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The very high energy gamma-ray diffuse emission from the Galactic Center

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We present a novel interpretation of the gamma-ray diffuse emission in the Galactic Center (GC) and the Central Molecular Zone (CMZ) regions. This is based on a scenario assuming a harder scaling of the diffusion coefficient with rigidity in the inner Galaxy which reproduces the radial dependence of the cosmic-ray (CR) spectral index recently inferred from Fermi-LAT. We compare our model with H.E.S.S. and (for the fist time in this context) with PASS8 Fermi-LAT data which allows to cover the entire energy range from few GeV up to 50 TeV and to infer the primary CR radial distribution above 100 GeV. We find that the bulk of the Galactic ridge emission can be naturally explained by the interaction of the diffuse, steady-state Galactic CR sea interacting with the gas present in the CMZ. As a consequence, the evidence of a GC Pevatron is significantly weakened.

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1. Introduction

The High Energy Stereoscopic System (H.E.S.S.) collaboration recently reported the discovery of a γ-ray diffuse emission from a small region surrounding SgrA* [1]. The emission spectrum is compatible with a single power-law with index close to 2.3 and it extends up to ~ 50 TeV with no statistically significant evidence of a cutoff. A γ-ray diffuse emission was also measured by H.E.S.S. from a larger region the so called Galactic Ridge (GR) [2] roughly corresponding to the central molecular zone (CMZ) – a massive structure rich in molecular gas that extends up to ~ 250 pc away from the GC along the Galactic plane (GP) [3]. The spectrum on the whole ridge continues, without statistically significant evidence of a cutoff, up to ~ 45 TeV at least and its matches that measured in the inner region surrounding SgrA*. Therefore, the emission from the entire CMZ is significantly harder than the local CR spectrum measured at the Earth position ($\Gamma_{\rm CR}(r_\odot) \simeq 2.7$ for $E_{\rm CR} > 300$ GeV/nucleon). The H.E.S.S. collaboration interpreted these findings as evidences of a freshly accelerated cosmic-ray (CR) population in that region possibly originated by the supermassive SgrA* black hole or by an intense star-burst activity in the GC.

Here we explore a different scenario: In our opinion the largest part of the energetic diffuse emission from the Galactic ridge and SgrA* is originated by the large scale, steady-state Galactic CR *sea* interacting with the massive molecular clouds in the CMZ under the assumption that the spectrum in that region is harder than the one observed on the Earth. Our scenario is motivated by recent analyses of Fermi-LAT data [4, 5] showing that the γ-ray diffuse emission of the Galaxy, and hence the CR primary spectrum, becomes progressively harder approaching the GC along the GP. We use here `PASS8` Fermi-LAT data to extend down to few GeV the measurement of the γ-ray diffuse emission spectrum in the CMZ and SgrA* surrounding, showing that this behaviour continue in the inner ~ 100 pc. Following [4] we interpret this behaviour in terms of a radial dependence of the scaling of the CR diffusion coefficient with rigidity. We will use the same scenario to compute the CR sea distribution in the GC region and the γ-ray diffuse emission produced by their interaction with the dense gas in that region and compare those predictions with Fermi-LAT and H.E.S.S. data.

2. H.E.S.S. and Fermi-LAT data

We extract Fermi-LAT data using the Fermi Science Tools `v10r0p5` [6]. We use 470 weeks of `PASS8` data with the event class `CLEAN` and we apply the recommended quality cuts: `(DATA_QUAL==1) && (LAT_CONFIG==1)`. The exposure is computed using the Fermi-LAT response function `P8REP2_CLEAN_V6`. Here the data are binned in 20 energy bins equally spaced in log scale between 300 MeV and 300 GeV. We subtracted the emission due to the point source obtained from the 4-year Point Source Catalog (3FGL) provided by the Fermi-LAT collaboration [7].

We consider two regions: the *Galactic ridge* (GR) which in Galactic coordinates is defined by the window ($|l| < 1^\circ$, $|b| < 0.3^\circ$) and almost include the whole CMZ and the so called *pacman, i.e.* an open annulus centered on SgrA* with $\theta_{\rm inner} = 0.15^\circ$ and $\theta_{\rm outer} = 0.45^\circ$. For each of these regions we report the spectra data point in the figures 1.

We found a remarkable continuity between Fermi-LAT and H.E.S.S. data which can almost be matched with a single power-law. This finding suggests that a single, almost uniform, emission

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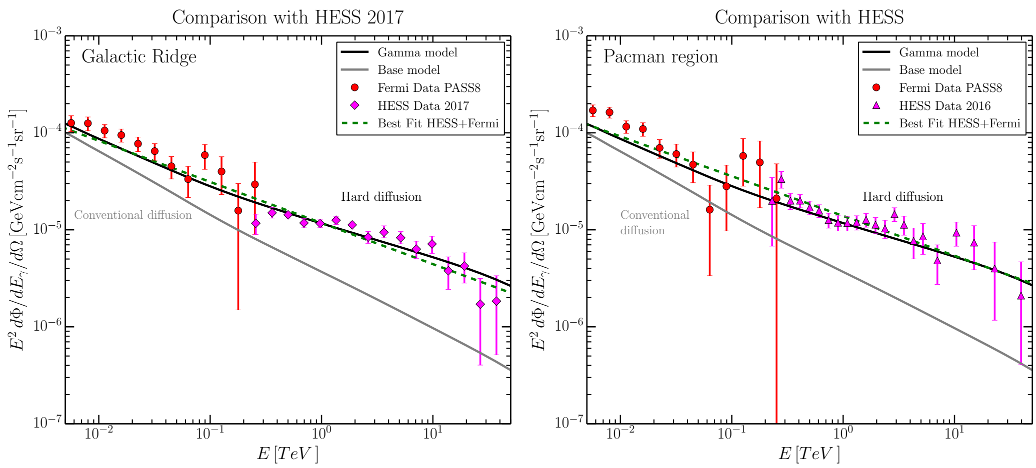

