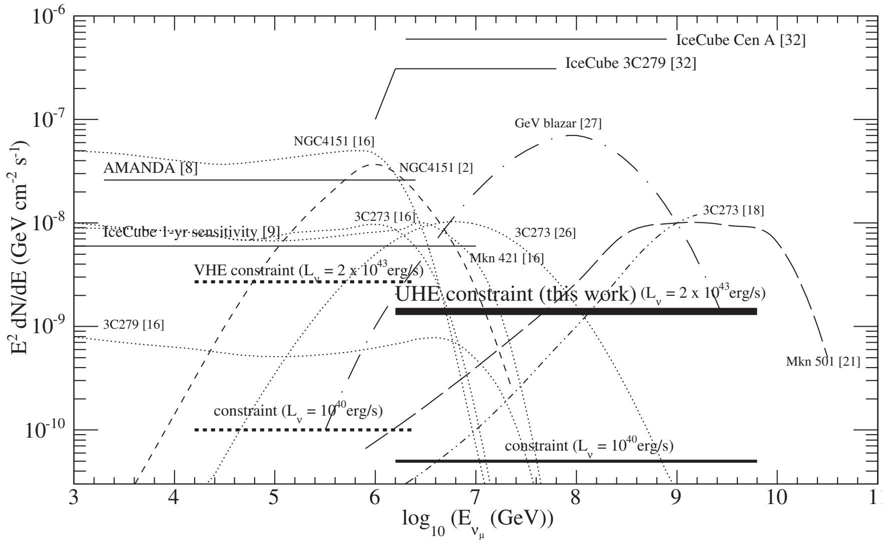

FIG. 2. Same flux constraints as Fig. 1 compared to a sample of model predictions for ν_μ-point flux from extragalactic sources are displayed in thin dotted-dashed lines, which strongly differ from an E^{-2} spectrum. Emission from 3C273 predicted by 3C273 [16], including pp and $p\gamma$ interactions (3C273 [18]); core emission due to $p\gamma$ interaction (3C273 [26]); AGN jet continuous emission (3C279 [16]); emission from NGC4151 by NGC4151 [16] and core emission from NGC4151 due to $p\gamma$ interaction (NGC4151 [2]); Spectra predicted for Mkn 421 (Mkn 421 [16]), and blazar flaring Mkn 501 (Mkn 501 [21]); GeV-loud blazars (GeV blazar [27]).

