

Gamma-Ray and Neutrino Emissions from Starforming and Starburst Galaxies

Antonio Ambrosone^{1,2,*}, Marco Chianese^{1,2}, Damiano F.G. Fiorillo⁵, Antonio Marinelli^{1,2,4}, and Gennaro Miele^{1,2,3}

¹Dipartimento di Fisica “Ettore Pancini”, Università degli studi di Napoli “Federico II”, Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy

²INFN - Sezione di Napoli, Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy

³Scuola Superiore Meridionale, Università degli studi di Napoli “Federico II”, Largo San Marcellino 10, 80138 Napoli, Italy

⁴INAF-Osservatorio Astronomico di Capodimonte, Salita Moiariello 16, I-80131 Naples, Italy

⁵Niels Bohr International Academy, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

Abstract. Experimental observations have demonstrated a strong correlation between the star formation rate and the gamma-ray luminosities of starforming and starburst galaxies (SFGs and SBGs). However, the real origin of these emissions is still under debate. In this contribution, we present several updates on their non-thermal radiations, revisiting both their point-like and cumulative (diffuse) emission properties. From the point-like side, we discuss the potentialities of future neutrino (KM3NeT/ARCA, IceCube-gen2) telescopes to quantitatively scrutinize their expected properties from different cosmic-ray transport models. From the diffuse perspective, we investigate a model based on a data-driven blending of spectral indexes, hence taking into account the changes in the properties of individual emitters. Strikingly, SFGs and SBGs can explain 25% (up to 40%) of the diffuse High-Energy Starting Events (HESE) data, without overshooting the gamma-ray limits regarding non-blazar sources.

1 Introduction

Starforming and Starburst Galaxies are astrophysical sources characterised by a high star formation rate (see [1–5]). This means that many stars are born and die in their astrophysical environment. This activity is principally expected to occur in their core, which is also called starburst nucleus (SBN) [1, 2]. Consequently, supernova explosions (SNe) are expected to inject a great amount of high-energy cosmic rays (protons with energies up to ~ 1 PeV) (see [3–5] and Refs. therein for other details). Furthermore, a gas density can be as high as 10^{2-3} cm^{-3} inside SBNi (see [5] for more details). Therefore, SFGs and SBGs should emit non-thermal particles such as gamma-rays and neutrinos through hadronic collisions between high-energy cosmic rays particles and molecular gas particles. In this contribution, we describe how current and future experiment can test the hadronic production of these sources. In particular, we follow the model put forward by [1], which considers cosmic ray transport dominated by advection phenomena. This is phenomenologically justified by the fact that gamma-ray spectra

*e-mail: antonio.ambrosone@unina.it

of most SFGs and SBGs are hard power-laws (see [6] for details about the observed spectra) which, to some extent, implies that the escape timescale is energy-independent. While, theoretically, it is justified because of the expected high-degree magnetic turbulence [7] which leads to a minor role for diffusion. From the point-like side, we analyze photons data from [6], namely 10-yr *Fermi*-LAT spectral energy distribution data. We also use VERITAS [8] and HESS data [9] respectively for M82 and NGC 253. For Circinus Galaxy, we use data from [10]. We analyze these data with the intention of evaluating the neutrino contribution of these sources and test if neutrino telescopes can trace these emissions. From the diffuse analysis side, we use the calorimetry assumption (see [2, 3] for details) to calculate the amount of gamma-rays and neutrinos coming to the Earth from all these sources in the Universe. The proceeding is organized as follows: in Sec. 2, we discuss the cosmic-ray transport mechanisms as well as the point-like analysis; in sec. 3, we discuss the diffuse contribution of SFGs and SBGs. Finally, in sec. 4, we draw our conclusions.

2 Cosmic-Ray Transport and Point-Like Analysis

The emissions of SBGs are usually regarded as steady because of the starburst timescale duration. In this context, it is possible to use a simple leaky-box model to describe the cosmic ray transport inside the nucleus. Therefore (see [1–5]):

$$\frac{f(p)}{T_{\text{loss}}} + \frac{f(p)}{T_{\text{diff}}} + \frac{f(p)}{T_{\text{adv}}} = Q(p) \quad (1)$$

