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Modeling the Galactic center emission from GeV to PeV

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Abstract. The H.E.S.S. collaboration recently reported a new analysis of the gamma-ray diffuse emission from a "semi-annulus" region of 1.4×10^{-4} steradiants around Sagittarius A*. The gamma-ray spectral energy distribution measured from this region suggests the presence of interacting cosmic rays at PeV energies. This analysis adds a important piece to the previous measurements obtained with Fermi-LAT, H.E.S.S. and VERITAS telescopes in this particular region of the Central Molecular Zone. Here we describe this diffuse gamma-ray emission observed around the galactic center within a comprensive model implying a cosmic-ray population with a harder spectrum in the central part of the galaxy respect to the standard scenarios. With this phenomenological model we obtain the expected diffuse gamma-ray and neutrino components for this target rich region considering the energy range from GeV to PeV. While for the gamma-ray expectations we compare the results with the data of the mentioned experiments, for the expected neutrino spectra we consider the possibility to observe the signal with Cherenkov telescopes.

1 Introduction

In 2006 the H.E.S.S. telescope reported the measurement of diffuse gamma-ray emission from a central ridge [1] of our galaxy after the subtraction of point-like contributions. The diffuse gamma-ray spectral energy distribution (SED) obtained from the ridge cannot be explained with a standard scenario where the transport of cosmic rays (CR) doesn't change moving from the periphery of the Galaxy to the central molecular zone (CMZ). A more recent publication of H.E.S.S. collaboration reported the results of a longer campaign [2], around ∼ 250 hours, focused on a "semi-annulus" region of 1.4×10^{-4} steradiants around Sagittarius A*. The SED obtained with H.E.S.S. observations, from this region around Sagittarius A*, can be fitted with a single power law up to tens of TeV without needing a cut-off and representing the first evidence of PeV cosmic-ray population in our Galaxy. In the past Sagittarius A* had periods of high activities in x-ray [3] and a outflow was also observed [4]; however his contribution to Galactic cosmic rays is still unknown. The H.E.S.S. collaboration argues that the measured spectrum from the "semi-annulus" region can be linked to the past emission [5] of Sagittarius A* [2]. However, in the H.E.S.S. analysis, the gamma-ray contribution from the interactions of cosmic-ray sea with the interstellar gas around Sagittarius A* was not taken into account. The

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expected diffuse gamma-ray and neutrino fluxes produced by these processes are strongly dependent on the considered CR transport scenario and the assumed gas distribution. Here we present the expected diffuse gamma-ray and neutrino fluxes produced in the "semi-annulus" region, considering a recently introduced scenario (KRA_γ) with a radially-dependent diffusion coefficient [6, 7]. To extend the gamma-ray analysis to lower energies we use the Fermi-LAT data extracted from the PASS8 catalog. The PASS8 gamma-ray events were recently obtained with a new selection algorithm released by the Fermi-LAT collaboration [8]. The new selection criteria increased the effective area, the energy estimation and the angular resolution of the detector, especially at high energy. After subtracting the point-like contribution from the Fermi-LAT data in the diffuse region around Sagittarius A* and adding the H.E.S.S. measurements we build a new SED lasting from 10 GeV to 40 TeV. We compare the whole spectrum with the expectations from the cited KRA_γ scenario and the standard KRA scenario where the CR propagation is homogeneous for the whole galaxy. For both cases we constrain the possible diffuse emission directly linked to Sagittarius A* activity. Finally we compute the KRA and KRA_γ diffuse neutrino expectation for the "semi-annulus" region introducing also a possible emission from RXJ 1745-290 [9].

