Insights on Galactic dark matter from polarized synchrotron emission

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Dark Matter constraints from Planck observations of the Galactic polarized synchrotron emission

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Dark Matter (DM) annihilation in our Galaxy may produce a linearly polarized synchrotron signal. We use, for the first time, synchrotron polarization to constrain the DM annihilation cross section by comparing theoretical predictions with the latest polarization maps obtained by the Planck satellite collaboration. We find that synchrotron polarization is typically more constraining than synchrotron intensity by about one order of magnitude, independently of uncertainties in the modeling of electron and positron propagation, or of the Galactic magnetic field. Our bounds compete with Cosmic Microwave Background limits in the case of leptophilic DM.

Introduction. High-energetic cosmic-ray (CR) electrons *and* positrons ($e^{\pm}$ in what follows) can be either accelerated in primary sources such as supernova remnants and pulsar wind nebulae, or produced by spallation of hadronic CRs. Besides, CR $e^{\pm}$ might also be produced by the annihilation or decay of dark matter (DM) particles in the Galactic DM halo. Relativistic $e^{\pm}$ then gyrate and propagate in the interstellar Galactic magnetic field (GMF), and produce secondary emissions such as radio and microwave emission through the synchrotron process.

sub-millimeter sky, in terms of the Stokes components I (intensity) and Q, U (polarization). The polarization amplitude is defined as $P = \sqrt{Q^2 + U^2}$. In particular, *Planck* has so far provided the deepest and highest-resolution view of the microwave and sub-millimeter sky by mapping anisotropies in the cosmic microwave background (CMB) radiation. This made possible to put strong constraints on the standard cosmological model and its possible variations [31].

arXiv:2204.04232, Phys.Rev.Lett. 129 (2022) 11, 111103

(No need for) Introduction

(WIMP) dark matter: talks by K.Boddy, S.Williams

Indirect dark matter searches: talk by F.Calore

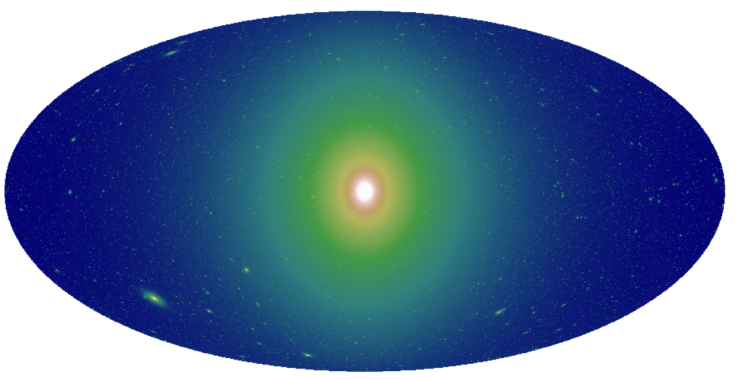
Complementarity among messengers (photons, cosmic rays), energies (radio to TeV), targets and observables

This talk: *First* constraints to annihilation signals using *polarized* emission observed by Planck satellite

Signature: excess photon flux

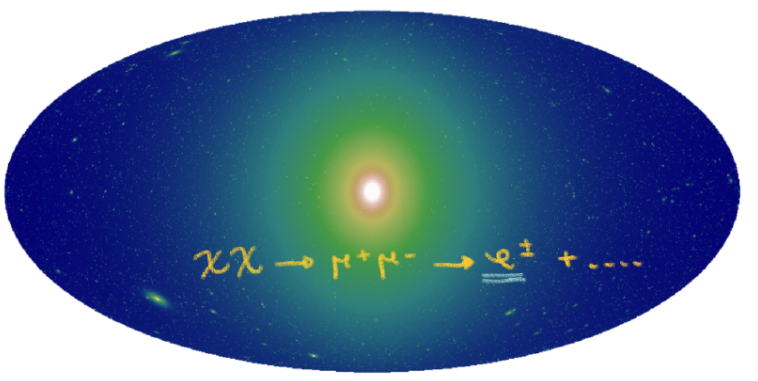
Observable: *polarized* microwave sky

Idea



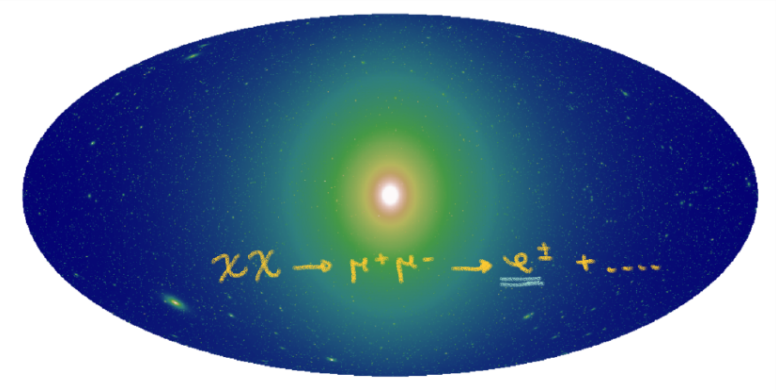
[J_{gal} from CLUMPY]

Idea

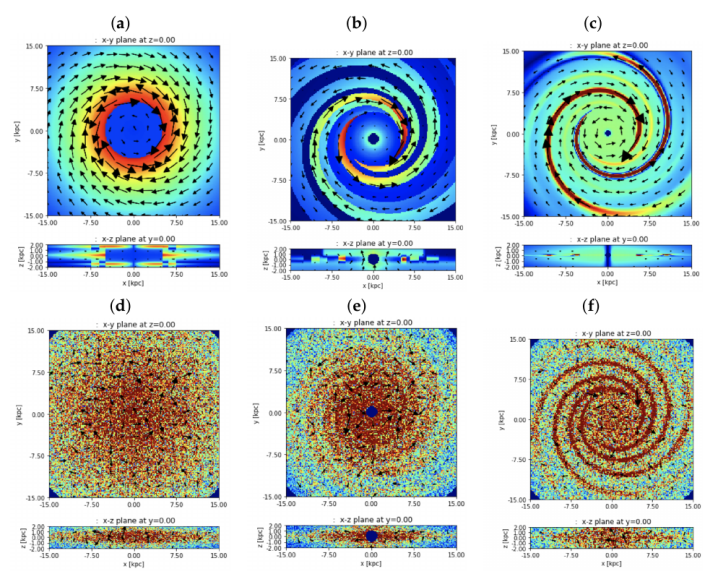


[$J_{\rm gal}$ from CLUMPY]

