On the Detectability of High-Energy Galactic Neutrino Sources

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Abstract

With the arrival of km^3 volume scale neutrino detectors the chances to detect the first astronomical sources of TeV neutrinos will be dramatically increased. While the theoretical estimates of the neutrino fluxes contain large uncertainties, we can formulate the conditions for the detectability of certain neutrino sources phenomenologically. In fact, since most galactic neutrino sources are transparent for TeV γ-rays, their detectability implies a minimum flux of the accompanying γ-rays. For a typical energy-dependence of detection areas of km^3 volume neutrino detectors, we obtain the quantitative condition $I_\gamma(20\text{ TeV}) > 2 \times 10^{-15}$ ph/cm^{2}s, that thanks to the normalization of the γ-ray spectrum at 20 TeV appears to be quite robust, i.e. almost independent of the shape of energy spectrum of neutrinos. We remark that this condition is satisfied by the young supernova remnants RX J1713.7-3946 and RX J0852.0-4622 (Vela Jr) - two of the strongest galactic γ-ray sources. The preliminary condition for the detectability of high energy neutrinos is that the bulk of γ-rays has a hadronic origin: A new way to test this hypothesis for RX J1713.7-3946 is proposed. Finally, we assess the relevance of a neutrino detector located in the Northern Hemisphere for the search for galactic neutrino sources. In particular, we argue that if the TeV neutrino sources correlate with the galactic mass distribution, the probability that some of them will be observed by a detector in the Mediterranean Sea is larger by a factor of 1.4-2.9 compared to the one of IceCube.

Keywords: high energy neutrino sources; high energy γ-ray observations; galactic astronomy

1. Introduction

The search for neutrinos with E_ν > TeV (Lipari 2006 [18]) with telescopes of volumes in the km^3 scale is considered important. IceCube is collecting exposures of the order of $\text{km}^2\times$year and this will be continued and extended by KM3NeT.[1] As has happened in the past (e.g., for X-ray searches) the new instruments could eventually lead to surprising outcomes. The hope for surprises is certainly one strong motivation of the search for the sources of high energy neutrinos that plausibly are also sources of cosmic rays. At the same time, there are many reasons why we would like to have defined expectations on high energy neutrinos: to interpret the results of the observations, to plan the future research, to better focus our goals, to optimize the new instruments. The trouble is that the hypotheses on which the present expectations are based are still rather uncertain and difficult to test. Thus we do not have reliable predictions yet, and this limits our capability to plan the next steps.

In this paper, we focus on this aspect of the search for high energy neutrino sources that we are now beginning. We discuss several aspects: We emphasize the relevance of γ-ray observations in the 10-100 TeV energy range for high energy neutrinos; we analyze the prospect to understand better certain γ-ray sources that have a special theoretical interest in connection with high energy neutrinos; we clarify the argument in favor of a neutrino telescope in the Northern hemisphere. We focus on the subclass of galactic sources that are of particular interest for future instruments located in the Northern hemisphere.

The outline of this paper is as follows. First, considering the high energy γ-ray sources that are transparent to the radiation, we characterize those of them that could be, at the same time, bright enough neutrino sources (Sec. 2). Next, after recalling the relevant theoretical context, we discuss the prospects of obtaining more defined expectations for one of the most interesting of these γ-ray sources, namely, the young supernova remnant named RX J1713.7-3946 (Sec. 3). Finally, we quantify in Sec. 4 the importance of monitoring the Southern high energy neutrino sky on the basis of the Galactic matter distribution.

[1] All considerations below apply to any large (i.e., with volumes of the order of one km^3) neutrino telescope of the Northern hemisphere; KM3NeT is taken as an example, being the most advanced project of this type at present.