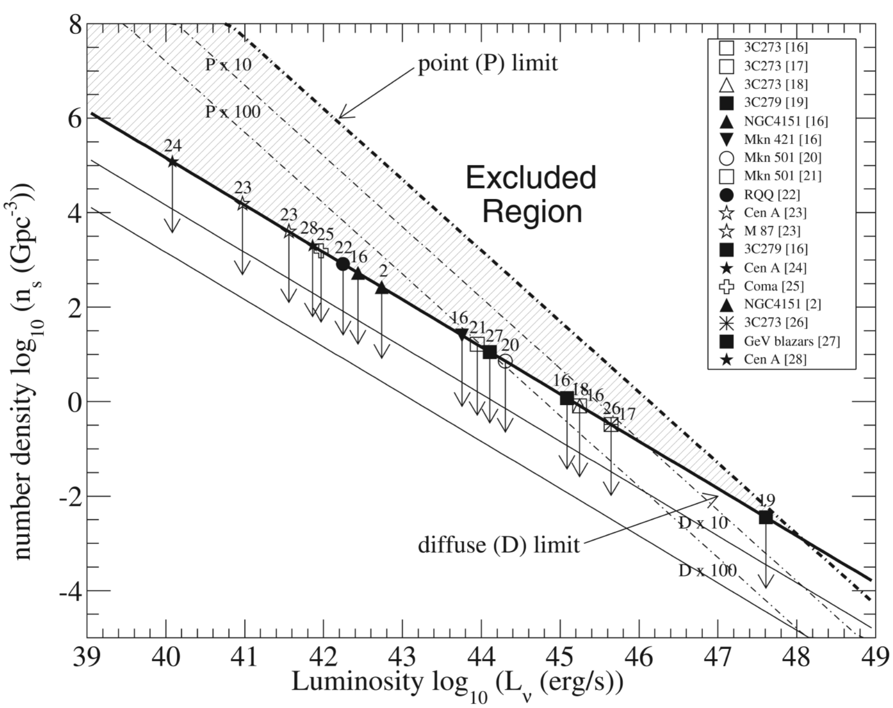

FIG. 3. The number density of neutrino sources n_s plotted versus the expected neutrino luminosity predicted according to the fluxes of the model tested. The derived upper bounds from the diffuse flux show a stronger constraint than the limit from point flux from direct searches. The hatched area represents the limits accessed by the diffuse flux, but not yet accessible by direct measurement from the point source searches. Upper bounds on number density n_s are computed for different neutrino sources (vertical arrows). Thin solid/dotted lines represent [diffuse (D)/point (P)] constraints on the number density with 1 and 2 orders of magnitude improvement. The region above the thick solid line is excluded by the diffuse flux limits.

Since the n_s scales as $(L_\nu)^{-3/2}$ the upper bounds set by direct point searches (thick dotted line) have a steeper slope compared to the diffuse flux constraints. For neutrino luminosity of bright extragalactic sources with values $L_\nu < 10^{46}$ erg/s, the upper bounds on n_s set by the diffuse flux are few orders of magnitude below the bounds reached by direct searches.

We derive limits on the number density for specific source predictions if $\Phi_\nu^{\rm model}$ is assumed to characterize the average flux for an ensemble of similar sources. The limits on n_s are shown as points in Fig. 3 and are summarized in Table I. The neutrino luminosity per energy decade is computed from the source distance d_s and the flux $\Phi_\nu^{\rm model}$ using the relation in Eq. (3), $L_\nu = \Phi_\nu^{\rm model} \times 4\pi d_s^2 \ln(E_{\rm max}/E_{\rm min})$, which assumes isotropic emission. The hatched area represents the parameter space accessed by the diffuse flux constraints but not yet accessible by the point flux limits from direct searches. Therefore, diffuse flux limits can constrain the physics mechanism of neutrino production from individual sources either to lower number density or to smaller fraction of power output of neutrino sources. The derived limits on the number density n_s of neutrino sources depend only on neutrino information, without making specific associations with source class based on electromagnetic measurements. The region above the thick solid line is the excluded region by the upper bounds on the number density derived from the diffuse limits.

The thick dark horizontal line in Figs. 1 and 2 indicates our primary constraint Φ_C. We address the robustness of the constraint by focusing the discussion on the three assumptions involved in the calculation of N_s.

The matter distribution within 5 Mpc of the Milky Way is far from uniform, which suggests the possibility that the local number density of neutrino sources, n_l, may be higher than the universal average of number density, $\langle n_s\rangle$. We argue that, in practice, the local inhomogeneity affects only the class of sources characterized by low luminosities. The bright sources are too rare to be affected by local matter density variation—the likelihood of finding a bright neutrino source within 5 Mpc is small to begin with (if electromagnetic luminosity and neutrino luminosity are comparable), and the local enhancements in matter density insufficient to change the probability of detection.

On the other hand, if sources have a low mean luminosity, then the nearest in the ensemble are more likely to be within a distance that could be affected by fluctuations in the local matter density. For example, within 4 Mpc, the ratio between local matter density to the universal average known as overdensity is estimated to be about 5.3 [29]. In this case, the flux constraint [Eq. (5)] should be adjusted to account for the higher density of local matter, $\Phi' = \Phi * (n_l/\langle n_s\rangle)^{2/3}$. However, as Table II shows, the adjusted fluxes are below Φ_C for a wide range of $\langle L_\nu\rangle$. For distances larger than 8 Mpc the overdensity of galaxies is rapidly approaching the universal mass density. To exceed Φ_C a source of a given luminosity L_ν must be within a distance $d_l = (4\pi/3)^{1/3} \cdot r_{\rm max} * (\Phi'/\Phi_C)^{1/2}$. Assuming that the neutrino luminosity is comparable to the maximum luminosity in any electromagnetic band, no sources are found within a distance d_l that would violate Φ_C.

