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Erratum: "Revised Predictions of Neutrino Fluxes from Pulsar Wind Nebulae" (2017, ApJ, 836, 159)

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1. Introduction

This is an erratum to correct the work published in Di Palma et al. (2017), with the title "Revised Predictions of Neutrino Fluxes from Pulsar Wind Nebulae." Members of the ANTARES Collaboration, to whom we are very grateful, pointed out issues with the estimates of neutrino fluxes and backgrounds that were provided in that work. After double checking our estimates and discussing with members of both the ANTARES and IceCube Collaborations, we are prompted to revise the contents of that article.

In the above mentioned work, we were estimating the expected neutrino flux from a collection of pulsar wind nebulae (PWNe) observed in very high-energy gamma-rays. We computed the expected neutrino flux from each of the sources in the 2 existing neutrino telescopes, IceCube and ANTARES, and in the upcoming KM3NeT, assuming that their entire gamma-ray flux above 1 TeV is of hadronic origin. The comparison of the computed flux with the relevant background, again computed theoretically, showed that a handful of objects in our list of sources should have already been detected by IceCube if all their gamma-ray emission derived from hadronic processes. The lack of detection was then turned into an upper limit on the fraction of γ-rays that could come from hadrons and in a revised estimate of the flux of neutrinos expected from these sources in ANTARES and KM3NeT.

The published work contained important flaws. We list them in the following and provide corrections.

Table 1
List of PWNe that Were Considered in the Original Article

Source Name	δ [°]	N_0 [10^{-11} TeV^{-1} cm^{-2} s^{-1}]	spectral index	reference
Crab	22.015	2.8	−2.6	Aharonian et al. 2004
Vela	−45.18	1.46	−1.32	Abramowski et al. 2012a
MSH15-52	−59.24	0.52	−2.21	Nakamori et al. (2008)
G54.1+0.3	18.87	0.075	−2.39	Acciari et al. (2010)
G0.9+0.1	−28.15	0.084	−2.4	Aharonian et al. (2005)
G21.5-0.9	−10.56	0.046	−2.08	Djannati-Ataii et al. (2008)
Kes75	−2.98	0.062	−2.26	Djannati-Ataii et al. (2008)
J1356-645	−64.5	0.27	−2.2	Abramowski et al. (2011b)
CTA1	72.98	0.102	−2.2	Aliu et al. (2013)
J1023-575	−57.79	0.33	−2.58	Abramowski et al. (2011a)
J1616-508	−50.90	0.67	−2.35	Aharonian et al. (2006a)
J1640-465	−46.53	0.3	−2.42	Aharonian et al. (2006a)
J1834-087	−8.76	0.26	−2.45	Aharonian et al. (2006a)
J1841-055	−5.55	1.28	−2.4	Aharonian et al. (2008a)
J1813-178	−17.84	0.27	−2.09	Aharonian et al. (2006a)
J1632-478	−47.82	0.53	−2.12	Aharonian et al. (2006a)
J1458-608	−60.88	0.21	−2.8	de los Reyes et al. (2012)
J1420-607	−60.76	0.35	−2.17	Aharonian et al. (2006b)
J1809-193	−19.30	0.46	−2.2	Aharonian et al. (2007)
J1418-609	−60.975	0.26	−2.22	Aharonian et al. (2006b)
J1825-137	−13.84	1.98	−2.38	Aharonian et al. (2006c)
J1831-098	−9.90	0.11	−2.1	Sheidaei et al. (2011)
J1303-631	−63.18	0.59	−2.44	Abramowski et al. (2012b)
N 157B	−69.17	0.13	−2.8	Abramowski et al. (2015)
J1837-069	−6.95	0.5	−2.27	Aharonian et al. (2006a)
J1912+101	+10.15	0.35	−2.7	Aharonian et al. (2008b)
J1708-443	−44.33	0.42	−2.0	Abramowski et al. (2011c)

Table 2
Amended Estimates of the Astrophysical Neutrinos for the Sources Listed in Table 1. The Number of Background Neutrinos Is Independent on Declination $N_{BG} = 0.42$. Corrected Version of Table 2 of the Original Article

ANTARES	
Source	N_ν
Crab	6.19×10^{-3}
Vela No Cut-Off	0.94
Vela with Cut-off	0.068
MSH15-52	0.012
G54.1+0.3	3.3×10^{-4}
G0.9+0.1	8.07×10^{-4}
G21.5-0.9	1.23×10^{-3}
Kes75	9.18×10^{-4}
J1356-645	6.45×10^{-3}
CTA 1	8.67×10^{-4}
J1023-575	2.57×10^{-3}
J1616-508	0.01
J1640-465	3.66×10^{-3}
J1834-087	2.15×10^{-3}
J1841-055	1.19×10^{-2}
J1813-178	6.92×10^{-3}
J1632-478	0.016
J1458-608	9.31×10^{-4}
J1420-607	9.26×10^{-3}
J1809-193	8.27×10^{-3}
J1418-609	5.85×10^{-3}
J1825- 137	0.02
J1831-098	2.76×10^{-3}
J1303-631	6.79×10^{-3}
N 157B	5.76×10^{-4}
J1837-069	7.17×10^{-3}
J1912+101	6.08×10^{-4}
J1708-443	0.015