N_γ		E_c =						
		10^0	$10^{0.5}$	10^1	$10^{1.5}$	10^2	$10^{2.5}$	10^3
	1.8	70	16	4.9	2.1	1.1	0.7	0.5
	1.9	86	20	6.7	3.0	1.7	1.1	0.8
α =	2.0	110	25	9.0	4.2	2.5	1.7	1.3
	2.1	130	32	12	5.9	3.5	2.5	2.0
	2.2	160	41	16	8.0	5.0	3.6	3.0

Table 1: *Normalization of the γ-ray fluxes N_γ, in units of* $10^{-12}/(\text{cm}^2\text{ s TeV})$ *that corresponds to an induced flux* $I_{\mu+\bar\mu}(>1\text{TeV}) = 1/(\text{km}^2\text{yr})$. *First column: slope of the γ-ray flux, α. First row: cutoff energy of the γ-ray spectrum, E_c, measured in TeV. See Eq. 1.*

2. Using high energy γ-rays as a guide for high energy neutrino search

Here we consider a precise assumption on the astrophysical neutrino sources: We suppose that they are transparent to the very high energy gamma radiation. In this way we can derive upper limits on neutrinos, by postulating that *all* γ-rays originate from proton-proton collisions. In fact, the yield of neutral mesons and of charged mesons are strictly connected and there is a linear relation between the fluxes of high energy γ-rays and neutrinos (Vissani 2006 [29], Villante & Vissani 2008 [28]).

We can then quantify the concept of "promising" γ-ray sources. Suppose that the γ-ray flux has the form:

$$I_\gamma(E_\gamma) = N_\gamma \times (E_\gamma/1\text{ TeV})^{-\alpha} \times \exp\left[-\sqrt{E_\gamma/E_c}\right], \qquad (1)$$

where we consider the ranges of parameters: $\alpha = 1.8-2.2$ (=slope) and E_c = 1 TeV−1 PeV (=energy cutoff). This form corresponds to an exponential cutoff in the spectrum of the cosmic rays that generate the γ-rays, see Kappes et al. 2007 [17], and has been tested for adequacy on the available γ-ray data. Following Villante & Vissani 2008 [28], and requiring an induced flux of 1 muon or antimuon per km^2 per year above 1 TeV (i.e. 1 signal event in a conventional neutrino telescope with an exposure of 1 $\text{km}^2\times$yr), we determine N_γ for each value of α and E_c; the results are given in Tab. 1 and are further illustrated in Fig. 1.

This table and this figure identify the transparent γ-ray sources that could be interesting neutrino sources. There is a wide variety of possibilities, ranging from intense γ-ray

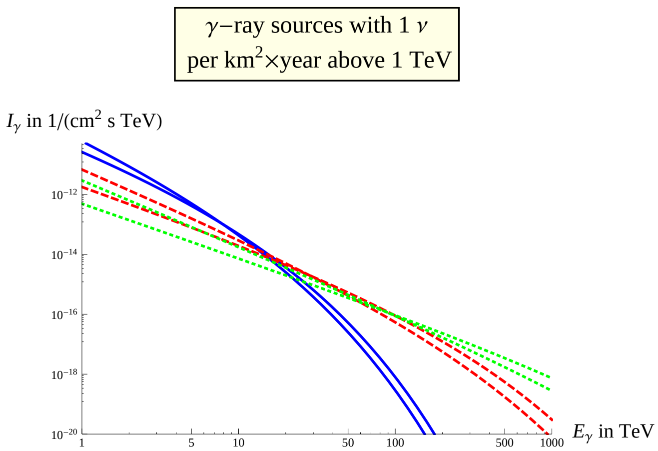

Figure 1: *Fluxes of γ-rays corresponding to 1 event above 1 TeV in a neutrino telescope with an exposure of 1 km^2×yr, as given in Eq. 1 and Tab. 1. We selected the values* $\alpha = 1.8$ *and* 2.2 *(the first being smaller at low energies and larger at high energies) and* $E_c = 1, 10^{1.5}$ *and* 10^3 *TeV (continuous, dashed and dotted lines, respectively).*

sources to weak ones; this is due to the fact that the main contribution to the neutrino signal is from energies larger than 1 TeV, where we still have limited information from γ-ray observations.