We address now the assumption that the neutrino luminosity distribution is proportional to a (possibly broken) power law, which is observed for several classes of sources in the electromagnetic band. It was shown in [12] that N_s computed from the full distribution agrees to within few percent with a simpler calculation using only the mean luminosity of the distribution. The reason is that the most common luminosities in the distribution can only be observed at relatively short distances, so source evolution and cosmological effects are negligible. Sources with large luminosities are too rare to contribute significantly. On the other hand, it could be argued that the unknown luminosity distribution function is not well described by a (possibly broken) power law that typifies electromagnetic sources [30]. In this scenario, by using the limit on the maximum power density in Eq. (4), it is possible to constrain the mean luminosity for a given source class, if the number density is known, using the relation [12]

$$L_\nu^C \leq 4\pi \frac{H_0}{c} \ln\left(\frac{E_{\rm max}}{E_{\rm min}}\right) \frac{K_{\rm diff}}{n_s} = \frac{\mathcal{P}_\nu^C}{n_s} \text{ erg/s}. \tag{9}$$

For AGN selected in the x-ray band, $n_s \sim 1.4 \times 10^4$ Gpc^{-3} [31], and the mean neutrino luminosity is $L_\nu^C < 2.4 \times 10^{41}$ erg/s, which is approximately 2 orders of magnitude lower than the average luminosity in the x-ray band.

The constraint can be extended to energy spectra that differ from the assumed E^{-2} dependence, but the constraint applies over a restricted energy interval that matches the energy interval of the diffuse neutrino limits. Experimental diffuse limits span two different energy regions, VHE and UHE, and either limit can be inserted into Eq. (5). The restriction in energy range is required to avoid extrapolating the energy spectrum to unphysical values. In other words, for power law indices far from 2, the spectrum must cut off at high energies for indices $\gamma < 2$, or at low energies for indices $\gamma > 2$. Subject to this restriction, we

TABLE II. Adjusted flux constraints Φ' to account for local enhancement of source density.

$\langle L_\nu\rangle$ erg/s	Φ GeV/cm^2 s	$n_l/\langle n_s\rangle$ [29]	$(n_l/\langle n_s\rangle)^{2/3}$	Φ' GeV/cm^2 s	d_l Mpc
6×10^{41}	4×10^{-10}	5.3	3	1.2×10^{-9}	4
2.5×10^{42}	7×10^{-10}	1.3	1.2	8.4×10^{-10}	8

find that the constraint depends weakly on the assumed spectral index. For example, the constraints improve by a factor 2 for hard spectra ($\gamma = 1$) and weaken by roughly the same factor for soft spectra ($\gamma = 3$) [12].

To summarize, we have presented in this paper the constraint on neutrino fluxes from extragalactic point sources, which is $E^2(dN_\nu/dE) \leq 1.4 \times 10^{-9}(L_\nu/2 \times 10^{43}\ \mathrm{erg/s})^{1/3}\ \mathrm{GeV\,cm^{-2}\,s^{-1}}$. These constraints are 1 order of magnitude below current experimental limits from direct searches if the average L_ν distribution is comparable to the electromagnetic luminosity that characterizes the brightest AGN. As experimental data improves the derived constraints on fluxes from extragalactic sources $E^2(dN_\nu/dE) \propto K_{\mathrm{diff}}^{2/3}$ improves with the diffuse flux limits to the $2/3$ power, while constraints on the number density $n_s \propto K_{\mathrm{diff}}$ and the total neutrino power density $\mathcal{P}_\nu^c \propto K_{\mathrm{diff}}$ improve linearly with the diffuse limits. We tested a number of model predictions for ν-point fluxes, and models which predict fluxes higher than the benchmark constraint have been restricted by this analysis. The constraint is strengthened for less luminous sources, and noncompetitive with direct searches for highly luminous explosive sources, such as GRBs. We found that the constraint is robust when accounting for the nonuniform distribution of matter that surrounds our galaxy, or considering energy spectra that deviate from E^{-2}, or various models of cosmological evolution. We also derived an upper limit on the maximum neutrino power density which is significantly below the observed power density from extragalactic cosmic rays. We showed that diffuse flux limits can strongly constrain the number density of neutrino sources n_s. The constraints derived from the diffuse limits for sources with luminosities $L_\nu < 10^{46}$ erg/s is stronger by few orders of magnitude compared to the point flux limits from direct searches. The parameter space accessed by the n_s constrained from the diffuse limits for sources within this luminosity range is a challenge for direct point searches even for kilometer-cube neutrino detectors. The constraint suggests that the observation of extragalactic neutrino sources will be a challenge for kilometer scale detectors unless the source is much closer than the characteristic distance between sources, d_l, after accounting for local enhancement of the matter density. Although the constraint cannot rule out the existence of a unique, nearby extragalactic neutrino sources, we note that assuming $L_\nu \sim L_\gamma$, we found no counterparts in the electromagnetic band with the required luminosity and distance to violate the constraint.

