Double-dipping for dark matter with gamma-rays

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Abstract

Gamma-ray probes have historically been a gold-standard in indirect dark matter detection due to their smaller set of complicating factors and generally lower backgrounds. However, they are most optimally sensitive to the traditional super-symmetric WIMP annihilation channels while leptophilic channels (particularly for larger masses) are much harder to probe effectively in this manner. However, these channels do produce strong neutrino emission, detection of which has been previously complicated by lack of neutrino telescope sensitivity. In this work we display a method for inferring neutrino fluxes from gamma-ray data and using this to achieve superior constraints on the leptophilic channels of WIMP annihilation. This allows us to 'double-dip' re-using the same gamma-ray data sets to get a wider range of robust and stringent WIMP annihilation constraints. We demonstrate this approach with data from HESS and Fermi-LAT and use it to probe dark matter models suggested to explain recently reported cosmic-ray excesses.

Existing gamma-ray limits on WIMP annihilation

We place limits on the cross-section $\langle \sigma V \rangle$, which is pretty much the annihilation rate of WIMPs. Some limits are shown in Fig. (1), from [1, 2], are derived from HESS observations of the galactic centre with 112 hours and 254 hours of data respectively. These are compared to limits from dwarf galaxy observations by Fermi-LAT [3]. **The goal is to be able to push models below the thermal relic line (black dashed in all figures) implying that model cannot constitute all cosmological dark matter as it annihilates too slowly**. It is clear that this is difficult to achieve, especially for larger WIMP masses!

