PROCEEDINGS OF SCIENCE

The connection between Cosmic-rays, Neutrinos and X-ray: the Case of Seyfert Galaxies

Antonio Ambrosone[a,b,*]

[a] *Gran Sasso Science Institute (GSSI), Viale Francesco Crispi 7, 67100 L'Aquila, Italy*

[b] *INFN-Laboratori Nazionali del Gran Sasso (LNGS), via G. Acitelli 22, 67100 Assergi (AQ), Italy*

The IceCube Collaboration has recently reported compelling evidence of high energy neutrino emission from NGC 1068, and mild excesses for NGC 4151 and CGCG420- 015, local Seyfert galaxies. This has increased the interest along neutrino emission from hot corona surrounding the super massive black holes of Seyfert Galaxies. In this contribution, we demonstrate that these sources are consistent with sub-equipartition between CR and the magnetic energy densities. Nonetheless, the energetics carried by CRs is rather high, making future analyses fundamental to investigate if such conditions can be met in the environment of seyfert galaxies. We estimate the neutrino flux of the whole seyfert population, and we will demonstrate that it might overestimate the diffuse neutrino flux at 1-10 TeV energies leading to a potential tension in the high-energy neutrino sky. We argue that not all the AGNs might be neutrino emitters. All in all, all these results point to the fact that regions surrounding the SBMHs in AGNs might be able to accelerate cosmic rays producing high-energy neutrinos.

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1. Introduction

The IceCube collaboration has discovered a diffuse astrophysical neutrino flux in 2013 whose origin is still a mystery [1, 2]. Recently, there has been growing evidence for TeV neutrino emission from some Seyfert Galaxies, such as NGC 1068, NGC 4151 and CGCG 420-015 [3–5]. Therefore, there has been an increased interest in studying the connection between these sources and high-energy neutrino production. In this contribution, we study this connection in terms of hot-coronae paradigm. We show that neutrino emission can be powered by the hot-coronae assuming a sub-equipartition between cosmic-rays (CRs) and magnetic energy densities, but a big portion of the bolometric fraction should be injected into CRs. Finally, we also show that in order not to overshoot the diffuse IceCube neutrino flux, not all the seyfert galaxies might be neutrino emitters (see [6] for more details).

2. Neutrino Emission Model

The neutrino emission reported from NGC 1068 is an order of magnitude higher than expected from the gamma-ray flux reported using the Fermi-LAT Telescope data [7] as well as the VERITAS Telescope upper limits [8]. Furthermore, we expect the neutrino emission to be powered by a hidden source, namely by a source able to trap gamma-rays inside the system. The hot-coronae is a compact small region extending up to $R_c \sim 10 - 20\, R_s$ with R_s being the Schwarzschild radius [9]. It strongly emits x-rays with a spectrum given by a power-law in the $0.1 - 300\,\mathrm{KeV}$ range [9]. The high x-ray density is able to strongly suppress the photon flux above $\sim 100\,\mathrm{MeV}$. Therefore, the hot-coronae provides a natural explanation for gamma-ray opaque sources. We estimate the neutrino emission from these sources using a leaky-box model for CR transport [6]

$$\frac{N_{CR}(E)}{\tau_{\rm esc}} - \frac{d}{dE}\left[\frac{E}{\tau_{\rm loss}} N_{CR}(E)\right] = Q(E) \tag{1}$$

where $Q(E) \propto E^{-\gamma} e^{-E/E_{\rm cut}}$ is the injected CR power-law flux. $\tau_{\rm esc}$ and $\tau_{\rm loss}$ represent escape and energy losses timescales (please see [6] for details). In order to normalise the spectrum, we impose that the CR energy density $U_{\rm CR}$ cannot be higher than the magnetic energy density $\frac{U_{\rm CR}}{U_B} = f \leq 1$. We fix this ratio imposing that only a fixed fraction η of the bolometric luminosity. In other words, $\int_{m_p c^2}^{+\infty} E Q(E) dE \leq \eta L_{\rm bol}$. The neutrino emission is calculated considering the proton proton (pp) contribution following the analytical prescription of Ref. [10], while the proton-photon ($\mathrm{p}\gamma$) contribution using multi-messenger relations [11].

3. Neutrino data and Results

We calculate the neutrino luminosity (L_ν) for NGC 1068, NGC 4151 and CGCG 420-015 integrated between $1 - 10\,\mathrm{TeV}$ using the contours reported by IceCube [3–5]. We also consider NGC 3079 which has been reported as a neutrino emitter by Ref. [12].