By a systematic exploration of the γ-ray sky till $E_\gamma \sim 100$ TeV and of the sources with an intensity above 10^{-12}/ (cm^2 s TeV) at 1 TeV, we could have a guide for the search of very high energy neutrinos, at least for the sources that are transparent to their γ-ray radiation. It is interesting to note that at 20 TeV, all fluxes of Tab. 1 are in the narrow range

$$I_\gamma(20 \text{ TeV}) = (2-6) \times 10^{-15} \text{ ph/ (cm}^2 \text{ s TeV)} \qquad (2)$$

that characterizes the region of energies and of intensities where the γ-ray observations are more relevant for the high energy neutrino detectors: see again Fig. 1.

We remark that Eq. 2 is a new result. Its relevance can be understood better by recalling that the existing γ-ray detectors have explored mostly the region of energy around the TeV. Thus, the future γ-ray measurements in the region 10-100 TeV–e.g. those by the Cherenkov Telescope Array (CTA) instrument–will have an important impact on the expectations of high energy neutrinos. In summary, it will be possible to clarify the expectations of neutrino astronomy, by the measurements of future γ-ray observatories.

SNR as a major example of transparent γ-ray source. Shell type supernova remnants (SNR) are an important example of astronomical sources of γ-rays that is expected to be transparent to their γ-ray emission. A few young SNR, recently observed in the TeV range,[2] are known to exceed the bound in Eq. 2, thus being of particular interest. We discuss them here to illustrate the issue further:

- The first example is the supernova remnant called RX J1713.7-3946 and measured by HESS, Aharonian et al. 2007 [3]. It has a γ-ray spectrum that is reasonably well described assuming $\alpha = 1.79 \pm 0.06$ and $E_c = 3.7 \pm 1$ TeV in Eq. 1 (Villante & Vissani 2007 [27]) and that has an intensity at 20 TeV of $(1.7 \pm 0.3) \times 10^{-14}$ / (cm^2 s TeV). Correspondingly, the maximum value of the neutrino signal from this source is larger than 1 event per km^2 per year, and more precisely we have:

$$I_{\mu+\bar{\mu}}(> 1 \text{ TeV}) = (2.4 \pm 0.3 \pm 0.5) \text{ / (km}^2 \text{ yr)} \qquad (3)$$

  see Tab. 2 and Sect. IV of Villante & Vissani 2008 [28].

- A second example is the SNR called Vela Jr (RX J0852.0-4622) as observed in Aharonian et al. 2007b [4]. The available γ-ray observations of this object are less complete. Its measured spectrum has been described simply by a power law and its emission at 20 TeV is in the range $(1-3) \times 10^{-14}$ / (cm^2 s TeV); however, 20 TeV is the highest measured energy.

Note that both these SNR's are in the South γ-ray sky, and are thus potentially interesting for neutrino telescopes located in the Northern hemisphere (see Sec. 4). In the next section, we recall the reasons why such SNR's are considered interesting and discuss in more details the present understanding of RX J1713.7-3946 and the prospects of improvement.

Remarks and caveats. We did not include latitude dependent effects, such as the limited time to observe a source (discussed in the last section) or the absorption in the Earth, in order to simplify the discussion. The latter effect is more severe for the fluxes that extend up to the highest energies,

[2] A useful resource is the HESS Source Catalog that can be consulted at: `http://www.mpi-hd.mpg.de/hfm/HESS/pages/home/sources/`.

namely those with a smaller value of α and/or a higher energy cutoff. We roughly take into account this, by limiting the spectrum to $E_\nu < 1$ PeV.

Let us repeat that the γ-ray data permit us to obtain an upper bound on neutrinos, postulating that the source is transparent to its γ-rays. But in some cases, high energy neutrinos and γ-rays do not correlate. This is thought to happen for certain interesting astrophysical objects such as galactic binary systems containing a luminous optical star and a compact object (microquasars) where the absorption of γ-rays is considerable. Cases like this increase the *a priori* chance of having surprisingly large neutrino fluxes. At the same time, such a situation causes further difficulties to obtain reliable expectations, due to the increased dependence on an uncertain theoretical modelling. For a more complete discussion of alternative galactic neutrino sources, see Aharonian 2007 [2].

3. Toward reliable predictions for the SNR RX J1713.7-3946

In this section we analyze why supernova remnants are expected to act as emitters of high energy neutrinos and discuss in details the promising case of the supernova remnant called RX J1713.7-3946.

