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Search for dark matter subhalos among Fermi-LAT sources in presence of dataset shift

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Main contribution:

This work aims to identify a signal from dark matter among gamma-ray sources detected by the Fermi Large Area Telescope using machine learning techniques.

For the first time, we write the full likelihood for a model of the unassociated gamma-ray sources, including a model for extragalactic as well as galactic gamma-ray sources and dark matter annihilating through the $b\bar{b}$ channel.

This will enable us to draw bounds on the annihilation cross-section of dark matter by employing a technique never adopted before (to the best of our knowledge), opening a new way to search for dark matter with considerable potential for further refinement and improvement.
As a corollary result, we achieve a principled probabilistic classification of the unassociated gamma-ray sources, making them no more unassociated, at least from a probabilistic point of view.

Physics background:

If dark matter particles annihilate and produce standard model particles, those particles may interact and produce gamma rays. Due to their high-energy nature, gamma rays suffer much less from absorption effects due to the interstellar medium as well as deviation in their trajectory due to electromagnetic fields. These properties paired with a comparatively lower astrophysical background point at gamma rays as a prime target of interest for Dark Matter indirect detection.

Among the gamma-ray sources identified by the Fermi Large Area Telescope, approximately one-third remain without a clear astrophysical association. While still unassociated, we expect most of them to be of astrophysical origin. Nonetheless, a small fraction of them could be dark matter sub-halos, whose signal we aim to disentangle.

In general, it is possible to study a gamma-ray source through several means. It is possible to study gamma-ray sources by themselves by analyzing their energy spectrum and/or variability index. In alternative, one can employ multiwavelength approaches, by comparing a gamma-ray signal with its counterparts in the entirety of the electromagnetic spectrum.

An accurate study for extragalactic gamma-ray sources is generally possible and it leads to a clear association for approximately 90% of the detected sources.
On the other hand, approximately 50% of the sources closer to the galactic plane remain unassociated. This is in part due to the higher density of gamma rays coming from the galactic plane which makes resolving and characterizing individual sources more difficult. Furthermore, the presence of absorption effects acting on radiation less energetic than soft X-rays makes it hard if not impossible to employ multi-wavelength approaches to classify these already elusive gamma-ray sources.

In this work, we focus our attention on the energy spectrum of the unassociated gamma-ray sources, as different classes of sources follow different energy spectrum distributions.
We parametrize the energy spectrum of the gamma-ray sources measured by Fermi-LAT using a LogParabola fitting formula with 3 free parameters: an overall normalization, the spectral index, and the curvature parameter.
Studying the distribution for these parameters, we will identify different regions in the parameter space corresponding to the distinct astrophysical and DM components. This would potentially enable us to disentangle a signal from Dark Matter or, as is the present case, draw bounds on the DM annihilation cross-section in its absence.

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