Galactic Centre and M31 EXCESS

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Excesses with respect to models of the Galactic diffuse emission in gamma-ray flux have been found around a few GeV at the position of the Galactic Centre (GC) and M31. The underlying physics causing the excesses in flux could be the same but the question remains, if it is due to astrophysical processes, such as Millisecond Pulsars (MSPs), or annihilation of Dark Matter (DM). This talk was given at the *13th Patras Workshop on Axions, WIMPs and WISPs* and is an overview of two Fermi-LAT publications focused on studying and understanding the cause of the excesses, one targeting the GC and one targeting mainly M31.

1 Introduction

The region around the GC is one of the brightest in the gamma-ray sky. Gamma-ray emission in this region includes products of interactions between cosmic-rays with interstellar gas as well as many individual sources such as pulsars and supernova remnants. Many DM theories predict that DM consists of weakly interacting massive particles (WIMPs) that can self-annihilate into final state gamma-rays. A hypothesised signal from such a process is expected to be brightest towards the GC.

Various groups have, since 2009, found an *excess of GeV photons* that extends from the GC up to mid-Galactic-latitudes,see e.g. [6–8]. Some of the works advocated that the data favours an astrophysical origin of the excess rather than evidence for a DM signal, such as [9] and more recently [5], which suggests that the excess can be caused by a population of yet undetected MSPs. The difficulty in distinguishing which theory is correct comes from the fact that the gamma-ray spatial and spectral signals are almost identical at the energies of the excess found.

Recently, gamma-ray emission has been found correlated with the position of M31. Both the GC excess and the M31 emission have been studied by the Large Area Telescope on board the *Fermi* satellite (Fermi LAT). Fermi LAT detects gamma-rays between 20 MeV and above 300 GeV. More information on Fermi LAT can be found in [3].

2 Analysis Methods

The analysis of the three targets were performed using the Fermi Science tools with Pass 8 and ∼6.5 years of Fermi-LAT data. Pass 8 is a new event reconstruction that improves the effective area, energy resolution, the point spread function and event reconstruction, [4]. The excess signal from the GC is found when simultaneously fitting the different components of diffuse emission, simulated using GALPROP, and a map of point sources, from LAT 4-year

Point Source Catalog (3FGL), to the Fermi-LAT maps independently in each energy bin by maximizing the likelihood function based on Poisson statistics, [1]:

$$\log\mathcal{L} = \sum_{i,j}(d_{i,j}\log\mu_{i,j} - \mu_{i,j} - \log(d_{i,j}!)), \tag{1}$$

where $d_{i,j}$ represents the photon counts in spatial pixel i and energy bin j, and $\mu_{i,j}$ is the model counts in the same bin. The model is constructed as a linear combination of templates:

$$\mu_{i,j} = \sum_m f_m P^m_{i,j}, \tag{2}$$

where m labels the components of emission, $P^m_{i,j}$ is the spatial template of component m in the appropriate energy bin corrected for exposure and convolved with the Fermi-LAT PSF. The coefficients f_m are adjusted to maximize the likelihood.
Unlike the GC, M31 was also modelled as a point source.

The DM and MSPs hypotheses where tested using various models of different DM and MSPs distributions to see which was the better fit to the data. The DM annihilation hypothesis is tested by assuming a Navarro-Frenk-White (NFW) DM density profile and a generalised NFW DM density profile. To model a possible population of MSPs in the GC bulge it was assumed that their distribution is traced by the old stellar population in the bulge or alternatively distributed like the dense interstellar gas in the central molecular zone. For M31 the MSP hypothesis is tested using an average spectrum derived form observed MSPs in the Galactic plane.

3 Results

Excesses have been significantly detected around a few GeV at locations consistent with the GC and M31.

In Fig. 1 the radial flux profile as a function of distance from the GC at 2 GeV for the total gamma-ray data is compared with the MSP-like spectral component and the generalised NFW profiles in the Sample Model, i.e. one of the models from [10] which assumes that the cosmic ray source distribution traces the measured distribution of pulsars [11], as well as for a standard NFW annihilation profile. The MSP-like profile and the DM annihilation profiles are similar within $\sim 5°$ of the GC, but MSP-like profile flattens at higher latitudes compared to the predictions of the generalised NFW profile.