For the intrinsic (absorption-corrected) X-ray luminosity (L_X), between $2 - 10\mathrm{KeV}$, we use reported values by the BASS AGN catalogue [13]. The uncertainty on L_X is set to 0.75 dex to account for the wide range of values reported in the literature. Fig. 1 reports L_ν in terms of L_X,

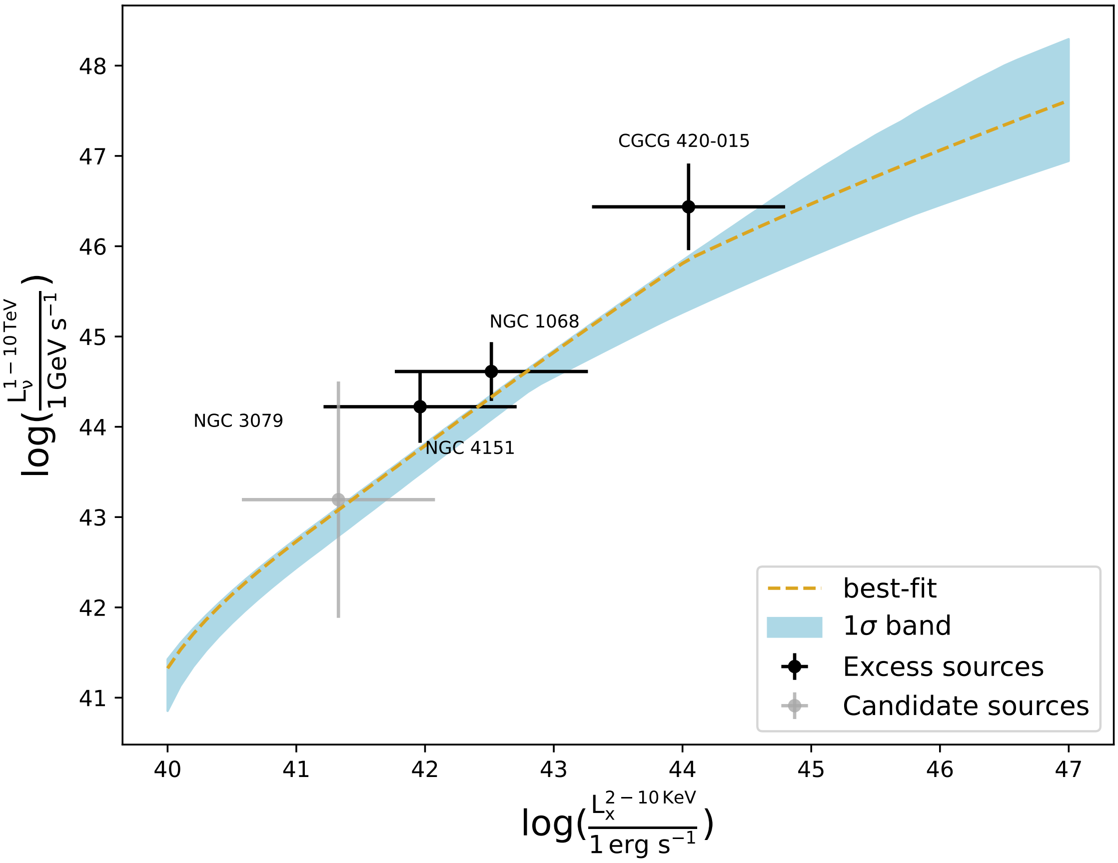

Figure 1: L_ν vs L_X for NGC 1068, NGC 4151, CGCG 420-015 and NGC 3079. The blue band corresponds to the 1σ uncertainty band from our statistical analysis, while the golden dashed line corresponds to the best-fit scenario. Image taken from [6].

clearly showing a potential connection between L_ν and L_X. We test if our model can explain these data employing a chi-squared test, fixing $\eta = 25\%$. The best-fit values and the 1σ band are reported in Fig. 1. The results show that the neutrino emission of these sources is compatible with the hot-corona paradigm assuming that a large portion of the bolometric luminosity goes into CRs. We also emphasise that the neutrino emission from CGCG420-015 can barely be accounted for. Furthermore, the spectral index required to produce such a high level of neutrinos is $\gamma \lesssim 1$ compatible with stochastic acceleration processes.