Idea

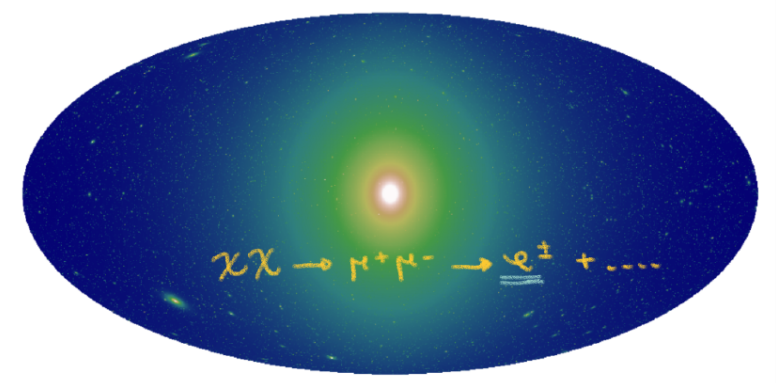


[$J_{\rm gal}$ from CLUMPY]

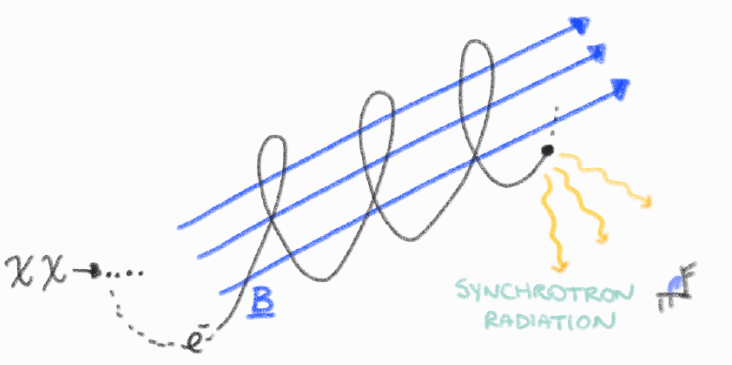


Coherent + random **B** [Jaffe, Galaxies'19)]

Idea

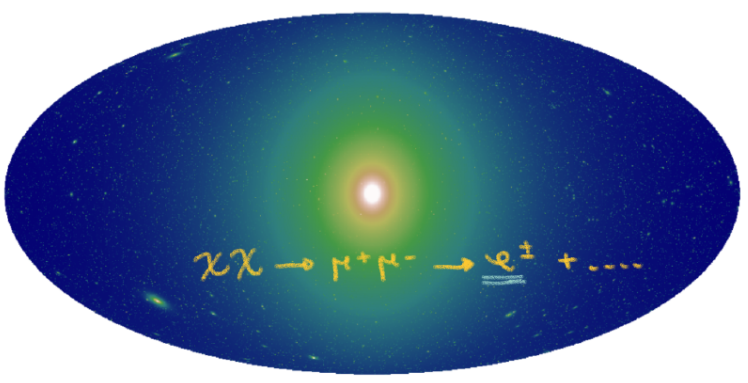


[J_{gal} from CLUMPY]

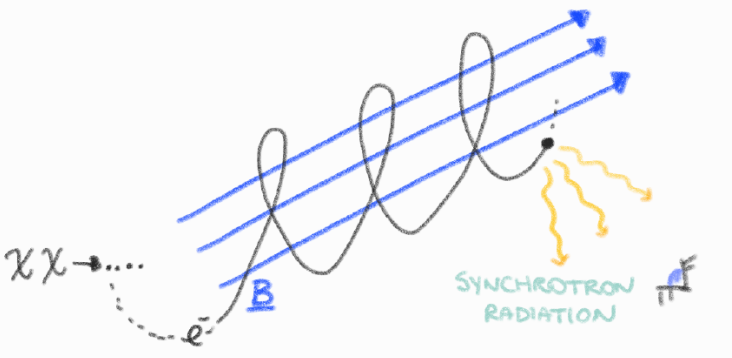


Secondary dark matter radiation
radio - microwave

Idea

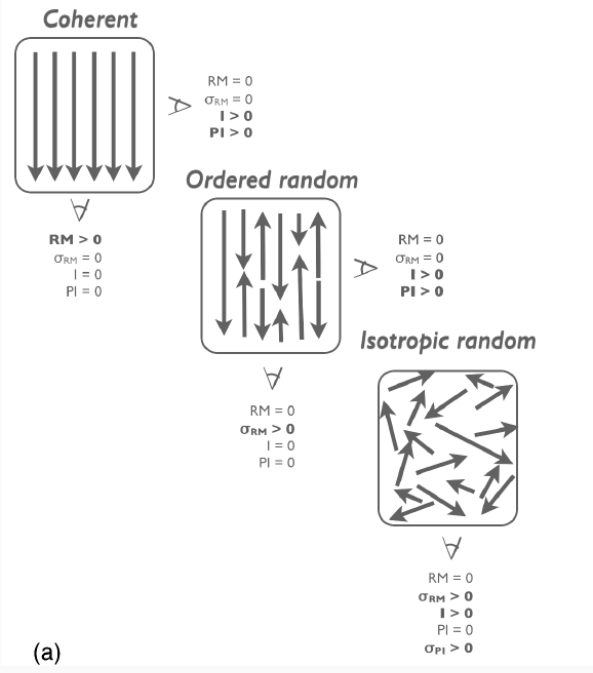


[$J_{\rm gal}$ from CLUMPY]



Secondary dark matter radiation
radio - microwave

Intensity (I)
Polarization ($P = \sqrt{Q^2 + U^2}$)

