PROCEEDINGS OF SCIENCE

Extra-galactic Star-forming Environments as Sources of High-Energy Neutrinos

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*

E-mail: antonio.ambrosone@gssi.it

Star-forming environments such as star-forming and Starburst Galaxies (SFGs and SBGs) experience intense phases of stellar formation activity, which is expected to increase the amount of gas and magnetic turbulence leading to confinement of high-energy cosmic rays (CRs) and high probability of proton-proton (pp) collisions. Therefore, these environments are expected to be powerful emitters of high-energy gamma-rays and neutrinos. In this contribution, using 15 years of public Fermi-LAT data, I will discuss the correlation between these emissions with the star formation rate and I quantify that the SFG and SBG contribution cannot saturate the the isotropic gamma-ray background (IGRB) measured by Fermi-LAT while being consistent with a $\sim 20\%$ contribution to the 6-year Cascade diffuse neutrino flux measured by the IceCube Neutrino Observatory.

12th Neutrino Oscillation Workshop (NOW2024)
2-8, September 2024
Otranto, Lecce, Italy

*Speaker

PoS(NOW2024)073

1. Introduction and Mathematical Framework

Extra-galactic star-forming environments such as SFGs and SBGs are usually characterised by intense stellar forming activity as well as large interstellar medium density witnessed by a larger supernovae explosion (SNe) rate than in the Milky-way, see for instance [1–5]. Therefore, since supernova remnants (SNRs) are supposed to power CRs up to ∼ PeV energies, SFGs and SBGs are expected to produce high-energy gamma-rays and neutrinos produced by the decays of pions after proton-proton collisions [4]. The CR proton spectrum can be approximated using the leaxy-box model [4]

$$N_{CR}(E) = \frac{F_{\text{cal}} \cdot \tau_{pp}}{E} \int_{E}^{+\infty} Q(E) dE \tag{1}$$

where τ_{pp} is the proton-proton timescale, F_{cal} is the so called calorimetric fraction, namely the fraction of CRs actually losing energy by proton-proton collisions and producing gamma-rays and neutrinos. $Q(E)$ is the injection spectrum of SNRs given by a power-law with an exponential cut-off $Q(E) \propto E^{-\gamma} e^{-E/E_{\text{max}}}$ normalised to a fraction of the kinetic energy of SNRs. The final gamma-ray and neutrino fluxes can be evaluated using the semi-analytical approach of Ref. [6]. Here, we stress that the gamma-ray and neutrino spectra are strictly connected in hadronic collision and they can be linked according to the multi-messenger relations with $\phi_\nu(E_\nu) = 2\phi_\gamma(2E_\gamma)$ [7]. This is because, on average, after each pp collisions a neutrino carry 5% of the parent high-energy proton while a gamma-ray carry 10%. Therefore, gamma-rays become a powerful tool with which constrain the neutrino budgets of SBGs. In Ref. [4], we have analysed a catalogue of 70 sources using the publicly-avaiable *fermitools* (you can find details on the catalogue in [4, 8]) and obtained strong constraints on F_{cal}. In particular, we have calculated F_{cal} for each source by matching the gamma-ray spectrum measured with the theoretical one. Only ∼ 16 sources provide a clear excess into the Fermi-LAT data. Results suggest that F_{cal} increases with the rate of supernovae explosions and it approaches 1 for very powerful sources.