The kinetic energy of supernova remnants (SNR) is one order of magnitude larger than the cosmic ray losses of the Galaxy (Ginzburg & Syrovatskii 1964 [15]) and diffusive acceleration on the shock wave (Fermi 1949 [13]) can provide the mechanism for cosmic-ray acceleration (see e.g., Malkov & O'Drury 2001 [20]): Thus, we expect that SNR's contain high densities of cosmic rays. The SNR can also be sources of high energy γ-rays and neutrinos, especially when they are associated with molecular clouds, that act as a target for the cosmic ray collisions (Aharonian, O'Drury, Völk 1994 [5], O'Drury, Aharonian, Völk 1994 [24]).

The spectrum of the young SNR RX J1713.7-3946, measured by HESS (Aharonian et al. 2007 [3]) till 100 TeV and (as already discussed) exceeding the bound of Eq. 2, has a special interest in the discussion of high energy neutrinos. This is even more true when one realizes that this SNR interacts with a system of molecular clouds detected by NANTEN (Fukui et al. 2003 [14], Sano et al. 2010 [25]). It is in the Southern neutrino sky, relatively close to us, $D \sim 1$ kpc.

These are the reasons why it is urgent to ask: How far we are from understanding the high energy neutrinos of *this* SNR? To address this question, we have to consolidate the physical picture of RX J1713.7-3946, that can be done only employing in the best way the available (theoretical and observational) information.

A model for the spectrum. A related question that we should tackle is which is the nature of the electromagnetic spectrum of RX J1713.7-3946. There are various models in the literature, e.g., Malkov et al. 2005 [19], Berezhko & Völk 2006-2010 [7], Morlino et al. 2009 [23], Zirakashvili & Aharonian 2010 [31], Ellison et al. 2010 [11], Fan et al. 2010 [12]. In a typical model, the γ-ray emission is dominated by a single mechanism at all energies, which reduces the question of neutrinos to a dichotomy.

We focus on one proposal of Zirakashvili & Aharonian 2010 [31], where the spectrum is instead composite: it has significant contributions both from the Inverse Compton (IC, i.e. leptonic mechanism) and from neutral pion decays (π^0, i.e. hadronic mechanism). Even if their model will turn out to be incorrect in some quantitative aspect, such a hypothesis allows us to make one step ahead in the right direction: to understand neutrinos, we need to know *which part* of the γ-ray emission is hadronic.

This proposal has good physical motivations: 1) The similarity of the features observed in X-rays is explained, since the IC dominates the integrated spectrum measured by HESS. 2) Attributing the high energy tail of the spectrum to π^0 decays instead overcomes the difficulties in accounting for it by IC, whose spectrum should be cut-off abruptly. The question we want to address becomes: How do we test the predictions of this model?

Prospects of observational tests. The measurements of Agile and Fermi in the energy range 1-10 GeV will be a key test (see e.g., Morlino, Blasi, Amato 2009 [23]), for the shape of the γ-ray spectrum at GeV energies depends on the mechanism of emission: Assuming that protons and electrons have power-law spectra with the same slope, $\propto E_{p,e}^{-\alpha}$, π^0 decays give $\propto E_\gamma^{-(\alpha-0.1)}$ whereas IC gives $\propto E_\gamma^{-(\alpha+1)/2}$; thus, extrapolating the γ-ray spectra from the lowest point measured by HESS, $E_\gamma = 300$ GeV, we find that the hadronic mechanism leads to an emission 3 times more intense than the one due to the leptonic mechanism already at 10 GeV. But it is unclear whether Agile or Fermi will attain sufficient angular resolution to reveal that the γ-rays come preferentially from

Energy of γ-rays	Dominant emission	Observational test	Relevant data
$\sim 1-10$ GeV	π^0	intensity & shape	Fermi, Agile
$\sim 1-10$ TeV	IC	SNR shell	HESS
> 10 TeV	π^0	molecular clouds	HESS

Table 2: *Tests of the Zirakashvili & Aharonian model for the γ-ray spectrum of the SNR named RX J1713.7-3946. First column, the energy range of the measurement; second, the dominant mechanism of emission expected in the model; third, the possible test; last column, the relevant experiment. See the text for details.*

the sites where cosmic ray collisions and π^0 decays are more frequent, i.e. the molecular clouds.