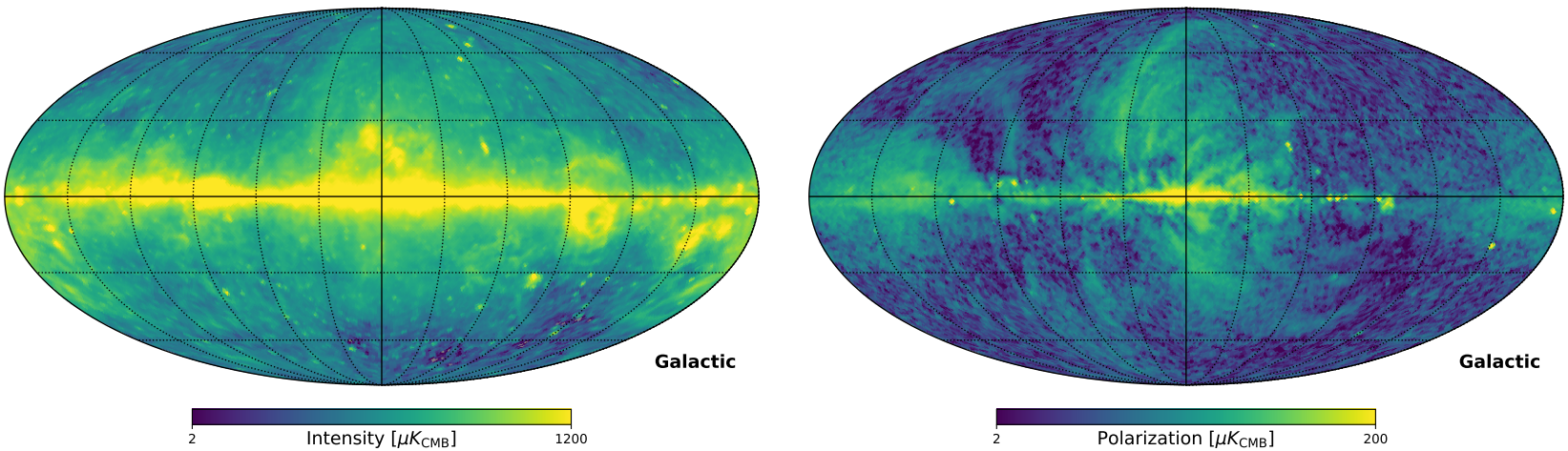


[Jaffe, Galaxies'19)]

Planck satellite data - not only CMB

Planck data =CMB + point sources + Galactic diffuse +... dark matter?

[talk by J.Errard]



Planck data [PR3 LFI 30 GHz, CMB subtracted, left: I, right: P]

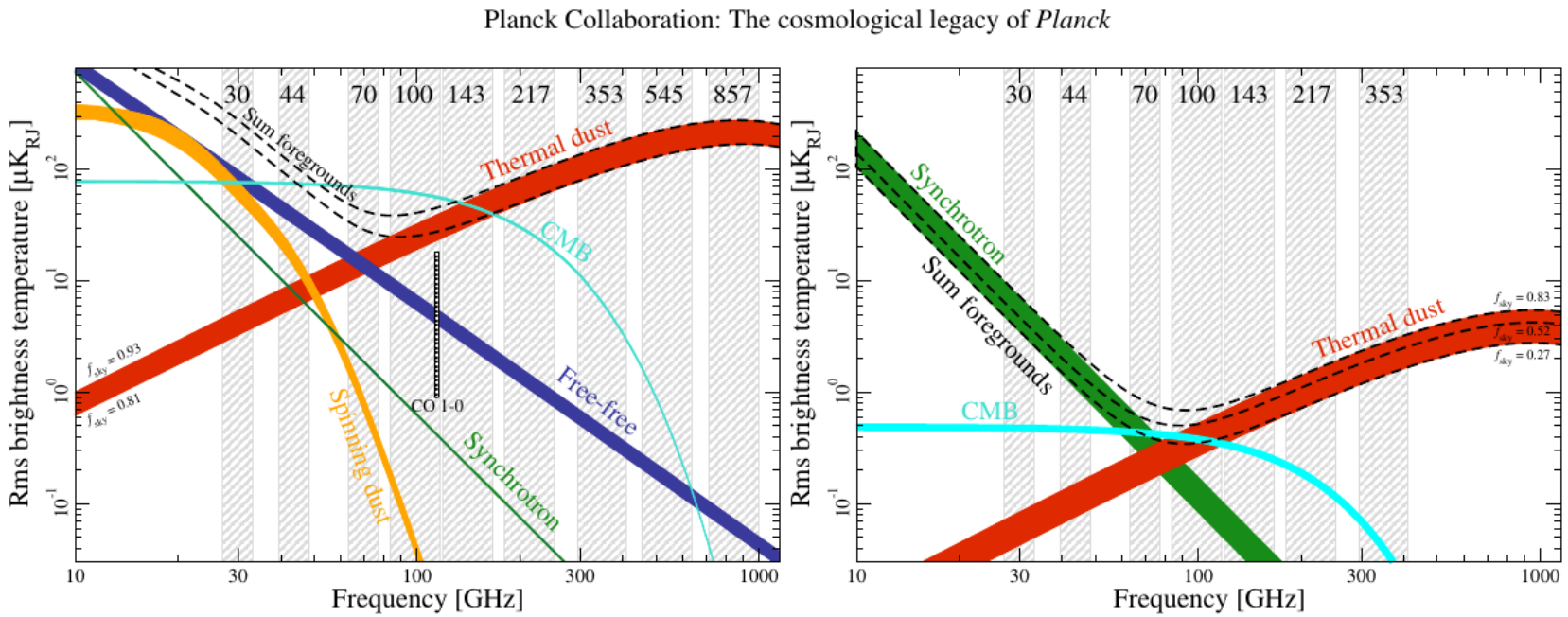
Intensity widely used in dark matter searches*, *Polarization never used*

*see full list of references in arXiv:2204.04232

Planck satellite data - not only CMB

Planck data =CMB + point sources + Galactic diffuse +... dark matter?

[talk by J.Errard]



[Planck 2018 results I]

Less competing backgrounds at $\sim 10 - 100$ GHz?