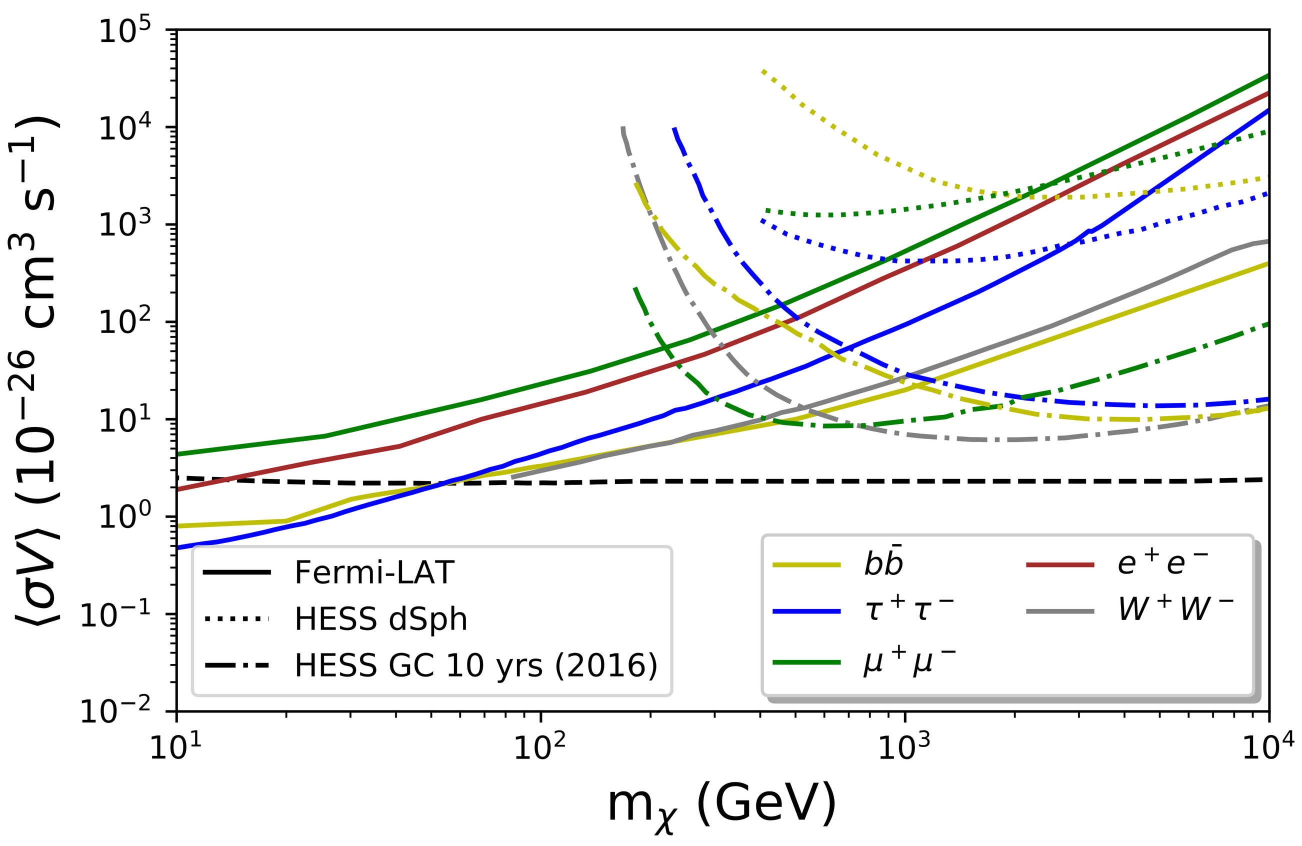

Figure 1: Comparison of cross-section limits between Fermi-LAT gamma-ray data from dwarf galaxies [3] and galactic centre limits from HESS [1, 2].

- Large masses and leptonic channels have weak results
- Can we remedy this with a detection method sensitive to lepton couplings?

Neutrinos are obvious candidate as they share many of the advantages as gamma-rays. However, we have never detected a localised neutrino source before and telescope sensitivities are not great. We can avoid this, however, with one simple trick...

A double-dip

- For putatively hadronic gamma-ray emissions
- Following [4, 5] we can use gamma-ray fluxes to estimate neutrino fluxes from a given source
- These will be best at limiting large mass, leptonic channels for WIMPs

The same data can be used twice to get a better set of results!

Figure 2: Seinfeld et al 1993

HESS galactic plane survey

A practical example using data from the HESS galactic plane survey within 0.1 to 1 degree from the galactic centre. This data is from [6], with 13% of the emission estimated to be from diffuse gamma-rays with a power-law index -2.3. This is compared to predictions for an NFW dark matter halo with scale length 20 kpc, normalised to our local DM density 0.4 GeV cm^{-3} at 8.5 kpc from the galactic centre (we use CLUMPY). The DAMPE parameter space is usually difficult to probe, HESS has a good start but double-dipping comes to the rescue.