This qualifying hypothesis could be verifiable at much larger energies. In fact, the model of Zirakashvili & Aharonian 2010 [31] predicts, at several tens of TeV, a γ-ray signal enhanced in the direction of the overdense molecular clouds of NANTEN, of size $(2-8)$ μsr (Sano et al. 2010 [25]), on top of the known background distribution due to misidentified cosmic rays and of a minor component of the signal distributed as the SNR shell.

Do we have enough data to test this picture? HESS (Aharonian et al. 2007 [3]) has 1021 (resp., 474) events ON against 751 (resp., 338) OFF above 20 (resp., 30) TeV, namely about 250 (resp., 130) signal events[3]. To illustrate the meaning of these numbers, suppose that 750 background events are uniformly distributed in 25 patches of equal area; thus, 30 signal events in a single patch are enough to double the average density of events. The low statistics conditions suggest an unbinned likelihood analysis of the γ-ray data, as those proposed for similar applications in neutrino astronomy by Braun et al. 2008 [8] and by Ianni et al. 2009 [16].

A résumé of possible tests is provided in Tab 2.

The above estimates show that the existing HESS data can only marginally provide a decisive study of energy dependent γ-ray morphology of RX J1713.7-3946. Thus, it is highly desirable to increase significantly the TeV photon statistics by new observations of the source. Presently such observations can be performed only by the HESS array of telescopes. However, because of the limited potential of HESS at energies above 10 TeV, we can hope for enhancement of photon statistics, for any reasonable observation time, only by a factor of two or so. A real breakthrough in this regard is expected only with the next generation γ-ray instruments like CTA.

Implications for high energy neutrino astronomy. If the model of Zirakashvili & Aharonian will be validated by future data analyses, the induced muon flux from RX J1713.7-3946 will be lower than the upper limit that we derive in the extreme hypothesis of hadronic emission from Eq. 3, namely: $I_{\mu+\bar{\mu}}(> 1\text{ TeV}) < 3.5 / (\text{km}^2\text{ yr})$ at 90 % CL. This will make the search for a signal more difficult but will be accompanied by a decrease of the background, for the sources of high energy neutrinos are the relatively small molecular clouds and not the much larger SNR.

By comparing the size of the overdense clouds with the one of the SNR, one would expect in ideal conditions a decrease of the background by a factor of ten; however, the decrease will be limited by instrumental features, if the angular resolution of the neutrino telescopes will be larger than the cloud size. Just for illustration, an angular resolution of $\delta\theta = 0.2°$ at the relevant energies corresponds to a search window of $\pi\,\delta\theta^2 = 40\ \mu$sr. Multiplying by the number of the main overdense clouds, i.e. four (see Sano et al. 2010 [25]) and comparing to the size of the SNR implies a decrease of the background by a factor of two.

We would like to emphasize that the model of Zirakashvili & Aharonian 2010 [31] does not necessarily imply a strong reduction of the neutrino detection rate compared to the pure hadronic model, because in the composite spectrum the most relevant γ-rays–those with energy above 10 TeV–are contributed mainly by cosmic ray interactions. On the other hand, the composite model implies that the γ-rays and of course the high energy neutrinos are produced in more compact regions, which leads to a significant reduction of background events.

We will be in a better position to quantify the expected, neutrino-induced muon flux when we will know the results of the analyses of Agile and Fermi. In order to predict the very high-energy neutrino flux, it would be even more important to know the amount of very high-energy γ-rays correlated with the molecular clouds. HESS could provide us with some evidence for such a hadronic emission, but future high statistics observations will be crucial to obtain reliable measurements (or strong limits) of this component of the γ-ray emission.

[3]The terminology ON/OFF refers to the two cases when the gamma ray telescope points to the source and when instead it points to a region where no signal is expected.