2. Conversion of γ-ray Fluxes into Neutrino Fluxes

The conversion of the high energy photon flux into a neutrino flux was wrong by a factor between 5 and 8 depending on the source, due to a mistake in the calculation of the integral:

$$N_\nu = T \int_{1\mathrm{TeV}}^{100\mathrm{TeV}} dE_\nu \; \Phi_0 \; \times (2E_\nu)^{-\Gamma} \; \times A_{\mathrm{eff}}(\delta, E_\nu), \tag{1}$$

where T is the integration time and E_ν is the neutrino energy in TeV. A corrected version of Tables 2 and 3 of Di Palma et al. (2017) is provided in Tables 2, 3, and 4 below.

We also report, in Table 1, a corrected version of the Table 1 of Di Palma et al. (2017) where we correct a flux that was wrongly reported and a reference (for source J1912+101 we refer now to Aharonian et al. 2008b).

3. Estimate of the Background

In Di Palma et al. (2017), the background was theoretically estimated as

$$N_{\mathrm{BG}} = T \int_{1\mathrm{TeV}}^{100\mathrm{TeV}} dE_\nu \; \Phi_{\nu,atm}(E_\nu) \; \times A_{\mathrm{eff}}(\delta, E_\nu), \tag{2}$$

with

$$\Phi_{\nu,atm}(E_\nu) = 12 \times 10^{-11} E_\nu^{-3.4} \; \mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}. \tag{3}$$

However, both the ANTARES Collaboration and the IceCube Collaboration found that our estimates were too optimistic.

For ANTARES, we have been advised to always use the maximum effective area when computing the background and also use 200 GeV as the lower limit of integration rather than 1 TeV. We then replace 1 TeV with 200 GeV and A_{eff} with $A_{\mathrm{eff,max}}$ in Equation (2), where $A_{\mathrm{eff,max}}$ corresponds to the largest effective area, relative to the declinations $-90^\circ < \delta < 45^\circ$, and corresponds to the black solid curve in Figure 2 of Di Palma et al. (2017). Revised estimates are reported in the second column of Table 2.

Table 3
Amended Estimates of the Astrophysical Neutrinos and Background for the Sources Listed in Table 1. Corrected Version of Table 2 of the Original Article. First Column: Name of the Source; Second Column: Number of Neutrinos Expected from that Specific Astrophysical Source; Column 3: Number of Background Neutrinos in 1° of Sky in One Year, Estimated Using the Integral from 1 TeV and Using the Effective Area Corresponding to that Specific Declination; Column 4: Number of Background Neutrinos Measured by IceCube, as Reported by Aartsen et al. (2017)

	IceCube		
Source	N_ν	$N_{\rm BG}$ theor	$N_{\rm BG}$ meas
Crab	2.66	2.6	9.4
Vela no Cut-off	0.65	6.4×10^{-4}	6.54
Vela with Cut-off	4.55×10^{-3}	6.4×10^{-4}	6.54
MSH15-52	3.93×10^{-3}	6.4×10^{-4}	6.4
G54.1+0.3	0.13	2.6	9.9
G0.9+0.1	0.024	0.37	7.4
G21.5-0.9	0.038	0.37	7.4
Kes75	0.028	0.37	6.8
J1356-645	$2.76 \times 10 - 3$	9.3×10^{-4}	6.05
CTA1	0.24	2.4	5.42
J1023-575	4.83×10^{-4}	6.4×10^{-4}	6.63
J1616-508	2.70×10^{-3}	6.4×10^{-4}	6.63
J1640-465	8.87×10^{-4}	6.4×10^{-4}	6.7
J1834-087	0.065	0.37	7.07
J1841-055	0.36	0.37	7.07
J1813-178	0.21	0.37	7.5
J1632-478	5.97×10^{-3}	6.4×10^{-4} 3	6.38
J1458-608	1.52×10^{-4}	9.3×10^{-4}	6.25
J1420-607	4.093×10^{-3}	9.3×10^{-4}	6.25
J1809-193	0.25	0.37	7.54
J1418-609	2.42×10^{-3}	9.3×10^{-4}	6.2
J1825-137	0.61	0.37	7.47
J1831-098	0.084	0.37	7.17
J1303-631	2.05×10^{-3}	9.3×10^{-4}	6.1
N 157B	9.43×10^{-5}	9.3×10^{-4}	6.05
J1837-069	0.22	0.37	7.57
J1912+101	0.27	2.6	10.45
J1708-443	8.14×10^{-3}	6.4×10^{-4}	6.52