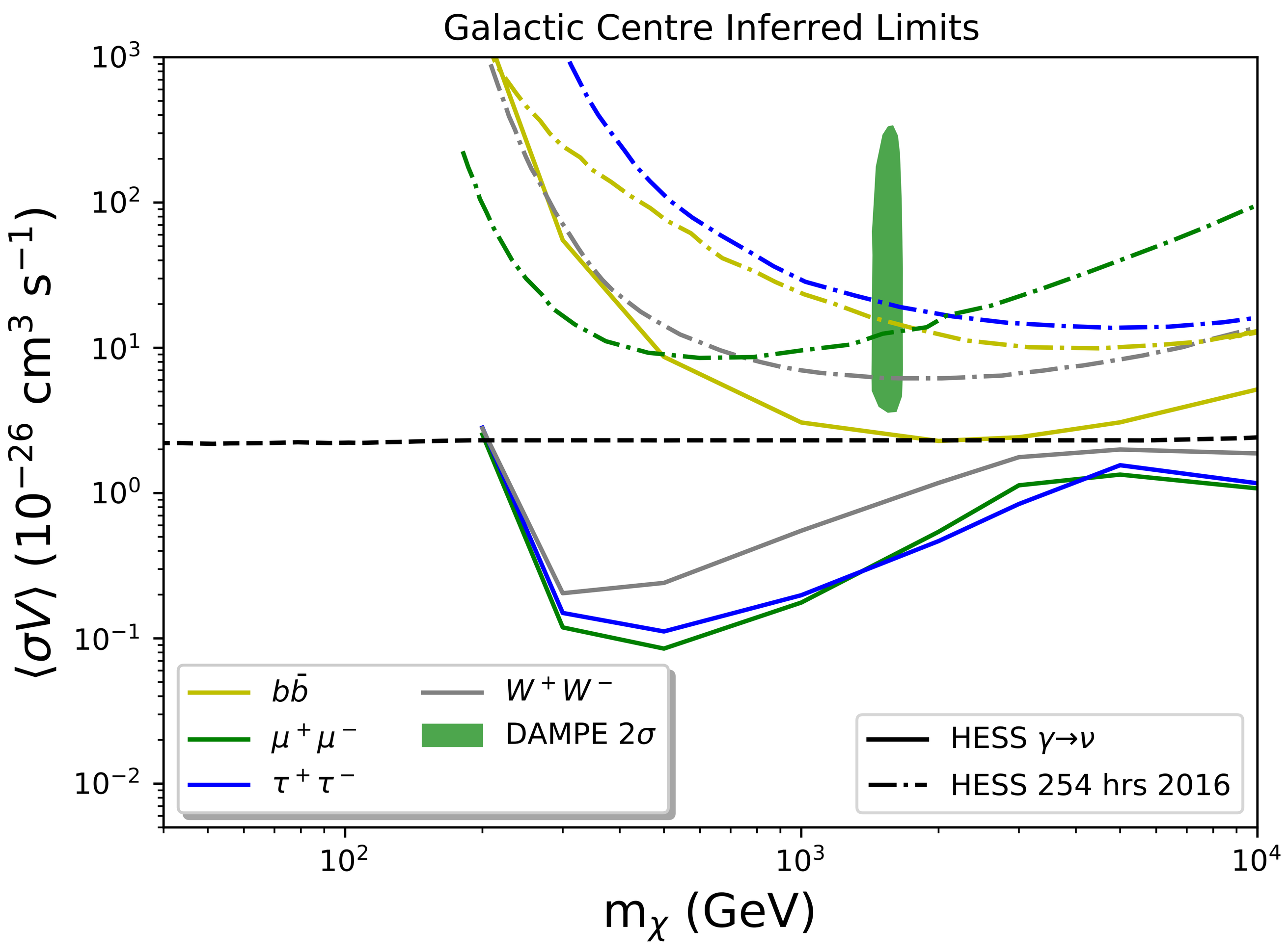

Figure 3: WIMP cross-section constraints from galactic centre neutrino flux estimation using HESS data [6].

- Order-of-magnitude improvement for light leptons!
- Even b-quark channel is slightly better than gamma-rays
- Lepton channels below relic limit from 200 GeV up to 10 TeV!
- Smaller diffuse fraction provides better limits
- Rules out DAMPE excess parameter space [7]

Fermi-LAT

For Fermi-LAT galactic centre we use annulus $0.1^\circ < b < 10^\circ$ from [8] with J-factors computed via CLUMPY. Unfortunately, we don't add any impact on the AMS-02 anti-proton excess parameter space (mainly as the displayed model region is for b quarks! [9]).