Implementation

WIMP dark matter annihilation: NFW profile, $b\bar{b}/\tau^+\tau^-$, spectra [Cirelli+JCAP'11]

$$q_{\mathrm{e}^\pm}(\mathbf{x}, E) = \frac{1}{2}\left(\frac{\rho_{\mathrm{DM}}(\mathbf{x})}{m_{\mathrm{DM}}}\right)^2 \Sigma_f \langle\sigma v\rangle_f \frac{dN^f_{e^\pm}}{dE}$$

Cosmic ray propagation: `Galprop` [custom]; $\hat{D}$: diffusion, E losses, 3D magnetic field

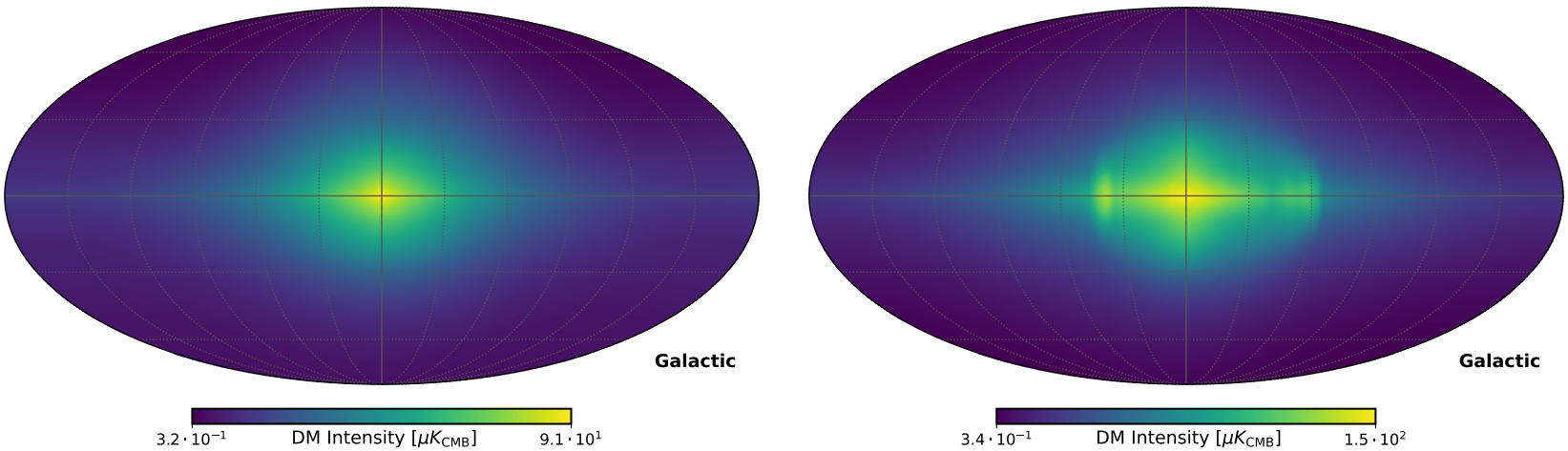
$$\hat{D}\mathcal{N}_{\mathrm{e}^\pm}(E, \mathbf{x}) = q_{\mathrm{e}^\pm}(\mathbf{x}, E)$$

Synchrotron emission: Stockes I,P

$$\mathcal{J}_{I,P}(\nu, b, l) = \frac{1}{4\pi}\int_{\mathrm{los}} ds \int dE\, \mathcal{N}_{\mathrm{e}^\pm}(E, \mathbf{x})\mathcal{P}_{I,P}(\nu, E)$$

Dark matter signal maps - Intensity

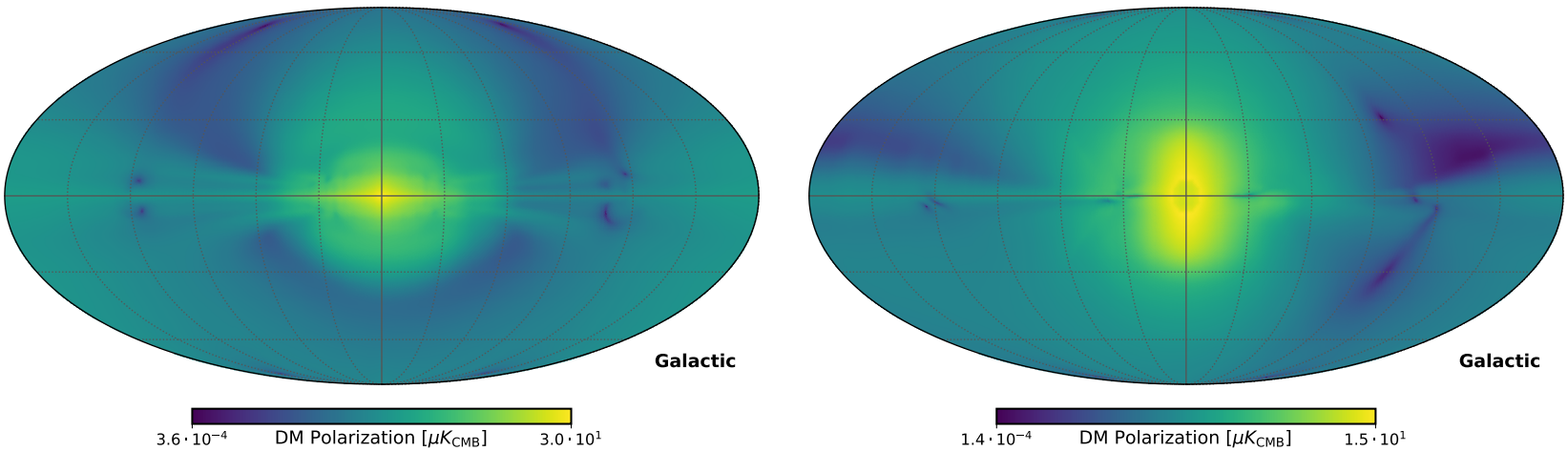
Left: magnetic field Sun+10 , Right: Jansson&Farrar 2012



[Manconi+PRL'22]

Dark matter signal maps - Polarization

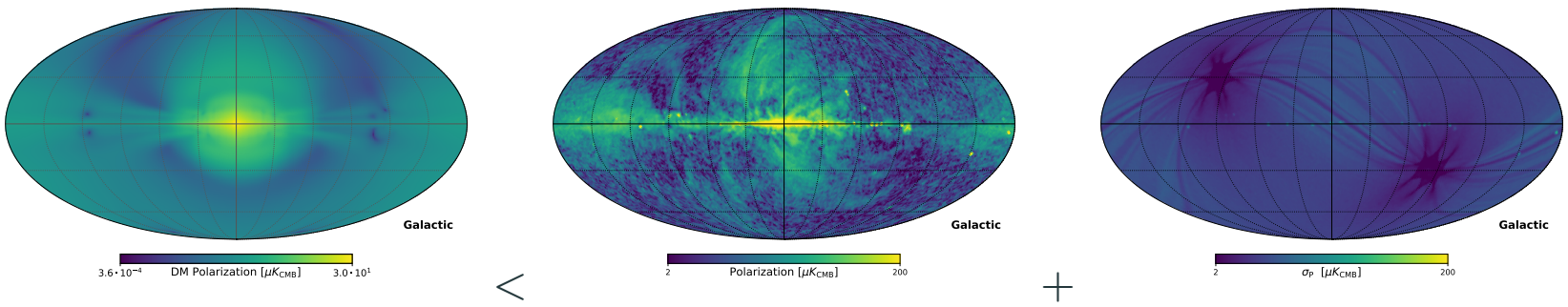
Left: magnetic field Sun+10 , Right: Jansson&Farrar 2012



