Search for DM signal features in the Galactic gamma-ray spectra with the *Fermi*-LAT

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Abstract

We have developed a dedicated dark matter (DM) line-like signal feature search in gamma-ray spectra using 13.75 years of *Fermi* Large Area Telescope (LAT) data from 1 GeV to 1 TeV in five regions of interest (ROIs) centered on the Galactic center, optimized for different DM density profiles and annihilation or decay channels. We find no statistically significant evidence of features and set constraints on the velocity-averaged DM annihilation cross section and on the DM decay time. Compared to the previous *Fermi*-LAT results [1], the limits on the DM parameters at 95% confidence level are even stronger up to 1-2 orders of magnitude, depending on the sky region and energy, thanks to the improved analysis method.

Introduction

Weakly Interacting Massive Particles (WIMPs) are among the most credited DM candidates. Their self-annihilations and decays into pairs of gamma rays are expected to yield monoenergetic photons. Since our galaxy is believed to be embedded in a large DM halo, line-like features in the galactic gamma-ray energy spectra are expected. The gamma-ray differential fluxes from a sky region covering a solid angle ΔΩ are given by[1]:

$$\left(\frac{d\Phi}{dE}\right)_{ann} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\left(\frac{dN_\gamma}{dE}\right)_{ann} J_{ann}(\Delta\Omega)$$

$$\left(\frac{d\Phi}{dE}\right)_{decay} = \frac{1}{4\pi}\frac{1}{m_\chi \tau}\left(\frac{dN_\gamma}{dE}\right)_{decay} J_{decay}(\Delta\Omega)$$

Here $\langle\sigma v\rangle$ is the velocity-averaged WIMP annihilation cross section into gamma rays and τ is the WIMP decay time, while the J-factors depend on the amount of DM along the line of sight.

Fit models

The photon flux from a given ROI is:

$$\Phi_{RoI}(E_t) = \Phi_{bkg}(E_t) + \Phi_{sig}(E_t)$$

The signal flux is the possible line-like feature and is given by:

$$\Phi_{sig}(E_t) = s\delta(E_t - E_{line})$$

where the parameter s ≥ 0 represents the line intensity. The background flux is the sum of a "smooth" contribution $\Phi_{bkg,smooth}(E_t)$, originated from known astrophysical processes, and from a possible additional line-like contribution $\Phi_{bkg,line}(E_t) = b\delta(E_t - E_{line})$, which could mimic a DM feature. The smooth background is modeled with a log-parabola in the energy interval 1 – 10 GeV and with a power law above 10 GeV [2].

Data Analysis

We perform the analysis in 5 different ROIs, with the axis pointing towards the Galactic Center (GC) and with different angular apertures, optimized to enhance the signal-to-noise ratio for different DM profiles in our Galaxy (*R3,R16,R41,R90*) or for DM decay (*R180*).

We have implemented a maximum likelihood fit procedure in sliding energy windows, each one centered at a given energy *E* with half-width *wE*. A possible gamma-ray line at energy E is expected to yield a signal spread over an energy interval with the size of the energy resolution. The results in this work are obtained by setting *w = 0.50*, corresponding to a window size larger than the energy resolution of the LAT, which is at most 30%. A possible line would be therefore fully contained within one of the sliding windows. We implement a combined analysis of the different data samples, each corresponding to one of the event types classified according to the quality of the energy reconstruction (EDISP0=worst, EDISP3=best [3]).