4. Diffuse Neutrino Emission

The results of previous section can be used to estimate the diffuse neutrino emission of seyfert galaxies. To such a purpose, we use the 2-10 x-ray luminosity function of Ref. [14]. We consider a fraction of 50% of Compton thick AGNs as well.

Fig. 2 shows the final diffuse spectral energy distribution predicted by the seyfert galaxy population compared with IceCube diffuse fluxes [1, 2] and the predicted KM3NeT shower differential sensitivity after 10 years of data taking [15]. The red band represents the 1σ variability of the fit

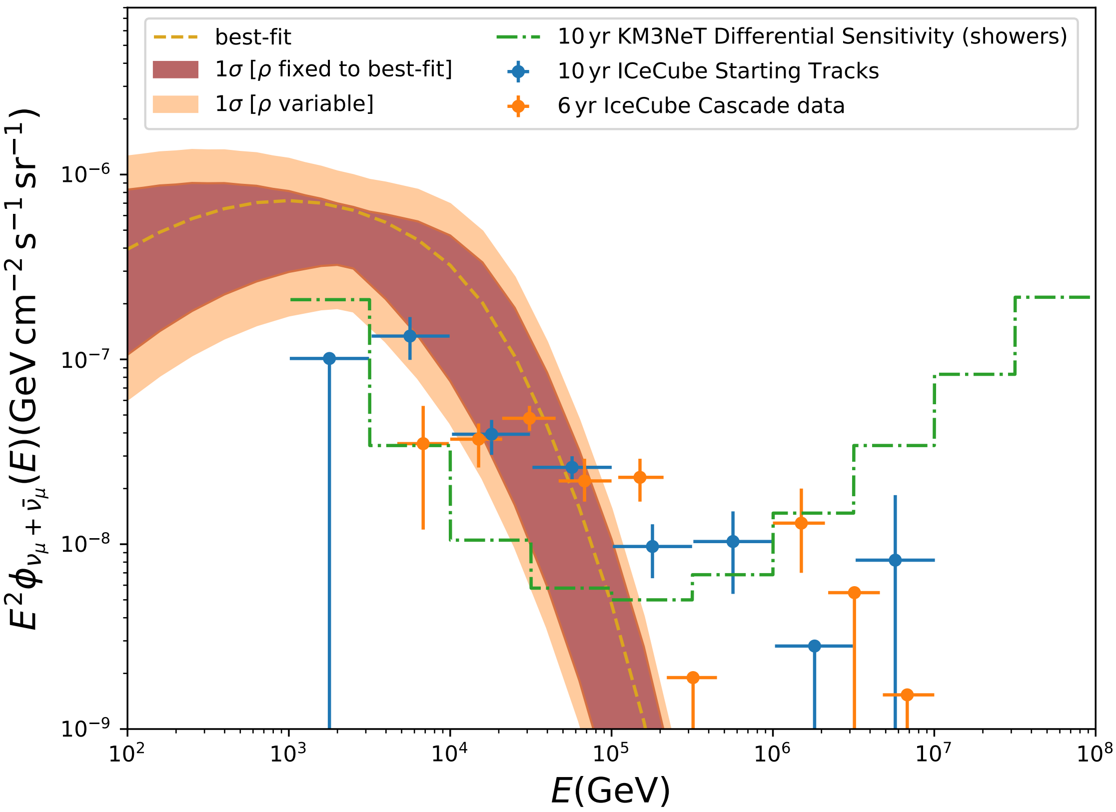

Figure 2: Diffuse Spectral energy distribution of the seyfert galaxy population as a function of the energy. The theoretical prediction is compared to the IceCube datasets [1, 2] and the KM3NeT Differential Sensitivity for the shower sample [15]. Image taken from [6].

shown in the previous section, while the orange band comprises also the uncertainty on the source density distribution. Our result suggests that if all the seyfert galaxies were to emit neutrinos with the same rate as NGC 1068, NGC 4151, NGC3079 and CGCG420-015, the diffuse neutrino flux from seyfert galaxies would overshoot the measured diffuse flux.

5. Conclusions

In this contribution, we have shown that recent IceCube observations regarding some nearby seyfert galaxies can be interpreted in terms of neutrino emission from the hot-coronae region. In doing so, we have estimated at least $\sim 20\%$ of the bolometric luminosity should be injected into CRs. We also evaluated the diffuse neutrino fluxes using our model and we have shown that this leads to an overproduction of neutrinos. Therefore, we conclude that not all the seyfert galaxies can be neutrino emitters.

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