As far as IceCube is concerned, a comparison of our published background estimates (computed according to Equation (2)), with the work of Aartsen et al. (2017), shows a large discrepancy, which is partly due to the fact that IceCube cannot eliminate completely background events below 1 TeV, where the atmospheric flux is large. Our discussion with members of the IceCube Collaboration convinced us that the most appropriate thing to do is to use the actual IceCube measurements of the background as a function of the declination, as they are provided by Aartsen et al. (2017). The corrected numbers are reported in column 4 of Table 3.

In both Tables 2 and 3, the Vela PWN appears twice. The two different estimates are associated with different assumptions on the Vela gamma-ray emission spectrum. The difference between the two depends on if one takes into account the fact that the Vela gamma-ray emission spectrum seems to cut off at 14 TeV as found by Abramowski et al. (2012a). If such a cut-off is taken into account the estimated number of neutrinos corresponds to the second entry in the Tables.

Based on the amended estimates of astrophysical and background neutrino fluxes, no sources are now above IceCube background. Therefore, IceCube non-detection does not provide any constraint on the fraction of TeV gamma-rays from PWNe that can be of hadronic origin. As a result, the calculations leading to the updated neutrino predictions reported in Table 5 of the original article loose significance: present day data do not allow us to put any constraint on the fraction of the gamma-ray flux observed from PWNe that can be of hadronic origin.

In Table 2, we report the number of neutrinos detectable from the source and the background for ANTARES. The number of background neutrinos for ANTARES is always the same independent on declination $N_{\rm BG} = 0.42$.

In Table 3, we report the number of neutrinos detectable from the source and the background for IceCube. In the third column of the table, we report the number of background neutrinos for IceCube computed according to Equation (2), while in the fourth column the number of background events as measured by Aartsen et al. (2017) is reported. We notice that the number of background events reported in the fourth column of Table 3, while much larger than our theoretical estimate for all the sources, are not very different from what can be estimated adopting for IceCube a procedure similar to that adopted for ANTARES, which is namely using the maximum effective area independently of the source declination and integrating in energy from 200 GeV rather than from 1 TeV.

In Table 4, we report the number of neutrinos of different types that could be expected from each of the considered sources in KM3NeT.

Also this number is lower than what was found in Di Palma et al. (2017).

Table 4

Corrected Results for the KM3NeT/ARCA Detector. The First Column Displays the Name of the Source, while Columns 2, 3 and 4 Report the Number of Expected Astrophysical Events for the Different Neutrino Flavors ν_μ, ν_e and ν_τ, Considering a Nominal Angular Resolution of 0.3°. Since the Effective Area of KM3NeT/ARCA Is Not Given as Function of the Declination, the BG Values Are the Same for Each Source and Are, Respectively: $BG_{\nu_\mu} = 18.4$, $BG_{\nu_e} = 46.6$, $BG_{\nu_\tau} = 19.3$. The Expected Background Events Are Computed in a Sky Patch of $3° \times 3°$

KM3NeT			
Source	N_{ν_e}	N_{ν_μ}	N_{ν_τ}
Crab	1.59	4.80	1.77
Vela no Cut-Off	35.44	155.93	47.54
Vela with Cut-Off	5.13	16.52	5.83
MSH15-52	0.75	2.57	0.88
G54.1+0.3	0.069	0.22	0.079
G0.9+0.1	0.076	0.25	0.087
G21.5-0.9	0.092	0.33	0.11
Kes75	0.079	0.26	0.091
J1356-645	0.39	1.37	0.47
CTA1	0.15	0.52	0.18
J1023-575	0.20	0.61	0.23
J1616-508	0.68	2.23	0.79
J1640-465	0.26	0.83	0.30
J1834-087	0.21	0.67	0.24
J1841-055	1.13	3.64	1.29
J1813-178	0.52	1.87	0.63
J1632-478	0.96	3.39	1.15
J1458-608	0.08	0.24	0.091
J1420-607	0.55	1.93	0.66
J1809-193	0.67	2.33	0.79
J1418-609	0.36	1.24	0.43
J1825-137	1.87	6.09	2.15
J1831-098	0.21	0.75	0.25
J1303-631	0.49	1.55	0.56
N 157B	0.05	0.15	0.056
J1837-069	0.61	2.07	0.72
J1912+101	0.17	0.49	0.18
J1708-443	1.06	3.89	1.29

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