The mysterious gamma-ray excess of Andromeda: Comparing millisecond pulsars to dark matter

Introduction

The origin of the gamma-ray excess of Andromeda is still unknown. Two of the leading hypotheses explain it with emission due to an unresolved population of millisecond pulsars or from annihilating dark matter. In this work, we have weighted these two hypotheses against each other by constructing templates specifically designed for this region of the sky. We also carefully investigated what impact the modelling of the gamma-ray background has on such claims using alternative diffuse models.

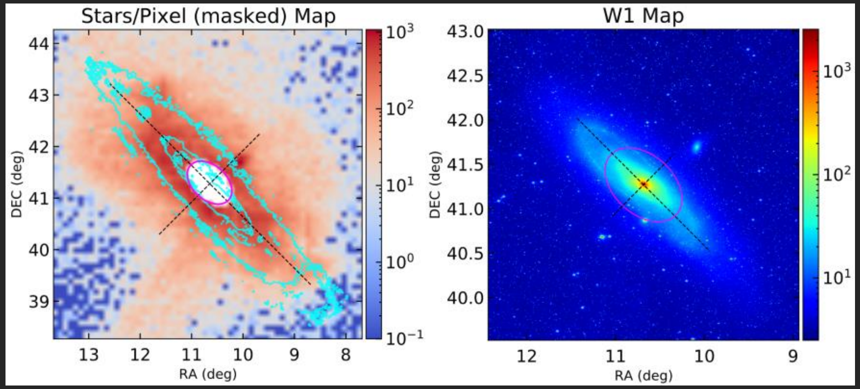
Data & Analysis

- 10 years of Fermi-LAT data
- Energy range between 500 MeV and 100 GeV

We used a bin-by-bin approach and therefore divided the data into 10 logarithmically spaced energy bins. For the test statistic we use the usual likelihood ratio of null to alternative hypothesis:

$$TS_{\rm bin} = -2\ln\frac{L_{\rm null}(\hat{\boldsymbol{\theta}}_{\rm BKG})}{L_{\rm alt}(\hat{\boldsymbol{\theta}}_{\rm M31}, \hat{\boldsymbol{\theta}}_{\rm BKG})}$$

Millisecond Pulsars



We use observational data – specifically old stars like red giants – to construct stellar density maps for the disk and the bulge of Andromeda. These are used to approximately trace the millisecond pulsar population.

Old Red Giants ⟶ Millisecond Pulsars

Dark Matter

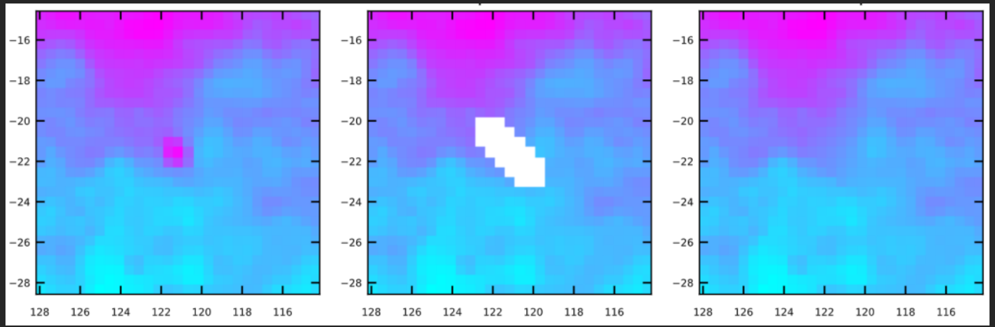
We assume the dark matter to be distributed spherically symmetric with the NFW profile:

$$\rho(r) = \frac{\rho_0}{\frac{r}{r_s}(1+\frac{r}{r_s})^2}$$

For each pixel, we integrate the squared density along the line of sight:

$$J_p(l,b) = \int_s \rho(r[s,l,b])^2 ds$$

Both the Andromeda and Milky Way dark matter halo are contributing to the total J-factor.



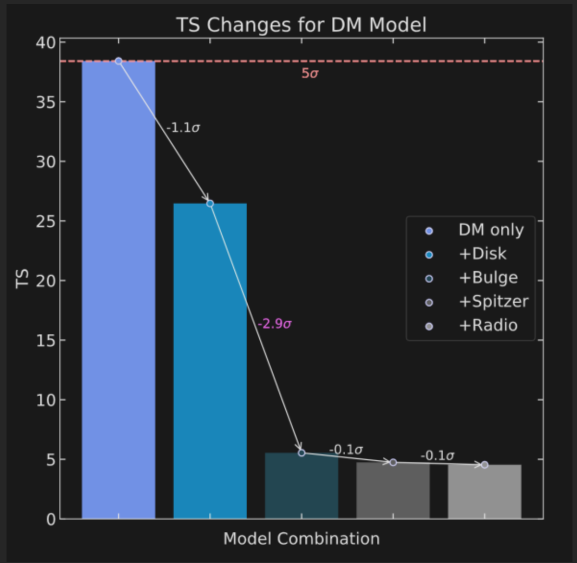
Left panel:
Original image

Middle:
Ellipse mask

Right:
Inpainted image

We used novel inpainting algorithms based on neural networks to build our alternative background models. With different hydrogen components, inpainting algorithms and inverse Compton models we arrive at 24 alternative diffuse background models.

$$2\,(\text{H1 components}) \times 3\,(\text{Inpainting Methods}) \times 4\,(\text{Inverse Compton Models}) = 24$$



Results & Conclusions

- We showed, that an additional dark matter component is unwarranted when accounting for the emission of millisecond pulsars in the disk and bulge of Andromeda!
- In case for our data set, which had better reconstructed direction but less counts, the errors on the flux are dominated by statistical uncertainties rather than systematics!
- We conclude the emission to be correlated to the distribution of the stellar mass in the bulge of Andromeda, which strongly favours the millisecond pulsar hypothesis!