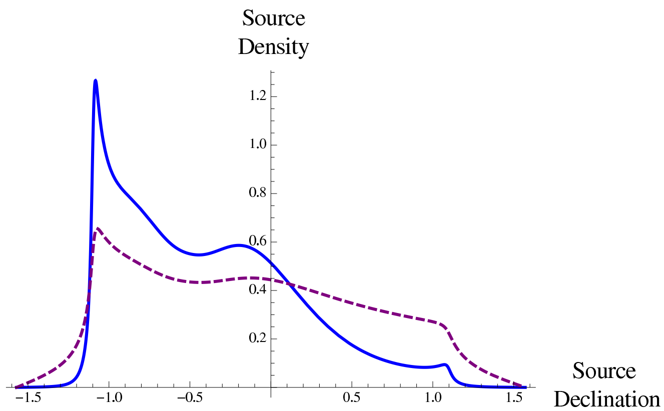

Figure 2: *Continuous line: normalized mass distribution of the Galaxy, as a function of the declination. Dashed line, the same but weighted with the inverse squared distance from the mass.*

4. An appraisal of a telescope in the Northern Hemisphere

In the last section, we discuss the importance of operating a new telescope for high energy neutrinos in the Northern Hemisphere. The discussion elaborates quantitatively the oft-heard observation: most of the Galaxy, being in the Southern Hemisphere, lies in the Northern neutrino sky.

We begin by considering an educated guess on the galactic sources of neutrinos. It is plausible that the distribution of neutrino sources follows the mass distribution of supernovae, young matter and/or star-forming regions. We use the distribution of neutron stars of Yusifov & Küçük 2004 [30], adopted for the study of supernova neutrinos of Mirizzi et al. 2006 [22] (see their Eqs. (1), (2) and (4) and compare with Costantini, Ianni, Vissani 2005 [9]). We set the x-axis from the galactic center to the Earth, the z-axis in the direction of the galactic North, obtaining for components of the Earth's rotation axis the unit vector $(u_x, u_y, u_z) = (.484, .747, .456)$.

Now we derive the normalized mass distribution as a function of the declination of the sources δ, that we regard as the probability of finding neutrino sources. Similarly, we derive the mass distribution weighted with the inverse of the squared distance of the source, accounting for the fact that the number of events scales as $1/r^2$ for a standard source. The results are given in Fig. 2 and are easy to understand: The angle between the galactic plane and the Celestial equator is $\sim \pi/3$, thus most of the matter is at $|\delta| < 1$; furthermore, the galactic center is at $\delta \sim -\pi/6$, thus the region $\delta < 0$ is more populated; finally, the features are less prominent when we include $1/r^2$ since this emphasizes the local patch of the Galaxy rather than the distant regions.

Let us consider the traditional signal of induced muons (see Markov 1963 [21] for the original references). High energy neutrino detectors observe only downward to safely avoid atmospheric muons; thus, a source at declination δ is seen only for a fraction of time:

$$f[\delta, \phi] = 1 - \frac{\mathrm{Re}[\arccos(-\tan\delta\tan\phi)]}{\pi} \qquad (4)$$

as a function of the latitude ϕ of the detector, as discussed e.g., in Costantini & Vissani 2005 [9]. For instance, the galactic center, that is in the Southern sky at $\delta = -29°$, is invisible in IceCube ($f = 0$) and it is seen for a fraction of time f =67%, 63%, 64% or 75% in Antares, NEMO, Nestor or Baikal respectively.

By convoluting f with the distribution of the matter in the Milky Way we estimate the relevance of a high energy neutrino detector. The result is shown in the curves Fig. 3. They are symmetric around 1/2 when $\phi \to -\phi$, just as f: $f[\delta, \phi] + f[\delta, -\phi] = 1$, for two antipodal detectors see the entire sky. From this figure, we verify that the South Pole is a less promising place to search for neutrinos from galactic sources. A detector in the Mediterranean, say with latitude $\phi = 36°30'$, has 2.9 times better chances; when we weight the mass distribution with $1/r^2$, the improvement is a factor of 1.4 instead. The first number applies if the hypothetical sources are so intense, that all of them can be seen; the second one is plausibly a better estimation of the factor of improvement if there is a sort of "standard source" with a fixed intensity, and the neutrino detectors are able to see only the closest ones.