2 Comparison between data and models

The first analysis we show in this work represents the comparison between the expected diffuse gamma-ray flux, obtained by the interaction of CR sea and the interstellar medium, and the measurements of H.E.S.S. and Fermi-LAT experiment in the defined "semi-annulus" [2] around sagittarius A*. Two different diffuse gamma-ray expectations are computed considering, the standard scenario with a homogeneous CR propagation for the whole galaxy (KRA) and the case with a radially-dependent CR diffusion properties inducing a hardening of CR spectrum toward the Galactic center regions (KRA_γ). As a target of CR interaction when producing gamma rays and neutrinos we use the 3-dimensional semi-analytic gas distribution presented in [10]. Where the molecular H_2 Hydrogen is obtained from the CO emission line with a conversion parameter $X_{\rm CO}(r \sim 0) \simeq 0.5 \times 10^{20}\ cm^{-2}\ K^{-1}\ km^{-1}$ with a factor 2 uncertainty, while a number density of $0.11\,(n_{\rm HI} + 2n_{H_2})$ is assumed for the atomic HI gas. The computed gamma-ray expectations are then compared with a wide energy range data, the low-energy ones extracted from Fermi-LAT PASS8 sample while the high-energy ones obtained by the new campaign published in 2016 by the H.E.S.S. collaboration, covering the window from 10 GeV to 40 TeV. It is interesting to notice that the entire studied SED can be fitted with a single power law, as shown in the left plot of fig. 1, suggesting the common origin for the gamma rays emitted in this energy range. The best fit for the two data samples considering a simple power law without cutoff $F = F_0 E^{-\alpha}$ is obtained for $F_0 = 1.9 \times 10^{-12}\ TeV cm^{-2} s^{-1}$ and $\alpha = 2.39$. On the right plot of fig. 1 it is shown also the difference between the best-fit analysis and the two computed scenarios (KRA and KRA_γ). The sum of hadronic and leptonic components of KRA_γ, represented on the right plot of fig. 1 by the blu solid line, results very close to the gamma-ray best fit over the entire SED leaving a small slot for possible diffuse component directly related to the central engine Sagittarius A*. In other words the gamma-ray component produced by the CR sea in the "semi-annulus" region account for the quasi-total measured flux, when the KRA_γ model is considered, and even in the standard CR scenario the diffuse sea component seems not negligible. The second analysis we present here is the expected neutrino emission from the "semi-annulus" region considering the two scenarios, KRA and KRA_γ for the diffuse galactic CR production. Taking into account the optimistic angular resolution of 1° for neutrino telescopes at TeV energy ranges, when reconstructing track-like events, it is opportune to add the possibility of having neutrino contribution from central point source $RXJ1745 - 290$, consistent with the Sagittarius A* position within $5''$. The same studies done through gamma-ray

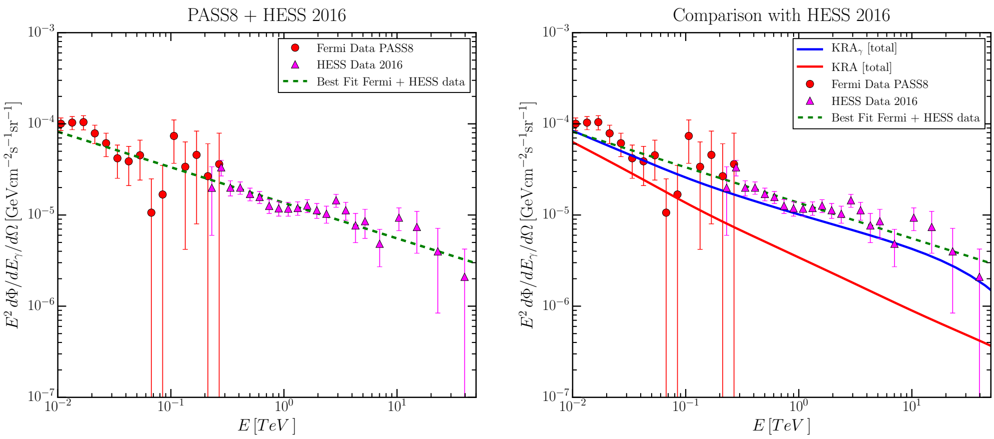

Figure 1. On left side are reported the differential flux measured by H.E.S.S. collaboration from the "semi-annulus" around Sagittarius A* and the differential flux obtained from the Fermi-LAT PASS8 sample for the same region. With the green dashed line the best-fit of the entire SED from 10 GeV to 40 TeV. On the right side are reported the same data compared with two different scenarios; the KRA_γ representing the case with a variable diffusion coefficient for the galactic CR in blu (the sum of leptonic and hadronic components is considered) and the *KRA* representing the standard case with a homogeneous CR transport for the whole Galaxy in red (also here we consider the sum of leptonic and hadronic components)