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[1] J. Abraham *et al.*, Science **318**, 938 (2007).
[2] F. Stecker *et al.*, Phys. Rev. Lett. **66**, 2697 (1991); **69**, 2738(E) (1992).
[3] F. Stecker, Phys. Rev. D **72**, 107301 (2005).
[4] K. Mannheim, Astropart. Phys. **3**, 295 (1995).
[5] F. Halzen and E. Zas, Astrophys. J. **488**, 669 (1997).
[6] R. J. Protheroe, arXiv:astro-ph/9607165.
[7] A. Silvestri *et al.*, in Proc. 31st ICRC, Lodz, Poland, 2009.
[8] R. Abbasi *et al.*, Phys. Rev. D **79**, 062001 (2009).
[9] J. Ahrens *et al.*, Astropart. Phys. **20**, 507 (2004).
[10] P. Lipari, Nucl. Instrum. Methods Phys. Res., Sect. A **567**, 405 (2006).
[11] A. Achterberg *et al.*, Phys. Rev. D **76**, 042008 (2007).
[12] A. Silvestri, Ph.D. Thesis, University of California, Irvine, 2008.
[13] A. Achterberg *et al.*, Astrophys. J. **674**, 357 (2008).
[14] T. K. Gaisser, arXiv:astro-ph/9707283.
[15] The NASA/IPAC Extragalactic Database (2009).
[16] A. P. Szabo and R. J. Protheroe, in *High Energy Neutrino Astrophysics* (World Scientific, Singapore, 1992), p. 24.
[17] L. Nellen *et al.*, Phys. Rev. D **47**, 5270 (1993).
[18] K. Mannheim, Phys. Rev. D **48**, 2408 (1993).
[19] A. Atoyan and C. Dermer, New Astron. Rev. **48**, 381 (2004).
[20] J. G. Learned and K. Mannheim, Annu. Rev. Nucl. Part. Sci. **50**, 679 (2000).
[21] A. Mücke and R. J. Protheroe, Astropart. Phys. **15**, 121 (2001).
[22] J. Alvarez-Muniz and P. Meszaros, Phys. Rev. D **70**, 123001 (2004).
[23] L. A. Anchordoqui *et al.*, Phys. Lett. B **600**, 202 (2004).
[24] F. Halzen and A. O'Murchadha, arXiv:astro-ph/0802.0887.
[25] S. Colafrancesco and P. Blasi, Astropart. Phys. **9**, 227 (1998).
[26] F. W. Stecker and M. H. Salamon, Space Sci. Rev. **75**, 341 (1996).
[27] A. Neronov and D. Semikoz, Phys. Rev. D **66**, 123003 (2002).
[28] A. Cuoco and S. Hannestad, Phys. Rev. D **78**, 023007 (2008).
[29] A. V. Tikhonov and A. Klypin, Mon. Not. R. Astron. Soc. **395**, 1915 (2009).
[30] M. Kowalski (private communication).
[31] G. Hasinger *et al.*, Astron. Astrophys. **441**, 417 (2005).
[32] R. Abbasi *et al.*, Phys. Rev. Lett. **103**, 221102 (2009).