where $f(p)$ is the CR momentum distribution inside the nuclei, $Q(p)$ is the injection rate from SNe. T_{loss} , T_{diff} and T_{adv} are the energy loss, diffusion and advection timescales, respectively. $Q(p)$ follows a power-law spectrum with α as a spectral index and an exponential cut-off. The neutrino and gamma-ray are mainly produced by the pion decays and we parametrize these emissions using the delta-function approximation, assuming pions carry 17% of the kinetic energy of the parent high-energy proton. We analyze every known (nearby) SFG, using *Fermi*-LAT data. We fit the gamma-ray data with this model in order to calculate the structural parameters needed to calculate the neutrino fluxes and test the potentiality of current and upcoming neutrino telescopes to constrain such scenarios. Fig. 1 summarizes our main result (see [4] for more details). It compares the 1 TeV neutrino SBG flux from our estimate with the IceCube [11] and the expected sensitivity of KM3NeT/ARCA detector [12] and IceCube Gen2. Importantly, SMC and Circinus cores emissions could be constrained by 6 years of data taking of the upcoming KM3NeT detector [13]. Furthermore, the neutrino excess detected from the direction of NGC 1068 cannot be generated by SBG activity. We stress that we find, along with [6], that gamma-ray emissions of NGC 1068 to be consistent with its SBG activity within the calorimetric limit. However, this cannot exclude further contamination to these data from hot-corona and jet activities.

3 Diffuse Analysis

In this section, we analyze the expected diffuse gamma-ray and neutrino contributions of these sources. In particular, we exploit the fact that the higher the star formation rate, the more calorimetric these source are going to be [2, 3]. Indeed, above a critical star formation rate value ($\approx 1 M_{\odot} \text{ yr}^{-1}$), SFGs are expected to be calorimetric [2]. In this scenario, it is possible to set a prototype galaxy (in this case M82) and then the generic flux of a source can be considered as $f_{\text{SBG}}(E, \alpha, \psi) = \frac{\psi}{\psi_{\text{M82}}} f_{\text{M82}}(E, \alpha)$ [2, 5]. Therefore, the diffuse emissions will predominantly depend on the distribution of the spectral shape as well as on the maximal energy reachable by protons in the SBN environment. We assume a maximal energy of 10 PeV.

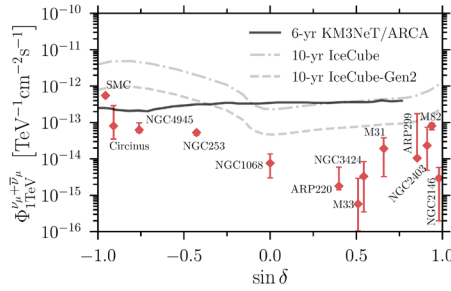


Figure 1. 1 TeV neutrino spectra normalizations compared with KM3NeT, IceCube and IceCube gen 2 sensitivities. Figure taken from [4].

For the α distribution, we consider the gaussian distribution considering the 13 best-fit values coming from point-like fit we have performed in the point-like analysis. Fig. 2 summarises the result comparing the Isotropic Gamma-ray background [14] and IceCube data [15] with the corresponding expected SBG spectra (see [5] for more details). Interestingly, we find

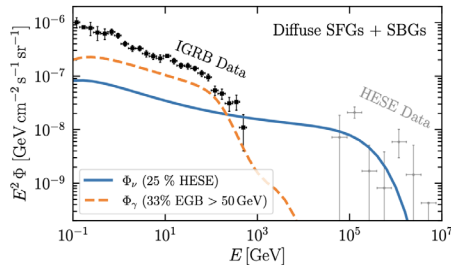


Figure 2. Diffuse Gamma-ray and Neutrino SBG spectra compared with IRGB [14] and HESE [15] data. Figure taken from [5].

that SFGs and SBGs give an important contribution to the Isotropic Gamma-ray Background light (IGRB), while being consistent with the Extragalactic Gamma-ray Background (EGB) constraints on non-blazar sources above 50 GeV ($\leq 30 - 40\%$) (see [16]). Moreover, the neutrino spectrum is expected to power about 25% of the HESE data. Indeed, the spectral index blending provides a hardening on the spectrum leading to a greater neutrino contribution. In Ref. [3], we also provided a multi-component analysis, using other sources (along with SFGs and SBGs) contributions such as blazars and radio galaxies. We have demonstrated that using a blending scenario, SFGs and SBGs can contribute to 40% of IceCube data at 2σ level.

4 Conclusions

In this proceeding, we have reviewed the gamma-ray and neutrino emission properties of SFGs and SBGs. In particular, using the state-of-the-art cosmic ray transport mechanisms scenario, we have provided a forecast for upcoming neutrino telescopes to understand if they can trace star formation activity. We obtained that the cores of SMC and Circinus could be constrained by future neutrino observations. This will be an invaluable test of such hadronic scenario. From the diffuse point of view, we have used the calorimetric scenario to evaluate

the diffuse gamma-ray and neutrino spectra and compared with the corresponding IGRB and HESE data. We have obtained that SFGs and SBGs can explain a considerable fraction of IGRB data and also a part of IceCube data.

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