[Manconi+PRL'22]

(Conservative) upper limits

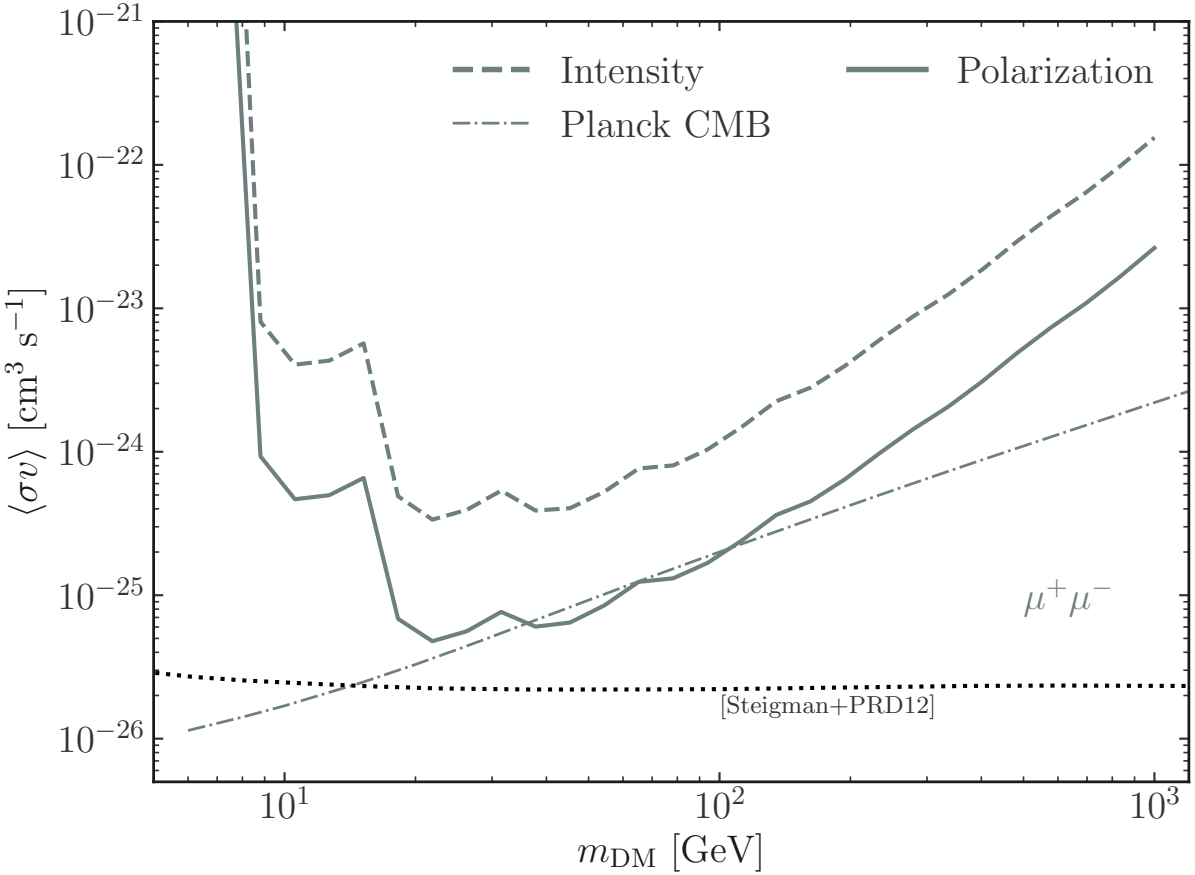
(68% CL) upper limits, each pixel: dark matter $<$ data + 1σ error