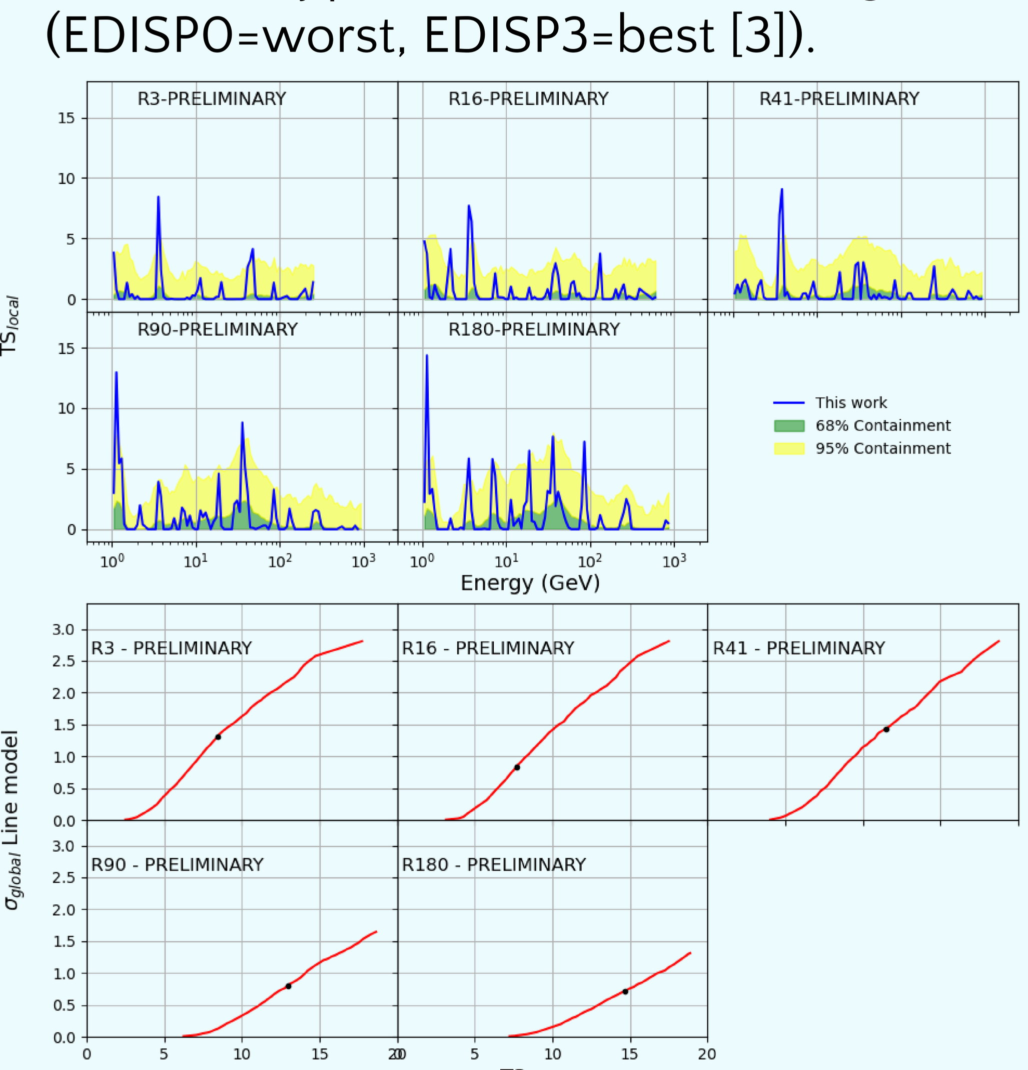

Figure 1. Top panel: TS values for each RoI in the combined likelihood analysis with 1000 background-only pseudoexperiments containment bands. **Bottom panel**: Global significance evaluated form TS distributions in pseudoexperiments, black dots are the max values obtained in the combined likelihood analysis

The top panel of Fig.1 shows, in each ROI, the TS compared with the expectations from a set of pseudoexperiments in which the null hypothesis is assumed. Almost all the measured TS values lie within the expectation bands, with a few outliers. We then evaluate the global significance assuming that it obeys a half-normal distribution. The potential feature with the highest global significance is found in R41, with a global significance **~ 1.5σ.**

Results

Since all potential features are not globally significant, we evaluate upper limits (ULs) on the line intensities. The ULs at 95% confidence level (CL) as a function of the line energy, together with their 68% and 95% containment bands obtained in the pseudoexperiments, are shown in the plots of the upper panel of Fig.2. The measured ULs lie within the containment bands and are therefore consistent with the expectations for the null hypothesis.

These ULs can be converted into ULs on the velocity-averaged annihilation cross section $\langle\sigma v\rangle$ or into lower limits on the DM decay time τ. At low energies (1-10 GeV) all limits are a factor ~ 100 stronger than those obtained in Ref. [1] (grey line).