Figure 1: *Left panel*: The γ-ray spectrum in the GR region ($|l| < 1.0^\circ$, $|b| < 0.3^\circ$). Fermi-LAT data, extracted with the Fermi Science Tools in this work, and H.E.S.S. data from [3] are compared with the contribution of the Galactic CR sea as computed with the *gamma* and *base* models discussed in the text. The single power-law best fit of the combined data is also reported. We have subtracted the contribution of point sources from Fermi-LAT data. *Right panel*: the same for the *pacman* region defined in the text.

process may be responsible for most of the emission of the whole CMZ.

3. The emission due to the CR sea

In this section we compare our previous results with the diffuse emission due to the interaction of the CR large scale distribution (the CR *sea*) with the gas in the CMZ. For conventional models, which assume the CR shape in the whole Galaxy to be the same as that measured at the Earth, the emission was estimated to be considerably smaller and flatter than H.E.S.S. finding.

Here we consider an alternative scenario in which the Galactic CR spectrum, hence the secondary γ-ray diffuse emission, undergoes a progressive hardening at low Galactocentric radii. In particular, similarly to what done in [4, 9] we adopt a model which reproduces that feature as a consequence of a radial dependent slope (δ) of the diffusion coefficient dependence on the particle rigidity. The scenario, which was implemented in the `DRAGON` code [10], assumes that the exponent δ, setting the scaling of the CR diffusion coefficient with rigidity, has a linear dependence on the Galactocentric radius (r): $\delta(r) = Ar + B$. The parameters A and B were tuned to consistently reproduce local CR and Fermi-LAT γ-ray data on the whole sky.

Respect to the model considered in [4] (KRA$_\gamma$), the *gamma* reference model considered here adopts a spectral hardening in the proton and Helium source spectra at ~ 300 GeV/n, in order to reproduce the local propagated spectra measured by PAMELA [13], AMS-02 [14] and CREAM [15]. We assume this feature to be present in the whole Galaxy, as it may be expected if it is produced by propagation effects. Under these conditions, the KRA$_\gamma$ model was shown [9] to reproduce the emission observed by Milagro in the inner GP at a 15 TeV median energy [16] consistent with Fermi-LAT data.

We compute the π^0, Inverse-Compton and bremsstrahlung components of the γ-ray diffuse emission, integrating the product of the spatially-dependent CR spectrum, gas/radiation density dis-

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tributions and proper cross-sections along the line-of-sight. The π^0 component is dominant in the GC region. With respect to what reported in [4], here we replace the hydrogen distribution in the inner 3 kpc with the 3-dimensional analytical model presented in [17], as required to properly model the hadronic emission in that region. The main components are molecular (H_2) and atomic (HI) hydrogen. HI, which is inferred from 21-cm lines, is less than 10% of the total mass. Since H_2 is not observed directly, the column density must be inferred from proper tracers, most commonly from the CO emission lines. Here we use a conversion factor $X_{CO}(r \sim 0) \simeq 0.6 \times 10^{20}$ cm^{-2} K^{-1} km^{-1}s, the value giving the best agreement with the integrated mass distribution, based on the CS emission map, used in [1].

Concerning the CR source distribution by default we use the one reported in [18] based on supernova remnant catalogs. This parametrization vanishes at the GC, a behavior in qualitative agreement with the γ-ray emissivity profile determined by the Fermi-LAT collaboration [5], which displays a dip in the GC.

In the Fig.s 1 we show, against the experimental data, the γ-ray diffuse emission spectra due to the CR Galactic sea interaction with the ISM in the Galactic ridge and in the *pacman*. For comparison, besides the prediction of our gamma model we also report the spectra computed for a conventional model (*base model*), sharing with the former all the properties but keeping the diffusion coefficient spatially uniform. As already well known, from those figures it is evident that the CR sea computed for the base model –as any other conventional model– cannot consistently account for the H.E.S.S. and Fermi-LAT measurements in the absence of an additional component with a harder spectrum. This conclusion does not hold for models accounting for the radial gradient of the CR spectrum. As the reader can see from our figures, the gamma model is in excellent agreement, both in shape and normalization, with those observations in the GR.

4. Conclusions

We have shown that the diffuse γ-ray emission from the CMZ measured by H.E.S.S. and Fermi-LAT from few GeV up to 50 TeV can be originated by the interaction of the Galactic CR sea with the dense gas in that region. This implies that a PeVatron at the GC may not be required to explain H.E.S.S. data.

In fact, we showed that those data can consistently be explained in terms of a model based on spatial-dependent diffusion, phenomenologically motivated by the radial gradient of the CR spectral index measured by Fermi-LAT. Our results provide a new strong evidence supporting the validity of that scenario in a region of the Galaxy were the discrepancies between the base and conventional model are expected to be maximal. From a more theoretical point-of-view, some of us recently showed as a similar behaviour can be originated by anisotropic CR diffusion for a realistic configuration of the Galactic magnetic field accounting for a poloidal component in the inner Galaxy. The observed radial dependence of the CR spectral index was reproduced under those conditions with the `DRAGON 2` code described in [12].

In future, the South site of CTA [19] may provide a further confirmation of the scenario discussed in this Letter with the detailed observation of a larger region centered on the GC.

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