No Galactic background subtracted, only CMB

Results

68% C.L. upper limits

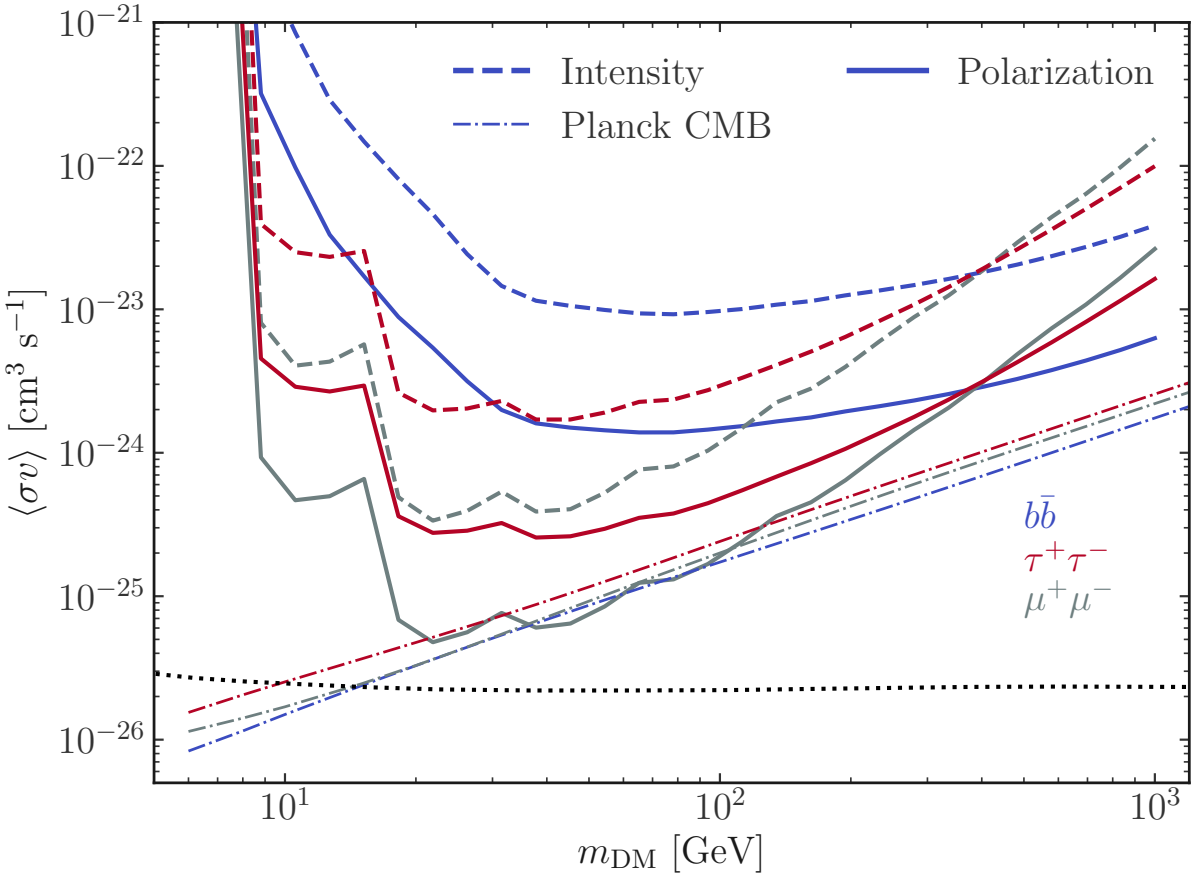


[Manconi+PRL'22]