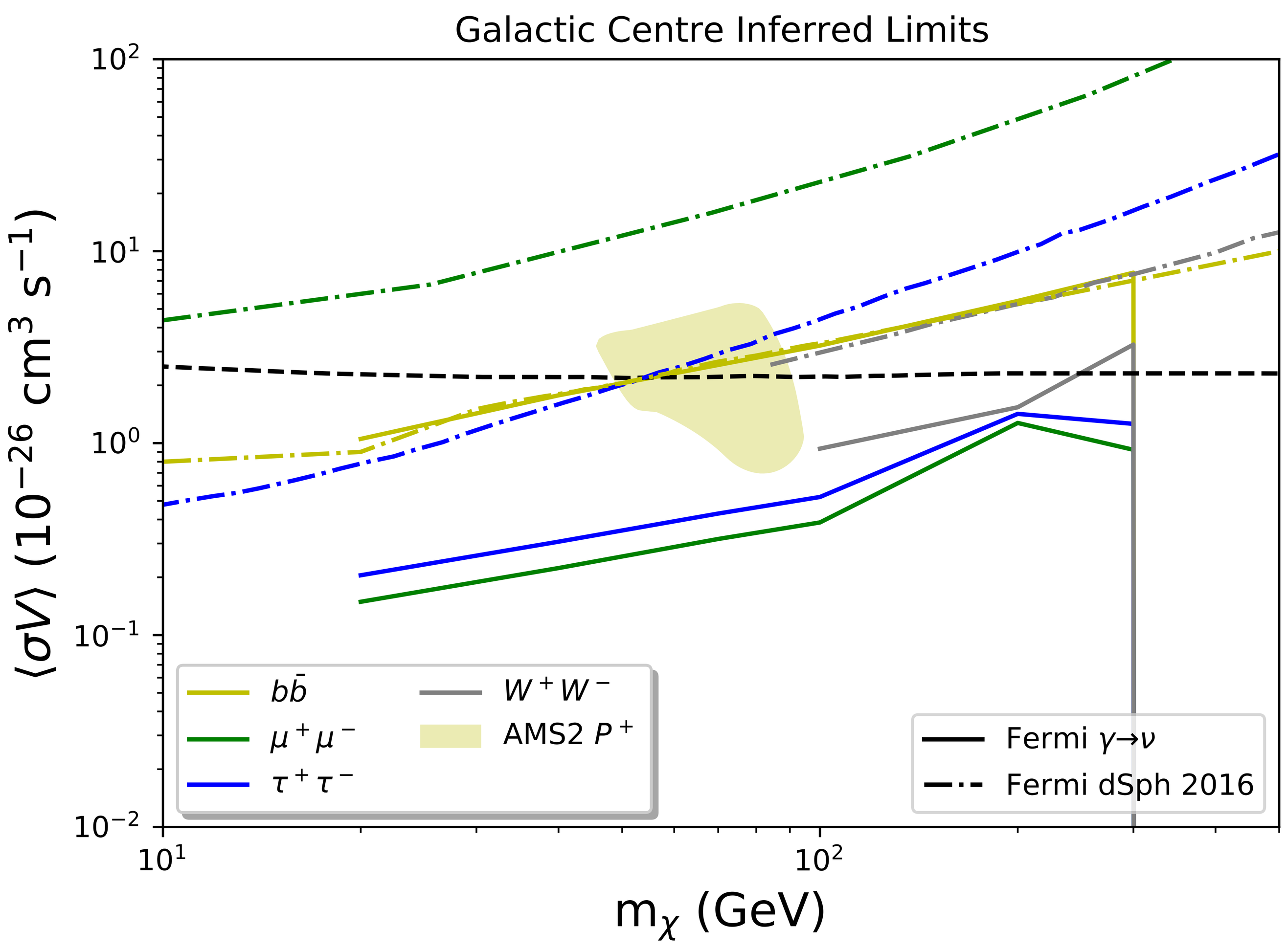

Figure 4: WIMP cross-section constraints from galactic centre neutrino flux estimation using Fermi-LAT excess data [8].

- Order-of-magnitude improvement for light leptons!
- b-quark channel is comparable to the gamma-rays
- τ-lepton below relic limit for masses below 300 GeV (rather than just 60 GeV)

Conclusions

Double dipping gets us some interesting results:

- Powerful limits for leptonic models
- Mainly effective above 20 GeV WIMP masses
- Strong complementarity between Fermi and HESS
- If gamma-rays are partly leptonic in origin: limits get better

Open questions:

- Is the Seinfeld joke any good?
- Correct neutrino physics for hadronic processes?

References

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Acknowledgements

G.B acknowledges support from a National Research Foundation of South Africa Thuthuka grant no. 117969.