Fig. 2 shows the best fit, a power law model, and spectral points fitted to the energy flux data for M31. However, an average MSP spectrum is almost an equally good fit to the data as the simple power law model with free parameters. It was found that a fit using an NFW profile expected for a DM signal matches the data well, due to the large uncertainty in J-factors. The J-factor determines the strength of the signal provided by annihilating or decaying DM and describes the distribution of it in an astrophysical system. In the end, neither the interpretation of the emission from M31 being due to populations of MSPs or DM can be rejected.

Based on the findings of the two papers neither of the two hypothesis, DM or MSPs, is preferred at high significance.

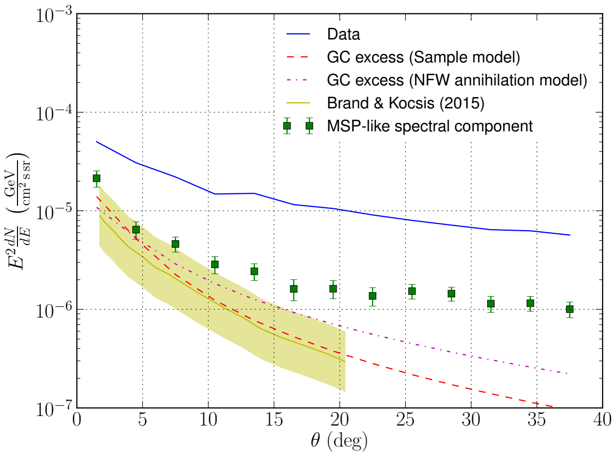

Figure 1: GC radial flux profile. Solid blue line: flux profile as a function of radial distance from the GC with bright point sources masked. Squares: radial profile of the MSP-like spectral component. Dashed red line: GC excess modeled with a general NFW (γ=1.25) profile. Dash-dotted magenta line: GC excess profile modeled an NFW profile (γ=1). Yellow band: expectation for a population of MSPs in the Galactic bulge from disrupted globular clusters. All values correspond to intensity at 2 GeV. The Fig. is from [1].

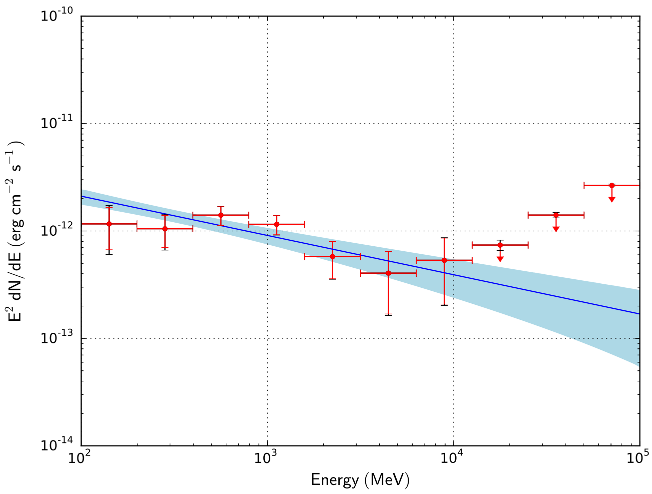

Figure 2: M31 spectrum. Solid blue line: best-fit power law model. Light-blue shaded area: 68% confidence level uncertainty domain. Red points: independent fits to data in individual energy bins. Red arrows: 95% confidence level flux upper limits. Red and black vertical error bars are the statistical and total uncertainties, respectively. The Fig. is from [2].

4 Summary

Earlier publications have found excesses of gamma-rays at a few GeV consistent with the locations of the GC and M31. The Fermi Collaboration has found that the M31 excess [2] is similar to the excess at the GC, [1]. It is still up for debate if the two similar excesses are due to DM or MSPs, or if there is another explanation altogether.

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