Why? Spectrum + morphology

Results

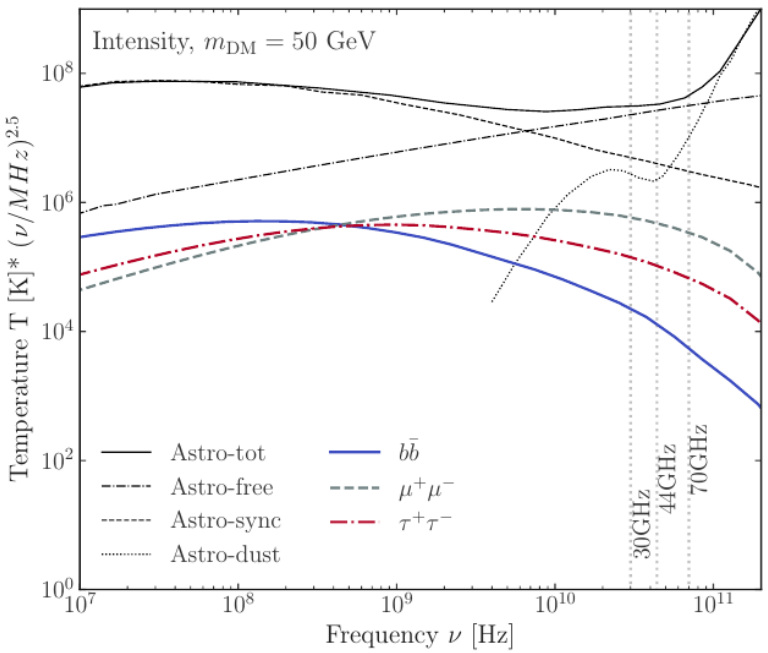
68% C.L. upper limits

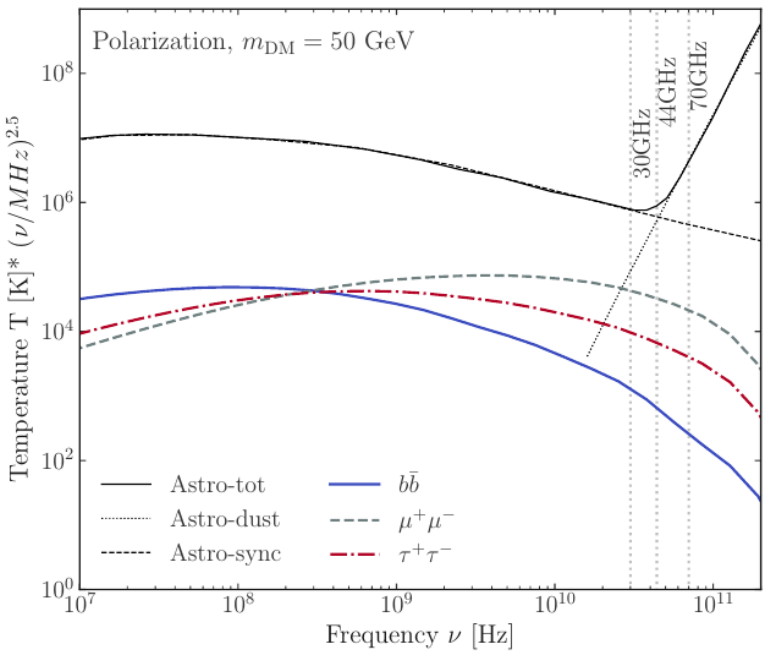


Manconi+PRL'22

Why? Spectrum + morphology

Why? Spectrum



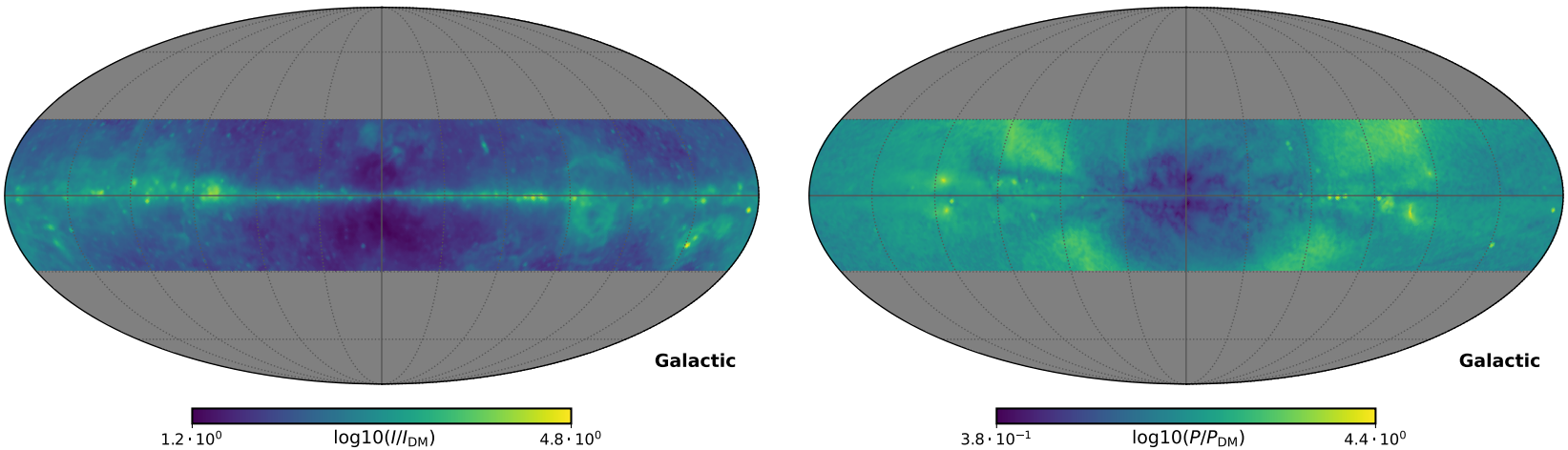


[Manconi+PRL'22]

For a DM signal peaked at ∼30 GHz lower background in P wrt I

Why? Morphology

Ratio data/dark matter, Intensity (left), Polarization (right)



[Manconi+PRL'22]

I map: best sensitivity $\sim$ 10 deg away GC

Filaments in P map: regions of low background very close to GC

More & systematics

Dark matter profile

Navarro-Frenk-White (NFW)
generalized NFW
Burkert (cored)

Galactic magnetic field

Phshirkov et al. 2011
Sun et al. 2010
Jansson & Farrar 2012

Previous works

Relevant bibliography
Validation

Cosmic ray propagation

Plain diffusion
(cosmic ray data + gamma + radio)
+ reacceleration
+ convection

Planck frequency

30 GHz vs. 44 GHz vs. 70 GHz

Pixel size

HEALPix NSide 16 to 512

Supplemental : arXiv:2204.04232
Discussion
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Takeaway from [Manconi+PRL'22 arXiv:2204.04232] :

- Microwave polarization *together* with intensity maps to constrain secondary emission from dark matter
- Polarization more constraining than intensity (factor ∼5-10)

Future / in progress

- Astrophysical foregrounds
- Other targets / exotic $e^{\pm}$ injections
- More full-sky observations of polarized millimeter sky [e.g. LiteBird 2202.02773]

Thank you!

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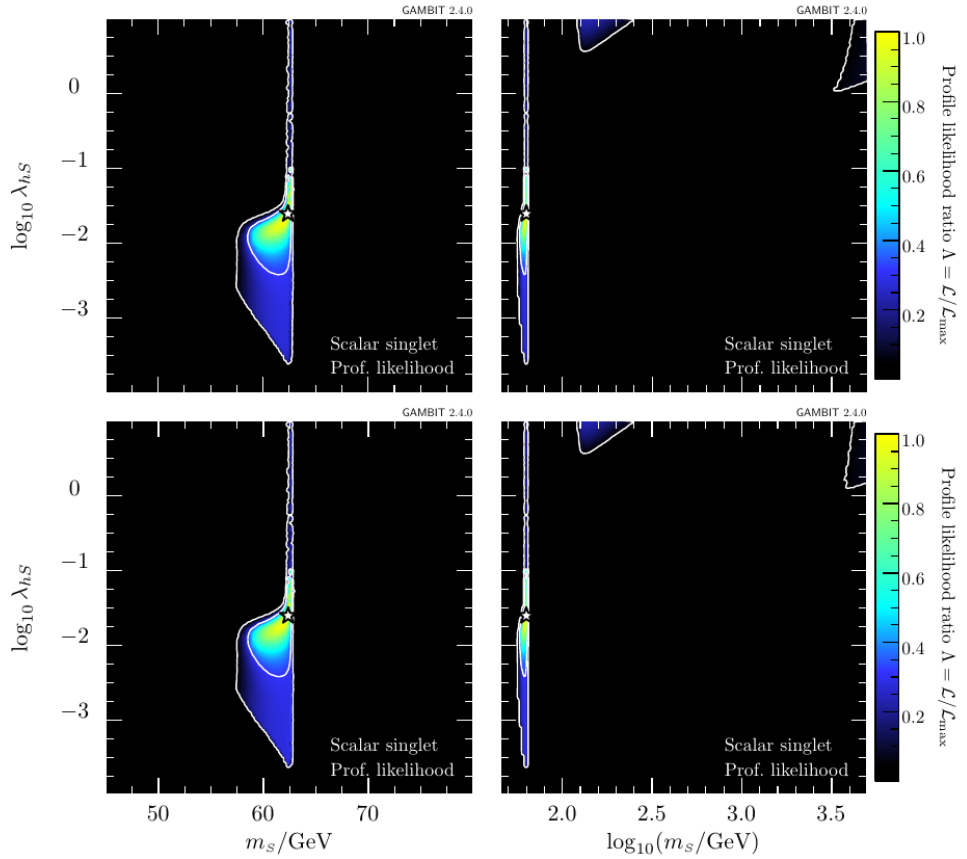
Bonus: cosmic antiprotons in GAMBIT