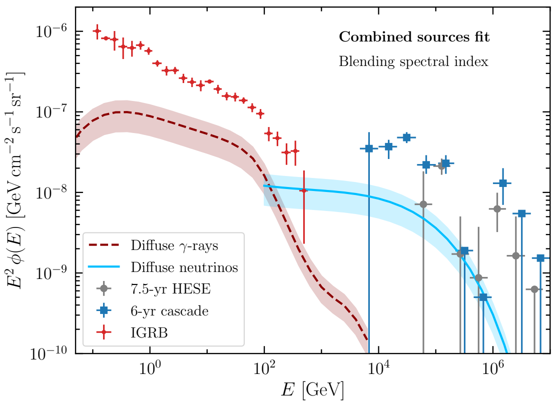

Figure 1: Diffuse 2σ γ-ray (red) and neutrino (blue) bands predicted with the fit over the 70 sources. the fluxes are compared with the Isotropic Gamma-Ray Background (IGRB) measured by Fermi-LAT [9], the 6 year Cascade neutrino flux [10] and 7.5 year HESE data [11] measured by the IceCube neutrino Observatory. Image taken from Ref. [4].

2. Neutrinos and Conclusions

The result outlined in the previous section indirectly constrain the neutrino contributions from SBGs. In particular, we calculate the diffuse emission of all SBGs in the Universe (see [4] for more details). Fig. 1 show the final contribution to the diffuse gamma-ray and neutrino fluxes from SFGs and SBGs. The gamma-ray observations constrain the neutrino spectrum to be below $\sim 20\%$ of total IceCube flux. This means that Multi-Messenger Astronomy is an invaluable tool with which unveil the origin of high-energy neutrinos.

References

[1] Antonio Ambrosone, Marco Chianese, Damiano F. G. Fiorillo, Antonio Marinelli, Gennaro Miele, and Ofelia Pisanti. Starburst galaxies strike back: a multi-messenger analysis with Fermi-LAT and IceCube data. *Mon. Not. Roy. Astron. Soc.*, 503(3):4032–4049, 2021.

[2] Antonio Ambrosone, Marco Chianese, Damiano F. G. Fiorillo, Antonio Marinelli, and Gennaro Miele. Could Nearby Star-forming Galaxies Light Up the Pointlike Neutrino Sky? *Astrophys. J. Lett.*, 919(2):L32, 2021.

[3] Antonio Ambrosone, Marco Chianese, Damiano F. G. Fiorillo, Antonio Marinelli, and Gennaro Miele. Observable signatures of cosmic rays transport in Starburst Galaxies on gamma-ray and neutrino observations. *Mon. Not. Roy. Astron. Soc.*, 515(4):5389–5399, 2022.

[4] Antonio Ambrosone, Marco Chianese, and Antonio Marinelli. Constraining the hadronic properties of star-forming galaxies above 1 GeV with 15-years Fermi-LAT data. *JCAP*, 08:040, 2024.

[5] Enrico Peretti, Pasquale Blasi, Felix Aharonian, and Giovanni Morlino. Cosmic ray transport and radiative processes in nuclei of starburst galaxies. *Mon. Not. Roy. Astron. Soc.*, 487(1):168–180, 2019.

[6] S. R. Kelner, Felex A. Aharonian, and V. V. Bugayov. Energy spectra of gamma-rays, electrons and neutrinos produced at proton-proton interactions in the very high energy regime. *Phys. Rev. D*, 74:034018, 2006. [Erratum: Phys.Rev.D 79, 039901 (2009)].

[7] Ofelia Pisanti. Astrophysical neutrinos: theory. *J. Phys. Conf. Ser.*, 1263(1):012004, 2019.

[8] M. Ackermann et al. GeV Observations of Star-forming Galaxies with the Fermi Large Area Telescope. *The Astrophysical Journal*, 755(2):164, August 2012.

[9] M. Ackermann et al. The spectrum of isotropic diffuse gamma-ray emission between 100 MeV and 820 GeV. *Astrophys. J.*, 799:86, 2015.

[10] M. G. Aartsen et al. Characteristics of the diffuse astrophysical electron and tau neutrino flux with six years of IceCube high energy cascade data. *Phys. Rev. Lett.*, 125(12):121104, 2020.

[11] R. Abbasi et al. The IceCube high-energy starting event sample: Description and flux characterization with 7.5 years of data. *Phys. Rev. D*, 104:022002, 2021.