Similar arguments are frequently invoked in favor of a detector in the Northern hemisphere; however, the quantitative evaluation of the factor of improvement that we obtained is, to the best of our knowledge, a new result.

Remarks and caveats. There are other aspects to be kept in mind; e.g., it seems possible to cover safely a few degrees above the horizon already with IceCube (Abbasi et al. 2009 [1]). Also, when KM3NeT will operate, a portion of the sky will be already explored by IceCube; however, some redundancy in the observations could be precious to cross check the proper functioning of the detectors.

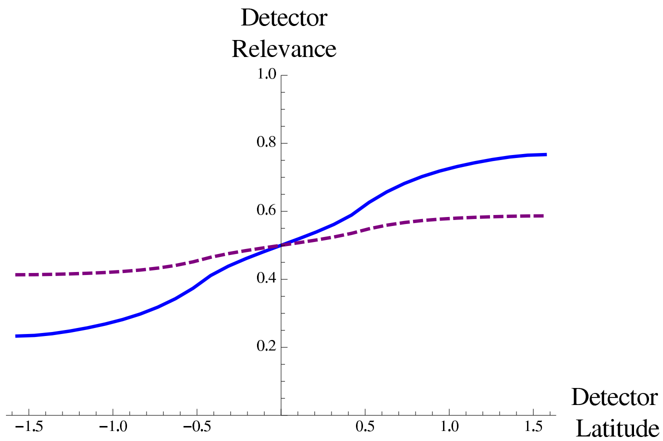

Figure 3: *Fraction of the Galaxy seen by a neutrino detector at a given latitude. For the dashed lines, the mass distribution was weighted with* $1/r^2$ *to take into account that nearby sources are easier to detect.*

One can repeat the calculations including the halo, or a "bar" as part of the Milky Way, possibilities that above we disregarded. Alternatively, one could consider suitable generalizations, for instance the case of dark matter decay or annihilation; the latter requires to weight the fraction f with the square of the density of the dark matter distribution. Many of these cases resemble closely a source in the galactic center, discussed above.

5. Summary and discussion

The discovery of sources of high energy neutrinos is a well-recognized scientific goal: The hunt has been opened by IceCube and will be complemented by KM3NeT, see Riccobene & Sapienza 2009 [26] and Anchordoqui & Montaruli 2009 [6] for reviews. However, we cannot rely on precise predictions yet. Clear expectations would be helpful or even necessary to focus the search and to optimize the new instruments: their area, geometry, energy threshold, etc.. The precise upper bounds that we can derive from γ-ray data are useful, but insufficient for these aims. With these considerations in mind, we made an effort to determine some of the boundaries of the present knowledge and to discuss the prospects to proceed toward definite expectations, focussing on the main target of KM3NeT: galactic neutrino sources.

A new high-energy neutrino telescope in the Northern Hemisphere is considered highly desirable. We discussed in Sec. 2 which γ-ray sources may yield a minimum signal in neutrino telescopes, assuming that the γ-rays are not absorbed. We found that, for high energy neutrino search, it would be particularly important to know the γ-ray sources with a sufficiently intense emission around 20 TeV: see Eq. 2. We argued in Sec. 3 that there are reasonable chances of getting a reliable prediction for RX J1713.7-3946, that could become a reference target for a telescope located in the Northern hemisphere. The chances are linked to future analyses of existing γ-ray data: those by Agile and Fermi, which should reveal an emission more intense than the one expected assuming the leptonic mechanism; those by HESS above $20-30$ TeV, that should reveal the correlation of the γ-ray events with the molecular clouds that interact with RX J1713.7-3946. Finally, we discussed the importance to have a new high-energy neutrino telescope in the Northern Hemisphere. We developed in Sec. 4 the oft-heard argument in favor of such an instrument, concluding that it will be superior by a factor of 1.4-2.9 to IceCube as a monitor of galactic neutrino sources distributed as the matter of the Milky Way.

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