detectors for the "semi-annulus" region are not feasible with Cherenkov neutrino telescopes for both statistics of events and angular resolution. However the standard *KRA* and the new KRA_γ scenarios give us the possible neutrino expectations from this region of the CMZ. This region is not preferential for the IceCube detectors being in southern hemisphere while represents a good target for the incoming KM3NeT detector [11]. However considering the sensitivies showed in [12] more than 5 years of data can be needed to observe the total SED indicated with the black solid line in fig. 2.

3 Conclusions

In this contribution we present the study of the emission from the "semi-annulus" region around Sagittarius A* indentified by the H.E.S.S. collaboration as a possible Petaelectronvolt CR engine. We show the best-fit analysis of the gamma-ray SED in the region between 10 GeV and 40 TeV collecting togheter the PASS8 data, from Fermi-LAT, and the H.E.S.S. data after the subtraction of point-like contribution. Then we compare the best-fit analysis with the expected gamma-ray diffuse emission produced by CR sea from this region of the sky considering the KRA_γ scenario with a radial dependent CR propagation and the standard *KRA* scenario with the same CR propagation properties for the whole galactic plane. The entire gamma-ray SED considered, well fitted with a single power law without cutoffs, is compatible with the KRA_γ SED (expected from the interaction of CR sea with the gas) leaving a small room for possible diffuse emission directly linked to the central source Sagittarius A*. We show also the study of the expected neutrino emission from "semi-annulus" region considering the *KRA* and KRA_γ scenarios and introducing a possible additional contribution from RXJ 1275-290. The expected total neutrino signal can be a challenge for the incoming KM3NeT telescope while can be hardly detected by the actual IceCube detector. With all mentioned results we show that the KRA_γ

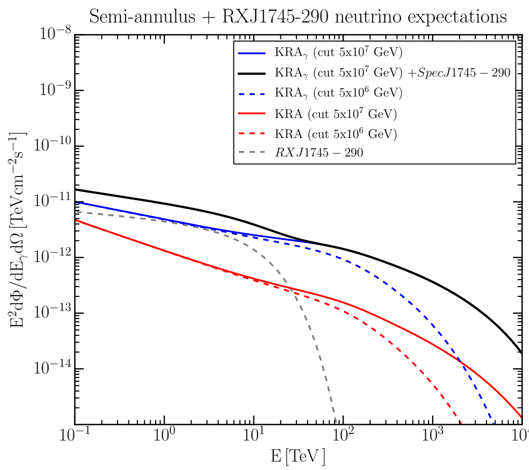

Figure 2. Neutrino expectation from the "semi-annulus" region considering also a possible additional component from RXJ 1745-290. The neutrino SED from KRA_γ scenario is reported with the blu solid line for the protons cutoff at 50 PeV and with the blu dashed line for the protons cutoff at 5 PeV. The neutrino SED from KRA scenario is reported with the red solid line for the protons cutoff at 50 PeV and with the red dashed line for the protons cutoff at 5 PeV. The grey dashed line is the possible RXJ 1745-290 contribution assuming the entire spectrum measured by H.E.S.S. [2], $\Phi_0 = (2.55 \pm 0.04_{stat} \pm 0.37_{syst}) \times 10^{-12} TeV^{-1} cm^{-2} s^{-1}$ with $\Gamma_0 = 2.14 \pm 0.02_{stat} \pm 0.10_{syst}$ and an energy cutoff of $E_{cut} = 10.7 \pm 2.0_{stat} \pm 2.1_{syst}$, of hadronic origin. The black solid line represent the sum of the KRA_γ (with protons cutoff at 50 PeV) expectations and the possible $RXJ1745-290$ neutrino contribution.

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model, tuned on larger galactic scale, gives a more consistent picture, respect to the standard scenario (KRA), also for this small region of the Galactic center.

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