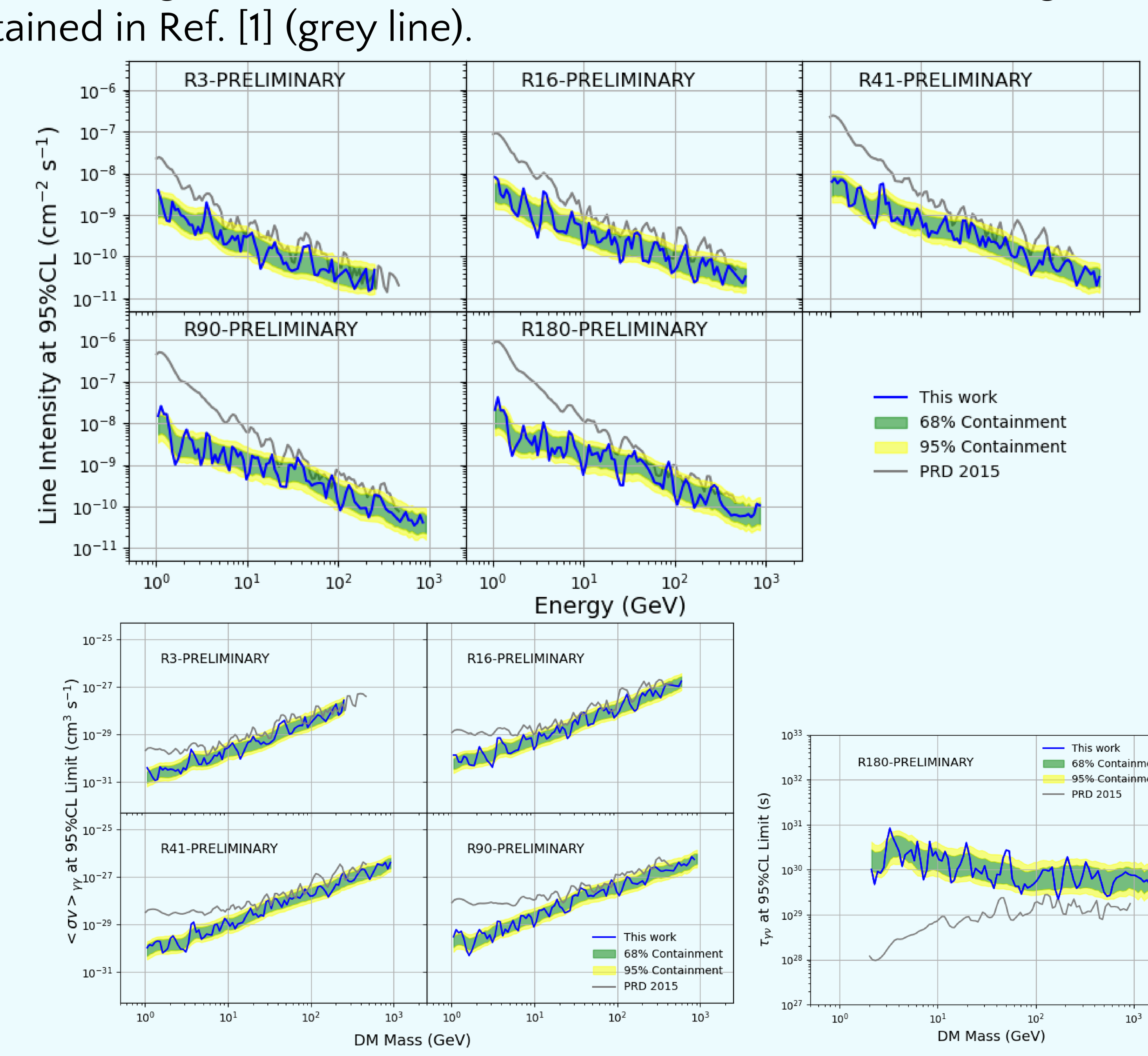

Figure 2. Top panel: upper limits on line signal strength for each RoI with the combined likelihood analysis. **Bottom panel:** Constraints on $\langle\sigma v\rangle$ and τ. Containment bands are obtained from a set of 1000 background-only pseudoexperiments

Conclusions

No significant features are detected (the highest global significance **~ 1.5σ).** The improvement on upper limits up to 1-2 orders of magnitude is due to the use of the combined likelihood analysis technique and to a more accurate modelization of the smooth component of the background flux.

References

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