Search for dark matter annihilation with a combined analysis of dwarf spheroidal galaxies from Fermi-LAT, HAWC, H.E.S.S., MAGIC and VERITAS

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Dwarf spheroidal galaxies (dSphs) are among the most dark matter (DM) dominated objects, with negligible expected astrophysical gamma-ray emission. This makes nearby dSphs ideal targets for indirect searches of a DM particle signal. The accurate knowledge of their DM content makes it possible to derive robust constraints on the velocity-weighted cross section of DM annihilation. We report on a joint analysis of 20 dSphs observed by Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS using a common maximum likelihood approach in order to maximize the sensitivity of DM searches towards these targets. Results for seven annihilation channels and spanning a range of DM masses from 5 GeV to 100 TeV will be presented. Furthermore, the systematic uncertainties coming from the astrophysical J-factor calculated from the dSph dark matter distribution will be discussed by comparing results obtained from two different sets of J-factors.

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1. Introduction

This project consists in the search for dark matter (DM) annihilation with a combined analysis of twenty dwarf spheroidal galaxies (dSphs) observations by five gamma-ray experiments: Fermi-LAT [1], HAWC [2], H.E.S.S. [3], MAGIC [4], and VERITAS [5]. The expected differential flux of gamma rays from the self-annihilation of two DM particles is:

\[
\frac{d^2\Phi(\langle\sigma v\rangle, J)}{dE d\Omega} = \frac{1}{4\pi} \frac{\langle\sigma v\rangle}{2m_X^2} \sum_f \text{BR}_f \frac{dN_f}{dE} \times \frac{dJ}{d\Omega},
\]

(1)

where \(m_X\) is the DM particle mass, \(\langle\sigma v\rangle\) is the velocity-averaged cross-section, and \(dN_f/dE\) is the differential spectrum for a given annihilation channel \(f\) and \(\text{BR}_f\) its corresponding branching ratio. \(dJ/d\Omega\), also known as the differential \(J\) factor, describes the expected amount of DM within a region of the sky \(d\Omega\) and can be written as:

\[
\frac{dJ}{d\Omega} = \int \text{l.o.s.} \rho_{\text{DM}}^2(l, \Omega) dl,
\]

(2)

where l.o.s. stands for line-of-sight and \(\rho_{\text{DM}}\) is the DM density distribution.

2. Method

The search for DM is performed via the maximisation of a joint likelihood function \(\mathcal{L}\) which is the product over the individual likelihood \(\mathcal{L}_{\text{dSph}}\) of the \(N_{\text{dSph}} = 20\) observed targets of our dataset \(\mathcal{D}_{\text{dSph}}\):

\[
\mathcal{L}(\langle\sigma v\rangle; \nu | \mathcal{D}_{\text{dSph}, l} ) = \prod_{l=1}^{N_{\text{dSph}}} \mathcal{L}_{\text{dSph}, l}(\langle\sigma v\rangle; J_l, \nu_l | \mathcal{D}_{\text{measured}}) \times J_l(J_l | J_{l, \text{obs}}, \sigma_{\log J_l}),
\]

(3)

where \(\mathcal{D}_{\text{measured}}\) is the dataset for the \(l\)-th dSph; \(\nu_l\) is the set of nuisance parameters associated to the \(l\)-th dSph excluding \(J_l\); and \(J_l\) is the total \(J\) factor of the \(l\)-th dSph.

3. Results

Two independent public software packages, gLike [6] and LklCom [7], are used to realize the final likelihood combination. Both software provide the same results. No DM signal was observed [8], hence 95% CL upper limits on the DM annihilation cross-section \(\langle\sigma v\rangle\) were derived for seven annihilation channels: \(b\bar{b}, t\bar{t}, e^+e^-, \mu^+\mu^-, \tau^+\tau^-, W^+W^-, \) and \(ZZ\).

4. Conclusion

The combined limits range from 5 GeV to 100 TeV and improve the individual experiment limits by up to a factor 2 to 3. Results obtained from two different sets of \(J\)-factors [9–11] allow to assess the systematic uncertainties coming from the astrophysical \(J\)-factor: the limits vary from a factor 2 to 6 depending of the DM mass. This is significantly less than individual dSph \(J\)-factor uncertainty than can be as high as 2 orders of magnitude.
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