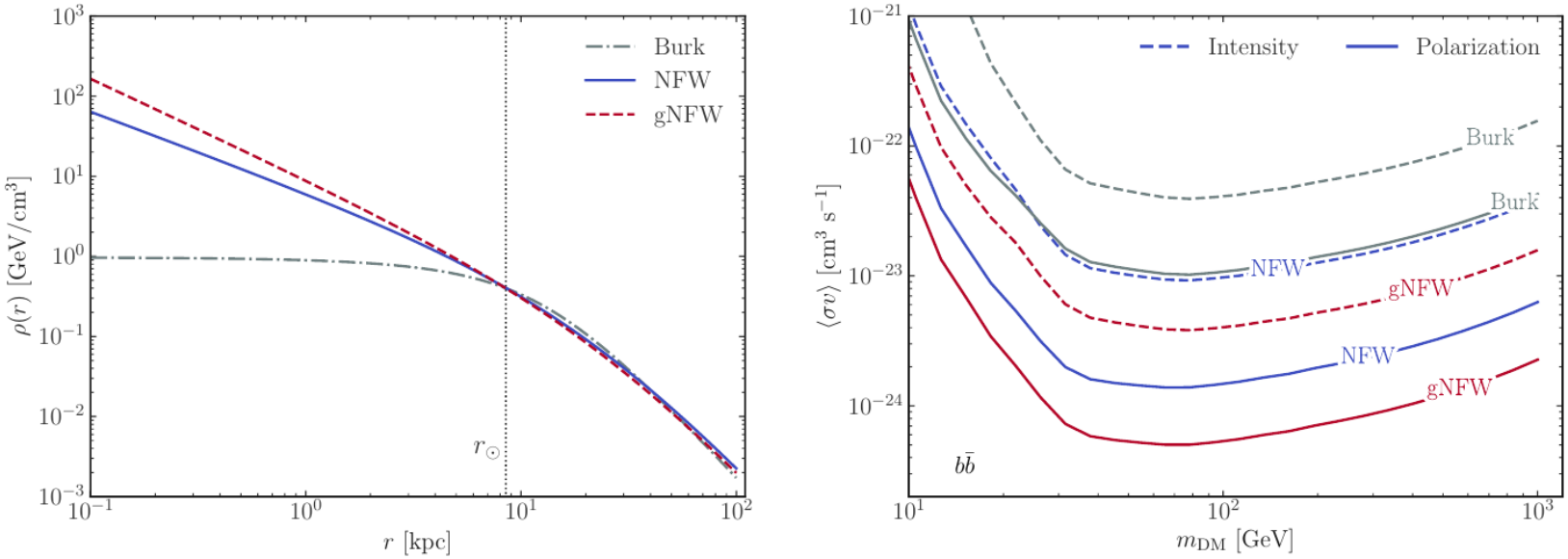
Dark matter constraints from AMS-02 antiprotons in GAMBIT: arXiv:2303.97362
(include likelihoods from direct, indirect, collider searches)



[Balan,Kahlhoefer,SM+23]

State-of-the-art global fit of Scalar Singlet Dark Matter model

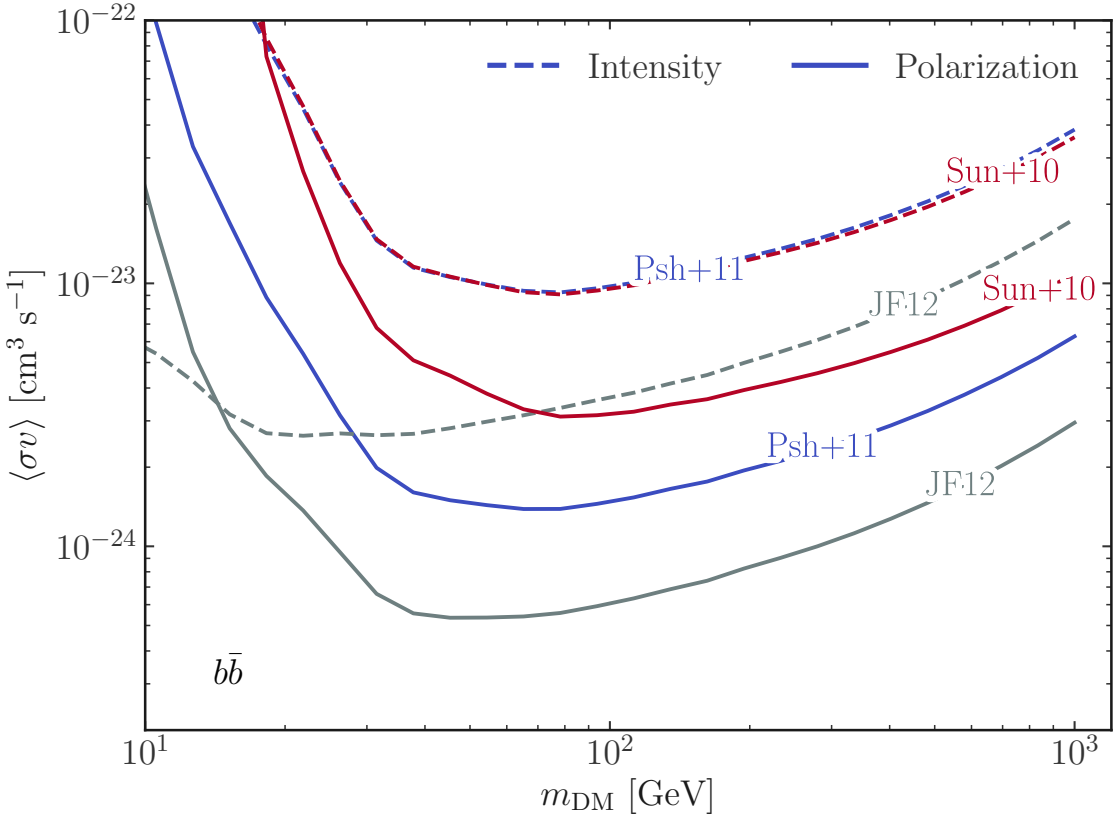
Dark matter profile



[Manconi+PRL'22]

factor ~ 10, but polarization consistently more constraining

Galactic magnetic field



[Manconi+PRL'22]

factor ~ 10, but polarization consistently more constraining

Brightness temperature - reminder

I, P maps in energy^2 x flux [erg cm^{-2}/s/Hz/sr] converted to RJ brightness temperature:

$$T_{I,P}(\nu) = \frac{c^2 \mathcal{J}_{I,P}}{2\nu^2 k_B} \,,$$

and then further in units of $K_{\rm CMB}$:

$$T_{I,P,\rm CMB}(\nu) = T_{I,P}(\nu) \frac{1}{\mathcal{C}_c(\alpha)} \frac{(e^{x_c}-1)^2}{x_c^2 e^{x_c}}$$

where $x_c = \frac{h\nu}{k_B T_{\rm CMB}}$, ν is the central frequency of the considered channel (e.g. 30 GHz), $T_{\rm CMB} = 2.7255$K, k_B is the Boltzmann constant and $C_c(\alpha)$ is a color correction factor, equal to $\mathcal{C}_{30\rm GHz}(-1) = 0.969$ for synchrotron radiation and 30 GHz.

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